Air-Sea Ice-Water CO\textsubscript{2} Balance: the Arctic Ocean

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CO$_2$ Fluxes above World Ocean (EOS, 2003)
Region under study
Point of observations near Barrow
The equipment for eddy correlation measurements, placed on fast ice

Big chamber on the melting fast ice

Submerged device SAMI for measurements of dissolved pCO2

Instruments, used for measurements of atmospheric and dissolved CO₂
Vertical turbulent CO₂ fluxes above melting fast ice

CO₂ turbulent flux during onshore (left) and offshore winds (right)
Results of CO$_2$ and pCO$_2$ measurements on fast ice with chamber technique

pCO$_2$ in brines and under fast ice (left) and CO$_2$ concentration in the air (1) and pCO$_2$ measured by chambers near (2) and in the center (3) of a growing melt pond whose depth is shown by line (4).
Spatial-temporal variability of CO₂ concentration in the atmospheric surface layer in the coastal zone of the East-Siberian Sea
The pCO₂ values decreased from the West (Dm. Laptev Strait, 400-500 µatm) to the East (Long Strait, 250-300 µatm). It means that the western nearshore zone is a source of atmospheric pCO₂, whereas the eastern nearshore zone is the pCO₂ sink. Note that the most high pCO₂ values were determined by Kolyma input.
Vertical distribution of sea water temperature, salinity, pCO₂, turbidity, and PAR attenuation coefficient along the coast of the East-Siberian Sea in September 2003.
Mean spatial distribution of turbidity and PAR attenuation coefficient by historical data
Shore erosion, Moastach island
The NOAA CMDL Carbon Cycle Greenhouse Gases group operates 4 measurement programs. In situ measurements are made at the CMDL baseline observatories: Barrow, Alaska; Mauna Loa, Hawaii; Tutuila, American Samoa; and South Pole, Antarctica. The cooperative air sampling network includes samples from fixed sites and commercial ships. Measurements from tall towers and aircraft began in 1992. Presently, atmospheric carbon dioxide, methane, carbon monoxide, hydrogen, nitrous oxide, sulfur hexafluoride, and the stable isotopes of carbon dioxide and methane are measured. Group Chief: Dr. Pieter Tans, Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678 (ptans@cmdl.noaa.gov, http://www.cmdl.noaa.gov/ccgg).
Mean annual variability of carbon dioxide

Year

Carbon dioxide, ppm
325 335 345 355 365 375

Barrow
Mauna Loa
South Pole
interannual variability of mean carbon dioxide concentration in Barrow and sea ice area in September

Var2 = -2629.8995 + 1.5*x

Var24 = 7.3729E7 - 34714.6002*x

Year

Carbon dioxide, ppm

Sea ice area, km


325 330 335 340 345 350 355 360 365 370 375

3.20E+06 3.40E+06 3.60E+06 3.80E+06 4.00E+06

5.40E+06 5.20E+06 5.00E+06 4.80E+06 4.60E+06 4.40E+06 4.20E+06 4.00E+06

CO2

Sea ice
Mean annual cycle of CO₂ concentration in the atmospheric surface layer in Barrow (blue), Mauna Loa (red) and South Pole (green)
Interannual variability of seasonal amplitude of CO$_2$ concentration in the atmospheric surface layer
Interannual variability of amplitudes of CO₂ seasonal cycles in atmospheric surface layer at Barrow (1) and sea ice area (2) of the Arctic Ocean including Eastern Central Arctic, Laptev, East-Siberian, Chukchi, and Beaufort seas.
The scheme of CO$_2$ seasonal amplitude increase due to decrease of sea ice extent in the Arctic Basin

**Summer – early autumn**
(Stable stratification of sea upper layer)

- Ice-free areas increase
- Concentration of leads increase
- Phytoplankton production increase and areas of cooling in early autumn increase
- Carbon dioxide uptake increase

**Autumn**
(Unstable stratification in sea ice-free parts)

- Sea areas occupied by convective processes increase
- Release of deep waters enriched by pCO$_2$ increase
- Carbon dioxide release increase

Seasonal amplitude of atmospheric CO$_2$ increase
Spatial distribution of pCO2 in the Buor-Khaya Gulf in April 2002 (upper) and in September 2000 (bottom).
\( pCO_2 \) in sea upper layer in early (left) and late (right) September
Conclusions

Eddy-correlation and chamber measurements made on fast ice near Barrow provide some insights into the influence of sea ice on carbon dioxide exchange between ocean and atmosphere through sea ice. We infer that in early summer absorption of atmospheric CO$_2$ by ice-covered ocean dominates. Our measurements also suggest the important role of melt ponds and brine channels on gas exchange.

Ship observations gave possibility to reveal differences in intensity and direction of gas exchange in dependence on underlying water masses. It was found that direction of CO$_2$ flux changes near the frontal zone between “freshened/source” and “Pacific/sink” waters, identified at the 170E.

Based on the data of routine measurements of carbon dioxide concentration at Barrow, Alaska, and on satellite data about sea ice extent in the eastern part of the Arctic Ocean we hypothesize that ice conditions in the Arctic Ocean influence on the long-term variability of atmospheric carbon dioxide concentration in the Arctic.

The data of ship observations in the Chukchi, Laptev, and East-Siberian Seas give some support to this hypothesis. We found that surface seawaters in the ice-free Arctic shelf seas during summer and early autumn mostly are undersaturated in pCO$_2$ and therefore serves as a sink for atmospheric CO$_2$. In contrast, during winter when the seas are ice-covered, the water beneath the sea ice is strongly oversaturated by pCO$_2$ and, respectively, reverses CO2 flux to atmosphere. Note that coastal areas, strongly influenced by coastal erosion and the river input of terrestrial carbon (suspended and dissolved), are the sources of CO2 into the atmosphere year-round.