# R2 

## Harnessing (Geo) Science & Technology for National Benefit

### & How that Benefit Can Be Enhanced and Sustained

American Meteorological Society
Policy Program Study
January 2017

Policy Program Study

# Harnessing (Geo)Science & Technology for National Benefit

## & How That Benefit Can Be Enhanced & Sustained

**William H. Hooke, Jennifer Arrigo, Margaret Hurwitz, Emily Laidlaw, Subhashree Mishra, Thalia Patrinos, Ya'el Seid-Green, Kathryn Shontz, Matthew Stepp, Sarah Tessendorf, Marian Westley, and Anastasia Yanchilina**

## American Meteorological Society

**This report should be cited as:**
William H. Hooke, Jennifer Arrigo, Margaret Hurwitz, Emily Laidlaw, Subhashree Mishra, Thalia Patrinos, Ya'el Seid-Green, Kathryn Shontz, Matthew Stepp, Sarah Tessendorf, Marian Westley, and Anastasia Yanchilina, 2017. Harnessing (Geo)Science and Technology for National Benefit—and How That Benefit Can Be Enhanced and Sustained. An AMS Policy Program Study. The American Meteorological Society, Washington, DC.

The American Meteorological Society's Policy Program is supported in part through a public—private partnership that brings together corporate patrons and underwriters, and Federal agencies. Sponsoring agencies include the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). Corporate partners include Ball Aerospace & Technologies and Lockheed Martin.

The American Meteorological Society (AMS) is a scientific and professional society of roughly 13,000 members from the United States and over 100 foreign countries.

Additional copies of this report can be found online at: http://www.ametsoc.org/studies

**Acknowledgements**: Thanks to Shali Mohleji and Dick Hallgren for valuable suggestions during the development of this study. This work was supported, in part, by grants from the National Aeronautics and Space Administration (grants NNX13AM26G and NNX14AC84G) and the National Oceanic and Atmospheric Administration (grant NA09NWS4670020).

Photo credit (cover): NASA, adapted

**Foreword**

The American Meteorological Society's Policy Program advances science and services relating to weather, water, & climate for the benefit of all people. Our goal is to help the nation and world avoid risks & realize opportunities associated with the earth system.

We focus on three primary approaches to accomplish this goal:

- We develop capacity within the scientific community for effective and constructive engagement with the broader society.
- We inform the broader society directly about established scientific understanding and the latest high-impact research results.
- We expand the knowledge base needed to use scientific understanding for societal advancement, particularly through our studies, research, and analysis.

The study presented here examines the challenges and opportunities associated with converting scientific advances into societal benefits (the research to operations cycle).

There is a great need for this study because the knowledge and understanding that science provides makes possible rational and informed decision making. Of course, science is only one ingredient in societal advancement. Decision makers must also account for ethical considerations, economic interests, and fairness among a broad range of constituents. But as the problems and opportunities we face grow ever more complex, a rational and informed basis for decision making becomes ever more critical.

We offer studies like this one in the belief that our policy decisions have the best chance to benefit society if we ground them in the best available knowledge and understanding. This study on the research to operations cycle will help inform out policy discussions, in part, by identifying those areas that haven't gotten the attention that they may need.

Paul Higgins
Director, AMS Policy Program

## Executive Summary

The Nation has much to gain from (1) advancing the geosciences and (2) harnessing those advances to guide decisions and actions with respect to extraction and use of natural resources, building resilience to natural hazards, and protecting the value of Earth's ecosystem services. This American Meteorological Society policy study examines that second step, and identifies ways and means for more effectively realizing societal benefit. The insights are summarized in a set of findings and recommendations:

Finding 1. The application of new knowledge for societal benefit is pivotal to the future of nations and global society. Such application can be accelerated. This represents a significant opportunity for the United States.

Recommendation 1. The nation—government at all levels, private enterprise, and academia—should give more attention and priority to this opportunity, and be more disciplined in its execution.

Finding 2. Innovation is not a one-way process leading from science and technology to societal benefit, but a two-way process, in which societal needs also often motivate and direct innovation. Similarly, innovation has more of an iterative, ongoing chicken–egg character; it doesn't feature any well-defined beginning and end.

Recommendation 2. Scientists and users should therefore see themselves more as co-producers of innovation, and invest more in ongoing, close communication and collaboration.

Finding 3. Infrastructure and capacity building are needed to support this.

Recommendation 3. Government, private enterprise, and academia should develop ways and means to provide sustained funding for science application as well as science per se. But the need goes beyond budgets. Institutions need to plan, organize, and measure the transition from science to application, identify means for breaking down transition into multiple, manageable, reversible smaller steps versus relying on major leaps from basic research to widespread adoption and use. They need to identify tailored positions, career tracks, recognition, and other incentives for applied work. Support for application needs to be both top-down and grassroots and allow for both specialization and for flexibility.

Finding 4. Innovative methods and techniques exist for accelerating and sustaining application, but are underutilized.

Recommendation 4. Institutions should explore and make broader use of tools and approaches such as test beds/rapid prototyping, pilot programs, big data/ data analytics, and crowdsourcing.

Finding 5. Both the means and the benefits of application have a strong private- sector dimension. The private sector, which in the United States amounts to 90% of the labor force, is unsurprisingly a primary means through which advances in science and technology ultimately lead to societal benefit. Because the U.S. private sector is increasingly embedded in a global economy, the benefits of application should be worldwide. However, two centuries of U.S. culture and regulatory framework have established boundaries separating the public and private sectors that are better equipped to deal with domestic rather than international aspects of science application.

Recommendation 5. Policy makers and business leaders should pay more attention to ways and means for public and private sectors to collaborate in innovation while maintaining the regulatory framework that provides for a level playing field, fair competition, and other social goals. In evaluating the cost– benefits (broadly construed) of science application, policy makers and business alike should look not just to domestic benefits but also to the international benefits and opportunities.

Finding 6. Sustaining application requires a scientifically literate public that holds its leaders and institutions accountable for continuing innovation.

Recommendation 6. The nation should place more emphasis on STEM education, both to provide the professionals needed by government, business, and academia to advance and apply science and technology, and to ensure the larger population understands the strategic importance of innovation, stays abreast of progress, and holds leaders accountable for sustained improvement.

## I. Introduction and Context

Throughout history, the American public and its leaders have supported science. This long-term commitment stems from the recognition that scientific progress has been and continues to be *essential*, not just incidental, to achieving a range of national goals. Ensuring public health and safety, creating jobs, protecting the environment, maintaining national security—and, for that matter, promoting broader ideals of democracy and individual freedom and liberty worldwide—all depend on sustained U.S. scientific advance.

But U.S. pursuit of *science* for its own sake is not enough. Additional steps and actions are required to translate the "progress of science" into the desired practical benefits for the American people and global society more generally—and to sustain that progress, and human well-being, over the long haul. That task—that essential component of *innovation*—is extensive; it threads through every federal agency, the academic community, and much of private enterprise. Though pervasive and important, this additional work involved in harnessing science for public benefit has been inadequately studied and remains unsatisfactorily understood. In consequence, society fails to realize the fullest benefit from investments in science.

What fosters such innovation? What threatens or inhibits the process? How might advances in science and technology be more effectively and rapidly achieved and exploited for societal ends? These and similar questions merit continual, widespread attention.

Indeed, getting innovation right matters. Three brief narratives make the point:

1. Matt Ridley, in his 2010 book *The Rational Optimist*, describes a notional American farm family of 1800 eating by firelight in the evening because candles are so costly (roughly a day's wage); he then notes that thanks to scientific and technological advance, today's average developed-world wage earner works mere seconds to pay for an hour of reading light. This example, one of many in Mr. Ridley's book, is but a single illustration of the power of science and technology to improve the human condition.

2. However, Daniel Boorstin, in his 1983 book *The Discoverers*, observes that societal benefit from such advances is not a given. He provides numerous examples to the contrary; here are two. The first relates to the discovery that time

could be divided into equal parts; we usually call this the invention of the clock. Mr. Boorstin tells us that when Europeans invented the clock they put them on bell towers. Everyone throughout Europe's villages and their surroundings knew the time of day. By contrast, the Chinese had invented clocks considerably earlier, but they concluded that the power derived from knowing the time was too great to be widely shared. Instead, the timekeeper would whisper the time to the emperor at regular intervals; it was their secret.

Boorstin's second comparison concerns the discovery in late medieval times that the earth's surface is primarily water, ushering in the so-called Age of Exploration. Europeans saw *riches*. They built small ships—the smallest able to make the voyage and the return—and sent out minimal crews—the fewer to divide the booty. They traded (and sometimes plundered) and the profit motive kept them going and innovating for centuries. In the early 1400s the Chinese also began shipbuilding. However, at that time their aim was to *impress*—to prove their superiority to other nations and cultures. In this they surely succeeded. They built ships 200–300-feet long (without using a single nail), manned by crews numbering in the hundreds. They went abroad in flotillas of hundreds of ships carrying as many as 20,000 men. One such expedition went up and down the coast of East Africa, content to return with a single giraffe as its major prize. When the emperor who had inspired all this effort died, the Chinese, dismayed by the cost of such enterprise, made it a capital crime to build ocean-going vessels. According to Mr. Boorstin, this explained why the west dominated ocean trade with the Orient extending into the 1800s, rather than the other way around. These and other examples from history make it clear that whether science and technology result in social benefit, and to whom, depends upon policy, culture, and values—factors additional to and quite independent of technical prowess.

3. Joel Mokyr, an economic historian, in his 1992 book *The Lever of Riches: Technological Creativity and Economic Progress*, puts forth data-based arguments suggesting that no country or culture has been able to maintain success/leadership in this arena for more than a century or two.

History thus offers three lessons:

- Rapid advances in science and technology are necessary but not sufficient to improve the human condition.

- Public policies that foster science and technology *and* their application and uptake by society are also needed.
- To date, no society has proven able to sustain either or both of these capabilities for any length of time.

The International Council for Science (ICSU), in a 2006 report on capacity building in science, sees in these realities an associated set of three challenges:

- *The first challenge, a development problem, is the widening gap between advances in scientific knowledge and technology and society's ability to capture and use them.*
- *The second challenge, a workforce problem, is the apparent declining interest in the study of science and engineering around the world.*
- *The third challenge, an institutional problem, is the need to turn knowledge consumers into knowledge creators.*

In other words, as science and technology have advanced at the hands of a relative few, it has become correspondingly more difficult to harness those advances to serve a growing and increasingly complex and diverse global society. These difficulties are exacerbated in part because the public is losing interest in science and technology as a profession. This diminishing interest in turn reflects a more significant societal drift, from an active interest in expanding the world's store of knowledge to a passive reliance primarily on what is already known.

It is therefore in both the global and national interest to explore these challenges. But remarkably, despite innovation's importance to society, it is often pursued by individuals, companies and governments in an almost haphazard, ad hoc way. This is especially true of the second step in the process. *Application* of science is not widely recognized or studied as a discipline or explicitly considered amenable to strategic innovation in its own right. Instead it's almost considered an art form. Institutions, public and private alike, often fail to give it visible attention or budgetary priority. Failure rates are high but complacently accepted as inevitable. The U.S. government (and other national governments, for that matter) has no all-encompassing policy for the application of science corresponding to its policy for science per se.

We might therefore do better. But how? What would that look like? This report suggests some answers. It summarizes the findings and recommendations from an American Meteorological Society (AMS) study, centered around a two-day workshop held in Washington, DC, on December 2–3, 2015, looking at these questions from the perspective of the geosciences.

## II. Why the Geosciences? And Why the American Meteorological Society?

Why should the geosciences be particularly germane to efforts to understand innovation? And why should the American Meteorological Society undertake such an ambitious effort? There are several motivations.

To start, geo-realities have been at the heart of American fortunes throughout our history. The young nation realized that the world's immense oceans had shaped the outcome of the War of Independence and continued to protect national security at the same time they offered immense natural resources ranging from food (fish and shellfish) to energy (whale oil), and trade corridors connecting the United States to the larger world. Democratic values sustained Americans throughout the Revolutionary War, but the country's vast natural resources also made it worth the fight. This appreciation would endure. Prior to World War II, U.S. science agencies (the Coast and Geodetic Survey; the Army Corps of Engineers; the great expeditions, starting with Lewis and Clark; the Signal Service, the Navy Hydrographic Office; and the Geological Survey) were devoted to characterization of these natural resources (and geo-hazards). American higher education was shaped significantly by the national desire to maintain and improve agricultural productivity and the resulting Morrill Act. Even today, the geoscience needed to manage coupled water–food–energy resource issues remains a fundamental national concern.

