Estimation of Cloud Droplet Number Concentration of Shallow Trade-Wind Cumulus using Synergistic Airborne Remote Sensing

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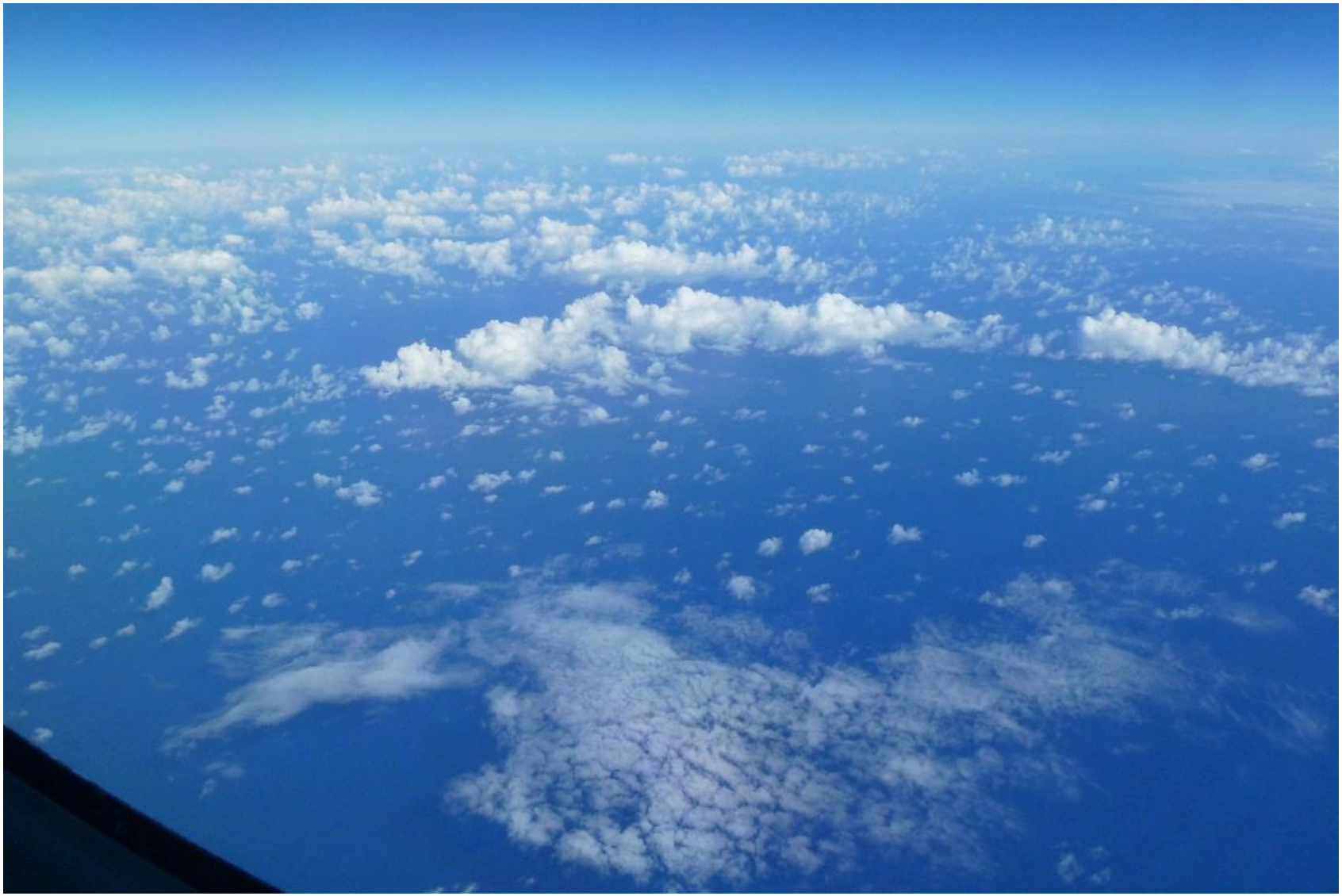
AMS, Vancouver, 12th July 2018

Trade-wind cumulus in Global Climate Models



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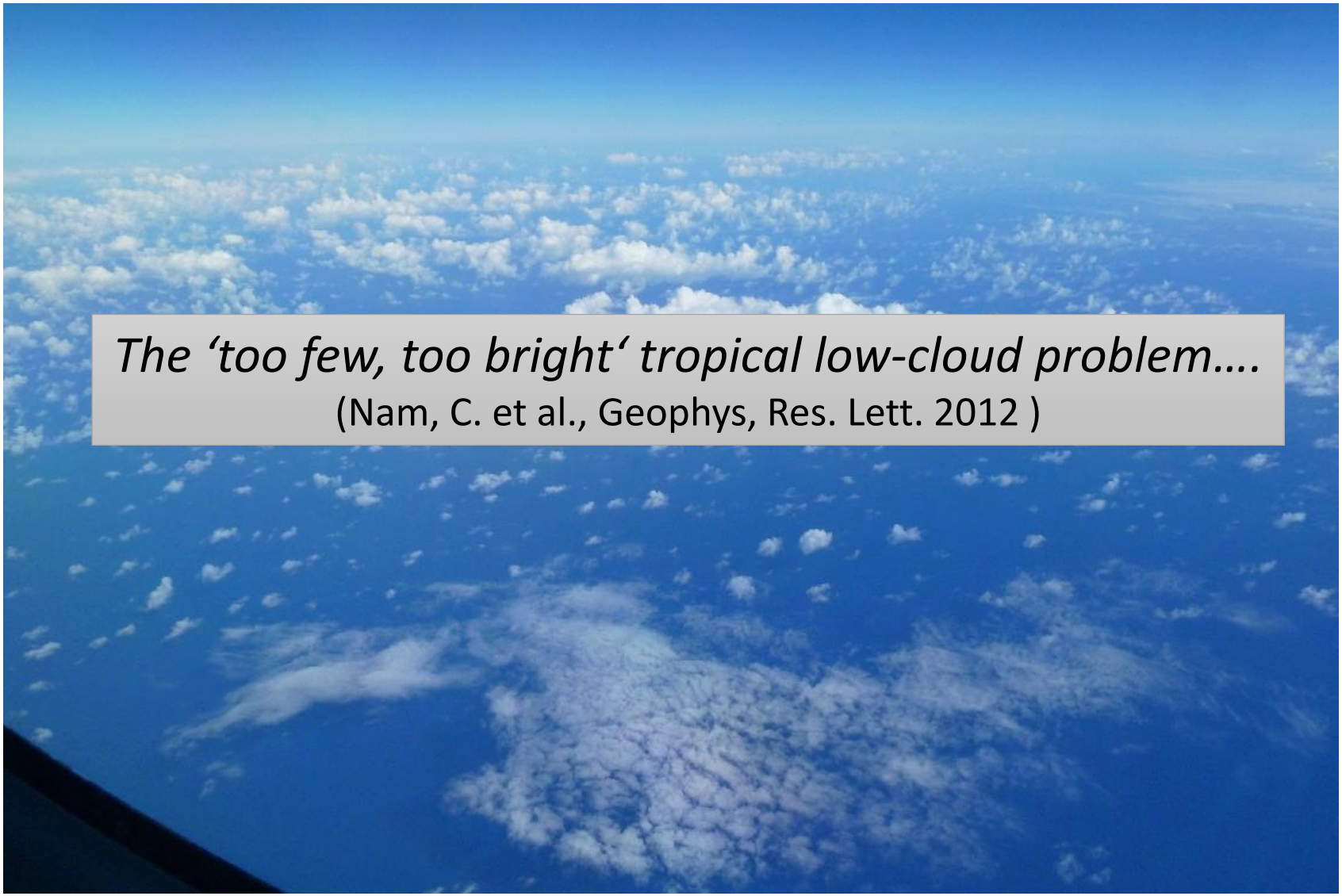

