Toward Better Intraseasonal and Seasonal Prediction: Verification and Evaluation of the NAVGEM Model Forecasts

PI: Zhuo Wang  
Email: zhuowang@illinois.edu  
Department of Atmospheric Sciences  
University of Illinois at Urbana-Champaign  
105 South Gregory St., Urbana IL 61801  
Phone: (217) 244-4270  
Fax: (217) 244-4393

Co-PI: Melinda S. Peng  
E-mail: melinda.peng@nrlmry.navy.mil  
Marine Meteorology Division  
Naval Research Laboratory  
#7 Grace Hopper Ave, Monterey, CA 93943  
Phone: (831) 656-4704

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LONG TERM GOALS

The long-term goals of this project are to understand the key physical processes for realistic simulation and skillful prediction of the intraseasonal variability and to improve the intraseasonal to seasonal prediction skills of the Navy’s global numerical weather forecast models.

OBJECTIVES

Intraseasonal and seasonal prediction provides important information for decision-making and resource management, and has received increasing attention in recent years. Despite substantial progresses in numerical modeling in the past few decades, skillful seasonal prediction remains a challenge for many models. Verification and evaluation of model forecasts can offer users necessary information on the model prediction skills and reliability and provide model development teams with useful information on model improvements. In-depth analysis of the model forecasts can also help to better understand the key physical processes involved in intraseasonal variability and to identify new sources of predictability.
The project has three specific objectives:

i) Evaluate the intraseasonal and seasonal predictions of the Navy’s global models (previously NOGAPS and now NAVGEM) against reanalysis data and satellite observations, and assess the prediction skills of the models;

ii) Assess the model parameterizations in different climate regimes, identify error sources, and provide the model development teams with concrete information on model deficiency and recommendations on model improvement.

iii) Examine the representation of known sources of predictability in the NAVGEM, in particular, the teleconnection patterns associated with the MJO, the ENSO and the AMM, etc.; investigate the new source of predictability or source of uncertainties.

APPROACH

Despite the rapid advancement of computing technologies, physical parameterization remains a major source of errors and uncertainties for both numerical weather forecasts and climate predictions. The overarching objective of the ONR DRI, “Unified parameterization for seasonal prediction” is to develop unified model parameterization for different spatio-temporal scales that are suitable for both short-term and extended range forecasts. Systematic evaluations of the model forecasts are an indispensable part of this team effort and is the focus of this project.

Standard performance-oriented metrics, such as anomaly correlation coefficient (ACC), root-mean square error (RMSE), mean square error skill score, are routinely used in operational centers for forecast verification, which provide guidance on model development and also provide users with information on forecast reliability (e.g., Richardson et al. 2013). There is an increasing demand in recent years in the community to adopt physics-oriented diagnostics or metrics for model evaluation (see the National Research Council Report: A National Strategy for Advancing Climate Modeling). Physics-oriented diagnostics focus on the critical processes or phenomena and, through evaluation of the evolution/distribution of key variables, shed light on the deficiencies of the physical parameterization or other errors in a model. In brevity, physics-oriented evaluation not only provides information on how well a model performs but also on why a model may fail in a certain aspect.

The NAVGEM forecasts and simulations will be evaluated in a systematic way with a focus on the following aspects: i) the low-frequency modes, including the MJO, ENSO, NAO and the associated teleconnection patterns; ii) precipitation processes and cloud properties/structures in different climate regimes; iii) new sources of predictability.

