



# What's it worth? Four Perspectives on the Valuation of the Weather, Water, Climate Enterprise

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## Executive Summary

Earth system observations, science, and services (OSS) inform and guide the activities of virtually every economic sector and innumerable institutions underlying modern civilization. OSS are a fundamental component of efforts to meet basic human needs including food, shelter, energy, health and safety. At the same time, opportunities to enhance the societal benefits of OSS are vast and increasing. Better understanding of the weather, water, and climate (WWC) enterprise's value could: create new opportunities to apply OSS for societal benefit; help justify public investments in OSS; and guide future investments in OSS to help ensure that they confer the maximum possible benefit to society. As a result, there is great need for efforts to understand, assess, communicate, and advance the value of OSS.

This study synthesizes the results of a multi-year project on the valuation of Earth system OSS. The conclusions are based on four studies relating to different aspects of the societal benefits of Earth system OSS: 1) Societal Benefits of Weather, Water, and Climate: Understanding, Communication, and Enhancement ([bit.ly/sbwxc](http://bit.ly/sbwxc)), 2) The Value Chain of Earth System Observations, Science, and Services ([bit.ly/3uAHjXG](http://bit.ly/3uAHjXG)), 3) Three Policies Shape Enterprise Value: Minor Adjustments Could Enhance the Societal Benefit (<https://bit.ly/3Wxpolicies>) and 4) Options for Enhancing the Value of the NOAA Weather-Ready Nation Ambassador Initiative (<https://bit.ly/3OqRnY1>).

### Key Overarching Findings:

- 1) Valuation efforts promote societal benefit by:
  - a) Enabling decision-making,
  - b) Allowing prioritization,
  - c) Improving investment decisions, and
  - d) Promoting the use of science and services.
- 2) Assessments of value depend on both complex factors and subjective choices (e.g. how we measure value, how decisions incorporate and weight information, and what information is considered).
- 3) Valuation clarifies options and makes comparisons more effective. Valuation efforts are most effective in comparing different options and identifying their relative strengths and weaknesses with respect to explicit assumptions and metrics, instead of trying to determine absolute values.
- 4) The value of the WWC enterprise has increased with the number of partnerships across sectors and in all phases of the value chain. It has made valuation efforts more complex.
- 5) One key limitation to valuation efforts is the difficulty to collect and research data on end users and their decision-making based on WWC products. These decisions ultimately realize much of the enterprise's value.
- 6) Effective methods to advance the value of the WWC enterprise are likely to build on adaptive responses to incremental changes whose effectiveness can be determined quickly and lessons learned disseminated broadly.

- 7) Partnerships and effective distributions of roles and responsibilities among public, private, academic, and NGO communities are crucial and must evolve over time as capabilities, conditions, opportunities, and interests shift. These partnerships require and promote understanding, respect, trust, and clarity with respect to roles, responsibilities, and rules of engagement.

Valuation is critical to decision making at all levels. The set of studies synthesized here can contribute to a common understanding how value can be enhanced and communicated within and outside of the weather, water, and climate enterprise. There are many opportunities to build on this work. One option is to explicitly include a larger number of stakeholders and partners and analyze value creation along the value chain and across sectors and agencies.

There are also new approaches to expand on the work in this program. It is likely that the value of weather, water, and climate intelligence varies between different sectors of the economy. A study that compares different sectors could lead to important insights about synergies and offsets in the WWC enterprise.

Finally, climate change and society's response to it is likely to have significant impacts on the investments and values created (and expected) in weather, water, and climate science. There is a need for socioeconomic assessments to define and communicate priorities as the US and the world prepare for decades of rapid transformation. In particular, renewed economic activity on the coasts and in the ocean ("the new blue economy"), and the ongoing national conversation about the delivery of climate services are great opportunities to use valuation in an effort to grow the WWC enterprise and serve society as effectively as possible.

The AMS Policy Program has established an interdisciplinary team to build on the results of this project and develop a proposal for a consortium for socioeconomic assessments of the WWC enterprise. This program would enable AMS to continue its internal work on valuation as well as funding external experts to advance our understanding and communication of Earth system OSS.



