An All-Season Multivariate MJO Index for Real-Time Monitoring and Prediction

Wheeler and Hendon (2004, Monthly Weather Review)

An Index for Real-Time MJO Monitoring and Forecasts

- Band-pass filters are commonly used in research papers to study the MJO. Such filters are effective because the MJO dominates the intraseasonal variability in the tropics. However, they are **not** practical for real-time forecasting or monitoring, because a digital filter often requires information beyond the end of the time series.
- Wheeler and Hendon (2004) developed the commonly used, real-time multivariate MJO index.
  - The index is based on the leading pair of empirical orthogonal functions (EOFs) of the combined fields of 850-hPa zonal wind (U850), 200-hPa zonal wind (U200), and outgoing longwave radiation (OLR) data.
  - Projection of the daily observed data onto the multiple-variable EOFs yields time series that vary mostly on the intraseasonal time scale of the MJO only. The pair of time series are often known as (RMM1, RMM2)
- Why does it work? Projection of the daily data onto the combined multivariable patterns increases the signal-to-noise ratio because there are fewer high-frequency weather variations that simultaneously have a structure similar to the MJO in multiple fields.

Data

- Three variables
  - OLR: from the National Oceanic and Atmospheric Administration's (NOAA) polar-orbitting satellites, as a proxy for convection
  - U850 and U200: from the NCEP/NCAR reanalysis
- Each variable was averaged over the latitudes of 15S–15N. The meridional averaging helps to remove some of the non-MJO, higher-frequency variability.

**For real-time applications, OLR is available within a day of when it is recorded. The reanalysis zonal winds run several days behind, but may be replaced by winds from operational analyses or operational forecasts*

Wheeler and Hendon 2004

Methodology

- Then several steps were taken to remove longer-time-scale components:
    - The influence of the seasonal cycle is removed by subtracting from each grid point the time mean and first three harmonics of the annual cycle (with period of 12, 6 and 4 months respectively).
    - Linear regression is used to remove the ENSO signals.
    - A 120-day mean of the previous 120 days is subtracted to remove any further aspects of interannual variability, decadal variability, and trends
- EOFs of combined fields (U850, U200, and OLR) are computed: covariance matrix is used to preserve the spatial variations of each variable; each field is normalized by its global variance before input so that each field contributes equally to the variance of the combined vector

Wheeler and Hendon 2004

Leading Pair of EOFs

- EOF1 and EOF2 explain 25% of the variance of the original atmospheric fields and are well separated from the remaining EOFs.
- EOF1 is corresponding to the MJO phase with enhanced convection over the Maritime Continent: low- level westerly anomalies over the Indian Ocean region and Maritime Continent, and low- level easterlies across the Pacific, while upper-level wind anomalies are in the opposite direction to those below.
- EOF2 has the convection center over the western Pacific and wind patterns that are in close quadrature to those of EOF1.
- U850 and U200 anomalies are nearly out of phase – a baroclinic structure.

