Satellite retrieval of cloud condensation nuclei (CCN) concentrations for convective clouds

Youtong Zheng [1], Daniel Rosenfeld [2], Zhanqing Li[1]

[1] Department of Atmospheric and Oceanic Science, University of Maryland, College Park, Maryland, 20742, USA.

[2] Institute of Earth Sciences, The Hebrew University of Jerusalem, Jerusalem, 91904, Israel.

Acknowledgement

Hebrew University of Jerusalem: Eyal Hashimshoni, David Giguzin, Tom Goren, Baruch Fischman

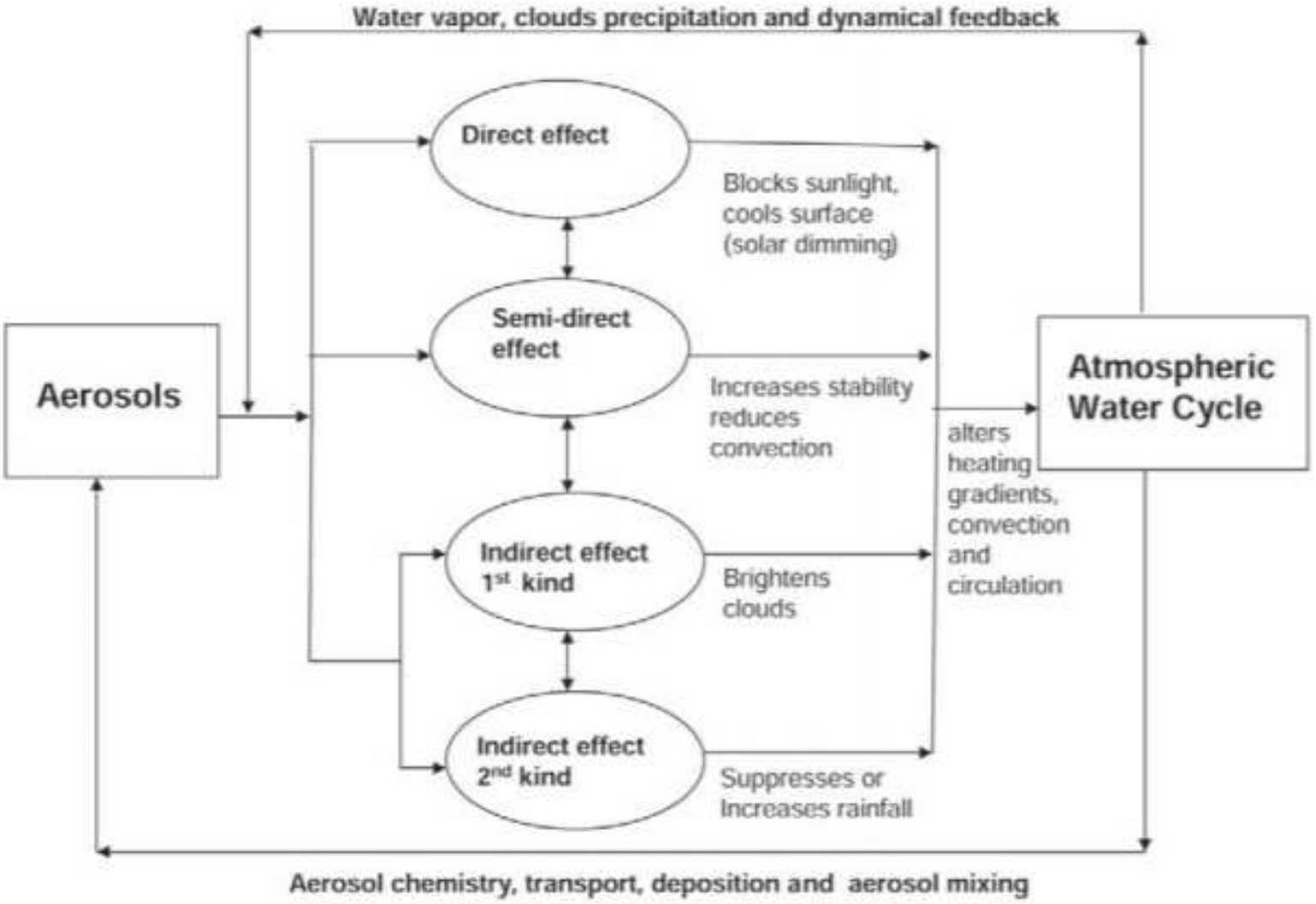
Meteorological Institute of Shaanxi Province: Yu Xing, Yannian Zhu, Guihua Liu, Zhiguo Yue

Max Planck Institute for Chemistry: Mira L. Pöhlker, Christopher Pöhlke, Ulrich Pöschl and Meinrat O. Andreae

NOAA ESRL: Anne Jefferson

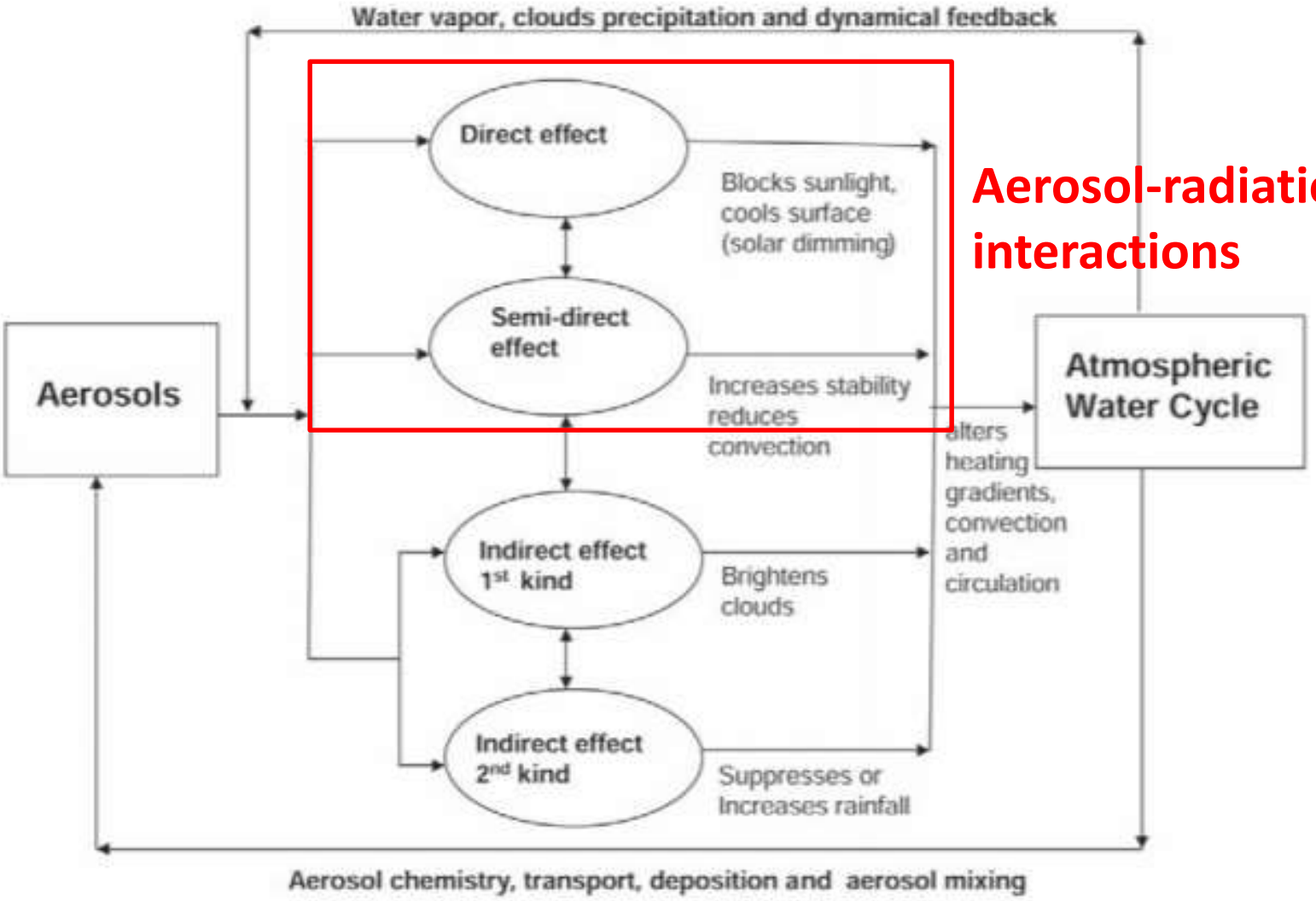
University of Sao Paulo: Paulo Artaxo, Henrique Barbosa

