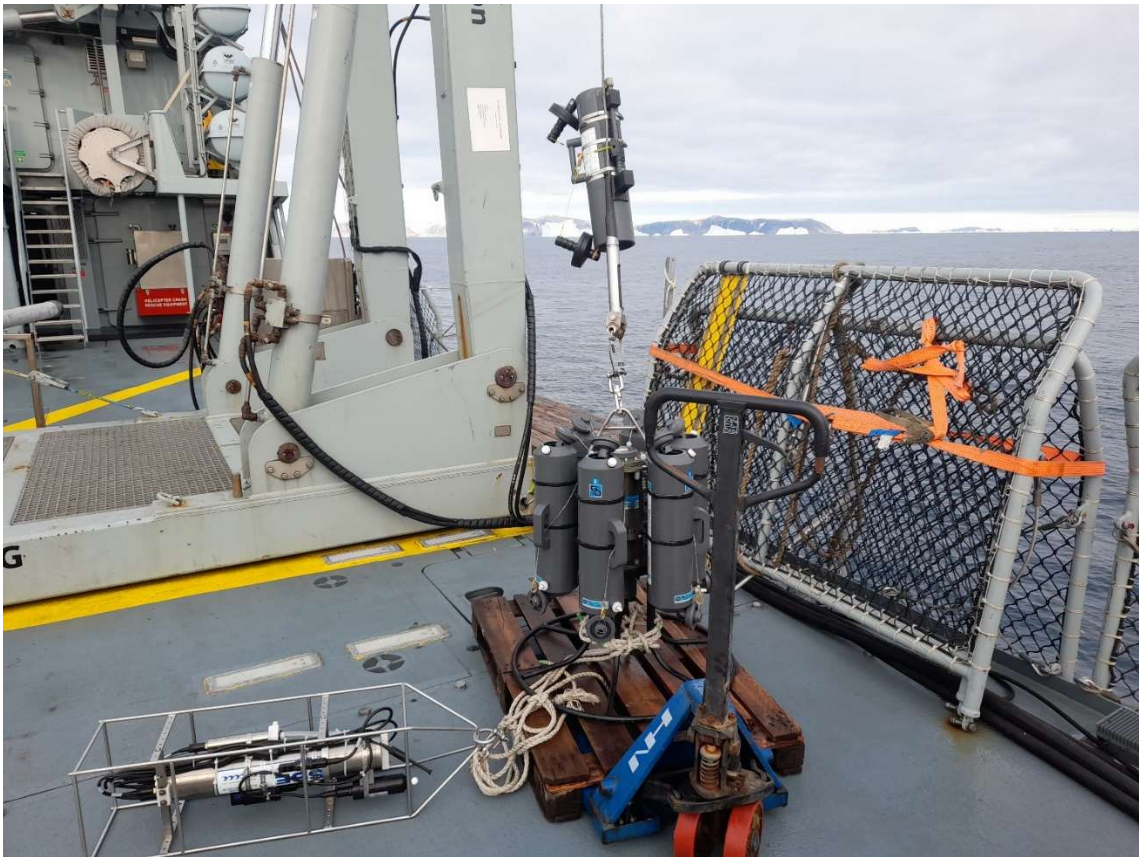
Danmarks
Meteorologiske
Institut

DMI Report 22-31
AMOC and beyond – tipping points

Final scientific report of the 2021 National Centre for Climate Research Work Package 4.4 AMOC and beyond – tipping points

Annika Drews, Marion Devilliers, Shuting Yang, Bo Christiansen, Torben Schmith, Steffen M. Olsen



Oceanographic investigations, West Greenland Shelf 2021 (Copyright NCKF/smo@dmi.dk)

Kolofon

Serietitel
DMI Report 22-31

Titel
AMOC and beyond – tipping points

Undertitel
Final scientific report of the 2021 National Centre for Climate Research Work Package 4.4, AMOC and beyond – tipping points

