Three Polices Shape Enterprise Value: Minor Adjustments Could Enhance the Societal Benefit

American Meteorological Society
Policy Program Study
January 2022

AMS

Policy Program Study

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This report should be cited as:
Hooke, W. 2022: Three Policies Shape Enterprise Value: Minor Adjustments Could Enhance the Societal Benefit. An AMS Policy Program Study. The American Meteorological Society, Washington, D.C. https://doi.org/10.1175/three-policies-shape-enterprise-value-2022.

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

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Acknowledgements:

Many people critical to the development of this study deserve thanks including Paul Higgins, Andy Miller, Emma Tipton, and Lauren White. This study was funded, primarily, through a grant from the National Oceanic and Atmospheric Administration (NA19NWS4620018).

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Executive Summary

"…it should be understood that weather forecasts contain no intrinsic value. They acquire value through their ability to influence the decisions made by the users of the forecasts."

– Allan Murphy[1]

This American Meteorological Society Policy Study examines explicitly the role that *public policy* plays in *determining the sum societal value* of Earth Observations, Science, and Services (OSS) as well as the *allocation* of that value and the *costs* of OSS production across society.

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

The study takes as its point of departure views of individual stakeholders in the so-called Weather, Water and Climate Enterprise (loosely speaking, the community of U.S. providers of weather, water, and climate information and services) with respect to these policies. Their perspectives were captured through informally solicited public and private comments from senior members of the Enterprise—most notably during a session of the 2021 AMS Washington Forum; during special sessions of the 2021 AMS Summer Policy Colloquium, spaced over several days; during virtual sessions of WMO virtual Data Conferences of 2020 and 2021; and through a series of one-on-one interviews. Individually and in aggregate the comments hint at or suggest opportunities for extending and improving Enterprise value by broadening collaboration, fostering innovation, and making the Enterprise more equitable.

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

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

1. Introduction

This is the third in an ongoing AMS Policy Program series of studies on valuation largely funded by a grant from the National Oceanic and Atmospheric Administration (NA19NWS4620018). The project supports NOAA (and indeed, community-wide) efforts to understand, communicate, and enhance societal benefits of its information and services in weather, water (fresh and salt), and climate.

The first of these AMS Policy Studies— Weather-Water-Climate Value Chain(s): Giving VOICE to the Characterization of the Economic Benefits of Hydro-Met Services and Products—develops and lays out a framework for understanding and characterizing the value of Earth System Observations, Science, and Services (OSS). It analyzes the contributions to that value at different stages and by different participants—government, private-sector, and academic *producers* of that intelligence; and (importantly, given Allan Murphy's insight) *end-users* of that intelligence.
The second of these studies— Societal Benefits in Weather, Water, and Climate: Understanding, Communication, and Enhancement—*"seeks to 1) characterize broadly the societal benefits of OSS, 2) identify the factors that limit the societal benefits of OSS, 3) develop approaches to enhance those societal benefits, and 4) communicate this information to internal audiences (i.e., the providers of OSS) and external partners (i.e., decision-makers, information users, the media, and the public)."*

This third study builds on the first two. It examines explicitly the role that *public policy* plays in *determining the sum societal value* of OSS as well as the *allocation* of that value and the *costs* of OSS production across society. These influences can be dramatic. Policy can serve either to add value or to drive it lower, even to zero in some cases (as noted, e.g., in a 2005 study by Rayner, Lach, and Ingram, demonstrating that water-resource management regulatory frameworks in force at the time proscribed the use of forecasts in day-to-day decision-making on dam operations). Policy decisions about the means of information delivery (e.g., digital vs analog; English-only vs multiple languages) can advantage certain sectors of society at the expense of others less fortunate, whether intentionally or incidentally.[1] Governments can fund the building, operating, and maintenance of observing systems, or leave the needed investments to the private sector (as has been increasingly the practice).

A broad range of policies play into determining and shaping OSS value in such ways, but this study is deliberately bounded. For the most part, it focuses only on three policy frameworks (a fourth policy is touched on) that currently play a proximate and outsized role in determining the following:

[1] It should be noted at the outset that value itself is only one end product of policy. Broadly speaking, policies are *frameworks* for making decisions. They have *emergent* consequences. Only some of these represent desired or intended ends. Others are unintended. Take the human tendency to specialize and trade goods and services; this has created enormous wealth or value, but only as one end result of other human development, such as agriculture, urbanization, mass transit, etc., all of which has changed weather sensitivities and thus the needs for and value of OSS.

- The potential utility (salience, accuracy, timeliness, etc.) of weather information,

- *How* that information is developed and made available to those who seek it—in particular, the partnering by government, industry, academia (and NGO's) to produce such information; and

- *Who* enjoys access and under what terms—the allocation of benefits and costs of such efforts.

The three primary policy frameworks in question are these:

- *Fair Weather: Effective Partnership in Weather and Climate Services* (*FWR*), was published in 2003 and contains recommendations of the National Academies of Science, Engineering, and Medicine for developing, improving, and exercising the partnership. Though it holds no force of law, it has remained hugely influential since. As the partners (known collectively as the Weather, Water, and Climate Enterprise, or more simply, the Enterprise) ***collaborate***, their efforts become more effective—and OSS grows more valuable.

- The *Weather Research and Forecasting Innovation Act of 2017* (*WRFIA*, and its successor, the *National Integrated Drought Information System Reauthorization Act of 2018*), were formulated by the U.S. Congress to establish priorities and spur innovation in those priority areas. Unlike the Fair Weather Report, WRFIA relies less on moral suasion and more on the power of Congress for its influence. As the Enterprise ***innovates,*** it becomes more effective—and OSS grows more valuable.

- Currently (as of this writing), the U.N. World Meteorological Organization is formulating and ratifying a so-called Resolution 42, to supplant its legacy Resolution 40. Put into force in 1995, Resolution 40 committed the WMO and its 195 national members *"As a fundamental principle… , and in consonance with the expanding requirements for its scientific and technical expertise, …to broadening and enhancing the free and unrestricted international exchange of meteorological and related data and products."* The current Resolution 42 seeks to protect and preserve this earlier intent and, at the same time, extend Resolution 40 in three respects: expand the purview of the free and unrestricted data exchange from meteorological data per se to include hydrometeorological, oceanographic, and cryospheric data; better accommodate the growing number of commercial data sources; and ensure that all countries enjoy equal access to "core" or "essential" data.[2] As ***access*** to Global Weather Enterprise services and products, and participation in their development expands and becomes more ***equitable***, the Enterprise becomes more effective—and OSS grows more valuable.

