Wave effect on air-sea CO_2 fluxes: A case study on Yellow Sea

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abstract

Based on the dissipation source function of SWAN wave model, gas transfer velocity in terms of turbulent kinetic energy dissipation rate is determined. Six parameterizations of gas transfer velocity are used to estimate the air-sea CO_2 fluxes in the Yellow Sea of China. It is shown that the wave-related gas transfer velocities can reduce the uncertainties of air-sea CO_2 fluxes. The results suggest that the Yellow Sea is a source of CO_2 in April, and is a sink of CO_2 in May, which can be explained by the more booming of phytoplankton in the latter situation.

Introduction

As the major uptake source of CO_2 in the atmosphere, ocean plays an important role in global carbon cycle and climate change processes. Many efforts have been made to accurately estimate CO_2 fluxes through air-sea interface. The air-sea CO_2 flux F is usually calculated by

$$F = k \cdot s \cdot \Delta pCO_2 \qquad (1)$$

where k is the gas transfer velocity, s is the gas solubility in seawater, and ΔpCO_2 is the partial pressure difference of CO_2 in seawater and air. Gas transfer velocity is directly regulated by the turbulence near air-sea interface, which indicates many dynamic processes, such as wind, waves and current, involved in the gas transfer through air-sea interface. However, gas transfer velocity has been traditionally parameterized as a function of wind speed (Liss and Merlivat, 1986; Wanninkhof, 1992; Wanninkhof and McGillis, 1999; Nightingale et al 2000; Sweeney et al.,2007). Recently, Zhao et al. (2003) and Woolf (2005) indicated that wind waves and their breaking affect the gas transfer significantly. Lorke and Peeters (2006) and Zappa et al.(2007) suggested that the turbulent kinetic energy (TKE) dissipation rate is the robust parameter to describe the air-sea gas transfer processes.

In this paper, the TKE dissipation rates are calculated by the source function of SWAN wave model. Then the gas transfer velocity is determined as a function of TKE dissipation rate. Various parameterizations of gas transfer velocity are used to estimate air-sea CO_2 fluxes at Yellow Sea of China. The comparisons show that the waves have great effect on the air-sea CO_2 fluxes.

Data and Methods

The turbulent energy dissipation due to wave breaking is calculated from a third generation wave model SWAN. According to dimensional analysis, the corresponding TKE dissipation rate is defined by

$$\varepsilon = \alpha \frac{Diss}{\rho_w H_s} \qquad (2)$$

where ρ_w is the density of sea water which is taken as 1025 kg/m^3 to keep consistent with SWAN model, *Diss* is the total energy dissipation calculated by the source function of SWAN model and H_s is the significant wave height, these two data come from the result of SWAN. Here α =0.604 which is determined by the comparisons of calculations with observations.

