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Research Article

RELATIVE VORTICITY AT THE PRESSURE LEVEL 850 hPa AND SSTA IN SOUTHEAST ASIA CAUSING PRECIPITATION ANOMALY OVER THAILAND

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ABSTRACT

Monthly relative vorticity and the relative vorticity anomaly at pressure level 850 hPa are computed to study circulation over Southeast Asia associated with the rainfall over Thailand. Monthly mean rainfall is averaged during the years 1979 to 2013 over Thailand to study the trends of rainfall and to analyze the difference between the SSTA in a dry year (1992) and a wet year (1999), and the precipitation anomaly. Rotation of the relative vorticity over Thailand during the rainy season in 1999 is supported by the westerly wind from the Indian Ocean. Relative vorticity over Thailand in October to December are brought by the wind from the east toward the west of the South China Sea. The positive value of relative vorticity in 1992 is less than in 1999. This is consistent with the precipitation anomalies in 1992 and 1999. Clearly, the rainfall and precipitation anomaly over Thailand in wet year 1992 and dry year 1999 are consistent with the relative vorticity at pressure level 850 hPa. Both years are also associated with the SSTA. It can be concluded that the large amounts of rainfall over Thailand are associated with the positive values of relative vorticity at pressure level 850 hPa and SSTA over Southeast Asia. The daily relative vorticity at pressure level 850 hPa and SSTA over Southeast Asia during Typhoon Linda is analyzed in the research. The positive value of relative vorticity is consistent with circulation during Typhoon Linda which is brought by winds from the South China Sea, and the SSTA is also unusual over the Gulf of Thailand and the Andaman Sea. These are the causes of violent storms in Thailand during Typhoon Linda.

Keywords: relative vorticity, SSTA, precipitation anomaly

INTRODUCTION

Natural disasters over Thailand are influenced from Tropical cyclones over Southeast Asia. Tropical cyclones and typhoons form in the tropical ocean, which has very warm sea surface temperatures and causes violent storms [Holton 2004]. In 1997, Dillon and Andrews [1997] reported that a tropical cyclone formed over the South China Sea and Tropical Storm Linda was speeding westward over southern Vietnam on November 2, 1997. The effects of Tropical Storm

Linda occurred not long after that in the Gulf of Thailand on November 3, 1997, shortly after moving into the Andaman Sea, causing severe weather in Thailand. Furthermore, the wettest year in the 61 period is 2011, which caused more rainfall in Thailand, especially during the summer and rainy seasons. It is recorded by the Climatological Center, Meteorological Development Bureau, Thai Meteorological Department [2015].

The relative vorticity related to cyclonic storms in the Northern Hemisphere and Southern Hemisphere, and its importance to analyze the weather is explained by Holton [2004]. According to Bartzokas et al. [2003], the correlation between the relative vorticity at 850 hPa with the precipitation in Greece and precipitation patterns indicated a relative vorticity mean anomaly over southern Europe. Wang et al. [2008] advised that atmospheric general circulation models of the past changes in Tibetan Plateau temperatures associated with the East Asia summer rainfall, and the increase of Tibetan Plateau temperatures may cause more summer rainfall in the East Asia area. Yue and Wang [2008] asserted that the spring North Asia cyclone (NACI) in the inter-annual variability had a significant positive correlation with the previous winter Southern Annular Mode index (SAMI) and the temperature gradient over South China with a strong low and high level. Krishnamurthy and Kirtman [2009] found that the slowly varying sea surface temperature (SST) anomalies in the areas of the Pacific and Indian Oceans were related to the monsoon rainfall over India. Felton et al. [2013] presented that the Bay of Bengal tropical cyclone activity was associated with the negative sea surface temperature (SST) anomalies of Niño3.4. Chen et al., [2013] concluded that tropical cyclones (TC) in the Philippine Sea developed from the warm SST anomalies, positive relative vorticity anomalies, and moved to the western boundary of the unusual anticyclone, crossing the northern Philippines toward eastern Taiwan or toward the open oceans, southwest of Taiwan. In 2014, Shukla [2014] studied the intra-seasonal variability of the Asian summer monsoon, which showed westerly 850 hPa wind anomalies to be the strongest and monsoon intra-seasonal oscillation was associated with the Indian summer monsoon rainfall.

As a result of these studies, we can identify an association between the relative vorticity at the pressure level 850 hPa and sea surface temperature anomaly (SSTA) over Southeast Asia which caused more rainfall over Thailand during 1979 to 2013 as well as the period of Typhoon Linda, during a dry year, and a wet year. These anomalies are beneficial to the prevention of natural disasters, including management of the water budget in Thailand

MATERIALS AND METHODS

Data sources

The daily sea surface temperature anomalies in 1–7 November 1997 are used in this study from NOAA OI SST V2 High Resolution Dataset with 0.25×0.25 degree resolution [The NOAA OAR/ESRL 2015]. The monthly sea surface temperature anomaly with resolution is 5.0×5.0 degrees taken from Kaplan Extended SST V2 data [The NOAA 2015]. The daily and monthly mean of wind vectors (*u* and *v*) are obtained from NCEP/NCAR Reanalysis datasets which have a resolution of 2.5×2.5 degrees at pressure level 850 hPa [The NOAA OAR/ESRL 2015, The NOAA 2015]. Moreover, the monthly mean precipitation over Thailand is acquired from GPCP (Global Precipitation Climatology Project) Version 2.2 Combined Precipitation Dataset; it is resolution 2.5×2.5 degrees. All data has been taken from the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA [The NOAA/OAR/ESRL 2015]. The study area is Southeast Asia, which is defined by the latitude 0–25°N and the longitude 85–120°E. The Southeast Asia coastline uses the coastline extractor, which was created by Signell [2014] of the U.S. Geological Survey / Geologic Division / Coastal and Marine Program / Woods Hole Field Center.

The relative vorticity

The relative vorticity is suggested by Holton [Holton 2004] and is calculated by

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \tag{1}$$

where: ζ is the relative vorticity;
u and *v* are the vector wind components;
x and *y* are the directions along longitude and latitude, respectively.

