

# Global Air-Ocean Coupling Development and Studies

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## LONG-TERM GOALS

The Navy has a need for global environmental prediction from the top of the atmosphere to the floor of the ocean. Forecast time scales are 7-10 days for the atmosphere and 30-60 days for the ocean. A coupled atmosphere-ocean prediction system for data-assimilation and forecast provides the best hope for achieving these ambitious goals. NRL-Monterey will develop the system with large contributions from the rest of NRL and the meteorological and oceanographic research communities at large. The target system will have horizontal resolution of  $O(1/4)$  degree in the atmosphere and  $O(1/8)$  degree in the ocean.

## OBJECTIVES

Our objective is to develop, test, and validate a global, scalable, coupled data assimilation system comprised of atmosphere and ocean components. The atmosphere and ocean components will each contain programs to perform data quality control, data analysis, initialization, and numerical forecasts. This coupled system will be used in this and other programs for basic and applied research topics and is also expected to eventually transition to operations through a related 6.4 program. In operations, it is expected that this system will provide improved capabilities to describe the atmosphere and the ocean at the analysis and forecast times and to provide high resolution initial and boundary data for the atmosphere, ocean, and ice to a mesoscale coupled data assimilation system.

## APPROACH

Our approach is to build the coupled system using a combination of existing and newly-developed components and a generalized flux coupler to allow for the exchange of relevant parameters across the air-ocean interface. For the atmosphere, the Navy Operational Global Atmospheric Prediction System (NOGAPS) has been shown to be among the leading atmospheric data assimilation systems in the world. NOGAPS will be used for the atmospheric component of the coupled system. For the ocean component, we will leverage work on-going at other institutions [e.g., Naval Postgraduate School (NPS), NRL Stennis Space Center (NRL SSC), Los Alamos National Laboratory]. Some of these projects include the development of a 3-dimensional ocean multivariate optimum interpolation analysis (3D MVOI, NRL MRY and NRL SSC), the testing of the Parallel Ocean Prediction (POP) ocean model at NPS, and the development of the next-generation Polar Ice Prediction System (PIPS 3.0) in a joint project headed by NRL SSC. The coupled system will be designed for scalable computer architecture. Initial development will involve the testing and/or development of key components of the system, improvements to parameterizations of NOGAPS physical processes that are critical for

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accurate simulation of air/sea energy exchange, and the development of atmospheric datasets that can be used for the validation of the ocean model. This development will transition to a related 6.4 project that will focus on the design and implementation of this system for operational use.

## **WORK COMPLETED**

The next element of the global atmosphere-ocean coupling, that of allowing two-way exchange of fluxes between the atmospheric model and the ocean model, has been accomplished by converting the POP ocean model into a subroutine that can be called by NOGAPS at arbitrary time intervals during the forecast cycle. When the POP subroutine is called NOGAPS passes a complete set of momentum, heat, and moisture fluxes to the ocean model and, on return, the ocean model returns surface temperatures and salinities to NOGAPS. The coupling period is arbitrary and has been tested at intervals down to one hour. Preliminary results from the fully coupled model show significant air-sea interactions particularly in the tropics.

This year's efforts also continued evaluating of the performance of the one-way coupled NOGAPS-POP system. Various configurations of data assimilation, vertical resolution and ocean mixed layer parameterization were tested. The model results were evaluated against independent data, not assimilated in the model experiments but available in a delayed mode. The independent data sets included temperature and velocity data from drifters (Flatau et al, 2002), salinity and current data from moorings, CTD data from hydrographic cruises and sea surface temperatures from satellite microwave measurements. We studied in detail the response of the coupled system to tropical convective forcing related to monsoon (Flatau et al, 2001) and tropical cyclones for the runs with and without data assimilation. Proper simulation of these processes will be crucial for the success of a fully coupled system.

In NOGAPS a new diagnostic cloud scheme (Teixeira and Hogan, 2002) has been developed and implemented that improves the representation of clouds like stratocumulus that have a profound influence on the radiation budget of the ocean surface. The new cloud scheme is also being test in the NRL coupled mesoscale forecast system, COAMPS.

A new closure for the eddy-diffusivity scheme (Teixeira and Cheinet, 2002(a)) has also been developed at NRL Monterey. In this new scheme the mixing length is proportional to the square root of turbulent kinetic energy (TKE). The new scheme is able to successfully simulate stratocumulus and shallow cumulus (Teixeira and Cheinet, 2002(b)) and has been implemented in a single column version of NOGAPS.

