THE PROSPECTS FOR RADARS ON SATELLITES TO PROVIDE BETTER OBSERVATIONS OF WARM CONVEYOR BELTS

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ECMWF Workshop on Warm Conveyor Belts.

10-12 March 2020

1. **CloudSat 94GHz nadir pointing radar launched 2006. 1km swath.**

2. **EarthCARE – 94GHz nadir pointing Doppler radar (1km swath), High Spectral Resolution Lidar, multi-spectral imager and broad band radiometer to be launched 2022,**

   Exploit the synergy of the four instruments

3. **WIVERN – 'WInd Velocity Radar Nephoscope' a conically scanning 94Ghz radar with an 800km wide ground track to provide global in- cloud winds to be proposed in response to ESA's EE11 call this year**

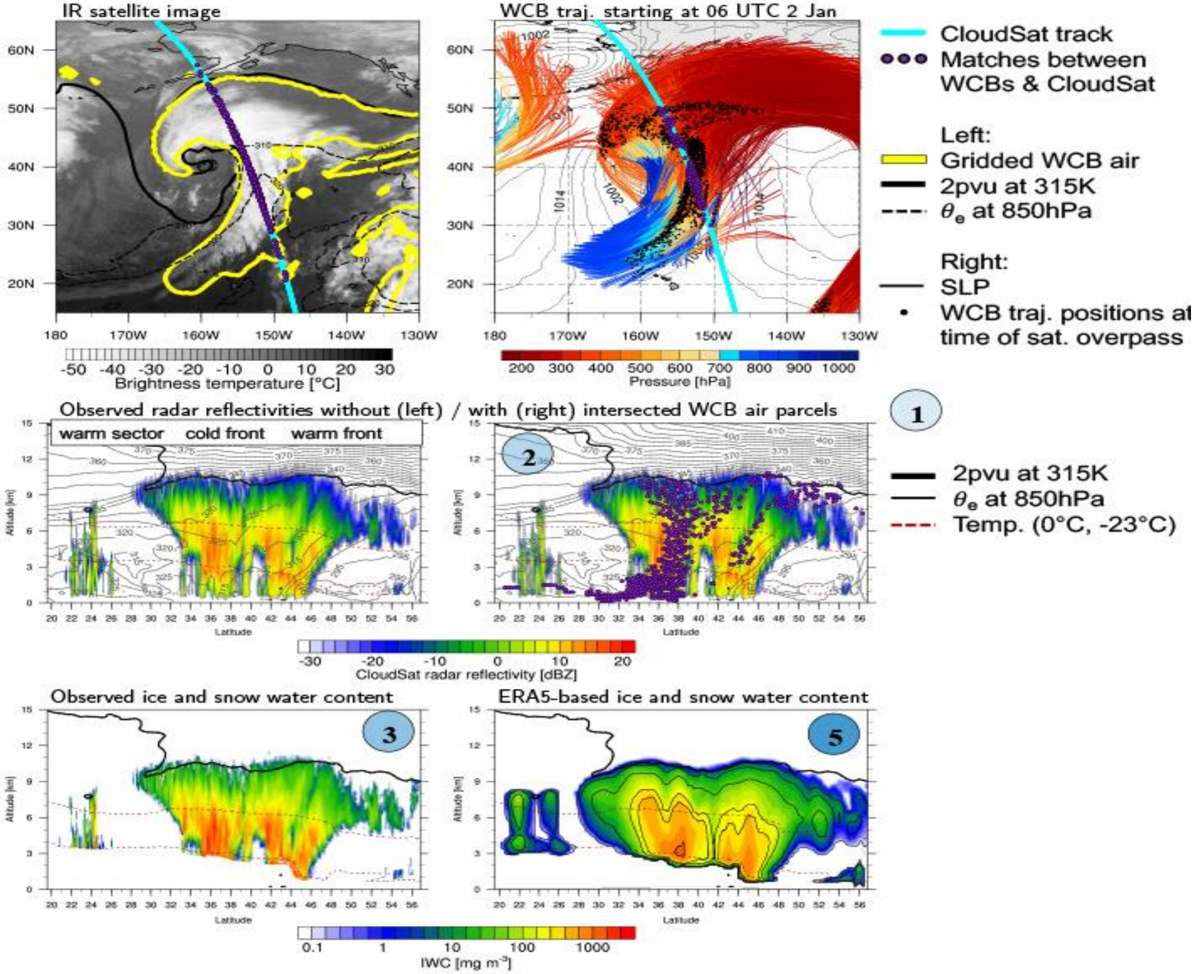
CLOUDSAT – Nadir pointing:
swath 1km wide
1.1km along track resolution
500m vertical resolution

Observe radar reflectivity $Z = \sum N D^6$
In tandem with Calipso lidar
(attenuated by thick cloud)
Backscatter $B = \sum N D^2$
Ratio of Z to B provides size information

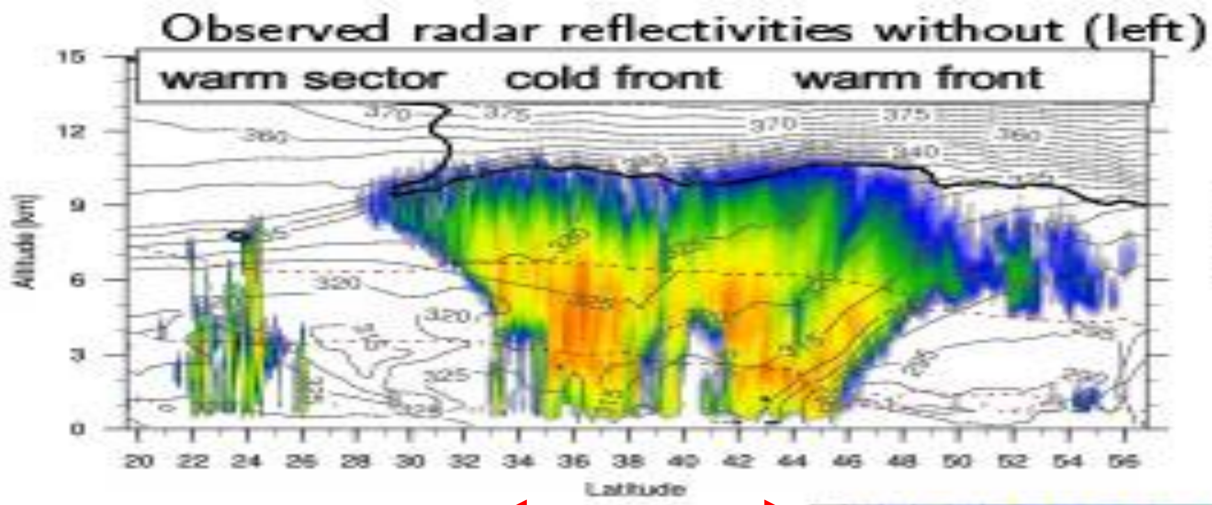
“DARDAR” (Delanoe and Hogan)
retrieval yields ice water content.

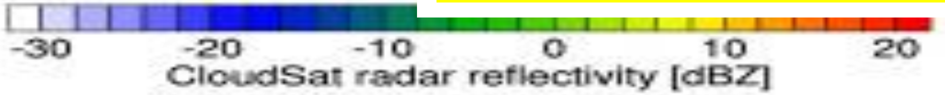
POSTER #1 by Binder et al. found
236,000 CloudSat WCB overpasses
and analysed the 5% with highest Z

Overpass of an explosive cyclone at the time of strongest intensity at 00 UTC 14 Jan 2014



- Warm sector: Shallow-to-midlevel convection above the WCB inflow.
- Cold and warm front: Strongly ascending WCB air masses form part of deep clouds, but not the entire cloud system is WCB air.
- Below 6-8km: high reflectivities and IWC values indicate heavy precipitation in the form of snow (rain) above (below) the 0°C isotherm. Above 6-8 km: ice clouds in the WCB outflow.
- The IFS operational analyses capture the broad structure and distribution of snow and ice associated with the WCB clouds.





> 1000 km

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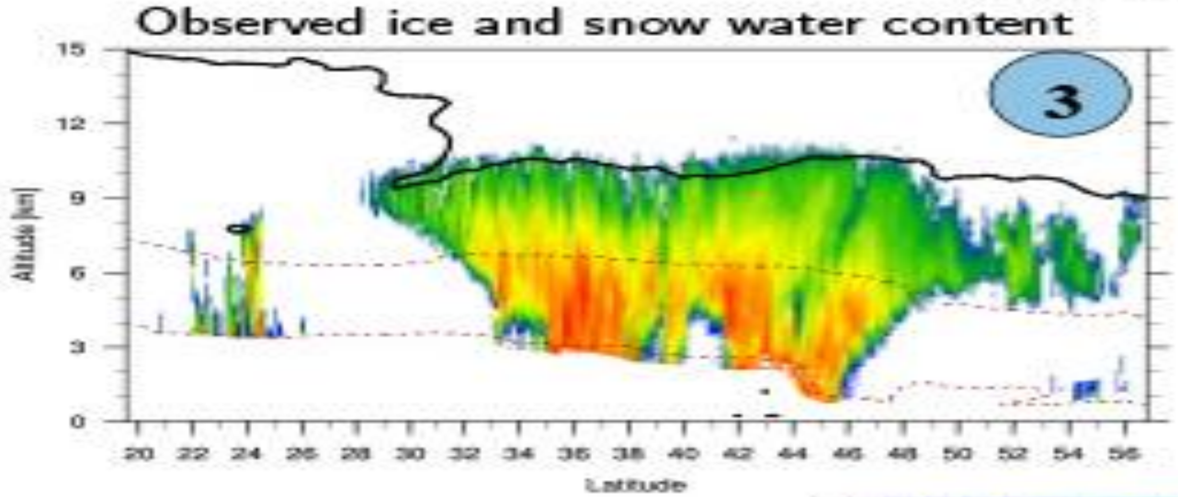
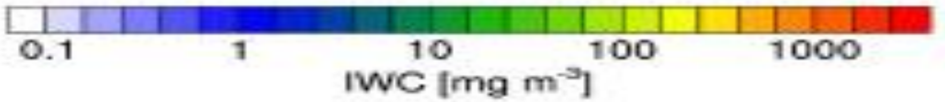


