

Interactive comment on “High Resolution Model Intercomparison Project (HighResMIP)” by R. J. Haarsma et al.

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Response to anonymous referee #1

"Main comments: 1. My main comment is that the current draft does not make a compelling case as why such a comparison is needed and what are the expected scientific benefits. Many are claimed but the current text does not justify them in a clear way."

We simply do not agree with this assertion. There are a large number of references in the manuscript which describe the impact of model resolution in single model or small-scale comparisons, and which also try to ascribe such changes to simulated processes and their representation. This can be extremely difficult using just one model, since it is not possible to discover if it may be caused by particular aspects of that model. The

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described protocol will, for the first time, enable a systematic evaluation of the impact of model horizontal resolution. The examples of CMIP3 and CMIP5 have demonstrated the tremendous advantages of a common protocol that enables a clear comparison between the models and improved understanding of the underlying physical processes.

"2. For example a major claim is that such a MIP will help model improvements. But I could not find in practice what will this mean, i.e. how the knowledge obtain will inform model development. Increasing the resolution has always been a natural pathway for modelling groups and it is unclear how having this MIP or not will change the related priorities."

We are slightly unsure what you mean here. The manuscript does not claim to help model improvements (please indicate specifically where if you think so) – it simply sets out a common protocol to provide the framework for understanding model differences due to horizontal resolution, and to ascribe these to process representation where possible. It will help to clarify which processes will benefit from increased horizontal resolution and how this will affect the model's climate, natural variability and the response to global warming. This will help in a better understanding of these processes that will ultimately result in improved representation, including in models of lower resolution.

We agree that increasing resolution is a natural pathway for modelling groups. However, an examination of the change in horizontal resolution of many models over the last few CMIP exercises reveals that it is much less emphasized compared to complexity – our aim is to examine whether that is the correct choice or not. The advantage of a common protocol is that the impact for an individual modelling center of their simulations with increased resolution will strongly increase, because their simulation will be analyzed by many researchers and compared with other high resolution simulations. In addition the standardized output following the HighResMIP/CMIP6 protocol will strongly facilitate the analysis. The fact that already 17 centers have expressed their intention to participate in the HighResMIP simulations indicates the strong appeal of a common protocol for high resolution simulations.

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"3. Another example is that only horizontal resolution is included in the protocol. This is a very serious shortcoming as many processes depend on both resolutions (horizontal and vertical) such as atmospheric convection or ocean mixing. As quickly alluded to, solving the diurnal cycle over the ocean requires 1m vertical resolution at the top level of the ocean and 2-3 hours coupling time step. I was surprised that this is not a requirement for this MIP."

We agree that the correct representation of physical processes depend on both resolutions. The scaling between horizontal and vertical resolution must obey N/f , where N is the Brunt-Väisälä frequency and f the coriolis parameter. This implies a factor of 100, between horizontal and vertical resolution. This is well satisfied by the model configurations in the HighResMIP group. We therefore focused on the increase in horizontal resolution, which we consider as the most limiting factor for many processes and makes this comparison tractable. From a practical standpoint, changing vertical resolution can be extremely complex (due to many interactions with parameterisations particularly in the atmosphere) and in our opinion more likely to be dependent on individual model choices, and hence does not lend itself to a clean intercomparison (at least at this time). In addition the combination of increased horizontal and vertical resolution would complicate to assign the contribution of each of those. We have added these arguments in the text (line 4-11 page 4.).

"4. The introduction suggests that modes of interannual variability can be analysed in these short simulations, which is not the case for ENSO for example (several centuries are needed). The details given near the end are careful not to include the modes prone to this sampling issue but the introduction should clarify these limits upfront."

This is a good point. We do not want to overstate this and we agree that this should be clarified already in the introduction. This is now discussed in lines 32-35 page 3.

"5. The forcings are going to be different between the CTRL and the HiRes simulations for some model (e.g. aerosols). This is an issue that will prevent a clean comparison."

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Along the same lines, when changing the resolution one can never have "exactly the same parameters". This limit also renders the comparison less informative."

