MiKlip II – report about the use of the computing resources 2018

Project for report: **Project 807 – MiKlip II all modules**

Project lead: **Jochem Marotzke**

Project manager: **Sebastian Hettrich**

Report period: **01.01.2018 – 31.10.2018**

I. MiKlip Overview and allocated computing resources for 2018

The German Federal Ministry for Education and Research has since 2011 funded a comprehensive national program on decadal climate prediction, MiKlip (Marotzke et al. 2016). A second phase, MiKlip II, has been approved until 2019 and started on 1 October 2015, building upon MiKlip to further improve the central decadal climate prediction system and by the end of the project to transfer the system for operational use to the German meteorological service DWD. The successful improvement and thus application of the prediction system depends on ongoing research of new initialisation, ensemble perturbations, and bias correction strategies that must be tested and, if applicable, incorporated into the prediction system. Furthermore, model resolution must be increased, which has been shown to improve the representation particularly of atmospheric processes, the limited representation of which currently reduces the forecast skill over continental areas.

The aim of MiKlip II is thus to further improve the decadal prediction system that was established during the first project phase, with the ultimate aim to provide a system that can be used operationally by the DWD. All five MiKlip modules (respectively represented in the projects below) work towards this aim with different research focusses, thereby making strong use of resources provided by the DKRZ, both through computing time allocated on shared resources and through the MiKlip Server.

Before 2017, the partners of the second phase of MiKlip (MiKlip II) have applied for computing time via the following five projects:

- project bu0801: MiKlip II Module A – Determination of initial conditions and initialisation,
- project bm0764: MiKlip II Module B – Processes and Modelling
- project bb0849: MiKlip II Module C – Regionalisation of Decadal Predictions
- project bm0807: MiKlip II Module D – Synthesis, and
- project bb0763: MiKlip II Module E – Evaluation of the MiKlip Decadal Prediction System.

The allocated times for 2018 including the additional allocations for quartal 3 and 4 are shown in table I. As of now (15th October), on average 72% of the allocated node hours for 2018 have been used for all the 5 different MiKlip modules.

Table I; Allocations for 2018

Project Number	Project Name	Mistral compute time [Node hours]	Lustre work [GiB]	HPSS arch [GB]	HPSS doku [GB]
bu0801	Module A	57,159	117,450	15,660	0
bm0764	Module B	300,373	289,003	578,005	58,670
bb0849	Module C	654,162	244,500	2,021,760	10,240
bm0807	Module D	1,200,341	1,827,000	1,845,720	0
bb0763	Module E	0	10,000	300,000	176,702
Sum ALL MiKlip		**2,212,035**	**2,487,953**	**4,761,145**	**245,612**

II. Table of content

1. Module A – Initialisation

Project **bu0801**

Project title: **MiKlip II Module A: Determination of initial conditions and initialisation**

Project leader: **Johanna Baehr** (CEN, UHH), **Andreas Hense** (Meteorologisches Institut University Bonn), **Detlef Stammer** (CEN, UHH)

Reporting period: **01.01.2018 – 31.10.2018**

Two work packages of MiKlip II Module A used resources within project bu0801 to carry out simulations with MPI-ESM: WP2 “Pastland 2”, and WP3.1 “AODA-PENG Breeding”. Two other work packages, WP1 “Module A Coordination” and WP3.2 “AODA-PENG EnKF”, which have been using resources from bu0801 in the previous years, moved to other DKRZ accounts in the beginning of 2018.

1.1 Module A – WP2 PastLand2

In preparation of the PastLand 2 hindcast ensemble, hydrological observation datasets were analysed for their suitability for land surface assimilation. As the major selection criteria are the area of coverage and the length of the time series, the ESA_CCI soil moisture (ESA_SM, Figure 1.1.1, left) and the GlobSnow Snow water equivalent (GS_SWE, Figure 1.1.1, right) were chosen. Both are available for a period of about 1980 until almost 2015. While GS_SWE only covers the northern hemisphere, ESA_SM has data for the whole land surface. However, the latter suffers strongly from missing data especially during its first decade and lacks information for areas with dense vegetation and snow cover.

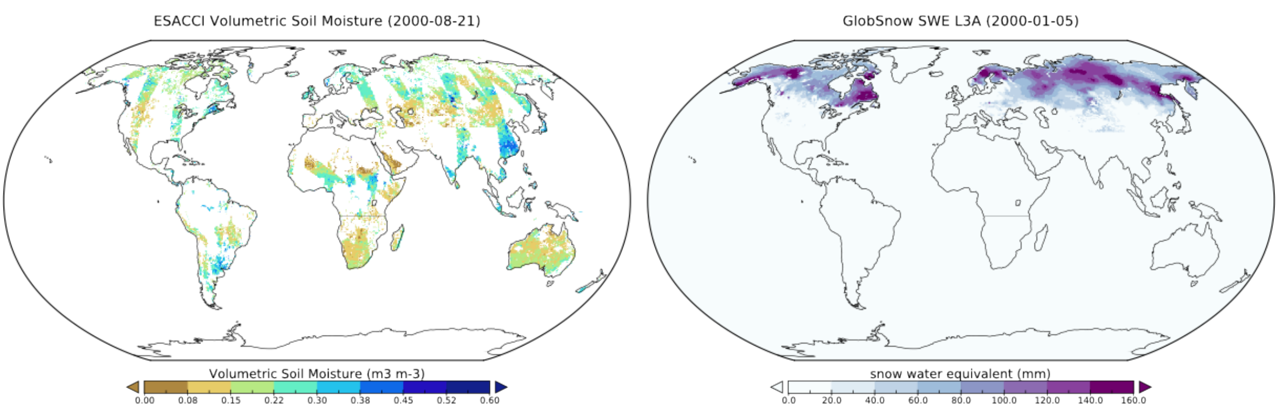

Figure 1.1.1: Snapshots of top layer soil moisture (left) and snow water equivalent (right) data used for assimilation.

These datasets cannot be assimilated directly, but have to be adapted to the simulated statistics of the respective variables in the model via CDF matching. Thus, only the temporal dynamics of the observations are assimilated into the model but no systematic biases. Figure 1.1.2 shows examples of observed, simulated and CDF match data indicating the general suitability of this approach.

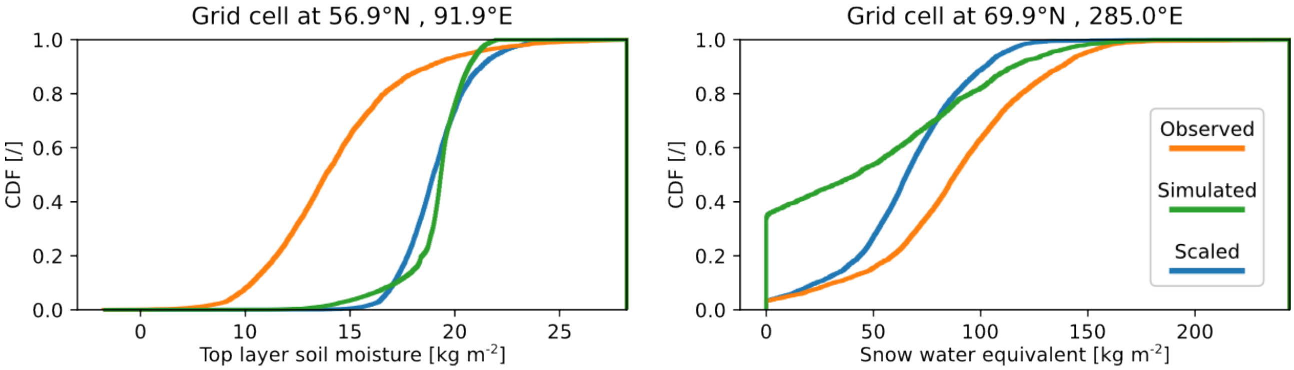

Figure 1.1.2: Cumulative density distribution of observed, simulated and scaled soil moisture (left) and snow cover equivalent (right) data at two example grid cells.

Using restart data from a pre-existing atmosphere-ocean assimilation simulation done by DWD for MiKlip, two assimilation runs were conducted. The first, PreOp+land assimilated the land states additional to the atmosphere and ocean states. The second, land-only, assimilated only land states. Based on these, two 10 member hindcast ensembles were generated, starting every November between 1980 and 2004 with simulation length of 10 years. The members were initialised from the respective assimilation simulation using 1-day lagged restart data.

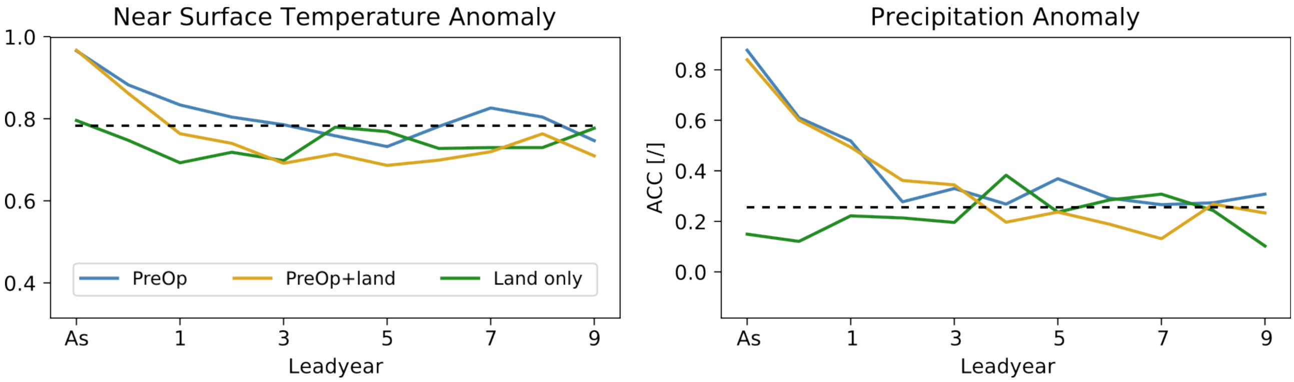

Figure 1.1.3: Anomaly correlation coefficient (ACC) for the assimilation simulation (As) and increasing lead years. The left panel shows the ACC for near surface temperature vs HadCRUT4. The right panel shows the ACC for precipitation vs GPCC. The black dashed line indicates the skill of the historical simulation.

For analysis, the two hindcasts were compared to the DWD PreOp hindcast as well as historical simulations. Figure 1.1.3 displays the predictive skill of the ESM for near surface temperature and precipitation. For global means, the skill of PreOp and PreOp+land is rather similar with the highest skill in the assimilation run and a decrease in skill for increasing lead years. For both variables, the predictive skill falls to the level of the historical simulation after two to three lead years. However, for land-only, the skill never raises above the historical level.

