Madden-Julian Oscillation Task Force: a joint effort of the climate and weather communities

Matthew Wheeler[1], Eric Maloney[2], and MJO Task Force

[1] Centre for Australian Weather and Climate Research, Bureau of Meteorology, Australia

[2] Department of Atmospheric Science, Colorado State University, USA

Background

It is widely recognised that improved understanding and prediction of the Madden Julian oscillation (MJO) and related tropical intraseasonal variability (ISV) is crucial for both the climate and weather communities, and the decisions they support. Because simulating and predicting this variability in global numerical models has been difficult, a 'task force' of 15 scientists was formed in early 2010 to foster further improvements in this area following the earlier success of the US CLIVAR MJO Working Group (from 2006-2009). Programmatically, the MJO Task Force (MJO-TF) sits within the framework of the joint WCRP/WWRP/THORPEX Year of Tropical Convection (YOTC)[1] activity, and is endorsed by CLIVAR. This article provides a summary of MJO-TF activities and accomplishments and its future plans. With the initial term of the MJO-TF coming to an end in December 2012, plans have been made for its continuation for another 3 years.

Overall goal

The overall goal of the MJO-TF has been to facilitate improvements in the representation of the MJO in weather and climate models in order increase the predictive skill of the MJO and related weather and climate phenomena.

Membership and contributors

The initial membership of the MJO-TF (in 2010) was Duane Waliser (initial co-chair), Matthew Wheeler (co-chair), Ken Sperber, Eric Maloney, Xiouhua Fu, Jon Gottschalck, Richard Neale, Chidong Zhang, Daehyun Kim, Augustin Vintzileos, Masaki Satoh, Hai Lin, Harry Hendon, Frederic Vitart, and David Raymond. The last three researchers have since stepped down and been replaced by Prince Xavier, June-Yi Lee, and Steve Woolnough. Eric Maloney replaced Duane Waliser as co-chair in 2011. Important contributions to the MJO-TF have also been made by Xianan Jiang, Nicholas Klingaman, Jim Benedict, Mitch Moncrieff, and Min-Seop Ahn.

[1] For a description of YOTC, see http://www.ucar.edu/yotc/index.html.

Communication and web-page

The MJO-TF has had 14 teleconferences and 3 face-to-face meetings. Meeting minutes and other information is disseminated through the web page at www.ucar.edu/yotc/mjo.html.

Subprojects

The previous version of this group, the US CLIVAR MJO Working Group, had success in three main areas: (1) Development of a set of MJO simulation diagnostics (Waliser et al. 2009); (2) Application of these diagnostics to a set of climate model simulations (Kim et al. 2009); and (3) Development and implementation of an MJO forecast metric for operational prediction models (Gottschalck et al. 2010). The support of these three areas by the MJO-TF has been ongoing, such as the continual evaluation of the operational model MJO forecasts. However, the new focus has expanded to four subprojects.

Subproject 1: Process-oriented diagnostics and metrics for MJO simulation

The MJO simulation diagnostics developed by the predecessor group assess whether models are successfully able to simulate the MJO. However, they provide limited insight into why models exhibit varying levels of success with their MJO simulations. The aim of this subproject is to explore and develop diagnostics that provide this insight. That is, what are the processes operating in a model that determine its MJO simulation fidelity?

Previous observational results indicate that a strong relationship exists between tropical precipitation and tropospheric humidity, such that heavy rainfall preferentially occurs in atmospheres that are relatively moist (e.g. Bretherton et al. 2004). Studies have also argued that the dynamics of the MJO are regulated by the processes that control tropospheric moisture (e.g. Benedict and Randall 2007). Further, many model convection parameterization schemes have been shown to be too insensitive to the effects of free tropospheric humidity (e.g. Derbyshire et al. 2004), and models in which the sensitivity of convection to that humidity has been increased tend to produce a more robust MJO (e.g. Hannah and Maloney 2011). This knowledge has led the MJO-TF to develop and test a set of process-oriented diagnostics based on interactions between convection and moisture.

One diagnostic based on this concept looks at the relationship between precipitation rate and column saturation fraction (e.g. Bretherton et al. 2004). In observations, precipitation rate is a strong non-linear function of saturation fraction. While work with a limited set of models suggested that models able to capture the strong non-linearity between precipitation and saturation fraction produce better MJO simulations (Zhu et al. 2009), further investigations by the MJO-TF have demonstrated that this diagnostic appears to be a necessary, but not sufficient, condition for a good MJO simulation.

