SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	QUECLIM - Quasi-equilibrium climates at increased greenhouse forcing
Computer Project Account:	spitfab2
Start Year - End Year :	2022 - 2024
Principal Investigator(s)	Federico Fabiano (CNR-ISAC)
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Other Researchers (Name/Affiliation):	S. Corti, P. Davini (CNR-ISAC)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The main goal of the project is to investigate the climate response towards stabilization of the climate system at various levels of external forcing. Also, there is interest in studying the internal variability of the climate system at various levels of global warming at quasi-equilibrium conditions. To do this, a set of 1000-years long climate simulations have been performed with the EC-Earth3 model, starting from different years of the historical and SSP5-8.5 scenario simulations and keeping the forcing fixed at the initial level.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

The simulations performed during this special project and the connected results are documented in Fabiano et al. (2024, https://doi.org/10.5194/esd-15-527-2024). A summary of the main results follows.

A series of abrupt stabilization simulations performed with EC-Earth3 is presented, focusing on the equilibration pathway of the climate system on multicentennial timescales and the effects of varying levels of forcing. The setup is compatible with, and partly inspired by, the LongRunMIP ensemble (Rugenstein et al., 2019). The six simulations, with external forcing ranging from the year 1990 (b990) to the year 2100 under the SSP5-8.5 scenario (b100), show a final temperature increase between 1.4 and 9.6 K compared to pre-industrial levels.

- **Stabilization timescale**: the global-mean surface atmospheric temperature stabilizes in all simulations after 600 to 900 years, except for the intermediate b050, which still shows a significant residual trend at the end of the simulation.

- **Hydrological cycle**: the global mean hydrological cycle response intensifies at multi-centennial timescales, leading to an increased trend per degree of global warming.

- **Sea-ice**: winter Arctic sea ice collapses in two simulations (b080, b100) and reaches a tipping point in b065, with the system periodically switching between low and high sea ice cover states.

- **Net feedback parameter**: the feedback parameter tends to become less negative in the second half of the simulation, consistent with previous research. Unexpectedly, it becomes more negative (more stabilizing) for the simulations with larger forcing (e.g. b100).

- **Temperature patterns**: in all simulations, there is a strong acceleration of the warming in the Southern Ocean. Some forcing-dependence is observed: at lower forcing the increase is concentrated in the south of the Atlantic and Indian oceans and extends to the Pacific region only at higher forcing.

- **Precipitation patterns**: drying trends found in the subtropical oceans and in Mediterranean-like hotspots during SSP5-8.5 tend to be reduced during stabilization or even reversed. The inversion of the trend is more clear for larger forcing, especially for the southern subtropics. At large forcing (b100), a strong perturbation is observed in the tropical region, with drying over the western Pacific warm pool and wetting of the Amazon.

- **Deep ocean**: the rate of deep-ocean warming is nearly independent of the external forcing, peaking at an intermediate forcing level (b050), indicating that the efficiency of heat transfer to the deep ocean decreases with larger forcing and over longer timescales. We hypothesize that this is due to a decreased ventilation of the deep ocean with larger forcing, resulting from ocean dynamical adjustments and a general reorganization of the MOC, which becomes shallower and weaker with larger forcing. The nonlinear behavior observed for warming at 2000–3500 m depth in the Atlantic, with decreasing anomalies under larger forcing, further supports this hypothesis. Also, the abyssal MOC in the Southern Ocean collapses during stabilization and may contribute to the observed behaviour.

Rugenstein, M., Bloch-Johnson, J., Abe-Ouchi, A., Andrews, T., Beyerle, U., Cao, L., Chadha, T., Danabasoglu, G., Dufresne, J.-L., Duan, L., Foujols, M.-A., Frölicher, T., Geoffroy, O., Gregory, J., Knutti, R., Li, C., Marzocchi, A., Mauritsen, T., Menary, M., Moyer, E., Nazarenko, L., Paynter, D., Saint-Martin, D., Schmidt, G. A., Yamamoto, A., and Yang, S.: LongRunMIP: Motivation and Design for a Large Collection of Millennial-Length AOGCM Simulations, Bull. Am. Meteorol. Soc., 100, 25512570, https://doi.org/10.1175/BAMS-D-19-0068.1, 2019.

List of publications/reports from the project with complete references

Fabiano, Federico, Paolo Davini, Virna L. Meccia, Giuseppe Zappa, Alessio Bellucci, Valerio Lembo, Katinka Bellomo, and Susanna Corti. "Multi-Centennial Evolution of the Climate Response and Deep-Ocean Heat Uptake in a Set of Abrupt Stabilization Scenarios with EC-Earth3." Earth System Dynamics 15, no. 2 (April 30, 2024): 527–46. https://doi.org/10.5194/esd-15-527-2024

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The analysis of the simulations is still ongoing, regarding:
- the evolution of modes of variability in warmer equilibrated climates;
- the response of the mid-latitude circulation;
- the evolution of individual climate feedbacks.