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Anomalous Winter Monsoon Season of 2012/2013 over the Malaysian Region

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ABSTRACT

The winter monsoon also commonly known as the northeast (NE) monsoon in Malaysia which typically lasts from November to March brings heavy rains to parts of Malaysia that faces the South China Sea (SCS). The eastern parts of Peninsular Malaysia and Western Sarawak in Borneo Island receives more than half its annual rainfall during this monsoon season and most of the heavy rains comes in episodes associated with northeasterly cold surges in the SCS. The NE monsoon season of 2012/2013 was atypical because its onset was earlier than the normal onset date and withdrawal was later than normal but in general its intensity was weaker than normal with fewer occurrences of cold surges. Analysis of the monthly rainfall pattern for the Malaysian region from November to March showed an interesting oscillatory pattern with a monthly cycle over the area most influenced by the effects of the NE monsoon circulation. The JRA25 reanalysis data for the period 1979 to 2012 was used to obtain the monthly climatology for various atmospheric parameters from which the anomaly for the 2012/2013 monsoon season was obtained to elucidate the anomaly in the regional synoptic circulation patterns that contributed to the anomalous rainfall pattern during the monsoon season. One of the main features that were observed during the monsoon season was the strong signal in the convection associated with the westward propagating easterly waves as shown in the OLR anomaly field. The convection associated with the easterly waves with a phase speed of about 30 days originated from the western Pacific and propagated westwards, intensifying over the Malaysian region. Among the other features that was examined which showed clear anomaly patterns in the monthly timescale that explains the anomaly in the observed rainfall are the 850 hPa wind, velocity potential at 200 hPa, vorticiy field, streamfunction and sea surface temperature.

1. Introduction

The Malaysian region experiences both the summer and winter monsoons corresponding to the boreal summer and winter respectively. In Malaysia, the winter monsoon which is commonly known as the northeast (NE) monsoon typically lasts from November to March. It is one of the most spectacular seasonal phenomena in the country. In the first half of the monsoon, east coastal region of Peninsular Malaysia which faces the South China Sea received as much as 50% of its total annual rainfall (Figure 1). However in some active monsoon years, as much as 70% of the annual total rainfall could occur between November and December (Moten et al. 2013). The heavy rainfall events occurred 3-4 times in the seasons are associated with the cold surges. Each episode of heavy rainfall lasting 3 to 5 days with large rainfall amounting to several hundreds to over a 1000 mm often menace the local population. These heavy rainfall events often cause devastating flood to the east coastal region.

Figure 1 : Rainfall distribution map

Previous study (Zhang et al. 1997) indicates that the key driving force for the winter monsoon is the available potential energy generated by the differential heating between land and sea with the main heating source exists near the equatorial western Pacific. The local Hadley circulation in the meridional direction is induced by the latent heat release by the extensive deep cumulus convection in the equatorial western Pacific. Far in the north of the intense convective center, a very strong cold high forms near the Siberian region. This cold dome in Siberia is maintained by the strong radiative cooling, large scale descending Hadley circulation with rising motions over the maritime continents of Indonesia and Borneo, and persistent cold air advection throughout the troposphere (Ding and Krishnamurthi, 1987). Murakami and Unninayar (1977) observed that during this period of maximum eddy kinetic energy at 200mb, the large-scale circulations are characterized by a strong jet stream over Japan. This jet is associated with intense baroclinicity, large vertical wind shear and strong advection of cold air (Lau and Chang, 1987; Boyle and Chen, 1987; Ding, 1994). As a whole, the Siberian high, the East Asian jet, the 500-hPa trough and the convection center near the western Pacific are inherently related to each other in the monsoon systems. These planetary-scale features characterize the winter monsoon circulation.

Although the monsoon systems in Asia show strong annual cycle from year to year, it is well known that the rainfall during the monsoon seasons exhibit considerable interannual (Chen et al. 2000) and intraseasonal variations with typical time scales of between 10 and 60 days (Yokoi et al. 2005). As the large scale circulation of monsoon is driven by the seasonal reversal of the large-scale atmospheric heating, a relatively small percentage of heating variation, when set against large seasonal rainfall totals, can set a dramatic impact to the monsoon. The active and inactive winter monsoon not only control the local weather and climate in East Asian region, but also even influence the convection and sea surface temperature (SSTs) near the Maritime Continent (Chang et al. 1979) and even exert a strong impact on the extratropical and tropical planetary-scale circulation (Chang and Lau 1982). The northeast monsoon season of 2012/2013 was atypical with abnormally low monsoon rainfall recorded in the east coastal regions in Peninsular Malaysia in the first two months of the season (Figure 2).

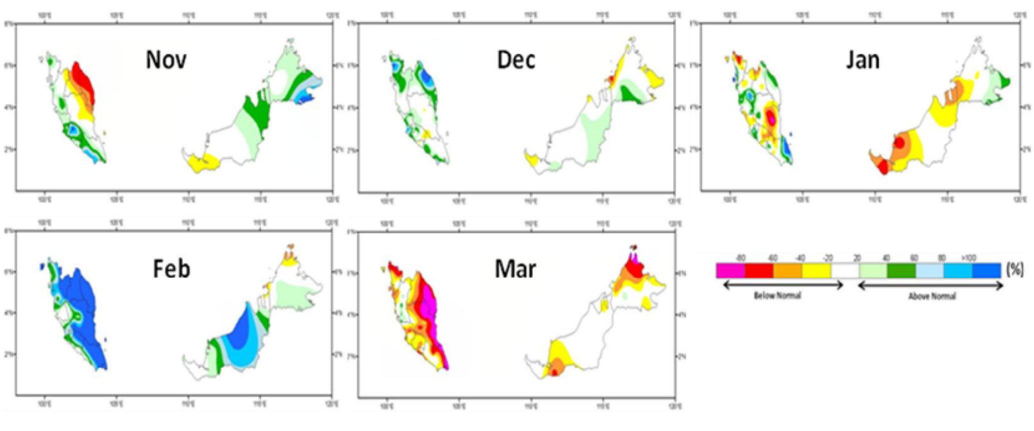

Figure 2: Monthly Rainfall anomaly pattern of winter monsoon 2012/13 season

This work aims to determine the causes of the weaker winter monsoon in the Malaysian region. Although many studies have shown that the El Nino Southern-Oscillation (ENSO) as an important factor that influence the rainfall in Southeast Asia during the monsoon (McBride et al. 2003; Juneng and Tangang, 2005), it is noteworthy that the 2012/2013 season has been identified as ENSO neutral season and therefore its influences will not be studied in this work. The other factor that influences the variation in the rainfall during the monsoon is attributed to the external surface boundary forcing and partly due to its internal dynamics (Kripalani et al. 2004). Therefore, synoptic and large-scale atmospheric disturbances with wide range of time scales ranging from several days to weeks are examined as such disturbances are known to play some role in the rainfall variability during the monsoon seasons. Section 2 briefly explains the data and method used in the present study. In Section 3, results have been given followed by discussion and conclusion in Section 4.

