Using observations of clouds and radiation at Chilbolton UK to evaluate NWP models.

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- Chilbolton 24h/7d vertical profiles of clouds
- 94GHz radar and lidar – profiles 30sec/60m resolution.
- Infer cloud properties and compare with values held in operational models for Chilbolton grid box.

- 35GHz radar, 22/28/38GHz Radiometers, Raman lidar.
- 1275 clear air radar – boundary layer + refractivity
- 3GHz polarisation radar for precipitation.

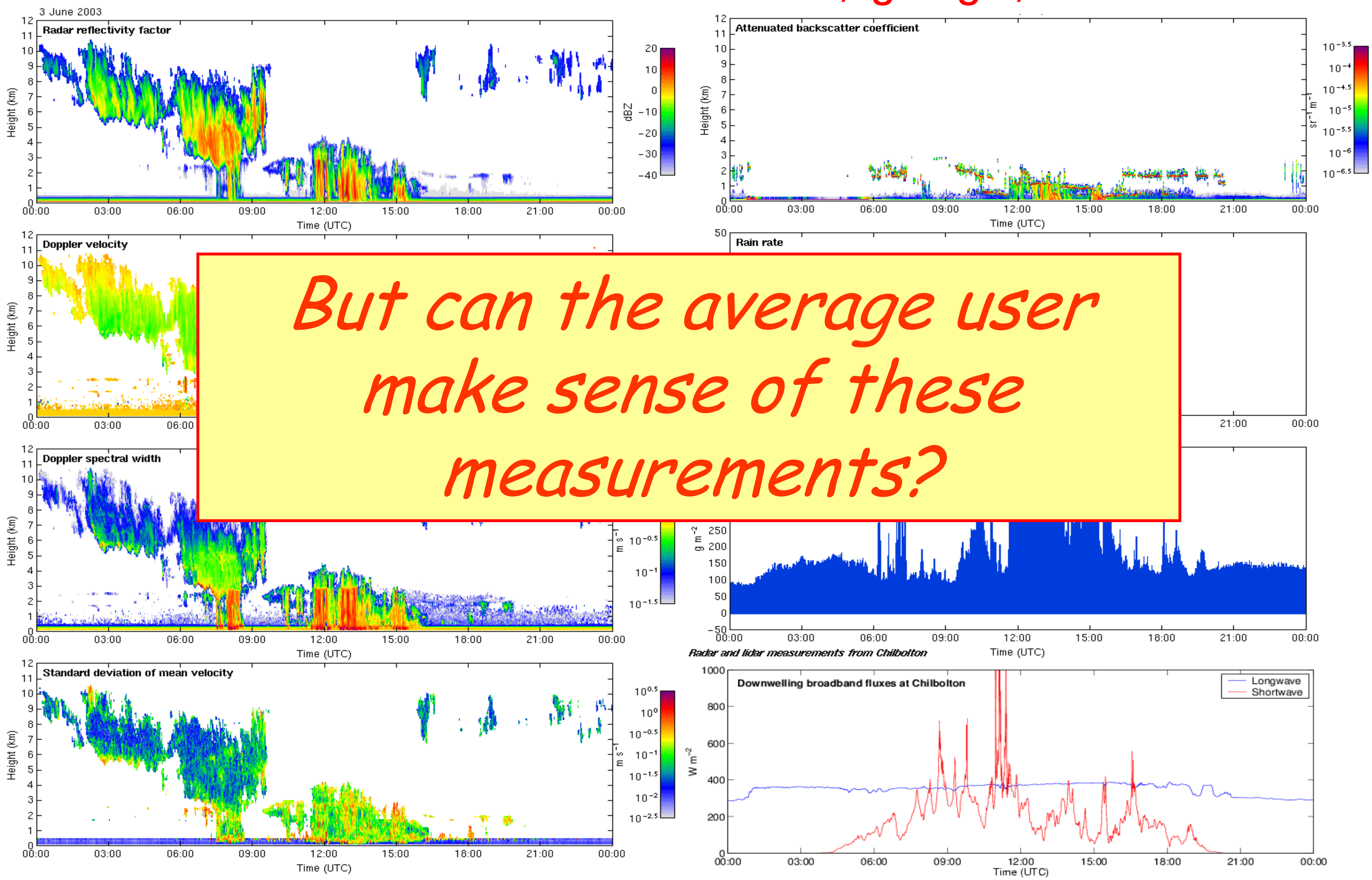
COMPARE OBSERVATIONS AND REPRESENTATION IN MODELS.

- Typical day
- Is cloud fraction correct? Pdf OK?
- Is ice water content correct? Errors? Pdf OK?
- Errors when classified by weather regime?
- Example of one month data and model
- Cloud overlap not really maximum random?
- Cloud inhomogeneity?
- Supercooled layer clouds are common.

Standard Chilbolton observations on the web

Radar

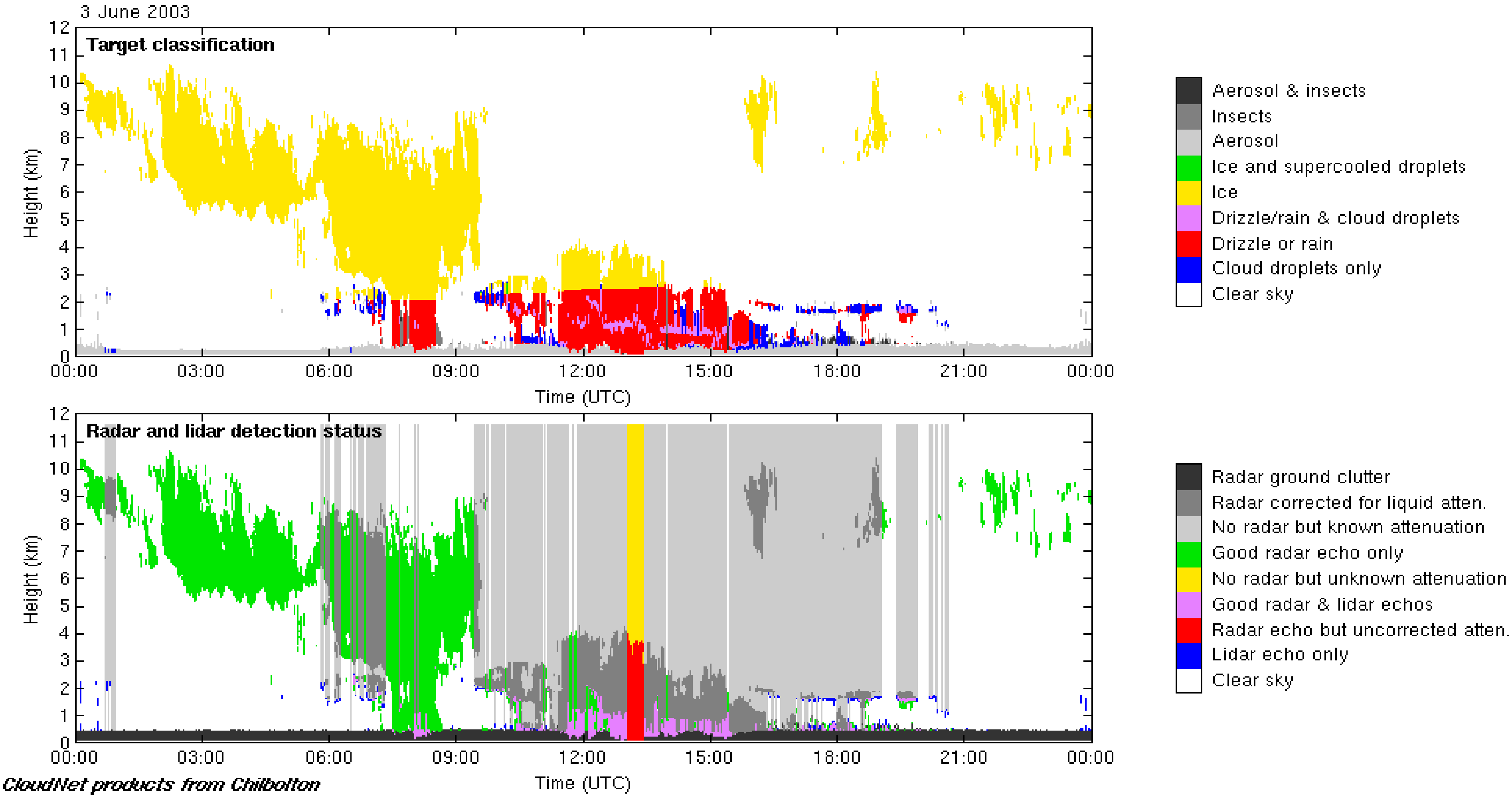
Lidar, gauge, radiometers



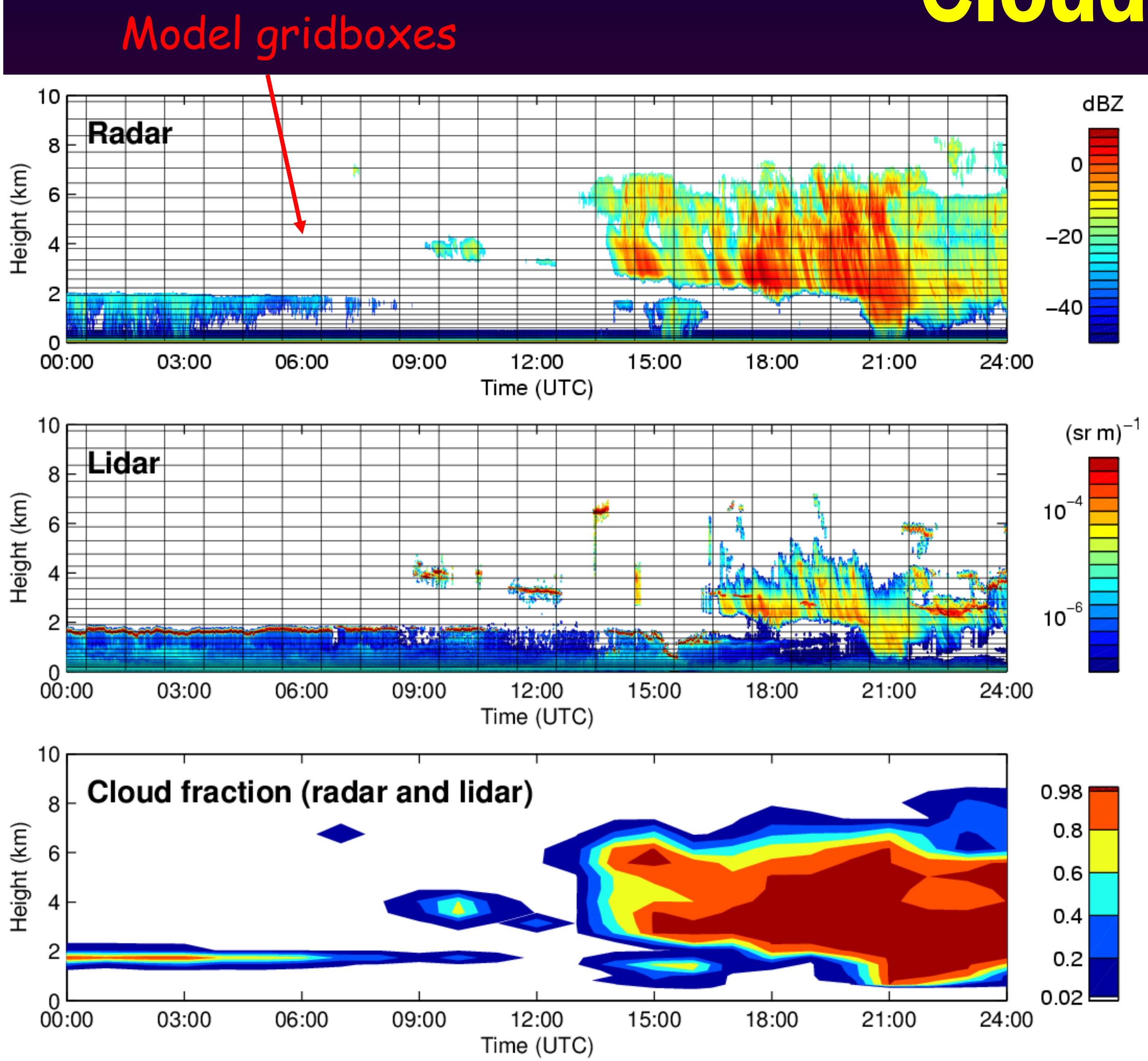
But can the average user make sense of these measurements?

Target categorization

- Combining radar, lidar and model allows the type of cloud (or other target) to be identified



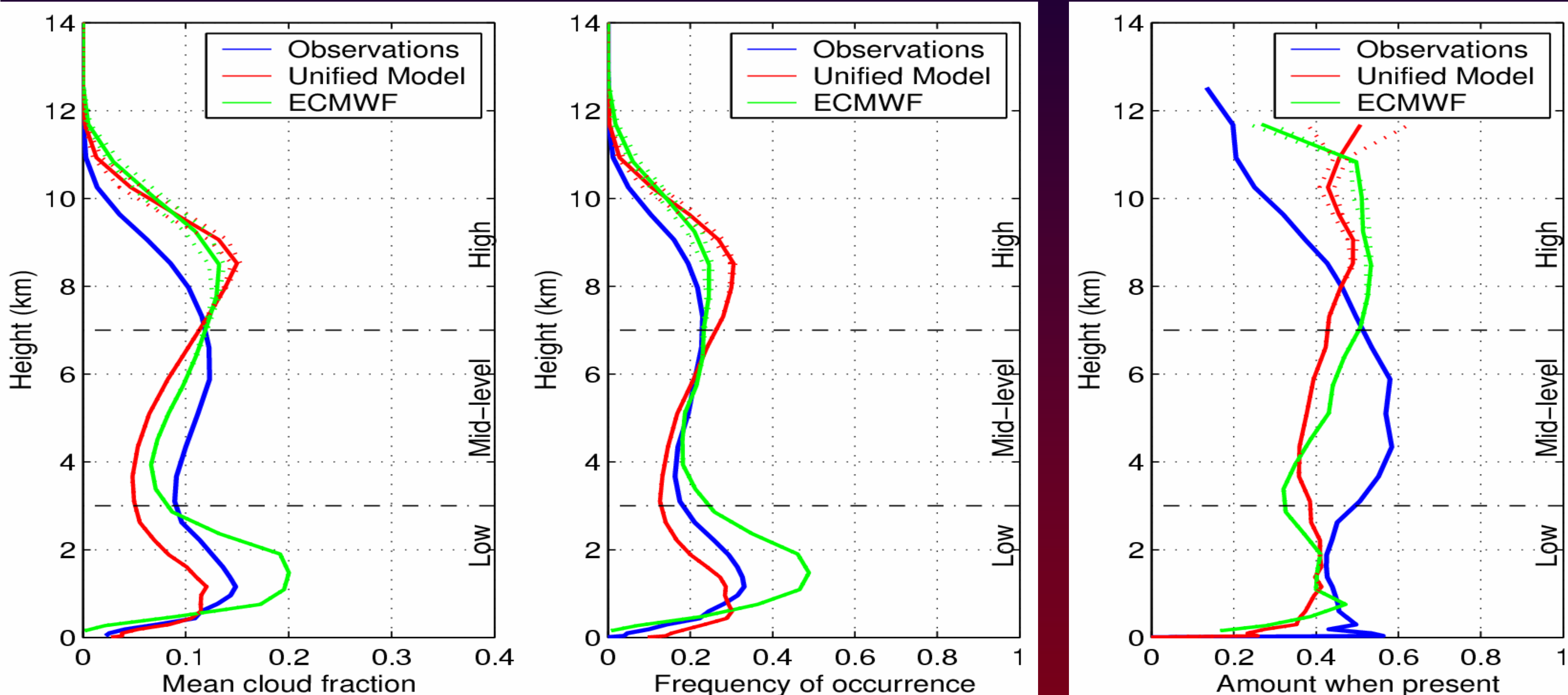
Cloud fraction



- Radar provides first guess of cloud fraction in each model gridbox

Lidar refines the estimate by removing drizzle beneath stratocumulus and adding thin liquid clouds (warm and supercooled) that the radar does not detect