Some further context is useful:

Though quite different in origin and duration, character, and focus, the three policy frameworks share points in common and overlapping goals. Collaboration, innovation, and equity are

necessarily interwoven. Emphasis on any one dimension incorporates explicitly or implicitly attention to the other two. Progress on any one attribute tends to advance the other two, and makes the Enterprise more effective with respect to its overarching goals and aspirations: namely, the advance of meteorology and its application for societal benefit. Yet the three policies, though vitally important, fall short of their aspirations for collaboration, innovation, and equity. Some of the limitations stem from the narrow framing of the policies; others reflect the stubbornly unyielding nature of a handful of challenges. Digging deeper:

The FWR focused a bit more in depth on collaborative *mechanics* than on Enterprise *goals*. Society has changed rapidly over the two decades of its lifetime, in ways that have not been fully internalized in the current Enterprise relationships. In particular, and partially in response to societal drivers, the relative capabilities of the partners have changed as well. The partners have not simply grown in size. They have expanded their capabilities—but at different rates and in varying ways. As a result, long-established rules of engagement no longer work so well; some of the earlier purposes have been achieved; new needs have emerged but have yet to be addressed. Some examples: under-attention to innovation means that the Enterprise has struggled to keep up with the host society's needs. Confining the collaboration to weather leaves unaddressed the potential for additional value implicit in other Earth-system observations—hydrology, climate, the oceans, etc. Insufficient attention to equity in access to Enterprise services has slowed progress with respect to service of underrepresented minorities. Articulation of the value of the Enterprise to society has been lacking; this latter consigns the Enterprise to a constant struggle for the funding levels adequate to meet societal needs that are growing in urgency, complexity, and scale.

In part, WRFIA was intended to correct this, especially with respect to innovation. But the Congressional legislation has attempted to foster innovation through top-down oversight and micromanagement versus a softer approach using a mix of encouragement and incentives. As the social science of innovation has shown, innovation is easier to suppress than to foster. Sometimes top-down command and control efforts can stultify rather than enhance innovation. Confining attention to weather alone forecloses benefiting from synergies potentially available through innovation in closely related fields of Earth system science and application. The legislation calls for harnessing social science to the task of risk communication, but fails to meet the needs of underrepresented groups as those are currently understood.

In attempting to address these challenges at the international level, the WMO effort also reveals their inherent difficulty The UN agency is finding it difficult to extend data sharing into arenas where there is little prior history and tradition, especially in disciplines more directly related to economic benefit and national security such as hydrology and water resource management. WMO and its member National Meteorological and Hydrological Services (NMHS) struggle to accommodate commercial data sources. Public–private partnerships in the developed world can have the unintended consequence of threatening the very raison d'être of meteorological and hydrological services in developing nations. As a result, the gap between underserved and well-served populations continues to widen.

Callout Box 1: National Weather Service

A *fourth* policy, though on the surface seemingly less formal than the three considered here, might prove equally powerful in creating and allocating value in the long run. It is embodied in the current articulation of the National Weather Service mission and vision:

NWS Mission

Provide weather, water, and climate data, forecasts, warnings, and impact-based decision support services for the protection of life and property and enhancement of the national economy.

NWS Vision

A Weather-Ready Nation: Society is prepared for and responds to weather, water, and climate-dependent events.

That vision of recent years sees the National Weather Service as going beyond mere forecasts of weather conditions per se to provide impact-based decision support services (or IDSS). Moreover, as the vision statement shows, it considers the larger society as no longer merely a passive recipient of weather services, but now as an essential, active participant or partner in the process of realizing value from weather forecasts—consistent with the Allan Murphy insight from a quarter-century ago.

As it happens, another recent AMS Policy Program Study addresses a significant piece of this additional dimension. It has not been considered as a formal component of the larger valuation project, but in some respects it should be. Titled *Options for Enhancing the Value of the NOAA Weather-Ready Nation Ambassador Initiative*, it surveys The Weather-Ready Nation Ambassador™ Initiative, designed to build partnerships across the Weather, Water, and Climate Enterprise and to leverage the community reach of partners in the public, private, academic, and NGO sectors. The study identifies options for strengthening the Weather-Ready Nation Ambassadors™ Initiative while holding true to its original intention: building a more resilient, responsive, and prepared American public. A Weather-Ready Nation, prepared for and actively and effectively responding to weather, water, and climate-dependent events in line with the vision, would dramatically increase the value and benefit of weather forecasts. As the NWS continues to move toward such a demand-pull view of its mission and services as opposed to a product-and-service push, the utility, reach, and aggregate benefit of its work will increase in like measure. Done properly, equity-of-information-access should also improve. (The EISWG weather research priorities report currently being prepared for SAB's submission to Congress, as referenced in the earlier footnote, also addresses this.)

This third study began with information gathering. Inputs included informally solicited public and private comments from senior members of the Enterprise—most notably during a session of the 2021 AMS Washington Forum; during special sessions of the 2021 AMS Summer Policy Colloquium, spaced over several days; during virtual sessions of WMO virtual Data Conferences of 2020 and 2021; and through a series of one-on-one interviews. This information gathering has extended over a period of about one year; it continues informally today.[3] Specific comments

punctuate the report throughout. A few were unique; others were representative of widely voiced opinions. Some were selected because they reveal shortcomings in the respective policy frameworks. Others are included because they identify ready opportunities for increasing OSS value. The comments are verbatim quotes or very nearly so. The latter have been lightly edited, but solely to improve syntax. In aggregate, they give readers a feel for the study's intellectual origins.

Additional context supplements these comments. A few key issues emerge that appear to be both salient and/or at the same time stubbornly resistant to progress. These have been *synthesized and distilled* to identify a small number of *opportunities for increasing the value and the equitable allocation of that value*; these are tabled at separate points in the report, and reassembled in the final section. The opportunities identified are not exhaustive; rather they have been surfaced for two reasons. First, they would appear to require minimal extra effort on the part of individuals and institutions operating with little margin (a hallmark of 21st-century work). That is, they are *doable*. Second, they show potential for emergent consequences driving outcomes in desired directions (a signature metric for useful policy).

The next three sections of this report explore each of the respective policy frameworks and their implications for value in greater depth.

2. Fair Weather Report[4]

Fair Weather: Effective Partnership in Weather and Climate Services, was published in 2003 and contains recommendations of the National Academies of Science, Engineering, and Medicine for the partnership. Though hugely influential since, it holds no force of law, and the societal needs and the capabilities of the partners and the partnership as a whole have changed substantially to the present day.