Second, the geosciences occupy a crossroads in innovation. To start, progress in geosciences relies on *application* of advances in other fields, such as physics, chemistry, biology, mathematics, space technology, and IT. The invention of the telegraph, rather than any breakthrough in meteorological understanding, prompted worldwide establishment of national weather services in the latter half of the nineteenth century. Much of the improvement in weather-prediction skill since World War II derives from advances in computer, satellite, and radar technology.

But there is more to this part of the story. The geosciences also pay it forward. Some 200 nations and seven billion people rely in turn on *innovation in the geosciences* to (1) boost the supply of and access to natural resources such as food, water, and energy; (2) build resilience to the threats posed by natural hazards; and (3) contribute to protection, maintenance, and where possible, enhancement of landscapes, habitat, biodiversity, and environmental quality and the ecosystem services they provide. Emergency responders now plan and act on forecasts rather than waiting for extreme weather to strike. At every stage from farm to market, agribusiness relies on weather forecasts and seasonal to interannual outlooks to help ensure a steady, affordable food supply to the world's peoples. Insurance and reinsurance firms use the same weather, water, and climate data to manage weather and climate risks to property and ensure business continuity. Electrical utilities use weather and climate forecasts to anticipate energy demand on every time scale from minutes to centuries. And advances in geological understanding have led to the widespread adoption of fracking and a complete makeover of the world's energy picture.

Innovation in the earth sciences and their application has helped make it possible for us to leave that farm Matt Ridley described and follow other pursuits. In the 1800s most Americans were farmers. Today, the few percent still on the farm are able to feed the rest of us. Similarly small numbers are required to meet basic needs for water and energy. Efficiently taking care of these basic needs allows most of the population to turn attention to education, healthcare, commerce—and more innovation—improving our quality of life and ability to help and partner with the rest of the world.

Third, the increase in world population has combined with advances in science and technology to accelerate resource consumption, decrease resilience to extreme events, and strain ecosystem services to such a degree that the three problems can no longer be treated in isolation. Instead, they must be treated together, holistically. At the same time, advances in the diagnostic power of earth observations, and the emergence of the new field of big data/data analytics offer unprecedented new tools for accomplishing just that.

The tale doesn't end there. Applications in the geosciences illustrate larger truths about science application more broadly that pertain across the entire spectrum of science and technology. Understanding the world as a complex, nonlinear dynamical system that humanity has the capacity to alter has proven a particularly profound insight. And the geosciences offer examples of *success*—positives to build on versus mere negatives to avoid.

Why the American Meteorological Society? AMS is similar to many scientific societies in fostering progress in science and technology. Like the others, the AMS mission statement explicitly references beneficial application of those advances. But AMS doesn't just pay this idea lip service. Because AMS is a *professional*—not just a *scientific*—society, application of science for societal benefit is an integral part of the Society, interwoven throughout the whole of the community it serves. Application and societal impacts are respected as disciplines in their own right and are the subject of the Society's meetings and journals. One-third of its membership is from the private sector. AMS members include not just service providers but users from all sectors of the economy. AMS certifies consulting meteorologists and broadcast meteorologists who are the face of the geosciences to the public. This demographic matters. The application of science for human benefit, as much as the advance of science, defines AMS—its goals and purposes, its actions, its members—and its influence.

AMS's focus on societal benefit has also led to the development of an innovative approach to public education in earth sciences that has proven eminently successful in reaching large numbers of teachers, and through them, millions of K–12 students. This introduction serves as a portal or gateway for them to develop interest in other fields of science. As Jack Marburger, George W. Bush's science advisor, once said, "American kids care about three kinds of science: dinosaurs, space, . . . and *weather*." [Emphasis his own; *not* added.]

Finally, this focus has directly and indirectly led to a focus on policy, not advocacy; on substance, not politics. Directly, because a third of the Society's members and leadership hail from the government sector; that and the broad political diversity of the private-sector and academic demographic preclude any advocacy role. Indirectly, because AMS members include practitioners and service providers across a range of disciplines, collaborating with a variety of publics, ensuring that serving the national interest preempts any particular political leaning. At the same time the policy framework at national, state, and local levels powerfully shapes service provision and its value, making these matters of broad national, not just AMS, concern.

### III. The Purpose and Structure of the Study

This study was framed to achieve three purposes:

- *advance and deepen understanding*: contribute to and at the same time inform the ongoing national policy dialog on innovation;
- *disseminate*: in particular, share the study content, findings, and recommendations with the scientific community, the public, the private sector, the Executive Branch, and Congress; and
- *build capacity*: equip study participants, as well as those attending the subsequent briefing(s) and reading this report and/or viewing videos of some of the presentations, to engage in the innovation process more effectively over the long term.

Early on, the AMS Policy Program conducted an informal, initial survey polling AMS members from the government, private, and academic sectors on their experience transitioning research to services/operations. Respondents generally found some cautionary tales of failure, and much room for improvement, but also several instructive examples of success. These responses and Policy Program staff professional involvement with such efforts shaped the December 2–3, 2015 workshop. Workshop presentations were chosen to illustrate federal-agency and private-sector experience with technology transfer and applied science and/or to provide context for such work. Speakers and topics were chosen to stimulate discussion versus substitute for it. Half the workshop time was allocated to such discussion. Workshop announcements made it clear that participation was free and open but an additional, separate invitation was sent to some 500 alumni of the AMS Summer Policy Colloquium (an annual event since 2001). More than 30 alumni from previous years attended, including some from as far away as Oklahoma and Colorado. A smaller subset of this group participated in the writing and editing of the main body of this report, as well as summaries of the individual speaker presentations. In this way, the workshop was able to take advantage of highly motivated and exceedingly bright professionals while helping equip early career professionals to approach innovation more effectively throughout their life's work.

AMS workshop participants looked at three components to successful, sustained innovation: (1) *advance* in science and technology per se; (2) *application* of science and technology (known by many names—*tech transfer*, *R2O*, *R2X*, *applied research*, *the transition to operations*, *the infusion of science into* *operations*, *reconciling supply and demand for science*, *the transition from science to services,* and more); and (3) *societal demand for and uptake* of science and technology. (Science and technology advance and application can be initiated by a relative handful of the population, but they can't be sustained unless the larger general population understands and supports—even *demands*—such work.).

The remainder of the report is organized as follows: Section IV jumps directly to a set of findings and recommendations emerging from the talks and the ensuing discussions over the two days of the workshop. A set of appendices provide brief summaries of the individual workshop presentations. The summaries are not full transcripts of the talks, but they do provide more detail than might otherwise be available from a mere title or an extended abstract. As mentioned, the talk summaries were prepared by workshop participants, and have been edited only lightly; no attempt has been made to conform them to a single particular style. The approach leads to language that might seem somewhat informal for a report but has the advantage of not filtering the speaker's presentations more than necessary, reflecting the great variety in speaker styles and approach, and giving the reader interested in such a level of detail more of a feel of "being in the room." Readers who do probe the appendices will find that there is some correspondence between the organization of the talks and the findings and recommendations, but this is by no means one to one. Names in parentheses following each summary title acknowledge the participant-summarizer(s), who are also listed as co-authors of this report.

## IV. Workshop Findings/Recommendations

The talks and the discussion from the two days of sessions led to the following findings and recommendations.

Finding 1. The application of new knowledge for societal benefit is pivotal to the future of nations and global society. Such application can be accelerated. This represents a significant opportunity for the United States.
Recommendation 1. The *nation*—government at all levels, private enterprise, and academia—should give more attention and priority to this opportunity, and be more disciplined in its execution.

Finding 2. Innovation is not a one-way process leading from science and technology to societal benefit, but a two-way process, in which societal needs also often motivate and direct innovation. Similarly, innovation has more of an iterative, ongoing chicken–egg character; it doesn't feature any well-defined beginning and end.

Recommendation 2. Scientists and users should therefore see themselves more as co-producers of innovation, and invest more in ongoing, close communication and collaboration.

Finding 3. Infrastructure and capacity building are needed to support this.
Recommendation 3. Government, private enterprise, and academia should develop ways and means to provide sustained funding for science application as well as science per se. But the need goes beyond budgets. Institutions need to plan, organize, and measure the transition from science to application, identify means for breaking down transition into multiple, manageable, reversible smaller steps versus relying on major leaps from basic research to widespread adoption and use. They need to identify tailored positions, career tracks, recognition, and other incentives for applied work. Support for application needs to be both top-down and grassroots and allow for both specialization and for flexibility.

Finding 4. Innovative methods and techniques exist for accelerating and sustaining application, but are underutilized.
Recommendation 4. Institutions should explore and make broader use of tools and approaches such as test beds/rapid prototyping, pilot programs, big data/data analytics, and crowdsourcing.

Finding 5. Both the means and the benefits of application have a strong private-sector dimension. The private sector, which in the United States amounts to 90% of the labor force, is unsurprisingly a primary means through which advances in science and technology ultimately lead to societal benefit. Because the U.S. private sector is increasingly embedded in a global economy, the benefits of application should be worldwide. However, two centuries of U.S. culture and regulatory framework have established boundaries separating the public and private sectors that are better equipped to deal with domestic rather than international aspects of science application.

Recommendation 5. Policy makers and business leaders should pay more attention to ways and means for public and private sectors to collaborate in innovation while maintaining the regulatory framework that provides for a level playing field, fair competition, and other social goals. In evaluating the cost–benefits (broadly construed) of science application, policy makers and business alike should look not just to domestic benefits but also to the international benefits and opportunities.

Finding 6. Sustaining application requires a scientifically literate public that holds its leaders and institutions accountable for continuing innovation. Recommendation 6. The nation should place more emphasis on STEM education, both to provide the professionals needed by government, business, and academia to advance and apply science and technology, and to ensure the larger population understands the strategic importance of innovation, stays abreast of progress, and holds leaders accountable for sustained improvement.

**Concluding Remarks**

*"Lastly, I would address one general admonition to all; that they consider what are the true ends of knowledge, and that they seek it not either for pleasure of the mind, or for contention, or for superiority to others, or for profit, or fame, or power, or any of these inferior things; but for the benefit and use of life; and that they perfect and govern it in charity. For it was from the lust of power that the angels fell, from lust of knowledge that man fell; but of charity there can be no excess, neither did angel or man ever come in danger by it."*

—Francis Bacon (*The Great Instauration*, 1620)

Francis Bacon lived and worked four centuries ago. The world has changed a lot since then. Nonetheless, the natural philosopher (for that was how he saw himself, what they called science in those days) articulated a vision for science and knowledge as harnessed to the benefit of life that remains compelling and fresh today.

The peoples of the United States and the world are concerned with many pressing issues: basic physiological needs for food, water, and energy; public health, and health care; jobs; safety in the face of natural hazards and enemies foreign and domestic, and much more. Each of these carries with it social and moral concerns that in aggregate can individually or institutionally seem overwhelming—so expensive, so complex, and so consequential and contentious as to defy solution. But that reflects a natural human tendency to try to solve *tomorrow's* problems using *yesterday's* tools. In consequence we see the options as limited and oppressively zero-sum. When instead we reframe the challenges as subject to the advance of science and engineering, technology transfer, and societal uptake of new ways of doing business, the problems reveal themselves to be tractable.

And the news gets even better. Investment in innovation worldwide amounts to no more than a few percent of global GDP. It starts from such a low-level baseline that reallocating additional small increments of governmental budgets worldwide in this direction and implementing the other recommendations of this report hold enormous potential. These measures won't lead to merely modest change. They will transform society's options and prospects.

