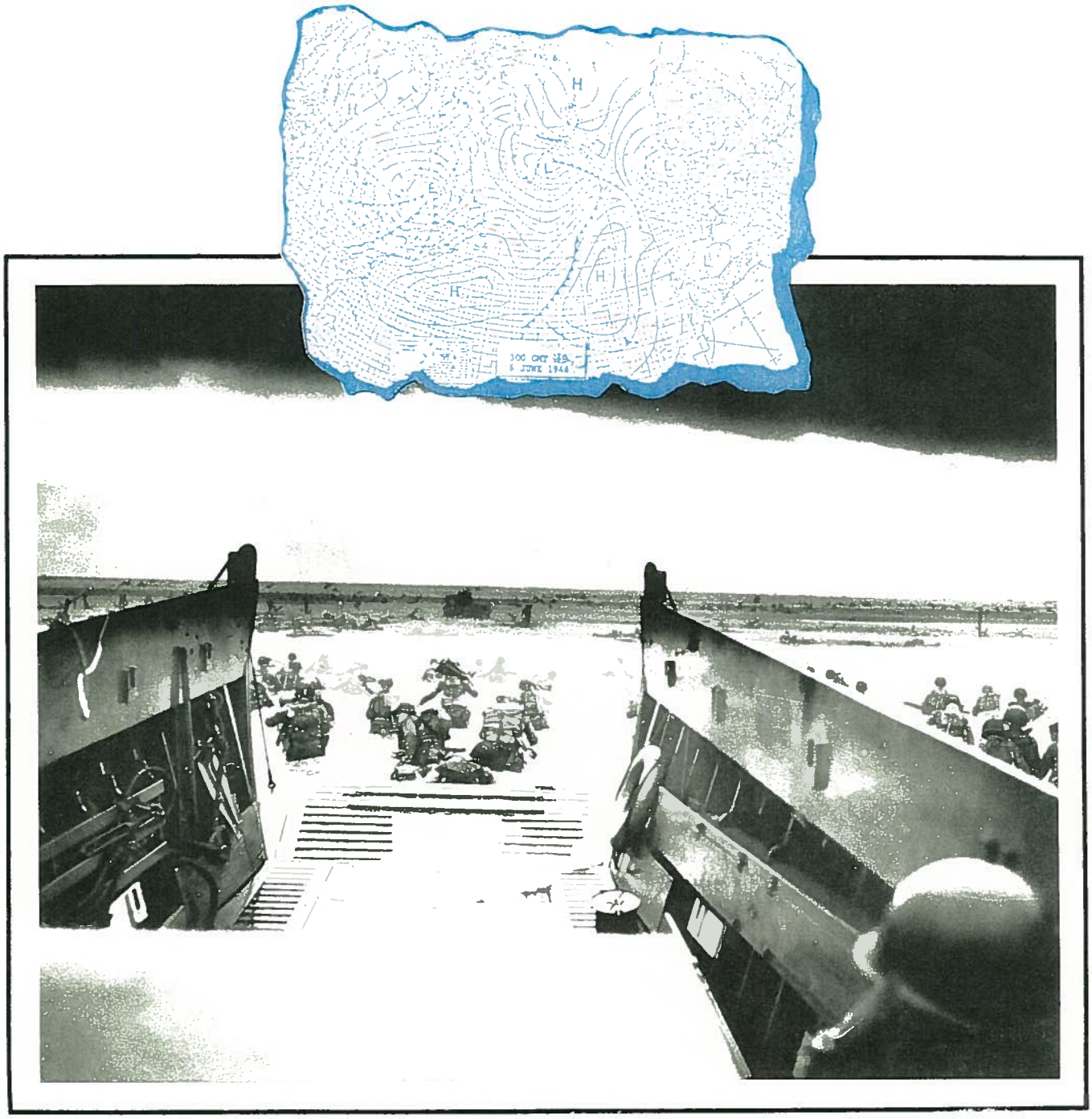
Some Meteorological Aspects of the D-Day Invasion of Europe

6 June 1944



COVER CAPTIONS

Cover 1: *A landing craft at the Normandy beaches. Photo, courtesy of the National Archives, Washington, D.C.*
Map, surface weather map about the same time as landing.
(See Apendix B, p. 166.)

Cover 4: *Surface weather map (enlarged) Same as above.*

Printing made possible through arrangements by

AMERICAN METEOROLOGICAL SOCIETY

45 BEACON STREET, BOSTON, MASSACHUSETTS 02108

Some Meteorological Aspects of the D-Day Invasion of Europe

6 June 1944

PROCEEDINGS OF A SYMPOSIUM
19 MAY 1984, FORT ORD, CALIFORNIA

EDITED BY
ROGER H. SHAW and WILLIAM INNES

Sponsored by the Monterey Peninsula,
Northern California, Sacramento, and
San Jose State University Chapters of the
American Meteorological Society

EDITORS' NOTE: Many diagrams contained in these pages are of poor quality. However, considering their historical significance and the impossibility of reconstructing or redrawing them without great expense, we hope the reader finds them acceptable.

Printing arrangements for this volume by the American Meteorological Society were carried out as a service to the California chapters who sponsored the meeting at which these papers were presented, as well as to those with an interest in the subject. This is not a publication of the Society in the sense of the papers having been reviewed or of the Society agreeing or disagreeing with any of the material included.

AMERICAN METEOROLOGICAL SOCIETY
45 BEACON STREET, BOSTON, MASSACHUSETTS 02108-3693 USA

PREFACE

On 19 May 1984, as a commemoration of the 40th anniversary of the D-Day invasion of Normandy, a one-day symposium was held at Fort Ord, California, to review and examine the meteorological aspects of the invasion. The meeting was sponsored by four chapters of the American Meteorological Society in northern California: Monterey Peninsula, Northern California, Sacramento, and San Jose State University.

Many of those who participated actively in the meteorological support for that historic event were present and many more contributed by correspondence. In addition, a large amount of supporting documentation, both allied and German, was displayed. The meeting, aside from mere historical interest, provided an insight, in the light of the existing state of the art, to the approach to this most-important meteorological problem, not only by the meteorological organizations, but by the senior decision makers and commanders as well.

These proceedings are an account of the Fort Ord symposium and are a compilation of the formal presentations (Chapters 2 to 10), correspondence received from several individuals involved in the D-Day forecast (Chapter 11), a panel discussion (Chapter 12), and of two of the many items relating to the meteorological events and to the D-Day forecast that were not part of the formal presentations but were available for viewing to the participants (Appendices). These items plus video recordings of all of the presentations made at the symposium will remain on deposit at the Department of Meteorology, San Jose State University, San Jose, California.

Roger H. Shaw
William Innes

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

JUNE BACON-BERCEY:

In 1776 during our war for independence, Thomas Paine wrote "These are the times that try men's souls." Those eloquent words could have been said with equal gravity this time 40 years ago in June 1944, when the fate of the free world hung in the balance, and that balance was controlled by weather, the only variable that the war-planners could not control.

For over a year the supreme allied commander, General Eisenhower, and his staff had been making plans for the biggest military expedition in history, one that involved millions of soldiers, sailors and airmen, thousands of boats and ships, and many more millions of dollars worth of military equipment. All of this required thorough coordination and painstakingly precise timing of countless details, down to the exact smallest troop unit.

To wind down and stop the momentum of that great and gigantic military machine was almost unthinkable. But it was equally unthinkable to risk the loss of that enormous invasion force in the English Channel, and on the beaches of Normandy.

The decision "to go" irrevocably forward or "not to go" turned on weather. At this point a lonely General Eisenhower turned to his commanders in Chief. They were no help. His senior field commander, General Montgomery, is said to have replied to Eisenhower's earnest request for advice with, "I am glad it's your decision and not mine." Therefore, General Eisenhower had no one else to turn to but to a handful of meteorologists on his staff. Never in history, before or since, has so much turned on a weather forecaster's skill.

In shaping today's program to honor and relive those historic days of early June 1944, we have been mindful that time is running out. The allied supreme commander, General Eisenhower, and most of his staff are gone now. Would it not be fitting to celebrate the 40th anniversary of D-Day by searching out the remaining courageous weather persons who provided the actual weather information, upon which General Eisenhower based his decision to go ahead with that invasion of Europe, known to history as Operation Overlord, and invite them to share with us this day their memories of those fateful and historic days? Well, some accepted our invitation. They are with us today. Others contacted us and are with us in spirit.

As program chairman of the Northern California Chapter of the American Meteorological Society, I welcome all of you. For some of you here, this will be a reunion. For the rest of us, it will be a commemoration. There may be different versions and serious divergences of opinion of what happened during the development of the forecasts leading up to D-Day. But we are not here today to determine which version was right and which was wrong but to hear from persons who were directly involved with those critical and highly important forecasts about some of the problems and concerns that occurred during those highly charged days, to learn how the problems were approached from different perspectives, and to commemorate that effort, an effort that helped to change the course of history.

I now have the privilege of introducing my colleague and one whose knowledge and inspiration contributed so much to make this all possible. His meteorological career spans over 30 years and includes heading National Weather Service forecast offices in Honolulu and Los Angeles. Joe chaired the Los Angeles Chapter of the AMS. A Fellow of the AMS, he has been widely published in scientific journals.

JOSEPH VEDERMAN:

I can think of no better way to begin a discussion of D-Day than to look at it through the eyes of the supreme commander, General Eisenhower. Here's a glimpse of how he saw it after the abandonment of the May target date that was the original one.[1] "The next combination of moon, tide, and time of sunrise that we considered practicable for the attack occurred on June 5, 6 and 7. We wanted to cross the channel with our convoys at night so that darkness would conceal the strength and direction of our several attacks. We wanted a moon for our airborne assaults. We needed approximately forty minutes of daylight preceding the ground assault to complete our bombing and preparatory bombardment. We had to attack on a relatively low tide because of the beach obstacles which had to be removed while uncovered. These principle factors dictated the general period, but the selection of the actual day would depend upon weather forecasts." That's the picture.

---

[1] Dwight D. Eisenhower, "Crusade in Europe", page 239; Doubleday & Company, Garden City, New York, 1948.

CHAPTER 2

THE WEATHER INTELLIGENCE FOR D-DAY AND 40 YEARS SINCE

INTRODUCTION BY JOSEPH WEDERMAN:

Our first speaker is Robert Allan Jr. Mr. Allan attended Stanford. He has worked as an economic planner and has been the head of a number of companies — large ones. Right now, he's the president of the trustees of the Foundation of the Naval Postgraduate School. He was a member of the first air force class in meteorology at UCLA, just before the war. But the real reason we've asked Mr. Allan to talk to us today is that he was the one who gave the weather briefing to General Marshall and other top government officials during the period leading up to D-Day. His topic is "Weather Intelligence for D-Day and 40 Years Since."

THE WEATHER INTELLIGENCE FOR D-DAY AND 40 YEARS SINCE

by

Robert M. Allan, Jr.
Captain, USAAF and Briefing Officer
in Pentagon, 1944

This special meeting of members of the American Meteorological Society has been called to review the weather intelligence that was built up and used in the invasion of Europe in June 1944. This period in May 1984 is just 40 years' anniversary of that final analysis that culminated in the decision to go ahead with the invasion in 1944 and not wait for later that year, or in 1945, for better weather. This decision was perhaps the most-important single decision made in the century as the delay would have allowed Germany to build up the jet fighter plane fleet of ME 262s and obtain control of the sky, and the German atomic bomb was coming into final focus. These factors could only have prolonged or extended the war.

It is a pleasure to be here. In my half hour I want to touch on four subjects. First, I want to acknowledge the excellence of the people who worked in the weather service in World War II and since. I will always remember George Forsythe, a classmate, who went on to become the head of mathematics at Stanford and has the mathematics building named after him; Ken Arrow, who has won a Nobel prize in economics; Cy Phillips who became president of the largest electric utility, Consolidated Edison, from Texas to Illinois; and many others. These three typify the variety of skills at the highest levels that worked on weather. We have the big names in weather science, and I was proud to have studied under Bjerknes and learn of his original ideas of fronts and air analysis. I also went to Dr. Krick's classes while I was still in high school near Cal Tech in the 1936 period. Perhaps my background in Stanford economics, statistics and Graduate School of Business, with analysis of facts for effect, was unique in the class of mostly academic mathematics people. But we needed all kinds, and we still do. Weather, like medicine or law, concerns everyone. But it is not an exact science, and it needs to be applied by people who can bring a variety of backgrounds to the arena.

Second, just what happened in my personal experience during the 1942-45 period of planning and decision making in HQ in the Pentagon, Washington, D.C.? I was first assigned to March Field, California, as weather and part-time operations officer. They were flying Liberator bombers to Alaska and back. During my first weeks, I remember going across the lunch cafeteria with my tray as a brand new second lieutenant and stopping by the commanding general of the local air group who was lunching with the football coach of the highly rated U.S. Army Air Force (USAAF) football team, due to play the navy all-American team for charity in the LA Stadium. I could not resist saying as I passed, "Good luck in the game in five days, and take your mud cleats as it will be a steady hard rain." They thanked me with some puzzled expressions. The following Monday, as I passed the same table, the CO called me over and told the four colonels sitting with him, "Say, this is the best weather officer we have had, and I want you all to take care to listen to him." The point is that I was lucky to have established CREDIBILITY. The same thing happened in the air force; we are very lucky indeed that Irving Krick, in his forceful way, had impressed General Hap Arnold and established a claim that weather for the air force planning was essential and could be helpful for the invasion. As many of you know, Dr. Krick later was made a specially appointed major in the USAAF to help the team effort that was made for weather planning success in World War II. I will be the first to point out that without his ability to get the ear of the top officers, our efforts would have been of little use.

My next job was to set up a verification program under Ken Spengler to see what reliability we could have on longer-range forecasts and any combination of methods. We took in forecasts by Namias, climatology, Krick, the U.S. Congress local astrologer, tree-ring experts, and anyone with suggestions. We then presented the results of our findings. General Arnold was furious with me as he picked out the top method at 84 percent, only to find it was 30 days of persistence repeating yesterday's weather. But he calmed down when I pointed out this was a control figure in statistics. Lieutenants Stein and Arrow were helpful in coming up with a "skill score," and to this day it should be used, as the real skill is in forecasting change, not climatology. In any case, we did find skill, and as Krick to this day says , "All we want to do is to help the house odds to be better than chance." We also found out that certain situations were better for forecasts than others. The system of analogues fitted today's maps to the finger-print file computer (it was one of the first under Dr. Wadsworth of MIT) to see if there was a similar map in the 40 years of north-pole projection maps we had prepared in a search of all weather observations, including explorers and ships at sea.

After my presentation of the verification results, I was assigned to the task of weather briefing in the Air Room, HQ AAF, Pentagon. A

captain at age 23 with a college degree and the equal of four years of graduate work behind me, it was a real rush time in my life and a challenge every day. Major Don Hamlin, the intelligence briefing officer for air strikes and foreign troop movements, assisted me. We soon came up with a combination that I recommend to the military today. That is, I did not just present the weather "cold-turkey" facts; I studied what was important in the world and gave the weather that concerned that operation or problem. Thus, this could be the monsoon in India for the gliders going on invasion there, the typhoon in the path of Admiral Halsey's fleet, or the mud or freezing or clearing for Patton's army; and always I kept touching on the coastal weather patterns of France. I was not concerned with the actual weather decisions. They were made in England by my boss, Colonel Yates, and a fine team of officers that left from our Weather Division HQ. My job was to inform daily the officers in Washington, often the Secretary of War, Mr. Stimson, and even the White House.

With this background, as we came into the spring of 1944, I was ordered to brief General George Marshall. He wanted to know just how much weather intelligence we had and how it could be depended upon. He had heard various rumors, from Dr. Krick saying the problem was solved, to the navy and Weather Bureau men saying it was impossible to forecast in advance of three days. Attached is a copy of the actual paper I presented to him. General Marshall was friendly, courteous, and we talked alone. His questions were to the point. He soon developed the attitude I had hoped for, namely that we did have information of value but it needed the personal understanding of the user. He then ordered a series of G-2 intelligence officers from various staffs into the Pentagon, and I briefed each of them during some other courses they were taking in code breaking, etc. This was leading to the invasion of Japan, already, without Europe solved.

At the end of May 1944, I presented daily briefings and, with the usual ten-day air brush painted cloud-pattern type of weather charts on the stage of the Air Room for the coming period. The northern reaches of the Atlantic were just one front after another. I also volunteered that the coming 30 days would be the worst weather we had found in the last 40 years of charts. This caused a complete uproar in the room; one general went out to get Secretary Stimson, and I was asked to repeat my comments. By now I knew the fat was in the fire, as up to that time I did not have the need to know the specific date of the invasion. Our analogue charts for June 1944, were good fits and with other upper-air analysis from Captain Bob Bundgaard, we had what today would be considered a series of excellent forecasts. The best part of it turned out to be the series of breaks in the storms and the avoidance of the real hurricane that came into the area several weeks later and destroyed the landing docks, etc. The time selected, it now turns out, was the only time possible in 1944 for invasion.

Looking back on the forecasts for D-Day, I think the talks today will show that we had three things going for the United States and allied effort that the Germans then and later did not have: namely, a file of 40 years of weather maps; the credibility factor of the general officers, willing and able to understand the weather forecasts and the lack of the exact science; and third, the Delphi approach to forecasts of the discussions between offices. I give credit to Cal Tech and Krick for the initiation of all these factors. Our team carried these items out and Krick should not say it was his effort alone, but certainly he was the prime mover in this epoch of weather forecasting.

I have no proof of this, but I am sure from other comments that the generals and Marshall had contact with Eisenhower prior to the final forecasts presented by the staff in England and, based on what we presented in Washington, D.C., the personal friends of Eisenhower encouraged him to go ahead and to accept the American view that the weather did have breaks and was possible for the invasion.

Now, I have told this story without science or historical academic style notes. I could spend hours on methods, the exact forecasts, the exact persons in the room, etc. but, in this short talk, I wanted to give you the flavor of the forecast, who made it, and why. A copy of the briefing to General Marshall will give you some further details and background reference to my facts. My life has been spent in economic forecasting, management of large corporations, and some personal long distance ocean racing in sail boats. In these pursuits I have used the methods of fact gathering, skill in analysis, and briefing that came to me in the weather forecasting five years of my life.

This has been interesting to spend this time with you on history, but before we close I have two more of my four points to share with you. Third, in the 40 years since 1944, it has been my observation that the use of military and civilian weather skills and intelligence has gone downhill. One of the ways to solve a problem is to know you have a problem. The weather services of the military or civilian side do not understand what they are missing in communication. Most important, if I make no other point clear today, is to make the forecasts relevant to the needs. The other side of the problem is to pre-educate the user.

In closing, my fourth point is to seriously and officially ask that the American Meteorological Society set up a committee to study the failure in weather communication during the past 40 years and work with the military and weather civilian forecast chiefs to correct this problem. It <u>starts</u> in the education of forecasters. To be specific, I think all forecasters should be required to attend schools every five years and build up their skills in communication. The weather services should make their addresses and the names of local chief forecasters <u>known</u> to the public. Media, TV, and newspapers should be approached to improve the image and use of weather. Important events should be listed and forecasts tied to them to bridge the gap to

users. Users should be encouraged to attend seminars to find out about weather.

PENTAGON BUILDING
BRIEFING OF GENERAL MARSHALL IN MARCH 1944

by
Robert M. Allan, Jr.
Captain, Weather Division HQ USAAF
Washington, D.C.

The development of new weather instruments and forecasting techniques, the scientific study of climatology, and the establishment of weather stations all over the world have made international weather planning a reality, and this war has put it to a critical test.

The Weather Division of the U.S. Army Air Force has investigated any type of forecasting method that showed promise. These investigations included enemy and allied techniques as well as our own. The division has found that a combination of forecasting methods is necessary, and the tool must be chosen to fit the task. In all cases, however, the reliability of the weather forecast is proportional to the amount of data available and the length of the forecast period.

The following lists the steps by which weather information is processed by the Weather Division in the Pentagon.

1. Every six hours individual stations throughout the world transmit observations of temperature, pressure, winds, clouds, rain, and other relevant weather data. As these observations are synoptic, i.e., taken at the same moment, a cross section of the earth's weather can be prepared.

2. The shorthand reports of the individual-station transmission are received in the Pentagon and plotted on a polar projection map of the Northern Hemisphere. A complete analysis of the map is then accomplished by trained weather officers. On these analyses the storm and pressure patterns around the world can be seen completely four times every day. This is the first time that such a weather map has been attempted. As the analyses are made for 10,000,20,000, and 30,000 foot levels, as well as the surface, weather over the great surface distances and extreme upper-air heights covered by modern aircraft can be foreseen.

3. The completed analysis is transmitted twice daily to the U.S. Navy, U.S. Weather Bureau, the Russians, and the British. The completed map is also coded and sent to the U.S. Army forecasters who employ it to supplement their local analyses in preparing one to two day forecasts for the tactical uses in the air, ground, and service forces.

4. One of the techniques used by the Headquarters Weather Central is the analogue approach. This method attempts to find weather situations in the past which were similar to the present day's weather and then make a forecast on the basis that "history will repeat itself" to some extent. The most important tool in this method is the file of 40 years of past maps analyzed by modern methods from collections of ships' logs, city records, etc. There are three methods of picking these analogues:

   a. The system most often used is an IBM machine sorting of punch cards, each of which represent the "fingerprint" of past weather patterns.

   b. A color graph is also useful as each colored square shows the type of air flow and general storm pattern on each day of the past years. By matching colors for several days with the present weather series, a historical sequence can be located.

   c. The third and most complicated means of obtaining the analogues consists of a statistical and mathematical means of identifying the map analyses so that objective comparisons are possible.

5. The case shown in an illustration indicates that the weather on 15 February 1934 was similar to that of 9 March 1944. This date is sent to the field forecasters who do not have the means of selecting the analogue at local stations but do possess a file of 40 years of maps.

6. A very important function of the Weather Division is the compiling of climatological records and estimating of the average weather to be expected in any part of the world during any season for the use of strategic planners and as a guide for the forecasters. Through the use of the IBM punch cards and the material gathered from the 40-year file of maps, this work can be accomplished in the most efficient manner.

7. Using the current weather analysis for all levels of the atmosphere, the past averages indicating what will most likely occur in the future, and the deviations from normal which are suggested by the analogue maps, the forecaster then prepares his forecast.

8. All forecasts issued, all techniques, enemy methods, and new uses of weather service are tested and verified. The accuracy of the forecasts declines with length of period, but by making intelligent use of climatological averages the forecaster can supply long-term outlooks that remain superior to a random guess of what weather will occur.

* * * * * *

Other samples which were presented include the following:

a. A complete Northern Hemisphere map with pressure systems, frontal patterns, and individual reports.

b. One of the color graphs used in the analogue process. Each square representing one day's weather during the past 40 years.

c. One of the books (containing the weather maps for 1934) from the 40-year map file.

d. A climatological study of France showing the relation of weather to military operations in that area.

e. The 10-day forecast book which is released once a week with forecasts and climatological averages for 60 stations throughout the world.

f. A table presenting the accuracy of the forecasts as to time elements predictable, geographical accuracy, and percent correct for each length of period.

General Marshall requested this briefing prior to final plans for the invasion of Europe and in foresight for invasion of Japan. He was alone and was very interested in the methods, and the accuracy. He was more interested in understanding the proper use of weather intelligence to fit the task at hand.

He personally set up further meetings and called in a series of G-2 (intelligence) staff officers from various commands during the following months, and they were each briefed on the importance of weather in planning, and how to get information that was useful.

All these briefing sessions were also conducted by Captain Robert M. Allan, Jr., under direction of Colonel Don Yates and Colonel Keene Watkins, U.S. Army Air Force Headquarters, Weather Division.

Analogues Selected for D-Day Invasion 1944 (Krick's recall)

June 15, '38 matched 29 May start date
May 12, '34 matched 5 June start date
June 19, '27 matched 31 May start date

CHAPTER 3

EISENHOWER'S METEOROLOGICAL SUPPORT FOR D-DAY

INTRODUCTION BY JOSEPH VEDERMAN:

Dr. Sutcliffe, who was one of the top forecasters in the office of the commander in chief, writing about D-Day said, "Meteorologically the occasion was remarkable not only for the degree of dependence on the weather but also the planned dependence on weather forecasts. Perhaps the greatest compliment ever paid to the science and organization of meteorological services was the decision by the great powers to assign an essential role to the weather forecasts to such a degree that they could be, and in the event actually were, critical for the final decision taken by the Supreme Commander, General Eisenhower." And then he goes on with one more sentence I think is interesting: "There were two aspects of the meteorological service for Overlord and which of the two was the more vital, more troublesome, is certainly arguable. These were the organizational and the scientific."

Our next speaker is Richard Simon who is going to give us an insight into the organization that supplied meteorological guidance to the supreme commander. Richard Simon is chairman of the Northern California Chapter of the American Meteorological Society. He received his meteorological training at San Jose State University. After graduation he worked as a meteorologist for Pacific Gas and Electric Company. Right now he's a consultant in wind energy.

EISENHOWER'S METEOROLOGICAL SUPPORT FOR D-DAY

by

Richard L. Simon

I will discuss primarily the organization and ultimate formation of the weather support services for D-Day. As you'll probably guess by looking at me I wasn't very old, in fact I was minus seven at the time, so I'll leave most of the details to the following speakers.

First I'd like to discuss the creation of the meteorological support group to advise the invasion planning staff and the supreme allied commander. In the fall of 1943 initial plans were formulating for the D-Day invasion, which was at that time expected to be in mid-1944. This would be one of the largest invasions ever undertaken, combining air, land, and sea forces of both the United States and Great Britain. All of these various armed forces already had their own forecast capabilities, and the planners realized that people would insist on continuing to make their own forecasts for their own invasion forces. This did make sense for reasons of continuity, specialization, and even pride. But because Overlord was such a grandiose operation, there was a need for the supreme allied commander and his invasion staff to have unified weather support. A precedent for this had been set earlier in the war both with the British Bomber Command and the U.S. Eighth Air Force, whereby several people would generate a single forecast via telephone. In November of 1943 the decision was made to create a two-person meteorological group which would include a senior post staffed by Great Britain and a deputy post staffed by the United States. Dr. James M. Stagg, a civilian of the British Meteorological Office, was selected for the senior post. Stagg was currently managing the British Army Weather Services and coordinating forecasts with the British Army and the Royal Air Force; thus he had some experience in getting people to cooperate on a forecast. Colonel Tieman was the U.S. Army Air Force person chosen initially for the deputy position. It was ironic that the Germans had simultaneously created their own forecast team to advise on the forecasts for potential invasion dates.

This two-man staff had three initial tasks. The first was to establish a climatology of the invasion operational area which would also be helpful in an input for D-Day selection itself. Past studies of the general climatology for the English Channel area had been made, but they conflicted grossly and were really of no use. The second task was to determine the operational weather requirements for a successful invasion. And third, perhaps prematurely, was to plan the post-invasion continental weather support and coordination. I'd like to focus on the first two. Stagg had been told that the invasion was planned for Normandy on the beach west of Cherbourg for May 1944 or a few months after.

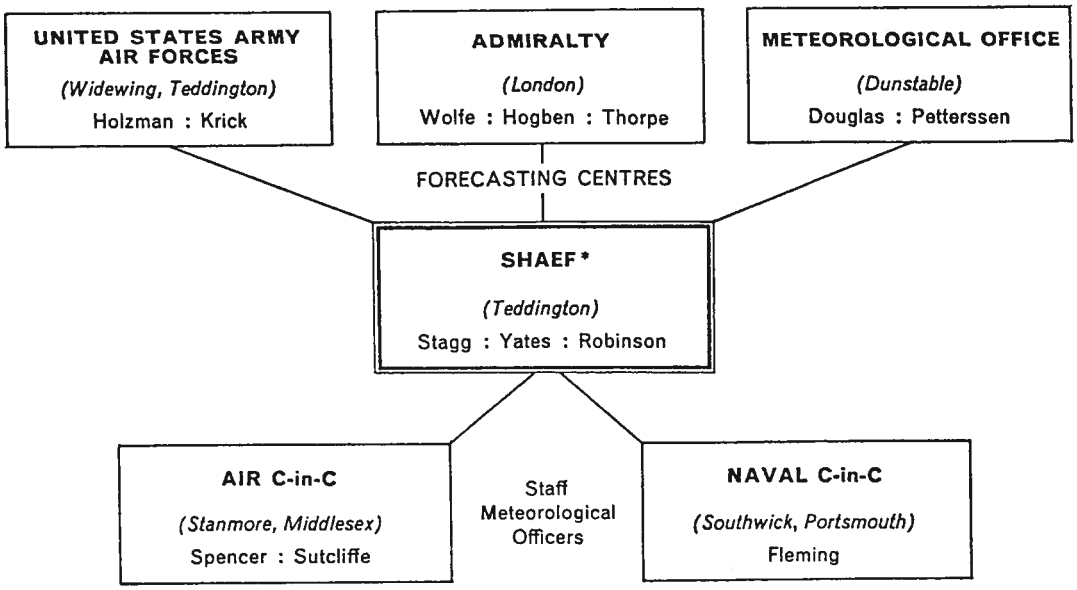
What were the weather requirements? The navy basically wanted light winds, good visibility, and no substantial swell in the channel. The air force was looking for various cloud cover and ceiling heights or minimum heights for different types of aircraft. The army wanted dry ground, certain light, visibility, and wind requirements, and a cloud-cover requirement for landing paratroops. Finally, low tide was important to avoid the beach obstacles and mines. Stagg, in his book Forecast for Overlord, notes that had we waited for the ideal conditions to occur, the invasion troops would probably still be in England now, waiting.

Stagg's and Tieman's task was to distill all these wish lists into one set of weather parameters that all branches could agree on. Stagg, in his book, notes that complete agreement was never achieved, but he came up with a fairly complex set of requirements at different times. In fact, the ideal weather conditions would change during the invasion and particularly in the immediate hours of the initial landing on Normandy. So once Stagg found out exactly where the and approximately when the invasion was to take place, he focused his climatology on this. Of May, June, and July, he determined that June would be the most favorable climatologically. Even still, the odds of the correct weather and tide were only about one in 25 or 30.

Now I will discuss the forecast teams involved. Eisenhower was appointed as the supreme allied commander in January of 1944 and the Supreme Headquarters of the Allied Expeditionary Force (SHAEF) was established in Teddington, which is just south of London. After Eisenhower consulted with his staff, the decision was made that five-day forecasts would be produced and the trial forecasts would begin in mid-February 1944. Figure 1 shows the Overlord weather forecast organization. There were three forecasting centers: the U.S. Army Air Force at Widewing, and two of those people are here today, Dr. Krick and Bob Bundgaard; the Admiralty Office, and Charles Bates is here today; and the Air Ministry Meteorological Office of Great Britain, represented today by Dr. Johannessen. The coordinators, the SHAEF team, were Dr. Stagg, and a Colonel Yates, who had replaced Tieman by this time, and George Robinson later on. Dr. Robinson is here with us. Finally, we have chief meteorological officers for the commanders in chief.

Yates had been the chief of all U.S. Army Air Force weather operations in Europe. Royal Air Force Squadron Leader Robinson joined the staff near the critical time just before D-Day, from approximately 1 May through 15 June. He was also the only person to take part in every single weather discussion after 1 June. The Widewing team was also based in Teddington and had several sections: a surface section run by Major Bounds; an upper-air section headed by Colonel Bundgaard; and four long-range forecasting sections. Lieutenant Colonels Benjamin Holzman and Irving Krick shared the briefing responsibilities in the overall forecast discussions, and were from the long-range section. Holzman and Krick had double duties as meteorologists, working also for General Spaatz who was the commander of the U.S. Strategic Air Forces in Europe, and they often worked overlapping 24 to 36-hour shifts. The Meteorological Office in Dunstable, fairly far north of London, had two weather leaders: a civilian, Mr. C. K. Douglas, who headed up the surface section, and Dr. Sverre Petterssen, who had been recently appointed as the upper-air leader. These two had very different personalities. Douglas seemed to be a "seat-of-the-pants" forecaster with a lot of experience who didn't really believe that forecasts beyond 12 or 24 hours were possible and often refused to make them. Petterssen, however, had been developing the whole concept of upper air-monitoring, and using upper-air data for forecasts was fairly new at the time. The Admiralty Office was in London with Thorpe, Wolfe and Hogben. Actually it was Wolfe and Hogben who did the briefings for the Overlord forecasts. Initially their participation was only to interpret the weather forecasts into a sea-state forecast. However, as time went on they took an increasingly greater part in the discussions. Finally, the staff meteorological officers of the air and naval commanders in chief mostly acted in a listening mode but were free to contribute in the discussions, and their agreement was not required to fashion the forecasts.

The joint forecasts were made by conference telephone call. The telephone conversations were electronically scrambled. Also, since it was very important to keep the actual date of D-Day quiet, there was top secrecy in this procedure. The people who made the forecasts were really about the only people at the forecasting center who knew that this was going on. As I say, the initial trial forecasts were made in February, four months before the invasion, so it was really a great job to have kept it a secret. Starting in February, there were two to three conferences per week to make the five-day forecasts. Stagg or Yates, as the SHAEF representative, whichever one happened to be there at that time, would be the chairman of this discussion. By mid-April the forecasts were being made daily, and in May there were three per day, particularly when large-scale exercises or operations preceding D-Day were occurring. These discussions were held at 5:30 P.M. (double daylight time), 9:00 P.M. (which was the main one). and an update the next morning about 7:30 A.M. In the days immediately preceding D-Day, forecast discussions were also held at 3:00 A.M. making it an around-the-clock venture.



*In the final stages the SHAEF Advance Command Post (Stagg, Yates) was at Southwick House, Portsmouth.

Figure 1. Schematic diagram of Meteorological Conferences by telephone.

The actual routines of making a forecast, were very different from today. For example, there was no facsimile transmission at the time, although it was installed later on in 1944. Therefore, the first thing the forecasters had to do was insure that they were all looking at similar maps. Occasionally this created some problems. One might expect a relatively sparse data network to have existed in those times; however, there was actually a fairly good surface and upper air coverage over the Atlantic as D-Day approached, due to the many military

operations going on. There were also problems in decoding the weather transmissions which occasionally led to discrepancies in the map analyses.

Once the forecasters established that they were looking at the same maps, a representative from one of the three forecasting centers would describe the current weather, how it evolved, and his center's prognosis for the next five days. Upon completion of this, the other two forecasting centers would add their ideas and comments. If the three were in basic agreement, the SHAEF team, Stagg and Yates, could easily fashion a forecast acceptable to all. As you can well imagine, this rarely happened, and never after April 1944. Often there was disagreement, and a discussion would ensue. More often than not there was at least a general agreement for the first two days and then a wide divergence on the forecasts out to days three and five. It generally required one to two hours to produce acceptable wording for a forecast. Several heated exchanges often took place, especially as D-Day approached. In general, the United States team from Widewing tended to make very specific forecasts of all weather elements for the entire five-day period. Dunstable, the British Meteorological Office, preferred to be more general, and the Admiralty was typically the most passive. Eventually the forecasts were agreed upon, even under duress, because about an hour and a half after the discussion began, Stagg or Yates had to go to Eisenhower and his commanders-in-chief and give the briefing. After 1 May 1944, Eisenhower had the forecast team project tentative days suitable for D-Day. For example, if there was any day, two days or more in the future, in which the forecast would call for weather suitable for D-Day, Eisenhower wanted to know about it. This procedure helped train the people for the time when it was really required. It turned out May 1944 had very quiet weather, and 18 dates (some overlapping, some the same date) were forecasted as suitable for D-Day.

Next I'll talk briefly about the forecasts for the days immediately preceding D-Day. On 22 May the forecast teams were officially given notice that 5 June had been selected for D-Day. On 28 May, eight days prior to this, two things happened. The first forecast was made for 5 June. At that time, all forecasting centers were optimistic as to the weather. Also on this day, Eisenhower and the entire SHAEF staff moved to Southwick House at Portsmouth on the English Channel. Stagg and Yates had to go back up to London because the telephone conference capability had not yet been installed.

During the last two days in May, the weather began showing signs of change. Strong upper-level westerlies were blowing across the Atlantic. There was a large pool of Arctic air to the north, and the weather situation was threatening. As May turned into June, Widewing, the United States team, kept a very optimistic outlook for 5 June, expecting a high pressure extending up from off the French coast to shunt the storm well to the north. By 31 May, however, Dunstable had changed to a pessimistic forecast, expecting low clouds and strong southwest winds which, of course, would be unsuitable for the invasion.

The rift between the two teams seemed to grow more entrenched as the days went on and the opposing dichotomous forecasts continued right up to the late evening of Saturday, 3 June, only one day before the proposed date of the invasion. Late in the evening of 3 June, all groups finally realized that a significant cold front would be passing late on 4 June and during the morning of 5 June. By this time, however, preliminary maneuvers had already been started to launch D-Day. Eisenhower made the decision at 4:15 a.m. Sunday, 4 June to postpone the invasion one day. Because of the tide situation, there were only two days out of every 14-day period that would be suitable, so if the invasion didn't occur on Tuesday, 6 June, it would be postponed to at least two weeks later. On Sunday, all forecasting groups expected clearing weather after this frontal passage but were unclear as to how long the clear weather would persist. Widewing called for a significant rebuilding of the high-pressure ridge with 36 hours, bringing fairly good weather. Dunstable expected only a temporary clearing. By late evening Sunday, all groups had changed and looked for a major clearing. Eisenhower then made the final decision to invade on 6 June.

It is interesting that the decision to postpone D-Day was made when the weather was perfect and the decision to reinstate D-Day on a new date was made in the middle of a major storm. The cold front that passed through was a true winter-like storm. The lowest June surface pressure in Great Britain in over 60 years was recorded. The facts show that the invasion would have been a disaster had the original 5 June data been kept.

After this strong front passed, the storm center made an unexpected turn to the southeast. No high pressure ridge built up behind the front, and this caused the winds to be fairly strong. Conditions were marginal, but adequate; however, the weather did cause some casualties. Over the next 10 days the weather was fairly unsettled, but sufficient for getting more of the invasion troops over. It also turned out that 6 June was the only suitable day for the next two months that could have been chosen for D-Day.

Finally, just a comment on how effective was this type of weather forecast group. Many of the key personnel who made the briefings have written, since the war, that it was an unwieldy method and that probably the best way to have done this would have been to have a joint forecast team. That would have yielded a smoother operating procedure. I'll leave it for the other speakers to comment personally on this. The fact does remain that, in spite of all the difficulties and the cumbersome nature of the forecast procedure, the forecasts were successful at keeping the invasion from happening 5 June when it would have been a disaster, and suitably forecasting the weather on 6 June, even though it did deteriorate. I thank you for your time.

QUESTION: Did the German forecast team accurately forecast the weather on this day? If so, did they not expect an attack by the allied forces?

ANSWER: The answer to that is they expected the weather to be so bad that they did not expect the allied forces to attack, and had called some of their key people and some of the key commanders away from the front lines.

CHAPTER 4

FORECASTS LEADING TO THE POSTPONEMENT OF D-DAY

INTRODUCTION BY JOSEPH VEDERMAN:

What were the techniques meteorologists had 40 years ago to forecast the weather? They were persistence, extrapolation, climatology, and experience. But just before the war another method was being developed. That was the use of upper-air data. A leading practitioner of this method was Colonel Robert Bundgaard. He was at Widewing with Colonel Yates, and Holzman and Krick. Within a few days after D-Day, Group Captain Stagg wrote a letter to the director of U.S Air Force Weather Service, and it said a lot of nice things about Robert Bundgaard. I'll read only the first paragraph. "Now that the first and most important meteorological decision related to the allied assault of western Europe has been made, I would like to express through you my gratitude for the help given me by the staff of the U.S. Air Force forecasting central, and particularly for the contributions to the advice given to the supreme commander by Colonels Holzman and Krick and Captain Bundgaard." Robert Bundgaard is going to discuss the forecasts leading up to D-Day.

PRELIMINARY REMARKS BY ROBERT BUNDGAARD:

It's a really remarkable thing that we are experiencing here today. For the very first time, we have the Admiralty weather, Dunstable weather, Widewing weather, and SHAEF (Supreme Headquarters of the Allied Expeditionary Force) weather together in the same room. It's never happened before. And you would think that with such a complex problem as was faced by this group, they should have an eyeball relationship. This never existed. But I think the AMS chapters here in northern California need to be complimented for making possible this occasion and not only bringing together these three centers and SHAEF weather, but also giving us a chance to look back on a very memorable occasion.

I've been trying to think what my contributions could be here this morning and at first I became very nostalgic, and vanity crept in, and I thought of all of the many experiences that I shared with many of you here. But it finally occurred to me that there would probably be just two points that might be worthwhile carrying away from the meeting here in Monterey today, and I would like to try to present those points and give some support to them. The first one is this: the invasion was made under a weather situation that was very, very marginal resulting in a postponement from the fifth to the sixth because of bad weather, high seas, large surf and breakers. I think that's a very important point to remember. We are talking about a post-analysis or a hindsight situation that shouldn't be very controversial; but it's not altogether sure that the postponement was absolutely necessary. Many of us believe it was and there are some here today that have taken the thought that perhaps we could have gone in on the fifth. In other words, it depends again on observations, so even in today's world with the progress in the science of forecasting, we're still faced and plagued with the idea of what actually happened. But anyway that's the first point that I would like to talk about. Now the second one is closely related to that and it follows from the marginal weather, the short period of improvement, and the postponement. Some say that the controlling factor that led to the success of the invasion was the postponement of the forecast. I don't think so. I think it may be possible that the postponement was a controlling factor but I really think the determinant factor that led to the success of the invasion was the optimism of the long-range forecast that Widewing put out that set the sluggish invasion armada into motion. Without that having been established, the invasion would never have taken place. Then the long-range forecast was timed with short-term forecasting that led to the success of the invasion and the most-important thing fell from that: it caught the enemy completely and totally surprised. The element of surprise, which comes from the principles of war, certainly existed as a result of the long-range forecast that put this armada into existence: a four-day operation that took place and was eventually executed in a period of 36 hours. It caught the German defense completely by surprise.

FORECASTS LEADING TO THE POSTPONEMENT OF D-DAY

by

Robert C. Bundgaard

On the battlefield, many military strategists often place much emphasis in getting the best weather conditions, rather than just the good, and have little interest for the barely useable. But, for Overlord, the meteorological problem was not to choose an ideal weather situation, but to examine certain days known beforehand, as to the weather, wind, and sea conditions that would meet the minimum demands, together with the combination of tide and dawn twilight.

The main military requirements for Overlord are, of course, now well known — favorable combination of tide and predawn twilight, for landing at the very lowest tide before daybreak. Whereas in June, the duration of civil twilight varied little from day to day, the time of low tide advanced 50 minutes a day. The landing forces must have just the right amount of morning twilight, not too much, not too little. Landing operations would not be effective during the first 10 minutes of the beginning of dawn civil-twilight. And, it would take an estimated 30 minutes of dusk for the first landing barges to get through the underwater defenses undetected.

For 4 June, the duration of useable twilight was only 15 minutes — not long enough. 5 June with 50 minutes was the most ideal; 6 June, about the same. But, 7 June had about two hours of predawn dusk after the lowest tide; and that was much too much. The next possibility was 14 days later.

As it turned out, the invasion was carried out under a weather situation that was on the edge of being minimal, in a period of short improvement within a longer period of storms in which the final crossing of the channel was postponed from the fifth to the sixth because of bad weather, high seas, and large surf and breakers. This is a personal account of the American forecast effort leading to the postponement of D-day.

First, a few words about the organization for Overlord forecasting. The Overlord weather organization was established in November 1943, at which time the United Kingdom's Dr. James Martin Stagg, as a civilian, became the chief meteorological officer to General Eisenhower, the supreme commander of the Supreme Headquarters Allied Expeditionary Forces (SHAEF). Stagg was later assigned Colonel Donald N. Yates, an American, as his deputy and Royal Air Force's (RAF's) Squadron Leader G.D. Robinson as their assistant. Not a forecaster, Dr. Stagg's field of work was always in earth magnetism and, to a lesser extent, in solar radiation — subject areas in the periphery of practical meteorology. Just seven weeks before D-day, Stagg was mobilized by the RAF to the rank of group captain.

For Overlord, the three participating forecast centers have been referred to as United King Admiralty, in London; the Air Ministry's Meteorological Center at Dunstable, well to the north of London; and United States' Widewing in Bushy Park at Teddington, which is south of London. The Admiralty was led by Royal Navy Captain L. G. Garbett, RN, a brother of the Bishop of York, with meteorologists Instructor Commander Wolfe, RN, and Instructor Lieutenant Hogben, Royal New Zealand Navy, providing the main weather-briefing support. At Dunstable, which had no single weather leader, the chief of the surface section, designated M.O.2(a), was a civilian, Mr. C.K.M. Douglas, with 25 years experience, having been involved in aircraft weather reconnaissance in World War I. The head of its upper-air section, M.O.2(c), was a Norwegian civilian, Professor Sverre Petterssen. Although Petterssen had been commissioned a lieutenant colonel in the Norwegian Air Force, he wore his uniform only when he traveled military. With independent responsibilities, Douglas and Petterssen made separate forecasts. In M.O.2(c), Petterssen also prepared five-day mean maps of sea-level pressure daily as part of his assigned effort for making long-range forecasts. Douglas had simply refused to make anything but short-range forecasts 12 to 24 hours ahead.

The third forecast center, Widewing, the American weather center, was colocated with SHAEF and the supreme commander. It was no accidental location. From the Pentagon's Directorate of Weather, the nucleus of Widewing was made up of a contingent that Colonel Don Yates was asked to take to General Carl Spaatz's headquarters for the United States Strategic Air Forces in Europe (USSTAF). SHAEF was later located with USSTAF at Bushy Park.

Widewing, which Yates commanded, was an involved organization. In addition to the surface and upper-air sections, which respectively were headed up by Major R.G. Bounds and myself, there were four small long-range forecast units, denoted LRFA to LRFD. Earlier at the Pentagon, Major Joseph J. George had adapted his Eastern Airlines North American analogue system to the Northern Hemisphere for making long-range forecasts. The practice of

this system was carried out at Widewing by the LRFA headed up there by Captain Rodney Jones. The LRFB, headed by Captain William H. Wyatt, applied California Institute of Technology's five-day weather type system, previously developed there by Lieutenant Colonel Irving P. Krick. The LRFC was a hodgepodge of symmetry points, Bauer, and periodicities carried out by Captain Donald T. Perkins and Lieutenant Morrison H. Beach. LRFD was a statistical method for supplementing the synoptic extrapolation of upper-air forecasting three to six days ahead, and was an integral part of the upper-air section. There was also a climatology section. Lieutenant Colonels Benjamin P. Holzman and Irv Krick, who provided technical direction to all these sections and units, shared briefing responsibilities under Yates. Yet, in spite of its complex organization, Widewing always sought to come up with a single, unified forecast, through a disciplined process that had been routinely practiced earlier back at the Pentagon under Joe George. In his book, Stagg compared Widewing favorably with Dunstable from which internal forecast disagreements would sometimes surface in the telephone conferences.

Actually, many felt that there should have been an Overlord joint forecast center, a colocated group working together at SHAEF, a unified group not interested in nationality, but one with personal contact among its participating allied meteorologists. Instead, Overlord would employ the normal and existing weather services of the allied participants at their separated forecast centers. Yates felt that the type of organization which had been planned to do the job

> ....was unwieldy as well as impractical from the outset. I understood at the time that the logical establishment of a forecast team at Supreme Hq. with joint membership was vetoed by the British. Ostensibly this would have provided too much Widewing influence. (A letter from Lieutenant General Yates, retired, dated 8 May 1979, to the author.)

In the months before 5 June the weather work at Widewing was to be carried out at just the same pace and attention as during February, so that no one else in the upper-air section — some 40 meteorologists and technicians — were to suspect that the invasion was impending and to detect or identify its date ahead of time.

In February, "scrambled" telephone conferences were quietly instituted between the three central forecasting centers, with Stagg acting as a spokesman among the centers' briefing meteorologists. Early in the spring, the conferences were held two or three times a week on five-day forecasting. For Overlord, forecasting four to six days ahead was a SHAEF requirement which Stagg had accepted; for, as he says in his book (p. 39), he never told any of SHAEF's commanders in chief that it could not be done, even in forecasting the individual channel weather constituents. From mid-April onward, the conferences were held twice daily. During much of May, they were held three times daily. And on the days immediately preceeding D-day, a further conference was held at 3:00 A.M. each morning for a briefing to Eisenhower at 4:15 A.M. Group Captain Stagg spent hours each day in Widewing, poring over its maps, a convenience for him since he had none of his own and since he was there because he was General Eisenhower's personal staff weather officer for Overlord.

The Overlord telephone conferences were not at all similar to those that had worked so well for Widewing in providing advice to the Eighth Air Force and its strategic bomb wings and squadrons throughout England. Each had its own forecast unit, and there was a fully equipped and well-staffed forecast center at High Wycombe, where Headquarters Eight Air Force was located. Their telephone conferences with Widewing were entirely consultative and were chaired by the staff weather officer in charge at Pine Tree. He alone was responsible for the advice, based on his own forecast work as well as that from Widewing. The purpose of the phone conference was to achieve general coordination. The phone conferences worked so well because the area of interest was a rather narrow one: take-off visibility, enroute winds, and icing, cloud cover at target, ballistic winds, and densities with altimeter settings for the Norden bomb sights, and for fog or no fog on return to base. And importantly, the forecast period was only for 18-hours ahead. Secondly, all participants were American and broadly in the same age group. They had a fairly uniform background, training, and experience, and they all knew one another personally. All shared the same responsibility and were eager to receive and give help.

By D-day there was a very considerable amount of upper-air weather information available (Fig. 1). The coverage was not as bad as thought. In the British Isles, aerological observations were made four times daily, at 00, 06, 12 and 18Z; here in North America, twice daily, at 04 and 16Z. And, there was an extensive RAF aircraft weather reconnaissance over the oceans. Some of the main tracks are shown in Fig. 1: low-flying Halifaxes, mid-level Lancasters, and high-flying Mosquitoes. The Luftwaffe weather reconnaissance was equally outstanding. The weather reconnaissance flew at 950, 750, 500 and occasionally at 300 mb. They also made "thumbs" or spiraling ascents and descents for taking aerological soundings.

About 300 nautical miles west of Ireland and Scotland, two stationary German subs surfaced regularly to make synoptic observations. West of the British Isles, there were also two allied surface weather ships that made upper-air balloon soundings. The Germans manned and operated a special weather observation station in Ireland.

In many respects, as far as weather was concerned, World War II warfare support was rather agonistic, being carried out and fought according to special game rules. This was especially true in the weather field, because of the past international character of meteorology. For example, almost daily, the Luftwaffe weather reconnaissance out of Brest and the R.A.F. Lancasters out of St. Mawgen, in Lands End, would meet over the water and rendezvous in the

Biscay area, saluting one another with wing dips. And those allied planes maintaining surveillance over the two German weather subs were carefully instructed, I was told, not to bomb them. Due to an error, however, one did. And, the next day or so thereafter, in retaliation, one of the allied weather ships was torpedoed and sunk by the Germans.

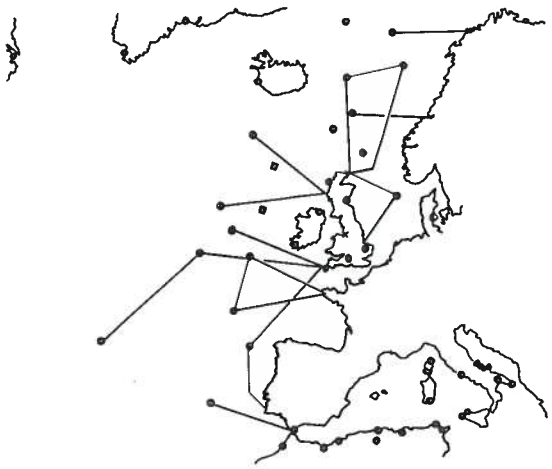


Figure 1. Location of upper-air stations and aircraft weather reconnaissance tracks at the time of Overlord, 1944.

Not as synoptically available nor as reliable as the British observations, aerological observations were also received from the Soviet area. Out of Uxbridge, in England, Colonel Thomas S. Moorman, commander of the 21st Weather Squadron and staff weather officer to the commanding general of the Ninth Air Force, operated a 40th Mobile (Weather) Communications Squadron detachment at Poltava, near Kharkarv in the Ukraine, that acted as a weather relay center for Russian weather data. The Eight Air Force would occasionally stage in and out of an airfield at Poltava on its long bombing runs into Poland. Finally, there were also the valuable, but delayed, aircraft observations from the American Air Transport Command's ferry routes across the North Atlantic. And there were the British sferic observations from England over the Atlantic.

The U.S. Army Air Force had a Directorate of Weather in the Pentagon, Room 4D260, and operated a weather center there. The center, which had already converted to constant-pressure upper-air analysis, provided Widewing with coded upper-air analyses on a current basis twice daily for the area of North America and the western Atlantic. At Dunstable, however, the upper-air analysis extended westward from the British Isles into the Atlantic only to about 50 degrees west longitude; this presumably handicapped the British interest and effort in extended forecasting. The American areal extension of the upper-air analysis as far west as to the Pacific was very important to Widewing in its long-range forecasting efforts with the planetary waves in the upper westerlies.

As a matter of fact, one of the functions of the upper-air section at Widewing was to prepare, collect, and transmit the European and Soviet upper-air observations to the Pentagon. And, believe it or not, throughout the war, all European radiosonde stations transmitted just their observed raw data. Thus, one of the main housekeeping jobs of the Widewing upper-air section was to work up the soundings, getting both constant-pressure heights as well as the constant-level pressure data (for Jerry Namias) for all map levels. Many European radiosondes in World War II then did not have a sensor for making humidity observations; so that limitation created added considerations in estimating the virtual temperature and getting compatible heights throughout the area of analysis.

Even so, one of the most prominent efforts in the Widewing upper-air section was that of estimating constant-pressure map heights from surface weather observations, especially from ships, in areas of sparse aerological data, using the methods of indirect aerology. Indirect aerology was sometimes the only source of upper-air information over the continent.

Needless to say, because of the practice of indirect aerology as well as the need to work up by hand the radiosonde data in the upper-air section at Widewing — as well as the other problems associated with delayed wartime communications and coding and breaking of codes — the whole process of upper-air analysis and forecasting was much slower and more delayed than it is now. And that delay increased the need then for pushing the forecasting further into the future and for lengthening the forecast period to 72 hours ahead. And, of course, military planning of missions, which was the main support responsibility of the upper-air section at Widewing, itself also demanded more than the customary short-range period forecasts.

It turned out that one of the main functions of the Widewing upper-air section was to make extended upper-air forecasts, including the surface maps and attending weather. These extended upper-air forecasts were for 72 hours ahead (twice daily and, experimentally, for 144 hours into the future). The method of extended upper-air forecasting was by statistical and synoptic extrapolation.

For the background of the method, one goes back to a year or two earlier and to the Pentagon. I'd been assigned at that time to the U.S. Weather Bureau, there to work at 24th and M Streets, Northwest, in Washington, D.C., along with Cecil Gentry and Gordon Dunn, under that grand old man, the dean of meteorology, Charles Mitchell, to learn how he made his five-day forecasts. Mitchell's shop was adjacent to Namias' long-range section as well as Bob Elliot's U.S. Navy long-range weather-type section. And, there, I tried to absorb all I could from all three groups.

At the same time, there was also an aggressive interest made in applying statistical extrapolation to weather forecasting, following the works of Wold in Sweden, Kolmogorov in Russia, and Norbert Weiner in the United States, with the aim to derive long-term empirical relationships between upper-air structures and developments at sea-level. Set up by Major Kenneth Spengler, a group from MIT tried to help

translate Mitchell's methods, especially into regression equations for predicting the residual 500mb heights. These persons were MIT's George Wadsworth and his assistant Joe O'Brian, who were working under Norbert Weiner. Another in the background of the effort was Lieutenant Kenneth Arrow, now at Stanford University.

The Widewing upper-air section had about 40 people practicing the LRFD method on a twice daily basis, making a basic 72-hour forecast, but attempting also to occasionally crank out a six-day forecast. It was based on a combination of statistical and synoptic extrapolation. At Widewing, the 500-mb progs were cranked out using desk calculators. The process is described in a 317-page AWS Technical Report (R.C. Bundgaard, Series 105, No. 30, published in 1944).

In some respects, 28 May became a turning point in our work at Widewing. The supreme commander, with Stagg and Yates, and key members of his staff, moved to Ramsay's Mess at Portsmouth, leaving Irv Krick and Ben Holzman at Bushy Park, along with G.D. Robinson, from the meteorological office of the Air Ministry, to participate in the telephone conferences. The next day, however, both Stagg and Yates did return briefly to Bushy Park for a three-day stay there.

From the point of view of large-scale features of the upper westerlies, the synoptic situation leading up to D-day may be summarized as follows. Figure 2 is a 500-mb "DN," or height-departure-from-normal chart for 4 June at 00Z, shown here at 200-foot intervals. Height lines below normal are continuous; above normal, dashed; and normal, heavied. The "B's" mark the below normal centers; the "A's" mark the above-normal centers. The normal used was valid for the period 1 — 10 June. Figures 2 — 5 are representative of some of the upper-air maps that were made at Widewing.

In this account the 4 June map, Fig. 2, is chosen, for it represents the same unchanging configuration that had existed for the week leading up to this map time. Although the DN pattern had looked pretty much like this from the end of May until 4 June the DN centers were steadily intensifying all during that period. The prognostic charts made from it also became the basis for postponement of D-day, as we shall see.

The main features of this DN map, Fig. 2, is the zonal, or west-to-east elongations of the DN centers across the Atlantic (actually tilted somewhat from west-southwest to the east-northeast). In the Atlantic there is an east-west moat or band of very much below-normal heights; it is north of a very much above-normal band; both stretch east-west across the Atlantic. (Actually, the height below-normal band tilts from around 50 degrees north latitude at the east coast of North America to 60 degrees

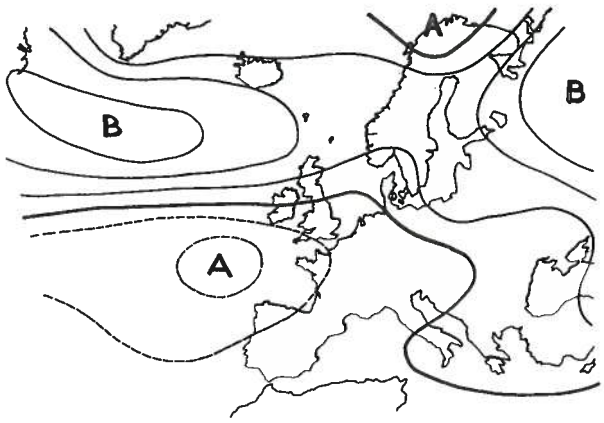
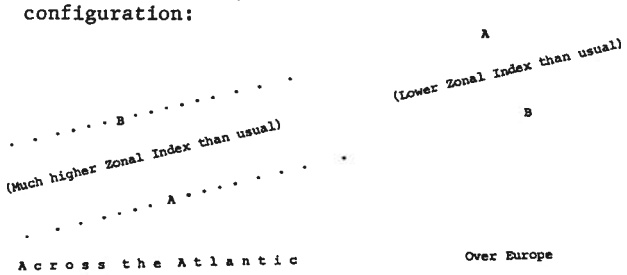


Figure 2. 500mb height departure from normal map for 00Z, 4 June 1944.

north at Norway.) And, note the basic configuration:



In this schematic diagram above, the A's represent the central positions of the above-normal patterns; the B's the minimum locations of the below normal moat or system in Fig. 2. Notice the reversal in the DN contrast over the Atlantic as compared with eastward into Europe and European Asia: (1) across the Atlantic a mid-latitude belt of almost straight and very fast energy transport eastward, but coming to an abrupt end in continental Europe; (2) from Nova Scotia to Scotland intense baroclinicity, with deep and intensive meridional gradients of atmospheric temperature and thermal wind; (3) an enormous mass of cold air trapped in the Arctic; (4) in the large-scale upper westerlies from the Great Lakes to the Baltic, pronounced hydrodynamic instability, although statically stable at the moment. The situation was excellent for the accumulation of lability energy up to some critical point, then for a rapid conversion into kinetic energy, i.e., into the rapid formation of vigorous cyclonic disturbances and production of storms, to be steered rapidly eastward. On 31 May, this was the predominant weather for the coming five-day period.

Let us now look at Fig. 3, a map of 48-hour change in the 500 mb height during the two days following the time of Fig. 2, to 6 June at 00Z, 2:00 A.M. (double daylight saving time) of the actual D-day.

Figure 3 shows three major centers or systems of 48-hour height change and their past two-day tracks. Along their tracks the 12-hourly positions are shown by the encircled crosses. Above each of these positions is written the maximum height-change values in hundreds of feet. The height-change lines are

drawn at 200-foot intervals, being dashed for rise, continuous for fall, and heavied for no change.

Over Finland there is a moderate +400 foot height-rise center of relatively less importance for the weather of Overlord operations than the other two systems. Over the Atlantic south of Iceland, the big 48-hour height-rise center R, originated during 2-4 June in Baffin Bay as a +200 foot rise centered there and followed at half-day intervals with central positions having rises of +200 feet, +400 feet, +400 feet, +500 feet and +700 feet in 500 mb height. In other words, this R-system was itensifying all along. As we shall see presently (Figs. 4-6), this R-system heralded the building at about 20 degrees west longitude of a blocking high-pressure ridge that protects the channel and the assault beaches with the minimal weather conditions needed for the invasion on 6 June.

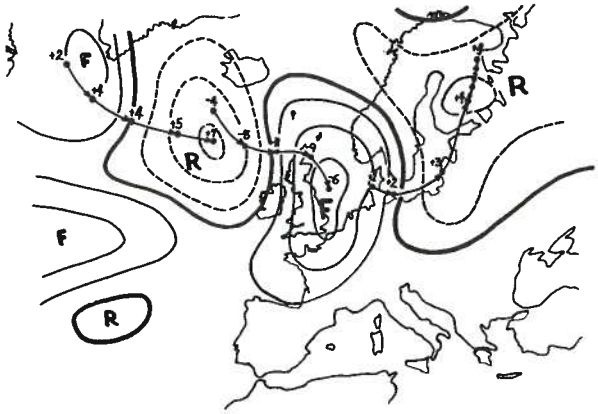


Figure 3. The 48-hour change in 500mb height for 00Z, 6 June 1944.

In the North Sea the all-important 48-hour height-fall center F first formed during 2-4 June just southwest of Iceland, very rapidly intensified within 24 hours and then decreased in intensity; viz., -400 feet, -800 feet, -1,100 feet, -900 feet and -600 feet. Of paramount concern to the Overlord forecasting of the channel weather was the approach and resulting proximity of this -600 foot system F to the invasion beaches, which are marked in Fig. 3 by the heavied coastal bar. Shortly after midnight on 5 June, the center of the F system was located just west of the northern tip of Scotland, where the 500 mb height fell over 1,100 feet from that on 3 June, a phenomenal fall. And during the preceeding day from the night of 3-4 June, it had rapidly intensified from its origin southwest of Iceland and rapidly moved southeastward toward the British Isles. Widewing's forecast that led to cancelling D-day for 5 June was supported by the upper-air analyses revealing the initial formation 3 June of this 500 mb height-fall center F southwest of Iceland and by F's LRFD predicted intensification along a path for the next day southeastward toward England and the channel. It turns out that F's decreasing intensity from midnight of 5 June to the 6 June — from -1,100 feet to -600 feet — eased the decision for the resumption of forecasted invasion weather for 6 June.

In summary, according to Fig. 3, the last two days, 4-6 June, were thus unlike the preceeding six days. Let us now look at the 500 mb height departure from normal map at the end of this period.

Figure 4 is the 500 mb height DN map for 6 June at 00Z, 48 hours after Fig. 2. The stagnant circumpolar moat of below normal along the 50-degree north latitude for two days previous (Fig. 2) has given away to two intense below-normal centers: - 1,000 feet and - 800 feet, separated by two above-normal wedges or ridges, especially the one just to the west of the British Isles. From this, we can seek to visualize the vast change in the predominant features of the circulation aloft — from strong zonal westerlies to a sinusoidal flow of large amplitude and short wave length. This is borne out in Fig. 5, a 300 mb map for 4 June at 00Z, but showing also, in heavied line, one of the same 300 mb contours for 48 hours later, on 6 June.

Beginning on 28 May, the analogue long-range, eight-days ahead forecast from the directorate of weather in the Pentagon called for an extension of the Azores high northeastward toward Ireland by 5 June and thus for protection of the channel. According to this forecast, the northeast extension of the Azores anticyclone would therefore press the eastward-moving Atlantic cyclones farther north, toward Iceland and Norway than they would otherwise go were the Azores high in their normal position, leaving acceptably good channel weather. So, storminess was not the question. It was how far to the north the Atlantic storm tracks would go. The speed and intensity of the cyclonic centers would not be important. According to the analogue forecast the formation and cyclogenesis of these storms would be near the Great Lakes in the United States, where the upper-air analysis showed that the upper current aloft curved from a southward to an easterly direction, while, their decay and end would be in Scandinavia, where the upper current fanned out and weakened. To this extent, excluding ridge building, Widewing's upper-air section lent support to this analogue forecast possibility.

Beginning on 28 May, Widewing's telephone conference forecasts for the channel weather foresaw a bad spell on 2 and 3 June, but otherwise had an optimistic outlook for the following weekend. The same held for Widewing's forecasts made on Monday and Tuesday, 29 and 30 of May. But, on Wednesday, 31 May, D-day was five days away, and Widewing's upper-air extended forecast called for a deterioration of the large-scale situation over the weekend of 3-4 June. Although within Widewing this upper-air outlook introduced some apprehension, the analogue projection of the extended Azores high-pressure "finger" west of the channel continued to form the basis for Widewing's conference forecasts.

The chart sequence in Fig. 6 shows the main features in the surface weather development during the first five plus days of June before D-day. This sequence, which was prepared by Douglas, and its account here are taken from the

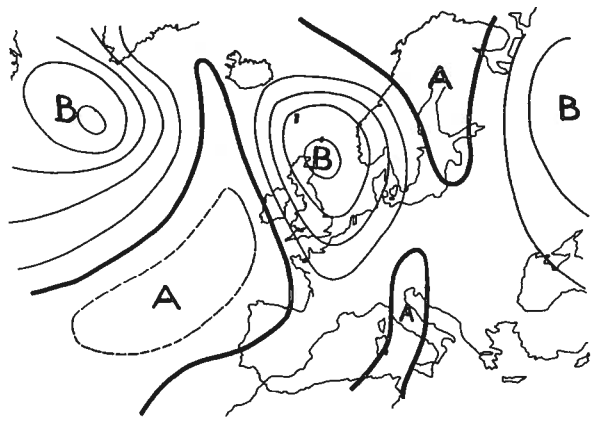


Figure 4. 500mb height departure from normal map for 00Z, 6 June 1944.

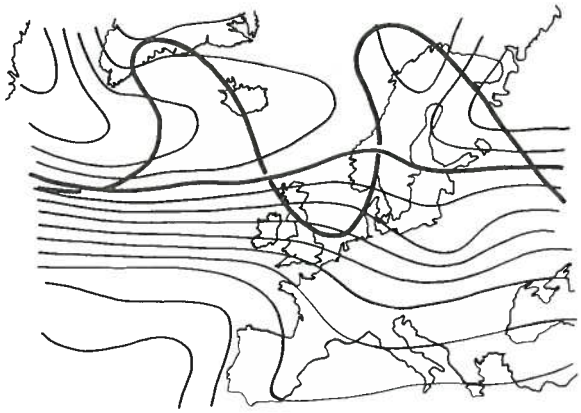


Figure 5. 300mb contour map for 00Z, 4 June 1944, with a selected contour superimposed from the 00Z, 6 June 1944 Map.

Sverre Petterssen Memorial Lecture, published in the March 1979 issue of BAMS. In the first chart for 1 June, the polar front is strongest west of C. Both C and D are expected to be fast moving because of very strong westerlies aloft. Trending towards Widewing's analogue long-range forecast valid for 5 June and made 28 May, the Azores high extends east of its normal position and the arctic high is unusually large and pronounced. In the 2 June chart, from which prognoses became available very late that evening, C has become stronger, and the Azores high is developing into the Bay of Biscay, nudging into Ireland and thereby continuing to give credence to Widewing's eight-day forecast valid for 5 June. Although cyclogenesis of E is indicated in the Eastern United States, the analogue forecast still looked like a good bet for 5 June to Widewing's briefing team; and Stagg didn't disagree. So, by early Friday, 3 June, the invasion ships in the northern ports had already been set in motion for D-day on 5 June. Based on Widewing's long-range forecast, the assault on the German occupation of western Europe was underway.

But, in the chart for 3 June in Fig. 6, there is an equatorward extension of extensive polar air over Baffin Bay. The storm activity is strengthening over the Atlantic, and the earlier ridging of the Azores high toward Ireland and the channel is now receding southward. Widewing's original analogue long-range forecasts made 28 May and thereafter were now in jeopardy. In the 5:00 P.M. conference of 3 June, Stagg nevertheless continued to hold invasion possibilities open for 5 June. At 11:00 P.M., Widewing made a special telephone call to Dunstable to discuss the critical situation. In its forecast efforts at Widewing, it became quite obvious that the cold front of the surface low C, which aloft was associated with rapidly deepening system F of Fig. 3, would likely traverse the British Isles on the night of the fourth and the channel during the early morning of the fifth, resulting there in up to Beaufort force six winds from the west-southwest and an overcast with 500-foot ceilings. Finally, the 3:00 A.M. meteorological conference on Saturday 4 June agreed on nonoperational weather for 5 June's D-day. At 4:15 A.M. on Saturday, 4 June, Stagg briefed in the Portsmouth Library. Admiral Creasy, RN, called him, "Six-feet-two of Stagg and six-feet-one of gloom." The operation was stopped, forces underway arrested and put in a holding position wherever they were. Overlord was postponed.

In Fig. 6, the evening chart for 4 June features E's enlargement and the joint development of C and D to form F. This surface low continues in its approach toward the northern tip of Scotland until shortly after the time of this chart, at 4:00 A.M. on the fifth, the observed sea-level pressure fell to 976.8 mb at Wick. Up until then, according to Douglas, this was the lowest June pressure of this century in the British Isles. The central position of this surface-low F corresponds to a geographical position in Fig. 3 halfway along the track between the -1,100 foot and -900 foot centers of the 500 mb height-fall F-system in Fig. 3. Of special interest, this evening chart for 4 June verifies the strong winds that had been forecast for the cancelled 5 June landing.

The final briefing conference to the supreme commander was scheduled for 4:15 A.M., 5 June, and the supporting meteorological discussion took place at 3:00 A.M. From the evening chart of 4 June in Fig. 6, there was agreement among Dunstable, Admiralty, and Widewing that the cold front, which had made a 5 June landing impossible, would on 6 June pass well southward into France, temporarily giving the channel area clearing skies and abating winds. In addition, the conference agreed with Widewing that behind this cold front the blocking ridge west of the British Isles, as seen in Figs. 3-5, would continue rapidly to develop and move slowly eastward to the channel area. Following after the first landings, this fair-weather, high-pressure ridge would provide at least a day of reasonably quiet weather for the post-D-day build-up, for which SHAEF, however, had earlier specified the need for a period of 10 such days. But, in the 3:00 A.M. meteorological discussion that need could not be met in its forecast weather outlook. As a matter of fact, as it did later turn out, the next front did pass across the invasion area early Thursday, on 9 June. The weathermen recognized their mutual concern for watching

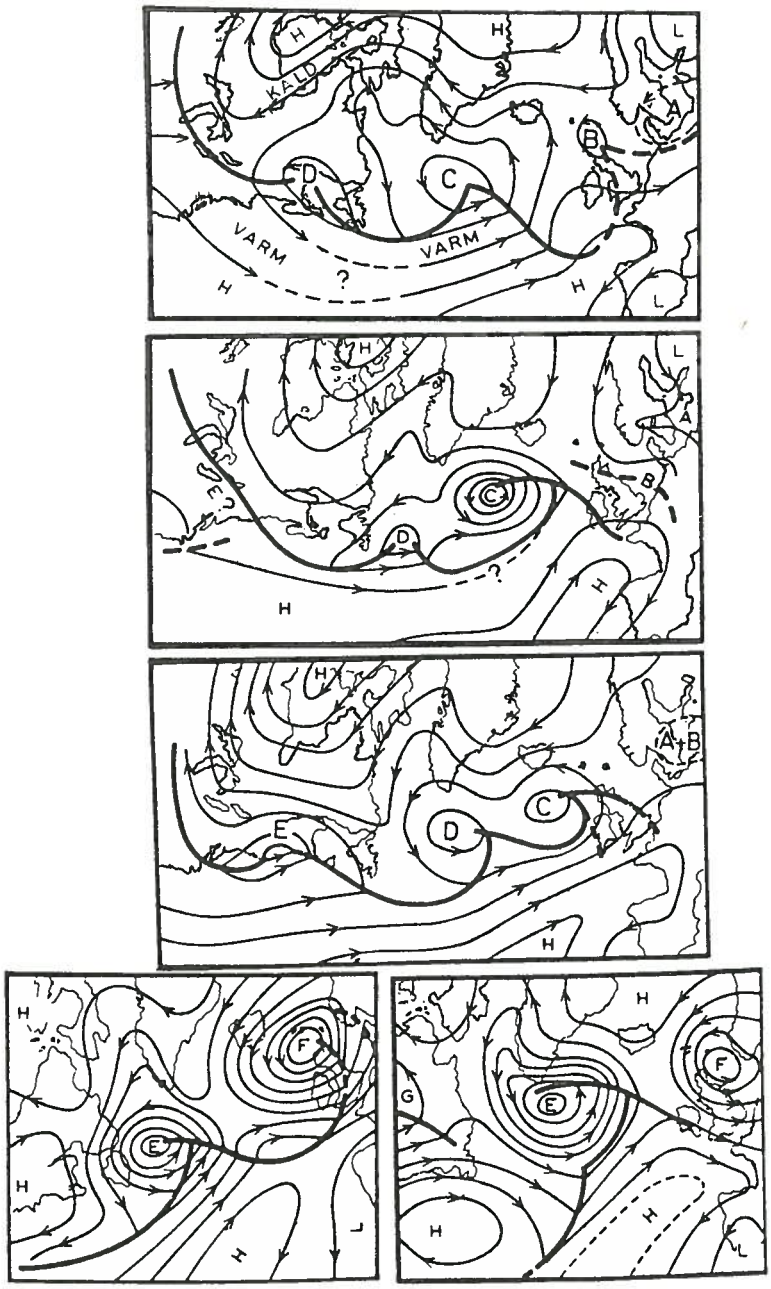


Figure 6. Prepared by Sverre Petterssen, a chart sequence showing the main features in the weather development during the first days of June 1944 before D-day. The charts for 1, 2, and 3 June are at 1300 GMT; while the chart for 4 June is at 1800 GMT; the chart for 6 June at 0700 GMT, is shortly after the time when the first landing took place.

just how storm F, Fig. 6, would progress. But, in all instances, it was agreed that there would be a period of improved weather between the two storms F and E in the 4 June chart of Fig. 6.

In the library at Portsmouth, while overhead a howling storm tore across the British Isles, the channel and northern France, Stagg was glad to be able to reveal that the only change since the last forecast was for the better, and forecast an interval of clearing over southern England, which would probably last well over 24 hours and into Wednesday afternoon, 7 June. And, at Widewing, I can remember Irv Krick standing beside my weather map table, at 6:15 A.M. on that morning of 6 June and quietly saying, as if to himself, "Boy, was that ever a horseshoe!"

Shortly after the first landing took place, the morning chart of 6 June in Fig. 6 shows a channel situation developing between these storms F and E. Much later, in 1967 (in the Quart. J. Roy. Meteor. Soc., no. 398, p. 413), Robinson imagines a state of affairs in which the south-southeastward moving storm F in the 6 June chart of Fig. 6, now a 998 mb low, was displaced just a short distance (200 km) farther south in the North Sea than it was, or in which it hadn't filled as rapidly as it did (it had filled 25 mb in the previous 36 hours). At the invasion beaches, the resulting winds would have been catastrophic for Overlord. As it turned out, on the western beaches the conditions were good. But, on the eastern invasion beaches at the time of the initial landings, the onshore westerlies just did exceed force three, the strongest deemed acceptable in the planning of Overlord. Later in the invasion day of 6 June, the beachhead winds did actually reach force five as the back-bent trough of F passed southeastward over the channel. So, barely adequate weather made possible the setting of the invasion into operation on the sixth after a 24-hour postponement.

From a military as well as from a meteorological viewpoint, although the postponement of D-day was a controlling factor for success in the invasion, it was not the determinant factor for its success. In having set the sluggish invasion armada in motion, Widewing's optimistic long-range forecast, when later refined with short-term forecasting, timed the invasion successfully and with an overwhelming essence of surprise to the enemy. In the long range, Widewing's unreserved optimism had prevailed over Dunstable's absolutely black view, which in the short range proved to be correct.

The German command could not conceive in any way that the allies could accomplish, in the interlude of just 24 hours between storms, the four-day preinvasion assembling and positioning of the invasion forces. This came to light in the interrogation of General Richard Habermehl by Widewing forecasters. Dr. Richard Habermehl, a Luftwaffe general, was chief of the German Weather Service from 1939 to 1944 (Fig. 7). During the later period, 1944-1968, some of us had a number of associations with Dr. Habermehl. Captured and interrogated before the end of World War II, he revealed details of the D-day weather forecasts that had decisive consequences as to the success of the allied invasion. Later, he was invited to lecture on different occasions to the U.S. Air Force cadets at the Air Force Academy on meteorology, weather forecasting, and military operations.

