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

William I. Gustafson Jr., Heng Xiao, & Hailong Wang

Atmospheric Sciences & Global Change Division
Pacific Northwest National Laboratory

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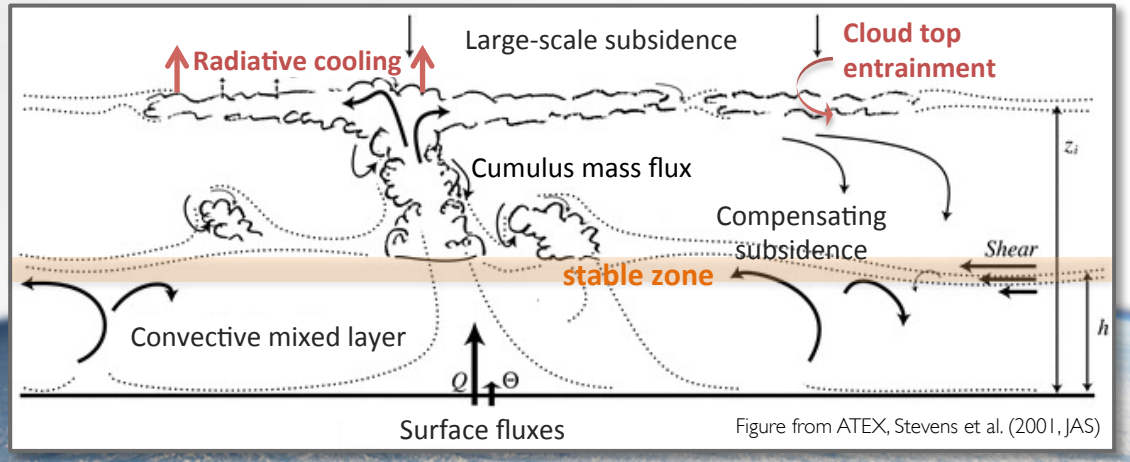

Figure from ATEX, Stevens et al. (2001, JAS)

Photo courtesy NASA, http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=ISS034&roll=E&frame=016601

