INTERANNUAL VARIABILITY OF AIR-SEA CO_2 FLUXES IN THE SOUTHERN OCEAN

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ABSTRACT
The role of the Southern Ocean as a source or a sink for CO_2 in the modern ocean is heavily disputed, its interannual variability is unknown, and its control on atmospheric CO_2 during glaciations is suspected but still not understood nor quantified. We estimate the variability of the air-sea CO_2 fluxes in the Southern Ocean for the 1992-2003 period using the spatio-temporal distribution of atmospheric CO_2 measurements from 12 stations in the Southern Ocean and 43 stations worldwide. Our results show basin-scale variability of ±0.1 to 0.3 PgC/y that are related to physical variability in the Southern Ocean.

INTRODUCTION
The increase in atmospheric CO_2 shows high interannual variability, in contrast to the smooth increase in emissions. The difference between the emissions and the atmospheric CO_2 increase is caused by the interannual variability in the land and ocean sinks of CO_2. The CO_2 sinks are strongly influenced by climate variability, a fact that is often used to improve our understanding and projecting capability of the fate of the CO_2 sinks in the future [*Cox et al.*, 2000].

Whereas the variability in the sum of the ocean and land sinks is well constrained by atmospheric measurements, the partitioning is not. There are no direct observations of the large-scale variability in the sinks. Indirect estimates based on the partial pressure of CO_2 in surface waters have been used to constrain the variability of the ocean sink in the tropics, where the seasonal signal is small [*Feely et al.*, 1999], and in the sub-tropics, where time-series stations exist [*Gruber et al.*, 2002, *Dore et al.* 2002]. At high latitudes however, the seasonality in CO_2 is large and existing measurements are insufficient to resolve the interannual variability over large basins.

METHODS
We estimate the interannual variability in air-sea CO_2 fluxes in the Southern Ocean using the spatio-temporal distribution of 43 atmospheric stations, 12 of which are located South of 30S. We use an inverse method that optimises the CO_2 flux distribution and variability that best matches the observed atmospheric CO_2. Fluxes and atmospheric concentration are linked by the TM3 atmospheric transport model. It uses 6-hourly winds from NCEP re-analysis. Flasks or continuous CO_2 observations are used as available. Although we focus on the Southern Ocean, the inversion is global as in Rödenbeck et al. [2003].

We compare results from the inversion with results from a process model. The model is based on the OPA General Circulation Model coupled to an ecosystem model. The physical model has a global resolution of 2 degree of longitude and 0.5 to 1.5 degree of latitude, and resolves 30 vertical levels. It is forced by daily winds and precipitations from the NCEP reanalysis. The model calculates heat fluxes based on temperature differences between the sea and the air. The ecosystem model represents two phytoplankton and two zooplankton functional types, which are co-limitated by light, P, Si, and Fe [*Buitenhuis et al.*, submitted].

RESULTS

The air-sea CO_2 flux variability from the inversion results is less than ±0.2 PgC/y (peak-to-peak of the monthly anomalies) averaged over the Atlantic, Indian, and Pacific sectors of the Southern ocean (Fig. 1). When integrated over the entire Southern Ocean, the variability is also less than ±0.2 PgC/y because the anomalies in the different basins partly cancel one another.

The air-sea CO_2 flux variability from the process model results agree well in phase with that of the inversion when integrated over the three basins (Fig. 1). The amplitude of the variability in the process model is about half that of the inversion. The process model results suggest that the variability is primarily driven by physical changes in the water column, both from changes in mixing and from changes in upwelling.

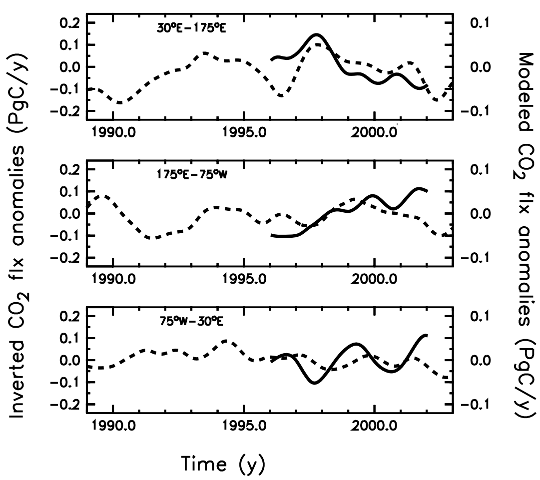

Figure 1. Anomalies in the air-sea CO_2 flux in the Southern ocean (PgC/y) for (top) the Indian (30°E-175°E), (middle) the Pacific (175°E-75°W), and (bottom) the Atlantic (75°W-30°E) sector. Results from the atmospheric inversion (full line) refer to the left axis. Results from the ocean biogeochemistry model (dashed line) refer to the right axis.

CONCLUSION

The CO_2 variability in the Southern Ocean appears well constrained by the inversion within the given uncertainty. Results of the inversion and the process model are in reasonable agreement when integrated over individual basins of the Southern ocean. The process model suggests that interannual variations are primarily driven by changes in the variations in ocean physical transport.

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