Project: **807**

Project title: **MiKlip II Module D – Synthesis**

Old title during MiKlip first phase: **A flexible forecast system for decadal climate predictions - FLEXFORDEC**

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Report period: **1.1.2016 – 31.10.2016**

## Overview

The basic objectives of MiKlip II Module D are the development of the central global decadal prediction and evaluation systems, 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. For the current report the development of the global prediction system attracted the majority of allocated computer time. As such we summarize here the benchmarks achieved for the development of the new system and the respective resources needed.

In general the project is responsible for providing all project partners with the newest central simulations of the prediction system. In contrast to previous versions, for the fourth development stage of MiKlip (DS4) a higher resolution was envisaged. For this, Module D has taken on the responsibility for the development of a higher resolved version of MPI-ESM (MPI-ESM-HR, atmosphere: T127L95, ocean: TP04L40), which now becomes one of the two versions of the MPI CMIP6 contribution (the other is MPI-ESM-LR). Within the allocated period the MPI-ESM-HR was tuned and the CMIP CORE experiments were performed to assess the overall performance of this model version (summarized in Müller et al., [2017]). Since the recommended CMIP6 forcing was not available these experiments were run with the CMIP5 forcing.

In addition, (the) decadal hindcasts were initialized and started. It was decided by the MiKlip steering group to use observational estimates from ERA40/ERAinterim for initializing the atmosphere and temperature and salinity from ORA-S4 for the ocean initialization. For the ocean initialization the anomaly initialization was recommended. Additionally, a new sea-ice assimilation was implemented based on anomalous values from the NSIDC data set. To date the first two ensemble members of the hindcasts are completed (60 initializations x 10 hindcast years) and the third member is underway. In addition, five historical runs are completed spanning the period 1850-2005. Their extension to 2030 is still underway and expected to be finished by the end of 2016.  Moreover, the output variables list was updated in accordance to the WCRP DCPP variables list and extended by the needs of the MiKlip partners.

## 1. Development of the MPI-ESM-HR climate model

For the fourth development stage of MiKlip (DS4) a higher resolution than during the first phase of MiKlip (DS1-DS3) was envisaged, with a resolution of ECHAM6 of T127L95 and MPIOM resolution of TP04L40. This so called MPI-ESM-HR setup is based on the latest version of MPI-ESM-1.1 and was developed and tuned during the reporting period. An extended spin-up of the control run was necessary in order to reach an acceptable equilibrium in the sedimentation rate of the HAMOCC component. After the spin-up of MPI-ESM-HR the CMIP CORE experiments were run. These consist of a 500 years control run, an abrupt 4 x $CO_2$ run, a 1% $CO_2$ increase run and several historical simulations. Because CMIP6 forcing was not available these experiments were run with the CMIP5 forcing. Most of the output variables are available in standardized format according to the CMIP5 CMOR standard, including a new variable lists from CMIP6 DCPP  that was furthermore extended by MiKlip partners needs.  The data is made available via the MiKlip-server to all MiKlip partners.

MPI-ESM-HR is well tuned and a description of the model and some results are prepared in Müller et al. [2017]. Climate sensitivity is ~3°K 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 drifts of global mean ocean temperature and salinity also exhibit only little magnitudes and are comparable to the lower resolved version of MPI-ESM-LR. This indicated that the model is in a stable state. The Atlantic meridional overturning circulation at ~ 26°N has a value of 16Sv on time mean average, which is close to observations. The CMIP5 forcing is similar to previous versions of MPI-ESM such as described in Giorgetta et al. [2013].

In the North Atlantic, strong SST biases of ~5°C are still present in both configurations of MPI-ESM-LR and MPI-ESM-HR. This is associated with a too zonal North Atlantic current and too zonal atmospheric storm tracks. The increase of atmospheric resolution in MPI-ESM-HR, however, reduces the bias of the upper level zonal winds and atmospheric jet stream position. This results in a decrease of the storm track bias over the northern part of the North Atlantic/European region, for both winter and summer season. Associated with the reduction of the zonal wind bias is an improvement of the blocking frequency over the European region, most pronounced during summer seasons (Figure 1). In addition, for winter seasons, the NAO and related storm track variations are improved in MPI-ESM-HR compared to MPI-ESM-LR (Figure 2). It can be shown that this improvement is associated with an improved representation of the transient eddy momentum fluxes and subsequent eddy-mean flow interaction in the MPI-ESM-HR configuration compared to MPI-ESM-LR.

