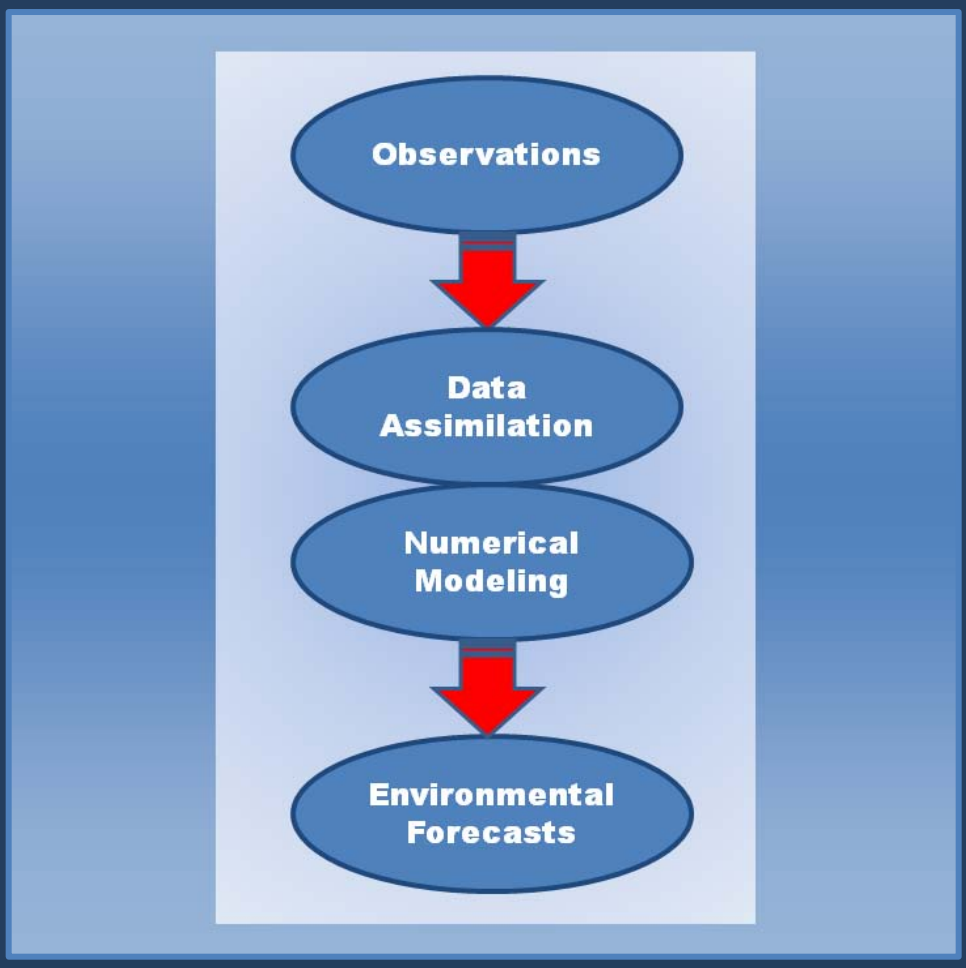
An Initial Inquiry into Meteorological Data Assimilation and Numerical Modeling Skills within the Federal Government



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Cover Image
Schematic representing the interconnections of surface observations, data assimilation, numerical modeling, and environmental forecasts (Credit: Joint Center for Satellite Data Assimilation)

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Foreword

The Nation requires credible and accurate weather, water, climate, and ocean information to minimize economic losses, enhance business and personal opportunities, save lives and property, and support national security. The Federal meteorological community's environmental prediction capability has proven to be critical to addressing these needs. It has been well documented that over the last two decades, noticeable improvements in numerical weather prediction (NWP) have occurred. In fact, the 72-hour forecasts of today are as accurate as the 36-hour forecasts were 10–20 years ago. This doubling of forecast skill has been attributed to advances in data assimilation and numerical modeling, which has directly contributed to advancing operational forecast and warning products and services. Furthermore, recent advances in coupled atmosphere-ocean modeling and data assimilation have brought weather and short-term climate forecasting (STCF) more into alignment.

With data assimilation and numerical modeling playing such a pivotal role in advancing NWP and STCF, it is clear that these skills are vitally important to our Nation. This report highlights the anecdotal evidence and perceptions from data assimilation/numerical modeling experts concerning the loss of skill in these areas and the potential impact that this skill loss might have on sustaining and advancing NWP and STCF capability.