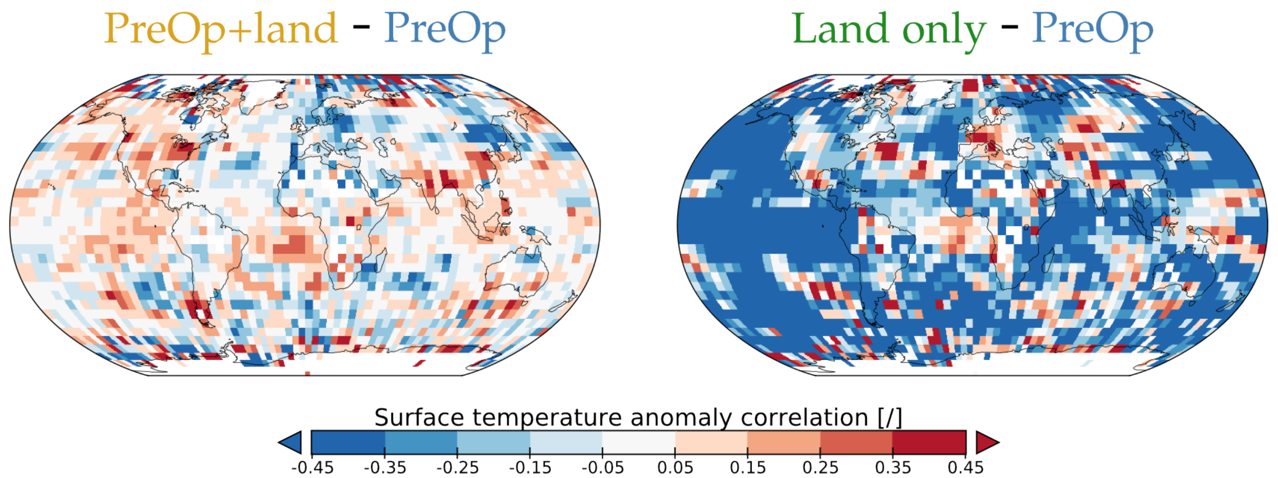

Figure 1.1.4: Predictive skill for the first lead year for near surface temperature. The left panel shows the difference between PreOp+land and PreOp. The right panel shows the difference between land-only and PreOp.

Looking at the spatial distribution of predictive skill for temperature for the first lead year (Figure 1.1.4), small improvements of predictive skill can be seen in the PreOp+land simulation over North America and Southern Asia while the skill decreases slightly over Europe and Eastern Asia. The skill in the land only hindcasts drops predominantly over the ocean, but a few patches of increased skill are visible over Europe and parts of Asia.

1.2 Module A – WP3 Atmospheric and Oceanic Data Assimilation & Ensembles Generation (AODA-PENG2)

WP3.1 (University Bonn): Breeding techniques

The breeding technique for ensemble generation was tested with T63L47/GR15L40 ESM with respect to the iteration steps. Figure 1.2 shows the evolution of the surface temperature with initialised increasing error growth on intermediate states during the iteration procedure for the bred vector construction. This study was important to investigate the strength and the areas of the fastest error growths and thus to justify the relevance of using bred vectors for climate initialisation. The results showed the necessity of using a damping coefficient at the last iteration step in order to keep the pattern values in appropriate magnitude. The additional iterative steps into the iterative procedure were done for two starting years one with strong El Nino and a second with a strong La Nina event (Fig. 1.2). We used 14 000 Node-h and needed about 8 TB to perform this study.

An additional resource consumption up to another 14 000 Node-h was necessary to be used in order to increase the number size of the bred vector hindcast. The BV hindcast was performed previously on 56 years with initialisation done for each year on 9 ensemble members. Performance of another ensemble member for the whole time period was required from the MiKlip Module A coordinator. Increasing the size of the BV ensemble up to 10 members enabled the consistency of the comparison study done in the coordination project. The total disc storage for the 10 member BV hindcast go up to approximately 80 TB.

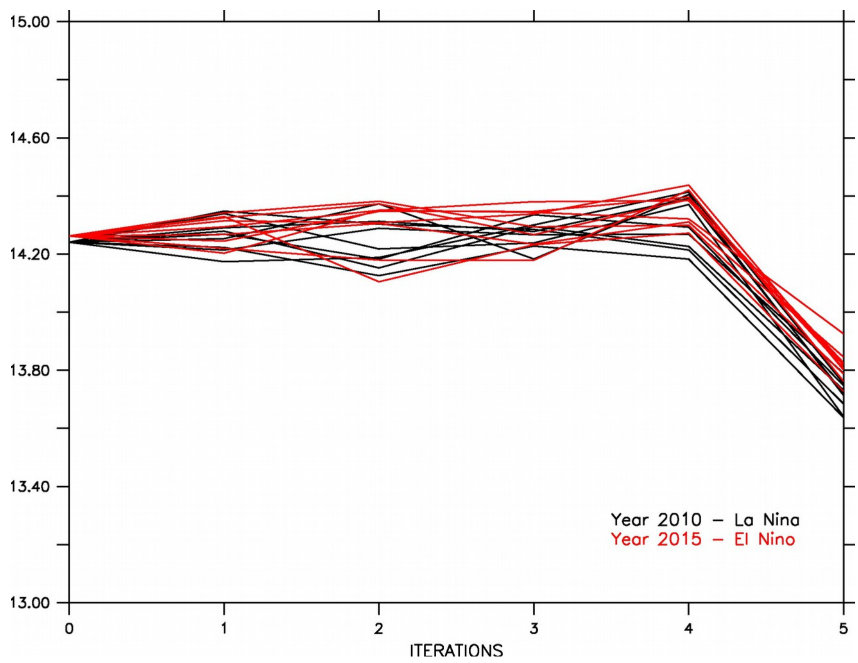

Figure 1.2: Evolution of the global ocean surface temperatures with the iteration steps for the year 2010 with La Nina event and the year 2015 with El Nino event.

1.3 Comparison to 2018 requested

Allocated resources for 2018 have been used according to plan.

2. Module B – Processes and Modelling

Project: **bm0764**

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

Module B coordinator: **Johann Jungclaus**

Sub-projects:

- **MOVIECLIP** (PIs: Johann Jungclaus, Jürgen Bader, Daniela Matei, Wolfgang Müller (MPI-M)),
- **ALARM-II** (Claudia Timmreck, Hauke Schmidt (MPI-M), Kirstin Krüger (Uni Oslo))
- **ATMOS-MODINI** (Richard Greatbatch (GEOMAR), Johann Jungclaus (MPI-M), Rüdiger Gerdes (AWI))
- **PROCUP** (Tatiana Ilyina, MPI-M)

Reporting period: **01.01.2018 – 31.12.2018**

2.1 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 initialisation 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 initialisations 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.

2.2 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 its predictability. 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 Inter-comparison Project on the climate response to Volcanic forcing (VolMIP, Zanchettin et al., 2016) or DCPP(Boer et al., 2016).

For 2018, CMIP6 (Coupled Model Inter-comparison Project, Phase 6, Eyring et al., 2016) related work was anticipated, but could not be carried out as the MPI-ESM CMIP6 model set-up was not finished. Instead we have focused on work related to the volcanic impact on seasonal to decadal prediction. Large volcanic eruptions affect global and regional climate on short-term and long-term time scales and therefore are a potential source of uncertainty in decadal predictions. The impact of volcanic aerosol on climate and on multi-year seasonal and decadal climate predictability is still largely unexploited. Open questions are:

- How strong will the volcanic perturbation effect seasonal and decadal climate predictions?
- How dependent is the signal to initialisation values?

We have addressed these questions with the MiKlip prediction system in 2018 for two cases: a hypothetical large Mt. Agung eruption in autumn 2017 (A) and a hypothetical Mt. Pinatubo like eruption in July 2013/2015 (B)

(A) In boreal autumn 2017, the likelihood of a large volcanic eruption was relatively high. Increased seismic activity was observed from Mt. Agung (Bali, Indonesia), which started on August 10th, 2017 and continued with intensity increasing over September and October and slowly declining in early November. Mt. Agung last erupted in 1963 with an estimated SO_2 emission of 6.5 Tg. It was one of the largest eruptions of the 20th century and lead to global cooling of 0.1 °C to 0.4 °C in the aftermath of the eruption (e.g. Fontijn et al., 2015). The fall 2017 unrest of Mt. Agung raised the possibility of the effects of another climatic relevant eruption in late 2017/early 2018.

To investigate on one hand the possible climate impact and to test on the other our prediction system we have performed together with module D FLEXFORDEC (H. Pohlmann, W. Müller) decadal climate forecasts with the MiKlip prediction system for an artificial Agung-like eruption starting in October 2017. We have simulated the evolution of the volcanic aerosol and the related radiative forcing with the global aerosol model ECHAM5-HAM with high vertical resolution (L90) and internally generated QBO (Stier et al., 2005; Niemeier et al., 2009). For this test case the SO_2 emission profile has been adapted from the 1963 eruption (Figure 2.2.1). In a second step these optical parameters are prescribed as monthly forcing data in the forecast system. In total 10 realisations with and without volcanic eruption (lagged initialisations) have been performed starting in October 2017. Figure 2.2.2 shows that if a hypothetical eruption of Mt. Agung had happened in boreal autumn 2017 in the order of the historical 1963 eruption, the surface air temperature would have been effected globally and regionally for a couple of years. Precipitation anomalies are only regionally significant for example a precipitation increase over the Gulf of Mexico in the 1st summer after the eruption.

B) To investigate the role of initial conditions for the volcanic impact on seasonal to decadal predictions we have also performed decadal forecasts with the MiKlip system for a hypothetical Pinatubo eruption for the initialisation years 2012 (exp-2012) and 2014 (exp-2014) (Illing et al., 2018). In December 2012 the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO) were in a negative phase, whereas at the end of 2014 PDO and NAO were in a positive phase. Each forecast experiment contains an artificial Pinatubo-like eruption starting in June of the first prediction year and consists of 10 ensemble members. For the construction of the aerosol radiative forcing, we used as for Mt. Agung the global aerosol model ECHAM5-HAM in a version adapted for volcanic eruptions.

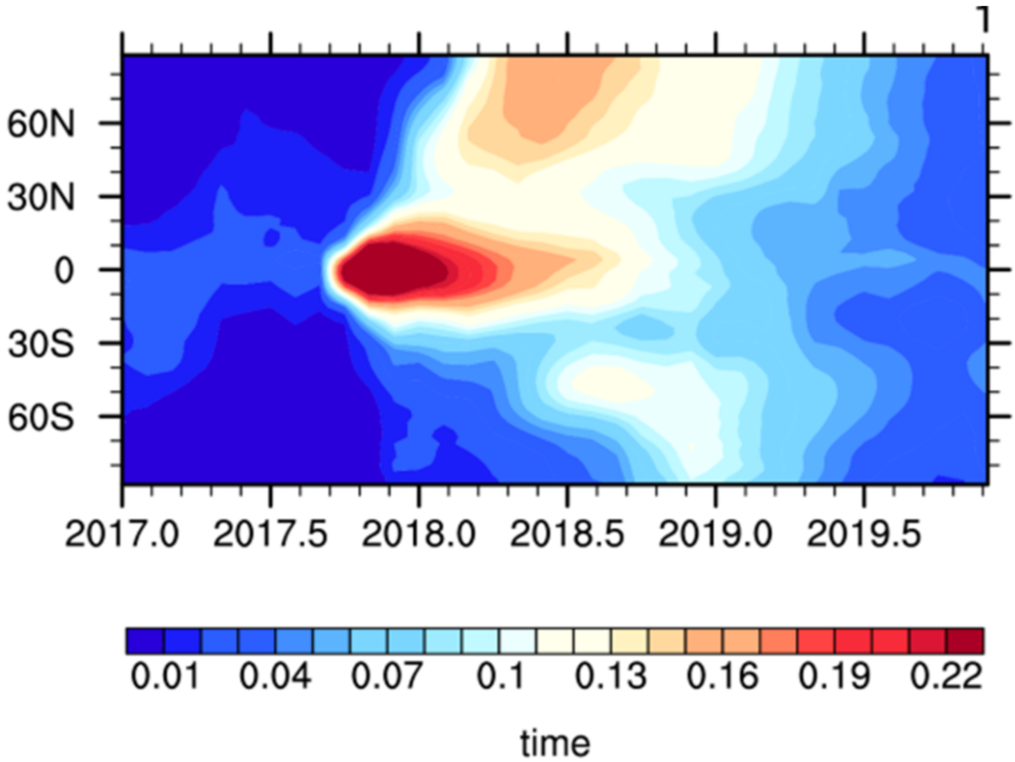

Figure 2.2.1: Time series of zonal mean stratospheric aerosol optical depth (AOD) between 2017 and 2020**.**