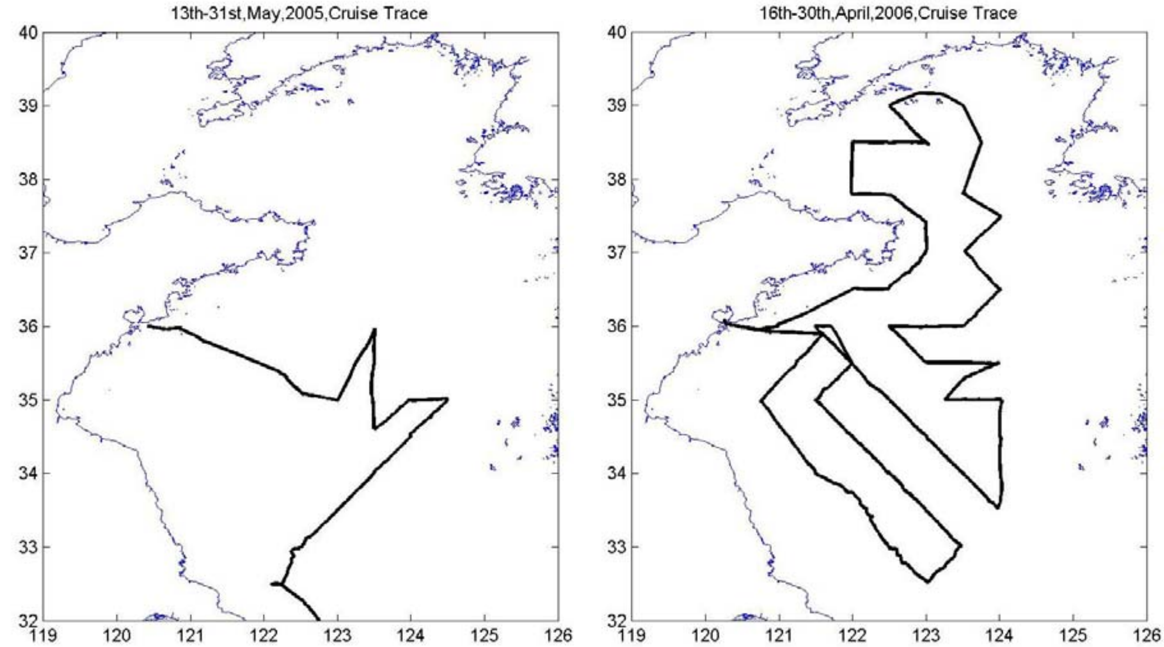

Fig.1. The cruises of May 2005 (left) and April 2006 (right).

The data of partial pressure of sea water and air was collected in the Yellow Sea of China during the cruise 13th-31st May 2005 and 16th-30th April 2006. Take 2° and 1.5° as the radius, interpolate the data to the grids range of 32-40°N,119-126°E with spatial resolution 2'×2'. Therefore, the air-sea CO_2 fluxes can be estimated in the whole Yellow Sea.

Air-sea CO_2 fluxes calculated by various gas transfer velocities

Three parameterizations of gas transfer velocity in terms of wave related parameters (Woolf, 2005; Zappa et al., 2007; Zhao and Xie, 2010), and three parameterizations in terns of wind speed (Wanninkhof, 1992; Wanninkhof and McGilis, 1999; Sweeney et al., 2007) are used to estimate air-sea CO_2 fluxes. The results are shown in Fig.2 and Fig. 3, respectively.

The total air-sea flux of carbon dioxide for the whole region considered during the last 19 days of May (i.e., from 13th to 31st) is given as:

$$F_{total} = F_{grid} \times 3600 \times 24 \times 19 \times (110/30)^2 \times 12 \quad (3)$$

where F_{grid} is the sum of air-sea CO_2 flux of each grid for the whole region in the unit of tC. We take the mean of flux of each grid's 4 points as the flux for this grid.12 denotes the mole mass of carbon with a unit of g/mol; 110 is approximately the length of 1° latitude. Here the spatial resolution is 2'×2', thus, there are 30×30 grid points within each 1°×1° area. The total fluxes are shown in table 1. The air-sea fluxes from 13th to 31st in May of 2005 calculated by these formulas are all negative, which imply that the ocean absorbs carbon dioxide from the atmosphere. The region releasing CO_2 to atmosphere is located in the offshore area near Jiangsu Province. The air-sea CO_2 flux is roughly meridional-distributed with positive values in the western boundary and negative in the eastern boundary of Yellow Sea.

The total air-sea flux of carbon dioxide for the whole region from April 16 to 30 can be estimated by Eq. (3) with replacing 19 into 15. The results are shown in Table 2.

The total air-sea fluxes from 16 to 30 in April of 2006 calculated by these formulas are all positive. The source of carbon dioxide is mainly distributed in the southern part of Yellow Sea and peaks near estuary of Yangtze River along the coast of Jiangsu Province. A relatively weak source exists to the east of Shandong Peninsula between 36-38°N and separates the sink of carbon dioxide on both sides.

Conclusions

The results show that the differences of gas transfer velocity significantly affect the estimation of air-sea gas fluxes. The wave-related gas transfer velocities can reduce the uncertainties of air-sea flux. In Yellow Sea, the main source of carbon dioxide is located in the western and southern parts near the coast of Jiangsu Province, while the sink is in the central and eastern South Yellow Sea. The Yellow Sea is the source of CO_2 in April, and is the sink in May. It can be explained by the more booming of phytoplankton in May than in April.

