RADAR-LIDAR SYNERGY FOR CLOUD STUDIES

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Product users!

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Outline

- Motivations
- Radar-lidar and clouds
- What can we observe ?
  - Applications
- What can we retrieve ?
  - Applications
- Way forward

Motivations

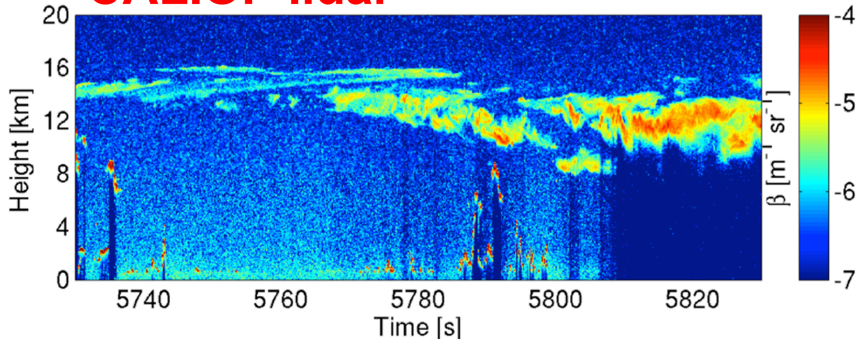
- Cloud process studies
- Cloud climatology
- Cloud-Aerosol interaction
- Cloud and models:
  - Are cloud properties/phase well represented in GCMs?
  - How could we improve cloud parameterization?

- Cloudsat –CALIPSO, first time, radar and lidar :
  - Lidar-radar synergy gives a few answers:
    - Synergistic classification (ice, water, rain, aerosols) DARDAR-MASK
    - Ice cloud properties (iwc, extinction, re…) DARDAR-CLOUD

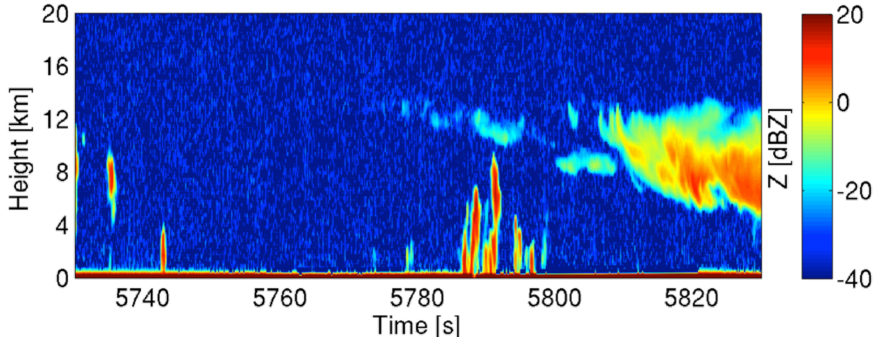
ftp://ftp.icare.univ-lille1.fr/

Why radar and lidar for clouds?

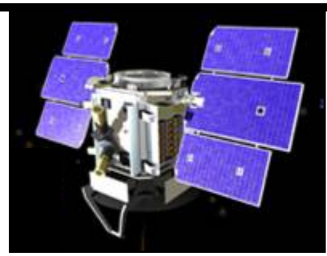
CALIOP lidar



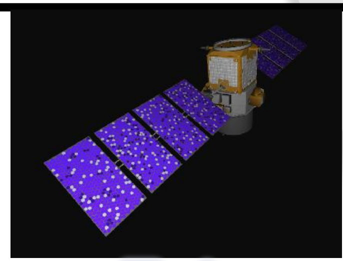
CloudSat radar

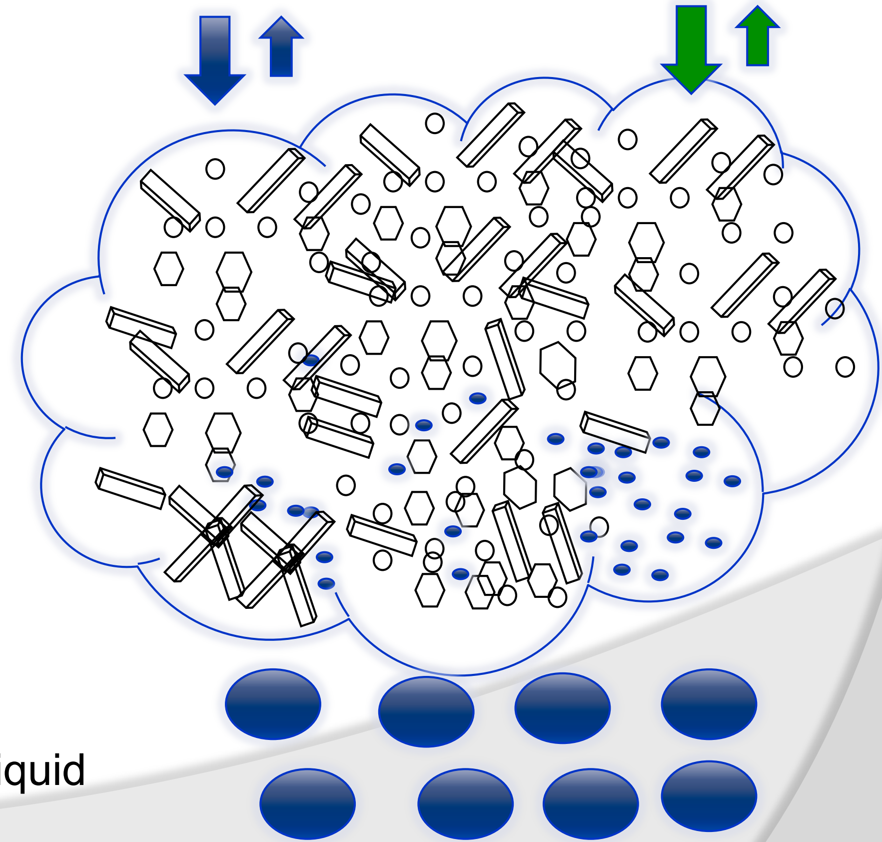


Cloud radar (95GHz)



Lidar (532-1064nm)

