Project: **1085**
Project title: **The response theory as a tool for investigating climate predictability and scale separation**
Principal investigator: **Valerio Lucarini**
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The MPI-ESM v.1.2 model has been run at its coarse resolution (CR), consisting of T31 spectral resolution (amounting to 96 gridpoints in the longitude dimension, 48 in the latitude dimension) and 31 vertical levels for the atmosphere, a curvilinear orthogonal bipolar grid (GR30) (122 longitudinal and 101 latitudinal gridpoints) with 40 vertical levels for the ocean.

A 4000-years control run has been produced in unforced conditions, representative of present-day atmospheric CO2 concentrations (i.e. 360 ppm). Initial conditions for a 20-members ensemble have been sampled from it every 200 years, in order to ensure reasonable oceanic decorrelation (cfr. Ganopolsky et al., 2002; Wunsch and Heimbach, 2008). Two ensembles have been run, one reflecting an instantaneous doubling in CO2 concentration (2xCO2abrupt) (for 2000 years), the other one an increase in CO2 emissions by 1% every year, until the CO2 doubling level is reached (1pctCO2) (for 1000 years). An additional individual run has been performed under initial abrupt quadrupling in CO2 concentrations, for 2000 years. This was performed as a test to investigate the scaling of the temperature response with the amplitude of the forcing.

Using the approach described in Ragone et al. (2016) and Lucarini et al. (2017), we have applied the linear response theory, based on the Ruelle's response theory (Ruelle 1998, 1999), to compute the Green function and predict the response of the climate to the 1pctCO2 forcing. With this approach, the task of retrieving the Green's function is very easily accomplished, when the time modulation of the forcing has the form of a Heaviside function, as in the case of the 2xCO2 forcing. The climate prediction of the response to the 1pctCO2 forcing has been compared to the actually simulated evolution.

We have chosen a subset of observables that are particularly relevant for the climate response at different timescales. For sake of comparison with previous works, and with the aim to investigate fundamental metrics of the climate response such as the Transient Climate Response (TCR) and the Equilibrium Climate Sensitivity (ECS), we investigated the near-surface temperature for the atmospheric domain. In addition to that, we have addressed the response of the oceanic overturning circulation, investigating the strength of the Atlantic Meridional Overturning Circulation (AMOC), in terms of oceanic mass transport crossing 26N of latitude (in Sv), and of the Antarctic Circumpolar Current (ACC), in terms of the strength of the barotropic streamfunction across the Drake passage. We have also taken into account the special case of a Green function characterised by a Dirac's delta at t=0, investigating the response of the Ocean Heat Uptake (OHU). Finally, we have addressed the response of near-surface temperature over a region which is crucially linked to the large-scale circulation of the atmosphere and the ocean, i.e. the Northern Atlantic.

The results of the analysis have been described in a paper that has been accepted for publication on Scientific Reports (Lembo et al. 2020). Remarkably, the linear response allows to predict very successfully not only the response of near-surface temperature, somewhat confirming what was achieved with atmosphere-only models in previous works (cfr. Ragone et al. 2016; Lucarini et al. 2017), but also the slow response of AMOC and ACC, and the transient response of the North Atlantic temperatures. Furthermore, the OHU relaxation to near-vanishing values, representative of the climate system approaching a new statistically steady state after the forcing is ceased, is skilfully predicted. Not only we show that this methodology, which is mathematically rigorous and robust, unlike previous applications of the pulse-response approach (cfr. Pillar et al. 2016; Cornish et al. 2020), provides skilful predictions. We also claim that it provides guidance to modellers' communities on how to prepare sensitivity experiments with appropriate forcings in an efficient way and minimising the need for computational resources. This is crucial, as the complexity of models is rapidly increasing and the need for model intercomparison is shifting to the provision of large model ensembles that allow to address for differences in the internal variability across disparate models.

The outputs of 2xCO2abrupt and 1pctCO2 ensemble runs are currently being uploaded on the CERA-DKRZ dataset for public dissemination, and will be soon available and advertised to whom it may concern.

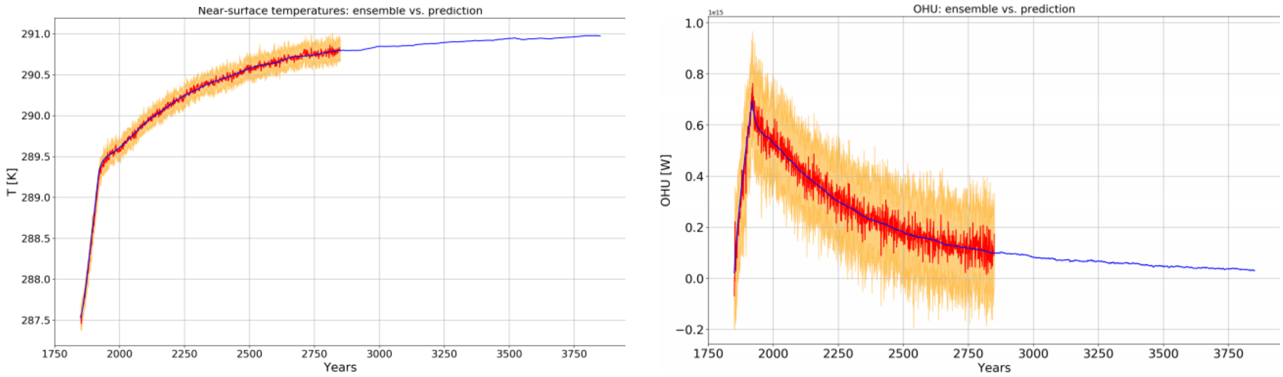

Figure 1: Comparison between (left) the simulated near-surface temperature (right) the OHU in the 1pctCO2 scenario (thick red line with ensemble mean uncertainty) and the prediction performed using the linear Green function computed from the 2xCO2abrupt scenario (thick blue).

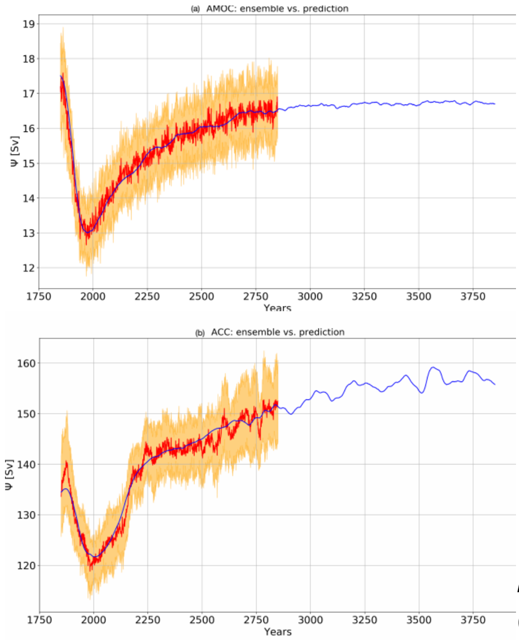

Figure 2: *Same as in Figure 1, for (top) AMOC at 26N (bottom) ACC across the Drake passage.*

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