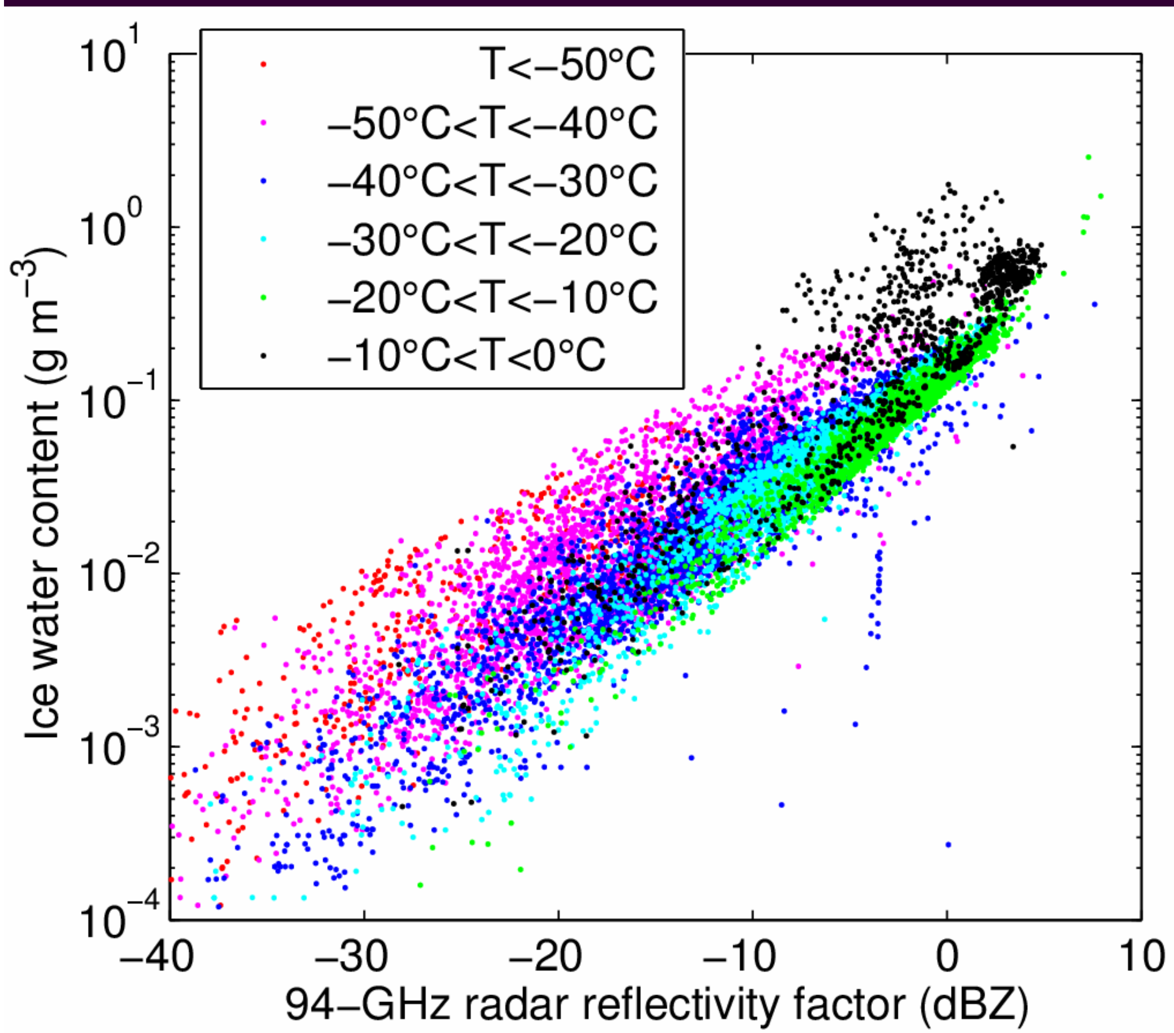
Cloud fraction: one year of data



- Too much cloud at high levels, too little at mid-levels
  - However, *frequency of occurrence* is better: suggests humidity structure is good, but *amount when present* is not so good
  - Low-level clouds are very different in the two models

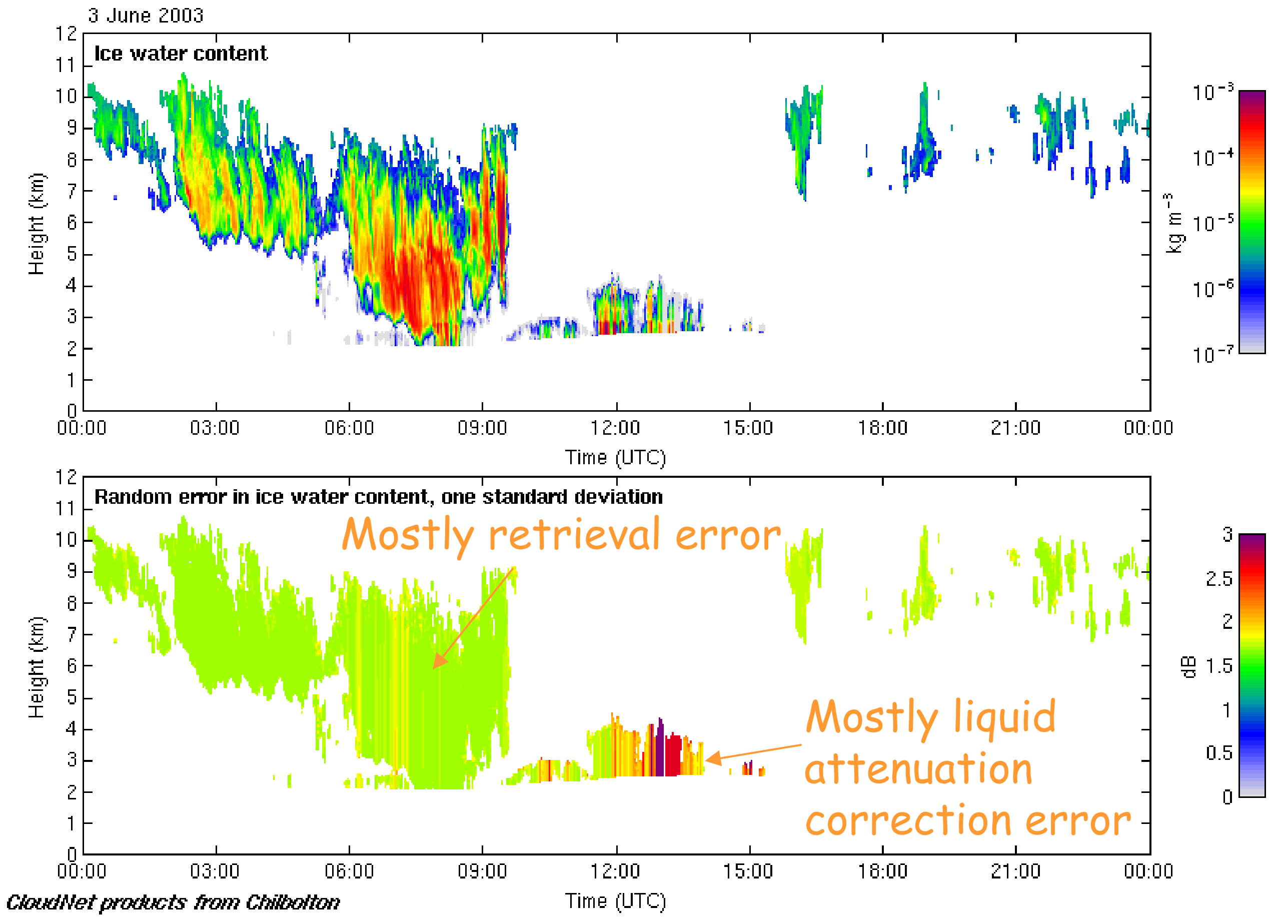
Ice water content

Met Office C-130 aircraft data

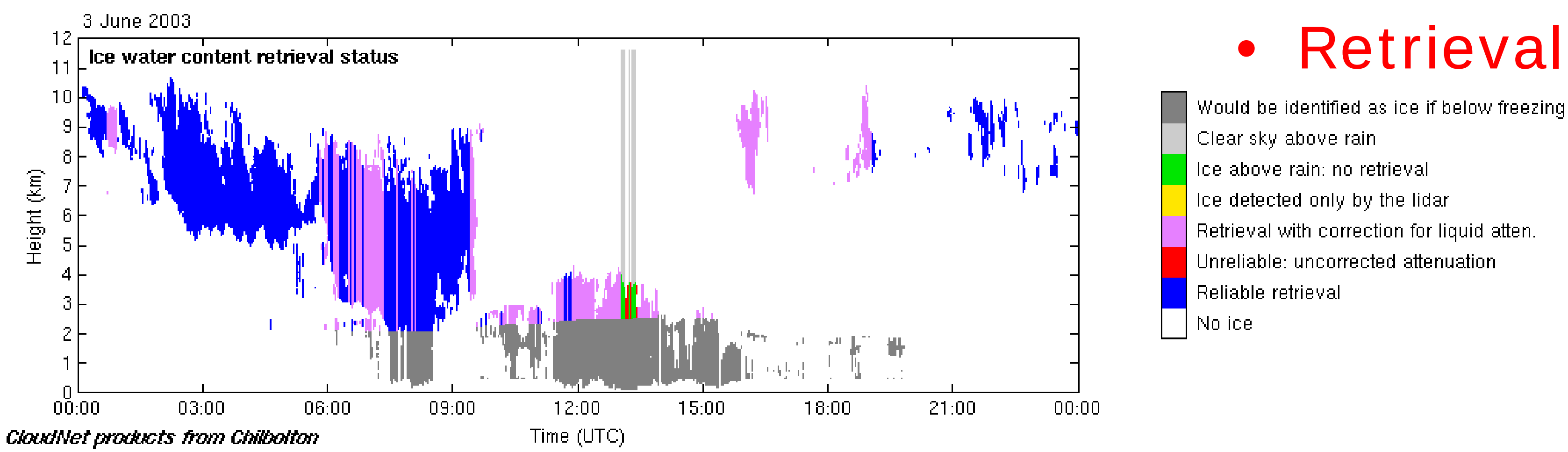


Cirrus *in situ* measurements suggest we can obtain IWC from Z to a factor of two

- Particles tend to be smaller at lower temperatures, so with additional use of temperature, error is reduced to -30%/+40%
- Less accurate between -10°C and 0°C because of strong aggregation

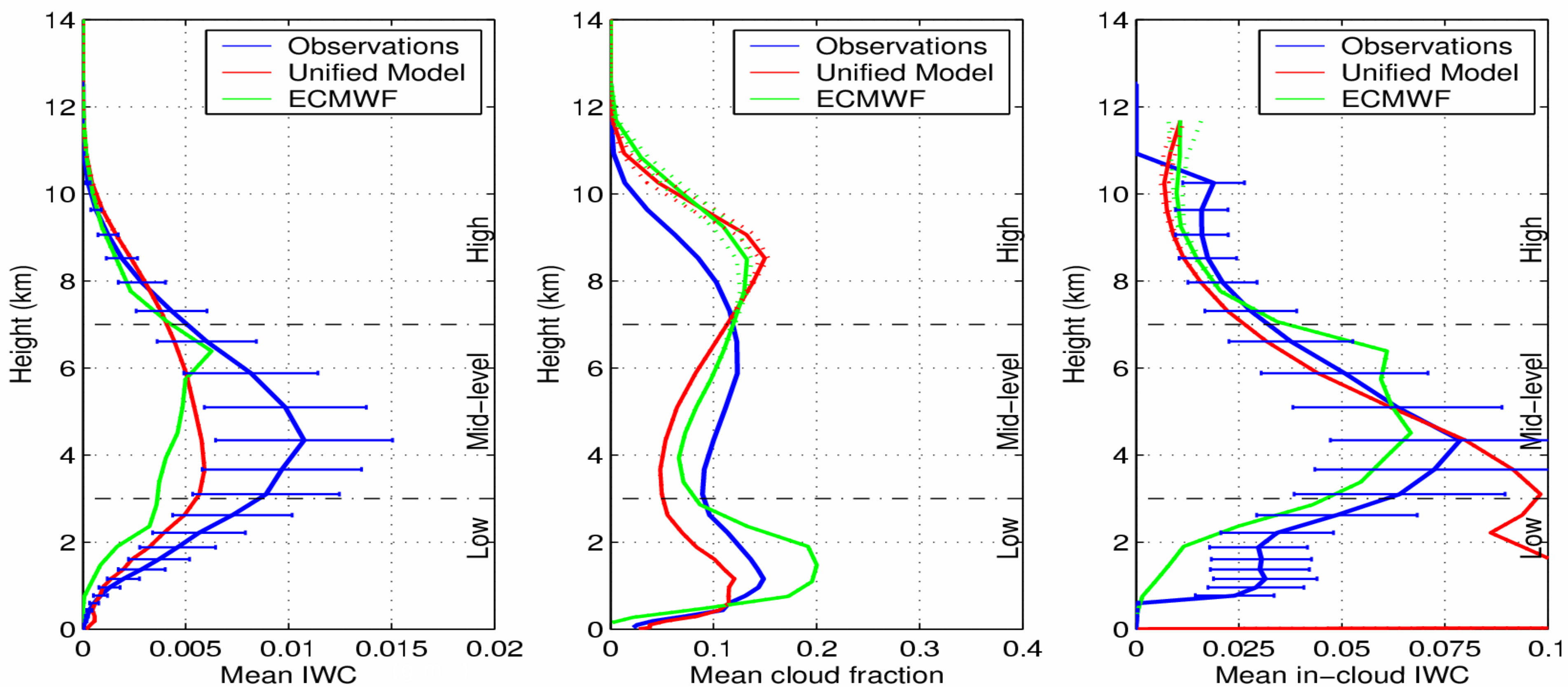


- Ice water content from Z and T
- Error in ice water content

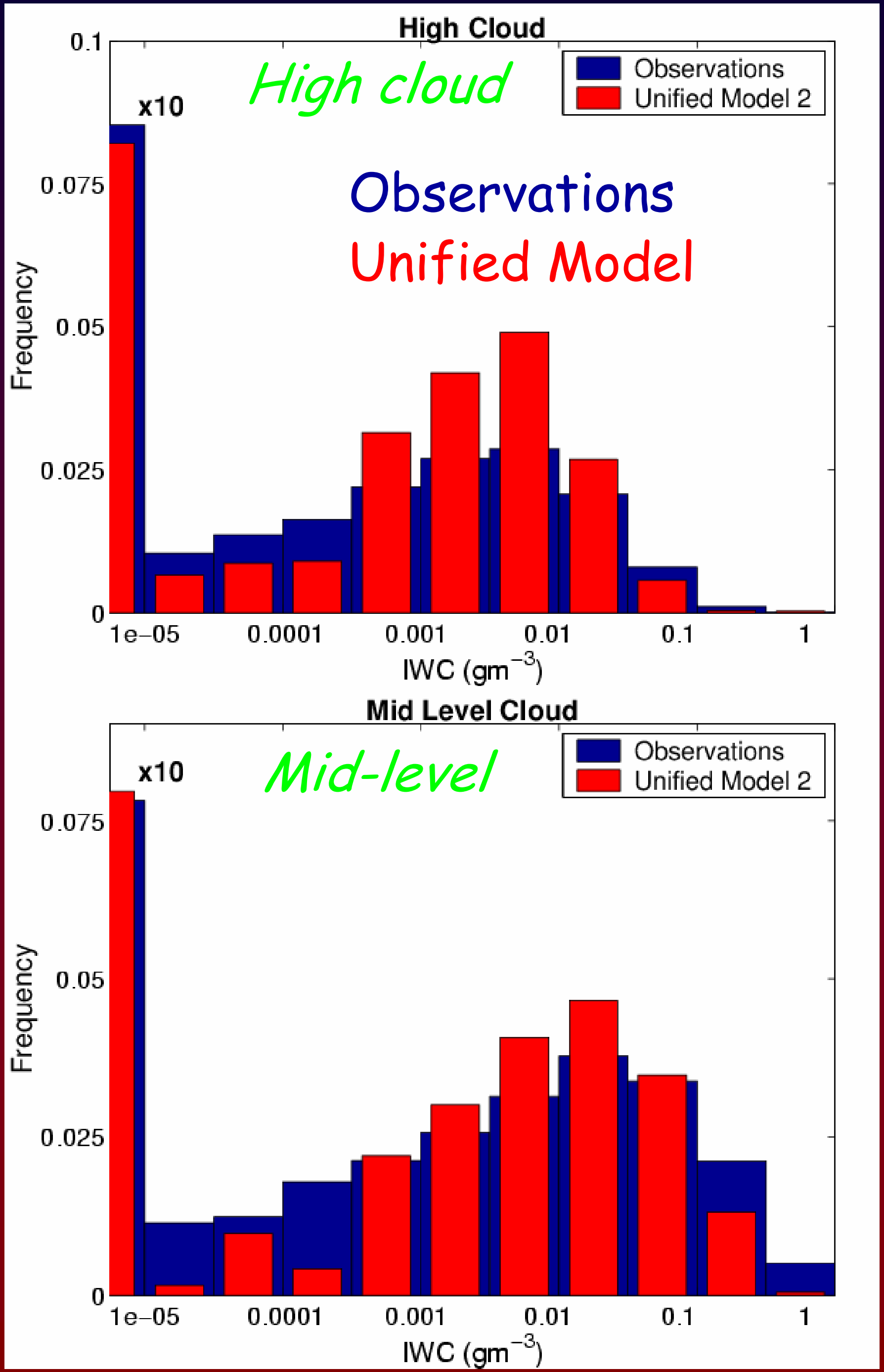


- Retrieval flag

Ice water content: results

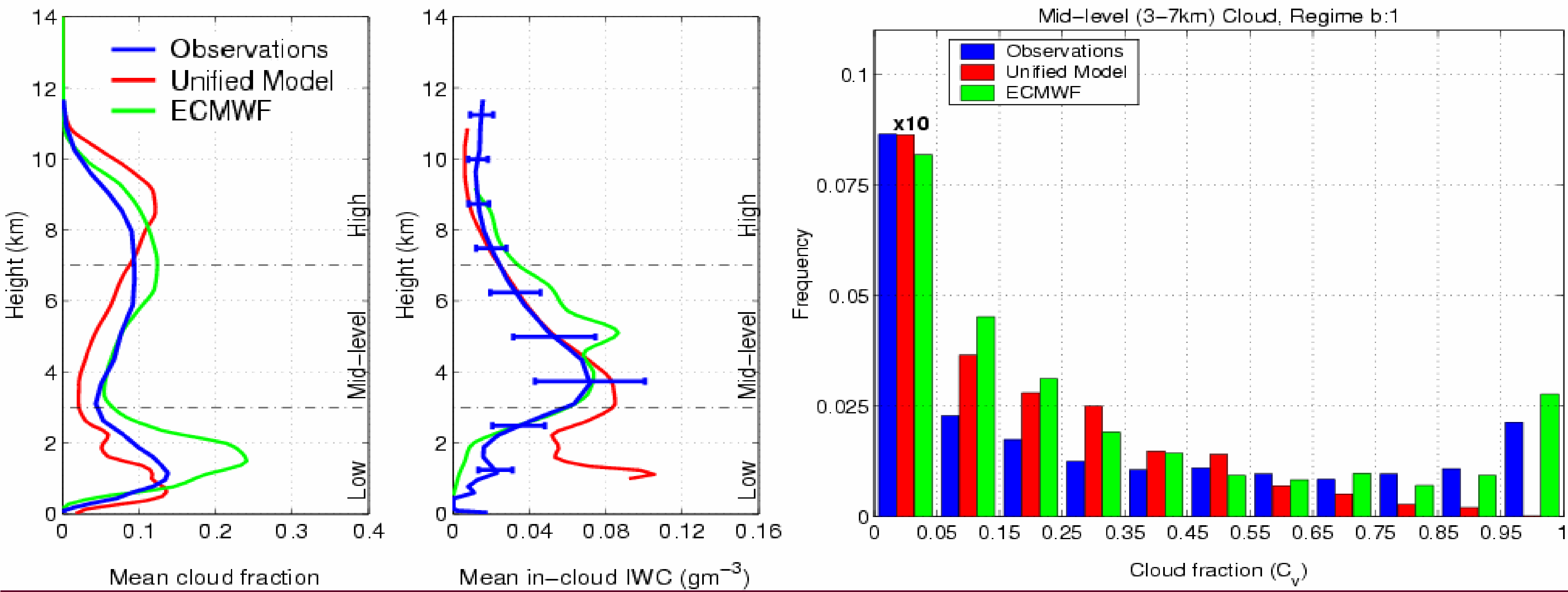


- First ever long-term evaluation of ice water content
- Underestimate of mean mid-level IWC in both models
  - *Seems to be due to factor-of-2 error in mean cloud fraction*
  - *Mean in-cloud IWC appears to be reasonably good above 4 km*

