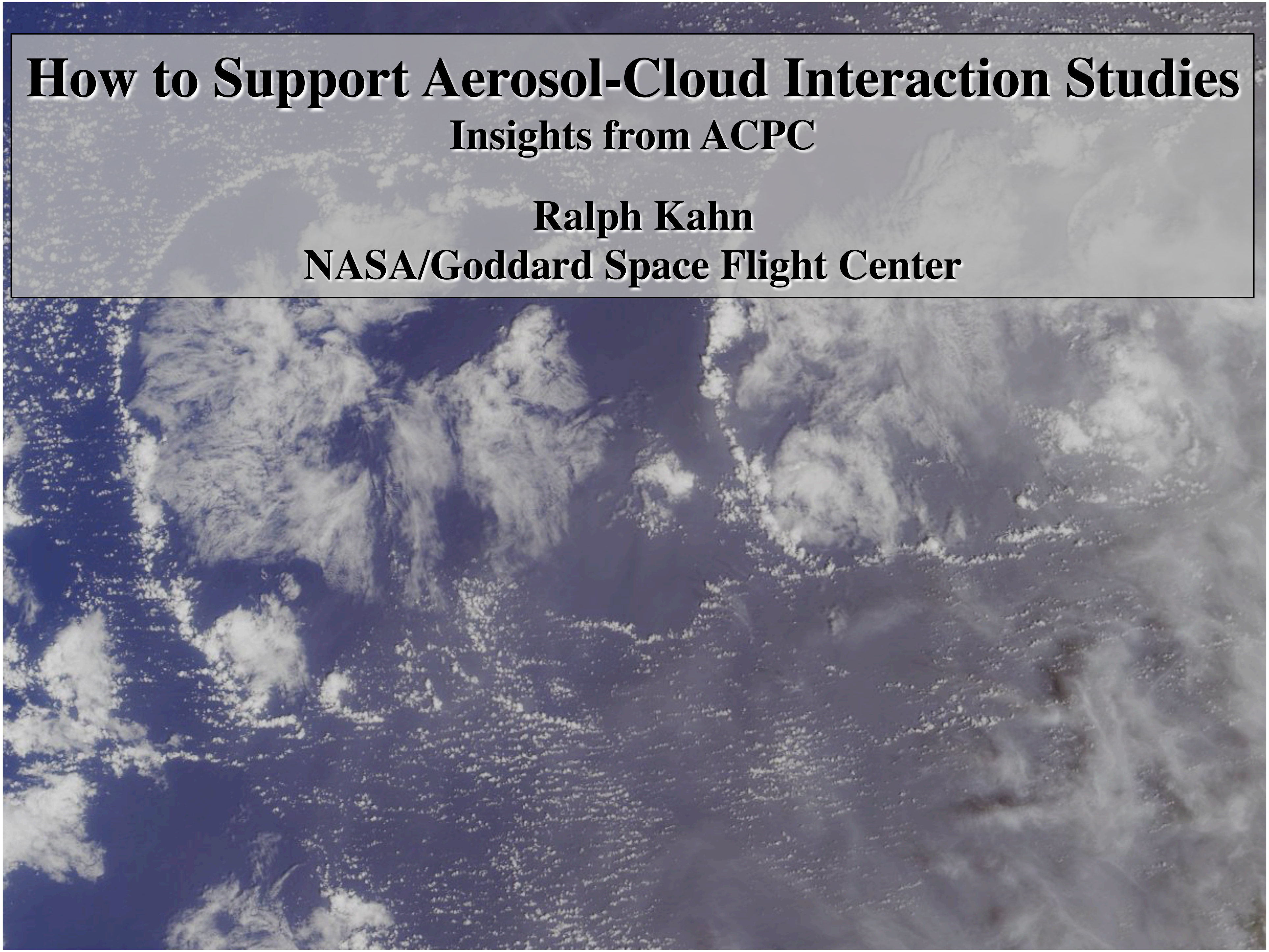


How to Support Aerosol-Cloud Interaction Studies

Insights from ACPC

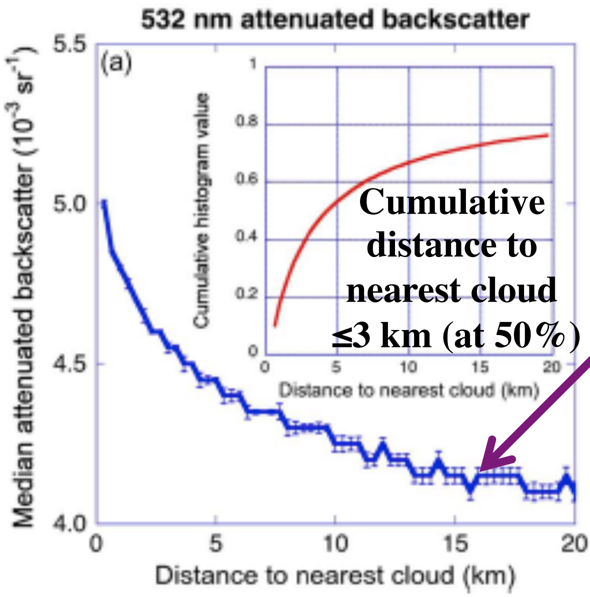
Ralph Kahn
NASA/Goddard Space Flight Center

Satellite Aerosol Retrieval *Limitations*

- Difficult to retrieve aerosols that are ***collocated with cloud***
  - -- ***Cloud-scattered light*** & cloud "contamination" can affect near-cloud aerosol retrievals
  - -- Aerosols can also affect the ***retrieval of cloud properties***
- Rarely can detect aerosol in ***droplet-formation region*** below clouds – need cloud & aerosol ***vertical distributions***
- Aerosols smaller than about ***0.1 micron diameter*** look like atmospheric gas molecules – must ***infer CCN*** number
