Evaluating Drizzle Formation Parameterization Using Ensemble Cloud Retrievals from the MAGIC Campaign

Christine Chiu, Mark Fielding, Robin Hogan

University of Reading

Graham Feingold, Peter Jan van Leewen, Richard Forbes, Maike Ahlgrimm,

Importance of warm rain observations

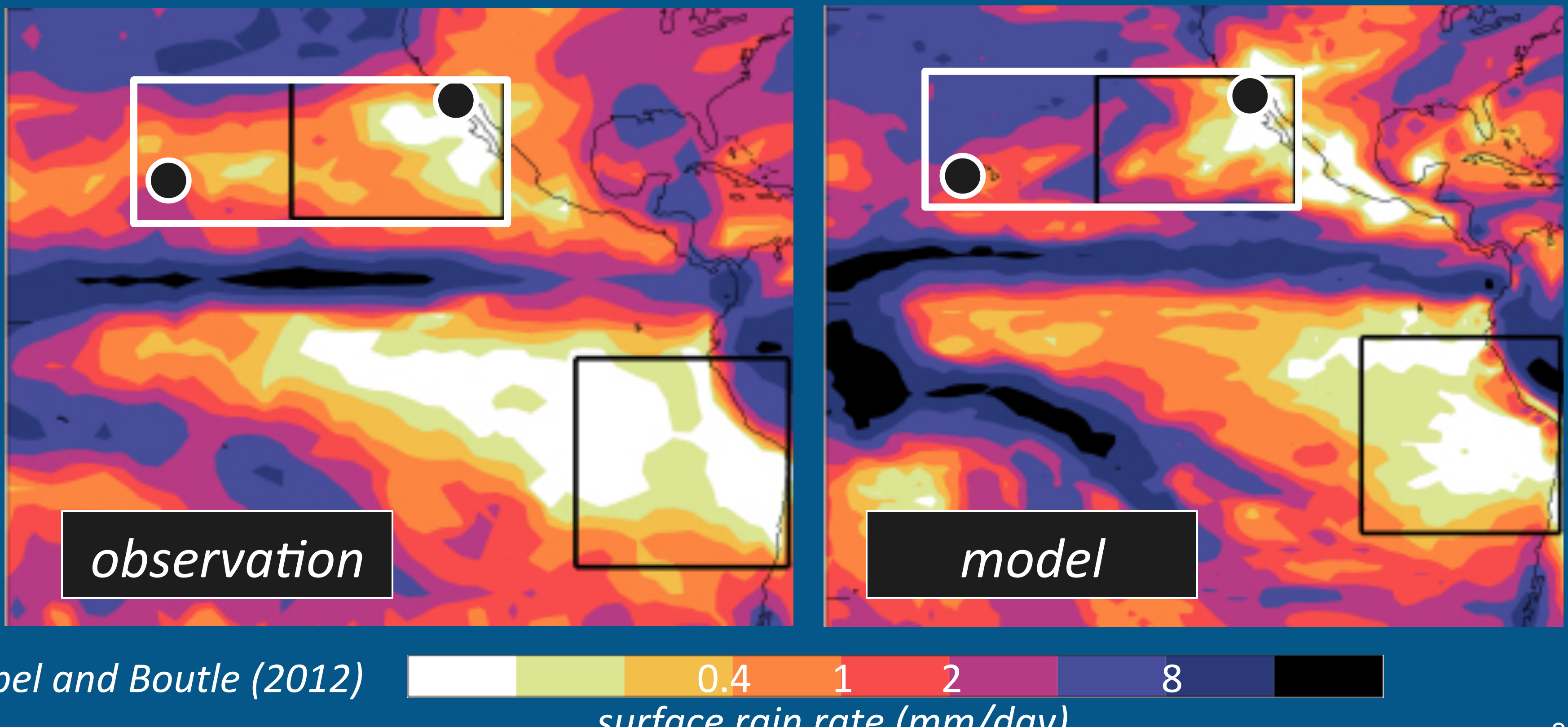
- Direct impact on the maintenance of parent clouds
- Impact on Earth's radiation budget and water cycle
- One of the key variables to constrain cloud-aerosol-precipitation interactions in climate models

Known issues about precipitation in models

- Too frequent by a factor of 1.5 – 2

Stephens et al. (2010)
Ahlgrimm and Forbes (2014)

- Too light by a factor of ~2 in general, but too heavy in marine Sc regions



Abel and Boutle (2012)

