EUCLIPSE

EU Cloud Intercomparison, Process Study & Evaluation Project

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Deliverable D4.2 Comparison study of the model sensitivity to the numerical structure of the computations (grid and time step) with the parameter sensitivity of the model.

Responsible Patner: MPG

Partners involved: METO, CNRS-IPSL, MF-CNRM, KNMI.

Delivery date: 36 months

Deliverable 4.2: Sensitivity of models to numerical configuration

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Aim: *A study comparing the sensitivity of the models to the numerical structure of the computations (grid and time step) with the parameter sensitivity of the model. This study will also provide best practices for future use of the models, for instance recommendations for integrating diverse physical processes in time and space.*

As initially conceived the idea for this project was to run the different EUCLIPSE models at different resolutions, particularly different vertical resolutions, and in different configurations, to explore their sensitivity to the numerical grid and compare this to the sensitivity to other parameters and aspects of the large-scale circulation.

To initiate the resolution studies, simulations were performed with highest resolution version (T255) of ECHAM6 with a much higher vertical grid spacing, using 199 levels as compared to the 95 levels used in the high resolution model, 63 levels in the standard resolution model and 31 levels used in the low resolution model. The 199 level model differed in the resolution of the entire troposphere, where as differences between the 31, 63 and 95 level models are confined to the upper troposphere (where convective detrainment plays an important role and water vapor and lapse rate feedbacks are strongest). Studies with the 199 level ECHAM model were computationally very expensive and showed that changes in the resolution of the lower troposphere have a strong influence on the basic climate – presumably because many of the physical parameterizations had been extensively tuned over the years to operate effectively at the default resolution of the lower troposphere. Similar sensitivities have been identified for the UKMO model, and in single column model studies. In addition sensitivity studies were performed as a function of timestep, for instance for the climate sensitivity of the very low resolution version of ECHAM (T31/L19), which had been used in perturbed physics experiments (Klocke et al., 2011; Tomassini et al., 2014).

For the high resolution model there was a significant deterioration of the base climate in ECHAM, which suggested that it did not make sense to explore the effect of vertical resolution on the climate sensitivity systematically in other models. This work also identified strong time-step dependencies, commensurate to parameter sensitivities (e.g., Tomassini et al., 2014; Lacagnina et al., 2014), in the low resolution version of model, which have since been tied to errors in the treatment of subgrid-scale cloudiness. For these reasons efforts toward this deliverable focused on sensitivity to horizontal resolution, less ambitious changes in vertical resolution focused in the upper troposphere, correcting the implementation of sub grid cloudiness in ECHAM, and identifying a hierarchy of simpler configurations that would allow the vertical resolution of the parameterizations to be studied. These are discussed in turn below.

Horizontal resolution was explored by Hourdin et al. (2012) using different configurations of the IPSL models (IPSL-CM4, IPSL-CM5A-LR and -MR) and the transient climate response to a 1% yr^{-1} increase in atmospheric CO_2 was shown to be relatively insensitive (10 % change) to a two-fold change in horizontal resolution. However horizontal resolution did have a large impact on the atmospheric energy budget, and the position of major circulation features, such as the mid-latitude jets. The UKMO model (HadGem3) was found to be similarly insensitive to modest changes in the vertical grid. The effect of vertical resolution on the upper troposphere was explored in the publications by Mauritsen et al. (2012) and Stevens et al. (2013) for the case of ECHAM. These authors found that vertical resolution alters parameter sensitivities, as one of the key parameters controlling climate sensitivity in a low resolution model (see also Tomassini et al., 2014) ceases to be important when resolution is increased in the upper troposphere. Further increases in the vertical resolution of the upper troposphere and through the stratosphere appear to have a less marked effect on the climate sensitivity, but were not tested in combination with parameter sensitivities. So for instance, the 47 level version of ECHAM6 is estimated to have an equilibrium climate sensitivity that is nearly ten percent higher than that of the 95 level model and has a somewhat smaller forcing (because of differences in adjustments) leading to a climate feedback parameter that is more than ten percent larger (implying a smaller sensitivity) with the more resolved upper troposphere Stevens et al. (2013). The studies with ECHAM were directly supported by EUCLIPSE, as was indirect support for the IPSL simulations and analysis of the UKMO simulations.

