Achievements in 2023 Project: JPI Oceans & JPI Climate project ROADMAP (bm1190)

In last year's report, we have demonstrated that individual ensemble members of ensemble prediction experiments with the MPI-M ocean-eddy-resolving climate prediction system can reforecast both strength and extent of the record-cold anomaly in the subpolar North Atlantic in the summer of 2015. Nine out of twenty ensemble members initialized in November 2014 and three out of ten ensemble members initialized in November 2013 reforecast cold conditions in the entire eastern subpolar North Atlantic in the summer of 2015 with maximum values reaching a similar magnitude as for the observed anomaly (in the following referred to as "cold" members). Five of the twenty ensemble members initialized in November 2014 show a warming trend after the initialization with a relatively cold state, leading to a positive SST anomaly averaged over the eastern subpolar North Atlantic in the summer of 2015. This evolution resembles the study of Maroon et al. (2021) based on prediction experiments with the Community Earth System Model. Also one of the ten ensemble members initialized in November 2013 exhibits a significant warming trend after a relatively cold state in November 2013. We note that the ensemble members initialized in November 2013 show a much wider spread of the SST state in the winter of 2014/15 compared to the ensemble members initialized in November 2014, due to initialization one year before. The record-cold anomaly in the subpolar North Atlantic in the summer of 2015 has not only been a surface phenomenon, but extended downward to a depth of at least 700 meter. Regarding the simulated upper-ocean heat content, all ensemble members initialized in November 2013 and November 2014 reforecast cold anomalies in at least the central eastern subpolar North Atlantic, with maximum values of similar order as in observations. Accordingly, no "warming trend" members are found for the upper-ocean heat content, in contrast to the SST.

Apart from demonstrating predictive skill, another important aspect of predictability studies is the assessment of the mechanisms underlying the predictive skill. In the real world, the main contribution to the record-cold anomaly in the subpolar North Atlantic in the summer of 2015 has been the large oceanic surface heat loss in the two preceding winters, associated with specific atmospheric circulation pattern: a record-strong positive East Atlantic Pattern (EAP) in the winter of 2013/14 and a persistent positive North Atlantic Oscillation (NAO) in the winter of 2014/15. Regarding our "cold" members, in five out of the nine "cold" members initialized in November 2014, a strongly positive phase of the atmospheric circulation dominates in the winter of 2014/15. In contrast to the observations, the EAP plays an important role in some of these members. The remaining four "cold" members initialized in November 2014 simulate a strongly positive phase of the atmospheric circulation only in individual winter months.

In contrast to the ensemble members initialized in November 2014, which get the fingerprint of the large surface heat loss in the winter of 2013/14 through the initialization of the oceanic temperature anomalies, the ensemble members initialized in November 2013 must simulate a strongly positive phase of the atmospheric circulation in two adjacent winters. In two of the three "cold" members initialized in November 2013, a strongly positive phase of the atmospheric circulation dominates in both the winter of 2013/14 and the winter of 2014/15. In contrast to the observations, the EAP does not play any role in the first winter in one of these members. The third "cold" member initialized in November 2013 simulates a strongly positive phase of the atmospheric circulation only in individual winter months.

All "cold" members dominated by a strongly positive phase of the atmospheric circulation in the winter of (2013/14 and) 2014/15 reproduce the large surface heat loss in the subpolar North Atlantic in the respective winter season, with the only exception of ensemble member r06 initialized in November 2014. The latter simulates a strongly negative phase of the NAO in January and February 2015 (apart from a strongly positive phase of the EAP in the remaining winter months) associated with a large oceanic surface heat gain in the subpolar North Atlantic. Most "cold" members simulating a strongly positive phase of the atmospheric circulation only in individual winter months, exhibit a near-zero surface heat flux or even a surface heat gain in the subpolar North Atlantic in the respective winter season. Only exception is ensemble member r19 initialized in November 2014, which exhibits a relatively large subpolar surface heat loss in the winter of 2014/15, caused by a strongly positive phase of the NAO in November and December 2014 (and near neutral phase of the atmospheric circulation in the remaining winter months).

