Toward the Development of a Coupled COAMPS-ROMS Ensemble Kalman Filter and Adjoint with a focus on the Indian Ocean and the Intraseasonal Oscillation

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LONG-TERM GOALS

The long-term goals of this research project are to:

1. Develop a regional coupled ocean-atmosphere model comprising the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) and the Regional Ocean Modeling System (ROMS).
2. Explore data assimilation strategies in regional coupled ocean-atmosphere models with a specific focus on air-sea interaction in the tropical Indian Ocean.

OBJECTIVES

The project has the following objectives:

(1) Interface ROMS and COAMPS with the Data Assimilation Research Testbed (DART) system at NCAR.

(2) Compare the performance of the Ensemble Kalman Filter (EnKF) using the Data Assimilation Research Testbed (DART) and 4-dimensional variational (4D-Var) approaches to data assimilation in ocean only and atmosphere only experiments.

(3) Develop a coupled model capability based on the pre-existing COAMPS and ROMS systems using the Earth System Modeling Framework (ESMF) NUOPC interface.

(4) Investigate the merits of the EnKF approach for assimilating data into a coupled model, particularly in the highly dynamic tropical Indian Ocean where air-sea interactions play a fundamental role shaping the monsoon circulation.

APPROACH

As part of this project, eight major research tasks are envisaged:

Task 1: Development of a coupled COAMPS-ROMS code using the ESMF NUOPC interface.
Task 2: Configuration of ROMS for the Indian Ocean and U.S. west coast.
Task 3: Configuration of COAMPS for the Indian Ocean and U.S. west coast.
Task 4: Interfacing ROMS with DART.
Task 5: Interfacing COAMPS with DART.
Task 6: Testing of the coupled model via a series of idealized problems.
Task 7: Configuration of the coupled COAMPS-ROMS system with DART.
Task 8: Preparation of observations from the Indian Ocean for data assimilation.

WORK COMPLETED

Task 1: Development of a coupled COAMPS-ROMS code using the ESMF

Both the COAMPS and ROMS coupling algorithms are being updated to the latest ESMF and NOUPC version 7.0 release. The NUOPC layer is a simplified infrastructure on top of the ESMF library that provides conventions and templates to facilitate the easy coupling between Earth System Models (ESMs). The NUOPC layer is already coded in COAMPS and it is being updated to include ROMS as the ocean model component using the ESPC-NUOPC infrastructure. A prototype of the ROMS NOUPC layer has been coded, and testing and tuning will begin soon performed by project personnel at Rutgers.

Significant progress has been made toward coupling COAMPS and ROMS. Project personnel from NRL-Monterey, Rutgers University and UC Santa Cruz are collaborating to develop the coupled version of the COAMPS-ROMS model. Our original strategy was to re-use the existing COAMPS coupling framework. In April 2016, we held a week-long development session at NRL-Monterey during which both Hernan Arango and Andy Moore were present. During this meeting NRL scientists learned how to compile and run ROMS on the Navy's High Performance Computing systems. During the same visit we attempted to compile ROMS model with an ESMF driver.

