Journal of the Korean Society of Oceanography
Vol. 38, No. 2, pp. 60 — 67 June 2003

Ocean Response to Typhoon Rusa in the South Sea of Korea and in the East China Sea

DONG-KYU LEE[1]* AND PETER NIILER[2]
[1]*Department of Sciences, Busan National University, Busan 609-735, Korea*
[2]*Scripps Institution of Oceanography, La Jolla, CA 92093, USA*

Typhoon Rusa passed over the East China Sea and crossed over the Korea Peninsula on August 31, 2002. The core of the typhoon passed directly over a data buoy mooring site at (127°45′E, 34°25′ N) and several ARGOS-tracked drifters capable of measuring salinity. Peak hourly mean wind speed reached 28 m/s at the mooring site and wind pattern in the East China Sea changed from southerly wind to northwesterly wind after the typhoon passage. Two or three days before the typhoon the drifter displacement changed significantly and the region-wide circulation pattern changed from a northeastward current to a westward current one week after the typhoon had passed. The surface water in the East China Sea was cooled to about 4°C under the typhoon core and a general cooling occurred in most of the East China Sea with the exception of the Chinese coast. The salinity as observed by the drifters in the East China Sea increased about 2 psu but the near-shore water along the Korean coast observed by the mooring was freshened about 3 psu. The freshening of near-shore water was caused by an intrusion of off-shore water rather than local freshening by typhoon precipitation.

Key words: Typhoon, Ocean Wind, Ocean Response

INTRODUCTION

Observations of ocean response to the typhoon force wind near the passage of the typhoon core have been rare. Although open ocean response to strong wind has been studied theoretically and numerically (e.g., Gill, 1982; Price *et al.*, 1994; Hong and Yoon, 2003), there are only limited observational data to support those studies (Ginis, 1995). The moored data buoy observations of hurricanes in the open ocean were obtained by Brink (1989) and recently by Dickey *et al.* (1998). Zelder *et al.* (2002) analyzed data obtained at the Bermuda Testbed Mooring site and they also successfully simulated upper ocean response to the hurricane. Cione *et al.* (2002) analyzed SST changes of 37 hurricanes between 1975 and 1998 and they found that most of the cooling occurred between 150 km and 350 km from the hurricane core. The vertical mixing beneath a hurricane was studied by D'Asaro (2003) using air-deployed deep floats.

In the near shore area, besides vertical mixing, horizontal mixing and flow changes of near-shore water with off-shore water are expected because coastal currents are known to be dependent upon winds (e.g. Ohlman *et al.*, 1999). Senjyu and Watanabe (1999) observed 6°C–7°C Sea Surface Temperature (SST) decrease along the northern coast of Japan by the coastal upwelling when typhoon Oliwa passed southern Japan in 1997. Increases of subsurface temperature by typhoon Abby in 1983 and Holy in 1984 at the eastern channel of Korea Strait were observed by Mizuno *et al.* (1986). Using a numerical model, Hong and Yoon (2003) explained that these increases were caused by the development of a strong coast jet along the western coast of Kyushu.

On August 31, 2002, typhoon Rusa crossed into the southern coast of Korea and passed over the Korean Peninsula (Fig. 1). A small moored data buoy was placed in the coastal waters at 127°45′E, 34°25′N to study the progression of ocean conditions that was possibly related to the red tide. A meteorological station was set up at 127°32′E, 34°25′N and several satellite-tracked drifters were deployed for studying the effect of the Yangtze River freshwater runoff into the East China Sea. These instruments happened to measure the ocean responses to the passing of Typhoon

---

*Corresponding author: lee@po.ocean.pusan.ac.kr

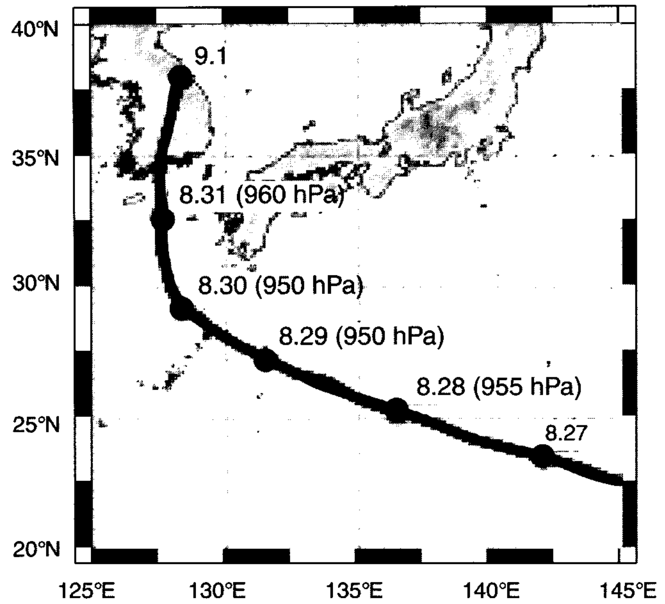

Fig. 1. Daily positions at 9:00 am local time and core air pressure of typhoon Rusa.