## APPENDICES. Supporting Materials: Talk Summaries and Links

*The summaries herein are not full transcripts of the talks, but they do provide more detail than might otherwise be available from a mere title or an extended abstract. They were prepared by individual workshop participants and have been edited only lightly; no attempt has been made to conform them slavishly to a single particular style. The language and variations in style from one talk to the next might seem excessively informal but have the merits of not filtering the speaker's presentations more than necessary, reflecting the great variety in speaker styles and approach, and giving the reader interested in such a level of detail more of a feel of "being in the room." While there is some correspondence between the organization of the talks and the findings and recommendations, this is by no means one to one. The findings and recommendations of section IV represent a synthesis derived from the talks and discussions over the two days. Names in parentheses following each summary title acknowledge the participant-summarizer(s), who also contributed to the main body of the report and are listed as co-authors.*

## Appendix 1. Overview/Theory

Two talks, serving as bookends to the first day of the workshop, provided an overview and some context. The first, by Daniel Sarewitz, served as a keynote to frame the discussion and generate thought. The second, by William Gail, was an after-dinner talk that same evening.

**Daniel Sarewitz**
**From Automatic to Manual Transition** (Jennifer Arrigo)

Sarewitz shares that he first began thinking about these issues in 1989 as a Congressional Science Fellow. He was "shocked to find out" that there was no systematic thinking about choices made about science and technology in terms of how resources were being allocated.

He's since been concerned with understanding the interactions among science, technology, policy, and innovations. Sarewitz argues for the need for transition from a "thoughtless" model—one where the prevailing thinking is that as long as there are enough resources in the "supply chain" of knowledge generation, we'll get what we need. Sarewitz contends that today we are reaching a "crisis moment" where the system as established is not able to deliver (sufficient) societal benefit from investments in science and technology research.

To understand how we got here, Sarewitz points to science history, beginning with the post–WW II establishment of the U.S. National Science Foundation through the efforts of Vannevar Bush. Bush's tenet was that scientific progress on broad fronts results from the "free play of intellect." It was what Sarewitz calls the "black box" model—we assume that social benefit automatically flows from investments in research.

It was not long before conflicting views emerged. Derek J. de Solla Price and Alvin M. Weinberg both sounded warnings about this model and pointed to aspects of it that Sarewitz contends predicted that we would be coming to this "crisis moment."

In 1963, Price looked at history and growth of science and demonstrated that it was exponential. He argued that this was not a sustainable trajectory—eventually we would enter a situation where there were not enough resources. There would be "too many scientists" leading to more diluted science; a prolific growth of information in journals with wild "overgrowth" in the amount of information and specificity and it would be too hard to understand (and realize benefit from) outside of specialized fields. This would lead to increasing stress and dysfunction in the system and "scientific doomsday."

In the debates around nuclear power that were occurring at about the same time, Weinberg observed that while many of the questions posed around this debate were framed as science questions, they were fundamentally ones to which we could never really know the answers—e.g., what are the exact risks of reactors? He defined this phenomenon as "transcience" where the debate is framed in a way that "looks like science," but science will never be able to answer the questions being posed. Politics and science were destined to be intermixed in this "transcience" realm. "One must establish what the limits of scientific facts really are," Weinberg said.

Sarewitz builds on these "early warnings" to analyze what we see today in science, technology and innovation. He identifies three problems:

(1) There is a Crisis of Reliability (Horton, *Lancet* April 2015)—the idea that much of the scientific literature may be untrue; bolstered by recent high-profile instances and studies of unverifiable results published in reputable journals.
(2) There is a Crisis of Politicization—we see that people's views of and on science map onto ideology. This is no more evident than with climate change—the ultimate transcience problem. Sarewitz gives as examples that Republican climate change "skeptics" are no less scientifically literate than their Democratic counterparts who accept the scientific basis for climate change. It is going to be intensely hard to disentangle science and ideology where the questions are fundamentally transcience.
(3) There is a Crisis of Public Value—this reflects the extent to which science is delivering "what it says it is delivering." Sarewitz argues that we see a mismatch between the amount of money being put into science and technology research and the innovation that results. Sarewitz uses measures of success of clinical trials to argue this point. He contends that measuring the success of clinical trials can show two things—first, they are a measure of "innovativeness," and second, they are a measure of the quality of science—the basic research that provided the foundation for the clinical trial. What we see today is that these trials aren't working to a great extent—that in some areas of medicine, clinical trials fail up to 90% of the time. Sarewitz argues that this shows that these trials are based on initial results that are "questionable science" and that it demonstrates that we are failing in the transfer of knowledge from these science studies into innovation and societal benefit.

Sarewitz contends that we are facing these crises in large part because of the current scientific research enterprise we have constructed. We have "locked-in institutions" that we must break out of to address these crises. Sarewitz concludes with three examples that show an active rather than passive role of the stakeholder, as exemplars of how we might do this. These examples demonstrate a very important point—knowledge creation occurs at all phases of the innovation process. We need to take that seriously in order to fully realize science's potential.

(1) National Breast Cancer Coalition

The National Breast Cancer Coalition is an organization that was formed in light of the billions of dollars that have been spent on cancer research. This group contends that ROI has been unacceptable in terms of that research translating to patient benefit and treatment advances, and has advocated and pioneered new ways to approach the problem outside of the standard NIH models of medical research.

NBCC worked with Congress, advocates, scientists to create a Department of Defense Breast Cancer Research Program that was results centered. The program includes innovative aspects such as having patient advocates on the review panels and has been much more innovative than NIH standard models.

The group is also creating a community of their own—they have formed the ARTEMIS project with a mindset similar to the Manhattan project: the aim is to "solve the problem as fast as they can." The strong role of activists in these efforts provides this constant push.

(2) Toxic Use Reduction Institute

TURI is a Massachusetts state agency established in 1989. It "collaborates with businesses, community organizations and government agencies to reduce the use of toxic chemicals, protect public health and the environment, and increase competitiveness of Massachusetts businesses" (TURI website). Reducing the use of toxic chemicals is often a difficult task—the burden of proof to identify toxicity is that, as Sarewitz puts it, "the cost outweighs benefits," and "that's a difficult standard." TURI took an innovative approach that helped identified significant toxic chemicals and work with industries to do alternative assessments and find substitutions. The key obstacle was "*not* that it can't be done, *but rather* that no one was working with the industry," and TURI provided the space to do that. Sarewitz highlights one institutional aspect of TURI—if you visit them it "looks like a 'shop class'—it's not a 'high class lab.'" This organization highlights the success of boundary-pushing and boundary-spanning organizations but one can see how it would be very difficult to think about how would reproduce something like this in the environment of current academic incentives.

(3) Yucca Mountain

Sarewitz's third example discusses the issues surrounding siting a nuclear waste storage facility, an intensely political issue that has been centered around Yucca Mountain in the United States. This is a vexing problem because, as Sarewitz states, "all the science can't solve the political problem—the opposition." However, rather than "convincing" the public with the science, Sarewitz discussed how they approached this problem in Sweden by bringing the public in as active participants in the siting process. When siting a nuclear waste disposal facility in that country, rather than "science" preselecting sites and then informing the public, the process began by asking for "volunteers"—communities and locations willing to be assessed. Municipalities were offered an award if they agreed to the assessment but there were no repercussions if locations did not volunteer. Three municipalities agreed, two of these were assessed, and one selected. In this way, the public opposition did not occur after selection; rather, the discourse and debate was in the hands of the municipalities before siting began. "Trans-science was not solved by more research, but by smart politics."

Sarewitz provides these examples to show a different way of thinking about the transfer of knowledge—it's not automatic, but rather takes persistence, networks of trust, nimble institutions, and knowledge flow in both directions. It's time to take these questions of science an innovation seriously and rethink our models. The *process of innovation* needs to be subject to the same rigor, review, and thoughtfulness as the *science* we are funding.

**William Gail**
**The Emerging Science of Environmental Applications: After-Dinner Talk** (Bill Hooke)

William Gail, Cofounder and Chief Technology Officer of Global Weather Corporation, closed the day with an after-dinner talk for participants that proved both reflective and informative—and inspiring as well. The talk was based on a paper by that title written by Dr. Gail and Dr. Jeff Dozier contributed as a chapter to a 2009 book entitled *The Fourth Paradigm*, written as a tribute to data pioneer Jim Gray.

In his talk Dr. Gail described the process of research-to-operations as *the **sustaining essence** of our lives as earth scientists and practitioners*. He provided two justifications for this bold assertion: first, *Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest **intellectual challenges** facing humanity*. Second, *it is also one of the most important **challenges for society** as it seeks to achieve prosperity, health, and sustainability*. He suggested seven significant differences between the science of environmental applications, and basic environmental science (this material is essentially quoted from the Gail–Dozier paper):

*Need-driven versus curiosity-driven*. Basic science is question driven; in contrast, the new applications science is guided more by societal needs than scientific curiosity. Rather than seeking answers to questions, it focuses on creating the ability to seek courses of action and determine their consequences.
*Externally constrained*. There's a ready-or-not aspect to applications science. It must be prepared to inform actions on a schedule and under circumstances

dictated by societal needs, not according to academic schedules based on when and how the best knowledge can be obtained.

*Consequential and recursive*. Actions arising from our knowledge of the earth often change the earth, creating the need for new knowledge about what we have changed. For example, the more we knew in the past about locations of fish populations, the more the populations were overfished; our original knowledge about them became rapidly outdated through our own actions. Applications science seeks to understand not just those aspects of the earth addressed by a particular use scenario, but also the consequences and externalities that result from that use scenario. A recent example is the shift of agricultural land to corn-for-ethanol production—an effort to reduce climate change that we now recognize as significantly stressing scarce water resources.

*Useful even when incomplete*. New means of making effective use of partial knowledge must be developed, including robust inference engines and statistical interpretation.

*Scalable*. For example, basic science tells us how to relate carbon content to measurements of vegetation type and density, but it does not give us the tools that scale this to a global inventory. New knowledge tools must be built to accurately create and update this inventory through cost-effective remote sensing or other means.

*Robust*. The decision-makers who apply applications knowledge typically have limited comprehension of how the knowledge was developed and in what situations it is applicable. To avoid misuse, the knowledge must be characterized in highly robust terms. It must be stable over time and insensitive to individual interpretations, changing context, and special conditions.

*Data intensive*. Basic science is data intensive in its own right, but data sources that support basic science are often insufficient to support applications. Localized impacts with global extent, such as intrusion of invasive species, are often difficult for centralized projects with small numbers of researchers to ascertain. New applications-appropriate sources must be identified, and new ways of observing (including the use of communities as data gatherers) must be developed.

He observed in closing that this is not just an idle intellectual exercise; that seven billion people are counting on us to get this science of environmental applications right.

## Appendix 2. Innovation: Remaking Knowledge *Consumers* into Knowledge *Creators* and Societal Uptake

**Lee Shanley**
**How to Use Crowdsourcing in Societal Uptake** (Anastasia Yanchilina; Sarah Tessendorf)

Lee Shanley discussed the contribution of citizen science and crowdsourcing (CS&C) to engage the public in science and at the same time to advance science itself. A citizen science project can identify research questions; design an investigation; accomplish data entry, as well as processing and analyzing the data (including the transcription of old documents); develop the data application, develop technology to advance science, and solve complex problems; and disseminate results.

There are many ways in which to involve volunteers in scientific research and monitoring such as data entry and/or problem solving. The benefits include the enhancement of scientific research and monitoring through data collection otherwise difficult to obtain due to physical constraints (e.g., geography, time, resources). A growing number of projects have been funded and papers published to which citizen science has had a large contribution.

Some successful examples include Galaxy Zoo, mPING, Tweet Earthquake Dispatch, Nature's notebook, Citizen Archivist Dashboard, MapGive, and Human Microbiome project. The Citizen Archivest Dashboard included a way to deliver high quality data, a project that involved different tiers of checking and cross-checking. These and other initiatives span many sectors and fields of science, such as communications (e.g., broadband speed tracking), mapping for the State Department, health (e.g., folding of protein challenge), and geoscience. Advances in technology, such as wearable technologies, mobile devices, and Unmanned Aerial Vehicles (UAVs), are enabling and enhancing CS&C opportunities. EPA is one of the many agencies that is working with communities to understand local problems and help with monitoring.

The Federal Community of Practice for Crowdsourcing and Citizen Science includes more than 200 members from >35 partner agencies, allows for networking that involves monthly meetings, an active listserv, and guest speakers, and has an impressive array of projects and applications. The National Action Plan for Open Government involves 125 federal employers developing an online toolkit targeted at agencies and focuses on how to use crowdsourcing know-how in program design and resolve data issues.