Aerosol-monsoon interactions



Lau et al., 2008

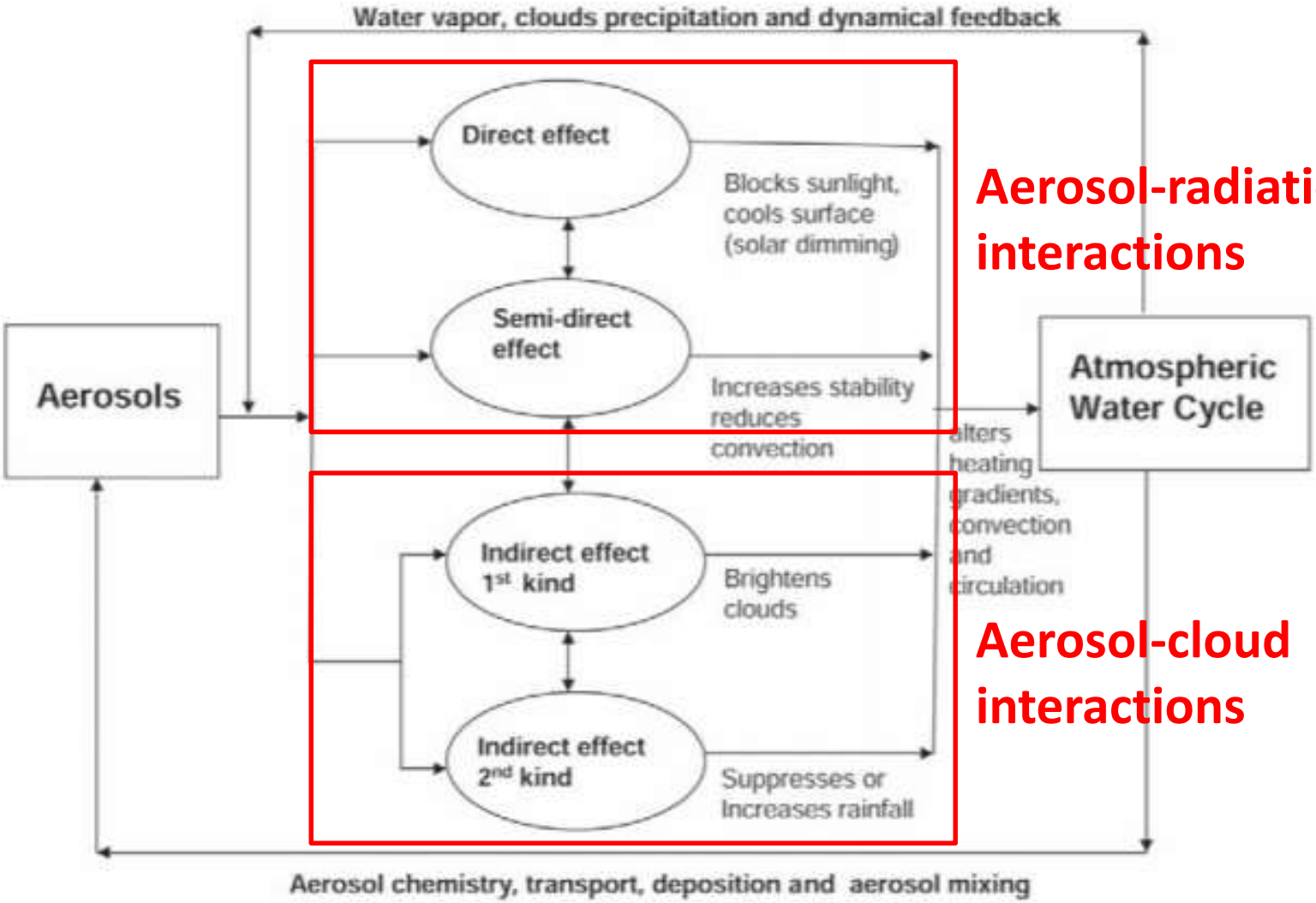
Aerosol-monsoon interactions



Aerosol-radiation interactions

Lau et al., 2008

Aerosol-monsoon interactions

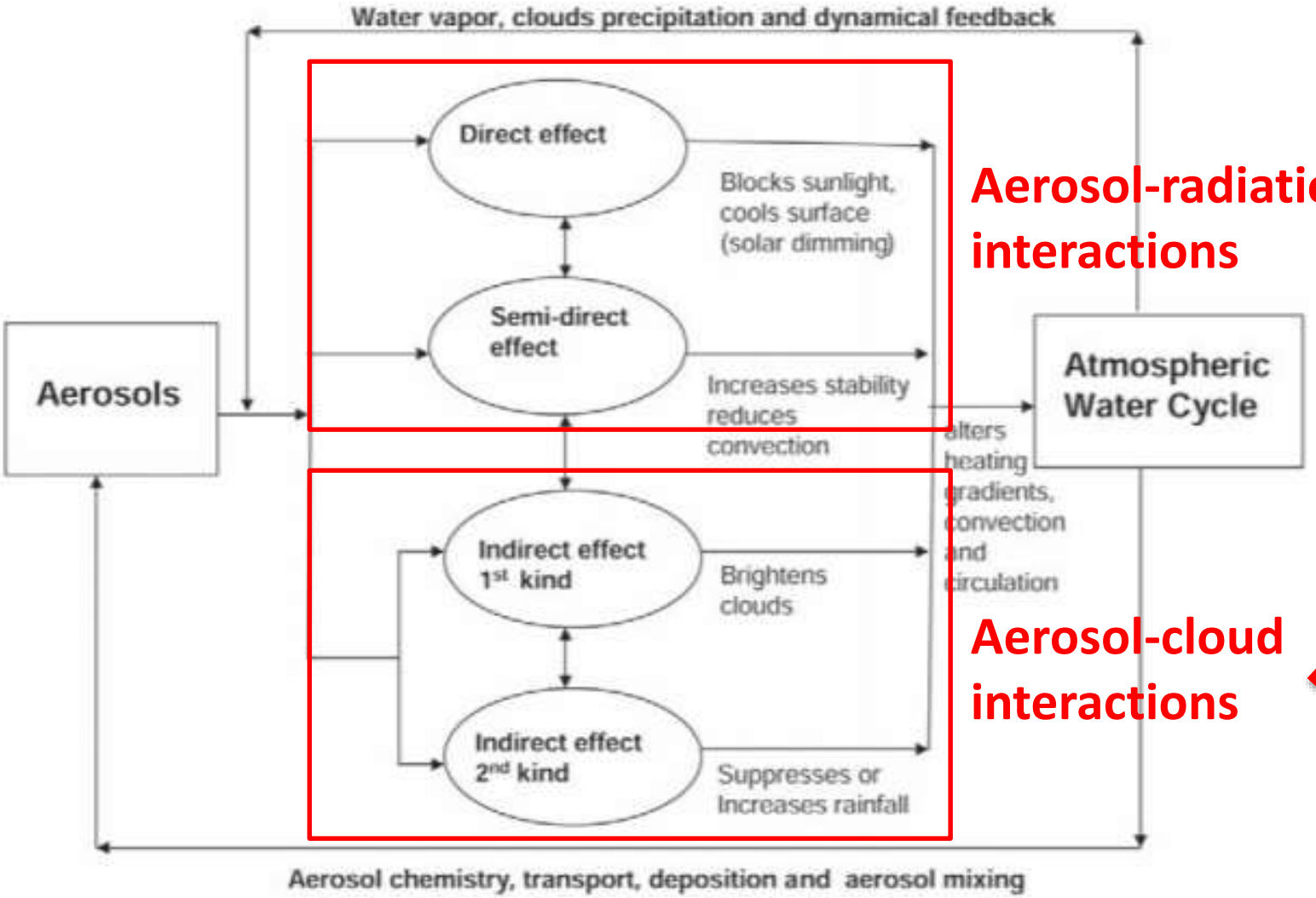


Aerosol-radiation interactions

Aerosol-cloud interactions

Lau et al., 2008

Aerosol-monsoon interactions

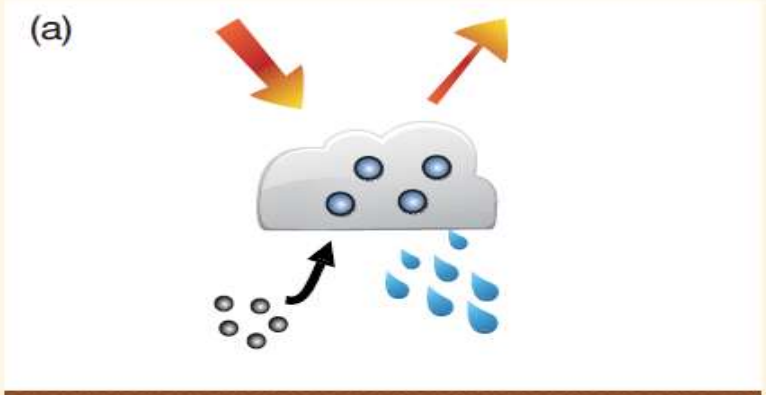


Aerosol-radiation interactions

Aerosol-cloud interactions

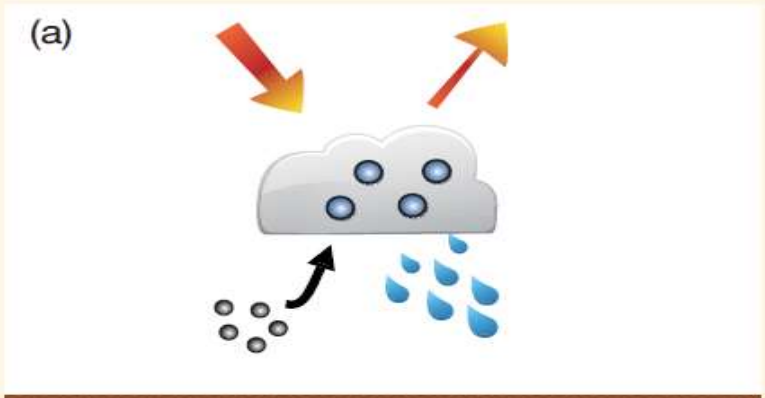
Lau et al., 2008

Aerosol-cloud interactions

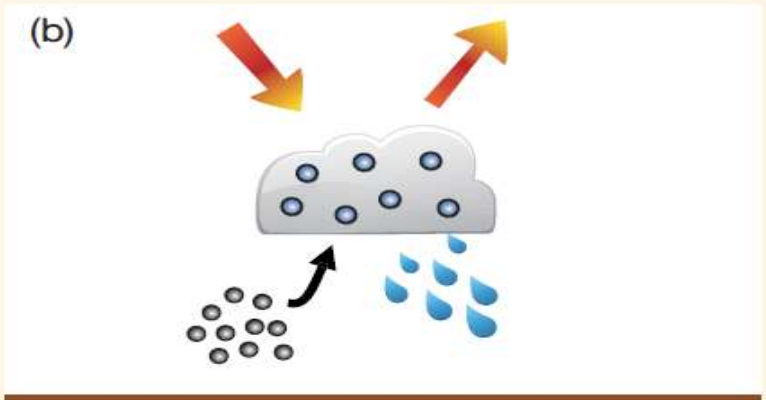


Aerosols serve as cloud condensation nuclei upon which liquid droplets can form.

