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RADAR-LIDAR SYNERGY FOR CLOUD STUDIES

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Workshop:
Observations and modeling of aerosol and clouds properties for climate studies
September 12-14, 2011

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MOTIVATIONS

We are interested in:

- Cloud process studies
- Cloud Climatologies
- Cloud and Models:
  - Are cloud properties well represented in GCMs?
  - How could we improve ice cloud parameterizations?
  - Is the cloud phase well represented in GCMs?
- Cloud-Aerosol interaction
- …

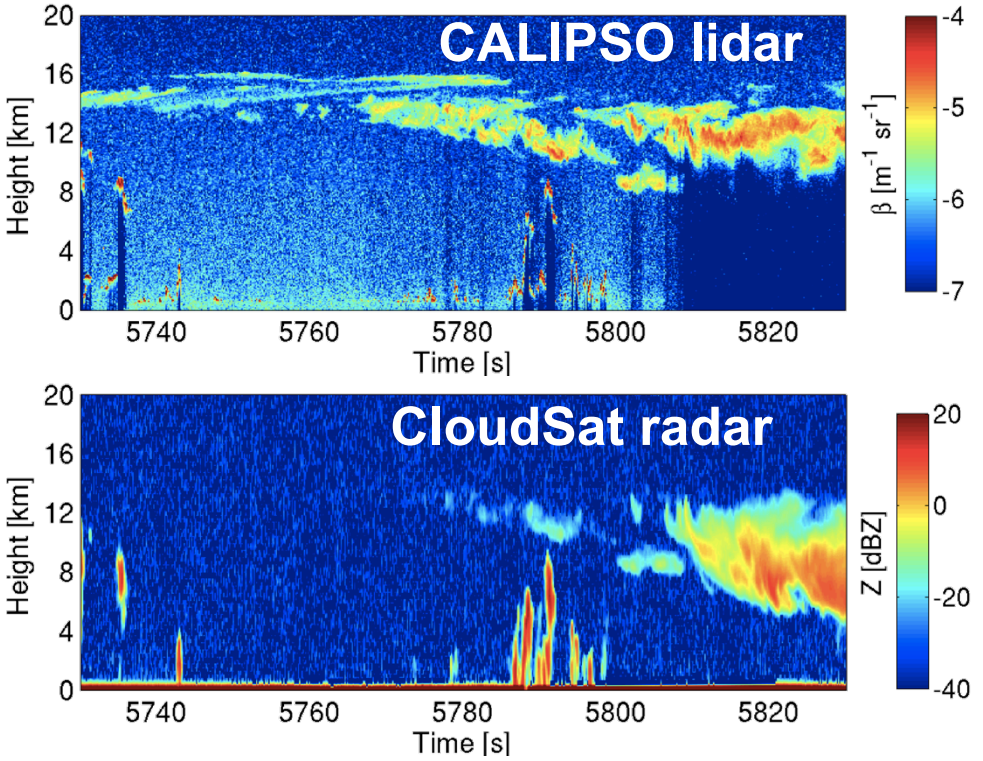
Exploit the radar-lidar synergy

- Ground based
- Airborne
- CloudSat/CALIPSO+(IIR or MODIS):

WHY A SYNERGISTIC APPROACH?

Radar $Z \alpha D^6$, lidar $\beta \alpha D^2$ so the combination provides hydrometeor size:

- *Lidar:* sensitive to hydrometeor concentration, can be extinguished
- *Radar:* very sensitive to the particle size, not very sensitivity to liquid clouds and small ice particles



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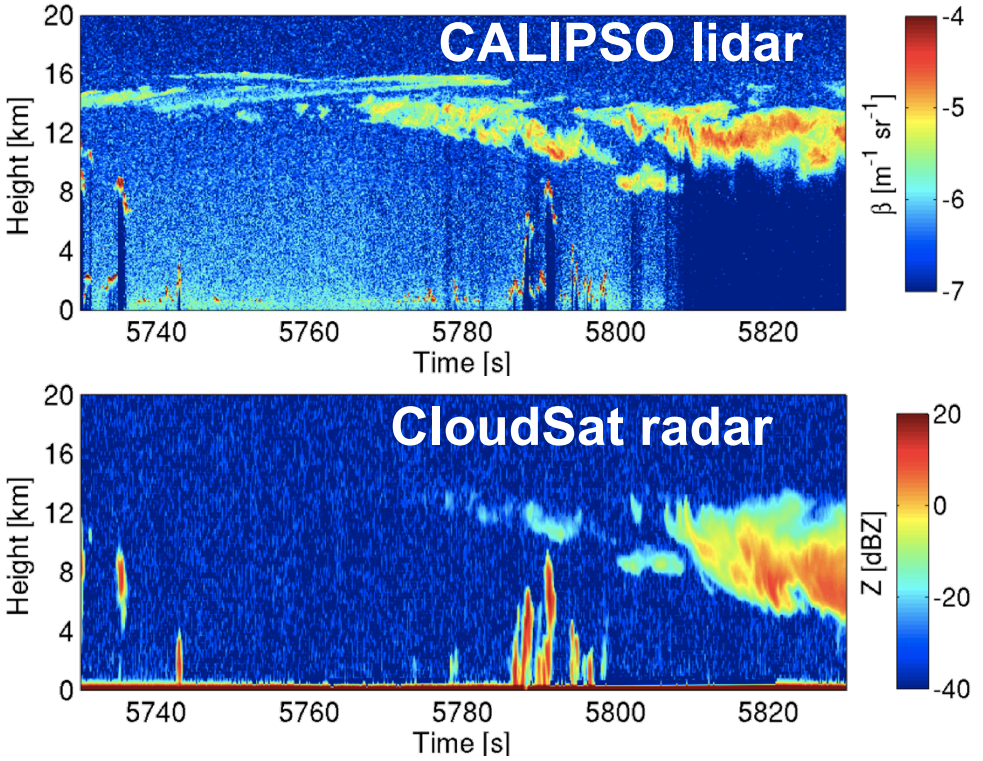

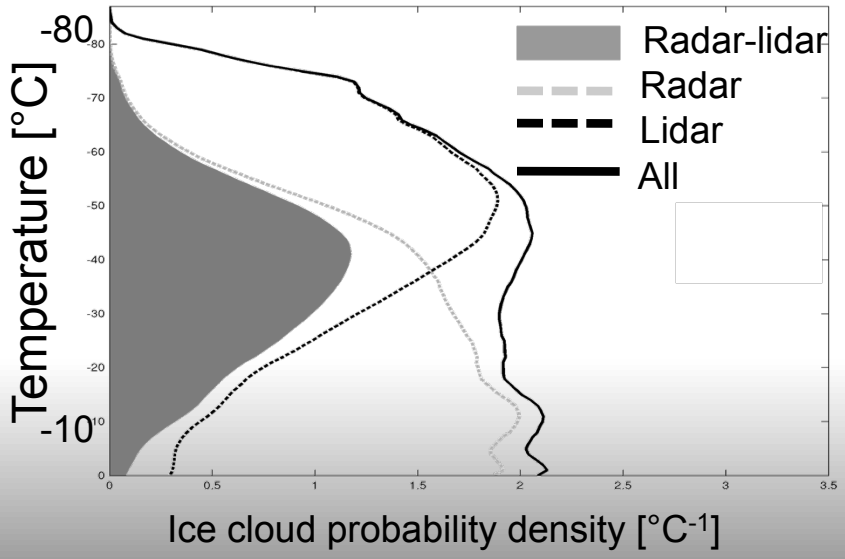

Stein et al. (2011):

- In **July 2006 and February 2007**, cloud occurrence in the subzero troposphere was **13.3%**
- The fraction observed by radar was **65.9%**
- The fraction observed by lidar was **65.0%**
- The fraction observed by both was **31.0%**

MEASUREMENTS => CLOUD PROPERTIES

We convert instrument signals into cloud properties:

- DARDAR-MASK
  - Cloud phase: ice and liquid and supercooled layer are distinguished (Different response of radar and lidar, strong lidar signal weak radar signal)

  => Cloud fraction/cloud phase climatology

- DARDAR-CLOUD (described in Delanoë and Hogan 2010)
  - Retrieval of IWC, extinction, r_e etc… seamlessly between regions of cloud detected by both radar and lidar, and regions detected by just one of these two instruments.