We agree that with built-in scale dependence of some parameters, one never can have "exactly the same parameters". We also agree that due to interpolation the forcings at different resolutions will be somewhat different (but as close as is currently possible). However, simply because the comparison is not perfect does not lessen the amount we can learn. As long as we can account for these inherent difficulties, we have the opportunity to find out if the impact of enhanced resolution is robust across models, given a common protocol. This has been clearly shown by the analyzes of the already existing high resolution simulations, discussed in the introduction. In addition these obstacles for a clean comparison will likely deviate between the models.

"6. The use of daily SSTs for the AMIP simulation is an issue I believe. As shown by several studies (Wu and Kirtman 2005, 2007, Cassou 2015), the mid-latitudes ocean is forced by the atmosphere, not the other way around. The classical use of smoothed monthly SSTs somewhat mitigates this problem. The use of daily SST requires a much better justification and an analysis that this will not have a impact on extremes over land (adverse impact was shown by Cassou 2015)."

The temporal resolution of SST in AMIP runs is indeed an issue. In AMIP runs the ocean has an infinite heat capacity. This has a deleterious impact on the phase relationships between SSTs, overlying atmosphere, and surface fluxes (Barsugli and Battisti, 1998). This occurs also on monthly time scales as outlined by Sutton and Mathieu (2002). Indeed there is in the mid-latitudes a strong forcing of the ocean by the atmosphere, however, recent studies (Minobe et al., 2008; Kirtman et al, 2012; Parfitt et al., 2015; Ma et al., 2015; O'Reilly et al., 2015) revealed that there is also a significant forcing of atmosphere by the ocean especially along ocean fronts, with sharp temperature gradients and energetic mesoscale eddy activities that are collocated in the genesis regions of the storm tracks. A correct simulation of these processes requires that the strong SST gradients and mesoscale eddies are resolved. This implies the use of daily

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data, because due to the strong meandering of the western boundary currents, time averaging will strongly smooth the SST fields. Because we focus in HighResMIP on the impact of horizontal resolution and how this affects the small scale processes we therefore will use daily, 0.25 degree SSTs.

In conclusion we state that due to the fundamental problems with AMIP runs, there is no general preferred time scale for averaging SSTs although for certain aspects and processes of the climate system the problem will somewhat mitigated by time averaging as explained by you. On the other hand time averaging will mask important processes that we hypothesize to be resolution dependent and therefore a focus of HighResMIP. We have added a discussion on the use of daily SSTs on page 8, lines 7-12.

We will make use of the DECK AMIP simulations, as well as our smoothed SST experiment, to better understand the impact of higher resolution and frequency SSTs. Most modeling groups typically use similar SST datasets (OI-SST, ESA CCI, ERA-Interim) for research purposes, particular as model resolution is enhanced, and hence one expected outcome of HighResMIP is an indication of the strengths and weaknesses of such an approach.

"7. Finally the discussion on the benefits of increased resolution is not balanced, and mostly ignores the studies that don't show any impact of resolution, for example on model biases. The role of physical parameterization is not discussed even though it is central. Improving this balance would strengthen the manuscript which currently mostly appears as a manifesto of like-minded people."

We realize that this manuscript is indeed written by researchers that support the idea of the added value of high resolution runs. This is part of how the new CMIP phase is organized along different specialized MIPs to address the great challenges of the WCRP. We subscribe the hypothesis that high resolution simulations will contribute in resolving those challenges. We are fully aware that other researchers may be more skeptical. Only by doing these experiments will we learn if our hypothesis is justified.

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At this moment there are sufficient centers and researchers that will participate in these experiments of HighResMIP to produce a much more robust understanding of resolution impacts across a multi-model ensemble, and from this evidence and model output the community will be able to draw its own conclusions.

Although we completely agree with the reviewer about the important role of physical parameterization we will not focus on this in the manuscript. The purpose of this GMD paper is to motivate and outline the high resolution simulations, not to give an overview of the causes of model errors. Other GMD papers in this issue will focus on the role of physical parameterizations (e.g. AerChemMIP, C4MIP and RFMIP) and completely ignore the role of horizontal resolution. We think that is fair and combined this issue will provide an overarching view of the different approaches within the scientific community to address the great challenges of the WCRP. To make this clear we have added in the discussion a section about the importance of parameterization and that it will be the central topic in other MIPs on page 17, line 37-41.

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