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THE INTEGRATED OCEAN OBSERVING SYSTEM (IOOS) MODELING AND ANALYSIS WORKSHOP REPORT

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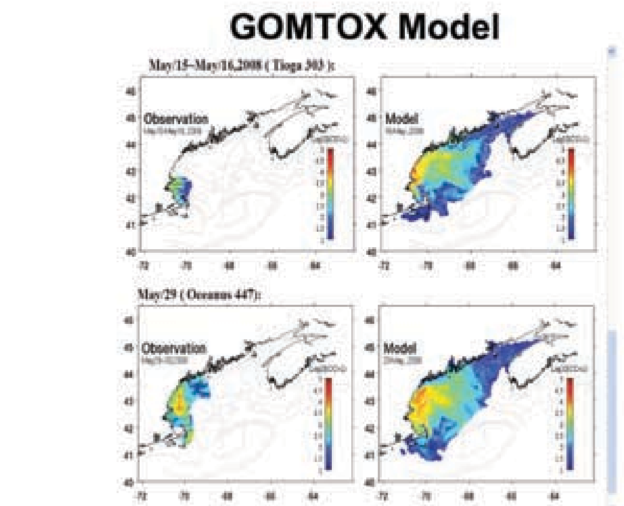
EXECUTIVE SUMMARY

The Integrated Ocean Observing System (IOOS©) aims to estimate the past, present, and future states of the ocean for addressing a variety of societal needs. It is impractical, if not impossible, to estimate accurately the complex variability of the ocean by observations alone. Computer models, which numerically represent ocean dynamics and thermodynamics, can be used to make comprehensive ocean state estimates, or ocean predictions, of currents, temperature and salinity structures, external and internal tides, surface waves, storm surges, etc. However, to make accurate ocean predictions, the models must be constrained by observations through realistic forcing and data assimilation. Accordingly, IOOS comprises three major technical components: observing subsystems (i.e., networks of *in situ* and space-borne and other remote sensors), modeling subsystems (as noted above), and information management subsystems (i.e., cyberinfrastructure designed to efficiently transport and handle large volumes of observational and model data). Consequently, the IOOS National Backbone (NB), provided by the federal government, consists of the triad of ocean observing subsystems, ocean modeling subsystems, and information management subsystems that cover a range of scales from the global ocean to the coastal ocean, including estuaries and the Great Lakes. Similarly, the IOOS Regional Coastal Ocean Observing Systems (RCOOSes), one for each of the 11 IOOS Regional Associations (RAs, see Appendix E "List of Regional Associations"), comprise the same triad of subsystems described above, but are implemented on the regional scale. With the RCOOSes focusing on the USA coastal ocean (i.e., U.S. EEZ), they utilize large-scale ocean model products from the Navy and NOAA National Backbone operational centers for downscaling to high-resolution coastal ocean domains. In turn, the RCOOSes provide observations, model products, and skill assessments at relatively high-resolution for feedback to the modeling subsystem of the National Backbone.



Ruoying He, NCSU. Dennis McGillicuddy WHOI. Resolution: 3-5 km. Model: ROMS + cyst function, swimming, growth/decay based on T,S, Light, climatological nutrients. Assimilates GOMOOS current data. Forecasts were used to guide red tide monitoring

Over 50 representatives of the IOOS National Backbone and RCOOS modeling and analysis communities, along with the National Science Foundation (NSF) Ocean Observing Initiative (OOI) investigators and various programmatic observers, met for two-and-a-half days in July 2008 to review their collective progress and to develop a plan for implementing the prediction and analysis component of IOOS. "Prediction" is used here in the broad sense of hindcast, nowcast, and forecast, plus simulation. Similarly, "analysis" is also used here in the broad sense of skill assessments, data assimilation methodology developments, sensitivity studies, dynamical diagnostic studies, re-analyses[1], etc. During the course of the workshop, it became clear that tremendous progress (http://www.ocean.us/2008_model_wkshp) is being made towards prediction of the ocean's physical state at both the National Backbone level and, in some cases, the RCOOS level. The stage has also been set for coupling physical predictions to biogeochemical, ecological, and other applications models in the foreseeable future.

To foster further rapid ocean prediction system development, implementation, and assessment, it is paramount that a joint working group and a periodic forum be established and maintained for cross-agency and ocean prediction and analysis-community exchanges. The short-term (1 to 5 years) plans require more communication, coordination, collaboration, and:

- improved cyberinfrastructure, including a standards-based national data portal and archive system built to leverage both the information resources of NOAA and Navy and the distributed infrastructure being built by OOI;
- a more logical and tractable division of effort between the National Backbone and the RCOOSes; and
- longer-term, more stable, and more adequate levels of funding for both the National Backbone and RCOOS prediction and analysis activities.
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Moreover, the long-term (5 to 25 years) conceptual plans are in critical need of:

- clear, quantified requirement statements from various categories of users;
- an overall Systems Engineering (SE) design and management scheme; and

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[1] Re-analyses consist of retrospective data–assimilative model runs made with the most complete and quality-controlled observational data sets available in delayed time and typically with the most advanced contemporary numerical models and data assimilation schemes. The re-analyses are frequently used for multi-decadal diagnostic studies of past climate variability, and, as such, are usually run at lower than operational Numerical Weather Prediction (NWP) resolution. They are also used for synoptic event reconstruction and process-oriented research.

• a Concept of Operations (CONOPS) linking the prediction and analysis National Backbone and the RCOOSes in defined roles and responsibilities and mutually beneficial partnerships. To that end, the "operational ocean model" concept (see Appendix F "An Essay on Operational Ocean Models") was examined in association with the workshop, highlighting some of the many issues that need to be considered in a CONOPS for IOOS.

The principal products of the workshop were the oral presentations and breakout group summaries (see http://www.ocean.us/2008_model_wkshp); the plenary deliberations summarized below; and **a set of nine Findings and Recommendations, as also summarized below in abbreviated form.** The first two recommendations are programmatic in nature and would provide continuity for the IOOS Ocean Prediction and Analysis (OPA) activity.

(1) the IOOS Modeling and Analysis Steering Team (MAST) effort, having served to foster the emergent partnership of the National Backbone and RCOOS communities, has naturally evolved into an IOOS OPA effort (this alternative terminology has the collateral benefit of being easier to explain to marine stakeholders and agency program managers) and should now be replaced with an OPA Joint Working Group (OPA-JWG); and
(2) the OPA Community needs a forum to maintain periodic group communications on a face-to-face basis for fostering research and operational partnerships; therefore, the OPA-JWG should be expected to sustain this activity.

The next five recommendations are first-year tasks for the OPA-JWG. They each require the development and vetting of first-generation items:

(3) aggregate a set of standard attributes (e.g., space-time resolution, accuracy, forecast horizons, and timeliness) for operational ocean prediction core variables that can be traced back to user requirements;
(4) assemble a suite of model skill assessment metrics which form the basis for uncertainty estimates of predictions, tradeoff studies between alternative observing system networks, and validation studies;
(5) summarize attributes of standard observational data (e.g., variables, including topographic, hydrological, meteorological, ecological, etc. data; space-time resolution; and accuracy) needed for multi-disciplinary model forcing, verification, validation, and data assimilation;
(6) define needs and outline design and implementation plan for a distributed, "one-stop shopping" national data portal and archive system for ocean prediction input and output data; and
(7) draft a CONOPS that delineates the respective roles and responsibilities of the National Backbone and RCOOSes, including joint activities; e.g., testbeds and ocean prediction experiments.

In subsequent years, the OPA-JWG would be responsible for maintaining and updating (3) to (7) and would be tasked to:
• assess present operational and R&D ocean prediction capabilities relative to the traceable user requirements determined in (3), yielding a gap analysis;
• recommend implementation and R&D strategies and required steps based upon the above gap analysis;
• foster discussions of implementation efforts, model skill assessments, other analysis activities, technical issues, extensions of the physical predictions to biogeochemical and ecological predictions, and other topics requiring coupled modeling;
• prioritize needed ocean model and data assimilation developments; and
• foster community-wide communications via periodic forums, as described above.

A specific recommendation, that would enable a "great leap forward" in initial coastal ocean prediction capability for both the National Backbone and RCOOSes, is:

(8) submit simultaneous Inter-Agency Working Group on Ocean Observations (IWGOO) requests to the Oceanographer of the Navy (N84) and the Commander, Navy Meteorology and Oceanography Command (CNMOC), to provide the regional ocean prediction products with mesoscale variability produced by the Naval Oceanographic Office (NAVO) to NOAA for use by the National Weather Service/National Centers for Environmental Prediction (NWS/NCEP) and the National Ocean Service/Center for Operational Ocean Products and Services (NOS/CO-OPS) and NOS Coast Survey Development Laboratory (NOS/CSDL), and by the RCOOSes for open boundary conditions applied to higher resolution coastal ocean models, skill assessments, diagnostic studies, etc.

The final recommendation addresses a forward-looking program design strategy:

(9) OPA activities are leading to infrastructure components (e.g., skill assessment metrics, testbeds [alias 'model evaluation environments' in NOS parlance], data assimilation schemes, and Observing System Experiments (OSEs)/Observing System Simulation Experiments (OSSEs)) that are essential to the overall system design and performance evaluation of IOOS in the logical context of systems engineering (SE), the pursuit of which is encouraged to provide a defensible, logical basis for the design and management of the long-term program.

