Overview of Operational Ocean Forecasting in the U.S. Navy: Past, Present & Future

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Introduction

"The future ain't what it used to be." Famous words from philosopher and National Baseball Hall of Famer, Yogi Berra. While his words are applicable in describing most situations, they are particularly relevant to this topic—future operational ocean forecasting in the U.S. Navy. To appreciate Berra's quote in this context, it is important to understand that operational oceanographic forecasting is a compromise between the scientifically possible and the operationally necessary and practical. Research and Development (R&D) advances provide the push of higher resolution and more sophisticated, physics-based, numerical models and prediction techniques. Meanwhile, the operational pull for accurate, rapid, and long-range, oceanographic products, based firmly on sound Navy requirements, is constrained by the personnel, communications capabilities, and computational resources available to accomplish the mission. This tension between R&D and operations likewise arises in the transitions of ocean observation systems, ocean products, and visualization systems. Numerous factors such as mission changes or technological breakthroughs can impact R&D programs and operational plans over time. Note that predictions made 10 years ago (Peloquin, 1992), regarding future operational ocean forecasts, could not anticipate the breadth of today's web connectivity and distributed computing.

This article first presents an overview of the current Department of Defense's (DOD), U.S. Navy's, and Oceanographer of the Navy's missions and requirements, to provide the reader with some rationale behind today's plans for operational oceanographic support. Next, a review of the support since 1992 up to the present provides the reader with an understanding of the enormous R&D and operational successes during the last ten years. Finally, a discussion of the future operational capabilities is provided. Each subsequent section revolves around the central issues that concern operational oceanographic prediction: computers and communication; ocean data assimilation and modeling techniques; and ocean applications.

What Drives the Navy's Mission?

The future employment of the nation's armed forces is conceptually described in documents such as the "National Military Strategy[1]," "Joint Vision 2010[2]," "Joint Vision 2020[3]," and, most recently, the second edition of the Chief of Naval Operation's "Navy Strategic Planning Guidance With Long Range Planning Objectives[4]." These documents prioritize a set of capabilities that determine DOD's planning and budget process. The National Military Strategy contains three components for how forces: 1) engage in peacetime operations, 2) deter and prevent conflict, and 3) fight and win wars. The Navy executes this strategy through overseas presence and power projection from the sea to the land. Operational oceanographic support must support these objectives.

The National Military Strategy also requires that the United States remains the pre-eminent military force in the world. This standing largely depends upon advances in technology, especially in Information Technology (IT), leading to information superiority. Future Naval oceanographic support must use IT advances to rapidly collect, quality control, and disseminate oceanographic observations and forecasts, in near real-time, to on-scene Fleet personnel, mission planning systems, and even weapon platforms. While the Naval oceanographic community already supports the Fleet in the manner described above; i.e. creating forecast products at the U.S. based Production Centers, enhancing and tailoring data at theater Regional Centers, and for-

[1]http://www.dtic.mil/jcs/nms/
[2]http://www.dtic.mil/jv2010/jvpub.htm
[3]http://www.dtic.mil/jv2020/
[4]http://www.hq.navy.mil/cno/n8/n80/PPBS/NSPG.pdf

Figure 1. *The Naval Meteorology and Oceanography Command's operational oceanography support structure. Two Production Centers (red stars) have responsibility for oceanographic data acquisition, assimilation and application. Regional Meteorology and Oceanography (METOC) Centers (yellow triangles), Facilities (green upside down triangles), and Detachments (orange circles) provide expert advice, products, and recommendations concerning theater or local oceanographic impacts and forecasts. Mobile Environmental Teams are small (1-3 person) components that augment ships without on-board oceanographic capabilities.*

warding the information to the Fleet (Figure 1); the Navy believes future IT advances will further increase the amount of products produced at sea.

The Office of Naval Research (ONR) performs a key role in making the Navy's future vision today's reality by tailoring new science and technology to meet Fleet requirements. ONR's Ocean Modeling and Prediction Program (Curtin and Harding, 1999) supports research in and development of new ocean forecast systems over a hierarchy of scales from the global scale to the surf zone. In ocean prediction, the Naval Research Laboratory (NRL) merges the potential of R&D to the reality of Fleet operations, with the support of ONR, through collaborations with ONR-supported University researchers, and by teamed transitions with the Naval operational oceanographic community. NRL conducts basic and applied ocean R&D focused on understanding oceanic processes via the combination of models, remotely sensed data, and *in situ* data. From these studies, real-time model/data combinations are developed and applied to the numerical prediction of coastal ocean conditions including temperature, salinity, currents, tides, waves, and surf (Harding et al., 1999a).