The report opens in this vein:

> *In the United States, the weather and climate enterprise has evolved since its inception in the 1800s to include three sectors, each of which plays a unique and vital role: 1. The National Weather Service (NWS) is responsible for protecting life and property and enhancing the national economy. To carry out its mission, it maintains an infrastructure of observing, communications, data processing, and prediction systems and conducts research on which the public (federal, state, and local government agencies), private, and academic sectors rely. It also negotiates data exchange agreements with other countries. 2. Academia is responsible for advancing the science and educating future generations of meteorologists. 3. The private sector (weather companies, meteorologists working for private companies or as private consultants, and broadcast meteorologists) responsible for creating products and services tailored to the needs of their company or clients and for working with the NWS to communicate forecasts and warnings that may affect public safety. This three-sector system has led to an extensive and flourishing set of weather services that are of great benefit to the U.S. public and to major sections of the U.S.*

economy. However, the system also has a certain level of built-in friction between the public, private, and academic sectors for the following reasons:

• Each sector contributes in varying degrees to the same activities—data collection, modeling and analysis, product development, and information dissemination—making it difficult to clearly differentiate their roles;

• The sectors have different philosophies of sharing data and models with the other sectors and the general public;

• Advances in scientific understanding and technology permit new user communities to emerge and change what the sectors are capable of doing and want to do; and

• All members do not share the same expectations and understanding of the proper roles and responsibilities of the three sectors.

FWR focused primarily on strengthening the partnership, as emphasized by its first three broad recommendations:

Recommendation 1. The NWS should replace its 1991 public–private partnership policy with a policy that defines processes for making decisions on products, technologies, and services, rather than rigidly defining the roles of the NWS and the private sector.

Recommendation 2. The NWS should establish an independent advisory committee to provide ongoing advice to it on weather and climate matters. The committee should be composed of users of weather and climate data and representatives of the public, private, and academic sectors, and it should consider issues relevant to each sector as well as to the set of players as a group, such as (but not limited to)

- *improving communication among the sectors,*
- *creating or discontinuing products,*
- *enhancing scientific and technical capabilities that support the NWS mission,*
- *improving data quality and timeliness, and*
- *disseminating data and information.*

Recommendation 3. The NWS and relevant academic, state, and private organizations should seek a neutral host, such as the American Meteorological Society, to provide a periodic dedicated venue for the weather enterprise as a whole to discuss issues related to the public–private partnership.

(Recommendations for each of the three individual sectors—government, industry, and academic—followed in the report itself.)

Study feedback on FWR included the following comments:

Concerns about age:

- *Good for its time.*
- [But] *A lot has changed since 2003. Back then, 100% of the private sector repackaged NWS info. Now more balanced. Fact is, the private sector can now do the whole value chain.*
- *Should recreate the entire value chain. However pricing is a problem. NOAA, government can tell the private sector what it <u>can't</u> do, but they can't tell the private sector what <u>to</u> do.*
- *NOAA can't be all things to all people; has to [continue to] choose what it's <u>not</u> going to do* [this comment reemerges at a later point, with regard to more than another challenge facing the collaboration].

Context: Age per se is not a bad thing. However, effective partnerships emerge when the partners share goals and need each other's help to get there. In 2003, the private sector needed government-based observing systems and platforms, as well as numerical modeling capabilities. In fact, in the years immediately following 2003, Enterprise partners were calling on NOAA to focus solely on those two pieces of the value chain, and steer clear of services tailored in any respect for particular weather-sensitive sectors of the economy. At that same time, some corporations argued that NWS should abstain from social-media-based forecast products and services.

Today's private sector of the Enterprise holds considerable observing and numerical modeling assets. Most private-sector stakeholders favor public–private cooperation, versus competitive efforts to "go it alone," in all elements of the value chain. This holds especially true with respect to innovation (as described further in the *WRFIA* section of this report). Additional incentives for collaboration remain. These include the following:

- protection from legal liability (which only the public sector enjoys);
- the need to provide equitable access to services across underrepresented groups (a high-cost, low-profit responsibility best left to government);[2]
- Enterprise contributions to the global arena (where only national governments have standing), and representation and pursuit of Enterprise interests in that arena; and
- articulation of the societal value of Enterprise products and services.

To date, the partnership has been slow to address these. The Enterprise needs to move on from general conversation content to break down sectoral stereotypes to more pointed consideration on how the Enterprise can *act* to address challenges such as these.

[2] This same role has come up repeatedly in American history; consider the 1936 Rural Electrification Act, and more recent efforts to improve internet access more broadly.

Shortcomings in communication across the sectors:

- *The public and private sectors don't understand each other. NWS fails to appreciate implications of private-sector diversity. NOAA [tends to be] big picture…needs more people looking at smaller, incremental pieces of the larger puzzle.*
- *Not all companies are the same.*
- *Private-sector doesn't understand how Congress drives NWS.*
- *Private sector trying to figure out if NOAA has a plan.*
- *Emergency managers always a moving grey area. Key aspect is NWS support for emergency managers.*
- *Emergency managers need weather info, but integrated into impacts.*
- *Dissemination challenge*
- *Want NOAA, private-sector to see each other as partners, not competitors.*
- *Taxpayers suffer when private sector and NWS don't work well together.*
- *AMS WWCE helpful.*

Context: These comments, and others like them, suggest that the Enterprise conversation has struggled to attain and maintain the degree of communication to go deeper and deal effectively with issues arising from its diversity. The comments do not identify any single shortcoming or single root cause of the problem. Instead, they identify several issues and suggest that several factors come into play: rapid societal change, rapid change in the capabilities of the institutions comprising the Weather Enterprise, lack of transparency, and lack of margin—individuals and institutions are maxed-out meeting day-to-day core needs with little additional resources available to consider longer-term or mutual interests across the Enterprise. Respondents see costs associated with these shortcomings in communication. Generally speaking, respondents seemed to think that AMS support of Enterprise communication has been helpful, but that the AMS might be called on to do more. There might be merit in an Enterprise-wide examination of its means of strategic communication, with an eye to addressing some of these shortcomings. Such an effort would require minimal resources, but holds promise for potentially useful payoffs.

Frustration with the slow and uneven pace of innovation:

- *NOAA reluctant to change.*
- *NOAA wants to be all things to all people. But NOAA has to choose what it's NOT going to do.*
- *Gap between analysis and action.*
- *Data throttling/data dissemination? That policy could negatively impact some companies.*[3]
- *Need to transition to the Cloud.*
- *Energy companies using sub-second data.*

Context: These comments reflect a general tendency in discussion of public–private collaboration to paint the private sector as nimble and innovative and the public sector as slow to change, and

[3] EISWG has submitted a brief report to the NOAA SAB on recent Enterprise experience with this.

if anything, resistant to change. The reality, as described by the economist Mariana Mazzucato in her 2018 book, *The Value of Everything: Making and Taking in the Global Economy*, is more nuanced. She argues that governments have played and continue to play a vital role in innovation, while many companies, including some widely regarded as leaders in innovation, are primarily rent seekers. Her comments would certainly apply to today's NOAA.

