TYPHOON EFFECTS ON THE SHORT-TERM VARIATION OF SST AND CHLOROPHYLL *A* IN THE EAST/JAPAN SEA DERIVED FROM SATELLITE REMOTE SENSING

Keiko Yamada, Sang-Woo Kim, Woo Jin Go and Lee-Hyun Jang

National Fisheries Research and Development Institute, keiko@nfrdi.re.kr

ABSTRACT ... The short-term variation of sea surface temperature before and after typhoons and increase of chlorophyll *a* concentration that accompany with the typhoons during summer in the East/Japan Sea were explored by satellite. Four typhoons (NAMTHEUN, MEGI, CHABA and SONGDA) and a typhoon (NABI) passed over the East/Japan Sea in 2004 and 2005, respectively. Decreasing of SST was observed in the every five typhoons, however the magnitude of SST decreasing were various from 1 to 5°C. Chlorophyll *a* increases were found after the typhoons (0.1-3 $\mu g\ l^{-1}$) except NAMTHEUN, and the area was approximately included in SST decreasing area by the typhoons. It suggests that chlorophyll *a* increase was caused by nutrient input from subsurface layer by strong mixing. On the other hand, rarely chlorophyll *a* increase was observed in northern area of polar frontal zone, which is located in 38-41°N, than northern area, and chlorophyll a increase in coastal area was higher (more than 3 times) than offshore area. It might suggest that chlorophyll *a* increase in the East/Japan Sea is also related with the depth or nitracline depth that affects the amount of nutrients supply to the upper layer by typhoon mixing.

KEY WORDS: Sea surface cooling, Mixing, Coastal upwelling, Bloom

1. INTRODUCTION

Many researchers have studied about the relationship between ocean condition and tropical storm such as typhoon, hurricane and cyclone. Some of these studies focus on the sea surface cooling (SSC) what is happened after typhoon passing on the sea (Price, 1981). It is said that the SSC is 4 to 6°C and the cooling continues 2 to 3 weeks. Two phenomenons are expected as causes of SSC; the first is the entrainment of cold subsurface water to surface, and the other is coastal upwelling by strong wind blowing right of the coast.

Furthermore, the increase of chlorophyll *a* with SSC was also observed by satellite ocean color images (Babin et al., 2004; Platt et al., 2005; Son et al., 2006). This chlorophyll *a* increase is expected to be happened by nutrient input from subsurface to surface by strong mixing of typhoon. The entrainment of chlorophyll *a* itself from subsurface chlorophyll *a* maximum is also possible.

In the case of the East/Japan Sea (EJS), Son et al. (2006) detected the SSC and chlorophyll *a* increase by satellite about the typhoon "MEGI" what happened in August, 2004. They focused on the single typhoon and did not take into account about the typhoons happened before and after MEGI. Objective of this study is to derive the relationship between SSC and chlorophyll *a* increase by plural typhoons in the EJS.

2. DATA

2.1 Satellite data

The data analyzed in this study were used from three kinds of satellite data. QuikScat wind direction and speed data was used. It is 0.25° spatial resolution and distributed by Remote Sensing System on the web site (http://www.ssmi.com/qscat/qscat_browse.html). New Generation Sea Surface Temperature (NGSST) provided by Tohoku University in Japan was used to grasp the sea surface temperature during the bad weather condition. NGSST is special composite by thermal infrared sensors

Table 1 Typhoons observed in this study. Period indicates the day that thetyphoons stayed in the EJS. U, Pc V indicate averaged transit speed, center pressure and wind speed during the period, respectively.

Typhoon	Period	U (m/s)	Pc(hPa)	V(m/s)
NAMTHEUN	2004 Jul. 31-Aug. 1	3.5	998	18.0
MEGI	2004 Aug. 19	11.8	973	32.1
CHABA	2004 Aug, 30 - 31	12.2	972	31.7
SONGDA	2004 Sep. 7	14.1	962	32.6
NABI	2005 Sep. 6-7	10.8	980	29.0

(MODIS and AVHRR) and a microwave sensor (AMSER-E). It is good for typhoon study to use NGSST data, because micro sensor can get the data through cloud. NGSST is 0.05° resolution and used daily data. For chlorophyll *a* concentration, SeaWiFS version 4 Standard Mapped Image provided by NASA was used. This is 9km resolution, and daily and 8days composite data were used in this study.