2. Data and methods of analysis

In order to determine the onset of the Northeast Monsoon of 2012/13 season, the method in Moten et al. (2013) is used in this study. In their study, the onset of the Northeast Monsoon in the Malaysian region is defined as at least seven days of average sustainable zonal wind at 925 hPa and 850 hPa within this period, with at least a day with speed greater than 5 knots (approximately 2.5 m/s) in the designated region (Figure 3). The withdrawal of the monsoon is said to be taking place when the easterly weaken to less than 5 knots for 7 consecutive days and westerly wind component starts to penetrate into Malaysian region. The intensity of the cold surges are determined when the average wind speed at the 1000-hPa over the enclosed region exceeded 20 knots and remains so for at least three days.

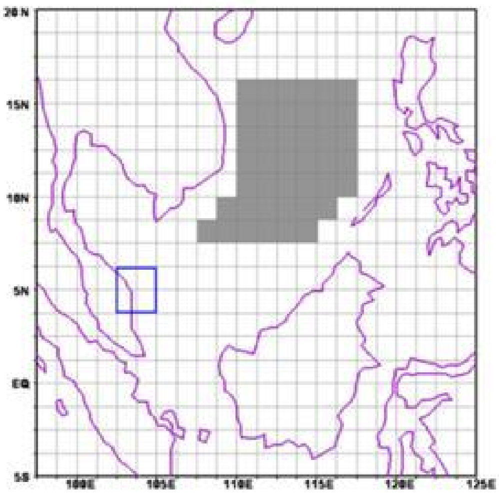

Figure 3: Blue box -region used for computing the onset and withdrawal of NE Monsoon. Grey box - area used to compute the cold surges. Figure after Moten et al. (2013)

To determine the synoptic and large-scale atmospheric circulation, the atmospheric circulation field dataset is obtained from the Japanese 25-year Reanalysis (JRA-25; Onogi et al. 2007) provided by Japan Meteorological Agency (JMA) and Central Research Institute of Electric Power Industry (CRIEPI). The atmospheric parameters such as zonal and meridional wind component (u,v), vertical velocity (w), are used in our studies. For the low level wind, we focus primarily on the 850-hPa wind field in this paper although there are 12 mandatory levels in the tropical troposphere (1000, 925, 850 700, 600, 500, 400, 300, 250, 200, 150 and 100 hPa). In addition, streamfunction (ψ), relative vorticity (ζ) and divergence (Div) were computed. As the Outgoing Longwave Radiation (OLR) is related to the cloud top temperature where the lower value of OLR is the manifestation of deeper cloud and higher OLR represents shallower cloud, an interpolated OLR dataset by JRA-25 was also used in this study. We also analyzed the anomalous field of various atmospheric variables, where the climatological mean is removed. The climatological normal values obtained the JRA-25 are calculated from 1981 to 2010. The monthly SSTs used here are obtained from NOAA.

In addition, the daily rainfall data are obtained from the Malaysia Meteorological Department rainfall stations. In order to investigate the rainfall pattern and variability, 5-day total rainfall starting from 1 October 2012 to 31 March 2013 are standardized and analyzed. This pentad rainfall is quite successful in identifying the rainy periods. In addition to the station rainfall data, gridded Tropical Rainfall Measuring Mission (TRMM) 3B43 monthly data (Huffman et al. 2007) and monthly gridded from Global Precipitation Climatology Project (GPCP) (Adler et al. 2003) rainfall data are also being utilized in this study.

To study the 10-60-day variation pattern in the atmospheric circulation and also the rainfall over the Malaysian region, the significant component of 10-60-day of variable is isolated using the Lanczos bandpass filter (Duchon, 1979) with cutoff periods of 10 and 60 days. Signals with periods longer than 60 days are effectively filtered out. The time-longitude cross section of the 10-60-day variation on OLR averaged between 10°S and 10°N is also examined. This fast moving convective anomaly which moves westward with time which originated from the western equatorial Pacific Ocean and its roles in the winter monsoon will also be discussed in this paper.

Empirical orthogonal function (EOF) is applied to identify quantitatively the dominant spatial and temporal patterns of the OLR, zonal wind and rainfall. In this study, EOF is applied to pentad OLR, zonal wind and rainfall anomalies data. The procedure for computing eigenvectors from a matrix of data is described meticulously by Murakami (1980).

3. Results

In the 2012/13 season, it is found that the onset date for the monsoon falls on 17 October 2012 while the withdrawal of the monsoon falls on 25 March 2013 (Figure 4). This shows that there is an early onset for the 2012/13 NE monsoon as the period of normal onset falls between 22 October and 23 November (Moten et al., 2013). From the same analysis and definition, it shows that the withdrawal date fall within the normal withdrawal dates.

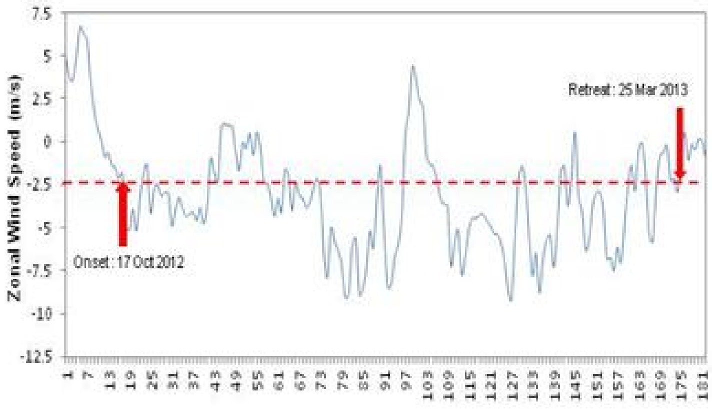

Figure 4 : Onset and Withdrawal date for the 2012/13 Northeast Monsoon

The outbreak of cold air from the Siberian High produces surges of strong northeasterly flow over the South China Sea are a major cause of heavy rainfall over the east coast areas of Peninsular Malaysia and western Sarawak. This strong northeasterly flow is known locally as northeasterly cold surges (CS) and is a common feature during the NE monsoon season. The intensity and frequency of the CS varies from year to year. Using the same method used by Moten et al. (2013), there is only 5 surge events (Figure 5) that took place during the 2012/13 NE monsoon season. The length of the surge days varies from year to year, the current study found that the duration of the surge days are short, with each surges lasting only 3 to 4 days. The first surge occurred on the 22 December compared to climatological average first surge on 25 November. This date falls near to the climatological latest first surge which is on 31 December.