  => Ice cloud climatology

Products available at ICARE, visit www-icare.univ-lille1.fr (entire CloudSat-CALIPSO period)

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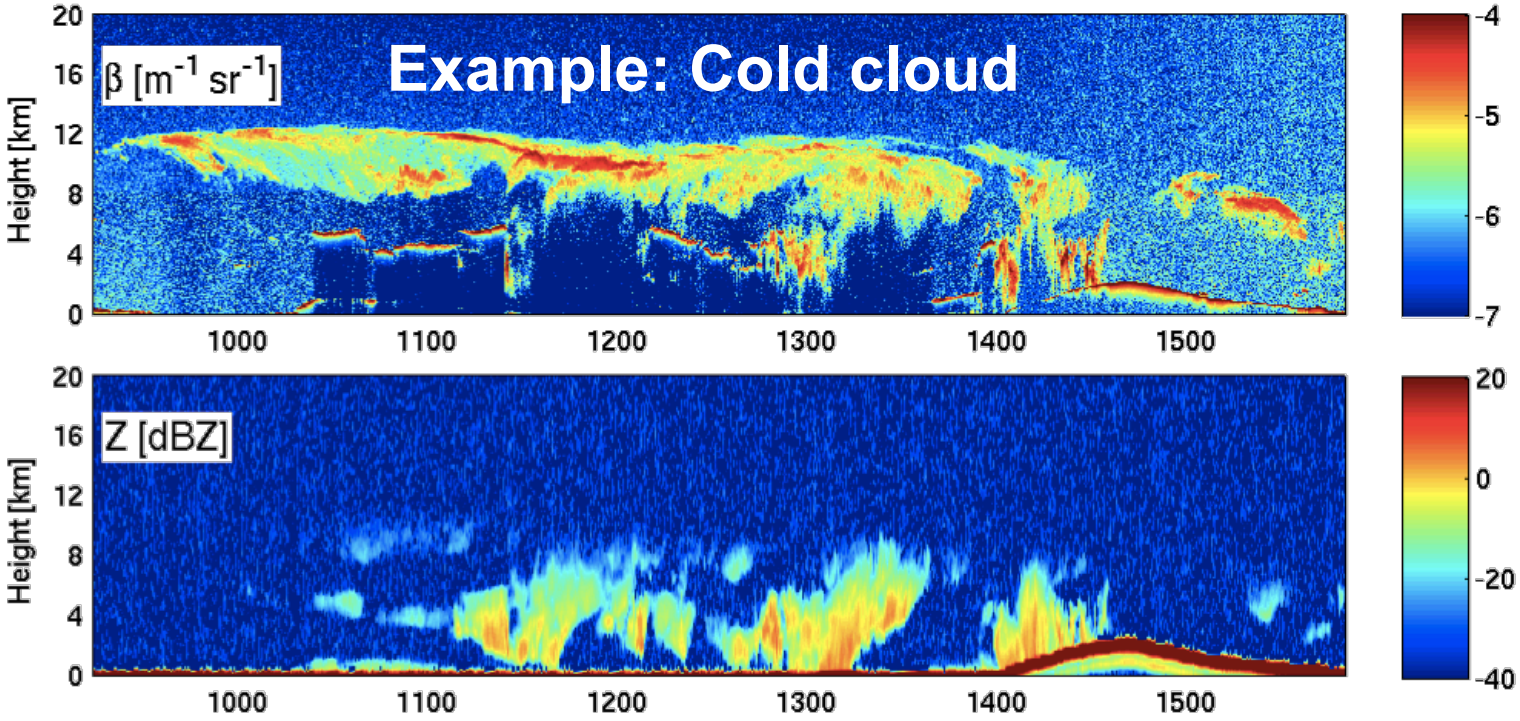
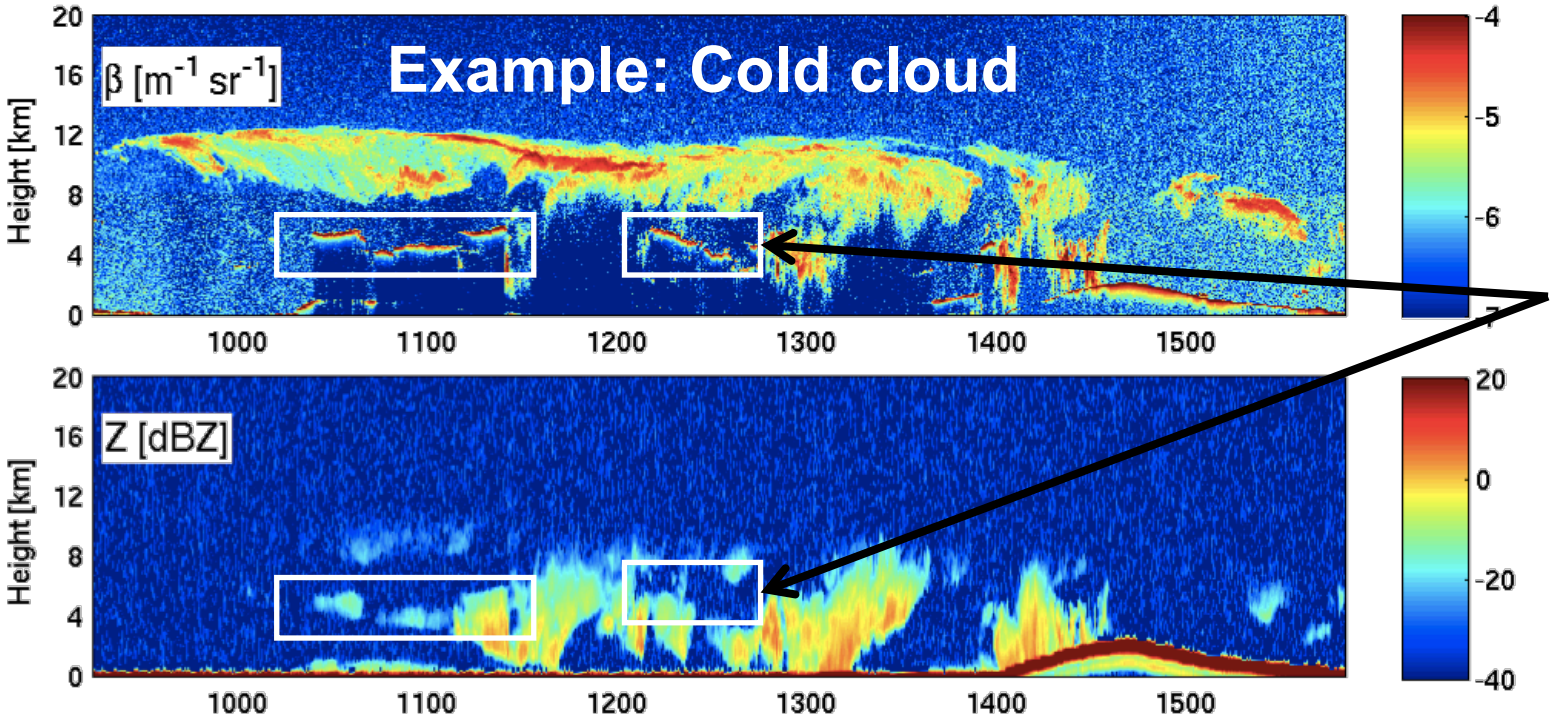
Cloud phase

CLOUD PHASE IDENTIFICATION



CLOUD PHASE IDENTIFICATION



Temperature model (ECMWF) => Ice / Liquid water

Simple method :