INTRODUCTION

The Integrated Ocean Observing System (IOOS©) (see Appendix D "List of Acronyms") Modeling and Analysis Workshop was conducted 22 through 24 July 2008 in Arlington, Virginia, and was facilitated by Ocean.US. It was co-sponsored by the IOOS Modeling and Analysis Steering Team (MAST) of Ocean.US, the Ocean Observing Initiative (OOI) of NSF, and the National Federation of Regional Associations (NFRA), all elements of IOOS. MAST, OOI, and NFRA were represented on the Organizing Committee (see Appendix A "Organizing Committee"). There were 57 attendees (of 115 invitees) from the federal and non-federal operational and research ocean modeling communities, plus various programmatic staff members and environmental industry representatives. In particular, 14 of the 20 MAST members, five OOI investigators, and seven of the 11 NFRA regional modeling and analysis representatives were present. Participants included four from the Navy, three from the U.S. Army Corps of Engineers (USACE), two from the U.S. Geological Survey (USGS), two from the National Aeronautics and Space Administration (NASA), one from the Minerals Management Service (MMS), and 17 from the National Oceanic and Atmospheric Administration (NOAA), including all five NOAA line offices. Three of the federal participants are members of the Interagency Working Group on Ocean Observations (IWGOO) which oversees IOOS. There were four participants from industry and 22 from academia.

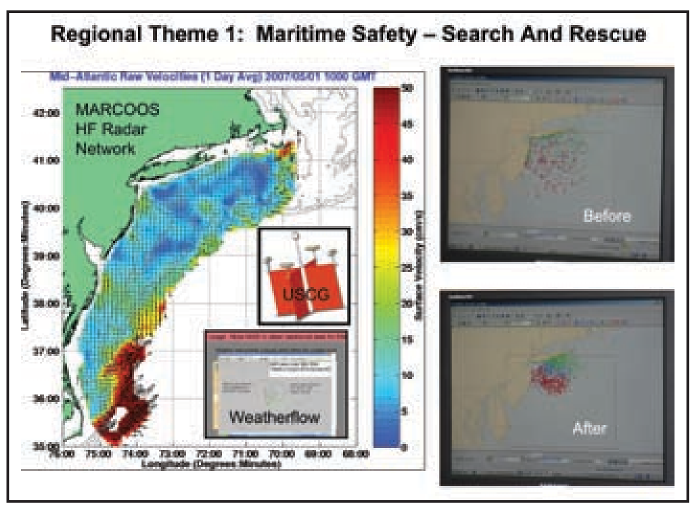
The term "analysis" is used variously. For example, in Operational Meteorology and Oceanography, it is commonly used synonymously with a nowcast based on data assimilation that provides the initial condition for a forecast. Here, it is used in the broad sense of all analytical activities attendant to ocean prediction; e.g., skill assessments, data assimilation methodology developments, sensitivity studies, dynamical diagnostic studies, and re-analyses.

The Workshop **Goal** was to *foster broad-based, partnership-community input to planning the IOOS Prediction and Analysis Subsystem.*

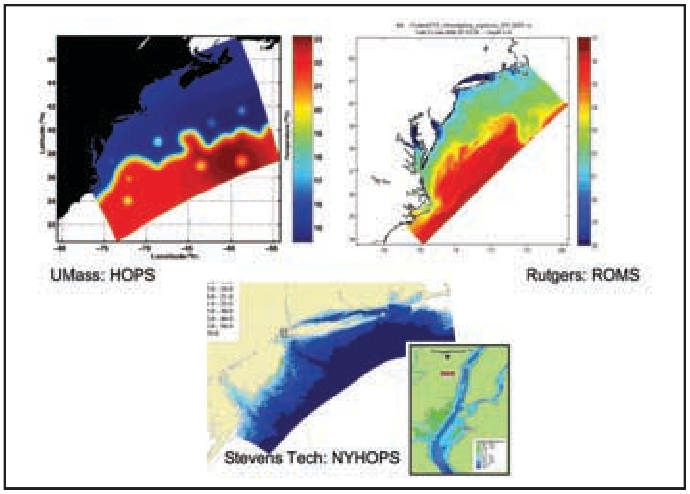
The supporting Workshop **Objectives** were to:

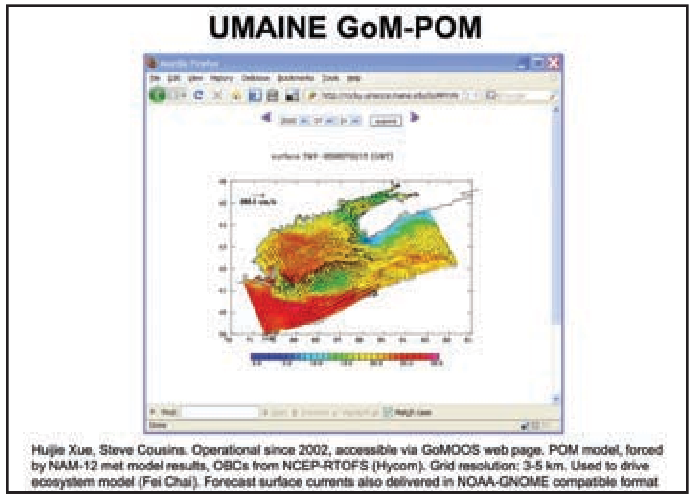
1. Engage the NFRA (and its 11 Regional Coastal Ocean Observing Systems (RCOOSes)), OOI, and NB ocean modeling and observing communities in planning the evolution of multi-model, multi-disciplinary operational and Research and Development (R&D) modeling subsystems on global ocean and coastal ocean scales;
2. Communicate existing operational modeling and analysis capabilities (especially those of the Navy and NOAA) and needed future directions, as well as contemporary and emerging R&D capabilities, in an ecosystem forecasting framework;
3. Develop a strategic approach to operational and related R&D modeling and analysis systems that links the operational ocean prediction centers, RCOOSes, and OOI investigators through delineation of roles and responsibilities;
4. Identify implementation issues (e.g., data portals, data archives, standards for model output, bathymetric/topographic data bases, forcing functions, performance metrics, testbeds, skill assessment, data assimilation, and OSEs/OSSEs) for the regional coastal ocean scales, including their links to the global/basin/intermediate scales and to local (estuarine, lagoonal, tidal riverine, Great Lakes, etc.) scales; and
5. Outline "pathfinder projects" based on regional scale R&D agendas that incorporate RCOOS and OOI research interests and newly emergent capabilities, and that identify processes and mechanisms whose prediction is critical to meet the societal applications of concern to IOOS.

Accordingly, on the first day (see Appendix B "Agenda"), the Workshop was organized into initial plenary sessions focused on presentations from each of the 11 RCOOSes (four given in absentia) on their status and plans for modeling and analysis, with some mention of their observing subsystems; from NB (NOAA and Navy) operational ocean modelers about their products and plans; and from several invited experts on related topics. On the second day, three Breakout Groups [(1) Pacific 3D Circulation and Marine Ecosystems, (2) Atlantic 3D Circulation and Marine Ecosystems, and (3) Coastal 2D Inundation and Coastal Ecosystems] addressed two thematic issues:
I - Regional-Scale Science Agenda Development and
II - Programmatic Opportunities and Requirements.
On the final day, in a slight departure from the original Agenda, a plenary session addressed a third thematic issue: III - Programmatic Requirements, as well as a Plan of Action. All workshop presentations and Breakout Group Summaries are found at http://www.ocean.us/2008_model_wkshp. Following a brief summary of the workshop deliberations, this report focuses on the principal Findings & Recommendations.



Summary of Workshop Deliberations. Based on the plenary presentations of the first day, the status and plans of each of the 11 RCOOSes, and the Naval Oceanographic Office (NAVO), NOAA (National Weather Service/National Centers for Environmental Prediction (NWS/NCEP), National Ocean Service/Coast Survey Development Laboratory (NOS/CSDL) and NOS/Center for Operational



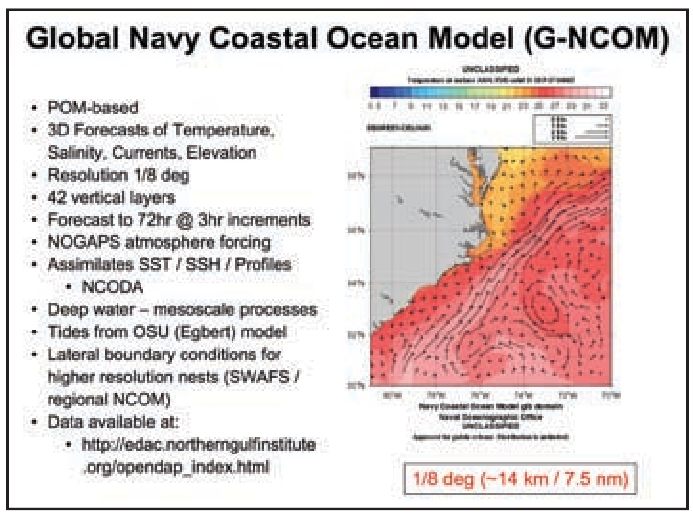


Oceanographic Products and Services (NOS/CO-OPS) operational ocean forecast centers indicate that remarkable, yet non-uniform, progress has been made since the initial MAST Workshop held in November 2006 (http://www.ocean.us/2006_model_wkshp). The present workshop was, in part, also a follow-up to two other recent workshops: (1) the NCEP Ocean Modeling Workshop held at NWS/NCEP (14 to 15 January 2008), and (2) an Initial Workshop for Creation of a National Capability for Conducting OSEs/OSSEs for the Ocean held at the NOAA/ Office of Oceanic and Atmospheric Research/Atlantic Oceanographic and Meteorological Laboratory (OAR/ AOML) (14 to 17 April 2008).

