Initial Workshop for the Creation of a National Capability for Conducting OSEs/OSSEs for the Ocean

Miami, 14 – 17 April 2008

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EXECUTIVE SUMMARY

From April 14-17 2008, a workshop was held at NOAA’s Atlantic Oceanographic and Meteorological Laboratory to consider the need for a rigorous and comprehensive Observing System Simulation Experiment (OSSE) capability for oceanographic science and operations. Approximately 40 scientists (researchers and managers) participated. These included representatives from NOAA and Navy research and operational entities, and from NASA, and academic research institutions throughout the Nation.

These scientists considered the current state of ocean OSSE capabilities. Based on successful experience in the atmosphere, they considered the rationale, methodology, and approaches for conducting ocean Observing System Experiments (OSEs) to evaluate existing observing systems, and Observing System Simulation Experiments (OSSEs) to evaluate potential observing systems. OSEs or OSSEs, respectively, can help assess the impact of extant or potential in situ and remote sensing observations on the skill of data-assimilative forecast models. The standard approach is to generate a high resolution, very realistic Nature (model) Run (NR) that can be treated as the “true ocean”. A community-based consensus skill assessment of the NR is an important task at this step. The NR is then sub-sampled according to the space-time sampling protocol of the observing system of concern. Insertion of the error characteristics of the observing system is an important task at this step. The sub-sampled fields are then assimilated into a second (typically a reduced-physics, numerically simpler, faster operational) model, and its change in forecast skill is then assessed as a function of the candidate observing subsystem’s attributes. These tasks are typically accomplished by different scientific groups to distribute the effort, ensure a community-consensus, and help maintain objectivity.

Subsequently, two thematic Breakout Groups were formed for detailed deliberations. One group considered the global and basin-scale ocean, including weather and short-term climate time scales. The other group considered the intermediate (large regional) and coastal ocean, including local, rapidly-relocatable, and adaptive observing systems. Both breakout groups addressed approaches, skill assessment for NRs, candidate alternative observing systems, OSE/OSSE designs, computational resource needs, skill-assessed NRs, human resources, goals and objectives, nominal schedules, and next steps. The final plenary session considered the management of OSEs/OSSEs, performance of ancillary (e.g., sensitivity) studies, and development of an OSE/OSSE Program Prospectus for NOPP and other potential sponsors to consider.

The workshop concluded that establishing a credible Ocean OSSE System is essential for ocean, weather and climate research and applications, and that its development should be initiated at the
earliest possible time. In establishing the desired ocean OSSE capability, it is essential to engage diverse areas of expertise, including numerical modeling, observations, dynamics, and data assimilation in order to identify the most promising areas for short-term gains and the long-term model and data assimilation improvements necessary for more comprehensive high-fidelity global and coastal ocean simulations and assessments. Continuity in support of the workshop’s goals should be pursued through an interagency ocean OSE/OSSE working group, with near-term goals to leverage existing efforts for some pilot studies/projects/partnerships. A consensus recommendation for a near-term target is funding for nature run evaluation/verification work. This work, is fundamental to all subsequent analyses and decision-making. Other recommendations include 1) Infrastructure to enable groups to share OSE/OSSE-enabling data and initial evaluation reports (2 years); 2) encourage immediate exercising of first-generation OSEs/OSSEs to develop/evaluate capabilities to utilize nature runs and data streams (3-5 years); 3) utilize OSEs/OSSEs to evaluate present and future observations, data assimilation, and complementary evaluation capabilities (3+ years); 4) exercise full OSE/OSSE capabilities (5+ years); and 5) produce and evaluate more comprehensive candidate nature runs (5-10 years).

Dr. Robert Atlas
Convener
FINAL REPORT

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• Objectives
To assemble researchers from diverse communities to define the topic area of ocean Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs). Specific objectives were to 1) frame the requirements, gaps and issues involved in establishing a national capability for ocean OSEs and OSSEs, 2) identify needed computational and other resources, 3) strengthen partnerships, and 4) outline an action plan to implement and coordinate an ocean model assessment system and a national program of rigorous OSEs/OSSEs.