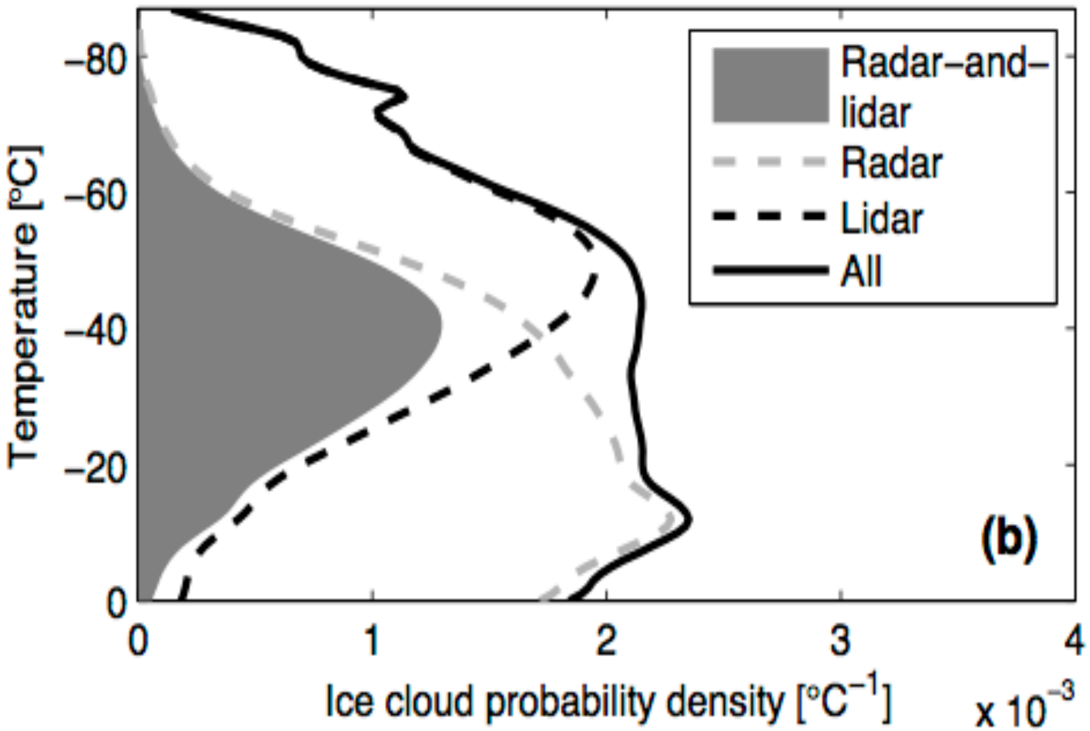




Radar more sensitive to ice (large particles)
Only attenuated in liquid cloud/rain
Can penetrate thick ice clouds

Lidar more sensitive than radar
but attenuated in ice cloud, extinguished in liquid

Why two are better than one?



Stein et al. (2011):

For 2008, Cloud in the subzero troposhere:

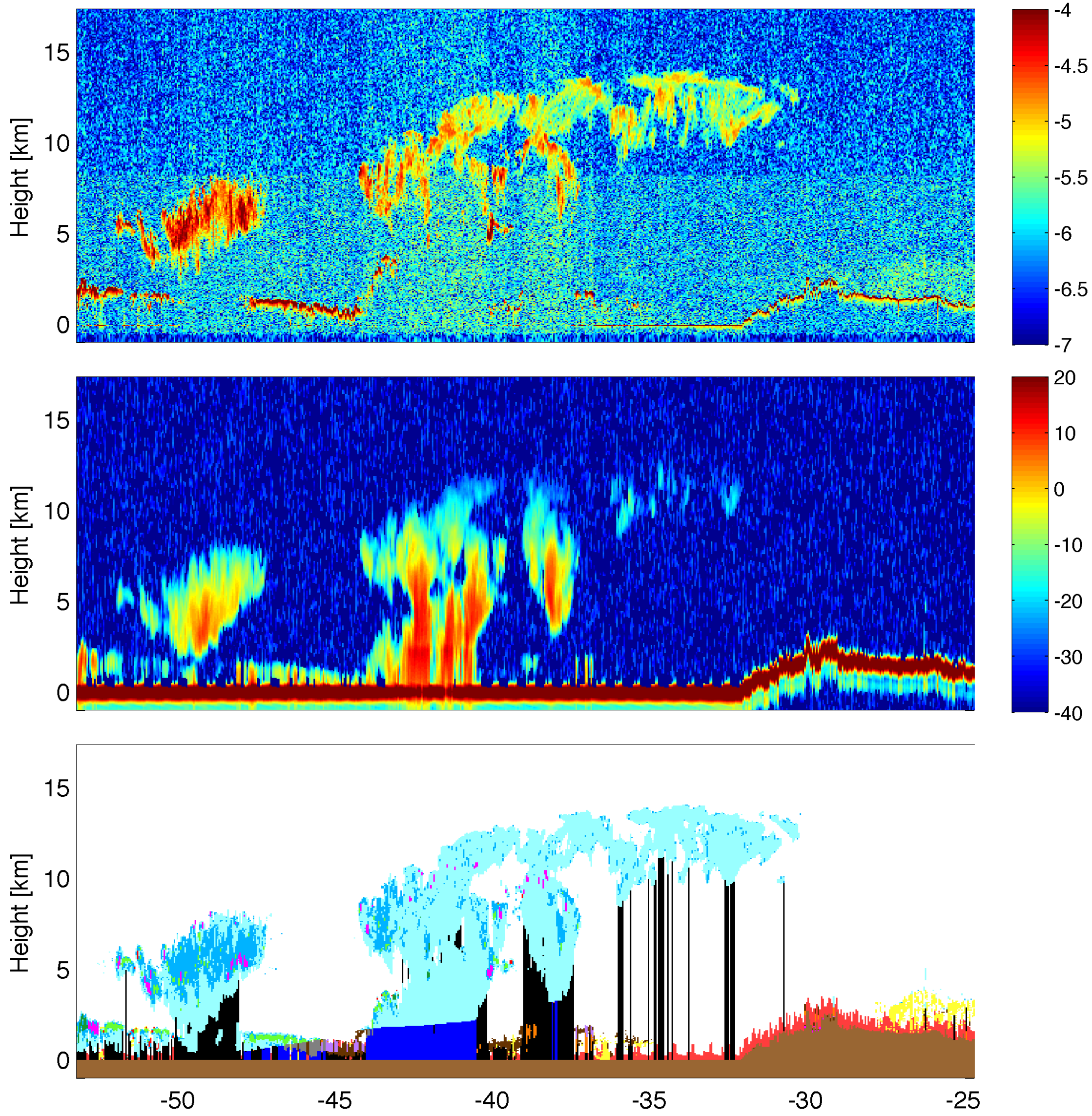
- for all radar and lidar observations: 15.3%
- Only the lidar: 9.6%
- Only the radar: 10.5%