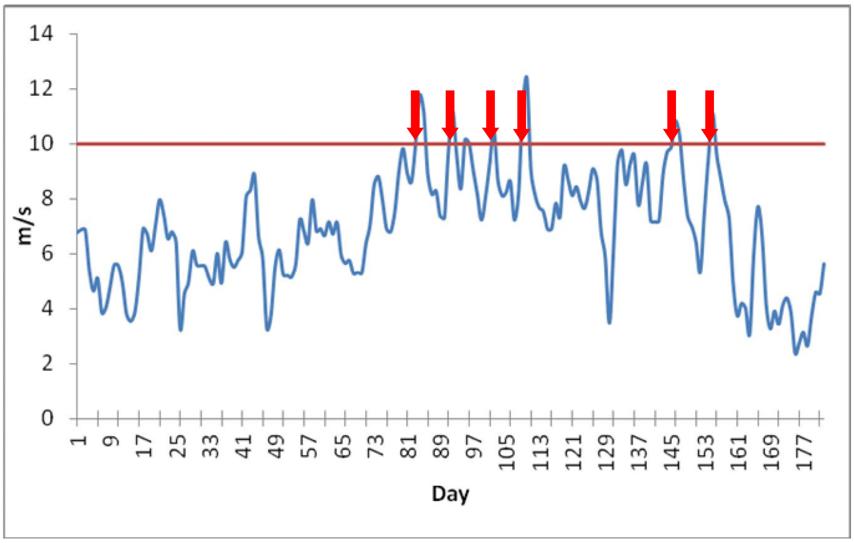

Figure 5: 1000 hPa Wind speed averaged over the enclosed region as defined in Moten et al. (2013). Arrow indicates cold surge event.

The first two eigenmodes of the EOF analysis performed using the pentad rainfall of 22 stations in PM are shown in Figure 6. The spatial distribution of the rainfall for the first mode which explains 20.9% of the variance typifies the intraseasonal variability in the rainfall during the season. The power spectrum for the principal component of this mode (Figure 7) shows an intraseasonal oscillation in the time scale of 15-55 days. The first principal component explains about 98% of the variance of the normalized average rainfall of PM. The time series of first principal component (PC-1) and the normalized rainfall is shown in Figure 8. The second eigenmode typifies the seasonal rainfall character of PM whose spatial distribution clearly resembles the mean climatological Nov-Dec rainfall for PM. The spectrum of the principal component for this mode indicates an oscillation in the time scale of 20-

120 days. The principal component of the second EOF (PC-2) captures about 54% of the variance of the rainfall over the east coastal region of PM. The time series of PC-2 and the normalized average pentad rainfall of 5 stations in eastern PM are shown in Figure 8.

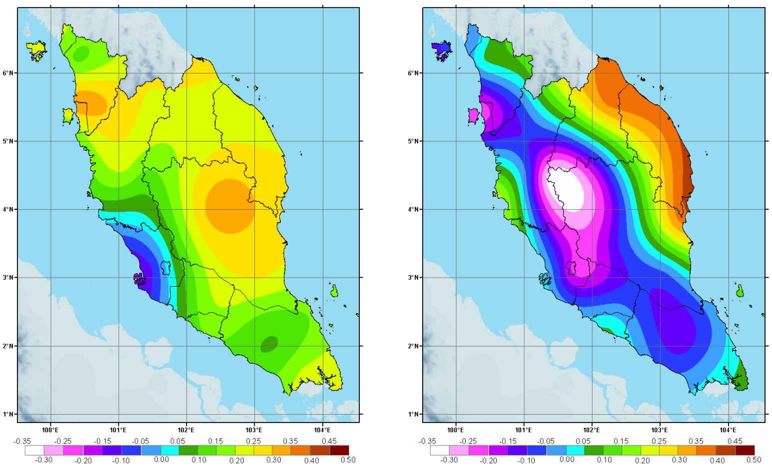

Figure 6 : EOF1 and EOF2 of Station Pentad Rainfall

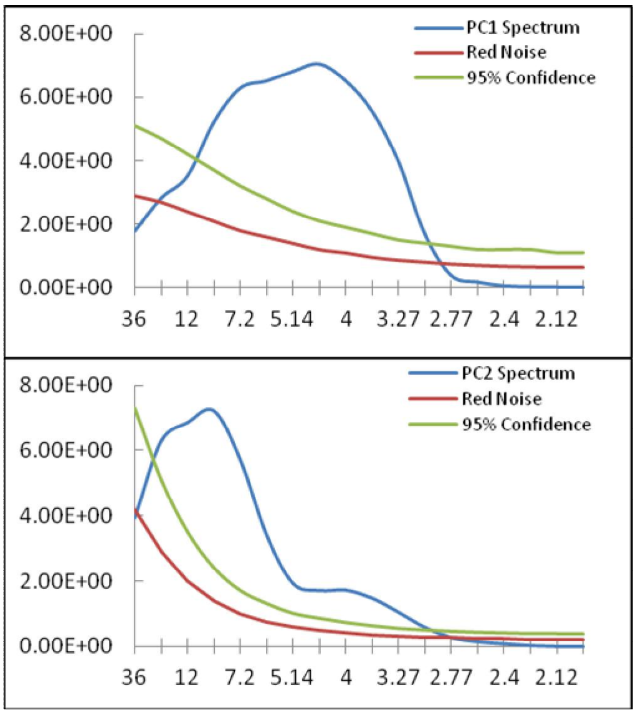

Figure 7 : Spectral Density of PCs

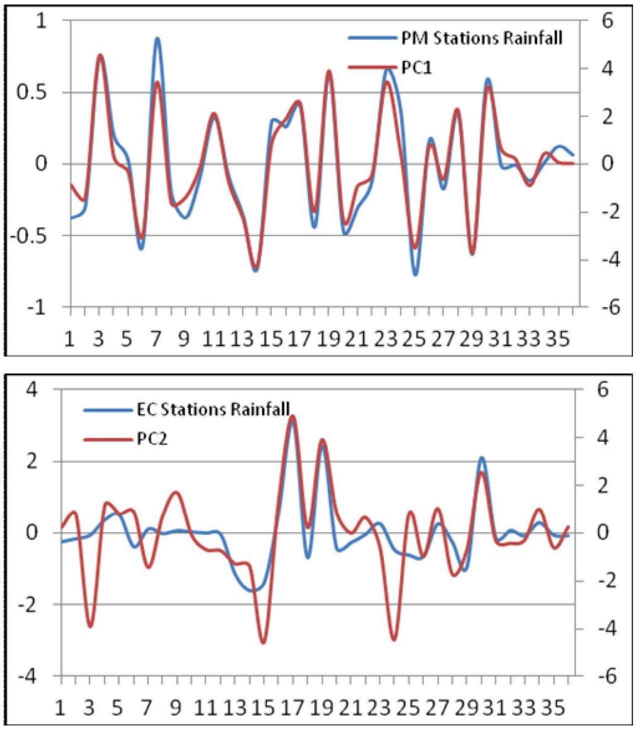

Figure 8 : Time Series of PCs vs. Stations Rainfall

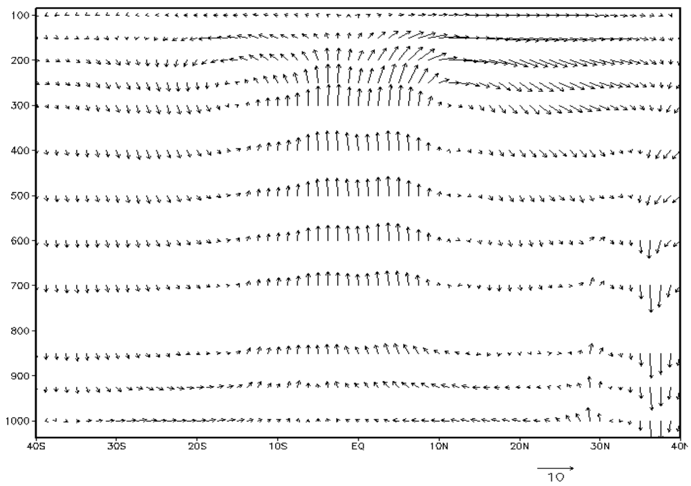
Figure 9 : Mean Monsoon Hadley circulation during 2012/13 monsoon season averaged over 70°-150°E.

