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Admiral Watkins, Commissioners,

I would like to thank you for inviting me to address one of the most challenging ocean issues facing us all today - data management. We live in a pivotal time for the advancement of oceanography. As our data acquisition platforms and sensors improve, our ability to collect environmental data increases at an exponential rate; as the capabilities of our customers grow, the performance of their systems is increasingly dependent on environmental data of even greater resolution and more rapid refresh rate. But our ability to assimilate and apply these data, and disseminate the associated products must keep pace with - and anticipate - these increased needs of the customers. We must deal effectively and efficiently with the increasing data flow that supports these needs. **We cannot meet 21st century data needs with a 20th century approach.**

Naval Meteorology and Oceanography (METOC) is successfully meeting this challenge. We have collected, processed, and distributed ocean data and derived tailored products worldwide for a variety of users for over 150 years, and will continue to do so. Our success was recognized in the 1995 report of the MEDEA Task Force - a team of world renowned environmental scientists - who said they were "greatly impressed not only with the unique environmental data sets [resident at the Naval Oceanographic Office], but also with the general scientific quality of the work and the processes of data collection, analysis, and product generation."

Today, I would like to share with the Commission some of the critical elements of Navy METOC data management that have made the program work, and work well. It is our hope that some facets of our program can be of benefit to you as a model as you develop an improved ocean data management governance framework for our nation. I would like to offer two over-arching themes relevant to the issue of ocean data management:

(1) The U.S. Navy uses a set of operational principles governing data management strategies. These principles emphasize that Navy data management is part of a greater overall process where we address the customers' needs, effectively utilize the capabilities of data acquisition, analysis, and fusion centers, and maintain a strong link with the research and development (R&D) community while robustly supporting our operational fleet at sea.

(2) The U.S. Navy has mechanisms and infrastructure to meet current data management needs, and plans to exploit fully the continued growth in volume and diversity of data (especially remotely sensed data) in order to meet future operational needs.

These two fundamental themes lead to a set of recommendations associated with our national imperatives in ocean policy - recommendations for extracting, translating, modifying, and expanding Navy METOC principles into a coherent national data management governance structure, and recommendations for establishing observational systems in a fully integrated manner.

OPERATIONAL PRINCIPLES

Navy METOC data management relies on certain operational principles that are robust, flexible, and well-tested. The operational principles that are key to Navy METOC management include the utilization of a rigorous requirements process, a production system organized by capabilities, and the efficient delivery of products to diverse and widely dispersed customers.

Rigorous requirements process

Navy's requirements process is a proactive rather than reactive approach to filling operational needs (termed "requirements") by acquiring and fully utilizing technology, tools, and resources to produce timely and relevant products for operational use. Because there are always greater operational needs than available resources, the requirements process also includes mechanisms for prioritizing needs and determining what types of resources (*e.g.* research, developmental, operational) would most appropriately meet these needs. Though I will focus my comments primarily on the Navy requirements process, a similar process could work equally well for any kind of operation, such as resource management at a state or regional level, or coastal hazard mitigation.

The first element of a solid requirements process is the formal accommodation of feedback by all stakeholders, including researchers, developers, evaluators and operators (i.e. users), in the process. Within the Navy METOC community, the Oceanographer of the Navy has the lead responsibility for funding Navy METOC activities and encouraging feedback. We help the **users** of oceanographic products - the warfighters - refine an unfulfilled operational need (for example, the need to be able to route a battlegroup to a crisis location) into a specific requirement (for example, the requirement to predict sea state over those sea lanes for an extended period), prioritize it together with other requirements, identify potential solutions, help translate those solutions into any necessary and relevant scientific objectives, oversee the full transition of programs from research to operational implementation, and, finally, ensure the lifecycle maintenance of the operational capability. This process is most successful when an Integrated Product Team is formed to see the requirement through from inception to solution. Such a team consists of knowledgeable, engaged, and empowered members of the scientific community, industry representatives, operational meteorologists and oceanographers, data management professionals, and the ultimate users of the final products. The Oceanographer of the Navy maintains a close relationship with **researchers** through informal contacts and formal membership on review and coordination panels. The Office of Naval Research (ONR) ensures that research is tailored to address the requirement, provides options for Navy acquisition and fleet users, and maintains a bridge to the academic and larger technical community. As science and technology products mature, increasingly intensive discussions between ONR and the Oceanographer's office ensue, and formal plans for transition (*e.g.* "roadmaps" with clear exit criteria) are developed collaboratively. The overall goal is to transition R&D in a timely and affordable fashion, and to provide regular and meaningful communication between all stakeholders in the transition process. The transition of a product from R&D is then managed by a **developer** who understands the users' needs, the language of the R&D community, and the capabilities and limitations of industry. The recipients of newly developed technologies are frequently one of the two Navy METOC Production Centers that many of you have previously visited - the Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California, and the Naval Oceanographic Office (NAVOCEANO) at Stennis Space Center, Mississippi.

