Remote Sensing of Clouds from Polarization

What polarization can tell us about clouds... and what not ?

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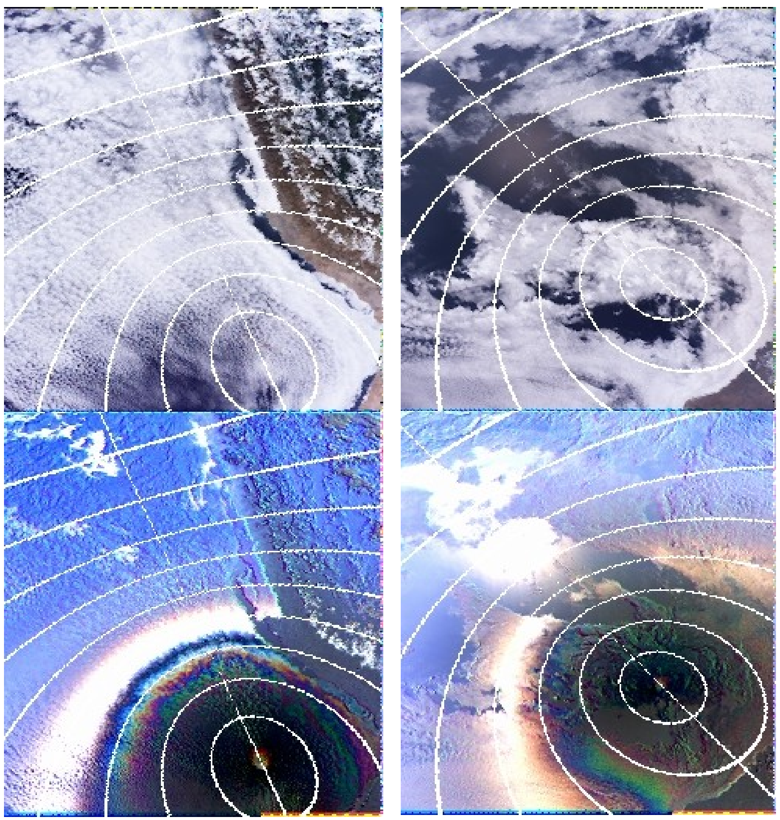
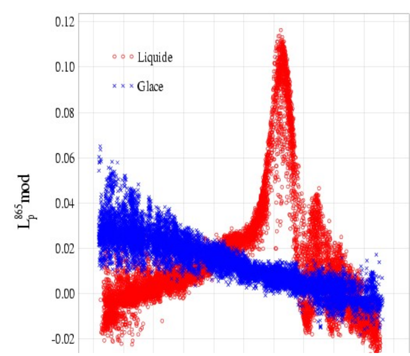
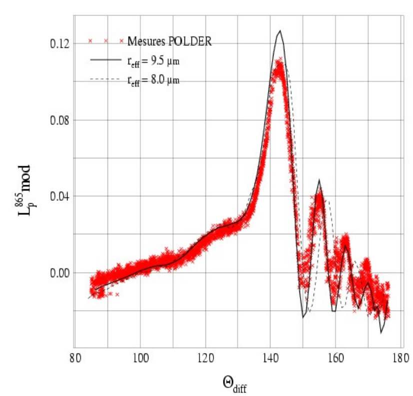
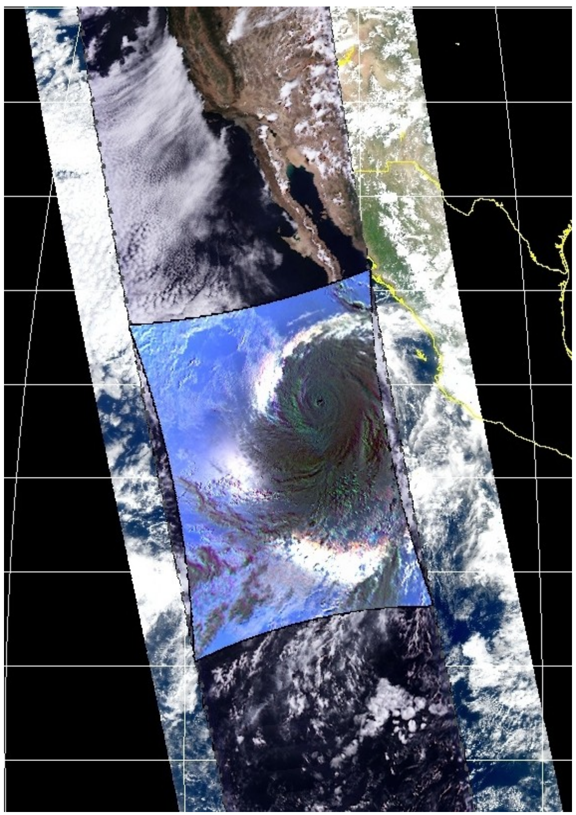








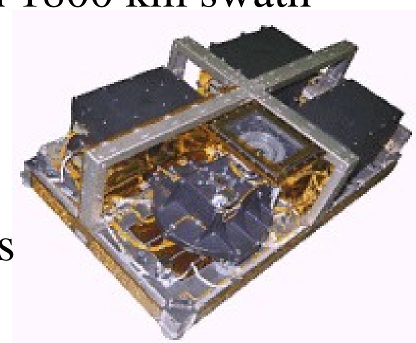
OUTLINE

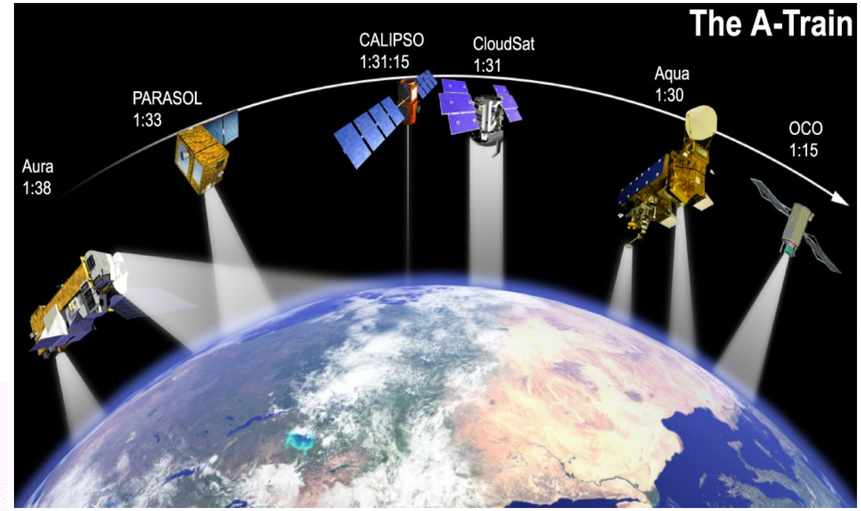
- What this talk is about :
  - passive measurement of polarized reflected sunlight
  - cloud remote sensing from polarization multiangle measurements
  - cloud microphysic (phase, shape, size distribution)
  - what is possible with polarization ...
  - ... what we can not or should not do with polarization
  - ... and what we may be able to do in a near future.

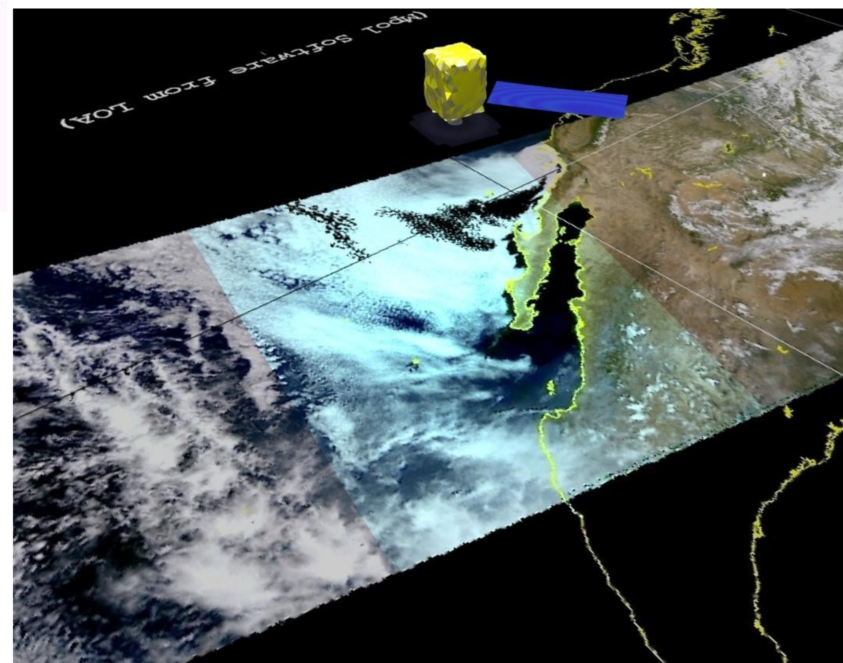
- What it is not about :
  - active remote sensing (lidar, radar)
  - multiangle without polarization ...
  - ... or polarization without multiangle.

Context & Instrumental Background

- CNES/LOA instrument, Parasol launched Dec. 2004
  - ~ 705 km polar orbits, ascending (13:30 a.m.)
- Sensor Characteristics
  - 10 spectral bands ranging from 0.443 to 1.020 µm
  - 3 polarised channels
  - Wide FOV CCD Camera with 1800 km swath width
  - +/- 43 degrees cross track
  - +/- 51degrees along track
  - Multidirectionnal observations (up to 16 directions)
  - Spatial resolution : 6x7 km
  - No onboard calibration system - Inflight vicarious calibration :
    - 2-3% absolute calibration accuracy
    - 1% interband – 0.1% interpixel over clouds







What we think we can do ...

Past Application to Clouds Remote Sensing

Polarization by clouds

D. Deirmendjian - Appl. Opt, 1964, J. E. Hansen – Journal of Atmos. Sci., 1971

Cloud phase

Goloub et al (2000), Riedi et al (2001)

Liquid Cloud Microphysic

Bréon and Goloub (1998), Bréon and Doutriaux (2005)

Ice Cloud Microphysic

Chepfer et al (2001), Liou and Takano (2002), Baran and Labonnote (2006)

Oriented Particles Detection

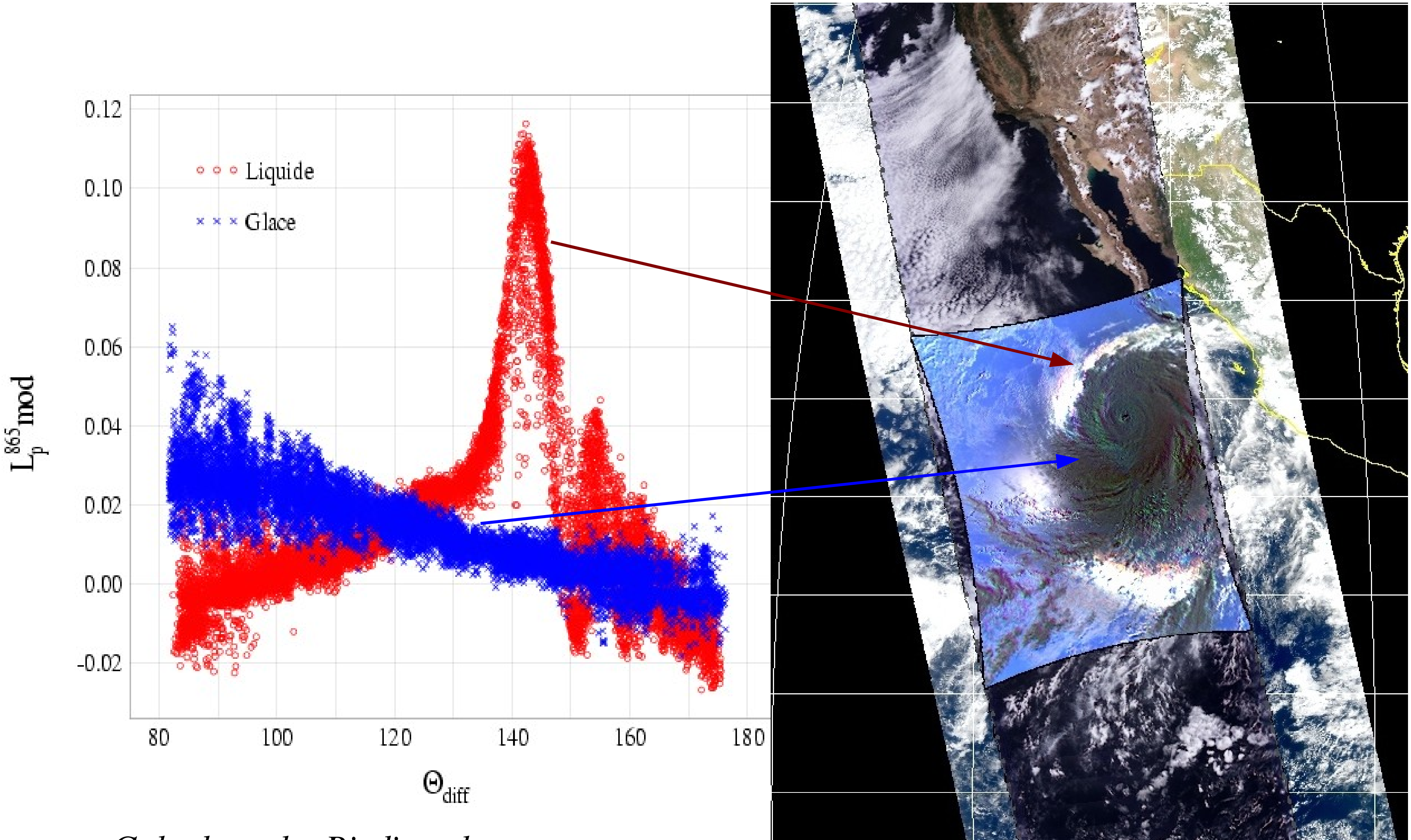
Chepfer et al (1999), Bréon and Dubrulle (2004), Noël et Chepfer (2004)

