International Max Planck Research School on
EARTH SYSTEM MODELLING

"Interannual and Decadal Variability in the Air-Sea Exchange of CO_2 - a Model Study"

Patrick Wetzel

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Abstract

Trends and variability in the ocean-atmosphere CO_2-flux and the uptake of anthropogenic CO_2 are simulated for the period 1948-2003, using a biogeochemical carbon cycle model (HAMOCC5) coupled on-line to a global Ocean General Circulation Model (MPI-OM). The coupled model is forced by daily NCEP/NCAR reanalysis data. The NCEP/NCAR reanalysis is a consistent set of atmospheric data from 1948 until today and shows trends and variability on interannual and decadal timescales. For the first time it is thus possible to analyze the physical and biological processes that drive the air-sea CO_2 fluxes on long timescales and in non-equilibrium conditions.

The simulated total interannual variability is ± 0.50 PgC yr^{-1} ($2\,\sigma$) and is largely dominated by ocean dynamics in the equatorial Pacific (65 %). In addition to the interannual variability, the Pacific climate also undergoes decadal-scale shifts with effects on the sea surface temperature and the trade winds. Because of the regime shift in 1975-1977, the modeled interannual variability of the equatorial Pacific changes from ± 0.32 PgC yr^{-1} to ± 0.23 PgC yr^{-1}. The Southern Ocean accounts for over 20% of the interannual CO_2 flux variability, which is mostly controlled by the winter mixed layer depth. Although one third of the global uptake of anthropogenic carbon occurs in the Southern Ocean, little anthropogenic CO_2 is actually stored there. Half of the anthropogenic CO_2 taken up by the Southern Ocean in the simulation is transported northward into the subtropical convergence zone. Trends in the modeled CO_2 fluxes over the 56 years period are caused by the increasing wind speed forcing, mostly over the southern hemisphere. We estimate an average CO_2 flux into the ocean of 1.74 PgC yr^{-1} for 1990 to 1999 which consists of an anthropogenic component of 1.91 PgC yr^{-1} and a flux of 0.17 PgC yr^{-1} out of the ocean from variablity within the physical forcing. The extremes are 1.20 PgC yr^{-1} at the La Niña event in 1996 and 2.10 PgC yr^{-1} during the El Niño events in 1993 and 1998. As a consequence of the rising CO_2 concentrations the upper ocean becomes more acidic. This slows down the uptake of anthropogenic CO_2 towards the end of the simulation. Overall about 124 Pg of anthropogenic carbon accumulated the simulation in the model ocean by the end of 2003. The inclusion of the effect of iron limitation on the biological production significantly changes the behavior of the model. It strengthens the south-north gradient by limiting the production on the Southern Ocean and lowers the interannual variability by altering the distribution of dissolved inorganic carbon (DIC) in the Southern Ocean and the equatorial Pacific.