Status of OPA Activities. Initial RA investments have emphasized observing and information management subsystems, outreach, K through 12 education, and governance. Consequently, a significant amount of the RCOOS modeling progress is due to highly-leveraged project support from non-IOOS sponsored programs, which is common for R&D projects but not characteristic of operational systems. Very significant progress has been made by both the federal ocean modeling groups functioning in an operational mode, mainly at Navy NAVO and NOAA NWS/NCEP for the global/basin-scale and at NOAA NOS/CSDL and CO-OPS for the coastal/estuarine/ Great Lakes scale, and by those RCOOSes, Naval Research Laboratory (NRL), Office of Naval Research (ONR) – sponsored, and NASA-sponsored modeling groups able to function in a quasi-operational[2] mode on the regional scale.

The following NB projects illustrate present operational modeling capabilities. (For an inventory of USA NB operational ocean models made for IOC in 2007, see http://www.ocean.us/2008_model_wkshp) The NAVO (via the NOAA/NESDIS National Coastal Data Development Center (NCDDC)) makes available, on a daily basis, three-day predicted global ocean fields from the Global-Navy Coastal Ocean Model (NCOM), while NCEP provides, on a daily basis, five-day predicted North Atlantic fields from the Real-Time Ocean Forecast System (RTOFS), a Hybrid Coordinate Ocean Model (HYCOM) implementation. NOS provides one-to-two-day operational forecasts of water levels, currents, temperature, and salinity for four estuaries and the five Great Lakes. Some of the quasi-operational RCOOS modeling subsystems make, on a daily update basis, several-day, higher-resolution regional predictions of the above core physical fields.

Several modeling groups are also conducting skill assessments by comparing predictions to available observations. A few groups have begun to introduce data assimilation into their quasi-operational systems; however, assimilation of newer data types (e.g., coastal HF radar-derived surface currents and glider-sampled temperature and salinity transects) acquired by the RCOOSes is still an active R&D area. Several prediction systems include Lagrangian surface particle trajectory and dispersion predictions that are potentially useful for search-and-rescue operations, deleterious spill mitigation activities, and larval transport and dispersion, as well as fisheries



recruitment and water quality issues.
Some RCOOSes have incorporated their own mesoscale NWP systems, and a few have embraced hydrological prediction systems. Other RCOOSes have included their own regional surface wave predictions driven by global wave predictions from NWS/NCEP.

Efforts to forecast biogeochemical and/or ecological responses to physical ocean processes are under

[2] The term "quasi-operational" is used to connote continually operating, real-time ocean prediction systems that do not meet the full suite of operational ocean model attributes, in particular certification (see Appendix F "An Essay on Operational Ocean Models").

development. For example, NOS has implemented a nascent operational harmful algal bloom forecast system in the Gulf of Mexico. Elsewhere in the USA, there are apparently no operational (nor quasi-operational) biogeochemical nor ecological predictions being driven by circulation prediction systems. However, several RCOOS modeling activities include Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) marine ecosystem modeling in a R&D mode. Further, NOAA is planning an expanded effort in marine ecosystem operational modeling to support ecosystem-based approaches to fisheries science and management. The integration of ecological data with the physical models is one of the important prospects that OOI presents IOOS.

Much of the emerging operational ocean prediction capability in the civil sector has been built upon the Navy's developments made in support of its global national security missions. The civil sector has been focused on addressing the requirements of three classes of users; namely, (1) marine emergency managers, (2) maritime operators, and (3) marine environmental and ecological managers of living marine resources and marine habitats, who collectively need real-time information and hourly predictions with a several-day forecast horizon. At present, the information requirements of a fourth class of users, namely, environmental and ecological stewards, plus fisheries and climate researchers, are not adequately addressed by IOOS. These users require delayed-time, large-scale information from, for example, re-analyses (as described above) for use in retrospective diagnoses and prognostic scenarios of the global and coastal ocean projected over weeks-to-decades. Some of these users may be able to begin by using coupled ocean-atmosphere re-analyses that are emerging from the global climate modeling community, though their value is limited by the relatively coarse resolution presently available.

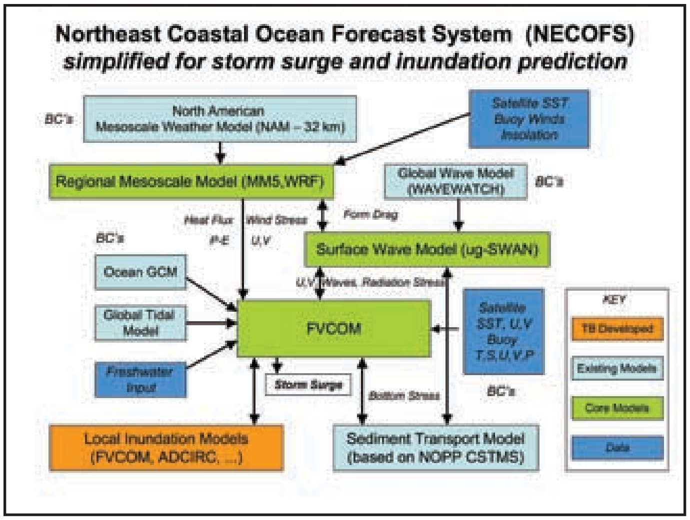
Prospects for OPA Activities. Based on the Breakout Group I & II Summaries of the second day, the role and value of the global/basin-scale NB prediction efforts in providing the RCOOSes with forcing, initial conditions, open boundary conditions, verification, and assimilation data are now recognized. Conversely, the role and value of the RCOOSes in providing the NB with additional 'critical eyes' for examining operational products and providing feedback are becoming appreciated, and RCOOS observations provided to the NB for data assimilation and skill assessment will be welcomed. Providing convenient, on-line access to real-time and archived observations and model predictions will overcome the present data management bottleneck and fully facilitate desired interactions between the NB and the RCOOSes. IOOS should also leverage the distributed cyberinfrastructure that OOI is building for efficient storage and transport of vast amounts of data (i.e., enormously larger volumes of data than presently experienced). There are some clear next steps to be taken for delivering output from diverse models in a uniform manner via standards-based Web services. However, there are many related issues yet to be resolved; e.g., should all of the model output be released or just the 'good' output, and how much model output should be archived short-term (ca. 30 da.) and long-term (in perpetuity)?

Breakout Group III dealt, rather uniquely, with coastal inundation in the broadest possible sense, i.e., it included surface wave, tidal, tsunamis, storm surge, flood, and long-term sea level change processes, because, in practice, two or more of these topics need to be considered together. Common needs of inundation modelers for bathymetric, geodetic, hydrographic, hydrological, meteorological, ecological, etc. databases were identified. Much modeling progress is needed in coupling these various phenomena across disciplines and space-time scales.

A general need was recognized for IOOS to embrace and implement a synergistic path between basic research and operations: the Navy's example of the transition between 6.1 (basic research), 6.2 (exploratory development), 6.3 (system demonstration), and 6.4 (system implementation) offers an applicable, successful paradigm. Presently, IOOS does not have an explicit R&D program and needs a champion(s) with funding for such. As a corollary, an oversight architecture is needed that coordinates funding between R&D evolutionary levels (e.g., 6.1 through 6.4). A long-term strategy and advocacy from resource sponsors is necessary to ensure continuity of development, moving from basic research that initiates new capabilities, thru development and demonstration of new technologies, and ultimately to operational implementation and assessment.

A CONOPS needs to account for those RCOOSes that will not be ready to become fully operational in the foreseeable future, yet which need to be part of the community efforts for transitioning models from R&D to operations, and which include setting standards, establishing an interoperable framework, conducting testbeds, performing skill assessments, executing OSEs/OSSEs, defining metadata standards, etc. It also needs to consider the roles of the states and the private sector, especially the value-added industry.

Data assimilation links IOOS observations to IOOS modeling. IOOS models are not yet using all of the available observational data, while IOOS is investing in convenient, not necessarily optimal, legacy (long-term) observations. Feedback is needed from modelers on requirements for "smart" observations ("smart" = strategically well-chosen variables, sites, etc.) to yield a robust observational network design, well balanced and integrated between *in situ* gliders, moored buoys, surface drifters, coastal tide gauges, meteorological buoys, etc., and remotely sensing coastal HF radars and satellites. In particular, long, "smart" time series of vertical profiles of currents, temperature, salinity, etc. are of high intrinsic value to modeling. OSEs/OSSEs are tools for measuring the impact on predictions of alternative observing systems, optimizing observing investments, and determining the value to predictions of extant and proposed observing networks, respectively. However, it should be appreciated that the applicability of results obtained from OSEs/OSSEs is somewhat inherently limited by the inevitable use of available models, data assimilation systems, and observational data retrieval systems.



In the scientifically and technologically complex and rapidly evolving area of environmental/ecosystem prediction, community development and coordination are critical. For example, the IOOS Ocean Prediction and Analysis (*nee* Modeling and Analysis) Workshop series plays a crucial role as an "information portal" connecting key personnel and projects across disciplines, sectors, and regions. In particular, communication and coordination with Canadian, Mexican, and Caribbean modelers and analysts concerned with ocean prediction will be mutually beneficial, especially for adjoining RCOOSes.

For the OPA Community, now in its early stages of development, there is widespread concern about present and prospective human resource limitations at all levels. Workforce development is an issue, in part because NSF and ONR student support continues to decrease. Support for modeling-oriented university students in general, and for USA graduate students in particular, are serious concerns.

Most of the following Findings and Recommendations were formulated based on the Plenary Session of the third day. Several additional salient points are also noted here.

