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	2014/2015
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)	11.250.000	10.173.134	4.000.000	216.150
Data storage capacity	(Gbytes)	24.000	24.000	12.000	0

Summary of project objectives

(10 lines max)

Within this project Atmosphere-Ocean-Chemistry-Climate Model (AOCCM) simulations with the MA-ECHAM5/MESSy/MPIOM (EMAC-O) were 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 simulations were 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)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

Two simulations with the Ocean-coupled Chemistry-Climate Model EMAC-MPIOM (hereafter EMAC-O) were completed on the ECMWF HPC Facility in 2014. The first one is a control simulation with perpetual boundary conditions representative for the year 1960 (e5ao_1960Ctl) but including the natural forcing by time-varying spectral solar irradiance. This simulation was run for 109 years. The other one was a transient simulation from 1960 to 2095 including all anthropogenic and natural forcings such as greenhouse gases (GHG), ozone depleting substances (ODS), volcanic eruptions and spectral solar variability. The prescribed GHG concentrations followed the RCP6.0 scenario (e5ao_rcp6.0). The latter simulation was recommended as reference simulation within the Chemistry-Climate Model Initiative (CCMI) framework (Eyring et al., 2013). In the following, results of the control simulation are presented.

The 11-year solar signal in the control simulation

The 11-year solar influence on the atmosphere is extracted from the raw model output by means of a multiple linear regression approach. All results presented in this section are given per 100 units of the F10.7cm solar radio flux which is closely correlated with solar ultra-violet variations during the course of the solar activity cycle and which was used as basis function for solar variability in the regression.

The annual mean solar signals in zonal mean short-wave heating rates, ozone and temperature are shown in Fig 1. An enhanced short-wave heating can be seen everywhere in the upper stratosphere and lower mesosphere which peaks at about 0.14 K/day near the tropical stratopause. A secondary maximum is found in the mesosphere which can be attributed to the absorption of oxygen at the Lyman-α line (121.5nm). Ozone is increased by about 1.5% over wide regions of the middle stratosphere with a peak near 3 hPa at low latitudes. These solar induced anomalies lead to an increase of temperature by about 0.7 K in the stratopause region with a double peak structure at northern and southern subtropical latitudes. The vertical dipole signal at high latitudes with positive anomalies on top of negative anomalies in the lower atmosphere originates in the respective winter season.

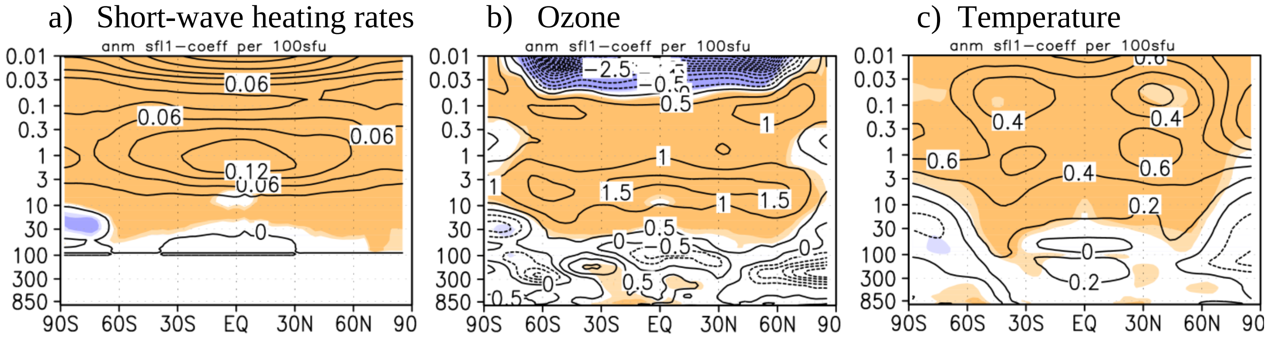

Figure 1: Annual mean solar signal in a) zonal mean short-wave heating rates in K/d, contour interval is 0.03 K/d, b) zonal mean ozone in %, contour interval is 0.5 % and c) temperature in K per 100 units F10.7 cm radio flux, contour interval is 0.2 K. Light (heavy) shading indicates statistical significance at the 95% (99%)-level.

