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Project title:

Multi-Model Ensemble Forecast of MJO

Progress Report of Year II

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PI: Bin Wang
Department of Meteorology and IPRC, University of Hawaii.

Co-PIs: Duane Waliser
JIFRESSE, University of California, Los Angeles.

1. Results and Accomplishments

a. Bimodal Representation of the Tropical ISO

The tropical ISO shows distinct variability centers and propagation patterns between boreal winter and summer. To accurately represent the state of the ISO at any particular time of a year, a bimodal ISO index was developed. It consists of Madden-Julian Oscillation (MJO) mode with predominant eastward propagation along the equator and Boreal Summer ISO (BSISO) mode with prominent northward propagation and large variability in off-equatorial monsoon trough regions. The spatial temporal patterns of the MJO and BSISO mode are identified with the extended empirical orthogonal function (EEOF) analysis of 31 years (1979-2009) OLR data for the Dec-Jan-Feb and Jun-Jul-Aug period, respectively. The dominant mode of the ISO at any given time can be represented by the proportions of the OLR anomalies projected onto the two modes. The bimodal ISO index provides objective and quantitative measures on the annual and interannual variations of the predominant ISO modes. It is shown that from December through April the MJO mode dominates while from June through October the BSISO mode dominates (Fig. 1).

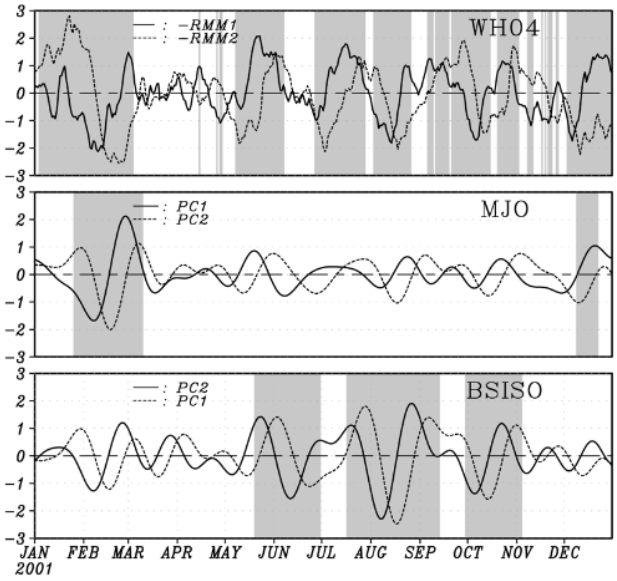

Figure 1 A comparison of the ISO index between the WH04 (upper), the MJO (middle) and the BSISO (lower) for the year 2001. Note that each PC is normalized by one standard deviation of the corresponding PCs during the period each EEOF analysis was performed to obtain the EEOFs. Significant ISO events are shaded in the background.

b. A Metrics for boreal summer ISO (MISO)

In order to facilitate detection, monitoring and prediction of the dominant northward/northwestward propagating BSISO over the entire Asian summer monsoon (ASM) region, we suggest a new BSISO metrics that consists of two indices: the BSISO1 and BSISO2 based on multivariate empirical orthogonal function (MV-EOF) modes of daily outgoing longwave radiation (OLR) and zonal wind at 850 hPa (U850) anomalies over the ASM region (10^{o}S-40^{o}N, 40^{o}-160^{o}E). The BSISO1 index represents the canonical northward propagating ISO in conjunction with the eastward propagating MJO with quasi-oscillating

periods of 30-60 days. The BSISO2 index mainly captures the northward/northwestward propagating ISO with period of 10-30 days during pre-monsoon and monsoon-onset period. The two BSISO indices together are capable of describing ISO variability center better, capturing more fractional variance and representing northward/northwestward propagating pattern better than the real-time multivariate MJO RMM index over the ASM domain.