The effect of horizontal resolution was explored more systematically in a study by Siongco et al. (2014). Here the representation of precipitation over the atlantic in CMIP5 models was studied through the identification of precipitation objects. The study suggested a resolution dependency whereby higher resolution models tended to have more orographically focused precipitation, and a displacement of the central Atlantic ITCZ precipitation maximum toward the African coast. Lower resolution models biased the central Atlantic precipitation feature to the west, off the coast of Brazil. Using a sequence of simulations with the MPI-ESM that spanned a four-fold increase in resolution it was shown that this apparent resolution dependency is also evident in individual models as a function of resolution (Fig. 1). Analysis of different resolutions of the GFDL model, and the results published by Hourdin et al. (2012) are also consistent with this interpretation.

Resolution was also explored in single column studies. Here individual models often showed a tendency to lock cloud features on a single grid level. This lack of smooth behavior made the interpretation of single model results very difficult, as shifts of cloudiness between levels had a profound effect on results but occurred from small, and seemingly unpredictable, interactions among parameterizations, even for simple forcing (Cheedela, 2014; Brient and Bony, 2013). Through EUCLIPSE, methods were developed for dealing with these sensitivities. Specifically Brient and Bony (2013) demonstrated that by adding noise to the large-scale forcing the response of the single column model was more predictable and more representative of the response of the full model in similar forcing regimes. This procedure was adopted in studies with ECHAM (Cheedela, 2014) where it was also found to be effective. Tests with large-eddy simulation as part of the CGILS [1] shows that shifts in cloudiness in large-eddy simulation are carried by small changes in cloud top height which would not be resolvable on a global models grid. Despite the sensitivity of the vertical structure of the lower troposphere to the vertical resolution of the model, the climate sensitivity appeared not to be strongly sensitive to the vertical grid, raising the question as to whether the processes that set climate sensitivity are robust, i.e., controlled by processes that are relatively independent of the grid (e.g., Rieck et al., 2012; Brient and Bony, 2013), or perhaps that the processes are so far from being adequately resolved that sensitivities

[1] CFMIP GEWEX intercomparison of large-eddy simulation and single column models, a project cosponsored by EUCLISE

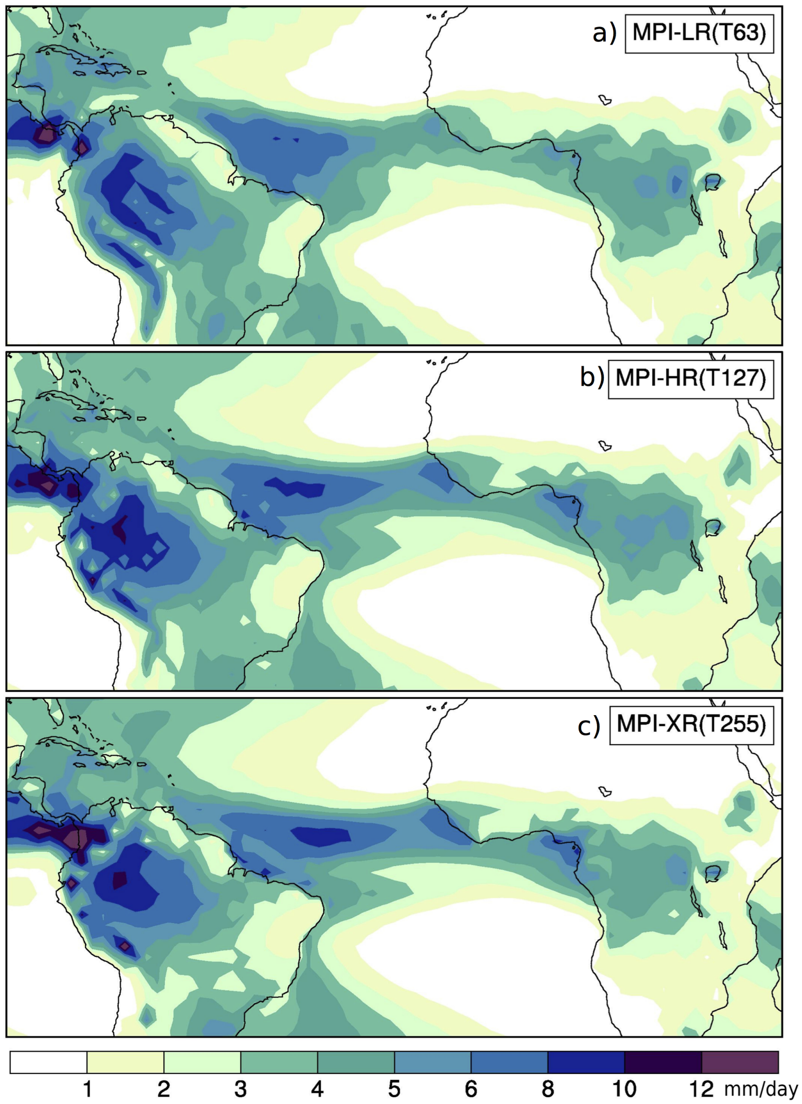

Figure 1: Mean state ITCZ structure in different resolutions of the MPI model: a) LR-T63, b) HR-T127, and c) XR-T255.

from a lack of resolution are not affected by what, in the end, are small changes.