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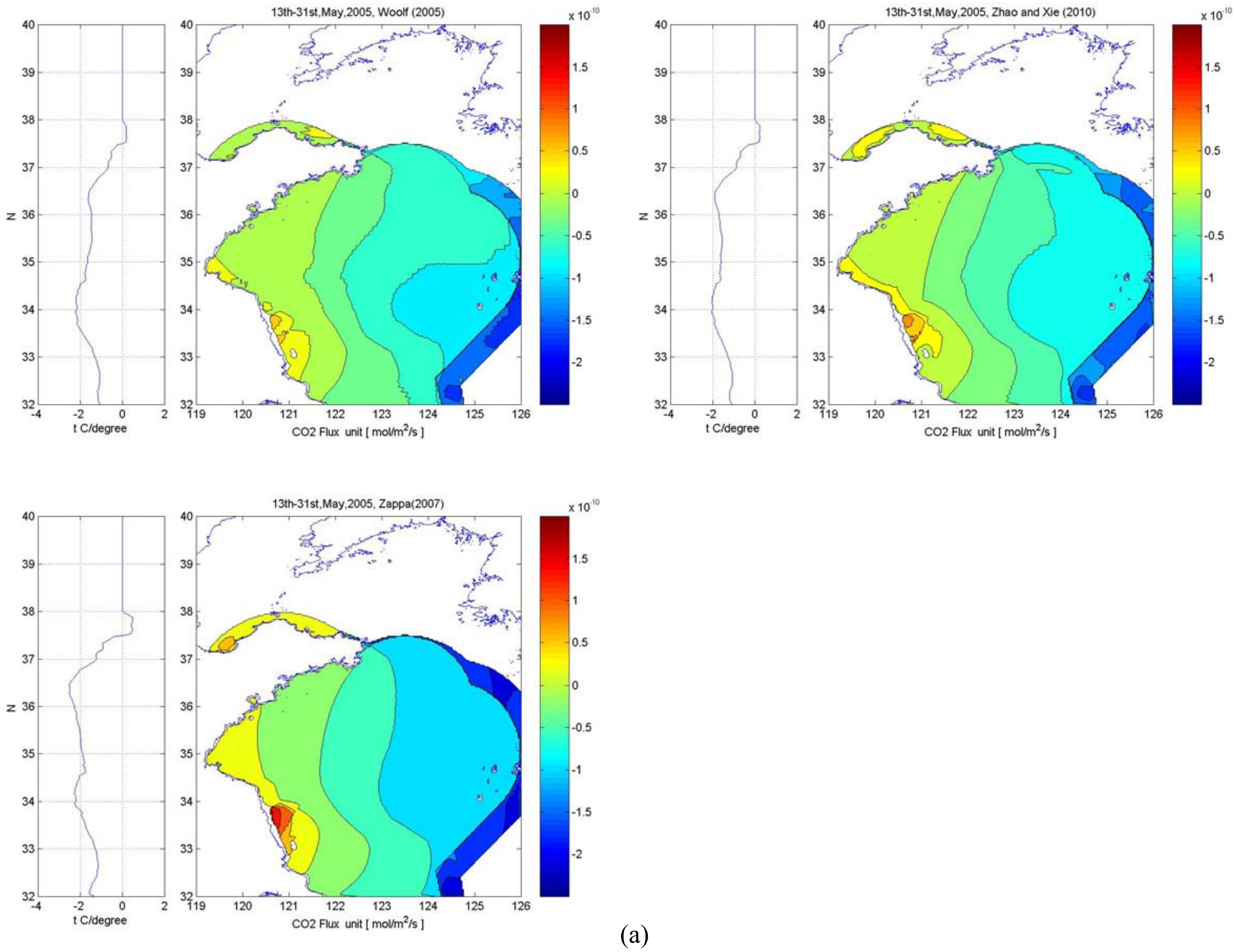
Table 1. The total fluxes in May.

May 13 -31 , 2005 unit [t C]					
F_{Woolf}	F_{Zhao}	F_{Zappa}	F_W	F_{WM}	F_S
-237.19	-241.71	-284.89	-285.11	-232.89	-197.39

Table 2 Total fluxes in April.

