Project: **1235**
Project title: **NextGEMS**
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1 nextGEMS: 30-year scenario simulations with IFS-FESOM and ICON at km-scale

In early 2024, two 30-year scenarion simulations with the IFS-FESOM and ICON models were successfully completed on the Levante supercomputer at km-scale resolution, which is a world-wide novelty. This was possible with the highly appreciated support from DKRZ in terms of providing extensive storage space, providing access to test reservations for model optimization, and granting reservations for efficient production. The spatial resolution of the atmospheric models was set to 9 km (10 km for ICON), which allowed us to perform necessary 30-year simulations within the granted computing time.

The 30-year scenario simulations for nextGEMS build on Cycle 3 experience, plus further adaptations for multi-decadal experiments. This includes improvements in the configuration (updated schemes and features) and some changes in the output. The simulations were analyzed during the 4th km-scale hackathon in Hamburg, in March 2024 (see below). As before, the scenario simulations can be accessed through the nextGEMS intake catalog.

1.1 IFS-FESOM

On the IFS-FESOM side, two 30-year production simulations (scenario and historical) were run. These simulations were run at 9km resolution in the atmosphere and with about 5km in the ocean (Tco1279-NG5)). The model physics mimics behaviour that has been tried before at even higher resolution of 4.4 km, with a substantially reduced (factor 6) cloud base mass flux in the deep convection scheme. Scientifically, the simulation uses the same IFS cycle as in nextGEMS Cycle 3 (Rackow et al. 2024). However, we adopted the boundary conditions:

- increasing GHG (CMIP6) concentrations, following the SSP3-7.0 scenario,
- CONFESS aerosols, SSP3-7.0 (CMIP6) ozone,
- and a background volcanic aerosol climatology extended with non-zero (non-volcano) year until 2049

From a technical point of view and for convenience of hackathon participants, the output of all fluxes (e.g. precipitation) is not accumulated over each month anymore, but has already been deaccumulated every hour.

Also, the IFS and FESOM model were writing both high-frequency and monthly-mean output to the HEALPix grid, at two resolutions (H512 and H128, or zoom level 9 and 7 in ICON terminology), in addition to writing to a 0.25° grid.

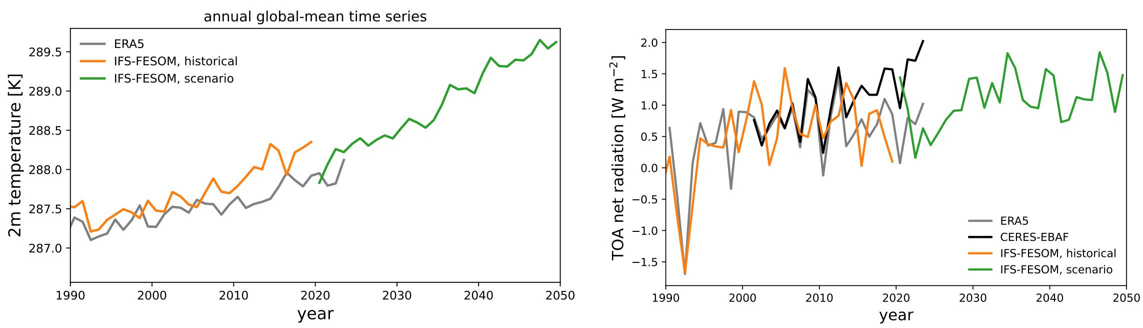

Figure 1: Annual global-mean time series of 2m temperature (left) and TOA net radiation (right), in 30-year IFS-FESOM production simulations (historical and SSP3-7.0 scenario), compared to ERA5 reanalysis and the CERES-EBAF satellite retrieval.

Results for global mean 2m temperature show that the IFS-FESOM historical simulation matches expectations from ERA5 reanalysis well (Figure 1, left). The drop in global mean temperature after the Pinatubo eruption in 1991 is captured well, in accordance with a realistic drop in top-of-atmosphere (TOA) radiation balance (Figure 1, right). In the following decades, global 2m temperature mostly stays within the range of internal variability, even though a small positive bias evolves in the last decade. The TOA radiation imbalance remains close to ERA5 throughout the whole historical period, but unlike the CERES-EBAF satellite observations, it does not increase over time. The SSP3-7.0 scenario warms by $\sim$1.5 K over 30 years, which is at the upper end of the range of CMIP6 simulations, while the TOA net radiation does not increase much over time. This indicates that the time scale at which the ocean responds to atmospheric forcing is quite short. This together with a strong positive cloud feedback (low cloud cover reduces in a warming climate) explains why the scenario is warming by $\sim$1.5 K over 30 years, and also why the historical simulation develops a bit of a warm bias over time.

1.2 ICON

We performed a 30 model-year production run, a SSP3-7.0 2020 - 2049 scenario. Horizontal resolution is 10 km (R2B8) for atmosphere and 5 km (R2B9) for ocean components, with 90 vertical levels and 72 levels, respectively.

This run was prepared by a series of tests to overcome deficiencies in the previous project cycle. Issues addressed were model energy conservation and representation of tropical cloud properties. These tests amount to an additional 21 model-years. During the hackathon, a few complementary runs refining the existing production data were initiated due to user feedback. The tests were also used to reduce and optimize the model output to allow for multi-decadal experiments. Here, we continued to use concurrent output processes optimized for the Zarr formatted HEALPix mapped data. This allows online multi-level spatial and temporal aggregration to support a broad range of research and process scales without further post-processing. Impact of storage characteristics on data retrieval was further analysed and optimized during the hackathon.

2 4th km-scale hackathon in Hamburg

nextGEMS held its fourth hackathon in Hamburg on 4-8 March 2024, at the premises of the Max Planck Institute for Meteorology (MPI-M). The km-scale Hackathon was co-organized by the three climate science projects, EERIE, WarmWorld, and nextGEMS, and welcomed over 130 professionals from different scientific backgrounds, levels of expertise, diverse nationalities, and a variety of institutions. Participants were creating valuable output while hacking and got some inspiring input by talks and keynotes throughout the week. Notably, a bug in the sea ice formulation of ICON was found and the likely reason for it found as well by hackathon participants.

3 Impact and outlook

The closing session on Friday during the km-scale hackathon was used by the thematic groups to share their observations, analysis, challenges, and suggestions. Participants also engaged in a discussion about their opinions or concerns regarding the Earth System Models, future publications, and possible collaborations between the different projects. A paper adopting an inclusive author list across the partnering institutions, documenting the combined efforts of the nextGEMS community, is in preparation (Segura et al.).

References

H. Segura, X. Pedruzo-Bagazgoitia, P. Weiss, S. K. Müller, T. Rackow, J. Lee, E. Dolores-Tesillos, I. Benedict, et al. (in prep.): **nextGEMS: entering the era of kilometer-scale Earth system modeling**

Rackow, T., Pedruzo-Bagazgoitia, X., Becker, T., Milinski, S., Sandu, I., et al (accepted): **Multi-year simulations at kilometre scale with the Integrated Forecasting System coupled to FESOM2.5/NEMOv3.4**, Geoscientific Model Development, `https://doi.org/10.5194/egusphere-2024-913`

News items from MPI and ECMWF: `https://destine.ecmwf.int/news/nextgems-an-excellent-example-of-european-collaboration/` and `https://mpimet.mpg.de/en/communication/news/a-new-generation-of-models-for-kilometer-scale-climate-predictions`