Project: **867**
Project title: **Suitability of the ocean observing system components for initialization**
Project lead: **Mojib Latif**
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We have performed a control and ensemble global warming simulations with the Kiel Climate Model (Park et al. 2009). The model is forced by enhancing the atmospheric CO_2 concentration at a rate of 1%/year from 286.2 ppmv (preindustrial level) to 1144.8 ppmv ($4\times CO_2$). CO_2-quadrupling is reached after 140 years and the integrations were continued for another 60 years with constant CO_2. We estimate the strength of the Atlantic Meridional Overturning Circulation (AMOC) in the control and ensemble members by taking the maximum streamfunction at 30°N in the North Atlantic. Mean AMOC strength is 13.1 Sv in the control run, which is lower than the observed estimate of 18.7 Sv from the RAPID array (Jones et al. 2014). This underestimation is likely due to missing and/or misplacement of deep convection in the Labrador Sea and model biases such as a cold sea surface temperature and fresh sea surface salinity bias (Ba et al. 2013; Park et al. 2016). The global warming simulations with increasing CO_2 clearly show AMOC slowing amounting to about 7 Sv after 140 years (Fig. 1a). The individual ensemble members start from different initial conditions in the ocean and atmosphere, and the AMOC evolutions in the first few decades closely follow the control run. This indicates significant impact of internal variability on the short-term AMOC evolution. We further investigate the ensemble spread. Figure 1b shows the ensemble mean (red line for the global warming simulations and black line for the corresponding years of the control run) and ensemble spread (one standard deviation, dashed lines) of the projected AMOC strength. The ensemble spread from the global warming simulations and the standard deviation of the control run overlap for about 50 years, suggesting a time of about 50 years until global warming signals in the AMOC strength can be detected with high confidence. This also implies the importance of high-quality initial conditions for short-term climate projections.

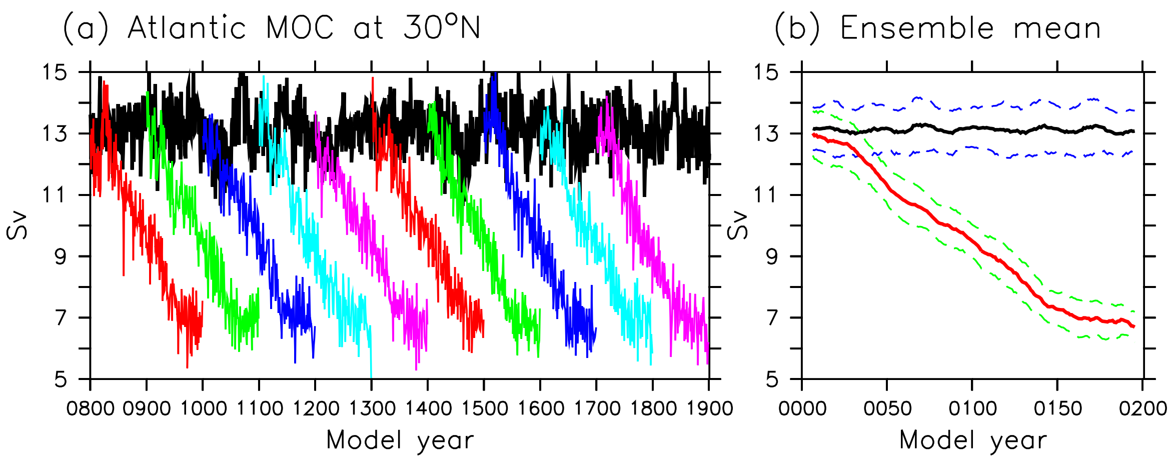

Figure 1: (a) Evolution of the maximum Atlantic Meridional Overturning Circulation (AMOC) at 30°N in the North Atlantic from control (black) and global warming simulations (color) started with different initial conditions. (b) AMOC strength in the control run (black) and the ensemble mean AMOC strength from the global warming (red) simulations. Dashed lines represent the standard deviation in the control run and spread of the ensemble members also measured by one standard deviation.

We also conducted climate simulations to identify internal and external variability of the North Atlantic Oscillation, an important climate mode in the North Atlantic sector. In particular, sub-decadal variability has been investigated, as solar forcing can influence the variability on this time scale. Thieblemont et al. (2015) argued that the 11-year solar cycle synchronizes quasi-decadal NAO variability intrinsic to the model. On the other hand, Reintges et al. (2016) showed that sub-decadal NAO variability can internally originate from dynamical large-scale air-sea interactions, in which the adjustment of the AMOC is important to provide memory of the coupled mode. A multi-centennial long simulation employing the chemistry-climate model CESM1 (WACCM) (Marsh et al. 2013) is used to analyze the influence of solar variability (namely the 11-yr solar cycle) on the NAO. The experimental set-up in our study follows that of a pre-industrial control simulation (pictl). Differing to a standard pictl-experiment, spectral solar irradiance forcing includes 11-yr solar cycle (and higher frequency) variability (SOLARIS-HEPPA variable picontrol solar forcing recommendation v3.2 for CMIP6, see Matthes et al. 2016). Additionally, the model is nudged towards a cyclic 28-month Quasi-Biennial-Oscillation (QBO) to improve the climatological ozone distribution and variability. The NAO power spectrum does not exhibit a significant peak at 11 years. Instead significant variability with periodicities of 7-8 years is present (Fig. 2 bottom). Preliminary analysis suggests no sustained synchronization of the NAO with solar variability in the experiment (see time series of F10.7 cm solar radio flux and band-pass filtered NAO in Figure 2 top and lead-lag correlation in Figure 2 middle). However, the (currently) last part of the simulation (after model year 230) qualitatively shows a temporal behavior of the two time series that are in line with the expected synchronization with approximately 2 years lag. Thus, further progress of the experiment is necessary to find robust results.

