P2.1 The U.S. Navy's On-Demand, Coupled, Mesoscale Data Assimilation and Prediction System

J. Cook*, M. Frost, G. Love, L. Phegley, Q. Zhao
Naval Research Laboratory, Marine Meteorology Division, Monterey, CA

D. Geiszler, J. Kent, S. Potts
Science Applications International Corporation, Monterey, CA

D. Martinez
Computer Sciences Corporation, Monterey, CA

T. Neu
Fleet Numerical Meteorology and Oceanography Center, Monterey, CA

D. Dismachek
Northrop Grumman Information Technology, Monterey, CA

L. McDermid
Planning Systems Incorporated, Slidell, LA

Abstract

For the past decade, the Naval Research Laboratory (NRL) has developed software to support reach-back operations for forward-deployed military personnel to configure and run the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®). The software is called COAMPS-OS® (On-Scene), and it is comprised of graphical user interfaces and automated data processing software to simplify an operator's interaction with COAMPS, which significantly decreases the time to respond to operational requirements. Recently, an enhanced version of COAMPS-OS has been developed to provide an hourly Rapid Update Cycle (RUC) procedure for applying a suite of new analysis and initialization techniques, with the results reported in a companion paper by Zhao *et al*. (2007). In addition to the RUC, a dynamic ocean circulation model and two ocean wave models are also being integrated into COAMPS-OS to provide a consistent environmental data assimilation and prediction capability for supporting maritime operations. When transitioned to operations, the coupled modeling system will be used for on-demand weather and oceanographic forecasting to help maintain situational awareness by providing anticipated environmental effects on military operations. This paper will describe the current capabilities of COAMPS-OS and discuss areas of future development.

1. Introduction

There is military value in understanding and anticipating the impact the environment has on sensors, systems, and tactics. Knowledge about the difference between environmental impacts between one's own forces and those of an adversary can be exploited for tactical and strategic advantage. Meteorological and/or oceanographic conditions impact nearly all military missions, and the ability to accurately assess and predict the current and future state of the environment and its impact is fundamental to conducting safe and efficient operations. As an aid to fleet operators and decision makers, NRL has developed the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS; Hodur 1997 and Chen *et al.* 2003), which is the operational, high resolution weather data assimilation and forecast system used by the U.S. Navy and other Department of Defense (DoD) entities. COAMPS has also been adopted to run at many other government agencies, universities, and for international customers. To meet Navy requirements in an situation demanding a rapid response to global conflicts, NRL has developed the COAMPS - On Scene (COAMPS-OS) system that provides an easy-to-use, web-based graphical user interface (GUI) to quickly locate, configure,

* Corresponding Author Address: Mr. John Cook, Naval Research Laboratory, 7 Grace Hopper Ave., Monterey, CA 93943-5502. (831) 656-4785; cook@nrlmry.navy.mil

and run COAMPS in an "on demand" scenario supporting crisis area and exercise requirements. COAMPS-OS is a fully integrated data assimilation system that includes a suite of software for automating data processing, web graphics and nowcast capability developed for COAMPS-OS. Section 5 describes how COAMPS-OS is used to support mission impact assessments, and Section 6 describes future plans for improving environmental assessment support to operations.

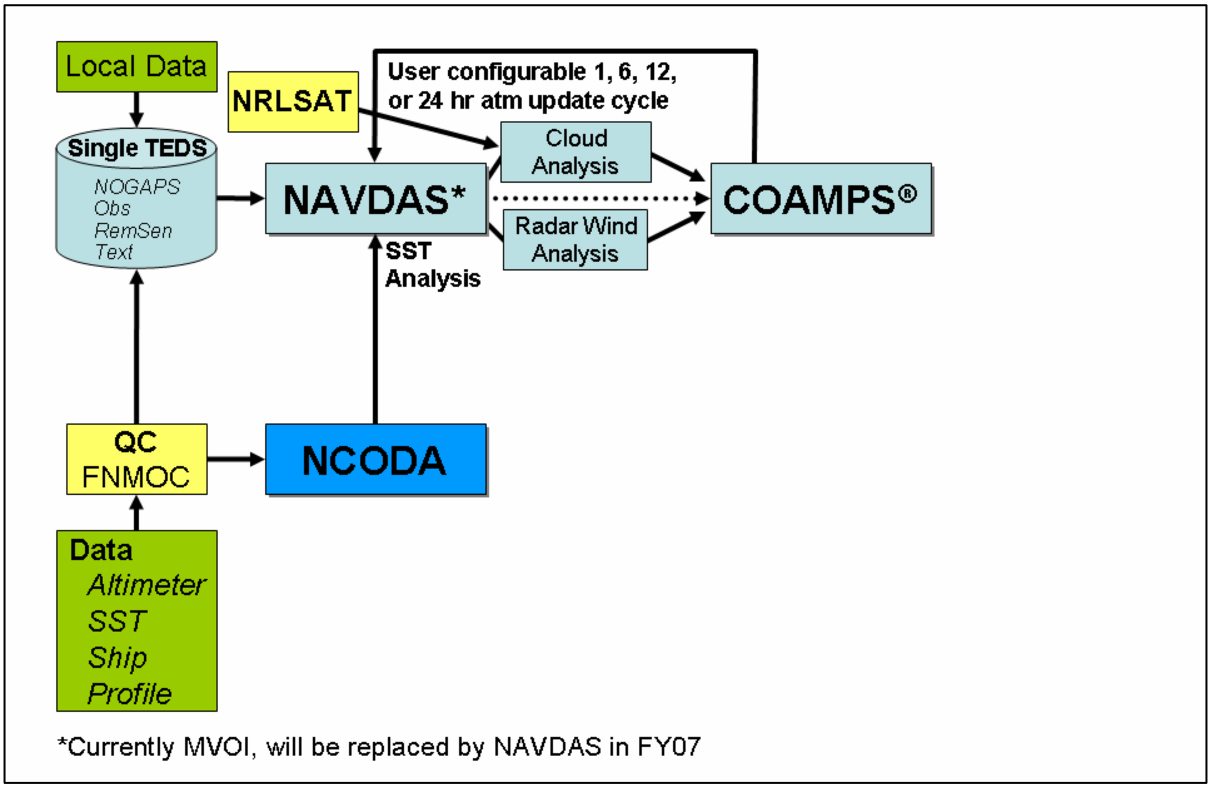

Fig. 1a. Schematic diagram showing the software components and data flow for the COAMPS-OS atmospheric data assimilation system.

creation, data dissemination, system monitoring, and application interfaces in addition to supporting the COAMPS model and the GUI. COAMPS-OS has evolved from an end-to-end, portable, workstation-based atmospheric mesoscale analysis and forecast system supporting the meteorologist/oceanographer forecaster customer to a fully coupled (atmosphere/ocean/wave) data assimilation and prediction system that includes interfaces to software designed to assess the impact of the environment on military operations directly supporting the end user.