Test importance of small-scale radiation-turbulence interactions w/ LES

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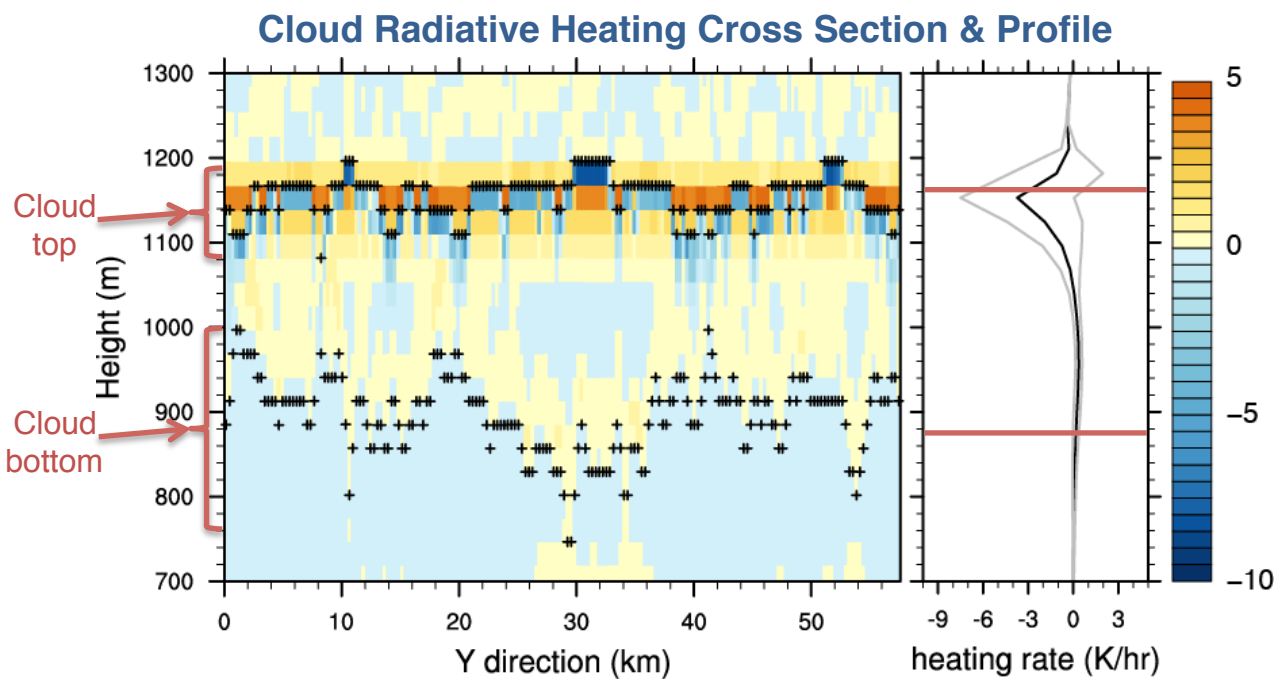
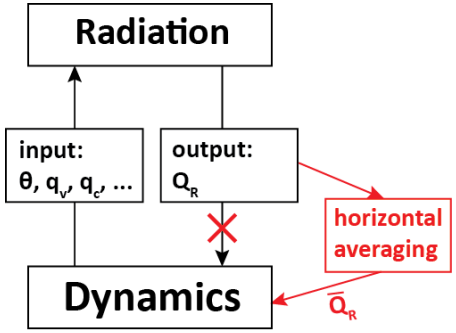
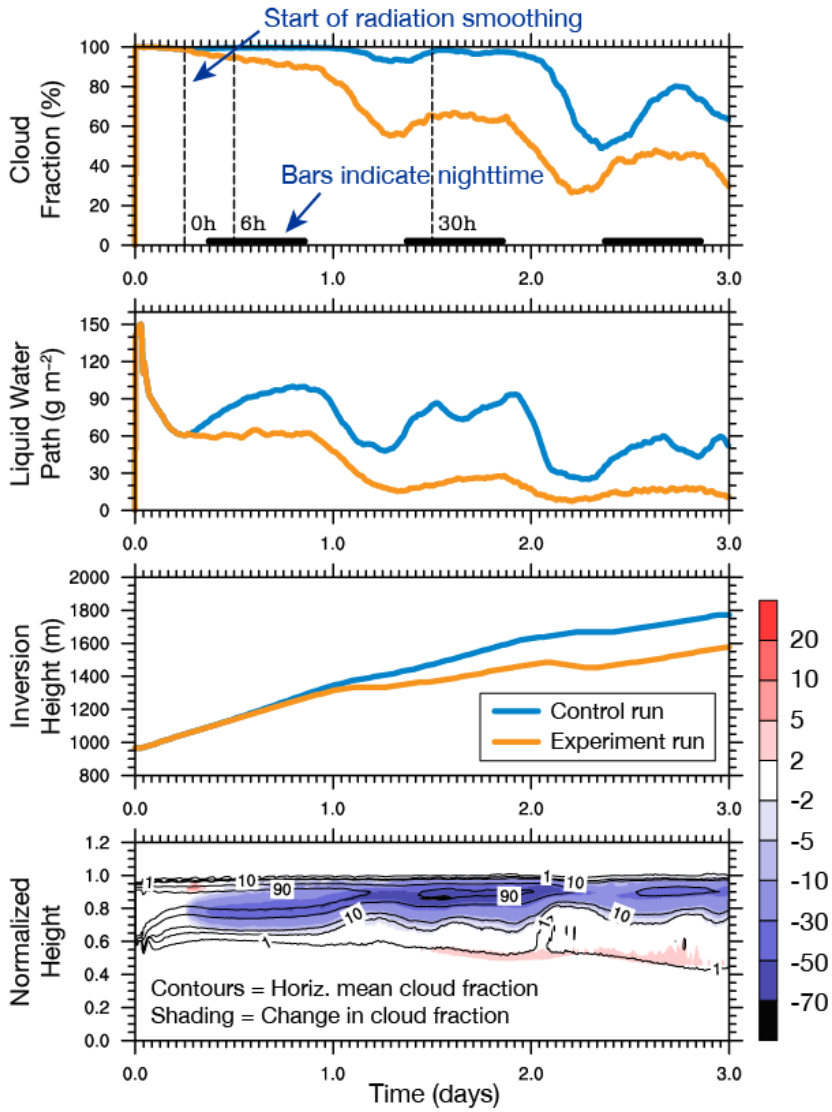
- Smooth the radiative tendencies over a specified area representative of a GCM grid cell to determine importance of small-scale variability on cloud characteristics
- Use WRF in LES mode for ATEX and Composite Transition cases





