The 3MI mission aboard METOP-SG A
Europe’s eyes on aerosols, clouds and their interactions

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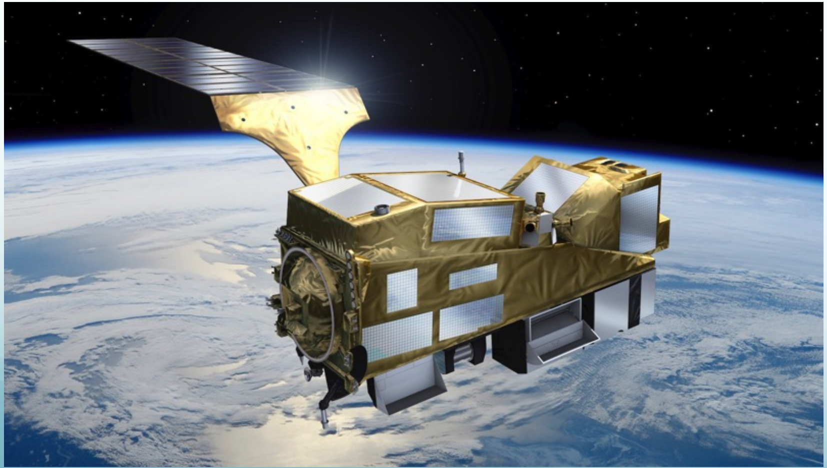

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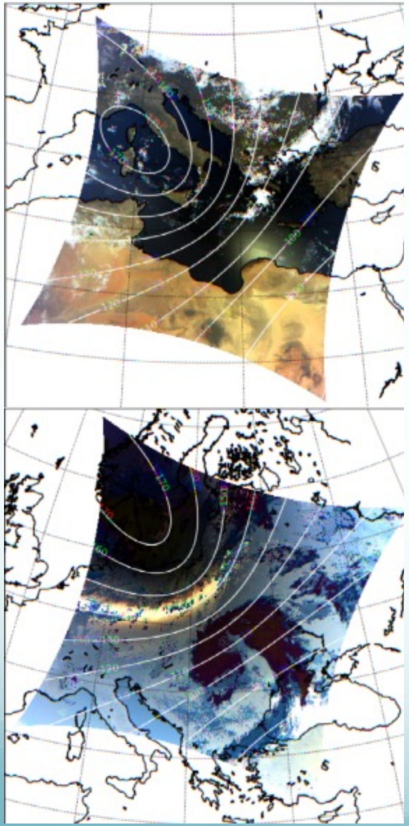
(3) Remote Sensing and Digital Earth, Chinese Academy of Sciences (4) EUMETSAT

And the 3MI team members at EUMETSAT and POLDER 1/2/3 contributors

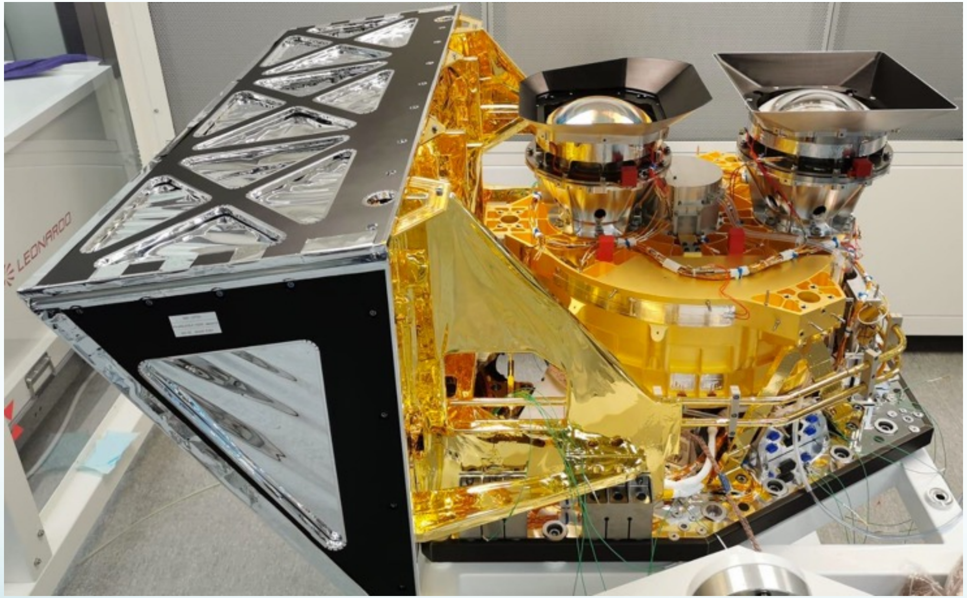
Outline

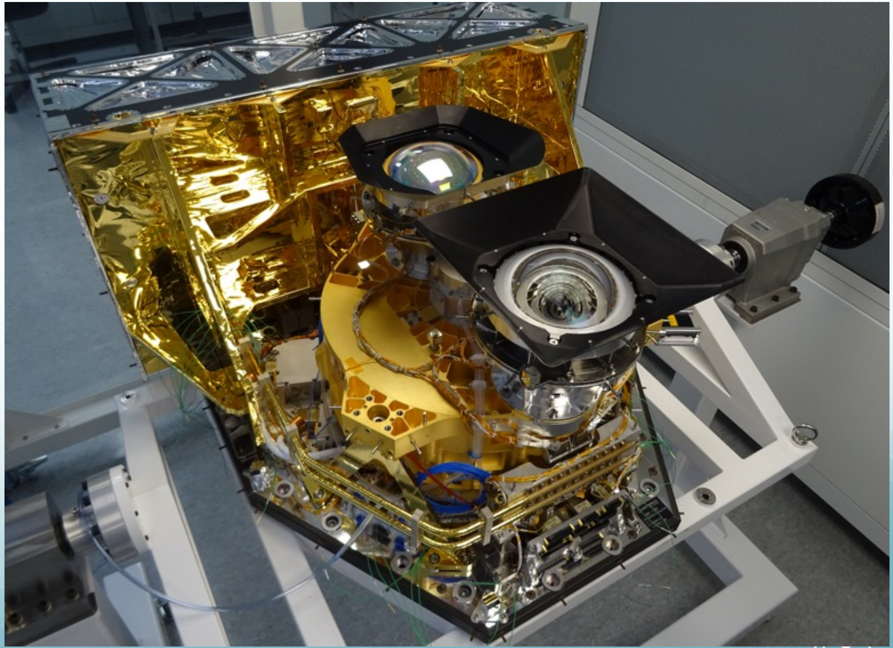


- 3MI currently under implementation phase by ESA/EUMETSAT - Launch on METOP-SG expected 2025
- An aerosol dedicated mission with advanced cloud observing capabilities building on POLDER / MODIS heritage
- How can we improve cloud retrievals using a synergy of 3MI and its companion instruments ?
- How and why 3MI cloud products can be useful for meteorological application in the context of EPS-SG ?

3MI in a nutshell

A wide field of view radiometric imager …





3MI in a nutshell

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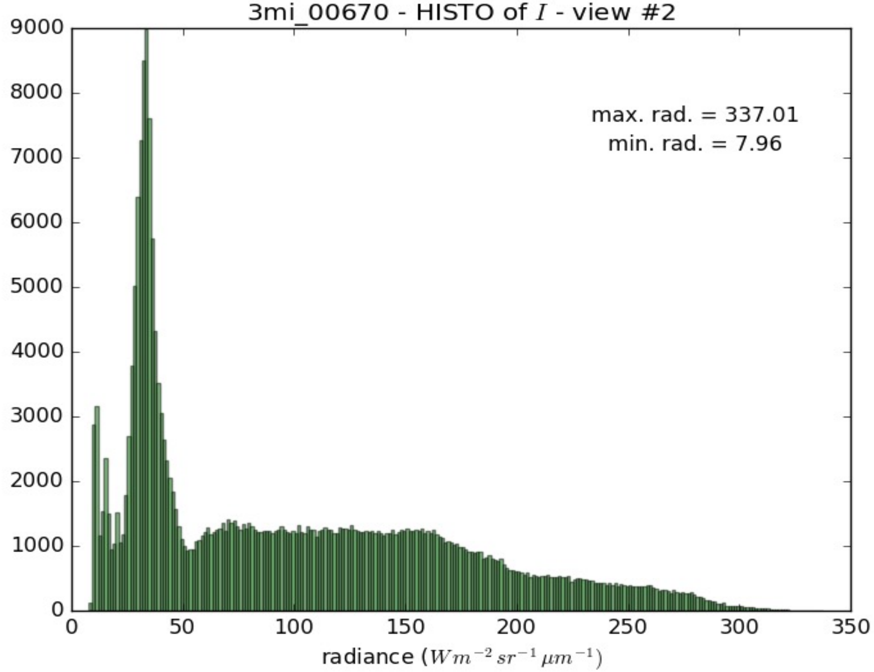
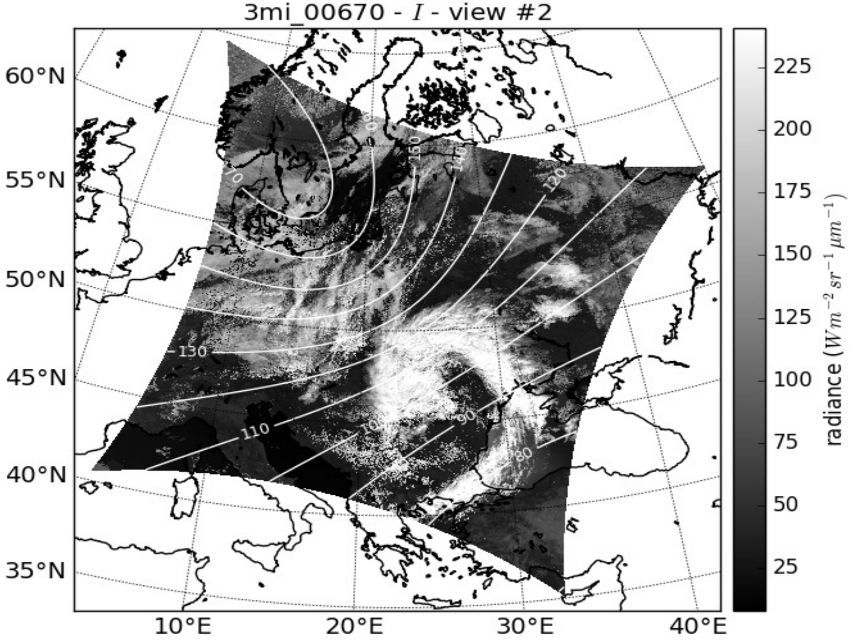
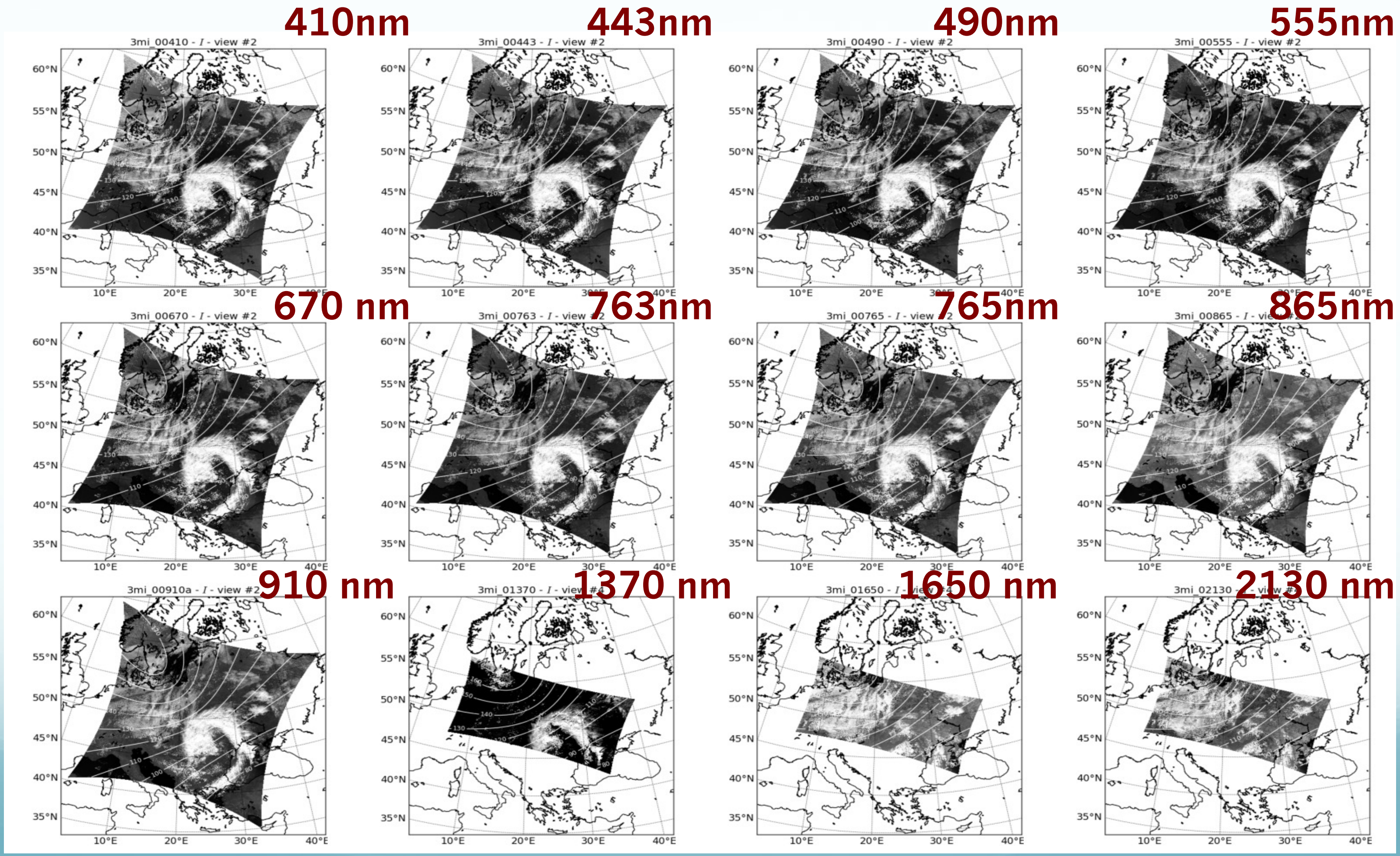


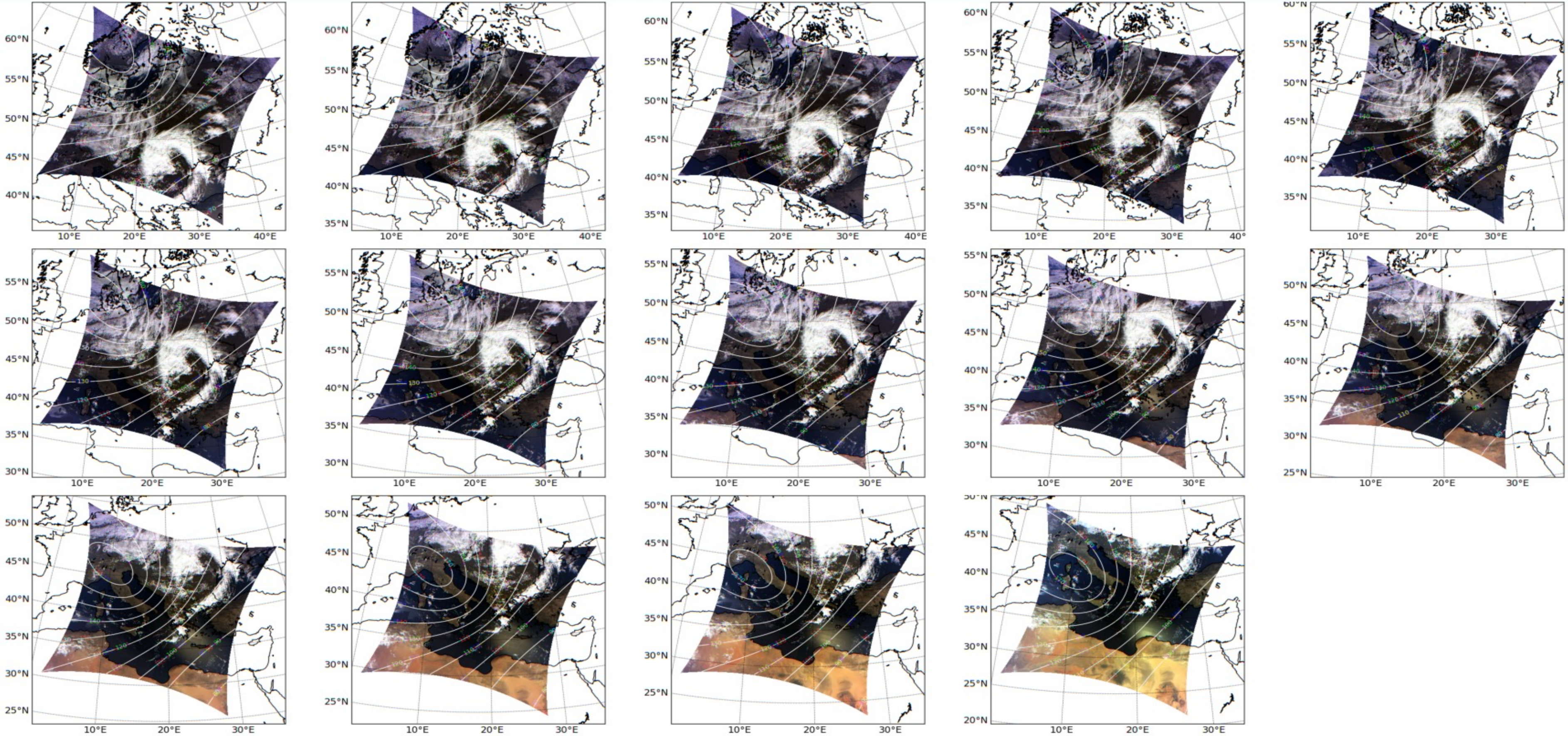


Images from the 3MI Synthetic data Simulator – LOA / HYGEOS for EUMETSAT

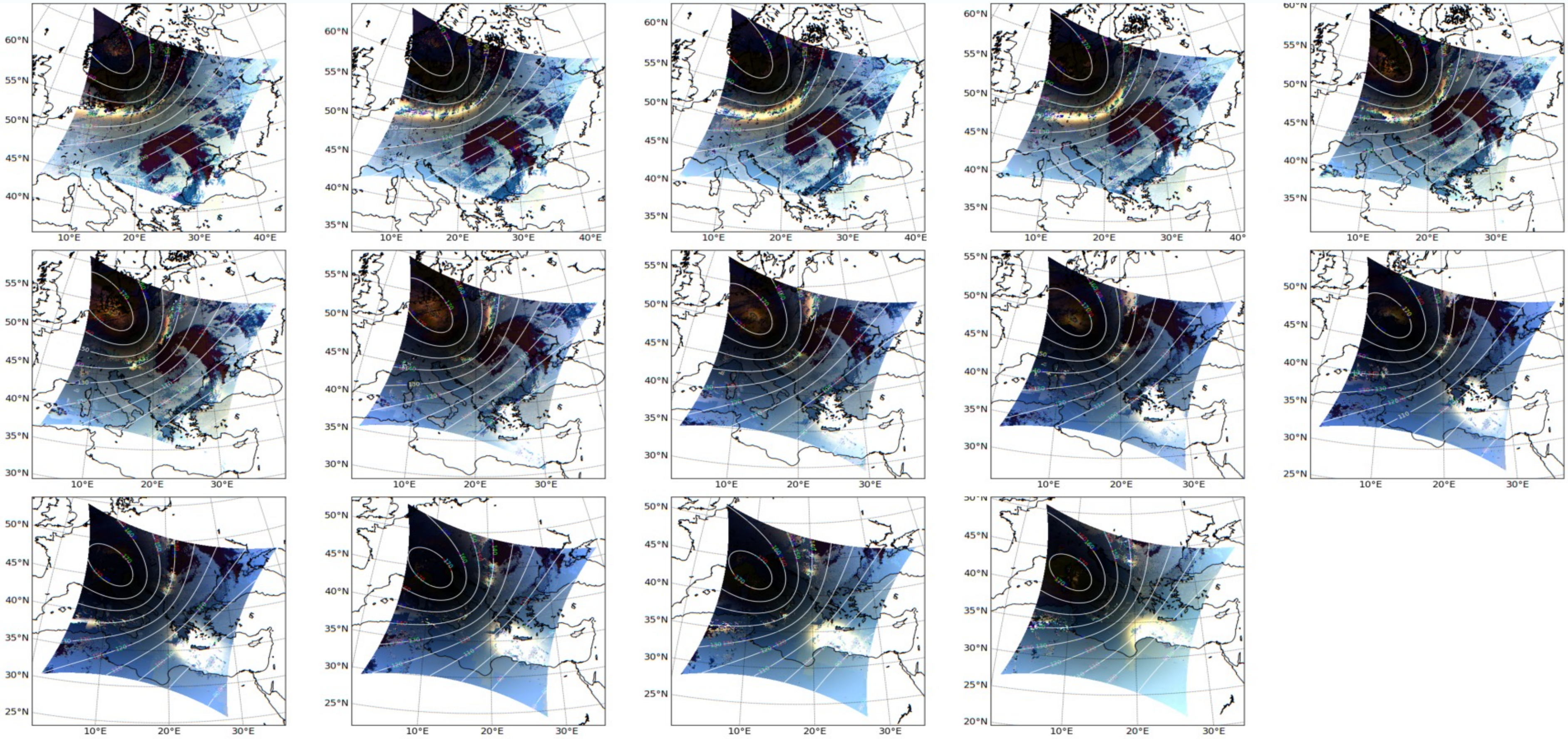
… Multispectral from 410 to 2130 nm …



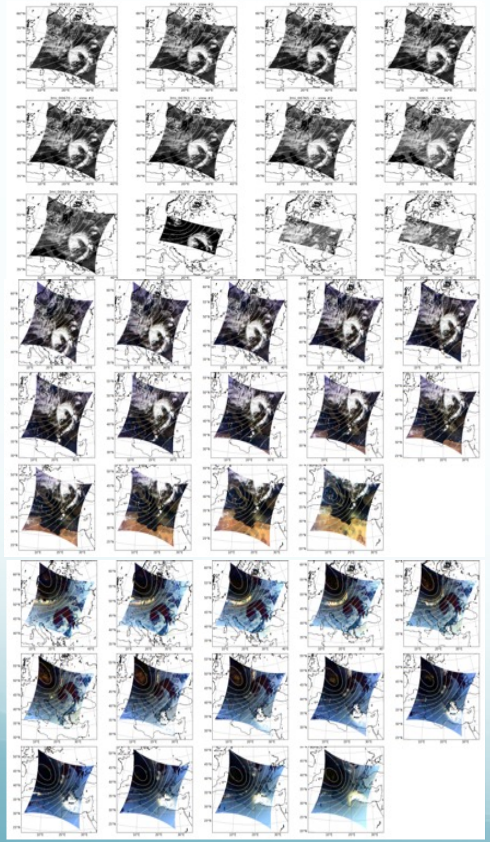
… with Multiviewing capabilities …



… and Polarization measurements (Stokes vector I,Q, U) …



3MI in a nutshell :
Multispectral, Multiview & Multipolarization Imager



High information content of 3MI (~500 individual radiances) allows and requires to account for cloud vertical variability because of spectrally varying weighting functions of channels (from 410 to 2130 nm and total vs polarized radiances)

A two steps approach is used for operational processing :

- **Day 1 algorithms (NRT)** infer "traditional cloud parameters" under plane-parallel homogeneous assumptions
- **Day 2 algorithms** use a priori information from Day 1 retrievals to constrain (using OE algorithm) a **more realistic cloud with variable vertical profile**