Aerosol-cloud interactions

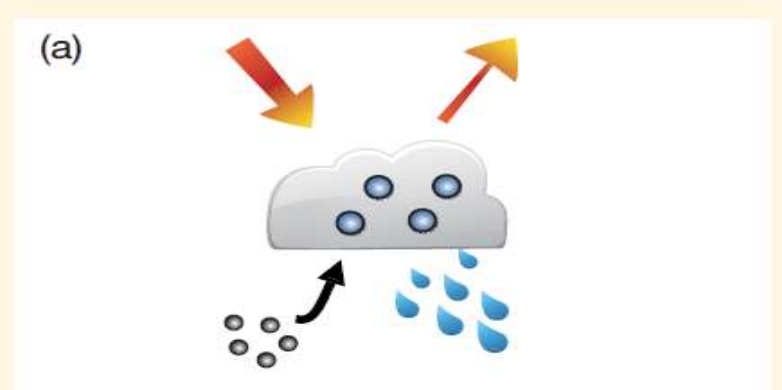


Aerosols serve as cloud condensation nuclei upon which liquid droplets can form.

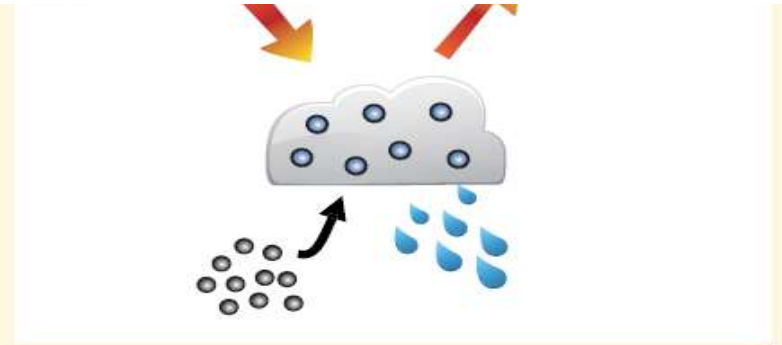


More aerosols result in a larger concentration of smaller droplets, leading to a brighter cloud. However there are many other possible aerosol–cloud–precipitation processes which may amplify or dampen this effect.

Aerosol-cloud interactions



Only CCN matters!



More aerosols result in a larger concentration of smaller droplets, leading to a brighter cloud. However there are many other possible aerosol–cloud–precipitation processes which may amplify or dampen this effect.

Key Gaps in understanding aerosol-cloud interactions

- CCN measurements are scant:
  - In-situ and ground-based remote sensing
  - No space-based measurements!

How about AOD?

Satellite-retrieved AOD is inherently not suitable for studying aerosol-cloud interactions:

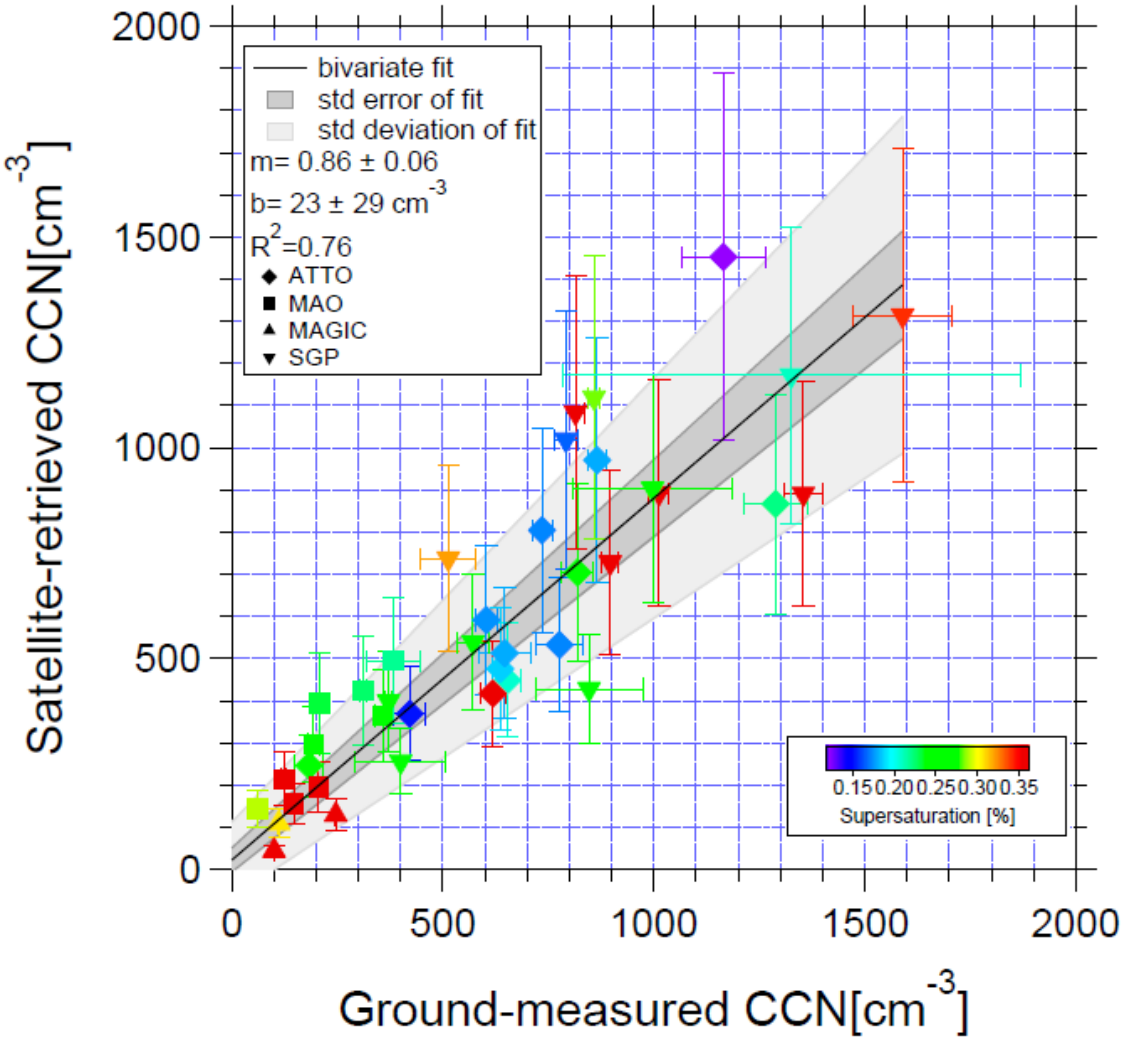
- AOD not representing aerosol concentration near cloud base
- Cloud contamination
- AOD retrieval is an ill-posed technique (The number of known variables is less than what is required)
- Lack of accurate AOD signal for the pristine boundary layer, where accuracy is most critical

Satellite retrieval of cloud condensation nuclei concentrations by using clouds as CCN chambers

Daniel Rosenfeld[a,1], Youtong Zheng[b,c,d], Eyal Hashimshoni[a], Mira L. Pöhlker[e,f], Anne Jefferson[g], Christopher Pöhlker[e], Xing Yu[h], Yannian Zhu[d,h], Guihua Liu[h], Zhiguo Yue[h], Baruch Fischman[a], Zhanqing Li[b,c,d], David Giguzin[a], Tom Goren[a], Paulo Artaxo[i], Henrique M. J. Barbosa[i], Ulrich Pöschl[e,f], and Meinrat O. Andreae[e]

PNAS PNAS PNAS

COLLOQUIUM PAPER



The retrieval concept

$$s_{\max} = C W_b^{3/4} N_d^{-1/2}$$

S_{max}: maximum super saturation

W_b: cloud base updrafts

$N_{d:}$ adiabatic cloud droplets number concentration

Pinsky et al., 2012

The retrieval concept

$$S_{max} = C W_b^{3/4} N_d^{-1/2}$$

S_{max}: maximum super saturation

W_b: cloud base updrafts

$N_{d:}$ adiabatic cloud droplets number concentration

Pinsky et al., 2012

The retrieval concept

$$S_{max} = C W_b^{3/4} N_d^{-1/2}$$

S_{max}: maximum super saturation

W_b: cloud base updrafts

$N_{d:}$ adiabatic cloud droplets number concentration

Pinsky et al., 2012

The retrieval concept

How can we retrieve W_b and N_d from satellite?