Cloud Top Pressure

Buriez et al (1997), Vanbauce et al (2002)

Cloud Top Thermodynamic Phase

Principle : particle shape discrimination spherical vs non sphe.



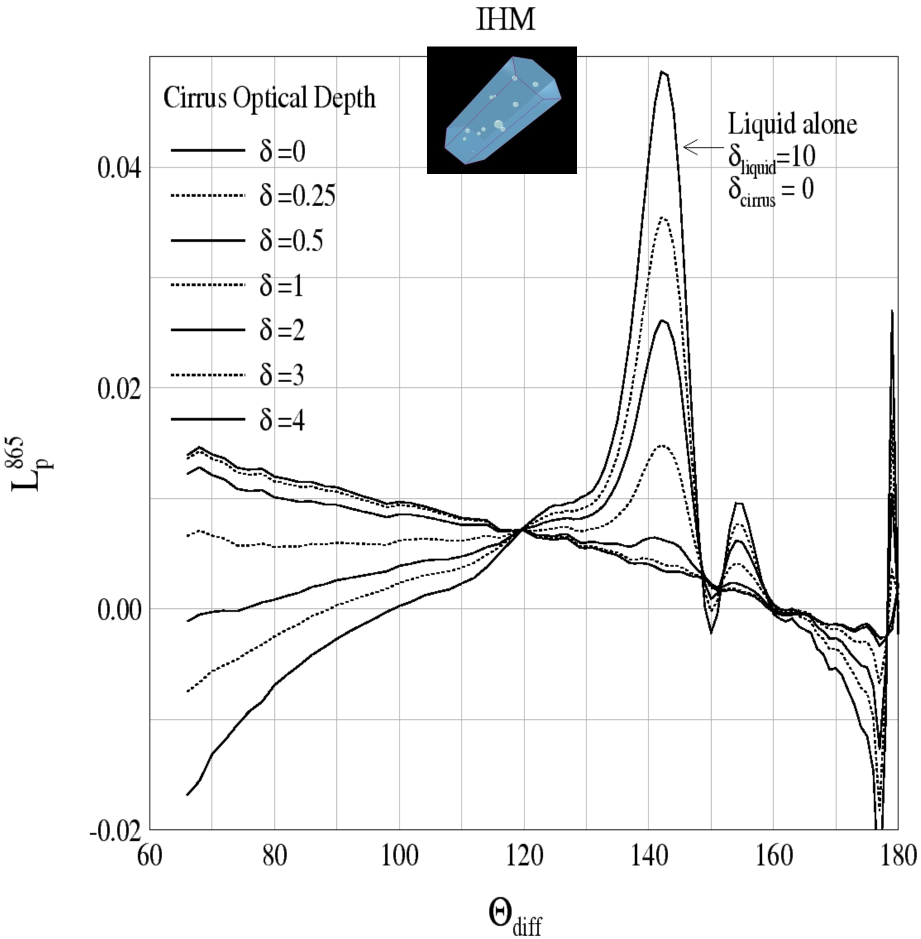
Goloub et al,   Riedi et al

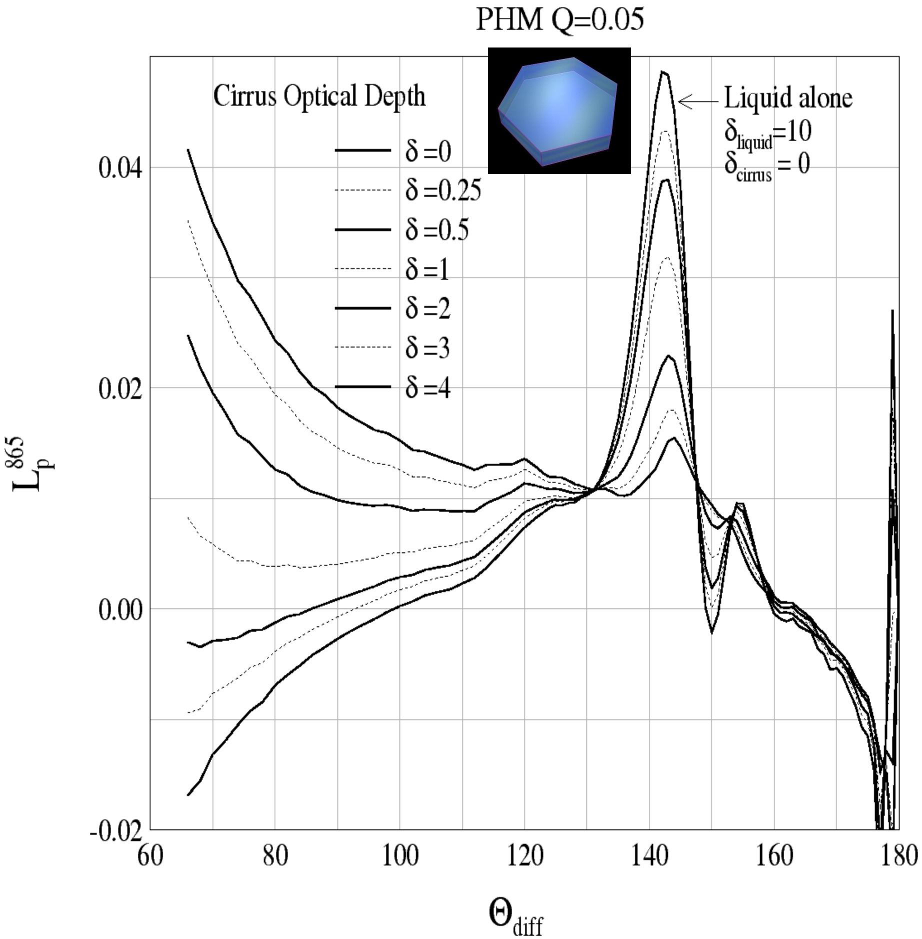
Cloud Top Thermodynamic Phase

How deep do we go inside clouds using polarization measurements ?

Multilayer Systems : Cirrus over liquid cloud.