The federal government is developing a community of practice for CS&C. As part of this effort, a toolkit for CS&C was developed that provides resources on how to design a CS&C project, work with participants, deal with data quality, etc. There has been a lot of interest in the federal agencies for CS&C, but initially, positive responses from upper levels had been lacking. However, recently agencies worked with OSTP to shape the Holdren memo, launched the toolkit, announced a Citizen Science Day for April 2016, and passed the Crowdsourcing and Citizen Science Act of 2015. Moreover, the NSF director announced CS&C as a core priority budget area for the coming year and the Innovation toolkit from the President's strategy for American Innovation includes CS&C as a means for low-cost innovation.

The Holdren memo (released September 30, 2015) included three principles for effective use of CS&C: data quality/fitness for use, openness, and *meaningful* public participation. The requirements for such projects were to improve coordination and support for CS&C within and between agencies, and contribute to a public database of federal CS&C projects.

The ensuing discussion raised some interesting questions from the group regarding implementation. The first question asked was about the value created by this information, and whether there will or should be any compensation paid to citizen scientists. Lee Shanley pointed out that the value of data lies in its information. This data often has a high value and is incorporated into publications. As an example, in a biodiversity project, half of the studies that involved 2 million volunteers resulted in publications. For the most part, the compensation to citizen scientists lies in seeing the usefulness of data and engagement with the scientists. A second question raised privacy issues involved with respect to data collection and the volunteers. This has been an issue; one way to ensure privacy is to offer privacy as an option when logging and providing data. As it relates to data collection about human subjects, in most cases, the volunteers contribute information but are not subjects themselves and the policy on using human subjects varies by nation (e.g., in the U.K., this is not an issue but in the U.S. it is). Regarding the question of data quality and data application, Lee Shanley stressed that at this moment, these data are not expected to replace other scientific data but to supplement them. Some of the challenges crowd sourcing and citizen science are facing are the application of the data collected and checking its validity. In one example, certain agencies raise standards of data quality to the point it becomes harder for volunteers to contribute, partially as a consequence of rising expenses from acquiring instruments necessary to allow for higher data quality. As another example, there have been cases known where volunteers distort data on purpose. In this case, it would be helpful to have several data entries to check and cross check to provide validity of data collected.

**David Campbell, NSF Education Directorate**
**STEM Education** (Sarah Tessendorf; Jennifer Arrigo)

Education and Human Resources (EHR) at NSF is committed to building the STEM workforce of tomorrow and a STEM-literate public by improving STEM learning and broadening participation in STEM fields. 97% of funding in EHR "goes out the door"—they have made over 700 awards and reached 145,000 students and teachers.

Themes include learning and learning environments, broadening participation in STEM, and STEM professional workforce. There are four divisions: graduate education, undergraduate education, human resource development (e.g., increased participation of underrepresented groups in STEM), and research on formal and informal education settings. Their programs are mostly organized by audience (i.e., K12 or graduate education), not by discipline, and they fund the research on, but not the implementation of, educational techniques and programs. Rather, the latter is passed on to other agencies or jurisdictions. The Core Research Program builds foundational knowledge in the area of education research and focuses on Research, Development, and Model Building for STEM Learning. EHR funds education research—when something is ready for the classroom, it needs to be handed off. An idea can progress through Core Knowledge > Design and Development > Impact Studies, at which point it is ready to be implemented on a wider scale. Translation comes only after research and evaluation show effectiveness.

Programs related to this workshop theme include Climate Change Education partnerships to improve education (formal and informal) on climate change, Innovation Corps (I-Corps) to foster entrepreneurship among scientists for commercialization activities, and Science of Science and Innovation Policy (SciSIP) to advance the scientific basis of science and innovation policy (funded by the Social and Behavioral Sciences directorate).

The discussion centered on mechanisms for societal uptake of and engagement with science and science information, training scientists to be better communicators of their science, and methods for evaluating when research is ready for the transition to provide societal benefit.

Citizen science programs were again mentioned as a method for societal uptake and engagement with science (i.e., CoCoRaHS). Contrasting strategies for how policy has played a role in mandating science education standards were discussed. With Common Core, the federal government provided incentives for schools to adopt it and therefore the adoption was rushed and teachers were not ready. In contrast, no such incentives are being offered for adoption of the Next Generation Science Standards (NGSS). Rather, states are allowed to adopt whatever standards they want, and the NGSS are provided as an option. The issue of how STEM education standards, quality, and school funding vary so much by state was raised as a possible reason for why the United States is so behind in STEM education compared to other countries. Ideas raised to counter this were to suggest there should be competition between states to want to be better and maybe make multi-state alliances to create common standards across regions and therefore have fewer than 50 different versions of standards. Moreover, a push for inquiry-based learning is needed so that students in the current technology-driven generation are not disconnected with the scientific origins of the technology and other commodities they may take for granted (e.g., food, water). This is part of the NGSS.

Science education and outreach requires good communication between scientists and students or the public. Therefore, more training for scientists to be better communicators is needed, perhaps from early ages at the K12 level as well as for those in later stages of their career. The former is being addressed with the 21$^{st}$-century skills movement in the K12 education system. A resource on this topic for scientists is Randy Olson's 2009 book *Don't Be Such a Scientist*. Nonetheless, the concern that we may be expecting too much of individual scientists was raised. A group consensus was that there is a need to allow specialization, so that we still have expert "superstar" scientists well trained in their specific discipline to drive innovative science, but then have more teamwork so that teams comprise the broad range of requisite skills to meet these modern day challenges. With a push for more team-oriented approaches, good managers of scientists are needed as well.

The other side to the improved communication of science is that the general public needs be more scientifically literate as well. Therefore, promoting general science literacy of the public and education on *system* science, as opposed to discipline-specific science, was discussed. One challenge raised was how teachers are able to do enrichment activities that address system science when their evaluation is based on standardized tests with a discipline-based focus. An overhaul in the standardized testing technology is really needed in order to overcome these challenges.

What are the metrics needed to show that the science is ready to transition for societal uptake? Peer review is the traditional method to decide if the science is sound, but not to evaluate if ideas are ready for societal application necessarily. Having a broad range of reviewers (i.e., physical scientists, education researchers, teachers, etc.) is important, especially for STEM education proposals. A big aspect of education proposals is evaluation of the technique or program, and physical scientists typically do not understand methods for such evaluation. It was suggested that physical scientists should collaborate with education researchers to realize the multi-disciplinary skill set needed to evaluate STEM education-related proposals.

What's needed to advance STEM learning and education research? Campbell believes the key is better agency coordination. "Grassroots" connections with NASA and NOAA have worked in the past, but these need to be institutionalized.

Campbell is concerned about the apparent declining interest in studying STEM. He questions whether "commoditization is abstracting the science one more level away?" Is the proliferation of technology to the point where "a push of a button makes getting information too easy," suppressing natural curiosity and investigative mindset. He believes we could do a better job blending "tracks" within our education system (e.g., not separating college vs technology education).

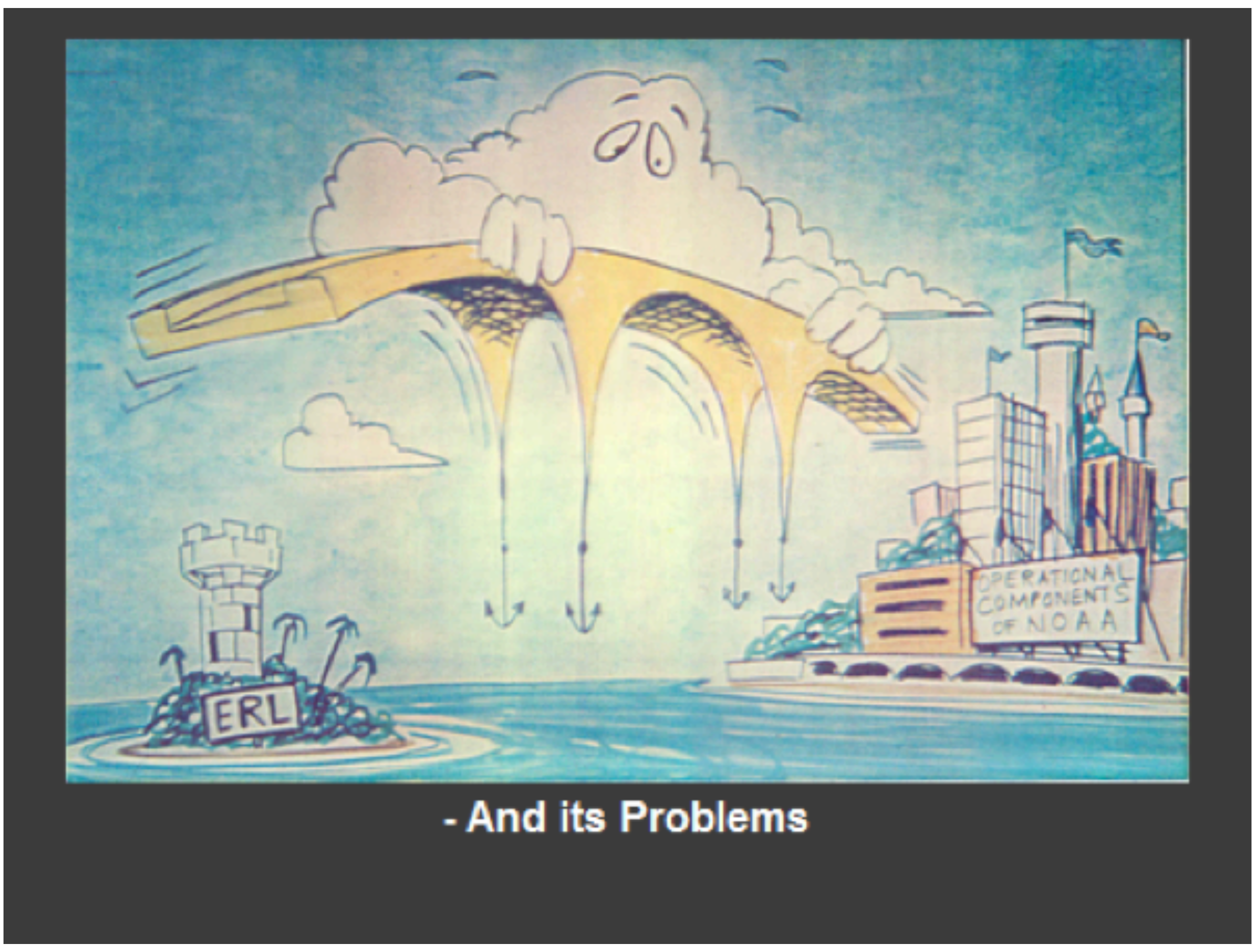
He believes we need to move from how we currently treat science as "just another subject"—this introduces an artificial separation—whereas science should really be framed as "the way we see the world."

## Appendix 3. Agency Approaches to Transition Research

**Rick Spinrad, NOAA Chief Scientist**
**Rebuilding/Creating Infrastructure from Within (NOAA)** (Subhashree Mishra, Maggie Hurwitz)

Using cartoon slides dating back to the 1970s, based upon Gordon Little's *"On Building Bridges,"* Dr. Spinrad opened his talk by (1) illustrating that research-to-operations is a longstanding challenge at NOAA and (2) listing R2O tactics to avoid: e.g., R2O driven by high-level managers in isolation or "forming a committee" rather than taking action. Successful R2O needs to involve both the researchers and the operational center. Possible approaches included:

Method 1: Policy
Method 2: Mandate
Method 3: Committee approach
Method 4: Assign it to the Weather Service or any Service
Method 5: Assign the task to ERL




Method 6: Wait for the "higher ups" to build the bridge


***Method 7: Resources for All—The One That Works!***

(Each approach had been illustrated by a slide in the original Gordon-Little presentations, but these slides give the flavor.)