Moreover, government must contend with an additional reality: private-sector companies are innovating at quite different rates. A NOAA example: the agency is asked to keep pace with those innovating most rapidly, while at the same time continuing to provide legacy services to the companies lagging behind. The resources for *either* of these inadequately funded mandates are not there; let alone for both. This challenge is the domestic microcosm of a similar problem facing the WMO and NMHS on an international level. U.S. experimentation, pilot studies, and demonstration projects might point the way for progress on the global stage.

Crucially, criticism of NOAA's resistance to change overlooks the importance of this attribute to the collaboration. To prosper, the private sector needs NOAA's aims and actions to be stable over the long haul. Without such a stable foundation, the private sector cannot develop and sustain dependable business models.

Need for an Enterprise narrative:

- *How do we articulate what the Enterprise does?*
- *Enterprise story best told by the users, beneficiaries.*
- *Who really advocates for the Enterprise?*

Context: the current Enterprise participants think the AMS could be of help here. But the help most needed would involve AMS collection and light synthesis of the feedback of true end users, rather than any Enterprise (and AMS) attempts to build such a case on its own. Alternatively, and perhaps preferably, the Enterprise might consider broadening its purview.

To start, the Enterprise should include users of weather information and services as well as information providers. Such an expansion would be consistent with the current NWS policy (the "fourth policy" cited above) shifting emphasis from production-push to user-pull in parallel with construction of an Enterprise narrative.

A second possibility for expansion would be with respect to the broader Earth sciences and science-based services. (This is discussed in the *WRFIA* section below.)

3. WRFIA

The *Weather Research and Forecasting Innovation Act of 2017* (and its successor, the *National Integrated Drought Information System Reauthorization Act of 2018*), were formulated by the U.S. Congress to establish priorities and spur innovation in those priority areas. At the time, the

legislation was hailed in some quarters across the Enterprise as demonstrating Congressional (and indeed national) interest in and priority for weather research and forecasting; providing a sound legislative mandate for that work; and for demonstrating that Congress was still capable of strong bipartisan action with respect to priorities, despite the polarization and rancor pervading much of recent politics.

The bills are extensive, running to many pages. Excerpts of summary material from Title 1 and Title 4 of the 2017 bill have been here to provide the reader a feel for the broad scope, the high level of specificity and the prescriptive level of detail, as well as for legislative structure and language:

> *TITLE I--UNITED STATES WEATHER RESEARCH AND FORECASTING IMPROVEMENT*
>
> *(Sec. 101) This bill requires the National Oceanic and Atmospheric Administration (NOAA) to prioritize weather research to improve weather data, modeling, computing, forecasts, and warnings for the protection of life and property and the enhancement of the national economy.*
>
> *(Sec. 102) NOAA's Office of Oceanic and Atmospheric Research (OAR) must conduct a program to develop an improved understanding of forecast capabilities for atmospheric events and their impacts, with priority given to the development of more accurate, timely, and effective warnings and forecasts of high impact weather events that endanger life and property.*
>
> *In carrying out the program, the OAR must collaborate with and support the nonfederal weather research community by making funds available through competitive grants, contracts, and cooperative agreements. Congress urges that at least 30% of the funds authorized for research and development be made available for this purpose.*
>
> *(Sec. 103) NOAA must establish a tornado warning improvement and extension program to reduce the loss of life and economic losses from tornadoes through the development and extension of accurate, effective, and timely tornado forecasts, predictions, and warnings, including the prediction of tornadoes beyond one hour in advance.*
>
> *(Sec. 104) In collaboration with the U.S. weather industry and appropriate academic entities, and through the National Weather Service (NWS), NOAA must plan and maintain a project to improve hurricane forecasting, including:*
>
> - *the prediction of rapid intensification and track of hurricanes,*
> - *the forecast and communication of storm surges from hurricanes, and*
> - *risk communication research to create more effective watch and warning products.*

(Sec. 105) The OAR must issue a research and development and research to operations plan to restore and maintain U.S. leadership in numerical weather prediction (processing weather data with computer models) and forecasting.

(Sec. 106) NOAA must: (1) prioritize observation data requirements necessary to ensure weather forecasting capabilities to protect life and property to the maximum extent practicable; (2) evaluate observing systems, data, and information needed to meet those requirements; (3) identify data gaps in observing capabilities; and (4) determine a range of options to address those gaps.

(Sec. 107) The OAR must undertake Observing System Simulation Experiments (OSSE) to assess the value and benefits of observing capabilities and systems…

…(Sec. 108) The bill requires an annual report on NOAA computing priorities and upgrades as they relate to weather prediction.

(Sec. 109) The U.S. Weather Research Program must: (1) report annually to Congress about on-going research projects and the five NOAA projects related to observations, weather, or subseasonal forecasts closest to operationalization; (2) establish teams with staff from the OAR and the NWS to oversee the operationalization of research projects; (3) develop mechanisms for research priorities of the OAR; (4) develop a system to track research goals; (5) provide testing facilities; and (6) facilitate visiting scholars.

(Sec. 110) The bill authorizes through FY2018: (1) the OAR's weather laboratories and cooperative institutes and weather and air chemistry research programs, and (2) a joint technology transfer initiative.

Under Title I the Congress makes its priorities clear.

Under Title IV, Congress establishes new entities to accelerate executive branch progress toward its weather priorities—the EISWG, a working group of NOAA's Science Advisory Board; and ICAMS—an interagency coordinating mechanism.

TITLE IV--FEDERAL WEATHER COORDINATION

(Sec. 401) The NOAA Science Advisory Board must continue to maintain the Environmental Information Services Working Group. Membership requirements and reporting requirements for the group are established.

(Sec. 402) The Office of Science and Technology Policy must establish an Inter-agency Committee for Advancing Weather Services to improve coordination of relevant weather research and forecast innovation activities…

…(Sec. 409) NOAA must contract or continue to partner with an external organization to conduct a baseline analysis of the NWS operations and workforce…

…(Sec. 414) The Department of Commerce must complete a study, within 180 days of the enactment of this bill, on gaps in the coverage of the NWS's Next Generation Weather Radar. Additionally, Commerce must submit recommendations to Congress for improving hazardous weather detection and forecasting coverage in areas of the United States where limited or no Next Generation Weather Radar coverage has resulted in insufficient warnings or degraded forecasts for hazardous weather events.

Other sections of the bill dealt with seasonal to subseasonal weather forecasts, weather satellites and data innovation, and tsunamis. Inspection shows that the language and tone of all these sections is prescriptive, as evidenced by repeated emphasis on "must." This is matched and reinforced by a high level of detail and specificity.

