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Band-by-band cloud radiative forcing: new dimension to evaluate the GCM simulation and understand cloud feedback

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Since mid 1980s, observed top-of-atmosphere (TOA) broadband radiant fluxes and cloud radiative forcings (CRFs) have served the climate community as standard datasets for evaluating GCM simulations and studying cloud feedbacks. A major dilemma of this approach is that compensating biases from different spectral bands could make the understanding of the broadband deficiencies difficult. Radiant fluxes and CRFs over each individual absorption band (hereafter termed as band-by-band radiation fluxes and CRFs) are what climate models directly compute, and therefore, comparisons of such quantities largely avoid the dilemma. Moreover, a unique characteristic of such band-by-band longwave CRFs is that the fractional contribution of each band to the broadband CRF is sensitive to cloud top height, but largely insensitive to cloud fraction. Recently the lead author have developed and validated an approach of deriving such band-by-band fluxes from AIRS (Atmospheric Infrared Sounder) spectra collocated with Aqua-CERES observations over the tropical oceans. We applied this algorithm to AIRS spectra collected from 2003 to 2007 and, for the first time, we are able to compile an observational dataset of band-by-band fluxes and CRFs over the entire longwave spectrum. Using such dataset, we evaluate how the climatology and seasonal cycle of band-by-band CRFs and clear-sky fluxes are simulated in three atmospheric GCMs: GFDL AM2, NASA GEOS-5, and CCCma CGCM3.1(T63) when they are forced with observed SST. The major findings are: (1) While three GCMs all have stronger clear-sky broadband greenhouse effects than observation, they achieve this status by different ways: the H2O far-IR band is mainly responsible in the stronger greenhouse effect in the GFDL AM2 model while the window band is major reason for two other GCMs. Such difference among band fluxes are then attributed to different underlying geophysical quantities. (2) For all 3 GCMs, their tropical-mean longwave broadband CRFs agree with observed one within 1 Wm-2. However, the difference in CRF of individual band could be as large as this or even larger. (3) When the fractional contribution of each band to LW CRF is examined, the largest discrepancies among GCMs and observation exist in window bands. The discrepancies can be further attributed to both lower tropospheric humidity and low cloud. Although low cloud contributes little to LW CRF, focusing on fractional contribution here effectively expose the large disagreements among models. (4) The seasonal variation of band-by-band CRF is small. The temporal correlation of CRF of H2O band and CRF of CO2 band is not well captured in the CGCM3.1 and AM2 model but reasonably well captured in GEOS5. We speculate that the treatments of cloud spectral properties are related to difference. Above findings quantifies and corroborates the arguments of compensating biases in GCM simulation of current climate. The implication for climate projection is further discussed.