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The impact of biology on decadal internal variability of the Southern Ocean carbon sink

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at the institute of Environmental Physics

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from

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ABSTRACT

The Southern Ocean is a major sink for anthropogenic CO_2 emissions and hence it plays an essential role in modulating global carbon cycle and climate change. Previous studies based on observations show pronounced decadal variations of carbon uptake in the Southern Ocean in recent decades and this variability is largely driven by internal climate variability. However, due to limited ensemble size of simulations, the variability of this important ocean sink is still poorly assessed by the state-of-the-art earth system models (ESMs). To assess the internal variability of carbon sink in the Southern Ocean, we use a large ensemble of 100 member simulations based on the Max Planck Institute-ESM (MPI-ESM). Here we use model simulations from 1980-2015 to compare with available observation-based dataset. We found several ensemble members showing decadal trends in the carbon sink, which are similar to the trends shown in observations. This result suggests that MPI-ESM large ensemble simulations are able to reproduce decadal variation of carbon sink in the Southern Ocean. Moreover, the trends of Southern Ocean carbon sink in MPI-ESM are mainly contributed by region between 50-60°S. Our results focus on the impact of biology on decadal trends of carbon sink. Primary production in area from 50-60°S is very sensible to euphotic water column stability. Changes in the physical state of the water column influence biological drawdown of ocean surface pCO_2 and hence the Southern Ocean carbon sink.

ZUSAMMENFASSUNG

Kurze Zusammenfassung des Inhaltes in deutscher Sprache…

CONTENTS

1 INTRODUCTION

(Sabine et al., 2004)
(Landschützer et al., 2015)
(Le Quéré et al., 2007)
(Sarmiento J. L. and Toggweiler J. R., 1984)
(Lovenduski and Gruber, 2005)
(Lovenduski et al., 2007)
(Lovenduski, Gruber, and Doney, 2008)
(Hauck et al., 2013)
(Wang and Moore, 2012)
(Wang et al., 2016)

2 BACKGROUND

2.1 MODEL DESCRIPTION

Previous studies assume gaussian statistics (Thompson et al., 2015) (Deser et al., 2012) The MPI-ESM version 1.1 with a low-resolution configuration (MPI-ESM-LR) is used for the large ensemble simulations (Giorgetta et al., 2013). The atmosphere component ECHAM6.3 is on a T63 grid, corresponding to 1.9° at the equator (better would be values of high latitudes), with 47 vertical layers up to 0.01 hPa (Stevens et al., 2013). Atmospheric pCO_2 uses prescribed and well mixed values. The carbon cycle is not coupled (so called diagnostic), so effects of changes in the terrestrial or oceanic carbon sink are not reflected in $pCO_{2,atm}$ and hence terrestrial and oceanic carbon sink can not interact.The ocean component MPI Ocean Model (MPIOM) has a horizontal resolution of 1.5° on average and 40 vertical levels (Jungclaus et al., 2013). The Hamburg Ocean Carbon Cycle Model (HAMOCC) (Ilyina et al., 2013) represents the ocean biogeochemistry component of MPI-ESM.

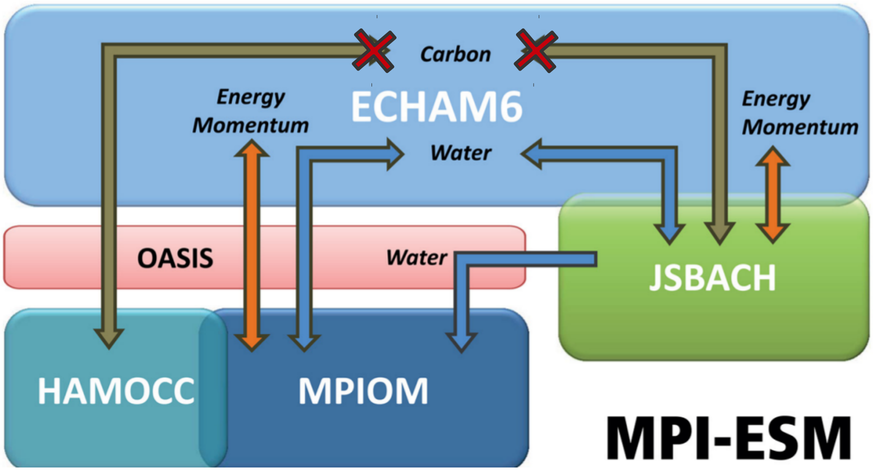

Figure 1: Schematic overview on the different components in MPI-Earth-System-Model