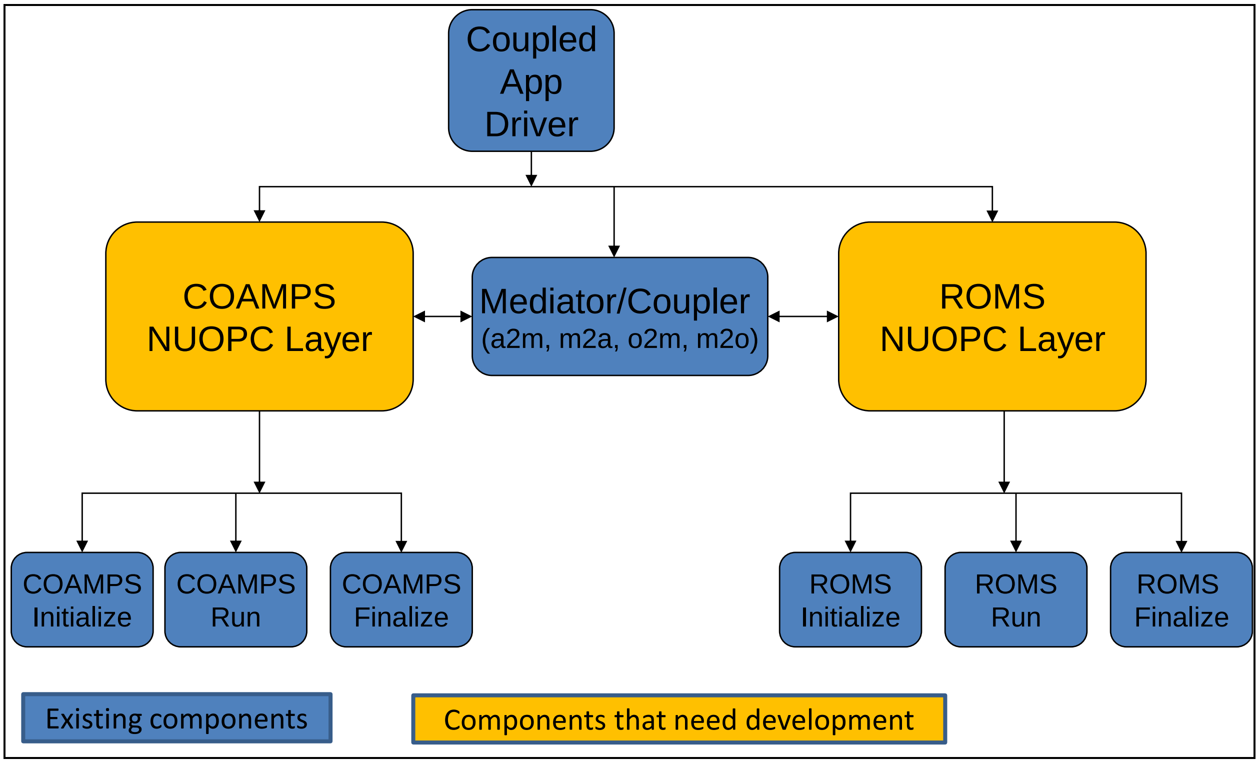

Figure 1: COAMPS-ROMS coupled infrastructure (ESPC-Regional).

After this initial meeting, it was decided that we will develop a capability specifically for this NOPP project based on the ESPC-Global NUOPC driver. The benefit of this new approach is that the coupling code will be lightweight and portable between the team members (see Figure 1). We are currently pursuing this new direction. Specifically, to date we have:

1. Developed an interface to obtain ROMS grid, latitude, longitude, land-sea mask, and domain decomposition information. This information was essential to setup ESMF grids.

2. Prototyped an export interface to extract fields from ROMS for the purpose of coupling.

3. Built an import interface to ingest fields from ROMS for the coupling purpose.

4. Built a prototype NUOPC driver/interface to drive the standalone ROMS and the coupled ROMS+Data/Atmosphere system.

5. Run the standalone ROMS under ESMF/NUOPC framework.

6. Run the prototyped coupled ROMS+Data/Atmosphere system, where the atmosphere came from an offline COAMPS run. The purpose of this run was to demonstrate that we have a functional ROMS+Data/Atmosphere system. However, the implementation is still very preliminary.

Lastly, we have now obtained the proper legal agreements between i) NRL and Rutgers, ii) NRL and UCAR, and iii) NRL and UC Santa Cruz, so that the atmospheric portion of the coupled model can be shared, as well as any jointly developed code.

