Multi-dimensional Effects in Longwave Radiative Forcing of PBL Clouds

David B. Mechem¹, Mikhail Ovtchinnikov², Y. L. Kogan¹, K. Franklin Evans³, Anthony B. Davis⁴, Robert F. Cahalan⁵, Ezra E. Takara⁶, and Robert G. Ellingson⁶

¹Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma
²Pacific Northwest National Laboratory
³University of Colorado
⁴Los Alamos National Laboratory
⁵NASA/GSFC
⁶Florida State University

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Motivation

• Numerical cloud models nearly universally use 1D radiative transfer (RT)
• 1DRT is computationally attractive but neglects horizontal photon transport
• The neglect of horizontal photon transport can introduce systematic biases that may lead to significant errors in heating rate
• MD effect particularly important for complex cloud geometries and internal cloud structure
• Previous studies and the I3RC have predominantly addressed how the multi-dimensional (MD) effect modulates albedo and shortwave heating rate (Welch and Wielicki 1984; Cahalan et al. 1994; Zuidema and Evans 1998; Di Giuseppe and Tompkins 2003)
• Studies have demonstrated that the MD effect is important for situations of complex cloud geometry and internal cloud structure

*These previous studies are mainly concerned with how the cloud spatial structure modulates the radiative characteristics of the cloud system.*
Motivation (continued)

The extent to which multi-dimensional radiative forcing affects the evolution of a cloud system relative to IPA forcing has not been deeply explored. Are IPA forcings sufficiently accurate for numerical models?

• Gu and Liou (JAS, 2001)
• Koracin et al. (Atmos. Res., 1998)
• MD longwave cooling addressed by Guan et al. (1995) and Guan et al. (1997)

We apply two techniques to investigate this MD effect in the longwave for a simulated stratocumulus cloud system:

“Snaphot” comparisons: Compare MD and IPA heating rates to infer feedback onto PBL dynamics. The difference in heating rates is a measure of the MD effect

Interactive MDRT simulations: MDRT scheme is coupled to an LES model to address the interactive and evolutionary nature of the MD-IPA bias.
Methodology

CIMMS LES model

SHDOM (Evans 1998) with 12 bands from 4-100 μm, correlated k-distribution

“Snapshot” comparisons:
• Calculate MD and IPA heating rates from LES-supplied LWC field
• Unbroken, lightly drizzling case
• 1000 × 126; dx = dz = 10 m
• Additional calculations for idealized rectangular and adiabatic LWC clouds

Interactive MDRT simulations:
• RT calculated every 10 timesteps (40 s)
• Two simulations: interactive MDRT and IPA
• 2D geometry; dx = 100 m; dz = 25 m
“Snapshot” calculations from simulated cloud field

LWC and $HR_{MD}$-$HR_{IPA}$

$HR_{MD}$ and $HR_{IPA}$

Virtually indistinguishable

PDF of $HR_{MD}$-$HR_{IPA}$
“Snapshot” calculations from simulated cloud field

\[ w^\prime \left( \frac{dT}{dt}_{MD} - \frac{dT}{dt}_{1D} \right) \]

is negative for anomalous cooling in updrafts and for anomalous warming in downdrafts.
“Snapshot” calculations of idealized cloud structures

- 200 m wide
- 400 m deep
- Cloud fraction from 0.11 to 1.0
- LWC of 0.5 g m$^{-3}$
“Snapshot” calculations of idealized cloud structures

Contribution from horizontal fluxes as a function of cloud fraction
MD radiative forcing of PBL clouds

LES simulation with interactive MD radiation
Discussion

• Strong negative correlation between longwave MD-IPA forcing anomalies and eddy structure for an unbroken cloud field implies negative feedback on PBL energetics

• RT calculations for the rectangular clouds demonstrate that the MD effect increases with decreasing cloud fraction

• Although not shown, drastic differences in the evolution of specific cloud and eddy structures are visible in the interactive simulation

Why then do statistics for our interactive MD and IPA simulations show so little systematic bias?
Discussion

Why then do statistics for our interactive MD and IPA simulations show so little systematic bias?

Possible explanations:

• In unbroken cloud systems (high cloud fraction regime), the horizontal flux convergence may be only a minor contribution to the total forcing

• The low cloud fraction regime exhibits a prominent MD effect but tends to be associated with boundary layer decoupling and energetics that may be more surface-based and less radiatively-driven

• Experimental issues for the interactive simulations: resolution?
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