## 2. Development of the MiKlip-DS4 decadal prediction system

### Full field versus anomaly initialization

During the first phase of MiKlip several initialization approaches have led to two sets of yearly initialised ten-year long decadal hindcasts from 1960 onward. The first set of hindcasts (baseline 1) is based on anomaly initialization with ocean data from ORA-S4. The atmosphere is assimilated by full fields of ERA40/ERAinterim. The ensemble size is ten. The second set of hindcasts (prototype) includes two 15-member ensembles initialised by full fields of GECCO2 and ORA-S4. Both sets of hindcasts were produced with a modest resolution of MPI-ESM-LR (T63L40 in the atmosphere and 1.5° in the ocean). A decision had to be made on which is the initialization method for the DS4 prediction system.

Analyzing the prototype system, which is using full-field initialization technique in the ocean, we found discrepancies in the North Atlantic ocean heat budget, that is, the sum of transient heat fluxes at the surface and in the interior due to ocean transport does not balance heat content tendencies. Discrepancies in the assimilation experiments with full-field nudging exceed those with anomaly nudging (used in the baseline systems) by a factor of 2-3.

Nudging in the ocean, in general, induces changes in both ocean heat content and ocean transport when compared to the corresponding unconstrained historical experiment. As opposed to the resulting evolution of the ocean heat content, induced changes in ocean transport differ severely between full-field and anomaly nudging, indicating that the resulting transports are of spurious nature. In addition, ocean transports differ also remarkably when applying full-fields of different ocean state estimates. The spurious transport signals continue to be present in the free running hindcasts, a clear expression of memory in our coupled system. In forecast mode, on annual to inter-annual scales, ocean heat transport appears to be the dominant driver of North Atlantic heat content. Thus, in this region, the spurious transport inherited from the assimilation leads to an initialization shock followed by a significantly reduced prediction skill of ocean heat content when using full-field instead of anomaly initialization (Figure. 3) [Kröger et al., 2016]. Therefore we use anomaly initialization in the ocean for the DS4 (pre-operational) MiKlip decadal prediction system.

**The DS4 assimilation experiment**

To get the starting fields for the hindcasts first an assimilation run had to be performed. For this purpose, the ERA40/ERAinterim data were interpolated to the T127/L95 resolution of the ECHAM6 model. Additionally, anomalies of the ORA-S4 data were calculated and interpolated to the TP04L40 MPIOM model grid. This interpolation was straight forward since we had used it already in the first phase of MiKlip for baseline1. As a next step, the initialization of sea-ice as a new component of the assimilation was considered. Here, we used a routine that is available in MPIOM based on a statistical relationship between sea-ice concentration and sea-ice thickness [Tietsche et al., 2012]. Therefore we needed only the sea-ice concentration observations (not the sea-ice thickness). However, observational sea-ice concentration fields are problematic before the satellite era (before 1979). We have considered two sea-ice products (sea ice concentration from the HadISST data set and from NSIDC) and two initialization techniques (full-field values and anomalies). The analysis of test runs led us to use anomalies of sea-ice concentrations from NSIDC from 1979 onwards and a climatology before as shown in Figures 4c-f. The NSIDC data set is also used for seasonal predictions [Bunzel et al. 2016]. Also we  refrained from using full field assimilation of sea-ice, as the biases in the model are large and the resulting freshwater release in the free run could lead to spurious effects in the density driven dynamics in high latitudes.

During the production of the assimilation run an imbalance emerged causing the global mean temperature to be 0.2 K cooler in the assimilation run than in the historical simulations. By excluding the assimilation in the boundary layer (lowest four atmospheric levels) we reduced the imbalance to 0.1 K (Figure 3a). Additionally, the CO2 uptake in the ocean component of the HAMOCC model was too small (even negative). In order to try to increase the CO2 uptake the assimilation run was started from an extended spun-up initial HAMOCC fields. This improved the CO2 uptake.