The relative vorticity in equation (1) is computed at the pressure level 850 hPa over Southeast Asia. Equation (1) can be described as a positive value and indicates that the rate of change of *v* along the x-axis is greater than the rate of change of *u* along the y-axis and is rotated counter clockwise. The negative value indicates that the rate of change of u along the y-axis is greater than the rate of change of v along the x-axis and is rotated clockwise [Kroon 2016, Harwood 2016]. The approximation of the relative vorticity in equation (1) is suggested by Kroon [2016] and is defined by

$$\zeta_{ij} \approx \frac{v_{i+1} - v_{i-1}}{2\Delta x} - \frac{u_{j+1} - u_{j-1}}{2\Delta y}, \quad (2)$$

where: i and j are the indexes along x and y directions.

The relative vorticity anomaly

The relative vorticity anomaly over Southeast Asia during the years 1979 to 2013 at pressure level 850 hPa is calculated by

$$\zeta_A = \zeta - \bar{\zeta}, \quad (3)$$

where: ζ_A is the relative vorticity anomaly (1/s); $\bar{\zeta}$ is the mean of the vorticity (ζ) during the years 1979 to 2013. The relative vorticity and the relative vorticity anomaly daily and monthly is computed to study the circulation over Southeast Asia.

The precipitation anomaly is analyzed to study unusual rainfall over Thailand, and is computed by

$$PA = P - \bar{P}, \quad (4)$$

where: PA is the precipitation anomaly (mm/day); P is the precipitation; $\bar{P}$ is the mean of the precipitation during the years 1979 to 2013. The anomaly in Equation (3) and (4) is suggested by Bell [2016].

The relative vorticity at the pressure level 850 hPa and SSTA over Southeast Asia was analyzed daily during Typhoon Linda. The monthly relative vorticity and the relative vorticity anomaly at the pressure level 850 hPa are computed to study circulation over Southeast Asia associated with rainfall over Thailand. The monthly mean rainfall in this study is taken from GPCP [Adler et al. 2003] which is averaged over Thailand during the years 1979 to 2013 to study the trends of rainfall and precipitation anomalies. In addition, the difference between the SSTA in wet year 1999 and dry year 1992 is analyzed. The SSTA data has been taken from Kaplan Extended SST V2 data [The NOAA 2015].

RESULTS AND DISCUSSION

The association between the vorticity and precipitation over Thailand

The average relative vorticity at pressure level 850 hPa during the years 1979 to 2013 are shown in Figure 1. The results show that 1999 has the highest value, followed by the year 2011. Both years have positive relative vorticity anomalies as shown in Figure 2, which is more than normal. The relative vorticity has the lowest value in 1997, followed by 1983, 1987 and 1992, respectively (Figure 1). The analyses of relative vorticity anomaly in Figure 2 during those years are also consistent. Those results are linked with average rainfall over Thailand during 1979 to 2013, and shows clearly that 1999 is the year of the highest rainfall, but 1992 is the year of lowest rainfall (Figure 3). The average precipitation anomaly over Thailand during 1979 to 2013 in

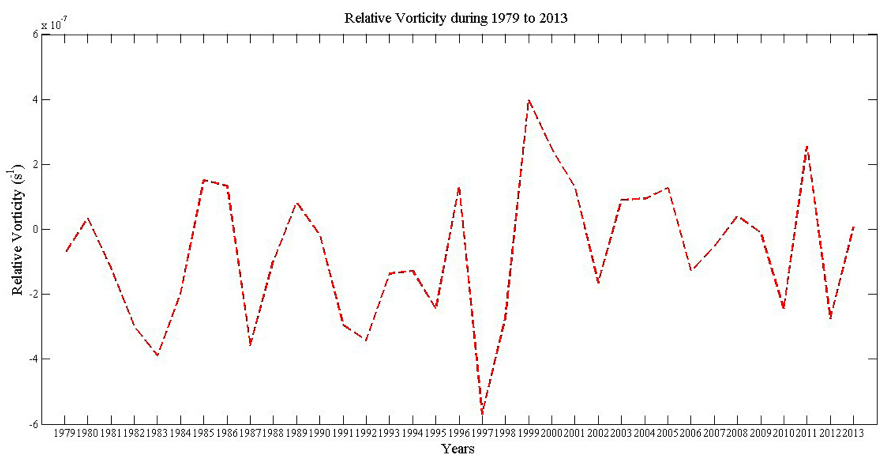

Figure 1. The average of relative vorticity (1/s) over Southeast Asia during 1979 to 2013 at pressure level 850 hPa.

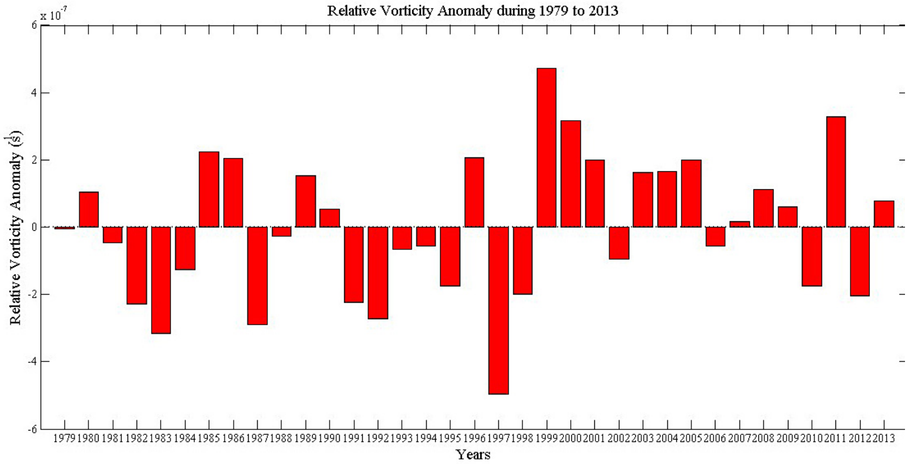

Figure 2. The average of relative vorticity (1/s) anomaly over Southeast Asia during 1979 to 2013 at pressure level 850 hPa.