The Oceanographer of the Navy, CNO (N096)—(referred to hereafter as The Oceanographer), is responsible for interpreting the Navy's policy and vision relative to ocean prediction, understanding ONR's and NRL's R&D possibilities, and coalescing them into an operational program that meet the Fleet's requirements. This is accomplished with the support of the Space and Naval Warfare Systems Command (SPAWAR) Meteorology and Oceanography Program Office. The Oceanographer works with ONR and SPAWAR to ensure that R&D performed for operational support meets the Navy's mission. The Oceanographer developed a visionary roadmap titled "Strategy for Research and Development[5]" for operational oceanography which states that all R&D sponsored by The Oceanographer will be in direct support of the Navy's mission as established by formal naval doctrine and policy. It is important to remember that all R&D investments and future naval operational oceanographic support must be translatable into impacts and recommendations tied directly to Navy missions.

ONR's and The Oceanographer's current requirements and R&D investments in operational ocean prediction focus on three key areas: 1) Data—the Navy will rapidly collect accurate oceanographic observations on-scene and via remotely-sensed systems, 2) Information—the Navy will rapidly assimilate and

[5]http://oceanographer.navy.mil

analyze all oceanographic data to create a 4-dimensional characterization of the ocean environment at the highest resolutions capable—both on-scene and at the Production Centers and the Regional Centers, and 3) Knowledge—the Navy will provide products and services that not only characterize and predict the ocean environment, but also describe the ocean environment's effect on people, marine life, weapons, sensors, and platforms. Carrying out The Oceanographer's operational guidance, the Commander, Naval Meteorology and Oceanography Command's (CNMOC) mission is to operationally collect, interpret, and apply the global oceanographic data, information, and knowledge to ensure safety at sea and increase the effectiveness of the Fleet in peacetime and in time of conflict. The next section will describe the CNMOC concept of operations based on the Navy's new littoral mission.

Concept of Operations

The current CNMOC Concept of Operations (CONOPS) for operational oceanographic support evolved during and after the Cold War. The goal is to maintain the capability for, in the words of the military, "peacetime forward presence, crisis response, and regional conflict, with emphasis on flexibility, mobility, and interoperability." Operational oceanographic focus has moved, since the Cold War, from the deep ocean to the shallow water environment—the coastal seas and hinterland. The Anti-Submarine Warfare (ASW) emphasis of the Cold War has shifted toward littoral warfare concerns (Kelso et al., 1992; Dalton et al., 1994).

During the 1991 Gulf War, oceanographic products and forecasts such as drifting mines and oil dispersion, wave, thermal structure, and circulation ocean models were produced at the Production Centers. The Regional Centers produced ASW and tactical oceanographic summaries, based on the Production Center's products, and tailored information for specific Fleet needs. Staff oceanographers, who directly support the Fleet/Battle Commanders and joint forces, would process this information to determine what effects the oceanographic environment would have on their Fleet assets. Similarly, small (1–3 person) component Mobile Environmental Teams would augment ships without an on-board oceanographic department and support the ship using information provided by the Regional Centers. Fleet decisions would be made based on the available information disseminated to the warfighter. This CONOPS was required since: (1) communications between ship and shore were of low-band width, and (2) computational processing power resided at the large Production Centers and not on the ship, nor for that matter at the Regional Centers.

This CONOPS and changes to future CONOPS are best understood in the context of the military decision process. Military decisions are based on the Observation, Orientation, Decision, Action (OODA) loop. In the past, the OODA loop included the decision-makers located in the Continental United States (CONUS). Observations and data streams were usually too large to be handled in the battlefield, and had to be relayed and processed in CONUS. Thus, the OODA loop took a long time to complete.

The goal is to minimize the military OODA loop. Remotely-sensed and *in situ* observations of the battlefield—for example, from Unmanned Aerial Vehicles (UAV) or Unmanned Underwater Vehicles (UUV)—will go directly to decision makers in the field. This data stream might be too large and too perishable to send back to CONUS, so the "orient, decide, and act" aspects of the loop will stay within the battlefield. Any opportunity for the operational oceanographer to influence and support the OODA loop will reside at the battlefield level, and the future CNMOC CONOPS will address this type of support.

CNMOC's future CONOPS synthesizes the Navy's future mission, the Oceanographer's R&D strategy, and the changing IT landscape (Figure 2). The name for this CONOPS is "NETCENTRIC Support" which reflects the OODA structure, while taking on a more network or web-like configuration. Current Navy exercises and operations are pointing to a future where network connectivity, communication bandwidth and computational processing power available to a battle group could be quite large. This fact is not only true for the ships, but also for the Regional and Production Centers that will have ever increasing connectivity to the warfighter. Therefore, the CNMOC CONOPS must flexibly address what military operations look like today as well as in the future, and how the operational oceanography community will support the Fleet based on changing military capabilities (Matthews and Willis, 2000).

The Past Ten Years

Rather than duplicate detailed descriptions of available ocean forecasting capabilities over the past ten years (refer to Harding et al., 1996, for further details), this section relates more to changes in technology and conceptual approaches that have driven present day ocean predictions.

