ESSAY

THE FUTURE OF THE GLOBAL WEATHER ENTERPRISE

Opportunities and Risks

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As the global weather enterprise undergoes significant change, increased dialogue and cooperation is needed to exploit opportunities and manage risks.

The term Global Weather Enterprise (GWE) has been coined to describe the totality of activities by individuals and organizations to enable weather information to be created and provided to society. It is fundamentally global because not only is weather ubiquitous, but the creation and use of weather information also require the efforts of all nations; no single country or region today produces the weather information and services its citizens need without this global effort. It is easy to lose sight of this interdependence when weather events and their impacts are frequently very localized in nature. The enterprise includes the full value chain of scientific research, observations of the Earth system, numerical models encoding the laws of physics applied to the system, supercomputing to integrate the models and observations, weather and hydrological forecasts from hours to weeks and potentially months ahead, and business-specific products and services enabling economic benefit and jobs to be created. The health of the whole enterprise strongly depends on the strength of each component.

The GWE is today contributed to in a substantial way by each of the public, academic, and private sectors. It has been very successful in delivering increasing quality weather information that helps save lives and property. It is a goal of the GWE to maximize value for all along the value chain. While the enterprise is fundamentally and irreducibly global and collaborative in nature, regional and national variations need to be factored into any discussions relating to the GWE. The characteristics of the enterprise, even among high-income countries, are radically different.

While the GWE can rightly claim, and be proud of, the progress that has been made in the provision and use of increasingly high-quality weather information (see, e.g., Bauer et al. 2015), many people still do not have access to it, and even when they do, many put themselves in harm's way by ignoring it. There are changes occurring both within and outside of the enterprise that lead to both opportunities and risks to future progress; this is being recognized in various recent public discussions facilitated by organizations such as the World Meteorological Organization (WMO), the World Bank, the Association of the

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Hydro-Meteorological Equipment Industry (HMEI),[1] and the American Meteorological Society. The urgency of managing risks and seizing opportunities if the GWE is to deliver what society requires of it to save lives and infrastructure, not least as climate changes, is becoming widely recognized.

Participants from across the public, academic, and private sectors contributed to a GWE seminar in Washington, D.C., in November 2017 (GFDRR 2018); the outcomes of that discussion and previous ones such as at the World Weather Open Science Conference 2014 (Hayes et al. 2014) form the basis of this essay. However, the authors of this essay take full responsibility for what is included herein; the essay is their personal perspective on these developments.

Clearly, past successes of the GWE are no guarantee of future success. The GWE is undergoing a period of unusually pervasive change across the value chain. It is the aim of this essay to raise awareness and stimulate debate regarding these changes and to propose ways to capitalize on the opportunities they represent while trying to mitigate the potential risks for the benefit of all actors in the enterprise and for the benefit of the users worldwide of high-quality weather information. Given the heterogeneity of the global weather enterprise, some of the points raised here will seem second nature to some readers, but other topics will be less familiar. To set the scene, our premise is that the GWE can and needs to grow if it is to fulfill the increasing requirements of society for weather information and that this growth will be best achieved by improved and more frequent dialogue and co-designed initiatives between the various actors in the public, private, and academic sectors. Such dialogue is being promoted by the recent formation (as discussed later) of a Global Weather Enterprise Forum, supported by international organizations such as the WMO, the World Bank, and HMEI. There are real and difficult problems, some of which are raised in this essay, not least arising from the changing roles played by organizations in the three sectors that need to be resolved by such dialogue and followed by concrete action.

CHANGES AFFECTING THE GLOBAL WEATHER ENTERPRISE.

The GWE is undergoing a period of pervasive change in the following ways.

Societal need for weather information. Societal need for weather information is growing fast as people are more vulnerable to natural hazards, including those exacerbated by climate change; this is the case everywhere but particularly true in low- and middle-income countries. Economic development in both developed and middle- and low-income countries (as encapsulated in the Sustainable Development Goals; see UN-DESA 2012) is put at risk if sufficiently accurate, reliable, and understandable weather, water, and climate information is not available to all who need it. Disruption to lives and livelihoods is manifested in loss of life, loss of income, food and water shortages, disease, and destruction of infrastructure. Reducing such adverse impacts of weather, climate, and hydrological hazards through the effective use of forecasts and warnings reduces exposure and builds resilient societies (see Rogers et al. 2018). In short, the need for weather information with greater accuracy, reliability, and specificity is growing rapidly.

