RESEARCH TO OPERATIONS: *BRIDGING THE VALLEY OF DEATH*

INTRODUCTION

The National Research Council's *Crossing the Valley of Death* report highlighted the fact that as we move into the twenty-first century, the weather sensitive sectors of society continue to expand. They include energy generation, agriculture, forestry, fisheries, construction, tourism, transportation and navigation, public utilities, retail trade, finance, insurance and re-insurance, recreation, and real estate. The utility of timely and accurate weather information is diverse--it impacts military operations; commercial airline scheduling, operations, and flight planning; space launch scheduling; agriculture crop selection, planting, cultivation, and harvest timing; water resource management; and a wide range of commercial industries that schedule outdoor activities like construction and transportation. Information about extreme weather, especially that which puts life and property at risk, is essential for all sectors, but particularly for the emergency management and disaster relief communities. Both the public and private sectors have a growing demand for accurate information about and prediction of extreme weather, ocean, and climate events.

To meet this demand, the federal government organizes the nation's weather, ocean, and climate prediction responsibilities into two related areas. First, *operations* provide the basis for the production and dissemination of official forecasts and warnings. Additionally, operational services are divided between public sector predictions, both civilian and military, and private sector, value-added dissemination and prediction services. Second, *research, systems development, and technology development and implementation* are supported to improve the skill of weather forecasts. These activities are in some cases tightly coupled to operational efforts, while others have a weaker connection. Research is carried out in both federal laboratories and universities; however, in either case, it is largely supported by funding from the federal government.

PURPOSE

In the National Research Council's Report, *From Research to Operations in Weather Satellites and Numerical Weather Prediction--Crossing the Valley of Death*, it was stated that the term "Crossing the Valley of Death" is sometimes used in industry to describe the fundamental challenge of transitioning research and development (R&D) programs to operations. Operational implementation is frequently difficult, and, if done improperly, these transitions often result in "skeletons in Death Valley." The purpose of this article is to characterize the challenges ahead for the federal meteorological community with regard to the user demand for improved products and services and to propose an initial framework for transitioning successful research results to operations to meet that demand. The goal is to begin "building the bridge across the valley of death."

New Demands on the Forecasting Community

As a result of significant improvements in forecast capability achieved during the past decade, the demand for other specialized forecast applications--and the potential for new, substantial public benefits--has grown rapidly in recent years. The public has become accustomed to ever improving forecast products that are incorporated more frequently into daily decision-making. Weeklong forecasts, not viewed as credible two decades ago, are now an indispensable part of our planning processes. Other new products have also shown their worth. For example, solar ultraviolet radiation forecasts, developed by the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS), alert beach goers to the need for sun screen and other precautions against harmful exposure to the sun.

It will soon be possible to deliver several new forecast products that will, at first, be unfamiliar to the public, but will become as indispensable as our present weeklong weather forecasts. They include:

- *Hurricane forecasts*. Threats to life and property and the costly and disruptive nature of evacuations have resulted in demands for improved hurricane forecasts of storm track, intensity, and precipitation. Hurricane Floyd in September 1999 had an economic impact of approximately $2 billion, while causing the largest peacetime evacuation in United States history. Improved forecasts of hurricane track and intensity will reduce the necessity and attendant cost of over-warning.
- *Lightning forecasts*. While lightning poses one of the greatest threats to life and property in the United States, at the present time, only general forecasts of lightning likelihood are produced (e.g.,

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60 percent chance of thunderstorms). With the increasing accuracy of small-scale weather system forecasting and better understanding of the physics of lightning, it will soon be possible to provide specific forecasts of lightning occurrences (i.e., the probability of lightning strikes at specific times and places).

⏩ *Temperature forecasts*. Increasing concern over the consequences of energy production will result in demand for improved planning and operations in power production. Improved temperature forecasts will result in significant fuel-cost savings and a more efficient electric industry.

⏩ *Seasonal outlooks*. The energy industries will also benefit from the improvements in seasonal to interannual forecasting, increasing the demand for products and services on that time scale. It has been estimated that the accurate seasonal outlook prior to the 1997-98 El Niño event allowed utilities to realize savings of about $500 million.

⏩ *Air quality forecasts*. The strong link between air temperature and air quality and the associated negative impact of poor air quality on all aspects of human respiratory health are creating demands for a whole new suite of air quality forecasts.

