REQUEST FOR A SPECIAL PROJECT 2016–2018

MEMBER STATE: Germany

Principal Investigator: Prof. Dr. Ulrike Langematz

Affiliation: Freie Universität Berlin

Address:

Institut für Meteorologie
Carl-Heinrich-Becker-Weg 6-10
12165 Berlin
Germany

E-mail: ulrike.langematz@met.fu-berlin.de

Other researchers:

Markus Kunze

Project Title:

Ocean-Atmosphere Chemistry Climate Model Simulations for new WMO-SPARC-Chemistry Climate Model Initiative (CCMI)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** DEWMO3	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2015	
Would you accept support for 1 year only, if necessary?	YES X	NO

Computer resources required for 2016-2018: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2018.)	**2016**	**2017**	**2018**
High Performance Computing Facility (units)	6.500.000	6.500.00	
Data storage capacity (total archive volume) (gigabytes)	12.000	12.000	

*An electronic copy of this form **must be sent** via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date):

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Extended abstract

Within this project Atmosphere-Ocean-Chemistry-Climate Model (AOCCM) simulations with the MA-ECHAM/MESSy/MPIOM (EMAC-O) will be conducted as contribution to the ongoing phase of the SPARC-CCMI initiative of WMO as well as to the research project "Quantification of Uncertainties of Solar Induced Climate Variability" (SOLIC) which is part of the German research programme "Role of the Middle Atmosphere in Climate" (ROMIC) funded by the German Federal Ministry of Education and Research.

The main focus will lie on the assessment of the interaction between climate change due to increasing greenhouse gas (GHG) concentrations and stratospheric chemistry. At present ozone recovery at polar latitudes is expected to take place until mid-century (WMO, 2011; WMO 2015), so that column ozone reaches 1980 values in southern polar latitudes. This development is determined on the one hand by a decrease in ozone depleting substances (ODSs) and on the other hand by a decrease in stratospheric temperatures due to GHG concentrations in the atmosphere, which affects polar stratospheric cloud formation and heterogeneous ozone destruction. However, there are indications that the recovery of total ozone in the tropics is strongly dependent on the GHG scenario (Eyring et al., 2013b; Meul et al., 2016). While stratospheric ozone columns are not projected to recover to 1980 values, the tropospheric column can compensate this to a certain extent depending on the RCP scenario. Interestingly, the RCP6.0 scenario yields the lowest total ozone columns in the tropics by the end of the century compared to RCP4.5 and RCP8.5 which is due to the strong stratospheric ozone decrease and a limited compensation from the tropospheric column.

So far most CCMs were not coupled to an ocean model. Therefore, it was necessary to prescribe sea surface temperatures and sea-ice conditions at the lower boundary. This was a limitation as it rendered the reaction of the ocean to any atmospheric changes impossible. It has been shown that,e.g., anomalies in the Southern Annular Mode have an impact on the southern circumpolar ocean circulation (Gupta and England, 2006) and on the extent of sea ice (Lefebvre and Goosse, 2008) with feedback on atmospheric climate variables. Sea ice loss at high northern latitudes is assumed to affect the atmospheric circulation and weather patterns through changes in the energy exchange between the ocean and the atmosphere (e.g., Francis et al, 2009).

For studies of the interaction between chemistry and climate it is of great importance to take into account interactions between radiation, dynamics and chemical composition of the atmosphere as well as interactions between the atmosphere and the oceans. Ozone is a major constituent in radiative processes and is also affected by dynamics and transport. Only CCMs can simulate the feedback of chemical processes on dynamics and transport of trace gases. The use of an ocean-coupled CCM opens the possibility for the full range of interactions between a high-top atmosphere and a deep-ocean model to occur.

<u>Model and experimental setup</u>

We intend to use the MA-ECHAM/MESSy/MPIOM (EMAC-O) AOCCM (Roeckner et al., 2003;

Jöckel et al., 2005; Jöckel et al., 2006, Jungclaus et al., 2006). Depending on the particular object of research EMAC-O allows for tailor-made configurations by switching on and off respective sub-models for e.g. atmospheric chemistry, radiation, microphysical processes amongst others. Within this project a model version including a spectrally resolved radiation routine (Nissen et al., 2007, Kunze et al. 2014), the atmospheric chemistry module MECCA1 (Sander et al., 2005) and the inter-active deep-ocean model MPIOM (Jungclaus et al., 2006) will be employed. The coupling of EMAC to the MPIOM ocean model has been performed at FUB. The EMAC-O model has been implemented on the Cray high performance computer system at ECMWF, and is currently used for production.

