Atmospheric and Oceanic Data Assimilation Plus ENsembles Generation (AODA-PENG)

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FONA Decadal Climate Prediction BMBF — MiKlip

The Project AODA-PENG aims to provide improvements to the MiKlip prediction system in three ways: (i) we will incorporate state-of-the-art ensemble techniques from weather prediction into the prediction system formed by the MPI-ESM, (ii) we apply 3D variational (3DVar) and EnKF data assimilation techniques in the atmospheric and oceanic component, and (iii) we will analyse the aerosol forcing being an important but still very uncertain external forcing factor.

Improvement of oceanic initial conditions

Sebastian Brune, Johanna Baehr (Uni Hamburg)

Aim: implementation of ocean assimilation

Method

- Full state ocean temperature and salinity assimilation in MPIOM (within the fully coupled MPI-ESM) using Ensemble Kalman Filtering (EnKF)
- Implementation of the Parallel Data Assimilation Framework (PDAF, Nerger et al 2005, http://pdaf.awi.de) for the EnKF analysis step

Preliminary Results

- PDAF implemented, with "offline" exchange of information between MPIOM and PDAF.
- Assimilation tested using synthetic observations derived from a high-resolution NCEP forced MPIOM simulation (STORM). Tests with synthetic observations were run for two start dates (1996 and 1997), using four ensemble members, an analysis step of one month, and a conservative estimate for the observation error.
- Tests with synthetic observations demonstrate the feasibility of MPI-ESM/PDAF (Fig. 1). In comparison with MiKlip baseline 1, even these early results indicate potential improvements (e.g., Labrador Sea, Fig. 2).

Next steps

- Comprehensive tests for ensemble size, and the treatment of observation error,
- Synthetic observations will also be used to test the assimilation for sparse data,
- Combination with AT method for ensemble generation,
- Preparation to include real observations (EN3).

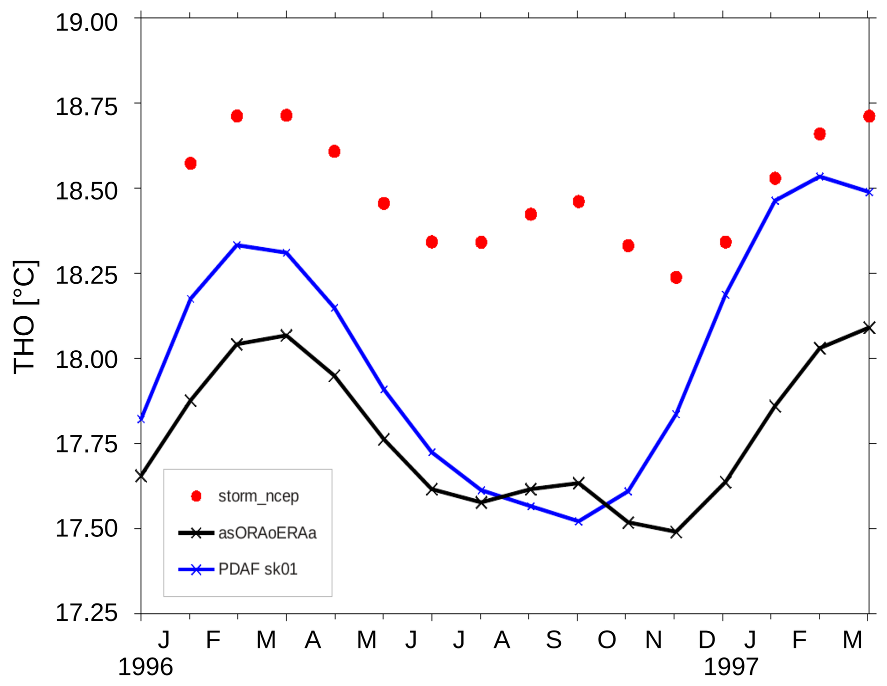

Figure 1: Time series of global mean ocean temperature (at 17m depth) for 1996 - 1997: from MPI-ESM/PDAF assimilation run with monthly EnKF interval (blue), from the STORM simulation as used for the assimilation in MPI-ESM/PDAF (red), and MiKlip baseline 1 assimilation run from which the PDAF assimilation run was initialized (black).