In this paper, Section 2 provides a description of COAMPS-OS, including the interfaces and basic data assimilation processes. Section 3 describes the recently completed rapid update cycle capability used for enhanced satellite and Doppler radar atmospheric data assimilation. Section 4 builds on the rapid update cycle concept and describes the rapid environmental assessment

2. Brief History and System Description

A key enabling technology for the U.S. military is the ability to access and use environmental information to help commanders make better decisions, to improve their situational awareness, and to improve the sharing of information between forces, thus providing U.S. forces a superior environmental situational awareness of the battlespace. To meet these goals, a deployable version of COAMPS called TAMS/RT (Tactical Atmospheric Modeling System/Real-Time) was developed by NRL in 1996 to support environmental battlespace characterization. In 1998, NRL delivered TAMS/RT to the Naval Central Meteorology and Oceanography Center in Bahrain to provide on-demand operational meteorological and oceanographic (METOC) support to forward-deployed forces. Following its successful demonstration in Bahrain, TAMS/RT was transitioned to operations at all the Naval METOC Regional Centers and to a number of other military, government agencies, and academic entities. Beginning in 2001, the focus shifted to providing the identical capability but in reach-back mode to the primary Navy METOC production node at the Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, CA. The FNMOC systems use the later version of the software called COAMPS-OS in their Centralized Atmospheric Analysis and Prediction System (CAAPS). CAAPS is capable of making parallel, real-time weather predictions for multiple tactical areas at horizontal grid spacing of less than 3 km, and provides user-customizable, fine-resolution, web-enabled information needed by the warfighters for mission planning and tactical decision-making, including a variety of tailored mesoscale applications including support of aviation and shipping operations, ocean wave modeling, and atmospheric dispersion modeling.

The COAMPS limited area, multi-nested, atmospheric mesoscale forecast model is the kernel of COAMPS-OS. As shown in the schematic in Fig. 1a, COAMPS is initialized using the Navy Coupled Ocean Data Assimilation (NCODA) system for the sea surface temperature (SST) and sea ice lower boundary conditions (Cummings 2005) and using either the Multivariate Optimal Interpolation (MVOI) system or the Navy Atmospheric Variational Data Assimilation System (NAVDAS; Daley and Barker 2001) for the initial atmospheric state. NAVDAS has recently started replacing older MVOI software used for many years to produce an analysis for initial conditions (IC); however, the transition has not yet been completed. MVOI, NAVDAS, NCODA and COAMPS are run in a data assimilation cycle within COAMPS-OS where the COAMPS forecasts provide the background conditions for each subsequent analysis using quality controlled (QC) observations from the Navy's operational Tactical Environmental Database System (TEDS). Satellite data products can be provided on demand by the COAMPS-OS NRLSAT software package that is hosted on a remote sensing ground processing station. Time-dependent atmospheric lateral boundary conditions (BC) for

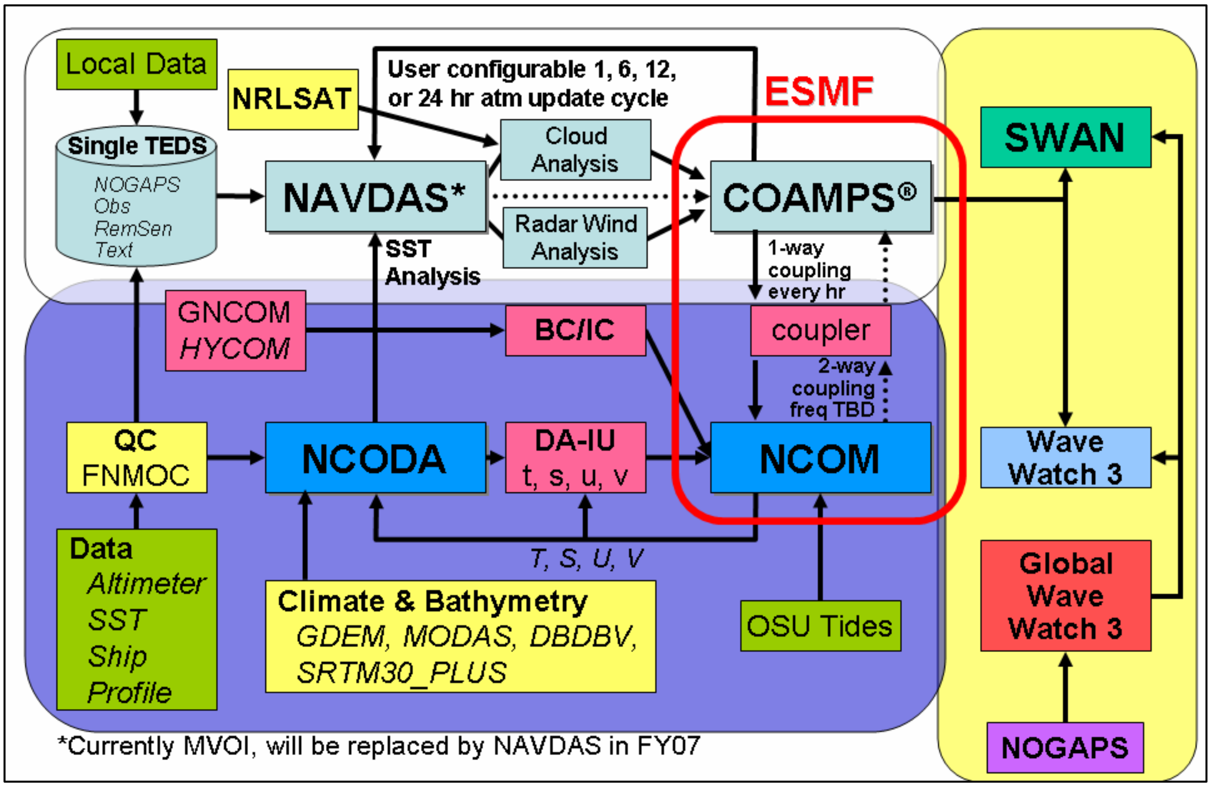

Fig. 1b. Similar to Fig. 1a except showing the additional components and data flow for the air-ocean coupled system, including ocean data assimilation and wave models.

the forecast can be provided from a number of sources including the COAMPS model, the Navy Operational Global Atmospheric Prediction System (NOGAPS) global model, the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) global model, the Canadian Global Environmental Multi-scale (GEM) global model, or from National Center for Atmospheric Research (NCAR)/NCEP global reanalysis fields downloaded from either their respective web sites or from the Global Ocean Data Assimilation Experiment (GODAE) server at FNMOC. COAMPS-OS includes software for downloading and managing these data sets and for extracting the NOGAPS data directly from TEDS. Because of the availability of the global boundary condition fields and global observation data sets, COAMPS can be relocated globally to support Navy operations world wide. COAMPS-OS provides a mechanism to cold-start COAMPS from an analysis using NOGAPS background fields. After the first data assimilation cycle, each subsequent analysis is initialized using the previous COAMPS forecast after first automatically checking for changes in the grid geometry. If the software detects that the grid has been changed, a cold-start will automatically be enabled.