Task 2: Configuration of ROMS for the Indian Ocean

ROMS has been configured for the Indian Ocean with a resolution that telescopes from 26 km at the northern and southern boundaries to 7 km the equator. The model has been spun-up for several years, followed by several simulation experiments which were validated against the available DYNAMO data. Specifically:

a) We performed an evaluation of possible surface forcing products (the Southampton Ocean Centre analysis, NOGAPS, COAMPS and the ERA-interim analysis of the European Centre for Medium-Range Weather Forecasts) by comparing them with atmospheric in-situ observations from the Research Moored Array for the African-Asian-Australian Monsoon Analysis and Prediction (RAMA) and performing forward model integrations. This allowed us to identify the ERA-interim analysis as the most realistic forcing to be used in future ocean stand-alone model simulations.
b) Tides were included in the model simulation using the tidal harmonics from the Oregon State University global inverse solution.
c) The input of freshwater by major rivers was included using the seasonal cycle provided by the Global Runoff Data Base.
d) The monthly seasonal boundary forcing from the SODA analysis was replaced by 5-day means from the HYCOM analysis.

In addition, satellite and in-situ data for the period of interest (2010 and 2011) was assembled from different sources, and the forward model was validated by comparing simulations with the observational data (see results section).

Task 4: Interfacing ROMS with DART

During FY 2016, we have made significant progress in interfacing ROMS with DART. In May 2016, Edwards, Arango and Moore spent 3 days at NCAR visiting the DART group, during which time we collectively worked on assembling all of the pieces of software specific to ROMS-DART communications. Since that initial visit, Arango has made several significant modifications to the ROMS source code to simplify the transfer of required information from ROMS to DART. Specifically: (a) a new output NetCDF file was added to ROMS to save the 4D-Var posterior analysis or the restart files required by DART; (b) The ROMS observation operator output was enhanced so that it now contains the complete field of observations in addition to the model sampled at the observation locations in space and time. In addition, DART personnel have developed a prototype version of DART-ROMS in the form of scripts so that ROMS to be cycled across multiple data assimilation windows. The test region chosen for the prototype system is the ROMS 30 km west coast configuration, which the ROMS developers have used routinely for testing and debugging the various ROMS drivers. At our May meeting, it was decided to adopt a First Guess at Appropriate Time (FGAT) approach for DART-ROMS in order to account for the very regular nature of the ROMS west coast observation data stream. The newly structured ROMS output file described in (b) greatly facilitates this approach. The use of FGAT is a significant departure from what is normally done in DART. Recently, UC Santa Cruz personnel have successfully run the DART-ROMS system for the US west coast configuration across 10 consecutive two-day assimilation windows using real ocean observations. This initial test is very encouraging, and analysis of this preliminary set of runs will continue in the coming months.

Task 5: Interfacing COAMPS with DART

In parallel to the model coupling efforts, the NRL-Monterey team is currently developing a stand-alone configuration of COAMPS with DART that covers the same model domain as the ROMS west coast model described in Task 4. This stand-alone configuration of COAMPS will be later used to configure the coupled version of COAMPS-ROMS.

Task 8: Preparation of observations from the Indian Ocean for data assimilation

The ROMS 4D-Var data assimilation system is currently being implemented in the ROMS Indian Ocean model, and is being used to produce an ocean analysis during the DYNAMO observational campaign (from Sept 2011 to January 2012). The ocean data mining and assembly done at this time, will also prove valuable later on for running the COAMPS-ROMS-DART system.

RESULTS

Configuration, testing and validation of the ROMS Indian Ocean model has proceeded well during FY 2016. The most skillful model configuration was found to be that forced by surface fluxes derived from ERA-interim and by HYCOM at the boundaries. Figure 2 shows the spatial distribution of all available in-situ observations (Fig. 2a) and a comparison of the model simulation with observations at selected depths taken at the RAMA mooring closest to the location of the DYNAMO field campaign. While the model exhibits substantial skill in reproducing the observed temperature (Fig. 2b), salinity (Fig. 2c) and currents (Fig. 2d), there are some periods with significant model errors that we believe can be alleviated by data assimilation (e.g., the temperatures at 100 m in April-July in Fig. 2b).