The German Weather Service had found May finely suited for invasion weather. The total number of dawn alerts which therefore were ordered at one spot or another was well-nigh astronomic. The strain on the men, who were already carrying out training exercises and building defenses at high pressure, was considerable, possibly even excessive. From 4 June to 6 June, General Habermehl forecast the weather situation to be unfavorable for a landing on the Normandy coast, an opinion which was shared by the German naval experts. The commander of the German Seventh Army, Colonel General Dollman, therefore, ordered a temporary relaxation of alert conditions and summoned his senior officers to Rennes on the fifth for a two-day map exercise.

About quarter-past nine in the evening of June 5th Lieutenant General Bodo Zimmermann, Operations Officer of OB West (German Supreme Command in the West) the headquarters for the whole German West Wall, was in the officers' mess at St. Germain outside Paris, when his Chief Intelligence Officer came excitedly to him with a British wireless message just decoded and sent to CIC West by the counterintelligence chief of the German Fifteenth Army. The message was the now famous "second Verlaine," which ordered the mobilization of the entire French resistance movement for the coming night. To Gen. Zimmermann this could have only one meaning: the invasion was about to begin.

It turned out that the 4-5 June storm F of Fig. 6, which grounded the Luftwaffe reconnaissance and harbored the German naval patrol boats, prevented the enemy from spotting the assembling of the allied invasion armada for its aborted assault on 5 June. Remarkably, this British signal Monday night to the French underground was the first sign to the enemy that the invasion was just a few hours away.

On 4 June Field Marshal Erwin Rommel had gone to Berlin to his wife's birthday with a pair of ladies shoes from Paris and was on his way back from Obersalzburg, where he had been to see Hitler and was not expected to arrive before the following afternoon (6 June).

Thus, the optimism of the American long-range forecast for the invasion, although not altogether a correct forecast, may have been responsible for proceeding with the invasion at a time that caught the Germans off-guard.

Before D-day, Widewing also foresaw continued worsening weather for some weeks, if the opportunity of 5-6 June was passed up. When Stagg's memo analyzing the terrible weather of the next possible invasion period after D-day, 17-21 June, was shown to General Eisenhower, he wrote this comment: "Thanks, and thank the gods of war that we went when we did." As it was, the four-day storm, 18-21 June, did smash up the artificial harbors. and set back the tempo of

the invasion by weeks. In retrospect, in 1944, May turned out better than June, which was worse than July. And, one would have had to go back to the end of the last century to have found a June as bad as the one in 1944.

A little after the invasion, I went with Widewing Advance to Granville-sur-la-Mer, on the Cherbourg Peninsula in Normandy, where we set up our weather shop in a barn and a former German barracks. Back at Bushy Park, Major Jay Treat, who was responsible for security matters, decided to burn and destroy all the weather-map analyses and upper-air prognostic charts, including those for the Overlord period. We thus lost original records of our prognostic efforts. Ben Holzman, who went along with Widewing Advance (Irv Krick at first stayed back at Bushy Park) somehow retained his notes of the Overlord telephone conferences. These conferences had been partly recorded on a Telefunken wire recorder, received earlier from a visit made to the German weather station in Ireland. From Normandy we ended up at the Ecole Normale in St. Germain en Laye, outside of Paris, the same buildings previously occupied by Lieutenant General Zimmermann and Field Marshall von Rundstedt, where we stayed for the remainder of the war.

A week after D-Day, J. M. Stagg wrote from SHAEF to the Director, U. S. Weather Service, USSTAF. In this letter to Yates, Stagg felt that it would be invidious and not helpful to try to decide which Central's advice was soundest. In his view expressed in this letter, no one Central was altogether right; each one, he felt, contributed his share to the advice presented to the Supreme Commander. Today, almost everyone would agree with Stagg that nothing is to be gained through a post mortem re-hash as to which Central was right or wrong. All that matters is that, through an admittedly cumbersome and diffused weather organization, the Overlord weather forecasts were adequate and met the test.

When people do such wonderful things as was done by all on D-day, it is hard to know how to express one's gratitude. Words always seem so inadequate, but that's all I have for this occasion. And so I would like to mention those at Widewing that contributed to the success of the invasion, what Sverre Petterssen has called "meteorology's finest hour." They are Colonel Donald N. Yates, Lieutenant Colonels Irving P. Krick, Benjamin P. Holzman, Majors Jay Treat, Edward O. Smith, John J. Jones, R.G. Bounds Jr., Captains Donald W. Roberts, Olav Njus, Donald T. Perkins, Thomas P. Wildman, William H. Wyatt, Rodney A. Jones, William L. Reeves, Harold L. Herzog, First Lieutenants Morrison H. Beach, Lloyd L. Falk, Arthur W. Wakeling, Clyde R. King, Joel M. Ginsberg, Kennelm C. Winslow, Frank Q. Ward, Edgar H. Fickensher, William D. Cooke, Chief Warrant Officer Lycurgis G. Tsimpides, Sergeants John D. MacDonald, Bert Vance, Fred Bedleyon, Willie Altman, Bob Zucherman, Ed M. Doherty, Albert Simonson, and Aragon.

In these four decades since Normandy, many of these colleagues have died, some have gone on to different and perhaps greater things. One became rated as one of the eight all-time best American chessmen. Another, the chairman of the board for the Travelers Insurance Company, one a Nobel Prize recipient, another a House representative, another a district judge, another a chief sanitation engineer for the city of New Jersey, one the founder and editor of the Reporter Magazine, a number of university professors. And, what a day this has been.

QUESTION: Since you were right on the line of Greenwich there should be no difference between local time and Greenwich mean time and yet for one 00 GMT map you said it was two o'clock in the morning. Would you explain that?

ANSWER: One of the luxuries of being in England during World War II was that you could benefit from double daylight saving time. They had two hours of daylight savings time. It meant that the sun didn't go down in the summertime until about 11:30 in the evening and, with the long twilight, that made for a very lovely existence in the summertime in London so it was double daylight saving time all through the war, both winter and summer.

QUESTION: Were Dr. Sutcliffe's thickness patterns, as related to surface-pressure centers deepening or filling, applied either at Dunstable or Widewing during the wartime period?

ANSWER: We were extremely dependent upon the papers that came out of the Met. Office authored by Sutcliffe, and we used the thickness analysis and built our analysis up in that fashion. It also turned out that Bob Allan's shop in the Pentagon, the Directorate of Weather, also had converted to constant-pressure analysis considerably before the rest of our country had done so. The Namais analysis and the U.S. Weather Bureau were still using constant-height analysis. And if I just may say a few other things here. Our upper-air section had an analysis that went from the eastern Pacific across the United States and North Atlantic into Europe and that made it possible for us to monitor planetary waves in the upper westerlies and this was an important aspect of the extended forecast that was done in the upper-air section. The Dunstable upper-air maps went out into the mid-Atlantic only to about 50 degrees west longitude and I think that short extension of their analysis limited them in their interest and effort in long-range forecasting. So it was a team effort that enabled Widewing to benefit by the analysis made of the directors of weather. They sent their coded analysis to us twice a day.

QUESTION: What system of five-day forecasting did you use?

ANSWER: I'm not a long-range forecaster and I therefore felt I'd be more free to make the statements I did on behalf of the long-range forecasting that Widewing did. The LRFD was a statistical method for supplementing the synoptic extrapolation of the upper-air forecasting and it was primarily a 72-hour forecast. In those days three-day forecasts were quite necessary because one of the things

we had to do in the upper air section was to compute the height of all of the soundings. In those days the soundings sent their raw data to you. You didn't get computed heights. So much of our time was taken in evaluating the soundings. Many of the soundings did not have a humidity sensor so we had to work out a virtual temperature so that the heights would be compatible. Then you had the problem of delayed wartime communications and the problem of breaking codes, and so on, so the analysis and prediction went at a much slower pace. And because a lot of our work was military planning, a 72-hour prog map in the upper air was a basic map. The statistical method was based upon a work which had been started in Sweden by a man named Wold, a Russian statistician Kolmogorov, and the work of Norbert Weiner which was done at MIT. Ken Spengler, who was in charge of the Directorate of Weather at the Pentagon, had hired Dr. George Wadsworth and Joe O'Brian from MIT to come down, and it was through their efforts that they developed a statistical method of LRFD that was used in the upper-air section. Stagg, in his book, gives an amazingly accurate description of that method in lay terms. It was a method of computing 500-mb height residuals by regression equations, and we would use desk calculators at Widewing and crank out twice a day a 72-hour 500-mb prog. We experimentally tried to make six-day progs.

CHAPTER 5

ROLE OG CALTECH METEOROLOGY IN THE D-DAY FORECAST

INTRODUCTION BY JOSEPH VEDERMAN:

In 1933 Dr. Krick established the Department of Meteorology, California Institute of Technology, and he was chairman of the department for many years. In 1936 he pioneered in the making of weather forecasts for the movie industry. He was a leader in long-range forecasting and weather modifications and a stack of other things. His activity of most interest to us today is that dealing with his forecasts during World War II and especially D-Day. Colonel Holzman and he were the chief forecasters for the air force at Widewing. Dr. Krick is the only, the highest-ranking, the most-senior forecaster of the three forecast centers of the supreme commander who is with us today. His topic is "The Role of Caltech Meteorology in the D-Day Operation."

NOTE: Dr. Krick's contribution was in the form of an informal presentation. The following is an unedited transcript of his presentation.

ROLE OF CALTECH METEOROLOGY IN THE D-DAY FORECAST

by

Irving P. Krick

Others have gone into the details on the weather, the D-Day forecast, the conflicts, and so on. You probably wonder why I titled this talk "Caltech's Contribution to the D-Day Forecast." Certain things that developed at Caltech gave us a somewhat different outlook on this whole situation from some of the other meteorologists. During the 30s, as Mr. Vederman pointed out, we not only got into long-range forecasts, but we were also operating out of the laboratory as a consulting service for many aspects of agriculture, industry, and indeed the military. And that's how we gained a certain feeling for the approach to the user groups and development of a communication method which gave us some experience, before we even got into the problems of World War II, in dealing with the consumer. Now I was associated, as Mr. Allan said, with General Arnold way back in the 30s and he, because of our training program for military personnel, and people from different governments, became interested in our longer-range work. He came into my laboratory in December of 1940. Previously we had received a telegram from a Christmas-tree outfit in Newfoundland. The purpose of the longer-range forecast being to let them cut their trees and get them out of the woods before a snowstorm covered them up and they couldn't find them. They had wired us saying their operation had been complete and thanks very much and so on. And Arnold said, "How in the hell do you make forecasts for Newfoundland when it's in a dark area? We don't even get any observations from there now because of the war that is going on." We told him of the method that we used to extrapolate from the observational network we had and he said, "I think that would have military value and I'd like you to pick four of your former students and give them a special course in these techniques," which we did in 1941.

One of the things we were working at was the idea of typing sequences of weather. These were called eventually the "Caltech weather types" and there's a book, which was published in December 1943, on the weather types of North America where we looked at the hemispheric pressure patterns and we found it was possible to relate sequential weather for about six-day periods between meridians 90 degrees apart, governed pretty much by the semipermanent features of the atmosphere like the Pacific high, the Azores high, and the semipermanent lows in Alaska, and the waters near Iceland, and so on. In the North American area, this zone extends from 135 degrees west to 45 west. In the Atlantic and in the European area from 45 degrees west to 45 degrees east. We found that these weather sequences could be typed in six-day intervals, each day being what we call a phase. And they would go through their evolution at a particular location in six days. Now, to this day, the types we discovered are still operative and today, for example, is a phase four and that's all anybody has to know now to get in step with us.

General Arnold asked me to come in and help out in 1942, and I arrived in Washington in February of 1942. I was put in command of a long range forecast unit, which was stationed in the Weather Bureau with the Weather Bureau people and the navy people, and we used to make long range forecasts for various aspects of the army operations. I was commissioned to give briefings in the War Room, the A-2 War Room, which was air force, and the G-2 war room which was army, and each week I would present a six-day, seven-day or 14-day projection, for the Atlantic and Europe and indicate what the implications were as far as our operations in ferrying aircraft across the Atlantic, or what the adversaries were up to, and so forth. By June of 1942 we were beginning to gain credibility at the highest echelons of command in the Pentagon. In the early days of June 1942 we noticed that the Japanese fleet in the Pacific was on radio silence. There was a cold front crossing the Pacific, which our aircraft reconnaissance from Alaska could not penetrate without icing up. So, in the War Room, I indicated that if the Japs were going to attack Dutch Harbor this would be the time. They'd come right in behind that cold front. Well General Strong of G-2 felt that this was important enough, so he took me up to brief General Marshall on it. Marshall was apparently impressed by this so he sent reinforcements up to Alaska and sure enough the Japs came in behind this front but they didn't make it because we were ready for them. So that established some credibility to the potentials of this approach that we had developed at Caltech.

A month or two later, General Arnold called me in and said, "I want you to make an operational plan so that the army air forces can eventually become responsible at whatever command we may be placed at, even if the highest echelons of the supreme command." I worked out a program and submitted it. Arnold approved it and said, "Now Doc how will we implement this?" And I said, "Well I'd like to go back to Caltech with about 40 officers and prepare an archive of Northern Hemisphere maps for a 40-year period from 1899 to 1940 so that we can classify and catalog the weather in sequences related to our

particular typing method at Caltech." He said to go ahead. Dr. Millikan gave us the room and the facilities to do this and simultaneously we set up a forecast unit called Long Range Forecast Unit A. Arnold had pulled us out of the Weather Bureau by this time and established a unit in Washington. We had Long Range Forecast Units A, B, C, D and so forth, but our unit was the one in Caltech that was transmitting long-range forecasts through the Signal Corps channels to headquarters in Washington. They were being used in various theaters of war. Even Mountbatten was getting our forecasts for the Dieppe raid and things of this kind. And it went along quite well. By the fall of '43 we'd had visits from the Russians. Major Pagava and his group were making long-range forecasts and things of this kind were going on, so our unit was gaining some recognition.

Arnold asked me to go to the Eighth Air Force in England in the fall of '43 to try to increase the number of daylight pinpoint bombing operations. The British were getting critical because we weren't making enough of them. So I wound up at the Eighth Air Force with one of my former students, Colonel Tieman, who is referred to by one of the speakers earlier, and we actually did begin to increase the number of raids, and some were very important and interesting ones. One of them was to knock out a heavy-water plant that the Germans had placed deep in a fjord in Norway, and the only time you could get at it for pinpoint bombing in November was at high noon. The only type of weather you could use was when a high was sitting over Norway with clear weather, which at the same time would be producing northerly winds across the North Sea into the bases in England and we'd ice up getting out of England. I had to indicate that we might lose some bombers on takeoff just from icing conditions that we couldn't handle. But we got enough of them off so that we wiped out that particular outfit.

By the time I had to come back to Washington in December of '43, General Spaatz had been assigned the task of setting up Widewing, which was the U.S. Strategic Air Force Headquarters, and because of the work that we were doing at Eighth Air Force, he became interested in having me establish a unit of somewhat similar nature at Widewing. In the interim, in November of '43, Colonel Tieman took me down to Eisenhower's headquarters in London because the G-2 down there, General Bull, wanted to get a weekly forecasting setup going before the invasion of Normandy. Now Group Captain Stagg was away at the time, but he had informed Bull that there was no way to make a five-day forecast and so Bull said, "Well, can you do it?" and of course I was dumb enough I guess to say, "Yeah, we could do it." We had been doing it for two years by that time for the military, so he wanted to set up a unit with me to do this. When Stagg returned from Africa he was not wild about this idea and so eventually what was developed was a cooperative effort between two British units and one American to try to get at D-Day forecasting. General Spaatz sent a letter by me back to General Arnold, when I went back in December '43, saying he wanted me to set up this unit and to give me the men I needed.

While I was away, my unit at Caltech had been part of Colonel Yates' unit because Yates had been there. Arnold wanted me to have people that would be more or less sympathetic to our work working in these areas. Yates had been a student of ours at Caltech and whenever I went to Washington from England and so forth, I would live at Yates' place and we would plan these things so that we decided that we'd have Yates command this unit. But I wanted Colonel Holzman, who had been a student of ours and had worked with me in my consulting service, to work with me as a briefing officer. We would be the two briefing officers to try to pull together all the data that we needed from Bundgaard's unit and from all the other units. Everything was coming in from Washington and Britain and everywhere else and we would try to make a forecast that would be viable. So that's the way the unit was established with Yates in command and Ben Holzman and me as his deputies and briefing officers.

As was pointed out, when it became close to D-Day, the weather over the Atlantic became extremely unstable. We had what we call the zonal weather type in which a front would pass over England every day or two. There was never any agreement between the British forecasters and ourselves. However, we did have a method of getting at the longer-range projections because we had something that the British didn't have. We had a 40-year archive of weather maps analyzed and classified in terms of our Caltech weather types for the European area. So we were always in step with what was going on. Now on 3 June that was a phase I of a particular weather type that would lead from the zonal-type flow to a more meridional type and a wedge of high pressure would come up from the Azores high and push the low centers farther north after the passage of a storm on Phase III which would pass England on 4 June and the front then would cross well into France by the morning of the fifth, which was the date that Eisenhower had chosen for the invasion. So our forecast was optimistic as others have pointed out. But we could not get the British to agree with this and Yates, who was doing the briefing down in Portsmouth, wanted us to try to agree with the British so it would make his job easier. Finally Holzman and I said, "The hell with it then, let's just go on the sixth," and that's what happened. But they could have gone on the fifth, the data that we have from all of the maps that were drawn subsequently showed that the front had been clear over to Paris by the morning of the fifth and the winds in the channel actually were less than they were at times on the sixth. So that we could have gone on the fifth and it would have surprised the Germans even more because they didn't have the northern hemisphere archive or a method of getting at these longer-range forecasts, and von Rundstedt and Rommel and the bunch of them were off to Paris somewhere. When we landed they had no idea that we were going into Normandy because we put a diversionary force out over the channel near Calais where they felt we were going to land, and it was socked in up there so they couldn't tell what the size of it was or what we were doing. So they never dispatched reinforcements to Normandy until it was too late. On the night of 4 June, which was the night Ike had to

make the decision to go, the British Admiralty began to waver and come over to our side, for which we were very thankful, and that's how the thing finally was resolved. But the main point was that my boss, General Spaatz, called Eisenhower and said, "My guys have been making excellent long-range forecasts for a very complex bombing operation and ferry mission over Russia and back, and down to Italy and so forth, and I think you ought to accept what they've got." Well that's what probably caused Eisenhower, along with everything else, to make that final decision and Spaatz then came to me and Holzman and said, "Well you guys will be making history if we get there, and if we don't we'll all be busted to privates." So it was a tricky situation because we were very intimate with our high command there in England. You couldn't be right every time. But we were right more times than we were wrong and we won the credibility that was necessary for our commanders to make judgments of this kind. After D-Day, Eisenhower saw that it was a fallacy to have this team of people with some who believed in long-range forecasting and others who did not. As a result, he relieved the British group and turned the briefing and forecasting over to our group in air force. Ben and I then went to France to brief Eisenhower and, ordinarily probably more of the time, Air Marshal Tedder who was the deputy in SHAEF. We went on that way for a while and eventually I became the chief of the weather information section for Eisenhower's headquarters, the forward headquarters at Reims, in more or less the job that Stagg had had in England.

QUESTION: What role did the weather play in the diversionary force at Calais?

ANSWER: The diversionary force was simply a bunch of boats that were sent out in the channel to let the Germans see on the radar that something might be going on where they were expecting the invasion, and that seemed to hold them in the area. Because the storm that passed across England on the fourth moved northward, it was still pretty active around Calais even on the sixth and kept the area pretty well clouded in, so that they might see our fleet out there by radar but their planes couldn't see anything from the air. It kept them pretty well grounded in the Calais area until they realized that the main thrust was in Normandy and the weather there played an important part. It was much more clouded in and nasty around Calais on the sixth than it was down in Normandy.

CHAPTER 6

WHAT IF THE D-DAY FORECAST WAS WRONG

NOTE: In his absence, Dr. Collis' paper was read.

WHAT IF THE D-DAY FORECAST WAS WRONG?

by

R.T.H. Collis

The Context

The invasion of Normandy was the key to the final defeat of the Germans by the allies in World War II.

The success of the crucial initial assault, on D-Day, 6 June 1944 is well known — and it has often been described as one of the most momentous undertakings in the history of war. It seems to be much less common knowledge, however, how narrowly the uncertainties and perils of this endeavor were overcome in the victors' favor.

A High Risk Operation

The fact is that this vast operation, involving emplacement of some 200,000 men on a strongly fortified, heavily defended enemy coast was nearly upset by unfavorable weather. What is remarkable is that in its planning and execution it was accepted that its success must depend heavily upon weather conditions — and even more remarkable, that so much store was placed on the ability of the meteorologists of the time to make accurate forecasts for the vital period. Only rarely in war does the weather contingency assume such critical importance — at least in a planned activity. In this case, where a period of several days of suitable weather was essential to the conduct of such extensive, complex air, sea, and land operations, it was asking much of the forecasters. In the event, they met the challenge and provided reasonably accurate predictions, upon which the supreme allied commander, General Eisenhower, made his well-judged decisions.

Knowing the limitations of extended forecasting, even today, particularly in the area of operations in question, one has to recognize how close a call it was — and how easily things could have gone wrong. Indeed, there were many then, and now, who believe that it was luck rather than the capability to make useful extended-term forecasts that saw it through.

What If?

To assess the enormity of the risks involved let's consider the way things could have turned out.

First, if the period had been in line with the climatological statistics, the weather would have been reasonably quiet and presented no great difficulties at the time (chosen for tide and moon conditions) of the actual assault; although Dr. J.M. Stagg, Eisenhower's chief meteorologist, calculated that the odds against meeting all the criteria stipulated by the various participants was 25 or 30 to one! (These requirements covered sea state, wind direction, cloud cover, visibility, etc. over the south of England, the channel, the assault area — between Cherbourg and Le Havre — and northern France.)

In the event, after some weeks of reasonable weather, the first week of June brought unusually stormy weather The month was one of the worst for decades.

The next decision point was whether the operation could go ahead as planned on 5 June. With strong winds and adverse clouds the conditions were impossible, and the meteorologists' successful warning of this resulted in a postponement of 24 hours. If they had incorrectly forecast tolerable conditions, one can only imagine the disaster that would have resulted. (The operation involved an airborne night assault by 18,000 parachutists and glider troops, followed by landings of up to 200,000 men from the sea. The latter involved some 5,000 ships of all sizes and types to achieve the lodgement and build up supplies for the subsequent phases. In addition, hundreds of aircraft were engaged in support and diversionary activities.)

The same risk of disaster hung over the actual landings made on the following day. It is generally accepted that it only just succeeded, for in a number of aspects the weather conditions were only marginal and in some cases, losses were incurred due to rough seas at the beaches.

What if the forecast had been too pessimistic — and Eisenhower had decided to call off the landings for the sixth? Here it is necessary to recall that once set in motion on 5 June, there was no way of postponing the assault for a further day, because so many of the craft involved would be unable to sustain a protracted period at sea — and once embarked, it would have been impossible to keep the assault troops cooped up in their vessels on a "stand-by" basis. Once under way there were only two options — to go ahead, or to cancel and call the whole thing off until later.

Here a further set of uncertainties prevailed. One of the major factors in the

success of the initial stages of the invasion was the element of surprise. This had been most elaborately developed by various security and diversionary measures. Given that nearly three million troops were briefed to take part in the battle, and so much preparation for concentrating and embarking them had gone ahead, and - although everybody, military and civilian alike, in England and on the other side of the channel, knew that the invasion was imminent, the secret of when or where was unknown but was becoming increasingly difficult to maintain as the hours passed.

In fact the Germans, surprisingly, were completely unsuspecting, and after a month of intensive preparations, the advent of the bad weather at the beginning of June brought a relaxation of alertness and their defenses were in a virtual "stand-down" mode. In this, the forecasts of the German meteorologists played a large part, and, on 4-5 June, the word was that sea operations were impossible and that the assault could not possibly be made for several days.

Even when the assault was launched, complex decoy operations further to the east, convinced the Germans that the Pas de Calais area was to be the real target and that the attacks in Normandy were a feint. All of the effort to maintain the surprise factor would have been lost if the attack had been aborted. It was too much to expect that once the nature and details of the operation had been revealed at its start, they could be kept from the Germans for long, even if they were not immediately apparent.

Finally, and perhaps most remarkably, is what would have happened if the 5-6 June operation had been called off, until the next available period of suitable low-tides. In that case the decision as to whether to go would have had to be made on 17 June or, at the latest, 18 June. As meteorologists well know, their credit with providence is limited. Having pulled off such a remarkable forecast in nearly impossible circumstances for 5-6 June, their luck ran out for the period two weeks later. On 17 June all was set for fair weather and the conditions actually forecast would have been near ideal for D-Day. On the eighteenth however, unexpected development brought strong and gale-force winds to the invasion area which persisted, only partly diminished, through the twenty-second, with continuous overcast and thick low clouds, and the forecasts were dead wrong. Severe damage was done to the artificial (Mulberry) harbors and the buildup was impaired.

One can only speculate on the magnitude of the catastrophe that might have resulted from all these circumstances, had D-Day not gone ahead as it did on 6 June. (During the 24-hour period of the assault total allied casualties [killed, wounded and missing] amounted to over 10,000, a relatively modest 5 percent - although the airborne troops suffered over 15 percent loss. (Estimates of German losses range from 4,000 to 9,000.)

The Forecasts

The forecasts themselves have two aspects — their technical basis, and the human aspects of the men who made them and the organizational structure in which they worked.

Their technical content can readily be analyzed and reviewed in the light of hindsight and the scientific record. The way the men involved thought and how they interacted in arriving at these forecasts is by no means so accessible — and for us to have this opportunity of hearing firsthand from some of the key protagonists is a unique opportunity, particularly since so little has been published on this topic.

The framework in which they worked was complicated by the sheer complexity of the international, interservice type of operation that this enormous undertaking was. Such "combined operations" bring together different types of people who do things in different ways and serve different immediate masters. To integrate their efforts is always difficult in such circumstances. To do so in the delicately balanced, judgemental process of predicting weather conditions in the English Channel of June 1944 was nearly impossible. But the Americans and Britons, the military officers of both nations' armies, air forces and navies, and the civilians of the British Meteorological Office, succeeded in doing it — just. Their collaboration was made no less easy by their diverse personalities — and in addition, the technical approaches to extended forecasting employed at that time were divergent. How the theoreticians and pragmatists, the scientists and the servicemen put it all together is a fascinating story — and one which we are very privileged to hear today.

CHAPTER 7

SEA, SWELL, AND SURF FORECASTING FOR OPERATION OVERLORD

INTRODUCTION BY JOSEPH VEDERMAN:

So far our D-Day discussion has not sufficiently stressed the key role of oceanography. The U.S. and British navies had the task of transporting their armies, together with all their equipment, across the treacherous English Channel, so listen for a minute while Chester Wilmont[2] describes the takeoff: "Within two hours of this decision, the invasion convoys were slipping out into the sea. Into the stormy channel on the far side of which lay the long-awaited second front. The wind came in fierce gusts. The waves were five to six feet high and the clouds were low and threatening. In the uneasy ships, those who knew their history recalled that the last invasion armada to sail the English Channel had come to grief in a southwesterly gale 356 years before. Some of the minor landing craft were driven back to port, but throughout the day the concourse grew as more and more ships sailed out from Falmouth, Fowey, Plymouth, and so on. By mid-afternoon, 3,000 landing craft and more than 500 war ships were moving towards the start of the swept channel which began south of the Isle of Wight on a point officially designated 'Area Z' but known to the navy as 'Picadilly Circus.' Here was the fulfillment of Britain's destiny at sea." And now a naval historian, S. E. Morison[3], portrays it like this (you always have to begin with a quotation from Shakespeare): "O, do but think you stand upon the rivage and behold a city on the inconstant billows dancing; for so appears this fleet majestical holding due course for Harfluer. Follow, follow. Grapple your minds to sternage of this navy and leave your England." Now Morison continues: "thus Shakespeare in King Henry V exhorted his audience to imagine the cross-channel operations of 1415." It is interesting that Harfluer is near LeHavre on the Normandy coast; the same spot we are talking about. But what words could he have found to describe that of 1944? "what striking metaphors, what bold similes for here was no mere 'city on the inconstant billows dancing' but the choice picked men of three nations in higher numbers than any city of his day, borne by more vessels than were in all the world when Elizabeth I was Queen of England. Majestical they are indeed whether proudly advancing by day or blacked out at night. Endless columns converging and then parting for their destination in the Bay of the Seine." That's pretty good, isn't it? That was the sailing but they had to land safely on the Normandy beaches where oceanographic factors, the sea's swell and surf, now played a vital role. Dr. Charles Bates, our next speaker, is the oceanographer who made the D-Day forecast for the Normandy beaches, for sea, for swell, and surf.

PRELIMINARY COMMENTS BY CHARLES BATES:

I'm glad to see we're getting away from the "airedales" and back to the basic facts of life, namely, that if we hadn't gotten people across the beach, I don't care how much bombing we would have done or how many people had rifles on their backs, they wouldn't be able to use them.

Prior to the attack on Pearl Harbor, the technique of forecasting sea, swell and surf was completely qualitative, and the navy admirals tended to keep a sharp eye on the glass and not put anything in numbers. So, oddly enough in the early summer of '42, the Air Weather Service, which it was already called in those days, had picked up a very controversial army reservist captain by the name of Richard Seiwell, who had been a chemical oceanographer at Woods Hole. He was very hard driving and, though he was an oceanographer in an air-force weather outfit, he realized there was a vacuum to be filled. He got working with Dr. Sverdrup who had been out at Scripps at that time, the world's most famous and best of the physical oceanographers, and a chap by the name of Walter Munk who had been a ski trooper. Walter ended up working for Seiwell trying to come up with a technique for forecasting waves. They used some Pan American data out of the Azores but found that every Saturday night the waves were twice as high as usual, so you don't base a technique on that type of observation. But he also found some data from building a breakwater in Morocco and, working with Dick Steere, a navy commander, started coming up with a semiquantitative technique. By the spring of '43, Sverdrup had gotten Munk back from the East Coast and both of them had been declared security risks by the navy because Sverdrup, a Norwegian, still had close relatives in Norway, and Munk had close

---

[2] Chester Wilmot, "The Struggle for Europe", Harper & Row, Publishers, New York, 1952.

[3] S.E. Morison, "History of United States Naval Operations in World War II, Volume XI, page 83. Atlantic Press Book, Little Brown & Co., Boston, 1957.

relatives in Austria. So that they were totally out of the navy sphere of influence, and instead they were drawing their problems from the Air Weather Service. By that time it was necessary to check out this technique on wave forecasting so they had eight of us fresh caught second lieutenants, who had done a combination course at UCLA and at Chicago, try out their technique. This is the air-force group at the Scripps Institution of Oceanography in June of '43. As I said, the navy would have nothing to do with oceanography when it came to forecasting at that particular time, at least sponsoring any research, and so we had an air-force group out there. From this unit, Dale F. Leipper later founded the Department of Oceanography at Texas A&M and then founded the one at Naval Postgraduate School. Boyd Olsen became technical and scientific director of the Naval Oceanographic Office after he followed me. So out of that first class we have three that have stayed very much in the oceanographic game. John Crowell, who eventually became one of the leading academic geologists in the country, immediately went over to the 21st Weather Squadron under Tommy Moorman, who was working overall for Yates, to start making some wave predictions for the training maneuvres at Woolacombe.

In addition to the British naval commander-in-chief, the American Task Force Number 122 had an aerologist, Dick Steere, who had done the Casablanca invasion, the Sicily invasion, and then the invasion of Italy. Dick was a very competent guy. The trouble was, when it came to the sea, swell and surf forecasting, the British had no one really trained in the technique. So the head of the British Admiralty Met. Office, Captain Garbett, worked with Dick Steere and Tommy Moorman and they decided it would be a joint operation. There would be one British naval meteorologist by the name of Cauthery. Since the U.S. Navy had no one, John Crowell and I from the Scripps class would be the U.S. surf forecasters assigned to work two floors underground at the British Admiralty.

As Bundgaard mentioned, I think this is the first time that some of us from all the different Centrals have been in the same room at the same time. Stagg for some reason was very anti-Admiralty and I think perhaps it was because the Admiralty was just about as anti-Stagg. As a senior service, they felt that the lead forecaster should know something about English Channel weather and Stagg's specialty was solar radiation and magnetism, and so it didn't fit that scheme of things. The backup, of course, was Don Yates. Don could perform well under stress, and he was a forecaster, having been a Caltech student under Krick.

Commander Fleming, a typical Royal Navy type with a silverheaded cane and stiff upper lip, really knew his English Channel weather. He'd been forecaster for the home fleet and went on to a very successful career in the Royal Navy after the war. He became what they call the director of education. He ended up being a rear admiral and also knighted before he retired. I have visited with him, and he's also written out his recollections for me of what he thought went on. On the last five days, Stagg and Yates had to leave Widewing in the Teddington area and go down and sit in, and work in, Fleming's little half of a Nissen hut and use Fleming's maps. As a result Fleming was busy keeping his own boss, Admiral Ramsay, clued in and, of course, Stagg wanted to have his own chance to study the charts, so that the Nissen hut got pretty small for all three of them. Again, about the British, they don't have a lot of people but they're damn good, the ones they do have. Their lead forecaster, Jeffrey Wolfe, was a graduate of Oxford and certainly one of the best forecasters around. His backup was Larry Hogben, a Rhodes Scholar out of New Zealand, who had been the aerologist on one of the ships that helped sink the Bismark, and Harold Cauthery, a double honors out of Cambridge in both history and math, whose last assignment in the British government before he retired was as the assistant administrator for the Royal Air Force, of all things, for the Air Ministry. Harold could seem to get more work done between high tea and quitting time than Crowell and I could do in a whole day, but that was the way it went. We were fresh out of Scripps, but we didn't know much. We had some diagrams of wave generation and surf generation based on a total of something like 69 points. Nobody had really tested them except ourselves, so it was a quick shake-down period, for the invasion was supposedly but three months away.

SEA, SWELL, AND SURF FORECASTING FOR OPERATION OVERLORD

by

Charles C. Bates
Lt. Colonel, USAF (Ret.)

ABSTRACT

Sea, swell, and surf forecasts for the English Channel and the Normandy beaches prior to and during the allied assault of 6 June 1944, were provided by the British Admiralty's Swell Forecast Section. A joint British-American unit, the section first tested the newly developed quantitative wave-forecasting techniques of Commander Claude T. Suthons, RN, and of Dr. Harald U. Sverdrup, and Mr. Walter U. Munk. In so doing, it was necessary to decide what was meant by the term, wave height, as well as to make adjustments for angle of approach to the beach, effects of strong reversing tidal currents, and diffraction introduced by the Cotentin Peninsula. Hindcast verification data came from a special 51-station surf observation network which extended from Land's End to East Anglia. The Sverdrup-Munk forecasting scheme proved more accurate and was used for the D-Day predictions as well as for subsequent beachhead operations. Excluding all cases in which wind forecasts were badly in error, wave forecasts up to five days in advance were correct 88 percent of the time between 6 June and 30 June 1944.

As the duty wave forecaster for the Admiralty's Swell Forecast Section, I spent the night of 5-6 June 1944, in the Royal Navy's fleet weather central two floors underground in the "Citadel" just off the Horse Guards' Parade. During a visit to flag plot at 3:00 A.M., it was evident that the airborne part of the invasion was going well. Then, after surfacing at early dawn, I was overjoyed to see clearing skies immediately behind the predicted cold frontal passage. Moreover, the sky was filled with scores of heavy bombers droning their way to soften up what would soon be the Normandy beachhead. The die had been truly cast. Now we would see how well the allies could carry off the world's greatest seaborne assault —Operation Neptune, the naval facet of the far more massive Operation Overlord.

Of particular importance was whether the storm-induced surf of 24 hours before had died down for the safe beaching of assault and supply craft along the coast of Normandy. Just two years before, the art of forecasting sea, swell, and surf had been empirical and qualitative, with state-of-sea observations expressed in a scale of one to 10. But because of wartime needs, we had gone quantitative in order to change an art into a science. Thirty-five years ago, your author published a paper in the annals of the New York Academy of Sciences delineating how this was done and what it meant during Operation Neptune.[4] Courtesy of the academy, pertinent excerpts are included here to explain what happened.

Introduction

The groundwork for the quantitative forecasts of sea, swell, and surf required by large-scale amphibious operations was laid in both Great Britain and the United States during 1942. In that year, Instructor Commander C.T. Suthons, R.N., of the British Naval Meteorological Service, correlated a number of wave observations with wind conditions and prepared a memorandum which contained certain "rules of thumb" and crude forecasting graphs. About the same time, Mr. W.H. Munk in the Oceanographic Section, Directorate of Weather, Headquarters, Army Air Forces, was assigned the problem of developing wave generation and decay diagrams which could be used for the invasion of North Africa. For the same invasion, Commander R. Steere, U.S.N., prepared the first quantitative surf observation code. This code, named after its originator, was eventually revised and is now the currently used Combined Surf Code.

During early 1943, Mr. Munk worked with Dr. H.U. Sverdrup, Director of the Scripps Institution of Oceanography, to develop a technique of wave forecasting based on theoretical, as well as empirical, considerations. By July of that year, the necessary relationships had been established and a group of eight Army Air Force meteorologists, including the writer, was already assigned to study and test the embryonic forecasting method. Trial "hindcasts" made for the North African coast from the Northern Hemisphere Weather Map Series by this group indicated that the technique could be used by meteorologists after a relatively small amount of training. In fact, the short course in military oceanography built around the technique and taught at the Scripps Institution of Oceanography was cut in duration from the original three months to one month as refinements and organized material became available.

Wave Forecasting for the Normandy Invasion

When, in the fall of 1943, Lieutenant J.C. Crowell, A.U.S., member of the initially trained group, arrived in England and was assigned the task of preparing wave

---

[4] Bates, C.C. "Utilization of Wave Forecasting in the Invasions of Normandy, Burma, and Japan." Annals New York Acad. Sciences 51 (May, 1949):545-572.

forecasts for the operations of the U.S. assault Training Center at Woolacombe, Devon, many problems were still unsolved. These included such fundamental questions as the type of wave height the generating graphs provided, the manner in which waves were transformed into breakers while passing through shallow water, the effect on wave height when the waves approached the coast at an angle, the effect of opposing and following tidal currents, and the relationship between wave conditions and the efficiency of an amphibious operation. Answers to most of the problems had to be forthcoming within the next few months, for General Dwight Eisenhower, U.S.A., arrived in Great Britain during January, 1944, to organize Operation OVERLORD, the invasion of Normandy.

It was evident to all concerned that the success of Operation OVERLORD hinged upon the efficiency of the flow of troops and supplies across the beachheads. Even with favorable weather, it was estimated fifteen weeks or more would be required to transport as many Allied divisions across the English Channel as the Germans had available in Northern France and Belgium[1]. To provide a satisfactory wave forecasting service for this operation, Captain L.G. Garbett, C.B.E., R.N., Director of the Naval Meteorological Service, collaborated with Colonel T.S. Moorman, Jr., U.S.A., Staff Weather Officer to the 9th Air Force and the 1st U.S. Army, in establishing the Swell Forecast Section, Admiralty. Organized with the approval of Commander R. Steere, U.S.N., aerologist to the Commander of U.S. Naval Task Force 122, the Section finally consisted of one British meteorologist (Instructor Lieutenant H.W. Cauthery, R.N.), two American meteorologists (Crowell and the writer), two American enlisted men (Technical Sergeant E.A. Lochner, A.U.S., and Sergeant E.L. Hynes, A.U.S.), and two WRNS ratings. Housed two floors underground, the Section had direct access to Admiralty's Forecast Section with its wealth of weather data and excellent communication facilities. The name, Swell Forecast Section, was not intended as a pun but rather as a security measure to direct thought away from the fact that the invasion might be scheduled for beaches not directly exposed to ocean swell.

The objects of the Section were to develop the technique of forecasting sea, swell, and surf, and to provide forecasts on the basis of this technique for the invasion of Europe. The technical problems facing the Section were four in number; (1) to forecast the height and period of ocean swell coming from the Atlantic; (2) to determine the extent to which this swell would penetrate the English Channel; (3) to forecast the height and period of waves caused by local winds in the Channel; and (4) to study the effects of shallow water, tidal currents, and coastal irregularities on waves. The final aim, of course, was to forecast surf heights on specific beaches. The investigations were carried out under two handicaps, security and limited time. Although the date, place, and other details of the impending operation were known to the Section, security measures were so rigid that wave researchers in the States could not be contacted concerning the problems mentioned earlier. As only three months were available, the empirical approach was adopted as the one most likely to provide the necessary information.

The first task undertaken was the organization of a synoptic network which eventually totaled fifty-one wave reporting stations (Figure 1), and was probably the largest of its kind ever organized. In the main, the stations were His Majesty's Coast-guard lookouts, manned by retired seamen. Visual observations made at these stations were reported in a seven-figure group, IIHHPPM, where II is the station number, HH the average wave height in feet, PP the average wave period in seconds, and M the difference in feet between the height of the maximum wave observed and the average height. Daily observations were made at 0700, 1300, and 1800 GMT for an interval lasting three minutes and included a wave count and an estimate of the height of each wave breaking during that time. Rocks or other objects of known size occurred in the surf zone at a few of the stations and aided in the estimation of height. As soon as observations were made, the data were phoned to district headquarters and then relayed as a collective by teleprinter direct to the Admiralty. To study the exposure of each location and to provide the necessary instruction, all the stations were visited by one or more members of the Section. Although visual observation is subject to considerable error, the close spacing of stations permitted checks of one against the other, and the large amount of synoptic information supplied was invaluable for verification and research purposes.

Four of the stations (Padstow, Pendeen, Weymouth, and Newhaven) had aneroid pressure-recorders installed in comparatively deep water by the Director of Mine Design. Reports from these stations, made in the same fashion as those from the visual stations, were extremely valuable in checking the visual reports and in providing data on waves in deep water.

A special reporting station was also established at Weston Mouth. This location was chosen because it is protected from Atlantic swell and the maximum fetch available is similar to that of Seine Bay, the site of the assault beaches. The station consisted of seven dan buoys, topped by graduated poles, and laid at equal intervals along a straight line to seaward. Observations were made by sailors five times daily with the aid of a graticuled theodolite and stop watch. However, the unusually calm spring weather prevented the achievement of the purpose of the station, i.e., the acquisition of a large group of reliable observations on the transformation of waves moving into shallow water. In fact, the station reported waves one and one half feet or higher on only forty-two occasions in four months of operation.

Wave information of lesser value was received from three anti-aircraft "forts" in the Thames estuary, from high-speed motor launches on night patrol out of Dover, and single-engined aircraft (P-51s) flying weather reconnaissance over the Channel. Checking of wave conditions on the assault beaches proper was carried out by studying aerial photographs of the beaches. This was accomplished by determining the depth of breaking from these photographs by referring to special tidal data and beach profiles prepared for the invasion and then converting depth of breaking into breaker height by assuming breaking occurred in water one and one half times deeper than the height. This method, although crude, indicated no great error in the forecasting technique being employed.

Early forecasting of the Section was directed toward predicting swell conditions at Land's End. A fair degree of success was achieved, although the rigid accuracy desired was not obtained in all cases. Work was also initiated into determining how far swell penetrated the upper reaches of the English Channel. Cornish[2] and various coast guard personnel had mentioned that swell occasionally penetrated at least as far as Bournemouth Bay. After studying the observations of the wave reporting stations, it was found that long-period waves rarely appeared at stations east of Start Point. By analogy, it was to be expected that swell approaching the assault beaches from south of west would be cut off by the Cotentin Peninsula and that swell from a direction close to due west, even though of appreciable height off Cherbourg, would be considerably reduced in height at the beaches. From this and certain theoretical considerations, it was decided that only extremely high swell from the west would need to be taken into account in forecasting surf heights on the beaches in question and that

such waves would diminish to less than half their original height. This conclusion was verified on October, 14, 1944, when the first really noticeable swell appeared at Omaha Beach with breaker heights of 2 to 3 feet and a period of 9 seconds, although heights of 12 to 15 feet were reported off Cherbourg. During the summer months, such a situation was unlikely and the problem resolved itself into forecasting waves and surf resulting from local winds.

observations which reported both average and maximum wave heights, particularly since the maximum height reported was often double that of the average height. It appeared that small craft operation was concerned neither with the occasional maximum wave nor with the average value, which is considerably depressed by the many small waves present in a wave train. However, a value half way between the average and maximum height appeared to be highly useful. This

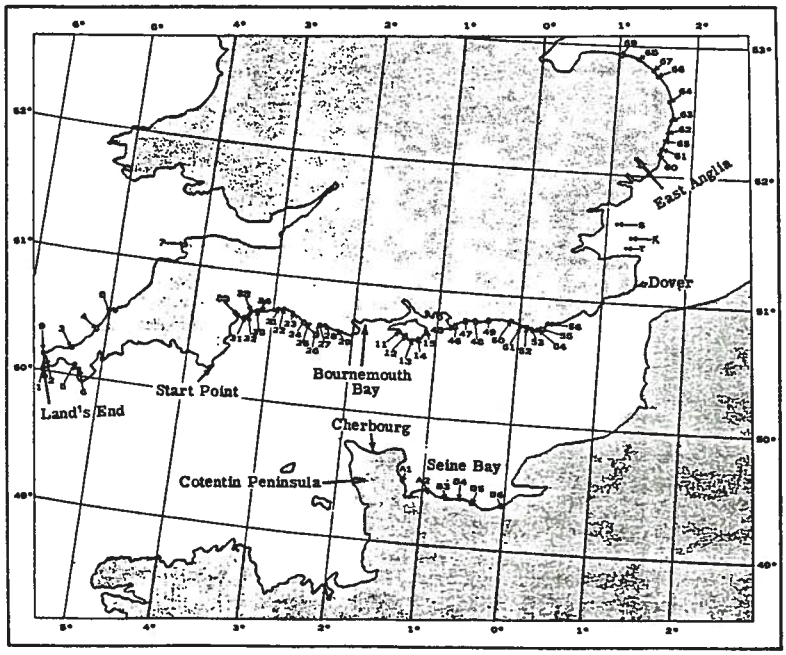


Figure 1. Index map showing location of English wave reporting stations and the invasion beaches of Normandy (for names of stations and beaches, see Table 1).

Fetches in the central part of the Channel and at the assault beaches were rarely greater than 120 miles. Verification of forecasts soon indicated the tremendous importance of correct wind forecasts. To provide accurate wave forecasts, i.e., those with an error of one foot or less in height if the heights were less than five feet, and with an error of 2 feet or less if waves were greater than five feet in height, wind forecasts had to be in error less than one Beaufort force and less than two points (22½ degrees) in direction. Forecasts of wave period were unnecessary because variation in the slope and period of wind waves did not appear to affect small craft operation noticeably.

Before surf heights could be predicted, it was necessary to estimate the effect of shallow water and coastal irregularities upon deep-water wave height. As mentioned before, a comprehensive theory of these effects was not available, and it was decided to obtain a direct relationship between observed breaker heights and wave heights computed from generation diagrams. Such a technique would also incorporate correction factors needed to take into account tidal stream effects influence of land bounding the channel, error in determining wind speed from meteorological charts, possible errors in the generation graphs, and several lesser considerations. If the necessary relationships between computed and observed data could be established for winds blowing onto the English coast, it was hoped that similar relationships would exist for winds blowing onto the French coast.

It was also necessary to determine how the height values extracted from generation graphs might be compared to value, termed the "Predicted Height", was used for purposes of comparison. The value falls amazingly close to the "Significant Wave Height" defined by Sverdrup and Munk about a year later.[3]

Although a complicated shoal system existed off part of East Anglia, the ten wave observation stations spaced four to fourteen miles apart along that coast proved particularly valuable in working out the relationship between computed and observed height. Figure 2 illustrates the results of a study the writer made of heights observed during nineteen synoptic weather situations in which the wind direction held with 15 degrees of a given direction for eighteen hours or more during the months April-July, 1944. The hatched areas of the illustration are the zones in which weighted values for over two hundred height values occurred, using both Sverdrup-Munk[4] and Suthons generation graphs. It is evident that, for waves approaching along the normal to the beach, the Sverdrup-Munk values were a trifle high. This discovery caused the Swell Forecast Section to apply a reduction of 10 per cent to values computed by this method to obtain breaker height. The computed Suthons values were much higher than the observed heights. Because of this, and because the Sverdrup-Munk curves were presented in a much more usable fashion, the latter curves were used in all operational forecasting. Other theoretical and empirical considerations likewise indicated that the increase in height of wind waves at the time of breaking could be neglected, a fact substantiated by later wave research.

Because the East Anglian stations had an accumulative exposure of about 268 degrees, the observations provided a clue as to the extent heights were reduced when waves

approached the shore at an appreciable angle. The spread of values for different angles of refraction is shown in Figure 2, while the values used in the Swell Forecast Section are given in Figure 3. It will be seen that the values used are in good agreement with the theoretical values given for a simple beach in the subsequently published "Breakers and Surf, Principles in Forecasting"[5] for refraction angles less than forty degrees, but that considerable discrepancy occurs for greater angles.

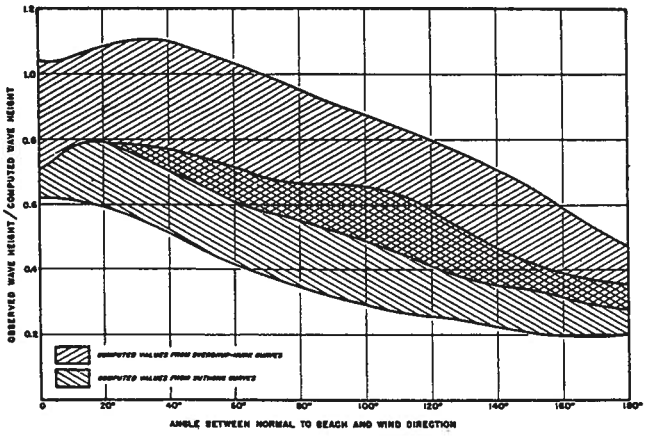


Figure 2. Variation of wave height with angle of approach to shore, according to observations made along the East Anglian coast.

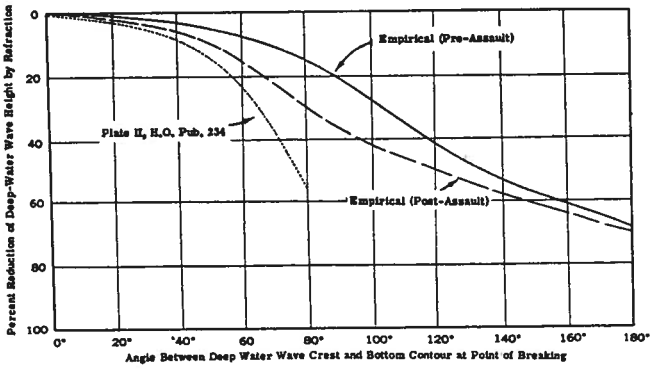


Figure 3. Values for reduction of wave height by refraction according to theory and two sets of empirical data.

The empirical values obtained for angles of refraction between ninety and one hundred and eighty degrees were particularly valuable because the technique of preparing wave refraction diagrams as developed by O'Brien and associates[6] was unknown to the Section at that time.

A third interesting feature found in the East Anglian data was that heights observed at certain stations within two hours of low water were inexplicably lower than the computed heights. This reduction, which averaged about twenty per cent, was particularly well evidenced in the distribution of height values for Cley, Norfolk, where the observations made more than two hours from low tide center about the ratio of 1:1 for observed versus computed heights, but the observations within two hours of low tide have only one value with a ratio greater than 1:1. (See Figure 4). Investigation indicated that there should be no appreciable error in observing at low tide, because the water line retreated only one hundred and fifty feet or so in most cases. The irregular offshore bottom topography likewise appeared to be incapable of causing the unusual decrease. In fact, one of the stations with a relatively smooth offshore profile had a greater height reduction than stations with irregular profiles. A third possibility was that strong tidal streams opposed the forward motion of the waves and caused a pronounced loss of wave energy offshore through partial breaking. This effect is believed to be the cause, inasmuch as this is a region in which the time of low water coincides roughly with the time of the strongest northerly-flowing tidal streams. Since these tidal streams range from 1.0 to 1.5 knots at neaps and from 2.0 to 2.5 knots at springs, and most of the situations studied were for waves approaching from the north, it is highly probable that the tidal streams acted as a partial breakwater. This phenomenon of opposing tidal streams acting like a breakwater has long been mentioned in the literature, one of the more remarkable examples being reported in the Shetlands by Stevenson[7] during the last century.

The tidal current effect on wave height was given additional scrutiny because one of the basic publications on English Channel weather maintained that the sea conditions raised by winds in the Channel depended largely upon the tidal streams. However, the wave observations along the Channel coast did not show any undue fluctuations in height, as were observed in East Anglia and as one might be led to expect from this statement. Although several stations did report suspicious heights, investigation indicated that the water line receded a considerable distance at these stations and reliability of observations made during low tide was open to considerable question. It was decided that tidal streams never raised the breaker heights if tidal streams opposed wave motion offshore. Tidal streams off the assault beaches generally paralleled the shore such that the effect could be ignored in forecasting surf conditions there.

However, it was recognized that strong tidal streams, such as those found off the northeast tip of the Cotentin Peninsula, would cause marked changes in deep-water wave characteristics. Before D-Day, the Section believed that only the wave steepness would be markedly changed, the height increase being of the order of a foot or less. Subsequent work at Scripps proved this assumption to be in error as it was found that the height increase could be two or three times the original deep water height if the opposing current were strong enough and breaking did not occur.

The rapidity with which the wave forecasts had to be prepared and the control exercised on fetch and refraction values by the complex coastal outline caused the Swell Forecast Section to develop "Surf Prediction Diagrams" for beaches with different characteristics, namely the British group, Omaha, and Utah. The diagram for Omaha Beach is shown in Figure 6. The polar section of the diagram delineates the maximum effective duration for various wind speeds from any direction, with the dashed parts of the curves indicating indirect fetches where waves were likely to appear because of refraction and diffraction processes

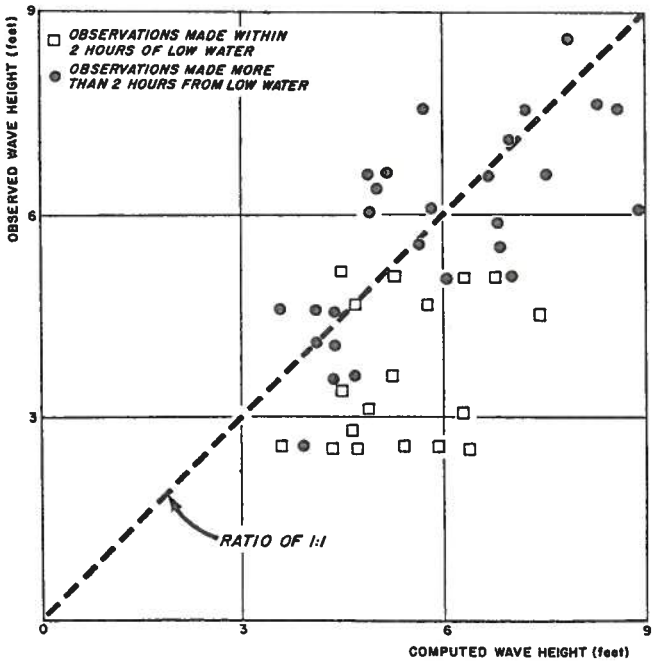


Figure 4. Computed versus observed wave heights for different tidal stages at Cley, Norfolk.

When in early April, 1944, the Supreme Headquarters, Allied Expeditionary Forces (SHAEF), required 5-day wave forecasts for the English Channel and adjoining sea areas, the Swell Forecast Section had acquired a considerable backlog of experience in handling the problems outlined here. Preparation of the OVERLORD weather forecasts was the result of frequent conferences held via private secure telephone between three weather centrals (Air Ministry, U.S. Strategic Air Forces, and Admiralty), and the three staff meteorologists representing SHAEF, Allied Air Headquarters, and the Allied Naval Commander, Expeditionary Forces. After the general synoptic picture for the next five days had been decided upon in each of the weather conferences, the conferees agreed on the wind forecast to which one of the wave forecasters had been listening at Admiralty. Then, either alone or in consultation with another wave forecaster, the wind-wave forecast was prepared and incorporated with the swell forecast made just prior to the conference, in order that the complete wave forecast could be given at the close of the conference.

From June 15 onward, forecasts for SHAEF were made daily for three-day periods, while Allied Naval Commander, Expeditionary Forces, received forecasts twice daily for a two-day period. Forecasts were also sent via radio to USAAF mobile weather stations in Normandy to aid in preparation of forecasts used in unloading operations, and to the Office of the Chief Engineer, European Theatre of Operations, for inclusion in the Daily Hydrographic Bulletin issued by that activity to the U.S. Ground Force Commands.

even though headlands intervened. A comparison was made between the maximum effective duration determined from the diagram and the actual duration. The lesser value was then entered along with the proper wind speed in the generation graph based on the Sverdurp-Munk curves. The wave height so determined was reduced by the appropriate correction factor given in the rim of the diagram, with the resulting value being considered the predicted surf height.

The accuracy of operational forecasts made in the above manner is of interest. Using the definitions given earlier for accuracy of wind and wave forecasts and excluding all cases in which wind forecasts were in error, it was found that wave forecasts were correct eighty-eight per cent of the time for the assault beaches in the period June 6-30. If all cases are excluded in which winds were light or directly offshore because no forecasting skill is involved, the forecasts were correct eighty-three per cent of the time for the same period.

In addition to information provided by the Swell Forecast Section, "on-the-spot" climatological studies and forecasts of wave conditions were supplied field commanders during the pre-assault and assault phases by staff meteorologists such as Steere with Task Force 122 and Lieutenant D.W. Pritchard, AUS, with Headquarters, 1st U.S. Army. These meteorologists had been supplied with special "Notes on the Sea, Swell, and Surf in the English Channel" and pertinent surf prediction diagrams prepared just before D-Day which incorporated most of the "know-how" acquired

during the four months of the Swell Forecast Section's existence.

Although the invasion was originally scheduled for June 5th, the passage of a cold front caused a 24-hour postponement of D-Day. During the early part of the 6th (D-Day), wind waves offshore still averaged three to four feet in height with occasional heights from interference as high as six feet. All the beaches with the exception of Utah were directly exposed to winds of 12 to 18 knots, which raised three to four foot surf throughout the day. On sheltered Utah, surf heights were two feet and less. This condition remained until the afternoon of June 7th, when the northwest winds dropped to 5 to 10 knots and permitted waves to be but 1 to 2 feet high on all beaches by evening.

For the next eleven days, wave conditions did not markedly hinder invasion operations. On June 19th, however, a steep pressure gradient between a large anticyclone, centered northwest of the British Isles, and a comparatively weak cyclone, spreading across France and Spain, caused strong northeasterly winds in the Dover Strait and the English Channel. Although the naval command ships, USS AUGUSTA and HMS SCYLLA, only reported average wind speeds of about twenty knots and maximum wave heights of ten to twelve feet off the beaches, this episode was called the "Big Storm," for seven hundred landing craft were damaged or lost and the floating Loebnitz piers on Omaha Beach wrecked beyond repair[8] (See Figure 7). The twenty-four hour forecast for the 19th called for an increase in wind strength sufficient to raise wave heights to four feet, but heights of six to eight feet actually existed by that evening. A revision prepared a few hours after the routine forecast, however, provided sufficient warning, if a storm plan had been placed in effect. Forecasting for the remainder of the storm was particularly accurate, the drop in wave heights to operational values being forecast within two hours of the actual time of occurrence.

It is interesting to speculate on what might have occurred if D-Day had been postponed to the next favorable tidal period which happened to fall just before the "Big Storm". With the large high-pressure cell centered just west of Great Britain, the temptation was to forecast light winds instead of the packing of the isobars and resulting strong northeasterly winds which actually occurred over the Channel. If such had occurred, the story of the buildup phase on the beachhead, by coming just at the time of the "Big Storm," would have been much different than it actually was.

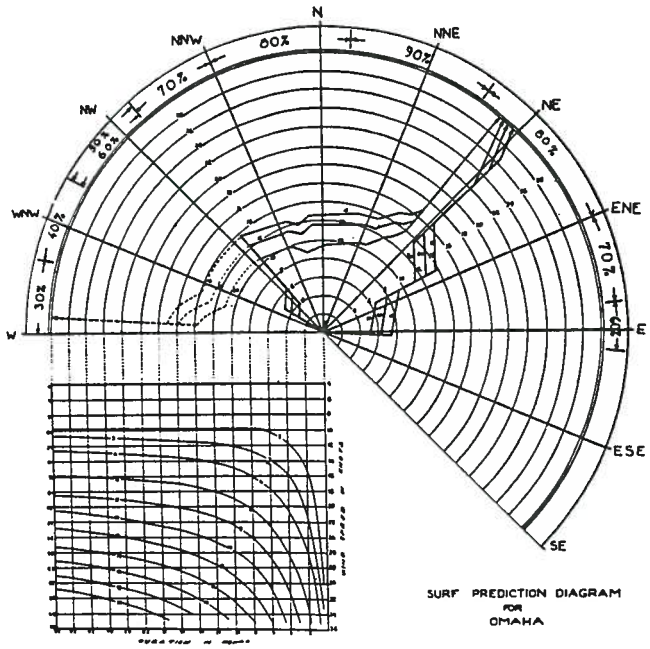


Figure 5. Surf prediction diagram as prepared for Omaha Beach a month before the Normandy invasion.

Conclusion

Forecasting of sea, swell, and surf conditions in quantitative terms developed during the early part of World War II and reached maturity within three short years. The techniques were basically correct and could be modified by meteorologists trained in the methods to provide reliable forecasts for amphibious operations wherever they might be held. The value of the information is well expressed in one of the citations given for wave forecasting in the Normandy invasion. The citation reads, in part, "The work has aided materially in the success of the assault operation and in operations on the beach after the assault. The efforts... have been a real contribution to the success of the present campaign."

References

1. Marshall, G.C., E. King, and H. Arnold. 1947. The War Reports. J.B. Lippincott. Philadelphia.
2. Cornish, V. 1934. Waves of the Sea and Other Water Waves. Cambridge University Press. Cambridge, England.
3. Sverdrup, H.U., and W.H. Munk. 1946. Empirical and theoretical relations between wind, sea, and swell. Trans. A.G.U. 27:823-827.
4. Hydrographic Office, U.S. Navy. 1943. Wind waves and swell: principles in forecasting. Navy Department, Washington, D.C.
5. Hydrographic Office, U.S. Navy. 1944. Breakers and surf: principles in forecasting. Navy Department, Washington, D.C.

6. Johnson, J.W., M.P. O'Brien, and J.D. Isaacs. 1948. Graphical construction of wave refraction diagrams. H.O., Navy Department, Washington, D.C.
7. Stevenson, T. 1886. The design and construction of harbours. A. and C. Black. Edinburgh.
8. Davies, A. 1946. Geographical factors in the invasion and battle of Normandy. Geog. Rev. 36(4):627.
9. Seiwell, H.R. 1947. Military oceanography in World War II. Mil. Eng. 39(259):202-210.
10. Scripps Institution of Oceanography. 1944. On wave heights in straits and sounds where incoming waves meet a strong tidal current. Wave Report No. 11 (mimeographed). La Jolla, California.

* * * * * * * * * * *

Sequel

During mid-September 1944, Detachment YK of the 21st Weather Squadron, using two Scripps trained oceanographers, First Lieutenants Donald W. Pritchard and Robert O. Reid, began directly supporting the Engineer Beach Command at Omaha Beach, a service continued until beach closure 10 weeks later.

The Admiralty Swell Forecast Section, complete with Americans, was moved early in 1945 to the British East Indies Fleet's weather central at Colombo, Ceylon (Sri Lanka), only to be disbanded after forecasting for the invasion of Rangoon, Burma (Operation Dracula) the following May.

During the post-war period, Commander Fleming rose to the rank of instructor rear admiral as director of the Royal Navy's educational service and was knighted during 1960. Cauthery reverted to civil life and eventually became assistant minister (administration) of the Air Ministry.

On the American side, Colonel Moorman achieved the rank of lieutenant general and held such posts as commander of the Air Weather Service, the 13th Air Force, and the Air Force Academy. A geology professor at the University of California, Santa Barbara, Crowell was elected to the National Academy of Sciences and served a term as chairman of the Earth Sciences Division, National Research Council. Lachner returned to icthyology and became curator of fishes, U.S. National Museum. Bates helped pioneer the provision of oceanographic forecasting services to the offshore oil industry and then went on to be technical director of the U.S. Naval Oceanographic Office and the science advisor to the commandant, U.S. Coast Guard.

APPENDIX

Critical Wave Forecasts for D-Day (Operation Overlord)[1]

Presentation Time to SHAEF

8:30 p.m., 4 June, 1944 (Sunday)

Forecast Area and Forecast[2]

Swell: Areas N,O, and F (south)--6 to 7 feet Monday, decreasing to 4 to 5 feet Tuesday: 3 to 4 feet remainder of period; from westerly direction throughout.

Sea:

Monday (6/5):
Areas N,O, and F (south): 8 to 10 feet of mixed sea and swell.
English Coast: 3 to 4 feet in Area F; 2 to 3 feet along rest of coast.

Tuesday (D-Day):
Areas N,O, and F (south)--3 to 4 foot wind waves.
English Coast: 2 to 3 feet becoming 3 to 4 feet in westerly portion.
French Coast and Area I: 3 to 4 feet except 2 to 3 feet in Area G (west).

Wednesday - Friday (6/7 - 6/9):
Areas, N,O, and F (south): 5 to 7 feet of mixed sea and swell.
English Coast: 2 to 3 feet with risk of 4 feet.
French Coast: 3 to 5 feet, but 2 to 4 feet in Area G (West).

* * * * * * * *

Assault Beaches Only

Presentation Time to SHAEF

3:00 a.m., Monday,

Surf:
Monday (6/5): 4 feet decreasing to 3 feet.
Tuesday (D-Day): 2 feet
Wednesday-Friday: 2 to 3 feet (6/7-6/9)

1. Swell Forecast Section predictions jointly prepared by 1/Lts Crowell and Bates.

2. Geography of Forecast Areas: N: south of Ireland; O: approaches to English Channel west of Brest, France; F: region between Land's End, England and Cherbourg, France; G: Bay of the Seine, including assault beaches; H: English Channel between Le Havre and Dover, and I: southern part of the North Sea.

CHAPTER 8

HINDCASTING WEATHER FOR THE NORMANDY INVASION 40 YEARS LATER

INTRODUCTION BY JOSEPH VEDERMAN:

Dr. Stagg ends his book[5] on this note. "Radar and radiosondes, weather satellites, automatic recording and telecommunicating devices, high speed teleprinters and facsimile reproduction machines, and electronic computer installations which can produce forecast charts directly and automatically from the observational data — all these have been introduced as every day aids since the years of the second World War ..... In particular, would our forecasts have been more accurate and more reliable? I believe they would not have been significantly more useful than those we achieved at the time." General Holzman[6] had a similar opinion. He said that "even with satellite information, computers, and upper air information, to me, today, there is still no reliable technique to predict weather beyond more than 24 or 36 hours. It is all a poker game."

Dr. Johannessen, our next speaker, has considered that challenge, and he has accepted it. During the D-Day period he worked with Douglas and Petterssen at the Met. Office Forecast Office in Dunstable near London. After the war, he was a consultant to the air force. Then he worked with the National Weather Service. When he retired, he was the associate director of the National Weather Service. He is about to show us, using only data then available, what the 500-mb forecast would have been for the period around D-Day if one had a high speed computer and a barotropic program.

---

[5] J.M. Stagg, "Forecast for Overlord", page 127. W.W. Norton & Co. Inc. New York, 1971.

[6] B.G. Holzman in Book Reviews section of Bulletin American Meteorological Society, Vol. 24, No. 6, June 1973, page 563

HINDCASTING WEATHER FOR THE NORMANDY INVASION 40 YEARS LATER

by

Karl R. Johannessen

On the sixth of June this year it will be 40 years since the allied invasion on the Normandy beaches, the greatest military operation of all times. The operation had all the ingredients of concern for the staff weather officers attached to General Eisenhower's headquarters: a fundamental and complex sensitivity to weather and, during the week leading up to the invasion, rapid, dramatic, and unusual storm developments.

As has been described by several authors including the general himself in "Crusade in Europe," the landings on D-Day were conditioned by many factors; tides on the beaches, daylight, sea and swell on the beaches and during the crossing of the channel, visibility, ceiling and cloud amount for naval and aerial bombardment in the assault area and over the enemy logistic arteries.

Figure 1 shows the landing area. Utah and Omaha beaches are marked as well as Mulberry Harbor.

As we know, two periods had been selected as being suitable for tides and daylight: 4-6 June, with 5 June as the ideal day, and 17-19 June. General Eisenhower had determined 5 June as the first possible day to launch the invasion.

It is now history that D-Day was postponed 24 hours from the fifth to the sixth on the advice of the staff meteorologists and that this postponement was crucial to the success of the landings. The provisional decision to postpone was made by General Eisenhower at the 9:30 P.M. meeting on the third, about 30 hours before the planned assault and based on a 36-hour forecast of conditions in the assault area. The provisional decision was confirmed the next morning at the scheduled 4:15 meeting, 24 hours before planned landings and roughly based on a 30-hour forecast. Forecast was for 10/10's cloud, down to 500 feet at times, wind force four-five and force six in exposed areas from the west-southwest. This put the whole gigantic operation in suspension for 24 hours.

Again, to relate history, the provisional decision to launch the assault on the morning of 6 June was made on the evening of 4 June at General Eisenhower's 9:30 P.M. conference. The cold front, which would have prevented an assault on the fifth was forecast to penetrate well into France on the sixth, and weather behind it would involve lessened winds and break-up of the cloud cover, suitable for an invasion. This preliminary decision was based on data about 36 hours prior to the new target hour for Overlord and was confirmed the next morning at 4:00 A.M. on the fifth.

And we know the verifying conditions:

On the assault coast the cold front gave unbroken cloud on the morning of the fifth and strong on-shore winds which would have made landings impossible for the airborne and seaborne invasion forces.

On the morning of the sixth, visibility was excellent along the coast of Normandy and the sky was less than half covered, wind was from the west to west-northwest, forces three to four. The wind and swell created some difficulties on the more-exposed eastern beaches, particularly the swell from the previous day's storm which had raised some rough seas.

There are several accounts of what took place meteorologically and also about how various forecasters' opinions were integrated into the decisive forecasts. We have seen that these were successful. But very little has been said about the development of the meteorological situations prior to D-Day from a scientific point of view, based on what progress we have made in the science of forecasting in the ensuing 40 years.

Five years ago I decided to try out some of the numerical weather prediction models. I went to the task blissfully unaware of the difficulties involved in unearthing data that go 35 years back in time.

In 1944 the knowledge of upper-air patterns as related to surface patterns was rudimentary. A network, as we know it today, did not exist. A network of sorts had been built up over allied territory over the previous two-three years, augmented by a few ships at sea and aerial reconnaissance over the oceans. Over enemy territory some data became available at times. But knowledge of the coupling of upper-air circulation and surface patterns had to be assimilated on the job. Practically, there was no applicable theory except the hydrostatic and geostrophic equations and the theory of modification of thickness patterns by advection, vertical motion, radiant, and turbulent fluxes. Few ideas about development had been formulated except those of the polar-front theory which were based on surface patterns. Sutcliffe's ideas on cyclonic and anticyclonic development

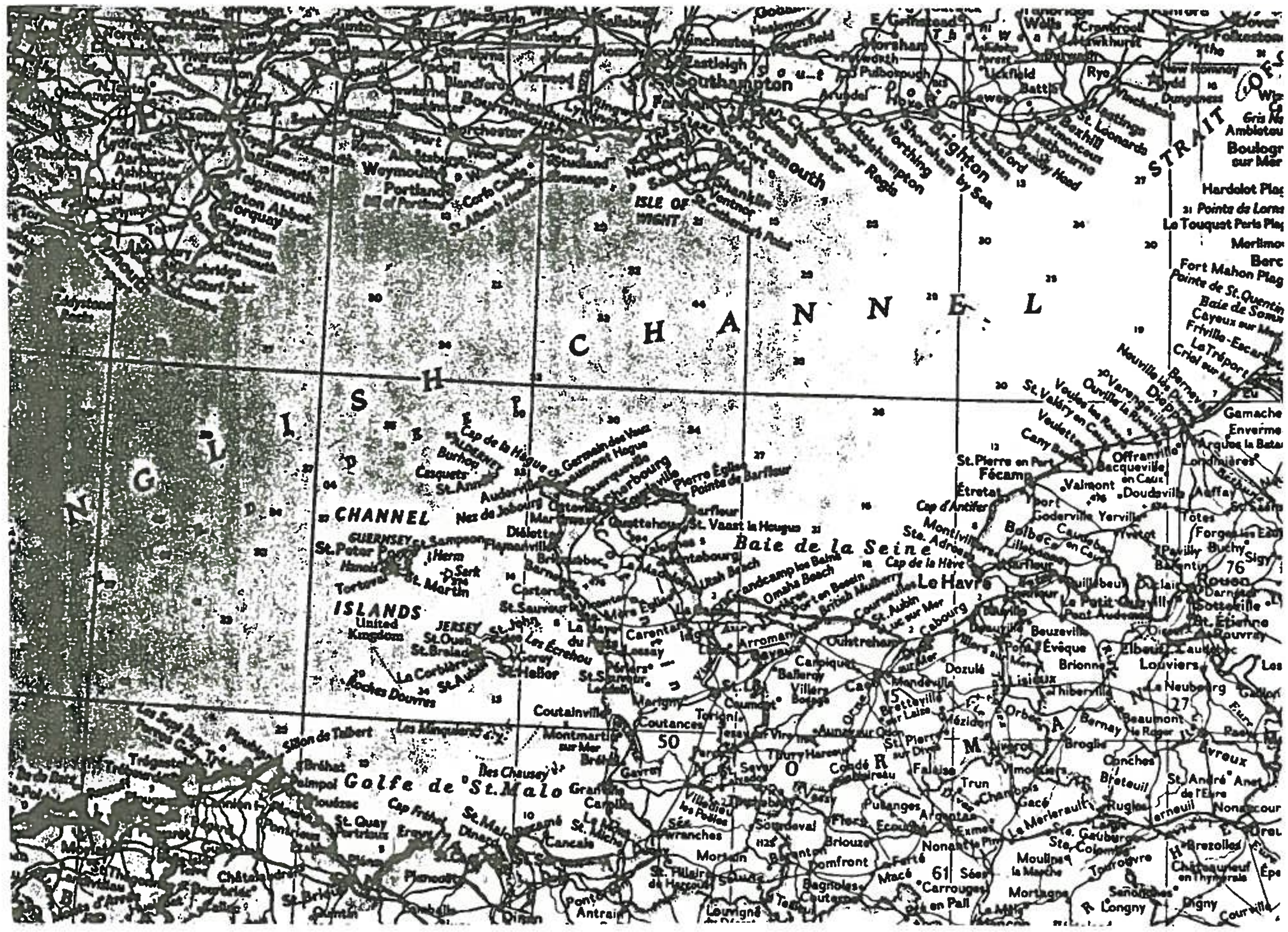


Figure 1.

(in his 1939 Quarterly Journal paper) were difficult to apply for lack of upper winds in the Atlantic.

I was able to get copies of the surface maps and upper-air maps for June drawn at the Dunstable Forecast Center of the British Air Ministry, where I was working at the time. Similarly I was able to get hold of maps drawn in the Pentagon by the army air force. Also, hemispheric surface analysis later became available from the Northern Hemisphere Historic map series.

The Air Ministry upper-air maps did not extend more than two-thirds across the Atlantic. The Pentagon maps stretched from about latitude 130 degrees west in the Pacific over to Europe, but the quality in the eastern part left much to be desired. It is evident to a modern analyst who looks through these maps that many of the rules we have learned to use today were violated, such as continuity and models of behavior of upper-air patterns in relation to surface patterns.

At any rate, I think it is possible to piece together today fairly decent analyses of the surface and upper-air patterns by using predominantly Air Ministry analyses in the east and Pentagon analyses in the west. I'll show in a minute these analyses and how they were joined together into analyses of about half the hemisphere. By what we have learned since 1944, we have come to recognize that we need at least that kind of coverage before we should attempt forecasts for several days. That was not universally understood in 1944.

The staff weather officers briefing General Eisenhower and his staff at SHAEF headquarters relied for their information and advice on three weather centrals which were accessed on schedule several times a day in scrambled telephone conferences. The three centers were: (1) Dunstable weather center of the British Air Ministry situated 40 miles northwest of London, (2) U.S. Army Air Force weather center at Bushy Park in southwest London near Henry VIII's Hampton court (code named Widewing), and (3) British Admiralty weather center in London. The latter was mainly responsible for forecasting sea and swell conditions in the channel and landing areas.

A most-valuable contribution to today's understanding would have been the weather maps drawn by the meteorologists at Bushy Park, but they were apparently lost in the turmoil following victory in Europe and return home of the U.S. Army Air Force. Colonel Robert C. Bundgaard, who was on the Bushy Park team, told

me that when he returned to Bushy Park after VE-Day, he found that the maps had been destroyed.