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



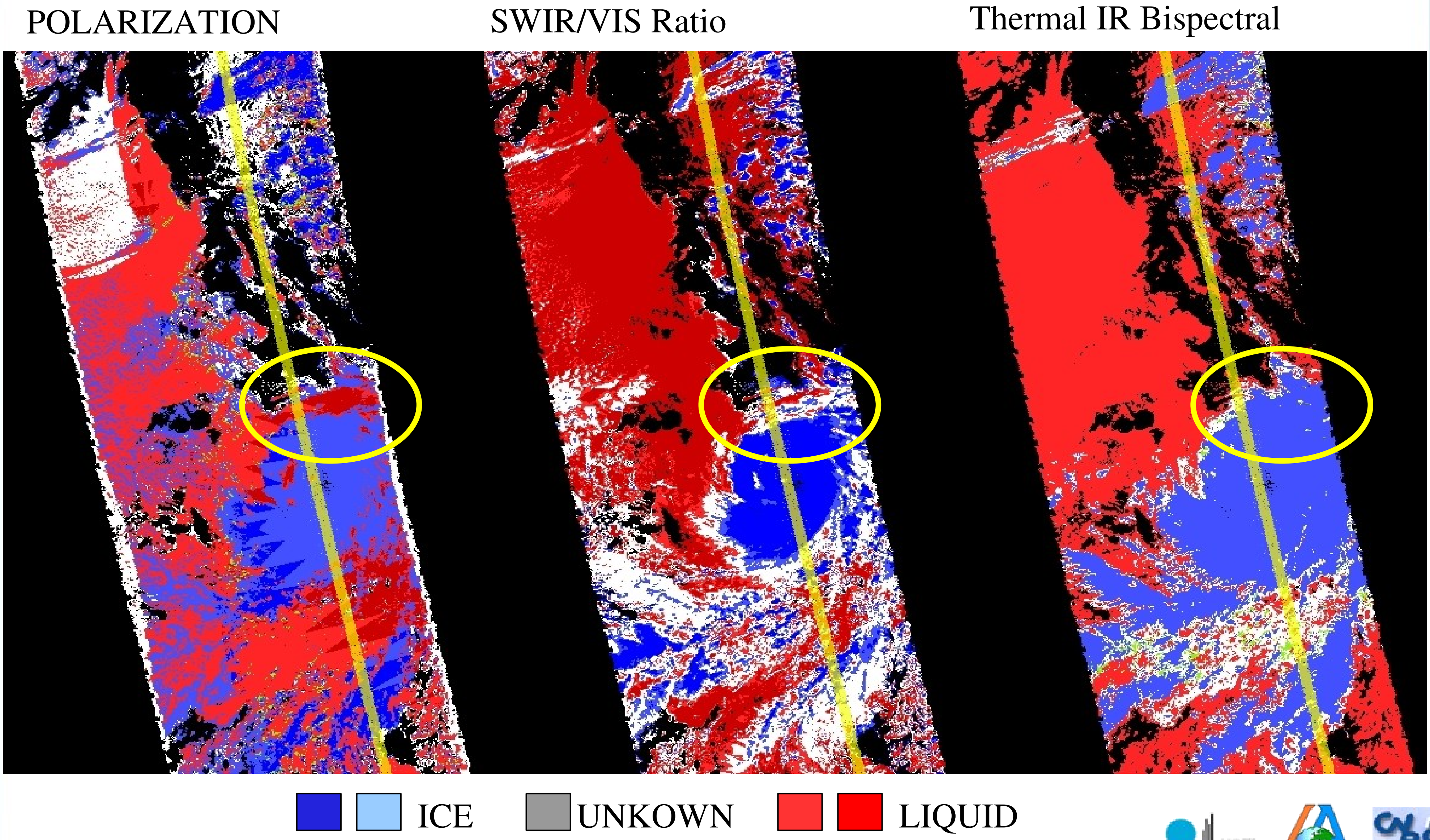


J. Riedi – PhD Thesis - 2001

Cloud thermodynamic phase

Combination of information on particle shape and absorption properties

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



Cloud thermodynamic phase

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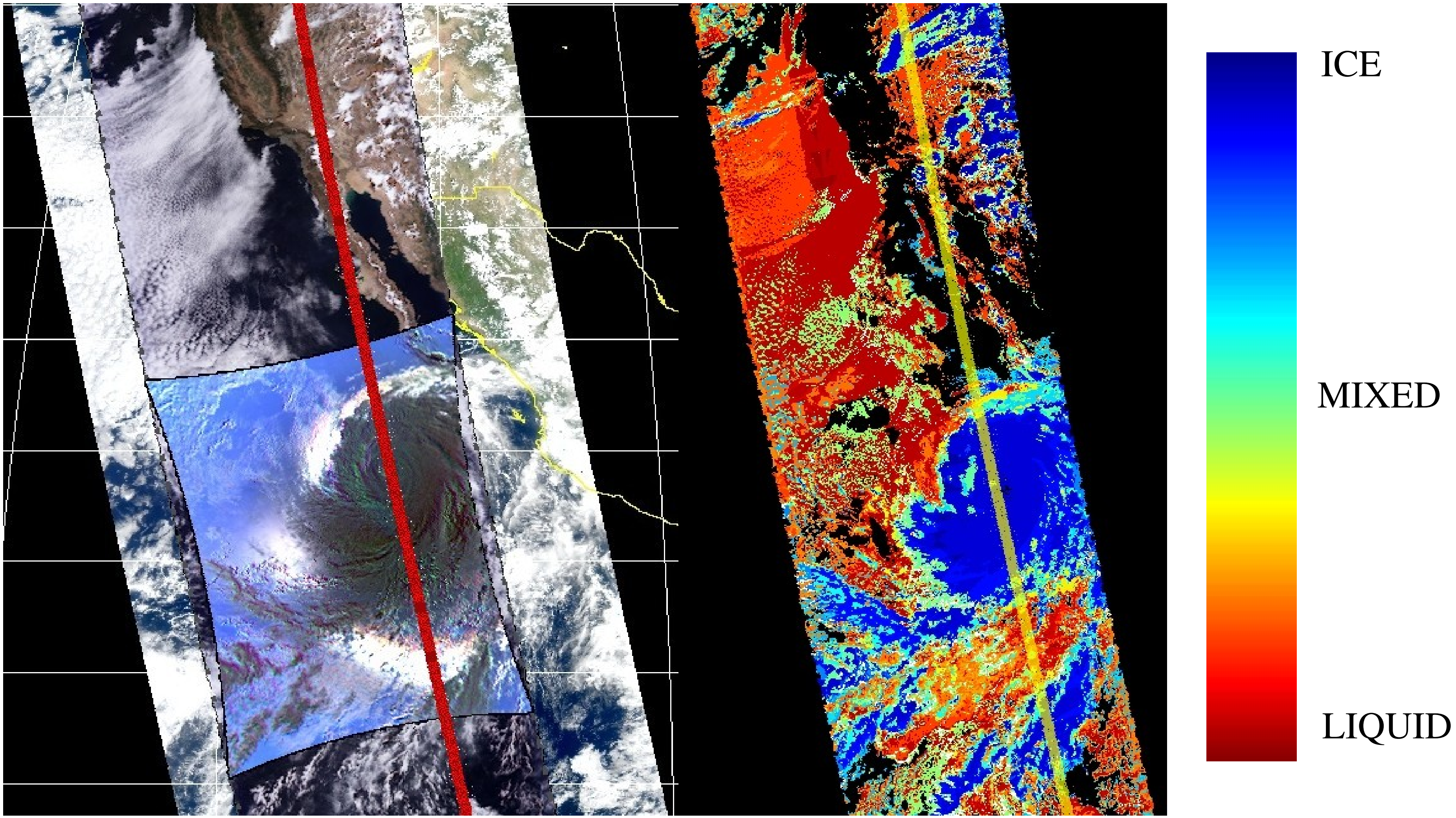
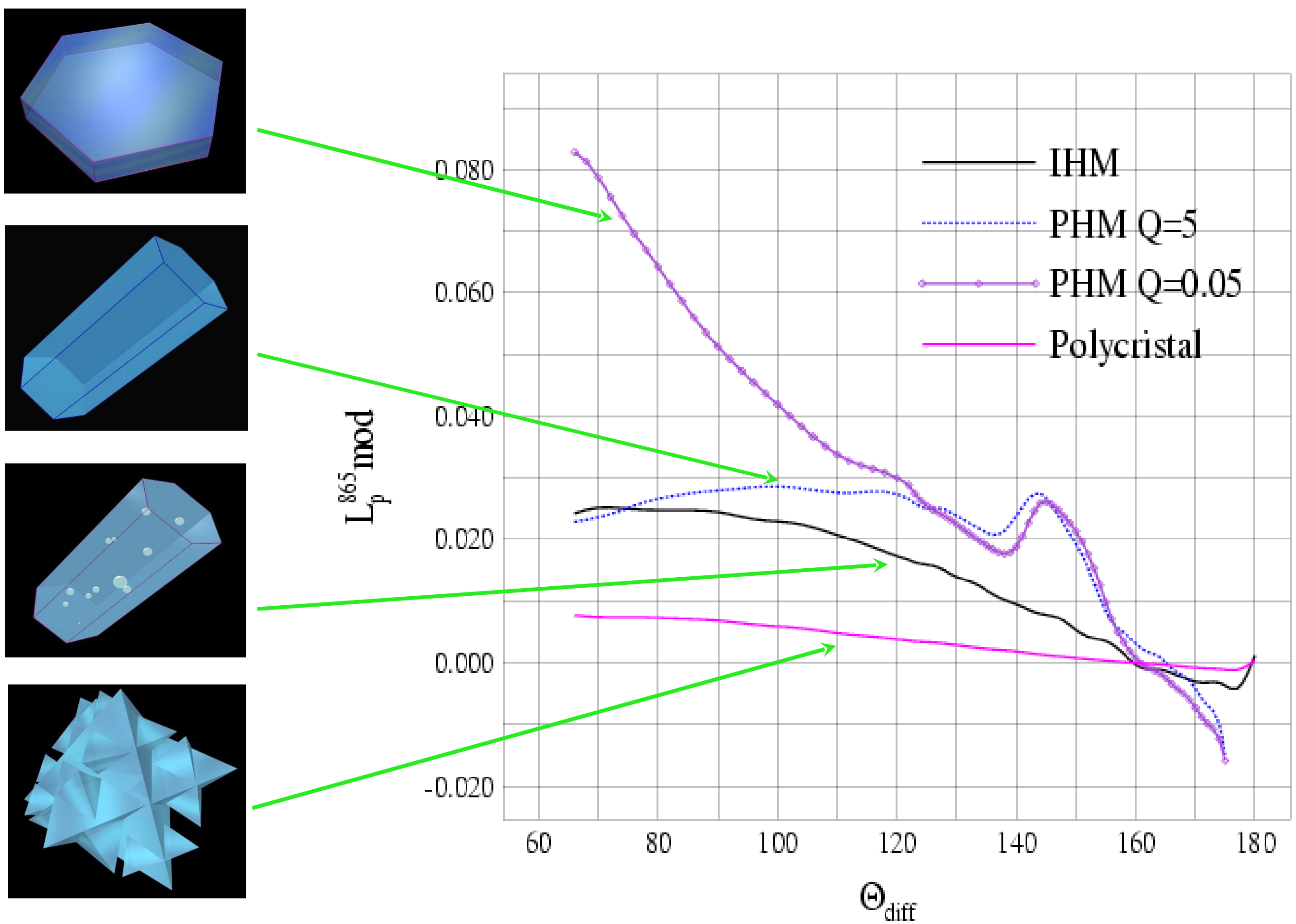


Riedi et al, 2007 (to be submitted to JGR)

Ice Cloud Microphysic

Principle : Polarized Phase function of single particle is strongly influenced by particle shape.

Computation of polarized reflectance for uniform layer ice cloud with single particle



Can be used to derive particle shape (Chepfer et al, 1998).

How representative of real cloud with size and shape distribution ?