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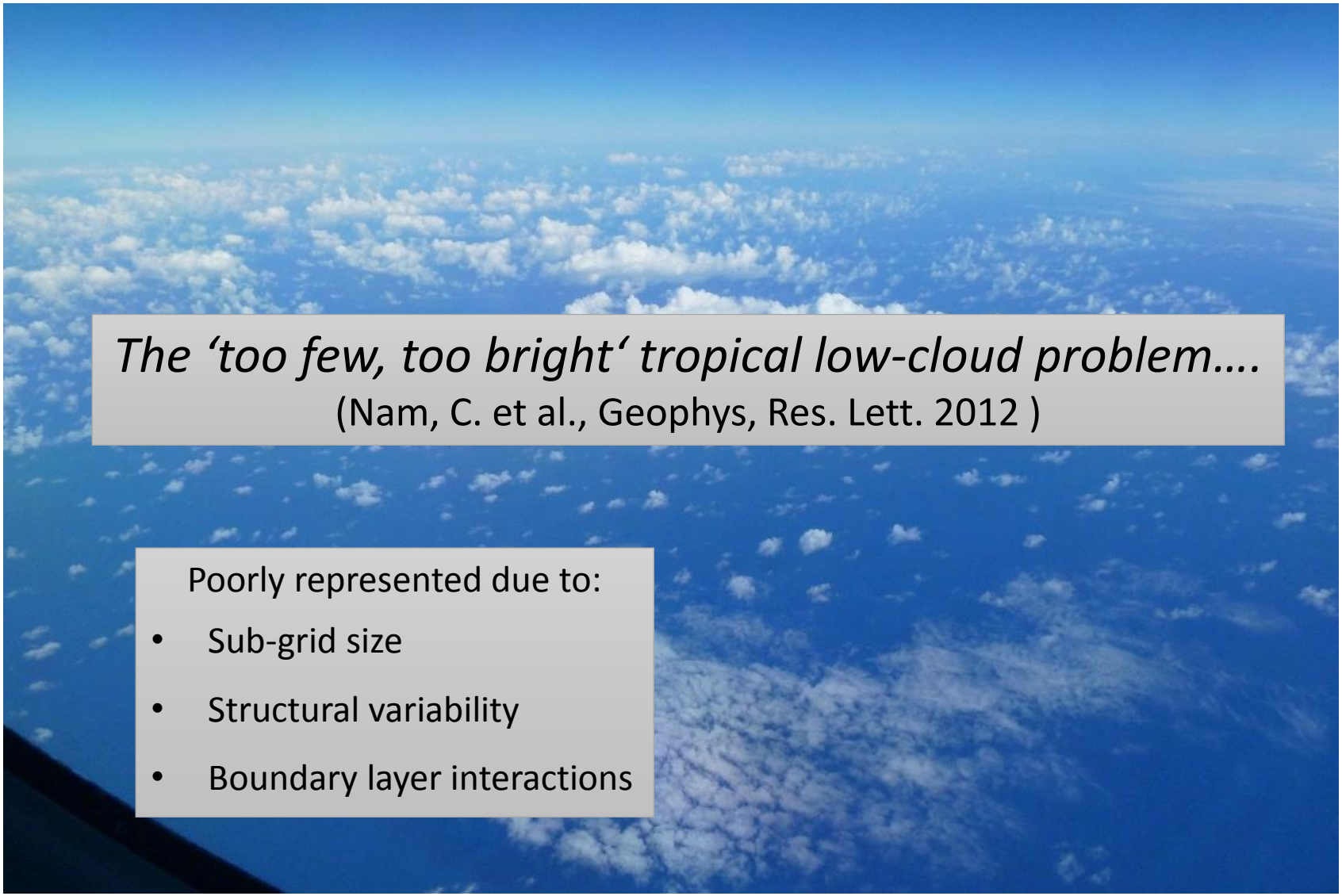
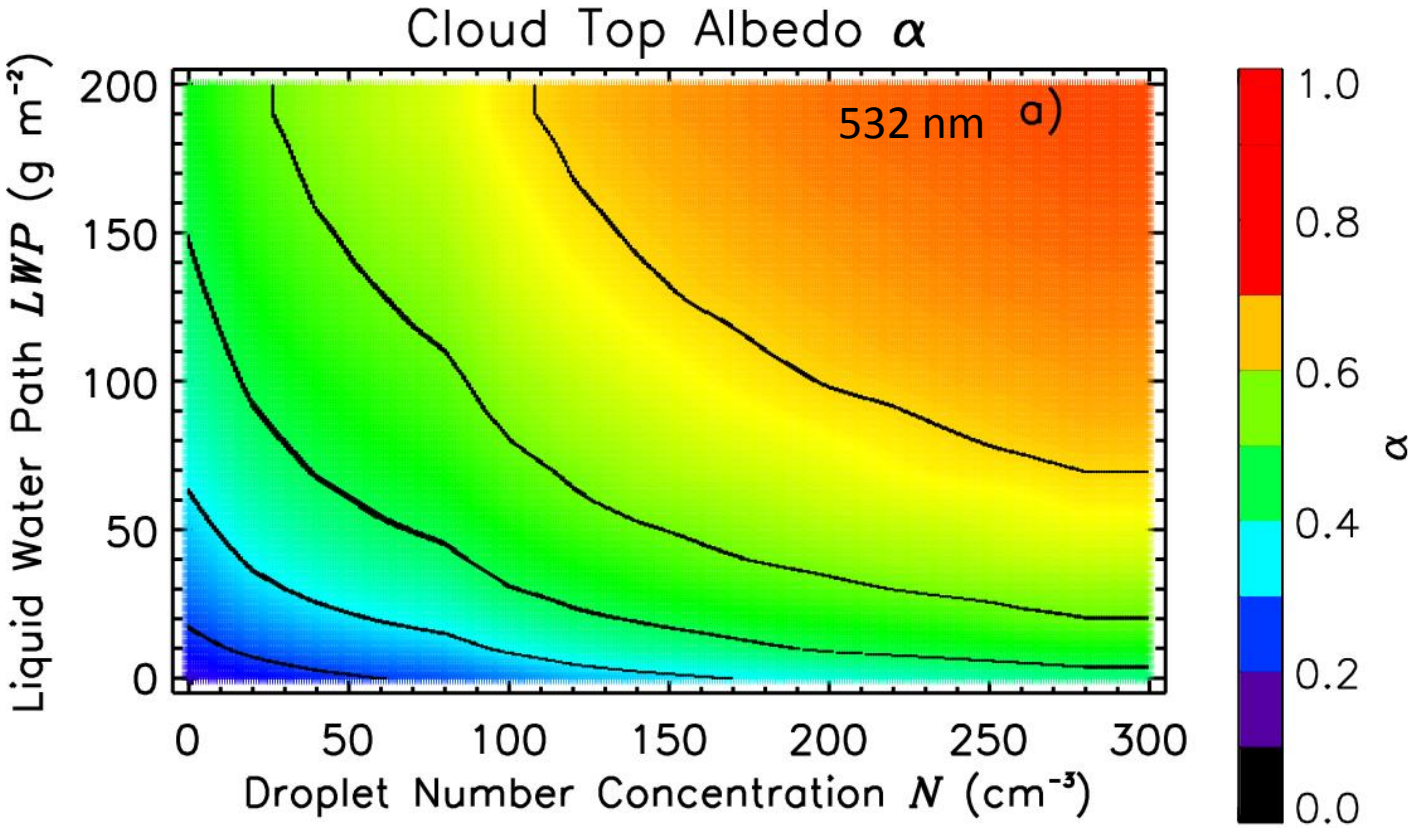


The 'too few, too bright' tropical low-cloud problem….
(Nam, C. et al., Geophys, Res. Lett. 2012)

Poorly represented due to:

