Shipboard Measurements of Ocean-Atmosphere Carbon Dioxide Exchange Made During ArcticNet 2005

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Introduction

The world's oceans are an extremely important sink for carbon dioxide, absorbing at least 40% of anthropogenic CO_2 (Takahashi et al., 2002). These estimates are derived primarily from observations made during ship-based research programs similar to ArcticNet. Unfortunately, due to a lack of measurements, the Arctic regions are poorly represented in global studies of CO_2 flux (Fig. 1).

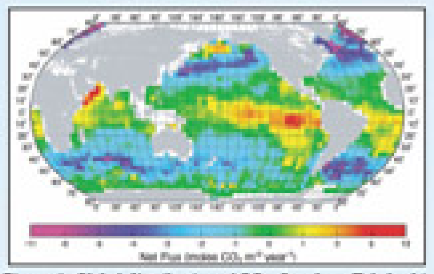

Figure 1: Global distribution of CO_2 flux from Takahashi et al., (2002). Note the lack of data for the Arctic regions.

Although studies such as Figure 1 are very important, they are subject to large uncertainties because the fluxes are computed by indirect parameterization. Typically, these models calculate CO_2 flux (F_c) by

$$F_c = k * s * (\Delta pCO_2)_{sea\text{-}air}$$

where k is an empirically derived gas transfer velocity, s is the solubility of CO_2 in seawater, and $\Delta pCO_{2sea\text{-}air}$ is the ocean/atmosphere CO_2 gradient measured as a partial pressure.

A superior method for measuring CO_2 flux is the eddy covariance method, which has been successfully employed on ocean-going vessels (McGillis et al., 2001). Eddy covariance allows for the direct measurement of atmospheric fluxes, thus eliminating much of the uncertainty. During both legs of ArcticNet 2005, we employed an eddy covariance system to directly measure the flux of CO_2 in the Canadian Arctic. This poster describes the eddy covariance system and other instrumentation that we used to measure aspects of atmosphere-ocean CO_2 exchange. We present preliminary results and discuss how we will use this data to improve our knowledge of CO_2 flux in the Arctic.

Methods

Eddy Covariance System

The eddy covariance system is shown in Table 1/Figure 2. A Licor open-path infrared gas analyzer was used to measure CO_2 and H_2O concentration at 10 Hz. A Campbell Scientific 3-axis sonic anemometer/thermometer concurrently measured temperature and three-dimensional wind velocity. A Systron-Donner MotionPak was used to monitor the angular rate and acceleration of the tower in order to correct the sonic anemometer data for ship motion.

Once the effects of motions are removed from the anemometer, a flux of CO_2 can be measured by calculating the covariance of CO_2 concentration with vertical wind:

$$F_c = \overline{w'c'}$$

where w' and c' are the fluctuating values of vertical wind velocity and CO_2 density around the long term average.

Meteorological Data

Table 1/Figure 2 also shows the meteorological instrumentation used in the experiment to gather information about boundary layer atmospheric conditions. In the future this data will be used to help determine the meteorological factors affecting CO_2 flux.

pCO_2 Pump

Figure 3 shows the custom-built pCO_2 pump used to measure the amount of dissolved CO_2 in the surface layer of the ocean. A hose attached to the pump was deployed over the side of the *CCGS Amundsen* during CTD casts and at long stations. The pump draws water into an equilibration chamber where the dissolved gases reach equilibrium with the air in the chamber. The air is then pumped into a Licor infrared gas analyzer which measures CO_2 in ppm. This sea surface pCO_2 dataset will help us determine the oceanographic factors affecting CO_2 flux, and will also allow us to calculate our own gas transfer coefficients (k).