Rusa. The study of ocean response to the typhoons in the seas around Korea has just begun and this paper presents observed data to initiate such research.

INSTRUMENTATION AND OBSERVATIONS

For wind measurement, the meteorological station was installed at Tanggeon-Yeo, south of Oenaro-Do, and the data buoy was moored 4 km west of Sori-Do. The wind sensors used in those instruments were marine model wind monitors manufactured by RM Young. The mooring site of the data buoy was located at the head of a submarine canyon where deep offshore water could enter into the coastal area. The subsurface temperature at every three meters and salinity at 29 m depth (1m above the bottom) were also measured by the data buoy. Three downward viewing ocean color sensors with wave lengths of 443 nm, 490 nm and 555 nm were attached to the bottom of the data buoy to observe phytoplankton growth. The data gathered from various sensors were transmitted to satellites (ARGOS) and thus time intervals for the data was dependent upon the number of ARGOS satellite passes. During strong winds, transmissions to the ARGOS were sometimes lost. The data gathered at the meteorological station were stored in a solid memory bank and were retrieved after the station was recovered.

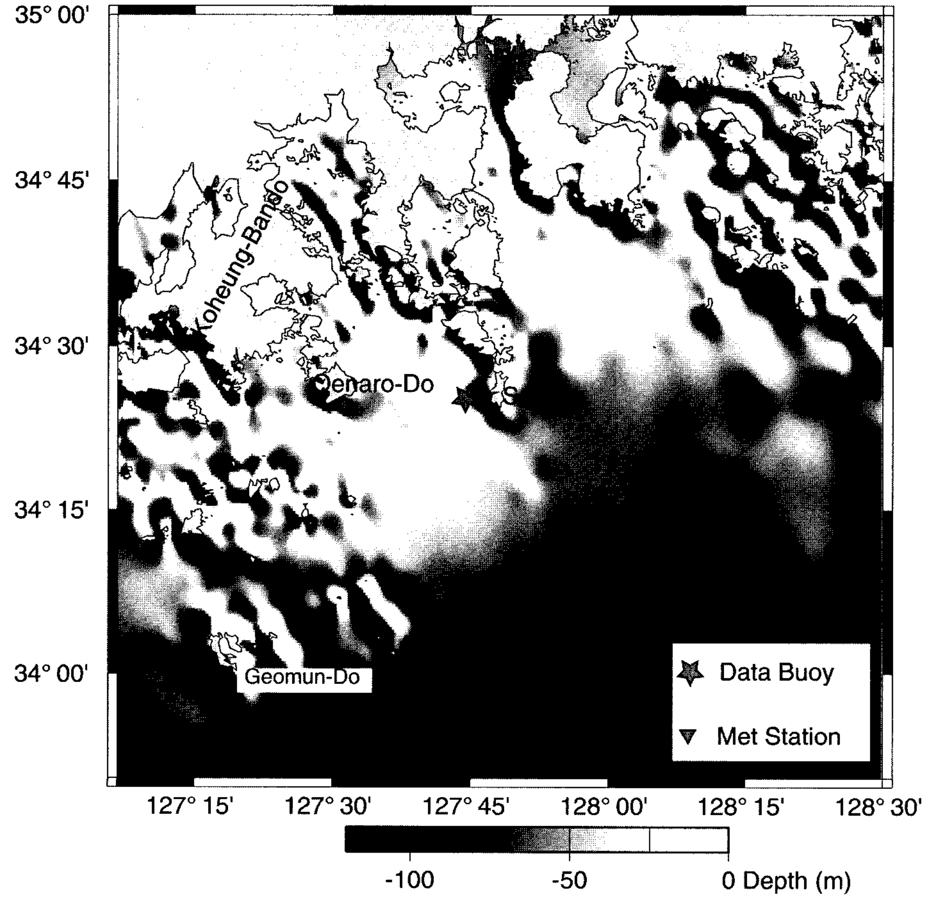

Fig. 2. Topography of the Southern Sea of Korea (Nam-Hae). The data buoy was moored at the head of submarine canyon.

Four satellite-tracked drifters equipped with Sea Bird Electronics Microcat SBE 37-SI temperature-conductivity sensors were deployed in the East China Sea from August 17 to September 21, 2002. Salinity and temperature were sampled at 30 minute intervals and were stored and transmitted at about 90 second intervals. ARGOS satellites received data when they passed over the drifters.