Forfatter(e)
Annika Drews, Marion Devilliers, Shuting Yang, Bo Christiansen, Torben Schmith, Steffen M. Olsen

Ansvarlig institution
Danmarks Meteorologiske Institut

Sprog
English

Url
http://www.dmi.dk/publikationer/

ISSN
2445-9127

ISBN
978-87-7478-733-4

Versionsdato
15. januar 2022

Link til hjemmeside
www.dmi.dk

København 2022

Contents

1. Scientific summary

Short description

In this activity we seek to establish how Arctic-Atlantic climate is connected through natural variability in ocean circulation, and how the interlinked system responds to external forcing. We will advance beyond the past understanding of a continuous conveyer type AMOC paradigm with coherent variability across latitudes and focus on the dynamics of regional subsystems. This includes understanding of tipping elements in both ocean exchange systems and water mass transformation regions. In this process we will supply new knowledge and data on specific ocean current systems key to the topic. In parallel, we will gain insight in dynamic processes and their predictability by tailored pacemaker experiments dedicated to understanding the impacts of subpolar variability beyond the region. In addition to CMIP6 data, DMI will make use of the coupled climate model EC-Earth for conducting process oriented sensitivity experiments but will also establish international collaboration on multi model coordinated experiments.

Overall results

Methods to gain new insight on processes leading to predictability includes dedicated pacemaker experiments. Using EC-Earth3, we have successfully designed and performed an experiment which targets drivers- and impacts of subpolar ocean variability. This includes its dynamic linkages to the regional branches of the AMOC as well as other climate system components.

A number of statistical methods to estimate long term memory internal to the climate system have been tested and applied to an ensemble of 28 models, making use of the CMIP6 pre-industrial control experiments. Results indicate that long term memory exists in the Arctic and the Southern Ocean system. Long term memory and slow response time can be indicative of approaching tipping points.

New observational data and knowledge on overflow across the Greenland Scotland Ridge of the North Atlantic have been generated based on new in-situ data from the region. The observations give for the first time clear indications of overflow across the south-eastern part of the Iceland Faroe Ridge.

Next steps

The results from dedicated pacemaker experiments will be advanced into a scientific publication. Issues of uncertain or poor data quality of the backbone DCPP experiment with EC-Earth will be dealt with by using a new limited and corrected prediction experiment targeting the 2014 period and possibly selected previous years of large anomalies in the subpolar North Atlantic. Continued collaboration with the NERSC in Bergen on the novel pacemaker approach is essential in order to understand better model dependencies.

Initial results on long term memory in the climate system can be used to assess critical slowdown in earth system components or early warning indicators of approaching bifurcation (tipping points). A modified version of the ARFIMA method is the most promising tool for future work.

Publication of new measurements of overflow will be pursued in 2022 in a collaboration between Havstovan (FAMRI) and DMI. A more detailed analysis of the link between overflow of the Iceland Faroe Ridge and sea surface height will be investigated combined with high-resolution numerical modelling and has the potential to enhance our understanding of Iceland-Faroe overflow substantially.

2. Scientific reporting

Pacemaker experiments and data quality control

Our protocol for the subpolar pacemaker prediction experiment conducted using EC-Earth3 includes restoring of ocean properties to observed anomalies in a critical region of the subpolar North Atlantic. This region is characterized by strong variability but also known to be associated with limited predictability and strong model biases. Following a literature research, scripts for analysis were set up for an adequate and state-of-the-art drift and trend correction of the retrospective forecasts constituting the experiment. We find initially that the regional restoring in the pacemaker experiment was successfully implemented and did not lead to spurious model features, model chock or strong drift.