On the intraseasonal to seasonal time scales, the low-frequency modes, such as the MJO and ENSO, provide an additional source of predictability other than the lower boundary conditions (SST and land surface conditions). The representation of such modes in a model thus needs to be evaluated. The mean states of model forecasts are important because a realistic basic state is a prerequisite for the realistic simulation of such low-
frequency modes (Kim et al. 2011). Clouds and their associated feedback processes are one of the greatest uncertainties in numerical models. Using satellite observations (including TRMM, AIRS, CloudSat/CALIPSO), we examined the cloud properties and structures in the NAVGEM in different climate regimes. To facilitate the comparison between model simulations and satellite observations, we employed the observation simulator package (COSP) developed by the Cloud Feedback Model Intercomparison Project (CFMIP). COSP converts the model hydrometers (condensate and precipitation) into pseudo-satellite observations. The synthesized cloud properties derived from model forecasts will be evaluated against the CloudSat/CALIPSO. This approach avoids the uncertainties from inversion models used in satellite retrieval algorithms and allows models to be evaluated against satellite retrievals in a consistent way.

WORK COMPLETED

In the past year we focused on the variability and prediction of tropical cyclones and completed the following tasks.

i) We developed a suite of diagnostics to evaluate the extended-range forecasts of tropical cyclones based the GEFS reforecasts, and examined the sensitivity of the subseasonal predictability to large-scale climate modes. The diagnostics can be applied to other models and on longer time scales.

ii) We identified a recurrent extratropical mode that affects Atlantic tropical cyclone activity via Rossby wave breaking. This mode is correlated with Atlantic hurricane frequency at a coefficient higher than that with Nino 3.4. The physical link between extratropical wave breaking and Atlantic tropical cyclone activity is missing in most statistical forecast schemes and may help to explain the seasonal prediction bust in 2013.

We have been working closely with Drs. James A. Ridout and Ming Liu at the NRL to examine the underlying causes for the model deficiency, and working with Mr. Tim Whitcomb to incorporate some diagnostic codes into the evaluation package of the NAVGEM system.

RESULTS

a) Evaluate the prediction skill and predictability of Tropical Cyclone Likelihood, Mean Track, and Intensity from Weekly to Seasonal Timescales

We developed a suite of metrics to evaluate the subseasonal to seasonal (S2S) prediction of tropical cyclone activity. These metrics include information on the regional distribution of tropical cyclones, which is more relevant for improving storm preparedness and mitigating life and property loss. We also carried out further analyses of the model forecasts to identify the possible source of the model deficiency. Since tropical cyclone development is a multi-scale process and is subject to the impacts of the large-scale circulation and mesoscale processes, a full investigation of the model deficiency is a daunting task. We focused on Atlantic tropical cyclones and evaluate how the known
sources of predictability are represented in a model. More specifically, we examined whether the physical linkages between some large-scale climate modes (the ENSO, AMM, MJO and Hadley circulation) and Atlantic tropical cyclone activity are captured by a model, and if not, why a model fails to do so. Impacts of some environmental condition parameters, such as mid-level moisture and large-scale subsidence, were examined.

Some metrics are shown briefly below for the GEFS reforecasts (Hamill et al. 2013) as an example. The GFDL vortex tracker (Trahan et al. 2012) was first applied to the GEFS reforecasts to determine geneses and storm tracks. The TC forecasts were categorized as miss, false alarm, hit, early genesis (EG) and late genesis (LG). If an observed storm can not find a match in the forecast within the radius threshold and time window, a miss will be identified (i.e., Misses = “Number of actual TCG” – (Hit + EG + LG)). It was found that the GEFS reforecast captures the seasonal cycle of Atlantic tropical cyclones reasonably well (Fig. 1), but it underestimates the tropical cyclone frequency. It was also found that the negative bias increases from week-1 reforecasts to week-2 reforecasts.