- Must deduce aerosol ***hygroscopicity*** (composition) from qualitative "type" – size, shape, and SSA constraints
- Environmental (Meteorological) Coupling – Factors can ***co-vary***
  - -- LWP can decrease as aerosol number concentration increases (also depends on atm. stability)
- Many aerosol-cloud interaction time & spatial scales do not match ***satellite sampling*** (horizontal & vertical res., snapshots, coverage)

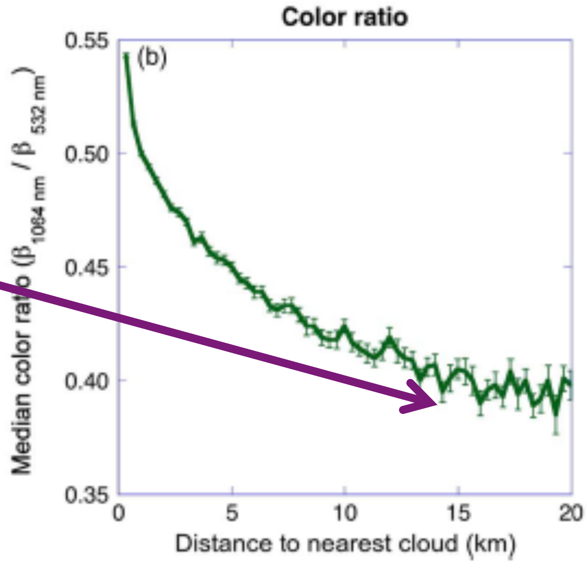
Satellites are fairly blunt instruments for studying aerosol-cloud interactions!!

Aerosol Properties Near Cloud



Cumulative distance to nearest cloud ≤3 km (at 50%)

