1.4 REAL-TIME OCEAN FORECASTING OVER THE MEDITERRANEAN SEA USING COUPLED OCEAN/ATMOSPHERE MESOSCALE PREDICTION SYSTEM (COAMPS™)

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1. INTRODUCTION

The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) (Hodur, 1997 and Hodur, et al. 2002), developed by the Naval Research Laboratory, is being used for real-time ocean forecasting over the Mediterranean Sea. Specifically, a 3-dimensional multivariate optimum interpolation (MVOI) program is used to construct the ocean analysis every 12 hours and the Navy Coastal Ocean Model (NCOM) is then used to generate ocean forecasts to 72 hours from each analysis.

Real-time ocean forecasting with one-way coupling over the Mediterranean Sea is performed for this study. Nested, real-time COAMPS atmospheric forecasts are provided by the Fleet Numerical Meteorological and Oceanography Center (FNMOC) and are used to provide hourly surface forcing for the ocean forecasts. The ocean feedback to the atmosphere model is not considered in this application. The real-time forecast results are verified with observational data, and the forecast images are available at an internal web site.

2. MODEL, DATA AND METHODS

2.1 *Ocean Model Description*

NCOM (Martin, 2000), the ocean model component of the COAMPS, is a three-dimensional, primitive equation, hydrostatic, baroclinic, free surface model. NCOM uses Boussinesq and incompressible approximations and is based on the Arakawa C grid. A hybrid coordinate system is used in the vertical, with sigma coordinates in the upper layers and z-level coordinates in the low layers. The time integration is leapfrog with the Asselin filter to suppress the time-splitting. The second-order centered scheme is used for spatial differencing and a third-order upwind scheme for the advection. Mellor-Yamada level 2.5 turbulence model is used for the vertical mixing and Smagorinsky scheme is used for the horizontal mixing. Radiation schemes are used at the open lateral boundaries.

2.2 *Model Setup*

This real-time forecast (as a test bed) is focused on the Mediterranean Sea since it is almost an enclosed basin and the forecast can be run without a global ocean model providing the lateral boundary conditions. The only lateral boundary conditions used for the NCOM grid are at the Straits of Gibraltar with an inflow of 1.0 Sverdrups in the top layers and a return flow of the same magnitude in the bottom layers.

The hourly atmosphere forcing fields are generated from double-nested grid COAMPS forecasts with grid resolutions of 81km and 27km over the Mediterranean area. The 27 km resolution forcing fields are saved hourly from the atmospheric model and are used as upper boundary conditions for NCOM. In the real-time ocean forecast, the Lambert conformal grid projection is selected and the horizontal grid resolution is 6 km. There are 40 ocean levels in the vertical, 15 sigma levels in the upper 100 m, and 25 z-levels below.

2.3 *Ocean Analysis*

The ocean MVOI analysis provides the initial fields for the ocean forecast. The first ocean forecast is regarded as a "cold start" since there is no previous forecast available. Otherwise, the forecast is considered as a "warm start". The "cold start" ocean MVOI analysis uses synthetic temperature observations generated from the Modular Ocean Data Assimilation System (MODAS) to construct initial temperature and salinity fields. The synthetic temperatures are based on statistics relating SST and sea surface height (SSH) to subsurface temperatures. In our application, we used 20 days of altimeter data to construct the initial SSH. In order to improve the "cold start" initial fields, the ocean analysis is cycled for five days on itself using a 12-hour incremental data assimilation cycle. Each ocean analysis uses the previous ocean analysis as the first guess. This approach expands the data time window, thereby significantly reducing the influence of climatology. For the "warm start", the previous 12-hour forecast fields are used as the first guess for the ocean analysis.

A good ocean analysis is very important for the real-time forecasting. The use of quality-controlled observation data is especially critical. Each analysis uses available observational data, including surface ship and buoy SST, bathythermograph (XBT), PALACE float profiles, and MCSST.

2.4 *Verification Techniques*

The real-time ocean forecasts are verified using observational data at 12-hour intervals. Observation innovation vectors are generated from each ocean analysis during the update cycles and they provide a measure of the 12-hour forecast skill of the model. Forecast data vectors are similarly constructed for

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forecast fields using the innovation vectors valid at the time of the forecast. The RMS and mean bias are calculated at each 12 hour forecast time to evaluate the performance of the system.