The MJO-TF has also considered diagnostics that assess the vertical distribution of relative humidity as a function of precipitation rate (e.g. Kim et al. 2009). An idea underlying several bodies of MJO theory is that before the enhanced convective phase of the MJO can begin, a period of gradual moistening occurs (e.g. Blade and Hartmann

1993). In observations, this moistening process is characterized by a gradual deepening of the tropospheric moist layer. Thus, diagnostics have been developed that characterize the relationship between the vertical profile of relative humidity and precipitation rate (e.g. Thayer-Calder and Randall 2009, Xavier 2012). Although a strong relationship with MJO simulation strength has not been found, preliminary work of the MJO-TF has found that models which reproduce the observed moistening behaviour tend to produce a more robust MJO simulation.

Another diagnostic of the processes that control tropospheric moisture is gross moist stability (GMS). Under the assumption of weak tropical temperature gradients, GMS becomes equivalent to the efficiency with which convection discharges moisture from the atmospheric column. It has been hypothesized that for an MJO moisture anomaly that supports convection to be sustained, GMS must be small or negative (Raymond and Fuchs 2009; Hannah and Maloney 2011). Thus, the MJO-TF has also been actively studying the utility of the GMS for understanding model MJO behaviour. Indeed, an initial assessment of 3 pairs of good/poor model simulations (**Figure 1**), shows that for each model pair the version with an improved (i.e. stronger) MJO is characterized by a lower normalized GMS (Benedict et al. 2013, in preparation).

Through increased understanding of the processes that each of these diagnostics highlights, improvements to models should ensue. In the same way as the MJO Working Group provided analysis code to the community for the calculation of the simulation diagnostics, the MJO-TF plan to provide code for these new diagnostics.

Subproject 2: Boreal summer monsoon ISV monitoring and forecast metrics
One of the successes of the predecessor group, in conjunction with the Working Group on Numerical Experimentation (WGNE), was the development and implementation of the MJO forecast metric as displayed at http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml. This display allows users to quickly and easily see the current state of the MJO and the prediction of its future evolution in each of the ~16 participating models. Daily model output is projected onto a pair of empirical orthogonal functions (EOFs) that describe the MJO's large-scale structure as derived from observations by Wheeler and Hendon (2004). Focussing on this pair of EOFs has proven useful for making forecasts of MJO impacts out to a lead of several weeks, as well as for assessing the real-time performance of the models (Gottschalck et al. 2010). However, by concentrating on the eastward MJO signal along the equator, they provide little information on the important northward propagating variability of the boreal summer monsoon. Therefore, the MJO-TF has worked to develop and implement a new forecast metric for the boreal summer ISV.

To achieve this, a new set of EOFs have been derived that capture the unique characteristics of ISV during boreal summer (Lee et al. 2012). This has been done using combined EOFs computed with daily maps of 850-hPa zonal wind and satellite outgoing longwave radiation (OLR) over the domain 10°S-40°N, 40°E-160°E. The first two EOFs show many of the important characteristics of the boreal summer intraseasonal oscillation (BSISO), including the northwest-southeast tilted rainband (OLR anomaly) and implied northward propagation from the quadrature phasing of the associated time series (**Figure 2**). We call this component of variability BSISO1. EOFs 3 and 4 are associated with the pre-monsoon and onset component, which we call BSISO2 (not shown).

As with the MJO forecast metric activity, the support of WGNE has been obtained to coordinate the implementation of the new metric within the operational forecast centres, and discussions have occurred to find a host of the new metric. The eventual goal is to have a web page depicting model forecasts of BSISO1 and BSISO2 in real time that can aid impacts forecasting and encourage further model improvement.

<u>Subproject 3:</u> Simplified MJO metrics and CMIP5 analysis
Following on from the predecessor group's effort on MJO simulation diagnostics, discussed above, this subproject has two thrusts: to create simplified metrics of the MJO that distil the information of the full set of diagnostics into 1 or 2 numbers; and to apply the full set of MJO diagnostics to the current generation of climate models that are included in the Coupled Model Intercomparison Project phase 5 (CMIP5).