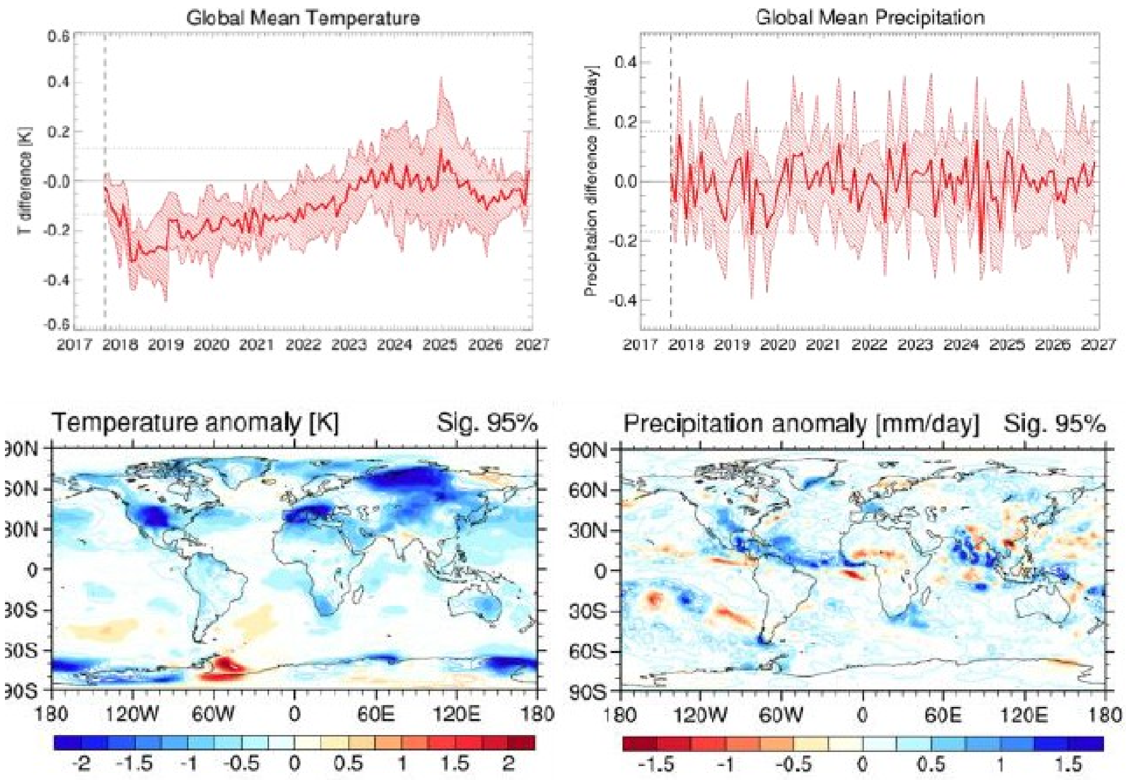

Figure 2.2.2: Time series of globally averaged surface air temperature and precipitation anomalies (top); seasonal averaged surface air and precipitation anomalies for summer 2018 (1st summer after the eruption, bottom)

Our results show that the average global cooling response over 4 years of about 0.2 K and the precipitation decrease of about 0.025 mm/day is relatively robust throughout the different experiments and seemingly independent of the initialisation state. However, on a regional scale, we find substantial differences between the initialisations. The cooling effect in the North Atlantic and Europe lasts longer and the Arctic sea ice increase is stronger in the exp-2014 simulations. In contrast, the forecast initialised in 2012 with a negative PDO shows a prolonged cooling in the North Pacific basin. One of the most substantial differences between the experiments can be found in the predictions of minimum and maximum sea ice area fraction. The volcanic eruption in exp-2012 has nearly no effect on the 4-yearly minimum sea ice cover (SIC), whereas in exp-2014 we see a significant increase of up to 4 % (Figure 2.2.3) This can be explained partly by the different phase of the PDO; a negative PDO, as in the 2012 initialised experiments, brings colder temperatures to Alaska (Wendler et al., 2013) and strengthens the Arctic wintertime warming (Screen and Francis, 2016) and therefore counteracts the volcanic cooling effect.

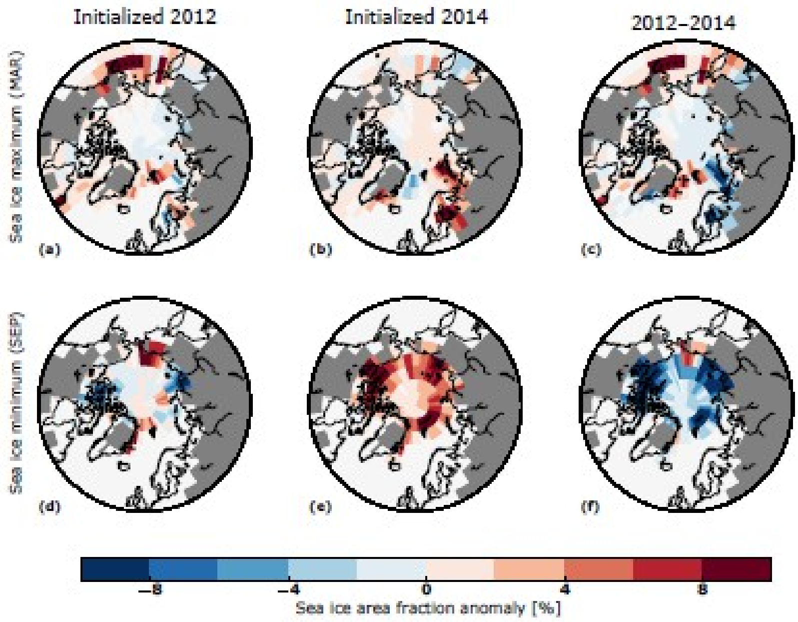

Figure 2.2.3: Differences in ensemble mean forecasts of sea ice cover (SIC) for prediction years 1–4, (a–c) for the 4-year mean maximum in March, and (d–f) for the 4-year mean minimum in September. (a, d) Exp-2012 (Pinatubo-2012–b1-2012), (b, e) exp-2014 (Pinatubo-2014–b1-2014), and(c, f) the difference between the two (exp-2012–exp-2014). Crosses denote values significantly different from zero exceeding a 5 % level. (Illing et al., 2018).

2.3 ATMOS/MODINI

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

The MiKlip subproject ATMOS-MODINI has two parts. ATMOS has the goal to alleviate the North Atlantic cold bias in the MPI-ESM with the view of testing the hindcast skill of the corrected model. The MODINI part is to explore ways to improve the initialisation of the MiKlip system in the tropics. Thereby, MODINI uses reanalysis wind stress anomalies seen by the ocean model in the coupled system to drive the initialisation run that is subsequently used for decadal hindcasts.

For the decadal hindcasts produced within the subproject MODel INItialisation (MODINI), the time series of observed (or reanalysis) wind stress anomalies is used to drive the MPI-ESM-LR to obtain a realistic climate variability, especially that associated with the Pacific Decadal Oscillation (PDO) and El Nino Southern Oscillation (ENSO). We then take the initial conditions for decadal hindcasts from these MODINI assimilation runs (see Thoma et al. 2015).

In 2017 we had produced a set of 5-year hindcasts to join an effort within MiKlip to compare different initialisation methods. We also extended the length of these hindcasts to 10 years by the end of 2017. However, the suite of retrospective forecasts (hindcasts) completed in 2017 was found to be in error, in that the wind stress used to drive the ocean model did not carry the climatology of the model. On the one hand, by this error, the poor performance of the MODINI hindcasts presented in the report for 2017 can be explained. On the other hand, we had to redo the whole procedure of producing MODINI assimilation runs and generating 12 ensemble members for the actual hindcasts, which were run for 5 years each. In addition to the original period of hindcasts, i.e. starting years from 1960 to 2011, we extended the MODINI hindcasts by the starting years 2012-2017 for some analyses.

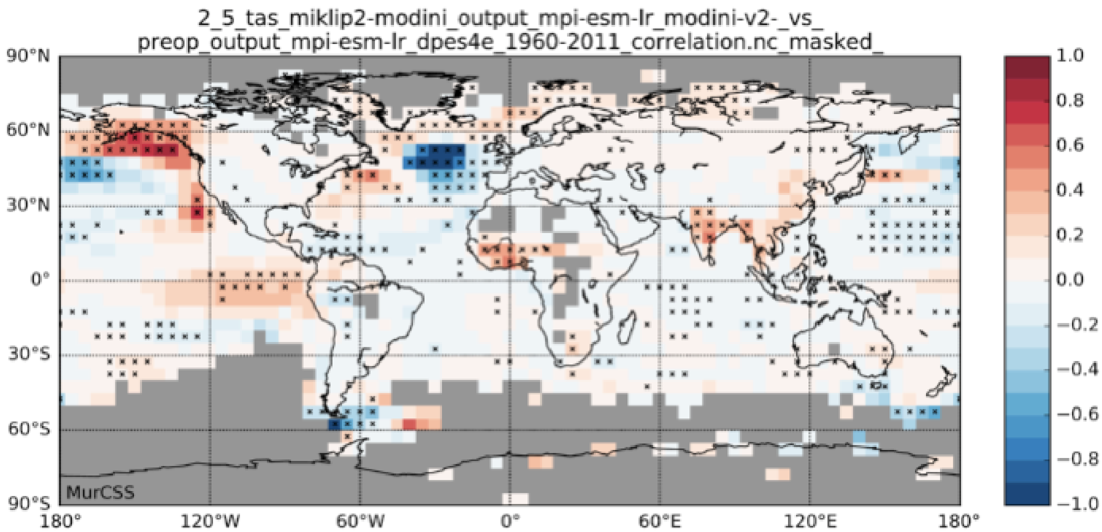

Figure 2.3: Difference between MODINI and PreOp hindcasts in ensemble mean correlation skill score of 2 m air temperature for the 2-5 year mean hindcasts evaluated against observations (HadCRUT4 ensemble mean) for SY 1960 – 2011. Hatching marks significance based on Monte Carlo tests and grid points with insufficient observations are masked. Generated using the MurCSS plug-in of the MiKlip Central Evaluation System (Kadow et al., 2015).

Figure 2.3 shows an example of the hindcast skill of the new set of MODINI hindcasts, comparing MODINI to the MiKlip pre-operational (PreOp) system for 2-5 year lead-time in terms of the skill in hindcasting 2 m temperature verified against HadCRUT4 observations. Note that the PreOp initialisation is done by nudging the whole ocean towards temperature and salinity data from ORA-S4 and by nudging the whole atmosphere to full fields taken from ERA-40 and ERA-Interim. As would be expected from the results by Thoma et al. (2015), MODINI outperforms PreOp in some important parts of the Pacific region, especially the eastern tropical Pacific, near the coast of California and the Gulf of Alaska. Further, MODINI shows improvement over the western North Atlantic and some hints of improvement towards the Arctic, although the confidence of observational data is smaller there (the masked regions). Also, some regions over land are improved in MODINI, such as western and southern Africa as well as India and Bangladesh. However, there are still some regions, where MODINI is worse than PreOp, like the eastern North Atlantic, and the western Pacific. It is not clear yet, why MODINI gives such a bad performance in the eastern North Atlantic, a region important for European climate.

A manuscript discussing the inter-comparison of the different initialisation methods within MiKlip, including MODINI, has been submitted to the Journal of Advances in Modeling the Earth System (JAMES).