Ice Cloud Microphysic

Modelled VS observed global mean polarized signature of ice clouds

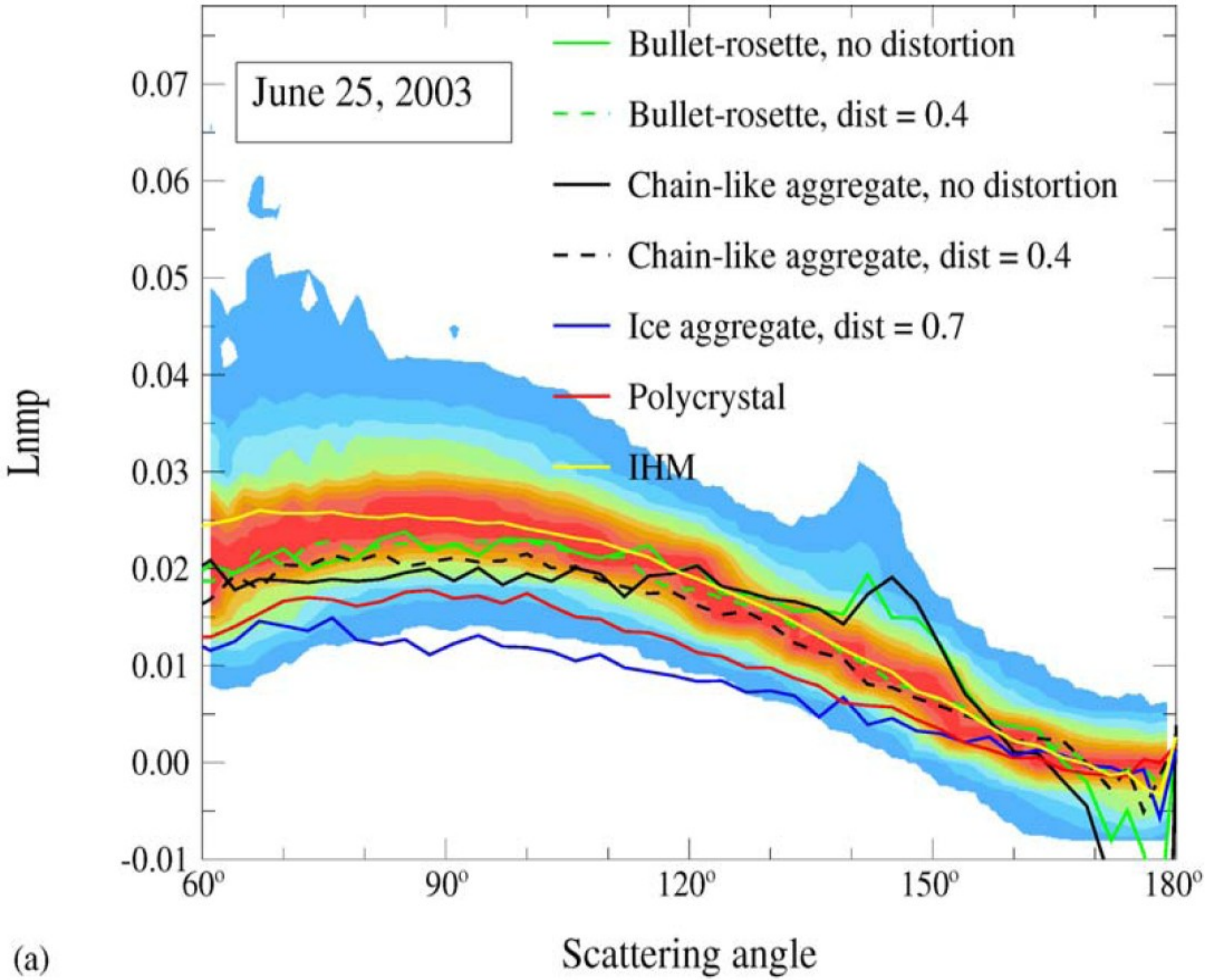


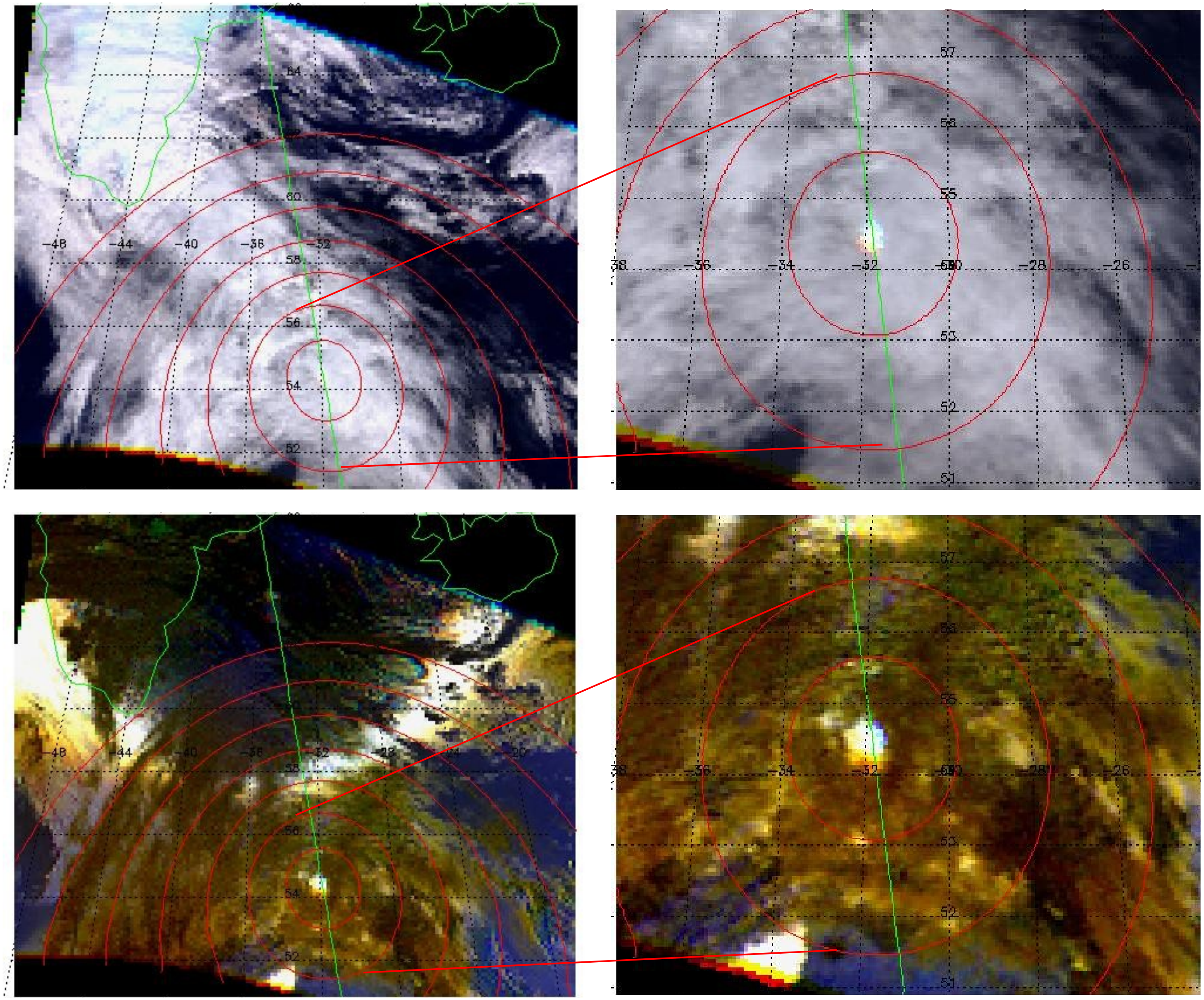
Figure from : A. J. Baran and L. C-Labonnote, JQSRT (2006)

Can also look for a mean equivalent model representative of an average ice cloud.

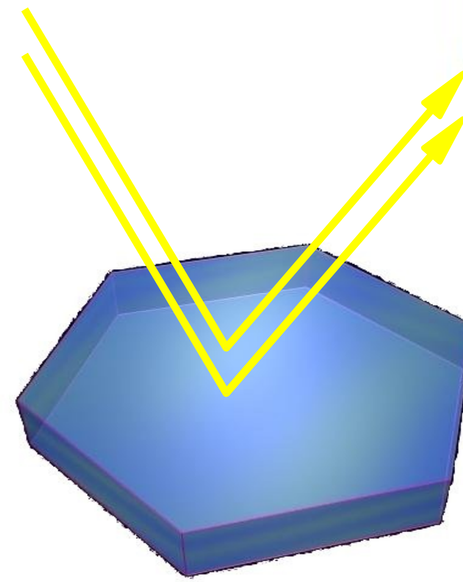
Labonnote et al (2001) demonstrated the **I**nhomogeous **H**exagonal **M**odel (IHM) can be used to fit well both total and polarized multiangle reflectances from POLDER.

Ice Cloud Microphysic

Specular reflection on Oriented Plates in Ice clouds



Classical three color composite

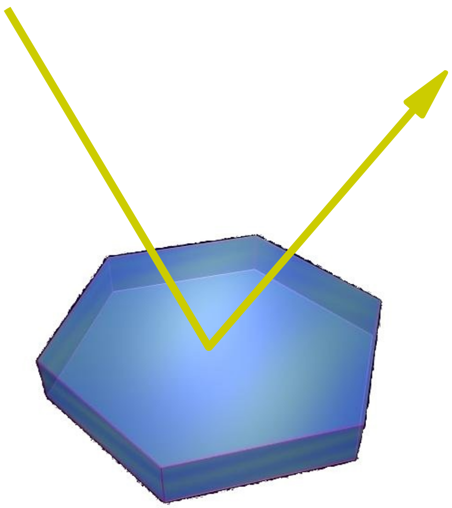


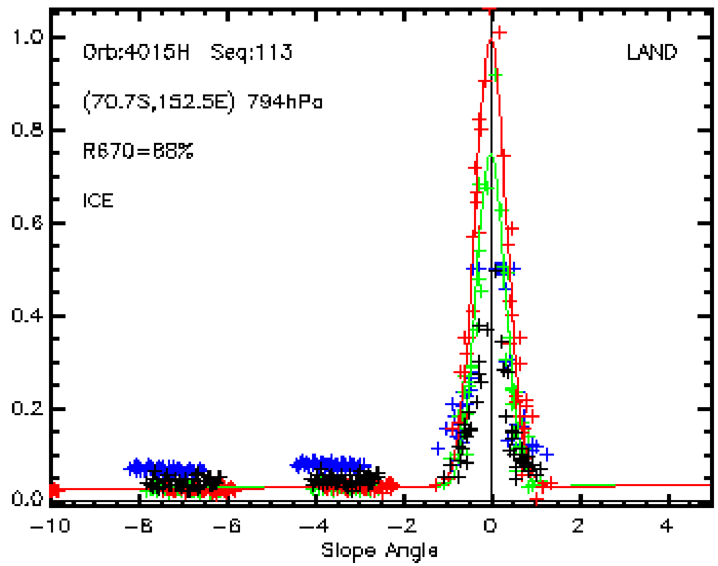
Polarized Reflectance

Bréon and Dubrulle (2004)

Ice Cloud Microphysic

Specular reflection on Oriented Plates in Ice clouds

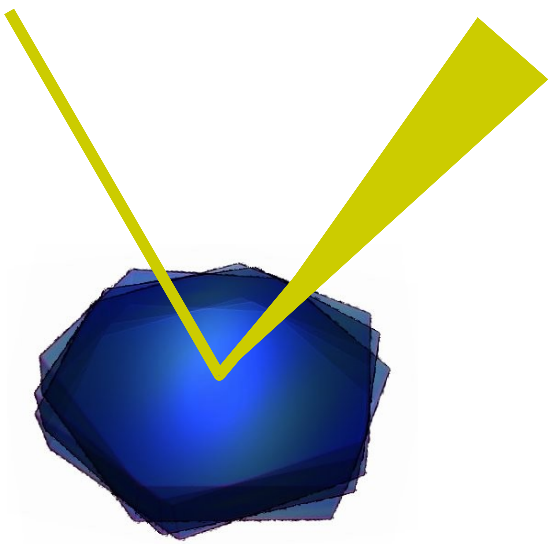




From : Bréon and Dubrulle (2004)

Width and intensity of specular peak depends on particle size, concentration and distribution of tilt angle.

Directional signature of oriented plates can be use to infer characteristic tilt angle and particle concentration



First study at global scale from Chepfer et al (1999) showed specular reflection can be observed for 50% of the high ice clouds.

Noel and Chepfer (2004), Bréon and Dubrulle (2004), using full RT or approximate calculation both agreed on :

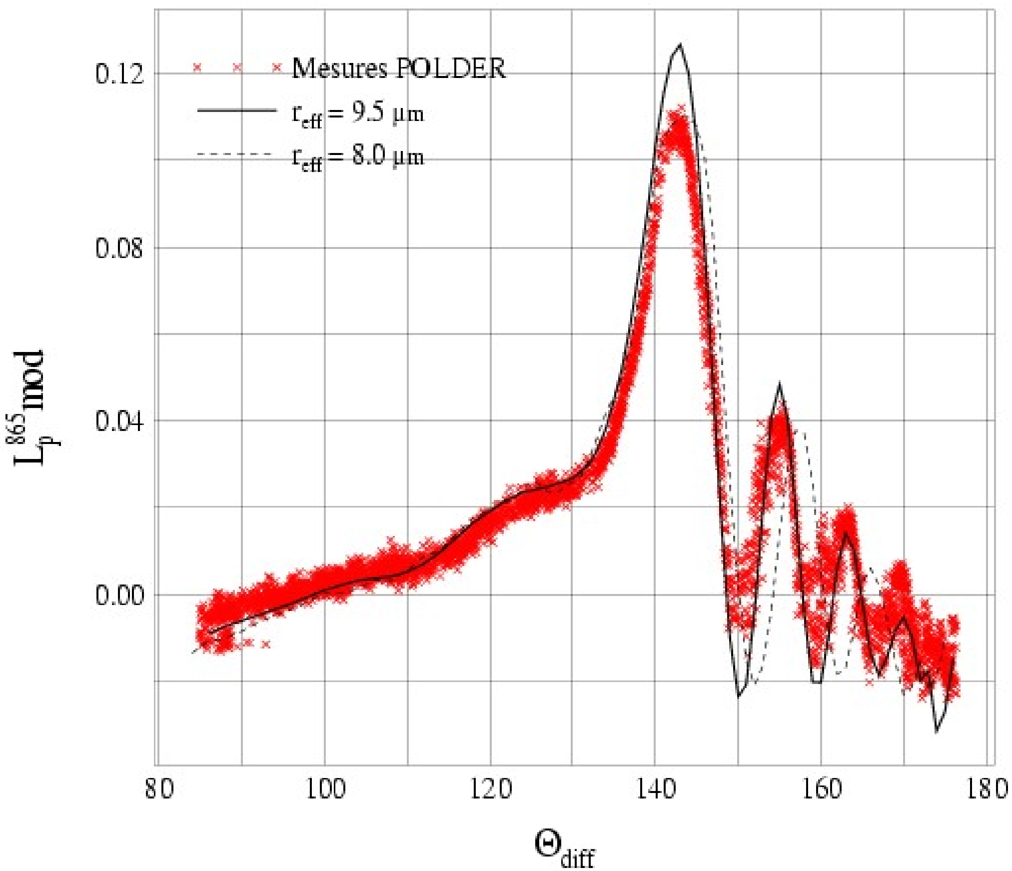
-the maximum tilt angle (typical 1°, maximum 2° to 3°)

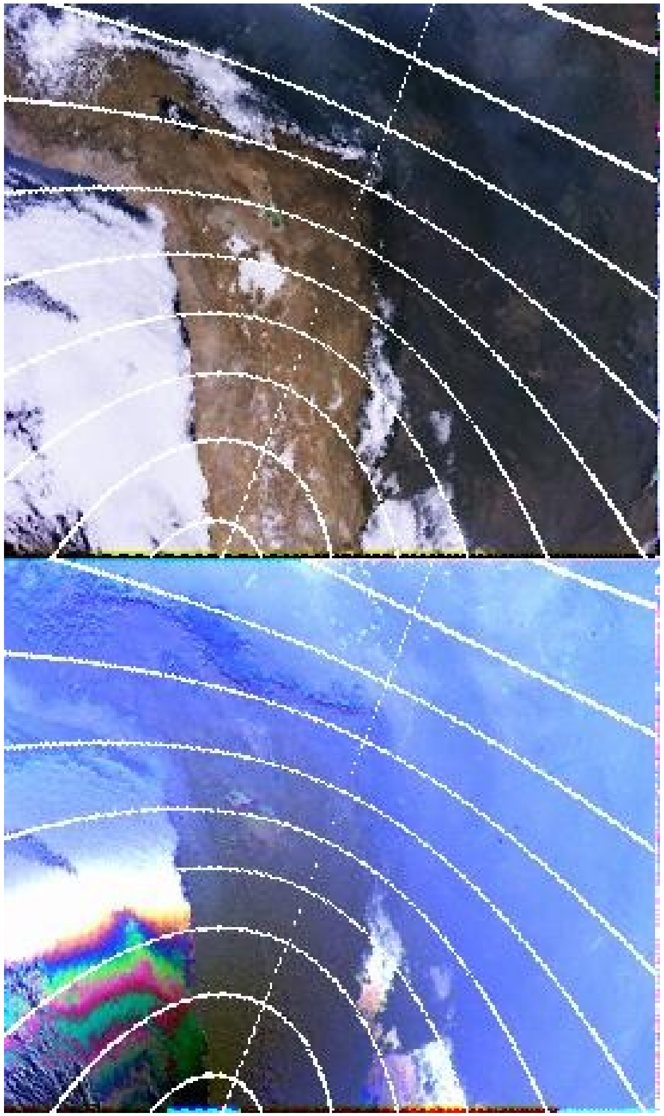
- the very small fraction of oriented plates necessary to

