AN ANALYSIS OF THE CHARACTERISTICS OF EQUATORIAL WESTERLIES①

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ABSTRACT

The real-time data of the high level atmosphere obtained by the R/V Xiangyanghong No. 5 involved in the international TOGA-COARE project at 2°S, 155°E and at fixed real time of 05, 11, 19 and 23 h GMT each day from Nov. 5, 1992 to Feb. 18, 1993 are used to analyze diagnostically the vertical structure of wind and humidity over the central area of the warm pool. The results show that (1) the low frequency oscillation of the equatorial westerlies (i. e. reconstruction—development—decline) is closely related to the vigour and interruption of the Asian-Australian monsoon (including air flow across the equator caused by East Asia cold wave), (2) the variabilities of the vertical structure of wind and humidity, and the processes of precipitation and gale weather in the troposphere of the warm pool area are closely related to the intensity of the equatorial westerlies, and (3) there are strong wind belts over the high and low level atmosphere in the western equatorial Pacific at the inception of the ENSO event, and jet flow at the high and low level atmosphere during the equatorial westerly burst.

Key words: equatorial westerlies, TOGA-COARE, equatorial westerly burst, upper-and low-level westerly jets

Researches in recent years have indicated that the variability of westerly in the western tropical Pacific warm pool area is not only intimately related to ENSO events, but also plays an important role in the evolution of atmospheric circulation in high and middle latitudes (Huang, 1988; Tang, Zeng and He, 1993). Therefore, a study of the characteristics of equatorial westerly has great significance for us to understand air-sea interaction in the tropical region and to motivate further study of ENSO events.

In this paper, the data on the high level atmosphere observed by the R/V Xiangyanghong No. 5 during the international TOGA-COARE IOP period at 2°S, 155°E

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and at fixed real time are used to analyze the process of the equatorial westerly burst and its stratified feature according to the analyses of synoptic scale process of the equatorial westerly reconstruction, development, decline and disappearance, and the vertical structure of wind, temperature and humidity over the central areas of the warm pool.

I. EQUIPMENT INTRODUCTION

CLASS (Cross-chain, LORAN, Atmospheric Sounding System①) provided by U. S. A. was used to explore the high level atmosphere and an electronic navigation sounding system, type PS80-15N was also used to measure air temperature, relative humidity, wind direction and speed, and air pressure. The sampling was taken every 5 m over an altitude of more than 20 km. The major technical criteria of the sounding meteorograph is shown in Table 1.

Table 1. Major technical criteria of sounding meteorograph.

	Air temp. (°C)	Air pres. (hPa)	Hum. (%)	Wind speed (m/s)	Wind dir. (°C)
Sensing range	60—-90	1060—3	0—100	0—100	0—360
Sensitivity	±0.2	±1	±2	0.1	0.1

The TOGA-COARE IOP cruise had three legs: for leg 1 the time period was from November 5 to 20, 1992, for leg 2 from December 15, 1992 to January 8, 1993 and for leg 3 from January 23 to February 18, 1993, with a total of 68 days. Normally, the observation was made four times per day, and more frequently in case of strong convective weather, the total being 284 times.

II. DATA ANALYSIS AND DISCUSSION

1. *Climate background and weather situation*

The observation position was located in the central area of the warm pool, which is a strong equatorial convection region (Yu, 1986). The lower level streamline field shows that the easterlies occurred from May to October, and the westerlies prevailed from December to the following March, which is known as the equatorial westerly. Parameters of all sorts of air-sea characteristics have shown that November of 1992 is considered the normal period, while the embryo period of the ENSO event is from December 1992 to February 1993 (Zou and Li, 1994). The observation was usually positioned within the meeting point between a cyclone in the southern Pacific convergence zone (or the zone itself) and the westerlies formed by the flow crossing the equator from the north. The observed enhancement of the westerlies are supposed to have direct

① This system has been available since April 1992.

link with the increase of the northeasterly caused by outbreaks of northern cold waves of air. Sometimes it was situated in the weak easterly or westerly of an equatorial anticyclone (Fig. 1a). It was shown from the wind field at 500 hPa that a strong easterly appeared and there was a divergent sinking air current in the confluence area of the mainly easterly air current on the edge of the subtropical high in the southern and northern hemispheres.