RESULTS

Wind and current

The Typhoon Rusa entered Korea through Koheung-Bando at 2 pm on August 31, 2002. The wind speed reached 33 m/s near Koheung-Bando when the core of the typhoon was about 250 km south of Koheung-Bando. Hourly mean wind speed measured by the meteorological station reached 28 m/s during the typhoon passage (Fig. 3). The general pattern of the north-south component of wind measured at the meteorological station was similar to the QuikSCAT measured wind (Fig. 3) but the east-west component of wind was significantly smaller than off-shore wind measured by the QuikSCAT. Both components of wind measured at the data buoy were close to the winds measured at the meteorological station, but were smaller than the winds measured at meteorological station because its sensors were located closer to the sea surface (boundary layer effect). The data transmissions from the data buoy to ARGOS were interrupted by a thick layer of moisture in the air during typhoon passage. Only one data packet was received on August 31 compared to the 5–6 data packets which were received per day on previous days.

Changes of ocean circulation pattern by a typhoon in general is very complicated. The most dramatic change occurred in the area close to the passage of the typhoon core (Drifter #12221 in Fig. 4). All three satellite-tracked drifters showed a large change of circulation three days before the typhoon passage. The curl of the wind is strongest at the margins of typhoon-like wind patterns and could well have been a cause of these changes before the eye of the storm passed over the area. Three to seven days after the typhoon passed, the broad north-eastward current changed to a westward current during the time of north-westerly winds. It was due to an Ekman surface current produced by these winds. But near Jeju Island, the current was in the opposite direction than that suggested by the Ekman current formation. The drifter there followed along the temperature front that was formed between cold near-shore water and warm off-shore water (see Fig. 8b).

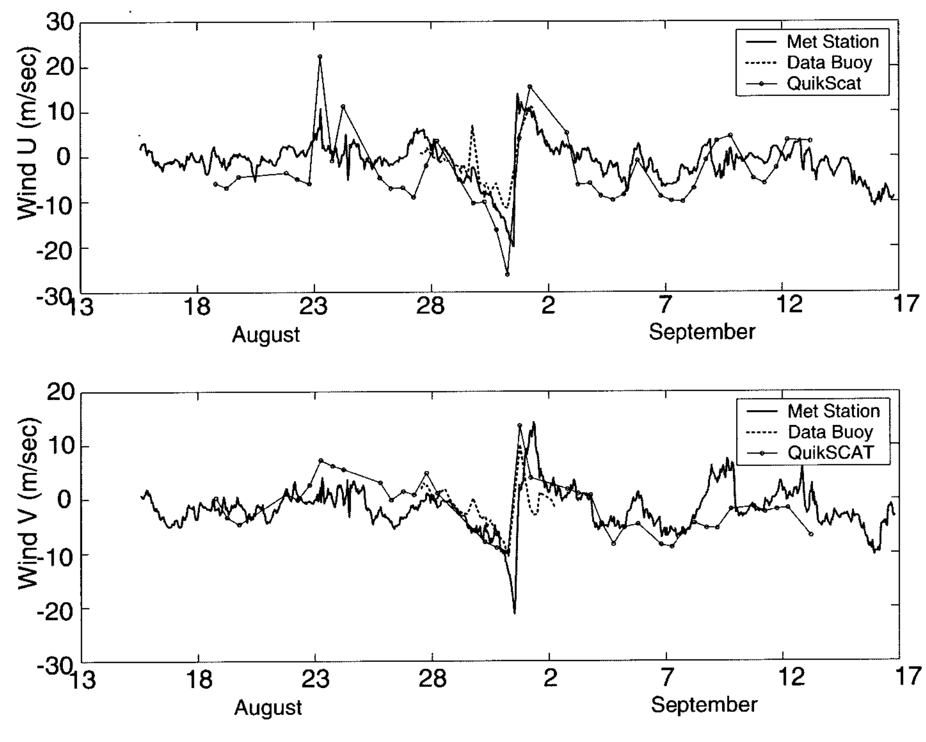

Fig. 3. Time series of (a) zonal wind and (b) meridional wind measured by meteorological station, data buoy and QuikSCAT.