Liquid Cloud Droplet Effective Size Distribution

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

Cloud Droplet Distribution : effective radius and variance

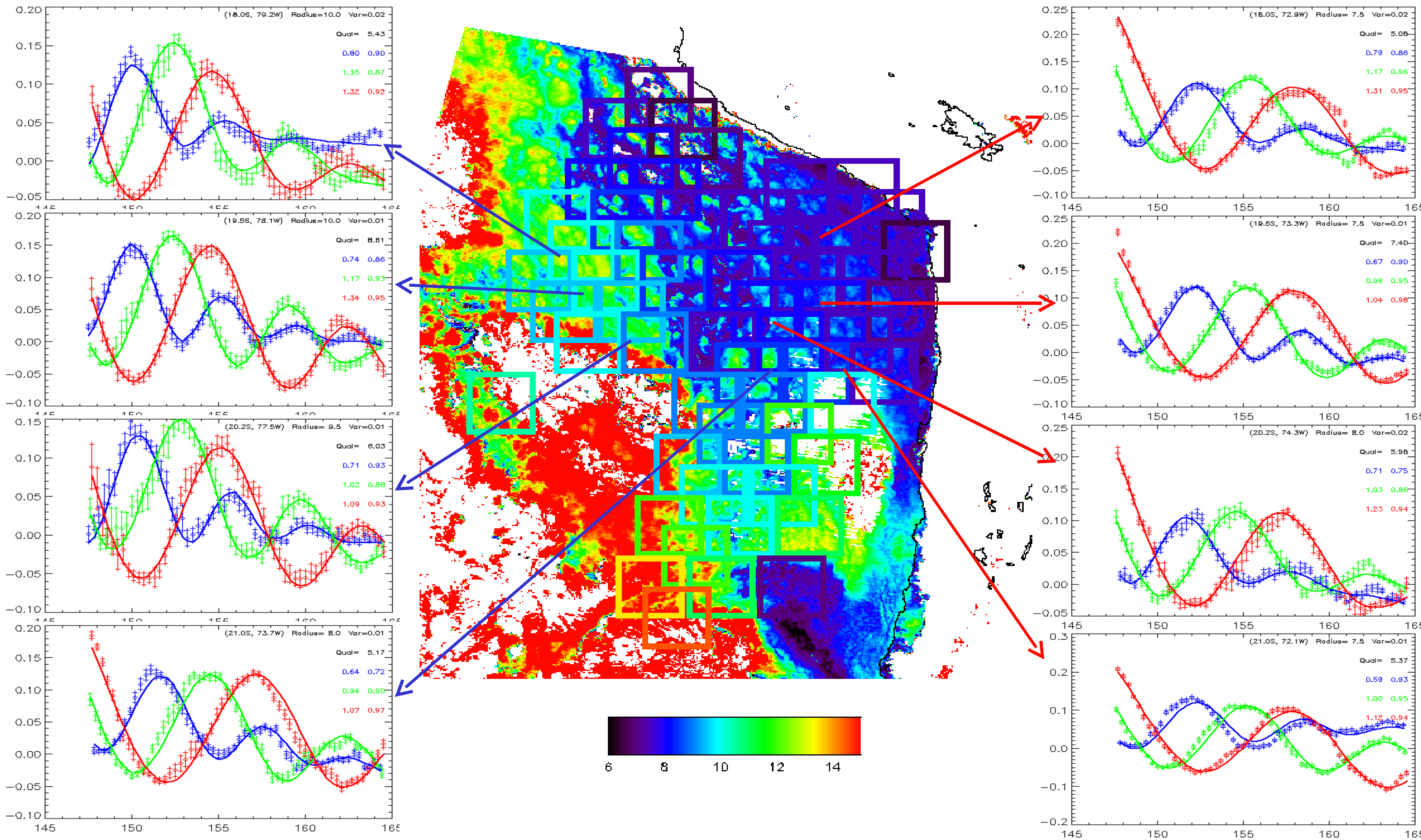




Bréon and Goloub, GRL, (1998)

Liquid Cloud Droplet Effective Size Distribution

Comparison with MODIS retrievals

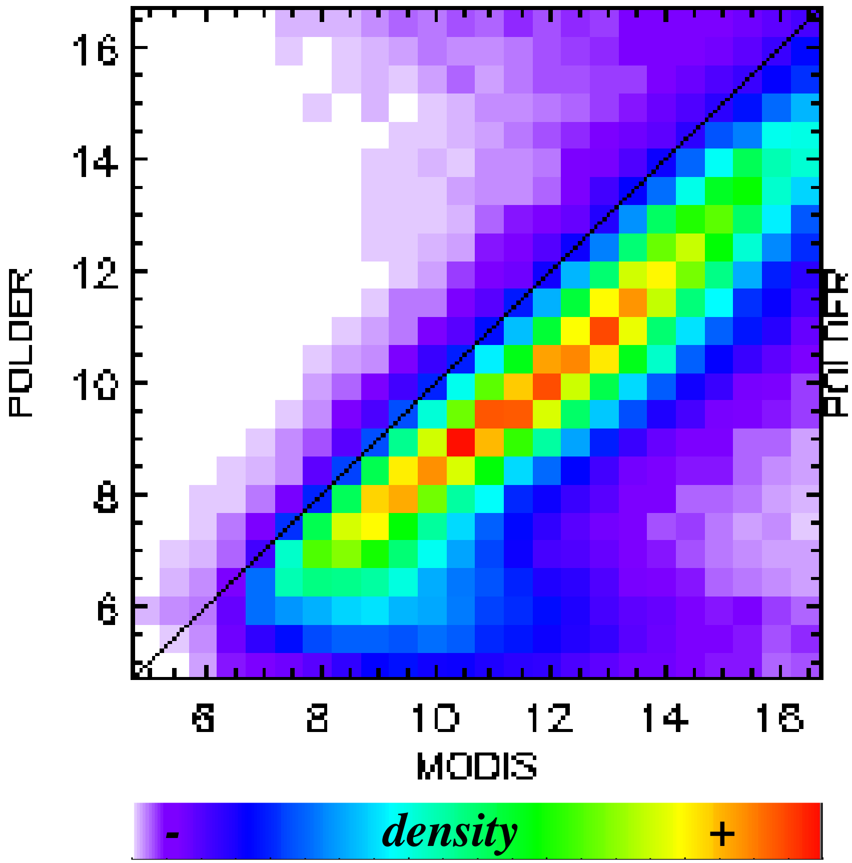


From : Bréon et Doutriaux, JAS (2005)

Liquid Cloud Droplet Effective Size Distribution

Comparison with MODIS retrievals

Comparison between POLDER and MODIS « effective » radii over ocean



Correlation is good but there is an apparent 2 microns bias between POLDER and MODIS retrievals.

POLDER sees smaller droplets than MODIS.

POLDER "less sensitive to biases and errors resulting from cloud heterogeneity, assumptions on the size distribution" when retrieval is possible according to authors.

Questions :

Is this real ?

Is one of them correct ? none ? both ?

From : Bréon et Doutriaux, JAS (2005)

Things we should consider carefully ...

What have we learned from previous studies ?

Polarization comes from single scattering so that phase function angular features are conserved in polarized reflectance.

Polarization provides information from the top (or edges) of the cloud

Polarization can provide different (not better, just different !) information than spectral observations.

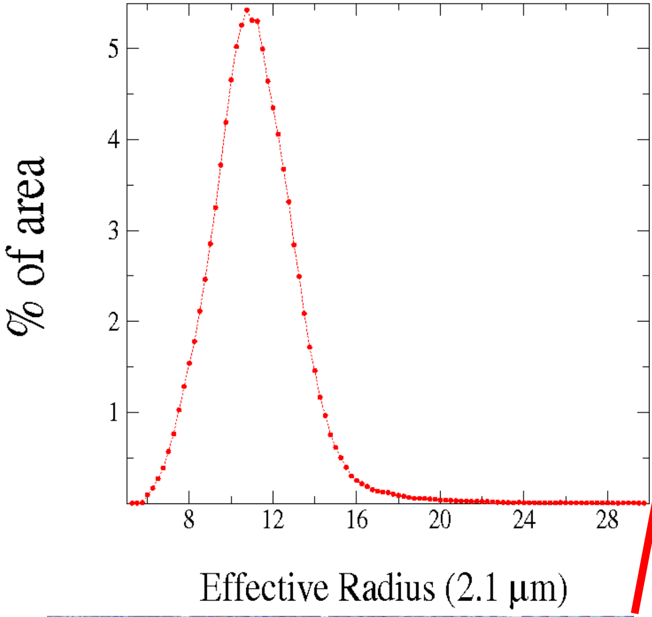
Polarization yields more or less useful information depending on the range of accessible scattering angle.

Polarization saturates for cloud OT greater than 2.0 : relatively thin, thick or very thick clouds contribute equally to polarized radiance but not to total radiance !

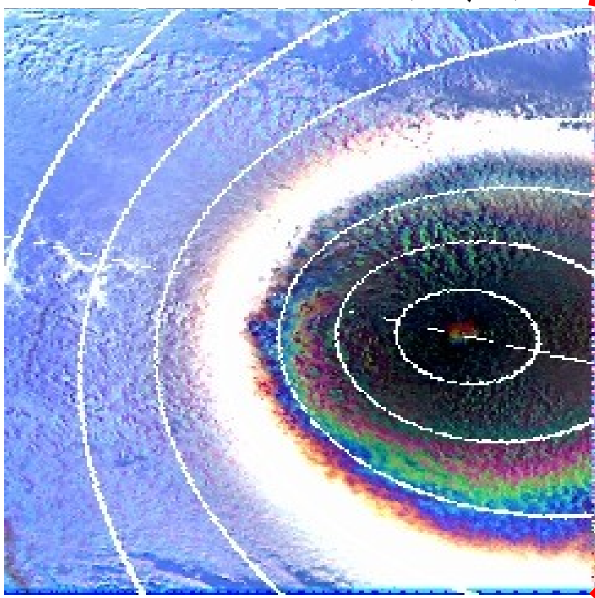
A small portion of particles can produce a significant polarized signal.

