HighResMIPv2 towards CMIP7

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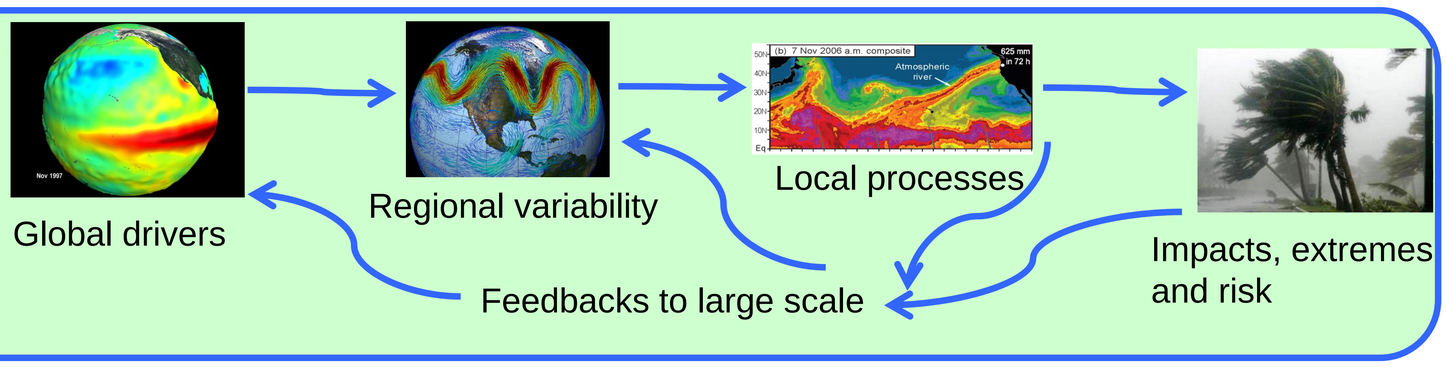


Introduction

CMIP6 HighResMIP [1] provided novel and insightful information on the role of model resolution in representing climate processes and their impact on the simulated mean state, variability, extremes and risk. It made a significant contribution to the IPCC AR6 WG1 report, and more than 160 papers using the data have been published so far.

The resolution for models participating in CMIP6 DECK typically remained at around 100km (Fig. 1), and hence key aspects of the climate system are not explicitly resolved. HighResMIP models began to investigate resolutions of ~25km, some even with an eddy-rich ocean, and one group produced a CMIP eddy-rich coupled simulation [2].

In HighResMIPv2 we plan to address some of the issues found in our previous experimental design, try to link with other communities, and further explore aspects of climate that need both longer simulations and explicit representation of key climate processes to assess future risks. With the recent surge in climate extremes and unprecedented changes in the Atlantic and Southern Ocean, the need for models that represent key processes in these regions becomes ever more urgent.

We also propose to include a new +4K uniform warming experiment to better link to the CMIP “DECK”. Note that the information here is currently a proposal, and still needs to be agreed with the HighResMIP and wider community, and may be adapted as further details of CMIP7 plans become available.

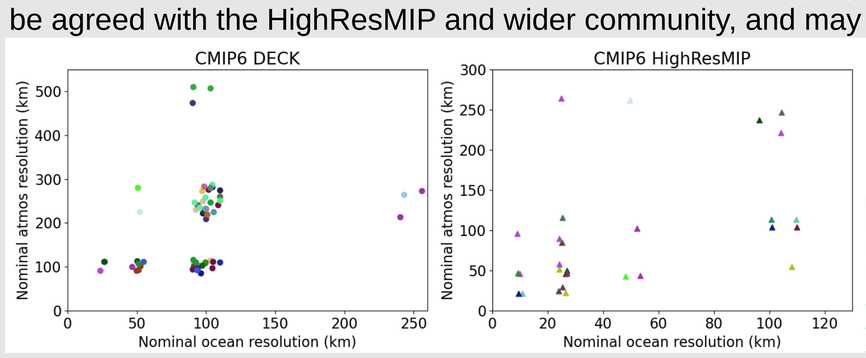


Fig. 1: Plot of the nominal resolution of the atmosphere and ocean components in CMIP6 DECK and CMIP6 HighResMIP models. Source: https://github.com/WCRP-CMIP/CMIP6_CVs/blob/master/CMIP6_source_id.json

Experiment protocol

We plan to modify the experimental design based on feedback from HighResMIP and our updated science questions. These changes include:

remove constraints on aerosol forcing choice;

allow model tuning to extract more from higher resolutions;

extend coupled simulations to 2100;

reduce time period of SST-forced simulations;

replace future AMIP with warming levels.