To depict the 2012/13 mean monsoon Hadley circulation, we took the isobaric height-latitude section of the wind vectors which is constructed using the meridional wind and negative of vertical pressure velocity wind averaged over the Maritime continent (70°E - 150°E, Figure 9) from October 2012 to March 2013. The ascending motion is found in the equator region. This rising currents at the equator diverged in the upper troposphere and flow poleward as anti-trades to give up heat and subside over the subtropical belt at around 35°N - 40°N. There is also a shallow rising motion at the 27°N - 30°N belt due to the mid-latitude system with its compensating downward motion over the subtropical belt.

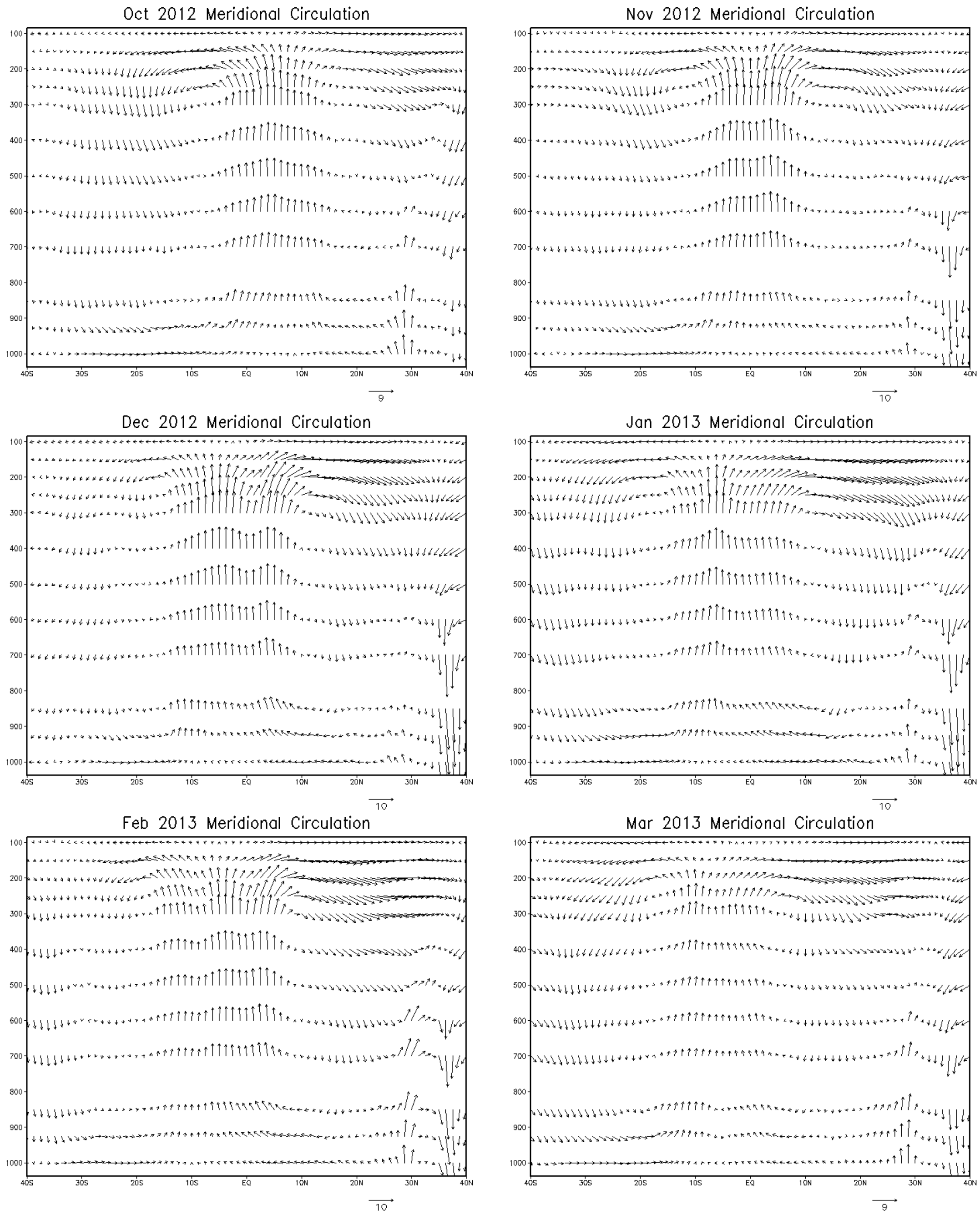

Figure 10 : Monsoon Meriodional Circulation avaraged over 70°-130°E.

Figure 10 depicts the monthly meridional Hadley circulation. In October and November, there is a strong upward motion in the equator region. However this upward motion shifted slightly to the south in December, January and February. In March, the circulation has weaken considerably. Shallow rising motion is found at the 27°N - 30°N belt throughout the period. Strong subsiding motion is found at the vicinity of Siberian cold dome throughout the period.

The 2012/13 winter monsoon 850 hPa anomalous mean circulation is shown in Figure 11. The easterly wind anomalies over the equatorial western Pacific which often associated with the La Nina event are observed in this season. Although the sea surface temperatures (SSTs) in the central and eastern equatorial Pacific were below normal (Figure 12), there is no La Nina event during this period of time. The anomalous easterly wind over the equatorial western Pacific is maintained by the anomalous anticyclonic circulation over the east of Philippines. The anticyclonic circulation in turn is maintained by the subsidence of the Hadley circulation at around 15°N.

