Section 8

Development of and advances in ocean modelling and data assimilation, sea-ice modelling, wave modelling

Rapid decreases in pCO_2 during the passage of Tina and Winnie (1997)

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1. Introduction

An automatic-measuring system for the partial pressure atmosphere and ocean carbon dioxide (pCO_2) mounted on the moored buoy in the East China Sea (28°10'N, 126°20'E) captured sudden decreases in oceanic pCO_2 (pCO_2^{sea}) during the passage of typhoons Tina and Winnie in 1997 (Nemoto et al., 2009). Wada and Midorikawa (2009) reported from numerical simulation results calculated by an ocean general circulation model that the oceanic physical responses to the two typhoons differed even though the magnitudes of analyzed air-sea CO_2 flux were on the same scale between them. During the passage of Tina, upwelling along the continental shelf played a crucial role in decreasing water temperature at depth of 1, 50 and 100 m at the moored buoy, while a mixed layer around the moored buoy deepened due to vertical turbulent mixing when Winnie approached to the buoy about 300 km to the southwest passed away, which was closest from Winnie's center to the buoy.

A simple chemical scheme formulated based on Dickson et al. (2007) is incorporated into the Meteorological Research Institute Community Ocean Model (MRI.COM) (Ishikawa et al., 2006). This report focuses on rapid decreases in pCO_2^{sea} during the passages of the two typhoons simulated by MRI.COM including the simple chemical scheme.

2. Chemical scheme

Dickson et al. (2007) pointed out that it was possible, in theory, to obtain a complete description of the carbon dioxide system in sea water at a particular temperature and pressure provided that sea water dissolved inorganic carbon (DIC) and total alkalinity (ALK) were given. The evolution of DIC can be calculated using an equation similar to temperature and salinity equations used in the MRI.COM. The temperature and salinity equations are formulated as a flux form and consist of advection, diffusion, convective adjustment and Noh and Kim's vertical mixing (Noh and Kim, 1999). The DIC equation is formulated in the same way as the temperature and salinity equations. In addition, the effect of air-sea CO_2, evaporation and precipitation fluxes on the evolution of DIC are incorporated into the DIC equation. Using numerical simulation results of temperature, salinity and DIC under the assumption that ALK, total phosphate and total silicate all are constant during the integration, pCO_2^{sea} is calculated in an iterative way based on carbon-based chemical equilibration. CO_2 flux is then calculated by using the short-time gas-exchange-wind relationships derived from Wanninkhof (1992) .

DIC and ALK at the initial time are determined from the following formulas.

$$DIC_{init} = \begin{cases} -3.7145T_1 + 2065.5 & (T_1 \geq 19.95) \\ -19.951T_1 + 2387.8 & (10.56 \leq T_1 < 19.95) \\ -27.848T_1 + 2471.2 & (2.70 \leq T_1 < 10.56) \\ 42.031T_1 + 2282.6 & (T_1 < 2.70) \end{cases}, \quad (1)$$

$$ALK_{init} = \begin{cases} 2500.9T_1 - 0.029 & (T_1 > 18.0) \\ 2299.818 & (T_1 \leq 18.0) \end{cases}. \quad (2)$$

where T_1 indicates surface water temperature. These empirical formulas are determined from observations by research vessels around 27.4-31.2°N, 136-138°E from 1994 to 2008. It should be noted that the normalization of DIC and ALK to a salinity of 34.5 from a salinity of 35.0 was performed at the initial time of numerical integration.

Experiment design in the present numerical simulation is the same as Wada and Midorikawa (2009). The 3-hourly observed values of pCO_2^{air} at the moored buoy are calculated by temporally linear interpolation every time step of the MRI.COM. In addition, pCO_2^{air} is assumed to be homogeneous every time step, provided to the chemical model as the surface boundary condition.

