Toward Better Intraseasonal and Seasonal Prediction: Verification and Evaluation of the NOGAPS 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

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 MJO and to improve the intraseasonal to seasonal prediction skills of the NAVGEM model.

OBJECTIVES

Intraseasonal and seasonal prediction provides important information for decision-making and resource management, and has received increased attention in recent years. Despite substantial progress 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 predictive skills and uncertainties, and provide model development teams with useful information on model improvements.

The project has two specific objectives:

i) Evaluate the intraseasonal and seasonal predictions of the NOGAPS model and the NAVGEM model against reanalysis data and satellite observations, and assess the prediction skills of the models;

Report Documentation Page

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Toward Better Intraseasonal and Seasonal Prediction: Verification and Evaluation of the NOGAPS Model Forecasts**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Meteorology Department, Naval Postgraduate School Monterey, CA 93943**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **SAR**	18. NUMBER OF PAGES **11**	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**			

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

APPROACH

GCMs have strong sensitivity to the PBL, cumulus, radiation and other physics schemes (e.g., Liu et al. 2012). Although modifications of a physics scheme can sometimes improve the simulation of a certain event or at a certain region, the improvement may result from error compensation. To ensure that a model has a good simulation and prediction for the right reason, it is necessary to evaluate the physical processes. Physics-orientated evaluations can help to identify the model deficiency and provide useful guidance on development of new physics schemes.

The NOGAPS and NAVGEM forecasts or simulations will be evaluated in a systematic way on the following three aspects, with a special focus on the relevant physical processes: i) the mean states and major climate components (including monsoons, ITCZ and ENSO); ii) the MJO and its teleconnection patterns; iii) cloud properties and structures in different climate regimes.

The MJO is the dominant intraseasonal mode in the tropics and provides a primary source of predictability on intraseasonal to seasonal time scales (Zhang 2005). As a multi-scale system, it offers an ideal benchmark for evaluating the model parameterizations across different time and spatial scales. Clouds and their feedback processes are one of the greatest uncertainties in numerical models. Using satellite observation (including TRMM, AIRS, CloudSat/CALIPSO), we will verify the cloud properties and structures in the NOGAPS in different climate regimes. To facilitate comparison between model simulations and satellite observations, we will employ the observation simulator package developed by the Cloud Feedback Model Intercomparison Project (CFMIP), COSP (BODAS-SALCEDO et al. 2011). COSP will convert the model hydrometers (condensate and precipitation) into pseudosatellite 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 satellite retrieval algorithms and allows models to be evaluated against satellite retrievals in a consistent way.

WORK COMPLETED

We have developed diagnostic tools for the model evaluation using both performance-oriented metrics and physics-oriented metrics. The NOGAPS analysis and short-range operational forecasts have been evaluated against the NCEP/DOE reanalysis-II (hereafter NNR2) and satellite observations. The performance of the NOGAPS operational forecasts was also compared to the GFS forecasts. It was found that the MJO signals in the NOGAPS analysis closely resemble those in the NCEP2 reanalysis. It was also found that the NOGAPS short-term precipitation forecasts have a general dry bias in the tropics, and that the ITCZ over the East Pacific has a northward shift compared to observation. The prediction skills of MJO in the NOGAPS operational forecasts drop quickly with forecast lead time, especially for phases 2 ad 5 of the MJO. Overall the evaluation implies the model's strength in data assimilation but weakness in the model physics. A manuscript is under preparation to report these findings.

We also work closely with Drs. James Ridout and Maria Flatau at the NRL to carry out a suite of AMIP runs and hindcasts using the NAVGEM model. The assessment of an AMIP run with Emanuel's cumulus scheme showed that the intraseasonal oscillation signals in the AMIP run were too weak with a dominant frequency too low. The diagnosis of the precipitation-water vapor relationship shows that the poor MJO simulation may be due to the dry bias in the model boundary layer. The evaluation of the model clouds using the COSP simulator shows that the model underestimates the low cloud fraction and overestimates the high cloud fraction. Based on these diagnoses, the model cloud scheme is being modified and tested to improve the cloud representation.