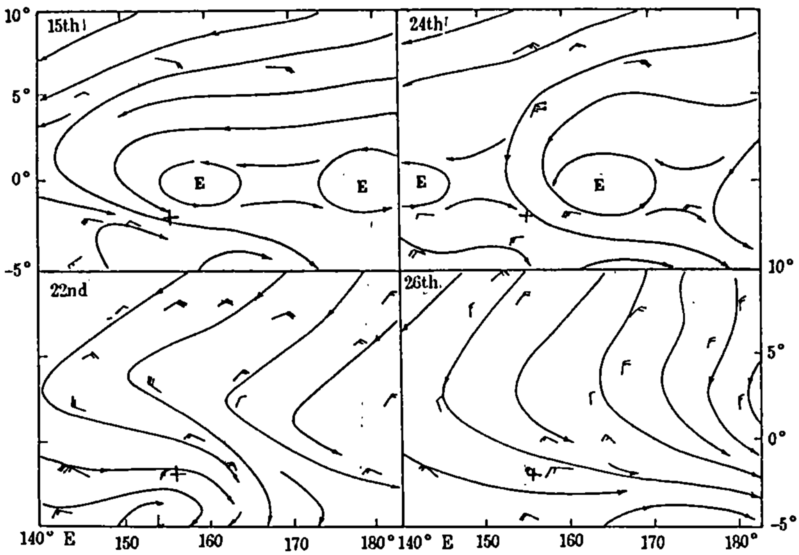

Fig. 1. Surface air current on December 15, 22, 24 and 26, 1992. The dates are indicated on the the upper right corner; the location of R/V Xiangyanghong No. 5 is shown by the sign of X.

2. *Strong wind belt and jet flow*

Usually there is a narrow strong wind belt in the atmosphere (Qu, 1987). The observational data showed that there was also a strong wind belt below 7. 5 km (400 hPa), its wind directions were mostly by the west, especially in legs 2 and 3, the wind frequencies for WSW—W—WNW accounted for 59. 3 % in leg 1, 80. 4 % and 76. 5 % in leg 2 and leg 3, respectively, while the total averaged wind direction for ENE—E—ESE only accounted for 7. 1 %. In this paper, taking as its strength (m/s) the maximum wind speed in the center of the strong wind belt, and defining it as jet flow when it is greater than or equal to 12 m/s (Qu, 1987), it was then found that the strength was quite weak for the easterlies , and relatively strong for the westerlies and the daily averages in the cruise reaching the intensity 4 times a day accounted for 25. 0 %, 60. 8 % and 55. 6 % for legs 1, 2 and 3, respectively .

There was also a strong wind belt on the upper part of troposphere, where the easterly prevailed and the wind direction for ENE—E—ESE accounted for 88.6 %, the westerlies rarely occurred, and its strength was also weaker. The strength of the strong easterly belt was usually twice as much as the strong westerly belt at lower levels, its criterion for the jet flow being greater than or equal to 30 m/s (Table 2). In this paper, the equatorial easterly and westerly are defined as the strength of easterly and westerly at the lower and upper part of the troposphere, i. e. the strength of the strong wind belt at high-and lower-level atmosphere.

Table 2. Time series of daily average intensity (m/s) of the strong wind belt during November 1992—February 1993. The brackets indicate negative and positive values in lower and high level atmosphere, respectively.

Leg 1			Leg 2			Leg 3		
Date	Intensity		Date	Intensity		Date	Intensity	
	Lower Level	Upper Level		Lower Level	Upper Level		Lower Level	Upper Level
Nov. 5	11.6	26.0	Dec. 15	(11.0)	20.1	Jan. 23	-11.0	17.2
6	14.2	21.1	16	(9.9)	22.1	24	-9.9	17.3
7	15.1	20.8	17	6.5	19.8	25	-19.4	14.2
8	10.7	17.8	18	6.0	18.2	26	6.8	16.1
9	9.0	17.9	19	8.7	20.4	27	8.1	18.5
10	11.1	18.3	20	14.5	21.8	28	11.2	17.4
11	15.3	14.0	21	13.9	22.8	29	14.0	23.6
12	18.1	18.0	22	16.2	29.8	30	15.1	27.8
13	13.0	22.1	23	14.6	33.2	31	19.6	31.9
14	(7.9)	21.3	24	14.1	31.9	Feb. 1	15.4	31.8
15	8.8	20.6	25	12.3	35.9	2	20.1	27.4
16	6.6	27.2	26	14.7	28.8	3	20.3	35.1
17	(7.4)	30.0	27	18.8	32.9	4	16.7	27.9
18	(7.2)	28.8	28	15.9	38.6	5	14.8	16.8
19	9.1	26.4	29	20.8	42.5	6	16.9	22.2
20	10.3	22.5	30	21.3	40.5	7	11.5	24.5
			31	23.9	36.9	8	15.8	23.4
			Jan. 1	22.8	39.9	9	14.7	30.8
			2	23.6	39.4	10	14.9	29.6
			3	20.0	36.7	11	15.0	31.4
			4	18.1	35.5	12	12.9	28.1
			5	13.6	20.3	13	12.1	32.1
			6	11.2	20.8	14	11.0	21.2
			7	9.2	12.7	15	9.8	21.0
			8	(8.9)	(12.6)	16	9.2	22.9
						17	8.3	19.7
						18	8.5	27.7