In recent years there has been a debate about the solar influence on temperature and ozone in the lowermost stratosphere in the tropics. From observations a secondary peak of positive temperature and ozone anomalies has been derived (e.g. Soukharev and Hood, 2006). Chemistry climate models show different results in this particular region. It has also been argued that aliasing with the El Nino Southern Oscillation phenomenon (Marsh and Garcia, 2007) or with major volcanic eruptions which happened close to the peaks of solar activity in the past (El Chicon in 1982 and Mt. Pinatubo in 1991) might play a role in generating this secondary response (Chiodo et al., 2014). Since a volcanic influence was neglected in the EMAC-O control simulation, we do not expect any aliasing effect from volcanic aerosol loading. A test has been performed to assess the robustness of the solar signal in temperature in the tropical stratosphere. As seen from Figure 1c EMAC-O does simulate a weakly ne-

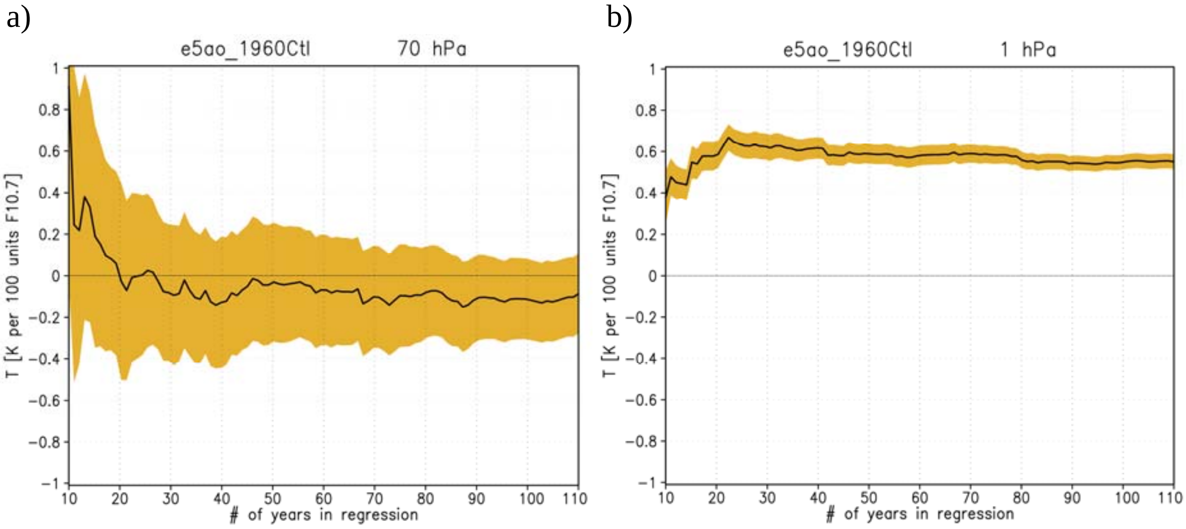

Figure 2: Solar signal in the tropical (25°N to 25°S) stratosphere as a function of the number of years in the input time series at a) 70 hPa, i.e. in the lower stratosphere and b) at 1 hPa, i.e. near the stratopause. The uncertainty range associated with each value is given by the orange shading.

gative temperature response to enhanced solar activity in the lowermost tropical stratosphere, just above the 100 hPa-level. The regression analysis has been repeated for the tropics (25°N to 25°S) with a fixed end year of the input time series, with ten years minimum length and with successively more years in the input time series until the whole 109 years of the simulation are covered.

It is found that the solar signal in the lower stratosphere is apparently positive when only a low number of years (20 to 25) is included in the regression analysis (Figure 2a). Then, a change of sign occurs and the signal remains negative until the whole simulation period is included. The signal is statistically not significant, i.e. the uncertainty range encompasses the zero line. But it can be noted that the uncertainty range decreases slightly as more years are included in the analysis. In the upper stratosphere, in contrast, the solar signal is rather stable and statistically highly significant, as seen in Figure 2b. However, with more years in the analysis the signal is somewhat reduced which might have to do with the double peak structure of the maximum temperature response at 30°N and 30°S over the full simulation period (cf. Figure 1c), i.e. outside the domain investigated in the current analysis.