The first of these thrusts was at the request of the Working Group on Coupled Modelling/WGNE Climate Model Metrics Panel. A simplified metric of the MJO, described in Sperber and Kim (2012), was defined from the lag correlation analysis of a pair of principal component time series (PCs), where the PCs are obtained by projecting maps of simulated 20-100 day bandpass filtered daily OLR onto the two leading EOFs of observed MJO variability. The metric has two components: the maximum positive correlation at any lag; and the lag at which this maximum correlation occurs. For observations this correlation is 0.69 at a lag of 11 days. Most models have a lower maximum correlation than observed, indicating less coherent large-scale propagation, and some of the poorer models have a negative lag, indicating an incorrect predominance of westward propagation. Further, it is shown that the maximum positive correlation from the many models is significantly correlated with the ratio of eastward to westward precipitation power at MJO time and space scales, indicating that it is a good indicator of coherent eastward propagation in the models. The east/west power ratio is another commonly used metric of the MJO in models (e.g. **Figure 1**).

The second thrust of this subproject is a comprehensive analysis of the MJO in CMIP5 simulations. Although some analysis of the MJO in CMIP5 models has already been performed (e.g. Hung et al. 2012), an analysis with the full set of MJO simulation diagnostics has not. With the help of graduate student Min-Seop Ahn from Seoul National University, this work is now under-way.

<u>Subproject 4:</u> Vertical structure and diabatic processes of the MJO
This subproject is being conducted jointly with the GEWEX Global Atmospheric Systems Study (GASS) panel. It was conceived by members of the MJO-TF when it was noticed how different the vertical structure of the MJO diabatic heating was between different satellite and reanalysis products (e.g. Jiang et al. 2011), and the realisation that understanding of this very important quantity for the MJO is quite limited despite its relevance to a number of theories. For example, to what extent is the vertical structure

in reanalysis products determined by the model cumulus parameterization, and to what extent is this structure essential for realistic MJO representation? Therefore, with the process modelling and parameterization expertise of GASS, this global model intercomparison project, focussing on the physical processes associated with the MJO, was launched (Petch et al. 2011).

The experimental framework of the project takes advantage of the known relationships between biases in short-range model forecasts and long-term simulations. It also considers how biases in the representation of the MJO may change with forecast lead time. Three different types of model runs have been sought: (1) 20-year climate simulations with 6-hourly global output that characterize each model's intrinsic MJO and related variability; (2) A series of daily 48 hour forecasts initialized during a few different case periods, with time-step output over the Indo-Pacific Ocean region; and (3) A series of daily 20-day lead forecasts with 3-hourly global output during the same case periods. A very detailed list of model outputs has been requested focussing on vertical structure and complete tendency terms for temperature, humidity and momentum, and additional quantities essential to diabatic and other important physical processes. The full specifications of the experimental framework are provided at http://www.ucar.edu/yotc/mjodiab.html. Two of the case periods selected occurred in 2009/10 during YOTC, and planning for a third case during the Dynamics of the MJO (DYNAMO)/Cooperative Indian Ocean Experiment on Intraseasonal Variability (CINDY) field program is underway. As of September 2012, runs from 20 different models had been received for (1); from 9 models for (2); and from 11 models for (3). The deadline for model submissions for inclusion in the initial set of publications was December 2012. Drafts of these initial publications are expected to be available by June 2013, with full community access to the model data allowed soon afterwards.

Objectives of the subproject are to provide information that helps model developers to make improvements to their physical parameterization schemes and to provide feedback to the satellite formulation and algorithm communities regarding strengths, shortcomings and gaps in satellite products. The outcome of this initial multi-model experiment may be utilized by GASS to develop a follow-on process modelling study for one or more of the most important yet uncertain processes identified in this subproject. Synergies exist with all of the other MJO-TF subprojects.

Conferences and workshops

Together with the CLIVAR Asian-Australian Monsoon Panel (AAMP), the MJO-TF organised the Monsoon ISV Modelling Workshop in June 2010 at the APCC in Busan Korea (Hendon et al. 2011). The MJO-TF also provided input to sessions at the WCRP Open Science Conference in Denver USA (October 2011), and the 1st Pan-GASS conference in Boulder USA (September 2012).

Other activities

Besides these defined projects and conferences, the MJO-TF has also been active in promoting coordinated MJO-related research and development among other scientific groups and projects. Two examples are MJO-TF involvement in guiding aspects of the multi-institutional ISV Hindcast Experiment (ISVHE; http://iprc.soest.hawaii.edu/users/jylee/clipas/), and in asking US CLIVAR to add the intraseasonal timescale to their draft mission statement for 2013 and beyond.

