A Rapidly Relocatable, Coupled, Mesoscale Modeling System for Naval Special Warfare

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Award Number: N0001406WX20125
https://jaws.nrlmry.navy.mil

LONG-TERM GOALS

This project is one coordinated component of a larger combined 6.2/6.4 Rapid Transition Project (RTP) to address specific Naval Special Warfare (NSW) operational decisions that are affected by fine scale meteorology and oceanography (METOC) processes. Our overall goal is to develop technology for a unique, rapidly globally-relocatable, coupled air-sea, high-resolution data assimilation system capable of utilizing the diverse, highly perishable, on-scene environmental data collected by NSW forces for improved forecasts and characterizations of the impact of rapidly changing, operationally significant environmental situations. We envision transitions to incorporate nowcasting and forecasting technology within NSW and other naval operations by continuously blending all data and projecting the fused information forward into the near future, applying the information to a wide array of mission specific decisions.

This project is in direct support of the Oceanographer of the Navy's (N84) Littoral Battlespace Sensing, Fusion and Integration (LBSF&I) initiative.

OBJECTIVES

The transition from open-ocean to littoral operations has increased the importance of understanding the detailed, complex environmental effects on weapon and sensor systems, particularly in shallow water operations. However, the environmental data collection network is relatively sparse and thus cannot adequately sample and characterize the battlespace environment. The NRL METOC coupled data assimilation telescoping strategy seeks to ameliorate this situation since given a few observations, model products are the only source of information that provide a realistic 4-D representation of the oceanic and atmospheric state consistent with known dynamical and physical relationships. The resulting system must be optimized to both provide the required data and products to both the end users and mission planning systems while efficiently utilizing available communications capability. Currently, the METOC specialist must interpret environmental products for the warfighter who then makes decisions and manual adjustments to weapon and sensor systems by trial and error. Efficient data collection, communications, processing, quality control, and automation are the keys to recovering this valuable time lost in a warfare situation.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **A Rapidly Relocatable, Coupled, Mesoscale Modeling System for Naval Special Warfare**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Marine Meteorology Division,7 Grace Hopper Avenue,Monterey,CA,93943-5502**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The specific objectives of this project within the larger effort are: 1) to design and develop the prototype coupled air-sea modeling and data assimilation capability within the existing NRL Coupled Ocean/Atmosphere Mesoscale Prediction System – On Scene (COAMPS-OS®) system, including a comprehensive Graphical User Interface (GUI) for easy set-up of the coupled system; 2) to invent the data acquisition and processing software necessary to utilize the variety of NSW collected data, including oceanographic, atmospheric, and bathymetric observations; and 3) to obtain end-user buy-in through a series of verification and validation experiments that encompass NSW-relevant scenarios and operations.

APPROACH

Utilizing the NSW Mission Support Center (MSC) as a beta test facility, we will invent, test, and implement a unique strategy for merging and coupling atmospheric and oceanographic models, and for assimilation of METOC data from NSW sensors in near real time, within the framework provided by COAMPS-OS. Our strategy allows for demonstrating operational support while at the same time providing a technology that can be scaled to larger systems and transitioned to Production Centers, i.e. Fleet Numerical Meteorology and Oceanography Center (FNMOC) if appropriate.
To meet the challenge of utilizing METOC data available at asynoptic times collected by forward-deployed NSW units, COAMPS-OS will be significantly enhanced to support an integrated ocean 3-dimensional analysis system (Navy Coupled Ocean Data Assimilation; NCODA), and an ocean circulation model (Navy Coastal Ocean Model; NCOM); we also plan to implement an integrated shallow-water wave modeling capability (Simulating Waves Near-shore; SWAN). Initially, NCODA and NCOM will be integrated into the COAMPS-OS software suite and the existing COAMPS GUI will be enhanced to control the oceanographic domain and other ocean model and data assimilation parameters. New interfaces will have to be invented to access and quality control ocean observations from both Central Site and local NSW sensors. Software to access and process lateral boundary conditions from a global ocean model will also be developed to support the limited area NCOM forecast model. Additionally, in collaboration with the NSW warfighters at the MSC, we will develop automated output products from the system that are tailored to mission requirements. These forecast products will be evaluated with data from the information-rich Southern California area, leveraging Intensive Observing Periods (IOP) for other experiments and NSW training operations.