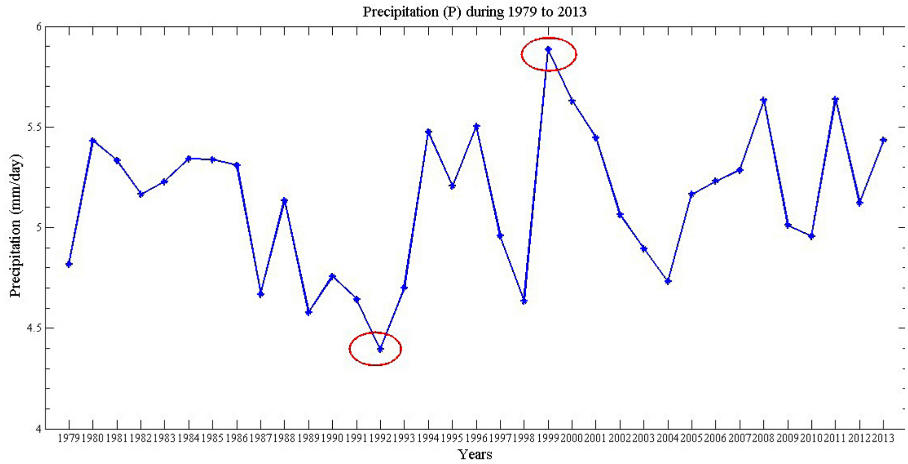

Figure 3. The precipitation (mm/day) taken from GPCP dataset [Adler rt al. 2003] is averaged during 1979 to 2013 over Thailand.

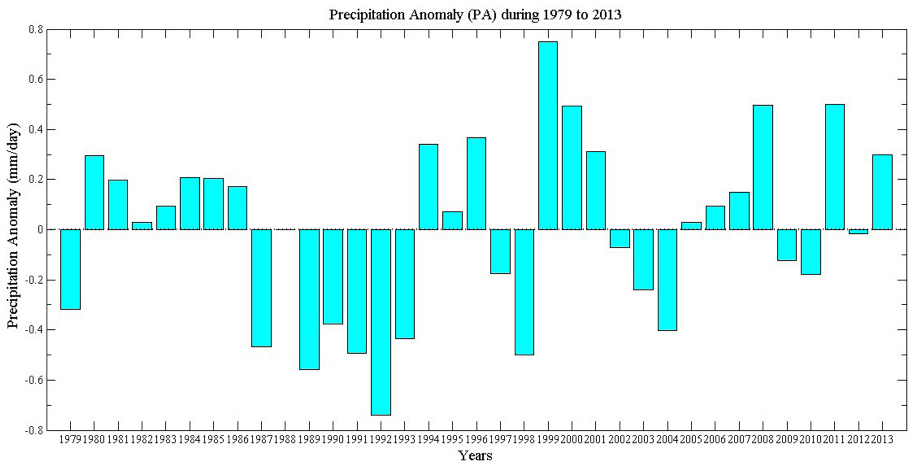

Figure 4. The average of precipitation anomaly (mm/day) during 1979 to 2013 over Thailand.

Figure 4 also shows unusual rainfall in 1999 and 1992. The highest precipitation anomaly in 1999 infers higher rainfall than normal, while the lowest precipitation anomaly in 1992 infers the rainfall is less than normal. Although 1997 was the year of typhoon Linda, creating severe losses to Thailand, it lasted only a short time, just a few days. When calculated, the average annual rainfall that year did not have higher rainfall.

We can analyze drought years and wet years as follows. The relative vorticity over Southeast Asia at pressure level 850 hPa in dry year, 1992, during January to December are shown in Figure 5(a) to Figure 5(l). They show that the positive values of relative vorticity from June to December are stronger than other months. Starting with the relative vorticity, June and July have positive values over the Gulf of Thailand and the southern