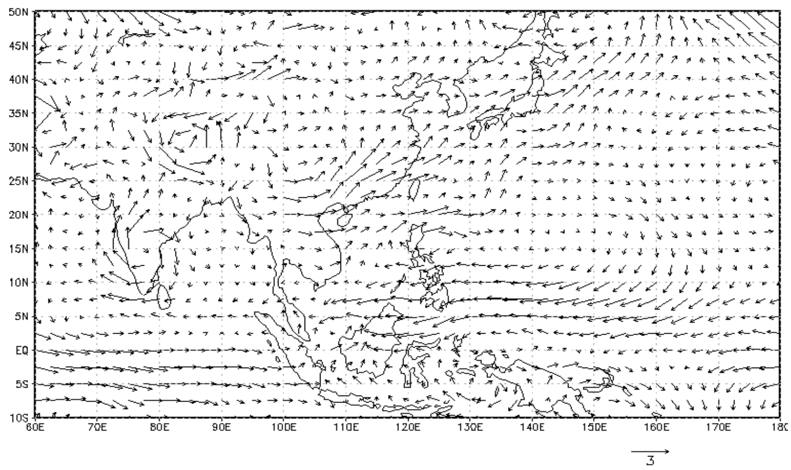

Figure 11 : 2012/13 winter monsoon anomalous mean circulation at 850 hPa

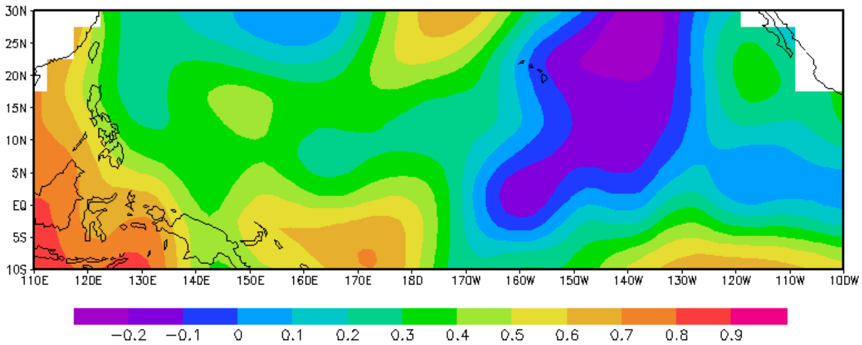

Figure 12 : 2012/13 winter monsoon anomalous mean SST

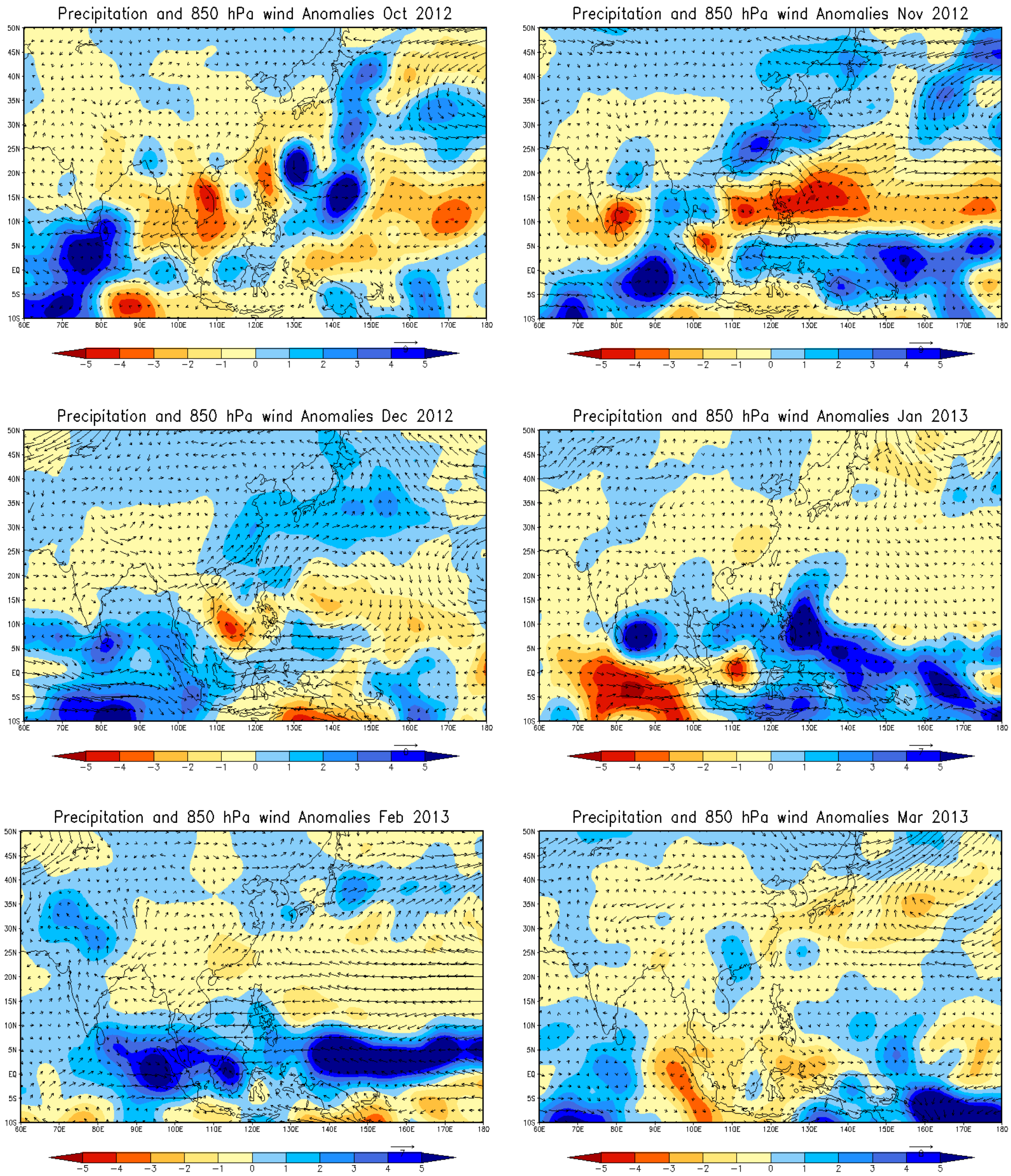

Figure 13 : Precipitation and 850 hPa wind Anomalies

In the monthly horizontal anomalous wind field at the 850 hPa level (Figure 13), there is an anomalous anticyclonic circulation appearing over the southeastern India and east of Luzon in November and December. This indicates that the cold surges are particularly weaker than normal during this period of time. These anomalous anticyclonic vortices then are replaced by the anomalous cyclonic vortices in January. Subsequently, in February, the stronger than usual near equatorial trough over the North Indian Ocean that extended in to Malaysian region enhanced the easterly flow over the region. However, this phase is reversed in March with anomalous westerly penetrating into our region during this period. This anomalous synoptic circulation in the lower troposphere observed between November and March explains the observed rainfall anomaly during this period.