The levels analyzed routinely in those days were about the same as today, surface maps (sea-level pressure), 700 mb (Dunstable drew 750mb charts), 500 mb, and 300 mb. Synoptic times were a bit different on the two sides of the Atlantic: 00Z and 1200Z (01Z, 07Z, 13Z and 19Z at surface) at Dunstable, but 04Z and 1600Z at the Pentagon.

A point that should be appreciated is that many details of the maps over the ocean areas were uncertain. Little information except a few ship observations and flight-level winds (from drift), air temperature, and, sometimes, D-values were available over the ocean. The gross features of the circulation patterns over the Atlantic were known, but the details of baroclinic concentrations were very uncertain. Understanding developed since then has taught us that such detailed knowledge is necessary for successful short-term prediction of developing storms. As it turned out, it was a rapidly deepening storm, unusually intense and fast moving for June, which caused the postponement of the invasion for 24 hours, but which also brought an interruption in low cloud and poor visibility conditions reigning in the channel area and created a go situation after the postponement.

In order to prepare the initial conditions for the model integrations, I have had to read off grid points by hand, about 2,000 of them for each integration. This is a laborious and time-consuming procedure, particularly since the map bases used from different sources had different scales and projections and had to be rectified to a uniform map base, that of the model grid. Through various photographic and eyeball techniques, this was accomplished. Since the model I used requires hemispheric data, the missing half of the hemisphere was filled in by easing the ends of isobars and contours into normals for the month of June.

So far I have carried out two hemispheric barotropic integrations run out to four days. It turned out that the simple barotropic model, run over four-day periods in two integrations, was able to account for the main changes that took place in the planetary wave pattern prior to D-Day and would have given good guidance to the crucial forecasts that were made for the D-Day operation.

Before I show the results of the computer runs, I'd like to go through the weather maps preceding D-Day. I think you'll gain better appreciation for them that way.

First, Figs. 2-12 show Air Ministry Surface Maps 0100Z, 2 June to 1300Z, 6 June 1944. Through the second and the third, the weather was acceptable in the channel. A series of disturbances moved rapidly east in the Atlantic on a path taking them north of the British Isles. But the frontal zone was being pressed gradually southwards both across the United States and in the Atlantic, and the cyclonic activity was increasing. On the evening of the third, it became likely that the cold front of a deepening cyclone was going to traverse the British Isles on the fourth and the channel during the night to the fifth, making a landing on the morning of the fifth extremely hazardous. The assault was postponed 24 hours. On the evening of the fourth, it began to appear that the frontal zone would pass well into France and a rapidly building ridge behind it would bring acceptable conditions of clearing skies and abating winds. The signals to go were given that evening and confirmed early the next morning. The invasion was on for the morning of the sixth!

Of course, we should remember that the ideas of development, in those days, were practically all based on the surface map. It was really the Bjerknes and Solberg theory of the polar front and the life cycle of cyclones which was the basis for it, of course augmented by empirical information, acquired by forecasters who had studied for their area thousands of weather maps. This is what Douglas at Dunstable was such a master at. He had been a forecaster for over 20 years before D-Day and he had an uncanny recall of past situations and an uncanny feeling for what cyclones would do or wouldn't do.

Now let me show you some of the upper-air maps that we had at Dunstable. This is the type of map that we drew (Fig. 13). We built it up by thickness, just like we do now but with the numerical models. The contour lines are solid and the dashed are thickness lines between the 500mb surface and the 300mb surface. Only data over the U. K. are blotted on these maps. The network was very limited. We had pretty good data (over Great Britain), Greenland, Iceland, some of the islands, and we had a few reconnaisance observations out over the Atlantic. We got some data out of enemy territory at times but, as you can see, part of the map was very uncertain.

Figures 13-21 show 500-mb Air Ministry maps, 00Z, 2 June to 00Z, 6 June 1944. There was no let-up in the strong westerly steering currents towards the British Isles until the morning of the fourth when the building of a ridge at about 40 degrees west started to show. On the morning of the sixth, this ridge had moved to about 20 degrees west and continued to move slowly east, giving the Normandy coast and the channel area the good weather needed for the post-D-Day build-up. The thickness pattern pretty much follows what we understand it to be today.

What did we know about development, and how did upper-air maps help us to tell what was going to happen near the surface? The answers are very, very little. There had been some theories about how the upper-air patterns related to the surface patterns developed in the 20s and the 30s, mostly of a statistical nature. Actually, we used a lot of those in building up, for instance, how the thickness lines, the thermal lines, were related to the surface fronts based on empirical statistical information. Now about development, there had been a few papers that had appeared. Jack

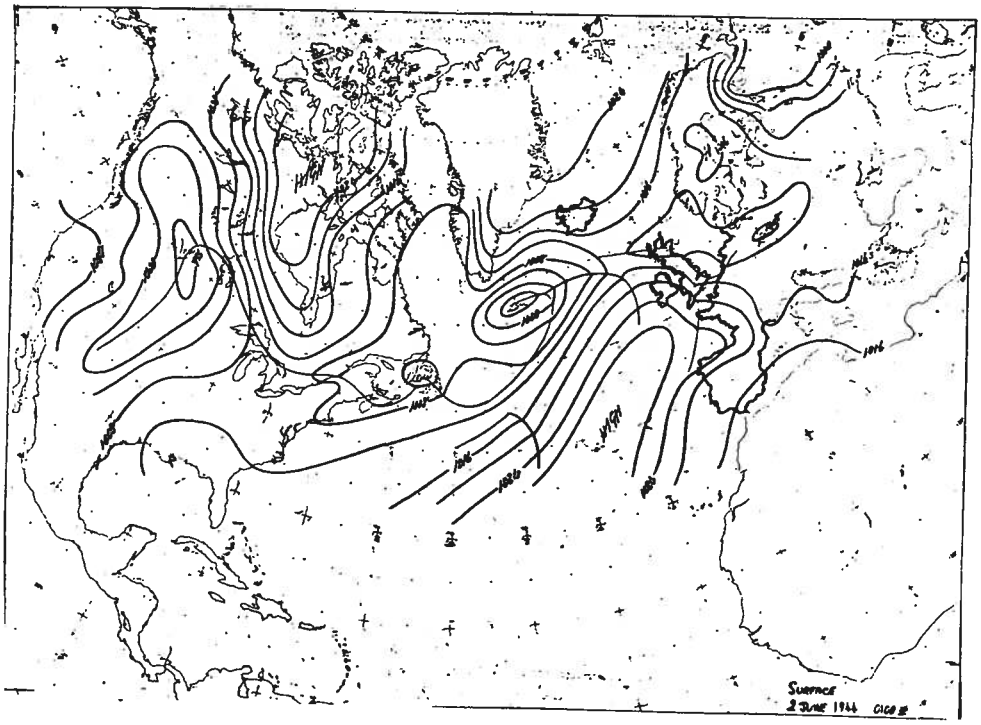


Figure 2. Surface 2 June 01Z

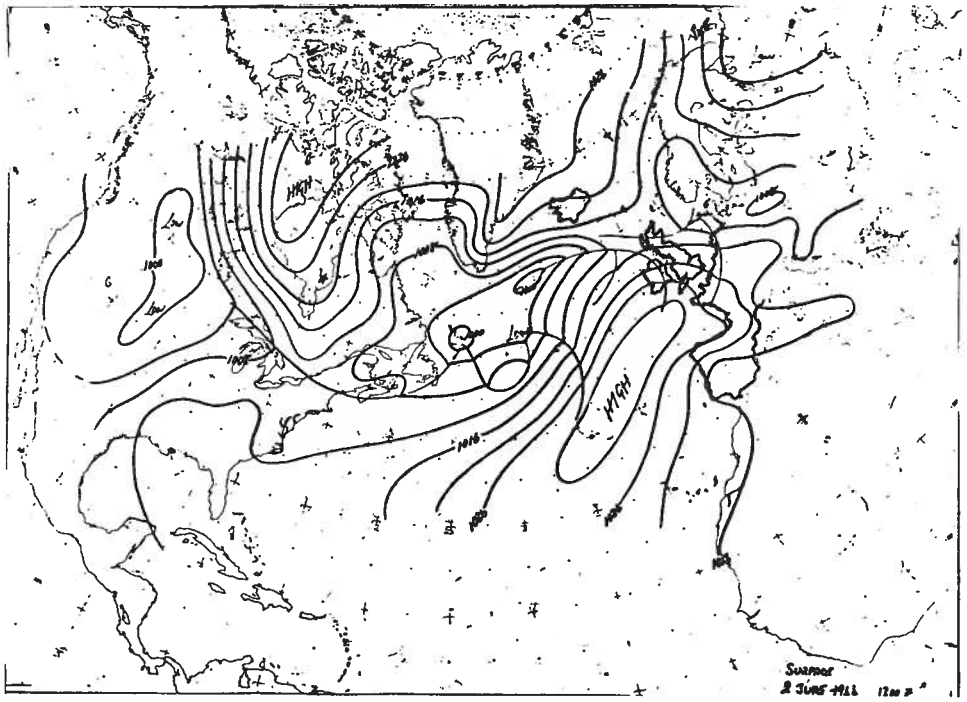


Figure 3. Surface 2 June 13Z

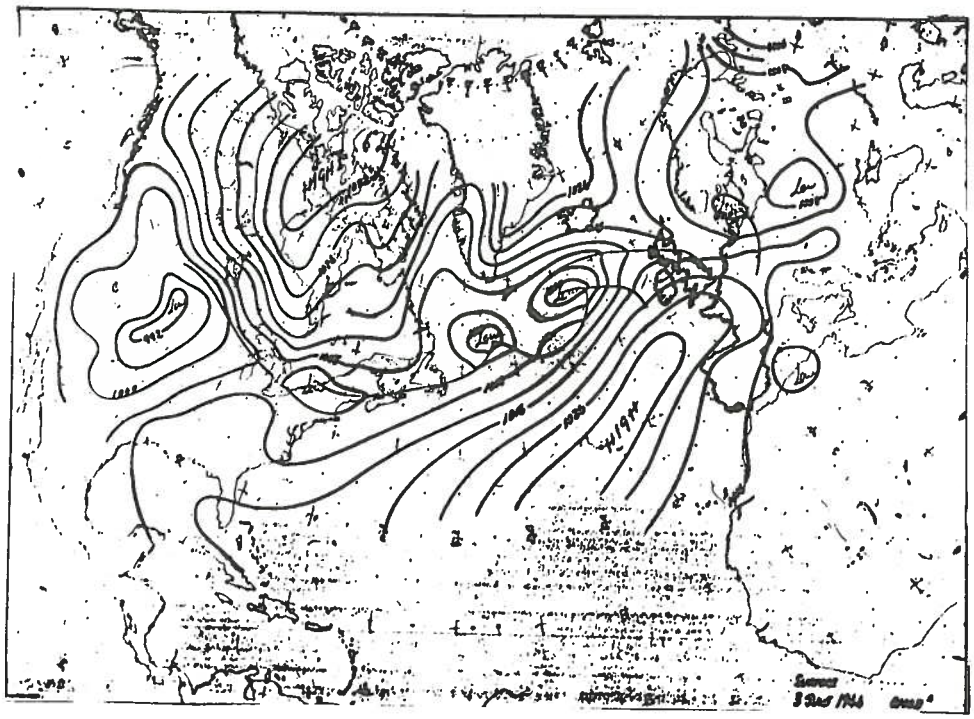


Figure 4. Surface 3 June 01Z

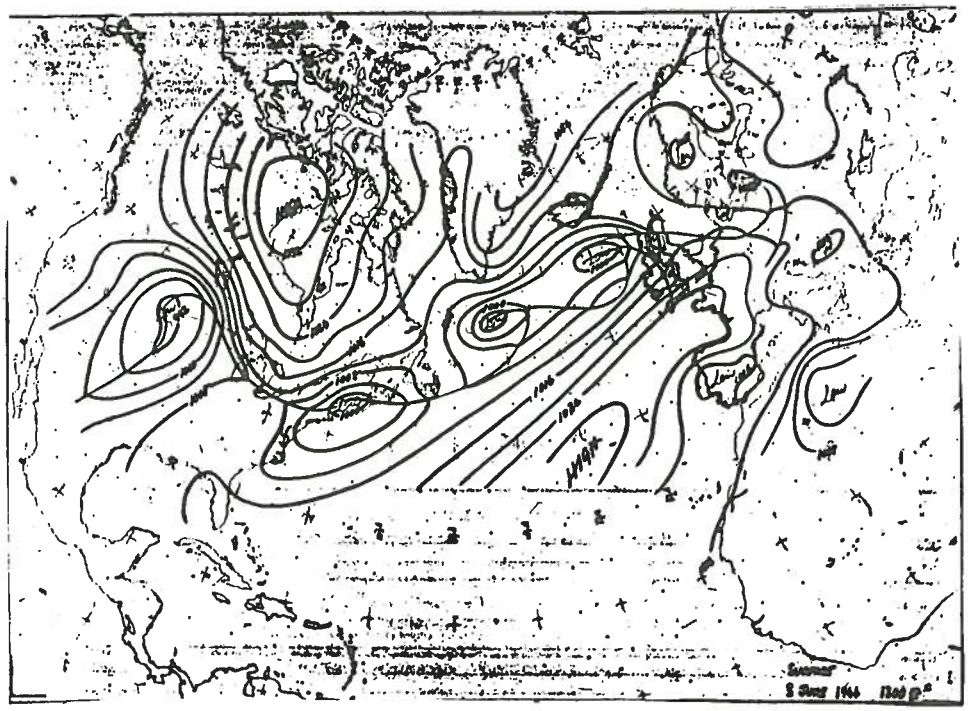


Figure 5. Surface 3 June 13Z

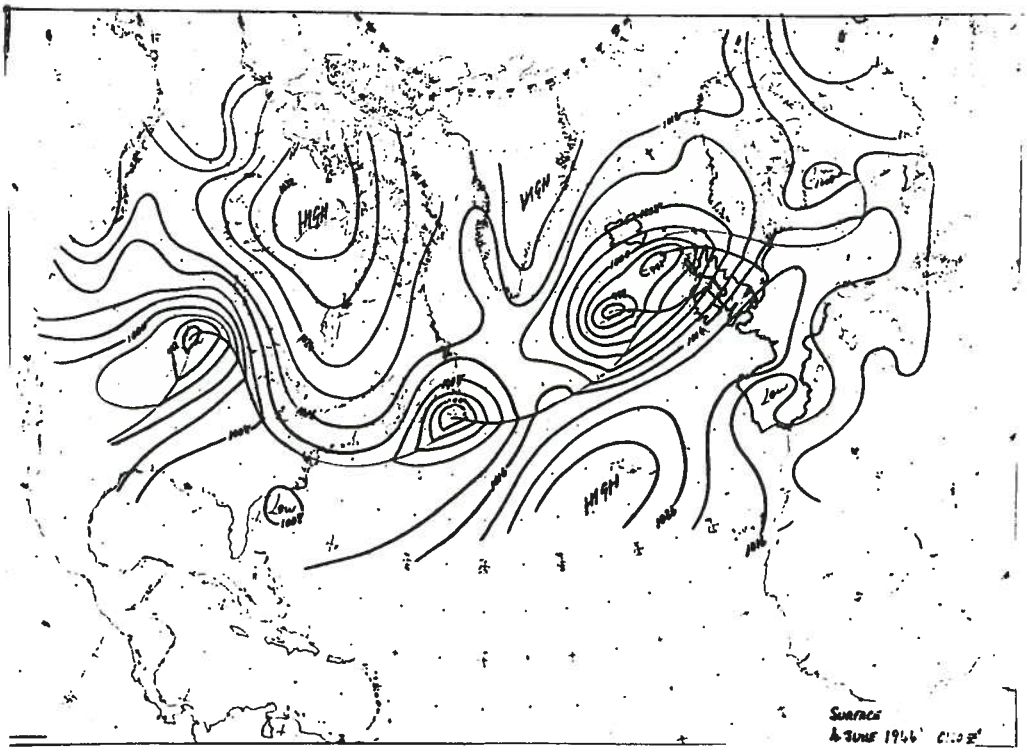


Figure 6. 4 June 01Z

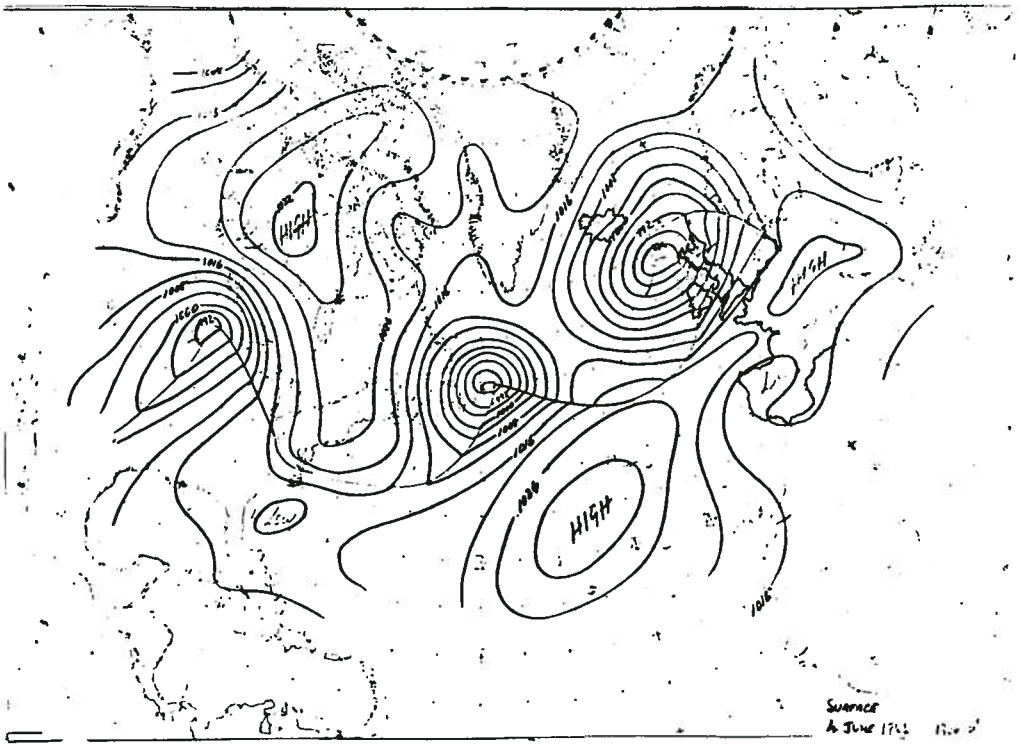


Figure 7. Surface 4 June 13Z

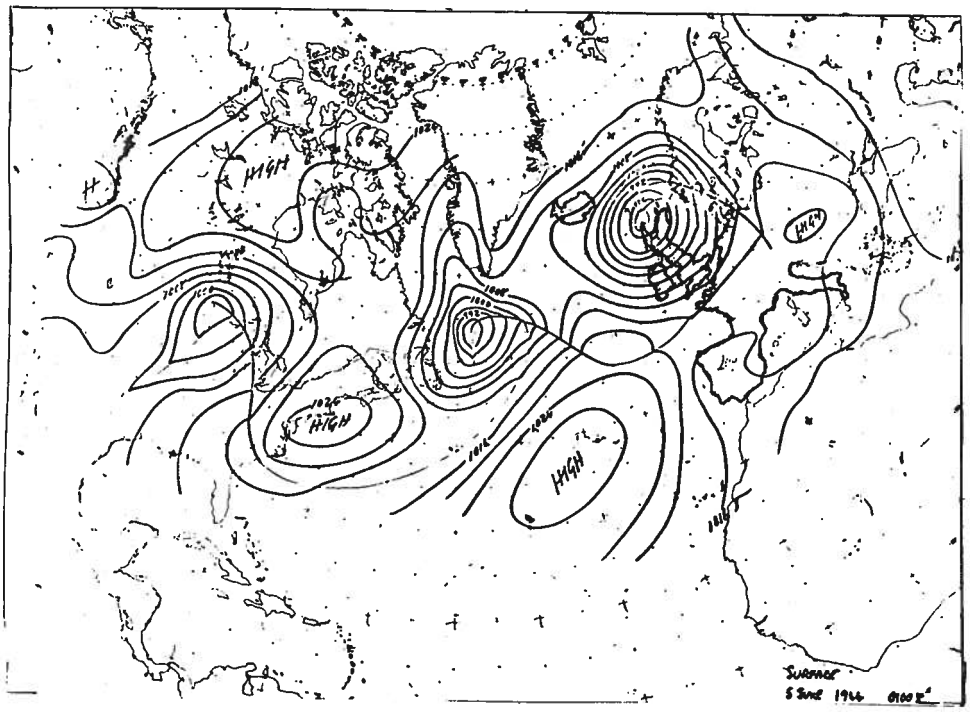


Figure 8. Surface 5 June 01Z

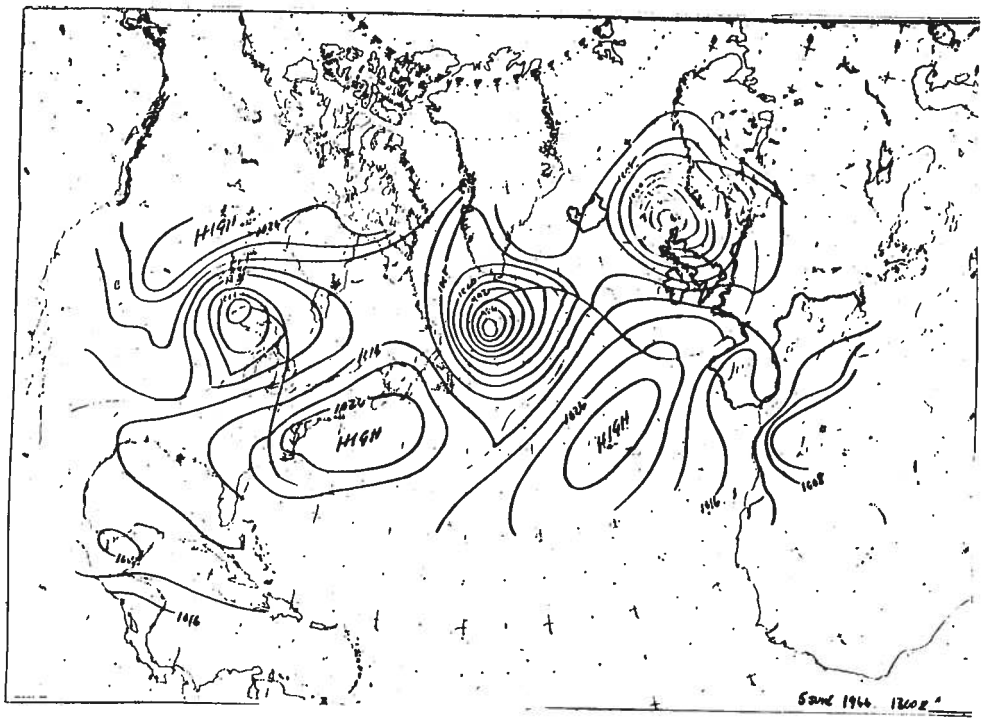


Figure 9. Surface 5 June 13Z

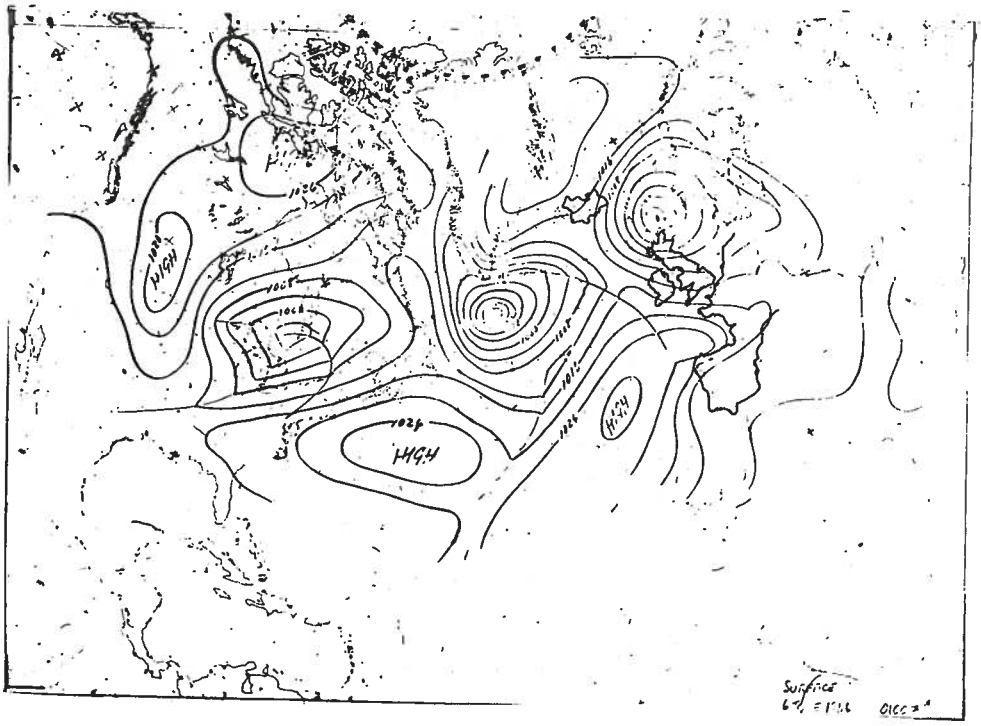


Figure 10. Surface 6 June 01Z

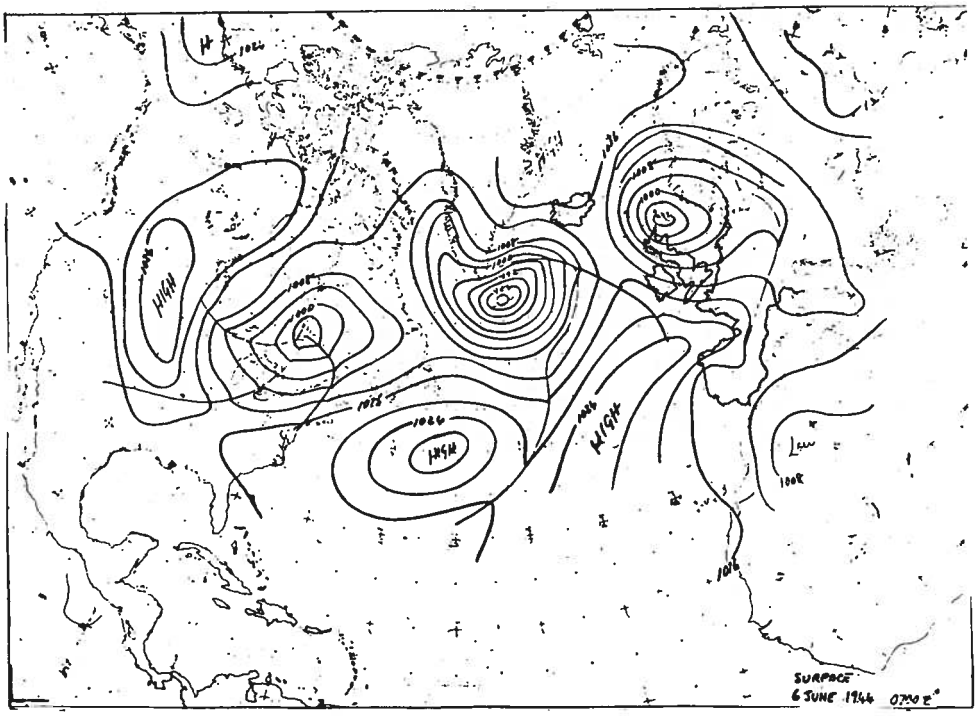


Figure 11. Surface 6 June 07Z

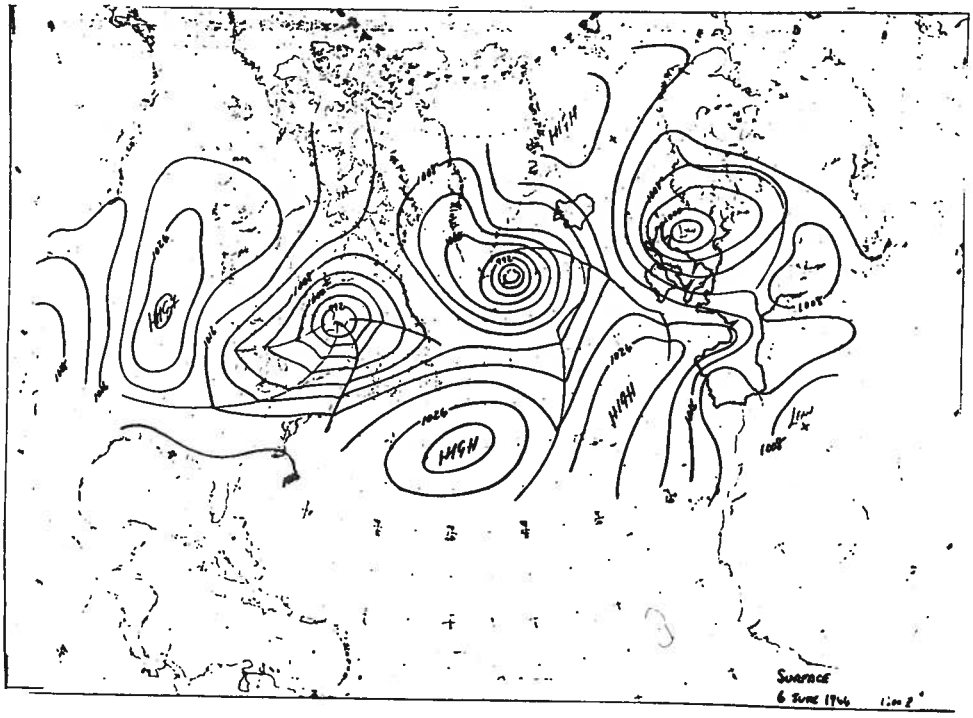


Figure 12. Surface 6 June 13Z

Bjerknes' paper from 1939 dealt with development but it was very difficult to apply if you didn't have the measurement that was needed. Sutcliffe, in England, had written a remarkable paper just about at the same time. It appeared in the Quarterly Journal, and was about how surface development is related to the configuration of the surface map and the thermal wind pattern above it. I cannot say that it was highly used, although there was a memorandum written and circulated by the people in Dunstable. We read it and tried to use it, but we came up against the problem that the important developments were those west of us, and out there we didn't really have the confidence in the thickness patterns that was required. We got a little bit discouraged about it, but you can say that in a general way it was useful.

I needed, of course, more than these surface and upper air maps from Dunstable to make numerical forecasts. To make a forecast of three, four, or five days with the barotropic model, you have to have data that stretches back at least across the United States. This is something we know today. So I had to augment them, and the only source of information that I had were the maps drawn in the Pentagon. There they drew an extensive series of maps, at least two maps a day at several levels to 300mb. These maps have been preserved on microfilm. The reproduction is not very good but we managed to blow them up and get data off them.

Next, Figs. 22-31 show 500-mb Pentagon maps, 0400Z, 2 June to 1600Z, 6 June 1944. We see again, over a wider longitudinal band, the same events. The pattern is zonal in the beginning of the period, buckling in mid-Atlantic on the fifth and taking on the appearance of a blocking pattern on the sixth.

Let me show you quickly the development of the upper air. Figure 28 shows the 500-mb surface on 5 June. You can see at this time that something drastic has happened; the pattern has buckled in the middle, a huge ridge was thrown up with a very deep trough across the North Sea. By this time, the actual cold front is pretty much in agreement with how you would expect the patterns to relate. When I glanced through these maps, I found that they weren't very accurate in the east, so that the data that I finally took off them was mainly in the western part. I used Pentagon data in the west and the Dunstable analysis in the east, and I was able in that way to get a pretty decent analysis of the Northern Hemisphere. I had at least 180 degrees of longitude: the rest I had to fill in with climatology.

Next, I will show the barotropic 500-mb prognosis. Figures 32-40 show the grid analysis for 12Z, 2 June, and prognoses to 96 hours (12Z, 6 June). An octagonal grid was used, containing about 2,000 points, a mesh size of 380 km and a one-hour time step.

I selected two initialization times. The first was selected at 12Z on the second as a point in time which would have given about a 72-hour guidance for the originally planned invasion on the fifth. The crucial feature here (Fig. 32) is the strong vorticity pattern just off the East Coast of the U.S.. What we were

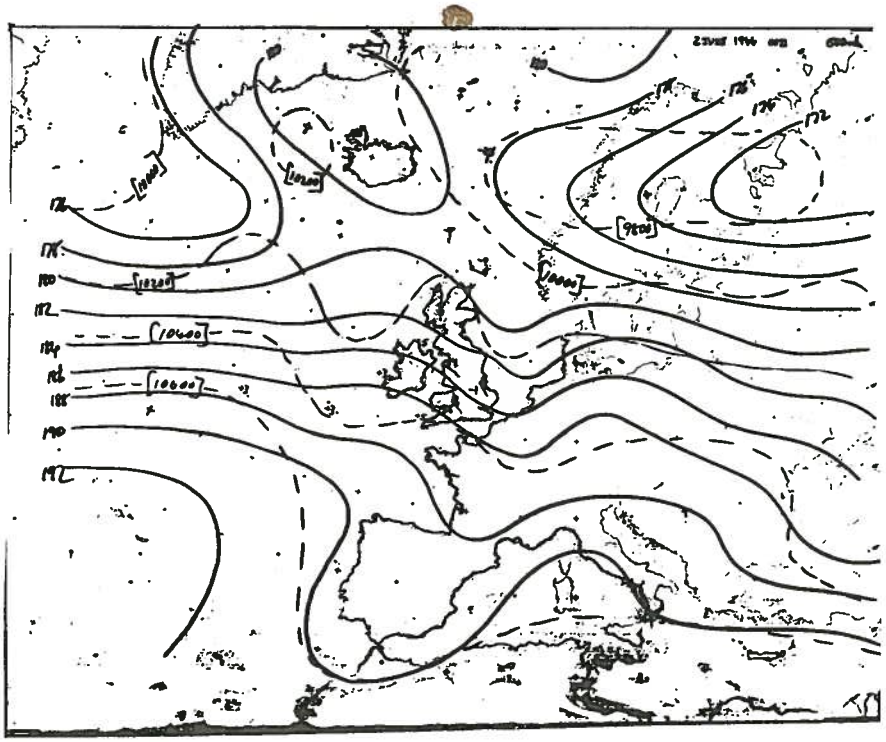


Figure 13. 500mb 2 June 00Z

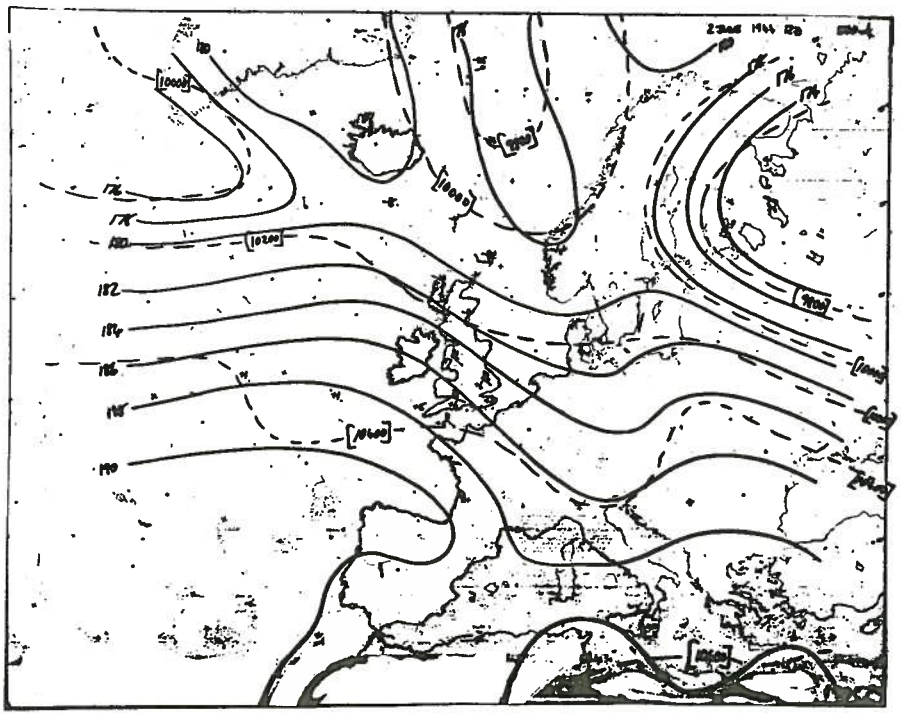


Figure 14. 500mb 2 June 12Z

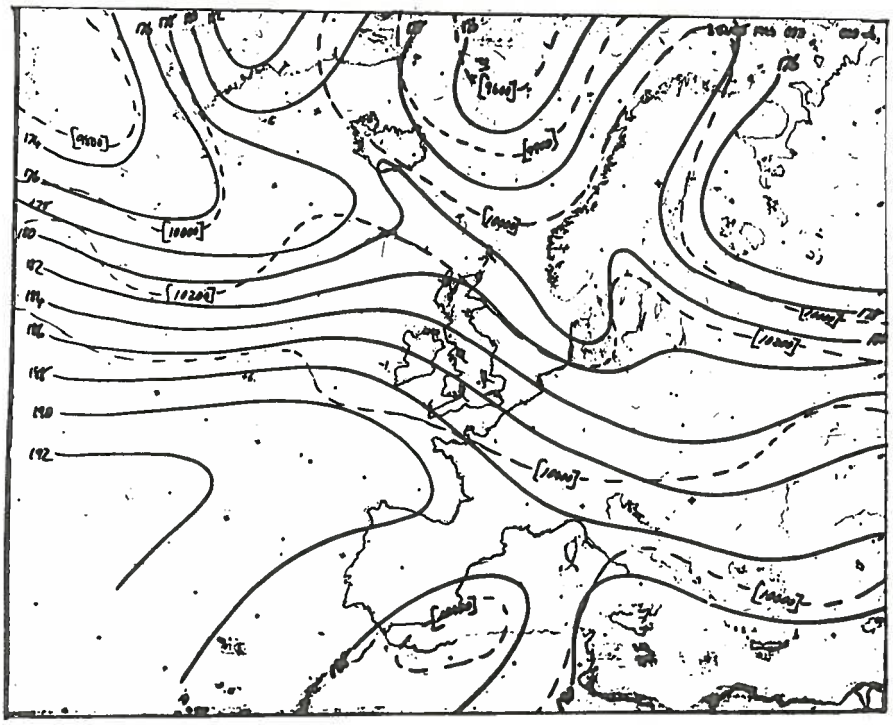


Figure 15. 500mb 3 June 00Z

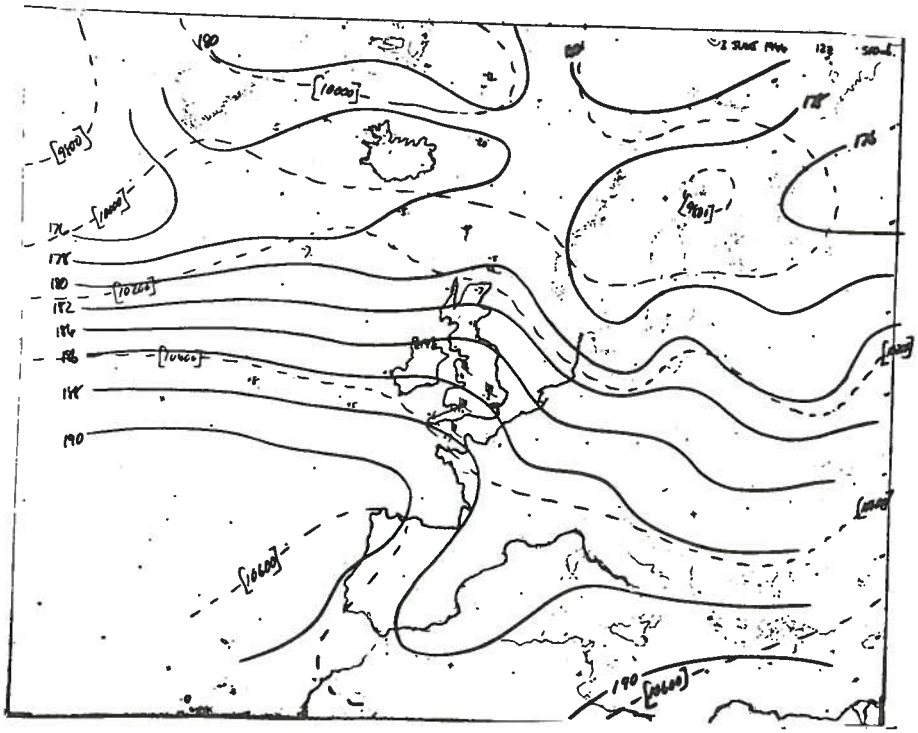


Figure 16. 500mb 3 June 12Z

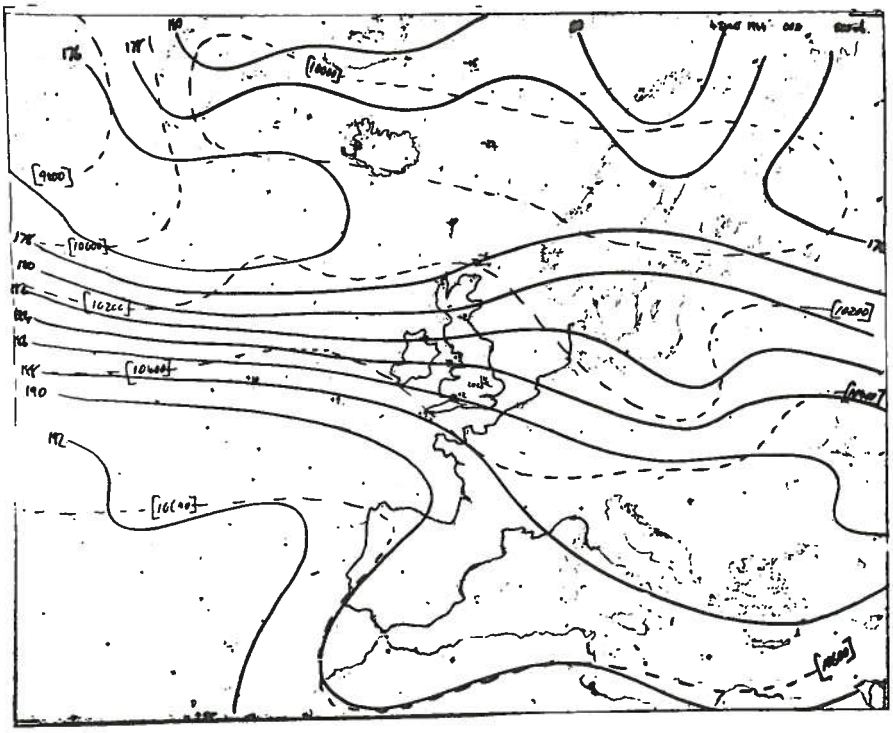


Figure 17. 500mb 4 June 00Z

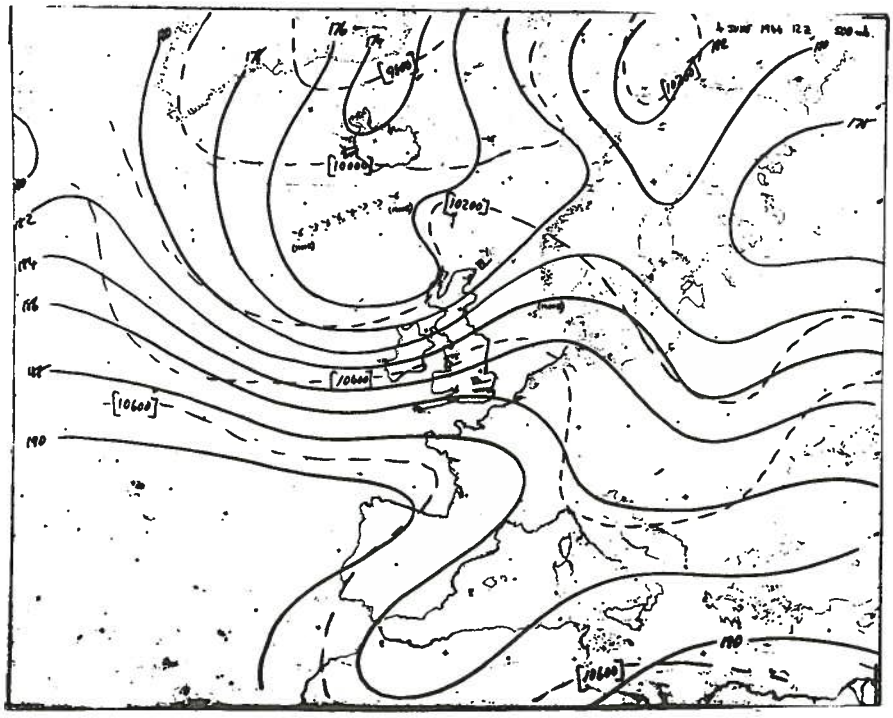


Figure 18. 500mb 4 June 12Z

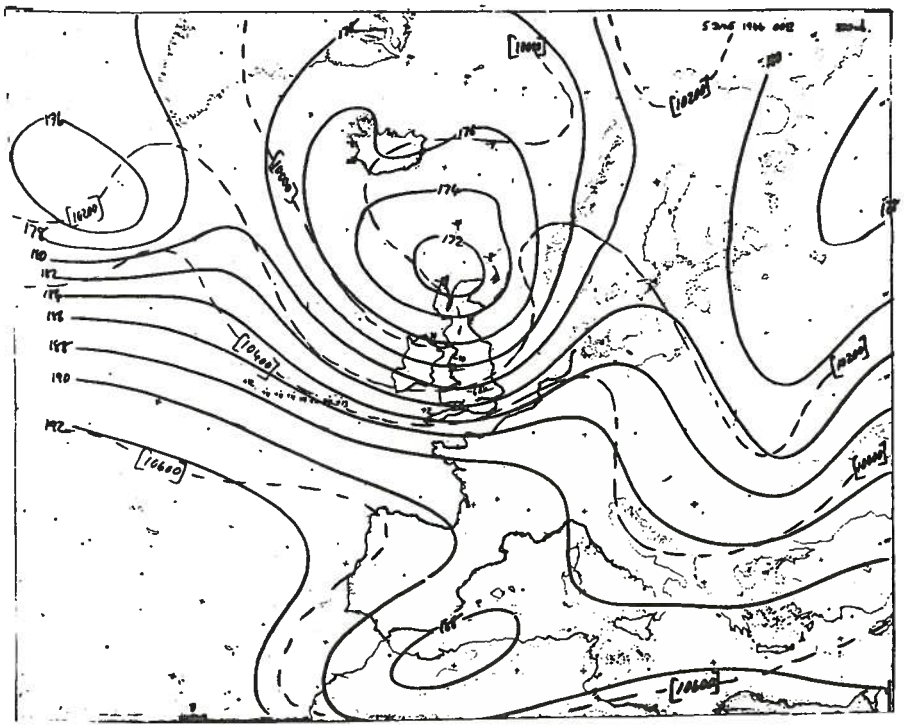


Figure 19. 500mb 5 June 00Z

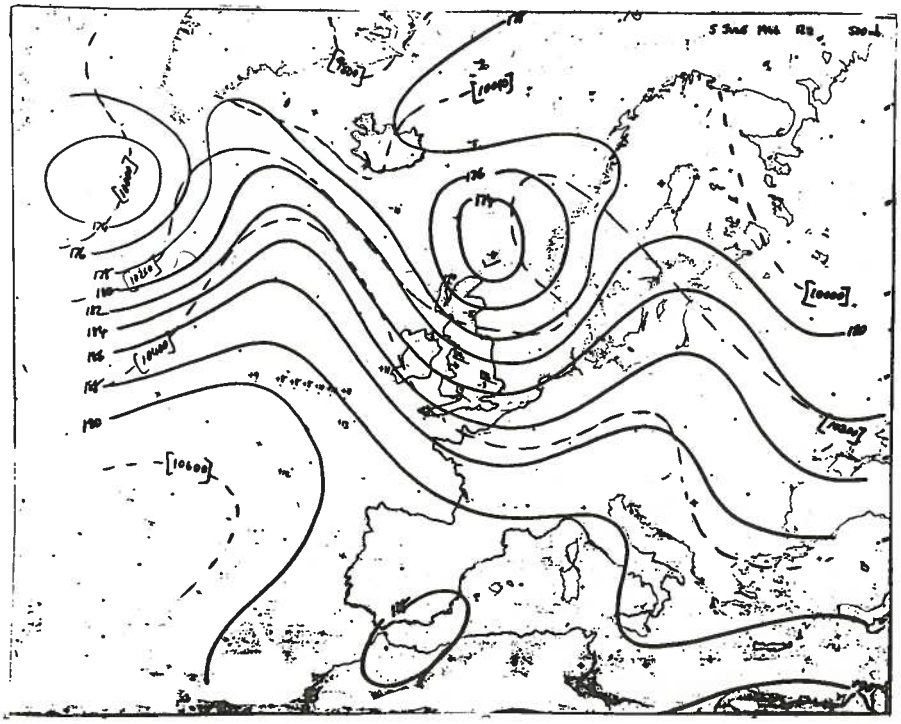


Figure 20. 500mb 5 June 12Z

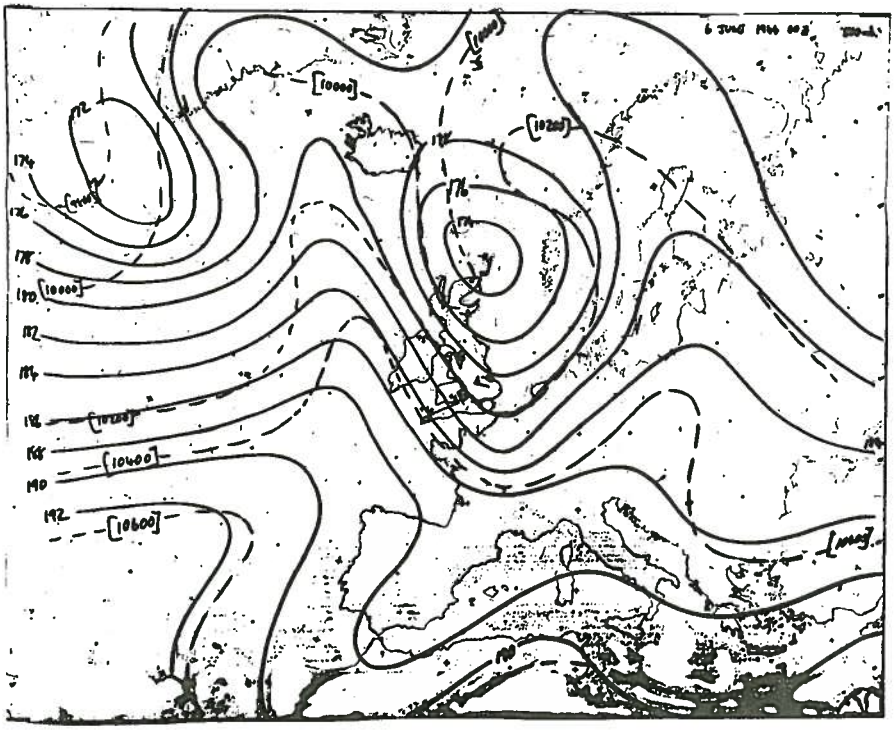


Figure 21. 500mb 6 June 00Z

looking for to improve the Channel weather was a ridge being thrown up over or west of the Channel to make the weather situation a little more stable, giving the invasion force three or four days of good weather they needed to land and build up the beach head. The following maps show predictions based on the 2 June analysis, at 12 hour intervals. On the third at 1200 Z, the trough is still off the U.S. East Coast, but you can see that the vorticity is moving out and the ridge is starting to build up. On the fourth at 1200 Z, the ridge is already in position, (as the cold front is passing Ireland.) On the fifth at 1200Z, there is a well-defined ridge and a trough across the North Sea pretty much as it happened. Judging from this 500mb prognosis the cold front associated with the trough would probably have passed the assault area at this time, but you must recall that the invasion depended very crucially on the weather in a very, very small area: a few tens of miles of beaches at the very crucial time between, say, midnight and 1200 on the 5th when the first assault forces were planned to go ashore and the naval bombardment was to take place, and this time frame was more important than any other.

On the next map, on 6 June, with the plunging of the trough down the North Sea, as predicted by the barotropic process, the ridge is moving in, perhaps guaranteeing fairly stable weather for a few days. The sequence does predict the change from a zonal pattern to the increased amplitude on the fifth. Of course, the bad weather on the morning of the fifth in the channel resulted from a relatively small baroclinic detail, the cold front associated with the deepening depression north of Scotland, the result of a strong baroclinic development. The storm registered the lowest June pressure recorded in the British Isles up to then, with 976.8 mbs at Wick at 0400 on the fifth. The prognosis does indicate that, if any weather would threaten, it would be from a cold front leading a substantial cold outbreak, not from a warm front type situation.

The next case was chosen beginning at 12Z on 4 June. Figures 41-49 show the the grid analysis for 12Z, 4 June, and prognoses to 96 hours (12Z, 8 June). At that point in time, the assault had been postponed 24 hours and the questions were: what would happen to the surface low and the associated cold front? Would it clear the channel area and the beaches by early the sixth and would the strong winds subside? What would happen on the seventh and the eighth, a period of great importance for the build-up of the invasion?

The barotropic prognosis carries the closed low almost due east, but slowly, and plunges the trough into central Germany, indicating that northerly winds and subsidence will prevail over the British Isles and Normandy from the sixth through the eighth. Not much can be inferred about the strength of the surface winds on the