- Sub-grid size
- Structural variability
- Boundary layer interactions

Sensitivity Studies



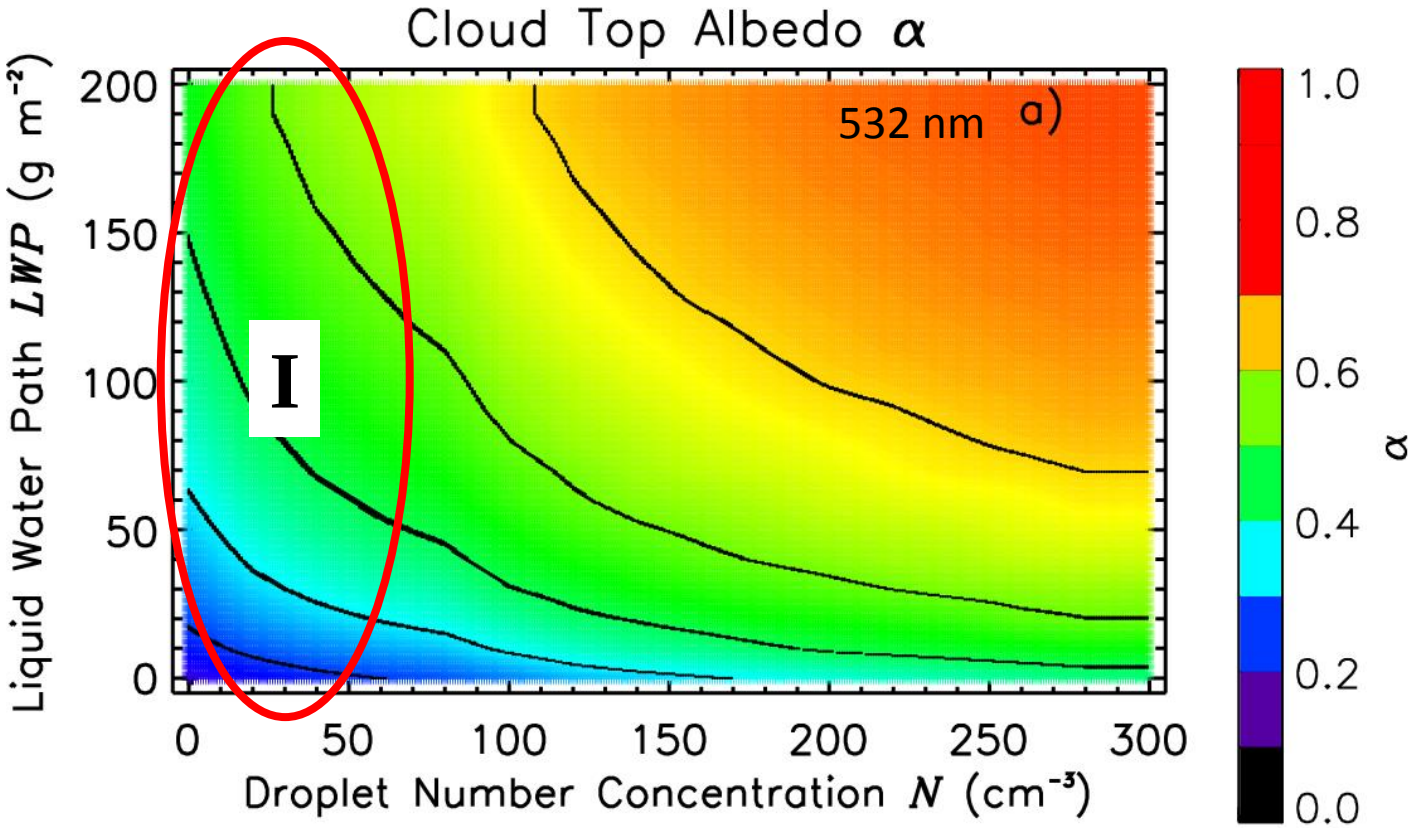
Liquid water path

$\mathcal{R}$ = f(**LWP,CDNC**, T,p,q)