## **1. Introduction and Background**

There is broad consensus across the political spectrum that Earth system science and services are valuable to many aspects of modern society. However, calculating and communicating the value can be challenging for at least four reasons: 1) The value of many weather, water, and climate products is dependent upon the effect they have on users' decision-making process. For example, improvements in severe weather forecast quality only create value if they enable better decisions by individuals and organizations. Thus, translating scientific and engineering progress into monetary value or societal benefit is tightly linked to hard-to-quantify societal processes. 2) Value is typically created by a combination of basic science, observations, processing, product development and design, and communication. These steps can be performed by a variety of actors in the academic, private, and public sectors. As a result, it can be difficult to determine the value of individual programs, products, or decisions. 3) The value of many weather, water, or climate science products strongly depends on the end user. For example, the value of wind forecasts might be particularly high wind power production, but less critical to solar power generation. 4) The general public is often unaware of alternatives to an investment, but without knowledge of the available options, it can be hard to determine if a decision was a good use of resources. Taken together, it is clear just how difficult and important it is to determine the value of investments into the weather enterprise. A transparent process to compare the value of different investments, actions, and programs can support the prioritization of resources and help to communicate choices to stakeholders and the public.

Recognizing the importance of valuation, many laws and regulations require governments to justify actions and choices by comparing them to alternatives. The most well-known example of such requirements is a cost-benefit analysis which is often part of the economic analyses at the White House Office for Management and Budget or during the rulemaking at the Environmental Protection Agency. The rest of this synthesis is structured as follows: Section 2 describes AMS Policy Program process of consulting a diverse set of experts and engaging the broader WWC community to build the foundation of the four studies which comprise this project. Section 3 goes into detail about the content of each study and section 4 draws conclusions that go beyond each individual topic.



## **2. Expert Consultation, Outreach Activities, and Community Engagement**

This study synthesizes the work of the AMS Policy Program on valuation over the last three years. It summarizes and synthesizes four previous studies: Study 1: Societal Benefits in Weather, Water, and Climate: Understanding, Communication, and Enhancement (Higgins, 2021), Weather-Water-Climate Value Chain(s): Study 2: Giving VOICE to the Characterization of the Economic Benefits of Hydro-Met Services and Products (Lazo and Mills, 2021); Study 3 The Impact of Policy on Value: 3 Case Studies (Hooke, 2021); and Study 4: Options for Enhancing the Value of the NOAA Weather-Ready Nation Ambassador Initiative (Grow, 2021). The key findings of each study are summarized below.

The findings of the studies are the result of research done by the AMS Policy Program and significant outreach efforts to the Weather, Water, and Climate (WWC) science community in the broadest sense. Most significantly, two non-resident fellows of the Policy Program, Erica Grow and Jeffrey Lazo, added unique expertise and experience to this joint effort and are the lead authors of the studies 2 and 4. Another non-resident fellow, Shawn Miller, was a critical link to AMS boards, committees, and volunteers. Seven external experts authored case studies for Study 2 and Weather Ready Nation Ambassadors responded to survey questions to strengthen the findings in Study 4.

Additionally, the AMS Policy Program organized sessions at the AMS Washington Forum 2021, and the AMS Annual Meetings in 2020 and 2021, virtually engaged with a group of experts from within and outside of NOAA over the course of months, and performed many one-on-one interviews with members of the WWC community.

AMS has conducted a number of studies that are beyond the scope of this project, but provide important context to the findings described here. ‘Socioeconomic Inequality and Climate Change Hazards: a Focus on the Great Lakes Region’ (Sullivan and White, 2021) explores how climate change and proposed climate action might affect groups of different socioeconomic status. ‘Framework for the Advancement of Inclusion, Equity, and Justice in the Weather, Water, and Climate Enterprise’ engaged a working group over the course of many months and is centered around the idea that society benefits if everyone is able to contribute to their fullest potential (White, Tipton, Higgins, in progress). In a project funded by the NOAA Climate Program office, the AMS Policy Program is developing a new model for climate assessments that identify scientific information, product, and research gaps based on user and stakeholder needs in order to maximize the value of summarizing state of the art climate science.

