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Impact of Resolution on Extended-Range Multi-Scale Simulations

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Award Number: N0001412WX20685

LONG-TERM GOALS

In this project we diagnose and characterize model error as a function of resolution in extended-range (monthly) prediction using a linked global (NAVGEM) and regional coupled (COAMPS®) forecast system. Diagnosing and understanding the characteristics of model error as a function of horizontal resolution is a necessary step toward our long-term goal of producing useful extended-range predictions, and will set the groundwork for the development of the seamless weather-climate Earth System Prediction Capability (ESPC). Nesting a cloud-resolving model inside a hydrostatic global model serves as a bridge toward the next generation high-resolution global cloud-resolving modeling capability.

OBJECTIVES

There are several specific objectives proposed to accomplish our goal of understanding how resolution-dependent model error in our NAVGEM-COAMPS forecast system impacts the utility of extended-range forecasts and how this may error be mitigated.

1. Diagnose and examine in detail the characteristics of model error, including model biases, model energy spectra, variability and frequency of events of interest (e.g., gale-force winds), and specific phenomena such as tropical intraseasonal oscillations.
2. Determine how error in the large scale model influences the performance of the regional model nested within it.
3. Determine how model error and forecast performance change as a function of resolution (in both the large-scale and mesoscale simulations). This includes basic research to determine what scales of motion are fundamental to simulating and predicting large-scale phenomenon such as the Madden Julian Oscillation (MJO) and blocking.
4. Assess the impact of new physical parameterizations (developed under this DRI and the previous DRI on unified physical parameterizations) on model skill.

APPROACH

Our approach includes performing extended integrations for both the Navy global and mesoscale models using different configurations to evaluate and understand the potential for predictability on monthly time scales.

1. Evaluate NAVGEM for monthly time scales at highest resolution possible, and at resolutions considered operationally feasible. Perform reforecasts with analyzed SST and SST information available in real time.
2. Evaluate COAMPS simulations nested within NOGAPS/NAVGEM analyses to examine COAMPS biases that develop during extended integration.
3. Run COAMPS nested within NAVGEM extended range forecasts in order to assess added value of an imbedded regional model for monthly forecasts.
4. Initially, perform COAMPS simulations without ocean component, but later experiments with coupled COAMPS will allow for an assessment of importance of coupled modeling on the mesoscale model performance.
5. Examine specific metrics of high interest to the Navy, such as frequency of occurrence of high-speed near surface winds, and larger-scale phenomenon, such as the MJO.

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WORK COMPLETED

Several experiments have been completed in which COAMPS extended-range forecasts have been run for a large domain over the Indian Ocean and western Pacific (see Fig. 1). The large domain is chosen such that the impact of the lateral boundary conditions is limited in the interior of the domain.

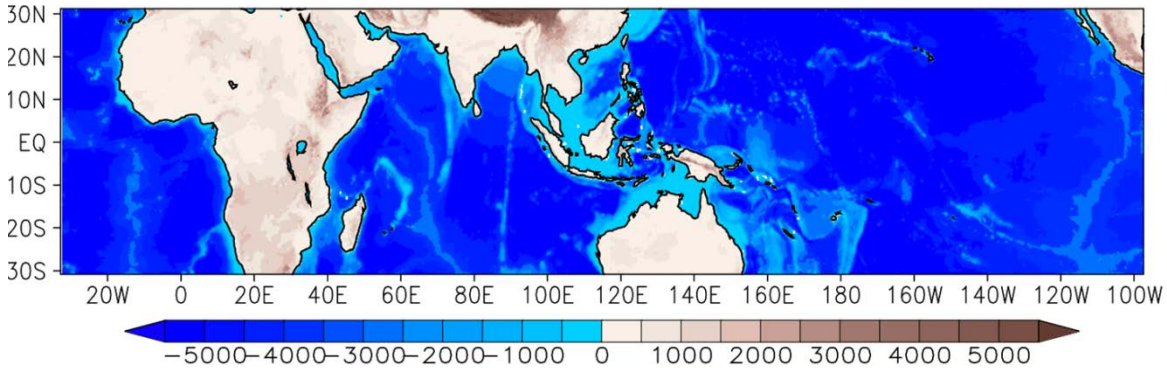

Figure 1: Domain of the COAMPS grid with topography (m).