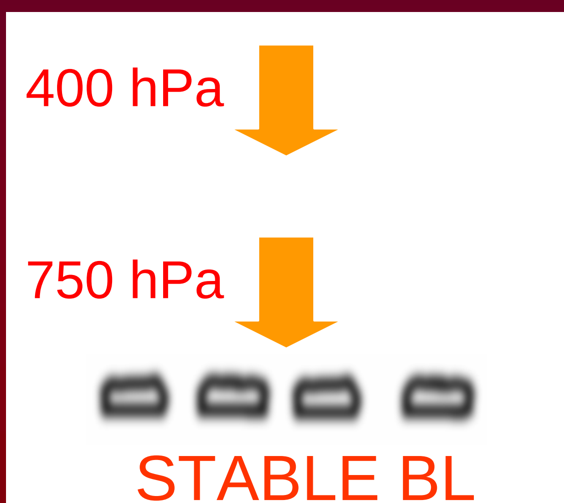


IWC distributions

- The Met Office Unified Model tends to simulate very high and very low ice water contents too infrequently



Clasification by regime

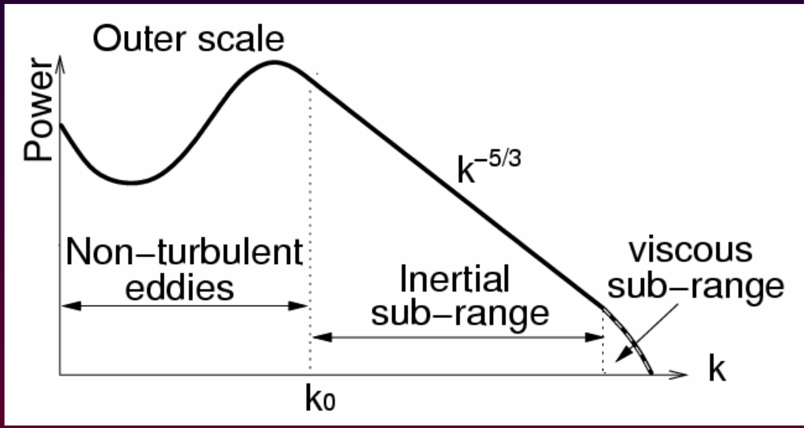


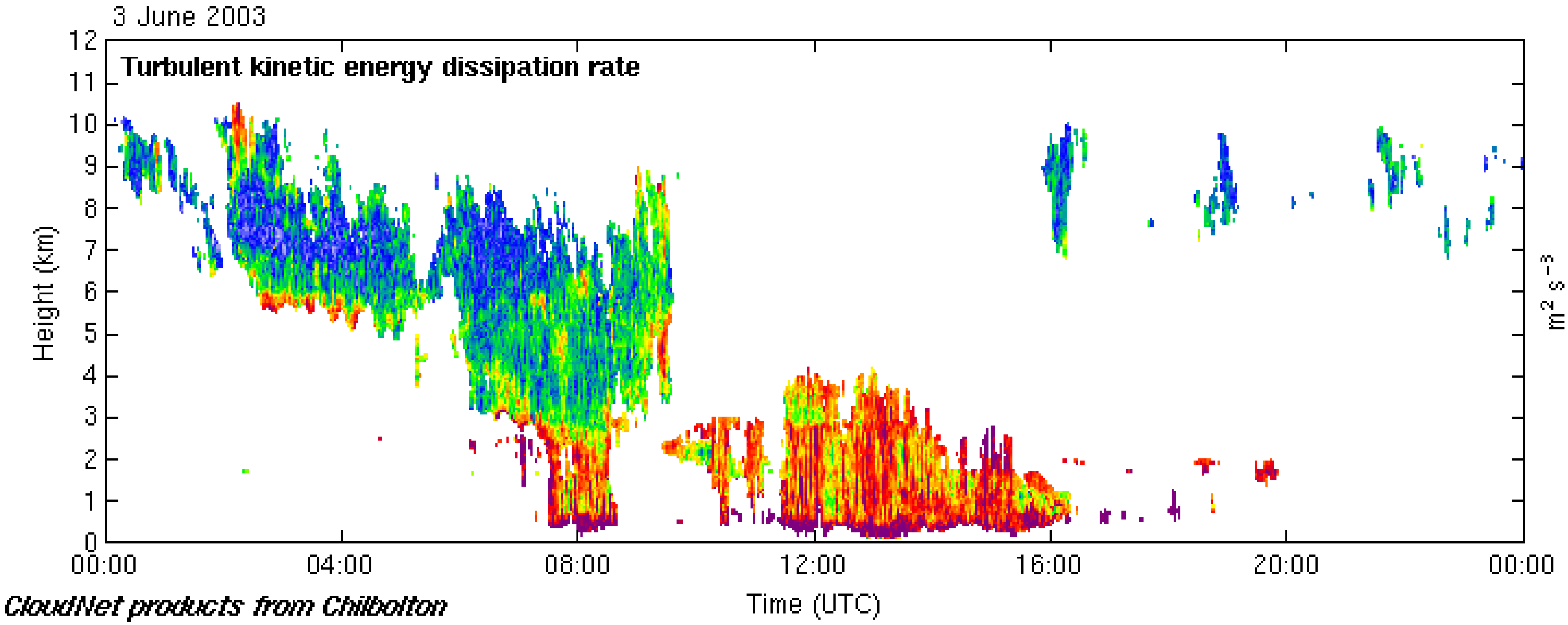
- Ascent at 700 hPa (>0.1 hPa/s)
- Ascent at 400 hPa (>0.1 hPa/s)
- Stability between 900 and 1000 hPa

- Descent and low level stable – UM can’t make 100% cloud cover

Eddy dissipation rate ε

- 30-s standard deviation of 1-s radar velocities, plus wind speed, gives eddy dissipation rate (Bouniol et al. 2003)

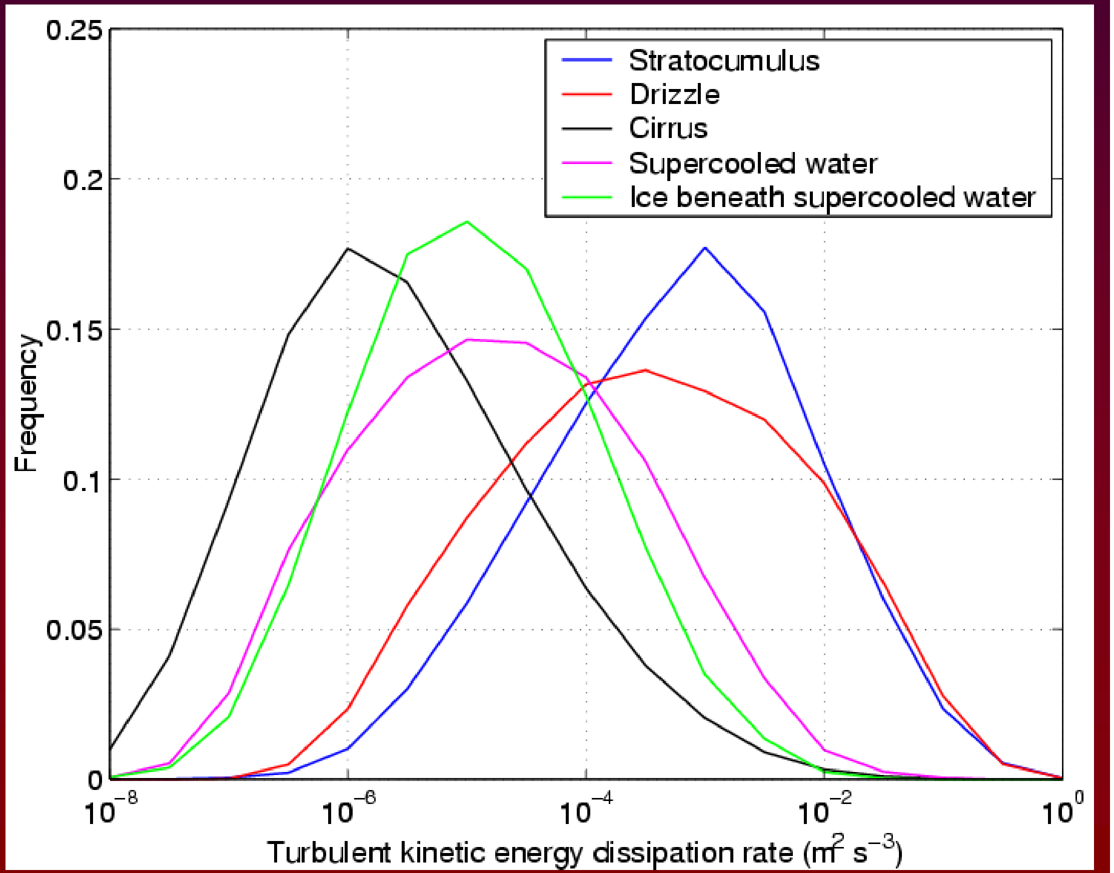




PDF of ε by cloud type

- Use classification product to define simple cloud types, then look at PDF of eddy dissipation rate for each

- Mean turbulence in different clouds:
  - Stratocu: 10^{-3} m^2s^{-3}
  - Mixed-phase: 10^{-5} m^2s^{-3}
  - Cirrus: 10^{-6} m^2s^{-3}



