MEETING SUMMARIES

PLANNING THE NEXT DECADE OF COORDINATED U.S. RESEARCH ON MINUTES-TO-SEASONAL PREDICTION OF HIGH-IMPACT WEATHER

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The end of 2014 marked the conclusion of The Observing System Research and Predictability Experiment (THORPEX), a 10-year research and development program organized under the World Meteorological Organization (WMO)/World Weather Research Programme (WWRP) and designed to accelerate improvements in the accuracy and use of 1-day to 2-week numerical weather predictions. As summarized by Chang et al. (2013), proposal development efforts and workshops have been organized to establish three new international 5–10-year THORPEX legacy projects under WWRP. The first two projects, Polar Prediction Project (PPP)

U.S. THORPEX LEGACY PLANNING MEETING

WHAT: Approximately 50 experts from the research and operational prediction communities in the United States met to discuss the planning of cooperative research activities in the post-THORPEX era.

WHEN: 5–6 June 2014

WHERE: Silver Spring, Maryland

and Subseasonal to Seasonal Prediction (S2S), have been formally established with their own International Coordination Office and Implementation Plan. The third, High-Impact Weather (HIWeather), has recently been established and the governance is being finalized at the time of writing. To engage the U.S. research and operational communities in these new legacy projects and begin to articulate a new U.S. science plan, a 1.5-day planning meeting organized by the authors was held on the NOAA Silver Spring metro campus in June 2014. The meeting was held immediately after the Second International HIWeather Workshop—a 3-day meeting that was held at the same venue.

The planning meeting attracted a diverse group of experts in atmospheric processes, predictability, numerical modeling, data assimilation, observing systems, forecasting, economics, and social science. The meeting comprised a series of presentations to provide the necessary background and three parallel

breakout sessions aligned with the legacy projects. Perspectives on the U.S. THORPEX program, which had focused on components of the forecast system, identified accomplishments including the development and implementation of a new operational hybrid 3D-Var/ensemble Kalman filter data assimilation scheme at NOAA, leadership in international ensemble forecasting (the North American Ensemble Forecast System), field campaigns, and global research initiatives. Reported obstacles in the United States included difficulties integrating social science research and researchers working in isolation as opposed to a coordinated community effort. The charge was laid to identify scientific and socioeconomic needs that align with multiple agency interests, the international legacy projects, and the research priorities and talents of the U.S. science community.

DISCUSSIONS. The three international legacy projects share the common purpose of improving predictions of and public resilience to extreme events. PPP is concerned with hourly-to-seasonal time scales, with the Year of Polar Prediction (YOPP, 2017–19) serving as a focal point for research on processes, forecasting systems, and service needs for the polar regions. Flagship themes include sea ice predictions, linkages between polar regions and lower latitudes, improved observations, and coupled modeling. S2S focuses on predictions ranging from 2 weeks to a season with scientific issues spanning predictability, teleconnections, and interactions between processes on multiple scales. Coupled models are a central component of S2S with challenges in initialization, coupling, resolution, systematic errors, verification, and uncertainty quantification. Subprojects include monsoons and the Madden–Julian oscillation. HIWeather focuses on predictions ranging from minutes to 2 weeks with the goal being to increase public resilience to five selected hazards comprising flooding, wildfire, extreme wind, winter weather, and urban heat and air quality. Similar challenges as for PPP and S2S were identified.

Given the natural overlaps in aspects of science, prediction, and response between the three legacy projects, it emerged that a U.S. science plan incorporating all the legacy project themes is best designed under one umbrella (Fig. 1) with a focus on the next decade of U.S. priorities. The seamless prediction across time scales from minutes to a season and across spatial scales from the microscale to the planetary scale would be achieved via a unified Earth-system modeling approach. Weather-related needs would become more sharply defined on a national level. Some significant hazards identified by the participants include water (e.g., flooding, surge, and ice), heat waves, winter weather, and extreme wind. The response to these urgent needs requires a concerted effort across multiple agencies, with requests for funding expected to be easier to justify and support if they are part of an integrated effort. On the other hand, the "stovepiping" of separate programs for different applications was perceived as being less productive or efficient.

Research activities are expected to meet national service needs and agency goals. One longstanding need is the advancement of operational forecasting including better numerical predictions, preparation, and communication of forecast products and services. Other needs include naval and air services worldwide and public preparedness through NOAA's Weather Ready Nation campaign. A goal of NASA is to improve the capability to predict extreme weather events—for example, via assimilation of data from the large number of NASA airborne and spaceborne missions. The National Science Foundation (NSF) supports cutting-edge and transformative science of benefit to society. One mark of progress to better integrate the science of prediction with social science is NSF's new Interdisciplinary Research in Hazards and Disasters program (HAZARDS SEES).

