Variation in air-sea CO_2 flux and pH induced by passage of typhoon Hai-Tang (2005)

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1. Introduction

Sudden variation in air-sea carbon dioxide (CO_2) flux has been studied from observational and numerical viewpoints so far. Air-sea CO_2 flux is usually calculated by empirical bulk formulas using gas transfer velocity (piston velocity) and a difference in partial CO_2 pressures (pCO_2) between the atmosphere and the ocean. The oceanic partial CO_2 pressure pCO_2^{sea} and the hydrogen ion concentration (usually reported by the normalization of pH to a temperature of 25ºC) can be diagnostically calculated by given water temperature, salinity, dissolved inorganic carbon (DIC) and total alkalinity(ALK). This report addresses the variation in pCO_2^{sea}, PH and air-sea CO_2 flux by passage of a tropical cyclone. A numerical experiment is performed to investigate the variations during the passage of typhoon Hai-Tang in 2005.

2. Experiment design

A simple chemical scheme (Wada et al., 2011) was incorporated into the atmosphere-wave-ocean coupled model (Wada et al., 2010). Initial conditions of DIC and ALK are provided from the empirical formulas derived from observations by research vessels (Wada et al., 2011). Water temperature and salinity at the initial time are provided from daily oceanic reanalysis data with a grid spacing of 0.5º calculated by the Meteorological Research Institute multivariate Ocean Variational Estimation system (MOVE) (Usui et al., 2006). The atmospheric partial CO_2 pressure pCO_2^{air} is assumed to be expressed as follows,

$$pCO_2^{air} = pCO_2^{sea}(t=0) - 20(ppm), \qquad (1)$$

where $pCO_2^{sea}(t=0)$ is pCO_2^{sea} at the initial time. A detail description of experiment design for the atmosphere-wave-ocean model is described in Wada et al. (2010). The specification of the coupled model is as follows. Oceanic roughness length is calculated based on Taylor and Yelland (2001). Exchange coefficients for momentum, heat and moisture fluxes are calculated by Kondo (1975).

3. Results

At the initial time, pCO_2^{sea} is 390 μ atom and almost horizontally uniform (Fig. 1a). At 72 h, pCO_2^{sea} is higher than that at the initial time along the track of predicted Hai-Tang particularly on the right side of the track from 144° to 148°E (Fig. 1b), corresponding to less intensification phase. In contrast, pCO_2^{sea} decreases behind the center of predicted Hai-Tang around 136°E.

pCO_2^{sea} is relatively high along Hai-Tang's track where sea-surface temperature (SST) becomes low (Fig. 2a) and DIC becomes high (Fig. 2b). Relatively low SST and high DIC along the track of predicted Hai-Tang result from Hai-Tang-induced vertical turbulent mixing in the upper ocean. The effect of the vertical turbulent mixing on the increase in pCO_2^{sea} and DIC and the decrease in SST differs depending on the oceanic environment such as a horizontal distribution of mixed-layer depth at the initial time (Wada et al., 2010). Oceanic environments can affect not only the intensity prediction but also the chemical oceanic response to Hai-Tang. It should be noted that the oceanic environment at the initial time can also affect a horizontal distribution of DIC.

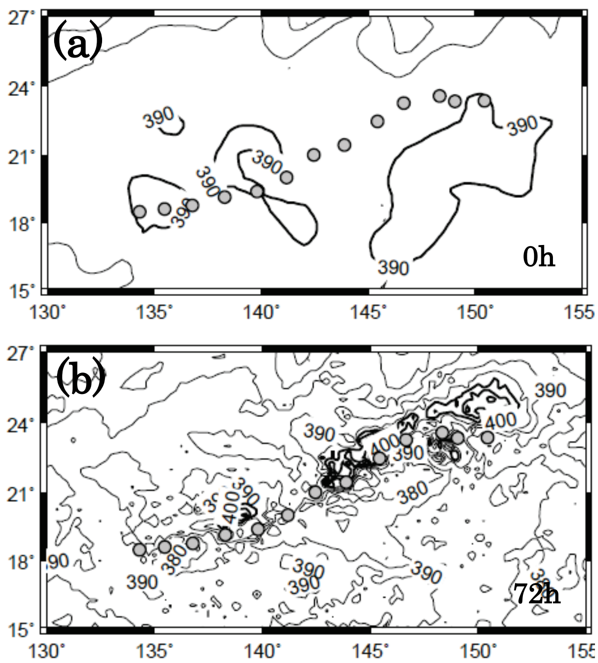

Figure 1 Horizontal distribution of predicted pCO_2^{sea} at (a) 0 h and (b) 72 h.