## **RESULTS**

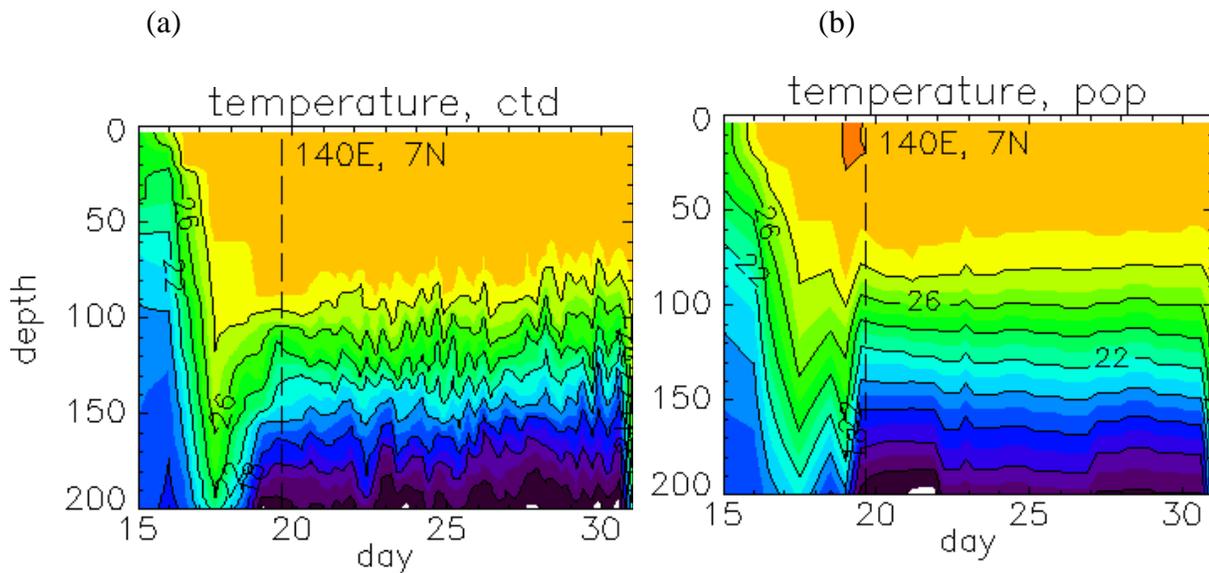
Testing of the coupled ocean data assimilation and ocean forecast programs (MVOI and POP) has shown that the system is robust and produces a skillful forecast of the sea-surface temperature. The strategy of using the analyzed increments of temperature and salinity to update the ocean model is feasible because the increments are small and because they are inserted into the ocean model on scales that are comparable to the adjustment scale of the ocean model. The increments are small because the short term (e.g. 24 hrs) background forecasts predict most of the subsequent changes in the ocean, yielding a good 'fit' of new observations to the predicted model state. The correlation scales of the optimal estimation procedure determine the scale of adjustments. Further examination of the results of

the MVOI/POP coupling will lead to better values of correlation scales, better quality control of the data stream, and some tuning of parameters in POP.

