EUCLIPSE

EU Cloud Intercomparison, Process Study & Evaluation Project

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Deliverable D4.4 New process representations to be implemented in ESMs which will rationalise the range of responses by the models.

Responsible Partner: KNMI

Partners involved: MPG, CNRS-IPSL, METO, MF-CNRM

Delivery date: 42 months

SEVENTH FRAMEWORK PROGRAMME

Deliverable 4.4: Rationalizing and Narrowing the Range of Modeled Cloud Responses to Forcing

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Aim: *New process representations that can be implemented in models and which will better rationalize (and hopefully narrow) the range of cloud responses by the models.*

This deliverable was addressed by process studies that attempted to narrow the range in estimates of climate sensitivity by bounding the behavior of specific processes, and where possible introducing new representations of processes. Several types of studies have been performed and coordinated through EUCLIPSE: process studies in which parameters, or parameterizations, were varied systematically to study the effect of specific processes on model biases; perturbed physics studies in which parameters are varied randomly over a range to assess uncertainty; and process denial experiments in which specific processes were identified, often on the basis of more fundamental models through efforts in WP3, and their effects explored by disabling these processes. In addition, ideas leading to new parameterizations With support from EUCLIPSE[1] two of the EUCLIPSE modelling groups systematically explored how the representation of convective mixing influences intra-seasonal variability as well as the structure and position of the tropical convergence zones. The CNRM (Oueslati and Bellon, 2012) group explored the response of the CNRM and LMDz models to differing meridional SST gradients in an aqua planet, and similar experiments were performed by the MPI group (Möbis and Stevens, 2012) using two different flavors of their models . Both groups found that the imposed SST gradients played a strong role in determining whether or not a single ITCZ formed over the equator, or whether a double, off-equatorial ITCZ structure developed. For strong meridional SST gradients precipitation maximized on the equator for all models, for weak gradients precipitation maximized off the equator, but at latitudes that were model dependent. In both studies the transition from a single to double ITCZ structure was found to be very model dependent, and could be related to specific parameterization choices.

A key parameter identified in both studies was the rate of lateral entrainment by convection, with more entrainment leading to a cooler free troposphere and more convection maximizing over the equator (Möbis and Stevens, 2012; Oueslati and Bellon, 2013). This sensitivity, initially identified in idealized aqua-planet configuration of the models was shown to extend to more realistic model configurations, so that more lateral entrainment by convection favored the development of the south-pacific convective zone in the fully coupled CNRM model (Fig. 1), and the development of on equator precipitation and the initiation of Madden-Julien like variability in the MPI-ESM (Crueger et al., 2013). Subsequent work with the MPI model, and the COOKIE experiments (deliverable 4.1 and 2.8) also have shown that cloud-radiative effects, particularly the reduction in atmospheric radiative cooling associated with the presence of high clouds, also plays an important role in the formation of an ITCZ on the equator for intermediate SST gradients.

Perturbed parameter experiments were conducted with the MPI-ESM by Tomassini et al. (2014) and with EC-Earth by Lacagnina et al. (2014). The MPI-ESM experiments were performed using the fully coupled model, albeit at lower resolution. The sensitivity

[1] Unless otherwise indicated, all of the publications were made possible through support by EUCLIPSE.

