Improving Cloud Parameterizations in Climate Models: Implications from CAM3 and WRF Simulations

Research Highlight

Representation of cloud processes is oversimplified in many climate models; this has significantly restricted our capability to project future climate in response to aerosols and other chemical components produced by human activities. The standard CAM3 uses a single-moment cloud microphysics scheme that only predicts the variation of the mass of cloud condensate. This scheme cannot respond to the impact of aerosols on cloud processes. Also, deep convective clouds are parameterized with some arbitrary assumptions in CAM3. Studies have suggested that excess water and heat may be transported to high levels based on the current parameterizations.

To address these issues, two investigations have been made using data from the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Tropical Warm Pool-International Cloud Experiment (TWP-ICE) field campaign to evaluate cloud parameterizations:

(1)A newly-proposed double-moment microphysics scheme was evaluated in the NCAR CAM3 in comparison with data from TWP-ICE. In the new ice microphysics parameterization, prognostic equations for cloud particle number concentrations were added. The effective radius of ice crystals were calculated from their prognostic mass and number concentrations rather than diagnosed from temperature as in the standard CAM3.

(2)High-resolution Weather Research Forecast (WRF) simulations were conducted to reproduce cloud properties during the monsoon period of TWP-ICE and to evaluate deep convective clouds.

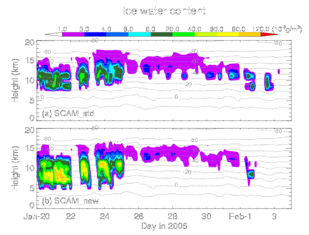
I. Comparisons of clouds from the standard and new microphysics schemes

Cloud properties were simulated by the single column version of CAM3 (SCAM) respectively with the standard and new schemes. A major difference lies in the simulated cloud ice water in the mixed cloud. While the magnitude and distribution of the total frozen water (FW) mixing ratio between two runs are similar, the ice mass fraction out of the FW from the standard scheme (SCAM_std) is significantly smaller than that from the new scheme (SCAM_new) during the monsoon period and slightly larger during the suppressed period. The base level of ice cloud is lower from the new scheme because the SCAM_std employs a temperature-dependent function to partition total cloud water into liquid and ice while the SCAM_new explicitly calculates the liquid conversion to ice through the Bergeron-Findeisen process.

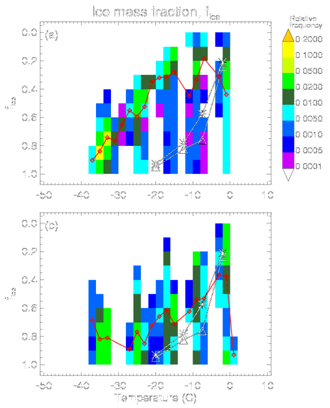
II. Ice mass fraction inside mixed-phase clouds

We constructed a joint frequency distribution of temperature and FW mass fraction (fice) in total cloud condensate during the monsoon period. A snow mixing ratio has been included in the ice phase for comparisons with observations.

Results from both SCAM runs exhibit large variability of ice mass fraction for a given temperature. The fice varies from 0 to 1 when the temperature nears 0 ºC, and increases with decreasing temperature. Liquid water can be present down to -37 ºC and ice water up to a few degrees above 0 ºC (which is precipitating snow). However, the ice mass fraction from the SCAM_std run is smaller than that from the SCAM_new run for a given temperature in most cases. The latter is closer to field observations from mid-latitude clouds. This suggests that the prescribed temperature-dependent partitioning relation in the standard CAM3 may underestimate the fraction of cloud condensate converted to ice; this is improved by applying the new ice



(a)Time-height distribution of the ice water mixing ratio simulated from SCAM_std,and (b)SCAM_new.Gray contours are temperature in °C.



(a)Joint frequency distribution of temperature and fractional ice water content in the mixed-phase cloud from SCAM_std,(b) from SCAM_new. Snow content has been included into ice content. Red diamonds denote the average fice for a given temperature interval. Black triangle and asterisk are derived from field observations.

parameterization assuming that ice mass fraction is similar in tropical and mid-latitude clouds.

III. High-resolution WRF simulation during the monsoon period

WRF model was run during the monsoon period of TWP-ICE. To simulate deep clouds, a horizontal grid spacing of 1.5 km was used to simulate the whole monsoon period, and a resolution of 0.5 km was used to simulate clouds during a 24-hr period of strong precipitation. A single-moment and a double-moment microphysics schemes were used to represent cloud microphysics. Results showed that WRF can reasonably simulate temporal and spatial distribution of cloud fraction and cloud water mixing ratio. However, quantitative differences in cloud and radiation fields from observations are still significant, suggesting inaccurate representation of cloud physics in the WRF model. We also used a Lagrangian approach to analyze individual deep updrafts and calculated convective fluxes for the updrafts. It is suggested that the entrainment rate is a function of height, rather than a constant with height as assumed in CAM deep cloud parameterization.

(1)Application of the double-moment scheme involving more detailed ice processes to CAM3 not only can better simulate ice and liquid clouds, but also can make CAM3 model be able to respond to aerosol produced by human activities.

(2)Deep convection parameterization may need to consider the variable entrainment rate. Also, improvement of WRF microphysics schemes is needed to more accurately simulate cloud and radiation fields in the tropical area.

Reference(s)

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Cloud Modeling