It is important to note that this formal requirements process is not limited in application to a single agency or mission. The National Polar-orbiting Operational Environmental Satellite System (NPOESS) demonstrates how the requirements process is employed today in a multi-agency environment. NPOESS is a cooperative program merging Department of Defense (DoD), Department of Commerce (DoC), and National Aeronautics and Space Administration (NASA) polar-orbiting environmental satellites into a single national asset that benefits military, commercial, and civil operations. User requirements are melded into a single document, which pulls together and prioritizes multi-agency needs into a single, cost-effective acquisition program. For example, this program allowed Navy to blend its requirement for slant range visibility with Air Force cloud ceiling needs into the same specification for atmospheric profile measurements. Other specific user requirements for new space sensors to measure environmental parameters (such as amount of sea ice coverage and concentrations of volcanic ash, suspended sand, and other battlefield particulates) have also been integrated into this single NPOESS requirements document.

The second element of a good requirements process is a formal full-product review process, to ensure that products under development will match user needs. The review process is conducted at a variety of levels, such as METOC community program reviews, and annual conferences sponsored by the Navy's fleet commanders. Fleet-level conferences ensure that the needs of the customers are being met and help to control the technical, programmatic, and operational suitability of the proposed solutions under development. Milestone review is inherent to the Navy's **"spiral development"** acquisition model, where the developer will "build a little, test a little, field a little," all in close coordination with stakeholders. Spiral development provides temporary versions of the product to the users, taking advantage of the latest in technology and allowing the users to start meeting their immediate needs more quickly. At the same time, developers receive timely feedback on evolving user needs.

In the case of atmospheric and oceanographic databases and models, a detailed verification and validation process is conducted that includes extensive peer review by independent and objective subject matter experts before the database or model may be accredited and accepted into a master library for fleet use. Verification and validation of new global and mesoscale models for ocean dynamics and acoustic propagation are formalized by the peer review authority inherent in the Administrative Model Oversight Panel, the body charged with overseeing the transition from exploratory development to operations. The Panel ensures that models used by the fleet are technically the most superior available and are responsive to fully-vetted operational requirements. It also establishes formal guidelines for management of model configuration. After verification and validation is complete, models, databases, or algorithms may be accredited by the Oceanographer of the Navy for storage in the Navy-wide Oceanographic and Atmospheric Master Library as a core product or "Navy Standard." NAVOCEANO then performs quality assurance tests before final library approval, to ensure that the products "perform as advertised" and comply with fleet requirements.

The third element of a good requirements process is the incorporation of well-defined (and mutually understood) metrics for system design and performance. The Oceanographer of the Navy's 2000 Strategy for Research & Development stipulates a prioritized set of metrics, including such elements as operational relevance, multi-mission applicability, and, of course, technical feasibility. Essentially, the success of the end product or system is ultimately determined by whether it can perform satisfactorily within those defined metrics and thus meet the user requirement.

For example, performance of the Landing Craft Air Cushioned Vehicles (LCACs) depends on accurate wave height forecasts. LCACs are used for transporting personnel, weapons, and cargo of the Marine Air-Ground Task Force. Conventional systems only allow for amphibious landings on 15% of the world's coastlines. LCACs enable our forces to land on 70% of the world's coastlines. Deployment of these craft, however, is limited by wave height, due to their high speeds and the fan-like mechanism by which they are propelled. If the wave height, surf, wind and atmosphere pressure and surge prediction models incorporated into the Distributed Integrated Ocean Prediction System do not operate within specific design metrics, boats, equipment, and human life will be lost during missions. This is a clear and unambiguous operational metric.