Science and technology innovation. Science and technology innovation, including from the academic sector, continues apace, with new approaches coming online such as satellite miniaturization, next-generation computer architecture, and science to model the system with much greater detail. The resolution of global and regional models of the weather system is now such that weather information is close, for the first time, to having the detail necessary to describe conditions local to individuals or groups of individuals. What makes the new era so special is that we are close to predicting the global weather[2] at close to the human scale (Gal-Chen 1982). As global grids for weather prediction approach 1 km or less in the next decade or two (and regional grids with even higher resolution), high-quality weather information representative of a small zone around the exact location of an individual (i.e., person-specific forecasts) will be available and potentially refreshed on much higher update cycle frequencies (e.g., Benjamin et al. 2016) than could have been imagined even a few years ago. While not wishing to downplay the huge scientific challenges of predicting on global grids at 1-km or higher horizontal resolution, the scientific community is optimistic that these challenges can and will be addressed in the next decades.

Public support for fundamental research. Public support for fundamental research to advance weather science remains as a crucial rate-limiting step for progress of the GWE. The academic and public sectors are tasked with such research that is also needed to provide new ideas to be utilized by the private sector. It is extremely unlikely that the private sector would be

[1] www.hmei.org.

[2] Noting that the accuracy of regional models is strongly dependent on the accuracy of global model boundary conditions, here we focus our attention primarily on the global domain.

able to provide such support, so all three sectors need to come together to make the case persuasively for maintaining and hopefully increasing the necessary public funds largely coming from governments. There is an important coordination role being played by the WMO via its various research programs[3] bringing the international community together to tackle key problems and address gaps.

Requirements for many more observations. Requirements for many more observations as the modeled scales reduce are huge. Weather prediction skill continues to be highly dependent on the amount and quality of the specification of the initial state. The drive to higher-resolution models requires increases in observational volumes. Weather science research and new observing technologies are poised to provide these increases, such as from private sector sources and crowdsourcing. Notwithstanding the power of data assimilation, this means that a substantial opportunity exists to improve forecast skill if the number of observations produced by the global observing system could be greatly increased. This opportunity can be exploited by using both public and private sector sources of high-quality observations. The private sector is currently showing considerable interest in, and capabilities to establish, proprietary observing systems using private capital. The data output volumes will also be commensurately much larger, recognizing the inexorable increases in resolution of weather models making the ability to access and mine the data in targeted ways critical.

The integrity of the global observing system. The integrity of the global observing system—the meteorological bellwether—is a precious resource that underpins the entire enterprise and is predominantly, but not exclusively, funded by governments. The global observing system relies on nations contributing so that it is a coherent and comprehensive global whole. This means it is vulnerable to reduced investment by particular countries leaving significant gaps in the network; this is happening already. It is not governed by any binding international agreements, so it is at most a "best efforts" system. The WMO helps to maintain informal agreements by creating and updating the strategies for the global observing system, the global data processing and forecasting system, and service delivery and by establishing working groups that examine how (or not) these strategies are actually being implemented. However, there are many regions around the world where the global observing system is suboptimal with a paucity of observations, such as ground-based and in situ observations in Africa. This has been a problem for many years and needs to be addressed. Given the irreducibly global character of the meteorological system, it is in the interest of all, including the high-income countries, to have access to improved networks of observations in such data-sparse regions—weather information everywhere is benefitted by improved observations in currently data-sparse areas. This represents an important underutilized opportunity for the GWE.

Funding pressures on the public sector. These developments are occurring at a time when the public sector [namely, the National Meteorological and Hydrological Services (NMHSs)] is under significant funding pressures, with many NMHSs shrinking in size and public funds for the global observing system becoming harder to secure. This is making it harder for the public sector, acting alone, to satisfy the increased requirements for weather information. The case for maintaining or increasing funding of NMHSs is strengthened by a more open and explicit recognition of the leveraging from such funding that comes from the linked growth in the private sector; such recognition appears lacking currently. This enabling role of public sector investment to stimulate the growth of private sector companies is one that underpins the modern economy of most countries.

Growth of private sector capabilities. In tandem, there has been and continues to be a significant growth of private sector capabilities throughout the value chain; availability of venture capital supports this growth and innovation, as do the resources of big companies newly entering this market [see NWS (2017) for a recent U.S. national perspective]. An example is that for the first time recently private companies have claimed to be capable of making operational weather forecasts utilizing the global observations and models built on the back of those available in the public sector (e.g., Panasonic and IBM[4]). As those companies freely acknowledge, this capability has to be built on the public investment in the global observing system, in the models that form the bedrock of their operations, and in long-term atmospheric research. In addition, impact-based forecasts are intimately user focused, and

[3] The World Weather Research, World Climate Research, and Global Atmosphere Watch programs.

