Vol.19 No.3 **JOURNAL OF TROPICAL METEOROLOGY** September 2013

Article ID: 1006-8775(2013) 03-0233-09

POSSIBLE IMPACTS OF MADDEN–JULIAN OSCILLATION ON THE SEVERE RAIN-SNOW WEATHER IN CHINA DURING NOVEMBER 2009

JIA Xiao-long (贾小龙), LIANG Xiao-yun (梁潇云)

(National Climate Center, Beijing 100081 China)

Abstract: Possible relationships between MJO and the severe rain-snow weather in Eastern China during November of 2009 are analyzed and results show that a strong MJO process is one of the strong impact factors. MJO is very active over the Indian Ocean in November 2009. Especially, it maintains 9 days in MJO phase 3, just corresponding to the two strongest rain-snow processes. Composites of MJO events show that when the MJO convective center is located over the Indian Ocean, the probability of rainfall is significantly increased and the temperature is lower than normal in eastern China, which is consistent with the situation in November of 2009. Atmospheric circulation anomalies of mid- and higher-latitudes can be influenced by the tropical MJO convection forcing and this influence could be realized by teleconnection. When the MJO is over the Indian Ocean, it is favorable for the maintenance of a circulation pattern of two ridges versus one trough at mid- and higher-latitudes. Meanwhile, the western Pacific subtropical high is stronger and more westward than normal, and a significant convective belt appears over eastern East Asia. All these circulation anomalies shown in the composite result also appeared in the observations in November 2009, which indicates the general features of relationships between the MJO and the circulation anomalies over the extratropics. Besides the zonal circulation anomalies, the MJO convection can also lead to meridional circulation anomalies. When the MJO convection is located over the Indian Ocean, the western Pacific is dominated by anomalous descending motion, and the eastern East Asia is controlled by strong convergence and ascending motion. Therefore, an anomalous meridional circulation is formed between the tropics and middle latitudes, enhancing the northward transportation of low-level moisture. It is potentially helpful to understanding and even forecasting such kind of rain-snow weather anomalies as that in November 2009 using MJO.

Key words: MJO; rain-snow weather; Indian Ocean; tropics; middle-high latitudes

CLC number: P423.3.5 **Document code:** A

1 INTRODUCTION

In November 2009, eastern China suffered three times of severe rain-snow and temperature dropping processes characteristic of early snow date, wide coverage and strong intensity of rain-snow weather, deep snow, large temperature drop, low temperature, etc. November rainfall amounts rank the second and third place in history over the mid- and lower-reaches of the Yangtze River basin and North China, respectively. Temperature decreased by 15 to 20°C in most of eastern China and even beyond 20°C and extreme lowest temperature below 0°C in some regions. Mean temperatures in North China and mid- and lower-reaches of Yangtze River basin are the lowest from 1951 to the present and from 2001 to the present, respectively[1].

Studies have indicated that the extratropical circulation response to diabatic heating associated with tropical convection is dependent not only on the background of mean airflow, but on the magnitude, position, and temporal evolution of diabatic forcing[2-4]. On the other hand, MJO is the major propagating mode of intraseasonal variability in the tropical atmosphere[5, 6]. Characteristics of this oscillation have been well documented in many observational studies[7, 8]. The importance of the MJO to tropical and global weather and climate has become increasingly apparent. The direct impacts of the MJO on tropical weather and climate have been widely documented. Besides, they are not only confined to the tropics. It can also significantly modulate variations in weather and climate in extensive subtropics and midlatitudes[9-16]. The tropical

---

Received 2012-04-24; **Revised** 2013-05-03; **Accepted** 2013-07-15

Foundation item: National Natural Science Foundation of China (40905035); National Basic Research Program of China (973 Program, 2010CB428606); National Department Public Welfare Research Foundation of China (GYHY200906015); Key Technologies R&D Program of China (2009BAC51B05)

Biography: JIA Xiao-long, Ph.D., primarily undertaking research on dynamic climatology.

Corresponding author: JIA Xiao-long, e-mail: jiaxl@cma.gov.cn

circulation system, including the tropical intraseasonal oscillation, plays important roles in weather/climate anomalies in China. However, most studies have focused on intraseasonal oscillations on summertime[17-26]. A recent study indicated that rainfall anomalies show systematic and substantial changes (enhanced/suppressed) in the Yangtze River basin and South China with the eastward propagation of the MJO convective center from the Indian Ocean to the western Pacific[27]. Present dynamical and statistical models indicated that useful predictive skill of MJO might exist out to at least 15 to 20 days[28]. In 2003, an experimental MJO prediction project was proposed by U.S. aiming at further improving the MJO prediction skill. The results indicated that the MJO is very important for predicting tropical circulation of 1 to 4 weeks, and skillful MJO prediction, on a certain extent, is helpful for predicting 1 to 2 weeks of subtropical weather and 3 to 4 weeks of extratropical circulation[29]. Therefore, the MJO could be an important predictability source for 10-to- 30-day extended range prediction.

It is noticed that there is a strong MJO event propagating from the Indian Ocean to the West Pacific in November 2009. Therefore, this work investigates whether this MJO event is the main contributor to the severe rain-snow disaster in November 2009 and what is the possible relationship between the MJO and the extratropical circulation.