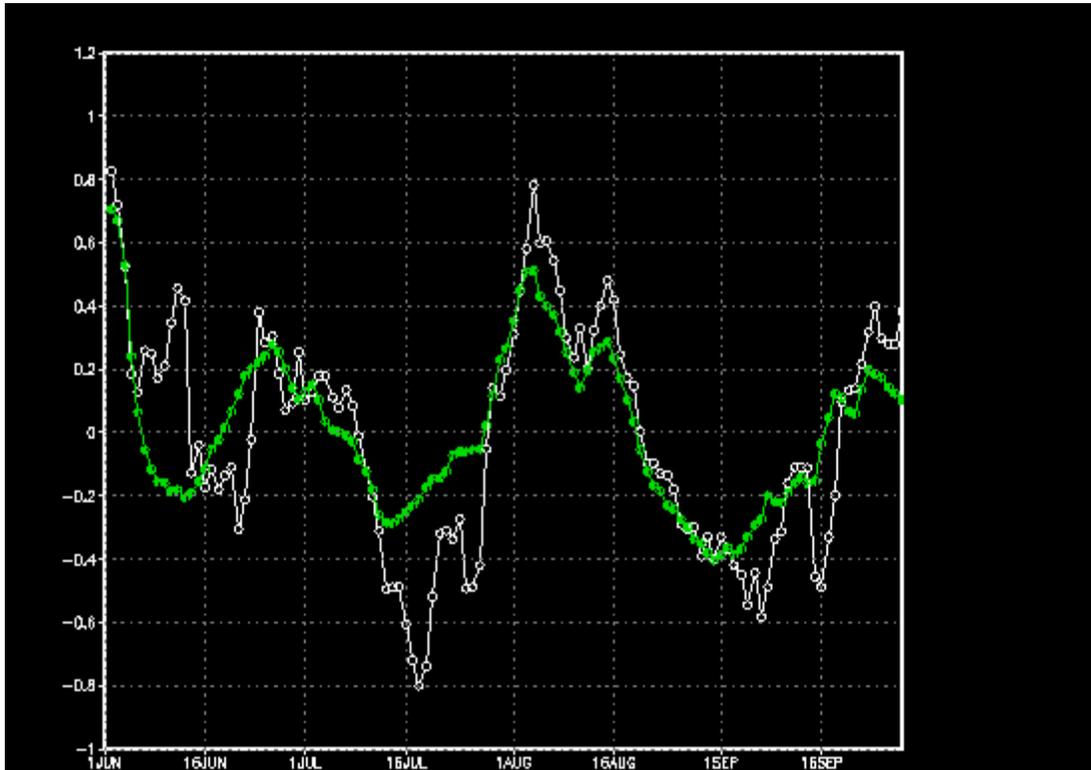
Our results indicate that the coupled NOGAPS/POP data assimilation system represents well the thermal structure of the upper ocean (Fig 1). The depth of the ocean mixed layer and the steepness of the thermocline are slightly underestimated, which is probably the result of limited vertical resolution rather than a problem with the parameterization of the ocean mixed layer. Because salinity data is relatively sparse, the salinity structure in the model is determined mostly by the MODAS dynamic climatology used in data assimilation. While this method gives the reasonable salinity values, the anomalies from the seasonal mean are difficult to assess.

Comparison of the POP model forced by NOGAPS fluxes without data assimilation shows a response to convection similar to that observed in the experiments with data assimilation. (Fig, 2) This suggests that the coupled system is well suited for simulating the air-sea interaction processes on short time scales. However, data assimilation is necessary to prevent the model from developing unrealistic long-term trends. Recent improvements to NOGAPS flux parameterizations should contribute to reducing these trends.

A more complex statistical/prognostic cloud scheme has been tested in NOGAPS. The new scheme represents the hydrologic cycle in a thermodynamically consistent way and allows a better understanding of the ocean atmosphere interactions in the context of the global water cycle.



**Figure 1: The temperature structure in the upper ocean from a) hydrographic data from the RV Mirai CTD measurements, b) ocean model with data assimilation. The measurements between June 15 and 19 were obtained at 140E between 30N and 5N (once per day). After June 19 (denoted at by the dashed vertical line) the data illustrate the time evolution of temperature at one station measured every 6 hours. The model data represent daily averages.**



*Figure 2: The detrended sea surface temperature in the Bay of Bengal during the monsoon season. The black line indicates the results for the run including data assimilation, the green line indicates the results without data assimilation. These results suggest a proper response of the model to the NOGAPS surface fluxes related to monsoon convection.*

## IMPACT /APPLICATIONS

Operational atmospheric data assimilation is a mature technology practiced at several major national weather centers around the world. Ocean data assimilation, on the other hand, is still in its infancy. Lack of observational data and daunting computational requirements have been primary obstacles in its progress. Recent advances in observing systems and computer technology are finally removing these obstacles, but there are still major challenges. The Navy has a critical need for global oceanographic environmental information to complement the global meteorological support that impacts virtually all Navy operations. The NRL coupled data assimilation and forecast system is the first step toward this goal.

## TRANSITIONS

Improvements and refinements of the One-way coupled NOGAPS/POP data assimilation system were transitioned to the 6.4 Global Coupled Data Assimilation System Evaluation project (see below). The new prognostic cloud scheme and vertical mixing parameterization were also transitioned to the 6.4 global coupled project, where extensive testing of the impact on NOGAPS performance is underway. Testing of these new schemes is also underway in COAMPS.

## RELATED PROJECTS

6.4 Global Coupled Data Assimilation System Evaluation (Award # N0003900WXDF217)

6.2 Mesoscale Air-Ocean Coupling (Award # N0001402WX20572)

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