3. RESULTS

Real-time ocean forecasting started in March 2003 and has been run daily for six months so far. The forecasting is run after every ocean analysis with the update cycle of 12h. The preliminary results from the forecasts demonstrate that NCOM is able to simulate some observed features of the general ocean circulations in the Mediterranean Sea. For this study, one recent day forecasting starting at 12 Z October 28, 2003, is selected to show the features of the forecasting.

The performance of the real-time ocean forecasting depends on the accuracy of the hourly surface wind stress and heat fluxes provided by COAMPS forecasts. Figure 1 shows the surface wind stress and surface heat flux at 72-hour from the forecast starting at 12 Z October 28, 2003. The southwesterly wind dominates most of the domain and a cyclonic (anti-clockwise) wind system is seen over the Ionian Sea. The upward surface heat flux covers the whole domain.

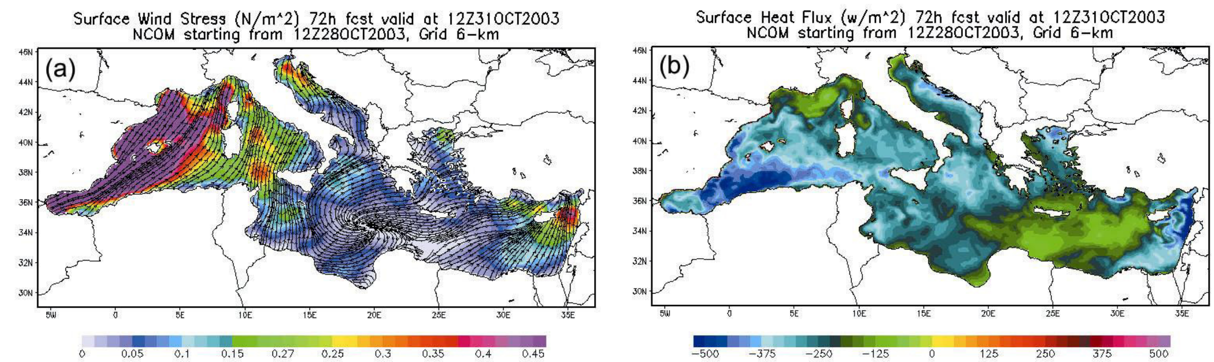

Figure 1. (a) Surface wind stress and (b) surface heat flux after 72 hours of forecast initialized at 12 Z October 28, 2003.

