VERTICAL MOIST THERMODYNAMIC STRUCTURE OF THE MJO IN AIRS OBSERVATIONS AND ECMWF INTERIM REANALYSIS

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I. Introduction

The Madden-Julian Oscillation (MJO) is the dominant form of intraseasonal variability in the tropical atmosphere, characterized by slowly eastward-propagating, large-scale oscillations in tropical deep convection and baroclinic wind field, especially during the boreal winter (November-April) over the warmest tropical waters in the equatorial Indian Ocean and western Pacific [*Lau and Waliser*, 2005; *Madden and Julian*, 1971; 1972; *Zhang*, 2005]. The MJO has been shown to have important influences on various global weather and climate phenomena. However, the MJO is still not well understood nor well represented in global climate models. The recent available satellite data provide an excellent opportunity to study the MJO, especially its vertical structure. For example, Tian et al. [2006] have documented the vertical moist thermodynamic structure of the MJO using the first 2.5-year (2002-2005) of Atmospheric Infrared Sounder (AIRS) data. Here, we re-examine the vertical moist thermodynamic structure of the MJO using the current available 7-year AIRS data (2002-2009) to test the robustness of the results of Tian et al. [2006] and their dependence of data record length, data resolution (daily versus pentad), and MJO analysis methods. We also compare the AIRS results to those from the ECMWF Interim reanalysis, a new global reanalysis data set from ECMWF.

II. Data

The following three data sets were used in this study. 1) Global, daily (arithmetic mean of ascending and descending nodes) Atmospheric Infrared Sounder (AIRS) Version 5 Level 3 atmospheric temperature and specific humidity profiles from September 2002 to July 2009. The AIRS data have a horizontal 1° x 1° resolution and are on 24 pressure levels from 1000 hPa to 1 hPa for temperature and 12 pressure layers from 1000 hPa to 100 hPa for water vapor [*Chahine et al.*, 2006]. 2) Global, daily (arithmetic mean of 4xdaily) ECMWF interim reanalysis atmospheric temperature and specific humidity profiles for the same period as the AIRS data. The ECMWF data have a horizontal 1.5° x 1.5° resolution and are on 37 pressure levels from 1000 to 1 hPa. 3) Tropical Rainfall Measurement Mission (TRMM) 3B42 Version 6 rainfall data from January 1st, 1998 to June 30th, 2009. The TRMM 3B42 data extends globally from 50°S to 50°N on 0.25° x 0.25° grid boxes every 3 hours [*Huffman et al.*, 2007].

III. MJO Analysis Methods

Two MJO analysis methods were employed and compared for this study. Method 1 is the MJO analysis method used by Tian et al. [2006]. Briefly, all data were first binned into pentad (5-day) values and then intraseasonal anomalies of the pentad data were obtained by removing the annual cycle and filtering via a 30–90-day band pass filter. To isolate the dominant structure of the MJO, an extended empirical orthogonal function (EEOF) analysis using time lags of ±5 pentads (i.e. 11 pentads total) was applied on boreal winter rainfall anomaly for the tropical Indian Ocean and western Pacific (30°S-30°N, 30°E-150°W). Next, MJO events were chosen based on maxima in the pentad amplitude time series of the first EEOF mode. For each selected MJO event, the corresponding 11-pentad anomalies were extracted. A composite MJO cycle (11 pentads) was then obtained by averaging the selected MJO events. Method 2 is the MJO analysis method introduced by Wheeler and Hendon [2004]. Briefly, the intraseasonal anomalies of daily data were obtained by removing the annual cycle and filtering via a 30–90-day band pass filter. Then, a composite MJO cycle (8 phases) was calculated by averaging daily anomalies for each phase of the MJO cycle. The MJO phase for each day is determined by the Real-time Multivariate MJO (RMM) index (a pair of principal component time series, called RMM1 and RMM2) based on a pair of EOFs of the combined fields of near-equatorially averaged (15°S-15°N) 850- and 200-hPa zonal winds from NCEP/NCAR reanalysis, and satellite-observed outgoing longwave radiation (OLR) data. Only strong MJO events ($RMM1^2+RMM1^2>=1$) during boreal winter are considered.

