Project: **764**

Project Title: MiKlip-II Module B: Processes and Modelling

Report period: **1.1.2016 - 31.12.2016**

Project overview

The overall aims of Module B are to gain a better understanding of the mechanisms of decadal variability and to improve the MiKlip prediction system by the incorporation of processes relevant for decadal climate prediction and by bias reduction including improved initialization in the tropics. MiKlip Module B consists of the sub-projects "Alert for LARge volcanic eruptions in Medium-term climate prediction (ALARM-II)", "Correcting the North Atlantic cold bias and improving tropical initializations in the MiKlip forecasting system (ATMOS-MODINI)", "Modes of Ocean Variability and their Implication for European continent CLImate Predictions (MOVIECLIP)", and "PRedictability of the Oceanic Carbon UPtake (PROCUP)", as well as two other projects that do not request DKRZ resources.

ALARM-II

Project Lead: Claudia Timmreck, Hauke Schmidt (MPI-M), Kirstin Krüger (University of Oslo)

The central goal of the MiKlip ALARM project is to study the response of the climate system to volcanic aerosol perturbations and the effects of past historic volcanic eruptions. For 2016, CMIP6 (Coupled Model Intercomparison Project, Phase 6, Eyring et al., 2016) related work was anticipated but could not be carried out as the piControl run was not finished. Instead we have concentrated on some preparatory work for CMIP6 (1.1) and on the analysis of an historic 100 member ensemble of the MPI-ESM (1.2).

<u>1. 1 VolMIP (Model Intercomparison Project on the climatic response to Volcanic forcing)</u>

An assessment of the climate impact of large volcanic eruptions cannot be achieved without a deep understanding of post volcanic climate variability. This task can only be addressed in a multi-model framework as will be done in the CMIP6 Model Intercomparison Project on the climate response to Volcanic forcing (VolMIP). VolMIP is coordinated by Claudia Timmreck (ALARM-II) together with Davide Zanchettin (U. Venice) and Myriam Khodri (IPSL) (Zanchettin, et al. 2016). In VolMIP different time scales are considered: the seasonal-to-interannual atmospheric response to a 1991 Pinatubo-like volcanic eruption and the long-term (up to the decadal time scale) climate response to very strong volcanic eruptions, like the 1815 Tambora eruption.

Different from the original plan in 2015, the VOLMIP MPI-ESM runs could not be carried out in 2016 because the CMIP6 model set up has not been fixed so far and the piControl run is therefore not ready. The latter is now expected for early 2017, which will be the start of the VOLMIP experiments in ALARM-II. In 2016 preparatory work for VolMIP has been performed with global aerosol simulations for the Tambora eruption of 1815 to obtain an idealized volcanic radiative forcing. The global aerosol model results show however considerable differences in aerosol optical depth (Figure AL-1) which are currently further analyzed. These differences emphasize also the importance of a model and data intercomparison for global stratospheric aerosol models which is under way (Timmreck et al., to be submitted 2016). For CMIP6 a simple approach based on analytical functions is proposed for Tambora and an observational based data set for Pinatubo.

