THE EARTHCARE CHALLENGE: EVALUATION AND IMPROVEMENT OF CLIMATE AND NWP MODELS.

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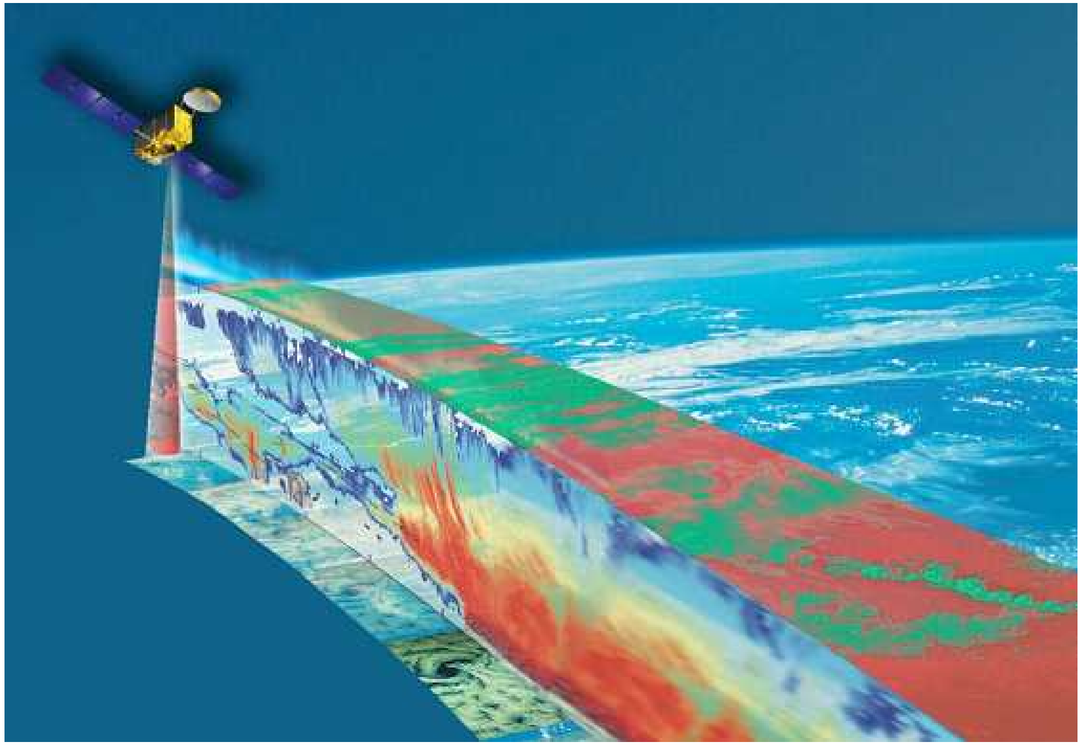


EarthCARE
Workshop
Kyoto
10-12 June April 2009

EarthCARE has been defined with the specific **scientific objectives** of quantifying aerosol-cloud-radiation interactions so they may be included correctly in climate and numerical weather forecasting models to provide:

- Vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds.
- Vertical distribution of atmospheric liquid water and ice on a global scale, their transport by clouds and radiative impact.
- Cloud overlap in the vertical, cloud-precipitation interactions and the characteristics of vertical motion within clouds.
- The profiles of atmospheric radiative heating and cooling through a combination of retrieved aerosol and cloud properties.

- **MORE SPECIFICALLY EarthCARE will measure:**

- **Properties of aerosol layers:**
  - **(a) The occurrence of aerosol layers, their profile of extinction coefficient and boundary layer height, and**
  - **(b) The presence of absorbing and non-absorbing aerosols from anthropogenic or natural sources.**
- **Properties of cloud fields:**
  - **(a) Cloud boundaries (top and base height) including multi-layer clouds.**
  - **(b) Height resolved fractional cloud cover and cloud overlap.**
  - **(c) The occurrence of ice, liquid and super-cooled cloud layers.**
  - **(d) Vertical profiles of ice water content and effective ice particle size and shape.**
  - **(e) Vertical profiles of liquid water content and effective droplet size.**
  - **(f) Small scale (1 km or less) fluctuations in these cloud properties.**
- **Properties of precipitation:**
  - **(a) Vertical velocities to characterise cloud convective motions and ice sedimentation**
  - **(b) Drizzle rain rates and estimates of heavier rainfall rates.**
- **Narrow-band and broad-band reflected solar and emitted thermal radiances at the top of the atmosphere.**

Launch 2013. State of the NWP and Climate models?

Current Resolution:

– NWP: e.g. ECMWF global now 25km, 16km in 2009

- Mesoscale: Met Office, DWD, Meteo France 1-2km 2009.

and by 2013 – 2016?

Earth simulator –JAMSTEC- Climate runs 15km, 0.1deg, depending upon the length of the climate runs.

If grid box is just a km or less, does this mean:

Convection is explicit?

Does the cloud overlap problem go away?

Sub-grid box variability (e.g. in ice water content) not a problem?