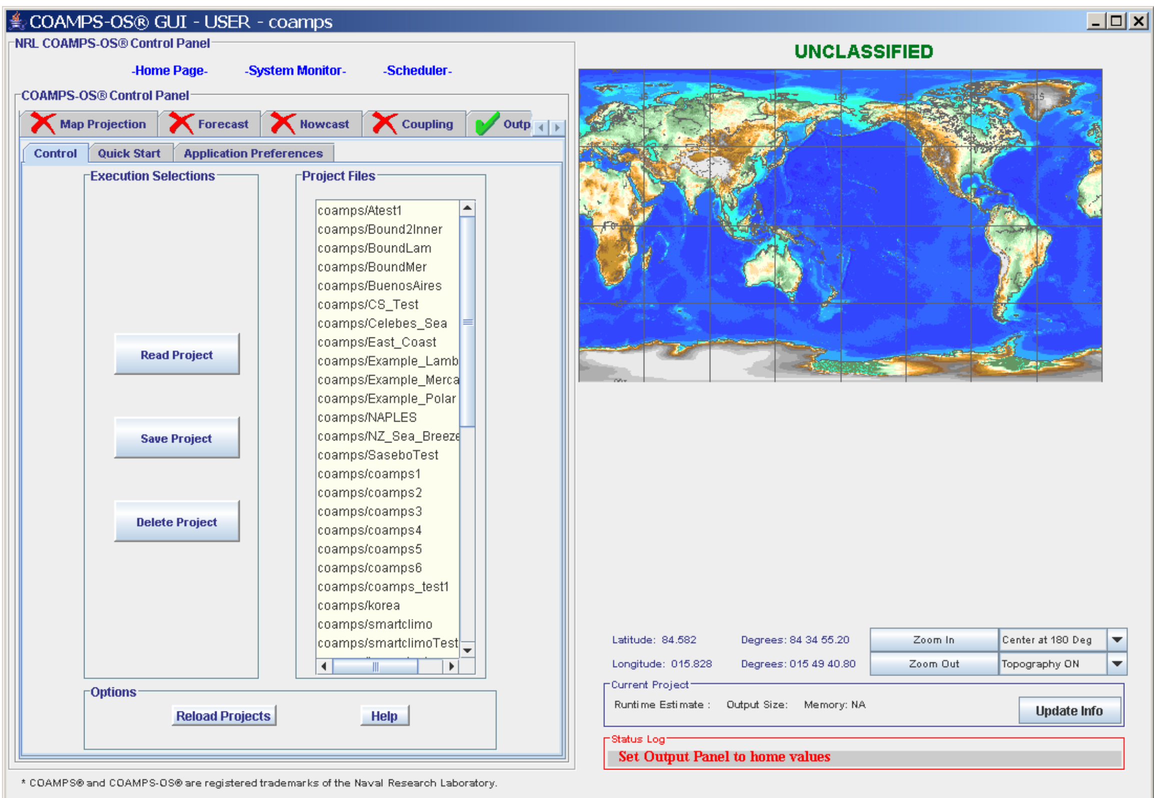

Fig. 2. COAMPS-OS web-based GUI Main Control Panel showing project file selection box, tabbed work flow, and map, including geospatial and bathymetry data.

COAMPS is considered a <u>coupled</u> air-ocean model/data assimilation system primarily because of the NCODA SST and sea ice analysis used for the initial conditions. However, as shown in Fig. 1b, NRL has recently extended the implementation of coupled modeling in COAMPS-OS by incorporating the relocatable version of the Navy Coastal Ocean Model (NCOM; Martin 2000 and Barron *et al*. 2006) for high resolution ocean circulation and thermodynamic predictions for regional domains and the Simulating WAves Near-shore (SWAN; Booij *et al*. 1999 and Ris *et al*. 1999) and WAVEWATCH-III (WW3; Tolman 2002) models for ocean surface wave prediction. SWAN is a high resolution model operated for regional, near-shore domains (less than 200-m depth). WW3 is used for deep water simulations and supports both global and limited areas. The global WW3 forecasts are run early in each watch with forcing from the NOGAPS 10-m wind fields and provide time dependent lateral boundary conditions for regional SWAN and WW3 forecasts. Neither wave model assimilates observations directly as used in COAMPS-OS.

Unlike SWAN and WW3, NCOM uses NCODA to provide the full three-dimensional data analysis and incremental update (DA-IU) cycling data assimilation capability for the ocean. Time dependent lateral boundary conditions for the NCOM high resolution regions are provided by the Global NCOM (GNCOM) or Hybrid Coordinate Ocean Model (HYCOM) run operationally at the Naval Oceanographic Office (NAVO) in Bay St. Louis, MS. FNMOC and NAVO are coordinating on the development of an operational data distribution mechanism for GNCOM fields that allows NCOM to be easily relocated along with COAMPS.

databases of salinity, temperature, and sound velocity from either the Modular Ocean Data Assimilation System (MODAS) or the Generalized Digital Environmental Model (GDEM). Tidal forcing is optionally introduced into NCOM through post-processing using the Oregon State University global tide constituent databases (OSU Tides).

In the initial version of the air/ocean/wave coupled COAMPS-OS system, the models have been coupled in a one-way sense with COAMPS providing the dynamic atmospheric forcing to NCOM, SWAN, and WW3, but with no feedback to COAMPS except at the analysis time through the NCODA SST and sea ice fields. The initial implementation lays the groundwork for a more fully integrated two-way coupled NCOM/COAMPS system utilizing the Earth System Modeling

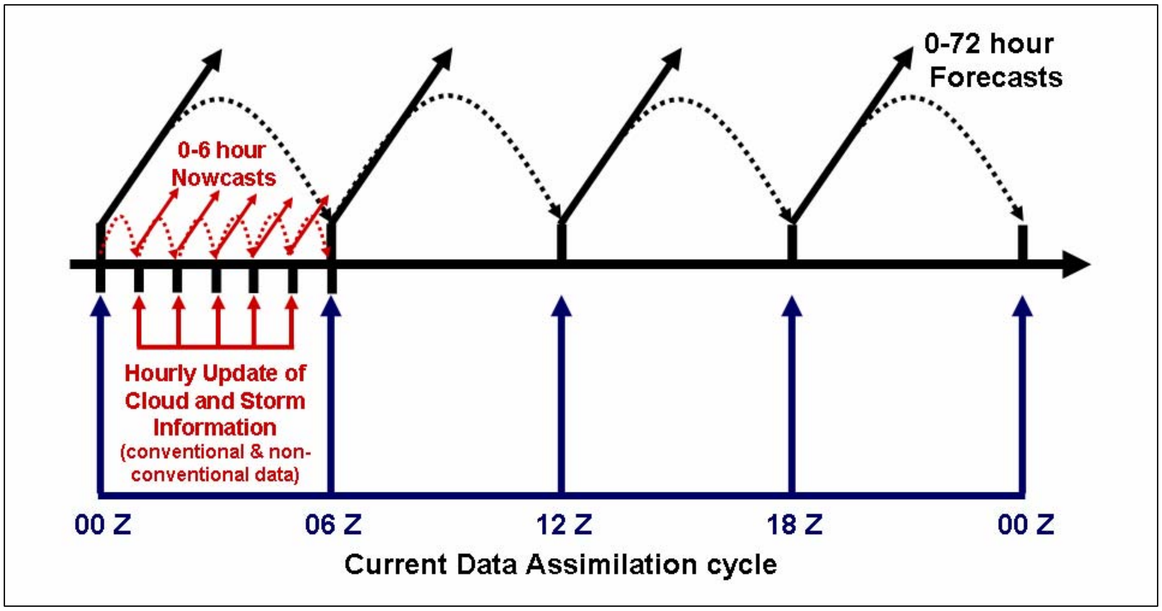

Fig. 3. The COAMPS-OS multi-scale, rapid update cycle, hybrid data assimilation system.

