Performance of Longwave Radiative Transfer Models for 3D Cloud Fields

Research Highlight

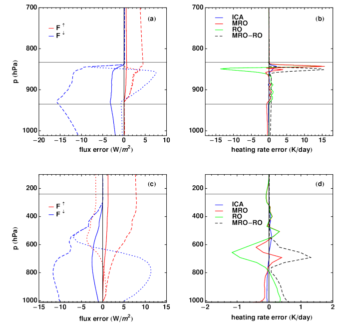
The climate system is substantially dependent on cloud radiative forcing and atmospheric heating rates. To keep climate simulations computationally manageable, it is necessary to use parameterized cloud-radiation schemes, and therefore, by design, all parameterizations produce systematic errors to some degree. Minimizing these errors is critically important to accurately quantifying the result of changing components in climate simulations (e.g., aerosols).

The purpose of this study is to compute longwave radiative transfer results for the third phase of the Intercomparison of Radiation Codes used in Climate Models (ICRCCM 3). A validated monte carlo model (3DMC) is used to compute the benchmarks, and comparisons are made with three approximate methods. These approximations include a high-resolution, one-dimensional monte carlo model that subdivides the domain into multiple independent columns (ICA), a maximum-random cloud overlap approximation (MRO), and a random cloud overlap approximation (RO). The two cloud-overlap methods are implemented by the AER Rapid Radiative Transfer Model and use a single independent column to represent the cloud domain. Six cases simulated from cloud-scale resolving models are used to test the effects of broken cloudiness on longwave fluxes and heating rates. Only liquid phase cloud matter is considered, and an effective radius of 10 μm is used for all cases. These choices are based on the need to isolate the effects of inhomogeneity in cloud morphology from other competing effects on radiative transfer.

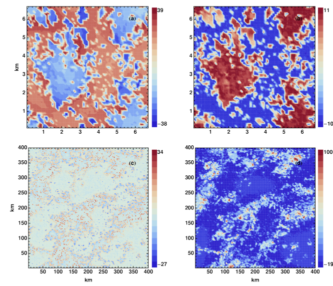
The results of this intercomparison show that neglecting horizontal radiative transfer can lead to significant errors in cloud-layer heating and fluxes at the vertical boundaries. The largest domain-averaged heating rate errors occur for cloud cases that are sampled at higher resolution, whereas cases with lower resolution make the models less sensitive to 3D effects. For example, the ATEX trade cumulus field has a 1-km-thick cloud layer extending from 1.6–2.6 km in altitude and has 32 levels within the layer. The horizontal dimensions are (6.8 km)# with (0.1 km)# resolution. Relative to the 3DMC results for this case, MRO and RO both overestimate cloud layer heating by a similar amount of about 16 K/day, whereas ICA overestimates by 2 K/day. The spectrally integrated flux differences at the surface and top of atmosphere have larger differences between MRO and RO. This is a result of different effective cloud fractions produced by each model.

When compared with the full 3D results, MRO underestimates downwelling flux at the surface by 11 W/m#, RO is within 0.5 W/m#, and ICA underestimates by 2 W/m#. MRO maximally overlaps clouds in consecutive layers, which reduces the effective cloud fraction, producing deeper vertical sections of clear sky relative to RO. RO randomly overlaps clouds in all layers, which tends to increase the effective cloud fraction. The treatment of vertical overlap by these models explains the large difference in downwelling surface flux by MRO and small difference by RO. For this case, 3D effects on surface flux under low, highly resolved inhomogeneous clouds are similar in magnitude to the increase in effective cloud fraction by RO. Similar results are found for the upwelling flux at the top of the atmosphere.

The differences between models are smaller for cases with larger physical domains and lower resolutions. Larger subgrid column dimensions reduce the domain-averaged differences by mitigating 3D effects; the chance for photons to cross subgrid boundaries is reduced due to the need of larger horizontal pathlengths. Also, as the resolution decreases, a particular subgrid sample will be more representative of the domain-averaged properties. The result is that coarser domains produce smaller errors, but depend on the cloud type/amount present. For example, the GATE A



The respective flux and heating rate errors (model-3DMC) for (a),(b) ATEX and (c),(d) GATE A. The error profiles in (a) and (c) are to be interpreted as ICA, solid lines; MRO, dashed lines; RO, dotted lines. (b) and (d) also show the differences between MRO and RO. The horizontal lines are the vertical cloud-layer boundaries.



The ICA individual column results subtracted from 3DMC for ATEX (a) $F\downarrow_{sfc}$ and (b) $F\downarrow_{TOA}$ and GATE A (c) $F\uparrow_{sfc}$ and (d) $F\uparrow_{TOA}$. All values in W/m#.

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cloud field is a GCM-size grid box with a domain of (400 km)# divided into (2 km)# subcolumns. The maximum heating rate difference is less than 1.5 K/day for all models.

These results provide benchmarks for comparing longwave methods that approximate broken cloud fields and show that errors associated with cloud overlap approximations depend on spatial resolution. A general conclusion is that the approximate methods tend to increase the upwelling flux at the cloud top and decrease the downwelling flux at the cloud base. The exception is RO, which can either increase or decrease the cloud boundary fluxes depending on the resolution and the cloud amount. ICA is shown to be a stable performer in for all resolutions. This model is the full solution to the widely used MCICA column sampling method, so the results of this study are beneficial to those who would like to know the maximum possible accuracy of 1D subgrid sampling. More detailed information on these results and more cloud cases can be found in the reference.

Reference(s)

Kablick III GP, RG Ellingson, EE Takara, and J Gu. 2011. "Longwave 3D benchmarks for inhomogeneous clouds and comparisons with approximate methods." Journal of Climate, 24, doi:10.1175/2010JCLI3752.1.

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Working Group(s)

Cloud Life Cycle