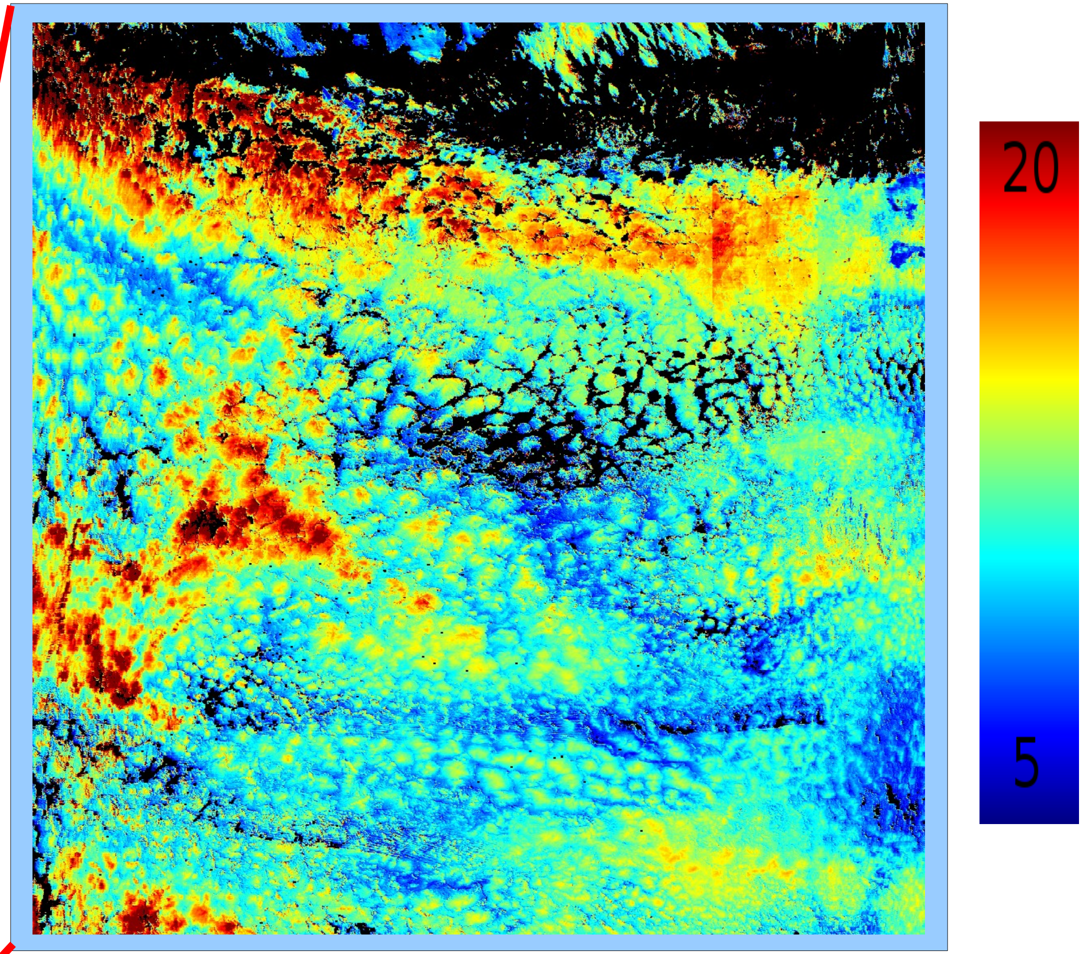
Liquid Cloud Droplet Effective Size Distribution

Considerations on the use of polarization for droplets size retrieval



Are large scale rainbows observed by POLDER consistent with MODIS effective radius variability ?





MODIS 2.1 micron effective radius

Liquid Cloud Droplet Effective Size Distribution

Considerations on the use of polarization for droplets size retrieval

There is an **apparent** discrepancy between observation of extended rainbow features and variability observed in MODIS data.

Facts about liquid cloud microphysic :

- non uniform size distribution occur for various reasons in cloud fields at small or large scale. There can be :

* *horizontal or vertical heterogeneities*

* *bimodal size distribution : for example when remaining aerosols rising with droplets get activated higher in the cloud*

* *small scales variability : in situ measurements show variation at high spatial frequency with pockets of small droplets, etc...*

- relation between Reff and Veff is not completely clear but different processes can contribute to a positive correlation between them (Veff increases with Reff)

What is the impact on polarization based retrievals ?

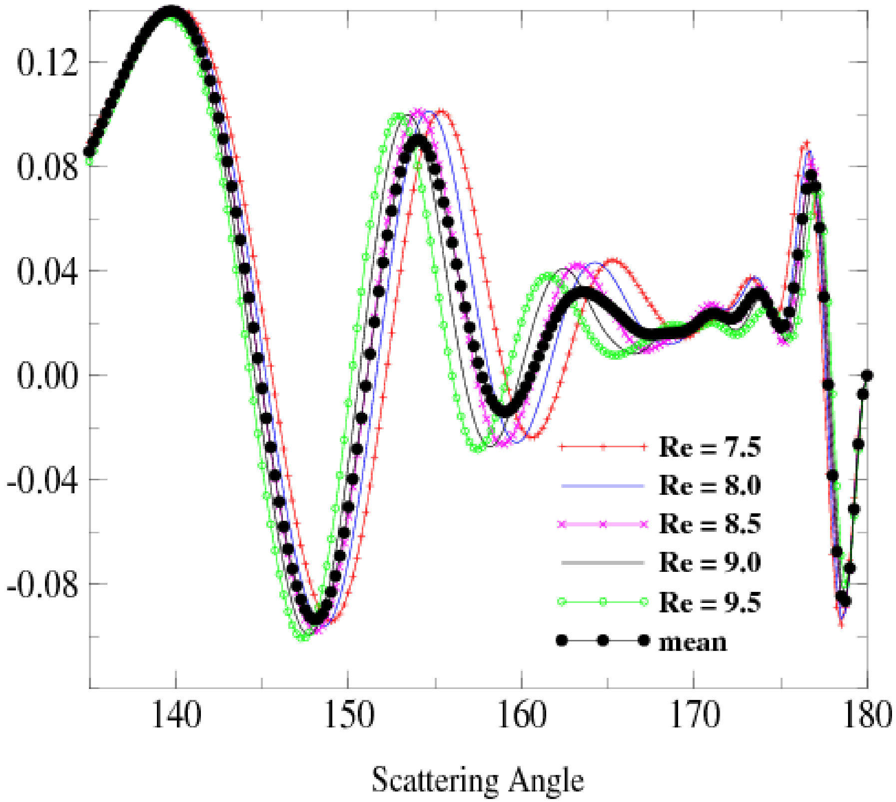
Liquid Cloud Droplet Effective Size Distribution

Considerations on the use of polarization for droplets size retrieval

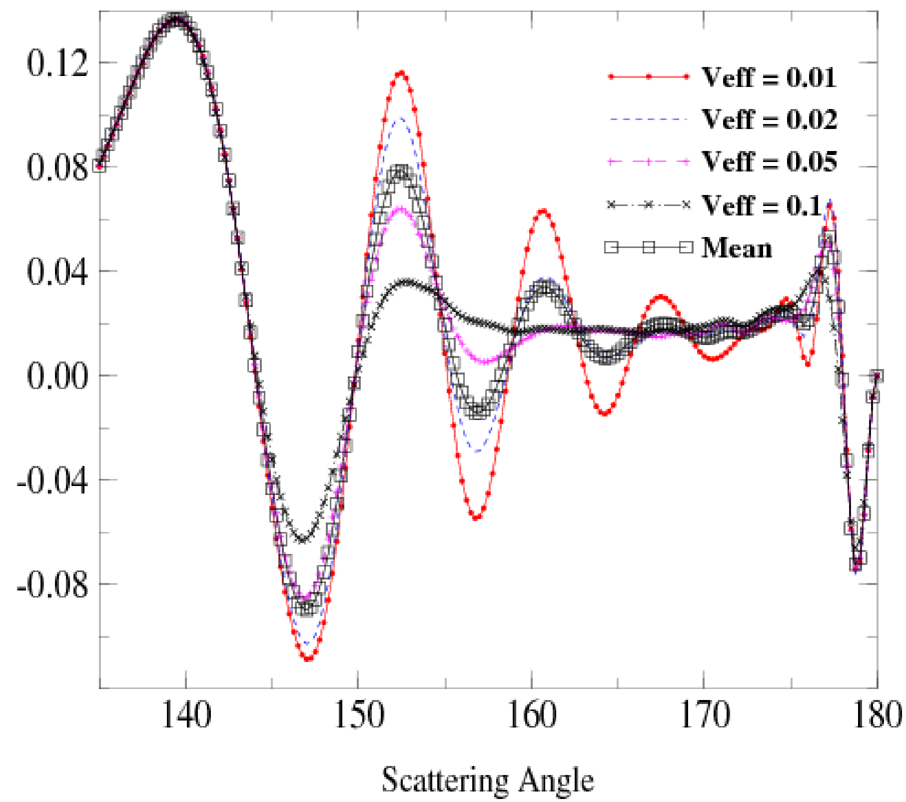
Mixing different distribution : impact on the phase function

Mean phase function resulting of equally weighted phase function with :