Study feedback on WRFIA included the following comments:

The prescriptive character of WRFIA was welcomed and hailed as needed by some:

- *WRFIA okay with specifics.*
- *Codified EISWG into law. Impetus for ICAMS.*

However, it raised many concerns, some of which also called attention to more general that issues were left unaddressed:

- *All too easy for Congress to micromanage.*
- *WRFIA doesn't have the right level of focus—too much micromanagement.*
- *WRFIA okay with specifics. EPIC successful. Codified EISWG into law. Impetus for the Interagency Council for Advancing Meteorological Services (ICAMS). But falls short in areas that are more nebulous.*

Context: The private sector is (rightly) concerned about the degree to which WRFIA not only specifies *what* should be done, but *how* it should be done. Unfortunately, this is not simple Congressional overreach. The legislation was shaped fundamentally by the deep sense of Congress in 2017 that the prior administration had stressed climate services at the expense of innovation with respect to weather services that were needed in the face of extreme events ranging from hurricanes to wildfires ravaging the nation. The lack of emphasis on climate services was not an inadvertent omission, but rather an intentional policy statement. Similarly, equity-of-access issues were not given the same priority in 2017.

Private-sector optimism with respect to ICAMS may also over time prove to be misplaced. This new interagency coordinating structure is rising out of the ashes of former interagency coordinating efforts [e.g., the Federal Council on Meteorological Services and Supporting Research (FCMSSR), the interagency Committee on Meteorological Services and Supporting Research (ICMSSR), coordinated by OMB].

These former entities and their associated staff support, the Office of the Federal Coordinator for Meteorology (OFCM), were once vibrant and consequential players on the interagency scene, but had fallen into disuse. As FCMSSR-level participants lost interest, they started sending junior members to the meetings and delegating-down the responsibility for moving the Enterprise forward. Is this a lesson for ICAMS from the FCMSSR experience? The coordination was most effective at times when real problems needed to be solved. One such problem was the NEXRAD program of the 1980s when aging weather radars needed to be replaced. FCMSSR played a key role in formulating and carrying out the interagency coordination needed across NOAA, the FAA, and the Air Force when it came to modernizing the nation's weather radar network, while avoiding duplication of effort.

The private sector is also skeptical about the degree to which NOAA is on board:

- *Not sure NOAA has bought-into WRFIA.*
- *NOAA sees WRFIA as a burden rather than as a benefit.*

Context: Though widespread, such views are in many respects unfair. NOAA is devoting considerable effort to respond to Congressional intent. In particular, in recent years, NOAA has produced extensive documentation to comply with WRFIA reporting requirements. But the efforts to comply are resource-intensive, placing a heavy burden on NOAA management. Senior staff are devoting considerable resources to generating Congressionally requested paperwork. And that is only the beginning of the process. Each report must go through several layers of executive branch clearance and revision before it can be submitted to Congress. In the zero-sum world of leadership attention, such time and effort come at the expense of the strategic management of innovation that both Congress and NOAA would both prefer to see.

The private sector sees the need to expand the WRFIA scope:

- *WRFIA embodies Senate, House consensus about NOAA role. But lots of states, communities can't afford tailored services. No visible policies addressing underserved communities.*
- *WRFIA needs to do something with climate services—particularly as they bear on decisions about building back better so that resilience is up to the risks nature is throwing at us.*

Context: The private sector is right in calling attention to the needs of underserved communities. This challenge is not unique to the weather enterprise. It is manifest in access to IT more broadly. The pandemic put a spotlight on this reality when education moved from schools into homes by means of the internet. The Weather Enterprise would be addressing this challenge at a time when the country as a whole may be making major investments in modernizing soft and hard infrastructure of every type. Any insights the Enterprise could draw and any progress the Enterprise could make would then guide efforts to deal with the corresponding inequities in service access at the international level, as discussed in the next section.

NOAA enjoys a number of near-term opportunities. EPIC is off to a good start. That can be built upon, both with respect to numerical weather prediction per se, and with respect to a complementary social-science program focusing on service delivery. Working with OSTP and the other federal agencies, NOAA can and should invest the attention and priority to ensure that ICAMS gets off to a strong start. Success here will depend on federal agencies' ability to focus on serious and urgent national challenges versus individual agency concerns and issues that might be considered more a matter of "process/hygiene."

The EISWG *Priorities in Weather Research* report should be available sometime near the end of calendar year 2021 and will identify areas for early progress and a path to longer-term innovation. EISWG itself can be tapped for more help over the long term.

Two important opportunities seem evident here. First, NOAA could undertake an intentional, sustained outreach to Congress, to strengthen existing communication with respect to weather services and innovation and build new ties. The outreach should be multi-faceted, and as informal and frequent as the legislative–executive branch independence and separation of powers will allow. Such communication would be inherently more fertile, nimbly responsive, and productive than the current cumbersome and slow exchanges of written, formal requirements and reports. The aim should be to develop a degree of trust and transparency that would greatly reduce the need for written material. It would foster the agility and innovation that is the mutual goal. And if the outreach were to bring the end users of weather research and forecasters into direct conversation with policy makers, it would build-out the Enterprise. ICAMS might be a useful instrumentality for such improved legislative–executive branch communication. AMS-sponsored Hill briefings might also provide a useful forum for the needed dialogue.

Second, the *WRFIA* focus, initially on weather research and forecasts narrowly construed, was later relaxed in the bill itself to include seasonal-to-subseasonal forecasts and tsunamis; then, in reauthorization language, linked to drought, and additionally, extended in spirit to cover space weather in the PROSWIFT Act. It is not too hard to imagine that building on the initial piecemeal approach to encourage NOAA to foster innovation more broadly across the entire range of hydrological, climatological, and other Earth system threats would be useful. This would mesh nicely with U.S. interests in the WMO policy changes being developed in Geneva, as discussed in the next section.