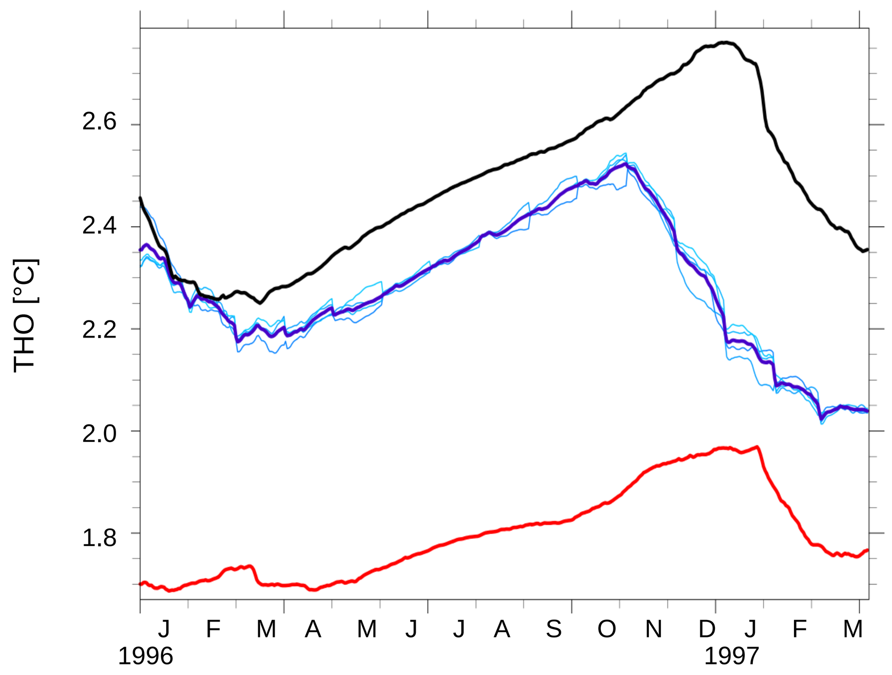

Figure 2: Time series of Labrador Sea temperature at 200m depth time series from MPI-ESM/PDAF assimilation run with monthly EnKF interval (blue), from the STORM simulation as used for the assimilation in MPI-ESM/PDAF (red), and MiKlip baseline 1 assimilation run from which the PDAF assimilation run was initialized (black).

Direct effect of aerosols

Muhammad Kaleem, Andreas Bott, Andreas Hense (Uni Bonn)

Aim: Quantitative analysis of the direct effects of aerosols on global climate by using ECHAM6

Method

- Comparison of ECHAM6 ensemble simulations with and without aerosol effect

Experimental design

- Two control simulations with (CON-AER) and without (CON-NAER) aerosols from 1995-2008 (AMIP-style)
- From each control simulation, an ensemble was generated from 5 restart files (one year apart, currently: 1998-2002). The model was integrated over 5 years (1995-1999) for each of the 5 ensemble members.

Preliminary Results

- Cooling over land and warming at 500hPa due to the presence of aerosols in the atmosphere, see Fig. 3.
- Correlation coefficient (Fig.4) for CON-AER and CON-NAER shows random effects while we expected larger correlation over south India and central Africa as we only selected the two neighboring grid-points of AOD over those areas and correlated it with global temperature field.

Next steps

- Increase of ensemble size to 10 members and integration time to 10 years, include ECHAM6-HAMMOZ.
- Multi-variant analysis (e.g. ANOVA-2) to separate effects due to aerosols from boundary forcing and random effects
- Investigation of direct, semi-direct and indirect effects of aerosols

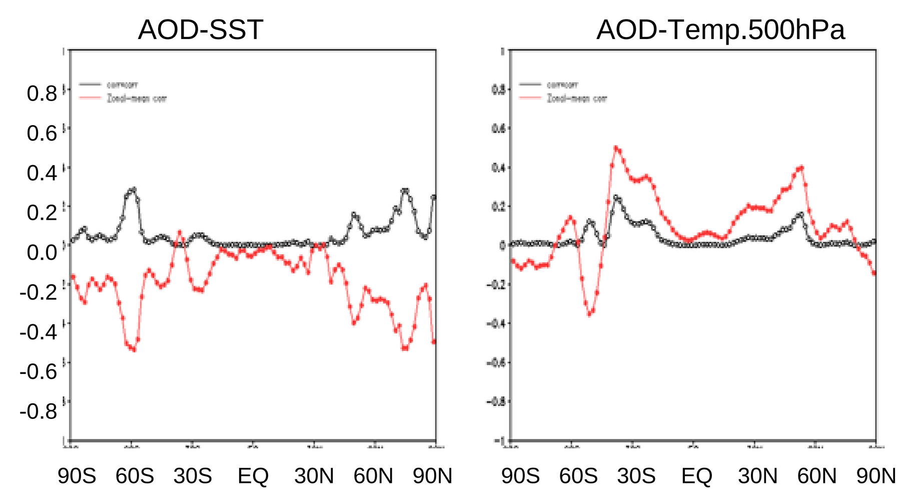

Figure 3: Calculation of ensemble average yearly mean zonal mean temperature correlation (red line) and correlation square (black line) at 500hPa from 1995 to 1999.