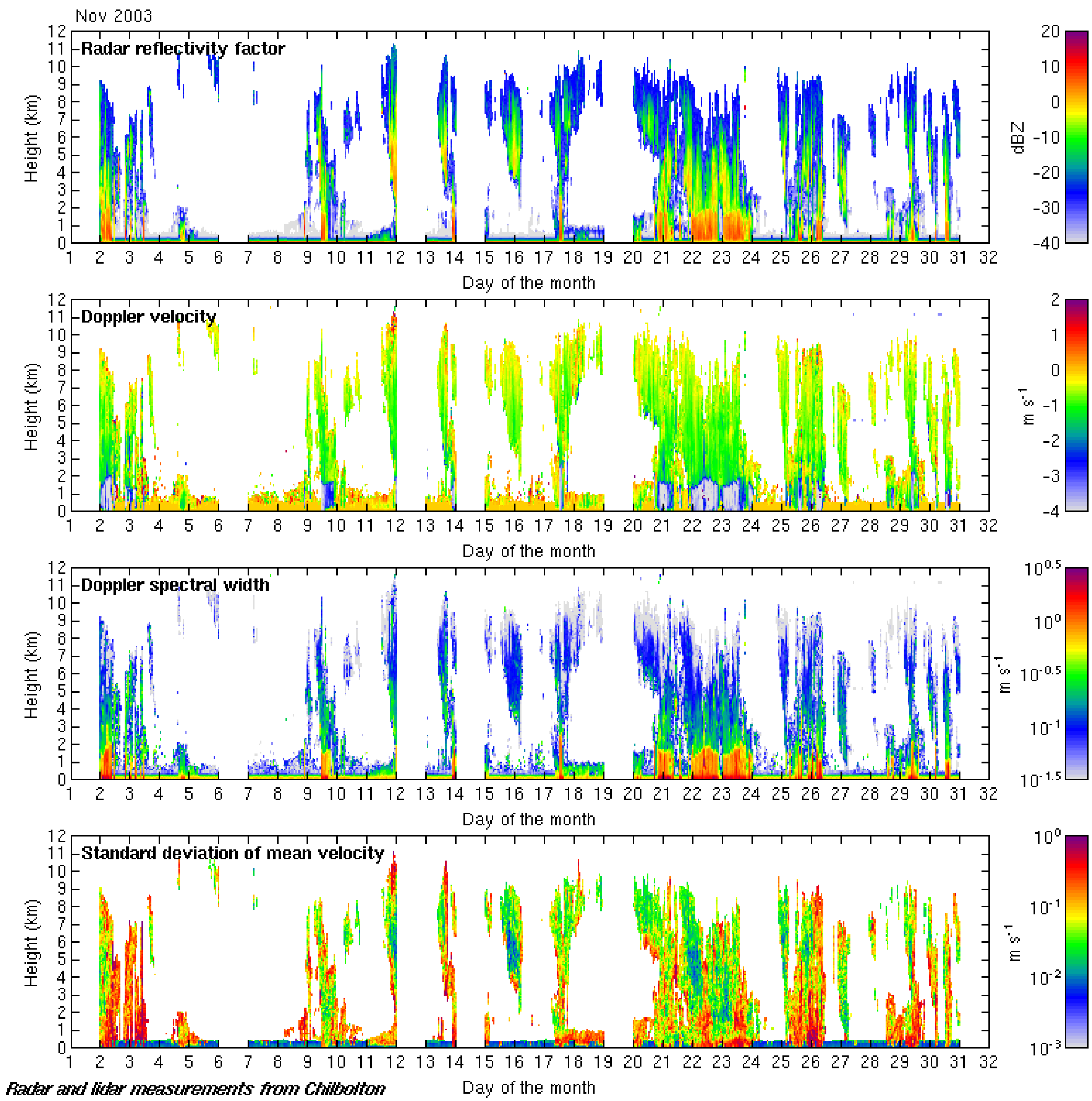
Radar Observations Nov 2003

Z

V

σ_v

$\sigma_{v(1sec)}$

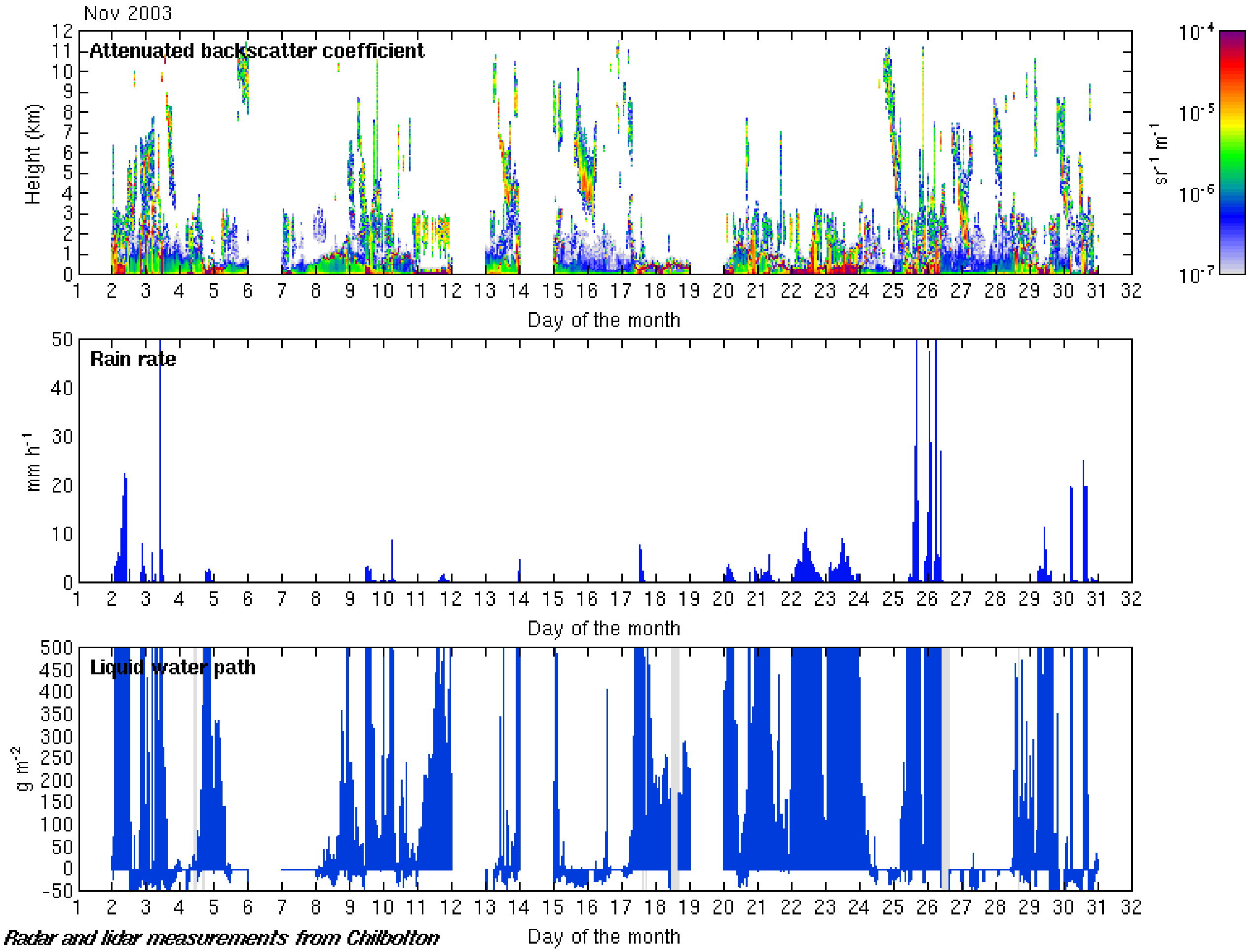


Observations Nov 03

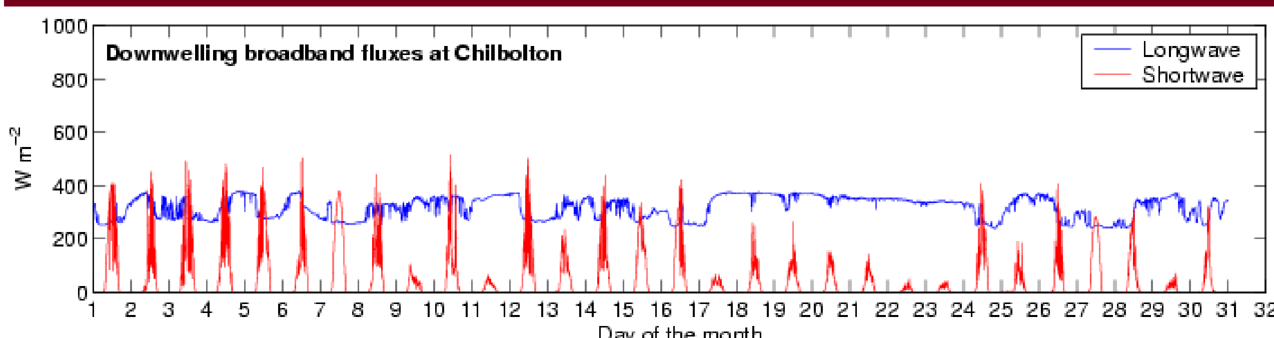
Lidar

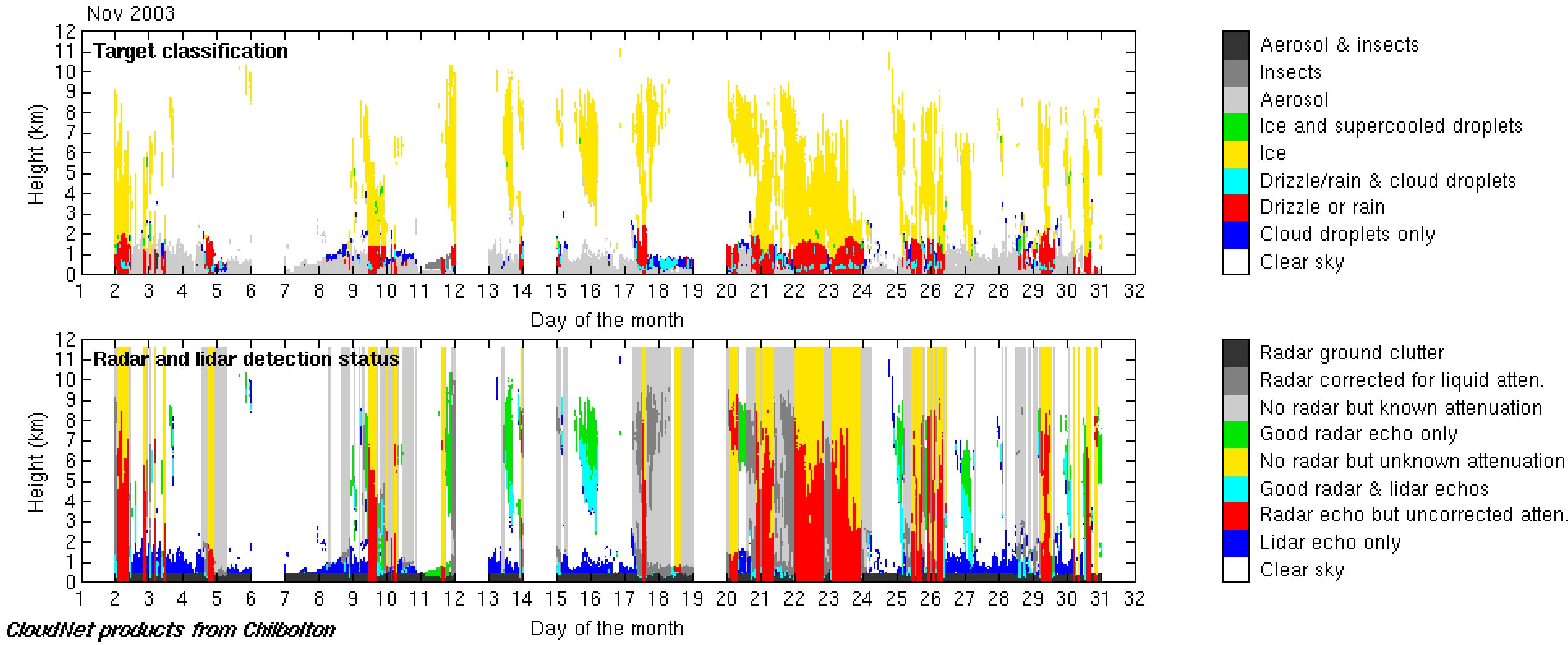
Rainfall

LWP



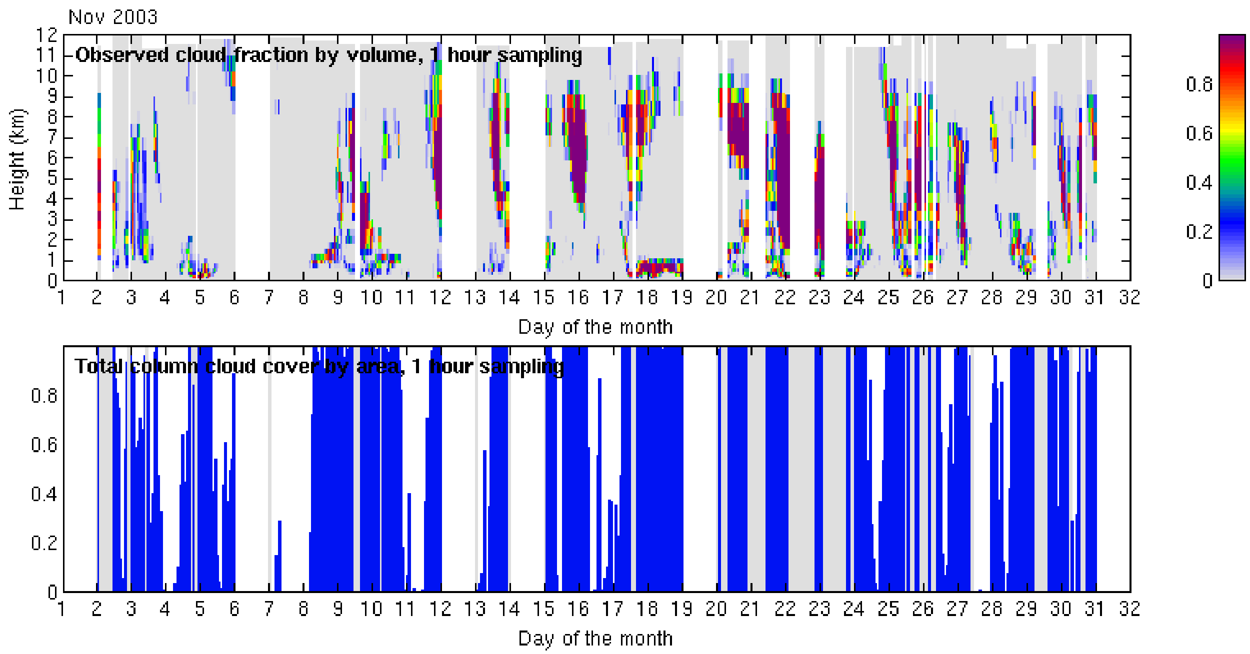
LW and SW flux





Status

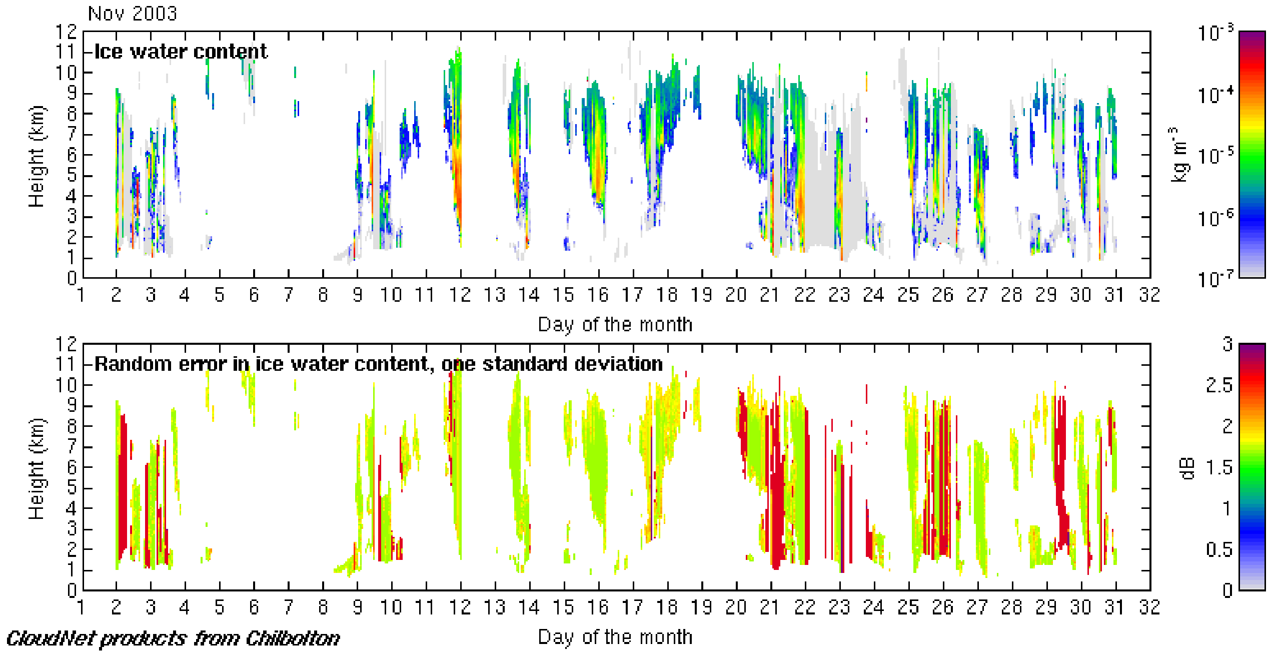
Observations Nov 03



Cloud fraction

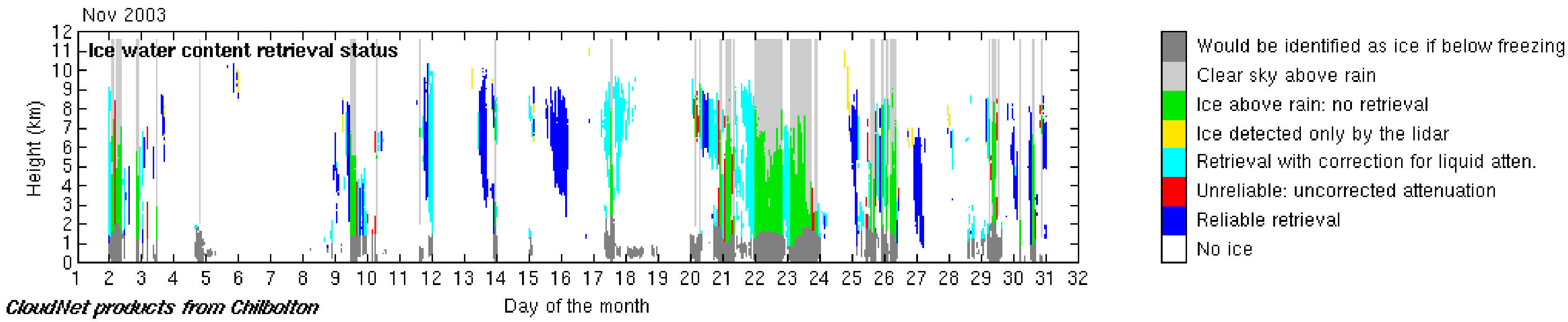
Total cloud cover

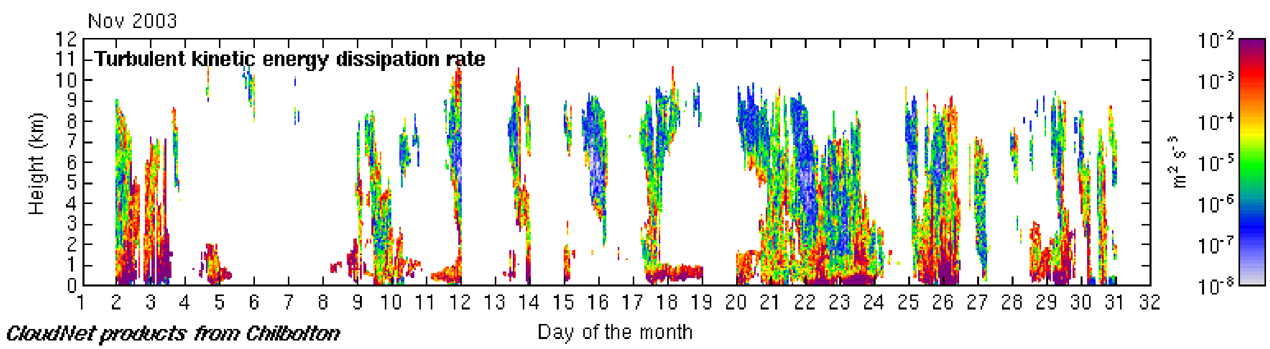