Future plans

For its second 3-year term, the MJO-TF plans to continue its work on the 4 defined subprojects and also establish one new subproject. Of the 4 subprojects listed above, the 1st and 4th will require significant and continued effort to complete. The difficulty arises from the complexity of the relationship of the MJO to the physical processes involved with moisture and convection. To bring in new and additional expertise to address these difficult problems, a rotation of 5 members of the current membership is occurring. A new subproject on MJO air-sea interaction will also be established. One of the aims of the latter will be to develop a process-oriented diagnostic that may be able to relate MJO simulation capability to the processes of air-sea coupling.

Coordination of the MJO-TF activities with other research programs is essential for its continued success. As well as the links already mentioned, coordination has occurred with DYNAMO/CINDY groups and will likely continue, especially for verifying the time-step model output being generated and archived for a November 2011 case in subproject 4. Dialogue has also occurred with the planning group of the Sub-seasonal to Seasonal Prediction Initiative (S2S; Vitart et al. 2012). The MJO-TF is well positioned to be the MJO (and other tropical ISV) research arm of the S2S project.

The research of the MJO-TF will also likely contribute to two of the recently-defined WCRP Grand Challenges: on the provision of skilful future climate information on regional scales, which includes an intraseasonal prediction component; and on clouds and climate sensitivity. For the latter, the importance of model cloud and convection parameterizations has been highlighted, consistent with the goals of the MJO-TF subprojects 1 and 4.

When appropriate, the MJO-TF plans to continue to help organise conferences and workshops. On our horizon is the WWRP International Workshop on Monsoons (IWM-V) planned for Macau in October 2013. The MJO-TF has accepted the role of co-sponsor of the workshop and will organise a full day of the scientific program, as well as one or two training lectures on intraseasonal monsoon prediction.

Linking the climate and weather scales and communities, the MJO-TF hopes to continue making steps towards its overall goal.

Update

Since preparing this article, WCRP and WWRP have confirmed the extension of the MJO-TF for another 3 years, with its official reporting now going through WGNE.

References

Benedict, J., and D. A. Randall, 2007: Observed characteristics of the MJO relative to maximum rainfall. *J. Atmos. Sci.*, **64**, 2332-2354.

Bladé, I., D. L. Hartmann, 1993: Tropical intraseasonal oscillations in a simple nonlinear model. *J. Atmos. Sci.*, **50**, 2922–2939.

Bretherton, C. S., M. E. Peters, and L. E. Back, 2004: Relationships between water vapor path and precipitable water over the tropical oceans. *J. Climate*, **17**, 1517-1528.

Derbyshire, S. H., Beau, I., Bechtold, P., Grandpeix, J.-Y., Piriou, J.-M., Redelsperger, J.-L. and Soares, P. M. M., 2004: Sensitivity of moist convection to environmental humidity. *Q.J.R. Meteorol. Soc.*, **130**: 3055–3079.

Gottschalck, J., M. Wheeler, K. Weickmann, F. Vitart, N. Savage, H. Lin, H. Hendon, D. Waliser, K. Sperber, M. Nakagawa, C. Prestrelo, M. Flatau, and W. Higgins, 2010: A framework for assessing operational Madden-Julian oscillation forecasts: A CLIVAR MJO Working Group project. *Bull. Amer. Meteor. Soc.*, **91**, 1247-1258.

Hannah, W. M., and E. D. Maloney, 2011: The role of moisture-convection feedbacks in simulating the Madden-Julian oscillation. *J. Climate*, **24**, 2754-2770.

Hendon, H.H., K.R. Sperber, D.E. Waliser, and M.C. Wheeler, 2011: Modeling monsoon intraseasonal variability: From theory to operational forecasting. *Bull. Amer. Met. Soc.*, doi:10.1175/2011BAMS3164.1

Hung, M.-P., J.-L. Lin, W. Wang, D. Kim, T. Shinoda, and S. J. Weaver, 2012: MJO and convectively coupled equatorial waves simulated by CMIP5 climate models. *J. Climate*, accepted pending revision.

Jiang, X., D.E. Waliser, W.S. Olson, W.-K. Tao, T.S. L'Ecuyer, K.-F. Li, Y.L. Yung, S. Shige, S. Lang, and Y.N. Takayabu, 2011: Vertical Diabatic Heating Structure of the MJO: Intercomparison between Recent Reanalyses and TRMM Estimates. *Mon. Wea. Rev.*, **139**, 3208–3223.