In 1992, ONR's Robert Peloquin stated, "The future direction of ocean prediction certainly depends on computational capabilities and our ability to efficiently access and use new high-speed computers." (Peloquin, 1992). The promise of operational oceanography came to lie in the capabilities of large computational systems like the newly installed Naval Oceanographic Office's (NAVOCEANO) CRAY C-90 supercomputer. The oceanographic community justified the need for the new supercomputer by proposing that R&D and operational numerical modelers share the system to ensure new oceanographic models are rapidly transitioned to operations.

However, something interesting happened in 1995. The DOD recognized the need for large computational centers, transcending in capability anything that could be reached by the individual services, where R&D

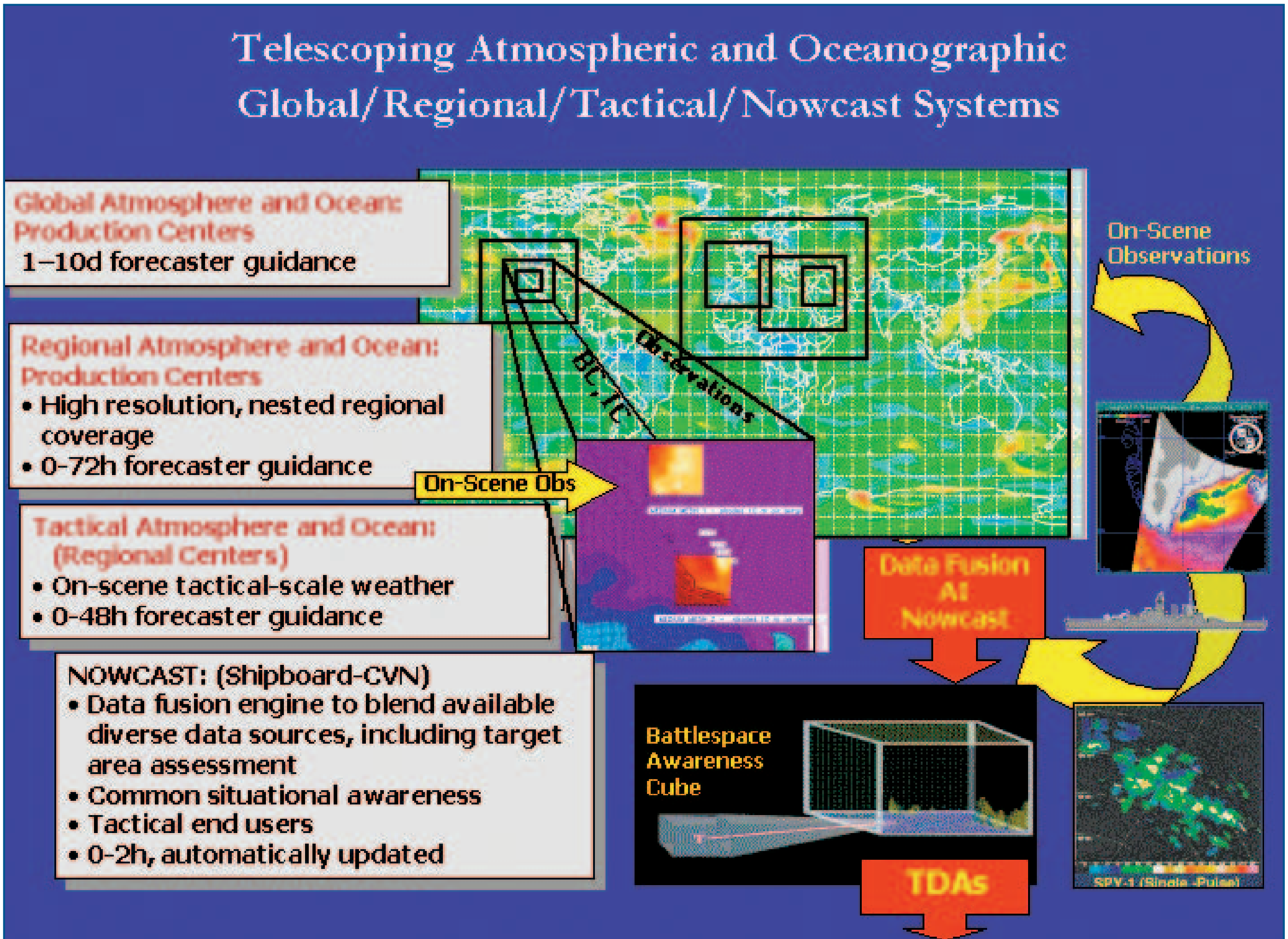

Figure 2. *The Observe, Orient, Decide, Act (OODA) loop for the atmospheric and oceanographic community. Global ocean models at NAVOCEANO and FNMOC provide initial and boundary conditions to the Regional Center's models. The Regional Center's models feed boundary conditions to the on-scene models. These "Nowcast" models fuse on-scene data with model forecasts to create an environmental battlespace awareness cube for the warfighter, and aid in reducing the oceanographic OODA loop.*

