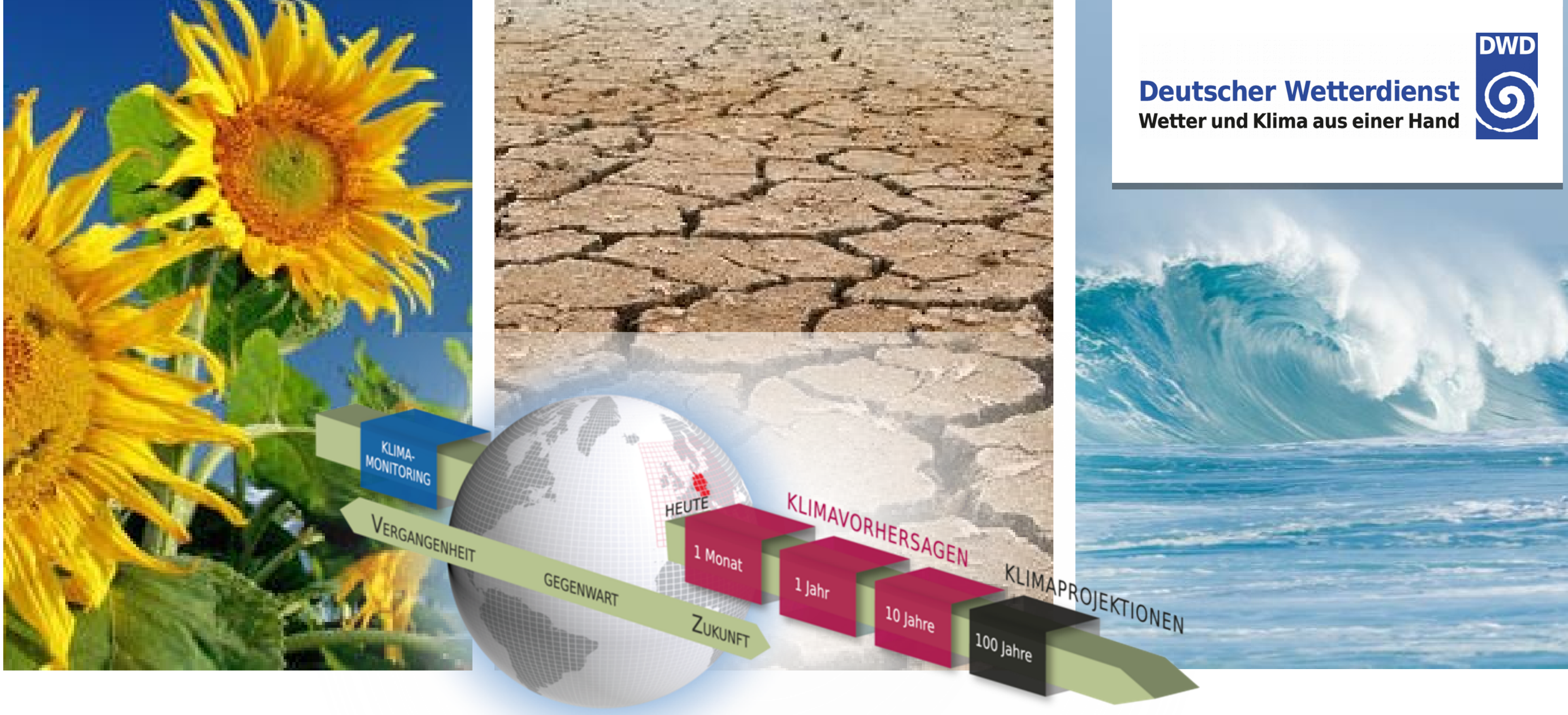

Climate Predictions with MPI-ESM: Recent Achievements and Challenges

Wolfgang A. Müller,
with support of many MiKlip members
S2D, Boulder CO, 18.09.2018

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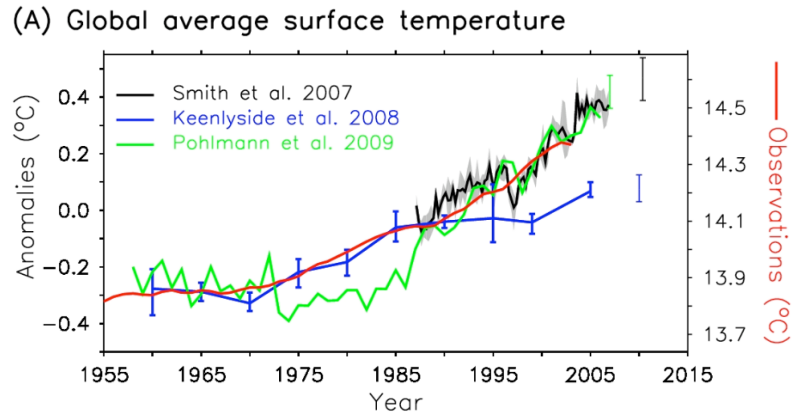
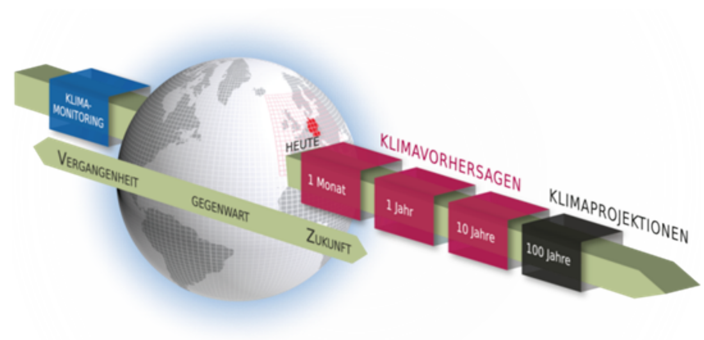
FONA Mittelfristige Klimaprognosen BMBF
MiKlip

Climate Prediction with MPI-ESM
From „scratch“ to operational within a decade

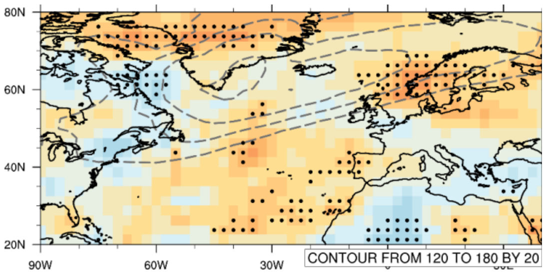
- S2D predictions in various EU-projects (N. Keenlyside, DEMETER, ENSEMBLES, SPECS ...)
- 2008/2009 First steps in decadal predictions (Keenlyside et al. 2008, Pohlmann et al., 2009)
- 2009 Seasonal Pediction WG launced at MPI-M
- 2011 MiKlip (Near-Term CP) project launched
- 2016 Seasonal predictions become part of the operational workflow at DWD (talk by A. Paxian B2-07)
- 2017 DWD become GPC of WMO-LRWF
- 2018 DWD become GPC of WMO-ADCP (WCRP-GC Near-Term Climate Predcition)
- 2019 MiKlip ends and handover decadal prediction system to operational workflow at DWD
- Provision of Decadal Predictions for CMIP5/CMIP6
- Here: Typical questions that come along with development of MPI-ESM for climate predictions …



