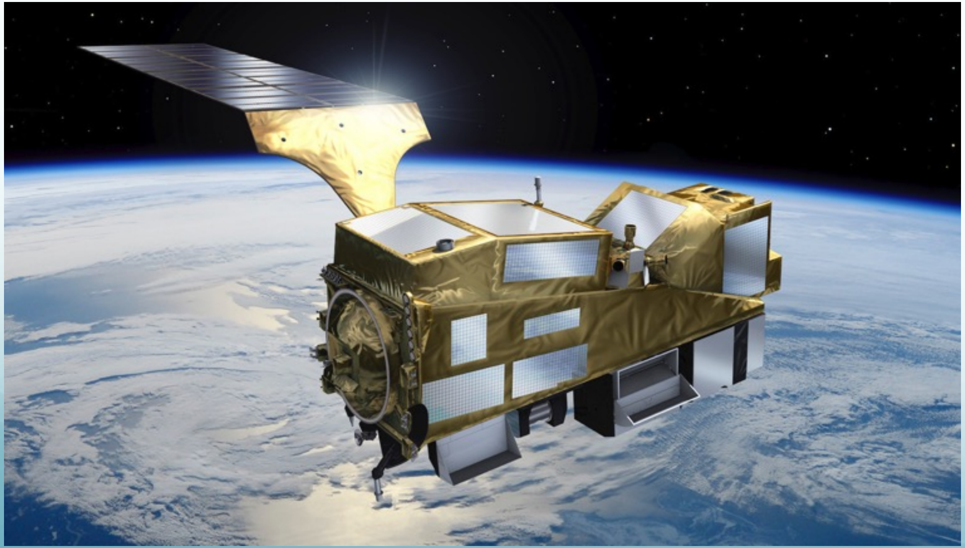
Current Status and Perspectives for the Operational and Research Cloud Products from the Multiview, Multichannel, Multipolarisation Imager (3MI) on METOP-SG A.



Riedi Jérôme[1], Fougnie Bertrand[2], Hioki Souichiro[1], Henriot Nicolas[1], Thieuleux François[1], Labonnote Laurent[1], Ferlay Nicolas[1], Compiègne Matthieu[3], Vázquez Margarita[2], Penide Guillaume[2], Cornet Céline[2], Parol Frédéric[1] and Dubuisson Philippe[1]

(1) Université de Lille, Laboratoire d'Optique Atmosphérique, Lille, France
(2) EUMETSAT, Darmstadt, Germany
(3) HYGEOS, Lille, France.

Context

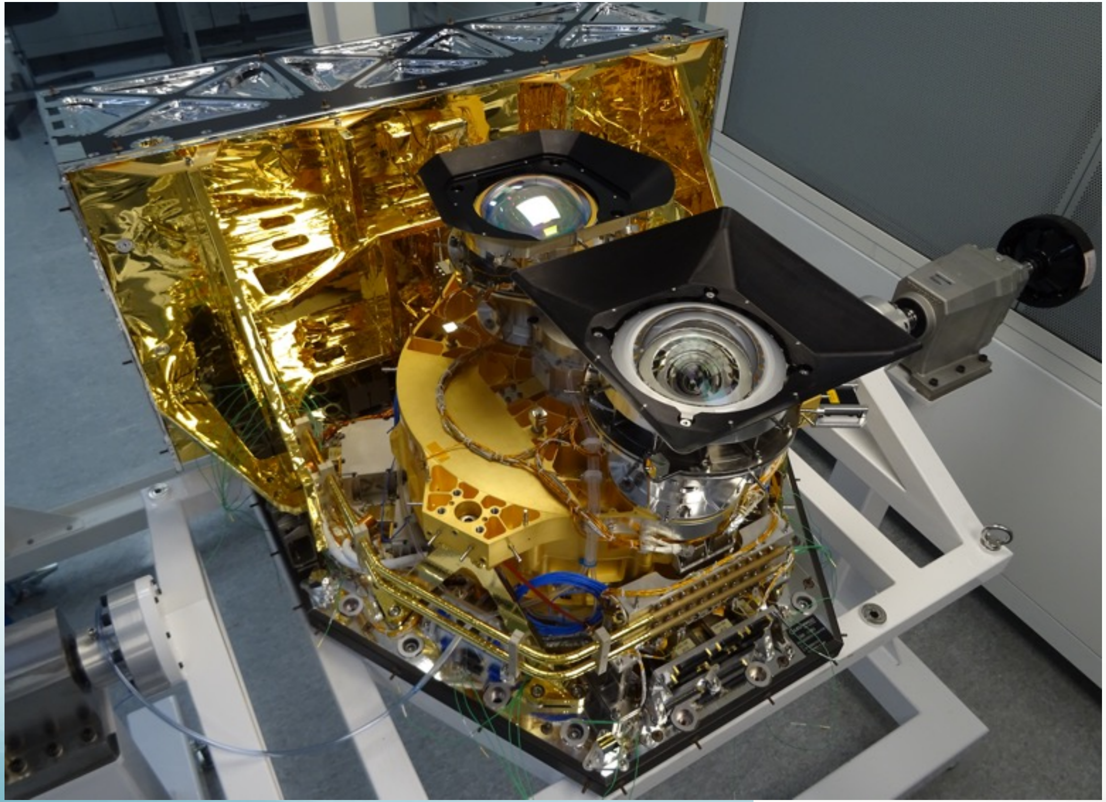
- EUMETSAT is in charge of supplying weather and climate related satellite data, images, or products, to the National Meteorological Services and other users
- Operational service, near real time dissemination, 24/7
- The EUMETSAT Polar System – Second Generation is under preparation with many sensors onboard MetOpSG-A and MetOpSG-B
- Launch expected in 2025

Outline

- 3MI is an aerosol dedicated mission with advanced cloud observing capabilities building on POLDER / MODIS heritage
- How do we leverage the unique assets of multiangle polarization observations to improve aerosols and cloud retrievals ?
- What are the perspectives of using 3MI in synergy with its companion instruments on MetOp-SG?
- What are the challenges for retrieval of cloud vertical properties from passive measurements ?

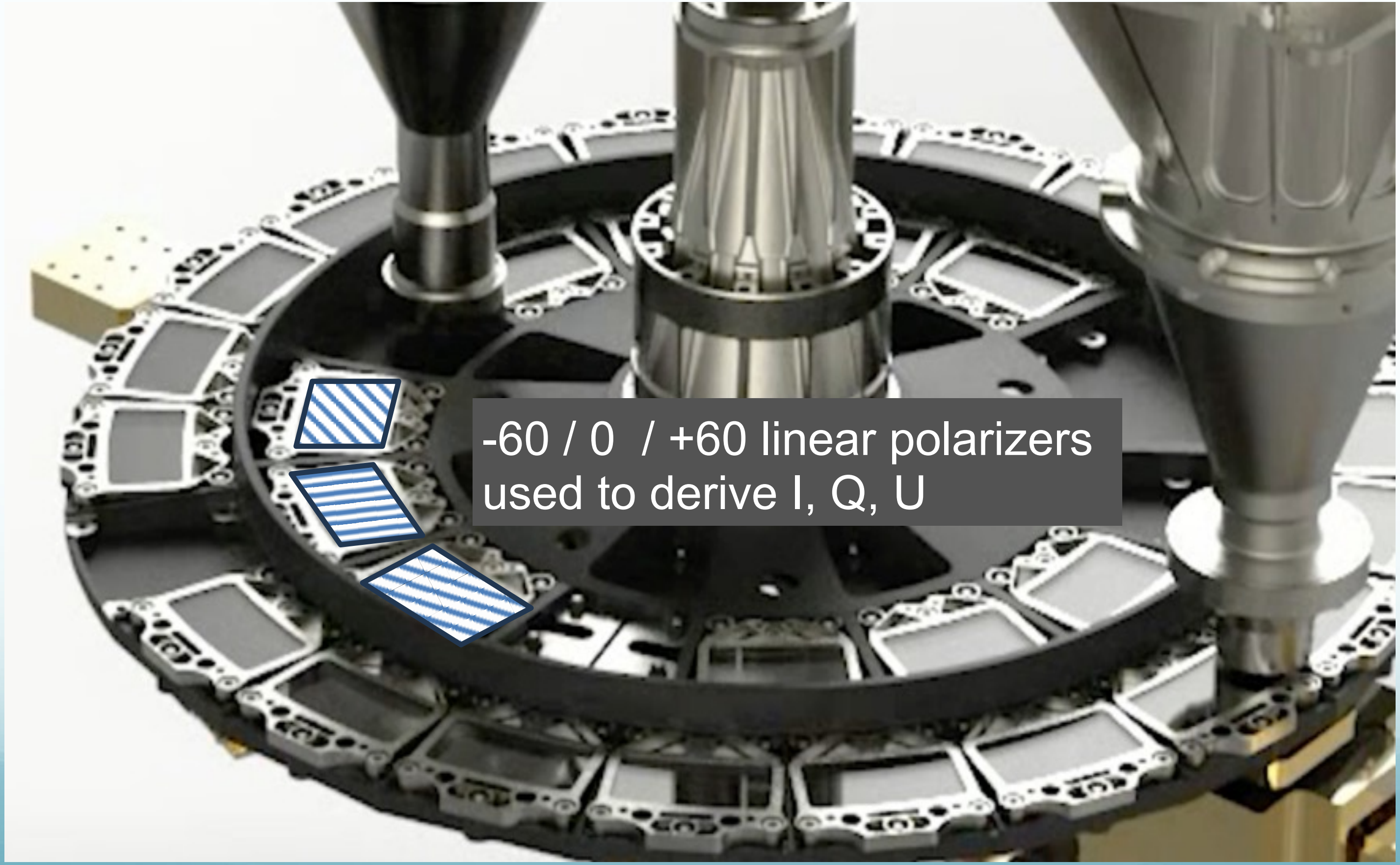
3MI in a nutshell

A wide field of view radiometric imager …



Filters Wheel Assembly

3MI in a nutshell
… with multispectral and polarisation capabilities

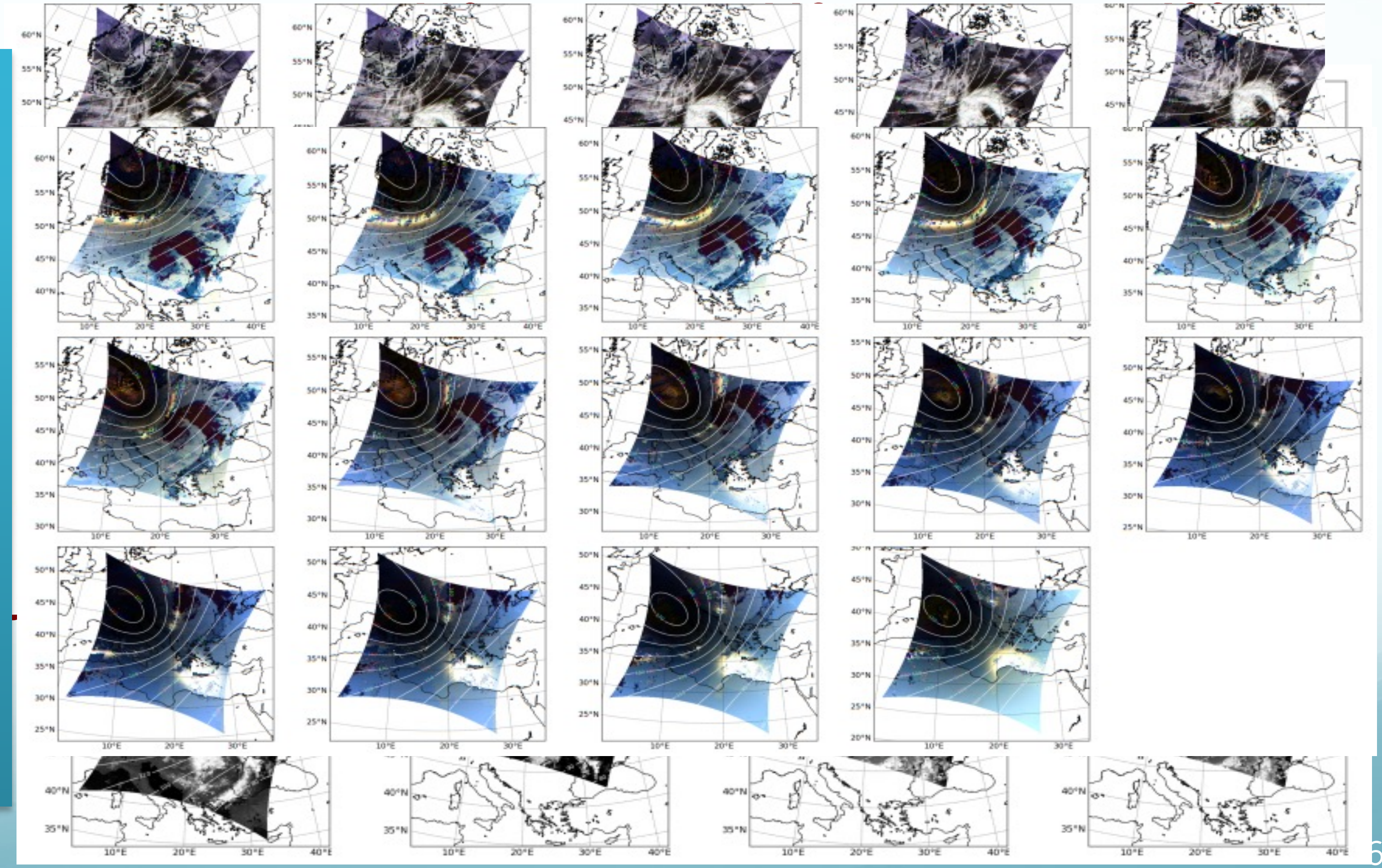


3MI in a nutshell : Multispectral, Multiview & Multipolarization Imager

12 spectral bands from 410 nm to 2130 nm

14 different viewing directions for each pixel (4km x 4km)