I wish to thank my colleagues in the Federal meteorological community and academia, especially those listed in Appendix B who participated in recent OFCM-sponsored activities related to this report. Their expertise and input were integral to the content of this report.

//SIGNED//
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Federal Coordinator for Meteorological Services
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An Initial Inquiry into Meteorological Data Assimilation and Numerical Modeling Skills within the Federal Government

1 Introduction

The American Meteorological Society (AMS) defines *data assimilation* as "the combining of diverse data, possibly sampled at different times and intervals and different locations, into a unified and consistent description of a physical system, such as the state of the atmosphere" (AMS 2000, pg. 200). This unified and consistent description of the atmosphere provides the initial conditions needed to run numerical weather prediction (NWP) or coupled short-term climate (STCF) models. Given the interconnectedness between data assimilation and numerical modeling, the National Research Council (NRC) concluded that data assimilation and numerical modeling are critical, interdependent components of an atmospheric information system and called for their optimization (NRC 1998, pg. 30).

The focus of this paper is on the future availability of expertise in data assimilation and numerical modeling. The anecdotal evidence and expert judgments presented in Section 3 supports the following conclusions about this human resource:

- The decline in personnel with advanced skills in data assimilation and numerical modeling within the Federal government's meteorological community is expected to continue.
- The demand for scientists working in data assimilation and related activities is expected to increase.
- Improvements in academic training for data assimilation and numerical modeling are necessary to (1) meet the growing demand for professionals skilled in data assimilation and numerical modeling and (2) continue to advance the science and technology of data assimilation and numerical modeling, in order to meet societal demands for improved environmental forecast products and services.

2 User Needs: The Ultimate Driver for Improvement of Data Assimilation and Numerical Modeling

There is a growing recognition that operational forecast products and services are, and must continue to be, useful and beneficial to end-users. Timeliness and relevance to the decision processes of all kinds of users are system-level requirements on the entire forecast cycle. Information products and decision-support systems tailored to specific user needs provide part of the system solution, but timeliness and relevance also generate pressure "upstream" in the forecast cycle. Data assimilation must be more accurate and continue to exploit information in all available observations to ensure that the right analysis and forecast information can get into the hands of downstream users in time to make a difference. User needs and user responses to the

utility of the forecast information provided to them will generate feedback in the form of *societal drivers for weather and related environmental information. In short, user needs are the ultimate driver for improvement of data assimilation and numerical modeling.*

Data assimilation and numerical modeling play a key role in the Federal government's end-to-end operational atmospheric prediction cycle.[1] Operational meteorological centers such as the U.S. Navy Fleet Numerical Meteorology and Oceanography Center, the U.S. Air Force Weather Agency, and the U.S. Department of Commerce/National Oceanic and Atmospheric Administration (NOAA)/National Centers for Environmental Prediction (NCEP) rely on data assimilation and numerical modeling techniques to initialize and run the models that generate the predictions on which forecast products and services are based.

Not only is there a link between data assimilation/numerical modeling and operational forecast products and services but there is also a direct link between *improvements* in data assimilation/numerical modeling and *improvements* in the forecast products and services provided to end users. Improvements in data assimilation and numerical modeling underpin these improvements in forecast products and services. "Over the last two decades, there has been a noticeable improvement in numerical modeling and the forecasts which these models produce. For example, the 72-hour [500 h-Pa] forecasts of today are as accurate as the 36-hour forecasts were 10-20 years ago. This doubling (or better) of skill in the forecasts is observed for other forecast variables, such as precipitation" (Kalnay 2003, pg. 2). According to Vukicevic et al. (2004), "the major progress made over the last two decades in numerical weather prediction (NWP) … can be attributed to advances in three areas: [numerical] modeling, observing methods, and, very importantly, the improved utilization of observations, a new discipline known as data assimilation" (pg. 48).