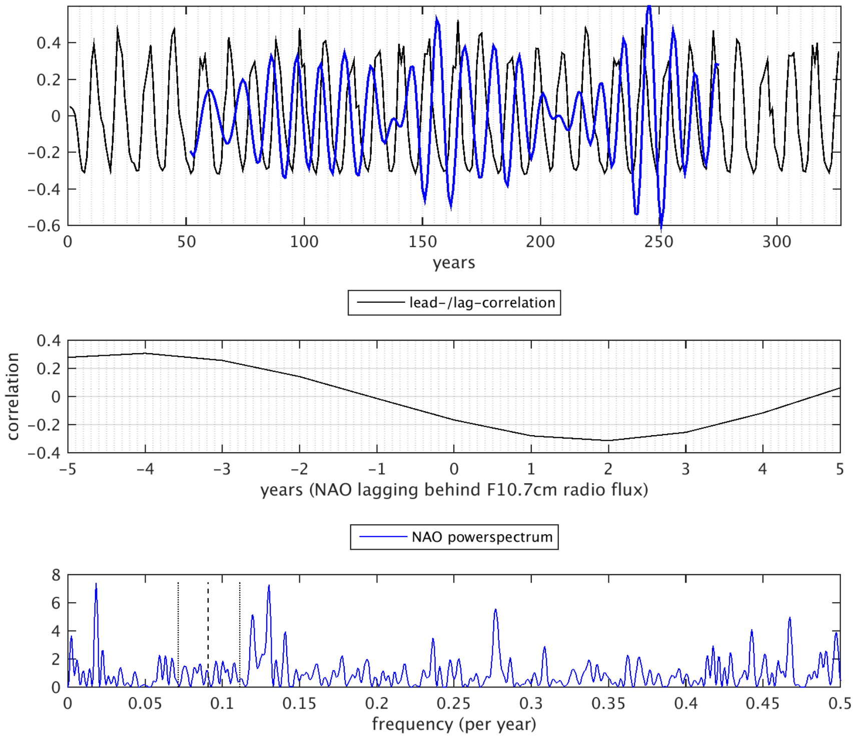

Figure 2: (top) time series of annual F10.7 cm solar radio flux (black; proxy for solar UV- variability) and band-pass filtered (9-14 yrs) NAO index (blue); (middle) lead-lag correlation of the two time series; (bottom) power spectrum of raw NAO index (vertical black dashed lines indicate 9-14 yr band-pass corridor and a periodicity of 11 yr.)

References:

Ba, J., N. S. Keenlyside, W. Park, M. Latif, E. Hawkins, and H. Ding (2013), A mechanism for Atlantic multidecadal variability in the Kiel Climate Model, Clim Dyn, 41, 2133–2144, doi:10.1007/s00382-012-1633-4.

Johns, W. E. et al. (2011), Continuous, Array-Based Estimates of Atlantic Ocean Heat Transport at 26.5°N, J. Climate, 24(10), 2429–2449, doi:10.1175/2010JCLI3997.1.

Marsh, D. R. et al. (2013), Climate Change from 1850 to 2005 Simulated in CESM1(WACCM), http://dx.doi.org/10.1175/JCLI-D-12-00558.1, 26(19), 7372–7391, doi:10.1175/JCLI-D-12-00558.1.

Matthes, K. et al. (2016), Solar Forcing for CMIP6 (v3.1), Geosci Model Dev, 1–82, doi:10.5194/gmd-2016-91.

Park, W., Keenlyside, N., Latif, M., Stroeh, A., Redler, R., Roeckner, E., & Madec, G. (2009). Tropical Pacific Climate and Its Response to Global Warming in the Kiel Climate Model. Journal of Climate, 22(1), 71–92. http://doi.org/10.1175/2008JCLI2261.1

Park, T., W. Park, and M. Latif (2016), Correcting North Atlantic sea surface salinity biases in the Kiel Climate Model: influences on ocean circulation and Atlantic Multidecadal Variability, Clim Dyn, 1–18, doi:10.1007/s00382-016-2982-1.

Reintges, A., M. Latif, and W. Park (2016), Sub-decadal North Atlantic Oscillation variability in observations and the Kiel Climate Model, Clim Dyn, 1–13, doi:10.1007/s00382-016-3279-0.