3. *The process of the equatorial westerly*

In order to study the variation of Walker Circulaton, the zonal wind component profile is drawn (as shown in Fig. 2). It can be seen from Table 2 and Fig. 2 that the first westerly process in leg 1 extended from sometime before Nov. 5 to 13, 1992 (more than 9 days) , and the wind directions from Nov. 14 to 20 were unstable. The easterly prevailed from Dec. 15 to 16 and there was a whole westerly process covering a long period of 22 days in leg 2 (Dec. 17 1992—Jan. 6 1993), in which the jet flow maintained for 17 days. The equatorial westerly process for leg 3 began on Jan. 26, 1993, decreased to less than the lower limit of the jet flow criterion on Feb. 14, but did not end on 18th when the survey was completed. The jet persisted for 16 days in a much similar way to leg 1. The percentage of the number of days with the westerly process accounted for 50%, 88% and 88% of the total number of days in each leg respectively, which suggested poorly-defined or short and weak processes of the easterlies during the observation, an important phenomenon behind the transportation of surface warm water from west to east during legs 2 and 3 (Zou and Li, 1994). The above characteristics were in close relationship with the normal and embryo periods of the ENSO event. What is stated above also reveals that the equatorial westerly oscillates in low frequency periods of about 30 days (Wang and He, 1991).

It can be seen from analyses of the surface wind field and satellite images in the western tropical Pacific, the development and decline of the equatorial westerly process are closely related to the variations of the Asian-Australian monsoon trough and western Pacific subtropical high north of the equator (north-south and east-west vacillation). The equatorial westerly would reconstruct and develop when the cross-equatorial air flow caused by the East-Asian cold wave and Australian monsoon trough in the southern summer strengthened and moved northward or during the development of cyclone (especially tropical storm). The westerly process would decrease, vanish or change into the easterly process, when the flow field mentioned above was destructed. It is evident from the above analyses that the onset of ENSO event is related to the activity of the East-Asian cold wave (Li, 1988), and is also associated with the reconstruction, development, and interruption of Asian-Australian monsoon (Wang and He, 1991). This is also a significant complement for the study of the mechanism of ENSO event.

4. *Equatorial westerly and vertical variation of wind*

1) WIND DIRECTION

The vertical variation of wind direction in troposphere is associated with the strength of the equatorial westerly. In this study, the two typical examples will be discussed in the following, that is, the gradual development and decline of the equatorial westerly (Fig. 3a, b). It was shown from Fig. 3 that the thickness of the easterly near 5. 5 km gradually decreased, the corresponding easterly component also gradually decreased and sometimes turned into the westerly when the equatorial westerly became stronger. In contrast, the westerly at the layer of 5. 5 km gradually decreased, and the easterly reappeared and strengthened when the equatorial westerly became weaker. The characteristics is directly related to the development of the equatorial convergence zone and the reduction of the influence of the edge of Pacific subtropical high and also acts as a distinct index for the variation of atmospheric convection (strong or weak) and Walker Circulation (strong and moves eastward or weak and shrinks westward).