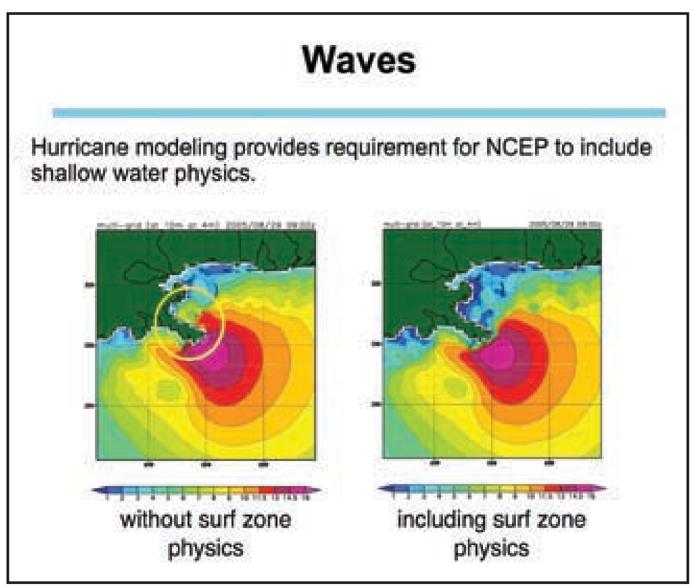
Model and Data Assimilation System Developments. Coupled wave-current interaction modeling will be a priority in the near future, and it has the potential of providing significantly improved predictions of storm surge, as well as both waves and currents.

Present trends in NWP techniques (e.g., ensembles of analyses and forecasts, ensemble of ensembles, and the very large archives utilized in reforecasting techniques) will likely "jump" to OPA. Multi-model ensemble forecasting is likely to loom large for IOOS as a means for producing better forecasts through consensus, as well as providing probabilistic application products that, in turn, can lead to risk and cost/benefit analyses. However, validation of probabilistic products can be challenging. In future IOOS planning, as the prediction system for physical variables becomes increasingly capable, a focus is needed on integrating and coupling ecological and biogeochemical models with the physical models to make ecological and biogeochemical predictions covering the full suite of societal needs for environmental and/or ecological information. For example, mesoscale-resolving, daily maps of surface and bottom mixed layer thickness, temperature, and salinity; upper ocean chlorophyll; and ice distribution, thickness, age, etc. will be in demand. Consequently, more ecosystem, biogeochemical, and sediment transport modelers should be included in future workshops to explore these and many other prediction and analysis topics.

In the coastal ocean, the scale of processes decreases exponentially approaching the coastline; thus, the spatial resolution required for coastal ocean prediction systems increases exponentially as the coastline is approached, perhaps only limited by the size of a human or equivalent, leading to an interest in variable mesh and unstructured grids. Models with such grids are promising and need further utilization and evaluation. They are also applicable to subdomains with bottom topographic anomalies. At a higher level of sophistication, adaptive grids for mobile oceanic fronts, jets, and eddies may become computationally practical. With these higher resolution grids, non-hydrostatic processes become resolved, and, hence, it may become important to switch from the hydrostatic models typically used at present to non-hydrostatic models with their higher computational demands.

The workshop focused on Eulerian models and their use in making Lagrangian predictions, a capability which underlies many applications and which must be submitted to the scrutiny of skill assessment. Conversely, in the future, it can be anticipated that Lagrangian predictions based on Lagrangian observations and models will be of interest to IOOS.

Further, the workshop focused on continually operating ("strategic") ocean prediction systems to support hour-to-hour user needs. In the future, it can be anticipated that there will also be an IOOS interest in very high (100 m or even 10 m or finer) resolution, rapidly-deployable ("tactical") ocean prediction systems to respond to environmental and ecological events.



Programmatic Developments. Just as MAST has represented the IOOS Modeling and Analysis Subsystem, and DMAC has represented the IOOS Information Management Subsystem, it would be valuable for planning and coordination of requirements and capabilities to have an analogous group representing the IOOS Remote Sensing and *In situ* Observing Subsystem.

Instances of model testbeds should be distributed around the country to cover different regimes, scales, and issues, but these should share a common infrastructure as agreed to by the community.

Finally, it is important to recognize, again, that scientific researchers are *bona fide* societal users of IOOS predictions, perhaps especially re-analyses, as well as IOOS observations, because they need the ocean state estimations IOOS will provide to accomplish their research investigations., As IOOS users, scientific researchers will provide penetrating critiques and diagnoses of the ocean prediction system, as well as of the ocean. Their feedback on the ocean prediction system performance, as well as their model and data assimilation system developments, will be invaluable for upgrading the operational systems in due course.

Overall, the workshop goal of community participation in planning the IOOS modeling and analysis subsystem was achieved. Moreover, Objective (1) fell short only in not successfully engaging the global ocean climate and mesoscale modeling R&D communities. Objective (2) fell short only with regards to the level of ecosystem framework communications. Objective (3) was achieved via the below findings and recommendations for enhancing community partnerships. Objective (4) was achieved via the below findings and recommendations for implementation in technical topic areas. Finally, Objective (5) fell well short in planning "pathfinder" R&D projects, probably due to a need for more clarity in IOOS product requirements, system design, and CONOPS; conversely, the opportunity to develop and pursue, for the first time, regional-scale science agendas based on present and prospective IOOS ocean state estimations remains an open challenge.

Findings and Recommendations. The first two Findings and Recommendations aim to carry forward the OPA Community planning, coordination, and communication activities begun by MAST.

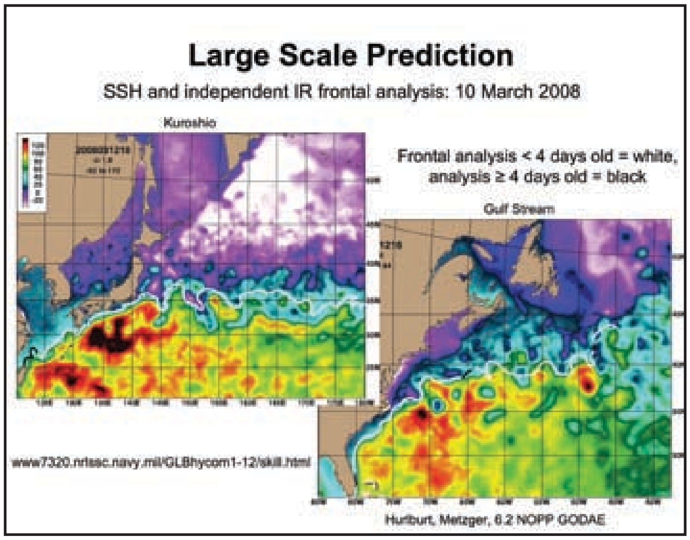
Finding I. The title "Modeling and Analysis" is abstract and does not convey adequately its outcome-based significance to laypersons and decision-makers, including those individuals with resource authority; thus, this descriptive title is an impediment to advancing IOOS efforts and implementation. The functional capability to which this term alludes is "Ocean Prediction and Analysis (OPA)", a phrase that now has broad appeal, and is critical for focusing IOOS for operational success. The "Steering Team" phrase in the MAST title suggests a group endowed with authority well in excess of the present reality. In practice, the value of an entity that brings operational and research modelers and analysts together on a multi-sector, multi-disciplinary, coastal ocean and global ocean basis has been demonstrated to be substantial for advancing IOOS.

Recommendation I. Henceforth, the term "Ocean Prediction and Analysis" should replace "Modeling and Analysis", and MAST should be replaced with an OPA Joint Working Group (OPA-JWG), whose charge and membership should be appropriately constituted. The term "joint" is used here to suggest representation from the operational and research, and federal and non-federal communities. Linking the OPA-JWG to the international community would be useful, especially to the newly formed Joint WMO-IOC (World Meteorological Organization - Intergovernmental Oceanographic Commission) Technical Commission on Oceanography and Marine Meteorology – Expert Team (JCOMM-ET) on operational ocean forecasting systems, and to the newly formed, Global Ocean Data Assimilation Experiment (GODAE)-derived working group on ocean forecasting/ocean prediction systems. Just as the IOOS Data Management and Communications (DMAC) Steering Team is concerned with the information management subsystem and can interact with OPA-JWG on topics of mutual interest, formation of an analogous working group concerned with the remote sensing and *in situ* observing subsystem would facilitate coordinated planning activities with OPA-JWG (and DMAC) and benefit the overall IOOS system design. In brief, the OPA-JWG should comprise ocean modelers and analysts from the NB and RCOOS operational and R&D communities.

Finding II. The substantial progress of the global/basin scale, regional, and estuarine operational and R&D modeling mentioned here has depended on much communication, cooperation, and, in some cases, collaboration between federal and regional groups. It is recognized that some regional modeling/prediction groups are notably more advanced than others, a few of which are just starting and need help with meeting expectations for a national network of regional coastal ocean prediction systems.

Recommendation II. To foster further professional communication, cooperation, coordination, and collaboration, multi-sector/multi-disciplinary/multi-regional IOOS OPA Workshops should be continued on at least an annual basis with IWGOO engagement and funding support. The format of these workshops will probably migrate away from discussion of concepts and opportunities toward substantive IOOS OPA forums for assessing progress and developing/revising plans, two-way exchanges with 'super users', and fundamental technical and scientific exchange. These forums will likely include "hands-on" working seminars in which operational modelers will interact with researchers interested in the installation, operation, and assessment of leading community modeling systems; e.g., ROMS, NCOM, POM, HYCOM, ADCIRC, and FVCOM; WaveWatch III (see Appendix D "List of Acronyms").

The next five Findings and Recommendations are intended to be addressed as tasks assigned by IWGOO to the OPA-JWG. A first-generation version of these tasks should be accomplished within one year.

