A-Train estimates of the sensitivity of warm rain likelihood and efficiency to cloud size

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Abstract

The warm rain process is an important part of shallow cumulus convection and can influence both cloud microphysics and cloud radiative effects. Model studies suggest that as shallow cumulus grow in size, the likelihood of warm rain increases due to a decreasing impact of entrainment on cloud updrafts. This implies a reduction in evaporative effects near cloud center that may result in more efficient conversion from cloud water to precipitation as cloud size increases. While these findings have been illustrated with cloud resolving models, the likelihood of precipitation and the sensitivity of precipitation efficiency to cloud size has not yet been tested by global observations. A-Train satellite observations, with sensors sensitive to both cloud and precipitation water, can be used to examine shallow cumulus behavior with cloud size. We combine CloudSat and MODIS observations to create a warm cloud climatology by identifying warm oceanic contiguous cloud objects with top heights below the freezing level from August 2006 - December 2010. The characteristics of each cloud object, including cloud top height, along-track extent (size), vertical reflectivity gradients, integrated cloud and precipitation water, and column water vapor (CWV) environment, are calculated. As a proxy for warm rain efficiency, the ratio of precipitation to cloud water is also analyzed for varying cloud object sizes. For a fixed top height, our results show rain likelihood increases with cloud size. Our initial results support the hypothesis that as shallow cumulus size increases and/or environmental moisture increases, shallow cumulus updrafts are able to support larger droplets that are more likely to fall out as rain. Planned analysis will determine how our proxy for warm rain efficiency changes with cloud size.

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Motivation

- Models and observations show warm rain onset may be more likely in larger shallow clouds or a moister environment due to the decreasing impact of entrainment on updrafts as the cloud size increases.
- This implies a reduction in evaporative effects near cloud center that may result in more efficient conversion from cloud water to precipitation as cloud size increases.

We use CloudSat observations within shallow cumulus clouds of different sizes to answer the following questions:

1. **Do satellite observations show a relationship between rain likelihood and cloud size?**
2. **Does a proxy for warm rain efficiency (WRE) change as a function of cloud size and environmental moisture?**

