Project report: Project report of bu0801
Project title: MiKlip II Module A: Determination of initial conditions and initialization
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Reporting period: 01.01.2016 – 31.10.2016

WP numbers follow the joint MiKlip II proposal (as used in the joint DKRZ proposal for 2017).

WP 1 Module A Coordination2 - Scientific activities conducted during the report time

To deal with model biases and initialization shocks in the MiKlip prediction system (MPI-ESM) for decadal climate predictions, we have been testing a new initialization method, which aims to reduce model initialization shock by filtering out the modes from initial conditions which cannot be represented by the climate model. The crucial and non-trivial part of this method is to derive the climate modes from the prediction system. The sections below summarize main steps achieved in the report period in designing this initialization method:

A To this end, we have derived a space of ocean-only modes (based on the multivariate empirical orthogonal function (EOF) analysis) from a number of historical runs performed with the MPI-ESM1.0 model. These historical CMIP5 simulations have been provided by the Max-Planck Institute for Meteorology.

B The initial conditions for retrospective predictions (initialized hindcasts) are prepared by projecting ocean synthesis anomalies (from GECCO2) onto a set of truncated climate modes and assimilating them into the MPI-ESM1.200p4 model. Since the sets of initialized decadal hindcasts are usually started once a year at the end of the year, we aimed to represent only December conditions by the EOFs, which simplified the reduced space tremendously since the seasonal cycle does not have to be represented. The caveat is however that only filtered initial conditions for Decembers spanning the period 1960-2014 become available. Therefore, the experimental set up for this assimilation run differs from the commonly used assimilation strategy used across the modules in MiKlip phase 1. To test how this new assimilation strategy will affect the assimilated properties, we have performed several assimilation experiments:

Commonly used setting for assimilation run	New setting
B1 Start the MPI-ESM model from the historical run and nudge the ocean and atmospheric states toward monthly mean states from the ocean and atmospheric reanalyses over 1960-2014.	**B2** Start the MPI-ESM model from the historical run and nudge the ocean and atmospheric states toward December monthly mean states from the ocean and atmospheric reanalyses. For this, we additionally repeated one of the ensemble members of the historical simulation for the period 1960-2015, to obtain restarts for the ends of Novembers. We have carried out the December assimilation run with the non-filtered initialized conditions (1960-2014).

B3 December assimilation run with the filtered initialized conditions (1960-2014).

Results from these assimilation experiments are provided in Figure 1 in terms of the mean state and the standard deviation for the December Atlantic meridional overturning circulation (AMOC). In the first column, the results for original GECCO2 synthesis are shown, in the 2nd and 3rd columns, those from all-months and December assimilation runs are shown, respectively. While the mean state from the assimilation runs might not necessarily be of interest for our experiments, since we assimilate not the mean but the anomalies of GECCO2, we find a surprising behavior in the AMOC from the one-month assimilation runs showing interrupted meridional streamfunction by some vertical structures. Also AMOC in the one-month assimilation runs exhibit somewhat weaker variability than in all-months assimilation run and the original GECCO2 ocean synthesis. Hence, before producing different sets of initialized hindcasts based on different truncation levels as we originally planned for 2016, we perform a more comprehensive analysis of the assimilation runs (to investigate the behavior of assimilated anomalies, understand the origin of the meridional streamfunction discontinuity and whether similar behaviors are observed in other ocean state properties), we will also conduct additional assimilation tests for different EOF truncation levels by the end of 2016.

