Predictability of the Madden and Julian Oscillation in JMA One-month Forecasts

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Abstract

Predictability of the Madden and Julian Oscillation (MJO) is investigated using Japan Meteorological Agency (JMA) operational 1-month forecasts in Northern Hemisphere winter seasons during 2001-2004. The anomaly correlations (ACs), which are utilized as a measure of forecast skill, for low-pass filtered velocity potential on 200 hPa surface (VP200) anomalies in equatorial region are above 0.6 until 6 days lead-time. ACs tend to become smaller than the averaged values when the MJO is quiescent. On the other hand, ACs of the strong MJO cases tend to be above the average. In particular, relatively skillful forecasts are found for the initial conditions with divergent anomalies over the Maritime Continent and convergent anomalies over the Atlantic. The relationship between the forecast skill and the MJO amplitude defined by the first two principal components at the initial condition are examined. At the 1-6 days lead-times, the variations of the forecast skill in the equatorial regions are significantly related to those of the initial MJO amplitude. This relationship, however, becomes insignificant after 7 days lead-time.

Keyword: Madden and Julian Oscillation, Predictability, Forecast skill.

1. Introduction

The Madden and Julian Oscillation is the dominant variability in intraseasonal time scales over the tropics (e.g., Madden and Julian 1994). It is characterized by eastward propagating tropical convective anomalies and associated circulation anomalies, with a period between 30 and 70 days. The onset and activity of the Asian monsoon system are strongly influenced by the eastward propagation of MJO events (e.g., Yasunari 1979, Lau and Chan 1986). The MJO is also linked to the onset and the variability of the Australian monsoon (e.g., Hendon and Liebmann 1990) and the modulation of tropical cyclone development (Nakazawa 1986, Liebmann et al., 1994). Furthermore, some papers reported that the MJO influences weather forecasts over the extratropical regions on medium-to-extended range (Ferranti et al. 1990, Tsuyuki 1990, Lau and Chang 1992).

However, it is well known that many atmospheric general circulation models cannot simulate the MJO realistically (e.g., Slingo et al. 1996). Jones et al.(2000) pointed out the MJO in their model was less intense and with faster eastward propagation. In dynamical forecasts by National Centers for Environmental Prediction (NCEP) medium range forecast (MRF) model, skillful forecasts are limited to 5 to 7 days lead-time (Chen and Alpert 1990, Lau and Chang 1992, Hendon et al. 2000, Jones et al. 2000).

Moreover, the relationship between the forecast skill and the MJO activity has provoked a controversy. Using the velocity potential from the NCEP MRF model, Jones et al. (2000) indicated a slight increase in the forecast skill for periods when convective anomalies with the MJO are intense. On the other hand, Boer (1995) showed little evidence of a dependence of forecast skill on the state of the MJO in the European Centre for Medium-Range Weather Forecasts (ECMWF) forecast system. Hendon et al. (2000) and Lo and Hendon (2000) using the streamfunction from the NCEP MRF model demonstrated that the forecast skill was found to be better when the MJO was quiescent than when it was active at the initial condition.

Purpose of this work is to investigate the predictability of the MJO using Japan Meteorological Agency (JMA) operational 1-month forecasts during boreal winter seasons. In particular, our concern is to examine the relationship between the forecast skill in the equatorial regions and the MJO at the initial condition in terms of the states and the amplitude.

2. Data and analysis method

Operational 1-month (34 day) forecasts of Japan Meteorological Agency (JMA) were produced every Wednesday and Thursday based upon a JMA operational model (GSM0103) with triangular 106 truncation (T106) and 40 vertical levels. The model top boundary is located at 0.4 hPa. A prognostic Arakawa-Schubert scheme by Randall and Pan (1993) is introduced for deep convection. In the numerical integration, sea surface temperatures are set constant values of initial conditions. The 1-month forecasts in JMA were carried out using ensemble integrations starting from the unperturbed initial condition (control forecast) and twelve perturbed initial conditions. In this paper, however, we analyzed only control forecasts from Wednesday and Thursday. The data are stored every 24 hours and presented on a 2.5°× 2.5 ° longitude-latitude grid at 22 levels from 1000 hPa to 1 hPa.

We used forecasts based upon the initial conditions from the final week of October to the second week of April during 2001-2004, that is, from 31st October 2001 to 11th April 2002, from 30th October 2002 to 10th April 2003, and from 29th October 2003 to 8th April 2004. In this period of 72 weeks, 144 control forecasts were performed.