⏩ *Operational space forecasts*. Space weather hazards are becoming increasingly important to the performance and reliability of space-borne and ground-based communications and observation systems. With the development of increasingly sophisticated technologies and the expansion of human activities into near-earth space, there will be an increasing need to forecast the changing fluxes of energetic particles, geomagnetic fluctuations, short wavelength solar radiation, and other upper atmosphere/near space conditions. Fortunately, an unprecedented armada of spacecraft is providing the required data, and there has been tremendous progress in research modeling of space weather phenomena. The OFCM-sponsored National Space Weather Program now seeks to implement operational space weather forecasting based on these advances.

⏩ *Water-related forecasts*. Clean, safe water is essential to human well-being. Recent research has uncovered some remarkable results that have significant implications for forecasting products. For instance, cholera outbreaks have been shown to be related to oceanic physical conditions and the resulting algal types and concentrations. Thus, we are now in a position to forecast the conditions leading to cholera outbreaks around the world. Other water-related forecasts dealing with water availability and quality will also be possible and will complement current drought and flood forecasts.

⏩ *Climate predictions*. The potential links between climate variability and ecosystem impacts (food, forage, timber, fiber, water) were enumerated in the first United States National Assessment of Climate Change Impacts. The linkage is expected to result in a growing demand for improved projections of future climate conditions.

The demand for new and diverse forecasting products will continue to grow and, with implementation, these expanded products will promote increased human safety and stimulate economic benefits in the United States and elsewhere. However, until current and future research advances are effectively incorporated into operational forecasts, the nation will not realize the attendant benefits of its research investment. It is important to understand the transition process and to ensure its efficient operation. Otherwise, impediments that may now exist will become more problematic in the future as a consequence of the anticipated, expanded demands on the nation's weather, ocean, and climate forecasting capability.

Improving the Research to Operations Transition Process

The challenge facing the federal meteorological community is to reduce the impediments that limit the efficient transfer of weather, ocean, and climate research findings into improved forecast capabilities. The operational forecast system is responsible for collecting and assembling data, and for using that data, in conjunction with models, to produce forecast products in a timely fashion. Consequently, the system encompasses many elements, from instruments on land, on and under the ocean surface, in the atmosphere, and in space, to the computational resources required to create, display, and disseminate the products. All elements of the system can be improved, and both the private sector and the academic research and development communities can contribute to that improvement.

To improve the transition process, strong interaction between the research and operational communities must exist. If the research community produces new science, one would expect opportunities to improve operations to result. Without effective transitions or a dialogue between research and operations about system performance, however, improvements to the skill of the operational system will be slow. Based on current research understanding, state-of-the-art sensors, and computers, the potential forecast skill is expected to be higher than that of the current operational system. Verification of forecast skill and ongoing dialogue about performance should guide operational practices toward improvement. Key issues for an operational system are to ensure that transitions do indeed result in improvements and that the effort required for transition is not overly disruptive. Feasibility must be demonstrated for the entire operational process, and the production of additional weather, ocean, and climate information must be accompanied by considerations of its dissemination, use, and impact.

If new research results have sufficient value, then a transition to operational status is desirable. The major challenges in accomplishing such a transition are institutional. Observations, modeling and prediction, and information dissemination to users should be tightly linked, and financial support of the operational system and transitioning new technologies and capabilities into operations requires long-term commitment. Also needed is the commitment for continued interaction with the research community to promote the opportunities to advance the state-of-the-art. The continued dialogue between the research and the operational communities is needed to guarantee that the latest techniques and current knowledge are available to transition for operational use. Through this dialogue, the operational services will be able to keep abreast of the latest research; assess ongoing development in observing, data assimilation, and modeling systems and determine how the information can be improved; and interface with the user community in the design of new useful products.

Guidelines for the Transition Process

The National Research Council's Board on Atmospheric Sciences and Climate (BASC) selected the following criteria as key to the effective transition of research to operations for the field of weather and climate prediction:

- A strong research program, including understanding the role of the operational user community in the broader context of the weather prediction system.
- A healthy infrastructure for transition. The forecasting system needs an observation, technology, and modeling capability that serves as a foundation for research and permits the demonstration of the potential for useful new products without drawing resources away from the operational forecast system. There is a need for a long-term commitment of adequate resources to maintain both research and operational programs. Mechanisms should be developed to enable continuous development and maintenance of state-of-the-art capabilities.
- Strong interface with the user community.
- International observation and data access partnerships.
- Continuous evaluation processes of each of the components of the weather prediction system as well as its subcomponents.