2 DATA AND METHODS

2.1 *Data*

2.1.1 THE MJO INDEX

The MJO index used was a real-time multivariate MJO (RMM) index developed by Wheeler and Hendon[30], downloaded from the website of the Australian Bureau of Meteorology[31]. This index defines the MJO by projecting daily anomaly data onto the leading pair of empirical orthogonal functions (EOFs) of combined fields of equatorially-averaged (15°S to 15°N) Outgoing Longwave Radiation (OLR), 850 hPa zonal wind, and 200 hPa zonal wind, to obtain the time series of two principal components (called RMM1 and RMM2). Longer-timescale variability, resulting from ENSO and other interannual variations and with a period longer than about 200 days, is removed prior to this projection. No temporal filtering is applied. Despite the lack of intraseasonal time filtering, the index strongly discriminates the 30-to-80-d MJO signals.

The RMM1 and RMM2 index defines a 2D phase space. In this phase space, the eastward propagation of the MJO can be categorized into eight phases, each corresponding to the geographical position of its active convective center (Figure 1). According to the magnitude and propagation of the RMM index, a strong MJO can be defined when $\sqrt{\mathrm{RMM1}^2+\mathrm{RMM2}^2}\geq 1$, and a weak MJO when $\sqrt{\mathrm{RMM1}^2+\mathrm{RMM2}^2}<1$. Therefore, in the 2D phase space diagram, strong MJO events appear as large anti-clockwise excursions about the origin, and weak MJO episodes usually appear as somewhat random movement near the origin. These phases make up a full MJO cycle originating from the western Indian Ocean and decaying over the central Pacific. For instance, phases 1 and 2 mark the time when the MJO convective envelopes center near the western Indian Ocean and phases 7 and 8 mark the time when it is near the dateline in the Pacific. The MJO index data used here is from 1 January 1975 to 30 November 2009.

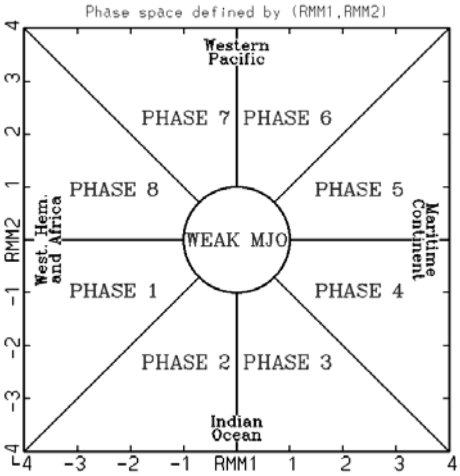


Figure 1. Phase space represented by the 2-component MJO index (RMM1, RMM2)[30].

2.1.2 RAINFALL AND CIRCULATION DATA

Monthly rainfall and temperature of November 2009 are from 160 stations and daily rainfall data used are from 545 stations in China covering the period of 1975–2006, collected and compiled by the National Meteorological Information Center of the China Meteorological Administration (CMA). In addition, the daily outgoing longwave radiation (OLR) dataset is from the National Oceanic and Atmospheric Administration (of USA) Advanced Very High Resolution Radiometer[32]. National Centers for Environmental Prediction / National Center for Atmospheric Research (of USA) daily reanalysis data[33] covering the period of 1 January 1975 to 31 December 2006 was also used.

2.2 *Methods*

2.2.1 COMPOSITE OF DAILY RAINFALL, TEMPERATURE AND CIRCULATION ANOMALIES

Using the MJO index, MJO can be categorized into eight phases. Jia et al.[27] indicated that the rainfall probability is significantly enhanced when the MJO is in phases 2 and 3 (with the MJO convective center located over the Indian Ocean). The MJO was very active in phase 3 during the period of severe rain-snow disasters in November 2009 in eastern China. Therefore, composites of mean daily anomalies of precipitation and temperature for 545 stations and large-scale circulation were calculated for phase 3 according to the RMM index in November during the period of 1975 to 2006. The detailed processing procedure is as follows:

First, daily anomalies of rainfall and other variables were calculated by subtracting their climatological means of 30 years (1971 to 2000) from the original data. Then, the total number of days for November are calculated when a strong MJO $(\sqrt{\mathrm{RMM1}^2+\mathrm{RMM2}^2}\geq 1)$ is in phase 3 from 1 January 1975 to 31 December 2006. Finally, the composite results for the anomalies of daily rainfall, temperature and circulation variables were determined for phase 3.

2.2.2 RAINY PROBABILITY TREND

Rain probability during MJO phase 3 at each of the stations is calculated and divided by the climatological probability of rain. The value represents the enhanced or reduced trend of rain probability. The detailed processing procedure for individual stations is as follows:

First of all, a rain day is defined when daily rainfall of at least 0.1 mm occurs at a station. Then, the climatological probability of rain for November at each of the stations is defined as the ratio of total rain day numbers to total number of days. Following this, the total rain days with phase 3 of MJO is calculated. Next, the rain probability with phase 3 is calculated: rain days are divided by total number of days when MJO is in phase 3. Finally, the trend of rain probability is defined as the ratio of climatological probability of rain to the rain probability when MJO is in phase 3.

3 CHARACTERISTICS OF RAINFALL, TEMPERATURE AND CIRCULATION ANOMALIES DURING NOVEMBER 2009

Figure 2 displays the departure percentage of rainfall and temperature anomalies in November 2009. It can be seen that rainfall is above normal in most part of China. Especially, it exceeds the climatological mean by 50% to 200% in most part of Northwest China. North China, region of Yellow River and Huaihe River, region of Yangtze River and Huaihe River, middle- and eastern-part of middle and lower reaches of Yangtze River and middle- and eastern-part of South China. Rainfall is below normal by 50% to 80% in the southeast part of Southwestern China and parts of South China. Temperatures in most of China are below normal, with some regions witnessing 2 to 3°C even 4°C lower than normal.

