Investigating short-term variations of some parameters during the selected typhoons in the South China Sea

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Abstract

Different parameters of sea surface temperature (SST), latent heat flux (LHF), sensible heat flux (SHF), sea level pressure (SLP), and precipitation rate were compared with their own related anomalies during different typhoons in the South China Sea, to determine the effect of the typhoon on the parameters. These effects were examined based on the archived data from the National Centers for Environmental Prediction and the National Center for Atmospheric Research to compute the anomaly of the parameters. The data of the typhoons obtained from the International Best Track Archive for Climate Stewardship. Two series of maps were considered, one for the first day and one for the strongest day of the typhoon occurrence. Using eyeball analysis of the maps showed the SST in the day that the typhoon had high intensity reduced relative to the first day due to cooling effect. The SLP anomaly reduction from the first day to the extreme day was obvious in all cases that could be connected to the typhoon strengthening. Furthermore, variations of LHF values between the first day and the extreme day increased, and their anomalies changed from negative values to positive values. The results also indicated a positive correlation between SHF and typhoon intensity.

Keywords: Sea surface temperature; Latent heat flux; Sensible heat flux; Sea level pressure; Precipitation rate; South China Sea.

1. Introduction

Typhoons are important events in the South China Sea as it can generate large-scale damage. They cause strong winds, heavy precipitation, and storm surge, which are significant natural disasters. According to the study by Zhou and Cui (2011), typhoons are a synoptic phenomenon over warm waters. They often generate rainstorms and storm surges, which are caused many financial and human losses in countries. More research about typhoons can improve understanding on their mechanisms,

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and provide a scientific foundation for short-term forecasting, increasing capability for defending against this kind of disasters, and reducing losses. In particular, latent heat flux (LHF) and sensible heat flux (SHF) have important roles during a typhoon (Shay *et al.*, 2000).

Typhoons obtain their energy from warm water, and ocean provides energy for typhoon's strengthening (Emanuel, 1991; Lin *et al.*, 2009). The TC intensity is caused by the interaction with warm water, which provides fuel. As the TC strengthens, the evaporation rate grows because of the increase in surface wind speed. The enhancement of the moisture supply from the ocean leads to an increase of the latent heat energy that drives the circulation of TCs (Bender *et al.*, 1993).

Using satellite observations, the interaction between tropical cyclone Nari in 2001, and Kuroshio Current was investigated. Nari crossed the Kuroshio several times, which caused variations in typhoon intensity. The cooling effect (up to 5 ˚C) was observed due to upwelling and vertical mixing in the upper ocean some days after the storm passed (Wu *et al.*, 2008).

Dare and McBride (2011) investigated the response of sea surface temperature (SST) to TCs using SST dataset and global cyclone tracks during the years of 1981–2008. The temperature time series were averaged before and after cyclone occurrence at individual cyclone positions. The results showed that maximum cooling effect occurred mostly a day after storm passage. Their study stated that the minimum SST anomaly was 20.98 ˚C and the data of SST anomalies were recovered with 44% within five days and with 88% in 30 days. This means that the SST reactions, and the recovery time were related to the cyclone strength and its speed.

Furthermore, at the ocean-atmosphere interface, heat exchanging occurs with a number of processes such as: solar radiation, long-wave radiation, SHF by convection and conduction, and LHF by sea-surface water evaporation. The distribution of heat flux over the oceans is a key element for climate studies, and they have an essential role in developing and maintaining of the cyclones (Yu and Weller, 2007). However, operational predicting of typhoon intensity variation is still a challenging task.