Backscatter & color ratio enhanced to ~15 km

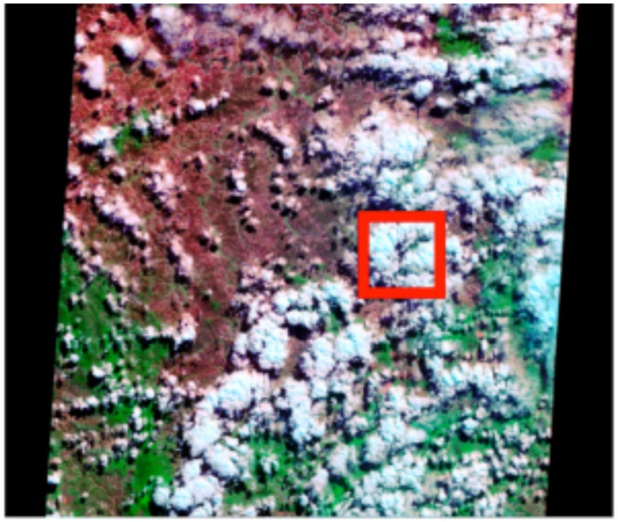


Global data

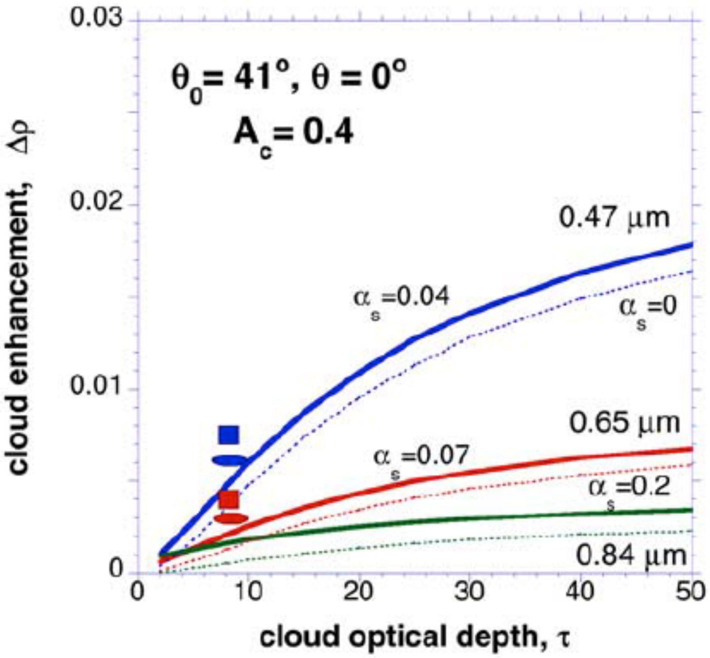
Sept. – Oct. 2008

Varnai & Marshak, GRL 2011

3-D Light Scattering Effects on Remote Sensing