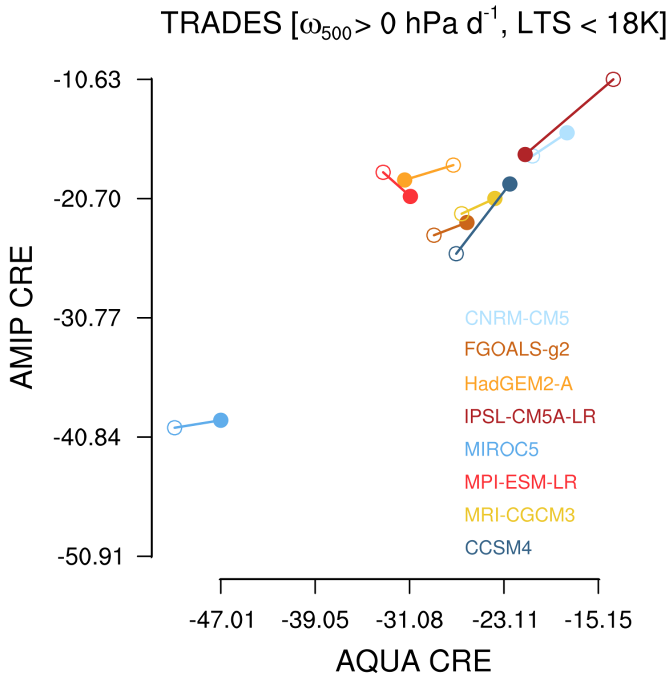

Figure 2: Cloud Radiative Effect W m^{-2} averaged over the trade-wind regions (LTS ¡ 18 K, $\omega_{500} > 0$) for the AMIP and AQUA simulations and their counterpart +4K experiments. All models except the MPI-ESM show a consistent response, the latter being related to differences in the change in the tropical circulation (strengthening with warming) in the AQUA as compared to the AMIP simulations. Taken from Fig. 18 of Medeiros et al. (2014).

The ability of simple model configurations to capture the different sensitivities of the EUCLIPSE models was also explored through EUCLIPSE by allowing the different centers to contribute aqua-planet versions of their models to CMIP6. The climate sensitivity and mechanisms underlying different climate sensitivities were compared to those of AMIP models and fully coupled simulations by Medeiros et al. (2014). Here it was shown that the aqua-planet simulations isolated the main differences in the representation of the climate sensitivity among models, namely different representations of low-level clouds in the trade-winds, across most models, as e.g., argued by Vial et al. (2013). Exceptions were those models that had a strong feedbacks in the stratocumulus regimes which are not sampled by the aqua-planets, or in the case of the MPI-ESM, when the change in the aqua-planet tropical circulation did not mirror that of the more realistically configured simulations. The similar trade-wind layer response among the models serves to strengthen the argument that low-cloud feedbacks are not too dependent on the details of circulation regimes, but arise because of basic differences in the representation of parameterized processes in the tropics.

Following on this work, Popke et al. (2013) developed a yet simpler representation of tropical circulations by configuring the MPI-ESM to run in radiative convective equilibrium, or RCE. The behavior of the RCE version of the MPI-ESM was shown to be very similar to the complete version of the model, encouraging the use of the framework by more groups.

This configuration of the model has also been adopted by the LMD/IPSL group. RCE has the great advantage that it is a configuration that can be simulated by cloud resolving models, so to the extent that basic differences among the models are also apparent in RCE it becomes possible to test the representation of convection through comparison to similarly configured large-eddy simulations, or cloud-resolving models. Such experiments are likely to play an important role in the next phases of CFMIP and CMIP.

In summary, large sensitivities of the basic state to vertical and horizontal resolution were identified which made it difficult to create a multimodel ensemble that systematically explored the effect of resolution or timestep on model climate sensitivity. Likewise studies showed that the parameter sensitivities of models is resolution dependent. In general this analysis showed that many features of the circulation improve with resolution, but in an incremental fashion. The position of the midlatitude jets are better represented at higher resolution, and atlantic precipitation biases are also somewhat reduced. Modest (factor of two) changes in horizontal and vertical resolution demonstrated a comparably small (10%) sensitivity of the climate sensitivity to resolution.

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