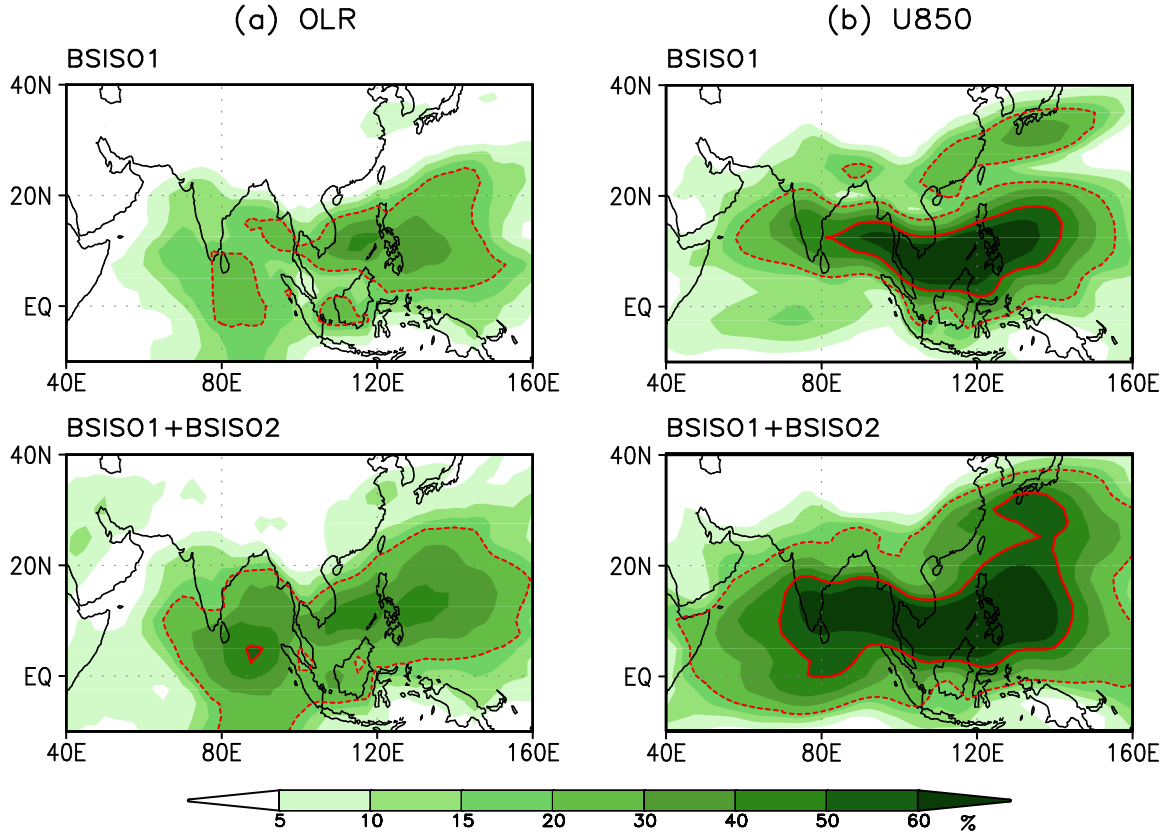

Figure 2 Spatial distribution of the fractional variances of pentad (a) OLR and (b) U850, and (c) V850 that are accounted for by the first two RMM modes (upper panels), the first two BSISO modes (middle), and the first four BSISO mode (lower).

c. MJO Modulation on 2009/10 Winter Snowstorms in the US

During the winter of 2009/10, a number of record-breaking snowfall events registered in the eastern United States are shown to have been modulated by pulsation of tropical MJO through an atmospheric teleconnection pattern. The ISV over the eastern subtropical Pacific near Mexico (the equatorial central Pacific) had reached the maximum (second largest) strength since 1979/80. From late December to mid-February, the convection over these two regions experienced a remarkable wet-dry-wet cycle; correspondingly, the daily snowfall over the eastern US also exhibited a wet-dry-wet cycle. As the MJO convection reached the central Pacific, a teleconnection pattern extends to North America, resulting in a westward-tilted deep anomalous trough anchored over the eastern US, producing a low-level pressure dipole anomaly with an anticyclone (cyclone) centered at the US west (east) coast. Warm moist air was transported from the tropical central Pacific

through Mexico to the southern US along with the upper-level subtropical westerly jet, which extended from the subtropical Pacific to the Atlantic Ocean. These enhanced warm moist air from the tropics and the cold air transportation from the high-latitude are also supported by the existing El Niño and negative AO, respectively and led the MJO teleconnection over the eastern US to be enhanced (counterbalanced) during wet (dry) cycle.