Observations Nov 03



IWC

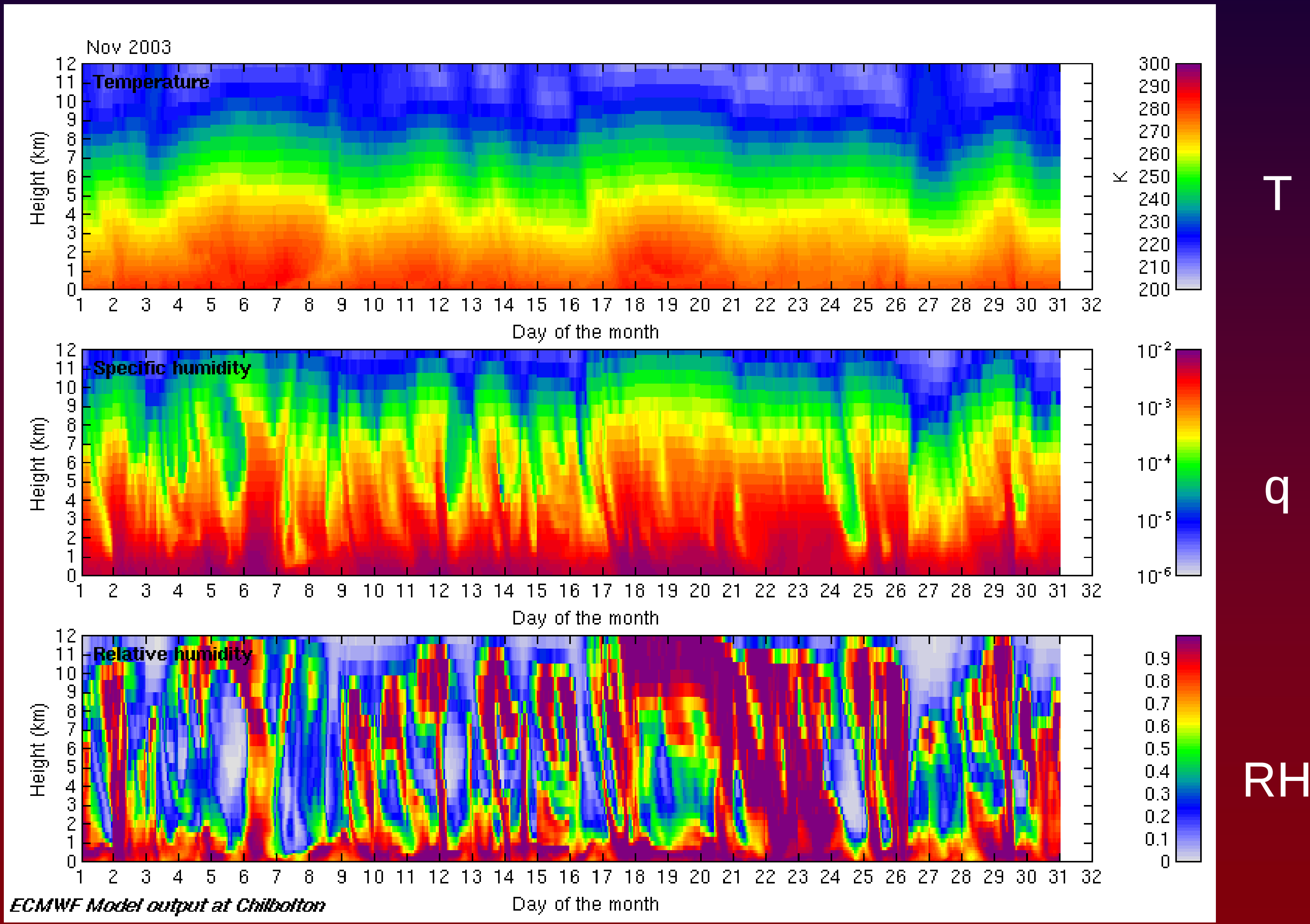
IWC Error



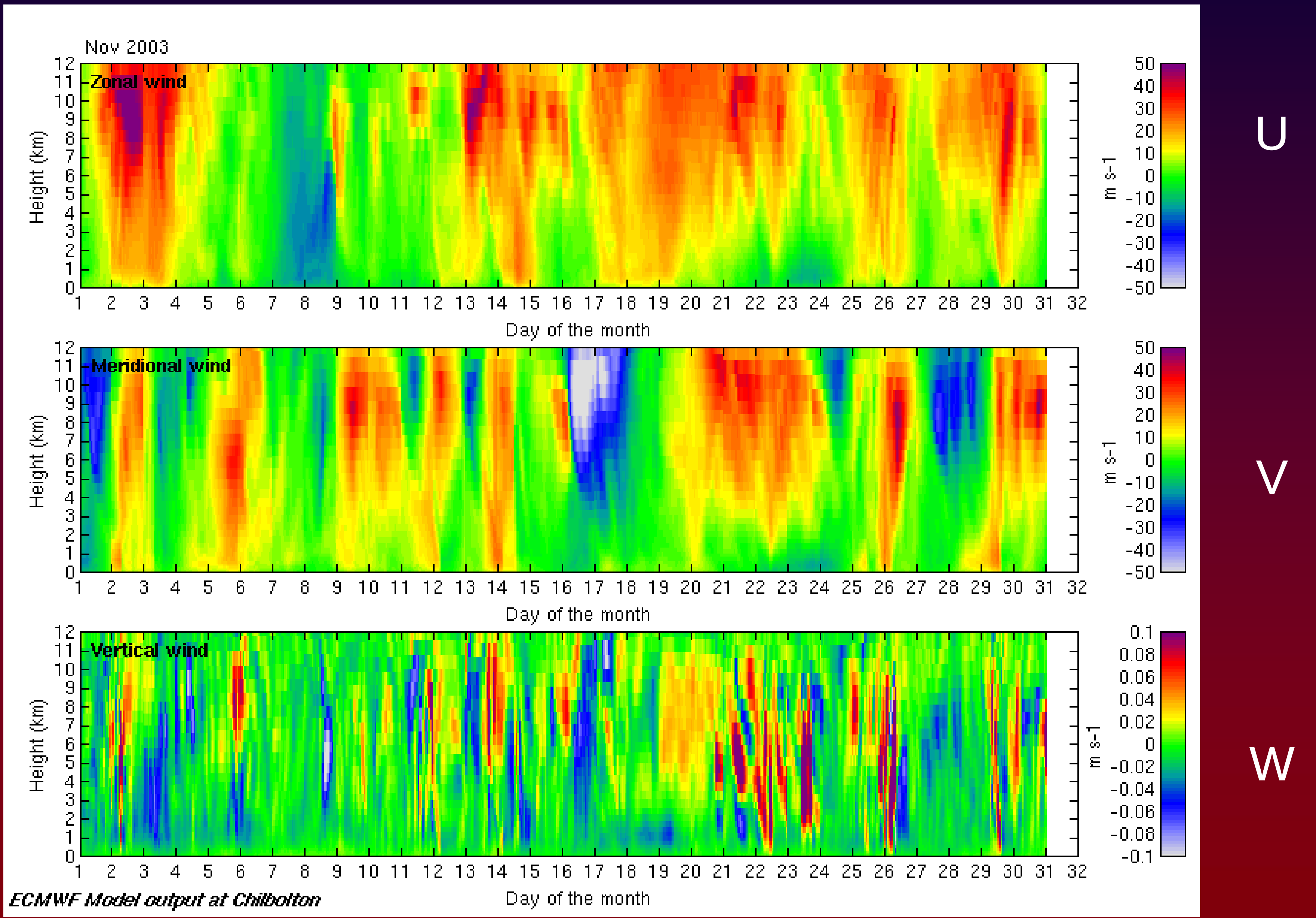


Turb K E Dissipation

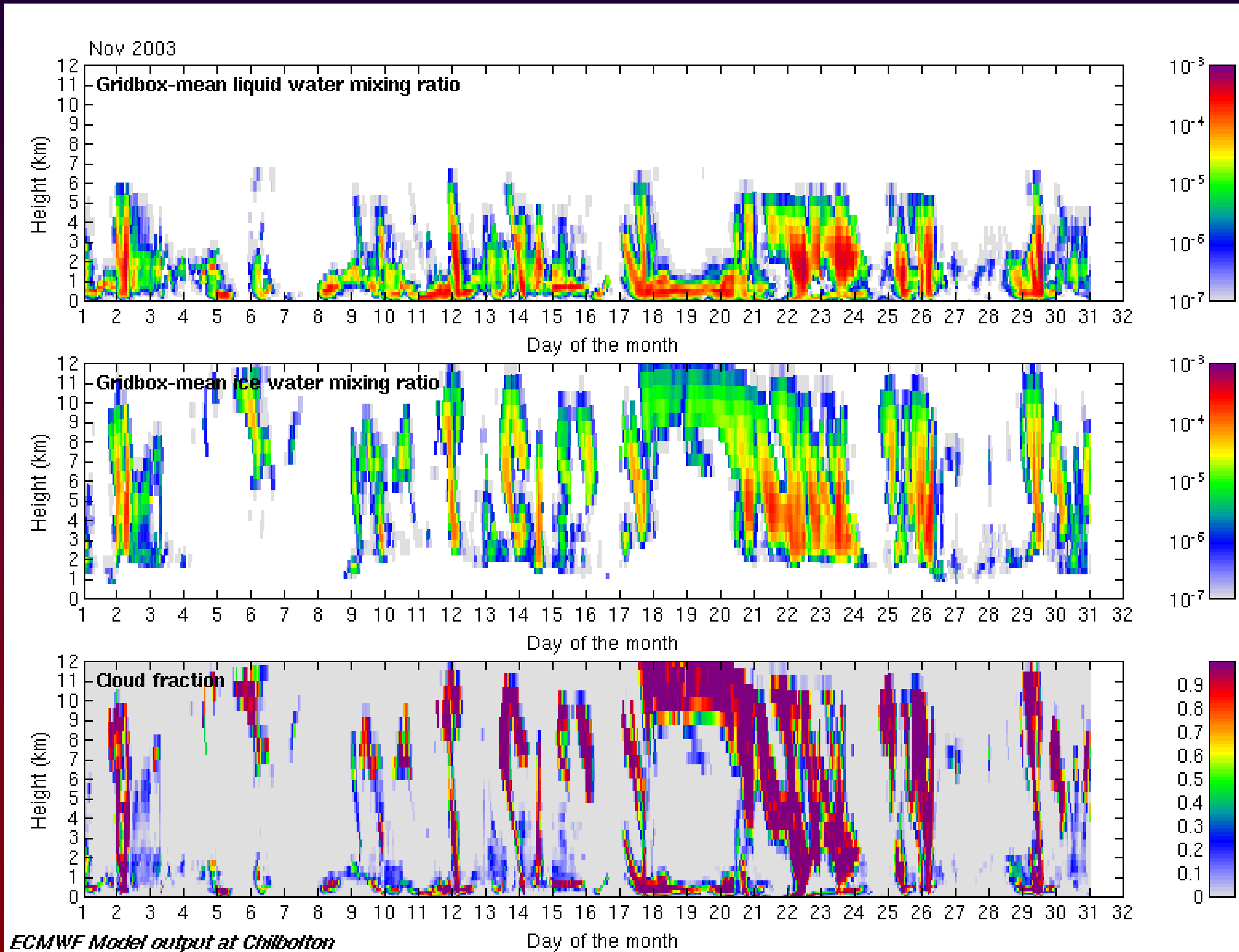
Nov 03 ECMWF Model



Nov 03 ECMWF model



Nov 03 ECMWF Model



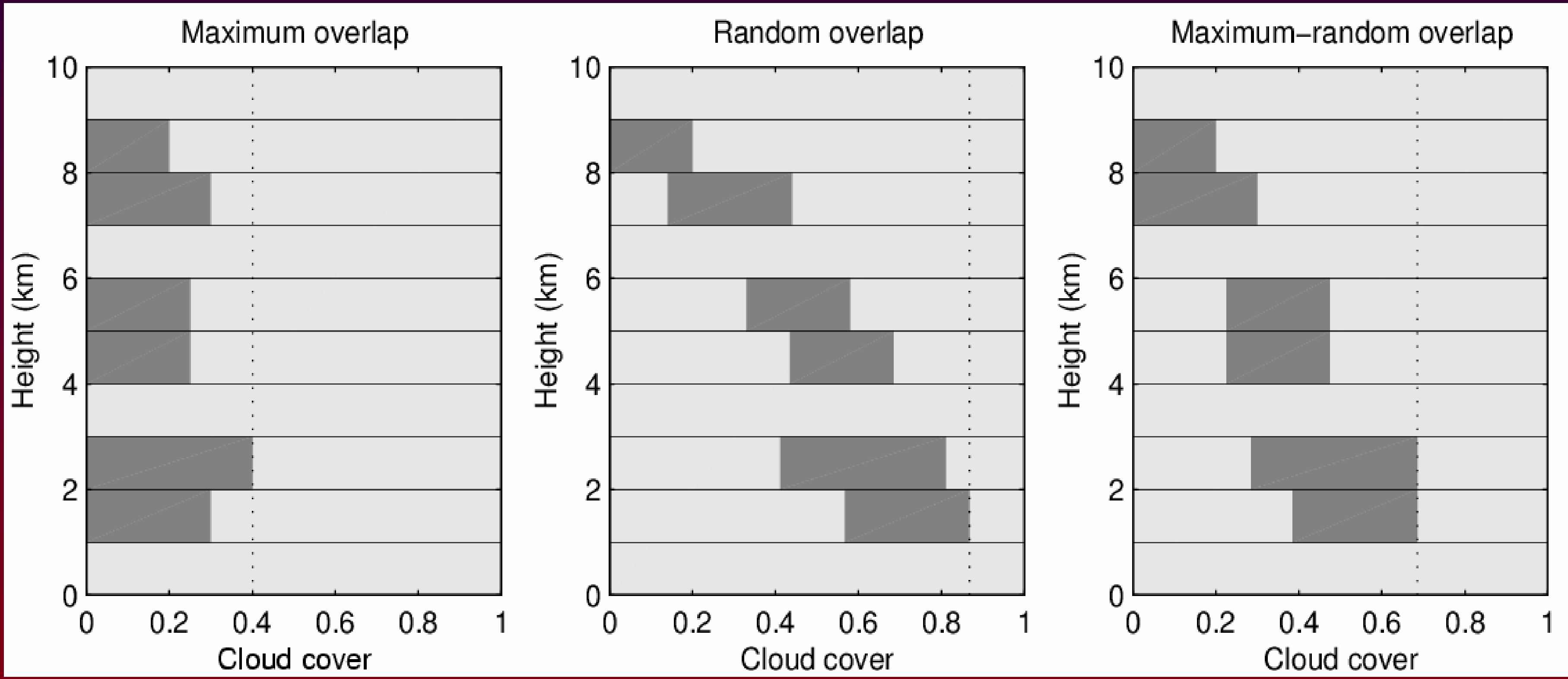
Lwc

Iwc

Cloud frac

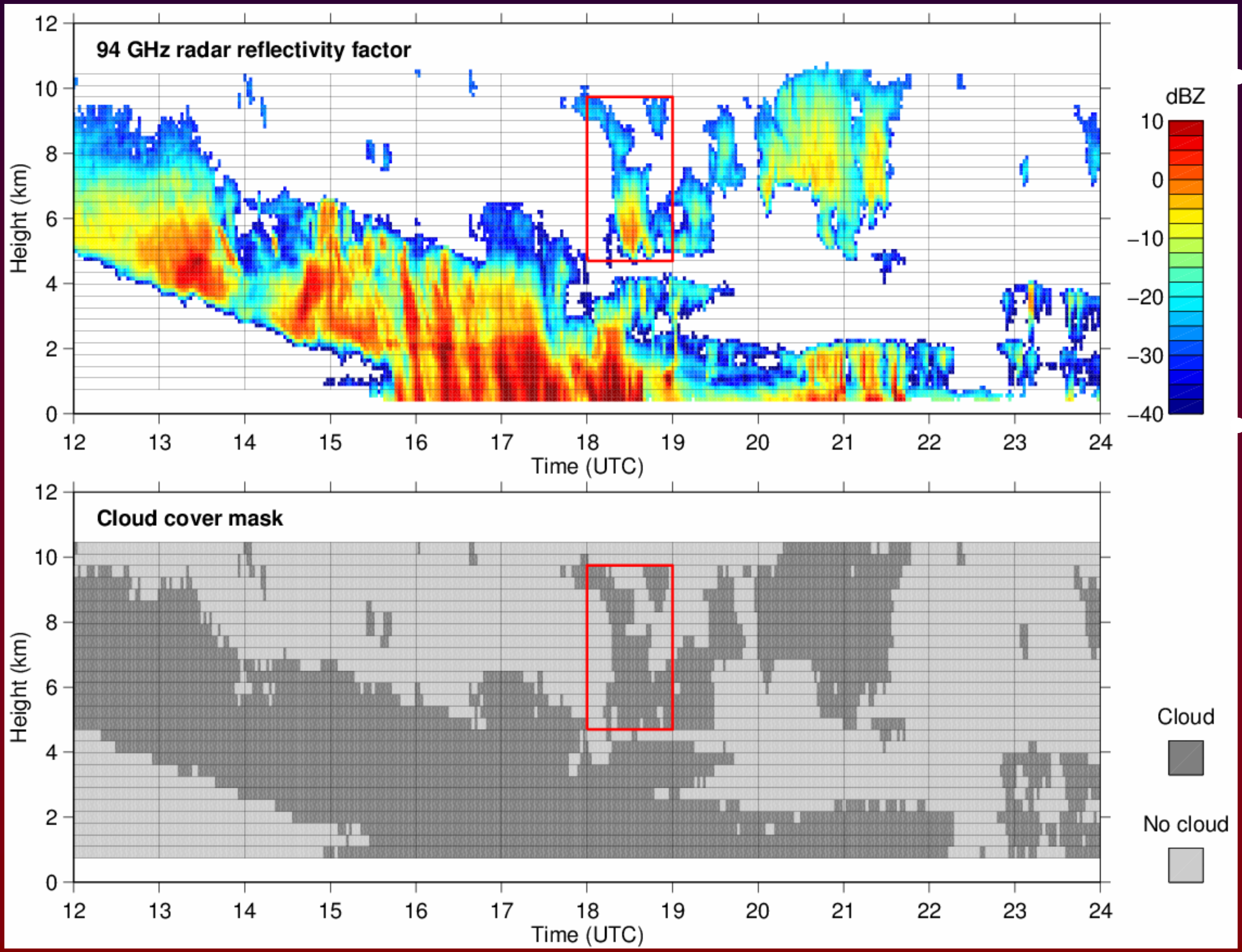
Cloud overlap assumption in models

- Cloud fraction and mean ice water content alone not sufficient to constrain the rad