Constant Veff and varying Reff



Constant Reff and varying Veff

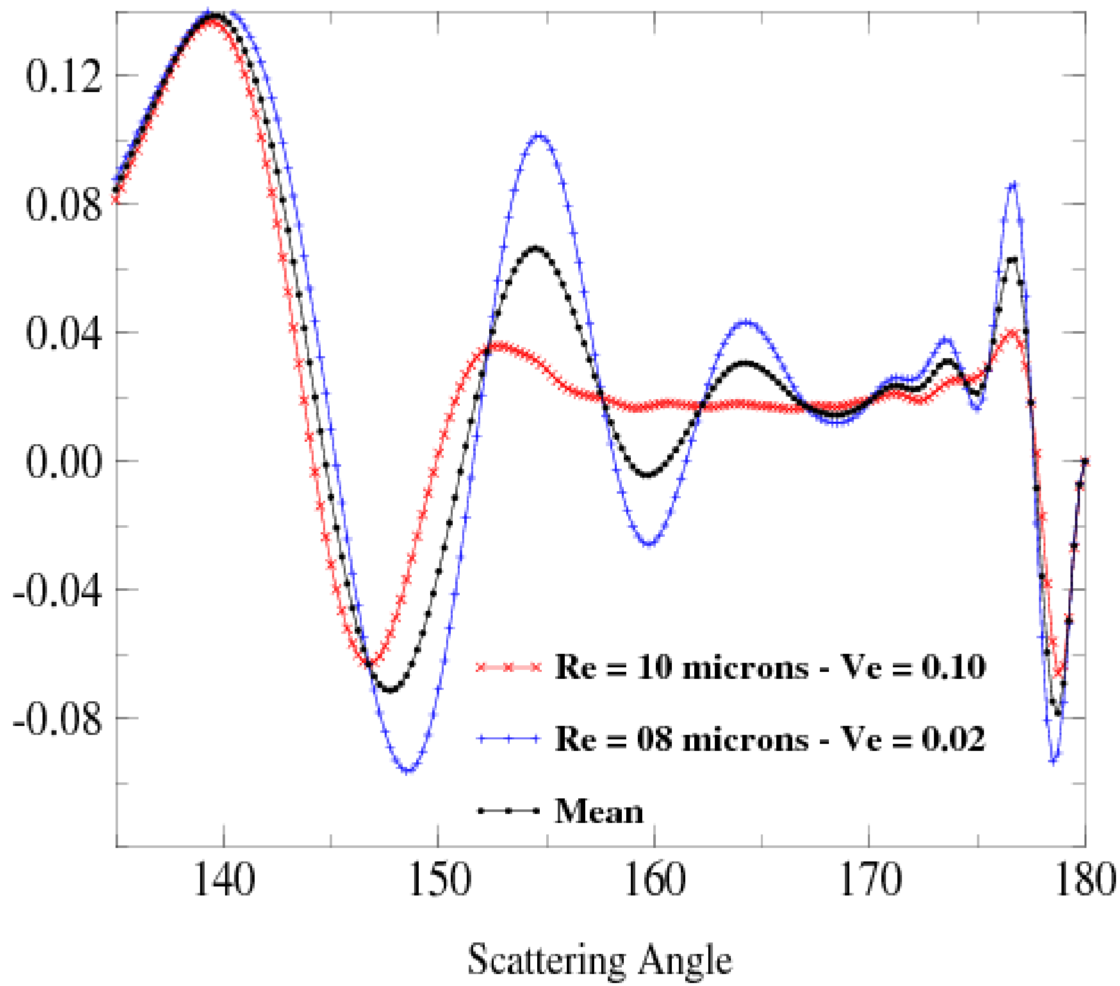


Liquid Cloud Droplet Effective Size Distribution

Considerations on the use of polarization for droplets size retrieval

Mixing different distribution : impact on the phase function

Mean phase function resulting of equally weighted individual phase function



Liquid Cloud Droplet Effective Size Distribution

Potential artifact to consider

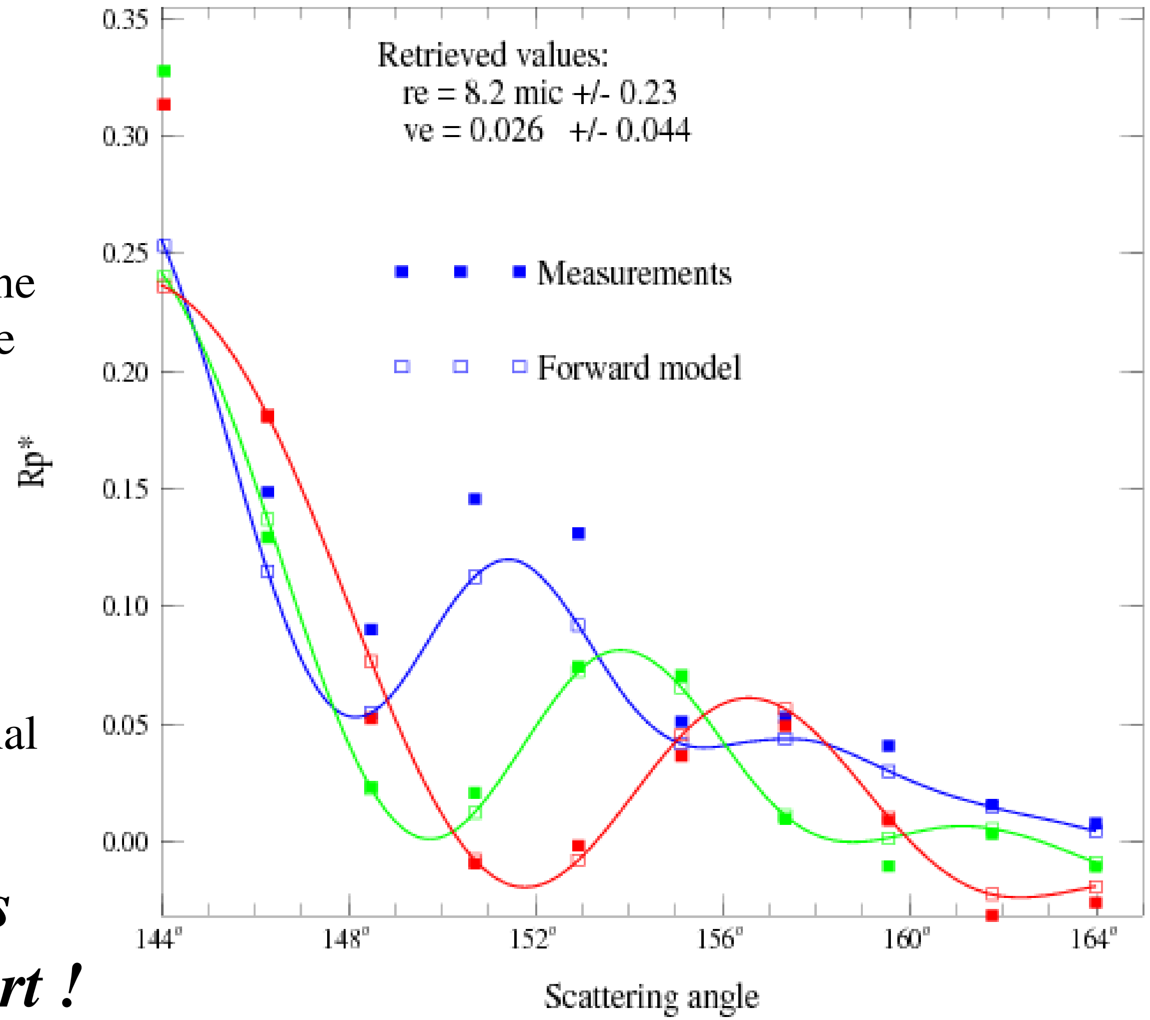
Sensitivity study principle :

- compute the signal observed over a cloud with non homogeneous size distribution (can be horizontal heterogeneities, bimodal size distribution, etc...). Here we consider one half of the pixel covered with re = 8, the other with re = 12 microns

- select about 10 directions in each spectral bands and add some noise to create realistic synthetic measurements

- perform an inversion using a variational method

Mixing (re=8,ve=0.02; re=12,ve=0.1) - ratio = 0.5



Results : the retrieved value is very close to the 8 microns part !

Riedi et Labonnote, 2007 (to be submitted to JAS)

Partial Conclusions

Polarization arises primarily from single scattering, hence it brings information from the top (or edges) of the cloud layers

Polarization saturates for cloud OT greater than 2.0 : relatively thin, thick or very thick clouds contribute equally to polarized radiance but not to total radiance !

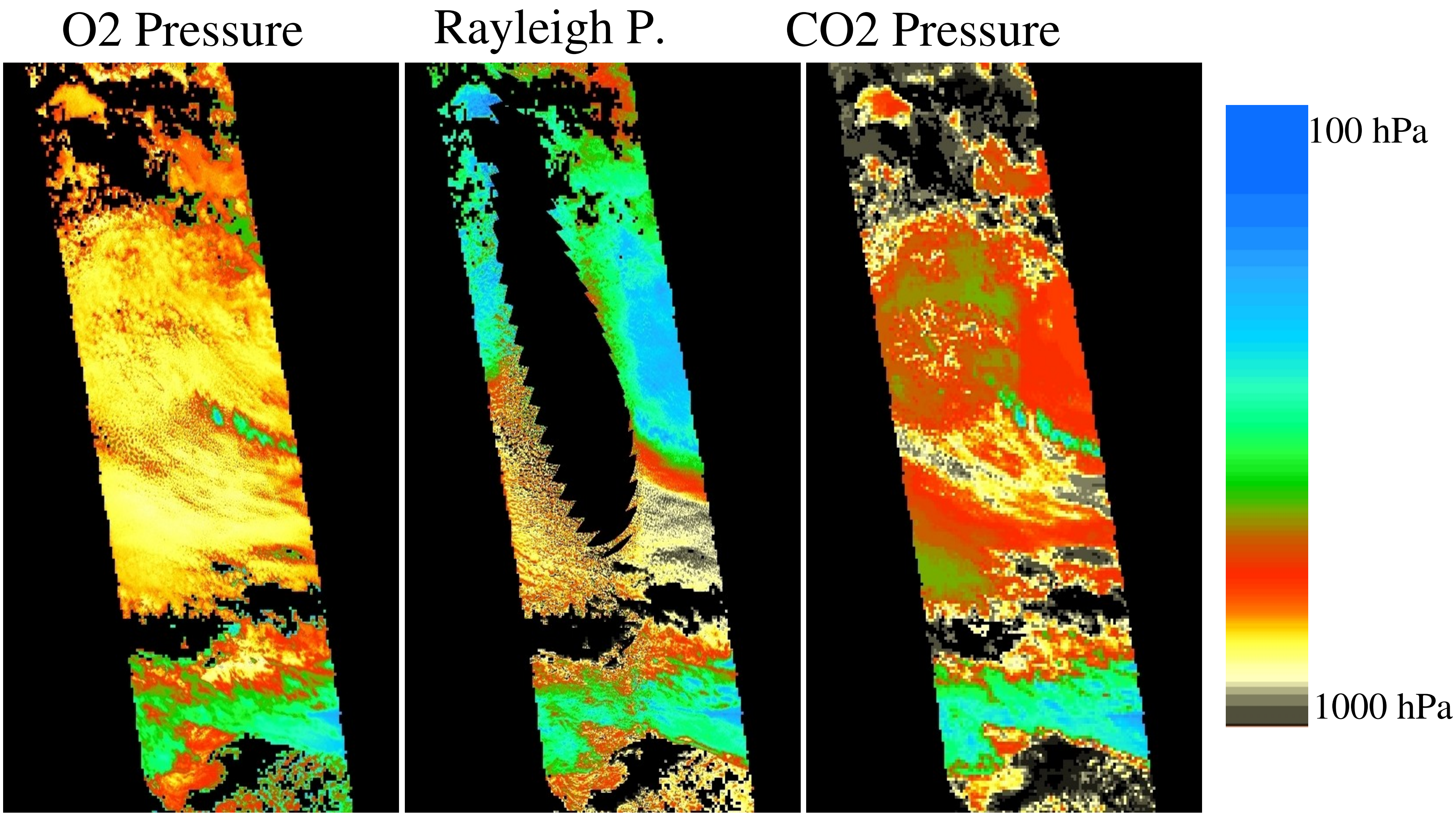
Small fractions of specific particles can contribute significantly to polarization signal

As for aerosol, polarization may be sensitive to the smallest droplets which contribute significantly to the signal.

Information derived from polarization need to be considered carefully : retrievals are also subject to potential biases which need to be understood and recognized

What is next step ?

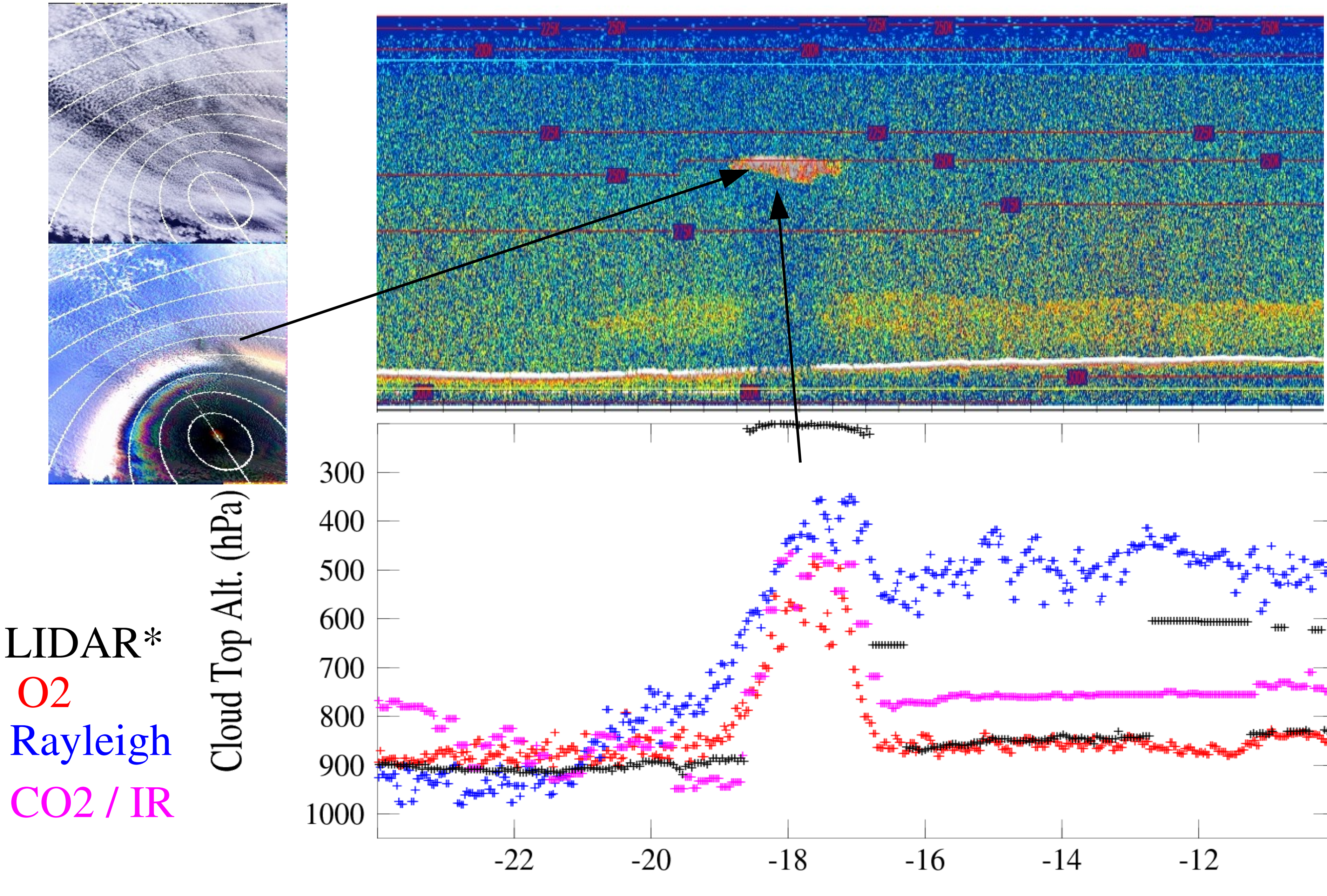
About aerosols over cloud



Presence of aerosol over a stratocumulus cloud layer causes strong divergence in the retrieved cloud top altitude from O2 band, Rayleigh and CO2 slicing methods.

