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South American monsoon indices

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Abstract

Four monsoon indices (the meridional wind shear index (MWSI), the zonal wind shear index (ZWSI), the 850-hPa zonal wind index (850ZWI) and the 850-hPa zonal and meridional wind index (UVI)) based on the characteristics of the wind circulation are used to identify the onset and the demise dates and the intraseasonal variability of the rainy season over the west central Brazil (WCB) region. All the four-index time series have a high correlation with the precipitation series over WCB. The UVI, MWSI and the 850ZWI represent very well the intraseasonal variability (break and active periods) of the precipitation over WCB and the 850ZWI is also useful for identifying the onset dates. Copyright © 2006 Royal Meteorological Society

Keywords: **South American monsoon; wind; index; precipitation**

1. Introduction

South America is not usually considered to exhibit a monsoon regime (Ramage, 1971). However, availability of good quality data, such as National Centers for Environment Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data, revealed that a large part of subtropical South America experiences typical monsoonal circulation (Zhou and Lau, 1998; Gan *et al*., 2004). In this region, the rainfall season is the austral summer (December–January–February) (Rao and Hada, 1990), similar to the Asian summer monsoon season (June–July–August). Recent studies of Gan *et al*. (2004) and Zhou and Lau (1998) described many similarities between the Asian and South American monsoon regimes. The South American monsoon system is characterized by an upper level anticyclonic circulation (called Bolivian high), a low-level cyclone (called Chaco low) and a temperature maximum just before the onset of the rainy season. However, the wind reversal in low levels does not occur as in the Asian monsoon. But the upper and low-level zonal wind over west central Brazil (WCB) changes its direction (Gan *et al*., 2004). Zhou and Lau (1998) note that even the wind reversal at low levels can be seen if the annual cycle is removed.

Several studies have been made to define the onset and demise dates of monsoon systems, e.g. Fasullo and Webster (2003) for the Indian monsoon and Gan *et al*. (2004) and Wang and Fu (2002) for the South American monsoon. Kousky (1988), Liebmann and Marengo (2001) and Marengo *et al*. (2001) used either outgoing long wave radiation (OLR) or precipitation data to define the onset of rainy season over South America. In these studies, different criteria, mostly based on rainfall or OLR, were used to identify the monsoon onset and demise dates over different monsoon regions. However, monsoon indices based on wind changes are important because the skill of the climatic models to predict the wind components is better than to predict the precipitation. Further, a monsoon index based on wind changes is useful in identifying the onset and demise dates and interannual variability of the monsoon activity. Thus, the purpose of the present study is to evaluate the applicability of some monsoon indices based on the wind components to identify the onset and demise dates of the rainy season in the WCB (60–50 °W; 20–10 °S). We choose the WCB region because it includes a portion of the summertime rainfall maximum where the mean annual cycle of circulation is strongly related to the South American monsoon system (SAMS) as identified by Gan *et al*. (2004). Also, this region contains the headwaters of major rivers, such as Araguaia and Paraguay, which flow into the Amazon and La Plata basins, respectively. In some years the lack of rain in the headwaters leads to dramatic situations, such as the one that occurred during the summer of 2000/2001 when power rationing was introduced in the state of São Paulo (Rao *et al*., 2001). To our knowledge, this type of analysis defining indices for the South American monsoon has not been done earlier.

2. Data and methodology

The data used in this study are pentad (five day averages) gridded precipitation values for Brazil (for more information see Gan *et al*., 2004) obtained from the Climate Prediction Center and pentads of the daily averaged fields of wind from the NCEP/NCAR reanalysis (Kalnay *et al*., 1996). The period used is July 1979 through June 1997. The precipitation time series are the pentad mean values averaged over WCB (10–20 °S, 60–50 °W).