The entry card for HighResMIP will be at least one of the Tier 1 simulations, either SST-forced or coupled. We encourage multiple ensemble members.

Tier 1a: *highresSST-present*. Historical AMIP-style simulation, 1980-2022. SST and sea-ice forcing based on the 0.05° daily ESA CCI dataset[3], either foundation SST or 20cm temperature.

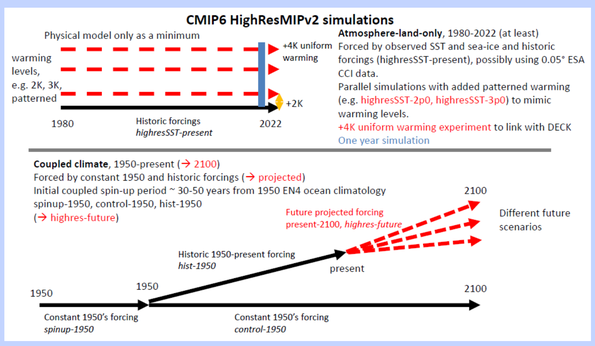
Tier 1b: *spinup-1950* + *control-1950* coupled simulations. These are as in HighResMIPv1, using constant 1950’s forcings, initialized from EN4 ocean analysis. spinup-1950 should be at least 30-50 years long, and control-1950 should be more than 100 years long (to give a baseline for hist-1950).

Tier 2: *hist-1950*. Coupled historical simulation for the period 1950-present using time-varying forcings. End of time period depends on CMIP6 (2014) or CMIP7 (2022?) forcings.

Tier 3a: SST-forced idealized warming level experiments, referenced to *highresSST-present*. Includes specification for +4K uniform warming (to link to CMIP “DECK”), as well as patterned warming (including sea-ice reduction) at different levels.

Tier 3b: *highres-future*, coupled present-2100 using one of several future scenarios.

Tier 4: One year experiment (year TBD) to bridge between km-scale efforts (e.g. DIAMOND+[4]) and CMIP/climate.



Science questions

Rainfall %age change, DJF, 2030-50 - 1960-80, over Europe 20W-30E, 40-65N from different multi-model ensembles

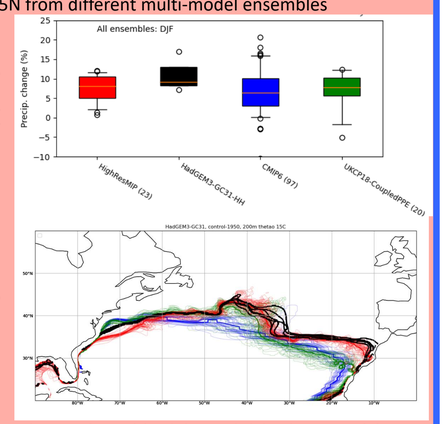


Fig. 2: The eddy-rich model (red contour) has Gulf Stream path different from the lower resolution models, which enables it to move northwards in future, causing enhanced future rainfall over northern Europe (black bar chart)

Enhancing model resolution has a role to play in better understanding uncertainties in the climate system at both the large-scale and smaller scales, as well as the interactions between them. The atmosphere-only and coupled simulations help us to address both aspects in a complementary way.

The SST-forced simulations (including the one year experiment) have the potential to bring new insights into long-standing questions about model development and application. With higher resolutions beginning to edge into the “grey zone”, aspects of climate variability, such as the Madden–Julian Oscillation, the diurnal cycle[6], and hot spots with complex terrain like the Pan-Tibetan Plateau, can be addressed. Extreme events like tropical cyclones, extreme precipitation, and mesoscale convective systems (MSCs) also require further investigation. It may also be possible to identify potential future risks associated with specified patterns and levels of warming.

The coupled simulations will investigate the robustness of projected large-scale changes to the climate as resolution is increased down to eddy-rich scales. Key processes such as air-sea interactions, ocean upwelling, heat uptake and the Southern Ocean circulation have all been shown to depend on scales at or below the ocean mesoscale [7,8,9,10], and hence there is significant uncertainty in projected future changes when such scales are not represented.

An example of how future climate risks may be missed in lower resolution models is shown in Fig. 3 [11], and demonstrates how a common bias in Gulf Stream separation in **all** CMIP6 models could mean that future risks are not able to be represented.