The temporal evolution of the solar signal in zonal mean temperature and zonal mean zonal wind during the dynamically active seasons is shown in Figure 3. In January a temperature dipole pattern emerges with a positive anomaly on top of a negative one at high northern latitudes. This pattern intensifies in the following months before it decays in April (not shown). The upper, positive, anomaly extends farther down in February and March (Figure 3a). However, there is no such extension or downward displacement of the negative anomaly below. It seems to halt at the 300hPa-level and does not reach the surface. A similar behaviour can be detected in southern late winter and spring from August to October (not shown). The zonal wind response to enhanced solar activity in northern winter is characterised by a statistically significant westerly anomaly which starts to develop in the mid-latitudinal lower mesosphere in December. Subsequently, the westerly anomaly grows in strength and moves poleward and downward. In the troposphere a statistically significant westerly anomaly is found at subtropical latitudes which translates into a strengthening of the subtropical jet at its core in January and February and at its northern flank in March. (Figure 3b) In southern winter and spring (August to October) also a westerly zonal wind anomaly is found in the lower mesosphere and in the stratosphere but its poleward displacement stops at about 60°S. The corresponding tropospheric signal is comparable to the northern hemispheric response, i.e. the subtropical jet is strengthened at its core but with a tendency to the equatorward side (not shown).

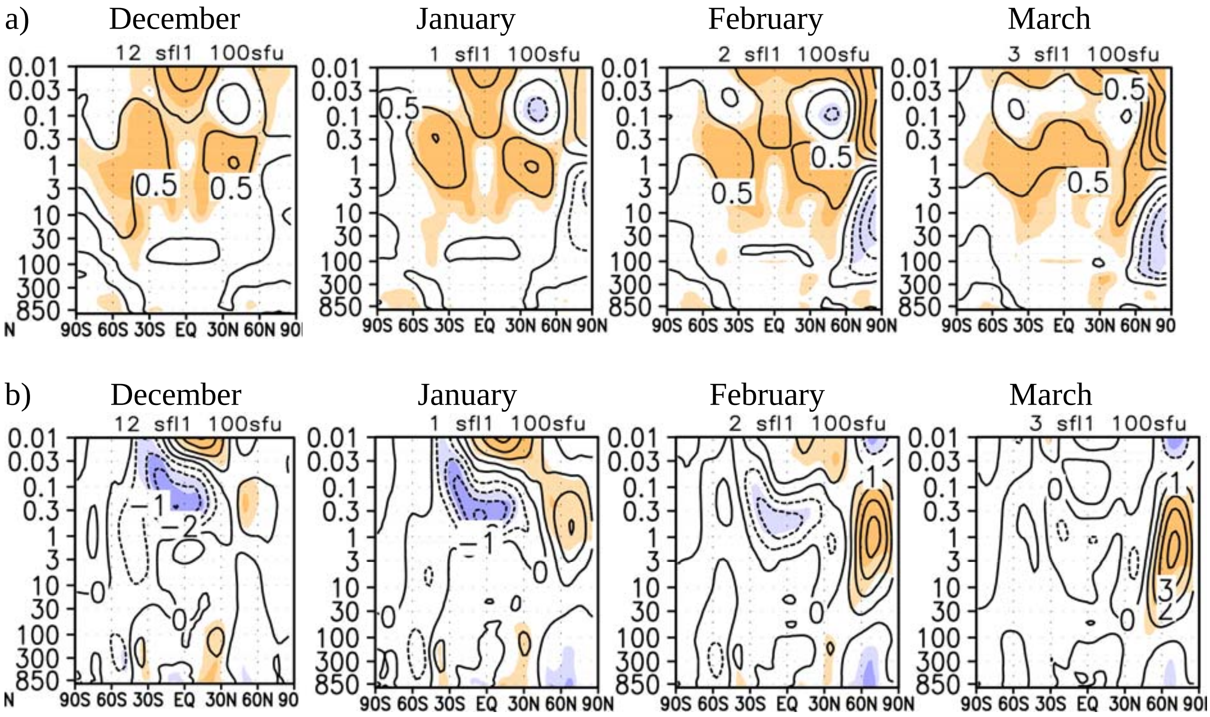

Figure 3: Solar signal in northern winter from (left) December to (right) March in a) zonal mean temperature and b) zonal mean zonal wind. The contour interval in a) is 0.5 K per 100 units F10.7cm radio flux and 1 m/s per 100 units F10.7 cm radio flux. Light (heavy) shading indicates statistical significance at the 95% (99%) level, respectively.

The mean sea-level pressure in northern winter (DJF) in this control simulation responds to enhanced solar activity with a positive anomaly at polar latitudes and negative anomalies at mid-latitudes, see Figure 4a. This pattern resembles the Arctic Oscillation (AO) in its negative phase. In consequence anomalously cool near-surface temperatures are found downstream of the pressure dipole over the Eurasian continent (not shown). We have tested the robustness of this signal, in particular the North Atlantic Oscillation (NAO) part of it, with a repetition of the regression analysis with successively more and more years included in the input time series as described above.