2.2 Typhoon data

The tracks of the typhoons, wind speed, air pressure data were extracted from web site of Typhoon Research Center in Korea (http://www.typhoon.or.kr/) for four typhoons (NAMTHEUN, MEGI, CHABA, SONGDA) and a typhoon (NABI) that passed over the EJS during July to September 2004 and early 2005, respectively (Table 1, Fig. 2). Furthermore, transit speeds of each of typhoon were calculated (Table 1). Average wind speed, air pressure and transit speed of NAMTHEUN in the EJS was weaker (18.0 m s^{-1}), higher (998 hPa) and slower (3.5 m s^{-1}) than other typhoons. Those of other typhoons except NAMTHEUN were 29.0-32.6 m s^{-1}, 962-980 hPa and 10.8-14.1 m s^{-1}, respectively.

2.3 Ship observation data

Ship observation data of Japan Meteorological Agency (JMA) was used. Correlation between SST and averaged NO3 between 0 – 50m was calculated.

3. RESULT & DISCUSSION

3.1 SSC by typhoons passing in the EJS

SST at southern part of the EJS and the polar frontal zone (38-41°N) were 26 and 24°C, 24 to 22°C and 26 and 24°C in the late July to the middle of August 2004, late August to early September 2004 and early September 2005, respectively. The amount of SST change (ΔSST) was defined as the SST difference between the five days average of the pre-typhoon and the post typhoon images ($\Delta SST = SST_{pre}\text{-}SST_{post}$). SST differences were observed after every five typhoons. However the magnitudes of ΔSST were quite different (Fig. 2). In the case of NAMTHEUN and CHABA, ΔSST were below 2°C. Magnitude of ΔSST after NAMTHEUN was small and appeared in the small area of the middle part of the EJS (100-200km square), and DSST below 2°C was observed at Japanese coast (36-39°N, 134-139°E) in the case of CHABA. On the other hand, ΔSSC over 2°C were observed by other three typhoons. Particularly, MEGI showed the remarkable ΔSST, sometimes over 4°C, in the wide area of southern part of the EJS. ΔSST by SONGDA was remarkable in the northern area (40-45°N, 135-138°E) and its center was the Japan Basin (44°N, 138°E). ΔSST by NABI was large at Japanese coast (35-38°N, 131-136°N). Price (1981) reported that the SSC by hurricane was observed at 30-150km right side of