The more extensive decadal prediction experiments with EC-Earth3 (Decadal Climate Prediction Project , DCPP) serving as the backbone of the more limited subpolar pacemaker experiments have been investigated in parallel. In this process, a number of issues have been flagged with this dataset contributing to the CMIP6. Considerable effort has been spent on understanding and discussing potential inconsistencies as part of an internal quality assurance. This includes the DCPP simulations from the EC-Earth3 system performed jointly by DMI and SMHI using anomaly initialization of both ocean and sea ice (to be detailed in a DMI report 2022).

The experimental protocol for the DCPP contribution to CMIP6 is described in Boer et al. (2016). ‘Component A’ of the DCPP comprises the production and analysis of an extensive archive of retrospective forecasts to be used to assess and understand historical decadal prediction skill. DCPP addresses a range of scientific issues involving the ability of the climate system to be predicted on annual to decadal timescales, the skill that is currently and potentially available and the mechanisms involved. In contrast to predictability which may be estimated from models, forecast skill, is measured by comparing initialized forecasts with observations and indicates the ability to predict the actual evolution of the climate system. The most essential requirement to Component A is the use of a coupled model (here EC-Earth3) with initialization based on observations (here the ORAS5 ocean reanalysis product).

Amongst the issues encountered in the screening of the DCPP dataset is that shortly after start of each run, the salinities and temperatures departs unrealistically fast from the initial state, apparently instantaneously. This was traced back to the construction of the initial state as follows: The EC-Earth model is started using a restart-file, which contains temperature and salinity and other fields at two consecutive time steps, called ’now’ and ’before’. In the DCPP-experiments, a restart file taken from a historical (i.e. non-initialised runs) is modified by inserting the observed temperature and salinity fields. These are constructed based on observations but essentially combining model climatology with observed anomalies year by year. This is done at time step ’now’ but not at time step ’before’. This means that temperature and salinity could differ a lot, which is unrealistic because these quantities change only little during one time step. The initial state constructed in that way is referred to as the ’OCE’ initial state, because it involves ocean fields. To sum up, the OCE initial states build on observations at time ’now’ but are incorrect at time ’before’. The OCE initial state is then used as a starting state for sea ice initialisation, which includes a short one-day spin-up run, leading to the OSI (’Ocean-sea ice’) initial state (Tian et al. 2021). For the OSI initial state, temperatures differ only little between ’now’ and ’before’, but can be very different from the OCE ’now’ temperature.

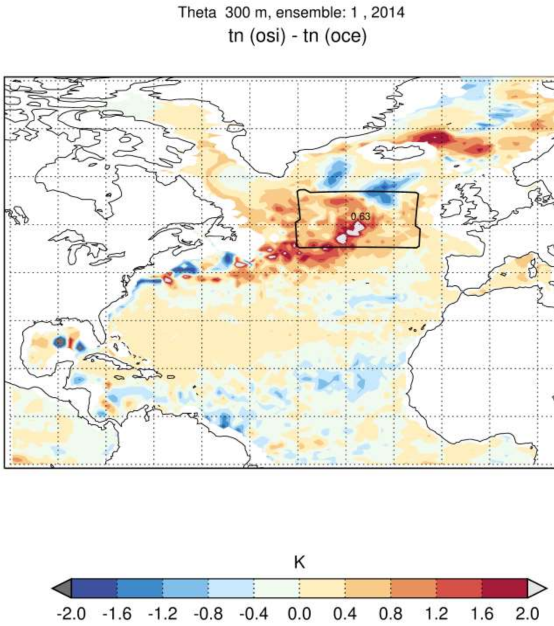


Figure 1 Difference between OSI (now) and OCE (now) initial temperature at 300 m depth at 1. November 2014.

The temperature difference at 300 m between OSI initial state (now) and the corresponding OCE (now) initial state (Figure 1) indicate errors up to 2 K in dynamically active regions of the ocean. This is comparable to the anomalies themselves. These concerns was presented and discussed at a mixed DMI/SMHI meeting.