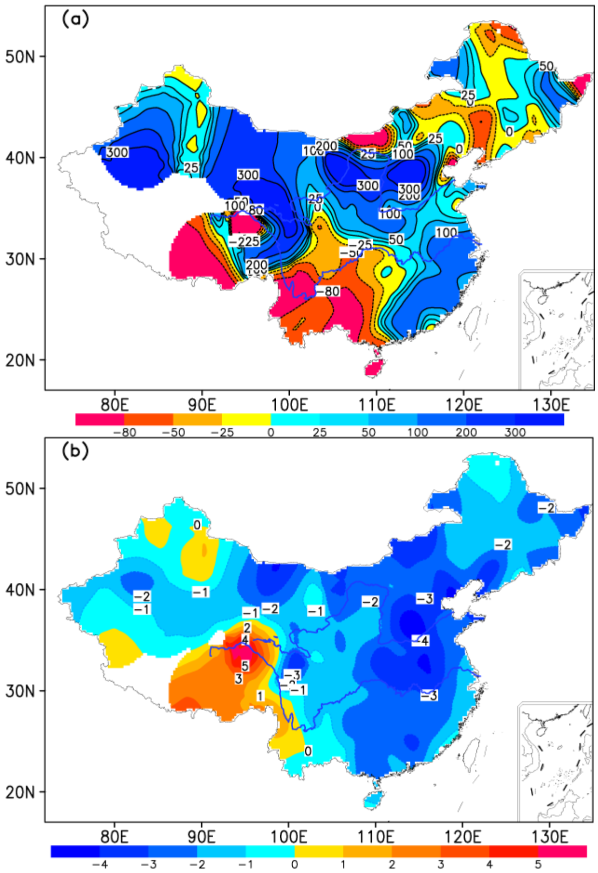


Figure 2. Rainfall departure percentages (a) and temperature anomalies (b, °C) in November 2009.

Figure 3 shows mean 500 hPa geopotential height anomalies during the period of 1 to 16 November 2009 when the severe rain and snow weather happens. It is noticeable that the mid- and higher-latitude circulation is characteristic of a zonal wave-number 3 structure. A ridge over the Ural Mountains area develops and extends northward into the polar region, and together with the ridge over the Okhotsk Sea, it leads to a “two ridges versus one trough” pattern over the Eurasian continent. Meanwhile, negative height anomalies dominate the wide region from West Asia to East Asia. This kind of anomalous circulation pattern is in favor of the invasion of cold air from the high latitudes into mainland China from the west and north. Seen from the low-level moisture transport during the period of 1 to 16 November (Figure 4), three moisture transportation channels contribute to the moisture supply over East China: the first one originates from the northern Bay of Bengal, passes Indochina Peninsula, and goes into the mainland of China; the second is from the South China Sea; the third one comes from the sea east of the Chinese mainland. These three branches of moisture converge over the eastern China, resulting in sufficient moisture supply.

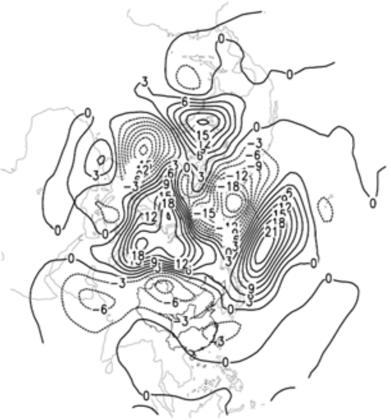


Figure 3. 500 hPa geopotential height anomalies for 1 to 16 November 2009 (geopotential meters, gpm hereafter).

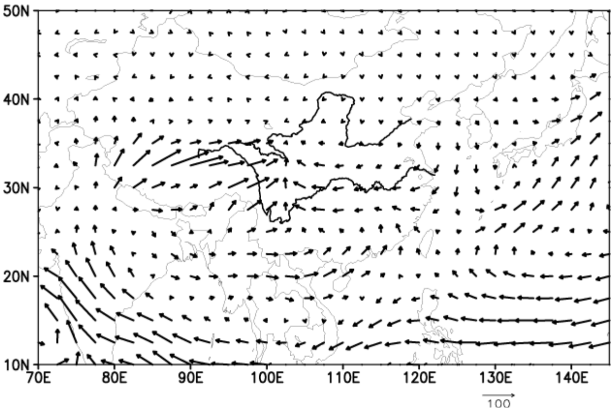


Figure 4. Moisture flux anomalies for 1 to 16 November 2009 (g kg^{-1} s).

Therefore, the analyses above indicate that the anomalies of large circulation over the Eurasia are the main contributors to the severe rain-snow weather in November 2009. The aim of this work is not to analyze how these circulation anomalies lead to the anomalous weather in November 2009, but to determine how these circulation anomalies can be so stable and strong and what may be the main contributors to these anomalies?