An important factor in successfully executing the coupled COAMPS/NCOM/NCODA system is the use of consistent bathymetry, coastline, and topographic databases. NCOM/NCODA supports Digital Bathymetric Data Base Variable resolution (DBDBV) 5-minute relief and 30-arc-second elevation data with bathymetry in the Shuttle Radar Topography Mission (SRTM) Plus database. COAMPS has been adapted to use the SRTM Plus topography database as well.

Climate data important for ocean data assimilation is provided by seasonal or monthly ocean profiles

Framework (ESMF; ESMF JST 2006). NCOM and COAMPS have been modified to utilize the ESMF, and the two-way coupled system is undergoing testing and validation for a future release of COAMPS-OS.

The COAMPS-OS GUI is the primary user interface for configuring and scheduling the models with COAMPS-OS. The GUI is a web-based application that uses Java Web Start technology to provide an interactive experience for the user without having to field or maintain a distributed software release. In Java Web Start, the application software is maintained on a central web server and downloaded when first used or when a software update has automatically been detected. Java Web Start ensures users have the latest version of the software without the problems associated with distributing media.

The terms “COAMPS-OS project” refer to the complete setup of all the models, data paths, output files, and visualization processing for a user-defined domain. The COAMPS-OS GUI allows an authenticated user to set up a COAMPS-OS project through a well orchestrated workflow. In the user interface, tabs are used to designate individual configuration panels (or screens) that intuitively lead the user from left-to-right through their workflow. As shown in Fig. 2, the primary tabs are: Main, Security, Map Projection, Forecast, Nowcast, Coupling, Output, and Run. Table 1 lists the major functions of each tab, and some tabs include additional sub-tabs to better organize the configuration options. An authenticated user configures a COAMPS-OS project by specifying the extent of the desired COAMPS domain, number of nests, grid configuration (number of points and spacing), and parenting (which nest provides the boundary conditions for each subsequent nest). The user then sets the forecast length, analysis options, and the atmospheric rapid update cycle options. After setting the configuration for COAMPS, a user can select the ocean models to run and configure each model within the spatial limits of the parent COAMPS nest. By default, the atmospheric forcing for all limited area ocean and wave models in COAMPS-OS is provided by COAMPS. Currently, the GUI only supports nested grids for the atmospheric model; however, future plans for the COAMPS-OS GUI include support for nested grids for the ocean models. After COAMPS and the ocean models have been configured, the COAMPS-OS GUI Output tabs are used to enable output forecast parameter fields from COAMPS (nests, times, levels), including the ability to post-process the fields into World Meteorological Organization (WMO) Gridded Binary (GRIB) format (GRIB1 and GRIB2) and distribute the GRIB fields to web-enabled directories for downloading by customers, or to distribute the data fields to local databases using the embedded database application programming interfaces (API). Currently, the output selections from the ocean models are set to defaults and not configurable from the GUI, but they do follow the atmospheric model forecast length. Tabs are also provided to manage the forecast schedule, to specify application preferences for input and output data paths and executable locations, and to set the project security labels. COAMPS-OS supports multiple users and multiple projects for each user, with authentication handled using the OpenLDAP (Lightweight Directory Access Protocol). COAMPS-OS also provides an interface to job schedulers including Platform Computing, Inc. Load Sharing Facility (LSF) and

Table 1. COAMPS-OS GUI functions.

Main	Security	Map Projection	Forecast	Nowcast	Coupling	Output	Run
Control	Label	Location	Length	On/Off	NCOM	Flat Files	On Demand
▪ Read	Data	▪ Projection	Analysis Options	RUC Options	SWAN	GRIB Files	Batch
▪ Save	Caveats	Positioning			WW3	Database Interface	
▪ Delete		▪ Nests			Options		
Quick Start		▪ Size					
▪ Run		▪ Position					
Application Preferences		Bounding Box					

Altair Engineering, Inc. Portable Batch System (PBS) Professional software.

A "local hook" function has also been implemented in COAMPS-OS that allows the user to run their own scripts and programs for customized post-processing and data dissemination. The local hook can be run both in parallel with the COAMPS forecast and after completion of the forecast.

runs. Check boxes in the GUIs allow the user to plot the selected stations on background maps, create model forecast skew-t diagrams and datagrams (ASCII representations of forecast profiles on the model computational grid), create meteograms and datagrams (ASCII time series of forecast data), and to enable and configure a hazardous release simulation during the model run using an embedded capability called HAZONE.

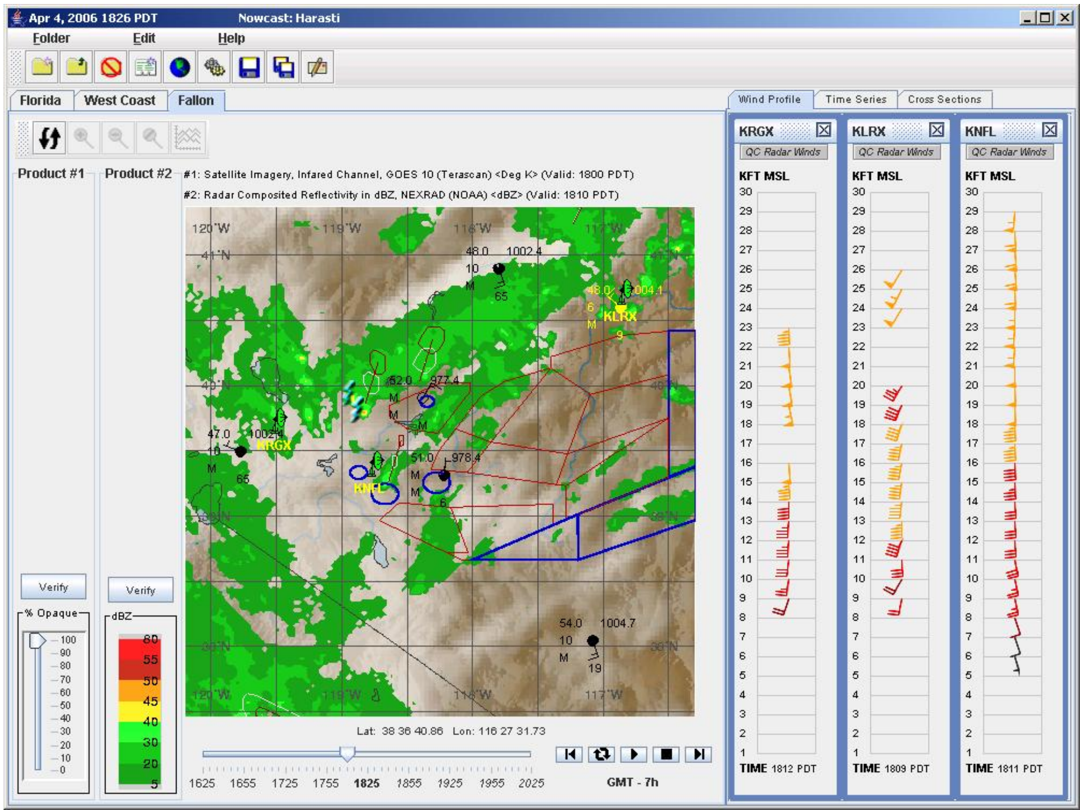

Fig. 4. Example of the Nowcast Java web-based product displayed over the Fallon, NV Range Training Complex domain.

