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A Potential Radiative Forcing Error from the Cirrus Cloud Pre-exiting Ice Assumption

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A relatively new theoretical understanding of the absorption differences between split-window channels on satellite instruments has led to a new method for processing and interpreting split-window satellite measurements (Mitchell et al., 2016, ACPD). Using the effective absorption optical depth retrieved from channels on the Imaging Infrared Radiometer (IIR) aboard the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) satellite, the ice particle number concentration (N), effective diameter (De), ice water content (IWC), ice water path (IWP) and the visible optical depth (OD) are retrieved from single-layer (no lower clouds) semi-transparent cirrus clouds having 0.3 < OD < 3.0 and cloud base temperature T < 235 K. Cloud temperature T was estimated from the CALIPSO lidar measurements. Retrievals of these properties between 70N and 25S latitude are consistent with in situ measurements of these properties over the same latitude range, based on 5 cirrus cloud field campaigns. The success of this approach is related to its sensitivity to the number concentration of small ice crystals (D < 60 μm).

A method was developed whereby the microphysical properties of cirrus clouds in the Community Atmosphere Model version 5 (CAM5) could be made consistent with these CALIPSO retrievals. That is, three latitude zones were defined for each hemisphere (e.g. for the N. Hemisphere; 0-30 °N, 30-60 °N, 60-90 °N), and within each zone, observed De-T relationships were determined for each season and surface type (land vs. ocean). The mass-weighted ice particle fall speed Vm was determined from De using the empirical relationships in Mishra et al. (2014; JGR). In this way, for T < 235 K, the CAM5 microphysics was modified, although the default CAM5 IWC was passed to the radiation module along with the De estimated from the retrievals.

The ± 30 °latitude zone is dominated by anvil cirrus and it contained the lowest N values. This is expected since anvil cirrus are a type of liquid origin cirrus where ice nucleation proceeds in the presence of pre-existing ice (e.g. Krämer et al., 2016, ACP). The ice surface area provided by the pre-existing ice keeps the relative humidity with respect to ice (RHi) relatively low, preventing the threshold RHi that activates homogeneous ice nucleation (henceforth hom) from occurring. By applying the De-T relationships in the ± 30 °latitude zone to the entire planet, a 5-year CAM5 simulation was conducted that assumes pre-existing ice everywhere. Another 5-year CAM5 simulation was conducted that was based on the retrieved De-T relationships (specific for each lat. zone, season and surface type). The difference in cloud net radiative forcing between these two simulations yields an estimate of the impact of the pre-existing ice assumption. Outside the ± 30° latitude zone, this difference was about 1 W m-2. Considerable evidence attributes much of the non-liquid origin (i.e. in situ) cirrus clouds to mountain-induced wave motions, where cirrus clouds form at their upwind-edge in the absence of pre-existing ice.