IV. Results

Figs. 1 and 2 show the composite MJO cycle of equatorial mean (8°S-8°N) pressure-longitude cross sections of specific humidity and temperature anomalies based on AIRS data and Method 1. Solid black lines denote TRMM rainfall anomalies. The comparison of the current Figs. 1 & 2 to Figs. 3 & 7 in Tian et al. [2006] indicates the vertical moist and thermal structures of the MJO are consistent between the current based on 7-year AIRS data and those based on 2.5-year AIRS data in Tian et al. [2006]. The AIRS data clearly show a low-level moisture and temperature preconditioning for the MJO in the equatorial Indian Ocean and western Pacific. Figs. 3 and 4 show the same quantities as Figs. 1 and 2 but based on the Method 2. The comparison of Figs. 1 & 2 to Figs. 3 & 4 indicates that the vertical moist and thermal structures of the MJO based on the Method 1 and pentad data are consistent with those based on the Method 2 and daily data. Figs.

5 and 6 show the same quantities as Figs. 1 and 2 but based on ECMWF data and Method 1. The comparison of Figs. 1 & 2 to Figs. 5 & 6 indicates that the MJO vertical moist thermodynamic structures are in general agreement between AIRS and ECMWF data. However, AIRS results seem to be drier in moist regions and moister in dry regions compared to ECMWF results. Nevertheless, the ECMWF interim reanalysis seems to be better than the NCEP/NCAR reanalysis in depicting the vertical moist thermodynamic structure of the MJO in comparison to AIRS observations.

V. Summary

The vertical moist thermodynamic structure of the MJO was re-examined using the current available 7-year AIRS data (2002-2009) and compared to that of Tian et al. [2006] based on 2.5-year AIRS data to test the dependence of the results of Tian et al. [2006] on data record length, data resolution (daily versus pentad), and different MJO analysis methods. The current analysis indicates that the results of Tian et al. [2006] are robust and independent on the AIRS data record length, AIRS data resolution, and MJO analysis methods. Compared to ERA-interim reanalysis, AIRS results seem to be drier (moister) in the moist (dry) regions. These results will be a useful metric for climate model diagnostics.

Acknowledgment:

This work was supported under grant ATM-0840755 from the National Science Foundation to University of California, Los Angeles and the Atmospheric Infrared Sounder project at Jet Propulsion Laboratory.

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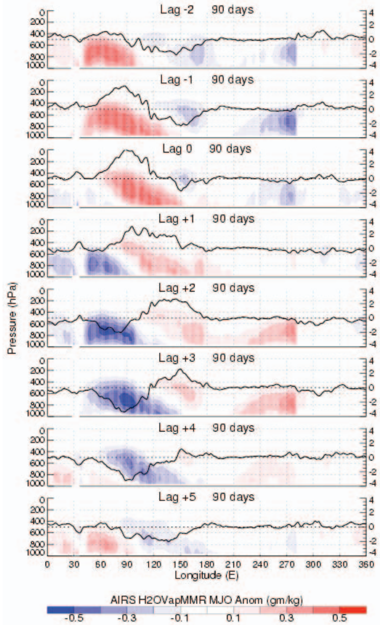

Fig. 1. Composite MJO cycle of equatorial mean (8°S-8°N) pressure-longitude cross sections of specific humidity anomalies based on AIRS data and Method 1.

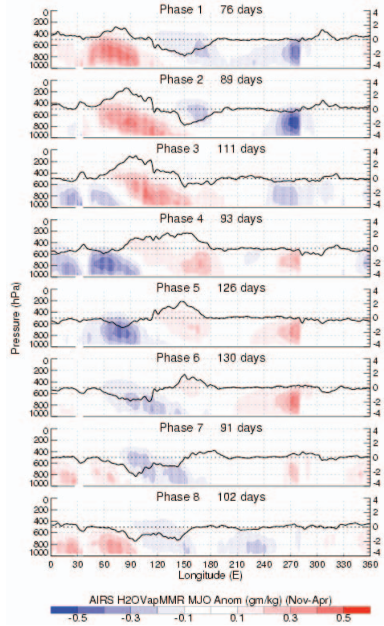

Fig. 3. Composite MJO cycle of equatorial mean (8°S-8°N) pressure-longitude cross sections of specific humidity anomalies based on AIRS data and Method 2.