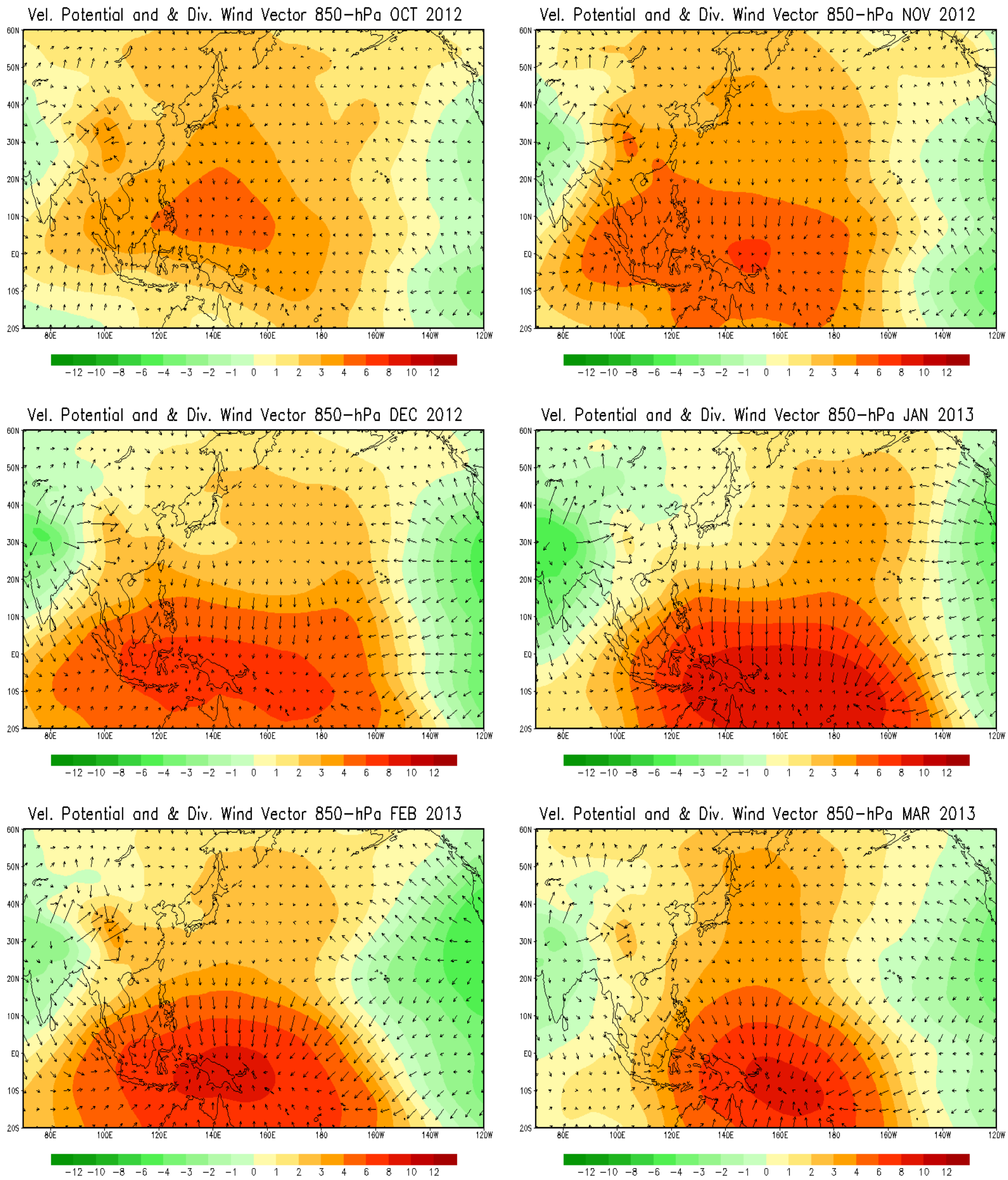

Figure 14: Velocity Potential and Divergent Wind Vector at 850 hPa.

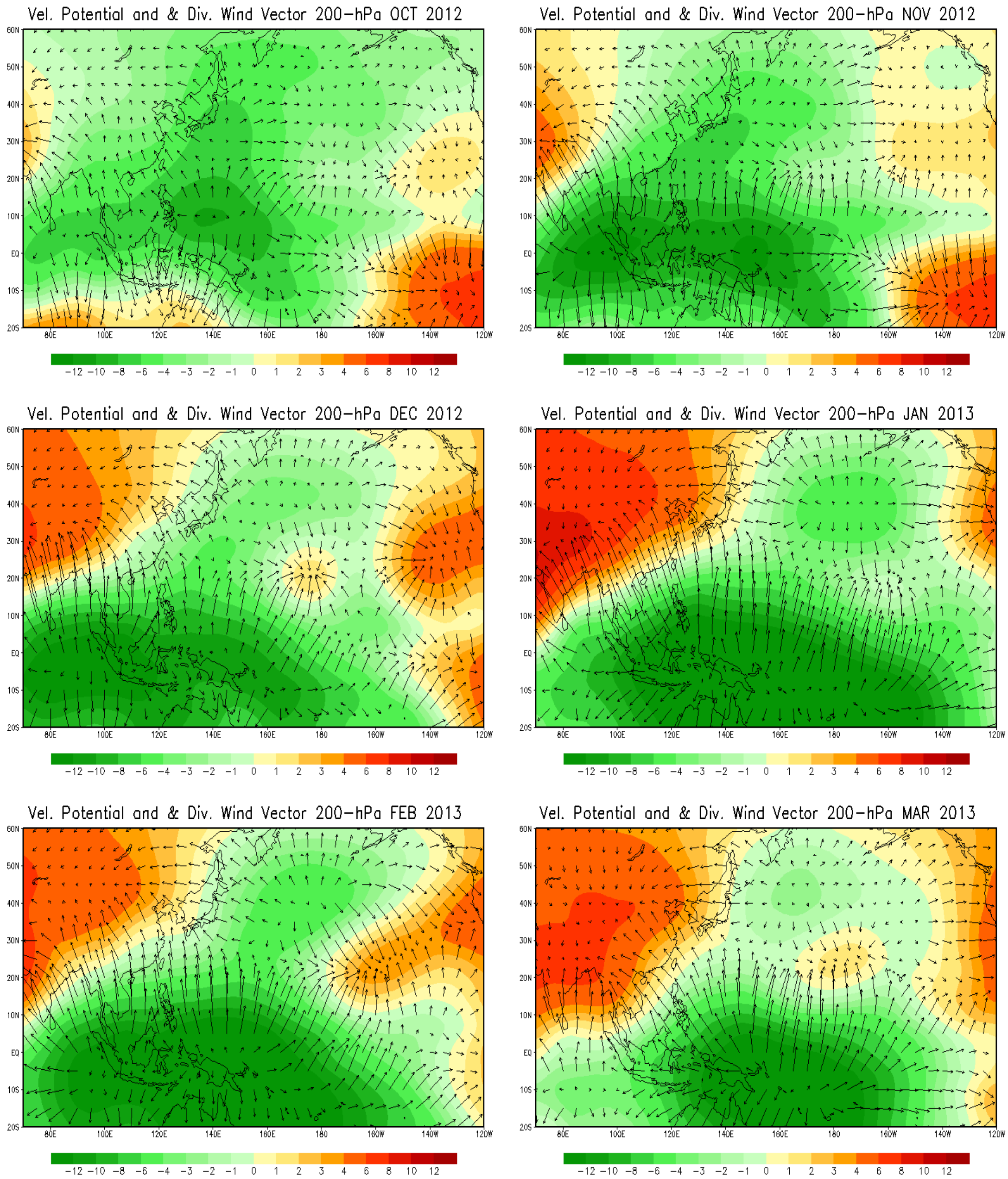

Figure 15: Velocity Potential and Divergent Wind Vector at 200 hPa.