$$S_{max} = C W_b^{3/4} N_d^{-1/2}$$

S_{max}: maximum super saturation

W_b: cloud base updrafts

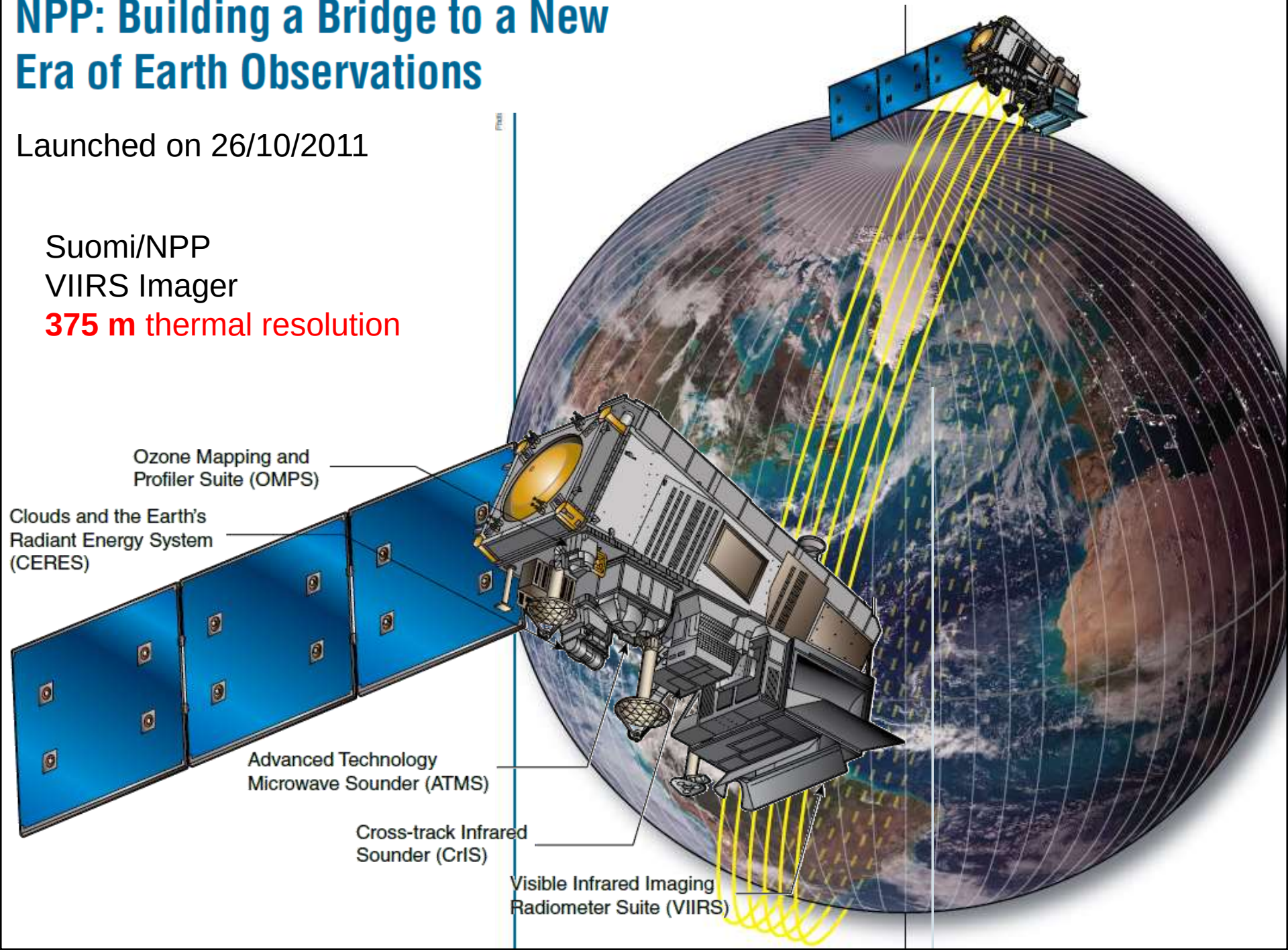
$N_{d:}$ adiabatic cloud droplets number concentration

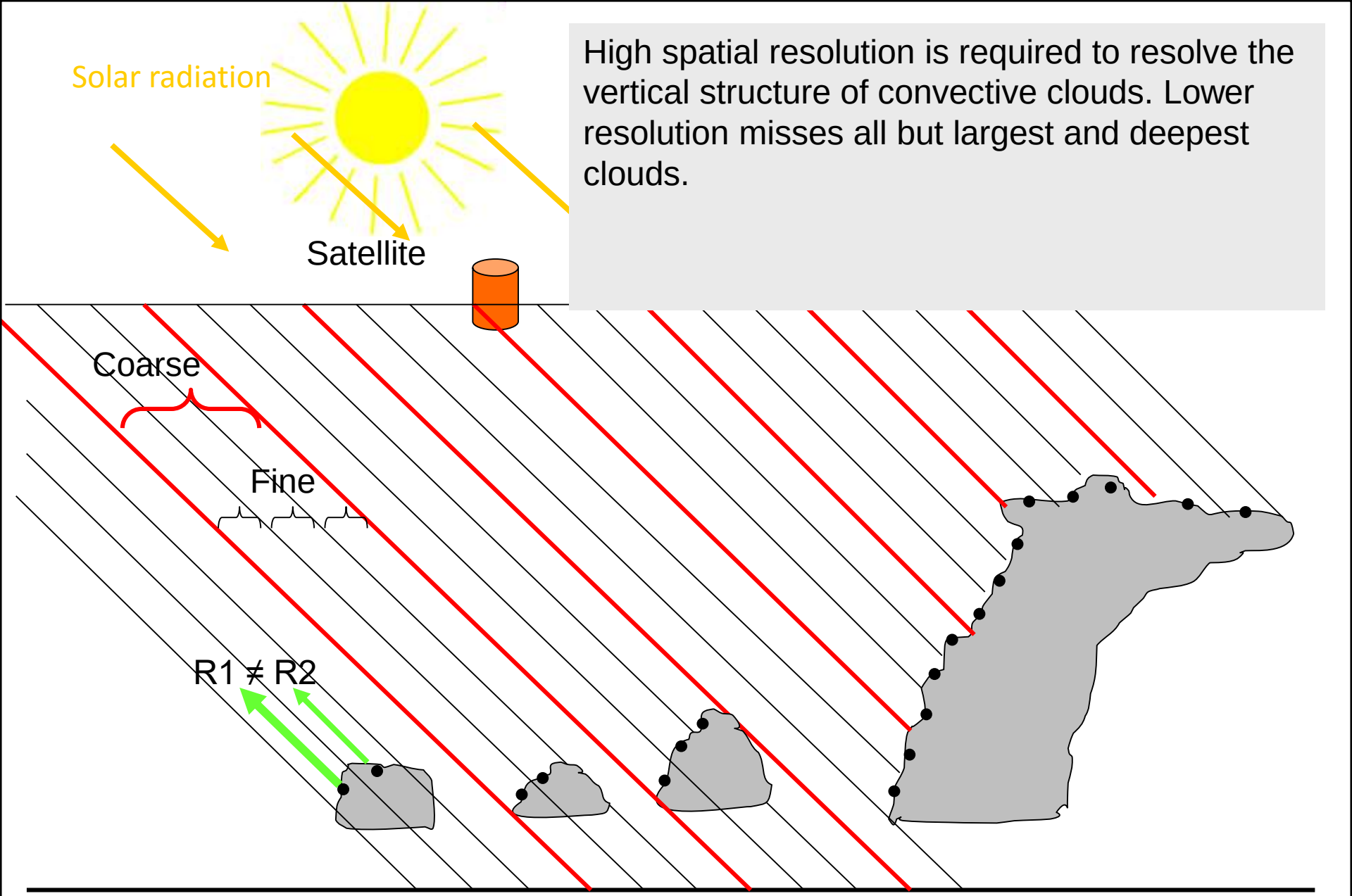
Pinsky et al., 2012

NPP: Building a Bridge to a New Era of Earth Observations

Launched on 26/10/2011

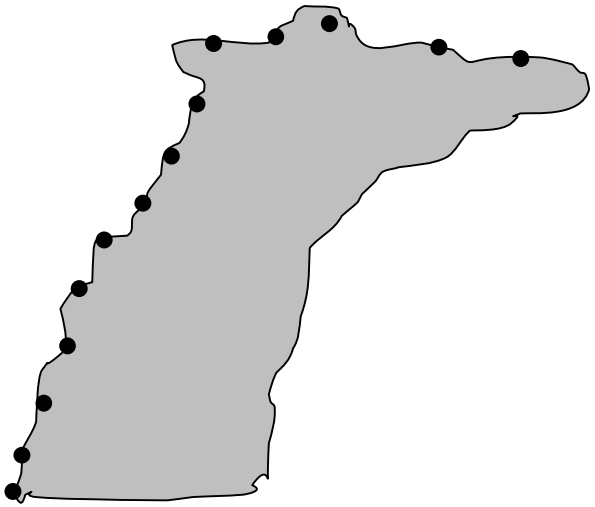
Suomi/NPP
VIIRS Imager
375 m thermal resolution



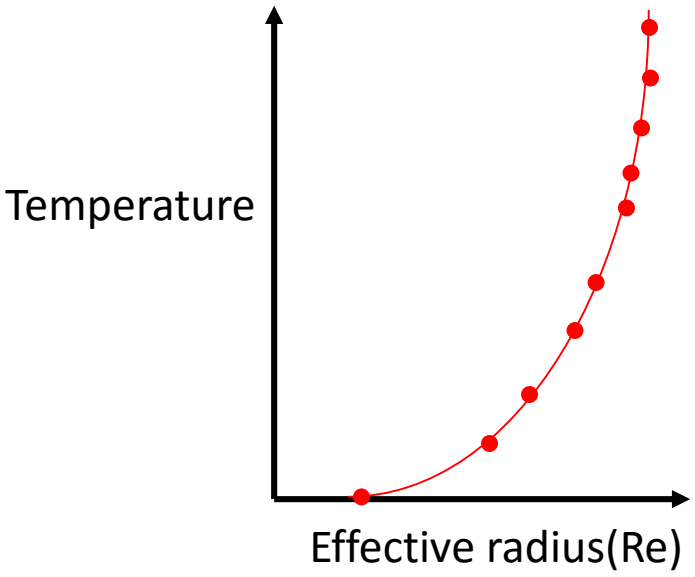


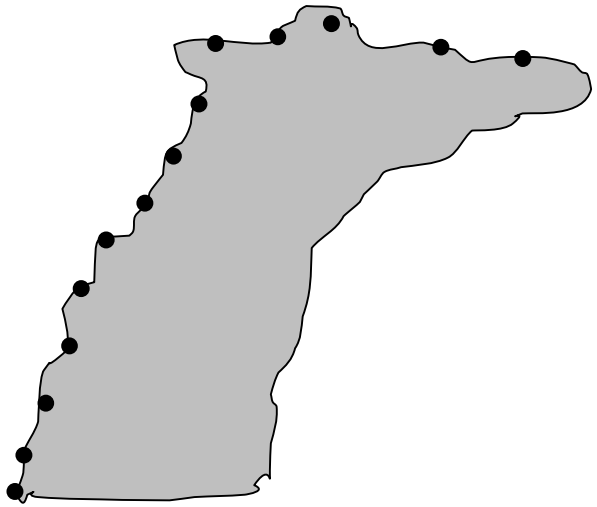
High spatial resolution is required to resolve the vertical structure of convective clouds. Lower resolution misses all but largest and deepest clouds.