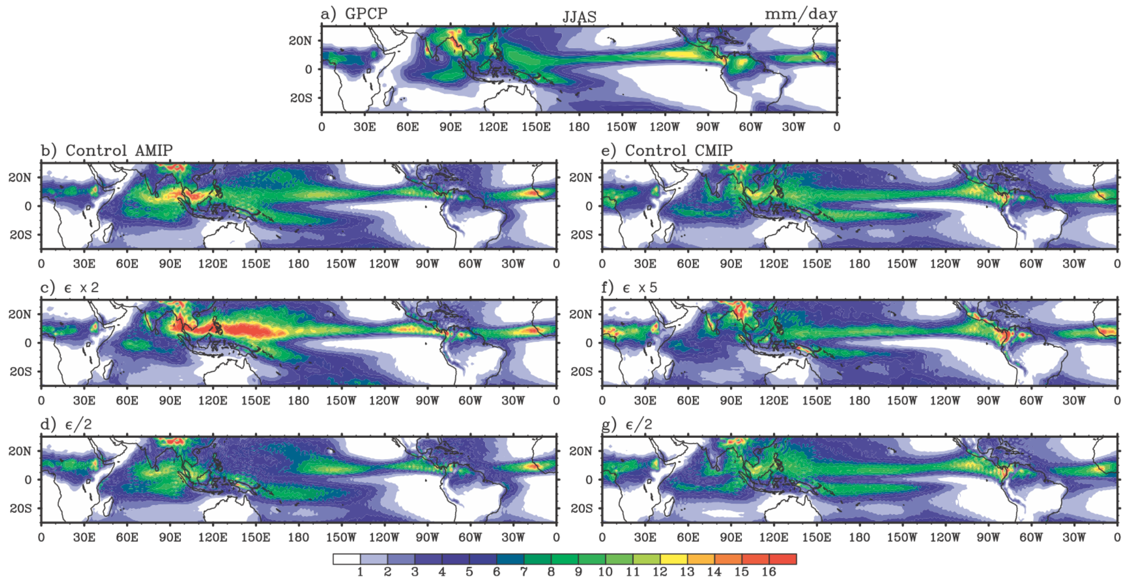

Figure 1: The 1979-1999 mean JJAS precipitation (mm day^{-1}) from (a) GPCP, (b)(d) AMIP, and (e)(g) CMIP sensitivity experiment ,from Fig. 1 of Oueslati and Bellon (2013). In the figures, ϵ measures the lateral entrainment rate by deep convection, so that experiments (c) and (d) are indicative of a fourfold change in the entrainment rate for the AMIP simulations.

of the cloud feedback parameter to model parameters was derived from EC-Earth model using pairs of AMIP simulations differentiated by a change in the globally averaged sea-surface temperature. The sensitivity of the standard resolution version of the MPI-ESM's representation of the equilibrium climate sensitivity to its tuning procedure was evaluated in a study by Mauritsen et al. (2012), complementing another study of the effects of tuning parameters by Hourdin et al. (2012). Hohenegger and Stevens (2013) also systematically explore the ability of diurnal changes in the entrainment efficiency of convection to better explain the diurnal cycle, and biases in the diurnal cycle common to climate models, but found that a proper representation of the diurnal cycle also required a better representation of convective triggering. All of these studies were conducted with the support of funding from EUCLIPSE, albeit the ones by Hourdin et al. (2012) and Hohenegger and Stevens (2013) only indirectly.

The parameterization perturbation experiments can, at best, be considered a weak representation of process sensitivity. And although the perturbed parameter experiments show, for the low-resolution version of the MPI-ESM, that a very large-range of climate sensitivities (from 3 to 8 °C) could be sampled by changing a few of the convective parameters (Tomassini et al., 2014), attempts to develop a compelling and well tuned model lead to a large reduction in the range of the climate sensitivity. For ECHAM6 following different parameter tuning strategies resulted in a range of climate sensitivities that varied by 20% across four 'plausible worlds' (e.g., Fig. 2 which is taken from Mauritsen et al., 2012), and were more concentrated toward the low end of the sensitivity range as sampled by Tomassini et al. (2014). Three of the four worlds created by Mauritsen et al. (2012) had values of the