Dr. Spinrad then raised several "theological" questions associated with transitioning research into operations:

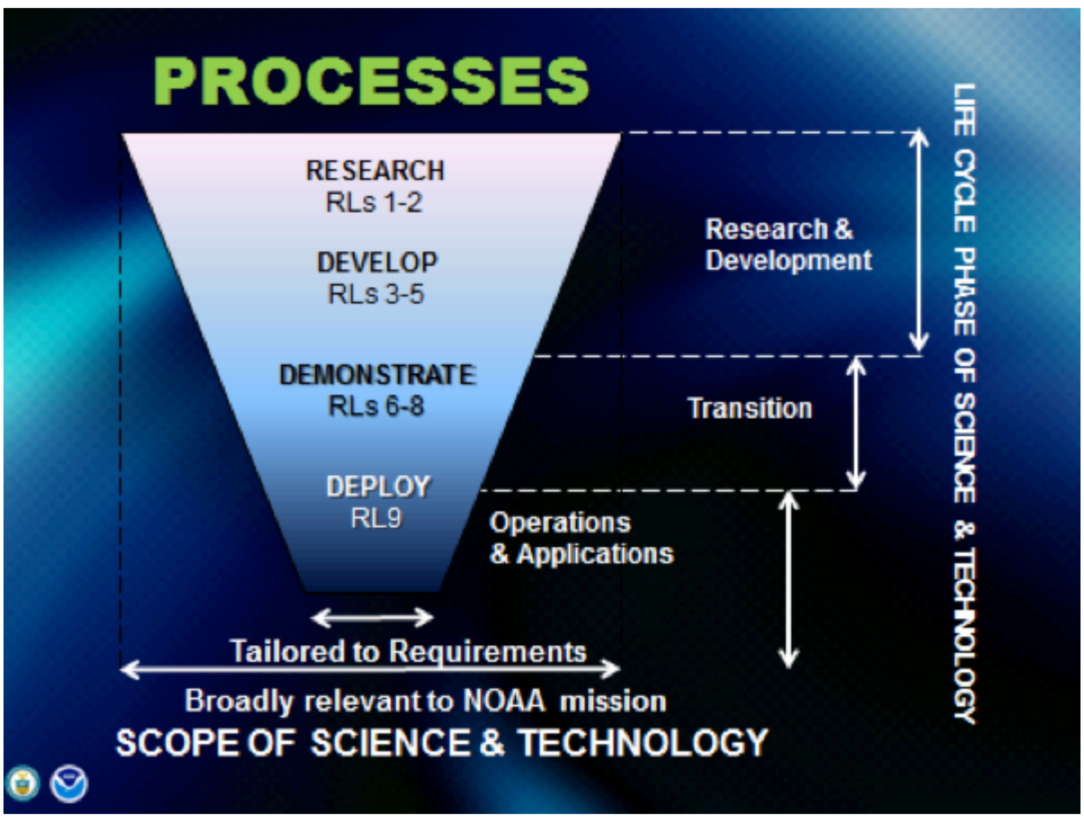
1. What is the problem?
2. What needs doing now?
3. Who needs to do what?

Working with the audience, and using the Socratic method, he walked through the example of multi-function phased-array radar (MPAR)—transition to operations and a comparison with the development and deployment of the antecedent WSR88D radars during the late 1980s and early 1990s.

The Navy had developed MPAR for military application, but provided a prototype unit to NOAA's National Severe Storms Laboratory in Norman, OK, to enable study of its potential for monitoring rapidly developing severe weather. DoD, DHS, NOAA/NWS, and the FAA were all interested in the project. Dr. Spinrad asked three questions:

**Q1. Why should we not buy a hundred phased-array radars tomorrow? What is the problem?**

It's important to get the process right. Dimensions of this challenge included the following: Funding, prioritization of funding and other resources, resistance to change, training (specifically, time for training, maintenance training, IT, and support systems), requirements (scientifically, operationally and from the user community), prioritization relative to other things, quantification of the value proposition, communication between the parties, outreach to Congress and the public, specifying requirements of the equipment and the end users, scheduling of technology deployment (e.g., FAA versus NWS), and the influences of politics and stakeholders.




Dr. Spinrad emphasized that we should accelerate the investment in the demonstration stage (so-called readiness levels RL 6-8) to get research to deployment. We need dedicated resources, which require significant budget increases in this area. (Note added in proof: the President's proposed FY2017 budget to the Congress provides for such augmentation.)

**Q2. What needs doing now?**

Answers included the following: Soliciting user requirements and training, demonstrating the business case, planning the O&M cost or the total life cycle cost, using a common lexicon for better communication, following an integrated deployment schedule, preparing a budget, etc.

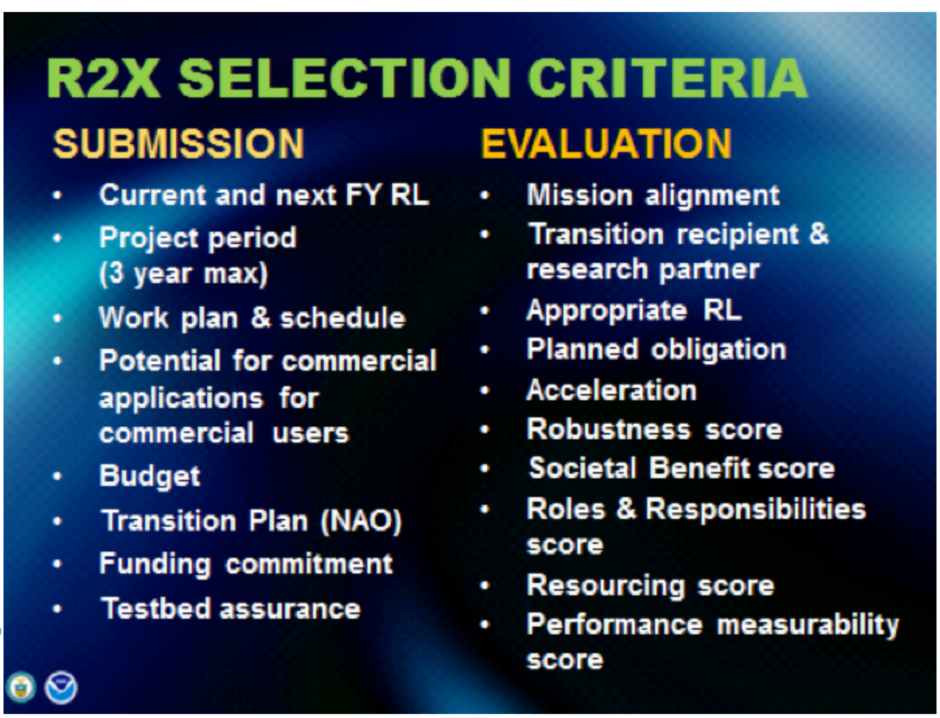
Spinrad noted that at the time of the workshop, NOAA has only two funding buckets or "colors of money": (1) operations, research, and facility money and (2) acquisitions and procurement money. Unlike DoD there is no dedicated budget for technology transfer for new advances such as MPAR. Spinrad indicated that this lack of a dedicated budget is the heart of the problem.

**Q3. Who needs to do what?**

Answers included the following: Leadership on inter-agency coordination, e.g., by the Office of the Federal Coordinator of Meteorology (OFCM); program management i.e., someone who "owns" the project and pushes it through; dedicated personnel to develop the business case; someone to set mission priorities; and finally, the leadership and personnel to sustain the enterprise.

**R2X—Transitioning Research to Operations, Applications, Commercialization, and Other Uses**

Spinrad indicated that NOAA is going to invest in earth system science and several other areas according to R2X selection criteria provided in the figure.



Mission alignment is the most important factor.

There is now a NOAA program called the Research Transition Acceleration Program (RTAP) with a total funding level of $191 million over three years. Returning to Gordon Little's slide-based narrative, Dr. Spinrad concluded: *here is a solution—**Method 7: Resources for all!!!***

**Lawrence Friedl, Director, NASA Applied Sciences Program**
**A Group Specializing in/Dedicated to Working with Outside Groups (NASA)** (Emily Laidlaw)

Bill Hooke introduced Lawrence, observing that the Applied Sciences Program has made great strides and that much of that progress can be attributed to Lawrence. Lawrence thanked AMS on behalf of NASA for their efforts and for holding the workshop.

Lawrence opened with a quote from James Allen Smith stating that the underlying problem of society is one of linking knowledge. He said he hopes that the workshop will ultimately produce recommendations for program managers at federal agencies in terms of resources, information, methods for transferring information, etc.

Lawrence then discussed policy, programs, and priorities, and said it's important to consider the following questions:

- Is policy needed and where is it needed?
- How do we structure federal-level programs? What are the structures, incentives, etc., that drive the programs we want?
- Is it a matter of priorities (prioritizing resources, statements from executives, etc.)?

Lawrence also said that we must consider the following:

- What problems are we aiming to fix? Are those problems real or perceived? Is the rate fast enough?
- Are we not seeing enough throughputs?
- Does it take longer than we think (duration of effort)? Is it not sustainable?
- Do we feel that we're not taking on enough risk?
- Do we have a general sense of inefficiency or underachievement, underappreciation, under-improvement?

He noted that we should remain aware of things that don't need to be fixed because they are working just right.

Lawrence then provided an overview of NASA's Applied Sciences Program and noted that the program supports basic and applied research on the earth system and its processes to advance knowledge and benefit society. NASA is trying to understand applications and do end-to-end research. Lawrence mentioned that the program also provides support to graduate students.

Lawrence posed the following question: How do we encourage uptake of earth science observation, and how do we broaden and expand that uptake? He noted that we in the science community have the notion that the benefits of our science are larger than public appreciation of the science.

NASA has redefined what science means to the organization, broadening the scope to include research, applied research, and applications. The Applied Sciences Program focuses on five application areas/lines of business (ecological forecasting, disasters, wildfires, water resources, and health and air quality) and also provides ad hoc opportunities in additional areas that focus on advancing knowledge and conducting assessments. Primary focal areas for the program are societal and economic applications, applications in mission planning, and capacity development.

The program is working to better determine how to encourage the application planning community to get involved early in the process. Lawrence noted that there is a whole culture change going on within NASA's research and mission side that's actively trying to determine the best ways to involve users and involve them earlier. The organization currently has a number of programmatic mechanisms that involve end users, such as webinars, trainings, hands-on case studies, and application project grants.

Throughout the course of attempting to better connect with users, the program has questioned the "under the bridge" metaphor and whether it's the right way to think of things. The metaphor implies that you can go directly from fundamental knowledge to the application of fundamental knowledge, but the straight-line model may not be the appropriate metaphor, Lawrence said. He posited that the broker model may be more appropriate, and noted that the agency is currently examining the merits of the broker model and whether it allows greater agility and flexibility.

Lawrence noted that NASA is facing a number of programmatic tensions that most program managers likely face when deciding how to set the strategy for a program and determine what to invest in. These tensions include

- Partner/user reach
- Program role and control

- Earth science missions and products
- Project portfolio
- Application enablement

Lawrence said that programs have historically asked users to articulate what baseline performance is for their decision-making, and users often can't give a good answer. The biggest value of the applied science projects funded by NASA, he said, is that users become able to answer that question. Lawrence suggested that we work to define recommendations about how to get user communities to better articulate their decisions, metrics, and actions. We also need to work to better set up connections between the research and applications communities.

NASA's Applied Sciences Program set up a one-year feasibility study of funded projects, and then selected a subset of projects to continue after that time. It was determined that the selected subset of projects would continue to get funding, but that funding would be contingent on partners' funding as well. NASA's cost sharing is as follows: 100% in Year 1, 80% in Year 2, 60–70% in Year 3, and 30–40% in Year 4. The program is now in the middle of the second year of Phase 2 and is now seeing the planned decrease in money that NASA is putting into the projects and an increase in the amount of money that project partners are putting in. Lawrence noted that they will use this as a programmatic model in some cases to ensure that partners stay engaged.

