CHAPTER 4
RELATIONSHIP AND ASSOCIATION BETWEEN THE VARIABILITY AND FORCING FROM SST

According to the previous analysis, the results show prevailing northeasterly wind representing the first EOF mode that has the possibility of having correlations with other climate forcing besides the relation with EAWM. The well known climate mode from SST forcing named ENSO has been indicated that there is some association with the EAWM (Zhang, 1997; Wang, 2000; Zhou, 2007; Zeng, 2011). Therefore, it has possibility to play important role on the variability of wintertime northeasterly over the IDP. Although the SST variation in the Pacific Ocean is important, the recent dipole mode of SST behaviour in the Indian Ocean named the Indian Ocean Dipole (IOD) (Saji, 1999) becomes the factor for consideration due to it is nearby the IDP region. The two famous SST forcing were considered that do they have linkage with the wintertime northeasterly wind variability represented by PC1s by correlation analysis. For their association, the lag correlation analyses were used, and related vertical circulation cells were used to describe the possible linkage. This section aims to present and describe the possible linkage and association of the wintertime wind variability over the IDP with ENSO and IOD.

4.1 Data and Methods

4.1.1 Sea Surface Temperature Data

The data used in this study consists of sea surface temperatures (SST) from the Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST) with 1°×1° resolution (Rayner, 2003) and horizontal wind components, pressure velocity, velocity potential from the JRA-25 (Onogi, 2007). The details of the JRA-25 data were mentioned in a previous chapter. The HadISST data was developed by the Met Office Hadley Centre for Climate Prediction and Research, and was used to support in processes for the 40-year ECMWF Reanalysis (ERA-40). The HadISST data set has global covering of 1°×1° horizontal resolution from 1870 to present. For the input data, in situ data were used. The individual ships' observation of the Met Office Marine Data Bank controlled by the quality processes by methods using for the Met Office Historical SST data set were used to construct 1° grid cells. The monthly median SSTs of the Comprehensive Ocean-

Atmosphere Data Set (COADS) were also used to enhance data coverage. The smoothed adjustment were used to blend the in situ data with COADS data, and also a cold bias of 0.08 °C of the modern insulated buckets collecting seawater relative to engine intake data was consider as bias adjustment for pre-1941 in situ data. The blended 1° gridded data were controlled its quality by neighbour-based concept that are comparing against a weighted average of neighbours, when there was mean anomaly value in more than one of eight grid cells neighbouring 2° or 4° SST anomaly. The reduced space optimal interpolation (RSOI) technique that quit similar to EOF projection but more rigorous by considering noisy and sparse data was used to reconstruct the data. Also, the satellite data from the advance high resolution radiometer (AVHRR) was used in combination of SST data (Rayner, 2003).

4.1.2 Analytical Methods

The SST were used for correlation analyses with PC components given by the EOF analysis to examine variability where there is a suspicion of a relationship and association of winter monsoon over the IDP and forcing from the Ocean as mentioned previously. Analysis on correlation maps between PC components and SSTA was performed to investigate the relationship in the Pacific and Indian Ocean, whereas lag correlation analysis was used to reveal the relation and association between them. Three months running means of SSTA was considered to remove seasonal signal before used it to construct indices for lag correlation analysis with consideration on □11 previous/following months centering at DJF mean value. Selected indices for the analysis are the Niño 3.4 and the dipole mode index (DMI) indices that represent major variability modes, ENSO and IOD, in the Pacific Ocean and Indian Ocean, respectively.

In addition, to understand of more the relationship between northeast (NE) monsoon variability represented by PC1s and the forcing from the Ocean, the analysis to describe the mechanism of the NE monsoon corresponding to its difference in phase in terms of vertical circulation was used.

4.2 The PC1s-SST Relationship

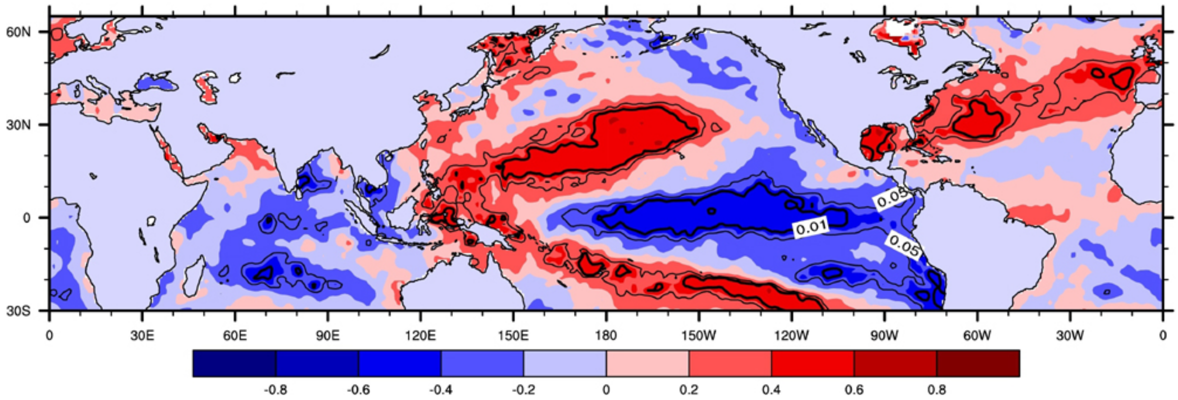
The ENSO is an important phenomena revealed by SST variability in the equatorial Pacific Ocean. Many studies indicate that there is good and close association between EAWM and ENSO (Zhang, 1997; Wang, 2000; Zhou, 2007; Zeng, 2011). Therefore, the analyses of correlations between PC1s and sea surface temperature anomaly (SSTA) is required to reveal relationship and between the NE monsoon over the IDP and SST. Emphasis is on interannual EAWM variability related to SSTA in the Pacific Ocean, strong EAWM associated with La Niña and weak EAWM associated with El Niño, which related to air ascending and descending at the equatorial and subtropical Pacific Ocean, respectively (Zeng, 2011).

There is a significant correlation of the northeast monsoon (NE monsoon) over the IDP represented by PC1s with low latitude EAWM characteristic, but there is another possible climate forcing that influences the variability of wintertime low-level wind over the IDP (as mentioned in the previous section). Also, it will be the forcing from SST variability in the Pacific Ocean. It is interesting to reveal the relationship between NE monsoon and SST in the Pacific Ocean, which has not been completely investigated. The primary and secondary components of PC1 were employed to construct the correlation maps of them with SSTA for investigation, as shown in Figure 4.1.

The figure shows negative correlation between PC1s and SSTA in the Indian Ocean with smaller magnitudes than those in the Pacific Ocean, while the significant correlated areas in the Pacific Ocean are wider than those in the Indian Ocean. Base on this evidence, it is possible that the SST variability in the Pacific Ocean plays a greater role on the wintertime low-level wind variability over the IDP than that of the Indian Ocean.