Existing efforts can be leveraged. These include the interagency Earth System Prediction Capability (ESPC) and the National Multi-Model Ensemble (Kirtman et al. 2014) for longer-range predictions. More than 10 NOAA test beds and proving grounds exist, some on given weather phenomenon (such as the Hazardous Weather Testbed and a new Arctic Testbed) while others provide infrastructure for coordinated activities (such as the Developmental Testbed Center and the Observing System Simulation Experiments Testbed). Furthermore, the vast quantity of satellite observations, together with airborne and
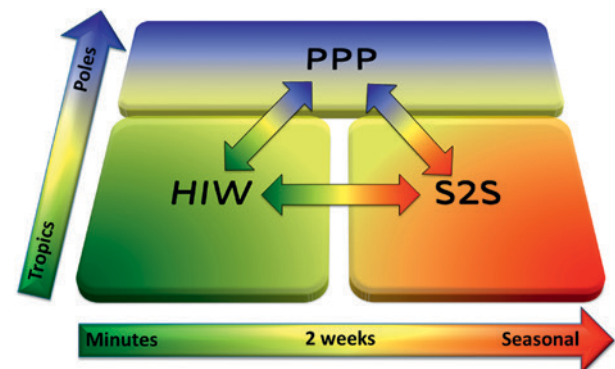

Fig. 1. Schematic of the three international post-THORPEX legacy projects: Polar Prediction Project (PPP), Subseasonal-to-Seasonal Prediction (S2S), and High-Impact Weather (HIWeather, HIW).

ocean data and the evolving land-based network including mesonets, can be exploited.

A series of one-slide presentations by participants indicated priorities that need to be addressed through a coordinated U.S. effort. These mapped onto many goals of the legacy projects and emphasized the need for central infrastructure that contained all relevant data for high-impact weather events, including observations, numerical model output, and forecast products. The need for operational models to be used as community models was reinforced as well as a review of institutional structures and the establishment of new partnerships to sustain linkages between science and practices.

Several critical gaps were identified. First, quantitative assessments of the key deficiencies are necessary in order to determine priorities and metrics of success in communication, forecasting, and research. An example of an initiative with well-defined metrics for success is NOAA's Hurricane Forecast Improvement Program (Gall et al. 2013), which has led to significant funding and coordinated teams working on tropical cyclone intensity prediction. As part of post-THORPEX research, it is similarly necessary to develop new products and metrics driven by the hazards and user-based value. In parallel, critical time scales for human response as well as decision makers' needs and how they "assimilate" forecast products require investigation. The interpretation of forecast uncertainty was identified as another priority area.

Critical gaps in existing forecast products can be addressed via novel research and testing of innovative products in both retrospective investigations and real-time "virtual field campaigns" and diagnostics of where the forecast is failing to capture the weather event or its impact. The need to improve predictive skill is expected to be addressed via the advancement of coupled models (e.g., adding sea ice), the amelioration of model error and bias, and superior assimilation of existing and new observations (e.g., accounting for nonlinearity in cloud-resolving models). Enhanced development and calibration of ensemble forecasts with user-focused metrics and evaluation remain necessary. The temptation to pursue detailed forecasts on the smallest scales at long lead times needs to be weighed against an assessment of the predictability limits of the hazard and what level of detail is necessary for users. Coupled with the emerging science of predictability for phenomena on the scales of minutes to months is the need to understand their processes and interactions spanning multiple spatial and temporal scales and multiple interfaces (air, sea, land, ice).

The identification of gaps and priorities led to a series of four proposed broad, overlapping research thrusts: 1) predictability and processes, 2) modeling and assimilation, 3) use and evaluation of forecasts, and 4) risk, impact, and communication. Several common themes cut across these research thrusts. These include the creative use of observations (e.g., advancing observing networks for both assimilation and verification) and uncertainty (e.g., in both ensemble prediction and risk communication). It was recognized that the complexity of the challenges necessitates a change from traditional individual research to large teams with diverse areas of expertise collaborating on common problems. In recognition of this, an integrated framework is necessary to conduct research across all the thrusts via the aforementioned database of high-impact weather cases (e.g., Sandy in 2012) and coordinated virtual field campaigns that involve all relevant disciplines. Many of the research thrusts and cross-cutting activities can also be considered in the context of operational linkages to research. A two-way interface would comprise research activities and products that demonstrate a quantitative benefit to operations and are considered for operational use [research to operations (R2O)] and also the access and support for researchers to use operational models and products [operations to research (O2R)].

In summary, the consensus view from the meeting was that the United States can successfully contribute to achieving the ambitious goals of the three legacy projects by establishing clear priorities and metrics of success and pursuing far-reaching, coordinated scientific efforts using accessible and well-supported infrastructure, models, and data.