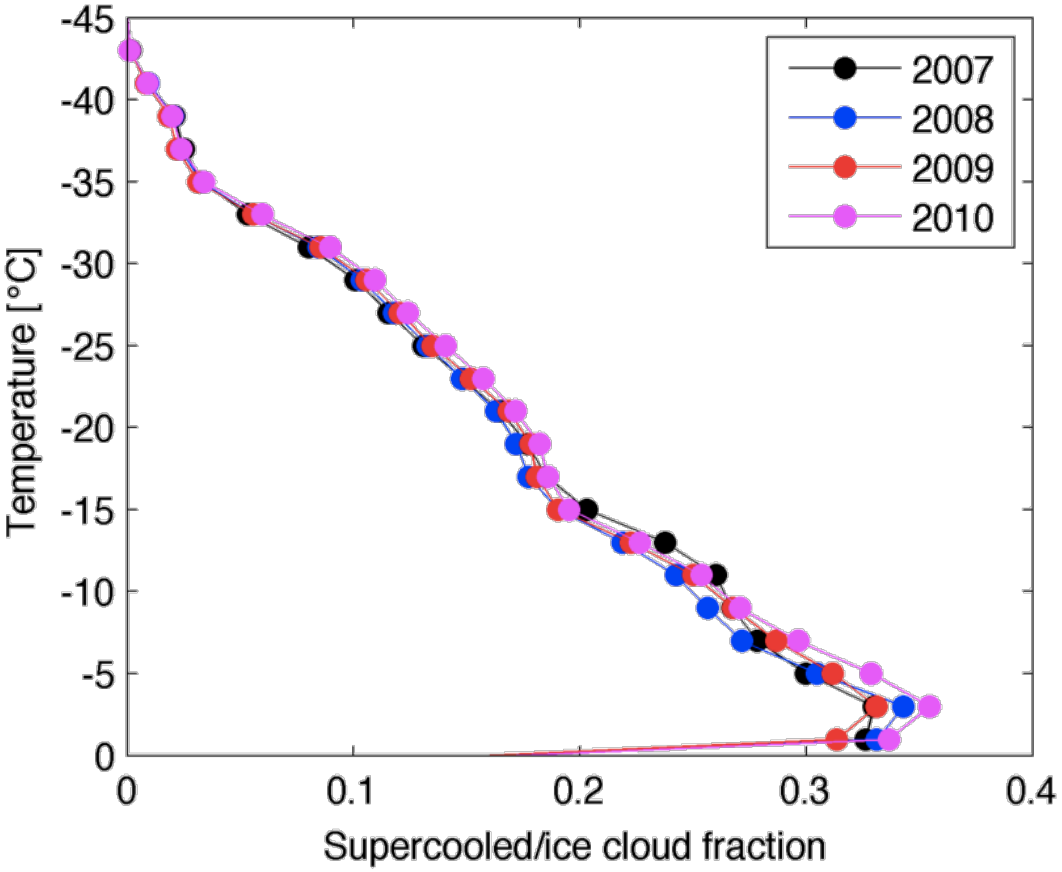
Different response of radar and lidar in presence of supercooled liquid water:

-Very strong lidar signal

-Very weak radar signal

Within a 300m cloud layer

SUPERCOOLED LAYER, GLOBAL DISTRIBUTION

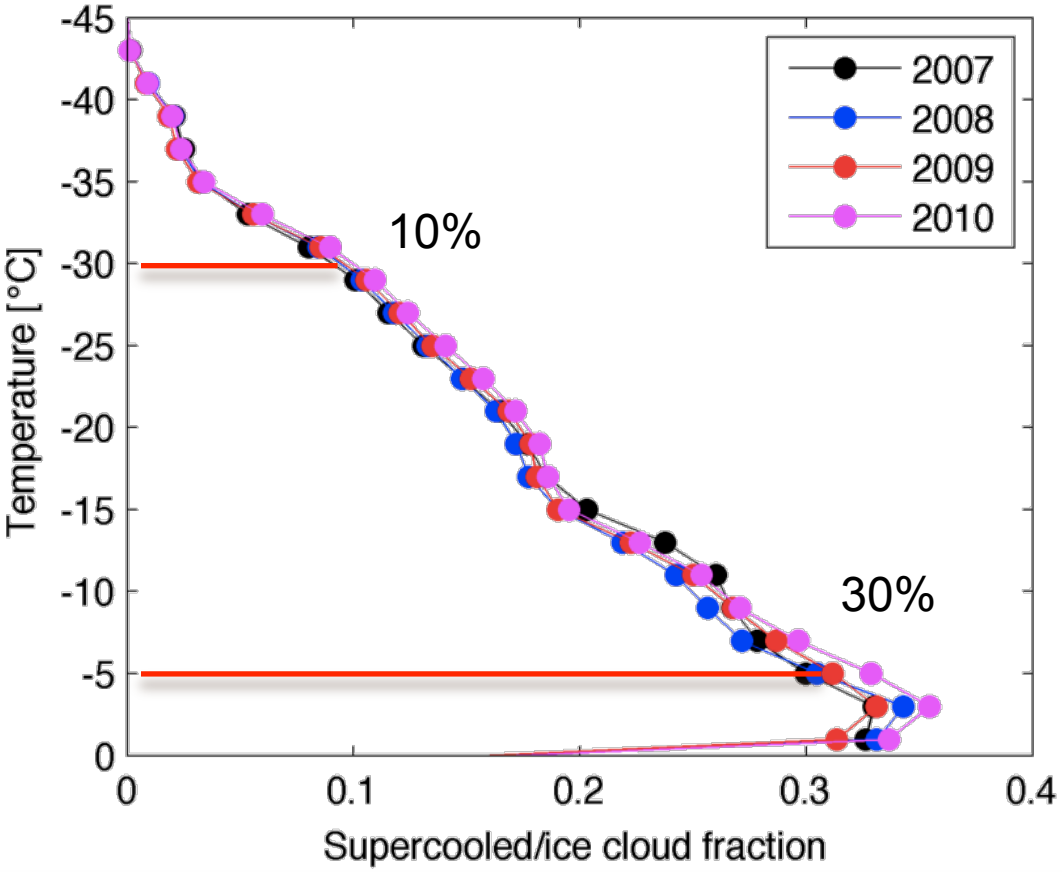


Supercooled fraction:

◆Nb (sc) / Nb (cloud)

Fraction of sc when cloud

SUPERCOOLED LAYER, GLOBAL DISTRIBUTION



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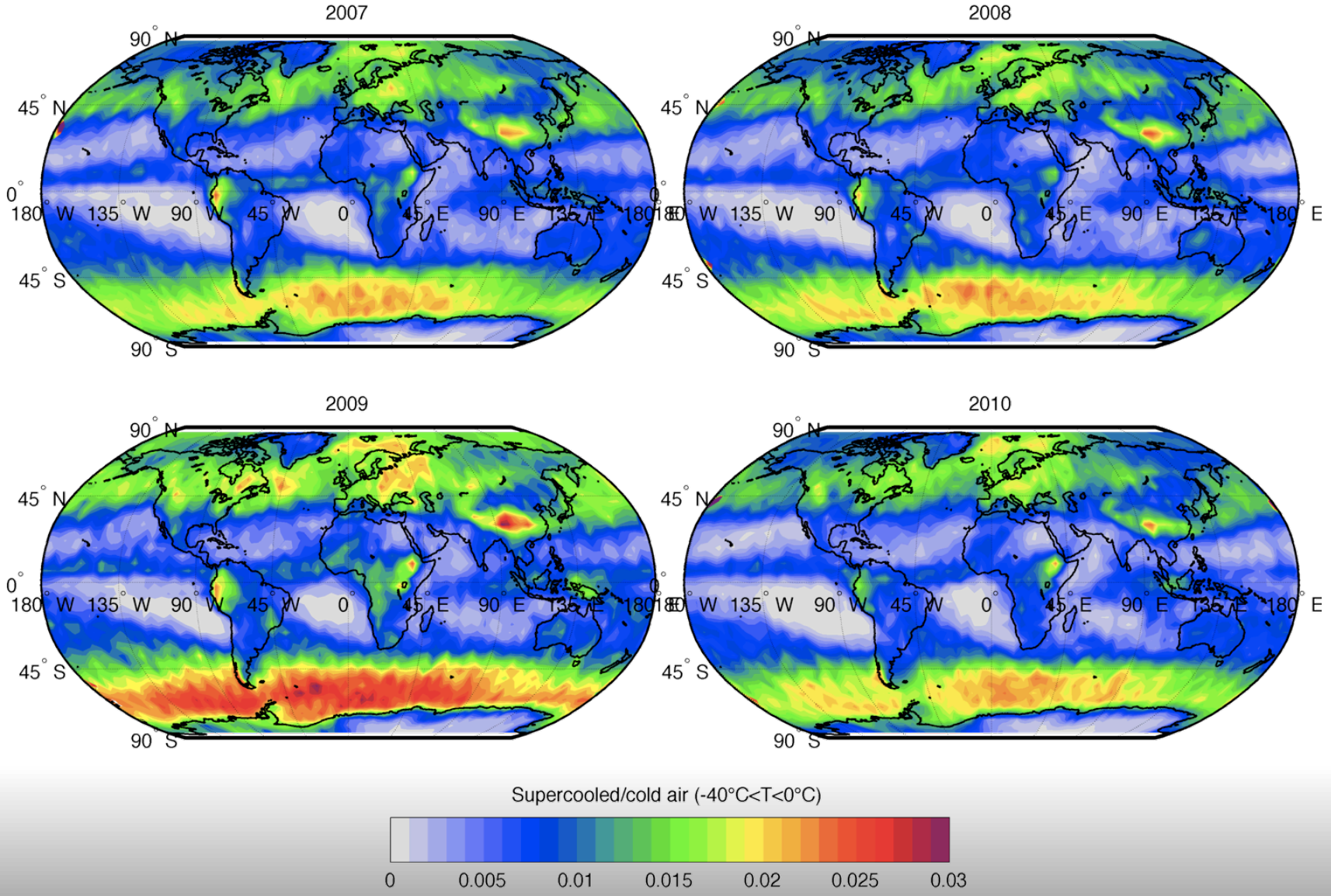
2007
2008
2009
2010
90° N
45° N
0°
45° S
90° S
180° W 135° W 90° W 45° W 0° 45° E 90° E 135° E 180° E
Supercooled/cold air (-40°C<T<0°C)
0
0.005
0.01
0.015
0.02
0.025
0.03