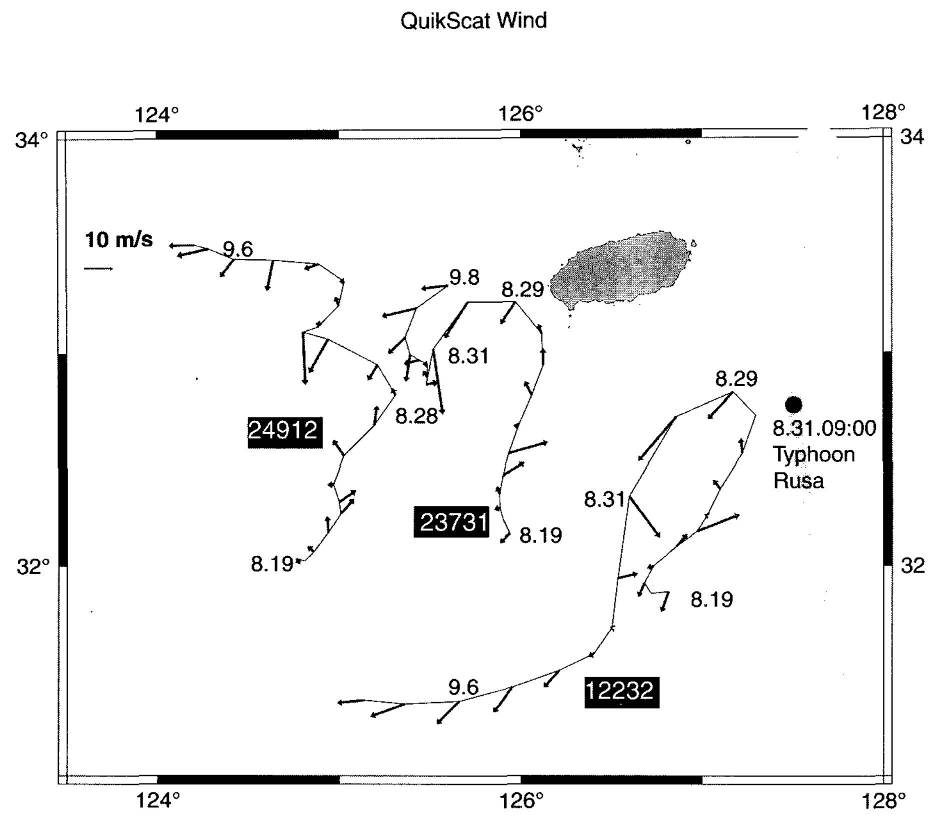

Fig. 4. Daily drifter tracks with daily mean winds (black arrows) measured by QuikSCAT. The numbers are month-day pairs. Drifter 15231 is not drawn due to its closeness to Drifter 23731.

Salinity

The salinity at the mouth of the submarine canyon changed dramatically from 33 psu to 30 psu after the passage of typhoon Rusa (Fig. 5). This freshening of sea water could have been caused either by an intrusion of well-mixed off-shore low salinity water of 30 psu - northward Ekman transport by easterly wind before the typhoon reached the mooring site (Fig. 3) - or by heavy local precipitation (about 400

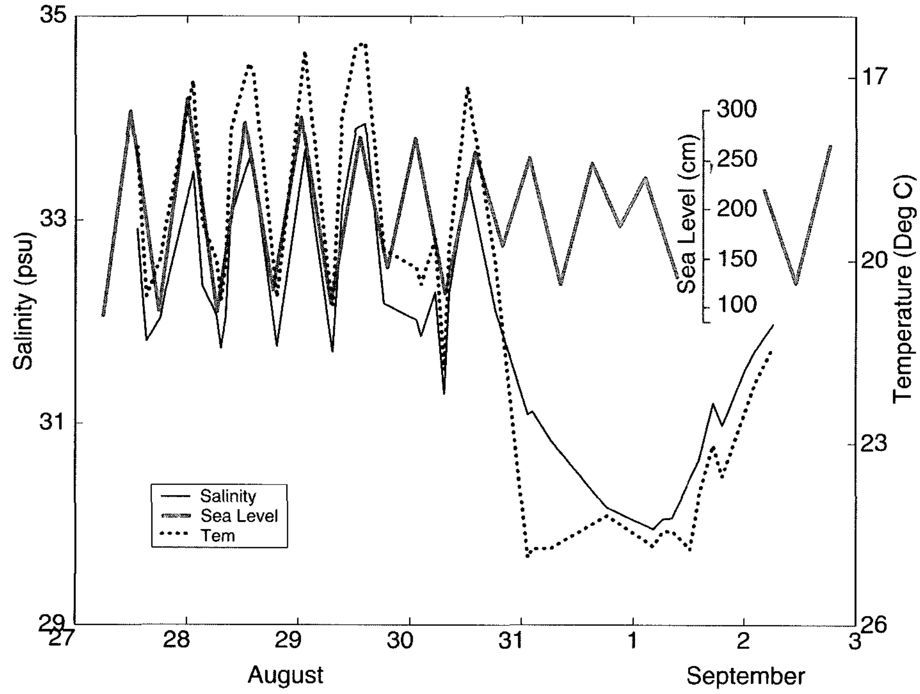

Fig. 5. Time series of salinity and temperature at the bottom observed by data buoy. Normalized sea levels at Geomun-Do are also drawn for comparison with salinity and temperature fluctuations.