In addition to the main model setup GUI, COAMPS-OS includes five other interactive, Java Web Start applications. These applications are currently used to support only the COAMPS atmospheric model forecasts. Two of the five applications provide a user interface to enable pre-configured graphical products for desired station locations. These two applications, the Station GUI and the Products-On-Demand GUI, allow a user to configure output products for fixed station locations selected either from a list of WMO station locations or by adding an arbitrary station to the project. Once configured, the products at each station are produced every time COAMPS

The remaining three Java Web Start applications are utilities for users to interactively create subsets of the COAMPS forecast fields formatted for use in other models. One utility provides external data sets specifically in formats supported by the Hazard Prediction and Assessment Capability (HPAC) application, another supports the Vapor Liquid and Solid Tracking (VLSTRACK) model, and the third supports the Advanced Refractive Effects Prediction System (AREPS) application. HPAC (DTRA 2001) is a sophisticated transport and dispersion model, as is VLSTRACK (Bauer and Gibbs 1998), and AREPS (Patterson 2000) is used for radar propagation assessment and prediction.

HAZONE is a capability embedded in COAMPS-OS and designed to be used to set up hazardous material release simulations at user-selected high-value locations within the COAMPS domain. While COAMPS is running, the forecast fields are used to drive internal VLSTRACK simulations of the user-specified releases with automated graphics depicting plume locations and concentrations created and posted on the COAMPS-OS web site. If the HAZONE box is checked in the Station GUI, a right click will bring up a properties dialog for configuring the release options. VLSTRACK was selected as the dispersion model for HAZONE because it runs from the command line in the LINUX environment and was readily scripted and integrated into the COAMPS-OS software infrastructure. COAMPS-OS includes a periodic nowcast option that runs the ocean and atmospheric analyses at a user-specified interval (typically hourly). If the COAMPS-OS nowcast option is enabled, the HAZONE software also runs again at each analysis time, using the analysis fields to initialize the VLSTRACK model, with the COAMPS forecast fields providing the time-dependent lateral boundary conditions.

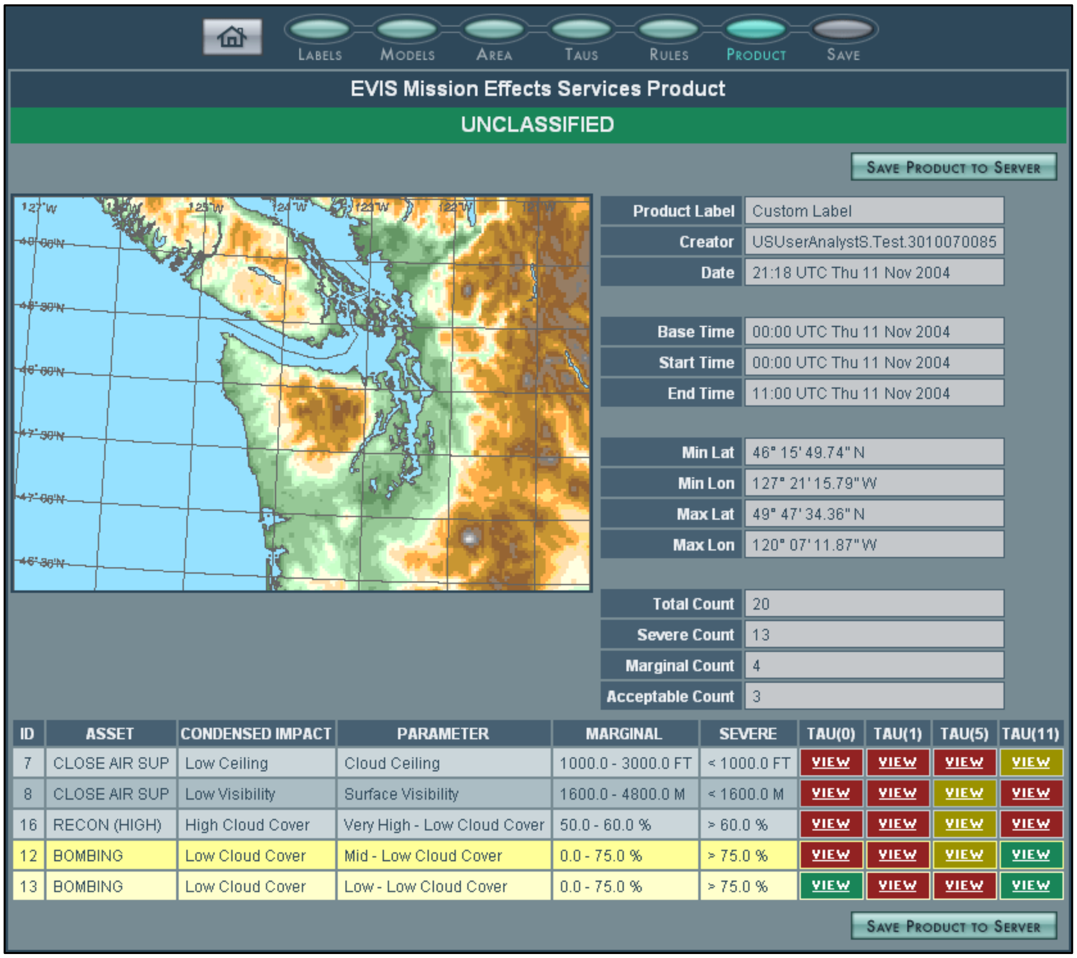

Fig. 5a. Web enabled EVIS mission impact spreadsheet threshold product.

In addition to the six Java Web Start applications, COAMPS-OS includes an interactive visualization application that can be used to design and automate the production of the atmospheric forecast charts. The Integrated Portable Visualization System (IPVS Charts) is an X-windows application based on the GrADS (Gridded Analysis and Display System) graphics package (Doty 1995) used to develop forecast map graphics, arbitrary cross sections, profiles, and times series. COAMPS-OS includes a number of user-editable, default IPVS graphical products and permits each user to create their own products and save the resulting product templates so the graphics are automatically produced every time COAMPS is run. Future plans include extending the capabilities of IPVS Charts to support visualization, design, and production of oceanographic forecast products as well. In addition to GrADS, COAMPS-OS includes the Generic Map Toolkit (GMT; Wessel and Smith 1991) that is used for a suite of pre-defined graphical map products and for the background maps used in each GUI. COAMPS-OS includes an interface to GMT to provide a web-based map service that is shared by many components of COAMPS-OS.