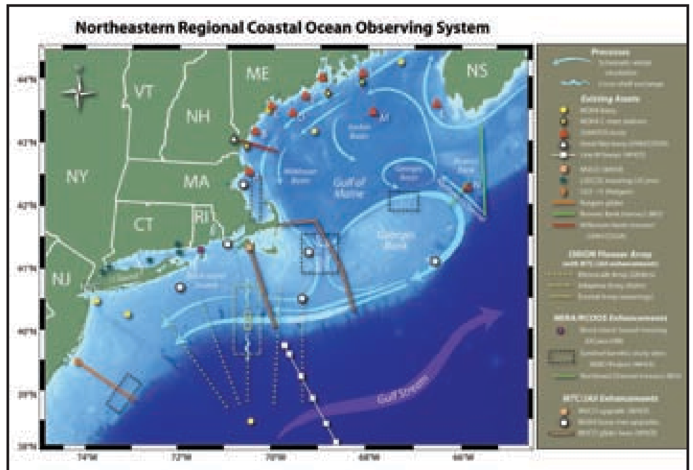


Finding III. The operational ocean prediction system for IOOS needs a design that seamlessly links the NB of observing and modeling subsystems with those of the RCOOSes, and which is guided by traceable operational requirements and documented procedures to serve user communities with environmental and ecological predictions and analyses. These requirements should be as quantified as possible, and they should lead to performance metrics for the prediction and analysis systems. Since there are various 'end user' groups which are serviced by pre-existing 'super users' (or 'intermediate users' or 'marine forecasters'), many of whom are NOAA or other federal and state employees, it would be most effective to work through the 'super users' in establishing the requirements, especially since they may have already addressed, or at least thought about, many of these issues.

Recommendation III. The OPA-JWG should be charged by IWGOO with developing a first-generation statement of traceable requirements for predictions of core variables. The RAs, selected 'super users', and value-added environmental industry representatives should be suitably engaged in the study process. Where appropriate, distinctions should be drawn between the requirements for synoptic (real-time) operational ocean prediction versus retrospective re-analyses and long-term (weeks to decades) forecasts.

Finding IV. Presently, community-wide metrics do not exist for IOOS model performance and products. Consistent community-endorsed prediction skill metrics are needed for quantitative comparisons between models and observations and between modeling techniques, for assigning generalized error bars to prediction products, and for tracking skill improvements. Various flavors of metrics are needed, such as:

1. operational performance (e.g., per cent of on-time product delivery);
2. dynamical consistency (e.g., validation of kinetic and potential energy spectra of predictions versus those calculated from observations);
3. verification of field variables (e.g., mean biases and root mean square errors of sea surface temperature and sea surface height);
4. applications-oriented characteristics (e.g., statistics of surface/bottom mixed layer depth/height, temperature, and salinity, plus particle trajectory and dispersion predictions for ecosystem-based resource management); and
5. feature-oriented and/or region-specific characteristics (e.g., the position of the Gulf Stream front and jet system off the East Coast and the position of the coastal upwelling front and jet system off the West Coast).



GOMOOS in operation since 2001. Designed as a general purpose system. System "pays for itself" in lives saved due to fog, wave and met measurements

Recommendation IV. The OPA-JWG should be charged by IWGOO with developing a first-generation suite of metrics that can be used provisionally and evaluated. Selected 'super users' and observationalists should be suitably engaged in the study process. NOS/CSDL has assembled a large set of metrics in use around the world that can be utilized and augmented. There are also lessons to be learned from recent European experience with "skill metrics" in GODAE/Marine Environment and Security for the European Area (MERSEA) program. For example, is there a global ocean metric equivalent in utility to the atmosphere's 500 mb geopotential anomaly correlation coefficient metric? Is there one for the coastal ocean?

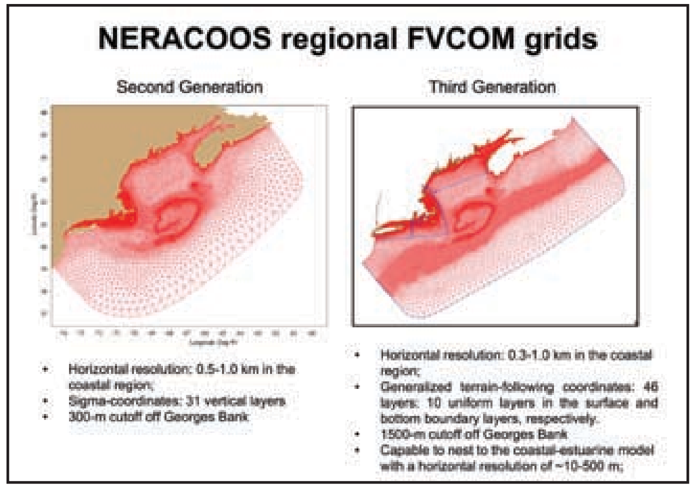
Finding V. The advance of operational and R&D ocean modeling, skill assessment, and data assimilation would be accelerated if standards are established for space-time resolution, accuracy, timeliness, etc. of various initial condition, boundary condition, and forcing information, and if such information was systematically available through the below mentioned national data portal and data archive system. The broad categories of gridded information needed include the following model input data types: bathymetric/topographic; hydrological (e.g., river discharge, ground water discharge, non-point source freshwater discharge, precipitation, and water quality); atmospheric forcing (e.g., surface wind stress and pressure, heat flux, evaporation, and precipitation); mesoscale-admitting global/basin scale model fields of waves, sea surface height, temperature, salinity, horizontal and vertical velocity, etc. over the water column; sea ice (thickness, type, age, distribution, etc.); and, eventually, biogeochemical and ecological fields.

Recommendation V. The OPA-JWG should be charged by IWGOO with developing a first-generation summary of the modeling community's observational data requirements and standard space-time resolution, accuracy, etc. attributes for the forcing and other data outlined above as guidance for the national data portal and data archive system design discussed below. Selected observationalists and cyberinfrastructure experts should be suitably engaged in the study process. Coordination with DMAC would be appropriate.

Finding VI. The progress of the NB and RCOOS modeling and analysis community would be greatly facilitated by a "one-stop shopping", national data portal for NB (and RCOOS) observational data and model fields. One proposed scheme, stemming from OOI, is a distributed, standards-based system utilizing existing and emerging technology to efficiently handle massive datasets. Another proposed scheme comprises centralized "data tanks" with operational forecasts placed in a "hot archive" (ca. 1 to 2 days at e.g., NWS/NCEP), a short-term archive (ca. 30 days at e.g., NESDIS/NCDDC)), and a long-term archive (in perpetuity at e.g., NESDIS/NODC). Note that these two schemes are not mutually exclusive, but complementary, with the first approach focusing on standards and distributed systems, and the second focusing on a sustainable (federal) system. With either scheme, it is essential to formulate standard data model formats for all commonly used forecast model products (e.g., those on unstructured grids, as well as those on structured grids), deliver these standardized data streams via standard Web services, and supply toolkits that facilitate the use of these services. At the same time, the standards need to be flexible and adaptive; otherwise, continuing progress will be stymied. Altogether, the national data portal and data archive component of the IOOS information management subsystem would enable broad societal use of IOOS observational data, predictions, analyses, and related information.

Recommendation VI. The OPA-JWG should be charged by IWGOO with developing a first-generation conceptual design and implementation plan for a national data portal and archive strategy for IOOS. Selected cyberinfrastructure experts and ocean scientists, specifically including ecological, biogeochemical, and sediment transport modelers, should be suitably engaged in the study process. The standards and standards-based toolsets that need to be implemented (and/or developed) should be identified to ensure that the national data portal and archive system can be efficiently used by the OPA community and others. Coordination with DMAC, and with the present Navy (NAVO)/NOAA (NCEP, NCCDC, & NODC) effort to establish a 24-by-7 operational data management system, will be important.

Finding VII. RCOOS (RA) and NB (federal) prediction and analysis activities have much to gain from each other. For



example, the RCOOS scientific community can contribute to the skill assessment of the NB global/basin-scale models from the perspective of their regional expertise. Conversely, the NB entities can contribute model fields to the RCOOSes for their use as open boundary conditions applied to higher-resolution regional models. As another example, with adequate financial support and workforce planning by, and for, the NB entities, the RCOOS community can contribute strongly to the education and development of the future workforce needed for both the operational and R&D dominions of IOOS. Cooperative co-existence between NB and RCOOS prediction and analysis entities, integrated activities, and products are needed for the overall ocean prediction system design. An initial Concept of Operations (CONOPS), derived from user requirements, and a clear definition and understanding of the problem set to be addressed by IOOS, is essential to the rational design and implementation of the first-generation operational ocean prediction and analysis subsystem of IOOS. The CONOPS is anticipated to evolve with operational experience, technological developments, scientific understanding, and growth in societal demands for environmental and ecological information.