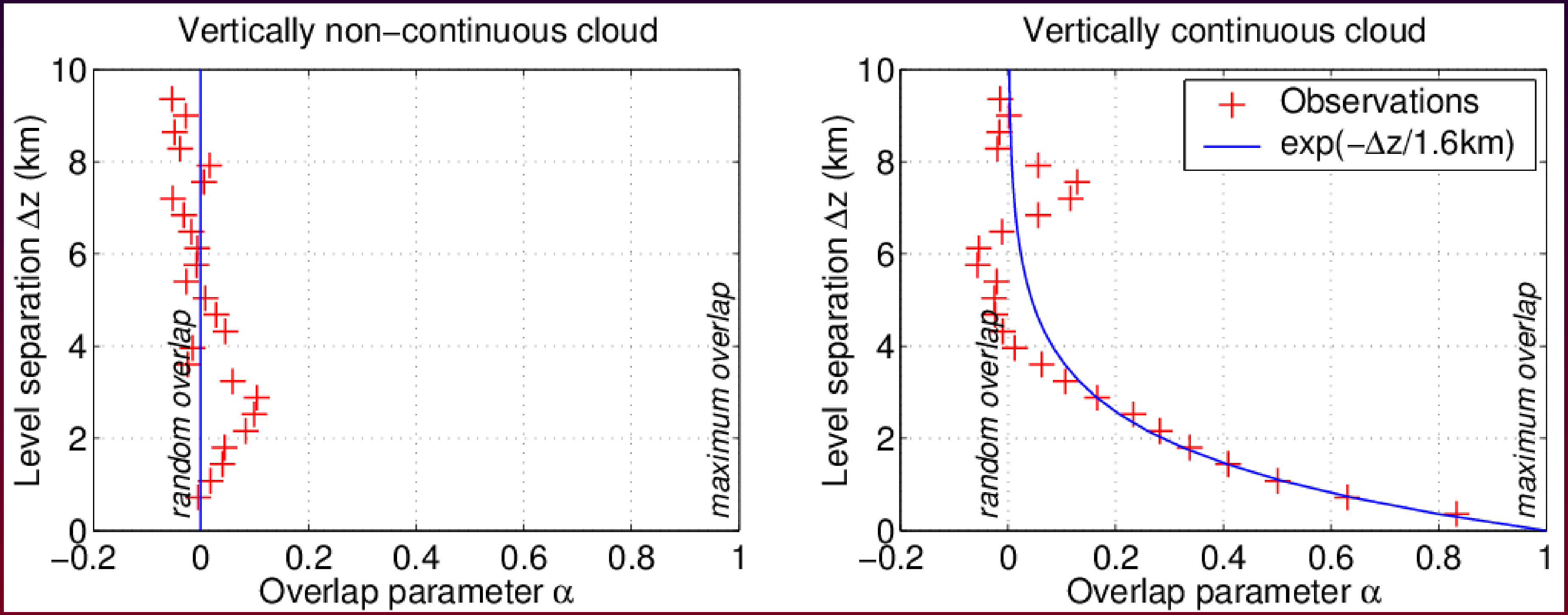
- Assumptions generate very different cloud covers
  - Most models now use “maximum-random” overlap, but there has been very little validation
  - of this assumption

Cloud overlap from radar: example



- Radar can observe the actual overlap of clouds
- We next quantify the overlap from 3 months of data

Cloud overlap: results



- Vertically isolated clouds are randomly overlapped
- *Overlap of vertically continuous clouds becomes rapidly more random with increasing thickness*

- **ANALYTICAL EXPRESSION FOR VERTICAL DECORRELATION** *Hogan and Illingworth (QJ 2000)*

5. Importance of ice-cloud inhomogeneity

- Non linear relation between optical depth and emissivity

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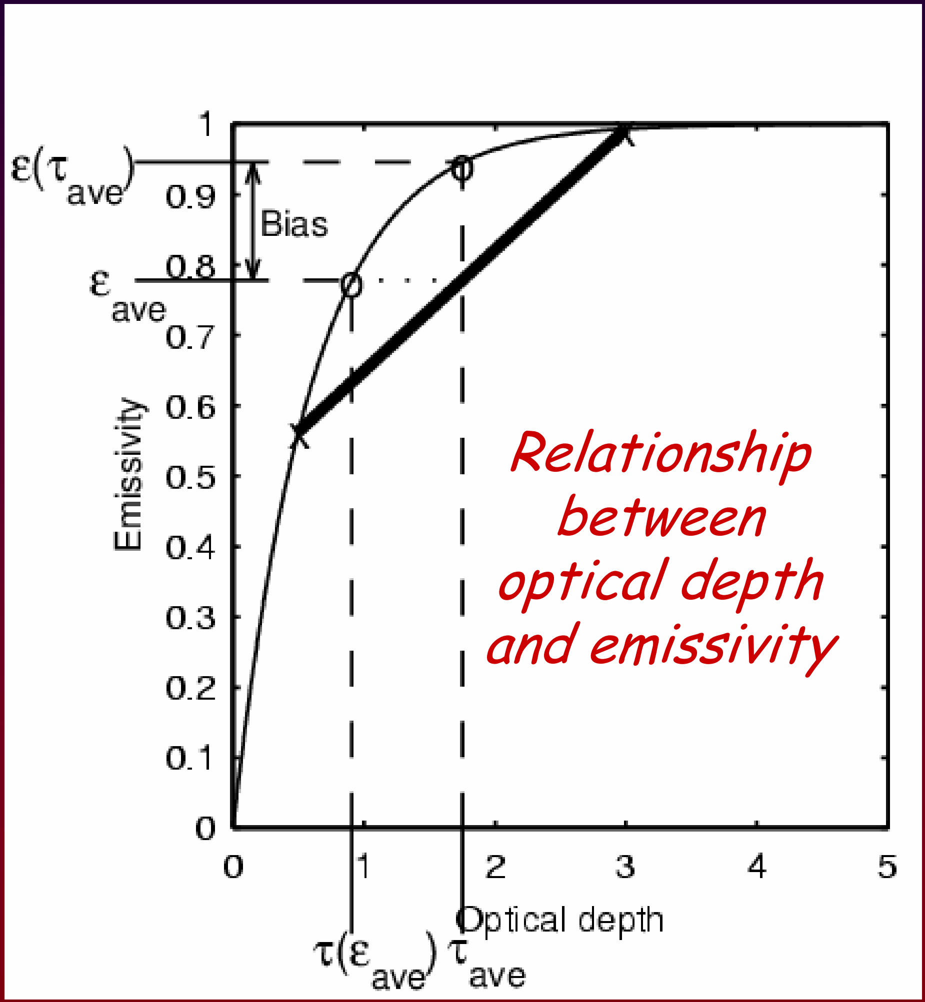
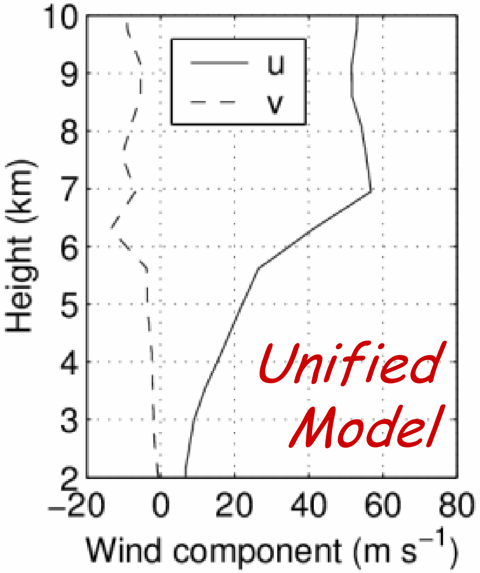
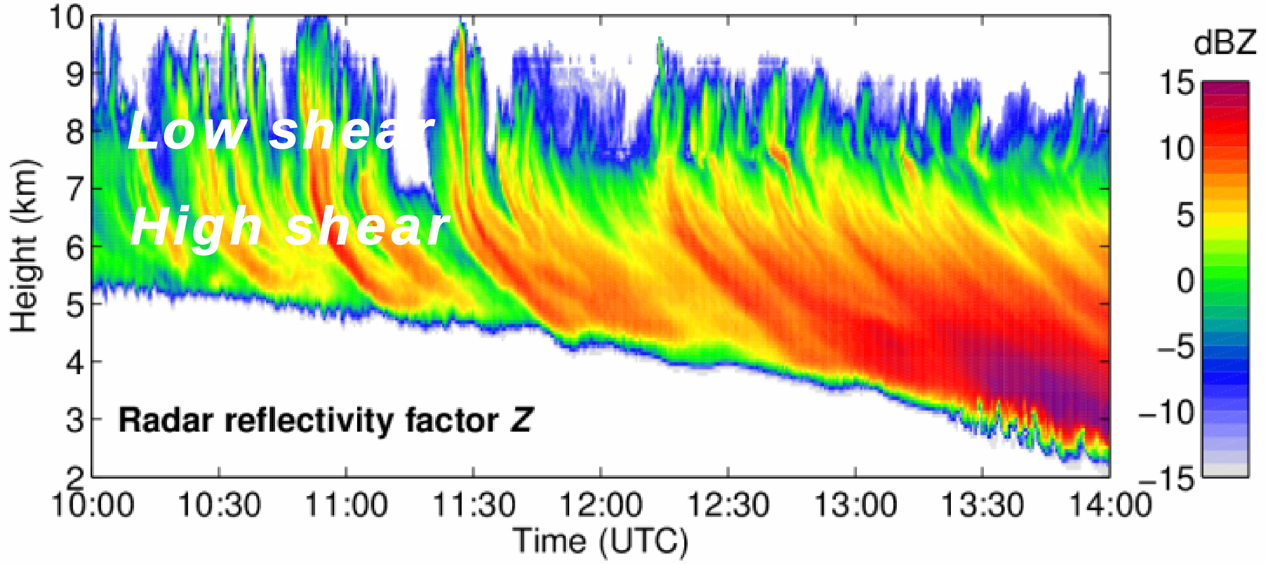
- For clouds which are inhomogeneous use of average optical depth gives wrong emissivity.

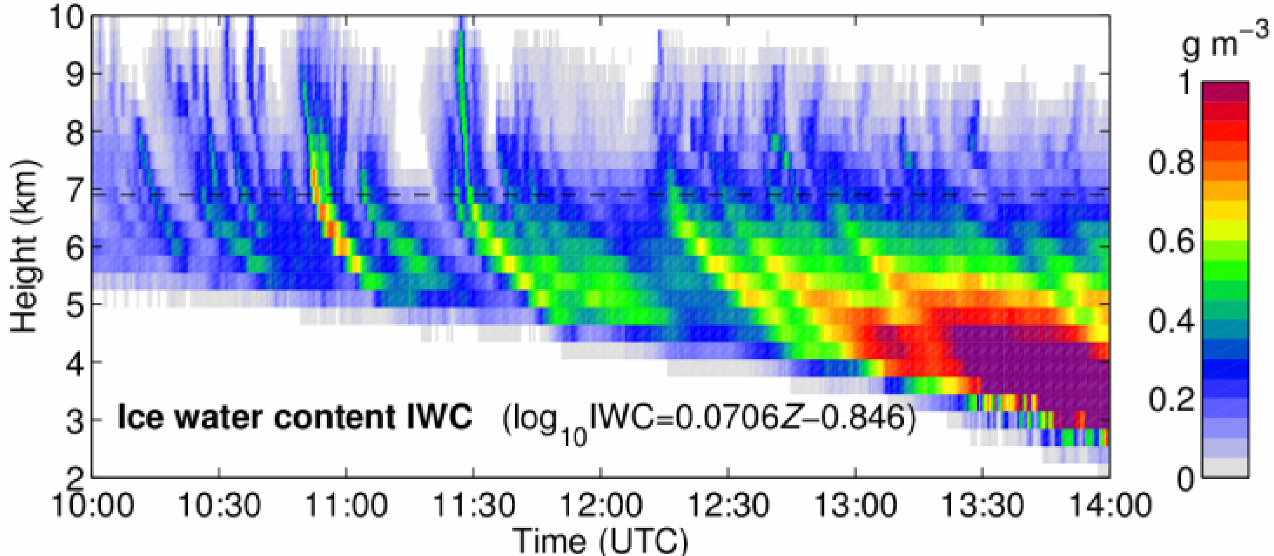


Pomroy and Illingworth (GRL 2000)

Cirrus fallstreaks and wind shear - inhomogeneities



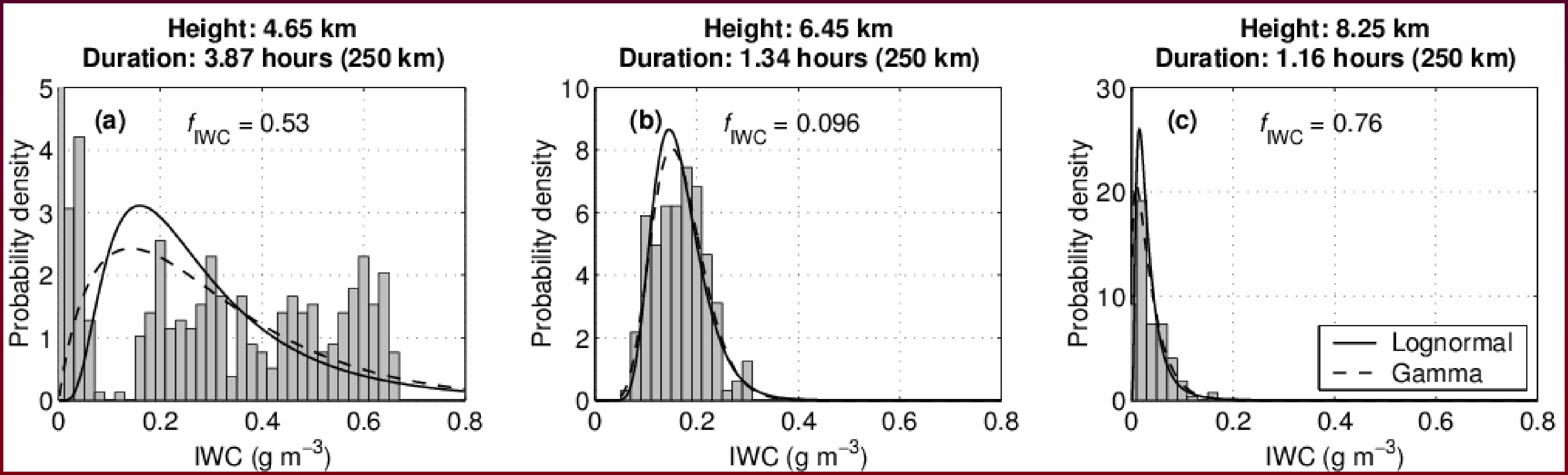




What this might look like...

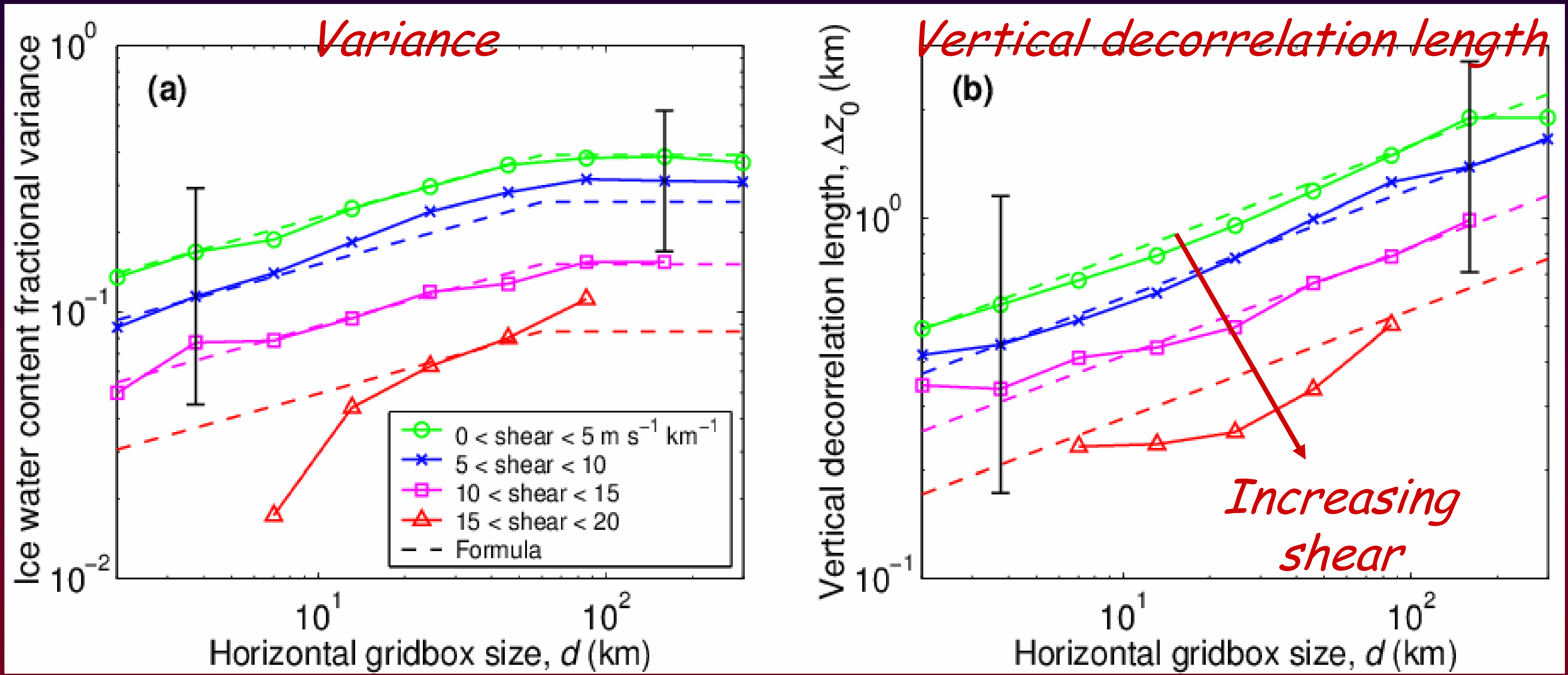
Ice water content distributions

- In the near future, models will carry variables for the variance of water content, as well as the mean
- Derive variance of ice water content of cirrus from radar



- PDFs of IWC within a model gridbox can usually be fitted by a lognormal or gamma distribution

Analytic expression for effect of shear on pdf of iwc and vertical decorrelation as a function fo grid box size.