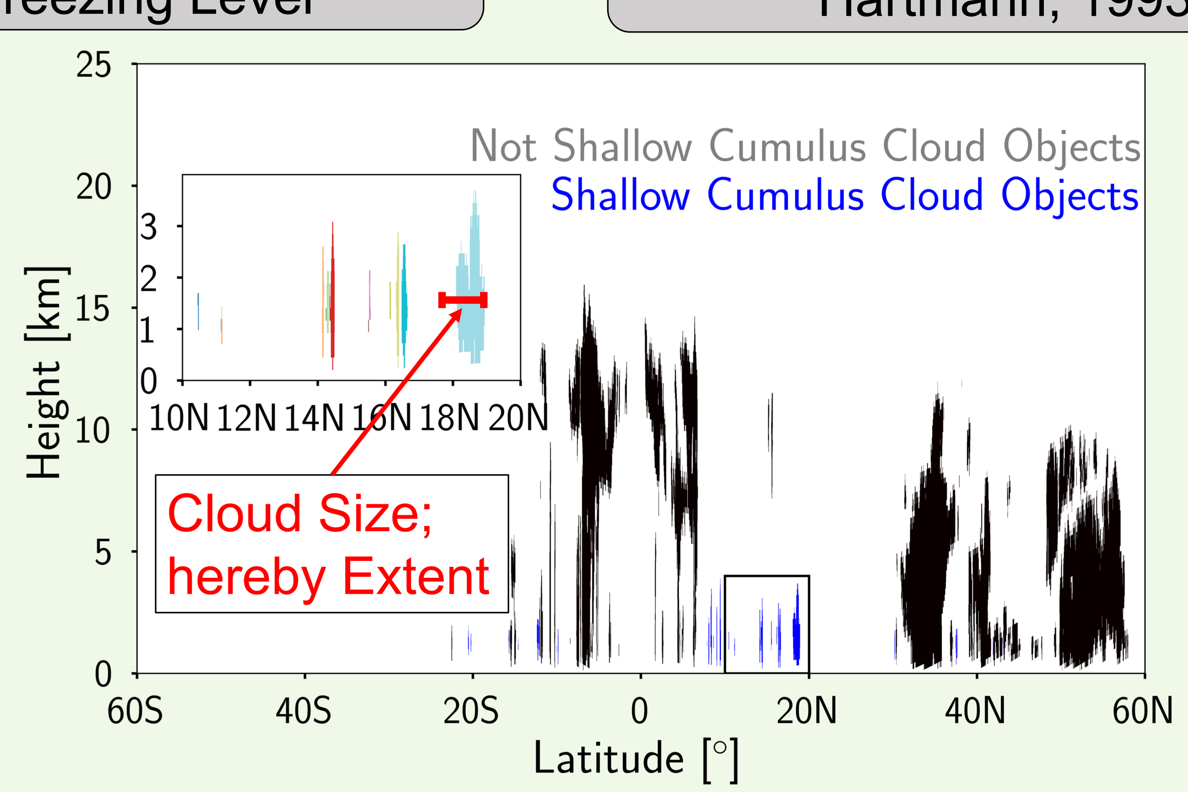
Data

Region: 60°N - 60°S   Timeframe: June 2006 – December 2010

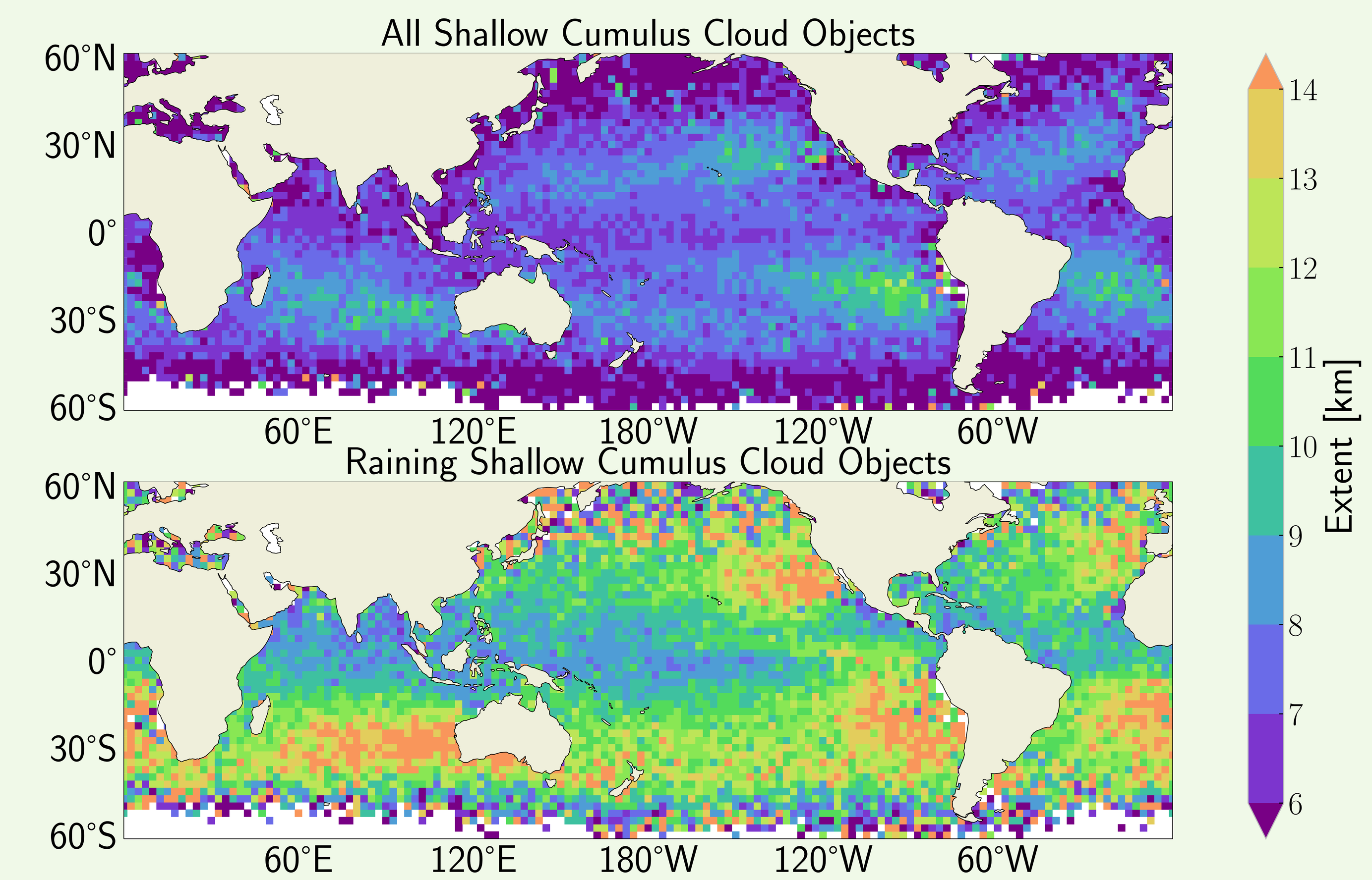
CloudSat Products	
Raw Reflectivity	2B-GEOPROF
Rain Water Path (W_p)	2C-RAIN-PROFILE
Freezing Level	2C-PRECIP-COLUMN
MODIS Products (MOD06-1KM-AUX)	
Cloud Water Path (W_c)	
ECMWF Products (ECMWF-AUX)	
Environmental Moisture	< 3km Relative Humidity (RH)
Lower Tropospheric Stability (LTS)	Temperature