April 16 -30 , 2006 unit [t C]					
F_{Woolf}	F_{Zhao}	F_{Zappa}	F_W	F_{WM}	F_S
102.83	153.78	149.16	107.08	86.22	69.64


13th-31st,May,2005, Woolf (2005)
13th-31st,May,2005, Zhao and Xie (2010)
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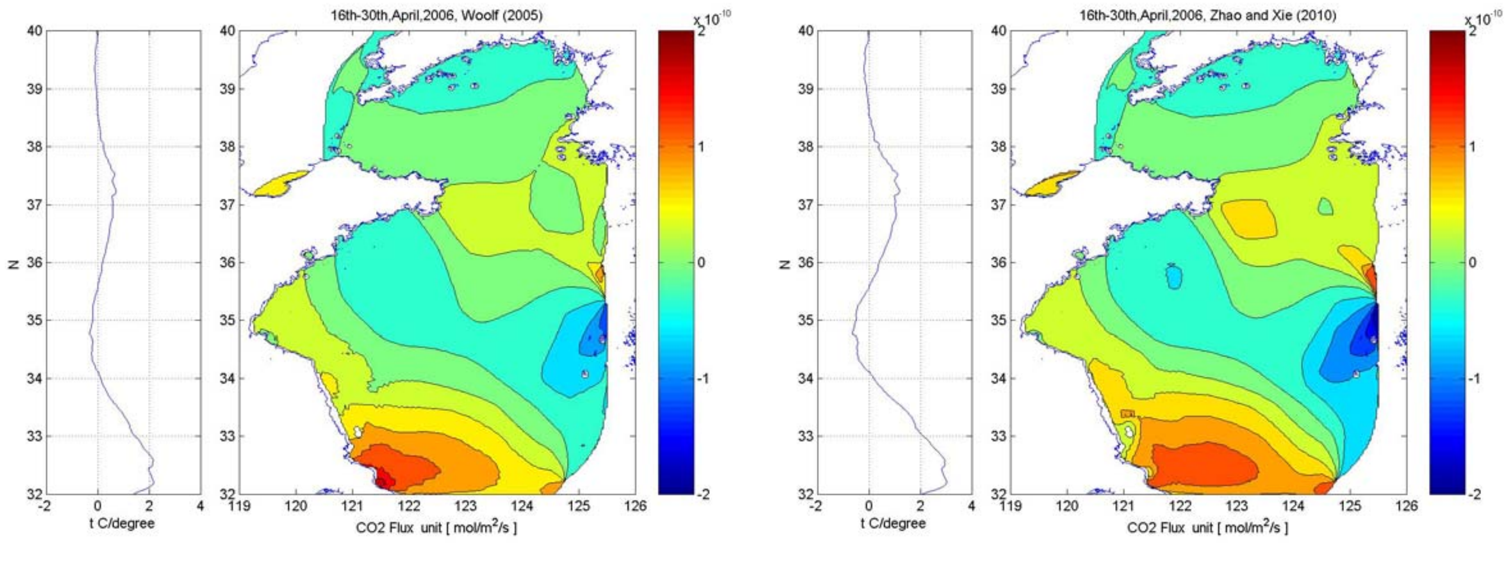
CO2 Flux unit [mol/m2/s]
x 10-10

(a)