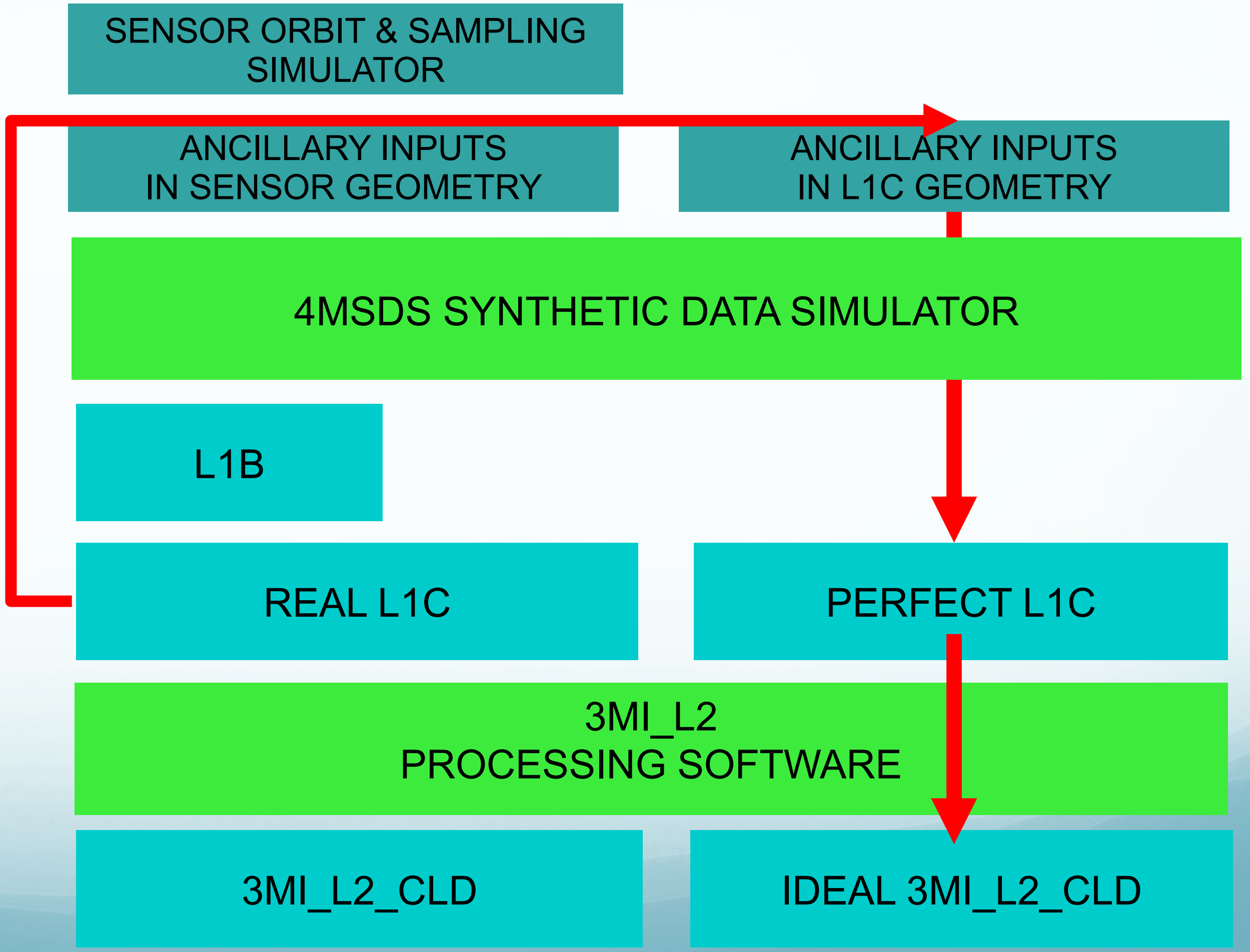
Algorithms are tested on two flavors for highly realistic synthetic test data :

- Homogeneous single phase cloud layers (ie "simplified physics")
- Enhanced complexity : mixed phase – vertical profiles – mixed aerosols and clouds (ie "full physics")

Algorithm development strategy

- Development and validation of proposed algorithms are partly relying on simulated observations to best evaluate performances of algorithms under real conditions : especially non optimal multi-angular registration, variability of angular sampling.

- Use of realistic and detailed optical properties of atmospheric constituents such as clouds and aerosols, as well as the absorption of atmospheric gases because they strongly impact the observed multi-angle and polarized radiances



Day-1 Cloud product specification

A1 Ingestion and acceptance of input

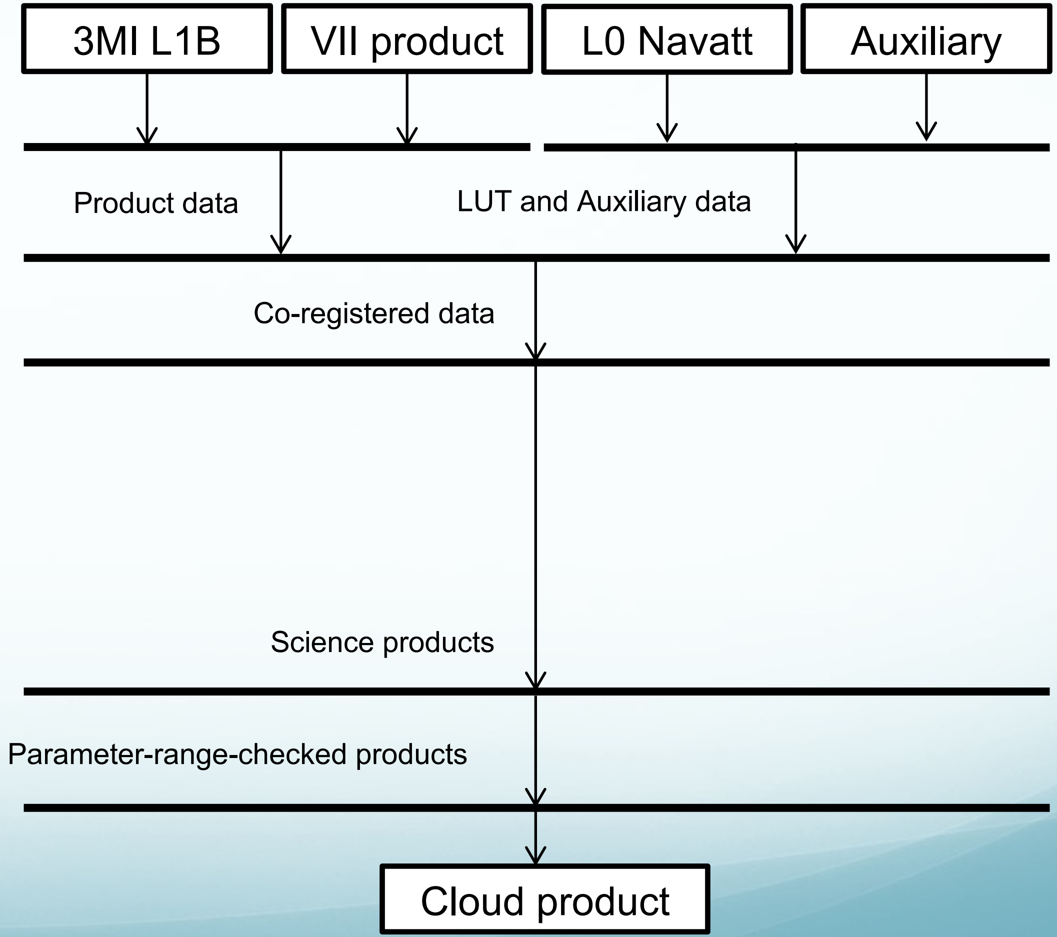
A2 Co-registration of input data

A3 Science data processing

A311 Cloud identification
A312 Cloud phase detection
A313 Ice phase retrievals
A314 Liquid phase retrievals
A315 Cloud vertical structure

A4 On-line quality control

A7 Formatting of output data



Day-1 Cloud product prototype

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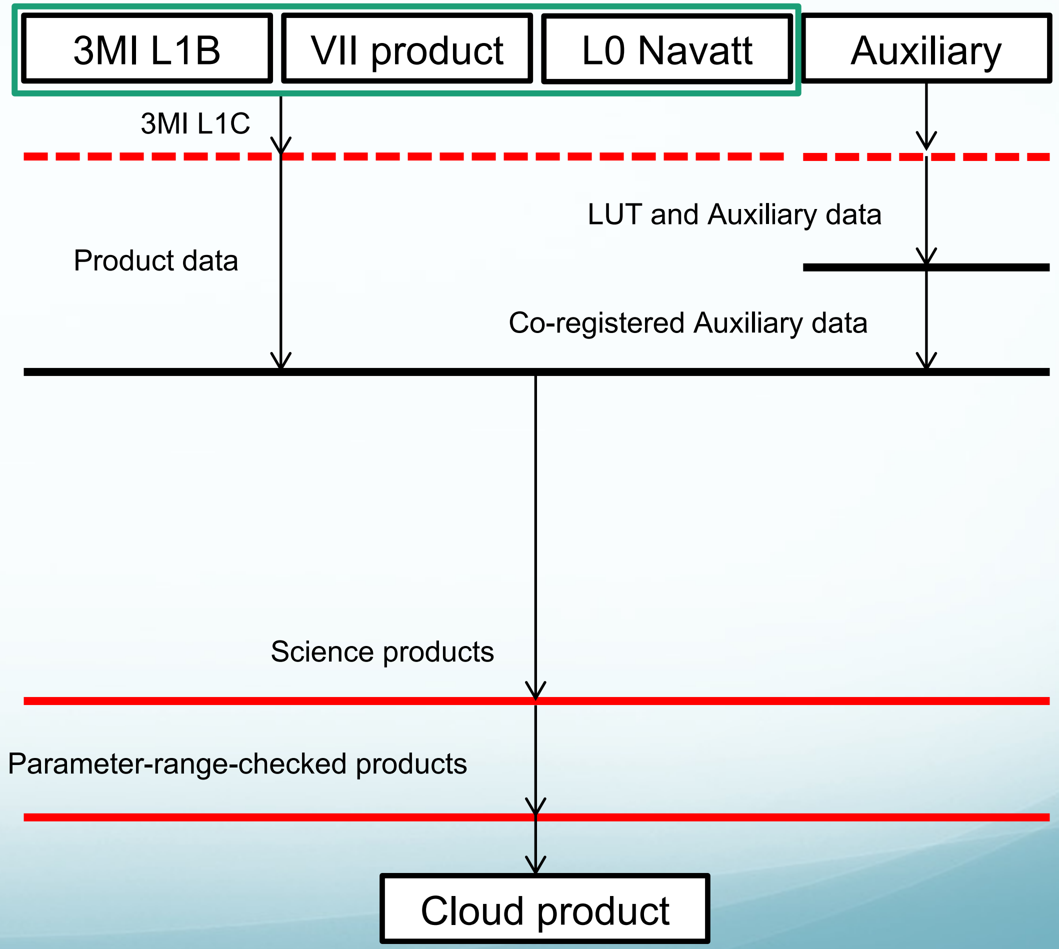


Main « day 1 » cloud properties retrieved from 3MI

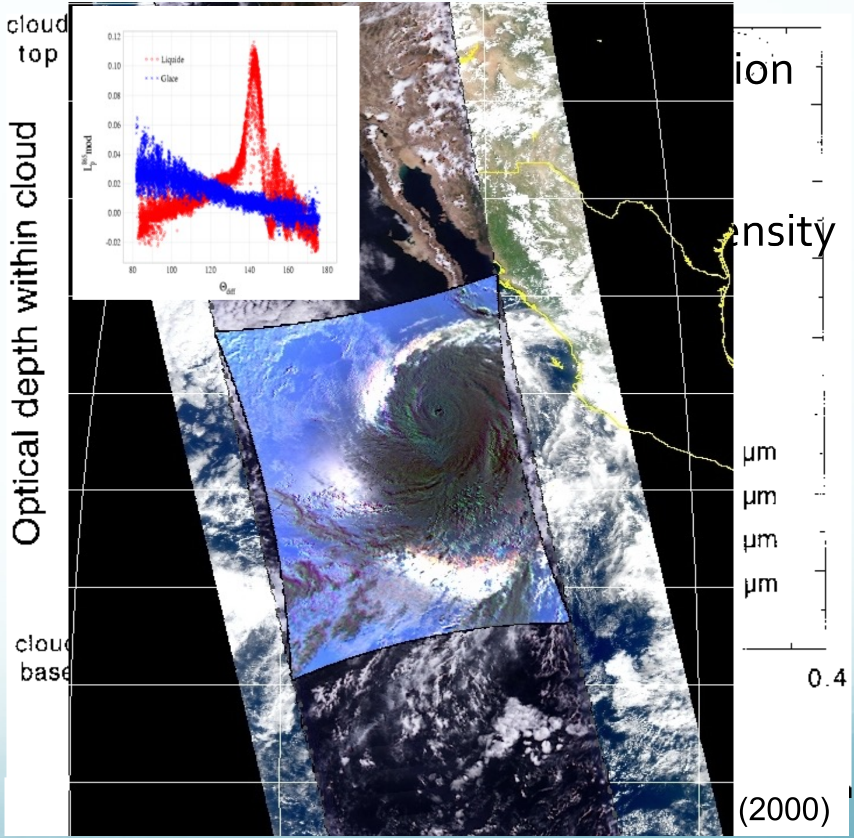
Cloud Thermodynamic Phase
from multiangle polarisation and VNIR/SWIR

Cloud Top Pressure (CTP)
from multispectral Rayleigh scattering

Cloud Geometric Thickness (CGT) and Multilayer detection
from Oxygen A-Band differential absorption and others

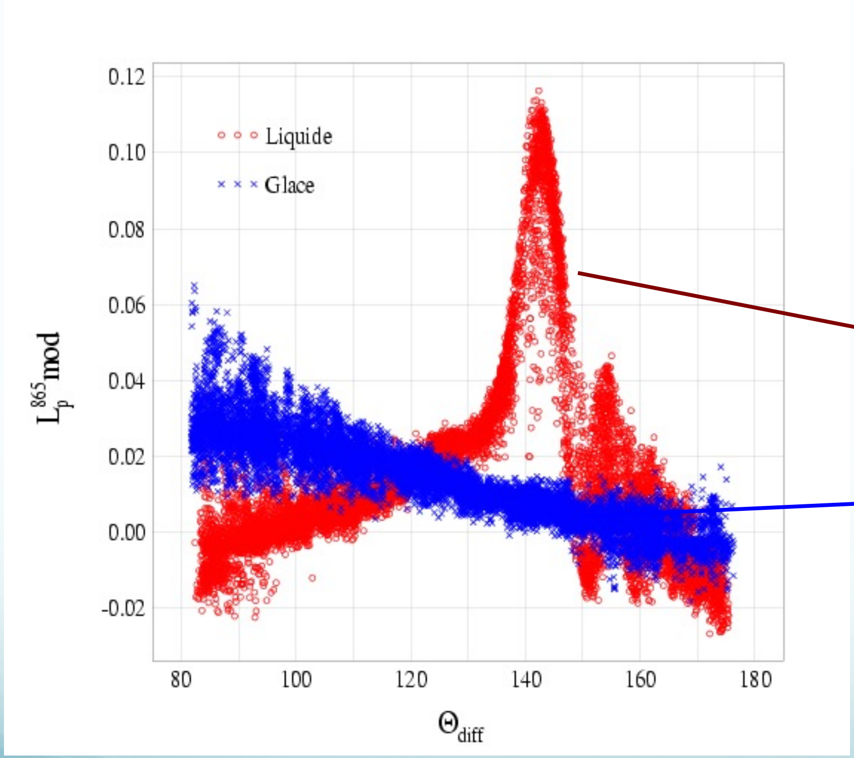
Cloud Optical Thickess (COT) and directional albedo
from multiangle VIS/NIR observations

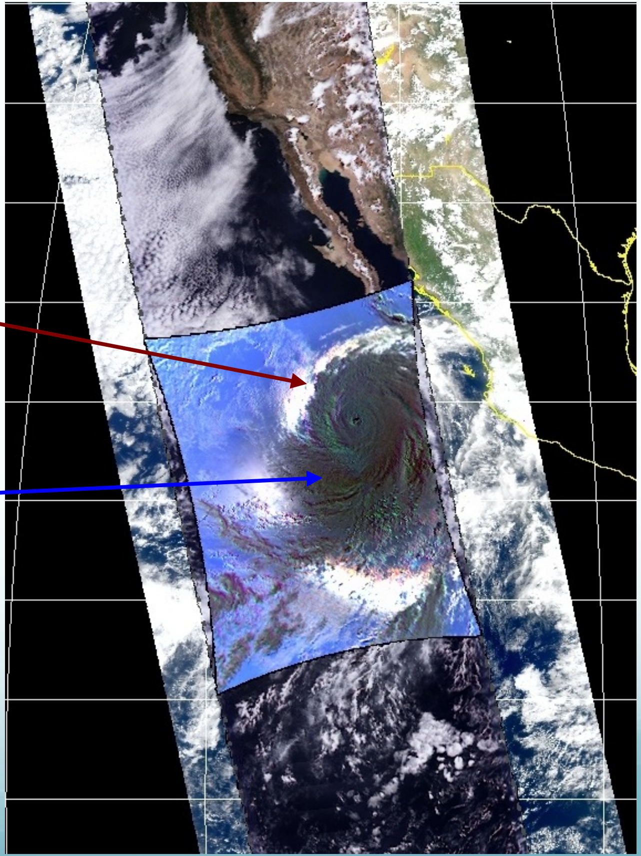
Cloud Particle Size (R_{eff})
using VIS/NIR/SWIR channels or multiangle polarisation signal -> different weighting functions = different values for a given cloud



Cloud Top Thermodynamic Phase

Principle : particle shape discrimination spherical vs non sphe.



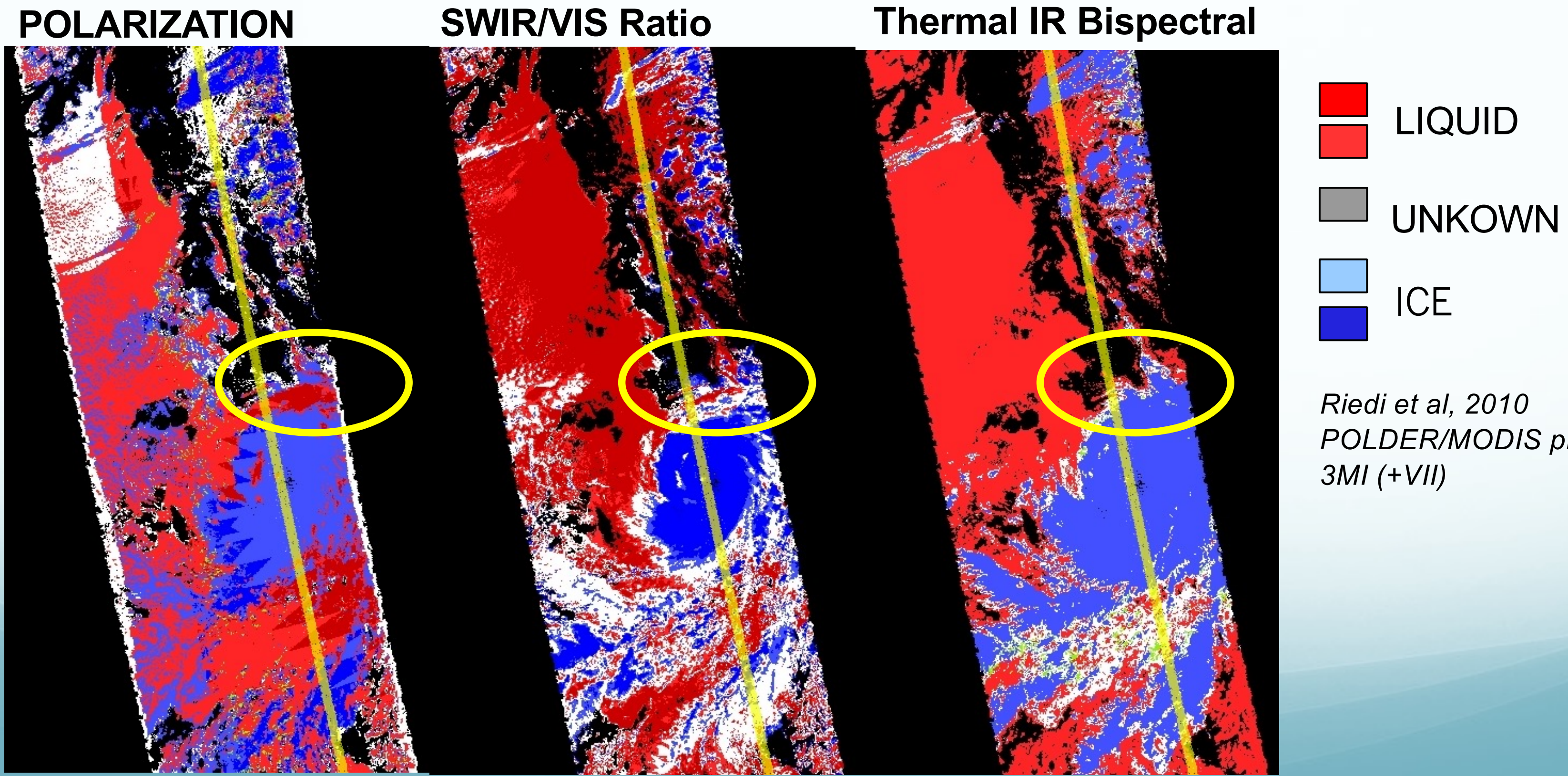


Goloub et al, 2000, Riedi et al, 2001

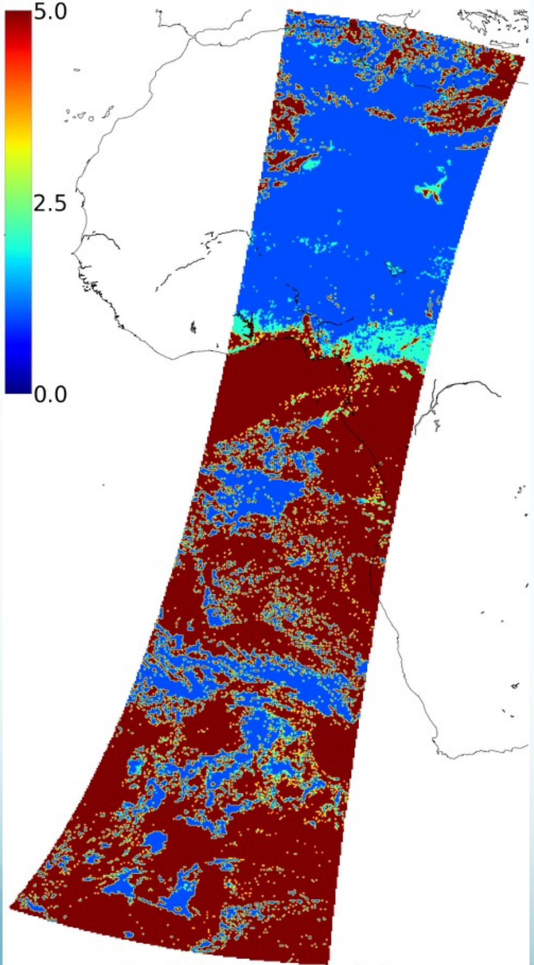
Cloud thermodynamic phase

Combination of information on particle shape and absorption properties

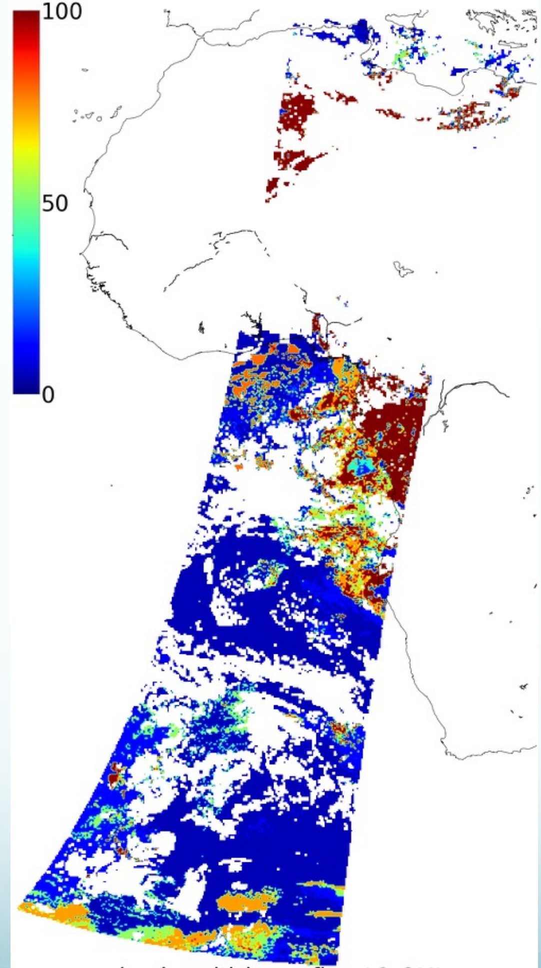
A-Train analysis : combining POLDER and MODIS to infer cloud phase