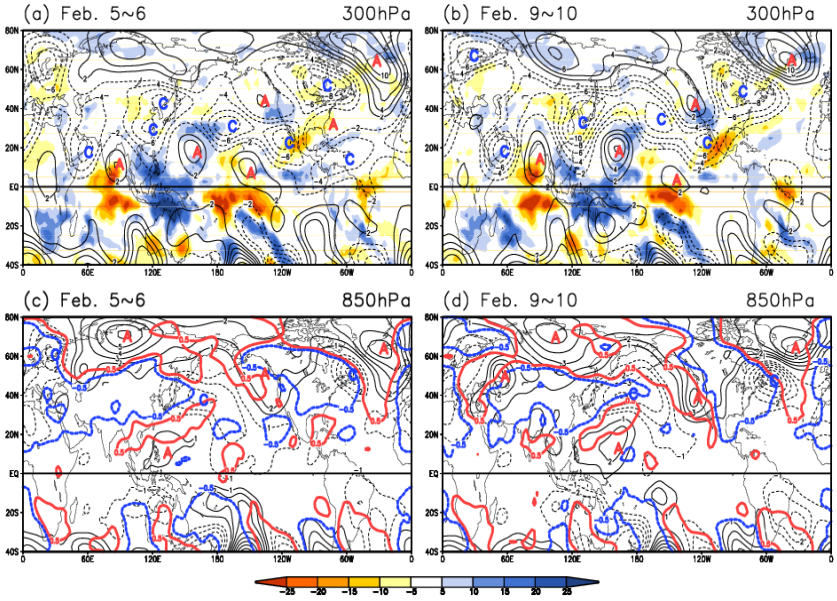

Figure 3 Composite anomalies of (a)(b) SF300 (contours) and (c)(d) SF850 (contours)and winds during February 5~6 (left panel) and February 9~10 (right panel). OLR is shaded in (a)~(b) and the 850 hPa temperature anomalies above (below) 0.5 (-0.5) ºC is in red (blue) thick contours in (c)~(d).

d. Teleconection associated with Boreal Summer ISO

The present study attempts to reveal BSISO teleconnection patterns associated with three dominant ISO variability centers. During the active phase of ISM, the extratropical circulation anomalies occur along the waveguides generated by the North African-Asian jet and North Atlantic-North European jet. When the tropical convection strengthens over the WNPSM sector, a distinct great circle-like Rossby wave train emanates from the WNP to the western coast of United States (US) with an eastward shift of enhanced meridional circulation. In the active phase of NASM, large anticyclonic anomalies anchor over the western coast of US and eastern Canada and the global teleconnection pattern is similar to that during a break phase of the ISM. The transient evolution of the BSISO teleconnection shows stationary characteristics with the preferred centers of teleconnection located at Europe, Russia, central Asia, East Asia, western US, and eastern US & Canada. Most centers are embedded in the waveguide along the jet stream, but the centers at Europe and Russia occur to the north of the jet-induced waveguide. The rainfall anomalies over the elongated band near the monsoon domain over the Indo – western Pacific sector have an opposite tendency with that over the central & southern China, Mexico & southern US. The BSISO teleconnection along and to the north of the subtropical jet in the NH extratropics had consistent anomaly pattern with the surface air temperature.

e. Intraseasonal forcasting of Asian summer monsoon in 4 CGCMs

The present study assessed the current status of intraseasonal forecast of rainfall in four conventional Coupled General Circulation Models (CGCMs): ECMWF, UH, and NCEP CFSv2 and CFSv1 for 2008 summer, which is a target year of two international programs: Year of Tropical Convection and Asian Monsoon Year. The useful skills, which are defined as the Anomaly Correlation Coefficient (ACC) drops to 0.4, are 21, 19, 12, and 7 days for rainfall over the global tropics (30^{o}S- 30^{o}N) by the four CGCMs in order. The skill of the CFSv2 is apparently better than that of the CFSv1 due to better initial conditions as well as improved representations of the BSISO genesis in western Indian Ocean and along-equatorial eastward propagation. The skill of the UH model is in-between the CFSv2 and the ECMWF models. The ECMWF model has the highest skill among the four. The CFSv2 and UH models are complementary to each other in terms of an out-of-phase temporal skill fluctuations as function of initial conditions. When initial intraseasonal convection locates in Asian summer monsoon trough (~ 15^{o}N), the CFSv2 has much higher skill than the UH model because the UH model has a tendency to produce an early false BSISO onset near the equator. On the other hand, when initial intraseasonal convection is near the equator, the CFSv2 has much worse skill than the UH model because the CFSv2 model has a difficulty to propagate the near-equatorial convection north of 10^{o}N.