Polarisation (I, Q, U) measured in 9 channels (all but O2-A band and WV channel at 910 nm



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

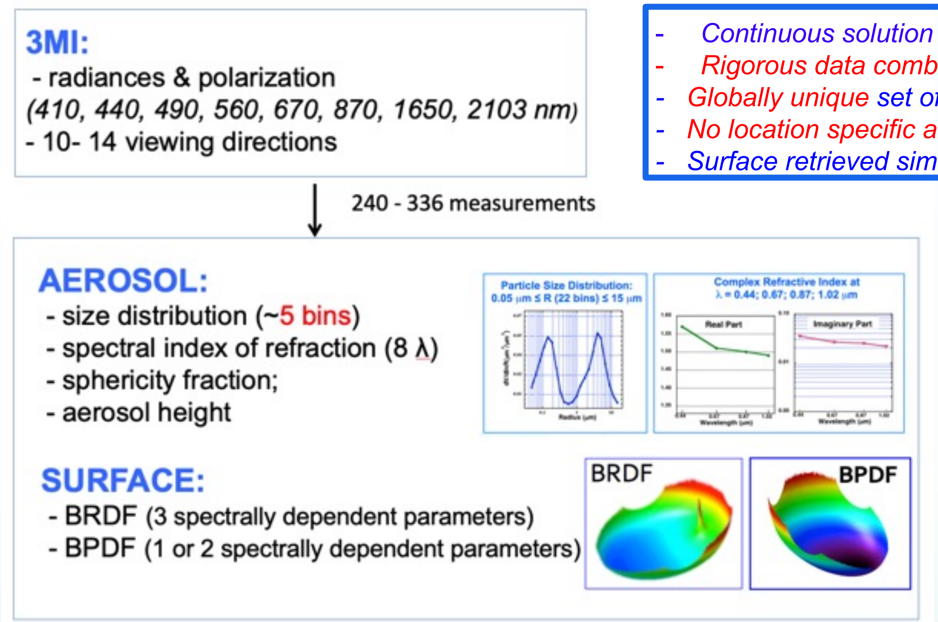
A two steps approach is used for operational processing for clouds :

- 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

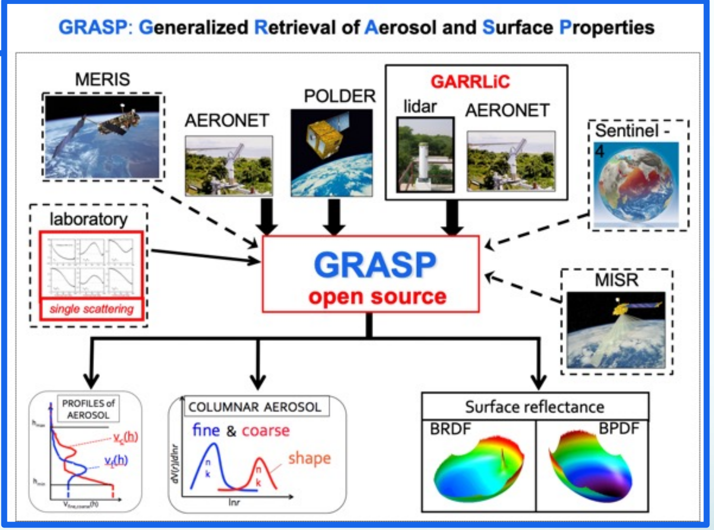
Algorithms are being developed and tested using highly realistic synthetic test data (available publicly from EUMETSAT)

GRASP is used for advanced retrieval of aerosol properties. Aerosol products will be delivered as NRT "Day 1+" products.

3MI NRT Aerosol Retrieval: Application of GRASP



- *Continuous solution space;*
- *Rigorous data combination and use of a priori information;*
- *Globally unique set of a priori constraints;*
- *No location specific assumptions;*
- *Surface retrieved simultaneously;*



55 parameters

5 - size distribution

16 = 2x8 - spectrally dependent index of refraction, i.e. real and imaginary parts at 8 wavelengths,

24 = 3x8 - spectrally dependent parameters of 3 Li-Ross BRDF model at 8 wavelengths;

8 - one spectrally dependent parameter for BPDF (Maignan, Breon, et al. model).

1 - fraction of non-sphericity;

1 - aerosol height.

See Oleg Dubovik presentation on Thursday - Session 4 - 9h30

Main « day 1 » cloud properties retrieved from 3MI

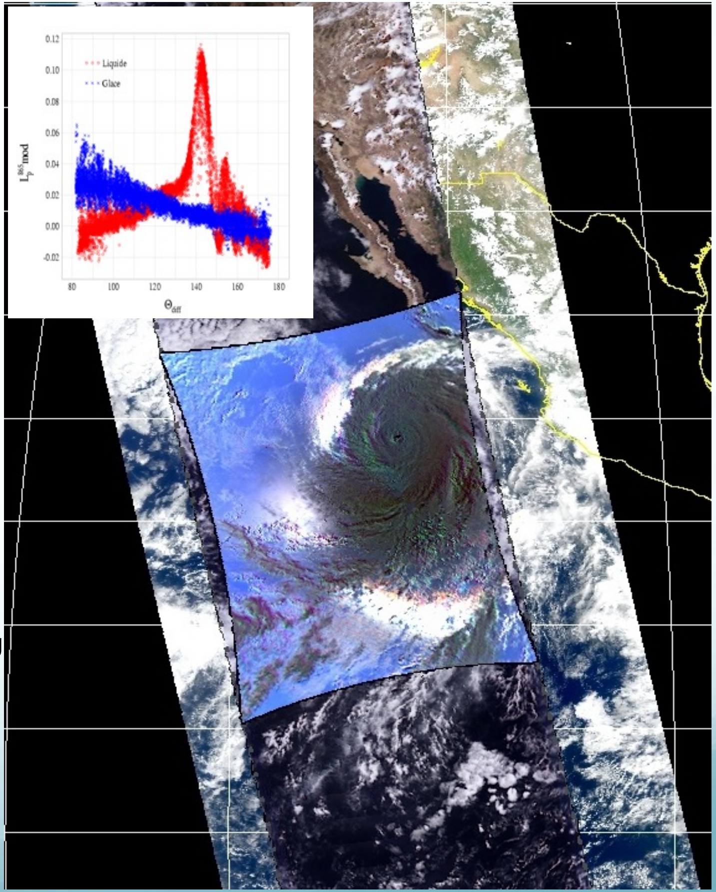
Cloud Thermodynamic Phase
from multiangle polarisation and VNIR/SWIR

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 clou



Status : algorithms delivered and under implementation within operational ground processing segment largely validated using test data and leveraging POLDER/MODIS heritage