RESULTS

a) Evaluation of the NOGAPS analysis
As the first step, we have evaluated the MJO signals in the NOGAPS analysis against the NNR2. The MJO simulation diagnostics (MSD) developed by the CLIVAR MJO Working Group (Waliser et al. 2009) was used to examine the MJO signals. As shown in Fig. 1, the power spectra of 200 hPa zonal wind (U200) derived from the NOGAPS analysis in the wavenumber-frequency space closely resemble those derived from the NNR2. We also constructed the composites of wind and moisture fields at different MJO phases based on the all-season real-time multivariate MJO index (Wheeler and Hendon 2004), and the NOGAPS analysis is in excellent agreement with the NNR2 (not shown).
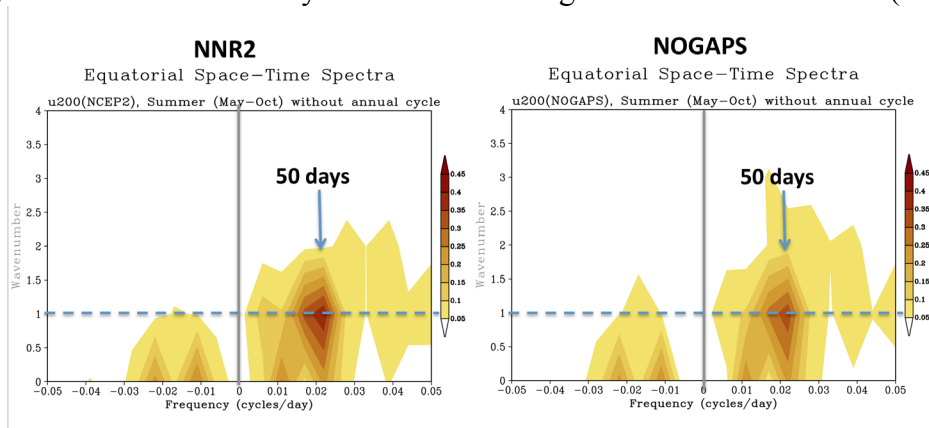

Figure 1 Wavenumber-frequency spectra of U200 from NNR2 reanalysis (left) and NOGAPS analysis (right). The MJO signals are highlighted by arrows.

*b) Evaluation of the GFS and NOGAPS Operational Forecasts*
The NOGAPS operational forecasts (1 day to 5 days forecasts) are evaluated in summer 2008-2011 and compared with the GFS operational forecasts.

The precipitation forecasts were evaluated against the CMORPH precipitation (Joyce et al. 2004). It was found that the NOGAPS and GFS forecasts both capture the broad precipitation patterns reasonably well, but the NOGAPS forecasts have a wet bias over the South Indian Ocean and a strong dry bias in most other tropical regions. The GFS has a dry bias over the subtropical western North Pacific and the equatorial African region, and a wet bias in many other tropical regions. In particular, the ITCZ over the East Pacific is displaced a few degrees northward in the NOGAPS forecasts while the GFS over-predicts precipitation along the ITCZ (Fig. 3). Over the East Pacific, the ITCZ has strong

impacts on the tropical cyclone activity. The displacement of the ITCZ in the NOGAPS forecasts may lead to errors of the tropical cyclone prediction.
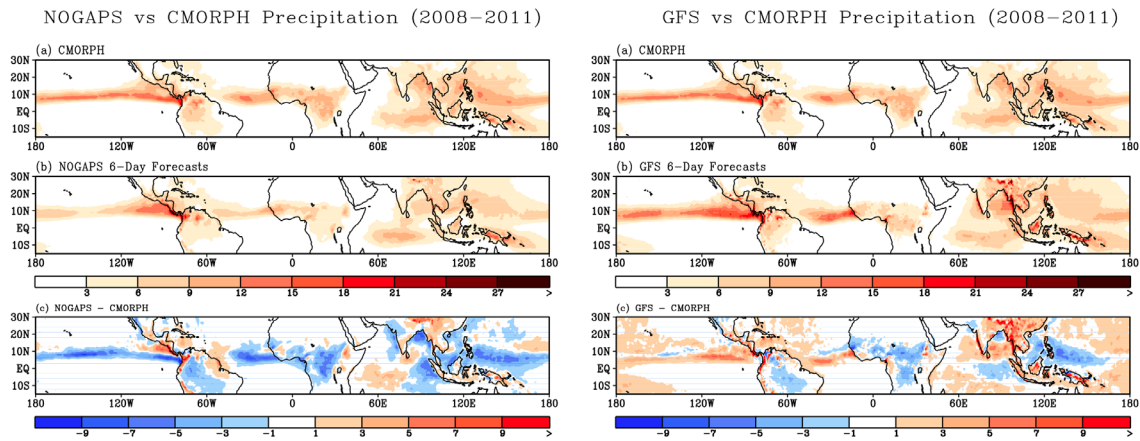