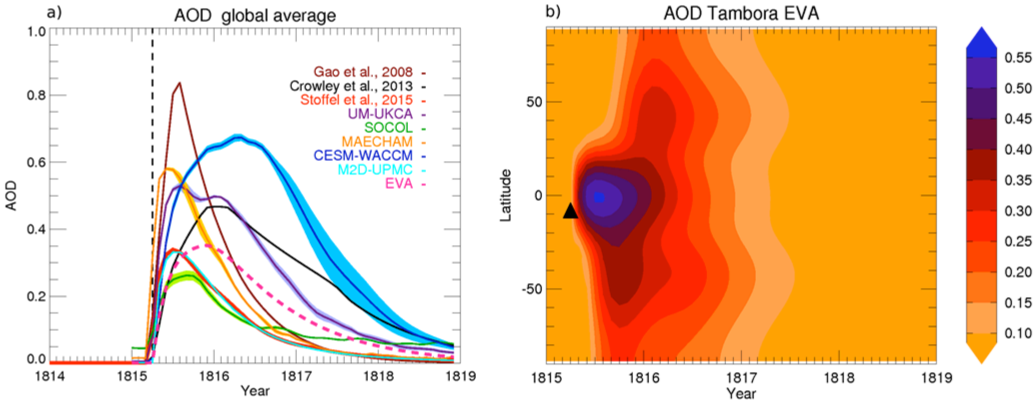

Figure AL-1: Uncertainty in estimates of radiative forcing parameters for the 1815 eruption of Mt. Tambora: global-average aerosol optical depth (AOD) in the visible band from an ensemble of simulations with chemistry–climate models forced with a 60 Tg SO_2 equatorial eruption, from the Easy Volcanic Aerosol (EVA) module (Toohey et al, 2016) with 56.2 Tg SO_2 equatorial eruptions (magenta thick dashed line), from Stoffel et al. (2015), from Crowley and Unterman (2013), and from Gao et al. (2008, aligned so that the eruption starts on April 1815). The estimate for the Pinatubo eruption as used in the CMIP6 historical experiment is also reported for comparison. (b) Time–latitude plot of the AOD in the visible band produced by EVA for a 56.2 Tg SO_2 equatorial eruption, illustrating the consensus forcing for the volc-long-eq experiment. The black triangle shows latitudinal position and timing of the eruption. Chemistry–climate models are CESM (WACCM) (Mills et al., 2016), MAECHAM5-HAM (Niemeier et al., 2009), SOCOL (Sheng et al., 2015), UM-UKCA (Dhomse et al., 2014), and CAMB-UPMCM2D(Bekki, 1995; Bekki et al., 1996). For models producing an ensemble of simulations, the line and shading are the ensemble mean and ensemble standard deviation respectively. Figure from Zanchettin et al. (2016).

Furthermore test runs have been performed with the MPI-ESM to test both the easy volcanic aerosol (EVA, Toohey et al., 2016) forcing for the 1809 and Tambora eruption and the new historical volcanic forcing (Thomason et al., in prep) .

1. 2 Analysis of the historic 100 member ensemble

The observed strengthening of the Northern Hemisphere (NH) polar vortex in the aftermath of large tropical volcanic eruptions appears to be underestimated by coupled climate models (Driscoll et al, 2012, Charlton-Perez et al., 2013). However, there are only a limited number of observed eruptions, which makes the attribution of volcanic signals difficult, because the polar vortex is also influenced by other external forcing factors as well as internal variability. We have analyzed a 100-member ensemble of historical (1850–2005) simulations with the Max Planck Institute Earth System Model and concentrated at first on the stratospheric temperature and wind response in the 1st post volcanic Northern hemisphere winter (Bittner et al., 2016). The focus has been placed on zonal wind changes particularly with regard to a NH polar vortex strengthening. It is shown that state of- the-art climate models are capable to simulate such a strengthening, but this evidence depends crucially on the number of ensemble members involved. Our results show that an ensemble larger than what is provided by the CMIP5 models is needed to detect a statistically significant NH polar vortex strengthening. The most robust signal can be found when only the two strongest eruptions over the historical period (Krakatau (1883) and Pinatubo (1991)) are considered in contrast to including smaller eruptions to increase the sample size. For these two strongest eruptions, the mean of 15 CMIP5 models shows a statistically significant strengthening of the NH polar vortex as well (Figure AL-2).