![Fig. 1 The seasonal cycle of tropical cyclone frequency from the IBTrACS (black), GEFS week-1 reforecasts (red) and week-2 (blue) reforecasts.](image1)

To examine the geographic distribution of genesis, the genesis density function was derived. As shown in Fig. 2, TC genesis in GEFS occurs in the Atlantic main development region (MDR) region as well as the subtropical West Atlantic, which is broadly consistent with that observed. A close inspection, however, reveals some quantitative differences: the genesis frequency is overpredicted off the coast of West Africa but underestimated over the western MDR, especially the Caribbean Sea and the Gulf of Mexico. Further analysis suggests that the high miss rate in these regions is likely related to tropical cyclone formation associated with the upper-tropospheric forcing (Davis and Bosart 2004; McTaggart-Cowan et al. 2014).
We also examined the interannual variability of tropical cyclone frequency. The ensemble mean TC number is calculated for week-1 reforecasts and week-2 reforecasts, respectively, and the time series are shown in Fig 3. Although the rank correlation indicates the reforecast time series is significantly correlated with the observation, large discrepancies, especially the negative biases, are evident. Given the short forecast lead time, the performance is not very satisfactory, but such errors can be reduced via the bias correction.

We also examined the impacts of the MJO on the prediction skill of the GEFS. Previous studies have shown that the MJO modulates tropical cyclone activity over the East Pacific and the Atlantic and affects the prediction skill of numerical models in midlatitudes. Figure 4 shows that the GEFS week-1 reforecast has high probability of
detection (POD) and lower false alarm rate in the phases 2 and 3 of the MJO, but the prediction skill is insensitive to the MJO phases for the week-2 forecasts.

The insensitivity of the prediction skill to the MJO phase in the week-2 reforecast can be attributed to the weak MJO signals beyond the one-week lead time. Although the GEFS analysis compares favorably with the ERAI, the MJO signals weaken with the increasing forecast lead time, and the MJO power spectra in the eight-day forecast is about 50% of that in the analysis. These results again highlight the importance of realistic representation of the MJO for skillful subseasonal and seasonal prediction. Further studies will be carried out to compare the NAVGEM with other models and examine the source of the model deficiency.

b) Exploration of new sources of predictability

A notable seasonal forecast bust of Atlantic TC activity occurred in 2013. The hurricane season in 2013 was preceded by warm SST anomalies in the tropical Atlantic and cold SST anomalies in the equatorial East Pacific, persisting well into the hurricane season. Both were expected to contribute to an active hurricane season. However, a hurricane-strength tropical storm failed to develop until September 11, and the accumulated ACE through early September in 2013 was only ~20% of the corresponding climatological mean. The seasonal forecasts of the hurricane numbers at various institutions suffered an unexpected fourfold discrepancy (http://coaps.fsu.edu/hurricanes/forecast-archive).

The probability distribution analyses of moisture and vertical wind shear (VWS) highlight an increasing frequency of occurrence of dry air occurrence over West MDR in the mid- to upper troposphere along with strong VWS, which inhibited the development of TCs in August 2013. Examination of the synoptic-scale flow evolution shows that the
equatorward propagating Rossby waves and the ensuing Rossby wave breaking lead to the equatorward intrusions of dry and cold air of high PV from the extratropics. The intrusions modulate the large-scale environment over the tropical and subtropical Atlantic, including the TUTT, VWS and dryness, and hinder TC development.

Further examination suggests that the active anticyclonic Rossby wave breaking and frequent equatorward intrusions of extratropical air in August 2013 were associated with the changes of the intensity and zonal extension of mid-latitude jet. A recurrent mode of interannual variability of 200-hPa zonal wind was identified over the North Atlantic using the EOF analysis (the second EOF mode; denoted as EOF2U hereafter) (Fig. 5). In the positive phase of this mode, the mid-latitude jet strengthens and has greater anticyclonic shear on its equatorward flank, and the anticyclonic RWB occurs more frequently equatorward of the jet. This is accompanied by the more frequent occurrence of dry air and stronger vertical shear in the Atlantic MDR (Fig. 6).