4 POSSIBLE RELATIONSHIP BETWEEN MJO AND RAIN-SNOW WEATHER IN NOVEMBER

A strong and coherent MJO event occurred in the tropics during November 2009, which can be identified from the longitude-time diagrams of the OLR anomalies as shown in Figure 5. This MJO event originated from the Indian Ocean in October and then propagated eastward with amplified amplitudes. During the early half of November, enhanced MJO convection was mainly situated over the Indian Ocean with the maximum negative anomalies exceeding −40 W s^{-1}. Meanwhile, suppressed MJO convection dominated the tropical western Pacific. Accompanying the eastward propagation of MJO, convections also rapidly developed over the western Pacific during the latter half of November and reduced over the Indian Ocean. Figure 6 displays the evolution of this MJO event described by the RMM index. It can be seen that this MJO event began propagating eastward from phase 1 in late October, and during the propagating process it maintains strong amplitude. Most noteworthy of all is that MJO convection is in phase 3 during the period of 7 to 16 November, which is just corresponding to the period of the severe rain-snow weather. A recent study indicates that rainfall probability is significantly enhanced in East China when the MJO convective center is located over the Indian Ocean[27]. Then, is the MJO event one of strong impact factors for the severe rain-snow weather in November 2009? Figure 7 shows composites of daily rainfall anomalies and rainfall probability for MJO phase 3 at that time. One can see when MJO is in phase 3, precipitation is above normal in most of East China with large positive values over the eastern part of the middle and lower reaches of Yangtze River and below normal in Yunnan province. This pattern of rainfall anomalies is much similar to that in November 2009. Owing to the fact that winter rainfall amounts are much less in North China than that in South China, Figure 7 mainly reflects differences in rainfall amount anomalies, but it cannot well depict rainfall anomalies in North China. So, a "rainy day" probability will be a better way to avoid this problem. Figure 7b shows the ratio of climatological rain probability to the rain probability when MJO is in phase 3. When the value is greater than one, it represents the rainfall probability exceeding the climatology, and the greater the value, the greater the rainfall probability. It can be seen that Figure 7b is much similar to Figure 2a and the correlation between this two fields is 0.58, which significantly exceeds the 99% confidence level. Composites of temperature anomalies for November when MJO is in phase 3, as shown in Figure 8, are also quite similar to the observation of November 2009, and the correlation between the composite and observation is 0.52, significantly exceeding the 99% confidence level.

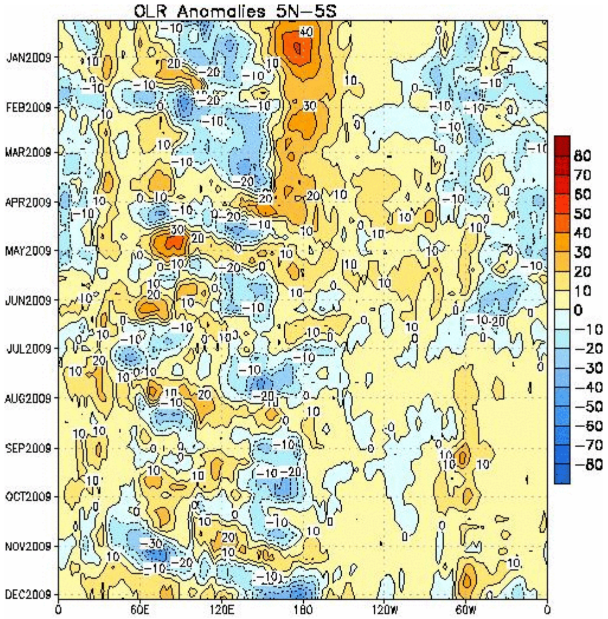


Figure 5. Time-longitude section for (5°S to 5°N) averaged OLR anomalies (W m^{-2})[35].

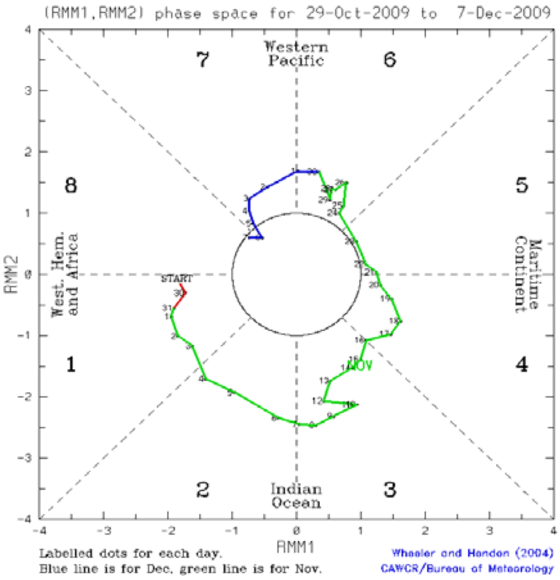
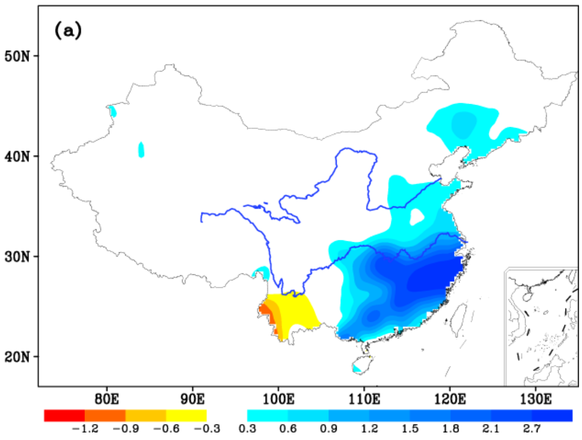


Figure 6. MJO monitoring represented by the 2-component MJO index (RMM1, RMM2) from 29 October to 7 December 2009 (Green line represents November 2009)[36].



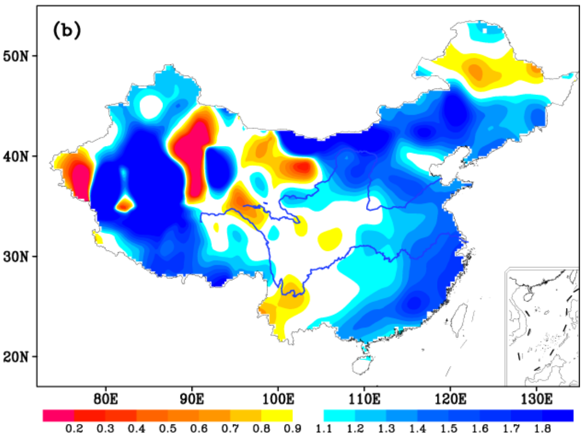


Figure 7. Composite daily rainfall anomalies (a, mm/day) and ratio of "rain day" probability (b) for MJO phase 3 during November.