**Hindcasts**

Producing the hindcasts with the MPI-ESM-HR we experienced many interruptions during the model run (most often with the error message: run-time limit exceeded or communication error). After restarting the model the simulations continued until the next failure some model-years ahead. Solving this problem delayed us several weeks before we could re-compile the model with the help of DKRZ (using intel-MPI 2017). Currently ensemble member 1 and 2 are finished and 3 is underway. A detailed evaluation of the hindcast is still pending. A high prediction skill is present in North Atlantic temperature and Arctic sea-ice area already with the first ensemble member (Figure 3b-d).

| Experiment | Node hours (Model years) | Used in Quater |
|---|---|---|
| Control-Spinup | 50 Thousand (264) | Q1 |
| Control | 90 T.(500) | Q1, Q2 |
| 1% CO2 | 30 T (150.) | Q1 |
| Abrupt 4 x CO2 | 30 T. (150) | Q1 |
| 5 x Historical | 140 T.(5x150) | Q1, Q2 |
| Assimilation | 110 T. (600) | Q2, Q3 |
| Ensemble member 1 | 110 T. (600) | Q3 |
| Ensemble member 2 | 110 T. (600) | Q3, Q4 |
| Ensemble member 3 | 55 T. (300) | Q4 |
| Historicals (not finished) | 40 T. (200) | Q3, Q4 |
| Expired | 21T., 68T., 153T. | Q1, Q2, Q3 |
| Others | 44T | Q1-Q4 |
| **Total** | **1051 T** | |

| | | |
|---|---|---|
| **Total (granted)** | **1347 T** | |

Table 1: Overview of the experiments undertaken with MPI-ESM-HR and estimated computer time. 1347 Thousand node hours were granted for MiKlip II Module D in 2016. These were shared according to 1/6, 1/6, 2/6 and 2/6 during the four quarters of 2016, i.e. 224 T., 224 T., 448 T. and 448 T. Only during the third quarter a considerable amount of computer time had expired due to problems with the Fortran compiler. (table from 26.10.2016)

## References


Bunzel, F., D. Notz, J. Baehr, W. A. Müller, and K. Fröhlich, 2016: Seasonal climate forecasts significantly affected by observational uncertainty of Arctic sea ice concentration, Geophys. Res. Lett., 43, 852-859, doi:10.1002/2015GL066928.

Müller, W. A., et al., 2017: A high resolution version of the Max-Planck Institute Earth System Model (MPI-ESM-HR), in preparation for JAMES.

Kröger, J., et al., 2016: Evaluation of full-field initialization for the MiKlip decadal prediction system: An initial shock in the North Atlantic, in preparation for Climate Dynamics.

Tietsche, S., D. Notz, J. H. Jungclaus, J. Marotzke, 2012: Assimilation of sea-ice concentration in a global climate model - physical and statistical aspects. Ocean Science Discussion, 9, 2403-2455, doi:10.5194/os-9-19-2013.

