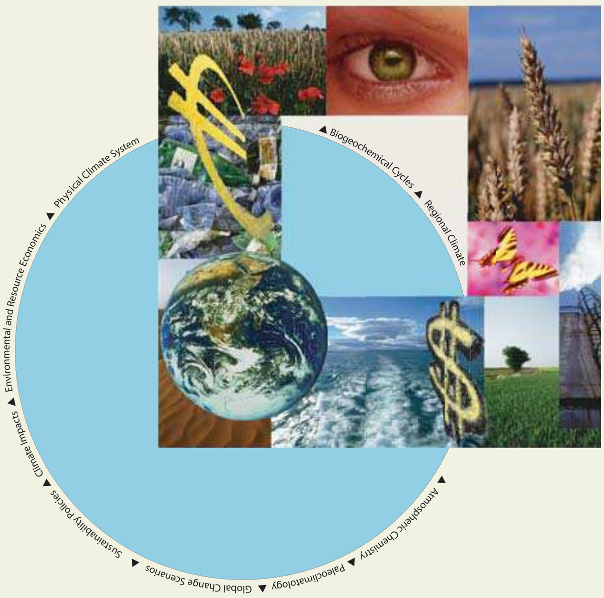
International Max Planck Research School on Earth System Modelling

Using CALIPSO and CloudSat satellite retrievals to evaluate low-level cloud parameterizations in ECHAM5 for cloud-climate feedback implications

Christine Cheung-Wai Nam

PhD Thesis prepared within the International Max Planck Research School on Earth System Modelling



Abstract

In recent decades the uncertainty in climate sensitivity has been traced back to cloud-climate feedbacks; a fact reiterated by the Intergovernmental Panel on Climate Change (Solomon et al., 2007). The magnitude which clouds respond to radiative forcings effectively determines the extent to which the Earth's temperature will amplify due to an increase in greenhouse gases. Boundary layer clouds, which reside in the lowest few kilometers of the atmosphere, are known to play a vital role in cloud-climate feedbacks. Currently, however, general circulation models are unable to realistically represent the cloudy boundary layer well.

This thesis uses cutting edge satellite retrievals from the CALIPSO and CloudSat satellites to evaluate different boundary layer cloud parameterization schemes in the ECHAM5 atmospheric general circulation model. The CALIPSO and CloudSat satellites host active lidar and radar instruments which provide global coverage of the vertical distribution of clouds and their properties. To compare CALIPSO and CloudSat retrievals with the ECHAM5 modelled output, the Cloud Feedback Model Intercomparison Project's CALIPSO and CloudSat simulators was first implemented into ECHAM5. The satellite simulators account for the sensitivity of the lidar and radar instruments, as well as the satellite's viewing geometry and perception of multi-layered clouds. This allows for a truer evaluation of the modelled boundary layer clouds with satellite retrievals.

Comparison of ECHAM5 with CALIPSO and CloudSat found that the geographical distribution of high-level clouds and cloud characteristics associated with the Hadley circulation are well captured. High-level cloud cover, however, is overestimated in certain situations; particularly for optically thin clouds. It was shown that an increase of the assumed ice crystal effective radius renders the highest level clouds detectable to the radar simulator, in better agreement with satellite retrievals. The increase in ice crystal effective radius also causes the lidar simulator to produce lower, more realistic scattering ratios and attenuating the lidar lower in the atmosphere, also in better agreement with the retrievals.

ECHAM5 was also shown to significantly underestimate the mid-level clouds, and even more so, the (Sub)Tropical low-level clouds. The low-level clouds which were produced were consistently perceived to be optically too thick by the lidar. In order to address these deficiencies, four boundary layer schemes were included within ECHAM5. They include: a standard convective mass-flux scheme (referred to as ECHAM5_Std; Tiedtke, 1989); a modified version of the Tiedtke (1989) scheme in which a new convective trigger alters the statistics of shallow convection (referred to as ECHAM5_Trig; Roeckner & Esch, 2010); a bulk parameterization of the effects of transient shallow cumulus clouds (referred to as ECHAM5_VSMF; Von Salzen & McFarlane, 2002; Isotta, 2010); and an eddy diffusivity Dual Mass Flux scheme adjusted to better represent shallow convection (referred to as ECHAM5_DMF; Neggers et al., 2009).

The four boundary layer parameterization schemes are run for first the present day climate. The question of how well does ECHAM5 represent clouds and precipitation in the present climate and whether the different representations of boundary layer clouds perform better compared to the CALIPSO and CloudSat retrievals is addressed. This is done by comparing the high, mid and low-level cloud cover maps derived by the lidar, the lidar and radar zonal hydrometeor fraction, lidar and radar joint cloud frequency-altitude histograms from the satellite retrievals and the model.

The evaluation of the ECHAM5_Trig, ECHAM5_VSMF and ECHAM5_DMF boundary layer cloud schemes found that all three schemes improved the representation of low-level clouds. The changes, however, were not always captured by the lidar and radar simulators; especially where there were fewer clouds. This is likely due to the fact that many of the new clouds were optically thin or lying beneath higher-level clouds. Although all three schemes increased the low-level cloud cover, including a significant amount by the ECHAM5_DMF, the schemes continued to underestimate the low-level cloud cover compared to satellite retrievals.

The radar reflectivity histograms showed that the three schemes have different distributions of moisture and cloud properties regardless of having similar projected cloud covers. The ECHAM5_Trig and ECHAM5_VSMF models increased the frequency of occurrence of high-level clouds and precipitation. In all versions of ECHAM5 the frequency of precipitation in ECHAM5 was found to be too high and its intensity too low. The schemes, however, did improve the frequency of large-scale precipitation; decreasing the number of low-intensity events and increasing the higher intensity events.

In order to assess cloud-climate feedbacks, and their sensitivity to boundary layer clouds, idealized climate change experiments were performed. In these experiments, the comparison of the cloud-climate feedbacks of the ECHAM5_Std, ECHAM5_Trig and ECHAM5_VSMF models showed that all three have positive, highly-sensitive cloud-climate feedback parameters. The three cloud-climate feedback parameters are of similar magnitude due to similar projected cloud covers.

Sensitivity experiments with the ECHAM5_Trig model showed that experiments with fewer present day low-level clouds produced lower cloud-climate feedbacks; whereas experiments with a greater amount of present day low-level cloud cover produced higher cloud-climate feedbacks. If indeed the present day low-level cloud cover is related to the cloud-climate feedback, then cloud-climate feedbacks to date may be underestimated as many general circulation models underestimate low-level cloud cover.