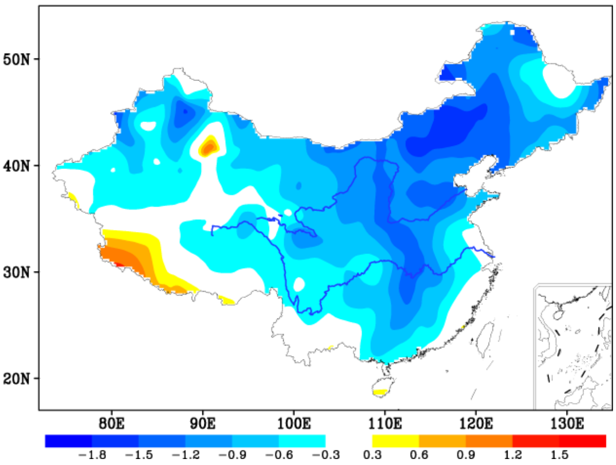


Figure 8. Composite daily temperature anomalies for MJO phase 3 during November (°C).

5 CIRCULATION ANOMALIES ASSOCIATED WITH MJO

The analysis above suggests that when MJO is in phase 3 (MJO convection is over the Indian Ocean), the composite distribution of rainfall and temperature anomalies quite resemble the observation of November 2009. Strong MJO events that occurred in November 2009 are likely a significant impact factor for the severe rain-snow weather in this year, because mid- and higher-latitude circulation anomalies can be modulated by MJO convection forcing, which can be realized by teleconnection. Figure 9 displays the composite anomalies of 500 hPa geopotential height for phase 3 of MJO in November for the period of 1975 to 2006. It can be seen that mid- and higher-latitude circulations show significant variations when the MJO convection is over the Indian Ocean. A high-pressure ridge develops over the Ural Mountains and the Sea of Okhotsk and extensive negative anomalies are located over the region stretching from the south of Lake Baikal to western Asia. In addition, the western Pacific subtropical high is also more westward and stronger. All these characteristics are much similar to the observations and the spatial correlation coefficient between the composite 500 hPa geopotential heights and the observation is 0.36, exceeding the 99% confidence level. Seen from the composites of OLR anomalies, convection is enhanced over the Indian Ocean and suppressed over the western Pacific when MJO is over the Indian Ocean (Figure 10a), which reflects the dipole pattern of MJO. Meanwhile, a negative anomalous west-east oriented OLR band appears along East Asia stretching from eastern China to Korea Peninsula and Japan. These characteristics also occurred in the observation of November 2009 (Figure 10b). From the spatial distribution of extremely dryness and wetness in November of 2009 (shown in Figure 11), we also note that southern Korea Peninsula and southwestern Japan also have many stations with extreme rainfall besides eastern China, which indicates a large-scale impact of MJO. The strongest MJO convection, in general, occurs in the Indian Ocean and the western Pacific, showing a “dipole pattern” over these regions, that is, when enhanced MJO convection is over the Indian Ocean, western Pacific is usually dominated by suppressed MJO convection, vice versa[30]. As shown in Figure 5, the MJO event that occurred in November 2009 is a typical one with large amplitude and coherent eastward propagation. Enhanced MJO convection over the Indian Ocean is accompanied by suppressed convection over the South China Sea and the western Pacific. Meanwhile, large-scale circulations with the structure of zonal wavenumber one response to MJO convection anomalies, which indicates that MJO is a convectively coupled mode, especially over the Indian Ocean and the western Pacific. On the other hand, besides the zonal circulation anomalies, MJO convective heating can also induce meridional circulation anomaly. Consequently, it can influence the weather and climate of extratropics. When MJO convection is situated over the Indian Ocean, western Pacific is dominated by anomalous descending motion and then low-level southerly anomalies control the coast of subtropical East Asia, which converge with cold air from mid- and higher-latitude and lead to anomalous ascending motion. And then, an anomalous meridional vertical circulation circle is formed between the tropics and the subtropics, which further enhances the northward transport of moisture from low latitudes. Figure 12 displays composite meridional vertical circulation anomalies along 115 to 125°E when MJO is over the Indian Ocean. It is obvious that an ascending branch near 30°N and a descending branch near 10°N compose an anomalous meridional vertical circulation circle. To the north and south of 30°N are the northerly and southerly anomalies, respectively. Therefore, anomalous ascending motions dominate the eastern mainland of China, which is favorable for more rainfall in this region.

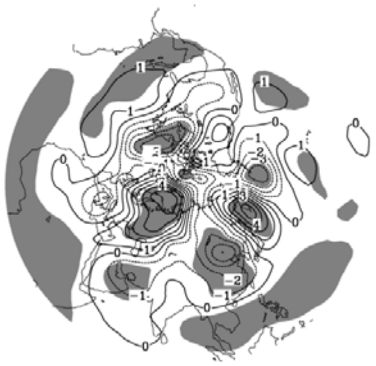


Figure 9. Composite 500 hPa geopotential height anomalies for MJO phase 3 during November (gpm, shading indicates the areas exceeding the 95% confidence test).

At present, useful predictive skills for empirical and dynamical models of MJO have lead time of about 15 to 20 days, which is very useful for extended-range forecast beyond 10 days and even the monthly climate prediction, such as the severe rain-snow weather in November 2009. Figure 13 shows the correlation between the mean MJO amplitude with strong MJO in November and the total rainfall of November. It can be seen that the MJO strength is significantly and positively correlated with the rainfall of East China in November. Obviously, good forecast of MJO is helpful for the improvement of monthly climate prediction skill.