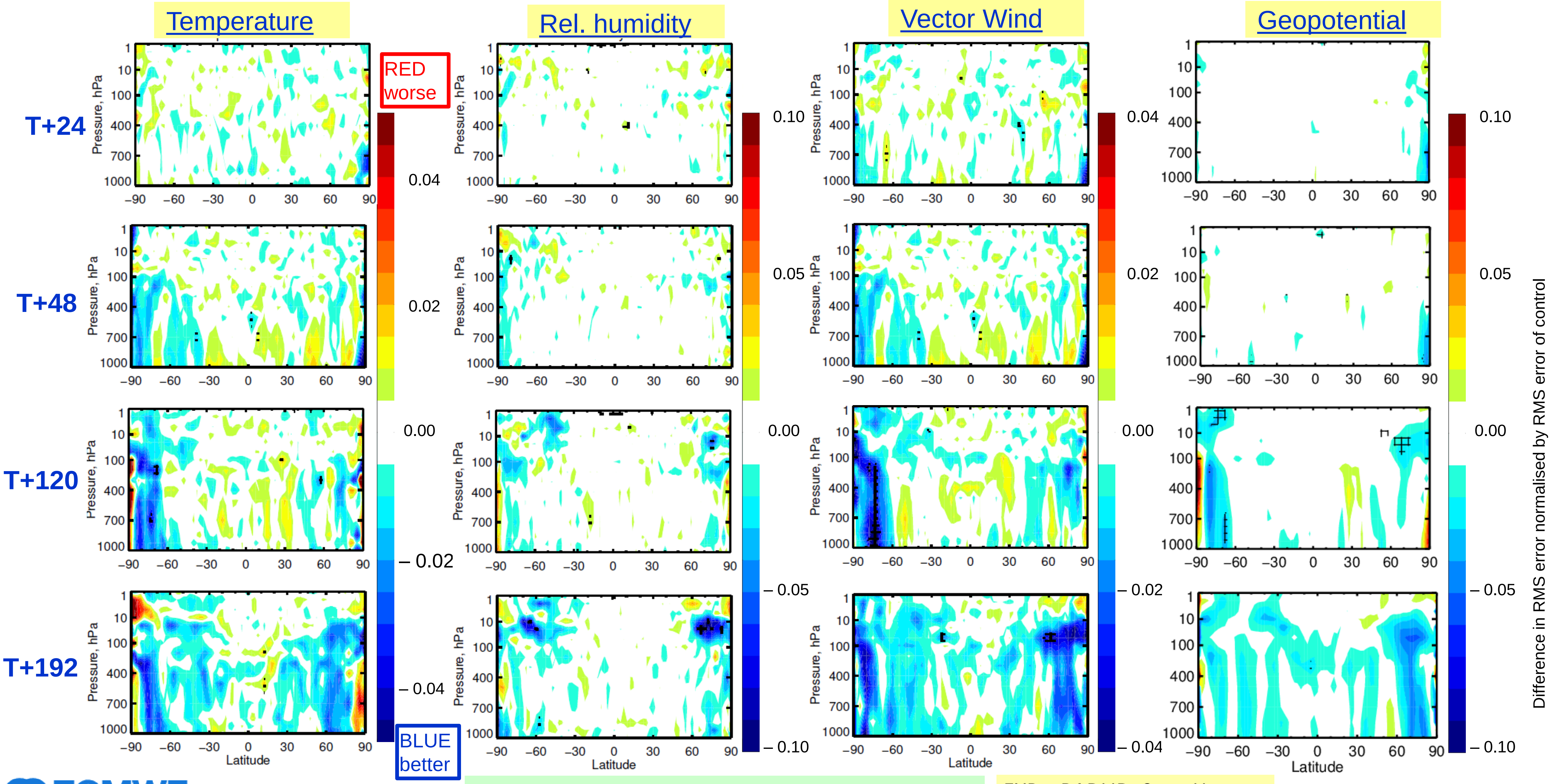


Annika Oertel – yesterday ~1g/kg   orange   - stratiform

~4 g/kg   red   - convective

CAN THESE 1km resolution values of Z be used to identify areas of embedded convection?

Assimilation of CloudSat (Z) and Calipso (B) : reduction in forecast error, Z has most effect. (from Janiskova and Fielding, ECMWF)



3-month period: 1 August – 31 October 2007

EXP = RADLID_2err_Ha

ECMWF

EarthCARE synergy

Robin Hogan[*+], Alessio Bozzo[+] and Shannon Mason[*]*
** ECMWF, + Univ of Reading, UK*

- The strength of EarthCARE will be the synergy of observations, but can we fully exploit this information to make the best retrievals?
- The "CAPTIVATE" algorithm will be used to produce the "ACM-CAP" product: retrieve cloud, precipitation and aerosol properties simultaneously using the Doppler radar and HSRL lidar, plus important integral constraints from solar and infrared radiometers and radar path integrated attenuation PIA (inferred from sea surface return)
- The EarthCARE level-2 team has prepared a set of simulated EarthCARE scenes derived from the Canadian "GEM" model with 250-m resolution, incorporating all possible sources of instrument noise
- Can we retrieve the "truth"?