Table 1: Summary of flux tower instrumentation with reference to Fig. 2

Instrument (Manufacturer Model)	Variable	Fig 2 ref.
RM Young wind monitor (model 15106 MA)	Horizontal wind speed and direction	1
Vaisala RH/Temp probe (model HMP45C212)	Temperature and relative humidity	2
Eppley pyranometer (model PSP)	Incoming shortwave radiation	3
Eppley pyrgeometer (model PIR)	Incoming longwave radiation	4
LI-COR Gas Analyzer (model LI-7500)	CO_2 and H_2O concentration	5
Campbell Scientific sonic anemometer (model CSAT3)	3-dimensional wind vector (x,y,z) and sonic temperature	6
BEI Systron Donner Motion Pak (Model MP-GCCCQBBB-100)	3D acceleration and angular rate (x,y,z) of tower	7

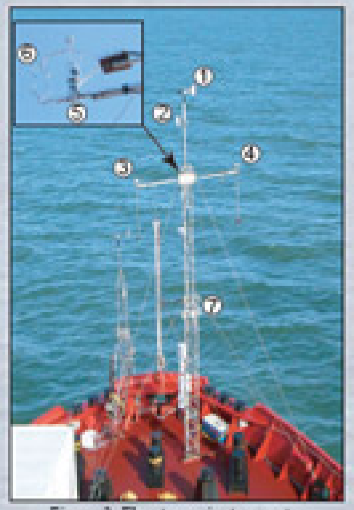

Figure 2: Flux tower instruments

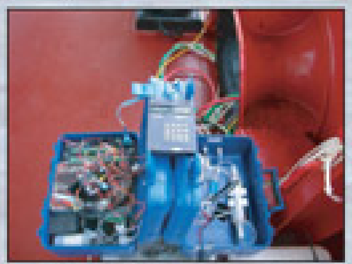

Figure 3: pCO_2 pump in operation

Study Area

The eddy covariance and meteorological tower was used on both legs of ArcticNet 2005. This poster focuses on work performed in Hudson Bay (leg 2) as an example of the data that was collected and to illustrate the methodologies that will be used in future analyses.