Several extended integrations have been produced starting 31 October or 1 November 2011, and have been run for at least 30 days. This time period was chosen to coincide with the Dynamics of Madden Julian Oscillation (DYNAMO) field project in order to facilitate validation and simulation inter-comparisons. Table 1 shows the completed experiments.

Table 1: Description of Model Simulations.

Experiment Name	Model	Resolution	SST
C45F	COAMPS	45km	Fixed
C45O*	COAMPS	45km	Observed
C27F	COAMPS	27km	Fixed
C270	COAMPS	27km	Observed
N37F	NAVGEM	37km	Fixed
N37O	NAVGEM	37km	Observed

Here, "Fixed" SST refers to the use of NCODA SST analysis valid at the start time of the simulation and held fixed through the integration. "Observed" SST simulations are performed with NCODA SST analyses that have been updated every 24 hours through the integration. Both COAMPS and NAVGEM simulations are run in "uncoupled" mode, that is, there is no interactive ocean component. Coupled runs will be performed in the third year of the project. COAMPS lateral boundary conditions are provided by NOGAPS analyses. For the C45O simulations 4 integrations started 6h apart on 31 October are performed to examine the impact of small initial condition differences on the monthly forecast.

Verification is based on NASA Tropical Rainfall Measuring Mission (TRMM) precipitation products and NOAA Outgoing Longwave Radiation (OLR) satellite observations, as well as NOGAPS analyses. Future verification will include in situ observations.

RESULTS

We first compare COAMPS precipitation biases as compared to TRMM observations for the second half of November (Fig. 2). The simulations with fixed SST (top panels) show significantly larger precipitation biases than the simulations with the observed SST (bottom panels), particular in the region to the east of the Philippines. Results for the first half of November (not shown) indicate a smaller impact from the fixed SST, as expected. The SST biases are consistent with the seasonal changes in SST that occur during the fall season (cooling to the north of the equator, and warming along the equator and to the south). Clearly, using fixed SST for extended integration leads to significant biases in precipitation (and other fields, not shown). Increasing the resolution from 45 km to 27 km does not reduce precipitation biases.

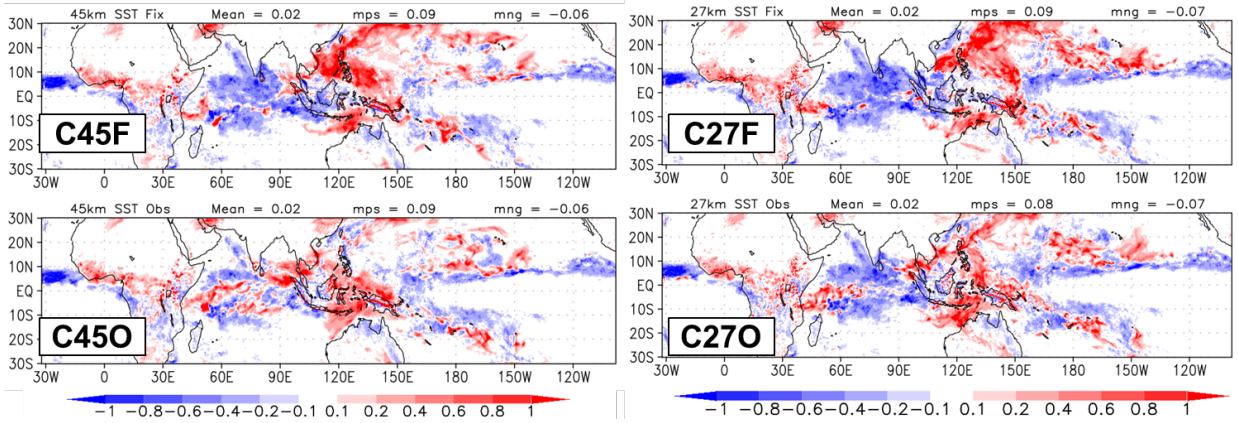

Figure 2: Average precipitation error (mm hr^{-1}), using TRMM precipitation as verification, for COAMPS precipitation for 16-30 November for the 45km simulations (left panels) and 27 km simulations (right panels) with fixed SST (top) and observed SST (bottom).