Figure 2 Comparison of the NOGAPS (left) and GFS (right) 6-day precipitation forecasts with the CMORPH precipitation. The bottom panels show the differences between the CMORPH precipitation and the forecasts.
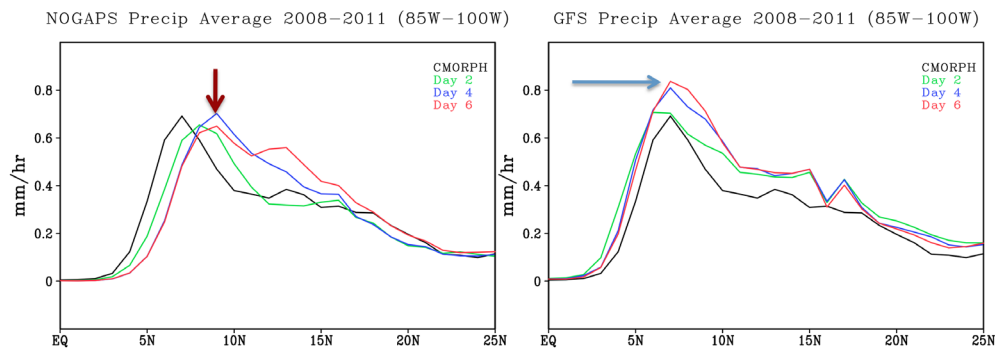
Figure 3 NOGAPS (left) and GFS (right) precipitation averaged over 85-100W at different forecast times.

The large-scale circulation and teleconnection patterns are sensitive to the diabatic heating profiles. To further evaluate the model physics, especially the cumulus scheme, we examined the apparent heat source (Q1) and the apparent moisture sink (Q2) (Yanai and Tomita 1998). Despite some quantitative differences from the NNR2, both the GFS forecasts and the NOGAPS forecasts capture the major features of the heating profiles in different climate regimes (Fig. 4). Over the western North Pacific (135-150E, 0-10N), which is characterized by active convection and heavy precipitation, the NOGAPS Q1 profile shows large heating with a maximum between 400-500 hPa, and the Q2 profile shows strong drying peaking at 700 hPa. The separation of the two peaks is a characteristics feature associated with cumulus convection. Over the southeastern Pacific (80-110W,10-20S), which has a frequent occurrence of marine stratus and stratocumulus clouds, the Q2 profile indicates evaporation in

the lower troposphere. The Q1 profile indicates evaporative and radiative cooling throughout the troposphere except near the surface. Over the South Indian Ocean (55-85E,10S-0), however, the Q1 and Q2 profiles change significantly from 2-day forecast to 5-day forecast in NOGAPS, and the profiles also differ ubstantially from those derived from the NNR2. This is consistent with the precipitation errors in this region, and the erroneous heating profile may induce errors in the large-scale circulation and affect the initiation and evolution of the MJO.
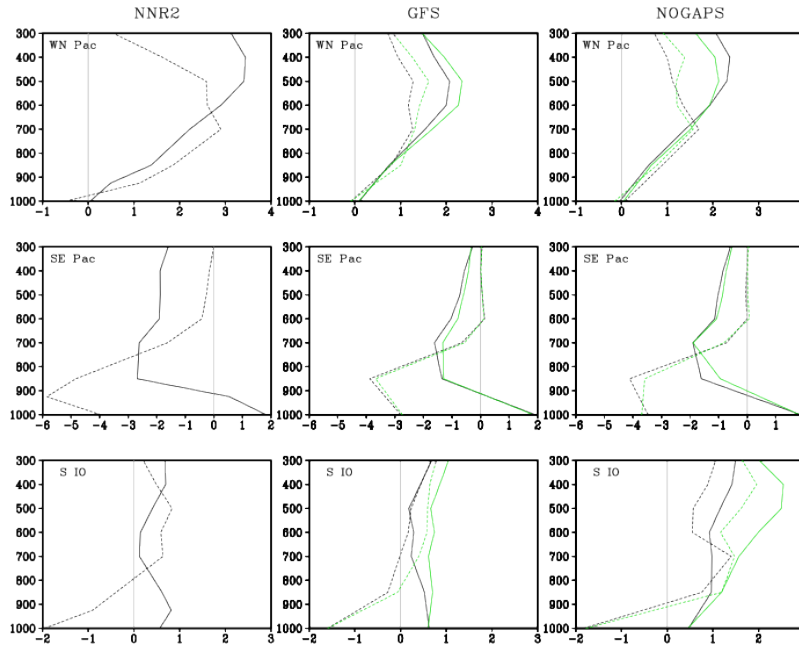