• Motivation: Why is this important?
NOAA, NASA and the Navy desire a strategic framework for ocean and coastal data requirements, addressing needs in terms of a constellation of in situ and remotely-sensed observation systems, while balancing what is necessary for research, operational forecasting, and tactical applications. Such a framework will consider alternative instruments/platforms, risk reduction, and transition strategies in the context of system optimization, forecast skill impact assessments, and cost-benefit considerations through appropriate sensor simulation studies and/or numerical analyses, such as OSEs and OSSEs, as well as independent cost analyses. Through informal discussions, planning sessions, and management requests for quantified impact assessments, the requirement for an ocean science community capability to perform ocean Observing System Simulation Experiments (OSSE) and Observing System Experiments (OSEs) has become clear. The basic requirement is for OSE and OSSE results to support the optimal design of ocean observing and data assimilation systems, specifically with regards to quantifying and optimizing the investments and value of existing and proposed ocean observing systems in the context of the Integrated Ocean Observing System (IOOS) and the Global Ocean Observing System (GOOS). The timing for such an endeavor appears to be at hand, given the recent creation of the NOAA/IOOS Program Office (IOOS serves as the national contribution to GOOS), and the near-term focus of the Ocean Research Priority Panel on the initiation of an Atlantic meridional overturning circulation observing and prediction system.
Applications for OSEs/OSSEs span a broad spectrum, including addressing the following types of questions:

- What instruments and variables are most needed?
- With these assets, how good is the solution likely to be?
- What are the optimal horizontal and vertical resolutions of observations for ocean prediction?
- Where is improved coverage needed?
- What are the accuracy requirements of the observations?
- What is the optimal mix of observing assets and what are the trade-offs for various resource/observation options?
- Why should a certain sensor be funded? Which of a choice of sensors should be funded?
- What is the marginal cost and benefit for additional observations?
- What is the impact of specific observations on different aspects of the forecast (e.g., location, new parameter, data loss)?
- Does the prediction meet mission requirements given the present asset allocation and sampling strategy? If not, should asset allocation be increased, sampling strategy modified, and/or mission area, duration, or requirements be reduced?
- What is the impact of different assimilation methods and what improvements to data assimilation and/or quality control procedures are most needed?
- How should future sensors be designed?
- What are the benefits of an observing strategy, i.e., what are the societal outcomes?
- How should field campaigns be designed?

### Background

Ocean OSSEs consist of controlled, quantitative assessments of the value/impact of a system of observations, determined through sophisticated numerical ocean models of governing dynamical, thermal, and radiative processes. Typical OSSEs include five major steps:

1. Identification or generation of an appropriate “Nature Run” (assumed truth) that is validated against available observations;
2. Computation of synthetic observations from the nature run;
3. Characterization of observational error attributes to be applied to assimilated synthetic observations;
4. Assimilation of the simulated observations into a forecast model (typically different from the Nature model and referred to as the operational model); and
5. Evaluation of the added value of the assimilated observations in terms of increased analysis and forecast skill and other metrics.

The first step in the development of the ocean OSSE capability should be to identify a model (or models) that can be used as a Nature Run. Models to be used as a Nature Run should, as free-running (i.e., without data assimilation) models, be able to reproduce the main statistical-dynamical characteristics of the ocean with reasonable fidelity to reality and have a documented history of reliable performance. Limited near-term progress on ocean OSSEs can be made even if not all ocean variability and processes are realistically simulated as long as the physics behind the specific process(es) being studied are reasonably reproduced. The next major task is identifying assimilating forecast models and assimilation systems that will constitute the
operational model. Lessons learned from the Global Ocean Data Assimilation Experiment (GODAE), such as downscaling to regional and coastal ocean models, should be helpful. Attributes of both of the main modeling elements (Nature Run and operational model) can be categorized by domain size (e.g., global versus coastal) and time scale (e.g., synoptic (ocean weather) versus climate). Ultimately, an eventual national OSSE capability needs to encompass ecosystem and fisheries models, in addition to ocean climate and “ocean weather” models; however, it was agreed that the focus of the initial capability would be the physical models. Existing diagnostic tools, plus generic and application-dependent metrics, need to be evaluated and a common set adopted in order to intercompare modeling quality, impacts, and forecast skill. In establishing the desired ocean OSSE capability, it is essential to engage diverse areas of expertise, including numerical modeling, observations, dynamics, and data assimilation in order to identify the most promising areas for short-term gains and the long-term model and data assimilation improvements necessary for more comprehensive high-fidelity global and coastal ocean simulations and assessments.