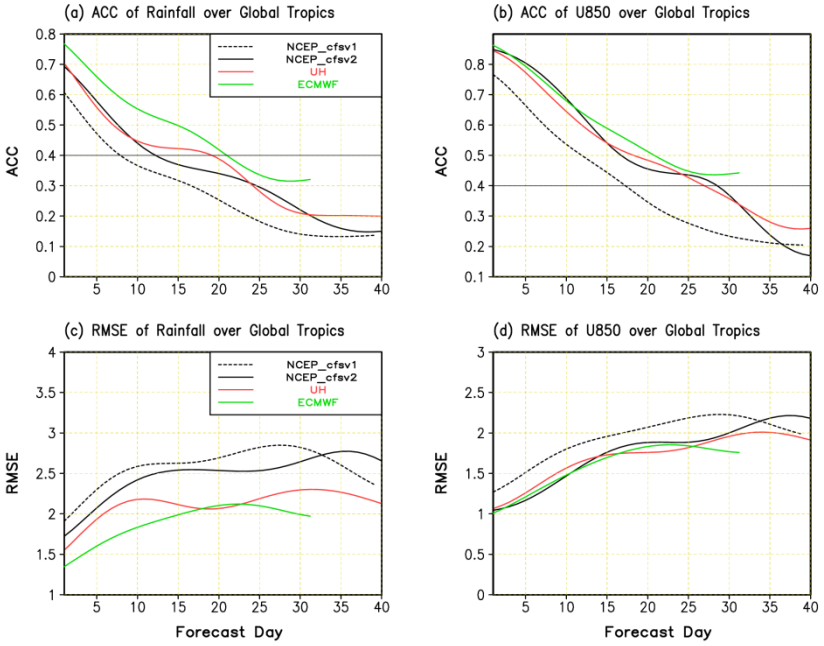

Figure 4 Anomaly correlation coefficients (ACC) of (a) intraseasonal rainfall and (b) 850-hPa zonal winds between the observations and those forecasted by CFSv1 & v2, UH, and ECMWF operational model over global tropics (30^{o}S-30^{o}N, 0-360) as a function of forecast lead time in days

f. Establishment of an Advanced Multi-Model Experiment focused on Vertical and Diabatic Processes of the MJO

Through participation and leadership within the Year of Tropical Convection (YOTC) and the MJO Task Force (MJOTF), an advanced multi-model experiment focused on the vertical and diabatic processes of the MJO has been established and is underway. Specifically, the MJOTF and the GEWEX Atmospheric System Study (GASS) have joined forces to develop an illustrative and strategic experimental modeling experiment to help improve the model representation and predictive skill of the MJO. The overall experimental design, which takes advantage of the known links between biases exhibited in short-range forecasts and long-term climate simulations, and evaluates these in the context of the MJO. The design is composed of the following three components:

I. Twenty-year climate simulations that provide a characterization of the models' intrinsic capabilities of representing MJO variability. Model simulations from both ocean-coupled global models, as well as those that use specified sea-surface temperatures will be evaluated with metrics that broadly describe the models performance in terms of the MJO and the associated vertical heating and moistening structures.
II. A series of daily initialized 2-day hindcasts for two MJO events within the YOTC period during boreal winter 2009-2010. A principal focus of this component of the experiment is on providing highly detailed and comprehensive (e.g., every time step) model output over a select near-equatorial Indian Ocean/Western Pacific Ocean domain.
III. Similar the II, except for global, albeit less detailed, output for forecast lead times up to 20 days for the purposes of characterizing the models' MJO forecast performance.