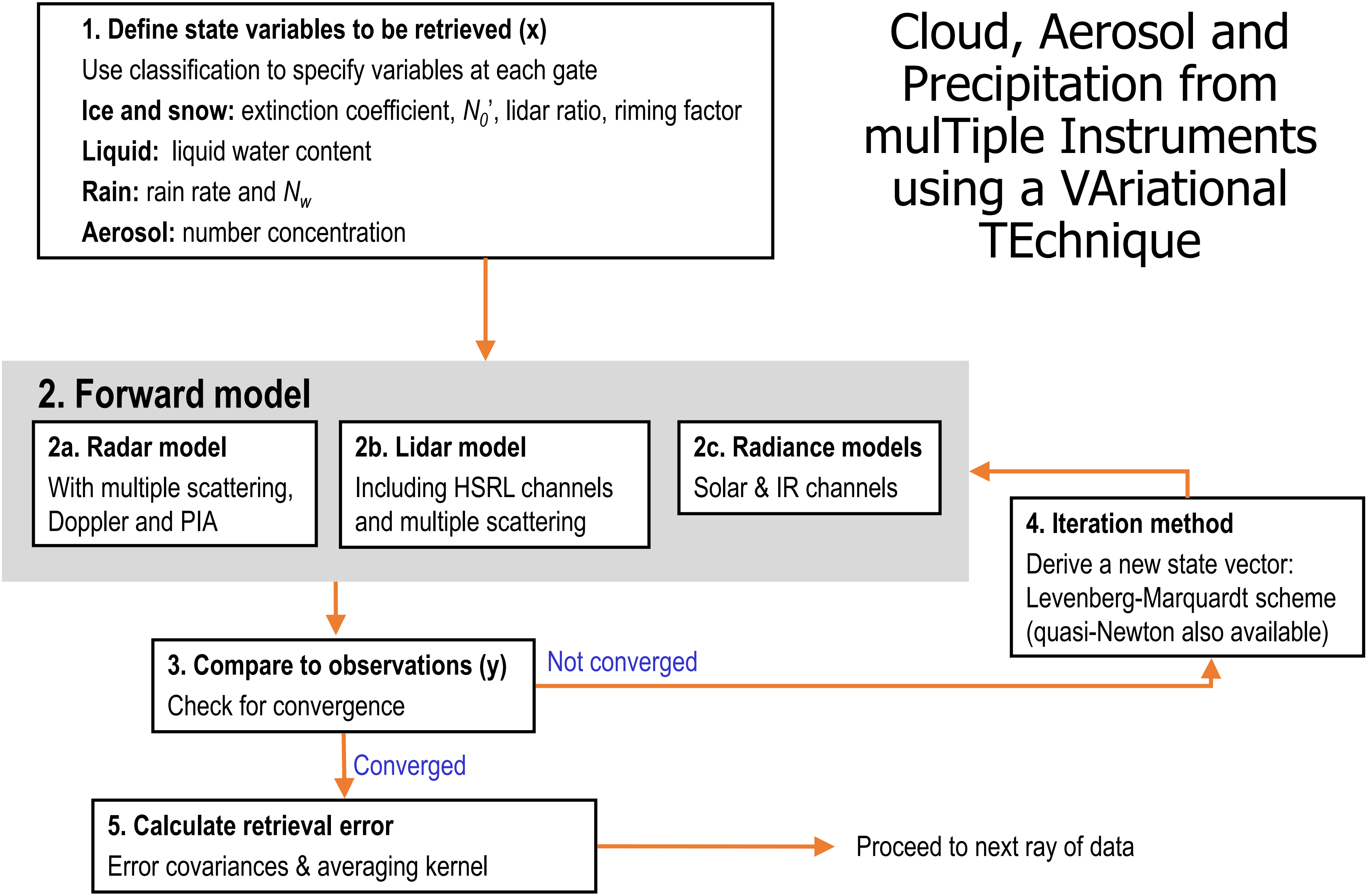
EarthCARE

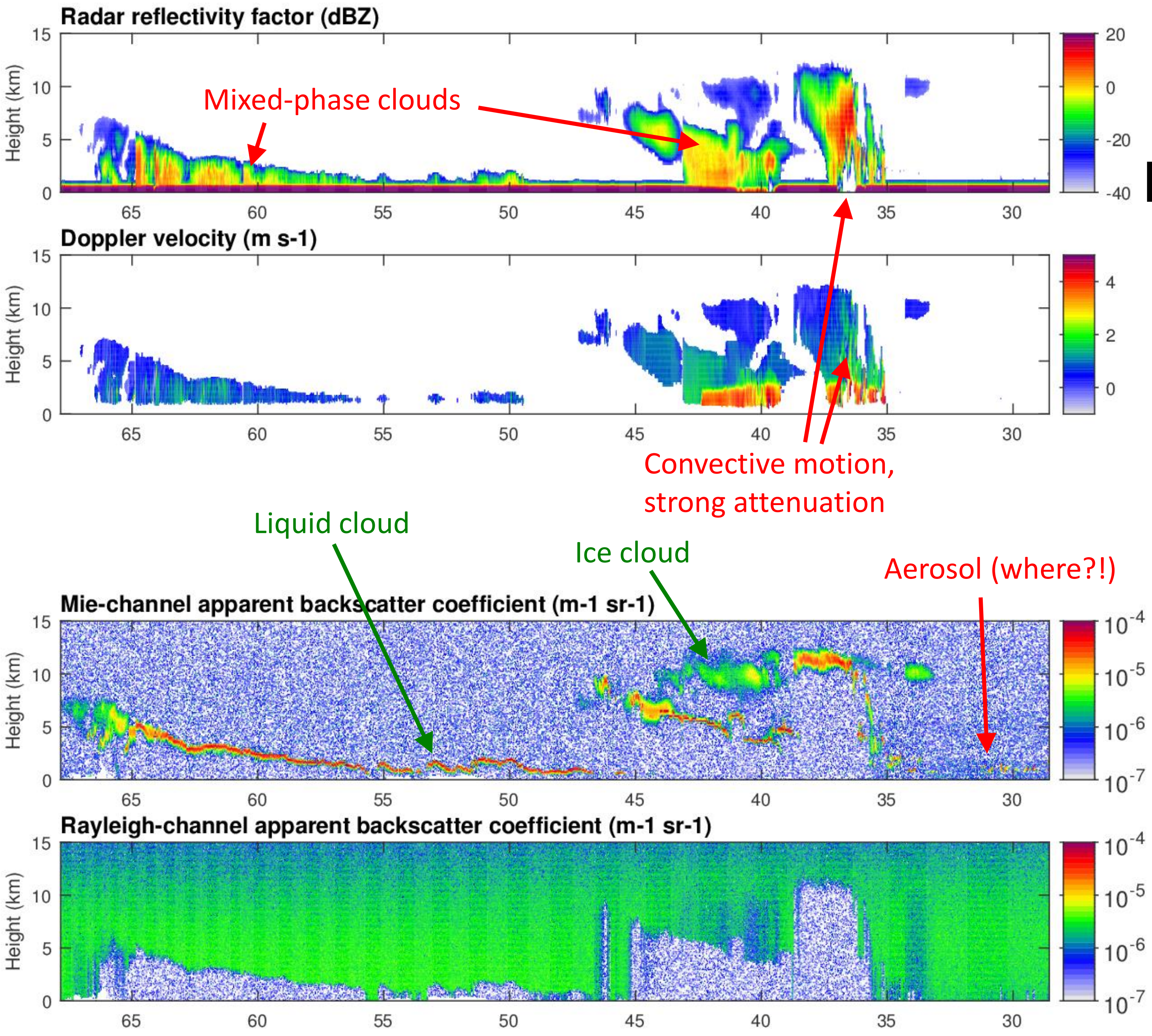
- RADAR: +7dB cf CloudSat: Doppler ± 0.5m/s? (5km integration)
- HSRL Lidar – extinction (α) from the molecular return; can derive lidar ratio, $S = \alpha/\beta$

- Challenges
- Ice particles and liquid water are uncertain below mixed phase cloud layers – lidar can't penetrate liquid clouds with $\tau >\sim 3\text{-}5$.
- These mixed phase clouds are ubiquitous in the extra-tropics and in convective clouds
- Ground based studies show that ~ 40% of ice mass is rimed.

CAPTIVATE:

Cloud, Aerosol and Precipitation from mulTiple Instruments using a VAriational TEchnique