- Outline

The workshop had four plenary sessions, consisting of prepared talks coupled with informal panel discussions, and breakout sessions for discussing global/basin-scale and intermediate/coastal considerations. The subjects of the plenary sessions were: 1) Why ocean OSSEs are needed; 2) OSE/OSSE methodology; 3) Ocean OSE/OSSE approaches, based on the state of the science; and 4) Resource requirements versus availability. Presentations covered: present and anticipated in situ and remote sensing data types and systems; general OSSE methodology; methods and applications of OSEs in GODAE; efficient allocation of observational resources using OSSE results; OSSE models and tools; model skill assessment; and resource requirements. The workshop concluded with discussion of next steps.

- Issues

The core consensus issue is the need to establish a national capability (backbone) supporting global/intermediate/coastal-scale ocean OSEs/OSSEs addressing synoptic to climate timescale investigations. This national backbone requires appropriate community-evaluated nature runs, data-assimilating forecast models, infrastructure to host data and results, as well as computational capacity, access/dissemination capabilities, and community-supported standardized evaluation metrics. A consensus recommendation promotes developing the infrastructure to facilitate use of OSEs/OSSEs by local groups for specialized local applications, linking in particular with IOOS efforts.

Justification for an investment in a national OSE/OSSE capability (backbone) is essential. The following questions must be answered: What are the requirements for an ocean OSE/OSSE backbone capability and how important are they? Specifically, to which ocean observing systems could or could not this OSE/OSSE capability be applied to provide feedback? With the current state of the science and computational capabilities, what questions can be answered and what trade-offs can be addressed? Which organizations and programs require this capability? What questions are they asking and are the questions well posed? Are they in a position to help pay for it? Are new resources required or just a re-prioritization and re-focus of existing efforts? Can existing individual efforts suffice or is a larger community effort required? How much of a
“community” effort is being considered? Are the various communities actually going to benefit from an ocean OSE/OSSE capability? Can ocean OSEs/OSSEs be done the right way with respect to resources, validation and verification, data, etc.? A white paper with a well-thought-out science plan, with clear, relevant, achievable goals addressing various high-priority needs of multiple agencies supported by “end users” is needed.

Ascertainment investment priorities requires answering how to allocate, in an economically efficient and effective way, observing system resources in pursuit of numerical prediction objectives. Consequently, the optimal level of forecast skill (i.e. the level of public investment in observations for numerical prediction) needs to be determined, as well as the optimal level/mix of observations to be used in producing that level of forecast skill. From a purely economic perspective, disregarding safety of life, maximum net economic benefit is the goal, taking into consideration marginal benefits and marginal costs to optimize the observing system.

A necessary first task in designing and assessing an OSE/OSSE is to define a well-posed observing system question, thereby constraining the problem. Assessment is a judgment about skill; consequently, measuring OSE/OSSE skill in a way that is relevant to the question of interest is critical because evaluating the wrong skill can be misleading. Evaluating skill in terms of potential measurable proxies is useful. A broad array of skill metrics was discussed, with the conclusion that appropriate metrics are highly dependent on the OSE/OSSE application and spatial/temporal scales. The consensus is that common skill metrics permit useful intercomparison of similar applications and extracting robust results.