2.4 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. During the report period MOVIECLIP continued the analysis of the Atlantic Multidecadal Variability (AMV) in the MPI Grand Ensemble, conducted new experiments using an idealised AMV forcing, and worked on the contributions to the CMIP6 DCPP project.

Contributions of the ocean circulation to the Atlantic Multidecadal Variability in the MPI Grand Ensemble under changing external forcing

The aim of this work is to get a better understanding of the mechanisms that control North Atlantic large-scale temperature variations on decadal time scales. Particularly we address the question, whether ocean dynamics is involved in controlling the AMV or whether the AMV is a mainly atmospherically driven mode. The MPI Grand Ensemble consists of a 2000-year pre-industrial control run, a 100-member ensemble of historical simulations covering the time period from 1850 to 2005 and a 68-member ensemble of 155 year long runs with an idealised forcing with an incremental CO_2 increase by 1%/year.

We found strong statistical evidence that AMV has a regional component that is driven through ocean heat transport changes: The variability in the region east of Newfoundland substantially contributes to the AMV in observations, the pre-industrial control experiment and the historical ensemble. In contrast, the AMV imprint on this region is much weaker in the ensemble with strong CO_2 forcing Also, both, AMV and AMOC variability are strongly reduced in the ensemble with the forcing with an incremental CO2 increase by 1% per year. This might be partly explained by a reduced ability of the atmosphere to trigger convection variability in the Labrador Sea changes under strong CO_2 forcing (Hand et al., submitted).

The Role of Ocean dynamics in shaping North Atlantic decadal to interdecadal variability in MPI-ESM1.2

Motivated by numerous studies drawing a link between the AMOC and long-term SST variability, idealised simulations are conducted, to determine the influence of ocean circulation on the climate system. A particular focus is put on interactions with dominant modes of atmospheric variability as the NAO, EA and Scandinavian pattern and the function of the response of the atmosphere to mediate the thermal signal within the North Atlantic region.

The conceptual idea of the experiments is to modulate the AMOC strength through adjustments of densities in the sinking regions on different timescales (20-120 years). Therefore a method of Delworth and Zeng (3), who implemented heat flux (HF) anomalies associated with the North Atlantic Oscillation (NAO), is applied. However, as this method hampers analysis of ocean-atmospheric feedback, the ocean circulation is driven internally by thermohaline restoring below 700m in the sub-polar ocean in another setup (THR). The AMOC is modulated sinusoidally in order to mimic decadal/multi-decadal variability (Fig. 2.4a). Any responses in the climate system that reflect the same temporal signature, for instance changes of sea ice extend or low frequency atmospheric circulation pattern, can thereafter explicitly be traced back to AMOC anomalies.

A hierarchy of model set-ups of the MPI-ESM1.2 LR is used. Both the heat-flux-forcing and the restoring methodology are applied to the fully coupled model. In addition, the density restoring methodology is implemented in a stand-alone ocean configuration and a slab-ocean atmospheric model with prescribed climatological ocean heat transport is included. The comparison of the ocean-only experiment, where SST is only affected by stochastic atmospheric forcing and AMOC related modulated ocean heat transport changes, with the fully coupled set-up, that includes atmospheric responses and feedbacks, allows to clearly segregating atmospheric and oceanic contributions (Master Thesis Julius Oelsmann).

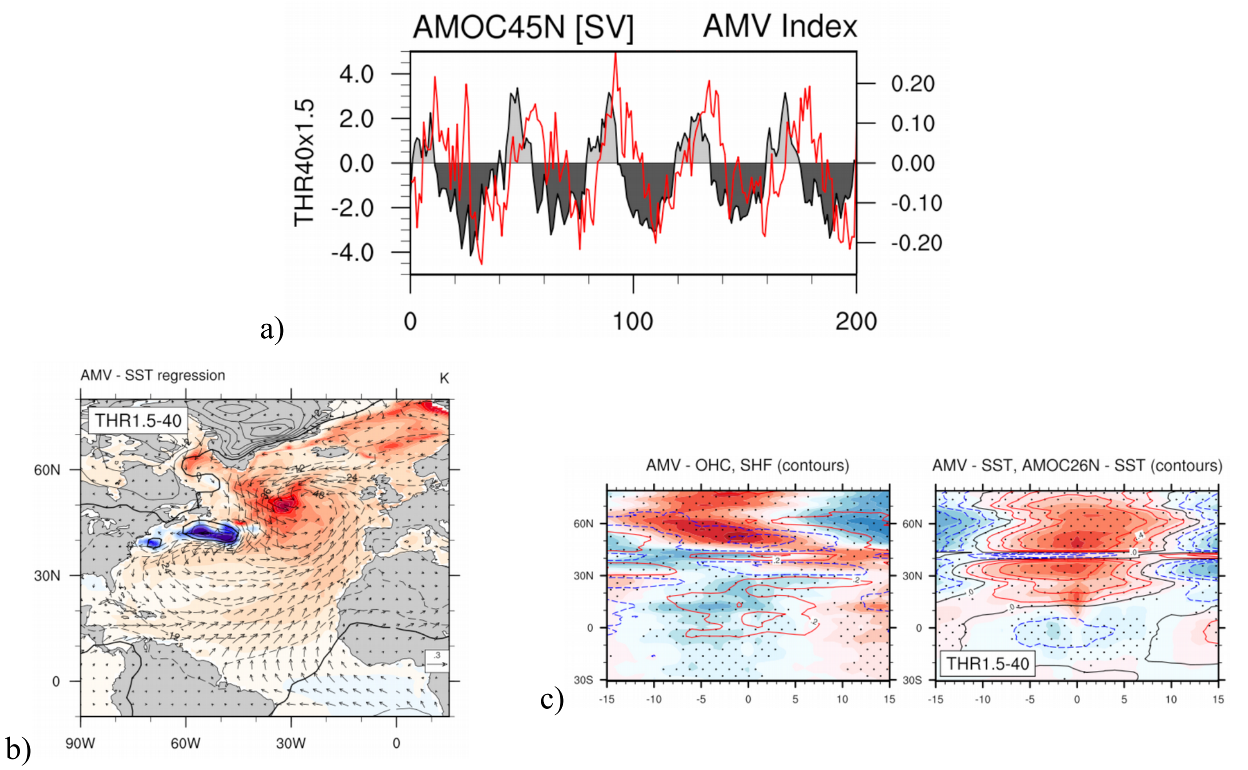

Figure 2.4: a) AMOC at 45N (grey) and AMV index (red: 0-60N,80-OW) of the 40y restoring experiment; b) regression SST (K, shading), 10m winds [m/s] and SLP (contours [hPa]) on AMV index; c) left: lead-lag correlation coefficients of atlantic zonal means of ocean heat convergence (shading, red: convergence) and surface heat fluxes (contours, blue: out of the ocean) on AMV, right: same for SST on AMV (shading) and AMOC26N (contours); lag [years] is negative (positive) when AMV lags (leads)

Decadal climate prediction project component C (DCPP-C) experiments

The Atlantic Idealised climate impact simulations which are planned for the Decadal climate prediction project component C (DCPP-C, Boer et al. 2016) experiments are developed in cooperation with the PRIMAVERA project which uses the same forcing method and the same SST pattern although with a doubled amplitude for the MPI-ESM-XR and MPI-ESM-HR model. In MOVIECLIP, it was envisaged to use the MPI-ESM-LR climate model for the DCPP-C simulations. Due to a delay in the finalisation of the climate model MPI-ESM-1.2-LR for CMIP6 simulations the model has been released only recently. However, the historical simulations with MPI-ESM-1.2-LR are still not finished. Therefore, we have started in 2018 to use MPI-ESM-1.2-HR model for the DCPP-C simulations. Since the computational costs with MPI-ESM-HR are higher than with MPI-ESM-LR we want to complete only the DCPP-C priority-1 simulations (AMV control, AMV+, AMV-, Pacific control, PDV+, PDV-) in 2019 and skip the DCPP-C priority-2 and priority-3 simulations

2.5 PROCUP

Project lead: Tatiana Ilyina (MPI-M)

The main goal of work package PROCUP is to investigate the variability and predictability of the oceanic carbon uptake and the underlying mechanisms. Our study can be summarised as follows.

I. Internal variability of the ocean carbon sink

In a new study [Li and Ilyina, 2018], we investigated the internal decadal variability of the ocean carbon uptake by using 100 ensemble simulations based on the Max Planck Institute Earth system model (MPI-ESM). We found that on decadal time scales, internal variability (ensemble spread) is as large as the forced temporal variability (ensemble mean), and the largest internal variability is found in the Southern Ocean, the North Pacific, and the North Atlantic, which are the major carbon sink regions (see Fig. 2.5). The MPI-ESM ensemble produces both positive and negative 10 year trends in the ocean carbon uptake in agreement with observational estimates. Negative decadal trends are projected to occur in the future under RCP4.5 scenario. With the large ensemble of 100-member simulation, we can quantify the required ensemble size for detecting the forced signal out of the large internal variability of the ocean carbon sink. Due to the large internal variability, the Southern Ocean and the North Pacific require the most ensemble members (from 46 up to 79) to reproduce the forced decadal trends. The number of ensembles increases in future decades as CO_2 emission trajectory changes under RCP4.5 scenario.

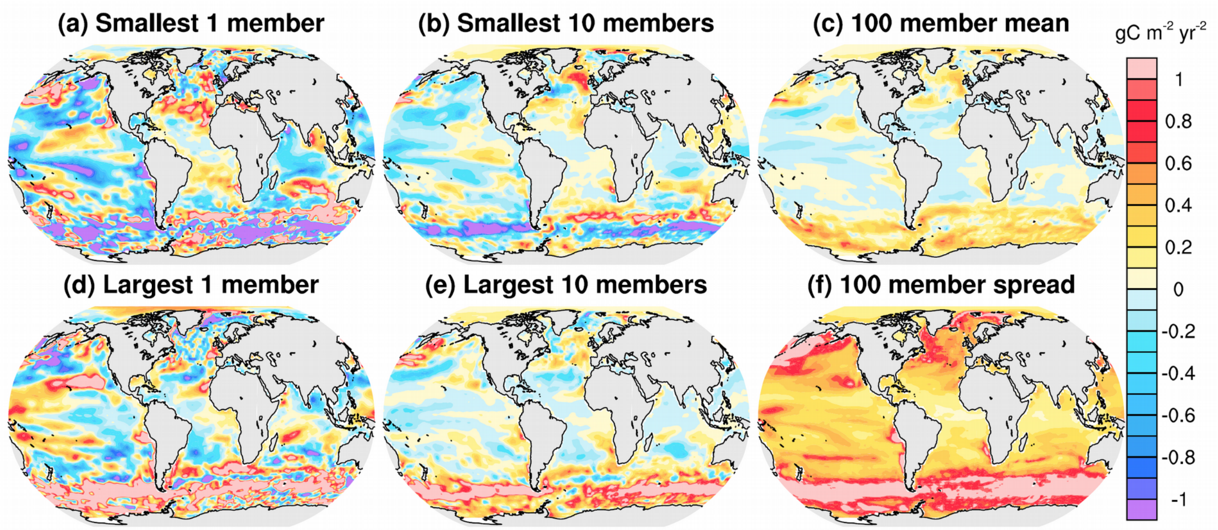

Figure 2.5: Spatial distribution of trends in the air-sea CO_2 flux during the period 1992–2001 based on varying ensemble size. (a and d) The single-member results with the smallest and the largest trend of the global integrated carbon sink. (b and e) The 10-member ensemble mean results with the smallest and the largest trends. The 100-member (c) ensemble mean and (f) standard deviation of the decadal trend. Note a negative trend indicates that the ocean carbon uptake is weakening.