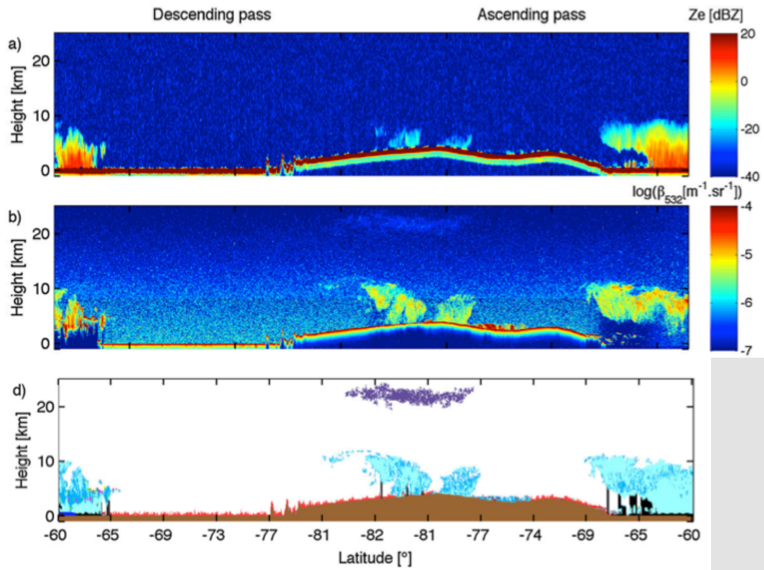
- Radar 68.4%
- Lidar 62.6% of tropospheric ice cloud
- 31.0% observed by both the radar and the lidar

What can we observe ?

Radar-lidar classification DARDAR-MASK

Target identification





Ceccaldi et al 2013

What can we observe ?

Radar-lidar classification
DARDAR-MASK
Examples

Examples of application

Battaglia and Delanoë 2013

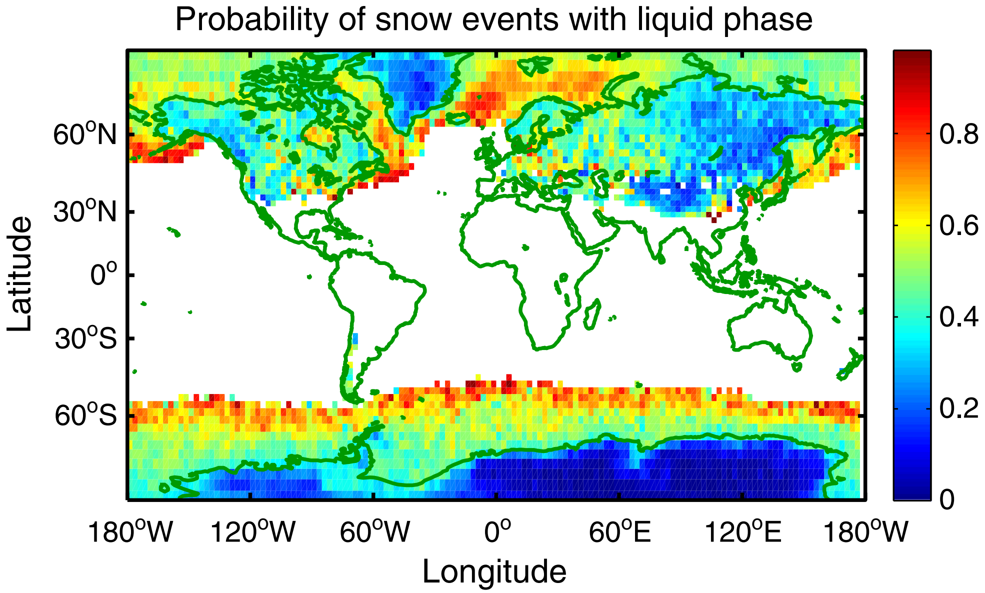


Figure 2. Global distribution of the probability of super-cooled water clouds for snow-precipitating events binned in **2.5**° × **2.5**° boxes. Results are presented only for pixels with a minimum of 500 counts.

Probability of liquid water clouds for snow-precipitating (2007–2010)

- Strong regional dependence with a marked land versus sea contrast
- Snow events occurring over ocean more likely to involve liquid phase
- 49% of the snowy profiles present SLW or mixed-phase layers
- Moves to 57% and 33% over sea and over land surfaces, respectively

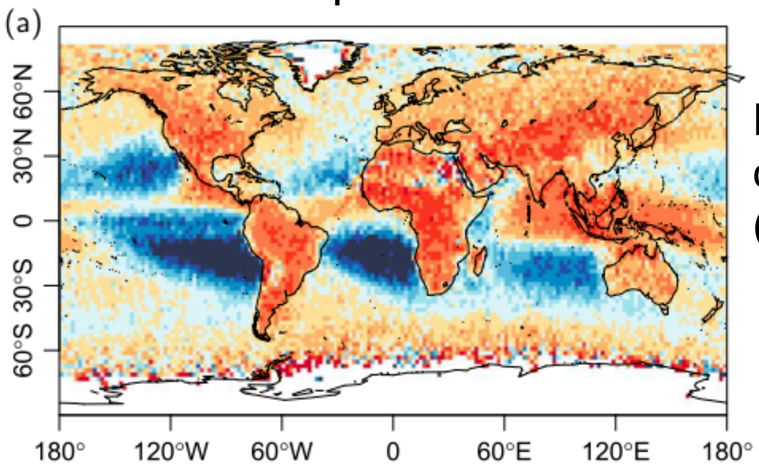
Antarctica, Greenland, Alaska, Siberia, and the Himalaya regions where snow is occurring more frequently via ice-phase-only.

Eastern part of US and some region in east Europe/west Russia seems to have more pronounced presence of mixed phase compared to continental regions at similar latitudes.