Over the tropical central-east Pacific Ocean, there are negative correlations between PC1s and SSTA. Increasing PC1s values correlated to decreasing SSTA. This indicates that the cooling (warming) of SST over the tropical central-east Pacific Ocean is relatively in phase with strengthening (weakening) of northeasterly winds over the IDP (Figures 3.5a, 3.5b, 4.1a and 4.1b). For the west Pacific Ocean, it shows positive correlation, which differs from the correlation presenting for the tropical central-east Pacific Ocean. The positive correlation shows a V-shape in horizontal plane pattern that extends eastward and poleward, indicating that the increase in PC1s values correlated to high SSTA. It implies that warming (cooling) of SST over the tropical central-east Pacific Ocean is related to strengthening (weakening) of northeasterly wind over the IDP. Since the strong EAWM associated with strong northeasterly wind, which correlated to positive PC1s, this result agrees with the study of Zeng (2011) that suggests the warm SSTA in the tropical central eastern Pacific Ocean leading to weaken the western Pacific Hadley cell causing the EAWM weakened, and vice versa for the cold SSTA in the central-eastern Pacific Ocean leading to present strong EAWM.

(a) PC1pri-SSTA



(b) PC1sec-SSTA

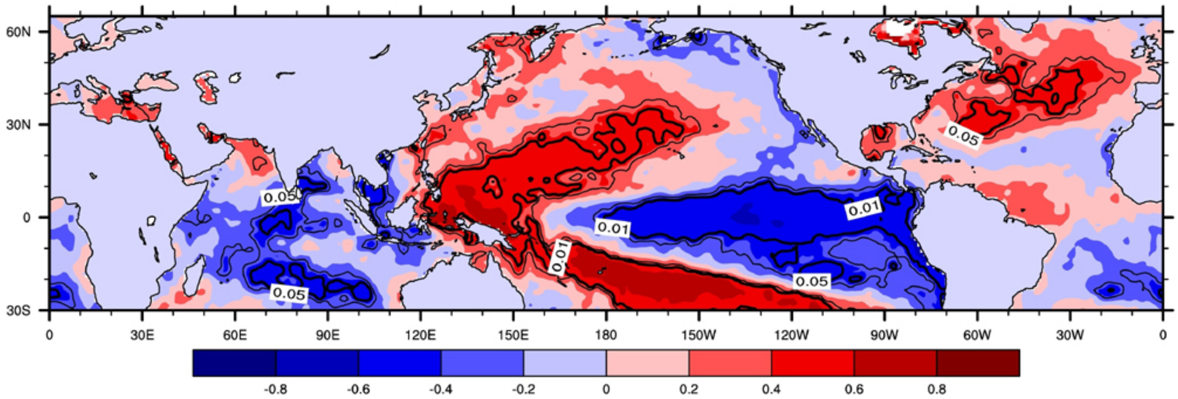


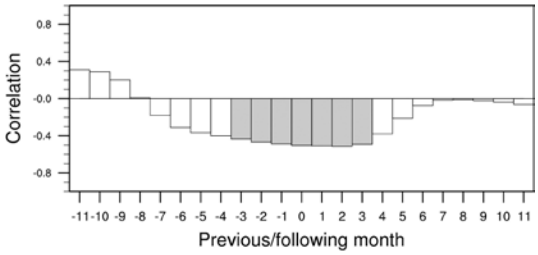
Figure 4.1: Correlation maps between (a) the primary part of the first leading principal components to sea surface temperature, (b) same as (a) but for the secondary part. Shading contour line represents correlation coefficient, and the contour line denote the significant correlations at 0.01 (thick) and 0.05 (thin) levels.

To confirm the relationship that there is an association between PC1s and SSTA in the equatorial Pacific Ocean, the correlation analysis for −11 to +11 month lag was performed. The important activity in the Pacific Ocean, El Niño, has been measured and monitored through SSTA variation (Trenberth, 2001). The Niño 3.4 index, which is averaged SSTA over 5°S-5°N, 170°-120°W was used for the analysis. For the important phenomenon in the Indian Ocean, the IOD is measured by the DMI index introduced by Saji (1999), which determined from the difference in SSTA between the tropical western Indian Ocean (50°-70°E, 10°S-10°N) and the tropical south-eastern Indian Ocean (90°-110°E, 10°S-Equator) and has been used to describe the Indian Ocean Dipole phenomenon, was used to confirm the less association between PC1s and SSTA in the Indian Ocean. Three months running means for SSTA was performed to reduce the influence of seasonal means before the analysis, as suggested by Wang (2009).

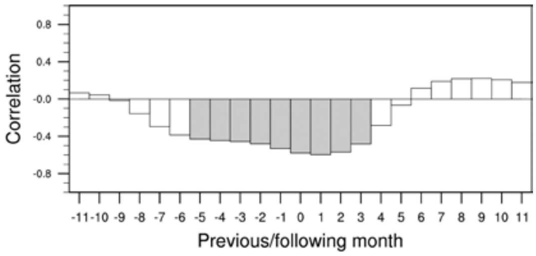
There are significant negative correlations of PC1s to Niño 3.4 index on previous months and following months, which starts from three months for the primary part (Figure 4.2a) and five months for the secondary part (Figure 4.2b) before DJF(0) and persists for three months later. Thus, the air-sea interaction over the equatorial Pacific Ocean affects the variability of NE monsoon represented by PC1s. This result indicates that there is an association between NE monsoon variability and ENSO. The negative correlations between PC1s and Niño 3.4 index imply that the strengthened NE monsoon associated with the negative phase of Niño 3.4, which is considered as La Niña when the Niño 3.4 values exceed −0.5°C consecutively, and vice versa for the weakened NE monsoon associated with El Niño. In addition, the correlation in a next month (+1) shows a slightly higher than the previous month.

For the IOD, there is no significant correlation between PC1s and DMI, as shown in Figures 4.2c and 4.2d. It shows less influence on the wintertime low-level winds over the IDP as compared to the SSTA variation in the tropical Pacific Ocean. The reason is perhaps the IOD is the 2nd mode of SST variability in the Indian Ocean Saji (1999), which is not strong as the ENSO. Although there is non significant correlation between PC1s and DMI, the Figure 4.1 shows some correlation of PC1s to SSTA in the southern Indian Ocean around Tropic of Capricorn. The correlated area (15°S-30°S, 65°E-105°E) of the Southern Indian Ocean denoted as SIO (IDP) was examined to reveal its correlation with PC1s, and found that there are non-significant correlation with PC1pri and weaker significant correlation with PC1sec than that of Niño 3.4. These indicate that the variation of SSTA in the SIO does not significant correlate to variability of the first mode of wintertime wind over the IDP in terms of magnitude, but it significant negative correlate to variability in rotation (PC1sec) from a previous month (1) to a following month (+1) as shown in Figures 4.2e and 4.2f, respectively. Thus, the NE monsoon variability is stronger associated with SSTA in the equatorial Pacific Ocean, particularly with Niño 3.4, than that of the Indian Ocean. This is useful information to possibly indicate the NE monsoon variability using the Niño 3.4 index.

