Impact of subgrid-scale radiation variability on the marine stratocumulus-to-trade cumulus transition

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1. Subgrid radiation-turbulence interaction is potentially important

Climate models typically do not include interactions involving subgrid variability between physics components. Instead, only the grid-box mean states are communicated between components. However, in certain instances the subgrid variability is important for accurately estimating the mean state response.

The marine low cloud field is a good example where subgrid variability is potentially important. Cloud-top radiative cooling drives turbulence, leading to cloud-top entrainment of free tropospheric air. The spatial heterogeneity of the cooling impacts the strength of the entrainment and cloud development.

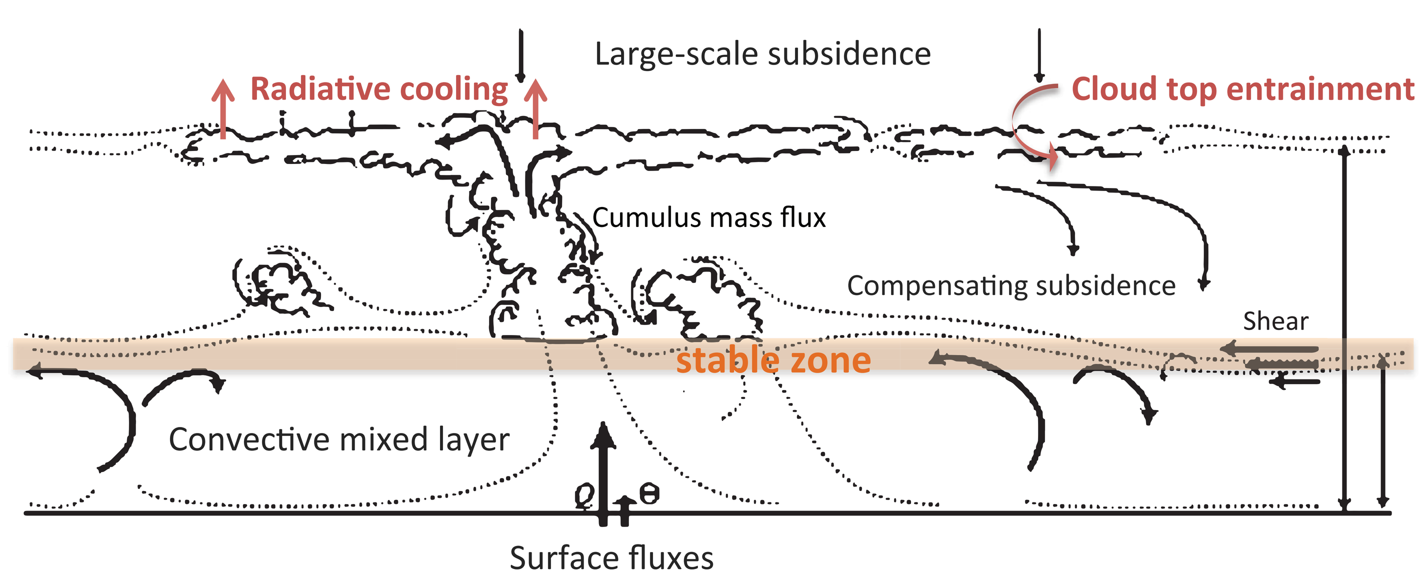

Figure 1. Characteristic features of a radiatively driven marine stratocumulus regime. Adapted from Stevens et al. (2001, JAS) for conditions during ATEX.

This study looks at the stratocumulus-to-trade cumulus transition and its sensitivity to the subgrid radiaiton heterogeneity.

2. Methodology

We use WRF in LES mode to simulate the Composite Transition Case from Sandu et al. (2010, ACP) representing the marine stratocumulus-to-trade cumulus transition in eastern subtropical oceans.

The *Control Run* is a traditional LES simulation. The *Experiment Run* horizontally smooths the radiation tendencies before applying them to represent the impact of gridbox-mean radiation tendencies present in regional and global climate models.

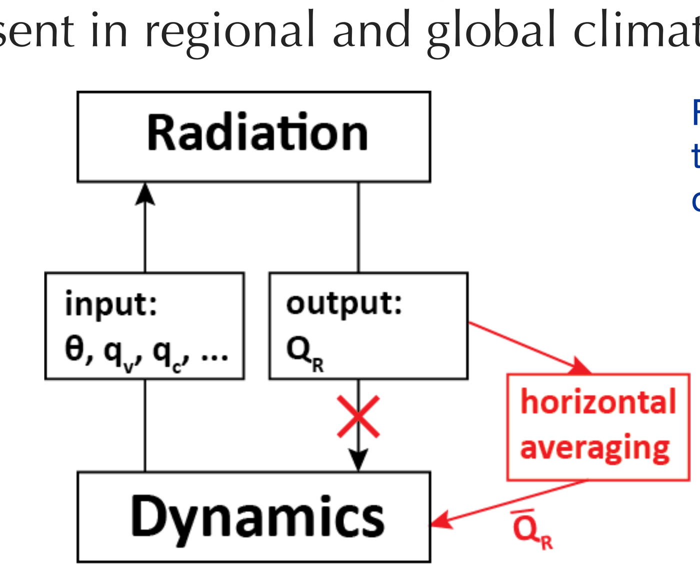

Figure 2. Schematic of change to radiation tendencies, Q_R, for the Experimental case with horizontal averaging.