could obtain enormous computational power, and so the DOD Major Shared Resource Centers (MSRC) were created. One MSRC was located at NAVOCEANO, with a focus primarily on climate, weather, ocean, and fluid dynamics. The MSRC provided R&D with the latest and most powerful computer systems available to test and evaluate large domain ocean models with different horizontal and vertical resolutions (Hurlburt and Hogan, 1998). Peloquin (1992) also correctly predicted that ocean prediction systems having 10 km horizontal resolution and 40 vertical levels, with complete thermodynamics and data assimilation schemes, would require processors with speeds approaching the teraflop range (1 trillion floating point operations per second). Yet the NAVOCEANO MSRC would not realize this computing power for another 5 years.

In the early to mid-1990s a new "concept" for network-supported, distributed, ocean prediction evolved at NRL's Oceanography Division at Stennis Space Center, MS. To support theater operations in the Pacific and the Mediterranean, NRL developed the Modular Oceanographic Data Assimilation System (MODAS), which ran on a high-end UNIX© desktop computer, ingested *in situ* oceanographic data, and assimilated the data into a background oceanographic field (e.g. a 3-dimensional temperature field of the Mediterranean Sea) to create a new oceanographic field (Rhodes et al., 1995). The interesting aspect of MODAS was that the system could be located at the theater Regional Center, at a Production Center or, more importantly, linked via network where the Regional Center could incorporate the additional information available from the Production Center. Thus, the Naval oceanographic community took the advantage of increasing computer processing power and networked communications (still at a low-baud rate of 36K) to shrink the oceanographic OODA loop to the theater level; a concept that was not yet realized by the overall Naval community

The idea of distributing ocean data assimilation systems did not to stop at the Regional Centers. While the ocean modeling CONOPS states that NAVOCEANO generates basin-scale oceanographic fields and the Regional Centers generate tactical oceanographic fields for Fleet support, there was a problem in supporting the submarine community. In 1998 the submarine community requested MODAS systems for their own platforms since submarines could not pass their classified operating areas to the Centers. These "MODAS-Lite" systems had reduced capability relative to those at the Regional Centers, yet conceptually, the oceanographic OODA loop had now shrunk to the Fleet level.

Remotely-sensed data collection capabilities did increase during the past ten years with altimetry and sea-surface temperature data becoming critical inputs to ocean systems such as MODAS. In 1992, oceanographers relied on polar orbiting satellites like the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometers (AVHRR) to analyze ocean features. It had been several years since the Navy's Geodetic Satellite (GEOSAT) had carried a satellite altimeter capable of detecting and measuring the ocean's surface height and the next Navy altimeter was 8 years away from launch. Thus, the Navy relied on NASA or foreign launched altimeters. In the middle to late 1990s, two other satellite systems were deployed that provided oceanographers with additional information: (1) a commercial ocean color detection satellite, and (2) scatterometer satellites capable of measuring the wind stress on the ocean.

While data assimilation, modeling, and remotely-sensed data (e.g. altimetry and sea-surface temperature) capabilities increased during the past ten years, *in situ* oceanographic data collection capabilities did not change significantly. The Fleet was still required to take oceanographic observations, primarily with expendable bathythermographs, every six hours, and to pass that information to the Production and Regional Centers. In 1995, NAVOCEANO developed a new class of survey ships that were able to collect an enormous wealth of bathymetry and oceanographic information using new capabilities such as the Integrated Survey System-60 (ISS-60), however the data tended to overwhelm NAVOCEANO's processing capabilities. The promises of Unmanned Underwater Vehicles, Airborne Laser Bathymetry Surveys, and other revolutionary data collection capabilities would have to wait for computers and communication capabilities to grow even further.

Current Operational Ocean Forecasting—2002

A list of the Navy's current oceanographic systems is provided in Table 1. Harding et al. (1999b) provide specific descriptions of present capabilities as of 1998. However, the past 4 years have witnessed a dramatic evolution of operational and near-operational Naval ocean prediction capabilities. Operational global atmospheric predictions, necessary for forcing the large-scale ocean wave and circulation models, have increased in sophistication and resolution (Rosmond et al., this issue). Regional atmospheric predictions have increased in capability to become useful in providing input to high-resolution coastal ocean predictions even to the point where coupled ocean-atmosphere models are advancing quickly in research and development (Hodur et al., this issue). High-resolution, operational littoral wave, surf, tide, and ocean dynamic predictions are now available to the warfighter (Allard et al., Blain et al., Fox et al.; all this issue). Larger scale oceanographic models for waves, ice, and ocean dynamics have also increased in sophistication and resolution taking advantage of available high performance computing capabilities (Jensen et al., Preller et al., Rhodes et al.; all this issue)