Figure 4 The Q1 (solid curves) and Q2 (dashed curves) profiles at the western North Pacific (upper panels), the southeastern Pacific (middle panels) and the South Indian Ocean (bottom panels) from NNR2, GFS forecasts and NOGAPS forecasts. In the middle and right columns, the black curves represent 2-day forecasts and the green curves represent the 5-day forecasts.

To objectively evaluate the MJO forecast skills, we calculated the spatial correlation of 200 hPa zonal wind (U200) between the model forecasts and the analysis at different forecast lead time. As shown previously, the NOGAPS and GFS analyses capture the MJO signals reasonably well. Both the GFS and NOGAPS 1-day forecasts show skillful prediction, with the GFS skills slightly higher. The prediction skills drop with the forecast lead time significantly for both models, especially for phase 2 and phase 5 of the MJO. Phase 2 is the MJO initiation time, and phase 5 is when the MJO convection center moves over the maritime continent. Previous studies have shown that these two phases are especially challenging for global models (see DYNAMO SPO).
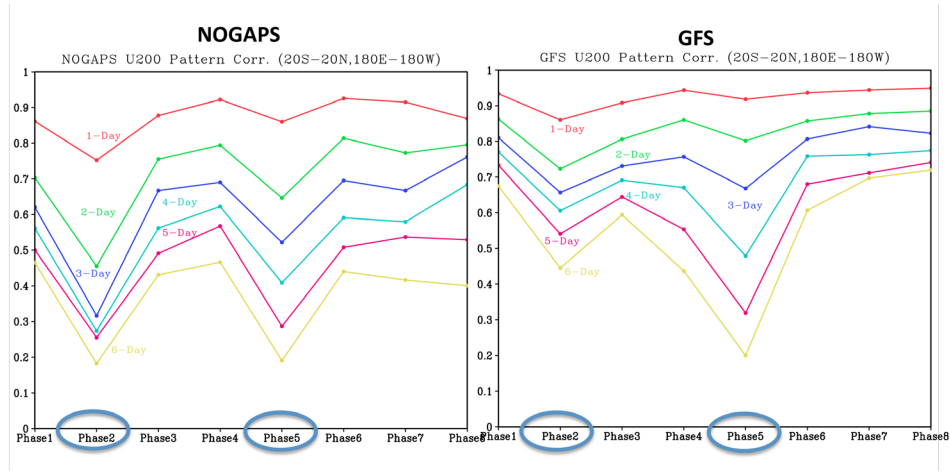
Figure 5 Spatial correlation of U200 over 20S-20N between forecasts at different lead times and the corresponding analysis. Left: NOGAPS; right: GFS.
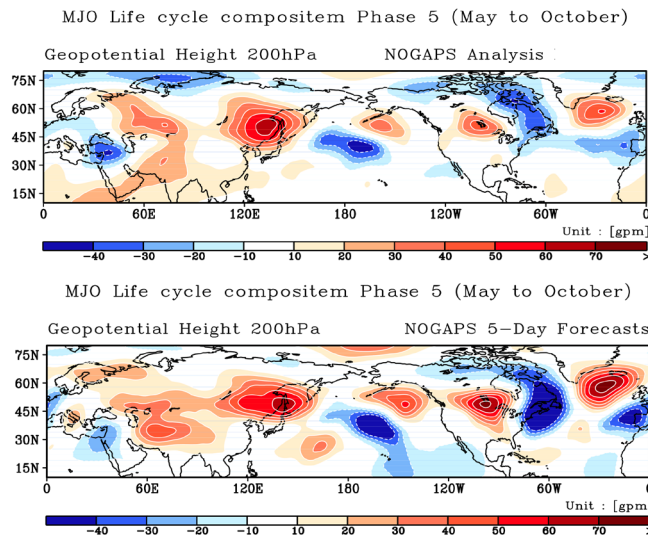