THE DOD MODEL

Within the DOD, there is a methodology (Figure 1-1) to provide a continuum of funding from basic research (6.1) to applied research (6.2) to advanced technology development (6.3) to demonstration and validation (6.4) to operational implementation (6.4/Operations and Maintenance (O&M)), and finally to operations (6.4/O&M).

Fundamental or basic research involves both broad exploration and user-needs driven research and normally results in a peer-reviewed publication, journal article, or technical report. As a result, a new operational capability could result from either a "research push" or an "operations pull" scenario. Applied research then takes promising basic research results from initial development through proof of concept. At that point, advanced technology development funds are used to complete the development effort which includes the scientific validation of the proof of concept. This effort should result in a decision/recommendation on whether or not to proceed with the transition process.

With the decision to transition, the demonstration and validation (DEM/VAL) phase begins. User needs/requirements are further refined, and initial budget, risk, and cost-benefit analyses are completed. The objective is to complete a thorough technical validation and demonstration of the capability, to include simulated implementation. Deliverables, as specified, may include source code, model transition plan, validation test report, and preliminary standard documentation.

Based on the results of the DEM/VAL, the decision is made on whether or not to proceed with operational implementation. With the decision to proceed, the capability is integrated into the operational system, and a comprehensive evaluation is conducted under operational conditions. The evaluation includes an initial operations check followed by a thorough test which is conducted in accordance with the operational test plan. The deliverables include the operational test report and the final and complete standard documentation.

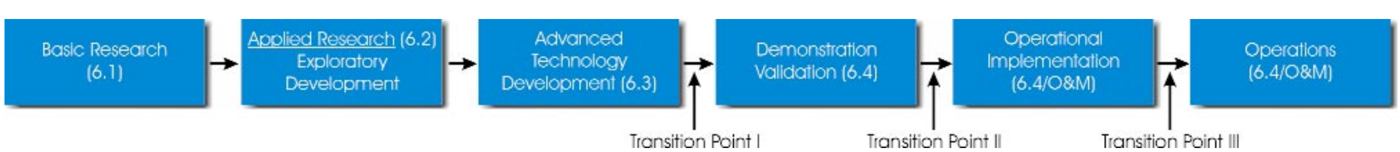

Figure 1-1. Department of Defense Transition Model.

The final point in the transition process is the decision to proceed with full implementation, which is made by the appropriate authority. At this point, the capability is fully integrated into the operational system. Validation, verification, upgrades, and fixes become ongoing operations and maintenance activities, which are part of the life-cycle support that is required until the capability is phased out. These activities are normally managed by the operational activity with the assistance of the developer.

The participants in the process include the researcher/developer, a technical validation panel to conduct the DEM/VAL in conjunction with the developer, the implementation panel to oversee the operational implementation and testing, and the operational activity which is the final user.

As an illustration, based on a requirement for tropical cyclone reconnaissance observations from the DOD's Joint Typhoon Warning Center (JTWC), the Marine Meteorology Division, Naval Research Laboratory, Monterey, California (NRL-MRY), developed the capability to provide reconnaissance information through the use of passive microwave (PMW) digital imagery. To date, NRL-MRY has completed the transition through demonstration and validation using 6.2 and 6.4 funding, and the capability is currently undergoing operational implementation at the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC), which is collocated with NRL-MRY. Full implementation into operations is scheduled for October 2001, assuming the operational testing and evaluation are successful.

NRL-MRY has provided the capability for near-real-time PMW imagery from both the Defense Meteorological Satellite Program's (DMSP) Special Sensor Microwave/Imager (SSM/I) and NASA's Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) to be available within 1-3 hours for tropical cyclones worldwide via the NRL-MRY tropical cyclone (TC) Internet Web page. The TC web page has significantly improved the availability and quality of PMW imagery/products for TC monitoring