Figure 14 and Figure 15 show the velocity potential and divergent wind vector at 850 hPa and 200 hPa respectively. The velocity potential and divergent wind vector 850 hPa shows that the center of the anomalous low level convergence is located between the 130°E-150°E longitudinal belt. This convergence zone at the western Pacific Ocean moves southward as the monsoon progresses. At the location where the anomalous convergence is located there is anomalous divergence found at the 200 hPa level. The most conspicuous anomaly in the rainfall is observed between February and March and this is well explained by the anomalous divergent flow in the lower and upper troposphere.

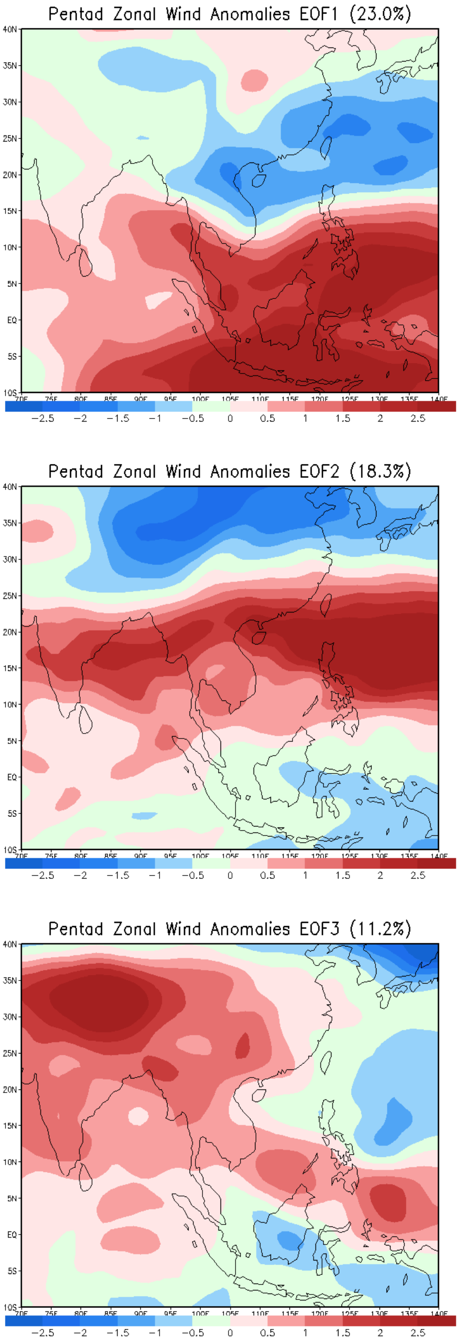

Figure 16 : Pentad Zonal Wind Anomalies

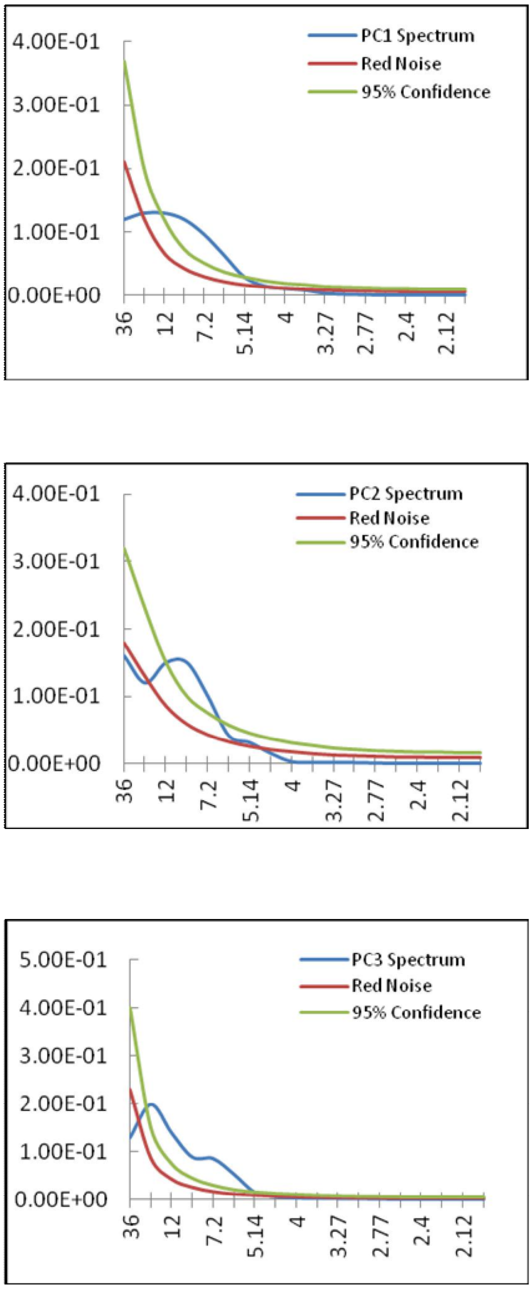

Figure 17 : Spectral Density of PCs

The spatial distribution of the pentad zonal wind anomalies for EOF1 which explains 23% of the variance typifies the intraseasonal variability in the zonal wind during the season is shown in Figure 16. EOF2 and EOF3 typify the seasonal zonal wind pattern. In Figure 17, the spectral density of PCs for EOF2 and EOF3 show 30-75 days oscillation and for the EOF1 a 25-60 days oscillation.

The band pass filtered OLR anomalies averaged between 5°S and 5°N from October 2012 to March 2013 (Figure 18) shows strong signal in the convection associated with the westward propagating easterly waves. The convection associated with the easterly waves having phase speed of about 30 days originated from the western Pacific and propagated westwards, intensifying over the Malaysian region and southern South China Sea.