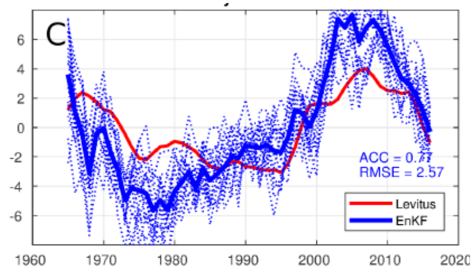


Contents:

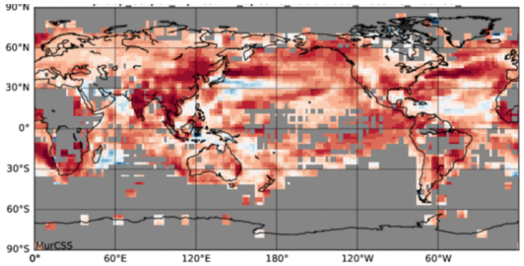
- Higher resolution, bias reduction and decadal climate predictions (e.g. NA storm tracks)
- Improving Earth system components and seasonal climate predictions (e.g. land surface)



- Need of a model-consistent assimilation for climate predictions
  - Full-field vs anomaly Initialisation
  - Ensemble Kalman Filter Approach



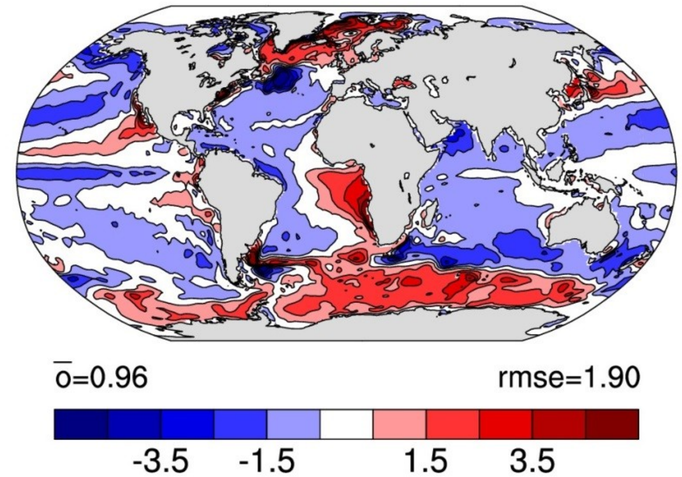
- Bias adjustment as a powerful tool to improve reliable climate information (e.g. calibration)



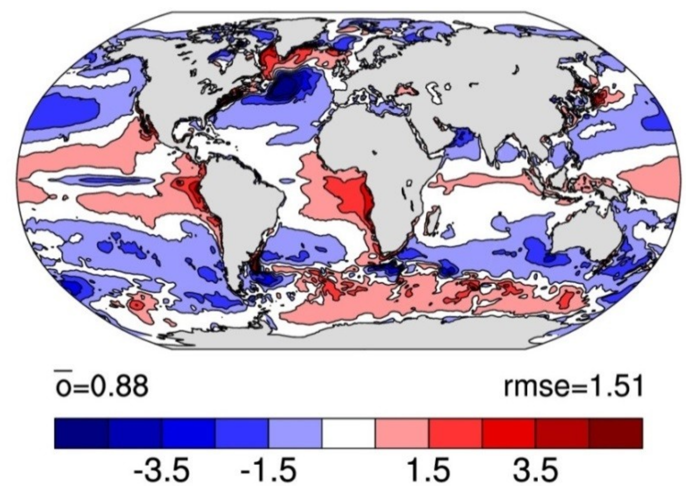
Higher Resolution and Mean Bias (SST)

- Two configurations of MPI-ESM1.2 (both core models for CMIP6)
  - LR: T63L47/1.5° (~50myr/day)
  - HR: T127L95/TP0.4° (~20myr/day)
- Both, well-balanced radiation budget and stable ocean circulation
- General decrease of mean bias of 20% across the board of HR compared to LR
- Long-standing patterns of mean bias (e.g. SST in upwelling regions, cold tongue…
- Increasingly frustrating is the North Atlantic SST bias, upto >6°C

LR minus Levitus



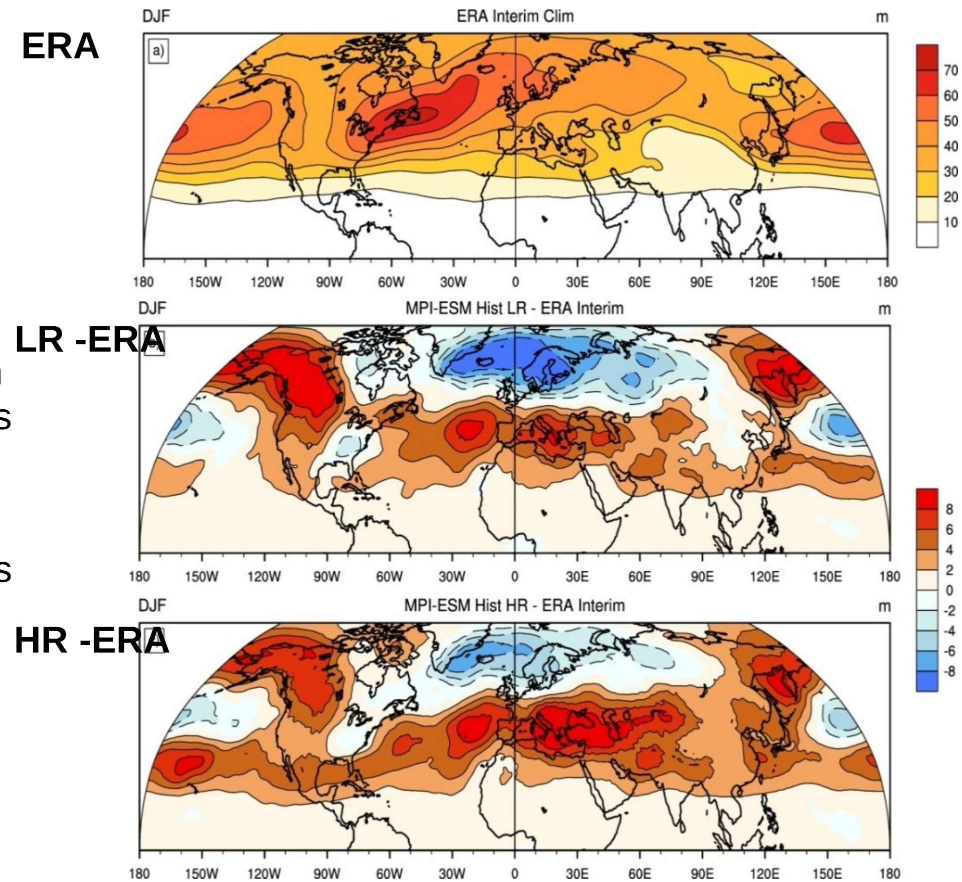
HR minus Levitus



Higher Resolution and Storm Tracks Bias

- Higher (atmospheric) resolution results in reduced bias of higher order moments in ECHAM6/MPI-ESM (Hertwig et al., 2014)
- Overall similar bias structures of winter storm track in both versions with an overestimated zonal structure
- However, increase of resolution improves North Atlantic storm tracks in higher latitudes, which is related to bias reduction of upper level zonal wind (U200, not shown)
- Improvement of NAO variability (e.g. E-P Fluxes in jet exit region)
- Reduction of U200 bias also shown during summer, together with improvement in blocking frequency.