3. Results

The time series of pCO_2^{sea} observed at the moored buoy indicated that pCO_2^{sea} rapidly decreased when pCO_2^{air} reached the minimum during the passages of Tina and Winnie, respectively (Fig. 1). Rapid decreases in pCO_2^{air} are due to relatively low sea-level pressure (not shown). A rapid decrease in pCO_2^{sea} on 7 August during the passage of Tina is well reproduced by the chemical scheme incorporated into the MRI.COM.

The normalized pCO_2^{sea} to a temperature 29ºC, representing the variation in pCO_2^{sea} independent of water temperature, shows that the normalized pCO_2^{sea} reaches the maximum when pCO_2^{air} reaches the minimum (Fig. 2). Simulated DIC also rapidly increases due to the passage of Tina. The numerical results well capture the rapid increase in the normalized pCO_2^{sea}. However, the amplitude of the increase in the normalized simulated pCO_2^{sea} is smaller than the amplitude observed at the moored buoy (Fig. 2).

After the passage of Tina, both the simulated and observed pCO_2^{sea} gradually increase and their normalized pCO_2^{sea} decrease. The rapid decrease in the normalized simulated pCO_2^{sea} is accompanied by a rapid decrease in DIC and a gradual increase in surface water temperature.

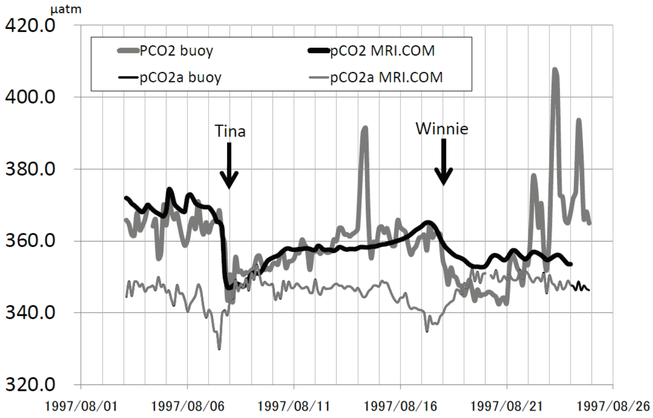

Figure 1 Time series of observed and simulated pCO_2^{sea} (thick solid black line) and observed and modeled pCO_2^{air} (thin solid back line) at the moored buoy.

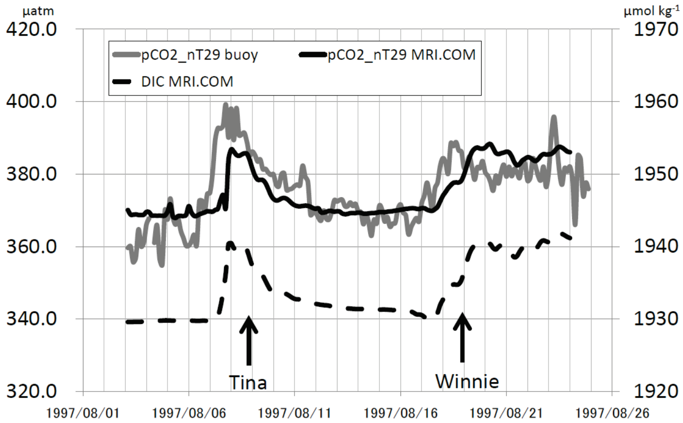

Figure 2 Same as Fig. 1 except for observed and simulated pCO_2^{sea} normalized to a 29ºC and DIC (dashed line with the right vertical axis).

In contrast, a rapid increase in observed pCO_2^{sea} on 14 August (Fig. 1) was accompanied by the sudden increase in surface water temperature observed at the moored buoy under a calm condition (not shown). Such sudden variation could not be simulated because the sudden increase in surface water temperature could not be simulated probably due to relatively strong modeled wind speed and lack of tidal effect in the MRI.COM. Because the normalized pCO_2^{sea} does not increase rapidly (Figure 2), the rapid increase in observed pCO_2^{sea} is determined only by surface water temperature. This report indicates the possibility of accurate pCO_2^{sea} simulation required for calculating sudden variation in CO_2 flux during the passage of a tropical cyclone. In order to improve the model, more observations are needed for validation.

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