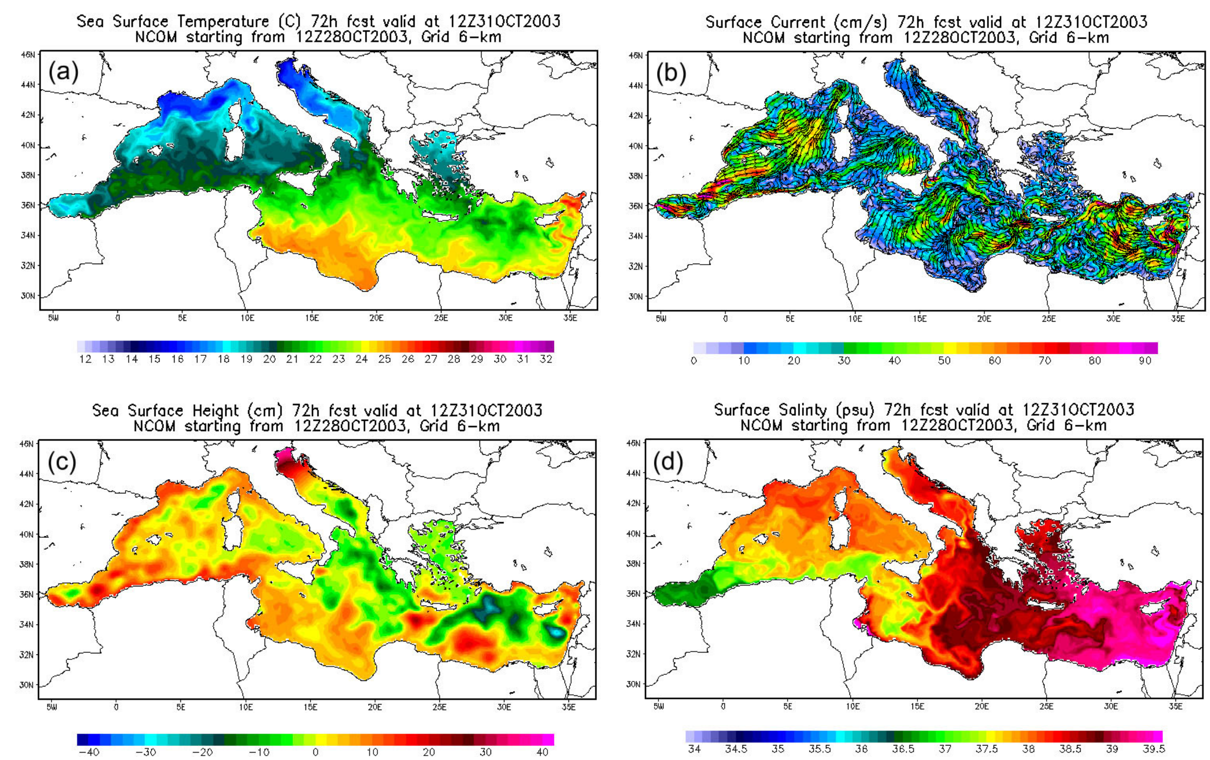

Figure 2. (a) Sea surface temperature, (b) surface current, (c) sea surface height and (d) sea surface salinity after 72 hours of forecast initialized at 12 Z October 28, 2003.

Under the influence of the cyclonic surface wind stress over the Ionian Sea, a cyclonic ocean circulation develops with the Ekman transports directed outwards resulting in upwelling in the center. This region is characterized with lower sea surface height and SST, but with higher salinities (Figure 2). The inflow of the cold and lower salinity water from the Atlantic Ocean through the Strait of Gibraltar results in the relatively lower SST and salinity in the Alboran Sea. Cyclonic ocean circulations, associated with the low sea surface height, are found in the Balearic Sea, Tyrrhenian Sea and near Rhodes and result in cold water and high salinity. The anti-cyclonic ocean circulations in the Gulf of Syrte and Levantine Sea are associated with the higher sea surface height, warm water, and lower salinity.

Monthly averaged RMS calculated for October 2003 is between 0.285 ^{o}C to 0.628 ^{o}C (Figure. 3a). The mean bias errors, ranging between -0.030 ^{o}C to -0.138 ^{o}C, indicate that the model has a cold bias for SST (Figure 3b). The total number of observations corresponding to each forecast hour for this month varies from 214,000 to 223,000.

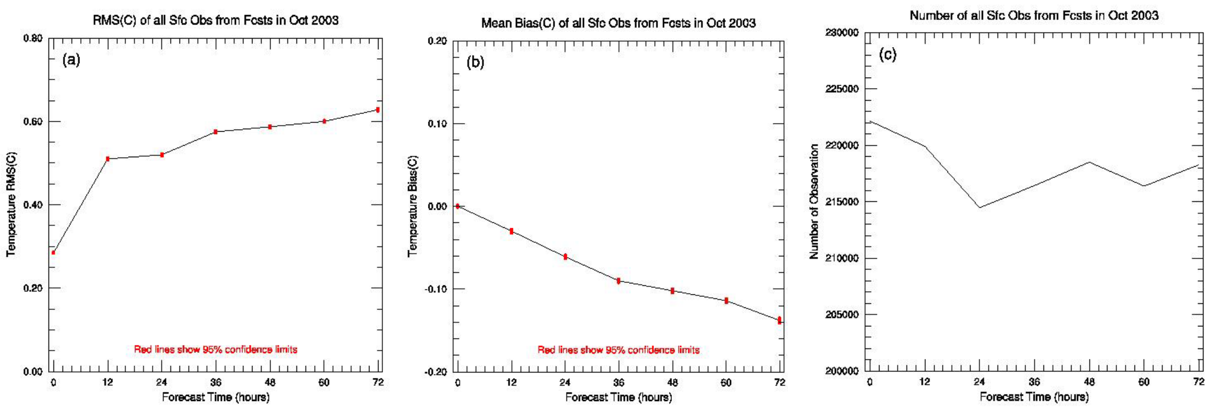

Figure 3. (a) RMS, (b) mean bias, and (c) total number of observations at different forecast times from the forecasts in October 2003.