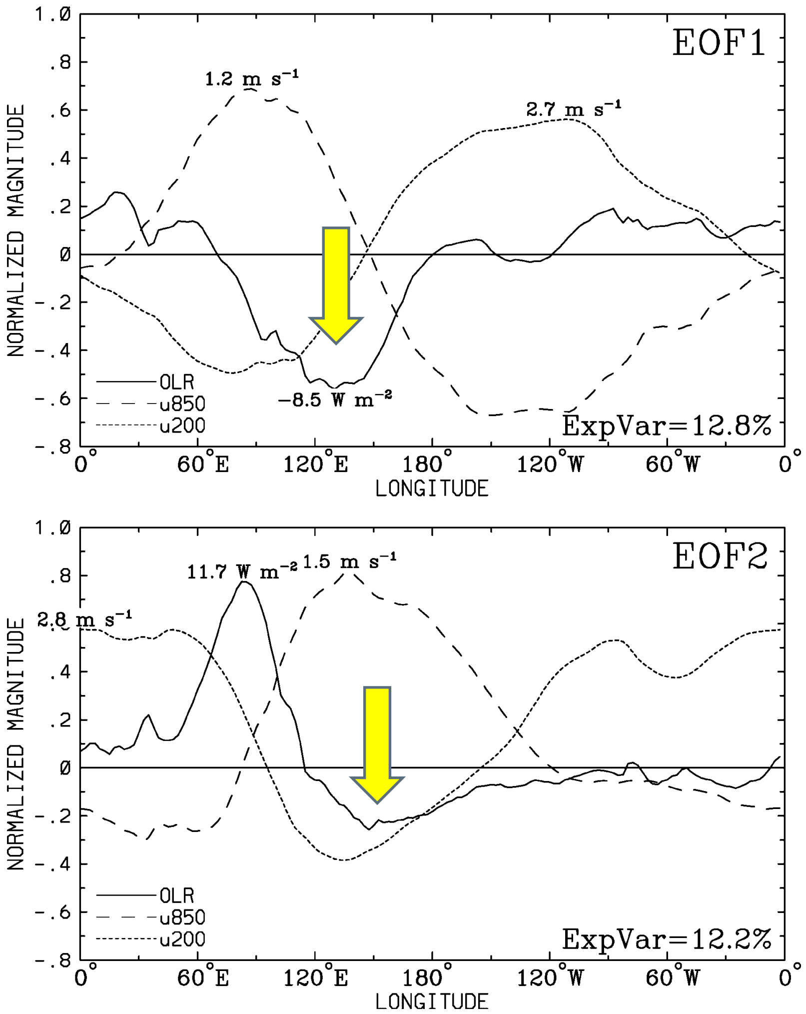
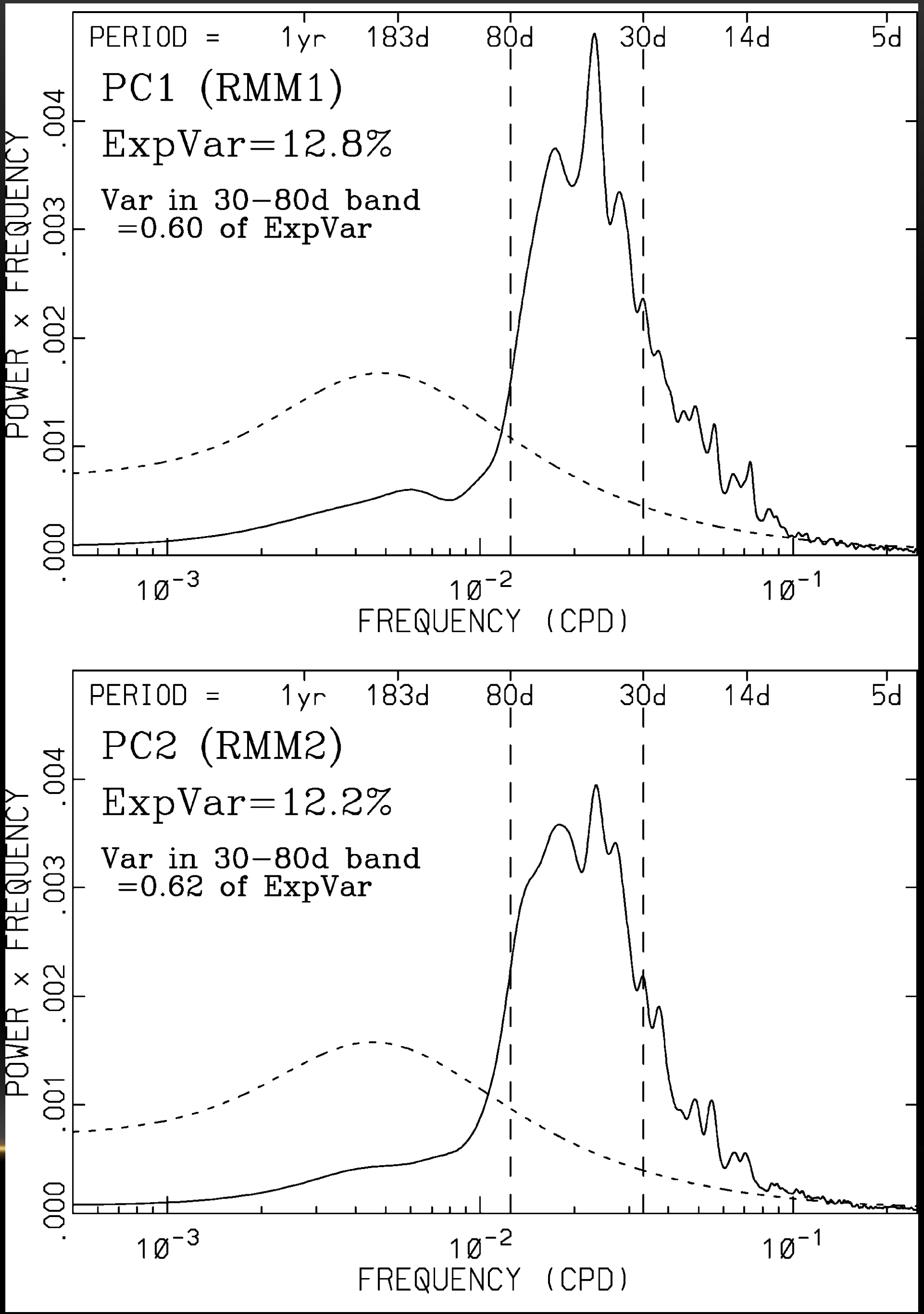