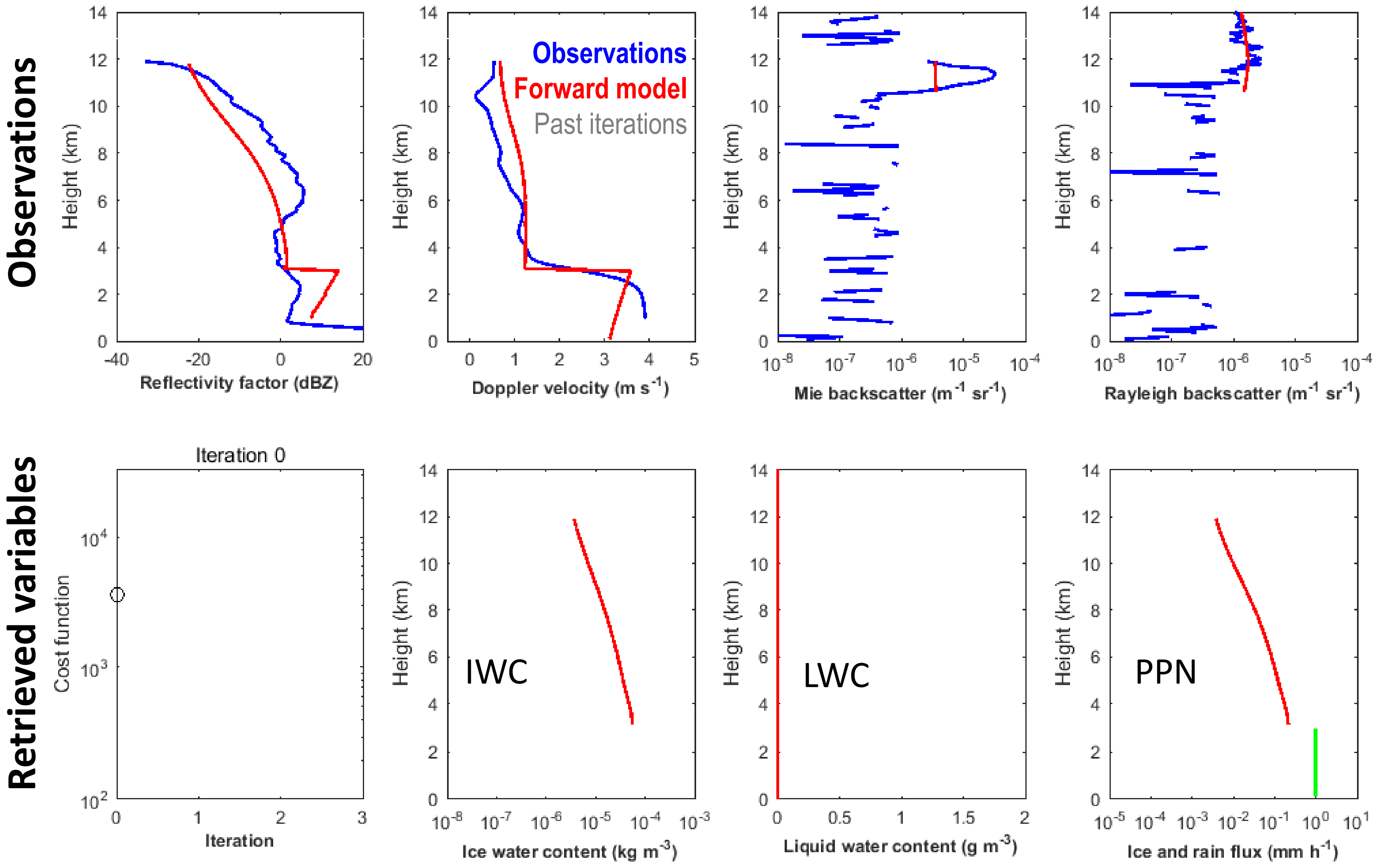




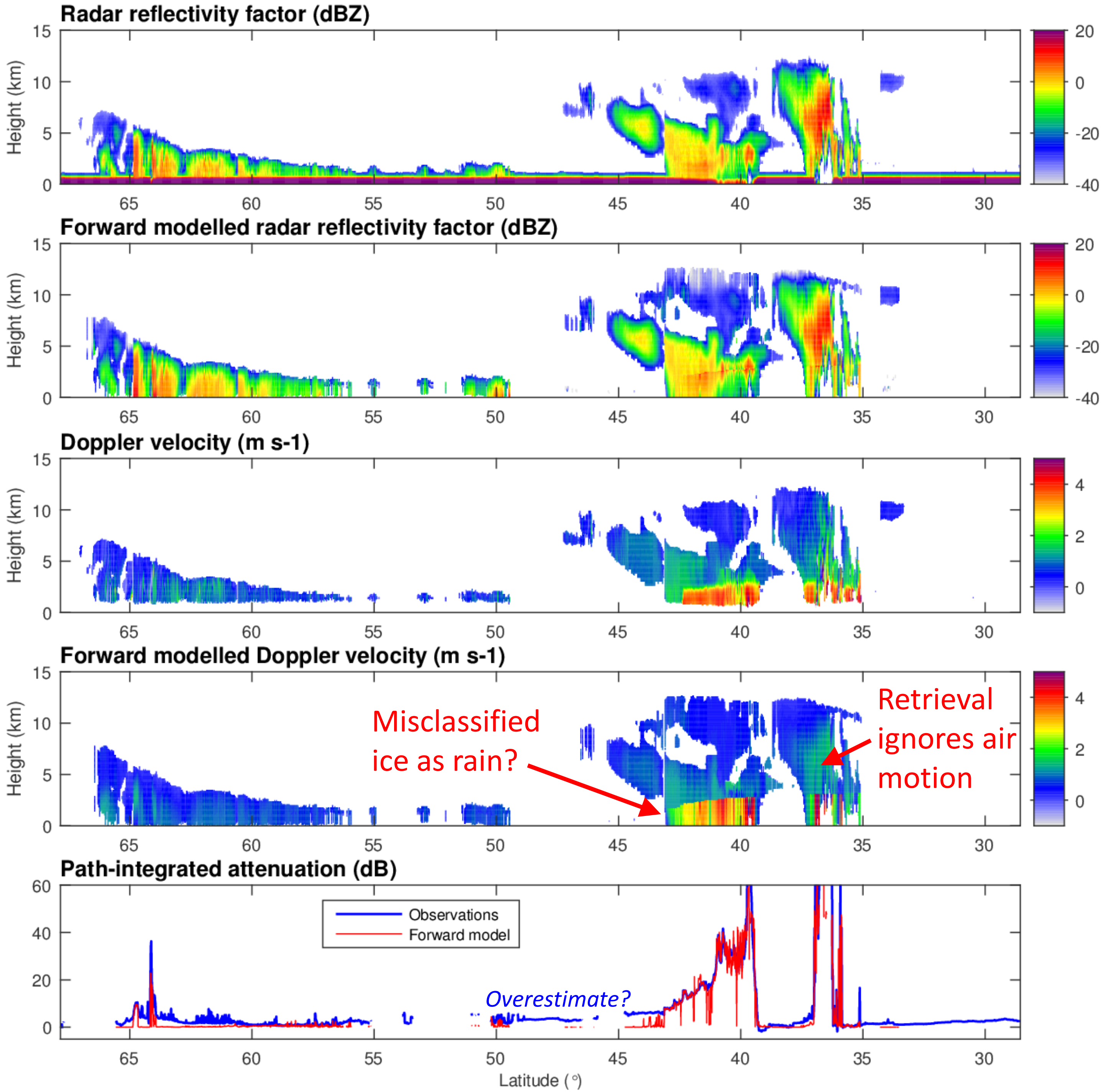
Simulated EarthCARE from the "Halifax" scene

Illustration of iterative retrieval: profile at 37°N

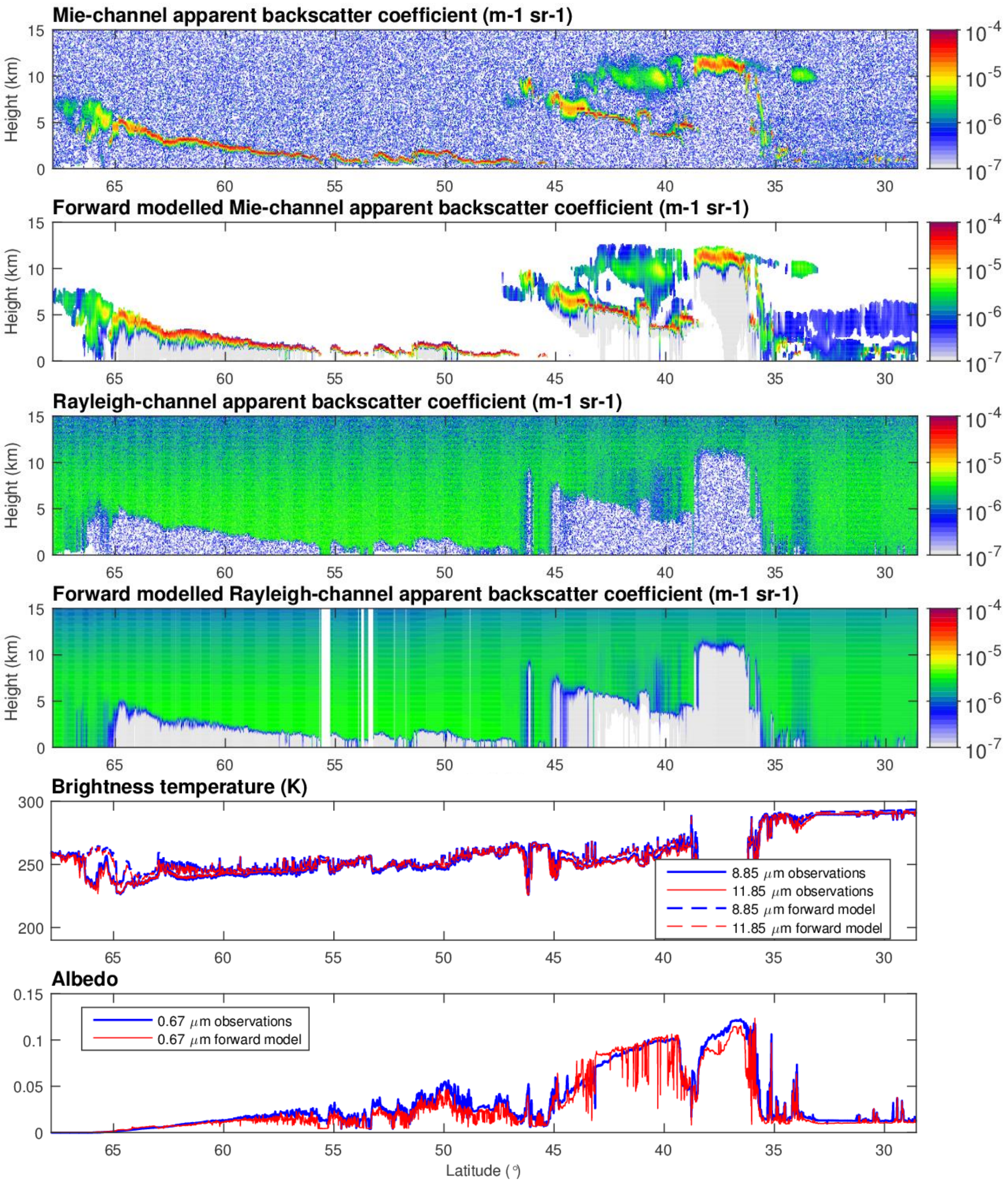
Z DOPPLER MIE (lidar) RAYLEIGH



Radar observations and forward model at final iteration

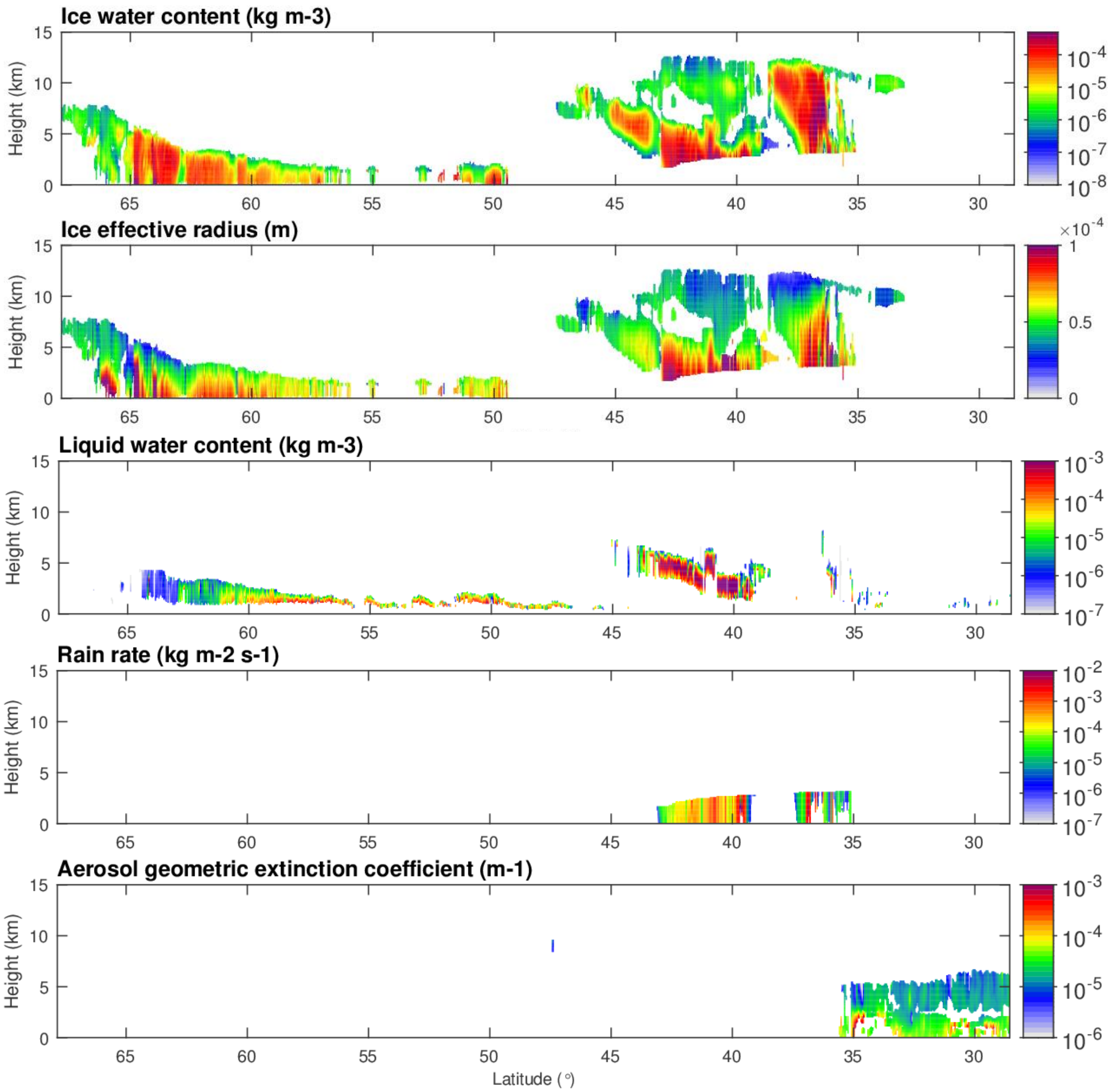


- Generally good match
- Low weight placed on Doppler
- Integral constraint from PIA, but rely on quality of PIA retrieval from earlier product (calibrate ocean return on clear-sky periods)