ASTER false-color image
Brazil, 09 August, 2001



Simulated cloud → Rayleigh scattered light enhancement vs. τ_c

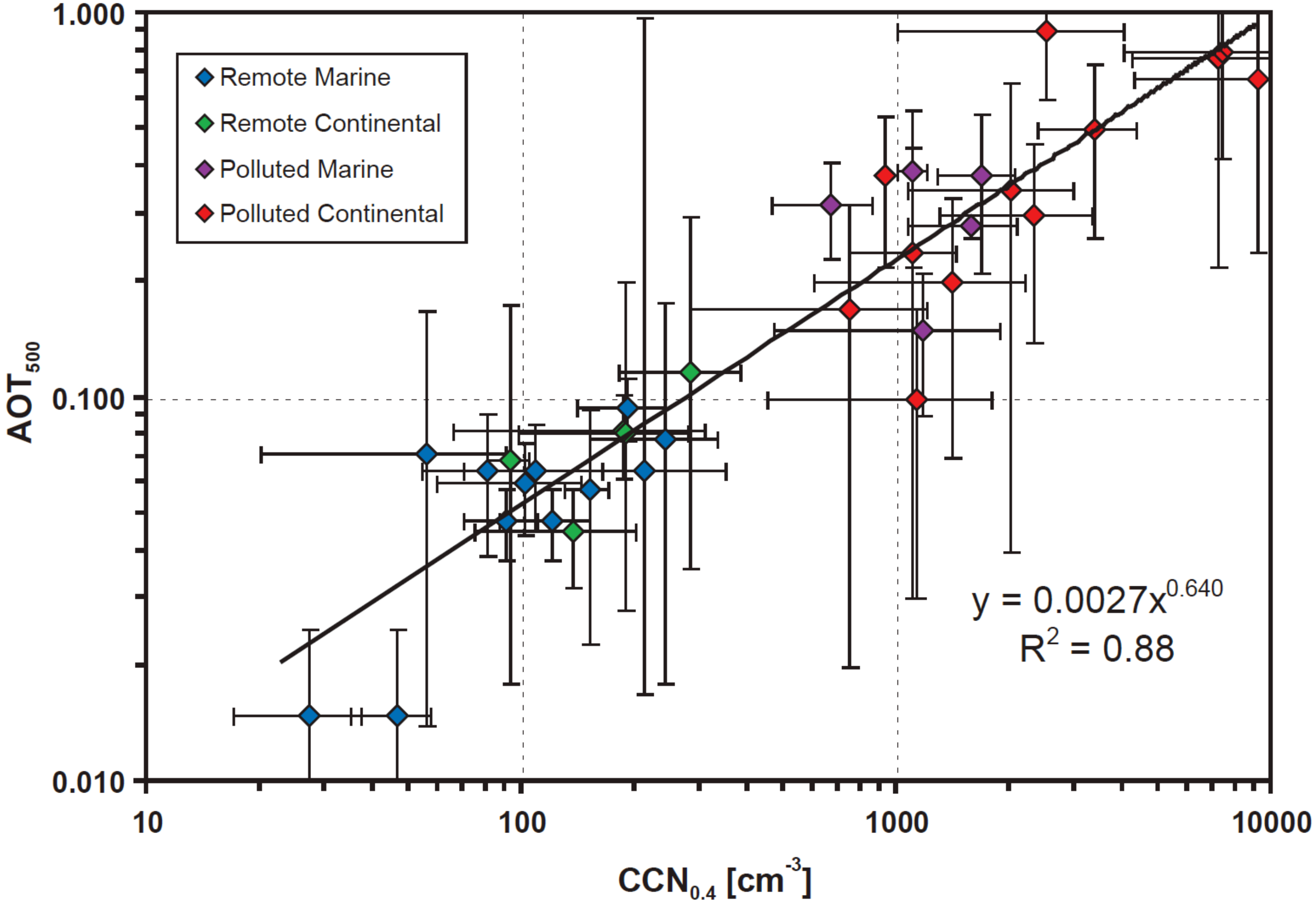
- Using the image geometry
- For three wavelengths
- For different surf. reflectances (α_s)