Day-1 Cloud product specification

A1 Ingestion and acceptance of input

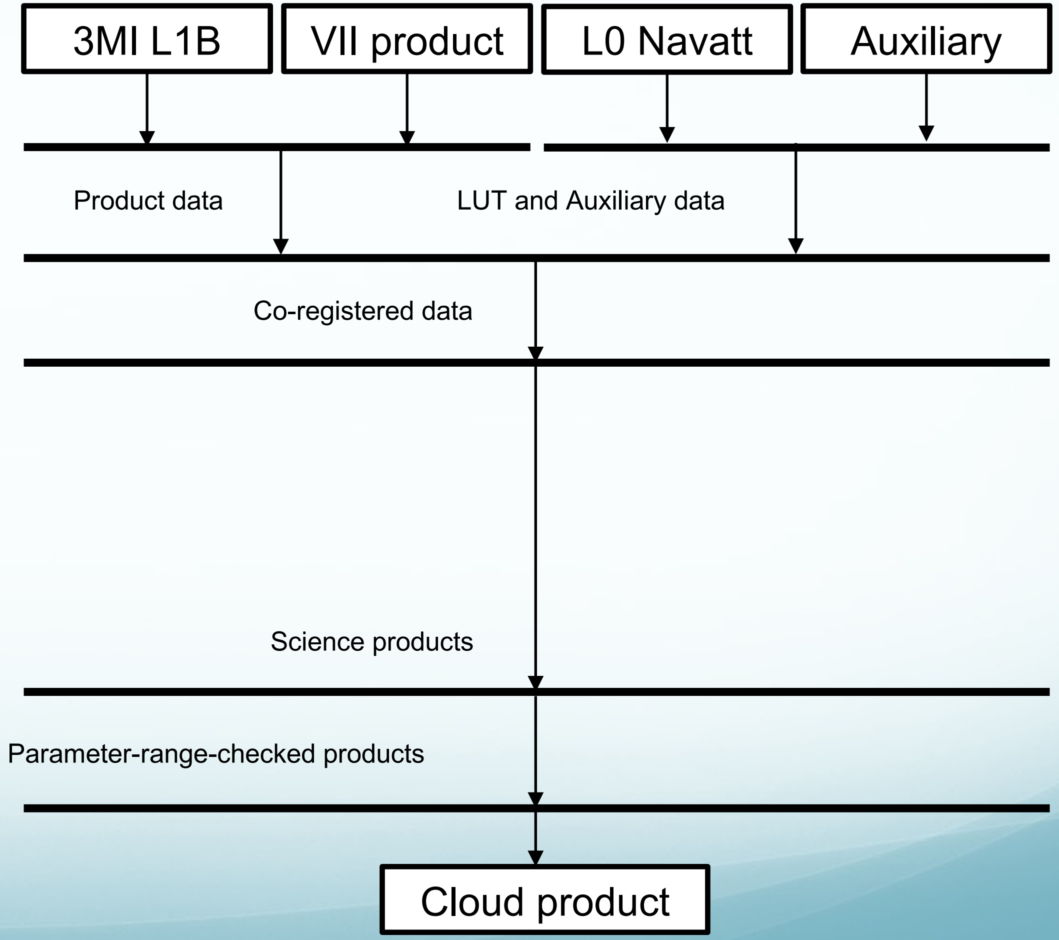
A2 Co-registration of input data

A3 Science data processing

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

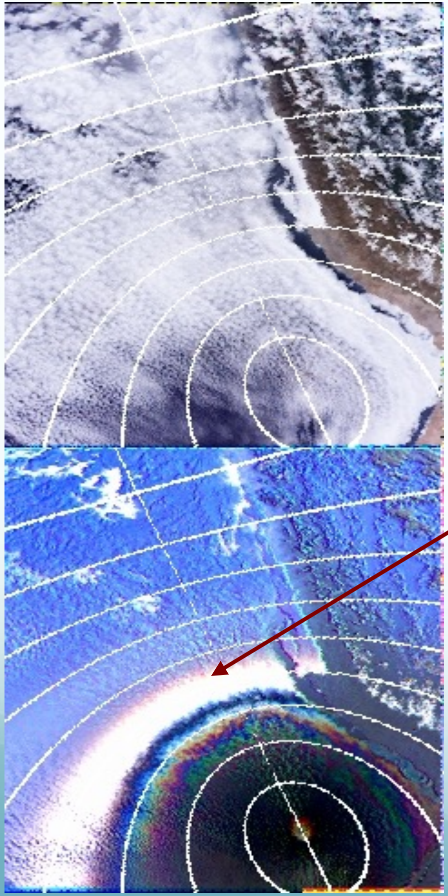
A4 On-line quality control

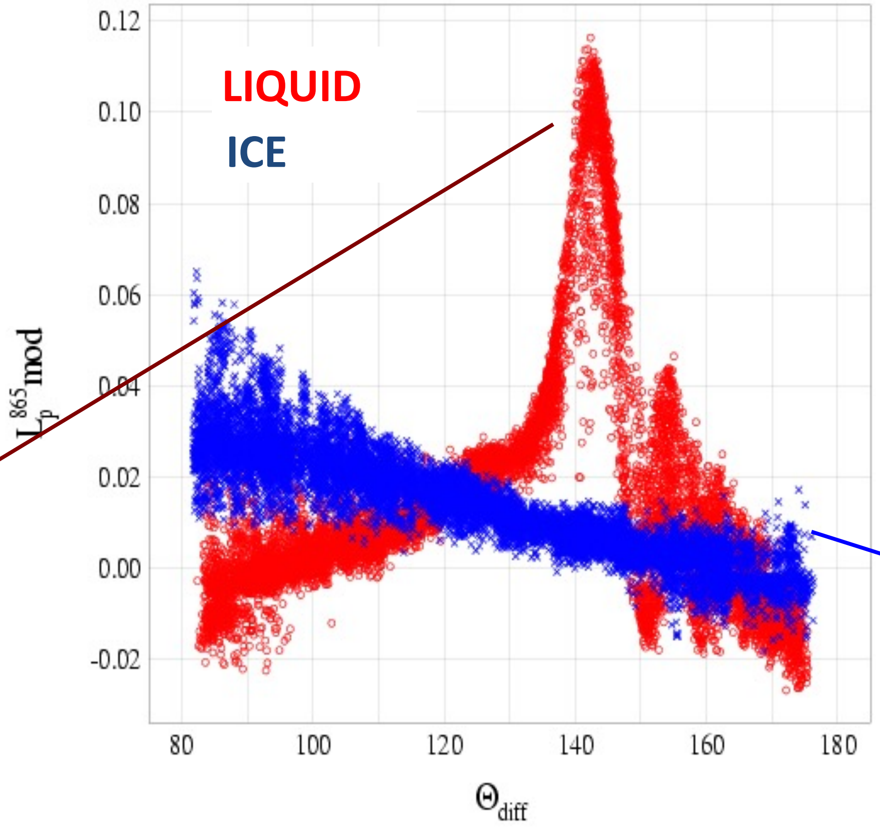
A7 Formatting of output data

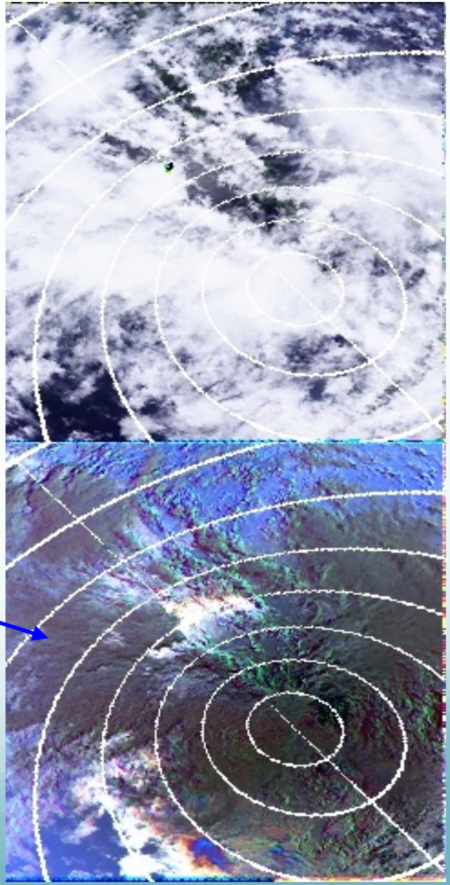


Cloud Top Thermodynamic Phase

Principle : particle shape discrimination spherical vs non sphe.



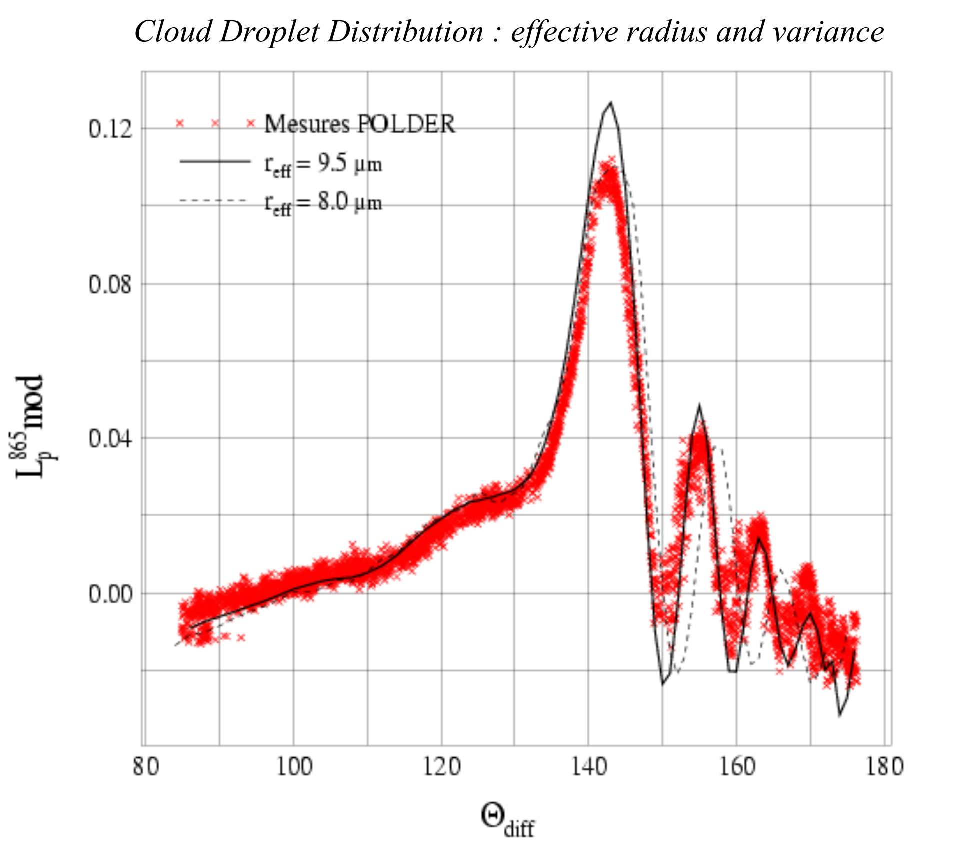


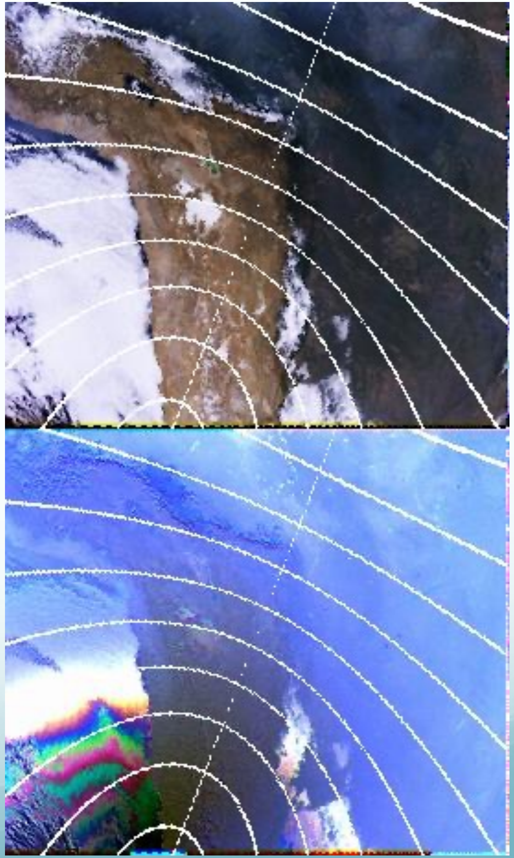


Liquid Cloud Droplet Effective Size Distribution

Principle : use of angular features above 140° (supernumerary bows).

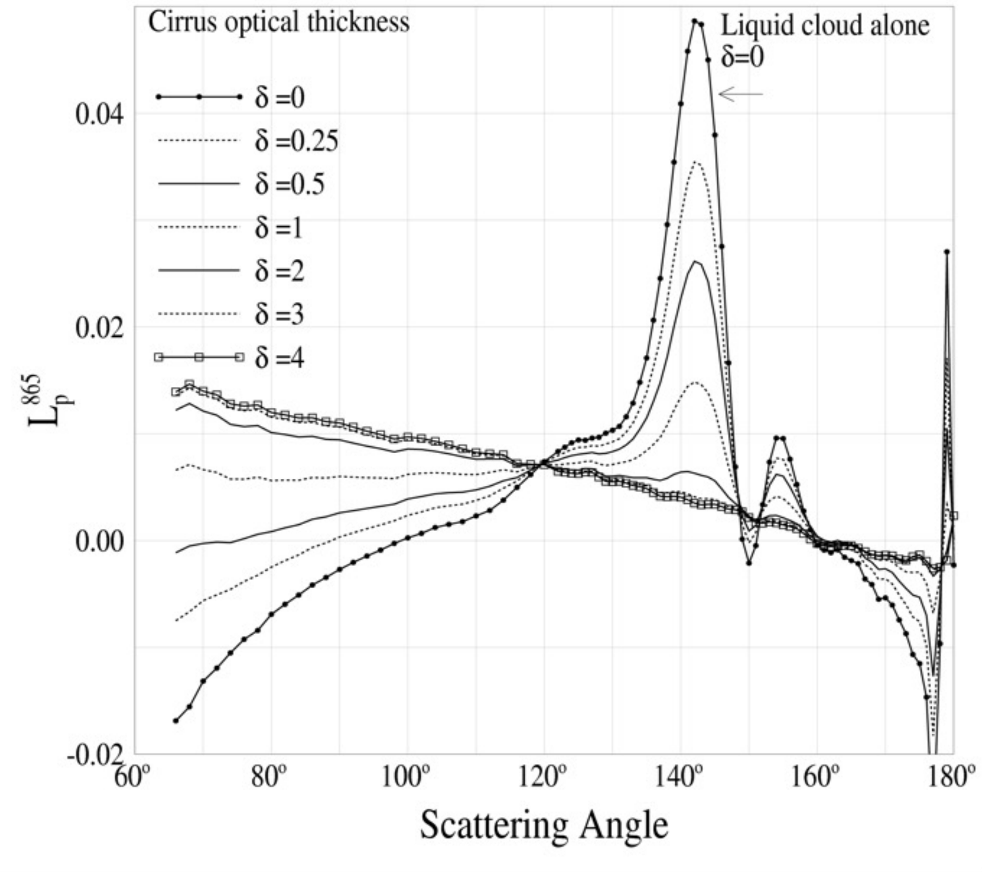
Bréon and Goloub, GRL, (1998)





Cloud Properties from Polarisation

How deep do we see inside clouds using polarization measurements ?



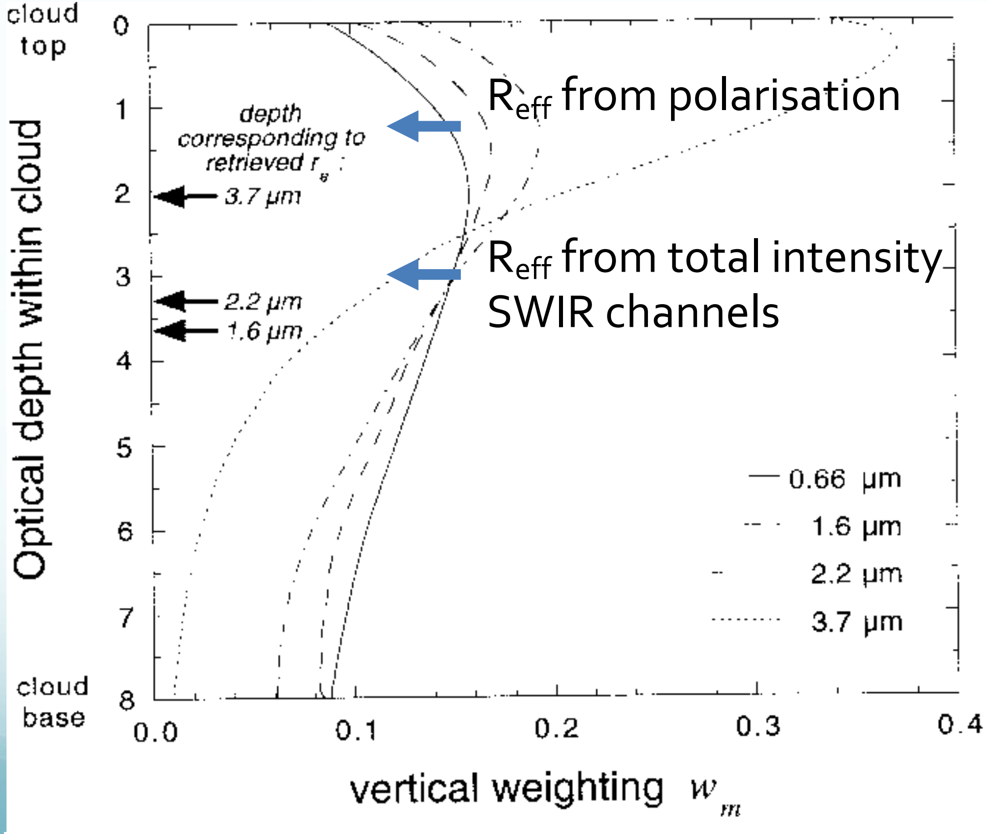
Simulations :

- Cirrus (10km) above low water cloud (2km)
- Polarized reflectance at 865 nm

Liquid cloud (rainbow) can be «seen» up to cirrus OD of 2.0

Cloud Properties from multispectral measurements

How deep do we see inside clouds using total radiance spectral measurements ?



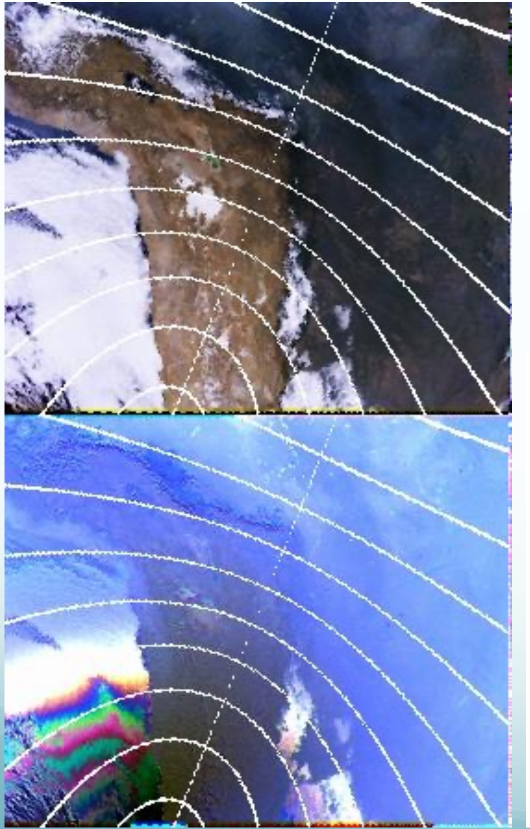
From Platnick (2000)

Mean photon penetration depth depends on absorption : different spectral channels "see" different parts of the cloud.