Cloud top albedo / Cloud top reflectivity

Cloud droplet number concentration

Sensitivity Studies



I) CDNC driven: change of **CDNC** dominates

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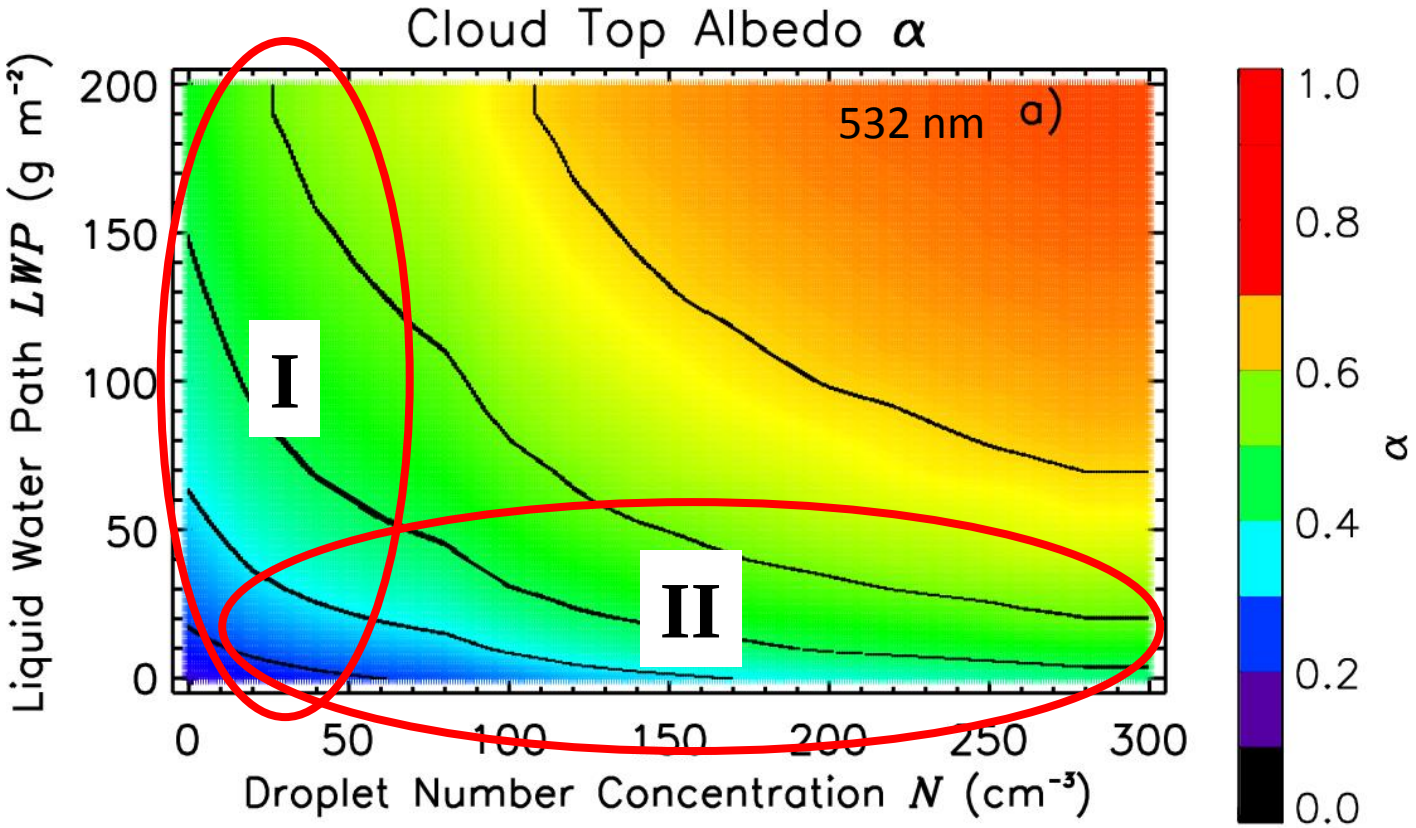
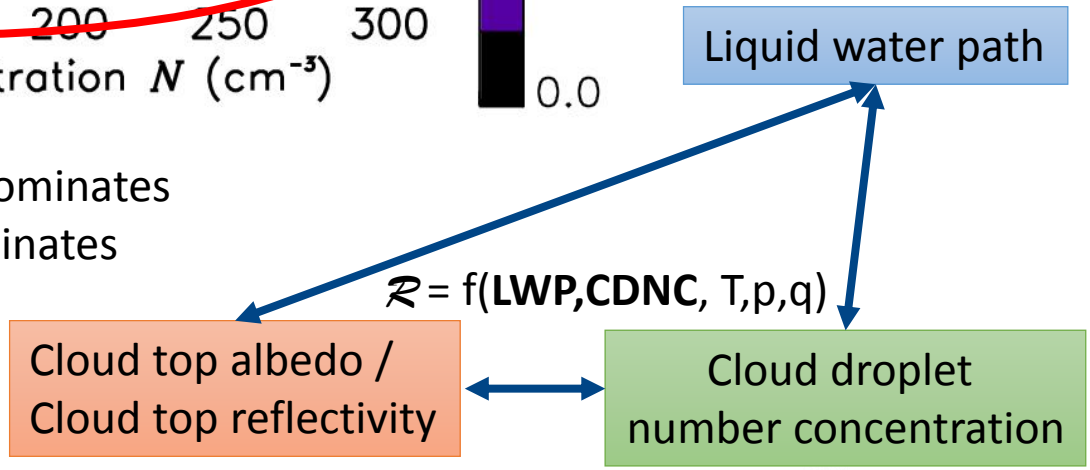
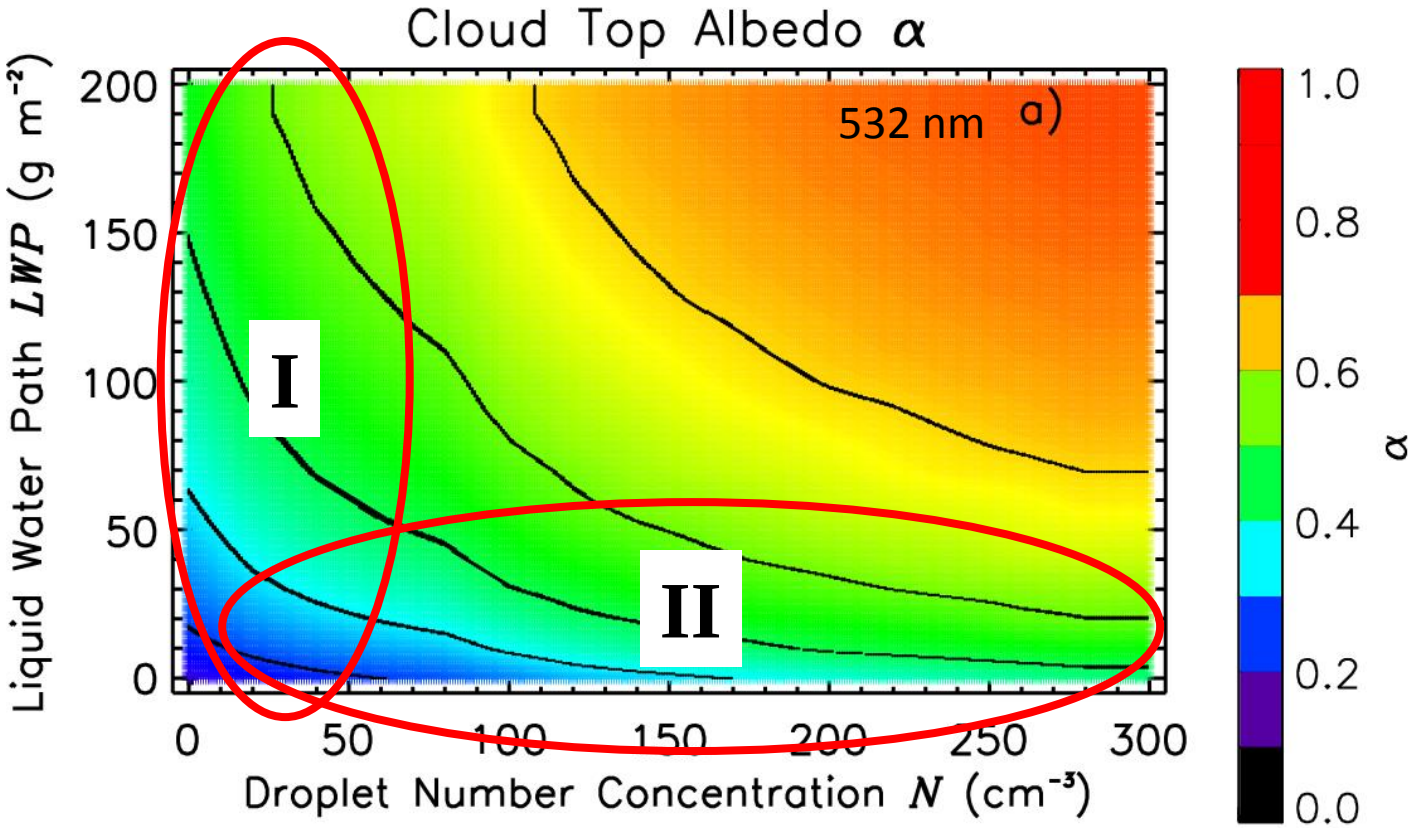


I) CDNC driven: change of **CDNC** dominates

II) LWP driven: change of **LWP** dominates



Sensitivity Studies



How to **separate** the radiative effect from varying environmental conditions?

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Cloud droplet number concentration

CDNC retrievals

Common satellite

τ and $\mathbf{r_{eff}}$ from bi-spectral retrieval (Nakajima and King, 1990)

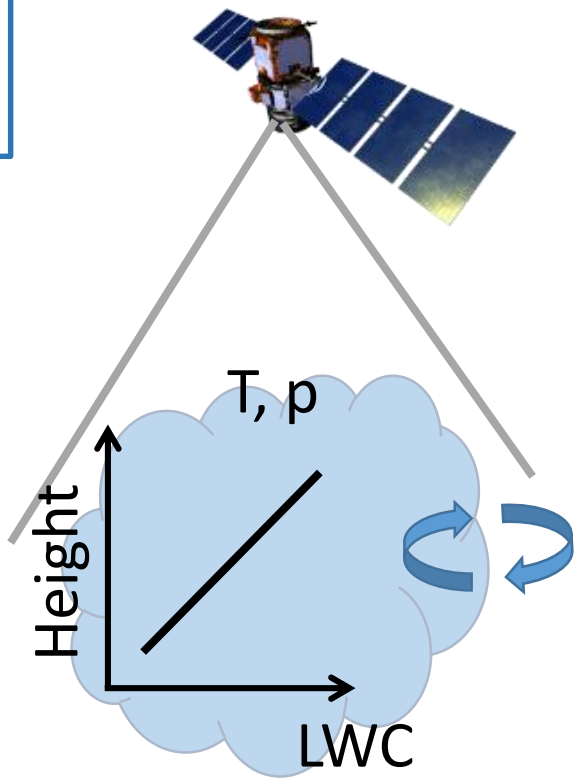
Cloud top **T** and **p**

Assumptions:

i) Adiabatic cloud profile

ii) Vertically constant CDNC

$$N_{\mathrm{d}} = \mathcal{A} \cdot \sqrt{f_{\mathrm{ad}} \cdot \gamma_{\mathrm{ad}}} \cdot \frac{\sqrt{\tau}}{\sqrt{r_{\mathrm{eff}}^{5}}}$$