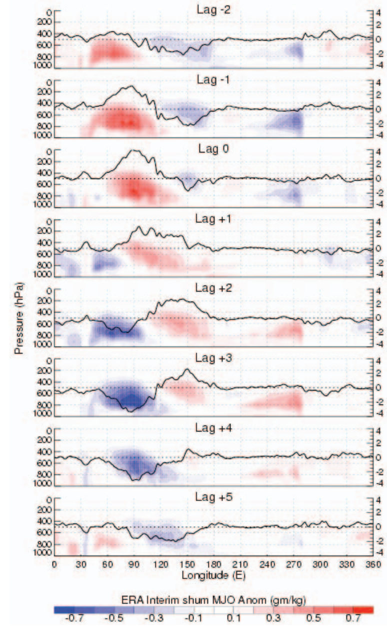

Fig. 5. Composite MJO cycle of equatorial mean (8°S-8°N) pressure-longitude cross sections of specific humidity anomalies based on ECMWF data and Method 1.

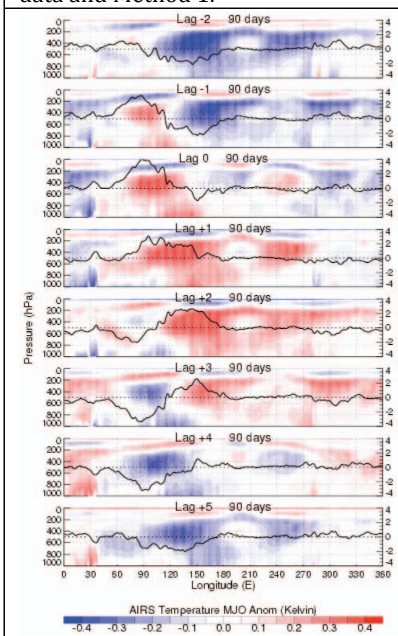

Fig. 2. Composite MJO cycle of equatorial mean (8°S-8°N) pressure-longitude cross sections of temperature anomalies based on AIRS data and Method 1.

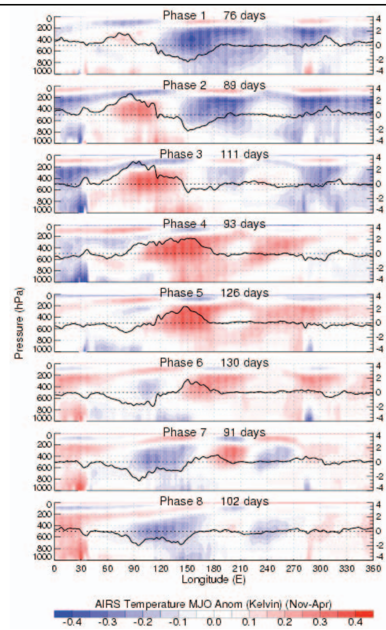

Fig. 4. Composite MJO cycle of equatorial mean (8°S-8°N) pressure-longitude cross sections of temperature anomalies based on AIRS data and Method 2.

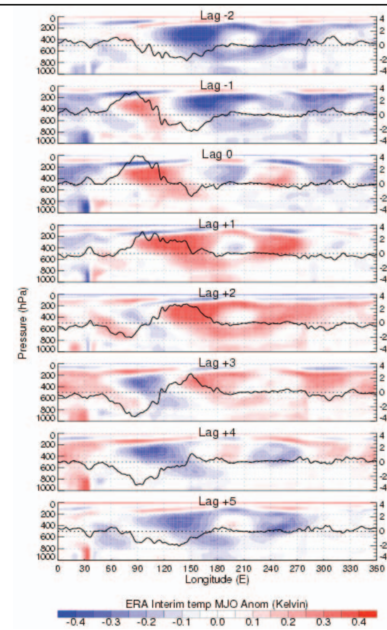

Fig. 6. Composite MJO cycle of equatorial mean (8°S-8°N) pressure-longitude cross sections of temperature anomalies based on ECMWF data and Method 1.