Kim, D., K. Sperber, W. Stern, D. Waliser, I.-S. Kang, E. Maloney, S. Schubert, W. Wang, K. Weickmann, J. Benedict, M. Khairoutdinov, M.-I. Lee, R. Neale, M. Suarez, K. Thayer-

Calder, and G. Zhang, 2009: Application of MJO simulation diagnostics to climate models. *J. Climate*, **22**, 6413-6436.

Lee, J.-Y., B. Wang, M.C. Wheeler, X. Fu, D.E. Waliser, and I.-S. Kang, 2012: Real-time multivariate indices for the boreal summer intraseasonal oscillation over the Asian summer monsoon region. *Clim. Dyn.*. Published online October 2012.

Petch, J., D. Waliser, X. Jiang, P. Xavier, and S. Woolnough, 2011: A global model intercomparison of the physical processes associated with the Madden-Julian oscillation. *GEWEX News*, August 2011, pages 3-5.

Raymond, D. J., and Z. Fuchs, 2009: Moisture modes and the Madden-Julian oscillation. *J. Climate*, **22**, 3031-3046.

Sperber, K.R., and D. Kim, 2012: Simplified metrics for the identification of the Madden-Julian oscillation in models. *Atmospheric Science Letters*, **13**, 187-193.

Thayer-Calder, K., D. A. Randall, 2009: The role of convective moistening in the Madden–Julian oscillation. *J. Atmos. Sci.*, **66**, 3297–3312.

Vitart, F., A. W. Robertson, and D. T. Anderson, 2012: Subseasonal to seasonal prediction project: bridging the gap between weather and climate, *WMO Bulletin*, *61*, 23-28.

Waliser et al. (CLIVAR Madden Julian Oscillation Working Group), 2009: MJO simulation diagnostics. *J. Climate*, **22**, DOI: 10.1175/2008JCLI2731.1.

Wheeler, M.C., and H.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.

Xavier, P.K., 2012: Intraseasonal convective moistening in CMIP3 models. *J. Climate*, **25**, 2569–2577.

Zhu, H., H. Hendon, C. Jakob, 2009: Convection in a parameterized and superparameterized model and its role in the representation of the MJO. *J. Atmos. Sci.*, **66**, 2796–2811.

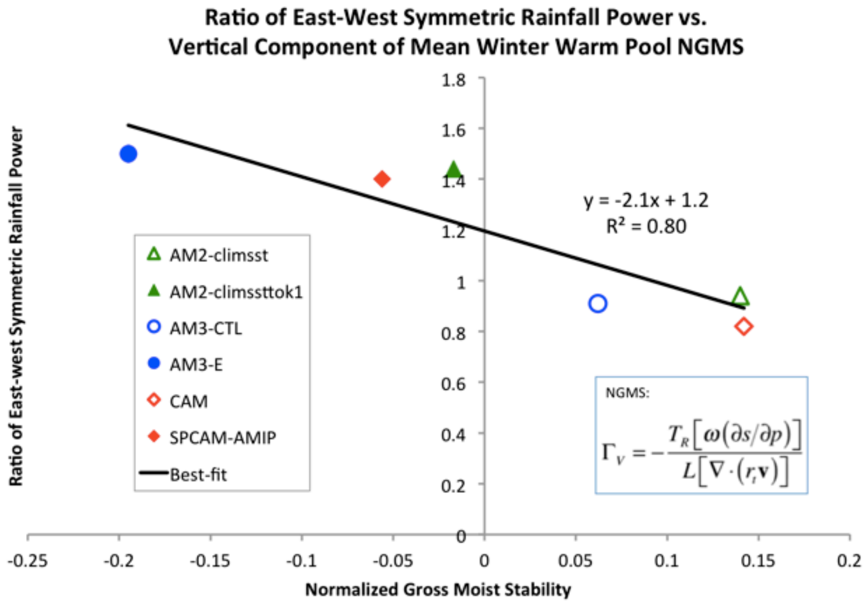

Figure 1. Ratio of east-west symmetric rainfall power (30-96 days, wavenumbers 1-3) versus vertical component of normalized gross moist stability (NGMS) averaged over the Indo-Pacific warm pool during boreal winter. The definition of NGMS is shown at the lower right, where s is moist entropy, r_t is the water vapor mixing ratio, and T_R is a reference temperature. The observed east-west symmetric rainfall power is 2.4 estimated from the TRMM satellite.