FIG. 1. Spatial structures of EOFs 1 and 2 of the combined analysis of OLR′*, u850′*, and u200′*. A key for the field described by each curve is given. As each field is normalized by its global (all longitudes) variance before the EOF analysis, their magnitude may be plotted on the same relative axis. Multiplying each normalized magnitude by its global variance gives the field anomaly that occurs for a 1 std dev perturbation of the PC, as given for the absolute maxima of each field. The variance explained by the respective EOFs is 12.8% and 12.2%.

Power Spectra

- The variance of PC1 (RMM1) and PC2 (MNM2) is concentrated at intraseasonal periods (30–80 days).
- The projection of the daily observed data onto the two EOFs acts as an effective filter for the intraseasonal frequencies associated with the MJO.



Lag-Correlation

- The autocorrection of the RMM1 decays slowly due to its low-frequency nature.

- The maximum correlation between RMM1 and RMM2 (~0.56) occurs at a lag of 9 days.

What is the dominant period of the MJO based on the lag-correlations?

- The timing of the maximum lag correlation indicates the MJO dominant period is around 40 days.

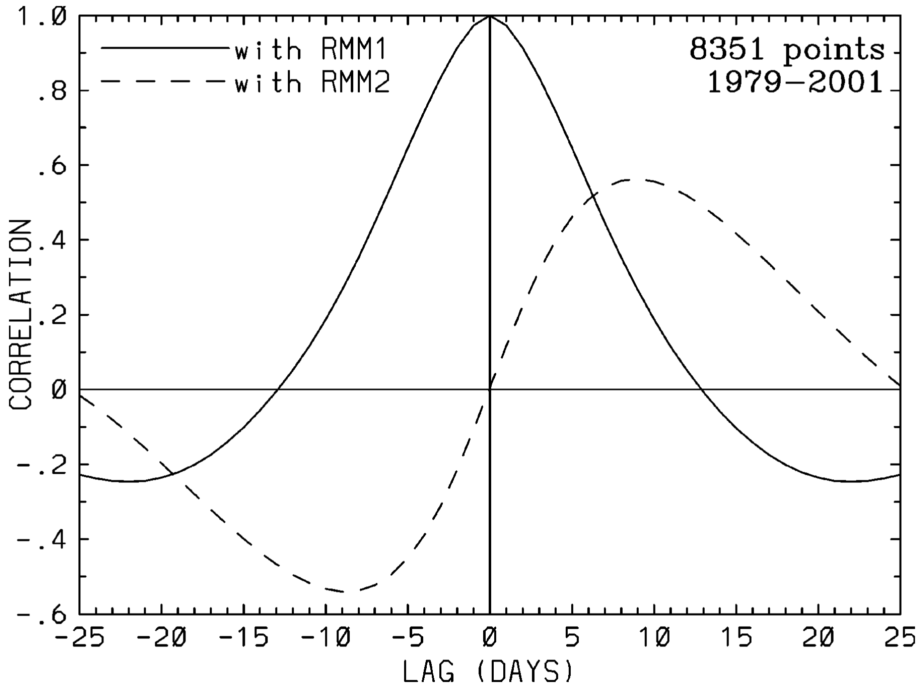


FIG. 6. Lag correlations between RMM1 and itself, and with RMM2 for all seasons.