- Variance and decorrelation increase with gridbox size
  - Shear makes overlap of inhomogeneities more random, thereby reducing the vertical decorrelation length
  - Shear increases mixing, reducing variance of ice water content

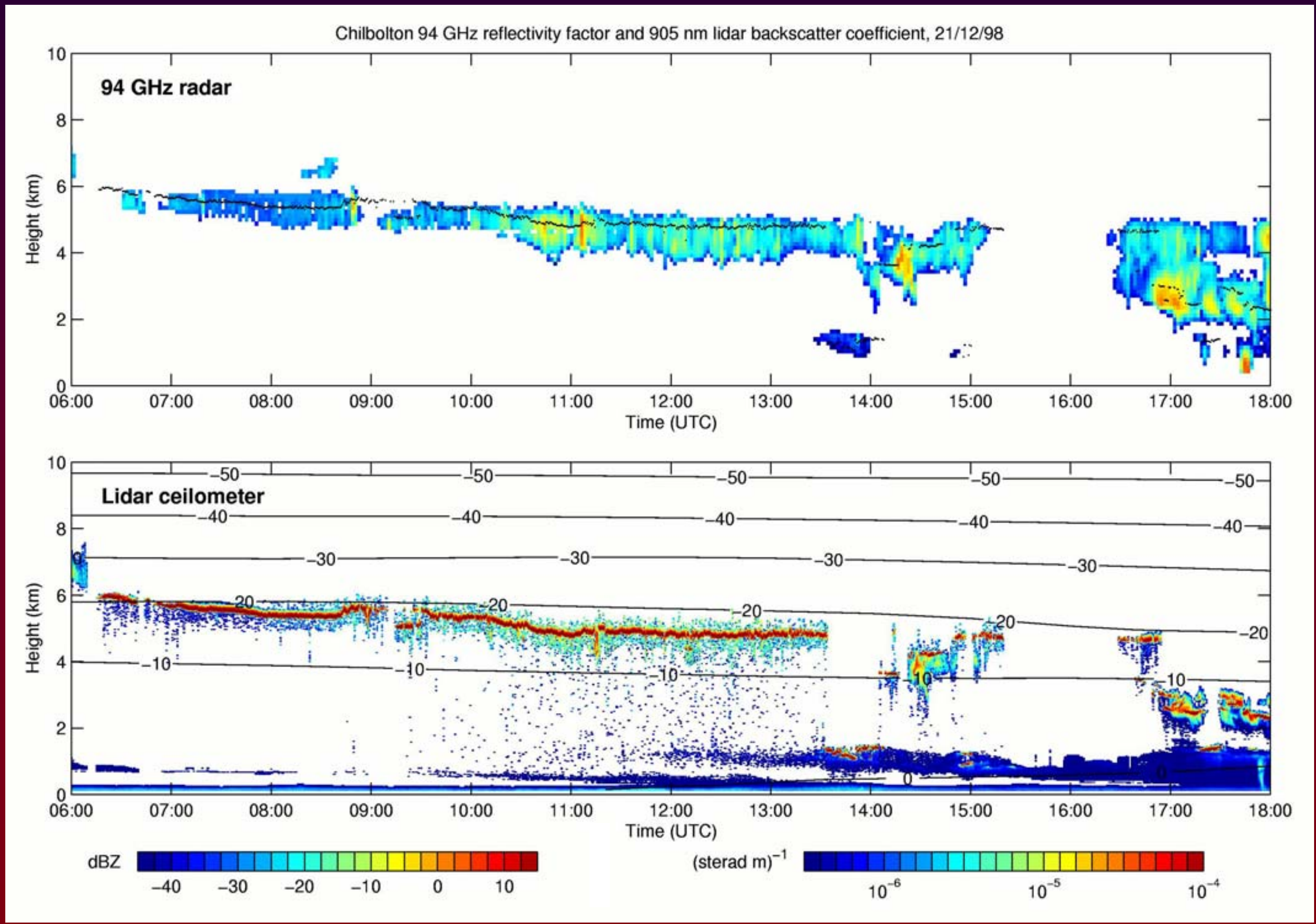
Hogan and Illingworth (JAS 2003)

Mixed-phase clouds – SUPERCOOLED LAYER CLOUDS

- SUPERCOOLED LAYER CLOUDS ARE COMMON
- SAME WATER CONTENT – BIG RADIATIVE EFFECT IF LIQUID DROPLETS – SMALL EFFECT IF ICE PARTICLES.

SUPERCOOLED CLOUD EXAMPLE

- Radar detects ice cloud (large D) at 5 to 6 km height
- Lidar detects highly reflecting layer at -20°C
- *in-situ* aircraft confirmed super-cooled droplets (100 Wm^{-2} impact)



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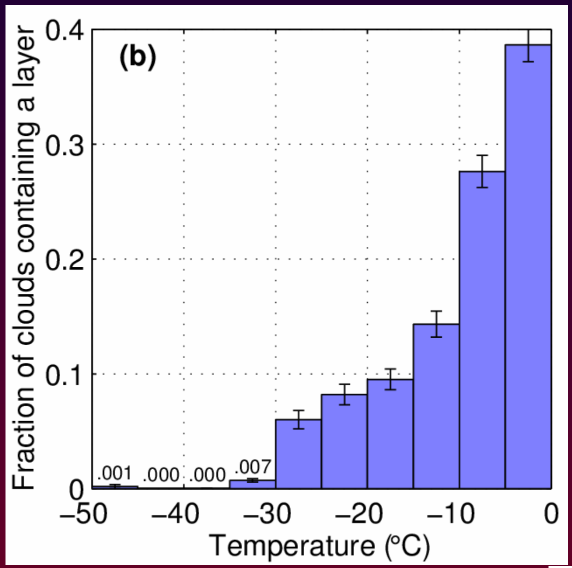
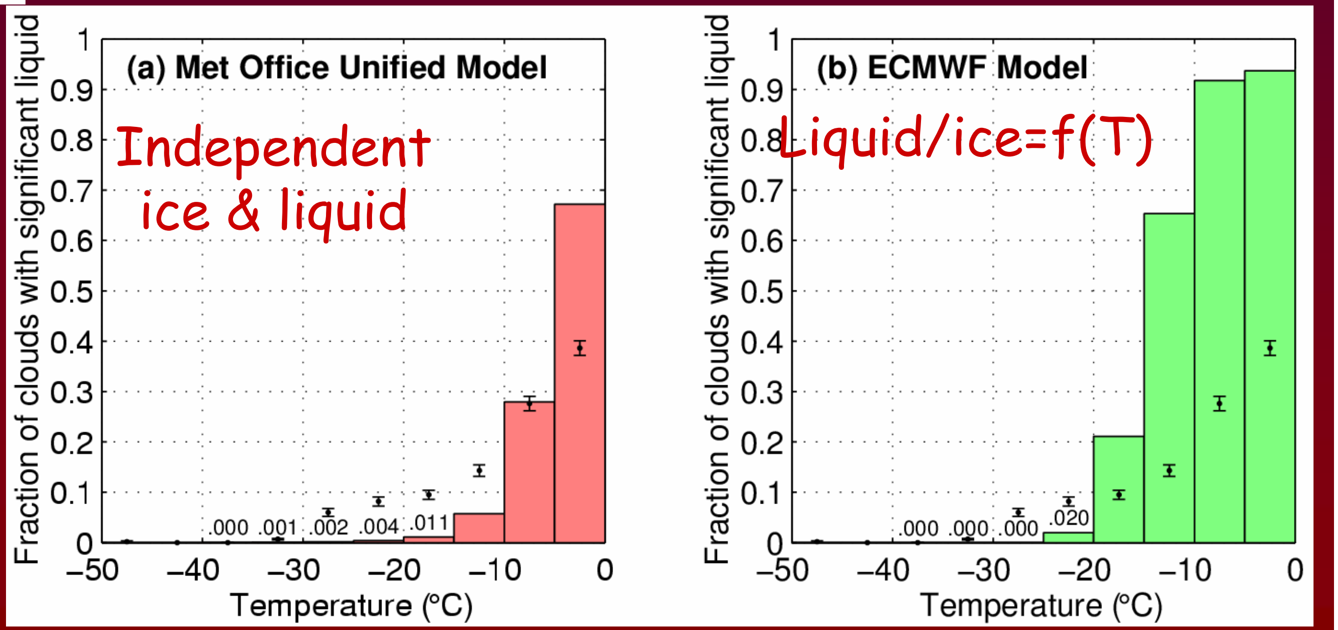
Supercooled water – model comparison



- Use ground-based lidar to estimate occurrence of supercooled water layers over a 1-year period
- Around 15% of mid-level ice clouds at Chilbolton contain liquid water with optical depth > 0.7

How does this compare with the representation in the Met Office and ECMWF models?



Hogan et al. (QJ 2003)

DUAL WAVELENGTH 35 AND 94GHZ RADAR

- LIQUID WATER CONTENT – THE 94GHZ RADAR IS ATTENUATED MORE THAN THE 35GHZ.

- ICE PARTICLE SIZE -

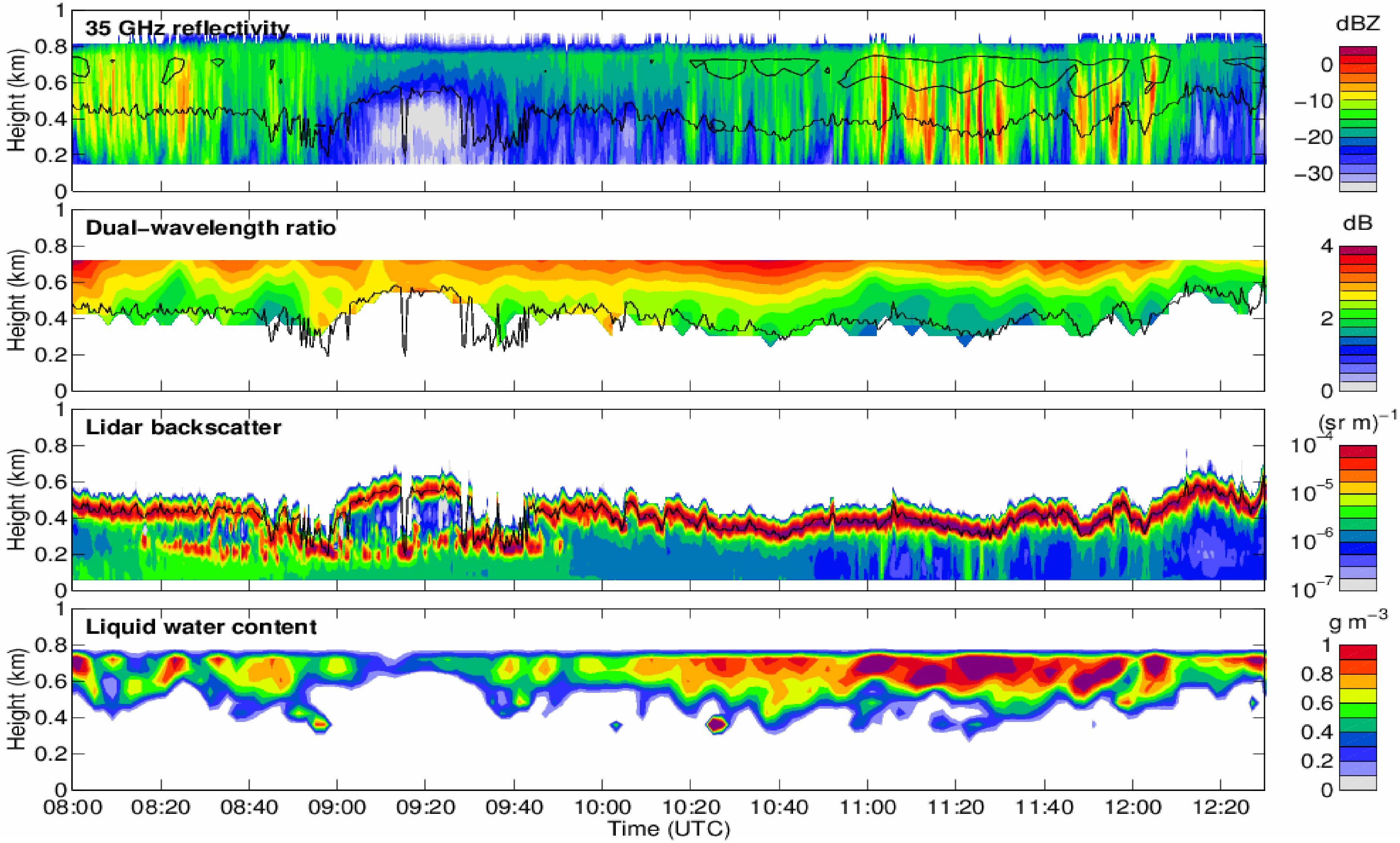
  Z AT 94GHz -MIE SCATTERING

  Z AT 35GHZ - RAYLEIGH SCATTERING

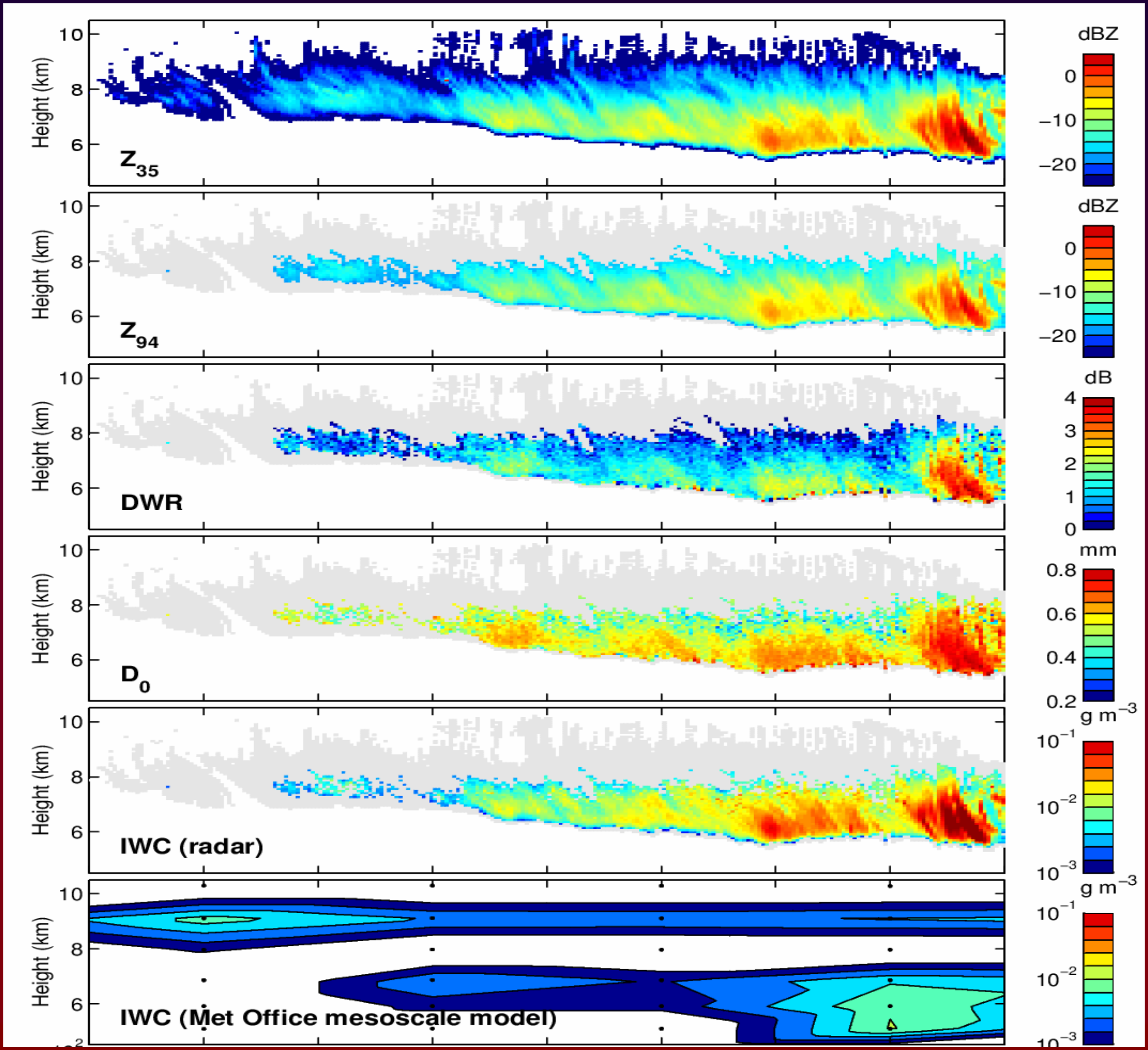
  RATIO OF Z GIVES PARTICLE SIZE.