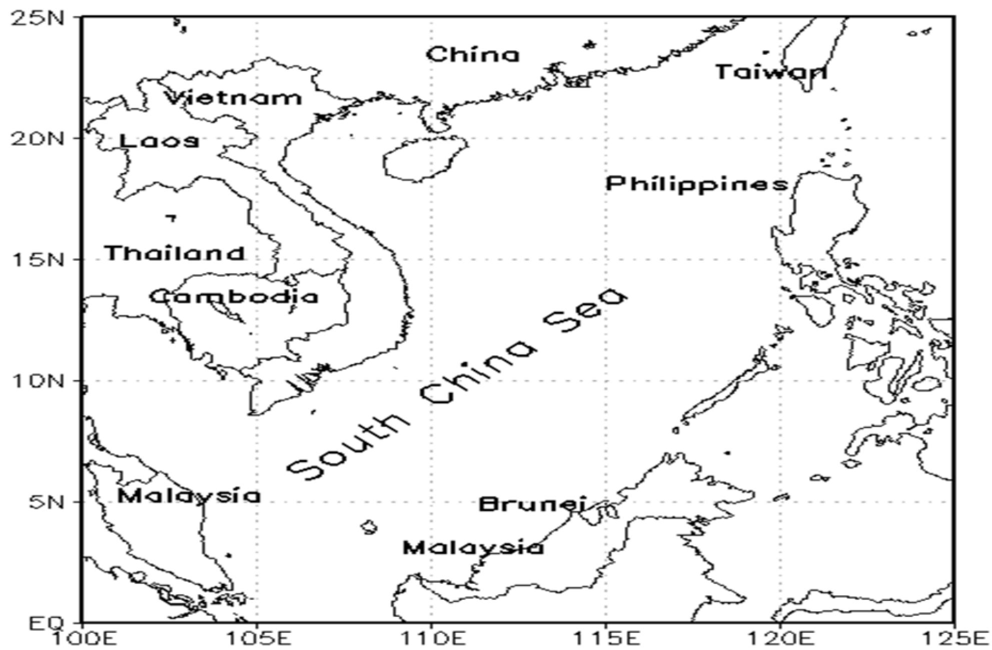

Figure 1. South China Sea

Table1. Selected typhoons in the study area

	Typhoon	Date	Affected areas
1	PEIPAH	2007	Philippines- Vietnam
2	Tropical Depression 01W	2008	South China Sea- Malaysia
3	NOUL	2008	Philippines- Vietnam- Thailand
4	KUJIRA	2009	Philippines- South China Sea
5	CHAN-HOM	2009	South China Sea- Philippines-Luzon
6	NANGKA	2009	South China Sea- Philippines-Calapan city
7	SONGDA	2011	Philippines-Taiwan
8	WASHI	2011	Philippines- South China Sea

2. Data

2.1. Study area

The South China Sea is the largest marginal sea placed at the western north of Pacific Ocean extending from the equator to 23 °N latitude and from 99 ºE to 125 ºE longitude (Figure 1). The area is a semi-closed ocean basin surrounded by South China, Vietnam, Cambodia, Thailand, Peninsular Malaysia, Borneo Island, Indonesia, the Philippines, Taiwan, and the Indo-China Peninsula (Ho *et al.*, 2000; Wang, 2008). The area connects with the east of China Sea, the Indian Ocean, and the Pacific Ocean through the Taiwan Straits, the Straits of Malacca, and the Luzon Straits, respectively. The South China Sea is one of the most important places of TCs generation. In this study, the study area is limited to the 1ºN to 16 ºN and from 100 ºE to 130 ºE, in latitude and longitude.

According to the study of Zuki and Lupo (2008) and Ariffin and Moten (2009), typhoons in the western Pacific Ocean and the South China Sea may have considerable effects on the precipitation and cause flooding in surrounding countries. Thus, predicting typhoon intensity is a challenge in these areas.

2-2 Selected typhoons

The eight selected typhoons originated in the study area, were used in this paper (see Table1), and obtained from International Best Track Archive for Climate Stewardship (IBTrACS) dataset (Knapp *et al.*, 2010). The typhoons were selected based on their generations, development, and dissipation in the study area.

3. Methods

To find the relationship between typhoon activities and some important parameters such as SST, LHF, SHF, precipitation rate, and sea level pressure (SLP), the NCEP-NCAR reanalysis data (Kalnay *et al.*, 1996) available from the Climate Prediction Center (CDC) are employed to compute the 21-year (1990-2011) mean anomaly of the parameters during the selected typhoons.

Two series of maps are considered, one for the first day of typhoon occurrence and one for the day when the typhoon was the strongest. Using eyeball analysis of the maps shows the variations of the selected parameters during the day and the related anomalies during different typhoons (i.e., Noul, Peipah, TD 01W, Chan-Hom, Nangka, Kujira, Songda, and Washi).

4. Results and Discussion

A comparison between the parameters SST, LHF, SHF, SLP, and precipitation rate, and their related anomalies during a typhoon was conducted to find the effect of the typhoon on the parameters. The maps (first day and strongest day of typhoon occurrence) show the variations of the selected parameters during different typhoons, Noul, Peipah, TD01W, Chan-Hom, Nangka, Kujira, Songda, and Washi. The maps of typhoon Noul as the first case study are given as follows and the maps for other typhoons are not available herein (they can be obtained from the corresponding author directly).