The experimental setup of the simulation will follow the recommendations by the SPARC Chemistry Climate Model Initiative (CCMI) group for CCM simulations (Eyring et al., 2013a). The experiment to be carried out is a CCMI-SEN-C2-RCP8.5 simulation. It is designed as an internally consistent simulation from the past into the future. The objective with this simulation is to deliver a possible estimate of the future evolution of ozone and climate change as a sensitivity study when compared with the existing REF-C2-RCP6.0 simulation. Greenhouse gas concentrations and ozone precursor emissions are prescribed following the RCP8.5 scenario (Meinshausen et al., 2011; Riahi et al., 2011) and ODS abundances are taken from the A1 scenario of WMO 2011. Volcanic eruptions are considered in the past but not in the future. Solar variability is accounted for by prescribing daily total solar irradiance (TSI) and spectrally resolved irradiance (SSI) data which are repeated in the future. The Quasi-Biennial Oscillation of the zonal wind in the lower stratosphere is included by nudging the model towards observed winds in the past which is continued in the future. In contrast to previous studies with the atmosphere-only CCM the sea surface temperatures and sea-ice will be modelled interactively in the AOCCM which allows for atmosphere ocean interactions in response to the applied natural and anthropogenic forcings.

We will use the model in T42L39 resolution with a model top at 0.01 hPa. The ocean model is run in GR15L40 resolution. The simulation will span the period from 1960 to 2100 with ten years spin-up prior to 1960.

The results will be analysed to quantify the response of the ocean-atmosphere system to the 11- year solar forcing and its two possible mechanisms, i.e. the transfer from the upper to the lower stratosphere and to the troposphere (“top-down”, Kodera and Kuroda, 2002) and/or the direct total solar irradiance changes at the surface (“bottom-up”, Meehl et al., 2009) as well as interactions of the solar forcing with the QBO. These analyses are part of a comparison with similar simulations where only SSI forcing (“bottom-up” effect suppressed) or TSI forcing (“top-down” mechanism suppressed) are used. From this comparison recommendations will ultimately be derived for upcoming IPCC simulations. Aspects of stratosphere-troposphere coupling, i.e. the effects of stratospheric perturbations on the troposphere including the surface climate, will also be the object of research.

The analysis will be done within the approved projects “ROMIC-SOLIC - Quantification of Uncertainties of Solar Induced Climate Variability” and “MiKlip-STRATO – The role of the stratosphere for decadal climate prediction”. Several institutions will jointly evaluate the model data for ROMIC-SOLIC and MiKlip-STRATO.

Ulrike Langematz, Univ.-Prof. Dr., is Professor at the Institut für Meteorologie of Freie Universität Berlin and head of the working group 'Atmospheric Dynamics'. Her scientific interests are in the fields of radiation, dynamics, and chemistry of the middle atmosphere with focus on stratospheric ozone, the interaction between stratospheric chemistry and climate change, and solar variability. She was/is PI in different national and European projects on climate change modelling (HGF-ENVISAT, EuroSPICE, SCOUT-O3, MiKlip), solar cycle modeling (BMBF-MESA, SOLICE and CAWSES ProSECCO, ROMIC-SOLIC) and planetary modeling (HGF-Allianz 'Planetary Evolution'). She is coordinating the DFG Research Unit SHARP. Ulrike Langematz is involved in the international climate modeling activity CCMI. She has been lead and co-author of several international assessments (e.g. the WMO Scientific Assessment of Ozone Depletion: 2006, 2010 and 2014).

References

Eyring, V., J.-F. Lamarque, P. Hess, F. Arfeuille, K. Bowman, M. P. Chipperfield, B. Duncan, A. Fiore, A. Gettelman, M. A. Giorgetta, C. Granier, M. Hegglin, D. Kinnison, M. Kunze, U. Langematz, B. Luo, R. Martin, K. Matthes, P. A. Newman, T. Peter, A. Robock, T. Ryerson, A. Saiz-Lopez, R. Salawitch, M. Schultz, T. G. Shepherd, D. Shindell, J. Staehelin, S. Tegtmeier, L. Thomason, S. Tilmes, J.-P. Vernier, D. W. Waugh, P. J. Young , 2013a: Overview of IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) Community Simulations in Support of Upcoming Ozone and Climate Assessments, *SPARC Newsletter* No. 40, p.48-66.

Eyring, V., J. M. Arblaster, I. Cionni, J. Sedlácek, J. Perlwitz, P. J. Young, S. Bekki, D. Bergmann, P. Cameron-Smith, W. J. Collins, G. Faluvegi, K.-D. Gottschaldt, L. W. Horowitz, D. E. Kinnison, J.-F. Lamarque, D. R. Marsh, D. Saint-Martin, D. T. Shindell, K. Sudo, S. Szopa, and S. Watanabe, 2013b: Long-term ozone changes and associated climate impacts in CMIP5 simulations, *J. Geophys. Res.*, 118, 5029–5060.

