# Radiative Heating and Mesoscale Vertical Motion in Cumulus Anvils

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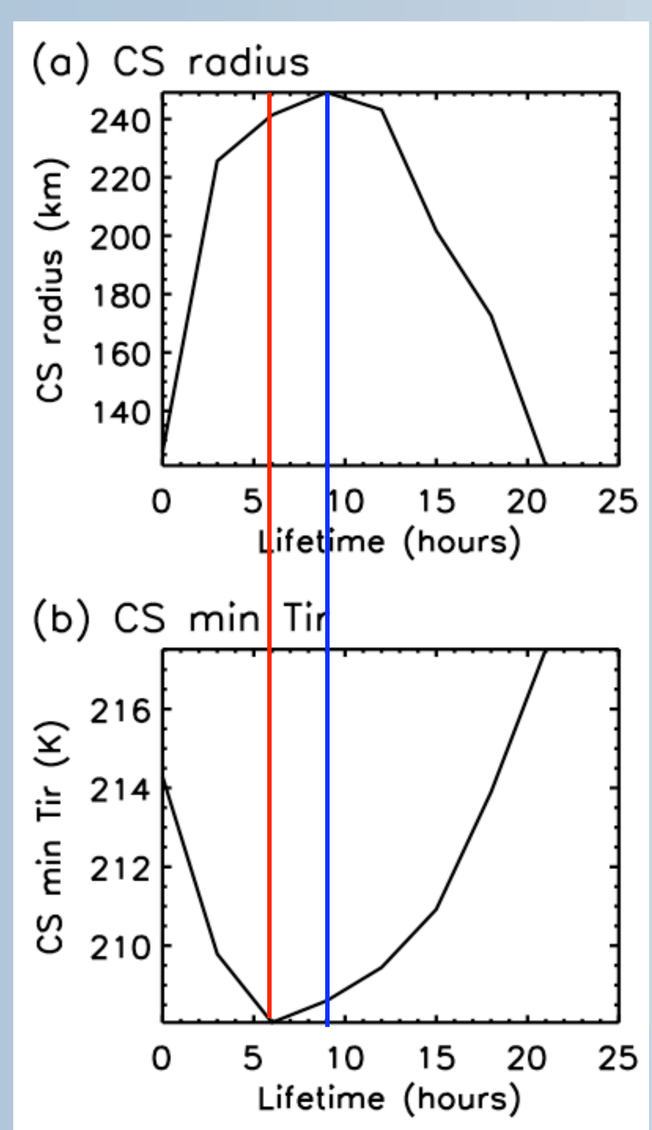
## Motivation

Errors in GCM tropical circulation are associated with the inappropriate representation of cumulus anvil clouds, which dominate tropical cloud forcing and account for ~30–70% of the total rainfall in convective systems. Most GCM cumulus parameterizations include the effect of stratiform anvils only via the condensate detrained from the convective updraft. However, anvils create their own mesoscale updrafts in response to diabatic (radiative plus latent) heating, and the properties of the anvils can be expected to evolve over their life cycle. In this study, we are combining geostationary satellite data and ASR data for the SGP and TWP to characterize the radiative component of the diabatic heating and corresponding vertical motion over different life stages of convective system and to obtain some observational constraints on mesoscale vertical motions in convective clusters.

## Datasets

- ISCCP 3-hourly Deep Convective Tracking Database — identify and describe the properties of mesoscale deep convective cloud systems.
- ASR PI Product: Tropical Cloud Properties and Radiative Heating Profiles at Manus — radiative heating, temperature and pressure profiles (2000 February to July)
- ASR Value-Added Product: Broadband Heating Rate Profile (BBHRP) at SGP — radiative heating, temperature and pressure profiles (2000-2005, May through October)