16th-30th,April,2006, Woolf (2005)
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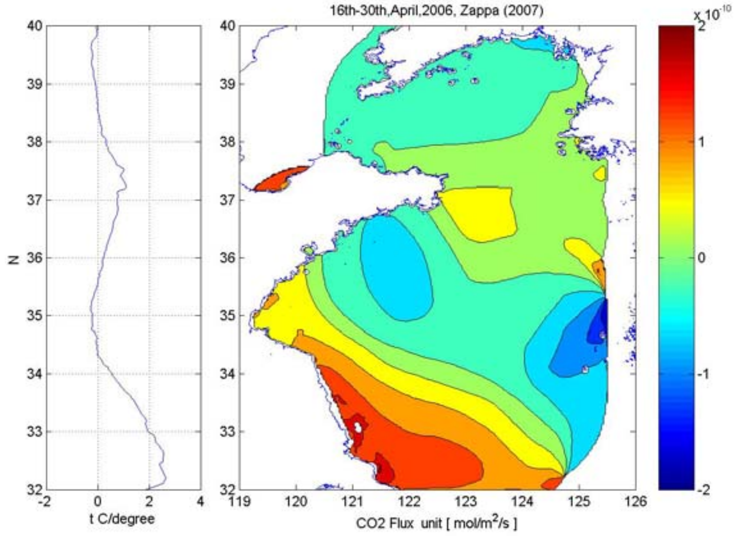
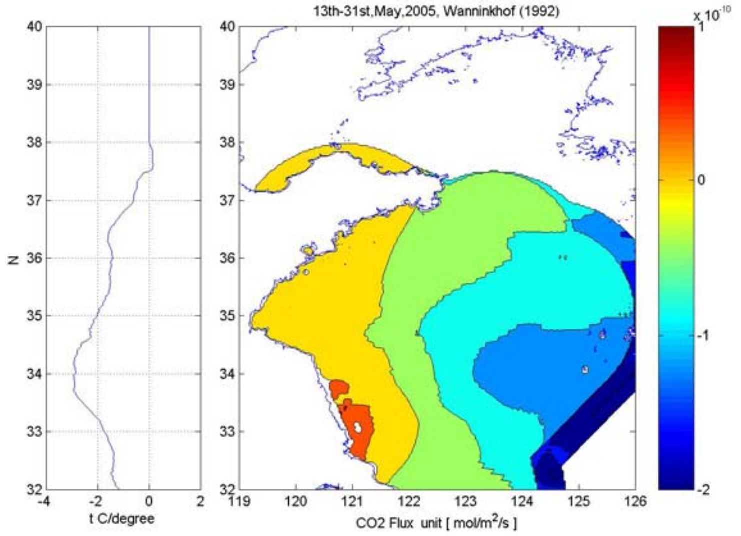
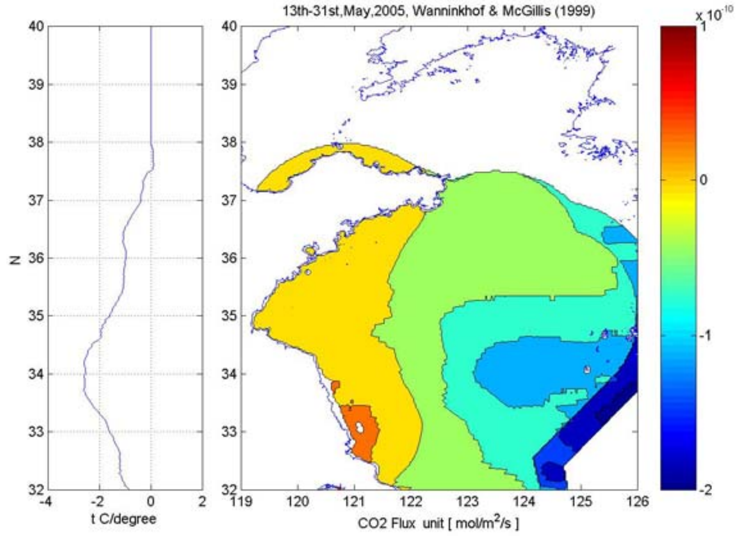
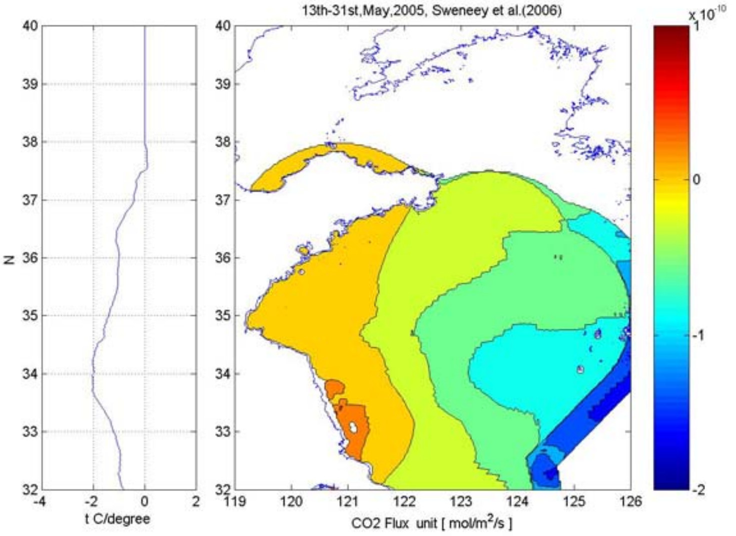


(b)