Domain mean radiation tendency is the same before and after smoothing for a given timestep.

3. Impact of homogeneous radiation field

Clouds introduce substantial horizontal and vertical variability in radiation tendencies that climate models do not see.

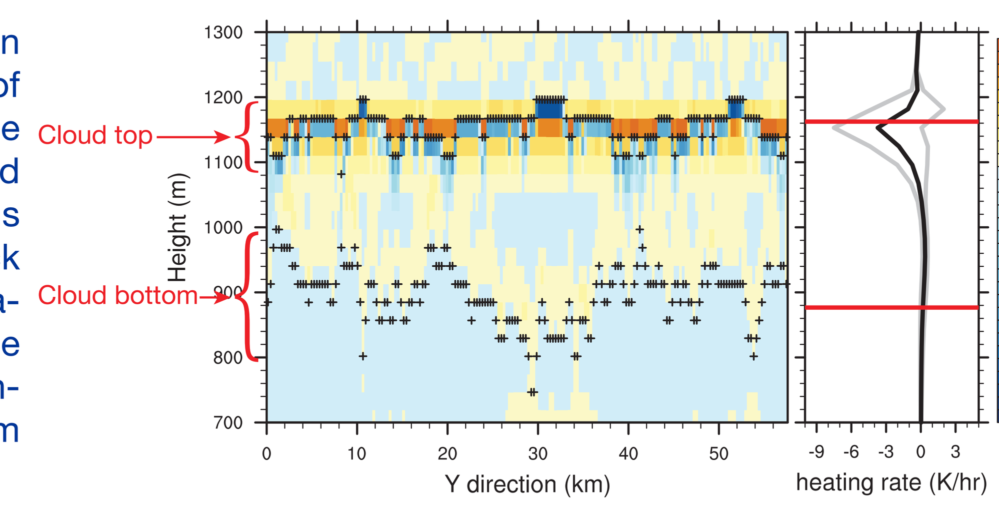

Figure 3. Cross section and mean profile of radiative heating rate (shading) and cloud tops and bottoms (symbols). The black profile is the mean radiative heating and the gray lines indicate minimum and maximum heating.

The *Control* essentially sees the detailed radiative heating in the cross section while the *Experiment* sees the mean profile.