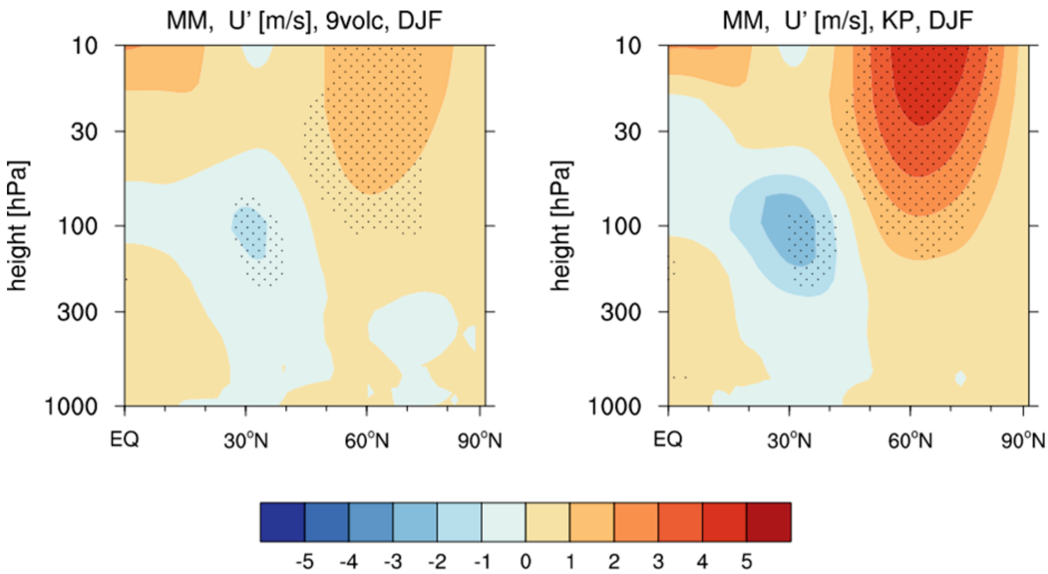

Figure AL-2: Multi-model mean of the zonal mean zonal wind anomaly in the first winter after the nine strongest tropical eruptions since 1880 (left) and after the two strongest eruptions since 1880 – Krakatau and Pinatubo (right). Stippling indicates where at least 14 of 15 models agree on the sign of the anomaly. Figure from Bittner et al. (2016).

ATMOS-MODINI

Project lead: Richard Greatbatch (GEOMAR), Johann Jungclaus (MPI-M), Rüdiger Gerdes (AWI)

ATMOS/MODINI will provide contributions to (i) reduce the North Atlantic cold bias in the MiKlip prediction system with a view to improving the performance of MiKlip forecasts in the Euro-Atlantic sector and (ii) to improve the initialization of the MiKlip prediction system in the tropics.

In the MPI-ESM, there is a large cold bias in North Atlantic sea surface (and subsurface down to 1000m) temperature, that we are attempting to correct using the flow field correction (FFC) method described in Drews et al. 2015.

Due to the parental leave of Gereon Gollan, the post-doctoral fellow working on Atmos-Modini, work on the FFC did not start at GEOMAR until the end of July 2016. In the meantime, Norman Steinert implemented the FFC module in the MPI-ESM at MPI-M as part of a Master Thesis. Although the mechanism could be brought to work successfully, not all problems could be solved owing to time limitation for the thesis work. G. Gollan started then with running the MPI-ESM on Mistral, results obtained by a Masters Student, Norman Steinert, at MPI Hamburg have been reproduced - parallel to a thorough analysis of the implementation of the FFC in the MPIOM model code - in order to understand why the results obtained by Norman Steinert differ somewhat from those obtained with the Kiel Climate Model (KCM) by Drews et al. (2015).

While minor improvements could be made in the implementation of FFC in the model code, no coding error has so far been found.