- Brenguier, J.-L. et al., 2000
- Grosvenor, D. P. et al., 2018
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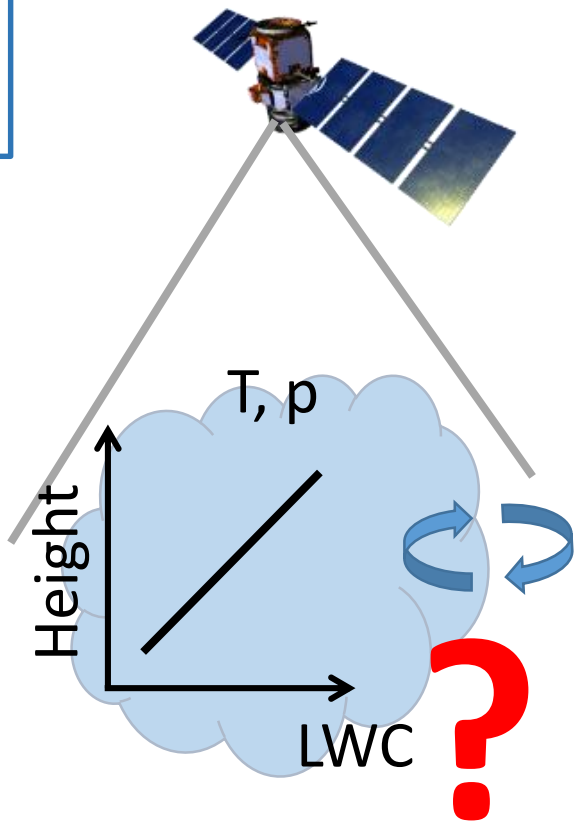
Shortcomings:

- Large scale averaging (T and LWP)
- Sub-pixel heterogeneity
- Precipitation ?



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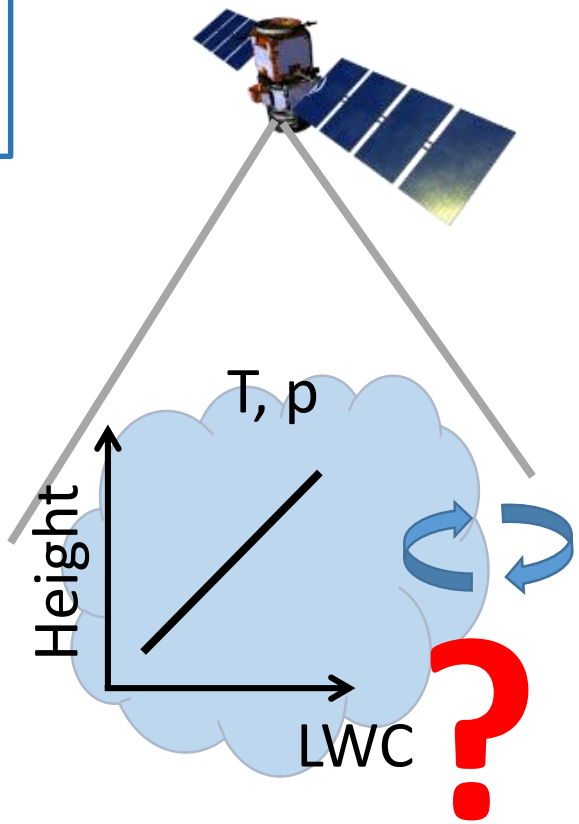


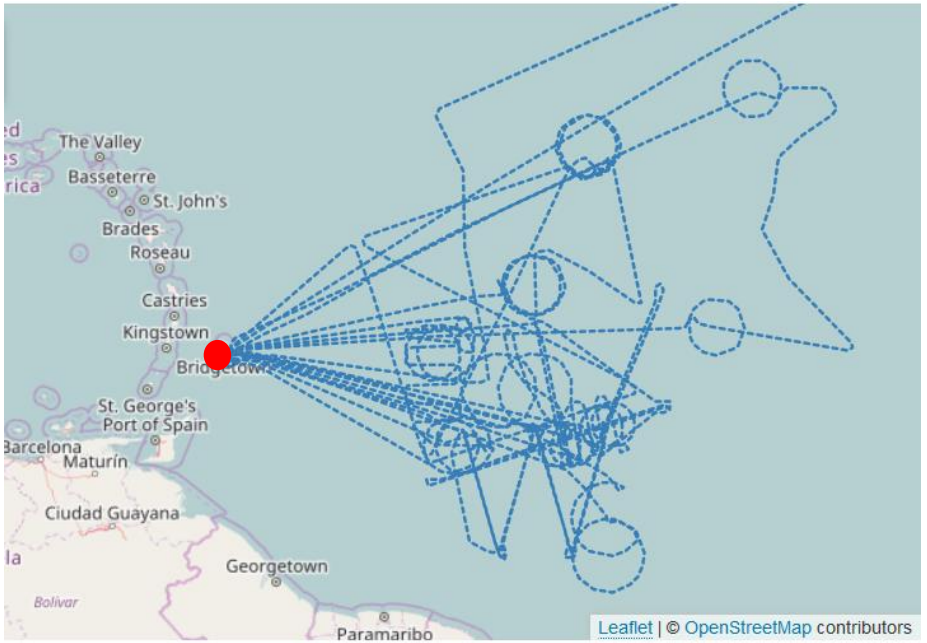
Combined airborne passive and active remote sensing

Campaign

- ***Platform***:

High Altitude and Long Range Research Aircraft (HALO)

- ***Area***:



Flight tracks of HALO during NARVAL-II

- ***Time***: 08. August – 31. August 2016
- ***Objectives***:
  - Trade-wind cumulus in the ITC region
  - Radiative effects
  - Structure
  - Evolution

Stevens, B. et al., 2018: (in prep.)

Instrumentation of HALO

Combination of active and passive remote sensing instruments

WALES

- Differential Absorption and High Spectral Resolution Lidar

- Cloud top height

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Combination of active and passive remote sensing instruments

WALES
- Differential Absorption and High Spectral Resolution Lidar

- Cloud top height

HAMP
- Microwave radiometer
- Cloud radar

- Liquid water path
- Radar reflectivity
- Temperature + humidity profiles

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- Temperature + humidity profiles

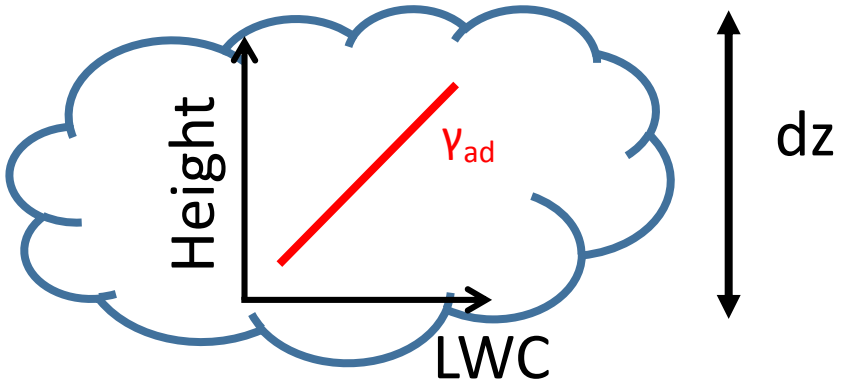
SMART
- Passive cloud spectrometer

- Irradiances
- Optical thickness
- Effective radius
- Cloud top reflectivity

Synergistic retrieval approach

SMART (Method A)
Cloud top reflectivity
Effective Radius

$$N_\mathrm{d} = \mathcal{A} \cdot \sqrt{f_\mathrm{ad} \cdot \gamma_\mathrm{ad}} \cdot \frac{\sqrt{\tau}}{\sqrt{r_\mathrm{eff}^5}}$$



Synergistic retrieval approach

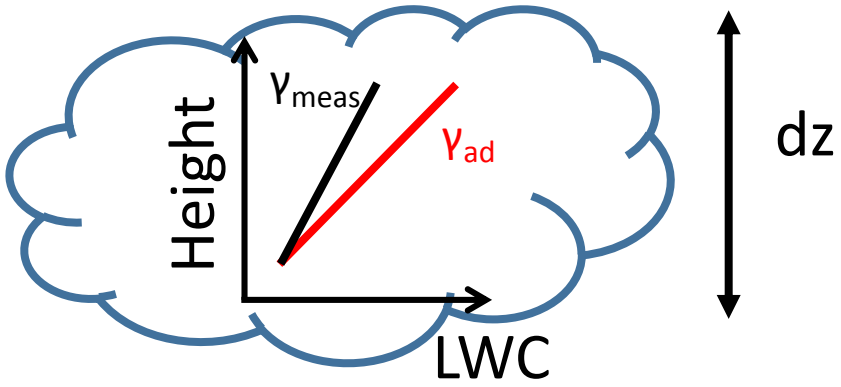
SMART (Method A)
Cloud top reflectivity
Effective Radius