Figure 6 Composites of 200 hPa geopotential height at phase 5 of the MJO from the NOGAPS analysis (top) and the NOGAPS 5-day forecasts (bottom)

To examine the teleconnection pattern associated with the MJO, we constructed the composites of 200 hPa geopotential height for different MJO phases. The composites for phase 5 are shown in Fig. 6. Despite the poor prediction skills of the 200 hPa zonal wind in the tropics at phase 5 of the MJO, the NOGAPS five-day forecast captures the mid-latitude wavetrain pattern reasonably well compared to the NOGAPS analysis. Previous studies have suggested that the extratropical teleconnection patterns are excited by the effective Rossby wave source in the mean westerlies and are rather insensitive to the detailed distribution of the heating in the deep tropics (Sardeshmukh and Hoskins 1988; Wang et al. 2005).

c) *Evaluation of Evaluation of clouds and precipitation in a NAVGEM*
   AMIP run

An AMIP run driven by the NCEP SST/Sea Ice data was carried out for 2004 Jan – 2010 Dec using a "prototype" version of the NAVGEM at the development stage. The model has semi-Lagrangian and semi-implicit scheme, and the model was run with T359. The simulation adopted the same model physics as the operational NOGAPS: Emanuel cumulus scheme (Emanuel 1991; Peng et al. 2004), a diagnostic cloud scheme by Slingo (1987) and Teixeira and Hogan (2002), and the boundary layer scheme following Louis et al. (1982).

The cloud properties were derived from the model using the COSP simulator and were evaluated against the CALIPSO-GOCCP dataset, which is a GCM-Oriented CALIPSO cloud product (Chepfer et al. 2011). The annual mean total cloud fraction in the AMIP is in good agreement with the CALIPSO-GOCCP data. The global mean bias is less than 2% and the root mean squared error (RMSE) is 12%, which compared favorably with CAM4 (bias -21% and RMSE 24%) and CAM5 (bias -10% and RMSE 12%) (Kay et al. 2012).
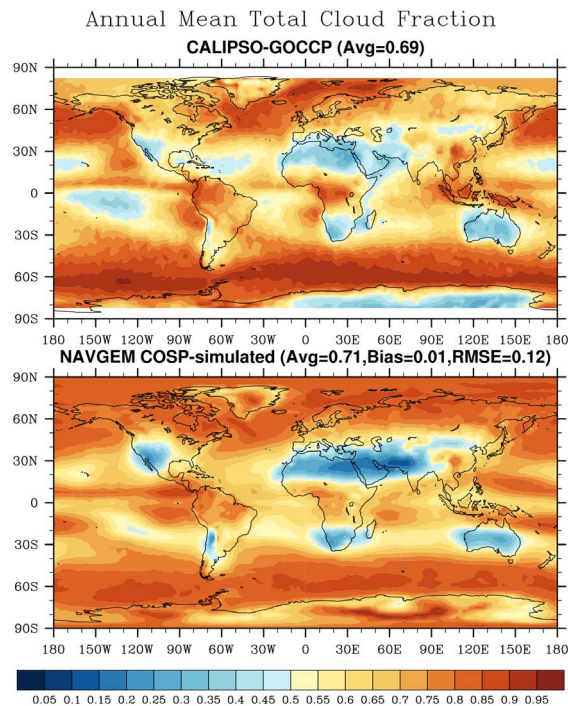
Figure 7 Annual mean total cloud fraction from CALIPSO-GOCCP (top) and the NAVGEM COSP simulation.