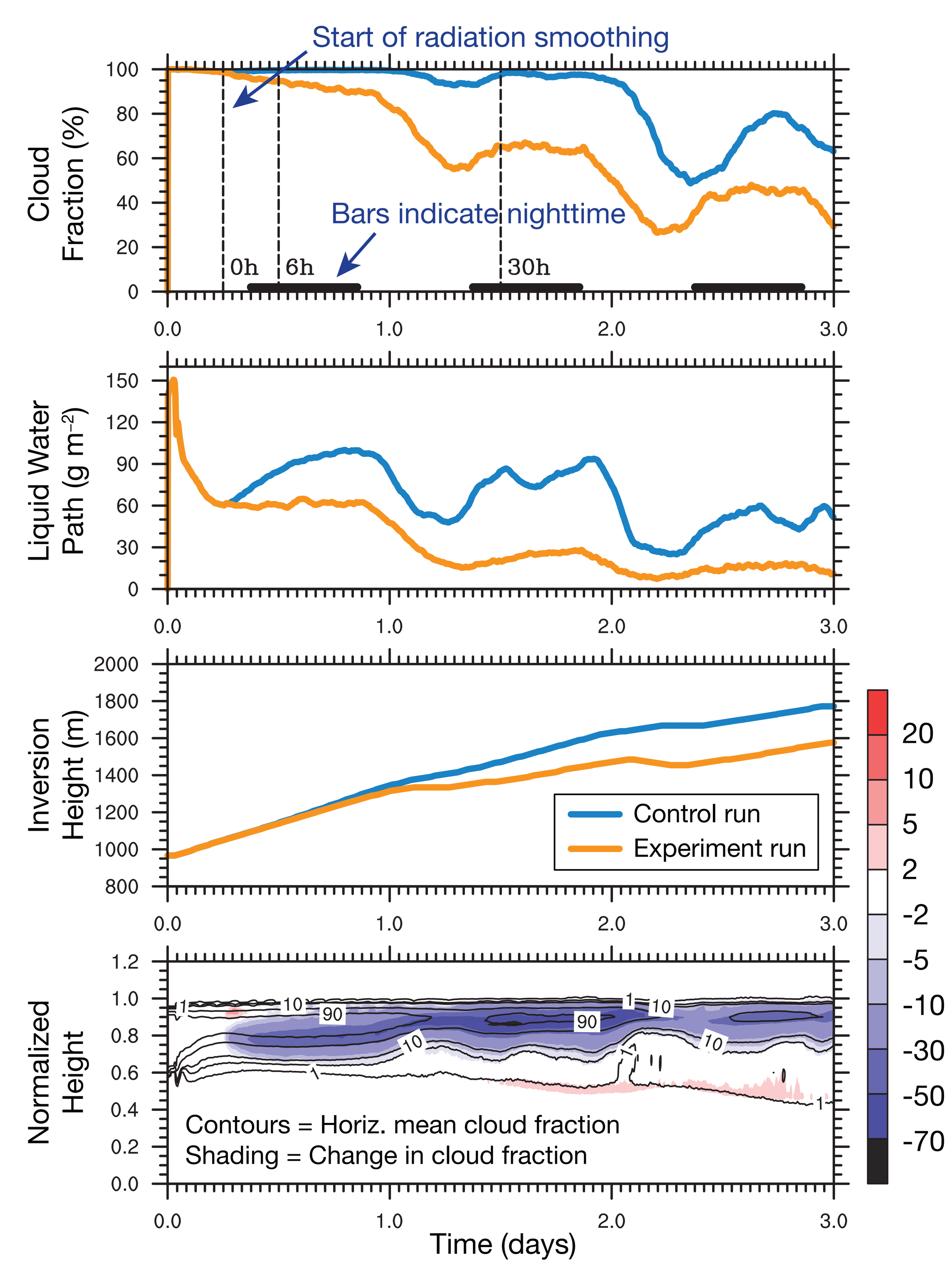

Figure 4. Domain mean time series for Composite Transition Case.

Removing radiative heating heterogeneity leads to:

- Quicker transition from stratocumulus to trade cumulus: reduced cloud fraction, reduced cloud water, cumulus characteristics emerge sooner.
- Altered mixing that lowers the inversion height, essentially the cloud top.
- Increase of ~25 W m^{-2} net surface shortwave flux averaged over 3 days.

4. Processes driving change

Reduced spatial variability of radiation leads to reduced buoyancy production, leading to reduced liquid water and an increased decoupling of the cloud layer from the surface.