II. Predictability of the ocean carbon sink (under review)

As observation-based studies [*Landschützer et al.*, 2016; *Landschützer et al.*, 2015];[*Rödenbeck et al.*, 2015] show that the oceanic carbon uptake has strong decadal variations over the last 3 decades, this challenges our ability to predict the strength and the variations of the ocean carbon sink. By assimilating atmospheric and oceanic observational data into MPI-ESM-HR, the decadal prediction system is capable to reproduce the observed variations of the ocean carbon sink. We find that variations of the global integrated oceanic CO_2 uptake are predictable up to 2 years in advance in comparing to observation-based estimates of ocean carbon sink. The potential predictive skill against assimilation is up to 3 years, albeit there is evidence for a higher predictive skill up to 5 years regionally. To further investigate the mechanisms in maintaining the predictive skill, we decompose the carbon uptake to thermal and non-thermal drivers, the thermal driver represents the effects of temperature changes, and the non-thermal represents the effects of biology and circulation induced dissolved inorganic carbon concentration changes, which are not at first order link to temperature. The results suggest that the thermal drivers largely determine shorter-term (<3 years) predictability of ocean carbon sink, however, the non-thermal drivers are responsible for maintaining longer-term (>3 years) predictability, especially for the high latitude and for the potential predictive skill.

2.6 References

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3. Module C – Regionalisation of Decadal Predictions

Project: **bb0849**
Project title: **MiKlip II Module C – Regionalisation of Decadal Predictions**
Project leader: **Hendrik Feldmann**
Allocation period: **01.01.2018 – 31.12.2018**

3.1 Project overview

MiKlip II module C works on the downscaling of global climate predictions with the regional climate model COSMO-CLM (CCLM). The project aims are to improve the regional prediction system and to provide reliable information about regional decadal predictability for Europe.
The efforts of Module C are an essential contribution to the development of an operational decadal prediction system within in the BMBF funded program MiKlip II. All regionalisation efforts of the research program are bundled within this DKRZ project bb0849.
MiKlip II module C is organised in eight work packages (Cx-WPy), with four WPs requiring considerable computing time at DKRZ, where the other four use these data for analysis and post-processing. The project has currently 19 members of whom 11 participants use the major part of the resources.
Participating institutions are: KIT Karlsruhe, DWD, Goethe University Frankfurt (GUF), University of Cologne and the University of Würzburg

3.2 Main work objectives

The computational work performed within this project at DKRZ in 2018 can be grouped into four main topics

1. **Ensemble generation (C3-WP3)**: The generation of the core regional decadal ensemble including decadal climate forecasts for the next 10 years using COSMO-CLM. This topic includes also development steps towards an operational use of the prediction system.
2. **Potential of very high-resolution predictions at a convection resolving scale (C1-WP2, C3-WP3)**: A small hindcast set has been generated to explore the potential added value of very high-resolution hindcasts for the greater Alpine area.
3. **Regionally coupled European marginal seas (C1-WP1, C2-WP3)**: Development, testing and application of a regional coupled ocean/atmosphere prediction system using COSMO-CLM and NEMO

4. Regional decadal forecasts for the period 2018-2027

3.2.1 Objective 1: Ensemble Generation (WP: C3-WP3)

Contributors: Hans-Jürgen Panitz (KIT), Sascha Brand (DWD), Hendrik Feldmann (KIT)

Main WP Goals

Module C of MiKlip II works on further improving the regional component for the operational use of MiKlip decadal prediction system using the Regional Climate Model (RCM) COSMO-CLM (CCLM), which is the climate version of the operational weather forecast model of the German weather service (DWD), with a regional focus on (Central) Europe. The model domain for the regional decadal simulations of MiKlip II coincides with the domain chosen in MiKlip I, respectively in the frame of EURO-CORDEX. The horizontal grid-spacing has been fixed to 0.22° (≈25 km).

The central task of this work-package is to produce an ensemble of regional decadal hindcast simulations using dynamical down-scaling with CCLM for the full MiKlip hindcast period from 1960 until the current year. This means about 5700 simulation years for a full hindcast set. Such a large ensemble is necessary to assess the skill of decadal predictions.

The goal of MiKlip regarding this "core ensemble" is to provide a full hindcast suitable for the CMIP6 Decadal Climate Prediction Project (DCPP). The use of the CMIP6 external forcing parameters is required within this project. There are still delays regarding the availability of some of these forcing parameters with respect to the period after 2014.

The so called "dcppA" hindcast generation uses the MPI-ESM-HR as global model which drives the regional simulations with the RCM CCLM version 5 and a resolution 0f 0.22°. Until now 10 realisations for the starting years 1960 – 2003 have been performed which amounts to 440 simulations or 4400 simulation years.

The preliminary analysis of the dcppA ensemble shows promising results for several basic climate indicators (Fig. 3.2.1.1). There is a high correlation of temperature related variables (Fig 3.2.1.1 a,c,d) and a smaller skill for precipitation (Fig. 3.2.1.1b). The experience from older ensemble generations let us expected a stronger further increase of the skill, when the hindcast period is extended to more recent starting years.

The skill and usability of the decadal predictions can be improved by a recalibration, following Pasternack et al. (2018). The recalibration reduces the conditional and unconditional bias of the ensemble and calibrates the ensemble spread and trend. The skill of the hindcast ensembles has been analysed for a variety of user-relevant climate indicators. Fig. 3.2.1.2 displays the Mean Square Error Skill Score (MSESS) for such a variable. The Expert Team on Climate Change Detection Indices (ETCCDI) developed a list of user-relevant and extreme value indices. The heating degree days (hd) are defined as follows:

$$hd = \sum max\left(17\,°C - T\,;0\,°C\right)$$

This variable gives an indication the amount of domestic heating necessary in a certain period. Already, the un-calibrated hindcasts show a significant skill over most Europe for the 4-year mean 2-5 years ahead (Fig. 3.2.1.2a), which is further improved by the recalibration (Fig. 3.2.1.1b).

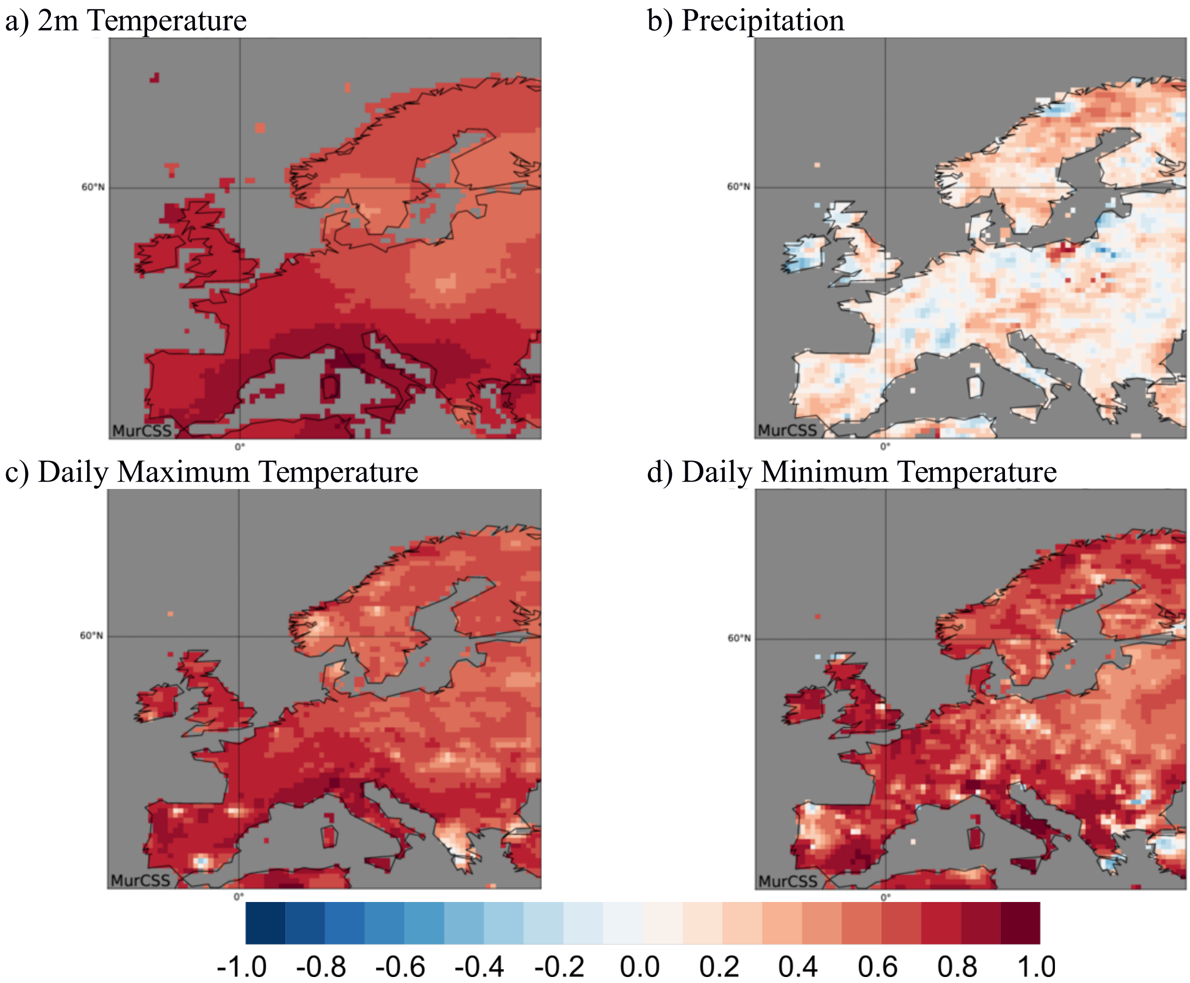

Figure 3.2.1.1: Correlation of the regional dcppA hindcasts with the E-OBS V17 observations for lead-years 2-5 of the starting years 1960 – 2003. a) annual 2m-temperature, b) precipitation, c) daily maximum temperature, and d) daily minimum temperature.

a) Heating Degree Days - un-calibrated b) hd Heating Degree Days – calibrated

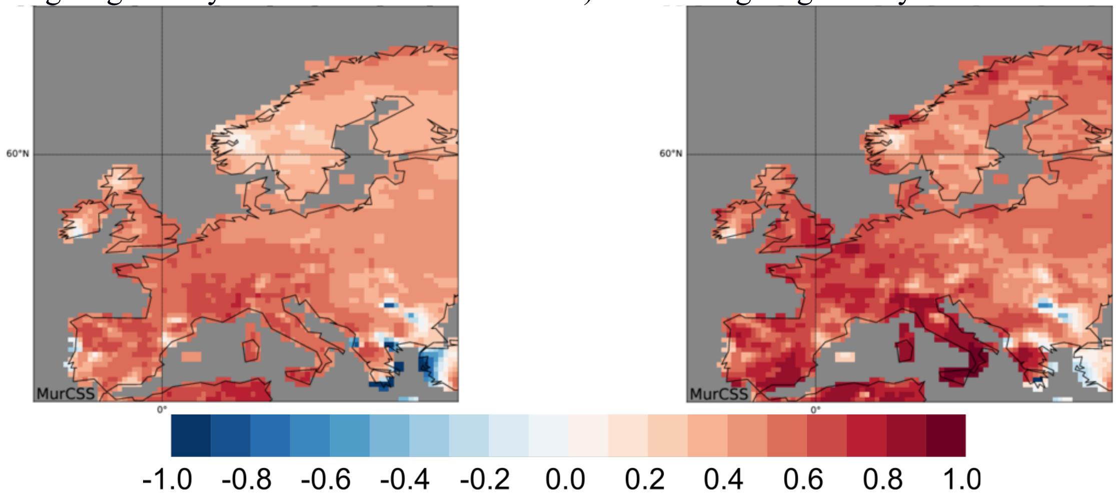

Figure 3.2.1.2: MSESS for ETCCDI index "heating degree days" (hd) CCLM for the period 1967 – 2015; a): Un-calibrated hindcasts, b): Recalibrated hindcasts.