4. WMO

The language and structure of the United Nations is precise, and lays a meticulous foundation for any and all resolutions. This is hardly surprising, as it is necessary for a single language to capture all the nuance of myriad languages and dialects in order to support (often-fragile) common understanding and agreement among nearly 200 nations. The result is something of an acquired taste, but appeals to nobler instincts and can often have a rhythmic, almost poetic feel. The World Meteorological Organization (WMO) draft language building on and extending Resolution 40 is no exception. Consider the following excerpts:

DRAFT RESOLUTION

Draft Resolution 4.1/1 (Cg-Ext(2021))

WMO Unified Policy for the International Exchange of Earth System Data

THE WORLD METEOROLOGICAL CONGRESS,

Recalling:

(1) Article 2 of the WMO Convention, which commits Members to facilitate worldwide cooperation in the establishment of observing networks and to promote the exchange of meteorological, hydrological and other geophysical observations;

(2) Resolution 40 (Cg-XII)—WMO Policy and Practice for the Exchange of Meteorological and Related Data and Products, including guidelines on relationships in commercial meteorological activities, which inter alia reminds Members of the need to ensure stable ongoing commitment of resources in order to meet their obligations under Article 2, in the common interest of all nations;

(3) Resolution 25 (Cg-XIII)—Exchange of Hydrological Data and Products;

(4) Resolution 60 (Cg-17)—WMO policy for the International Exchange of Climate Data and Products to Support the Implementation of the Global Framework for Climate Services;

(5) Resolution 80 (Cg-18)—Geneva Declaration-2019: Building Community for Weather, Climate and Water Actions, which presents the WMO high-level policy for partnership and engagement among the stakeholders from public, private, academic and civil sectors;

(6) The long-term goals and strategic objectives of the Organization as laid out in the WMO Strategic Plan 2020–2023 (WMO-No. 1225) and Vision 2030, which require more data from an ever-broadening range of disciplines and sources to be exchanged,…

… ***Recognizing:***

(1) The key role of access to timely and reliable weather, climate, water and related environmental data [5] as a basis for informed decision-making at all levels to underpin essential public services that help save lives, protect property and foster economic prosperity;

(2) *That the overall economic benefits of the weather, climate, water and related environmental services have grown by orders of magnitude over the last 25 years, enabled by WMO's data policies;*

(3) *That the growing impact of and reliance on these services continues to increase our dependence on weather, climate, water and related environmental data;*

(4) *The critical role played by the output of global numerical prediction systems in underpinning all weather, climate, water and related environmental products and services, and thus the importance of broadening and enhancing the free and unrestricted access to such output for all Members;*

(5) *That these global prediction systems in turn depend on a continuous, robust and reliable supply of observational input from all areas of the globe provided by both surface- and space-based [6] observing systems;*

(6) *The need to take an integrated Earth-systems approach to monitoring and prediction, and the critical dependence it places on data spanning all relevant components of the Earth system and the interactions between them;[7]*

(7) *The experience and lessons gained by WMO in the development and implementation of Resolutions 40 (Cg-XII) and 25 (Cg-XIII) and 60 (Cg-17),…*

…***Acknowledging:***

(1) *The WMO long-term goal of closing the capacity gap on weather, climate, hydrological and related environmental services among Members, including their ability to acquire and benefit from the model data and derived products which are essential for the critical mission of saving life and protecting property;*

(2) *The need for all Members to contribute to maximizing the benefits of global modelling products by participating more fully in the exchange of observational data on which these products are based…*

…

(6) *The crucial function of the Permanent Representatives to WMO and the role of Hydrological Advisers in helping to maximize the societal impact of Earth system monitoring and prediction efforts, both through coordinating with all stakeholders from the public, private and academic sectors in their States and Territories, and through promoting relevant WMO activities, policies and standards;[8]*

(7) *The wide range of technical, human and technological capacities at the disposal of the individual Members when implementing the WMO policy;*

(8) *The need for consistency of WMO Data Policy, and of national implementations thereof, with other policies based on international law, including, in particular, the rules governing marine scientific research in the United Nations Convention on the Law of the Sea (UNCLOS);*

(9) *The right of governments, having done their utmost to implement the decisions of Congress, to, based, on their national laws and policies, choose the manner by, and the extent to which, they make data available domestically or for international exchange, while still understanding that without reciprocity, international data exchange cannot be sustained,…*

***…Agrees** to have one unified data policy for all WMO domains and disciplines;*

***Decides** that the scope of the data policy shall cover Earth system data exchanged among Members under the auspices of the WMO Convention and decisions of Congress, as described in Annex 1 and Annex 4 of this resolution and specified in detail in the WMO Technical Regulations;*

***Adopts** the following policy on the international exchange of Earth system data:*

As a fundamental principle of WMO and in consonance with the expanding requirements for its scientific and technical expertise, WMO commits itself to broadening and enhancing the free and unrestricted [9] international exchange of Earth system data;

***Agrees further** to maintain a two-tiered approach to the international provision and exchange of Earth system data via the following practice: [4], [10]*

(1) *Members shall provide on a free and unrestricted basis the **core** data that are necessary for the provision of services in support of the protection of life and property and for the well-being of all nations, at a minimum those data described in Annex 1 to this resolution which are required to monitor and predict seamlessly and accurately weather, climate, water and related environmental conditions;*

(2) *Members should also provide the **recommended** data that are required to support Earth system monitoring and prediction activities at the global, regional and national levels and to further assist other Members with the provision of weather, climate, water and related environmental services in their States and Territories. Conditions may be placed on the use of recommended data;[11]*

***Agrees also** that Members should provide without charge access to all recommended data exchanged under the auspices of WMO to public research and education communities, for their non-commercial activities;*

[4] Colored emphasis added, to direct attention to the germane portion of the WMO language.

Encourages *all users of Earth system data to honour reasonable requests for attribution of input data wherever possible;*

There is much more but these excerpts, building toward and following the highlighted text, convey the United Nation's intent.

Study feedback on RESOLUTION 42 included the following comments:

- *Resolution 42 is a survival issue for many countries.*
- *Including ocean data is a challenge*

Context: Countries indeed need data and more of it. Even in prosperous countries like the United States, purse strings are constrained; most of the 195 member nations in the UN are in far worse straits. Moreover, the difficulties of finding resources for critically needed environmental information have been exacerbated by the pandemic. And although there exists a decades-long tradition of exchanging weather data per se, the situation is different when it comes to hydrologic, oceanic, cryospheric, and other environmental data. Often the economic value is more evident, issues of national sovereignty and even national security come into play, and there is little or no history of data sharing. Here nations, though they see common benefit, tend to be more protective. They are prone to distrust others and more inclined to go it alone.

Some U.S. private-sector leaders also see the United Nations efforts (just like NOAA efforts at the domestic level) as backward looking:

- *WMO is carrying forward a notion of NMHS' wedded to the past.*
- *What has been done in the past shouldn't necessarily be the right model for a developing country. Perhaps a developing country's met services could be provided by another country.*
- *UN preoccupation is really with maintaining existing services. The extensions language is largely aspirational.*
- *Countries vary in wherewithal for making decisions.*

Context: As true at the domestic level, this private-sector view is too negative. The WMO faces responsibilities both for innovation to keep up with the social and technological advances made by the world population as a whole, while at the same time providing continuity of services to countries struggling to keep pace. Moreover, based on recent experience, nations can see all too clearly how historic alliances and international promises can turn on a dime (the breakdown in sharing medical supplies in the face of COVID, contention over offshore resource rights, the U.S. pullout from Afghanistan, etc.). Nations can be forgiven for wanting to maintain their own domestic meteorological and hydrological services and infrastructure.