The biases in OLR (Fig. 3) indicate different sensitivities. The biases no longer show a large sensitivity to SST (that is, top and bottom panels are similar), however, there are substantial differences in the characteristics of the biases between the 45 km (left) and 27 km (right) resolution simulations, reflecting sensitivity of the sub-gridscale parameterizations to resolution. For example, the 27-km simulations have a high OLR bias over much of the Indian Ocean, while the 45 km simulations have a low bias over most of that region. Typically, high OLR bias would be indicative of clouds that are not deep enough or frequent enough, often related to a deficit in convection, but both 27 km and 45 km simulations show a deficit in precipitation over the Indian Ocean, indicating a complex relationship between OLR and precipitation.

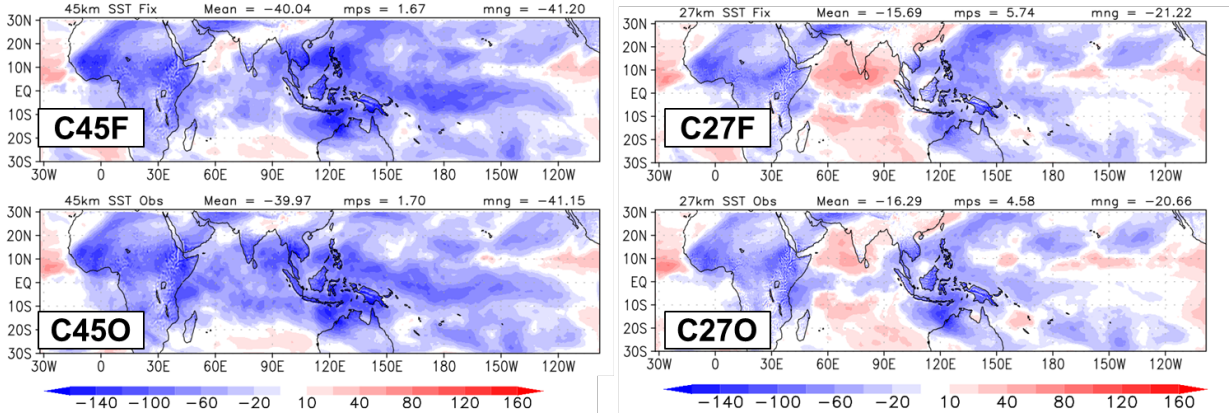

Figure 3: Average OLR error (W m^{-2}) for COAMPS precipitation for 16-30 November for the 45km runs (left panels) and 27 km rms (right panels) for the fixed SST (top) and observed SST (bottom) simulations.

To gauge the ability of the COAMPS simulations to capture interannual variability, particularly the MJO, time-longitude diagrams of preciptation along the equator are examined (Fig. 4).