Refl. in "clear" pixels used for MODIS AOD Retrievals (***squares***)

Refl. in pixels 3 km away from cloud (***ovals***) [*Wen et al*. 2007]

Marshak et al., JGR 2008

Correlation Between AOD from Space and CCN in Remote & Polluted Regions



Andreae ACP 2009

Using ***AI* (= τ_a x *ANG*)** to Estimate ***CCN***

Kapustin, Clarke, et al., JGR 2006

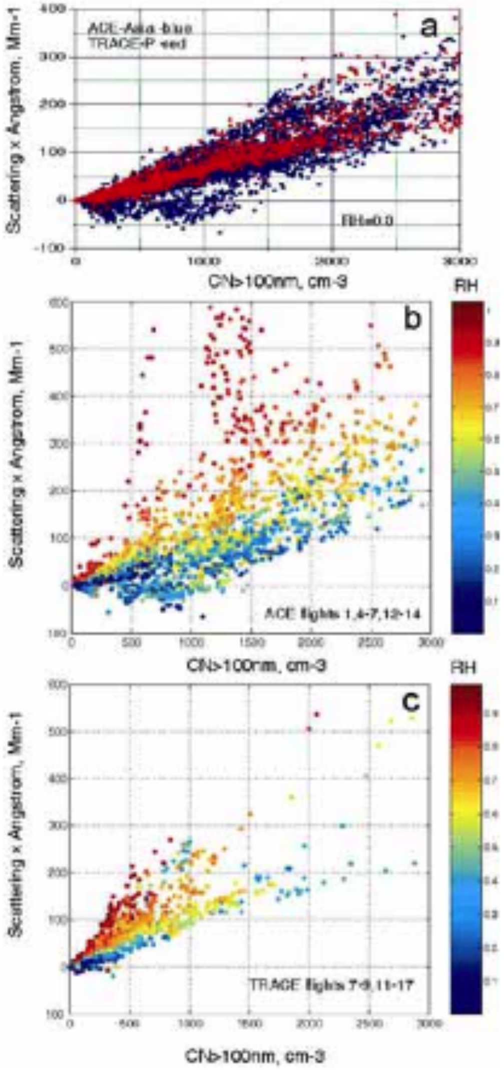
- Test Idea: Smaller particles more likely to become *CCN; **Ang*** is a smaller quantity for larger particles
- ACE-Asia, Trace-P *in situ* **field data** – *CCN* proxy
- **AI does not work quantitatively in general**, but can **if the data are stratified** by:

-- ***RH*** in the aerosol layer(s) observed by satellites
-- **Aerosol Type** (hygroscopicity; pollution, BB, dust)
-- **Aerosol Size** (*Ang* is not unique for bi-modal dist.)

