Stratocumulus cloud top radiative cooling and cloud base updraft speeds

Graham Feingold1 Joseph Balsells2 Carolin Klinger2 Jan Kazil1

Motivation
- Doppler radar, microwave radiometer, and lidar measurements enable the retrieval of cloud condensation nucleus (CCN) properties in the stratocumulus-capped marine boundary layer (Feingold et al., 1998).
- The retrieval utilizes the relationship between the cloud drop number concentration, cloud base updraft speed $w_b$, and the cloud base CCN spectrum.
- An empirical relationship between stratocumulus cloud-integrated radiative heating + cooling ("cloud-top radiative cooling", CTRC) and $w_b$ (Zheng et al., 2016) enables
  - the use of satellite-derived cloud parameters to determine the CCN concentration below clouds using satellite observations of cloud radiation,
  - and the parameterization of cloud base updraft speed in climate models to improve the representation of aerosol-cloud interactions.
- We investigate the relationship of CTRC and cloud base updraft speed $w_b$, in a stratocumulus cloud using a large eddy simulation.

Methods
- Large eddy simulations (LES) of a shallow, non-drizzling stratocumulus (GCMS112, Blossey et al.; JAMES, 2013, Kazil et al., JAMES 2017) with the System for Atmospheric Modeling SAM.
- Large-eddy simulations (LES) of a shallow, non-drizzling stratocumulus-capped marine boundary layer (Feingold et al., 1998).
- Doppler radar, microwave radiometer, and lidar measurements enable temperature ($T$) and water vapor ($q$) profiles, turbulence increases overnight by the action of latent heating/cooling, rather than the action of CTRC.

Results
- Cloud liquid water path ($\theta$) and cloud optical depth ($\delta$) grow stronger in the afternoon and over the course of the night.
- CTRC falls over the course of the night ($\delta$), despite the concurrent increase in liquid water path ($\theta$).
- Daytime CTRC ($\delta$) is suppressed due to short-wave heating.
- Reduction in nighttime net long-wave cooling ($\delta$) arises from:
  - Nighttime saturation of gross LW cooling ($\delta$)
  - Nighttime increase in gross LW heating ($\delta$)
- Cloud base updraft velocity $w_b$ drops between sunset and sunrise ($\delta$), then faster towards noon, and recovers by sunset ($\delta$).
- Time of day determines the relationship of $w_b$ and cloud-integrated radiative cooling/heating:
  - Stronger CTRC is associated with stronger $w_b$ ($r = -0.99$)
  - $w_b$ (cm s$^{-1}$) = -6.8*CTRC(W m$^{-2}$) (72)
  - Time of day determines the relationship of $w_b$ and cloud-integrated radiative cooling/heating:
  - Stronger CTRC is associated with stronger $w_b$ ($r = -0.68$)
  - $w_b$ (cm s$^{-1}$) = -6.8*CTRC(W m$^{-2}$) (64)

Conclusions
- Stratocumulus cloud-integrated radiative heating + cooling ("cloud-top radiative cooling", CTRC) and cloud base updraft speed $w_b$:
  - Are well correlated as determined in observations (Zheng et al., 2016).
  - Linear regressions give different functional relationships of CTRC and $w_b$ for daytime and nighttime.
  - The correlation of CTRC and $w_b$ is not causal at night.
  - Therefore, empirical relationships of CTRC and $w_b$:
    - should not be constructed using nighttime observations,
    - should not be used to parameterize nighttime $w_b$.

References
- Graham Feingold
  - Graham.Feingold@noaa.gov
- Joseph Balsells
  - Joseph.Balsells@yale.edu
- Carolin Klinger
  - Carolin.Klinger@physik.uni-muenchen.de
- Jan Kazil
  - Jan.Kazil@noaa.gov

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