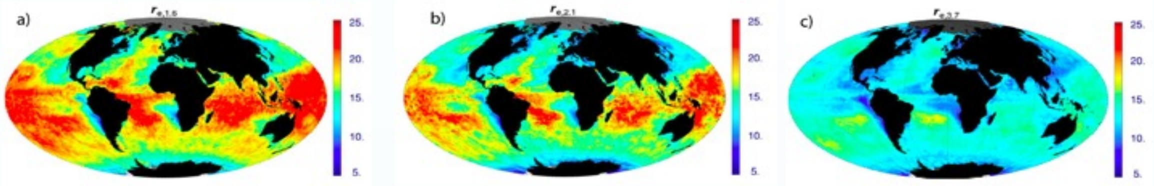
Moreover, polarization signal arises from the very top cloud layer

Liquid clouds particle size retrievals from 3MI

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

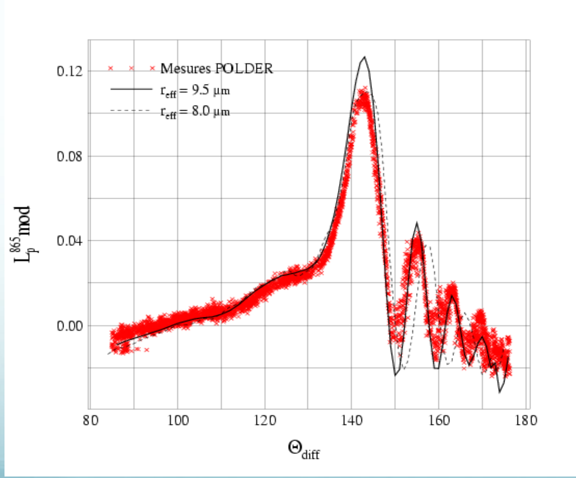


✓ NIR / SWIR bispectral method ➡ Effective radius at 1.6, 2.1 and 3.7 μm

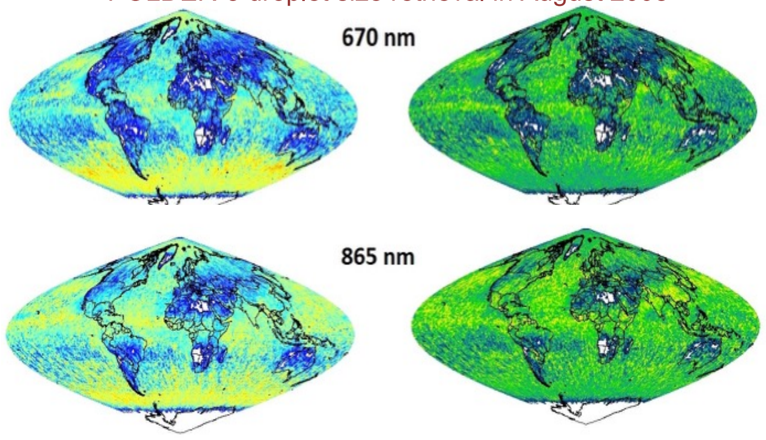


The retrieval of R1.6 and R2.1 in April 2005 (Zhang and Platnick, 2011)

✓ 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

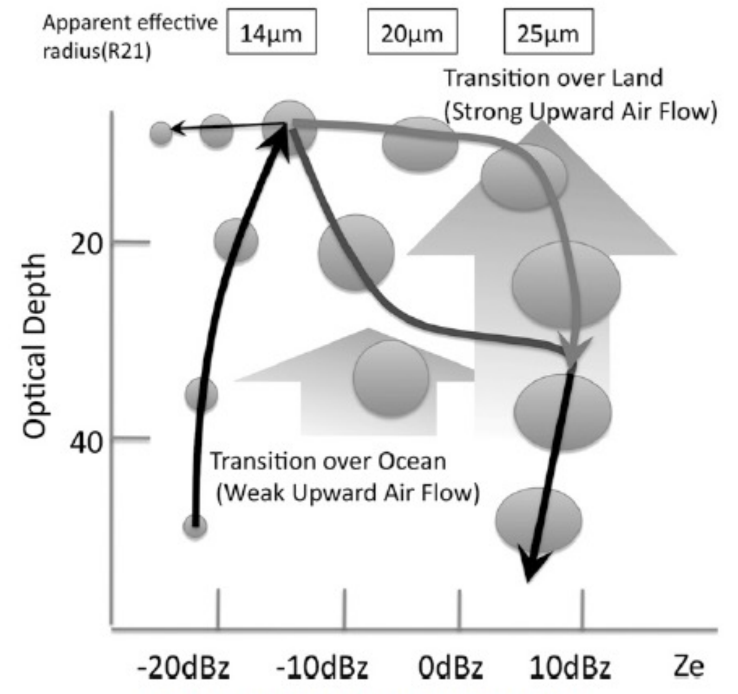
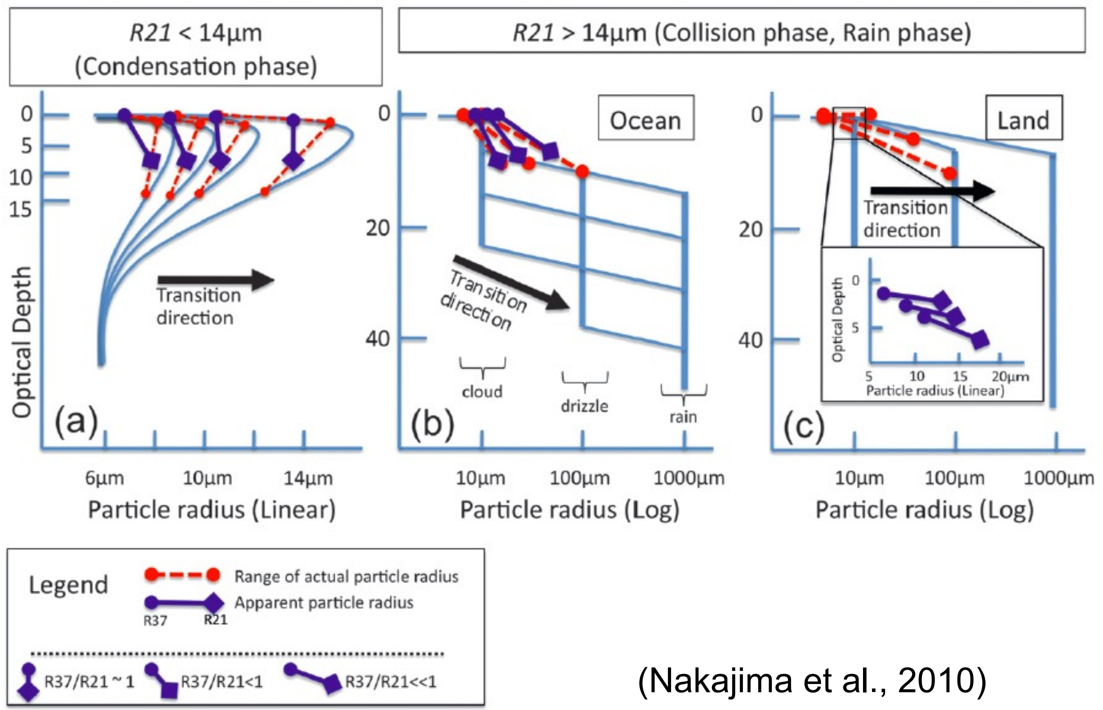


FIG. 6. Transition diagram of the CFODD.



(Nakajima et al., 2010)

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).

Day 2 algorithms objective and approach

Objective : Obtain a physically realistic vertical description of clouds to:

- Improve consistency among retrieved parameters
- Provide cloud properties that can be more easily related to processes
- Allow for synergistic use of 3MI with other MetOp-SG instruments
- Improve TOA and Surface SW & LW flux estimates

Approach

- Initiate a vertically inhomogeneous cloud layer using Day-1 properties
- Improve a priori profile using statistical information
- Adjust a physically realistic cloud profile model using OE based algorithm

Estimating liquid clouds droplets size vertical profile

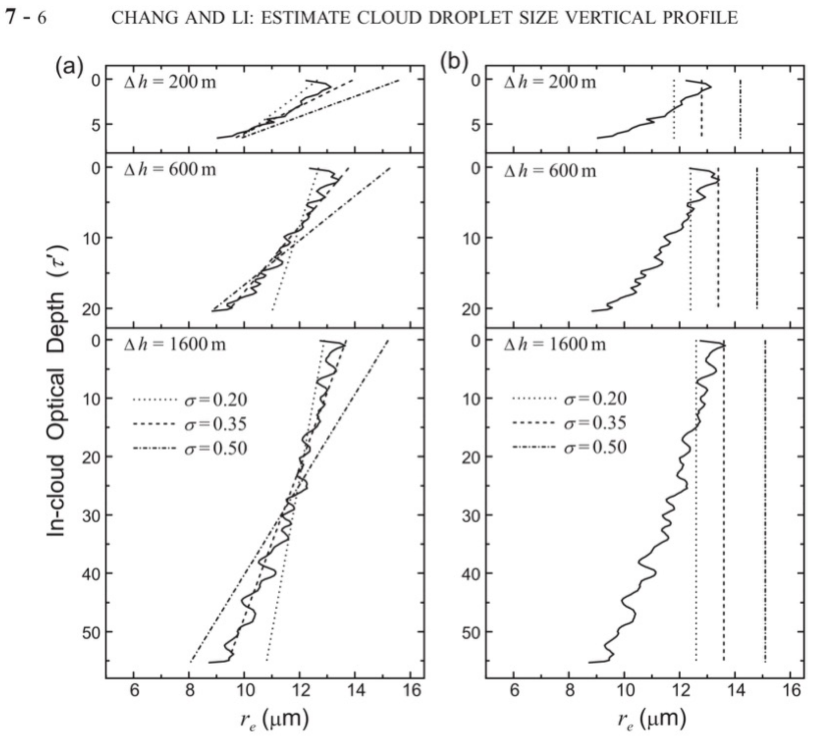


Figure 5. Comparisons between the observed (solid) and retrieved DER profiles using (a) the linear DER retrieval method and (b) conventional 3.75-μm method for the three cloud cases shown in Figure 2. Three different DER profiles were retrieved using σ = 0.20 (dashed), 0.35 (dotted) and 0.50 (dash-dotted).

From Chang & Li, JGR (2002)

Not a new idea .. and still being actively investigated

See later Andrew Buggee talk in this session on the use of hyperspectral measurements

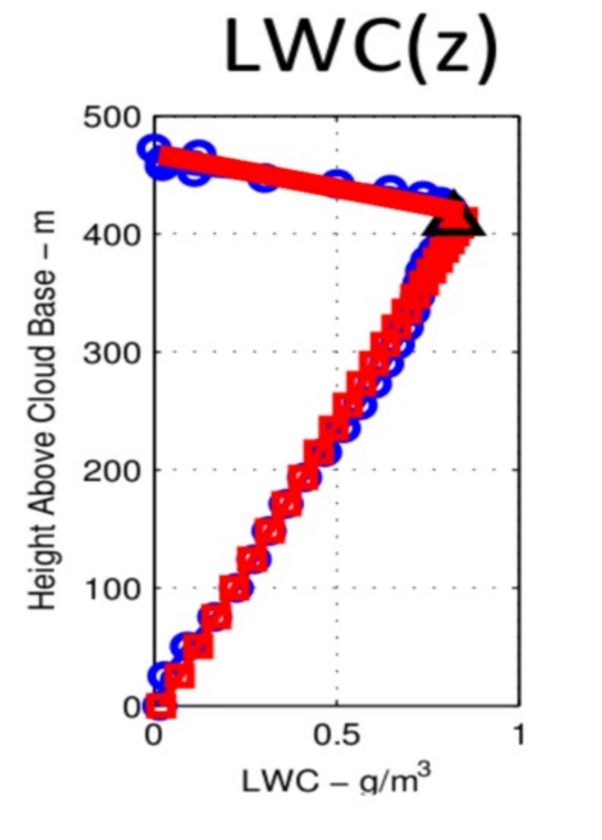
Estimating liquid clouds droplets size vertical profile