In turn, the unintentional construction of the restart files means that the ocean initialization of the DCPP retrospective forecasts includes information on both variability in the historical simulation and from observations with some weighting. Effectively we find that the evolution of key properties in the subpolar region such as subsurface temperature and the AMOC (Figure 2) mimics the interannual variability in the historical simulation which was unintended. For the AMOC, it is essential to note that ocean velocities and sea surface heights are not initialized and that some information from the historical state would spill over to the initialized forecasts. For the retrospective forecasts, this is a critical realization and limits the usability of the DCPP experiment as a reference for the pacemaker experiments. Data are obviously also not useful for understanding signal to noise issues in predictive systems, but may have some applications. The known limitations will be fully documented when to be published on the ESGF nodes as part of NCKF Theme 4 activities.

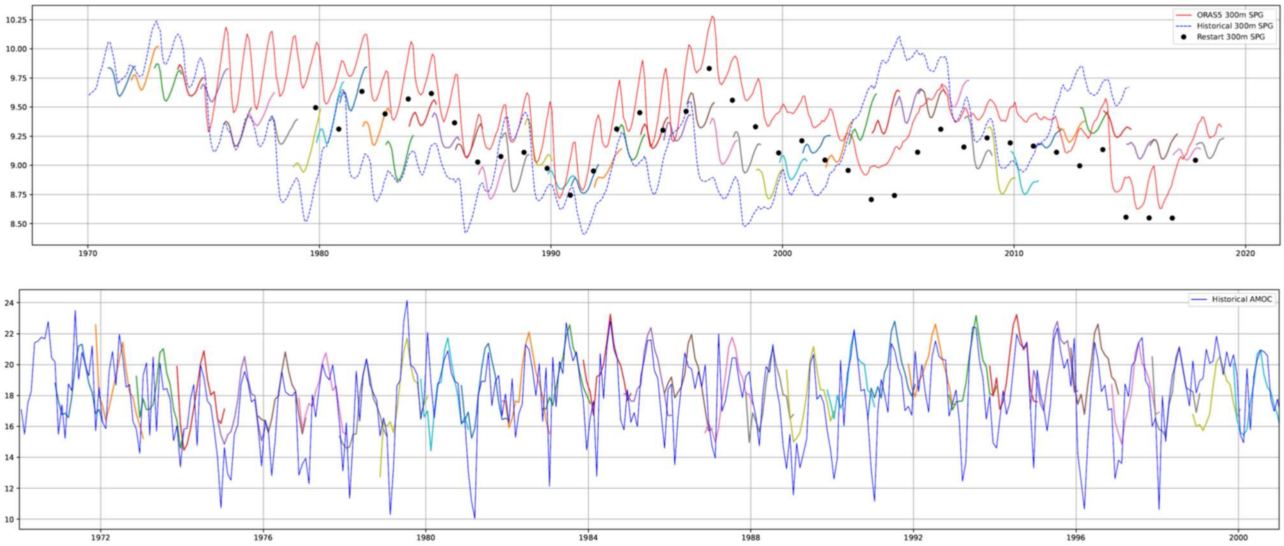


Figure 2. Top: Time evolution of 300m subpolar ocean temperature time evolution from ORAS5 reanalysis (red), EC-Earth3 historical simulations (blue), and the ensemble mena of first 1.5 year of the retrospective forecasts (coloured lines). Black dots depicts intended initial states shifted only by a model climatological offset compared to ORAS5. Bottom: AMOC strength at 40N, 1000m depth in the historical EC-Earth3 simulation (blue) overlaid by ensemble mean strength of the retrospective forecasts.