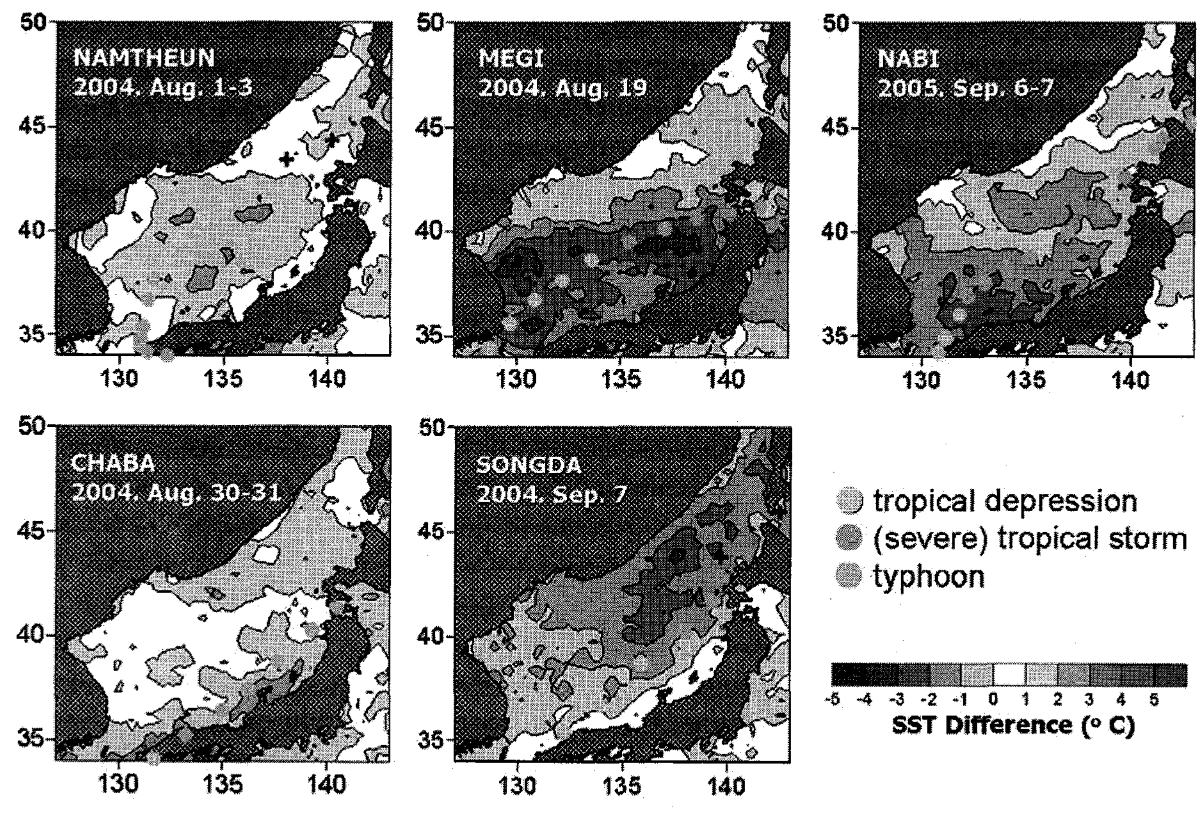

Fig.2 Difference of five days average of the sea surface temperature before and after typhoons (NAMTHEUN, MEGI, CHABA, SONGDA and NABI). Blue colour indicates the area sea surface cooling was observed. Coloured dots indicate each of typhoon paths.

hurricane path. However, SSC in the EJS showed more complex distribution. It might to be because that the EJS is closed small area to the typhoons scale and has a complicated current structure.

As the reason of SSC, mixing of surface water by strong wind was expected. Kim et al. (submitted) reported that a buoy located at Gangneung showed the decline of temperature at 1m and increase at 15 and 30m depth after NABI passing. Furthermore, Hong et al. (2004) described that temperature at 50m was risen by typhoon passing during 1983 – 2000 by the buoy observation that located at the middle part of the EJS. Their results indicate that mixing by typhoon passing was developed by around 50m in the EJS.

We also tried to consider about the possibility of the coastal upwelling by the typhoons in this study. Senjyu and Watanabe (1999) described that large SSC about 6°C was observed along Sanin coast in Sep. 1997, when typhoon OLIWA passed near Japan. During OLIWA passing, easterly wind was dominated at the Sanin coast for more than three days. They explained that large SSC was caused by coastal upwelling due to the continuous blowing of easterly wind. The wind conditions at Japanese coast by each of typhoons in this study were checked by image of QuikScat. Wind by NAMTHEUN was quite weaker comparing with other typhoons (<15m/s). It might be a reason that SSC was not intensive. Easterly wind was weak (<10m/s) by MEGI and SONGDA. In the case of NABI, easterly wind was relatively stronger (>10m/s) and continued more than 1 day, coastal upwelling was expected in the case of NABI. However, distribution of daily sea surface temperature derived from NGSST did not show the coastal upwelling (Kim et al., submitted). Thus, it is expected that SSC observed in this study were attribute to mixing by strong wind more than coastal upwelling. However, slower transit typhoon might cause coastal upwelling more intensively as OLIWA observed by Senjyu and Watanabe (1999). It is needed to analysis using various typhoons that have a range in transit speed and wind condition to derive distinct mechanism.

3.2 Chlorophyll *a* increase with SSC in the EJS

Chlorophyll *a* increase was observed after those typhoons passing expect NAMTHEUN (Fig. 3). Average surface chlorophyll *a* concentration in the EJS from July to September is relatively low, about 0.2 and 0.3 μg l^{-1} in the eastern and western part, respectively (Yamada et al., 2004). In the case of MEGI and SONGDA, chlorophyll *a* increases were observed around the path of the typhoons widely (0.1–1 μg l^{-1}). Chlorophyll *a* increase after CHABA was happened at Japanese coast (134-139°E) and concentration was quite high (1-3 μg l^{-1}).