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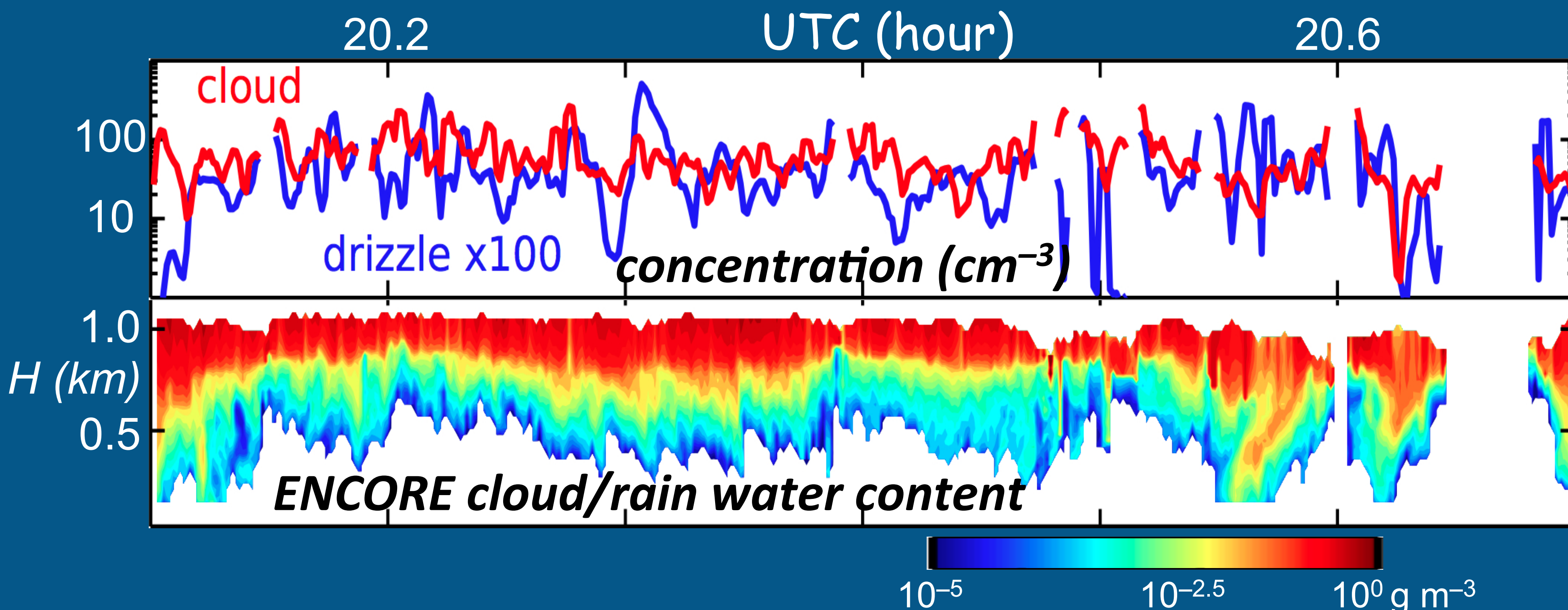
Two (entwined) problems –
representation of clouds and representation of precipitation