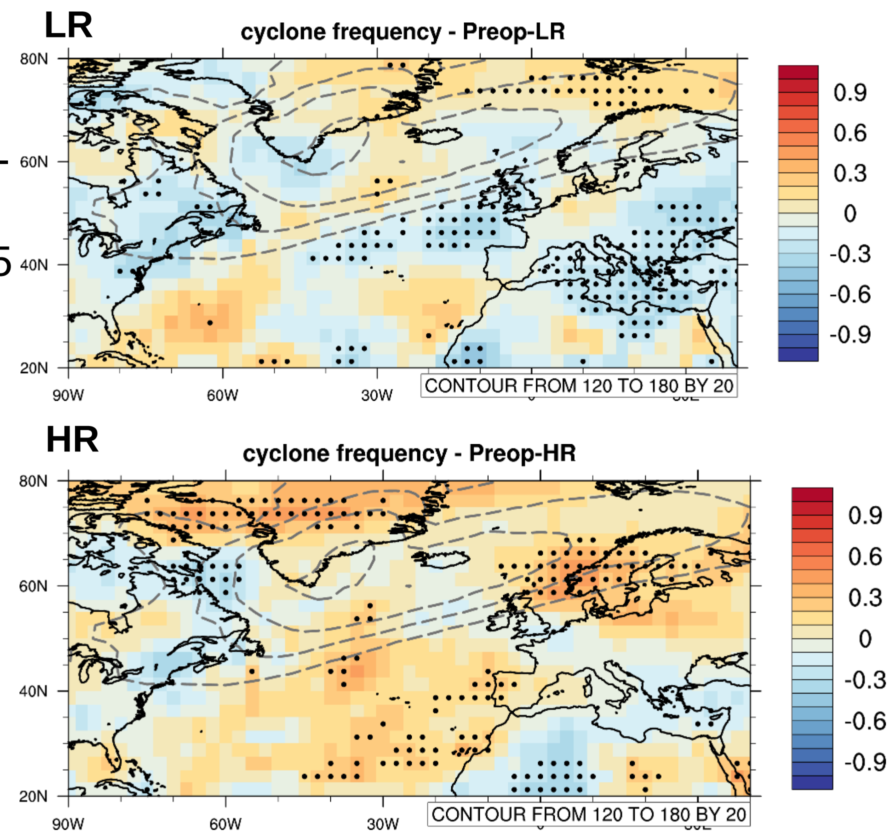
Variance of bandpass filtered GPH500 for winter



Müller et al., 2018, JAMES

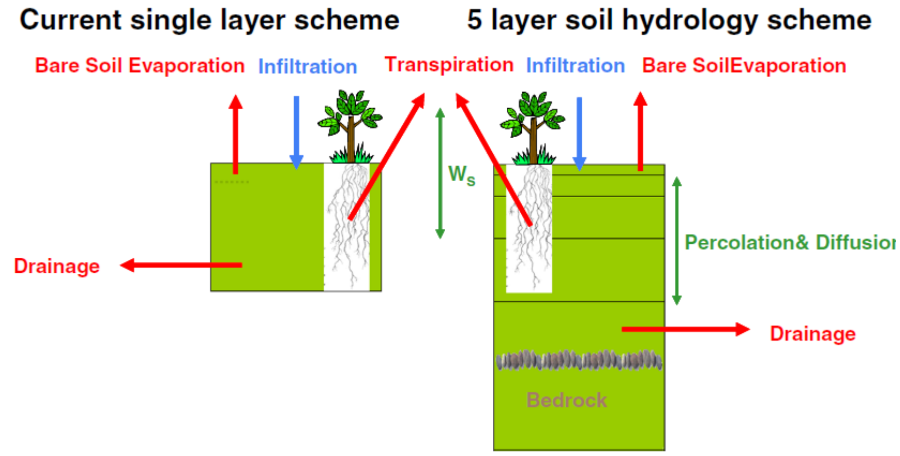
Higher Resolution and Storm Track Predictions

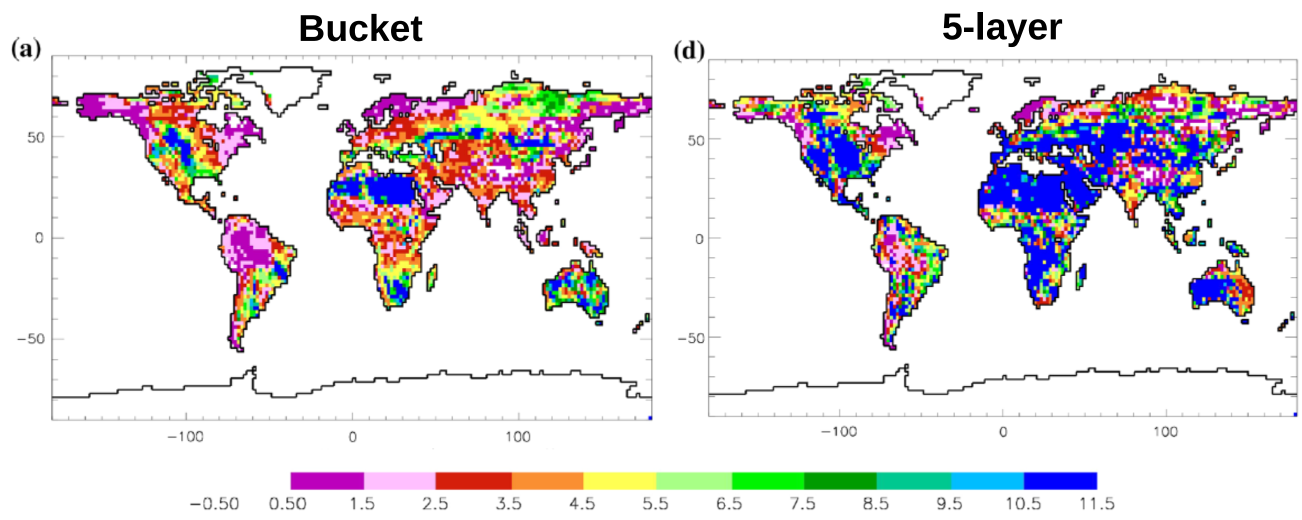
- Hindcast with CMIP5 forcing, LR and HR, 1960-2012, 10 (5) members
- Significant increase of skill (ACC wrt ERA-Interim) in winter (OCT-MAR) cyclone frequency, HR compared to LR, here yr2-5 (Mareike Schuster, FU Berlin)
- Simliar results for winter storm track, windstorm frequency
- Significant increase of skill in winter yr2-5 blocking