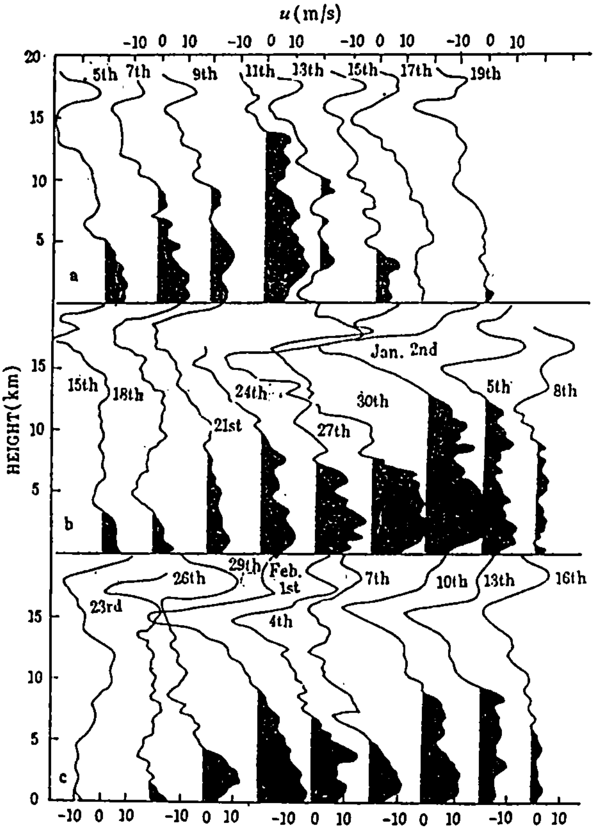

Fig. 2. Zonal velocity profile at 17 h GMT in every other day Nov. 5 through 19, 1992 (a) and in every other two days Dec. 15 1992 through Jan. 8, 1993 and Jan. 23 through Feb. 16, 1993.

2) THE THICKNESS OF WESTERLY

It is shown from Figs. 2 and 3 that the thickness of the westerly in the lower part of troposphere usually does not exceed 5. 5 km during weak phases of the equatorial westerly and in the initial and final stages of the strong westerly process, and its thickness could reach the maximum of the whole period (more than 5. 5 km) when it is in the mature stage, especially in the middle and final stages. The occurrence of maximum thickness for three westerly processes during the whole cruise was covering Nov. 11—12, 1992, Jan. 2—5 1993, and Feb. 1—2, 1993, respectively, with most of them being more than 7. 5 km and the maximum value up to more than 14. 0 km (150 hPa). Thus it should be noted that when the westerly makes temporary appearance in the wind field of 200 hPa during the embryo period of ENSO event, it does not necessarily mean that the easterly in the upper level atmosphere has decreased but sometimes just the contrary might be true.