Shallow Cumulus Cloud Object Identification

Identify Contiguous Cloud Objects → Remove Land Cloud Objects → Remove Non-Raining Cloud Objects → Cloud Top Heights > Freezing Level → LTS < 18.55 K [Klein and Hartmann, 1993]

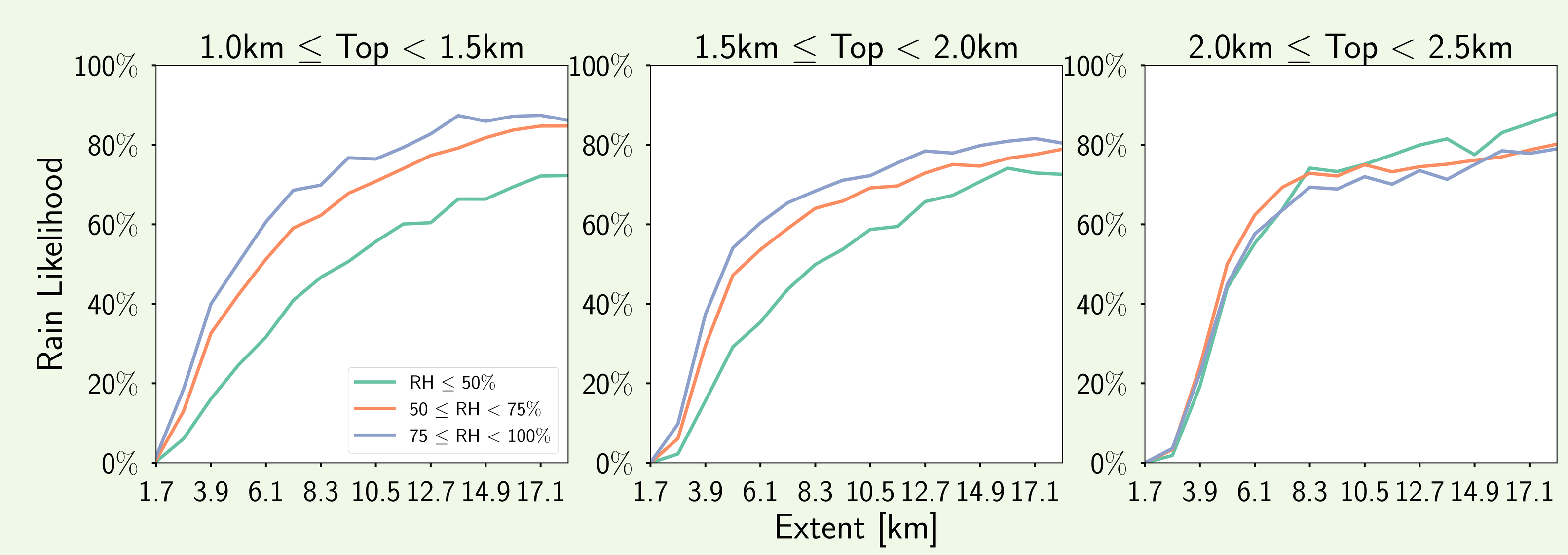


Rain Likelihood



- **Globally, raining cloud object extent is larger than non-raining cloud object extent**
- **Tropical cumulus in moister environments are smaller than subtropical cumulus**

Cloud Objects Binned by Top Height and RH

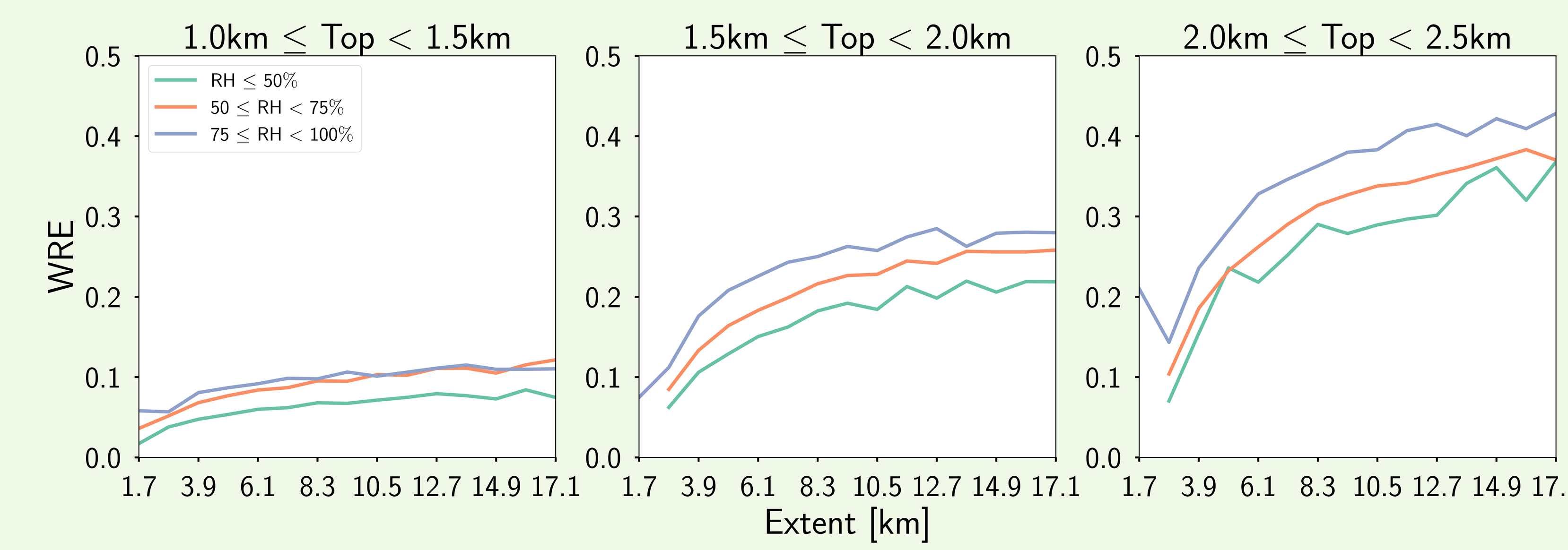


For a fixed depth:

- **As extent increases, rain likelihood increases**
- **As RH increases, rain likelihood increases**