Detailed descriptions of this experimental design, including the specifics of the model output request, can be found on the project website (www.ucar.edu/yotc/mjodiab.html). Note that all 3 components include vertical structure information on all diabatic and momentum source and sink processes. Hindcast components II and III will provide the framework for an analogous case to be examined from the DYNAMO/CINDY field program. At present, 42 modeling groups have indicated their interest for participating and over a dozen have already completed their simulations/hindcasts. We expect this multi-component, multi-model, and multi-institution modeling experiment to provide a key (community) resource for characterizing and improving MJO simulations and forecast skill in follow up research.

g. Edited/Contributed to the 2nd Edition of the Intraseasonal Variability of the Atmosphere-Ocean Climate System

As a means to establish a community research resource and graduate text book for intraseasonal variability and MJO studies, the PI and co-PI have contributed to editing and/or authoring the 2nd Edition of: Lau, W. K. M., and D. E. Waliser, Eds, 2011: Intraseasonal Variability of the Atmosphere-Ocean Climate System, Springer, Heidelberg, Germany,. 2nd Edition. In particular, the PI authored the revised version of the main chapter on Theories of the MJO (Wang, 2011) and the co-PI authored the revised version of the main chapter on Prediction and Predictability of the MJO (Waliser, 2011), as well as served as co-editor.

2. Highlights of Accomplishments

- We have advanced a bi-modal representation, monitoring, and prediction of the Tropical ISO. Distinguished the spatial temporal patterns of the MJO and BSISO mode are with the extended empirical orthogonal function (EEOF) analysis of 31 years (1979-2009) OLR data (Kikuchi et al. 2012)
- We design a new boreal summer ISO (MISO) index to monitor, evaluate and predict the BSISO, which represent a larger fractional variance over the Asian monsoon region than RMM indices, and hence the reconstructed life cycle of the boreal summer MISO captures more realistic features of the observed phenomenon. (Lee et al. submitted)
- We reveal that a number of record-breaking snowfall events registered in the eastern United States during 2009-2010 winter were strongly modulated by pulsation of tropical MJO through an atmospheric teleconnection pattern. (Moon et al. 2012)
- To predict boreal summer extratopical ISO anomalies three teleconnection patterns are identified that are associated with active phases of the Indian, western Pacific and North American summer monsoons.
- Assessment of intraseasonal forecasting of rainfall in ECMWF, UH, NCEP CFSv1, and CFSv2 indicates that the useful skills are 21, 19, 12, and 7 days for rainfall over the global tropics by the four CGCMs in order during the 2008 summer. The CFSv2 and UH models are complementary to each other in terms of an out-of-phase temporal skill fluctuations as function of initial conditions.
- We have provided leadership in establishing an advanced multi-model experiment focused on vertical and diabatic Processes of the MJO to understand and improve our model representations of key physical processes needed for advancing MJO forecast skill. See www.ucar.edu/yotc/mjodiab.html for details and a list of over 40 participating modeling groups.
- We have contributed to authoring and/or editing of the 2011 2nd edition book on Intraseasonal Variability of the Atmosphere-Ocean Climate System which serves as a community research resource and graduate text book for intraseasonal variability and MJO studies.

3. Refereed Publications from the Project (including submitted)

Kkiuchi, K., B. Wang, and Y. Kajikawa, 2012: Bimodal representation of the Tropical intraseasonal osciilation. Climate Dynamics, DOI 10.1007/s00382-011-1159-.

Moon, J.-Y., B. Wang, and K.-J. Ha, 2012: Modulation on 2009/10 winter snowstorms in the United States. Journal of Climate, *J. Climate*, 25, 978-991. DOI: 10.1175/JCLI-D-11-00033.1.

Lee, J.-Y. and B. Wang, , M. Wheeler, X. Fu, D. Waliser, and In-Sik Kang, submitted: A metrics for Boreal Summer Intraseasonal Oscillation over the Asian summer monsoon region.Moon, J.-Y., B. Wang, K. Kikuchi, J.-Y. Lee, and K.-J. Ha, : Dominant modes in the boreal summer intraseasonal oscillation teleconnection.In revision.

Fu, X., J.-Y. Lee, B. Wang, W. Wang, and F. Vitart, submitted: Intraseasonal forecasting of Asian summer monsoon in four conventional general circulation models.

Waliser, D. E., 2011: Predictability and Forecasting. Intraseasonal Variability of the Atmosphere-Ocean Climate System, W. K. M. Lau and D. E. Waliser, Eds., Springer, Heidelberg, Germany 2nd Edition, In Press.