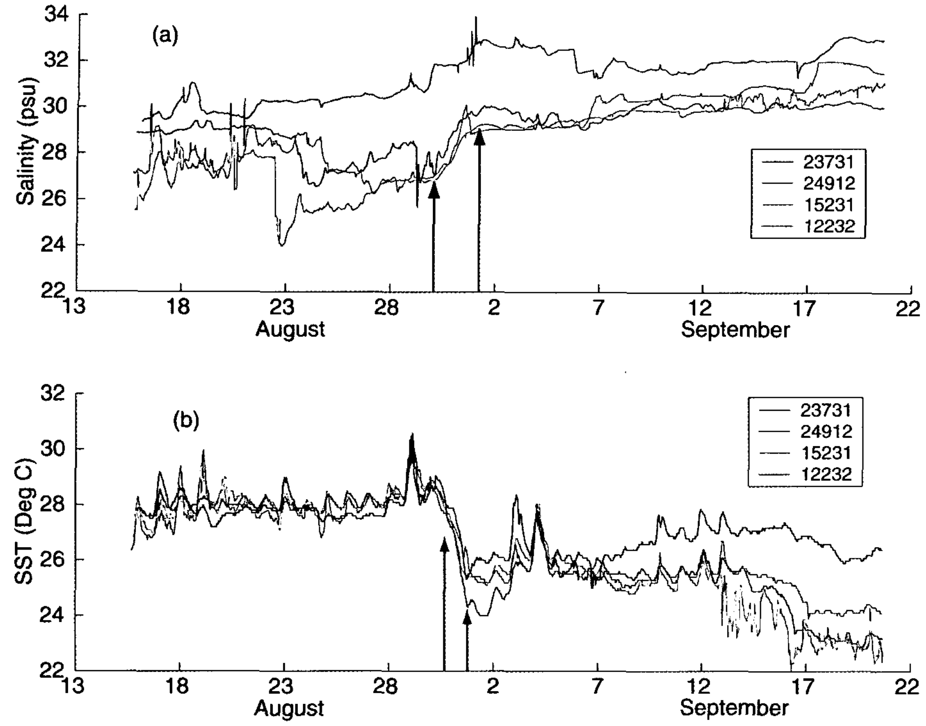

Fig. 6. Time series of (a) salinity and (b) sea surface temperature (SST) observed by drifters in the East China Sea. Arrows mark the start and end time of vertical mixing.

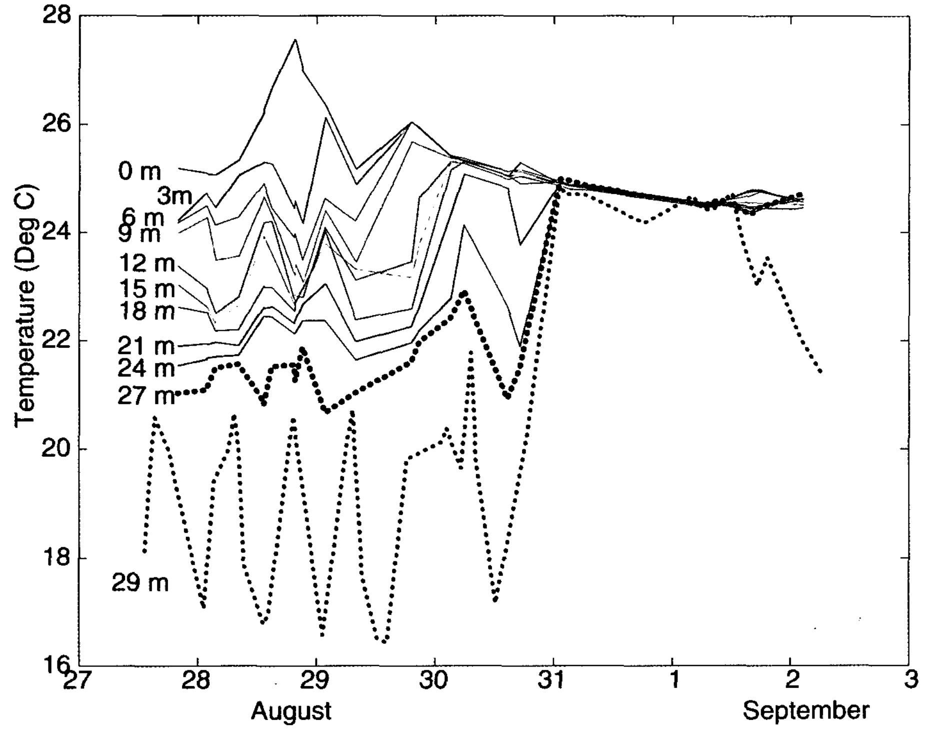

Fig. 7. Time series of vertical profiles of temperature observed at data buoy.

mm on August 31). The temperature of the mixed water column at the mooring site (Fig. 7) supports the occurrence of off-shore water intrusion rather than local mixing. A quantitative analysis of the local effects on freshening cannot be done with our data because no vertical profiles of salinity were measured- only salinity at the bottom was measured. In addition, the measurements of river run off are required for quantitative analysis.

Before typhoon passage, there was a daily salinity change of 1.5 psu at the ocean bottom that followed closely to the time series of the tidal sea level at

Geomun-Do (Fig. 5). The semi-diurnal tide moved the halocline vertically and the mooring location was at the boundary of cold and high salinity offshore water and warm and low salinity near-shore water. This tidally forced inflow of offshore water can rectify in a manner that, on the average, nutrient rich off-shore water is brought into near-shore area. It is apparent that the salinity distributions in this heavily studied area for red tide occurrences depends upon tidal cycle, a consideration that has not been given credence in past sampling methodologies. The salinity measurements should be done continuously at various locations or they should be done repeatedly using fast towed CTD.

