Max-Planck-Institut
für Meteorologie

LongRunMIP – a large collection of millennial-length model simulations

LongRunMIP is a model inter comparison project of millennial-length general circulation model (GCM) simulations. These simulations are necessary to understand the overall net response to external forcings, and the relationship between transient and equilibrated states. Unforced millennial-length simulations are useful as well, as they allow to study how long a record of internal variability ideally should be to make its interpretation statistically robust. In that sense, the long simulations fulfill similar purposes as large ensemble simulations.

The story

In a discussion about the meaningfulness of climate sensitivity measures, Jonah Bloch-Johnson (now University of Reading, UK) and Maria Rugenstein (Max Planck Institute for Meteorology (MPI-M), now Colorado State University, Boulder, USA) decided during a meeting of the American Geosciences Union (AGU) to ask around for existing millennial-long simulations of atmosphere-ocean general circulation models to determine the true equilibrium climate sensitivity (ECS). The ECS number might be the most sought-after number in climate science research. It quantifies the change of the global mean surface air temperature of the Earth that arises from doubling the atmospheric concentration of carbon dioxide, CO_2 over pre-industrial levels. This number is mostly estimated for climate models and may not even have a realistic equivalence in the real world. Few modelling centers know the exact value for their own climate model. Through her own simulation with the Community Earth System Model (CESM) in 2016 Maria Rugenstein had worked on the influence of ocean heat uptake on radiative feedbacks changing during equilibration, but was bothered by the limitations of just having one version of simulating the climate [1].

Rugenstein and Bloch-Johnson soon made contact with Chao Li at MPI-M, who had published on the equilibration of ocean heat uptake and sea ice in ECHAM5/MPIOM a few years earlier during his PhD [2, 3]. Chao Li was one of the most enthusiastic contributors to LongRunMIP, so Rugenstein and Bloch-Johnson held a helpful workshop about the LongRunMIP data and science at MPI-M in 2016. Still it took two years to gather and homogenize the data. Currently, the dataset consists of 16 models, from 10 modeling centers, with 53 simulations, each at least 1000 years long, often up to 6000 years. The contributions span CMIP3 to CMIP6 models. Several more centers are interested in contributing more recent versions and the initiators are thinking about how to keep the effort going.

The goals

Scientifically, the initial focus was to test how accurate estimates of equilibrium climate sensitivity are from its actual value. The most commonly used estimate in the field are based on linear extrapolations, or energy balance model fits to climate model output of about 150 years. However, the deep ocean needs several thousand years to equilibrate. The LongRunMIP contributors show that — in these type of complex models — the deep ocean equilibration leads to changes at the surface even after several hundred and thousand years, enough to still change radiative feedbacks. The “true” equilibrium climate sensitivity is — depended on the model — 5-40% higher than the commonly used estimates. Radiative feedbacks change continuously in these simulations [4].

LongRunMIP simulations offer a testbed for different methods and theories to calculate feedbacks and climate sensitivity [5] and is used as such for example in the recently much discussed WCRP report on climate sensitivity [6].

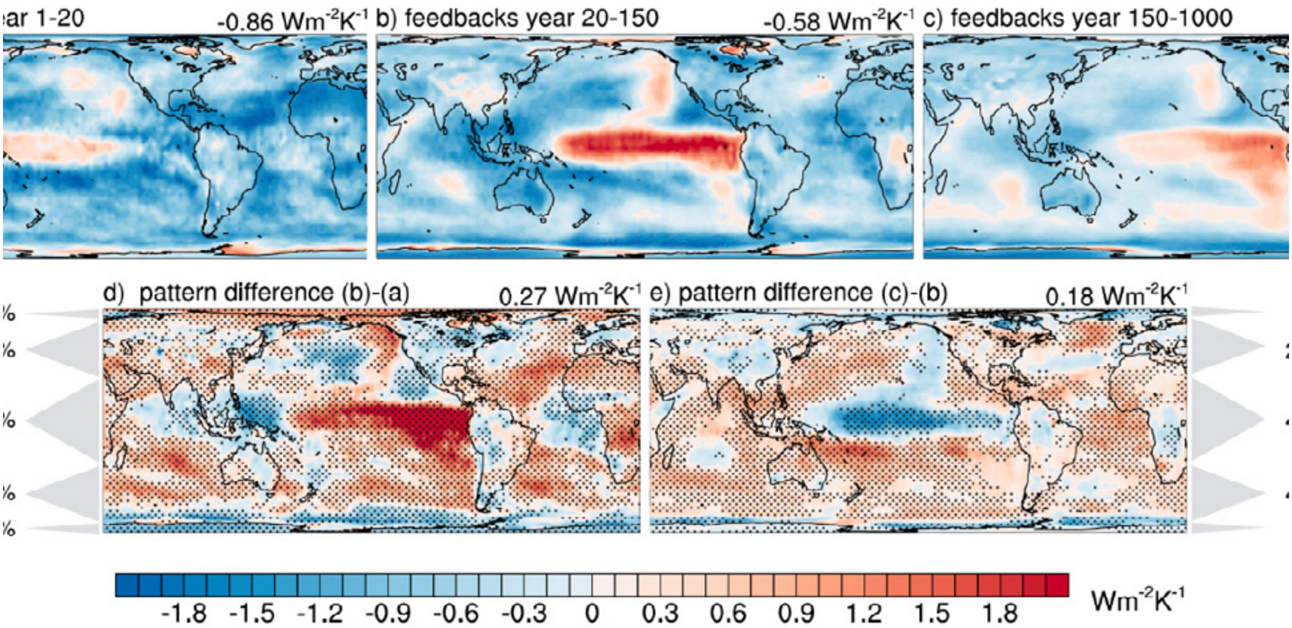
Other scientific findings include

- a new method for defining local and remote influences of radiative feedbacks: Given a long enough record or model simulation, the method predicts radiative feedbacks under warming from internal variability alone [7].