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

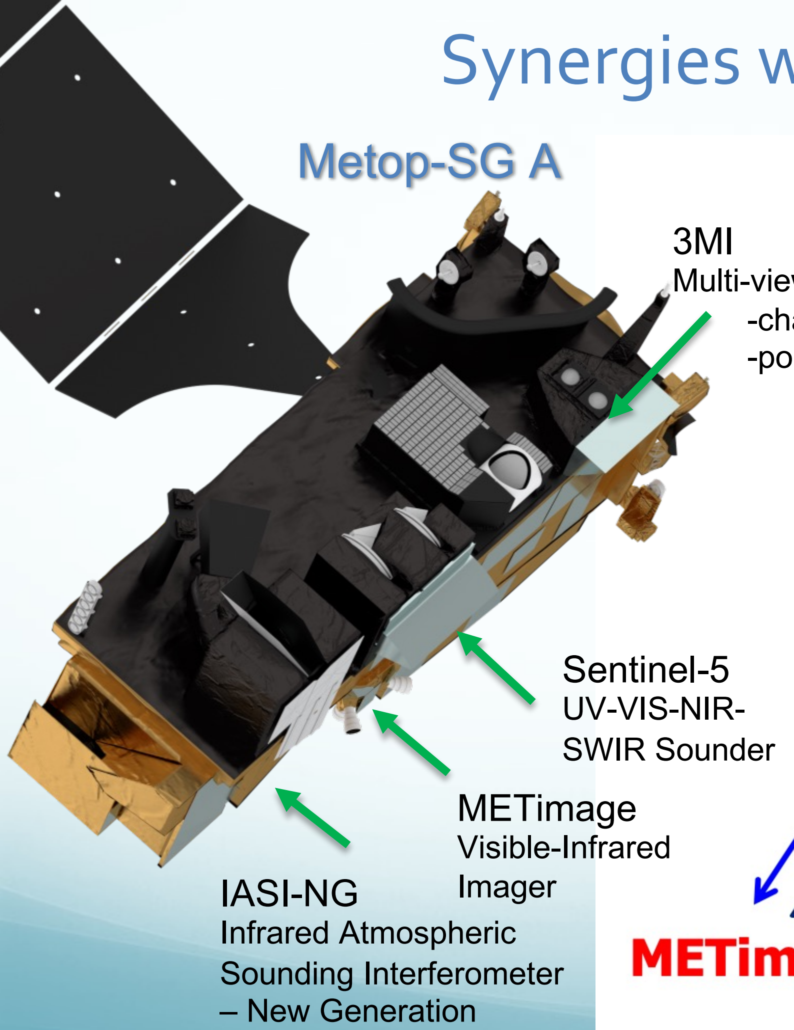
DOFs	CGT	CTOP	COT	p	LWP
I_{vis}	0	0	0.18	0	0.8
$L_{p,vis}$	0	0	0	0	0
I_{SWIR}	0.02	0	0.78	0.03	0.19
$L_{p,SWIR}$	0.98	0	0.03	0.97	0.01
R_{Aband}	0	1	0	0	0
Total	1	1	1	1	1

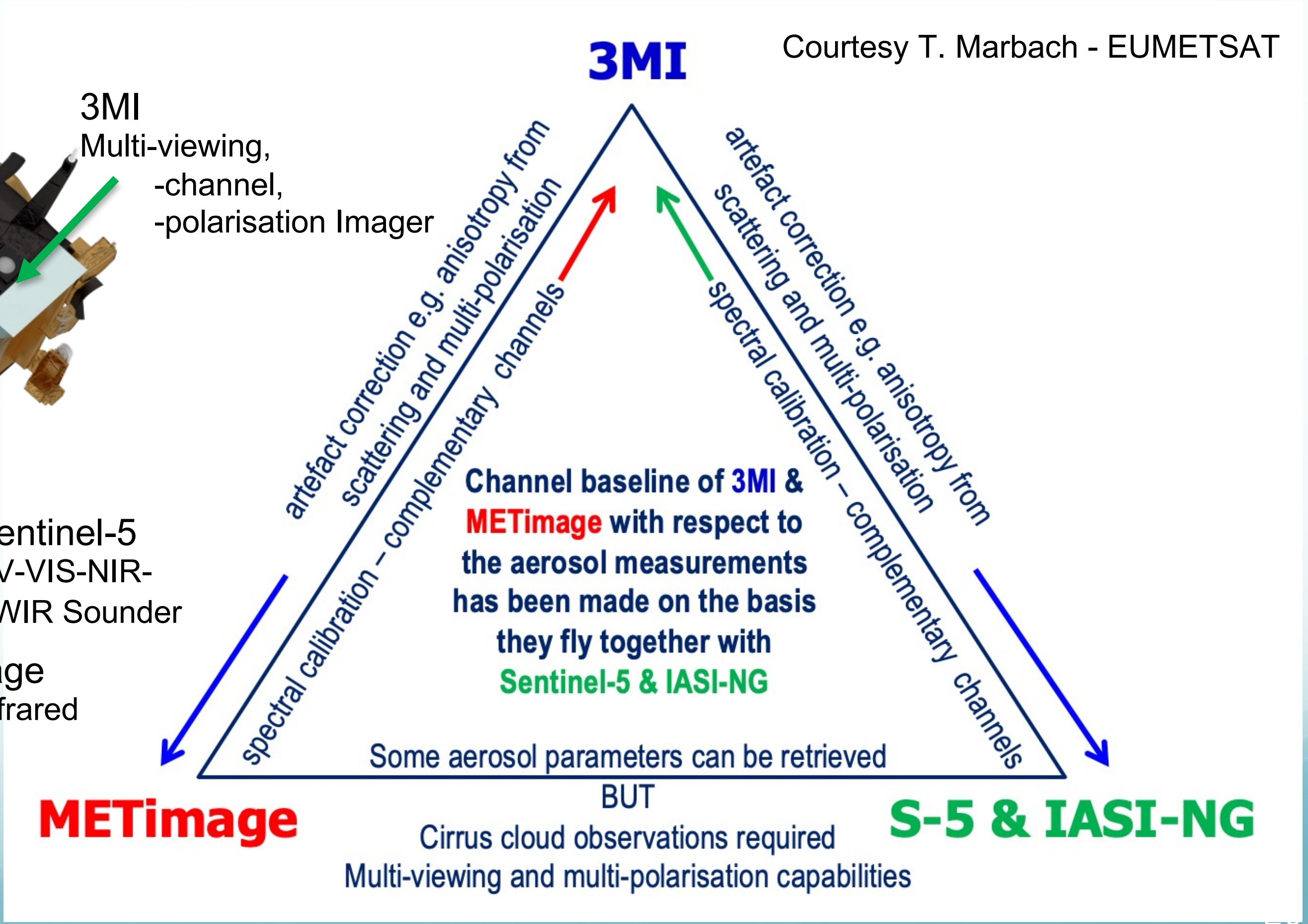
(g) LES Miller et al.

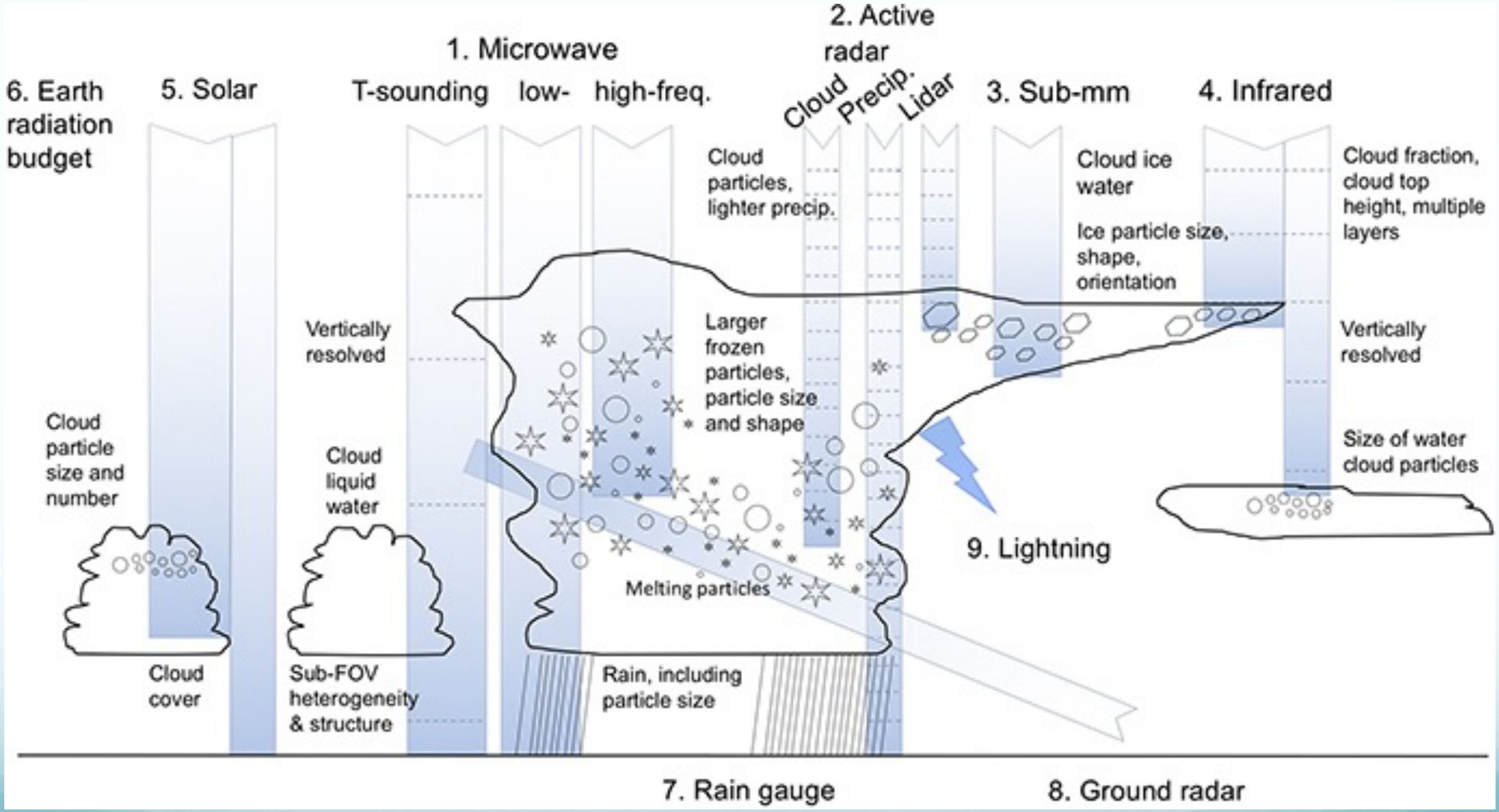


From G. Merlin, 2016 PhD thesis

Synergies with EPS-SG instruments

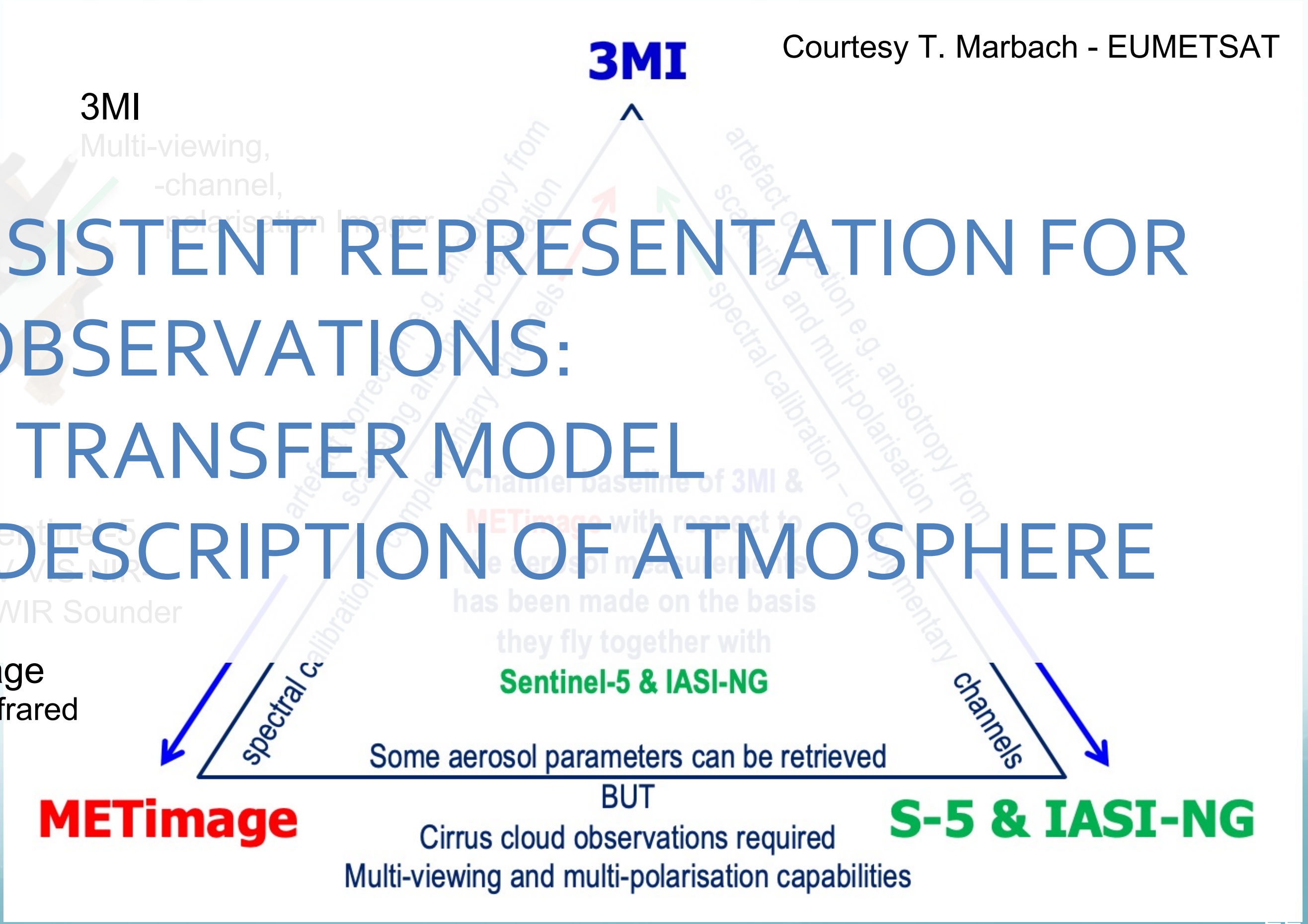






From A. Geer et al "Recent progress in all-sky radiance assimilation" Newsletter Number 161 – Autumn 2019

