SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2015/2016
Project Title:	Ocean-Atmosphere Chemistry Climate Model Simulations for new WMO-SPARC-Chemistry Climate Model Initiative (CCMI)
Computer Project Account:	SPDEWMO3
Principal Investigator(s):	Prof. Dr. Ulrike Langematz
Affiliation:	Institut für Meteorologie, Freie Universität Berlin
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	2015
Expected end date:	2017

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	4.000.000	4.000.000	6.500.000	2.300.307
Data storage capacity	(Gbytes)	24.000	24.000	12.000	?

Summary of project objectives
(10 lines max)

Within this project a simulation with the Atmosphere-Ocean-Chemistry-Climate Model (AOCCM) ECHAM/MESSy/MPIOM (EMAC-O) was conducted as contribution to the German research programme "Mittelfristige Klimaprognosen" (MiKlip). The main focus within this project lies on the assessment of the importance of stratospheric solar forcing, decadal stratospheric internal variability and the role of atmosphere-ocean interactions in view of the development of a mid-term, i.e. decadal, climate prediction model. Furthermore, the simulation was analysed in the projects SHARP and ISOLAA, both interested in the atmosphere-ocean interactions.

Summary of problems encountered (if any)
(20 lines max)

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Summary of results of the current year (from July of previous year to June of current year)

An important simulation with the Chemistry-Climate Model EMAC coupled to the ocean model MPIOM (hereafter EMAC-O AOCCM) was completed on the ECMWF HPC Facility in January 2016. It represents a control simulation with perpetual boundary conditions representative for the year 1960 (EMAC-O 1960CTL) but including the natural forcing by time-varying spectral solar irradiance. Using this simulation, the natural climate variability of the atmosphere-ocean system is accessed. This simulation was run for 141 years to capture the natural variability of the earth-ocean system on longer time scales. Due to the high demands of time and resources by the AOCCM, this simulation could not be carried out for a longer time period. In the following, results of the control simulation are presented.

El Niño-Southern Oscillation signal in the control simulation

The variability of the tropical sea surface temperatures (SSTs) has a direct impact on the general atmospheric circulation through enhanced convection in the areas with higher SSTs as well as via teleconnections by the El Niño-Southern Oscillation (ENSO) phenomenon. Enhanced convection in the tropical region leads to an enhanced poleward transport of trace gases such as water vapour or ozone, which contributes to the radiative forcing of the atmosphere.

The variability of the SSTs is represented by the time series of the NINO3.4 index, an areal average of the monthly SSTs in the eastern equatorial Pacific (Rasmusson and Carpenter, 1982). The power spectrum of the SSTs in the NINO3.4 region in the EMAC-O 1960CTL simulation (**Fig. 1**) shows that the Pacific SSTs vary with a mean period of 40 months (3.3 years), well capturing the main period of the observed NINO3.4 index (Bellenger et al., 2014). The ocean components of some CMIP5 models suffer from a too short period of the ENSO events by around 2 years, with a strongly periodic occurrence of the ENSO events. With the occurrence of the distinct secondary maxima in the power spectrum with time periods of 34, 43 and 95 months in **Fig. 1**, the ability of EMAC-O to simulate irregular (non-periodic) SST variability is given.

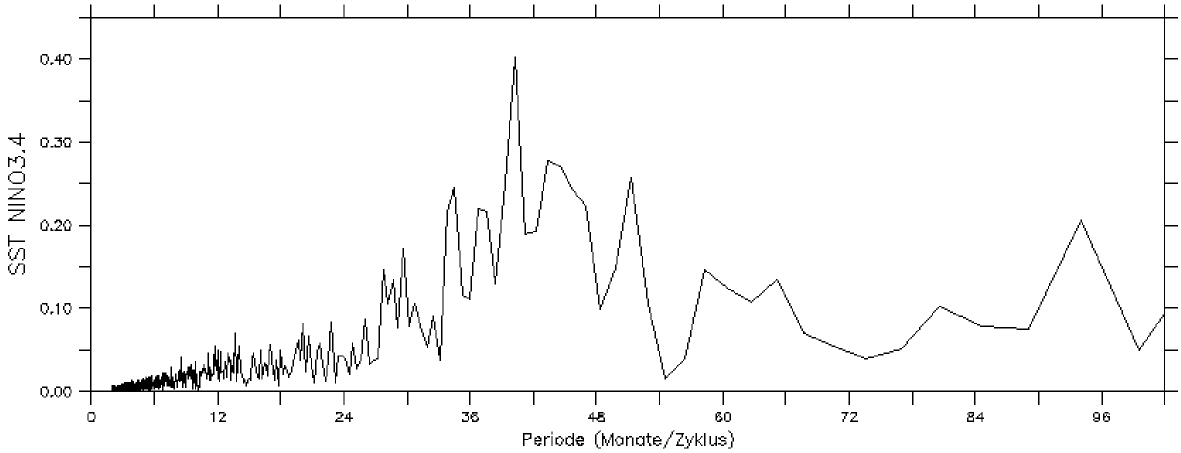

Figure 1: Power spectrum of the monthly NINO3.4 index in the EMAC-O 1960CTL simulation (141 years).