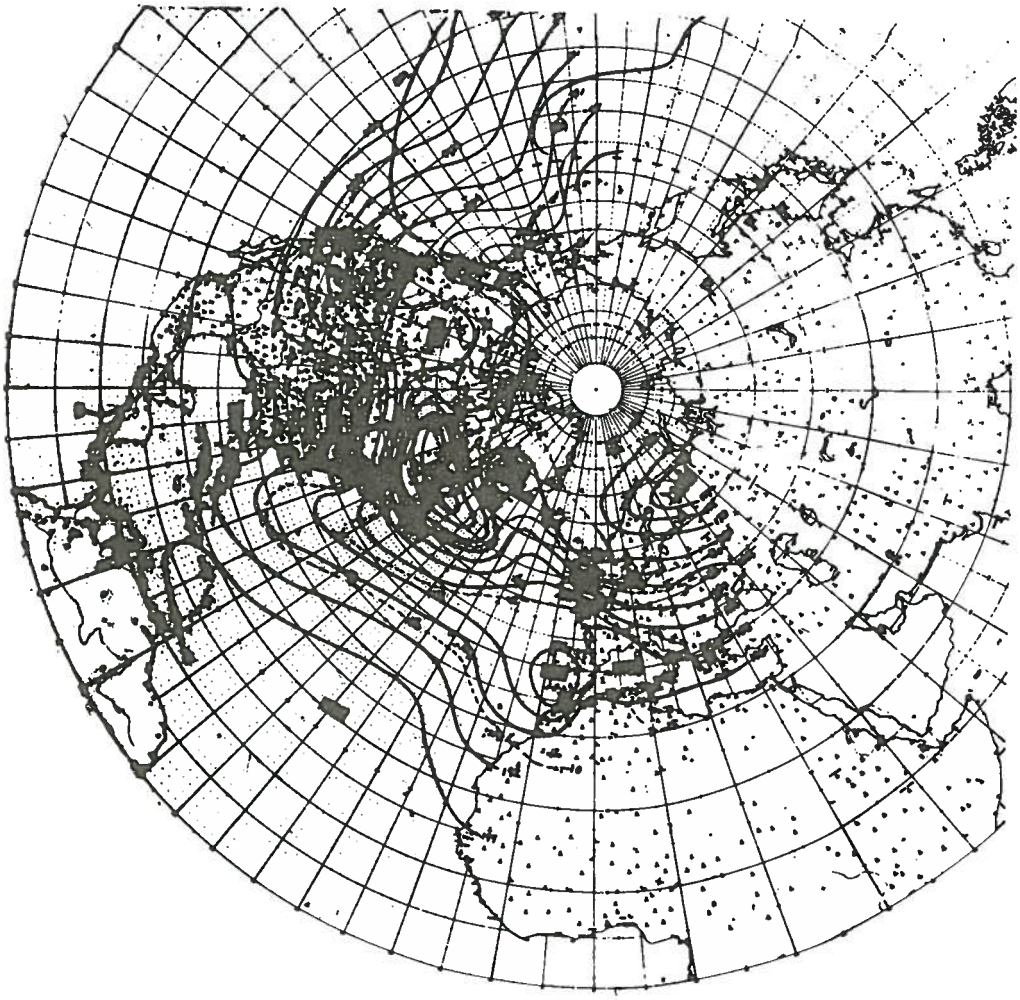


Figure 22. 500mb 0400Z June 2, 1944

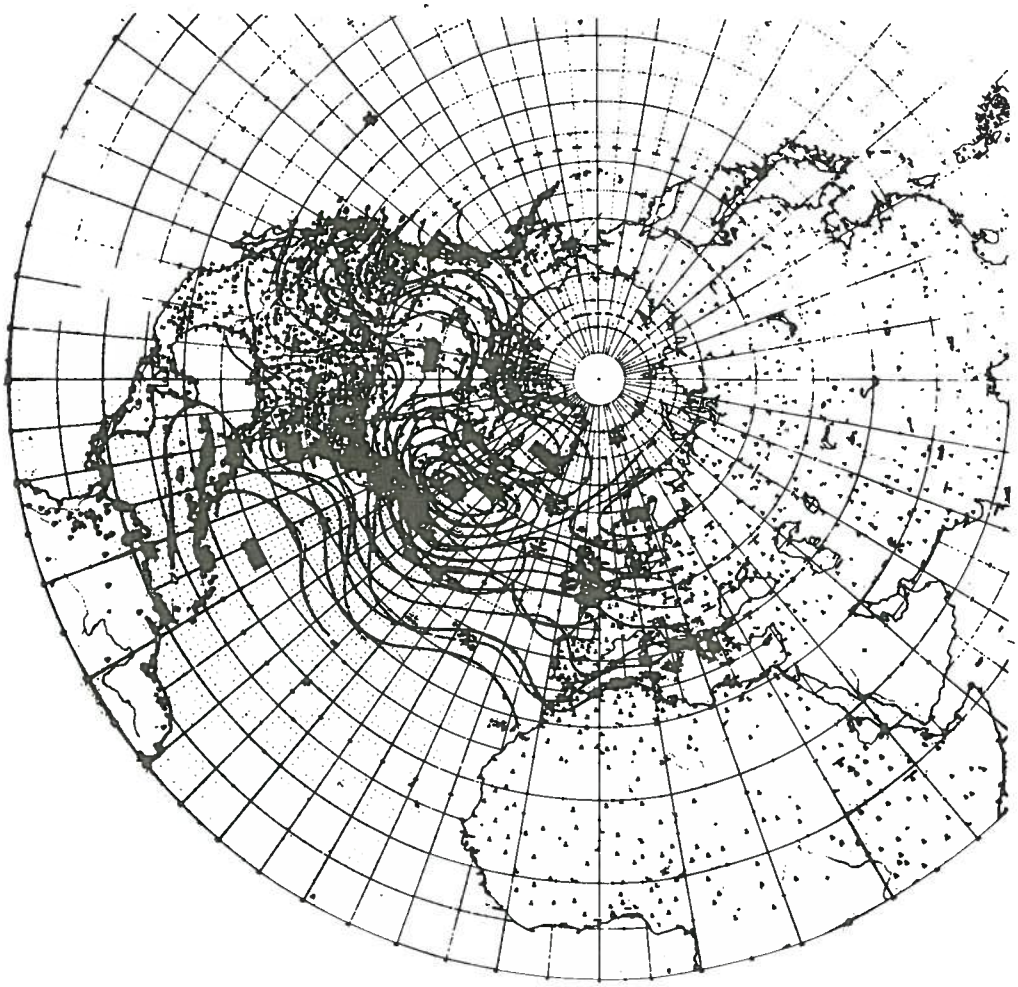


Figure 23. 500mb 1600Z June 2, 1944

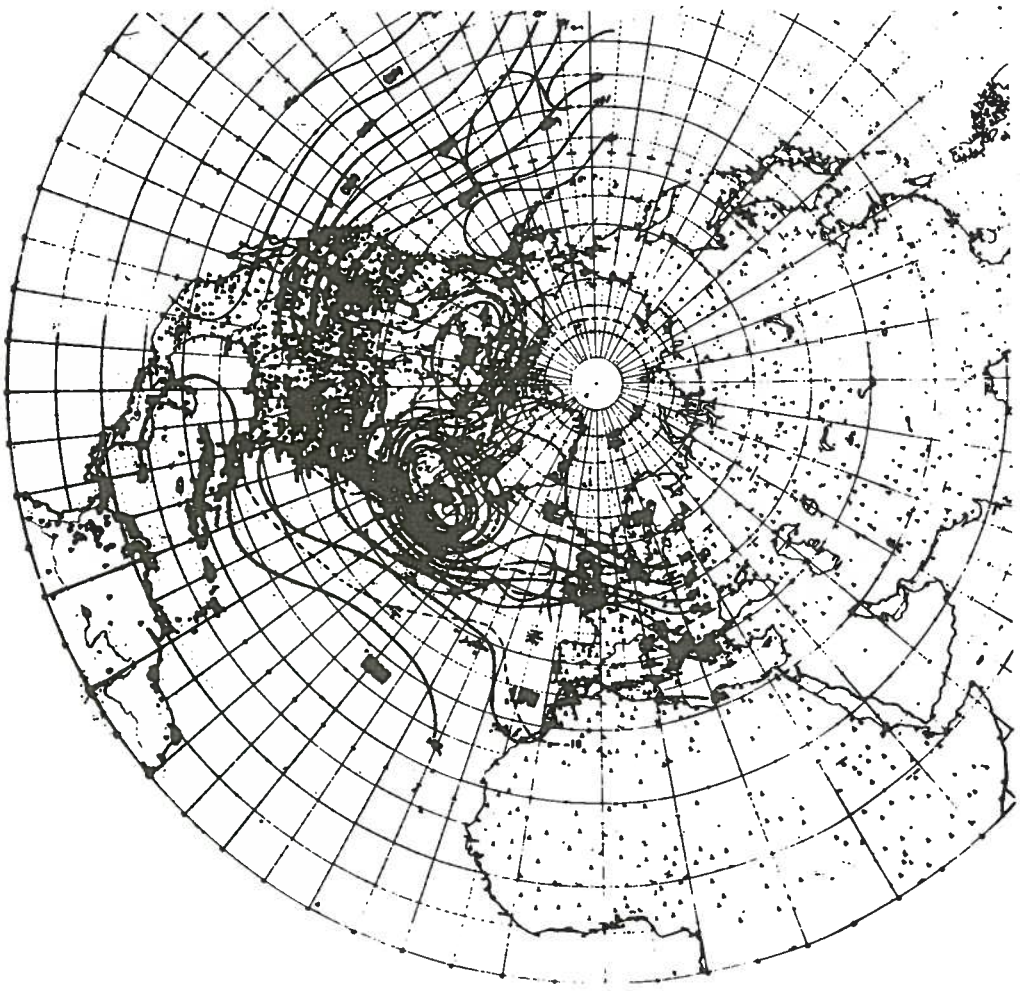


Figure 24. 500mb 0400Z June 3, 1944

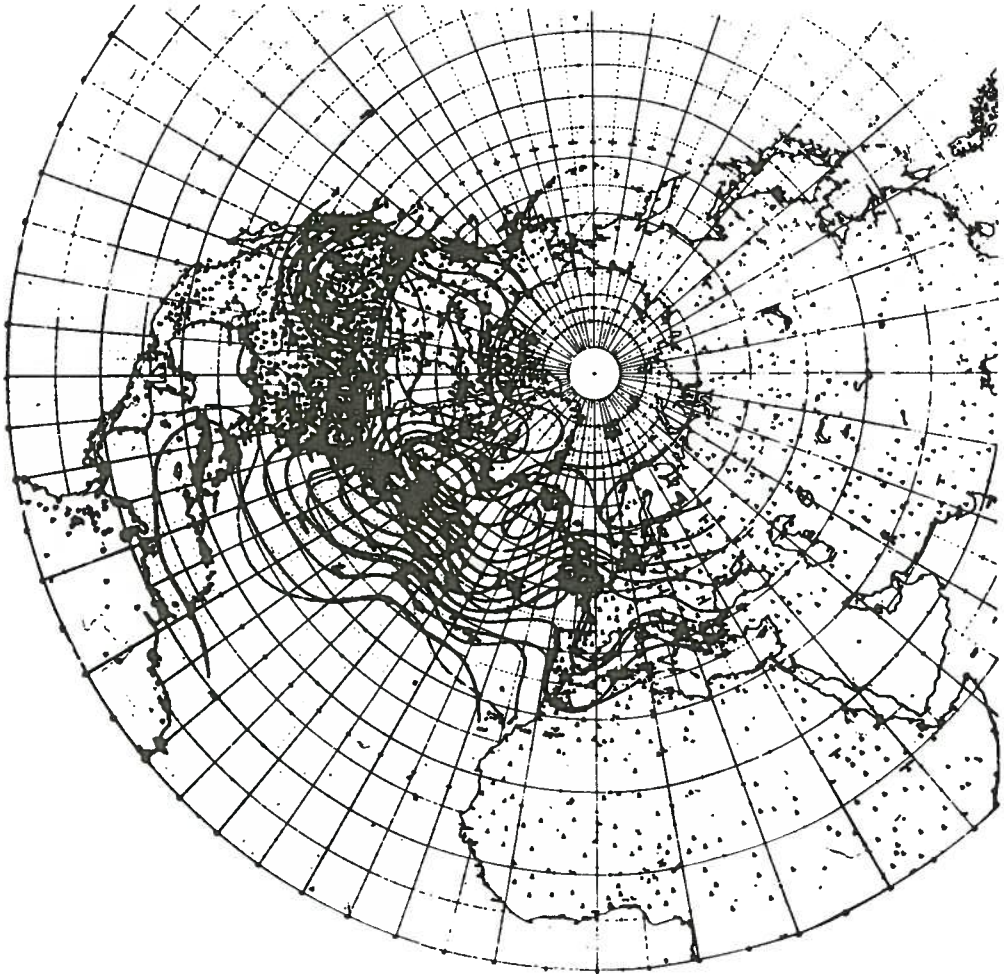


Figure 25. 500mb 1600Z June 3, 1944

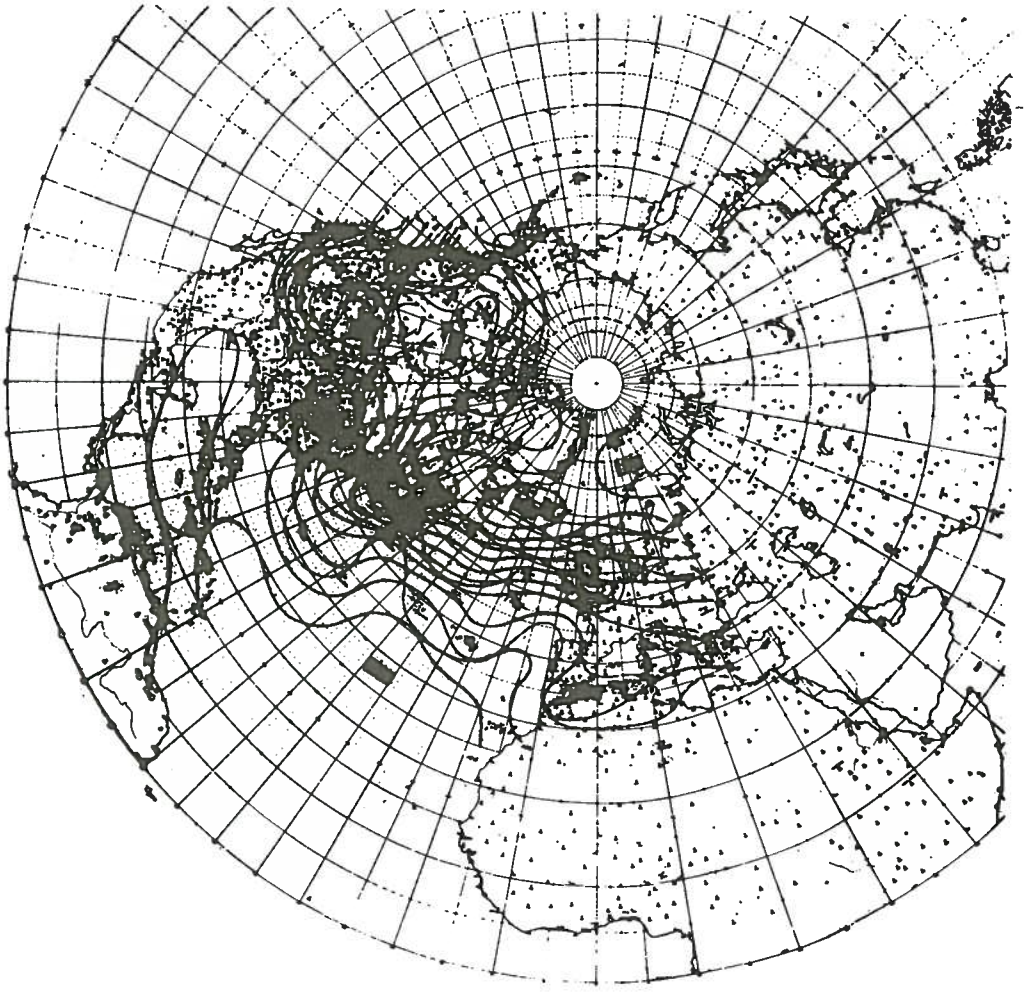


Figure 26. 500mb 0400Z June 4, 1944

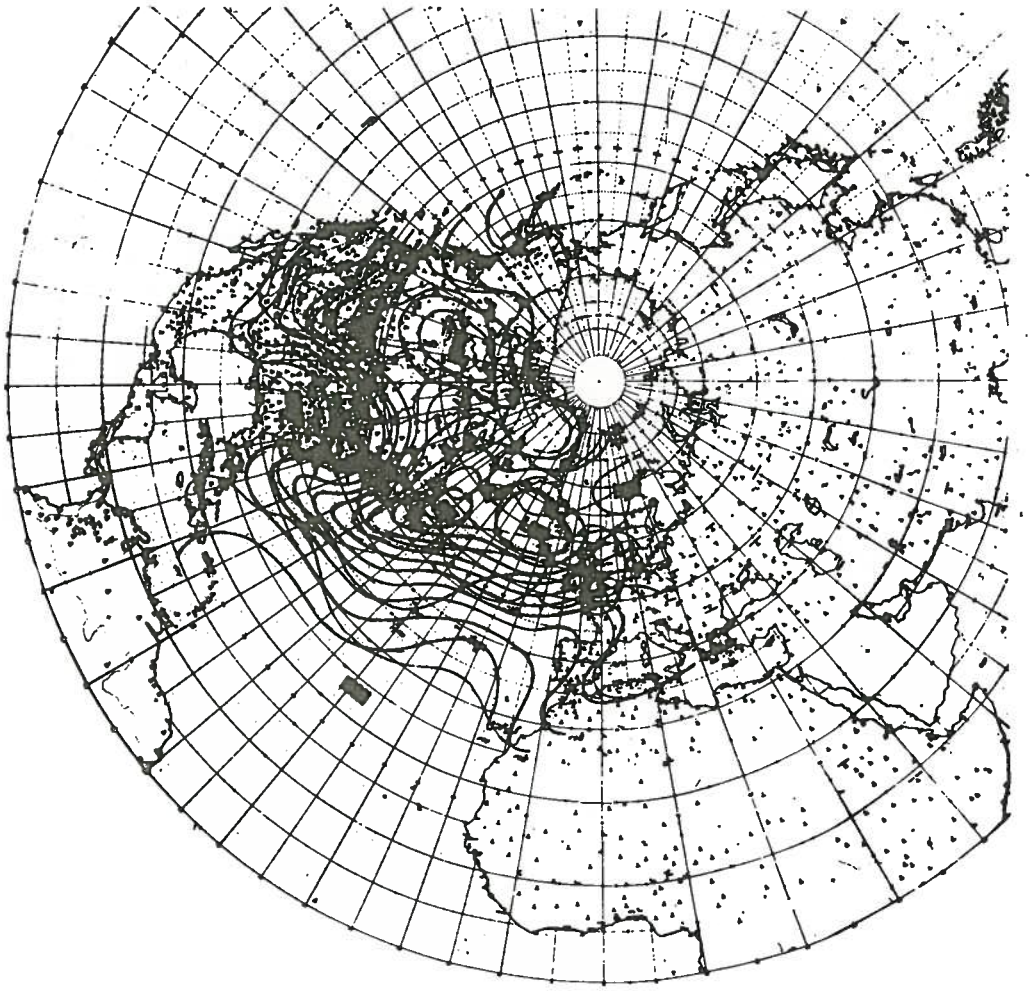


Figure 27. 500mb 1600Z June 4, 1944

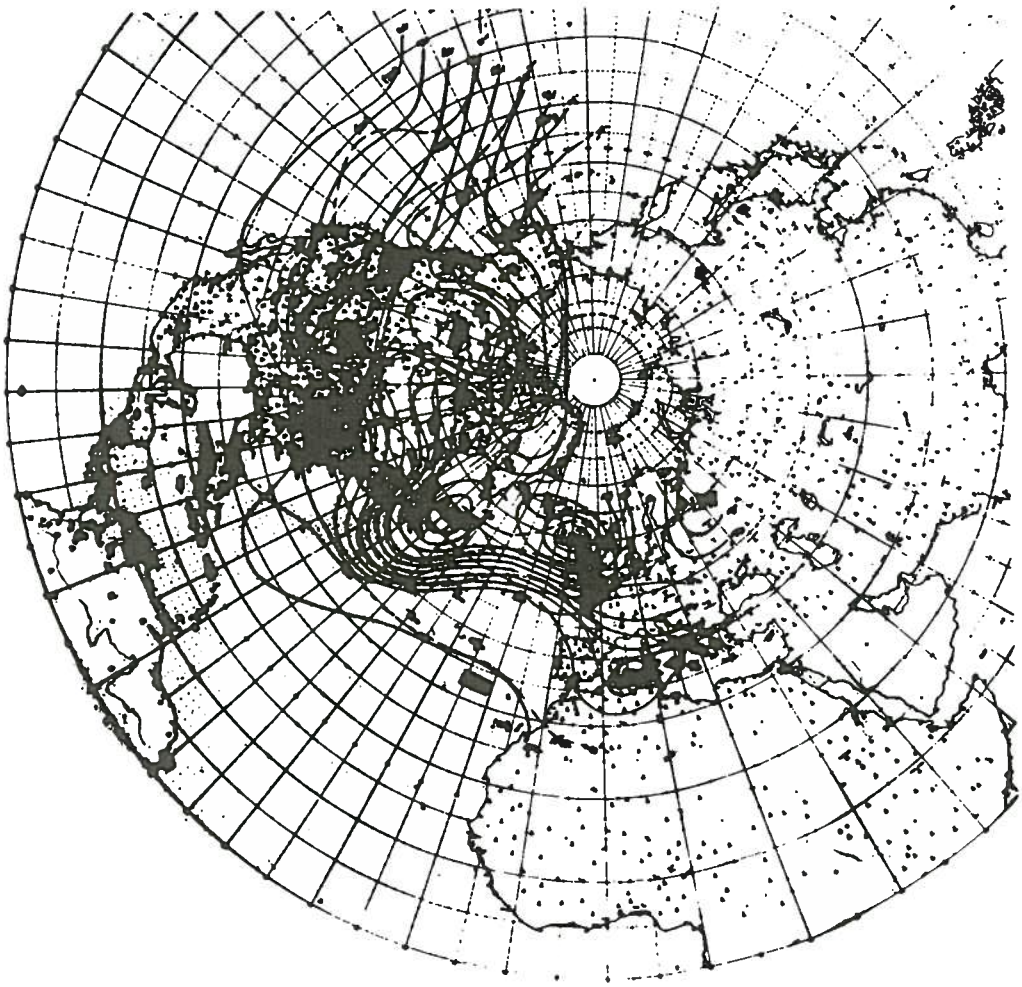


Figure 28. 500mb 0400Z June 4, 1944

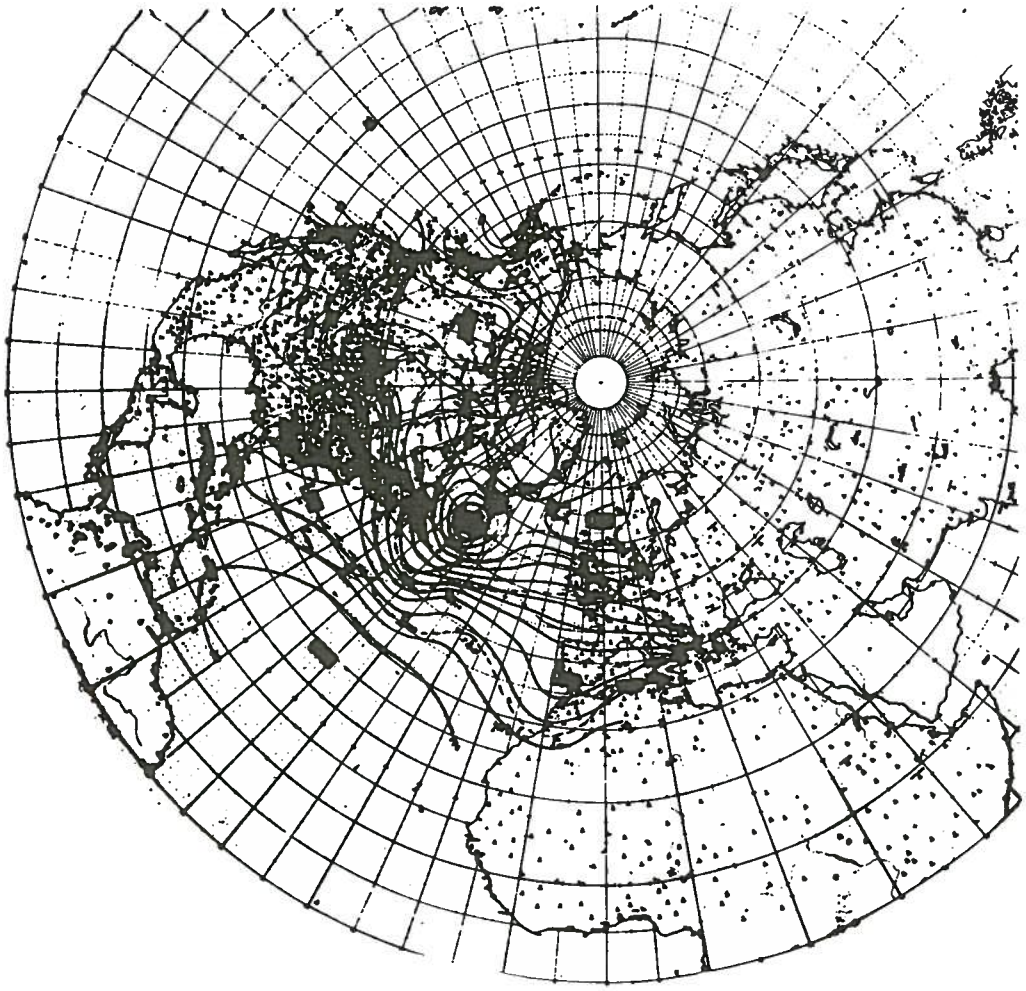


Figure 29. 500mb 1600Z June 5, 1944

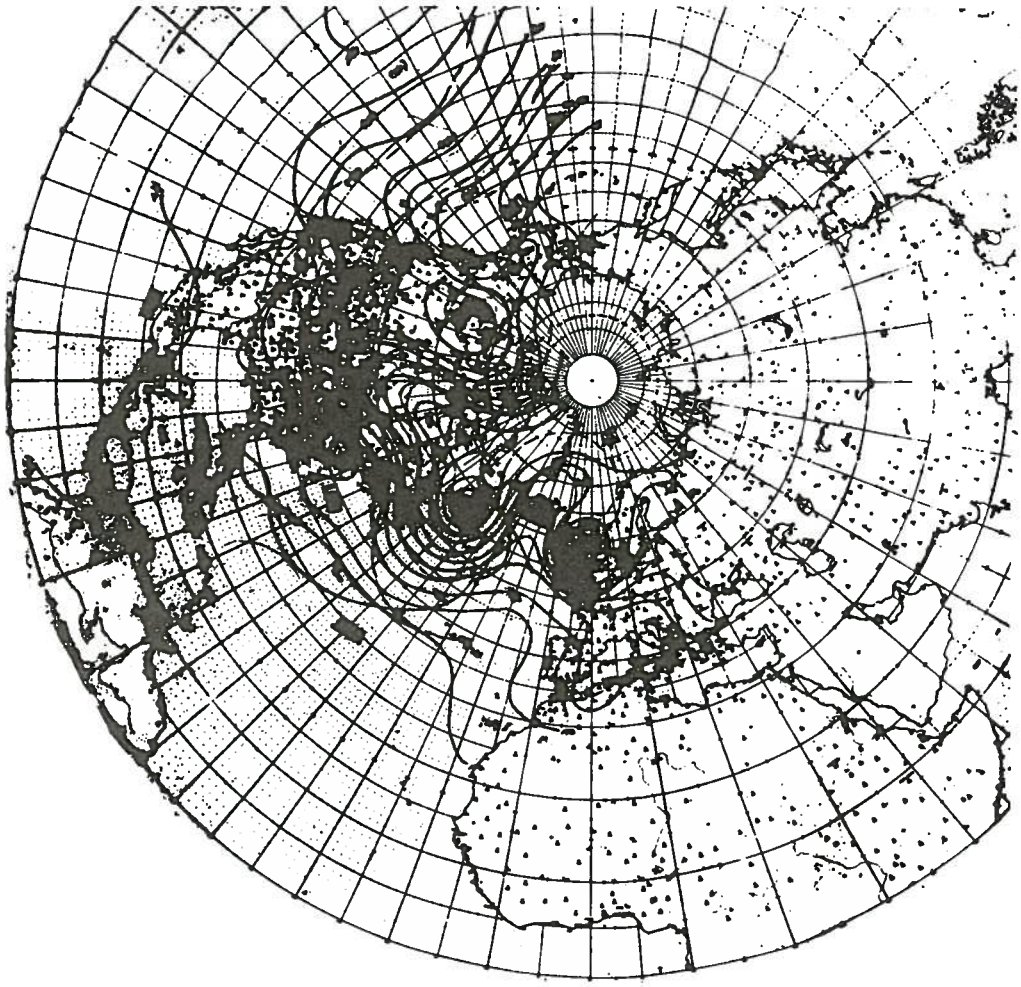


Figure 30. 500mb 0400Z June 6, 1944

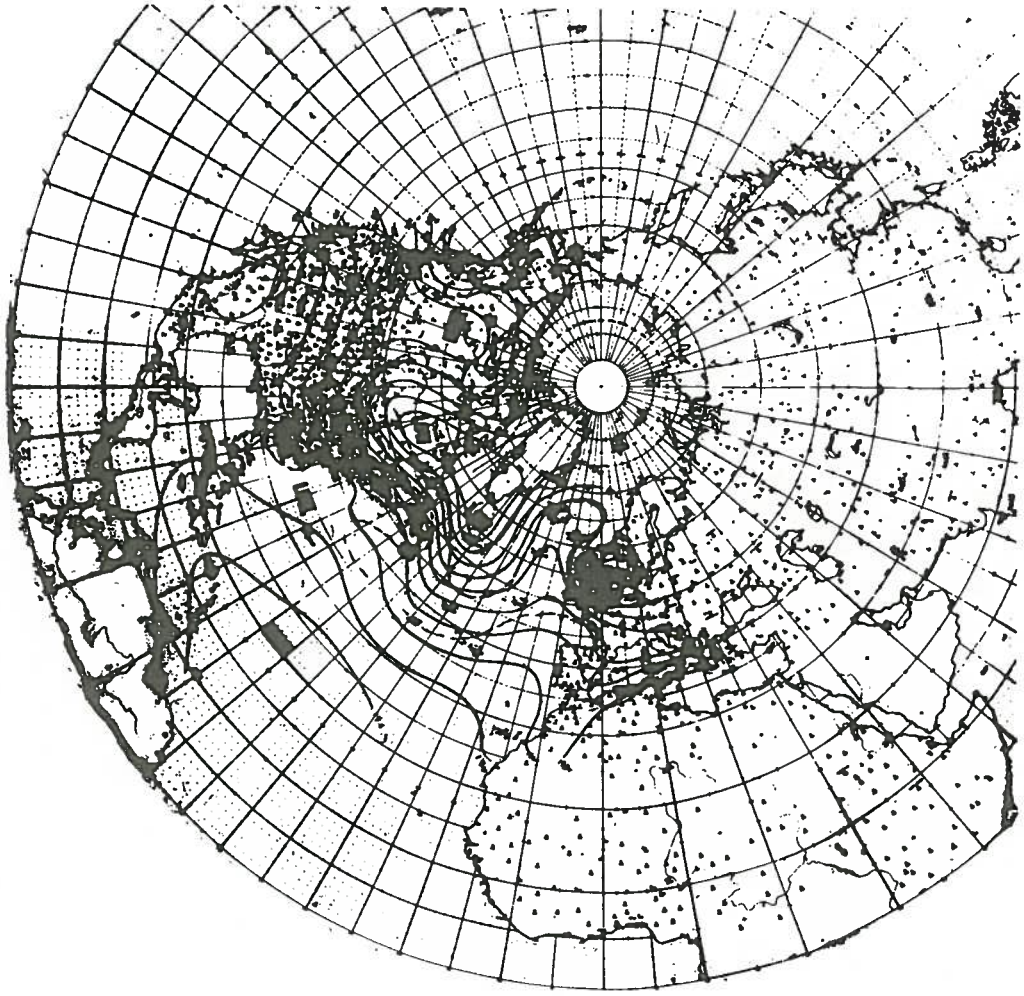


Figure 31. 500mb 1600Z June 6, 1944

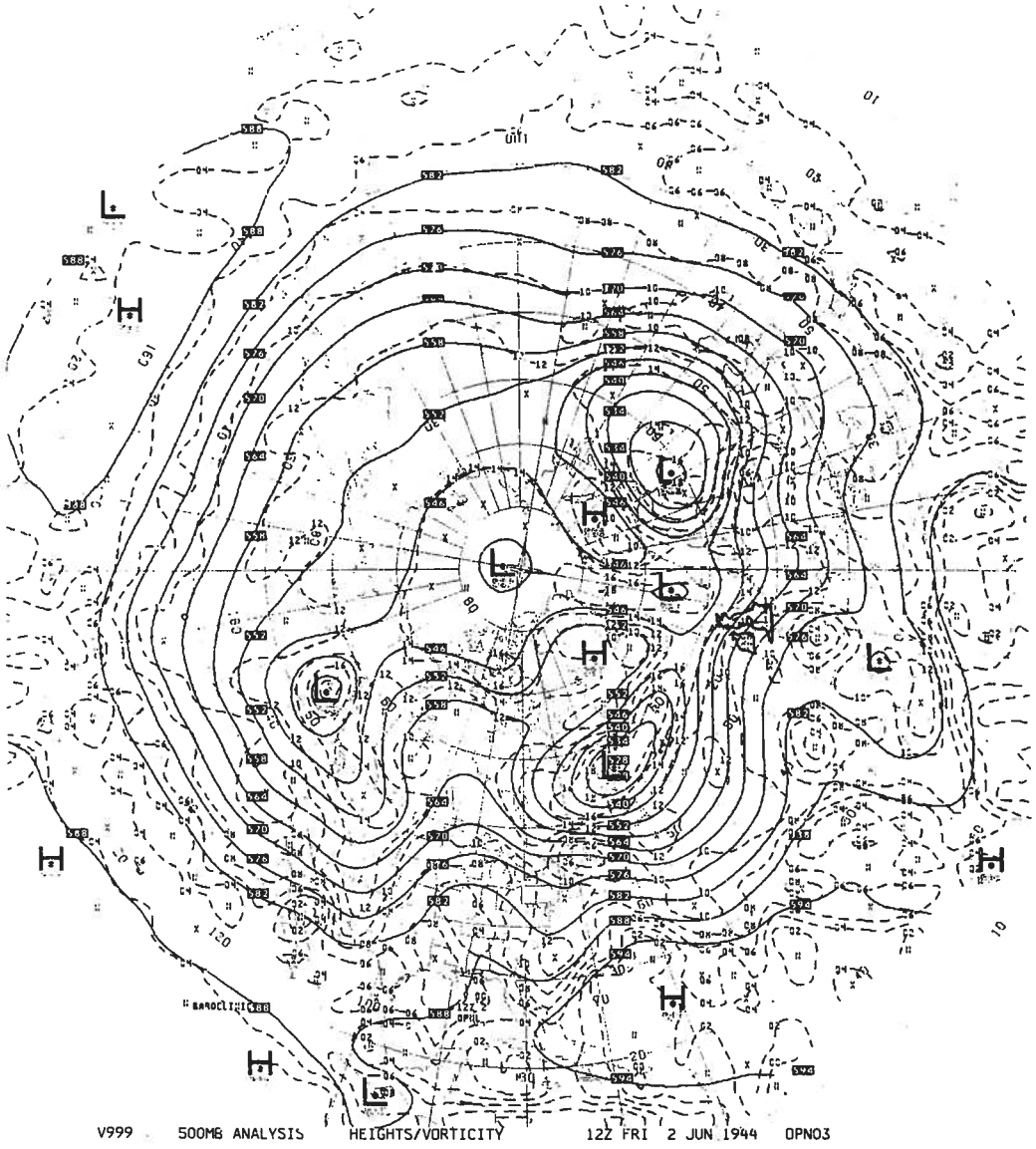

V999 500MB ANALYSIS HEIGHTS/VORTICITY 12Z FRI 2 JUN 1944 OPN03

Figure 32

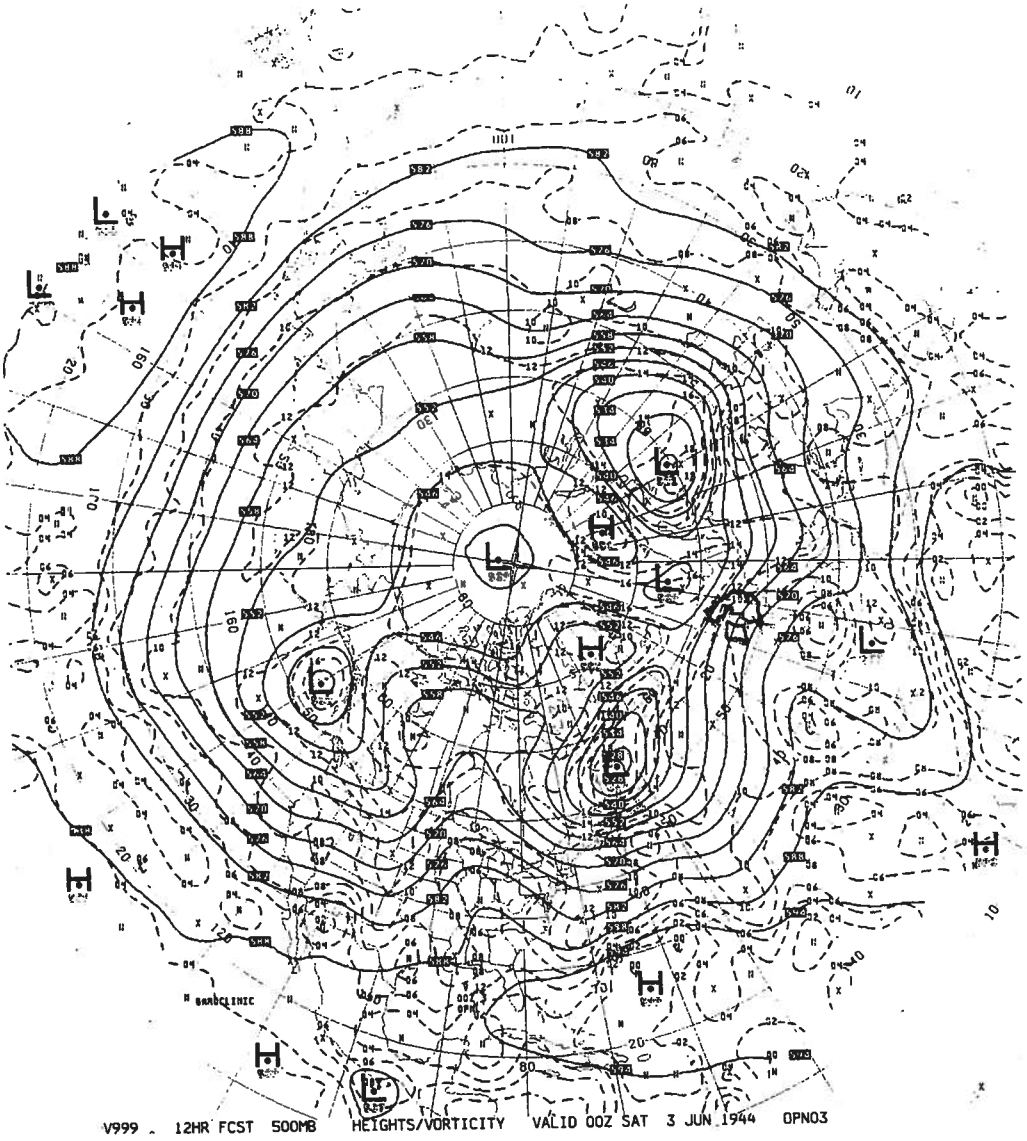

V999 . 12HR FCST 500MB HEIGHTS/VORTICITY VALID 00Z SAT 3 JUN 1944 OPN03

Figure 33

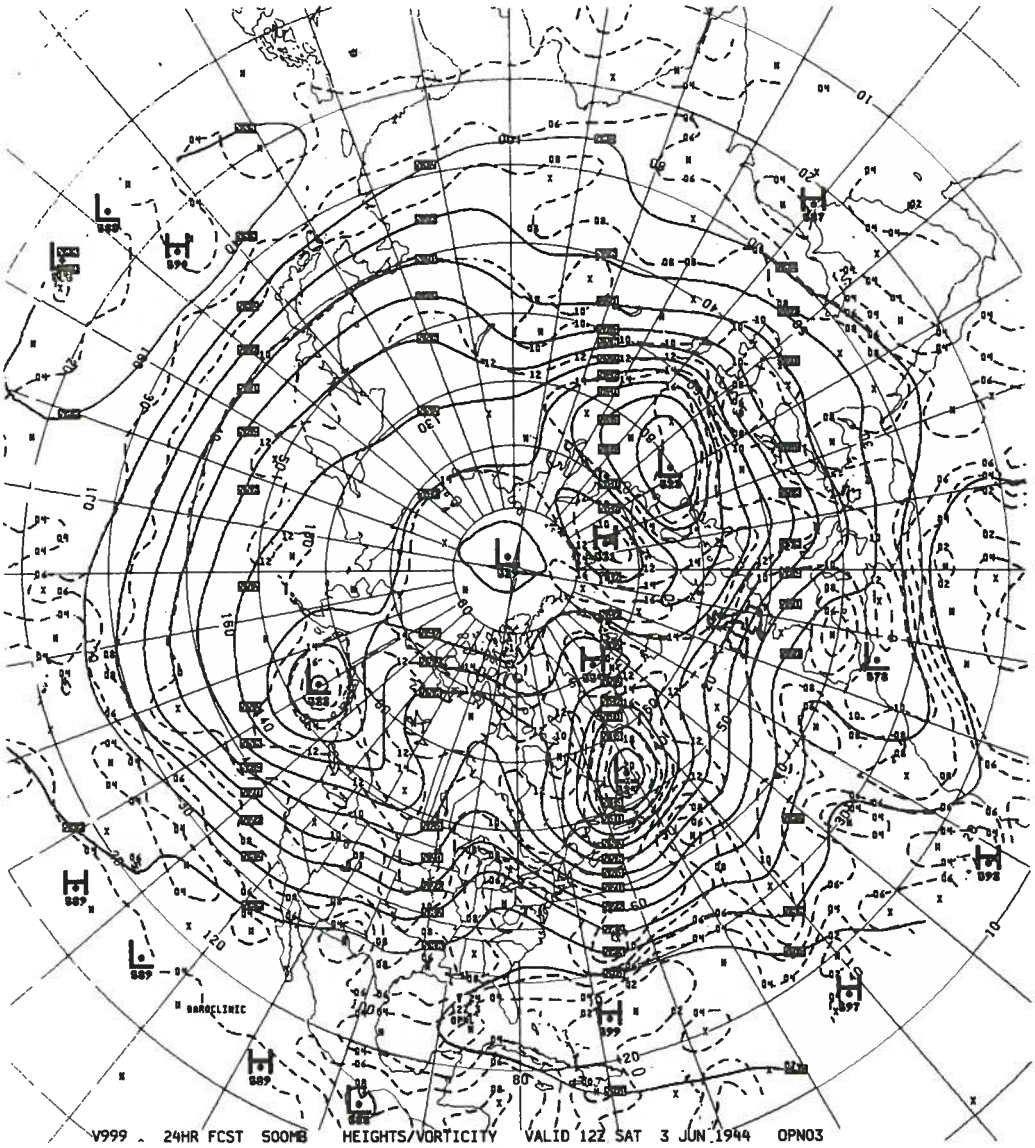

V999 24HR FCST 500MB HEIGHTS/VORTICITY VALID 12Z SAT 3 JUN 1944 OPN03
BAROCLINIC

Figure 34

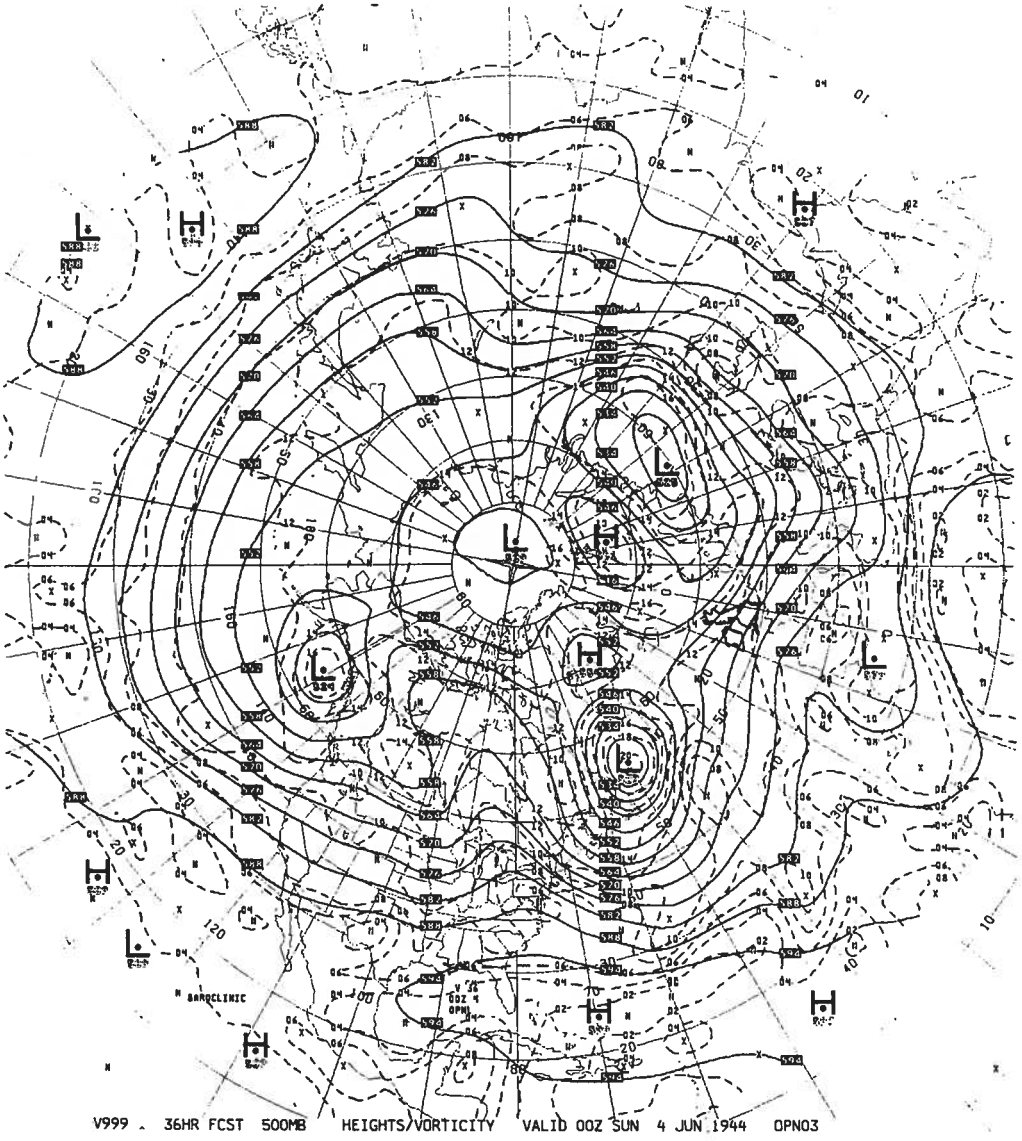

V999 - 36HR FCST 500MB HEIGHTS/VORTICITY VALID 00Z SUN 4 JUN 1944 OPN03
BAROCLINIC

Figure 35

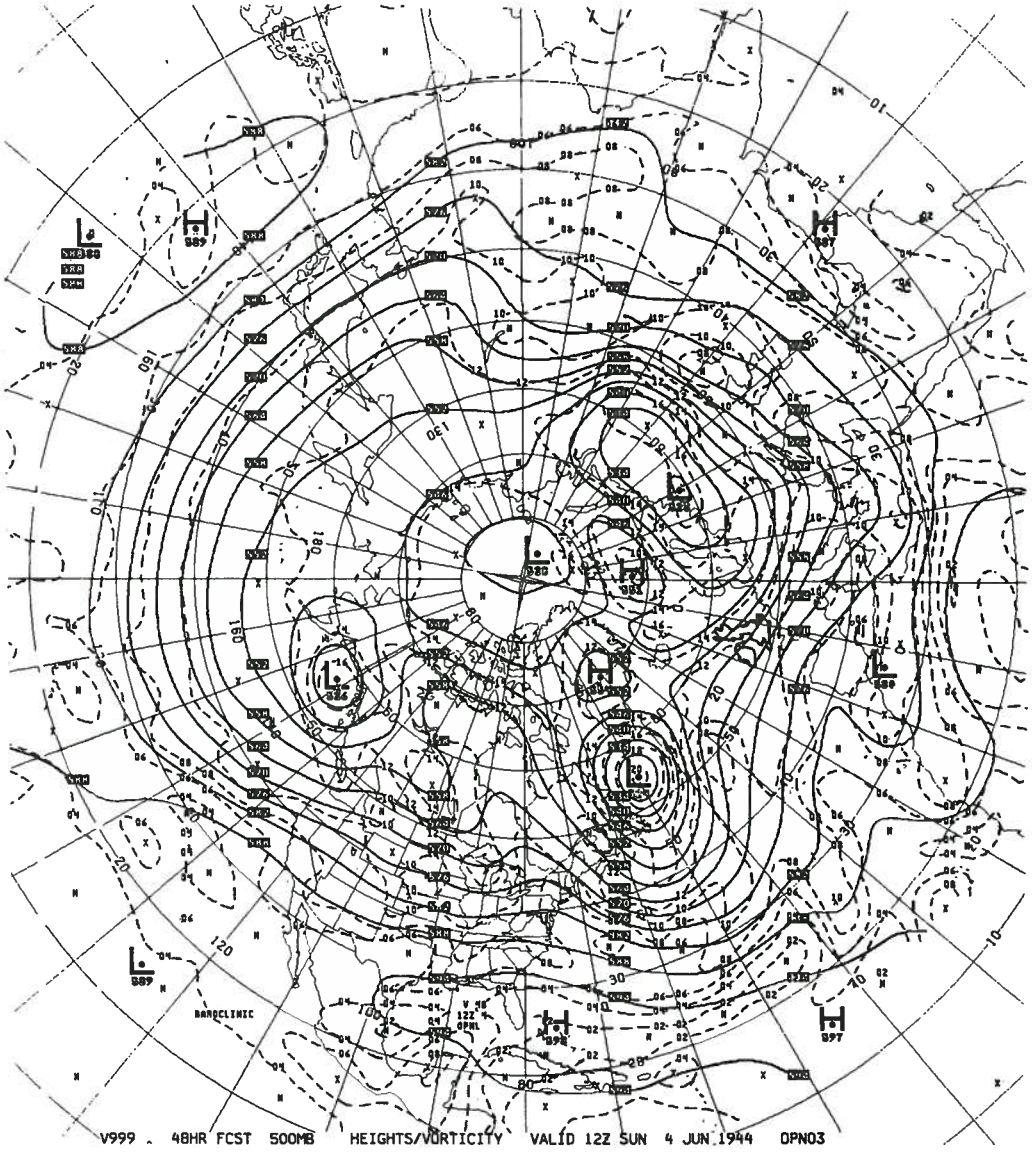

V999 48HR FCST 500MB HEIGHTS/VORTICITY VALID 12Z SUN 4 JUN 1944 OPN03
BAROCLINIC

Figure 36

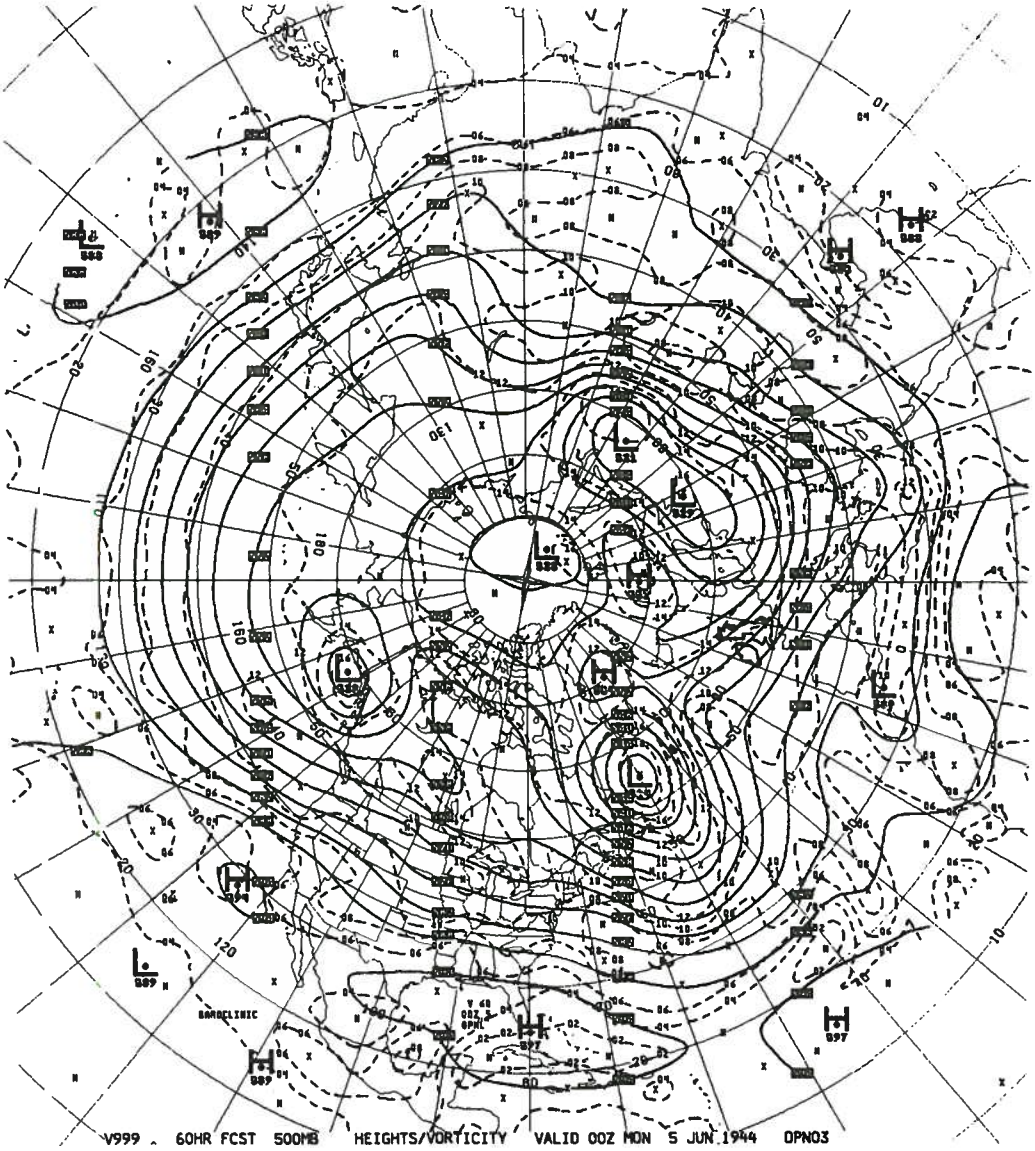

V999 . 60HR FCST 500MB HEIGHTS/VORTICITY VALID 00Z MON 5 JUN 1944 OPN03

Figure 37

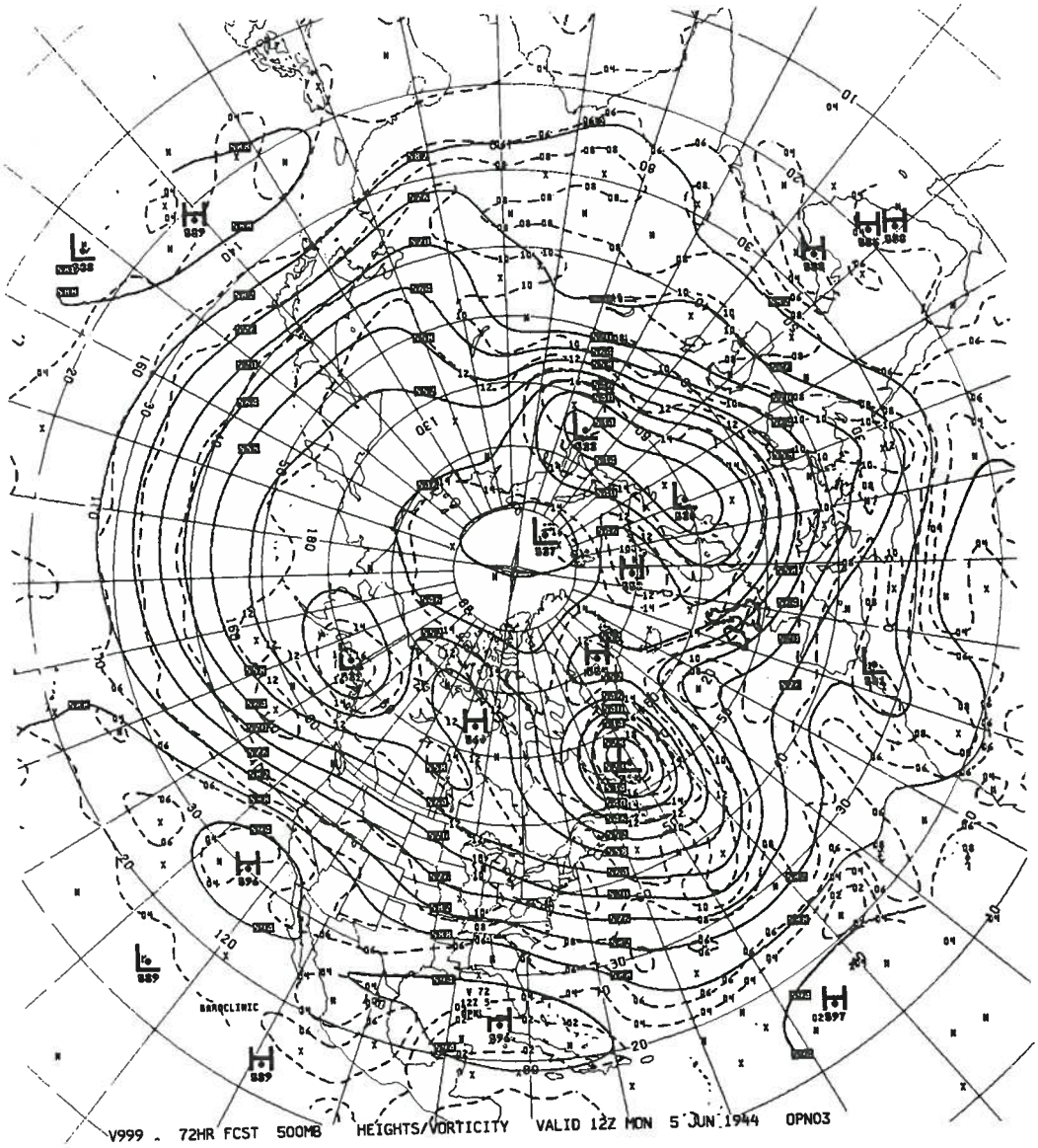

V999 . 72HR FCST 500MB HEIGHTS/VORTICITY VALID 12Z MON 5 JUN 1944 OPN03
BAROCLINIC

Figure 38

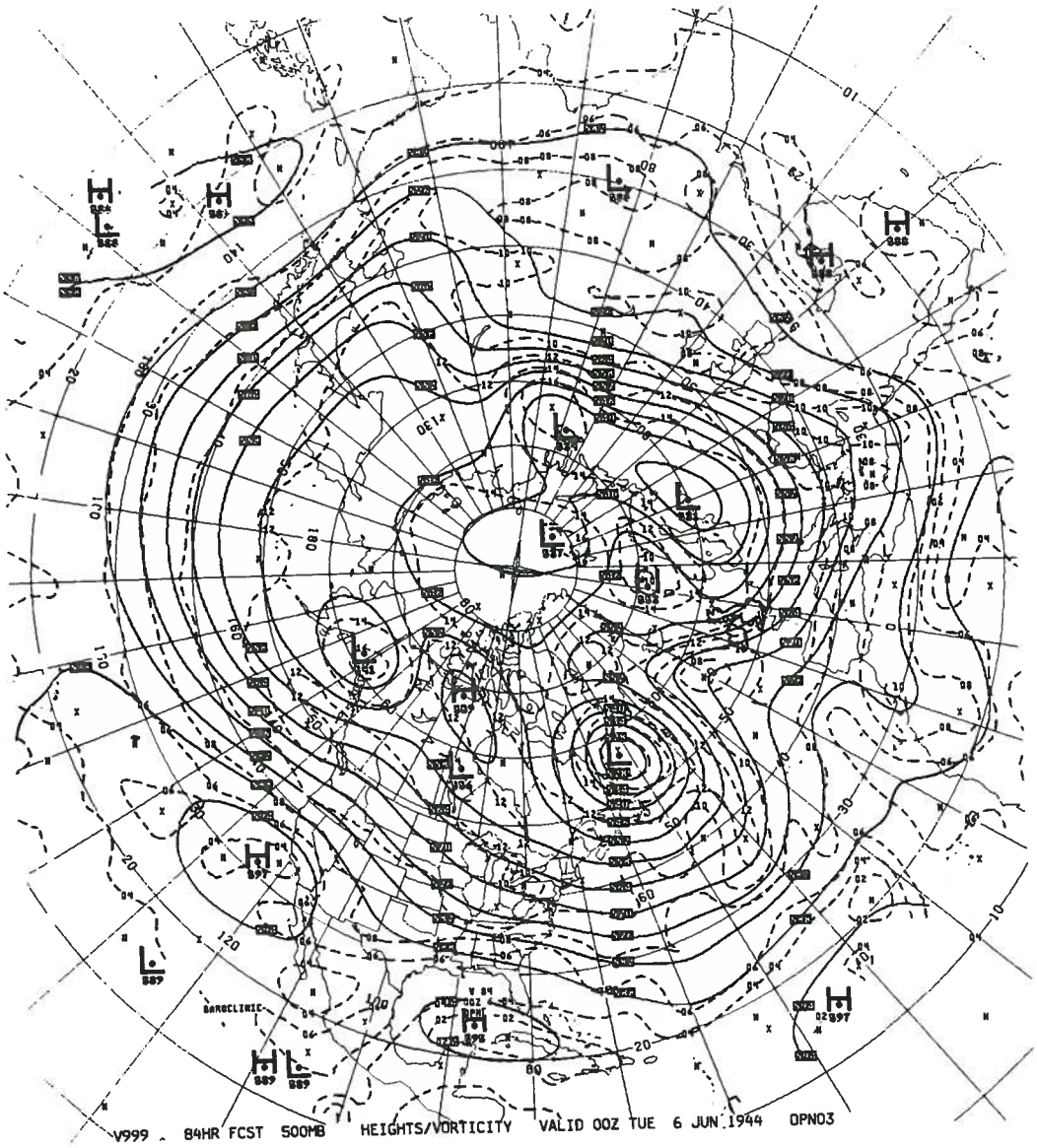

V999 84HR FCST 500MB HEIGHTS/VORTICITY VALID 00Z TUE 6 JUN 1944 OPN03
BAROCLINIC

Figure 39

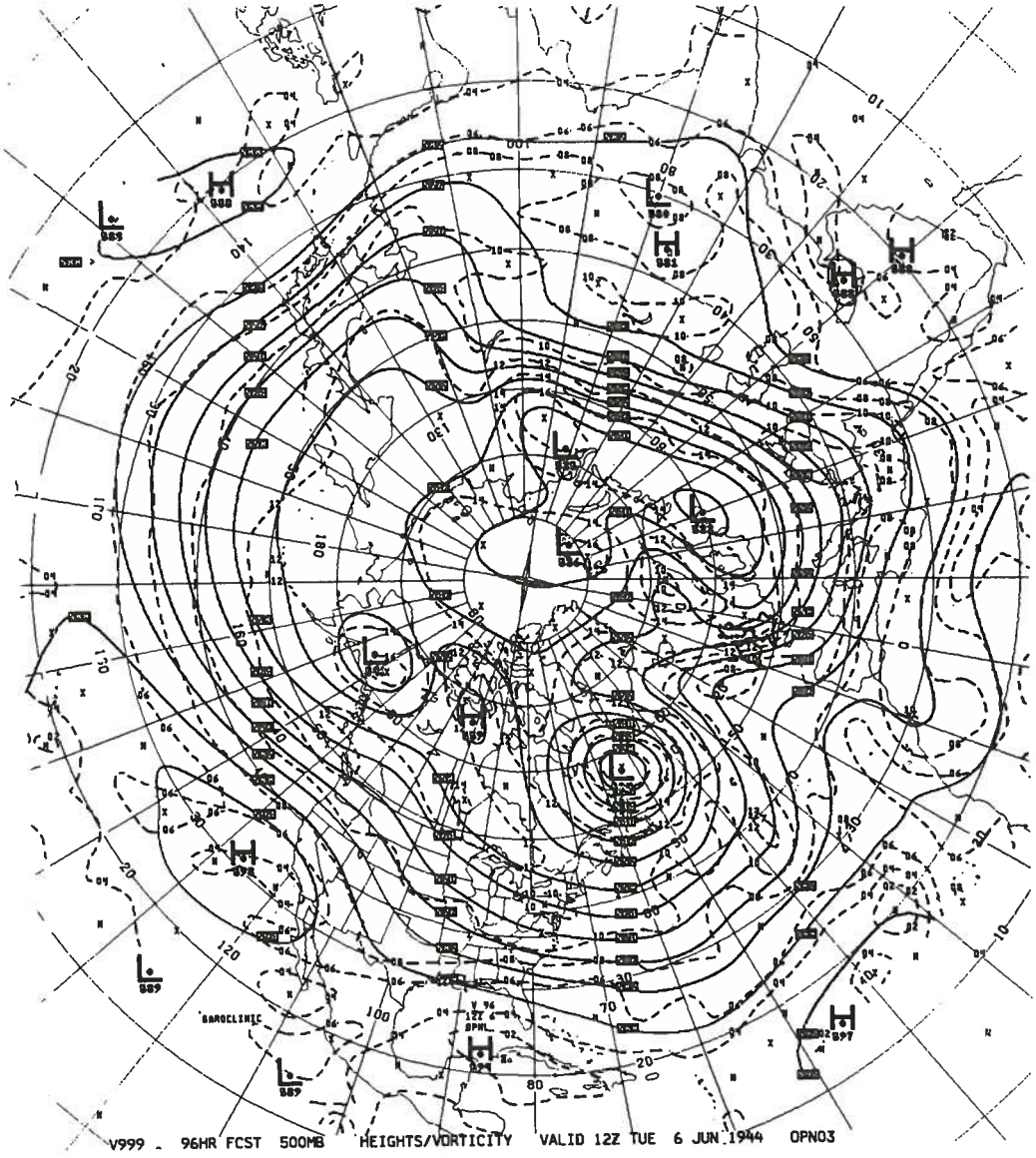

V999 - 96HR FCST 500MB HEIGHTS/VORTICITY VALID 12Z TUE 6 JUN 1944 OPN03
BAROCLINIC

Figure 40

sixth. The plunging trough indicates that winds might be a problem on the sixth but should ease towards the eighth.

In summary of what I can say about these calculations, I believe that barotropic processes can explain largely the changes that took place in the planetary waves over Europe and the Atlantic, even though it will be necessary to try baroclinic models to predict the details of passage of minor troughs and ridges and the deepening of systems in the baroclinic zones. For the rather-exacting conditions required for the invasion area, the latter features turned out to be of crucial importance as the weather situation unfolded, and would, in my judgment, have been difficult to predict with any precision in timing for more

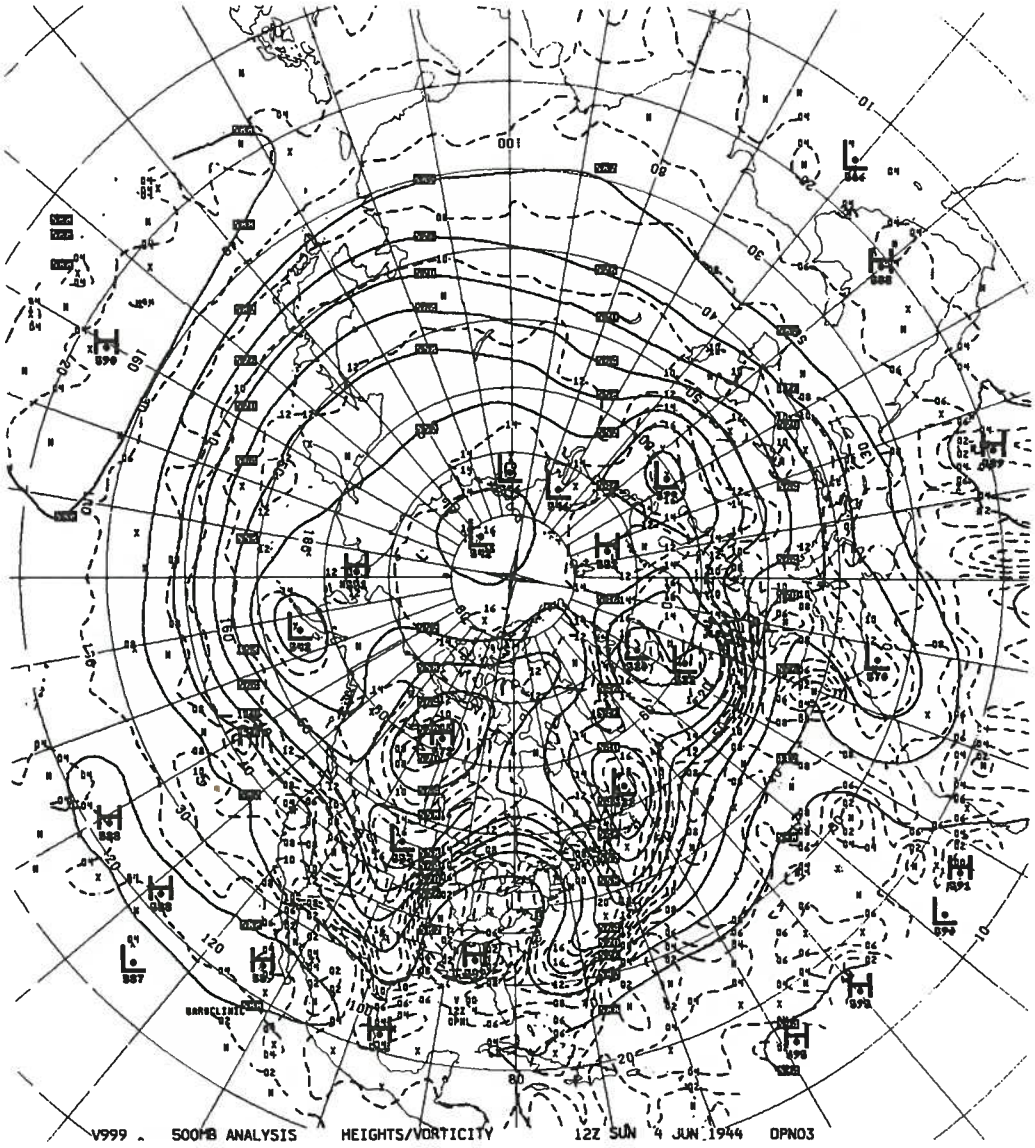


Figure 41

than one or two days ahead, even with the best of today's models. In view of the uncertainty of the conditions that existed over the Atlantic, it probably would have been very difficult to give an invasion forecast, a forecast "to go," with the confidence that was required by this very important and crucial operation. It certainly wasn't something you would like to have been set off on a 50-50 chance. To have that confidence, it would have been extremely difficult, even with today's models, to make that forecast for much more than one or two days ahead.

QUESTION: Concerning the 500-mb maps that you showed, were there observations from ships Easy, Dog, Able, and Charlie in the North Atlantic? If so, why weren't they plotted on the maps from Dunstable that you showed?

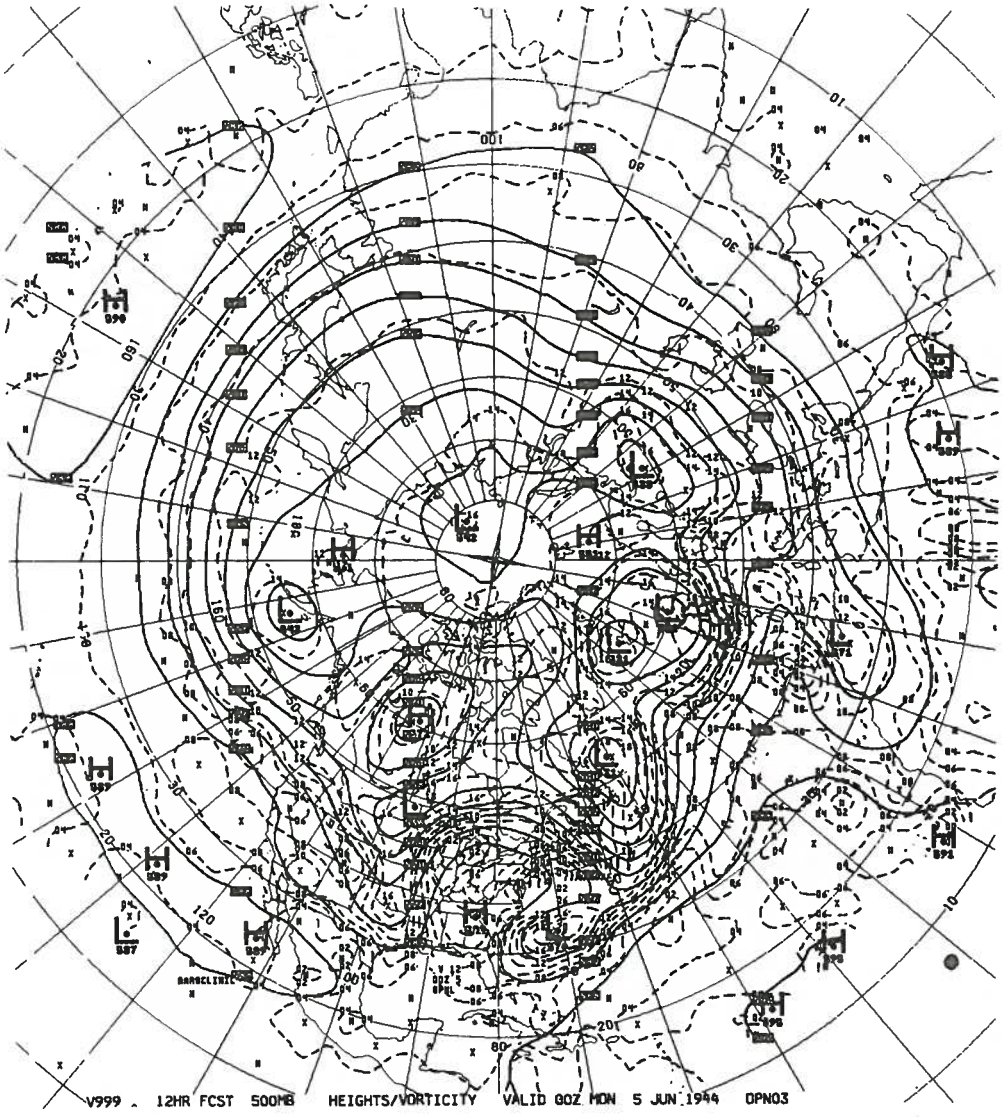


Figure 42

QUESTION: Do you conclude that, with numerical weather prediction in the computer, the D-Day forecast could have been improved, as it was given that day?

ANSWER: Yes. The medium-range forecasts could have been improved, particularly the outlooks beyond 36 hours. I don't think the forecasts of detailed conditions - cloud, ceiling, visibility, surface winds in the Channel area for the next 36 hours - would have been improved much. In the final week before D-Day General Eisenhower received each day forecasts for conditions in the Overlord area for the next five days. The forecasts he received on the 1st, 2nd, and 3rd of June for the planned D-Day on the 5th were gloomy, calling for overcasts of low cloud, much reduced visibility and strong winds at times, and holding out little prospect for a change before the 7th. as we have seen,

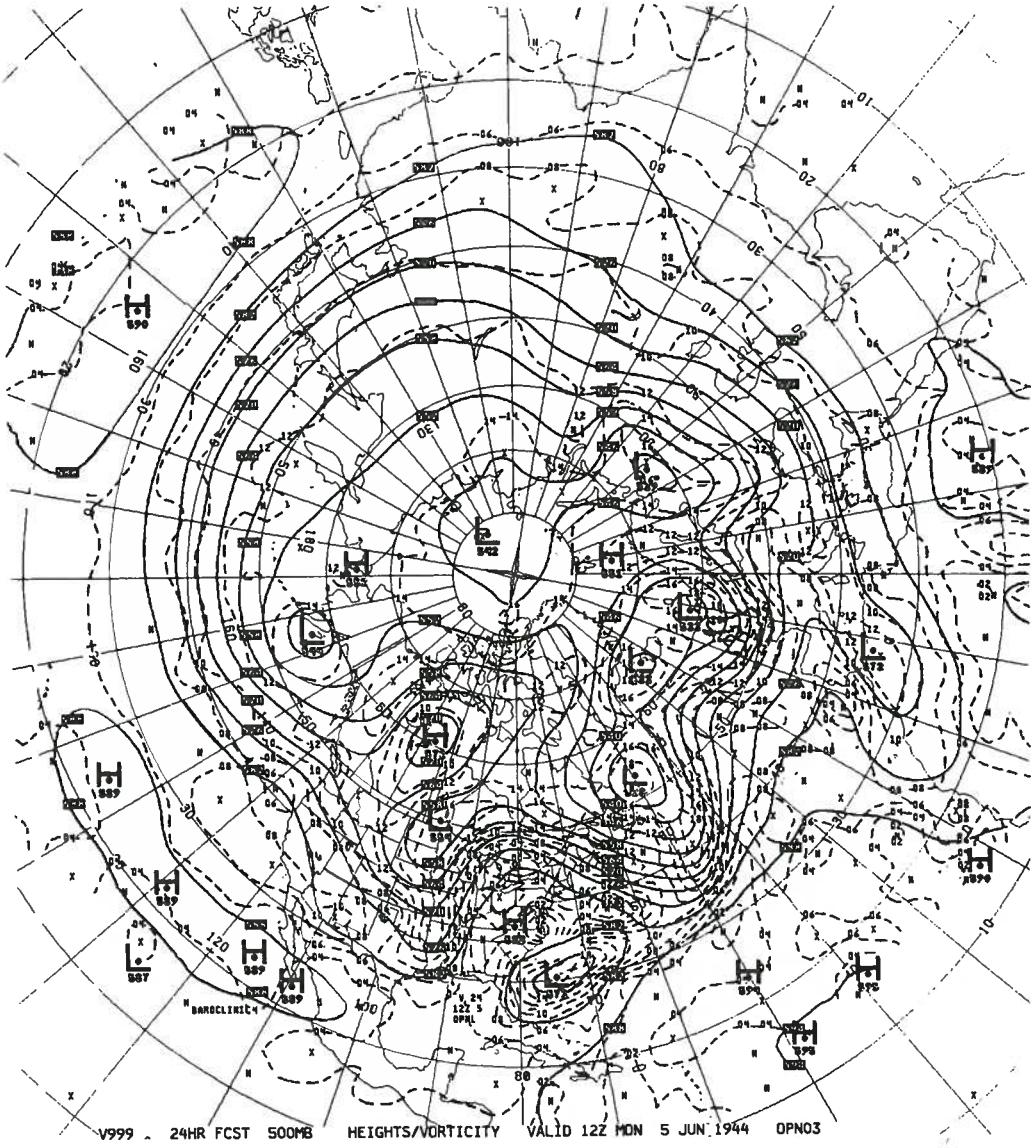


Figure 43

the barotropic prog started on the 2nd indicated that intense ridgeing just west of the British Isles called for a change during the period 5-6 June, warranting a more positive outlook. But it is uncertain if a better outlook would have had any influence on the military decisions. I doubt it. As it turned out, the change in weather for Overlord came in the form of a change of airmass, led by a vigorous cold front which crossed the Channel area early in the morning of the 5th. Even with the best of today's models this front would have been a small detail and could not have been expected to be forecast - with the precision required for Overlord - more than 24 to 36 hours ahead. It was fortunate indeed that the invasion plans had the built-in flexibilities that permitted the one-day postponement that took place. So, such as the weather situation around D-Day developed, the extrapolation techniques tied to fronts and cyclones that were available 40 years ago, did well enough in this case. These techniques did

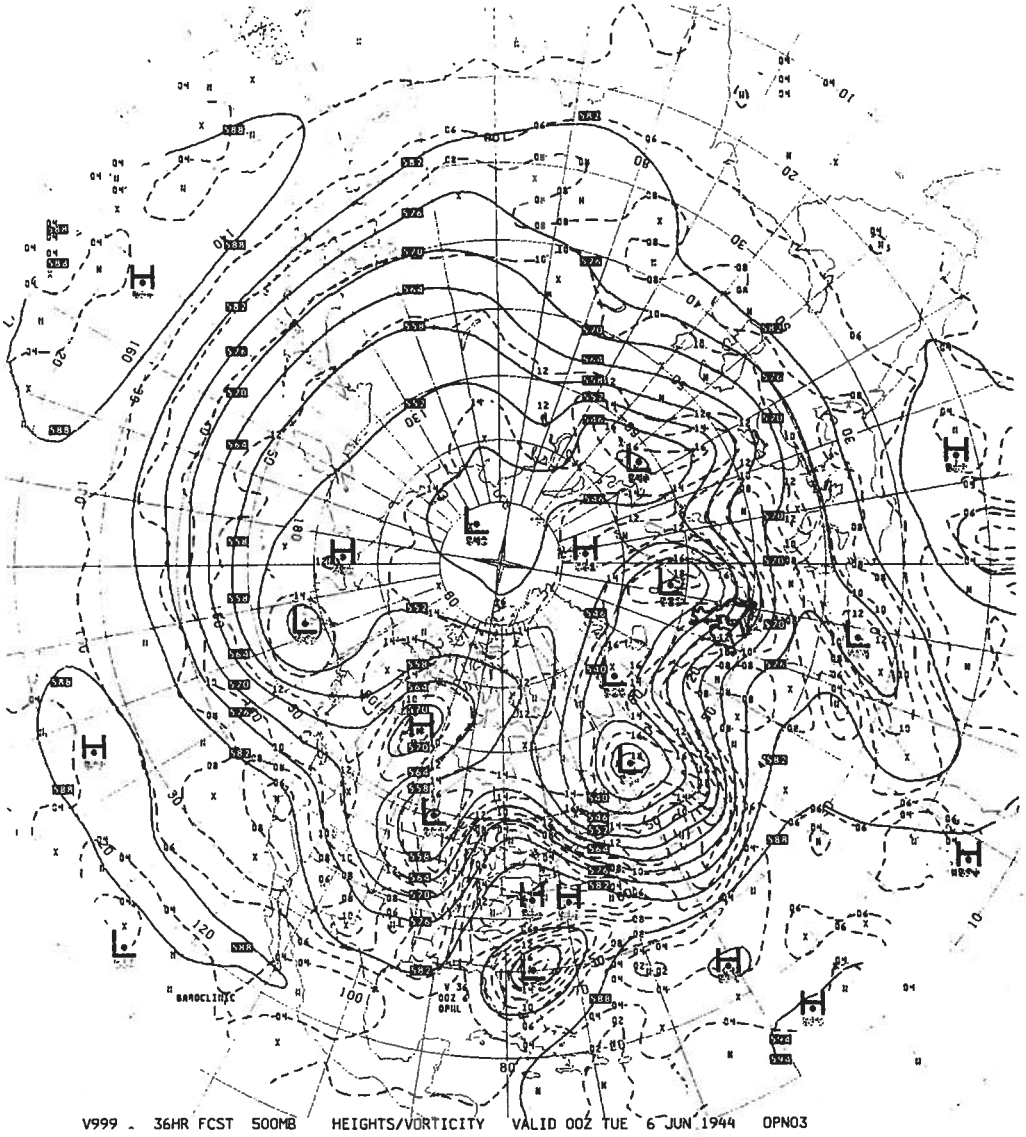


Figure 44

not have the required precision beyond 30 hours. It is doubtful that any of today's numerical models in this case would possess the required precision for longer forecast periods.

As it were, Eisenhower, aided by his weather advisors, picked the only suitable day in the whole month of June, the 6th. It would have been a catastrophe to go on the 5th. The next time conditions of moonlight, daylight, and tides would have been right, would have been from the 17th to 20th of June. Had they delayed till then, it would also have been a catastrophe to launch an invasion, because then strong winds developed rapidly and unexpectedly out of the east, a very unusual situation with a locally tightening pressure gradient over the Channel area. The long fetch, more exposed beaches, and winds of force 6, up to 7 in places, destroyed the British "Mulberry" harbors. That was a situation which would have been much more difficult to forecast, because it wasn't tied

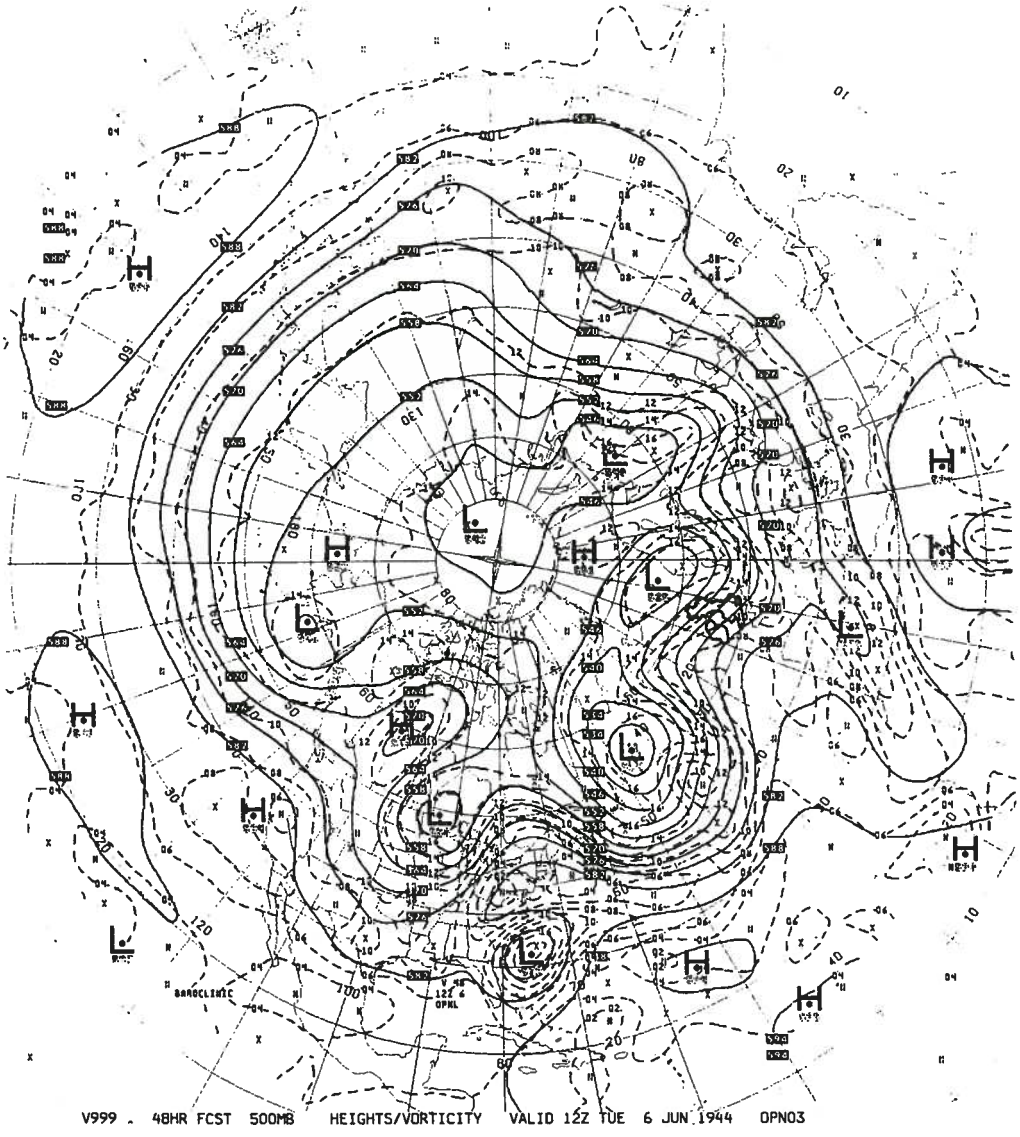


Figure 45

really to any typical polar front cyclone that we knew how to deal with. It was simply a local tightening of the pressure gradient. It would have been a catastrophe to go at that time too, and much more so than going on the 5th."

QUESTION: When are you going to make a baroclinic forecast with your sea-level map?

ANSWER: Well, that's an interesting question. As a matter of fact, at the time that I was preparing this barotropic forecast, I also saved the data at other levels, 1000 mb, 700 mb, 300 mb, so I do have the data. What remains to do is to put it in a data set that is acceptable for a baroclinic model. But that can all be done, of course, if you complete the data set with climatological information which I don't think would do any harm for two or three days. It would have been a very interesting experiment and maybe one day I'll do it.

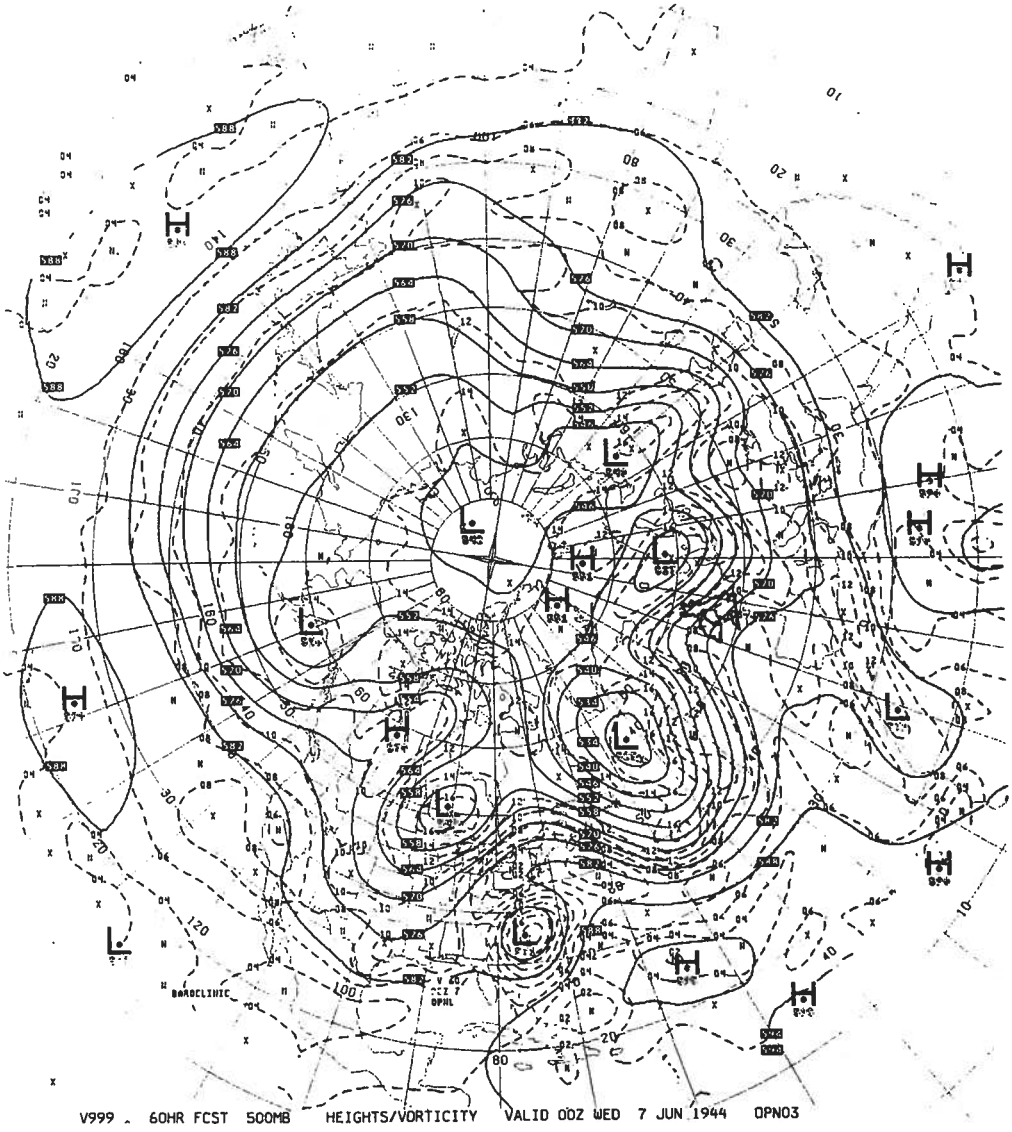


Figure 46

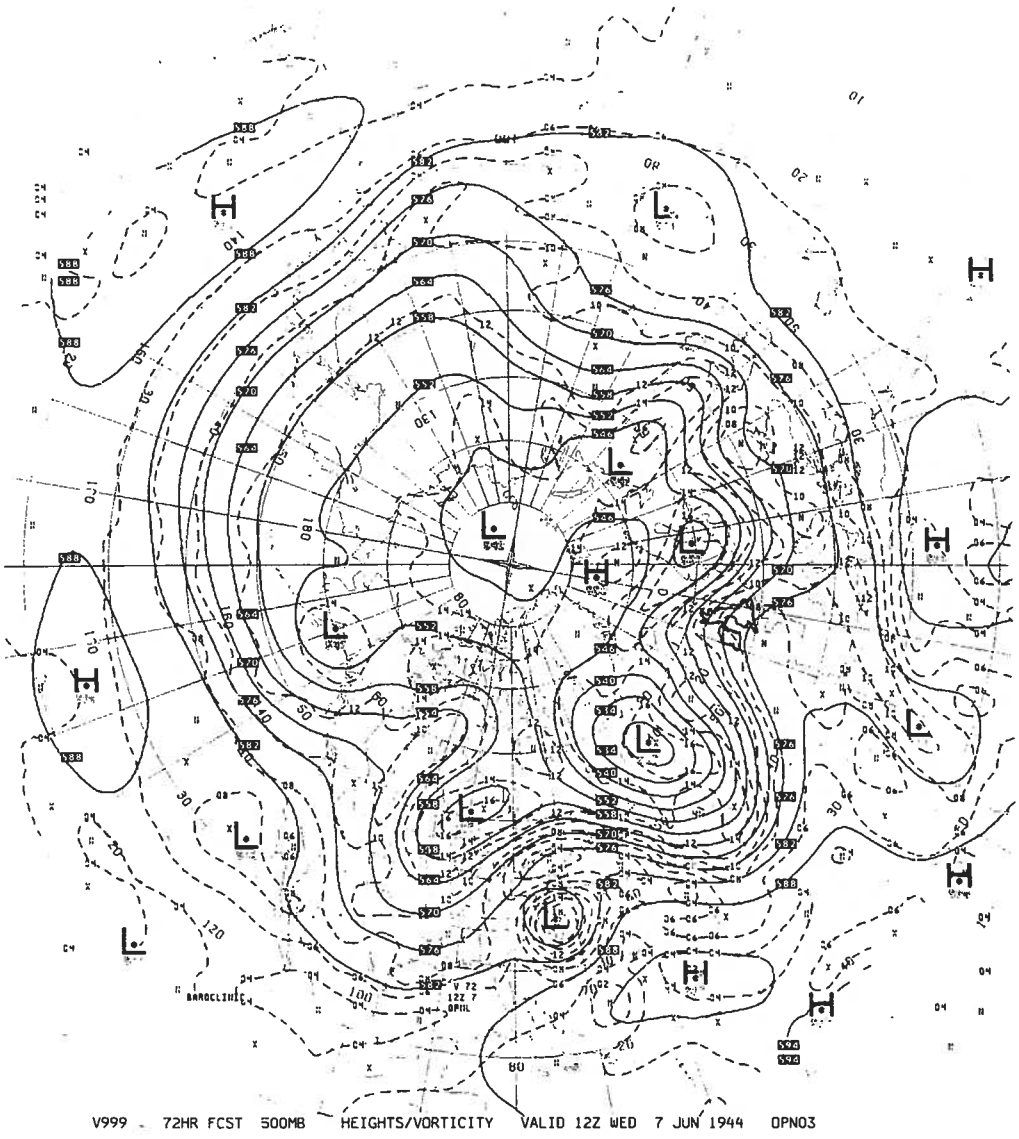

V999 72HR FCST 500MB HEIGHTS/VORTICITY VALID 12Z WED 7 JUN 1944 OPNO3

Figure 47

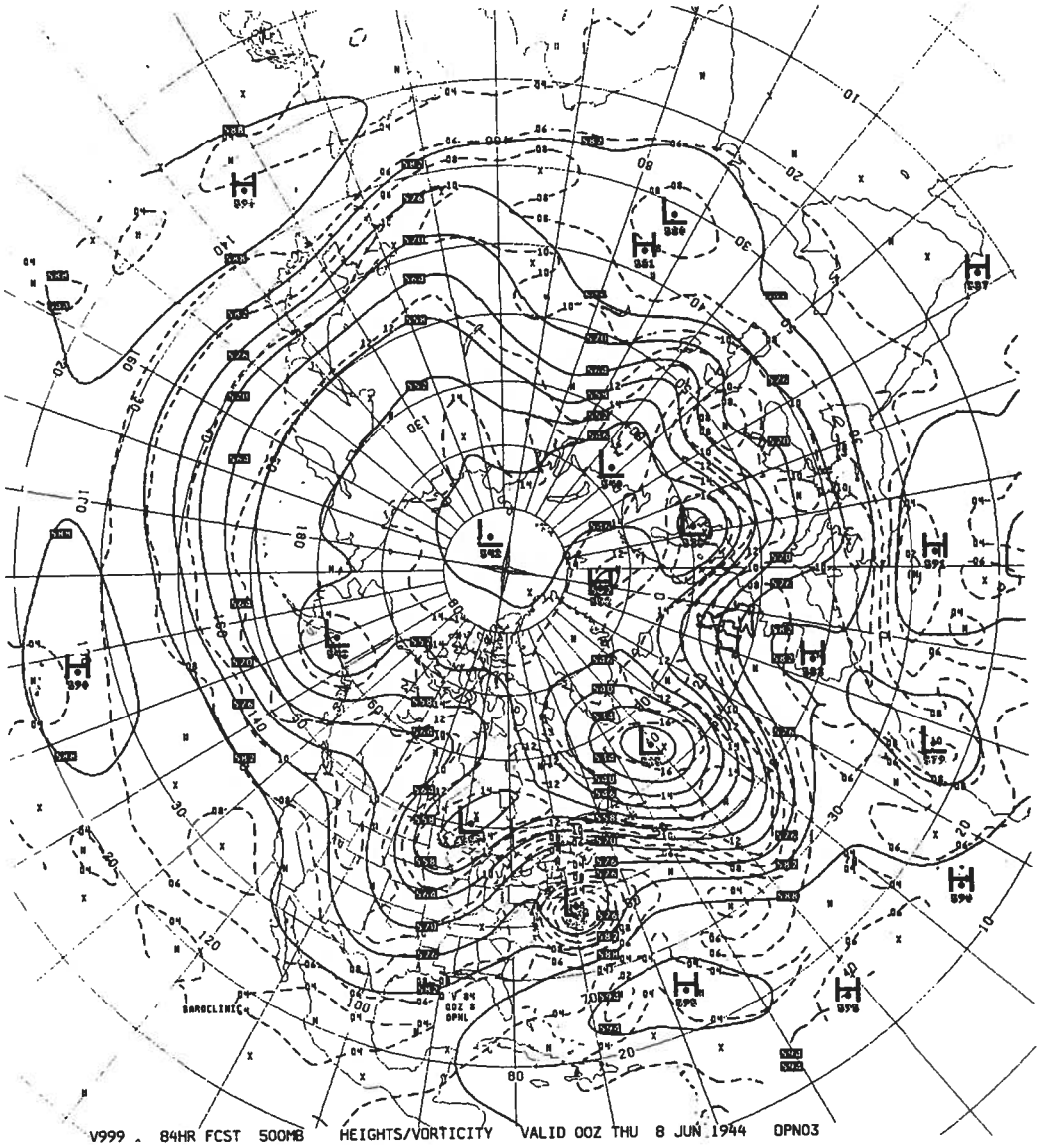

V999 84HR FCST 500MB HEIGHTS/VORTICITY VALID 00Z THU 8 JUN 1944 OPN03

Figure 48

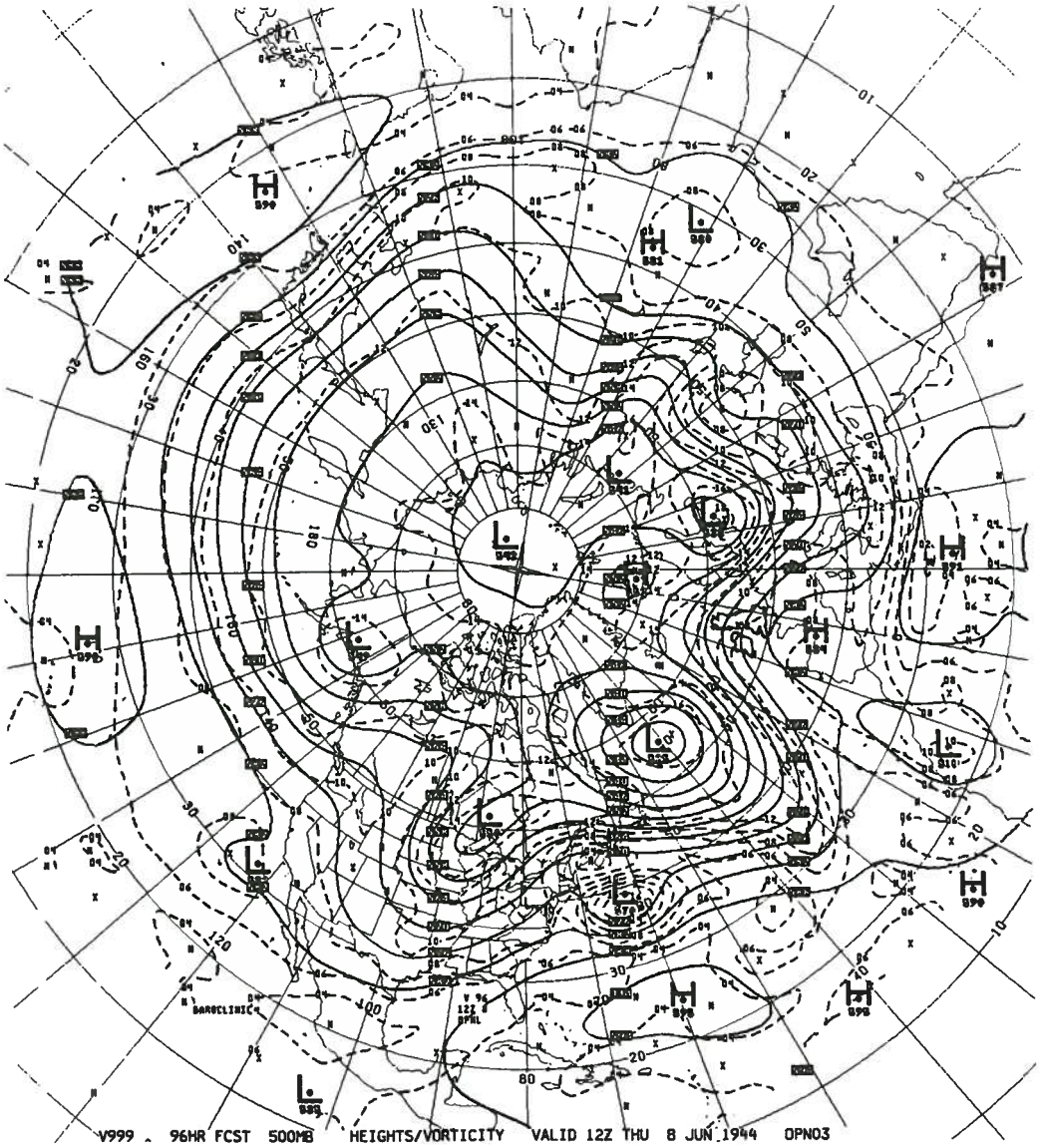

V999 . 96HR FCST 500MB HEIGHTS/VORTICITY VALID 12Z THU 8 JUN 1944 OPN03

Figure 49

CHAPTER 9

OVERLORD: H MINUS 5 TO D PLUS 24

INTRODUCTION BY JOSEPH VEDERMAN:

John Fuller is the historian for the U. S. Air Force Air Weather Service (AWS) and works in the Command Historical Office, Headquarters Military Airlift Command, Scott Air Force Base. He joined the air force in 1958 and flew the F101B before he was honorably discharged as a captain in 1965. In October 1967, with a master's degree in history, he accepted a position with the AWS historical function and became the AWS historian in 1970. John Fuller has published several articles in air force and historical journals, and bylines a "Lesson from History" column in AWS's monthly command newspaper, the Observer. Together with Dr. Bates, he is co authoring a book, tentatively entitled:

Meteorologists in Uniform: An American Chronicle, the manuscript of which is currently being reviewed by the Texas A&M University Press for publication this fall. His topic today is "Overlord: H minus 5 to D plus 24"

PRELIMINARY COMMENTS BY JOHN FULLER:

We are part of the elite of this most-important forecast ever issued, and I think there is a tendency to overlook the role that was played by other meteorologists there on the scene at the time. Let me just give you a feel for how many we're talking about. In January 1944, Air Weather Service, or our predecessor organization, the Army Air Force Weather Service, had two squadrons in the British Isles — the 18th Weather Squadron and Tommy Moorman's 21st Weather Squadron. The 18th, by the first of January 1944, had about 1,000 people assigned to the British Isles. By 1 June 1944, the 21st had 1,051 weather people assigned to the British Isles. Well over 2,000 men just for our standpoint. That doesn't talk about the navy, and what we have a tendency to do is to forget the role that was played by some of these other weathermen, not just the forecasters but the observers. What I would like to do today is to take a few minutes to review with you the role that was played by just a handful. We can't go into all 2,000 of them, but just the role that was played by the others that had a part, indirectly, in this most famous of all forecasts.