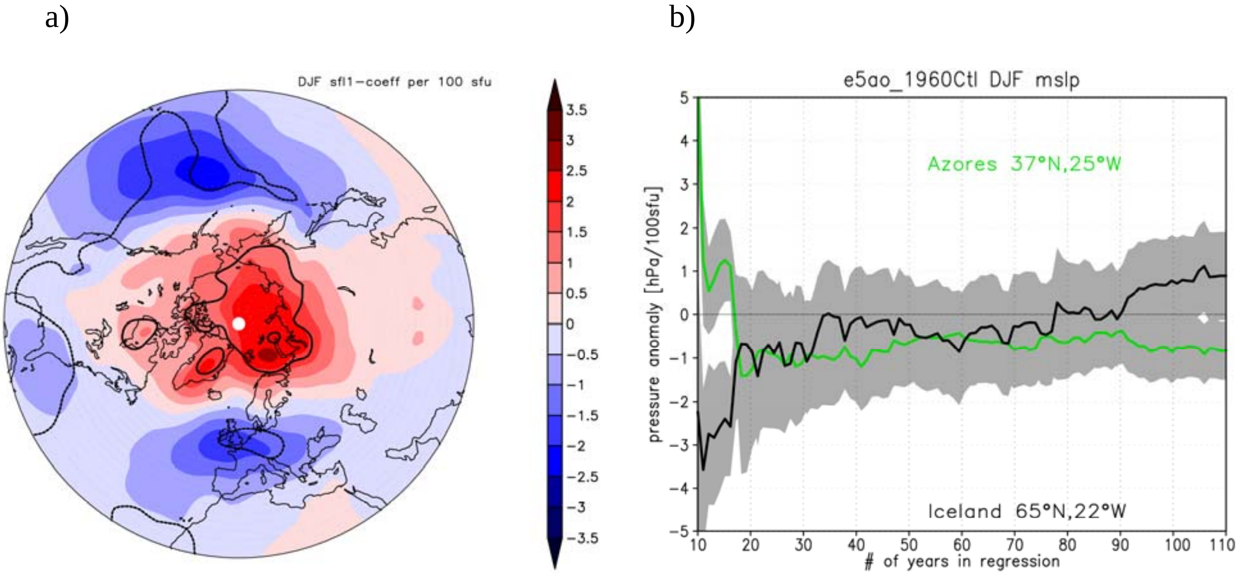

Figure 4: Solar signal in DJF mean sea-level pressure in hPa per 100 units F10.7 cm solar radio flux. Thick black contours in a) enclose regions with statistically significant anomalies at the 95% level. b) Pressure response near Iceland and the Azores as a function of the number of years in the input time series.

It turns out that with only a low number of years available (less than 20) a positive NAO response is obtained. With increasing time series length, however, the signal changes sign and converges to a negative NAO phase, cf. Figure 4b. The change of sign happens early and rather abruptly near the Azores and later and more gradually near Iceland.

The response of the modelled sea surface temperatures (SSTs) in the equatorial Pacific to the 11-year solar forcing has a non-uniform character. It neither resembles an El-Nino nor a La-Nina signal as has been discussed in literature (e.g. Van Loon and Meehl, 2008; Meehl et al. 2009; Roy and Haigh, 2010; Tung and Zhou, 2010). Also, there is no basinwide warming in the EMAC-O control simulation as was described by Misios and Schmidt (2012) from another model of the ECHAM-MPIOM family. In the north Pacific the 11-year solar signal is comparable in shape to the signal derived from a long observational data set (Hood et al., 2013) but it is considerably stronger.

Major stratospheric warmings in the control simulation

Major stratospheric warmings (MSWs) are the most abrupt events of boreal wintertime polar stratospheric variability, whose influence may extend down to the troposphere. They are identified by applying the standard criterion for MSWs, i.e., the simultaneous reversal of the zonal mean zonal wind at 60°N and 10 hPa and the meridional temperature gradient between 60ºN and the pole at the same level. The comparison of the MSW statistics between the control simulation and the first 40 winters of the transient RCP6.0 scenario simulation yields an overall number of 7.8 events per decade in the control run and 9.3 events per decade in RCP6.0. Thus, the EMAC-O model shows a higher variability in the northern winter stratosphere than the NCEP/NCAR reanalysis data with 5.5 events per decade. The monthly distribution of the MSWs is given in Figure 5 for the two EMAC-O simulations. It is seen that the MSW frequency is rather similar in both simulations from January to March, i.e. in mid and late winter. Larger differences are seen in early winter where the control simulation shows nearly equal frequencies in November and December while there is a clear preference for warmings in December in the transient simulation. This unrealistically high number of major warming events in early winter is a known problem of models from the ECHAM family (Charlton et al., 2007) and it seems to persist also in the ocean-coupled version used here.