ONCE SIZE IS KNOWN CAN FIND N FROM Z,
AND SO MORE ACCURATE IWC.

LIQUID WATER CONTENT PROFILE – FROM DIFFERENTIAL ATTENUATION OF Z AT 35 AND 94GHZ



ICE PARTICLE SIZE FROM 35 AND 94GHZ



Z -35GHz

Z–94GHz

DELTA Z

Do

Better

IWC

Model

IWC

25m dish: Scan on interesting days.

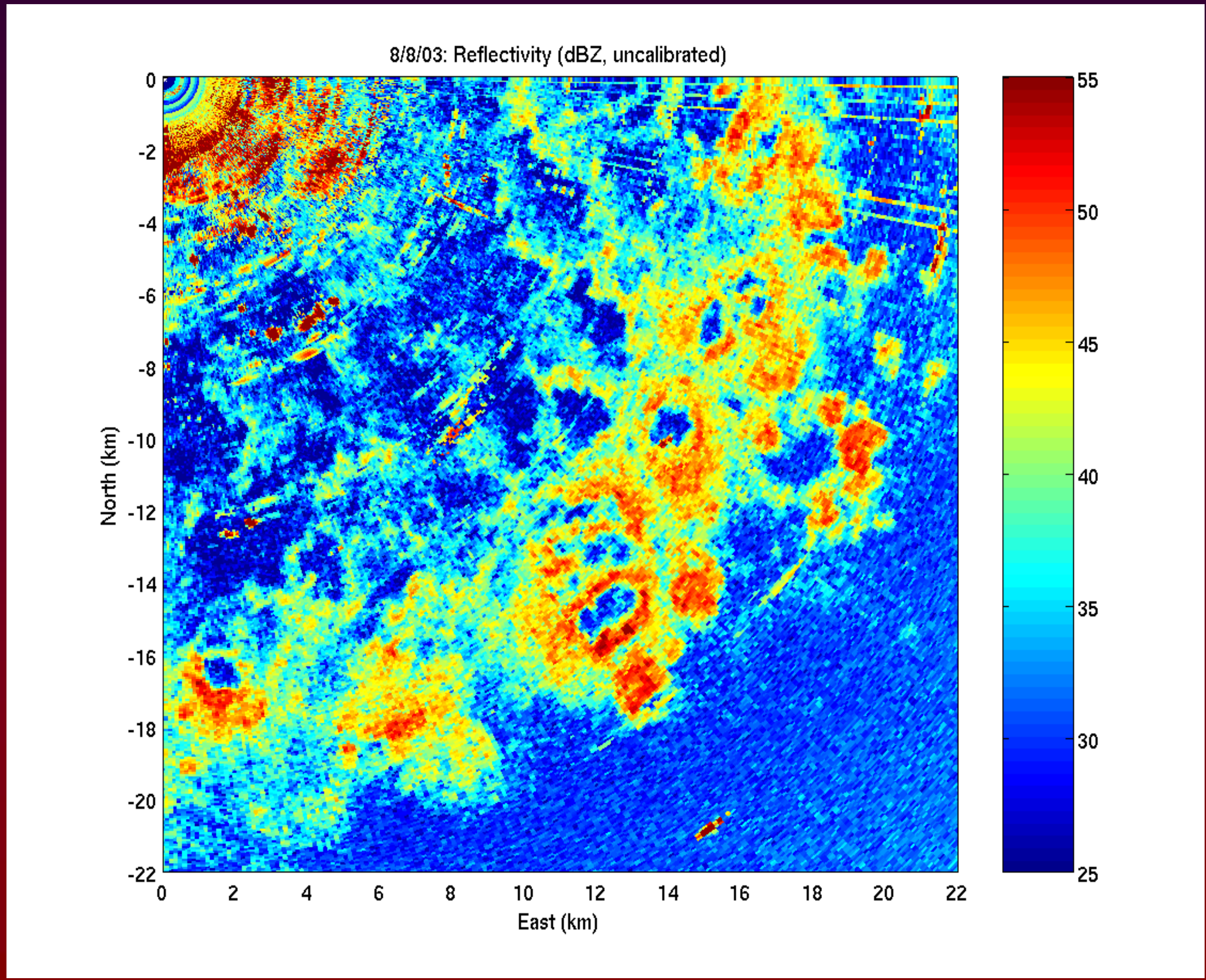
1275MHz clear air
Refractivity

3Ghz – polarisation
Precipitation radar.

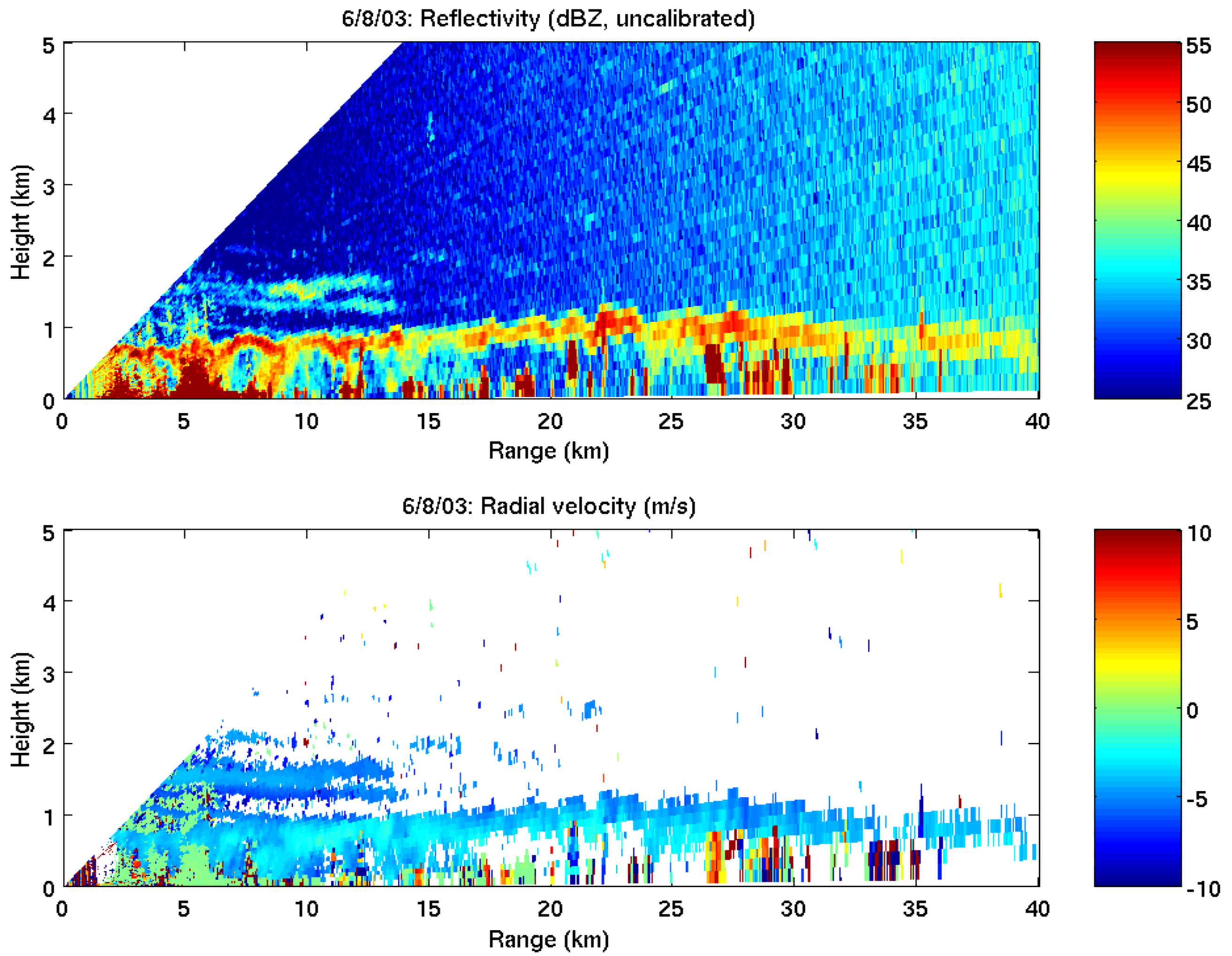
1275MHz Clear air 'acrobat' radar.

- Return is from changes in refractive index – turbulence on the scale of $\lambda/2$ or 11.7cm.
- Changes in the summer dominated by humidity.
- Beamwidth 0.75degs – 660m at 50km range

CONVECTIVE 'DONUTS'



RHI–6 AUG-03 TOP OF THE BOUNDARY LAYER



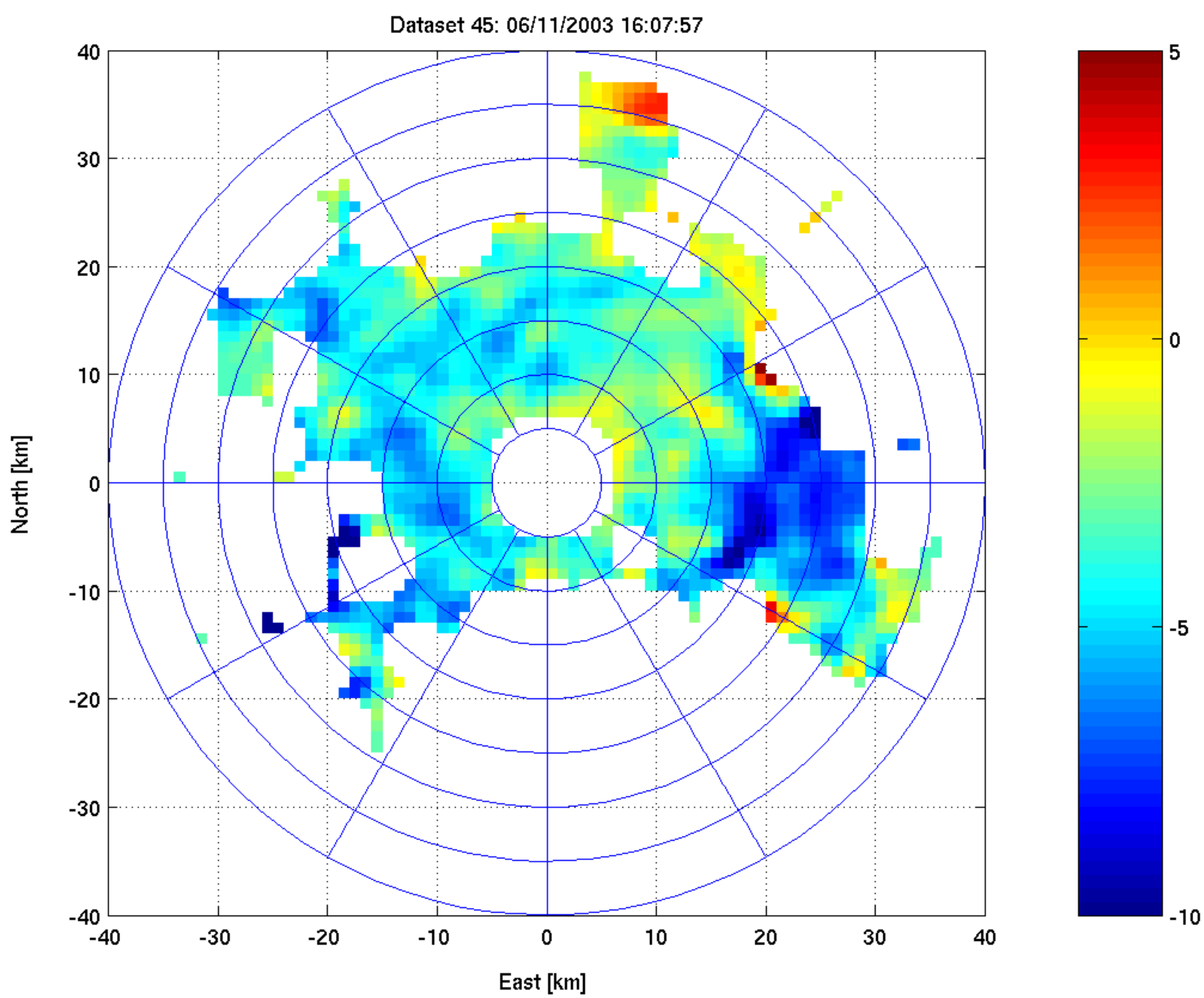
REFRACTIVITY in the boundary layer.

- Ground clutter targets

- Round trip time changes with refractive index.
- Detect as phase change in return.

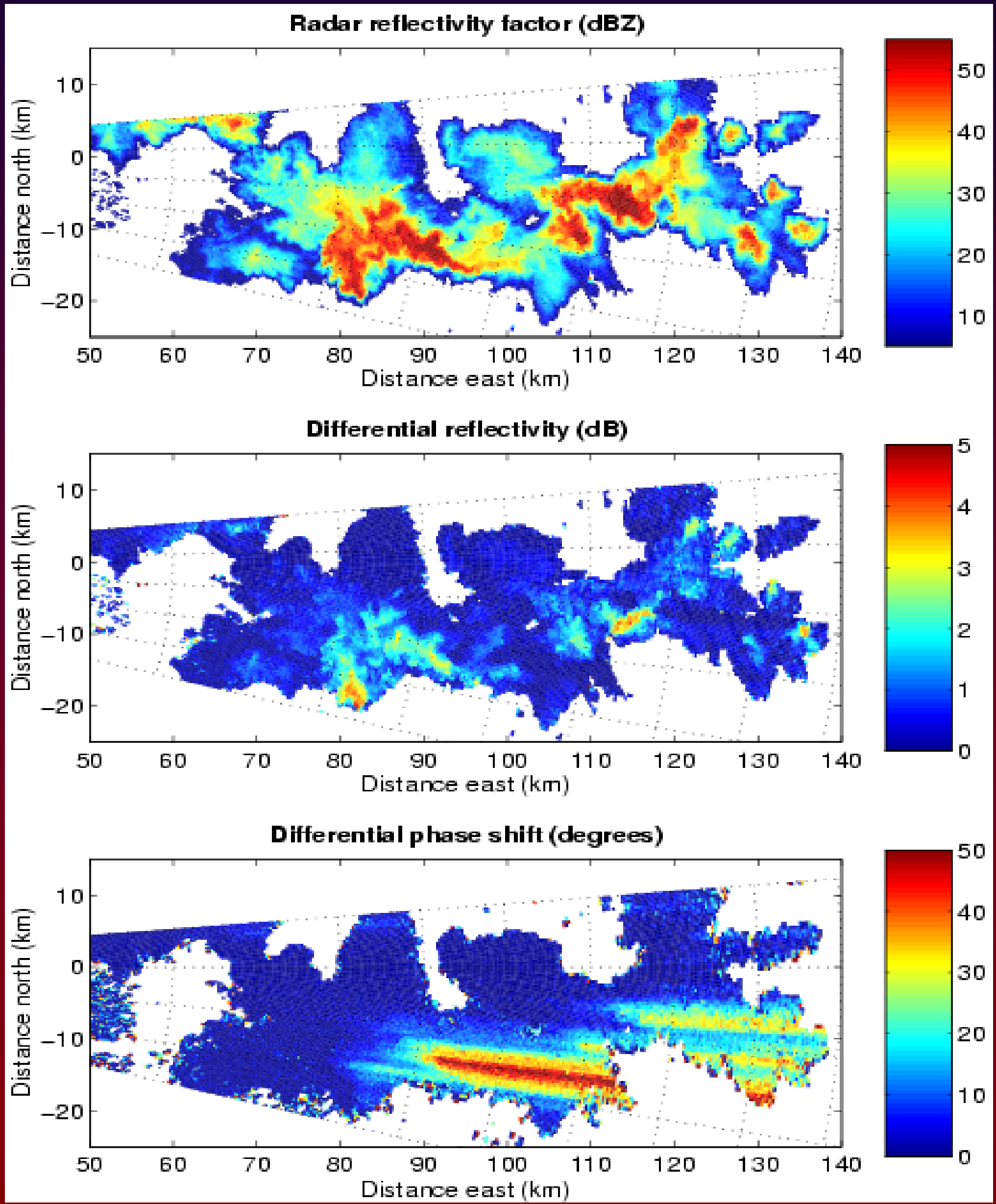
- Refractivity, N, 1ppm change in refractive index.
- $\Delta N = 1$ gives $\Delta\phi = 3$ deg/km (round trip).
- $\Delta N = 1$: $\approx 1\%$ change in RH (summer) or 1K
- Technique developed by Fred Fabrey

Refractivity change over four hours in Nov 03.



10% fall in RH

3GHz/10cm BETTER RAINRATES - ZDR AND KDP IN RAIN



Z >40dBZ
In heavy rain

Big drops
are oblate:
ZDR>2dB
In heavy rain

Extra horiz
phase delay
40degs thru
heavy rain

Cloud products on the web

http://www.met.reading.ac.uk/radar/cloudnet/quicklooks/

Interested in data/collaboration?

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