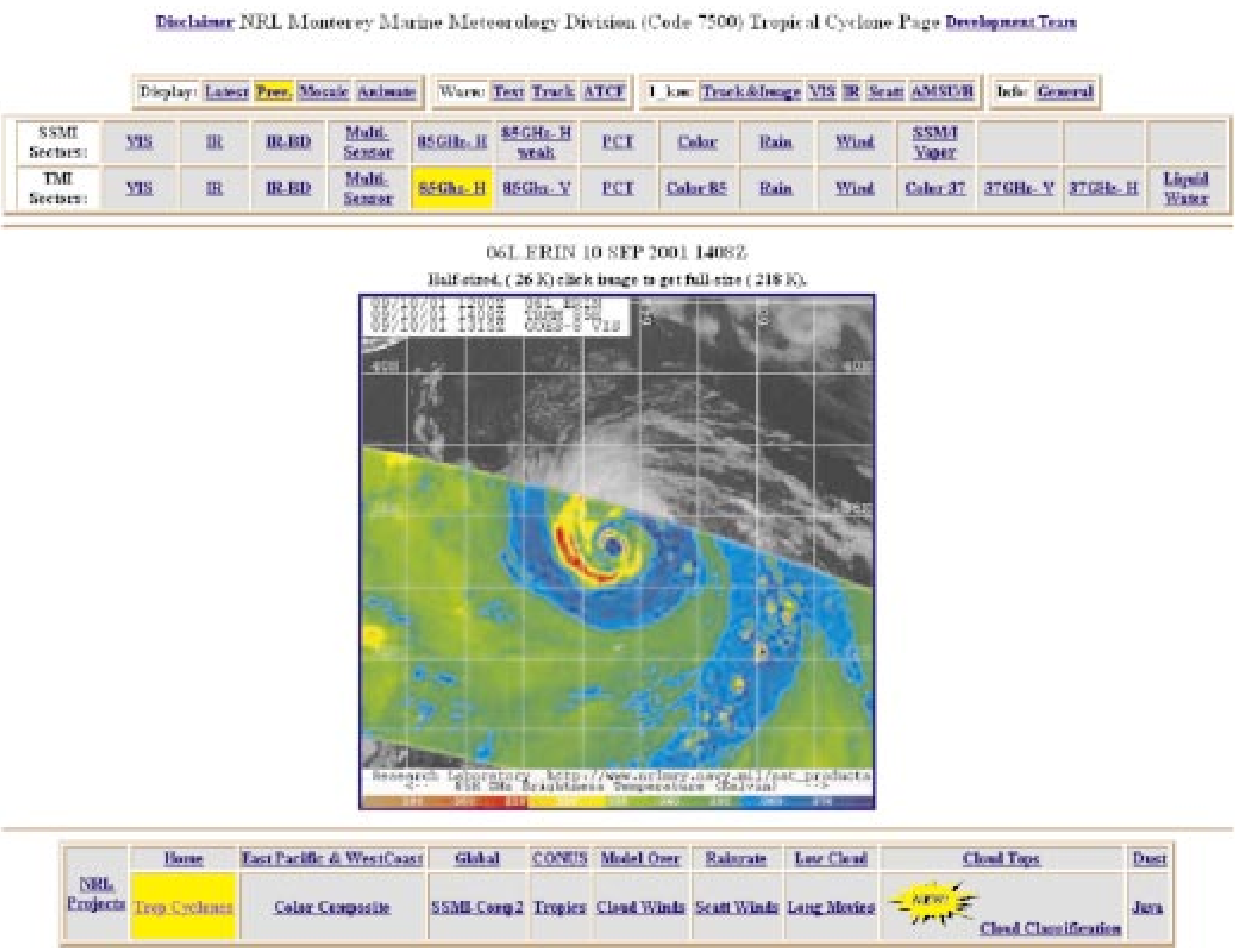

Figure 1-2. NRL-MRY web page for Satellite Products for Tropical Cyclone Reconnaissance.

around the globe. PMW data are basically a "poor-man's" radar since one can map the rainbands and TC organization not always seen in visible and infrared (IR) imagery (Figure 1-2). Distribution to a large audience of researchers, operational centers, and the general public has increased the awareness of how PMW data can be applied to increase the confidence in TC positioning and intensity estimates. The Internet has enabled NRL to carry out rapid prototyping with a superb feedback mechanism while users make suggestions for improved products and displays. While the reliability of the Internet was an early concern, the point has now been reached where JTWC and the NWS National Centers for Environmental Prediction's (NCEP) Tropical Prediction Center/National Hurricane Center (TPC/NHC) routinely access the NRL-MRY site (*kauai.nrlmry .navy.mil/sat-bin/tc_home*) in their search to assemble key storm characteristics. Once fully operational, FNMOC will maintain the Web site 24 hours-a-day and provide enhanced continuity. Figure 1-2 also illustrates the NRL-MRY TC web page to include the variety of products and capabilities that are made available to support the tropical cyclone forecast and warning effort.

The NRL-MRY demonstration via the Web has provided the operational user with a new tool to monitor TCs via PMW imagery. The learning process continues as the dataset expands, and new and improved sensors come online, which will nicely augment the existing dataset both temporally and with enhanced capabilities. Thus, the continued close working relationship between researchers and operators will provide future opportunities for TC applications, using passive microwave data in concert with collocated data that will increase the accuracy of TC location and intensity.