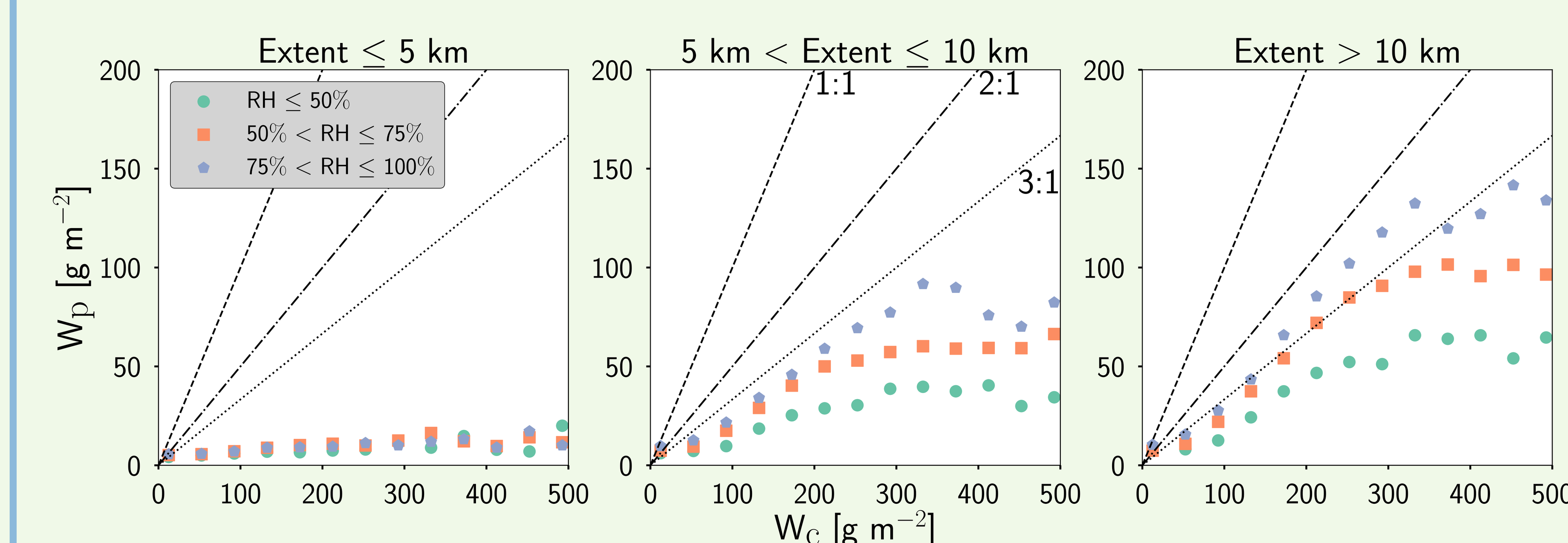
Warm Rain Efficiency

$$\mathrm{WRE} = \frac{\mathrm{Wp}}{\mathrm{Wc}}$$



For a Fixed Top Height:

- **WRE increases as extent increases**
- **WRE increases as RH increases**



For extents < 5 km:

- **W_p does not change as W_c increases**
- **Little RH sensitivity**

For extents > 5 km:

- **W_p increases with W_c**
- **W_p increases with RH**
- **WRE increases with cloud size**

Conclusions

Analysis of the likelihood of warm rain occurrence as a function of cloud extent and environment shows:

1. **Larger shallow cumulus cloud objects are more likely to produce warm rain.**
2. **Objects in wetter environments are more likely to produce warm rain.**

These results suggest that cloud object updrafts in larger clouds or wetter environments may be more protected from mixing which increases the likelihood of warm rain onset.

Analysis of Warm Rain Efficiency as a function of cloud extent and the environment shows:

1. **Larger shallow cumulus cloud objects have a greater warm rain efficiency.**
2. **Larger cloud objects occurring in wetter environments have a greater rain efficiency.**

These results suggest that larger shallow cumulus cloud objects or objects occurring in wetter environments are more efficient at converting cloud water to rain.

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