Since the onset of monsoon is associated with changes in the circulation features in lower and upper troposphere, we propose some indices associated with the basic dynamical features of the atmosphere such as the Hadley cell, west–east circulation and the low-level jet which can be identified by the vertical wind shear and the wind in lower and upper levels. Here we propose to examine four indices in order to choose the index that describes best the SAMS.

The first index called meridional wind shear index (MWSI) is the difference of the meridional wind between 850- and 200-hPa levels averaged over 40 °W–30 °W and 10 °S–5 °S area (over northeast Brazil). A similar index was first proposed by Goswami *et al*. (1999) for the Indian subcontinent, northern Bay of Bengal and a portion of the south China, and it represents the influence of the ascendent branch of the regional Hadley circulation. Since the basic monsoon processes such as those discussed by Webster (1987) should be similar in South American and Asian monsoons, the indices used over India and China are also relevant over South America. The meridional wind is selected over northeast Brazil because it is positively correlated at 200-hPa and negatively correlated at 850-hPa with the precipitation over the WCB, as can be seen in the Figure 1(a) and (b). These figures show the correlation coefficients (CC) between the pentadal precipitation series of the whole year and the pentadal meridional wind series at 850-hPa and 200-hPa, respectively. As can be seen in these figures, the 850-hPa meridional wind over Amazon and northeast Brazil regions is negatively correlated (all the CC grater than 0.1 are significant at 99% confidence level by a two-sided students t-test) with the precipitation over WCB and the correlations are positive over Bolivia, Paraguay and the northern region of Argentina. The 200-hPa correlation coefficient chart (Figure 1(b)) shows the northwest–southeast-oriented positive centers over the South American tropical region.

The zonal wind shear index (ZWSI) is defined as the difference of the zonal wind between 850- and 200-hPa levels averaged over 60 °W–50 °W and 15 °S–10 °S area. This area is selected because the 850-hPa zonal wind is positively correlated and the 200-hPa zonal wind is negatively correlated with the precipitation over WCB as can be seen in Figures 1(c) and 1(d). This index is associated with the west–east circulation.

The 850-hPa zonal wind index (850ZWI) is defined because Gan *et al*. (2004) identified that the zonal wind is easterly during the dry season and westerly in the rainy season and this reversal occurs during