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Ice cloud properties

DARDAR-CLOUD PRODUCT

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

Radar model

Forward model

Lidar model

Including multiple scattering

(Hogan 2006)

Radiance model

IR channels

Compare to observations:

with an **a-priori** and **measurement errors** as a constraint

Check for convergence

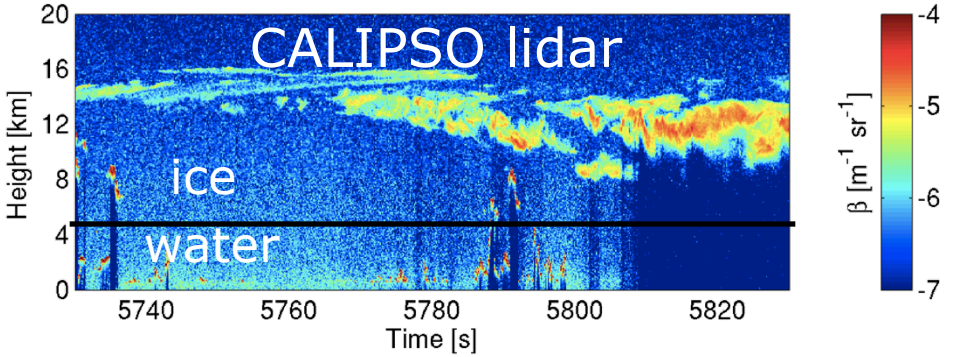
Not converged

Gauss-Newton iteration

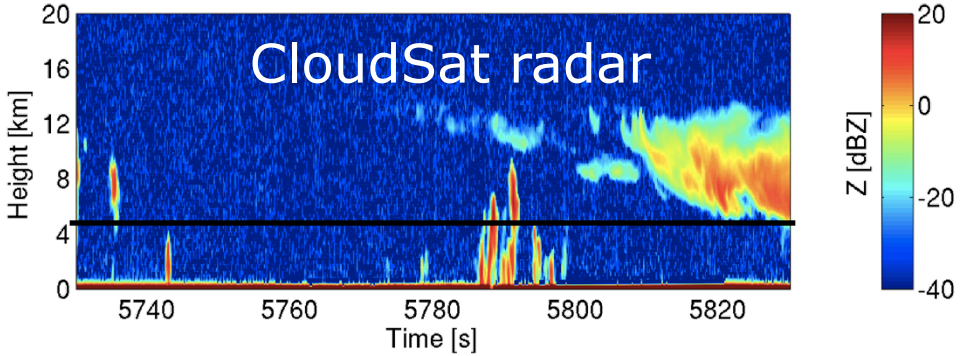