Effect of improved soil hydrology scheme on soil moisture memory

- New soil hydrology scheme: 5-layers plus layer below root-zone
- Soil moisture memory is of several months upto a year and generally enlarged with 5-layer scheme
- Soil moisture memory is particulary enlarged during dry season where SM buffer is present below root zone

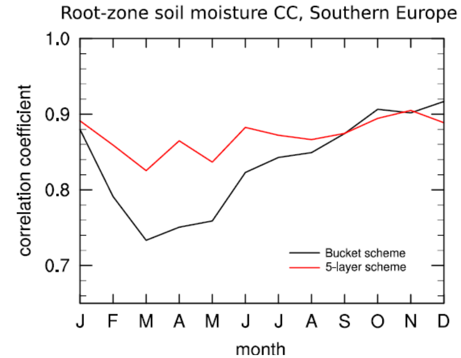


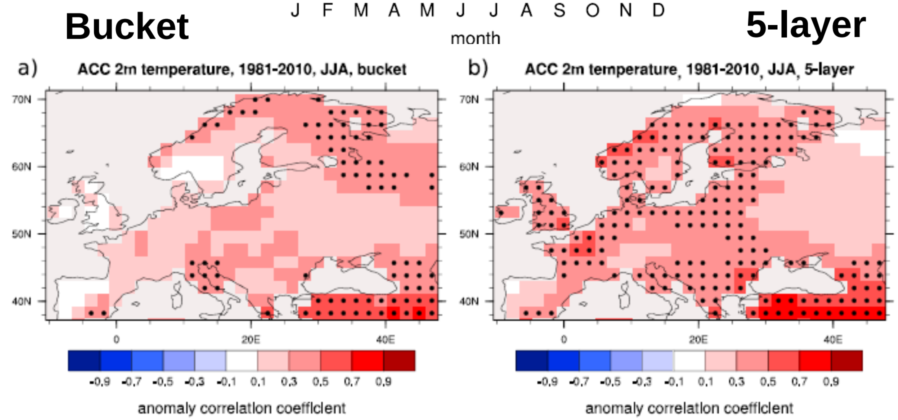


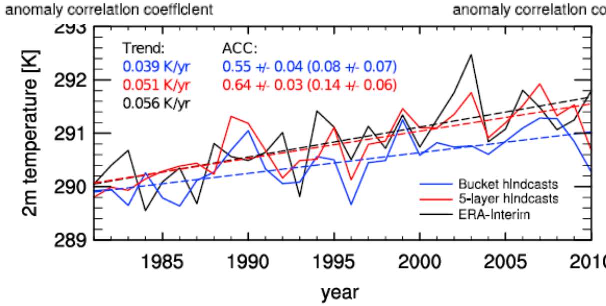
Hagemann et al., 2015, ClimDyn

Effect of improved soil hydrology scheme on seasonal climate predictions: surface layers

- Summer (JJA) hindcasts initialized May, 10 members, bucket and 5-layer soil model, MPI-ESM-LR
- Increase of soil moisture correlation in assimilation in 5-layer (upper panel)
- Improves the prediction skill of T2m in JJA in 5-layer compared to bucket over Europe (middleand lower panels)
- Due to water storage below root-zone, e.g. during dry season available water is evapotranspirated relatively fast in bucket, but is kept in 5-layer scheme



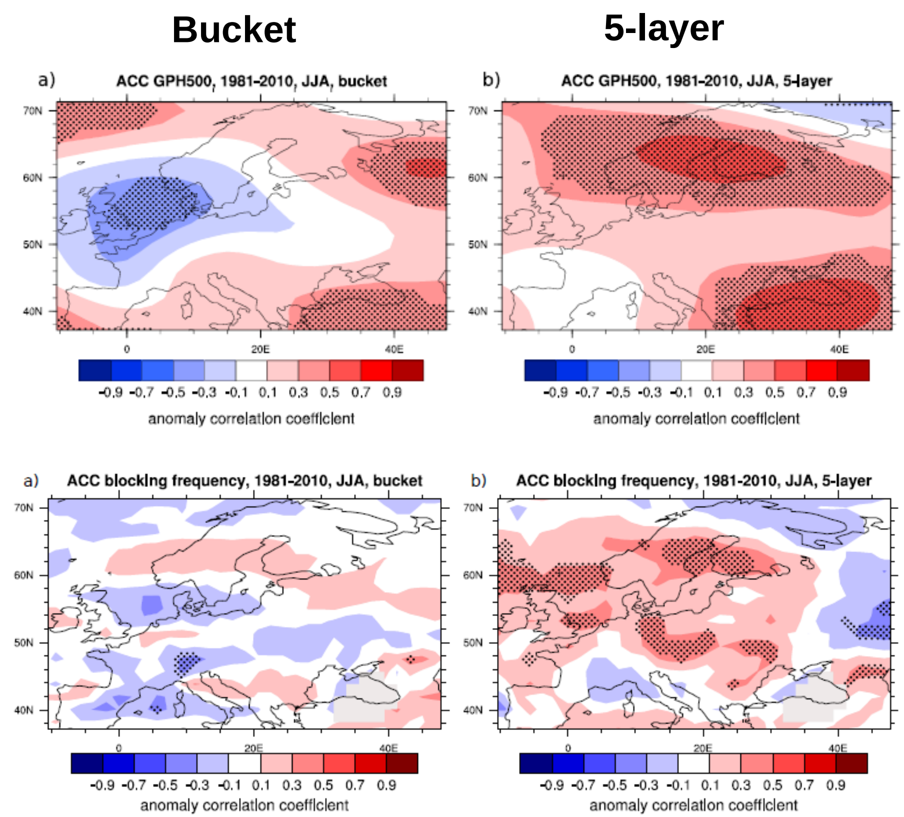




Bunzel et al., 2017, GRL

Effect of improved soil hydrology scheme on seasonal climate predictions: upper layers

- Improved soil moisture scheme also enhance skill in upper layers and „possibly“ large-scale circulation
- Predictions with 5-layer scheme show higher and significant ACC in Northern Europe in GPH 500hPa (upper)
- Predictions of JJA Blocking frequency are also improved (lower), but in this analysis dominated by single events (e.g. 2003)



Bunzel et al., 2017, GRL

Summary Model Development

- Fundamental limitations of prediction skill by long-standing bias (e.g. SST North Atlantic and storm tracks)
- A higher-resolution version of MPI-ESM1.2 does improve higher-moment biases (e.g. higher-latitude NA storm tracks, blocking, in winter and summer)
- This result in improvement of decadal prediction skill of NA storm tracks