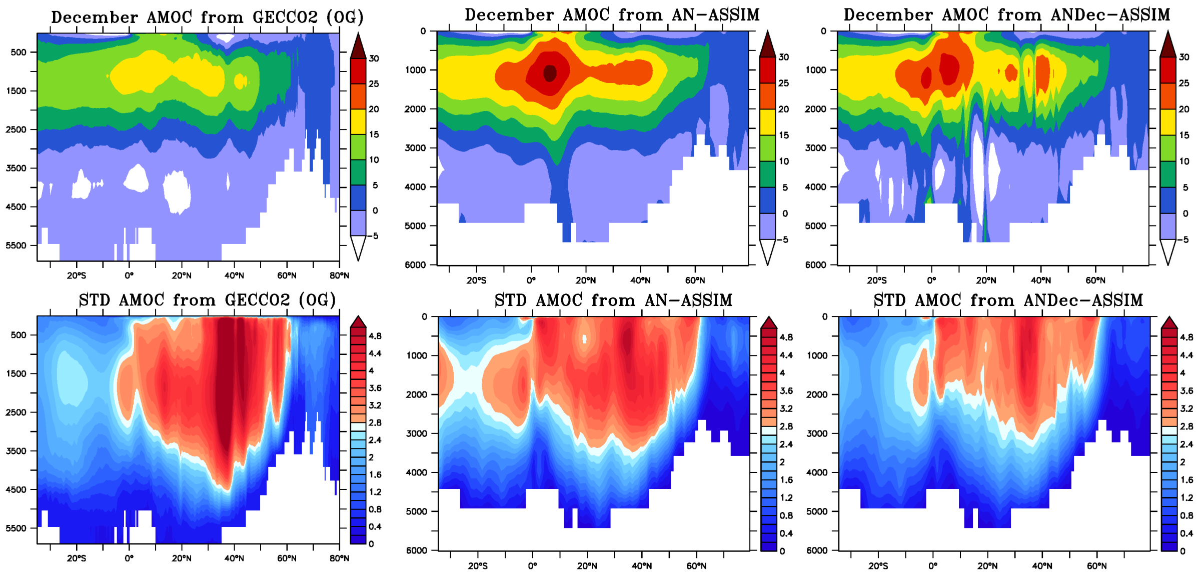

Figure 1: *AMOC time-mean and standard deviation (STD, in SV) from the assimilation runs and GECCO2 (based on Decembers over the period 1961-2013).*

WP 2 Pastland 2 - Scientific activities conducted during the report time

During the first year of MiKlip 2 the main focus of Pastland 2 was the implementation of a simple nudging scheme for the assimilation of land surface soil moisture data into the MPI-ESM 1.2.00. Currently, a first implementation is tested using AMIP type simulations with MPI-ESM-LR. Their analysis is ongoing, but first results demonstrate the implementation of the assimilation infrastructure into the model as well as its effect on several water fluxes on the land surface.

This work was preceded by a sensitivity study on the general effect of soil moisture initialization on the fully coupled MPI-ESM. This exercise is a follow-up to the Stacke & Hagemann (2016) paper which already demonstrated the effect of soil moisture initialization on land surface fluxes in an AMIP setting. The actual experiment consists of three ensembles with 10 members each running over a period of 10 years. While one ensembles is used as reference (initialized from a historic simulation) the other two are initialized with the monthly soil moisture minimum and maximum respectively retrieved from the historical run. The anomalous soil moisture state was preserved for the first two simulation months to allow other states to adapt to the drier/wetter conditions. Following this initial period, the simulations run freely for the remaining 9 years and 10 months. Similar to the earlier study, the soil moisture shows strong memory especially in the lower layers (Figure 2). In terms of feedback to other model components, the strongest effect is seen in river discharge for the wet initialization. In this rather extreme setup, river discharge increases by several orders of magnitude resulting in a pronounced freshwater peak that feeds low salinity water into the ocean. This results in ocean salinity anomalies which slowly spread over large parts of the ocean and last for several months and longer.

These simulations required a total of 4348 Node h. Thus, the experiments consumed about three times as much computing time as requested in our original computing time application.