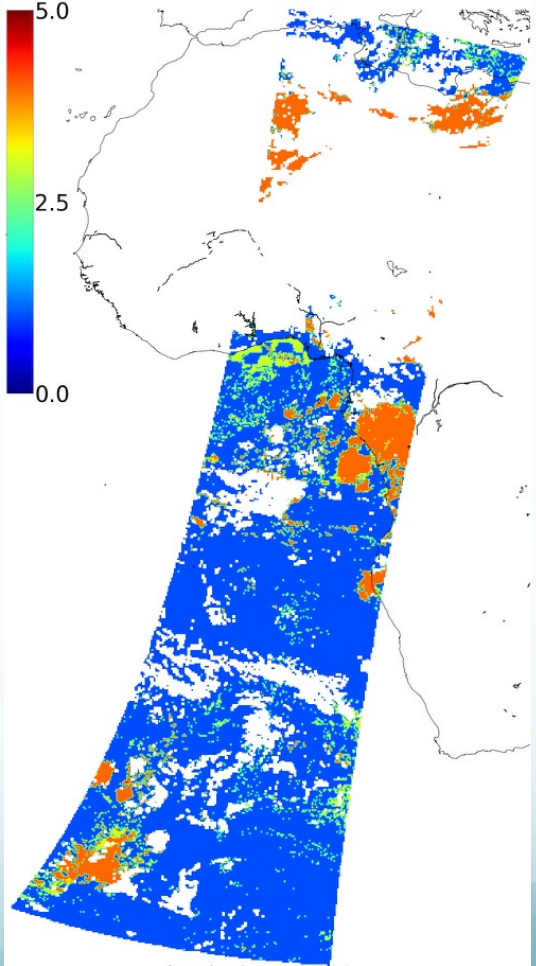
Riedi et al, 2010
POLDER/MODIS precursor for 3MI (+VII)



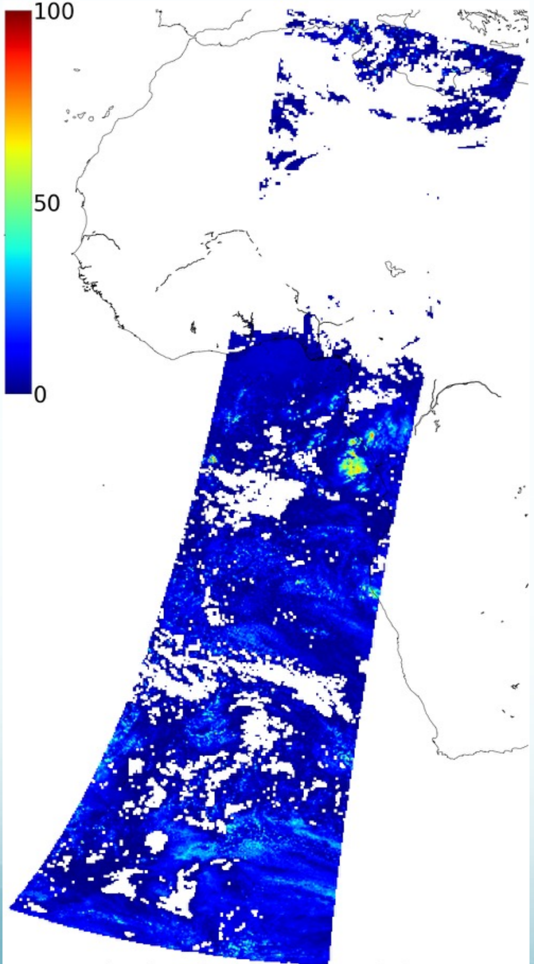
cloud_classification_L2_3MI



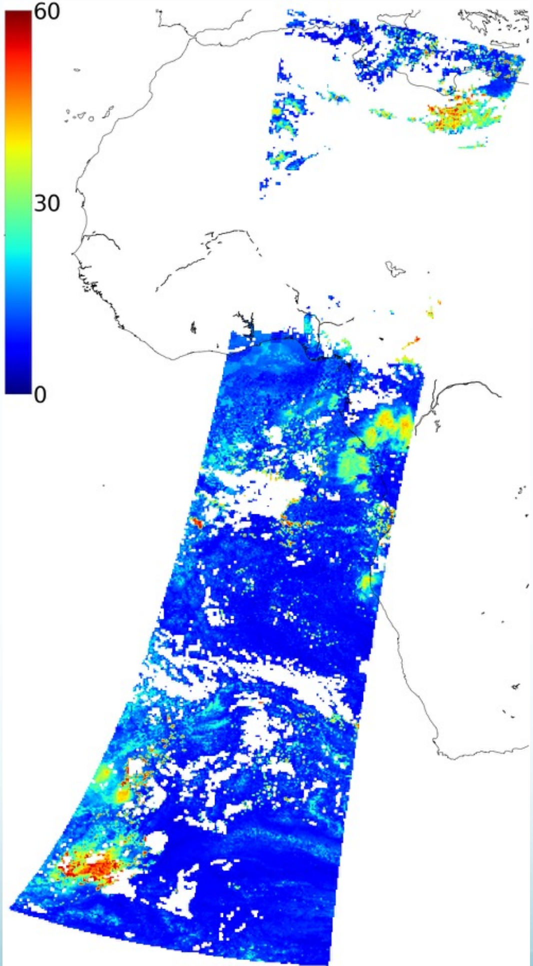
cloud_multi_layer_flag_L2_3MI



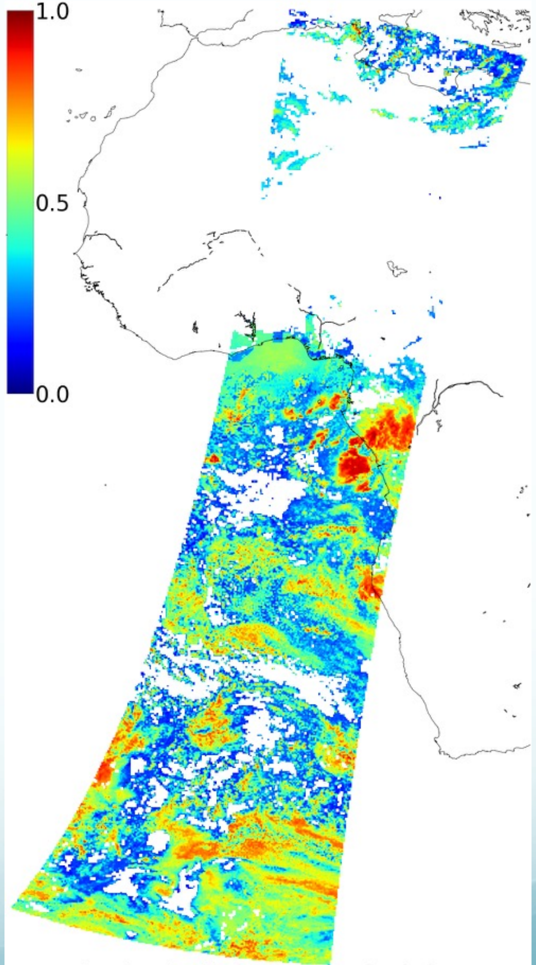
cloud_phase_L2_3MI



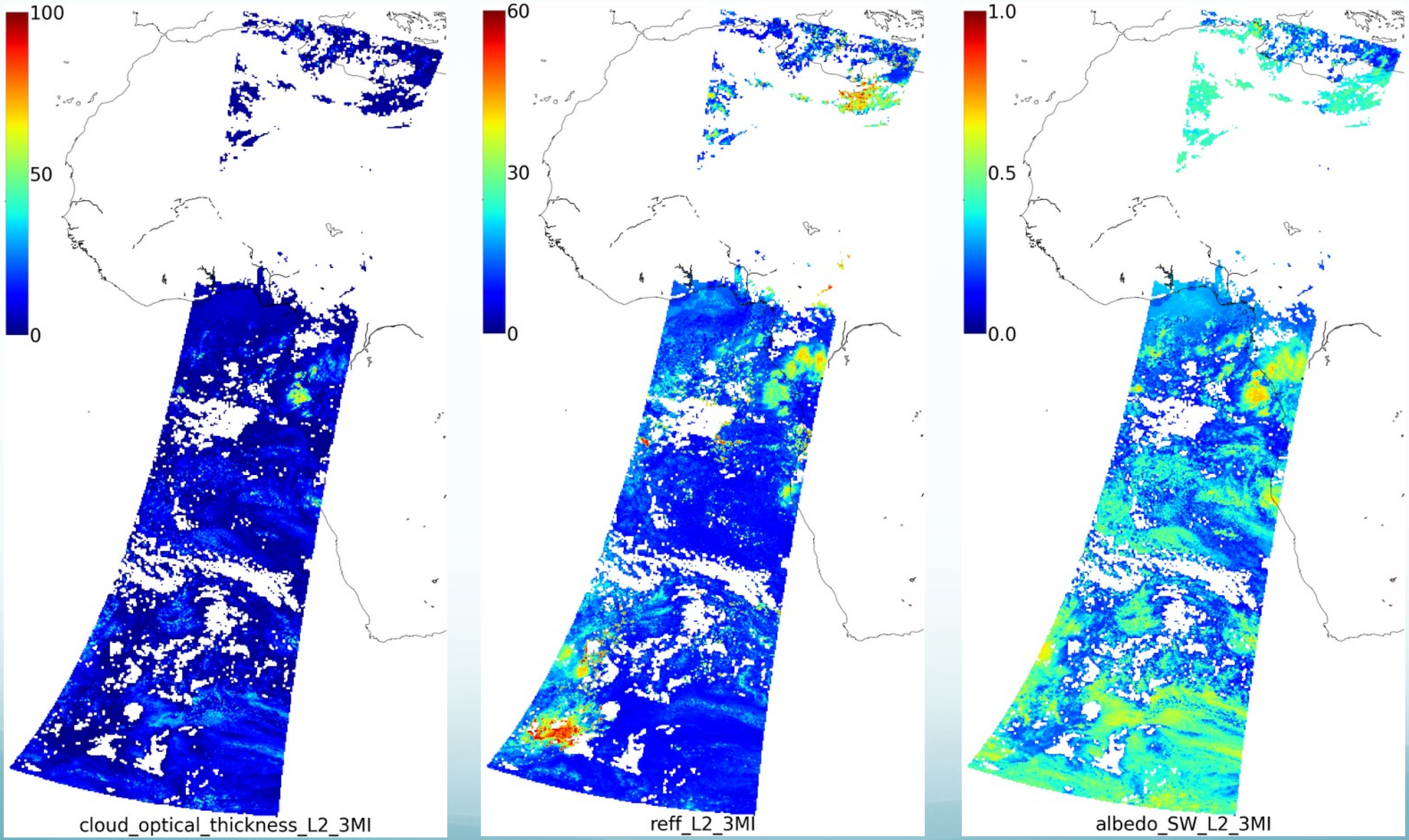
cloud_optical_thickness_L2_3MI

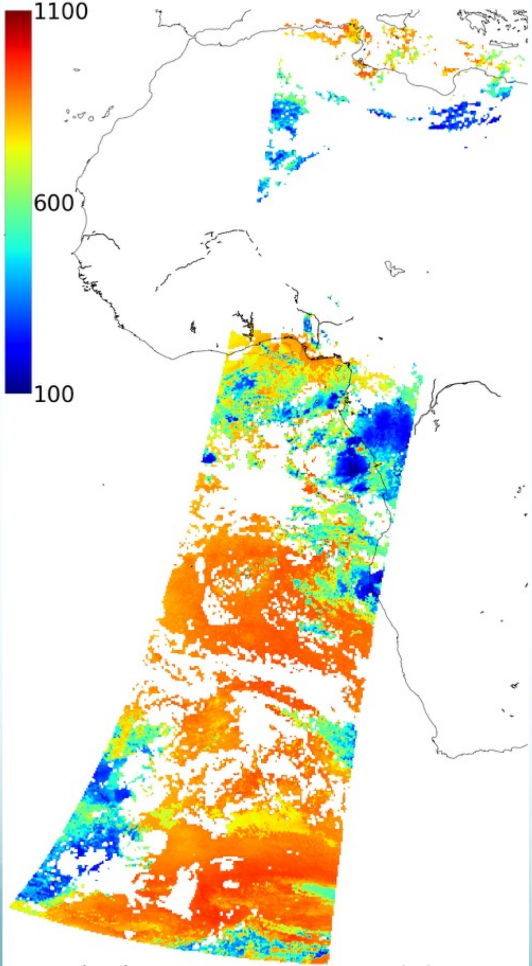


reff_L2_3MI

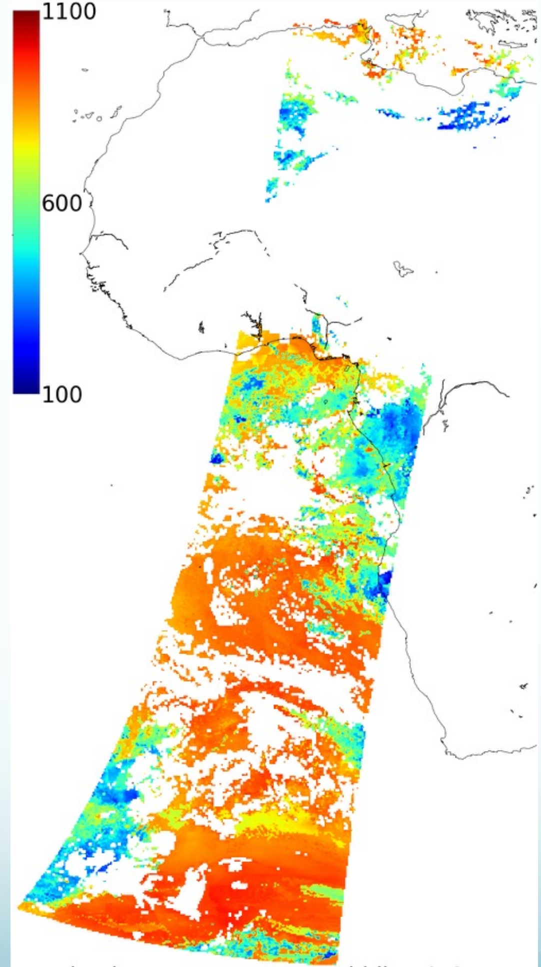


cloud_spherical_albedo_VIS_L2_3MI

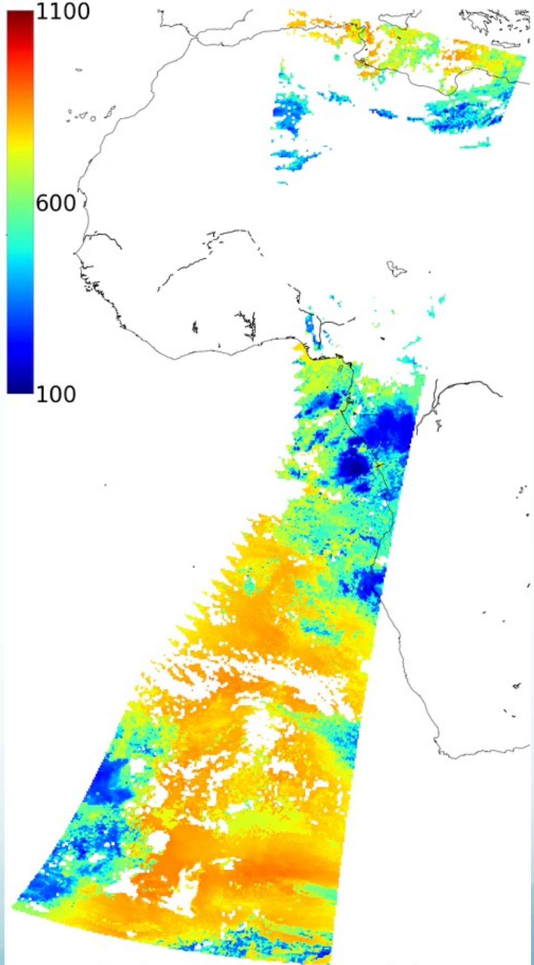

100
50
0
cloud_optical_thickness_L2_3MI
60
30
0
reff_L2_3MI
1.0
0.5
0.0
albedo_SW_L2_3MI



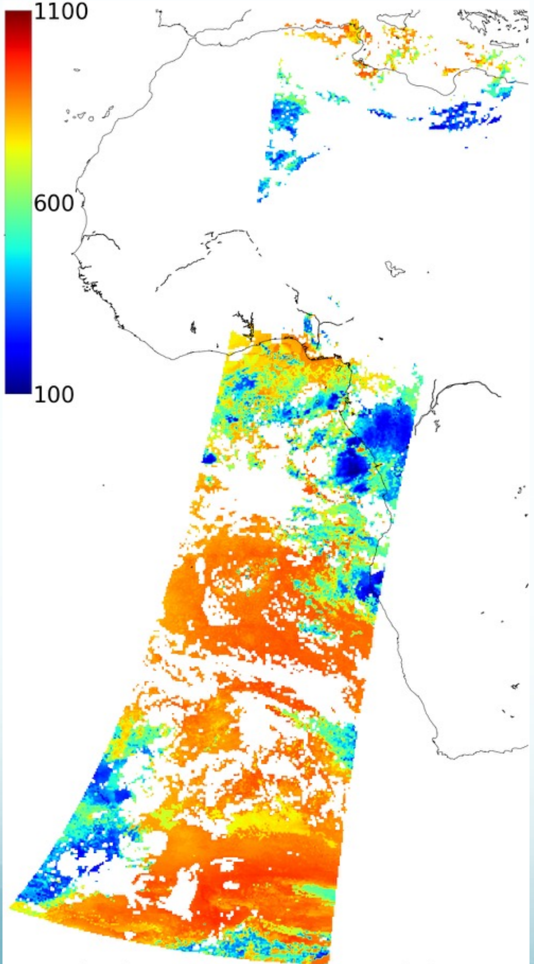
cloud_oxygen_pressure_top_L2_3MI



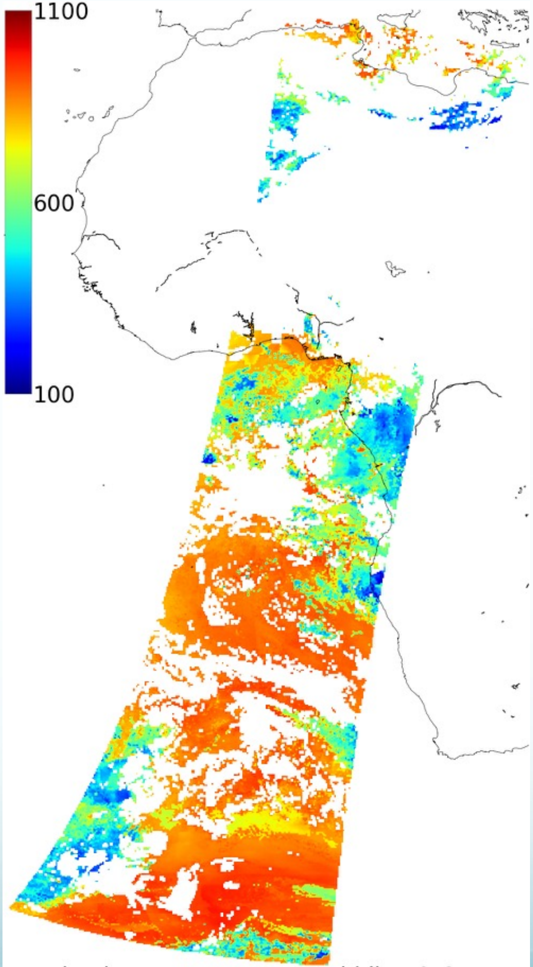
cloud_oxygen_pressure_middle_L2_3MI



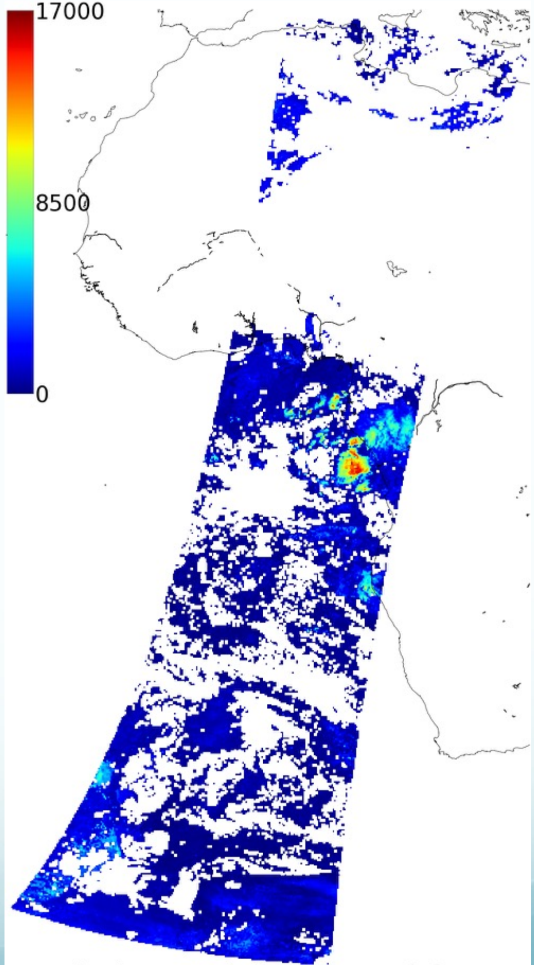
cloud_Rayleigh_pressure_L2_3MI



cloud_oxygen_pressure_top_L2_3MI

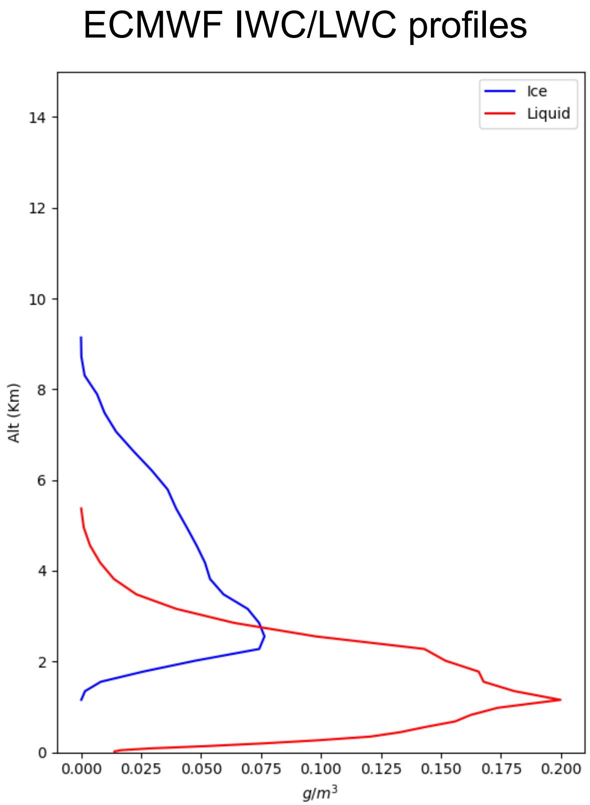


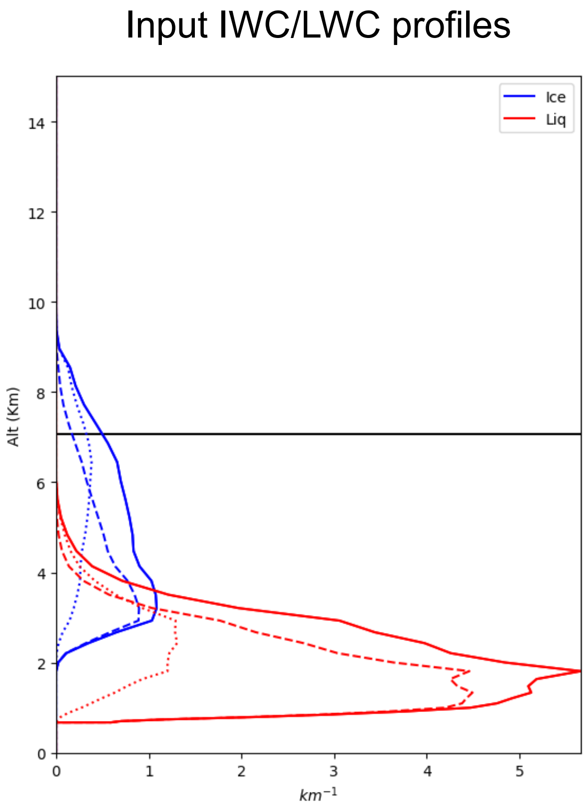
cloud_oxygen_pressure_middle_L2_3MI



cloud_geometrical_thickness_L2_3MI

What is a realistic cloud vertical description ?