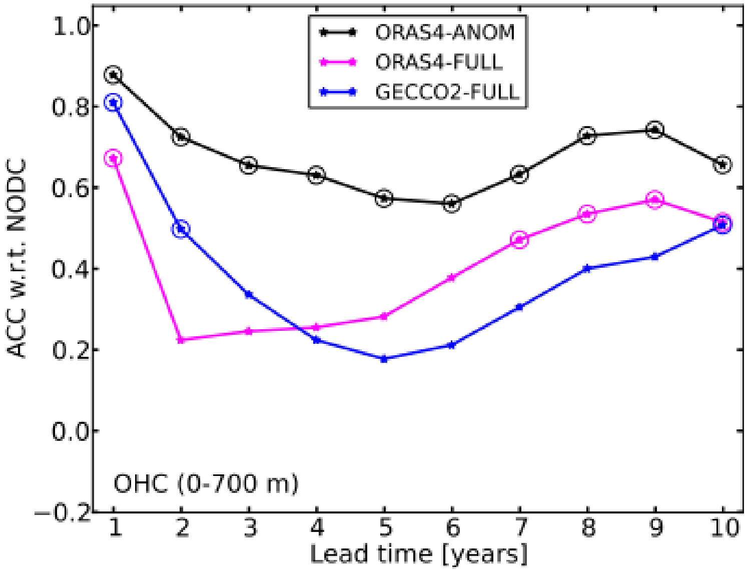
- Implementation of improved soil scheme increase the memory of soil-moisture regionally up to 1 year
- This result in an improvement of seasonal predcition skill, e.g. in Europe during summer, for surface (temperature) and upper layers (geopotenial 500hPa).
- This may have impact on prediction skill of large-circulation (e.g. blocking), though needs more testing.

The Initialization Struggle with MPI-ESM

- A specific target in MiKlip: Finding the right intialization method (with focus on the ocean component and decadal predictions)
- Starting with Anomaly Initalization (AI, Pohlmann et al., 2009, 2013, Matei et al., 2012, Müller et al., 2012)
- Replaced by **Full-Field Intialization** (FF, Polkova et al., 2014, Kröger et al., 2017)
- For CMIP6: Back to „Anomaly Initialzation“ (Poster H. Pohlmann P-B2-11)
- Beyond CMIP6: **Ensemble Kalman Filter** (EnKF, Brune et al., 2017)
- Survey of Methods (Polkova et al., 2018, submitted):
  - Full Climate Mode Initialization (talk Y. Polkova B2-12)
  - Ensemble Dispersion Filter (Kadow et al., 2017, talk C. Kadow B2-11)
  - Breeding Methods (Romanova et al., 2017)

Full-field Initialization (FF)

- Full-fields initialization is considered as alternative to Anomaly I. (e.g. Smith et al. 2013, Hazeleger et al., 2013, Carassi et al., 2014, Belucci et al., 2015, Volpi et al., 2016 …)
- Two sets of 15-member ensemble with FF, 1960-2015, yearly initialized, GECCO2 and ORAS4, ERA in the atmosphere.
- Compared with 10-member AI
- Drop of skill in North Atlantic OHC for FF



OHC, SPG region, ACC w.r.t NODC,
Circles hindcast outperform historical

Kröger et al., 2017, Clim Dyn

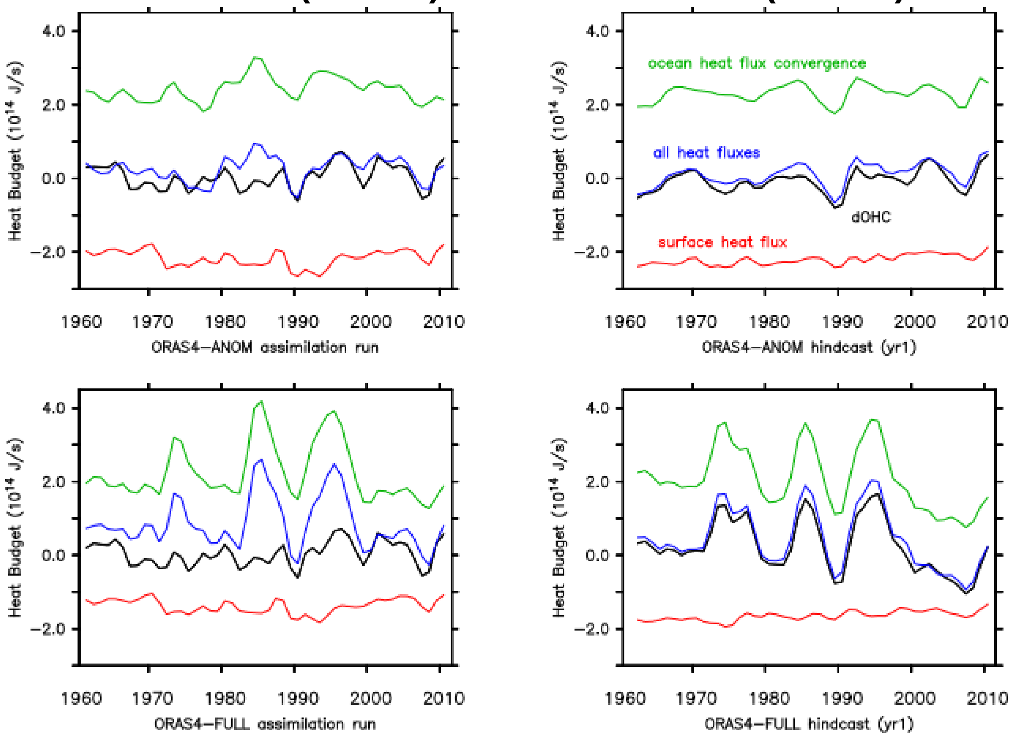
Ocean Heat Content (OHC) Budget, SPG Region