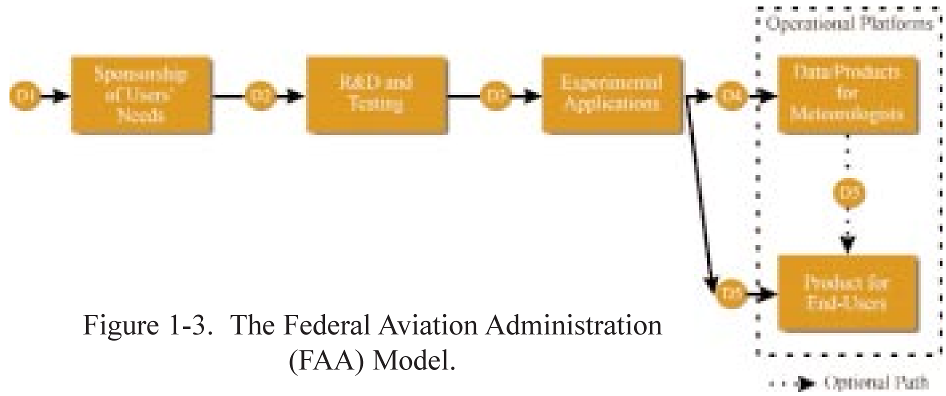

Figure 1-3. The Federal Aviation Administration (FAA) Model.

THE FAA MODEL

The FAA model is an "operations pull" approach; the goal is to accelerate the transfer of research and development into operations. The process begins with an analysis of user needs. Based on those needs and an initial concept of use (decision point 1), user advocacy or sponsorship is established. The user sponsor within the FAA (normally Air Traffic Services or Aviation Flight Standards Service) will assess the scientific and economic feasibility of producing the capability to meet specified performance metrics; i.e., the estimated risks of producing the capability or product, and then refine the concept of use/operations. The concept of use/operations includes, but is not limited to, the following: users' decisions requiring information, users' needs, performance metrics/thresholds, architecture, usage, training, accessibility, reliability, disclaimers, security, and a cost/benefit analysis.

With the decision to proceed (decision point 2), the research and development (R&D) project(s) needed to support the requirements are selected and funded. The deliverable is research-developed product or capability that is evaluated at decision point 3.

At decision point 3, the initial concept of use/operations and requirements are approved, risks are quantified, the initial scientific and technical review is conducted, the operations and maintenance budget is requested, the regulation and certification approval or approval plans is/are in place, and the acquisition process, if needed, is begun. Based on these inputs and the approval of the Aviation Weather Technology Transfer (AWTT) Board, the product/capability is released for experimental application and testing under an FAA test plan.

Once testing is successfully completed, the product/capability is released for operational use by the experts (meteorologists) (decision point 4), or it is released directly to the end user for operational use (decision point 5). At decision point 4, point 5, or both, the final concept of use/operations is approved, the scientific/technical review is completed and approved, the final regulation and certification approvals are in place, the budget is in place, and the acquisition process, if needed, is completed. The decision to release the product to the experts or directly to the end users or, as an optional path, through the experts to the end users rests with the AWTT Board.

The National Convective Weather Forecast (NCWF) was developed to satisfy both an operational meteorological and end-user requirement. Operational meteorologists will use the NCWF to prepare more concise convective hazard forecasts, and the end-users--pilots, airline dispatchers, and air traffic managers--will use the product to avoid flying into hazardous areas and to proactively help minimize schedule and flight disruptions.