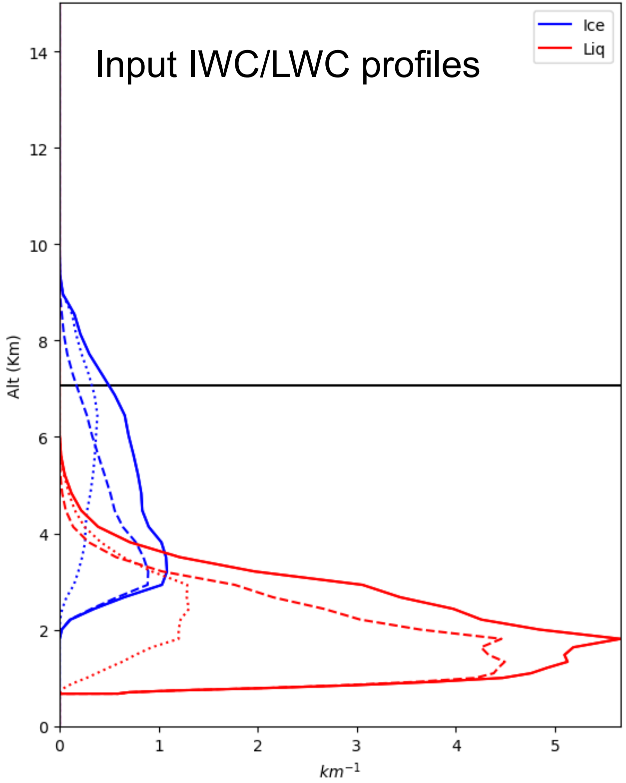
Goloub et al, 2000,   Riedi et al, 2001

ECMWF profiles are used as vertical distribution guidelines.

Particle size is varied linearly from Reff_top to Reff_bottom.

Cloud top altitude, COT and Reff information at cloud top is from AVHRR CLAVR-X product (A. Heidinger)

More questions ...



What is the phase ?

Where is cloud top ?

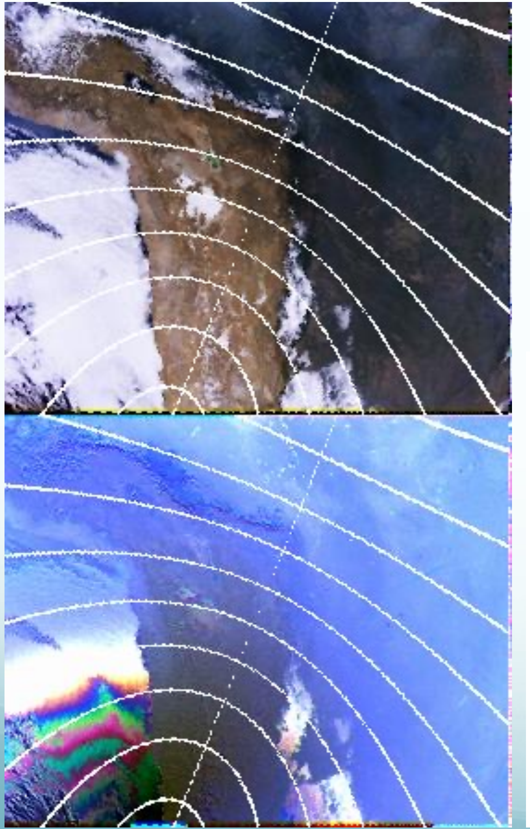
How many layers do we have ?

How can we provide meaningful numbers for particle size ?

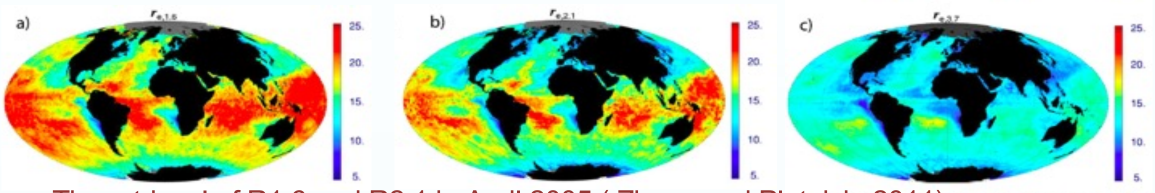
Relations between extinction, LWC/IWC, particle size ...

Liquid clouds particle size retrievals from 3MI

The 3MI measurements enable the cloud droplet size in both POLDER and MODIS ways

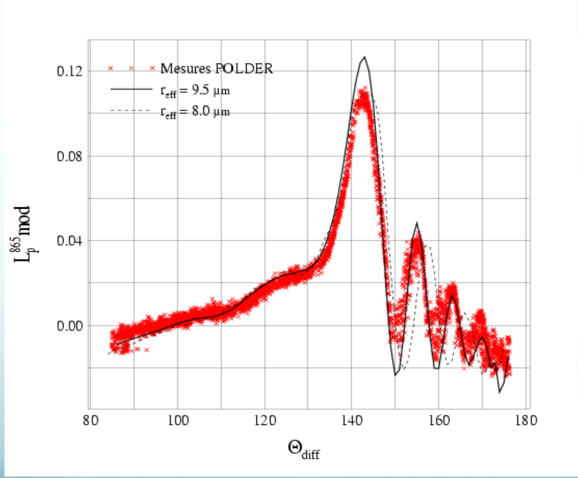


✓ NIR / SWIR bispectral method ➡ Effective radius at 1.6, 2.1 and 3.7 μm

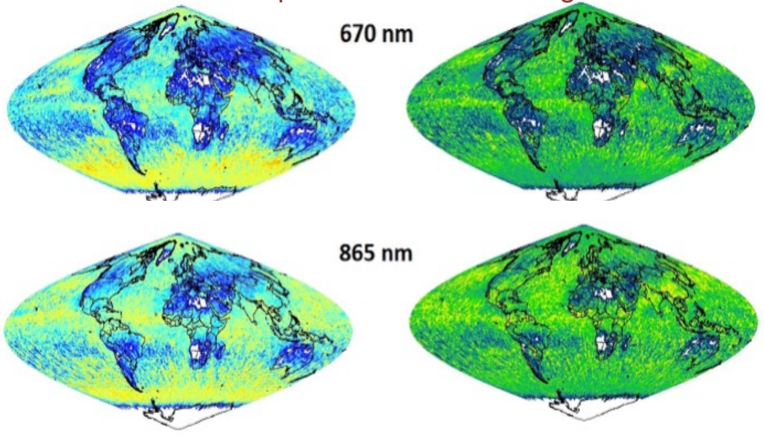


The retrieval of R1.6 and R2.1 in April 2005 (Zhang and Platnick, 2011)

✓ POLDER method ➡ Effective radius and variance from polarization



POLDER-3 droplet size retrieval in August 2008



Process-oriented study : the need for Cloud Effective Radius Profile

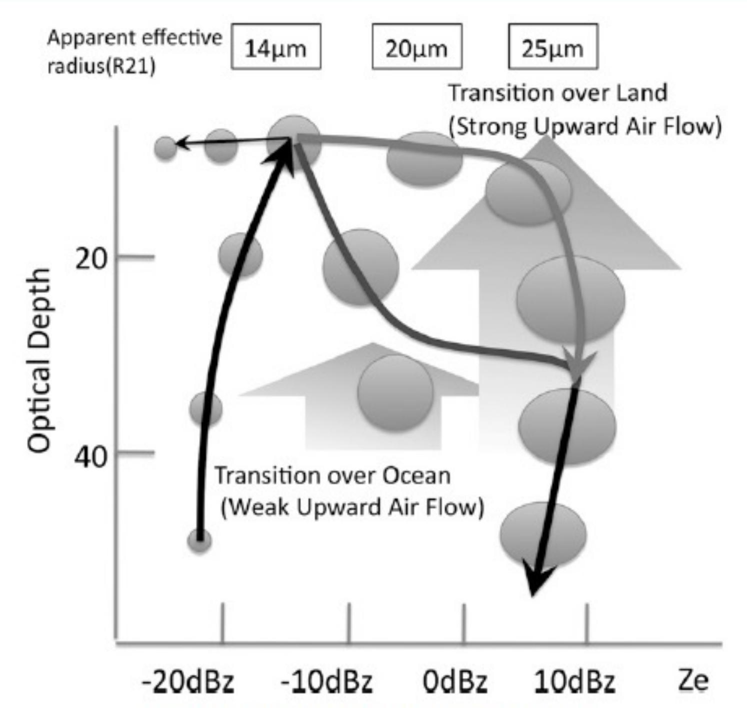


FIG. 6. Transition diagram of the CFODD.

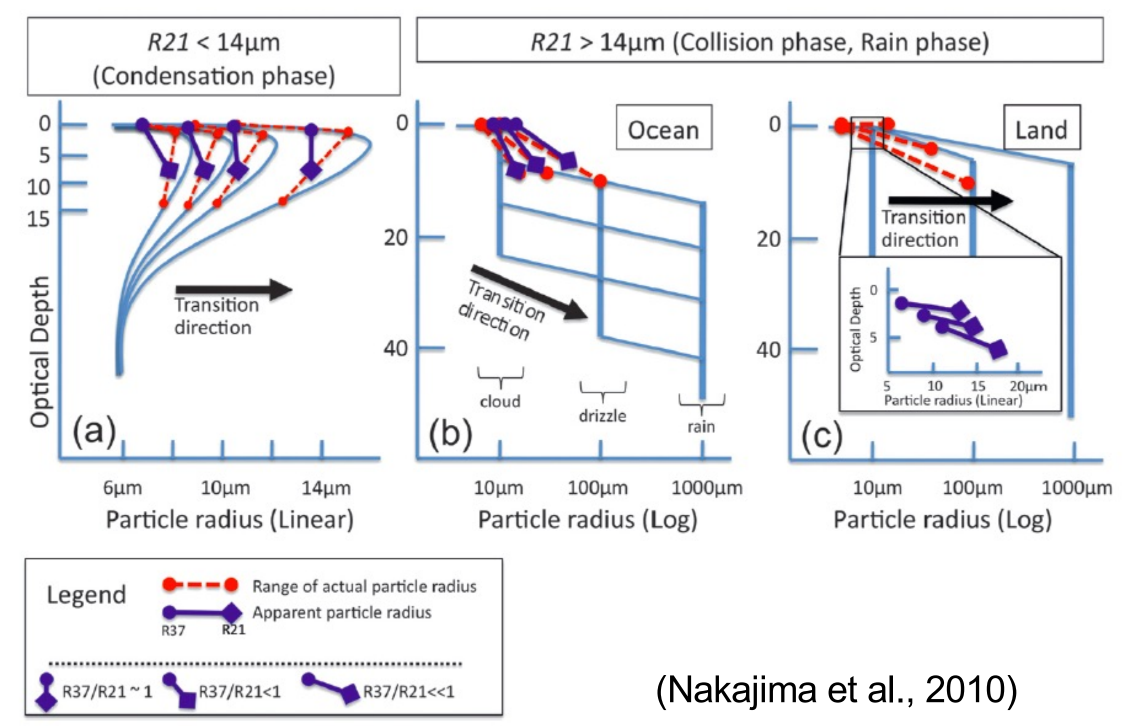
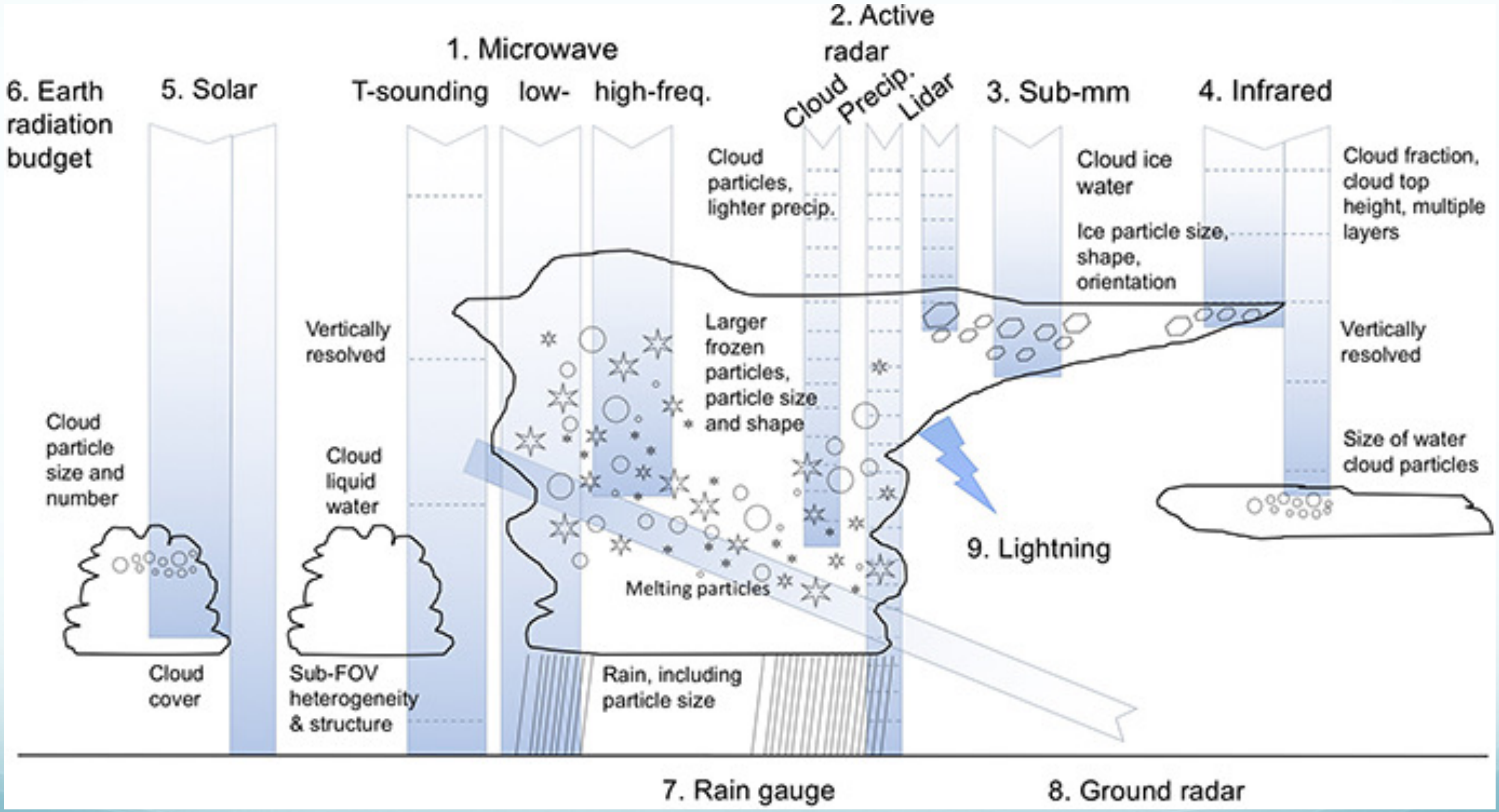


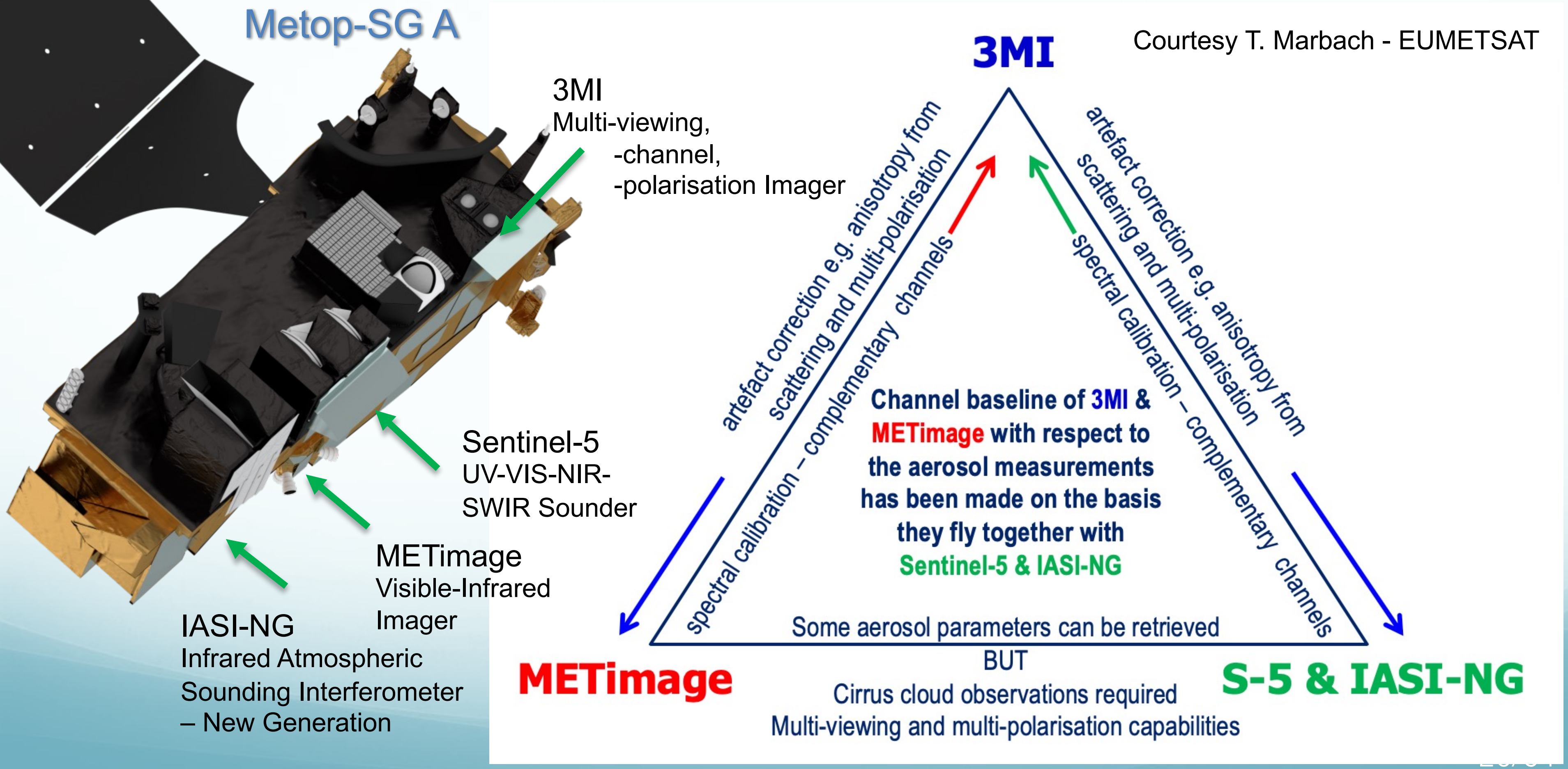
FIG. 7. Schematic diagram that explains the values of R21, R37, and R37/R21 associated with cloud growth processes.

Note: the R1.6-R2.3-R3.7 relationship are also related to the cloud top entrainment and 3-D radiative effects (Seethala and Horváth, 2010) , e.g., the shadowing and illumination (Marshak et al., 2006).