3 Evidence of a Skills Shortage

3.1 2004 *Bulletin of the AMS* Article

A 2004 *Bulletin of the AMS* (*BAMS*) article entitled "The Need for a National Data Assimilation Education Program" sounded the initial alarm about an emerging shortage of data assimilation professionals. This early concern continues to be supported by the evidence outlined in Sections 3.2 through 3.6. In this seminal article, Vukicevic et al. (2004) noted that there is a "serious scarcity of young professionals" who have both an understanding of and experience in data assimilation (pg. 48). They noted that there is a "lack of formal education" in data assimilation, although they also recognized that several universities have "existing education efforts" (pg. 48). For example, several universities "include elective graduate-level courses that contain data assimilation topics." However, these courses "do not reach out to the wider pool of future professionals at the B.S., M.S. and Ph.D. levels required to support demands of the research and operational institutions for expertise in data assimilation" (Vukicevic et al. 2004, pg. 48). Because of the scarcity of young data assimilation professionals and the lack of formal data assimilation education, the authors stated that on-the-job training is required in both research and

[1] Within the context of this report, the end-to-end operational prediction cycle is defined as the sequence of events which includes forecast model input (which includes data assimilation), model integration (the numerical model run), and forecast model output (e.g., forecast fields of atmospheric variables).

operational settings. This type of training, the authors noted, requires "significant time" and "provides a "limited scope of experience about different [data assimilation] methods" (Vukicevic et al. 2004, pg. 48).

3.2 The OFCM-sponsored Interdepartmental Hurricane Conference

In spring 2004, attendees at the 58th OFCM-sponsored Interdepartmental Hurricane Conference (IHC) recommended that a comprehensive strategy be developed to guide interagency tropical cyclone research and development (R&D) over the next decade. That recommendation was subsequently supported by two key OFCM interdepartmental coordinating committees: (1) the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) and (2) the Federal Committee for Meteorological Services and Supporting Services. The 2007 OFCM-sponsored report entitled, "Interagency Strategic Research Plan for Tropical Cyclones: The Way Ahead," which resulted from this recommendation, included the following major finding with respect to the supply of skilled data assimilation and numerical modeling professionals:

> An area of extreme importance for improving tropical cyclone forecasts is advancing data assimilation and tropical cyclone [NWP] modeling systems. An important example of a deficiency in workforce development is that the United States is not producing enough new personnel with the education and training required for improving tropical cyclone forecasts via advanced data assimilation and numerical modeling systems. Resolving this deficiency in human resources will require strong backing (advocacy) by professional organizations (e.g., American Meteorological Society (AMS), American Geophysical Union, American Association for the Advancement of Science), as well as long-term commitment from Federal agencies (e.g., NSF, NOAA, NASA) and from the academic institutions that are the principal providers of degreed personnel employed by agencies that conduct the Nation's sophisticated NWP activities (pg. 3-65).

3.3 The AMS/OFCM-sponsored Data Assimilation Education Forum

As a result of the concern expressed by IHC participants and documented in the 2007 Strategic Research Plan, the OFCM conducted a Data Assimilation Education Forum in January 2008 as part of the 88th annual meeting of the AMS in New Orleans, Louisiana. Forum presenters stated that (1) the current cadre of Federal personnel skilled in data assimilation and numerical modeling techniques is decreasing due to those professionals leaving Federal service and (2) there is a scarcity of young professionals and scientists to replace those professionals who are leaving Federal service. They also stated that a shortage of personnel with programming and computing skills for high-end computers markedly contributes to this skills shortage. The forum presenters concluded that the Federal environmental modeling and prediction area is losing data assimilation and numerical modeling skills. They also concluded that, because of this decline in skilled personnel, progress in making improvements to environmental modeling and prediction could be hindered. These conclusions are consistent with those made in the 2004 *BAMS* article by Vukicevic et al.

3.4 2009 JCSDA Data Assimilation Forum

The Joint Center for Satellite Data Assimilation (JCSDA) is sponsored by NOAA, the National Aeronautics and Space Administration (NASA), the U.S Navy, and the U.S. Air Force. Its mission is to accelerate and improve the quantitative use of research and operational satellite data in weather, ocean, climate, and other environmental analysis and prediction systems.

In the summer of 2009, JCSDA held a special Colloquium on Data Assimilation. Participants in this colloquium echoed the conclusions offered by the presenters at the January 2008, OFCM-sponsored Data Assimilation Forum. They noted that "while the need for scientists working in satellite data assimilation and related activities is growing, there is no commensurate output of scientists with data assimilation backgrounds or training from universities" (Ohring et al. 2010, pg. 446). In fact, they continued, "no major academic program specifically … exposes new researchers to data assimilation expertise. As a small step [toward addressing the loss of skill in data assimilation, the JCSDA invited] … 20 data assimilation experts from the United States and Europe" to the colloquium. These experts "gave lectures in their respective areas of proficiency…[to 36 colloquium] attendees who expected to receive their Ph.D.'s prior to June 2010 or had no more than 2 years of postdoctoral experience" (Ohring et al. 2010, pg. 448).