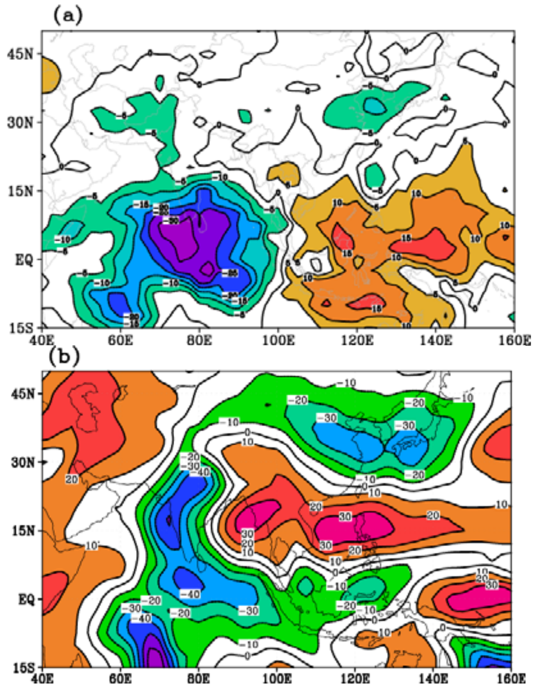


Figure 10. Composite OLR anomalies for MJO phase 3 during November (a, W m^{-2}) and OLR anomalies for 7 to 16 November 2009 (b, W m^{-2}).

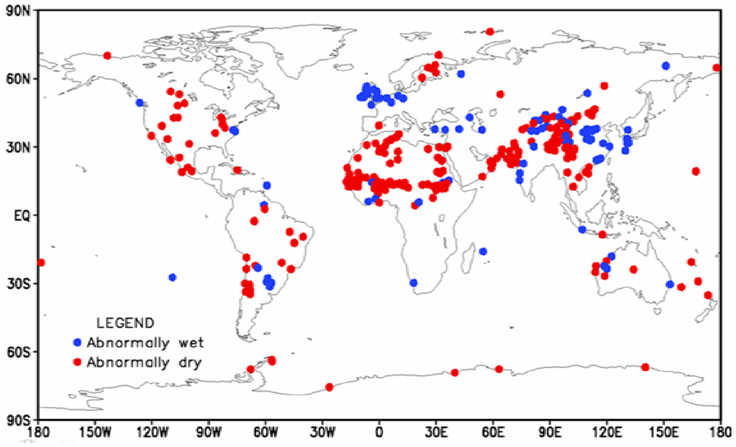


Figure 11. Distribution of meteorological stations where rainfall anomalies are more than one standard deviation (blue dots) and less than one standard deviation (red dots).

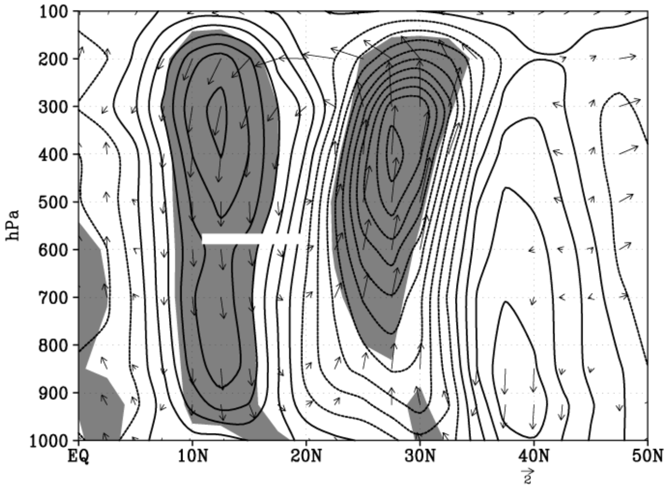


Figure 12. Meridional-vertical wind vectors (plotted only where they pass the 95% confidence level) and vertical velocity anomalies (hPa s^{-1}, shading indicates the areas exceeding the 95% confidence test) averaged between 110°E and 120°E for MJO phase 3 in November. 9

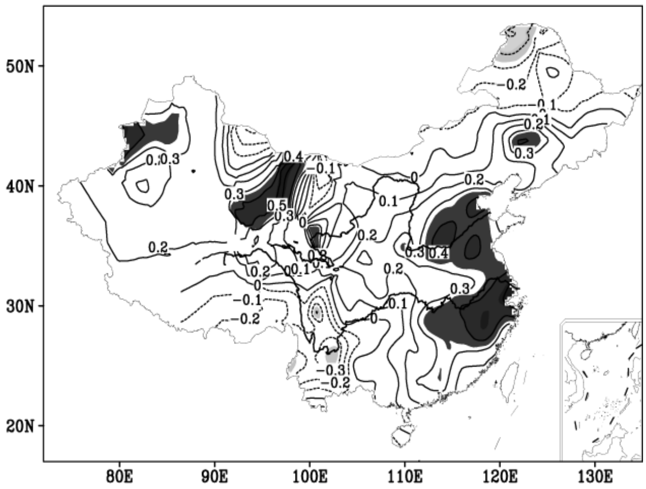


Figure 13. Correlation coefficient between the amplitude of MJO in phase 3 and rainfall in November (Shading indicates where the significant test exceeds 95% confidence level).

6 CONCLUSIONS AND DISCUSSION

This study investigates the possible impact of MJO on the severe rain-snow weather in November 2009. Main conclusions are as follows.