3. Rapid Update Cycle

Feedback from individuals using the initial versions of COAMPS-OS included requests to include an atmospheric mesoscale cloud and moisture analysis capability with a rapid update cycle. After a multi-year development effort, the latest version of COAMPS-OS (V1.7) includes both features. The cloud and moisture analysis capability is based on a variation of the Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS; Albers *et al*. 1996 and Zhao *et al*. 2005). An MVOI analysis using conventional observations follows the ADAS cloud and moisture analysis, and the output from the two analysis packages is used to initialize COAMPS for a short forecast. This cycle and the length of each forecast are configured by the user and can be as frequent as every hour with the forecast length varying from 1 to 3 hr. When released in summer 2007, COAMPS-OS version 1.7 will be run in two modes: (1) an hourly analysis and subsequent 1 hr forecast and (2) longer forecasts (48 to 72 hr) every 6 or 12 hours. Fig. 3 shows schematically the rapid update cycle procedure. Zhao *et al*. (2005) have found that the hourly periodic data assimilation procedure significantly increases the skill of the mesoscale cloud and wind forecasts. If satellite data and Doppler radar data are not available, COAMPS-OS will use only the MVOI analysis for the rapid update cycle and the NAVDAS analysis for the 6 or 12 hourly data assimilation cycle. NAVDAS will completely replace the MVOI in a future release of COAMPS-OS. Also planned for future integration is a Doppler radar wind analysis based on Xu *et al*. (1995) and Zhao *et al*. (2006).

4. Rapid Environmental Assessment

In addition to the rapid update cycle that includes the hybrid mesoscale analysis and COAMPS forecasts, a capability has been integrated with COAMPS-OS to provide a nearly continuous environmental assessment or nowcast (Cook *et al.* 2007). Nowcast is a suite of software that processes observational data, including conventional observations, aircraft reports, Doppler radar data, and satellite data asynchronously and in parallel to the model forecasts. Nowcast uses observations and forecasts as input to data fusion and extrapolation algorithms; for example, the Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN) system (Dixon and Wiener 1993). Products from the data, model, and fusion results are published in a variety of methods including hyperlinked web pages, a Java Web Start user interface, and an integrated set of Geospatial Information Services (GIS) using Open Geospatial Consortium (OGC) web service standards. OGC standards provide a common language for sharing and distributing GIS products over a network and ensure compatibility with a large number and wide variety of third-party commercial and open-source GIS clients.

Fig. 4 shows a screenshot of the nowcast Java Web Start display showing layers of data from satellite, Doppler radar, lightning sensors, and surface observations. The infrared satellite cloud image is a white translucent layer over a map background of color-shared terrain height. The Doppler radar reflectivity data shows areas of precipitation in green. In this example, the radar reflectivity data set is a composite of data from 13 WSR-88D (NEXRAD) radars and one Navy Supplemental Weather Radar (SWR) from Fallon, NV. The northern rain band shows 30- and 60-min TITAN storm cell forecasts by the white and black polygons, respectively, with a black line showing direction of movement from the center of the forecast cell. The blue lightning bolts show the location of embedded cloud-to-cloud lightning strikes. The right panel shows wind profiles from the Fallon SWR (KNFL), Elko (KLRX) and Reno (KRGX) WSR-88D radars in a Vertical Azimuth Display (VAD). This display is designed to run continuously as a short animation showing products from the last two hours. The display is updated automatically over the web with newer products replacing the older products in the animation. Each layer is updated asynchronously only when a newer product is detected on the server. In this manner, users and decision makers can be kept apprised of the environmental conditions for their areas of interest, with the universal network accessibility providing the ability to share the environmental situational awareness among all interested parties.

orchestrated to provide mission impact spreadsheet products over the network (Ballas *et*

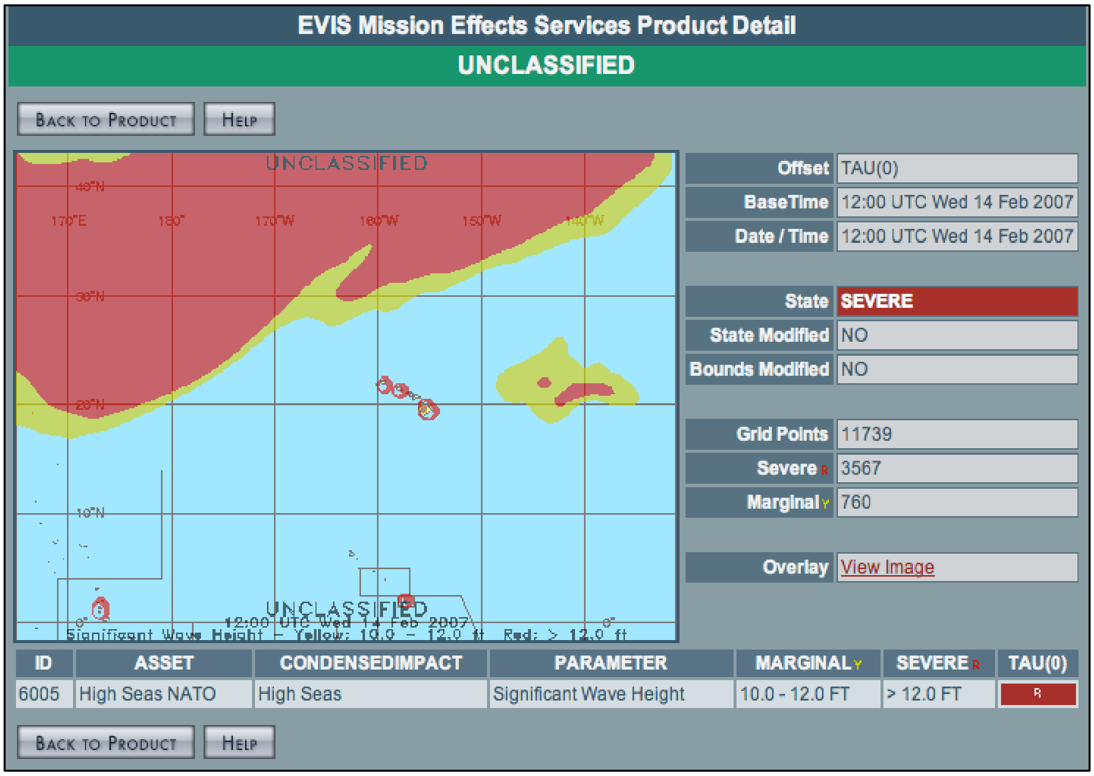

Fig. 5b. EVIS map overlay showing forecast areas of marginal (yellow) and severe (red) impacts to operations for user selected area, parameter, and thresholds.