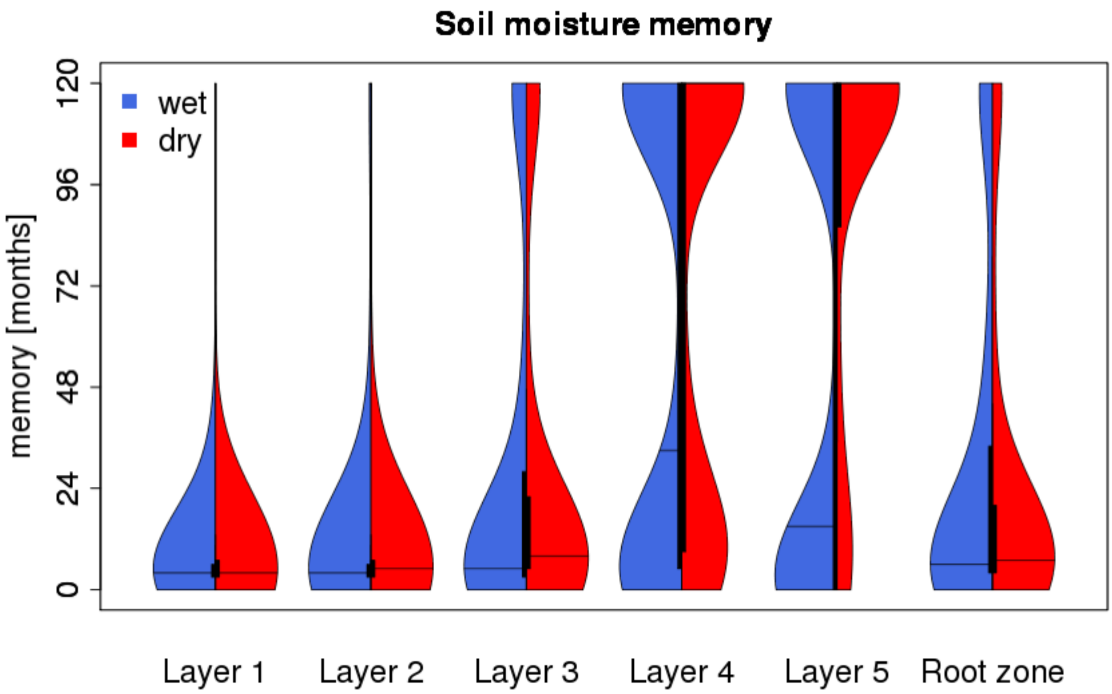

Figure 2: Memory distribution for wet (blue) and dry (red) soil moisture initalization in different soil layers

WP3: Atmospheric and Oceanic Data Assimilation & Ensembles Generation (AODA-PENG2) - Scientific activities conducted during the report time

WP3.1: Breeding techniques

A modified, non-standard Breeding technique has been used for constructing a set of disturbances on the atmosphere/ocean variables, such as surface pressure, temperature, salinity and zonal and meridional velocities. These disturbances are derived from an almost fixed initial model state and are added as additional disturbances on each given starting year/month for performing hindcast or a forecast. We planned the following steps for implementing the breeding technique into the prediction system. First of all we had technically to set up the exchange between the breeding routines and the LR coupled model system. The transition from the T31L31/GR30L40 to T63L47/GR15L40 was successfully done and the system was run on the Mistral computing system. Second we performed 10 year long hindcast, initialized with Bred vectors for the period from 1990 until 2000 (Figure 3). We used simplified rescaling scheme for adjusting the initial perturbations.

For the development phase, preliminary experiments and the hindcast we used around 23 000 node-h. We spend 6 000 node hours more than what we initially required, due to some complications connected with the physical construction of the perturbation amplitude. Additional tuning and experiments were necessary to investigate the problem. This issue is still under development.