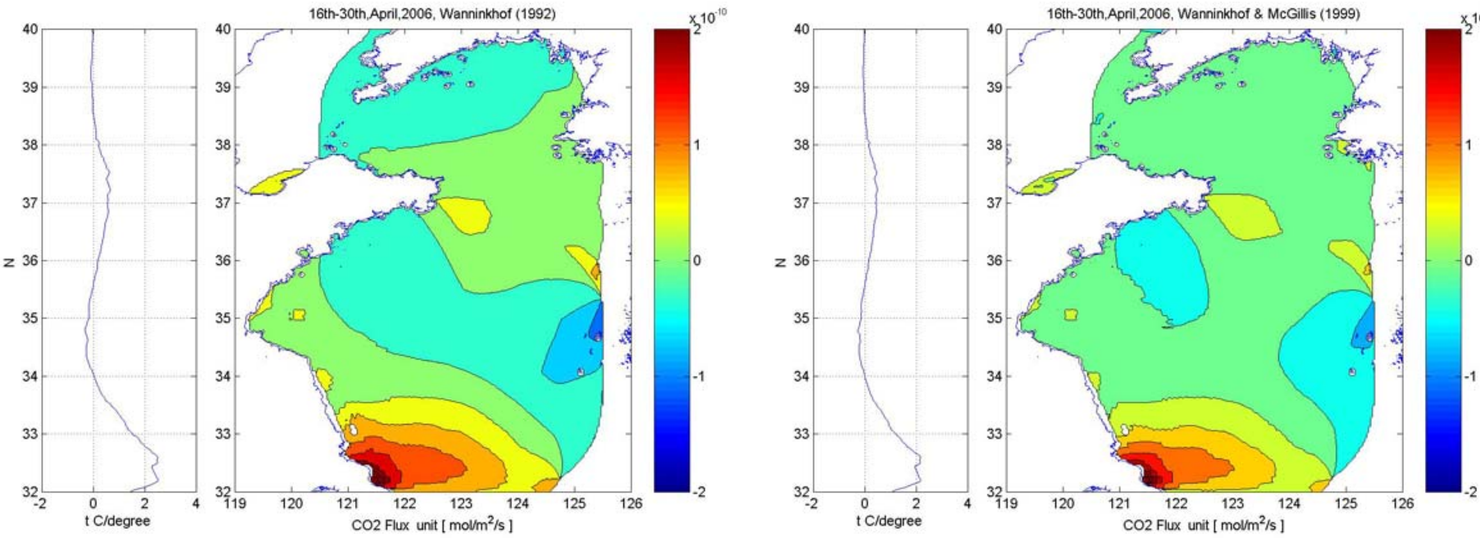
Fig.2 Air-sea CO_2 flux distribution calculated by Woolf (2005), Zappa et al. (2007), and Zhao and Xie (2010) in May 2005, respectively. Fig. 3a and 3b represent the fluxes in May and April. The left panel in each subplot is the zonal sum of air-sea CO_2 fluxes.

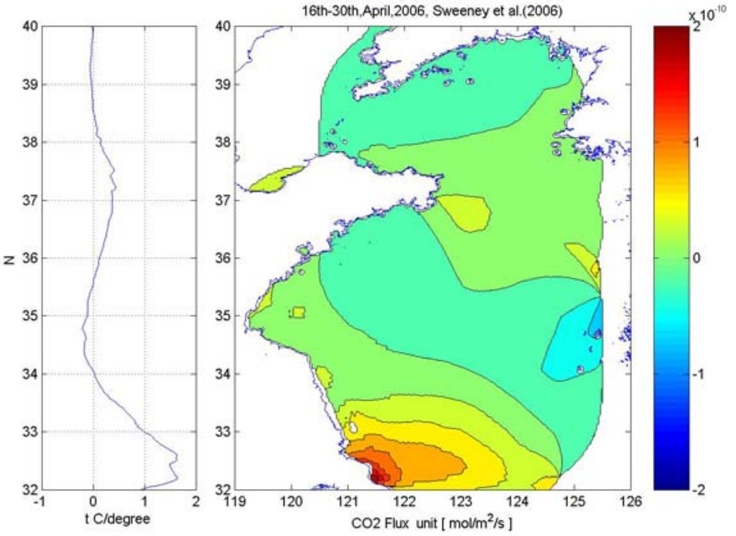






(a)





(b)

Fig.3 Air-sea CO_2 flux distribution calculated by Wanninkhof (1992), Wanninkhof and McGilis (1999), and Sweeney et al. (2007) in May 2005, respectively. Fig. 3a and 3b represent the fluxes in May and April. The left panel in each subplot is the zonal sum of air-sea CO_2 fluxes.