EMS Annual Meeting Abstracts,
Vol. 6, EMS2009-509, 2009
9th EMS / 9th ECAM

Low Cloud Feedback Diagnosed from Observations and LES Modeling

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The negative cloud optical depth feedback (Somerville and Remer 1984) was based upon the increase of liquid water content with the ambient temperature (T) inferred from in situ observations. Recent satellite observations from ISCCP, AVHRR and CERES (Tselioudis et al. 1992; Chang and Coakley 2007; Eitzen et al. 2008) indicate that cloud optical depth may decrease with T, instead of increase with T, thereby suggesting a positive cloud optical depth feedback to a climate warming. We have analyzed the monthly gridded cloud and radiative property data from CERES (Clouds and the Earth's Radiant Energy System) and examined the rate of changes in cloud and radiative properties with sea surface temperature (SST) anomaly from the annual mean SST. It is found in the boundary-layer cloud regions that the cloud radiative cooling effect, cloud fraction and cloud optical depth decrease with the increase of SST anomaly. All of these trends imply a positive cloud feedback. However, these rates of change are mostly contributed by changes in dynamic and thermodynamic state of the atmosphere, which can be represented by the mean rates projected to the joint lower tropospheric stability vs. vertical velocity at 700hPa distribution. The residual rates are close to nearly neutral, compared to the original rates, thereby suggesting that the positive cloud feedback is unlikely to occur.

An LES (large-eddy simulation) model is used to understand the low cloud feedback mechanisms, based upon the configuration designed by the Cloud Feedback Model Intercomparison Project (CFMIP). Three CFMIP configurations (cases) are simulated, corresponding to shallow cumulus, stratocumulus and solid stratus clouds. The UCLA LES is run for 30 days in order to reach cloud-radiative equilibrium. The SST increases by 2 K in the perturbed simulation from that in the control simulation. The last ten days of the integrations are analyzed. The cloud feedback effect is negative (0.4 – 6.0 W m-2 K-1) for all three cases, which is consistent with prior modeling results, while the clearsky feedback effect is positive, due to large increase in lower-tropospheric water vapor. The clearsky feedback effect is the largest for the shallow cumulus simulation, arising from the largest increase in water vapor related to the highest SST among the three configurations. The increase of liquid water path and cloud optical depth, which is related to the increase of cloud thickness and liquid water content, is caused by the increase of surface latent heat flux and precipitable water in the warmer climate. The increased surface latent heat flux is the major driver for the negative cloud feedback mechanism. The changes in cloud fraction do not contribute to the negative cloud feedback in the stratocumulus case, but somewhat do in the cumulus case. The increase in cloud thickness in the perturbed simulations is resulted from a larger increase in cloud top altitude than in cloud base altitude in the stratocumulus case but the cloud thickness does not change much in the cumulus case.