Wang, B., 2011: Theory. Intraseasonal Variability of the Atmosphere-Ocean Climate System, W. K. M. Lau and D. E. Waliser, Eds., Springer, Heidelberg, Germany 2nd Edition, In Press.

4. PI Contact Information

PI: Bin Wang
Professor of Meteorology
Department of Meteorology and IPRC
SOEST, University of Hawaii
POST 401, 1680 East-West RD.
Honolulu, HI 96822
Tel: 1-808-956-2563
Fax: 1-808-956-9425
Web: http://www.soest.hawaii.edu/users/bwang/

Co-PIs: Duane Waliser
JIFRESSE, University of California, Los Angeles.
Jet Propulsion Laboratory, MS 180-400
California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109
Tel: 818-393-4094
Fax: 818 393-3379
http://hydro.jpl.nasa.gov
duane.waliser@jpl.nasa.gov

6. Future Work

a. Evaluation of ISVHE on MJO prediction

While there have been considerably more studies that have examined MJO prediction skill, particularly recently, the number of studies are simply too few to adequately explore and quantify the sensitivity of prediction skill to model formulation, initialization methods, MJO phase, seasonal and interannual modulation, etc. In addition, our models are slowly getting better at representing the MJO, particularly if one compares older multi-model comparisons with more recent evaluations or compares original forecast skill studies from operational models to more recent ones. To provide a robust assessment of MJO predictability and prediction skill, we will utilize the proposed hindcast data set to carry out a multi-model assessment that will be based on present-day coupled GCMs. Important to this endeavor is the use of a common metric for identifying the MJO. Using the eight coupled models' ISO hindcast data, we will evaluate the current status of coupled models' forecast for MJO and boreal summer monsoon ISO. The assessment will include (1) the effectiveness of MME approach for improving MJO forecast skill, (2) sensitivity of the forecast skills to dataset for validation, (3) total anomaly vs ISO component forecast, (4) dependence of the forecast skill on ENSO phase, (5) dependence of the skill on the initial phase of MJO. The coupled models' skill for boreal summer monsoon ISO will be addressed using the newly developed monsoon ISO index.

b. MME Technique for MJO

While the MME has proven to be an effective technique to deliver better seasonal prediction, it has not been demonstrated whether a MME can improve MJO forecasts and thus the possible/expected benefit of an MME to the subseasonal problem (and in turn a more seamless prediction suite) has not been realized. A major stumbling block to such an effort and demonstration has been the lack of a quality long-term multi-model hindcast data set to develop effective MME schemes suitable for MJO prediction. A major aim of this proposal is to use the proposed hindcast dataset to develop an optimal MME technique for forecasting the MJO and in so doing test the hypothesis that an MME – as opposed to any single model - will also provide the best MJO forecast.

In order to develop the optimal MME technique for the MJO, we shall explore the following hierarchy of methods and others: 1) simple arithmetic average, 2) weighted method using multiple linear regression, and 3) optimal selection method. The arithmetic average method for seasonal climate prediction has turned out to be the simplest but yet still an improvement, and our preliminary results using six coupled-models from ISVHE shown in Figure 1 illustrate this to be the same for the MJO. In particular, the best three MME show better skill than all models' MME at long lead, indicating optimal selection method will be applicable for the MJO MME prediction. Using eight coupled models, we will further explore how to optimally select models being used for the MJO MME prediction.

c. North America composite response and predictability

A number of studies have shown important impacts of the MJO on boreal winter circulation conditions and extreme precipitation events. However a systematic description of these impacts for operational forecasting, including uncertainties and dependence on ENSO and other modes of climate variability have not been readily available. Recently Dr. Ja-Yeon Moon and Prof. Bin Wang have investigated on the composite North American response to the boreal winter MJO in observation and they have showed different composite response depending on ENSO phase. We will investigate the predictability of the composite response using the ISO hindcast data. Particular attention will be paid to the US west coast extreme precipitation events associated with the MJO and ENSO phase. Use of the observation data and the hindcast/MME data set will provide the means to also compute the signal-to-noise ratio and estimate uncertainties associated with the composites. In addition, the hindcast data will be used to examine the inherent predictability of North American impacts of the MJO.