Radiative variability drives stratus production

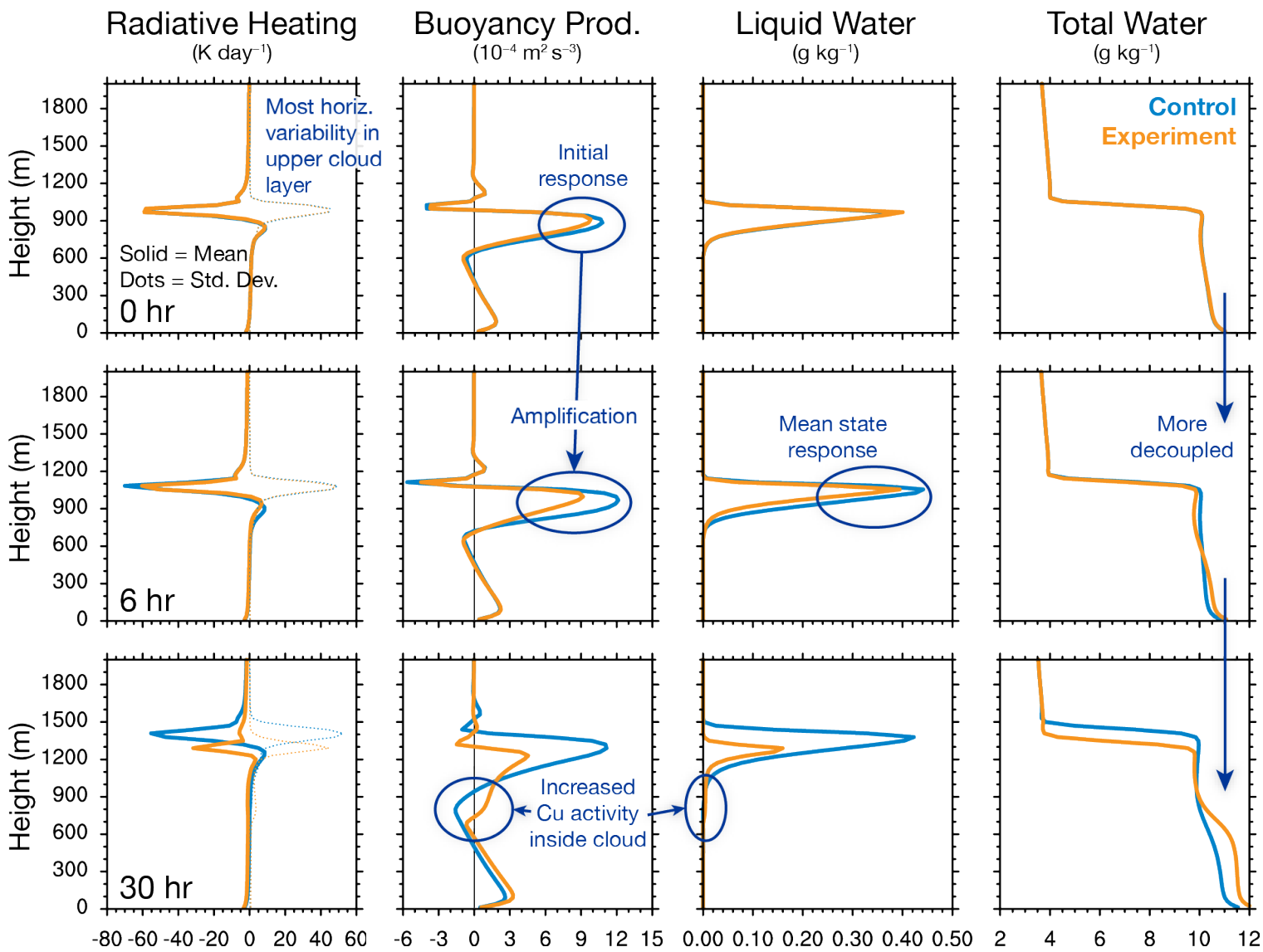
Composite transition case