The vertical-cross section of the cloud fraction, however, reveals larger errors at different levels. NAVGEM overestimates the high cloud fraction and underestimate the low cloud fraction. Mid clouds are under-predicted in the tropics and over-predicted in higher latitudes. Also note that the boundary layer cloud forms at a higher altitude compared to the CALIPSO-GOCCP, which is related to a low-level dry bias (Fig. 10). Overall the diagnosis suggested that deep convection is overactive while shallow clouds are underestimated in the model. This is likely due to a weak detrainment rate in the cumulus scheme.
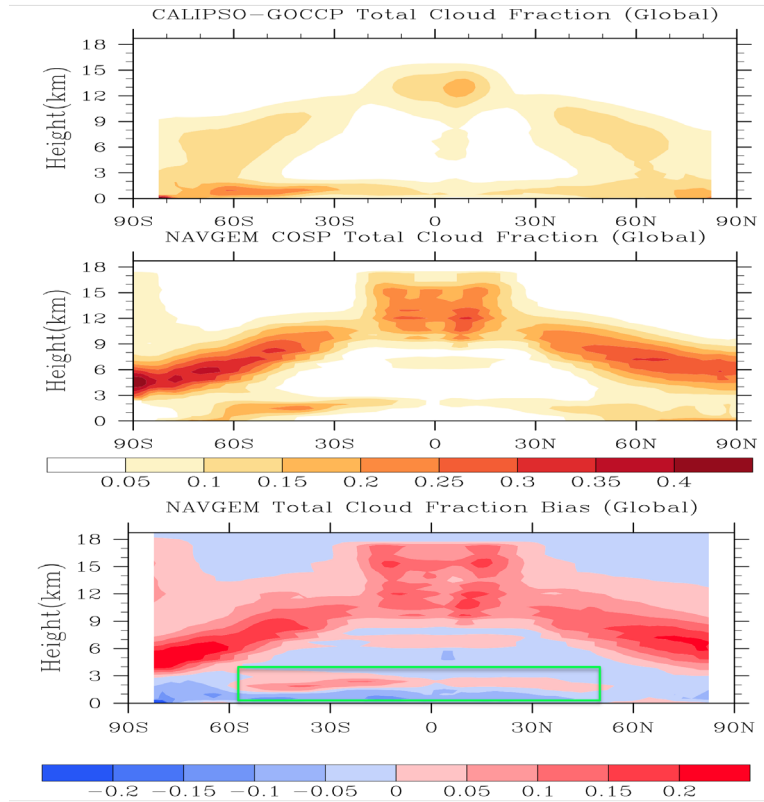
Figure 8 The vertical cross sections of cloud fraction (averaged over 0-360E) from CALIPSO-GOCCP (top), the NAVGEM COSP simulation (middle) and the difference between the two (bottom).

To further evaluate the moist processes, we examined the relationship between precipitation rate and column wave vapor (W). The model captures the power-law pickup of precipitation rate with w when W exceeds a certain threshold (Neelin et al. 2009). The distribution of W, however, shows a strong dry bias. The diagnosis of satellite retrieval by Bretherton et al. (2004) shows a bimodal distribution, with the primary peak frequency of W at 55 mm and a secondary peak around 30 mm. The NAVGEM simulation shows a single peak around 48 mm. The distribution also suggested that the NAVGEM model underestimates the frequency of occurrence of light precipitation and heavy precipitation.

NAVGEM-derived relationships

SSM/I-derived relationships
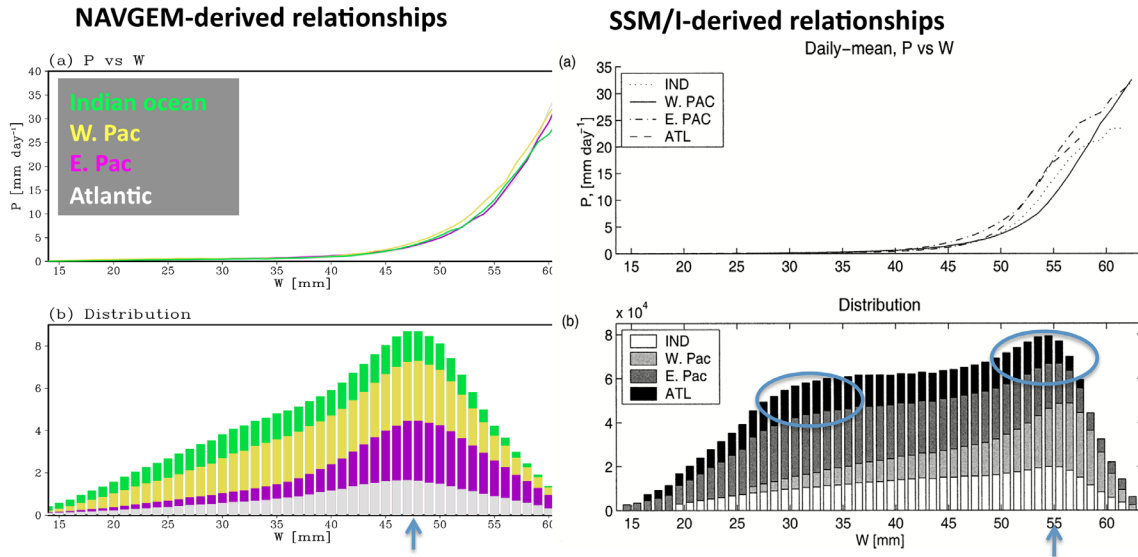
Figure 9 (upper panels) Mean daily averaged precipitation (P) in 1-mm-wide bins of column water vapor (W) for the four tropical ocean regions; (lower panels) number of observations in each bin in the four regions. The panels in the left are from the NAVGEM AMIP run and the ones on the right are from satellite observation (Bretherton et al. 2004).