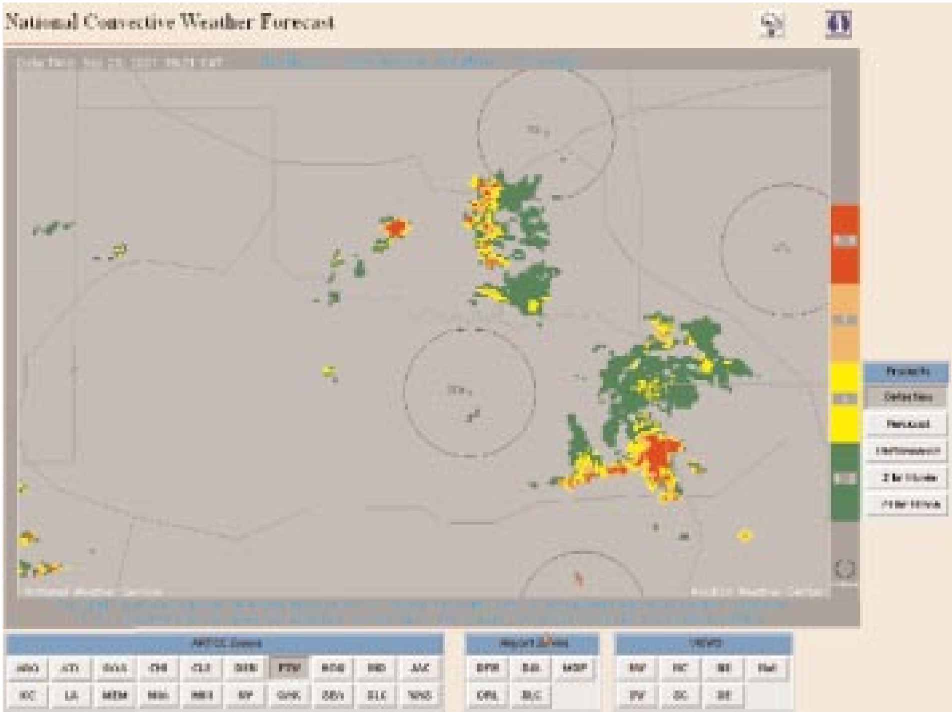

Figure 1-4. Example screenshot of the National Convective Weather Forecast.

Current research efforts have delivered the Stage I product, which is intended to complement current convective SIGnificant METeorological information (SIGMET) produced by the NWS NCEP's Aviation Weather Center (AWC). The NCWF is a 1-hour extrapolated forecast of the convection hazard detection field based on radar and lightning data (Figure 1-4). The convective SIGMETS are human-generated, 0-2 hour forecasts, issued every 60 minutes as simple polygon areas. In contrast, the Stage I NCWF is an automated, 1-hour forecast, issued every 5 minutes as a complex polygon area. The rather large areal extent of the convective SIGMET produces its trend to over-warn. The more compact and definitive NCWF, on the other hand, tends to under-warn new and growing storms, and over-warn dying storms. Stage I, however, is only the first step, and research is ongoing to extend the range of the forecast beyond 60 minutes and to improve the accuracy, especially during the growth and decay phases of convective storms.

To date, the implementation team has navigated the path from experimental application to operations. The final concept of use is approved, and the technical and regulatory reviews have been completed. The AWTT Board has approved the Stage I NCWF for implementation, and the NCWF will be implemented on the AWC production system in September 2001. In October 2001, *Air Transportation Operations Inspector's Handbook 8400.10* will be updated to authorize the operational use of the NCWF, and the air carriers will be notified. In January 2002, general aviation pilots will be formally notified through an update to the *Airman's Information Manual*.

THE COMPOSITE MODEL

If we take a systems approach to transitioning research to operations, we must begin with the definition phase--the user-needs analysis. The user could be an operational civilian or military meteorologist or oceanographer, or an end user like an emergency manager, aircraft pilot, or bus dispatcher. The user-needs analysis must identify what products or capabilities are needed to improve decision making and how good they must be to support the decision-making process; i.e., the performance metrics.

Similar to the FAA model, the user-needs analysis should generate an initial concept of operations, which includes at least the following: users' decisions requiring information, users' needs, performance metrics/thresholds, architecture, usage, training, security, and an initial cost/benefit and risk analysis. If research is needed to satisfy the user need for a new product or capability, then the scientific and economic feasibility of developing the product or capability should be assessed. Then, if development is feasible, a research plan should be developed.

We generally put research into two categories: basic or fundamental and applied. We also label the research infusion process as either "research push" or "operations pull." In the foreseeable future, we envision that both basic and applied research will be predominately user-needs driven--operations pull. We should, however, continue to encourage and fund broad exploration and scientific curiosity; i.e., basic research, because a research breakthrough could drive a significantly improved change in existing products and services--the classic research push.

The funded research effort, which should include close collaboration between the researchers and operations personnel, should evolve from basic research, if necessary, to applied research, then on to advanced technology development. The deliverable should be a research-grade product or capability which provides an initial proof-of-concept to meet the user need/requirement.