2.1.1 *HAMOCC*

2.2 LARGE ENSEMBLE

An ensemble of 100-member CMIP5 historical simulations and runs under Representative Concentration Pathway (RCP) 4.5 scenario are

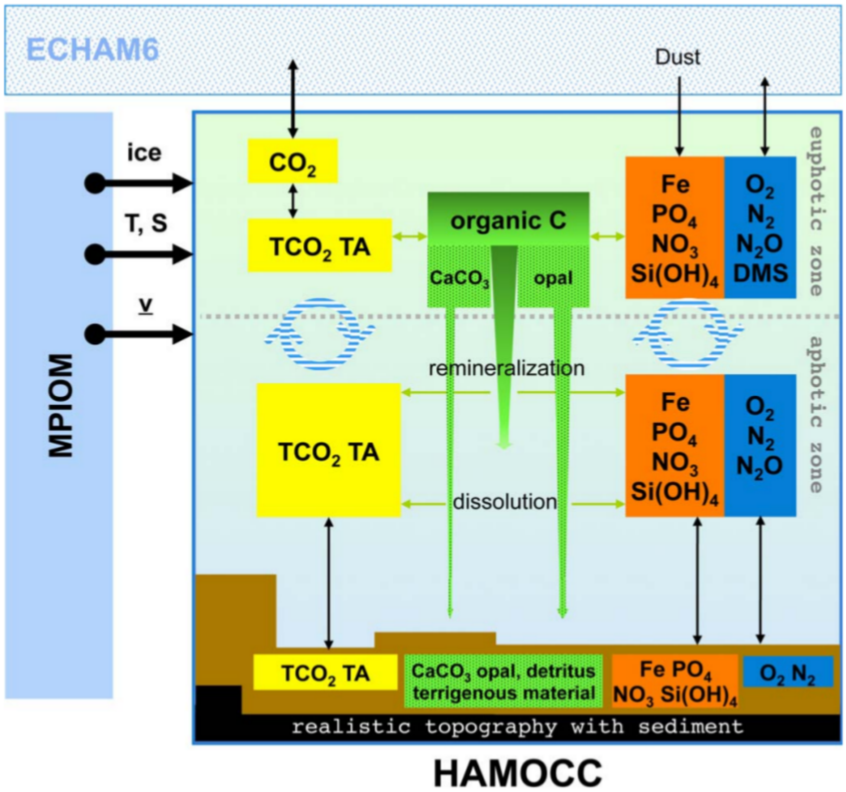

Figure 2: A schematic overview of the global ocean biogeochemistry model HAMOCC

integrated for the periods from 1850-2005, and 2006-2100, respectively. Ensemble members differ through starting from different year of the pre-industrial control simulation, so ocean and atmosphere have different initial conditions in each run.

2.3 FUNDAMENTAL PROCESSES OF MARINE BIOGEOCHEMISTRY

no separation but classification, difficult to separate in nature, no single and only cause

2.3.1 *Physical processes*

circulation
windstress
upwelling

2.3.2 *Biological processes*

primary production (Six and Maier-Reimer, 1996) limitations: nutrient, light, temp (Eppley, 1972), stability (Sverdrup, 1953)

2.3.3 *Chemical processes*

Revelle?

2.4 STATISTICAL METHODS

which I used

Linear Trend

significance via student t-test

3

TEMPORAL EVOLUTION OF THE SOUTHERN OCEAN CARBON SINK

3.1 INTERNAL VARIABILITY OF THE SOUTHERN OCEAN CARBON SINK

(Landschützer et al., 2015)

The large ensemble median represents the forced signal and the standard deviation represents internal variability (Deser et al., 2012). The forced signal shows a dominant increasing trend in the Southern Ocean carbon sink (Fig. 3). Observations show strong decadal trends (Landschützer et al., 2015).