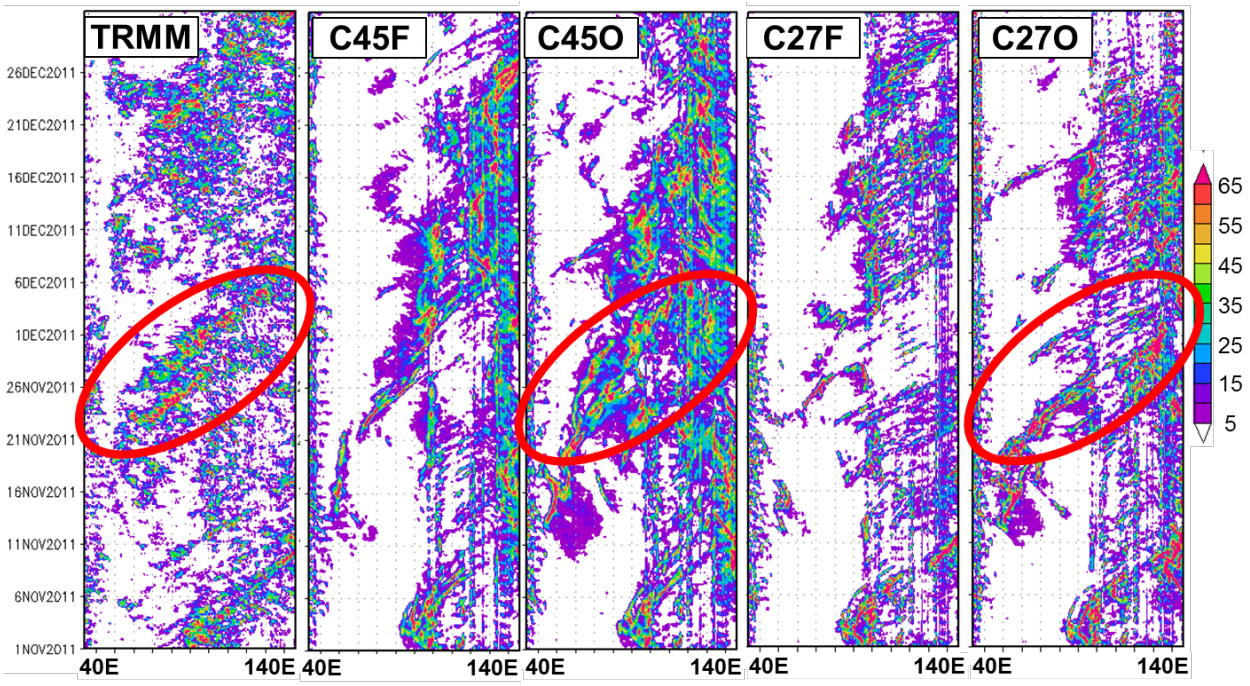

Figure 4: Time-longitude diagrams of precipitation (mm day^{-1}, scale given by color bar) from 40 E to 140 E, averaged between 5 S and 5 N, from 1 November through 30 December (time increases along the y axis) for TRMM (left) and C45F, C45O, C27F, and C27O simulations.

The red oval in the left panel of Fig. 4 highlights the observed MJO the propagated through the Indian Ocean into the Western Pacific during late November. Comparison with the four COAMPS simulations indicate that this feature is simulated more successfully in the observed SST experiments (C45O and C27O) than in the fixed SST experiments (C45F and C27F). It is also clear that the simulation of the MJO is better in the 45 km experiments than the 27 km experiments. These experiments indicate that accurate lateral boundary conditions are not sufficient to produce a good MJO three weeks into the COAMPS simulations, but a good MJO simulation is possible if the SSTs are also accurate. Even given the strong constraint of the analyzed lateral boundary conditions and observed SST, the remarkably good simulation of the late November MJO in the C45O simulation is encouraging, indicating that COAMPS is capable of realistic MJO simulations in extended forecasts.