OVERLORD: H MINUS 5 TO D PLUS 24

John F. Fuller

Often overlooked in discussions of the famous D-Day forecast are some of Overlord's weather support aspects that transpired on and immediately after 6 June 1944. Indeed, on 6 June another phase of weather support to American forces commenced, provided by the men of Colonel Tommy Moorman's 21st Weather Squadron on the beaches and behind German lines in Normandy. It is that phase that I will dwell upon for a few moments today.[1]

The first American weatherman to reach France was the 21st Weather Squadron's Sergeant Charles J. Staub. He parachuted into Normandy at 0100 hours (H-5) on 6 June with an element of the 101st Airborne Division. About half an hour later, Corporal Warren F. Wolf went in with a glider unit in the predawn darkness. Following closely was Staff Sergeant Robert A. Dodson, who jumped with 82nd Airborne Division elements behind the beaches at 0230 hours.

Each of these three 21st Weather Squadron weathermen fared poorly. Dropped into separate areas, each carried a small radio, a psychrometer, and weapons. Germans attacked Dodson's force, and for the first 36 hours he acted as a rifleman. After the attack was repulsed, Dodson began taking and transmitting hourly weather observations. He did so until 21 June, at which time the front lines overtook him and he was sent back to a hospital to have the knee he injured upon landing treated. Suffering multiple gunshot wounds, Staub became a casualty before he ever took an observation. Wolf was never heard from, and right up until the war's end the 21st Weather Squadron's rolls carried him as missing in action. Fortunately, however, Wolf survived and was honorably retired from the army in 1965.

While that trio preceded the invasion, some 20 other 21st Weather Squadron weathermen, assigned to air support parties with the infantry, waded ashore beside the first assault troops on 6 June, or landed behind the beaches with glider units. Usually consisting of eight men, a half-track, and a radio-equipped jeep, the air support parties guided air strikes. The assigned weathermen briefed incoming fighter pilots on target weather, and transmitted surface observations hourly to ships offshore.

Late on 6 June, Corporal Eugene Levine, a 21st Weather Squadron observer assigned to an air support party with the 82nd Airborne Division, left England for France in a glider towed by a C-47 flying at 500 feet. Although the C-47 was hit by flak over Normandy and crashed, Levine's glider was released and landed okay. But he spent most of the next day dodging Germans, and it was 8 June before he began taking and transmitting hourly observations.

The immediate job of Sergeant Patrick L. Kelley, a 21st Weather Squadron observer attached to the Fourth Infantry Division's Eighth Regiment, was to drive a radio-equipped jeep ashore at Normandy's Omaha Beach. When his LST touched bottom, it was some 200 yards offshore, in 18 inches of water. As the landing craft's ramp door was dropped, heavy gunfire greeted Kelley. Looking toward shore for a place to beach his jeep, he saw what looked like logs the Germans used as obstacles. As he floored the jeep's accelerator, he saw that they were not logs. They were bodies! The LST's waves washed them aside, so Pat was not forced to drive over them.

Following the air support parties came entire 21st Weather Squadron detachments. Fully mobile, each would furnish 24-hour observing and forecasting support to designated ground or air units. None landed on D-Day however.

Detachment YF was to have hit Omaha Beach at 1800 hours, 6 June. But as the LCT approached its assigned landing area, it met such intense mortar, 88 millimeter, and small-arms fire that a landing was out of the question. Debris prevented the craft from moving to a cleared area, so the LCT commander was ordered to remain offshore overnight. The second attempt, made after 35 tense minutes of hugging the shore while shells "literally rained down on the craft, also failed when the anchor caught on a submerged truck, making it necessary to put to sea to free it. The third try succeeded, although the truck preceding the detachment's weather van received a direct hit from an 88-millimeter shell and blocked the exit. The weather van had to push it aside to get out. Once ashore, the weathermen found they were already at the front. German lines were just 100 yards inland!

By 1 July, when the assault phase of Overlord officially ended, 14 complete 21st Weather Squadron mobile weather detachments were ashore in France, five supporting ground forces of the First Army, and nine supporting the IX Tactical Air Command. Most operated at, or near, the front-lines, and when the lines moved, so did the weather detachments. Detachment YD, which was a part of the XX Corps, moved seventeen times between 21 July and 25 September, supporting what was reported to be one of the fastest sustained marches in history when the corps covered 600 miles between St. Jacques and Verdun.

---

[1] All of the facts presented herein were extracted from the "History, 21st Weather Squadron", for the period 6 June - 31 Dec. 44.

Everything considered, the 21st Weather Squadron's casualties were light. Sergeant Louis J. Heller, an air support party observer with the Fourth Armored Division, was wounded by enemy shell fragments on 24 September and succumbed two days later. Within a fortnight, Corporal Leonard S. Harrow, an observer assigned to Detachment E, was riding in a truck that suddenly found itself in the middle of a fire fight with German infantry. In an attempt to turn the truck around after the driver was shot, the vehicle detonated a land mine, which killed Harrow instantly.

I think it fitting that we here today, some 40 years later, remember these brave weathermen, and scores of others, who were killed or declared missing in action during World War II.

In conclusion, back at Scott Air Force Base, Headquarters AWS, there's a plaque on the wall of the lobby, and on that plaque are inscribed the names of all the weathermen in AWS or the Army Air Corps Weather Service or the Army Air Force Weather Service who have been killed in action in World War II, Korea, and Southeast Asia. The names of the two observers who were killed while serving with the 21st Weather Squadron are only two of 70 who were killed in action in World War II.

CHAPTER 10

LIMITS OF PREDICTABILITY WITH EMPHASIS ON D-DAY

INTRODUCTION BY JUNE BACON-BERCEY:

I take great pleasure in introducing our guest speaker Dr. George Robinson, a Yorkshireman, certainly not dour, and certainly canny. He has lived on this side of the ocean for several years so I believe we can partially claim him as our own. He and General Yates were Group Captain Stagg's assistants. This troika labored under overwhelming pressure at times, trying to carve out a concensus of the D-Day forecast and come up with the nearly impossible prediction the supreme commander wanted.

PRELIMINARY COMMENTS BY GEORGE ROBINSON:

Thank you, indeed, for the very kind introduction. Thank you for having me here. I think it was Andre Gide who said that everything worth saying has already been said. On the matter of the D-Day forecast, you have heard a lot today and most of the things that are worth saying have been said. Andre Gide went on to say that because people do not listen, it is necessary to say it again. That's not why I'm going to say it again — I was asked to.

LIMITS OF PREDICTABILITY WITH EMPHASIS ON D-DAY

by

Dr. George D. Robinson

I have been asked to speak about the preparation of a specific weather forecast in the summer of 1944. I have refreshed my memory from two sources: one, the published book, Forecast for Overlord by J.M. Stagg. The other, my own disintegrating copy of the SHAEF Chief Meteorological Officers' Report, submitted on 22 June 1944. Since many of you were probably not practicing forecasters at that time, my first task should be to give some idea of the methods in use then. I do not know how I can do this except by quoting from my friend and mentor, R.C. Sutcliffe, the opening of his address in 1959, to the United Kingdom Institute of Physics, on the occasion of his receiving the Charles Chree Medal. I change the four opening words to apply them to my own limited, rather than Sutcliffe's vastly greater, forecasting experience.

For four years during World War II, I was a practical weather forecaster and found it an interesting and satisfying occupation and, in so far as I was attempting to predict the state and behavior of the atmosphere, I suppose my activity could be described as fluid dynamics if the term is stretched sufficiently. But the main fascination of the work was in a sense its scientific weakness, for the essence of scientific method is that it should be communicable, reproducible and objective, whereas much of forecasting was and is an art not only empirical but also personal and subjective. The exercise of expert judgment based on knowledge is of course among the most satisfying of intellectual activities, analogous to the exercise of expert skills in physical activity.

We were not entirely in the dark ages. We had read Margules. Vilhelm Bjerknes' paper was published in 1904, and L.F. Richardson's book in 1922. Harold Jeffreys worked on the general circulation problem in the 1920s. In 1944, Rossby and Jacob Bjerknes were visiting, encouraging, and instructing American military meteorologists in the various war theatres. I can refer here to three of the forecasters actually concerned in the D-Day work. Sverre Pettersen's book, Weather Analysis and Forecasting was in print and is not entirely empirical in content. If you read Arndt Eliassen's Symons lecture on Geostrophy in the January 1984, Quarterly Journal of the Royal Meteorological Society, you will find reference to mathematical work by C.K.M. Douglas (1928) on the isallobaric equation and to R.C. Sutcliffe's "most remarkable paper" of 1939 "which represents a theoretical breakthrough." Nevertheless, I remember production of the D-Day forecasts preeminently as an exercise not only empirical but personal and subjective in the extreme.

Let us take a quick review of the forecasting problem. The immediate military objective was to establish on a 40-50 mile stretch of enemy-held coastline, a military force strong enough, with supply lines secure enough, to resist quick dislodgement. The men and material were in place in the launching area. The initial attack was to be at, or near, first light — it was to be "the longest day" — and at low tide to ease negotiation of underwater obstacles. Moonlight before dawn would be desirable for airborne landings. These astronomical constraints severely limited the available periods (time slots in NASA parlance). Sea, land, and air arms in all their functions were to be involved, and their planners had produced sets of required meteorological conditions. Search of the climatological record showed that the required set had never been observed, and the planners were reconciled at a very early stage to the fact that they would not get what they required. Without formal documentation they began to think in more realistic terms. The really critical elements of the forecast were the state of the sea, predominantly dependent on the strength of the wind on the beaches, and the amount and height of clouds (including the possibility of fog). Unforecast onshore winds of 20 kt, sustained for any length of time, would have been catastrophic. Cloud conditions which would prohibit air reconnaissance and spotting, and interdiction of operation of enemy surface craft, would also be catastrophic. Sufficiently broken cloud cover to allow operation of medium and heavy bombers was very desirable.

Technically, clouds and wind were everyday problems of the World War II meteorologist in the United Kingdom, and we considered ourselves competent to handle them at the prediction times usually called for. But the "Neptune" operation was so ponderous that the first warships were to be on the move three days before H hour, and it was considered that the required cloud and wind conditions should be maintained to two days after H hour to ensure a firm lodgement. So a five-day forecast was called for. No one with any experience of detailed forecasting in western Europe believed that it could be done. Douglas has been quoted as saying, "In all but exceptional circumstances, a forecast for more than a day or two ahead in this country can be nothing more than speculation." He spoke from long experience and he had a phenomenal weather memory.

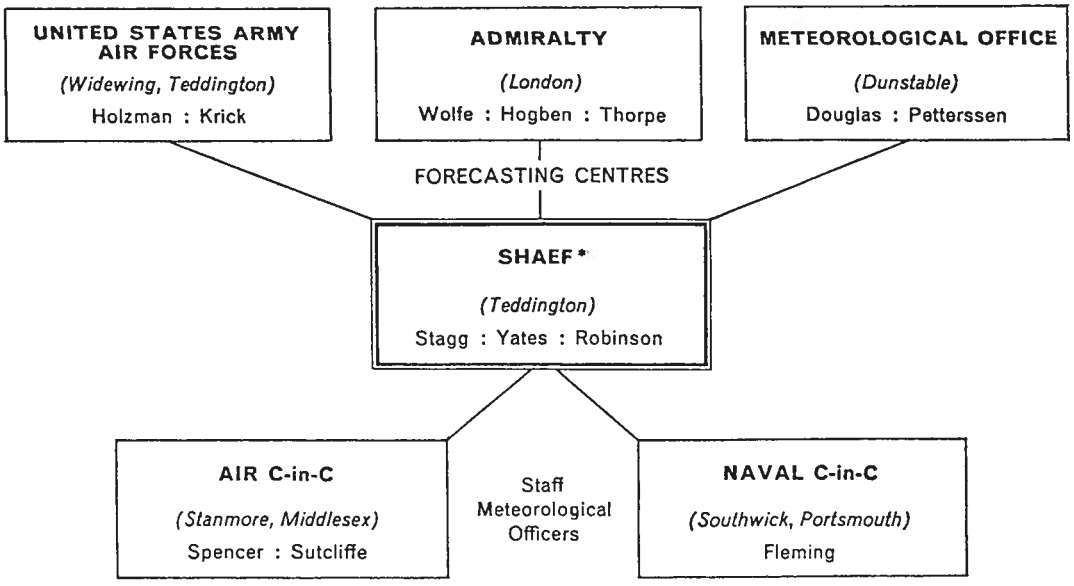
The American meteorologists I had met were more inclined to believe in the possibility of extended forecasts and had some hopes of the analogue technique, without being convinced. Our own short, experimental experience of applying the United States analogue selection to European weather was very discouraging.

I think I can just take a minute to tell you a little story about Douglas. I was at his side at the forecast bench at Dunstable when the very first teleprinter message conveying the chosen analog came through and Douglas looked at it and said "I can soon find them a better one than that." He went out to the library and within three or four minutes, in the time it took him to go to the library and back, he produced two volumes of the Daily Weather Report that is the published weather map of the British Meteorological Service. The circulated analog was about 1935 and Douglas opened it and showed it and it looked reasonable enough, and then he opened the other book he brought out, which was in the early 1920s, and it was indeed a better looking analog. So that was the sort of memory that Douglas had, an absolutely phenomenal memory for weather situations. And he was, amongst all those concerned, the most disbelieving of the possibility of forecasting, except in exceptional circumstances, for more than two, or at the very most, three days, in that part of the world, even in midsummer.

THE ARRANGEMENTS FOR FORECASTING AND THE FORECASTERS

The first landings called for cooperation between three branches of the armed services of two nations, six organizations, each conditioned to consider itself the finest or most-experienced fighting force then in existence, and each with its own arrangements for provision of meteorological information. Who was to forecast for the landings? Some unnamed genius came up with the answer — a committee. It was not obviously a silly idea. It had been used successfully for three years or more in RAF Bomber Command to ensure coordination of advice to the staff and the air crews of the bomber groups engaged in combined night operations. But in this case, the forecasters concerned knew each other well and had a simpler (but not simple) task, normally involving forecasting for periods of 12 to 18 hours.

Figure 1, from Stagg's book, shows the committee and its members. Each of those boxes was surrounded by a team of helping forecasters surrounded by a cloud of observers. There were many, many, many people in the team. The individuals identified in the figure are just the people who took part actually in the telephone conferences producing the forecast. Group Captain Stagg and Colonel Yates were physically and temperamentally just about as different as two people could be. Stagg was six foot four, short tempered, and inclined to be quarrelsome. Yates was shorter than I am and not so broad, very small, very athletic, and he was extremely patient and the most unquarrelsome man I have ever met in my life. They really made a remarkable pair. I sat in an office with them for about a month and just from the point of view of watching two human beings, it was an extremely interesting experience, and I have the highest opinion of both of them. They had to go before that array of generals and present a forecast knowing what the forecast meant, and knowing that to produce the forecast they often had up to two hours of argument. Yet, they went in and did a magnificent job, and the meteorological community, as a whole, owes them a great debt, because they produced a pretty remarkable effect on the people they were talking to. I know people who would have made a



*In the final stages the SHAEF Advance Command Post (Stagg, Yates) was at Southwick House, Portsmouth.

Figure 1. Schematic diagram of Meteorological Conferences by telephone

much-worse job of it. I know people who would have made a disastrous job of it. I don't know how they were chosen to get there, but they did it. You owe them a debt. Those of you who are professional meteorologists to this day owe a considerable debt to those two men.

The telephone conferences were convened from SHAEF. At each, the discussion was initiated by one of the centers; the lead position changing with each conference. The first order of business was a comparison of analyses (facsimile equipment was not yet in general use, and the scarcity of Atlantic observations could lead to quite significant differences). The lead forecast center then outlined its prognosis, followed in turn by the others. The chairman (Stagg or Yates) in open discussion tried to reconcile differences and produce an agreed forecast. The process took between one and two hours. I joined the committee in the second week of May 1944. The confirmation of the final date for the planned assault, D-Day, 5 June, was made to the meteorologists on 22 May. (The choice of date was probably not actually made by the generals until 17 May).

On May 28, General Eisenhower with his deputy chief of staff and the commanders in Chief of the forces involved in the first landings, moved to an advanced post on the south coast, taking Stagg and Yates with them. I was left behind to work the telephones. Regular weather briefings of the assembled commanders began on 29 May. (Figure 2 lists the times of these briefings). Each was preceded by a forecaster's telephone conference. Two hours were allowed for this conference, and were required more than once. None of the conferences lasted less than one hour. On two occasions indicated in Fig. 2, we meteorologists felt the need for an extra conference. When I look at Fig. 2, I realize why I have felt sleepy for the last 40 years!

THE SYNOPTIC SITUATION AND FORECASTS

In Fig. 2 you will note four entries in the action column. These occasions were the critical contributions of meteorology to the conduct of the operation, and I will try to give you some indication of the process of production of the forecasts concerned. I have a series of synoptic charts to illustrate this. I myself sketched these charts in the few days I remained at SHAEF after 6 June, using diagrams and notes made during the conferences concerning the forecast centers' analyses. They have been embellished by a draughtsman, and I disclaim any responsibility for sources and sinks of isobars. You must realize that between about 17 degrees west and about 45 degrees west even production of these charts was an "empirical" exercise, subjective and personal. Very few observations were reported in this region during this period and, at one critical juncture, the two we had were mutually inconsistent. Low centers L_2, L_3, and L_4 were reasonably well-documented entities when first introduced on the charts at the end of May, but after they entered the gray zone in longitudes east of the southern point of Greenland, no one really knew what happened to them. I found my own reconstruction unconvincing then, and I do now. I could not construct an alternative then and am certainly not going to try now. If synoptic meteorology is still taught, this might make an instructive exercise for the student.

Met. conferences and Commander's meetings

Date and	Time	Action
Thur., June 1	0845	
Fri., June 2	1000	
	2130	
Sat., June 3	0800	
	2130	Provisional postponement
Sun., June 4	0415	Postponement confirmed
	1600	(met. only).
	2100	Provisional order for June 6
Mon., June 5	0415	Order for June 6 confirmed
	0845	
	1730	(met. only)
	2100	

Figure 2

At the commanders' conference at 2130 on 3 June, in consequence of meteorological advice, the decision was made provisionally to postpone the assault planned for 5 June on a day-to-day basis. Everyone knew that logistically the off-on process took more than one day, and that the astronomical time-slot could not be stretched beyond the seventh. The provisional decision was confirmed at 0415 on 4 June, with no significant change in the meteorological advice. Figure 5 (1300 — 3 June) is the latest in the series of charts leading to the forecast. The forecasts, as summarized in the SHAEF report are the following:

Dunstable.

L_5, L_3, and L_6 moving east. The first cold front through the Channel would be that of L_6, probably on the 7th or 8th. Tropical air in the Channel during the period 5th to 7th.

Widewing.

Immediate development. L_5 moving ESE into North Sea, with active cold front through Channel on 4th and 5th. L_3 and L_6 moving to south of Iceland with cold front of L_6 reaching British Isles on the 8th.

Admiralty.

Small low L_5 expected to move ESE. L_3 and L_6 combining and eventually moving to Norwegian Sea with cold fronts through Channel on 7th and 8th.

The advice to the commander's meeting was that a series of depressions moving across the

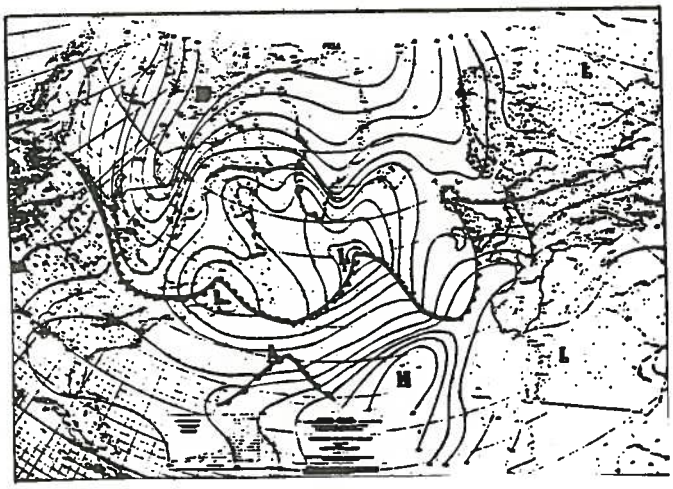


Figure 3. 1300Z 1 June 1944

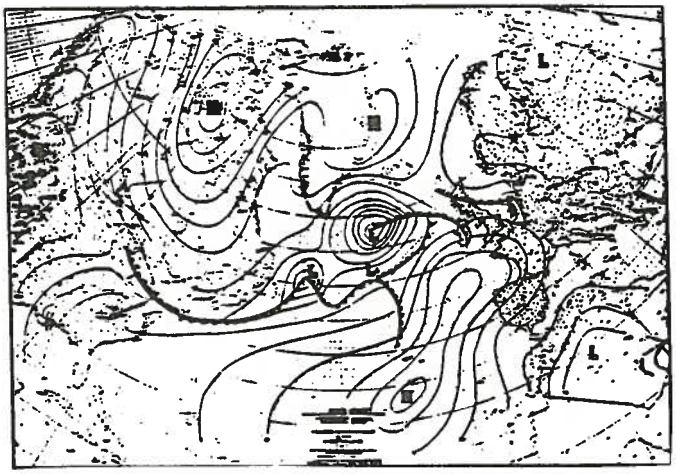


Figure 4. 1300Z 2 June 1944

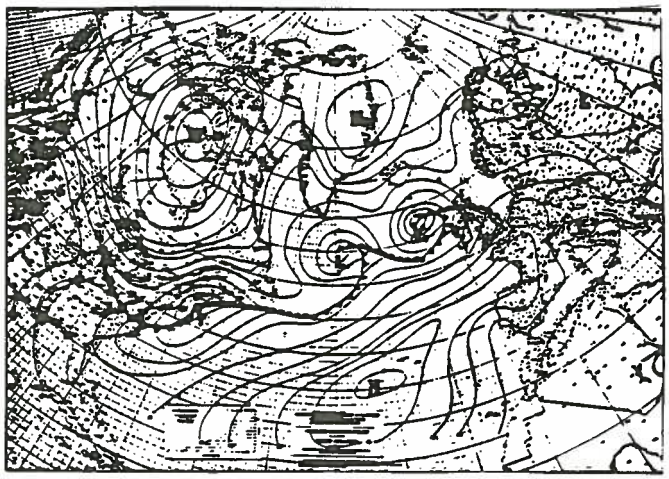


Figure 5. 1300Z 3 June 1944

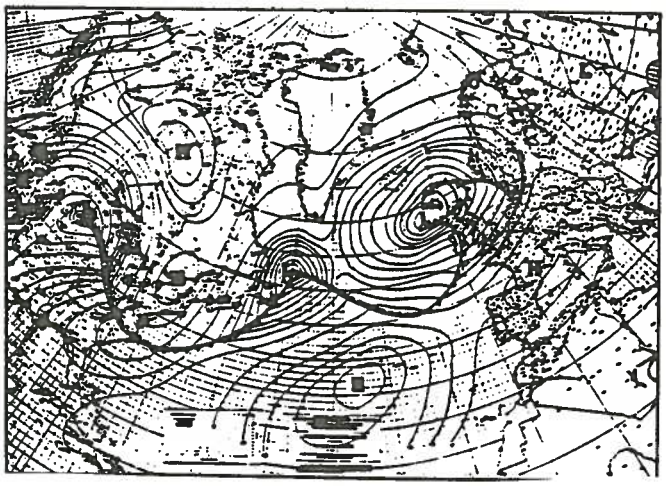


Figure 6. 1300Z 4 June 1944

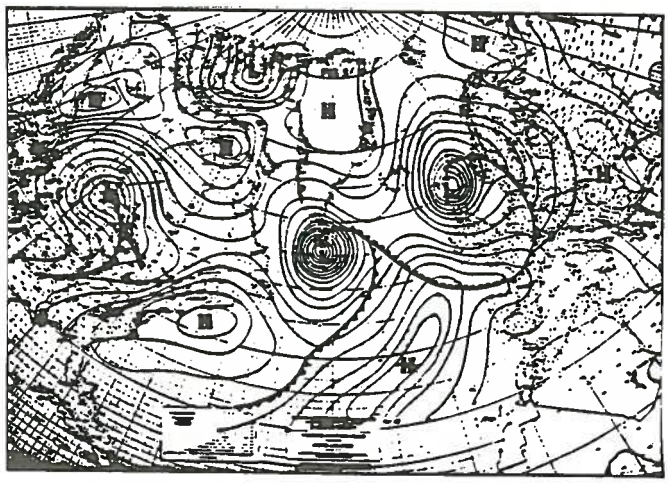


Figure 7. 1300Z 5 June 1944

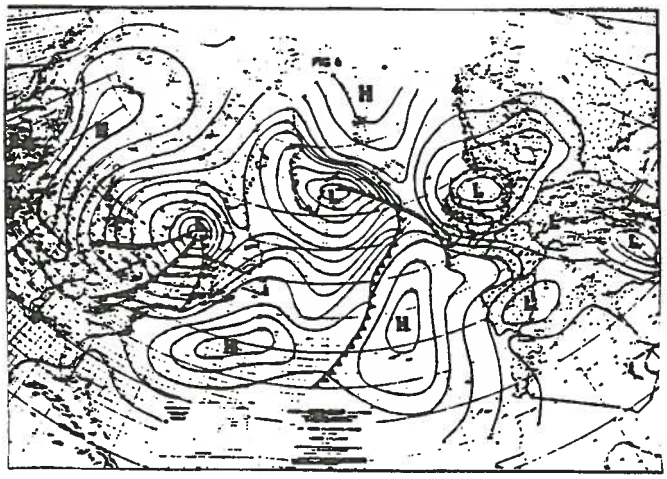


Figure 8. 1300Z 6 June 1944

Atlantic would produce prolonged disturbed conditions in the channel from early Sunday, the fourth, until a cold front passage sometime on Wednesday, the seventh. Wind force five on English Channel coasts; three to five on French coasts. Overcast at 500-1,000 feet in the channel, breaks to perhaps five to 10 inland over France.

At the early conference on 4 June, Dunstable and Admiralty made no significant change in their forecast. Widewing, however, now expected a "finger of high pressure" from the Azores to northern France to maintain sufficient intensity to allow good conditions in the channel with the zone of activity too far north to be troublesome. No specific mention on this forecast of L_5 and its cold front.

Advice to the commanders was not substantially changed, and postponement was confirmed, and their next meeting set for 2100 hours.

As you will see from Fig. 6 this is when things began to happen. I clearly recall a telephone conversation with Stagg late in the morning of the fourth when, fresh from watching the Widewing teleprints, I said to Stagg, "A cold front has turned up from somewhere and is already through the Irish west coast." To this day, I cannot expand on that "turned up from somewhere". In view of this chart, there was a special forecasting conference convened at about 1600 hrs.

The salient points of the forecasts were the following:

Dunstable.
L_5 moving east and then northeast to the Norwegian Coast by the 6th and filling. L_6 continues to move east. Cold front of L_5 clearing the Channel but trailing across France. The strong warm front of L_6, well forward, with minimal ridge between L_5 and L_6.

Widewing.
L_5 moving northeast. L_6 moving into Denmark Straight, front approaching Iceland on 7th. Channel area in flat wedge with temporary deterioration of conditions at fronts of L_6 on the 8th.

Admiralty:
L_5 moving northeast. L_6 moving into Denmark Strait. Wedge between the two building slightly. Occlusion of L_6 in the Channel on the 7th, followed by building ridge.

Following this conference, the chiefs of staff were informed that the commanders' evening conference would probably be informed of an interval of much-improved weather for Monday night and Tuesday.

The centers' forecasts were little changed at the evening conference, with Widewing and Admiralty becoming more specific about positions of pressure centres and fronts in the period up to 8 June. At the 2100 hours meeting on the fourth, the commanders were advised of an interval of fair conditions with force three-four winds and less than 5/10 clouds at 3,000 feet, lasting into Tuesday morning, followed by increasing cloudiness but not general increase of winds. After some very intense questioning of Stagg and Yates, orders were issued to prepare for assault at 0630 on the sixth.

The forecasters conferred again at 0300 on the fifth. Dunstable now agreed that L_6 would not continue to move east, but emphasized the forward portion of its warm front and accompanying clouds. The notes do not indicate any discussion of the fate of L_5. The commanders were informed of no substantial change in the forecast; the units in movement were not recalled, and the operation proceeded irrevocably.

THE ACTUAL WEATHER

Figure 8 is the 1300 chart on 6 June. The cold front which "turned up from somewhere" has reached the Mediterranean and the Alps. The ridge between L_6 and L_5 has not developed. L_5 has moved southeast into the North Sea while filling, as the Widewing forecasters predicted on the evening of the third before changing their minds. The consequences of this movement were to delay arrival of the warm, moist air associated with the front of L_6, but to maintain and, later in the day, increase the strength of the wind on the beaches to a disturbing extent.

PREDICTABILITY

The title of this talk, not of my choosing, though I do not complain, contains the word predictability. I believe that calls for some explanation of a personal nature. I was demobilized in June 1946, and since then have not made a single weather forecast except for my own amusement. Many years later I become involved, through the World Meteorological Organization, in the early planning of the Global Atmospheric Research Program and the World Weather Watch. I became disturbed by some of the claims made by some of the scientists campaigning for financial support of these projects. I took the opportunity at a scientific meeting to put forward what I still consider a philosophically sound, though mathematically naive, method of estimating the limitations on prediction of the nonuniform motion of a viscous fluid.

I did not know there were science journalists in the audience, or that one of them would contribute an article on my talk to the Washington Post at a critical point in Congressional examination of the Weather Service budget. I did not invent the word predictability. In the 1950s, R.C. Sutcliffe wrote at least two papers with a thorough qualitative discussion of the question, and P.D. Thompson made quantitative estimates, giving the word a precise definition and relating it to the spacing of observations. I believe there is a real limit on the possibilities of prediction of development of internally driven viscous fluid systems, and of the statistics of ensembles of such systems, and that we have now come close to the limits. However, this had little impact on empirical, personal, subjective weather forecasters. The only relevance of the modern

concept of predictability to the history of D-Day which occurs to me now is that the idea of exchange of information between unobserved and observed scales exposes the fallacy of forecasting by analogue. But in spite of the implications of Stagg's book, I don't think the analogue method had any real impact on the D-Day forecast. The real difficulty in early June 1944, was a lack of observations. Even now, computers cannot integrate equations without initial conditions.

CHAPTER 11

LETTERS FROM PARTICIPANTS IN D-DAY FORECASTS

INTRODUCTION BY JOSEPH VEDERMAN

It occurred to me that there may not be a 50th anniversary, and so I thought I had better get in touch with everyone I could to get input into this 40th anniversary conference. I wrote to a lot of people, practically all over the world, to all the Americans I knew or had read about. If I didn't know, someone else would recommend to me that I ought to get in touch with this fellow, or that fellow, and so I obtained their names and I wrote to them, and I got some replies. I got in touch with people in Great Britain, in France, in Australia, in Germany, and in Russia. I didn't get replies from all of them but I got replies from many of them.

Let me begin with this one by Professor Flohn, German Meteorological Service. The way I contacted him, I wrote to the German Weather Service and asked them if they knew any of the people who were still alive. They recommended two people. They said most of the people had died or they don't know what happened to them. Two of them are still very interesting. One is Dr. Flohn, whose letter I'm about to read, and the other was Professor Schuster. They said that Schuster is very reluctant to talk. He was the one who conferred with the Fuehrer on that critical day and gave him the forecast and discussed the weather with him. But I decided I would write to him anyhow. I haven't gotten a reply yet. Listen to what Dr. Flohn says 40 years after he participated.

NOTE: The letter writers who follow are identified by their military rank or organizational affiliation at the time of the D-Day event. Only the text of the letters has been reproduced.

LETTERS FROM PARTICIPANTS IN D-DAY FORECASTS

read by

Joseph Vederman and
Nicholas Powell

Letter from
Professor Dr. H. Flohn — Headquarters of the German Air Force.

Immediately after the beginning of the war between Germany and the USSR (i.e. end of June 1941) I had been transferred to the "Zentral Wetterdienstgruppe" at the Headquarters of the German Air Force, where I was mostly occupied with climatology, medium and long range forecasts. At this position I remained until the end of the war. About late summer 1943 the "Chef Wetterdienst" who was at this headquarter, was requested to form a small group of experts and responsible meteorologists from air force, navy and army to advise the general staff of the Wehrmacht at the earliest possible date on the probability of landing. This was done; Prof. L. Weickmann (then 61) was asked to take the leadership of this group, which met perhaps twice a week at the headquarters in the forests west of Potsdam. Among the foreign experts (not directly in a military position) were Prof. F. Baur and H. Wagemann; however, their advice proved to be not very helpful. During each meeting the meteorologists discussed their data (e.g. something like a Hovmöller diagram, which we used regularly at least since late 1941) in great detail to get acquainted with the large-scale behaviour of the atmosphere.

At this time we used routinely twice daily maps of 500 mbs, surface and 500/1000 mb thickness, plus once daily 225 mb, 96 and 41 mb maps as described in R. Scherhag's book published 1948 in German (Neue Methoden der Wetteranalyse und Wetterprognose); the stratospheric levels were of little help. We had often speculated if the Allied Forces used a similar analysis technique and assumed that they had much more and better data over the Atlantic than we had. (During the winter 1943/4 a single experience — a group of Allied planes were forced by strong head winds of the order 400 km/h, to abandon their plans over French territory — seemed to indicate that the occurrence of jet-streams were either not known or not accurately measured by them.) Our 500 mb and surface maps extended from Long. 15°W to 40°E and from Lat. 30°N up to 80°N, data received from regular reconnaissance flights and polar weather stations. I was surprised to learn from Col. Stagg's book - which contains only surface maps - that we apparently overestimated the meteorological technique used in the Allied Forces — however, this statement may be incorrect. At any rate, we had at this time — after 9 years experience in isobaric contour analysis (not isentropic!) - some empirical insight into the 3-dimensional time-dependent behaviour of the atmosphere — this was not the case with the foreign experts as named above. Quasi-periodic phenomena etc. have been used, but were not generally accepted by the participants. The same was also true for the "singularities" (i.e. weather frequencies at given calender days); at this time we had become critical against such handwaving arguments.

The prerequisites for our medium-range (2-5 days) forecast of the weather situation in the region of the British Channel — our unofficial term was "Kanalvorhersage" — had been formulated by the Navy. I do not remember those for the moon's position and the tides — I only remember that one of the most important conditions were light winds (not above Bft. 4). Due to the role of the tides, only a few dates could be selected — one of them was the night 5/6 June. Thus we concentrated our discussions on this date. Our last forecast had to be issued on either June 3rd or 4th (the latter day is much more probable). At this date weather reconnaissance (or a submarine?) had taught us that in an airflow generally from westnorthwest (or northwest) a new vortex was expected to intensify and to cross the channel region probably in the night between 5th and 6th. With the passing cold front and in the unstable cold air after it we expected winds from westnorthwest Bft. 5-6. If the Navy prerequisite was correct — we had no background (and certainly no allowance) for judgement of this constraint — a large-scale landing operation should be too risky. One of our arguments was also, that the Allied force must have much better data and knowledge about the risk involved.

I do not know any details of the forecasts made by other meteorologists within staffs at a lower level, for example at the Air Force Command or Navy Command in France. Most probably they had been similar, since some responsible high-ranking officers took leave during the day. (As a much younger meteorologist — then 32 — I did the same, visited my family and our little baby, which I had not seen since several months. I remember vividly how surprised I listened to the radio news; at this time everyone of us felt that this was the beginning of the end.) Discussions were quite vivid after the event — we came to the

conclusion that most probably the prerequisite fixed by the German Navy was too limited, or either that the Allied Commander-in-Chief could not postpone the operation for other four weeks (or both). Anyhow, we could not find that our two day (or three day) forecast was substantially wrong: there were gusty winds Bft. 5 or more and the losses were at first rather high.

---

*Beaufort scale

Letter from
Colonel Thomas Moorman - Commander 21st Mobile Weather

Squadron

It's been a long time and my memory is not getting any better. However, I have tried to focus on my reactions to that period - and herewith a few thoughts.

The events of the several days preceding, during, and after the mission impressed on me indelibly the importance of weather and sea conditions to an operation of this sort. The abortive sortie a couple of days before, the marginal weather and sea conditions, and timing the actual landing, the importance of air superiority and air support together with the importance of weather and weather forecasts - all these factors made believers of most Army, Navy, and Air Force Commanders. They must consider expected weather conditions in their planning and their operations.

The second biggest impression was the tremendous pressure placed on the forecasters during the planning period and particularly in the several days and hours preceding the invasion. I thought so at the time, and still do admire the way all the principals involved in the weather and sea conditions forecasts reacted to the pressure. It's most difficult to think clearly and logically and to consider all the possibilities and options when one is under such heavy pressure and under limited deadlines.

I guess another strong impression is that the pressure didn't stop with the initial landing but continued day and night, month after month. But all concerned came through and their good scientific and military training proved to be more than adequate to the demands. My best to all!

Letter from
Larry Hogben - British Admiralty Staff Weather Officer

In passing, may I say that for a man who has never been west of Denver, I have the happiest memories of my work and friendship with two great Caltech forecasters, Ben Holzman and Irv Krick. If all you Californian meteorologists are as likeable and knowledgeable as they, you will have a spendid meeting on May 19th. In my view the D-Day forecasts left us with military, meteorological and philosophical questions which deserve discussion, even if answers fail to emerge.

Pettersen had, at the time, no practical body of support for his ideas on the use of upper air information - but he kept claiming that he had. It is possible that he later found out things which would have been useful to us - but upper air charts were at that time too new to us all to be more than a useful additional element of our analysis.

The analogue method was also virtually useless (I know a lot more about it now because I worked on it with Krick after the war) because there was not enough data to give a good analogue on more than a handful of occasions — a good analogue system would need hundreds of years of historical data, in my opinion (though an analogue system in conjunction with other techniques has more potential).

The Naval Forecasters knew this problem of extending beyond about 36 hours — we had our own long range adviser, in John Thorpe who had all the current long range methods at his finger tips - and always gave us his best views - but he didn't make any reliability claims for them.

The truth about our techniques is that they were rather primitive, I now speak about all six forecasters, and they were more or less the same for all of us.

1. Analysis of current data. Here the Americans and we were better on the broad picture, than Dunstable who were of course all right over the British Isles & Northern France. We had long ceased to accept Dunstable analyses over ocean areas, and Stagg's assertion (page 55 of his book on the forecasts) that for British naval purposes unconnected with SHAEF we accepted Dunstable prognoses is quite untrue — they were so bad that the Royal Navy had to form the Admiralty Forecast Section to do our own. But for D-Day purposes the analyses did not present a problem.

2. Production of a Forecast Chart (24 & 48 hours ahead of data). This was done by extrapolating movements of pressure centres and fronts, - and by using our experience and, if possible, analogous situations. But extrapolation was the main weapon. Upper air charts had a limited value for confirming or not the movement of depressions, at the surface.

3. Making the forecast by interpreting the isobaric forecasts. Here Douglas, of course was specially good, because of his knowledge of British weather associated with isobaric formations in this area. But both he and the Americans were absolutely lousy for wind strength over the sea - and here the Admiralty had to put the others right - because the wind strength over the

sea (as opposed to the land) is close to the geostrophic value (which Geoffrey Wolfe and John Fleming and I alone seemed to know). And of course, Charles Bates gave us the sea conditions, based on our wind forecasts, AND THE OPERATION WAS A SEA BORNE ONE.

After 48 hours — for which the forecasts were made as I have described above, the future became hazy — I agree with what Stagg quotes of Robinson's findings and I do not believe that any of us was able to make scientific forecasts for more than 48 hours after the last recorded observations.

To summarize then, our forecasts were based on analysis by Norwegian principles, common to all of us, and subsequent extrapolation, mainly without much aid from upper air charts, but using every ounce of experience & knowledge from all six forecasters. And they were a combined effort — in which we rubbed out our differences by discussion. No one of the six was always right or always wrong — even if on the vital two days only the Navy was right both times! And we were all wrong on the alternative date — the 19th June.

Letter from
Captain Rodney A. Jones - forecaster USSTAF Weather Center

For many of us who were to be directly involved in weather forecasting for the invasion of Europe and operations leading up to it, D-Day really occurred on 27 January 1944. On that date, a small group of us led by Colonel Don Yates, then Chief of the Air Weather Service, departed our secure fifth floor Pentagon offices and flew to Prestwick, Scotland with a refueling stop for our C-54 at Gander. An overnight train ride took us to London with its mournful air raid sirens and endless coal-fed chimneys doing their best to hide everything under a blanket of smog and grime.

At Bushy Park we were joined by a couple of Royal Air Force officers plus several US Air Force meteorologists and other support personnel who were transferred from operational air bases in England. Within a few days we were an operational Weather Central! To those of us at the working level, it was not always clear as to who was making what use of our maps, charts, studies and forecasts. Weather briefings within the headquarters complex were routinely carried out by our immediate supervisors, Ben Holzman and Irving Krick, but with wartime security, feedback was minimal. However, everyone was convinced that weather forecasts were going to be a key factor in the anticipated Allied invasion back into Europe. Our initial concern, therefore, was to establish a reputation that General Eisenhower and the established meteorological network would take seriously.

Good fortune presented us a rare opportunity about the middle of February. While researching our 50 years of past weather maps of analogous situations, as part of making an extended forecast, Wyatt and I became convinced that we were moving into a stable pattern that would lead to an unusual period of 3 to 5 days of visual, high altitude bombing weather over central Europe! Krick concurred and apparently did a good job of selling the forecast. General Spaatz called off most B-17 and B-24 raids for several days to prepare for an all out bombing effort. The rest is history! The weather turned out almost as good as forecast and the raids in late February against ball bearing factories, I believe, became known as the three days which broke the back of the German Air Force! We were now ready to concentrate on forecasting for the anticipated Allied invasion of Europe.

Actually, as it turned out, the invasion forecast was pretty much a "non forecast." It was generally recognized from climatological studies, that the period from about 15 May to 15 June offered the highest probability of at least a week of fairly good weather, free from serious frontal storms and rough seas. Furthermore, well established tide tables defined quite specifically the days of the year on which a large scale amphibious operation should be initiated along the coasts of France and the Low Countries. On this basis, the date of 4 June was selected. It would be interesting to know the details of the selection process and when it was made. As far as I can recall, none of our 10 day forecasts or monthly and seasonal outlooks issued up through about the middle of May, did anything but confirm the validity of the climatological history. It appears that up to then, weather was not of major concern to the high level planners. They had picked what was normally the best time of the year and would stick with that unless circumstances dictated otherwise.

I was not involved with the hour by hour monitoring of the intensifying storm system approaching southern England on the 4th of June but it was receiving lots of attention! It was apparent that something big was cooking but no one was talking! Early on the 6th we got word that the invasion was finally under way with wind and sea conditions marginal but operational and improving! As I was leaving the Headquarters area that morning, formations of white banded planes overhead were heading to the south east. Winston Churchill was also departing in his staff car. He had his ever present cigar and gave us his V for Victory sign; things must be going well or he wouldn't be leaving.

The invasion was held up at the starting gate for 48 hours from the originally planned "kick off" time, waiting for an unusually intense summer storm to clear the area. In my opinion, the only significant impact made by meteorologists on the entire operation up to departure time, was made in those last two or three days. Human endurance and security considerations dictated no further delay. Hence, if conditions weren't going to be operational by then, the whole thing would have to be scrubbed! As we know, it wasn't scrubbed and the Germans were caught by surprise; quite possibly because a handful of meteorologists

knew what they were doing and had the confidence of the man in the driver's seat when the chips were down!

Letter from
Robert Ratcliffe - Upper Air Unit British Meteorological Office
- later Executive Secretary, Royal Meteorological Society

I was deputy to Sverre Peterssen in the British Upper Air Unit. C.K.M. Douglas and Sverre handled all the forecasting from the British forecast centre at Dunstable. The forecasting procedure was set up several weeks before the invasion and we didn't know when D-day would be. Forecasts were made daily for several weeks for as long ahead as possible but the planned date was kept secret.

My job was to draw upper air charts at 700, 500, 300 and 200 mbs and forecast these levels for the Atlantic and Europe for 24 hrs ahead. At this time we were just beginning to understand cyclonic and anticyclonic development as subsequently described by Sutcliffe (Q.J.R. Met. Soc. Vol. 73 pp. 370-383). We were also using these ideas to forecast development as subsequently reported by Sutcliffe and Forsdyke (Q.J.R. Met. S. Vol. 76 pp. 189-217). The upper air forecaster at Dunstable had discussions with the senior forecaster who produced the forecast surface charts. The upper air forecaster was, in fact, very influential in this respect.

As D-day approached, the key factor was whether or not a strong ridge would develop and hold firm from the Azores to the Channel or North France, or whether the approaching Atlantic depression would deepen and force the ridge southwards. The U.S. forecasters in Britain (at Widewing) favoured the anticyclonic development while we in the upper air section persuaded the surface forecaster and Douglas that the strong diffluent upper thickness pattern in the Atlantic and what would now be called a westerly jet stream with its left exit approaching the U.K. would mean the depression deepening considerably and probably stagnating near north Britain. Of course in the event we were right and D-day was postponed 24 hrs.

You ask about anecdotes. I can give only two. Firstly, C.K.M. Douglas was the greatest forecaster at the time but he liked to think things out for himself and was not easily persuaded by others. One day he took the baby out in its pram and as usual walked to the top of Dunstable Downs, the highest point in the area, where he could study the clouds. This he did with his usual intense concentration noting the direction and speed of the winds at various levels by using a branch of a tree as a nephoscope. He became so absorbed that he went home leaving pram and baby on the top of the Downs!

Secondly, one of our upper air forecasters who was very highly strung had just finished drawing all the actual upper air charts at various levels (about 3 hrs work and based on few actual observations) when an important observation came in and was plotted on his charts. Unfortunately it didn't fit and clearly showed that the charts were wrong. He stamped about in a rage for a while and then took some postage stamps out of his wallet and stuck them over the offending readings!

Letter from
Captain Don Roberts - Assistant Staff Weather Officer 8th Air Force

I was a captain in the Army Air Corps assigned to the Headquarters of the Eighth Air Force in High Wycombe 35 miles west of London. We operated there with an Army Air Weather Service detachment and separately with three persons assigned as Staff Weather Officer and Assistant Staff Weather Officers to the 8th Air Force. I was an "Assistant SWO" — my counterpart, Jeter Pruitt.

The roles of the Asst. SWO's were to participate in the telephone weather conferences during which the principal US and UK weather organizations offered their views, take down the consensus forecast and prepare and deliver the operational briefing to the 8th Air Force commander. (Usually the commander, Jimmy Doolittle, was off at General Eisenhower's Headquarters or at US Strategic Air Forces or visiting tactical units. So we were briefing the Chief of Operations, Major General Orville Anderson — in my opinion the real directing tactician of the strategic bombardment of Europe.)

We gave the general the official forecast, then we were required to give him our estimate of: how could it be wrong? Also we stayed with the mission from the 4 PM briefing until mission completion the next day, frequently 24 hours on duty.

The priorities of the day heavily favored heading out on marginal chances of successful visual bombing. So if the briefing weather officer offered some reasonable, even if slight, chance that visual bombing of, say, a major oil refinery might be possible, the 8th Air Force with 1500 heavy bombers and up to 1000 fighter aircraft would be mobilized and sent on its mission. As you can imagine, the state-of-the-forecasting-art being what it was (and still is as it seems to me) we missed some big ones!

In other words we were not muzzled and frequently there were disputes between the generals at the various levels because their weather forecasters offered differing opinions. A sporty course!

With respect to the D-Day forecast, I had only a peripheral role. Security on the actual launching of this effort was very tight, but there wasn't much chance to avoid knowing that the invasion was imminent.

Beginning about June 3 we began intensive forecasting for the support role the 8th Air Force would have. As the invasion was originally planned for June 5 we all knew it couldn't go because of the active low pressure cold front situation moving over England and the Channel.

The key people in briefing General Eisenhower, who had to make the big "go-no go" decision were Colonel Don Yates for the USAF and Group Captain Stagg for the RAF. The main supporters of Yates were Col. Ben Holzman and Dr. Irving P. Krick from Cal. Tech. These men were supported by a high powered Weather Central complex, one of the key persons (who then as for many years later pioneered high altitude forecasting) being Bob Bundgaard. The "big story" comes from that group.

We at 8th Air Force participated in the group telephone review of the overall weather situation. Our specific role was to maximize the 8th's support role--get 'em out early and often! As I recall, we mainly supported the decisions, first to hold up and then to go! But there were many in England who thought the situation too risky. And indeed it was. The landings were difficult and follow-on support for a few days after the landing was intermittently not possible. But the ultimate proof that the forecast worked is history.

Once the decision was made and the forecasts out we could only wait, watch, and pray. Once launched, the invasion could not be recalled. Surprise would be lost and the summer would have passed. A delay meant another year of war in Europe.

So we left our underground blockhouse just before dawn on June 6, 1944 and went to the top of the hill over our cantonment area. Almost immediately we heard the roar of heavy bombers. Before long the sky from horizon to horizon was literally full of B-17s, B-24s and RAF bombers. (High Wycombe was directly on the flight path from all the Central and Northern England airbases to the landing zones and interdiction targets.)

I can't to this day find the words to express my awe and my unarticulated prayers for success for the hundreds of thousands of men who were on their way.

I don't suppose I'll ever again be a part of such an operation. I don't suppose that there will ever again by anything quite like it.

Letter from
Major John J. Jones - senior forecaster USSTAF Weather Center

As you know the invasion of Europe was about 40 years ago and most of our memories have grown dim. As the fatal day drew near, the Senior Forecasters were responsible for briefing Holzman and Krick. They worked alternate days. There was an upper air section headed by Bob Bundgaard and a long range forecasting section that no one paid much attention to. They spent most of their time and effort trying to work out what Krick had called TYPES for the Atlantic. I don't remember who was in charge but the long range section included Dr. Don Perkins (deceased), Cis Wyatt (deceased), Rodney Jones and others. The Senior Forecasters were all majors and R.G. Bounds was in charge. The others were Olav Njus, E. O. Smith and me.

The responsibility for the final forecast and for briefing Eisenhower fell on Group Captain Stagg who later became chief of the British Met Office. He was a man of outstanding ability and a fine temperament. His forecast was a distillation from many sources. What he got from us (The USSTAF weather section) was colored greatly depending on the day. From Krick he got a view of extreme optimism, from Holzman a much more pessimistic view. My analysis would leave me with the impression that no one in the USSTAF weather section had a basis for being proud of their contribution. The long range forecast was utter nonsense, the Upper Air section was about a day late in completing their analysis and issuing their forecast. My associates in the surface section were all very competent but we had so very little to work with over the Atlantic.

Letter from
Dr. R. Sutcliffe - Headquarters Air C-in-C

This is in reply to your letter of March 8 in which you ask for information about the forecasts leading up to D-day, June 6, 1944.

I was indeed involved in those deliberations but I have never considered that I played a key role and have no wish to claim such a position now. Taking your acquaintance with Stagg's book as a convenient starting point I will try to explain. His Fig. 1. shows the organization for the meteorological telephone conferences where I and Colonel Norman Spencer U.S.A.F. are shown as meteorological Staff Officers at the Headquarters of the Air C-in-C. I understood our task to be that of listening in to the telephone discussions and commenting upon the specific aviation aspects of the forecast weather.

That Headquarters was of course a combined unit with, as it so happened, a British C-in-C and a U.S. deputy, and had a considerable staff more or less duplicated throughout. It was created specifically for the invasion operations.

I was posted there, as I remember sometime in April (I have no ready way of being definite about the dates) as opposite number to Colonel Spencer who had been in post for some time. He had a small weather section to maintain a series of synoptic charts and other information obtained through the U.S. Weather Service - one top sergeant and a few men. I had no staff but

it was understood that I should make use of the Meteorological section at R.A.F. Fighter Command located nearby.

Spencer as a full colonel in the U.S.A.F. had established a routine in which the only function that I can recall was to present a general weather briefing at the daily Staff Conferences held at that Headquarters. The briefing was a perfunctory affair as the crucial operational decisions were not to be made there. The point is that Spencer and I were not called upon to make independent forecasts and indeed we did not have the facilities to do so. I do not recall that during the telephone conferences which Stagg describes, Spencer ever put forward a view beyond his brief as a Staff Officer but Stagg, who knew that I had been intensively occupied for some four years in regular forecasting for Bomber Command operations, and had been accustomed to telephone conferences in that connection, did rather press me to comment and occasionally I did so. Actually in his book Stagg refers to me several times and not entirely in complimentary terms (as though he expected better of me!) but I knew my Stagg and took no exception to his remarks then or later. In sufficiently close terms, Stagg's account of the whole enterprise was and is quite acceptable to me and while I believe that some participants have given different accounts I have never felt moved to enter the arguments.

Within a few days of D-day Spencer was transferred to some U.S. Headquarters in France and employed himself, I believe, in liaison with the French meteorological service. A week or two later I (now mobilised as a Group Captain in the R.A.F.) followed to a British Headquarters in Norway, then to Paris, and in due course to Brussels becoming Chief Meteorological Officer for the British Air Forces and the Army through to V-day, continuing under 1946 with the Forces of occupation in Germany. That was satisfying, responsible work but is another story.

I soon lost sight of Spencer and in later years my inquiries on several occasions to my surprise yielded no news of him. He must have dropped out of the meteorological world but presumably the U.S. Air Force must have a record of Norman Spencer Junior, I think a regular officer, West Point trained, a pilot with, I thought, a combat record.

During the weeks before D-day I was able to renew my old acquaintance with Stagg and Robinson and also to enjoy on several occasions the company of Yates, Holzman and Krick. Stagg was super-concientious, deadly serious as no doubt the occasion required, but an awkward character not well-suited to a diplomatic position; Robinson with his practical good sense must have been a great comfort to him. I formed the highest opinion of Yates as a strong military character yet with a light touch and sense of humour who managed I thought admirably well to smooth the way around Stagg's prickly corners. Holzman was obviously a genuine scientist, Krick a colourful personality less easy to place. In common with some others I thought Krick's system of analogue forecasting, what I knew of it, could be no basis for forecasting but, then, we had at the time no methodology for prediction beyond a day or two, the extent of simple extrapolation of current trends and general judgment. Any plausible evolution was more or less as convincing as any other and there was enough experience and talent available to ensure that the predictions were at least reasonable. Actually it was the skill in short-range forecasting which finally carried the day and there was no one better than C.K.M. Douglas in that speciality. Petterssen was a real source of strength giving a beneficial theoretical and scientific stiffening to the British team although his personal vanity was sometimes a little trying.

I hope the above remarks will be of some interest to you. Naturally I had much to do with some of the personalities in later years but I have tried not to let my comments be too much coloured by later events.

Letter from
John R. Thorp - British Admiralty Staff Weather Officer

I received your letter dated 14th March, and have been cudgeling my memory to recollect the events of 40 years ago which at the time seemed little more than routine. My associates were Geoffrey M. Wolfe and Larry Hogben (New Zealander), both hostilities-only officers and we had a telephone hook-up at intervals with the British Met Office, the USAAF (Widewing), and Channel HQ Group Captain Stagg. At a later stage Dr. Sutcliffe joined the circus — I believe he represented Bomber Command HQ. These conferences were good for a laugh or two; the telephone system was stretched to capacity and too often we collected successfully three out of four only to get one cut off while trying for the fourth. Our brief was to offer the prospect of five days of wind force 3 or less with, hopefully, reasonably fair weather in at least substantial intervals. There were other constraints affecting parachute drops, still rather untried on the scale envisaged. Also spring tides — not our direct concern — were a vital element of the assault plan and June 10th was considered a key date. On June 5th we meteorologists were in complete agreement on one thing, light winds were not on, so far as we could foresee and we opted for westerly force 4 to 6 — a pretty stable state in the English Channel. In spite of, or perhaps because of our predictions, our military commanders decided the same day to start the assault and caught the Germans completely by surprise as we now know. No credit to us, who did what any professionals would have done in the circumstances, but rather to the bosses who made the decisions and to the troops who have to endure the conditions and who made such a good showing when it came to close fighting. Larry Hogben kept on inserting "risk of haze" into our forecasts — I recall that Col. Krick slyly altered this to "risk of smoke" after battle had been joined.

The most searching test came about 10 days after June 6th when an easterly gale sprang up

and battered the landing beaches where consolidation operations were in full progress. I remember Juno being named as suffering particular damage. This gale was particularly severe on the French coast. On the English side it was fairly quiet and we had no idea of the severity being experienced — shades of Julius Ceasar(!) — for weather reports from France were badly organized.

At this point I must conclude my narrative of the events but I will try to fill in if you have any questions. I must ask you to forgive my atrocious handwriting; I have, alas, no typing facilities at hand. I have lost touch with Geoffrey Wolfe; he is probably retired like me. He was managing director of Wolf Electric Tools at Hanger Lane, Park Royal, London W5 who sold the familiar domestic electric drills but have, I suspect, lost that end of the market to Black and Decker and some of the German/Swiss/Swedish firms though they probably have ongoing contracts of industrial tools. I have initiated an effort to regain touch if he is still alive and will write again if I have any success but offer no promises. Larry Hogben is out of my circuit altogether — he is the sort of bloke I used to meet spontaneously outside Harrods or elsewhere in London, but not for many years now though I suspect he is around London and not in New Zealand.

I hope you will have a successful meeting on May 19 with a representative gathering. I hope that my far from adequate notes will provide you a basis for local colour and that others will be able to fill in the gaps. Thank you for offering me the opportunity to recall those events; I only wish I could do better justice to it.

Letter from
Col. Olav Njus - senior forecaster USSTAF Weather Center

After 40 years many details have faded from my memory. Also, memory is selective and often plays tricks. I hope my memories are accurate but if there is a conflict in what I recall and the recall of the memory of others, please understand.

My activities through this period were quite routine. The U.S. forecast Center was divided into two sections, the surface forecast section and the upper air forecast center. (By June 5th the long range forecast section was out of the picture). I was the duty forecaster in the surface forecast section. In collaboration with the upper air forecaster our forecasts were issued. (I do not recall the duty forecaster in the upper air section but it probably was Bundgaard). Yes, we sweated the forecast. Need I say more.

After the forecast was issued I went off duty returning to duty late afternoon or early evening of the 6th. By then the die was cast — the operation was underway and nothing could stop it. As I recall it, I was a bundle of nerves and spent most of the night pacing the floor while monitoring the weather. The weather was developing much as forecast. I am sure there must have been some updated forecasts for the paratroop drops and the glider landings but I recall nothing of that. I recall the relief I felt as the news of successful landings came in.

Anecdotes — I have none. If there were any humorous moments they have faded from my memory — crowded out by the stress I still feel when I recall those hours.

Letter from
G.D. Robinson - SHAEF

Thank you for your letter and invitation to your meeting on May 19. I am sure I would enjoy the meeting, but there is no way that anyone is going to pay for a ticket to Monterey (Editors note: Dr. Robinson did, of course, attend and participate in the conference).

However, the enclosed document (Appendix B) might make an interesting exhibit. I came across my own copy, turning brown and falling to pieces, a short time ago. It could well be the only existing original, and this is the only copy I have made.

I was at SHAEF from the beginning of May to about the middle of June. Stagg (J.M. then Group Captain RAFVR) Yates (D.N. then Colonel USAF) and myself (then Sq. Ldr. RAFVR) were the only meteorologists actually at Headquarters. I was the only person to take part in all the telephone conferences between 1 and 6 June. Looking now at the record I don't know when I got any sleep. Appendix B of the report is based on my notes taken during those conferences. Stagg edited out the more intemperate sections. I also drew the surface maps in the report — (a draftsman seems to have cleaned them up). They were drawn before June 10 but after June 6. They look, and probably are, wrong, but no one at the time could come up with a better guess.

Of the main contributors to the conferences, Stagg, Holzman and Petterssen are dead. Yates, Douglas and Sutcliffe retired years ago, literally to cultivate their gardens. I hope (and believe) they are still doing this. I don't know what happened to the British Admiralty forecast team.

I hope you can read this and that you have a good meeting.

Letter from
Major Lawrence A. Atwell - operational Staff Weather Officer

Thank you for your letter of March first in which you inquired about my role in the D Dav

invasion of Normandy. Also, it is great to hear that Bob Bundgaard — truly one of the very best meteorologists and persons that I have known — referred my name to you. Please do me the favor of extending my very, very best wishes to Bob.

Yes, I believe that I did play a key role in the June 6th, 1944 invasion, and I will recall for you that it began with a secret meeting with Brigadier General William Gross, USAF, Commander of the First Air Combat Wing, in March 1944. At that time I was stationed at Bassingbourne, England (a R.A.F. permanent air field) holding a dual role as Staff Weather Officer of the First Combat Wing and Staff Weather Officer of the 91st Bomb Group, commanded by Colonel Stanley Wray.

When General Gross called for me to meet with him privately I had some idea that an important subject was to be discussed for earlier I had received a call from a Colonel Ed Simonsen at 8th Air Force Headquarters informing me that he had just received a telegram from General Hap Arnold. He said it was necessary that he come to Bassingbourne to meet with me. The Colonel arrived that afternoon and said the telegram from General Arnold directed that Major Atwell be named Staff Weather Officer of the 8th Air Force. Colonel Simonson explained that this action would be a waste of technical manpower. He said the assignment was purely administrative as he was presently the 8th Air Force Staff Weather Officer, and the Air Force needed me in an operational capacity. He went on to tell me that a super operation was coming and that I would be vitally needed for that. Thus, when I went to see General Gross I believed that this was the "big" one. It was. General Gross said that the invasion of Europe was going to take place within a few months, that he was going to lead the 8th Air Force Heavy Bombardment Force in support of the invasion and that he wanted me to start thinking and planning on the best time weather-wise for the operation (Invasion).

For the next few weeks I met constantly with an R.A.F. Liaison Officer at Bassingbourne who obtained for me previous years' meteorology maps and charts. If I decided to formulate a plan, I would at least have some historical basis.

In late March 1944 I concluded that the first ten days in [illegible] usually offered an occasional opportunity [illegible] meet required goals — ocean swells, wind limitations, drop-zone needs such as winds, visibility, turbulence and terminal weather for departures and returns of troop carrier planes, reconnaissance, bomber and fighter aircraft. I went to General Gross and gave him my results. He reviewed my work and said, "Can you pick a day?" I replied that I would if it really was necessary at this early date. He said it was and then told me that they pooled for the D-Day date and I could pick my date - it would just cost me one pound (then $4.05 to a pound). Without hesitation I chose June 6th. During April and May I worked night and day with my loyal weather group at Bassingbourne so as to be ready on a moment's notice should the day become known. Around the first of June I began to notice the Bay of Biscay's surface maps and the eastern Atlantic surface maps began to look like the ones I was waiting for. On the third of June I went to General Gross and said he should be ready on a minute's notice for we could get a break within a couple of days, but I emphasized June 6th for sure. He made some calls to 8th Air Force Operations but nothing had been decided.

On the fourth of June he called me at 3:00 a.m. and said, "It looks like we're going on the 5th — he had just been told that." I immediately objected, pointing out that data in the Bay of Biscay from an unknown source (a German U Boat and a fishing boat) indicated June 5th was not the day. I urged him to go back to 8th Air Force and hold out for the 6th. We soon received word that the 5th had been scrubbed. I said, "Great, we can go on the 6th for sure".

Around midnight on the 5th I briefed General Gross, then the operational crews of the 91st. After the briefings General Gross sent for me and said, "Larry, you have worked hard and successfully on this and I wish I could take you with me." I immediately urged him to let me go, saying if the weather changes, we'll know it first-hand and I can get the info to 8th Air Force Headquarters (as well as the Supreme Commander's Invasion Staff). Further, I told him that I wanted to go up or down with my forecast, but would need to see the meteorological conditions at first hand if a vital change were necessary. We led the 8th Air Force Heavy Bombardment aircraft June 6th and going over the Channel we could see the Naval gunfire and the Channel below, noting the conditions. As soon as we hit the coast, I could see that there was a broken cloud cover and estimated it would soon cover the sky, although it was clear above us. I called General Gross on the intercom and requested that he immediately turn the plane around and let the others continue as I needed to get back to England as soon as possible. I emphasized that we should call the Supreme Allied Commander's Invasion Staff and tell them of the exact weather conditions. General Gross turned off and headed back to southern England. Peculiarly, the Germans sent up only two fighters that day and they promptly jumped us, but their gunfire did not hit us. At this point I urged General Gross to land at the first airfield we saw. Upon landing I was whisked off to its Operations to use a "scramble" phone to inform General Anderson, Operations for General Eisenhower. I strongly emphasized to him that he should call off all heavy bombardment for the rest of the day and send in medium and fighter bombers below 8000 feet, adding that they could operate all day with clear visibility and no lowering of ceilings. This was his first actual report and he said he would do just that. He then said he was going to transfer me to Colonel Ben Holzman and Krick, Assistant Weather Officer to Colonel Don Yates. When I reached Ben I gave him a complete meteorological report. Thirteen days later I was transferred to Colonel Don Yates (now Lt. General, retired) and became Executive Director to him as the Director of Weather for Europe.

Although, as everyone knew at the time, I was strongly opposed by many for my aggressive approach to D-Day (as well as many other

operations). However, I based 99% of my decisions on actual meteorological data which were available to me and to all interested parties.

Additionally, it was financially worthwhile to me as I won the pool worth $405. (100 players) and promptly took off for London's shows, nightclubs and galas.

Joe, this reply to your letter is delayed as I have just returned from a long trip. I know that you will have a very successful and interesting meeting.

Letter from
Lt. Arthur W. Wakeling - upper air forecaster
USSTAF Weather Center

During the D-Day period I was a member (with the rank of Second Lieutenant in the U.S. Army Air Corps) of an upper air analysis and forecasting unit commanded by Captain Bundgaard (I believe that was his rank at the time) and consisting of a couple of Second Lieutenant forecasters and a couple of non-commissioned forecasters as well as a number of enlisted chartmen. The upper air section in conjunction with a "surface" section and an "analogue" section comprised the primary operational analysis and forecasting units of the USTAF (U.S. Strategic Air Forces in Europe) weather central.

Our weather central was located on the site of Hdq. USTAF which in turn was co-located with General Eisenhower's headquarters near Teddington on the northwestern outskirts of greater London.

I recall working late night and morning shifts during the days immediately preceding D-Day. The focus of my labor was upper air analysis while the primary forecasting and briefing duties were assumed by Captain Bundgaard and the commanders of the other weather central sections as well as, of course, Lt. Cols. Krick and Holzman and Col. Yates. I recall briefing Col. Yates and Lt. Cols. Holzman and Krick on the upper air situation in formal morning briefing sessions during the D-Day period. I also recall the relative severity of the weather over the British Isles and northern France preceding D-Day with strong low pressure systems moving into the region from the north. The intensified activity and obvious concern of my superior officers caused me to be vaguely aware that an invasion of the European continent was approaching. The jubilation and expressions of relief and satisfaction on the part of my superior officers during the hours following the invasion brought the fact of its success home to me.

I believe this is the first time I've been asked about my activities during those days. It's nice to be asked. Best of luck, and have a wonderful meeting!

Letter from
Major R.G. Bounds - short range forecaster
USSTAF Weather Center

As to your specific request, I must confess that history and nostalgia have always been my weakest subjects, and these weaknesses are now being aided and abetted by a memory which seems to be a negative exponential function of my age.

I'm afraid there's little I can add to what Bob Bundgaard, John Jones, Irv Krick and others have probably already told you. The details of organization of the forecasting team is pretty well known by everyone at this point.

As I am sure you already know, Col. Yates was Director of Weather Services for USSTAF. As such it was his job, among other things and along with Dr. Krick and Ben Holzman, his two deputies, to keep Gen Spaatz and his staff briefed on weather conditions and forecasts for all operations, including D-Day.

Group Captain Stagg is reputed to have had similar responsibilities with respect to SHAEF and Gen. Eisenhower and his staff. To this end we saw him occasionally wandering through our forecast center and conversing with others. Apparently he derived most of his meteorological information from ETA — the British Meteorological office's forecast center.

Closer to home, in the USSTAF weather center, I recall John Jones, Kenneth Winslow, Holmes (can't remember his first name), Snuffy Smith (all Smiths are Snuffy, of course), and I held down the short range forecast section including all surface analysis, surface prognostic charts, telephone conferences (of which there were plenty), and 24 hr forecasts.

Bob Bundgaard was in charge of the upper air section and his own long range forecasting methods. I am sure he has described all this to you.

A section which devoted itself to selection of analogues from historical maps was run, as I recall, by Rodney Jones and Cis Wyatt and supervised rather closely by Dr. Krick. Much of the long range forecasting was the work of this group.

In the final days before D-Day we were joined by Dr. Bjerknes as a sort of roving consultant.

Every morning we had a coordinating meeting when a forecast, both short and long range, would be agreed upon and would be the basis for briefings by Dr. Krick and Col. Holzman to Col. Yates and to the USSTAF staff. After our in-house conference came telephone conferences with Hq 8th AF, Hq 9th AF, ETA and others to get theater-wide agreement on a forecast.

Through these people and many others and this organization we made it through the D-Day forecast somehow. In fact it was a pretty good forecast for middling bad weather.

Letter from
Paul Brand - Headquarters Allied Naval C in C (Southwick)

As per your request today I am putting some rambling reminiscences to paper.

Location: Forecast was communicated to the Allied commanders (Eisenhower, Ramsay, etc.) in the Map Room at Ford Southwick - specifically in Southwick House, now part of H.M.S. Dryad, a top security Royal Navy establishment near Portsmouth, Hampshire.

Comment: By an R.N. planner who was slated to make an early appearance on the beach (Far Shore): "That bloke had better be right or we're going to be totally buggered."

The Map: The room is still in the condition it was at H-hour, D-Day. Access is not general today, but can be arranged with approval of the Security Officer. Southwick House is not sensitive from a security point of view, but the base itself is.

Southwick House was formerly an English "stately home" - requisitioned for wartime use by the SHAEF group as advanced HQ for Operation Overloard (invasion of Normandy). I am sure that the technical aspects of the weather picture are well known to your group (the "miracle high" that opened the window on June 6, etc), so my remarks are confined to the background of what was certainly the most important meteorological decision in the history of the world. Though none of we laymen verbalized it at the time — and really didn't even think about it — there was in the back of our heads a recognition that the rest of our lives might depend on the success or failure of Overlord. We had already experienced the fiasco of Dieppe (though valuable lessons were learned at great cost). Should Overlord suffer the same fate, it seemed unlikely that a second invasion could be mounted that year and given the precarious position of the Red Army, things looked pretty bleak.

I should point out that my role was non-meteorological. I was a Sergeant in the British Royal Marines, concerned with counter intelligence and the security of the Allied Naval Commander in Chief for Overlord - Admiral Sir Bertram H. Ramsay.

Southwick House was the focal point of the launch strategy. By June 3, certain naval and transport units had in fact departed from Devon en route for the Far Shore. During the evening, the word filtered down that D-Day had been postponed — even though some units were on the way and many others were on board and swinging round an anchor chain. Seasickness was a major problem and the morale effect was totally negative. There was also a problem in finding and turning around some of the ships, who might have made a solo beaching with rather weird results! The really surprising factor was the total failure of the Luftwaffe and German intelligence to catch on to the situation. In fact, the German weather men (unknown to our people) had advised their High Command that no landings could possibly be undertaken during that period. Rommel, as a result of that reading, had gone home to celebrate his birthday. So set were the HQ people in this estimate that a visual sighting of hundreds of vessels was discounted when reported by a coastal artillery officer. In addition, a superb deception program had convinced the other side that the main invasion would be in the Pas de Calais — a feeling shared by Hitler's astrologer. No one can overestimate the importance of Stagg's counsel, Eisenhower's luck and guts, and the German errors of judgement.

The word then was that if we didn't go on June 6 by the latest, there would be a two week wait for the tide and several weeks more for the right tide and moon conditions. With no guarantee that storms would not occur at those times.

The final huddle was in the early hours of June 4. Stagg supposedly was saying that all he could do was lay out the conditions and possible situations. Any iron clad "go or no go" would be guesswork. Ike, I believe, made the only and final decision. June 6. The rest is history.

Should any of your members be in that area I would recommend an attempt to visit the Operations Room. It is now part of the Officers' Mess, but proper identification and a statement of interest re the history of the Great Decision, hopefully, will result in a memorable experience. A letter or phone call in advance to the Meteorological Section might smooth the way.

Letter from
A. H. Gordon - British and Allied weather service in Iceland

As you will note, I was not directly involved, but to some extent indirectly as I was in Iceland in charge of the British and Allied (excluding the Americans who had their own service based at Meeks Field, Keflavik) meteorological service. However, we were responsible for the coding, transmission etc. of all the Icelandic observations to the U.K. and I doubt if a forecast for D-Day could have been made if those vital obs from Iceland (and Jan Mayen) had not been available on time. The Icelandic service was under direct British control via myself.