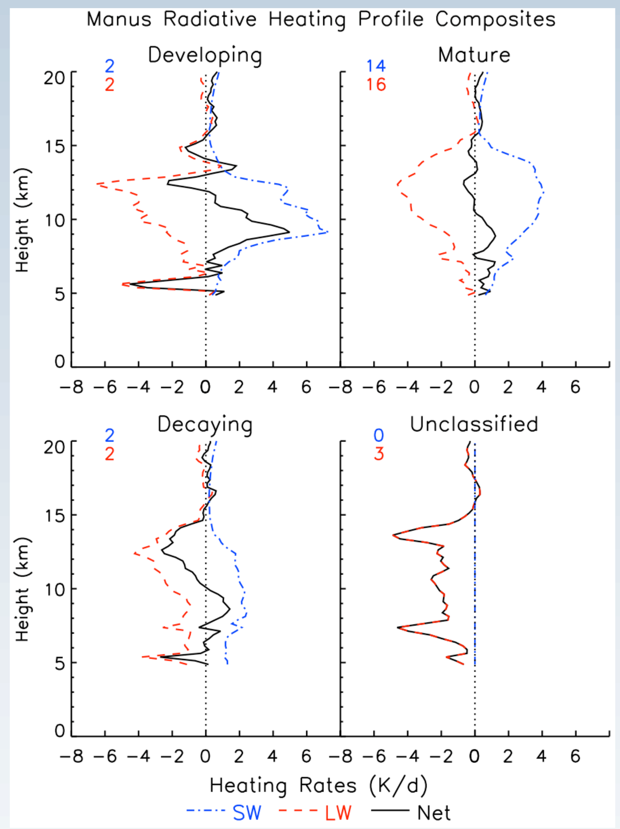
## Methodology — Define Lifecycle Stages