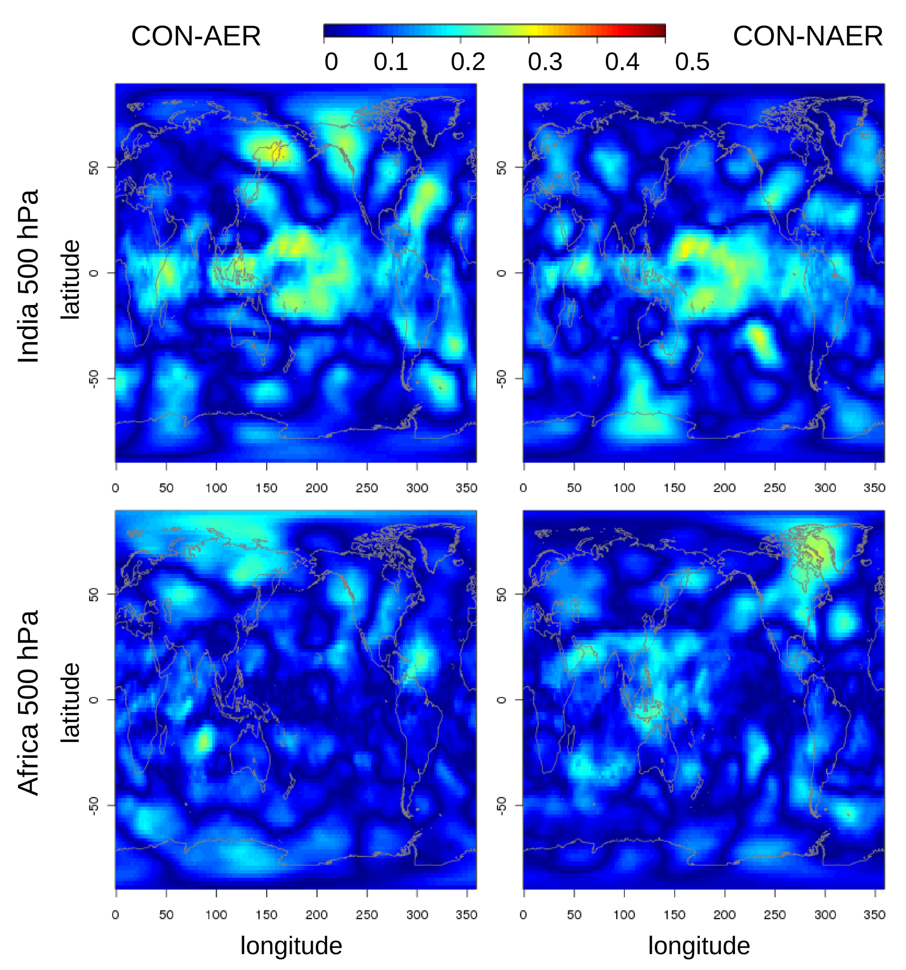

Figure 4: Calculation of the control yearly mean correlation coefficient for two neighboring grid points over south India and over central Africa at 500hPa CON-AER [left] and CON-NAER [right] from 1995 to 2008.

Improvement of atmospheric initial conditions

Ketan Kulkarni, Luis Kornblueh, Wolfgang Mueller (MPI-M), Andreas Rhodin (DWD)

Aim: transferring the current operational assimilation methods at DWD to the atmospheric component of MPI-ESM (ECHAM6)

Method

- Adaption of the global data assimilation system of DWD to ECHAM6 and implementation of 3DVAR/LETKF (localized Ensemble Transform Kalman Filter),

Advantage

- full assimilation cycle allows for potentially using a higher degree in uncertainty in the models state by using error covariance matrices estimates

