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FACTORS CONTRIBUTING TO THE ONSET OF THE AUSTRALIAN SUMMER MONSOON

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1. Introduction

The land-sea thermal contrast is believed to be the primary factor for the evolution of monsoons. The Australian summer monsoon is thought to be ideal for examining this concept, because flat land surface of Australia has no complexity of topography. The Australian summer monsoon usually begins in December and ends in March. Its mature stage is characterized by heavy precipitation and low-level westerly wind in northern Australia. In addition to the thermal contrast, Hendon and Liebmann (1990, hereafter HL90) suggested that the Madden-Julian oscillation (MJO) acts as a trigger for the monsoon onset. On the other hand, an earlier study by Davidson et al.(1983) suggested that the tropical-midlatitude interaction plays a role. In this study, these major factors are re-examined using a 15-year dataset.

2. Data

The primary data used in this study is the 15-year (1979-93) European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA). The daily outgoing longwave radiation (OLR) measurements and monthly Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP)(Xie and Arkin, 1997) for the same period are also used. Using the ERA data, daily 3-dimensional Q_1 (apparent heat source) and Q_2 (apparent moisture sink) are calculated for the further analysis.

3. Definition of Australian summer monsoon onset

Traditionally, the onset of the Australian summer monsoon has been defined by records at Darwin (12°S, 130°E) or stations in the vicinity of it (Troup 1961 ; HL90). However, in the present study, to capture the large-scale circulation changes before and after the onset, strong low-level (850 hPa) westerly wind and convective activity (OLR, precipitation) over a region in the northern Australia (2-15°S, 115-150°E; hereafter NAU) are used to determine the onset dates (Fig. 1).

The first day with the average 850 hPa zonal wind exceeding 2 m s^{-1} in NAU is chosen as the onset day when the westerly wind lasts longer than 10 days and the OLR is lower than 210 W m^{-2} for a few days during the 10-day period. The onset dates selected by the present study are close to the previous results by HL90. The 15-year mean onset date is December 25th which is the same as the result by HL90 for the 30 years (1957-87).

4. Composite features of the onset

On the monthly time scale, significant heating in a layer below 700 hPa over the Australian continent starts in September prior to the monsoon onset. The heating is mainly caused by sensible heat flux from the land surface. A typical mean vertical profile of Q_1 in November is shown in Fig. 2. A reversal of meridional temperature gradient between the Australian continent and the Arafura sea in this layer occurs from September to March. The warming over the continent dominates the meridional temperature gradient, because the temperature over the Arafura sea has very small change. On the daily time scale, the composite average Q_1 over Australian continent based on the onset dates in 1979-93 reaches a maximum value 20 days prior to the onset in a layer below 850 hPa. In this layer the composite temperature over the same region becomes warmer than that in NAU about 7 days before the onset. This shows that the condition of lower troposphere is ready for onset.

The composite westerly wind from surface to 500 hPa in NAU abruptly increases after the onset. The so-called monsoon westerlies appear with strong upper level easterlies. With additional information from OLR, this is identified as the arrival of MJO in NAU. The composite 850 hPa streamlines and temperature show another interesting feature. Starting from about one week before the onset, temperature over Australia increases significantly, while a trough in the midlatitude westerlies extends to the western coast of Australia (Fig 3a). This trough gradually moves into the continent, and a cyclone is generated in the western part of Australia. When the trough moves further to the central Australia, the cyclone merges with the MJO system in NAU. A commonly observed horizontal structure of Australian summer monsoon then establishes: one monsoon low stands in NAU, while anticyclones occupy the west-

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ern and eastern sides of Australia (Fig. 3b). At this stage, the monsoon onset occurs. We confirmed these synoptic sequences for 14 monsoon cases, and found that only one case (1992-93) has no midlatitude trough involved in the onset.

5. Discussion and conclusion

Prior to the onset of Australian summer monsoon, sensible heating from land surface sets up a thermally-induced meridional-vertical circulation, as seen from the outflow between 800 hPa and 400 hPa and low-level inflow below 800 hPa over the continent. This circulation is originally a separated system from the upward branch of Hadley circulation near the equator. However, these two systems merge together after the season proceeded and become the monsoon system in NAU. The composite low-level temperature shows that the meridional temperature reversal occurs prior to the onset. This supports the traditional view that the thermal condition of the lower troposphere has to be ready before the onset.

