Multi-Dimensional Longwave Forcing of PBL Stratocumulus in an LES model

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Background and Motivation

- PBL clouds profoundly influence the global shortwave radiation budget through their effect on albedo.
- The source of turbulent energy for the PBL clouds themselves is long-wave cooling.
- Current large eddy simulation (LES) codes use 1D radiative transfer.
- Assumes PBL clouds are horizontally uniform.
• Real PBL clouds show horizontal structure: billows and valleys that arise from convective overturning of the boundary layer.

• Guan et al. (1995) show that horizontal photon transport reduces net cloud top cooling.

• The I3RC project has demonstrated that the plane-parallel assumption is frequently unwarranted.

Goal: In order to explore the evolutionary nature of this radiative-dynamic interaction, we have coupled to an LES the sophisticated multi-dimensional radiative transfer scheme of Evans (1998; Spherical Harmonics Discrete Ordinate Method — SHDOM).
Methodology

• CIMMS LES and SHDOM coupled in an interactive fashion.

• LES supplies cloud field to SHDOM, which calculates optical properties and computes RT in 12 bands from 4-100 μm.

• Includes emission, absorption, and scattering.

• **Case 1:** lightly drizzling, unbroken stratocumulus.

• **Case 2:** heavily drizzling, cloud breakup.

• For each case, perform MDRT and IPA runs.

• SHDOM calculates droplet radius based on a concentration of 50 cm\(^{-3}\) and assumes a U. S. Standard Atmosphere profile.

• 2D simulations, 500×51 and 100×51.
Lightly drizzling scenario (case 1)
Lightly drizzling scenario (case 1)

Liquid water and $F_x$ at $t=3$ h (case 1, cloud top)
Lightly drizzling scenario (case 1)
and LWC (intervals of 0.1 g m$^{-3}$) at 3 h
Vertical velocity, LW forcing anomaly, and cloud top
Vertical profile of covariance

\[ w' \left( \frac{dT}{dt}_{3D} - \frac{dT}{dt}_{IPA} \right) \]
Lightly drizzling scenario (case 1)

**$Z_i$**

**LWP**

$q_l \text{ max}$

Surface drizzle rate

Buoyancy flux

TKE
Heavily drizzling case (case 2)

Liquid water and $F_x$ at $t=3$ h (case 2)

Height (km)

Distance (km)

$q_i$ (g kg$^{-1}$)
Conclusions

• We have attempted to identify the existence of an evolutionary bias arising from the use of a 1D radiative forcing of simulated PBL cloud.

• For lightly drizzling, unbroken cloud, the differences between MDRT and 1D are subtle but seem systematic.

• Evolutionary differences appear to be driven by a combination of the reduced mean cloud-top LW forcing and the negative local correlations between the dynamics and the LW forcing anomaly.

• The differences are more pronounced for case 2, though they are nearly as large as estimated error.

• These subtle sensitivities to longwave forcing could conceivably lead to pronounced shortwave consequences.

• Many issues remain to be explored to enhance confidence in the quantitative aspect of these results, e.g. vertical model resolution, time between RT calculations, angular resolution of the RT calculation.