The program has also been exploring the mechanism of applied science teams to increase agility and flexibility in serving user needs and to put scientists and researchers in listening mode. Lawrence said this grew out of situations where other government agencies, such as the EPA, were coming to NASA because they wanted to use NASA's earth observations. NASA would agree to the use, but then it would take several years to implement the transfer of information. NASA realized that they needed a mechanism to add flexibility into the system while still honoring the competitive application system and the peer review process. So they set up a way to fund a number of researchers in team environment (e.g., USAID, air quality). For the air quality team, NASA recruited 15 people with several years of experience on the research side and told them that they would be getting core funding, as well as tiger team funding for ad hoc projects. Every year the team would have to identify ad hoc projects to work on, and those projects would be dependent on the team going out and talking to users to glean needs and research priorities. This put the team in listening mode, since they would have to understand what users were saying. Lawrence noted that it took several years for the teams to begin functioning in an ideal way. In the beginning, the researchers were in their own cliques and were in "talk" mode and wanted to present to air quality managers. It took several years to get the researchers on the team to become the audience and swap to "listening" mode. Lawrence said the applied science teams have been successful and that they have received a lot of positive feedback. Researchers are excited about engaging with users, and users have been able to have a voice to identify issues that are important to them. The researchers also realized that journal articles were not the best form of communication with air quality managers (i.e., they realized that air quality managers were not all out there reading the journal articles).

The Applied Sciences Program also has an early adopters program to bring in public and private organizations with their own money (e.g., SMAP). Through this program, each participating organization receives simulated data and can test it. This enables the organizations to be ready to go once real data becomes available, and they are better able to use the data soon after it launches as a result (Lawrence referenced this YouTube video).

NASA has also instituted an Applications Readiness Level (ARL) index that mimics the Technology Readiness Level. The index goes from ARL 1 to ARL 9, with ARL 1 constituting "Basic Research (Baseline Ideas)" and ARL 9 being "Approved, Operational Deployment and Use in Decision Making (Sustained Use)". The purpose of the scale is not to have people try to race up it, Lawrence said (and every project is not expected to go through all 9 stages), but to better understand at what stage a particular project is and how it is maturing. Managers talk to project teams about where project is and what it will take to get to the next level to better understand where are things breaking down (e.g., between ARL 4 and ARL 5) and what the reasons for any delays are. This enables managers to know if they can design an intervention to help projects along.

Lawrence also discussed the topic of accelerating innovation and noted a number of relevant topics from the workshop readings, such as tolerance of failure, ambiguity, communication, integrity, and hands-on management. He noted Roger Pielke Jr.'s call for having a well-articulated demand function and emphasized the need to ask, "What are users' characteristics, behaviors, and preferences?" He mentioned the "Three Es" from Brooks' reading and asked:

- Are we getting out and assessing user needs and preferences?
- How are we pursuing evaluating ourselves?
- Are we encouraging entrepreneurism?

Lawrence said we should consider alternative ways to think about evaluating programs and how best to encourage the use of earth sciences and geosciences data, as well as ways to use crowd expertise to refine ideas and provide input for program managers. Lawrence noted that many organizations undertake user and market studies to better understand users' behaviors and preferences. Companies like Amazon, Trip Advisor, and Yelp have gone to great lengths to understand their users and refine their websites over time so that people know where to go to get what they need. Lawrence asked how we in the earth sciences community set up similar mechanisms that provide data in user-friendly ways. “What would the earth sciences world be like if earth observation data were just as easy to get as a book on Amazon?” he asked. Lawrence suggested mocking up designs of such interfaces and testing them with users. Science teams could then see what issues people were having and what people thought of the datasets.

Lawrence mentioned project brokering websites (and noted the Engineering for Change website as an example), where people can put out a bulletin saying they need a hydrologist, etc. Are there ways for the earth sciences community to set up infrastructure to facilitate such matchmaking? Is such matchmaking happening at a rate that’s insufficient for the type of objectives that we have?

Lawrence also noted that we should consider ways to take and refine crowd-generated ideas. The TSA has created an “idea factory” where the crowd can propose ideas, and others can build on those ideas. The UK has been pursuing the CATAPULT model, which is a government-funded effort to reach out to industries within the UK and conduct market research to understand data products. Data products can then be developed based on that market research, which is a vast improvement over the more typical model in which the research community develops data products first and then tries to find users for those products. The best products are developed with input from industry, Lawrence said.

Lawrence also discussed the Applied Sciences Program’s influence and involvement in the creation and pursuit of the G20 initiative Agricultural Market Information System (AMIS). This initiative aims to enhance food market transparency and encourage coordination of policy in response to market uncertainty. Each month the project produces a global map showing wheat, soybeans, rice, and corn conditions in multiple parts of the world. These maps are not just images of remote sensing data and coloring for different indices; instead, the project team worked with graphic artists and economists at agriculture bureaus in different countries to help understand how to take the information and data being applied and provide/convey it in a way that supports analyses that users are doing. This constitutes a different take on research-to-applications, where users are able to provide input on how to better discern information rather than just being expected to be consumers of products.

Lawrence also discussed the need for bridging communities. If we are going to promote research that spans research and applications, then we need to recognize how to bridge communities, he said. An important part of bridging communities is assessing whether we have a shared understanding between communities (e.g., make a list of terms used on different sides; may not find a lot of connection). For example, economists use the term “productivity” in a different way than the remote sensing community does, Lawrence said. We aren’t expecting earth scientists to become economists or vice versa, but there needs to be a shared understanding.

Lawrence ended the talk by going back to the discussion of determining what problem we're facing. He asked how the interventions we're discussing would fit into the three categories of policy, program, and priority.

The audience had several questions and points of discussion, including the following:

- A workshop participant asked, "How do you determine when to stop, and how do you determine priorities?"
  Lawrence's response: It's certainly something you think about as a program manager and something that would come out of market research, which we haven't been doing enough of. In some cases, organizations are using data more than they thought, but also in some cases they haven't been using data—both have been surprising. We will examine this more when we start doing more market research. There has been a lack of complaints from organizations about the fact that the Applied Sciences Program is also supplying grants to organizations' competitors, and that makes him think there's room for improvement. The program needs to do a better job of marketing and advertising grants or consider that the money they are offering isn't enough to get more organizations involved.

- A workshop participant made a comment about incremental benefits. Lawrence's response: Is it done at the project level or should we step away and ask if we'll get a better return if we provide incentives for users to access data?

- Bill Hooke noted that we should think about what other parts of the government and the legislative branch are doing (e.g., OMB, OSTP). Lawrence noted that he would appreciate other organizations underscoring NASA's definition of the three pillars of science (research, applied research, applications). He noted that there is a cultural issue between physical and social sciences and that it would be good to break down the hierarchy and help everyone identify ways to provide reward structures for people to work on cross disciplinary projects. The workshop group noted the issue that it is often really hard to know where to publish interdisciplinary research when the majority of journals are set up as disciplinary.

- A workshop participant alluded to the metaphor of the broker and asked whether NASA is using the Applied Sciences Program as an example of a broker. The participant noted the membership seems to be almost entirely academic, which seems contrary to notion of broker. He asked whether the teams have representation in the private sector. Lawrence's response: The people who submitted proposals were largely from the academic sector. In addition, the proposals that scored better were typically from academia and government. There is no reason that private-sector entities couldn't submit proposals, but NASA just has to make sure they're not favoring one company more than another.

**Alex MacDonald, Program Executive for Emerging Space, Office of the Chief Technologist, NASA**
**A Complementary NASA Effort: Commercialization of Space** (Kathryn Shontz)

When the public at large has a stake in science, the translation of this science into societal benefit is accelerated through private funding. This funding source signals the importance of science in society, and serves as the impetus for creation of governmental institutions that serve as foundational and inspirational centers of excellence.

Specifically, in the case of the National Aeronautics and Space Agency (NASA) space flight program, societal signaling can be traced back to the public investment in observatories going back two centuries. John Quincy Adams heralded national observatories as national symbol of science and began to tirelessly promote their construction throughout the United States. During the 1800s, wealthy investors funded observatories as monuments to themselves, signaling that astronomical science represented a prestigious achievement in American culture. The public at large then became inspired by this, and cities such as Cincinnati, Ohio, funded their own regional observatories. Americans funded this because they were interested in astronomical science, with the possibilities it represented, not because they expected to turn a profit.

The collective fascination with space exploration only grew as contemporary authors first envisioned spaceships for their audiences. Jules Verne envisioned a fantastical future in which people launched into space on a rocket ship from Florida—how close he really was! The difference is that Verne saw the public funding this launch, leveraging the strong American desire to bring the ideas of science fiction into reality.

It is this public interest that inspired people to make these dreams reality with really no market incentives—there was an intrinsic supply of motivated and brilliant labor, which inherently replied upon the public signal that space exploration was important. Indeed, NASA was born from this early investment and scientific innovation coupled with inspiration cultural narratives. Though it is a governmental agency, NASA has continued its originating tradition of working with the private industry and greatly relies upon those fascinated by space as its labor supply.

Some crucial lessons can be gleaned from the founding of NASA. First, public signaling and interest in a scientific topic is critical to the creation of institutional centers of excellence. And, maybe more importantly, it is the private funding of science in that manner that demonstrates the public interest is piqued. Second, it is important to recognize that public and private organizations act differently—the public modulates public institutions and can potentially discourage far-sighted innovation. Instead, private companies can more readily harness the intrinsic motivation of an individual to steer toward cutting-edge science. Lastly, resources to fund scientific innovation are more easily accessible from private industry and individuals. For research to be accomplished, private funding advocates are almost necessary.

Turning then to atmospheric science, and more specifically to climate, how does the United States repeat the space exploration institutional successes for environmental issues? How do we encourage societal uptake, and promote and finally sustain this? America needs to better harness the private sector and the public at large. If climate scientists can inspire the nation to rally behind climate change initiatives, the public will then signal the need for institutional centers of excellence and moreover be inspired to devote their labor to climate innovation. America also needs to invest in the younger generation—the private industry in Silicon Valley has seen huge payoffs when investors back young visionaries. Finally, to change the national view of environmental issues, a distinct and reverent culture must be present. This culture is dependent upon the fascinating narratives and institutional credence created around the issue. America is signaling the need for a change in how the issue of climate is considered—it is now time to build the institution that inspires environmental change.

**Dr. Roger Wakimoto, Assistant Director for Geosciences (GEO), NSF**
**Projects Arising Organically within a Pure Science Agency (NSF)**
(Thalia Patrinos, Emily Laidlaw)

Dr. Roger Wakimoto approached his presentation from the perspective of the Assistant Director of the National Science Foundation's (NSF) Directorate for Geosciences (GEO). The GEO Directorate funds and supports core research in the atmospheric, polar, earth, and ocean sciences—Dr. Wakimoto himself is a geophysicist with expertise in tornadoes, thunderstorms, and other types of severe weather. Dr. Wakimoto noted that although basic research is fundamental to NSF, that doesn't mean that NSF doesn't appreciate and contribute to applied research. For example, before Google Inc. became the multinational technology company it is today, it began merely as a research project by two Ph.D. students at Stanford University. Those submitting the proposal had a vision, but they didn't know where it was going initially.

Dr. Wakimoto said that NSF tries very hard to foster collaborative research and to try to accelerate the transition of NSF-supported inventions into commercial products, and to educate the workforce. He noted that the education system isn't preparing people to go into private sector, but many (~60%) are choosing to do so.

He showed a list of varied ways that NSF-sponsored research impacts our lives, including anti-virus software, bionic limbs, and Doppler radar. He then discussed innovation investments for geosciences as part of NSF's FY16 budget request. Top priorities include the following:

- Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS)—This is compelling anyway, he said, but it also has a really nice connection to societal impacts/benefits; not possible to separate water from food from energy

- Prediction of and Resilience against Extreme Events (PREEVENTS)—As Dr. Wakimoto says, "When you think of an idea for an initiative, you need a good acronym." PREEVENTS focuses on the development of models and tools that help understand the impact of natural disasters on natural, social, and economic systems, and how to best prepare for them. PREEVENTS aims to enhance understanding of the fundamental processes underlying geohazards; improve models of geohazards, extreme events, and their impacts on natural, social, and economic systems; and develop new tools to enhance societal preparedness and resilience against such impacts.

Dr. Wakimoto also discussed the GEO innovation call and noted that NSF has been trying to get the word out to PIs and industry partners that NSF is very open to tech transfer, commercialization, etc. He also mentioned I-Corps, a public-private partnership designed to provide seed funding to transition research into operations (development of technologies, products, and processes). NSF has developed MOUs with ARPA-E, NIH, and DHS to date. Dr. Wakimoto provided an example of an I-Corps innovation—a portable, inexpensive device to measure $N_2O$—that won an innovation prize at Princeton and has broken into the market.