Meridional overturning circulation

The seasonal cycle of the oceanic meridional overturning circulation (MOC) in the Southern Hemisphere is shown in **Fig. 2**. In red colours, the equatorward branch of the circulation and mass transport at the sea surface, connected with the clockwise direction of the MOC, is shown. This branch, which represents the main wind driven branch of the MOC in the Antarctic vicinity, is connected with the upwelling of so-called Intermediate Antarctic Waters near the coast of Antarctica. This water subsides in mid-latitudes near 40°S and is transported poleward. Thus it is warmer, less salty and less dense compared to the surface water at the coast of the Antarctica. The MOC ensures the poleward transport of the heat stored in the Southern Ocean.
The intensification of the MOC during the autumn and winter months (MAM and JJA) is connected with the intensification of the surface zonal wind through the Ekman mechanism. With the transition from the winter to the summer atmospheric circulation the strength of the MOC declines (**Fig. 2a, d**).

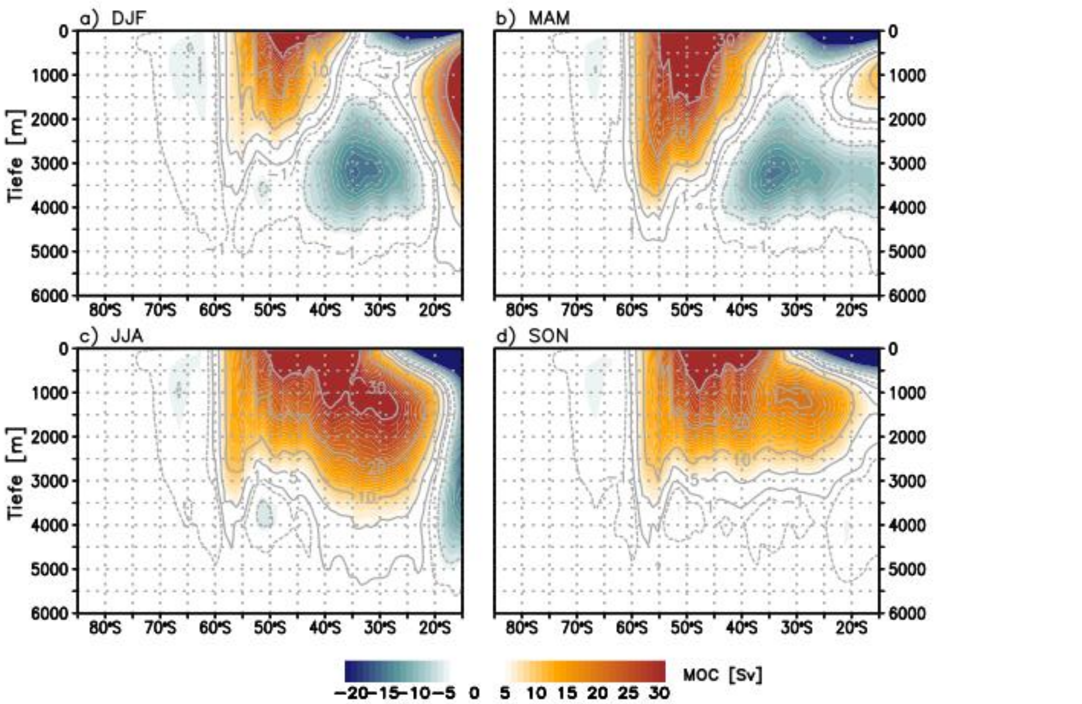

Figure 2: Depth-latitude sections of the climatological MOC in Sv in the EMAC-O 1960CTL simulation. Red shading denotes the clockwise direction of the circulation, while blue shading stands for the anti-clockwise circulation of the MOC.

An intensification of the atmospheric circulation during the summer months in the late 20th century is strongly connected with an intensification of the MOC. In **Fig. 3,** decadal trends in the MOC during summer from a transient EMAC-O simulation of the period 1960 to 2100 (the EMAC-O RCP6.0 simulation, carried out in 2015) are presented. The intensification of the MOC is associated with a poleward shift of its position during the years 1980-1999. The intensification of the surface atmospheric circulation is the manifestation of the occurrence of the Antarctic ozone hole. An enhanced upwelling in the Southern Ocean is in line with observations (Waugh et al., 2013).