Another key element of our approach is to closely coordinate with other projects at NRL. NRL is already established as a leader in the development of high-resolution atmospheric and ocean models, and air-ocean coupling. The atmospheric component of COAMPS has established itself as a state-of-the-art mesoscale model, providing high-resolution (as low as 1 km grid spacing) guidance for many regions over the earth. The NRL NCOM ocean model was developed in a joint ONR-sponsored program with NRL Stennis Space Center (NRL SSC). NRL Monterey (NRL MRY) is now running NCOM in a one-way coupled mode in a near-real time application over the Mediterranean, while NRL SSC is testing the relocatability of NCOM to various other geographic locations (e.g., East Asian Seas). Our approach is to merge these two components of the mesoscale environmental simulation systems into one coherent system to explore the physics of air-ocean interactions important for NSW operations.

In the technical assessment of the environment as proposed, it is important not to lose sight of the end-state user needs and requirements from both the METOC community and the warfighters. Without a feedback mechanism between the science and development process and the end-state user, it is

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possible to be scientifically and technically correct, but produce results that are not used or useful. To this end, we propose that in coordination with an NRL 6.2 Base Project for Coupled Data Assimilation, we have a well-defined periodic involvement of selected end-state users from the NSW community to help solidify interoperability and user-specific product issues.

WORK COMPLETED

A Workshop on Oceanographic Studies in the SOCAL area was held at Scripps Institute of Oceanography to identify ongoing and planned oceanographic studies that can be used for testing the coupled modeling system. A number of coordination meetings were held at NRL MRY to discuss the coupled modeling tools and approaches. The coupling strategy was defined and software to provide COAMPS data for NCOM was developed. NCODA (Message Passing Interface version) was installed and tested in COAMPS-OS and software development for the interface to NCOM was begun. Initial concepts for modifications to the COAMPS-OS GUI were developed to accommodate NCOM. A small (24 processors) LINUX cluster was procured and set up at NRL MRY for model integration, software development, and verification testing and evaluation.

We have merged the operational COAMPS version 4, including the Multivariate Optimum Interpolation (MVOI) and components of the NRL Atmospheric Variational Data Assimilation System (NAVDAS), with the NCODA-MPI and the NCOM components into a single coupled system using the COAMPS-OS version 1.2 framework running on the LINUX testbed cluster. COAMPS, MVOI, NCODA, and NCOM are loosely-coupled and cycling on the system for the Southern California area, including COAMPS atmospheric forcing interfaced to the SWAN model. We have started exploring the short-term coupled data assimilation cycle methodology and the Alpha test of the one-way coupled system is scheduled for Q4 CY 2006.

We have also coordinated with the NATO Undersea Research Centre (NURC), Scripps Institution of Oceanography, and other ONR supported experiment programs for in-situ observations that will be assimilated into the enhanced air/ocean predictive system and used to study the performance of the integrated prototype capability. The ASAP - Monterey Bay experiment has been identified and data from the August 2006 experiment have been gathered for testing.

We are collaborating with the Battlespace Environments Institute in the development and testing of an ESMF (Earth System Modeling Framework) compliant version of the coupled COAMPS/NCOM system and, in collaboration with the Naval Special Warfare operators, we have designed some operationally useful high-resolution products for use in validation and verification of the coupled system, including an interface to the Delft3D model used to support NSW operations.

Figure 1 shows the regional sea surface temperature analysis and surface currents from NCOM for a San Diego (5 km) ocean domain designed for testing NCOM and COAMPS coupling.

RESULTS

The scientific and technical challenges of developing a unique, globally-relocatable, coupled air-ocean data assimilation and forecasting system are daunting, particularly while trying to coordinate with multiple groups of scientists and trying to focus the operational support on relevant issues to the NSW warfighter. The NSW operational requirements of 1 km horizontal resolution (requiring approximately 250 m grid spacing) and 5-h nowcasts to 96-h forecasts will not be realized in the near future. Based on what we discover as we plow this ground, our goals are to prototype the system and demonstrate an enhanced capability. Issues identified and recommended solutions for data collection and connectivity (communications) and security (both OPSEC and information technology) will need to be addressed by the broader Navy METOC operational community.