Concerning the people I knew, of course Jimmy Stagg was the number one, the personal met adviser to General Eisenhower. I knew him well, better after the event than before, since I was his deputy at Air ministry in 1944 and took over from him as head of Coastal Command Met Branch when he went into Berlin as Chief Met Officer on the Allied Control Commission. I have made some personal comment about him in the enclosed notes. Perhaps the most interesting bit from the notes is that out of a personal letter from C.M.K. Douglas.

ATTACHMENT

The following material is excerpted from a copy of a talk by Mr. Gordon to the Australian Meteorological Association that he included with his letter.

.....Iceland was occupied by the British without invitation very largely for meteorological reasons. It was most important for the U.K. and the Allies to safeguard reports from the country which was the centre of much weather activity. Stations were set up at RAF airfields but the Icelanders continued to make their own routine reports. Three British airmen in the Met contingent were posted to the main Icelandic Met Office in the centre of the town of Reykjavik to collect, code, and transmit the routine observations to the Air Force H.Q. Office where they were transmitted point to point to Prestwick and thence distributed on the internal landline teleprinter system.

Incidentally the person I replaced in taking over the Allied Met. Service in Iceland in May 1943 was David Arthur Davies, the incumbent Secretary General of the WMO since 1955.....

.....Although the secret of D-Day was well kept there were signs for us in Iceland that something was afoot. Early in May 1944 all leave and posting movements were cancelled. Late in May rumors reached us that all incoming and outgoing mail had been suspended. Obviously something big was about to happen.

Although I was not directly involved I like to think I was in an indirect way, as I was responsible for the efficient transmission of the Icelandic observations.....

.....Just a few days ago (1977) I had a letter from Douglas. He is now in his middle eighties and he writes a most lucid letter about meteorology in general and the D-Day forecast in particular. I quote some extracts:

> A point that I could enlarge on was the element of luck. The onshore wind was above the permissible limit previously laid down by the Admiralty, and by all accounts must have been near the actual limit above which the landings would have been impossible.
>
> The depression which moved quickly northeast to North Scotland became exceptionally deep for June, and this hastened the advance of a cold front needed to clear the thick low cloud of 5th June, the original D-Day. Everyone thought it would go on moving NE, even if more slowly, but it suddenly became stationary and moved slowly SE while filling rapidly. This held up the next front and prolonged the tolerable interval.

After the occupation of Germany and Austria by the Allies at the end of the war the Met. Office took on the important role of participating with them in setting up an Allied Weather Service and in later supervising the establishment of reconstituted meteorological services. Jimmy Stagg had been appointed to Berlin long before the war was actually over. Between September 1944 and March 1945 he prepared for this job in London while at the same time assuming the administration of the Meteorological Branch concerned with Coastal Command, of the Air Ministry.

..... A year later Stagg was promoted to the number two spot in the Met. Office, the Deputy Director, a post which he held for sixteen years until his retirement.....

CHAPTER 12

PANEL DISCUSSION

PANEL DISCUSSION

with

Irving Krick, Karl Johannessen, George Robinson,
Charles Bates, Robert Allan, and John Fuller
Moderated by Roger Shaw

SHAW: I would like to know from those people who were there at the time, how their forecasts might have differed if they had the knowledge of the atmosphere that they have now, but no more information, and no different facilities than they had at the time.

KRICK: I'm not too sure that we would have made different forecasts because, even with the satellite data and the communications that we have now, all of the computer material, and so forth, there still is a problem which can't be solved through the use of just current data, and therefore my view is that we probably would have made some refinements in timing, but the basic forecast would have remained somewhat similar.

BATES: As somebody pointed out earlier, there wasn't a lot of latitude. We worked up a lot of emotion, but that polar front was extremely active. A map shown earlier showed storms only back to, say, Chicago but actually we had waves on that front all the way to the Aleutians. I have looked at the map since then and it essentially boils down to a couple of things. One was predicting when these storm centers were going to come barreling through, and the other was where the storm track was. The big debate was whether the Azores lobe was going to keep storms up over the Shetlands or not, and the other point really wasn't made that the invasion was supposed to go in May, which would have been a walk. I mean it would have been a walk for the meteorologists, but it would probably have been hell for the troops. There weren't enough LST's because they were still tied up in the Mediterranean. The other thing was that the air force had to knock out all the bridges across the Seine at least as far as Rouen. That is another reason why we picked the invasion area; with all the bridges out across the Seine river, all those troops that were guarding the Pas de Calais couldn't move south, and so we lost good weather but still lucked in, and you know that's the game of meteorology.

KRICK: I think one comment that may have been made previously is that we did have difficulty reaching a common opinion in these early days in June, when there was so much activity —one front after another passing from west to east. However, in May, as Charlie (Bates) has pointed out, there were many periods of stable weather, where you just have a high sitting over the whole area, and we all agreed beautifully. Boy, when it started getting rough in early June everything got pretty hectic and that's why trying to reach a common opinion over scrambler telephones with six or eight people coming together, was not the way to do it. That is why subsequent to D-Day, Eisenhower reduced the thing to just the one unit. I think that is important and points out that there should be one meteorological unit responsible to whatever is the highest command or highest echelon of command in any operation, whether it be a simple bomb wing, an infantry brigade, or the whole joint operation. There should be one unit that has responsibility.

SHAW: In hindsight, what kind of organization do you think would have worked best at that time, knowing what you know now and had you been able to reorganize those teams of forecasters? Was there a better way that the organization could have been handled?

KRICK: Well, in my view, if you can find one unit that has demonstrated its ability to meet the demands of the user and do the briefings in a way that is understandable, then give the assignment to that unit, but don't have many units with different operational modes trying to coordinate together. Wouldn't you say that, Bob (Allan)?

ALLAN: It reminds me a great deal again of the similarity to medicine and law, where often you will go for a second opinion, but when you're actually in operation you deal with one lawyer and one doctor, and I think the same thing applies to this science.

KRICK: We have practiced that sort of situation in our forecast work since World War II. We have a multinational company now serving a clientele throughout the free world, from one small operating center in Palm Springs. We learn the users requirements and then are able to give them information in a form which they can utilize to make decisions. Putting a unit like that together with the expertise in the meteorological field, and the ability to supply data in a form that the user can apply effectively, is really

the outcome of what we learned during the war. This is the thing that Don Yates and I were discussing the other day. It was really brought out very clearly that that would be the way to eventually handle these situations.

ROBINSON: I can assure you from having been in the same office with them on the sixth, seventh, eighth, and ninth and perhaps the tenth of June 1944, that both Stagg and Yates were of very firm opinion that this sort of thing cannot be done again. It has to be done by one unit, and not by a committee. They were very firm about that indeed, and at the time I certainly agreed with them. Having thought about it some 40 years later, I am not too sure they thought the thing was the success it was. It is really because these excellent people didn't compute the same answers. And out of their talks came, in fact, the right answer but no one of them, I think, would have been right all the way through. First one was right, and then the other, and then the other. The fact is that, talking together, they came out with a series of forecasts which were far from perfect but which did the job they were supposed to do. It makes me think again that the obvious answer is yes, one unit reporting to one commander; but that unit might be wrong.

ALLAN: This goes back to the comment that someone made one time: that the camel was designed by a committee. Certainly that's true, but as I mentioned the Rand corporation and the article on the Delphi technique of predictability are very, very firm, that prediction is something that can be done and it does work well in this kind of context but it isn't easy.

SHAW: Let's try something a bit more controversial because I know that I've heard differing opinions today on this question. Could the invasion have actually been successful on June the fifth?

KRICK: Let me answer that one. I think it could have been successful, based on the data that we have now and the situation as it evolved. If you look at the map for June fifth, the front that was giving everybody so much trouble passed across England on the fourth and was halfway through France by the morning of the fifth, and there were divergent isobars behind it. It was Ben Holzman, General Bull, and my opinion on the third of June that that would be a good time to go because of the analogy with the operation in February that somebody mentioned earlier. We launched that 1,000 bomber raid into East Germany on 20 February and it was still snowing at the prime target around Leipzig when the bombers took off. In fact, during the night, Jimmy Doolittle, commander of the eighth Air Force, on the basis of the information he was getting from his meteorologist, scrubbed the mission but we didn't agree with that because we felt it would clear before they got there and our General Spaatz countermanded that order and we did come in right behind the front which was in this case moving from the east to west. And, it was this sort of thing that we felt would cause the greatest chagrin among the Germans. They would certainly have been bottled up in all the harbors. Unfortunately, some of the data we feel was not interpreted correctly on the fifth. Later maps that were drawn simply by the routine drawing of the Northern Hemisphere archive showed quite clearly that the winds at times were stronger on the sixth in the area near Cherbourg than they were on the fifth. So I still think it would have been possible, but we were in such conflict with the British with regard to the launching of the operation on the fifth. Yates was saying that he wished we conformed more to the general opinions as it would have made the job of briefing easier. He certainly had a tough job. We finally gave up and said the hell with it then let's go on the sixth. The diaries that Holzman and I kept religiously after each telephone conference are still in existence. I don't know how many copies there are around, but June Bacon-Bercey, I think, has taken excerpts from those diaries that were in the book Storm that I released to the author from my files for the first time and it shows the differences that we had.

Of course, now that the thing is over and we're not all emotional about it, I suppose none of us made a perfect forecast. Who does? We still don't make perfect forecasts, but our interpretations are such that we get the message across to our clientele. We'd been doing this for 10 years before we ever got this D-Day in Europe, so we weren't doing anything really very different than we had been doing, but I'm not sure that the British meteorologists had had that experience before they got into this thing during the war. They were not synoptic meteorologists. They had not been accustomed to interpreting their data in a form that a guy could use effectively, and point out the areas that were not too clear.

Now when I went to the Eighth Air Force in the fall '43, my mission was to improve the number of missions that the Eighth Air Force ran and so I told General Anderson, who was the boss at that time, that I would cut the forecasts as soon as he wanted them, and although we did improve the missions there were some aborted ones. There would be times when the B17's could climb higher and would climb higher, because of their specifications, than the B24's and they would get out in the North Sea and the B24's, couldn't make it so they would have to come back. We had cases like that and those in a sense we called busted forecasts. But we were getting the job done, so that eventually the British began to respect the daylight and point bombing, which they had been critical of up to that time. So again, we're all meteorologists and we're all human. We're still making mistakes but you have to try to put the odds on the house.

ROBINSON: I was at that time a British meteorologist. I would just like to remind Dr. Krick that the war in western Europe began in 1939 and we had been forecasting for operations of one kind or another since 1939, and we were used to working with the military, even though they addressed many of us as civilians, and we had the same sort of problems and we had handled them with the same sort of success. There wasn't an awful lot of difference between the British and the American meteorologists who were working with the air forces at that time. I don't know much about the British Navy because they of course were a breed apart. They were uniformed serving meteorologists, and it was very rarely that we had any contact. But Dr. Krick gave you the impression that the British meteorologists weren't interested in this one thing, but we were. We weren't interested in five-day forecasting because we had never had a problem for which we had to do a five-day forecast, until this one turned up. We became interested in it and we learned a lot from Dr. Krick and the Widewing people about long-range forecasting, but please don't think that we were not used to collaborating with the military and that we did not know the operational characteristics of our own forces methods and that we did not forecast for those. We did.

KRICK: I didn't want to imply that you were not expert in your field but Stagg was the first one to tell General Bull down at SHAEF in the fall 1943 that there was no way to make a five-day forecast, so this is the sort of thing that we had to try to bring into the picture. Now this doesn't cast any aspersions on any of the meteorologists that were doing an excellent job, including yourself.

JOHANNESSEN: The outcome for mankind would indeed have been different if we hadn't had the adequate meteorological advice on that occasion. Actually that shouldn't really be a matter of dispute. All we have to do is to collect the weather conditions in the channel which are available. The French meteorological observations are still available from the coast and I'm sure a study of those would convince you that it could have been really disastrous if the operation had been launched on the fifth. So from the point of view of, perhaps most of all, the transport of the troops landing craft across the channel. The wind force in the channel was measured force six, at times up to seven, and the maximum conditions for the landing craft before they would be swamped was force four. Isn't that right, Charlie (Bates)?

BATES: Yes, remember those LCI's, LCT's and LST's were manned and officered by some very green people. Hell, they probably didn't know how to spell the word navy about two years before, and so the ship handling was not the world's best. They were loaded to the gunwales with troops and ammunition and were probably overloaded. I just can't imagine over 2,000 vessels winding around in a very confined space in the middle of a cold-front passage and getting away with it. Krick thinks only of the air operation, but the naval operations had to get started so many hours before. These guys had to move in formation and were probably only doing about eight knots. Then you've got all these tide streams in there. The other thing is that with the damn airplanes you replace them, and you can fly some more guys over from the States. They had 50,000 planes or so, something like that. But you couldn't have replaced the LSTs and you couldn't replace LCT's and LCI's and they were needed for the invasion in southern France. They never needed them for the Pacific. We were just pinched. We couldn't lose craft like the air force could.

SHAW: If what had been forecast for the fifth and sixth had been better weather, do you think that the Germans would have been more prepared, and would the invasion have met with much-stiffer opposition?

BATES: Well, I don't know if anybody wants to comment on this but of course one method of trying to verify our own wave forecast was to look at the new aerial photography and I tell you that, every time I looked, it made me shudder because the Germans had put in more fortifications. The other problem I didn't mention, and I should, the Germans had about 60 divisions available they could deploy between central France to Holland or Belgium. Now when you realize that on this huge base of Fort Ord you're talking one division. We're talking 60 of those that we were going in against with three airborne and about five land divisions. That means we had to have perfection on our side and a lot of luck. And luck's probably better than perfection. We took something like 12-14 weeks to get up to the number of divisions the Germans could bring in there.

ALLAN: The comment was noted earlier that the Germans did not put to sea, and a number of historians point out that they did not have any observations at sea that morning or the day before. In the Air Room in Washington, we had all the German divisions as nearly as possible placed on the charts on the wall and they were all in places to be brought in but as Bundgaard pointed out, the general officers were away and Rommel was not coming back for 36 hours. If you'd had better weather you wouldn't have had that element of surprise. I think those two points are something that could be judged from history.

JOHANNESSEN: I certainly can agree that the rough weather on the fifth put the Germans a little bit at their ease and many people might have gone on leave, but I think that we shouldn't be ready to put too much emphasis on it. Surely they gave out more weekend passes than otherwise but you can be sure that there was no opportunity for opposition that wasn't being used by the

Germans. I think the main problem, the main strategic factor, is that Von Rundstedt, on the insistence of Hitler, kept most of his reserves in the back area but he couldn't put them in right away at the time of the invasion because our air force had bombed the living daylights out of all of the arteries of Sedan.

SHAW: I have a question from the audience. There have been a few comments on the German weather service. Do you feel that the German service was more or less effective than that of the allies? Was the invasion successful perhaps because the German forecast was not as good, or was it really because they didn't believe that, on this occasion with the weather as it was, the allies would move?

JOHANNESSEN: I'm sure that the German forecasters were just as capable as the allies but they didn't have the advantage of information to the west that we had. As a matter of fact, the maps they based their decision on were quite deficient about what was going on in the west. But, the low had already approached at that time, and they had that well in hand on their maps, so they were aware that it was going to be a very rough night and rough day on the fifth. I think what they did was to underestimate the great development in landing craft; they were bigger and sturdier, and could stand more rough sea. I think that was the point where they hurt more than the weather.

SHAW: Let me ask another one from the audience. What words, phrases, anecdotes, etc. did you find most effective in persuading or convincing the commanders in chief of the credibility or importance of your forecasts?

ROBINSON: I never had a commander in chief but I have had a commander of a group and on one occasion I had General Montgomery's chief of staff in my office. It is simply not a matter of words, phrases, and jest. It comes slowly and it comes by working visibly, and by being just yourself. If you don't let them see what you're doing you'll get nowhere with them and if you do it badly you'll get nowhere with them. But it is not a matter of gimmicks or glossing over. You just have to be good and that means that you have to be a member of a good team and you have to take every opportunity, without intruding on their privileges, to let them know that you're there.

BATES: Some manage to get where they are by thinking they can bull ahead and Mother Nature doesn't have anything to say about it. The trouble with this is that Mother Nature can end up being an enemy as well as an ally. In this case Eisenhower and his staff, Ramsay and Montgomery and Tedder and the rest, were willing to work with the weather. But read what happened to Bull Halsey who didn't give a damn about typhoons. He was worrying about raiding the Philippines on that December '44 storm and so was planning ahead, and the naval ships and naval airplanes were not allowed to break radio silence and give any signs of impending storms, so Fleet Weather Central Pearl mislaid that particular typhoon in a track maybe 125-150 miles. That doesn't sound like much, but in this case the storm went on through 60 ships and those destroyers started capsizing.

ALLAN: I thought Dr. Robinson made a very, very careful and well-worded comment here about doing your job. But, Dr. Robinson, you told me the other day that Air Marshall Tedder was a trained meteorologist in his own right. Is that correct? That would make a good deal of sense to me because he later on carried on the communication.

ROBINSON: No, he was not a trained meteorologist. He had been before the war, before he got that enormous rank, director of research and development Royal Air Force, in the Air Ministry. He was an engineer, he knew what research scientists were doing, he knew what meteorology was doing. He had the frame of mind and he was trained. He would listen to any scientist or technician as long as he thought the man was good. He would listen and he would listen intently.

BATES: I have just a quick historical comment. The actual amphibious assault was not Operation Overlord. The amphibious assault was Operation Neptune, which was part of the overall battle plan, and it amazed me how we knew where we were going to be, long before we invaded, on D+10, D+15, and D+30. It was an interesting thing that we came a lot closer to the master plan than I thought. I was a 25-year-old first lieutenant working two floors underground in the Admiralty but we had complete access to the thinking, and we had the top-secret landing maps in a foot locker in our office. The British couldn't afford safes but they could afford some pretty tight security and so really there was a lot of faith put in a lot of junior people. Doing our best job possible gained us credibility.

ROBINSON: The little office that the three SHAEF meteorologists had was next door to the War Room at SHAEF and we had free access, as they had to us.

FULLER: I might just add that I had a telephone call shortly before I came out here. I believe it was Wednesday, from Artie Casper in the Pentagon. They are the ones, among other responsiblities, who have the responsibility for supporting Air Force One. It appears that President Reagan is going to France on the sixth of June to commemorate, with other heads of state, the invasion that we have had so much discussion on today. This officer (a lieutenant colonel in the air force), was calling me to ask: what was the weather on the sixth of June 1944, and was it as forecast? This gentleman plans to pass a

paper to the president as part of the folder that goes with Air Force One. As a courtesy, they forecast the weather for the destination of the President. They plan to inform president Reagan that yes, the weather essentially was as forecast 40 years ago on this very beach that you're standing on today, and of course, go on to say this is what the weather is supposed to be on the sixth of June 1984.

SHAW: With that I think we should close this panel discussion. I would like to thank you all very, very much indeed.

APPENDIX A

Weather Maps and Weather Summaries by the German Weather Service Group 2 June 1944 Through 6 June 1944

The following weather summaries, surface, and upper-air synoptic charts, thickness charts, and maps of 24-hour thickness and height change were made by the German Central Weather Service Group during the period up to and including D-Day. Dr. John P. Monteverdi, associate professor of geosciences at San Francisco State University, completed the translations based upon originals of these weather summaries. Dr. Monteverdi notes that his translations are not literal in some instances in order to make the English less cumbersome and more easily understood.

WEATHER SUMMARY Friday 2 June 1944

The Spitzbergen High is a warm anticyclone and therefore can be associated with a warm, stationary high at upper levels. It is disturbing the weather of central Europe indirectly by channelling cold tropospheric air masses southward in a zonal ring encompassed by 65 degrees north and a frontal zone on the south at 50 degrees north. At the same time, in the last 24 hours, vigorous westerlies over the Atlantic have strengthened in the region between 47 degrees north and 65 degrees north while weak surface and upper level flow characterizes the patterns over the Mediterranean.

The cold arctic surface flow which is now pounding out over Russia, White Russia, and east Prussia on the west side of a deep monsoon low is subsiding strongly near the border region under a weak highpressure area which extends from southern Scandinavia to the northern Balkans. Meanwhile, over northern Finland, pressure falls are suggesting the development of a new convergence zone in the polar air mass which is stretched out over that region.

The progressive eastward displacement of a warm air mass over central Europe dominated the weather of eastern France and southwest Germany yesterday and was associated with pronounced cyclonic weather. The moist and unstable layers of this subtropical air were responsible for the upslope thunderstorms in the mountain regions and thunderstorms in the convergence zone along the front.

The center of the low which yesterday lay over the Irish Sea has been slowly wandering today into the North Sea. The front associated with this low, now located over the southern section of the North Sea, was responsible for the development of vertically-extensive rain clouds; a portion of this frontal system has a small likelihood of dragging across northern France this morning. Following the passage of this low will be a strong highpressure area whose development will be foreshadowed by strong pressure rises surging across the region towards the east. This high will in turn be followed by a new cyclone moving with the Atlantic westerlies.

The most noteworthy development of the last 24 hours was the development of an intense lowpressure area over eastern Europe and its associated frontal system which extended from the northern Balkans to southern England. Associated with this frontal passage were widespread pressure falls and convective cloudiness. Of special note was the intensification of a weak convergence zone and an associated front over France, which yesterday afternoon produced active weather in the form of a line of thunderstorms over the Rhine River region. Also, the disturbance thus formed moved into a region of falling pressures over Germany and thereby stimulated cooling, although only at lower levels. With the development of the disturbance over Germany and France the northern portions of the low and the associated frontal system over northwest Germany dissipated totally; at the same time a small pool of cold air could yet be discerned in that area. Associated with this pattern was a remarkably strong shear zone between surface and upper-level air streams.

There are yet no clear indications that the period of unsettled weather over central Europe initiated in the manner summarized above will end soon.

--Siegel-- Central Weather Service Group.

Wetterübersicht Freitag den 2. Juni 1944

Das Spitzbergen-Hoch ist ein warmes und dabei gerade in höheren Schichten deutlich ausgeprägtes und stationäres Hoch. Es wirkt auf das Wetter Mitteleuropas dadurch mittelbar ein, daß die kältesten tropospärischen Luftmassen wirklich nach Süden abgedrängt und als zonaler Gürtel etwa längs des 65. Breitengrades angeordnet sind und die Frontalzone auf seiner Südseite bis über den 50. Breitengrad nach Süden reicht. Die zugehörige lebhafte Westdrift zwischen 47 und 65° N hat sich jedoch erst innerhalb der letzten 24 Stunden deutlich ausgeprägt. Im gesamten Mittelmeerraum sind Boden- und Höhenströmung gleicherweise schwach.

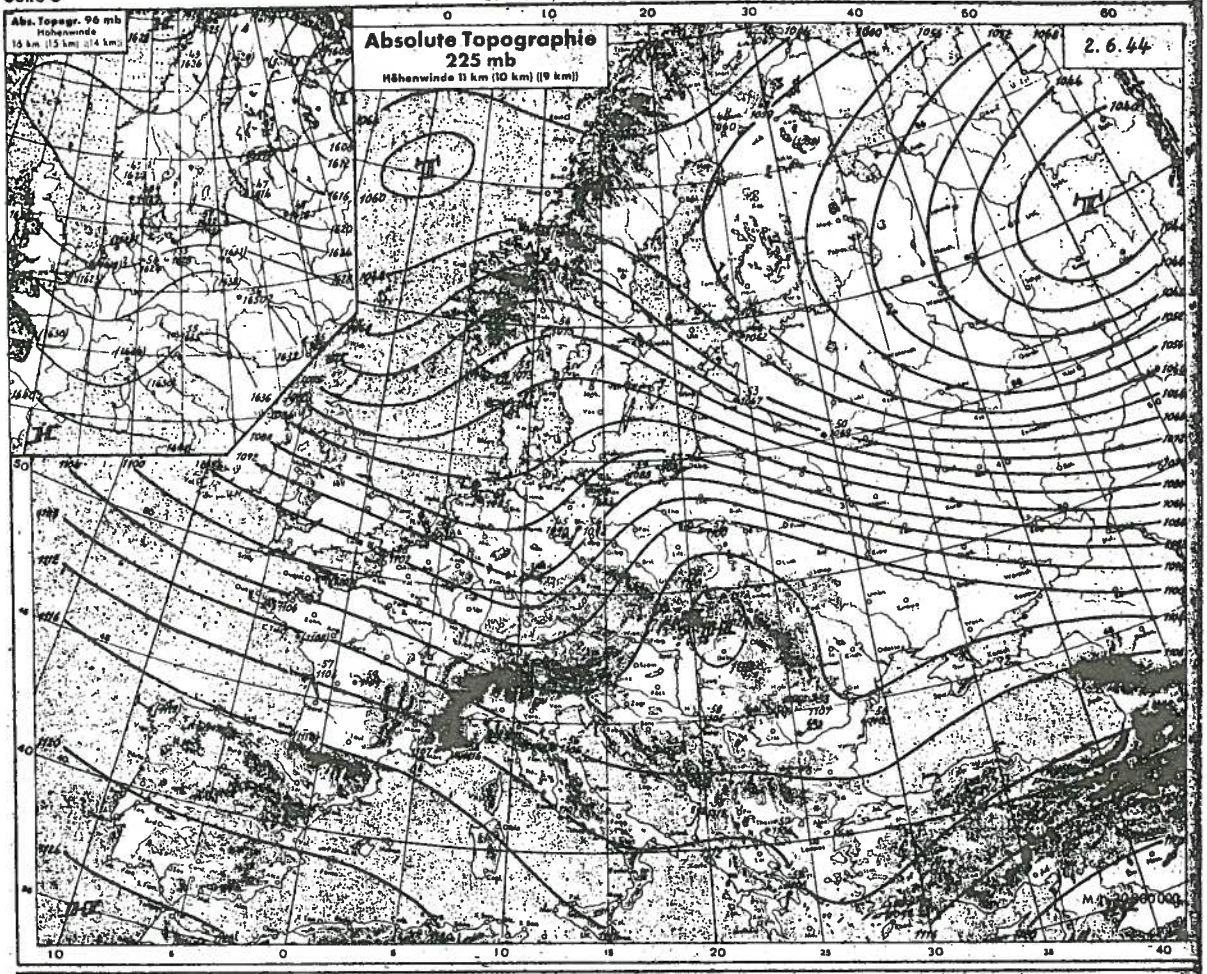
Die arktische Kaltluft, die auf der Westseite eines wohl recht kräftigen Monsuntiefs über Rußland bis Ostpreußen und Weißrußland vorgestoßen ist, sinkt in den Randgebieten im Bereich eines schwachen Hochdruckrückens von Südskandinavien bis zum Nordbalkan stark ab. Über Nordfinnland deutet jedoch Druckfall die Ausbildung einer neuen Konvergenz in der ausgedehnten zyklonalen Kaltmasse an.

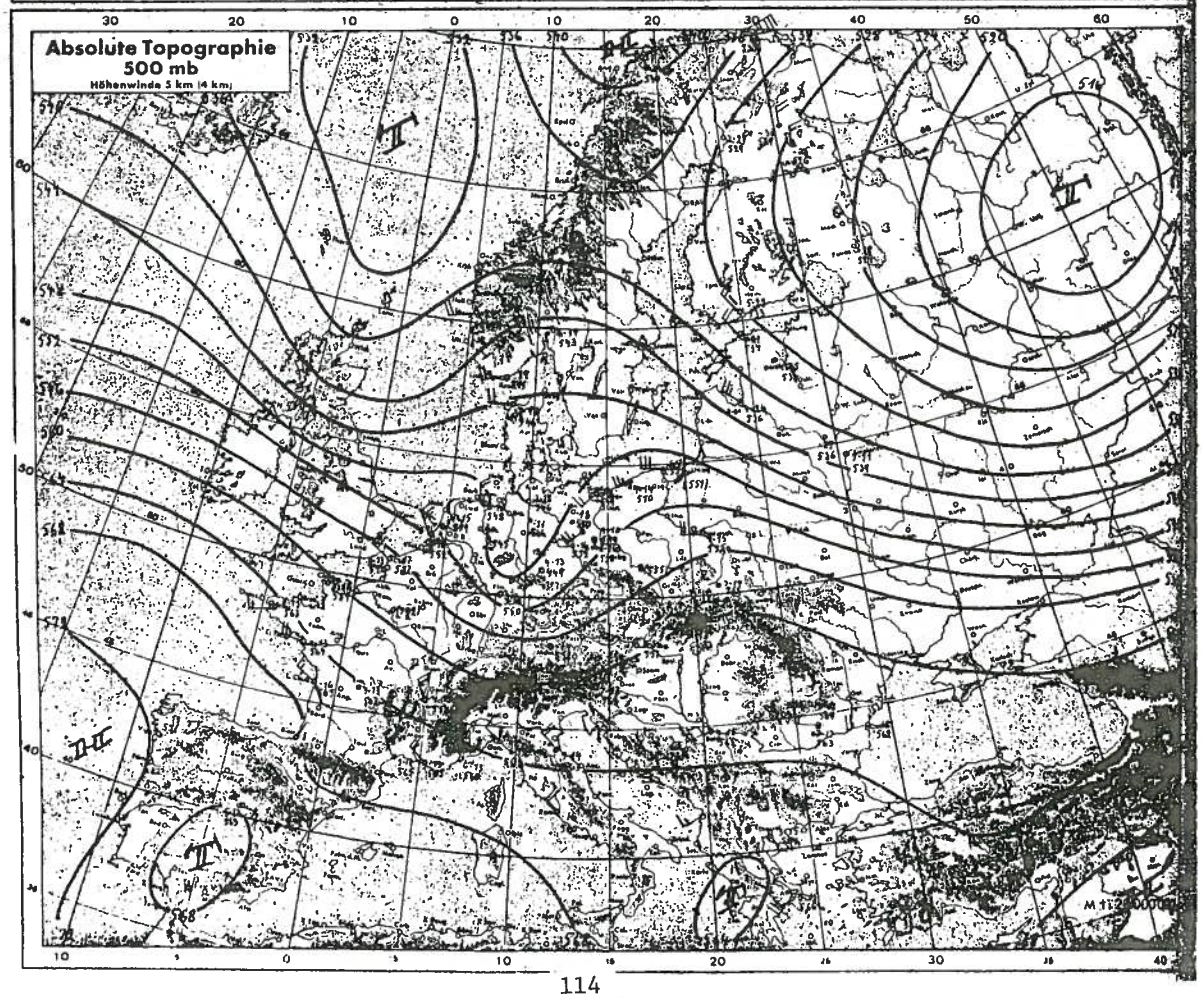
Über Mitteleuropa vollzog sich seit gestern ein Übergang zu ausgesprochen zyklonalem Wetter unter fortschreitender Verdrängung der Warmluftmassen, die gestern Ostfrankreich und Südwestdeutschland beherrschten. Die feuchtlabile Schichtung dieser subtropischen Warmluft wurde einmal durch orographische Aufwindströme in den Gebirgsgegenden und zum anderen an den Strömungskonvergenzen der Fronten ausgelöst. Der Kern des gestern über der Irischen See gelegenen Tiefs wanderte bis heute langsam in die Nordsee. An seiner Hauptfront haben sich dabei über der südlichen Nordsee sehr hochreichende Regenwolken ausgebildet, während der heute morgen über Nordfrankreich nachschleifende Teil nur wenig wetterwirksam ist. Anschließend folgt ein kräftiges Zwischenhoch, das entsprechend dem kräftigen Druckanstieg ziemlich rasch nach Osten vorankommen wird, dem aber mit der atlantischen Westdrift eine neue Zyklone folgt.

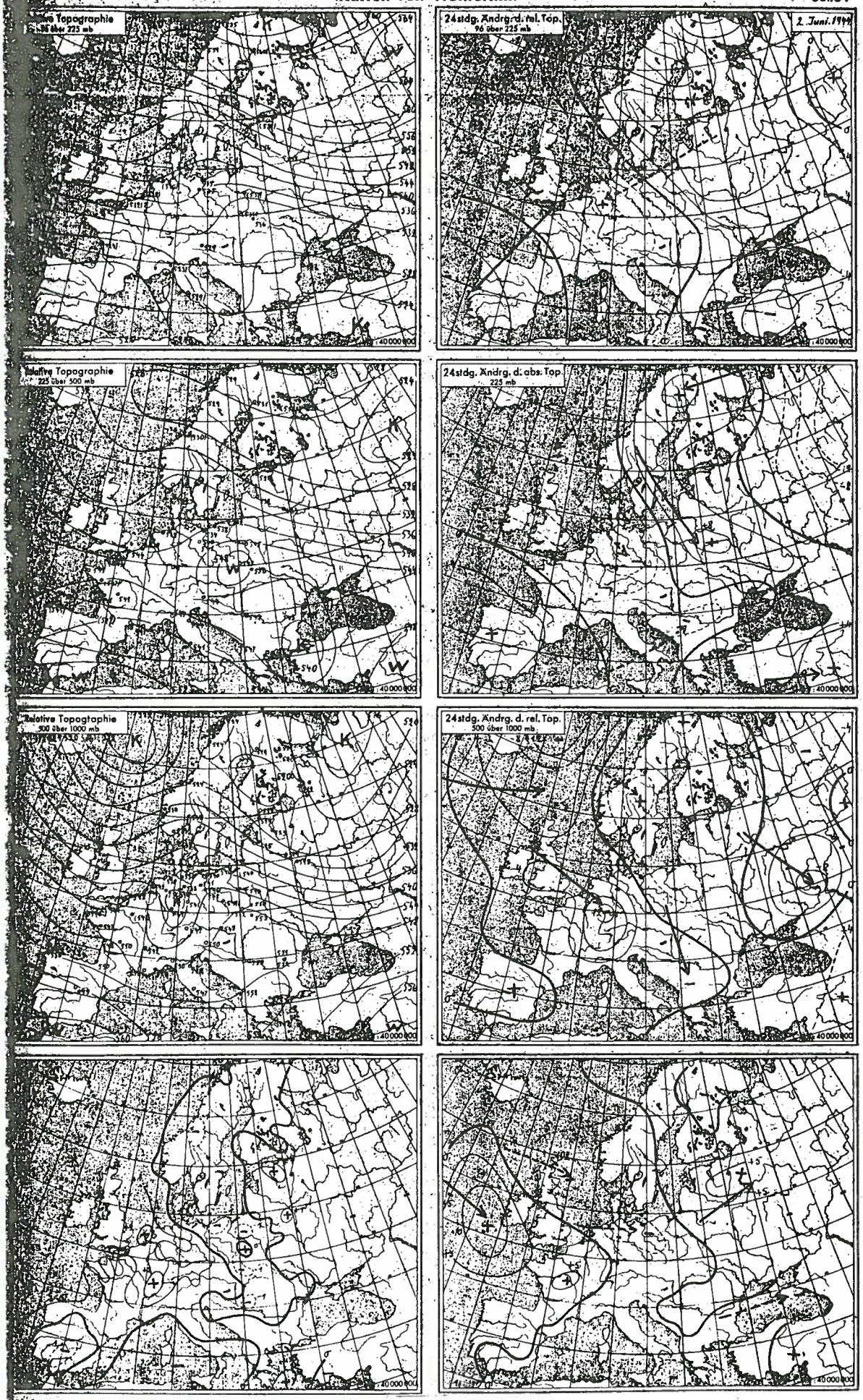
Am bemerkenswertesten in der Entwicklung der letzten 24 Stunden war die Ausbildung eines eigenen kräftigen Tiefdruckgebietes an dem gestern noch vom Nordbalkan bis Südengland durchlaufenden Frontenzug. Eingeleitet wurde der Vorgang durch verbreiteten Druckfall und Ausbildung verbreiteter Aufgleitbewölkung. Eine wesentliche Rolle spielt dabei die Verstärkung einer schwachen Konvergenz über Frankreich, die im Laufe des gestrigen Nachmittags als Gewitterfront im Rheingebiet recht wetterwirksam wurde und die Funktion einer Kaltfront des sich über Deutschland ausbildenden Tiefs übernahm, wobei die Abkühlung zunächst nur in den unteren Schichten festzustellen war. Mit der Verstärkung einer zweiten von Mitteldeutschland in das Kattegat verlaufenden Konvergenz löste sich die bis heute morgen noch erkennbare Konvergenz des alten Frontenzuges über Nordwestdeutschland völlig auf; zugleich ließ sich in diesem Raum ein Kaltlufttropfen feststellen. Über dem mittleren Norddeutschland ergibt sich dabei ein bemerkenswerter Gegensatz zwischen Boden- und Höhenströmung. Eindeutige Anzeichen, daß die damit eingeleitete Periode unbeständiger Witterung über Mitteleuropa rasch enden würde, liegen nicht vor.

gez. Siegel
Zentrale Wetterdienstgruppe

Karten vom Frühtermin






Relative Topographie
96 über 225 mb
24stdg. Ändrg. d. rel. Top.
96 über 225 mb
2. Juni 1944
Relative Topographie
225 über 500 mb
24stdg. Ändrg. d. abs. Top.
225 mb
Relative Topographie
500 über 1000 mb
24stdg. Ändrg. d. rel. Top.
500 über 1000 mb

WEATHER SUMMARY Saturday 3 June 1944

Of special note yesterday was the organization of a stationary anticyclone in the vicinity of Spitzbergen and a low-pressure area near 65 degrees north, both features apparent at the 500-mb level. These features were responsible for the maintenance of a retrogression of cold air masses westward over northern Scandinavia. The westerlies between 45 degrees and 65 degrees north were disturbed by a cutoff low-pressure area at upper levels which today is located in the vicinity of Denmark and which yesterday was centered north of the Shetland Islands.

The southeastward motion of this upper-level low, along with the erosion of the surface high in the northern portions of the Baltic Sea, which has been affecting the regions farther south, suggest loosening of the zonal organization of the upper-level flow and the transition to meridional flow.

The displacement of the unstable subtropical warm air has continued today and the air mass has advanced so far eastward over the continent that it can only be discerned over the Balkans. Associated with this air mass today is a fresh outbreak of thunderstorms which were strongest in the afternoon hours near the occlusion point of the occlusion located over the South Gouvernement Region [sic.]. The increase in thunderstorm activity is in direct contrast to the abating activity of the last several days.

The convergence zone which yesterday extended from Denmark to Schlesien has now stretched out along with its 200-km wide rain band slowly northeastward. As a result, light rain of long duration produced accumulations between 8 and eleven mm in many sections of the northeast portion of the Reich. On the west side of this convergence zone the influx of cool air masses from the northwest has peaked so that all of the western and central portions of Europe have experienced cooling. Over the central sections of Germany, the warming trend of the last few days has therefore slackened and temperatures there are more typical of the incoming arctic air mass. Developing cloudiness in this region suggests the modification of the cyclonically-flowing cold air mass as it makes slow progress over the continent, as is typical for this time of year.

In concert with the slight eastward shift of the convergence zone into the eastern Baltic region, the upper-level flow in the west has also encroached slowly over the continent. In any event, portions of the Atlantic cyclones which are progressing around the north side of an upper-level ridge which extends from the Azores to France will be affecting the northern sections of central Europe over the next few days.

--Siegel-- Central Weather Service Group

Wetterübersicht Sonnabend den 3. Juni 1944

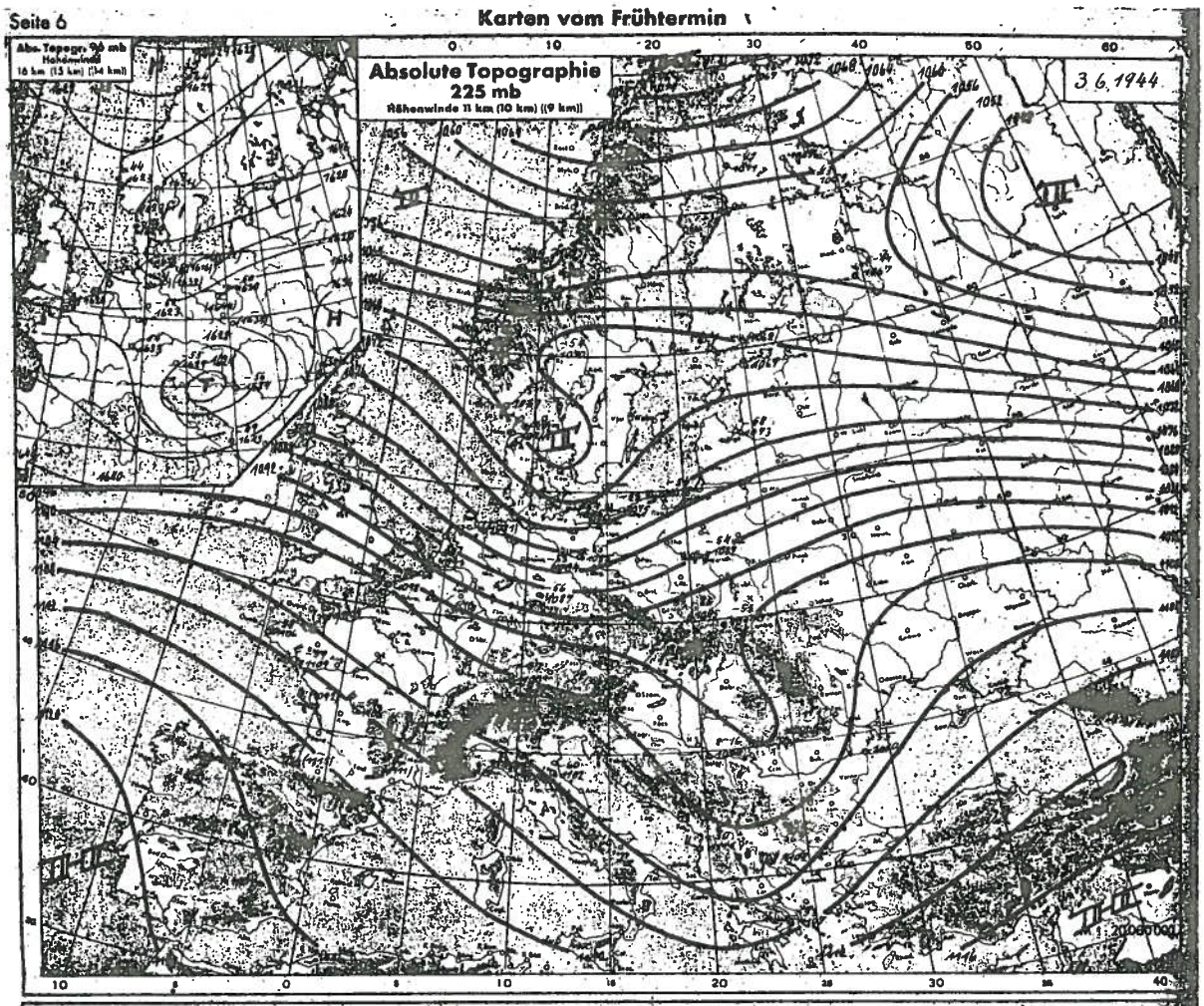
Eindrucksvoller noch als am Vortag ist in der absoluten Topographie der 500 mb Fläche die Gliederung in eine stationäre Antizyklone im Raum Spitzbergen und eine Tiefdruckrinne längs des 65. Grad Nordbreite. Dieser Zone entspricht auch ein Gürtel kalter Luftmassen, die über Nordskandinavien dauernd Nachschub erhalten. Die Westdrift zwischen 65 und 45 Grad Nordbreite ist durch ein abgeschlossenes Höhentief im Raum Dänemark gestört, das wahrscheinlich dem gestern nördlich der Shetlands gelegenen entspricht.

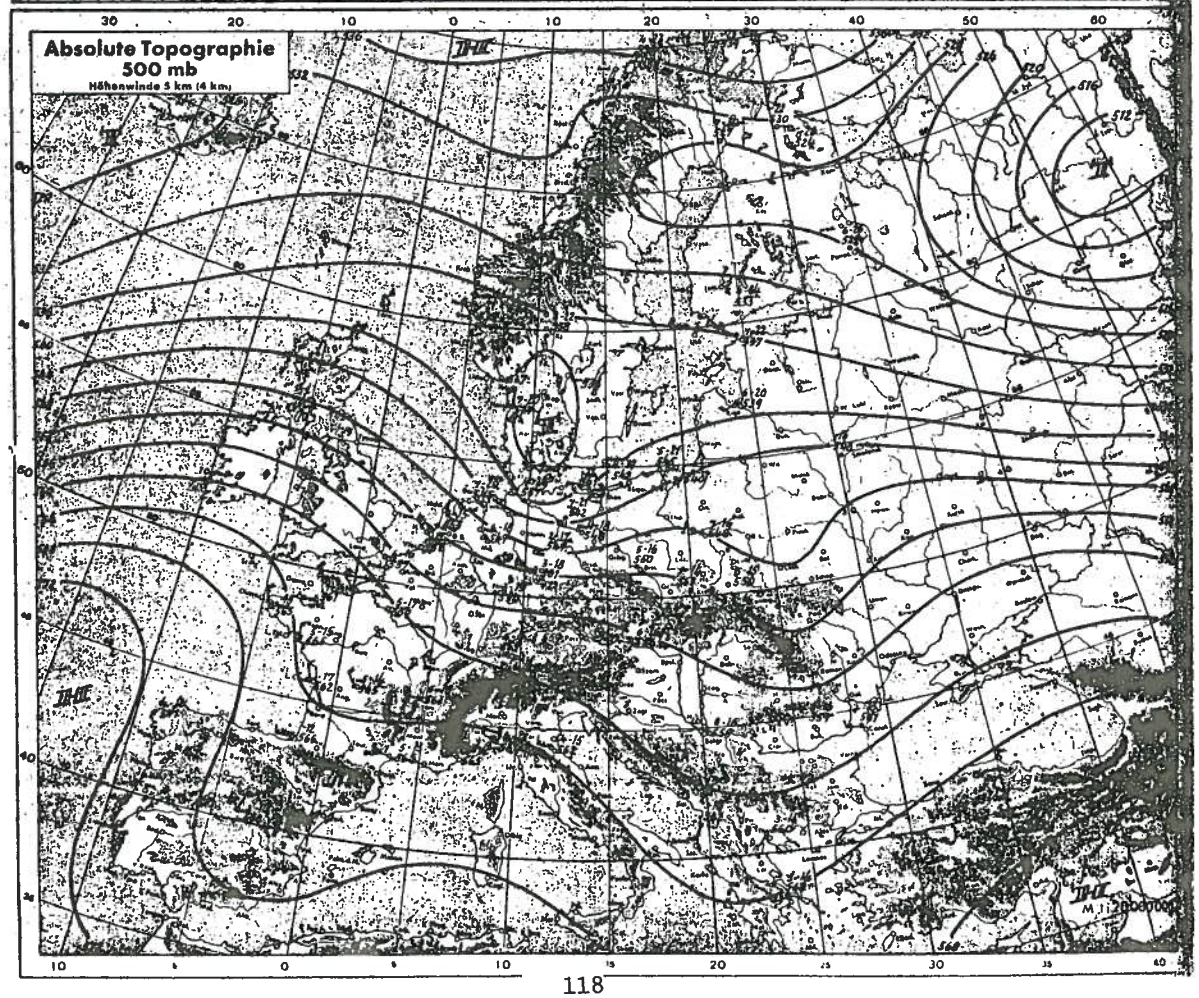
Sowohl die Südostwanderung dieses Höhentiefs als auch die Deformation des Bodenhochs im nördlichen Nordmeer zu einem weit nach Süden reichenden Keil sprechen für eine Auflockerung der zonalen Gliederung und Überleitung in eine meridionale.

Die Verdrängung der labilen subtropischen Warmluft ist auf dem Kontinent nun schon so weit fortgeschritten, daß sie nur noch auf dem Balkan zu finden ist. Es kam dabei wiederum zu lebhafter, wenn auch gegen die letzten Tage etwas abgeschwächter Gewittertätigkeit, die am stärksten in den Nachmittagsstunden nahe dem Okklusionspunkt über dem Südgouvernement festzustellen war. Die Konvergenz, die gestern von Schlesien bis Dänemark reichte, hat sich mit ihrem etwa 200 km breiten Regenstreifen nur sehr langsam nordostwärts verlagert, sodaß die an sich nicht sehr kräftigen Niederschläge infolge der langen Dauer im Nordosten des Reichs vielerorts noch 8-11 mm gebracht haben. Auf der Westseite dieser Konvergenz hält der Zustrom kühler Massen aus Nordwesten an, so daß ganz West- und Südeuropa Abkühlung zeigt. Über dem mittleren Nordosteuropaland ist der Wärmeinhalt bis nahe an die typischen Werte arktischer Kaltluft abgesunken. Bei der kräftigen Bewölkung im zyklonalen Teil der Kaltmassen macht die Alterung auch über Land langsamere Fortschritte als es sonst der Jahreszeit entspricht. In Übereinstimmung mit der geringen Vorlagerung der Konvergenz im Ostseeraum hat auch das Hochdruckgebiet im Westen nur langsam auf dem Kontinent übergegriffen. Auf der Nordseite dieses von den Azoren bis Frankreich reichenden Hochdruckkeils werden die atlantischen Zyklonen oder wenigstens Teile von ihnen auch in den nächsten Tagen noch bis in das nördliche Mitteleuropa vorankommen.

gez. Siegel.
Zentrale Wetterdienstgruppe.

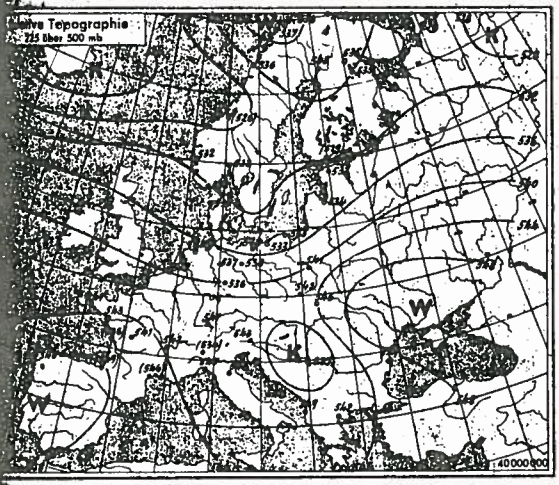
Karten vom Frühtermin



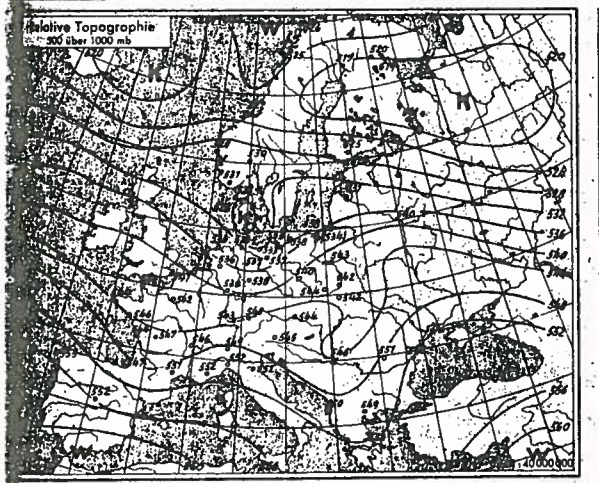


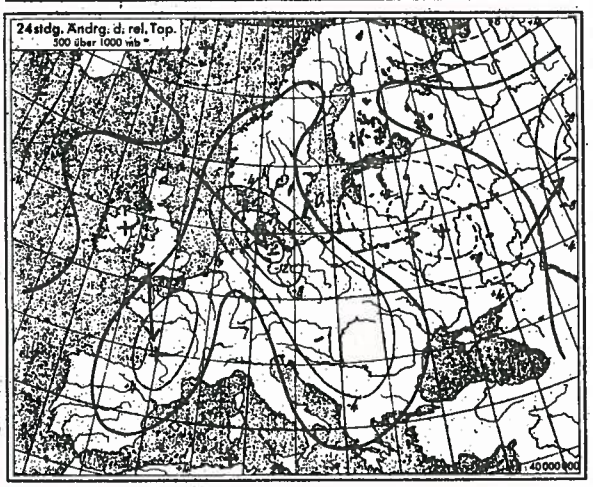

Topographie
über 225 mb

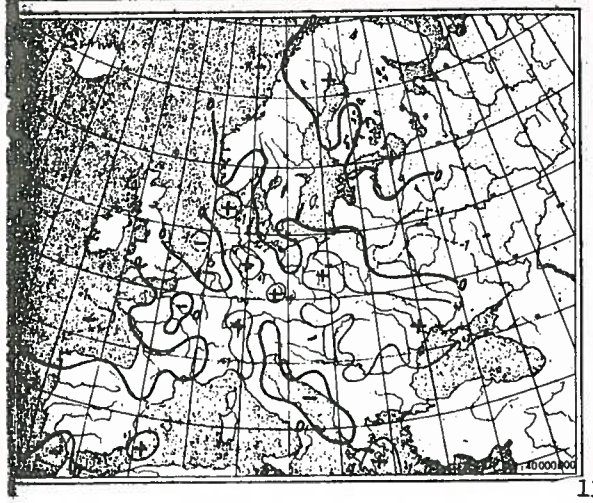

24stdg. Änderg. d. rel. Top.
96 über 225 mb
3.6.44


Topographie
225 über 500 mb


24stdg. Änderg. d. abs. Top.
225 mb


Topographie
500 über 1000 mb


24stdg. Änderg. d. rel. Top.
500 über 1000 mb



WEATHER SUMMARY Sunday 4 June 1944

A well-marked frontal zone of unchanging intensity continues to steal into Europe and is influencing the region from the Atlantic to Russia. This zone is flanked by a strong high located near the Azores and a major upper-level low-pressure area located west of the islands. At the same time, high pressure in the northern portions of the Baltic Sea and a particularly well-developed monsoon low over Russia have sagged southward over central and southern Europe and have been associated with a decreasing influx of cold air in that region. The pool of cold air found yesterday over Denmark is still recognizable as a tongue extending from the Baltic to the Beskides Mountains [Translator's note: Poland] and even could be detected in the north central portions of the Mediterranean. As a result, cold air covers all of the region from central Europe eastward at the same time that the upper-level zonal flow has weakened considerably. Following the passage of this cold tongue, which brought at most a cooling of about 7°C, subsidence and decreasing cloudiness were characteristic and widespread ground frost developed.

The low which was centered over White Russia yesterday has moved towards southern Russia and has induced severe instability over the central and southern sections of the eastern front and another outbreak of thunderstorms near the Advance across the Balkans. Occasionally thunderstorms are also advancing across the higher sections of Italy and earlier today were associated with about 3°C cooling. However, due to the large size of the dominating anticyclone which is affecting the region, there is no danger that a deep disturbance could develop today over the Mediterranean.

With these developments, the cold period has seen its peak. A strong influx of warm air from the Atlantic has developed in association with the intensification of the pressure gradient over the eastern Atlantic. This intensification is due to the marked, continuous pressure falls over the North Sea region under the delta region of the upper current where divergence is occurring. Vertically-extensive masses of nimbostratus have developed in the region where this warm air has pushed against the lingering cold air mass described above. The second of the arriving disturbances is especially strong and will be located tomorrow near the central low-pressure area. It is not yet clear if the second disturbance will be drawn due eastward. There is evidence, namely continuous pressure rises in eastern Europe and widespread pressure falls and persistent flow of warm air over the North Sea, that at least most of the effects of the low will be diverted northeastward. In any case, especially suggestive that this may take place is the fact that during the past night the eastward approach of the frontal zone in the western Azores was stalled and diverted to a more northeasterly direction. The progression of warm air into the far north is of overriding importance in this connection because it portends the development of a weak warm front over the Baltic Sea.

--Brezowski-- Central Weather Service Group

Wetterübersicht Sonntag, den 4. Juni 1944.

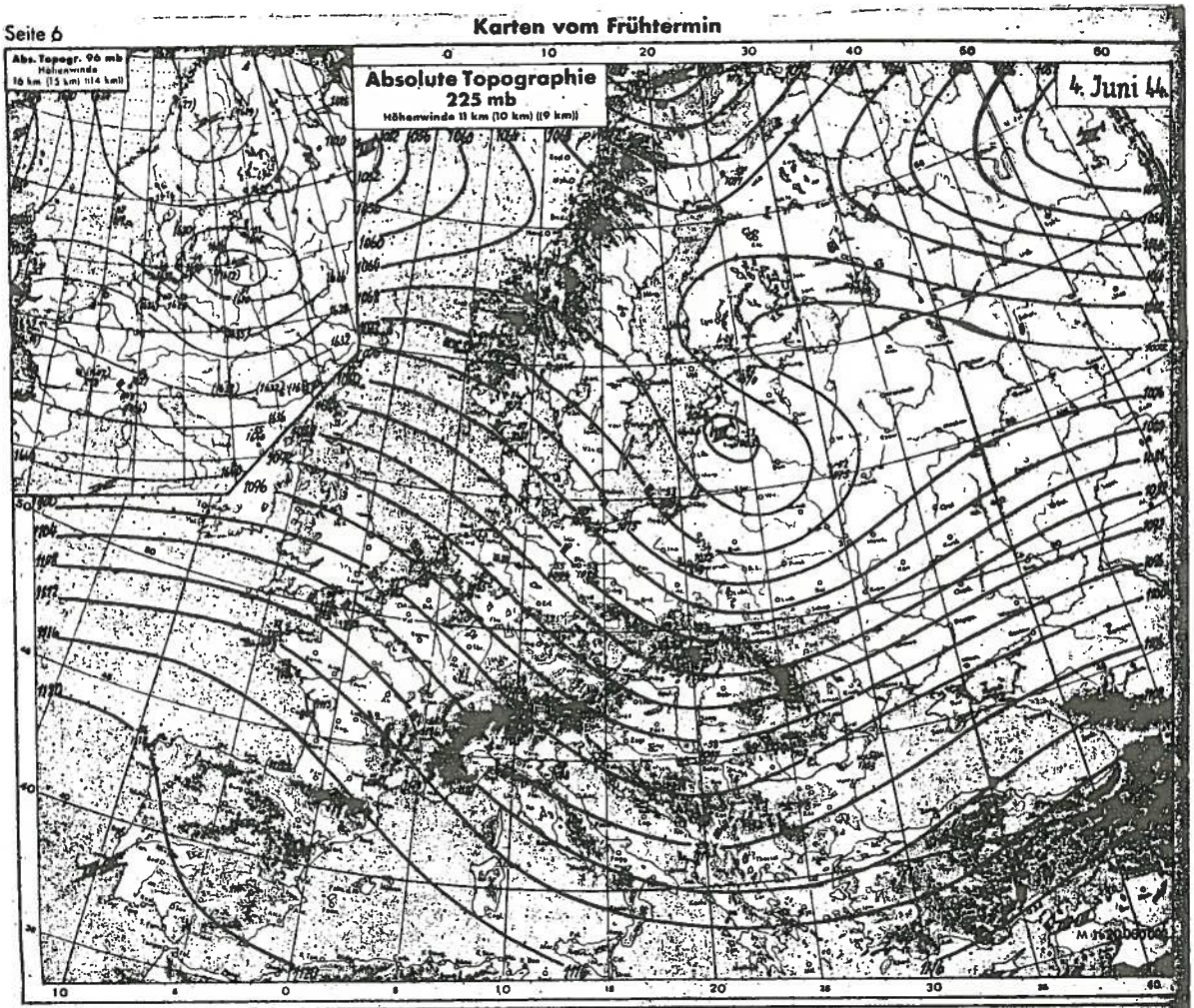
Noch immer besteht in unveränderter Intensität eine ausgeprägte Frontalzone vom Atlantik bis nach Rußland hinein, flankiert von einem kräftigen Azorenhoch und einem zentralen Höhentief westlich Island. Bei gleichzeitig hohem Druck über dem nördlichen Nordmeer und dem besonders gut entwickelten Monsuntief über Rußland hat sich mit dem anhaltenden Einschieben kälterer Luftmassen das Temperaturniveau über Mittel- und Osteuropa weiter gesenkt. Der gestern über Dänemark gefundene Kaltluftropfen konnte sich weiter halten, ist heute noch als Zunge am Balkan vom bis nach den Beskiden erkennbar und sogar noch bis ins Nordmittelmeer zu verfolgen. Damit ist nun der mitteleuropäische Raum nach Osten hin von einer einheitlichen Kaltluft überdeckt, und die Höhenströmung hat sich entsprechend rasch abgeschwächt. Nach Durchzug der Kältezunge, die maximal dem Gouvernement erneute Abkühlung um 7° brachte, hat daher rasch Bewölkungsabnahme und Abkühlung eingesetzt, und in größeren Gebieten traten wiederum Bodenfröste auf.

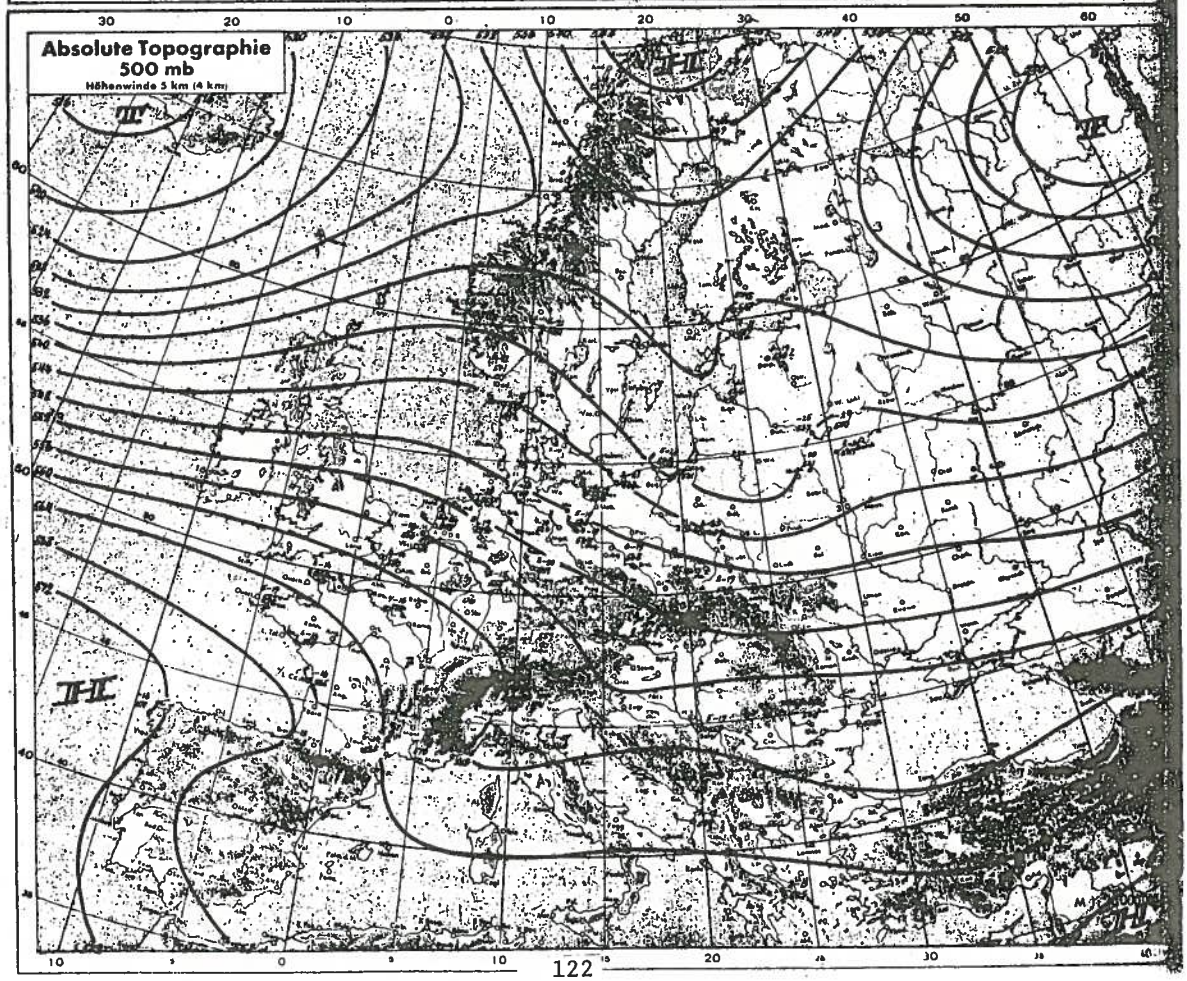
Das gestern über Weißrußland gelegene Tief hat sich nach Südrußland bewegt, seine Rückseitenkaltluft die Ostkampfräume Mitte und Süd stark labilisiert und bei der Überquerung des Balkans wieder gewittrig ausgelöst. Auch über Oberitalien traten zeitweise Gewitter auf, und heute früh ist dort Abkühlung um 3° festzustellen. Bei überwiegend antizyklonalen Verhältnissen ist jedoch eine stärkere Störung des Mittelmeerraumes nicht zu befürchten.

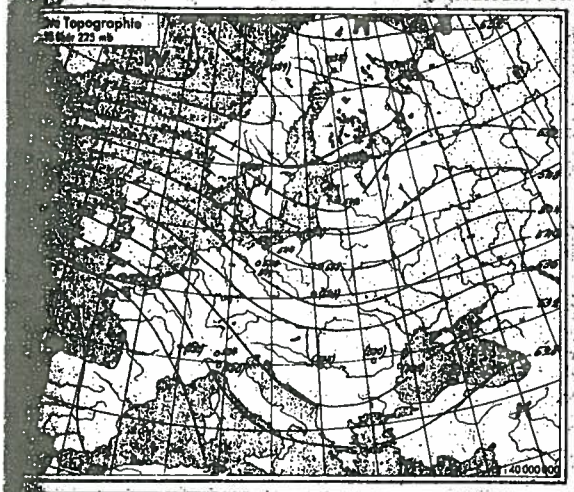
Mit dieser Entwicklung hat die kühle Periode ihren Höhepunkt überschritten. Vom Atlantik her hat starke Warmluftzufuhr eingesetzt, und so ist es durch die Gradientverschärfung über dem Ostatlantik zur Ausbildung einer ausgeprägten Divergenz der Höhenströmung über dem Nordseeraum gekommen, in deren Delta nun lebhafter, anhaltender Druckfall beobachtet wird. An der Begrenzung dieser neuen Warmluft gegen die vorgelagerte Kalte haben sich hochreichende Nimbostratusmassen entwickelt. Besonders die zweite der ankommenden Störungen ist sehr kräftig und wird morgen das Hauptief des Systems darstellen. Bei dem beträchtlichen Druckanstieg, der über Osteuropa auftritt, ist noch nicht klar, ob auch diese zweite der Störungen später nach Osten hin durchziehen wird oder ob vielmehr bei anhaltender Warmluftzufuhr und angesichts der Tatsache, daß auch das Nordmeer von dem Druckfall weitgehend erfaßt wird, mindestens ein Teil des Tiefgebiets nordostwärts abgelenkt wird. Bemerkenswert ist in diesem Zusammenhang jedenfalls, daß in der vergangenen Nacht eine Annäherung der Frontalzone an die Westazoren festzustellen war, was eine mehr nach Nordosten weisende Komponente unterstützen könnte. Jedenfalls überwiegt nun auch im hohen Norden die Zufuhr wärmerer Luft, wie die Ausbildung einer schwachen Warmfront über dem Nordmeer zeigt.

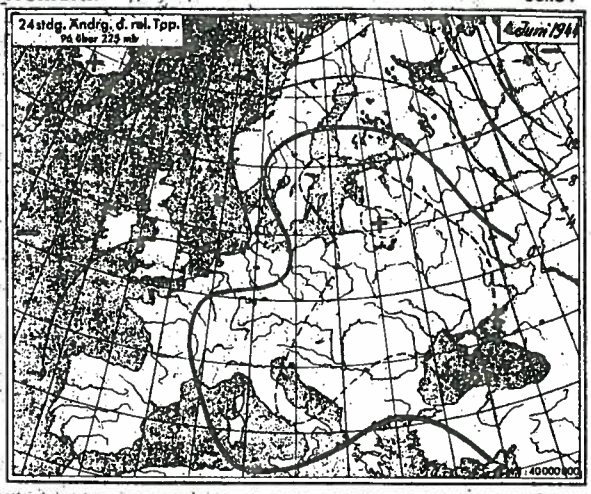
gez. Brezowsky,
Zentrale Wetterdienstgruppe.

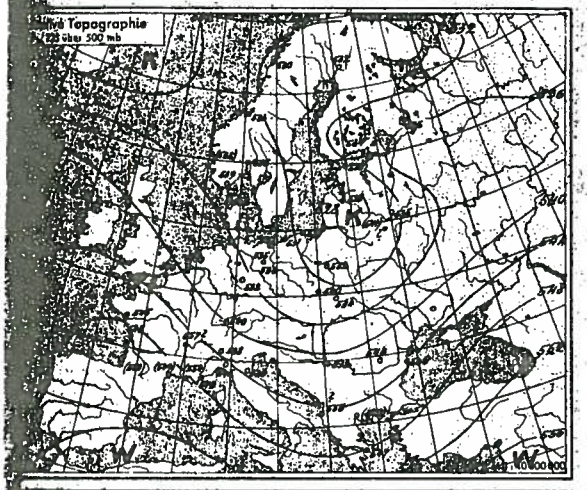
Karten vom Frühtermin

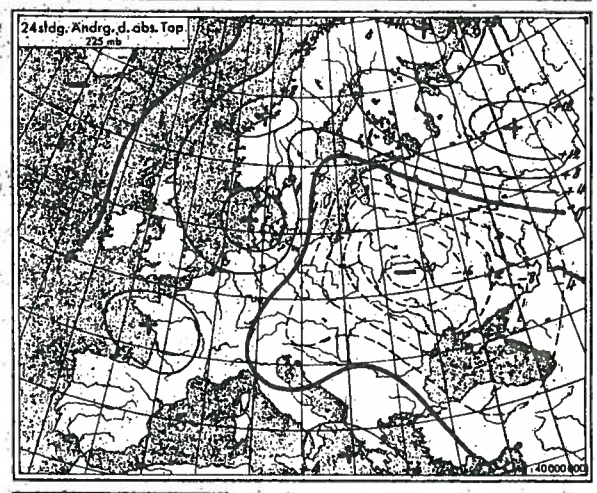


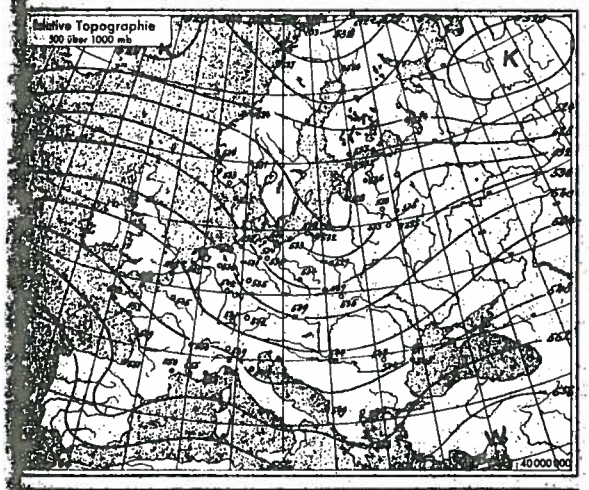


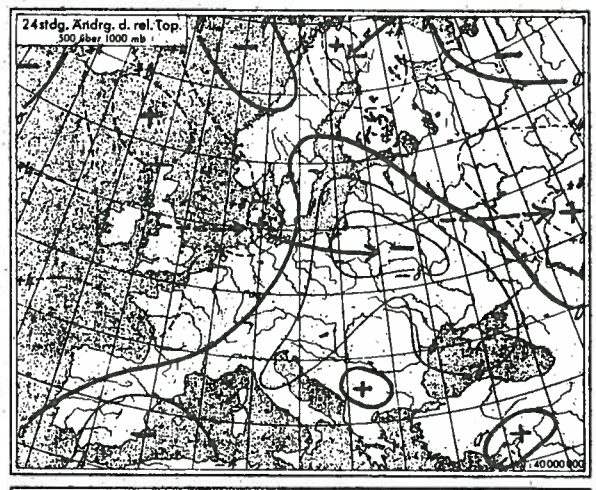

Topographie
über 225 mb

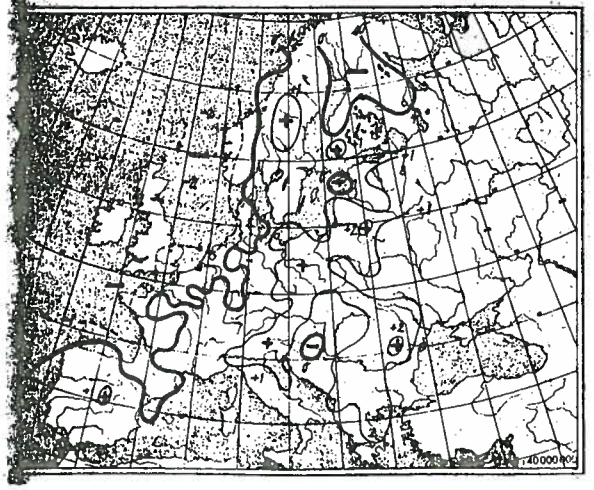

24stdg. Ändrg. d. rel. Top.
über 225 mb
4. Juni 1944

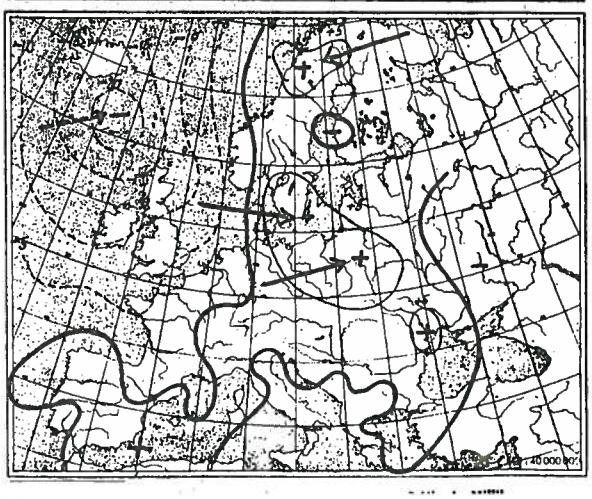

Topographie
über 500 mb


24stdg. Ändrg. d. abs. Top
225 mb


Relative Topographie
500 über 1000 mb


24stdg. Ändrg. d. rel. Top.
500 über 1000 mb





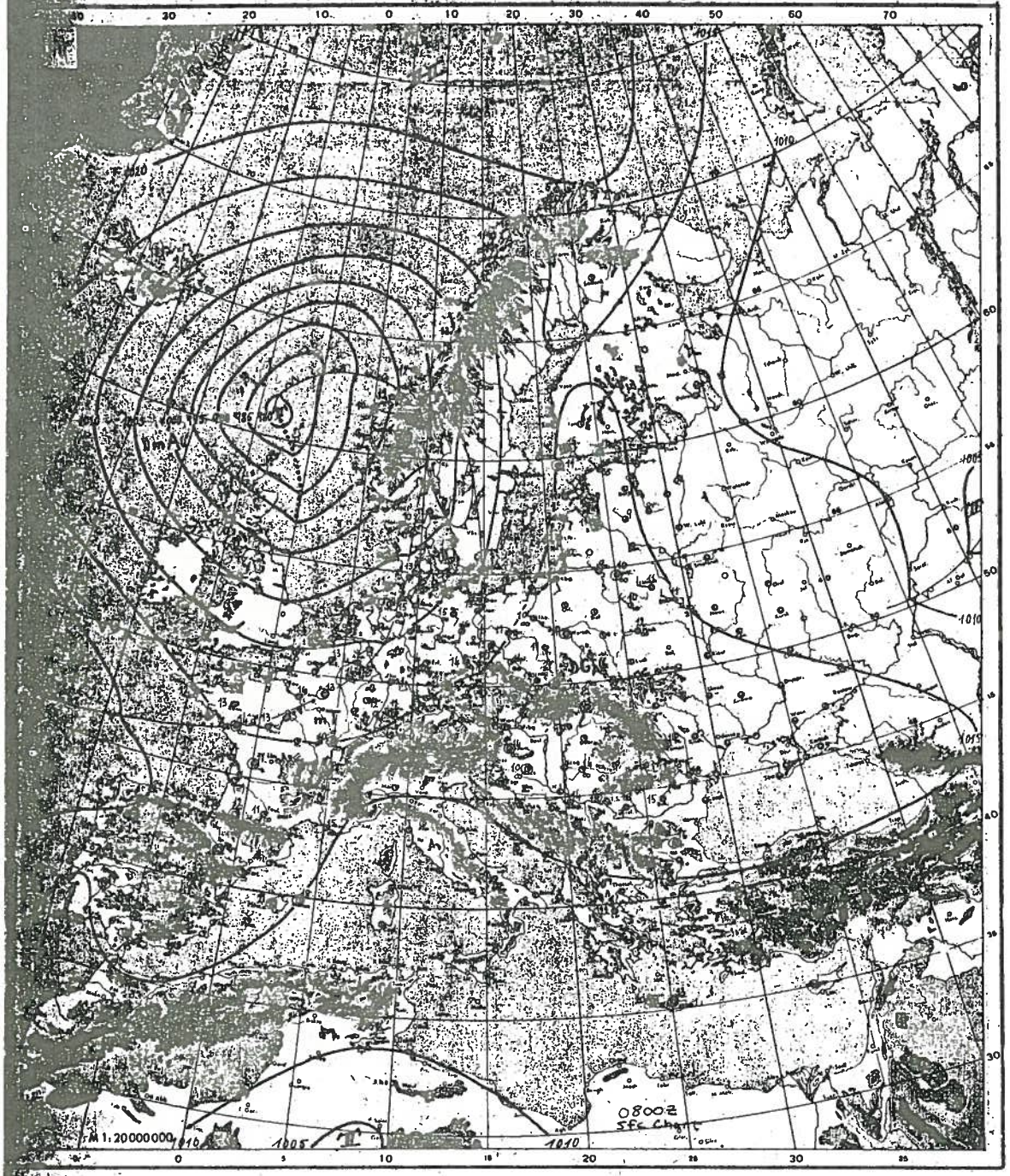
WEATHER SUMMARY Monday 5 June 1944

The cyclone in the Atlantic has developed into a major storm center and has undergone a deepening to a central pressure of 980-mb at the same time that it has drifted 1000-km eastward of its previous position. On the forward side of the cyclone warm air flowed over central and northern Europe. The strongest warming was established over central Norway with simultaneous temperature increases at the surface to the Tropopause at 150 mb of around 13°C in the Drontheim region. Warming on the order of 6 to 10°C proceeded over central Europe. Here, only slight subsidence was observed in the region from Biskaya to Hungary under the influence of a weak high-pressure ridge which was a consequence of the warm air advection and could be contrasted with the precipitation observed in the Scandinavian region where precipitation totals up to 28 mm were recorded in the last 24 hours. With the eastward progression of the Atlantic low, the weather of northwestern central Europe has taken on a distinct cyclonic characteristic: the retrogression of cold air over Holland is associated with a 7000-meter thick deck of nimbostratus and thick altostratus with tops to 3000 to 4000 meters are streaming over Paris.