The salinity in the East China Sea increased about 2 psu during Rusa passage (Fig. 6a). The strong wind mixed surface warm-and-low-salinity water with deep cold-and-high-salinity water. Time changes of surface salinity on the drifters show that vertical mixing appeared to have been completed in about 48 hours. Quite surprisingly, the temperature changes took only one day. Thus the horizontal gradients of both the salinity and the temperature fields were different and the changes could not be interpreted to have happened due to vertical mixing alone.

Water Temperature

The intrusion of well mixed warm water near Sori-Do is apparent in Fig. 7. The tidal influence is apparent only at a depth close to the bottom (29 m). The fully vertically mixed or homogeneous state began 14 hours before the eye of the typhoon passed and lasted about 30 hours. It is interesting to note that nighttime temperature inversion occurred after daytime heating of the thin surface layer. Inversions like these occur when thin layers of fresh water overlie deeper and saltier water.

In the off-shore area, the sea surface temperature (SST) dropped by about 3°C, from 28°C to 25°C, presumably due to vertical mixing (Fig. 6b). Near Jeju Island, SST measured by drifter #23731, which followed the current against the Ekman current (Fig. 4), continued to drop to 24°C because of the expansion of cold near-shore water (Fig. 8b). The horizontal distribution of SST in the East China Sea was relatively homogeneous (Fig. 8a) before the Rusa, but a thermal front between warm off-shore water and cold near-shore water formed near Jeju Island after the typhoon. The water that was cooled during the passage of the typhoon never warmed to its pre-typhoon temperature. The width of the cooled water strip was about 500 km (Fig. 9) and the width of the most strongly affected area - the right side of typhoon core - was reduced by the presence of the islands near Kyusyu. The shape of cooled area in this shallow sea was quite different than that of the open ocean. In contrast, Hurricane Felix's pass over the deep water left a narrow cooled area in the left side of its core and a broad cooled area in the right side (Dickey *et al.* 1998).

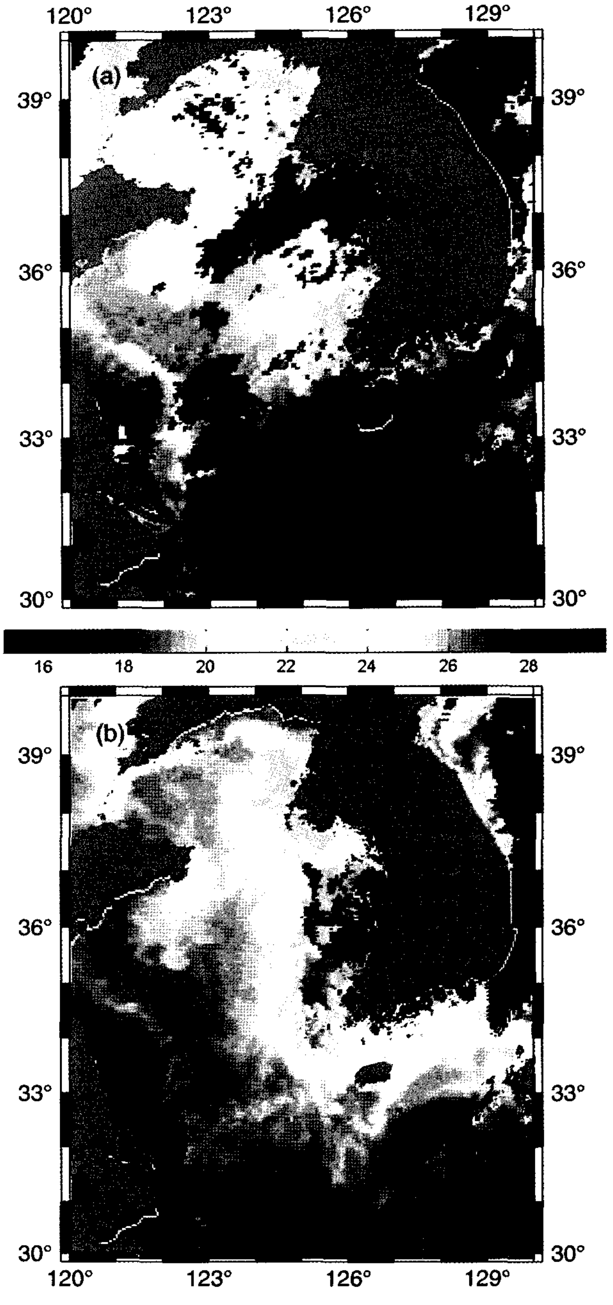

Fig. 8. Night time sea surface tempearture (a) on August 29 and (b) on September 2 observed from Moderate Resolution Imaging Spectroradiometer (MODIS) 4 μm band.

