Seventh Framework Programme
Theme 9 Space FP7-SPA.2009.1.1.02
Monitoring of climate change issues (extending core service activities)

Grant agreement for: Collaborative Project (generic).
Project acronym: **MONARCH-A**
Project title: **MONitoring and Assessing Regional Climate change in High latitudes and the Arctic**
Grant agreement no. 242446
Start date of project: 01.03.10
Duration: 36 months
Project coordinator: Nansen Environmental and Remote Sensing Center, Bergen, Norway

D3.3.1: Spin-up of coupled physical biogeochemical ocean model run

Due date of deliverable: 29.02.2012

Actual submission date: 02.03.2012

Organization name of lead contractor for this deliverable: UiB

Authors: Christoph Heinze, Nadine Goris

Project co-funded by the European Commission within the Seventh Framework Programme, Theme 6 Environment		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group specified by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

ISSUE	DATE	CHANGE RECORDS	AUTHOR
0	08/04/2011	Template	K. Lygre
1	02/03/2012	1st version	C. Heinze, N. Goris

SUMMARY
An 800 years spin-up was carried out with the stand-alone coupled physical-biogeochemical ocean model MICOM-HAMOCC as pre-requisite for the marine carbon cycle hindcast in MONARCH-A. As sub-modules of the new NorESM Earth system model, the MICOM-HAMOCC coupled physical biogeochemical ocean model was adapted yielding the new MICOM-HAMOCC-M model. With its shifted north pole and its refined grid resolution, the new set-up is better suited to compare the model output to the data-sets compiled in WP3.1 and WP3.2. Due to several implementation problems and development needs, the spin-up of MICOM-HAMOCC-M was started only in November 2011. 800 years of spin-up are completed at this point in time. The first order validation of the spin-up results against climatological data shows that the MICOM-HAMOCC-M reproduces the observation-based estimates reasonably well in both spatial distribution and absolute value. Based on these promising spin-up results, the MICOM-HAMMOC-M will be started at 1948 in two modes: with free floating atmospheric CO_2 (for drift test cases) and with prescribed atmospheric CO_2 for the marine carbon cycle hindcasts with special focus on the Arctic Ocean.

MONARCH-A CONSORTIUM

Participant no.	Participant organisation name	Short name	Country
1 (Coordinator)	Nansen Environmental and Remote Sensing Center	NERSC	NO
2	The University of Sheffield	USFD	UK
3	Universität Hamburg	UHAM	NO
4	Centre National de la Recherche Scientifique	CNRS	FR
5	Scientific foundation Nansen International Environmental and Remote Sensing Center	NIERSC	RU
6	Universitetet i Bergen	UiB	NO
7	Danmarks Tekniske Universitet	DTU	DK
8	Institut Francais de Recherche pour l'Exploitation de la Mer	IFREMER	FR

Table of Contents

List of Figures

1 Introduction

Being the major carbon sink since the beginning of the industrial revolution, the ocean plays a dominant role in the Earth's carbon cycle (Sabine et al, 2004). The positive climate-marine carbon cycle feedback modeled by future climate predictions using an IPCC SRES A2 emission scenario and coupled carbon cycle climate models (Friedlingstein et al., 2006) stresses the importance of reliable analyses, resting on carbon related observations in the ocean. Since these observations are largely "under-sampled", especially in high latitude oceans, an inventory of existing in-situ and remotely sensed observations was build up in WP3.1 and WP3.2. The respective observations data will be used to validate time dependent hindcast model computations and to furthermore integrate those observations yielding a better estimate for carbon related variables.

In order to supply a synoptically forced coupled physical-biogeochemical ocean model run over the past 50 years fitting to the data-sets of WP3.1 and WP3.2, the MICOM-HAMOCC model had to be adapted to the NorESM context first. We run the stand-alone ocean model within the technical framework of the NorESM Earth system model, but replace the coupling to an atmosphere model by reading in observed (re-analysed) synoptic atmospheric data. The newly adapted model MICOM-HAMOCC-M is described in Section 2. After implementing the MICOM-HAMOCC-M, the model was spun-up for 800 years to generate a pre-industrial steady state climate which can be utilized as initial state for the present day simulations. The validation of the spin-up against climatological data estimates is described in the Section 3. Model simulations over the last 50 years as well as the associated comparison and integration of carbon-related observations will follow in the next deliverable report.