### **3. Study Summaries**

#### **3.1. Study 1: Societal Benefits in Weather, Water, and Climate: Understanding, Communication, and Enhancement**

One key goal of this grant was to develop a common understanding and language to discuss the value of weather, water, and climate observations, science, and services (OSS). Higgins, 2021 lays out a framework to discuss valuation among natural scientists, economists, policymakers, and the general public. The study covers topics ranging from the types of goods and services to opportunities to enhance societal benefits from Earth system OSS.

Modern systems and physical infrastructure are built around capabilities in EOSS. This allows cost savings and the realization of benefits that would otherwise not be possible. Efforts to quantify these societal benefits via economic valuation contribute to two critical yet somewhat distinct goals: 1) to promote deeper understanding of value and 2) to assist in decision-making. As a result, economic valuation is central to efforts to understand, communicate, and enhance the societal benefits of Earth system OSS. Notably, different metrics or “numeraires” are more and less capable of capturing different aspects of value. This is because the choice to use a specific numeraire emphasizes and obscures different aspects of what matters to us: valuation is inherent in the format by which information is communicated. Valuation inspires consideration of what matters to us, contributes to informed decision-making, and helps us systematically weigh tradeoffs when we face them.

Valuation efforts are particularly useful for accounting simultaneously for market and non-market goods and services. Without valuation efforts, even critical goods and services are easy to overlook. Valuation is also particularly helpful for identifying and addressing market failures—cases when market transactions lead to suboptimal outcomes. Addressing market failures is an opportunity for policies to enhance public well-being at no net cost overall. Efforts to enhance the societal benefits of Earth system OSS are most effective when they recognize and account for linkages that permeate WWC information and services. For example, benefits emerge from the combination of observations, science, and services—like a car’s steering wheel or engine, each part is necessary, but the true value emerges from the whole of the vehicle.

Each component of the enterprise contributes to societal well-being, albeit in very different ways, with different motivations, and with different limitations. Public investments are often foundational to goods and services provided by the private sector and to the advances that occur through academic research. This potential can be realized through efforts to 1) provide actionable information; 2) prepare and empower information users; 3) create decision-support products and services that harness scientific advances for societal benefit; 4) build strong partnerships among stakeholders, practitioners, and information providers; 5) develop the next generation workforce; 6) recognize and account for linkages; 7) provide an effective policy framework for

enhancing both the availability of information and society's ability to use it; 8) create, strengthen, and evolve partnerships among public, private, academic, and NGO communities; 9) engage and empower the public to demand, understand, use, and contribute to water information and services; and 10) reduce or eliminate market failures, when they occur.

The ongoing expansion in capabilities of and needs for Earth system OSS create tremendous opportunity that will benefit from careful management in the decades ahead.

### **3.2. Study 2: Weather-Water-Climate Value Chain(s): Giving VOICE to the Characterization of the Economic Benefits of Hydro-Met Services and Products**

Study 1 is focused on developing a broad general language on the valuation of Earth system OSS. Study 2 addresses the details on how to determine the value along the weather information value chain from an economist's perspective. The value chain concept provides a useful approach to understanding and discussing the entire process of information creation, communication, and use. A primary reason for adopting the concept in hydro-meteorological studies is to explicitly connect the information service or product (e.g., observation, data, forecasts, warnings) being evaluated with relevant societal decisions and outcomes to ensure the validity and reliability of economic analyses. The value of weather information is related to avoiding impacts, facilitating more efficient response, or realizing new opportunities. There are many different uses and approaches to characterizing a value chain or an information process. Relationships among components of the enterprise also shift. Notably, the private sector now plays a more significant and growing role not only in the provision of hydro-met information but also in observation systems, modeling, forecasting, and dissemination.