HAMP (Method B)
Liquid Water Path
Effective Radius
Cloud base height

WALES (Method C)
Cloud top height

$$N_{\mathrm{d}} = \mathcal{A} \cdot \sqrt{f_{\mathrm{ad}} \cdot \gamma_{\mathrm{ad}}} \cdot \frac{\sqrt{\tau}}{\sqrt{r_{\mathrm{eff}}^5}}$$

$$\gamma_{\mathrm{meas}} = \frac{2 \cdot LWP}{(dz)^2}$$



Synergistic retrieval approach

SMART (Method A)
Cloud top reflectivity
Effective Radius

HAMP (Method B)
Liquid Water Path
Effective Radius
Cloud base height
Radar reflectivity
Precipitation flag

WALES (Method C)
Cloud top height

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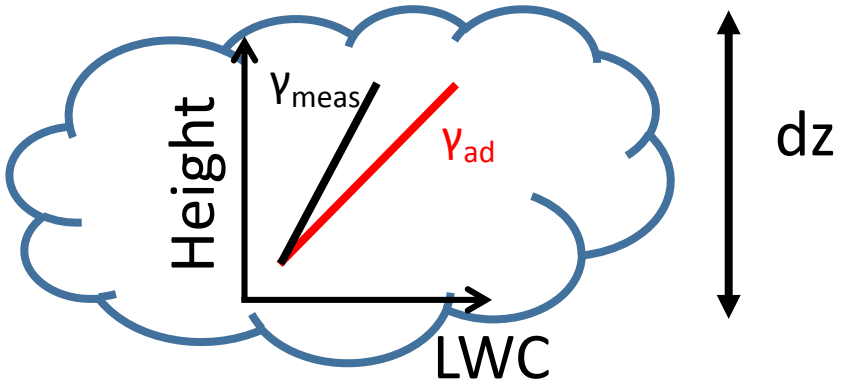
$$N_\mathrm{d} = \mathcal{B} \cdot \sqrt{\gamma_\mathrm{meas}} \cdot \frac{\sqrt{LWP}}{r_\mathrm{eff}^3}$$



Synthetic measurements

	Cloud I adiabatic	Cloud II sub-adiabatic	Cloud III adiabatic	Cloud IV sub-adiabatic	Cloud V adiabatic	Cloud VI sub-adiabatic
N_{Cloud} [cm^{-3}]	50	50	100	100	200	200
LWP_{Cloud} [$\mathrm{g\,m}^{-2}$]	362.5	217.5	362.5	217.5	362.5	217.5

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uncorrected adiabaticity

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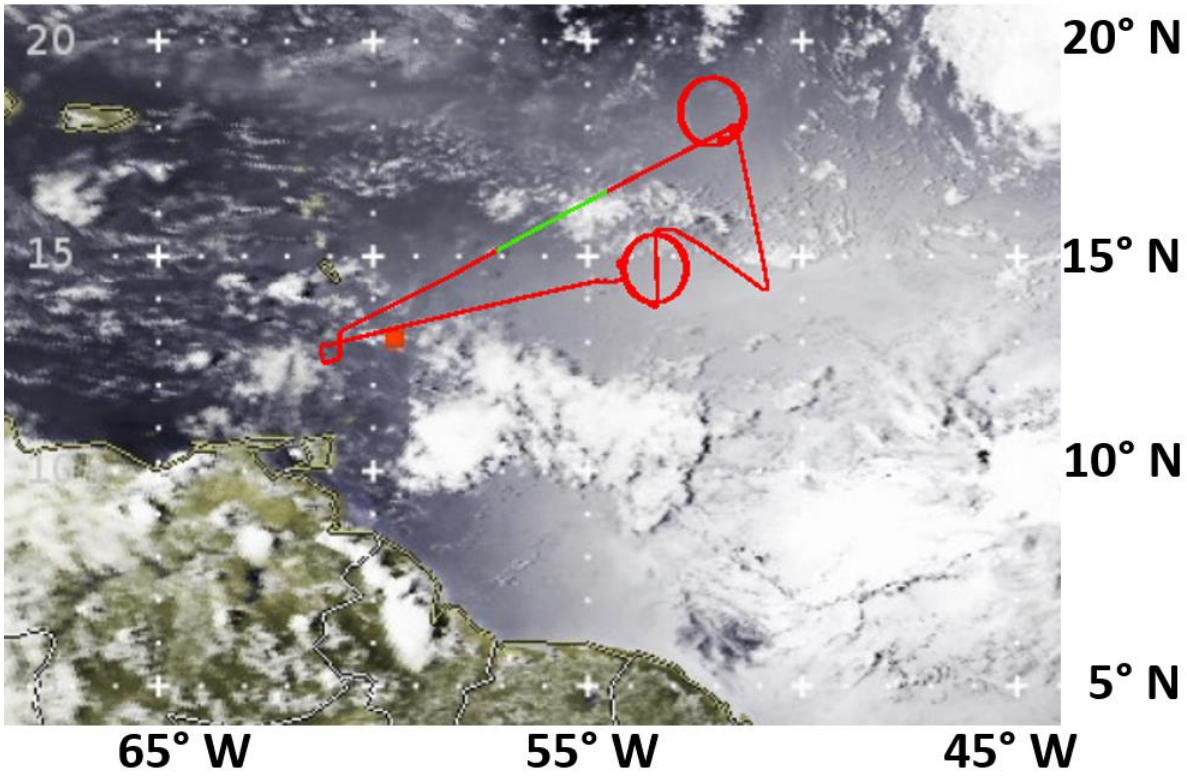
	adiabatic	sub-adiabatic	adiabatic	sub-adiabatic	adiabatic	sub-adiabatic
N_{Cloud} [cm^{-3}]	50	50	100	100	200	200
LWP_{Cloud} [$\mathrm{g\,m}^{-2}$]	362.5	217.5	362.5	217.5	362.5	217.5
$N_{\mathrm{A,lib}}$ [cm^{-3}]	53	69	106	137	215	274
$N_{\mathrm{B,lib}}$ [cm^{-3}]	52	68	105	134	211	268
$N_{\mathrm{C,lib}}$ [cm^{-3}]	52	53	105	104	211	208