2 Model description

The deployed coupled physical biogeochemical ocean model MICOM-HAMOCC-M is based on the MICOM-HAMOCC version described in Assmann et al., 2010 (this model version is denoted as MICOM-HAMOCC-BCM in the following). In contrast to the MICOM-HAMOCC-BCM which is embedded in the Bergen Climate Modell framework, MICOM-HAMOCC-M is integrated in the new NorESM framework. NorESM is a state-of-the-art Earth system model originating from the Community Climate System Model 4. It differs from the CCSM4 in the ocean component (MICOM), the ocean carbon cycle (HAMOCC) and the treatment of atmospheric chemistry, aerosol and clouds. In order to adapt MICOM-HAMOCC-BCM to NorESM, the north pole of the model was shifted from Siberia to Greenland. Moreover, the model resolution was refined, so that two model versions are now available: MICOM-HAMOCC-L (3.6° resolution) and MICOM-HAMOCC-M (1.125° resolution). Since the finer resolution is advantageous for the planned data-model comparison of MONARCH-A, MICOM-HAMOCC-M is deployed here.

The new NorESM framework required the migration of MICOM-HAMOCC from a shared memory OpenMP system to a distributed memory MPI computing architecture. This time-consuming adjustment as well as the fixation of an error in the revised numerical scheme for passive tracer advection regarding the mass conservation of tracers caused an unforeseen delay of implementation. Further some biogeochemical process parameters had to be re-adjusted. In November 2011 finally the MICOM-HAMOCC-M was ready for operation.

2 First order validation of the MICOM-HAMOCC-M Spin-up

The Spin-up simulation of the MICOM-HAMOCC-M model is initialised with climatology-data from the World Ocean Atlas (WOA). Subsequently, the model is integrated for 800 years with a constant preindustrial atmospheric CO_2 concentration of 278 ppm. During this integration time the modelled marine carbon cycle approaches a steady state which is utilised for initializing present day simulations.

The spun-up model reproduces the carbon-related observation estimates relatively well. Regarding the variables temperature, salinity, nitrate, phosphate, silicate and oxygen out of the variable list for the subsequent data-model comparison (not presented variables are not part of the World Ocean Atlas), it can be found that both the MICOM-HAMOCC-M as well as the MICOM-HAMOCC-BCM are to a large degree consistent with observations. Based on monthly output-files of both model versions, Figure 1 shows the corresponding Taylor-diagrams for January and July. A Taylor-diagram (Taylor, 2001) is a well arranged diagram that summarizes normalized standard deviation, centered root-mean-squares and pattern correlation. Thereby all observations are normalized so that for a perfect model fit the model would overlie the observations in the Taylor-diagram. In this manner, the distance between the observation point and the model point of the Taylor-diagram is a measure of the data-model fit. Accordingly, Figure 1 points out that both MICOM-HAMOCC-M and MICOM-HAMOCC-BCM have a very good estimate for salinity, temperature and oxygen in the surface layer (with approximately the same quality of fit). However, for phosphate and nitrate the performance of MICOM-HAMOCC-M exceeds the performance of MICOM-HAMOCC-BCM. While MICOM-HAMOCC-M shows correlations around 0.8 and 0.9, respectively, MICOM-HAMOCC-BCM has only correlations around 0.6 and 0.8, respectively. The maps of surface layer phosphate for both models confirm this finding (see Figure 2). They point out, that the MICOM-HAMOCC-BCM overestimates phosphate in the southern latitudes and underestimates phosphate in the northern latitudes. On the contrary MICOM-HAMOCC-M underestimates phosphate in northern and southern latitudes. Still the general distribution of phosphate is noticeably more in consistence with the World Ocean Atlas. Especially in the northern latitudes both the general distribution and the absolute values of phosphate are far better matched, allowing for a more fruitful data-model comparison within MONARCH-A. The same feature applies for nitrate: MICOM-HAMOCC-M does reproduce the observational estimates in northern latitudes by far better than MICOM-HAMOCC-BCM. Figure 1 illustrates furthermore that surface silicate is better represented within the old model MICOM-HAMOCC-BCM. Vertical cross-sections of silicate show, that the vertical silicate distribution of the new model MICOM-HAMOCC-M is as well not matching the observations very well with too high values in the deep ocean. These vertical and horizontal discrepancies of silicate occur due to an overestimation of the sinking speed of silicate in the Spin-up configuration of MICOM-HAMOCC-M. In order to resolve this problem, the Spin-up was prolonged with a reduced sinking speed of silicate. Preliminary results of this currently started model run look promising.