The study proposes the "Value of Information Characterization and Evaluation," or VOICE approach. The value of information (VOI) depends on changes in outcomes that result from decisions made (or potentially made) using the information. Ultimately, VOI is a function of the ability of decision-makers to receive, understand, and act on information about uncertain future events. The VOICE approach provides a framework to gather and organize the relevant data to rigorously tell the end-to-end story of any given weather information chain or explain explicitly how the information relates to decisions, outcomes, and values. The value chain framework encourages consideration of the relative merits of investing in different areas of the information process, not just those associated with improvements in prediction quality attributes. For example, investments in communication may yield higher payoffs than improving on the accuracy and precision of hydrological, meteorological, and climate information.

The value chain concept can be used for multiple purposes, as illustrated by the case studies included in this study. The seven case studies provided by contributing authors

include U.S. and international studies as well as applied and theoretical work. We highlight four recommendations, which follow from the development of this study, discussions with researchers, practitioners, and decision-makers across the weather enterprise, and the professional experience of the authors:

1. All major investments or changes in hydro-met services should be subject to economic analysis. We believe that the value chain approach and VOICE template provide a useful framework to organize such an undertaking.
2. A critical review should be undertaken of the use of economics in national hydro-met service policy-making to identify where and why it has been helpful or unhelpful in policy making, and under what conditions it could have been more beneficial. More and better primary studies on the value of hydro-met information across a broad range of hydro-met phenomena, information products and services, stakeholders, and end users should be implemented to build the body of knowledge to support and improve the weather enterprise.
3. Those funding new studies should require them to meet higher design, implementation, and documentation standards such as those recommended for the evaluation of studies for use in benefits transfer to ensure quality and transparency of the study and enhance the value of studies as resources in future benefits transfer applications.
4. Researchers should begin to evaluate the potential contributions of behavioral economics (and closely related fields) more thoroughly to understanding and improving weather information processes and decision-making across the value chain.

### **3.3. Study 3: Three Policies Shape Enterprise Value: Minor Adjustments Could Enhance the Societal Benefit**

This study examines explicitly the role that public policy plays in determining the sum societal value of Earth system Observations, Science, and Services (OSS) as well as the allocation of that value and the costs of OSS-production across society.

The study examines three policy frameworks of different origin, purview, and standing. The first is the 2003 Fair Weather Report developed by the National Academy of Sciences. That policy focuses on collaboration. The second is the 2017 Weather Research and Forecasting Innovation Act enacted by the U.S. Congress. It focuses on innovation. The third is the current World Meteorological Organization development of Resolution 42, which seeks to make international contributions and access to data and information more equitable, and at the same time expand the domain of data and information sharing from weather per se to Earth observations, science, and services more broadly.

The study takes views of individual stakeholders in the Weather, Water and Climate Enterprise with respect to these policies as its point of departure. Their perspectives were captured through informal interviews; individually and in aggregate they hint at or suggest opportunities for extending and improving Enterprise value by broadening collaboration, fostering innovation, and making the Enterprise more equitable.

These opportunities have been captured here. They include but are not limited to:

1. Broadening Enterprise purview: to include disciplines other than weather; to extend to end users and Congress; to document and articulate Enterprise value; to shift focus from inward-looking dialog to externally-purposed action.
2. Fostering innovation: by building Congressional trust, thereby allowing legislators to shift from oversight and prescriptive approaches to development of incentives and resources for the Enterprise; by emulating the success and promise of Earth Innovation Prediction Center (EPIC), developing similar open-science approaches to other elements of the value chain such as data commercialization and risk communication.
3. Advancing global equity, with respect to both participation and access to beneficial outcomes: by strengthening U.S. preparation for and participation in formulating WMO purposes and work.
4. Fully harnessing AMS experience and resources as a means toward these ends.

#### **3.4. Study 4: Options for Enhancing the Value of the NOAA Weather-Ready Nation Ambassador Initiative**

The Weather-Ready Nation (WRN) Ambassador™ Initiative is designed to build partnerships across the WWC Enterprise and to leverage the community reach of partners in the public, private, academic, and nongovernmental organization (NGO) sectors. The 11,000 WRN Ambassadors represent a wide assortment of businesses, government entities, school organizations, and nonprofit groups. The purpose of this study is to identify options for strengthening the Weather-Ready Nation Ambassadors Initiative while holding true to its original intention: building a more resilient, responsive, and prepared American public. The resulting options include those that would seek to enhance community engagement, training modules and educational programs for Ambassadors, public service campaigns, and means for increasing involvement of end users or members of the communities served by the Enterprise. Some of the options identified were presented in an online survey in the spring of 2020. The options included in the public survey were the Safe Place Selfie Challenge; Training Webinars; WRN Messaging via Marketing Materials, Flyers, Pamphlets, etc.; Joint

Events between WRN Ambassadors and Impact-Based Decision Support Services (IDSS) Core Partners; and Expansion and Integration of AMS Local Chapter Events.

