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A comparison of perturbed physics ensembles constructed with different models

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F. Niehörster (Freie Universität Berlin), M. Collins (Hadley Center, Met Office)

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

Executive Summary:

Similarities between feedbacks in PPEs based on two structurally-different models gives evidence that the technique is a suitable tool for the quantification of model uncertainties in climate projections. Nevertheless, the differences between the two PPEs suggest that the combination of output from many different PPEs with the output from multi-model ensembles is likely to lead to a better process understanding and a more complete evaluation of uncertainties.

Abstract:

The perturbed physics approach recently has been used in several studies to study the uncertainty in climate sensitivity of GCMs. This method tries to sample the uncertainty in possible model behaviour by varying uncertain parameters in the description of sub-grid scale processes of climate models, effectively de-tuning models from their standard parameter settings. Thereby, not only the uncertainty in climate sensitivity in general but also the contribution of different parameters to the uncertainty can be quantified. In this report, we compare perturbed physics results generated with different GCMs, namely HadSM3 (HadAM3 with slab ocean) (Pope) and EGMAM (ECHO-G with Middle Atmosphere) (Huebener).
Where the models share the same parameterisation schemes we compare the effects of parameter perturbations directly. We find a model response of same sign to perturbations of certain parameters, but with a higher magnitude in HadSM3 than in EGMAM.
A more general comparison of PPEs in terms of ranges in climate sensitivity and different feedback processes are presented by comparing the EGMAM ensemble with a 181 member perturbed physics ensemble (PPE) of HadSM3 versions (QUMP ensemble) together with results of a subset of the AR4 multi-model ensemble. Both PPEs show highest uncertainty in the shortwave cloud feedback, which is consistent with the AR4 ensemble. In EGMAM the shortwave feedbacks of different model versions are anticorrelated with the negative cloud feedback processes reducing the spread in total cloud feedbacks. This anticorrelation is not shown in the QUMP and AR4 ensembles and thus, the ensemble spread in cloud feedbacks in those ensembles is higher than in the EGMAM ensemble. Consequently, this is true also for the total climate feedback parameter.

Introduction:

A perturbed physics ensemble (PPE) of a GCM is generated by sampling the uncertainty in model parameters describing sub-grid scale processes, thus, creating different perturbed versions of one particular model, called model versions. Recently, the method of PPEs to quantify uncertainty in climate sensitivity of GCMs has been used in a variety of studies using the Hadley Centre climate models (Murphy, Stainforth, Webb, Collins). Large ranges in climate sensitivity and feedback mechanisms can be found in these ensembles.
In the framework of the ENSEMBLES project a PPE with the GCM EGMAM was created which focuses mainly on uncertainties in the cloud parameterisations of the

model. This is done to quantify uncertainty in cloud feedbacks which are found to be the main drivers for climate sensitivity of climate models (Bony, Webb).
This report presents a comparison of the results from these PPEs. The study is motivated by the question of consistency between perturbed physics results obtained with different models and thereby assessing the objectivity of perturbed physics results with a single model.
EGMAM and HadSM3 share the same parameterisation of stratiform clouds which is based on the scheme of Sundqvist (Sundqvist). Two model parameters in this scheme, namely the ice fall speed of ice crystals in cirrus clouds (ICE) and the rain efficiency in large scale clouds (RAIN), are perturbed in both models. The former parameter describes the speed of the sedimentation of ice crystals from cirrus clouds and thus controls thickness and lifetime of this cloud type. The RAIN parameter controls coalescence of rain drops in low stratiform clouds and thereby cloud water content and lifetime of this cloud type. The effect of these perturbations on the climate sensitivity of the two models is directly compared.
The models have different convection schemes (EGMAM: Tiedke, HadSM3: Gregory). Only one perturbation parameter is included into the comparison, namely the entrainment rate coefficient (ENTR) which has a physical comparable meaning in the different convection schemes. The ENTR parameter controls the mass inflow into convective updrafts and thereby contributes to the amount of vertical transport of moisture. Other perturbation parameters of the convection scheme are judged as not being directly comparable in their physical meaning and are excluded from the direct comparison.
In addition to the direct comparison of particular perturbations, an uncertainty analysis of feedback mechanisms is done by comparing results from the entire QUMP PPE (53 single parameter perturbations (Murphy) and 128 multi parameter perturbations (Webb)), the EGMAM PPE (10 single and 22 multi parameter perturbations) with results from a subset of the AR4 multi-model ensemble (Webb) which also contributed to the CFMIP project (McAvaney).