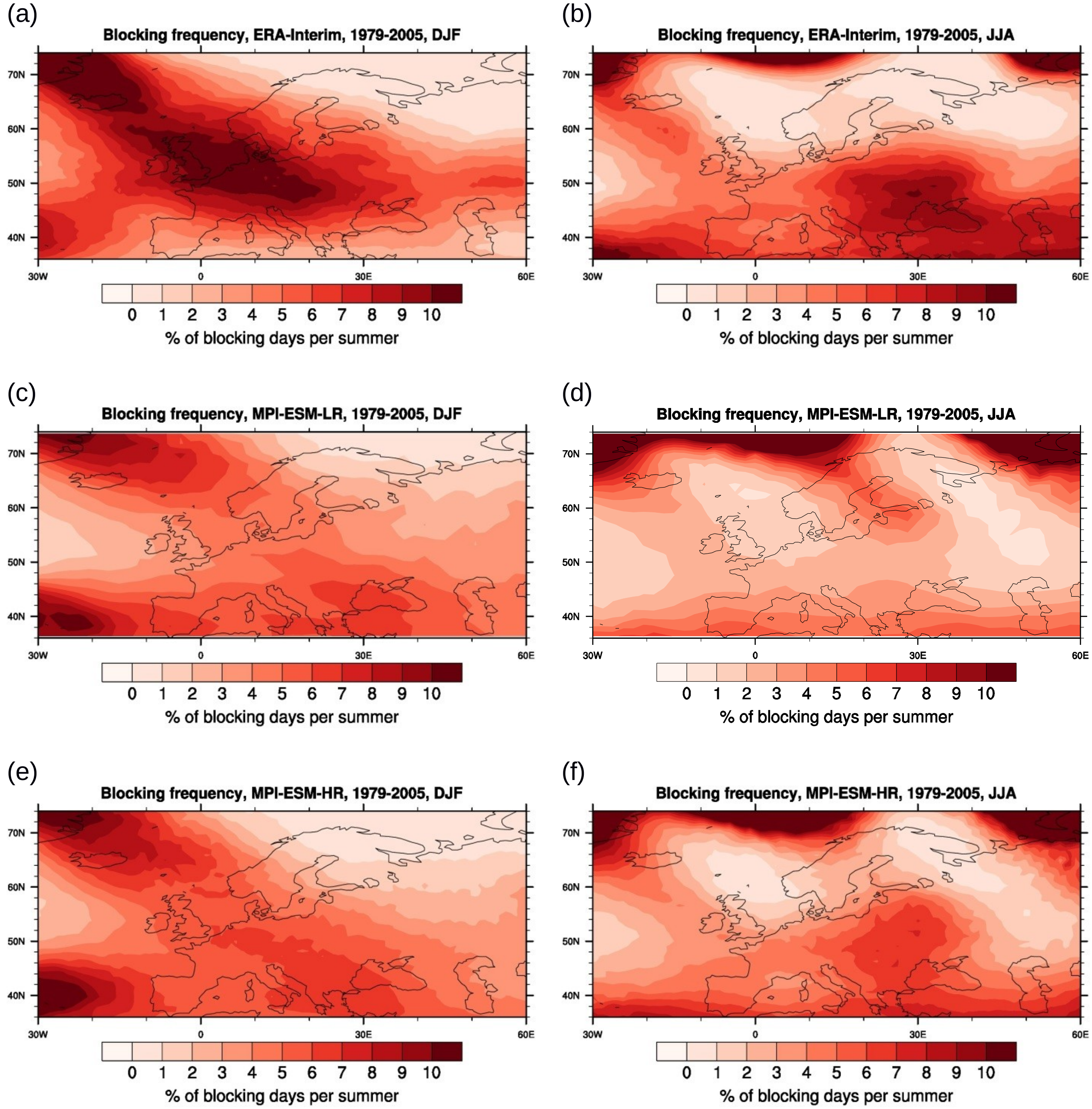


**Figure 1:** Blocking frequencies for (a,c,e) winter (DJF) and (b,d,f) summer (JJA) for (a,b) ERA interim, (c,d), MPI-ESM-LR and (e,f) MPI-ESM-HR. Shown is the percentage of blocking days per season based on Scherrer et al [2006]. The results for MPI-ESM-LR and MPI-ESM-HR are based on a mean of blocking frequencies of 5 historical experiments. Here the period 1979-2005 is considered. Units are in percentage [%].