This section continues by describing the technology and programs that have driven the development of today's capabilities. The Navy's two Production Centers, The Fleet Numerical Meteorology and Oceanography Center (FNMOC)[6] and NAVOCEANO[7] require ocean modeling systems to support their specific models and products (Harding et al., 1996). These Production Centers recently addressed the issue of operational ocean modeling, including the new aspect of operating distributed ocean models at the Regional Centers, with an updated ocean modeling CONOPS. FNMOC now concentrates on operating atmospheric and tightly coupled ocean-atmosphere models primarily designed to improve atmospheric predictions. NAVOCEANO concentrates on transitioning and operating fully 3-D data assimilative oceanographic forecast models. While, the Regional Centers operate theater ocean models for direct tactical support, typically with support and guidance from the two Production Centers.

Computers and communication capabilities continued to increase in the latter part of the 20th Century. Not only are Regional Centers operating ocean data assimilation systems such as MODAS, but they are now running very sophisticated, limited-area, mesoscale, atmospheric prediction models (Hodur, 1997), thus shrinking the atmospheric OODA loop as well. At the same time, the NAVOCEANO MSRC reached the two teraflop plateau in 2000. This, combined with the real-time operational altimetry processing (Jacobs et al., this issue), has allowed NAVOCEANO to bring on-line the first operational, altimetry-assimilating, eddy-resolving, global dynamic ocean model—at $1/16°$ horizontal resolution and 6 vertical layers (Figure 3) with near-term plans to increase to $1/32°$ (Rhodes et al., this issue). Similarly, regional coastal circulation prediction systems, available in the last decade, are now able to increase their resolutions to more tactically relevant

[6]http://www.fnmoc.navy.mil
[7]http://www.navo.navy.mil

Table 1. *Operational oceanographic Navy models currently available or undergoing operational evaluation.*

	OCEAN SYSTEMS
Data Assimilation	**OCEAN ANALYSIS**
OCEAN MVOI	3-Dimensional Ocean Multi-Variate Optimal Interpolation System
MODAS	Modular 3-Dimensional Ocean Data Assimilation System
Model	**OCEAN CIRCULATION MODELS**
TOPS	Upper Ocean Mixed Layer Forecast (global & fixed regions)
NLOM	Deep Ocean Mesocale Prediction (global)
NCOM	Upper Ocean & Coastal Ocean Prediction (global initially)
SWAFS	Coastal Ocean Prediction (various fixed regions & nests)
ReloPOM	Rapidly Relocateable Ocean Prediction (regional & nests)
ADCIRC	Advanced Hydrodynamic Circulation Model for Shelves, Coasts, and Estuaries
	WAVE, SURF, AND TIDE MODELS
WAM	Third Generation Wave Action Model (global & regional)
WW3	Wave Watch III - Next Generation Wave Model (global)
STWAVE	Near Shore Spectral Wave Model (regional)
NSSM	Rapidly Relocateable Navy Standard Surf Model
PC TIDES	Rapidly Relocatable Tidal Model
	ICE MODEL
PIPS	Polar Ice Prediction System (Northern Hemisphere to 30°N)
	ATMOSPHERIC MODELS
NOGAPS	Atmospheric Prediction System (global)
COAMPS	High Resolution Atmospheric Prediction System (regional & nests)
GFDN	Tropical Cyclone Model with Imbedded Nests

scales. The NAVOCEANO MSRC also operates a Visualization Center, which allows modelers and operators to visualize their data using new, visually intuitive graphics that support the Fleet as well as benefit researchers.

International collaborative opportunities in ocean data assimilation increased in 2000 with the establishment of the Global Ocean Data Assimilation Experiment (GODAE), a planned, practical data assimilation demonstration for using remotely-sensed and *in situ* observations and products on a global scale (Smith and Lefebvre, 1997). The primary operational applications of GODAE, besides real-time applications of interests to the Navy, include climate and seasonal forecasting, marine safety, fisheries, offshore industry, and management of coastlines. A GODAE Monterey data server was established at FNMOC with oversight from the U.S. GODAE Steering Committee and funding from ONR. The types of data available include satellite, and *in situ* observations, as well as global and regional model fields created by FNMOC and NAVOCEANO.

A data acquisition project strongly endorsed by GODAE is the ARGO Project (Roemmich and Owens, 2000). This pilot project of the Global Ocean Observing System (GOOS) is designed to create a global ocean observing system capable of providing observations of seasonal to decadal variability, but will also provide useful input on the oceanic mesoscale for real-time Navy applications. The backbone of the global observing system is the array of surface to subsurface profiling floats capable of returning a temperature and salinity profile from 2000 m depth to the sea surface every 10 days. The expected distribution in the global ocean is about one every three degrees in latitude and longitude. The information will be returned to FNMOC via satellite, usually in less than 12 hours, and provided on the GODAE server.