Derive a new state vector

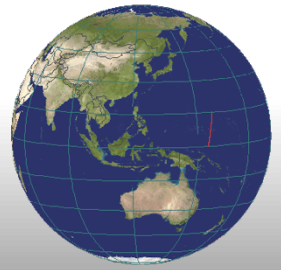
Converged

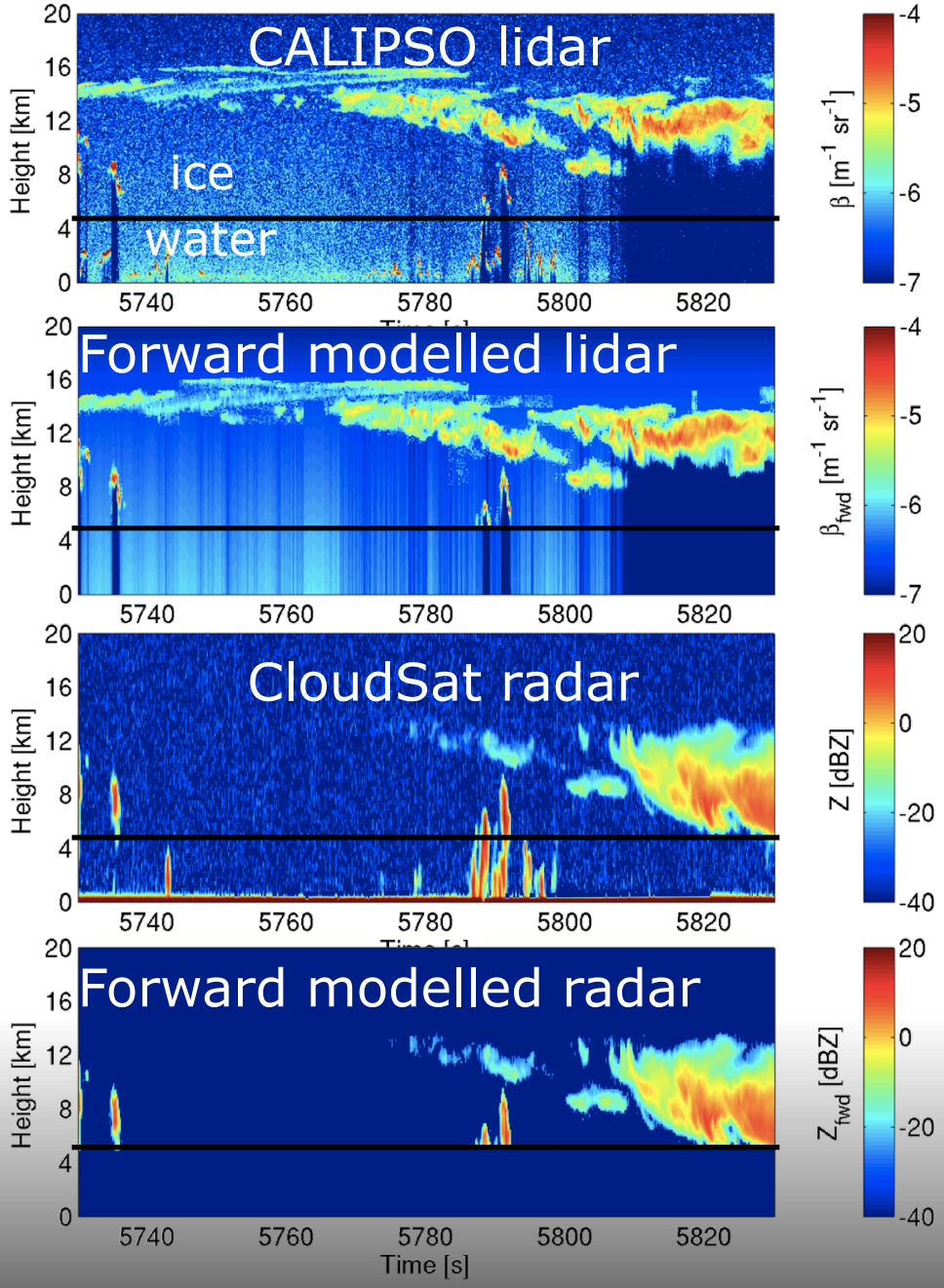
Proceed to next ray of data

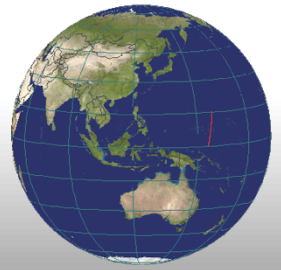


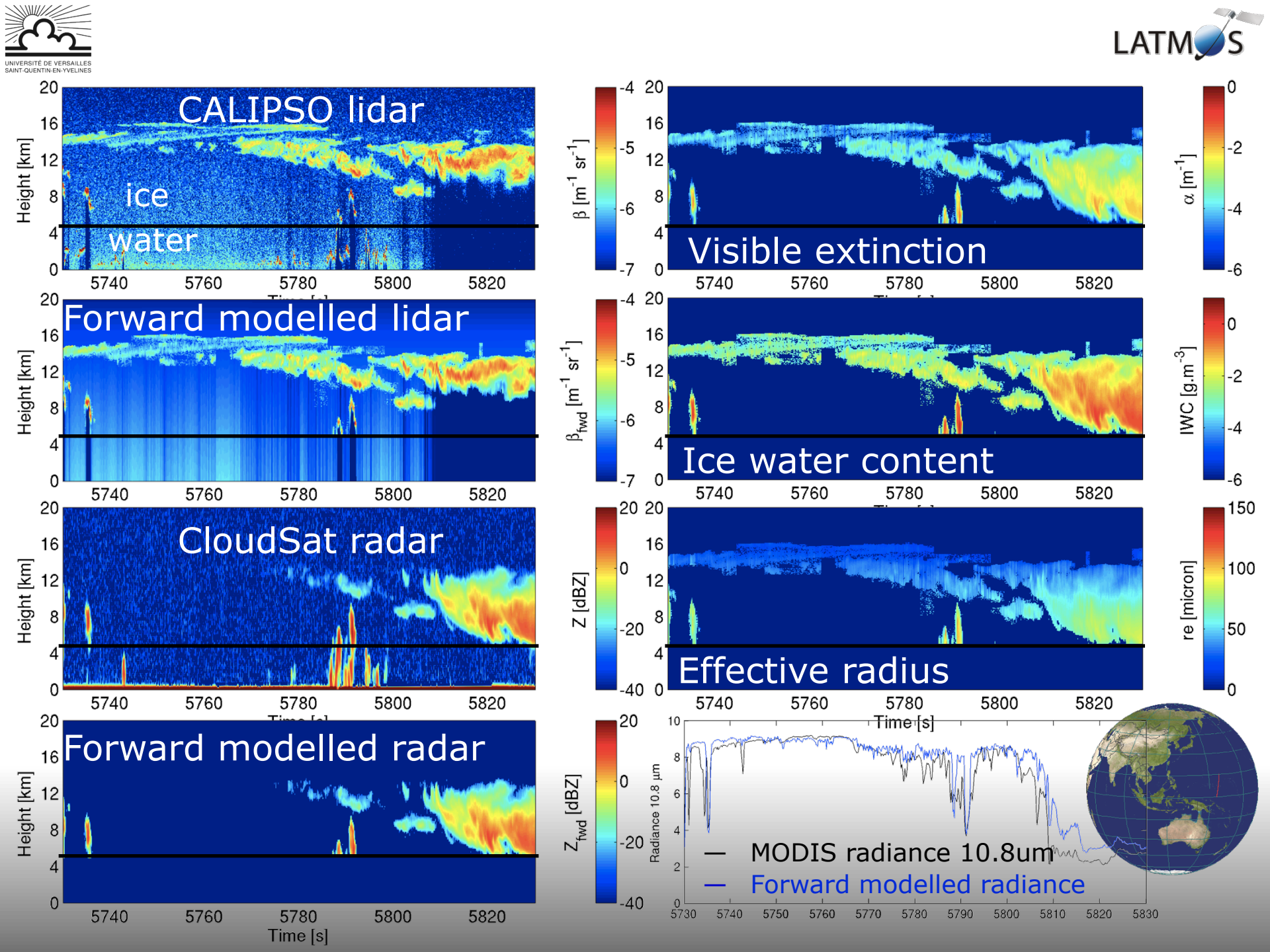
Pacific Ocean 2006-9-22

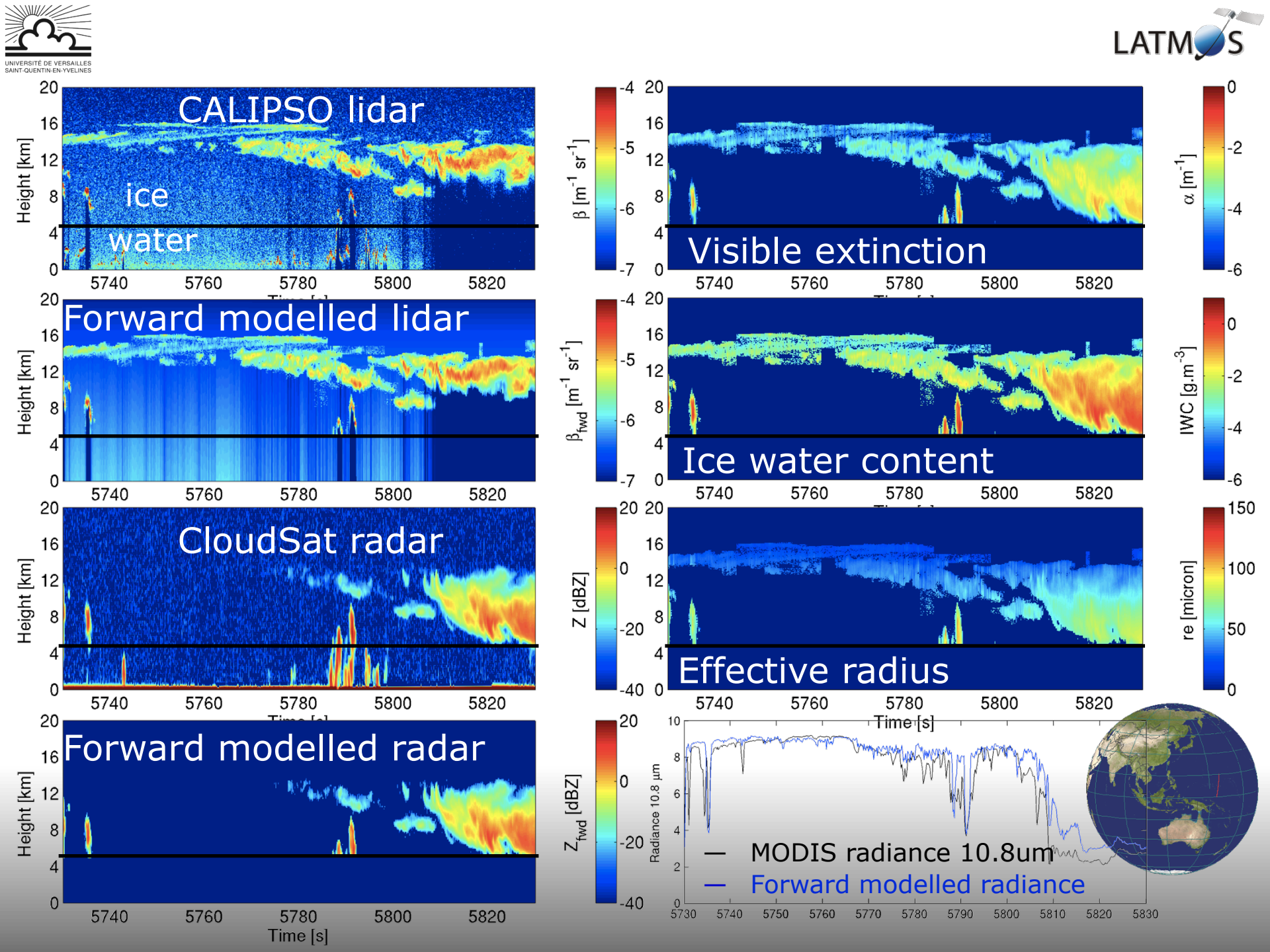





CALIPSO lidar
ice
water
Forward modelled lidar
CloudSat radar
Forward modelled radar
Height [km]
Time [s]
β [m⁻¹ sr⁻¹]
βfwd [m⁻¹ sr⁻¹]
Z [dBZ]
Zfwd [dBZ]