Vertical cross-sections of the other analyst variables show very good agreement between observations and models for both salinity and temperature. Again, phosphate and nitrate are better represented by the MICOM-HAMOCC-M compared to MICOM-HAMOCC-BCM (Figure 3 shows a vertical cross-section for phosphate). Looking at the vertical distribution of oxygen, a slight overestimation in the deeper ocean becomes apparent.
Altogether, the MICOM-HAMOCC-M does perform well and occurring discrepancies between model and observations are within an acceptable range. Furthermore, the discrepancy within silicate is hopefully going to be reduced when the Spin-Up with the reduced sinking speed is completed.

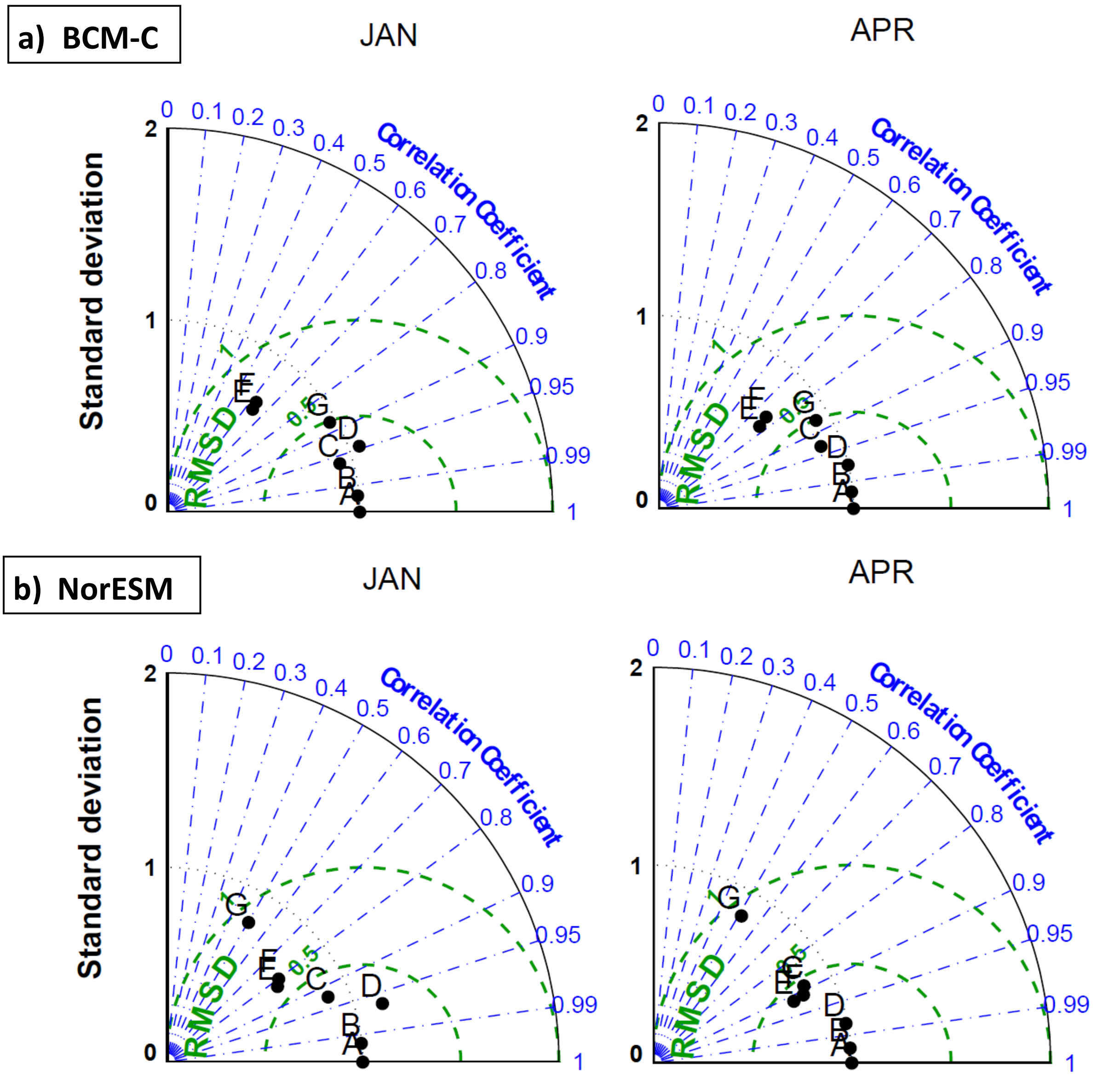

Figure 1: Taylor-diagram for surface layer (A) observations, (B) temperature, (C) salinity, (D) oxygen, (E) phosphate, (F) nitrate and (G) silicate. Depicted are results for MICOM-HAMOCC-BCM (top panel) and MICOM-HAMOCC-M (bottom panel) for January (left panel) and April (right panel).

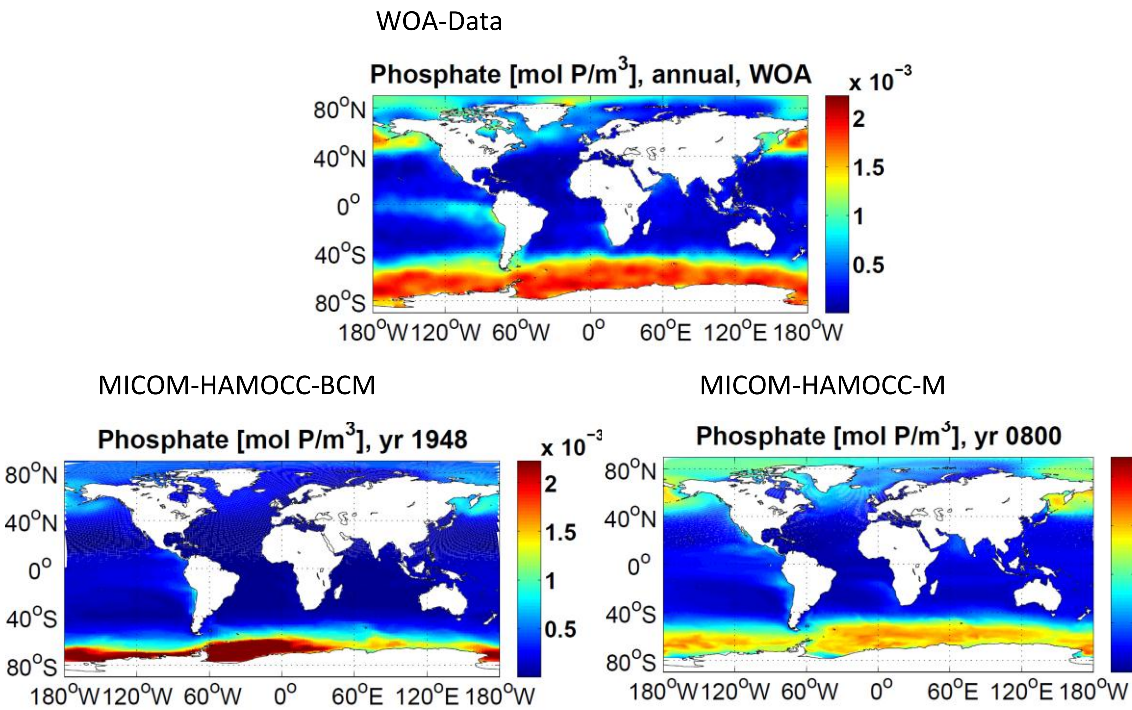

Figure 2: Global phosphate surface concentrations: World Ocean Atlas (top), MICOM-HAMOCC-BCM (bottom left) and MICOM-HAMOCC-M (bottom right).