Beyond altimetry and sea-surface temperature data, ocean assimilation of remotely-sensed data is still in its infancy especially for shallow water applications. *In situ* capabilities are expanding as NAVOCEANO currently supplements their survey ship capability with Hydrographic Survey Launches (HSL) and tethered unmanned vehicles that can survey shallow-water areas. Relevant to high resolution, nearshore coastal prediction, Airborne Laser Bathymetry surveys are also now operational. However, the numbers of surveys conducted are limited due to the resources available to conduct the survey. NAVOCEANO also took the initiative to reduce the oceanographic data collection OODA loop by developing a new concept called Fleet Survey Teams. These small (3–5) person teams trained in geospatial information and hydrographic surveying deploy to areas of operational concern and rapidly collect oceanographic and hydrographic information using the HSLs or boats of opportunity. While data can be rapidly collected on-scene, most of the information is still processed at NAVOCEANO before it is returned to the Fleet. This will be one likely new source of data for future nearshore high-resolution prediction.

Future Operational Ocean Forecasting—2003 and Beyond

Based on the U.S. Navy's vision that IT will maintain the United States military superiority, a future Fleet capability will be the collection of massive amounts of ocean observations from on-scene sensors and weapon systems. This data, called "through the sensor" observations, will come from a number of tactical sonar sensors such as the BQN-17 (for bottom sediment properties) and the SQS-53C (for acoustic reverberation levels and sound speed measurements using data inversion techniques). Other observational data will come from *in situ* oceanographic observations like the Submarine Tactical Environmental Data System (STEDS), Environmental Acoustic Recording System (EARS), and Unmanned Aerial/Underwater Vehicles. Since the volume of information will be enormous, the focus of R&D over the near term will be on the on-scene quality control, management, and assimilation of these observations to ensure the Fleet does not experience "information overload."

In a Navy "NETCENTRIC" future, the information collected by the Fleet will be constantly distributed to the Production and Regional Centers for assimilation into global and regional forecasts. Ultimately, NAVOCEANO will also be tasked with quality controlling the data and updating their databases. In addition to their real-time forecasts, NAVOCEANO will continue to produce climatological products for long-range mission planning. It remains to be seen if the Fleet will require climatological databases if they are receiving a real-time environmental "cube."