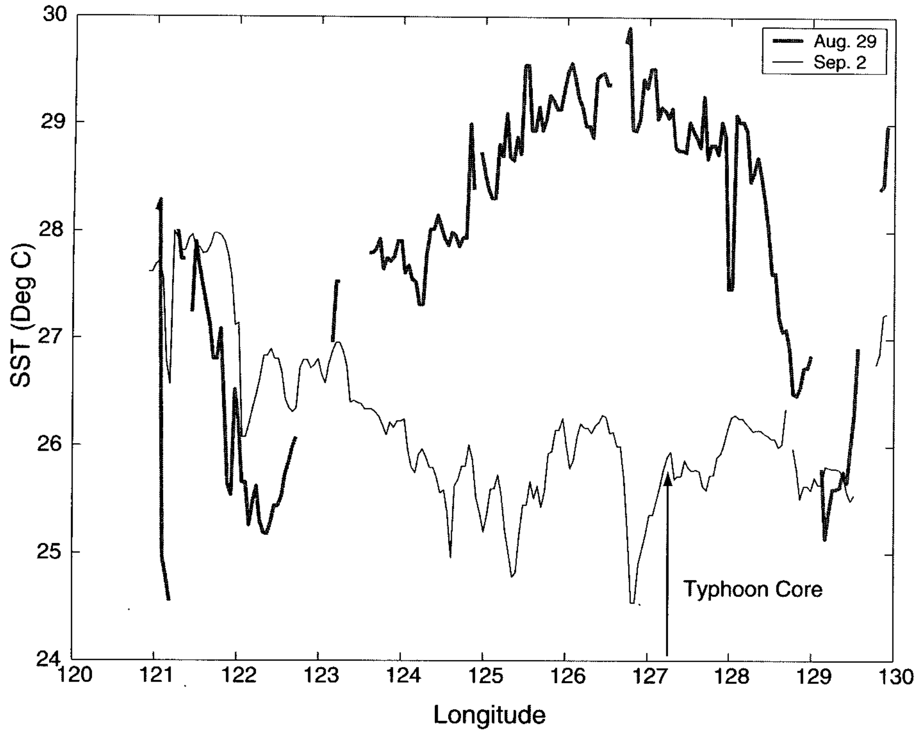

Fig. 9. Sections of sea surface temperature (SST) along 33° N from Fig. 10.

Ocean color

The signals in all three channels of ocean color increased after the typhoon passed (Fig. 10). Although the empirical relationship of measured irradiance with chlorophyll concentration has not yet been determined at this point, the daytime irradiance change after the typhoon is interesting enough to present here. The color intensities of all three wave lengths increased about four to eight times within one day after the typhoon. When the relationship of ocean color radiance at 555 nm with field chlorophyll-a by Suh *et al.* (2002)

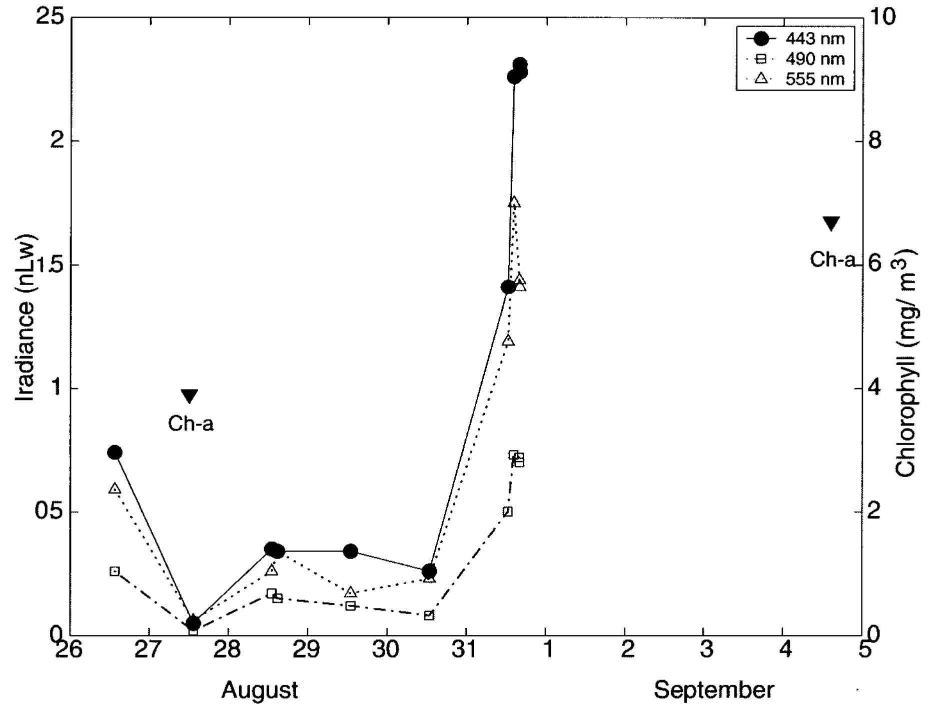

Fig. 10. Time series of color irradiance observed at data buoy with field measured chlorophyll-a.

was applied, the chlorophyll-a increased by one-and-a-half to two times the concentration before the typhoon passage. The directly measured chlorophyll-a concentration at the depth of 5 m increased (reverse triangles in Fig. 10) to about 1.7 times than before the typhoon passage.