With respect to a national OSE/OSSE backbone capability, model criteria vary by temporal and spatial scale. For global OSEs/OSSEs, climate applications find long-term model drift to be the key criteria; whereas, synoptic applications require fidelity in representing mesoscale features. The Navy primarily focuses on very-high-resolution representations/predictions of ocean mesoscale and finer features, comparable to the National Centers na for Environmental Prediction (NCEP)’s synoptic-scale requirements within the National Oceanic and Atmospheric Administration (NOAA)’s National Weather Service (NWS). NCEP also addresses seasonal-interannual variability, while the NOAA/Office of Oceanic and Atmospheric Research (OAR)/Geophysical Fluid Dynamics Laboratory (GFDL) examines longer-term climate time scales. There is consensus and strong justification for pursuing both weather and climate time scales. A parallel track to the global scale effort is required for intermediate/coastal spatial scales. In general, OSEs and OSSEs require many common elements. Providing these elements via a common infrastructure will reduce redundant effort and allow local investigations to focus on using OSEs/OSSEs to answer locally relevant questions. A consensus recommendation is to minimize the number of necessary nature runs: at the global scale, separate nature runs are anticipated for the weather and climate time scales, while, for intermediate/coastal scales, approximately five nature runs are envisioned to provide adequate coverage and spatial resolution of U.S. coastal areas. A challenge will be how to promote agreement on consensus intermediate nature runs to facilitate integration and reduce duplication of effort among local groups. A consensus of the workshop participants recognized that the evaluation of a nature run is more credible if it has been done by a variety of institutions independent of the production of the model run. Further into the future are more comprehensive, second generation nature runs, e.g., present nature runs will not support simulated observations for chlorophyll, waves, or
sediments. No conclusions were reached on which candidate models to be used for the various nature runs. Additional information, investigations, and trade-off decisions are required.

Combining global synoptic- and climate-scale OSSE needs leads to global nature run requirements of 1/25° (~3.5 km mid-latitude resolution) spatial resolution in conjunction with a processing speed of at least 100 years per month. As a minimum, about 50 layers are needed to adequately resolve the mixed layer and deep water masses. These combined requirements are well beyond current computing speeds and capacities. For now, an acceptable synoptic spatial resolution is 1/12° (~7km mid-latitude resolution), with resolution (~1/8°) compromised for the climate runs in order to retain the 100 years per month processing speed requirement. Data assimilation is computationally expensive, especially for the ensemble calculations favored for climate studies. Spatial resolution must be sufficient to resolve Rossby wave information everywhere, which creates challenges in polar regions. Higher spatial resolutions are needed in the climate nature run for exploring how small-scale variability rectifies into long-term variability. Tides need to be incorporated to address sea-surface height information, as well as freshwater fluxes. Two-way coupled ocean-atmosphere-sea ice nature runs are the ideal case. In the absence of mature coupled modeling, the use of a good atmospheric reanalysis could probably suffice. Atmospheric forcing must be of sufficient temporal and spatial resolution to force ocean features of interest and for comparison with observing system data. Sea ice modeling must be coupled and dynamic. For now, the focus is on physical models, deferring biogeochemical processes, although bio-physical feedback from chlorophyll absorption of solar radiation has been shown to be important at longer time scales. It is expected that a 10- to 20-year nature run will be required for synoptic time scale OSSEs, allowing approximately 10 years for global model spin-up. A minimum of 50 years is required for spinning-up the climate nature run, with a minimum of 100 years needed for studying such issues as the Atlantic Meridional Overturning Circulation (AMOC). The IPCC climate runs, while long enough, are coarse resolution, insufficient to even adequately reflect Gulf Stream fluctuations.

The global nature run(s) also directly support(s) intermediate/coastal OSSE activities. Consensus specifically concludes that the global nature run is important to regional/coastal OSSEs, serving as a validated open ocean state providing boundary conditions for developing intermediate/coastal OSSE nature runs. However, intermediate/coastal OSSEs are not dependent on a global nature run and can and should proceed without it, albeit with the additional burden of “validating” boundary conditions. In general, what are the important characteristics of a global run (or boundary conditions) to support boundary conditions for an intermediate nature run? The global nature run design should support a range of information at resolutions higher than typical global operational runs. A consensus recommendation is to define metrics for a global nature run that will show that it is useful for intermediate/coastal OSSEs.