Change of OHC (dOHC) = lateral + surface heat fluxes

Assimilation (0-700m) **Yr1 (0-700m)**

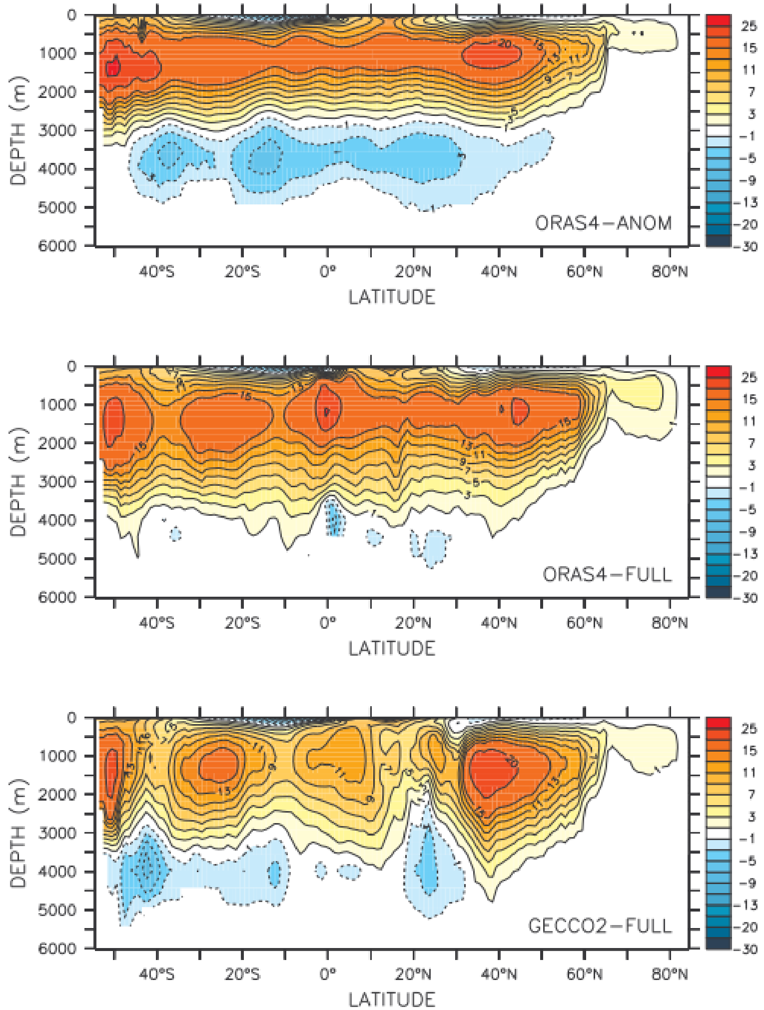
ORA_AI

ORA_FF



- In assimilation, dOHC is NOT balanced by surface and lateral heat fluxes (FF>AI)
- Deviations stem from large anomalous heat flux convergence through lateral boundaries
- The free running model (hindcast) then balances dOHT towards lateral heat fluxes

Kröger et al., 2017, Clim Dyn



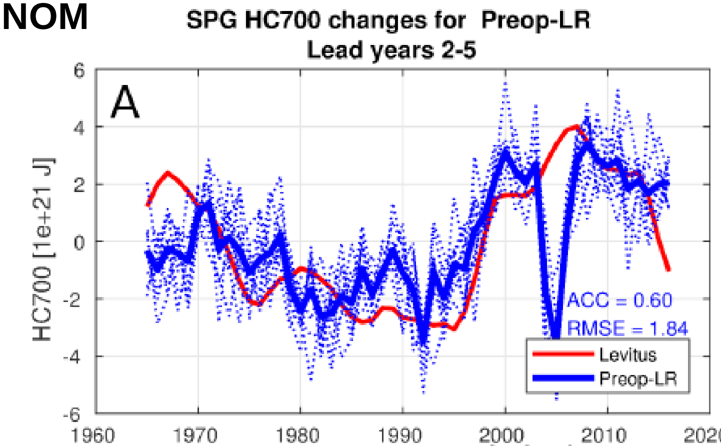
- AMOC in assimilation runs is significantly „disordered“
- GECCO2_FF << ORAS4_FF << ORAS4_AI
- Slow adjustement time-scale of the AMOC in hindcast (see also Huang et al., 2015, Sachez-Gomez et al., 2016)
- As a consequence, back to AI for CMIP6

Beyond CMIP6
Ensemble Kalman Filter

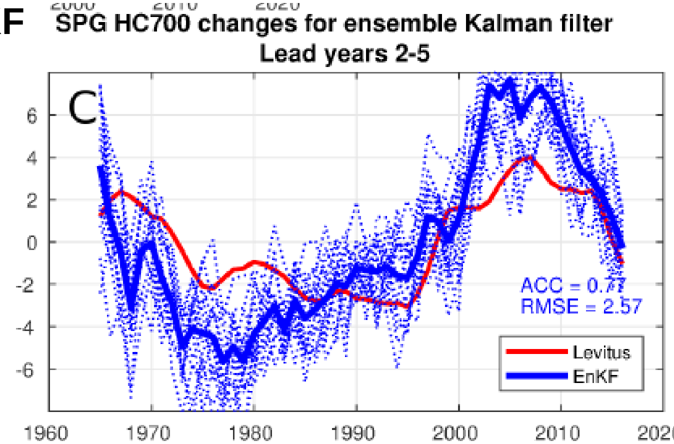
- EnKF tested for low-resolution of MPI-ESM (Brune et al., 2017)
- Based on Parallel Data Assimilation Framework (PDAF, Nerger and Hiller 2013)
- Full values of monthly T&S profiles from EN4, and monthly ERA, 1958-2016
- Local variant of EnKF, with a 10° radius

- For NA:
  - Bit larger variability and RMSE compared to reference (AI)
  - But cooling 1960s and 2000s much better captured