The results of the survey show that actively engaged WRN Ambassadors view all five options as both relevant and helpful to the WRN Initiative. In particular, Ambassadors showed a high level of interest in the production of training webinars for Ambassadors, the holding of joint events between Ambassadors and IDSS Core Partners, increased integration of WRN messaging by Ambassadors, and the expansion of AMS Local Chapter events to include partnership with WRN Ambassadors. In addition, the survey responses show that, in the opinion of the survey participants, the above options are viable and would further the goals of the WRN Ambassadors Initiative.

The five options in the survey were identified through interviews with more than a dozen NOAA employees and NWS partners. Several other options were identified during the interview process that were not included in the survey. They include designating Weather-Ready Nation “Block Watch Captains”; compiling a formal WRN Certification Program; expanding IDSS Core Partner “Tabletop Exercises” to a broader number of entities, including some WRN Ambassadors; encouraging Ambassadors to get certified as StormReady™ by the National Weather Service; encouraging Volunteer Organizations Active in Disaster (VOAIDs) and Community Organizations Active in Disaster (COAIDs) to consolidate their efforts with Weather-Ready Nation as a point of synergy; and increased outreach to the community via the AMS Weather Band, which launched in the fall of 2020.

The resulting options, from the survey and otherwise, can be grouped into two categories. One category of options would define WRN Ambassadors as members of an awareness campaign, helping build resilience through public safety messaging and the like. The other category of options, if implemented, would result in WRN Ambassadors becoming bona fide force multipliers for the National Weather Service, working together in the mission to protect American lives and property. Options from each category may ultimately be in the interest of NWS and NOAA if the Initiative continues to grow in numbers and scope.

## 4. Synthesis of Findings & Future Directions

Earth system observations, science, and services (OSS) inform and guide the activities of virtually every economic sector and innumerable institutions underlying modern civilization. OSS are a fundamental component of efforts to meet basic human needs including food, shelter, energy, health and safety. At the same time, opportunities to enhance the societal benefits of OSS are vast and increasing. Better understanding of the weather, water, and climate (WWC) enterprise's value could: create new opportunities to apply OSS for societal benefit; help justify public investments in OSS; and guide future investments in OSS to help ensure that they confer the maximum possible benefit to society. As a result, there is great need for efforts to understand, assess, communicate, and advance the value of OSS.

This study synthesizes the results of a multi-year project on the valuation of Earth system OSS. The conclusions are based on four studies relating to different aspects of the societal benefits of Earth system OSS: 1) Societal Benefits of Weather, Water, and Climate: Understanding, Communication, and Enhancement ([bit.ly/sbwxc](https://bit.ly/sbwxc)), 2) The Value Chain of Earth System Observations, Science, and Services ([bit.ly/3uAHjXG](https://bit.ly/3uAHjXG)), 3) Three Policies Shape Enterprise Value: Minor Adjustments Could Enhance the Societal Benefit (<https://bit.ly/3Wxpolicies>) and 4) Options for Enhancing the Value of the NOAA Weather-Ready Nation Ambassador Initiative (<https://bit.ly/3OqRnY1>).