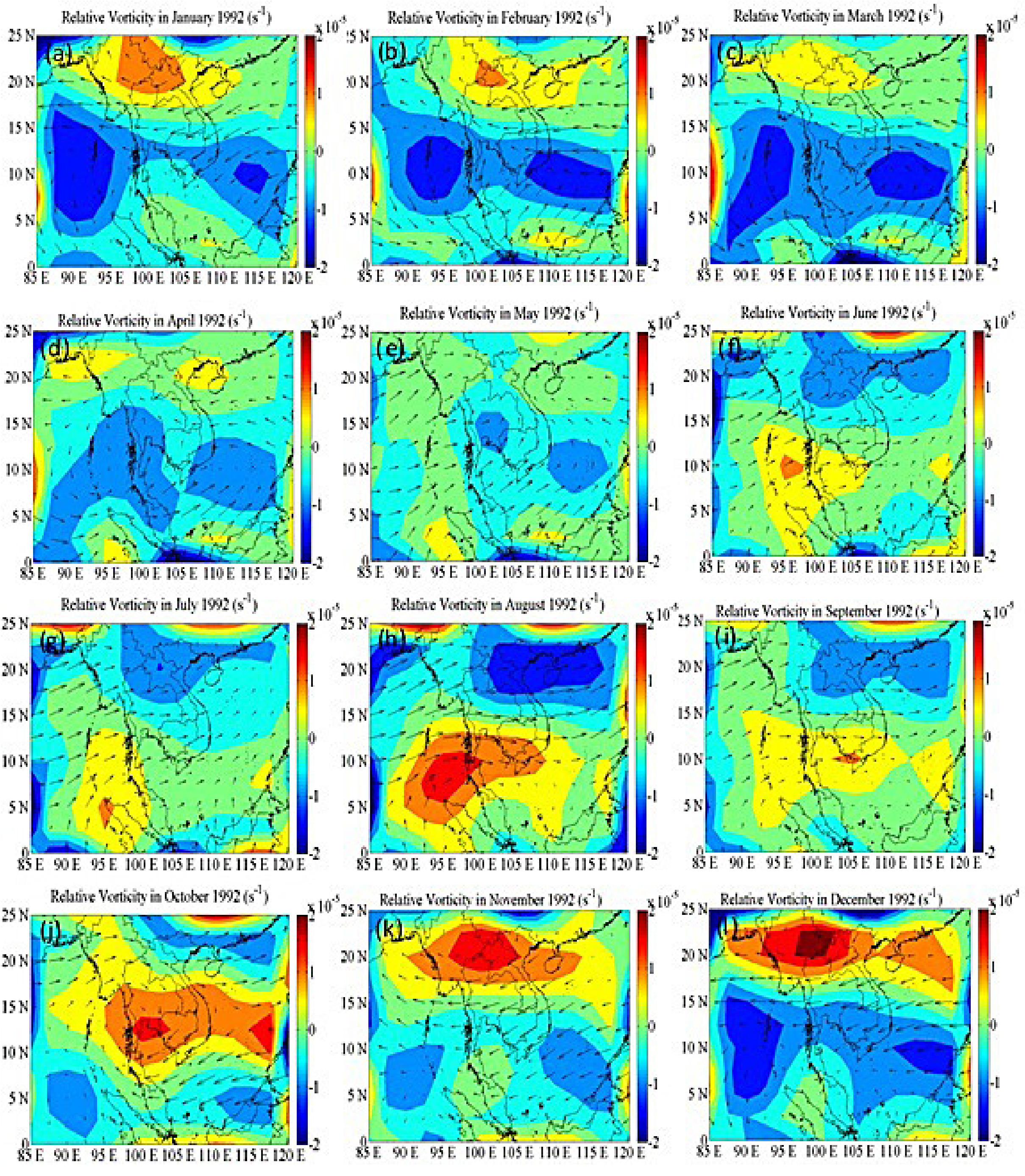

Figure 5. The relative vorticity (1/s) over Southeast Asia at pressure level 850 hPa in dry year, 1992, during (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December.

coast of Thailand (Figure 5(f) and Figure 5(g)). The relative vorticity has strong positive values over the Gulf of Thailand and the Andaman Sea during August (Figure 5(h). During September to October there is strong, positive, relative vorticity over the Gulf of Thailand and the South China Sea (Figure 5(i) and Figure 5(j)). The wind vector changed direction in October, and with a clear change of direction from east to west in November, giving a strong, positive relative vorticity in North Thailand, continuing through December (Figure 5(j) to Figure 5(l)). All this may be the cause of more rainfall during this period. However, during January to May, the month of December showed a negative relative vorticity in the Bay of Bengal, the Andaman Sea, the Gulf of Thailand and the South China Sea, which is winter and summer in Thailand (Figure 5(a) to Figure 5(e), Figure 5(l)).

In the wet year, 1999, a strong negative value of relative vorticity occurred during January through March in the North of Thailand and the winds blew from East to West (Figure 6(a) to Figure 6(c)). Starting in April, the wind changed direction, blowing from West to East in Thailand, with positive values of relative vorticity in the Bay of Bengal and the Andaman Sea until September (Figure 6(d) to Figure 6(i)). Strong positive values of relative vorticity during June to September are supported by the wind blowing eastward from the Indian Ocean during the rainy season in Thailand (Figure 6(f) to Figure 6(i)). After that, the strong positive values of relative vorticity moved to the top of Thailand. In October to December, the wind direction changed to a westerly wind, blowing from the South China Sea, causing strong positive values of relative vorticity in Northern Thailand. That may be the cause of the circulation over Northern Thailand (Figure 6(j) to Figure 6(l)). Similarly, the positive value of relative vorticity in January and February 1999 were strong over Northern Thailand (Figure 6(a) to Figure 6(b)). Commotion relative vorticity throughout the year could have been the cause of the storm winds, causing rainfall to be higher in 1999 than in a normal year.

Furthermore, comparison of SSTA data, which has been taken from Kaplan Extended SST V2 data [The NOAA 2015] between 1992 and 1999 over Southeast Asia and the difference of SSTA between 1992 and 1999 are shown in Figure 7, Figure 8 and Figure 9. The SSTA during January to April and October to December in 1999 are strong over the Andaman Sea, the Gulf of Thailand and the South China Sea. In 1992, the SSTA is strongest during April to June over the Gulf of Thailand. Analysis of the difference of SSTA between the wet year (1999) and the dry year (1992) shows that the SSTA during January to April and October to December 1999 are more than in 1992 over the Andaman Sea, the Gulf of Thailand and the South China Sea, while the SSTA during May to September 1992 are more than in 1999 over the Gulf of Thailand. This shows that the rainy season in Thailand had higher than normal sea surface temperatures, and sea surface temperatures in the wet year was greater than in the dry year, which corresponds to a rotation of relative vorticity. The analysis of the SSTA and the difference of SSTA between 1992 and 1999 was found to be consistent with rainfall and relative vorticity.

THE VORTICITY AND SSTA DURING TYPHOON LINDA

Figure 10 shows the relative vorticity at pressure level 850 hPa with wind vectors u and v during Typhoon Linda on November 1–7, 1997. On November 1–4, 1997 (Figure 10(a) to Figure 10(d)) strong positive vorticity over Gulf of Thailand at pressure level 850 hPa was presented, and it had a counter clockwise rotation. The strong wind derived from the northeast toward the west (South China Sea toward Thailand). On November 1, 1997 wind spanning wind vectors u and v blew with violence from the South China Sea causing a relative vorticity with a very positive value over the Andaman Sea and having a positive value over the Gulf of Thailand (Figure 10(a)). The relative vorticity on November 2, 1997 was also positive in the Gulf of Thailand (Figure 10(b)), and it was a more positive value of relative vorticity over the Gulf of Thailand on November 3 and 4, 1997 (Figure 10(c) to Figure 10(d)). The most positive value of relative vorticity over the Gulf of Thailand occurred during November 4, 1997 (Figure 10(d)). After that the winds moved to the southern coast of Thailand on November 5, 1997 and blew toward the Andaman Sea into the Bay of Bengal (Figure 10(e)). The positive vorticity on 6–7 November 1997 moved to the Andaman Sea and the Bay of Bengal (Figure 10(f) to Figure 10(g)). The result was the cause of violence rainfall in Thailand during Typhoon Linda according to the study associated with Dillon and Andrews [1997] and Aschariyaphotha, et al. [2011]. The SSTA on November 1–7, 1997 over Southeast Asia are plotted in Figure 11 taken from NOAA OI SST V2 High Resolution Dataset [Reynolds et al. 2007]. The consistency of the