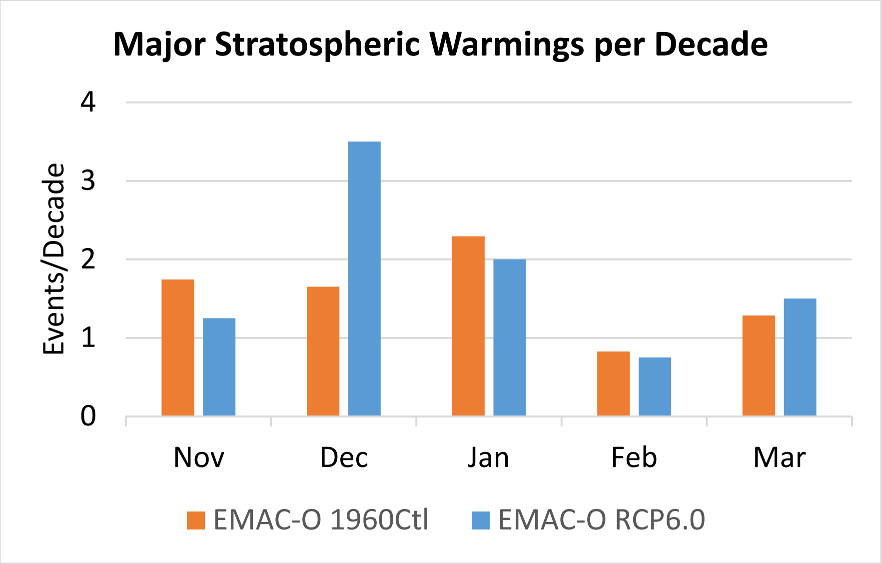

Figure 5: Monthly distribution of Major Stratospheric Warmings in two ocean-coupled simulations given as events per decade. The orange bars depict the control simulation results while the distribution for the first 40 years (i.e. 1960/61 to 1999/2000) of the transient simulation are given in blue.

Sea ice and ocean component

The coupled ocean component MPIOM (Marsland et al., 2003) with integrated sea ice module has replaced the prescribed Sea Surface Temperatures (SSTs) and Sea Ice Concentrations (SICs) at the lower boundary of EMAC. The great benefit of this constellation is the both-way interaction between the ocean and the atmosphere models in simulating surface variables, such as mean sea level pressure and surface winds, and the instantaneous adaptation of the ocean component to the atmospheric forcing.

MPIOM is well capable to simulate the key variables of the ocean circulation, such as strength and position of the Atlantic Meridional Overturning Circulation (AMOC), which varies between 10 and 20 Sv during the 1980-2015 period (Figure 6 a)), being well in consensus with the observations (black bars in Figure 6 b)).

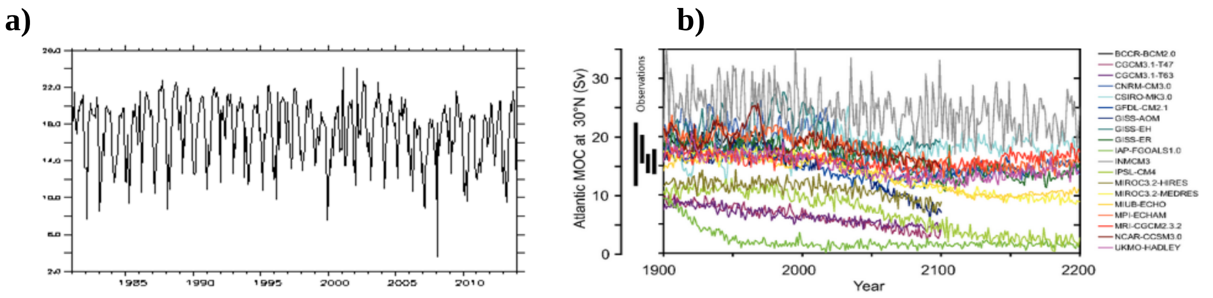

Figure 6: a) AMOC in Sv at 30°N over the period 1980-2015 in EMAC-MPIOM, b) AMOC in observations (black bars on the left) and CMIP5 models over the period 1900-2200, IPCC 2007.

