A 3-D coupled physics-CO_2 flux model of the Hudson Bay system: a dark ocean experiment

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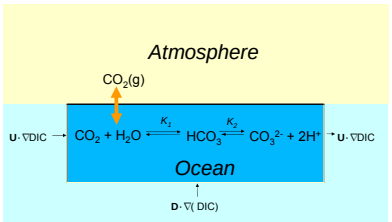
Introduction

Most of the Hudson Bay is located in the Subarctic and connects to the Arctic Ocean to the north, and receives freshwater discharges from surrounding rivers and land. The outflow of the Hudson Bay surface water discharges to Labrador shelf along its coast.

Global climate model predicts that the high latitude regions are more sensitive to climate change than the rest of the globe. Under the climate change scenarios, the warming may change the way the Hudson Bay system interacts with its surrounding environments. The physical structure of the water column and the circulation, among others, will be changed by the warming. These changes will affect the function of oceanic biological pump in taking up CO_2 from air to sea.

The objective of this study is to understand how the physical properties of the water column and circulation affect the CO_2 flux across the air-sea interface by coupling a CO_2 flux model with 3-D ice-ocean physics model of Saucier et al. (2004). This will lay a base for building a fully coupled biogeochemical model to predict the response of carbon cycle in the Hudson Bay system to the changing climate, and the contribution of Hudson Bay to the regional atmospheric CO_2 concentration, under the changing climate.

CO_2 flux model



Main model equations:

The model domain covers the Foxe Basin (FB), Hudson Strait (HS), and the Hudson Bay (HB).

(1) $dDIC/dt = DIC_0 + FCO_2 - \mathbf{U}\cdot\nabla DIC + \mathbf{D}\cdot\nabla(DIC)$

(2) $FCO_2 = k\, s\, (pCO_{2a} - pCO_{2w})$

(3) $k = 0.0283\, u10^3$ (Sc/660) (Wanninkohf & McGillis, 1999)

(4) $DIC = (as \times pCO_2) + (HCO_3^-) + (CO_3^{2-})$

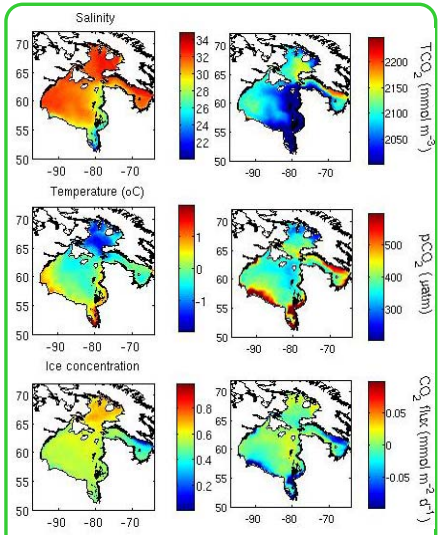
(5) $pCO_{2w} = (2 \times DIC - Ac) / [as\,(2 + K1/aH)]$

Apparent dissociation constants (Kc1, Kc2) of carbonate used for calculating carbonate components, and pCO_2 are from Mehrbach et al. (1973)