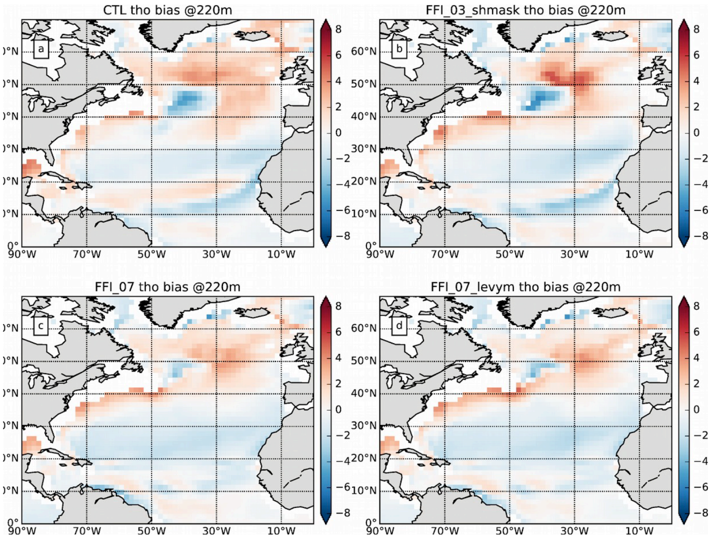

Figure A-M-1: Potential temperature bias (K) at 220m depth of MPI-ESM LR runs without (a, CTL) and with (b-d, FFI) interactive correction referenced to the Levitus (1998) climatology. Shown are ten year means, after 40 years of simulation for CTL and after 60 years for the FFI experiments.

A total of 887 model years in the LR resolution have been run and below there are some example plots, showing the potential temperature bias at 220m depth as referenced to the Levitus (1998) climatology.

Panel a shows the Control (CTL) run without flow field correction, indicating a cold bias in the Northwest Corner (NWC) region of about -5K that extends towards the surface (not shown) and also to deeper depths (not shown) and over large parts of the North Atlantic. Panels b-d show the same but from runs using an interactive flow field correction (applied in the hydrostatic equation) in the North Atlantic basin towards a target density from a restoring run. The correction has been applied from the surface down to different depths (b: 310m, FFI_03_shmask, c: 740m, FFI_07) and using a seasonally varying correction term (b: FFI_03_shmask, c: FFI_07) as well as a constant correction throughout the year (d: FFI_07_levym). Another difference between FFI_07 and FFI_03_shmask is the horizontal transition from uncorrected to corrected that is linear in FFI_07 and quadratic in FFI_03_shmask. In none of these experiments is the NWC cold bias really alleviated, but all of them even show an enhanced warm bias on the southern side of the Gulf Stream and, more problematic, a warm bias downstream in the North Atlantic Current region. A small reduction of the NWC cold bias can be seen in FFI_07 (c) and FFI_07_levym (d). The improvement between the experiments shown in panels b and c, however stems, from the greater extend in depth in FFI_07 compared to FFI_03_shmask. FFI_03 (not shown here), also using a correction mask down to 740m (as FFI_07), yields a similar temperature bias as FFI_07, meaning that the difference in transition zone between FFI_07 and FFI_03_shmask does not influence the results. Research is ongoing on this topic.

In preparing the MPI-ESM to produce assimilation runs with the MODINI-technique, we produced a historical run from 1850-2005, i.e. 156 years. The historical run provides the model wind stress climatology for MODINI: Observed wind stress anomalies are added to the wind stress climatology from the historical run to yield the MODINI wind stress forcing. Additionally, the historical run provides initial conditions for MODINI assimilation runs. Although historical runs exist, a new model version of the MPI-ESM has been issued recently (version 1.2.00p1). Changes in the model made it necessary to repeat a historical run for our purposes to make sure that our reference is consistent with our subsequent MODINI experiments.

PROCUP

Project lead: Tatiana Ilyina (MPI-M)

A main goal of the MiKlip PROCUP project is to evaluate and to improve the representation of the ocean biogeochemical processes in the MiKlip decadal prediction system. In the current MiKlip assimilation system, we nudge the modeled ocean temperature and salinity towards the ORAS4 reanalysis data. Model drifts are found for many ocean biogeochemical tracers as they adjust to the new ocean physical states, especially in the first 10-15 years of assimilation run. We proposed to run several cycles of spinup like simulation with fixed atmospheric CO_2 concentration for ocean biogeochemical component HAMOCC, to allow the model to slowly adjust to the assimilated ocean physical states, in the hope to eliminate the model drift.