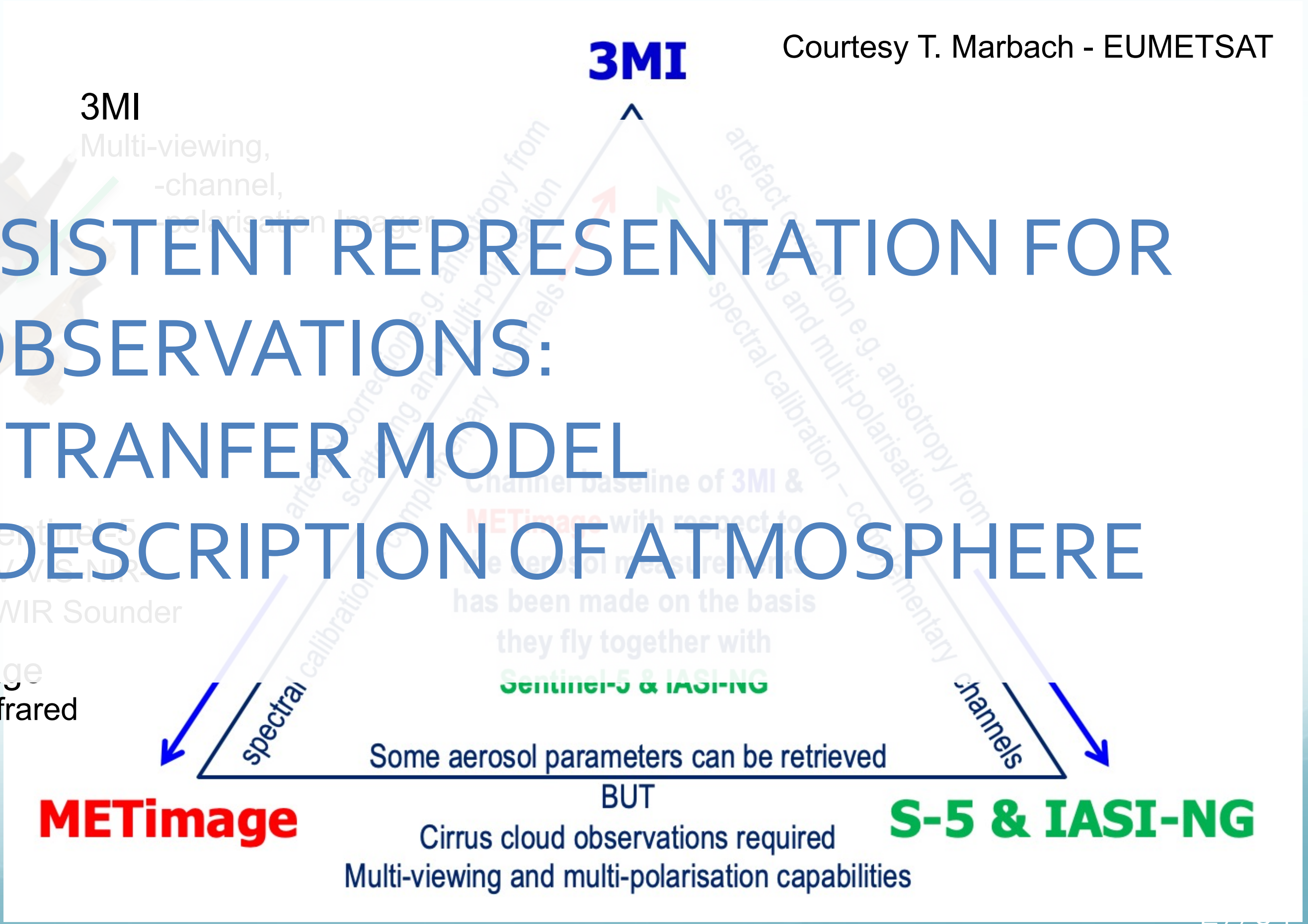


From A. Geer et al "Recent progress in all-sky radiance assimilation" Newsletter Number 161 – Autumn 2019

Synergies with EPS-SG instruments



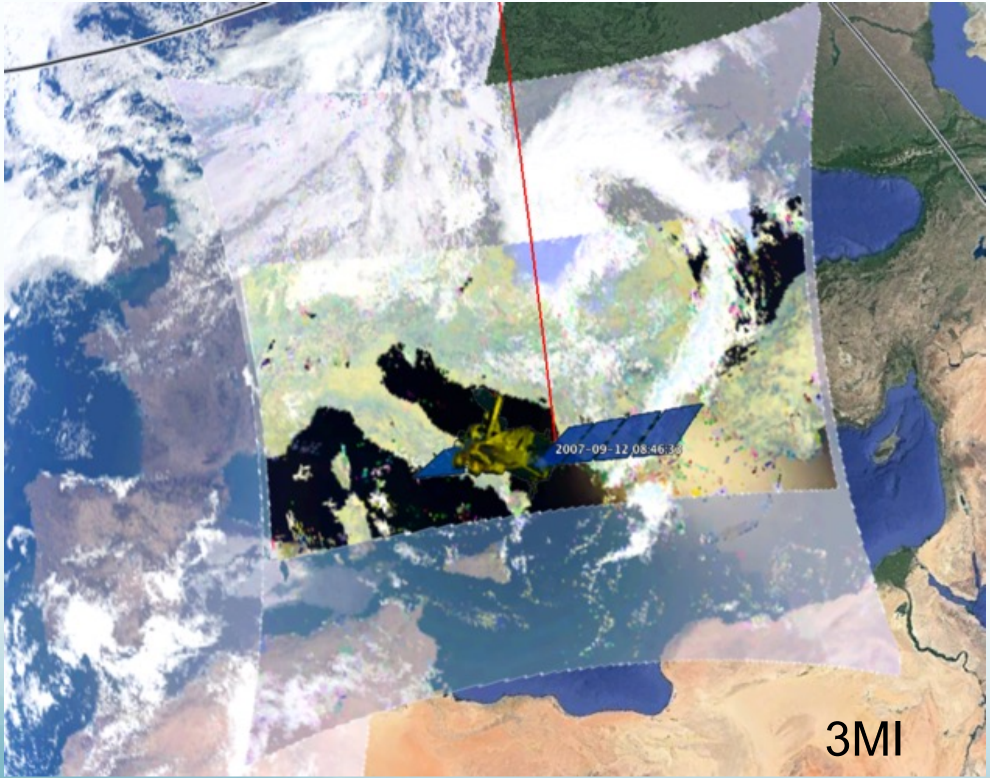
Synergies with EPS-SG instruments

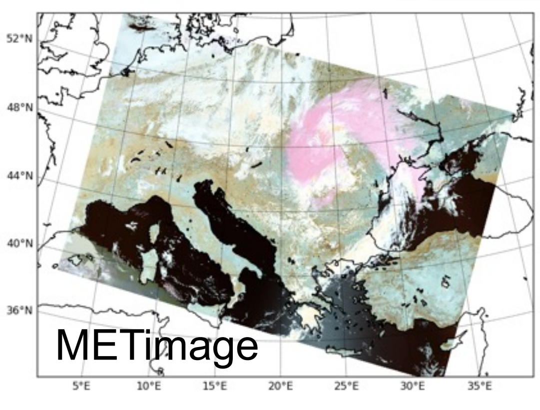


NEED A CONSISTENT REPRESENTATION FOR ALL THESE OBSERVATIONS:

- RADIATIVE TRANFER MODEL
- PHYSICAL DESCRIPTION OF ATMOSPHERE

4MSDS : building a comprehensive simulator for METOP-A SG





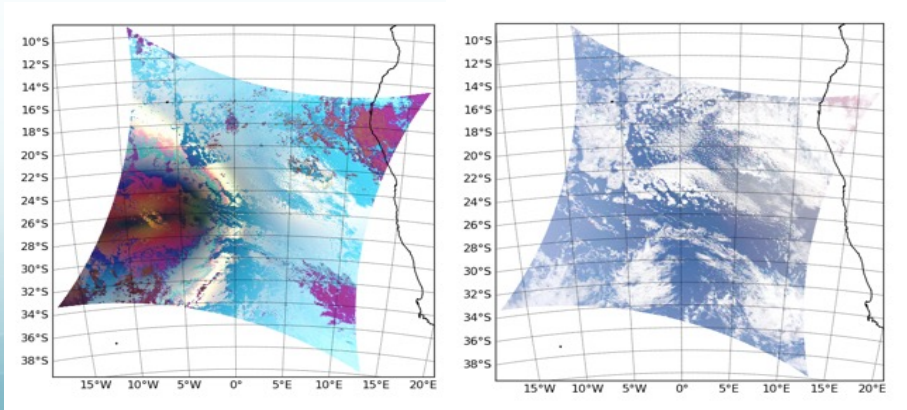
2250 nm

1630 nm

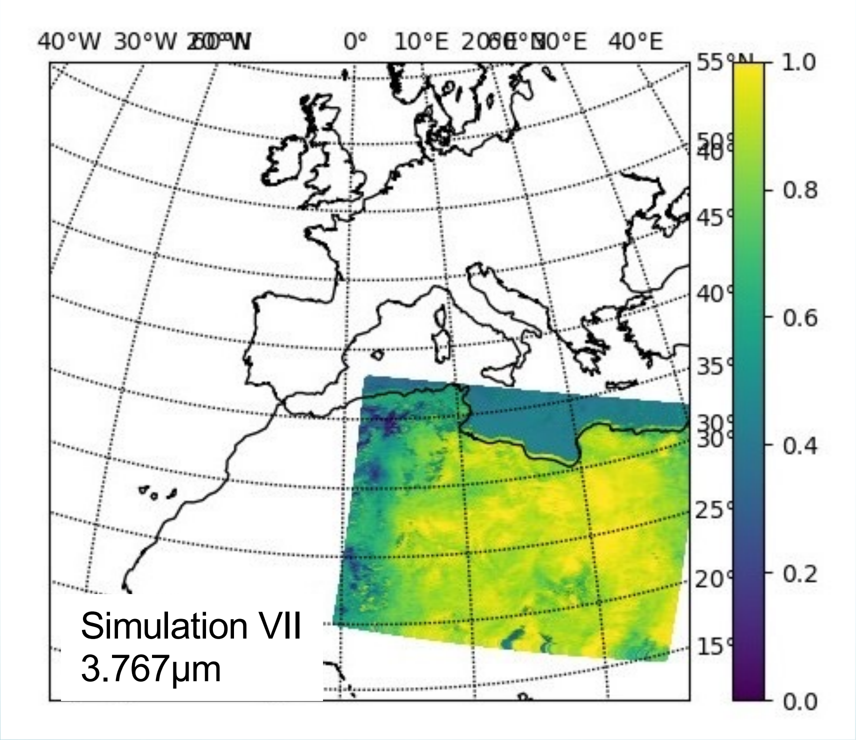
865 nm

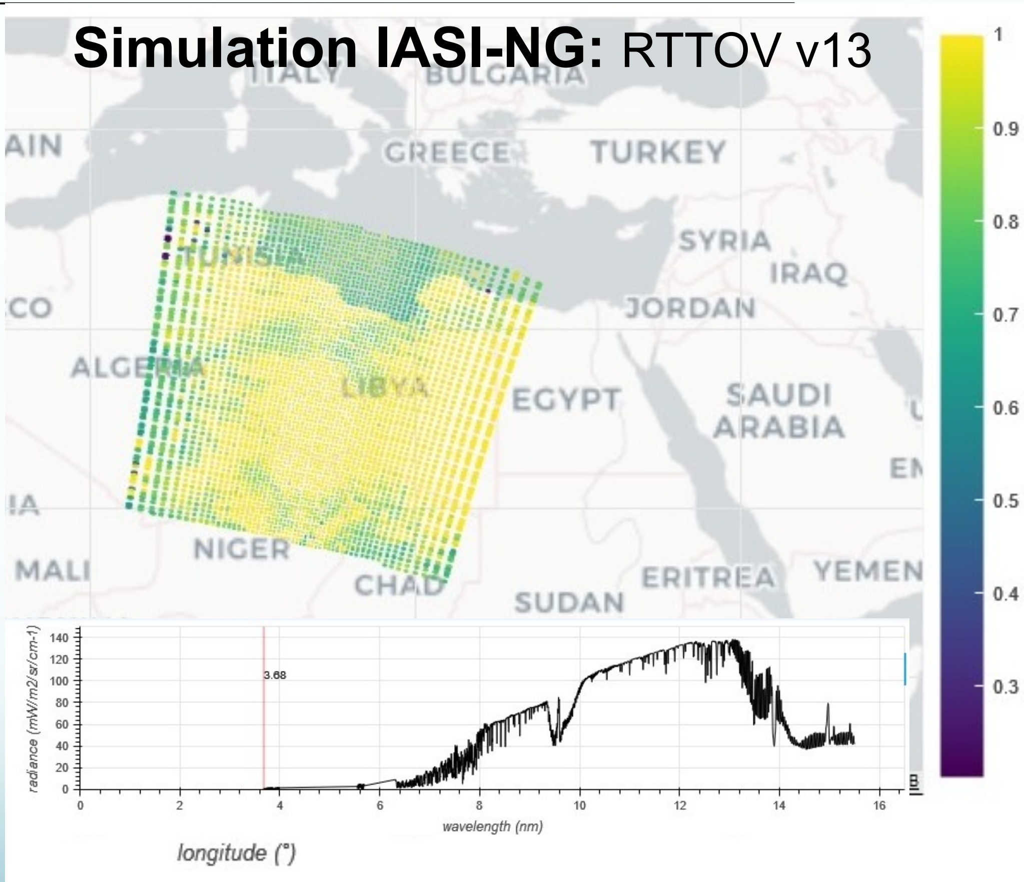
METimage RGB

3MI RGB (polar and total) 410 nm, 555 nm, 865 nm

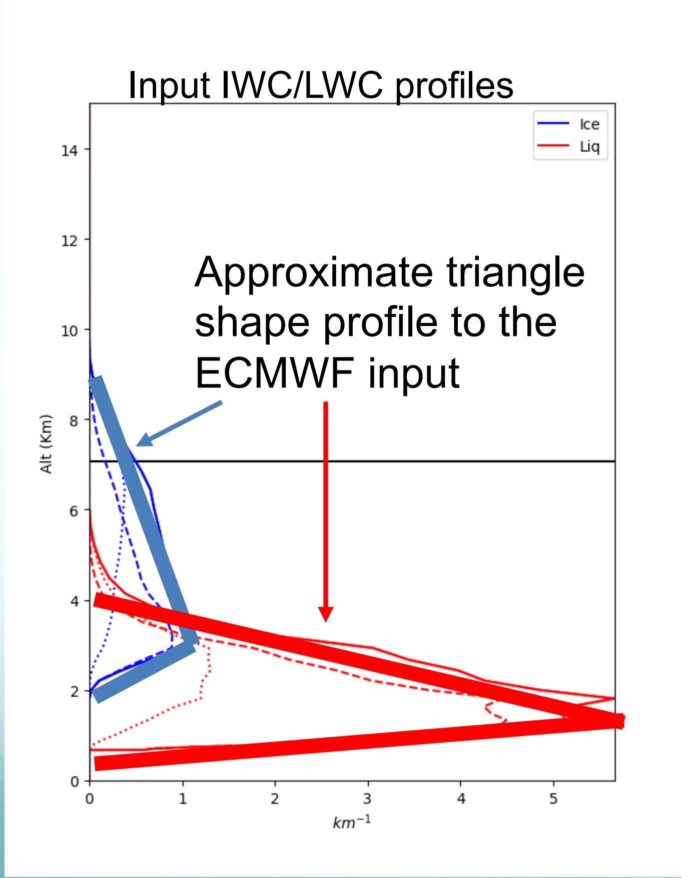


4MSDS : building a comprehensive simulator for METOP-A SG





Approach for « advanced » retrievals (day 2 algorithms)



Constrain a simplified cloud profile described by a limited number of parameters starting from a priori obtained through classic retrievals

Cloud Top Pressure (CTP)
Use multispectral Rayleigh scattering

Cloud Geometrical Thickness (CGT)
Use Oxygen A-Band differential absorption

Cloud Optical Thickess (COT)
Use multiangle VIS/NIR observations

Cloud Water Path (LWP/IWP)

Shape of LWC/IWC profile
parameter p describing the LWC/IWC triangle profile

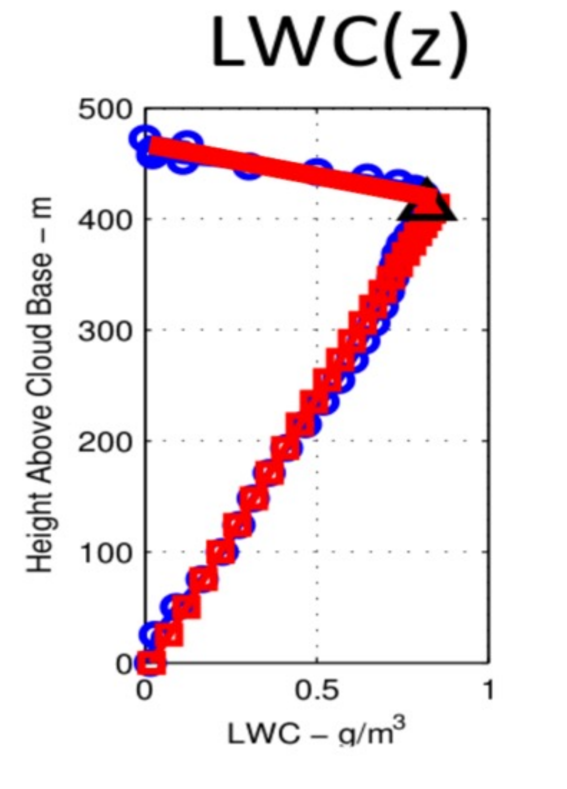
Approach for « advanced » retrievals (day 2 algorithms)

Retrieval of vertical profile of cloud properties (LWC,IWC, Extinction profile, …) under assumption of "schematic" triangle cloud profile (using p "shape" parameter).

Example : Information content for a LES stratocumulus cloud case study

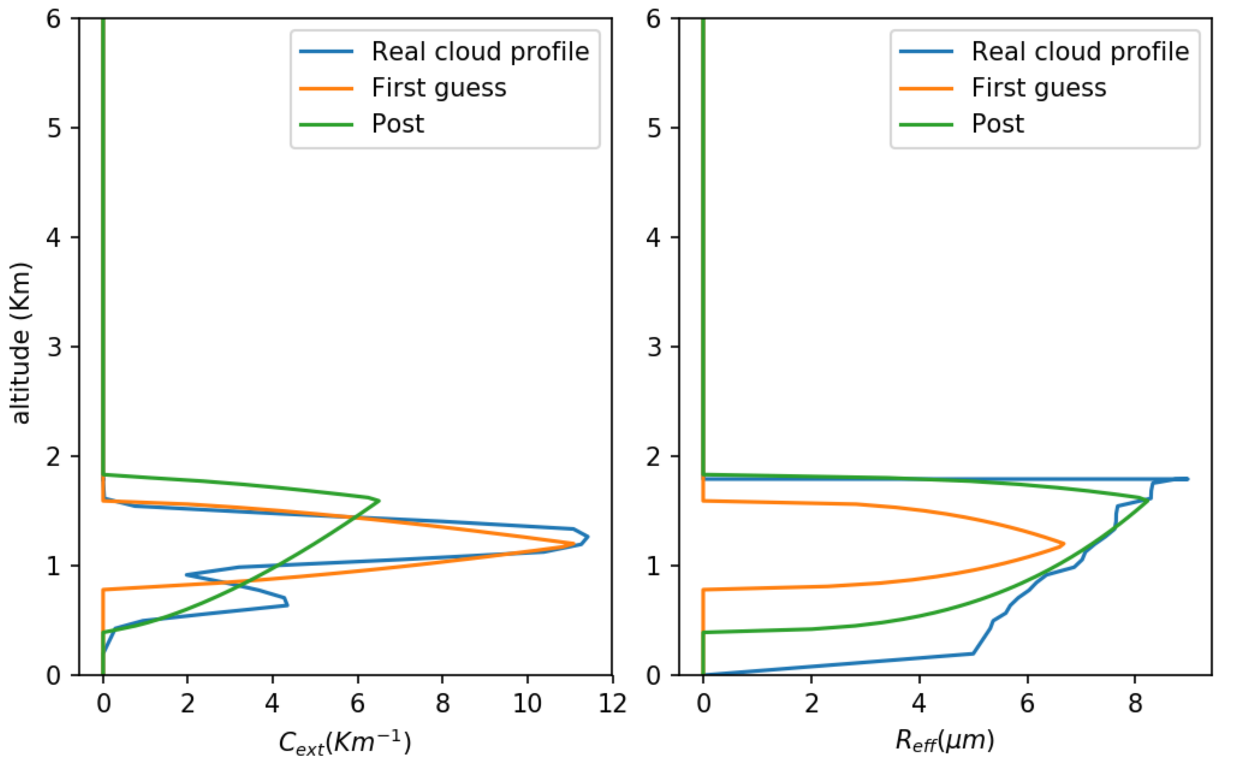
DOFs	CGT	CTOP	COT	p	LWP
I_{vis}	0	0	0.18	0	0.8
$L_{p,vis}$	0	0	0	0	0
I_{SWIR}	0.02	0	0.78	0.03	0.19
$L_{p,SWIR}$	0.98	0	0.03	0.97	0.01
R_{Aband}	0	1	0	0	0
Total	1	1	1	1	1

(g) LES Miller et al.



From G. Merlin, 2016 PhD thesis

Approach for « advanced » retrievals (day 2 algorithms)



Case study

COT ~ 6.2

CTP~ 860hPa

First guess (Day 1 products)

COT (bi-spect) = 5.37 +/- 0.63

Reff (bi-spect) = 6.72 +/- 0.81

CTP (first) = 843.78 +/- 5.20

Retrieved after 3 iterations :

COT 5.56 +/- 0.00

R_{eff} 8.26 +/- 0.01

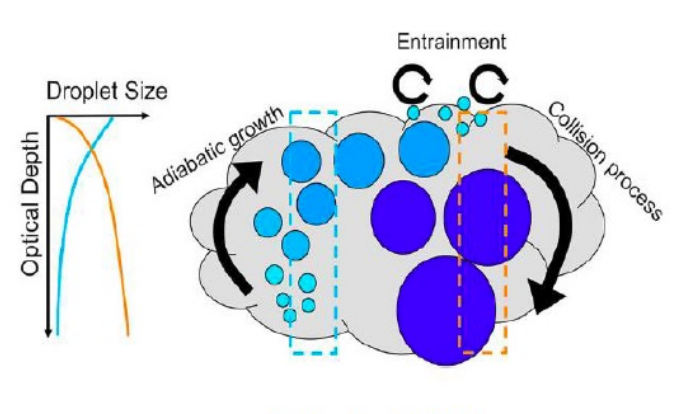
CTP 821.66 +/- 5.01

CGT 1.37 +/- 0.21

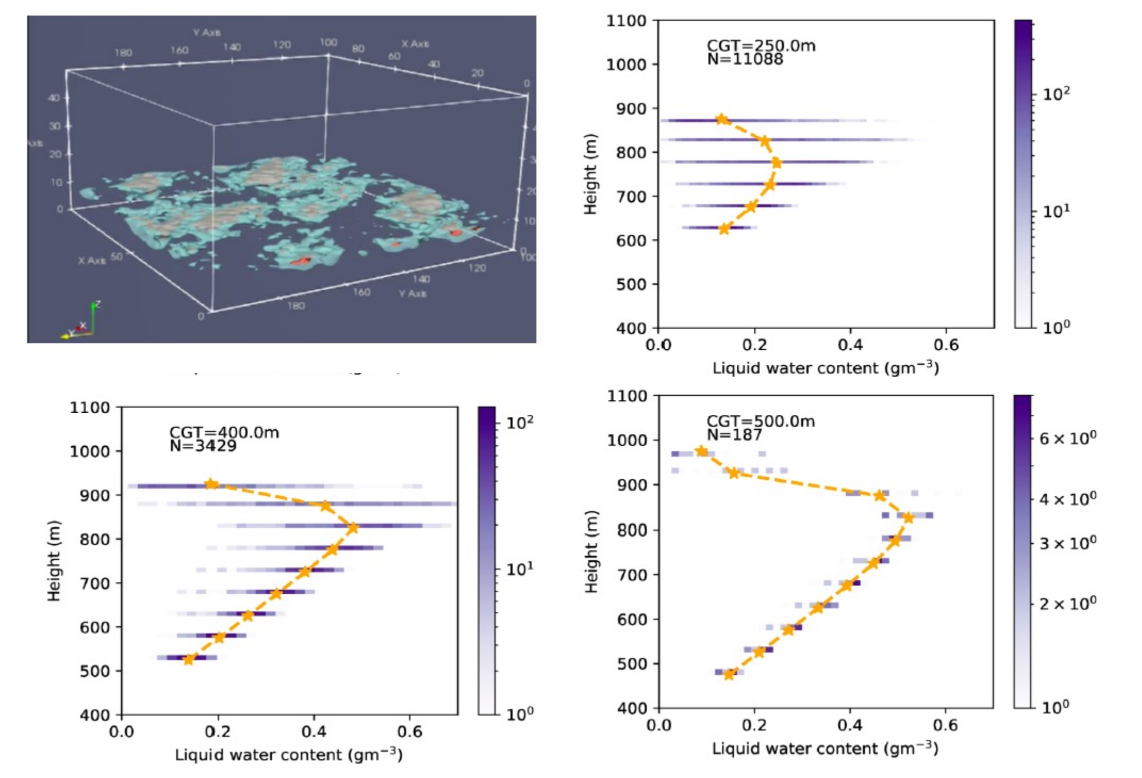
p 0.15 +/- 0.00

V_{eff} 0.09 +/- 0.00

Can we use a more physically realistic profile model ?

