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THE U.S. WEATHER RESEARCH PROGRAM AND ITS CONTRIBUTIONS TO UNDERSTANDING THE VARIABILITY OF WATER IN WEATHER

Ward R. Seguin and John E. Gaynor
U.S. Weather Research Program Interagency Program Office, Silver Spring, Maryland

and

Robert Gall
National Center for Atmospheric Research, Boulder, Colorado

1. INTRODUCTION

The United States (US) has an opportunity to accelerate the rate at which weather forecasts are improved because of advances in atmospheric sciences and rapid evolution of information technology. This is occurring at a time when the economic well-being and safety of the American citizens are growing ever more dependent on accurate and timely weather information. Over the last twenty years, major improvements have been made in our ability to observe and forecast atmospheric phenomena. Because of major infrastructure investments by the National Weather Service (NWS) in its modernization and the National Aeronautics and Space Administration (NASA) with its advanced satellite development programs, expectations by the American public are very high for improved weather data and information services.

Several Government departments and agencies have weather-related missions and have carried out or sponsored research and development (R&D). The United States Weather Research Program (USWRP) was established to facilitate coordination and collaboration among agencies supporting weather-related research and to allow USWRP members to leverage sponsored R&D. The initial USWRP membership included the National Oceanic and Atmospheric Administration (NOAA), NASA, the US Navy, and the National Science Foundation (NSF). Over the last year, the Departments of Transportation (including the Federal Aviation Agency and the Federal Highways Administration), Energy, and Agriculture, the US Air Force, and the Environmental Protection Agency joined the USWRP.

Corresponding author address: Ward R. Seguin, NOAA, Silver Spring, MD 20910, e-mail: ward.seguin@noaa.gov

2. OBJECTIVES IN WATER FORECASTING

Two of the principal objectives of the USWRP have been to accelerate our understanding and forecast skill (see Figure 1) for high-impact weather including the forecast timing, location, and specific rainfall amounts associated with hurricane landfall and flood

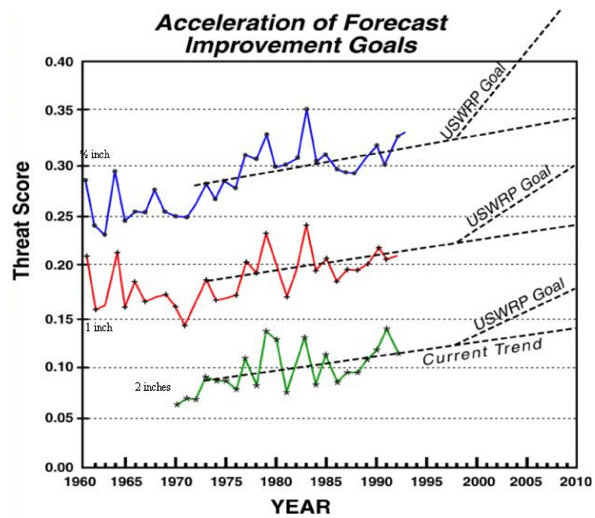

Figure 1: USWRP concept for accelerating operational forecasts.

events that significantly affect the lives and property of US inhabitants. By way of example, some of the USWRP water-related forecast objectives are to: increase the flash flood warning times from 52 minutes (1998) to 65 minutes (2005), extend the precipitation forecasts to Day 3 and attain Day 2 accuracy at Day 3, provide weather and water forecasts in probabilistic terms, and for hurricane landfall, extend quantitative precipitation forecasts (QPF) to Day 3 to improve the skill of forecasts of inland flooding.

These water forecast objectives along with several others are defined in two foci of the Program: "USWRP Implementation Plan – Hurricane Landfall" and "An Implementation Plan for Research in Quantitative Precipitation Forecast and Data Assimilation" (http://box.mmm.ucar.edu/uswrp/implementation/implementation.html). The Program is refining the QPF focus by splitting it into short term (Day 1 and 2), extended (Day 3 through Day 14), and into the Cool and Warm seasons for the short term. The Program is also adopting an air quality focus. In addition to addressing the science pro-blems, the Program seeks to define the societal benefit of its research for the purpose of setting goals and stimulating the transfer of knowledge and techniques into operations.