A technical oversight panel should conduct a scientific review of the technology and validate the initial concept of operations and proof-of-concept. The risks and benefits associated with implementing the new product or capability should be quantified, and the needed funding to proceed with the transition must be obtained. Plans should also include the operations and

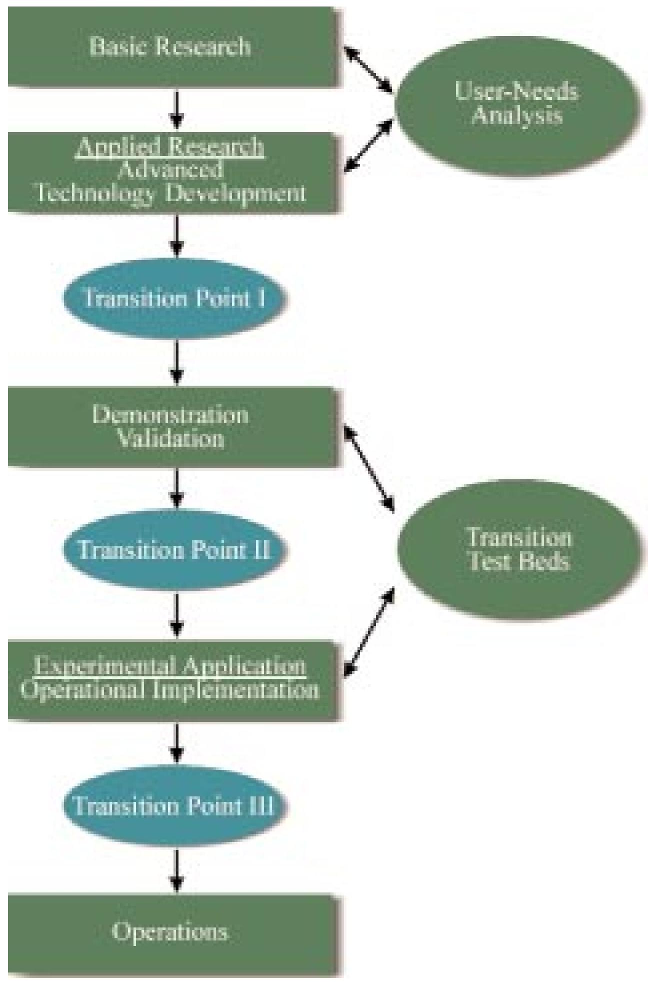

Figure 1-5. A Composite Model for Transitioning Research to Operations.

maintenance budget request to support operational implementation and life-cycle support once full operational capability is achieved. Based on the recommendation of the panel, demonstration and validation will proceed.

A technical validation panel of users, developers, and product managers should work together to validate and demonstrate the technical goodness of the product/capability, to include simulated implementation. The evaluation should include performance-testing and operational metrics initially documented in the concept of operations and refined by the panel. The deliverables should be a product or capability ready for operational implementation, together with preliminary standard documentation, anticipated training needs, and the validation test report. NOAA and the United States Weather Research Program (USWRP) have proposed a national testbed configuration (shown in Figure 1-6) which would significantly enhance the federal meteorological community's ability to conduct both demonstration and validation, and operational implementation, and the community should actively support its development.

With the decision of the technical oversight panel to proceed, experimental application or operational implementation is begun. The product or capability is integrated into the operational system or an optional testbed which could run in parallel with the operational system, and a comprehensive evaluation is conducted under operational conditions. The evaluation should include an initial operations check followed by a thorough test which is conducted in accordance with an operational test plan. The deliverables include the operational test report and complete standard documentation and training package to support the product/capability.

Based on the results of the operational test and the decision of the appropriate authority, the product or capability would be released for use by operational meteorologists or oceanographers or directly to the end-user or, as an optional path, through the operational users to the end users. At this point, the final concept of operations and scientific/technical review have been reviewed and approved, user requirements have been validated, and the operations and maintenance budget should be in place. Future upgrades and fixes, and ongoing verification and validation will be part of the life-cycle support to the new operational product or capability.

SUMMARY

In the "Crossing the Valley of Death" report, it was concluded that successful research-to-operations transitions require four things:

- An understanding of the importance (and risks) of the transition.
- Development and maintenance of appropriate transition plans.
- Adequate resource provision.
- Continuous feedback (in both directions) between the research and operational activities.

We would add to those conditions a clear understanding of user needs/requirements and administrative and technical oversight by the transition decision-makers throughout the process. Also, the testbed concept proposed by NOAA and the USWRP has tremendous potential to improve and facilitate the transition process and should be aggressively pursued.

The next step is to begin testing the framework, which should start with the development of a needs analysis for each user group within or served by the federal meteorological community.