Figure 2 shows the variations of SST, LHF, SHF, SLP, and precipitation rate during the first day of typhoon Noul and their related anomalies. SST in start point had a value of about 29 ºC. A positive anomaly of about 0.3 ºC relative to the 21-year mean of SST was seen in the figure. The LHF value in the start point was about 30-60 W/m^2 with an anomaly of -30 W/m^2, which shows that the LHF value is lower than the 21-year mean value during the day. The SHF values ranged from 0 W/m^2 to 10 W/m^2 with no special anomaly for this parameter. The SLP value in the first day of the typhoon was about 1007 mb with a negative anomaly about -2 mb, which shows that the value is lower than the mean value. The amount of precipitation rate during the day was approximately 5E-05 $kg/m^2/s$, which shows no significant difference with the 21-year mean value.

This comparison was conducted for seven other typhoons, namely, Peipah, TD 01W, Chan-Hom, Nangka, Kujira, Songda, and Washi. The investments showed that the initial SST value in different typhoons and its extent can affect typhoon intensity and its duration. As an example, Washi as a strong typhoon had an initial SST value of about 30 ºC, which occupied a wide area. In comparison with the 21-year mean value, SST had a positive anomaly of 0.5 ºC. Schade and Emanuel (1999), and Schade (2000) also investigated the effect of initial SST and its amplitude on TC intensity and minimum central pressure.

The strongest typhoons, Washi and Songda, had the highest positive initial LHF (higher than the 21-year mean), and Peipah and TD 01W (weakest typhoons) had the lowest negative initial LHF anomaly (lower than the 21-year mean). The precipitation rate reported for typhoons Washi and Songda were the highest, and this parameter was lowest for Peipah, TD 01W, and Noul. These findings can represent that the higher LHF cause much more rain, but this result cannot be generalized because some inconsistencies were seen in some cases, such as in the cases of Kujira and Nangka. Cayan (1992) stated that LHF is one of the key elements to enhance the energy in the lower tropospheric layers, which are strongly associated with the formation of precipitation. Greater thermodynamic effects, such as LHF, would increase water vapor. In fact, the larger LHF values would increase the water vapor, which was greatly attributed to occurrences of extreme precipitation, which was also quoted by Gao and Xie (2014). LHF variations indicated that evaporation changes during the typhoon. Furthermore, Juneng *et al.* (2007) found this relationship in the case of typhoon Vamei in 2001. They stated that the intensification of the LHF suggesting the role of air-sea interaction in the development and evolution of a cyclone, and caused more evaporation and consequently more rainfall.

Analyzing the initial values of SHF for different typhoons did not show special variations, and no considerable anomaly was reported during the initial day. However, the SHF anomaly was positive for typhoon Songda (increasing relative to mean value) and was negative for TD 01W and Peipah (reducing relative to mean value). Compared with the initial SST values, Songda had the highest initial SST, and Peipah and TD 01W had the lowest initial SST values. Thus, SST and SHF can have a positive correlation. Loh *et al.* (2011) mentioned this relationship from another point of view. Their study results showed that SHF reduced when surface temperature declined during landfall, which resulted in rapid weakening of the typhoon.