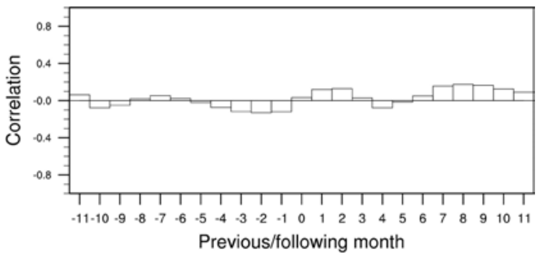
(a) Correlation of PC1pri to Niño 3.4



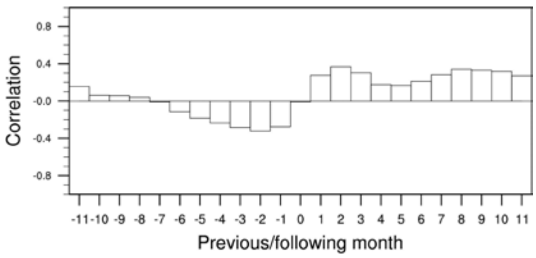
(b) Correlation of PC1sec to Niño 3.4



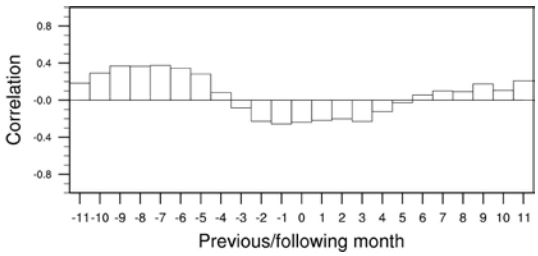
(c) Correlation of PC1pri to DMI



(d) Correlation of PC1sec to DMI



(e) Correlation of PC1pri to SIO



(f) Correlation of PC1sec to SIO

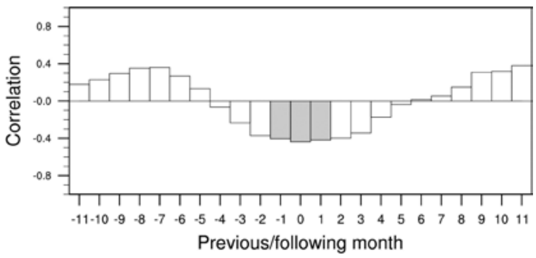


Figure 4.2: Correlation between (a) the primary part of the leading principal component and Niño 3.4 represented by the three months running means of SSTA (0 represents the corresponding the DJF mean of SSTA variation, the negative and positive running means represent previous and following months considered at the middle point, respectively), and (b) same as (a) but for the secondary part. Figures (c) and (d) are similar to (a) and (b), but for the DMI index. Figures (e) and (f) are similar to (a) and (b), but for the SIO. Shading presents statistical significance at 95% confident level.

4.3 Vertical Circulation Related to NE Monsoon Variability

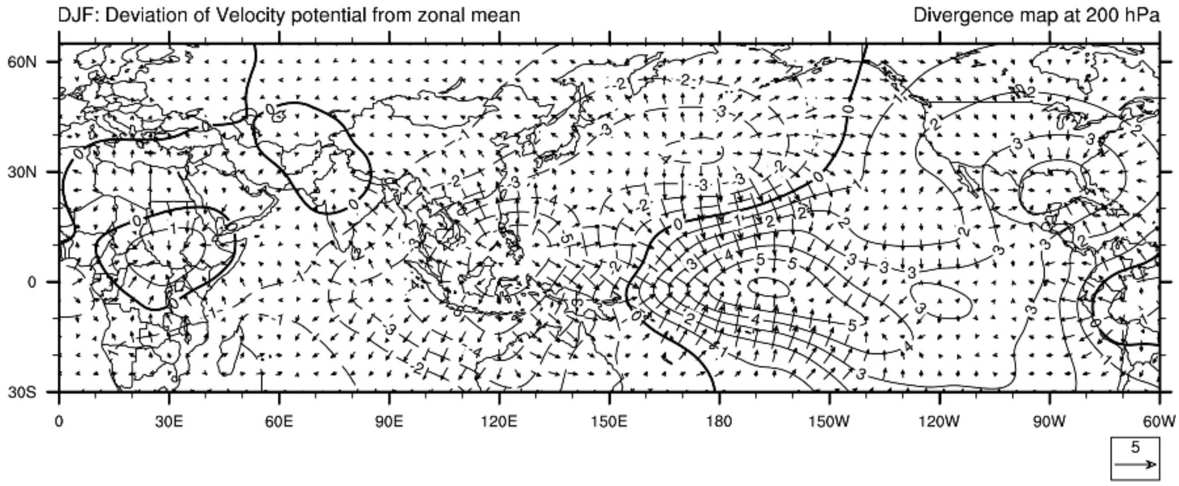
To investigate the mechanism on difference phases of NE monsoon variability in terms of vertical circulation, the air ascending and descending represented by the differences of velocity potential and divergent wind between the strong and weak phases of PC1s are used as shown in Figure 4.3. A criterion is that used to classify the PC values into the strong and weak phases is the value exceeding a range □1SD. At 200 hPa level, there are two large different areas presenting convergences over the Africa continent and the tropical central-east Pacific Ocean, while a large difference on divergence presents over the Maritime Continent near the IDP (Figures 4.3a and 4.3b). On the other hands, the difference at 850 hPa present convergence (Figures 4.3c and 4.3d), which locates at the Maritime Continent, and the divergence presents at the tropical central-east Pacific Ocean. The obvious differences on air ascending at the Maritime Continent and air descending at the tropical central-east Pacific Ocean support the relation of NE monsoon variability with changing of SSTA in the Pacific Ocean.

Over the Maritime continent, there is more (less) air ascending when PC1s increase (decrease) as shown in Figure 4.3 that agree with warming (cooling) of SST in the west Pacific Ocean and cooling (warming) of SST in the tropical central-east Pacific Ocean as shown in Figure 4.1 This is a possible cause to enhance NE monsoon strength when PC1s increase, and vice versa for the opposite PC1 phase. This notice will be described by vertical circulation cells, which give more understanding on the mechanism related to NE monsoon variability.

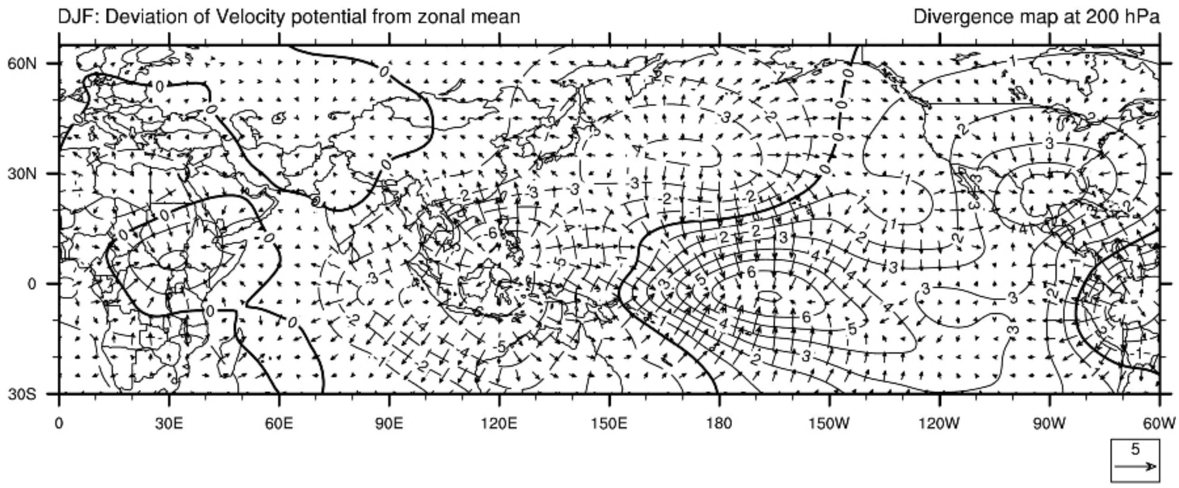
There is the well-known equatorial zonal circulation, the Walker circulation, hereafter called the zonal Walker circulation cell (ZWC). As the study of Zeng (2011), the latitude band 5°S to 5°N is used to reveal the ZWC. The climatic ZWC obtained by averages of the zonal divergent wind component and pressure velocity deviations from the zonal mean, which similar to the concept suggested by (Tanaka, 2004). A climatic mean of meridional vertical circulation cell focusing on the large difference of air ascending/descending closing to the IDP is revealed by the averages of the wind divergent component and pressure velocity over 110°E-140°E, here after the circulation cells is called the West Pacific Hadley circulation cell (WPHC). The averaged area representing the WPHC quit agrees with the area used in the study of Zeng (2011).