Tipping elements

Long-term memory in a time-series means that the variance continues to grow for decreasing frequencies. Long-term memory in the climate system will have important consequences as it will increase the variability of trends and averages and will also increase the possibility of clustering of extremes. We use two different methods to detect long-term memory: a model based method fitting an ARFIMA model given the fractional dimension and the empirical based de-trended fluctuation method giving the Hurst exponent. After thoroughly testing the methods, we have applied them to an ensemble of 28 models from the CMIP6 pre-industrial control experiments. Using pre-industrial experiments allow us to identify memory internal to the climate system and not related to changing forcings. Figure 3 shows the average fractional dimension in the surface temperature over the 27 models. The dimension (dim) reflects the scaling of the power for small frequencies and values larger than zero therefore indicate long-term memory. Fractional dimension different from zero can be seen in the Arctic and the Southern Ocean. The results are rather consistent when looking at individual models. When a system approach a tipping point, where the current state becomes unstable, it often becomes slower in its response to perturbations. Such critical slowdown can be used as an early warning to identify systems approaching a bifurcation. In the future we will use a modified version of the ARFIMA method to detect such slowdown.

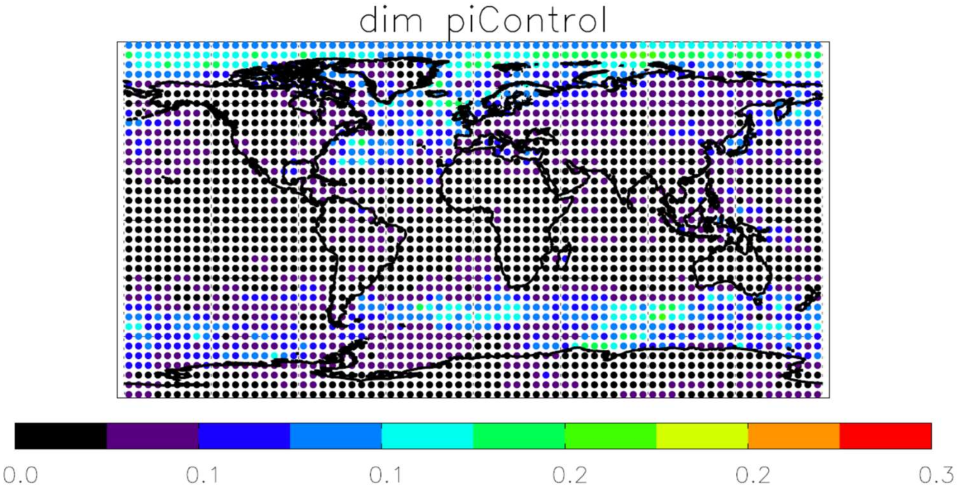


Figure 3: Fractional dimension in the surface temperature over CMIP 27 models using preindustrial control simulations (piControl).

Overflow studies using new ADCP data

Results from Acoustic Doppler Current Profiler (ADCP) deployments on the Iceland-Faroe Ridge has been reported in detail by Bogi Hansen, Karin Margretha Húsgarð Larsen, and Hjálmar Hátún in a report titled “ADCP deployments on the Iceland-Faroe Ridge” available from NCKF. Observations of overflow and Atlantic inflow from the ADCP data on the ridge is carried out by funding from the Danish National Center for Climate Research (NCKF). The main focus is on observations over the south-eastern part of the ridge, previously not well studied for overflow. This includes analysis of data from two recent (2020-2021) deployments at sites, but also analysis of older data from three sites. Summarizing, the observations reported give clear indications of overflow across the south-eastern part of the Iceland Faroe Ridge. It is highly variable, but much of that variation seems linked to variations in the Atlantic water flow across the ridge in the upper layers, which seems fairly well represented by satellite altimetry data.

The results have documented a number of interesting aspects of the overflow across the south-eastern part of the Iceland-Faroe Ridge, but still leave open questions. There are clear indications that the near-bottom flow at all overflow sites in this region is linked to the near-surface flow of the Atlantic water and to the sea level tilt represented by altimetry data on long (weekly to monthly) time scales. These links do, however, seem to involve the flows over the whole ridge, rather than being localized close to the sites. A more detailed analysis of the overflow-altimetry link, combined with high-resolution numerical modelling, has the potential to enhance our understanding of Iceland-Faroe overflow substantially.