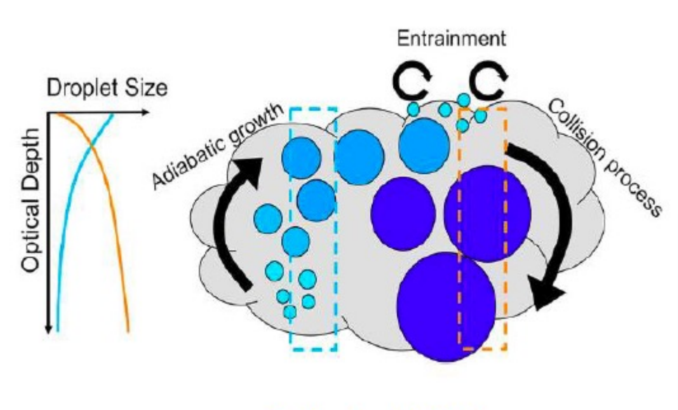
Synergies with EPS-SG instruments



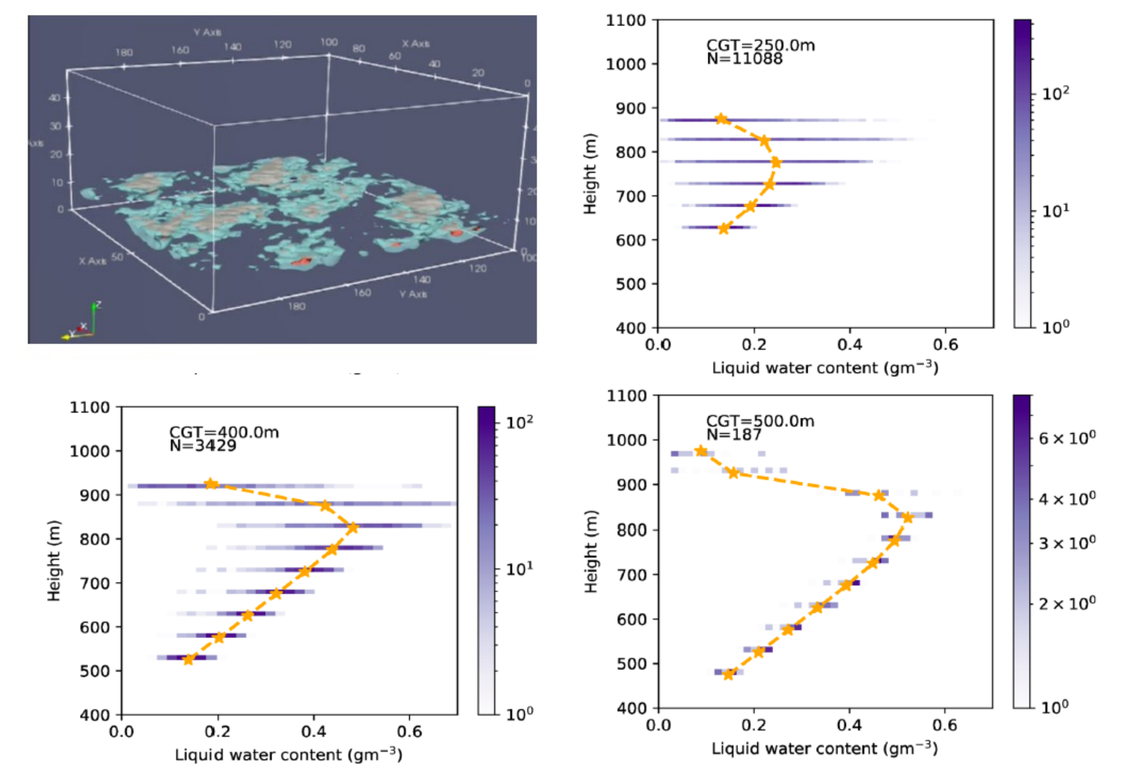
NEED A CONSISTENT REPRESENTATION FOR ALL THESE OBSERVATIONS:

- RADIATIVE TRANSFER MODEL
- PHYSICAL DESCRIPTION OF ATMOSPHERE

Can we use a more physically realistic profile model ?

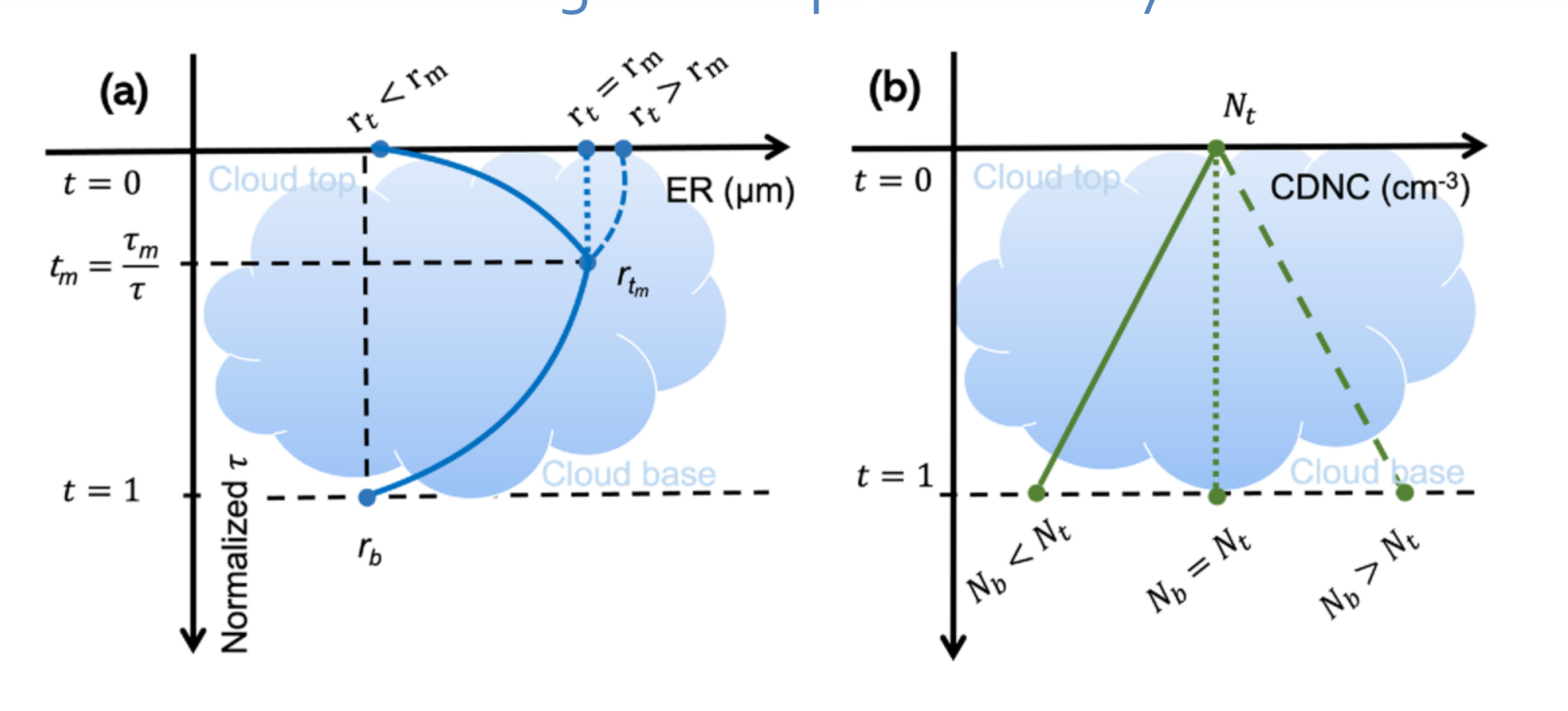


(Saito et al., 2019)



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.

The "Two-Regimes" liquid cloud toy model



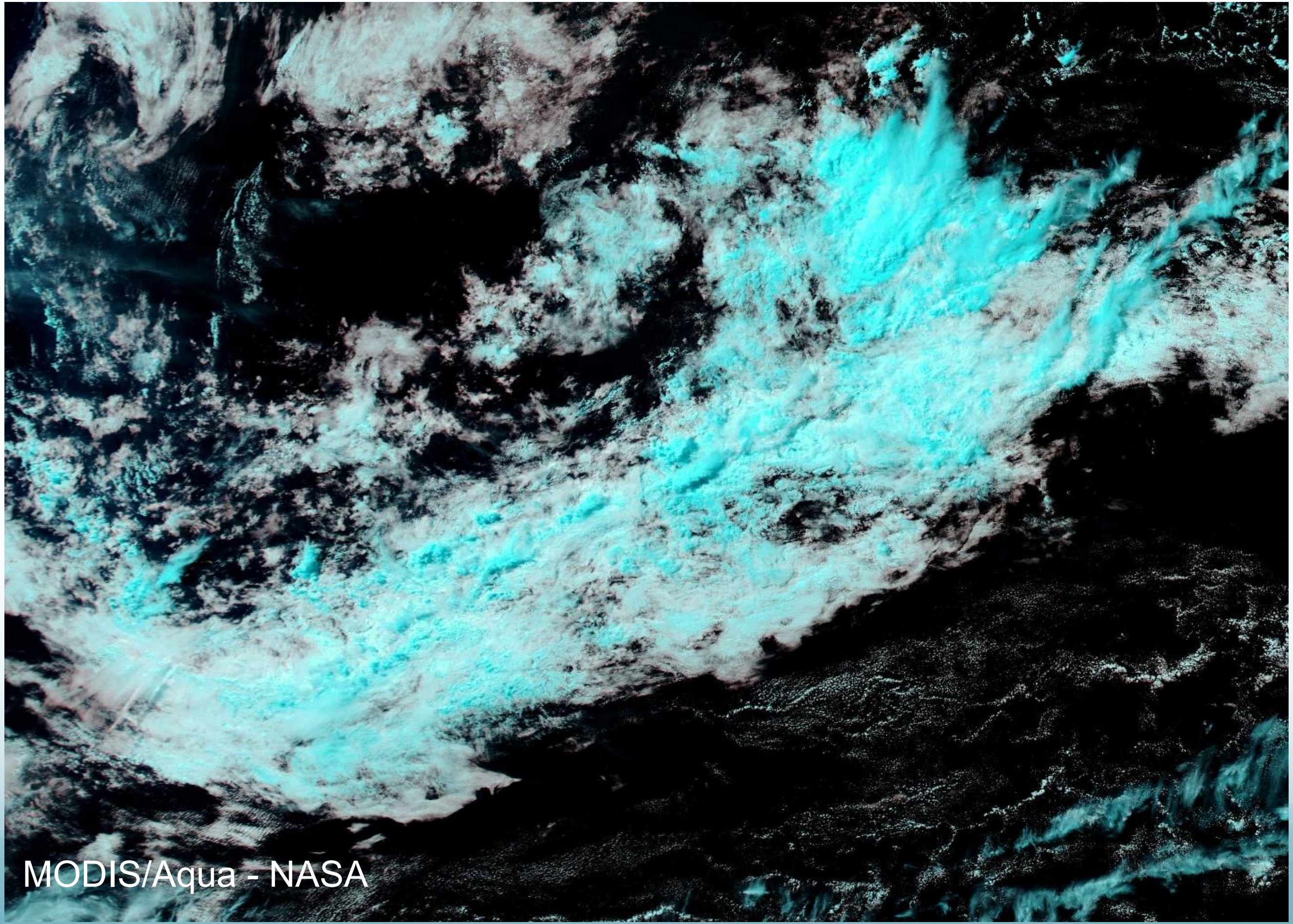
Shang, H., Hioki, S., Penide, G., Cornet, C., Letu, H., and Riedi, J.: Establishment of an analytical model for remote sensing of typical stratocumulus cloud profiles under various precipitation and entrainment conditions, Atmos. Chem. Phys., 23, 2729–2746, https://doi.org/10.5194/acp-23-2729-2023, 2023. **See presentation by Huazhe Shang -Session 10 Thursday - 11:45**

How can we actually perform
OE-based retrieval
of cloud vertical properties
AND
deliver products before 2050 ?