Comparing the SLP value and its anomaly among

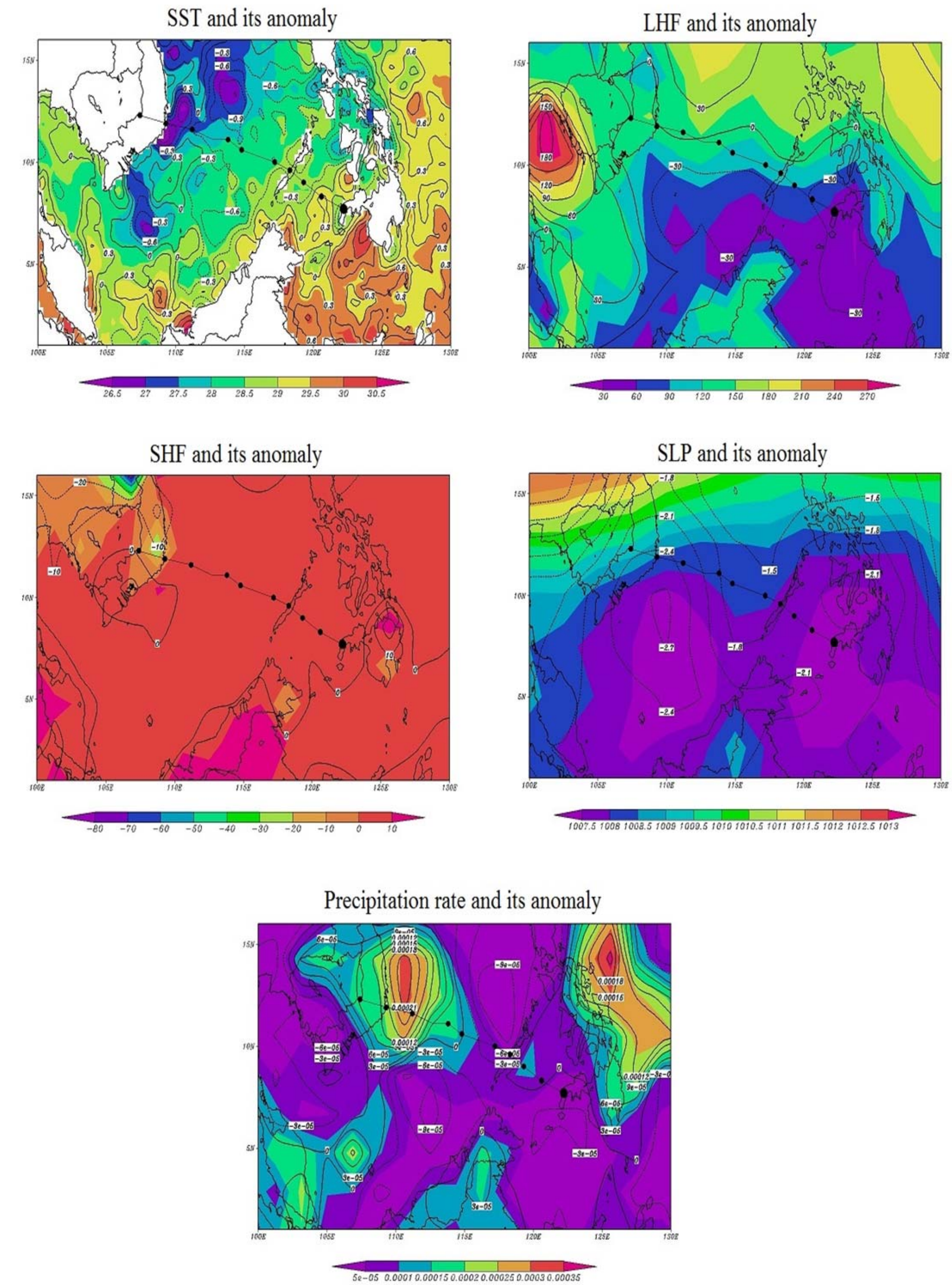

Figure 2. Variations of different parameters values, SST (ºC), LHF (W/m^2), SHF (W/m^2), SLP (mb), and precipitation rate (kg/m^2/s) (shaded areas), and their anomalies (numbers) in the first day of typhoon Noul

the typhoons showed that the typhoon intensity is related to these initial values. The considerable result is that all SLP anomalies were negative, which means the reduction of SLP relative to long-term average. This finding showed that on stormy conditions, the amount of SLP was lower than the relevant 21-year mean value. The initial SLP value and its anomaly can affect typhoon intensity. In fact, the negative SLP anomalies were related to the low-pressure disturbances and the convection development in the northwestern Pacific region and cyclogenesis. This is also was mentioned by Zhou *et al.* (2008).

Figure 3 illustrates the variations of SST, LHF, SHF, SLP, and precipitation rate and their anomalies in the strongest day of typhoon Noul. The SST in the day that the typhoon had high intensity reduced about 0.5 ºC relative to the first day, which shows the cooling effect. This SST reduction feeds the typhoon. The LHF values showed an increase of 20-30 W/m^2 comparative to the first day. The range of SHF also declined in the extreme day relative to the first day. The precipitation rate in the extreme day of typhoon Noul showed a little enhancement. The amount of SLP had no considerable change from the first day to the extreme day, but its anomaly showed -1 mb more reduction. The SLP anomaly reduction from the first day to the extreme day was obvious in all cases, which is connected to the typhoon strengthening; Durden (2012) also mentioned this relationship. The reported SLP anomalies during the extreme day in most typhoons were -3 mb, which can be considered as a special condition for typhoon strengthening. The SLP anomalies during the extreme day were also negative relative to the long-term average. This finding showed the negative relation between SLP and typhoon intensity.