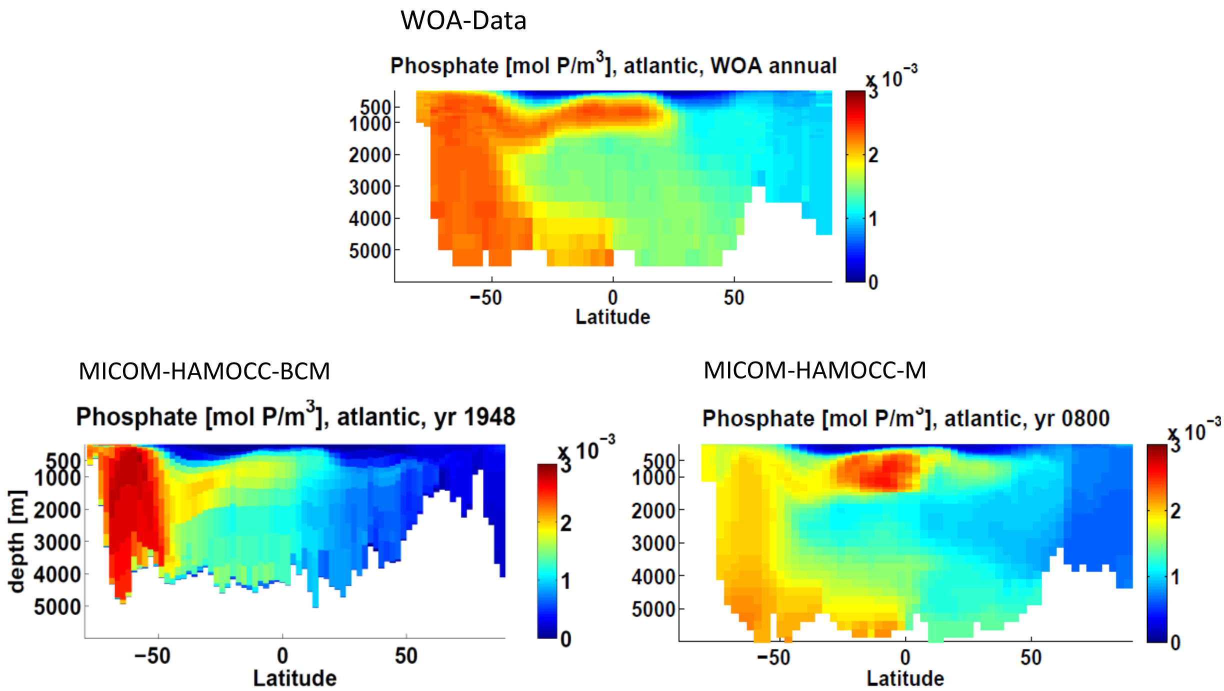

Figure 3: Atlantic cross-section of phosphate: World Ocean Atlas (top), MICOM-HAMOCC-BCM (bottom left) and MICOM-HAMOCC-M (bottom right).