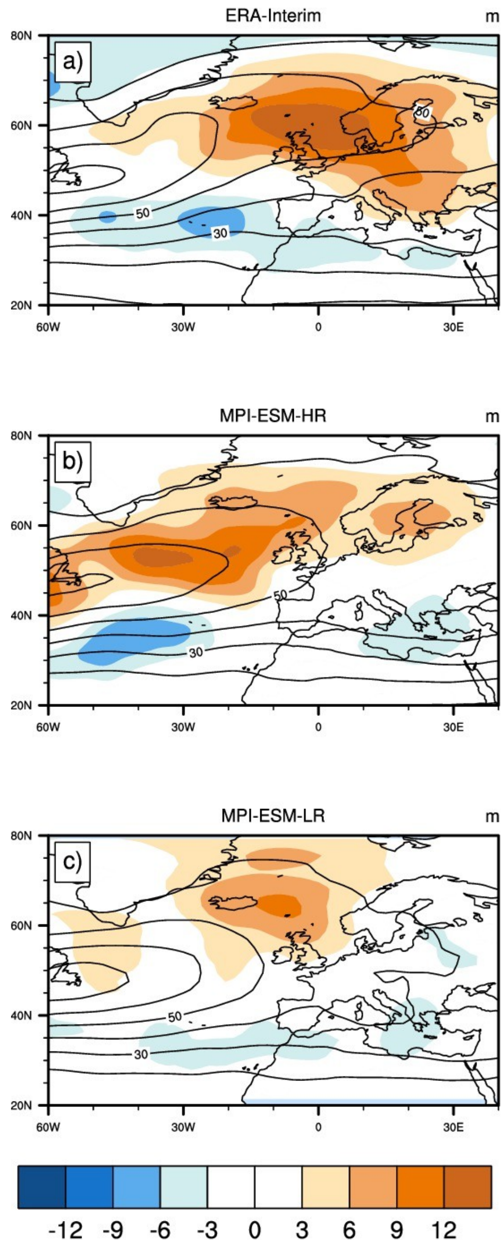


**Figure 2:** Composites of storm tracks (2-6 day band-pass filtered geopotential height at 500hPa) with respect to positive minus negative NAO phases for (a) ERAinterim, (b) MPI-ESM-HR and (c) MPI-ESM-LR. Here the period 1979-2005 is considered and the for the models 5 members of the historical runs are used. Contours show climatological mean. Units are in meter.

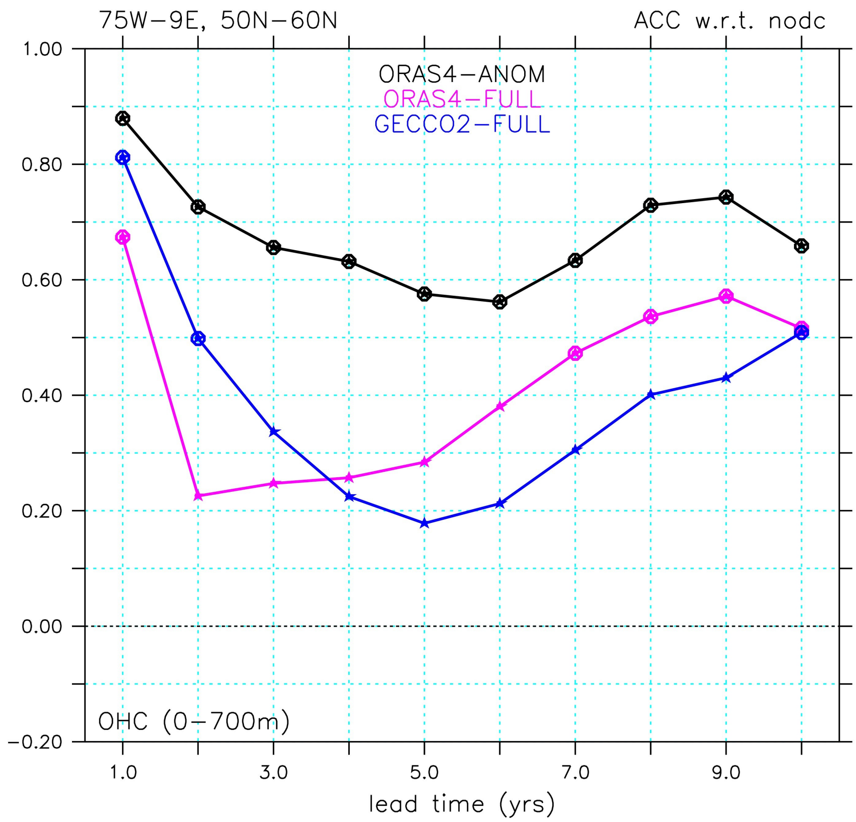


**Figure 3:** Anomaly correlation coefficients (ACCs) of hindcasts of OHC in the upper 700m in the SPG region (50N-60N, 75W-9E) as function of lead time; correlations were calculated for baseline-1 (ORAS4-ANOM, black), prototype-oras4 (ORAS4-FULL, magenta) and prototype-gecco2 (GECCO2-FULL, blue) with the observational estimate from NODC. Circles indicate significance at 95%.