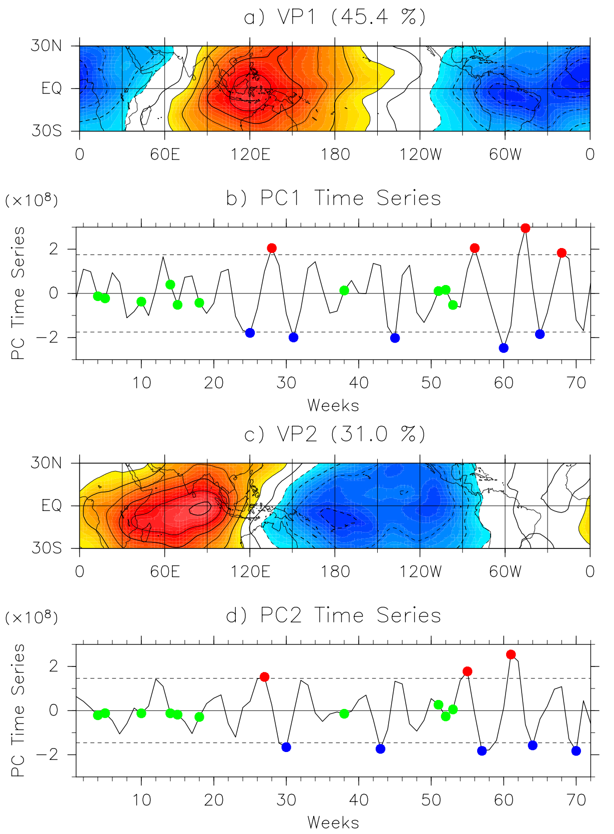

Fig. 1: Principal component analysis of intraseasonally bandpass filtered 200hPa velocity potential (VP200) anomalies in the tropics (30°S-30°N). a) 1st eigenvector, b) PC1 time series, c) 2nd eigenvector, d) PC2 time series. Red and blue solid circles represent the weeks selected for initial conditions with the strong MJO events. Green solid circles denote the week selected for little or no MJO activity (i.e., the Null events). Dashed lines along the horizontal axis in b) and d) indicate 1.5 standard deviations.

To verify model forecasts, a JMA Global Analysis (GANAL) dataset with 1.25° horizontal resolution was used from June 2001 to May 2004.

The velocity potential on 200 hPa (VP200) is examined to assess the predictability of the tropical convective circulation. As analysis procedure, the annual cycle was removed from the forecast and verification fields. The annual cycle was defined as the annual mean with first two harmonics from the climatological time series created by the 3-year mean for each day of the GANAL. The model systematic error was removed for the examination of the forecast skill in the intraseasonal time scales.

The prediction skill is examined for the forecast fields applied by a 9-day moving average to remove high frequency variations (Jones et al. 2000). The beginning of the forecasts was padded with four days of verification analyses. Note that this procedure can slightly inflate some of the skill measures for short lead times.

In order to select initial conditions for the MJO phases, we performed the principal component (PC) analysis of VP200 anomalies of the GANAL in the tropics (30°S-30°N) during 72 weeks in the above period. Anomalies were averaged weekly and filtered between 3 weeks (21 days) and 14 weeks (98 days). The results are shown in Fig.1. The leading two eigenvectors (VP1 and VP2) accounted for the 44.5 % and 31.0 %, respectively. The spatial structure of VP1 and VP2 shows the familiar MJO pattern (e.g. Lorenc, 1984). We define a period of the strong MJO activity when either of the two leading principal components exceeds 1.5 standard deviations (cf. Hendon et al., 2000). Events are selected when the magnitudes of 1st PC time series are larger than 1.5 standard deviations (PC1+), when the magnitudes of 1st PC time series are less than minus 1.5 standard deviations (PC1−), when the magnitudes of 2nd PC time series are larger than 1.5 standard deviations (PC2+), and when the magnitudes of 2nd PC time series are less than minus 1.5 standard deviations (PC2−). When the succeeding two or more weeks exceeded 1.5 standard deviations, the week with the peak score was selected (see marks in Fig. 1b and d). The cases are denoted by Null when the absolute values of the both first and second PC time series are less than 0.5 standard deviations. In this work, 8(4), 10(5), 6(3), 10(5), and 20(10) forecasts (weeks) were taken for PC1+, PC1−, PC2+, PC2−, and Null, respectively.

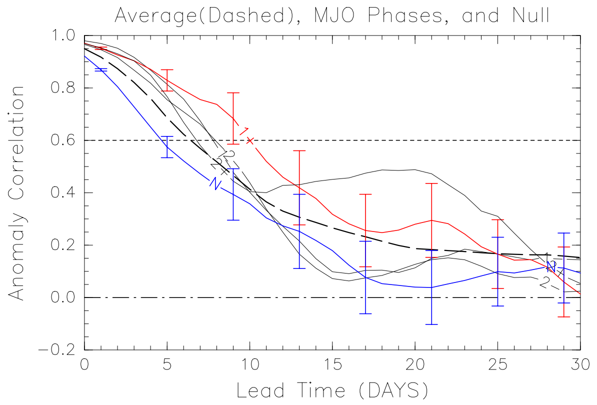

Fig. 2: Anomaly correlations (ACs) in the equatorial region (10°S-10°N) between forecast and verification of VP200 as a function of lead-time. The dashed black line represents values averaged for 144 forecasts, and solid lines denote ACs in the different phases of the MJO and the Null case. Error bars attached in PC1+ (red), and Null (blue) cases show the standard deviations in the selected forecasts.