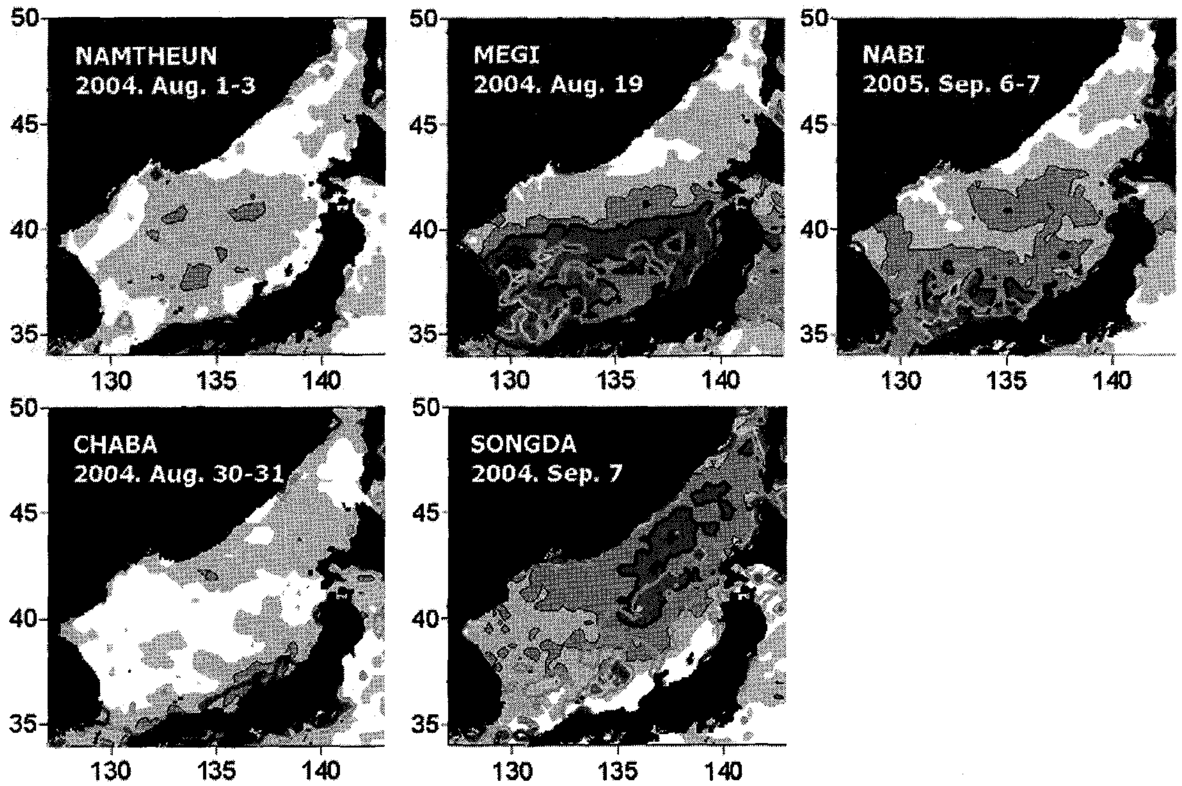

Fig. 3 Chlorophyll *a* increase by each of typhoon overlaid on the distribution of sea surface cooling (Fig. 2). Thick and thin black contours indicate sea surface cooling by 2 and 1°C, respectively. Green, yellow, orange, pink and red indicate chlorophyll a increase by 0.2, 0.4, 0.6, 0.8, 1 μg l^{-1}, respectively.

Chlorophyll *a* increase after NABI was happened in the south western part of the EJS, especially at the Japanese coast (36-38°N, 131-136°E).