Many studies try to tackle the problem of clouds or clouds and precipitation

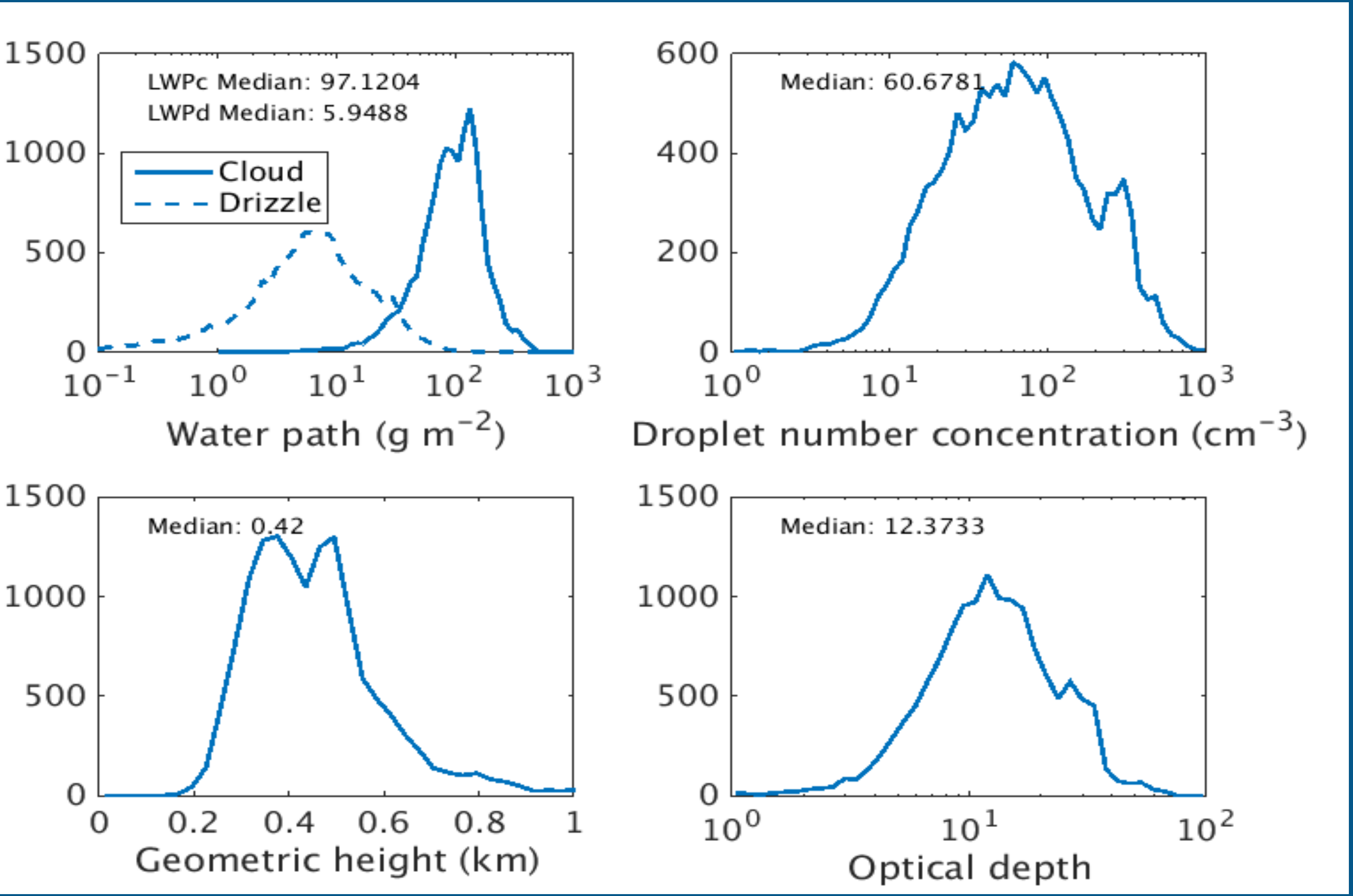
Isolate rain formation processes from cloud issues

Ship-based observations from MAGIC in 2013

- Ensemble Cloud Retrieval (ENCORE; *Fielding et al., 2014; 2015*):
  - *Combine cloud radar, lidar and shortwave zenith radiances*
  - *Use the Iterative Ensemble Kalman Filter as an optimal estimation framework*



Cloud/drizzle statistics from MAGIC



Schemes for warm rain formation

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- Either diagnostic or prognostic