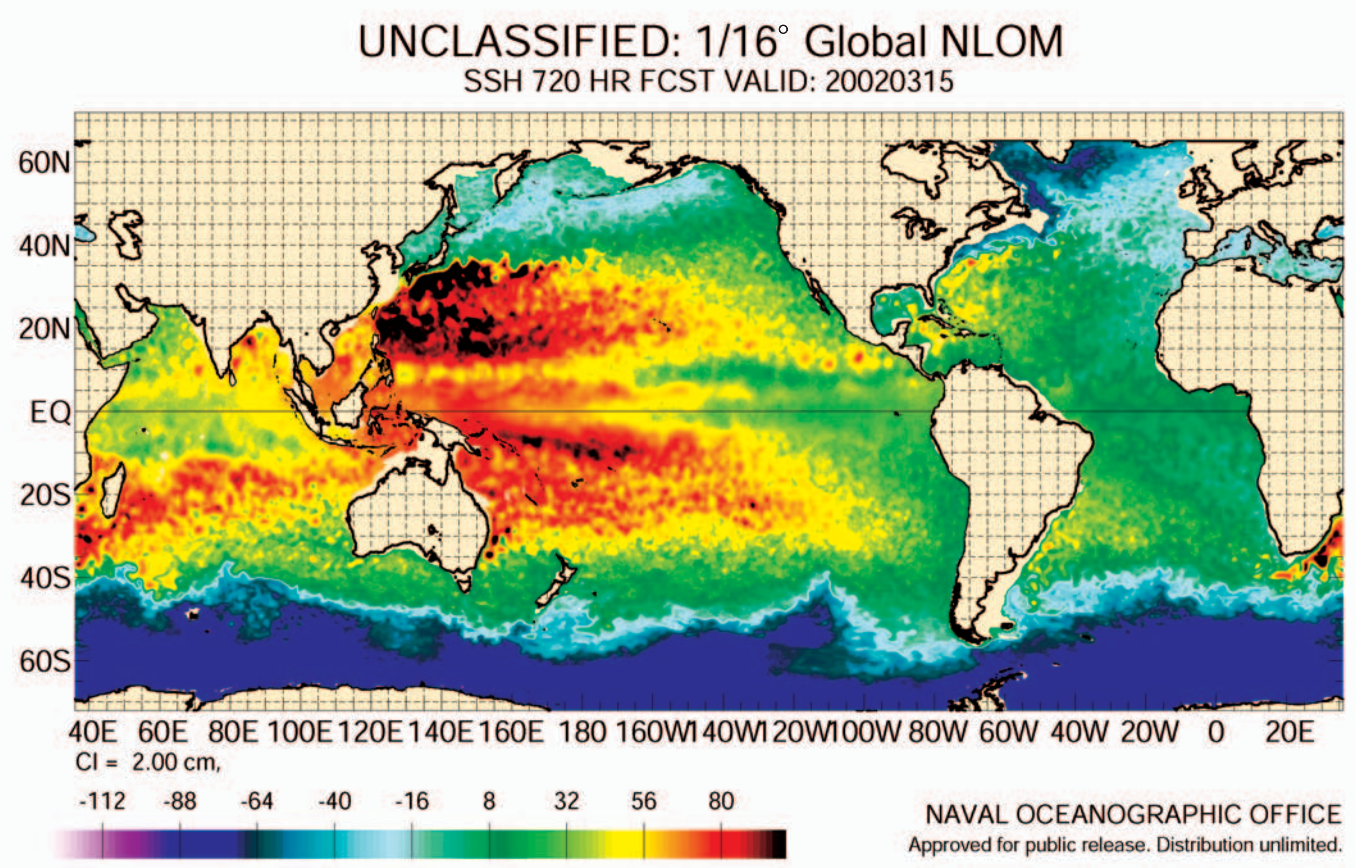

Figure 3. *30-day forecast valid for 15 March 2002 of global mean sea-surface height created by the NAVOCEANO operational, 1⁄16°, 6-layer, global ocean model. The model has realistic deep-water bottom topography. Color bar is in centimeters with values labeled on the color bar. Real-time output and skill measures of this product are available on http://www7300.nrlssc.navy.mil/global_nlom.*

