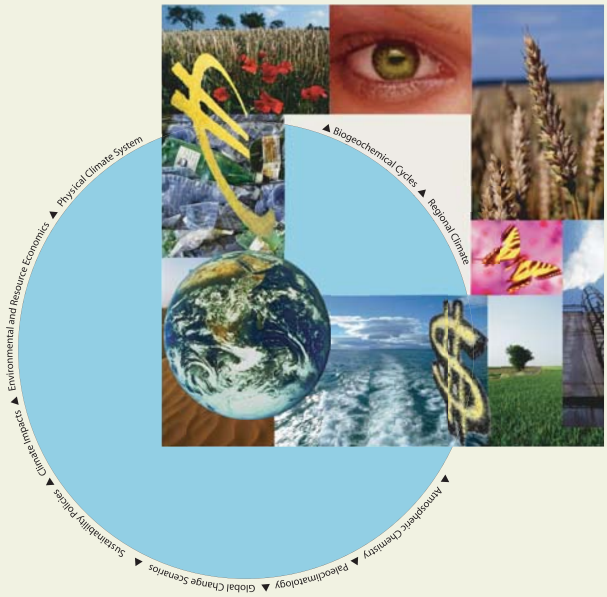
International Max Planck Research School
on Earth System Modelling

Using Atmospheric Potential Oxygen to Gain Insight into Climate Drivers of Ocean Biogeochemistry

Valentina Sicardi

PhD Thesis prepared within the
International Max Planck Research School on
Earth System Modelling



Abstract

This thesis investigates the use of atmospheric tracers to gain insight into the climatic drivers of ocean circulation and biogeochemical changes.

The results from the IPSL-CM4 coupled climate model for the period 1861-2100 have been analyzed. The fluxes generated by the climate model have been transported into the atmosphere using the TM3 atmospheric transport model to provide atmospheric tracer concentrations. We infer climate-induced changes in the ocean circulation and biogeochemistry from the changes in atmospheric tracer concentrations. To retrieve the oceanic signal from the atmospheric tracer concentrations, O_2 and CO_2 have been combined to form the Atmospheric Potential Oxygen (APO = O_2+1.1CO_2). APO removes the influence of the terrestrial biosphere and isolates the oceanic signal in the atmosphere. APO is thus influenced by the oceanic changes only. Any changes in the ocean physics will be reflected in changes in APO concentration. We explore the potential of inferring such changes from the APO observations.

Two scenarios have been considered: (a) the increasing atmospheric CO_2 leads to changes in climate and ocean physics, (b) the increasing atmospheric CO_2 does not change climate. In the first scenario the climate model projects several changes in the oceanic physics and in particular a reduction of the Atlantic Meridional Overturning Circulation by ∼70%. We explore the contribution of O_2, and CO_2 to APO and find that, O_2 dominates the APO signal on seasonal to decadal time scale, while CO_2 dominates the APO signal on longer time scale. The change in the APO interhemispheric gradient projected in the future is small and does not relate directly to the large-scale changes in the ocean circulation. The small latitudinal gradient has to be attributed to the fast mixing of the atmosphere. Changes in the amplitude of the APO seasonal cycle in the future vary between 2 to 4 ppm, depending on the location. These changes would be detectable as their amplitude is above the detection limit for the present APO measurements. Thus changes in APO seasonal cycle can be used to detect large-scale changes in ocean physics in the future.

Even though the interest in the potential applications of APO has increased in the past years, the drivers of APO variability are still poorly understood. We investigate the APO variability to understand whether the observed APO variability is driven by the variability of the air-sea fluxes of APO or by changes in the atmospheric transport. In particular, our attention is focused on the APO interannual variability, which is not yet fully represented by the models, but is very important in order to quantify the response of the ocean to natural climate variations. Oceanic fluxes generated by a biogeochemical model have been used to carry out a sensitivity analysis combining constant and variable fluxes driven by constant and variable meteorological fields. We look at model results at 9 selected stations and compare them with the observations. The agreement between model results and observations is very good on seasonal time scales, but not on interannual time scale. This study confirms previous results, which indicate that the APO seasonality is driven by the variability of the oceanic fluxes, and further shows that the interannual variability in APO is also driven by the variability of the oceanic fluxes. A brief comparison with fluxes from another biogeochemical model confirms these results.