Simulating natural climate variability and man-made climate change

Simulation and predictability of present-day climate

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In Short

- Improve current state of climate model simulations
- Disentangle effects of natural climate variability and man-made climate change in recent decades
- Understand the role of individual processes on the simulated climate

The world has witnessed a series of extreme weather events around the world, such as the 2019-2020 Australian bushfires, 2021 West-Canadian heat wave, and the 2022 flooding in India and Bangladesh. We may then ask ourselves: How have human activities changed the Earth's climate in recent decades? As the weather on a given day or season depends both on human activities, e.g. emissions of greenhouse-gases and particulates, and natural climate variations, e.g. El Nino-Southern Oscillation (ENSO) and Atlantic Multi-decadal Variability (AMV), it can be difficult to distinguish man-made climate change from natural variability in observational records.

Climate models offer a process-level understanding of the Earth's climate as sensitivity experiments can be run to study how individual process such as cloud microphysics or rising CO2 concentrations alter the climate compared to control simulations. Long single-ensemble or shorter large-ensemble simulations can be made to increase the sample size of natural climate variability, making it easier to detect man-made climate change. Finally, climate models can also be used to project how climate change will unfold in the 21st century and beyond following prescribed scenarions of human development set by the CMIP6 protocol[1].

This project aims at enhancing our understanding of present-day climate variability and predictability, and improving simulations with climate models, which will reduce uncertainty in our projections of future climates. The climate during the 20th and early 21st century shows a gradual increase in global mean surface temperature but there are also variations superimposed on the warming trend likely driven by natural climate variations. Hence, to detect and project anthropogenic climate change in the 21st century we must understand and be able to simulate both the climate response to external forcing, e.g., anthropogenic greenhouse gas emission, and natural climate variability such as the El Niño/Southern Oscillation (ENSO).

Climate models are indispensable tools to simulate and predict natural climate variability and to project future climate change in response to external forcing. Efforts have been undertaken during the last decades to improve the performance of climate models and reduce errors. The Southern Ocean - a key region for oceanic uptake of heat and carbon - is simulated more realistically in the most recent CMIP6 models compared to the older CMIP3 and CMIP5 models[2]. Improvements have also been made in simulating the main weather patterns over Europe, and also Artic sea-ice extent. However, significant systematic errors remain in many models: Ocean mesoscale eddies, which are known to play a large role in air-sea interactions and oceanic redistribution of heat and salt, are poorly represented, and many models struggle with reproducing the observed surface climate of the North Atlantic and Tropical Atlantic oceans.

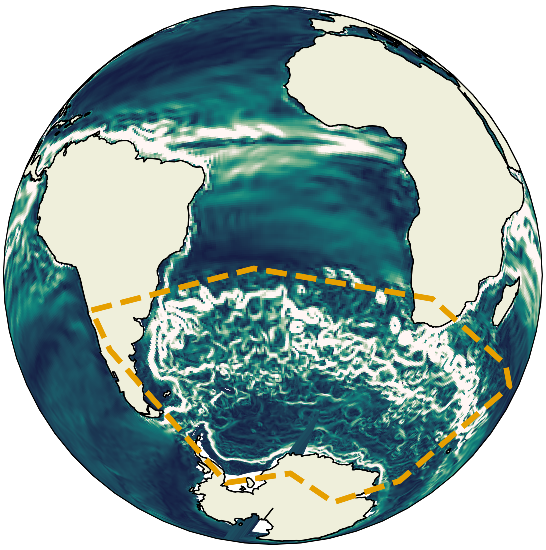

Figure 1: *Instantaneous eddy-kinetic energy (EKE, indication of current speed) in the FOCI climate model with locally refined ocean grid over the Weddell Sea. The model configuration, dubbed FOCI-WG10, will be used in this project.*

Some systematic model errors can be attributed to insufficient resolution of the model grid. Oceanic mesoscale eddies become much more realistic when the horizontal resolution of the ocean grid is refined, which through non-linear interactions produces a more realistic mean flow and variability (Fig. 1). In the atmosphere, flow over steep topography and the precipitation patterns that follow, is often improved when using finer horizontal resolution over coarse resolution (Fig. 2). In this project we will use models of both coarse and fine resolution to understand the role of horizontal resolution in simulations of climate variability and change. In particular, we will adopt a technique to refine the ocean model grid only locally which can reduce model errors in key regions while saving computational cost elsewhere. By pushing the horizontal resolution in the atmosphere and ocean to 25 km and 8 km respectively, using nearly 300 times more grid points than a typical climate-model configuration, we aim to simulate the variability and long-term change in the Gulf Stream and possible impacts on the main weather patterns over Europe.

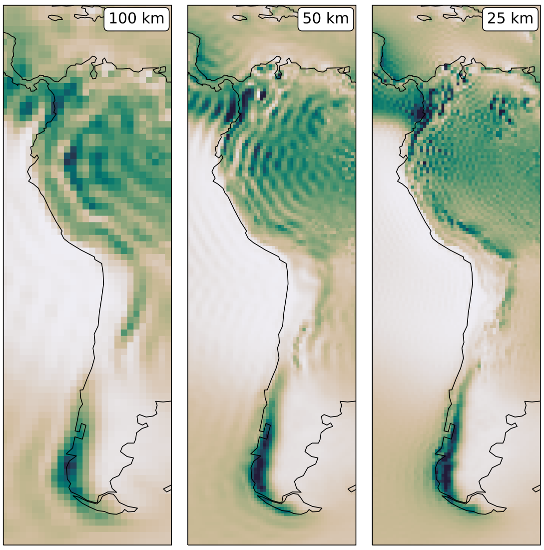

Figure 2: *Time-averaged precipitation over South America as represented in the OpenIFS atmosphere model at 100km, 50km and 25km horizontal resolution. The model struggles to represent land-sea contrasts and steep orography at coarser horizontal resolution, leading to a loss of detail in precipitation patterns.*

We will also conduct targeted sensitivity experiments where only one aspect of the model is perturbed and then compared to a control simulation. For example, we will conduct simulations of the ocean and its biogeochemical cycles where the atmospheric forcing is filtered in time which will help us understand the role of day-to-day atmospheric variability on ocean climate variability and change. We will also perform climate-model experiments where the ocean surface state is altered in various regions, e.g. the North Atlantic, to examine the remote impacts on Tropical Atlantic variability and associated air-sea interactions. Furthermore, we will investigate the role of the Atlantic Multidecadal Variability (AMV) has played in the warming of the Northern Hemisphere in recent decades by running simulations with the AMV-signal removed and study the remaining climate change. Climate models are the optimal tool for conducting such sensitivity experiments as observational records often suffer from low sample size and non-linear interactions between different modes of variability.

We will make use of the FOCI and FOCI-OpenIFS modelling frameworks[3,4], both of which are developed and maintained at GEOMAR Helmholtz Centre for Ocean Research Kiel. These models are the culmination of many years of work in collaboration with external partners both in Germany, e.g. the Alfred-Wegener Institute (AWI), and abroad, e.g. the European Centre for Medium-Range Weather Forecasting (ECMWF). Our project will also focus on further improving these models, which will allow us to simulate more complex process, e.g. melt ponds on sea ice, while also using a spectrum of solar radiation and concentrations of stratospheric ozone that are closer to observations.

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https://www.geomar.de/jkjellsson

More Information

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Funding

DFG (SynVarBio, NOVEL), BMBF (ROADMAP via JPI Oceans), EU Horizon 2020 (SO-CHIC)

DFG Subject Area

313-01, 313-02