Both climatic circulation cells, the ZWC and WPHC, are investigated before considering their anomalous circulation cells to understand the different mechanisms between the strong and weak phases of NE monsoon variability. The climatic circulation cell of the ZWC shows the air ascends in the western tropical Pacific, turns eastward and westward in the upper troposphere, then sinks in the eastern Pacific Ocean and the west India Ocean, respectively, and returns to the western Pacific Ocean in the low-level (Figure 4.4a). For the WPHC, ascending air presents at south of the IDP around 10°S and descending air presents at north of the IDP around the subtropical high belt, resulting the low-level wind blows from north to south over the region (Figure 4.4b).

(a) Differences of PC1pri at 200 hPa level



(b) Differences of PC1sec at 200 hPa level



(c) Differences of PC1pri at 850 hPa level

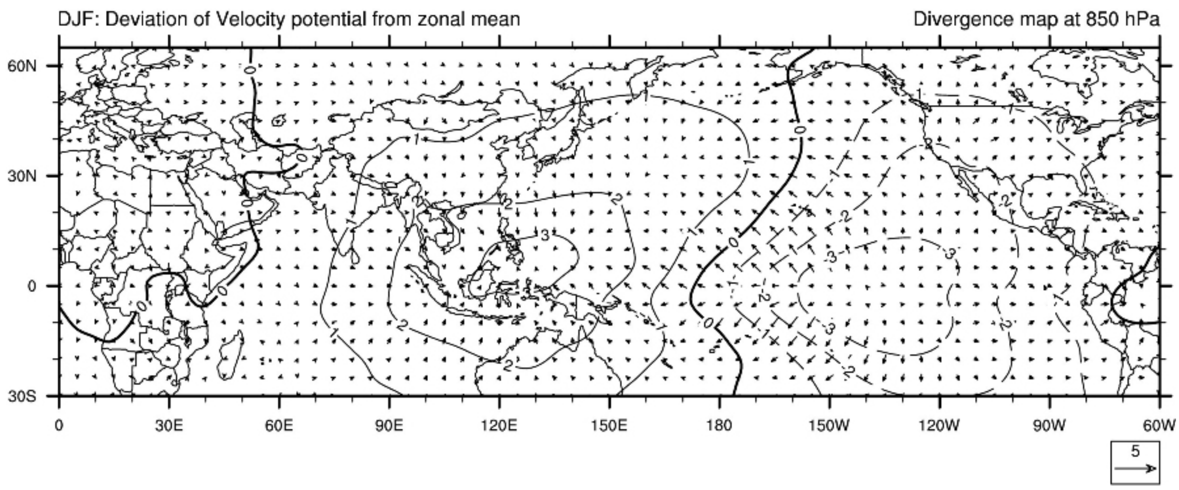


Figure 4.3: Divergent wind and velocity potential differences (strong−weak) of (a) the primary part and (b) secondary part PC1s at 200 hPa, and (c) and (d) same as (a) and (b) but for the 850 hPa level.

(d) Differences of PC1sec at 850 hPa level

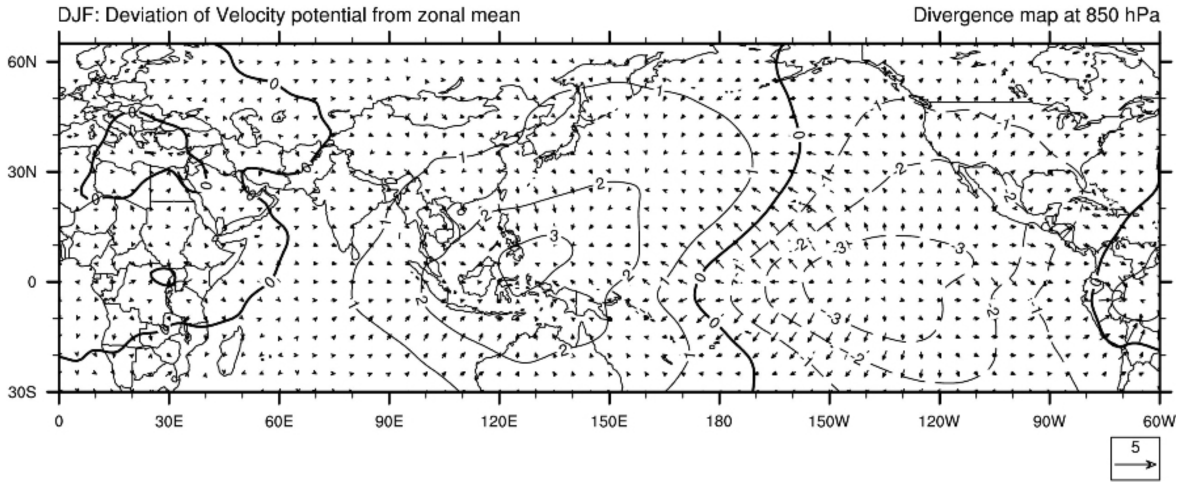
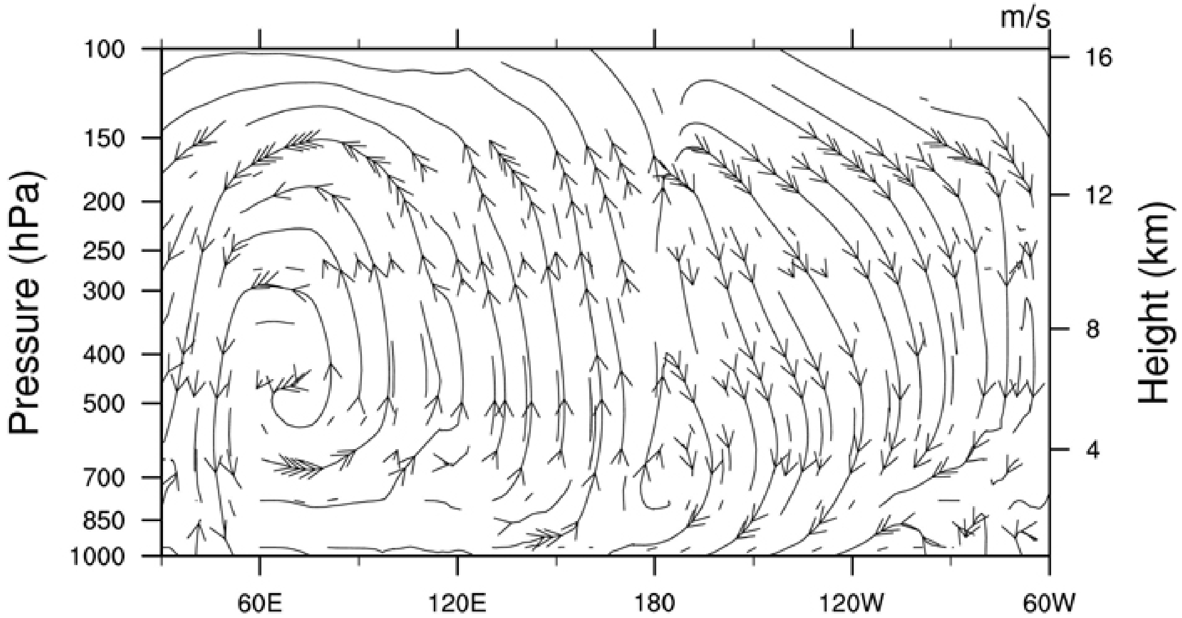