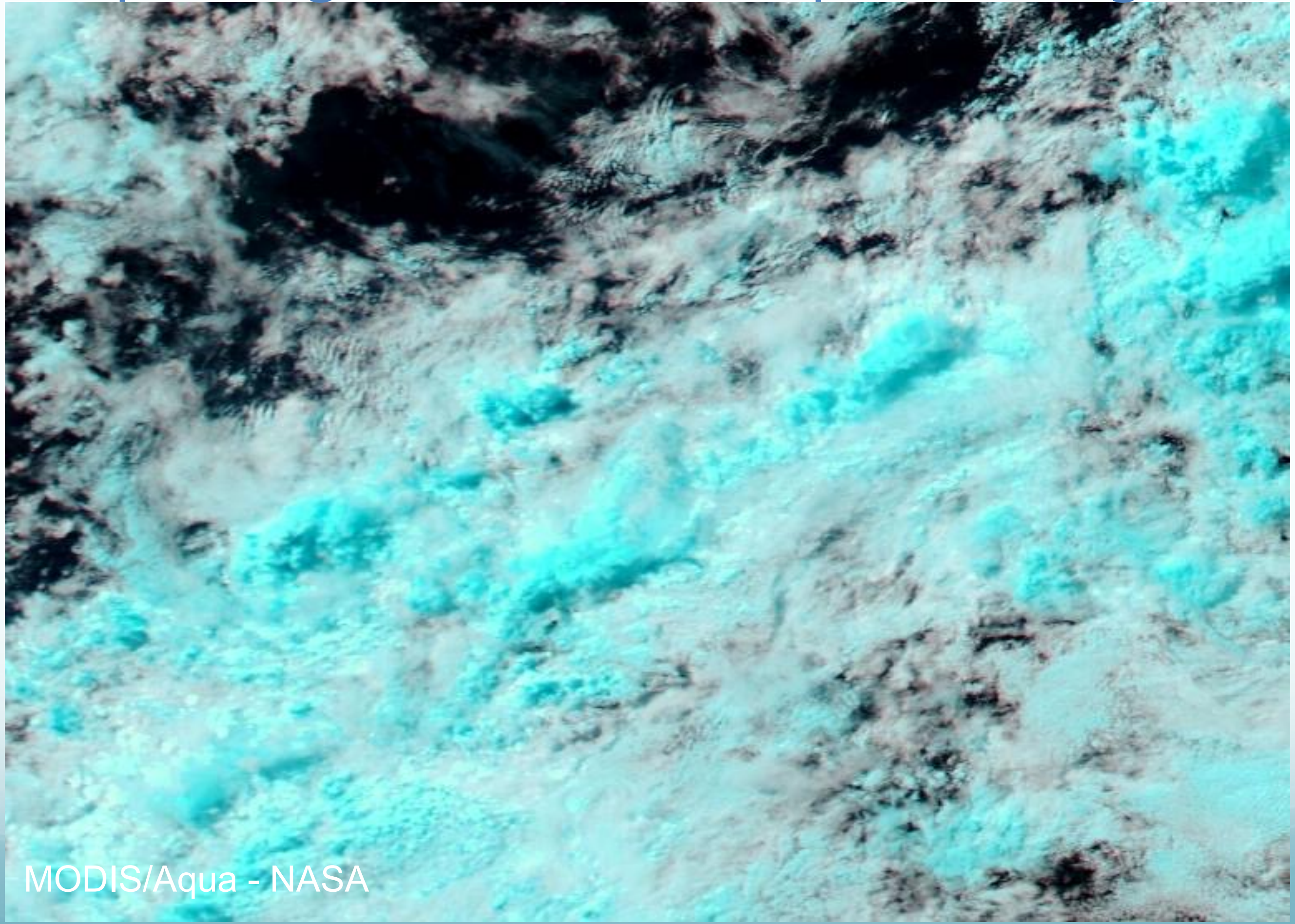
Improving Cloud Profile a priori using ML

Quoting Steve Ackerman :
"I know a cloud when I see one !"

Improving Cloud Profile a priori using ML



Improving Cloud Profile a priori using ML

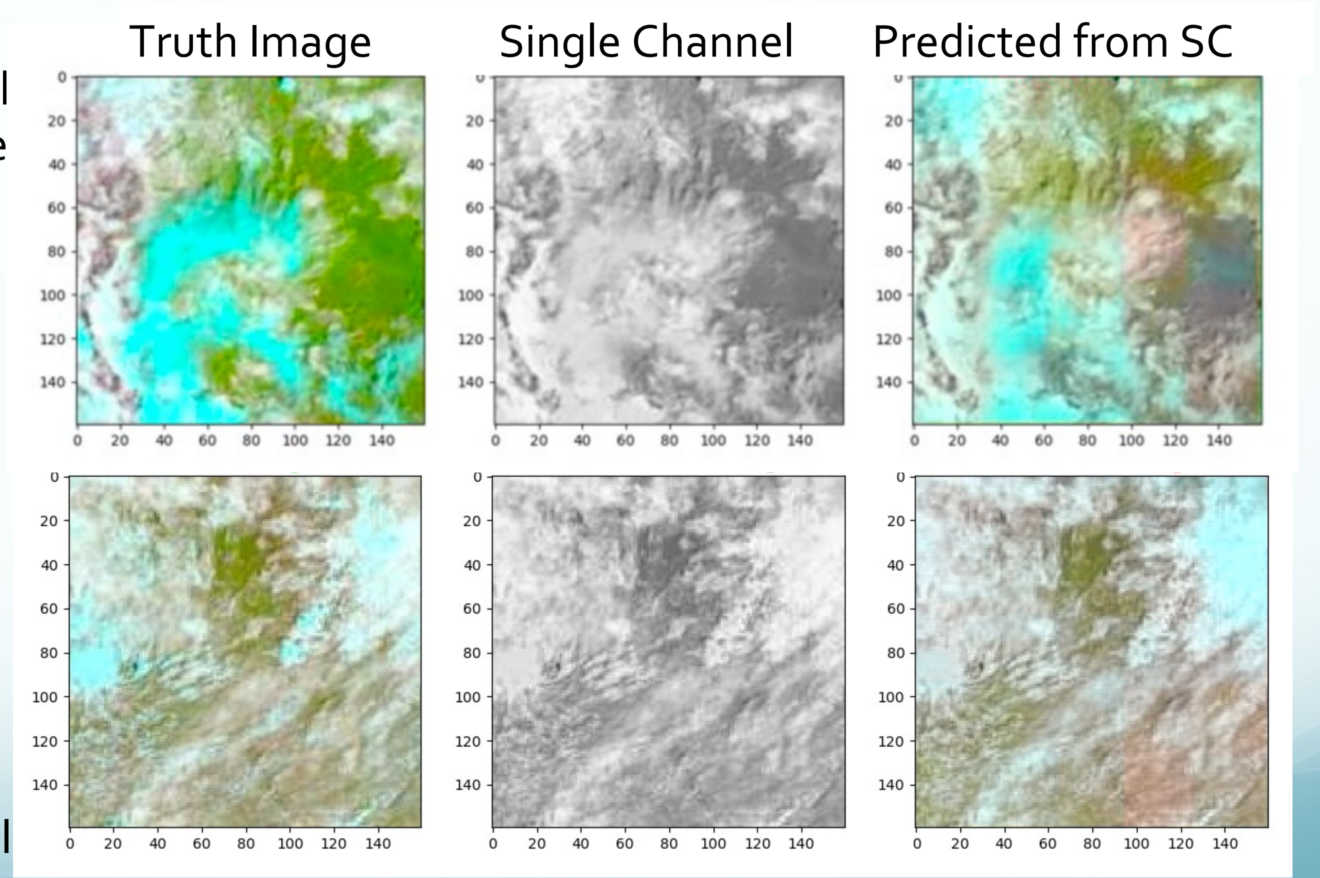


Improving Cloud Profile a priori using ML

- Clouds 2D texture can tell a lot about their structure and properties

- METImage higher resolution can be used to extract a priori information on cloud types and cloud profile using ML techniques

- Example here : a simple CNN auto-encoder can generate realistic spectral information from a single channel (grayscale image)



Example of colorization based on DCGAN neural network (courtesy B. Delcamp)

Improving Cloud Profile a priori using ML

- Clouds 2D texture can tell a lot about their structure and properties
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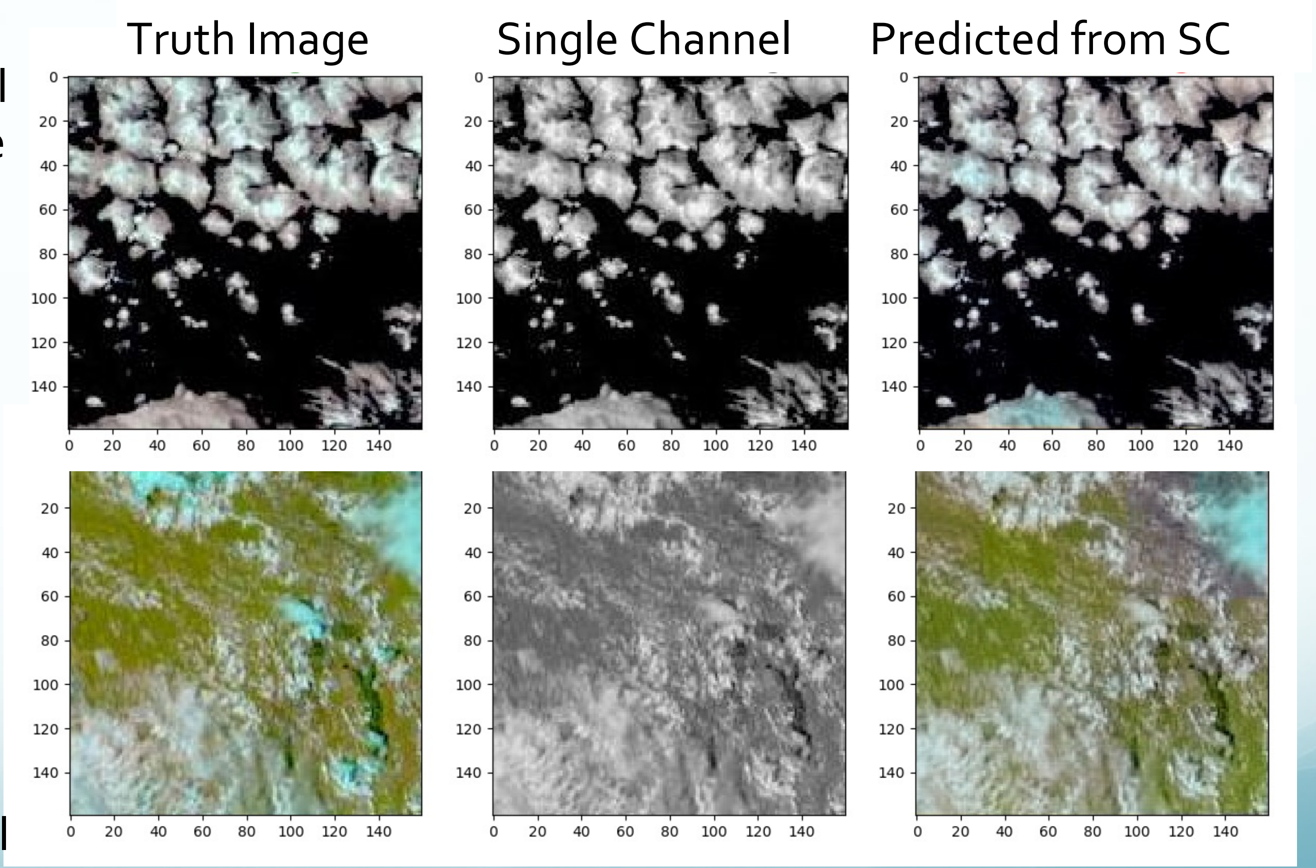


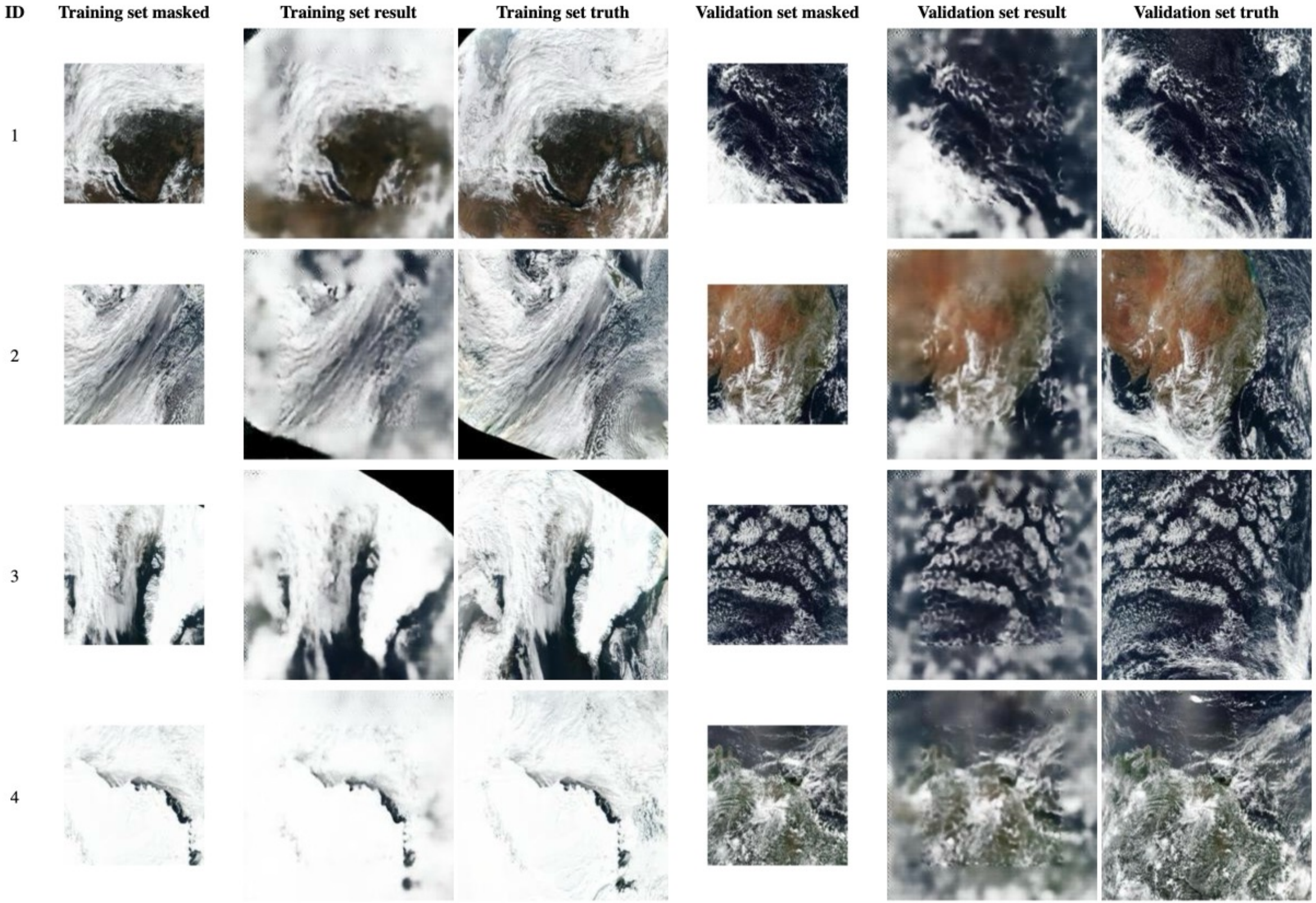
Example of colorization based on DCGAN neural network (courtesy B. Delcamp)