ANOM

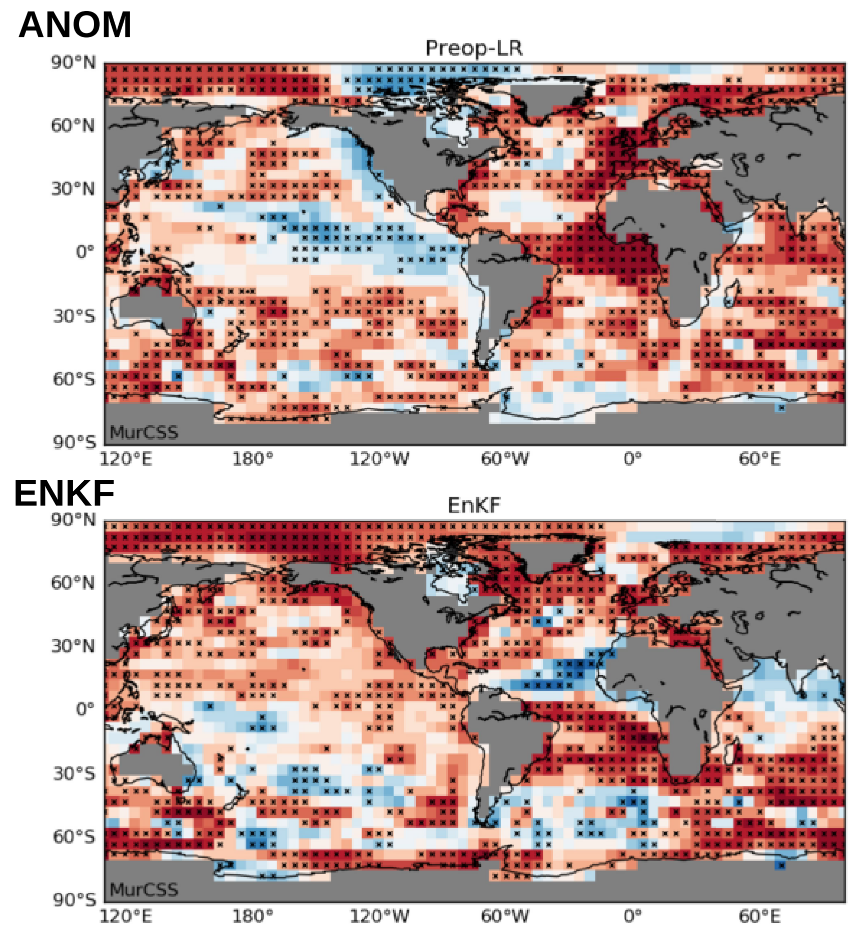


ENKF



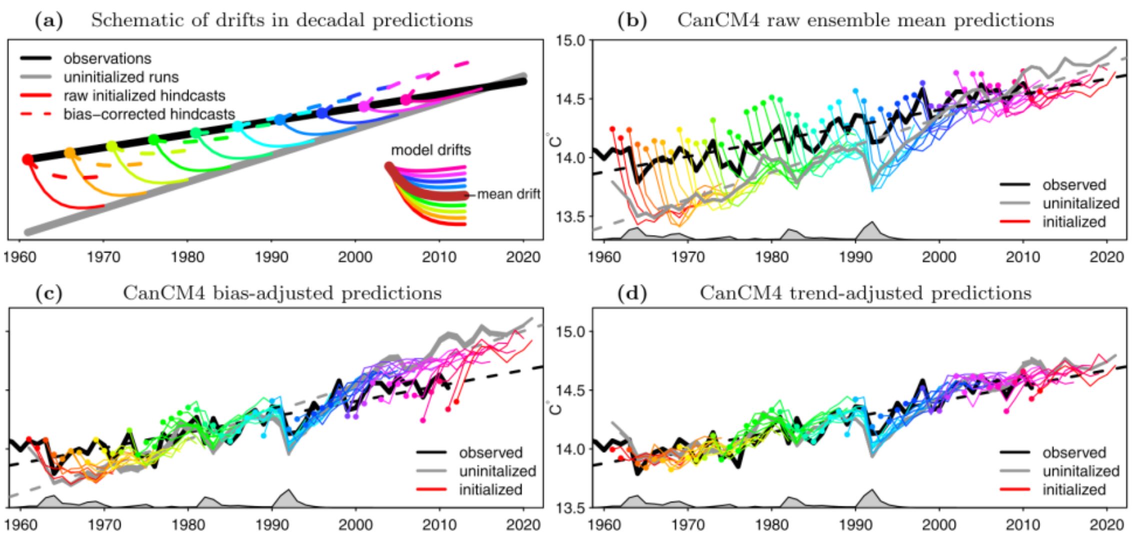
EnKF: OHC700 global skill

- ENKF produce general skill pattern (ACC)
- North Atlantic and North Pacific sticks out
- Currently been tested for higher-resolution version of MPI-ESM
- Replacing nudging method in a next version of the decadal prediction system
- Will be tested in seasonal prediction system, too



The bias struggle

- Early basic bias correction (mean bias adjustment, DCPP/CMIP5&6, ICPO 2011, Boer et al., 2016)
- Since then more sophisticated methods developed accounting for:
  - lead time and start date (Fyfe et al., 2011, Kharin et al. 2012, Kruschke et al., 2015),
  - plus observational states (Fuckar et al., 2014)
  - ensemble dispersion (Eade et al., 2014, Sansom et al., 2016, Pasternack et al., 2017)
- Overview paper on bias adjustment in S2D (in cooperation with MiKilp/DCPP, Grieger et al., in prep)
- In MiKlip two new methods: Quantile Remapping (Sienz et al, in prep), **Calibration** (Pasternak et al., 2017)

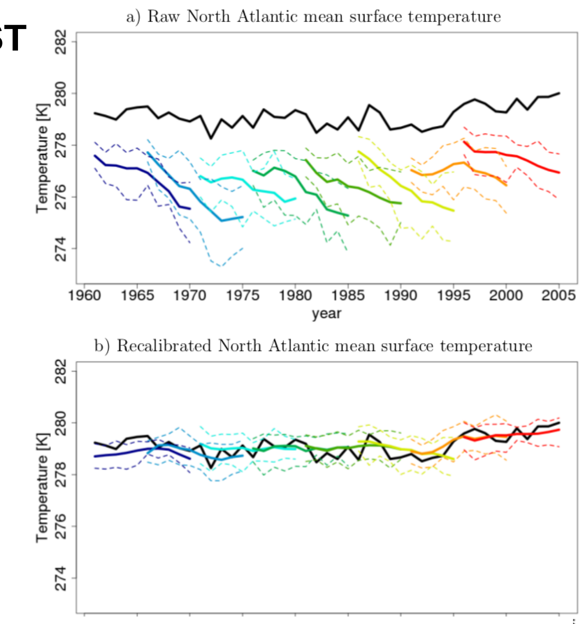


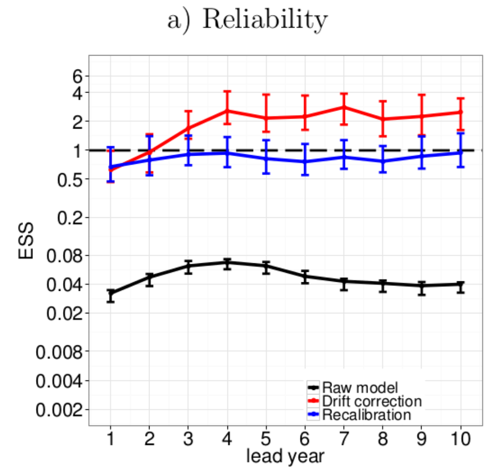
Kharin et al., 2012, CanCM4

Calibration of DCP

- Calibration corrects ensemble dispersion and succcessfully applied in seasonal climate prediction (e.g. Weigel et al., 2009)
- For decadal prediction, the situation is different, e.g. trend, short sample etc
- Calibration method based on a parametric approach and corrects for:
  - bias and drift $\alpha(t,\tau)$
  - conditional bias $\beta(t,\tau)$
  - ensemble spread $\gamma(t,\tau)$
- Parmeters estimated via 3rd order polynomial and by minimizing the average CRPS
- Improvement of reliability, MSESS and others of decadal climate predictions