Lidar and radiometer observations and forward model at final iteration

- Forward model does not have the noise of the observations
- Integral constraints from infrared and solar radiances (when available)



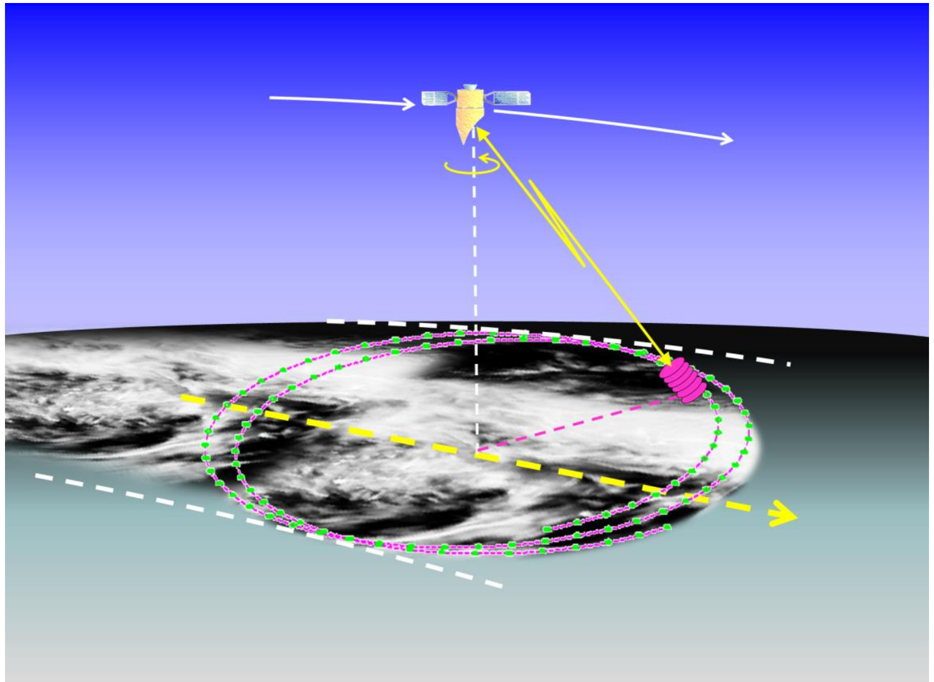
Retrieved variables

- Details of mixed-phase clouds are uncertain: lidar locates liquid cloud top, and shortwave radiances constrain optical depth

Summary

- Scenes generated by the GEM cloud-resolving model provide an invaluable opportunity to test algorithms
- With appropriate configuration, CAPTIVATE ought to be as good as or better than any single-instrument algorithm
- The "Halifax" scene highlights two very challenging cloud types:
  - In mixed phase clouds the vertical profile of liquid is poorly constrained, and the ice particle size has to come from prior information
  - In convective clouds we may be missing liquid water deep in the cloud, but work is in progress to use the Doppler to retrieve the degree of riming (denser ice falls faster). $m = a' D^{b'}$; have relationship between a' and b'
- Several further cases are being generated and will allow for other cloud types to be tested
  - But we should be careful not to tune the retrieval to the assumptions made in the GEM model!

3. WIVERN – RADAR CONCEPT



500kmm orbit

800km wide ground track:

Slant range 651km

Conical scan 37.9° off-nadir

(41.4° off zenith at surface)

Scan every 7 seconds

- move 50km along track

For winds accurate 2m/s:

- sample 20km around the arc if Z >-20dBZ

1km around the arc if Z > -7dBZ

94GHz: 2.9m elliptical antenna: 1.23mrad:

Beamwidth 800m: Pulse length 500m (3.3μsec) **1km vertical resolution**

For 500m resolution need 6m antenna – too expensive

Radar Reflectivity: cloud profiles, precipitation rate, ice water content.

DOPPLER line of sight winds – using cloud particles as tracers.

COMPLEMENTS: the predominantly clear air winds from AEOLUS

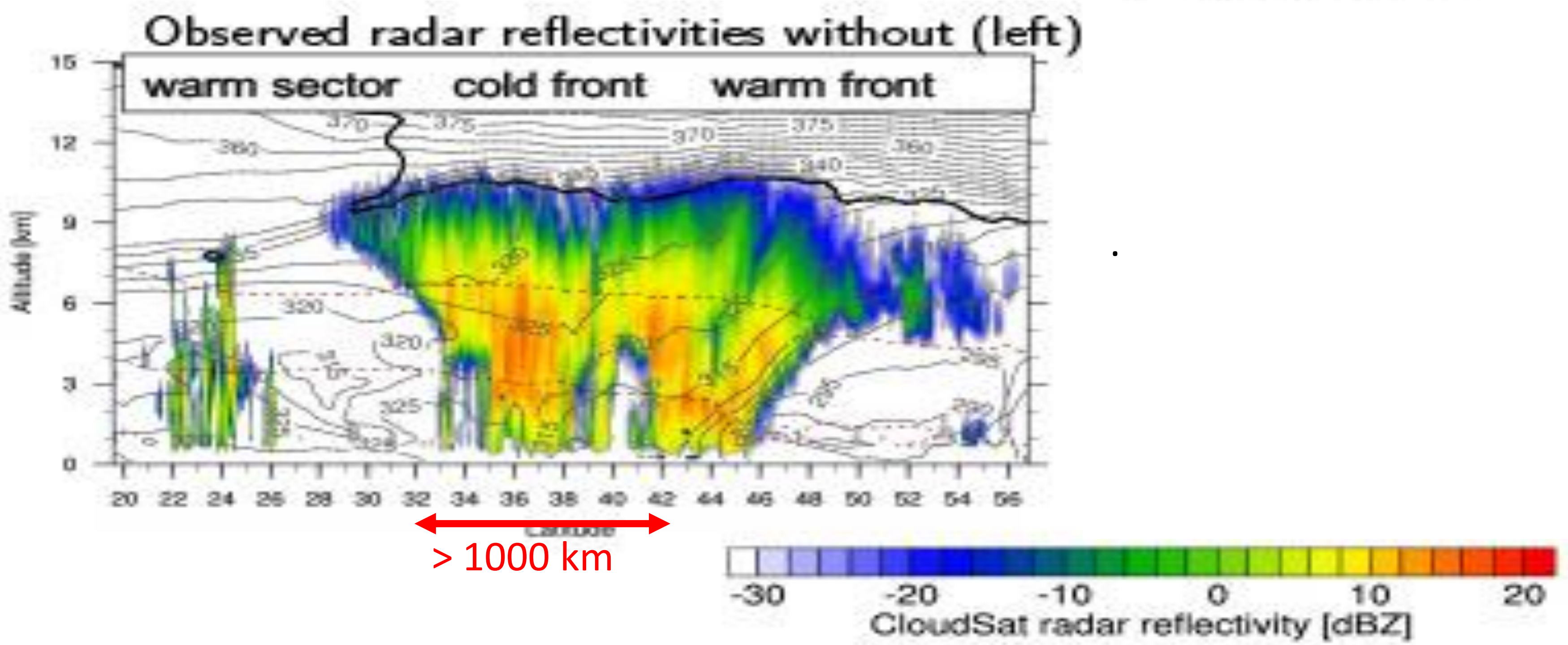
HOW MANY WINDS WILL WIVERN MEASURE IN A WCB?

Scan every 7 seconds - move 50km along track

For winds accurate 2m/s: - sample 20km around the arc if Z >-20dBZ: all the blue echoes winds throughout the WCB

1km around the arc if Z > -7dBZ all the green echoes

How far into the jet stream does the cloud cover extend? Does AEOLUS penetrate?

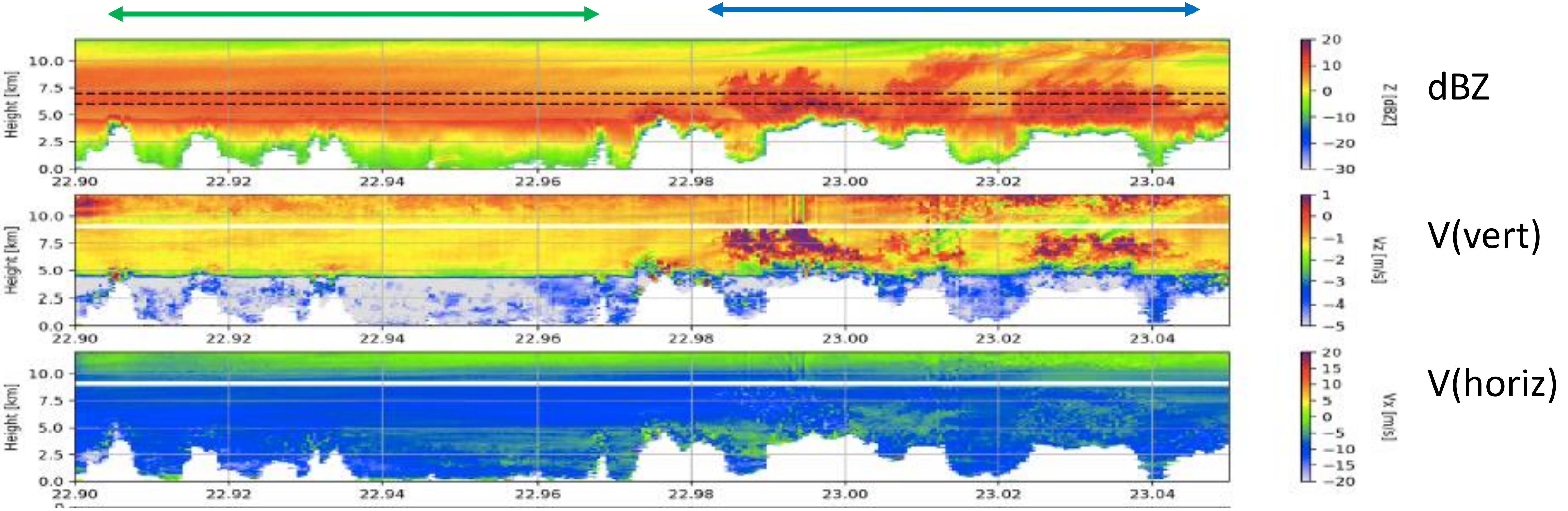


Can we derive true horizontal winds when looking 41 degrees off nadir?