Production system organized by capabilities – data acquisition, assimilation, archiving, and fusion

The Navy's acquiring, assimilating, archiving, and fusing of data is a multi-faceted production system organized by capabilities. The process includes a wide range of platforms, sensors, computational hardware and software, storage methods, and data communications.

The Commander, Naval Meteorology and Oceanography Command (CNMOC) at Stennis Space, Mississippi, operates a variety of platforms and sensors to **acquire** METOC data. NAVOCEANO maintains a fleet of survey ships and unmanned underwater vehicles (as well as drifting buoys) to collect military oceanographic, geophysical, and hydrographic data in, on, and above all the oceans, in support of well-established and prioritized requirements of the joint, United States and combined allied forces combatant commanders. These vessels also have the capability to launch, recover, and tow scientific packages, both tethered and autonomous (autonomous underwater vehicles). As you are all aware, data acquisition is expensive; the cost of operating a T-AGS-60 ship for a day is approximately $65,000, and the data collected cost approximately $45 per minute or $430 per gigabyte. This means we must do it right the first time. Also, since re-survey of an area may not be possible, quality control of these data is crucial.

As data acquisition from satellites becomes increasingly important, new sensors are being developed for operational use. For example the imminent launch of remote sensors for passive microwave polarimetry will allow us to measure wind speed and direction over the ocean under a wide range of atmospheric conditions. The Naval Research Laboratory, NOAA CoastWatch, and Louisiana State University are working together to build a database to calibrate satellite products derived from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Moderate Resolution Imaging Spectroradiometer (MODIS), Terra, and Aqua. These products, such as chlorophyll and ocean optical properties of absorption and backscattering, provide a comprehensive picture of the real-time littoral environment and establish new capabilities for monitoring the changing coastal environment. Applications of remote sensing technologies are expected to expand even more and eventually incorporate such elements as bathymetry from lasers aboard unmanned aerial vehicles as well as declassified National Technical Means satellite imagery.

After data are acquired, they can either be **assimilated** into a product, pulling together similar types of data from different sources, or **archived** for future use. CNMOC's two world-class centers of expertise, FNMOC and NAVOCEANO, assimilate and archive Navy's ocean data. NAVOCEANO has the world's largest oceanographic supercomputing facility and the world's largest oceanographic library. NAVOCEANO's Modular Ocean Data Assimilation System (MODAS) is used to produce a wide variety of ocean products for the fleet, assimilating approximately 800,000 observations a day – including remotely-sensed sea surface temperature and sea surface height, as well as *in situ* observations from buoys, drifters, and ships. The Master Ocean Observation Data Set is maintained by NAVOCEANO as a living data base, occupying 122 gigabytes online and growing at a rate of 2.6 megabytes per day. Survey vessels collect more than 150 gigabytes of acoustic and oceanographic parameters a day, meaning that the Survey Operations Center is processing and archiving more than 313 terabytes of data per year, or about 2 megabytes per dollar spent - roughly the same as the purchase price of just the storage capability of a CompactFlash memory used in a family digital camera. FNMOC produces numerical atmospheric and oceanographic models for global and regional-scale meteorological and oceanographic prediction. In order to perform this function, the supercomputer assimilates over 5.5 million observations collected daily, including remotely sensed sea surface temperatures, sea surface heights, soundings, geostationary winds, scatterometer winds, ocean features, and *in situ* data such as those obtained from radiosondes, aircraft, and ships.