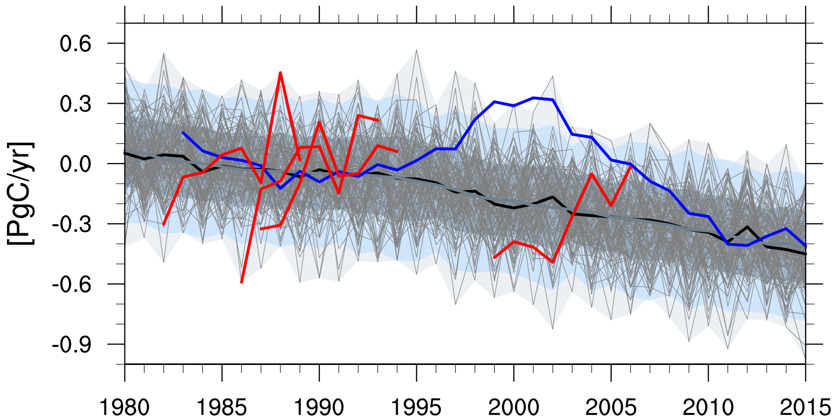

Figure 3: Evolution of the Southern Ocean carbon sink anomaly south of 35°S. Grey lines show the 100 ensemble members, the black line the ensemble median, the gray shading is the range of the ensemble, the blue shading is the 2σ ensemble spread, the red lines are decreasing sink trend candidates, the blue line is the SOM-FFN observation-based estimate (Landschützer et al., 2015); negative values indicate anomalous uptake with respect to the 1980s

SPATIAL DISTRIBUTION OF THE SOUTHERN OCEAN CARBON SINK

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4.1 SPATIAL INTERNAL VARIABILITY

The large ensemble median represents the forced signal and the standard deviation represents internal variability (Deser et al., 2012). The forced signal shows a dominant increasing trend in the Southern Ocean carbon sink (Fig. 4 top left). Also in spatial distribution, the carbon sink in each grid point follows a normal distribution (Fig. SI 8). The standard deviation (Fig. 4 top right) shows differences in magnitude of internal variability in a zonal pattern. The largest internal variability appears in 50-60°S south of the polar front. Internal variability drops north of 45°S, showing the large internal variability of the Southern Ocean compared to other ocean basins.

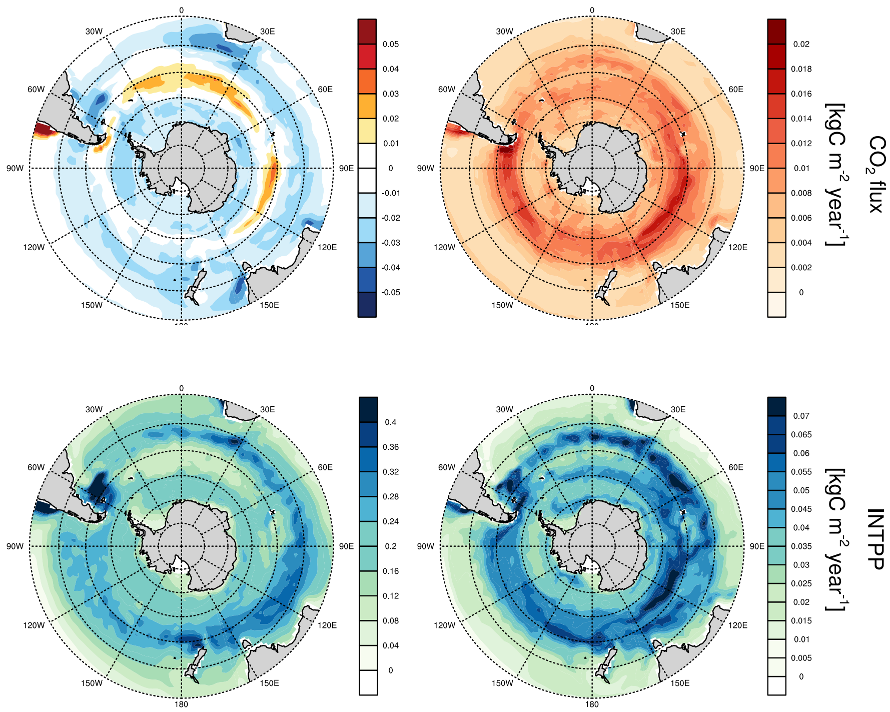

Figure 4: Southern Ocean CO_2flux where negative values indicate ocean uptake (top) and primary production (bottom): ensemble median (left) as forced signal and ensemble standard deviation (right) as internal variability