[4] www.panasonic.aero/2016/01/06/panasonic-weather-solutions-introduces-panasonic-global-4d-weather-the-worlds-most-advanced-global-weather-forecasting-platform; www.theweathercompany.com/newsroom/2017/06/21/weather-company-ibm-business-and-ucar-collaborate-advance-weather-science.

so their production is attractive to private companies wanting to create services for businesses (WMO 2015).

Structure of international financing. Also in parallel, changes are occurring in international financing (e.g., from development banks such as the World Bank Group), which increasingly favors private investment or joint investment in the public and private sectors. Basically, it is likely to be very difficult in the future to finance the public sector exclusively in domains such as that of the GWE, where it is recognized that both the public and private sectors contribute to the provision of weather information. This means that it is in the interest of all in the GWE for a more collaborative way of working between the public, private, and academic sectors to become the norm in the future.

Roles of public and private sectors. These factors (funding pressures on the public sector, growth of private sector capabilities, and structure of international financing) have the potential to lead to a degree of protectionism and distrust by the public sector of the private sector as the private sector develops further. It is causing a reexamination of the roles of national meteorological services and their relationship with the private sector. It is frequently said that distinctive roles and responsibilities for the public, private, and academic sectors should be clearly articulated to prevent confusion, unnecessary duplication, and undue tension, thereby ensuring complementarity. However, to create an optimal market for weather forecasts and services, it is also essential to ensure there is a level playing field such that, for example, commercial arms of NMHSs, where they exist, and private companies can compete on equal terms without undue subsidies distorting the commercial market. Unsubstantiated claims of the superiority of forecasts by either public or private sectors are counterproductive, undermining societal confidence in the GWE.

Growth of a service-based approach. There is a discernible move in the private sector from the provision of capital-based infrastructure (e.g., observing technology hardware) to a service-based approach (e.g., provision of data services; see Moninger et al. 2010; Voosen 2016; Amos 2017); this will have a significant impact on how the GWE operates. Appropriate business models (and their risks for different actors) for sustainability of public and private data services need to be explored, including an exploration of the consequences of the ownership of data.

Weather information standards and access. As these changes develop, weather information quality/standards, ownership, and access principles need updating. As wide as possible access and exchange are needed for both public and private sources of data; in this context, review of WMO Resolutions 25, 40, and 60[5] is probably needed. These resolutions, for example, draw a distinction between so-called essential data (for producing public weather information) and the rest, referred to as additional data. The guidance is that essential data should be made freely available at the point of use via global redistribution of the data. There is scope for clarification and revision of these WMO resolutions, and even for them to be raised up to the level of international regulations if clarity and simplification is to be achieved. WMO Resolution 40 itself is only a set of guidelines that are as notable in their breach as for their observance. For example, different countries and NMHSs interpret in very different ways both the international sharing of essential data and the definition of additional data that can be sold commercially multiple times. And the very fact that many NMHSs sell observations at all is potentially contrary to open public-data policies that many governments purport adhering to. The grave risk is that without action in this area, the global observing system is vulnerable to become weakened rather than strengthened. In conclusion, it can be argued that a more enforceable mechanism is needed to ensure such resolutions are actually implemented. Industry self-policing may not be sufficient. The concept of open access data, while applying in many countries (but by no means all) to data paid for by taxpayers, is demonstrably inappropriate for commercial data services (see also "Growth of a service-based approach").

Support for low- and middle-income countries. A goal for the GWE regarding data access could be to make weather information as available as possible to those who currently do not have access or cannot otherwise afford it, such as in low- and middle-income countries. Currently, people die because they only have access to poor-quality information or indeed cannot afford to access any data at all. The weather community in developed countries cannot be satisfied with this status quo continuing when it is capable of being dealt

[5] Resolution 40: WMO policy and practice for the exchange of meteorological and related data and products including guidelines on relationships in commercial meteorological activities; Resolution 25: WMO policy and practice for the exchange of hydrological data and products; Resolution 60: WMO policy for the exchange of climate data and products to support the implementation of the Global Framework for Climate Services.

with and should be dealt with. The benefits of a very significant global investment in the GWE already made by advanced economies are not currently being transferred effectively and efficiently to middle- and low-income countries, even though the provision and use of weather information could occur with no or limited incremental cost. This severely limits the ability of these countries to meet their national requirements for meteorological and hydrological services, especially severe weather impact forecasts and warnings. The World Bank Group, the Global Facility for Disaster Reduction and Recovery, and other development partners continue to address this issue through technical assistance and major hydrometeorological modernization projects.[6] This has been achieved through large-scale investment in NMHSs' infrastructure and by strengthening their operational capabilities in the short term by pairing with more advanced NMHSs.