3.2.2 Objective 2: Predictive potential of land surfaces (WP: C1-WP2)

Contributors: Marcus Breil (KIT), Gerd Schädler (KIT)

The goal of this objective is to assess the added value of very high resolution hindcasts with respect to the predictive skill for extremes. These simulations are computationally very demanding and can therefore only be performed for selected periods. Special focus was on the years 2002 (flooding) – 2003 (heat wave). For the decade 2000 (2001 – 2010) 3 members of the CCLM preop ensemble were used for further down-scaling down to the convection permitting scale with 3 km resolution.

The modelling domain (Fig. 3.2.2.1) covers the "Greater Alpine Area (GAR)" as defined in the CORDEX Flagship Pilot Study on "Convective phenomena at high resolution over Europe and the Mediterranean".

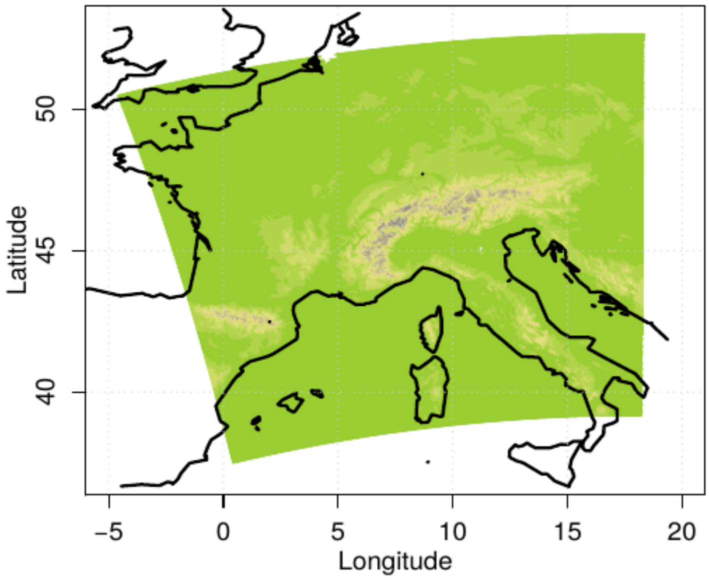

Figure 3.2.2.1: Simulation domain GAR used for the MiKlip hindcasts with convection permitting resolution

a) *b)*

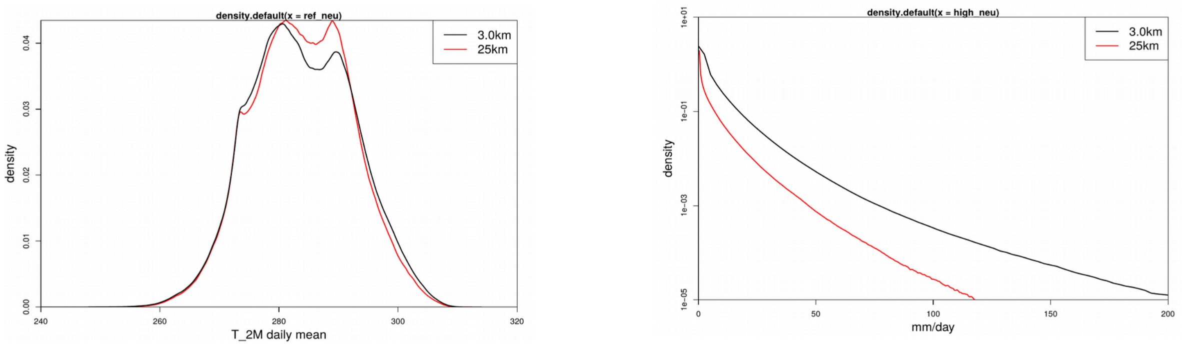

Figure 3.2.2.2: Comparison of the frequency distribution for temperature (a) and precipitation (b) for the high resolution hindcasts at 3 km resolution (black lines) and the standard 25 km resolution (red lines).

It could be shown that at this high resolution the representation of high temperatures (Fig. 3.2.2.2a) as well as extreme precipitation (Fig. 3.2.2.2b) was improved to the standard hindcasts with a resolution of 25km.

3.2.3 Objective 3: Regionally coupled European marginal seas (WP: C1-WP1, C2-WP3-GUF)

Contributors: Fanni Kelemen, Anika Obermann, Nora Leps, Bodo Ahrens (GUF)

Coupled 20th century simulations with CCLM and coupled European marginal seas have been performed in 2018. Within these experiments CCLM has been coupled to the Mediterranean (NEMO-Med) as well as for the Nordic/Baltic Sea (NEMO-Baltic). CCLM itself uses the same grid and resolution as for the MiKlip Module C standard hindcasts with 232 x 226 x 40 grid points (lat x lon x vertical levels). The NEMO-Med domain uses 567 x 264 x 75 grid points and 619 x 523 x 56 grid points for NEMO-Baltic.

The simulations required 6675 node-hours on Haswell nodes and 14559 node hours on Broadwell nodes. Furthermore, the evaluation of these simulations was performed at DKRZ. This with done among others with Python scripts, which required a few further node hours.

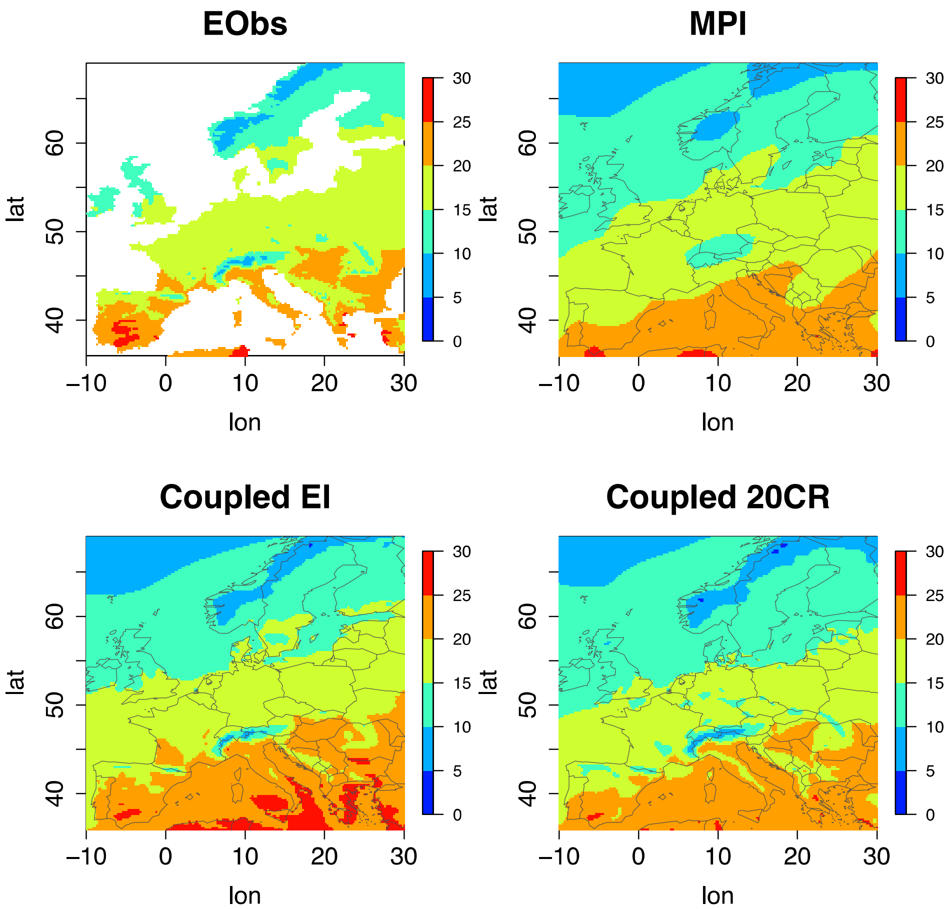

Figure 3.2.3.1: shows the mean summer (JJA) 2-temperature over the periods 1979 – 2009 for the EObs Observations (upper left), MPI-ESM (upper right), CCLM-NEMO with ERA-Interim boundary conditions (lower left) and the 20th century simulation from MiKlip (lower right).

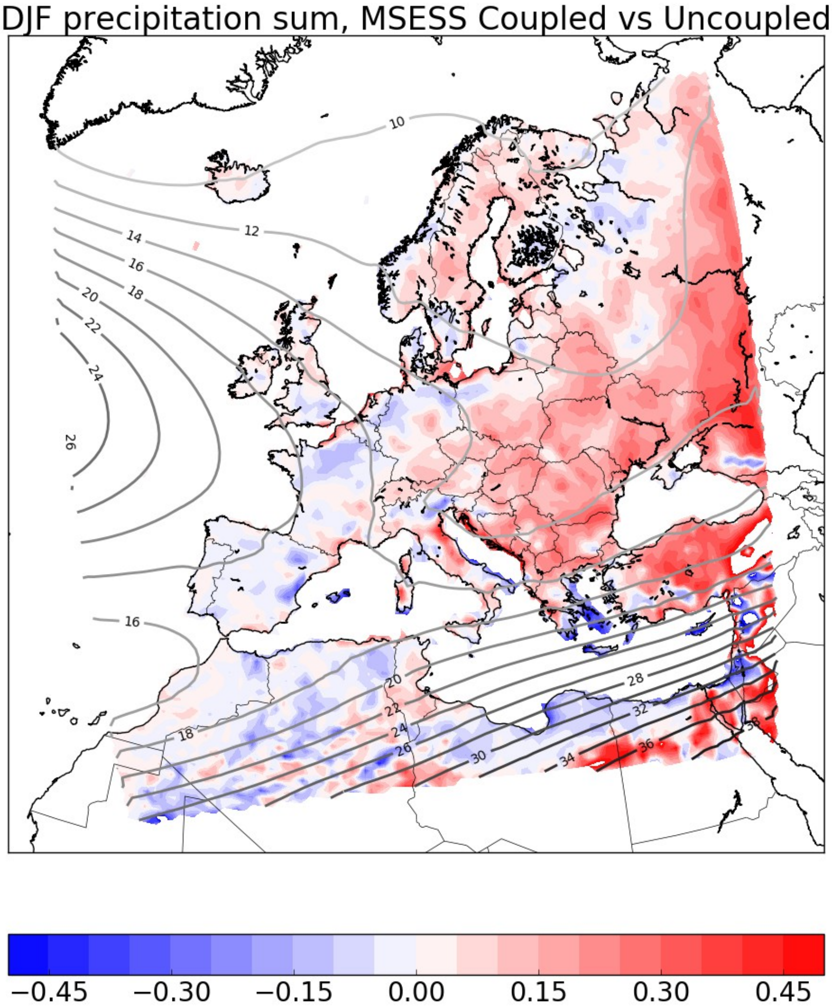

Figure 3.2.3.2: shows a comparison between the regional MiKlip coupled and un-coupled 20th century simulations. It shows the Mean Square Error Skill Score (MSESS) for precipitation in winter (DJF) together with the seasonal mean wind speed (grey lines). The coupled simulation displays a higher skill (red colors) in some coastal areas and for Eastern Europe.

Further analyses and additional simulations are planned for 2019

3.2.4 Objective 4: Regional Decadal Forecasts (WP: C3-WP3)

Contributors: Hendrik Feldmann (KIT)

In 2018 the MiKlip decadal forecast web page (http://www.fona-miklip.de/decadal-forecast/decadal-forecast-for-2018-2027/) included the regional forecasts performed with CCLM (Figure 3.2.4). These forecasts will also be performed for the year 2019.