Model implementation

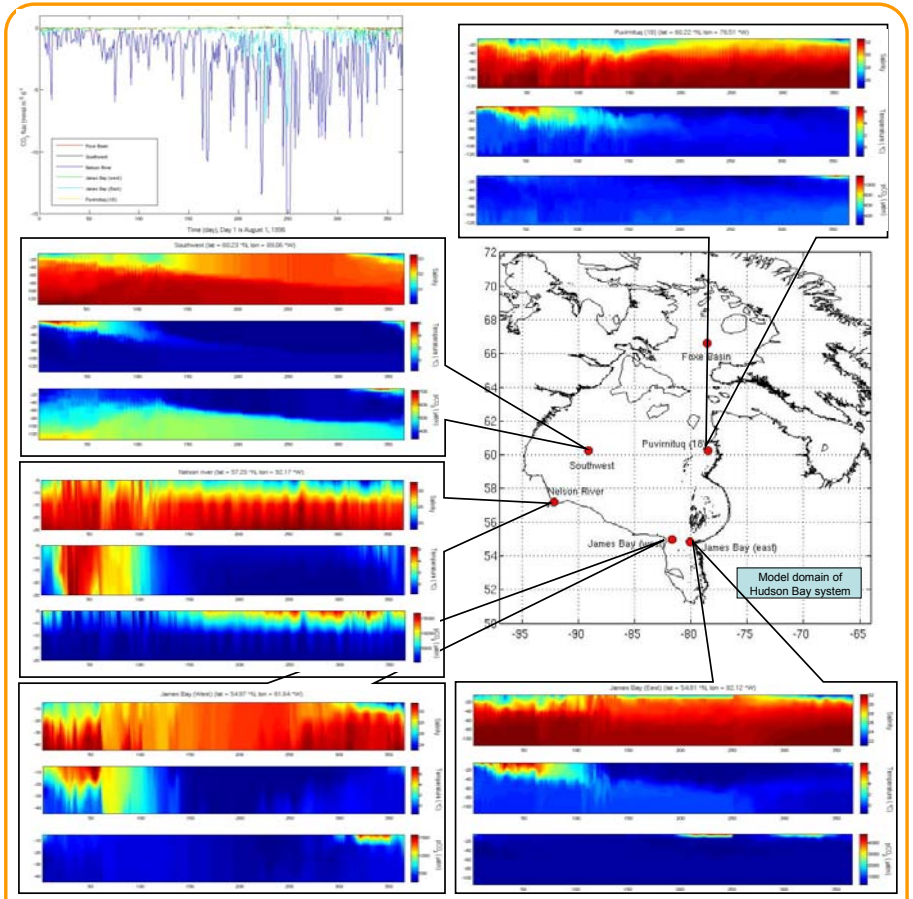
Initial conditions: Nutrients (NO_3^-, PO_4^{3-}, and $Si(OH)_4$ were fixed at winter time level); DIC and TA were initialized as a function of salinity based on MERICA dataset (Azetsu-Scott, unpublished data) and Jones and Anderson (1994).

The atmospheric and runoff forcing, initial conditions for salinity and temperature, and boundary conditions are described in Saucier et al. (2004). Simulation was started on August 1, 1996, and ended on July 31, 1997.



Annual mean distribution of salinity, temperature, ice concentration, surface TCO_2, pCO_2, and CO_2 flux across the air-sea interface

TCO_2 is lower, while pCO_2 and CO_2 flux are higher, in southern and southeast coast than in the north and west of the HB. Low TCO_2 in the southeast is due to dilution by freshwater from surrounding rivers. The accompanied high pCO_2 and CO_2 flux is due to lower solubility of CO_2 in low salinity and alkalinity water in southeast coast.



Time series of simulated CO_2 flux across the air-sea interface (top-left), and salinity, temperature and pCO_2 profiles at selected stations during August 1 1996 to July 31 1997.
Day 1 is August 1 1996, and Day 365, July 31 1997.

High pCO_2 is simulated for periods of low salinity, because solubility of CO_2 decreased with salinity.

Discussion

The CO_2 flux is determined by the wind speed, turbulent mixing and the variation of pCO_2 in the surface water, as pCO_2 in the air is set to be constant (see eq. 2). Ice concentration modifies CO_2 flux by blocking the air-sea gas exchange.

While the variation in DIC affects the pCO_2 of surface water, solubility of CO_2 in the water decreased with salinity. Therefore, high pCO_2 is simulated at coastal regions with strong freshwater signal.

Ecosystem processes, including CO_2 drawdown by primary producers, respiration by heterotrophic organisms, will be included.

Input of DOC, POC, DIC, and alkalinity and nutrients along with freshwater discharges to, and their transformation in the Hudson Bay will be resolved.

However, the results of our model simulation revealed that the dynamics of freshwater and the transportation of Arctic Water, dominantly regulate the pCO_2 and CO_2 flux across the air-sea interface of the Hudson Bay.

Under the dark ocean scenario, the Hudson Bay system is a source of atmospheric CO_2.