Comparison of the values of the selected parameters during the day when the typhoons were strongest with those in the first day showed that the amount of SST anomaly was reduced considerably, which was evident of the cooling effect during the typhoons. This SST reduction fed typhoon that was claimed by Uram (2005) and Zhang *et al.* (2014). These variations show that typhoon feeding is still ongoing. As an example, the SST anomaly of typhoon Chan-Hom changed approximately from -0.5º to -3º from the first day to the day with maximum intensity, which represents the cooling effect during the typhoon. This cooling effect was different in the typhoons, which is related to their maximum wind speed. In fact, the SST anomalies reduction was marked of the cooling effect during the typhoons, which is also stated by Bender *et al.* (1993). Wu *et al.* (2007) mentioned this effect as a negative feedback, which showed that cooling effect or SST reduction is due to TC strengthening.
Variations of LHF values between the first day and extreme day in most typhoons indicated considerable differences. Mostly, the LHF values increased, and their anomalies changed from negative values to positive values, which correspond to evaporation enhancement that is related to water phase change. These variations were very considerable in typhoon Chan-Hom, Kujira, Peipah, and Songda, with +30, +50, +110, and +140 (W/m^2) anomaly variations, respectively. This LHF enhancement had affections on typhoons' intensity and their growth. Tangang *et al.* (2006) also represented that both sea-surface heat transfer and LHF have positive effects on cyclogenesis and its development. Actually, LHF variations indicated evaporation changes during the typhoon.

Comparison SHF values and their related anomalies during different typhoons between the first day and the extreme day indicated no considerable change. The maximum change was seen for Songda, i.e., about 5 W/m^2 SHF reduction and 10 W/m^2 SHF anomaly decrease, which was the strongest typhoon among the rest. In the case of Washi, about 10 W/m^2 SHF reduction was observed, but no change in its anomaly was seen. In fact, there may be a positive correlation between SHF and typhoon intensity (maximum wind speed). Ding *et al.* (2006) explained this correlation when the SHF values are higher than 10 W/m^2, which are in agreement with the results of this study. The SHF changes show that the environmental temperature variations can affect typhoon intensity.

Thus, heat exchange is obvious during the typhoons.

The speed of typhoon Noul changed from 20 knots to 35 knots between the first day and extreme day, which caused the cooling effect. Moreover, a connection was found between SST and heat fluxes change with the speed of storm movement. When a storm has a sluggish variation in its speed, the SST and heat fluxes changed with a slow slope. Bender *et al.* (1993) demonstrated that SST cooling by the TCs resulted in an important effect on the storm in-