In order to save computing time, we first use the ocean only model with ERA40 atmospheric forcing, and run the model for several cycles of the available ocean ORAS4 data. Although strong nudging is applied to the ocean temperature and salinity fields, the AMOC in the ocean only model simulation is much weaker than in the MPI-ESM-HR simulation. We learned from this simulation that the atmospheric coupling process might play a crucial role in maintaining the strength of AMOC.

To be consistent with assimilation run conducted by Module D, we carried on our spinup like simulations with earth system model MPI-ESM-HR. The nutrient, primary production, and many other variables in the upper ocean levels show large trend along with integration time, especially in the first cycle of the spinup run. This trend can also be seen in the original assimilation run made by Module D. The global ocean shows prominent outgassing, which is opposite to observations (see Fig. P-1d). Further investigation of the spinup like simulation and the assimilation run reveals that the strongest HAMOCC model drift/adjustment is in the equatorial and tropical regions. Comparison of vertical profile of tracers in the beginning and in the end of both spinup like and assimilation run (figure omitted) suggests that more nutrients are brought from the depth to the upper levels as long as the integration with nudging. This process leads to higher concentration of nutrients in the upper ocean and lower concentration of nutrients in the deeper ocean, therefore it forms a new steady state for ocean biogeochemical tracers corresponding to the new ocean physical states.

We have tried several ways to balance the strong upwelling of the nutrient and hence keep the ocean carbon uptake in a reasonable level. In our final spinup like simulations, we reduced silicate and dissolved inorganic carbon globally so that the global ocean carbon sink is closer to historical simulation and observation. The restart state of ocean biogeochemical fields from the spinup run is provided to Module D as initial state of MPI-ESM-HR new assimilation run. Time series of some variables simulated in the new assimilation run as well as in the original assimilation run are shown in Fig. P1. In the new assimilation run, the evolution of all the ocean biogeochemical parameters is more stabilized; and the oceanic carbon uptake is in the right sign, i.e., the ocean is taking up carbon from the atmosphere.