The surface heat loss or gain in the subpolar North Atlantic is reflected in the changes of its upper-ocean heat content. Most "cold" members reproducing the large subpolar surface heat loss in the winter of (2013/14 and) 2014/15, reproduce the observed strong decrease in the upper-ocean heat content in the respective winter season (about 1 GJ/m2 in the winter of 2013/14 and 0.5 GJ/m2 in the winter of 2014/15). The surface heat flux anomalies counteract the subpolar SST anomalies in some of the cold members, indicating that both the ocean dynamics and surface atmospheric forcing play an important role in shaping the SST anomalies. The SST in the eastern subpolar North Atlantic is mainly impacted by the (upper-ocean) heat transport difference between 50^{o}N and the Greenland-Scotland-Ridge. The latter leads to a large heat loss of the subpolar North Atlantic especially in those "cold" members, which simulate maximum cold anomalies exceeding the observed ones. The subpolar heat transport difference does, however, not lead to a large heat loss in those "cold" members simulating a large surface heat gain, indicating the importance of further ocean processes (strong increase in subsurface heat content or in SST in western part of subpolar North Atlantic).

The summer of 2015 was characterized not only by the record-cold anomaly in the subpolar North Atlantic but also by strong heat waves over central and southern Europe. Individual ensemble members are indeed able to reforecast strength and extent of the European summer heat wave (Figure 1). Based on monthly data, five ensemble members reforecast warm conditions in central and southern Europe in at least one summer month of 2015, with maximum values reaching a similar magnitude as for the observed anomaly. There is, however, only little overlap between the five "heat wave" members and the "cold" members identified earlier. Comparing the SST between observations and ensemble members over a larger region reveals that all "heat wave" members reproduce the strong warming in the western Mediterranean Sea in the summer season of 2015

(Figure 2). We will further assess the predictability of the 2015 European summer heat wave in the MPI-ESM1.2-ER prediction experiments as well as mechanisms underlying its predictive skill, based on weekly rather than on monthly data.

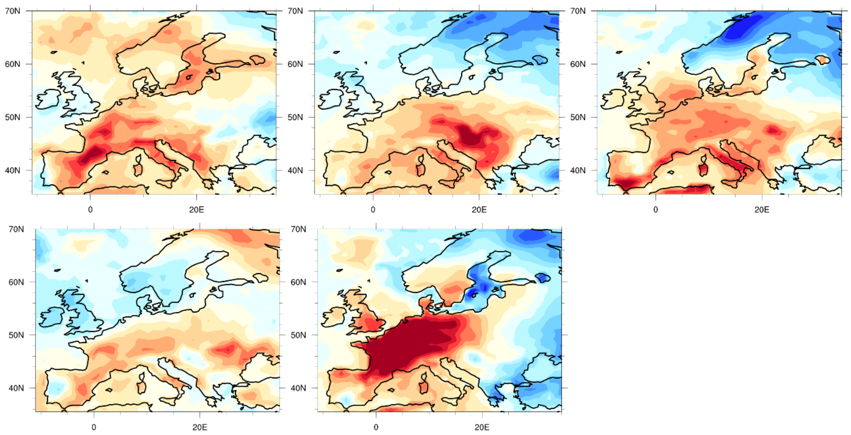

Figure 1: *Surface air temperature anomalies in June/July 2015 in selected ensemble members.*