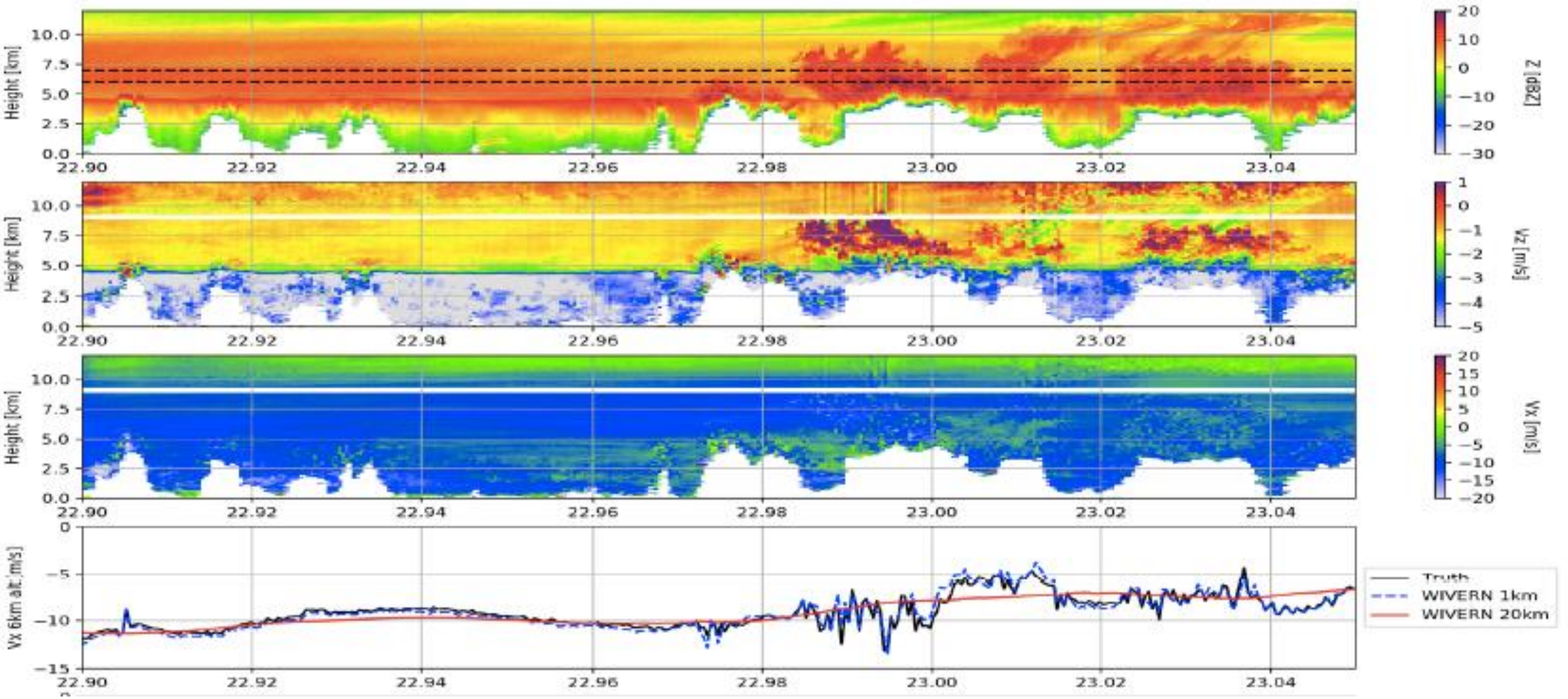
Radar observations by the French Falcon aircraft with three antenna pointing in different directions through a tropical rainstorm near Darwin. (Courtesy Julien Delanoe, LATMOS)

An 80 km vertical cross section of tropical rainfall observed by a 94 GHz radar showing the reflectivity and 3-D velocities. Heavy rain completely attenuates the signal below ~ 2.5km.

First 40 km of stratiform rainfall   Second 40km of convective rainfall.



Can compute WIVERN line of sight (LOS) wind, and apparent **HLOS** = LOS (cos 41degs)



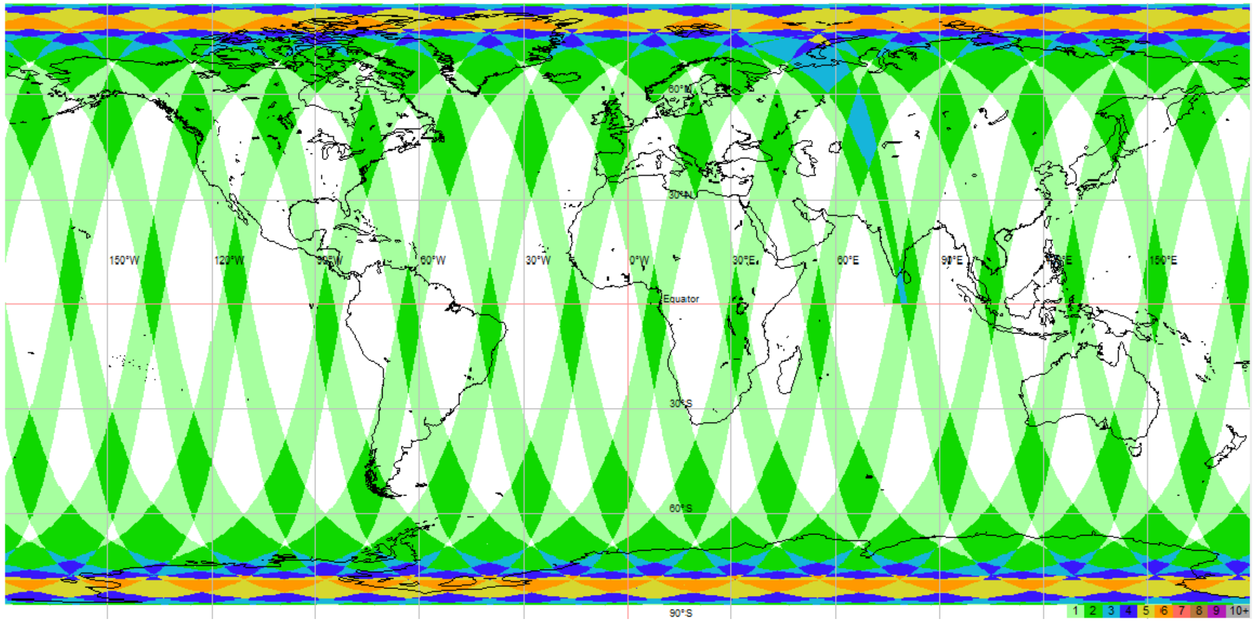
Bottom panel: the HLOS velocity at 1 km resolution and 20 km resolution inferred by WIVERN at height of 6km BLACK line is the true horizonal velocity measured by the radar. (Assume ice falls at 1m/s)

HYPOTHESIS IF the rms variation of 1km wind over 20km is < 0.5m/s – we have stratiform rain

if rms variation of the km to km wind over 20km is > 1.3m/s - we have convective rain

MORE FLIGHTS CAPE VERDE JULY 2020: also analyse 'EPATAN' flights near Iceland/Greenland 2016