Examples of application

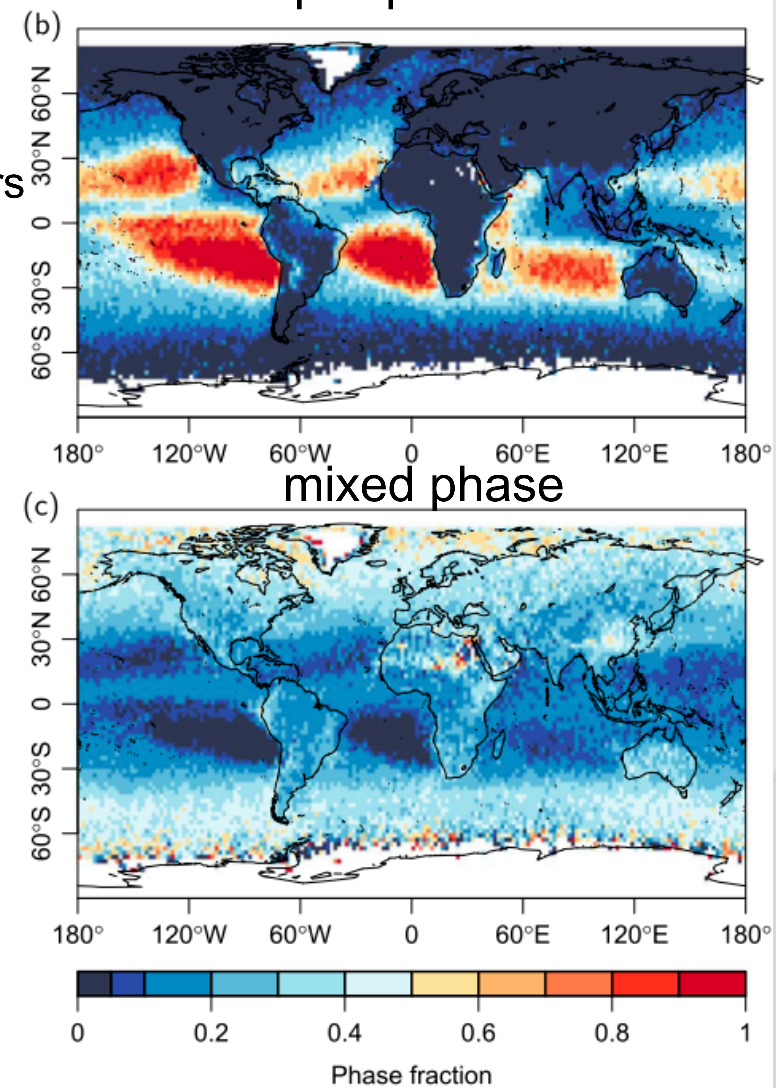
Mülmenstädt et al. 2015 (GRL)

Ice phase



Fraction of raining clouds over 5 years (2006-2011)

liquid phase



- Warm-rain phase fraction highest in the tropical and subtropical oceans outside the ITCZ
- Cold rain dominates in the ITCZ, over the midlatitude oceans, and in general over all continents.
- Mixed-phase tops depends mainly on latitude, ranging from 10% over the tropical oceans to 30–50% at 60° north and south latitude, with higher values over the continents.

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LATMOS

What can we retrieve ?

Radar-lidar ice cloud microphysical retrieval DARDAR-CLOUD

Radar-lidar cloud retrieval method

Variational scheme:

We know the **observations** (instrument measurements) and we would like to know **cloud properties** : α, IWC, re...

New ray of data: define state vector

Use classification to specify variables describing ice cloud at each gate: *extinction coefficient and N_0**

Delanoë and Hogan JGR, 2008-2010

$$\mathbf{y} = \begin{pmatrix} \ln \beta'_1 \\ \vdots \\ \ln \beta'_n \\ Z_1 \\ \vdots \\ Z_m \\ I_{10\mu m} \\ \Delta I_{8.5-12.0\mu m} \end{pmatrix} \qquad \mathbf{x} = \begin{pmatrix} \ln \alpha_1^{ice} \\ \vdots \\ \ln \alpha_n^{ice} \\ \ln N'_1 \\ \vdots \\ \ln N'_m \\ a_{\ln S} \\ b_{\ln S} \end{pmatrix}$$

Assumptions and tricks:

- Mass-Area-size relationships from modified Brown and Francis 1995 and normalised PSD framework (Delanoë et al. 2005, 2014)
- $N' = N_0^* / \alpha^{0.6}$
- IWC, r_e are derived from extinction and N_0' via lookup tables

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Delanoë and Hogan JGR, 2008-2010

Radar model

Forward model

Lidar model

Including multiple scattering

(Hogan 2006)

Radiance model

IR channels

- When radar and lidar are simultaneously available: 2 moments of PSD are available (6^{th} moment/2^{nd} moment).
- When only one instrument available, we rely on our a-priori lnN'(T)
- S assumed linearly varying with temperature $S=\exp(a_{lnS}*T+b_{lnS})$.
- Use molecular signal beyond the cloud as a constraint on optical depth