He also discussed the Industry and University Cooperative Research program (I/UCRC), that aims to develop long-term partnerships among industry, academia, and the government. The program plans to create centers that will do research that is of interest to both industry and academia and bring together universities, companies, state/federal/local governments, and nonprofits. Principal investigators find research appropriate for commercialization and connect students with counterparts in industry that share the same focus. A couple of examples of these interdisciplinary teams are the Center for Unmanned Aircraft

Systems (C-UAS), Sustainably Integrated Buildings and Sites (SIBS), and Water and Environmental Technology (WET).

Grant Opportunities for Academic Liaison with Industry (GOALI) also promotes university–industry partnerships by providing project funds or fellowships to combinations of faculty, students, and industrial scientists. Engineering Research Centers (ERCs) provide a space where academia, industry, and government can solve engineering challenges together. An example of one of these is Collaborative Adaptive Sensing of the Atmosphere (CASA). CASA worked with cell phone companies to place the atmospheric sensors on cell phone towers, and program officers from GEO assisted in this partnership.

Dr. Wakimoto noted the Research Application Laboratory (RAL) at the National Center for Atmospheric Research (NCAR) as an example. A prior panel review called RAL the "crown jewel of NCAR." Dr. Wakimoto said that if RAL didn't exist today, NCAR and NSF would be forced to create it. "It really is science serving society," he said. Over 200 staff members work together across disciplines to address the impact of weather and climate on societal issues like transportation, national security, and human health. RAL started with research on the microburst phenomenon, which used to cause many aircraft crashes and hundreds of deaths. Their efforts led to the development of wind shear avoidance training and Terminal Doppler Weather Radars (TDWRs). Since then, the threat from this hazard has been neutralized, and countless lives have been saved.

Other programs highlighted by Dr. Wakimoto included GEO Ocean Sciences, which creates cutting-edge technology platform developments, and the Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) program, which supports high-risk and innovative projects with potentially high payback (commercial/broader impact). For example, an SBIR award was awarded to Fallgatter Technologies for designing a Multi Angle Snowflake Camera (MASC) that takes stereographic images of snowflakes and measures their fall speed. MASC data verifies snowfall predictions and winter precipitation algorithms for weather radars. MASC systems also provide real-time imaging and accumulation estimates for transportation planners, road crews, and emergency managers.

Dr. Wakimoto then discussed NSF merit review criteria and noted that these criteria consist of two main components: intellectual merit and broader impacts. To meet the criterion of intellectual merit, a proposal should be "great science," with the potential to advance knowledge. Dr. Wakimoto noted that the second criterion, broader impacts, often gets lost in shuffle. This criterion encompasses the potential to benefit society and contribute to the achievement of specific desired societal outcomes. He noted that NSF does feel really strongly about second criterion and that the organization would like to figure out how to better emphasize it. "If we're successful, that would likely benefit a lot of people at this workshop," he said.

Dr. Wakimoto stressed the need to prevent "drive-by broader impacts." Questions that proposals should consider include

- How well does the activity advance discovery and understanding while promoting teaching, training, and learning?
- How well does the proposed activity broaden the participation of underrepresented groups?
- To what extent will it enhance the infrastructure for research and education?
- Will results be disseminated broadly to enhance scientific and technological understanding?
- What may be the benefits of the proposed activity to society?

Suggested outcomes of proposals include increased participation of women, people with disabilities, and minorities; improved STEM education; increased partnerships; and increased economic competitiveness of the United States.

Dr. Wakimoto then concluded his presentation and took questions from the audience. One participant noted that there is often little incentive at universities at the pretenure level to participate in applied research. Dr. Wakimoto acknowledged that academics often conduct research that is stand-alone and doesn't scale up. He said NSF would like to engage university administrators to help connect faculty to better facilitate research that scales up nationwide. The biggest obstacle isn't money, he said. Rather, the biggest obstacle is convincing PIs to go into this area.

Another workshop participant asked how tech transfer is different in the federal government. Dr. Wakimoto said, "Bureaucracy." He joked the best way he's found to get things done is to go through NOAA.

Another participant asked how Dr. Wakimoto sees the future of the individual scientist working on basic research. Will every scientist need to be integrating basic and applied research, or will there still be room to conduct basic/individual research? Dr. Wakimoto answered by saying that the pendulum isn't swinging to all integrated research. He gave the example that each university has faculty who can teach non-science students and faculty who can't. "It's dumb to put someone in front of 400 students who can't," he said. But he noted that the younger generation has embraced the idea of applied and integrated research much more, and they often tend to favor interdisciplinary work. He said he thinks that there will always be a group of scientists who do basic research, and that people will ultimately benefit from that research (even if it's a couple of decades down the road and even if those doing basic research aren't immediately aware of those benefits). He said NSF isn't going to move to applied-only proposals, but noted that we need to pay attention to those proposals.

A participant asked whether people can write their own criteria for a proposal, and Dr. Wakimoto said not currently. He noted that NSF has been very cautious about defining criteria because they are supposed to serve as examples, but people will often take the criteria as a checklist rather than thinking more broadly about it.

Another participant mentioned dropping success rates for junior faculty. Dr. Wakimoto said he thinks they do a good job of grant management and that NSF's director feels very passionate about early career scientists and improving their success rates.

All in all, the discussion that resulted from Dr. Wakimoto's presentation ranged from highlighting the important efforts NSF has been making to increase technology transfer and foster interdisciplinary connections, to exploring options on how to do even better. It was a productive conversation that highlighted connecting members of academia and industry who share common interests through programs and initiatives that are supported by incentives. Stressing the importance of "broader impacts" through grant proposal criteria, as well as just NSF rhetoric in general, will hopefully increase how much technology and research eventually finds its way on the path to societal benefit.

**Celinda Marsh, White House Office of Management and Budget OMB** (Maggie Hurwitz, primary; Subhashree Mishra, backup)

Ms. Marsh tracks federal R&D and technology transfer, worth approximately $128 billion in 2015 (mainly at DoD and NIH) and projected to increase to $140–150 billion in the coming years. She emphasized the close links between OMB and OSTP. She noted that OMB tends to react to the budget submission from an agency head rather than setting its own budget, unless there is a strong reaction from OSTP.

Ms. Marsh mentioned the federal government's recent emphasis on evidence-based policy making, and the need for metrics to track R&D investments. She referred to President Obama's "lab to market" program, accelerating and institutionalizing technology transfer, which was introduced in memos in 2011 and 2015. Federal agencies were asked to develop tech-transfer programs and performance metrics. The I-Corps program provides NSF-funded scientists with entrepreneurial training; this type of program will be extended to other agencies in 2016. DoE has started a voucher program (worth $20 million in 2015) whereby small businesses compete to work with DoE technical experts. Performance.gov can be used to track progress on the "lab to market" initiative. In November 2015, a White House forum (Connecting Regional Innovation Ecosystems to Federal and National Labs) brought together federal labs, small businesses, and the manufacturing sector; the meeting focused on transferring knowledge from the national laboratories to small, high-tech businesses. There are plans to develop regulations for engaging customers in R&D, and for formalizing relationship between the government, academia and the private sector.

Total funding for tech transfer between federal agencies is not tracked. Also, Ms. Marsh noted that communication among the R&D community is difficult, because the language used across agencies is inconsistent.

Ms. Marsh mentioned growing interest in 2-year federal budgeting, to alleviate difficult budget scheduling, increase the chances to pass appropriations bills, and stabilize research and program funding.

**Kenneth Olsen, Consultant, Accelerator Stewardship, Office of High Energy Physics, DOE**
**A DoE Case Study: Moving Accelerator Technology to Commercial Markets** (Matthew Stepp, Marian Westley)

Ken Olsen described a pilot project to open up the facilities and expertise housed in the Department of Energy National Labs to private-sector partners. The DOE labs not only contain facilities in the form of particle accelerators per se but also contain the unique engineering, fabrication, and testing expertise and facilities necessary to build and maintain such devices.

Particle accelerators aren't the first technology to come to mind when assessing how the geoscience community should accelerate innovation, but the comparison is apt. Like many of the innovations developed within the geosciences (e.g., new radar systems such as MPAR), accelerators are complex systems of hardware, data analysis, and basic science. While the larger public may only view accelerators as chief tools in particle physics, the impact of its innovations on the global economy is far broader. In fact, accelerators result in $500 billion in new products and services for cancer therapy, semiconductors, and food irradiation to name a few.

It's this realization that accelerator applications reach further than just their scientific users that led DoE to advance the transfer of accelerator research, development, and innovations to academic and industrial interests. Following a 2009 DoE workshop, "Accelerators for America's Future," Congress requested that DoE set up a task force and develop a 10-year plan for technology transfer from accelerator-based science into industrial and medical applications. A $10 million Accelerator Stewardship Program grew out that plan, resulting in the launch of a $1 million "Science Accelerator Stewardship Test Facility Pilot Program" in 2015. The goals of the pilot were to broaden public awareness of the R&D facilities contained in national labs, survey the potential demand for accelerator R&D facilities, provide seed funding for a few collaborative R&D

efforts, and test the process and logistics involved in engaging "stewardship partners" (i.e., private industry).

Six DOE labs participated in the pilot: Fermilab, Argonne, Brookhaven National Laboratory (BNL), Lawrence Berkeley National Laboratory (LBNL), and the Stanford Linear Accelerator (SLAC). The labs took slightly different approaches: BNL conducted a survey and held industry group meetings; LBNL hosted a webinar; JLAB held a networking meeting, and SLAC, Argonne, and Fermilab all held open houses. Open houses consisted of talks, tours, and one-on-one meetings—sort of a speed dating for technology partners. The combined events reached over 450 people, with 58% from industry and 25% from universities.

To date, the program has conducted and published reports on three accelerator application workshops for medical, laser, and energy and environment applications. In addition, the Department initiated a pilot program to transfer the knowledge within its laboratory accelerator programs to the private sector that is described in more detail below. It represents a potentially powerful illustration of best practices and learning that might shed light on how geoscience institutions like NOAA, NSF, and NASA can advance greater societal benefit within their own confines.

The DoE owns and provides oversight of 17 National Laboratories (herein called Labs) sourced around the United States. The Labs conduct basic and applied research across a number of nationally critical issue areas including nuclear weapons, clean energy, and basic science. Their strengths are its highly trained workforce of scientists and engineers as well as the unique facilities and capabilities it manages that are often not found anywhere else in the world. For accelerator research, the Labs are the premier places to conduct cutting-edge research.

Understanding the institutional context in which potential innovations and technology transfer occur is critical because there are no one-size-fits-all solutions. The DoE has established several policies and directives to guide Lab technology transfer; however, each scientific discipline requires the Labs to tailor these activities to fit its unique technological, industrial, and socioeconomic characteristics. For particle accelerators, innovation occurs within a complex system of laboratories within the DoE.

The DoE contracts with third-party organizations to manage the individual Labs. These contracts are either with universities, non-profits, or high-tech industrial companies. Seven of these Labs contain core accelerator capabilities, facilities, and research capacity. These facilities are well known within the scientific and industrial communities, such as Argonne National Labs Advanced Light Source. In total, DoE estimates that it manages at least 50 different accelerator testing and research facilities within the Lab complex to support these major facilities

Accelerator technology and knowledge transfer most often comes from two pathways. Users who want to use a major accelerator facility propose research through a peer review process that includes the Labs and academia. Those chosen can run experiments on the major accelerators free of charge as long as the results are published. Industrial users that want to keep the results private or are developing specific IP-protected technology through the project must pay for the use of the accelerator. The Labs also have developed a major technology base in accelerator science and technology when designing and operating these major facilities. Any technologies developed at the Labs, including those associated with its accelerator programs, can be licensed for third-party use.

While these avenues for Lab partnerships seem straightforward, significant barriers exist that stifle advancing innovations out of the Labs. For accelerators, two barriers are most important to address: Lack of knowledge on Lab capabilities and a somewhat complicated Lab-to-industry collaboration process. Many potential industrial and academic users have commented that the Labs do not effectively advertise their capabilities and properly explain how to access them. As a result, many potential partnerships are never explored or, as many within the Lab system note, the facilities don't have an "obvious front door" for potential partners to enter through. And for those that do engage with the Labs on accelerator innovation, the process appears to be onerous, costly, and time consuming. For many smaller firms or universities, it's often too difficult to leverage Lab innovations.