corrected adiabaticity

Measurement Example

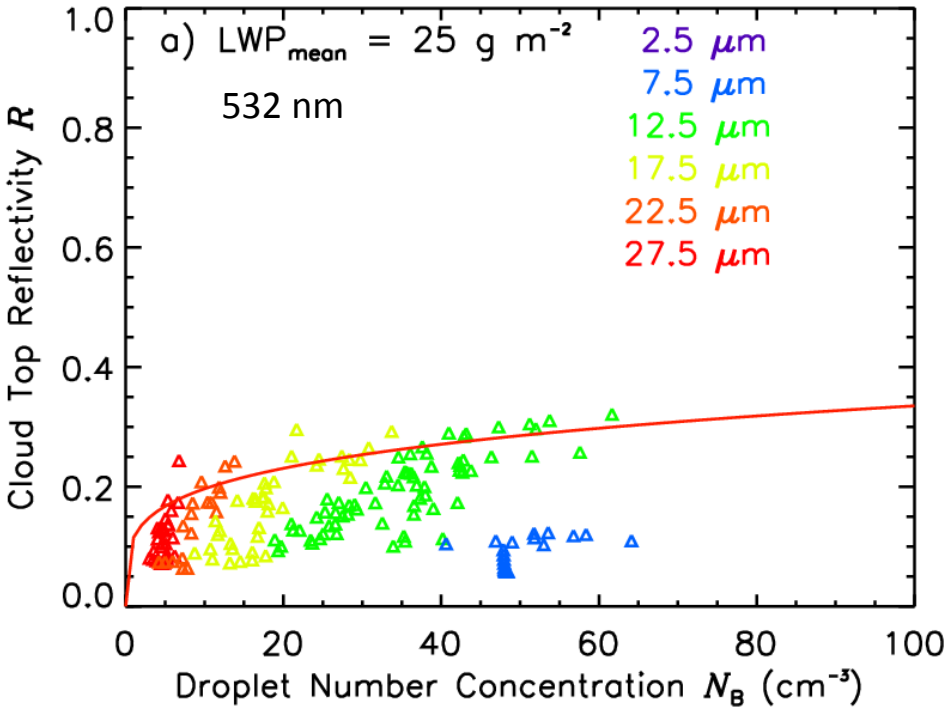


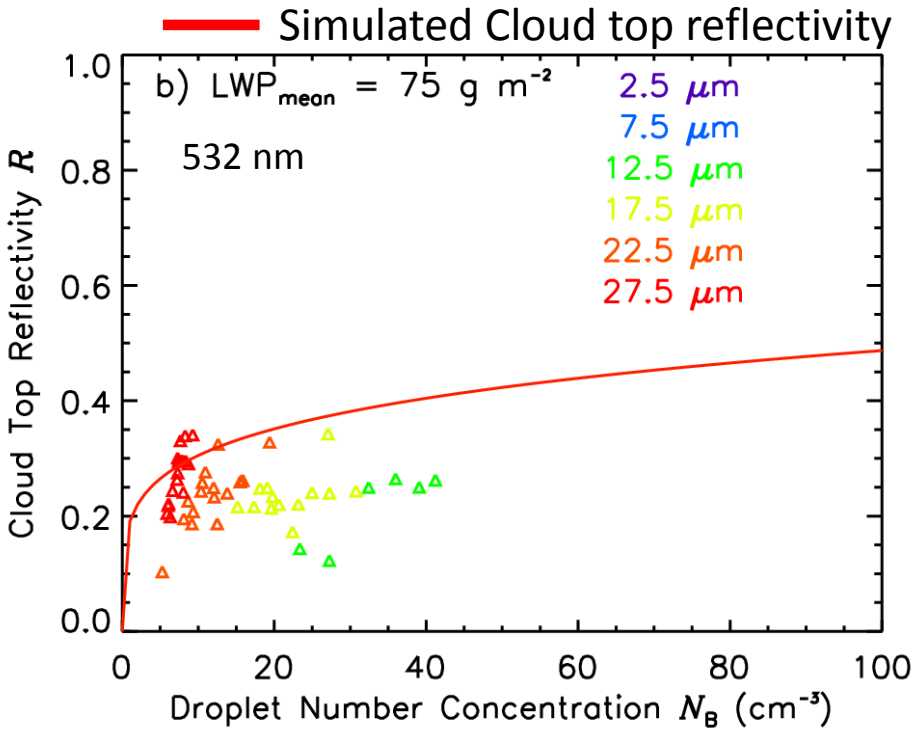
Meteosat satellite image of 19:30 UTC

Date: 19.08.2016
Time: 12:29 – 20:52 UTC
Duration: 8h 23 min
Weather situation:

- moderate convection
- larger fields of shallow trade-wind cumulus
- zonaly winds