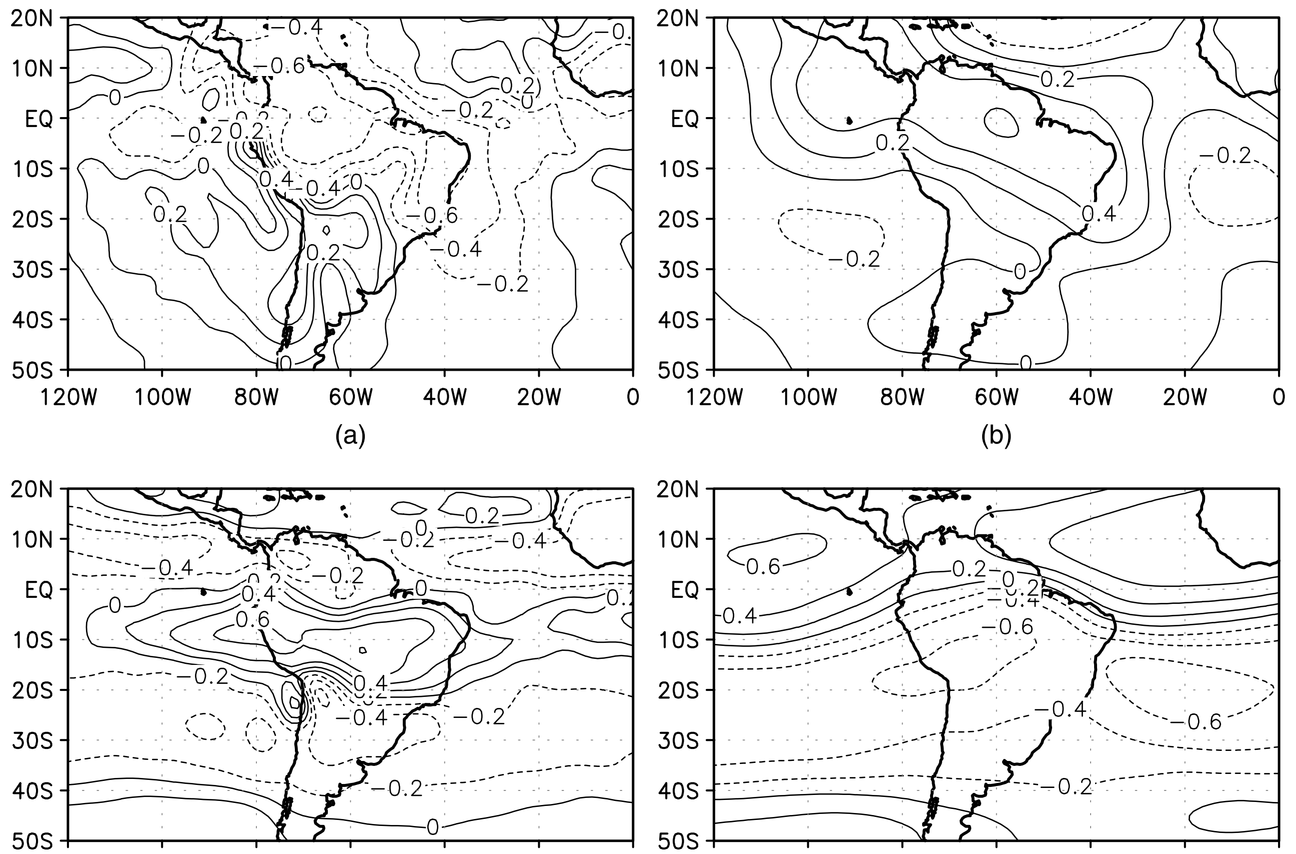

Figure 1. Correlation coefficient between the precipitation over WCB and the meridional wind at 850 hPa (a) and 200 hPa (b), and the zonal wind at 850 hPa (c) and 200 hPa (d)

the onset of monsoon. They associated this index with the beginning or the end of rainfall to identify the onset and demise dates. In their criterion, the onset (demise) of the rainy season was defined as the first occurrence of 850-hPa westerly (easterly) winds along 60 °W in the band 10 °S–20 °S together with rainfall rates reaching values greater (less) than 4 mm d^{-1} for at least 75% of the subsequent eight pentads.

To examine the influence of the moisture transport by the low-level jet found on the eastern side of the Andes over precipitation in the WCB, we define the 850-hPa zonal and meridional index (UVI) as the sum of the 850-hPa zonal wind averaged in the 60 °W–50 °W and 15 °S and 10 °S area and the 850-hPa meridional wind averaged in the 65 °W–60 °W and 25 °S–20 °S area. Ferreira *et al.* (2003) and Gan *et al.* (2004) noted that during the active (break) periods in the rainy season there is a cyclonic (anticyclonic) anomalous circulation. The UVI index is related to this change in circulation.

To evaluate which of these indices represent better the onset or demise dates, we identify these dates using an index based on the precipitation. This index is obtained using the WCB area mean precipitation for each pentad. The onset (demise) is defined when the precipitation is more (less) than 4 mm d^{-1} for at least six of the subsequent eight pentads.