5. Environmental Mission Impact Assessment

For nearly ten years, COAMPS-OS has provided an easy-to-use, customizable mesoscale forecast and data assimilation capability for the Navy forecaster. Recent enhancements to COAMPS-OS include the rapid update cycle and rapid environmental assessment capabilities. However, perhaps more importantly, outside of the COAMPS-OS framework, model analysis and forecast fields have been interfaced to a rule-based threshold software package that allows an authenticated user to quickly assess the impact the forecast environmental conditions may have on their operation. The Environmental Visualization (EVIS) system is a suite of accredited, secure web services that can be

al. 2004). EVIS accesses COAMPS and other model fields stored in a TEDS relational database, and exposes the model field catalog and associated geographic model domain map metadata. A user application can select model data and request that sub-areas be extracted from the database and processed with a threshold engine to provide counts and GIS-type map overlays showing where the model forecast parameter values exceed the user-defined marginal and severe threshold limits. Rules defining the mission limits associated with atmospheric and oceanographic parameters are stored in a separate, web-accessible database and the rule thresholds can be locally modified in the threshold request.

Fig. 5a is an example of an EVIS hyperlinked spreadsheet product and Fig. 5b is an EVIS map display showing mission impact thresholds for high seas in the Hawaii area forecast by WAVEWATCH-III. Forecast areas exceeding the marginal threshold at the valid time are colored yellow, and red coloring indicates the areas where the forecast exceeds the severe threshold value. EVIS allows users to modify the computer generated spreadsheet results and store their results on the EVIS web server for centralized hosting and dissemination. EVIS is an operational product at FNMOC.

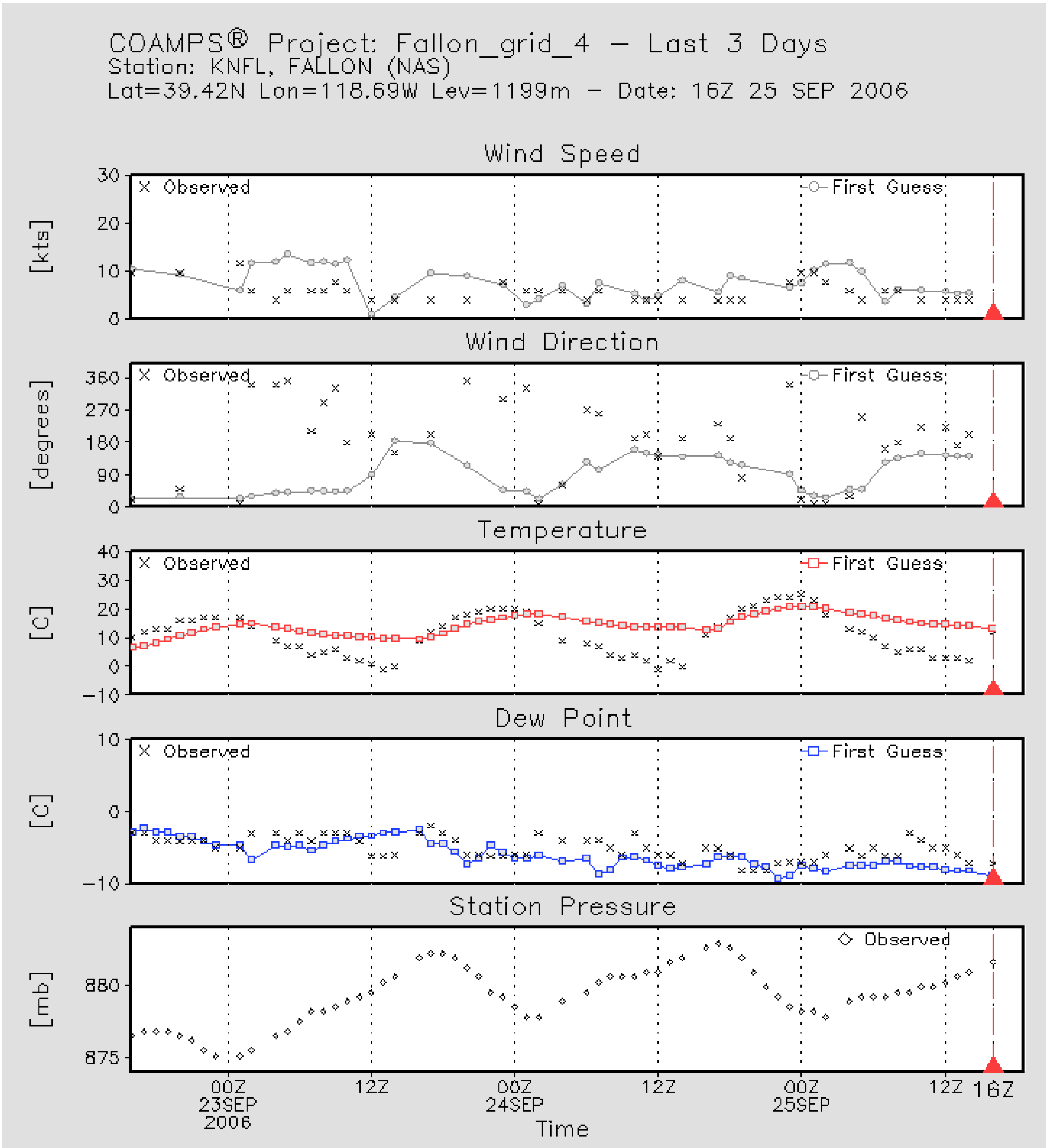

Fig. 6. MetQC web page graphic for station KNFL (Naval Air Station Fallon, NV) showing time series of observations and model forecasts. Station pressure forecasts were not processed.

As an example of COAMPS-OS applied to every day military operations world-wide, a sample demonstration is described using the operational CAAPS and EVIS systems at FNMOC. Our case begins with a hypothetical operational request for high resolution forecast support for a quickly developing situation. Once the request is received by the Command Duty Officer (CDO) at FNMOC, vetted, approved, and the resources allocated, the

24/7 military watch standers use the COAMPS-OS GUI (Fig. 2) to set up, configure, and schedule a project. After a quick cold-start from NOGAPS background fields and a data assimilation cycle, the full COAMPS forecast cycle is initiated. Meanwhile, the operator can configure model output at station locations; check how well the forecasts are verifying when compared to land and ocean surface observations (Fig. 6) and satellite imagery; develop visualization graphics including maps and arbitrary path cross sections; process the model output through transport and dispersion applications; evaluate predicted radar propagation and coverage; share model results with ocean and wave modelers; and evaluate the impact the expected environment has on critical mission assets using EVIS.

The quality of COAMPS-OS surface forecasts of temperature, humidity and winds are scored by Meteorological Quality Control (MetQC) software using hourly observation reports. Automated software downloads observations from a database, computes the innovation vectors (observations minus model background), and creates a set of hyperlinked model verification web pages. The information provided to the forecasters and planners by the verification scores either assures confidence in the model forecasts or highlights when the model forecasts are not reliable. Fig. 6 is an example of a COAMPS-OS web page graphic showing the high level MetQC display for the Fallon (KNFL) site. Each time series represents about three days of hourly data. The lack of a strong diurnal cycle forecast for the high desert region indicates a potential problem with the surface model used in COAMPS. A more advanced model of the surface and subsurface layers may improve the nighttime low temperature forecasts.