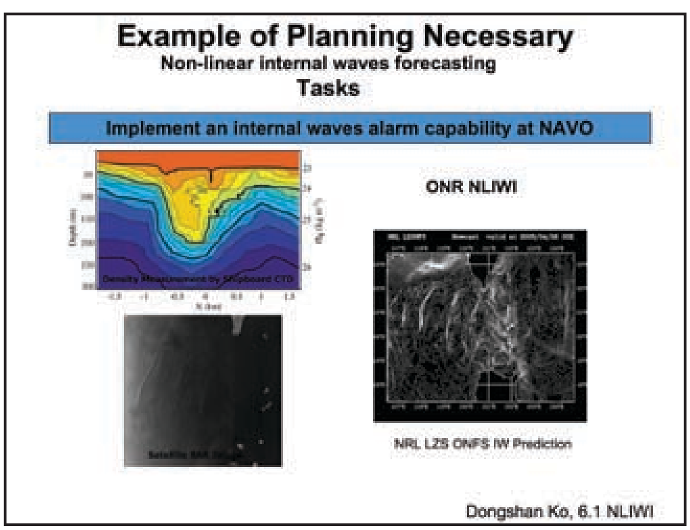
Recommendation VII. The OPA-JWG should be charged by IWGOO with developing and drafting a first-generation CONOPS for the IOOS ocean prediction and analysis subsystem, delineating the prediction and analysis roles and responsibilities of the NB and RCOOSes. For example, mechanisms would be proposed by which the non-government research community could access elements of the NB (data streams and model configurations) for experimental development and skill assessment. In turn, the NB could transition new algorithms, methodologies, and prediction products from the RCOOSes to operational use. There would be some truly joint activities that should be undertaken; e.g., the adoption of common modeling frameworks that promote interoperability, the design of infrastructure for testbeds, and the operation of testbeds for the support of ocean prediction experiments evaluating the skill of existing and prototype systems. If necessary, other experts should be suitably engaged in the study process.[3]

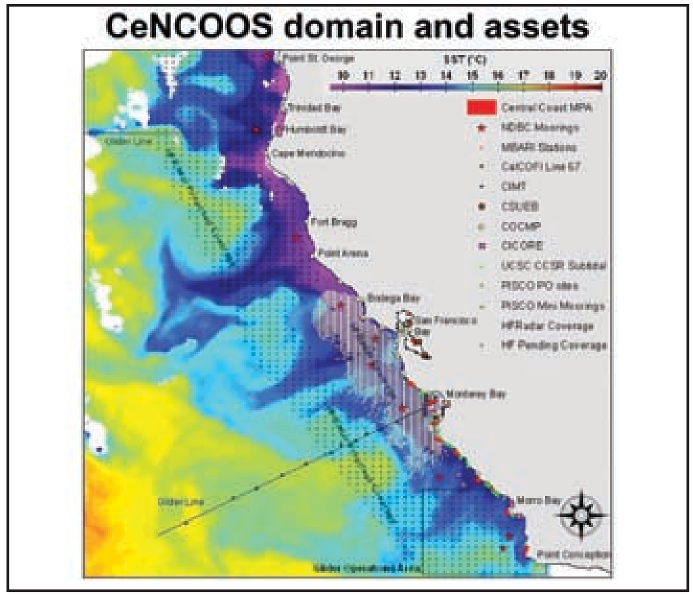
[3] Logically, a CONOPS would be developed for each of the other two IOOS subsystems, and the three CONOPS would be coordinated and rationalized into an overall IOOS CONOPS.

The next Finding and Recommendation is intended to produce a "great leap forward" for IOOS by capitalizing upon the Navy's operational ocean predictions to provide a first-generation capability in the USA EEZ.

Finding VIII. NAVO's Global NCOM has been running operationally with deep water (global ocean) mesoscale-admitting (i.e., 1/8 degree) resolution and data assimilation for several years, providing open-boundary conditions to several operational regional NCOM models around the world. The R&D community has had access to these fields through NCDDC for nearly four years and has used them for conducting analyses and downscaling to their IOOS regions or other subdomains of interest. NCOM model data are now also becoming available in near-real-time with 7/24 support through NOAA/NCEP. NAVO currently downscales NCOM to domains that cover some of the IOOS regions with 3-to-5 km resolution for operational Navy support. These predictions could be made available, benefiting both NOAA and the RCOOSes, which could then focus on nesting regional models with the 1-km or finer resolution needed to resolve shallow water (coastal ocean) mesoscale variability and ecological processes. A CONOPS would need to cover the roles and responsibilities of the Navy production center (NAVO), the NOAA operational centers, and the RCOOSes, for example, with respect to consistent skill assessment procedures (advocated in Recommendation IV) relative to this invaluable Navy information resource. Interestingly, to address skill in representing the mesoscale variability manifest in the coastal ocean observations, it may be important to skill assess the NB predictions indirectly through examination of the output of the high-resolution downscaled predictions.

Recommendation VIII. Formal requests should be simultaneously submitted by IWGOO to the Chief of Naval Operations/Oceanographer of the Navy (CNO-N84)) and CNMOC for NAVO to provide the analysis and forecast fields from Global-NCOM and regional nests of NCOM that cover the USA EEZ; i.e., covering the 11 RCOOS domains, as described above. The request should note the benefits of this activity to the Navy; e.g., providing additional skill assessments of operational prediction products, fostering the transfer of new technology from the R&D community to the Navy, and recruiting technical personnel from academia and elsewhere thru positive, professional interactions with the OPA Community.





The final Finding and Recommendation aims to provide a strong, logical basis for the design, implementation, operation, management, assessment, and evolution of IOOS.

Finding IX. Certain ocean prediction system development and evaluation activities involve federal, academic, and private sector participants, at both the NB and RCOOS levels, lending themselves to partnerships, through a CONOPS, that build on the necessity and value of proceeding with a community consensus approach. Examples include: development and maintenance of prediction system metrics; design and operation of model testbeds ("model evaluation environments"); thorough model skill assessments; and design and evaluation of OSEs/OSSEs, sensitivity studies, diagnostic analyses, etc. From another perspective, these activities constitute elements of a Systems Engineering (SE; see Appendix G "Commentary on Systems Engineering") approach to designing, operating, evaluating, representing (explaining/justifying), and evolving the IOOS ocean prediction system.

Recommendation IX. The programmatic infrastructure outlined above should be incorporated into a SE design, implementation, management, and assessment strategy for IOOS. To build community awareness and consensus, the SE activity should commence with a pilot study, led by ocean scientists working with systems engineers, to introduce carefully the SE methodology to the IOOS community and to explore fully its applicability to the IOOS topic area.

APPENDICES

Appendix A. Organizing Committee

Chris Mooers, MAST Chair
Frank Aikman, MAST Vice-Chair
C.J. Beegle-Krause, MAST Vice-Chair
Tom Malone, MAST
Oscar Schofield, OOI
Mark Moline, OOI
John Wilkin, NFRA/MAST
Richard Signell, NFRA
Yi Chao, NFRA/OOI

Appendix B. IOOS Modeling and Analysis Workshop Agenda

Dates: 22 to 24 July 2008
Location: Arlington Residence Court Hotel, Arlington, VA
Co-Sponsors: Ocean.US/MAST, OOI, and NFRA

DAY I. PLENARY

0800 – Register, submit PowerPoint presentations, Continental Breakfast
0830 – **Background, Motivation, and Expectations**, Chris Mooers

RA/RCOOS modeling & observing subsystems: (1) Vision, (2) Status, and (3) Plans,
Session Chair/Hendrik Tolman

0845 – GLOS, David Schwab
0900 – NERACOOS, Rich Signell
0915 – MACOORA, John Wilkin
0930 – SECOORA, Chris Mooers (for Mark Luther)
0945 – CaRA, Jorge Capella (for Jorge Corredor)
1000 – Coffee Break
1015 – GCOOS, Chris Mooers (for Buzz Martin)
1030 – SCCOOS, Yi Chao
1045 – CENCOOS, Francesco Chavez
1100 – NANOOS, Antonio Baptista
1115 – AOOS, Yi Chao (for Mark Johnson)
1130 – PacIOOS Chris Mooers (for Jim Potemra)
1145 – **OOI plans and preparations**,
-Oscar Scofield, Session Chair/Chris Mooers
1215 – Lunch

"National Backbone" operational models and remote & *in situ* observations and assorted analysis topics
Session Chair/Rich Signell

1330 – Navy ocean models and observations, Steve Payne
1400 – NOAA/NWS global & basin scale ocean models and observations, Hendrik Tolman
1430 – NOAA/NOS intermediate & regional (coastal & estuarine) operational ocean modeling, Frank Aikman
1500 – Coffee Break
1515 – NOAA marine ecological forecasting framework, Marie Colton
1545 – ECCO-GODAE results & coastal ocean data assimilation, Ross Hoffman
1615 – NRL model skill assessment datasets, Gregg Jacobs
1645 – HYCOM-GODAE downscaling to coastal ocean, Bob Weisberg
1715 – Day I Synopsis, Panelists: Hendrik Tolman, Rich Signell, Oscar Schofield, and Chris Mooers
1730 – Adjourn for the day
1730 – No-Host Reception

DAY II. Three Breakout Groups (BGs)

(1) Pacific 3D circulation and marine ecosystems (baroclinic), Co-Chairs, Yi Chao and Frank Bub
(2) Atlantic 3D circulation and marine ecosystems (baroclinic), Co-Chairs, John Wilkin and Avichal Mehra
(3) Coastal 2D inundation and coastal ecosystems (barotropic), Co-Chairs, Rick Luettich and Frank Aikman

0800 – Continental Breakfast
0830 – **A few initial thoughts on common interests of IOOS R&D and operational communities (e.g., RCOOSs and National Backbone, scientific questions and experiments, skill assessment, and interoperability)**, Chris Mooers
0845 - **BG Session I: regional-scale science agenda development**
(e.g., RCOOS design considerations, scientific questions, and experimental designs)
1000 – Coffee Break
1015 – Continue BG Session I

First BG Preliminary Summaries, Plenary Chair, CJ Beegle-Krause

1130 – BG (1) Yi Chao & Frank Bub
1140 – BG (2) John Wilkin & Avichal Mehra
1150 – BG (3) Rick Luettich & Frank Aikman
1200 – Lunch

1300 – **Emerging Cyber-Infrastructure Capabilities, etc.**
- Rich Signell, Session Chair/Chris Mooers

1330 – **BG Session II: programmatic opportunities and requirements** (i.e., follow-ups from BG Session I)
- resources available
- additional resources required
- timelines
- observational & model data access (portals, servers, inventories, archives, etc.)
- data assimilation modules, etc.