Unsurprisingly, the business model is seen by the private sector as fundamental:

- *Commercialization of data is moving in a good direction, but pricing is a problem.*

- *Commercial data sources? Perhaps countries could pool funds, pay pro-rata for data services according to GDP.*
- *Countries shouldn't be able to subsidize their for-profit subsidiaries.*
- *WMO needs to incentivize value of data. Enable as much data as possible to be utilized by as many as possible. Develop the most level playing field possible so competition may take place.*
- *Data the heart/lifeblood of the value chain.*
- *To deliver local value need global data.*
- *Unified data policy/shared benefits.*
- *Need to incentivize commercial data provision, protect value: You can tell the private sector what they can't do, but you can't tell them what they should do.*
- *(Toward this end of protecting value, should the Enterprise look into) Blockchain?*

Context: The Enterprise, the U.S. Congress, and the end users of weather services in the United States should see a special opportunity here. Working out the data commercialization complexities in the United States does not automatically imply a solution to the more complex and fraught international problem, but it may provide signposts that will be useful.

This brings us to an important private-sector insight raised in the interviews:

- *The government plays a key role in nation-to-nation negotiations*

Context: While the private sector may now be capable of providing all the elements of the value chain, the U.S. government is the only entity having international standing. Accordingly, in many respects the Enterprise coordination that matters most relates to the U.S. stance abroad. What kind of global weather enterprise is needed, and why? What is the appropriate U.S. role in partnering with other nations to build such an Enterprise? What steps and actions get the United States to the desired goals? The Enterprise has underinvested in the thought given to such questions. Congress and the end users need to be brought in.

5. Opportunities for Increasing Enterprise Value

"…it should be understood that weather forecasts contain no intrinsic value. They acquire value through their ability to influence the decisions made by the users of the forecasts." – Allan Murphy[1]

The Murphy insight bears reemphasis here. For purposes of this study, *collaboration*, *innovation*, and *equitable access* are not goals in themselves but means to an end: increasing the value of Earth OSS and the equitable access to and benefit from that value.

Collaborate

As the partners (known collectively as the Weather, Water, and Climate Enterprise, or more simply, the Enterprise) ***collaborate***, their efforts become more effective and OSS grows more valuable.

All three policy frameworks—FWR, WRFIA, and WMO, have helped public-sector, private-sector, and academic stakeholders open up a stronger, more positive, more vibrant conversation; develop a sense of community and give their community a name—the Enterprise.

Opportunity

The current Enterprise collaboration can be beneficially expanded and deepened in several ways:

-- *Broadening participation*. Enterprise participants could certainly begin by encouraging larger numbers of weather science and service providers into the tent, with special recruitment of early-career professionals and professionals from underrepresented groups. But they need not stop there. Other sectors of Earth system science depend in the same way on a public–private partnership to accomplish their work—oceanographers, hydrologists, climatologists, cryospheric scientists, and specialists in space weather. It would be natural to build on preexisting relationships in these disciplines and mount a parallel strategic dialogue.

But, taking a cue from the current NWS vision, which emphasizes weather research and services is not an end in itself, but rather a means to end use of all kinds—emergency management, agriculture, energy, transportation, water resource management, and so on—the *broadening should extend to the end users as well*, with a similar goal of widespread participation, diversity, equity, and inclusion. The approach need not be a sudden-step-function increase so much as an organic, steady extension into end use.

Similarly, as the *WRFIA* history indicates, it is vitally important to have *stronger Congressional participation in the conversation*. An informed Congress, whose intentions and needs are heard and valued, will not feel the need for onerous written reports and will be more inclined to support innovation in positive ways (as described in the next opportunity below). Again, the emphasis in slow but steady growth in Congressional participation, beginning with the "nearest-neighbors"—staff with relevant committee and office assignments whose work makes them natural stakeholders in weather and related Earth-science issues and appropriations—and then working outward.

-- *Richer content*. The Enterprise conversation needs to move from the historic purpose and current emphasis on broadening understanding across the sectors, replacing stereotypes with more nuanced appreciation for differences and characteristics. National and global needs make it imperative that the conversation move toward problem solving. The greater inclusiveness and diversity of the Enterprise as envisioned above, as it is implemented, should help make this shift natural.

The problem solving should not focus on or be limited to problems internal to Enterprise functioning (though these matter). Instead, the emphasis should quickly shift focus to urgent and

growing national and global problems: meeting the food and water requirements of a more populous world; building resilience to natural hazards; protecting habit, biodiversity, and the environment.

-- *Transition from talk to action*. In a similar way, greater diversity and inclusion and the shift in conversation emphasis should make it natural to move the collaboration from mere conversation to effective action, preferably user-driven.

-- *Extension from forecasts alone to broader-based societal actions and policies*. The vision of a Weather-Ready Nation, shifting the focus from service-driven push to end-user pull, is a powerful step forward for the Enterprise. But the Weather-Ready Nation language and intent as currently implemented is confined largely to preparation for and execution of forecast driven societal response to hazardous weather. By contrast, many of the most important and valuable actions society can take to build resilience to weather hazards involve time scales far larger than the weather forecast horizon. Particularly important in this regard are considerations of land use and building codes, designed to increase societal ability to shelter-in-place, make critical infrastructure more resilient to hazards (ensuring that electrical power, water supplies, etc., are uninterruptible), and thus reducing the need for and scale of evacuations and other emergency measures.

Enterprise conversation and action, therefore, need to give attention to broader policy frameworks that will improve resilience, foster innovation across the Enterprise and its application, and ensure these efforts are sustained.

-- *Extension from a solely domestic focus to international needs and opportunities*. (More on this in the discussion below with respect to the third opportunity.)

-- *Characterization and articulation of the Enterprise value*. The Enterprise and its conversations and collaborations, extended along the lines indicated above—especially those focused on problem-solving and more effective end use—lay the foundation needed to support and sustain ongoing understanding and articulation of the value of the Enterprise to the larger society. This should be a major goal of the Enterprise—not for justifying societal investment in the Enterprise (though this may follow), but instead and primarily because the characterization of value and its limits will help identify priorities for future innovation. As hinted in the *FWR* discussion, what is needed is more than mere claims of value; or anecdotal, fragmented estimates of this or that piece of the value proposition. Instead what is needed is a robust disciplined assessment of value that is the subject of active, continuing research and refinement. NOAA is necessarily a foundational player. ICAMS can be of some help, but as the comments emphasized, assessments of value are most compelling when they come from users.

Innovate

Opportunity

As the Enterprise ***innovates***, it becomes more effective—and OSS grows more valuable.

