

## **Leveraging ISI Multi-Model Prediction for Navy Operations: Proposal to the Office of Naval Research**

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### **LONG-TERM GOALS**

The potential to leverage existing and planned efforts to produce intra-seasonal to seasonal and interannual climate predictions, by U.S. national laboratories participating in the National Multi-Model Ensemble (NMME) project and by U.S. Navy research and operational entities, for the purpose of advising and enhancing Navy operations will be exploited. The proposed work will build on a review of the existing and planned efforts at the relevant U.S. Navy centers and will enhance existing operational climatological products developed by the Climatology Division at NRL-Monterey and will seek to include Navy models in the NMME project.

The accuracy, timeliness, and information content of Navy operational products intended to provide tailored long-range operational environmental information for planning and decision support can be significantly enhanced by the targeted application of dynamical ensemble predictions.

### **OBJECTIVES**

Stream-2 of the NMME project is ideally suited for collaboration to enhance ongoing Navy efforts in providing operational climatological products and in developing the next generation Navy seamless weather and climate prediction system. We propose to foster this collaboration in two areas: operational climatological products and the development of the next generation prediction system.

## APPROACH

We propose to developed methods and procedures by which the NMME Stream-2 data can be blended with the current use data sets to produce improved guidance. The development will focus on the top-10 ACAF requested products, as determined from our initial investigation of Navy requirements:

- (1) Waves
- (2) Winds
- (3) Ceiling and visibility
- (4) Precipitation
- (5) Storm formation and tracks and (tropical and extra-tropical)
- (6) Evaporative duct heights
- (7) Air temperature
- (8) Freezing level(s)
- (9) Sea surface temperatures
- (10) Currents

While the hypothesis is simply stated, the implementation is challenging. In particular, the ISI predictability of some of these quantities is well known, while it has not been evaluated for others that are more commonly used in weather prediction than climate analysis.

For illustrative purposes, we first note some universal or overarching processes and analyses that will need to be developed and then we describe how we will evaluate using the NMME Stream-2 data to improve the provision of two of the top-10 ACAF requests. These two examples are chosen because they demonstrate contrasting approaches (i.e., statistical post-processing of forecast data vs. applying forecast data to drive or force application models) to using the NMME data.

Regardless of whether the NMME data are used via statistical post-processing or in forcing a specific application model, some universal processes and analysis will need to be developed and applied. To understand the challenges we note several characteristics of the required processing and analysis:

- (1) The NMME Stream-2 data includes hindcasts and real-time forecasts, generated each month for 30 years, and for each hindcast or forecast there are approximately 100 ensemble members.
- (2) Depending on the field and the way it is used, the data are either monthly, daily or 3-hourly, so that ingesting, formatting and quality controlling this data for Navy application requires substantial effort.
- (3) The data must be bias-corrected and calibrated, which is typically done based on the hindcasts and may include simple linear corrections or more sophisticated techniques.
- (4) The quality of the bias-corrected and calibrated NMME data must be assessed against available observational estimates.

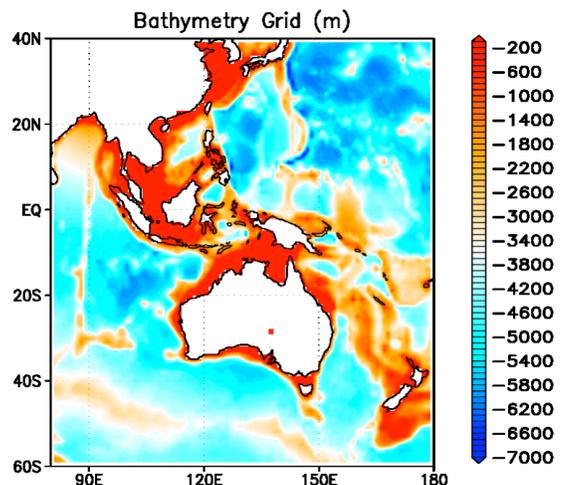


Figure 1: Bathymetry for Wave-Watch III experiments

- (5) The NMME data need to be applied as done in ACAF or other application models (e.g., Wave Watch III, or WW3) for the 30-year hindcast period.
- (6) The NMME based climatological products must be evaluated against existing products to develop the best strategies for combining the products.

It should be noted that the fact that the NMME data includes approximately 100 ensemble members for each forecast means that rather detailed probabilistic information could be provided. Moreover, we also emphasize that the development of all of the processes and analyses requires close collaboration and interaction with the Climatology Division.

## WORK COMPLETED

In the past year we have finalized the configuration of Wave Watch III (WW3) for initial prediction and predictability experiments with NMME (CCSM4) high frequency forcing. Specifically, we have configured WW3 for an Indo-Pacific region (see Fig. 1). This required implementing the appropriate bathymetry grid, land-sea mask and the obstruction grid. The WW3 configuration includes: the “Ultimate quickest” scheme of Tolman (2002) and the flux computation uses the frictional velocity following Tolman and Chalikov (1996). We have also post-processed the daily CCSM4 retrospective forecasts initialized each January and May for 1981-2010 for forcing WW3. The retrospective forecasts include 12-months lead-time and all leads are used to force WW3. For validation we have also forced WW3 with exactly the same configuration with observational estimates of the surface wind from NCEP Reanalysis. Based on these retrospective forecasts we have completed a forecast skill assessment and a predictability assessment. These results are briefly summarized below.