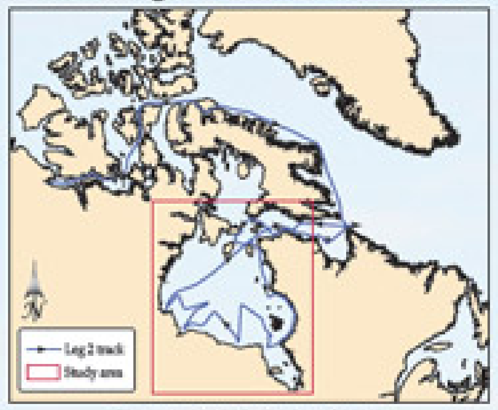

Figure 4: ArcticNet leg 2 study area

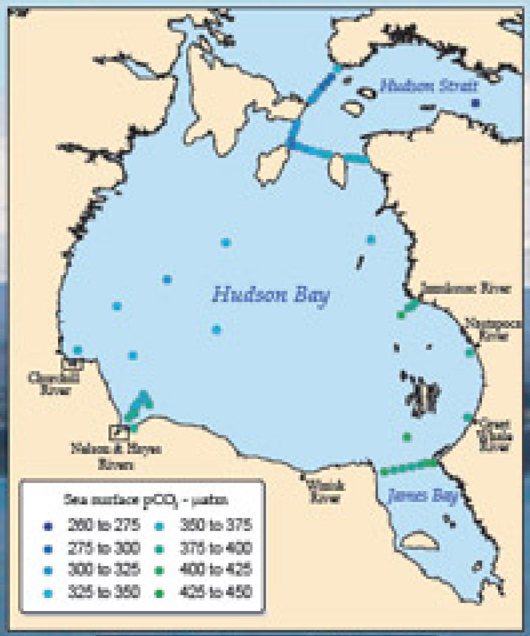

Figure 5: Partial pressure of dissolved CO_2

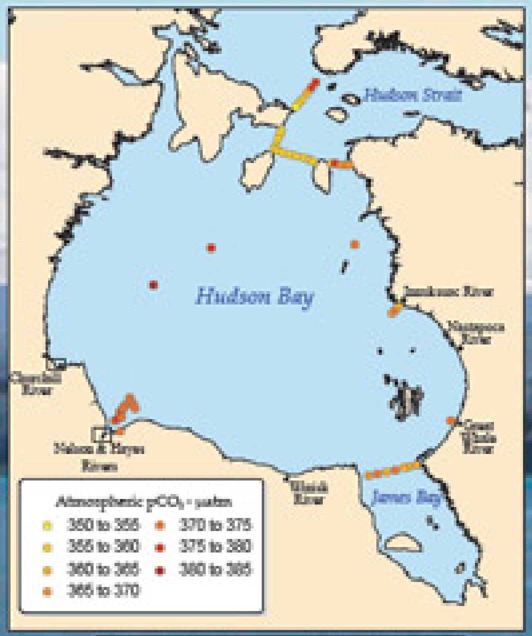

Figure 6: Partial pressure of atmospheric CO_2

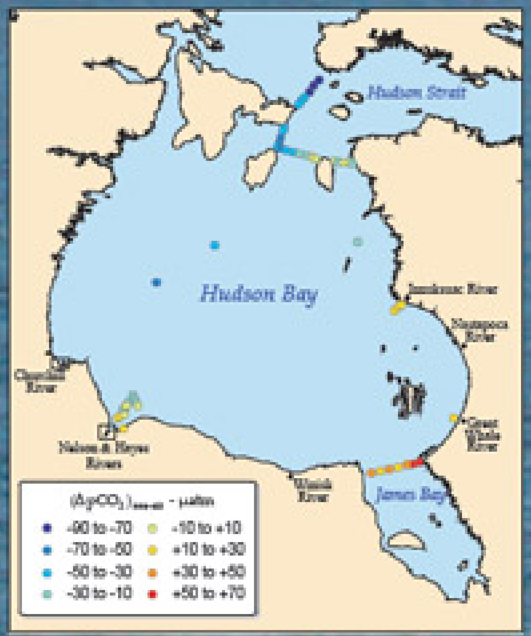

Figure 7: Partial pressure of CO_2 gradient

Preliminary Results/Discussion

The computation of fluxes by eddy covariance from a mobile platform requires considerable effort. At this early stage in data processing we are unable to report any fluxes calculated by this method. Fortunately, the partial pressures of CO_2 in the sea and air can easily be calculated from the tower and pump gas analyzers. This data is presented here as an overview of the atmosphere-ocean CO_2 system of Hudson Bay observed during the cruise.

Sea Surface pCO_2

Results from the pCO_2 pump are shown in Figure 5. A minimum value of 260 µatm was observed in the Hudson Strait. A maximum value of 427 µatm was measured at the mouth of James Bay. High pCO_2 values are located close to shore and near the influence of fresh water. This pattern is similar to findings in the Laptevs Sea by Semiletov (1999), who suggested that this effect is caused by carbon-rich riverine input oxidizing to CO_2. Low pCO_2 values tend to be located away from the influence of fresh water, towards the middle of the bay.

Atmospheric pCO_2

Atmospheric pCO_2 was calculated for the locations where seawater CO_2 samples were taken (Figure 6). Atmospheric data was not available for all sites because the gas analyzer does not work if it is wet due to rain or sea spray. Atmospheric CO_2 showed less variation: a minimum of 353 µatm was measured near South Hampton Island, and a maximum of 383 µatm was measured off shore to the north-east of Churchill.

pCO_2 Gradient (ΔpCO_2)

To assess where significant sinks and sources of CO_2 may exist over Hudson Bay, pCO_2 difference was calculated (pCO_2 sea - pCO_2 air) (Fig. 7). Negative values indicate undersaturation of seawater with respect to the atmosphere, and are regions of CO_2 flux into the ocean. Positive values indicate supersaturation of seawater with respect to the atmosphere, thus indicating outgassing. Supersaturated areas seem to be confined to a small band near the coast where river influence is strong. Undersaturated areas exist away from the influence of freshwater, and cover a much larger extent. We therefore speculate that most of Hudson Bay is a significant sink for CO_2, but small source regions exist near river mouths.

Future Work

Work in the immediate future will focus on the calculation of fluxes by eddy covariance. This process includes the correction of the sonic anemometer data for ship motion, and the application of standard eddy covariance corrections. Since the cruise was only capable of sampling in a small area of Hudson Bay, we hope to scale our data up to a regional level by combining our *in situ* measurements with remote sensing data to create a reliable estimate of CO_2 flux over the entire bay.

References

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Acknowledgements

The authors wish to thank C.J. Mundy & Mats Granskog for their help with sampling and Philippe Constant for his help calibrating the gas analyzers. We are also very grateful for the logistical support provided by the crew of the *CCGS Amundsen*. This work is supported by an NSERC PGS-M grant to Brent Else.

ArcticNet

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