- 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

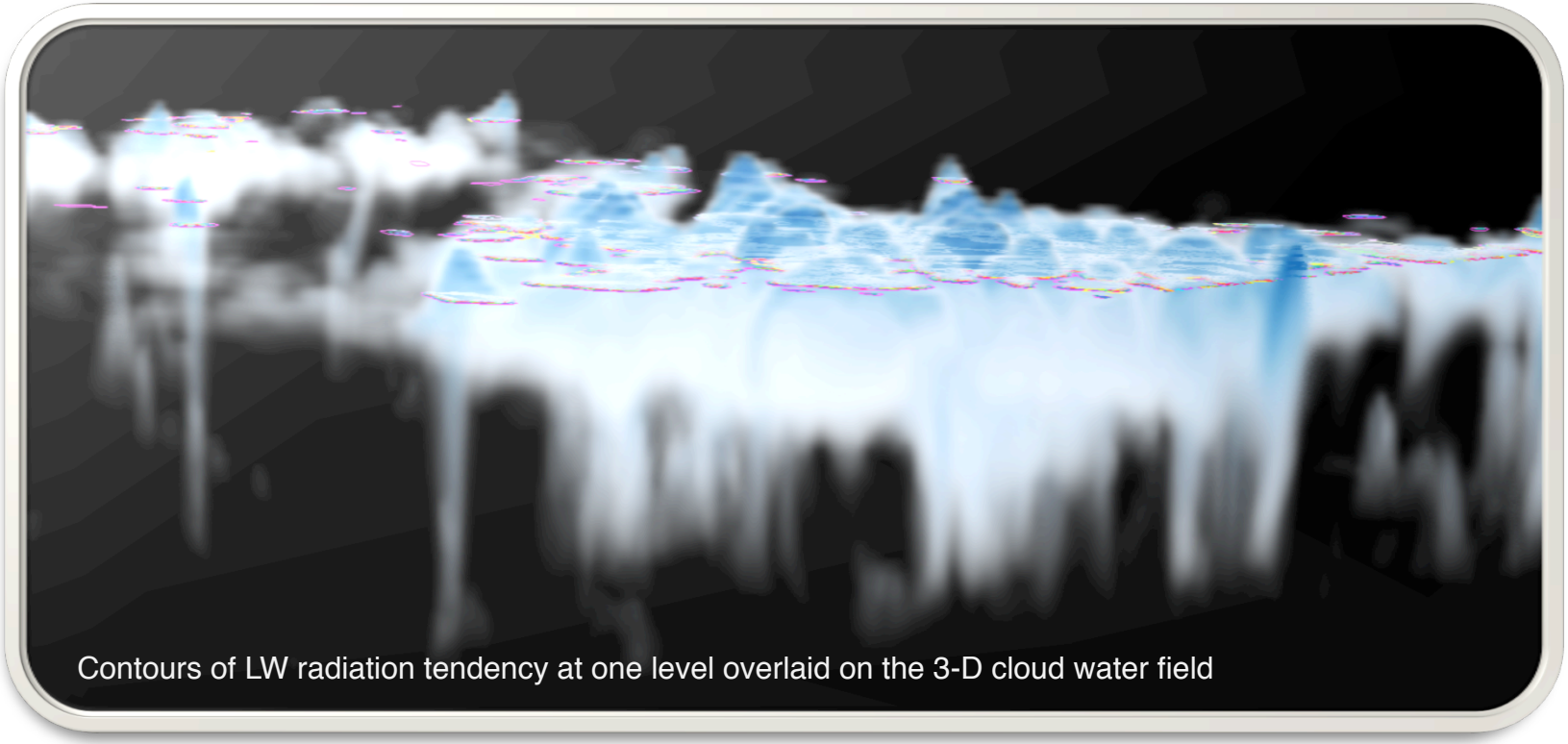
Smoothing radiation hastens transition to Cu