3. Results

To verify how well these four indices are associated with the precipitation over the WCB, we calculated the correlation coefficient with lags varying from −10 to 10 pentads in the pentadal series. Figure 2 shows the

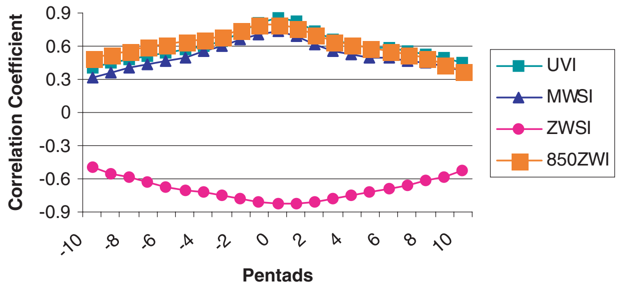

Figure 2. Correlation coefficient between the precipitation over WCB and the four monsoon indices

CC between the pentadal precipitation series and each pentadal wind index series of the whole year. All the CC are statistically significant at the 99% confidence level. In this figure we can see that the MWSI, the UVI and the 850ZWI are positively correlated with precipitation, but the ZWSI is negatively correlated. The maximum values of these CC are in the lag = 0. Also, it can be seen from Figure 2, that the CC between the wind index a few days (two pentads) earlier and precipitation on a later date are high. That is, the CC for lag −2 is high (more than 0.6). Thus, the wind indices have some predictability.

Since these index series have been well correlated with the precipitation series, we can use these indices to identify the onset and demise dates. The criterion to define onset and demise dates using the 850ZWI is the same as that used by Gan *et al.* (2004). We used the threshold of 8 m s^{-1} for the ZWSI and 12 m s^{-1} for the UVI to identify the onset and demise dates. For the MWSI, we used the reversal of the sign (positive to negative) as the criterion for the onset. Using these criteria, we identified the onset and demise dates for

Table I. Onset (left) and demise (right) dates of the rainy season determined with the four indices and the rainfall. Also given are the respective earliest and latest dates and the mean and the standard deviation. The dates correspond to the centered date of the pentad

	Precipitation		**850ZWI**		**ZWSI**		**UVI**		**MWSI**	
79/80	30 Oct	18 Apr	04 Nov	18 Apr	04 Nov	18 Apr	30 Oct	27 Feb	30 Oct	18 Apr
80/81	30 Oct	08 Apr	30 Oct	08 Apr	30 Oct	08 Apr	29 Nov	19 Mar	04 Nov	08 Apr
81/82	05 Oct	23 Apr	05 Oct	23 Apr	15 Sep	23 Apr	09 Nov	28 Apr	05 Oct	28 Apr
82/83	20 Sep	13 Apr	15 Sep	18 Apr	25 Sep	23 Apr	30 Sep	23 Apr	30 Sep	08 Apr
83/84	05 Oct	18 Apr	10 Oct	13 Apr	15 Oct	—	15 Oct	13 Apr	20 Oct	28 Apr
84/85	15 Oct	28 Apr	15 Oct	03 May	10 Oct	18 May	20 Oct	28 Apr	19 Nov	18 Apr
85/86	10 Oct	03 Apr	05 Oct	03 Apr	30 Oct	28 Apr	30 Oct	29 Mar	30 Oct	—
86/87	05 Oct	08 Apr	14 Nov	08 Apr	09 Nov	13 Apr	04 Dec	18 May	14 Dec	02 Jun
87/88	20 Oct	28 Apr	25 Oct	28 Apr	15 Oct	03 May	30 Oct	28 Apr	09 Nov	28 Apr
88/89	25 Oct	03 May	25 Oct	23 Apr	25 Oct	13 May	15 Oct	24 Mar	05 Oct	13 May
89/90	20 Oct	18 Apr	10 Oct	23 Apr	15 Oct	08 May	20 Oct	18 Apr	30 Oct	18 Apr
90/91	25 Sep	23 Apr	30 Sep	08 Apr	15 Oct	23 Apr	04 Dec	08 Apr	03 Jan	13 Apr
91/92	04 Nov	03 May	04 Nov	28 Apr	05 Oct	13 Apr	09 Nov	03 May	09 Nov	13 May
92/93	10 Sep	13 Apr	25 Sep	13 Apr	15 Oct	18 Apr	04 Nov	13 Apr	30 Sep	08 Apr
93/94	20 Oct	23 Apr	15 Oct	23 Apr	25 Sep	28 Apr	29 Nov	18 Apr	29 Nov	18 Apr
94/95	20 Oct	23 Apr	20 Oct	23 Apr	10 Oct	23 Apr	19 Nov	18 May	14 Nov	23 May
95/96	10 Oct	23 Apr	10 Oct	23 Apr	15 Oct	28 Apr	10 Oct	23 Apr	19 Nov	23 Apr
96/97	20 Oct	28 Apr	10 Oct	28 Apr	10 Oct	08 Apr	19 Nov	03 May	05 Oct	03 May
Early	10 Sep	03 Apr	15 Sep	03 Apr	15 Sep	08 Apr	30 Sep	27 Feb	30 Sep	08 Apr
Mean	15 Oct	18 Apr	15 Oct	18 Apr	15 Oct	23 Apr	04 Nov	18 Apr	04 Nov	28 Apr
Late	04 Nov	03 May	14 Nov	03 May	09 Nov	18 May	04 Dec	18 May	03 Jan	02 jun
Std dev	3	2	3	2	3	2	4	4	5	3