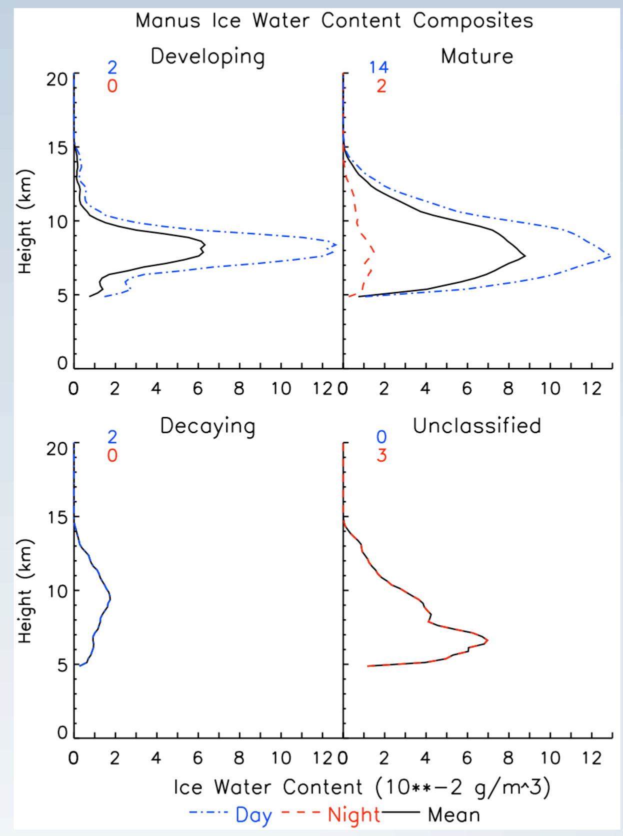


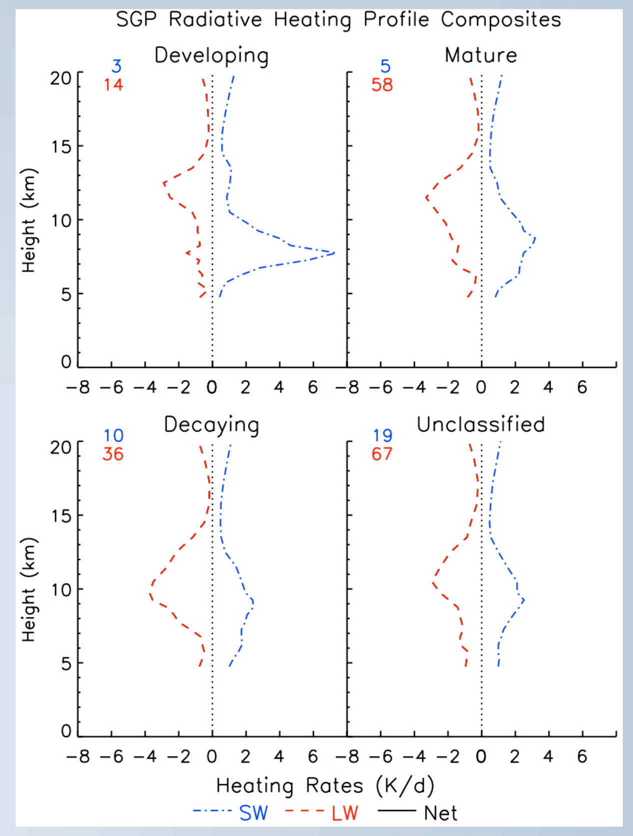

Two quantities, maximum equivalent radius ($R_{max}$) and minimum IR temperature ($T_{IRmin}$) of a convective system, are used to define three stages over its life cycle: developing, mature, and decaying (Futyan and Del Genio, 2007). The figure to the left shows the composite behavior of all convective systems with lifetime ~21 hours at SGP. Before reaching the minimum in $T_{IR}$ (red line), the system is deepening and is considered to be in its developing stage. After reaching $T_{IRmin}$ but before $R_{max}$ (blue line), the system is still growing horizontally and is considered to be in its mature stage. The system is considered to be in its decaying stage after the maximum radius is reached.

The ASR data are rebinned to 3-hourly resolution to match the ISCCP data. Based on the distance from the center of a convective system in the ISCCP data to the ASR site location, those systems passing over the ASR sites are identified.