(RMM1, RMM2) phase Space

- The two-dimensional phase space defined by RMM1 and RMM2 is often used to diagnose the evolution of the MJO.
- Points trace counterclockwise circles around the origin, signifying the systematic eastward propagation of the MJO.
- The distance of a point from the origin represents the MJO magnitude.
- Eight phases are defined, corresponding to the different locations of the MJO-related active convection.

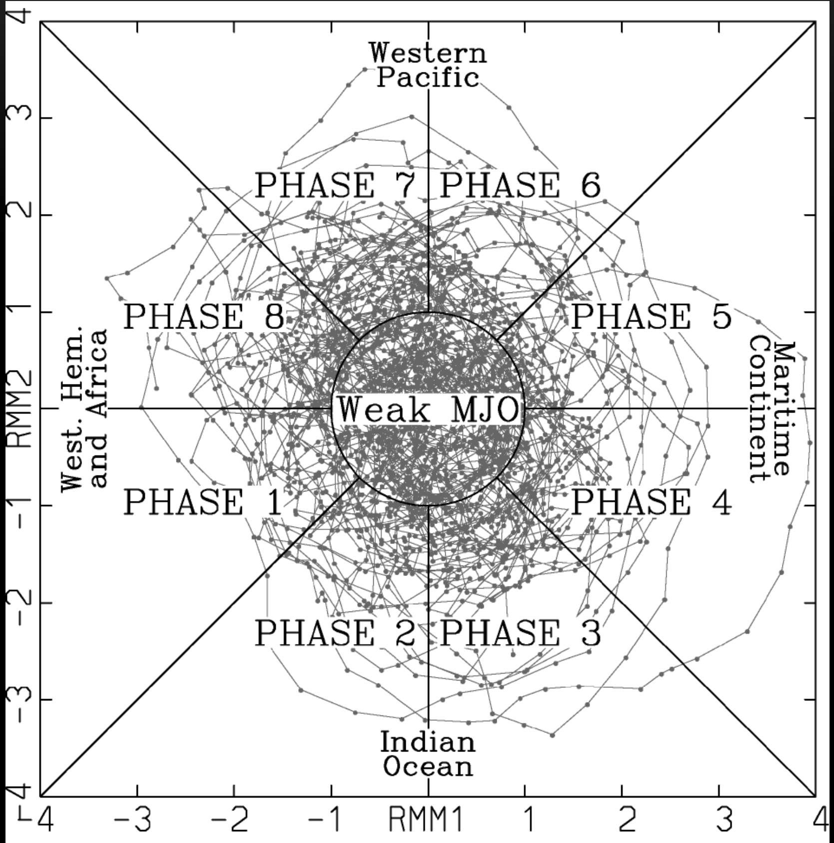


FIG. 7. (RMM1, RMM2) phase space points for all available days in DJF season from 1974 to 2003. Eight defined regions of the phase space are labeled, as is the region considered to signify weak MJO activity. Also labeled are the approximate locations of the enhanced convective signal of the MJO for that location of the phase space, e.g., the "Indian Ocean" for phases 2 and 3.

MJO Composites of OLR (shading) and 850-hPa wind

- Eastward propagation and the OLR signals weaken east of the warm pool.
- Phase 1: MJO initiation over the Indian Ocean
- Phase 3: active convection over the Indian Ocean
- Phase 4&5: MJO propagates over the Maritime Continent
- Phase 6: active convection over the western Pacific
- Phase 7: active convection over the Central Pacific and convection is suppressed over the Indian Ocean