Measurement concept for T-r_e based CCN retrievals

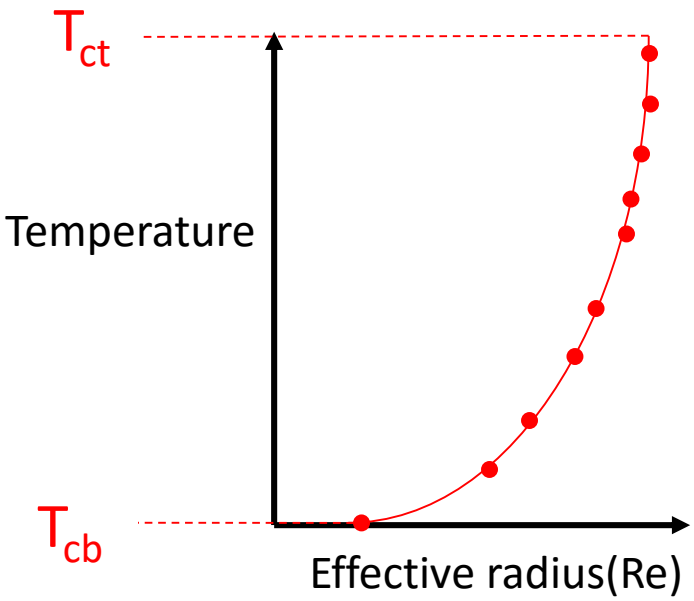


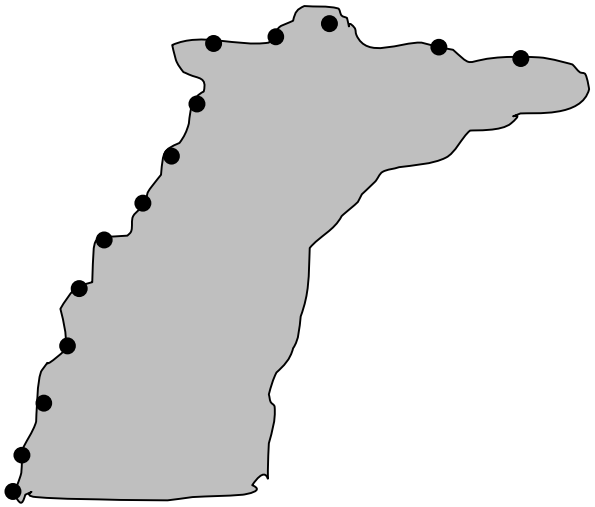
Measurement concept for T-r_e based CCN retrievals





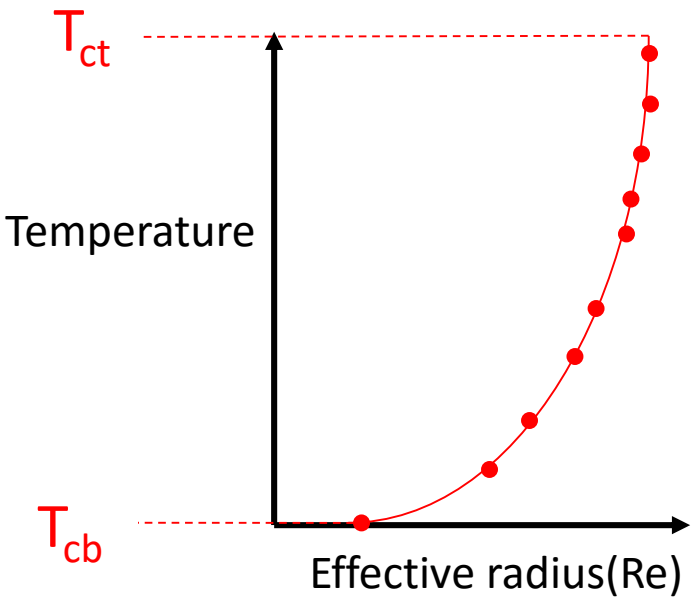
Measurement concept for T-r_e based CCN retrievals