For a poor country, it is likely to be more beneficial to invest in accessing and using the best NWP forecasts in real time than, for example, in developing its national observing system. Nonetheless, there is a paucity of high-quality national observations in too many poor countries. Consequently, it is in the interest of all that can to help correct this situation, because more high-quality, well-managed observations anywhere help weather analyses, forecasts, and verification everywhere.

RESPONSES BY THE GLOBAL WEATHER ENTERPRISE. In recognition of these changes, and particularly those that relate to the development of the private sector within the GWE, the WMO has committed itself to being more collaborative with the private sector. As stated by Secretary-General Petteri Taalas at the Washington seminar in November 2017, "the WMO permanent representatives are appointed by the governments to represent the interest of their countries including the private sector." He further stated that "WMO is interested in playing a leading role in engaging private sector service and measurement actors in its activities. This engagement is expected to speed up within the coming months…. WMO is interested in hearing concrete proposals from private sector on how to become more engaged in WMO activities" (GFDRR 2018). The WMO expects to consider a new resolution regarding the involvement of the private sector in its activities at its next Congress in 2019. Other UN agencies such as the International Telecommunications Union (ITU)[7] have established themselves with both member states but also member organizations, predominantly from the private and academic sectors, and this could be a good model for the future structure of the WMO. The ITU describes itself as "an organization based on public-private partnership since its inception" that "currently has a membership of 193 countries and almost 800 private-sector entities and academic institutions."

In recognition of this pressing need, discussions between the WMO, the World Bank, and HMEI following the Washington seminar have resulted in the formation in March 2018 of an independent Global Weather Enterprise Forum (GWEF). The basic aim of the GWEF is to provide a platform for consultation and to facilitate cooperation, engagement, and liaison between the public, private, and academic sectors in the global weather enterprise for the benefit of all. It will endeavor to build trust between the sectors and identify a common vision and mission in line with the societal needs for information and services provided by the GWE sectors. Membership of the GWEF is drawn from leaders within each of the public, private, and academic sectors.

CONCLUDING REMARKS. The GWE needs to come together to make the most of these changes by harnessing the opportunities and managing the risks to continue to be successful and grow to deliver the greater requirements that society places upon it (see sidebar). Any lack of clarity in the respective roles

[6] World Bank investments in this sector are currently approaching US$800 million (or 0.001% of global GDP) and increasing. With 30% of global GDP being impacted by weather, clearly this is not enough.

[7] www.itu.int/en/Pages/default.aspx.

THE FUTURE OF THE GLOBAL WEATHER ENTERPRISE

Drivers of change:
- New science and technology
- Increased hazard vulnerability and climate change
- Societal need for improved weather information
- Societal need for wider access to weather information
- Growth of private sector capability

Ways forward:
- Shared vision of public, private, and academic sectors
- Increased dialogue and trust among all actors
- Enhanced international and sectoral cooperation
- Better regulatory framework for input and output data
- New business models enabling as wide as possible data access

and responsibilities of the different actors would contribute to mistrust and would need to be resolved if the full potential of the GWE is to be realized. A case in point relates to what is often referred to as the "single authoritative voice" for NMHSs regarding issuing of national weather warnings.[8] This could be interpreted as implying governmental control of weather information, which would stifle innovation in what is today a global market for such information. Confusion could arise in the minds of users if weather forecasts from individual providers were to contradict the "official" warnings. Therefore, greater clarity and recognition regarding the roles and responsibilities of the public and private sector in delivery of operational weather information would greatly reduce the potential for confusion and misunderstandings.

Consequently, the threat of the GWE not delivering what society needs will be greatly diminished by enhancing the mutual respect and trust across the sectors; this will come from greater dialogue and understanding leading to co-designed action. In this regard, the GWE stakeholders need to act quickly—there was an acceptance at the Washington seminar in 2017 that they have been too slow in the past to address issues that would improve the collaboration between the public, private, and academic sectors.

It is our opinion that business as usual will not lead to these opportunities being fully grasped, and indeed it could instead lead to the gradual decline of what could be called the traditional entities within the GWE. Partnership across what are culturally rather different sectors offers the promise of a growing GWE where all can benefit.

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[8] Note that in some countries the concept of a single authoritative voice is not enforceable by law, as freedom of speech is considered more significant, while in others provision of all weather information aside from that issued by the NMHS has been made illegal by the government.

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