Project: **1235**
Project title: **NextGEMS**
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nextGEMS: What is new in Cycle 3 compared to Cycle 2?

During the report period, we performed the main Cycle 3 simulations for the nextGEMS project with the coupled ICON model at 5 km horizontal resolution for five years. In addition, 5 years were performed with the Integrated Forecasting System (IFS) at 4.4 km coupled to a 5 km ocean (FESOM2.5).

Figure 1: Artistic representation of the urban areas over Europe as included in the Integrated Forecasting System (IFS) for the nextGEMS Cycle 3 simulations. The image shows the three resolutions utilized, from left to right: 28 km , 9 km, and 4.4 km. The particular choice of colormap gives an impression of "city lights" on the night side of Earth // nextGEMS calendar entry by Xabier Pedruzo Bagazgoitia.

Generally, for both ICON and IFS the Cycle 3 simulations allowed us to get to a more stable climate. From the analysis performed by the model development teams and hackathon participants, IFS is ready for multidecadal simulations, while ICON shows good improvements but still needs some final adjustments (e.g. a recently available energy leak fix that needs to be tested in our requested pre-final simulations). Obvious improvements are also the higher realism and more physical representation of high-resolution land features (Fig.1). Examples include the Swiss lakes in ICON, or urban areas and improved land use/land cover maps in IFS. A great step for nextGEMS was also the fact that Cycle 3 had for the first time 5yr-long simulations that allow to make first 'climate'-relevant analyses that were just not possible with the shorter simulations performed for Cycle 2.

IFS-specific improvements include:

- A reduced Southern Ocean sea surface temperature (SST) bias
- More realistic rapid intensification of tropical cyclons (TCs) with good representation at 9km, but even better representation at 4.4km. This might have been the case already in Cycle 2, but this was not possible to state clearly with the too small sample size
- Reduced errors in the top-of-the-atmosphere (TOA) radiation imbalance, leading to a (so far) stable climate (Fig.2) which is a prerequisite for climate change experiments (pre-final simulations on DKRZ Levante in the next period, and on EuroHPC for the final scenario simulations)
- Efficient on-the-fly postprocessing (remapping to different grids and resolutions, computing temporal means)

ICON-specific improvements include:

- River discharge monthly averages now fall within observational range
- Direct output to Healpix grid, which was welcomed by the nextGEMS community as a great step change of working with high-res data

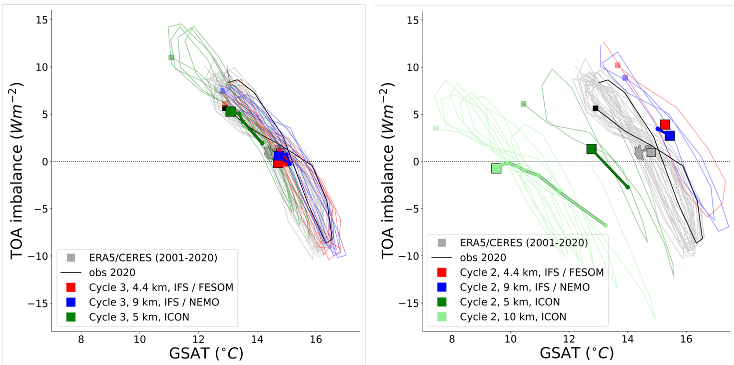

Figure 2: Top-of-the-atmosphere (TOA) radiation balance as function of the varying global mean surface air temperature (GSAT) for the ICON and IFS-based models (colored lines) and observations from CERES/ERA5 (gray lines). The models mostly fall within the uncertainty of the observed 8-shaped range in Cycle 3 (left), while in Cycle 2 all model systems showed a clear offset and larger drift over time (right). Squares depict the final point of the annual mean values.

Third nextGEMS hackathon

The simulations where analysed by more than 130 scientists from Europe and Africa at the third nextGEMS hackathon in Madrid in May 2023. A focus of this hackathon was the evaluation of the key aspects of oceanic circulation. A first comparison was made between high-resolution model output of parameters influencing marine ecosystems and observations of sardinella biomass along West Africa. This is an exciting demonstration of how such models can be useful for the fisheries communities. While the hackathon participants agreed that 5yr simulations are a great improvement over the previous year-long simulations in Cycle 2, it was repeatedly stated that several climate-relevant analyses require longer simulations of, at least, 10 years.

Expected impact

Many publications have so far been written based on nextGEMS data (see nextGEMS publication list that was uploaded), results have been presented at international conferences, and several more publications are in preparation, such as a common paper comparing ICON/IFS results that will likely be led by the Early Career Researchers within the project, and a specific paper on the IFS-FESOM configuration.

It is worth mentioning that the EERIE project, which looks into the effect of mesoscale ocean eddies on many aspects of climate (change), will benefit greatly from nextGEMS in the early phase of the project, as the current and future nextGEMS data on /work will also be used in the first EERIE hackathon in November 2023.

Developments such as the online postprocessing and interpolation capabilities in IFS, HEALpix support in ICON, tuning of the TOA imbalance for a more realistic model climate, and other code optimisations also immediately benefit the Climate Adapation Digital Twin in the Destination Earth initiative.

The pre-final and final scenario simulations with ICON and IFS in the Application phase will address the scientific need for longer simulations that was repeatedly raised during the previous hackathons. These will be the first nextGEMS simulations with full scenario forcing covering the period until 2050. The simulations will allow us to understand and reliably quantify how the climate will change on a global and regional scale, and how the weather, including its extreme events, will look like in the future. An exciting further development is that we are adding novel processes that are important at the km-scale resolutions applied here, and which will become increasingly important in future assessments of climate change, such as the inclusion of cities (Fig.1).