4. FORECAST ON-LINE

The results of the real-time ocean forecasts, the data assimilation, and the surface forcing fields are displayed on a local web server and updated every 12 hours. A table of all variables available at the most recent time is listed in the first page (as default) for easy use. The display (Figure 4) includes surface variables, 3-D variables, and their animation. Surface variables, such as sea surface temperature, sea surface currents, sea surface height, surface wind stress, surface heat flux, and surface solar flux, are available hourly for each 72-hour forecast. 3-D fields, such as temperature, currents, and salinity, are available at 25m, 125m and 500m depths every 12-hour for each 72-hour forecast.

Users can select time to display the archived data or can specify starting time and ending time to display an image animation consisting of the first 12-h from each forecast during that period of time (Figure 5). As shown in Figure 6, the user can select a forecast time or a variable to view the forecast images. The user also can view the animation of the hourly surface fields or 3-D fields every 12-hour. A dynamic web page is created to compare two different real-time forecast variables at different time based on the user's choice. Users can easily study the influence the ocean analysis by comparing two different forecasts with the same validation time (Figure 7). Although two fields are very similar, there are still some differences, such as the higher temperature found in the later forecast near the Syria coast. Users can also compare two different variables or the same variable at two different times/forecasts.

Real-time NCOM Forecast over Mediterranean

Forecast | View Figure | Compare | Archive

Ocean forecast starting at 2003102812

Surface fields with hourly output

Sea Surface Temperature (SST)	00h	12h	24h	36h	48h	60h	72h	Animation
Sea Surface Current (SUV)	00h	12h	24h	36h	48h	60h	72h	Animation
Sea Surface Height (SSH)	00h	12h	24h	36h	48h	60h	72h	Animation
Sea Surface Salinity (SSS)	00h	12h	24h	36h	48h	60h	72h	Animation
Surface Wind Stress (SWS)	00h	12h	24h	36h	48h	60h	72h	Animation
Surface Heat Flux (SHF)	00h	12h	24h	36h	48h	60h	72h	Animation
Surface Solar Flux (SSF)	00h	12h	24h	36h	48h	60h	72h	Animation

3-D fields with output of every 12 hours

Temperature 25m depth (T25)	00h	12h	24h	36h	48h	60h	72h	Animation
Current 25m depth (V25)	00h	12h	24h	36h	48h	60h	72h	Animation
Salinity 25m depth (S25)	00h	12h	24h	36h	48h	60h	72h	Animation
Temperature 125m depth (T125)	00h	12h	24h	36h	48h	60h	72h	Animation
Current 125m depth (V125)	00h	12h	24h	36h	48h	60h	72h	Animation
Salinity 125m depth (S125)	00h	12h	24h	36h	48h	60h	72h	Animation
Temperature 500m depth (T500)	00h	12h	24h	36h	48h	60h	72h	Animation
Current 500m depth (V500)	00h	12h	24h	36h	48h	60h	72h	Animation
Salinity 500m depth (S500)	00h	12h	24h	36h	48h	60h	72h	Animation

Figure 4. A table of all variables from the real-time ocean forecasting at a default time (the most recent forecast) is available on the internal web site

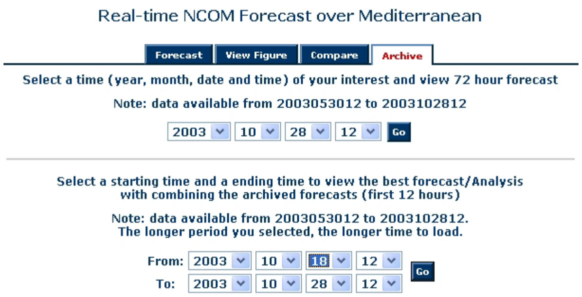

Figure 5. Users can select a time to view the forecast results from database. User also can select a starting time and an ending time to view the animation of the combined forecasts.