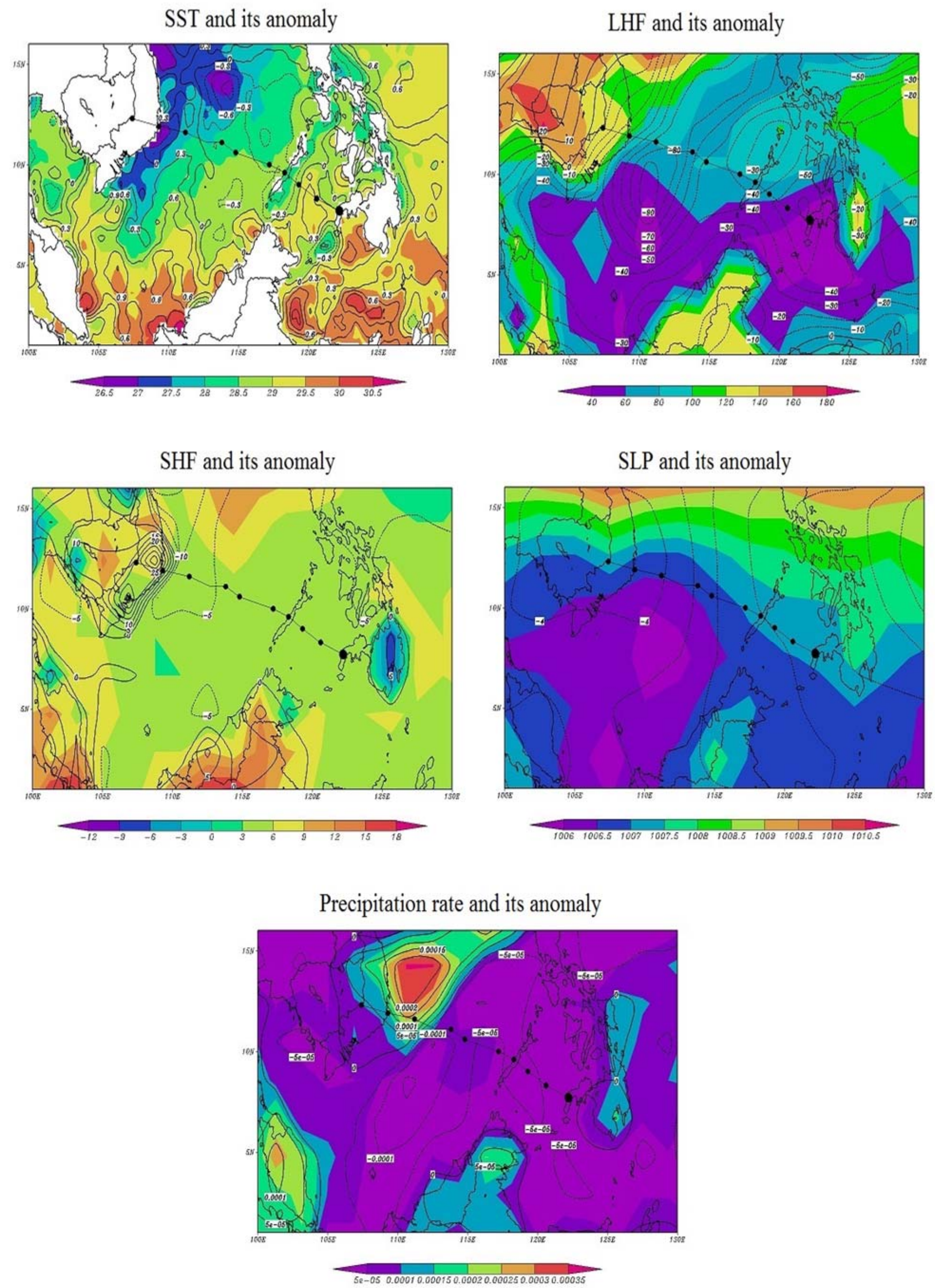

Figure 3. Variations of different parameters values, SST (ºC), LHF (W/m^2), SHF (W/m^2), SLP (mb), and precipitation rate (kg/m^2/s) (shaded areas), and their anomalies (numbers) in the strongest day of typhoon Noul

tensity due to decreasing total heat over the area. Results showed that the cooling of the sea-surface due to TCs was larger when the storms moved slower.

The amount of precipitation rate in extreme day of most typhoons relative to the first day showed reduction, and the anomaly in the extreme day was lower than that in the first day. Despite this reduction, the amount of anomaly increased in the extreme day relative to the first day in the case of Songda and Washi. These enhancements can be attributed to the increasing LHF values, which were explained earlier. In fact, the results showed that LHF and precipitation rate were connected together. This relationship was also mentioned by Cayan (1992) and Gao and Xie (2014). The SLP anomalies were reported to be -3 mb for the extreme day of all typhoons, except Peipah (-0.5) and Songda (-1). This amount of anomaly maybe considered a special condition for typhoon strengthening.

Conclusion

A Short-term analysis on some parameters during the selected typhoons was conducted. SST, LHF, SHF, SLP, and precipitation rate and related anomalies during different typhoons was compared to determine the effect of the typhoon on the parameters. The results showed that the initial SST value in different typhoons and its extent can affect the typhoon intensity and its duration. Higher LHF caused more rain. Furthermore, when the SHF anomaly was positive (negative), the initial SST value was the highest (lowest). Thus, SST and SHF anomalies had a positive correlation. Moreover, all SLP anomalies were negative, which means the reduction of SLP relative to long-term average. The initial SLP value and its anomaly can affect typhoon intensity.

The variations of SST, LHF, SHF, SLP, and precipitation rate and their anomalies in the strongest day of different typhoons were analyzed in comparison with the parameters during the first day. The results showed that the SST in the day that the typhoon had high intensity reduced relative to the first day, which showed the cooling effect. In addition, the SLP anomaly reduction from the first day to the extreme day was obvious in all cases, which can be connected to the typhoon strengthening. Variations of LHF values between the first day and extreme day in most typhoons indicated that the LHF values increased, and their anomalies changed from negative values to positive values. Comparison of the SHF values and their related anomalies during different typhoons showed a positive correlation between SHF and typhoon intensity (maximum wind speed). The amount of precipitation rate in the extreme day of most typhoons relative to the first day showed reduction, and the anomaly in the extreme day was lower than that in the first day. Despite of this reduction, the anomaly values increased in the extreme day relative to the first day in the case of Songda and Washi as strongest typhoons. In fact, the results showed that LHF and precipitation rate were connected.

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