Experimental design:

The perturbations of parameters in the GCMs were made according to an estimate of the highest and the lowest plausible value for a particular parameter. These estimates are based on experts judgements and sensitivity tests of the control climate to perturbations of the parameter values. The standard model version is then perturbed and compiled with a high or low value for a single or multiple parameters. Each perturbed model version is integrated under pre-industrial conditions ($1XCO_2$) and with a doubled CO_2 concentration in the atmosphere ($2XCO_2$), as an idealized surrogate of anthropogenic CO_2 emissions. The difference between the decadal means of the two runs for each model version is interpreted as its climate change signal.

Method:

We analyse the ensembles not only in terms of global mean temperature response (ΔT) to the doubling of the CO_2 concentration but also in terms of feedback mechanisms which contribute to the temperature response to a doubling of the CO_2 concentration. This is done by looking at the changes (Δ) of top of the atmosphere radiative fluxes in the control climate ($1XCO_2$) and the climate change simulation ($2XCO_2$). This is done separately for full ten year means and for ten year means only clear-sky (CS) conditions. Both flux changes can be further divided into their longwave (L) and shortwave (S) components to distinguish between different feedback mechanisms, e.g. shortwave and longwave cloud feedbacks (SCF and LCF). In the following we show how feedback parameters for different physical feedback processes are constructed according to the radiative forcing method (Boer&Yu). Although the method is shown to have some weaknesses (Soden) we use this method because it still represents a reasonable measure of feedback mechanisms and is consistent and straightforward to implement for a comparison of different models.

The feedback parameter λ is a linear factor between radiative response of the climate system $\Delta(L\text{-}S)$ and the global mean surface temperature change. The feedback parameters are calculated as change of radiative response per degree of surface temperature increase as follows:

$$\lambda := \Delta(L - S) / \Delta T \qquad \text{(total feedback parameter)}$$
$$\lambda^{CS} := \Delta(L^{CS} - S^{CS}) / \Delta T \qquad \text{(clear-sky feedback)}$$
$$\lambda^{LCS} := \Delta L^{CS} / \Delta T \qquad \text{(water vapour+lapse rate feedback)}$$
$$\lambda^{SCS} := \Delta S^{CS} / \Delta T \qquad \text{(surface albedo feedback)}$$
$$\lambda^{CF} := [\Delta(L-L^{CS}) - \Delta(S-S^{CS})] / \Delta T \qquad \text{(cloud feedback)}$$
$$\lambda^{SCF} := \Delta(S - S^{CS}) / \Delta T \qquad \text{(cloud SW albedo feedback)}$$
$$\lambda^{LCF} := \Delta(L - L^{CS}) / \Delta T \qquad \text{(cloud LW greenhouse effect)}$$
$$\lambda^{LW} := \Delta L / \Delta T \qquad \text{(longwave feedback)}$$
$$\lambda^{SW} := \Delta S / \Delta T \qquad \text{(shortwave feedback)}$$

It holds :

$$\lambda = \lambda^{CS} + \lambda^{CF}$$
$$\lambda^{CF} = \lambda^{SCF} + \lambda^{LCF}$$
$$\lambda^{CS} = \lambda^{SCS} + \lambda^{LCS}$$

and $$\lambda = \lambda^{LW} + \lambda^{SW}$$

For a climate system in equilibrium, when climate's radiative feedbacks $\Delta(L - S)$ have compensated the forcing F ($\Delta(L - S) = F$), λ_{eff} is equal to the negative inverse of the well known equilibrium climate sensitivity.

Results:

Fig 1 shows a comparison of the sensitivity of temperature responses to single parameter perturbations of HadSM3 and EGMAM. The standard model versions of HadSM3 and EGMAM show a global mean temperature response of 3.39K and 2.13K respectively. Therewith, EGMAM is on the low end of the spectrum of GCM climate sensitivities shown in multi-model-ensembles (Meehl), whereas HadSM3 shows a value close above the median of the AR4 set of models.
For all three perturbation parameters the change from a low to a high value causes the model's temperature responses to change in the same direction, but with considerable differences in the magnitude. The magnitude of change in HadSM3 is about five times higher for the ICE (0.7K to 0.15K) and RAIN (1.1K to 0.2K) parameters of the large scale cloud scheme. For the ENTR parameter of the (different) convection schemes the magnitude is even about 13 times higher in HadSM3 than in EGMAM (3.8K to

0.3K). In both models changing the ENTR parameter from the standard to the high value has nearly no effect. Changing it to a low value causes the biggest increase in temperature response of all perturbation in both models.