4.2 NEGATIVE TREND OF THE SOUTHERN OCEAN CARBON SINK

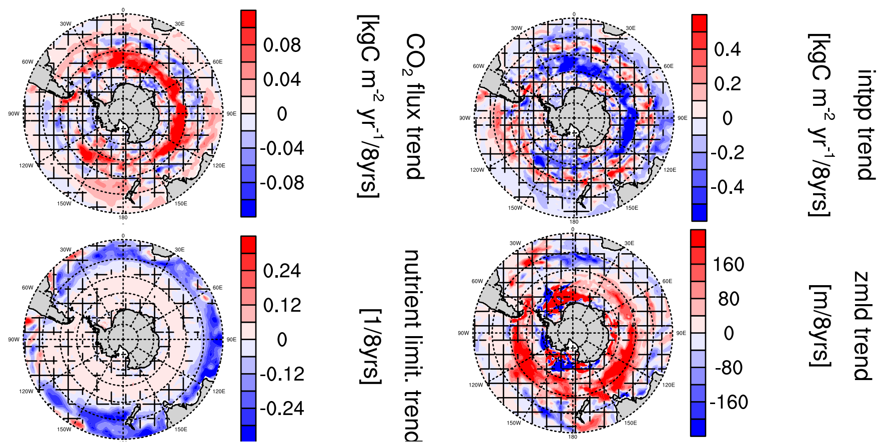

Figure 5: Southern Ocean austral summer trends per per 8 years: CO_2flux (top left), vertically integrated primary production (top right), nutrient limitation (bottom right) and mixed layer depth (bottom left); hatched areas indicate where trends were below 5% significance

4.3 POSITIVE TREND OF THE SOUTHERN OCEAN CARBON SINK

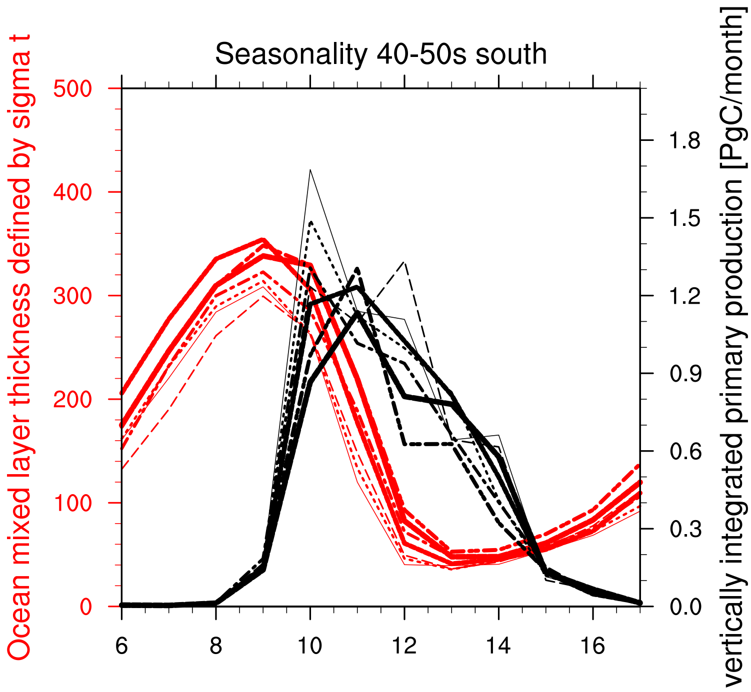

Figure 6: Seasonality of vertically integrated primary production (black) and mixed layer depth (red) at 50-60°S over 8 years; thicker lines are later years

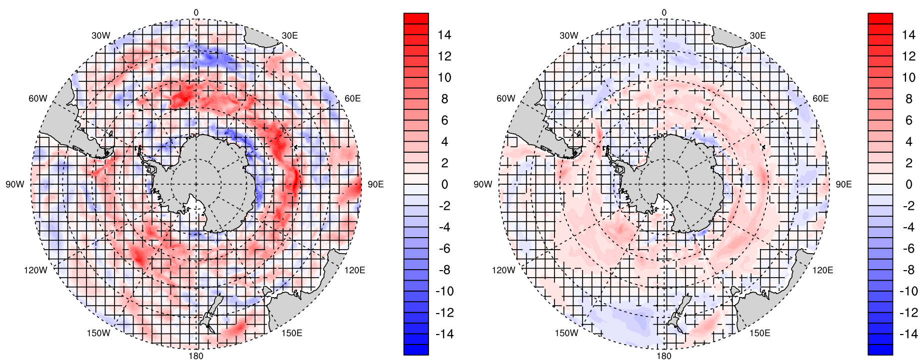

Figure 7: Trends in [m/8yrs] for phytoplankton average depth (left) and average depth of vertical diffusivity due to wind (right); hatched areas indicate where trends were below 5% significance

5 DISCUSSION

(Landschützer et al., 2015)
(Le Quéré et al., 2007)
(Lovenduski and Gruber, 2005)
(Lovenduski et al., 2007)
(Lovenduski, Gruber, and Doney, 2008)
(Hauck et al., 2013)
(Wang and Moore, 2012)