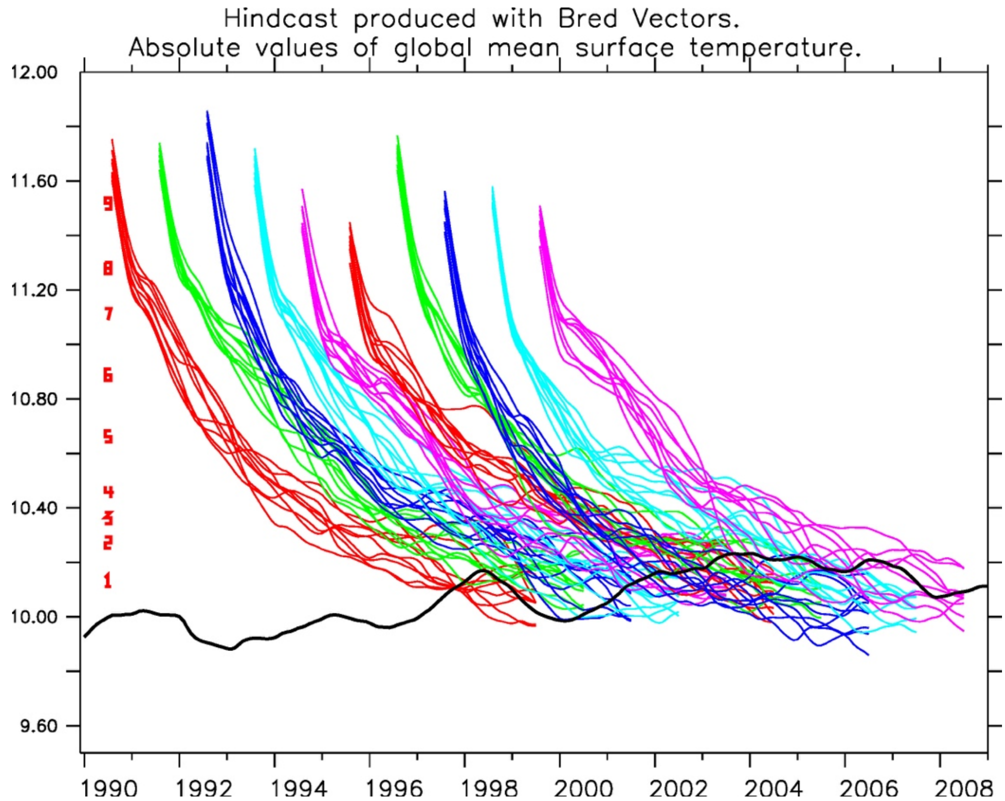

Figure 3: The absolute values of the global mean surface temperature with applied 12 months running mean for the BV hindcast from 1990 until 2000. The numbers of the plot show the global mean temperature after each of the ten sequent iteration steps for one ensemble member.

WP3.2: Ensemble Kalman Filter

The Ensemble Kalman Filter (EnKF) for MPIOM (MPI-ESM 1.0) has already been successfully implemented (Brune et al. 2015) in its global variant using the Parallel Data Assimilation Framework (PDAF, Nerger & Hiller 2013). In 2016, our work was dedicated to the improvement of the performance of the existing weakly coupled assimilation system with PDAF/EnKF used to assimilate ocean temperature and salinity and, similar to the central prediction system (Baseline1/Prototype) within MiKlip, nudging to ERA40/ERAInterim in the atmosphere.

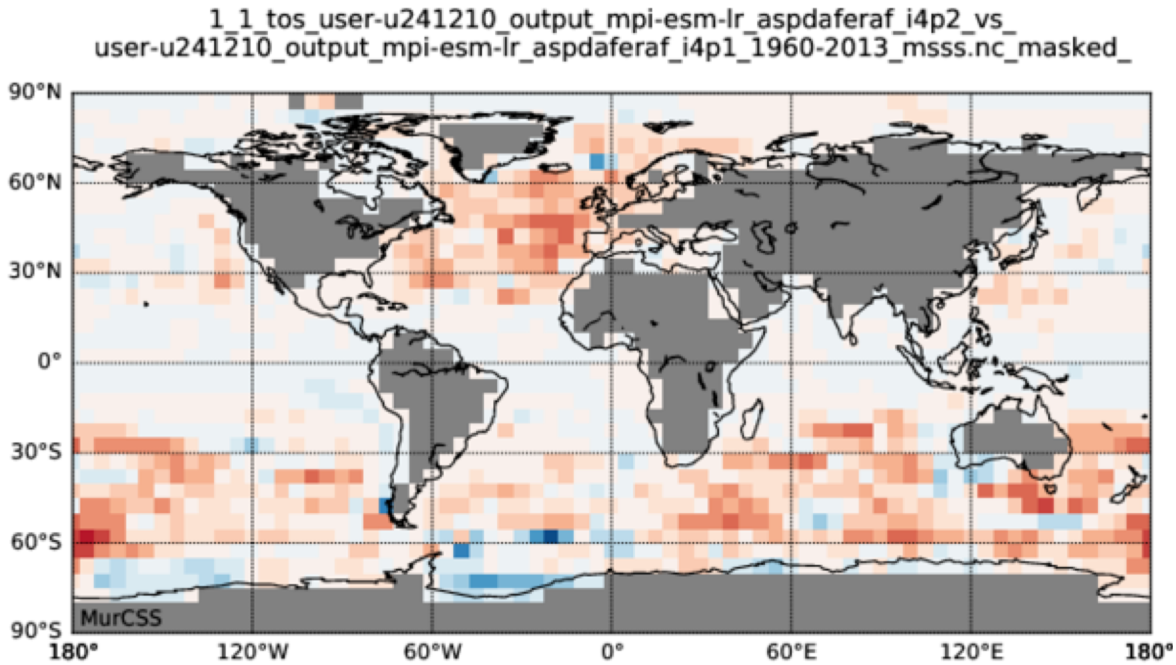

Figure 4: Difference in Mean Squared Error Skill Score of 1961-2014 yearly mean sea surface temperature between localized EnKF and global EnKF assimilation experiments.