The four studies above analyze valuation at different levels of abstraction and application, and with a focus on different audiences. Study 1 develops a terminology that facilitates the communication between scientists, developers, economists, and end users. It also points at approaches to maximize value in the weather, water, and climate enterprise. Study 2 directly addresses the challenges of economists in valuation studies of the Earth system OSS. While it does not attempt to evaluate individual programs or products, it uses previous experiences and case studies to develop concrete recommendations on how to improve valuation studies going forward. Study 3 analyzes community feedback on three landmark policies to identify opportunities and challenges to maximize the value of NOAA's work and of the weather, water, climate enterprise as a whole. Finally, Study 4 goes one step further than the other studies. It focuses on one particular program and the question of how its value might be maximized. It lays out a number of possible adjustments to the WRN initiative and discusses the pros and cons of the surveyed changes. Taken together, the analyses demonstrate the large number of decisions that determine the value of Earth system OSS. While many conclusions are difficult to generalize across studies, seven findings thread through the work on this project:

- 1) Valuation efforts promote societal benefit by:
  - a) Enabling decision-making,
  - b) Allowing prioritization,
  - c) Improving investment decisions, and
  - d) Promoting the use of science and services.



- 2) Assessments of value depend on both complex factors and subjective choices (e.g. how we measure value, how decisions incorporate and weight information, and what information is considered). As a result, there is no one correct measure of value, but multiple useful approaches to describe and quantify options. It is critical to public understanding that the assumptions underlying the valuation studies are clearly stated.
- 3) As a result of 2.), it is almost impossible to determine value independent of context. Valuation clarifies options and makes comparisons more effective. Valuation efforts are most effective in comparing different options and identifying their relative strengths and weaknesses with respect to explicit assumptions and metrics, instead of trying to determine absolute values.
- 4) The value of the WWC enterprise has increased with the number of partnerships across sectors and in all phases of the value chain. It has also made valuation efforts more complex, because the greater number of stakeholders and linkages lead to more options and more complicated decision trees.
- 5) One key limitation to valuation efforts is the difficulty to collect and research data on end users and their decision-making based on WWC products. These decisions ultimately realize much of the enterprise's value. For example, the value of a forecast is not sufficiently described by its skill score, but depends on the decisions it enables. It is much more difficult to reliably measure decisions across a diverse range of stakeholders and consumers than to verify the skill of WWC products.
- 6) Effective methods to advance the value of the WWC enterprise are likely to build on adaptive responses to incremental changes whose effectiveness can be determined quickly and lessons learned disseminated broadly. As value is context-dependent and the WWC enterprise complex, it is important to test hypotheses early and often in an effort to maximize value effectively and equitably.
- 7) Partnerships and effective distributions of roles and responsibilities among public, private, academic, and NGO communities are crucial and must evolve over time as capabilities, conditions, opportunities, and interests shift. These partnerships require and promote understanding, respect, trust, and clarity with respect to roles, responsibilities, and rules of engagement.

Valuation is critical to decision making at all levels. The set of studies synthesized here can contribute to a common understanding how value can be enhanced and communicated within and outside of the weather, water, and climate enterprise. There are many opportunities to build on this work. One option is to scale the approaches in this study to include a larger number of stakeholders and partners and analyze value creation along the value chain and across sectors and agencies.

The work performed during this project lays a foundation for future work on value creation in the weather, water, and climate enterprise. The language and principles in study 1 combined with the value chain approach in study 2 can be applied to an almost endless number of programs, projects, and decisions. Engaging stakeholders like the survey summarized in study 4 or the interviews in study 3 can provide valuable insights and feedback and can also be expanded to other policies and programs.

There are also new approaches to expand on the work in this project. It is likely that the value of weather, water, and climate intelligence varies between different sectors of the economy. A study that compares different sectors could lead to important insights about synergies and offsets in the WWC enterprise.

Climate change and society's response to it is likely to have significant impacts on the investments and values created (and expected) in weather, water, and climate science. There is a need for socioeconomic assessments to define and communicate priorities as the US and the world prepare for decades of rapid transformation. In particular, renewed economic activity on the coasts and in the ocean ("the new blue economy"), and the ongoing national conversation about the delivery of climate services are great opportunities to use valuation in an effort to grow the WWC enterprise and serve society as effectively as possible.

The AMS Policy Program has established an interdisciplinary team to build on the results of this project and develop a proposal for a consortium for socioeconomic assessments of the WWC enterprise. This program would enable AMS to continue its internal work on valuation as well as funding external experts to advance our understanding and communication of Earth system OSS.