the four indices (Table I). An analysis of the onset dates shows that the UVI and MWSI have a tendency to indicate a slightly delayed onset (in the mean, it is in the pentad centered on 04 November) compared with the ZWSI and 850ZWI (in the mean, it is in the pentad centered on 15 October). These results suggest that when west–east circulation (ascending motion over the continent and descending motion over the ocean) starts earlier, the monsoon begins earlier and the regional Hadley cell is displaced to south. To initiate the rainy season, increase of the moisture flux into the WCB is necessary, and therefore the 850ZWI can represent the onset dates better. This result is confirmed when we compare the onset dates from 850ZWI with the precipitation index. We can see that in 7 years the dates are the same and in the other 7 years the dates differ just by one pentad. For the demise dates, the MWSI has the tendency to indicate a little delay (in the mean, the demise date is in the pentad centered on 28 April) in the withdrawal of the rainy season. The 850ZWI also represents better the demise dates; in 11 years the dates are the same if we compare with the precipitation index and in 5 years it differs by one pentad.

Another use for these indices is to identify the break and active periods. As an example, the 1984/85 rainy season is selected. The pentadal series of the four indices for this season with respect to the precipitation series averaged in the 60 °W–50 °W and 20 °S–10 °S (Figure 3) shows that the UVI, the MWSI and the 850ZWI represent very well the intraseasonal variability (break and active periods) of the precipitation. Since the meridional wind is associated with the Hadley circulation, this suggests that the northwesterly low-level flow and the position of the regional Hadley cell are important to the intraseasonal variability of the precipitation over WCB. In the WCB region, the skill of wind prediction by numerical models is better