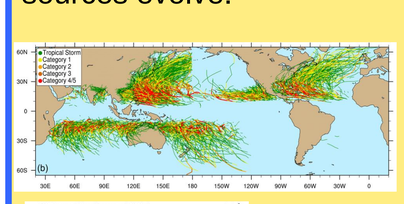
The IPCC AR6 WG1 chapter on extremes described the uncertainty in future changes to processes such as tropical cyclones, which need both high resolution and decadal-centennial simulations to assess variability and change. It is hoped that HighResMIP simulations can help address some of these uncertainties.

Using the one year experiment as a common baseline for models from CMIP6 resolution down to km-scale, we hope to better understand the drivers and processes that govern such extremes (e.g. pre-cursor TC seeds, MCSs) and hence better constrain likely future change.

Metrics and diagnostics

A challenge for HighResMIP is how to balance the needs of data analysis (higher spatial and temporal resolution of more variables to assess weather/climate phenomena against observations) and data providers (finite data production/processing/storage resources). We will use data access patterns from HighResMIPv1 to help prioritise variables and frequency of outputs in our Data Request for publication to ESGF. We have already produced a draft DReq as part of EU EERIE[12].

We will also recommend more automated production of standard metrics and outputs from models using standard packages such as TempestExtremes [13], for example tropical and extratropical storms, atmospheric rivers, MCSs, ocean eddies and metrics associated with the Atlantic Meridional Overturning Circulation. We propose to publish these directly to ESGF since our experience from CMIP6 is that there is huge demand for such derived datasets from the community, which can be used as a starting point for produce further products and insight. One goal with such metrics will be to enable process-based assessment of precipitation [14] and its future change based on how the sources evolve.



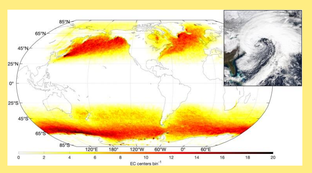


Fig. 4: Examples of extra-tropical cyclones [15] (left) and Mesoscale Convective Systems [16] (below) diagnosis

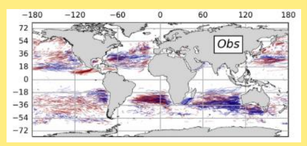


Fig. 5: Ocean eddy tracks [17] (above) and Atlantic Meridional Overturning Circulation obs sections from METRIC [18] (below).

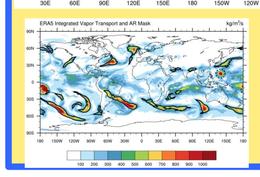
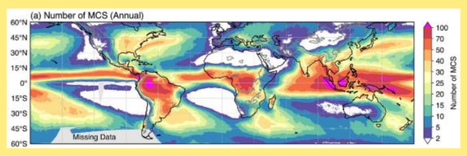
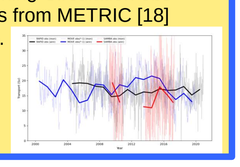


Fig. 3: Tropical cyclones (above) and Atmospheric Rivers (left) diagnosed from ERA5 [13]





Links to other projects and activities

HighResMIP aims to explore aspects of climate on multi-decadal to centennial timescales, at the highest resolutions possible, in multi-model ensembles. It therefore has natural links to the existing CMIP DECK (AMIP-style, +4K, and coupled) and CMIP MIPs (multi-model, standard experiments and diagnostics) as well as to the fast-evolving global multi-model km-scale efforts in atmosphere and ocean (DYAMOND, EVE, EU nextGEMS etc). There is also scope for increased collaboration with regional CORDEX groups and simulations [5], to better understand the role of global drivers and variability and links to regional extremes.

Another driver is the link to observational datasets. Recent and new satellite missions (e.g. NASA SWOT, ESA CCI etc) are producing datasets that enable much finer scale assessment of process representation and sensitivity studies (for example filtering ocean eddies from SST datasets to better understand the role of the ocean mesoscale). Many recent workshops and reports (e.g. US CLIVAR working group on air-sea interactions, Gulf Stream workshop) are illustrating how synergy between new observations and modelling can really help improve process understanding.

Future work

- Further discussion of HighResMIPv2 design with community, aiming to have full draft protocol by end 2023 (but flexible enough to account for later CMIP7 decisions).
- Actively participate in discussions for preparation of CMIP7, including forcing datasets, data request and required diagnostics, data publication standards, potential for DECK-lite and/or producing metrics of model performance for comparison with CMIP.
- Initial HighResMIPv2 simulations with three European models as part of EU Horizon Europe project EERIE during 2023/24.
- Further test and explore ideas around one year simulations, how to choose year(s), how to establish further links with other communities

References

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