1445 – Coffee Break
1500 – Continue BG Session II

Second BG Preliminary Summaries, Plenary Chair, Mark Moline
1630 – BG (1) Yi Chao & Frank Bub
1640 – BG (2) John Wilkin & Avichal Mehra
1650 – BG (3) Rick Luetich & Frank Aikman
1700 – DAY II Synopsis, Panelists: Frank Aikman, CJ Beegle Krause, Mark Moline, and Chris Mooers
1730 – Adjourn for the day

DAY III. BGs (same three)
0800 – Continental Breakfast
0830 – **Results of a recent Ocean OSE/OSSE Workshop**, Chris Mooers (for Bob Atlas)
0845 – **BG Session III: programmatic needs** (i.e., follow-ups from BG Sessions I & II)
- skill assessment (testbeds, metrics, ocean prediction experiments, etc.)
- OSEs/OSSEs
- potential NOPP "pathfinder topics"
- RCOOS Systems Engineering Designs
- RCOOS & National Backbone partnerships, desirable attributes for (e.g., CONOPS: roles & responsibilities; division of labor; standards)

1000 – Coffee Break
1015 – Continue BG Session III

Third BG Preliminary Summaries, Plenary Chair, Steve Payne
1130 – BG(1) Yi Chao & Frank Bub
1140 – BG (2) John Wilkin & Avichal Mehra
1150 – BG (3) Rick Luettich & Frank Aikman
1200 – Lunch

Final BGs Overall Summaries, Plenary Chair, Rich Signell
1300 – BG(1) Yi Chao & Frank Bub
1320 – BG (2) John Wilkin & Avichal Mehra
1340 – BG (3) Rick Luettich & Frank Aikman
1400 – **Plan of Action**, Chair, Chris Mooers
- Recommendations for NOPP, IWGOO, OOI, RCOOS, et al. on infrastructure (including the roles and responsibilities linking operational centers & RCOOSs) needed to support the advance of global ocean and coastal ocean modeling in a marine ecosystem forecasting framework for both R&D and operations
- Formation of topical working groups for follow-on re: infrastructure needs, "pathfinder projects", etc.
- Production of WS report (summary, plenary talk PPTs, breakout group reports, etc.)

1500 – **Workshop Adjourns**

Appendix C. List of Workshop Attendees

Last Name	First Name	Organization	Email
Aikman	Frank	NOAA-NOS-CSDL	frank.aikman@noaa.gov
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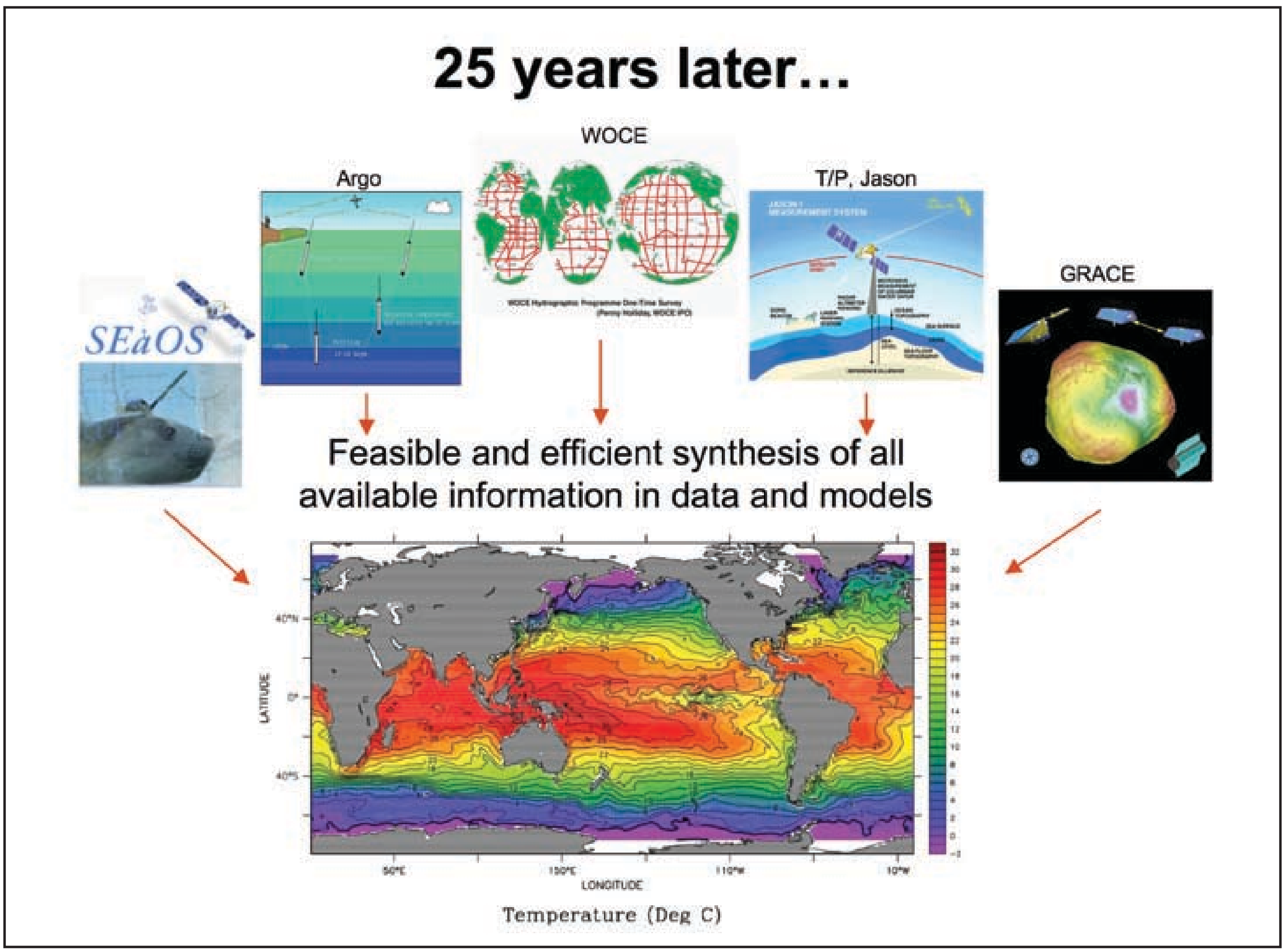
Zheng	Lianyuan	USF	lzheng@marine.usf.edu



Appendix D. List of Acronyms

ADCIRC	Advanced Circulation Model
AOML	NOAA Atlantic Oceanographic and Meteorological Laboratory
CI	Cyber-Infrastructure
CNMOC	Commander Naval Meteorology and Oceanography Command
CNO	Chief of Naval Operations
COL	Consortium for Ocean Leadership
CONOPS	Concept of Operations
CO-OPS	NOAA Center for Operational Oceanographic Products and Services
CSDL	NOAA Coast Survey Development Laboratory
DMAC	IOOS Data Management and Communications Steering Team
EEZ	Exclusive Economic Zone
FVCOM	Finite Volume Coastal Ocean Model
GODAE	Global Ocean Data Assimilation Experiment
HYCOM	Hybrid Coordinate Ocean Model
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated Ocean Observing System
IWGOO	Inter-Agency Working Group on Ocean Observations
JCOMM	Joint IOC-WMO Technical Commission for Oceanography and Marine Meteorology
MAST	IOOS Modeling and Analysis Steering Team
MERSEA	Marine Environment and Security for the European Area
MMS	Minerals Management Service
NASA	National Aeronautics and Space Administration
NAVO	Naval Oceanographic Office
NB	National Backbone
NCDDC	NOAA National Coastal Data Development Center
NCEP	NOAA National Centers for Environmental Prediction
NCOM	Navy Coastal Ocean Model
NESDIS	NOAA National Environmental Satellite and Data Information Service
NFRA	National Federation of Regional Associations
NMFS	NOAA National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NODC	NOAA National Oceanagraphic Data Center
NOS	NOAA National Ocean Service
NPZD	Nutrient-Phytoplankton-Zooplankton-Detritus Ecosystem Model
NRL	Naval Research Laboratory
NSF	National Science Foundation
NWP	Numerical Weather Prediction
NWS	NOAA National Weather Service
OAR	NOAA Office of Oceanic and Atmospheric Research
OOI	NSF Ocean Observing Initiative
ONR	Office of Naval Research
OPA	Ocean Prediction and Analysis
OPA-JWG	Ocean Prediction and Analysis – Joint Working Group
OSE	Observing System Experiment
OSSE	Observing System Simulation Experiment
POM	Princeton Ocean Model
RA	Regional Association
RCOOS	Regional Coastal Ocean Observing System
R&D	Research and Development
ROMS	Regional Ocean Modeling System
RTOFS	Real-Time Ocean Forecast System
SE	Systems Engineering
USA	United States of America
USACE	U. S. Army Corps of Engineers
USGS	U.S. Geological Survey
WFO	Weather Forecast Office
WMO	World Meteorological Organization

Appendix E. List of Regional Associations (Acronyms)

Great Lakes Observing System (GLOS)

Northeast Regional Association Coastal Ocean Observing System (NERACOOS)

Middle Atlantic Coastal Observing Regional Association (MACOORA)

Southeast Coastal Observing Regional Association (SECOORA)

Caribbean Regional Association (CaRA)

Gulf of Mexico Coastal Ocean Observing System (GCOOS)

Southern California Coastal Ocean Observing System (SCCOOS)

Central and Northern California Coastal Ocean Observing System (CENCOOS)

Northwest Association of Networked Ocean Observing Systems (NANOOS)