NA SST

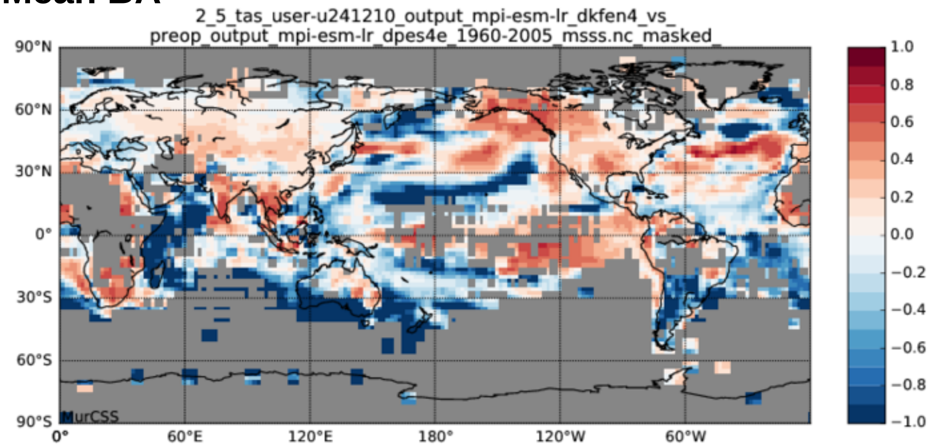




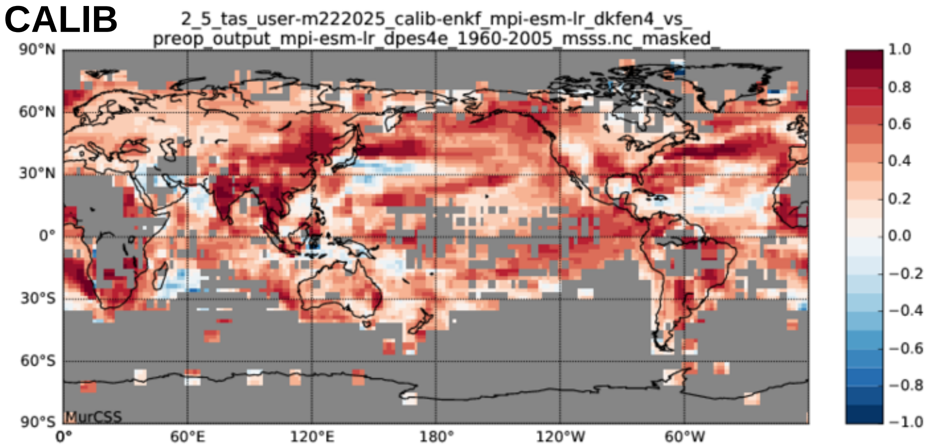
Calibration of DCP

- Calibration tool available as plug-in in the MiKlip evalutaion tool (FREVA)
- Example: EnKF plus calibration
- Calibration is included in the quasi-operational workflow of the MiKlip forecast web page (Kadow et al., in prep.)
- Calibration will be implemented in the DWD operational DCP
- To be tested for: MPI-ESM-HR, seasonal predictions, user-specific variables

Mean BA



CALIB



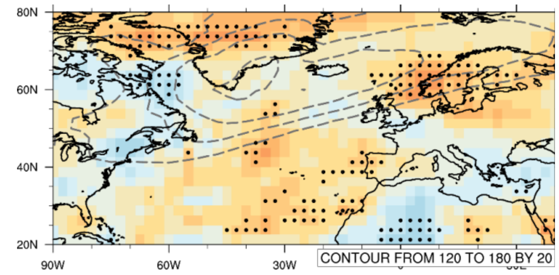
Summary Initialization and Bias Adjustment

- ➔ Starting from simple nudging method we examined several initialization methods (Polkova et al. 2018, submitted).
- ➔ With focus on NA: nudging of “model-external” reanalysis has its limits and produces imbalances of OHT and OHC dependent on method (FF, AI), but also dependent on reanalysis (GECCO2, ORAS4)
- ➔ A „model-consistent” approach (EnK) seems to improve the “baseline” methods and is suggested to be implemented in the next version of decadal predictions (some further testing required for seasonal predictions)

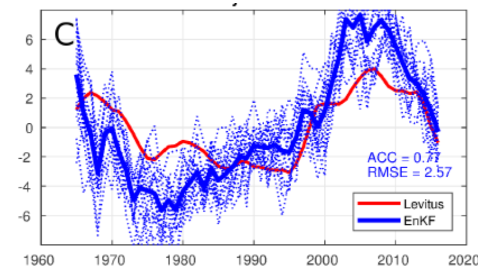
- ➔ A calibration method has been developed for DCP (Pasternak et al., 2017)
- ➔ Works well for toy model and applied for MiKip DCP, with general improvement of skill for various forecast attributes (reliability, rmse etc)
- ➔ Prospect to serve „more“ reliable forecast information, but it is no „all-in-one“ solution and requires testing for every single variable

Discussion:

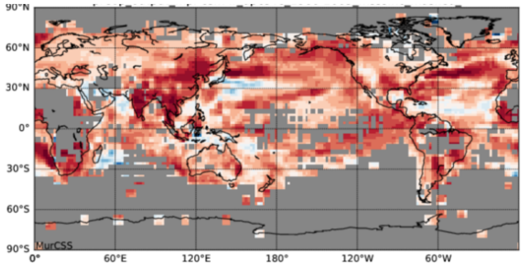
- Long-standing biases in MPI-ESM fundamentally limit predictions skill (NA SST & storm tracks), and some improvements can be achieved by increase of resolution
- Common strategy to reduce bias is required, in the context of huge resources needed to tune a coupled ESM and produce the hindcast



- Within MiKlip, we have examined several initalisation methods and some give reasonable predictions skill
- Data assimilation for climate states must not be equal to data assimilation for climate predictions (Poster J. Baehr)

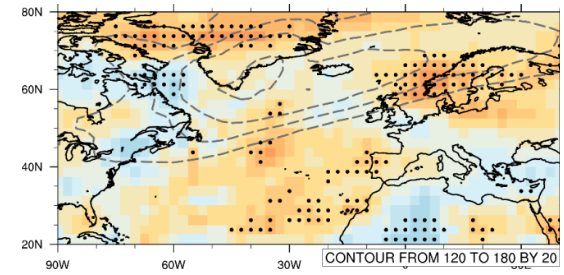


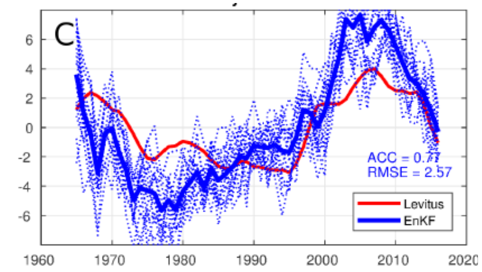
- Bias adjustment (BA) is a powerful tool to improve reliable climate information (e.g. calibration) and therefore of great value to be implemented in the operational workflow

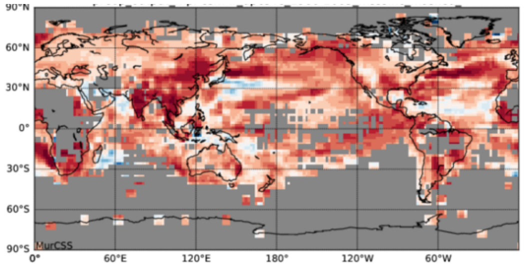


Discussion:

- Long-standing biases in MPI-ESM fundamentally limit predictions skill (NA SST & storm tracks), and some improvements can be achieved by increase of resolution
- Overall strategy to reduce this bias required, also in context of huge resources needed to tune a coupled ESM and produce hindcast
- Within MiKlip, we have examined several initalisation methods and some give reasonable predictions skill
- Data assimilation for climate states must not be equal to data assimilation for climate predictions (Poster J. Baehr)
- Bias adjustment (BA) is a powerful tool to improve reliable climate information (e.g. calibration) and therefore of great value to be implemented in the operational workflow







Vielen herzlichen Dank!