SSTA analysis found that the SSTA on November 1, 1997 and November 2, 1997 have stronger positives than other days (Figure 11(a) and Figure 11(b)). It shows that the temperature anomalies can clearly explain sea surface temperatures that are higher than normal. The positive SSTA on November 3, 1997 continued strong near the Gulf of Thailand and the Andaman Sea (Figure 11(c). The SSTA was less severe during November 4–7, 1997, but violence is clearly seen in the Andaman Sea and the Bay of Bengal (Figure 11(d) to Figure 11(g)). The SSTA over the South China Sea and the Gulf of Thailand have strong positives during this period. This means that the SST was greater than normal. The high SSTA is probably another reason for the intensity of the rainfall during the period. So there is a correspondence between the relative vorticity and SSTA.

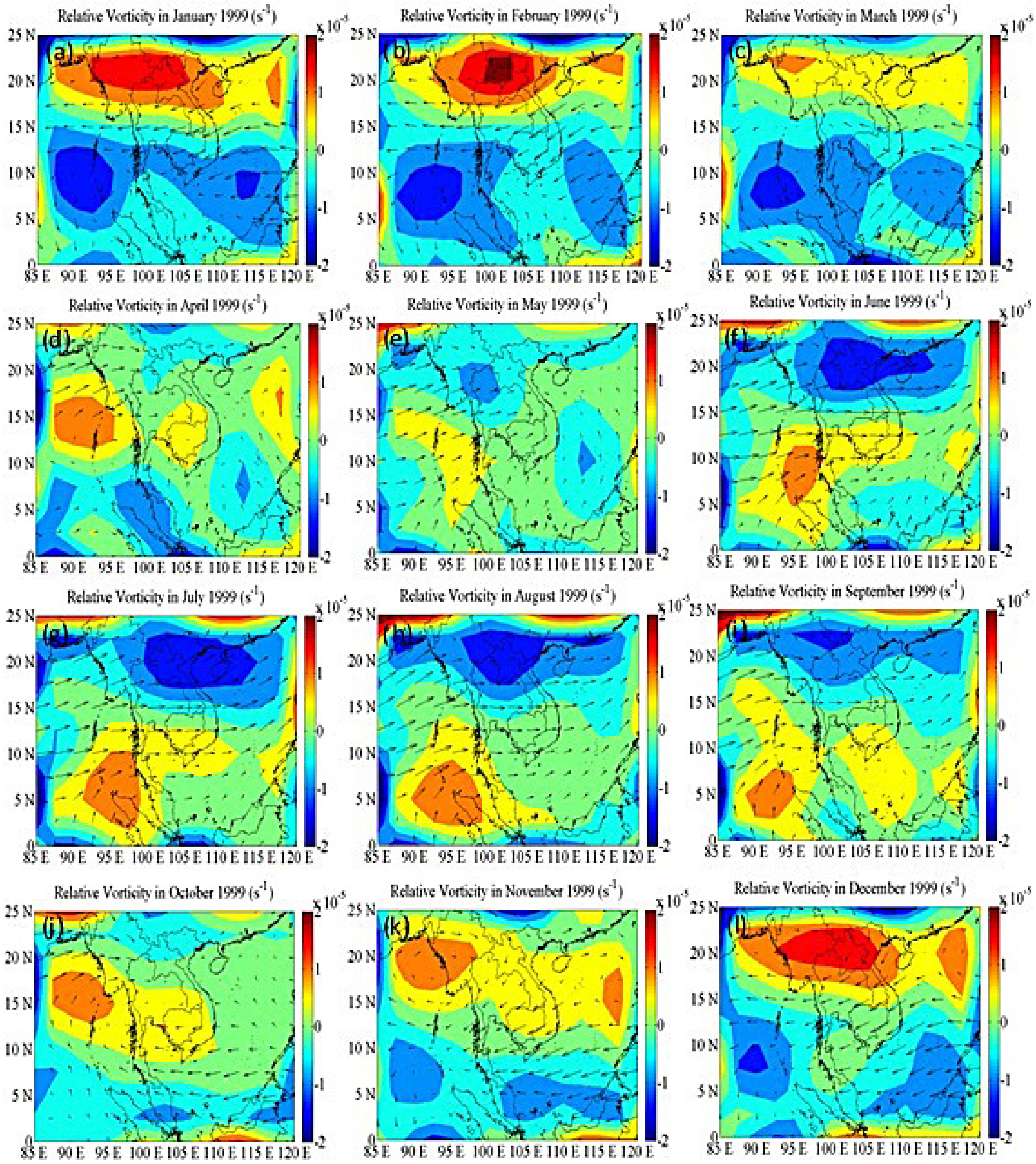

Figure 6. The relative vorticity (1/s) over Southeast Asia at pressure level 850 hPa in wet year, 1999, during (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December.