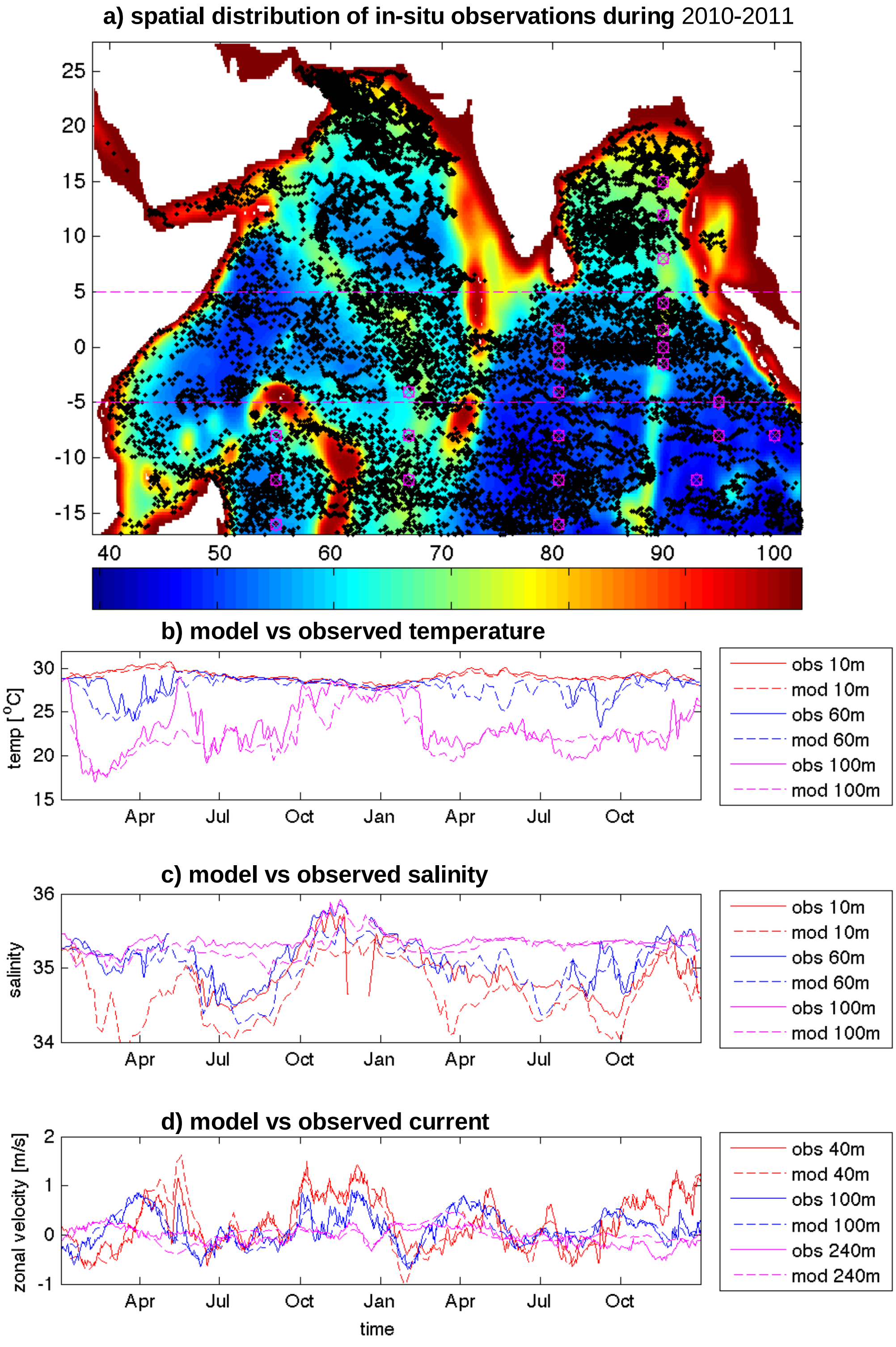

Figure 2: a) Model bathymetry (color) and spatial distribution of all the available in-situ observations during 2010 and 2011 (black dots). The magenta squares indicate the position of the RAMA moorings that recorded data during this period. Data from the RAMA mooring located at 0°N and 80.5°E is used to compare the observed temperature, salinity,

and zonal current at selected depths with the model simulations in (b), (c), and (d) respectively.