The average onset date of Australian summer monsoon in the present study is December 25th which is a few days after the summer solstice. The composite results show that, for most cases, the tropical MJO and midlatitude systems are the major factors that trigger the onset of the Australian summer monsoon. When an MJO system approches NAU prior to the onset, the midlatitude trough moves from the western to central Australia and a cyclone is generated. Once the lower level tropical MJO system and the cyclone merge together and couple with the upper level outflow accompanied with MJO, the monsoon onset occurs.

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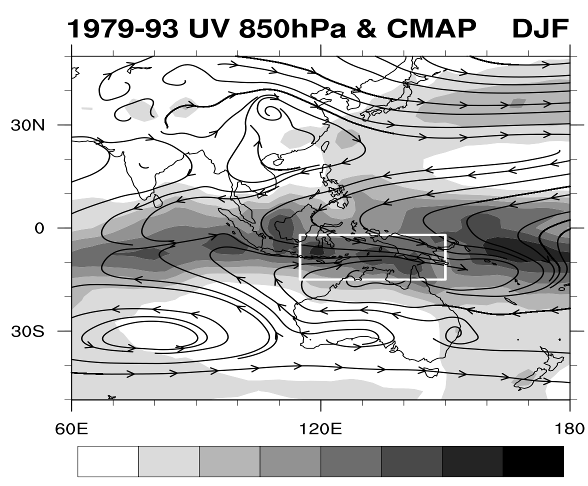

Fig. 1. The 1979-93 average 850 hPa streamlines and precipitation rate (mm d^{-1}) for December-February. A rectangular box shows the NAU region.

6. References

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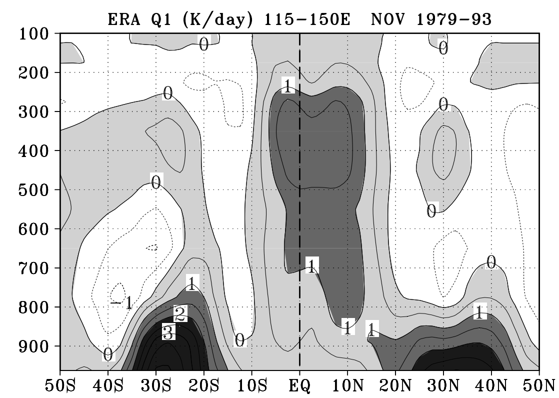

Fig. 2. Latitude-height section for the mean November Q_1 averaged between 115-150°E.

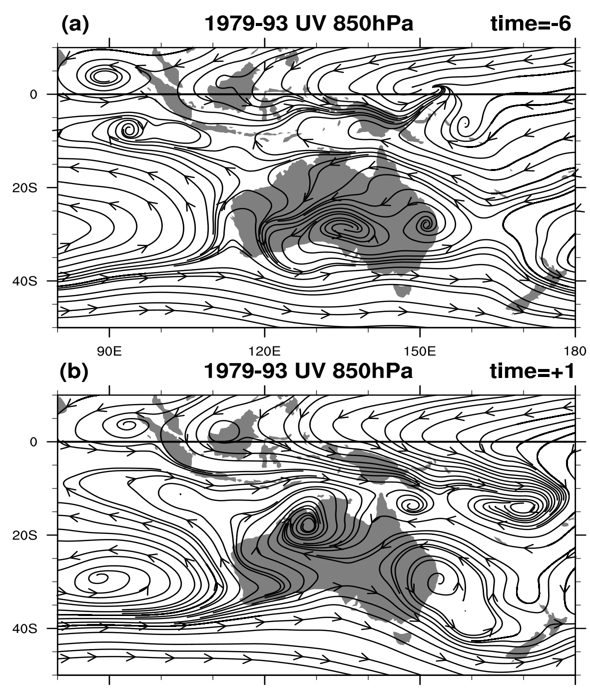

Fig 3. The composite 850 hPa streamlines for 14 monsoon cases. (a) 6 days before the onset. (b) 1 day after the onset.