The dry bias in the model can be attributed to the low moisture content in the boundary layer (Fig. 10), where most water vapor resides. The boundary layer dryness also has implications for the MJO simulations. Previous studies have suggested that the MJO initiation is preceded by low-level moistening (see DYNAMO SPO). It is conceivable that a dry boundary layer may prolong the moisture preconditioning process and makes the environment less favorable for the MJO initiation. This may be a major source of the model deficiency in the ISO simulation. The moist bias in the upper troposphere is consistent with the overactive deep convection indicated by the cloud diagnosis. As shown in Fig. 11, the ISO signals are too weak, and the frequency is too low in the NAVGEM AMIP run.
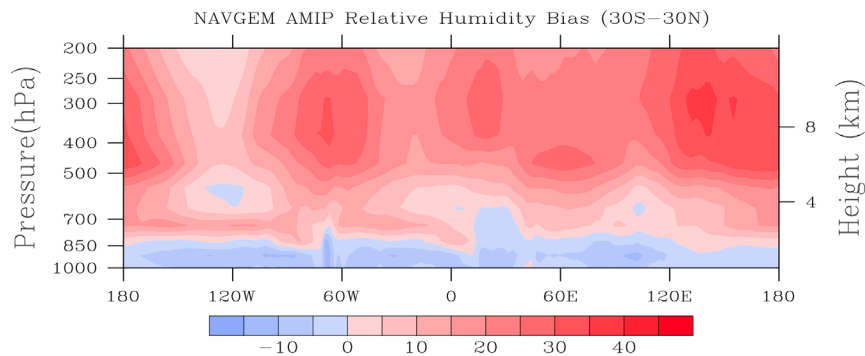
Figure 10 Bias of the relative humidity from the NAVGEM AMIP run with respect to the NNR2 reanalysis averaged over (30S-30N)

9
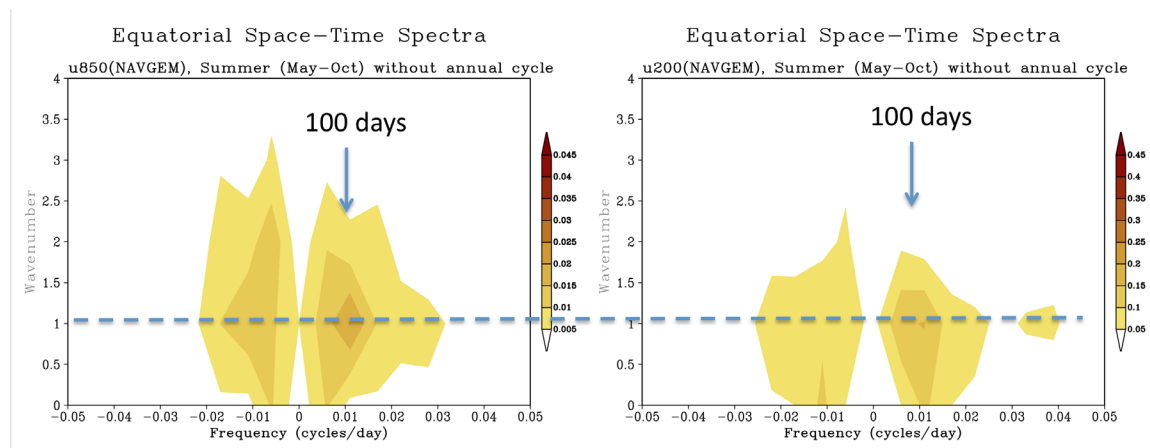
Figure 11 Wavenumber-frequency power spectra of 850 hPa U (left) and 200 hPa U (right) from the NAVGEM AMIP run.