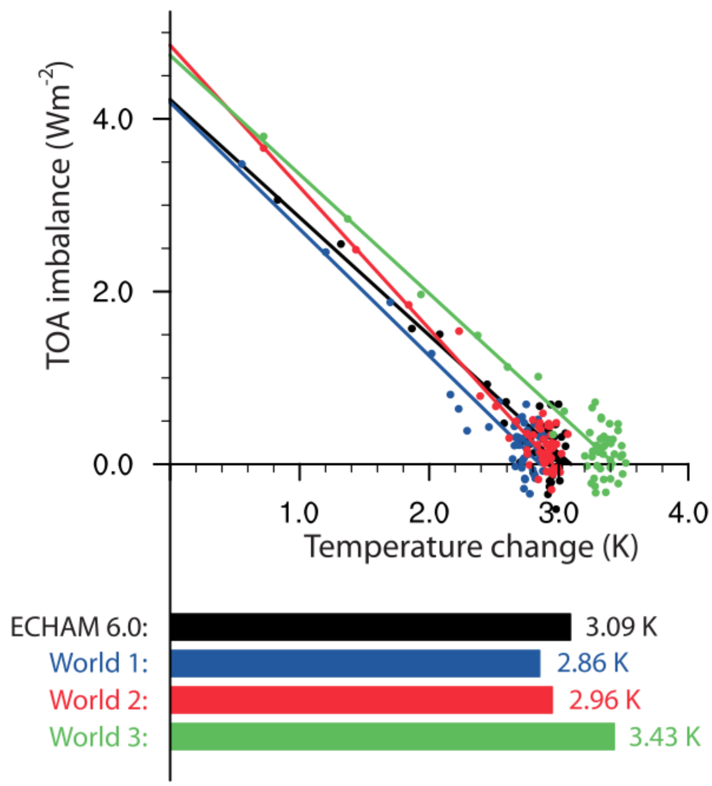

Figure 2: Global mean temperature versus TOA radiation imbalance after an instantaneous doubling of CO2. Lower part shows the estimated equilibrium climate sensitivity based on the linear regression. Figure taken from Fig. 13 of Mauritsen et al. (2012)

equilibrium climate sensitivity that were smaller than any of the models generated through the parameter perturbation experiments in Tomassini et al. (2014).

Most of the work on this deliverable concentrated on the role of specific processes, particularly the role of convective parameterization, precipitation efficiency and radiative processes. Following on the work of Brient and Bony (2013) in which the energetic demands of the moist static energy budget were shown to be satisfied by a reduction in low cloud amount, Brient and Bony (2012) demonstrated that the strength of the cloud feedback depended on low-cloud radiative effects, something they called the β-feedback, and that this mechanism might be responsible for the tendency of cloud feedback strength to scale with low cloud amount in some perturbed parameter experiments. Turning this feedback off in the IPSL model, by making low clouds invisible to radiation reduced the low-cloud response to warming by a factor of three, consistent with this this hypothesis. Overall the work suggests that a better representation of present-day ACRE can translate (to some extent) into a more reliable strength of PBL cloud feedbacks. This work of the IPSL group motivated a coordinated sensitivity study of all the EUCLIPSE models (and some partner models through coordination within CFMIP) called COOKIE, for the Clouds On-Off Klima Intercomparison Study and a follow up series of experiments called SPOOKIE (for Selected Processes On-Off Klima Intercomparison Experiment). Some of the results from these coordinated experiments have been presented in Deliverable 2.8 (Webb 2013); a fuller analysis remains on going. One initial finding (Crueger and Stevens in preparation) is that the cloud-radiative effects are important for sustaining intra-seasonal variability as was earlier hypothesized by Bony and Emanuel (2005). Another is that in the four models initially participating in SPOOKIE, the range in global cloud feedback reduced by 40 % with the removal of parametrized convection.