3. DEFINING RESEARCH PROBLEMS

Traditionally, the USWRP has assembled Prospectus Development Teams (PDT) to identify research opportunities for improving operational forecasting. PDT-8 (Fritsch et. al, 1998) met to considered issues and opportunities associated with QPF and convection. PDT-9 (Droegemeier et. al, 2000) met to consider hydrological aspects & flood prediction (http://box.mmm.ucar.edu/uswrp/PDT.html). Using these, the USWRP Science Steering Committee (SSC), under the direction of the Office of the Lead Scientist (OLS), identifies where the initial research emphasis should be placed based on where the SSC believes rapid progress can be made and where the impact on forecasts will be significant. The OLS commissions workshops to refine the science objectives. The Program then creates implementation plans which lay out how the research should be carried out. Normally such implementation plans will recom-mend data-gathering activities such as field programs, data assimilation, and numerical weather prediction (NWP) R&D.

The USWRP seeks to involve the entire physical scientific community in the necessary research. To do this, competitive research announcements of opportunity are issued by the member agencies and deserving proposals are funded as resources allow. It is important that researchers have a vision of how their research will contribute to improving operational weather and water forecasting, and how their work will be integrated with that of others to contribute to the total solution. For example, it is important for observational programs to obtain data based on the requirements of the NWP research and for observationalists to work with the data assimilation community to ensure that the data are usable by modelers.

With the addition of the new agencies, the USWRP is reviewing its operational requirements to better understand their underlying science needs. The new agency requirements are predominantly in aviation, surface weather for ground transportation, and energy/air quality. For the first two, the short-term forecasts are the most important. Energy and air quality requirements span a range of time scales. In all instances, however, accurate and timely precipitation forecasting is very valuable for commerce and human safety. All three need areas require much higher resolution forecasts (e.g., one to four km) than are available routinely today; and while none of them will change the basic thrust of atmospheric research, the small scale requirements will tax current computing capabilities and well as the approaches used in the models to represent boundary layer features, cloud physics, convection, and radiation.

4. TRANSFER TO OPERATIONS

A major thrust of the USWRP is to ensure that the promising research and development are transferred to the operational community, whether a Government agency or a private company. Each year, Government departments and agencies and NSF provide millions of dollars for basic and applied weather research, but there are only a few effective processes to ensure that the operational agencies benefit from this R&D.

To address this, the Program is supporting the development of community numerical models, referred to as Weather Research and Forecasting (WRF) models, for operational hurricane forecasting and mesoscale to regional weather forecasting, and eventually for global forecasting. The concept is that a community model will allow the research community to contribute (see figure 2) component techniques to the model in a plug and play compatible manner.

In concert with this, a Development Testbed Center (DTC), run jointly by NOAA, members of the Department of Defense, and the National Center for Atmospheric Research (NCAR), is being established where WRF models can be developed and tested in an operational-like environment on a non-interference basis. The intent is to provide a facility where the strengths and weakness of new techniques can be tested, assessed, and compared with operational models before recommending new technologies to