Fig. 5 The EOF patterns (a, b) and time series (c, d) of two leading EOF modes of the 200-hPa zonal wind in August. EOF1U (left) explains 26.0% of total variance and EOF2U (right) explains 12.5% of total variance. Gray contours in (a) and (b) represent the climatology August zonal wind at 200hPa. Solid and dashed green lines in (c) and (d) represent the NAO/CPC and the NAO/Jones indices in August, respectively. Note the two indices are scaled for the better display effects.
Figure 8. Same as Figure 2, but the composites for the positive (left) and negative (middle) phases of EOF2U, as well as their differences (right). The contour intervals for (c) and (f) are 0.05% and 0.5%, respectively.

Figure 9. Tropical Cyclone (TC) track composites for the positive (upper) and negative (lower) phases of EOF2U. The years used to construct the composites are denoted above the subplots. Pink dots denote the initial locations when the storm systems are tracked. Coloring of tracks correspond to wind speed (m s$^{-1}$). Note HURDAT2 includes some subtropical storms.

Fig. 6 Two-dimensional Probably Distribution Function (PDF; %) of Precipitable Water (mm) and VWS (m s$^{-1}$).

Fig. 7 Tropical Cyclone (TC) track composites for the positive (upper) and negative (lower) phases of EOF2U. The years used to construct the composites are listed on the top of each panel. Pink dots denote the genesis locations. Storm intensity (maximum wind speed; m s$^{-1}$) is indicated by colors of the track. (Note HURDAT2 includes some subtropical storms)
The significant impacts of this extratropical mode on Atlantic TC activity are shown in the TC track composites (Fig. 7). In the positive phase of EOF2U, the TC track density is evidently reduced over the MDR, and the storms are generally weaker with a smaller fraction of TCs reaching hurricane strength (9 out of 27 cases). Most storms recurved poleward over the Atlantic, and less storms impacted the southeast coast of North America. In contrast, more TCs developed in MDR in the negative phase of EOF2U, a larger fraction of which reached the West Atlantic and strengthened into hurricanes (23 out of 39 cases). The recurrent mode of the 200-hPa zonal wind has a significant correlation with the hurricane frequency: the correlation coefficient is higher than that with the Nino3.4 index and is comparable to the MDR relative SST (Table 1).

Table 1. Correlation coefficients of the Atlantic hurricane frequency with various climate modes during 1979-2013. MDR-SST is the SST over the Atlantic MDR region. The CPC NAO index was used in the table.

<table>
<thead>
<tr>
<th>Year</th>
<th>ENSO</th>
<th>MDR-SST</th>
<th>NAO</th>
<th>EOF2U</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979-2013</td>
<td>-0.35</td>
<td>0.43</td>
<td>-0.19</td>
<td>-0.48</td>
</tr>
</tbody>
</table>

In brevity, our analyses suggest that extratropics impacts the variability of Atlantic TC activity via RWB in the upper troposphere. The RWB and the associated extratropical dynamics imply a source of uncertainty in the seasonal TC prediction. On the other hand, the linkage of this extratropical upper-level mode with the ENSO and the NAO implies that this mode may have predictability beyond the synoptic time scale. In addition, the oceanic circulation shapes the atmosphere eddy activity in extratropics (e.g., Woollings et al. 2012) and may also provide a source of predictability.

**IMPACT/APPLICATIONS**

Our studies contribute to a better understanding of the key physical processes for the intraseasonal and seasonal variability of tropical cyclones, which will help to improve the intraseasonal and seasonal prediction skill of the Navy’s global models.

**TRANSITIONS**

We are working closely with Dr. James A. Ridout, Dr. Ming Liu and Mr. Tim Whitcomb at the NRL, Monterey. The modifications of the model physics will be vigorously tested and available for transition to the operational model. Some of the diagnostic codes have been delivered to the NRL modeling and parameterization team and are expected to be incorporated into the NAVGEM analysis packages by the NRL modeling team.

**RELATED PROJECTS**

This project is related to the other projects under the “Seasonal and Unified Parameterization” and “Seasonal Prediction” DRIs. The model evaluation tools developed can be used by other groups to diagnose the model physical processes and to evaluate the new parameterization schemes.
PUBLICATIONS


REFERENCES