Radar-lidar cloud retrieval method

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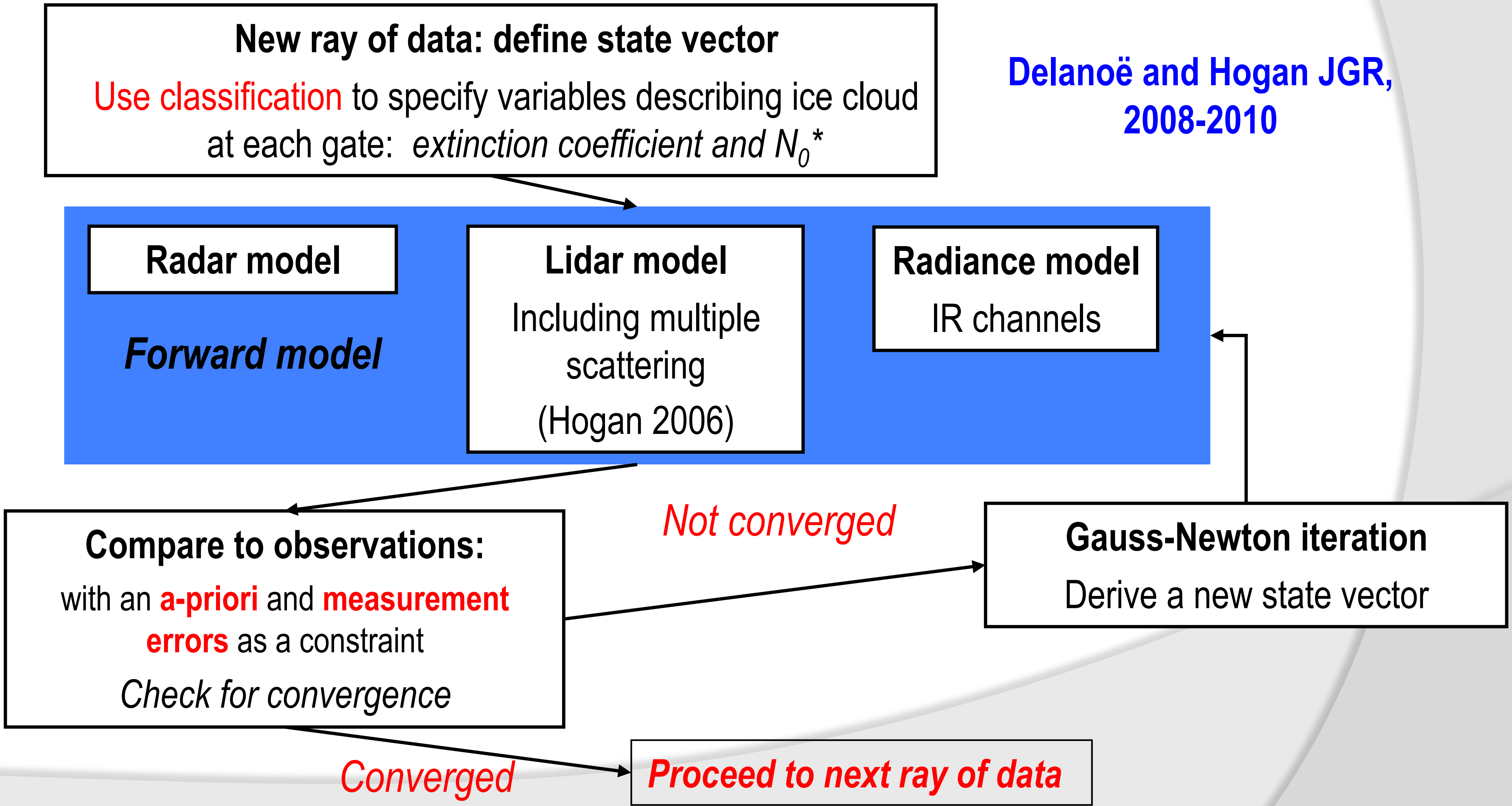
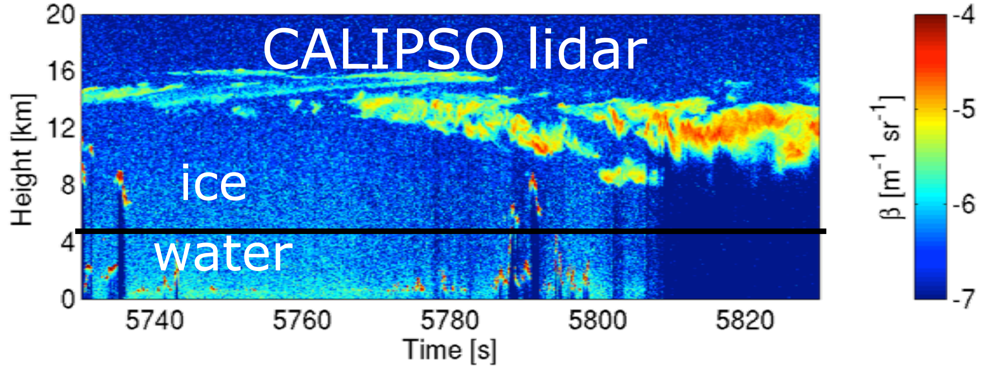
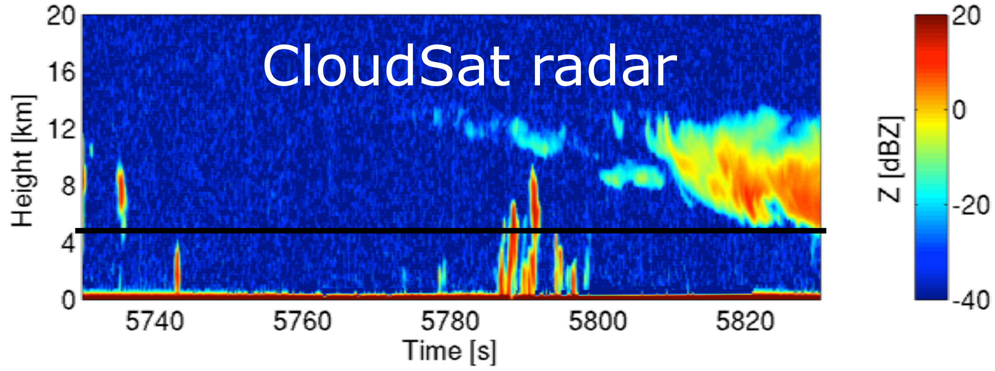
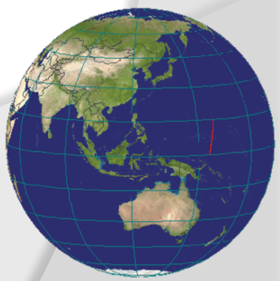
Delanoë and Hogan JGR, 2008-2010