(Lovenduski and Gruber, 2005): how is model different, how are results different

1. our MLD responds differently than Lovenduski2005 Fig.2 schematic illustration
2. increase in SAM –> increase in chlorophyll south of PF/45°S because of iron supply from below (we have phy-decrease)
3. increase in SAM –> reduction in chlorophyll north of PF/45°S because of increased ZMLD (we have a slight phy-increase)
4. BUT we dont have iron limitation in SO, so this study can be used as a direct physical effect of stronger winds on primary production excluding nutrient supply changes

(Hauck et al., 2013): stronger winds, increased upwelling, more iron supply, higher primary production
(Wang and Moore, 2012):

1. forced model, 25yr trends, so rather climate change impact than decadal variability
2. some regions: more upwelling, more iron, more primary production
3. I dont get the clear storyline of the whole paper

Limitations of HAMOCC vs obs/other models:

1. too early and enhanced Southern Ocean seasonal cycle (Nevison et al., 2016)
2. not eddy resolving, has impacts (**somestudy**)
3. location of polar jets in ECHAM
4. basically no nutrient limitation in SO? - other models and observations disagree
5. other observation studies use sparse for pCO2 or proxy (satelite chl-a)
6. MPIOM performance on circulation patterns and water masses in SO
7. only one phytoplankton type in HAMOCC? - more variety of plankton species might be able to adapt to depth? or is this too unrealistic for a global model such as HAMOCC?
8. MPI-ESM zmld performance in SO (Sallée et al., 2013)

6 CONCLUSION AND SUMMARY

MPI-ESM large ensemble simulations produces internal variability of the Southern Ocean carbon sink including decreasing decadal carbon sink trends over the past decades, which were seen in observations. Decreasing carbon sink trends are accompanied by intensified winds as in previous studies (Le Quéré et al., 2007; Lovenduski, Gruber, and Doney, 2008). The changes in circulation induce a different response to biology as in previous studies(Hauck et al., 2013; Lovenduski and Gruber, 2005; Wang and Moore, 2012), which is mainly attributed to differences in nutrient availability. Our results suggest that increasing winds not only enhance upwelling of carbon-rich waters, but also decrease water column stability which inhibits primary production. An overall decrease in primary production decreases the Southern Ocean carbon sink.

A APPENDIX

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A.1 STATISTICS OF SOUTHERN OCEAN CARBON SINK

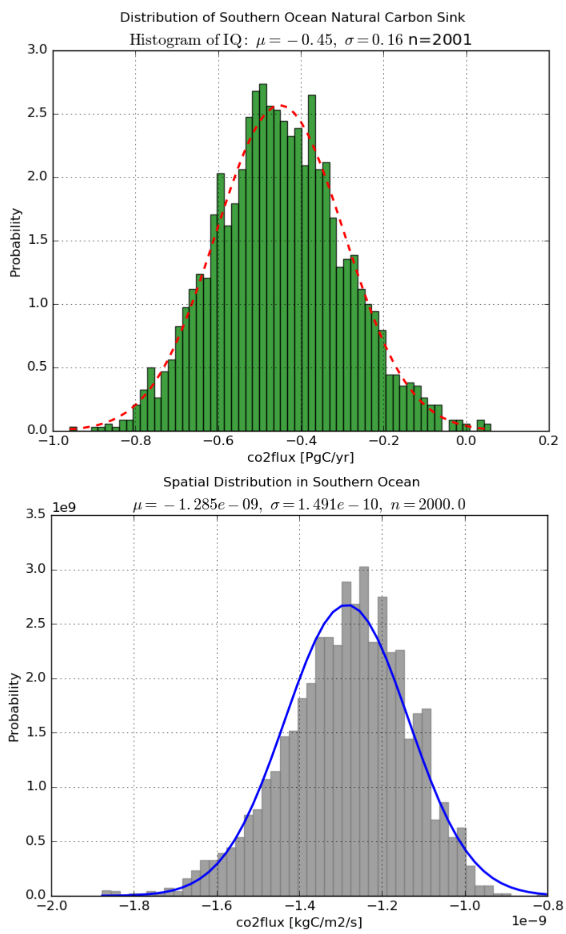

Figure 8: Southern Ocean carbon sink: yearmean fieldsum 35-90S (left) and yearmean in a random grid cell (right)

LIST OF FIGURES

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DECLARATION

Erklärung:

Ich versichere, dass ich diese Arbeit selbstständig verfasst habe und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Heidelberg, Juni 2017

Aaron Spring