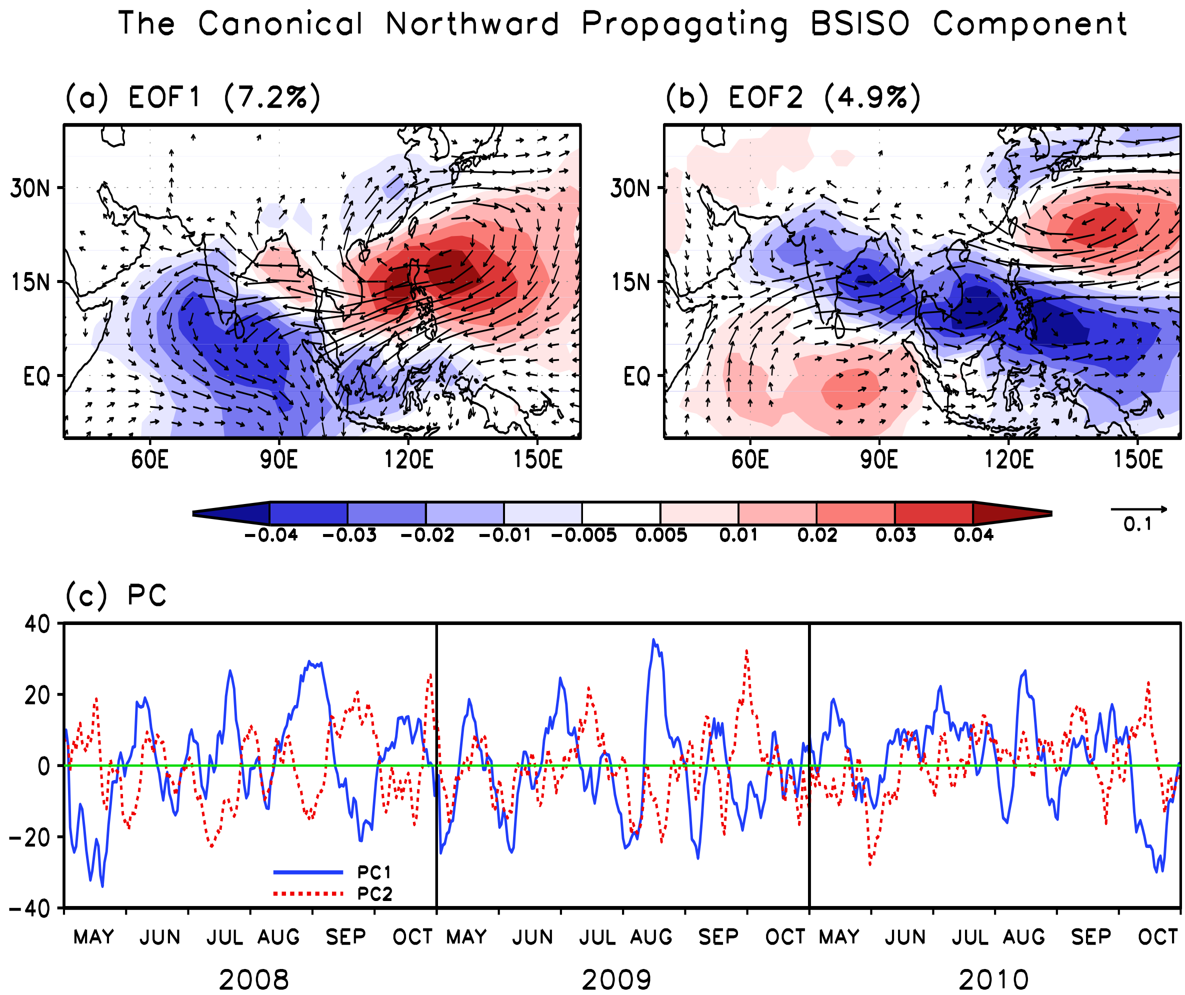

Figure 2. Results from a combined EOF analysis of 850hPa zonal wind and OLR over the latitude/longitude domain as shown, as discussed by Lee et al. (2012). (a) and (b) show the spatial structure of the leading 2 EOFs with OLR shaded and the winds displayed as vectors. Note that the meridional component of the wind, which was not used in the EOF analysis, was reconstructed for this figure using regression against the PC time series. (c) Example PC time series for the leading 2 EOFs for the boreal summer monsoon months during 2008-2010.