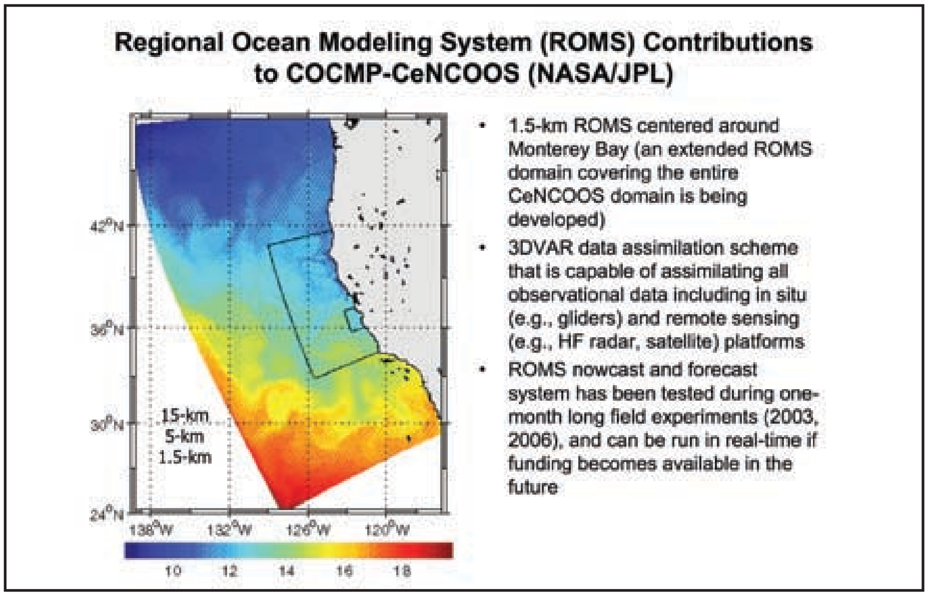
Alaska Ocean Observing System (AOOS)

Pacific Islands Ocean Observing System (PacIOOS)

Appendix F. An Essay on Operational Ocean Models

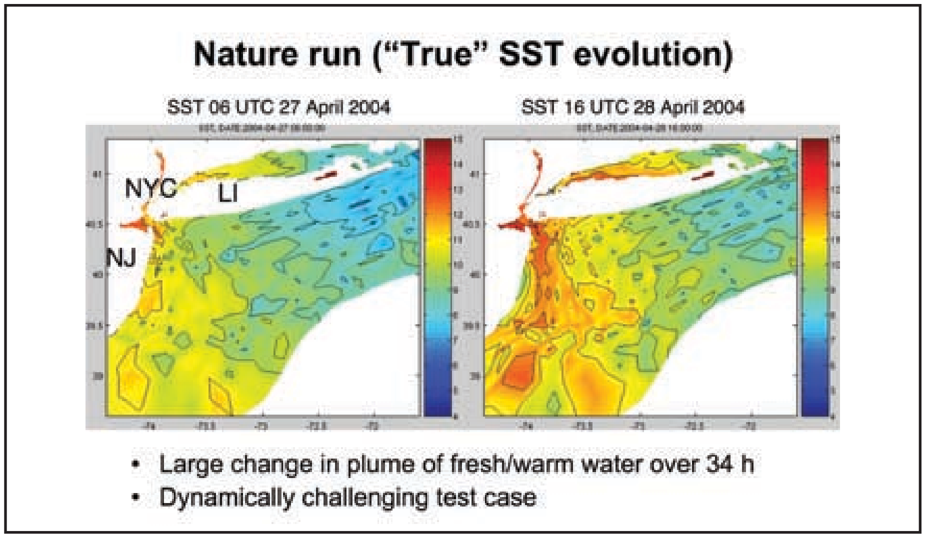
[by Chris Mooers with substantial input from Rich Signell and comments from Alan Blumberg,
Yi Chao, Ming Ji, Reginald Beach, Ross Hoffman, Josie Quintrell, Hendrik Tolman, and Gregg Jacobs]

Background. The topic of "operational (ocean) models" often arises and frequently leads to heated, circular discussions. Because it has been stated that the IOOS RAs will run RCOOS activities, including numerical forecast models, in an "operational" mode, it is important to provide some clarity to the subject of "operational ocean models". {BTW, similar logic would pertain to the RCOOS observing subsystems and information management subsystems, as well as to the models that are central to the ocean prediction and analysis subsystems discussed here.} In other words, in the USA, operational ocean models are not exclusively in the provenance of NCEP, CSDL/CO-OPS, and NAVO, but there are strictures as discussed below.



Discussion. No official (i.e., authoritative), universal definition of an operational ocean model seems to exist; however, thru interactions with practitioners, the following characterization has been surmised. Operational ocean models should have the following attributes:

- they respond to (formally established and/or officially sanctioned) user-requirements for field variables, timeliness, resolution, accuracy, etc.
- they function in "real time" (as defined by applications)
- they are numerical models that run automatically
- they operate continually (24 x 7 x 52), which implies adequate measures need to be in place to handle exigencies around the clock, including nights, weekends, and holidays
- they produce and deliver products ("numerical guidance") on a schedule to "marine forecasters" or 'super users'; i.e., on-time product delivery is essential
- their products perform with a specified degree of reliability and resiliency, which includes arrangements for alternative air conditioning services, power supplies, computational resources, and products from alternative operational models, etc., and which may entail the establishment of remote "mirror sites" separated at a significant geographical distance
- their operation and maintenance is sustained and assured by a sponsor's (or sponsors') long-term commitment to financial support
- they are documented in the refereed literature and with technical reports and metadata
- their results are reproducible
- their operational products are distributed with "tags" that unambiguously describe the version of the model used; hence, a managed, controlled, and well-defined configuration system is required
- they are skill-assessed with common metrics to establish "error bars" and, thus, meet the standards of the pertinent professional community
- some skill –assessments need to be conducted in real-time to track the performance of the ongoing operational system
- these skill-assessments are performed in an open, community-based, peer-reviewed fashion to ensure credibility and utility
- their products are increasingly accompanied by probabilistic uncertainty estimates for the more sophisticated 'super users'
- they are 'inoculated' against liability, typically by distributing products thru governmental channels (e.g., Weather Forecast Offices (WFOs)), or by affixing a disclaimer to products that describes them as advisory only, not official warnings;



noteworthy is that Congress is considering IOOS legislation that would indemnify the RAs; surely, in regard to liability issues, there should be a distinction between numerical guidance of core field variables delivered to ‘super users’ and public warnings of hazards to lives and property issued by ‘marine forecasters’

- they are supported technically by a continuing R&D program that analyses their performance and develops upgrades for the modeling and data assimilation subsystems
- they are “certified” by a government agency or a professional association to meet the above standards.

Alternatively, as quoted from the “IOOS Community Modeling Prospectus” (Ocean.US, 9 SEP 06): “To be operational, a model must meet the following criteria: (1) provides reliable predictions (hind-, now- or fore-casts) used by decision makers responsible for one or more of the seven [IOOS] societal goals; (2) provides such predictions in forms and at rates approved by the users (on a schedule or on demand); (3) performs model operations, including quality control, under the guise of a sponsor in an institutionalized fashion; and (4) meets performance standards agreed to by both operators and users.”

NOTE: the above-cited Ocean.US document provides the rationale behind the formation of MAST and the delineation of its charge.

These two characterizations are mutually consistent and differ mainly in their degree of detail and mode of expression. The overall approach to operational model certification might find a useful framework in the ISO 9000 certification process developed by the NATO Undersea Research Centre (http://en.wikipedia.org/wiki/ISO_9000). In general, the framework includes:

- establishing a set of procedures that cover all key processes in modeling
- monitoring processes to ensure they are effective
- keeping adequate records
- checking output for defects, with appropriate corrective action where necessary
- reviewing, on a regularly basis, individual processes and the quality system itself for effectiveness
- auditing of the system and system artifacts by internal and external experts, and
- facilitating continual improvement.

Accordingly, the RAs (and the IOOS-NB) should:

- develop a plan to guide the modeling workflow, identify metrics for performance, define the delivery system, and set meeting and reporting schedules;
- document the plan;
- meet regularly to see how well the plan is being followed: if the work is not proceeding according to the plan, address the problems with the work, or the problems with the plan; and
- conduct independent reviews periodically to see if the organization is following the plan.

NOTE: there are also “non-real-time” ocean model applications at the RA level (e.g., model-based “what if” scenarios, event reconstructions, and re-analyses that are run on demand) that would benefit from the above professional discipline.

Recommendations. The above thoughts need to be further vetted by the sub-community of ocean modelers concerned with operational models, and by other interested parties. {Significantly, strict adherence to the above stringent notions leads to the conclusion that no fully operational ocean models may yet exist! However, NAVO, for example, runs useful ocean models that they consider operational based on satisfying the Navy’s established acceptance procedures that have been long-established for operational atmospheric models. They meet most if not all of the above attributes.} These thoughts need to be conflated with the development of a CONOPS design for the NB and RCOOSes, and with the plans to certify RAs. Finally, the Systems Engineering design needed for IOOS should incorporate the topics discussed here.

Appendix G. Commentary on Systems Engineering (SE)

In the course of the workshop, it became clear that some participants were not familiar with Systems Engineering (SE) and others were not “comfortable” w/SE based on a limited experience with a SE study, conducted a few years ago, applied to the cyberinfrastructure of the IOOS information management subsystem. An informative and short (i.e., only three pages long) introduction to SE by leading practitioners can be accessed thru:

http://www.incose.org/practice/fellowsconsensus.aspx

Of related interest, a New York Times front page article on 25 June 2008 entitled: “Top Engineers Shun Military; Concern Grows” highlights a number of DOD and NASA projects that failed to use SE logic and ended up as costly disasters.