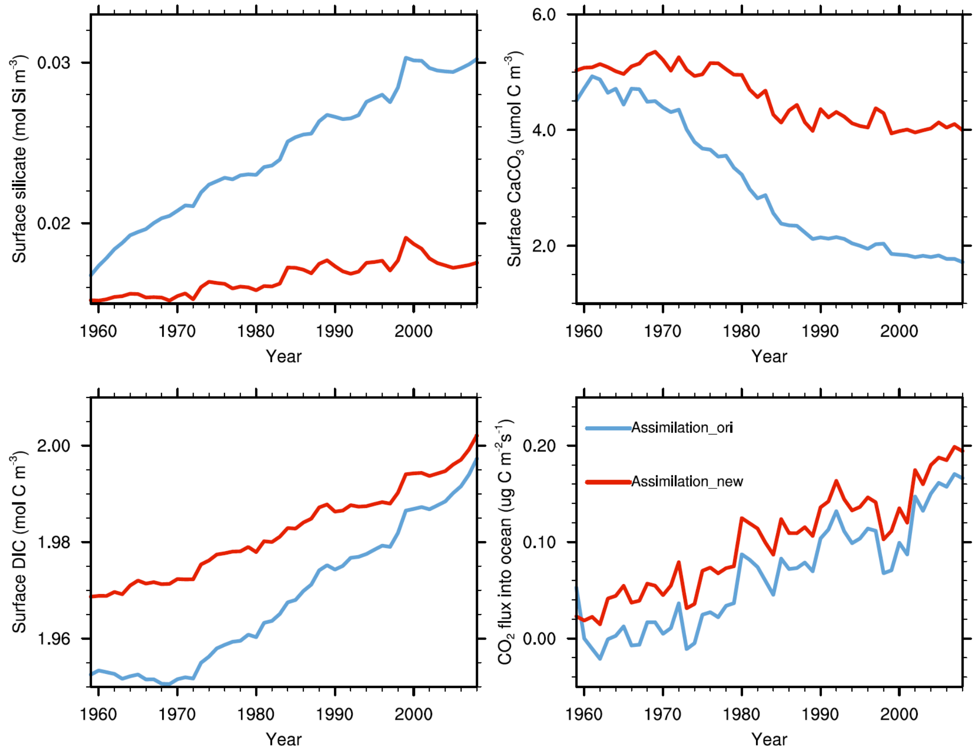

Figure P-1 Global mean surface silicate concentration (a), $CaCO_3$ concentration (b), dissolved inorganic carbon (c), CO_2 flux into the ocean (d) simulated in the original assimilation (blue) and new assimilation (red) run.

MOVIECLIP

Project lead: Johann Jungclaus, Jürgen Bader, Daniela Matei, Wolfgang Müller (MPI-M)

MOVIECLIP aims at an assessment and improved representation of key oceanic and atmospheric processes in the MiKlip prediction system that are important for decadal predictability in the North Atlantic region and Europe. In particular, MOVIECLIP investigates the role of oceanic variability modes, such as the Atlantic Multidecadal Variability (AMV) and Pacific Decadal Variability (PDV). The modeling activities on this topic will contribute to specific components of the CMIP6 Decadal Climate Prediction Project (DCPP) and Global Monsoon Model Intercomparion Project (GMMIP). The second topic of MOVIECLIP is the investigation of ocean-atmosphere interactions in the Atlantic and on teleconnections that transfer signals from the ocean to the land. Here we focus on biases in the Atlantic and how they affect the atmospheric response and how they can be alleviated in the atmospheric component of the MiKlip sysyem.

Owing to delays in the definition of the DCPP protocol and the finalization of the MPI-ESM-1.2 for use in CMIP6, we decided to postpone the originally planned sensitivity experiments with nudging of North Atlantic temperature and salinity conditions to an idealized AMV cycle. Instead, we performed a linear regression analysis on an existing set of MPI-ESM-LR runs which consist of a 2000-year pre-industrial control run, a 100-member historical and a 68-member ensemble with RCP 4.5 radiative forcing with 150 year simulation period each. The benefit of this additional analysis is a better understanding of the factors that influence or are influenced by the AMV in the freely running, un-nudged model system. The pre-industrial control run and the historical ensemble show a qualitatively robust relationship between the AMV and the AMOC with a strong AMOC leading a warm North Atlantic, and a cold North Atlantic leading AMOC maxima. However, quantitatively the strength of the regression varies temporarily for different periods of the control run, as well as between the individual ensemble members of the historical ensemble. A second focus of our analysis was the evaluation of the role of external forcing and changes to it. The historical ensemble shows a distinct imprint of the temporally varying radiative forcing. Furthermore, in the future scenario AMV and AMOC variability are strongly reduced, and therefore internal variability might mask the previously mentioned links in a future climate. The results from this work will allow us to design a more purposive set-up for the idealized experiments that are now planned within 2017.

As part of the MOVIECLIP work-package on sea surface temperature (SST) biases in climate models we performed investigations on the notorious SST biases in the upwelling regions of the tropical Atlantic and in the sub-polar North Atlantic.

A study on SST biases in the tropical Atlantic was carried out as part of a Master Thesis (Sebastian Milinski). These experiments were motivated by the fact that most current coupled general circulation models suffer from large sea surface temperature (SST) biases in the tropical Atlantic region. It has been shown that these biases impair the simulation of variability in the tropical Atlantic region and model simulations with an artificially reduced SST bias indicate the potential for improved predictability (Ding et al.,2016).