Figure 4.3: Divergent wind and velocity potential differences (strong−weak) of (a) the primary part and (b) secondary part PC1s at 200 hPa, and (c) and (d) same as (a) and (b) but for the 850 hPa level (Cont.).

(a) ZWC (5°S-5°N)



(b) WPHC (110°-140°W)

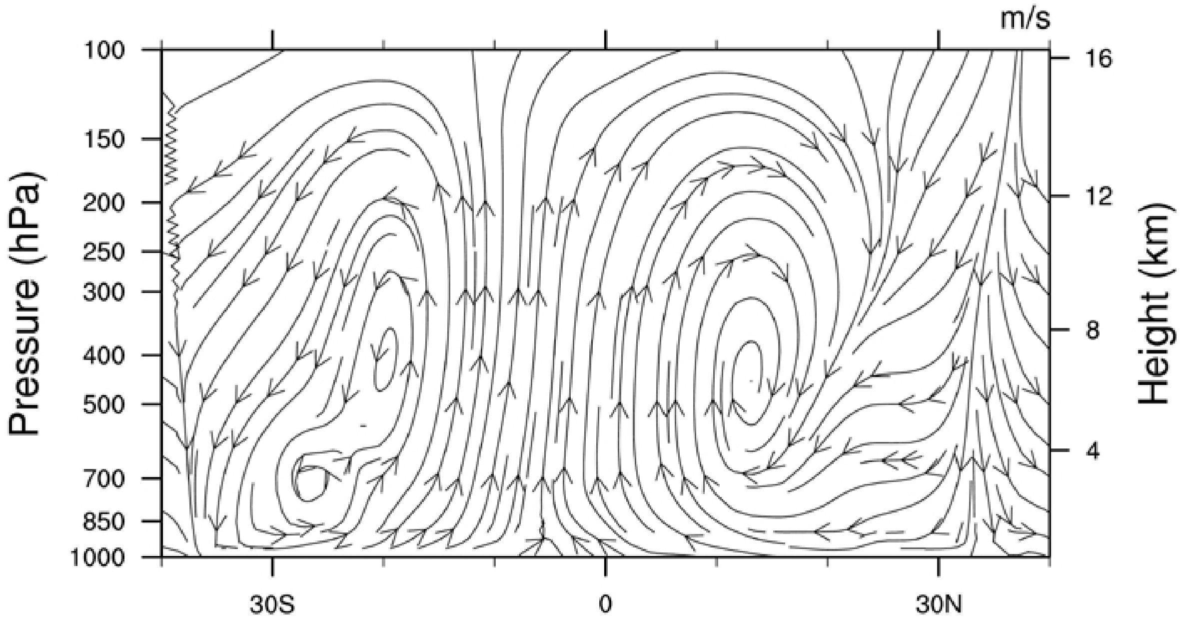
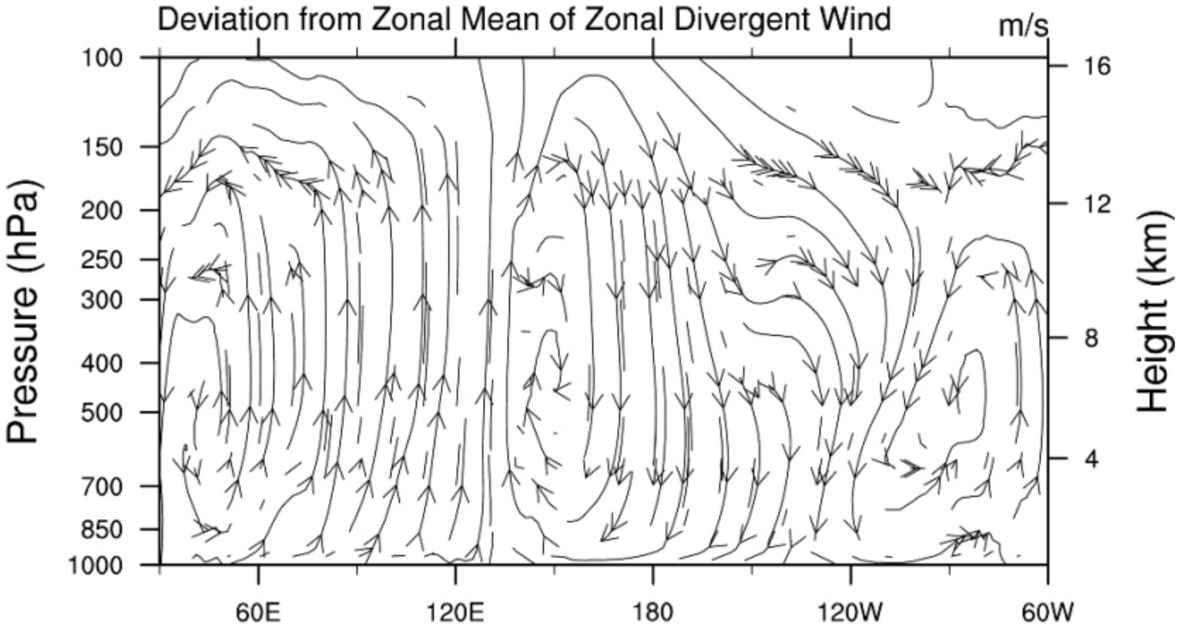


Figure 4.4: Climatic zonal and meridional vertical circulation cells averaged over (a) 5°S-5°N (ZWC), and (b) 110°-140°E (WPHC). Units of zonal wind and vertical speed are m/s and hPa/s, respectively, and the vertical speed scaled by multiplication of 30 to display the circulation cell vectors.

During the strong phase, the composite circulation cells of PC1pri and PC1sec (Figures 4.5a and 4.5b) for anomalous ZWC show that the centers of anomalous ZWC located around 150°E differ from the centers of the climatic ZWC locating around 180° (Figure 4.4a), resulting in enhanced air ascending at the equatorial longitude band around 80E-130°E located at the south of the IDP. This agrees with the correlation between PC1s and SSTA over the west Pacific Ocean (Figure 4.1), and indicates that the enhanced air ascending is resulted from the warming of SST over the area. For the WPHC, the enhanced air ascending presents at the equatorial (Figures 4.5c and 4.5d), whereas the climatic mean air ascending is at 10°S (Figure 4.4b). The enhanced air ascending at the south of the IDP induce more low-level wind blow southward, which causing to strengthen NE monsoon over the IDP. On the other hand, Figures 4.6a-4.6d show the anomalous circulation cells of ZWC and WPHC for the weak phase.