Practically, in addition to τ_a and *Ang*, this requires:

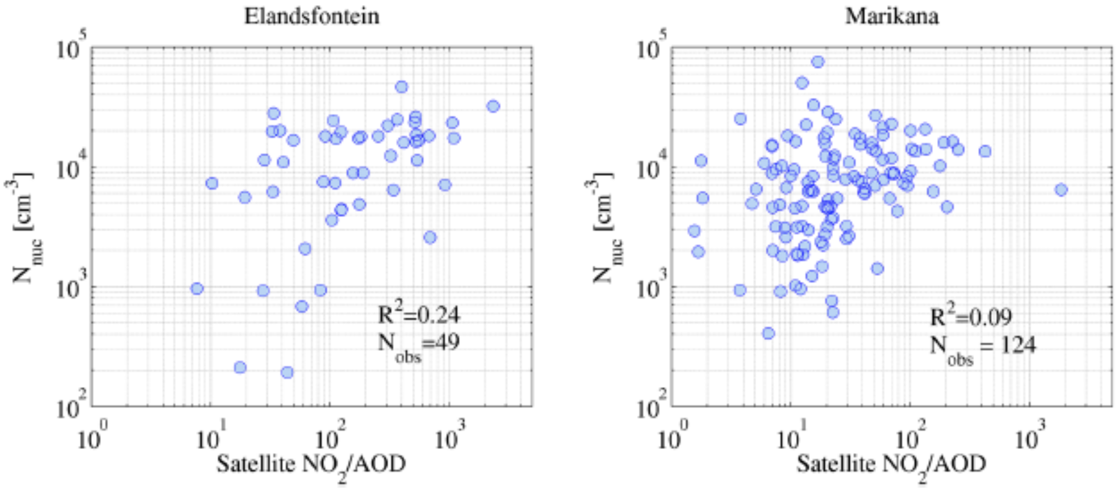
-- Vertical **humidity structure**
-- **Height-resolved** aerosol **type**
-- **Height-resolved size** dist.
[extrapolated to small sizes(?)]

This study includes enough detail to assess *AI* ~ N_a *and* *AI* ~ *CCN*



AI vs. *in situ CCN* proxy
(a) all ACE (blue) & Trace-P, **dry**
(b) ACE - OPC-only, amb. *RH*
(c) TP - OPC-only, amb. *RH*

Satellite-Derived Proxies for CCN



Satellite
NO_2/AOD proxy
vs.
in situ nucleation
particle concentration

Sundstrom et al., ACP 2015

- OMI NO_2 Column
- OMI SO_2 Column (mainly near-surface)
- *OMI* UVB (310 nm) Surface noontime irradiance to form secondary sulfate
- *MODIS* AOD [*attempt* to represent the condensation ***sink*** for nucleation particles]

These are quantities we can retrieve from satellites,
though they are not necessarily the ones we really want

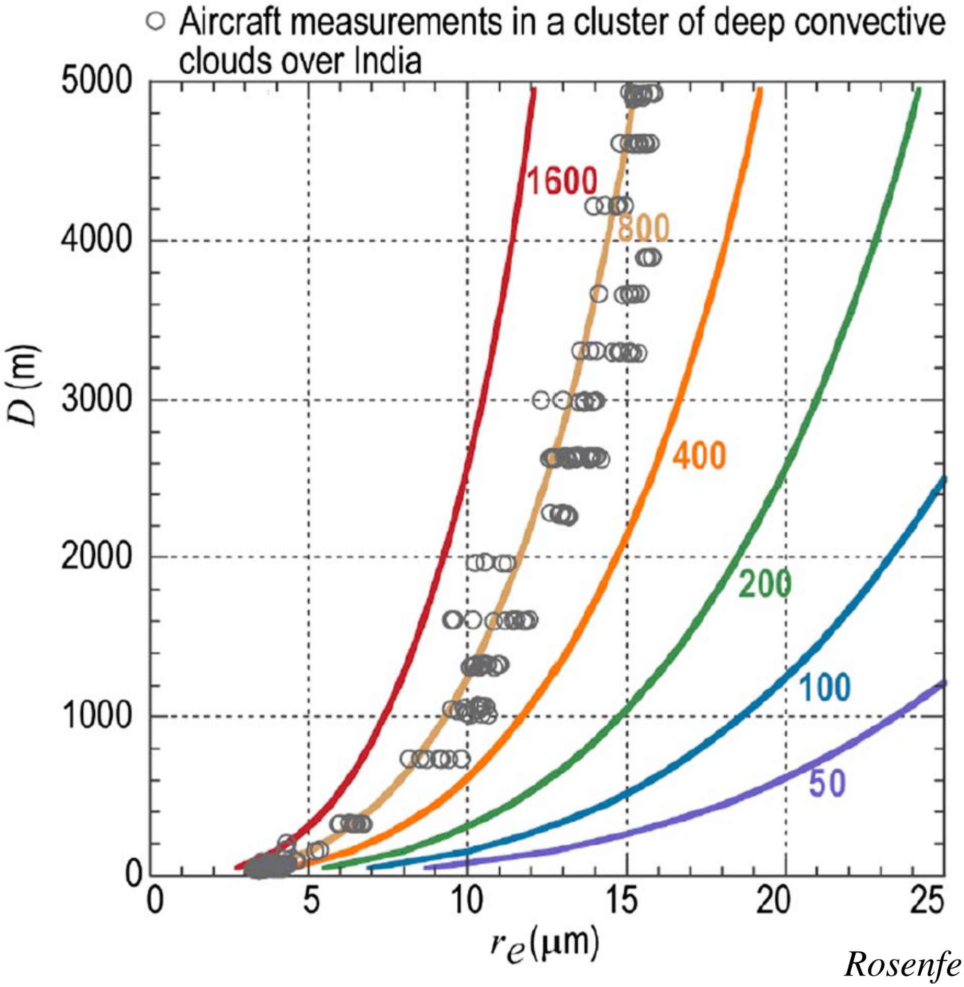
→ Ambiguity in vertical distributions of formation areas and sinks
→ Lack of information about diurnal variation from satellites
→ The 2-D spatial distribution of proxies compares ~ better with *in situ* observations for S. Africa, except where gas column concentrations are low