4 Discussion of prescribed vs. free floating atmospheric pCO_2

The HAMOCC biogeochemical ocean model includes a one layer bulk atmosphere in order to exchange CO_2 between an atmospheric reservoir and the ocean surface layer. There are in general two ways of treating the atmospheric CO_2 concentration in ocean only model runs. Either one can prescribe the atmospheric CO_2 concentration, or one can let the atmospheric CO_2 content in the model atmosphere reservoir be predicted by the ocean model. We planned to carry out both runs for the stand-alone model. For the MONARCH-A hindcast simulations, we want to simulate the carbon cycle in the ocean and its variability as close as possible to observations (and respective atmospheric forcing variations). Therefore, we will primarily focus on simulations using prescribed CO_2 in the atmosphere. Nevertheless, we plan to later on also carry out a model run with free floating atmosphere primarily in order to see how large the model drift will be after cancelling the fixing to observed atmospheric CO_2 values. However, the ocean carbon content cannot be simulated correctly for the anthropocene with free floating atmosphere ocean models as the sinks/and sources of terrestrial carbon cycling would have to be included as well (these are implicitly accounted for, if uses instead prescribed atmospheric CO_2). We also carried out a spin-up for the fully interactive NorESM Earth system model with free floating atmosphere in order to carry out interactive carbon cycle climate model runs forced by emissions and including a terrestrial carbon cycle model. These runs will not be evaluated in MONARCH-A for the marine part. The reason for this is that fully coupled Earth system models have their own weather and interannual variability, which do not agree with the observed variability at respective calendar years. Therefore, for the GMES-related purposes we planned to do here, the ocean-only model runs with the MICOM-HAMOCC system using prescribed atmospheric CO_2 are the only useful set-up. In order to illustrate the mistake in atmospheric CO_2 and anthropogenic carbon in the ocean, we carried out two 300 years simulation with the extremely cost efficient HAMOCC2s model (cf. Heinze et al., 2009). The model uses fixed ocean circulation, an E-grid with 3.5 degrees horizontal resolution, and a 1-year time step. It had been run into quasi-perfect equilibrium over 100,000 years of integration including marine surface sediment. We forced the model in case E with emissions from fossil fuel combustion and cement manufacturing (Boden et al., 2011) and for in case P with prescribed atmospheric CO_2 from ice core and instrumental records (Etheridge et al., 1998; Keeling et al., 2009) and ran it over the period of 1700-2000. Figure 4 shows the atmospheric CO_2 curves where the prescribed atmospheric CO_2 case yields much higher values in the middle of last century than the emission driven model. The two curves meet each other for the beginning of the present century, as the earlier on missing land source in the emission driven case is compensated by the missing evolving land carbon sink at higher CO_2 levels. Also the anthropogenically induced excess carbon in the ocean shows two low values in the emission driven case with free-floating atmospheric CO_2. We will therefore, primarily focus in the marine carbon cycle work in MONARCH-A on the model runs with prescribed atmospheric CO_2.

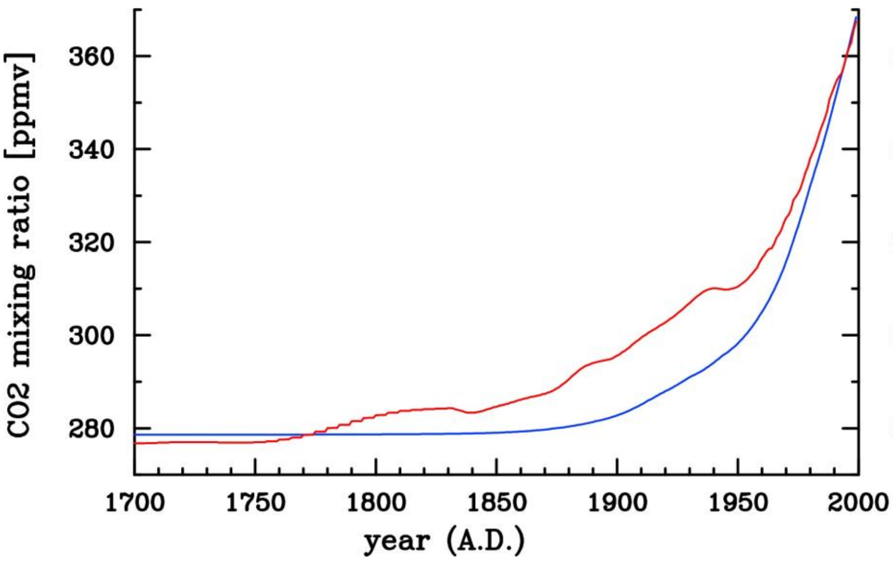

Figure 4: Atmospheric CO_2 mixing ratio with the simplified HAMOCC2s model for the emission driven case E (blue) and the prescribed atmospheric CO_2 case P(red).