IMPACT/APPLICATIONS

The scientific impact will be an better understanding of the key physical processes for the MJO simulation/prediction and improved representation of the moist processes in global models, which will lead to better intraseasonal and seasonal prediction of the Navy's global model.

TRANSITIONS

We are working closely with Dr. James Ridout at the NRL, Monterey. The modifications of the model physics will be vigorously tested and will be available for transition to the operational model.

RELATED PROJECTS

This project is closely 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 evaluate the new parameterization schemes.

REFERENCES

Bodas-Salcedo, A. et al, 2011: COSP: Satellite simulation software for model assessment. *Bull. Amer. Met. Soc.*, **92**, 1023-1043.

Bretherton, Christopher S., Matthew E. Peters, Larissa E. Back, 2004: Relationships between Water Vapor Path and Precipitation over the Tropical Oceans. *J. Climate*, **17**, 1517–1528.

Chepfer, H., S. Bony, D. Winker, G. Cesana, J. L. Dufresne, P. Minnis, C. J. Stubenrauch, and S. Zeng, 2010: The GCM-Oriented CALIPSO Cloud Product (CALIPSO-GOCCP), *J. Geophys. Res.*, *115*, D00H16, doi:10.1029/2009JD012251.

Emanuel, Kerry A., 1991: A Scheme for Representing Cumulus Convection in Large-Scale Models. *J. Atmos. Sci.*, **48**, 2313–2329.

Joyce, R. J., J. E. Janowiak, P. A. Arkin, and P. Xie, 2004: CMORPH: A method that produces global precipitation estimates from passive microwave and infrared data at high spatial and temporal resolution. *J. Hydromet.*, 5, 487-503.

Kay, J. E. et al., 2012: Exposing global cloud biases in the Community Atmosphere Model (CAM) using satellite observations and their corresponding instrument simulators. *J. Climate,* **25**, 5190-5207.

Liu, Ming, Young-Joon Kim, Qingyun Zhao, 2012: Numerical Experiments of an Advanced Radiative Transfer Model in the U.S. Navy Operational Global Atmospheric Prediction System. *J. Appl. Meteor. Climatol.*, **51**, 554–570.

Louis, J.F., M. Tiedtke, and J. F. Geleyn, 1982: A short history of the operational PBL-parameterization at ECMWF. Proc. Work- shop on Boundary Layer Parameterization, Reading, United Kingdom, ECMWF, 59–79.

Neelin, J. David, Ole Peters, Katrina Hales, 2009: The Transition to Strong Convection. *J. Atmos. Sci.*, **66**, 2367–2384.

Peng, M. S., J. A. Ridout, and T. F. Hogan, 2004: Recent modifi- cations of the Emanuel convective scheme in the Navy Op- erational Global Atmospheric Prediction System. Mon. Wea. Rev., 132, 1254–1268.

Sardeshmukh, P., and B. J. Hoskins, 1988: The generation of global rotational flow by steady idealized tropical divergence. *J. Atmos. Sci.,* **45**, 1228–1251.

Slingo, J., 1987: The development and verification of a cloud prediction scheme for the ECMWF model. Quart. J. Roy. Meteor. Soc., 113, 899–927.

Teixeira, J., and T. F. Hogan, 2002: Boundary layer clouds in a global atmospheric model: Simple cloud cover parameteriza- tions. J. Climate, 15, 1261–1276.

Yanai, Michio, Tomohiko Tomita, 1998: Seasonal and Interannual Variability of Atmospheric Heat Sources and Moisture Sinks as Determined from NCEP–NCAR Reanalysis. *J. Climate*, **11**, 463–482.

Waliser et al. 2009: MJO Simulation Diagnostics. *J. Climate,* **22**, 3006–3030.

Wang, Z., C-P. Chang, B. Wang, and F.-F. Jin, 2005: Teleconnections from Tropics to Northern Extratropics through a Southerly Conveyor. *J. Atmos. Sci.*, **62**, 4057–4070.

Wheeler, Matthew C., Harry H. Hendon, 2004: An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction. *Mon. Wea. Rev.*, **132**, 1917–1932.

Zhang, C., 2005: Madden-Julian Oscillation, Rev. Geophys., 43, RG2003, doi:10.1029/2004RG000158.