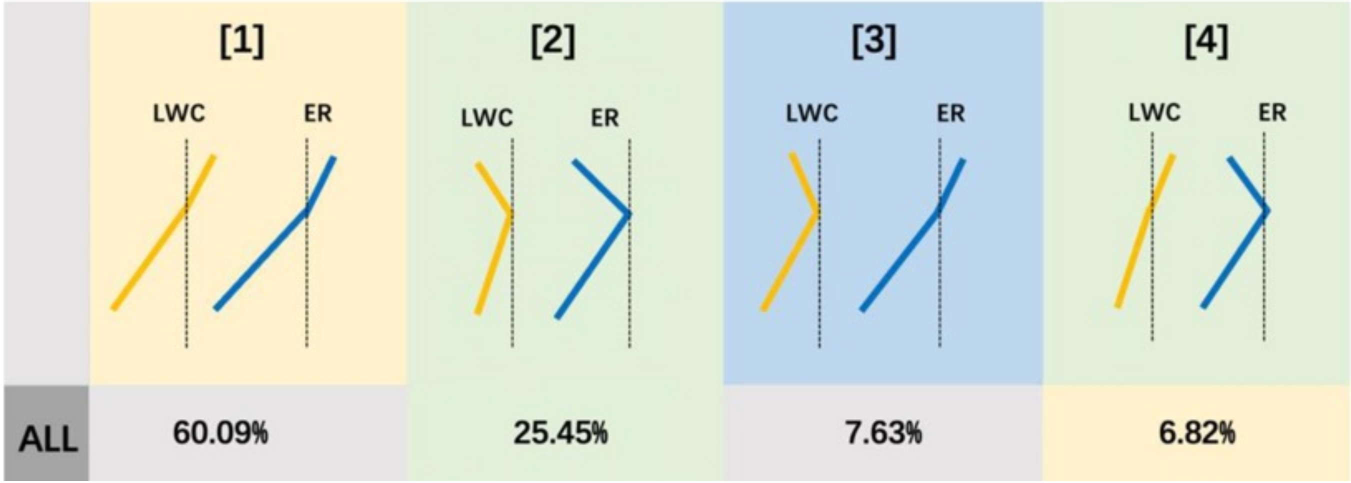


(Saito et al., 2019)



Approach : use LES simulation to study main characteristics of liquid cloud profiles for a large variety of atmospheric conditions and develop and analytical model for particle size, LWC and CDNC vertical profile.
(H. Shang, S. Hioki, G. Penide, J. Riedi)

What are the dominent features of LWC/Reff profiles ?



WE : Weak Entrainment

SE : Strong Entrainment

WP : Weak Precipitation

SP : Strong Precipitation

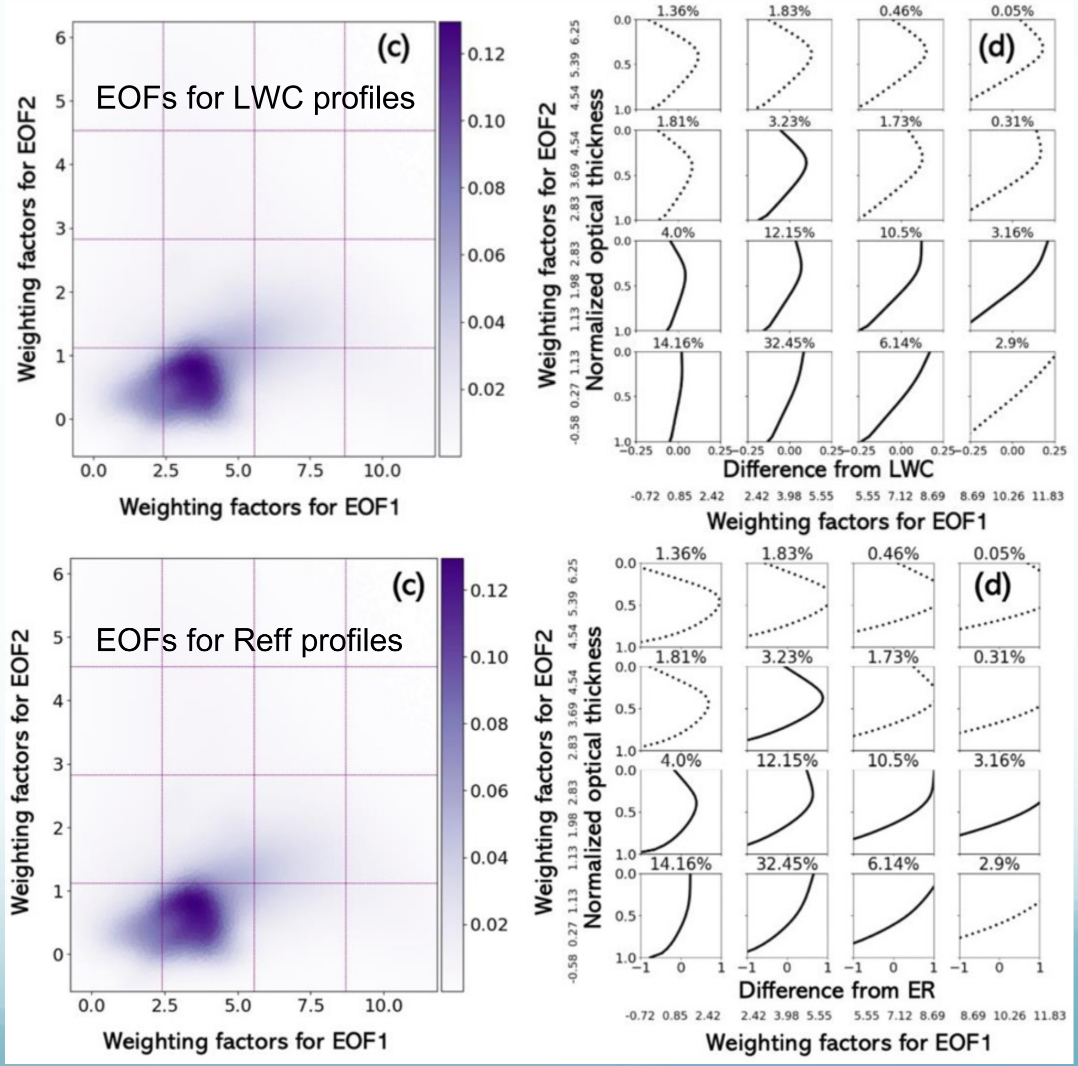
Can we see an impact of entrainment and /or precipitation ?

To go further ...

The LWC and Reff are decomposed into Empirical Orthogonal Functions.

3 EOFs are enough to explain 91% of the profiles variability

Profiles are analyzed along the first 2 EOFs to investigate the main features of cloud profiles



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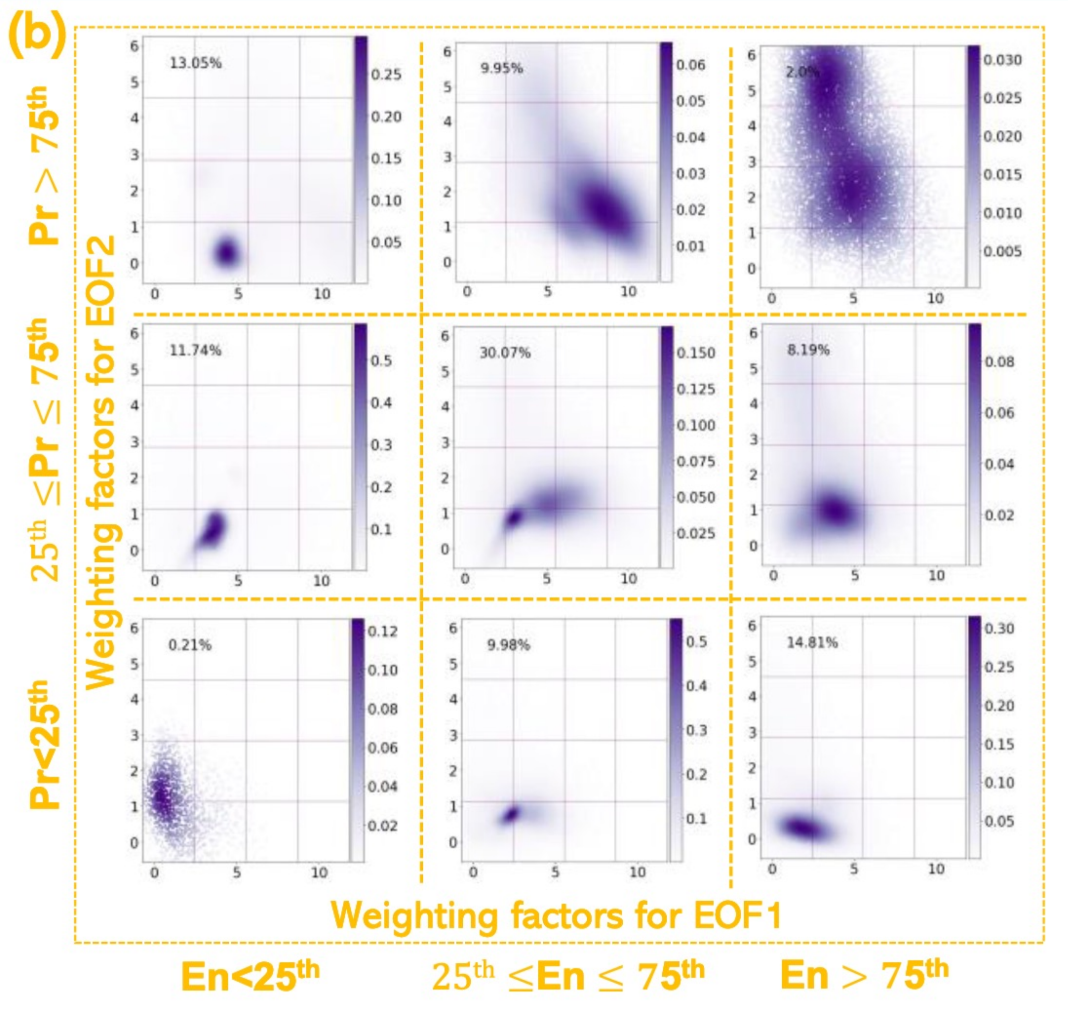
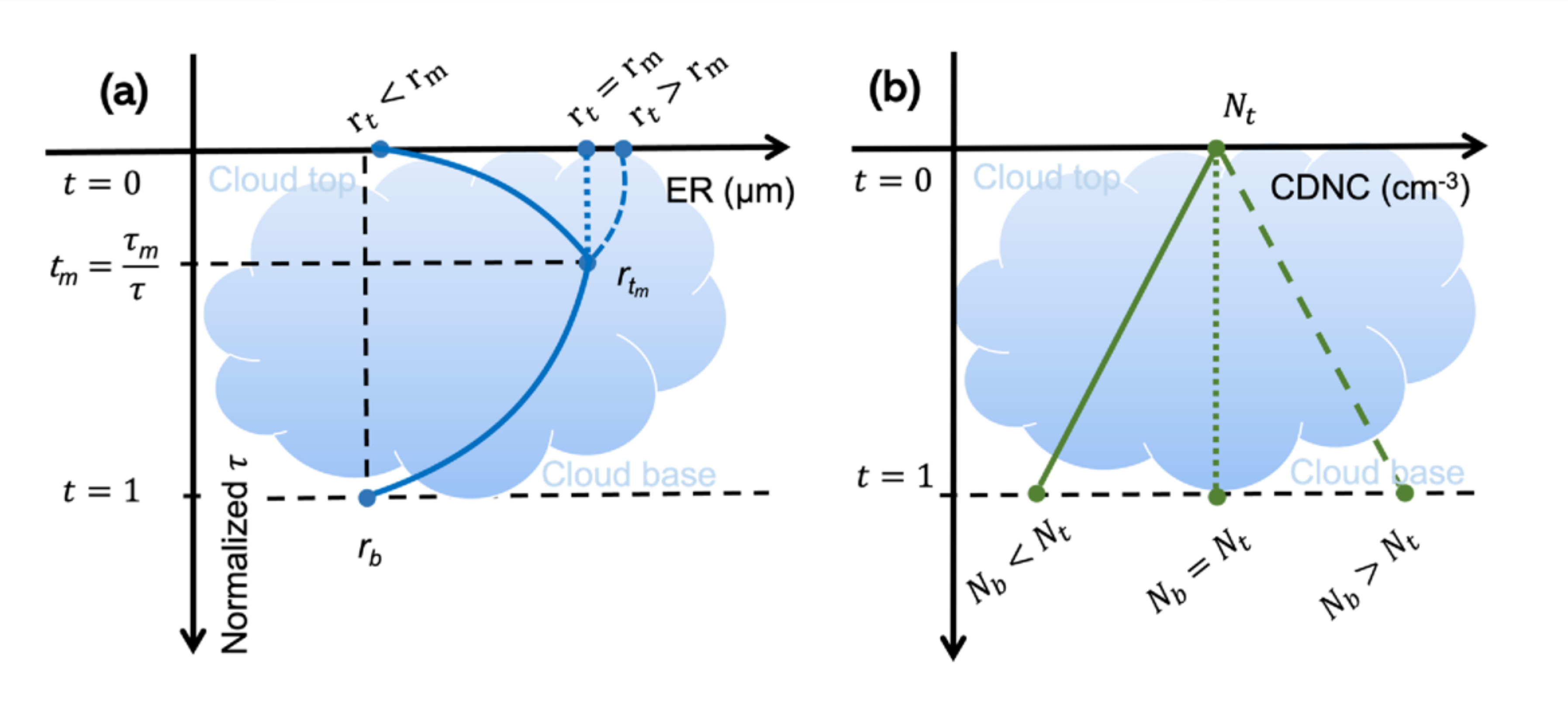


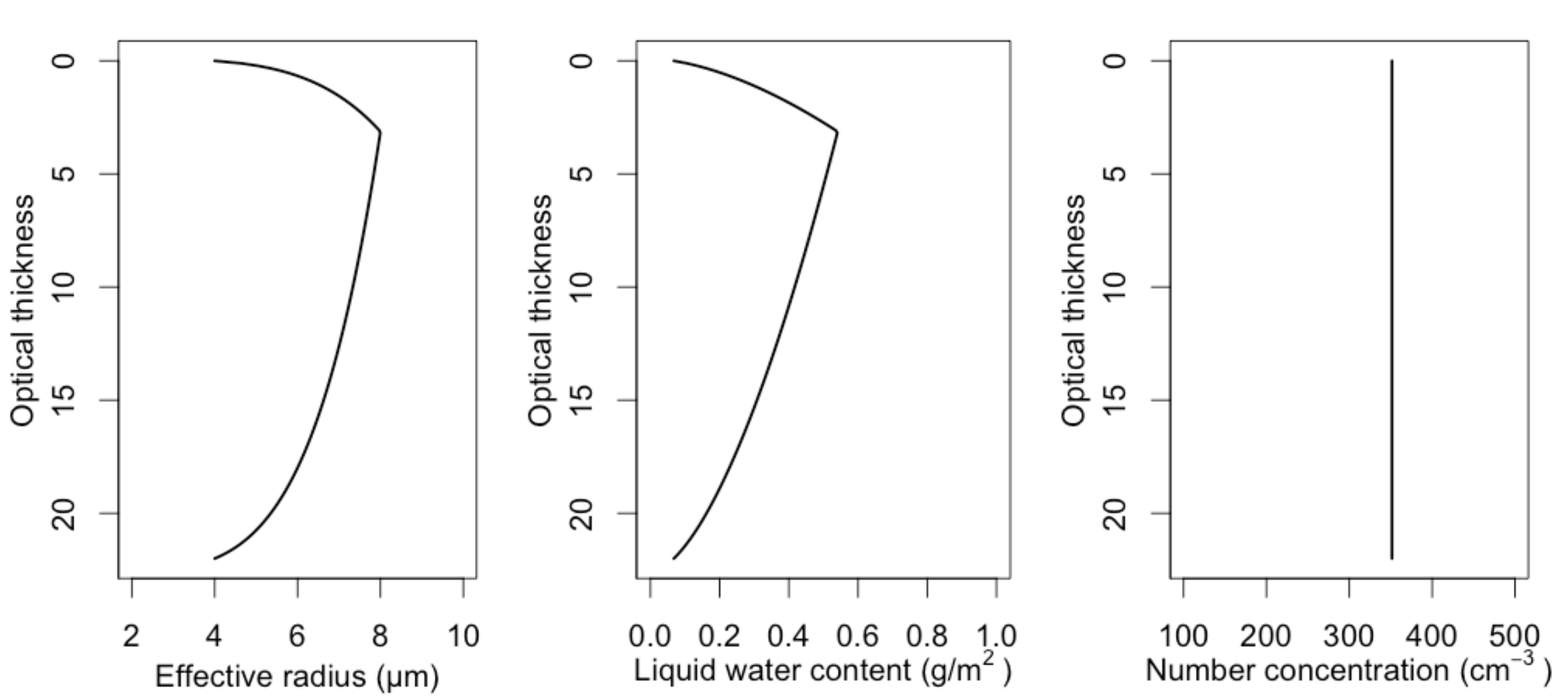
The “Two-Regimes” model



Two-regime model examples

Traditional example (Type 1):

- Slope of number concentration = 0
- Geometric thickness = 0.3 km
- Cloud top effective radius = 4 μm
- Regime boundary effective radius = 8 μm
- Cloud bottom effective radius = 4 μm
- Regime boundary optical thickness = 3.13
- Cloud optical thickness = 22

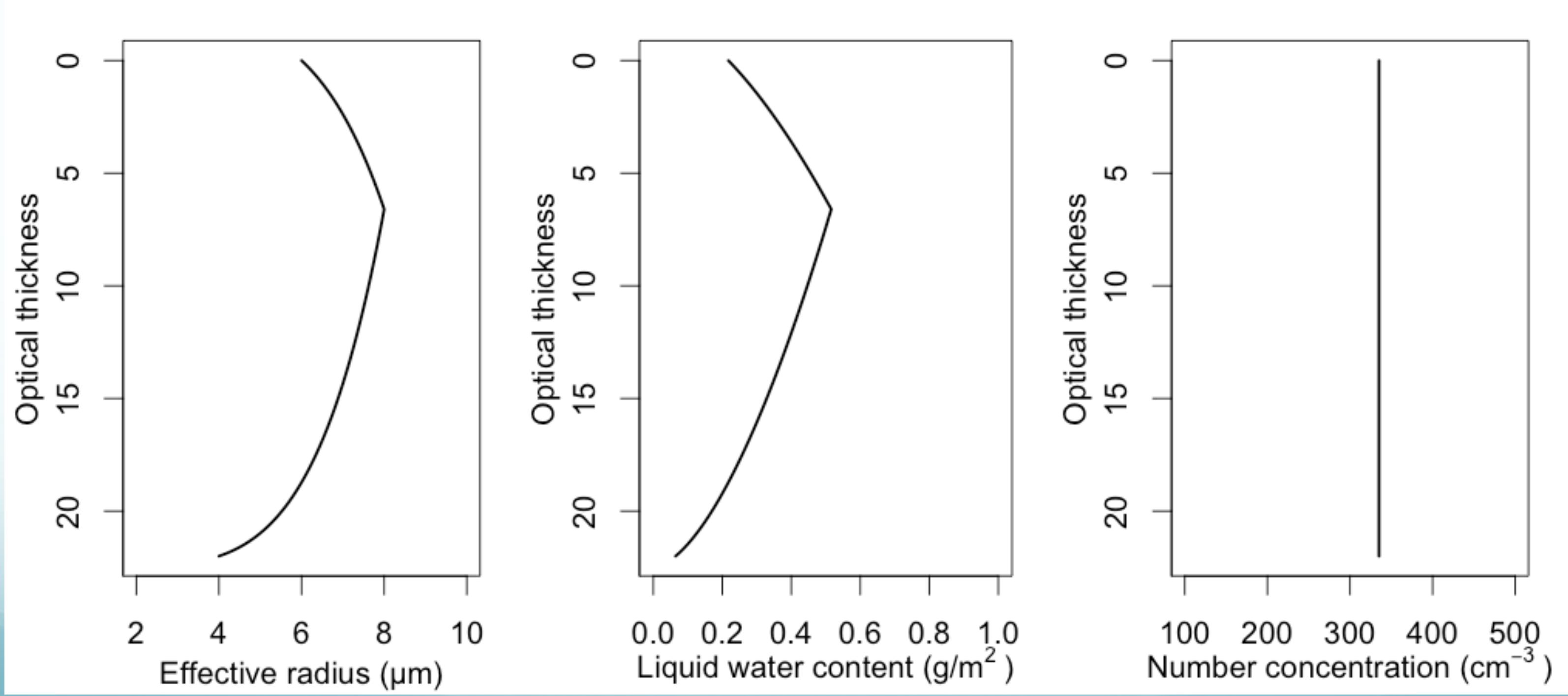


Shang et al, 2023 (ACP)

Two-regime model examples

Profile Type 1:

- Slope of number concentration = 0
- Geometric thickness = 0.3 km
- Cloud top effective radius = 6 μm
- Regime boundary effective radius = 8 μm
- Cloud bottom effective radius = 4 μm
- Regime boundary optical thickness = 6.6
- Cloud optical thickness = 22



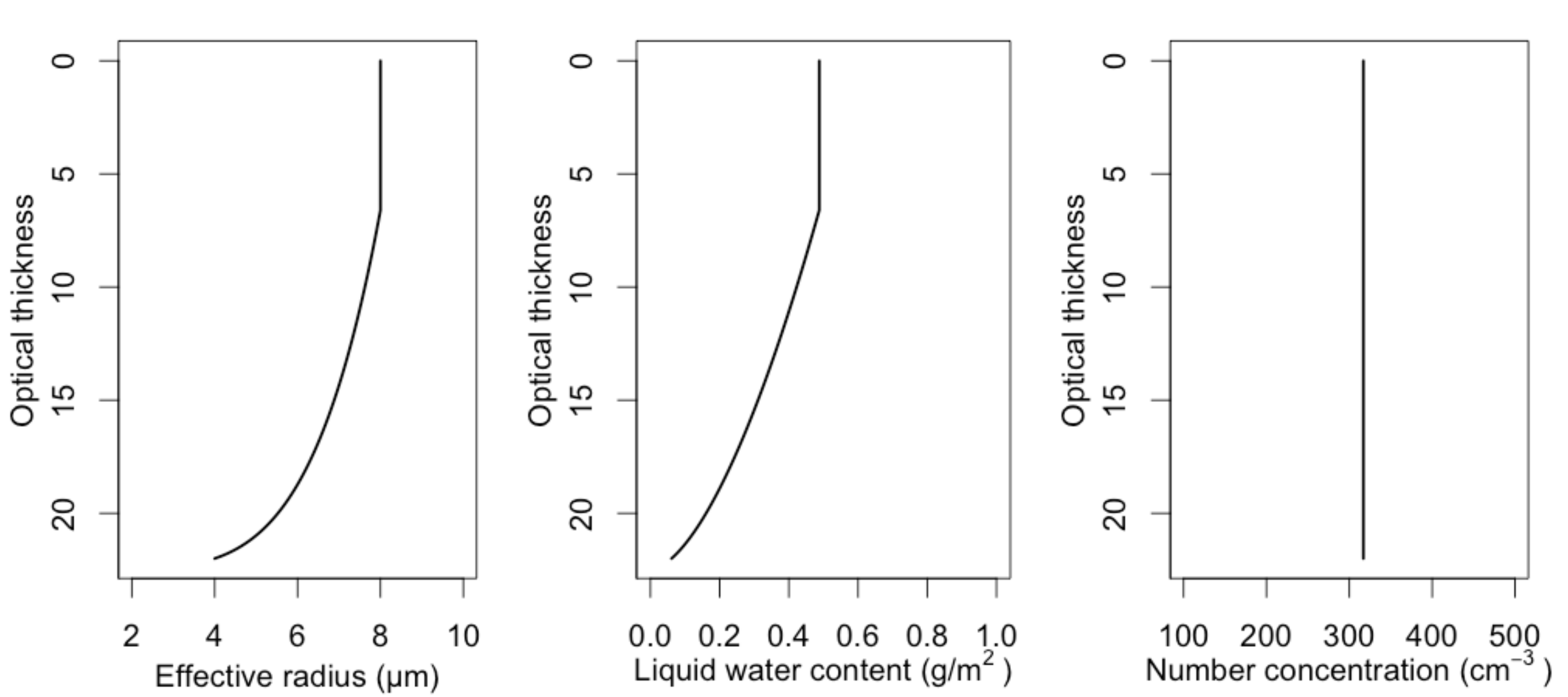
Shang et al, 2023 (ACP)