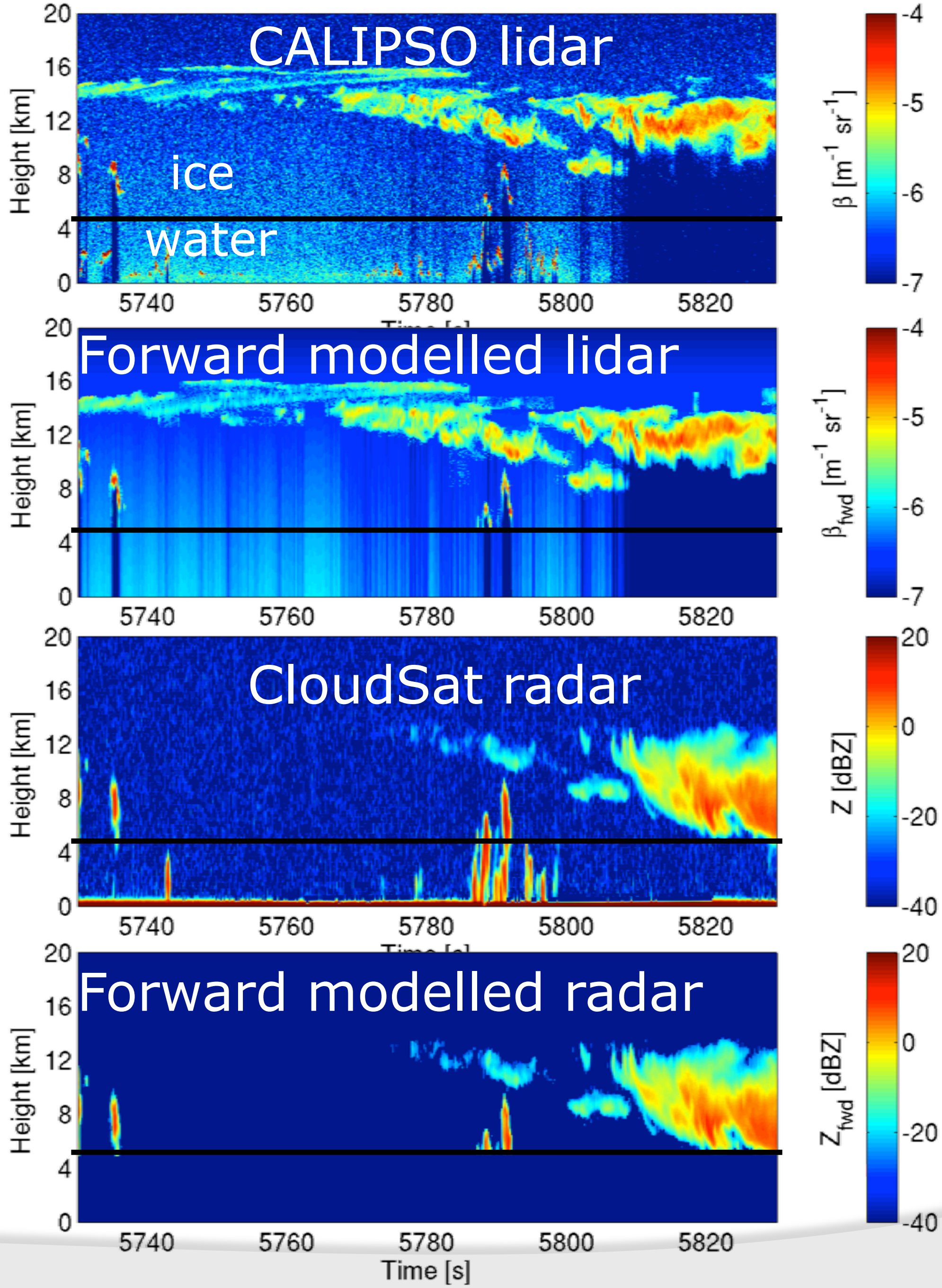
Example of retrieval

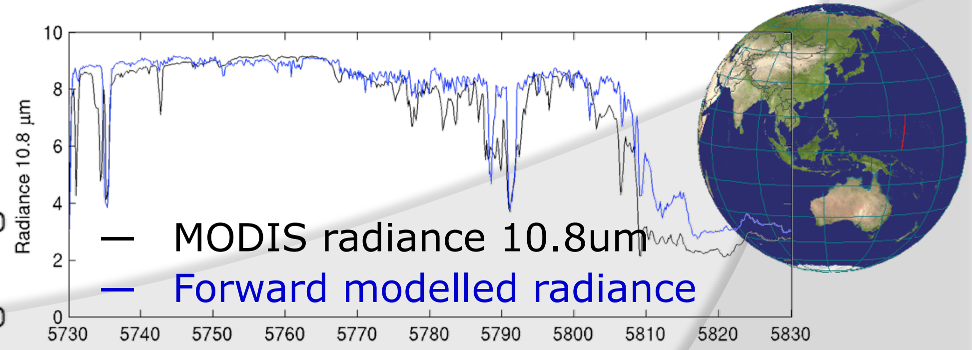




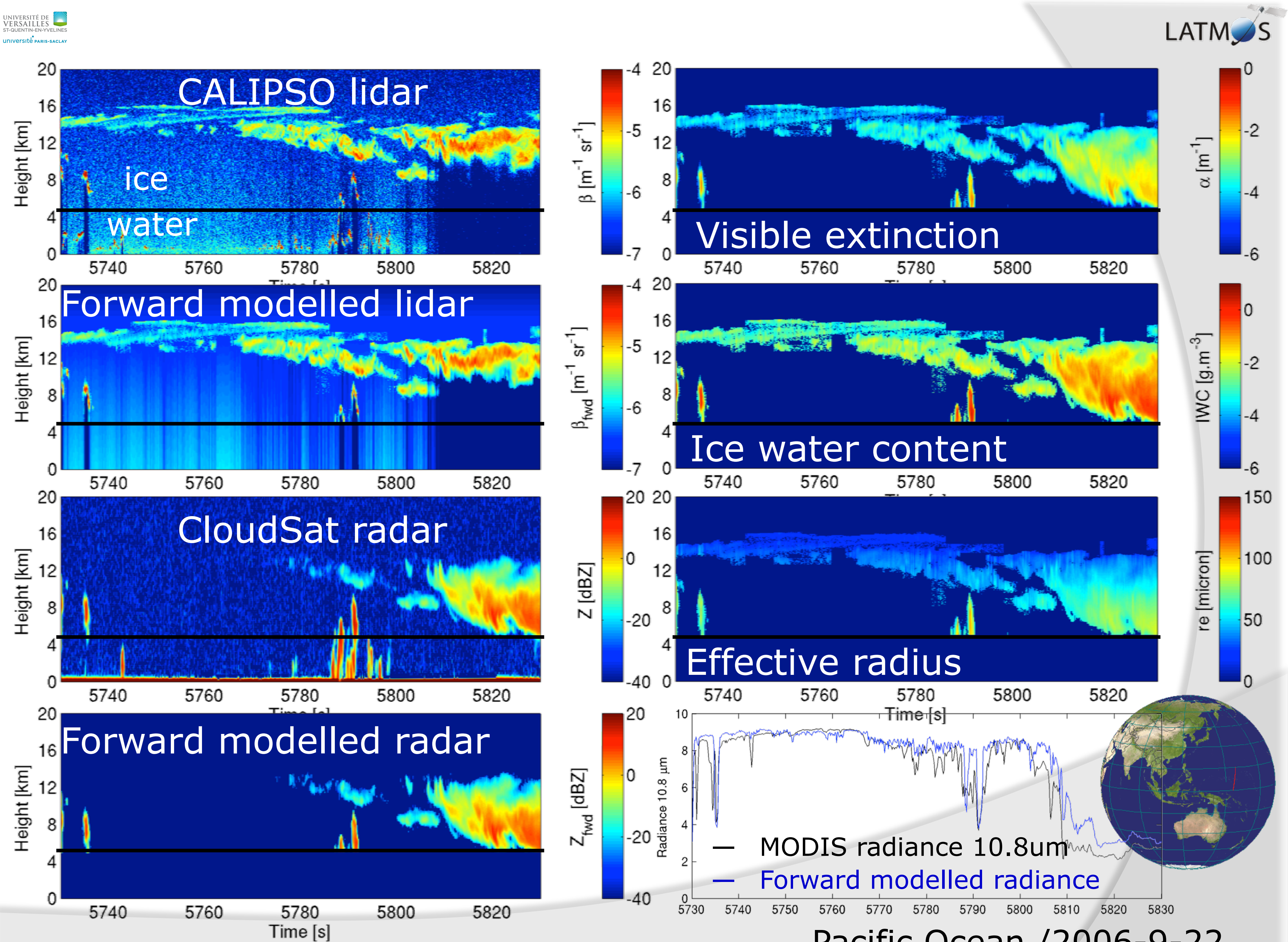


Pacific Ocean /2006-9-22





Pacific Ocean /2006-9-22


LATMOS
CALIPSO lidar
ice
water
Visible extinction
Forward modelled lidar
Ice water content
CloudSat radar
Effective radius
Forward modelled radar
MODIS radiance 10.8um
Forward modelled radiance
Height [km]
Time [s]
Radiance 10.8 µm
β [m-1 sr-1]
α [m-1]
IWC [g.m-3]
Z [dBZ]
re [micron]
Pacific Ocean /2006-9-22

What can we retrieve ?

Radar-lidar ice cloud microphysical retrieval DARDAR-CLOUD: example of application

Example of application

Delanoë et al 2011

Evaluation of ECMWF and UK-Met Office

Methodology: model/observations comparison

- 3 weeks in July 2006
- Vertical profiles were extracted from both models along the CloudSat-CALIPSO track at the closest time to the observations.
- IWC retrieved from CloudSat and CALIPSO averaged to the model grids, using the boundaries of the models boxes.

UK Met Office model

- MetUM global forecast model at cycle G40
- The horizontal resolution: around 40 km at midlatitudes. 50 vertical levels up to 63 km.