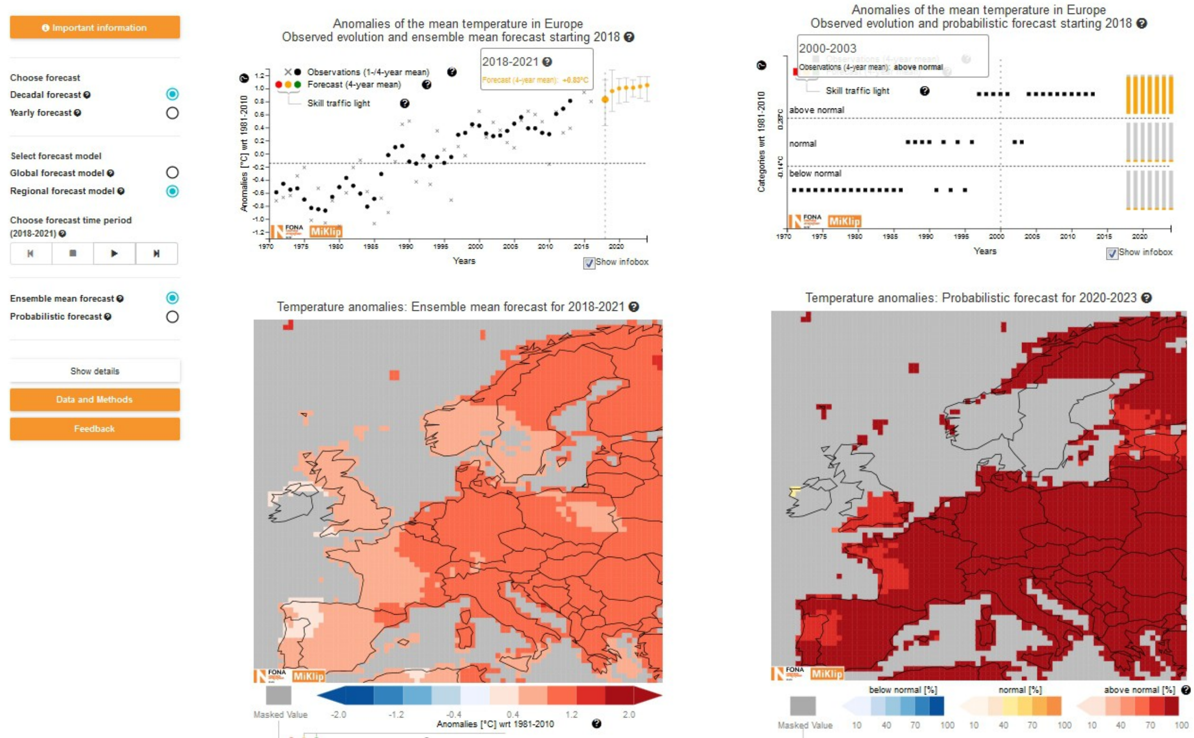

Figure 3.2.4: Regional decadal forecasts with CCLM for the period 2018 – 2027 (from: http://www.fona-miklip.de/decadal-forecast/decadal-forecast-for-2018-2027/)

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4. Module D – Synthesis

Project: **bm0807**
Project title: **MiKlip II Module D – Synthesis**
Old title during MiKlip first phase (**A flexible forecast system for decadal climate predictions - FLEXFORDEC)**
Project lead: **Jochem Marotzke**
Reporting period: **01.01.2018 – 31.10.2018**

4.1 Project overview

Module D is responsible for developing the global decadal climate prediction system and the accompanying central evaluation system, the transfer of the system to DWD, and the setting up of pilot studies for the application of decadal predictions by government agencies and by the private sector. The project consortium consists of 4 project partners and is described in the CPU request for 2016, 2017 and 2018.

Strategically, MPI-M leads the coordination of MiKlip II and Module D, with the overall project being led by J. Marotzke, the scientific and technical implementation being led by W. Müller, and the MiKlip Office being led by S. Hettrich. MPI-M takes the lead in the development of the global prediction system and supports the transfer of the global model to operational use (**FLEXFORDEC**). FUB takes the lead in the development of the central evaluation system (**INTEGRATION**), hosted on the MiKlip Server. FUB also supports DWD in the transfer of the evaluation system for operational use of global decadal climate predictions. DWD implements both the global prediction and the central evaluation system on their local machines for operational use (**OPERATIONS**). Moreover, DWD provides a pilot study for the use of decadal predictions for government agencies (**SUPPORT**) and GERICS provides a pilot study for the use of decadal predictions for the private sector (**IPRODUCTS**).

In addition to the MiKlip II project objectives, **FLEXFORDEC** also coordinates the MPI-M contribution to the CMIP6 decadal predictions (organised by the WCRP Decadal Climate Prediction Project (DCPP) with W. Müller as a member, Boer et al. 2016) and takes the responsibility for providing the CMIP6 DECK experiments for the high-resolution version of the MPI-ESM (MPI-ESM-HR, Müller et al., 2018). MiKlip is also partner of the WCRP Grand Challenge on Near Term Climate prediction (with W. Müller as a member, Kushnir et al., 2018). Their overall objectives are the production of standards, verification methods and guidance for near term predictions in collaboration with the WMO Commission for Basic Systems / Commission for Climatology (CBS/CCL) Expert Team, the achievement of WMO recognition for operational decadal predictions, and the initiation and issuance of a real-time Global Decadal Climate Outlook once each year in consultation with CBS/CCL and following the template of the Global Seasonal Climate Update (GSCU) for seasonal predictions.

MiKlip II Module D develops and provides the decadal prediction and evaluation systems of MiKlip II. As such the project is responsible for providing all project partners with the newest central simulations of the prediction system. MiKlip II Module D will also provide the Max Planck Institute for Meteorology's contribution to the DCPP of CMIP6. The main model used for the MPI-M CMIP6 simulations and for MiKlip is the MPI-ESM in its low and high resolutions (LR and HR). The MiKlip II Module D project has taken on the responsibility for setting up the MPI-ESM-HR (atmosphere: T127L95, ocean: TP04L40) for CMIP6.

The decadal hindcasts of the central prediction system and the DECK experiments are performed with the coupled model ECHAM6/MPIOM in high resolution, MPI-ESM-HR (T127L95/TP04L40). The model is already implemented in the DKRZ HPC infrastructure Mistral. MPI-ESM-HR is well tuned and a description of the model, its tuning and results is in preparation (Müller et al. 2018). Climate sensitivity is ~3K and similar to MPI-ESM-LR. The atmospheric global mean surface temperature exhibits no drift and stays on the target value of 13.8°C. The drift of global mean ocean temperature and salinity exhibits only little magnitudes and are comparable to earlier version of MPI-ESM-LR. The Atlantic meridional overturning at 26°N has a value of 16SV on time-average and is comparable to observational estimates. This shows that the coupled model is in a stable state. For CMIP6 major changes include the use of MAC-v2-SP for the anthropogenic tropospheric aerosols, ozone data, volcanic aerosols, solar irradiation and new land-use data (LUH2).

4.2 DECK and decadal hindcast simulations with CMIP6 forcing

FLEXFORDEC is in charge of providing the CMIP6 DECK experiments with MPI-ESM-HR. The CMIP6 forcing is now available (except the scenario forcing) and, in association with the MPI contribution to CMIP6, the DECK experiments are completed. An extended spin-up of the control run was necessary in order to tune the sea-ice properties of the model and additionally to reach an acceptable equilibrium in the sedimentation rate of the HAMOCC component. This run was followed by the CMIP6 DECK experiments (control run, 1% CO2 increase, abrupt 4 x CO2 and 5 historical runs) for MPI-ESM-HR. Additionally, 10 ensemble members of the decadal hindcast simulations are completed with yearly initialisation during 1960-2003. The remaining decadal hindcasts/forecasts with initialisation during the period 2004-2018 are missing since the CMIP6 scenario forcing is actually delayed by more than 1 year.

As a first step to get the starting fields for the decadal hindcast simulations, an assimilation run was performed. The assimilation run is similar to the previous one performed with CMIP5 forcing. Atmospheric temperature, vorticity, divergence and pressure data were nudged towards data from ERA40/ERAinterim. It was decided not to use the new ORA-S5 ocean reanalysis since problems were discovered, especially in the North Atlantic with this data set. Instead, the ORAS4 ocean reanalysis was used for nudging ocean temperature and salinity anomalies. As in the system with CMIP5 forcing sea ice concentration data from NSIDC is used together with a statistical relation between sea-ice concentration and sea-ice thickness (Tietsche et al. 2013). Starting from the initial conditions of the assimilation run decadal hindcast simulations with CMIP6 forcing are run with yearly initialisation during the period 1960-2003.

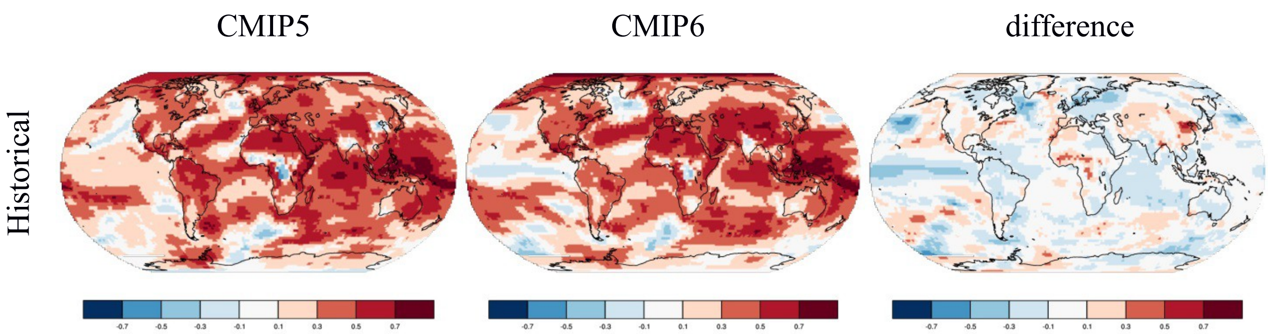

Figure 4.2.1: Surface air temperature correlation of annual and ensemble mean historical simulations with GISTEMP based on 1961-2005.

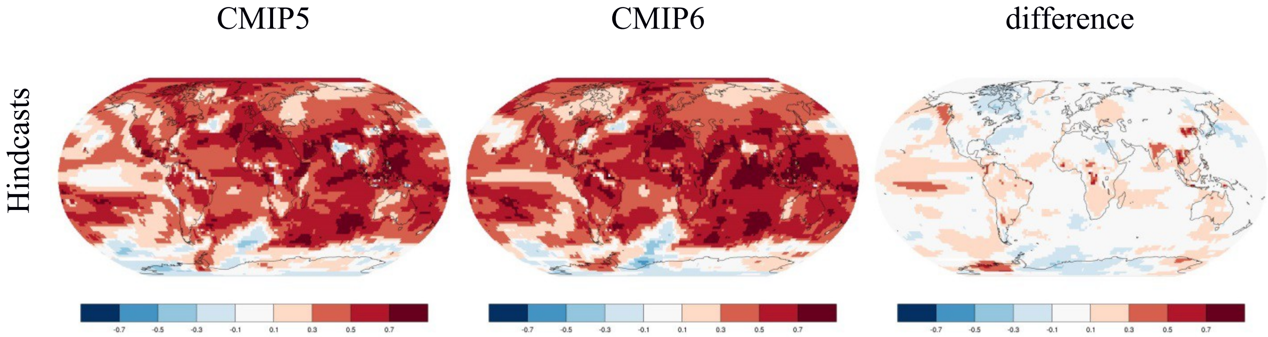

Figure 4.2.2: Surface air temperature correlation of ensemble mean hindcast simulations with GISTEMP for the temporal mean over the first 5 prediction years based on 1961-1965 to 2004-2008.