Francis, J. A., W. Chan, D. J. Leathers, J. R. Miller and D. E. Veron, 2009: Winter Northern Hemisphere weather patterns remember summer Arctic sea-ice extent, *Geophys. Res. Lett*., Vol. 36, L07503, doi: 10.1029/2009GL037274.

Gupta, A.S., and M.H. England, 2006: Coupled Ocean-Atmosphere-Ice Response to Variations in the Southern Annular Mode, *J. Clim.*, 19, 4457-4486.

Jöckel, P., R. Sander, A. Kerkweg, H. Tost, and J. Lelieveld, 2005: Technical Note: The Modular Earth Submodel System (MESSy) - a new approach towards Earth System Modeling, *Atmos. Chem. Phys.*, 5, 433-444, SRef-ID: 1680-7324/acp/2005-5-433.

Jöckel, P., H. Tost, A. Pozzer, C. Brühl, J. Buchholz, L. Ganzeveld, P. Hoor, A. Kerkweg, M. G. Lawrence, R. Sander, B. Steil, G. Stiller, M. Tanarhte, D. Taraborrelli, J. van Aardenne, J. Lelieveld, 2006: The atmospheric chemistry general circulation model ECHAM5/MESSy1: consistent simulation of ozone from the surface to the mesosphere, *Atmos. Chem. Phys*., 6, 5067- 5104.

Jungclaus, J., N. Keenlyside, M. Botzet, H. Haak, J.-J. Luo, M. Latif, J. Marotzke, U. Mikolajewicz, E. Roeckner, 2006: Ocean circulation and tropical variability in the coupled model ECHAM5/MPI-OM, *J. Clim*., 19, 3952-3972.

Kodera, K. and Y. Kuroda, 2002: Dynamical response to the solar cycle, *J. Geophys. Res*. 107, D24, 5-1-5-12.

Kunze, M., M. Godolt, U. Langematz, J.L. Grenfell, A. Hamann-Reinus, and H. Rauer, 2014: Investigating the Early Earth Faint Young Sun Problem with a General Circulation Model, *Planet. Space Sci.*, 98, 77-92.

Lefebvre, W. and H. Goosse, 2008: Analysis of the projected regional sea-ice changes in the Southern Ocean during the twenty-first century, *Clim. Dyn*., 30, Number 1, 59-76.

Meehl, G.A., J.M. Arblaster, K. Matthes, F. Sassi, and H. van Loon, 2009: Amplifying the Pacific climate system response to a small 11-year solar cycle forcing, *Science*, 325. 5944, 1114–1118, doi:10.1126/science.1172872.

Meul, S., M. Dameris, U. Langematz, J. Abalichin, A. Kerschbaumer, A. Kubin, and S. Oberländer-Hayn, 2016: Impact of rising greenhouse gas concentrations on future tropical ozone and UV exposure, *Geophys. Res. Lett*., doi:10.1002/2016GL067997.

Nissen, K.M., K. Matthes, U. Langematz and B. Mayer, 2007: Towards a better representation of the solar cycle in general circulation models, *Atmos. Chem. Phys*., Vol.7, pp. 5391-5400, SRef-ID: 1680-7324/acp/2007-7-5391

Roeckner E., et al., 2003: The atmospheric general circulation model ECHAM 5. PART I: Model description, *MPI-Report 349*

Sander R., A. Kerkweg, P. Jöckel and J. Lelieveld, 2005: Technical Note: The new comprehensive atmospheric chemistry module MECCA, *Atmos. Chem. Phys*., 5, 445-450.

WMO (World Meteorological Organization), 2007: Scientific Assessment of Ozone Depletion: 2006, Global Ozone Research and Monitoring Project – Report No. 50, Geneva, Switzerland.

WMO (World Meteorological Organization), 2011: Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project – Report No. 52, Geneva, Switzerland.

WMO (World Meteorological Organization), 2015: Scientific Assessment of Ozone Depletion: 2014, Global Ozone Research and Monitoring Project – Report No. 55, Geneva, Switzerland.

Request for increased computing resources:

In the request form from 2015 an amount of 4.000.000 SBUs for each year from 2015 to 2017 was inquired. This amount was based on the mean usage of SBUs per simulation month with EMAC-MPIOM model optimized for the AIX system.

Since the switch to the CRAY XC30 operating system the compilation of the model could be achieved with a different level of optimization resulting in enhanced run times:

- One simulation cycle (one month) is done in ~ 1h 20 min - 1h 25 min (real time), with noticeable variations of the run times.
- It needs on average 10-15 min more compared to the simulation cycle on the previous operating system (~1h 10 min).
- The average consumption is around 3400 SBUs per simulated month.

For the simulation of ~150 years a total amount of 6.300.000 SBUs is needed; an additional bulk amount of 200.000 SBUs for the case of reruns with slightly altered parameters after model crashes (due to extreme winds) is expected.