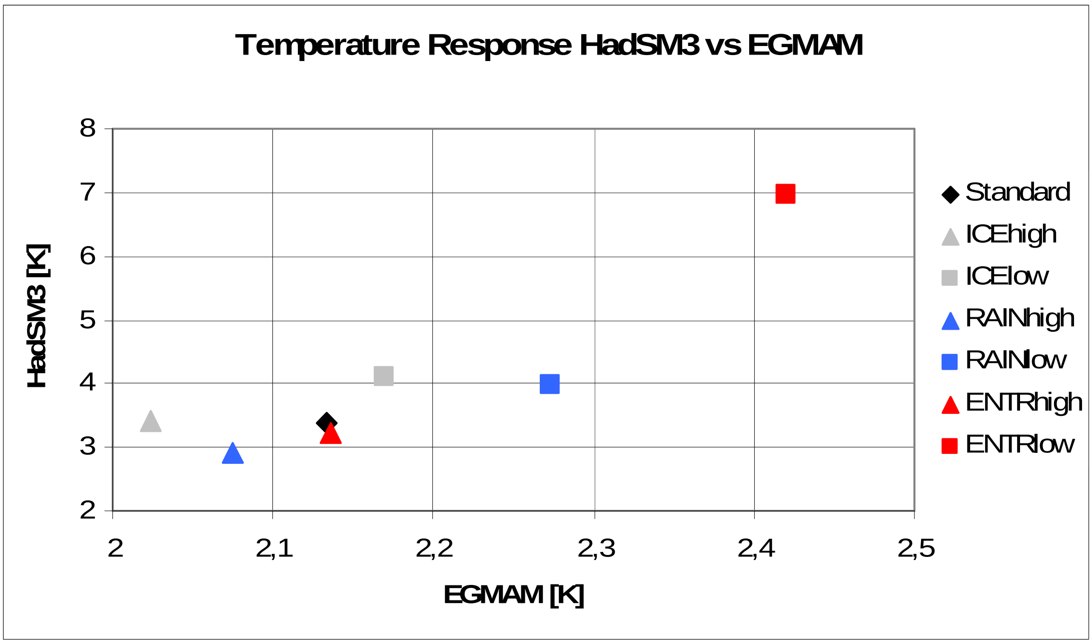

Fig 1: Global mean temperature responses of different perturbed model versions of HadSM3 and EGMAM for low (squares) and high (triangles) values for the entrainment rate (red), the rain efficiency (blue) and the ice fall speed (grey) different parameters. The standard model versions are shown in black. Note the differences in the scalings of the axes.

Fig 2 shows the comparison of the different feedback parameters in the QUMP (green) and EGMAM (blue) PPEs as well as a subset of the AR4 multi-model ensemble (red). The shortwave cloud feedback shows the highest range of all physical assignable feedback mechanisms (longwave and shortwave feedback parameters excluded) for all three ensembles. The range is around 1 W/(m²K) for the PPEs (0.99 for QUMP and 0.85 for EGMAM) and 1.7 W/(m²K) in the AR4 multi-model ensemble.

The cloud feedbacks in EGMAM differ from those in the QUMP and the AR4 ensemble. The shortwave cloud feedback is negative in all ensemble members, representing a robust result against parameter perturbations. Whereas in the QUMP and AR4 ensembles members with both, positive and negative shortwave cloud feedbacks are found. The same can be seen for EGMAM's positive longwave cloud feedbacks, which are robust against parameter perturbations. The total cloud feedback is negative for all EGMAM ensemble members because of the dominating negative shortwave cloud feedback. This is not the case for the QUMP and AR4 ensembles where models include both positive as well as negative cloud feedbacks.

The range in total cloud feedback is smaller in the EGMAM (0.49 W/m²K) ensemble than in the QUMP (0.79) and the AR4 (1.28) ensemble. These characteristics stem from an anticorrelation between positive longwave and negative shortwave cloud feedbacks among the EGMAM ensemble members. This causes an increased positive longwave feedback to be overcompensated by a decreased negative shortwave cloud

feedback (see Fig3a). In contrast, a comparable strong relationship between these two quantities can not be found in the QUMP or AR4 ensemble (see Fig3b/c).
The ranges in the clear-sky feedbacks found in the PPEs are also different. In contrast to only weak affected clear-sky feedbacks (range of 0.28 W/m²K) by parameter perturbations in the QUMP ensemble the clear-sky feedback in the EGMAM ensemble, which is generated by cloud parameter perturbations only, show a higher range (0.65). The AR4 multi-model ensemble shows by far the highest range in the clear-sky feedbacks (1.25).