The consensus perspective for intermediate/coastal nature runs is that intermediate/coastal nature runs nested within a global nature run (or equivalent) will be a necessary step towards coastal/local OSSEs. How will consistent “validation” of these nature runs be handled? Whether the intermediate/coastal nature run is assimilative, operational, and/or coupled is unresolved. Also unresolved are the trade-offs between using assimilation to provide the “best” possible representation of poorly represented phenomena versus a “pure” free nature run. The
intermediate/coastal nature runs will initially be approximately three times finer resolution (e.g., 3 km to 1 km resolution) than the global nature run used, with the goal of final intermediate/coastal nature run resolution being less than 1 km. Consensus concluded that the intermediate/coastal nature run should provide the best possible representation of relevant phenomena and that a set of model results can not be considered a nature run unless it provides necessary data fields that have been sufficiently evaluated to enable a consensus that actual ocean conditions are adequately represented. Consensus identified that the point of an intermediate (regional) nature run is to accommodate dynamics/processes unlikely to be properly represented in the global nature run. The consensus recommendation of fundamental intermediate/coastal processes to be represented includes: realistic bottom topography; mesoscale-resolution atmospheric forcing (resolving diurnal signals); buoyancy forcing (rivers, run-off, etc.); coastal currents and deep boundary currents; cross-shelf exchanges and transports; the bottom boundary layer; mesoscale variability and fronts; and barotropic and internal tides. A consensus recommendation was also to push the state of the science for the following processes to permit representation in future modeling efforts: coastal inundation; sediment and nutrient transport; surface waves and wave-driven processes; coupled air-sea interaction; bio-physical feedback; biogeochemical processes (ecosystems); and intermediate downscaling of climatological issues.

Consensus recommends that, since this ocean OSE/OSSE capability is planned as a community effort, it is necessary to develop a data-serving infrastructure that integrates OSE/OSSE data serving with data serving for the ocean observing system, cutting across regions. The IOOS Data Management and Communications (DMAC) subsystem needs to remain the central data management and communications system. Given the existing DMAC, what additional infrastructure (beyond DMAC) is needed to serve nature runs and data streams necessary to support OSEs/OSSEs? The HYCOM GODAE project, and the NOAA IOOS Program Office modeling liaison, could provide a first order budget estimate.

### Next Steps

An initial task is to find a way to articulate to the lay person what OSEs/OSSEs are and what they are used for, relaying the complexity of the task and what is needed. A consensus recommendation for moving forward toward the goals of this workshop was to show how OSEs/OSSEs could be used to answer questions relevant to funding agencies and “customers/users”, demonstrating the impact of a national ocean OSE/OSSE capability, in particular a white paper with a well-thought-out science plan for OSEs/OSSEs, with clear, relevant, achievable goals addressing various high-priority needs of multiple agencies supported by “end users”. Near-term goals leverage existing efforts for some pilot studies/projects/partnerships. Candidate topics include HF radar, a meridional overturning circulation observing system, high-resolution satellite observations, the next-generation high-resolution scatterometer, satellite sea-surface salinity, deep Argo (approximately 4000 m profiles versus 2000 m profiles), harmful algal blooms (HAB), fisheries management, hurricane prediction, acoustic detection, and assimilation methodologies. The output from this workshop will be used to engage near-term funding opportunities and long-term budgeting processes. When targeting community investment, tractability is an issue that must be considered in conjunction with the ideal of what is needed. A consensus recommendation for a near-term
target is funding for nature run evaluation/verification work. This work, while not glamorous, is fundamental to all subsequent analyses and decision-making. Other recommendations include 1) establishing infrastructure to enable groups to share OSE/OSSE-enabling data and initial evaluation reports (2 years); 2) exercising first-generation OSEs/OSSEs to develop/evaluate capabilities to utilize nature runs and data streams (3-5 years); 3) utilizing OSEs/OSSEs to evaluate present and future observations, data assimilation, and complementary evaluation capabilities (3+ years); 4) exercising full OSE/OSSE capabilities (5+ years); and 5) producing and evaluating more comprehensive candidate nature runs (5-10 years). Continuity in support of the workshop’s goals will be pursued through an interagency ocean OSE/OSSE working group.