(1) The severe rain-snow weather in November 2009 is closely related to a stable pattern of “two ridge-one trough” circulation over the mid- and

higher-latitude Eurasia (with a strengthening ridge over the Ural Mountains and the Sea of Okhotsk and an anomalous low trough south of Lake Baikal) and strong moisture transport from the tropics to the subtropics. During the period from late October to November, a strong MJO event occurs in the tropics and enhanced MJO convection is quite active over the Indian Ocean during the first half of November. In particular, it maintains 9 days from 7 to 16 November in phase 3 (in eastern Indian Ocean), just corresponding to two strong rainfall processes.

(2) Composite analysis using long-term data shows that when MJO is in phase 3 (with the MJO convective center over the mid- and eastern-Indian Ocean), rainfall probability is significantly enhanced and temperature is significantly dropped in most parts of East China, which is much similar to the situation in November 2009. Further analysis on the atmosphere circulation indicates that the mid- and higher-latitude circulation can be significantly modulated by MJO convection forcing through teleconnection. When MJO convection is over the Indian Ocean, it is favorable for the maintenance of a pattern of “two ridges and one trough” circulation pattern at mid- and higher-latitudes. Meanwhile, the western Pacific subtropical high is stronger and more westward than normal, and a well-defined convective belt appears over eastern East Asia. All these circulation anomalies shown in composite results also appeared in November 2009, which indicates the general features of relationships between the MJO and the circulation anomalies over the extra tropics. MJO is one of the important impact factors of the severe rain-snow weather in eastern China in November 2009.

(3) In addition, MJO can also modulate meridional circulation anomalies through anomalous convective heating forcing in the tropics. When MJO convection is located over the Indian Ocean, the western Pacific is controlled by anomalous descending motions. Meanwhile, anomalous southerlies dominate the coast of East Asia and converge with cold air from the mid- and higher-latitude, forming an anomalous meridional circulation between the tropics and midlatitudes, which further enhances the northward transportation of low-level moisture.

(4) At present, although useful MJO prediction skill can have about 15 to 20 days of lead time, it is much shorter than its period (30 to 60 days). Therefore, it is possible to further improve the MJO prediction skill. MJO is one of the important sources of predictability for 10-to-30-day extended range forecast. Accordingly, if MJO could be predicted more accurately, it is possible to well predict severe rain-snow disasters such as that that occurred in November 2009.

This study just analyzed the possible influences of MJO on the severe rain-snow weather in November 2009, but why MJO can persist for such a long time in phase 3 needs to be further studied. One point of view is that MJO can be influenced by ENSO. For instance, Chi et al.[37] analyzed the impact of the tropical intra-seasonal oscillation and ENSO on the extremely cold events in East Asia in February 2008, and suggested that westward extension of cold sea water associated with a La Niña episode prevent the eastward propagation of MJO, which contributes to the MJO-associated convection maintaining over the maritime continent for a long time. It is noteworthy that the mid- and eastern-Pacific is in an El Niño state in November 2009. Therefore, impacts of tropical SST on the intra-seasonal oscillation need more analysis.

REFERENCES:

[1] NATIONAL CLIMATE CENTER. China Climate Impacts and Assessment Briefing, November, 2009. [EB/OL]. [2011-10-25]http://ncc.cma.gov.cn/influ/moni_china.php?product=moni_assessment.

[2] TING M, SARDESHMUKH P D. Factors determining the extra-tropical response to equatorial diabatic heating anomalies [J]. J. Atmos. Sci., 1993, 50(6): 907-918.

[3] JIN F, HOSKINS B J. The direct response to tropical heating in a baroclinic atmosphere [J]. J. Atmos. Sci., 1995, 52(3): 307-319.

[4] BLADE I, HARTMANN D L. The linear and nonlinear extra-tropical response of the atmosphere to tropical intraseasonal heating [J]. J. Atmos. Sci., 1995, 52(4): 4448-4471.

[5] MADDEN R A, JULIAN P R. Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific [J]. J. Atmos. Sci., 1971, 28(5): 702-708.

[6] MADDEN R A, JULIAN P R. Description of global scale circulation cells in the tropics with 40-50 day period [J]. J. Atmos. Sci., 1972, 29(6): 1109-1123.

[7] LI Chong-yin. Atmospheric low frequency oscillation [M]. Beijing: China Meteorological Press, 1991: 14-19 (in Chinese).

[8] JIA Xiao-long, Li Chong-yin. Tropical atmospheric intra-seasonal oscillation and numerical simulation. [M]. Beijing: China Meteorological Press, 2009: 25-60 (in Chinese).

[9] JONES C. Occurrence of extreme precipitation events in California and relationships with the Madden-Julian oscillation [J]. J. Climate, 2000, 13(20): 3576-3587.

[10] BOND N A, VECCHI G A. The influence of the Madden–Julian oscillation on precipitation in Oregon and Washington [J]. Wea. Forecast., 2003, 18(4): 600-613.

[11] CARVALHO L M, JONES C, LIEBMANN B. The South Atlantic convergence zone: Intensity, form, persistence, and relationships with intraseasonal to interannual activity and extreme rainfall [J]. J. Climate, 2004, 17(1): 88-108.

[12] BARLOW M, WHELLER M, LYON B, et al. Modulation of daily precipitation over southwest Asia by the Madden-Julian oscillation [J]. Mon. Wea. Rev., 2005, 133(12): 3579-3594.

[13] DONALD A, MEINKE H, POWER B, et al. Near-global impact of the Madden-Julian oscillation on rainfall [J]. Geophy. Res. Lett., 2006, 33, L09704, doi: 10.1029/2005 GL0 25155.