Two-regime model examples

Profile Type 2:

- Slope of number concentration = 0
- Geometric thickness = 0.3 km

- Cloud top effective radius = 8 μm
- Regime boundary effective radius = 8.3 μm
- Cloud bottom effective radius = 4 μm
- Regime boundary optical thickness = 6.6
- Cloud optical thickness = 22



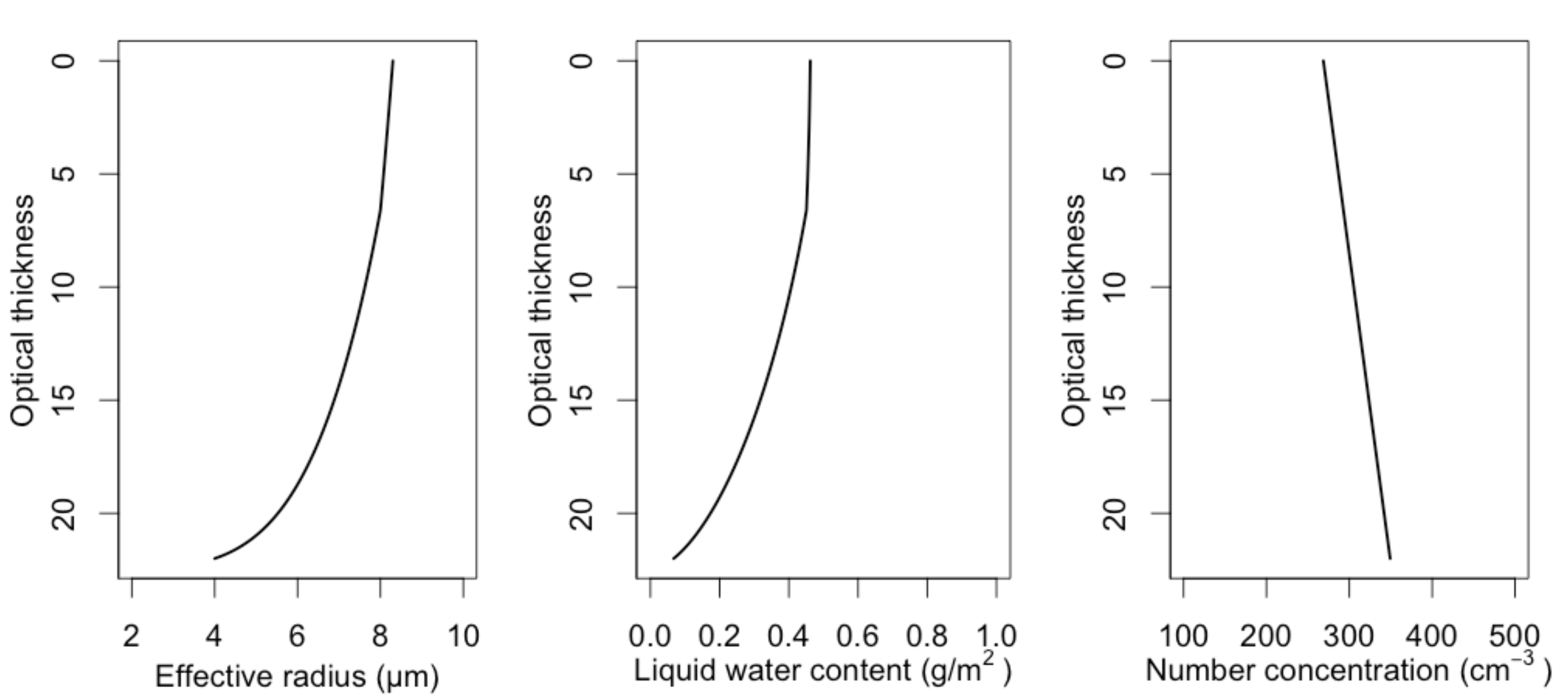
Shang et al, 2023 (ACP)

Two-regime model examples

Profile Type 3:

- Slope of number concentration = 0
- Geometric thickness = 0.3 km

- Cloud top effective radius = 8 μm
- Regime boundary effective radius = 8.3 μm
- Cloud bottom effective radius = 4 μm
- Regime boundary optical thickness = 6.6
- Cloud optical thickness = 22



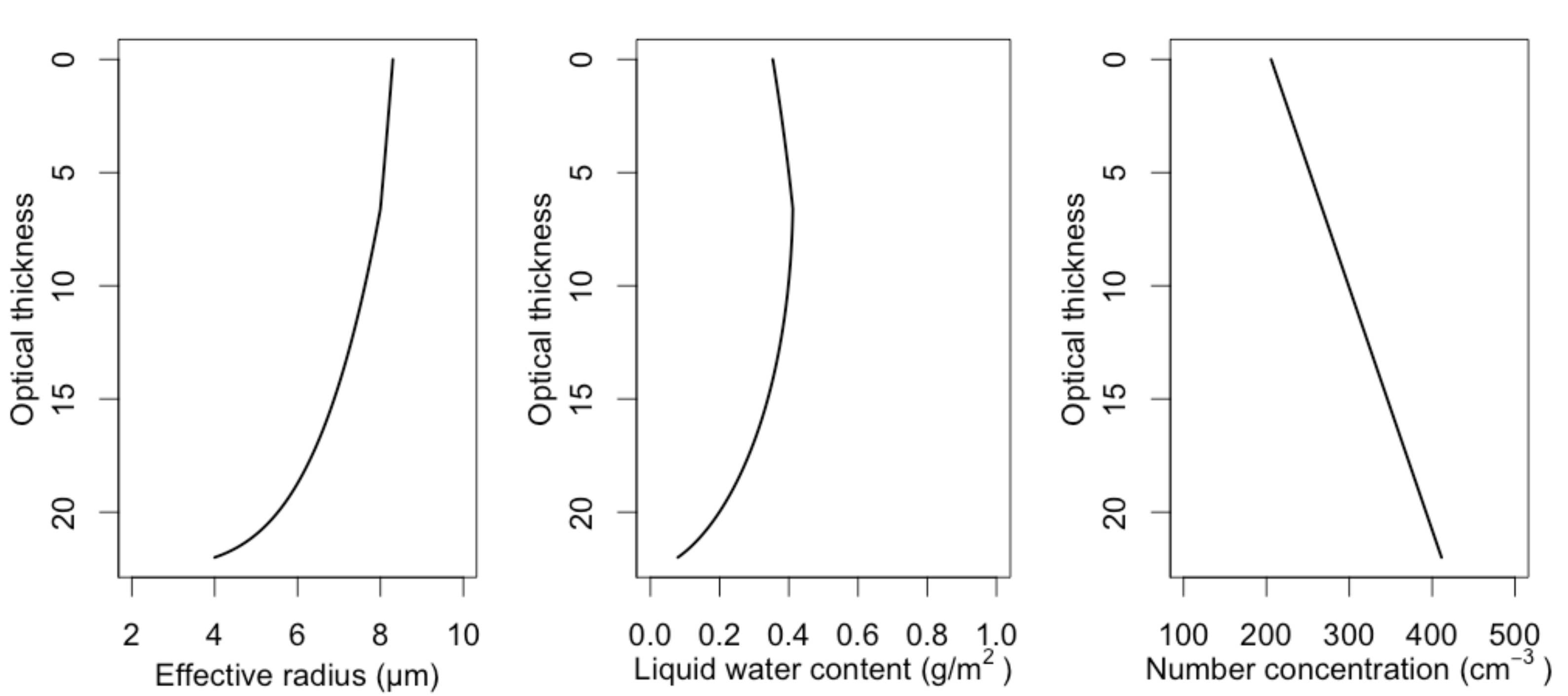
Shang et al, 2023 (ACP)

Two-regime model examples

Profile Type 4:

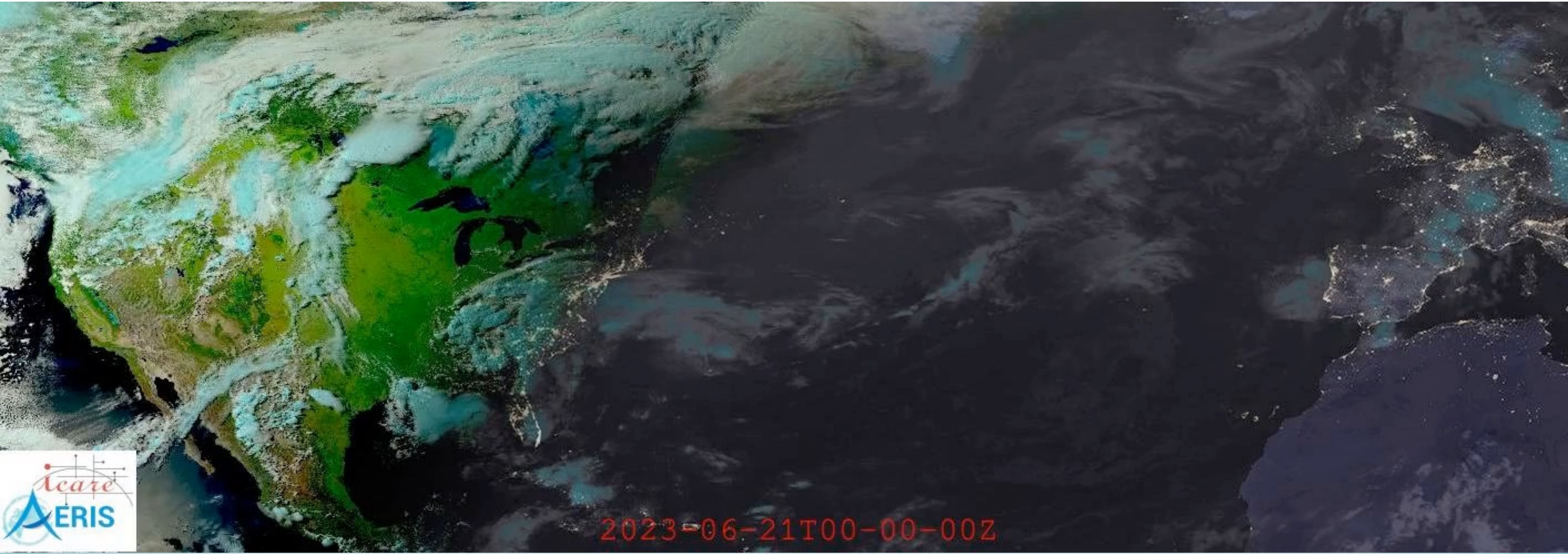
- Slope of number concentration = 0
- Geometric thickness = 0.3 km

- Cloud top effective radius = 8 μm
- Regime boundary effective radius = 8.3 μm
- Cloud bottom effective radius = 4 μm
- Regime boundary optical thickness = 6.6
- Cloud optical thickness = 22



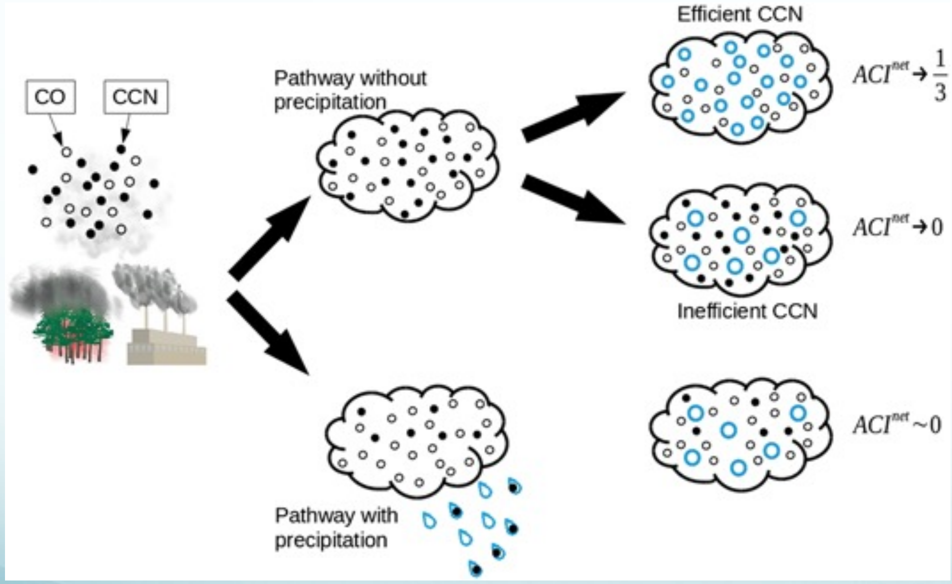
Shang et al, 2023 (ACP)

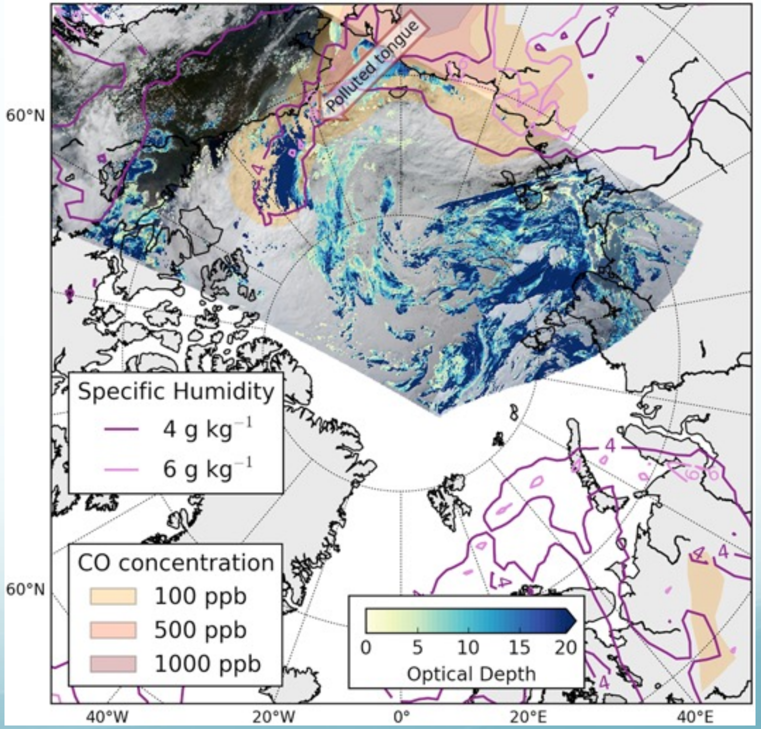
Combining LEO & GEO to study cloud processes and dynamics



Studying Cloud / Aerosols interaction

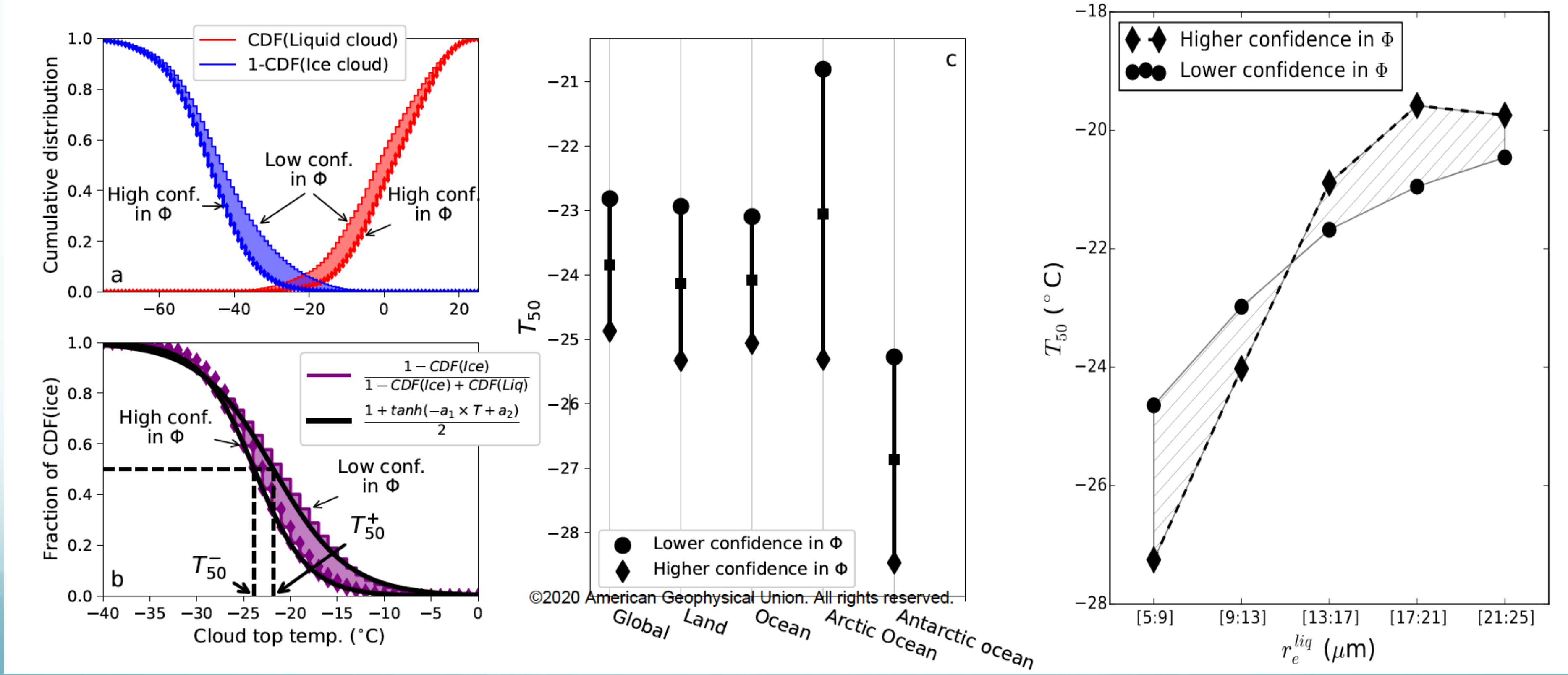
Q. Coopman, T.J. Garrett, J. Riedi, S. Eckhardt, and A. Stohl. Effects of long-range aerosol transport on the microphysical properties of low-level liquid clouds in the arctic. Atmospheric Chemistry and Physics, 16(7) :4661–4674, 2016.
Q. Coopman, T. J. Garrett, D. P. Finch, and J. Riedi. High sensitivity of arctic liquid clouds to long-range anthropogenic aerosol transport. Geophysical Research Letters, pages n/a–n/a, 2017. 2017GL075795.





Space-based analysis of the cloud thermodynamic phase transition for varying microphysical and meteorological regimes,

Q. Coopman, J. Riedi, S. Zeng, T. Garrett, Geophysical Research Letters (2020)



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Impact of particle size on cloud glaciation temperature

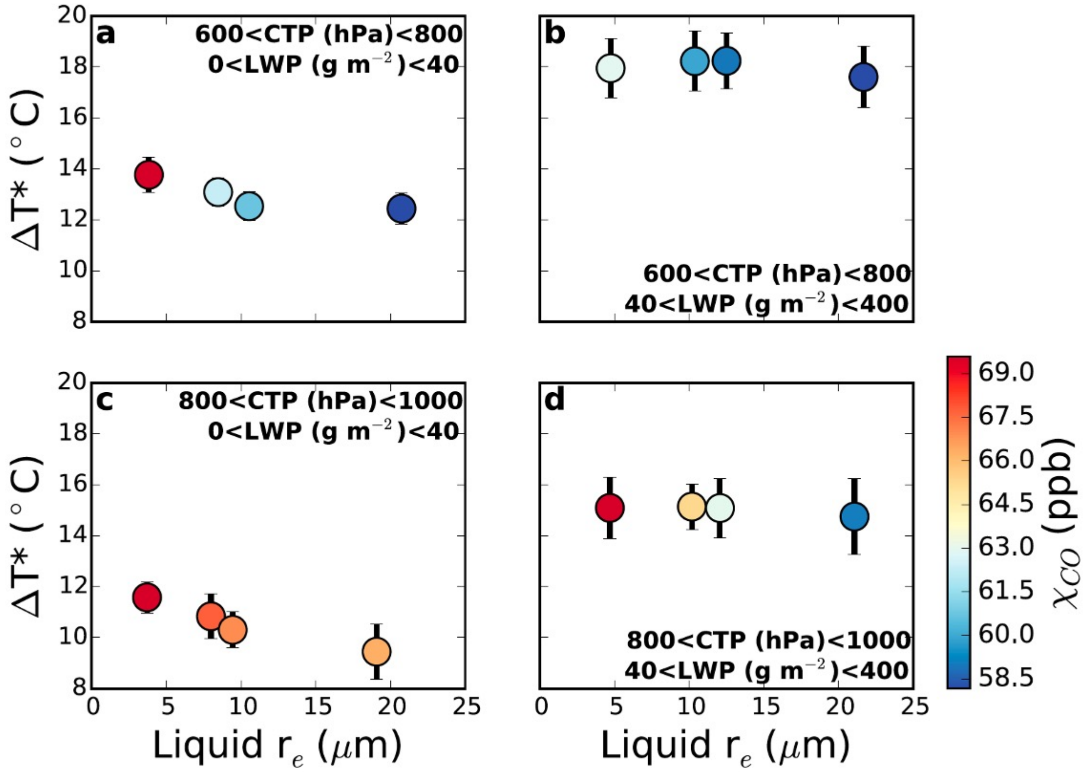


Figure 3. Supercooling freezing temperature (ΔT^*) as a function of the liquid-cloud-droplet effective radius (r_e) for four cloud categories differentiated by their liquid water path (LWP) and cloud top pressure (CTP). The color scale corresponds to the associated mean CO concentration (χ_{CO}). The uncertainty bars are calculated from equation (6).