The anomalous cells show the weakening of air ascending along the equatorial longitude band from 90°E-150°E for ZWC (Figures 4.6a and 4.6b) and the weakening of air ascending around the equator for WPHC (Figures 4.6c and 4.6d). Furthermore, the anomalous WPHCs are anticlockwise, and show the weakening of wind blowing southward. It agrees with the relation of PC1s with SSTA (Figure 4.1) showing that the positive correlation over the west Pacific Ocean means the decreasing of PC1s related to cooling of SST that leads to increase surface air pressure over the area resulting to enhanced air descending, whereas the negative correlation over the central-east Pacific Ocean means decreasing of PC1s related to warming of SSTA leading decreasing of surface air pressure over the area resulting to weaken wind blowing westward. This results show that there is decreasing of the southward air mass transportation that indicates the NE monsoon is weakened. Aside EAWM, another possible forcing that influences the NE monsoon over the IDP is the forcing from SST in the Pacific Ocean. The relation of ENSO and NE monsoon over the IDP and its impact on environment of the region are of interest for further study.

(a) Strong ZWC for primary part



(b) Strong ZWC for secondary part

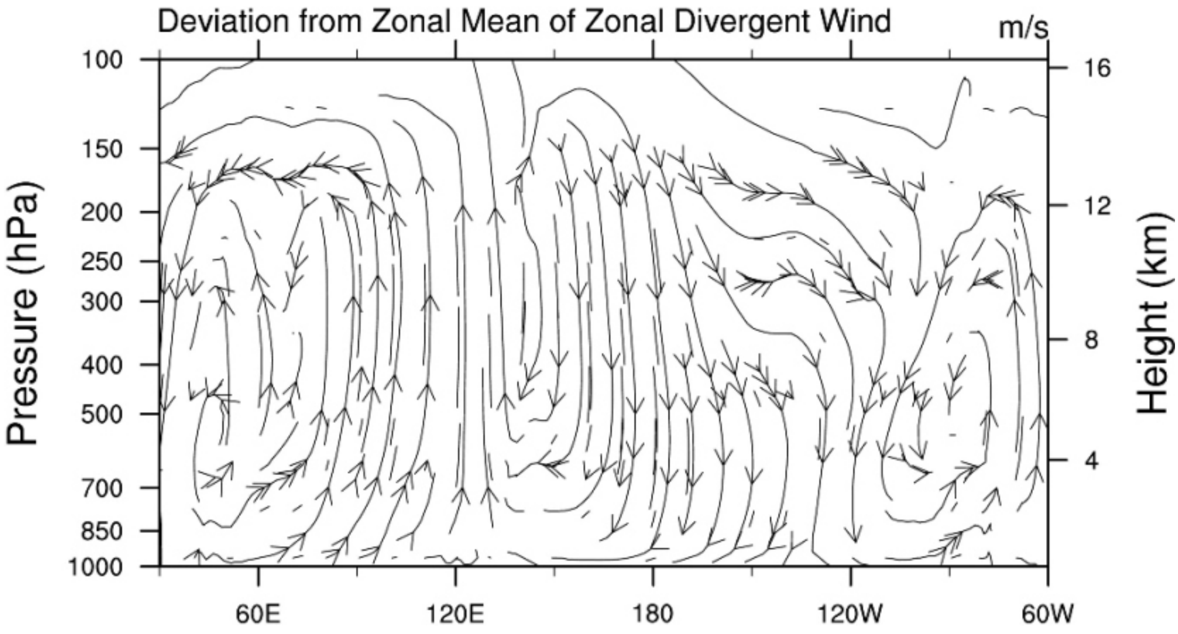
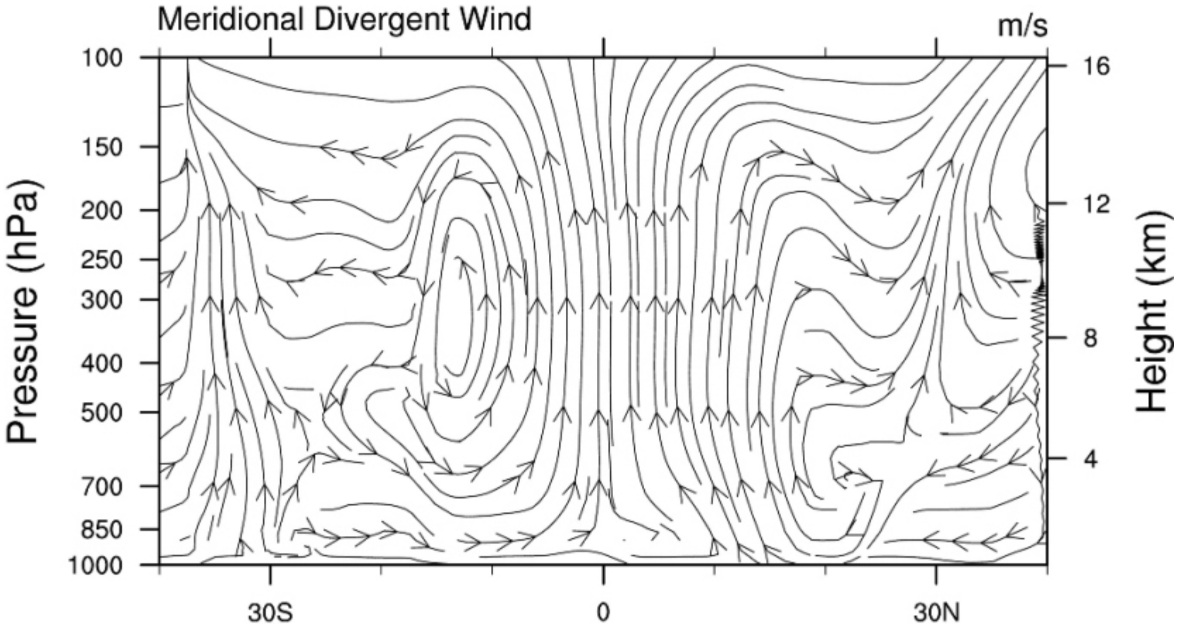


Figure 4.5: The strong phase anomalous ZWC of (a) the primary part of PC1 and (b) secondary part of PC1, whereas (c) and (d) same as (a) and (b) but for the WPHC. Units of zonal wind and vertical speed are m/s and hPa/s, respectively, and the vertical speed scaled by multiplication of 30 to display the circulation cell vectors.