As examples of some of the needs in the science and technology areas, we include understanding the physical oceanographic and atmospheric processes at the air-sea boundary, including the development and testing of sub-grid scale parameterizations required for the forecast models; development of sampling strategies for unmanned vehicles and other deployed sensor arrays; development of coupled data assimilation, data fusion, and analysis techniques; and validation of the analysis and forecasting technologies using a wide variety of observation data including ships, aircraft, satellites and other remote sensors.

The coupled system will need real-time access to all available atmospheric and ocean observations. The system will also need real-time access to the latest available analysis and forecast fields from both NOGAPS and global NCOM (run at NAVO), for lateral boundary conditions, and for initial conditions in the event of a cold start. Furthermore, the system must include all relevant surface data bases (e.g., terrain, bathymetry, land/sea boundary, ground wetness, ice cover) and would benefit from a single, consistent combined global terrain-bathymetry database. If Wave Watch III fields are not available for lateral boundary conditions, global Wave Watch III will be run within COAMPS-OS to provide boundary conditions for regional SWAN forecast areas.

The completely coupled air-ocean-wave system is expected to take no more than 50% more computational time, and approximately 50% more memory and 100% more disk space than the uncoupled atmospheric COAMPS model now takes alone. These numbers are preliminary estimates. The actual requirements may vary considerably based on the areas to be covered and the exact configuration of the ocean model grids compared to the atmospheric model grid (the ocean models are typically operated at higher resolution than the atmospheric driver grids).

IMPACT/APPLICATIONS

NSW operations are optimally supported by dedicated mesoscale atmospheric and oceanographic modeling responsive to temporal and spatial requirements. NSW forces operate and employ platform/vehicles, weapons, and sensors especially sensitive to the environment – both atmospheric and oceanographic. NSW operations are focused on small geographic areas for short duration. Rapid spin-up of globally relocatable models and production of model data for the forecasters over relatively short time frames is important to maintain advantages over adversaries. Mission analysis and execution benefit from high resolution atmosphere and oceanographic modeling that accurately characterizes and forecasts the battlespace and distributes the important information to NSW systems.

Thresholded atmospheric and oceanographic requirements for NSW operations and platforms/vehicles are documented in SOCOM Directive 525-6 and Naval Special Warfare Mission Planning guides. High-resolution modeling coupled with the NSW Business Line Manager initiative to deploy sensors (via Environmental Reconnaissance Teams) with data accessible from the MSC, will improve the accuracy of high resolution forecasts supporting NSW operations. Model experts present in the MSC will allow for the input into the deployment of METOC sensors to best support the models. In addition, specific lessons learned from combat operations in support of Operations Iraqi Freedom and Enduring Freedom and more recent combat operations highlight the shortfall that exists today in the absence of dedicated coupled mesoscale modeling. Tactical Decision Ads (TDAs), such as the Advanced Refractive Effects Prediction System (AREPS) and the Target Acquisition Weapons Software (TAWS), are used to support NSW operations and will benefit from the increased resolution and accuracy of high resolution model data. Coupling of atmospheric and oceanographic models will also provide more accurate waves in the near-shore area using the wave model SWAN. The MSC is a supportive environment for beta-testing systems and can provide an ample opportunity to demonstrate technologies and capabilities in multiple exercises and operations.

Coupled data assimilation technology, including data fusion algorithms, automated data quality control software, and data assimilation software will transition to FNMOC CAAPS system and to the NSW MSC. This research effort bridges the meteorological and oceanographic research communities in the numerical prediction, data fusion, and data assimilation areas. Some key issues in coupled systems development that will be addressed by this effort are also important to further improve environmental prediction and assessment technology currently used by many scientists in the research and development community. The developments of this effort can be applied to other weather and ocean forecasting and nowcasting systems used by civilian agencies such as the Department of Homeland Security, NASA and FAA, and within the broader research and development community.