## Mean Radiative Heating Profiles

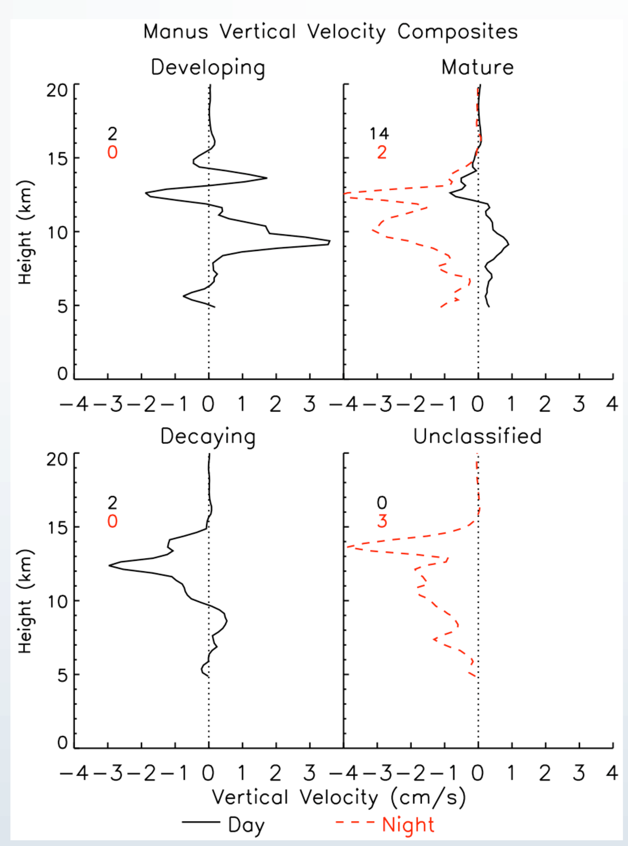


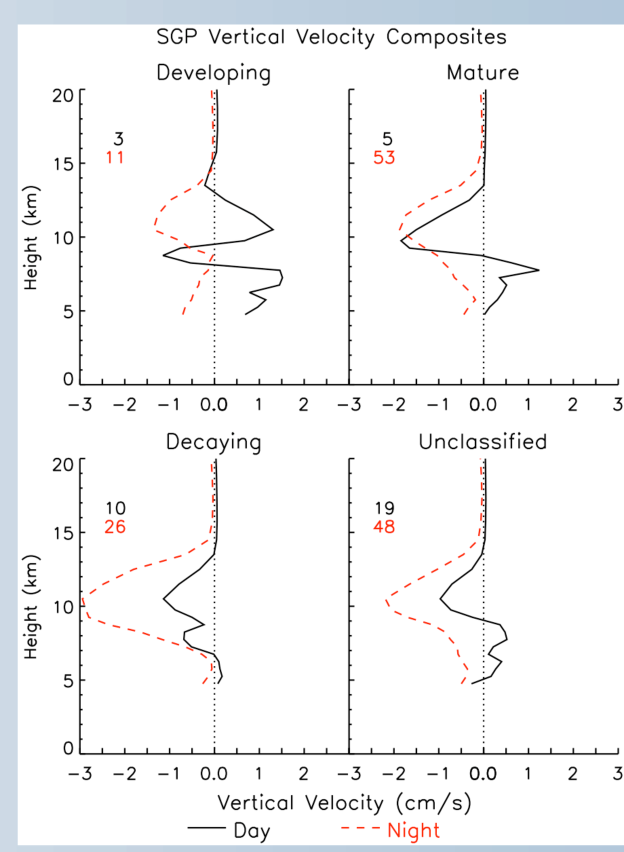




The figures above show mean radiative heating profiles at Manus (left, along with day/night/mean ice water contents in the middle panel) and the SGP (right). The numbers of convective systems used to create the LW and SW composites are also indicated. At Manus, LW cooling peaks at 12-13 km altitude during all stages, but significant cooling extends to higher altitudes during the mature phase, consistent with a broader IWC distribution. SW heating peaks at or extends to lower altitude, producing a net heating/cooling dipole, but net heating is small during the mature phase when sample size is largest. IWC is smaller at night than in the daytime, suggesting we may have sampled anvil edges at those times. A second peak in IWC and LW cooling just above 5 km suggests possible coincident congestus detrainment. At the SGP, LW cooling also peaks at 12-13 km altitude in the developing stage but descends several km and strengthens somewhat in the later stages. SW heating peaks at lower altitude than at Manus. The SW and LW curves suggest a net heating dipole as at Manus but there are too few SW samples to calculate a representative net heating profile for all times.

## Mesoscale Vertical Velocity from Radiative Heating




Contributions to the mesoscale vertical motion from the radiative heating are estimated assuming the radiative heating is balanced by mesoscale adiabatic cooling (Ackerman et al., 1988). The estimated vertical velocity is shown at the left for Manus and the right for the SGP for day and night separately. During daytime, net cooling/heating in the developing and to a lesser extent the mature stage induces upward motion within the anvil that reinforces ascent due to latent heating, but downward motion occurs near anvil top; there is generally downward radiatively driven motion during the decaying stage and during all stages at night. The magnitudes are comparable to the 3.3 cm/s estimate of Ackerman et al. (1988).




## Discussion

- Radiative heating profiles are composited based on the lifecycle of convective systems as judged by ISCCP. The heating/cooling dipole structure is consistent with previous estimates from TRMM radar (Li et. al. 2008) for thick anvil clouds over TWP region, but our heating rates are slightly stronger. The cooling peak is elevated by several km relative to that for all clouds as estimated by Mather et al. (2007). However uncertainty exists in the heating rate estimate when precipitation occurs.
- Mesoscale updraft response to the radiative heating is estimated at different convective life stages. The results suggest a non-negligible effect of radiative heating on upward motion during the growth of a convective system but a suppression during the decaying stage and at night. However, the mesoscale motion due to radiative heating is an order of magnitude smaller than that from latent heating (Biggerstaff and Houze 1991; Houze 1993). It mainly modulates the vertical motion due to latent heating by changing the location of the peak and weakening the upward motion when shortwave heating is absent.

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