(c) Strong WPHC for primary part



(d) Strong WPHC for secondary part

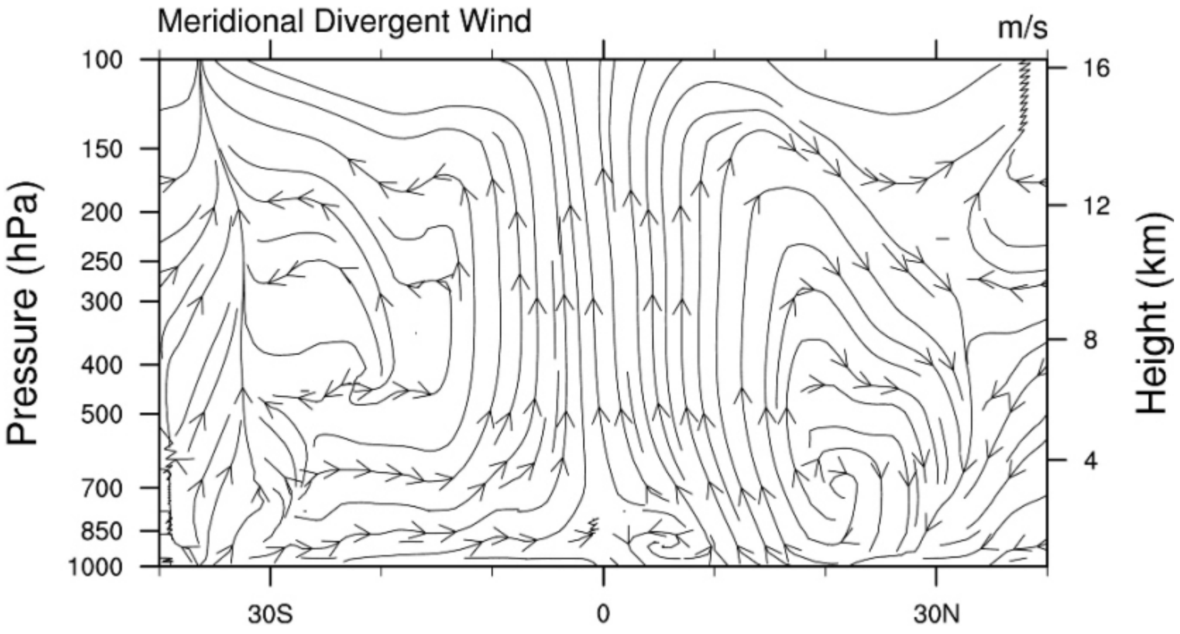
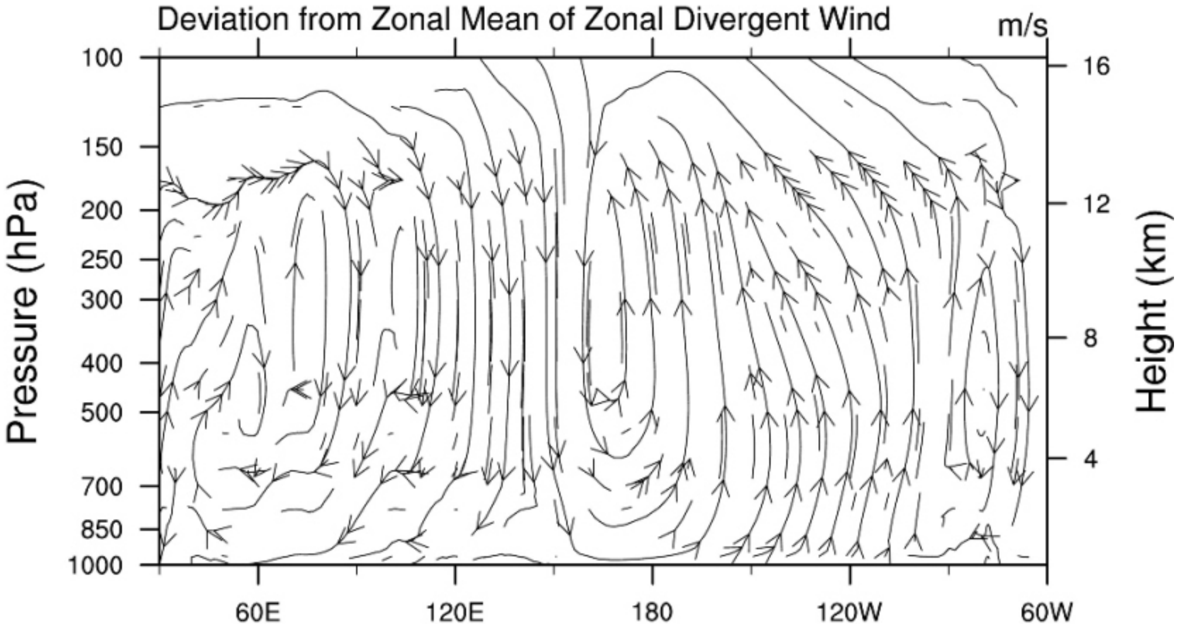


Figure 4.5: The strong phase anomalous ZWC of (a) the primary part of PC1 and (b) secondary part of PC1, whereas (c) and (d) same as (a) and (b) but for the WPHC. Units of zonal wind and vertical speed are m/s and hPa/s, respectively, and the vertical speed scaled by multiplication of 30 to display the circulation cell vectors (Cont.).