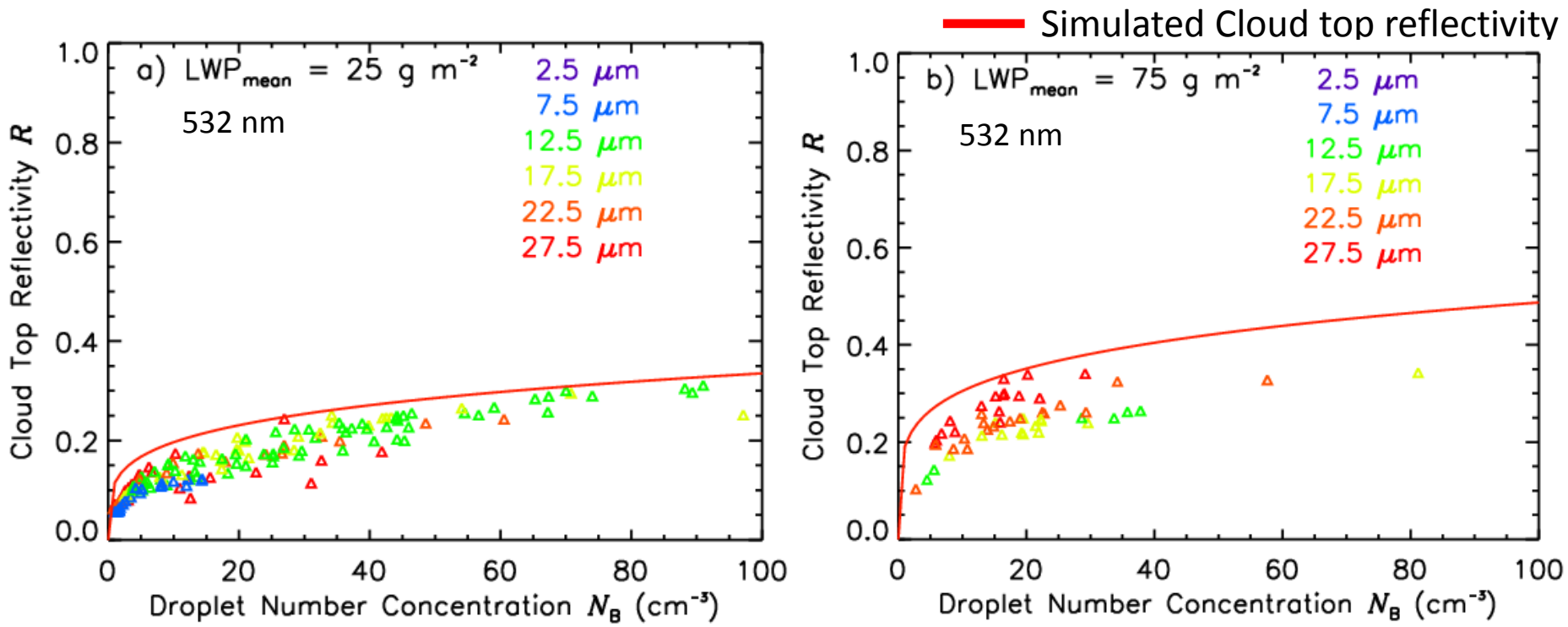
Correlation Reflectivity - CDNC





uncorrected adiabaticity

Correlation Reflectivity - CDNC



corrected adiabaticity

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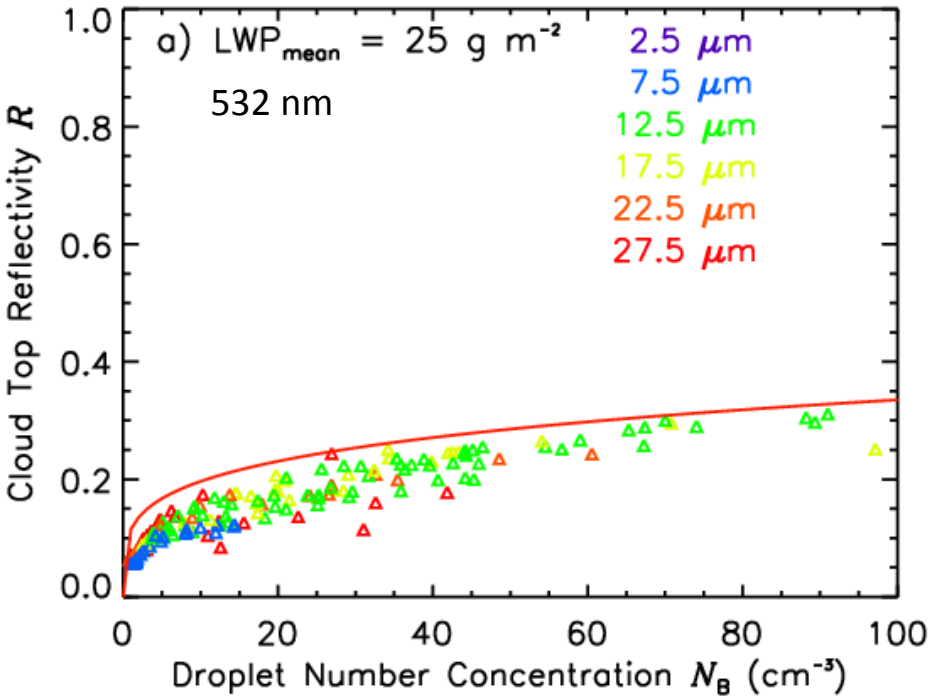
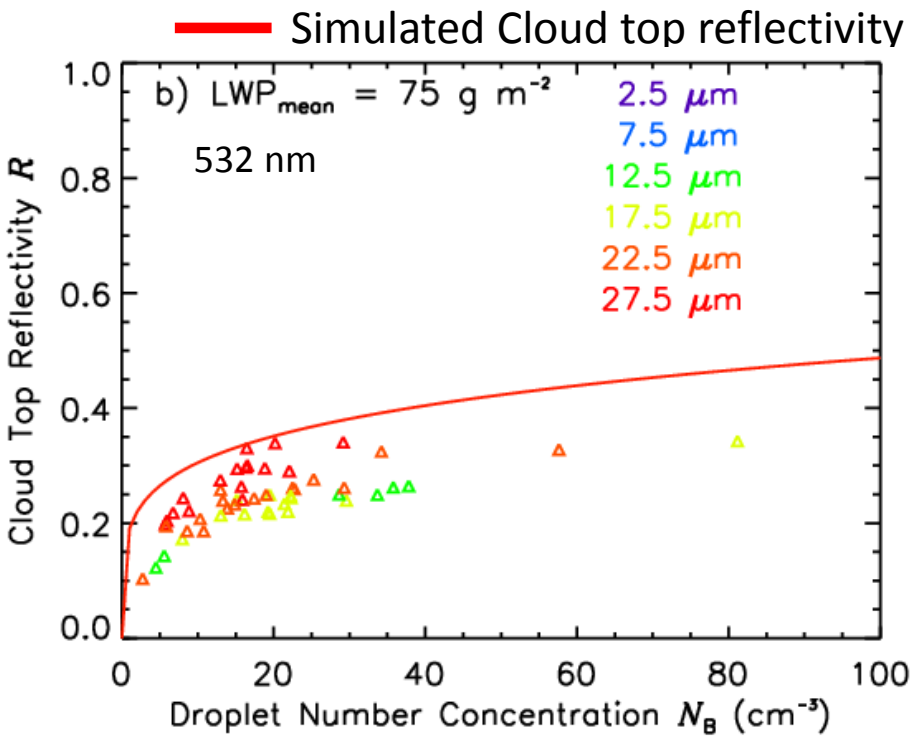
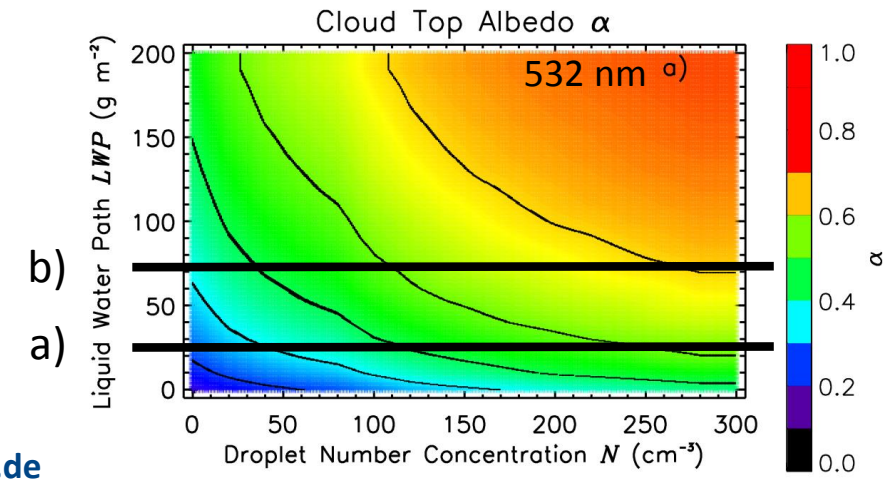
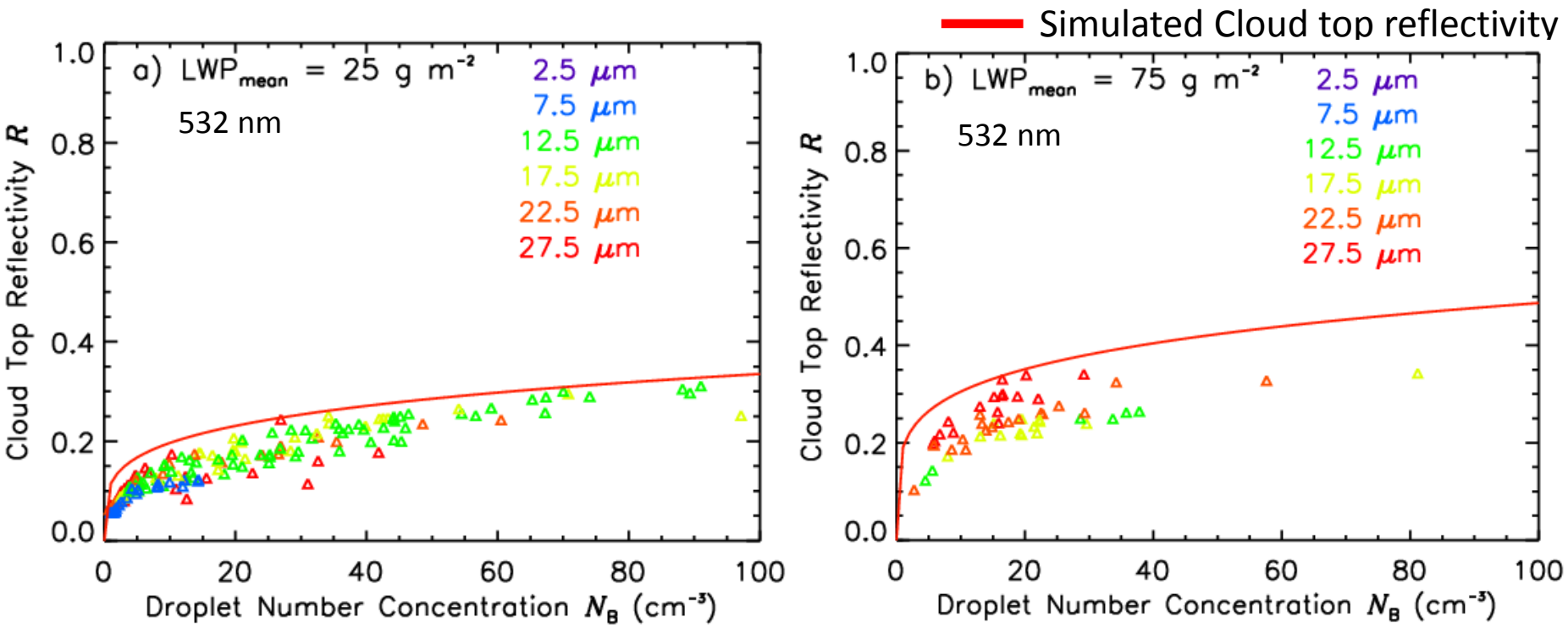






Conclusion



How to **separate** the radiative effect from varying environmental conditions?

- Reflectance measurements
- Independent Cloud Droplet Number Concentration
- Separated for Liquid water path and droplet size

- Correct adiabatic assumption (calc. adiabaticity)
- Precipitation flag