cloud layer

Autoconversion term

+

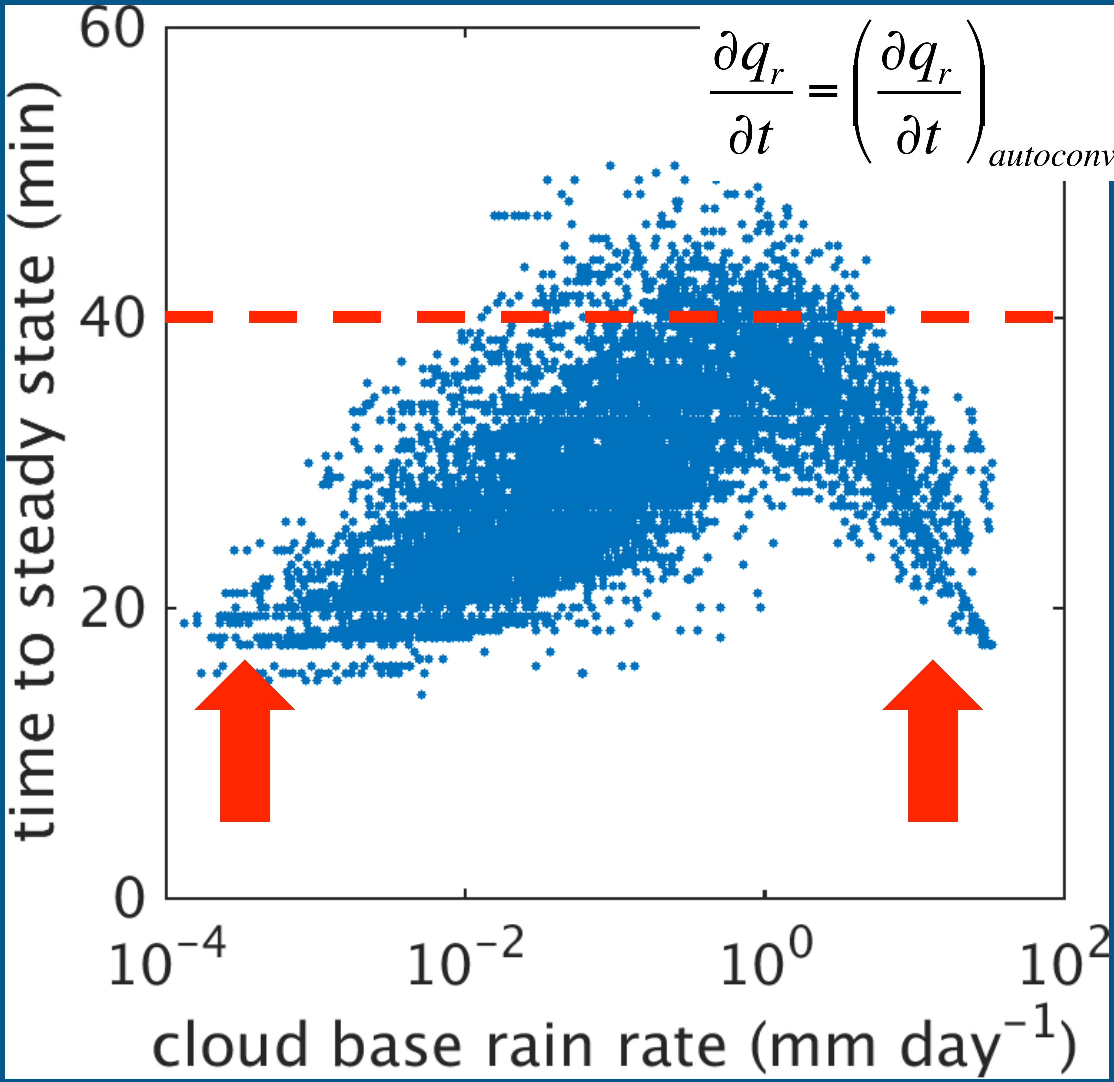
Accretion term

Sedimentation term

(fall speed, rain drop size distribution)

Time to reach steady state

$$\frac{\partial q_r}{\partial t} = \left(\frac{\partial q_r}{\partial t}\right)_{autoconversion} + \left(\frac{\partial q_r}{\partial t}\right)_{accretion} + \left(\frac{\partial q_r}{\partial t}\right)_{sed}$$



- Use all observed cloud profiles
- steady state: less than a 1% change in the cloud base rain rate
- 95% of time periods shorter than 40 min

Case selection

- Cloud fraction greater than 0.5
- Cloud water path variability (standard deviation/mean) less than 0.5
- Rain water path variability less than 1.0
- About fifteen 40-min long data (retrieval available at 5-sec resol.)

Coefficient optimization for autoconversion and accretion

$$V_{r,k}q_{r,k} - V_{r,k-1}q_{r,k-1} = C_1 \cdot q_{c,k}^{a} \cdot N_d^{b} \cdot \Delta z_k + C_2 \cdot \left(q_{c,k} \cdot q_{r,k}\right)^{c} \Delta z_k$$

sedimentation autoconversion accretion

- Give a set of coefficients (C_1, a, b, C_2, c)
- Minimize difference between the left and right hand sides using observations

Optimized coefficients

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autoconversion

$$C_1 \cdot q_c^a \cdot N_d^b$$

accretion

$$C_2 \left(q_c \cdot q_r\right)^c$$

	C_1	a	b	C_2	c
Solution	1270 ± 86	2.83 ± 0.16	−1.17 ± 0.14	63 ± 8	1.11 ± 0.01
KK	1350	2.47	−1.79	67	1.15
Solution 2	1270 ± 88	2.68 ± 0.18	−1.67 ± 0.17	59 ± 9	1.11 ± 0.01

The prognostic equation for warm rain

$$\frac{\partial q_r}{\partial t} = advection + \left(\frac{\partial q_r}{\partial t}\right)_{autoconversion} + \left(\frac{\partial q_r}{\partial t}\right)_{accretion} + \left(\frac{\partial q_r}{\partial t}\right)_{sed}$$

$$-\vec{V} \cdot \nabla q_r$$

horizontal gradient of rain properties is missing in current observations !!

Summary

- New observations of in-cloud rain water content allow us to better understand process rates of warm rain formation.

- Observations suggest that autoconversion models may be too sensitive to cloud droplet number concentration, but two possible optimal coefficients remain.

- Measurements of rain horizontal gradient will be invaluable to help constrain the autoconversion rate.