3.5 2009 OFCM-Sponsored Mini-Workshops

In April and September 2009, the OFCM conducted two mini-workshops on addressing critical skills shortages in meteorology, including weather and climate science and technology. These mini-workshops were in response to an ICMSSR action item calling for "data collection and analysis of current and projected shortages in the [critical] skills required for the Federal meteorological services and supporting research enterprise" (M. Babcock 2008, personal communication). The mini-workshops involved thirteen subject matter experts (SMEs) representing such diverse meteorological areas as radar meteorology/radar engineering, space weather, satellite remote sensing, agroclimatology/agrometeorology, and marine meteorology.[2] The SMEs were asked to articulate the current and projected critical skills shortages in their subject areas that are needed to sustain the Federal meteorological workforce pipeline now and in the future. The loss of skills in data assimilation and numerical modeling was the capability gap most often cited by these experts. The SMEs also noted that if this capability gap is left unaddressed, there will be a reduction in progress toward improved forecast systems and services" (S. Lord 2009, personal communication).

To address the data assimilation and numerical modeling capability gap, the SMEs recommended (1) supplementing permanent staff (with data assimilation and numerical modeling expertise) to train new recruits (S. Lord 2009, personal communication), (2) supporting educational programs that "plant the seeds early in students' careers by exposing them to

[2] The list of subject areas which the mini-workshop SMEs represented includes: (1) radar meteorology/radar engineering, (2) environmental modeling and prediction, (3) space weather, (4) atmospheric transport and diffusion/boundary layer meteorology, (5) satellite remote sensing, (6) agroclimatology/agrometeorology, (7) wildland fire research, (8) marine meteorology, and (9) tropical cyclones (operations and research).

research issues, tools … and applications" (F. Marks 2009, personal communication), and (3) supporting the UCAR Visiting Scientist Programs[3] (S. Lord 2009, personal communication).

3.6 University Corporation for Atmospheric Research (UCAR) Assessment of NOAA/NCEP's Environmental Modeling Center (EMC)

Based on the findings of a 2009 UCAR assessment of the EMC, it appears that this major national center for development and operational transition of improved environmental modeling technology is challenged with a loss of data assimilation and numerical modeling skills. UCAR "was requested in November 2008 by the National Centers for Environmental Prediction (NCEP) to facilitate a thorough and thoughtful community review of the nine centers that comprise NCEP" (UCAR 2009, pg. 1). The EMC is one of these centers. UCAR's assessment of the EMC, as articulated in the document entitled, "2009 Community Review of the NCEP Environmental Modeling Center," found that "because the threat to life and property from weather, climate and space weather anomalies has never been higher and continues to rise, the products and services of NCEP must be of the highest quality, timeliness and impact" (UCAR 2009, pg. 3). Therefore, the "EMC is continuously challenged to stay at the cutting edge of science and technology in environmental prediction, including software frameworks, data assimilation [and] numerical techniques…" (UCAR 2009, pg. 20).

The review panel went on to note that the "EMC is now facing considerable turnover and the loss of significant experience and knowledge" (UCAR 2009, pg. 24). The panel found that addressing this experience and knowledge loss at EMC is impeded by "cumbersome personnel practices," the consequences of which "work against the superior achievement evident in competing organizations that today are best in the world" (UCAR 2009, pg. 24). Moreover, "physical access to and account authorization on NCEP's National Critical Systems is strictly limited due to export restrictions." Consequently, "contractors, especially those without U.S. citizenship, face a lengthy and difficult process, beyond EMC's control, to gain access to the computing resources they need" (UCAR 2009, pp. 27-28).

In short, UCAR found that the loss of data assimilation and numerical modeling skills, and the challenges to address that loss, adversely impact the EMC's ability to significantly advance its data assimilation and numerical modeling capability, which is the foundation of NOAA's operational warning and forecast products and services. To the extent that data assimilation and numerical modeling capability underpin NOAA's operational warning and forecast products and services, losing data assimilation and numerical modeling skills impedes improvements to products and services used and needed by society to save lives, reduce injuries, protect property, and reduce vulnerabilities of American citizens to the impacts of environmental events.

