Some Indications of Excess CO$_2$ Penetration near Cape Adare off the Ross Sea

Chen-Tung Arthur CHEN

Abstract: The Antarctic Bottom Water (AABW) is generally believed to be formed in the Weddell Sea. It contains little anthropogenic CO$_2$. The role of the Ross Sea as a sink for excess CO$_2$ is perhaps even smaller as it contributes much less to AABW than does the Weddell Sea. On the other hand, I have reported earlier that excess CO$_2$ is found on the shelf around the Antarctica. Excess CO$_2$ is also found to penetrate rather deeply off Cape Adare at the northwest corner of the Ross Sea. I report here more detailed analysis using the GEOSECS, International Geophysical Year and the R/V Polar Sea data.

1. Introduction

Thermohaline circulation transports warm water poleward from low latitudes. As surface waters cool, their capacity to absorb CO$_2$ from the atmosphere increases and they act as a sink for anthropogenic CO$_2$. The ability of the North Atlantic Deep Water to absorb the excess CO$_2$ has been demonstrated (CHEN, 1982, 1987) but the situation is somewhat different in the Southern Ocean where the Antarctic Bottom Water (AABW) plays a major role. The AABW is generally believed to be formed in the Weddell Sea. Sea ice, however, blocks the air-sea exchange of gases thus limits the influx of excess CO$_2$ to the surface water. The upwelled Weddell Sea Deep Water (WSDW) dilutes the anthropogenic CO$_2$ concentration in the surface water, which then mixes with the Weddell Sea Shelf Water and more WSDW to from AABW. Since the WSDW probably was formed before industrialization and the surface water is also deficient in excess CO$_2$, the AABW contains little anthropogenic CO$_2$ (6±5 μmol kg$^{-1}$) (CHEN and POISSON, 1984, POISSON and CHEN, 1987). As a result, the Weddell Sea is not a major sink for excess CO$_2$ (CHEN and RODMAN, 1990; CHEN, 1991).

The role of the Ross Sea as a sink for excess CO$_2$ is perhaps even smaller as it contributes much less to AABW than does the Weddell Sea. Recent data, however, indicates that freons have penetrated throughout the shelf area and have even appeared near the base of the continental slope at depths of 2.5 to 3.0 km. This is a good indication of newly formed AABW (MICHEL et al., 1985; TRUMBORE et al., 1991) which may carry some excess CO$_2$.

CHEN (1982) reported earlier that excess CO$_2$ is found on the shelf around the Antarctica. Excess CO$_2$ is also found to penetrate rather deeply off Cape Adare at the northwest corner of the Ross Sea (CHEN, 1987; 1993a). I report here more detailed analysis using the GEOSECS and International Geophysical Year (IGY) data. The R/V Polar Sea (JACOBS et al., 1989) CO$_2$ data are spaced too far apart vertically and can not be used to estimate the excess CO$_2$ signal. The chlorofluorocarbons (CFCs) collected during the R/V Polar Sea cruise are, however, quite useful for tracing newly formed waters. To my knowledge no other CO$_2$ or tracer data are available. The station locations are given in Fig. 1.

2. Method

The method of excess CO$_2$ computation and its limitations have been described in detail elsewhere (CHEN and MILLERO, 1979; CHEN and PYTKOWICZ, 1979; CHEN et al., 1982; CHEN, 1982, 1984; CLINE et al., 1985). The method involves a back-calculation of the CO$_2$ concentration of a parcel of seawater to its initial concentration at the sea surface by correcting
for changes due to the decomposition of organic material and dissolution of carbonate tests.

Specifically, the method assumes that a water parcel maintains a fixed degree of saturation with respect to atmospheric CO$_2$ at the sea surface. Respiration and carbonate dissolution add carbon dioxide to the water parcel after it sinks. The respiration induced increase in CO$_2$ can be calculated from the oxygen data using Redfield ratio (Redfield et al., 1963) while CO$_2$ changes due to carbonate dissolution can be calculated from the alkalinity changes. By correcting the CO$_2$ data for these changes, estimates can be made of the CO$_2$ concentration of the water parcel when it was last in contact with the atmosphere. These back calculated CO$_2$ concentrations of waters with various ages are then compared with each other and with the contemporary surface CO$_2$ concentrations to obtain the oceanic CO$_2$ increase.

3. Results and Discussion

Fig. 2 shows the north-south cross-section of excess CO$_2$ centered along 160°E based on IGY data. The lower boundary of penetration is taken as the level where the excess CO$_2$ signal equals to 5 ± 10 μmol/kg. The depth could be up to 100 m to deep or 300 m to shallow because of the vertical sample spacing and because of the uncertainty in the method.

The thin broken line shows the minimum temperature layer which is probably the modified remnant of the isothermal layer produced during the previous winter (Foster and Carmack, 1976; Weiss et al., 1979). The excess CO$_2$ content falls between 20 and 30 μmol/kg with an average of 25 μmol/kg in this layer.