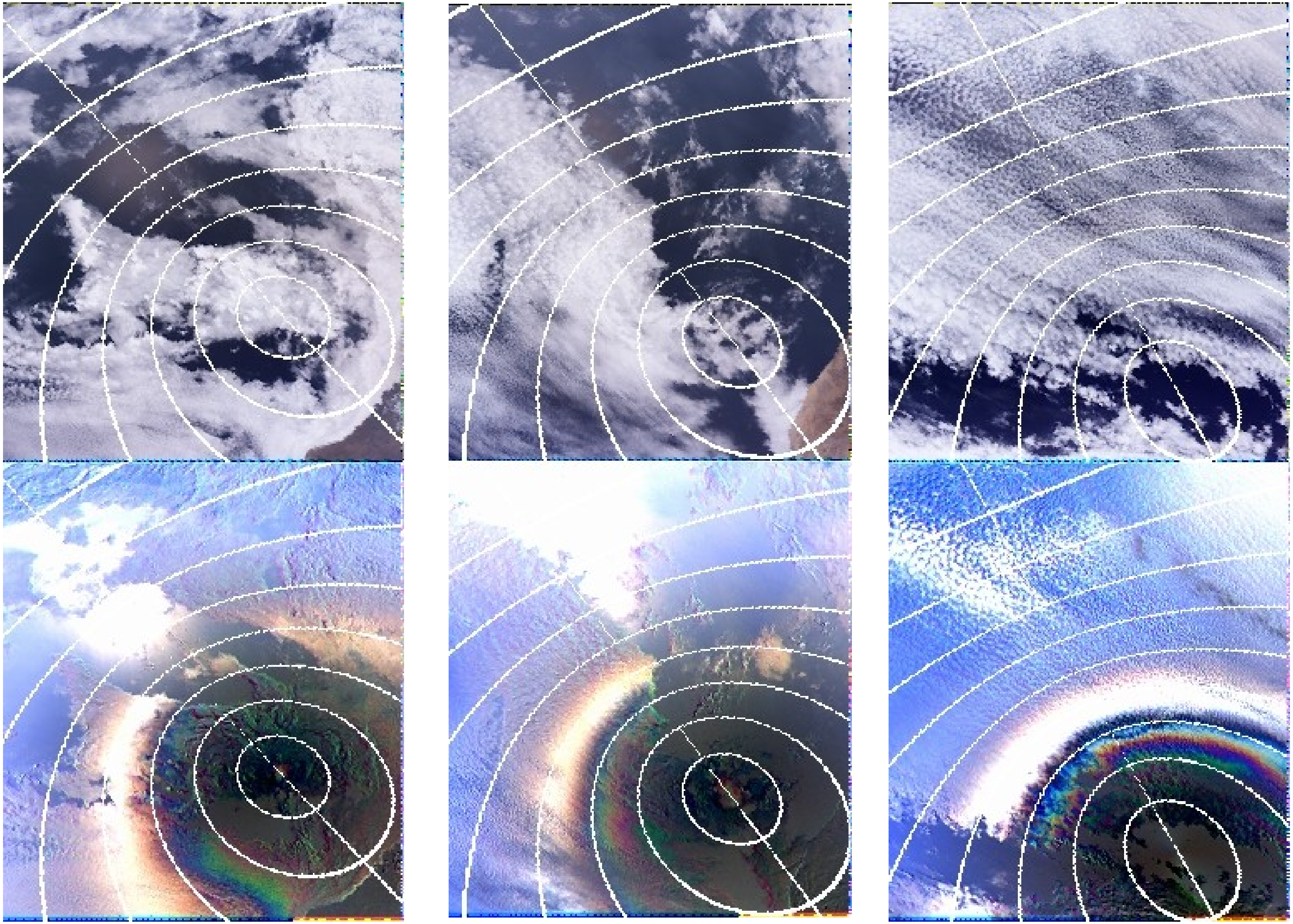
-> Polarization is very sensitive to aerosols.

About aerosols over cloud



*LIDAR Alt from 5km Cloud Layer product

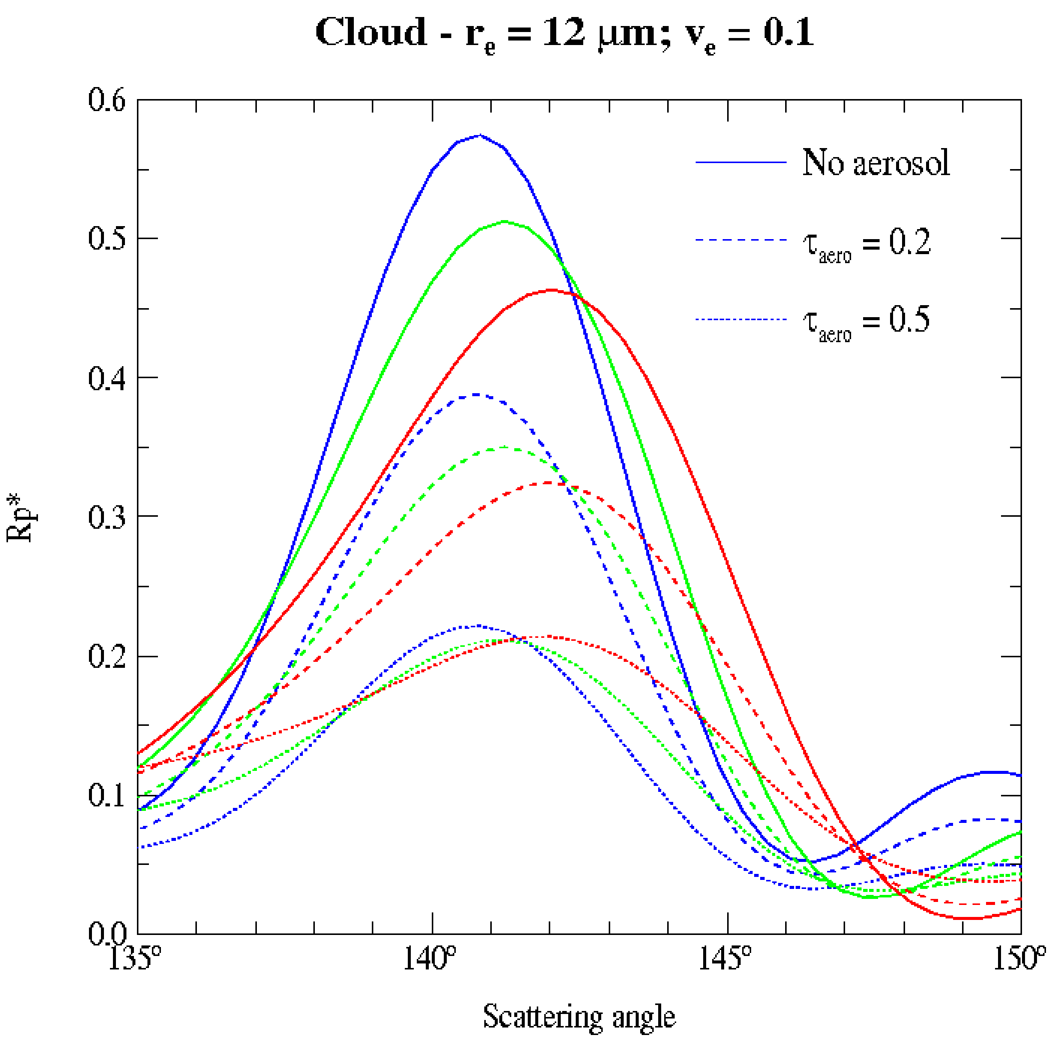
About aerosols over cloud



Polluted Polluted Clean

Aerosol layers over extended cloud fields

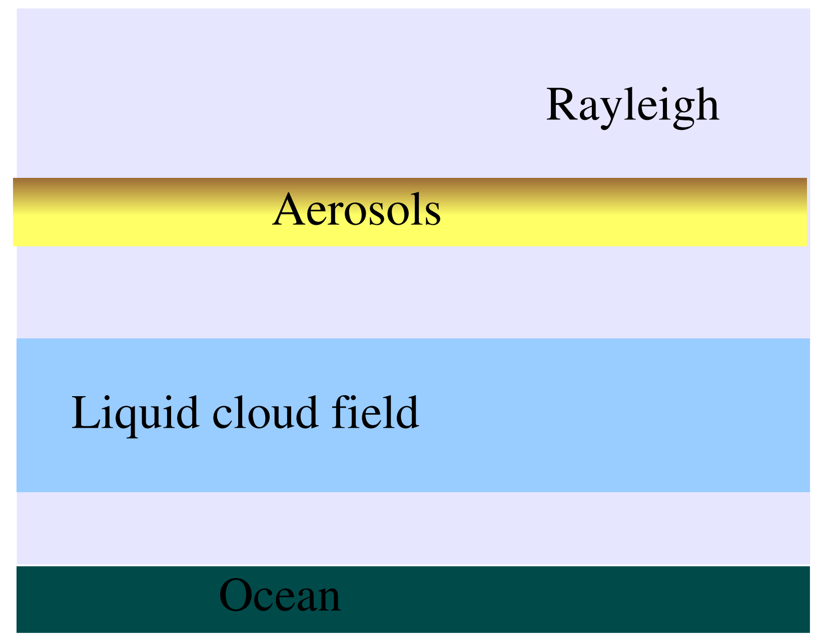
Can we derive information on aerosols using cloud are a « source » of polarized light ?



Why is the primary rainbow turning brown ?

Simulation of an aerosol absorbing layer over a liquid cloud (OT = 5)

The relative contribution of the red channel increases with aerosol optical thickness



Aerosol layers over extended cloud fields

Can we derive information on aerosols using cloud as a « source » of polarized light ?

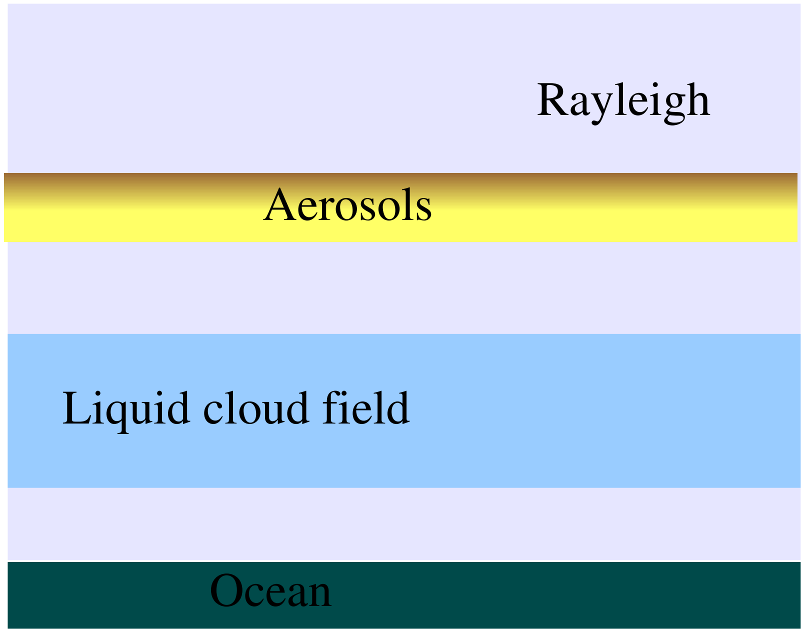
Basis

Use the rainbow as a “source” of polarized light and measure extinction through the aerosol layer

$$R_p^{TOA} = R_p^{Cloud} \exp^{-\tau/\mu} + R_p^{Aerosol+Rayleigh}$$

Use a band where the aerosol contribution is the lowest to retrieve cloud properties and recompute the signal for other 2 bands to get aerosol layer information.

Iterate using aerosol information previously retrieved to improve initial cloud signal estimate.



Advantages

The cloud signal can be determined consistently for the 3 bands.

Rayleigh contribution is reduced in the rainbow region

Knowing the cloud optical thickness is not necessary as long as the cloud is thick enough for polarization signal to saturate (> 2.0)

Conclusions and Perspectives

As early recognized, there is no doubt polarization contains information on cloud microphysic because the polarized phase function is very sensitive to particle shape.

Polarization multiangle measurements have been used to retrieve properties of both liquid and ice clouds.

Polarization arises primarily from single scattering, hence it brings information from the top or edges of the clouds where processes are not very well understood and where interaction between aerosols and clouds are important.

Small fractions of specific particles can contribute significantly to polarization signal

Conclusions and Perspectives

Information derived from polarization need to be considered carefully : retrievals are also subject to potential biases which need to be understood and recognized

Differences between polarization and spectral based retrievals could carry new information on cloud microphysic variability.

As for aerosols, polarization seems to be sensitive to the «small mode» of droplets distribution.

Clouds could be used to retrieve information on aerosols : the so-called 13^{th} indirect effect !! *(Labonnote and Riedi – In preparation - 2007)*

As far as polarization is concerned, this is definitely not the END ...

But I'll stop here anyway ...

THANKS FOR YOUR ATTENTION.