In the series of high-resolution coupled experiments we have been able to disentangle the different SST biases and isolate the mechanisms causing the coastal SST bias (Milinski et al., 2016). At high atmospheric resolution, an improved representation of the surface wind stress leads to an improved ocean circulation that eliminates the coastal part of the SST bias. Half of the improvements in the wind-stress are caused by a better representation of the coastal orography at high resolution while the remainder can be attributed by a higher resolution of the atmosphere dynamics (Figure M-1). We used computation time in the first quarter year to run coupled high-resolution sensitivity experiments on Mistral quantifying the contributions of the orography. These simulations ultimately lead to the publication of the results in Geophysical Research Letters in October 2016.

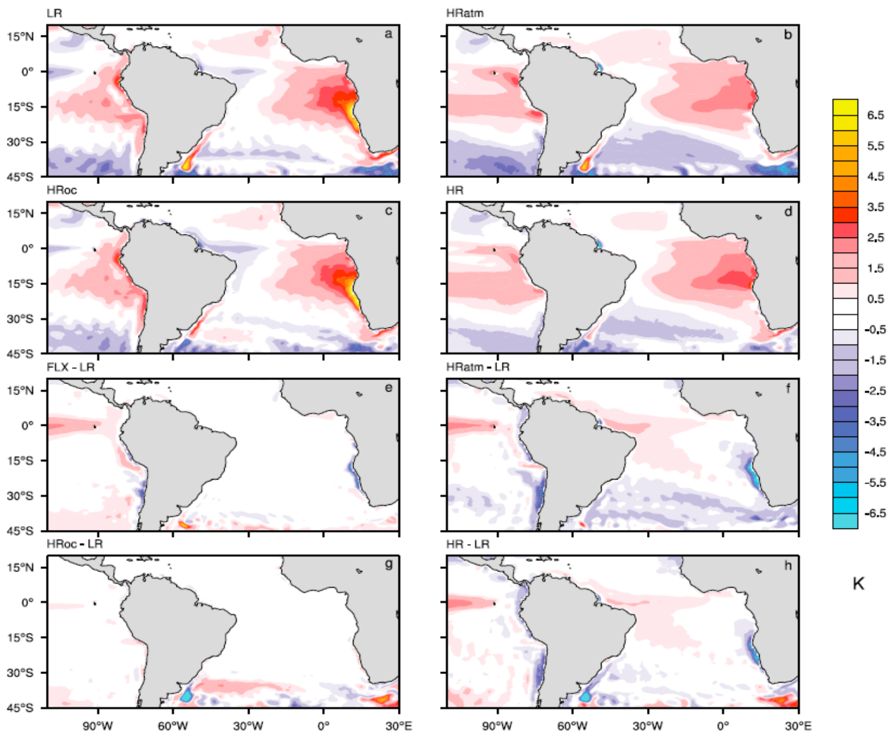

Figure M-1a-d: SST bias at different oceanic and atmospheric resolutions, e: SST differences between LR and an experiment with flux correction on the surface wind-stress and (f,g,h): different high-resolution model setups. At high atmospheric resolution (f,h), the coastal warm biases in the Atlantic and Pacific are reduced, at high ocean resolution (g), there is no significant change in the equatorial or southeastern tropical Atlantic. The flux adjusted experiment (e) shows that the coastal warm biases are reduced due to the improved surface wind-stress at high atmospheric resolution but no other region is significantly affected.