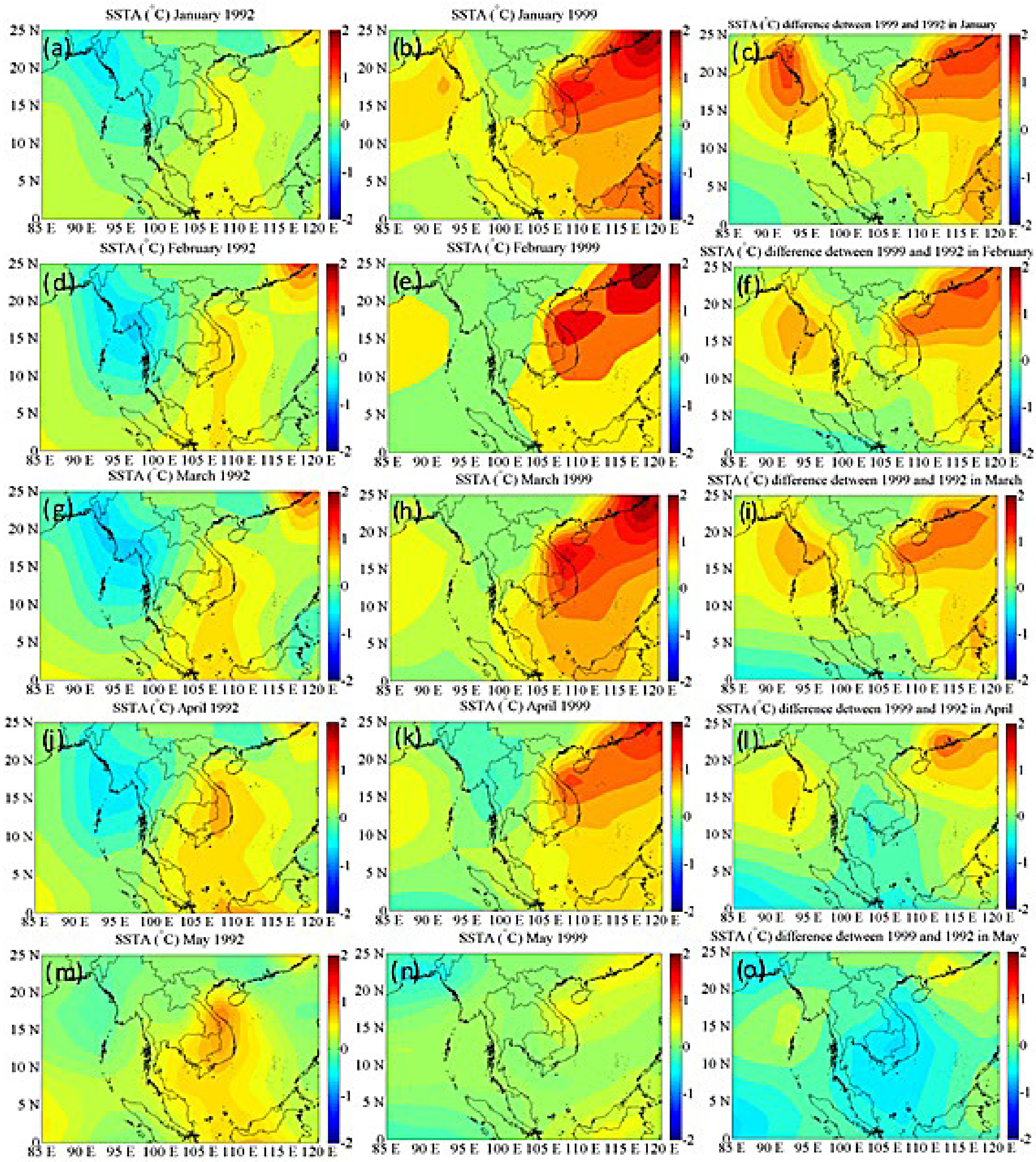

Figure 7. The SSTA data taken from Kaplan Extended SST V2 data [The NOAA 2015] over Southeast Asia (a) January 1992, (b) January 1999, (c) the difference between 1999 and 1992 in January, (d) February 1992, (e) February 1999, (f) the difference between 1999 and 1992 in February, (g) March 1992, (h) March 1999, (i) the difference between 1999 and 1992 in March, (j) April 1992, (k) April 1999, (l) the difference between 1999 and 1992 in April, (m) May 1992, (n) May 1999, and (o) the difference between 1999 and 1992 in May.