3. Results in JMA 1-month forecasts

3.1. Relationship between the forecast skill and the initial MJO states

The forecast skills of the JMA 1-month forecasts are examined for low-pass filtered equatorial variations during the boreal winter seasons. Anomaly correlation (AC) is the commonly used measure of association that operates on pairs of gridpoint values in the forecast and observed fields (e.g., Wilks 1995). Here, the AC is designed to detect similarities in the patterns of departures from the climatological fields in the equatorial (10°S-10°N) region.

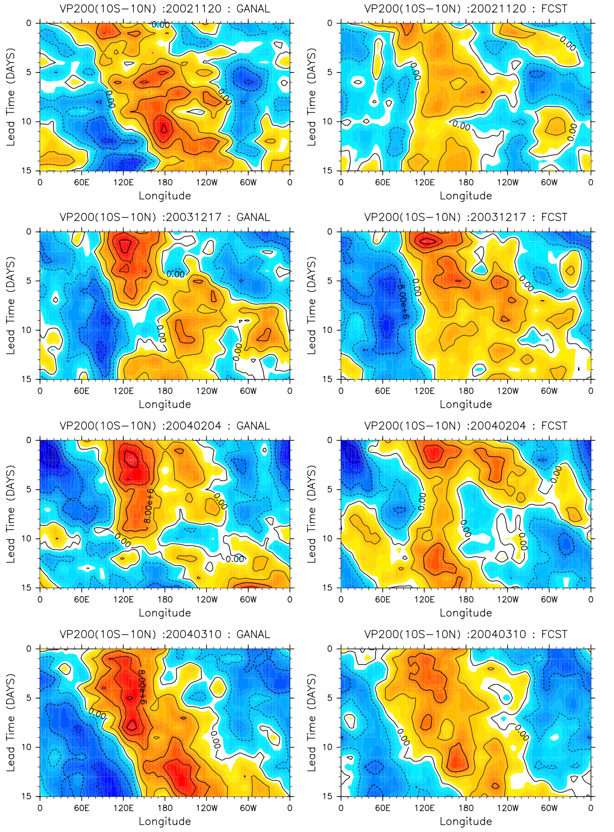

Fig. 3: Longitude-time diagrams of "unfiltered" VP200 anomalies in the equatorial region (10°S-10°N) for each PC1+ event. Panels in the left column show values of the analyses and panels in the right column show those of the forecasts.

The forecast skill is generally evaluated relative to a reference values of AC= 0.6.

In Fig.2, the dashed black line represents the averaged values of ACs for 144 control forecasts. On average, ACs are above 0.6 until 6 days lead-time. In the next step, the relationship is examined between the forecast skills and the states of the MJO at the initial condition. Figure 2 shows that there is a clear difference between the strong MJO cases and the Null case. ACs of the Null case (the line with the character "N") are always below the averaged values. ACs for the Null case were above 0.6 until 4 days lead-time. This feature seems to be common to the individual forecasts because standard deviations denoted by error bars are small. ACs for the strong MJO cases tend to be above the average during the lead-times when the ACs are above 0.6. This result is consistent with Jones et al.(2000) using zonal winds on 200 hPa of the NCEP MRF model. Figure 2 also shows that ACs for the PC1+ case (the line with the character "1+") are the highest, although the result is less significant. ACs averaged for the PC1+ case are above 0.6 until 9 days lead-time. The PC1+ case corresponds to the initial conditions with divergent anomalies over the Maritime Continent and convergent anomalies over the Atlantic.

Figure 3 shows longitude-time diagrams of unfiltered VP200 anomalies in the equatorial region of the individual

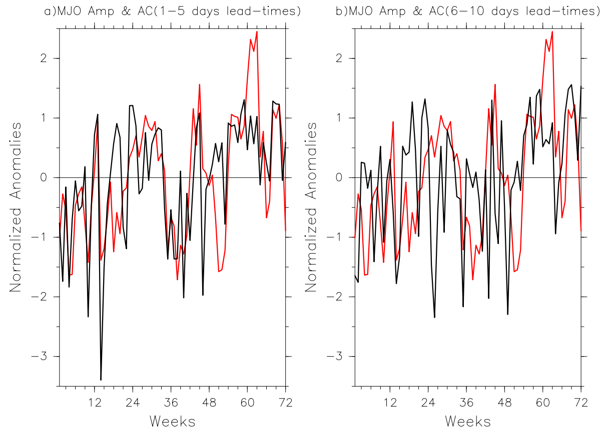

Fig. 4: The amplitude of the MJO (red lines) and ACs (black lines) averaged a) between 1-5 days lead-times and b) between 6-10 days lead-times. Horizontal axis denotes weeks. Variables are normalized by their standard deviations.