Improving Cloud Profile a priori using ML

- Clouds 2D structure can tell a lot about their dynamics

- Large scale information can be used to infer information on cloud system structure

- Example here : a trained DC-GAN can generate realistic cloud fields and surface images to extend a scene (out



Improving Cloud Profile a priori using ML

Reconstruction of Cloud Vertical Structure With a Generative Adversarial Network

Jussi Leinonen[1,2], Alexandre Guillaume[1], and Tianle Yuan[3,4]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [2]Environmental Remote Sensing Laboratory, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, [3]Joint Center for Earth Systems Technology, University of Maryland, Baltimore County, Catonsville, MD, USA, [4]Earth Sciences Division, NASA Goddard Space Flight Center, MD, USA

Work in progress : Development of DC-GAN model for generation of vertical profile information from 2D textural/spectral information.

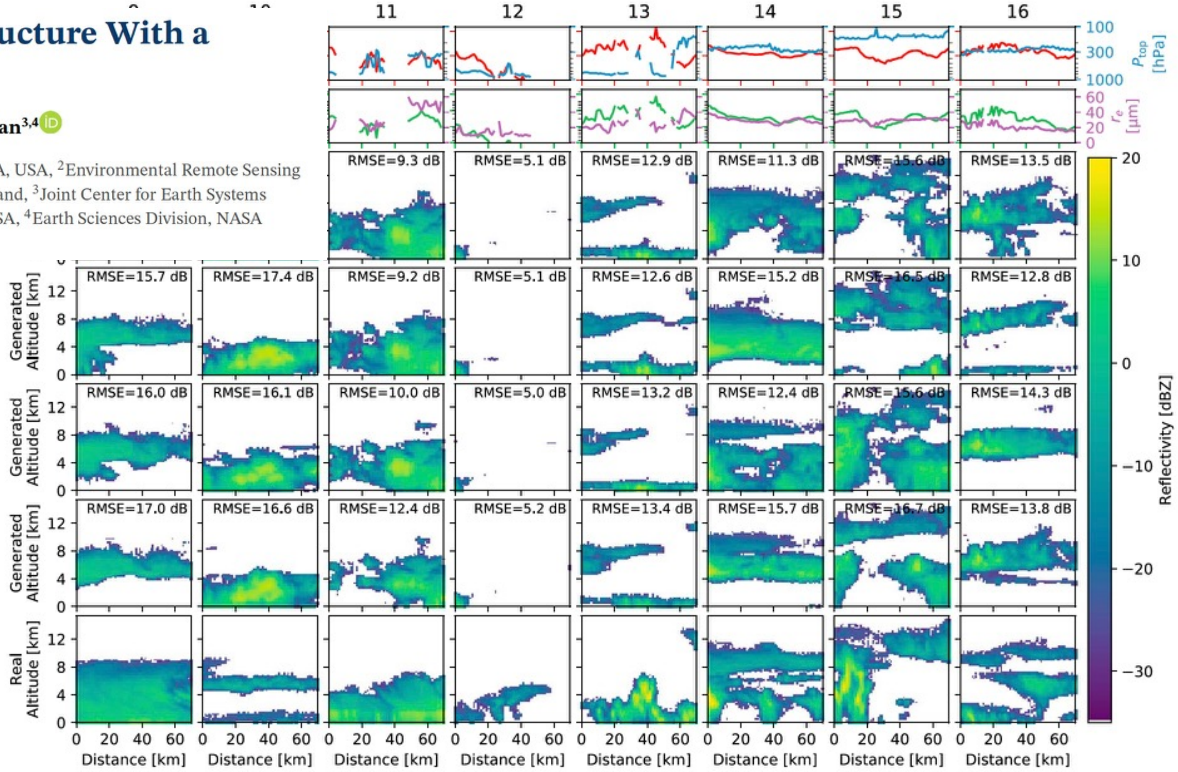


Figure 1. Examples of cloud scenes generated by the conditional generative adversarial network. Each of the 16 columns corresponds to one scene; the first two rows show the Moderate-Resolution Imaging Spectrometer variables, the following four rows show examples of generated scenes (the first of these generated with zero noise), and the final row shows the real scene (i.e., the correct solution). CWP = cloud water path; RMSE = root-mean-square error.

Take home messages …

1. 3MI brings a whole "new" vision to the atmosphere within an operational meteorological system : polarization and multiangle
2. L2 Cloud products are readily implemented for Day-1 and will be delivered right after mission commissioning - Day-2 research products are under continuous development
3. In synergy with its companion instruments aboard METOP-SG A 3MI, METimage, IASI-NG and Sentinel-5 (UV-NS) offer a unique opportunity to improve vertical description of cloud cover from passive measurements
4. Goal is to physically constrain the profile of cloud properties: need fast radiative transfer model, consistent across the spectral range covered by METOP-SG A
5. A priori information is needed to physically constrain the profile of cloud properties: model simulation as well as ML learning techniques are investigated in order to face the computational burden of OE based retrieval

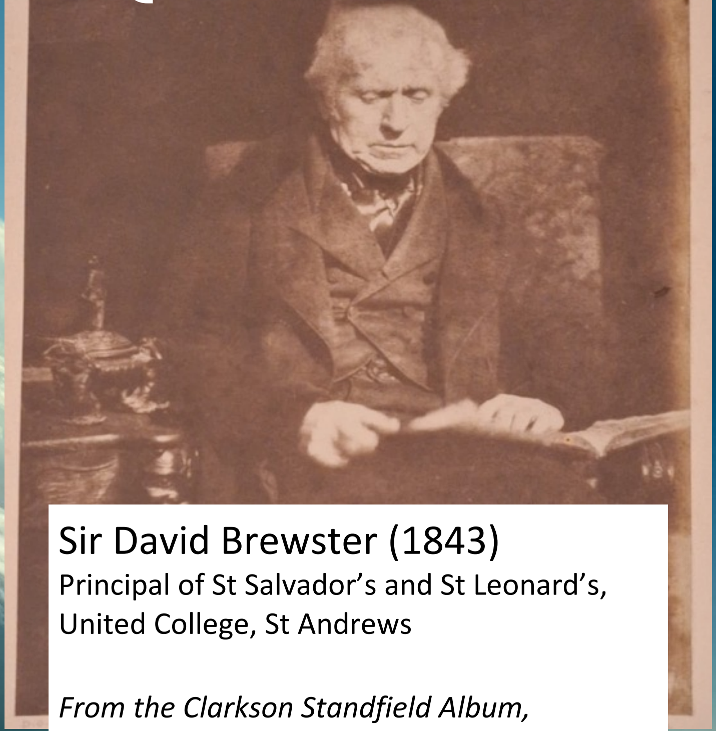
Sun Glint off the coast of Japan – Kujūkuri
35.54 latitude – 140.59 longitude
12 November 2022 – 11:26 AM

Sun zenith angle : 53.18º

≈

Brewster angle over salt water : 53.27º

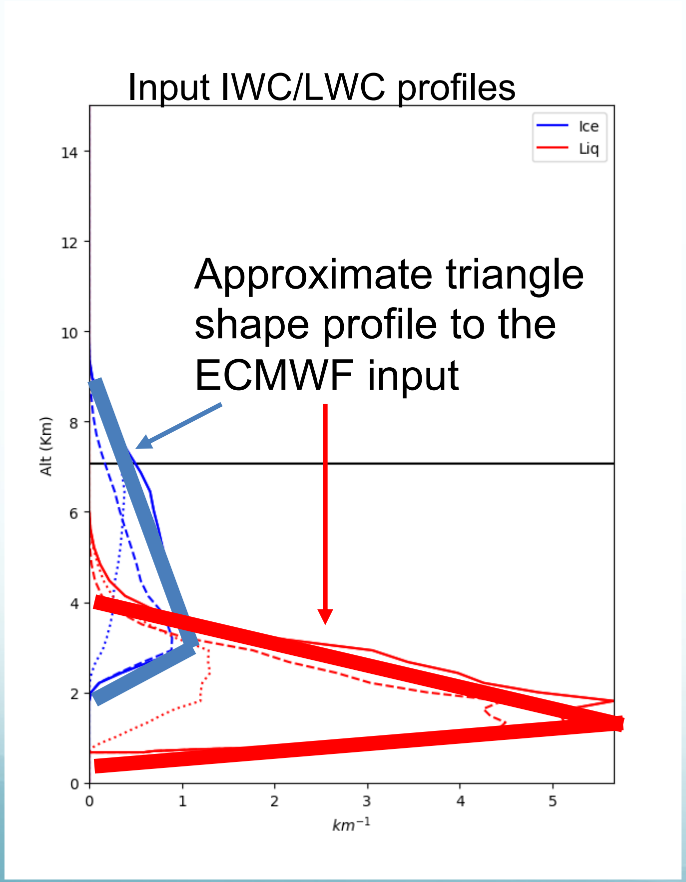
QUESTIONS ?



Sir David Brewster (1843)
Principal of St Salvador’s and St Leonard’s, United College, St Andrews

From the Clarkson Standfield Album, 100 Calotypes by D.O Hill, R.S.A and R. Adamson, Edimburgh, 1845

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

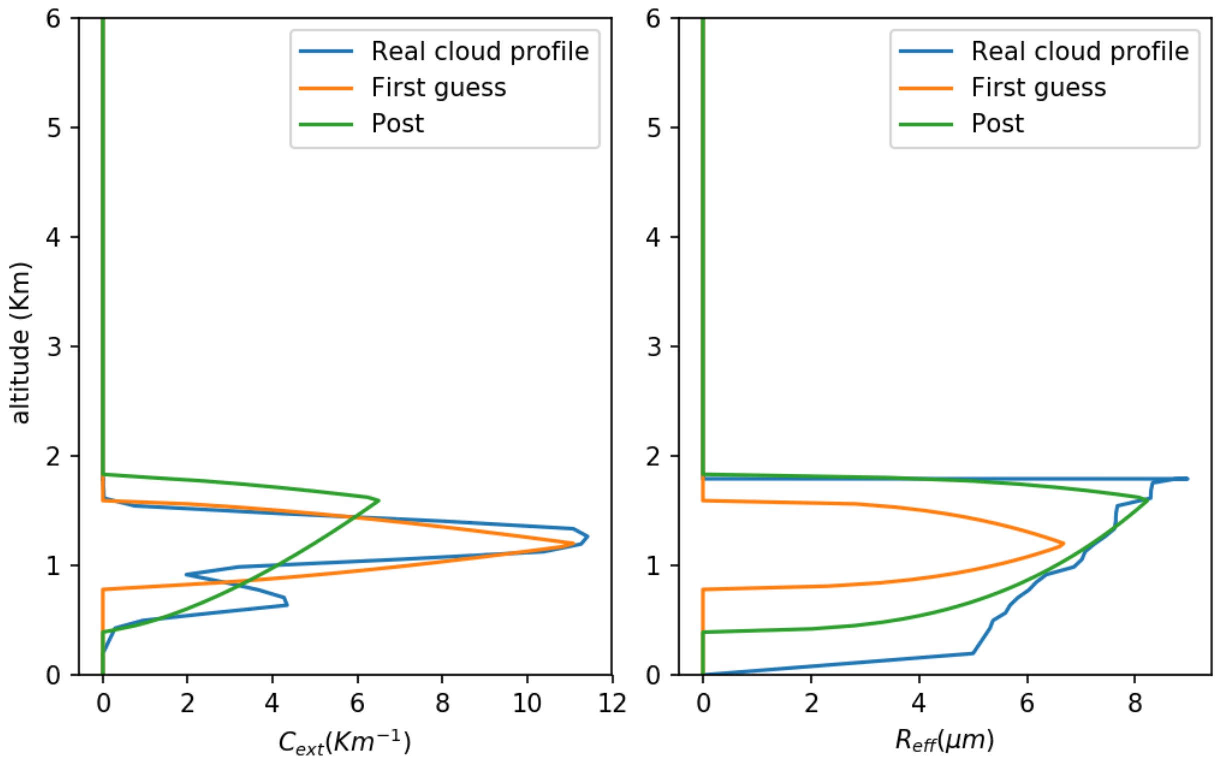
Cloud Geometrical Thickness (CGT)
Use Oxygen A-Band differential absorption

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)



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