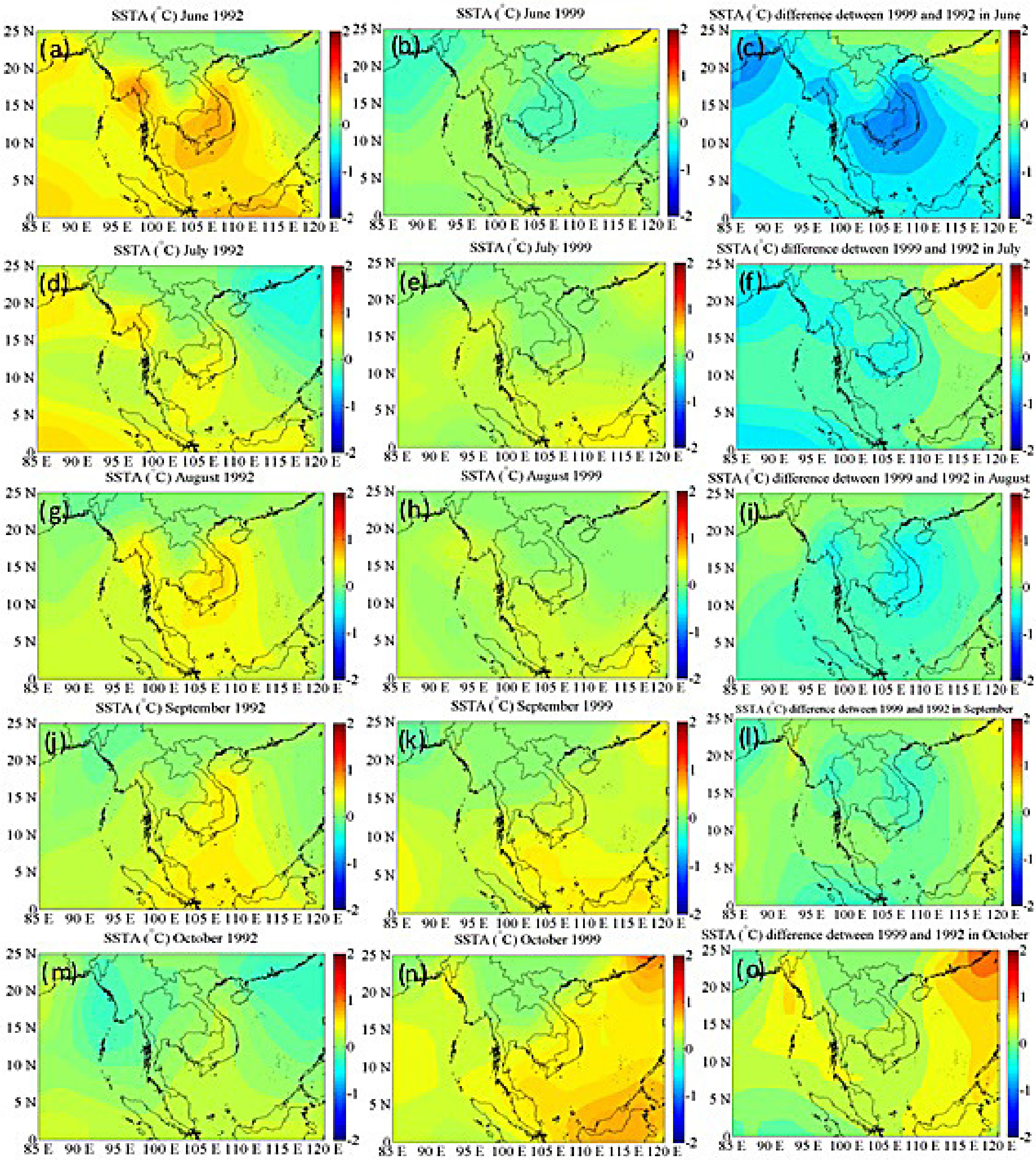

Figure 8. The SSTA data taken from Kaplan Extended SST V2 data [The NOAA 2015] over Southeast Asia (a) June 1992 and (b) June 1999 and (c) the difference between 1999 and 1992 in June, (d) July 1992, (e) July 1999, (f) the difference between 1999 and 1992 in July, (g) August 1992, (h) August 1999, (i) the difference between 1999 and 1992 in August, (j) September 1992, (k) September 1999, (l) the difference between 1999 and 1992 in September, (m) October 1992, (n) October 1999, and (o) the difference between 1999 and 1992 in October.

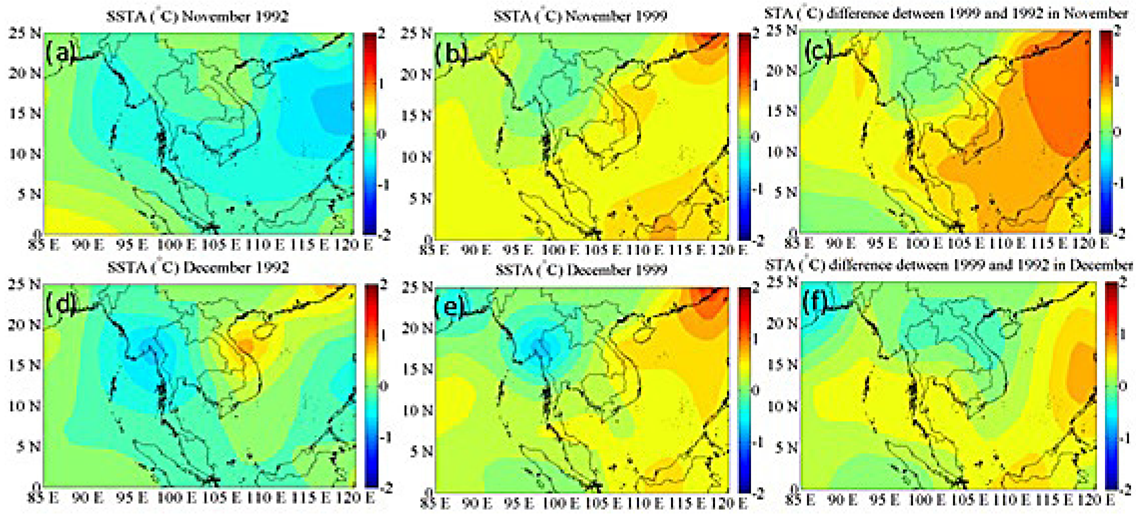

Figure 9. The SSTA data taken from Kaplan Extended SST V2 data [The NOAA 2015] over Southeast Asia (a) November 1992, (b) November 1999, (c) the difference between 1999 and 1992 in November, (d) December 1992, (e) December 1999 and (f) the difference between 1999 and 1992 in December.