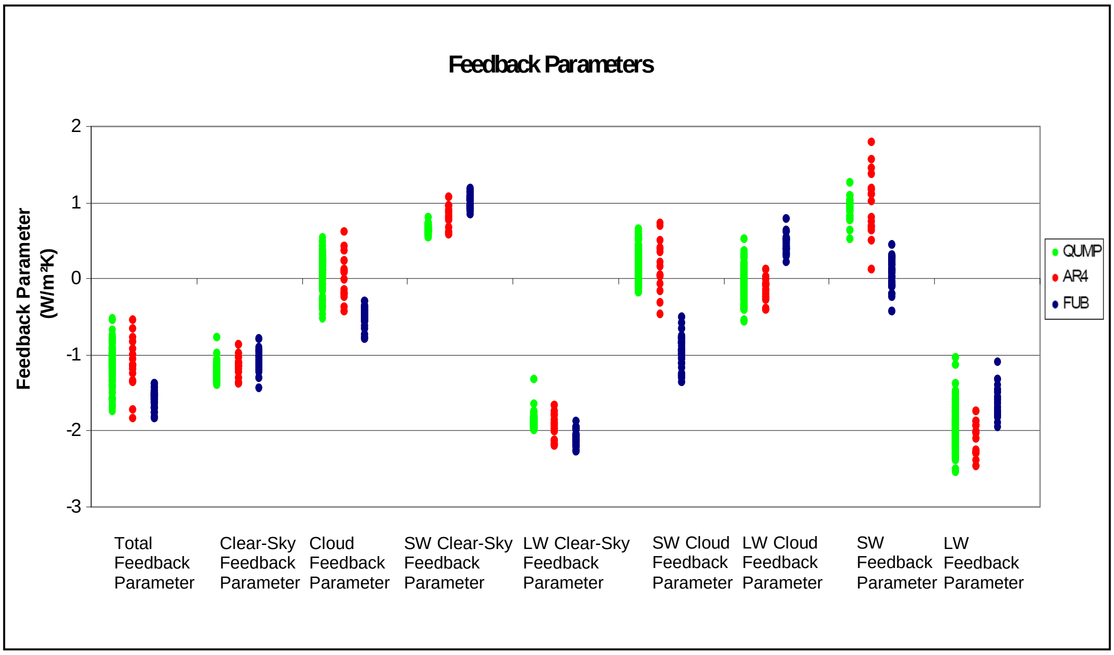

Fig 2: Comparison of the different feedback parameters in the QUMP (green), EGMAM (blue) and the AR4 (red) ensembles

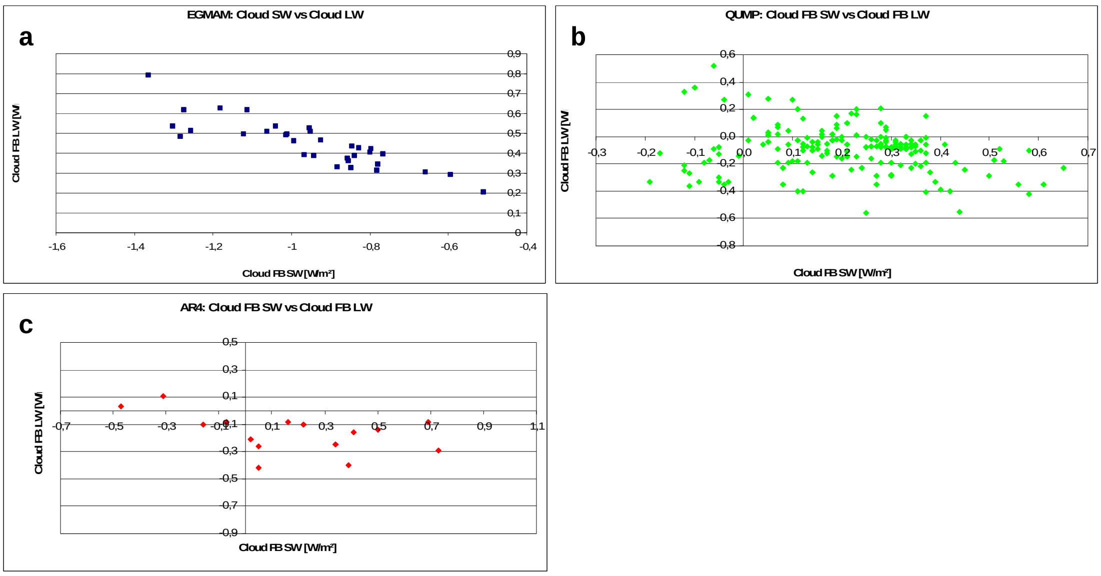

Fig 3: Shortwave cloud feedbacks versus longwave cloud feedbacks in the (a) EGMAM, (b) QUMP and (c) AR4 ensembles

Discussion:

HadSM3 and EGMAM show sensitivity of their temperature response to parameter perturbations of same sign but different magnitudes. Both models have the highest sensitivity of this quantity to perturbations in the entrainment rate coefficient in the convection scheme. This indicates that a physical interpretation of single parameter perturbations might be possible.
Despite this, differences in relationships between different feedback mechanisms across the ensembles hinders an interpretation of perturbed physics results from only one model as a reliable estimate of uncertainty in climate sensitivity and feedback mechanisms.

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