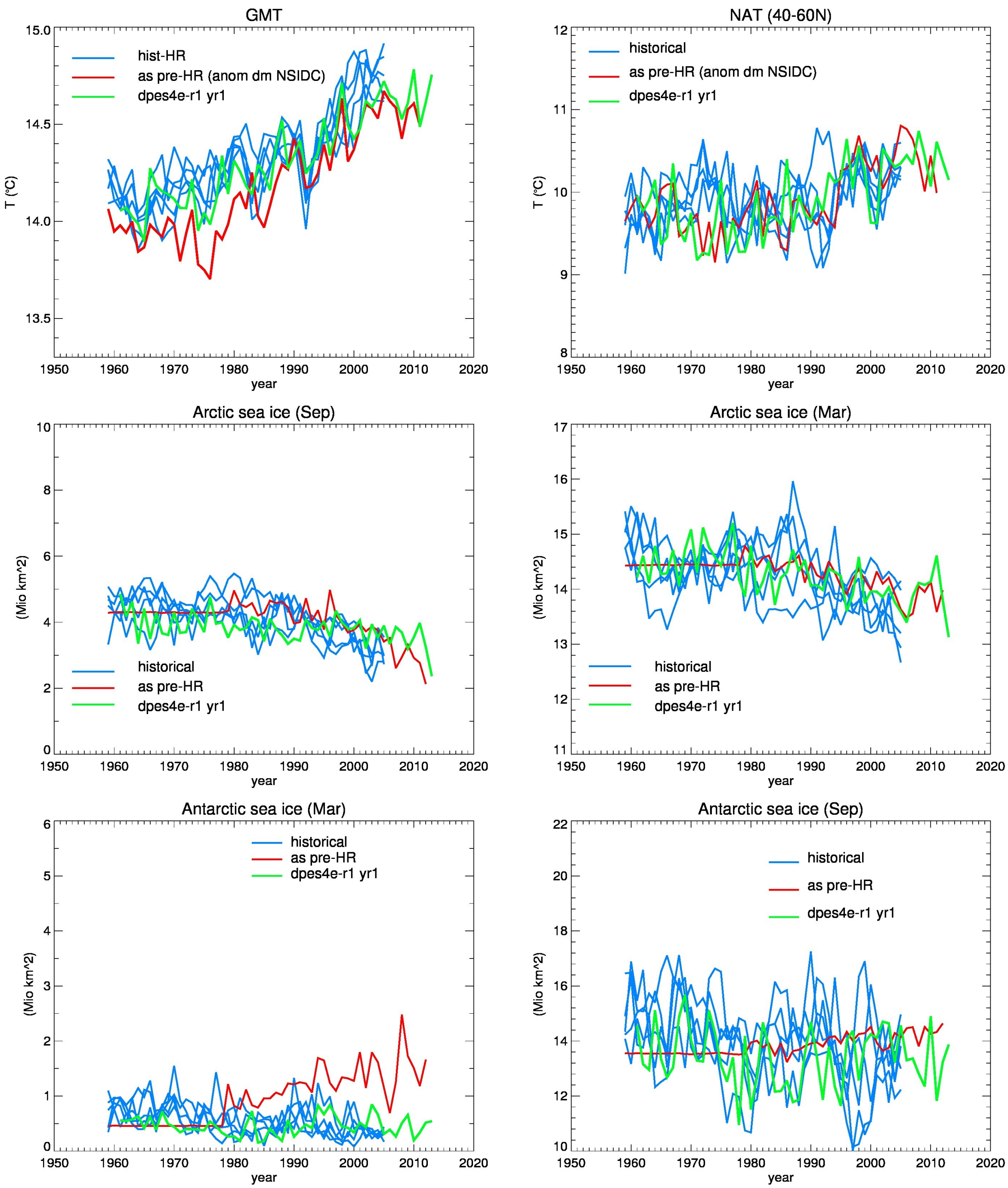


**Figure 4:** Preliminary results from MPI-ESM-HR simulations of global annual mean temperature (a, GMT), North Atlantic annual mean temperature (b, NAT), Arctic sea-ice area in September (c) and March (d), Antarctic sea ice area in March (e) and September (f) for the assimilation run (red), the 5 ensemble members of the historical simulations (blue), and the first year of the hindcasts (ensemble member 1, green).