CALIPSO lidar
ice
water
Forward modelled lidar
CloudSat radar
Forward modelled radar
Visible extinction
Ice water content
Effective radius
Height [km]
Time [s]
β [m⁻¹ sr⁻¹]
α [m⁻¹]
IWC [g.m⁻³]
re [micron]
Z [dBZ]
Radiance 10.8 µm
MODIS radiance 10.8um
Forward modelled radiance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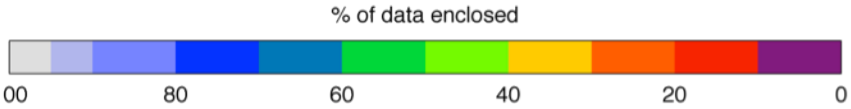
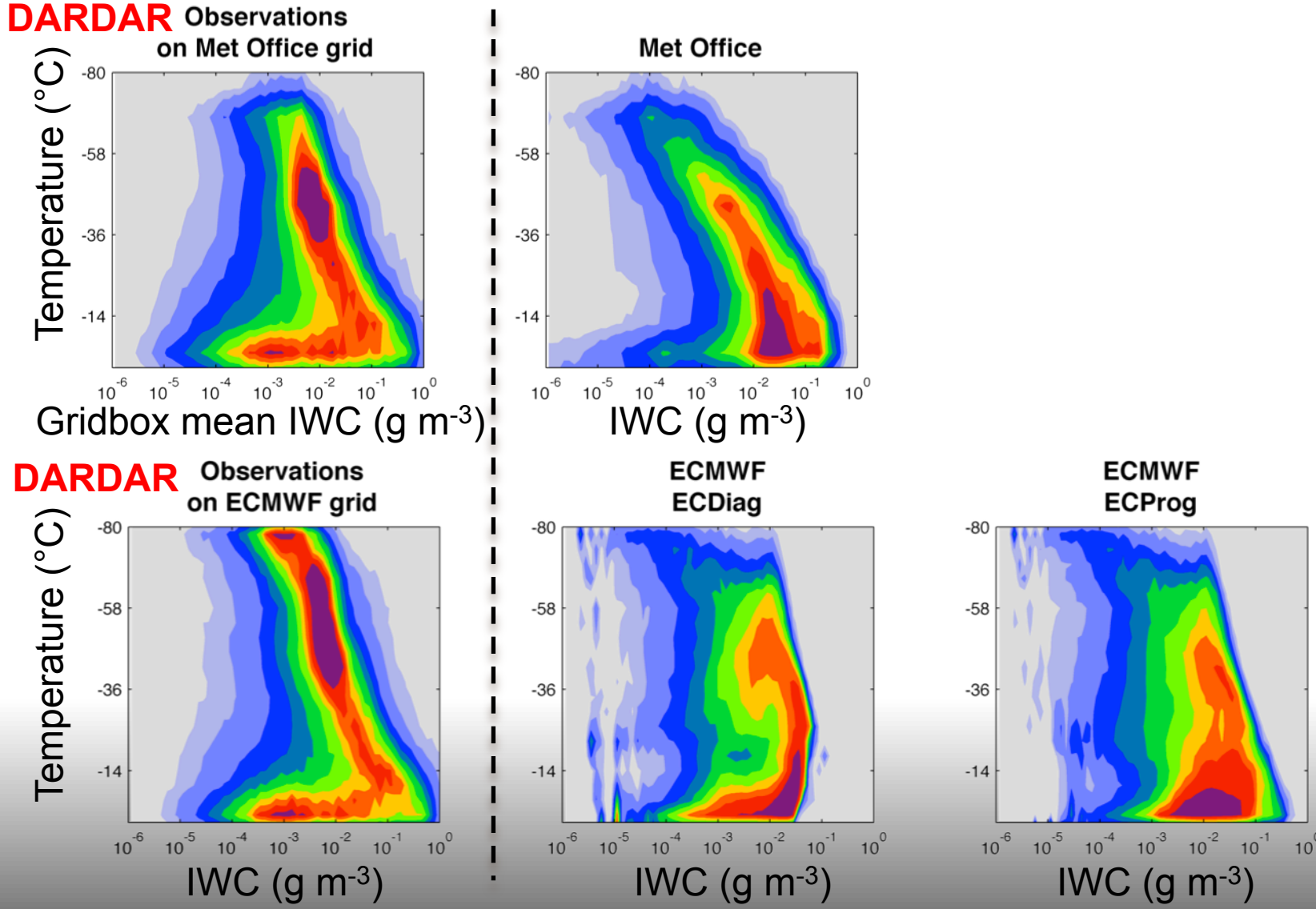
MODEL EVALUATION USING RADAR-LIDAR SYNERGY

WEIGHTED OCCURRENCE IWC vs T

Delanoë et al 2011 (QJRMS) DOI: 10.1002/qj.882



- 3 weeks in July 2006



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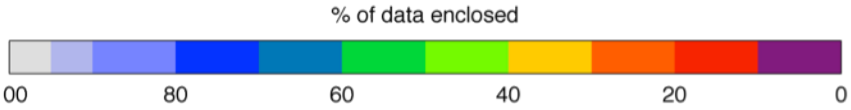
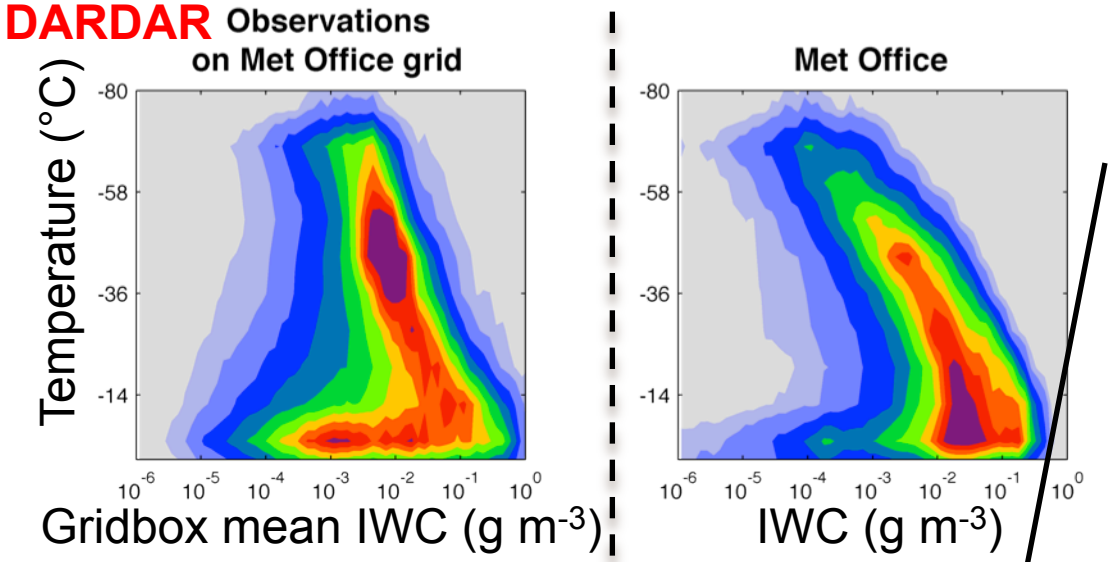
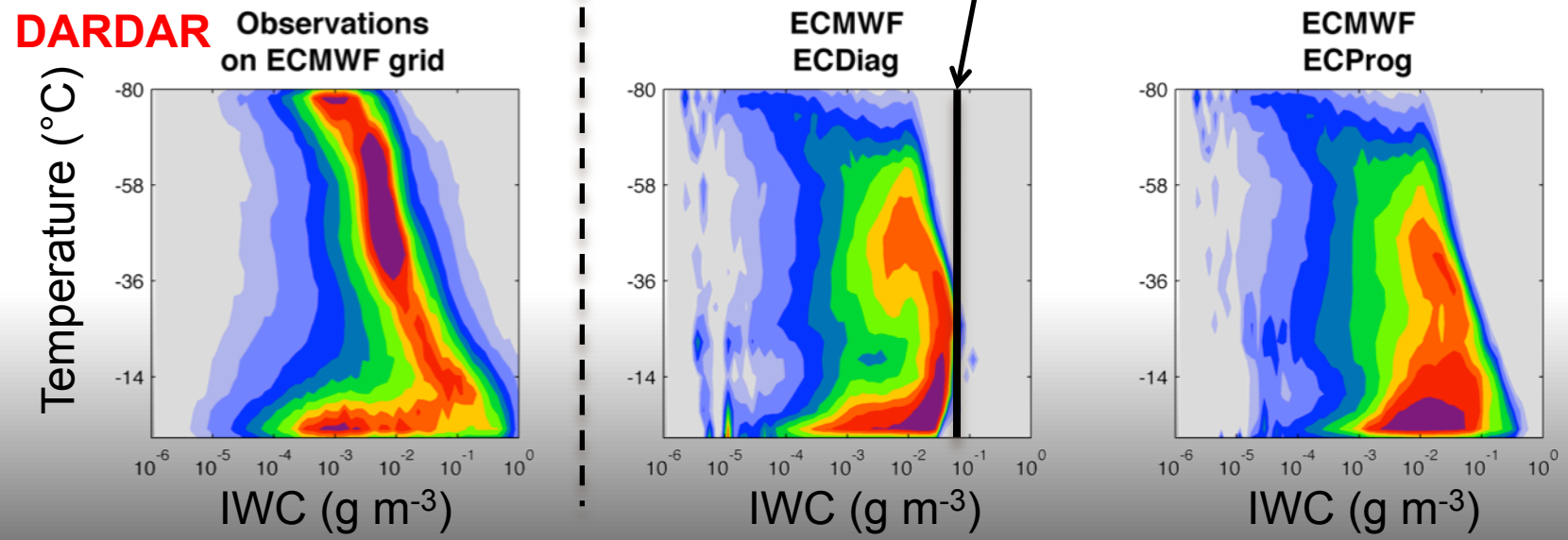