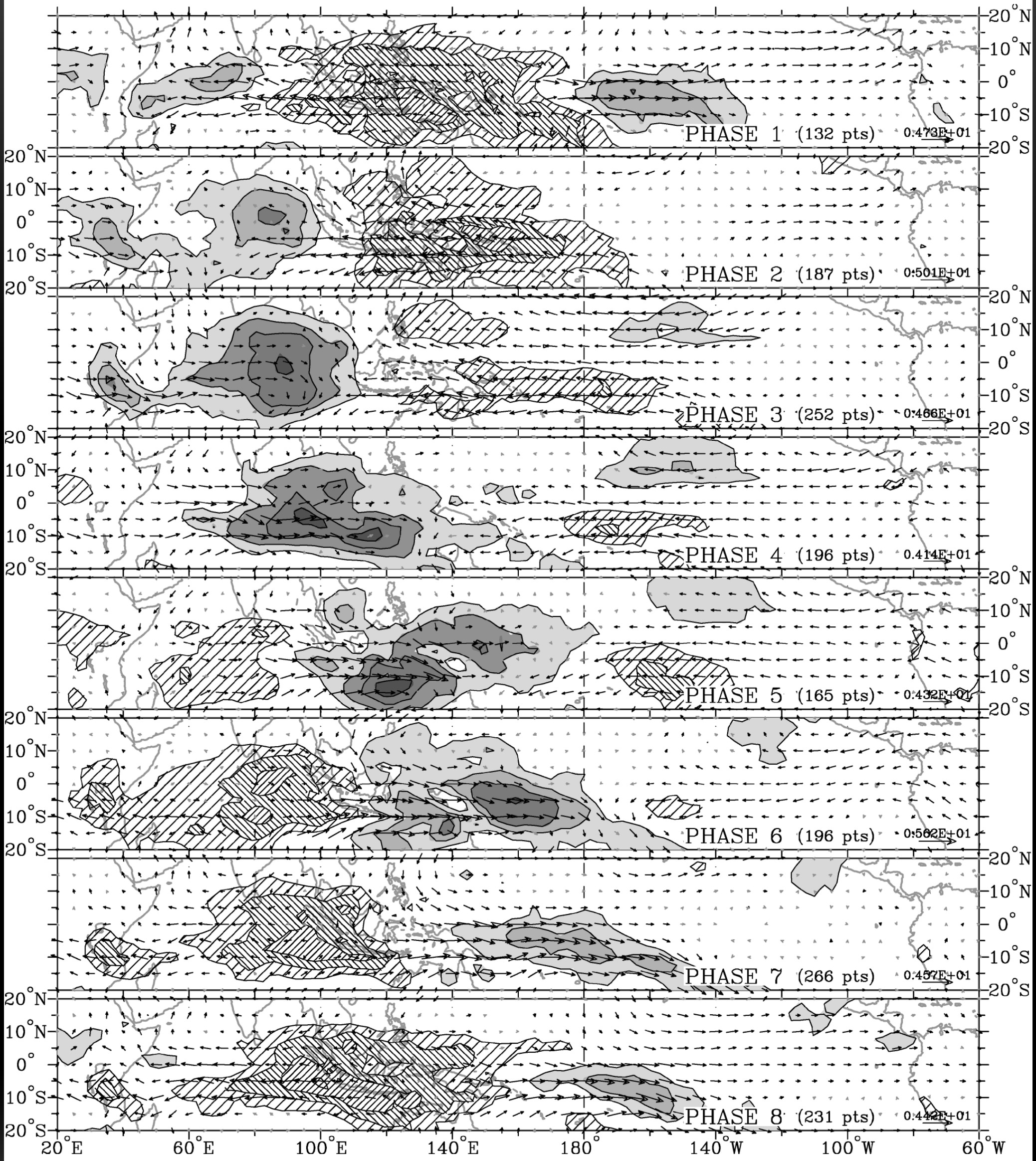


FIG. 8. DJF composite OLR[A] and 850-hPa wind vector anomalies. Shading levels denote OLR anomalies less than −7.5, −15, −22.5, and −30 W m^{-2}, respectively, and hatching levels denote OLR anomalies greater than 7.5, 15, and 22.5 W m^{-2}, respectively. Black arrows indicate wind anomalies that are statistically significant at the 99% level, based on their local standard deviation and the Student's *t* test. The magnitude of the largest vector is shown on the bottom right, and the number of days (points) falling within each phase category is given.

Useful Links

- Wheeler, M. C., & Hendon, H. H. (2004). An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction, *Monthly Weather Review*, *132*(8), 1917-1932
- NOAA CPC MJO composites: http://www.cpc.noaa.gov/products/precip/CWlink/MJO/mjo.shtml#composite
- NOAA CPC MJO Forecast: http://www.cpc.noaa.gov/products/precip/CWlink/MJO/mjo.shtml#forecast
- Australian Bureau of Meteorology: http://www.cawcr.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/
- Australian Bureau of Meteorology, Monitoring and Prediction of Modes of Coherent Tropical Variability: http://www.cawcr.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR_modes/index.htm
- CLIVAR-MJO Science: MJO Science: http://www.usclivar.org/mjosci.php