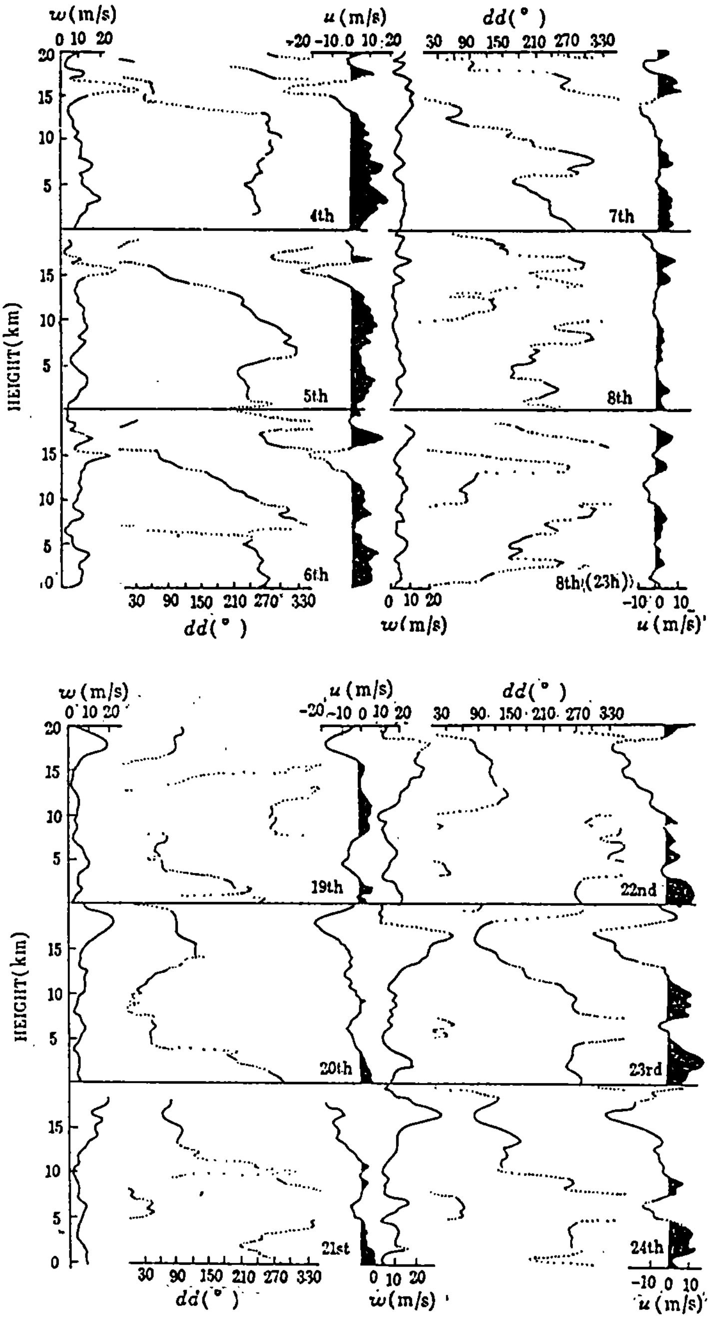

Fig. 3. Daily equatorial westerlies profiles at 05 h during Dec. 19—24 1992 (a), and at 05 h through Jan. 4—8, 1993 and at 23 h Jan. 8, 1993 (b) W is the observed wind speed, *dd* and *U* represent wind direction and zonal wind speed, respectively. (Shaded positive values are for the westerly.)

3) WIND SPEED

During the initial stage of transformation of the low-level equatorial easterly to the equatorial westerly, the easterly at upper level and the westerly at lower level were weak and bore no close relation with one another. Analysing the variation of wind strength at upper-and lower-level atmosphere or the timing of the jet occurrence, the strong easterly at high level was found to be 2 days lagging behind with respect to the strong westerly at lower level during Dec. 15, 1992—Feb. 18, 1993 in the mature stage of the equatorial westerly. During the period, two eastward-moving jets persisted for about 17 and 16 days, respectively, from Dec. 20, 1992 to Jan. 5, 1993 and from Jan. 29 to Feb. 13, 1993, to which the upper-level jet also made an active response. The persisting time for the jet flow accounted for 65.4 % during Dec. 5, 1992—Feb. 18 1993 (see Table 2).

5. *The equatorial westerly and weather*

The variation of the equatorial westerly has distinct influence on the variation of weather. The variations of precipitation, lower-level cloudage and sea surface wind speed are briefly illustrated in this paper. It can be seen from Table 3 that the averaged sea surface wind speed was large, and there were a large amount of cloud and rainfall when there was a westerly jet flow over the equatorial area and vice-versa.

Table 3. Statistics of the strength of strong westerlies (expressed by occurrence, or, O), daily mean of sea surface wind speed (W), lower level cloudage (C) and the times of daily precipitation (P).

Intensity≥12.0 (m/s)						Intensity<12.0 (m/s)				
Leg	Date	O	W (m/s)	C (%)	P	Date	O	W (m/s)	C (%)	P
1	Nov. 5—7, 1992	21	5.5	72	3.0	Nov. 8—10, 1992	21	4.8	41	1.0
	Nov. 11—12, 1992	16	5.0	63	4.0	Nov. 13—20, 1992	64	3.2	34	0.4
2	Dec. 22, 1992—Jan. 6, 1993	130	6.9	65	3.0	Dec. 15—21, 1992	47	4.9	69	2.0
						Jan. 6—8, 1993	19	4.4	27	1.0
3	Jan. 28—Feb. 13, 1993	131	6.0	59	1.6	Dec. 23—28, 1992	37	3.5	26	0.7
						Feb. 13—18, 1993	42	4.2	48	0.7
	Average		6.3	63	2.5	Average		3.9	44	0.9

6. *The equatorial westerly and humidity*

Air humidity has a close relationship with wind direction and speed (except for the boundary layer).

1) DRY AND WET TONGUES

It can be seen from Fig. 4 that the variation of humidity with altitude was very complicated, but it had an obvious stratified feature. There were a number of other strong wind belts with relatively weaker intensity apart from the upper and lower level ones. To tell one from another, the weaker belts are called strong wind tongues. It is interesting to note that the easterly and westerly wind tongues often correspond in geographic location to dry and wet tongues, respectively, and the wet tongue tends to be over the westerly tongue, which was related to the upward transfer of convective water vapour. As the lower limit of relative humidity in the cloud during the cruise was 75 %, any deep atmospheric layer with the relative humidity greater than or equal to 75 % is called the high humidity layer. Fig. 4 shows that there was always a well-defined high humidity tongue (see the mark "5" in Fig. 4) due to the obstructing effect of sinking airflow at the edge of the subtropical high, and it would significantly strengthen and get thicker, turning in the extreme case (Nov. 5—11, 1992) the whole layer below 5. 5 km into one with high humidity, when the equatorial westerly was strong, especially with the prevalence of the westerly jet. In contrast, when there was prevailing easterly or weak westerly below 5. 5 km (Nov. 15—17), the high humidity tongues can still be found near the height of 5. 5 km and in the boundary layer, but mostly with humidity below 60 %, causing less precipitation and lower cloudage.