Impact of aerosol on cloud glaciation temperature

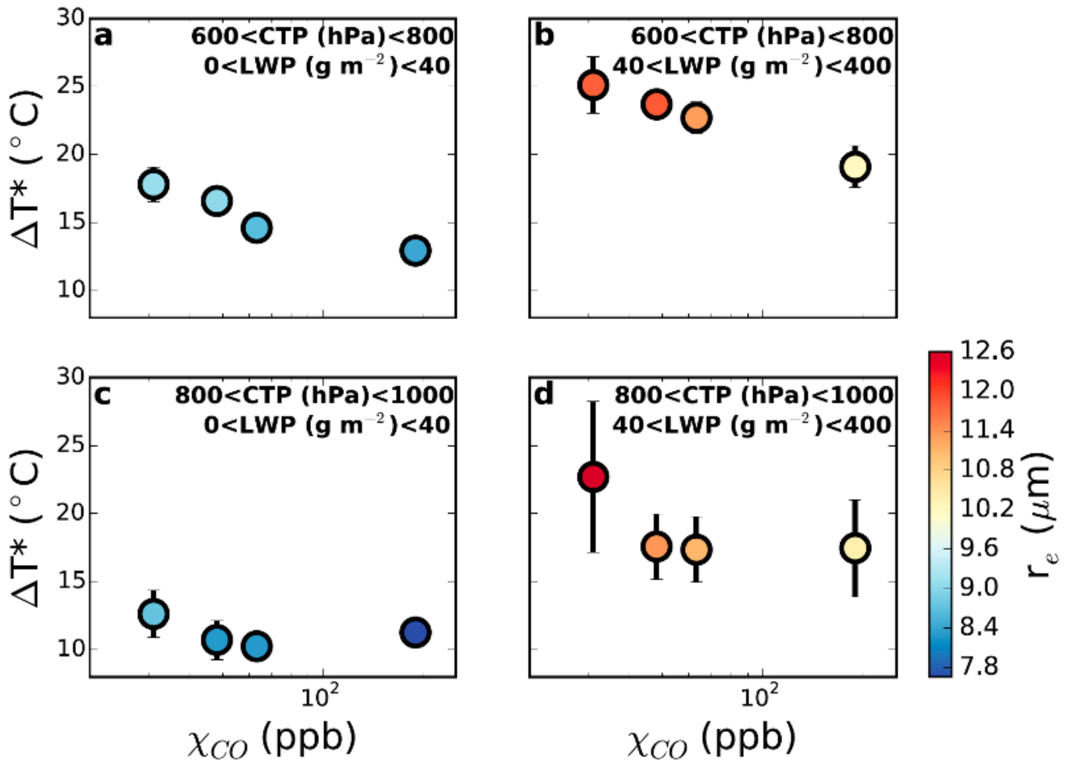
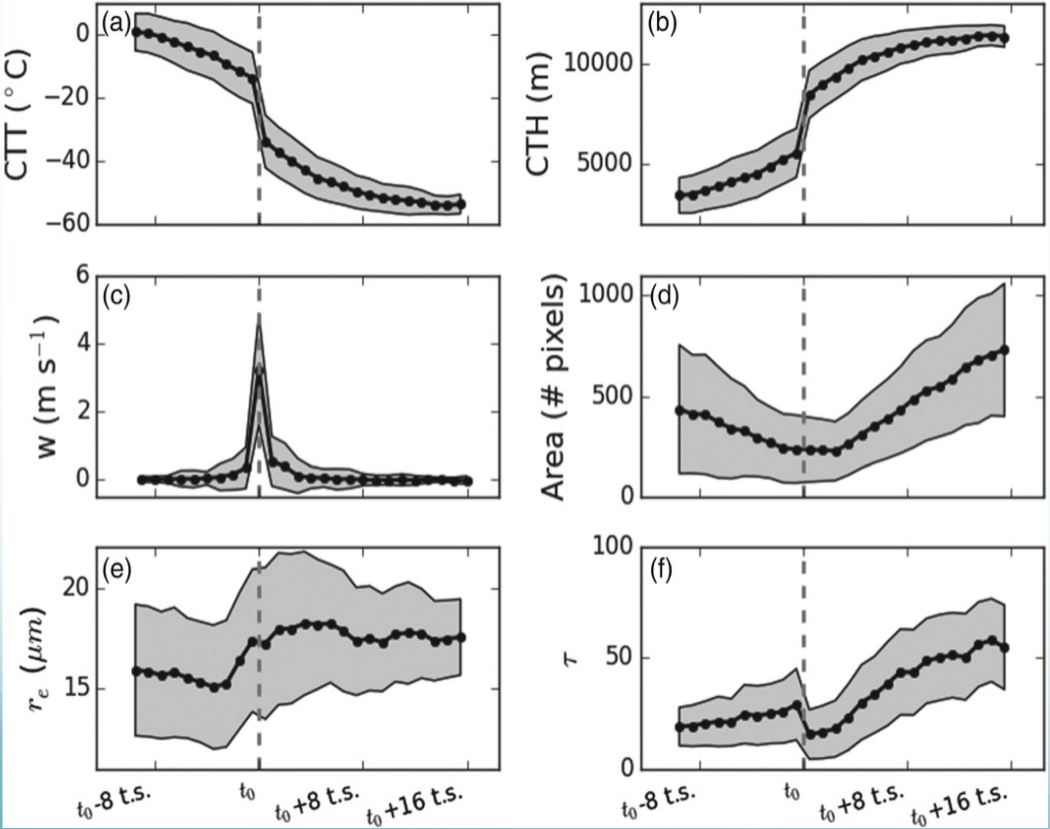


Figure 4. Supercooling freezing temperature (ΔT^*) as a function of the CO concentration (χ_{CO}) for four cloud categories differentiated by their liquid water path (LWP) and cloud top pressure (CTP). The color scale corresponds to the associated mean liquid-cloud droplet effective radius (r_e). The uncertainty bars are calculated from equation (6).

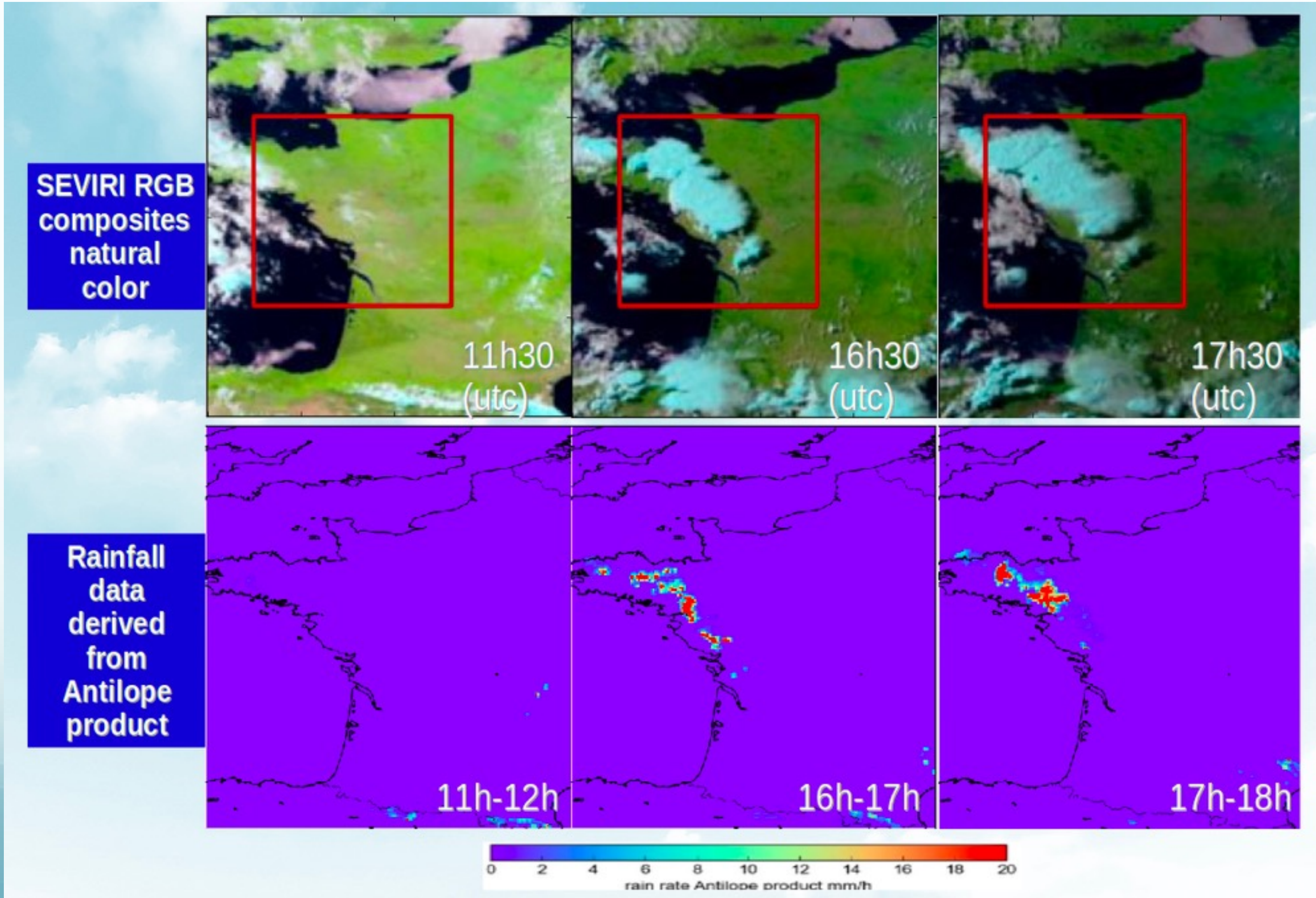
Analysis of the Thermodynamic Phase Transition of Tracked Convective Clouds Based on Geostationary Satellite Observations (Coopman et al, 2020)



(a) Average of the temporal evolution of the cloud top temperature for 796 tracked using the phase transition time as a reference and the shaded area represents the standard deviation. The sub-figure *b* is the same as *a* but for the cloud top height (CTH), *c* for the apparent ascent speed of the cloud top (*w*), *d* for the cloud area, *e* for cloud particle radii (r_e), and *f* for the median of cloud optical depth (τ).

JGR Atmospheres, Volume: 125, Issue: 11, First published: 21 May 2020, DOI: (10.1029/2019JD032146)

Studying Life Cycle of Precipitating Cloud Systems

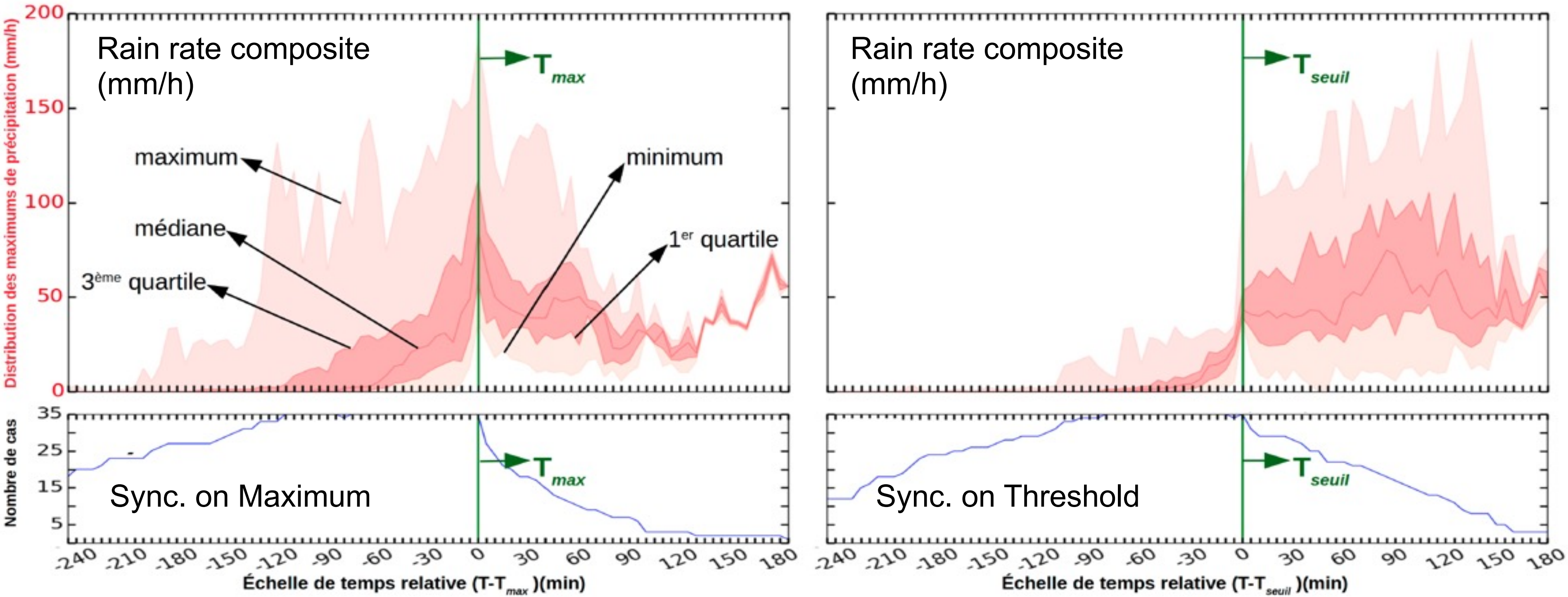


Combination of ground based radar network and GEO observation at high temporal resolution to study precipitation processes (From M. Patou - PhD Thesis)

Principle of analysis : create composite evolution of cloud system but synchronizing different cases based on reference time defined by rainfall rate

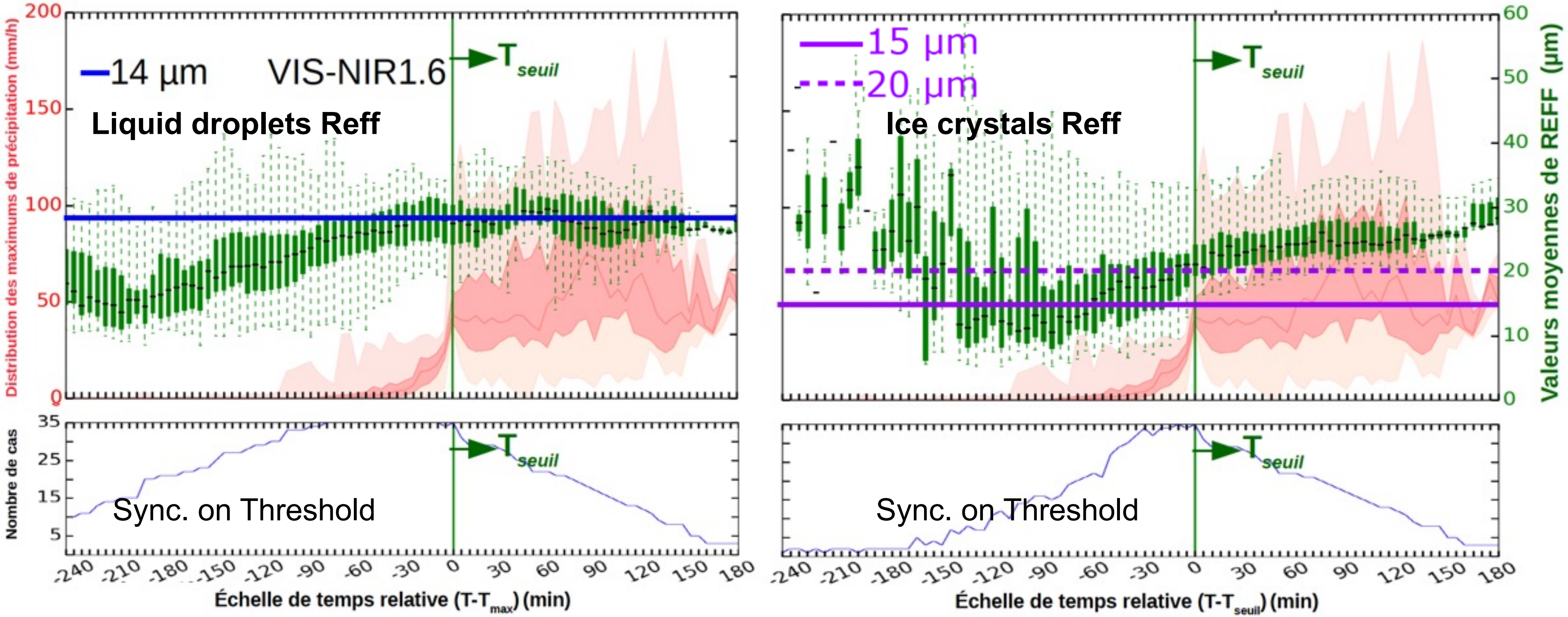
Patou et al (2018) : Prediction of the onset of heavy rain using SEVIRI cloud observations, J. Appl. Met. Clim

Example of Temporal Analysis of Cloud Properties during precipitation development



Composite of precipitation rates for 35 cases observed using MeteoFrance radar network – Left : synchro at time of Maximum rate – Right : synchro at threshold value of 36 mm/hour

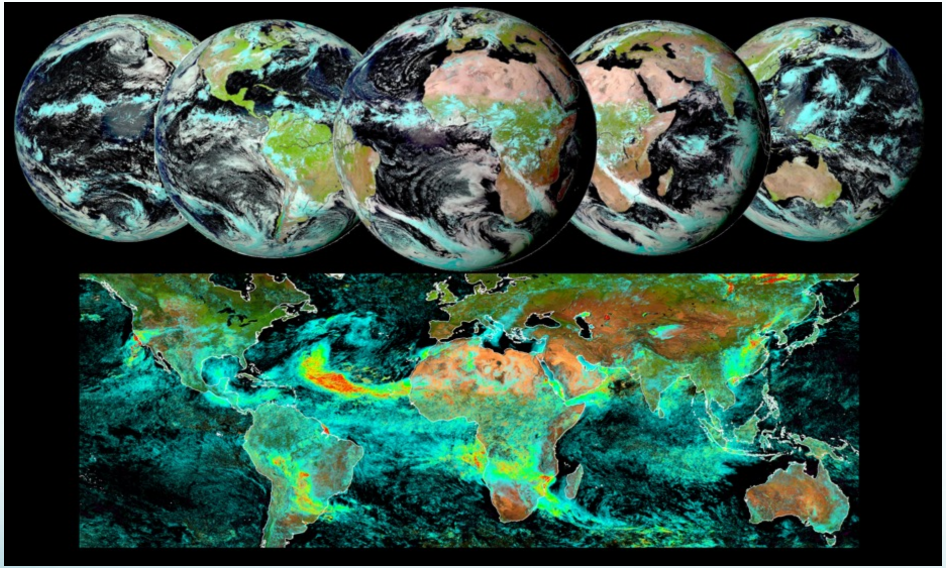
Example of Temporal Analysis of Cloud Properties during precipitation development



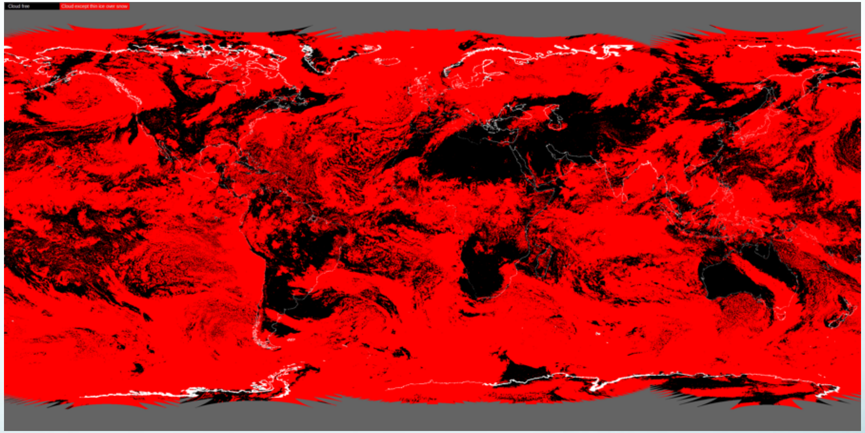
Composite of liquid (left) and ice (right) Cloud Effective Radius for 35 cases
SEV06-CLD applied to 5min RSS - Synchro made at threshold value of 36 mm/hour

The Geostationary Ring for continuous global observation

Provide high temporal resolution observation for clouds and aerosols at global scale with continuous coverage



GEORING AERUS-AEROSOL-D3



GEORING Cloud mask SAFNWC

Take home messages …

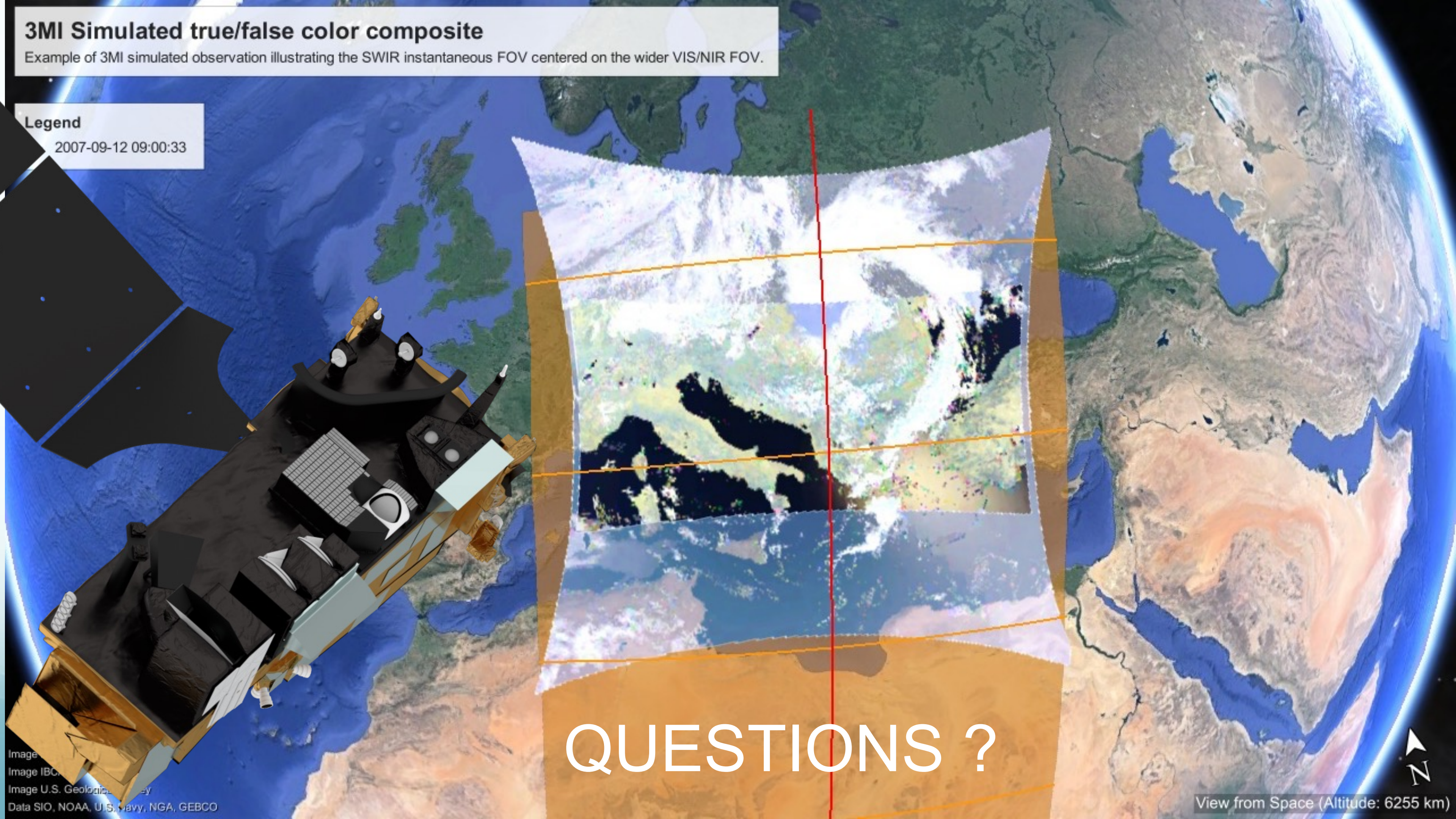
1. 3MI brings a whole “new” vision to the atmosphere within an operational meteorological system : polarization and multiangle

2. Day-1 algorithms are “almost” ready – Day-2 development is on-going

3. In synergy with its companion instruments aboard METOP-A SG 3MI, METimage, IASI-NG and Sentinel-5 (UV-NS) offer a unique opportunity to improve vertical description of cloud cover from passive measurements

4. In combination with GEO observations vertical cloud properties obtained from 3MI & METOP-A SG can be analyzed accounting for their temporal evolution

5. Many questions can be investigated specifically : clouds/aerosols interactions shallow/deep convection and relation with cloud processes, convection aggregation, …


3MI Simulated true/false color composite
Example of 3MI simulated observation illustrating the SWIR instantaneous FOV centered on the wider VIS/NIR FOV.
Legend
2007-09-12 09:00:33
QUESTIONS ?
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
View from Space (Altitude: 6255 km)
N