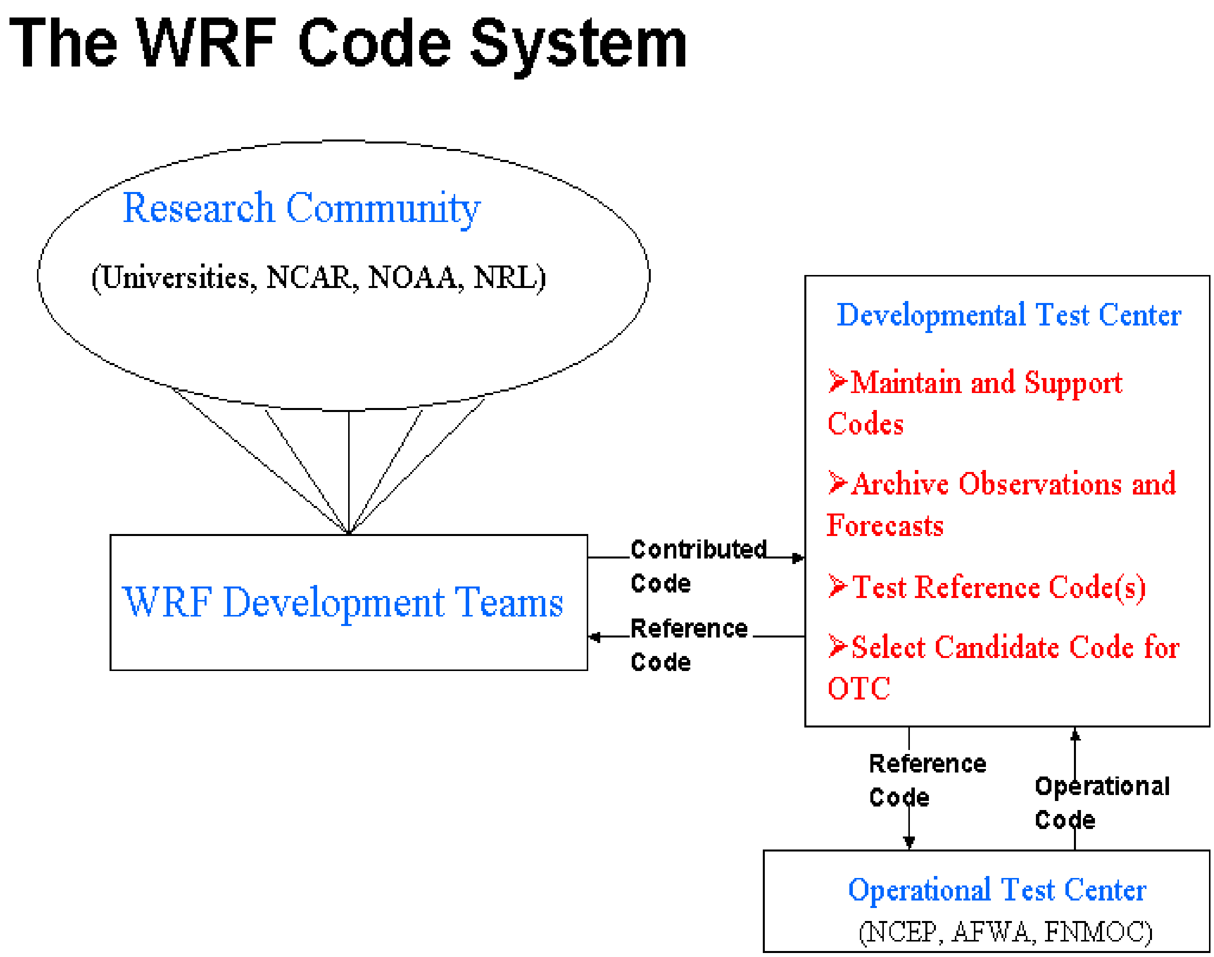

Figure 2: The concept of community-developed numerical models.

the operational communities. This approach holds promise for accelerating science improvements into operations because DTC development will mirror operational information technology (IT) as much as possible. At the same time, it is envisioned that an Operational Testbed Center will be established whereby operations centers can tailor the new model technologies to their operational environments.

Because data assimilation is such a key component of NWP, member agencies (initially NASA and NOAA) have developed a Joint Center for Satellite Data Assimilation (JCSDA) to expand on techniques for assimilating the large amounts of new satellite data that will become available during the next decade.

The NWS and the US Navy have joined forces to create the Joint Hurricane Testbed (JHT). Like community models and the DTC, the JHT is intended to facilitate and accelerate the transfer of applied research to operations. The JHT has been in existence for three years. Through announcements of opportunity for research, investigators are funded to do the development necessary to implement promising science advances on the Tropical Prediction Center (TPC) computers to be used by operational forecasters so they can be be evaluated.

5. QPF RESEARCH ACTIVITIES

In the USWRP report prepared by the PDT-8 in September 1996, the abstract states:

"Quantitative precipitation forecasting (QPF) is the most important and significant challenge of weather forecasting. Advances in computing and observational technology combined with theoretical advances regarding the chaotic nature of the atmosphere offer the possibility of significant improvement in QPF. To achieve these improvements, this report recommends research focusing on 1) improving the accuracy and temporal and spatial resolution of the rainfall observing system; 2) performing process and climatological studies using the modernized observing system; 3) designing new data gathering strategies for numerical model initialization; and 4) defining a probabilistic framework for precipitation forecasting and verification. Advances on the QPF problem will require development of advanced ensemble techniques that account for forecast uncertainty, stemming from sampling error and differences in model physics and numerics and development of statistical techniques for using observational data to verify probabilistic QPF in a way that is consistent with the chaotic nature of the precipitation process."

A recent draft report to the SSC of the USWRP entitled: "Research and Development to Improve Quantitative Precipitation Forecasts in the Warm Season" states:

"Because precipitation strongly affects many aspects of our economy and general livelihood, efforts to improve warm-season QPF have commanded a high priority in meteorological research. Nevertheless, despite steady improvements in forecasting precipitation amount, a very low level of skill persists in summer. The high societal impact of warm season rainfall, together with the low operational forecast skill, suggests that warm season rainfall prediction should be established as a principal focus of the USWRP."

The USWRP sponsors field observation programs in support of research goals cited above. Some of the field programs are small annual programs usually carried out by one or two agencies while others are fairly large field programs that occur only once, involve several agencies, and are frequently international in nature. All are designed to address the critical need for greater understanding of the variability of water in all of its phases to allow the science to increase its predictive skill.