Satellite Capabilities

- *Polar orbiting imagers* provide ***frequent, global coverage***
- *Geostationary platforms* offer ***high temporal resolution***
- *Multi-angle imagers* offer ***aerosol plume height & cloud-top mapping***
- *Passive instruments* can retrieve total-column ***aerosol amount (AOD)***
- *Active instruments* determine aerosol & some cloud ***vertical structure***
- *UV imagers* and *active sensors can* retrieve ***aerosol above cloud***
- *Multi-angle*, *spectral*, *polarized* imagers obtain ***some aerosol type info.***
- *Active sensors* can obtain ***some aerosol type info., day & night***
- Satellite trace-gas retrievals offer ***clues about aerosol type***
- *Vis-IR imagers* can retrieve ***cloud phase***, r_c, T_c, p_c, τ_c, α_c, C_f, **LWP**

Need to be creative &
Play to the strengths of what satellites offer!!

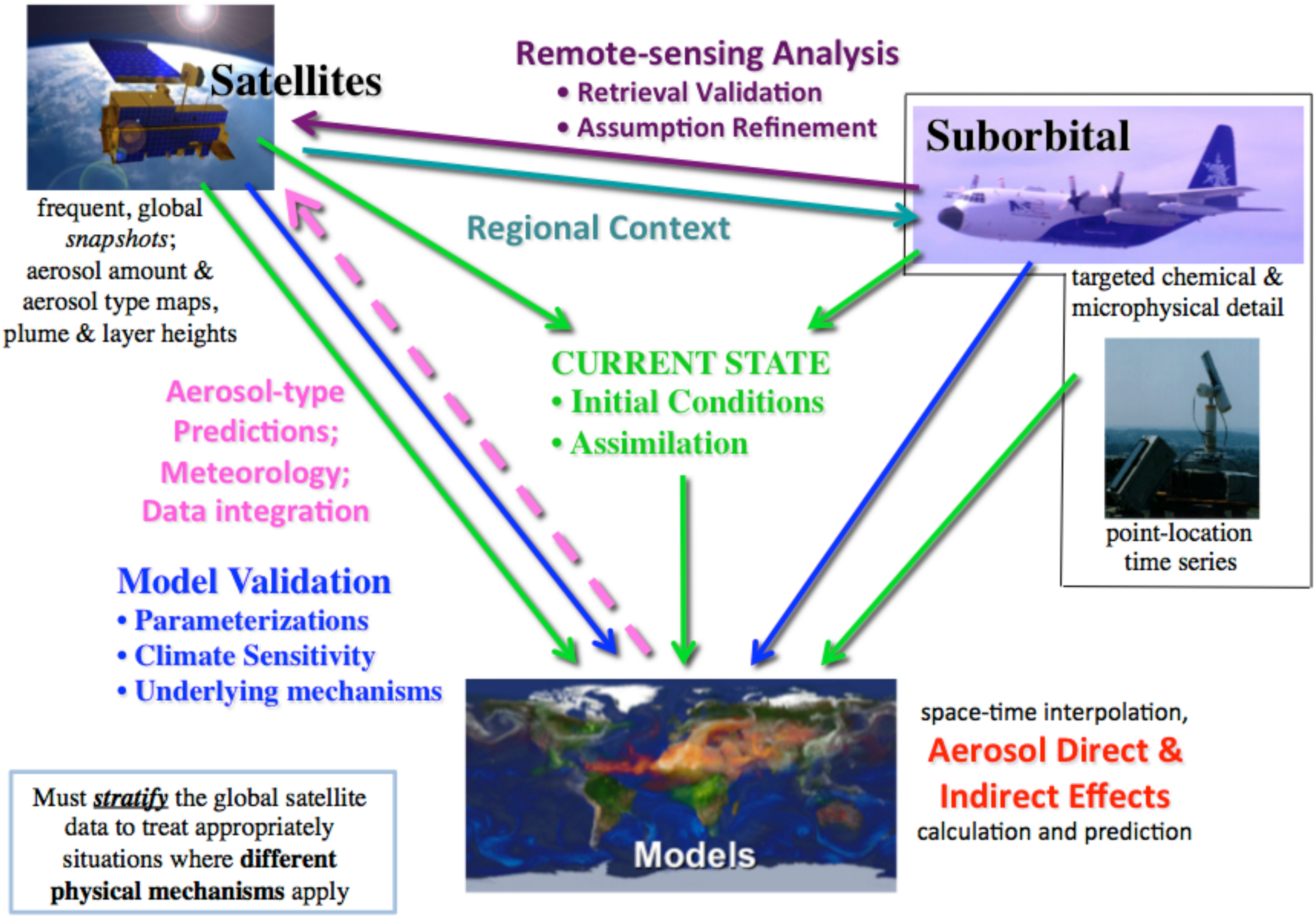
“Cloud-Chamber” Satellite CCN Retrieval



Knowing $r_e(D)$, ***n_c at cloud base*** can be deduced for an adiabatic cloud with limited entrainment

Rosenfeld et al., Rev. Geophys. 2014

Figure 9. The adiabatic effective radius as a function of height above cloud base (*D*) for clouds with various number of cloud drop concentrations at their base, for cloud base at a height of 2 km and temperature of 15°C. Actual aircraft measurements of 1 s r_e are shown for a cloud that had 610 drops cm^{-3} at its base. From



Satellites

frequent, global *snapshots*; aerosol amount & aerosol type maps, plume & layer heights

Remote-sensing Analysis

- Retrieval Validation
- Assumption Refinement

Suborbital

targeted chemical & microphysical detail

point-location time series

Regional Context

CURRENT STATE

- Initial Conditions
- Assimilation

Aerosol-type Predictions; Meteorology; Data integration

Model Validation

- Parameterizations
- Climate Sensitivity
- Underlying mechanisms

Models

space-time interpolation,
Aerosol Direct & Indirect Effects
calculation and prediction

Must ***stratify*** the global satellite data to treat appropriately situations where **different physical mechanisms** apply