We have also begun to configure WW3 for initial prediction and predictability experiments with the CFSv2 high-frequency output. The same settings are being used with both CCSM4 and CFSv2 data, as described above. A test data set composed of high-frequency output from a subset of the CFSv2 hindcasts has been obtained and re-formatted for ingest by WW3. In the case of CFSv2, the 10-m wind components diagnosed in the course of the hindcasts are used as input to WW3. The subset of hindcasts applied to WW3 is in the process of being generated.

In addition, an independent altimeter-based estimate of near-global ocean surface wave heights has been obtained and gridded for comparison with the model-based hindcasts. This validation data set will be used in addition to the WW3 forced with NCEP Reanalysis.

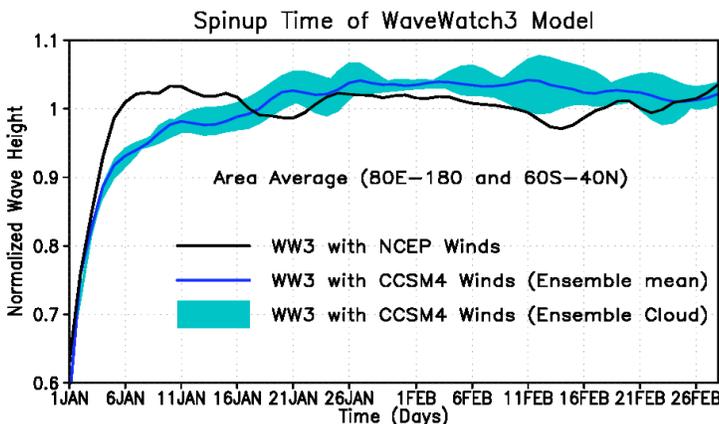


Figure 2: Initial climatological spin-up of wave watch-3 with CCSM4 January forecast forcing and with NCEP forcing.

## RESULTS

For the sake of brevity in the analysis below we refer to the WW3 experiment with NCEP Reanalysis surface winds a “truth” and the retrospective forecasts with CCSM4 daily forcing as the “forecasts.” Here we focus on the January initialized forecast, but we have also completed WW3 forecast with CCSM4 forcing from the May initialized forecasts. All the forecasts are made with 10-member ensembles.

Figure 2 show the initial evolution of the normalized wave height. In terms of daily variability the model reaches equilibrium in about 7-14 days.

To quantify the forecast verification, we show the anomaly correlation and the root mean squared error for wave height and peak direction anomalies predicted using the CCSM4 winds with WW3. Figures 3 and 4 show the correlation as a function of lead-time. The hatched areas in Figs. 3 and 4 indicate statistical significance at the 95% level. The wave height anomalies show somewhat more skill than the peak direction. This is particularly true at longer leads where the significant wave heights seem to have skill in the northwest tropical Pacific at lead-times of up to 10 months.

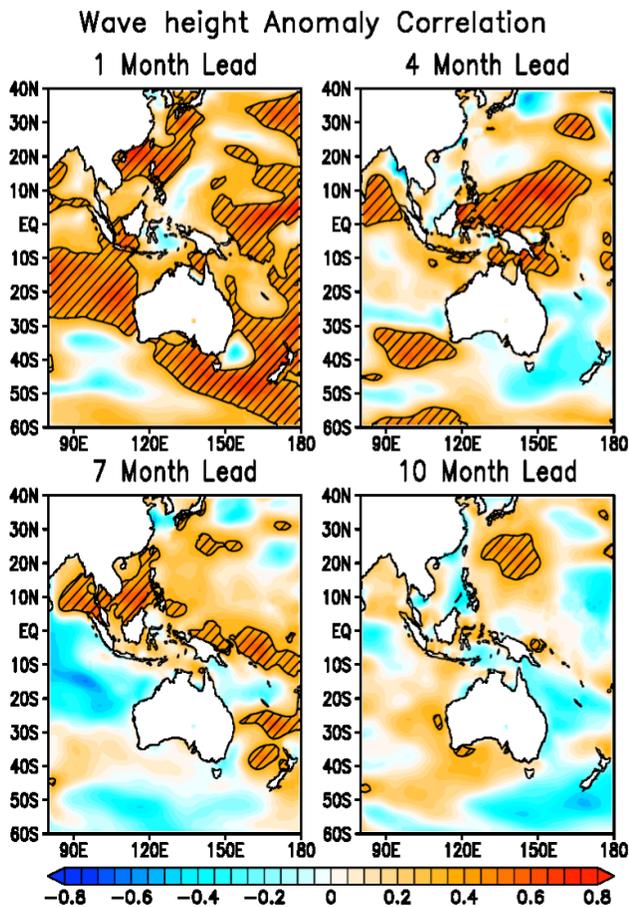


Figure 3: Correlation between significant wave height anomaly from the forecast using CCSM4 forcing and NCEP reanalysis forcing