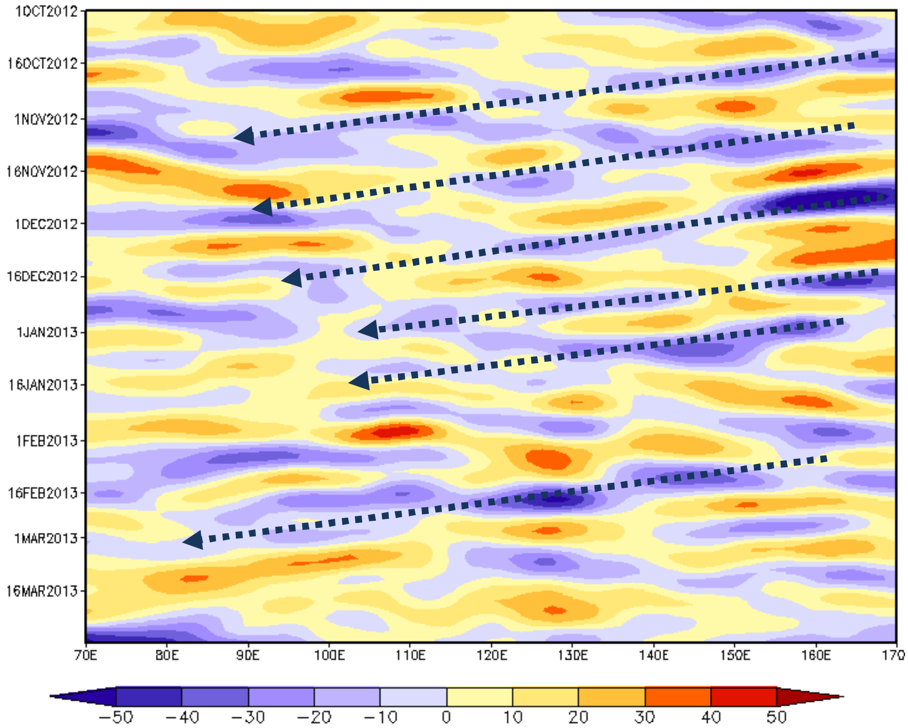

Figure 18 : Band pass filtered OLR anomalies

Figure 19 shows the spatial pattern of EOF1 and EOF2 of the OLR anomalies. It indicates that the convection over the entire Malaysian region is in phase. The spectral density of PCs for EOF2 and EOF3 show a single dominant mode on 30-90 days oscillation band (Figure 20).

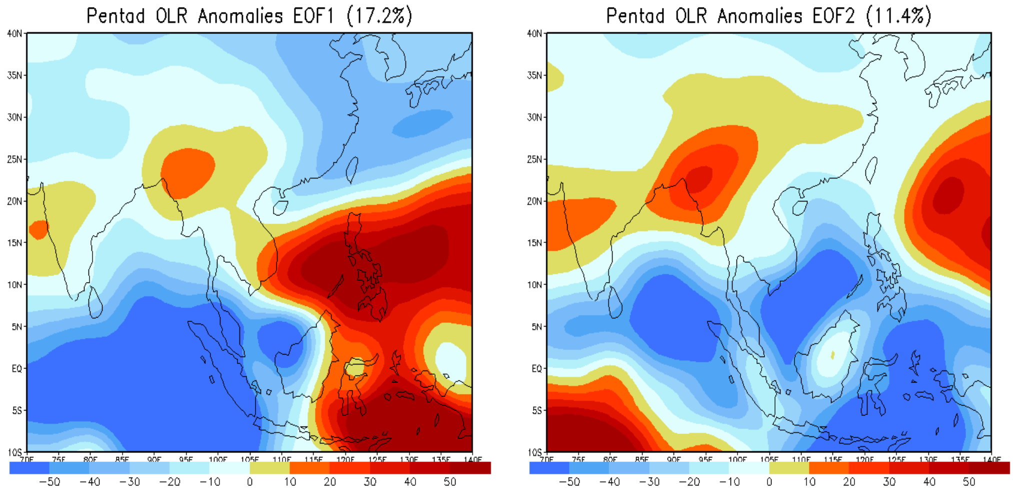

Figure 19: EOF1 & EOF2 of OLR anomalies

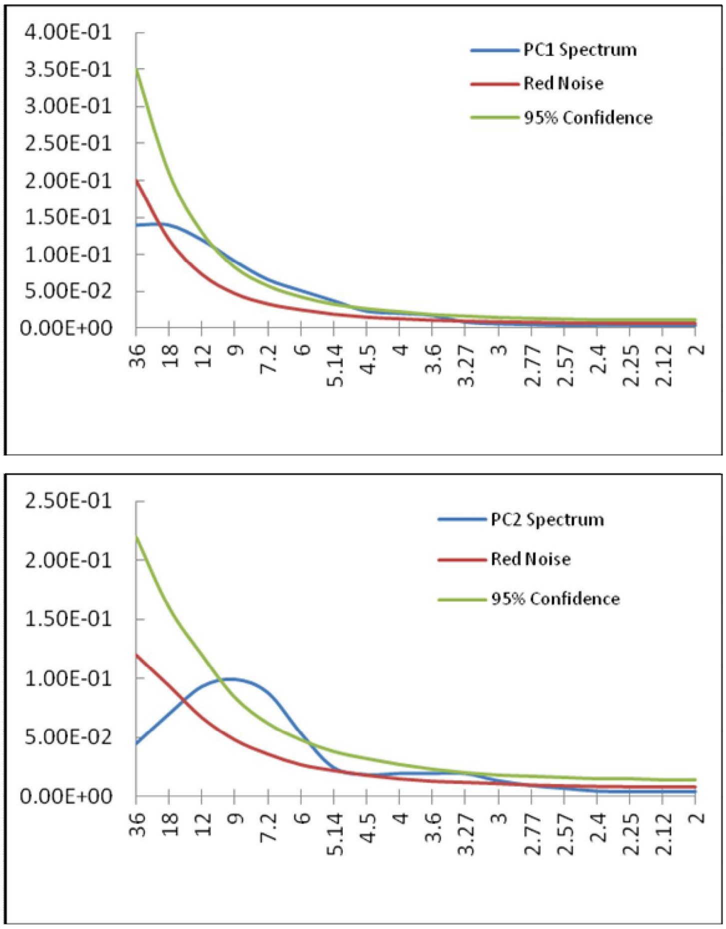

Figure 20: Spectra Density of OLR PCs.

4. Discussion and summary

The winter monsoon of 2012/13 was in general weak in intensity. Typically, the cold surges which are the major cause of heavy rainfall over the east coast of Peninsular Malaysia and western Sarawak occur during the peak monsoon months of December to February. However in this season, the cold surges are particularly weak with the anomalous anticyclonic circulation appearing over the east of Luzon in November and December 2012. These anomalous anticyclonic circulations over the east of Luzon are often associated with weak East-Asian winter monsoon. Obviously this anomalous anticyclonic circulation will maintain the anomalous easterly wind over the equatorial western Pacific. However in January, the anomalous anticyclonic circulation at the east of Luzon is replaced by the anomalous cyclonic circulation. This caused the anomalous westerly to penetrate into the Malaysian region during this period. Although there have been studies linking the anomalous atmospheric circulation with the interannual and interdecadal variability of Hadley Circulation, the dynamic mechanism of the process is not very clear (Zhou et al. 2008).

In this particular season, strong intraseasonal oscillation centered around 35 days period in the rainfall was observed over the Malaysian region. One of the main contributing factors is the westward propagating easterly waves as clearly observed in the OLR fields. In consonance with westward propagation of the convective cells is the anomalous synoptic circulation in the lower troposphere, which further contributed to the spatio-temporal variation in the rainfall distribution between November and March. On a larger scale, over the entire Malaysian region a complete reversal in the rainfall was noted in February and March, which was largely influenced by the anomalous divergent circulation over the South East Asia region in these two months. EOF analysis of the pentad rainfall for Peninsular Malaysia revealed two important modes of variation. The first eigenmode bringing out the intraseasonal oscillation with the PC explaining nearly 98 percent of the variation in the observed pentad rainfall of the season. The second eigenmode represents closely the seasonal pattern in the rainfall distribution over Peninsular Malaysia. The PC of this mode explains nearly 54 percent of the variation of the rainfall over the eastern part of Peninsular Malaysia, which receives the heaviest rains during the monsoon season.

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