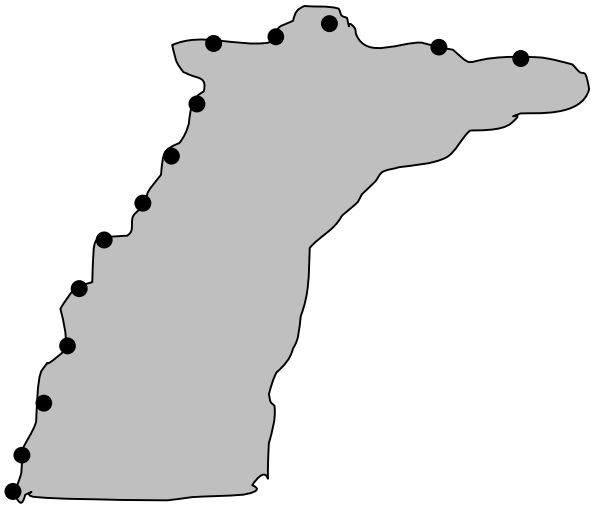




Measurement concept for T-r_e based CCN retrievals

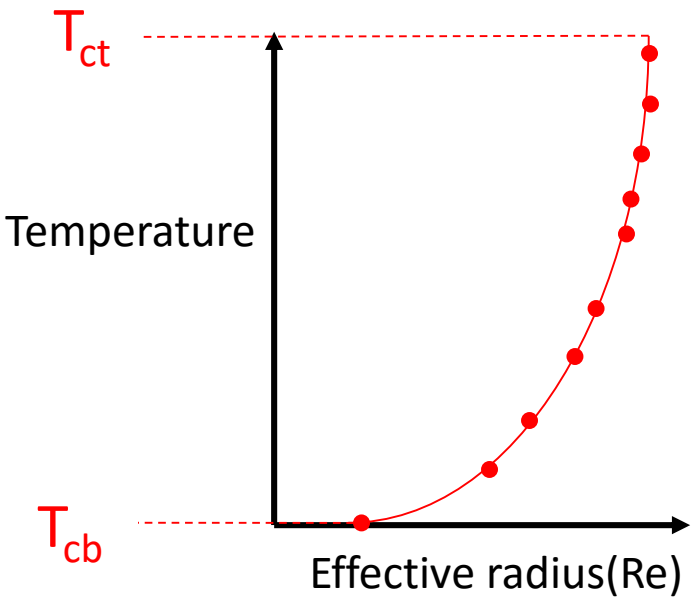
T_{cb}, T_{ct} -> adiabatic LWC

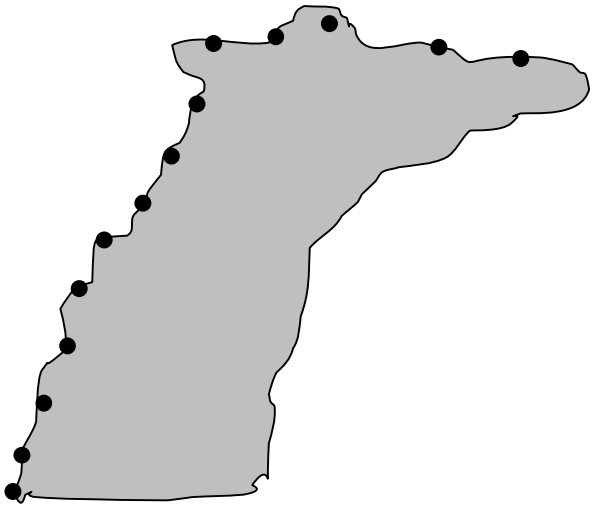




Measurement concept for T-r_e based CCN retrievals

T_{cb}, T_{ct} -> adiabatic LWC
R_e

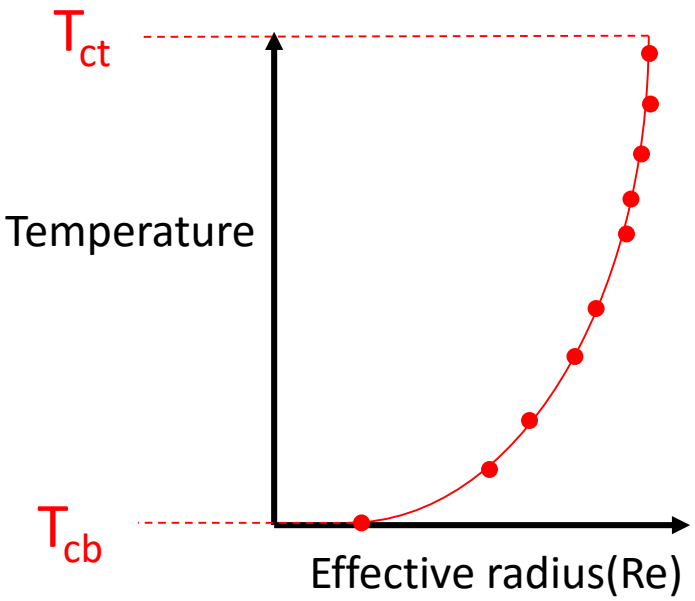


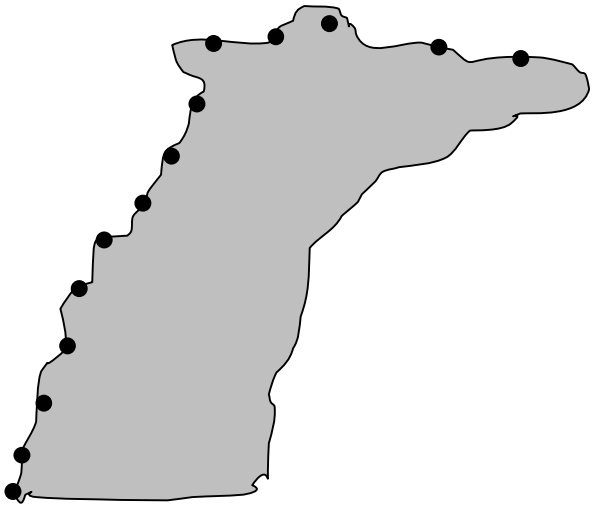


Measurement concept for T-r_e based CCN retrievals

T_{cb}, T_{ct} -> adiabatic LWC

R_e -> adiabatic R_e

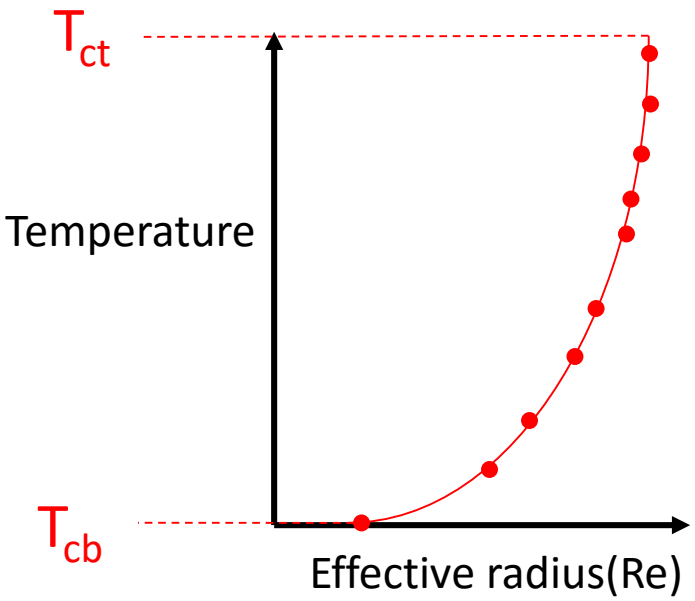


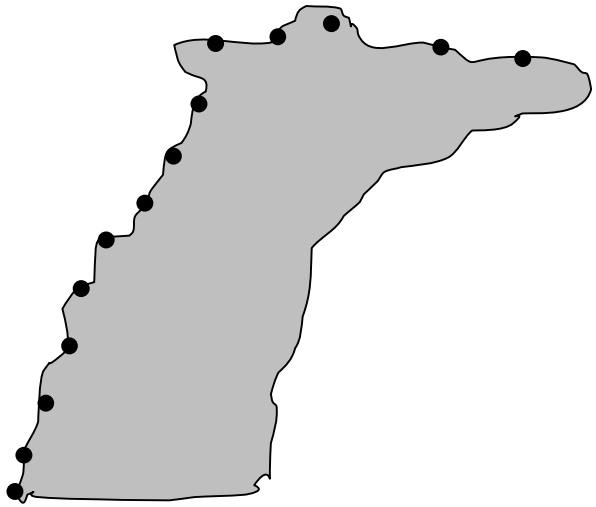


Measurement concept for T-r_e based CCN retrievals

T_{cb}, T_{ct} -> adiabatic LWC

R_e -> adiabatic R_e -> adiabatic M_a

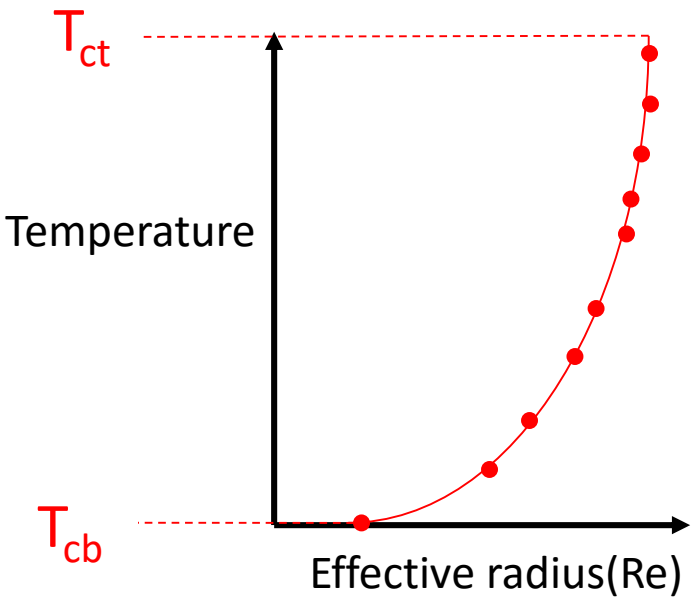


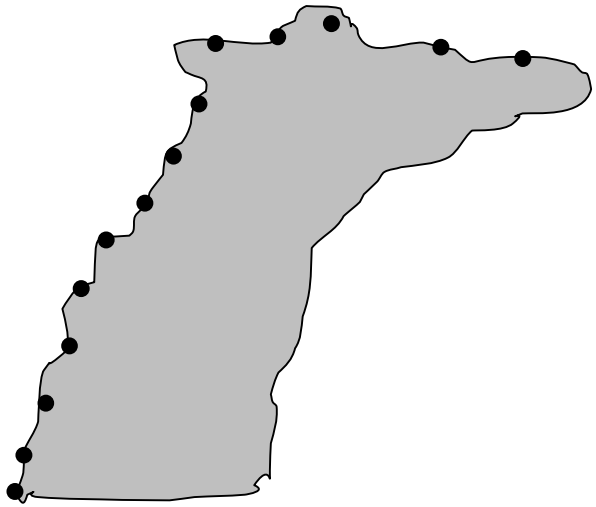


Measurement concept for T-r_e based CCN retrievals

T_{cb}, T_{ct} -> adiabatic LWC

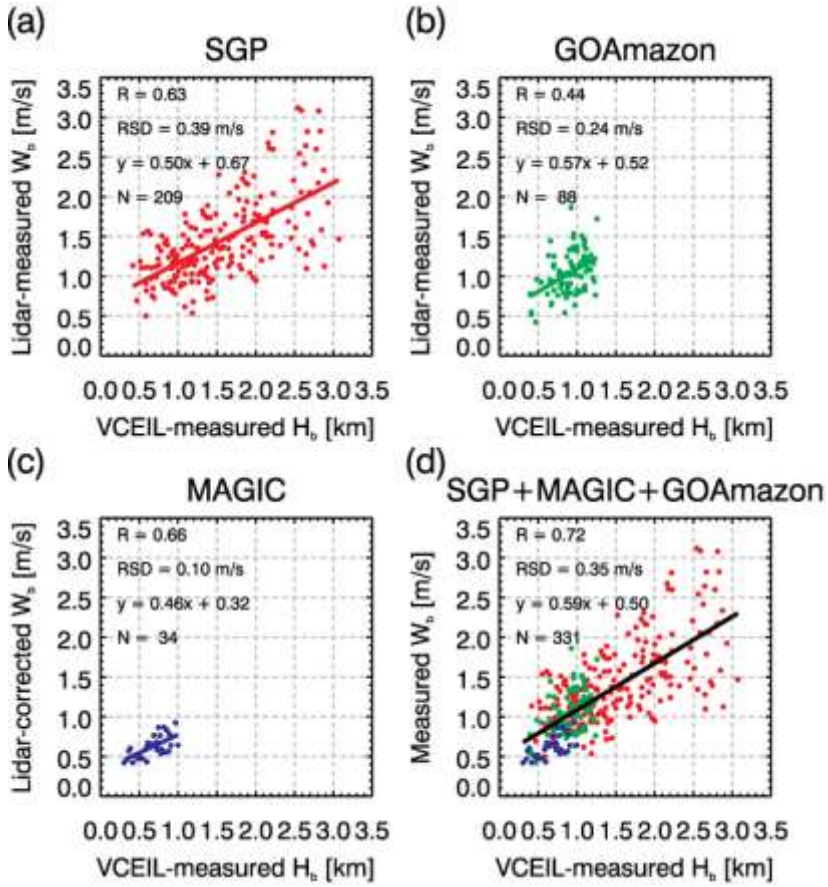
R_e -> adiabatic R_e -> adiabatic M_a } N_d



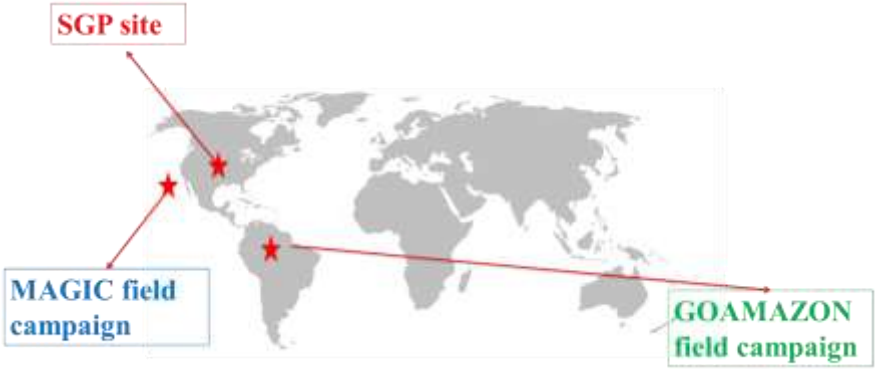


Measurement concept for T-r_e based CCN retrievals

Satellite retrieval of W_b



$$W_{max} = 0.94H_b + 0.49 \quad \text{[m/s]}$$
$$W_b = 0.59H_b + 0.50 \quad \text{[m/s]}$$