The EMC recognizes that "universities do not provide sufficient practical training and experience" (S. Lord 2009, personal communication) in data assimilation and numerical

[3] UCAR's Visiting Scientist Programs facilitate interaction between the Federal meteorological community and the next generation of scientists with unique and/or in-demand skills (such as data assimilation and numerical modeling).

modeling. To address this shortfall, EMC trains all incoming personnel. These new recruits serve as data assimilation and numerical modeling apprentices to more senior EMC scientists. However, it "takes 1–2 years before a new recruit becomes [a] fully functioning team member" (S. Lord 2009, personal communication). Thus, addressing the loss of data assimilation and numerical modeling skills takes time. There is no "quick fix."

4 Summary

This paper has presented the evidence and expert judgments supporting the following conclusions:

- The decline in personnel with advanced skills in data assimilation and numerical modeling within the Federal government's meteorological community is expected to continue.
- The demand for scientists working in data assimilation and related activities is expected to increase.
- Improvements in academic training for data assimilation and numerical modeling are necessary to (1) meet the growing demand for professionals skilled in data assimilation and numerical modeling and (2) continue to advance the science and technology of data assimilation and numerical modeling, in order to meet societal demands for improved environmental forecast products and services.

Together, these conclusions suggest that without addressing the expected shortage of data assimilation and numerical modeling professionals, progress toward making needed advances in data assimilation and numerical modeling will be impeded; in turn, this means advances in environmental prediction capability will be impeded as well as improvements to the operational forecast products and services.

Addressing a shortage of skilled data assimilation and numerical modeling professionals in the Federal service will take time and will require a concerted and coordinated effort on the part of the public, private, and academic sectors. Suggested approaches include increased opportunities for on-the-job training; support for visiting scientists/internship programs; changes to Federal rules and regulations to facilitate hiring and access to computer resources; and required, formal data assimilation and numerical modeling curricula at the undergraduate and graduate levels. Because of the importance of data assimilation and numerical modeling to the Federal government's operational environmental modeling and prediction activities, there is a need to closely monitor the progress in growing the workforce of skilled data assimilation and numerical modeling professionals needed to facilitate advances in NWP and climate. These advances ultimately lead to the production of forecast and warning products and services—products and services society needs to save lives, reduce injuries, protect property, and reduce vulnerabilities of American citizens to the impacts of environmental events.

Appendix A

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Appendix B

Participants in Recent OFCM-sponsored Activities Related to this Report

OFCM/AMS-sponsored 2008 "Data Assimilation Education Forum"	
Name	**Affiliation**
Dr. Stephen Lord	U.S. Department of Commerce (DOC)/ NOAA/NCEP/EMC; Camp Spring, MD
Ms. Patricia Phoebus	Naval Research Laboratory; Monterey, CA
Dr. Michele Rienecker	NASA/Global Modeling and Assimilation Office Greenbelt, MD
Dr. Jeffrey Anderson	NCAR; Boulder, CO
Dr. Richard Clark	Millersville University; Millersville, PA
Mr. Andrew Jones	Colorado State University; Fort Collins, CO
Dr. Eugenia Kalnay	University of Maryland; College Park, MD
2009 OFCM-sponsored Mini-workshops on "Addressing the Federal Community's Critical Skills Shortages Related to the Field of Meteorology (Weather and Climate)"	
Name	**Affiliation**
Dr. Walter Bach	DOD/U.S. Army Research Laboratory/Army Research Office; Research Triangle Park, NC
Dr. Thomas Bogdan	DOC/NOAA/NCEP/Space Weather Prediction Center; Boulder, CO
Dr. Russell Elsberry	DOD/U.S. Navy/Naval Post Graduate School; Monterey, CA
Mr. David Feit	DOC/NOAA/NCEP/Ocean Prediction Center; Camp Springs, MD
Mr. Douglas Forsyth	DOC/NOAA/National Severe Storms Laboratory/Radar Research and Development Division; Norman, OK
Mr. Elliott Jacks	DOC/NOAA/Office of Climate, Water and Weather Services/Fire and Public Weather Services Branch; Silver Spring, MD
Mr. Rich Jeffries	DOD/U.S. Navy/Commander, Naval Meteorology and Oceanography Command; Stennis Space Center, MS
Dr. Delores Knipp	DOD/U.S. Air Force/U.S. Air Force Academy; Colorado Springs, CO
Mr. Douglas LeComte	DOC/NOAA/NCEP/Climate Prediction Center; Camp Springs, MD
Dr. Frank Marks Jr.	DOC/NOAA/Atlantic Oceanographic and Meteorological Laboratory /Hurricane Research Division; Miami, FL
Dr. Jean Steiner	U.S. Department of Agriculture/Agricultural Research Service/Grazinglands Research Laboratory; El Reno, OK