- Water vapour, liquid and ice (+precip) are represented as prognostic variables (mean values in the model grid-box).

ECMWF model

- IFS (Integrated Forecast System) Cycle 32r3 global model
- Horizontal resolution of the model is about 40 km with 91 vertical levels up to 80 km altitude.

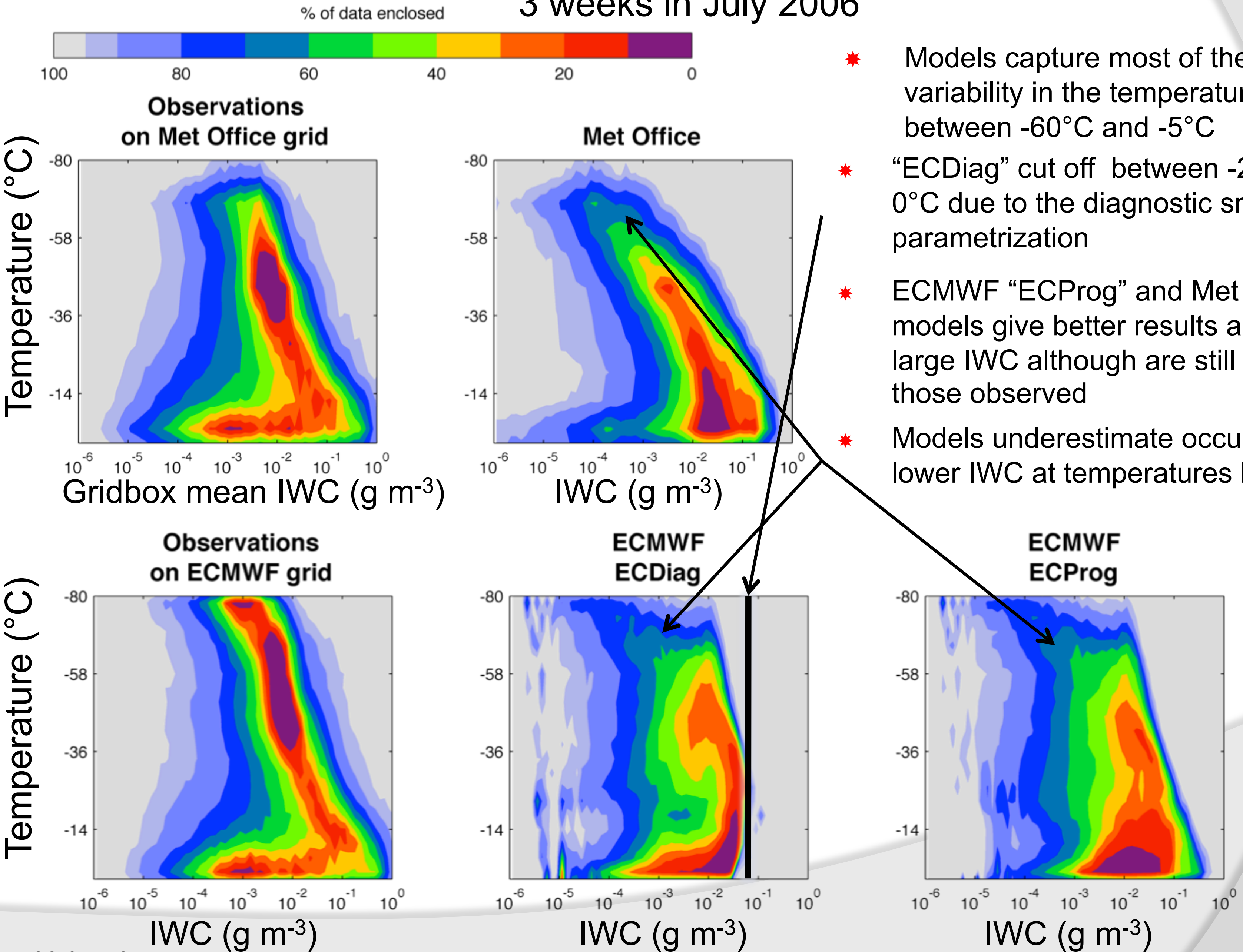
- **ECDiag**: Grid-box mean specific humidity / cloud condensate and cloud fraction => prognostic variables. Liquid and solid precipitation are diagnostic variables.

- **ECProg**: Scheme using separate prognostic variables for cloud liquid water, cloud ice, rain and snow as well as retaining the prognostic cloud fraction.
  LWC and IWC vary independently of temperature => Snow is included in IWC

Weighted occurrence IWC vs T

Delanoë et al 2011

3 weeks in July 2006



- Models capture most of the observed variability in the temperature region between -60°C and -5°C
- "ECDiag" cut off between -20°C and 0°C due to the diagnostic snow parametrization
- ECMWF "ECProg" and Met Office models give better results and produce large IWC although are still smaller than those observed
- Models underestimate occurrence of the lower IWC at temperatures below -70°C.