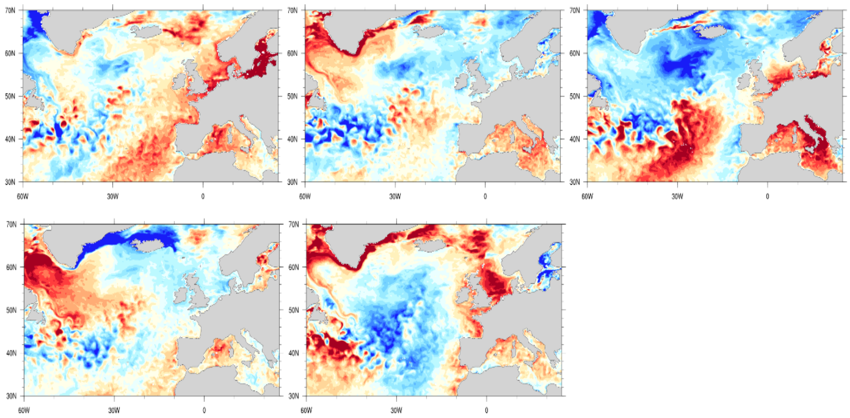

Figure 2: *SST anomalies in June/July 2015 in selected ensemble members.*

Nonlinearity and asymmetry of the ENSO Stratospheric Pathway

Nonlinearities in El Niño (EN) and La Niña (LN) teleconnections can arise for many reasons, involving nonlinearities in the two phases of El Niño Southern Oscillation (ENSO) itself and those occurring along the pathway of an atmospheric response (Frauen et al 2014). Here we search for nonlinearity in the ENSO stratospheric pathway. The ENSO stratospheric pathway is a teleconnection linking Equatorial Pacific SST anomalies to the North Atlantic and European regions, mediated by the stratospheric polar vortex (Cagnazzo and Manzini et al 2009, Manzini et al 2006). To address the question of the nonlinear responses to ENSO, we use Large Ensembles (LEs, ~30 member each) of historical simulations by six CMIP6 models. In addition, we consider the MPI-GE, a set of 95 members. In doing so, we assess the role of internal variability on ENSO related nonlinearities, with consistent atmosphere – ocean coupling. Manzini et al (2023, submitted) show that for the models with a stratospheric pathway, three key pathway metrics (tropospheric North Pacific low, polar night jet and North Atlantic pressure dipole) tend to show linearity only in the response from weak to moderate and to strong EN events (Figure 3, for MPI-GE). Not so for LN events. Common to these models is also the tendency for asymmetry of strong events, with the EN response larger in amplitude. The largest variety of outcomes across the models is found for the North Atlantic sea level pressure response, possibly because of the contribution of other factors, such as tropospheric processes, affecting the response.

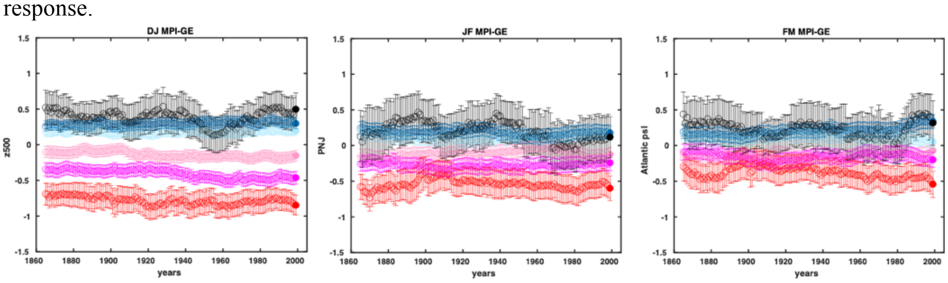

Figure 3: *MPI-GE results. Composite means for weak (pink / azure, 0.5 < |STD| < 1), moderate (magenta / blue, 1 < |STD| < 2) and strong (red / black, |STD| > 2 0.5-1) EN / La events. Each composite mean (circle) is based on a 30-year period and 95 members. Bars denote 95% confidence intervals calculated using 2-sided T-test. (left) DJ tropospheric North Pacific low (geopotential height averaged over 150°E-120°W, 30°N-65°N). (middle) JF zonal mean zonal wind averaged over 55°-70°N at 10 hPa. (right) FM pressure at sea level difference between the Atlantic midlatitudes (60°W-60°E, 30°N-55°N) and the Arctic (polar cap, 60°N-90°N). All (standardized) anomalies are detrended by removing the ensemble mean.*