- 3 weeks in July 2006
- Models capture most of the observed variability in the temperature region between -60 °C and -5 °C
- "ECDiag" cut off between -20 °C and 0 °C due to the diagnostic snow parameterization





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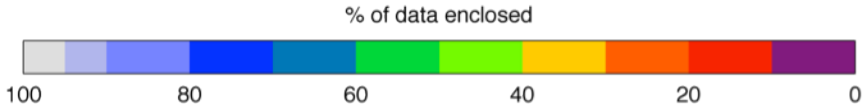
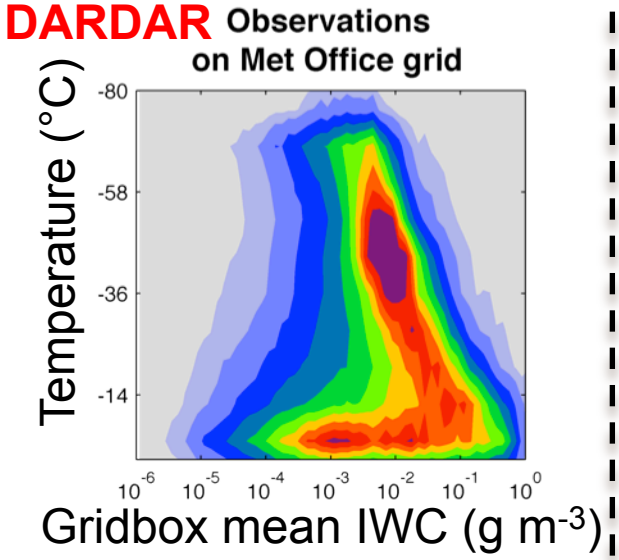
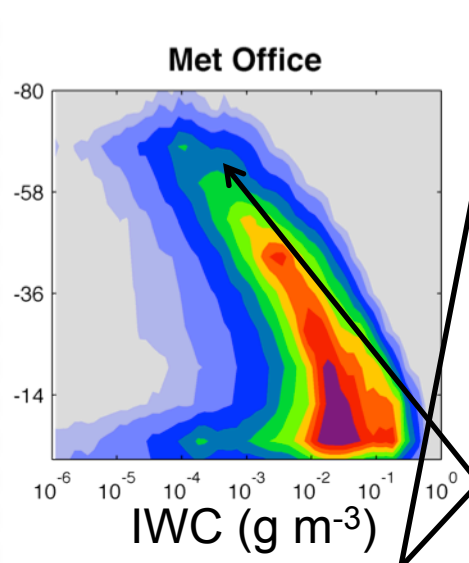
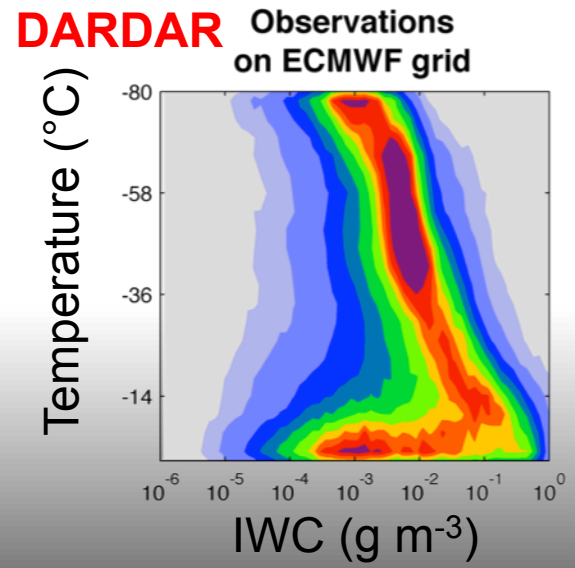
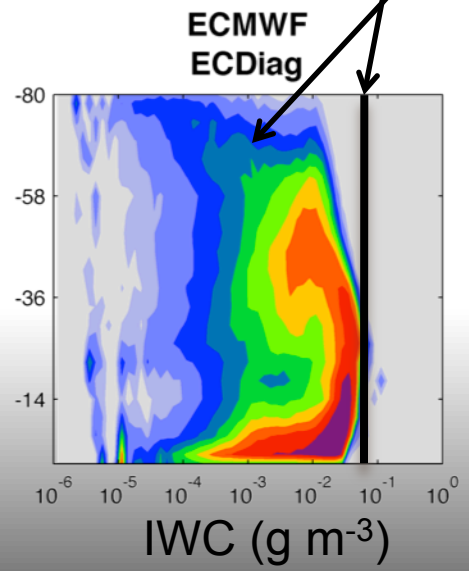
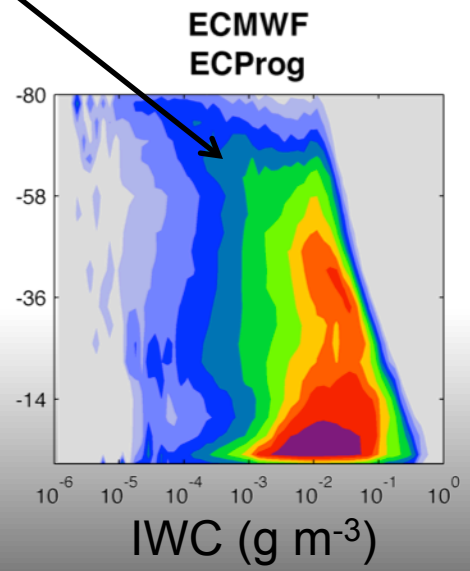












- 3 weeks in July 2006
- Models capture most of the observed variability in the temperature region between -60 °C and -5 °C
- "ECDiag" cut off between -20 °C and 0 °C due to the diagnostic snow parameterization
- Models underestimate occurrence of the lower IWC at temperatures below -70 °C.

PERSPECTIVE

Product improvements:

- Improve the DARDAR-MASK: problem with a few liquid clouds
- Add the liquid cloud retrieval
- Comparison with other stand-alone products

Scientific exploitation:

- More IWC/re/extinction climatologies
- Model evaluation over several years
  (Work of C. Bardeen, NCAR)
- Aerosol and Cloud
  (Work of S. Massie, NCAR)

Prepare EarthCare !