Composite transition case



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

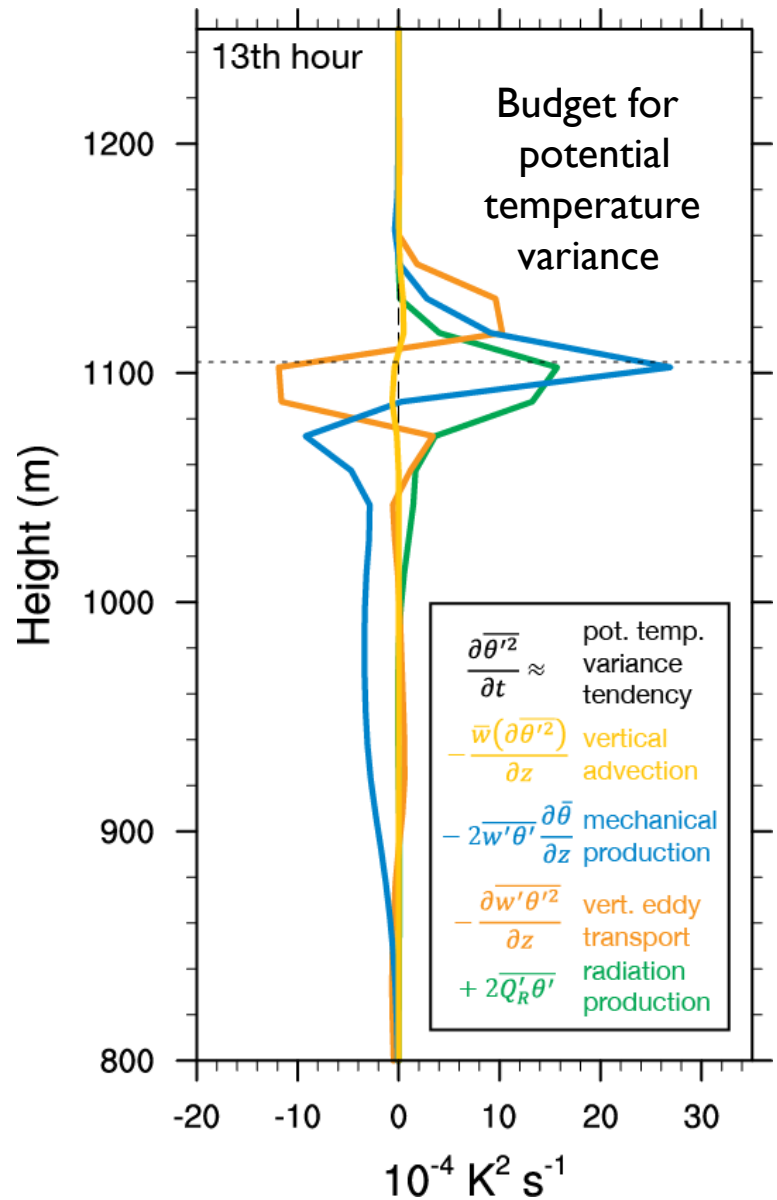


Contours of LW radiation tendency at one level overlaid on the 3-D cloud water field

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.



Parting thoughts…

- 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?