Way forward?

- Keep improving radar-lidar combination: better categorisation, improve ice retrieval
- More retrieval? Liquid cloud, rain
- CloudSat-CALIPSO follow up: EarthCare
  - Ensure continuity in the products

Acknowledgement

- Spaceborne data were provided by NASA/CNES and we thank the ICARE Data and Services Center (http://www.icare-lille1.fr) for providing access to the data used in this study
- CNES support (EECLAT project)

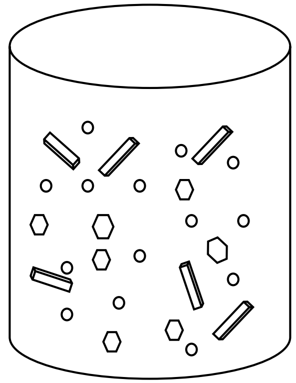
Supplementary material

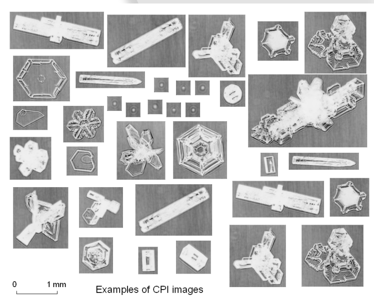
Cloud particles and radar-lidar

Radar and lidar give us information on a sampled volume

How to link measurements to cloud content?

Particle size distribution « N(D) » and micro/radiative properties (Mass, Area, etc) for each diameter « D ».





Courtesy LAMP

- **Reflectivity**

$$Z = \frac{\lambda^4}{|K_W|^2 \pi^5} 10^{18} \int N(D)\sigma_{bsc}(\lambda, D, \rho) dD$$

Assuming no attenuation

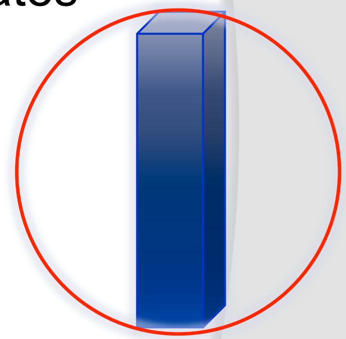
$$Z = 10^{18} \int N(D) D^6 dD$$

Rayleigh approximation

$\sigma_{bsc}(D, \lambda, \rho)$ scattering coefficients (Mie,1908) or T-matrix…

Hexagonal plates

Column

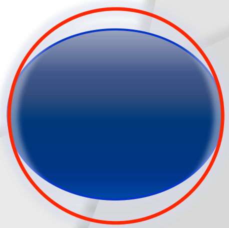


Radar more sensitive to size

- **Backscatter and visible extinction**

$$\alpha = 2.10^3 \int N(D) A(D) dD$$

A(D) represents the projected cross sectional area



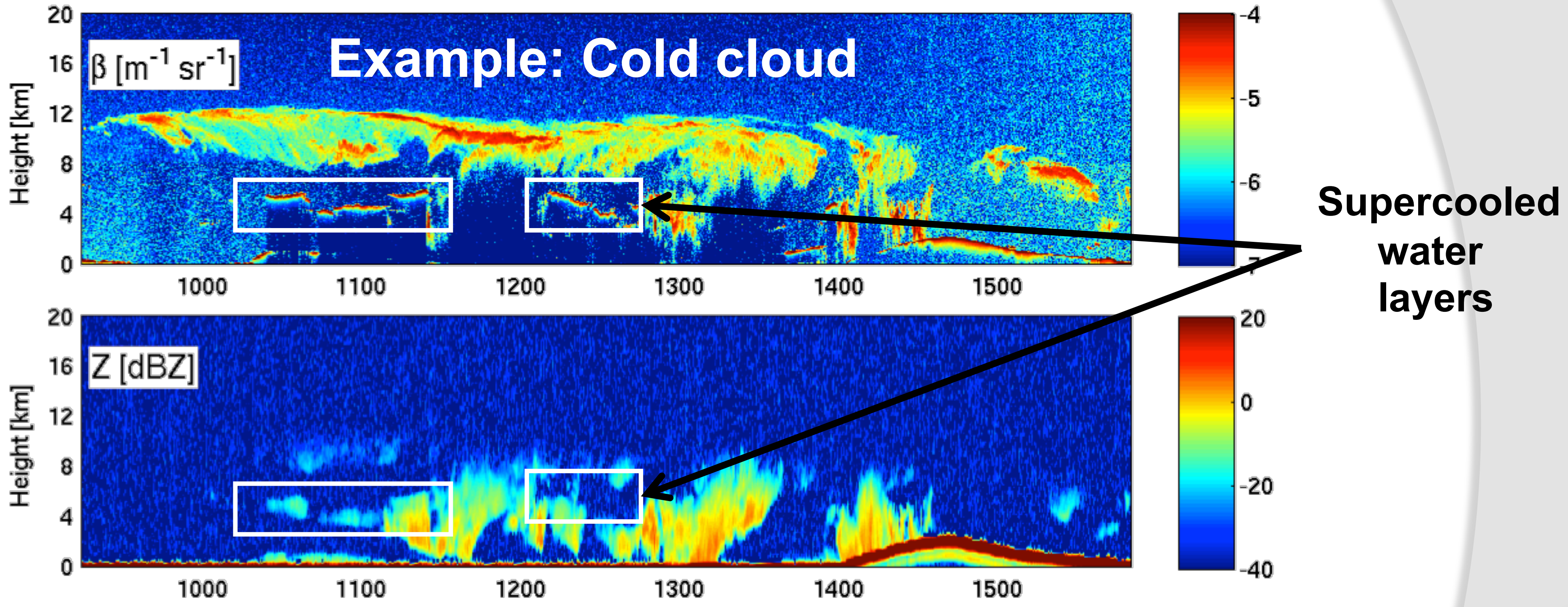
Water drop

$$\beta(r) = \frac{\alpha(r)}{S(r)} \exp\left[-2\int_0^r \alpha(r')dr'\right]$$

Assuming no multiple scatter

Lidar more sensitive to concentration

Cloud phase identification



Temperature model (ECMWF) => Ice / Liquid water

Simple method :

Different response of radar and lidar in presence of supercooled liquid water:

-Very strong lidar signal

-Very weak radar signal

Within a 300m cloud layer