The simulation of the sea ice in coupled atmosphere ocean models is more complicated. In terms of extent and seasonal cycle it is well reproduced in both the Arctic and the Antarctic regions in EMAC-MPIOM. Compared to the observations (e.g. Turner et al., 2009) the sea ice retreat in the Arctic region is similar throughout the year (1,8% in EMAC-MPIOM vs. 2% observed), but underrepresented in size during the maximal retreat in september/october (3% in EMAC-MPIOM vs. 10% observed), although in good seasonal agreement.

In the Antarctic the model simulates a general retreat of the sea ice area, with exception of the december trend. This is common to the main part of the CMIP5 models. A possible explanation is the underrepresentation of the Antarctic ozone hole in the CMIP5 models, as well as a smaller ozone hole in EMAC compared to the NIWA observations (see Figure 4 for comparison). The small effect of the ozone hole on the Antarctic surface climate is the december trend, since it is most pronounced during the Antarctic summer.

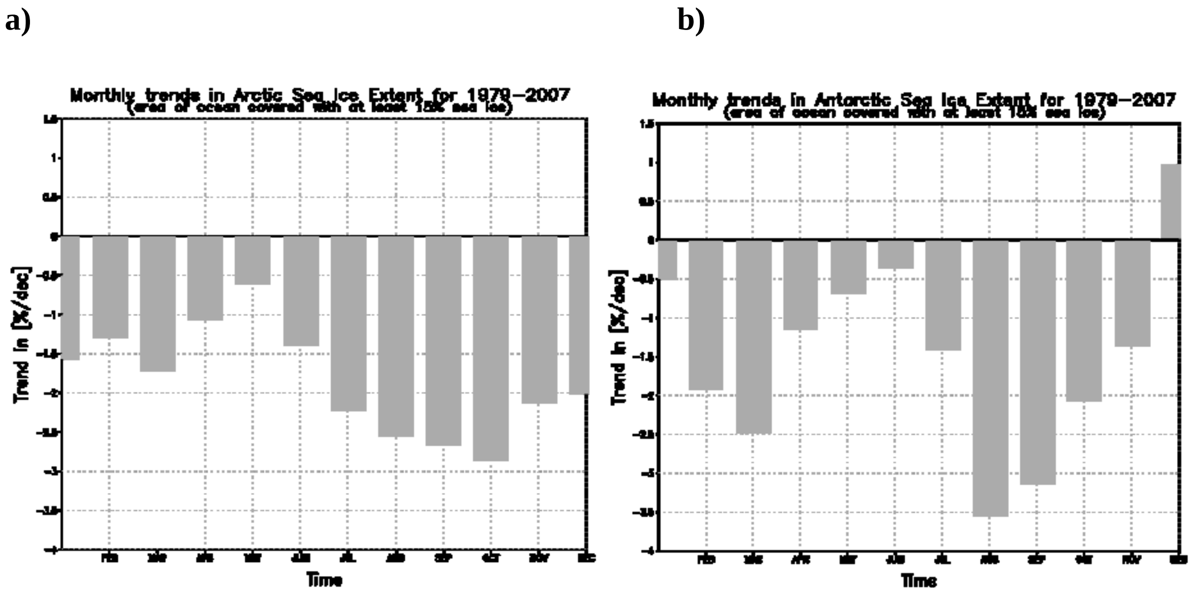

Figure 7: Decadal monthly trends in sea ice extent in % over the period 1979-2007 in EMAC-MPIOM: a) Arctic region b) Antarctic region.

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List of publications/reports from the project with complete references

Several publications including results of the new coupled EMAC-O simulations are in progress.

Summary of plans for the continuation of the project

(10 lines max)

Currently, a transient simulation of the period 1960 to 2100 with interactively coupled ocean (EMAC-O) is running which follows the recommendations for a CCMI SEN-C2-fGHG simulation. In this set-up greenhouse gas concentrations are fixed at 1960 level but ozone depleting substances (ODS), natural forcings such as volcanic eruptions and solar irradiance variability are prescribed transiently. The sea surface temperatures are not fixed at 1960 values, but are allowed to respond interactively to the transient forcings. Thus, the ocean and the sea ice can respond e.g. to the effects of rising and decaying ODS levels.

We apply for high performance computing resources in 2016 to conduct another simulation with the ocean-coupled chemistry-climate model EMAC-O out of the list of sensitivity simulations recommended by CCMI.