The pressure pattern in the free troposphere is evolving significantly as a result of the deepening of the cyclone in the Atlantic and the warming associated with the rising air masses on its southeastern flank. Also, a closed vortex centered north of Scotland can be discerned in the upper pattern near the Tropopause. Earlier today the contrast between adjacent air masses of the southeastern flank of the vortex intensified and high-level winds near 140 km per hour have been observed. The upper-level high over Scandinavia has drifted to the eastern Baltic Sea and has intensified. In the region where the upper-level high overlapped the previously mentioned weak surface high fine cloudless weather was the rule over the northern Scandinavia-Finland region. Only the region eastward of the North Cape from the Barents Sea to the central Finnish mountains was experiencing building cloud development. However, despite the presence of high pressure at the surface and the outflow of air from the upper-air high over Russia, it is important to note the presence of thick cloudiness in the eastern Baltic, White Russia, and the Carpathian Mountains.

There is evidence that southwest of the main low previously described in the Atlantic a new disturbance is developing. This is causing the cold air which was moving southeastwards over central Europe to retrogress northwestward. Therefore, a strong advance of cold air in the western Mediterranean should not be expected and the weather of this region should remain for the most part undisturbed. However, in the eastern Mediterranean, thick cloudiness will develop produced by the convergence of the cold air over the Aegean and the advection of warm air from the African region.

-- Kunner-- Central Weather Service Group.



Wetterübersicht

Montag den 5. Juni 19 64

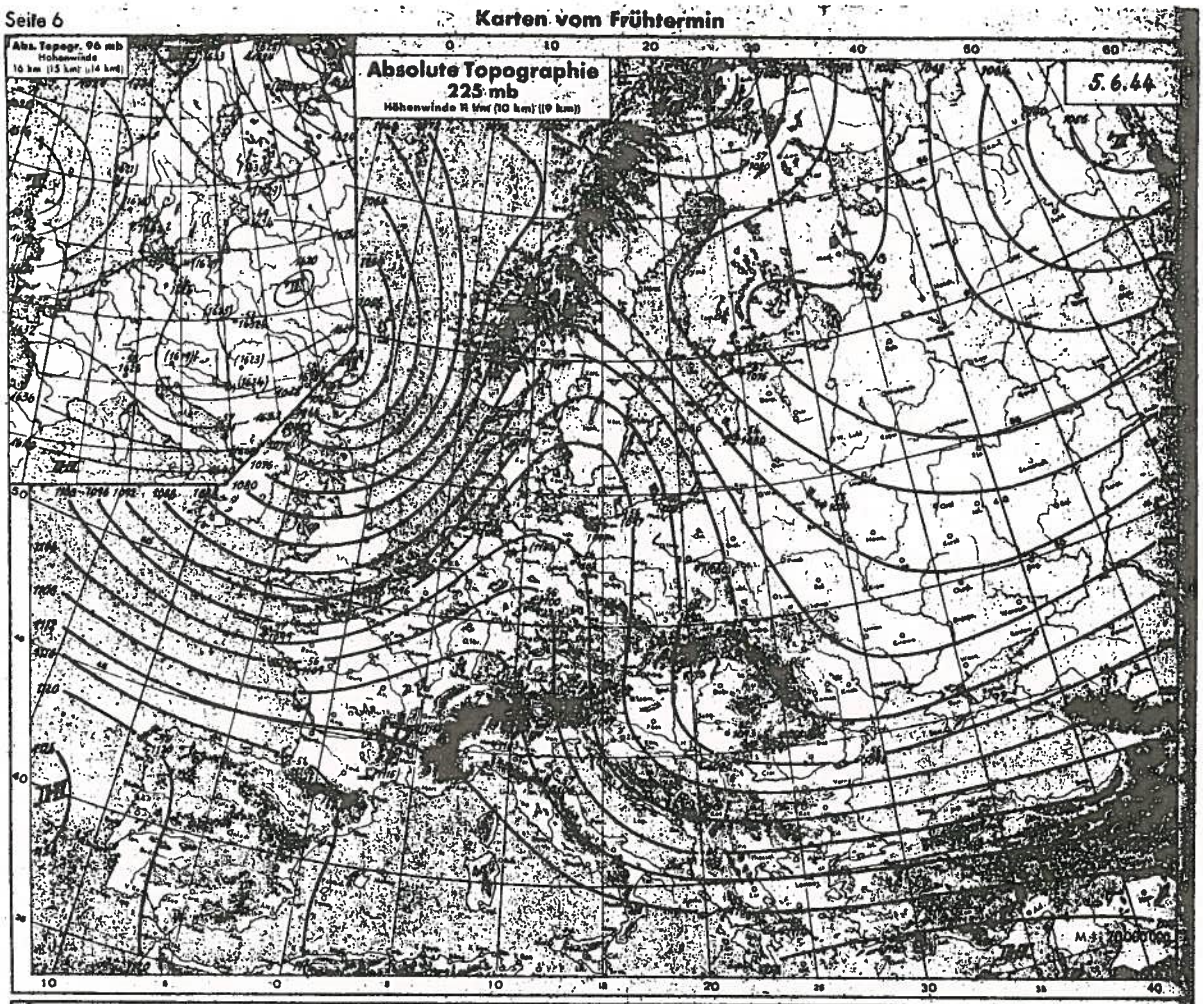
Die atlantische Zyklone hat sich unter erheblicher Vertiefung auf einen Kerndruck von 980 mb nunmehr zu einem Tiefdruckzentrum entwickelt, nachdem sie sich in den letzten 24 Stunden noch um rund 1000 km ostwärts verlagert hatte. An ihrer Vorderseite hielt der Warmluftvorstoß nach Mittel- und Nordeuropa an. Die kräftigste Erwärmung wurde in Süd- und Mittelnorwegen festgestellt mit Temperaturzunahme im Drontheimer Raum bis zu 13° bei gleichzeitigem Anheben der Tropopause um 150 mb. In Mitteleuropa trat nach Erwärmung um 6 - 10° ein, hier sind jedoch infolge des kräftigen Abbaus im Bereich der von der Biskaya nach Ungarn reichenden Hochdruckbrücke die Auswirkungen der Warmluftadvektion im Gegensatz zum skandinavischen Raum, wo Niederschläge bis zu 30 mm in den letzten 24 Stunden gemessen wurden, nur gering. Mit der Abschwächung und Ostverlagerung des Atlantiktiefs hat nunmehr die Witterung im nordwestlichen Mitteleuropa wieder zyklonaleres Gepräge angenommen: Kaltlufteinbruch nach Holland ist mit einem bis 7000 m reichenden Cumulonimbusstratus verbunden, und auch in Paris wurde dichter Altostratus von 3 - 4000 m bis über Gipfel erflogen.

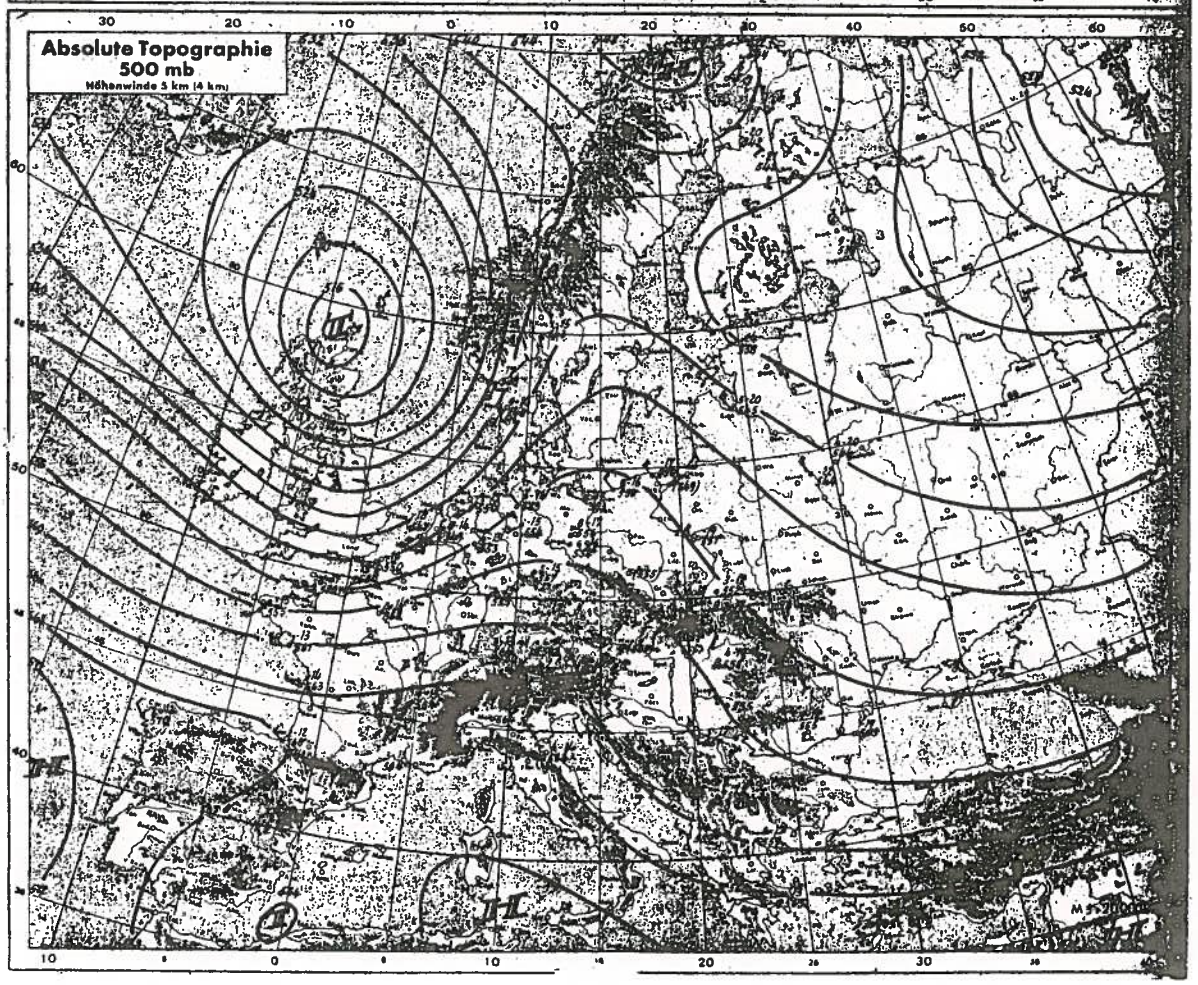
Das Druckbild der freien Troposphäre hat sich bei den erheblichen Luftmassenverlagerungen an den Flanken der Atlantiktyklone und bei ihrer Vertiefung wesentlich verändert. Auch hier zeigt sich in der Tropopause ein abgeschlossener Wirbel mit dem Kern nördlich Schottlands. An seiner Südostflanke wurden infolge der Verschärfung der Massengegensätze heute früh Höhenwinde bis zu 140 km/h gemessen. Der skandinavische Höhenhochkeil hat sich unter Kräftigung in den Ostseeraum verlagert. Im Bereich der Überlagerung von Boden- und Höhenhoch herrscht im nordskandinavisch-finnischen Raum heiteres bis wolkenloses Wetter, lediglich ostwärts des Nordkaps tritt durch Stau verstärkte Bewölkung von der Barentssee bis zum finnischen Mittelgebirge auf. Land über; im Baltikum, in Weißrußland und im Karpatenraum dagegen macht sich trotz der Lage dieser Gebiete im Bodenhochkeil noch der Einfluß des russischen Höhentiefs durch stärkere Bewölkung bemerkbar.

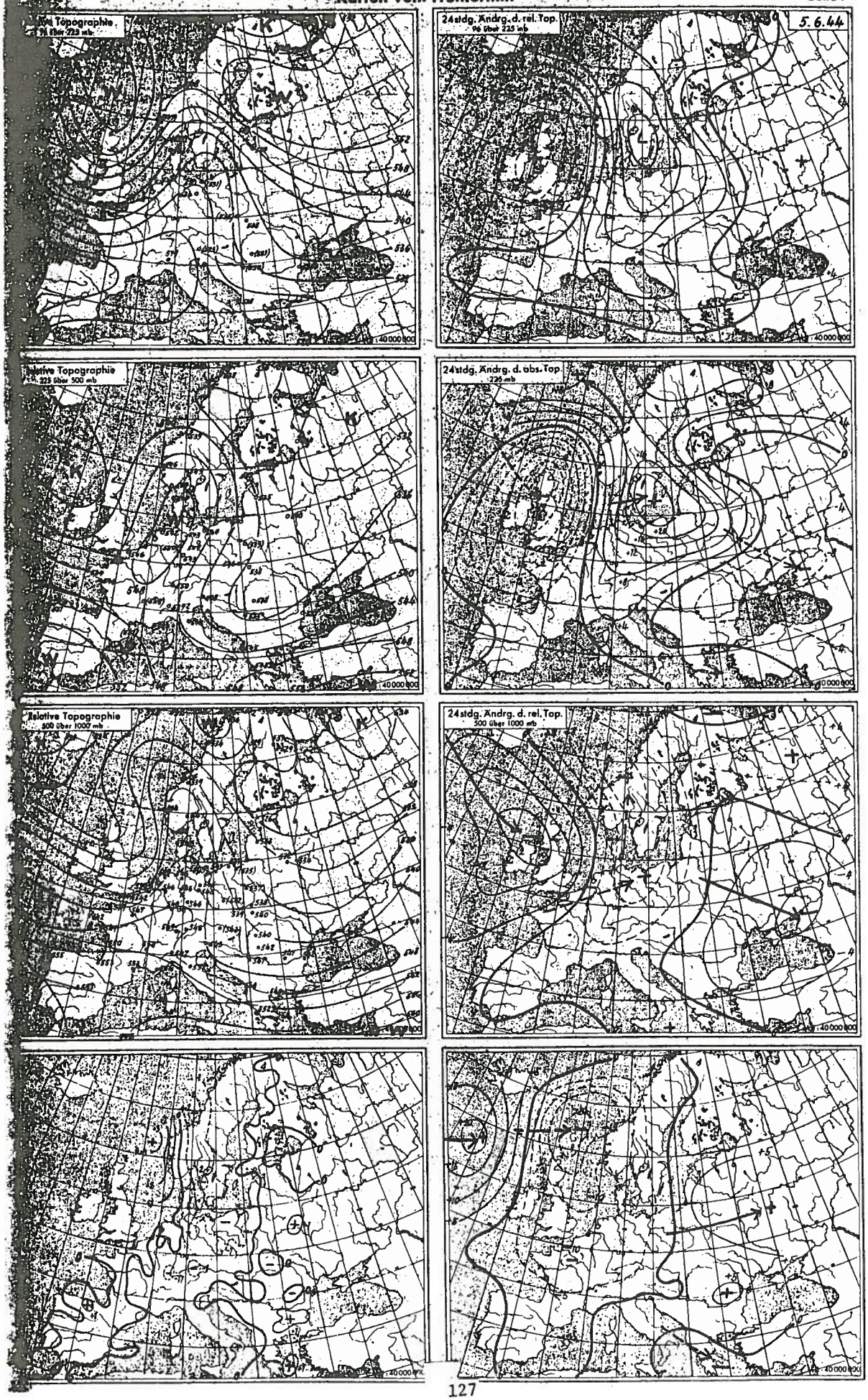
Da südwestlich des atlantischen Steuerungszentrums ein neuer Wirbel belegt ist, wird die nach dem nordwestlichen Mitteleuropa eingebrochene Kaltluft bald wieder rückläufig. Ein kräftigerer Kaltluftvorstoß in das westliche Mittelmeer ist demnach nicht zu erwarten, sodaß dieses im wesentlichen ungestört bleiben wird. Das ostwärtige Mittelmeer weist bei dem noch anhaltenden Einfließen von Kaltluft in die Ägäis und der Warmluftadvektion aus dem afrikanischen Raum stärkere Bewölkung auf.

ges. Künner
Zentrale Wetterdienstgruppe

Karten vom Frühtermin






Rel. Topographie
24 über 225 mb
24stdg. Änderg. d. rel. Top.
96 über 225 mb
5. 6. 44
Relative Topographie
225 über 500 mb
24stdg. Änderg. d. abs. Top.
225 mb
Relative Topographie
500 über 1000 mb
24stdg. Änderg. d. rel. Top.
500 über 1000 mb

WEATHER SUMMARY Tuesday 6 June 1944

The warm high over the northern portions of the Baltic and the cold low over the northern portions of the North Sea both remain persistent and stationary features. This does not portend an end to the first summertime cold-air outbreak of the year over western and central Europe. In addition, the ridge which extends from the high over the Baltic towards the southeast has moved only slightly eastward since yesterday and has solidified its influence in the upper atmosphere. This a sign that the impetus of the influx of cold air over the eastern portions of the Reich will slacken.

By about midday the front in the Atlantic had advanced about 400 km east of the Atlantic coastline with a post-frontal rain band found 100 km west of the wind convergence zone. In the course of the afternoon a wave developed along this front over the central Alps. Severe thunderstorms sprang up in the rainy frontal zone, kindled around midnight by the lifting of the warm unstable air. During the second half of the night, the swift southward progression of the rainfall region associated with the northern part of the Atlantic front was halted, and it became stationary this morning over the eastern Baltic Sea. The post frontal convergence zone which was moving through the cold air passing through northwestern Europe quickly dissipated. In addition, the occluded portions of the Atlantic cyclone, which was located over Norway, are having only a small effect on the weather there. More significant is the development of a new region of bad weather which is developing at the axis of the upper-level low over the North Sea and Holland near which the coldest (a building arctic) air mass lies. The temperature gradient across this cold front is on the order of 4 to 5°C.

The weather events described above represent a departure from the usual cyclonic weather for this season and strongly imply that at least a modest cold air outbreak over western and central Europe is in the making. The southern portion of the progressing Atlantic disturbance will be directed into northwestern France by a strong northwesterly jet stream. The dominant control of the weather over central Europe remains the cyclonic wind flow aloft and the southward sag of the associated pool of cool air. Whether this cold air will advance over the Mediterranean Sea will depend upon the nature of the development of the wave cyclone previously mentioned over the Alps at 40 to 45 degrees north latitude.

--Siegel-- Central Weather Service Group

Wetterlage von heute morgen: Dienstag, der 6. Juni 1944.

Wetterübersicht

Dienstag den 6. Juni 1944

Das warme Hoch über dem nördlichen Nordmeer und das kalte Tief über der nördlichen Nordsee - beide hochreichend und stationär - kennzeichnen die Lage gegen Ende der ersten typisch sommerlichen Kaltlufteinbrüche dieses Jahres nach West- und Mitteleuropa. Die Hochdruckbrücke vom Nordmeerhoch nach dem südosten Europas ist seit gestern nur wenig ostwärts zurückgewichen und hat sich in der Höhe noch gefestigt. Das ist bezeichnend für das Erlahmen der Wucht des Kaltluft einbruches im Osten des Reiches.

Bis etwa mittags war die Front etwa 400 km landeinwärts vorangekommen, dabei hatte sich das postfrontale Niederschlagsgebiet bereits bis zu 100 km von der Windkonvergenz abgesetzt. Im Laufe des Nachmittags setzte Wellenbildung an der Front besonders im Mittelgebirgsraum ein, und in dem Raum zwischen der Bodenfront und dem Regengebiet begann eine sich gegen Mitternacht verstärkende Gewittertätigkeit bei der die feuchtlabile Schichtung der vorgelagerten Warmluft ausgelöst wurde. In der zweiten Nachthälfte holte das Niederschlagsgebiet die Front wieder ein, die ihre Wanderungsgeschwindigkeit von Nord nach Süd fortschreitend auffallend verlangsamte und die heute morgen im Ostseeraum fast stationär geworden ist. Die im Laufe der Nacht innerhalb der Kaltluft aufgebrochenen Konvergenzen haben sich rasch wieder aufgelöst. Auch die Okklusion über Nordnorwegen ist nur noch von geringer Auswirkung auf das Wetter. Wichtiger ist die Ausbildung des Schlechtwettergebietes in der Achse des Höhentiefs über Nordsee und Holland, nahe dem auch die kälteste - eine sich umbildende arktische - Luftmasse liegt. Die Temperaturgegensätze im Kaltfrontbereich selbst betragen im Mittel etwa 4-5 Grad.

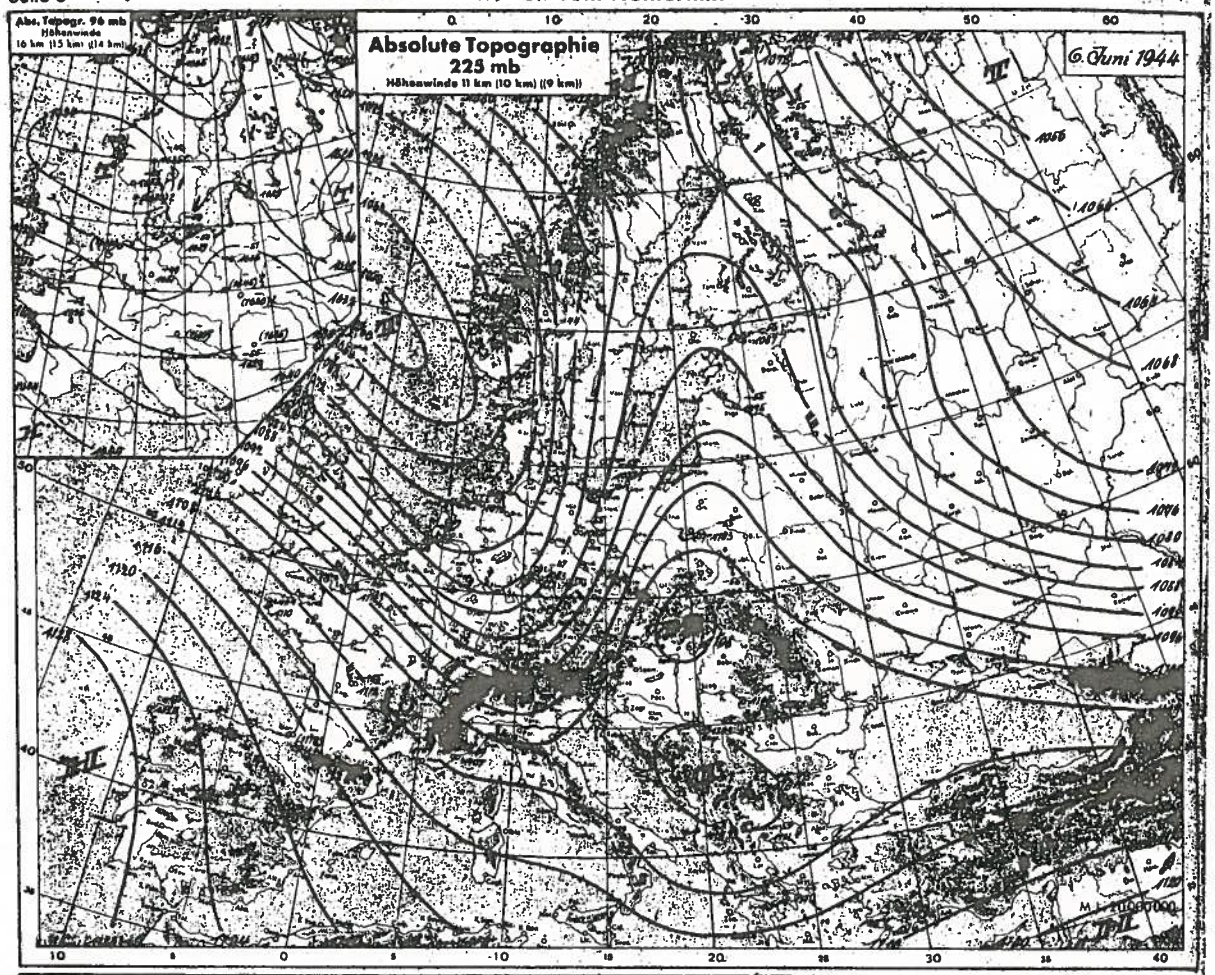
Der dargestellte Wetterablauf weist viele für einen mäßigen sommerlichen Kaltlufteinbruch nach West- und Mitteleuropa typische Abweichungen von der Idealzyklone auf.

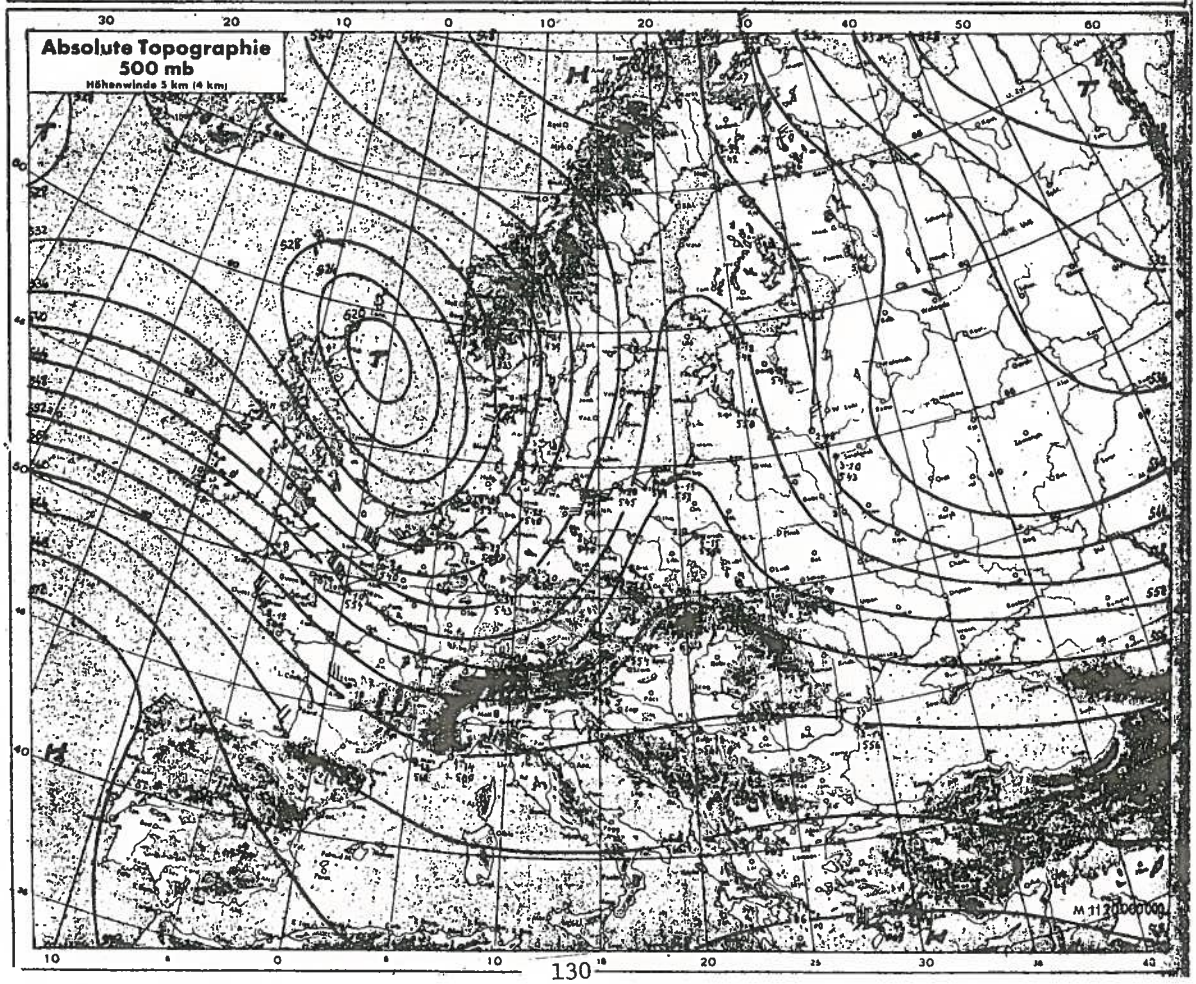
Mit der kräftigen nordwestlichen Höhenströmung sind Teile einer atlantischen Störung nach Nordwestfrankreich herangeführt worden. Für Mitteleuropa bleibt die zyklonale Höhenströmung und die Südvorlagerung der Kaltluft tropfens vorerst wetterbeherrschend. Bei dem Vordringen der Kaltluft bis in den Mittelmeerraum ist zwischen 40 und 45° Nordbreite Wellenbildung zu erwarten.

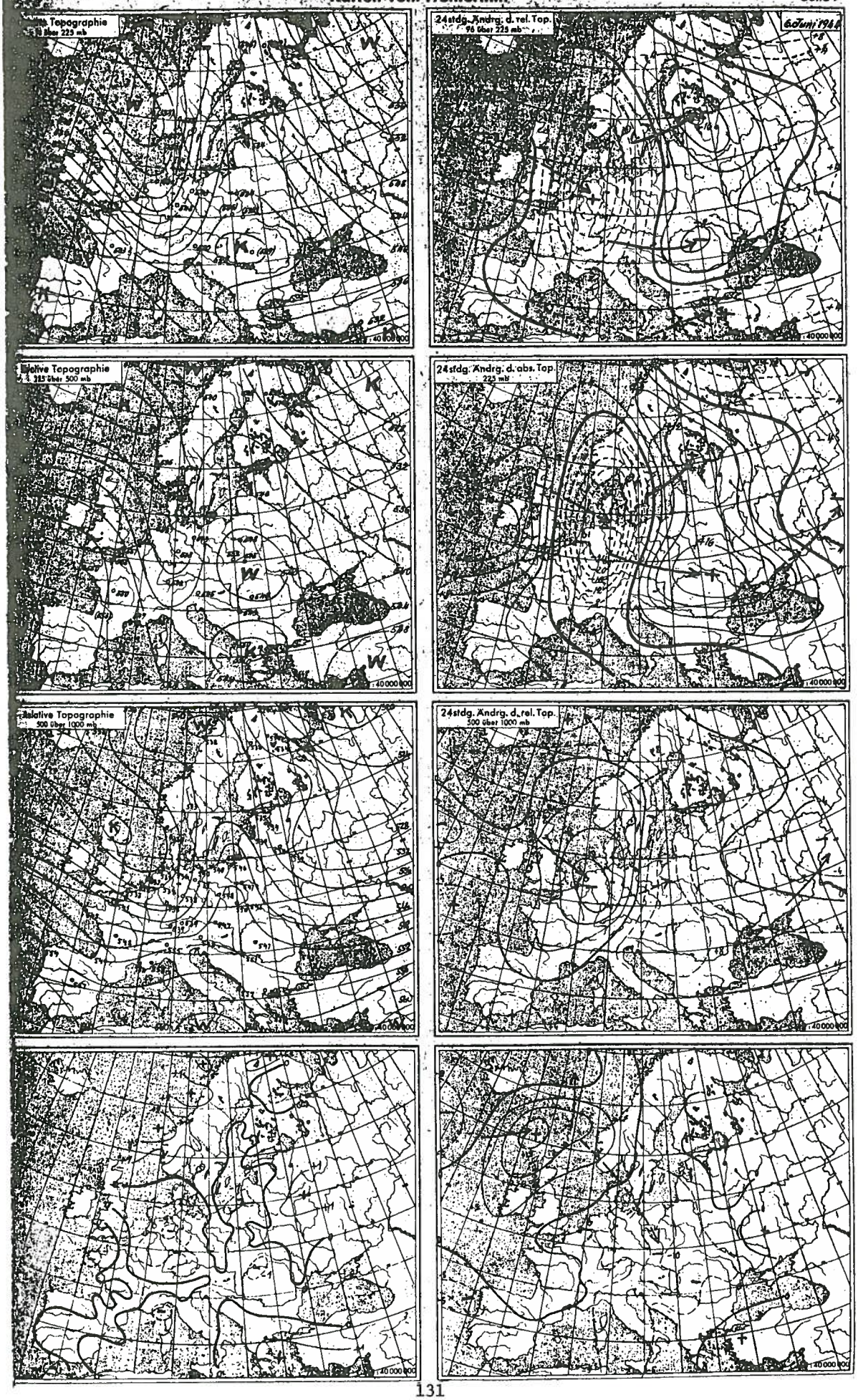
gez. Siegel.

Zentrale Wetterdienstgruppe

Karten vom Frühtermin






Topographie
über 225 mb
24stdg. Ändrg. d. rel. Top.
über 225 mb
6. Juni 1966
Relative Topographie
über 500 mb
24stdg. Ändrg. d. abs. Top.
225 mb
Relative Topographie
500 über 1000 mb
24stdg. Ändrg. d. rel. Top.
500 über 1000 mb

APPENDIX B

Report on the Meteorological Implications in the Selection of the Day for the Allied Invasion of France, June 1944.

Supreme Headquarters Allied
Expeditionary Force
22 June 1944

Report on the Meteorological Implications
In the selection of the day for the Allied Invasion of France,
June, 1944

FOREWORD

1. The Report embodied in the following pages is an attempt to summarise some of the more important aspects of the manner in which meteorology, more particularly weather forecasting, was involved in the decisions which led up to the invasion of France on 6th June 1944 by the combined naval, air and army Forces of Great Britain and the United States. The operation was known by the codeword NEPTUNE and is referred to by this word in the Report.

2. While aiming at completeness the Report is intended to bring out only those aspects which are necessary adequate appreciation of the problems confronting the meteorological advisors of the Supreme Commander. In that the Report has been prepared in the Meteorological Section, Supreme Headquarters, without reference to the various meteorological Services which contributed so valuably to the forecasts used in the decisions, the views expressed are solely those of the SHAEF Meteorological Section.

3. Every effort has been made to do adequate justice to the contributions of each of the Forecasting Centrals, made during the course of the long and difficult series of conferences conducted by telephone by day and by night. Whatever procedure may be adopted for any similar operation in the future, it is unlikely that a greater degree of enthusiastic and helpful co-operation on the part of all the participants will be achieved.

4. A Report of this nature made primarily to be a record of the part played by organised meteorology in an important invasion operation, would normally end with a review of the military decisions as affected by weather forecasts. It has however, been considered that any value the Report may have, might be enhanced by summarising the experience of the Supreme Commander's meteorological advisors in a Section of "Comments and Recommendations". Such a Section has, therefore, been included.

5. All the purely technical discussions have been relegated to Appendices not because they are less important than any of the other sections, but because the Report is primarily a Report to the Supreme Commander and his Staff. The material in the Appendices is intended to provide information about the purely meteorological background for those readers who may wish to evaluate the contents of Section VI against the synoptic situation and developments during the most critical period.

SUPREME H.Q. ALLIED EXPEDITIONARY FORCE

J. M. STAGG
Group Captain
Chief Meteorological Officer

OFFICIAL

Meteorological Section,
Supreme Headquarters Allied Expeditionary Force,
22nd June, 1944

Report on the Meteorological Implications in the Selection of the day for the Allied Invasion of France, June 1944.

Report on the Meteorological implications in the selection of the day for the Allied Invasion of France, 1944.

I. Meteorological Requirements for the Various Phases of the Assault.

a. General Considerations

For such a complex operation as a landing on a heavily fortified coast, it is not an easy matter to determine one set of meteorological conditions which would be ideal from the points of view of all the arms concerned. The ideal conditions would change with the stage of the operation; in the hours immediately preceding and following the actual hour of first landing, the conditions would vary almost from hour to hour. Cloud conditions that would be most suitable for the landing of Airborne forces at HH-X hours would not necessarily be those that would give the heavy bombers their best opportunities at HH-Y hours; and those conditions in turn might not be necessary or even most advantageous for medium and light bombers at HH-Z hours; fighters might operate successfully under conditions different from those considered ideal for the troop carriers or for the heavy or medium bombers.

Probably the only firm prerequisite is the restriction on the strength (and in part on the direction) of the surface wind with its immediate effect on the state of the sea both for the crossing before the landings and its effect on the waves and surf on the landing beaches. But the wind at the time of crossing and at the time of landings is not the only factor affecting this aspect of the operation. If the sea and the beaches are open to the direction from which swell produced by high winds up to hundreds of miles away, is liable to come, then the force and direction of winds hundreds of miles away from the operational area has to be taken into account. And the local conditions of sea are affected by the strength, direction and duration of the local winds for a number of hours before the critical time, depending on the fetch of the particular coast.

Hence, from the viewpoint of naval operations alone, the ideal conditions would be little or no wind within the actual sphere of operations and no swell-producing wind for the whole period covering the time of sailing of the assault forces to their landings on the beaches.

Visibility, as affected vertically by cloud and horizontally on the surface by fog, mist/haze, is one of the most important factors for the Air and Naval aspects of the operation. Visibility must be good enough to let the various types of aircraft take off from, and assemble over, their bases and see their targets in and behind the assault area; visibility must be adequate at sea to allow the multitude of craft involved keep their proper station and also allow the naval bombarding forces see their targets on land in close bombardment the aircraft spotting for the naval bombarding force must also have visibility adequate for directing the force on to its land or sea targets.

There are other factors; for example, the condition of the ground in the operational area as regards softness (mudiness) for the movement of heavy vehicles both tracked and untracked. This factor is taken account of in the planning stages but in certain circumstances may also be important in deciding the day of assault.

Of a more detailed character, but in certain contingencies by no means unimportant, are the actual conditions as regards vertical temperature structure in the atmosphere and wind speed and direction along the coast line immediately preceding, at, and following HH hour. These conditions determine the behavior of smoke screens.

b. Actual Limiting Conditions Used for the NEPTUNE Operation

In English weather, even English summer weather, it was clearly impracticable to set up an ideal set of conditions even if such were possible and defer the assault until this set of conditions was obtained. In the summers of some years they would never be obtained within any predetermined period of, say, a month or even two months. Besides, other factors quite apart from the purely military and political factors, are (unfortunately) at least as important in

determining the period within which the assault must be affected. These factors include the times of high and low tides and the intensity of ground illumination as affected by twilight and phase and altitude of the moon.

It was therefore necessary to define a set of minimum meteorological conditions which could be accepted by all arms as being the worst conditions in whic the operation could be launched.

Such a set of minimum conditions were never wholly accepted by all the forces but the following represents the conditions which the Meteorological Section SHAEF kept in mind:

NAVAL Requirements.

(1) Surface winds should not exceed Force 3 (8-12 mph) on shore or Force 4 (13-18 mph) off shore in the assault area during the days D to D plus 2. Winds might be Force 5 in the open sea but only for limited periods.

(2) In the days preceding D-Day, there should be no prolonged periods of high winds of such direction and in such Atlantic areas as to produce any substantial swell in the Channel.

(3) Visibility, not less than 3 miles.

AIR FORCE Requirements.

(1) Airborne transport; (HH-6 to HH-4):

(a) Cloud ceiling at least 2500 feet along the route to and over the target area.

(b) Visibility at least 3 miles.

(2) Heavy Bombers (HH-4 to HH):

(a) Not more than 5/10 cloud cover below 5000 feet and cloud ceiling not lower than 11000 feet over the target area.

(3) Medium and Fighter Bombers (HH-2 onwards):

(a) Cloud ceiling not less than 4500 feet, visibility not less than 3 miles over the target area.

(4) Fighter and Fighter Bombers (HH-18 onwards):

(a) Cloud base not less than 1000 feet.

(5) Base areas:

(a) Cloud not below 1000 feet and visibility not below a mile except for heavy bombers for which there is the additional stipulation that low cloud tops must be less than 5000 feet high and there should be only fragmentary middle cloud.

ARMY Requirements.

(1) Airborne Troops Landings:

(a) For Paratroops, the surface wind over the target area should not exceed 20 mph in the target area and should not be gusty; and for gliders the surface wind should not be over 30-35 mph.

(b) The intensity of the ground illumination should not be less than half moon at 30° altitude or the equivalent in diffuse twilight.

(2) Ground Forces:

The ground should be sufficiently dry to allow movement of heavy vehicles off made-up roads.

II. Summary of Results of Statistical Examination of the Probability of Obtaining Most of the Above Requirements on Any One Day or Sequence of Days.

In the months preceding the launching of operation NEPTUNE, examinations of weather statistics for past years were made from many different angles with a view to estimating the probability of obtaining specified weather conditions at various periods from April onwards. Some of the results obtained at various times, using different sets of basic information, were as follows:-

Defining a quiet day as one with wind less than Force 3 onshore and Force 4 offshore, on the Normandy Coast of France and stipulating the following overall requirements for the periods of the assault:

(a) D-Day be within the period of one day before to four days after new or full moon (that is assuming landing of Airborne troops could be affected irrespective of ground illumination from moon light)

(b) D-Day be itself quiet and followed by a sequence of three quiet days.

(c) Cloud less than 3/10 below 8000 feet and visibility more than 3 miles.

(d) Alternative to (c), cloud base generally above 3000 feet and with morning mist or fog not excluded.

The following arithmetical values were obtained for the probabilities of the various conditions (a), (b), (c) and (d) abve:

		May	June	July
		Chances to 1 Against		
(1)	(a) (b) and (c) together	24	13	50
	(b) and (c) without (a)	9	4½	19
	(b) and (c) with (a) limited to full moon	49	24	100
(2)	(a) (b) and (d) together	11	6	16
	(b) and (d), without (a)	4	2	5
	(b) and (d) with (a) limited to full moon	24	13	33

Of these various sets of conditions, the third set in the second group was the most likely to have to be accepted, viz. D to D plus 3 quiet as regards wind, cloud base generally above 3000 feet and the conditions restricted in any one month to six days around full moon. Even with those conditions which did not cover the minimum requirements for some of the phases of the operations, the chances of obtaining the conditions together over a set of days were very low, viz. 24 to 1 against in May, 13 to 1 against in June and 33 to 1 in July. One important result did come out from these and many other examination, viz. that June was likely to be the best of the three early summer months. So that if the operation was planned for May and postponed, June, with better chances, was still to come; but if the operation were planned for June and deferred, its chances of similar conditions in July (and subsequent months) would be less good than for May or June.

There were, of course, meteorological reasons for avoiding May for Channel operations if at all practicable; one of these was the statistical frequency of occurrence of winds from between northeast and east in the eastern and central Channel area. These winds coming over the water of the cool North Sea bring low stratus cloud liable to persist with 10/10 cover for days at a time in the central and eastern Channel area.

III. The procedure for achieving an agreed weather forecast for the NEPTUNE Operation.

As statistics from past years' weather were known to be quite an unreliable and unhelpful guide for the actual selection of D-Day, it was decided at a meeting of the Directors of the Meteorological Services concerned (Air Ministry, U.S. and Naval) in January 1944, that the utmost efforts should be directed to framing as a routine procedure each week, a forecast of weather conditions covering as long a period ahead as could be issued with substantial confidence; 5 days was the period aimed at.

It was arranged that regular conferences be held using scrambler telephone conference facilities and with the following participants:

Air Ministry Forecasting Central, Dunstable
U. S. Forecasting Central, Widewing
Naval Meteorological Forecasting Central, Admiralty

The Chief Meteorological Officer at SHAEF or his Deputy was to be the Chairman at each of the conferences which would include the Meteorological Staff Officer of the Naval Commander in Chief, and the Chief Meteorological Officer (or his Deputy) at the Headquarters, Allied Expeditionary Air Force.

The purpose of the conferences was to arrive at an agreed forecast for a period of 5 days; the advice to be submitted to the Supreme Commander and his Commanders-in-Chief would be based on this agreed forecast.

These conferences started in February 1944, at first on a two or three times a week basis; from the middle of April, the conferences were held each day.

Actually the need for daily conferences became necessary for at least two different reasons:

(1) In all but abnormally (for England) quiet conditions, the expert and experienced meteorologists at the participating Centrals seldom found it practicable to forecast with any useful confidence beyond 2 or 3 days; and

(2) The original intention of restricting the functions of the conferences to the framing of an agreed planning forecast developed into aiming at giving broad operational details for at least the first two or three days. Events soon showed that daily modification of the forecast was necessary to ensure that those details be operationally useful to the senior meteorological officers at the lower formations to which the agreed forecasts were distributed.

For large scale exercises and operations preceding the actual NEPTUNE assault (e.g. the FABIUS operation on 35d May 1944), and more particularly as the scheduled day of the NEPTUNE operation approached, the number of conferences between the forecasting Centrals and the Meteorological Advisors to the Naval and Air C's-in-C was increased to three a day:

(1) A preliminary conference in the late afternoon (1730 h) to allow the Centrals to discuss the lines on which they were thinking about synoptic developments over the next five days.

(2) A main conference in the late evening (2100 h) at which the terms of a 5-day forecast (agreed or accepted by all concerned) were discussed. And

(3) A morning conference (varying in time from 0630 to 0830 h) at which any necessary modifications in the operational part of the previous evening's 5-day forecast were discussed and a modified forecast issued if required.

On the days immediately preceding D-Day, a further conference was held at 0300 each morning on which to base the final advice given to the Supreme Commander's meetings at 0415.

Each of the conferences usually lasted about one hour; they sometimes extended to two hours, particularly the evening conferences preceding D-Day.

IV. Forecasts of Weather suitable for Assault Operations, submitted during May, 1944, to Supreme Commander or his Staff:

With a view to testing the effectiveness of the information contained in the five-day forecasts prepared by the procedure outlined in the preceding section, the Meteorological Section, SHAEF, was instfucted to submit each day those dates at least two days ahead when it was thought that conditions would fulfil most of the requirements referred to in Section I. In effect, each day more than two days ahead was to be considered as a possible D-Day, and the conditions on that day and on immediately preceding and succeeding days were to be considered in the light of their suitability for launching an assault. If the conditions were considered as likely to be suitable, the Assistant Chief of Staff, Plans and Operations (G-3) Division was informed.

From the early days of May, a total of eighteen dates (including the first two days of June) were submitted either separately or in sequences of two or more days, as days for which the weather was forecast at least two days in advance as being suitable for launching an attack on the selected coast of France.

Considering that the weather in May was mainly of a settled type, it was not surprising that the weather on these dates did in fact turn out to be substantially as forecast and suitable for launching a large scale assault.

V. Weather information and advice furnished to the Supreme Commander's Staff in the preparatory stages of Operation NEPTUNE (viz. on May 28th, 29th, 31st and June 1st.)

(1) In this period during which decisions had to be taken for the sailing of those assault and naval bombardment forces which were coming from a considerable distance, it was recognized that no definite forecast could be given for conditions on and immediately following the scheduled D-Day, 5th June.

(2) On Sunday, 28th May, the Supreme Commander was advised through the Assistant Chief of Staff, G-3 Division, SHAEF, that the evidence then was that mainly quiet wind conditions would continue during the week. Even in the present stable situation, nothing helpful could be said about wind or cloud conditions on D-Day but the risk of conditions changing so much from what they are now as to produce a gale in the Channel then seemed rather small.

(3) On Monday, 29th May, to a meeting at 1000 hours at Portsmouth, of the Supreme Commander, his Commanders-in-Chief, and their Chiefs of Staff, the following forecast was presented for the five days until Friday, 2nd June.

Mainly quiet wind conditions (not more than Force 4) throughout the period except for a wind of Force 5 in the extreme western Channel areas on Thursday and Friday.

Variable cloud conditions with an average of 5/10 to 7/10 except in local thunderstorms during the first two or three days; cloud would probably increase from the west at the end of the period. The visibility would be good except for morning coastal haze and in thundery showers.

The confidence was given as moderate for continuation of quiet wind conditions but low for details of cloudiness and developments toward Thursday and Friday.

In course of questioning at this meeting about conditions for Saturday, 3rd June, it was repeated that there was a risk of deterioration at that time especially as regards cloud conditions, but that the outlook was favorable from the viewpoint of wind in the Channel.

The basis of this advice was that there was no evidence to indicate that the existing northeasterly extension of the Azores high pressure area would be substantially modified in the next four or five days; it was therefore a reasonable expectation that, even if it did begin to recede or collapse at the end of that time, it would still influence the movements andintensities of any low pressure systems that might effect the operacional area by giving them a northeasterly track away from the English Channel.

(4) 0830, Wednesday, 31 May. The Assistant Chief of Staff, G-3, SHAEF, was advised that since Monday morning's conference at Portsmouth, the situation did not look as favorable as it then did for weather in the Channel area from Sunday, 4th June, onwards. But there was as yet no definite evidence that winds would be sutstantially above Force 4 for long periods; nothing helpful could be said at that stage about cloud conditions on June 4th and 5th.

This advice was based on the prognostic analyses agreed by the forecasting cehrals to the effect that there were indications that the Azores high pressure area was beginning to show signs of weakening, though there was time for a replacement high pressure area to move in or resuscitate it from the west.

(5) 0845, Thursday, 1st June. The AC of S, G-3, (General Bull) was advised that there was no new evidence to change the forecast as give. him yesterday (para.(4)). The balance ofevidence was that wind in the Channel area should continue not more than Force 4 over the weekend and on Monday, 5th June, but no forecast for cloud could be given. The confidence in operationally quiet wind condition con tinuing into Monday was somewhat less than in the forecast given on Wednesday.

VI. Summary of Meteorological statements made at the Supreme Commander's meeting at Portsmouth (Friday 2nd June to Monday 5th June).

In their essentials, the statements are reproduced in as nearly as practicable the same form of words as were used at the meetings.

1000 Friday, 2nd June.

Winds in the Channel and particularly in the Normandy area will probably be Westerly, mainly not above Force 4, but Force 5 at times particularly in the western channel towards the end of the period (Monday and Tuesday).

Cloud conditions on Sunday and Monday cannot be forecast with any degree of confidence; they will be variable. Amounts will be 7/10 to 10/10 in the early morning in the operational area, clearing partially in the forenoon to 5/10 or less but with patches up to 10/10 for considerable periods.

Visibility will be moderate to good generally but with risk of fog patches in the Channel and coastal areas on Monday morning.

The general type of weather is westerly in which Force 5 winds cannot be ignored at any time and in the warm humid air brought across the Atlantic from lower latitudes, cloud conditions are always uncertain particularly over higher ground in coastal areas and in the southwest of the Channel area.

There is now indication that the present relatively quiet weather may end about Tuesday.

2130 Friday 2nd June.

The general meteorological situation has not changed substantially and the forecast presented at the morning conference still stands. The flow of moist warm air over the operational areas will produce much low cloud. The whole development is at the moment sluggish and slow to show its hand; but, on the whole, the outlook for Sunday and Monday seems not unfavorable from the point of view of wind speed, namely, mainly Force 4; but there is a risk of Force 5 winds on Tuesday. The outlook for cloudiness is very uncertain; considerable periods of 10/10 cloud cover with base about 1000 feet must be expected. The times of the periods cannot be forecast accurately.

To a question (Supreme Commander) about conditions on Tuesday and Wednesda the reply was that the evidence at present did not indicate much difference on those days from the conditions as just described for Sunday or Monday; there was no basis for forecasting persistent high winds though there was a risk of Force 5 on Tuesday; cloud conditions would probably continue poor with periods of 10/10 at 1000 feet.

Another inquiry (D/Air C-in-C: Gen. Vandenburg) was directed to conditions for the transport and landing of Airborne troops overnight Sunday-Monday. The reply was that cloud base would probably be mainly above 1000 feet but there would be patches with base at or below 1000 feet after 0200 on Monday morning.

0800, Saturday, 3rd June.

AC of S, G-3 (Gen. Bull) was informed by telephone that there was no indication of improvement from the terms of the forecast presented at 2130 the previous evening. But the risk of Force 5 winds then forecast for Tuesday had now to be brought into Monday and even the latter part of Sunday. The view at the moment was that these Force 5's would be mainly on the English Channel coast

The cloud forecast is still very uncertain; the most likely cloud conditions are 7/10 to 10/10, base 1000 feet, especially in the early morning hours No opinion can be expressed about exact times of clearances, except for areas well inland during the afternoon.

General Vandenburg (D/Air C-in-C) and Admiral Creasy (C of S to Naval C-in-C) were given the same information. It was emphasized that the synoptic situation had become an extremely difficult one, and forecasts as to details were given with low confidence.

2130, Saturday, 3rd June. Supreme Commander's Meeting.

The high pressure area over the Azores is rapidly giving way and a series of depressions across the Atlantic is moving rapidly eastward; these depressions will produce disturbed conditions in the Channel and assault area.

Winds will be west-southwest, Force 5 on English Coast, Force 3-4 on the French Coasts from early Sunday, until a cold front trough passes. That passage is timed to be sometime on Wednesday, 7th June

From Sunday morning onwards, cloud will probably be mainly 10/10 with bas 500-1000 feet in the morning hours. This cloud may break in inland areas durin the day and become about 5/10, but will continue of variable amounts in the Channel area and on both coasts with considerable patches of 10/10; its base will be at or below 1000 feet. The time of incidence and local distribution of these patches of low cloud cannot be forecast with confidence.

Some patches of medium and high cloud, mainly confined to South England must also be expected; amounts of this type of cloud will be less in areas well inland, e.g. over the Eastern Midlands and over the East Anglia bomber base areas.

Visibility will be mainly 3-4 miles, though 5-6 miles inland in the afternoon can be expected. There is a risk of fog spreading from the West up the Channel to sea and coastal areas. After Monday this risk of fog will decrease.

These details cover the period Sunday to Tuesday and at first on Wednesday, as far as can be seen with any confidence at the moment.

During Wednesday, a front associated with a depression now off Nova Scotia and the New England States will probably pass through the assault area.

Just preceding this front there will be a period of 10/10 multilayer cloud (low, medium and high); then as the front passes there will be a decrease of cloud amount and increase of cloud base heights, becoming 5/10 to 2500 feet. Visibility on Wednesday will be moderate at first becoming good after the front passes.

Further meteorological forecasts and statements made at this meeting were as follows:

(a) Air C-in-C, on a question about likely conditions for heavy bombers taking off from bases early on Monday morning:

10/10 stratus cloud, base 500-1000 feet and about 3000 feet thick; with a second layer of medium cloud base between 8000 feet and 12000 feet. This second upper layer will probably not be a continuous 10/10ths sheet.

(b) Air C-in-C, about conditions for enemy aircraft using their own bases:

Cloud along the French Coasts will probably be 10/10, base 500-1000 feet; but inland, away from the coastal strip, cloud amounts may be expected to be less during the middle part of the day.

Conditions over enemy bases on Monday will, on the whole, be better than over bases in England.

(c) Naval C-in-C, whether Force 5 winds along the English Channel are likely to continue through Monday and on Tuesday. Force 5 winds must be expected on Monday and on Tuesday.

(d) Naval C-in-C; would cloud conditions also be similar on Tuesday?

Similar cloud conditions will probably continue from about Sunday forenoon until Wednesday, when the clearing front is due to pass through the operational areas.
No useful forecast can be given beyond that at present.

(e) To a general question about probable weather conditions after Wednesday, the reply was that weather could not be expected to settle down quickly after the present very disturbed situation. But the prospects were, alternation of periods of greater and less cloudiness with mainly moderate westerly wind though fresh at times, associated with minor fronts and ridges of high pressure.

(f) The Supreme Commander commented on the slightly more optimistic note that he felt had come into the picture between the morning and evening conferences on Friday; and asked whether the forecast might not be more optimistic again tomorrow morning.

There is very little chance of any information being received before 0300 which is likely to give a more optimistic turn to the forecast. Since at least yesterday (Friday) morning, the whole meteorological situation has looked very unpropitious for a Monday assault but the outlook has been finely balanced, in that it might have swung to better or much worse. On Friday evening there was a very slight tip of the balance on the favorable side but the balance now has swung too far to the unfavorable side for it to be quickly counteracted.

The supreme Commander said that he had certainly been left on Friday morning with the impression that the situation was both difficult and uncertain.

(g) Deputy Supreme Commander asked whether the meteorological centrals were all agreed about the forecast as presented.

The centrals have agreed to accept the forecast.

(Following the presentation of this information, the assault was provisionally postponed for 24 hours.)

0415, Sunday, 4th June.

No new evidence has been received which allows any substantial change in the forecast presented last (Saturday) evening. The only small change is that the front, which was then expected to clear the Channel areas of low cloud on Wednesday, is now expected in the first part of Wednesday.

Winds will be Force 5 in the Channel from early Monday onwards, though somewhat less in sheltered areas on the French Coast.

10/10ths cloud, base 500-1000 feet are expected along the Channel area, with no forecastable difference in these conditions from Sunday to Tuesday.

The Naval C-in-C asked when these overcast skies would appear at Portsmouth, commenting that it was a practically clear sky with calm wind at the time of the meeting. He was advised that the cloud would increase during the early forenoon, of that day (Sunday).

(Following this presentation the time of the assault was deferred by 24 hours in the first instance.)

1745, Sunday, 4th June.

AC of S, G-3 was informed that there had been a substantial change in the situation since the early morning. It is now likely that there will be a fair interval starting about midnight today and lasting till about dawn on Tuesday morning. During this fair interval, and particularly from Monday evening to Tuesday morning, cloud amounts will probably be substantially smaller than given in forecast this morning; winds will also moderate temporarily, particularly over Monday night and at first on Tuesday.

A deterioration will probably set in again during Tuesday; weather on subsequent days will continue unsettled and disturbed.

On General Bull's request this same information was conveyed to General de Guingand (Chief of Staff to Army C-in-C).

2100, Sunday, 4th June. Supreme Commander's meeting.

Since the statement made before the meeting on Saturday evening, there have been some rapid and unexpected developments in the weather situation over the Atlantic. A front from one of the deep depressions in the northwest Atlantic has moved much farther south than was expected and is now traversing the Channel areas. It is almost over Portsmouth now and will clear the eastern Channel at least on the English side overnight. When that front has passed there will be an interval of fair conditions which, from the evidence we now have, should last until at least dawn on Tuesday.

Wind speeds by Monday evening should decrease to Force 3-4 on the French Channel coasts and cloud will become mainly less than 5/10, with base 2-3000 ft.

After that interval, lasting till Tuesday morning, cloud will probably increase to 8/10-10/10 from the west during Tuesday afternoon and will continue so overnight Tuesday.

From a time on Wednesday which cannot be defined from present information, mainly cloudy conditions will continue; but there should be some intervals of broken cloud. In this period from Wednesday to Friday, there will probably be intervals of 10/10ths cloud with base at 1000 feet; these overcast intervals of low cloud may be expected to last 4-6 hours at a time.

Wind will be mainly Force 4 on the English Channel coasts and Force 3-4 on French Channel coasts; in sheltered stretches of the French Channel coast periods of Force 2-3 could be expected. The wind direction throughout will be Westerly.

Additional meteorological statements were made at this meeting in reply to specific questions as follows:

Admiral Creasy (C of S to Naval C-in-C) asked if there was a chance that conditions from Wednesday to Friday might be better than those described in the main statement. He was advised that there was a reasonable chance that the weather systems which were expected to cause the temporary deteriorations after Tuesday would follow a more northeasterly track to Iceland or Southeast Greenland and if that happened the cloud conditions would probably be better than these now forecast. But nothing definite could be said at present about such future developments.

General Eisenhower asked if anything could be said about conditions beyond Friday. He was advised that the forecast even up to then could not be given with any substantial confidence. The general weather conditions must continue to be regarded as disturbed and unsettled; after the very vigorous shake-up in the whole synoptic situation over the North Atlantic which we are going through now, conditions cannot settle down immediately.

But considering the time of year and the evidence we now have, there is a reasonable prospect of weather slowly improving after Friday if the present trend of development over the period Wednesday to Friday comes out as now expected.

A.C.M. Tedder asked about the confidence in the forecast. In reply it was explained that pressure systems had formed, deepened and crossed the Atlantic at a rate appropriate to mid-winter. Confidence in the forecast for more than a short period ahead cannot be high; but there is a fair chance that the low pressure system now in the Newfoundland area will move on a northeasterly track and more slowly than its predecessors; if developments go that way, that should give the azores high pressure system a chance to build up again and at least partially to protect the Channel areas from future depressions traversing the Atlantic from the west.

To A.C.M. Leigh-Mallory and General de Guingand who asked about the detailed cloud conditions expected overnight Monday-Tuesday, the information given was that following the clearance on Monday, cloud over the assault areas and the immediate hinterland would probably remain well broken from midnight Monday to Tuesday morning. The base of this cloud would probably be about 2500-3000 feet and could be expected to be not more than 5/10ths at any time in that area

Asked by A.C.M. Leigh-Mallory if his meteorological advisors at Hq, AEAF agreed with views presented at this meeting, the reply was that they did; their view was that good though not uninterrupted conditions for visual bombing by heavy and medium bombers could be expected from Monday evening till early forenoon Tuesday; then periods of good bombing alternating with poorer periods after the deterioration on Tuesday-Wednesday had passed.

Naval C-in-C, commenting on conditions for operation of spotting aircraft for naval bombardment, which required cloud base heights not below 2500 feet, was assured that conditions would probably be favorable for these spotting and reconnaissance operations.

(Following this meeting, provisional instructions were issued for launching the assault at 0630 on Tuesday morning.)

0415, Monday, 5th June.

There has been no substantial change in the information available since, or in the forecast presented at, the meeting yesterday (Sunday) evening.

The fair to fine interval which by 0415 had begun at Portsmouth will probably last into the forenoon of Tuesday. During this interval, cloud will be mainly less than 5/10ths, with base at 2500-3000 feet.

Wind on the beaches in the assault area will probably not exceed Force 3 in this interval and will be westerly. Visibility will be good.

During Tuesday, cloud will very probably increase again from the west giving a period of overcast sky with cloud base at about 1000 feet in the assault area later in the day; these cloud conditions will continue overnight Tuesday-Wednesday. Winds will be westerly Force 4 on the English coasts and mainly Force 3 on the French coasts.

Conditions will probably continue unsettled after Tuesday and it is difficult to time further changes. But it is likely that after another front has passed on Wednesday when the 10/10ths cloud at 1000 feet lasting over Tuesday night become broken, the cloud base will increase to 2000-3000 feet, though the average amount will probably remain at about 7/10ths. In this period from the passage of Wednesday's front till about Friday, beyond which no useful forecast can be given, there will be intervals of completely overcast sky with cloud base down to 1000 feet. Considerable fair periods of broken cloud can reasonably be expected between the overcast intervals. Visibility will be good throughout.

A.C.M. Tedder said that on Friday and Saturday, the effects of moist warm air coming into the Channel and producing much low stratus cloud had been prominent in the forecast presented. What had happened to clear this air from the Channel so quickly?

There had been considerable doubt about the real synoptic situation on the Atlantic over the last 48 or 60 hours. It had been considered that a front trailing from one depression now off Northwest Scotland was bent away sharply to the west into another low pressure system off Nova Scotia and Newfoundland and that this front did not extend far enough south to come through the Channel areas. This analysis had been faulty mainly because of inaccurate and inadequate reports. The front had actually swept down southeastward and crossed the northern coasts of the Central Channel in the last few hours.

In answer to other questions at this meeting, the following information was given:

(1) There is a reasonable chance after Wednesday of further low pressure systems from the western Atlantic taking a more northeasterly courseinto the Iceland area instead of towards northwest Scotland; if this occurs, the fronts associated with these low pressure systems will not have such an intense effect on the wind and cloud conditions in the Channel and French Coasts.

(2) The situation even after Wednesday must continue to be regarded as disturbed; a quiet settled spell cannot be expected to start immediately after such an intensely disturbed situation. But the time of year suggests that changes after Wednesday may be expected to be in the direction of improvement rather than of renewed or further deterioration to the present intensity.

(Following this meeting, the final and irrevocable decision to launch the assault on Tuesday morning was taken.)

0845, Monday, 5th June.

AC of S, G-3 (Gen. Bull) was informed by telephone (1) that there was nothing further to add to the forecast presented at 0415 and (2) that recent reports had shown that the clearance in cloud cover which had set in at Ports-

mouth in the early morning hours had not reached the area where the assault would have been taking place until at least 0600. Conditions there were 10/10 low cloud, base at about 1000 feet and had been so throughout the night. Airborne landings and medium bomber support would almost certainly have been impracticable; heavy bombers would have had no opportunity for visual bombing and aircraft spotting for naval bombardment would also have found conditions impracticable. Winds had been and continued a good Force 4 on the beaches.

VII. Brief description of the Weather in Normandy and the Channel

(i) Period 4th to 9th June, 1944:

The two preceding Sections have summarized the meteorological advice given to the Supreme Commander and his staff about the weather likely to be experienced around the scheduled date of assault. This Section provides a summary of the main weather phenomena actually observed during the most critical period, 4th to 9th June, in the Channel and Normandy beachhead.

The summary has been compiled from notes based on reports from operational aircraft and naval vessels and on reports transmitted back by the earliest Meteorological Sections to land with the Expeditionary Forces.

Sunday, 4 June:

0100 — Wind: WSW, Force 2-3.
Cloud: 2-3/10 high.

0400 — Wind: WSW, Force 3.
Cloud: No low cloud over beachhead; 9/10, base 1-2000 ft. in Cherbourg Peninsula.

1000 — Wind: WSW, Force 3-4.
Cloud: Variable high cloud. Low cloud on Cherbourg Peninsula dissipated to 2-3/10.

After 1000 — Wind: WSW, Force 3-4.
Cloud: Small amounts over Channel and Northern France.

Monday, 5 June:

Prior to 0400 — Wind: WSW, Force 5.
Cloud: 10/10 multi-layer cloud.

0400 — Wind: W, Force 4-5.
Cloud: 10/10, base 1-2000 ft.

0700 — Wind: W-WNW, Force 4.
Cloud: 10/10, base 1500 ft.

1300 — Wind: W, Force 3-5.
Cloud: 7-10/10, base 3-4000 ft.

1800 — Wind: W, Force 4.
Cloud: 7-10/10. base 4-6000 ft. with broken cloud at 2000 ft.

Tuesday, 6 June:

0100 — Wind: W, Force 3.
Cloud: 7-10/10, base 3-5000 ft.

0400 — Wind: WNW, Force 3.
Cloud: 4-6/10, base 3000 ft.

0545 — Cloud: Beachhead clear, with 6/10 low cloud inland.

0800 — Wind: WNW, Force 3-4.
Cloud: 7-9/10, base 3000 ft., tops near 7000 ft., with 10/10 medium cloud above 11-12000 ft.

Late Forenoon	Cloud:	Clouds broke and cleared over Channel.
1700	Wind:	WNW, Force 4, 5 at times.
	Cloud:	Clear conditions over Channel. Variable amounts of low cloud, mainly 6-9/10 over beachhead and further inland. There was a clear area over the Seine Estuary.
1800	Cloud:	At Cherbourg, 4-6/10, base 3-5000 ft.; at Havre, 1-2/10 low cloud, 2-3000 ft., with patchy medium

Wednesday, 7 June:

0100	Wind:	WNW, Force 4.
	Cloud:	At Havre, 9/10, base 2-3000 ft.
0700	Wind:	WNW, Force 4.
	Cloud:	Low cloud became more broken.
During Day	Wind:	NW, Force 4, decreasing to Force 3.
	Cloud:	Large amounts mainly 2000 ft. but 1000 ft. locally in showers at first, decreasing and lifting in afternoon. Small amounts at times later, especially near coast.
1800	Wind:	At Havre, N-NW, 2-3.
	Cloud:	2-3/10.
1800 - 2100	Cloud:	Variable, 4-6/10, base 2000 ft. in beachhead and inland.

Thursday, 8 June:

0100	Wind:	NW, Force 3-4, Force 4-5 in Channel.
	Cloud:	Small amounts in Channel, 9/10 broken low cloud Le Havre base 2-3000 ft.
0400-0700	Wind:	WNW, Force 3-4, Force 4-5 in Channel
	Cloud:	Small amounts of cloud over the Channel, 2-3/10 beachhea area, maximum Le Havre, base 3000 ft.
Forenoon	Wind:	WNW, Force 4, Force 4-5 in Channel.
	Cloud:	Small amounts of low and high cloud, base 1-2000 ft.
Afternoon and Evening	Wind:	W, Force 4, increasing to Force 6 by 1800 hours, Force 5 in Channel.
	Cloud:	Increasing multi-layer cloud, base of low cloud 1000-150 ft rain beginning 1600-1800 hours.

Friday, 9 June:

0100-0400	Wind:	W-WSW, Force 5, Force 6 in Channel.
	Cloud:	10/10 multi-layer, base 500-1000 ft., light rain.
0400-0700	Wind:	WSW, Forcd 3-4, Force 4-5 in Channel.
	Cloud:	10/10 multi-layer cloud, base 1-2000 ft., locally 500 ft light to moderate continuous rain.
0700-1300	Wind:	WSW-WNW, Force 5, Force 6 in Channel.
	Cloud:	10/10 multi-layer cloud, base 1,000 ft., light intermittent rain.
Afternoon and Evening	Wind:	NW, Force 4, Force 5 in Channel.
	Cloud:	4-6/10 low cloud, occasionally overcast, base 1-2000 ft. occasional showers.

(ii) Period 17th to 21st June, 1944:

Reference is made in Section VIII (v) to the following paragraphs c weather during this later period:

Saturday, 17 June:

0100	Wind: NW, Force 4, Force 5 in Channel. Cloud: Overcast, ceilings near 2-3000 ft.
Forenoon	Wind: N, Force 5, Force 6 in Channel. Cloud: Overcast, ceilings near 2-3000 ft.
Afternoon	Wind: N, Force 4, but Force 6 and 7 in Straits. Cloud: 2-3/10, ceilings near 2500 ft., scattered showers.
Evening	Wind: N, Force 3-4, Force 6 and 7 in Straits. Cloud: Cleared at beachhead.

Sunday, 18 June:

0100	Wind: NE, Force 3-4, Force 4-5 in Channel. Cloud: Overcast conditions, ceilings near 2-3000 ft.
Forenoon and Afternoon	Wind: NE, Force 4, Force 5 in Channel. Cloud: Broken, ceilings near 3000 ft.
Evening	Wind: N-NE, Force 2-3, Force 3-4 in Channel. Cloud: Multi-layer clouds, causing overcast conditions.

Monday, 19 June.

0100-0400	Wind: NE, Force 4, Force 5 in Channel. Cloud: Overcast conditions thickened, light rain, ceilings 1-2000 ft.
During Day	Wind: NE, Force 5 and 6, Force 6 and 7 in Channel. Cloud: Light to moderate rain persisted, ceilings below 500 ft.
2200	Wind: NE, Force 5, increasing to Force 6 and 7 in Channel. Cloud: Broke to 9/10, rain intermittent, ceilings near 3000 ft.

Tuesday, 20 June:

0100-0400	Wind: NE, Force 5 and 6, Force 6 and 7 in Channel. Cloud: Multi-layer clouds cleared, and small amounts were observed.
0400-Forenoon	Wind: NE, Force 5 and 6, Force 6 and 7 in Channel. Cloud: Stratocumulus cloud cover developed, ceilings near 1000
Forenoon and Afternoon	Cloud: Cloud deck persisted in forenoon but broke to small amounts during afternoon.
After 1800	Wind: ENE, Force 6, NE, Force 6 and 7 in Channel. Cloud: Low cloud deck re-formed, ceilings near 1000 ft.

Wednesday, 21 June:

0100-
Afternoon Cloud: Overcast conditions, ceilings between 500 and 1000 ft.

Late
Afternoon Wind: NE, Force 5 and 6, NE, Force 6 in Channel.
Cloud: Small amounts of cloud.

VIII. Review of the military decisions as affected by the meteorological advice.

(i) Earlier sections of this report have summarized the procedure adopted for providing meteorological advice, particularly weather forecast advice, to the Supreme Commander and his Staff; a summary of the forecast actually presented has been given (Sections V and VI) and also a synopsis of the weather as it actually turned out to be (Section VII).

Technical details relating to (a) the weather situations and its developments during the critical period, (b) the views expressed by the forecasting centrals, which took part in the meteorological conferences, and (c) some of the problems of forecasting which were encountered during that time - these have been relegated to Appendices A, B and C respectively.

So far as the general Report is concerned, it is desirable at this stage to consider some of the implications of the meteorological advice and the alternatives which might have been adopted. Those matters are reviewed in the following paragraphs.

(ii) General and Preliminary Decisions.

Apart from the fact that the scheduled date for launching the assault was set early in June, and not in May or July, a decision which may well have been influenced much more by military necessity than by information of the type referred to in Section II, the main facts from the meteorological point of view are:-

(1) that the scheduled assault at 0630 on Monday 5th June was deferred on a day-to-day basis from Monday 5th June to Tuesday 6th June, on a weather forecast given 30 hours before the scheduled time of the landings, and
(2) that the decision to proceed with the assault on Tuesday 6th June was taken on a forecast presented on the evening of Sunday 4th June.

It is true that decisions had been taken on May 28th and 31st and June 1st which involved the sailing of naval bombarding forces and the more distant assault Forces, and that those decisions were at least partly influenced by meteorological advice; but it had been made clear that those Forces would not be allowed to sail on the scheduled dates in advance of D Day only if the meteorological advice was that conditions eight days ahead (in the case of the forecast on 28th May and correspondingly shorter periods for May 31st and June 1st) would be prohibitive for the assault in the Channel area and Normandy coast by reason of continued gales or continuous low cloud.

In the circumstances of the weather situation at the time the probabilities were against such contingencies, and the Supreme Commander was advised accordingly (see Section IV).

Decision to defer from 5th to 6th June.

As regards the decision to defer the assault, made provisionally on Saturday 3rd June and confirmed early on Sunday 4th, mainly on a forecast of likely conditions in the central Channel and Normandy areas from 0001 hrs on Monday, the description of the actual conditions given in Section VII(i) shows that cloud conditions were continuously overcast and wind was Force 4-5.

Those conditions continued till at least 0600 on Monday and the improvement thereafter was slow and irregular. It was not till well into the forenoon of Monday that low cloud began to break to any operationally useful extent; wind remained fresh in the beachhead area until the evening of Monday.

It is therefore fairly certain that the weather conditions in Normandy during the crucial hours immediately before and at the scheduled time of launching the assault were prohibitive, at least from the points of view of airborne troop landings, and the actual landings on the beaches; the heavy bombers would have had to operate by non-visual technique and the medium and fighter bombers would have been seriously hampered. Aircraft spotting for naval bombardment would probably not have been practicable.

(iii) Decision to proceed on 6th June.

As regards the decision to proceed with the plan after 24 hours' postponement on the basis of a meteorological forecast presented on Sunday evening, 4th June, Section VII (a), shows that the actual conditions in the hours immediately preceding and following the time of landings, though not the ideal or even the complete minimum requirements, were decidedly better than those on the preceding and succeeding nights.

The surface wind, and therefore the sea roughness, had moderated during Monday evening; and the amount of the cloud and the height of its base at various times of the night and early morning were such as to allow all phases of the assault to be carried out according to plan.

In particular, the conditions for airborne landings were somewhat better than forecast in that the cloud ceiling was at the unusual height of 4000-5000 feet; and by the time the heavy bombers were due to operate, the cloud was sufficiently broken to allow use of visual technique. The medium and fighter bombers were not hampered, nor were the spotting aircraft. The wind conditions on the beaches were within the limits set, though the sea and surf still suffered from the stronger winds of Sunday and Monday.

That the weather deteriorated again during Tuesday and continued poor into Wednesday could not have surprised the Supreme Commander and his Staff; considerable emphasis was put on this deterioration at the meetings leading to the final decision (Section V).

(iv) Possible alternative decisions.

It should be mentioned that the Supreme Commander's meteorological advisors gave much consideration on Sunday, 4th June, to the question of whether conditions for an assault on Tuesday, 6th June would be more or less favorable than on Thursday, 8th June. They understood that as the assault forces from greater distances were already at sea, at least a proportion of them would require to return to base for about 12 hours if decisions went against launching the assault on Tuesday. This would preclude a Wednesday assault.

In this connection, the alternatives from the meteorological point of view were

(a) a reasonable confidence in a favorable interval, even if of limited duration, just preceding and at the time of an assault on Tuesday,

(b) less confidence in an only possibly better interval on Thursday morning.

Keeping in mind the extent to which the whole weather situation had so quickly and intensely been disturbed since Thursday, 1st June, and the proneness of disturbed conditions to continue once they had started (particularly when that start had been so violent for the time of year) it was considered that the alternative (a) should be emphasized

in the advice given to the Supreme Commander. If in fact the conditions turned out so that Thursday, 8th June, would have been a better day for the assault, then those conditions would be equally valuable for the immediate follow-up phase of the operation. Whereas, if the opportunity of favorable conditions overnight Monday-Tuesday were missed, and if information on Monday and Tuesday showed that Thursday would be less favorable than it seemed on Sunday, then the whole position would have become extremely serious from the viewpoint of holding up such a huge and complex operation.