A second study has been initiated to examine extra-tropical North Atlantic SST biases: As many coupled atmosphere-ocean general circulation models, the coupled MPI-Earth System Model

(MPI-ESM) suffers from severe sea-surface temperature (SST) biases in the extra-tropical North Atlantic. We performed a set of SST sensitivity experiments with its atmospheric model component ECHAM6 to understand the impact of extra-tropical Atlantic SST biases on atmospheric circulation, storminess, and precipitation. The model was forced by a climatology of observed global SSTs to focus on simulated seasonal mean state climate and variability. Through the superposition of time-varying extra-tropical Atlantic bias patterns extracted from the MPI-ESM on top of the control field, we investigated the relevance of the seasonal variation of extra-tropical North Atlantic biases for the simulated response. Results show that the SST bias has substantial effects on the precipitation and the atmospheric circulation. To first order the oceanic North Atlantic precipitation anomalies follow the SST anomaly pattern (see Figure M-2). The effect on the precipitation is not limited to the ocean regions. Also significant changes are seen over central Europe. The SST bias leads to a dipole-like change of the zonal wind over the extra-tropical Atlantic Ocean (see Figure M-3).

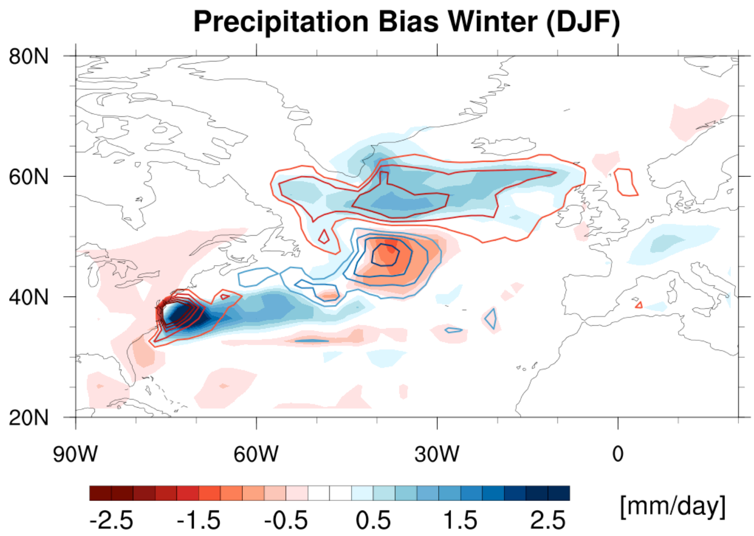

Figure M-2: Winter precipitation response due to the SST bias in the extra-tropical North Atlantic. Shading: Shows the precipitation response between the SST-sensitivity experiment and the control simulation. Only significant changes at the 95% confidence level are shaded according to a two-tailed t-test. Units are mm/day. The contours show the prescribed SST anomaly pattern in Kelvin.

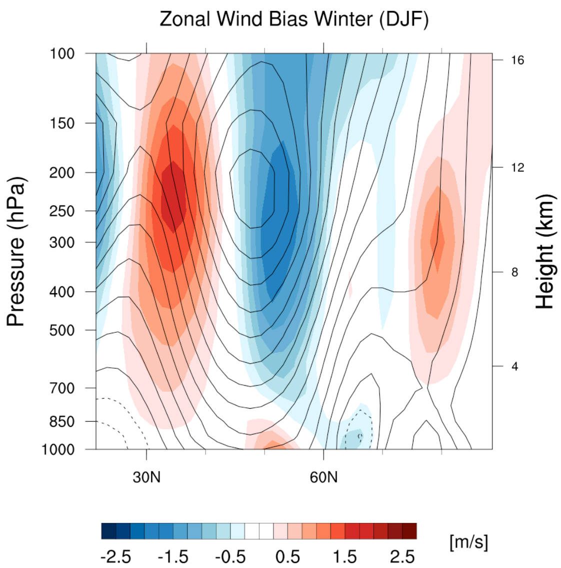

Figure M-3: Shading shows the winter zonal wind response. Only significant changes at the 95% confidence level are shaded according to a two-tailed t-test. Units in m/s. The contours show the zonal wind winter climatology in the control simulation in m/s

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