Data **fusion** is the last, critical step in production. Whereas data assimilation pulls together similar types of data, Navy METOC's data fusion capability merges different, but complementary data types. Of course, bringing together disparate data sets means that the data sets must be in the same geospatial frame of reference. This commonality is provided by the "4-D cube" concept. This theoretical model visualizes the battlespace in three spatial dimensions, and the fourth dimension – time, with a universally agreed-upon datum for referencing and "overlaying" additional layers of relevant data and information. NAVOCEANO's Data Fusion Center at the Warfighting Support Center (WSC) at Stennis Space specializes in data fusion. Their mission is to provide specialized near real-time oceanographic products and services to characterize the ocean to tell the customer what the ocean environment is like from the mesoscale to the beach scale.

As an example of the application of data fusion, consider the scenario of Navy Special Forces (SEALS) performing a mission in an area totally unfamiliar to them. The WSC will work with this customer to precisely define their needs – such as water depth, location of navigation aids, velocity of currents, beach profile, probability of bioluminescence, navigability of rivers, and location of land features such as buildings, fences and pier facilities. The WSC then tailors products to the specific needs of the customer. By incorporating data sets such as satellite imagery, digital nautical charts, and current data into a single useful product or set of products, the SEALS will be armed with the best environmental information available to allow them to complete their mission. Navy's regional centers located globally are developing a capacity to augment the WSC in support of their customers in this way.

Coordinated data fusion capabilities could prove useful in virtually all applications, military and civil. For instance, in the case of coastal zone management, satellite data combined with current velocities and data sets from *in situ* coastal and riverine platforms, could provide a resource manager with the most likely dispersion plume for a sewage outfall under dynamic conditions. Fused products could also assist in determining beach closures for public safety, help predict coastal erosion, assist with fisheries management decisions, and predict the spread of harmful algal blooms.

Summarizing, then, the Navy's data management system is quite diverse and multi-faceted. We acquire data using manned, drifting, fixed and autonomous platforms, under, in, and above the ocean. We assimilate those data into complex, computationally-intensive models. We blend and fuse the data and build products for multiple users (often on tactically-relevant timescales).

Efficient delivery of products

The next challenge is to ensure delivery of the **right product**, to the **right user** at the **right time**. Our customers are diverse, and dispersed around the world, from the North Pole to the southern oceans. The more remote the users, the more important METOC is to them. Efficient product delivery is essential to the success of every mission on every remote point of the globe. Often, the survival of our customers depends on our ability to support them. Out of necessity our distribution mechanisms are robust, well-tested, able to meet many needs, redundant to allow a back-up capability, and specifically designed to support the mission. Vital to successful product delivery is an intelligent communications architecture.

Through a predominantly web-based product dissemination architecture, we balance a "smart pull" system (where the customer can access products of their choice), with a "push" of tailored products. The architecture for the push/pull includes our two production centers (FNMOC and NAVOCEANO), six regional centers, and numerous smaller fixed and mobile ground sites, as well as any United States Navy ship on duty around the globe. Each of these facets of our organization has a unique push/pull capability defined by the needs of their customers. The power of this system is in its ability to constantly evolve as capabilities improve and customers' needs change. For example, "My Weather Map," a web-enabled program from FNMOC, is a tailored product that is pushed through the web and pulled off the server by the users. Products pushed are in response to the needs of the users. Navy recognizes, and is working to exploit the fact, that industry has developed these similar capabilities in a more general sense, such as the delivery of tailored, regional weather forecasts to members of the public. In fact, for the broader set of potential users of oceanographic products, industry may thus serve as a product broker, suggesting the possibility of a burgeoning commercial sector.

MEETING CURRENT AND FUTURE DATA MANAGEMENT NEEDS

It is inevitable that operational demands for new products, and for products with higher resolution, will increase in the future, if for no other reason than the availability of high quality oceanographic data. If we look back just ten years, our ability to use our operational sonars and radars to observe and measure the ocean and atmosphere was nearly non-existent. Today, our ability to use tactical shipboard, submarine-based, and airborne sensors to collect METOC data is increasing at an amazing pace. It is also a certainty that remote sensing capabilities and use of tactical sensors will become increasingly important in the future.