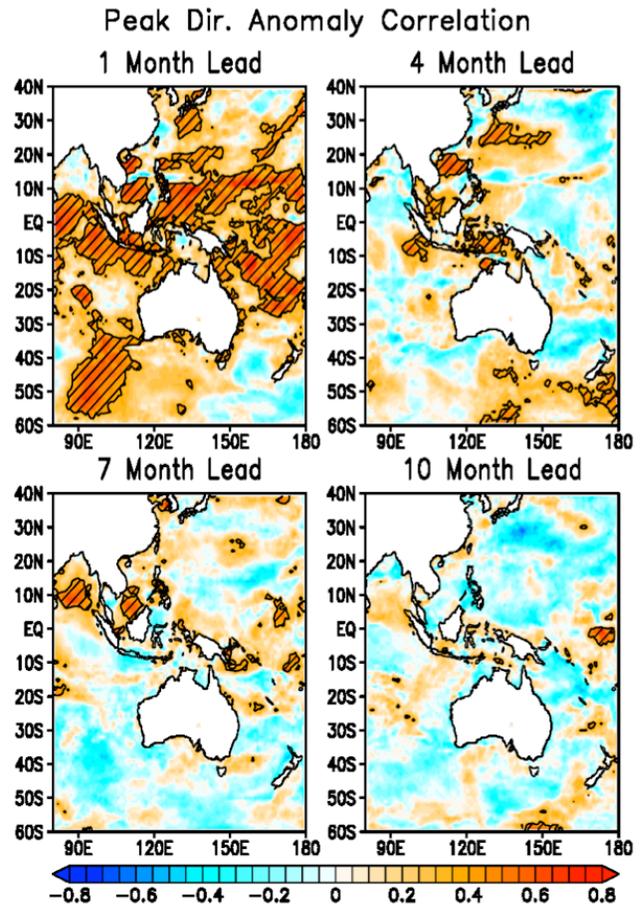


Figure 4: Correlation between peak wave direction anomaly from the forecast using CCSM4 forcing and NCEP reanalysis forcing

The predictability shown in Fig. 3 is largely due to large-scale climatic forcing from NINO3.4 and the Dipole Mode Index (DMI) in the Indian Ocean. This conclusion is based on the contemporaneous correlation between the NINO3.4 SSTA index (left panel) and the DMI index (right panel) and significant wave height from the NCEP reanalysis WW3 simulation.

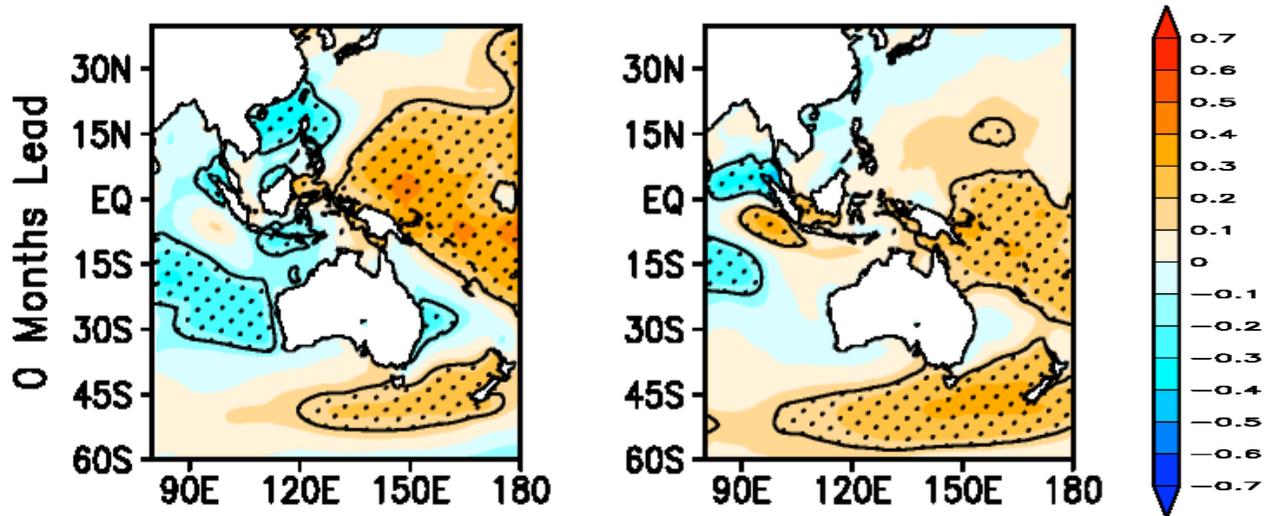


Figure 5: Contemporaneous correlation between significant wave height from the NCEP reanalysis forced simulation and observed Nino3.4 SSTA (left panel) and observed DMI index (right panel).

## IMPACT/APPLICATIONS

Ultimately, our goal is to make the NMME results useful and used in Navy climatological operational support.

## REFERENCES

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