All Kinds of Integration

WMO's Strategy for Seamless Prediction

Adapted from the article, “Advancing Research for Seamless Earth System Prediction,” by Paolo Ruti (World Meteorological Organization), Oksana Tarasova, Julia Keller, Greg Carmichael, Øystein Hov, Sarah Jones, Deon Terblanche, Cheryl Anderson-Lefale, Ana Barros, Peter Bauer, Véronique Bouchet, Guy Brasseur, Gilbert Brunet, Phil DeCola, Victor Dike, Mariane Diop Kane, Christopher Gan, Kevin Gurney, Steven Hamburg, Wilco Hazeleger, Michel Jean, David Johnston, Alastair Lewis, Peter Li, Xudong Liang, Valerio Lucarini, Amanda Lynch, Elena Manaenkova, Nam Jae-Cheol, Satoru Ohtake, Nadia Pinardi, Jan Polcher, Elizabeth Ritchie, Andi Eka Sakya, Celeste Saulo, Amith Singhee, Ardhasena Sopaheluwakan, Andrea Steiner, Alan Thorpe, and Moeka Yamaji. Published online in *BAMS*, January 2020. For the full, citable article, see [DOI:10.1175/BAMS-D-17-0302.1](https://doi.org/10.1175/BAMS-D-17-0302.1).

I ncreasing society's resilience to high-impact natural events requires coordinated research and new investments in observation and prediction. To enable all nations to benefit from these investments, scientific and technical advancements need to be more accessible and usable. The new research strategy of the World Meteorological Organization (WMO), dating from the 2017 Science Summit, highlights the benefit of seamless Earth system science. The impacts of weather extremes and environmental change can only be mitigated—or adapted to—through this seamless approach, which would break down the artificial barriers created by the different observing systems, models, time and space scales, and compartments of the Earth system.

Seamlessness and the value cycle

The generation and delivery of weather and climate services can be considered as a value cycle linking the production of information and services (through observing, modeling, forecasting, and service delivery) to the outcomes and value resulting from user decisions, while also providing a feedback loop and opportunities for co-design. All elements of that value cycle are encompassed by seamless prediction, which has expanded from its initial definition based on time and space scales to now consider the needs of users, stakeholders, and decision-makers for continuous and consistent information despite the different sources from which the information is generated. Advance of seamless Earth System Prediction depends on all kinds of integration—not just of the processes of the climate itself, but also of specialties, data systems, user needs, research interests, and other factors throughout the value chain.

The need for seamless prediction is underpinned by the fact that human activities, such as water management or policymaking, can directly modify the very system that we want to predict. Accelerating improvements in prediction and services requires comprehension of the complexity of the technological and human dimensions of the value cycle together with the interactions, synergies, and feedbacks between the various components of the Earth system. This integrated approach broadens Earth system science, extending the concept of seamless prediction to draw on social sciences and the knowledge and experience of users.

Co-design for societal needs

Reducing risks of natural hazards and disasters, the goal of seamless Earth System prediction, depends increasingly upon interdependencies between people and their environment. Consider a tropical cyclone threatening an urban area. Decisions based on the landfall forecast feed back into the system behavior. For example, releasing water to prevent dam failure may magnify the flood threat. The coupled natural and infrastructure systems need to be represented in models with a high level of granularity and continuous monitoring. Introducing land use and other anthropogenic effects allows more effective prediction of extreme weather impacts.

More cornerstones of WMO's research agenda

- Work with users to integrate data from different observing systems, models, and prediction products.
- Rolling review of user requirements to help shape science priorities.
- Academic training around the concept of the value cycle.
- An international coordinating mechanism to ensure development of basic and applied themes of the seamless Earth system prediction.
- Regional dedicated networks for interconnecting academic and operational institutions in the most vulnerable regions.

Flexible development of high-quality products and expanded services requires more collaboration among disciplines, sectors, and organizations. Only a co-designed approach that involves all relevant parties will allow this novel provision of seamless Earth system information. The energy sector provides examples: ramps in wind or photovoltaic power production due to weather threaten the security of energy supply if not predicted with the required accuracy. Such situations lead to new definitions of high-impact weather—such as low stratus affecting solar power production—that must be considered by scientists and forecast providers, requiring data for multiple time scales to respond to current needs and infrastructure for future demands. The value cycle approach, integrating user needs into science planning, thus becomes a concrete tool for co-design.

Future infrastructure

Earth system sciences are increasingly a big data problem—a new machine learning frontier bridging outputs and services. This requires a paradigm shift in scientific methodologies and a strengthening of collaboration across sectors and resources to meet future requirements.

The accessibility of observations is indispensable. Under WMO, the worldwide access and exchange of observational data has therefore been organized in an efficient way. All relevant observations must be “Findable, Accessible, Interoperable, and Re-usable.”