OUTCOMES AND NEXT STEPS. The planning meeting served to introduce the international post-THORPEX legacy projects and relevant national interests and it enabled participants to identify critical gaps in progress, common scientific challenges, and research priorities. The meeting also offered a structure to plan a new U.S. initiative, within which a coordinated community science plan would be developed. The science plan would collectively address elements of all three legacy projects (Fig. 1) directed at the unified mission "to promote national and international cooperative research to understand, evaluate, and improve the skill and socioeconomic value of forecasts of high-impact weather events on time scales of minutes to seasonal." It is intended to be cohesive yet far reaching, fiscally responsible, and driven by both short- and long-term benefits. The ultimate goal is for the community to reinvigorate

the weather research agenda in anticipation of an integrated, multiagency program.

In the months following the planning meeting, the broader U.S. community is being engaged and encouraged to contribute to the new program and science plan, initially via town hall meetings and e-mail circulations. Experts in the broad community would define priorities in their areas with specific linkages developed as the priorities are identified. These priorities can lie geographically within or outside the United States (including global problems), provided that they map onto the missions of the U.S. agencies. The science plan will emphasize coordinated tasks that are expected to improve markedly upon the present model of individual investigators and small groups tackling problems in isolation. In parallel, mechanisms will need to be created to integrate collaborations with international partners on the legacy projects, defining how the U.S. will contribute to the international efforts and how the international activities will benefit U.S. needs.

The concept of a program aimed at improving predictions of and responses to high-impact weather events is not new, given that the U.S. Weather Research Program and U.S. THORPEX had been established to achieve similar goals. Several shortcomings and recommendations relevant to a national effort have been articulated by Mass (2006), many of which remain pertinent nearly a decade later. Successful national programs in other fields will be reviewed as a potential blueprint. It is recommended that the U.S. THORPEX organizational committees be transformed and renamed into new committees that lead and coordinate the next decade of U.S. weather research. A new executive committee would include senior management from several agencies, potentially including those not involved in THORPEX. A new science steering committee (SSC) comprising experts in the physical and social sciences and the operational forecasting arena would advise the executive committee. The SSC would receive input from the U.S. community for the science plan development and coordinate cross-cutting research nationally as well as foster international interactions. The SSC would also interact with related disciplines that have similar challenges [e.g., model physics (Wolff et al. 2012) or hydrological prediction (see special issue of *Hydrological Processes,* 2013, Vol. 27, No. 1)]. The executive committee would provide overall leadership, ensuring that the U.S. research efforts map onto agency priorities and interests and the United States has a well-coordinated input to evolving WMO/WWRP projects.

If practical challenges can be overcome, the proposed new U.S. high-impact weather research initiative promises significant benefits for the nation in terms of research advances that will directly benefit the entire weather enterprise in reducing loss of life and property.

APPENDIX: LINKS TO PROJECT PAGES.

- U.S. THORPEX Legacy Planning Meeting
http://somas.stonybrook.edu/~na-thorpex/meeting_files/Meeting_2014/Meeting_2014.html
- WMO/WWRP International THORPEX program (concluded at the end of 2014)
www.wmo.int/pages/prog/arep/wwrp/new/thorpex_new.html
- U.S. THORPEX (concluded at the end of 2014)
http://somas.stonybrook.edu/~na-thorpex
- Polar Prediction Project (PPP)
http://polarprediction.net
- Subseasonal-to-Seasonal Prediction Project (S2S)
www.wmo.int/pages/prog/arep/wwrp/new/S2S_project_main_page.html
- High Impact Weather Project (HIWeather)
www.wmo.int/pages/prog/arep/wwrp/new/high_impact_weather_project.html
- NOAA Weather-Ready Nation
www.nws.noaa.gov/com/weatherreadynation
- Earth System Prediction Capability (ESPC)
http://espc.oar.noaa.gov
- NOAA Testbeds
www.testbeds.noaa.gov

REFERENCES

Chang, E. K. M., M. Peña, and Z. Toth, 2013: International research collaboration in high-impact weather prediction. *Bull. Amer. Meteor. Soc.,* **94,** ES149–ES151, doi:10.1175/BAMS-D-13-00057.1.

Gall, R., J. Franklin, F. Marks, E. N. Rappaport, and F. Toepfer, 2013: The Hurricane Forecast Improvement Project. *Bull. Amer. Meteor. Soc.,* **94,** 329–343, doi:10.1175/BAMS-D-12-00071.1.

Kirtman, B. P., and Coauthors, 2014: The North American Multimodel Ensemble: Phase-1 seasonal-to-interannual prediction; phase-2 toward developing intraseasonal prediction. *Bull. Amer. Meteor. Soc.,* **95,** 585–601, doi:10.1175/BAMS-D-12-00050.1.

Mass, C., 2006: The uncoordinated giant: Why U.S. weather research and prediction are not achieving their potential. *Bull. Amer. Meteor. Soc.,* **87,** 573–584, doi:10.1175/BAMS-87-5-573.

Wolff, J. K., B. S. Ferrier, and C. F. Mass, 2012: Establishing closer collaboration to improve model physics for short-range forecasts. *Bull. Amer. Meteor. Soc.,* **93,** ES51–ES53, doi:10.1175/BAMS-D-11-00248.1.