PC1+ events for the forecasts with the initial condition on Wednesday. Modest similarity until about 10 days lead-times is seen. The forecast based upon the initial condition on 10th March 2004 (the bottom panel) demonstrates an eastward propagating disturbance clearly although magnitudes of the predicted anomalies are smaller than those in the analysis fields.

3.2. Relationship between the forecast skill and the initial MJO amplitude

In this subsection, the relationship is documented in detail between the forecast skill and the amplitude of the MJO at the initial condition. Here, the amplitude $A(t)$ is defined by the first two PCs as shown in Fig.1; $A(t) = \left[PC1^2(t) + PC2^2(t)\right]^{1/2}$ (cf. Matthews 2000). Red lines of Fig.4 show the amplitude $A(t)$. We examine the relationship between the amplitude and the ACs calculated in previous subsection. ACs based upon the initial conditions of Wednesday and Thursday are averaged in the same week, and weekly series are analyzed here.

Figures 4a and b indicate ACs averaged between 1-5 days lead-times and between 6-10 days lead-times, respectively (black lines). In Fig.4a, the variations of the ACs were significantly related to those of the MJO amplitude. A correlation coefficient between the MJO amplitude and the AC are 0.61. Here, the 1 % significance level is 0.42, based on the assumption that independent events occur every 3rd-week, according to the *e*-folding time for the autocorrelation of the MJO amplitude. This indicates that the predictions of the MJO by the JMA 1-month forecasts are skillful at the early period of the forecast when the MJO amplitudes at the initial conditions are large. This is consistent with the results in the previous section. On the other hand, this relationship is not found in the 6-10 days lead-times as shown in Fig.4b. The correlation coefficient is 0.26.

In order to investigate the relationship further, we cal-

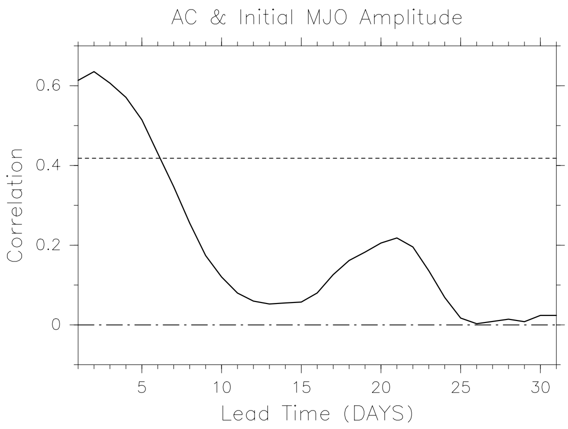

Fig. 5: Correlation between the ACs and the initial MJO amplitudes as a function of lead-time. The dashed line along the horizontal axis denotes the 1 % significance level.

culate correlation coefficients between the ACs and the initial MJO amplitudes as a function of lead-time. As shown in Fig.5, the correlations are significant until 6 days lead-time. The same analysis as Fig.5 except for the unfiltered forecasts (not shown) indicates that the correlations are significant until 5 days lead-time. This demonstrates that this relationship is not established by the padded verification analyses in a 9-day moving average for the early lead-times.

4. Summary

The predictability of the MJO was examined using Japan Meteorological Agency (JMA) operational 1-month forecasts during boreal winter seasons of 2001-2004. The averaged values of ACs for low-pass filtered velocity potential on 200hPa (VP200) anomalies in the equatorial (10°S-10°N) region were above 0.6 until 6 days lead-time.

We examined the relationship between the forecast skills and the states of the MJO at the initial condition. ACs tended to be lower than the averaged values when the MJO was quiescent. On the other hand, ACs for the strong MJO cases tended to exceed the averaged values. In particular, relatively skillful forecasts were found for the initial conditions with divergent anomalies over the Maritime Continent and convergent anomalies over the Atlantic.

The relationship between the forecast skill and the MJO amplitude at the initial condition was also examined using the amplitude defined by the first two PCs. At the 1-6 days lead-times, the variations of the ACs were significantly related to those of the MJO amplitude. This indicates that the predictions of the JMA 1-month forecasts were more skillful in the equatorial region at 1-6 days lead-times when the MJO amplitudes were large at the initial conditions. However, this relationship became insignificant after 7 days lead-times.

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