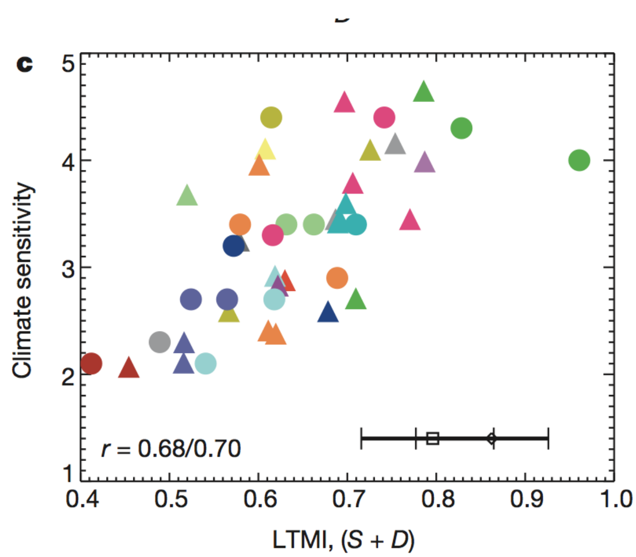

Figure 3: Climate sensitivity of the CMIP3 and CMIP5 models plotted against the lower tropospheric mixing index. Figure taken from Fig. 5 of Sherwood et al. (2014)

Another idea to emerge with the support of EUCLIPSE funding is that increases in surface evaporation expected to accompany a warming atmosphere will promote convective mixing that will, lead to an overall drier boundary layer (Rieck et al., 2012). In the case that surface evaporation does not increase with Clausius Clapeyron, which is expected because of energetic constraints on the surface energy budget, boundary layer drying will take place in a relative sense as surface fluxes will be unable to keep pace with entrainment fluxes for a fixed boundary layer depth. This too would act to dry the boundary layer and like the energetic insights put forth in the concurrent work by Brient and Bony (2013) presages a positive low-cloud feedback. These ideas were also tested in the EUCLIPSE project by limiting surface evaporation in the UKMO model (Webb and Lock, 2012), with the model response being consistent with the ideas developed on the basis of LES and single column models, thereby underpinning belief in robust positive shortwave cloud feedbacks from shallow maritime convection. Analysis of the CMIP5 models by Sherwood et al. (2014) also suggests that the aforementioned convective mixing processes regulate the humidity of the lower atmosphere in a way that explains differences in the strength of low-cloud feedbacks, and hence the climate sensitivity across the CMIP3 and CMIP5 ensemble.

Within EUCLIPSE experimental strategies have also been developed to explore the possibility of what would otherwise be considered to be a very low or very high climate sensitivity. One controversial hypothesis maintains that increased warming leads to greater convective organization, so that convective areas contract with warming, much like the eye's iris when it is exposed to more light. If true such an effect could lead to more efficient heat export from the climate system, effectively lowering the climate sensitivity. The processes underlying a possible iris are unclear, but large-eddy simulations support an enhanced tendency toward aggregation with increasing temperature, and observations analyzed as part of EUCLIPSE Tobin et al. (2012) support the idea that the efficiency with which the local environment radiates energy to space increases with greater aggregation. To mimic this effect the parameterization of convective precipitation was made temperature dependent in ECHAM. Simulations with this ECHAM-IRIS were found to have modestly reduced (2.2 - 2.5 K) climate sensitivity, and an increased hydrological sensitivity Mauritsen and Stevens (2014). These changes were most pronounced in the tropics, which reduces also apparent biases in model predicted versus observed warming, thereby suggesting that a better understanding of processes that control convective organization may be important for climate.

EUCLIPSE was also influential in introducing new, improved, parameterizations. Cloud overlap studies large-eddy simulations of shallow convection performed by EUCLIPSE investigators (indirect support, not acknowledged Neggers et al.) demonstrated how cloud overlap from shallow convection depends on vertical resolution. Based on these results EC-Earth simulations were analyzed by Neggers and Siebesma (2013) to show how the mis-representation of shallow convective anvils (the detraining stratiform component) in EC-Earth were being compensated by the traditional (max-random) overlap assumption, demonstrating that improvement associated with the new cloud overlap parameterization is only possible if both biases are cured the same time.

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