We focused on two aspects: the increase in ensemble size from 8 to as large as 32, and the implementation of the localized variant of the EnKF. For a consistent comparison of all the assimilation setups we used the latest release 1.2 of MPI-ESM, issued in February 2016. Right after the model release we adapted the EnKF technical setup to the new model environment. We thereafter commenced with assimilations using the global variant but with different ensemble sizes: 8,16,24,32. By the end of September 2016, these tests had been accomplished.

Simultaneously, we technically implemented the simple localized variant of the EnKF with PDAF. We started to test this variant in October and continue assimilation tests and assimilation comparison until the end of 2016. As a preliminary result, the localized EnKF has improved the Mean Square Error Skill Score of sea surface temperature over the global EnKF almost everywhere (Figure 4). A short hindcast set is planned to be simulated based on the result of all this comparison, but most probably these simulations will not start before 2017.

We initially planned to use version 1.1 of MPI-ESM, released in 2015, but switched to MPI-ESM 1.2, when it became clear that this model version will supersede version 1.1. Since the release of v1.2 was in February, our planned schedule is shifted by two months. As a result, the small hindcast set initially planned for the end of 2016 will most probably shifted to the beginning of 2017. Nevertheless most of the allocated resources for 2016 have been used according to plan.

Comparison to 2016 request

Most of the allocated resources could be used as planned; some minor delays in the model version (WP3.2) could be compensated for by more extensive than planned use of the resources by other workpackages (WP3.1 and WP2). WP1 had to postpone initialized hindcast simulations due to unforeseen issues with the assimilation procedure but will result in a more robust implementation in 2017 (and hence a more sensible use of the resources).

A summary of the resources can be found below. As for the last column: the discrepancy between the top three rows and the last row represent the expired resources, which occurred mostly in the first quarter of 2016, when it was decided to wait for MPI-ESM 1.2. We expect that we will be able to use all remaining resources in 2016 within the project (either by WP1 or WP3.2, performing an additional reference experiment enabling a clean comparison of the new implementation against the old implementation using the new model version; which was originally not applied for).

WP	Node-h applied	Node-h granted	Node-h consumed
WP1: Improving ocean initial conditions and initialization methods (A-Coordination2)	53644		~ 3300
WP2: Parameter and state estimation of the land and biosphere (PastLand2)	765		~ 4600
WP3: Atmospheric and Oceanic Data Assimilation & Ensembles Generation (AODA-PENG2)	158.508		~ 110.000
Total	**226.228**	**167.409**	**~ 134.000**

Publications resulting from previous use of HLRE2/3

Brune, S., L. Nerger, J. Baehr, 2015: Assimilation of oceanic observations in a global coupled Earth system model with the SEIK filter, *Ocean Modelling,* 96, Part 2, 254 – 264.

Brune, S., A. Duesterhus, H. Pohlmann, W.A. Mueller, J. Baehr: Time dependency of the North Atlantic subpolar gyre evaluation in initialized decadal hindcasts with the global coupled climate model MPI-ESM, *to be submitted to Climate Dynamics*.

Romanova, V. and A. Hense, 2015: Anomaly Transform Methods Based on Total Energy and Ocean Heat Content Norms for Generating Ocean Dynamic Disturbances for Ensemble

Climate Forecasts. ClimDyn. DOI: 10.1007/s00382-015-2567-4

Romanova, V., A. Hense, S. Wahl, S. Brune: Skill assessment of different ensemble generation schemes for retrospective predictions of surface freshwater fluxes on inter and multi-annual timescales. *Meteorologische Zeitschrift, in review.*

Stacke, T. and Hagemann, S.: Lifetime of soil moisture perturbations in a coupled land–atmosphere simulation, Earth Syst. Dynam., 7, 1-19, doi:10.5194/esd-7-1-2016, 2016

Marini, C., I. Polkova, A. Köhl, D. Stammer, 2016: A comparison of two ensemble generation methods using oceanic singular vectors and atmospheric lagged initialization for decadal climate prediction. Monthly Weather Review, 144, 2719-2738, DOI: http://dx.doi.org/10.1175/MWR-D-15-0350.1