Unfortunately, one day after the Rusa, the data buoy was cut off by fisherman and the time change of color radiance long enough to match observed diatom growth after the typhoon could not be measured.

SUMMARY AND DISCUSSION

The analyses on observations before and after Typhoon Rusa in the East China Sea show several large and coherent patterns of change that have not been observed before. Most notable are the different water characteristics and circulation changes between near-shore areas and off-shore areas. Well mixed offshore water intruded into the southern coast of Korea by strong northeasterly wind and near shore water expanded into the open sea west of Jeju Island. In the East China Sea the current changed from northeastward to westward because of wind field change but the current was against westward Ekman transport near Jeju Island. Near Sori-Do, the bottom salinity decreased by 3 psu but the surface salinity in the off-shore area increased to about 2 psu. The completely mixed water appeared and existed 12 hours before the passage of the eye of Typhoon Rusa over the data buoy. The SST drop observed by the data buoy was less than 1°C and implied the intrusion of off-shore water rather than the local mixing process. The SST drop in the East China Sea was dramatic and was 500 km wide. The cooled water did not warm up to pre-typhoon status by the change of circulation in the area. The lack of sub-surface current measurement hinders full dynamic analysis of ocean response to typhoons in southern seas of Korea but the observations reported here can be a basis for future dynamic analysis and numerical model experiment.

ACKNOWLEDGEMENT

The supports from the Ministry of Maritime Affairs and Fisheries through the Korea Sea Grant Program and the National Ocean and Atmospheric Administration, Office of Global Programs, through the "Consortium of Ocean's Role in Climate" Program at the Scripps Institution of Oceanography are gratefully acknowledged. The satellite-tracked drifters with salinity sensor used in this study are furnished and deployed by the National Fisheries Research and Development Institute. Reviews from Prof. C.-H. Hong and Dr. S.-H. Kang made substantial improvements on this paper.

REFERENCE

Cione J., P. Black and S. Houston, 2000. Surface observations in the hurricane environment. *Mon. Wea. Rev.*, **128**, 1550–1561.

DAsaro E., 2003. The ocean boundary layer below Hurricane Dennis. *J. Phy. Oceanogr.*, **33**, 561–579.

Dickey T., D. Frye, J McNeil, D. Manov, N. Nelson, D. Sigurdson, H. Jannasch, D. Siegel, T. Nichaels and R. Johnson, 1998. Upper-ocean temperature response to Hurricane Felix as measured by the Bermuda Testbed Mooring. *Mon. Wea. Rev.*, **126**, 1195–1201.

Gill, A. E., 1982. Atmosphere-Ocean Dynamics, Academic Press, 662 pp.

Ginis, I., 1995. Ocean response to tropical cyclone. Global perspectives on tropical cyclones, World Meteorological Organization Tech. Documentm WMO/TD-No. **693**, 198–260.

Hong C.-H. and J.-H. Yoon, 2003. A three dimensional numerical simulation of typhoons in the northwestern Pacific Ocean. Part I: a response of sea water to typhoon Holly. *J. Geophys. Res.*, In printing.

Mizuno S., K. Kawatate and T. Miita, 1986. CUrretn and temperature observations in the east Tsushima Channel and the Sea of Genka. *Prog. Oceanogr.*, **17**, 277–295.

Ohlmann, J., P. Niiler, 1999. A two-dimensional response to a tropical storm on the Gulf of Mexico shelf. *J. Mar. Sys.*, **31**, 87–99.

Price, J., T. Sanford and G. Forristall, 1994. Forced stage response to a moving hurricane. *J. Phys. Oceanogr.*, **24**, 233–260.

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

Suh, Y.-S., L.-H. Jang, B. G. Mitchell, M. Kahru, K. Prasad and H.-Y. Shin, 2002. Study on the Korean waters using the CAL/VAL of the OSMI Level 2 data. *Kor J. Rem. Sens.*, **18**, 127–139.

Zelder S., T. Dickey, S. Doney, J. Price, X. Yu and G. Mellor, 2002. Analyses and simulations of the upper oceans response to Hurricane Felix at the Bermuda Testbed Mooring site: 13–23 August 1995. *J. Geophy. Res.*, **107(C12)**, 3232–3261.

Manuscript received April 10, 2003
Revision accepted June 17, 2003
Editorial handling: Jae-Hak Lee