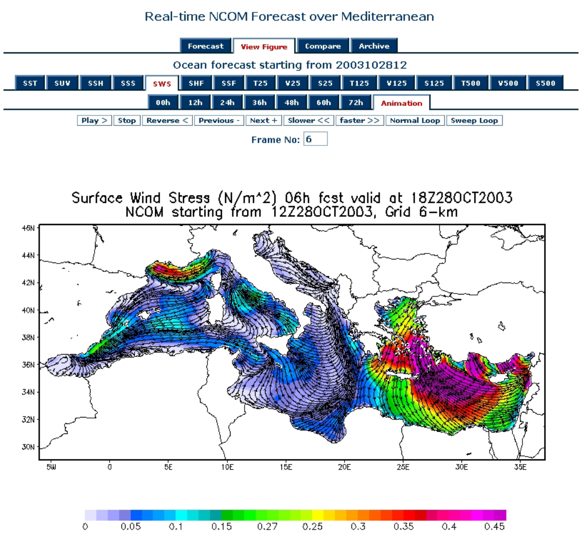

Figure 6. Surface wind stress at 6-hour of ocean forecasting starting at 12 Z October 28, 2003 is displayed at COAMPS web server.

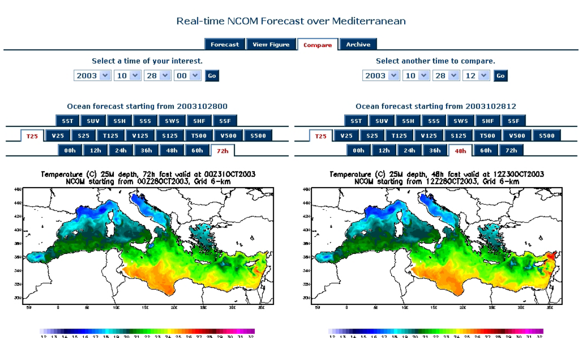

Figure 7. Comparison of the temperatures at 25 m depth from two real-time forecasting, with the same validation time: (a) 72-hour forecasting start at 00 Z October 28 and (b) 48-hour forecasting start at 12 Z October 28, 2003.

5. SUMMARY AND FUTURE PLANS

The preliminary results show that the real-time ocean forecasting over the Mediterranean Sea performs very well and captures the main features of the ocean circulations in that region. The use of an incremental ocean data assimilation cycle can improve the performance of the forecasting. In the future, real-time forecasting will be expanded to additional regions and use global NCOM forecasts as the first guess for the "cold start". The global NCOM will also be used to provide lateral boundary conditions for regional NCOM forecasts. High-resolution atmospheric forecasts will be used to increase the accuracy of the surface momentum and heat fluxes, which are very important for the study of ocean-atmosphere interactions. Furthermore, two-way ocean-atmosphere interactions will be studied instead of the one-way coupling currently in use.

Another important issue for the real-time ocean forecasting is how to schedule forecasting to get the best results. Each COAMPS atmosphere forecast is delayed for about 6 hours. The ocean observational data collections are typically delayed for 24 - 48 hours based on different types of datasets. The delayed forecasting with more observation data can improve forecasting, while long time numerical integrations can introduce more computational errors. The question is: how much time delay is best for the 72-hour forecasting? We need to reach a compromise between the delay time and data availability. More details of the results will be presented at the conference.

6. REFERENCE

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

Hodur, R.M, X. Hong, J.D Doyle, J. Pullen, J. Cummings, P. Martin, and M.A Rennick, 2002: The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Oceanography.* **15,** No. 1, 88-98.

Martin, P.J., 2000: A description of the Navy Coastal Ocean Model Version 1.0. *NRL Technical Report* 7322-00-9962, 45pp.

7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the sponsor of this project, the Office of Naval Research, through program element PE 0602435N. Computations were performed on SGI O2K at the Naval Research Laboratory. Thanks to Dr. Jason Nachamkin for helping transfer the COAMPS atmosphere forecast data. The authors also wish to thank Dr. Paul May for discussions on the ocean circulations in the Mediterranean Sea.