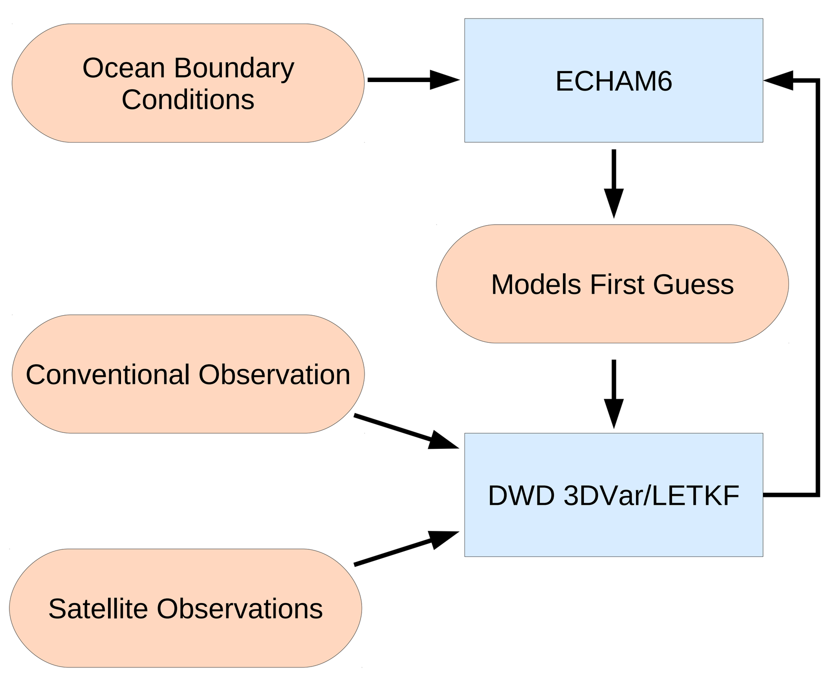

Figure 5: Basic workflow for using standard weather prediction assimilation cycle

Development of ensemble strategies

Vanya Romanova, Andreas Hense (Uni Bonn)
Jürgen Kröger, Jin-Song von Storch (MPI-M)

Aim: Development of ensemble strategies and extracting uncertainties which grow over seasonal and decadal time scales

Method

- Test Anomaly Transform(AT) and breeding methods
- Monitor growth of the uncertainties by selecting appropriate norm for ocean and atmosphere
- Select the slow modes which represent physical processes on decadal time scale and project into the initial conditions

Preliminary Results

- Investigate Anomaly Transform as alternative to breeding
- Perturb the initial conditions of the ocean part of a coupled model; select a metric: total energy (1) and ocean heat content (2):

$$\|Z_1\| = \frac{w_u}{2}\int u'^2 dV + \frac{w_v}{2}\int v'^2 dV + \frac{w_\rho g}{2\rho_0}\int \frac{\rho'^2}{\rho_z} dV \quad (1)$$

$$\|Z_2\| = w_T c_p \int \rho T' dV \quad (2)$$

- Select a time period for creating the energy matrices (lowpass filter) and provide orthogonal initial conditions
- Include STORM data constrains to determine the rescaling factor
- Perform ensemble runs, evaluate the instability growth and ensemble spread (Fig.3)