(a) Weak ZWC for primary part



(b) Weak ZWC for secondary part

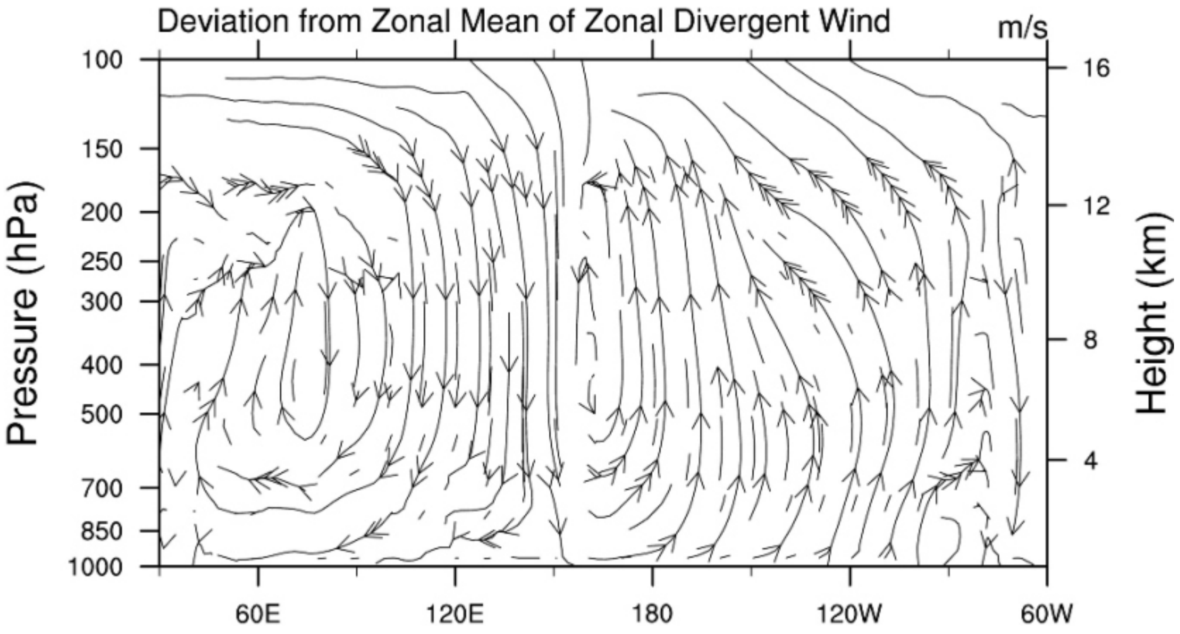
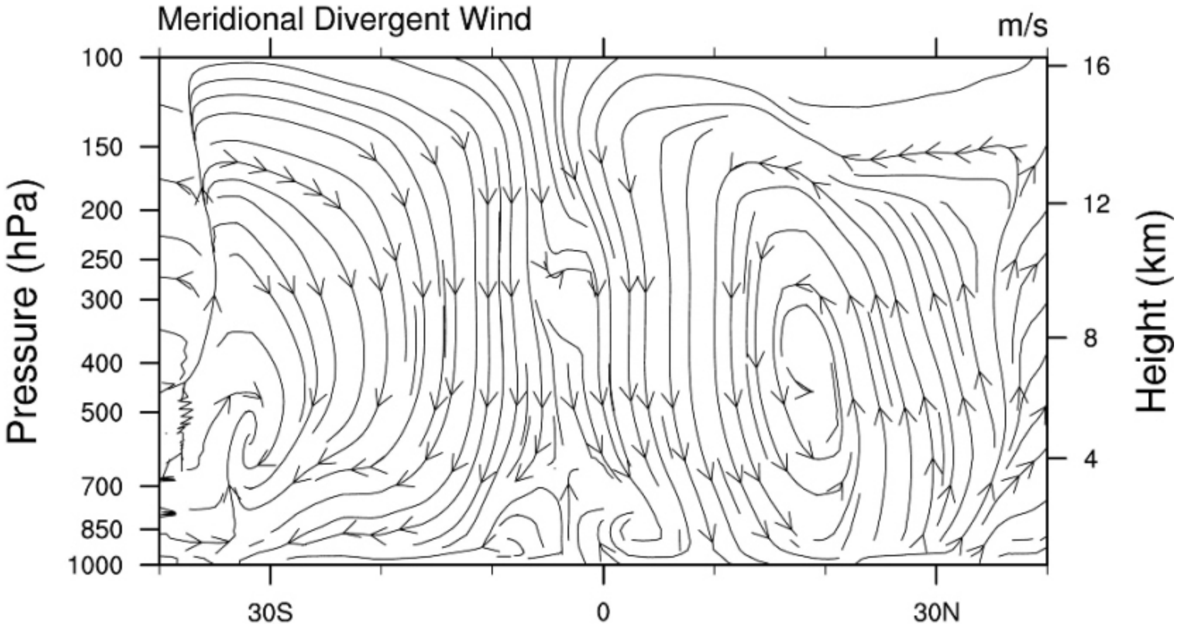


Figure 4.6: The weak phase anomalous ZWC of (a) the primary part of PC1 and (b) secondary part of PC1, whereas (c) and (d) same as (a) and (b) but for the WPHC. Units of zonal wind and vertical speed are m/s and hPa/s, respectively, and the vertical speed scaled by multiplication of 30 to display the circulation cell vectors.

(c) Weak WPHC for primary part



(d) Weak WPHC for secondary part

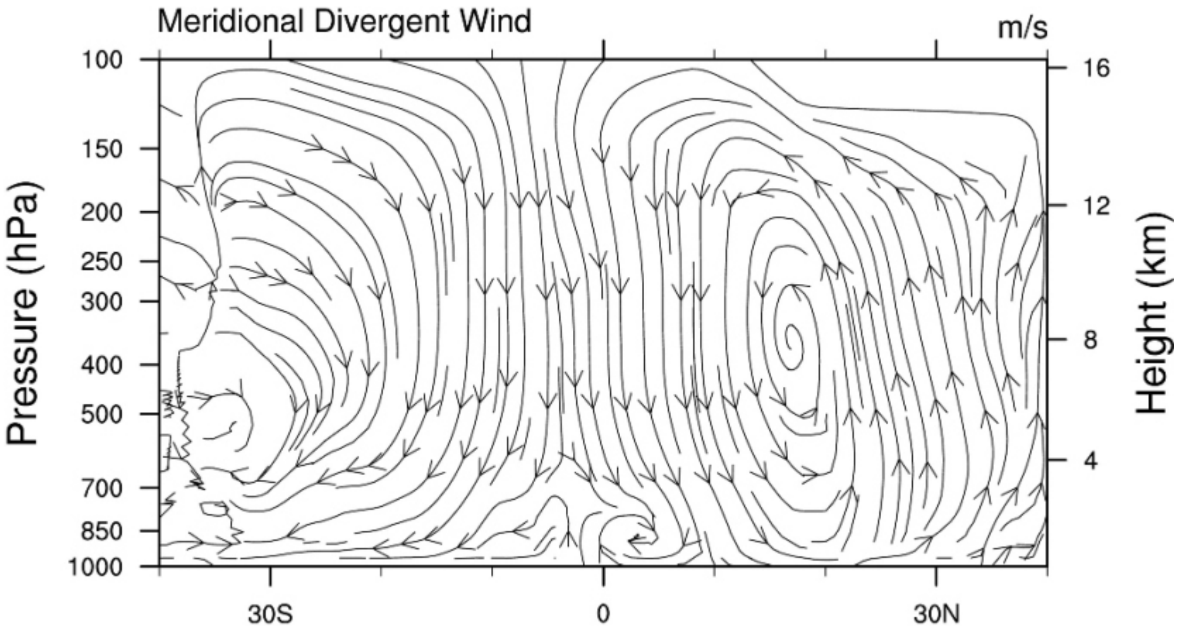


Figure 4.6: The weak phase anomalous ZWC of (a) the primary part of PC1 and (b) secondary part of PC1, whereas (c) and (d) same as (a) and (b) but for the WPHC. Units of zonal wind and vertical speed are m/s and hPa/s, respectively, and the vertical speed scaled by multiplication of 30 to display the circulation cell vectors (Cont.).

4.4 Summary

This section presents another forcing that correlates to the variability of wintertime northeasterly winds over the IDP. The correlation analyses show that there is more significant correlation between PC1s and SSTA in the Pacific Ocean than that in the Indian Ocean. Thus, the possible forcing influences the NE monsoon variability over the IDP is mainly related to SSTA in the Pacific Ocean. It was confirmed by correlations of PC1s to Niño 3.4 and DMI indices. The correlation analyses show that there is association between PC1s and Niño 3.4 index from previous five months to following three months, whereas the correlation between PC1s and DMI is not significant. This indicates that NE monsoon variability over the IDP represented by PC1s associated with ENSO represented by Niño 3.4 index.

In addition, the ZWC presents the enhancement of air ascending in the Southern part of the IDP, and the WPHC presents the enhancement of air ascending around the Equator during the positive phase of PC1s that agrees with the correlations of PC1s with SSTA show warming (cooling) of SST in the west (central-east) Pacific Ocean resulting in strengthening low-level easterly wind in the equatorial Pacific Ocean and air ascending in the West. These result in enhancement of cyclonic circulation near the Borneo during the positive phase as shown in Figure 3.5, and vice versa for the negative phase. There is interesting challenge for understanding more on the winter monsoon over the IDP associated with ENSO such as its impacts on precipitation and temperature.