New players, including commercial data service providers, are generating and providing observations of the environment or creating their own prediction systems. More unconventional data will continue to become available, for example, from mobile phones, cars, and

WMO Science Summit

The WMO “Science Summit on Seamless Research on Weather, Climate, Water, and Environment” was held in Geneva, Switzerland, 20–22 October 2017. The objectives were to improve research collaboration, to develop the future WMO research agenda, and to ensure societal benefits from the research. The agenda builds on closer collaboration between weather, climate, water, and environment research. See <https://public.wmo.int/en/events/meetings/science-summit-seamless-research-weather-climate-water-and-environment>.

other Internet-connected devices, most of them privately owned. This increasing volume of data in the public domain—of varying quality, provenance, and reliability—opens up opportunities for advancing prediction and user-tailored products but requires a policy on data usage, sharing, and interoperability.

Collaboration and partnerships among the private and public sectors are therefore vital to seamless prediction and to ensure data availability, including for research. At the same time, these data and technologies must yield information of the right quality for decision-making.

An open question is how the growth of the private sector can strengthen overall investment in the value cycle in an enterprise built on public investment in observing, models, tools, and long-term research. The development of public–private partnerships further necessitates clear definition of the roles in providing information. The WMO is promoting a dialogue among different players to ensure coordinated growth of the Global Weather Enterprise.

Substantial advances in assimilating the increasing volume of data into models have led to prediction products that help close the gap between nowcasting and numerical weather prediction, forming the basis of seamless prediction from minutes to hours.

The increasing volume of data to handle and transfer requires new data-management models, such as distributed systems or cloud-based solutions that rely on big data techniques

and build on modularity of algorithms, data assimilation, numerical models, verification tools, and more. Machine learning and big data techniques also provide new possibilities to expand a seamless prediction system, in particular for decision-making on the time scale of minutes. For example, roadway information can be shared instantaneously and processed by smart networks of interconnected cars, issuing an automatic warning. Capitalizing on these new data, methods, and systems will also require continuous investments in research, infrastructure, and human resources.

Nurturing talent and innovation

Developing science guided by the value cycle requires an interdisciplinary mindset alongside in-depth work in individual disciplines. This includes expertise in data handling and understanding emerging technologies in computational sciences, infrastructure, and more. Improving information for decision-making involves risk communications, behavioral sciences, and economics. Early exposure to, and training in, interdisciplinary approaches is essential in linking natural and social sciences.

Cloud-based access to tools may foster research worldwide. The creation of both virtual and real scientific educational hubs might help development and retention of scientific talent. There is a need to connect people in academia, government, and the private sector, facilitating local and global research collaborations and broadening participation. Breaking down barriers—including gender disparity—is a key to supporting an emerging generation of scientists.

In a science-driven inquiry framed by real-world problems, there is a growing interaction between science and applications. The proposed seamless Earth system science will advance knowledge of the system itself, improve predictive capabilities, and foster policy-oriented research.

The way science and its connection with stakeholders is organized needs to change to develop flexibility to answer emerging and urgent societal requirements. Both short-term, targeted innovation and long-term, continuous improvement are needed to progress toward seamless Earth system prediction. Engaging researchers, users, and stakeholders is crucial to ensure that the delivery of information about the changing environment addresses the needs of society. ●●

METADATA

BAMS: How did you become interested in the topic of this article?

Paolo M. Ruti (WMO): *As chief of the World Weather Research Division at the World Meteorological Organization, I lead an international research network engaging operational and academic institutions. It is a great opportunity to collaborate with key scientists across fields and continents to foster science-oriented solutions and to make our society more resilient.*

BAMS: What was your goal for this article?

Julia Keller (Deutscher Wetterdienst): *The WMO Science Summit in 2017 featured very inspiring discussions and interactions of researchers from a variety of institutions across the globe. Our goal, but also our challenge, was to also bring this stimulating exchange and the vibrant atmosphere across in this article, and make the discussions and outcomes accessible to all readers.*

BAMS: What, then, stands out in this stimulating atmosphere that you are conveying?

PMR: *The fascinating complexity of designing and implementing interdisciplinary projects. The foundation of seamless Earth system prediction and the benefit for modern society. New predictive methods that are able to detail air quality conditions to the neighborhood level, provide early warnings a month ahead, and forecast weather-related impacts such as flooding and energy consumption will be the main tools that future society will use to make decisions. How to make it come true will need a bit of this paper . . . just what the doctor ordered.*

BAMS: What surprised you the most about the work you document in this article?

PMR: *The excitement from different communities to participate in an international endeavor.*

JK: *To discover interconnectivities and dependencies within the seamless approach to Earth system science and to explore the opportunities and challenges that lay ahead of us when we—as researchers, users, and stakeholders—work together to advance Earth system science for the benefit of society.*