Chlorophyll *a* increases after typhoons in this study were located in the SSC area. As mentioned in the section 3.1, it is expected that mixing was developed by about 50m in the EJS. It also means that there is possibility of nutrient supply to surface layer from nutrient-rich deeper layer. Son et al. (2006) calculated the nutrient supply by passing of typhoon MEGI by using the correlation between SST and nutrient, and estimated that nitrate was increased 90%. However, they used the nutrient data that located east coast of Korea that is expected as the coastal upwelling area. Therefore, nutrient might be overestimated in the case when the correlation was applied to the middle part of the EJS. In this study, the correlation was recalculated by the nutrient data of Japan Meteorological Agency that collected from wide area for the EJS (Averaged NO_3 from 0 to 50m = -0.14*SST + 4.00, R = 0.397, P < 0.01, N = 375). Furthermore, NO_3 inputs of each of typhoons were estimated by this equation applying NGSST. NO_3 input by NAMTHEUN that showed rarely cooling and chlorophyll *a* increase was 0.1μg l^{-1}. In the case of CHABA, NO_3 input about 0.2 μg l^{-1} was happened along only Japanese coast. Nutrient input after MEGI, SONGDA and NABI was observed in the wider area of the EJS (0.2-0.5 μg l^{-1}).

NO_3 input by typhoon MEGI was about 30% of the estimation of Son et al. (2006). However, not all part of cooling area showed the chlorophyll *a* increase. Chlorophyll *a* increase was mainly observed in the southern part of the EJS and was rarely observed in the northern part even if SSC was observed. It seems to be related with the depth and the depth of nitracline, more analysis using vertical profile of NO_3 will be needed to derive relationship in detail.

4. CONCLUSION

The passing of five typhoons during summer 2004 and 2005 brought SSC in the EJS, and the magnitude of cooling was different typhoon by typhoon (1–5°C). Distributions of sea SSC area showed that cooling was sometimes happened in wider area to the typhoon paths. It might be caused by the complex current system and closed structure of the EJS. It was thought that possibility of coastal upwelling at Japanese coast by easterly wind. Even though easterly wind existed briefly, intensive coastal upwelling was not found in the daily SST image. It is expected that SSC by five typhoons in this study attributed to the direct mixing of surface water by typhoon more than coastal upwelling.

Chlorophyll *a* increase was also observed with the SSC except NAMTHEUN (0.1–3μg l^{-1}). Chlorophyll *a* increased area was included in the SSC area. It was expected that nutrient was input from subsurface layer in the cooling area, NO_3 input was estimated by using the correlation between SST and NO_3 (0.2–0.5μM l^{-1}). However, the distribution of chlorophyll *a* increase cannot be explained by only SSC. Other factors such as depth and depth of nitracline should be also taken into account to evaluate the chlorophyll *a* increase by typhoons in the EJS.

5. REFERENCES

Babin, S. M., J. A. Carton, T. D. Dickey and J. D. Wiggert, 2004. Satellite evidence of hurricane-induced phytoplankton blooms in an oceanic desert. J. Geophys. Res., 109, C03045, doi:10.1029/2003JC001938.

Hong, C. H. and I. S. Sohn, 2004. Sea surface cooling in the East Sea with the passage of typhoons (in Korean with English abstract). J. Kor. Fish. Soc., 37(2), pp. 137-147.

Kim, S. W., K. Yamada, L. H. Jang, W. J. Go and J. Lee, submitted. Sort-term of sea surface temperature caused by typhoon NABI in the East Sea derived from satellite data.

Platt, T, H. Bouman, E. Devred, C. Fuentes-Yaco and S. Sathyendranath, 2005. Physical forcing and phytoplankton distribution. Sci. Mar., 69(1), pp. 55-73.

Price, J. F., 1981. Upper ocean response to a hurricane, J. Phys. Oceanogr., 11, pp. 153-175.

Senjyu, T and T. Watanabe, 1999. A sudden temperature decrease along the Sanin coast induced by a typhoon (in Japanese with English abstract), UmitoSora, 75, pp. 1-8.

Son, S. H., T. Platt, H. Bouman and D. K. Lee, 2006. Satellite observation of chlorophyll and nutrients increase induced by Typhoon Megi in the Japan/East Sea. Geophys. Res. Lett., 33, L05607, doi:10.1029/2005GL025065.

Yamada, K., J. Ishizaka, S. Yoo, H. C. Kim and S. Chiba, 2004. Seasonal and interannual variability of sea surface chlorophyll a concentration in the Japan/East Sea (JES). Prog. Onceanogr., 61, pp. 193-211.

6. ACKNOWLEDGEMENT

This study was supported by Post doctoral program of National Fisheries Research and Development Institute in 2006.