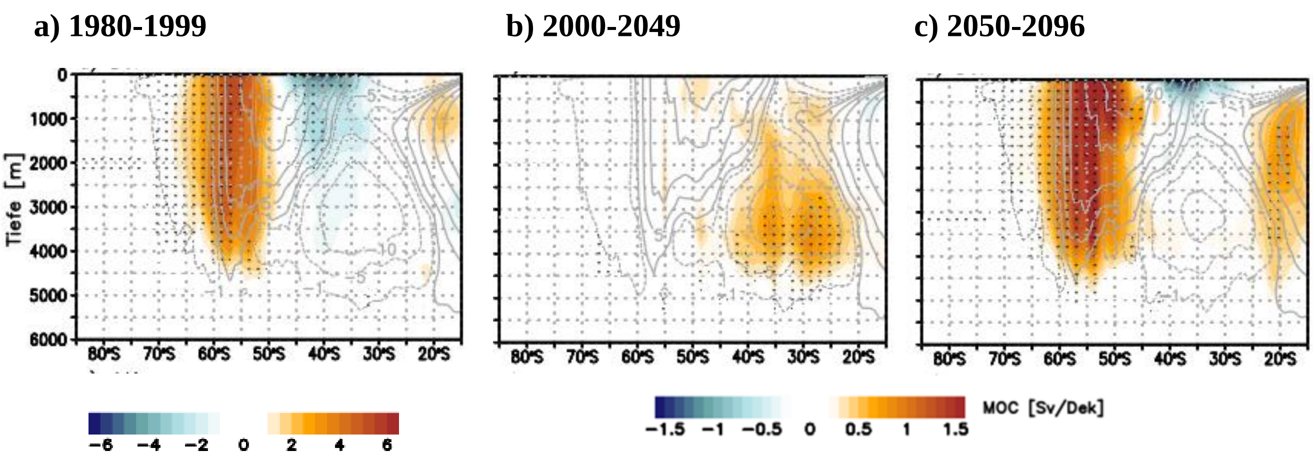

Figure 3: Decadal trends of the MOC during southern hemisphere summer (DJF) over the periods a) 1980-1999, b) 2000-2049 and c) 2050-2096 in the EMAC-O RCP6.0 simulation. The first color bar is valid for the time period 1980-1999. The second color bar stands for the periods 2000-2049 and 2050-2096. The difference in the range of the color bars (6 Sv/dec vs 1.5 Sv/dec at maximum) denotes the smaller trends in

the 21st century.

During the recovery phase of Antarctic ozone, there is almost no change in the surface atmospheric circulation (not shown). Neither shows the strength of the MOC a visible trend during this time (**Fig. 3b**). A new intensification of the MOC as well as of the atmospheric circulation occurs however in the second half of the 21st century due to an enhanced heating of the tropical troposphere by increasing concentrations of greenhouse gases (GHGs) in the atmosphere, while there is only a slight warming of the SH polar region.

References

Bellenger, H., Guilyardi, E., Leloup, J., Lengaigne, M., and Vialard, J., 2014: ENSO representation in climate models: from CMIP3 to CMIP5, *Climate Dynamics*, 42(7), 1999–2018.

Eyring, V. et al., 2013: Overview of IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) Community Simulations in Support of Upcoming Ozone and Climate Assessments, *SPARC Newsletter*, 40, 48-66.

Marsland, S.J., H. Haak, J.H. Jungclaus, M. Latif, F. Röske, 2003: The Max-Planck-Institute global ocean/sea ice model with orthogonal curvilinear coordinates, *Ocean Modelling*, Volume 5, Issue 2, 91-127.

Rasmusson, E. and Carpenter, T., 1982: Variations in tropical sea surface temperature and surface wind fields associated with the southern oscillation/El Niño. *Monthly Weather Review*, 110(5):354–384.

Waugh, D. W., Primeau, F., Devries, T., and Holzer, M., 2013: Recent changes in the ventilation of the southern oceans, *Science*, 339(6119), 568–70.

List of publications/reports from the project with complete references

Abalichin, J., 2016: Natural variability and anthropogenic impact in simulations with the coupled CCM EMAC-O: atmosphere-ocean interactions in the Antarctic climate change. PhD thesis, Freie Universität Berlin.

Abalichin, J., Langematz, U. et al.: Role of the atmosphere-ocean interactions in the recent Antarctic climate change, in preparation.

Oberländer-Hayn, S., E. P. Gerber, J. Abalichin, H. Akiyoshi, A. Kerschbaumer, A. Kubin, M. Kunze, U. Langematz, S. Meul, M. Michou, O. Morgenstern, and L.D. Oman, 2016: Is the Brewer-Dobson circulation increasing or moving upward?, *Geophys. Res. Lett.*, 43, 1772-1779.

Wunderlich, F., 2016: Darstellung der Madden-Julian Oszillation und deren Einfluss auf die boreale Stratosphäre im Winter durch das Klima-Chemiemodell EMAC-O, Master thesis, Freie Universität Berlin.

Summary of plans for the continuation of the project

Currently, a transient control simulation under GHG and ODS conditions of the year 1960 but with amplified solar cycle is in preparation. The solar intensity is enhanced by about 10 % compared to the mean solar activity.
The response of the ocean by means of heat storage and transport, as well as the atmosphere-ocean coupling will be assessed.