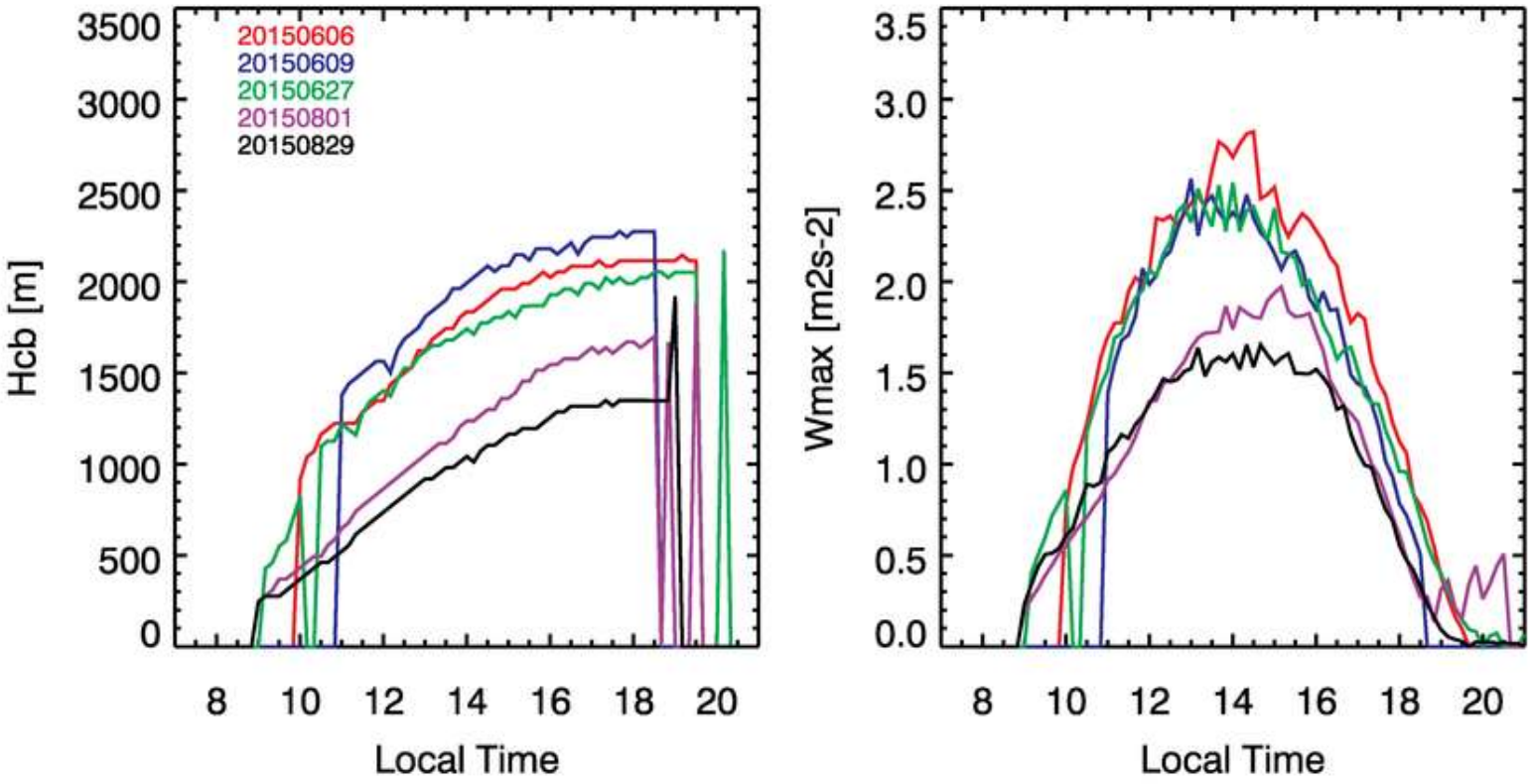


Zheng and Rosenfeld , GRL, 2015

LES simulations

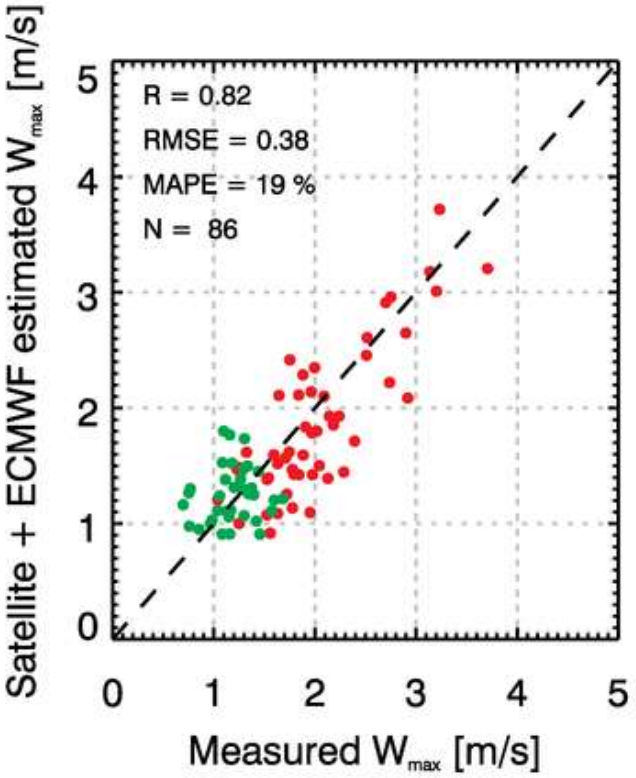
Large Eddy Simulation (LES):

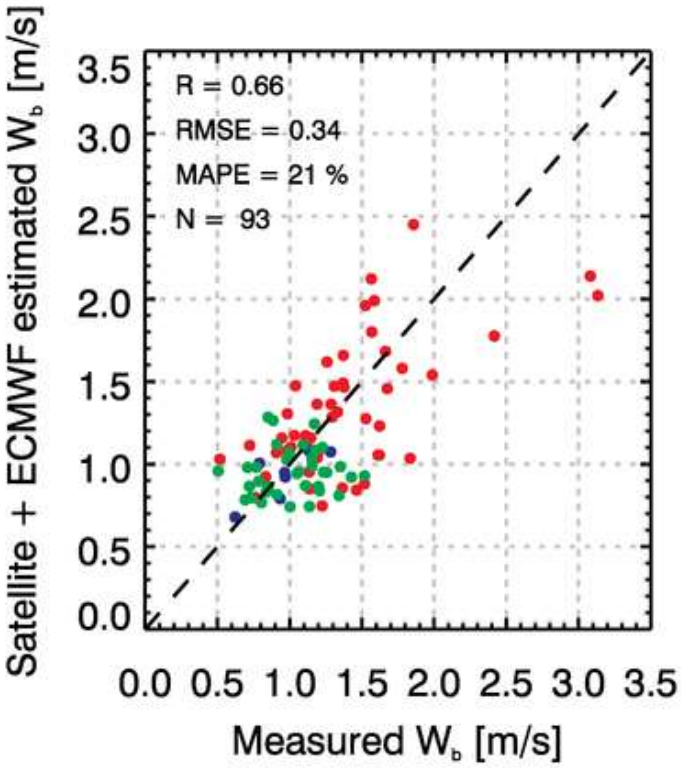
- Resolution: 100m
- Region: Southern Great Plains
- Time: 6~24 hrs (local time) for five dates



Validation against ground-based Doppler Radar/lidar

$$W_{max} = 0.94H_b + 0.49 \quad \text{[m/s]}$$
$$W_b = 0.59H_b + 0.50 \quad \text{[m/s]}$$