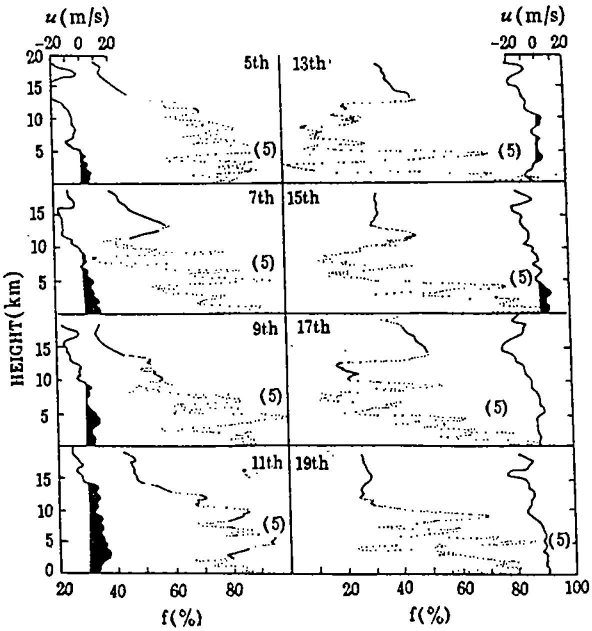

Fig. 4. Zonal wind speed (u) and relative humidity (f) profiles at 17 h GMT every other day during Nov. 5—9, 1992. "5" marks a high humidity tongue around 5. 5 km.

As the strong westerly rapidly decreased and changed into the easterly on Nov. 13, 1993, the wind field on the same day was very similar to the situation of the prevailing easterly, and it looks much the same as that of the westerly prevalence when the strong easterly shifted to the westerly on 19th of the month, suggesting linkage of changes in the relative humidity to the tendency of easterly and westerly variation.

2) THE THICKNESS OF HIGHLY WET AIR LAYER

During the slightly strong westerly period (Nov. 5—11) , the atmosphere in the lower part of troposphere was mainly controlled by highly wet air, whose upper boundary often reached about 7.5 km, a height that roughly coincided with that of the interface between the easterly and westerly, particularly so below 5.5 km. The situation was completely different during Nov. 12—19, in which a shallow tongue of large humidity existed at 5.5 km and in the boundary layer, but was hardly found in the lower part of troposphere.

Ⅲ. CONCLUSION

Through analyses of the data obtained from *in situ* observation in the central area of the warm pool of western tropical Pacific during Nov. 1992—Feb. 1993, conclusion can be reached as the following points:

a. There were jet flow processes in the strong wind belt at high and lower level atmosphere during the embryo period of ENSO event. For instance, during the two legs covering Dec. 15, 1992—Jan. 8, 1993 and Jan. 23—Feb. 18, 1993, the jet at the lower level atmosphere persisted for 16 and 17 days, which accounted for 64 % and 63 % of their observational days respectively. This means that the existence of the jet is an important feature for the embryo period of ENSO.

b. The reconstructing, strengthening, declining (disappearing) stages of the equatorial westerly tend to have close association with the reconstructing, vitalizing, declining (disappearing) stages of the Asian-Australian monsoon.

c. In the meteorological community, the wind field at 200 hPa is usually used to analyze the variability of the uppper level easterly component of the Walker Circulation. It is worth noting that the upper boundary of the easterly branch could exceed the height of 200 hPa at times when the equatorial westerly develops to its prime stage, which does not suggest the decrease of the Walker Circulation and just on the contrary, implies a lifting of the branch to higher altitudes (sometimes as high as the tropopause) , indicating the association of the equatorial westerly with the strengthening and eastward movement of the Walker Circulation.

d. The vertical variation of humidity is closely related to wind speed and direction. The humidity for the layers of the westerly (easterly) was in positive (negative) correlation with windspeed . Additionally , there was often a highly wet tongue near 5.5 km, which was strong, thick and at high altitudes (sometimes around 7.5 km), accompanied by high relative humidity in the lower troposphere during the enhancement or prevailing stages of the equatorial westerly, while the case is just the opposite when the easterly was in control, suggesting that the equatorial westerly jet acts as a channel of transporting water vapour in close association with the weather changes.

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