6. Summary and Plans

Since the Continental Congress authorized a small fleet in October 1775, the U.S. Navy has had a rich history of deploying as far forward as possible the responsibility and decision-making authority for military operations. After initial development and operational deployment in the late 1990s, the COAMPS-OS software suite has provided well used capabilities to quickly setup, configure, schedule, manage, visualize, and verify COAMPS mesoscale forecasts for supporting focused, limited duration operations. Recently, major upgrades to COAMPS-OS include a rapid update cycle mode of operation; interface with a nowcasting system for rapid environmental assessment; use of web services to provide rule-based mission impact assessments and GIS product layers; and the coupling of COAMPS with the NCOM ocean circulation model and the SWAN and WAVEWATCH-III wave models. These enhancements provide the basis for improved environmental support for years to come. Plans include extending the current one-way coupling to two-way coupling within the ESMF; enhancing the COAMPS-OS GUI to utilize web portlet technology with a redesign for increased ease of use, particularly for configuring the complex output parameters required for supported other models and a diverse array of external applications; providing support for moving nests for following tropical cyclones, ships, and other non-stationary features; and integrating support for the transport options in COAMPS to add dust and aerosols to the forecast repertoire.

Acknowledgements

The authors gratefully acknowledge the support of our sponsors: The Oceanographer of the Navy (N84) through the Program Executive Office for Intelligence, Surveillance, Reconnaissance, and Information Operations (PMW 180) and the Commander, Naval Meteorology and Oceanography Command (CNMOC) via Fleet Numerical Meteorology and Oceanography Center (FNMOC); the Office of Naval Research (ONR 322MM); and the Defense Threat Reduction Agency (DTRA).

References

Albers, S. C., J. A. McGinley, D. L. Birkenheuer, and J. R. Smart: 1996: The Local Analysis and Prediction System (LAPS): Analyses of clouds, precipitation, and temperature. *Wea. Forecasting,* **11,** 273–287.

Ballas, J., D. Jones, S. Kirschenbaum, T. Tsui, K. Kerr, J. Cook, B. Kirby, M. Gibson, R. Mantri, and R. Carr, 2004: Improved workflow, environmental effects analysis and user control for tactical weather forecasting. *Proceedings, Human Factors and Ergonomics Society 48th Annual Meeting*, 20-24 September 2004, New Orleans, LA.

Barron, C. N., A. B. Kara, P. J. Martin, R. C. Rhodes, and L. F. Smedstad, 2006: Formulation, implementation and examination of vertical coordinate choices in the Global Navy Coastal

Ocean Model (NCOM). *Ocean Modelling*, **11**, 347-375.

Bauer, T. J., and R. L. Gibbs, 1998: Software user's manual for the Chemical/Biological Agent Vapor, Liquid, and Solid Tracking (VLSTRACK) computer model, version 3.0. NSWC Doc. NSWCDD/TR-98/62, Systems Research and Technology Department, Dahlgren Division, Naval Surface Warfare Center, Dahlgren, VA, 170 pp.

Booij, N., R. C. Ris, and L. H. Holthuijsen, 1999: A third-generation wave model for coastal regions – 1. Model description and validation. *J. Geo. Res.*, **104**, C4, 7649-7666.

Chen, S., J. A. Cummings, J. D. Doyle, R. M. Hodur, T. R. Holt, C. S. Liou, M. Liu, A. Mirin, J. A. Ridout, J. M. Schmidt, G. Sugiyama, and W. T. Thompson, 2003: COAMPS Version 3 model description. NRL/PU/7500-03-448. Available from the Naval Research Laboratory, Monterey, CA, 93943-5502, 145 pp.

Cook, J., M. Frost, P. Harasti, G. Love, D. Martinez, L. Phegley, S. Potts, Q. Zhao, R. Cantu, M. Young, Q. Xu, C. Kessinger, James Pinto, D. Megenhardt, B. Hendrickson, and D. Smalley, 2007: Real-Time Meteorological Battlespace Characterization in Support of Sea Power 21. NRL Report (in preparation).

Cummings, J. A., 2005: Operational multivariate ocean data assimilation. *Quart. J. Royal Met. Soc.*, Part C, **131 (613)**, 3583-3604.

Daley, R., and E. Barker, 2001: NAVDAS Source Book 2001. NRL/PU/7530-01-441. Available from the Naval Research Laboratory, Monterey, CA, 93943-5502, 163 pp.

Dixon, M., and G. Wiener, 1993: TITAN: Thunderstorm Identification, Tracking, Analysis, and Nowcasting—A radar-based methodology. *J. Atmos. Oceanic Technol.,* **10,** 785–797.

Doty, B., and J. L. Kinter III, 1995: Geophysical Data Analysis and Visualization Using GrADS. Visualization Techniques in Space and Atmospheric Sciences, eds. E. P. Szuszczewicz and J. H. Bredekamp. (NASA, Washington, D.C.), 209-219.

DTRA, 2001: HPAC hazard prediction and assessment capability, version 4.0. Defense Threat Reduction Agency, Alexandria, VA, 605 pp.

ESMF Joint Specification Team, 2006: Earth System Modeling Framework (ESMF) Reference Manual for Fortran Version 2.2. NASA Earth Science Technology Office Computational Technologies Project CAN 00-OES-01, 525 pp.

Hodur, R. M., 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev*., **125**, 1414-1430.

Martin, P. J., 2000: Description of the Navy Coastal Ocean Model Version 1.0. NRL/FR/7322--00-9962. Available from the Naval Research Laboratory, Stennis Space Center, MS. 42 pp.

Patterson, W. L., 2000: Advanced Refractive Effects Prediction System (AREPS) Version 2.0 User's Manual, SSC San Diego Technical Document 3101.

Ris, R. C., L. H. Holthuijsen, and N. Booij, 1999: A third-generation wave model for coastal regions – 2. Verification. *J. Geo. Res.*, **104**, C4, 7667-7681.

Tolman, H. L., User manual and system documentation of WAVEWATCH-III version 2.22. NOAA / NWS / NCEP / MMAB Technical Note **222**, 133 pp.

Wessel, P. and W. H. F. Smith, 1991: Free software helps map and display data, *EOS Trans*. AGU, **72**, p. 441.

Xu, Q., C. J. Qiu, and J. X. Yu, 1995: Simple adjoint retrievals of microburst winds from single-Doppler radar data. *Mon. Wea. Rev.,* **123,** 1822–1833.

Zhao, Q., J. Cook, Y. Jin, M. Frost, Q. Xu, P. R. Harasti, and S. Potts, 2007: Improving very short range prediction of high impact weather using radar observations. *18th Conf. on Numerical Wea. Pred.*, 25-29 June 2007, Park City, UT.

Zhao, Q., J. Cook, Q. Xu, and P. R. Harasti, 2006: Impact of Doppler radar wind data observations on high-resolution numerical weather prediction. *Wea. Forecasting,* 21, 502-522.

Zhao, Q., J. Cook, Q. Xu, and P. R. Harasti, 2005: Improving very-short-term storm predictions by assimilating radar and satellite data into a mesoscale NWP model. *32nd Conf. Radar Meteor.*, 24-29 October 2005, Albuquerque, NM.