WIVERN REVISIT TIME and ORBIT



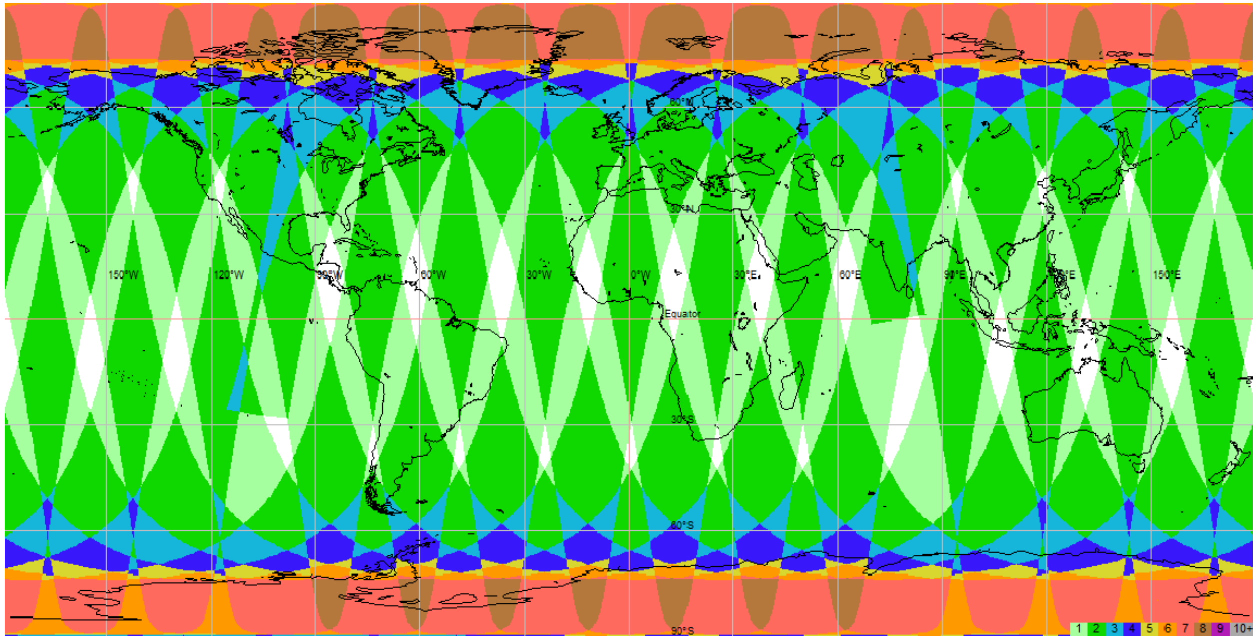
500km ORBIT

800km wide ground track

Dark green twice a day

Light blue three times

Much more than AEOLUS with its lidar dwelling across track at 35 deg off-nadir



700km ORBIT

1800km WIDE GROUND TRACK

Slant path 1178 not 651km,

BEAMWIDTH 2km

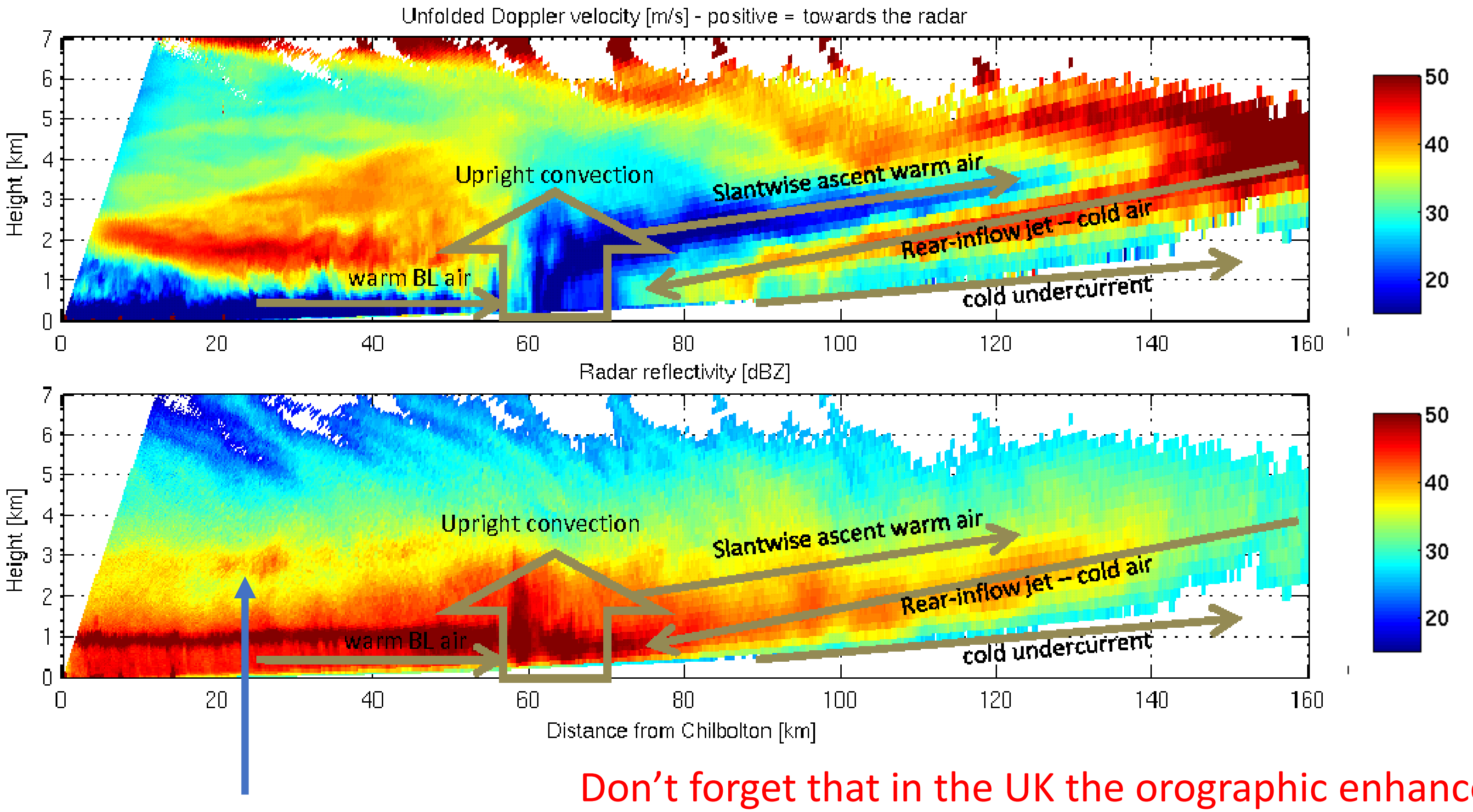
2km VERTICAL RESOLUTION

2km   Blind zone near ground

REJECT

What is the effect of WIVERN's 1km resolution?

VERTICAL SLICE THROUGH A COLD FRONT 3 MARCH 2009
RADAR BEAMWIDTH , ¼ degree, 250m wide at 57Km
LOOKING TO THE SW (courtesy Chris Westbrook, U of Reading)



DOPPLER VELOCITY m/s
POSITIVE TOWARDS THE RADAR.
SYSTEM MOVING TOWARDS AT ABOUT 30m/s (140km/hr)

RADAR REFLECTIVITY AT 10cm WAVELENGTH - Rayleigh scattering

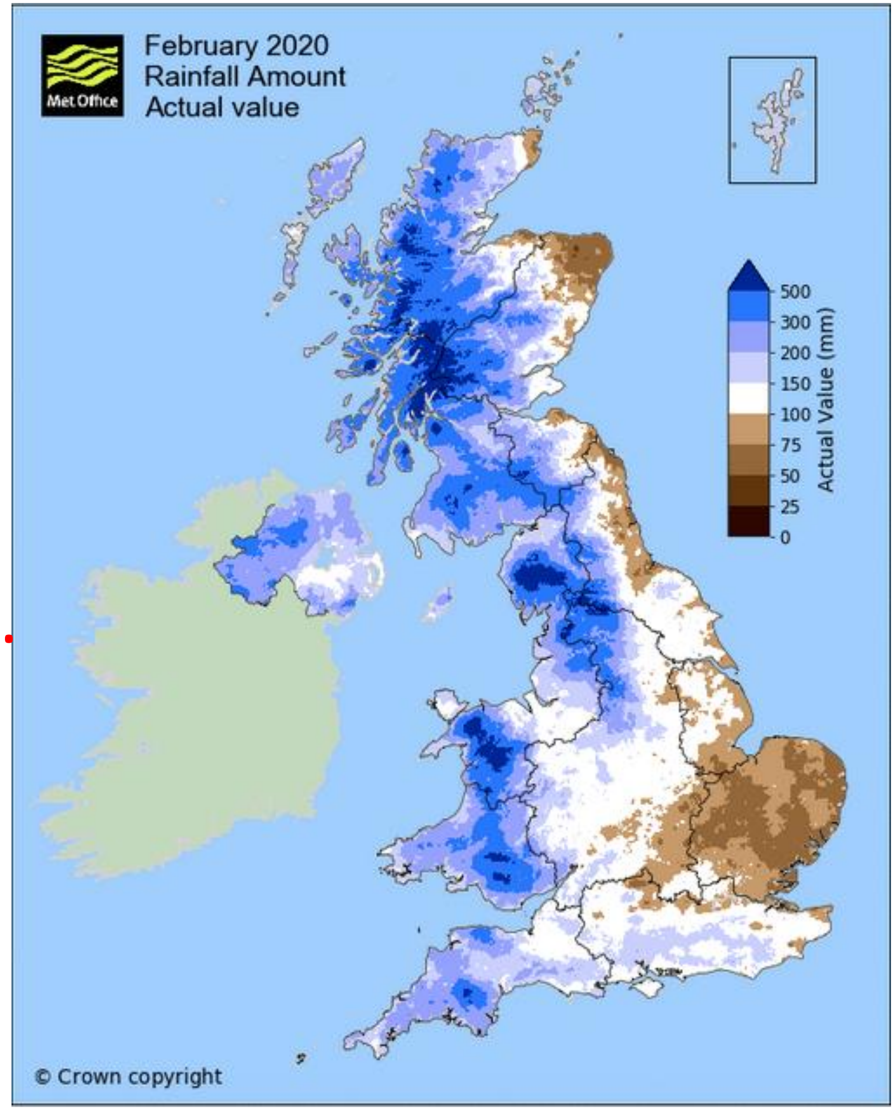
Remember at 94GHz (3.2mm) large raindrops Mie scatter, so Z much lower