[14] JEONG J H. BEAKMK M K, CHANG H H, et al. Systematic variation in wintertime precipitation in East Asia by

MJO-induced extratropical vertical motion [J]. J. Climate, 2008, 21(4): 788-801.

[15] WHEELER M C, HENDON H H, SAM C, et al. Impacts of the Madden-Julian Oscillation on Australian Rainfall and circulation [J]. J. Climate, 2009, 22 (6): 1482-1498.

[16] ZHANG L N, WANG B Z, ZENG Q C. Impacts of the Madden-Julian Oscillation on summer rainfall in Southeast China [J]. J. Climate, 2009, 22(2): 201-216.

[17] SHI Xue-li, DING Yi-hui. A study on Extensive Heavy Rain Processes in South China and the Summer Monsoon Activity in 1994. [J]. Acta Meteor. Sinica, 2000, 58(6): 666-678 (in Chinese).

[18] HE Jin-hai, ZHI Xie-fei, NAKAZAWA T. Seasonal Interlock of the Intraseasonal variations of Rainfall in East China [J]. J. Trop. Meteor., 1995, 11(4): 370-374 (in Chinese).

[19] LI C Y, LONG Z X, ZHANG Q Y. Strong/weak summer monsoon activity over the South China Sea and atmospheric intraseasonal oscillation [J]. Adv. Atmos. Sci., 2001, 18(6): 1146-1160.

[20] ZHANG Xiu-li, GUO Pin-wen, HE Jin-hai. Characteristics of low frequency oscillation of precipitation and wind field in the middle and low reaches of the Yangtze River in summer 1991 [J]. J. Nanjing Inst. Meteor., 2002, 25(3): 388-394 (in Chinese).

[21] XIA Yun, GUAN Zhao-yong, WANG Li-juan. Association of 30-70d oscillations with the heavy rainfall over Changjiang-Huaihe River valley in summer 2003 [J]. J. Nanjing Inst. Meteor., 2008, 31(1): 33-41 (in Chinese).

[22] ZHANG Qing-yun, TAO Shi-yan, ZHANG Shun-li. The Persistent heavy rainfall over the Yangtze River valley and its associations with the circulations over East Asian during summer [J]. Chin. J. Atmos. Sci., 2003, 27 (6): 1018-1030 (in Chinese).

[23] YANG H, LI C Y. The relation between atmospheric intraseasonal oscillation and summer severe flood and drought in the Changjiang-Huahe basin [J]. Adv. Atmos. Sci., 2003, 20(4): 540-553.

[24] JU Jian-hua, ZHAO Er-xu. Impacts of the low frequency oscillation in East Asian summer monsoon on the drought and flooding in the middle and lower valley of the Yangtze River [J]. J. Trop. Meteor., 2005, 21(2): 163-171 (in Chinese).

[25] LIN Ai-lan, LIANG Jian-yin, GU De-jun. Review of impacts of tropical atmospheric intraseasonal oscillation on East Asia monsoon and multiple time scales variation of tropical atmospheric intra-seasonal oscillation [J]. J. Trop. Meteor., 2008, 24(1): 11-19 (in Chinese).

[26] WU Jun-jie, YUAN Zhu-jian, QIAN Yu-kun, et al. The Role of Intraseasonal oscillation in the Southern China Snowstorms during January 2008 [J]. J. Trop. Meteor., 2009, 25 (suppl.), 102-112 (in Chinese).

[27] JIA X L, CHEN L J, REN F M. et al. Impacts of the MJO on winter rainfall and circulation in China [J]. Adv. Atmos. Sci., 2011, 28(3): 521-533.

[28] WALISER D E, LAU K M, STERN W, et al. Potential predictability of the Madden-Julian Oscillation [J]. Bull. Amer. Meteor. Soc., 2003, 84, (1): 33-50.

[29] WALISER D, KLAUS W, RANDALL D, et al. The Experimental MJO Prediction Project [J]. Bull. Amer. Meteor. Soc., 2006, 87(4): 425-431.

[30] WHEELER M C, HENDON H H. An all-season real-time multivariate MJO Index: Development of an index for monitoring and prediction [J]. Mon. Wea. Rev., 2004, 132(8): 1917-1932.

[31] Australian Meteorological Bureau. An All-season Real-time Multivariate MJO Index [EB/OL]. [2012-04-12] (http://cawcr.gov.au/staff/mwheeler/maproom/RMM/).

[32] LIBERMANN B, SMITH C A. Description of a complete (interpolated) outgoing longwave radiation dataset [J]. Bull. Amer. Meteor. Soc., 1996, 77(7): 1275-1277.

[33] KALNEY E, KANAMITSU M, KISTLER R, et al. The NCEP/NCAR 40-year reanalysis project [J]. Bull. Amer. Meteor. Soc., 1996, 77(3): 437-471.

[34] ZHANG C D, GOTTSCHALCK J. SST Anomalies of ENSO and the Madden–Julian Oscillation in the equatorial Pacific [J]. J. Climate, 2002, 15(9): 2429-2445.

[35] NATIONAL WEATHER SERVICE (US). Monitoring & Data [EB/OL]. [2012-04-12] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/

[36] Australian Meteorological Bureau. An All-season Real-time Multivariate MJO Index [EB/OL]. [2012-04-12] http://cawcr.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/phase.Last90days.html.

[37] HONG C C, TIM L. The extreme cold anomaly over Southeast Asia in February 2008: Roles of ISO and ENSO [J]. J. Climate, 2008, 22(15): 3786-3801.

Citation: JIA Xiao-long and LIANG Xiao-yun. Possible impacts of Madden–Julian Oscillation on the severe rain-snow weather in China during November 2009. *J. Trop. Meteor.*, 2013, 19(3): 233-241.