Red: SGP
Blue: MAGIC
Green: GOAmazon

Zheng and Rosenfeld , 2015

The retrieval concept

$$S_{max} = C W_b^{3/4} N_d^{-1/2}$$

S_{max}: maximum super saturation

W_b: cloud base updrafts

$N_{d:}$ adiabatic cloud droplets number concentration

Pinsky et al., 2012

The retrieval concept

$$s_{\max} = C W_b^{3/4} N_d^{-1/2}$$

S_{max}: maximum super saturation

W_b: cloud base updrafts

$N_{d:}$ adiabatic cloud droplets number concentration

Pinsky et al., 2012

The retrieval concept

$$S_{max} = C W_b^{3/4} N_d^{-1/2}$$

✓ ✓ ✓

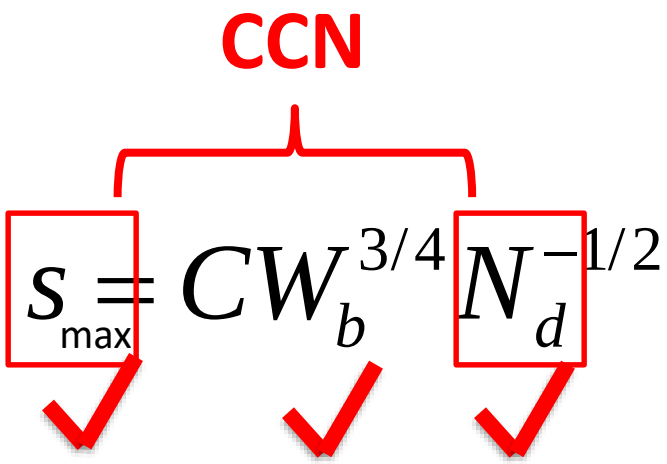
S_{max}: maximum super saturation

W_b: cloud base updrafts

$N_{d:}$ adiabatic cloud droplets number concentration

Pinsky et al., 2012

The retrieval concept



S_{max}: maximum super saturation

W_b: cloud base updrafts

$N_{d:}$ adiabatic cloud droplets number concentration

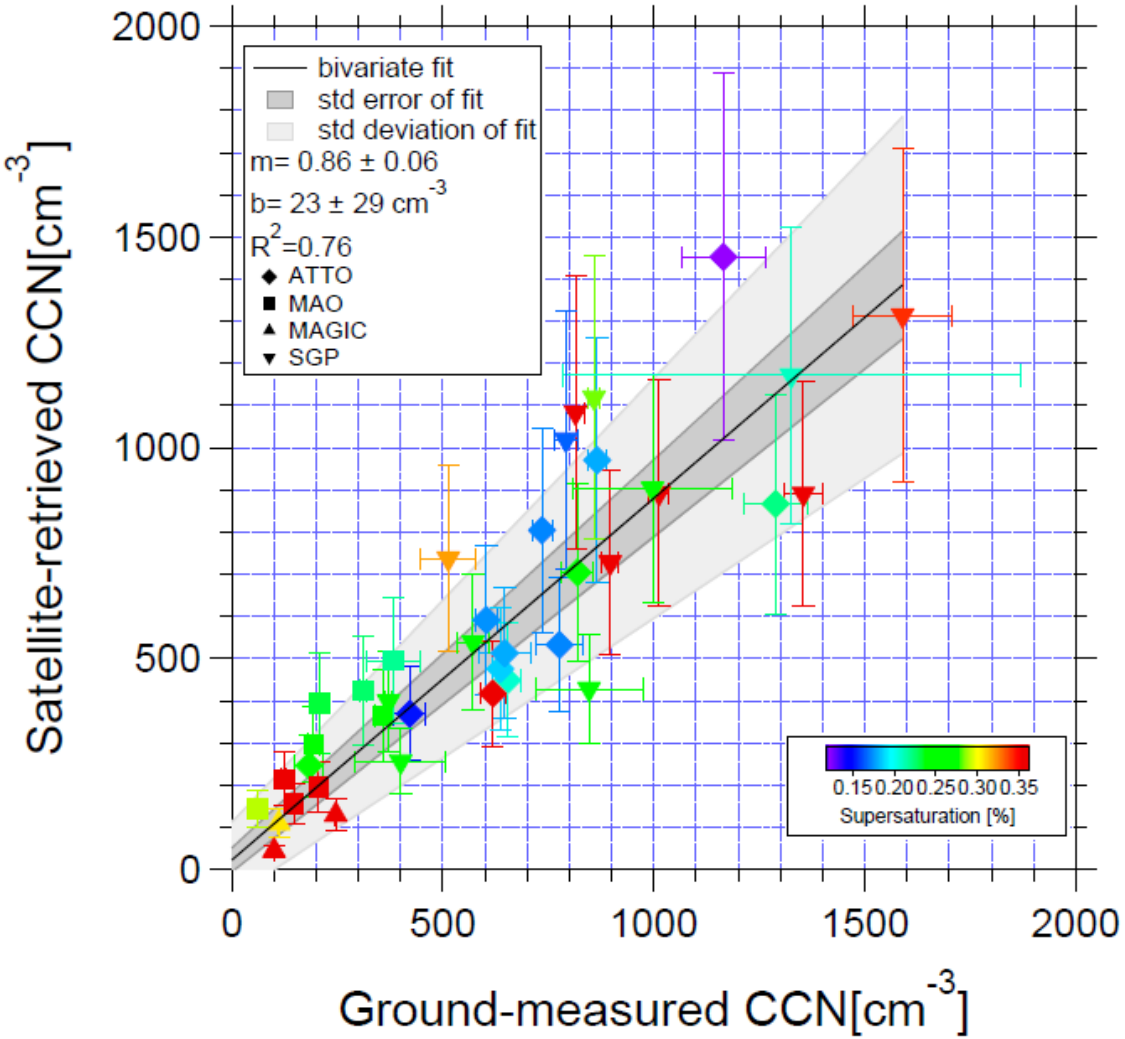
Pinsky et al., 2012

Satellite retrieval of cloud condensation nuclei concentrations by using clouds as CCN chambers

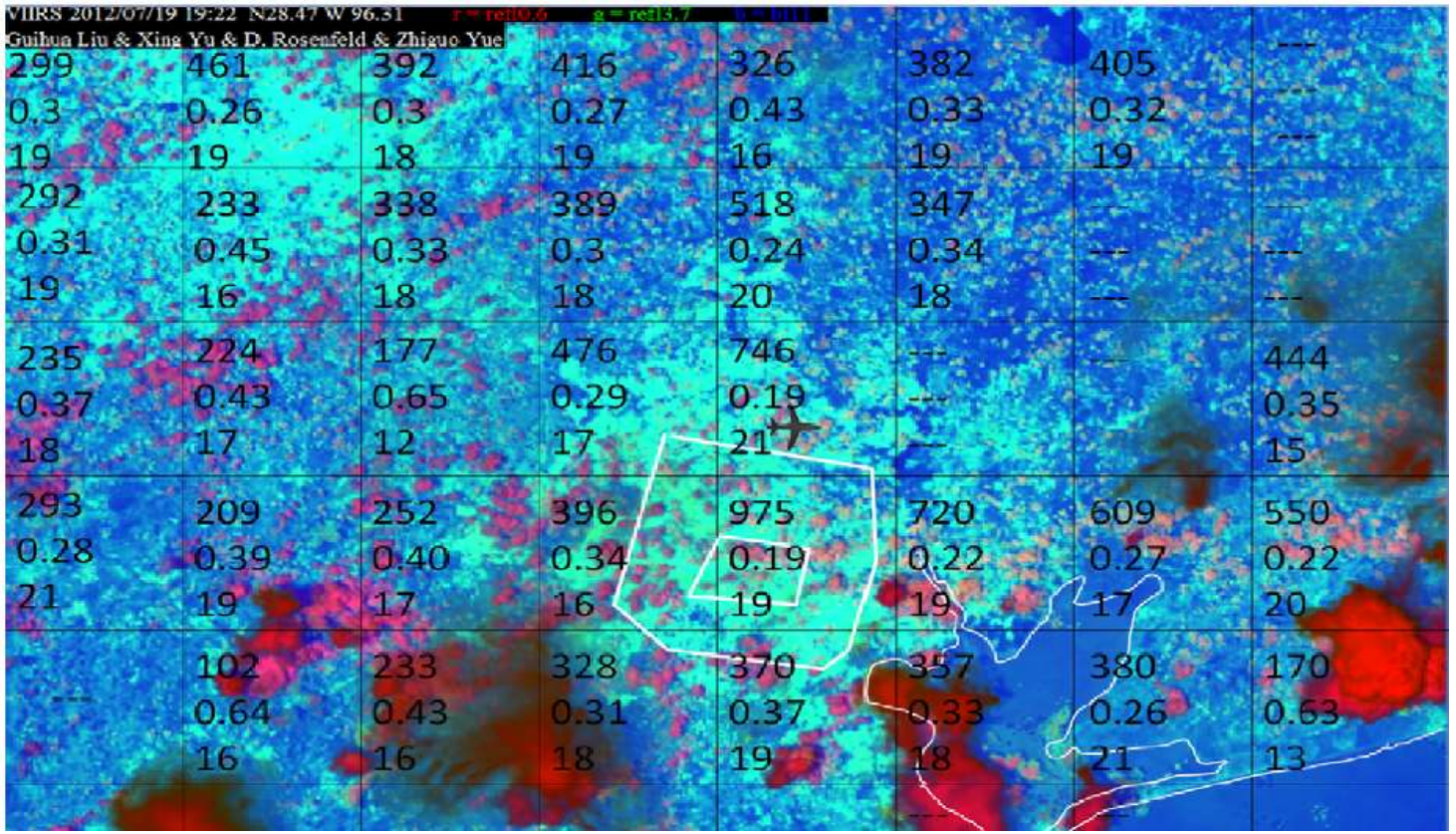
Daniel Rosenfeld[a,1], Youtong Zheng[b,c,d], Eyal Hashimshoni[a], Mira L. Pöhlker[e,f], Anne Jefferson[g], Christopher Pöhlker[e], Xing Yu[h], Yannian Zhu[d,h], Guihua Liu[h], Zhiguo Yue[h], Baruch Fischman[a], Zhanqing Li[b,c,d], David Giguzin[a], Tom Goren[a], Paulo Artaxo[i], Henrique M. J. Barbosa[i], Ulrich Pöschl[e,f], and Meinrat O. Andreae[e]

PNAS PNAS PNAS

COLLOQUIUM PAPER



Application to Houston region



The numbers in each area are, top: CCN (cm^{-3}); middle: *S* (%), bottom: cloud base temperature (°C). Unstable clean tropical air mass flows northward (upward in the image) from the Gulf of Mexico. The Houston urban effect is clearly visible by more than tripling the CCN concentrations over Houston

D Rosenfeld, YZheng et al., 2016

Summary

1. Aerosols, which serve as CCN, can affect cloud properties, which alter the heating gradients, convections and circulations, thus affecting the hydrological cycle of the monsoon climate.
2. Measuring cloud-aerosol interactions requires disentangling CCN from updraft effects, both of which were not measurable until very recently.
3. Existing satellite data is an under-exploited resource, which can still provide new fundamental insights.
4. **More investigations** (extensive validations and modeling study) are needed before the algorithms can be applied operationally.

THANK YOU!