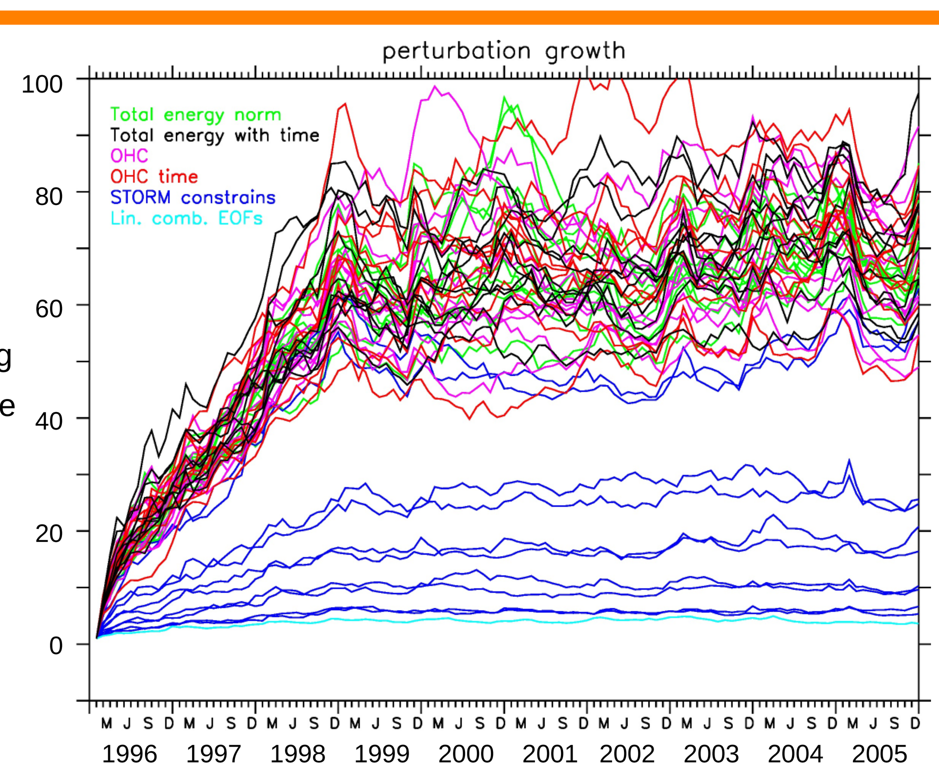

Figure 6: Time series of energy perturbation growth for each member of the five ensemble simulations initialized with total energy norm including seasonal anomalies (Total energy norm) and decadal anomalies (Total energy norm with time); and ocean heat content norm based on seasonal anomalies (OHC) and decadal anomalies (OHC time); fifth ensemble uses the total energy norm and the amplitudes are constrained to STORM data (STORM constrains). One single run which is initialized with amplitudes equal to the linear combination of the first five orthogonal modes of the STORM constrained fields (Lin. comb. EOFs) is also shown on the plot..

Next steps

- Use AT method to create initialization for the prototype forecast system
- Evaluate the AT based fields within MiKlip Module A
- Develop breeding for low resolution model version
- Compare anomaly transform and breeding
- AT will be applied in initialization scheme for oceanic data assimilation with MPI-ESM/PDAF
- At MPI-M, coupled singular vectors will be tested with respect to their improvement of the ensemble spread on decadal timescales compared over lagged initialization in individual components.

Synthesis

Wolfgang Müller, Ketan Kulkarni, Holger Pohlmann (MPI-M)

Aim: Assessment effectiveness of decadal predictions of a coupled system, considering coupled assimilation and ensemble generation.

Preliminary Results

- Verification of predictions with different initialization strategies, including simplified nudging for atmosphere and ocean (Fig. 7).

Next Steps

- Transfer of technical framework for ensemble initialization and assimilation methods in atmosphere and ocean to current version, and tests in hindcast simulations
- Merge methods from improved atmospheric and oceanic initializations to investigate feasibility of coupled assimilation

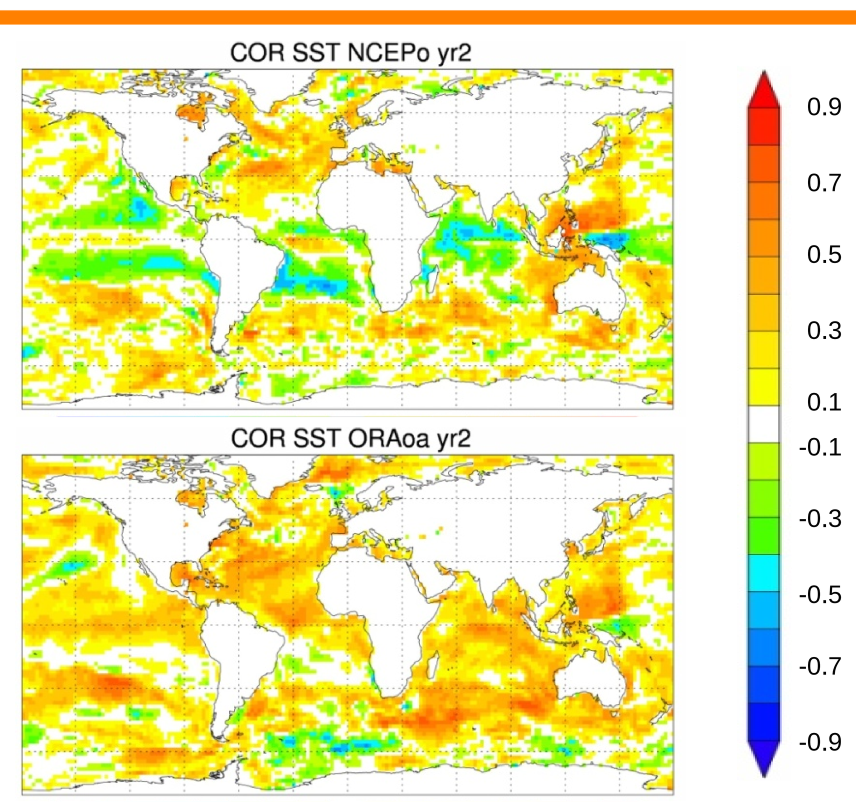

Figure 7: Correlation coefficients of sea surface temperature between HadISST and forecast after year 2 for version 0 (above) and version 1 (below) of the baseline coupled model

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