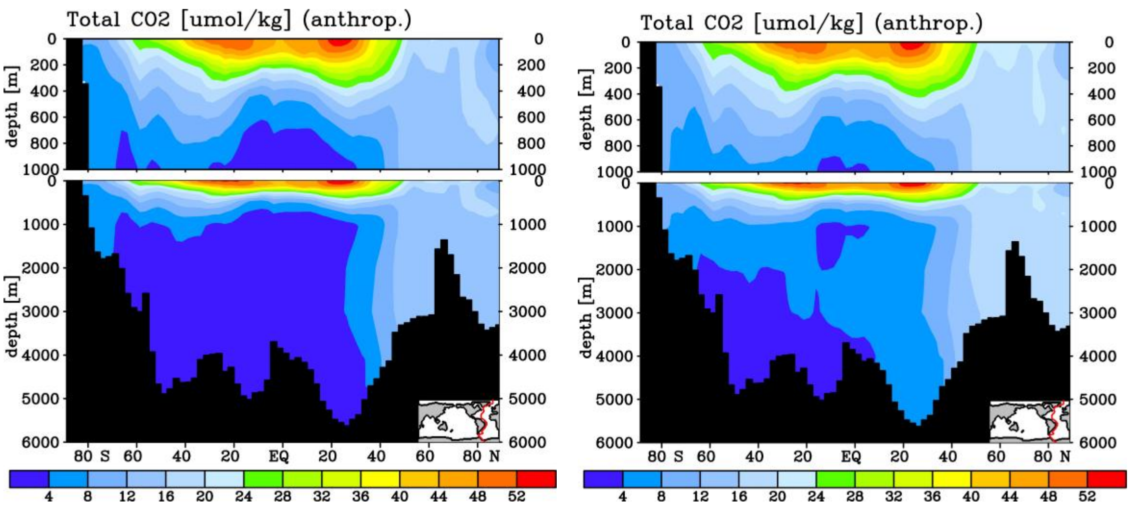

Figure 5: Atlantic Ocean cross sections for anthropogenic carbon with the simplified HAMOCC2s model for the emission driven case E (left) and the prescribed atmospheric CO_2 case P (right).

5 References

Aßmann, K. M., M. Bentsen, and C. Heinze, An isopycnic biogeochemical ocean general circulation model, manuscript in preparation.

Boden, T.A., G. Marland, and R.J. Andres. 2011. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2011

D.M. Etheridge, L.P. Steele, R.L. Langenfelds, R.J. Francey, J.-M. Barnola and V.I. Morgan. 1998. Historical CO_2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Friedlingstein, P., P. Cox, R. Betts, L. Bopp, W. Von Bloh, V. Brovkin, P. CADULE, S. Doney, M. Eby, I. Fung, G. Bala, J. John, C. Jones, F. Joos, T. Kato, M. Kawamiya, W. Knorr, K. Lindsay, D. Matthews, T. Raddatz, P. Rayner, C. Reick, E. Roeckner, K.-G. Schnitzler, R. Schnur, K. Strassmann, A. J. Weaver, C. Yoshikawa, and N. Zeng, 2006, Climate–Carbon Cycle Feedback Analysis: Results from the C4MIP Model Intercomparison, J. Clim., 19, 3337–3353.

Heinze, C., I. Kriest und E. Maier-Reimer, 2009, Age offsets among different biogenic and lithogenic components of sediment cores revealed by numerical modeling, *Paleoceanography*, 24, PA4214, 17p., doi:10.1029/2008PA001662.

Keeling, R.F., S.C. Piper, A.F. Bollenbacher and J.S. Walker. 2009. Atmospheric CO_2 records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/atg.035

Sabine, C.L., R.A. Feely, N. Gruber, R.M. Key, K. Lee, J.L. Bullister, R. Wanninkhof, C. S. Wong, D.W.R. Wallace, B. Tilbrook, F.J. Millero, T.-H. Peng, A. Kozyr, T. Ono, and A.F. Rios, 2004, The Oceanic Sink for Anthropogenic CO_2, Science, 305, 367-371.

Taylor, K.E., Summarizing multiple aspects of model performance in a single diagram, J. Geophys. Res., 106, 7183-7192.

END OF DOCUMENT