- the differentiation of time- and state dependence of radiative feedbacks: Radiative feedbacks vary both with surface temperature patterns and with global mean or local temperature. The two are difficult to disentangle. Climate sensitivity is further influenced by the overall forcing level. The authors find that robustly across models, climate sensitivity increases with increased forcing due to feedback temperature dependence, not forcing definition dependence. In some models, the feedback temperature dependence causes several additional degrees of warming by 2300 (publication in preparation).

- Atlantic Meridional Overturning Circulation and Southern Ocean Overturning Circulation response timescales: The overturning initially decreases strongly with warming but recovers on century timescales. David Bonan, Maria Rugenstein and others test existing theory on North Atlantic density contrasts on the recovery mechanisms with LongRunMIP models (publication in preparation).

- an understanding of response timescales and local dynamics of the climate system, such as the Tropical Pacific and the behavior of the El Niño/Southern Oscillation (ENSO) (publication in review by Chris Callahan).



Modellmittelwert des lokalen Beitrags zum globalen Rückkopplungsparameter (oben) und dessen Veränderung zwischen verschiedenen Zeitskalen einschließlich Flächenmittelwerten (unten). Mittlere Breitengrade werden relativ wichtiger für die Veränderung von Rückkopplungen im Laufe der Zeit. Aus: Rugenstein et al (2020), GRL. ©2020. John Wiley and Sons. All Rights Reserved.

At MPI-M, there are currently two Master students working with LongRunMIP data: Yiyu Zheng studies how the predictability of ENSO is changing in a warmer world in which the Equatorial Pacific background climate state is very different from today's state. Moritz Witt works on how well functions of two, three, or four exponentials fits can predict the equilibrium climate and sea ice responses. PhD candidate Tim Rohrschneider works on the ocean's slow response mode and provides understanding of long-term climate change.

Conclusion

Maria Rugenstein: "It was a fun process, entirely bottom-up, and learning-by-doing. We were two graduate students and nobody told us what to do and what to take care of. In hind side we would have done a lot of things differently, such as sharing protocols or meta-data requirements, but the science is very motivating."

Maria Rugenstein worked for nearly two years as a Humboldt Postdoctoral Fellow at MPI-M with the departments "The Atmosphere in the Earth System" and "The Ocean in the Earth System". End of July 2020 she moved to Colorado State University, USA, to take over an assistant professorship in the Department of Atmospheric Science.

Publications

[1] Rugenstein, M.A.A., K. Caldeira and R. Knutti (2016) Dependence of global radiative feedbacks on evolving patterns of surface heat fluxes. Geophysical Research Letters, 43 (18), 9877-9885.
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016GL070907

[2] Li, C., D. Notz, S. Tietsche and J. Marotzke (2013) The transient versus the equilibrium response of sea ice to global warming. J. Climate, 26 (15), 5624–5636.
https://journals.ametsoc.org/jcli/article/26/15/5624/34216/The-Transient-versus-the-Equilibrium-Response-of

[3] Li, C., J.-S. von Storch and J. Marotzke (2012) Deep-ocean heat uptake and equilibrium climate response. Climate Dynamics, 40, 1071–1086.
https://link.springer.com/article/10.1007/s00382-012-1350-z

[4] Rugenstein, M., J. Bloch-Johnson et al. (2020) Equilibrium climate sensitivity estimated by equilibrating climate models. Geophysical Research Letters, 47 (4).
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL083898

[5] Rugenstein, M., J. Bloch-Johnson et al. (2019) LongRunMIP. Motivation and design for a large collection of millennial-length AOGCM simulations. Bull. Amer. Meteor. Soc., 100 (12), 2551–2570. (Overview pape
https://journals.ametsoc.org/bams/article/100/12/2551/344532/LongRunMIP-Motivation-and-Design-for-a-Large

[6] Sherwood, S., et al. (2020) An assessment of Earth's climate sensitivity using multiple lines of evidence. Review of Geophysics, online available.
https://doi.org/10.1029/2019RG000678

[7] Bloch.Johnson, J., M. Rugenstein and D.S. Abbot (2020) Spatial radiative feedbacks from internal variability using multiple regression. J. Climate, 33 (10), 4121–4140.
https://journals.ametsoc.org/jcli/article/33/10/4121/345928/Spatial-Radiative-Feedbacks-from-Internal

More information

Website LongRunMIP: **http://www.longrunmip.org/**

"Focus on" ECS: **https://www.mpimet.mpg.de/en/communication/news/focus-on-overview/equilibrium-climate-sensitivity/**

Animations

https://vimeo.com/304642757

Contact

Dr Maria Rugenstein
Now at Colorado State University
Website: **https://mariarugenstein.github.io/**
Email: **maria.rugenstein@colostate.edu**