We have also performed a more objective evaluation by comparing the model simulations with all the available observations shown in Fig. 2a in the latitudinal band 5S-5N. The skill of the model in hindcasting the observed variability was quantified by computing the correlation, root mean square (rms) and bias between the observed and modeled values at different depths. For all the variables (temperature, salinity, and zonal current) correlations are above 0.6 at almost all depths (Figs. 3 a,d,g). The rms of the difference between the model simulations and observations is reasonably small (Figs. 3 b,e,h), except for temperature with a maximum of about 3°C at around 100 m depth, the position of the climatological thermocline. Similarly, the model biases are reasonably small (Figs. 3 c,f,i).

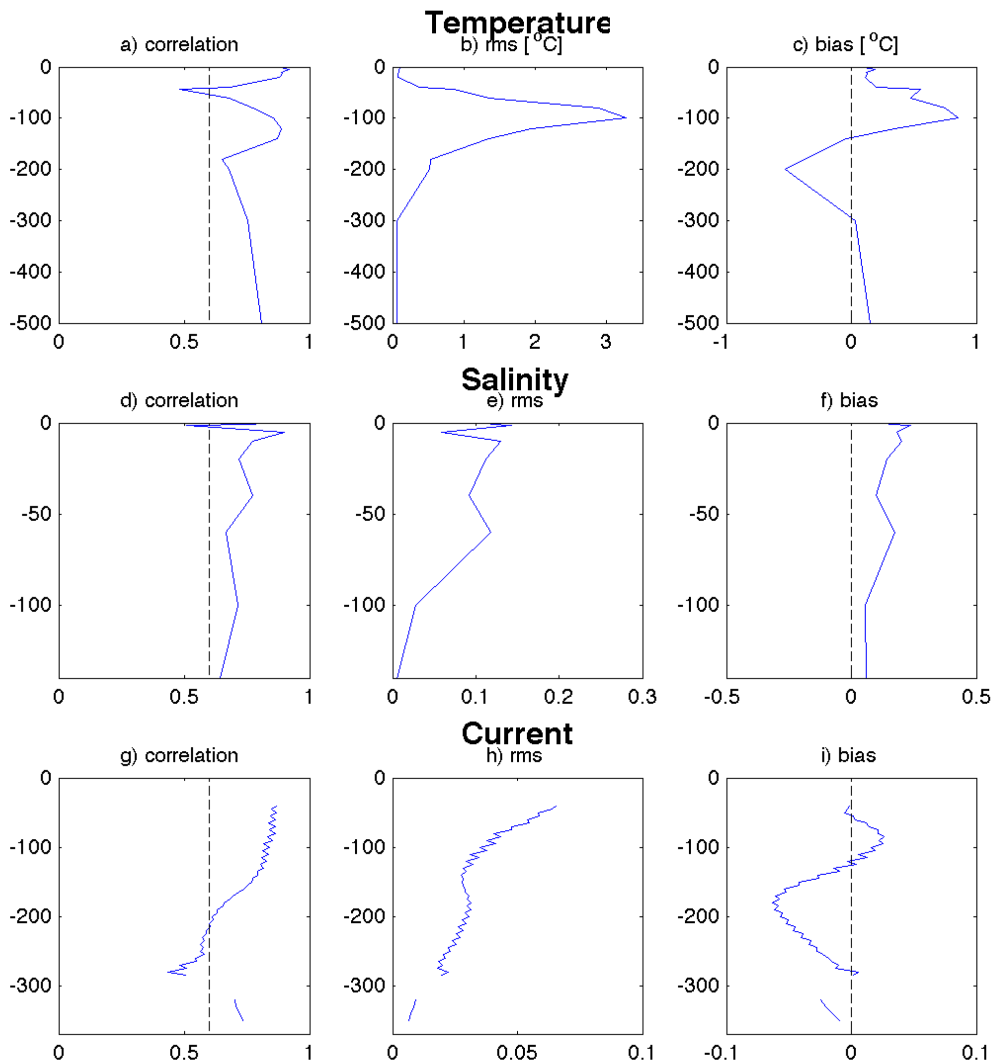

Figure 3: The correlation, root mean square (rms) difference, and mean difference (bias) between the model simulations and observations for temperature (a-c), salinity (d-f), and zonal current (g-i).

In addition, 4D-Var data assimilation has been implemented in the ROMS Indian Ocean application and is currently being used to compute an ocean analyses during the time period of the DYNAMO campaign. Data streams being considered are the satellite SST and SSH anomalies and the in-situ observations presented in Fig. 2a. Temperature anomalies around the thermocline are highly correlated with the SSH anomalies and therefore we anticipate a reduction in the rms errors shown in Fig. 3b.

PLANS FOR FY 2017

NRL-Monterey:
In collaboration with all NOPP partners, project personnel at NRL-Monterey plan to achieve the following milestones during FY2017: (1) Establish a version control repository for the project branch of the system that will be accessible by all partners, and commit all the appropriate source code for the coupled system to the repository. (2) Complete the development of the coupled forecast model using the ESPC-NUOPC infrastructure, and demonstrate this capability using a 5 day forecast. (3) Upgrade the DART version for the NOPP stand-alone COAMPS to the DART – RMA version that is currently under the development for the ROMS code. (4) Establish a scripting infrastructure for the cycling NOPP COAMPS-ROMS-DART system, and demonstrate this capability for an extended period of time (possibly a month-long dataset).

Rutgers University:
The model validation presented in this report focuses in the equatorial region since that was the region targeted by the DYNAMO campaign. In the upcoming year the model validation will be extended by project personnel at Rutgers to include the entire model domain. We will also continue with the 4D-Var data assimilation experiments, and then implement the EnKF when testing of the implementation of DART-ROMS is complete. In addition, we plan to document the Indian Ocean ROMS application, its validation using all the available observations, and the data assimilation experiments in a scientific manuscript to be submitted for publication. Of particular interest will be a comparison of the performance of the EnKF and 4D-Var systems, and the possibility of combining them in a hybrid data assimilation scheme.

NCAR:
The DART team will continue with the development of the required software interfaces between DART-RMA and COAMPS, and DART-RMA and ROMS. This will be done in close collaboration with the groups at NRL-Monterey, Rutgers and UC Santa Cruz.

UC Santa Cruz:
Testing and validation of the DART-ROMS system will continue during the coming year. This will initially be done using the standard 30km resolution west coast configuration of ROMS which is

computationally efficient, and for which we have a great deal of experience. We then anticipating transitioning DART-ROMS to a 10 km resolution west coast model and to the ROMS Indian Ocean configuration summarized above.

IMPACT/APPLICATIONS

This project will contribute significantly to the functionality and utility of COAMPS and ROMS, both widely used and important community models and resources.

TRANSITIONS

The new ROMS utilities developed as part of this project will be freely available from the ROMS web site http://myroms.org and will be actively used and further developed by other research groups in the U.S. and elsewhere as user competence increases. Improvements to the COAMPS systems will be transitioned through the Navy's 6.4 Small-Scale Modeling program.

RELATED PROJECTS

COAMPS and COAMPS-TC will be used in related 6.1 projects within PE 0601153N that include studies of tropical cyclone dynamics, air-ocean coupling, and boundary layer studies, and in related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components (QC, analysis, initialization, and forecast model) of COAMPS and COAMPS-TC.

None.

REFERENCES

None.