As matters actually turned out, the weather overnight Wednesday-Thursday (7th and 8th June) was probably not quite as good as the weather from midnight on Monday 5th to early Tuesday 6th June, and during Thursday wind increased to Force 6 accompanied by multilayer clouds and rain; by evening, winds were mainly Force 6. These conditions continued throughout Friday with overcast skies of multilayer cloud, base at times down to 500 feet.

The weather throughout the whole period from 3rd June to at least 22nd June (when these notes were written) remained unsettled with intermittent spells of strong wind and cloudy to overcast skies.

(v) Weather a fortnight after the scheduled date for assault

Although the deliberations at the meteorological conferences did not explicitly take into account the contingency of the assault having to be postponed beyond a few days from the scheduled date of 5th June, it is of interest to look briefly at what the sequel might have been had the Supreme Commander found it impracticable to decide on a date in the first batch of possible dates, viz. 5th to 8th June.

In this contingency, it is likely that for other than meteorological reasons the operation would have had to be postponed for a 12-14 day period.

Section VII (ii) shows that the early hours of 17th June would have been favorable for the actual assault and its associated operations, but the immediately following days would have been prohibitive for the follow-up and early build-up phases. Force 5 winds with Force 6 and even 7 at times from a northeasterly direction with long periods of overcast sky and low ceiling (1000 feet or less) would have seriously hampered all naval and most air operations, as indeed they did, though at a somewhat less critical stage of the operation.

IX. Comments and Recommendations

1. General

The following paragraphs summarize some of the more important impressions and views derived from taking part in the meteorological arrangements and in the presentation of forecasts and information. The comments are not offered in any sense of criticism; they are included in this report primarily in the hope that they may be of use in any similar circumstances that may arise in the future.

From the viewpoints both of the procedure adopted for obtaining the meteorological advice, and of the complexity of the operation for which the advice was given, the arrangements were probably unique; it is therefore not surprising that the arrangements were not perfect. But the experience gained should be of value for the future and it is the aim of this Section to indicate along which lines improvement might be sought.

2. From the Military Point of View

(a) Information on Operational planning made available to Meteorological advisors.

The Meteorological Section was not set up at Supreme Headquarters until a considerable time after the initial plans for the operation had

been made, but facilities were provided for the Section to become conversant with whatever details were necessary for giving meteorological guidance in the later planning stages. Besides access to relevant papers opportunity was given for discussion with the planning authorities.

This latter aspect is important in all military operations. With a technical and complex subject like meteorology, written statements (or "appreciations") about likely implications of meteorological factors on an operation are a very poor substitute for oral discussion with the appropriate authorities.

From the viewpoint of the operational staff such discussion allows the meteorologist to explain the implications and significance of aspects of meteorological information which are liable to be overlooked and at the same time care can be taken to ensure that unwarranted emphasis is not attached the operational staff to weather statistics.

From the opposite angle, the meteorologist learns by discussion much better than by paper statements which aspects of weather at which precise times are most important from the operational standpoint and so can give more effective advice whether it be in planning or in decisions on actual operations.

A case in point was the airborne part of the NEPTUNE operation. According to the requirements as set out in Section I(b) a cloud ceiling of 2500 feet had been accepted as the minimum along the route from base to target and over the target area. But on the 3rd June when it became fairly certain that cloud conditions were likely to be poor on the night of the 4th-5th, discussion with the ultimate authorities elicited the information that airborne landings might be effectively made with a 10/10 cloud ceiling at or even somewhat below 1000 feet.

(b) Elasticity in selection of D-Day.

With the magnitude, range and complexity of the military and political factors concerned in the NEPTUNE operation, elasticity in decision must necessarily be limited. Even such details as tides, light and clearance of under-water obstacles practically pre-determine when such amphibious operations must be launched. Nevertheless NEPTUNE was deferred one day and would doubtless have been further deferred had weather prospects justified it.

The inference is that no matter how complex the operation is, plans should always allow for a postponement because of weather. In the last resort the success of the initial landings and therefore of the whole operation is determined by weather conditions allowing effective co-operation of all arms.

(c) Rehearsal of procedure involving meteorological advice leading to Military decisions.

As had been described in Section III, the Supreme Commander's Staff arranged for meteorological briefings for dummy D-days to be given in the weeks preceeding the actual operation. It was realized that the actual making of the final decision, taking into account the likely weather conditions, was an important phase of the whole operation.

This was an effective and profitable innovation in military operations and one that should be followed in similar operations in the future. It might have been even more profitable if the weather in South England and the Channel in the weeks before the invasion had not been so consistently good. For the complete break in the weather at the time when the real decision had to be made introduced complications which could hardly have been provided against with the blue skies and light breezes which formed the background of most of the rehearsals.

3. From the Meteorological Point of View

(a) The procedure for obtaining the agreed Meteorological Advice

There are inherent defects in the kind of meteorological procedure

adopted for the NEPTUNE operation. So long as accurate weather forecasting involves a subjective analysis and interpretation of observational data with a blended background of experience and technical knowledge which necessarily varies with each individual forecaster, so long will forecasting centrals with the same basic data produce different forecasts of future weather.

Such differences in interpretation and analysis cannot adequately be resolved by telephone conferences, however frequent. Aids such as facsimile reproduction processes for synoptic charts might reduce some of the differences by ensuring that each of the advising Centrals realizes clearly what different premises the other centrals are using for making their forecasts. But in the circumstances described in Appendix A where it is shown that interpretation of a report from one ship was all-important, it is doubted whether an interchange of each other's synoptic charts by facsimile process would have helped. As in the meteorological conferences at that time, each Central would naturally adopt the interpretation which best fitted its general trend of analysis.

Another aspect of this same matter is the drawback arising from the need for achieving and disseminating an agreed forecast for coordinating the meteorological advice at operational levels. As soon as a main decision is made for starting complex operations of the NEPTUNE nature, instructions are issued to the various force commanders, Naval, Air and Ground, both U.S. and British, to proceed with the execution of the plan. It is therefore necessary that the meteorological advice given to these force commanders does not conflict with the advice on which the primary decision has been taken. This necessitates that each of those advisors be provided with a statement of the forecast on which the advice to the Supreme Commander has been based, and this in turn requires that the outcome of meteorological conferences on which the Supreme Commander's advisor has based his views be framed in strict meteorological terms.

Now it is one thing to convey orally a description of future weather, stressing aspects that are essential and minimizing others sufficiently to allow decisions to be made; it is another thing to commit such advice to paper in a way which will be useful to meteorological advisors at specialized operational formations. To be of any value to such advisors, the statement requires definition of the timing of weather sequences, the intensity of the accompanying weather, the specific localities affected and so on. And to get a number of forecasting Centrals to agree to such a detailed statement on occasions when, for example, passage of fronts cannot be accurately timed, either means that only one of the Centrals' advice must be taken, or that the statement must be so worded for acceptance by all the Centrals as to be of little value to the meteorological advisors at operational formations.

It is not clear what the solution to this difficulty may be for future operations of this kind. One solution might be to establish one Central at which the best qualified and experienced representatives of the various meteorological services concerned work together instead of in separate institutions connected only by wires; it would be agreed beforehand by the various services concerned that the forecasts issued by that Central would be accepted by all the services involved in the operation. This kind of arrangement is known to function on the military side, but whether meteorological services could be fitted into a similar framework is questionable.

A second solution might be found on the lines of restricting the function of the conferences solely to providing an exchange of views about analysis and future trends and developments; there would be no responsibility at the actual time of the conference on the part of the chairman to find an agreed development and forecast acceptable to all the participating Centrals.

With the views of the Centrals in mind, the Chairman would use his own discretion as to which, if any, of the sets of views offered he would adopt as the basis of the advice to be given to the Supreme Commander and also to be used in framing coordinated forecasts for distribution to the meteorological sections at operational formations.

(b) The value of long range forecasting in military operations.

Reference has been made elsewhere in this report to the accuracy of forecasts for more than 24 or 36 hours except in stable weather situations. Cursory examination of the series of 5-day forecasts submitted to the Supreme Commander and his Staff during April and May, 1944 has shown that even in the rather abnormally stable weather circumstances of those months, the operational value of forecasts fell away quickly after the second or third days after the issue of each forecast; when the synoptic situation was changing rapidly, the forecasts frequently required substantial modification before the first day was past. If specific details of cloud, wind and visibilities for limited areas had had to be included in each forecast, even this 24 hour period might well have been too long in some types of English weather.

Although every effort should therefore continue to be made by the various Meteorological Services in improving their several techniques for extending weather forecasts beyond 24 hours, it has to be appreciated that at the present time forecasts in sufficient detail to be of operational (as distinct from planning) value can seldom be made with useful confidence for more than a 24 hour period in advance.

For assistance in planning, statements can be made to the effect that "weather is likely to continue to be unsettled with considerable general cloudiness though with intervals of well-broken cloud and good visibility", or, in more exceptional circumstances, that "mainly settled weather will persist for next few days with light, moderate northwesterly wind and well broken cloud, minimum at night". But the discovery of a technique by which even first approximations to such details of weather as are required for specialized operations can be forecast as a regular daily procedure with useful accuracy for any day more than two or even more than one day ahead still remains a matter for future research.

APPENDIX A

Description of the Synoptic Meteorological Situations and Their Developments over the Period 1st to 6th June 1944

1. Introductory Remarks.

The material in this Appendix and Appendices B and C is primarily of technical (meteorological) interest. The aim in compiling these Appendices has been to reconstruct some of the problems with which the Forecasting Centrals were confronted during the critical phases prior to launching operation NEPTUNE.

The paragraphs which follow contain a suggested post facto analysis of the weather situation covering the period of operational interest. Though every care has been taken to utilize every piece of evidence in reconstructing the situations, the analysis is not necessarily a final statement capable of acceptance by all the meteorological authorities; it is primarily intended for consideration in conjunction with the forecasts offered to the Supreme Commander and his Staff (Sections V and VI) and secondarily for appreciating the difficulties with which the forecasting Centrals contended during the conferences summarized in Appendix B.

Particular mention should be made at this stage of the vital assistance in the analysis and forecasting provided by ships which had been assigned to predetermined locations in the Atlantic by the United States Navy and the British Admiralty. The United States Navy augmented their regular complement of six ships by two additional ships for the critical period. These eight ships operated mainly west of 30°W. The British Admiralty provided two ships from Day D-7, one to function between 20 and 25°W longitude, due south of Iceland and the other in a similar longitude north of the Azores.

2. General Comment.

Some of the main difficulties of analysis are referred to as they arise in subsequent paragraphs; they were such that at the time it was possible for the forecasting Centrals to differ from each other by as much as 10 mbs. in their interpretation of the pressure in an important area, and even after the event it is difficult to place much confidence in any reconstructed chart.

The critical developments took place in the area bounded approximately by 55°N-60°N and 15°W-35°W between the early hours of the 2nd and midnight of the 4th. The western section of this area (25°-35°W) is normally an "empty" area from the viewpoint of reports; normally, the eastern section is at least partially covered by the "Bismuth" meteorological reconnaissance flight, and during the time of the operation a ship reported from the area between 22° and and 25°W, and 52° and 59°N.

When movement and development is rapid, the interpretation of reconnaissance flights is a matter of considerable difficulty; past experiences have led the majority of forecasters to treat aircraft pressure reports with great caution. In the event the reports from the single ship became all important, and it is greatly to be regretted that at the critical time (from both the synoptic and operational viewpoints) very substantial doubt was introduced into the definition of the situation by a jump of 20 mbs. in reported pressure; this was repeated in the next observation then, and the discontinuity followed. In addition, the ship began its southward run on the 2nd, and was to the south of the area of maximum development on the 3rd and 4th. When this is considered in conjunction with the somewhat unreliable reports to the south of Greenland on the 1st, there can be no surprise at the existence of considerable differences in analysis between the Centrals.

It should also be remembered (a) that the period under consideration followed a long spell of mainly anticyclonic conditions and (b) that during the period when the main decision had to be taken a situation developed which can only be described as very disturbed even by winter standards.

The charts (reproduced as Figures 1 to 7) which have been prepared for use with the following notes represent the reconstruction by the Meteorological Sec-

tion, SHAEF, of the main essentials of the synoptic pressure distributions during the period 1st to 6th June. The series of charts used by each Central at the time probably differed in greater or less detail from Figures 1 to 7.

Upper Air Contours.

Figures 8 to 11 are included for the purpose of indicating the general nature of the upper air circulation on 5th and 6th June. In those figures the bold continuous lines are pressure contours drawn for each 200 feet; the thinner dottted lines are isotherms (5°C) and the very thin continuous lines confined to the British Isles and immediately adjacent areas are "thickness lines" in 200 feet intervals between the 750 and 300 mb. levels. Short heavy arrows represent flow of cold air between the levels of 750 and 300 mb. and the short skeleton arrows do the same for warm air. Arrows connecting encircled courses indicate trajectory of the associated systems, and black arrows with W or K show advection of warm or cold air at the 500 mb. level.

The figures 8 to 11 have been supplied by the Director United States Weather Services to whom acknowledgement is made for permission to reproduce them

3. Analysis

At 0100Z on 1st June, a complex low presure trough extended from a shallow centre to the west of Scotland (L1)* southeastward over the British Isles. A cold front lying north to south over central France was moving east. Pressure was high in the Jan Mayen region with a flat ridge down to the North Sea. A ridge from an anticyclone centered over the Azores extended into the south of the Bay of Discay.

A comples depress ion east of Newfoundland (L2) was moving northeast, and a further depression (L3) was forming in the St. Lawrence region.

A wave disturbance (L4) with no closed centre but with very warm moist air in its warm sector to the northeast of Bermuda was moving northeast (Fig. 1).

The 500 mb chart showed a centre to the south of Greenland, with a col between Iceland and Scotland. The air between Greenland and Iceland was warmer than that immediately to the south, with cold air over Scandinavia. There was a strong west southwesterly flow from southeast of Newfoundland to the col, and strong easterlies over south Greenland.

During the 1st, L1 moved east towards northern Scotland, and cold air from northern Scandinavia moved westward on the southern side of the Jan Mayen high, with the formation of a col at the surface and at 500 mb to the south of Iceland.

2nd June

It seems probable that a trough from L2 developed to the east with the main centre following more slowly (at 20-25 mph) on an east northeasterly track; but the detail in this area is obscure owing to the corrupt and conflicting nature of the few reports available in the area south of Greenland. The depression has a complex history and seems to have had two separate centres at 0100 on 1 June. However, a front (probably the occlusion of L2) passed the ship in 57°N 24°W between 0100 and 0700 on the 2nd. There is also little direct evidence of the progress of the tropical air in the wave L4; but at 0900 hrs. it had reached the ship at 51°N 32°W. In this vicinity it would come under the influence of the cold front of L2, and by 1300 on the 2nd it is probable that a complex wave was forming in the region 50°N, 30-35°W. In the meantime, L3 had moved into a position east of Newfoundland. (Fig. 2).

The 500 mb chart on the 2nd showed a very strong west southwesterly sweep from south of Newfoundland to Scotland, with the warmer air between Greenland and Iceland being displaced by colder air from the east and an elongated col from south of Iceland to south Norway. Conditions has then become suitable for cyclonic development in the region between Iceland and Scotland.

Developments in the 24 hours after 1300 hrs. on the 2nd are difficult to follow, particularly in view of the nature of the reports received from the ship in about 55-57°N 25°W. There is some evidence that the pressures reported by this ship were for a time low by an amount of the order of 5 mbs. but this is not cer-

tain. The confusion was increased by a jump of 20 mb in reported pressure from the same ship at 0300 on the 3rd; this discontinuity was maintained by the 0600 report but had disappeared by the time the 1000 report was received.

At 1300 on 2nd June, the diffuse warm front of L2 had spread into west Ireland and pressure was falling in the region 25°W, where the wave L4 was approaching the trough of L2, resulting in a low pressure area of complex frontal structure.

3rd June

The cold front of this depression appears to have passed the ship at 55°N 22° between 0100 and 0300 on the 3rd, but there was no appreciable rise in pressure and the front does not appear to have passed far south of this point before returning as the warm front of L3. The ship was again in warm air by 1600 hrs on the 3rd.

* See Figs. 1 to 7 for positions of pressure systems identified by symbols in these paragraphs.

In the meantime, cold air had been spreading south to the east of an anticyclone in the Hudson Bay area and the eastward movement of colder air to the south of Greenland had continued. The result was the establishment of an intense west-southwesterly gradient at 500 mb. from Newfoundland to Scotland with a flat area from Labrador to the Faroes. In this intense gradient the systme L3 appears to have moved quickly east, the cold front progressing at about 40 mph, passing a ship in 51°N 33°W between 1300 and 1600 on 3rd June. During this rapid movement, the centre would not be expected to deepen appreciably and a trough would probably be left in about 55°N to 60°N. The very moist warm air of L4 had spread into the west of Ireland by 1300 on the 3rd, and the considerable pressure falls in this region which had first appeared on the 0100 chart continued after the passage of this warm front.

During the 3rd the depression L6 formed in the region of Nova Scotia; and, drawing polar air from the Hudson Bay anticyclone, began to deepen very rapidly whilst moving ENE. The suggested position of low pressure systems and major fronts at 1300 on the 3rd are shown on Fig. 3.

4th June

The rapid easterly motion of L3 and the deepening of the complex system L5 continued, and the cold front of L3 passed the ship at 52°N 20°W between midnight and 0400 on the 4th, and was over Ireland by 1300 hrs. By this time the circulation of L3 had combined with L5 and the centre was moving more slowly. There had been considerable deepening late on the 3rd, which continued on the 4th. A suggested analysis for 0100 hrs. 4th June, is shown of Fig. 7, with tracks of the low pressure systems.

During the 4th June, the cold front of the combined depression L5 continued to move across the British Isles, with an average speed of about 30 mph, whilst L6 deepened very rapidly indeed, with the centre slowing and moving NE or N. This simultaneous deepening of L3 and L6 was a most remarkable development. The strong westerly flow at upper levels was distorted by the two deepening and occluding depressions and an intense NW'ly gradient developed at upper levels to the west of the British Isles. A very sharp and deep upper air trough moved over the country, the trough line being about 400 miles behind the surface cold front of L5 on the 5th, and rises of pressure at the surface were inappreciable until the upper trough line had passed.

5th June

The frontal systm of L6 was carried forwerd to the south of the centre, which continued to move slowly NE on the 5th. The surface warm front was carried forward almost to the ridge line, over which there was a fairly strong gradient at all levels. In these circumstances no building of the ridge could be expected, and pressure in the col between L5 and L6 probably remained at about the same leve (1010 mbs.) throughout. L5 probably attained its maximum depth about 0100 hrs. on the 5th when it was estimated at below 975 mbs. in 60°N 5°W. It was moving very slowly East, and by 0700 hrs. was filling rather rapidly.

By 1800 hrs. on the 5th, L6 had reached its maximum depth, a pressure of 975 m

being reported near the centre at 55°N 45°W. The col was then in the neighborhood of 60°N 22°W and the centre of L5 just north of the Shetlands. By this time warme air had been carried well round the north of L5, isolating a pool of colder air in the eastern North Sea. Rises in this region were small, and the tendency for a southeastward transference of the centre of lowest pressure was obvious by 0700 hrs. on the 6th; a gradient of 25-30 mph. from the northwest was maintained over the Channel area throughout the 6th by this means. The surface warm front of L6 had been carried forward to the ridge line, and its outward movement had ceased by 1300 hrs on the 6th. Ther upper winds over Western England and the Channel during the 6th reached a speed rare even in disturbed winter conditions.

APPENDIX B

Summary of views of the Forecasting Centrals as expressed at the Meteorological Conference held from 1st to 6th June.

1. Introductory Remarks.

(a) Sections 2 to 4 of this Appendix summarise in the form of brief notes the views of the three forecasting centrals on synoptic developments covering the period of decisions for launching the assault; they are based on notes made hastily during the meteorological conferences by telephone. The Figures 1 to 7 referred to in the notes and the nomenclature adopted for the various pressure systems are as described in Appendix A, particularly Section 2.

(b) Although the series of synoptic charts reproduced as Figures 1 to 7 are referred to in the brief summary of analysis in Section 2 as if they constituted the single and unique series of charts which each central used at the time of conferences, the charts are post facto reconstructions prepared by the Meteorological Section SHAEF: each of the Figures 1 to 7 is known to differ in greater or less detail from the actual working charts used by the centrals at the time of the conferences.

These differences naturally have important bearings on the significance of the views expressed by the Centrals as briefly summarised in Section A below. To do complete justice to each Central it would have been necessary to reproduce three sets of charts, one fore each central. But early enquiry with this in view made it clear that it would not be practicable to obtain reproduction of the charts exactly as they were when the discussions took place.

It was therefore considered that the best course was to draw one independent set of charts using all the later data and subsequent history of developments; it was realised that this set of charts in all probability would not be accepted by any of the centrals and would make the analysis as summarised below appear too pessimestic or too optimistic. But it would serve the purpose of illustrating the general trend of development as envisaged by the centrals.

(c) Another aspect of the conferences should probably be kept in mind in reading the summary of analyses. The conferences were hardly ever shorter than one hour and sometimes extended to almost two hours; it cannot therefore be expected that the views expressed by the centrals can be adequately compressed into a very btief summary. Further, that central which opened the conference - the opener changing in rotation - generally presented a comprehensive analysis, and the presentations of succeeding centrals were mainly confined to emphasising points of difference. It therefore comes about that the summaries of the analyses tend to lay undue stress on differences of opinion and make little or no mention of those important aspects of the analyses which were more or less agreed by all the centrals.

(d) Little mention has been made in these motes of the actual forecasts of weather in the Channel made by each central; it is, however, probably a fair summary to say that Dunstable expected a westerly flow into the Channel area of the moist humid type of air, with a high average cloudiness and low base height. These conditions were forecast to return after a brief interval when it became clear that the cold front would pass through the area. For the whole of the period, Widewing, on the other hand, tended to minimise cloud amounts and wind strength in the Channel, basing their argument on the maintenance of relatively high pressure from the Azores to North France, with the moist humid air being carried further North. When it became clear that the cold front (of L3) would

cross the area, the view was unchanged as a wedge development was expected behind it. The Admiralty central generally maintained a view midway between the two.

2. Brief Summary of Contral's Analyses.

Evening, 1st June.

Dunstable:- L1 is expected to move east and deepen; L2 coming out at 60°N to into frontogenetic region lying east to west in 60°N to north of Scotland. Generally cloudy westerlies in Channel area. Lows not intense. Agreed that there would be a tendency to fill as lows moved south of Iceland, and regenerate in Norway region.

Widewing:- Strong upper easterly airflow over south Greenland is preventing rapid eastward movement of lows. Azores ridge building up to north and northeast. L1 moving east and deepening. Anticyclonic conditions will develop later in Channel areas.

Admiralty:- L1 expected to move east-southeat and deepen. Ridge building temporarily behind it. L2 probably held in west Atlantic, but perhaps moving east, filling slowly, followed by L3, bringing cold front through Channel on 6th June.

Morning, 2nd June.

Dunstable:- Situation deteriorating with strong westerly flow developing aloft, L2 less deep but coming through, followed by L3. (Cold air from Scandinavia area spreading west and replacing warm air to the southeast of Greenlnad.) The result expected would be a fairly vigorous westerly type of weather but with cold fronts not reaching Channel area. Warm air with much low stratus in Channel.

Widewing:- Azores pressure rising and L2 filling. Cannot agree that westward spread of cold air from Scandinavia will favour eastward passage and deepening of L2. Warmest moist humid air on Atlantic spreading east into northwestern districts of the British Isles, but not affecting the Channel area, which is expected to have little cloud.

Admiralty:- No change of view. Sluggish movement of shallow depressions from west for some time; slightly more pessimistic than yesterday.

Evening, 2nd June.

Dunstable:- Situation more obscure. Depressions on A tlantic not intense, but danger of intensification in region between Scotland and Iceland. Small system with tropicalair to northwest of Azores (L4) moving northeast. Channel area in flow of moist warm air round the Azores high with falls of pressure to the northwest causing winds to back sufficiently to push low stratus cloud up Channel.

Widewing:- L3 not expected to move east rapidly. Azores ridge expected to be oriented in a more northeast-southwest manner than hitherto, with axis extending into the Channel area until 5th; at later stage the wedge axis will retreat south. No fronts coming through Channel during the critical period.

Admiralty:- Still expect L2 to move east as a feeble system in about 60°N with following systems taking a more northerly track as Arctic anticyclone is transferred slowly westward to Greenland. Not hopeful about cloud conditions for 5th, as light westerlies are expected in Channel.

Morning, 3rd June.

Dunstable:- Some clarification. Frontal zone from Nova Scotia to northwest Scotland with wave in mid-Atlantic coming across (L4), followed by L3. Polar air behind L3. Warm moist air still expected in the Channel area during the period.

Widewing:- Holding to previous ideas of development. Although pressures are falling in Ireland, pressure still rising at upper levels to the West, (Epicure ascent.) Upper rises from the west; on extrapoletion, these rises come into British Isles in 24 hours' time. Falls of pressure occuring in Ireland are

due to approach of warm front of L2. No cold air to intensify the system so ridge expected to build behind this front. Conditions expected to be 5/10 cloud or less through Wednesday in Channel areas.

Admiralty:- No change of view.

Afternoon, 3rd June.

Dunstable:- Great reservoir of polar air in the north from Russia to Canada but no indication of break through except behind L6; L6 will move eastward and should be near Scotland on Wednesday morning. After warm front of L5 has gone through Channel area tomorrow, Channel will be in WSW air flow of moist humid air, until Wednesday.

Widewing:- L5 moving east. L6 moving northeast, then slowing and moving into Denmark Strait absorbing L3. Fronts of L6 coming through, perhaps with minor development at point of occlusion. Cold front of L5 coming through but inactive south of 52°N. Main cold front of L6 possibly retarded by further wave development. Flat ridge crossing British Isles ahead of fronts of L6; ridge line will be over North Sea on the 6th.

Admiralty:- Situation still borderline. L5 slowing down moving NE (pressure falling in southern Ireland). L3 not important; but ENE movement of L6 will be rapid with outbreak of cold air behind it. Possible that cold front may come through our areas before cold front of L6.

Evening, 3rd June.

Dunstable:- Similar to morning analysis. Situation becoming unpleasant. Complex low to south of Iceland (L5) moving east. Cold front extimated just south of 54°N at 0700 hrs. and not expected through Channel area as L3 would follow L5 eastward across the Atlantic, followed in turn by L6. Cold front coming through behind L6 probably on 7th or 8th. Tropical air in Channel area during the period 5th to 7th.

Widewing:- Immediate development will be L5 moving east-southeast into North Sea, with active cold front through the Channel on 4th-5th. L3 and L6 moving to south of Iceland with cold front of L6 reaching British Isles on the 8th.

Admiralty:- Small low near northwest Scotland (L5), with associated wave running ESE across Scotland, expected to move east-southeast; low L3 slowing down and moving northeast. Atlantic ship reports not showing substantial falls. L6 will have cold outbreak behind it and probably move into and absorb L3, the combined centre eventually moving into the Norwegian Sea. Tropical air from L4 still well to west but reaching Channel area on the 4th. Possibility indicated that cold front of L5 will come through, but this was discarded later in the evening. Azores ridge expected to move southward and weaken with first cold frontal passage (front of L3) on 7th and another (cold front of L6) on 8th.

Morning, 4th June.

Dunstable:- Little change in picture. Cold front of L6 will move to West of Ireland on 6th, trailing into the Channel area on Wednesday, 7th. Centre of L6 might be held back in western Atlantic.

Widewing:- Expects axis of finger of high pressure Azores- North France not to move much, but some decrease of its intensity is indicated. Broad southwesterly flow on Atlantic with zone of activity far enough to northwest (Cape Hatteras to 60°N 10°W) to allow of good conditions in Channel.

Admiralty:- L1 and L3 have combined and will continue to deepen. Ridge from Azores to Biscay weakening in east and will allow fronts to come through. L6 moving rapidly east at the moment and cold front may be through Channel early 7th. Deterioration in situation supports more pessimestic parts of previous analysis.

Afternoon, 4th June.

Dunstable:- Cold front of L5 well to south, position not known, but not

south of 48°N in 30°W. Doubtful of development of wedge between L5 and L6 as reports in this region are conflicting. Still consider L6 will continue to move east with L5 moving northeast fairly slowly. Cold front of L5 passing through Channel areas on 5th but trailing across France. Strong front (warm front of L6) well forward into Atlantic wedge so ridge effects should be minimised.

Widewing:- L5 moving northeast. L6 moved into Denmark Strait area, with fronts approaching Ireland on Wednesday. Mainly flat wedge conditions over Channel area with temporary deterioration at front of 8th.

Admiralty:- L6 moving into Denmark Strait. L5 moving northeast. Atlantic wedge building slightly and coming in, but remaining flat. Occlusion of L6 in west Channel on 7th, with good wedge behind.

Evening, 4th June.

Dunstable:- L5 not expected to have passed Shetland on the 5th, therefore still expect L6 to move east, not northeast. Ridge between L5 and L6 weakening. L5 moving northeast to Norway coast on 6th, and filling. L6 south of Iceland Tuesday morning, with wave on cold front. Disturbed conditions after 6th.

Widewing:- L6 expected to Move NE so that by midday 5th June its centre will be about 59°N 35°W with 980 mbs. centre, and by midday 6th June at 64°N 35°W with 990 mbs. centre.

Admiralty:- Cold front of L5 through area early 5th, linking back through flat wedge to warm front of L6. L6 expected to move into Iceland area and fill. Warm front of L6 near Scillies by 1300 hrs. 6th, moving east slowly. Cold front of L6 through Channel area on 8th or 9th.

Morning, 5th June.

Dunstable:- Now agree that L6 not moving east as anticipated, but wedge in advance of centre has front across it and will not build any more. Warm front of L6 expected to move into west Ireland by evening of 6th.

Widewing:- Situation as anticipated. L6 not moving East. Wedge between L6 and L5 is building; fronts as anticipated on the 4th.

Admiralty:- L5 moving very slowly. L6 moving north but fronts coming throug British Isles. Warm front reaching west Ireland by evening of 6th. Wedge between L5 and L6 not pronounced but building a little.

Afternoon, 5th June.

Dunstable:- No material change of view. Warm front in the assault area about mid-day on 6th. Extensive cloud under inversion in wedge which is not expected to build up. (Front has moved forward almost to wedge line.)

Widewing:- L6 stationary. L7 moving into it and eventually into Davis Strai L5 and low pressure at point of occlusion of L6 moving slowly east-northeast, then northeast. Large anticyclone to east and west of Azores with flat ridge over west Atlantic and British Isles. Effect of frontal passages British Isles minimised.

Admiralty:- Little change in view from morning. Warm front of L6 expected in assault area about mid-day 7th. Cloud breaking in wedge during night of 5th-6th.

Evening, 5th June.

Dunstable:- L5 filling, moving very slowly northeast. L6 moving slowly northeast with L7 moving into it. No change of cloud forecast.

Widewing:- No change.

Admiralty:- L5 filling and moving slowly northeast. Azores high moving east-northeast with ridge building again over France. No change in timing warm front of L6. Winds less than Force 4 in Channel.

Morning, 6th June.

Dunstable:- Little change. L5 now stationary and warm front of L6 retarded somewhat.

Widewing:- Still substantially same analysis. Expect warm front of L6 will dissipate south of 51°N. Cold front expected 8th or 9th.

Admiralty:- No substantial change but warm front retarded somewhat.

APPENDIX C

Notes on the Problems of Forecasting, 1st to 6th June

1. General

It has been explained in the preceding Appendices that the principal fore-casting problems arose from the difficulty of analysis of each current forecasti. chart in the series. Even in retrospect this is not surprising. Apart from the obscurity of the actual pressure distributions over the most important areas of the Atlantic, the general level of activity rose rapidly over the most critical period to a level far above the normal, even for disturbed conditions in summer.

The pressure reading of 976.8 mb. at Wick at 0400 on 5th June was probably the lowest June reading on record in the British Isles. The previous lowest, 978.3 mb. at Malin Head on 11th June 1926 was recorded in the Meteorological Magazine (Vol. 61, p.155) as the lowest for at least half a century. This makes the 5th June 1944 reading the lowest for at least 68 years and probably the low-est on record.

Apart from this isolated pressure, a search through the synoptic charts of the last forty years has shown that during this period there has been no situation of similar intensity (two depressions with centres below 980 mbs. simultaneously in the Atlantic) and rate of development within the period 15th May to 15th June.

A reluctance to forecast movements of systems across the Atlantic at an average speed of 40 mph. or more in June therefore hardly requires justification.

2. The operational forecasts and the Weather in the Channel area from evening 4th June to evening 6th June

The assault was originally planned for the morning of the 5th, and the decision to proceed had to be taken on the evening of the 3rd, with a possibilit of last-minute cancellation early on the 4th. Until early on the 3rd, it had seemed that a light or moderate West to WNW wind was reasonably assured, the difficulty being to predict amounts of low cloud.

The proximity of the ridge line made it rather doubtful whether the subtrop ical air in L4 (see Fig 1 - 6) would reach the Channel area with its consequence of very low cloud. The fact that falling pressure in West Ireland continued after the arrival of the main warm front indicated that conditions were liable to be much more disturbed, but a firm forecast as opposed to a statement of possibilities could not be made.

The arrival of the cold front on the 4th set these doubts at rest, and on its passage through the Channel area on the night of the 4th-5th it gave rise to Force 5 winds, with rain and much cloud at 1000 feet or below. Those cloud con-ditions were not clear of the assault area until after 0600 on the 5th.

Hence, although the cold front did not figure in the forecasts issued on th 3rd, the cautious attitude necessitated by the continued pressure falls were fully justified in the event.

The difficulty of producing a detailed 36 hour forecast in disturbed condi-tions is well brought out by the fact that the cold front was far beyond the

range of the routine meteorological reconnaissance flights (to about 25°W) made on the 3rd, and would have been beyond the range of a special flight timed to report at the last possible moment if such a report had been made available.

During the 4th, the situation clarified somewhat. It became evident that the rapid eastward movement of centres had been broken by the deepening of L6 and the main problems became the determination of the speed of eastward movement of the fronts of L6 and the nature of the wedge between L5 and L6. Advice was needed on the evening of the 4th, with a view to assault early on the 6th, and the synoptic picture on which this advice was based was a flat wedge moving east, with the warm front of L6 approaching the West Channel on the morning of the 6th. This would mean light to moderate westerly winds, with little cloud for the immediate assault, followed by a great deterioration to generally cloud conditions after midday on the 6th. In the event the centre L5 began a southeasterly movement on the 5th, whilst continuing to fill. A northwesterly gradient was maintained over the Channel areas, but did not reach its maximum until after the actual assault. There can be little doubt that there were Force 5 winds for a time on the beaches on the afternoon of the 6th, but not during the actual assault. This development held back the surface warm front, and the very damp air did not penetrate the Channel. Nevertheless, the warm air aloft played a part in conjunction with a series of upper level troughs in the maintenance of a thin but persistent layer of cloud at low medium levels, which greatly reduced the diurnal variation of the lower convective cloud. This diurnal variation was, however, sufficient to produce large local clearances by dawn on the 6th, and again on the afternoon of that day.

The southeastward movement of the centre was not forecast on the 4th, though it had been suggested by Widewing on the evening of the 3rd when the situation was less clear. The movement of the centres of rapidly filling occluded depressions, particularly when the history was as complicated as that of L5, is not a matter on which any firm opinion can be expressed. It is perhaps surprising that this movement was not mentioned as a possibility, but it could only have been put forward as the worst possible movement from the point of view of Channel weather. On the morning of the 4th it was a much more obvious possibility. This is yet another illustration of the difficulty of forecasting details over a period of about 40 hours in disturbed conditions.

3. Long Range Forecasting Techniques

Reference is made elsewhere (see e.g. Section IX), to the assistance given by the various long range forecasting methods used by the Centrals; here it can only be remarked that it is doubtful whether the views of any of the Centrals were greatly influenced during the critical period by the semi-statistical methods mainly employed. The, may perhaps have been useful as confirmation of views arrived at by more normal sysnoptic methods and may therefore have had an appreciable effect on the confidence with which those views were put forward.

4. Observational reports

See paragraph 2 of Appendix A.

FIG 1

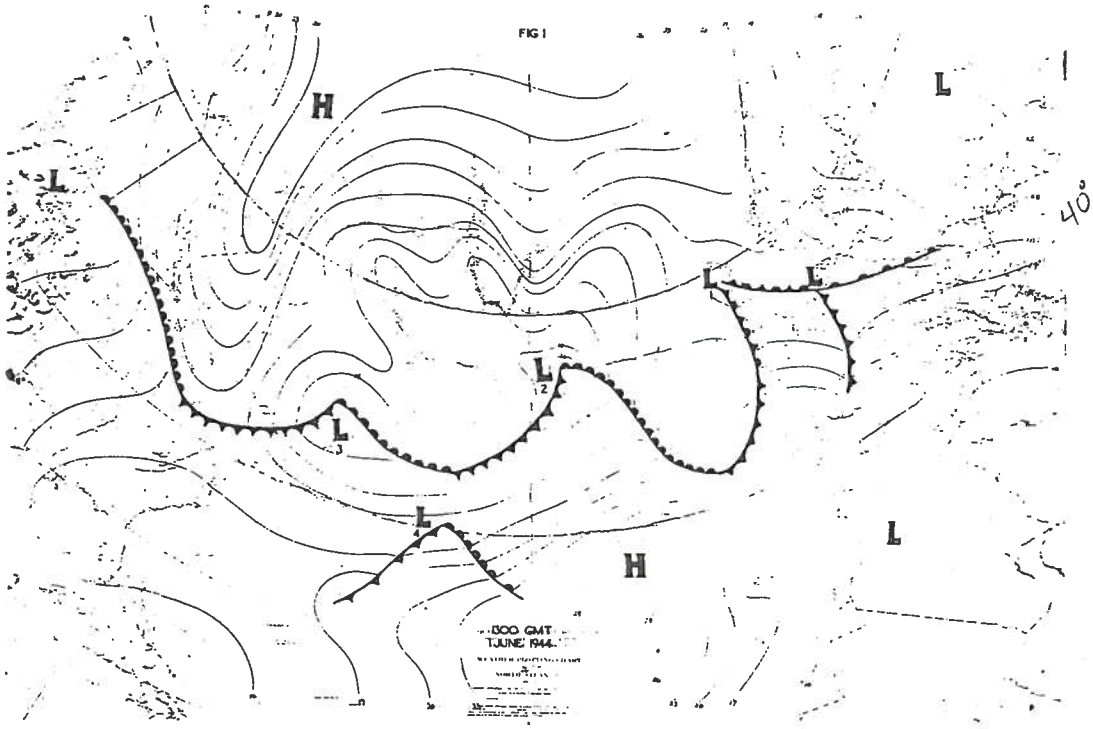
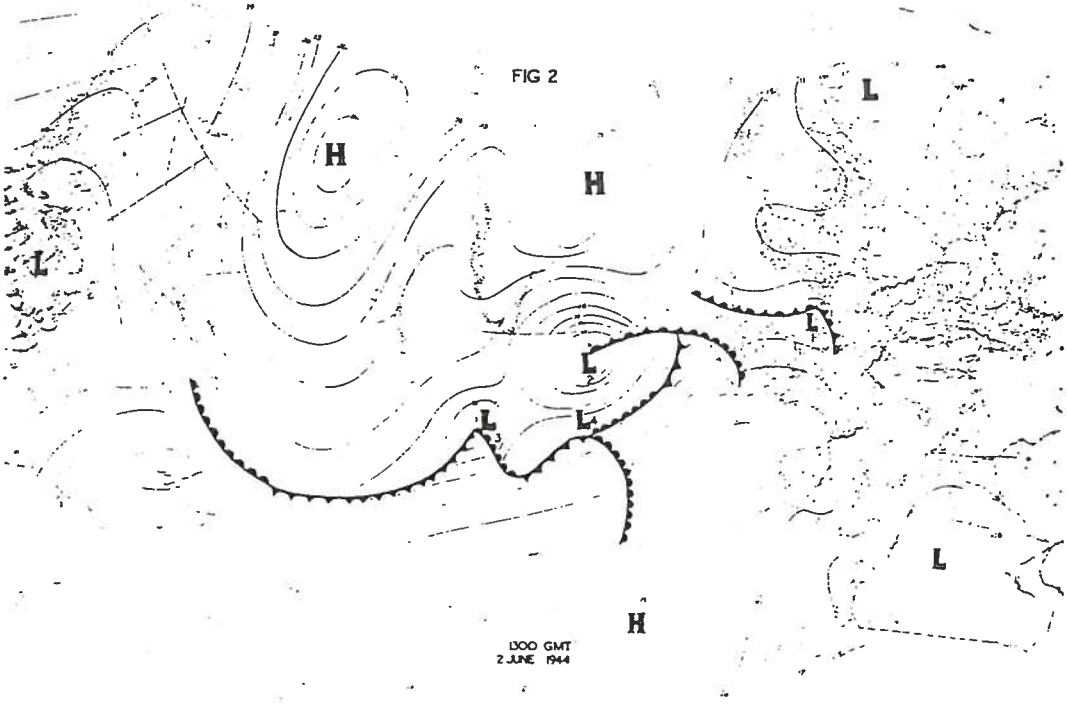

H
L
L
L
L
L
L
L
H
40°
0300 GMT
1 JUNE 1944

FIG 2


H
H
H
L
L
L
L
L
L
L
0300 GMT
2 JUNE 1944

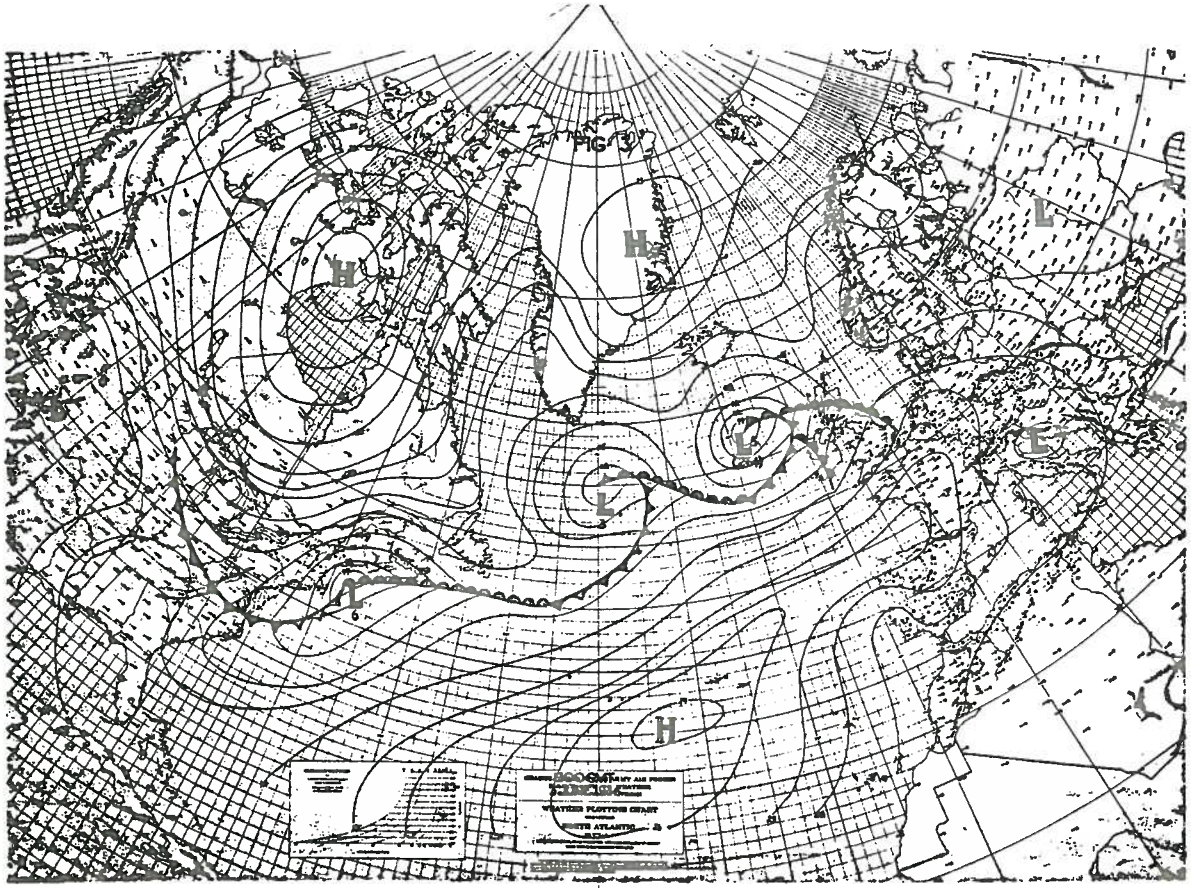


FIG 3
H
H
L
L
L
L
L
H

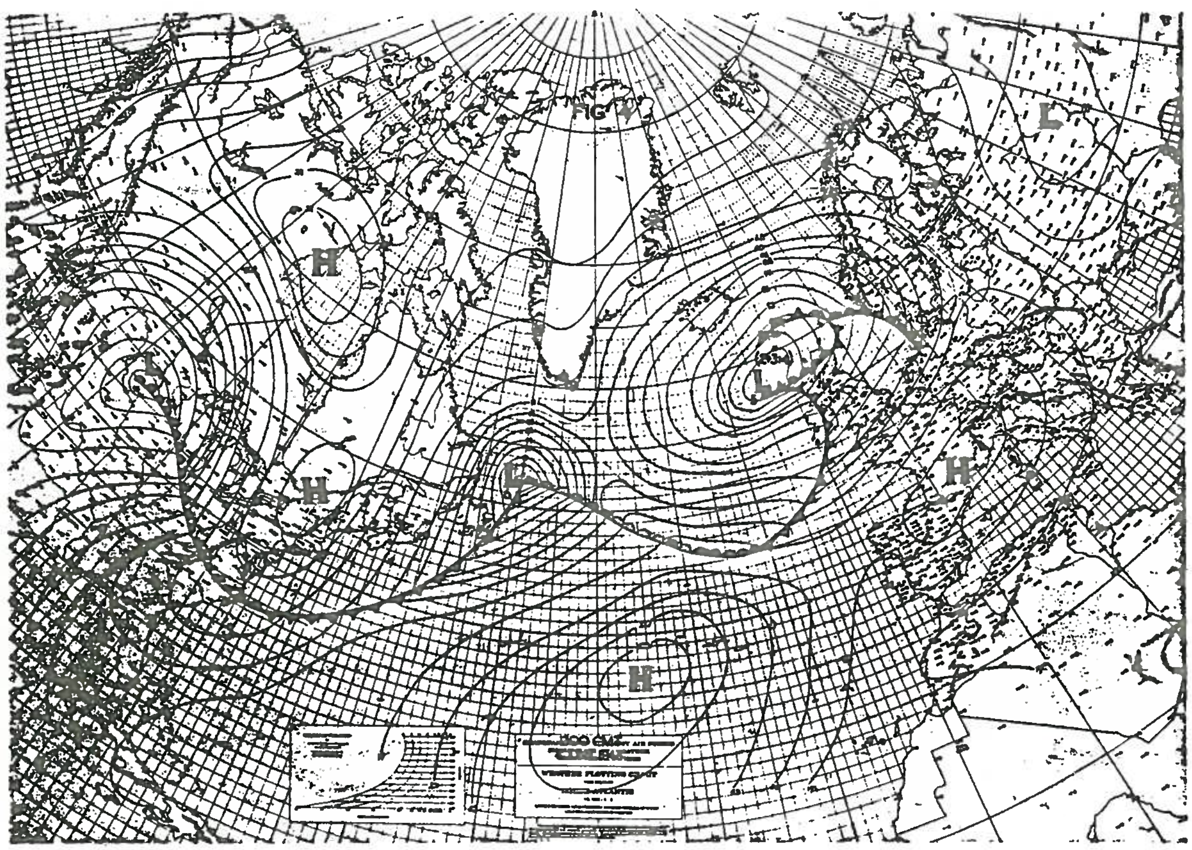


FIG 4
H
L
L
L
L
H
H
H

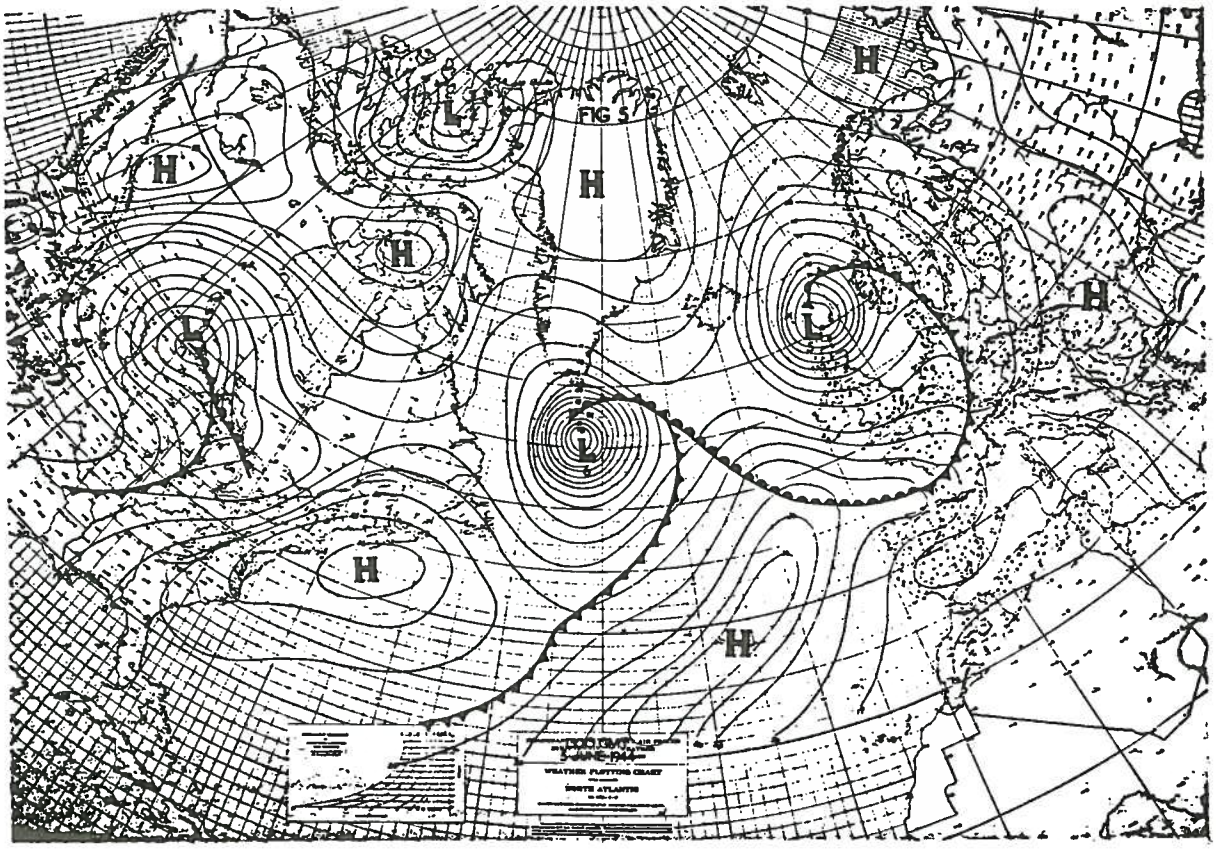


FIG 5
H
L
H
H
H
L
L
H
H
H
H
1200 GMT
5 JUNE 1944
WEATHER PLOTTING CHART
NORTH ATLANTIC

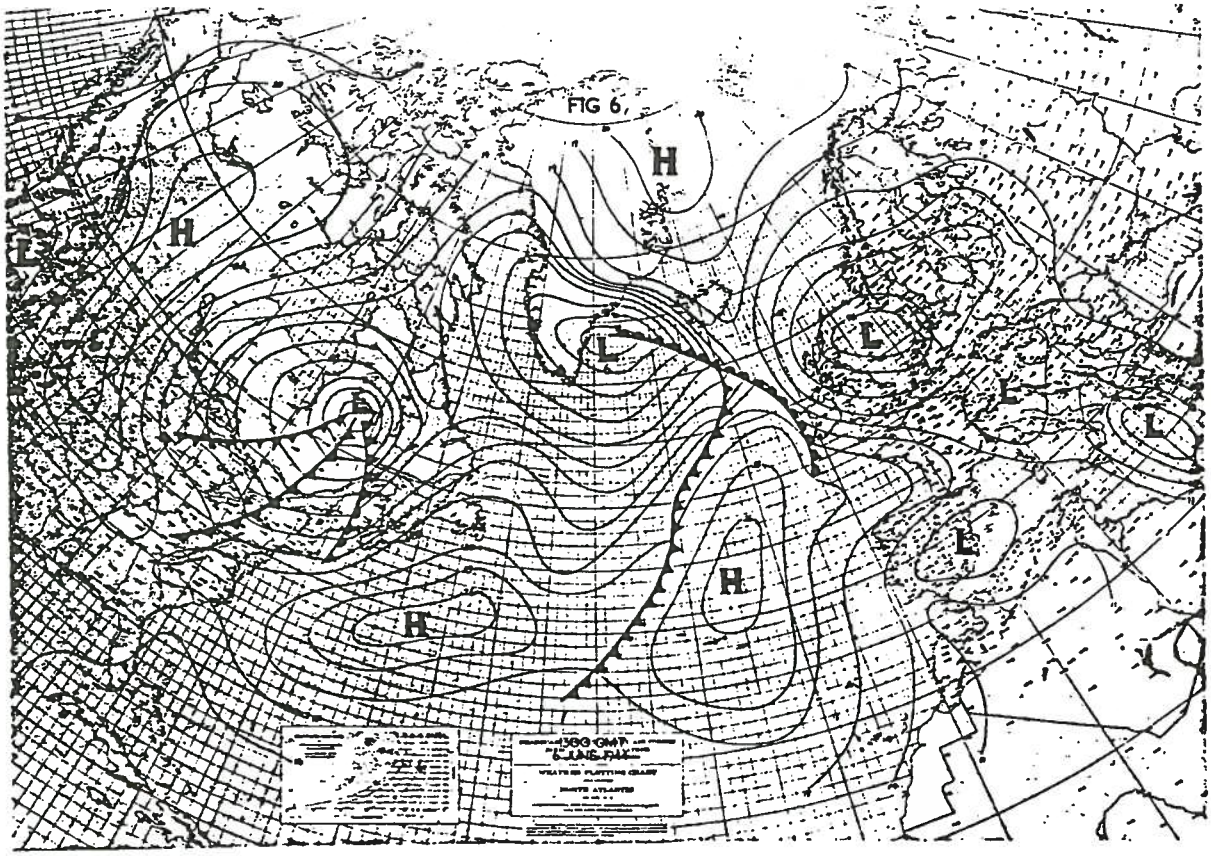
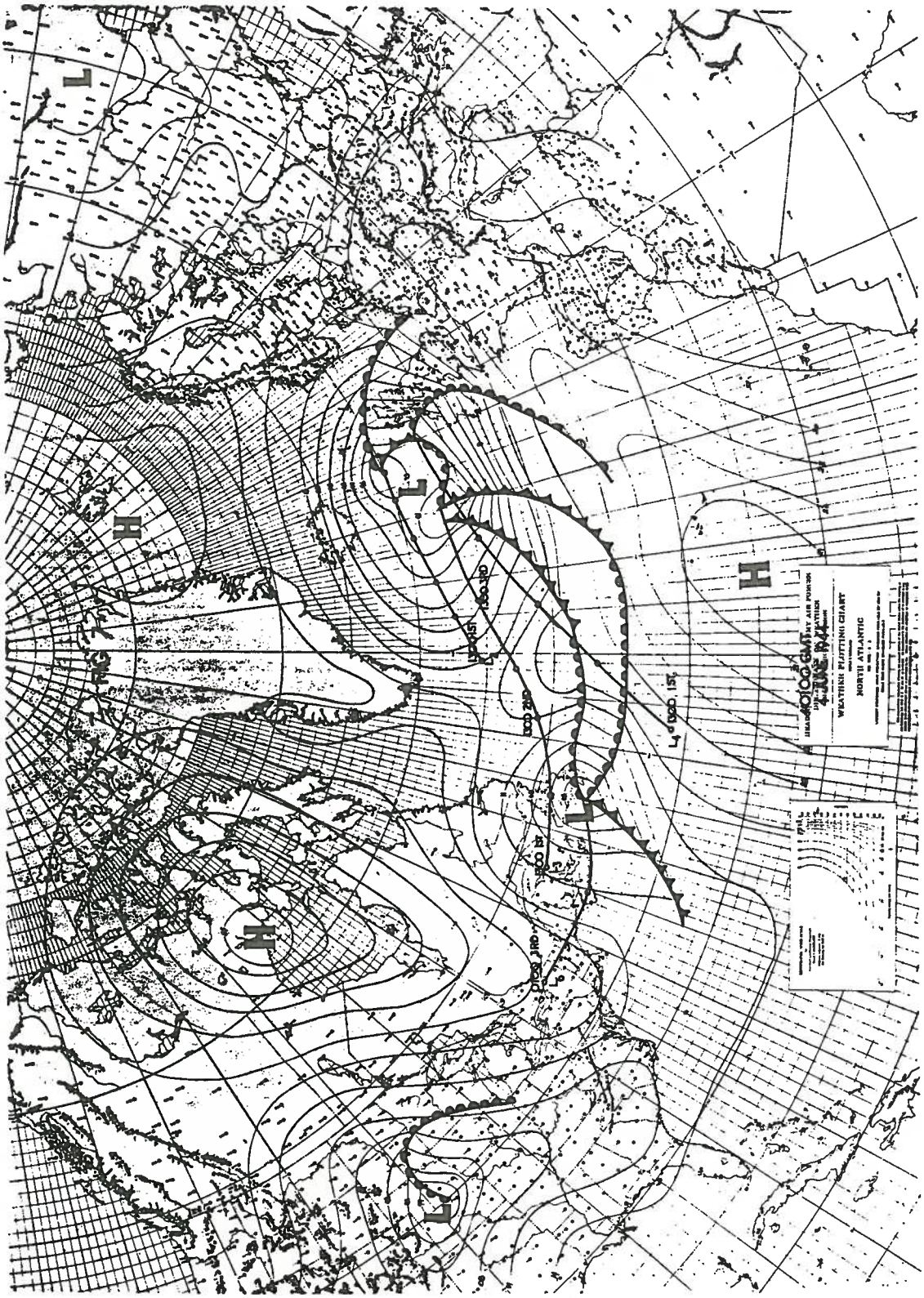


FIG 6
H
H
L
L
L
L
L
H
H
H
1200 GMT
6 JUNE 1944
WEATHER PLOTTING CHART
NORTH ATLANTIC


L
H
H
L
L
L
H
L
WEATHER PLOTTING CHART
NORTH ATLANTIC

LEGEND

FULL HEAVY LINES ARE CONTOUR LINES OF EQUAL HEIGHT (HUNDREDS OF FEET).

DASHED HEAVY LINES ARE ISOTHERMS (FIVE DEGREES CENTIGRADE).

FULL LIGHT LINES ARE THICKNESS LINES IN HUNDREDS OF FEET BETWEEN 750 MILLIBAR LEVEL AND 300 MILLIBAR LEVEL.

BROKEN, DASHED, AND DOTTED LINES DEFINE AREAS IN WHICH THERE IS ADVECTION OF WARM OR COLD AIR THROUGH THE LEVELS BETWEEN 750 MILLIBARS AND 300 MILLIBARS.

BLACK ARROWS INDICATE ADVECTION OF COLD AIR BETWEEN THE LEVELS OF 750 MILLIBARS AND 300 MILLIBARS.

WHITE ARROWS INDICATE ADVECTION OF WARM AIR BETWEEN THE LEVELS OF 750 MILLIBARS AND 300 MILLIBARS.

ARROWS CONNECTING ENCIRCLED CROSSES INDICATE TRAJECTORY OF SYSTEMS.

BLACK ARROWS WITH "W" INDICATE WARM AIR ADVECTION AT 500 MILLIBARS.

BLACK ARROWS WITH "K" INDICATE COLD AIR ADVECTION AT 500 MILLIBARS.

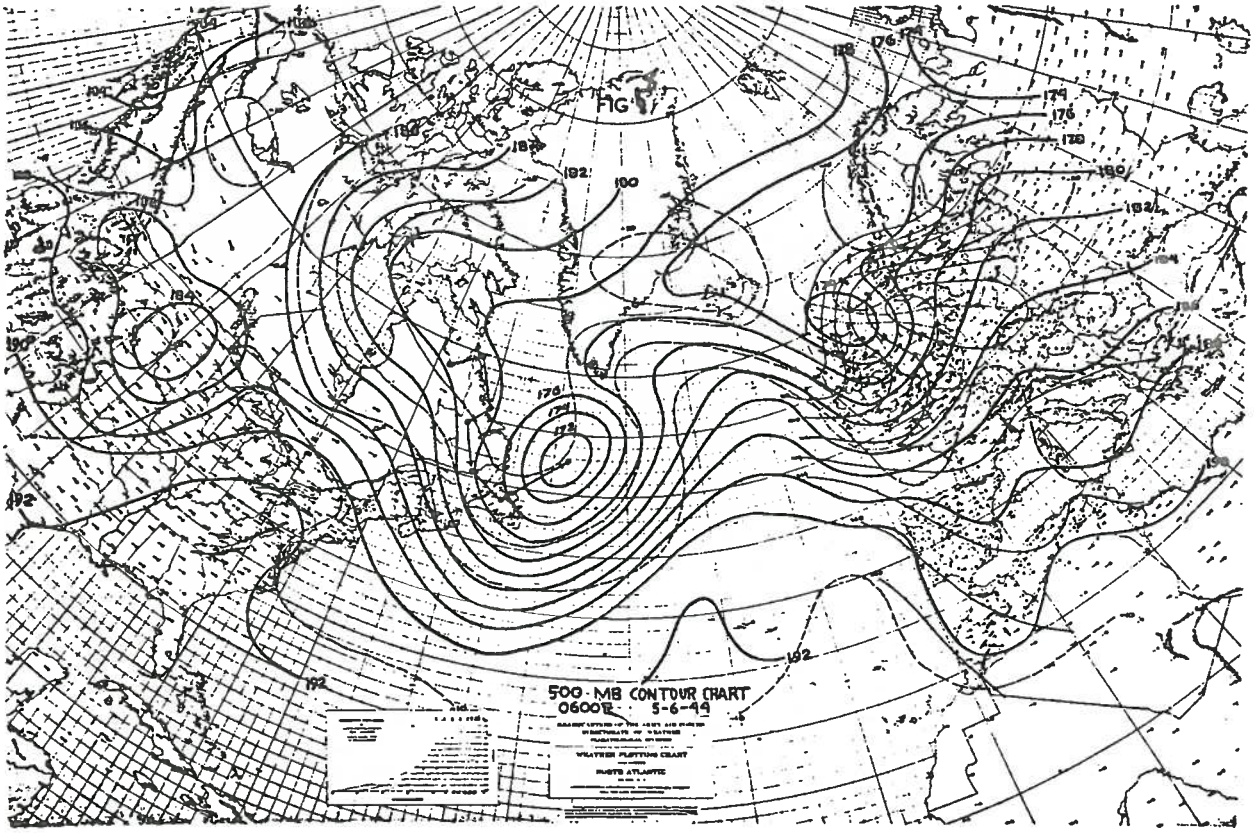


FIG 1
500 MB CONTOUR CHART
0600Z 5-6-44

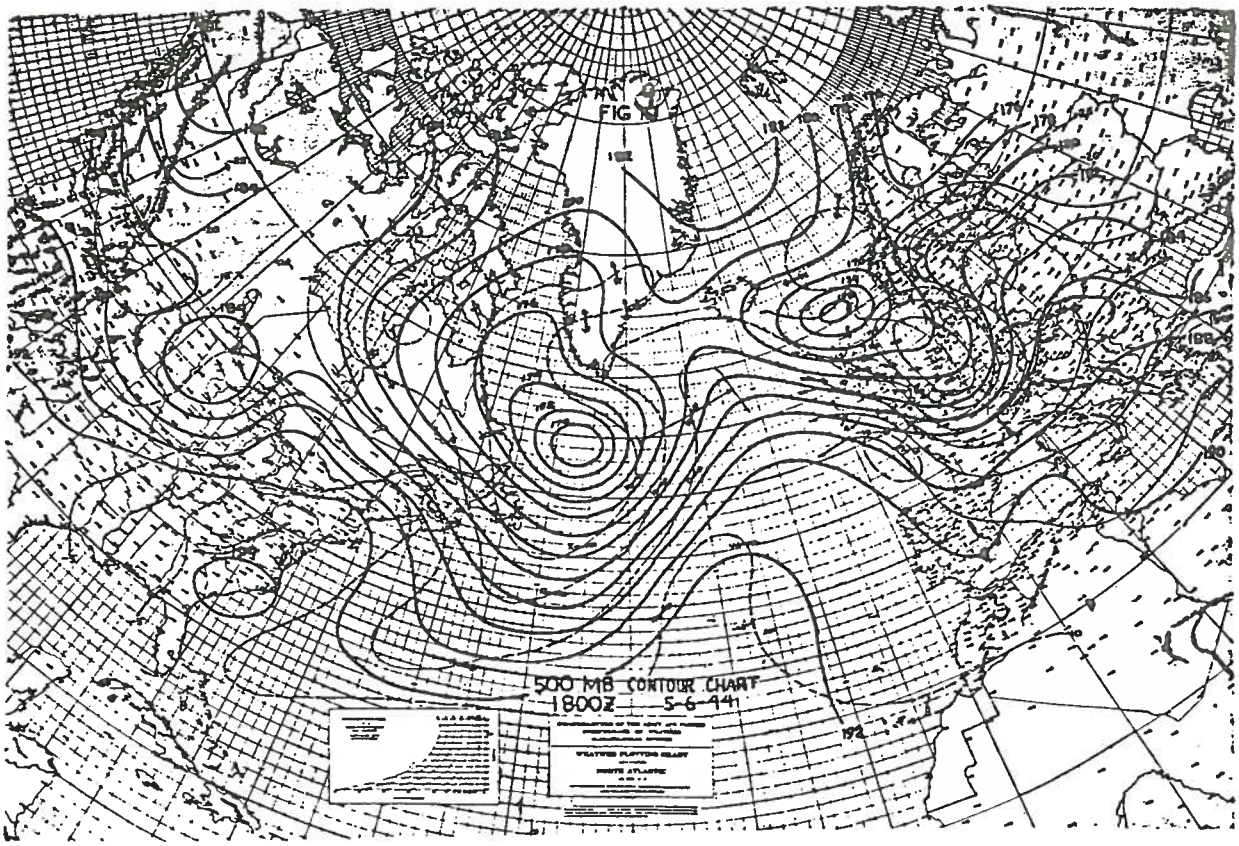


FIG 2
500 MB CONTOUR CHART
1800Z 5-6-44

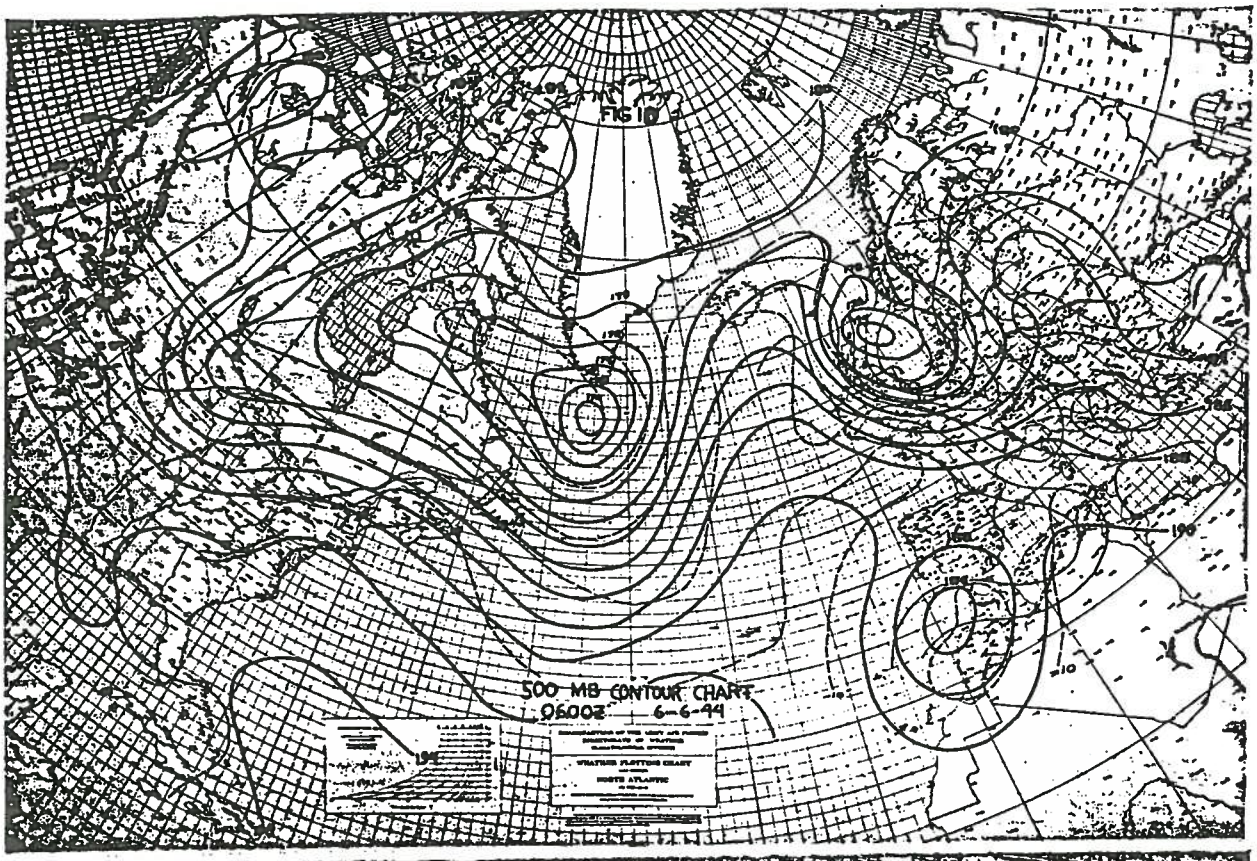


FIG 10
500 MB CONTOUR CHART
0600Z 6-6-44

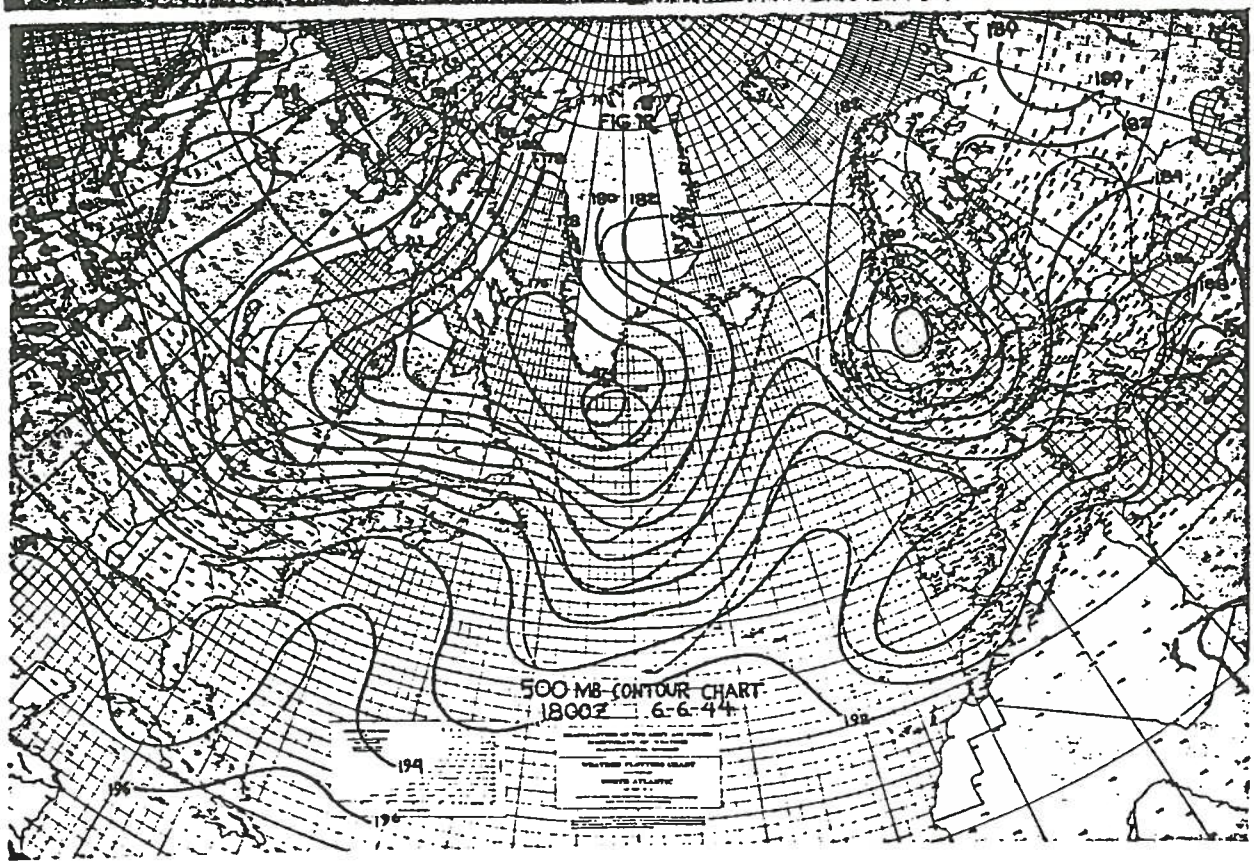


FIG 12
500 MB CONTOUR CHART
1800Z 6-6-44

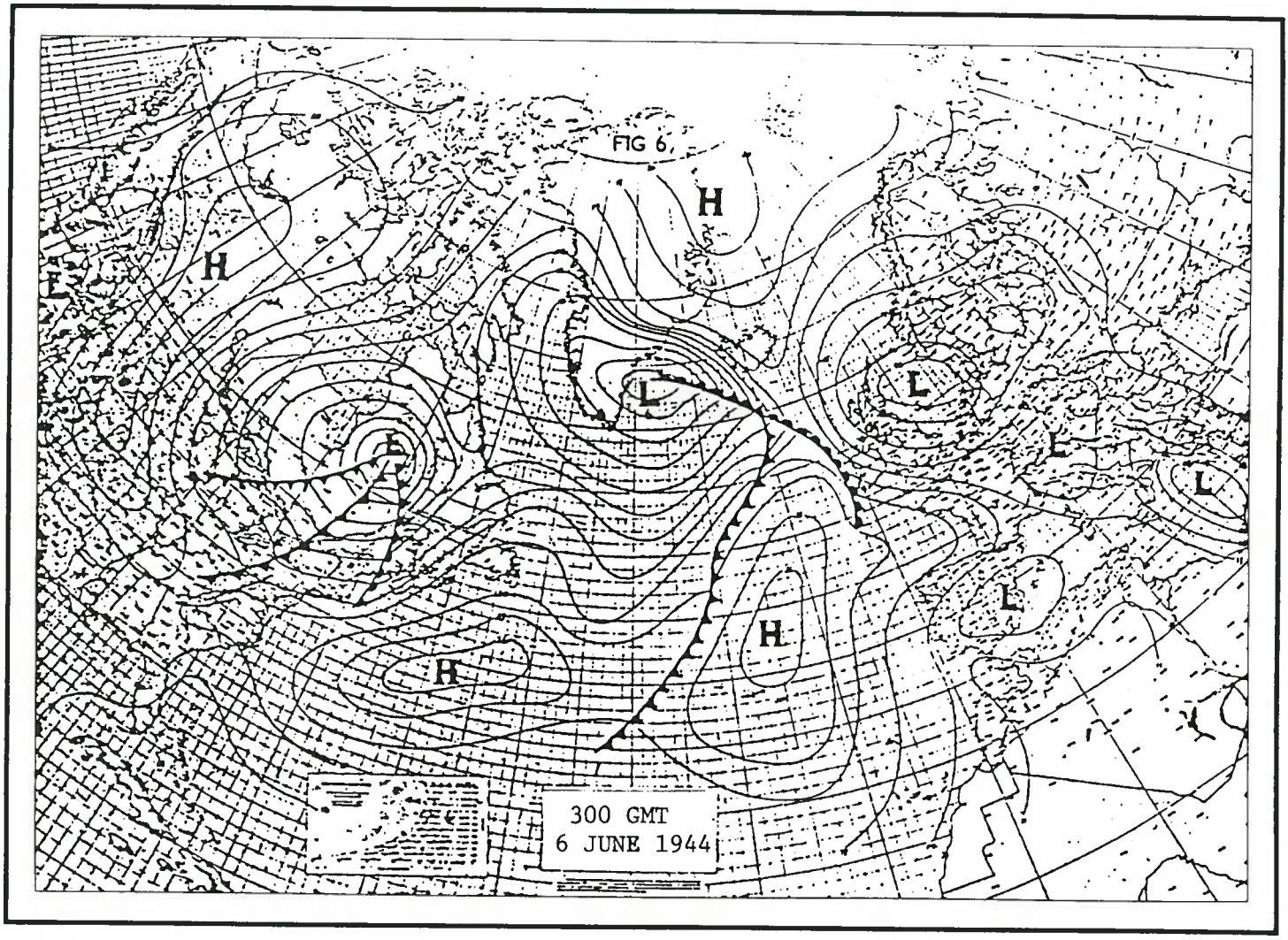


FIG 6.
H
H
L
L
L
L
H
H
300 GMT
6 JUNE 1944