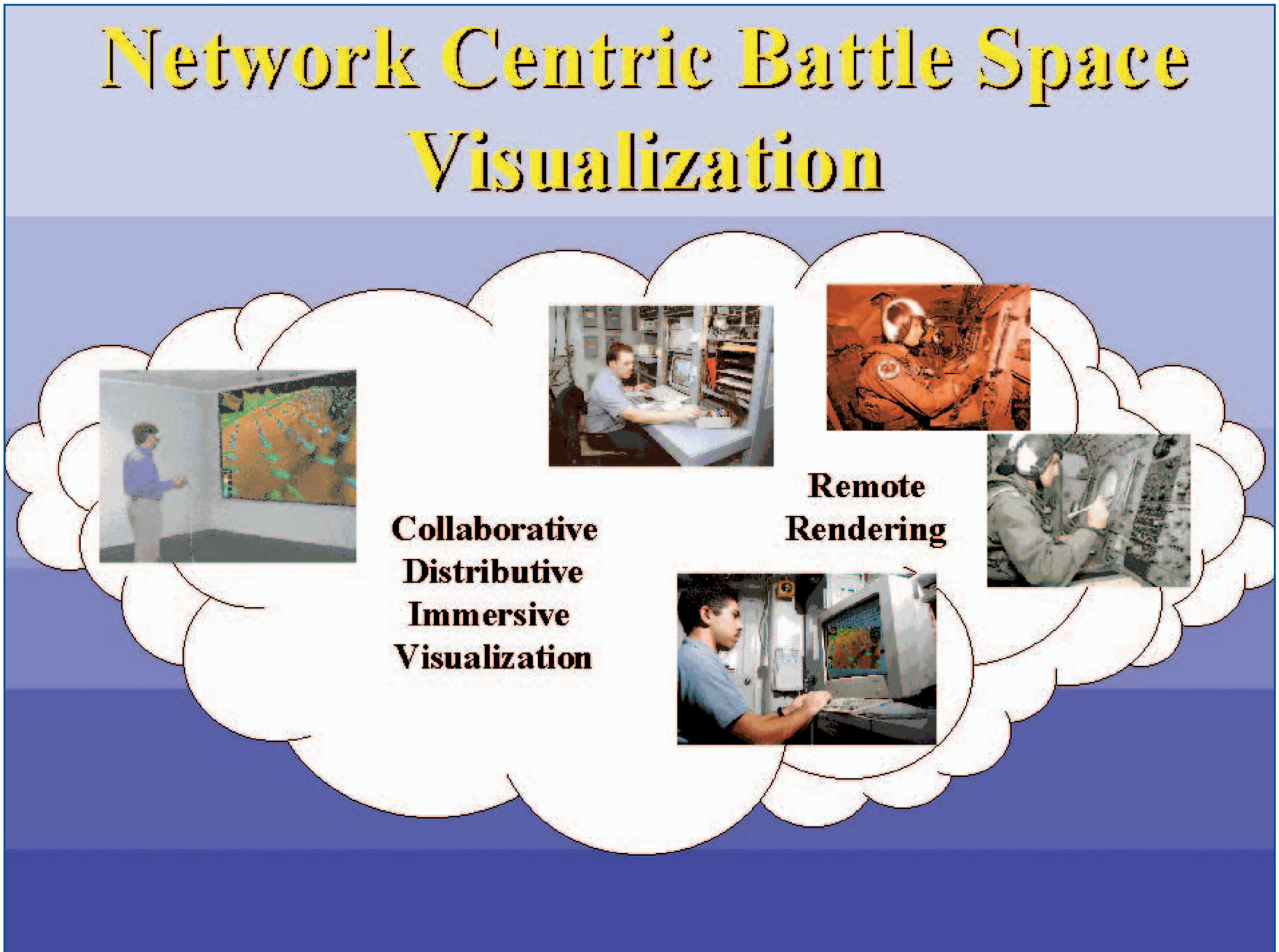

Figure 4. Virtual environments created by oceanographic models and data will provide the warfighter with "Watch Out" warfighting products and new ways to derive knowledge from binary data sets.

With observations available on-scene, and high bandwidth network connectivity to the Production and Regional Centers, the ship's on-board computing systems will assimilate the information and produce local prognostic forecasts. A series of steps must occur before the Fleet produces their own forecasts. First, NAVOCEANO must create high-resolution, global oceanographic forecast fields, forced by high-resolution atmospheric global forecasts produced by FNMOC. Regional Centers will then access subsets of these global oceanographic fields to create theater/tactical oceanographic fields for vessels that do not have an oceanographic prediction capability. These forecast fields would extend to 4 days, or longer, with horizontal and vertical resolutions similar to the global ocean forecasts. For Fleet components capable of operating their own ocean models, the global ocean fields will be used to initialize very-high resolution, "postage stamp" size ocean forecasts for the ship or for an entire battle group. These local forecasts might also extend to 4 days, however the forecast area would follow the battle group while in transit instead of being a static forecast area.

While there will be a plethora of oceanographic observations on-scene, there will also be a number of oceanographic models available; covering the range of Navy requirements. These could include circulation, wave, surf, tide, biological, riverine, and acoustic models. Can all these models be operated in the Fleet? Shipboard computing systems and available personnel will only be able to do so much. Most likely it will be a distributed modeling capability that includes the network-linked Regional and Production Center computing architectures.

The ocean community will derive additional benefits from the DOD MSRC's enormous computing capabilities. One will be the capacity to create ensemble forecasts and the other is the production of high-resolution visualization products. The atmospheric community is currently refining ensemble-modeling techniques, where a model is operated hundreds or thousands of times to produce forecasts using perturbed initial values. Meteorologists use these multiple forecasts to determine the probabilities that an atmospheric condition may or may not occur at a certain time and a certain location. One example is hurricane forecasting, where ensemble models predict the spread of probable locations and strengths of one hurricane, and this allows forecasters to create strike probabilities for various locations. Given the probable size of the NAVOCEANO MSRC architecture in the future, ensembles of global or regional ocean models might allow ocean forecasters to determine the probable strength and location of numerous ocean features that will greatly aid the safety and tactical strike capabilities of the Fleet.

Visualization of oceanographic information is another important MSRC benefit. While a ship's mission planning system will directly ingest the oceanographic "cube" of data, on-scene oceanographers and decision makers will require the ability to derive direct knowledge from the enormous amount of information. A number of R&D initiatives are in progress to fully exploit current distributed visualization techniques (Figure 4). The NAVOCEANO MSRC's Visualization Laboratory is testing the ability to create high resolution visualization products on their platforms, consolidate the information to movie formatted products that use less bandwidth, and disseminate the movie files in real-time to the Fleet. This type of support is the ultimate use of IT and NETCENTRIC operations, with observations, predictions, visualizations, and decisions being made in near real-time at all locations to shrink the oceanographic OODA loop as small as possible.

Summary

In the context of a changing Navy mission and rapid technology changes, this article addresses the past, present, and future operational oceanographic capabilities of the U.S. Navy. DOD and the U.S. Navy provide the vision and the mission; the Fleet provides the requirements; ONR and NRL develop the science and R&D to address the requirements and meet the mission; the Oceanographer, SPAWAR, NRL, and the CNMOC subcommands team to directly support the Fleet. These roles will not change significantly. However, scientific and technological breakthroughs in ocean prediction, computer, and communication capabilities will continue to increase. These Information Technology enhancements and increased capabilities will result in more information and technology available to the warfighter. The Navy's oceanographic community has developed an R&D strategy and a Concept of Operations to address this "new frontier" to ensure the Fleet's safety and provide them with tactical advantage.

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