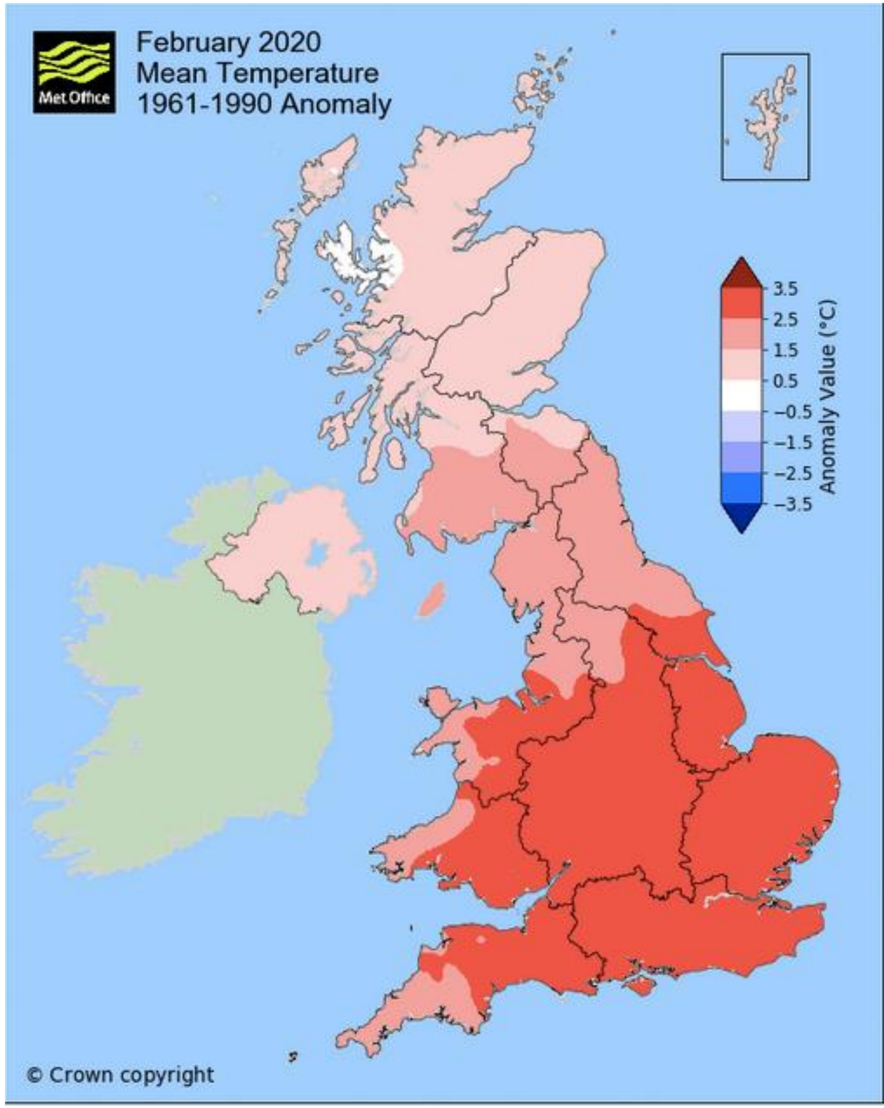
WCB ahead of and parallel to the cold front

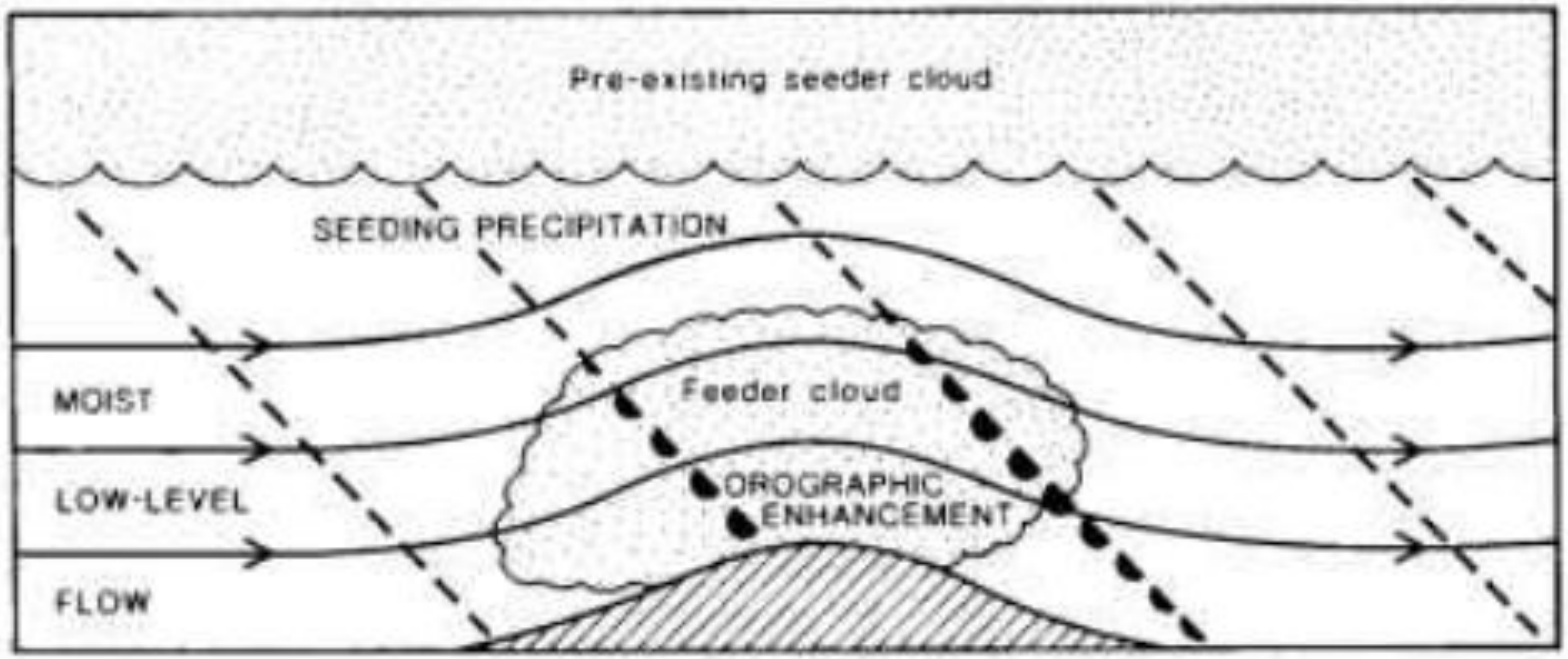
Don't forget that in the UK the orographic enhancement (X2 or X 3) results from the seeder-feeder mechanism in cap clouds over the hills in the west just ~ 500m -1km high
Neither ground-based or satellite radars can detect this because of ground clutter

Don’t forget that in the UK the orographic enhancement (X2 or X 3 or X5) results from the seeder-feeder mechanism in cap clouds over the hills when the moist low level jet rises over western hills just ~ 500m - 700m high.

Neither ground-based nor satellite radars can detect this rain because of ground clutter.

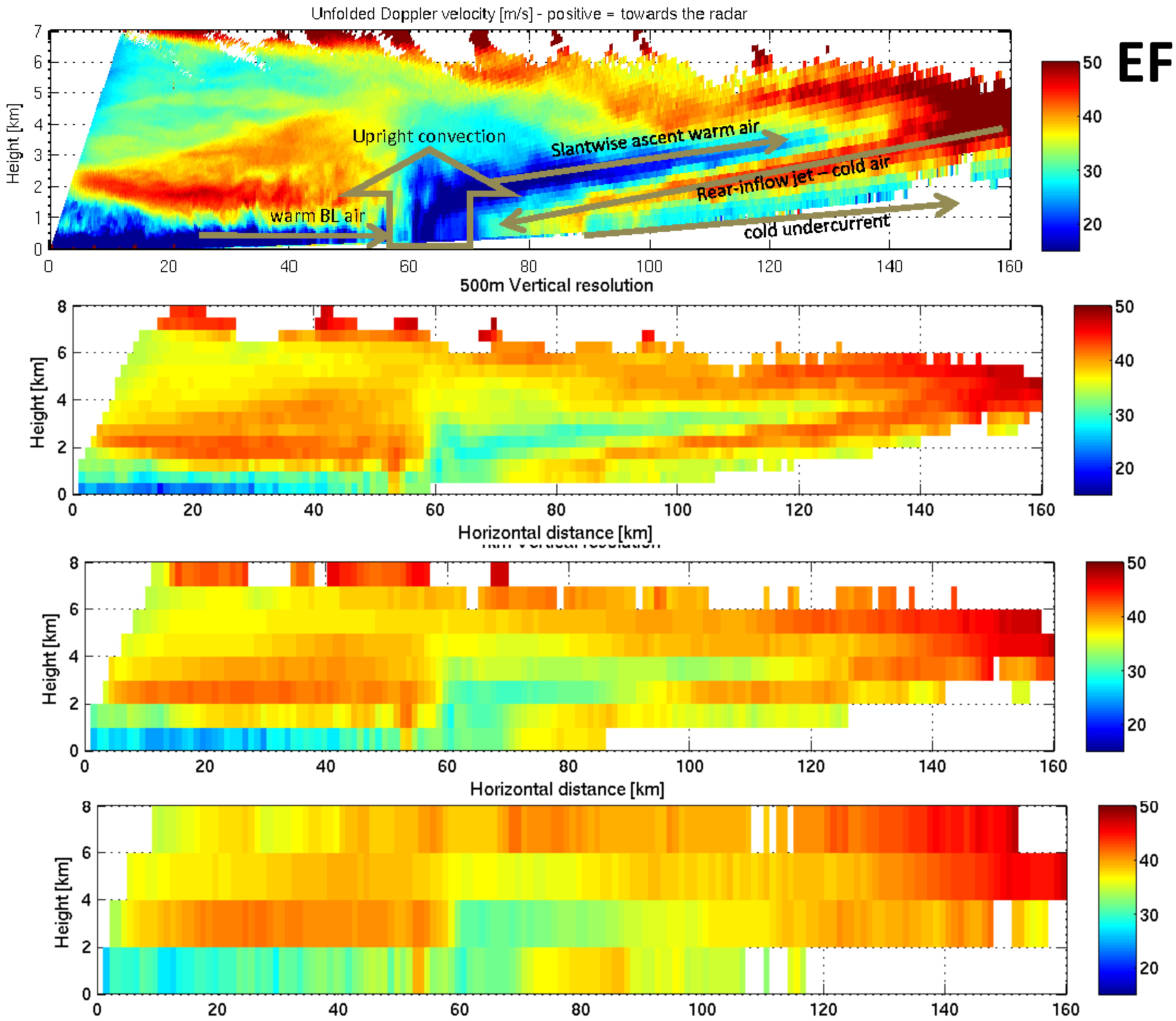






Browning and Hill (1981)

EFFECT OF RESOLUTION



Chilbolton 25m dish
250m vertical resolution

500m vertical resolution

WIVERN
1km vertical resolution
is adequate

2km vertical resolution