Adapted from: Kahn, Survy. Geophys. 2012

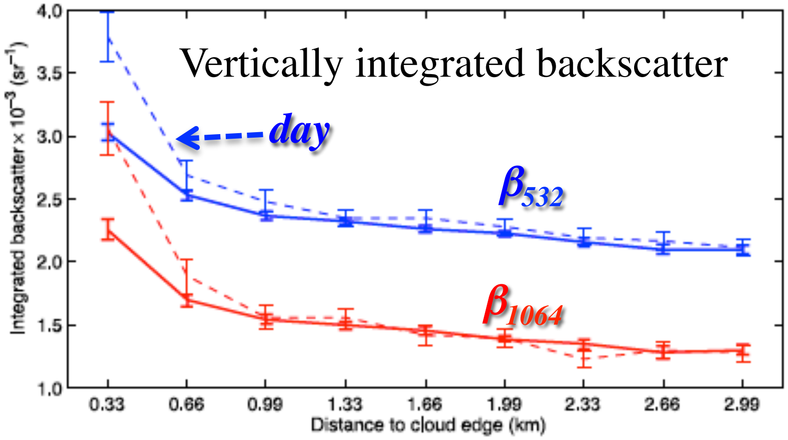
Backup Slides

For Aerosol-Cloud Interactions – Overall Satellite *Limitations*

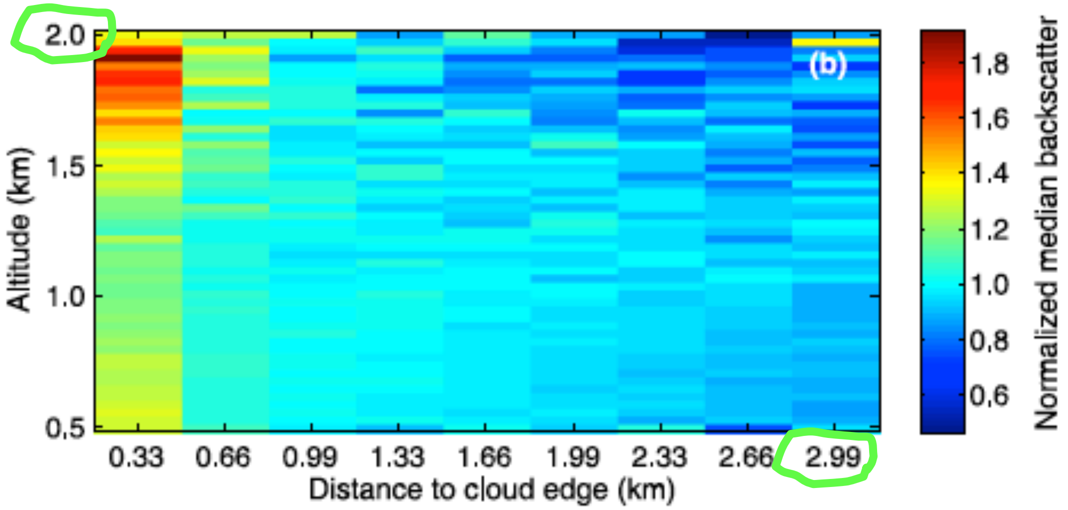
- *Polar orbiters* provide ***snapshots only***
- Difficult to probe ***cloud base***
- Typically ~100s of meters or poorer ***horizontal resolution***
- *Passive instruments (imagers)* offer little ***vertical information***
- *Active instruments (e.g., lidar)* offer little ***spatial coverage***
- Little information about aerosol ***particle microphysical properties***
- Bigger issues retrieving aerosols ***in the presence of clouds!***
- Cloud property retrievals can be aliased ***by the presence of aerosols***

Aerosol Properties Near Cloud

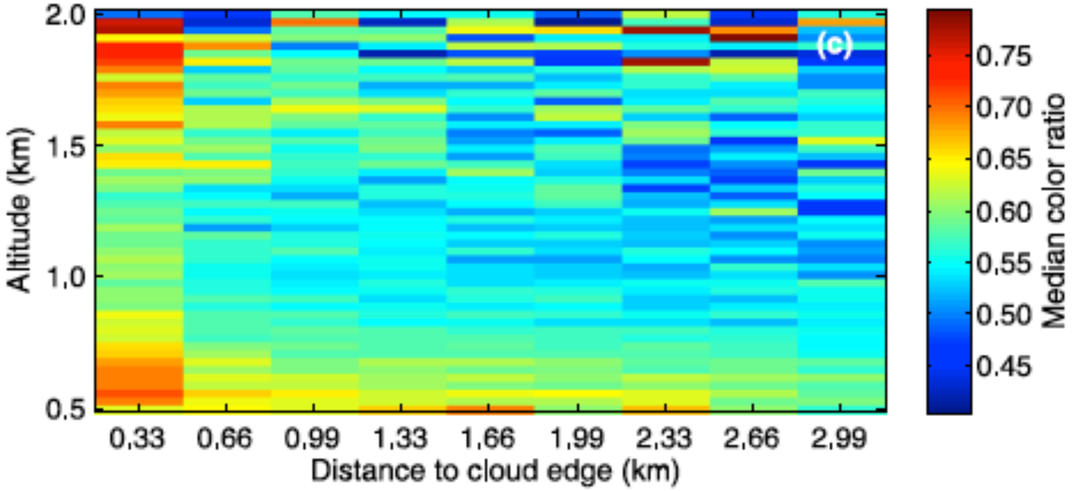
CALIPSO nighttime 532 nm backscatter, normalized over 2.99 km. ***Enhanced aerosol opacity*** near cloud edge, especially at ***cloud top and bottom***.



CALIPSO median nighttime 1064/532 nm color ratio. ***Larger particles*** near cloud edge, especially at cloud top and bottom.



Detrainment at cloud top??
Hygroscopic growth at cloud bottom??
Collision Coalescence (R↑; N, σ↓)?



Tackett & Di Girolamo GRL 2009