Climate Sensitivity Related to Cloud Processes in the General Circulation Model ECHAM5

Introduction:
- Clouds play a key role in climate as they strongly modulate the evolution of the atmosphere by affecting the radiation budget in the thermal and solar spectra.
- Cloud feedbacks remain one of the biggest single sources for the spread in model projected climate sensitivity.
- Perturbed experiments are a good indicator to test a models sensitivity to certain parameters.
- Skill scores help to evaluate models and to quantify performance.

Diagnosing feedback factors using the PRP method:
A single column radiation model based on the ECHAM5 radiation code is used to calculate feedback factors using the partial radiative perturbation (PRP) method. Radiation fields were calculated by substituting cloud, water vapor, temperature and surface albedo fields separately from a double CO2 run, while taking all other radiation-relevant input fields from a control run (present day CO2 concentrations). This method allows to separate feedbacks neatly from each other. For the calculation of the cloud feedback, cloud cover, cloud cover, cloud water and cloud ice were substituted.

Partial radiative perturbation (PRP) method:
\[ \lambda = \frac{\partial R}{\partial x} \]

\( R = \) Radiative forcing (net TOA radiative flux)
\( x = \) replaced variable

The plots above show the change in top of the atmosphere cloud feedback factor and the zonally averaged cloud feedback factor due to doubling CO2 using the PRP method. Cloud radiative forcing increases mainly in the subtropical subsidence regions and decreases in the inner tropics. In global average the cloud feedback factor is positive with a higher contribution in the SW spectrum (see table).

<table>
<thead>
<tr>
<th>Cloud</th>
<th>Planck</th>
<th>Albedo</th>
<th>Lapse rate</th>
<th>Water vapor</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW [Wm(^{-2})]</td>
<td>0.29</td>
<td>-0.03</td>
<td>0.19</td>
<td>-0.01</td>
</tr>
<tr>
<td>LW [Wm(^{-2})]</td>
<td>0.18</td>
<td>-3.5</td>
<td>0.09</td>
<td>-0.86</td>
</tr>
<tr>
<td>NET [Wm(^{-2})]</td>
<td>0.47</td>
<td>-3.54</td>
<td>0.19</td>
<td>-0.87</td>
</tr>
</tbody>
</table>

Changes in the net top of the atmosphere (TOA) radiation are dominated by changes in the SW spectrum. The change in LW emissions at the TOA are altered by the change in high level clouds. Increases and tropical and polar regions while LW emissions decrease in the mid latitudes and at the north pole.

Other Feedback factors:
- Lapse rate and Planck feedback factors are mostly negative. Assuming linearity between all feedbacks, the total feedback factor could be calculated by adding the individual feedback factors.
- Changes in SW and LW spectra:
- Perturbed physics experiments:

Perturbed physics experiments were carried out with ECHAM5 (T31L19). Sea surface temperatures and sea ice concentrations were taken from a control experiment. Greenhouse gas concentrations were set to 1960 AD amounts. 350 runs with changes in a set of parameters were performed. All simulations of one year were performed for each parameter or a set of parameters. As an example variations in entrainment of penetrative convection (ENTRPREN) are shown. Skill scores following Pinson et al. (J. Geophys. Res., 2008) are used to evaluate the simulations. Shortwave- and longwave-cloud radiative effects (SWCRE/LWCRE), total cloud cover (CLT), and precipitation (PR) are compared against the CERES-ES-4, ERBE, ISCCP D2, MODIS, CMAP and GCPC v2 datasets, respectively. Additional TRMM data is used for the distinction between stratiform and convective precipitation between 40N and 40S. Climatological monthly-mean fields on a 2.5\(^{\circ}\) x 2.5\(^{\circ}\) grid are used. Skill measures are the root-mean-square error (rms), mean error (bias), ratio of the standard deviations (rstd), and the correlation (corr).

Conclusion:
- Cloud, Planck, water vapor, lapse rate and albedo feedback factors were calculated using a single column radiation model with the partial perturbation method.
- The change of cloud radiative forcing following a doubling of CO2 is strongest in the solar spectra.
- The skill of simulations with perturbed cloud parameters shows different influence on the quality of the representation of cloud related fields. The effect on stratiform and convective precipitation is oppositional for some parameters.

Daniel Klocke\(^1\), Johannes Quaas\(^1\), Marco Giorgetta\(^1\)

\(^1\)Max Planck Institute for Meteorology, Hamburg, Germany
\(^2\)International Max Planck Research School on Earth System Modelling