As a result, there is a general belief among DOE that the accelerator programs aren't producing enough innovation outside of the scientific community, even while they continue as a foundational tool for basic research.

To begin addressing these barriers and to advance accelerator innovation, the DOE created the Accelerator Stewardship Pilot Program, a one-year program to broaden public awareness of its accelerator technology programs. Its purpose was to gauge the demand for its capabilities and seed fund high-impact research collaborations with industry and academia.

To kick off the program, six Labs with major accelerator user facilities advertised and hosted open houses for the public, industry, and universities over the summer of 2015. Researchers, Lab managers, and scientists were on hand to give tours of the facilities and host one-on-one meetings with potential partners. Over 450 participants, largely sourced from those that haven't engaged with the Labs or DOE before, attended the first open houses. Of those 450 participants, 100 individual project proposals were submitted to the Labs for partnership. Each Lab was then asked to choose two that it proposed to DOE for funding jointly with their outside partners.

The projects were not long-term engagements; rather they were well-defined projects less than 12 months long. DOE funded each project with grants ranging from $50K to $300K, relieving the cost issue many potential outside partners raise as a barrier. And these projects were not the typical science proposals; Lab-Partner groups submitted short five-page narratives that expressed how this could advance technology outside of the Lab.

Ultimately, DOE funded seven of the 12 projects proposed by the Labs. Projects were purposely diverse and represented the broad interest in accelerator innovation, including testing high-voltage insulating gases to replace sulfur hexafluoride, a potent and potentially dangerous greenhouse gas, and improving superconducting materials used in cryogenics. Early indications are the pilot program was a positive experience and DOE plans to solicit a second round of project proposals for new partnership projects in FY2016.

*Lessons Learned from the Pilot Program*

In the short period of time that the Accelerator Stewardship Pilot Program has been engaging industry and university partners, a number of useful lessons have been learned.

Results of the pilot program will be evaluated in the spring of 2016. Ken Olsen shared some early observations and lessons learned. To start:

- Open houses can be very effective of properly structured including robust mechanisms for capturing contact information and feedback.
- Brochures, posters, and webpages are useful and important.
- The frames of reference inside and outside the Lab are typically very different, so face-to-face communication is essential to develop mutual understanding and trust.

As the last bullet suggests, most important was gaining researcher, engineering, and Lab management buy-in. The Labs have a long history of one-off technology transfer programs that ultimately fade over time or have trouble starting at all. While DoE managed the program, it delegated significant responsibility to the Labs to gain grassroots support, which helped build excitement for the program and the potential for joint projects.

The pilot program also supported a broader group of proposals by offering grants for joint projects. Costs, particularly if a small business wants to use the research to support IP-protected technology development, can be very high at a Lab because of the overhead. Offering grants for the projects allowed for a more inclusive process and a more diverse set of proposals.

The pilot project also put into focus areas of institutional weakness on innovation and technology transfer that need additional work. Namely, the DOE should embrace the unique capabilities of the Labs and develop a nationwide strategy for industrial competitiveness. Allowing the Labs to take the lead on proposing the pilot projects encouraged the Labs to take ownership and put their creative spin on the process.

The United States often relies on the Labs and other research agencies to keep the country at the cutting edge of science. But given the capabilities of the Labs and the potential for industrial partnerships, that strategy can be more expansive in the technology-transfer area as well. Doing so will stimulate technological innovation, move technologies from the Labs to the commercial markets, and bring the benefits of basic science to society.

**Ariel Gold, Program Manager, World Wide Public Sector, Amazon Big Data/Data Analytics** (Kathryn Shontz, Ya'el Seid-Green)

The National Oceanic and Atmospheric Administration (NOAA) faces both extraordinary challenges and opportunities with respect to its large, diverse, and rapidly growing datasets: how best to mine the environmental intelligence in those datasets, and harness them to societal benefit? A major issue is wider user access to the datasets.

With this goal in mind, NOAA entered into Cooperative Research And Development Agreements with five private-sector organizations: the Open Cloud Consortium, Microsoft, IBM, Google, and Amazon Web Services (AWS). The rapid access and processing-on-demand capabilities these partners can provide reflect a great enhancement over the traditional approach of tape-based storage and then file transfer protocol (ftp) done within NOAA. This heritage approach to data archival and access limited the number of people able to utilize the data and therefore detracted from the scientific usability of the data.

By contrast, AWS is able to leverage cloud-based computing and applications, which then allows researchers to spin up projects on the fly, thereby enabling innovation to occur. It is this type of community that spawns an ecosystem wherein collaboration flourishes.

NOAA approached AWS for aid in this effort, targeting the Next-Generation Radar (NEXRAD) dataset as the first test case for the new accessibility model. Where once a complete historical archive of the NEXRAD data was thought impossible, AWS was able to build this database out and continue to ingest current data in near-real time. Radar data, from past to ongoing present is now easily available on Amazon. Moreover, users are able to view and process the NEXRAD data on Amazon's platform with the help of tutorials and pipeline tools created around the data. As the ecosystem builds, so does innovation and collaboration as the user community expands and learns collectively.

In coordination with AWS, NOAA plans to scale the success of the project to further datasets such that the true innovative benefit of the organization's investment in Environmental Intelligence can be realized.

At the time of the workshop, Ariel Gold was the program manager for Open Data at Amazon. She spoke about the Amazon open data program and discussed the current project putting NEXRAD data on the Amazon cloud computing platform AWS.

Amazon cares about open data because it is important to its customers. Amazon's work on cloud-hosted open data is driven by customer interest and demand, and projects are chosen based on the use case. In choosing a project, Amazon goes through three phases: 1) upfront research period, 2) proof of concept, and 3) scaling. Amazon researches what data people want and, if there is a clear market signal, they do a proof-of-concept project. If that is successful, they build it out and scale it up.

There is a big value proposition for open data, enabling rapid access to nearly limitless compute and other capabilities. Users are able to quickly develop value-added applications and cut the time and investments needed for innovation. Amazon tries to supports the development of an entire "ecosystem" around newly opened data sources. The business case for Amazon is in providing services to support the activities of this newly developed ecosystem.

When putting a new dataset up on AWS, Amazon focuses on ensuring adequate documentation and tutorials to support the rapid uptake and use of the new data. Original data files are broken up into segments to make them more accessible and usable. For example, LandSat data is traditionally provided in .tar file format, and each .tar file contains all the light bands for that scene. In hosting the LandSat data on AWS, Amazon unpackaged each scene by pulling apart each .tar file into smaller files. Users can now access the specific bands they want, zeroing in on what they want and eliminating the need for "undifferentiated heavy lifting." Amazon is not interested in producing value added products and solutions in house; instead, Amazon prioritizes giving users the tools to easily use the data to create their own solutions and applications.

As part of Amazon's CRADA with NOAA, they are hosting NEXRAD data on AWS. Accessing NEXRAD data has traditionally been very difficult, and accessing the historical archive was nearly impossible. Amazon is working with several partners, including Unidata, The Weather Company, The Climate Corporation, and CartoDB. It launched in October with data, documentation, and tutorials. The project is in its early days, but Amazon is excited by what they've heard so far. For example, a commercial customer reported that they shaved two weeks off developing a new product because of the new ease of accessing the NEXRAD data. In the next few months, Amazon is actively soliciting new use cases and improving the data documentation and availability.

Discussion with workshop participants covered a variety of topics. There was discussion about the latency and reliability of data. The NOAA–Amazon CRADA does not have any hard-and-fast requirements, but Amazon is voluntarily providing different types of performance metrics. Their focus is on acquisition of data and building an optimized architecture for inputting and serving up data. There was some concern about how reliable the real-time data is for an operational context. Users are responsible for assessing their own risk tolerance for using Amazon to access real-time data. Amazon is focused on being as transparent as possible on how they are handling the data so that each individual user can make an informed decision on how much to depend on them as a provider of data. This is also not a replacement for NOAA's own approach to disseminating data.

This is also Amazon's approach to dealing with concerns about data quality and verification. Users are interested in the data service, even if they cannot programmatically verify that the data is the exact same as NOAA's. Amazon developed check zones on all the sourced data and openly publishes the scripts they use. Users are responsible for making decisions based on this transparent process.

There was a question about formatting standards, and how Amazon chooses whether to keep the data in its original file format or change it. Ariel answered that Amazon makes this decision based on user demand. However, we are undergoing a fundamental shift in how we deal with data. Cloud computing allows for "on the fly translation zones" if data does need to be re-formatted. This is part of the shift to "bringing the tools to the data, not the data to the tools." This effort can also be seen in the context of personalization of weather products and services.

Security and privacy are primary concerns for cloud computing. Amazon already deals with customers, like the financial industry, who are extremely concerned with security, and this is a priority. Additionally, Amazon is not necessarily an advocate of making all data public. Some data they share to only a limited pool of users. For example, they host data from NIH on the cancer genome, and this data can only be accessed by a few thousand researchers who must first go through an accreditation process. Amazon's emphasis is on having the right architecture and the right policies in place for handling each particular case.

Finally, with every project, as discussed above, Amazon tries to tap into the existing user community, including super users, intermediaries, and service providers. For NEXRAD and the NOAA CRADA, Amazon is interested in tapping into the AMS community. There will be a Tuesday Town Hall at the AMS Annual Meeting in 2016, and they are looking for new partners and new use cases for the NEXRAD data. There is a short-term role for AMS as a matchmaker, connecting the data community and the weather, water, and climate community.

## Appendix 4. Workshop Agenda

*From Innovation to Societal Benefit: The Way There*
An American Meteorological Society Policy Study
Workshop Agenda (December 1, 2015)
LOCATION/VENUE:
Johns Hopkins University
School of Advanced International Studies
Kenney Herter Auditorium
1740 Massachusetts Avenue, NW
Washington, D.C., 20036

---

Wednesday morning, December 2, 2015
7:00 LIGHT BREAKFAST
8:00 SETTING THE STAGE. Workshop overview (William H. Hooke)
8:30 Speaker: Daniel Sarewitz, Co-Director, Center for Science, Policy, and Outcomes, Arizona State University
9:30 Speaker: Lea Shanley, Ph.D., Fellow, University of Wisconsin–Madison
10:30 BREAK
11:00 Speaker: STEM education speaker: Dr. David Campbell, Program Director for Division of Research on Learning in Formal and Informal Settings, NSF

12:00 LUNCH

Wednesday afternoon
1:00 Speaker: Richard W. Spinrad, Chief Scientist, NOAA
2:00 Speaker: Lawrence Friedl, Director, Applied Sciences Program, Earth Science Division, NASA
3:00 BREAK
3:30 Speaker: Celinda Marsh, Program Examiner, Science and Space Branch of the Office of Management and Budget.
4:30 GROUP BRAINSTORMING: first-cut findings and recommendations

Wednesday evening
6:00 WORKING DINNER

DINNER TALK/Keynote: Bill Gail, co-founder and Chief Technology Officer of Global Weather Corporation (speaking to his article *The Emerging Science of Science Applications*)

Thursday morning, December 3, 2015
7:00 LIGHT BREAKFAST
8:00 FURTHER GROUP REFLECTION: findings and recommendations

8:30 Speaker: Alex MacDonald, Program Executive for Emerging Space, Office of the Chief Technologist, NASA Headquarters
9:30 Speaker: Roger Wakimoto, Assistant Director for Geosciences, NSF
10:30 BREAK
11:00 Speaker: Kenneth O. Olsen, Consultant, Accelerator Stewardship, Office of High Energy Physics, DoE

12:00 LUNCH

Thursday afternoon
1:00 Speaker: Ariel Gold, Program Manager, Global Public Sector at Amazon
2:00 Final Workshop discussion: Findings and recommendations.
3:00 Closing Remarks/ADJOURN

AGRICULTURE · ENGINEERING · INDUSTRY · COMMERCE · AERIAL AND MARINE NAVIGATION · PUBLIC HEALTH

AMERICAN
METEOROLOGICAL
SOCIETY
1919