Today, nearly every METOC product we disseminate incorporates satellite data, and more than 95% of Navy METOC data are derived from satellites. We expect that remotely sensed data stream to increase more than four-thousand-fold between now and 2012 from NPOESS data delivery to NAVO and FNMOC. In years to come, we will see the Navy's utilization of remotely sensed data grow for four additional fundamental reasons:

- New sensors will offer users the means of measuring parameters previously undetectable with remote sensing (*e.g.* sea surface salinity, passive microwave polarimetry);
- New applications will be developed for existing data streams, such as those from national technical means remote sensors;
- Training and experience with remotely sensed data will be improved, to the extent that the ability to tap into remotely sensed data streams will be a common skill among apprentice forecasters, for example;
- Remotely sensed data will become increasingly integrated into networked systems of environmental observations.

The burgeoning stream of oceanographic data will not be limited to the growth in availability of military or remotely sensed data. Recently, Navy and NOAA commissioned an informal assessment of the expected data streams that will evolve from the Ocean.US recommendations set forth in "An Integrated and Sustained Ocean Observing System (ISOOS) for the United States: Design and Implementation." Data flow will increase on the order of megabytes per day from direct observation systems (*e.g.* moored and drifting buoys), ship observations systems (including National Ocean Service charting activities), and non-NPOESS remote sensing systems (also to include high frequency coastal radars). The expected annual data flow for ISOOS alone will be approximately 3 terabytes to start, increasing to 100 terabytes by 2010. With the inclusion of the large cabled observatories, currently in planning (*e.g.* NEPTUNE), that number could swell by a factor of 15-20.

With these trends in mind, Navy is gearing up to handle tremendous future growth in volume and diversity of data streams. We have the capability today to fuse and assimilate disparate data from commercial and military remote and *in situ* sensors - our investments will ensure that capability keeps pace with the increasing quantity and variety of tomorrow's data sets.

Having defined the Navy's system for data management, with some emphasis on the expected trends for future data acquisition and applications, I believe there are some excellent lessons learned. Our experience with oceanographic data has led us to a set of recommendations for potential application to a broader set of national ocean issues.

RECOMMENDATIONS:

We need an effective data management governance framework. Authority for such a framework exists today in the National Oceanographic Partnership Program's National Ocean Research Leadership Council (NORLC). I believe that it is appropriate for NORLC, via its Ocean.US office, to design the governance structure for an Integrated Sustained Ocean Observing System (ISOOS), because the very agencies that make up the NORLC will be the primary Federal operation and coordination entities of the ISOOS. This is a challenging, but not insurmountable, task. Dr. Rita Colwell, Chair of the NORLC and Director of the National Science Foundation, stated in her testimony before this Commission at the Northeast Regional Meeting in July that "Implementing the Observing System will test the grit of the NORLC. Determining how best to budget for, and manage, an effort of this magnitude on an interagency basis is new territory that will require a new way of thinking. We are presently looking at a number of interagency and international models as we evaluate options for budgeting and management."

We also need a data management infrastructure that integrates all appropriate systems, platforms, and sensors. This coordinated national strategy for ocean observation integration should include expansion of NPOESS's and NOPP's authority. I echo the recommendations of Dr. Ron McPherson, the Director of the American Meteorological Society, who testified before this Commission at the Great Lakes Regional Meeting in September that an integrated global observing system for monitoring the state of the coupled ocean-atmosphere-land system should be built, by extending the existing system of *in situ* and remotely sensed observations of the oceans, atmosphere, rivers, streams, and lakes, ice-covered areas, and land surfaces, to be more comprehensive than at present. I believe that the Navy, with its management and assimilation capabilities of disparate data, and institutionalized process of responding to user needs through its requirements process and other operational principles, can serve as a model for the management of ocean data at the national level. This is consistent with the 1995 report of the MEDEA task force, which suggested that an exploitation center should be established at the Stennis Space Center to "allow access to most classified and unclassified Naval Oceanographic Office databases, models, and product synthesis capabilities to appropriately cleared and United States government-sponsored civilian scientists."

In your mid-term report, you recognized that, with modern technological advances, we have the opportunity to develop truly integrated ocean and coastal observing and prediction systems that are more sophisticated than ever before. I agree. But without an effective data management governance framework and infrastructure, our ocean knowledge will still progress too slowly, with far too much redundancy, duplication of effort, and waste of precious resources.