Impact of Subgrid-Scale Radiation Variability on the Marine Stratocumulus-to-Trade Cumulus Transition

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Figure from ATEX, Stevens et al. (2001, JAS)
Test importance of small-scale radiation-turbulence interactions w/ LES

- Smooth the radiative tendencies over a specified area representative of a GCM grid cell to determine importance of small-scale variability on cloud characteristics
- Use WRF in LES mode for ATEX and Composite Transition cases
Radiative variability drives stratus production

Composite transition case

- Removing heterogeneity of radiative tendencies reduces stratiform cloud
  - Reduced cloud fraction, particularly during the first daytime period
  - Reduced cloud water
- Altered mixing lowers the inversion height (essentially the cloud top)
- Cumulus characteristics emerge sooner
  - Quickened Sc-to-Cu transition
- Increased net surface shortwave
  - ~25 W m\(^{-2}\) averaged over 3 days
Smoothing radiation hastens transition to Cu Composite transition case

- **Radiative Heating** (K day⁻¹)
  - Most horizon variability in upper cloud layer
  - Solid = Mean
  - Dots = Std. Dev.

- **Buoyancy Prod.** (10⁻⁴ m² s⁻³)
  - Initial response

- **Liquid Water** (g kg⁻¹)

- **Total Water** (g kg⁻¹)
  - Control Experiment
  - More decoupled
  - Increased Cu activity inside cloud

Graphs showing changes at 0 hr, 6 hr, and 30 hr.
Turbulence needs to see sub-grid radiation tendencies

- Radiation typically sees sub-grid cloud variability in terms of “cloud fraction” but radiative tendencies are output as grid cell volume means.
- Need to maintain estimate of sub-grid radiative variability for use in turbulence parameterization.

Contours of LW radiation tendency at one level overlaid on the 3-D cloud water field.
Parameterization implications

- Leading order impact from subgrid radiative heating on turbulence is the radiation production term in tendency of potential temperature variance, $\overline{\theta'^2}$.

- Radiation production term increases temperature variance for cloud-topped boundary layers.
  - Past assumptions have assumed a damping effect (e.g., André et al. 1978, JAS).
  - In contrast, we show a positive effect.
Neglecting sub-grid variability in cloud-top radiative cooling adds a bias to the marine stratocumulus cloud system in models:
- Assuming mean horizontal heating rates leads to reduced turbulence at cloud top and ultimately to reduced stratus.
- The stratocumulus-to-cumulus transition is decelerated by the variability.

Halving or doubling the mean radiative tendencies gives a proportional response in cloud behavior similar to what is shown.

Potential solution…
- Sub-grid radiation variability needs to be passed into the turbulence parameterization for use in determining the buoyancy generation.

Open issues for radiation-turbulence interaction…
- How small of a scale needs to be considered for radiation-turbulence interactions to accurately simulate the Sc-to-Cu transition?
- What is the relative importance of radiation-turbulence interaction vs. other sub-grid processes such as microphysics variability?