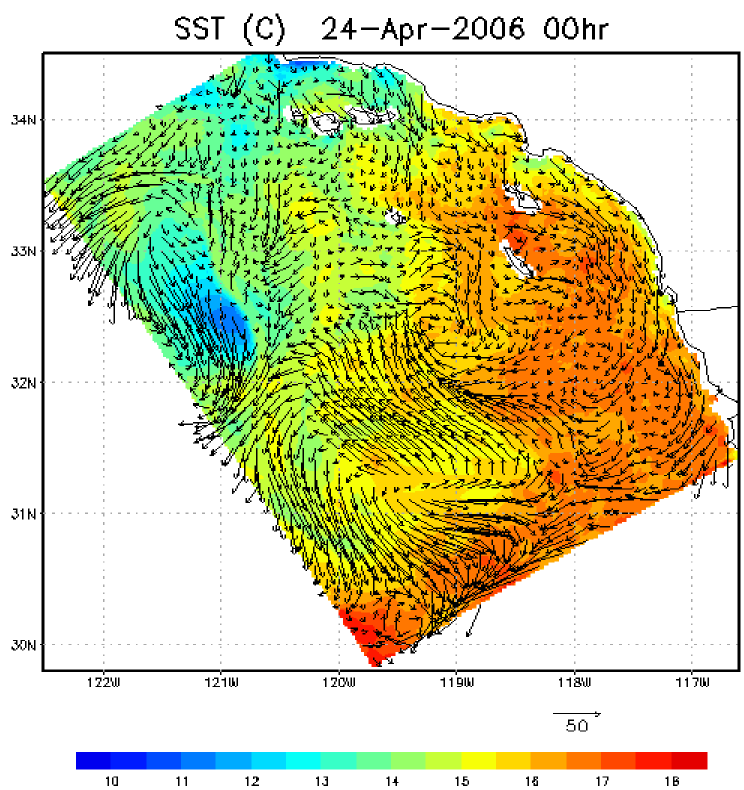

Figure 1. NCOM coarse regional mesh (5 km horizontal grid spacing) running on the prototype LINUX cluster system showing colored sea surface temperature (C) overlaid with surface current vectors (cm/s).

RELATED PROJECTS

This project is one of a number of coordinated and inter-related projects at NRL for development of a high-resolution forward-deployed navy forecasting and nowcasting capability in the oceanography and meteorology areas. The companion coupled modeling project at NRL SSC is supported by ONR Award Number N0001406WX20126 (PI: Rick Allard). Other related projects include:

- Battlespace Environmental Assessment for Situational Awareness [PI: Cook – NRL Base] addressing development of a coupled air-ocean data assimilation capability.

- Air-Ocean Coupling in the Coastal Zone [PI: Pullen – NRL Base 6.1] addressing basic research issues related to the identification and understanding the interaction between the ocean and the atmosphere in the littoral region.

- Assessing the Effectiveness of Sub-mesoscale Ocean Parameterizations (AESOP) [PI: Hodur – ONR DRI] studying sub-mesoscale parameterizations for high-resolution (regional scale) models with a strong focus on multi-scale interactions and acquisition of new field data.

- Hybrid Coordinate Ocean Model (HYCOM) [PI: Pullen - NOPP] developing and evaluating a hybrid isopycnal-sigma pressure (generalized) coordinate ocean model, including data assimilation.

- Battlespace Environments Institute (BEI) [PI: Hodur – CHSSI 6.3] migrating existing DoD atmosphere, ocean, and space modeling applications to the Earth System Modeling Framework (ESMF) and assisting in transitioning non-DoD ESMF applications to DoD.

- Littoral Warfare Team Adaptive Sampling Integration [PI: Bishop - RTP] developing and transitioning the capability to the Naval Oceanographic Office (NAVO) to utilize adaptive sampling to improve predictions of sound speed velocity fields for Anti-Submarine Warfare (ASW).

- Coastal Ocean Currents Monitoring Program – Northern and Central California (COCMP-NC) [PI: Doyle – California State through SFSU] monitoring ocean circulation for the region between Pt. Conception and the California/Oregon border using a combination of Surface Current Mapping (SCM) instruments and both 3-D coastal ocean and 2-D San Francisco Bay circulation models.

- NRL is working with several other research groups funded through related programs. The National Center for Atmospheric Research has developed forecasting and nowcasting system technology. WL|Delft Hydraulics has developed Delft3D, an advanced modeling environment for near-shore ocean hydrodynamics, waves, and sediment transport.

- NRL and the NATO Undersea Research Centre (NURC) have a joint research program to evaluate and validate the coupled air-sea modeling system.

PUBLICATIONS

Geiszler, D., J. Kent, S. Potts, J. Cook, G. Love, L. Phegley, J. Schmidt, A. Zhao, F. Franco, L. Frost, M. Frost, D. Martinez, G. Sprung, and L. N. McDermid, 2005: COAMPS-OS: An Update on Current and Future Developments. *Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) Conf.,* Monterey, CA. Paper 5.05.

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