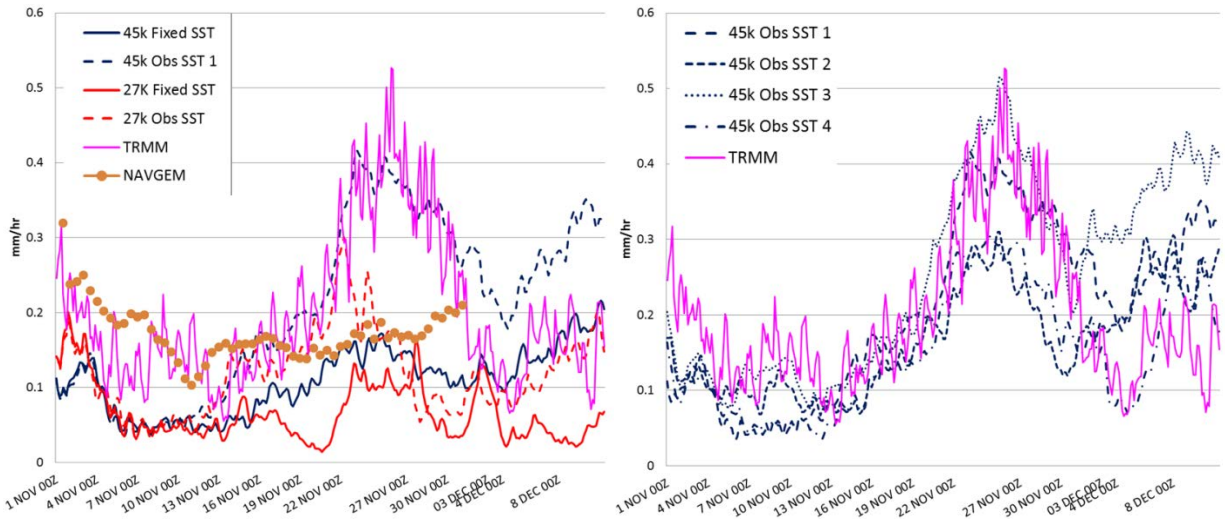

Figure 5: Time series of precipitation (mm hr^{-1}) over the tropical Indian Ocean for TRMM observations (pink) and model simulations as denoted in key.

Another way to evaluate the MJO is to compare the time series of precipitation over the Indian Ocean in the TRMM observations and the model simulations. The left panel of Fig. 5 shows the large increase in precipitation during late November associated with the MJO in the TRMM observations (pink curve). The 45km COAMPS simulation with observed SST, (C45O, dashed blue line) captures this trend very well. The 27km COAMPS simulation with observed SST (C27O, dashed red line) captures the initial increase, but decreases too quickly and does not match the peak observed precipitation levels. The COAMPS simulations with fixed SST (solid red and blue lines) and the NAVGEM simulation with fixed SST (brown circles) do not capture the MJO-related increase in precipitation. The right panel shows the same TRMM observations as the left panel, in pink, but now the model simulations included are all 45-km COAMPS simulations with observed SST (C45O), starting from analyses at 00, 06, 12, and 18 UTC 31 October. While all C45O simulations capture the rapid increase in Indian Ocean precipitation in mid-November, the simulations diverge in maximum amounts of precipitation during the peak, and diverge further in early December, indicating substantial sensitivity to initial conditions in the later part of the forecasts. This result confirms the need for ensemble forecasts that take into account initial condition uncertainty.

IMPACT/APPLICATIONS

These experiments allow for an assessment of potential extended range forecast utility (both global and regional) for Navy-relevant metrics such as potential for high winds, extreme events, or tropical cyclones. This work allows for an evaluation of the value added to GCM extended-range forecasts through nested high-resolution mesoscale forecasts. The assessment of model errors as a function of resolution also allows for feedback to model developers. Experience gained under this project will also have relevance for the potential development of a global model with adaptive mesh refinement capabilities. Understanding what resolution is needed for skillful extended range forecasts will also pave the way for the next generation fully coupled earth system prediction capability. For example, these experiments indicate that accurate SSTs are needed for skillful forecasts of tropical precipitation and the MJO on monthly time scales.

TRANSITIONS

The potential for extended-range forecasting demonstrated in this program will be transitioned to operations through existing and future 6.2 and 6.4 programs.

RELATED PROJECTS

COAMPS is being used in related 6.1 projects within PE 0601153N that include studies of air-ocean coupling and the simulation of the Madden-Julian Oscillation, and in related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components of COAMPS. Improvements to NOGAPS/NAVGEM developed under an ONR Unified Physics DRI and 6.4 NAVGEM projects, are being leveraged for this project.