The comparison of historical simulations with CMIP6 compared to those with CMIP5 forcing shows a cooler stratosphere and a higher tropopause. The historical simulations are also warmer over tropical land and cooler over northern extratropics. Historical simulations have on average with CMIP6 – compared to those with CMIP5 – forcing a lower SAT-correlation especially over the tropical Pacific (Fig. 4.2.1). The comparison of the hindcast simulations with CMIP6 forcing – compared to CMIP5 forcing – shows a higher prediction skill especially in the tropical Pacific for 5 year means (Fig. 4.2.2). We speculate that the weaker volcanic aerosol forcing in CMIP6 leads to a reduction of correlation skill in the historical simulations, enabling the initialisation in the hindcasts to lead to an increased improvement.

4.3 Ensemble Dispersion Filter Experiments with MPI-ESM-1.2 and Preop-LR

INTEGRATION investigates a new re-initialisation method called ensemble dispersion filter (EDF). Here, individual members of the hindcasts are rescaled to the ocean state of the ensemble mean (details in Kadow et al. 2017). In 2017 the EDF was adapted to the MPI-ESM1.2, taking part in an assessment of new methods for MiKlip organised for MiKlip-Module A. With the new model system, 10 members, in the longer time frame 1960-2016 the EDF still boosts the prediction skill of its reference system up to 5 years ahead (Fig. 4.3). The skill scores show improvements in the climate-relevant regions of the Central and North Pacific, and the North Atlantic for 2m temperature. Other climate diagnostics like ocean heat content support these results (not shown). Due to the long assembling time to get the EDF within the new MPI-ESM1.2, more node hours were necessary to test the system for the MiKlip Module A assessment, which only requested up to 5 lead years. The longer runs up to 10 years are postponed. However, as the main boost-effects happen in the later lead years (4 and 5), probably the improvements are even stronger in the later stages (LY6-10). With the new stable version of the EDF further analysis will be done in the future.

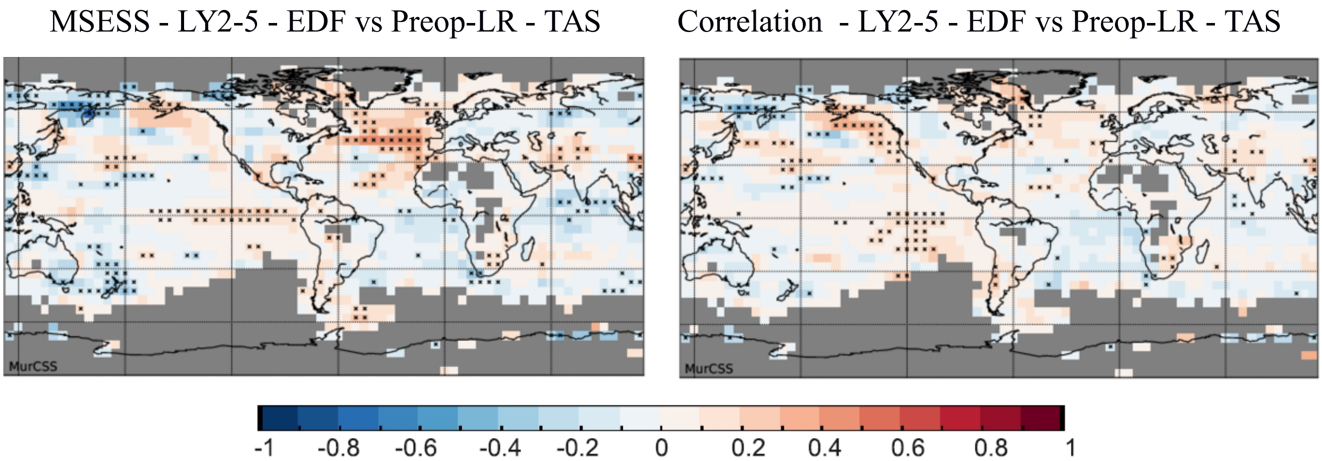

Figure 4.3: Mean Squared Error Skill Score (left) and Correlation (right) of the EDF with the Preop-LR as reference – each as a 10 ensemble member system. Near Surface Air Temperature is analysed in the lead years 2 to 5 hindcast compared to HadCRUT4. Significant differences are marked by crosses. Gray areas mark missing values with less than 90% data consistency in the observation. The analyses cover the time period from 1962 to 2016.

4.4 Computing time

1,200,341 node hours were granted for MiKlip II Module D in 2018. These were shared according to 19.5%, 19.5%, 30.5% and 30.5% during the four quarters of 2018, i.e. 234 T., 234 T., 366 T. and 366 T. Almost all of the allocated computing time for 2018 has been consumed until today. Our estimate of 181 node hours per model year was correct for the hindcast simulation started during 1960-1986. However, for the hindcast simulations started during 1987-2003 the simulations were run with the 'satellite simulator' resulting in a doubling of the consumed node hours. During Q3 some of the CPU time had expired due to a delay of the scenario external forcing data which are necessary to extend the hindcasts/forecasts beyond 2014 (the year when the forcing for the historical simulations end).

Table 4.4: Overview of the experiments undertaken with MPI-ESM-HR and estimated computer time.

Experiment	Model years (node hours)	Used in Quarter
Hindcasts (ens mem: r1, r2)	1000 (277 Thousand)	Q1
Hindcasts (ens mem: r3, r4)	1000 (234 Thousand)	Q2
Hindcasts (ens mem: r4, r5), Historical	500, 150 (240 Thousand)	Q3
Expired	(0, 0, 120 T.) 0 %, 0 %, 10 %	Q1, Q2, Q3

4.5 References

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5. Module E – Evaluation of the MiKlip Decadal Prediction System

Project: **bb0763**
Project title: **MiKlip II Module E – Evaluation of the MiKlip Decadal Prediction System**
Project lead: **Marc Schröder**
Reporting period: **01.01.2018 – 31.12.2018**

5.1 Description of work and summary of results

The PROVESIMAC project focuses on the evaluation of the decadal climate prediction system developed within the second phase of MiKlip (http://www.fona-miklip.de/) utilising satellite data. Satellite simulators for usage with MPI-ESM are developed for the Special Sensor Microwave Imager (SSM/I) and for the Special Sensor Microwave Imager and Sounder (SSMIS) utilising the CFMIP Observation Simulator Package (COSP, Bodas-Salcedo et al., 2011). On the reference side the SSM/I & SSMIS Fundamental Climate Data Record (FCDR) provided by the CM SAF (DOI: 10.5676/EUM_SAF_CM/FCDR_MWI/V003) is used which covers the period from 1987 to 2015 (inter-calibrated using SSM/I on the F11 satellite as reference).
The COSP SSM/I satellite simulator is applied to the MiKlip II pre-operational hindcasts to evaluate the predictive skill of the system. Simulated brightness temperatures for selected channels which are sensitive to water vapour content and to precipitation are used. Data from hindcasts driven with CMIP5 (ensemble size #=4) and CMIP6 (#=5) forcings is available. Hindcasts with CMIP5 forcing cover the full SSM/I & SSMIS observational period (1988-2014). Hindcasts with CMIP6 forcing currently cover the period from 1988-2008. Evaluation results are presented for the 22 GHz channel, which is sensitive to the water vapour content. The focus is on lead years 2-5 (Fig. 5.1).

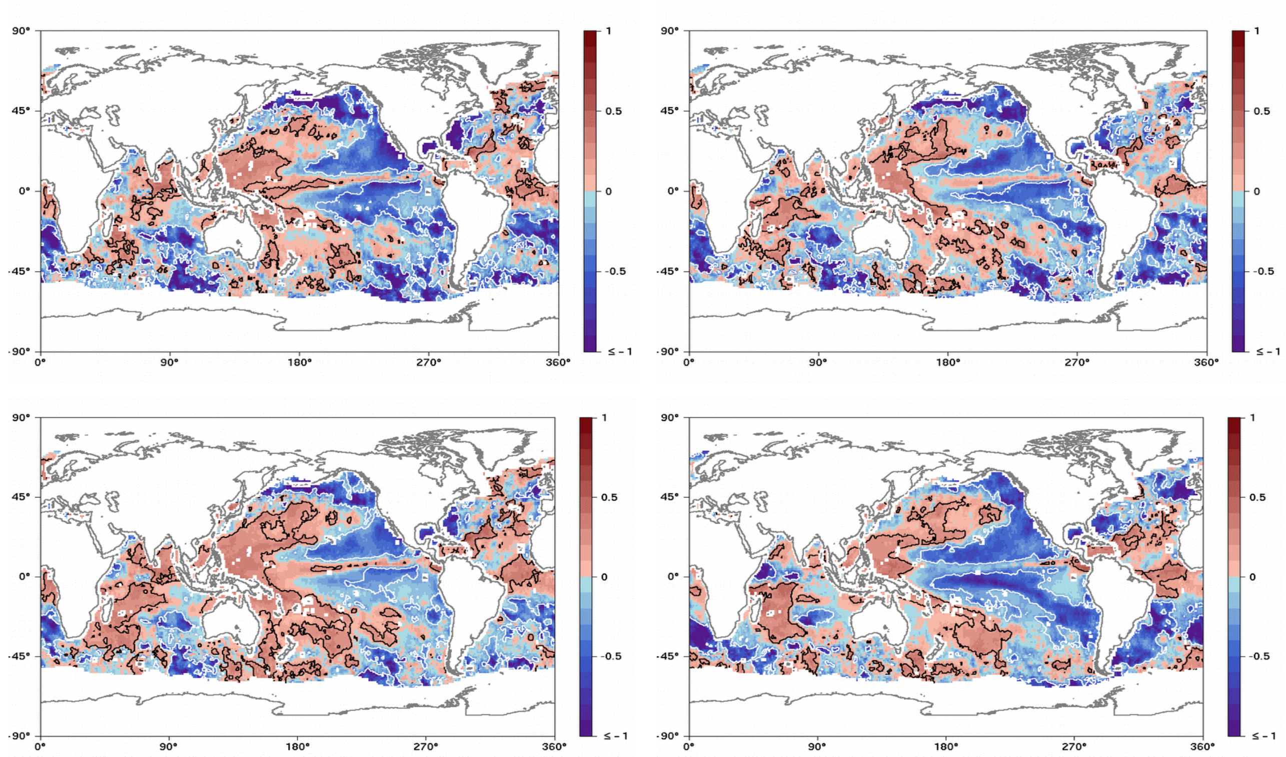

Figure 5.1: MiKlip II pre-operational system forecast evaluation for lead years 2-5 of brightness temperature for the 22 GHz channel of SSM/I and SSMIS. The CRPSS is shown. Climatology is used as reference forecast. The CM SAF FCDR (DOI: 10.5676/EUM_SAF_CM/FCDR_MWI/V003) is used as observational reference. Top left for hindcasts with CMIP6 forcing (ensemble size of #=4, time period 1989-2008). Top right for hindcasts with CMIP5 forcing (#=4). Bottom left for combined hindcast ensemble with CMIP5 (#=4) and CMIP6 (#=5) forcing (#=9, time period 1989-2008). Bottom right for hindcast with CMIP5 forcing (#=4, time period 1989-2014). Black/white contours show areas for which the results are statistically significant. Land areas are masked out due to lack of surface information.

5.2 References

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