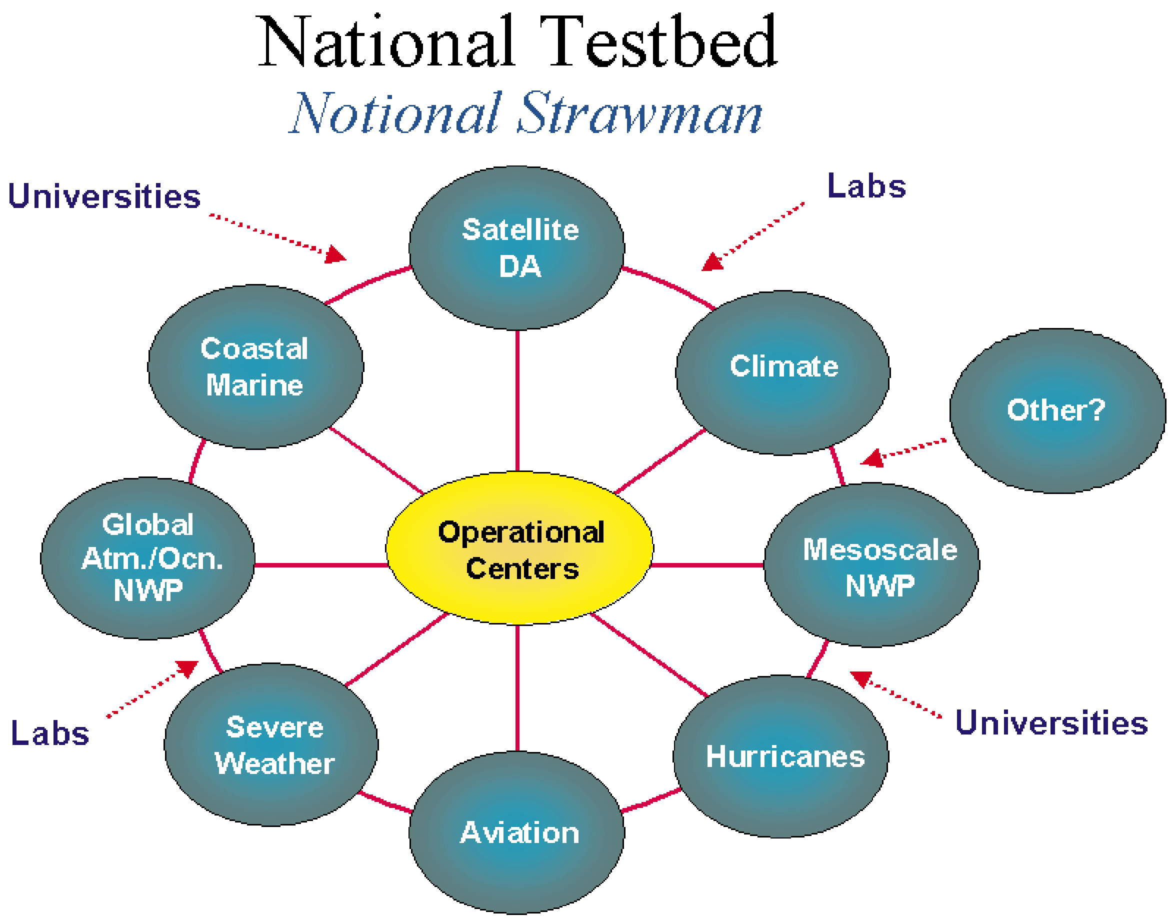

Figure 1-6. Proposed National Testbed Configuration.

The FAA has a head start with the aviation community, but that's only the tip of the iceberg. The demands on our community for improved products and services are only going to increase, and we need to have a process in place, plus the commitment of sufficient funding and resources, to meet those legitimate demands.

ACKNOWLEDGMENTS:

Portions of the article were excerpted from the National Research Council's report, *From Research to Operations in Weather Satellites and Numerical Weather Prediction--Crossing the Valley of Death*, 2000. Other references include Hawkins, J.D., T.F. Lee, J. Turk, C. Sampson, J. Kent, and K. Richardson, 2001: *Real-Time Internet Distribution of Satellite Products for Tropical Cyclone Reconnaissance*. Bull. Amer. Metero. Soc., 82, 567-578, and presentations given by the Navy's Naval Meteorology and Oceanography Command, the Federal Aviation Administration's Air Traffic System Requirements Service, and Air Traffic Systems Development, and the United States Weather Research Program.