As relationships between the executive and legislative branch are strengthened, the Enterprise will be better positioned to identify scientific and technological advances and other societal trends that are reshaping society's vulnerability to weather and, at the same time, providing society new tools for resilience in the face of weather changes and weather threats, provided only that the necessary are forecasts are available.

The Enterprise will at the same time be better able to translate those changing societal requirements into innovations needed across the Enterprise.

The Enterprise already has an emerging success story—EPIC—illustrating the power of open science, and inspiring ideas for matching that success in other areas of Enterprise purview.

The comments from Enterprise members so far suggest three areas for priority attention:

The first is to apply the open-science mindset to identify and stand up accommodations to data commercialization that will sustain ongoing industry and government investment and innovation with respect to observing instruments and instrument platforms and, at the same time, maintain the public good.

The second, closely related, is to apply the open-science approach to improve mass risk communication with respect to natural hazards, especially with respect to "the last mile," the essential link to communicating risk and options for evasive action to those in harm's way. A special priority is ensuring equitable access to such vital weather information across the whole of society.

A third, spanning both these efforts, is an open-science approach harnessing artificial intelligence/machine learning to these tasks.

ICAMS, if properly constituted and exercised, could contribute powerfully to the accomplishment of these goals.

Participation in this progress would ideally not be limited to the domestic United States, but open to the larger world.

Foster equity of participation and access

As ***access*** to Global Weather Enterprise services and products, and participation in their development expands and becomes more ***equitable***, the Enterprise becomes more effective—and OSS grows more valuable.

Opportunity

The previous two opportunities focus domestically but hint at international potential. What works for the United States does not necessarily work for the rest of the world (as well-meaning but counterproductive 20th-century U.S. efforts to "help" African agriculture painfully demonstrate).

Nevertheless, each informs the other. And the basic challenges to the Weather Enterprise: food, water and energy; resilience to natural hazards; environmental protection—must be achieved both locally and globally to be effective over the long term.

To date the Enterprise has underinvested in both conversation and actions with respect to the domestic and global challenges to equitable access. The Enterprise has a short-term opportunity (and responsibility) to better coordinate the development and implementation of U.S. participation in the global arena, particularly with respect to WMO participation. Other WMO members are hoping for strong, effective U.S. participation, ranging from policy levels to details of implementation, and covering the full range of issues involved in Resolution 42.

Responsibility for organizing and leading the needed domestic preparatory collaboration most naturally falls to the U.S. Permanent Representative to the WMO. In recent years, this has generally been the NWS Director or Deputy Director. The quality and effort devoted in the United States to preparing for WMO work has ebbed and flowed depending upon interests of the incumbents. But much would be gained by giving this high priority in the United States, bringing in public, private, and academic sectors, and including the State Department and Congress in the conversation.

The opportunity here cannot be overemphasized. The world faces existential challenges with respect to food, water, and energy production and management. Nations will need to spend the order of $100T on the needed infrastructure over the next two decades.[5] Understanding the related weather, water, and climate impacts on the return from these investments, and corresponding opportunities for optimizing those expenditures, is a universal need that must be addressed most urgently. Fortunately, the Earth observations, science, and services required to guide such investments are relatively inexpensive in comparison. By strategically partnering in such work, the United States will help make a more sustainable world; and do its part as a "good neighbor."

6. AMS's Role?

Government agencies, corporations, and academic institutions stand the most to gain or lose from any or all of these policy initiatives, and also have most of the resources that can be brought to bear to address them. At the same time, conflicts of interest preclude giving any one sector a leadership role. This understanding prompted NASEM in its *Fair Weather Report* to suggest that… *NWS and relevant academic, state, and private organizations should seek a neutral host, such as the American Meteorological Society, to provide a periodic dedicated venue for the weather enterprise as a whole to discuss issues related to the public–private partnership*.

The two decades since have seen the AMS and the Enterprise make a fair initial start at the needed discussions. As the Enterprise seeks to expand size and diversity of its ranks, reaching out to end

[5] Allocated, very approximately, as follows: $50T on energy (International Energy Agency); $30T on water (World Economic Forum), and $20T on food (Food and Agriculture Organization).

users, and the Congress, and working internationally; as it shifts from talk to action; and as it works to accelerate innovation; it might usefully consider how it might more fruitfully bring to bear the AMS to facilitate these efforts.

7. References

[1] Murphy, A. H., 1993: What is a good forecast? An essay on the nature of goodness in weather forecasting. *Wea. Forecasting*, **8**, 281–293, https://doi.org/10.1175/1520-0434(1993)008<0281:WIAGFA>2.0.CO;2.

[2] At the same time, member nations are ensuring that the existing technical arrangements on which all nations currently depend are maintained and continue uninterrupted.

[3] During this period, the study author, a member of the Environmental Information Services Working Group (EISWG) of NOAA's external Scientific Advisory Board (SAB), has also helped develop a report requested by the U.S. Congress in language for the FY21 appropriation, directing: *NOAA's Science Advisory Board to publish a report, not later than one year after enactment of this Act* [i.e., fall of 2021]*, that provides policymakers with the relevant information necessary to prioritize investments in weather forecasting, modeling, data assimilation, and supercomputing over the next ten years; and that evaluates future potential Federal investments in science, satellites, radars, and other observation technologies, to include surface and boundary layer observations so that all domestic users of weather information can receive data in the most efficient and effective manner possible.*
That work has also informed this study.

[4] The FWR NASEM report, the WRFIA legislation, and the WMO resolution are too lengthy to incorporate fully here. The reader should use the links provided to access and fully explore the three policy documents that are the basis of the report. However, the reading of the report would appear to benefit from a bit more background information than provided in the introduction. Accordingly, this, and subsequent sections on WRFIA and the WMO, provide brief excerpts from the documents to give a flavor, highlight their different character, and feel.

[5] Environmental data here refers to data (observed and modeled variables) beyond those directly pertaining to weather, climate, or hydrology; in particular, atmospheric composition, properties of the marine environment, the land surface, and the exosphere.

[6] The term surface-based observing systems is taken to encompass all systems not deployed in space.

[7] Earth system data here encompass data pertaining to weather, climate, hydrology, atmospheric composition, oceans, cryosphere, and space weather. For further details on these domains and disciplines, see Annex 1. For a precise definition of Earth system data, see Annex 4.

[8] For guidance to Members regarding coordination of the implementation of this resolution, see Annex 2. Guidelines for public–private sector engagement on Earth system data are provided in Annex 3.

[9] "Free and unrestricted" defined in Annex 4.

[10] The basis for the practice is that Earth system data required to fulfill Members' commitments under the WMO Convention and WMO strategic objectives are encompassed by the combination of core and recommended data exchanged by Members and relevant international organizations.

[11] "Conditions" may be applied by licensing agreements or other appropriate arrangements.


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