A horizontal distribution of PH at 72 h is shown in Fig. 3. PH clearly decreases from 144º to 148ºE on the right side of the track of predicted Hai-Tang. The area of low PH corresponds to the area of high pCO_2^{sea}, high DIC and low SST. This indicates that PH tends to become low when a mixed layer is thin underneath Hai-Tang. In other words, PH hardly decreases when Hai-Tang passes across warm-core eddies with horizontal scale of a few hundred kilometers. In addition, PH tends to easily decrease when Hai-Tang passes over the area where DIC is high and SST is relatively low.

After the passage of Hai-Tang, it is interesting that low PH remains around 24ºN, 148ºE where predicted Hai-Tang undergoes recurvature. This implies that surface-water acidification due to the passage of Hai-Tang is affected by moving speeds of Hai-Tang as well as oceanic environment. The process associated with low PH induced by Hai-Tang is similar to Hai-Tang-induced sea-surface cooling due to Ekman pumping and vertical turbulent mixing. The transport of cool water with low PH from a seasonal thermocline is efficiently mixed in the upper ocean at the recurvature phase and plays a crucial role in surface-water acidification.

Sea-to-air CO_2 flux is remarkable around the center of predicted Hai-Tang (Fig. 4). After the passage of Hai-Tang, CO_2 flux rapidly decreases due to a small △ pCO_2 and weakening surface wind speed. It should be noted that there is still uncertainty in the gas transfer velocity under high winds.

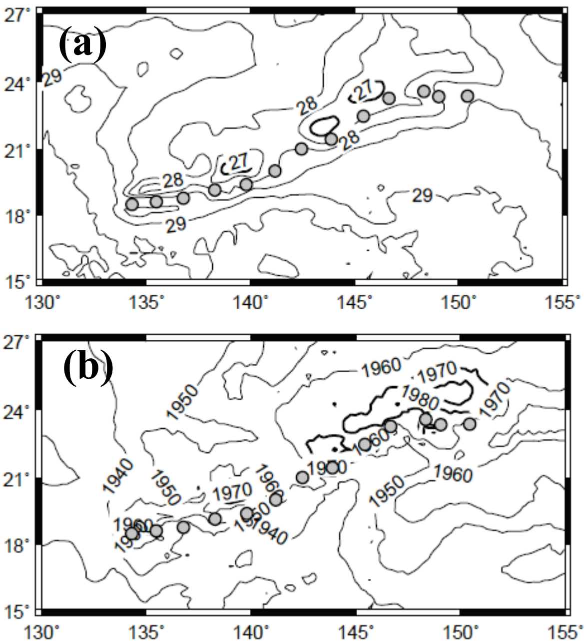

Figure 2 Same as Figure 1 except for sea-surface temperature at 72 h and (b) DIC at 72 h.

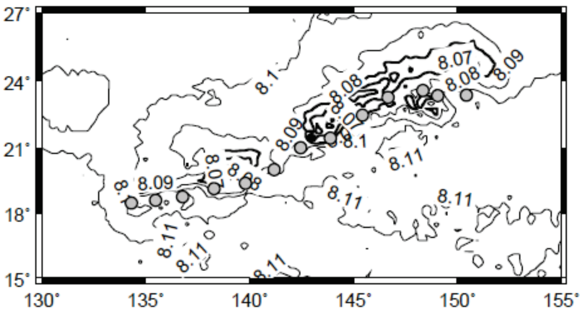

Figure 3 Same as Figure 1 except for PH at 72h.

Because there is little chemical observation around the area where Hai-Tang passed, it is difficult to validate the present numerical results. Chemical observations during the passage of a tropical cyclone (TC) will be needed to develop the present coupled model. This report proves that rapid increases in sea-to-air CO_2 flux occurs during the passage of TCs. The coupled model will contribute the estimate of the abrupt sea-to-air CO_2 flux on global carbon circulation.

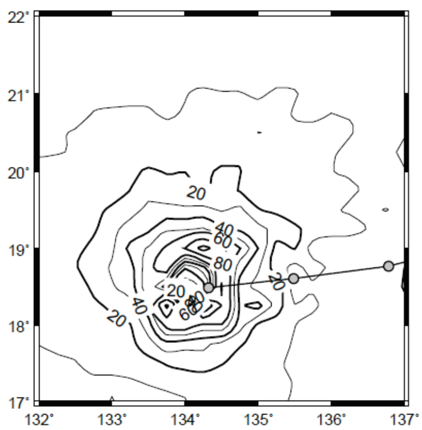

Figure 4 Horizontal distribution of sea-to-air CO2 flux at 72h.

Acknowledgement

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