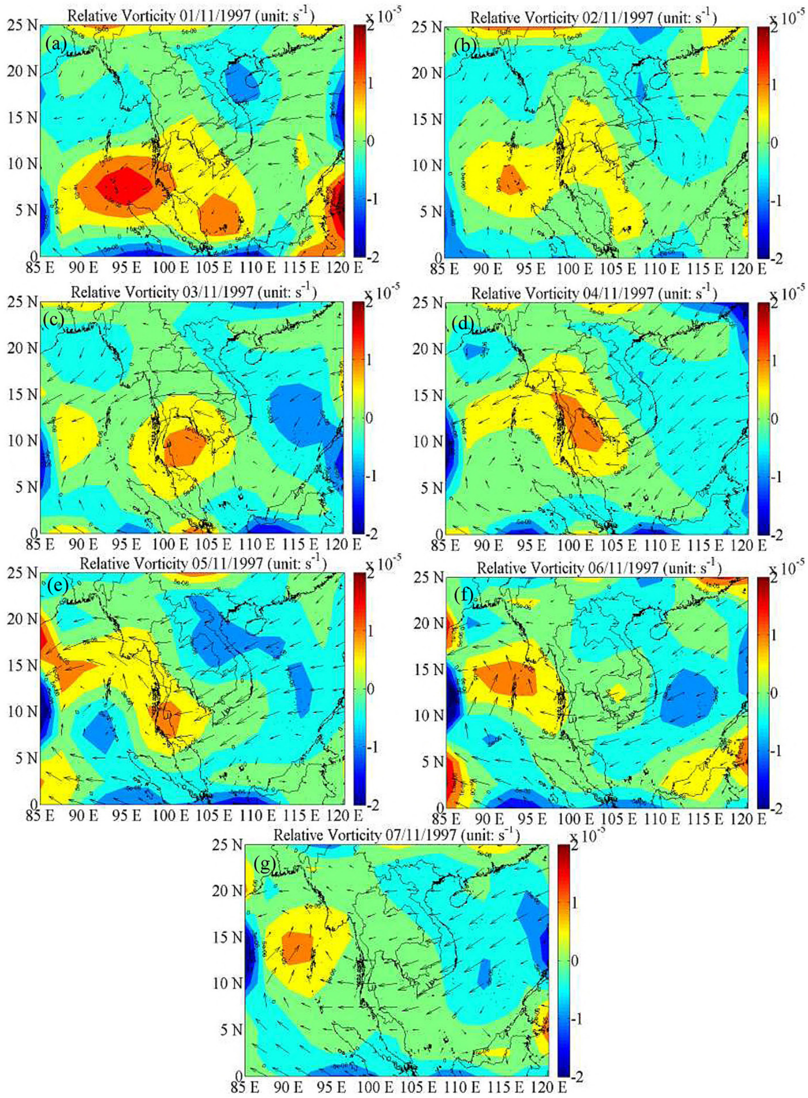

Figure 10. The relative vorticity (1/s) with wind vector u and v plotted over the study area at pressure level 850 hPa on (a) November 1, 1997, (b) November 2, 1997, (c) November 3, 1997, (d) November 4, 1997, (e) November 5, 1997, (f) on November 6, 1997 and (g) November 7, 1997.

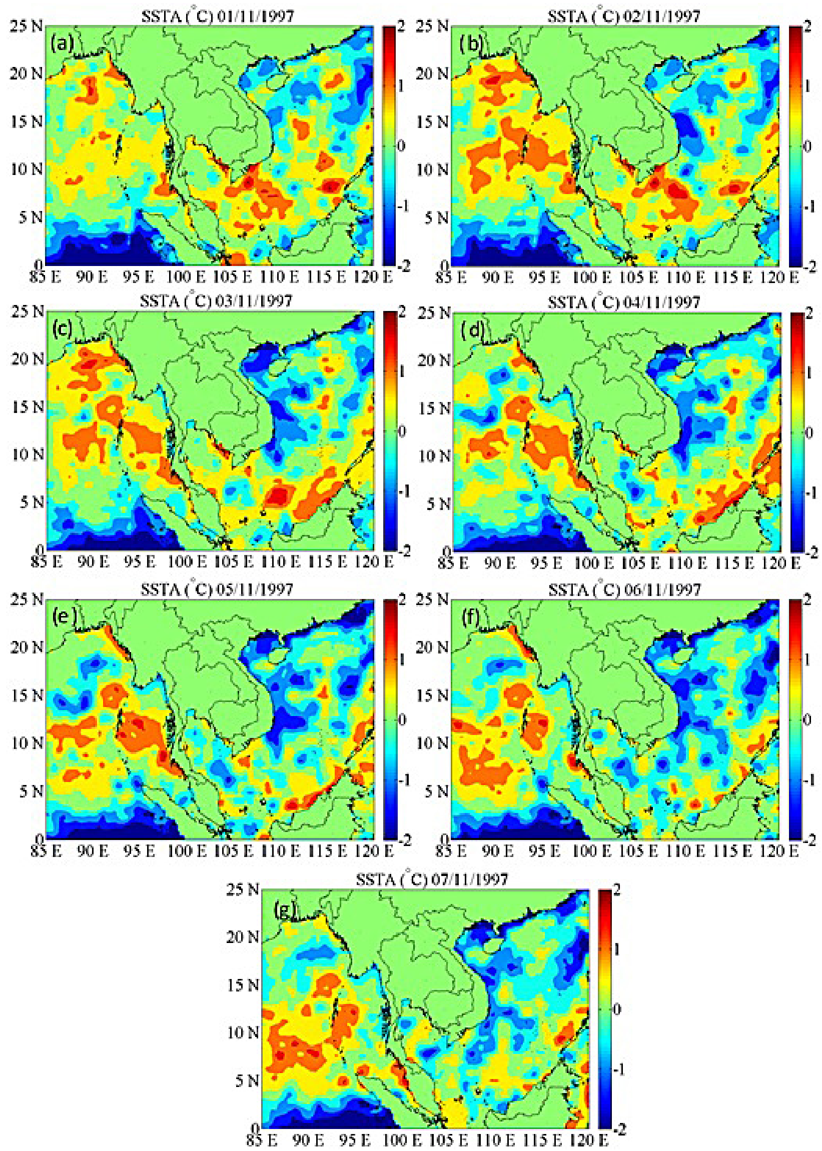

Figure 11. The SSTA taken from the NOAA OI SST V2 High Resolution Dataset [Reynolds et al. 2007] plotted over study area on (a) November 1, 1997, (b) November 2, 1997, (c) November 3, 1997, (d) November 4, 1997, (e) November 5, 1997, (f) November 6, 1997 and (g) November 7, 1997.

CONCLUSIONS

According to the relative vorticity over Southeast Asia at pressure level 850 hPa and SSTA during Typhoon Linda, it can be concluded that the positive values of relative vorticity are consistent with the circulation during Typhoon Linda taken by wind from the South China Sea. The SSTA over the Gulf of Thailand and the Andaman Sea are also unusual. These are the causes of violent natural disasters in Thailand during Typhoon Linda.

Rotation of the relative vorticity over Thailand during the rainy season in 1999 was carried by the wind blowing from the Indian Ocean, west to east. Relative vorticity over Thailand in October to December was brought by the wind from the east to the west in the South China Sea. Relative vorticity in 1992 is similar to 1999, but the value is less positive than in 1999. Analysis of the average rainfall over Thailand during 1979 to 2013 found that the year 1999 is a wet year, and 1992 is a dry year. This is consistent with the precipitation anomaly in 1999 and 1992. The rainfall was consistent with the relative vorticity at pressure level 850 hPa, and these two years are also consistent with the very unusual SSTA. It can be concluded that the amount of rainfall over Thailand is associated with positive values of relative vorticity at pressure level 850 hPa and SSTA over South China Sea.

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