Forcing Boundary Layer Cloud Systems with Multi-Dimensional Radiation

Contributors

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Research Highlight

From large-scale global climate models (GCMs) down to small-scale large eddy simulation (LES), numerical models most commonly employ simple treatments of radiative transfer, where radiation streams upward and downward through the atmosphere. While computationally attractive, this simplification neglects horizontal radiation transport and associated effects such as cloud shadowing and cooling of lateral cloud boundaries. It is well understood that atmospheric radiative transfer is fundamentally multi-dimensional (MD), and that employing one-dimensional (1D) radiative forcing can introduce systematic bias, leading to significant errors in forcing. A long-standing issue is to quantify the effects of MD radiation on the evolution of cloud system properties. Is simple 1D radiative transfer adequate?

In order to address this question, we have coupled a MD radiative transfer scheme (SHDOM; Evans 1998) to an eddy-resolving model (ERM) (CIMMS LES; Kogan et al. 1995). The model is applied to cases of boundary layer stratocumulus (ASTEX) and trade cumulus (BOMEX). In stratocumulus, radiative processes are the most significant external source of boundary layer turbulence, while the low cloud fraction of trade cumulus implies that strong MD radiative effects should be present. We address only the longwave portion of the spectrum, and because of computational constraints, all simulations are two-dimensional (2D).

Instantaneous "snapshot" calculations of longwave MD and 1D radiation for identical cloud fields indicate substantial MD effects, as demonstrated in Figure 1 for a field-of-trade cumulus. MD radiative effects tend to enhance cooling of narrow, isolated cloudy updrafts and reduce cooling of cloud crevices or valleys. The differences, however, are highly localized and have minor impact on the mean radiative forcing. The interactive simulations demonstrate only subtle differences between MD and 1D radiation schemes, as evident in Figure 2, especially for quantities like inversion height which are more time-integrated in nature. We attribute this result to the fact that radiative cooling is a relatively minor contribution to the total energetics for the low cloud fraction cumulus case. For the solid cloud case, employing MD radiation slightly reduces the entrainment rate and boundary layer energetics, relative to the 1D case, which is consistent with the local radiative forcing patterns. Our results indicate that the common assumption of 1D longwave radiative transfer, applied in models column-by-column, appears to be reasonable, at least so far as direct impact on the cloud dynamical structures is concerned.

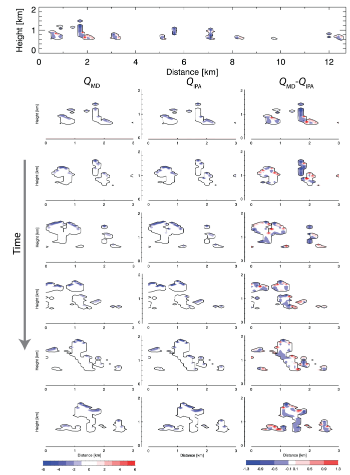

Figure 1. The evolution of a typical BOMEX broken cloud structure and its associated radiative forcing rates [K/h] employing MD (left) and the independent pixel approximation (IPA, center) radiative transfer. Here, IPA is synonymous with 1D radiative transfer. The cloud fields are obtained from the MD simulation. The right column represents the heating rate difference between MD and IPA rates. The small panels are from an enlarged portion of the domain from x = 0-3 km. Each successive row represents instantaneous samples of the cloud and radiative forcing fields taken every 5 minutes.

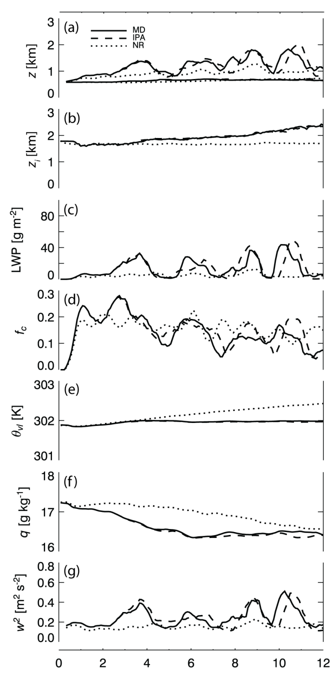

Figure 2. Time series of ERM quantities from 1-12 h for the broken BOMEX simulations. The solid and broken lines represent the MD and IPA cases, respectively, while the dotted line

Reference(s)

Mechem, DB, YL Kogan, M Ovtchinnikov, AB Davis, KF Evans, and RG Ellingson. 2008. "Multi-dimensional longwave forcing of boundary layer cloud systems." Journal of Atmospheric Sciences, in press.

Working Group(s)
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represents no radiative forcing. (a) Mean cloud base and cloud top height; (b) Mean inversion height; (c) liquid water path (LWP); (d) Cloud fraction; (e) Surface liquid water virtual potential temperature; (f) Surface mixing ratio; and (g) Vertical velocity variance.