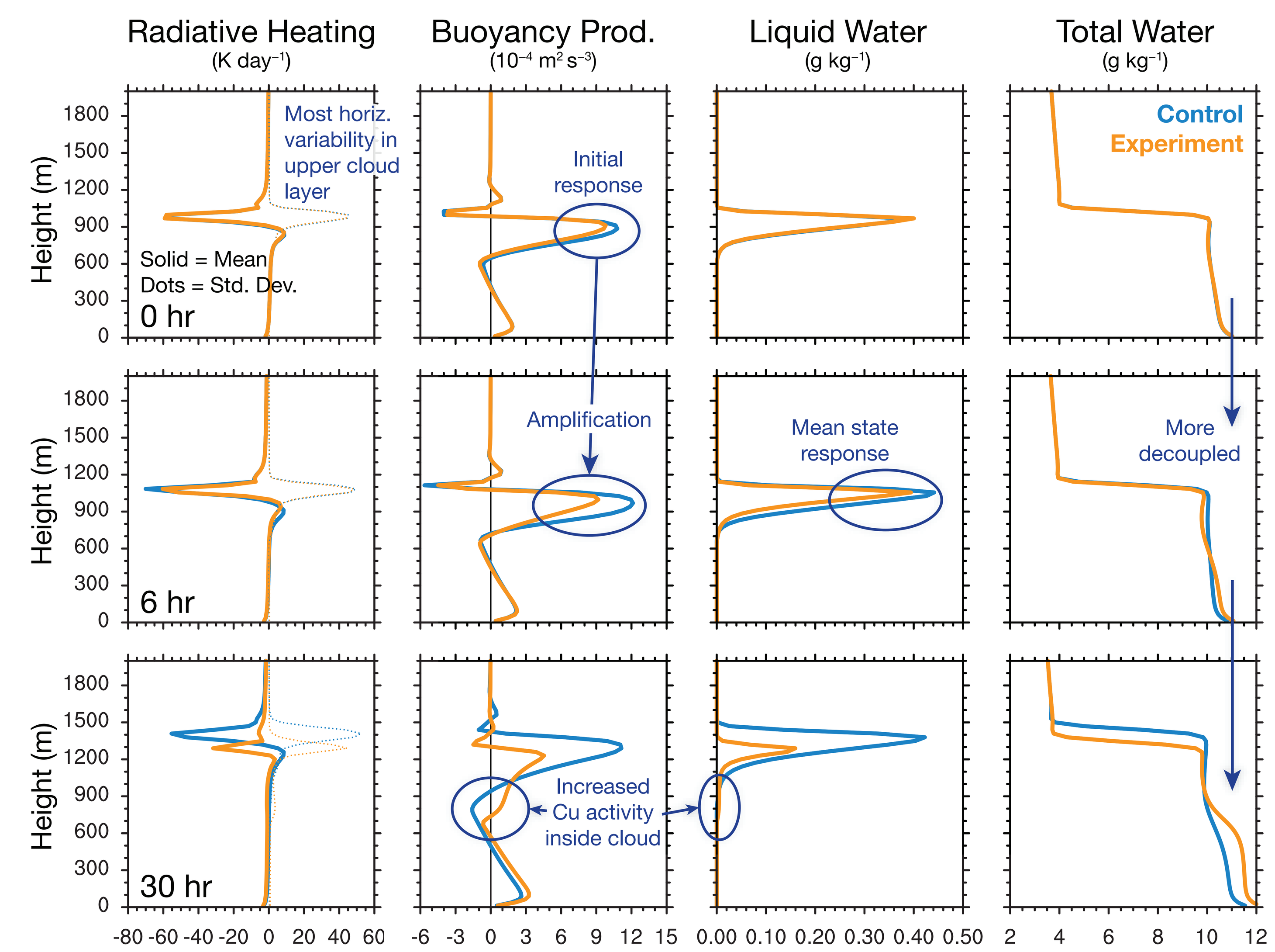

Figure 5. Mean profiles at 0, 6, and 30 hours after start of smoothing (times indicated in Fig. 4). Look for progressive changes leading to altered mean state.

5. Implications for parameterizing low clouds in GCMs

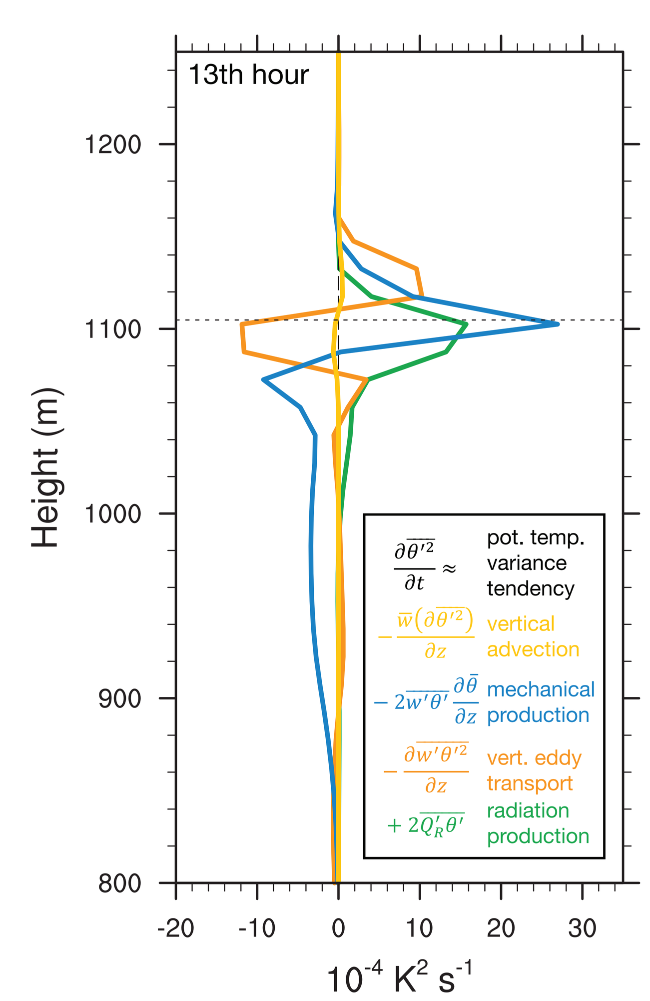

Figure 6. Domain mean profiles of terms contributing to potential temperature variance 13 hours after smoothing begins.

Within the tendency eqs. for buoyancy flux, $(g/T_v)\overline{w'\theta'}$, and potential temperature variance, $\overline{\theta'^2}$, the leading order impact of subgrid radiative heating, Q'_R, is the radiation production term, $\overline{Q'_R\theta'}$, of the potential temperature variance.

Unlike ealier assumptions that radiation production is negative, e.g., André et al. (1978, JAS), we show that for cloudy marine boundary layers the radiation production can be positive.

Results suggest higher-order cloud schemes, e.g. CLUBB, should include the effects of subgrid radiation-turbulence interaction.

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