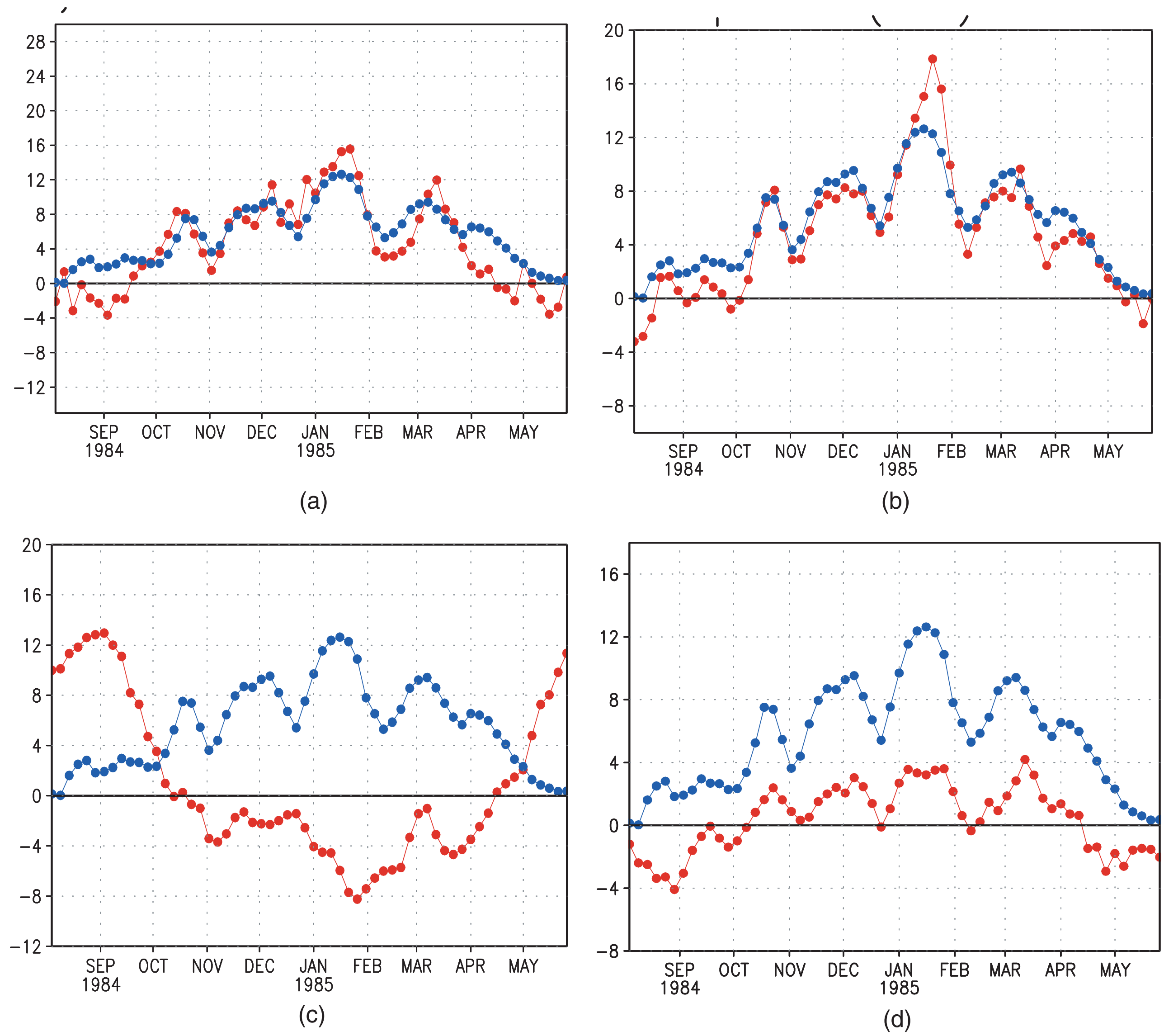

Figure 3. WCB indices for 1984/85 rainy season: MWSI (a), UVI (b), ZWSI (c) and 850ZWI (d). In these figures, the values of the indices were adjusted to agree with precipitation values, ZWSI was divided by 2 and UVI increased by 8 m s^{-1}. The blue line represents the precipitation series and the red line the index

than that of the precipitation predictions. Thus, indices based on wind are very useful. Further, WCB is a crucial region for the agricultural production of Brazil.

4. Conclusions

We examined four indices to identify the onset and the demise dates of the rainy season over the WCB. All four-index series have a high correlation with the precipitation series over the WCB. Since the MWSI is associated with the regional Hadley cell, the results suggest that the latitudinal variation of this cell is responsible for the convection and therefore determines the variability of the monsoon over WCB. We also observed that the 850ZWI, UVI and MWSI pick up very well the intraseasonal variability, showing that the northwest low-level flow (the low-level jet), which transports warm moist air from the Amazon region to WCB, has an important role in the intraseasonal variability of the precipitation over WCB. A careful examination of the four indices showed that all are useful and 850ZWI can represent better the onset and demise dates.

Acknowledgements

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