To address QPF problems and issues, particularly for the summer season, the International H2O Project (IHOP) (Weckwerth and Parsons, 2003) was held during spring 2002 in the central United States (http://www.atd.ucar.edu/dir_off/projects/2002/IHOP.html). IHOP was designed to address several key issues associated with the three-dimensional distribution of water vapor in the troposphere. The major goals were to: determine the degree of improvement in forecast skill that occurs through improved characterization of the water vapor field, seek to further understand and eventually predict the processes that determine where and when convection forms, improve understanding of the relationship between atmospheric water vapor and surface and boundary layer processes as they relate to quantitative forecasts of precipitation, and determine the optimal mix of water vapor measurement strategies to better predict warm season rainfall.

Two field programs are closely supporting the USWRP Hurricane Landfall foci. The Coupled Boundary Lay-ers/Air-Sea Transfer, Defense Research Initiative (CBLAST DRI) (http://www.whoi.edu/science/AOPE/dept/CBLASTmain.html) is an Office of Naval Research observational and modeling program designed to study low wind and very high wind energy fluxes across the atmospheric-oceanic boundary layer in stable and unstable flows. During field programs, observations are being made from fixed towers and moorings, remote sensors, and unmanned and manned aircraft. Modeling efforts are focused on developing improved physics-based parameterizations of momentum and sensible and latent heat fluxes. One objective is to develop techniques for the larger scale coupled ocean-air models.

The Convection and Moisture Experiment (CAMEX) (http://camex.msfc.nasa.gov/) is also directly linked to the Hurricane Landfall foci. It is a series of field research investigations sponsored by the Earth Science Enterprise of NASA. The fourth in the series was held in August and September of 2001 and focused on the study of tropical cyclone (hurricane) development, tracking, intensification, and landfalling impacts using NASA-funded aircraft and surface remote sensing instrumentation.

The Improvement of Microphysical PaRameterization through Observational Verification Experiment (IMPROVE) (http://improve.atmos.washington.edu/) was an observational and numerical modeling study to improve QPF in mesoscale models through the comprehensive observational verification of model-paramertized cloud precipitation microphysics.

Pacific Landfalling Jets experiment (PACJET) (http://www.etl.noaa.gov/programs/2002/pacjet/) is a series of field experiments to focus on improving short-term forecasts on the U.S. West Coast in landfalling winter storms emerging from the data-sparse North Pacific Ocean. Research goals are to test new observing strategies appropriate for West Coast storms, assimilate the specialized data for mesoscale forecasts, and gauge the effects. The Program also seeks to study physical processes leading to excessive rain and test parameterizations for them. PACJET seeks to use as much of the field experiment data in real time as possible in operational NWP and to create new forecast techniques based on observations and observing strategies. An evaluation aspect of the program seeks to assess the impact of field data on the issuance of warnings.

To address the QPF forecast problems for the extended range, The Hemispheric Observing system Research and Predictability Experiment (THORPEX) is being planned as a five- to ten-year international and interagency program of theoretical and phenomenological research, atmospheric observing system development and testing, societal impact research, and experimentation with data assimilation and numerical forecasting systems. The primary objective of THORPEX is to test the hypothesis that 2- to 10-day numerical forecasts of high-impact weather events can be significantly improved by adding high-quality observations in critical areas of the extra-tropical oceanic storm-tracks and other data-sparse remote areas, and that cost-effective new in situ observing systems can be developed to provide these required observations.

6. SUMMARY

Meeting the Nation's increasing needs for improved weather forecasts requires a coordinated program of research, development, and technology transfer. The USWRP has specific goals for improved QPF through improved observations, weather prediction models, and use of weather information. The USWRP is a partnership among science and operational governmental agencies, and the academic and commercial communities. The broad purpose of the Program is to increase the resiliency of the Nation to weather to ensure that the federal, state, and local governments, the private sector, and general public make well-informed and timely weather-sensitive decisions with respect to past, present, and future weather conditions.

The vulnerability of the United States to weather is increasing because rapid growth in the need for weather information has outpaced improvements in weather prediction technology. Forecasts of precipitation are unlikely to be improved without improved observations over data-sparse areas and our ability to assimilate them for numerical weather prediction and techniques. The lack of data or our inability to use existing data limit the accuracy and lead times of QPF. Through the cooperation, coordination, and support of eight Government agencies, and the academic and commercial communities, the Program has and will continue to implement highly focused projects that span atmospheric, oceanic, in situ, and remote sensing technologies for time scales from a few hours to two weeks. They are addressing the needs to observe weather and water in all of its phases to improve our understanding of temporal and spatial variability and their relationships to predictability.

7.0 ACKNOWLEDGMENTS

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