DARDAR-CLOUD: KEY INFO

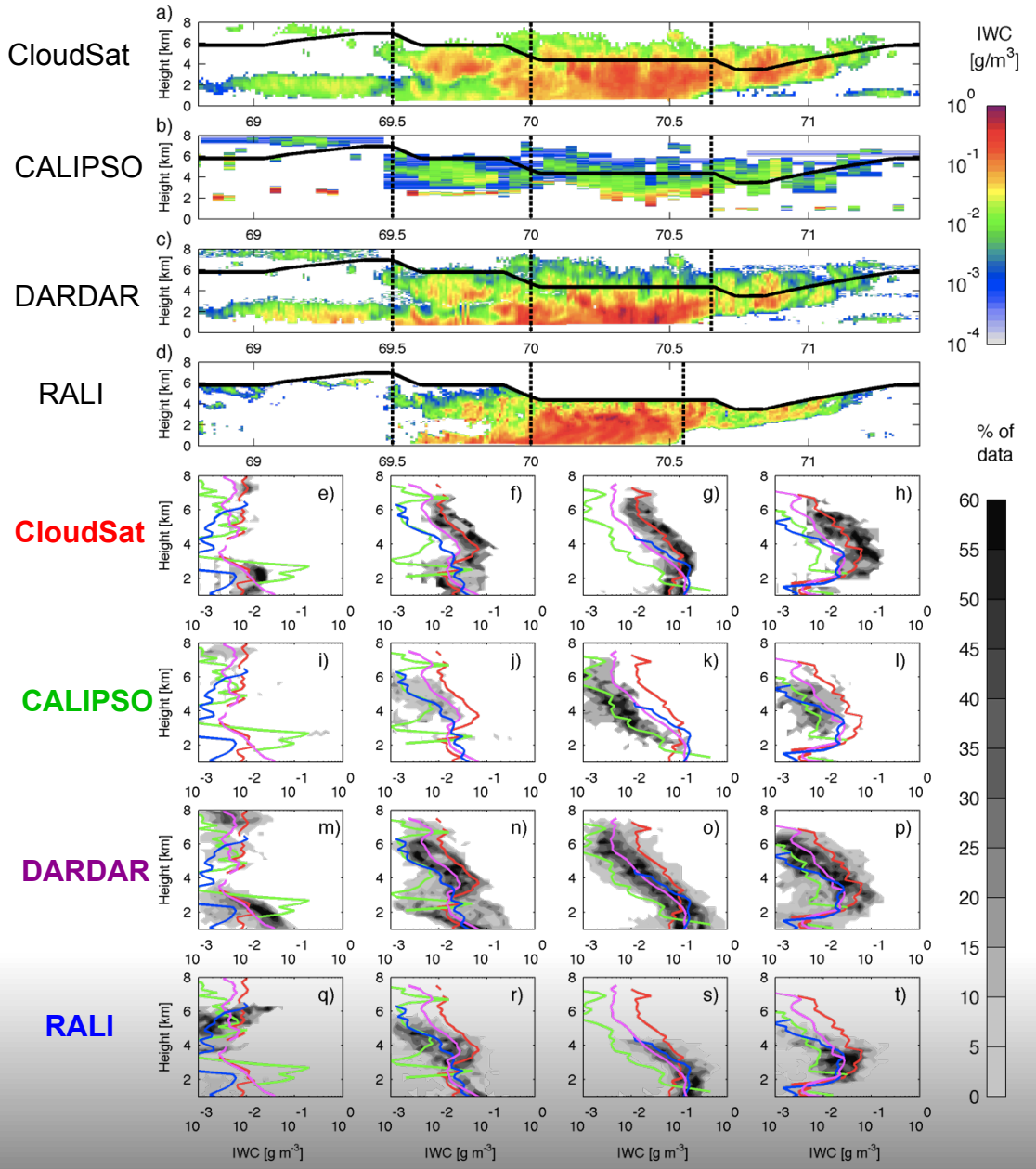
$$\mathbf{y} = \begin{pmatrix} \ln \beta'_1 \\ \vdots \\ \ln \beta'_n \\ Z_1 \\ \vdots \\ Z_m \\ I_{10\,\mu m} \\ \Delta I_{8.5-12.0\,\mu m} \end{pmatrix} \quad \mathbf{x} = \begin{pmatrix} \ln \alpha_1^{\text{ice}} \\ \vdots \\ \ln \alpha_n^{\text{ice}} \\ \ln N'_1 \\ \vdots \\ \ln N'_m \\ a_{\ln S}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

Assumptions and tricks:

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

- When radar and lidar are simultaneously available: 2 moments of PSD are available.
- When only one instrument available, we rely on our a-priori lnN'(T)
- S can assumed constant with height Or can be assumed linearly varying with height if radiance used $S=\exp(a_{lnS}*T+b_{lnS})$.
- Use molecular signal beyond the cloud as a constraint on optical depth

CASE STUDY AIRBORNE+ATRAIN-IN-SITU



POLARCAT campaign (1st April 2008, polar cloud)

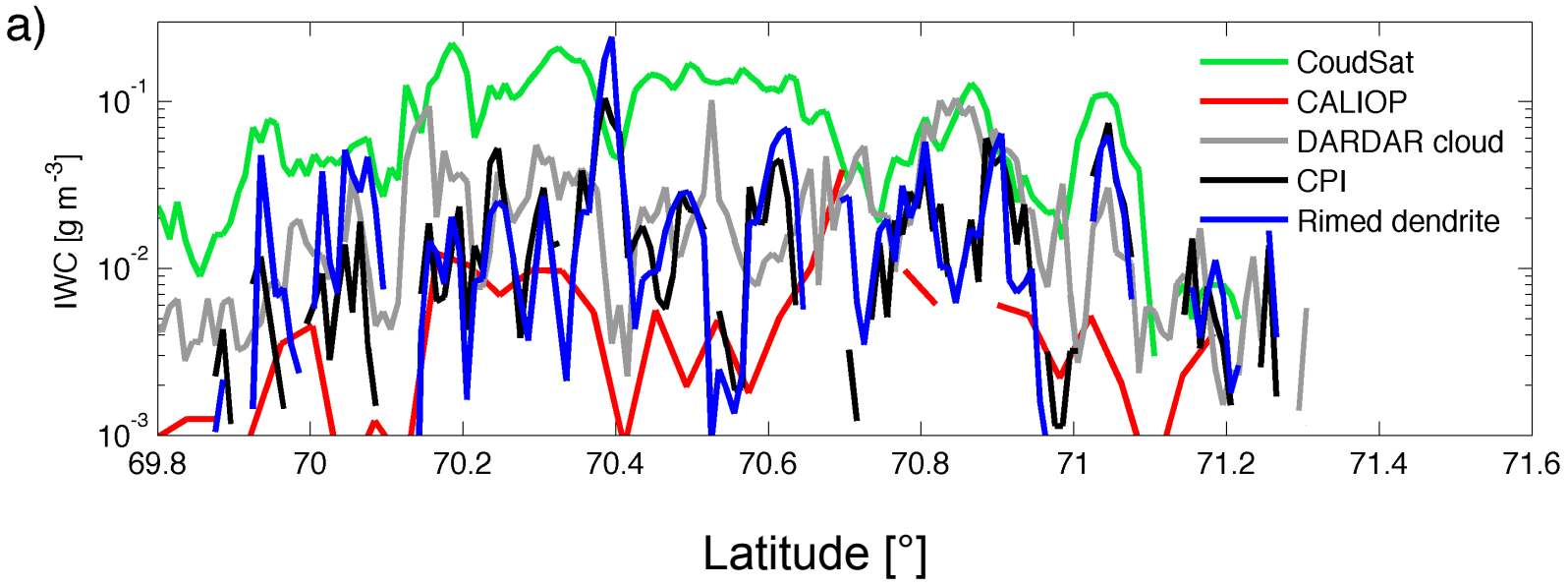
- 2B-CWC-RO (1km-240m)
- CALIPSO Lidar Level 2 Cloud Profile data at 5 km (V3-01 version) (5km-60m)
- DARDAR (1km-60m)
- French airborne radar-lidar RALI

CloudSat: highest values of IWC

CALIPSO: lowest values of IWC

DARDAR: in between and close to RALI

VS IN-SITU


a)
IWC [g m-3]
10-1
10-2
10-3
69.8
70
70.2
70.4
70.6
70.8
71
71.2
71.4
71.6
Latitude [°]
CoudSat
CALIOP
DARDAR cloud
CPI
Rimed dendrite