The maximum temperature contour (broken lines) is near the core of the Circumpolar Deep Water (CDW) which is also at approximately the same level as the maximum AOU (apparent oxygen utilization) layer. Excess CO$_2$ does not appear to penetrate deeply enough to reach the core of the warm, old CDW. Also the deep and bottom waters do not appear to contain significant amounts of anthropogenic CO$_2$.

Temperature contours indicate that IGY 62 (at 60°S) is north of the Polar Front. Antarctic Intermediate Water (AAIW), formed by strong vertical convection, apparently carries anthropogenic CO$_2$ with it more deeply north of the Polar Front. The anthropogenic CO$_2$ penetrates
Excess CO₂ Penetration Near Cape Adare

less deeply at the more southerly stations due to the upwelling of the old CDW, evidenced by the upwardly concaved structure of the maximum temperature contour. The CDW pushes upward on and disperses the younger Antarctic Surface Water (Gordon et al., 1977, 1984). As a result, the excess CO₂ penetrates less than 300 m between 61 and 66 °S.

South of IGY 54, however, the maximum temperature contour deepens again and intersects the bottom at IGY 336 and 337 near Cape Adare. This is an indication of some downwelling of the fresher, newly cooled seawater. Excess CO₂ also penetrates to near the bottom at these stations which are located on the upper continental slope.

Figure 3 shows the excess CO₂ values at roughly 166°E based on IGY and GESECS data. Excess CO₂ penetrates deeper north of the Polar Front near IGY 365. South of the Polar Front the contour concaves upward due to upwelling of CDW but deepens at the southernmost station, IGY 373. No excess CO₂ is evident in the bottom layer.

Figure 4 shows the west-east cross-section of
excess CO\textsubscript{2} concentration along roughly 69°S based on IGY and GEOSECS data. All stations are south of the Polar Front, and all stations, except for IGY 337, have a water depth deeper than 1000 m. As mentioned earlier, the excess CO\textsubscript{2} penetrates to near the bottom at IGY 337 on the upper continental slope.

IGY 339 sits on the lower continental slope with a water depth of 3350 m. No excess CO\textsubscript{2} could be detected below 250 m at this station (Fig. 4). In fact, all stations except IGY 337 in the cross-section show rather shallow excess CO\textsubscript{2} penetration.

Circulation and hydrography in the vicinity of
Excess CO$_2$ Penetration Near Cape Adare

...with surface and other shelf waters. Direct gas exchange with the atmosphere, however, is limited in winter to breaks and polynyas in the sea ice canopy (TRUMBORE et al., 1991) as sea ice is not entirely permeable to gases (CHEN, 1988). As a result, only limited amount of excess CO$_2$ moves into the winter-formed deep waters on the shelf. The partially ventilated deep water mixes with the surrounding waters as it flows out near the bottom, further diluting the excess CO$_2$. Finally, the excess CO$_2$ becomes undetectable except in shallow waters or near an area where vertical mixing of the water column occurs quickly.

IGY 337 is an example where vertical mixing occurs quickly as evidenced by its uniformly low temperature throughout the water column, all between $-1.2$ and $-1.8^\circ$C. The salinity varies only between 34.4 and 34.5 below 100 m. AOU varies between 80 and 105 $\mu$mol/kg below 100 m (Fig. 5). The relatively low temperature and AOU are indications of rapid turnover.

Earlier work elsewhere has shown a correlation between CFC-11 and excess CO$_2$ (CLINE et al., 1985; CHEN, 1993b). The Polar Sea stations 87 and 92 sit on the continental slope (Fig. 1). CFCs 11 and 12 are found throughout the water column (to 339 m for PS 92 and to 2058 m for PS 87). Excess CO$_2$ probably also exists where CFCs are found. The combined Polar Sea CFCs show a decreasing trend when plotted vs. AOU (Fig. 6), reaching zero at an AOU of only about 150 $\mu$mol/kg. The IGY and GEOSECS excess CO$_2$ signals disappear at an AOU of only about 120 $\mu$mol/kg. Because of the poor precision of the excess CO$_2$ signal, it can not be judged whether the difference is because the excess CO$_2$ (and CFCs) has penetrated deeper during the Polar Sea expedition, reaching older, higher AOU waters.

4. Conclusion

The excess CO$_2$ does not penetrate more than a few hundred meters south of the Polar Front near the Ross Sea except for a small area near Cape Adare. As a result, the Ross Sea probably has not been a significant excess CO$_2$ sink.

Acknowledgements

This research was supported by the National...
Science Council (NSC 83-0209-M110-002K).
I thank S.S. Jacobs for providing the Polar Sea data.

References


ロス海アデーレ岬沖における過剰 CO$_2$ 透入の微候

Chen - Tung Arthur Chen

要旨：南極底層水 (AABW) は一般にウェッディ海で形成されると考えられており、人為起源の CO$_2$ をわずかに含んでいる。ウェッディ海に比べ、ロス海は過剰 CO$_2$ の沈降の場としての役割は小さいと考えられるが、GEOSECS, IGY および R/V Polar Sea のデータのより詳細な解析により、ロス海北西かどのアデーレ岬沖において、過剰の CO$_2$ がより深い層へ透入している事実が明らかとなった。