Will the aerosol have structure on this scale?

How good will the humidity fields be?

Model errors often assumed constant in space and time.

Will the errors in the model become meteorology dependent?

PROGNOSTIC VARIABLES IN NWP AND CLIMATE MODELS.

AEROSOLS:

NWP – aerosol type often prescribed – urban, marine….

- vary concentration.
- ice nuclei usually prescribed

GEMS (ECMWF) + JMA many different aerosols + size information.

CLOUDS:

Cloud Fraction, Ice and liquid water content, implicit overlap

COMING SOON?

Double moment schemes? i.e size and concentration.

(Careful – underconstrained model, instability?)

More (ice) hydrometeor classes?…….

Will we have prognostic aerosol control of nucleation of water clouds?
Will we have prognostic ice nucleation controlling glaciation?
How will we evaluate these processes?

94GHz Spaceborne Radar

Very powerful: CloudSat > 150 publications!

$Z = ND^6$

Radar detects many ice clouds.

No explicit size/conc information.

Misses quite a few liquid water clouds – unless they have drizzle.

EarthCARE radar ≈ 6-8dB more sensitive: smaller blind zone nr ground.

(Larger antenna, lower orbit)

How many more high altitude ice clouds will be detected?

How many more liquid water clouds will be detected?

EarthCARE has Doppler:

Terminal velocity of ice particles. (Improve IWC, size information)

Terminal velocity of precipitation – drizzle – better ppn rates.

Convective motions – better parameterisation/representation in models.

Doppler from space?

Performance is very dependent upon the radar prf and antenna diameter.

Increasing prf leads to remarkable increase in Doppler performance.

(The Doppler width due to the radar beamwidth and the 7km/s movement of spacecraft means target decorrelates)

With a 2.4m antenna 7500Hz much better than 6400Hz

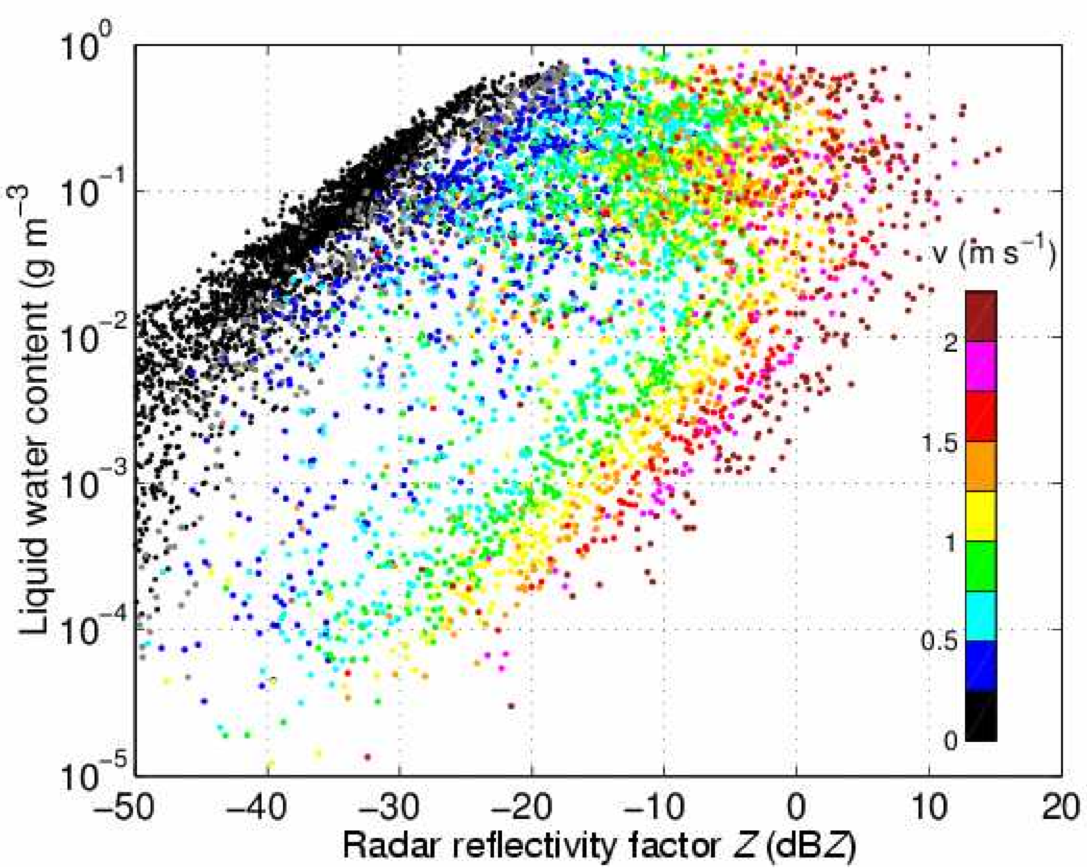
– but at 7500Hz max cloud height detectable about 16km.

TRADE OFF – lidar detects clouds above 16km very well.

Can we sacrifice radar for high clouds and transform Doppler quality for lower clouds?

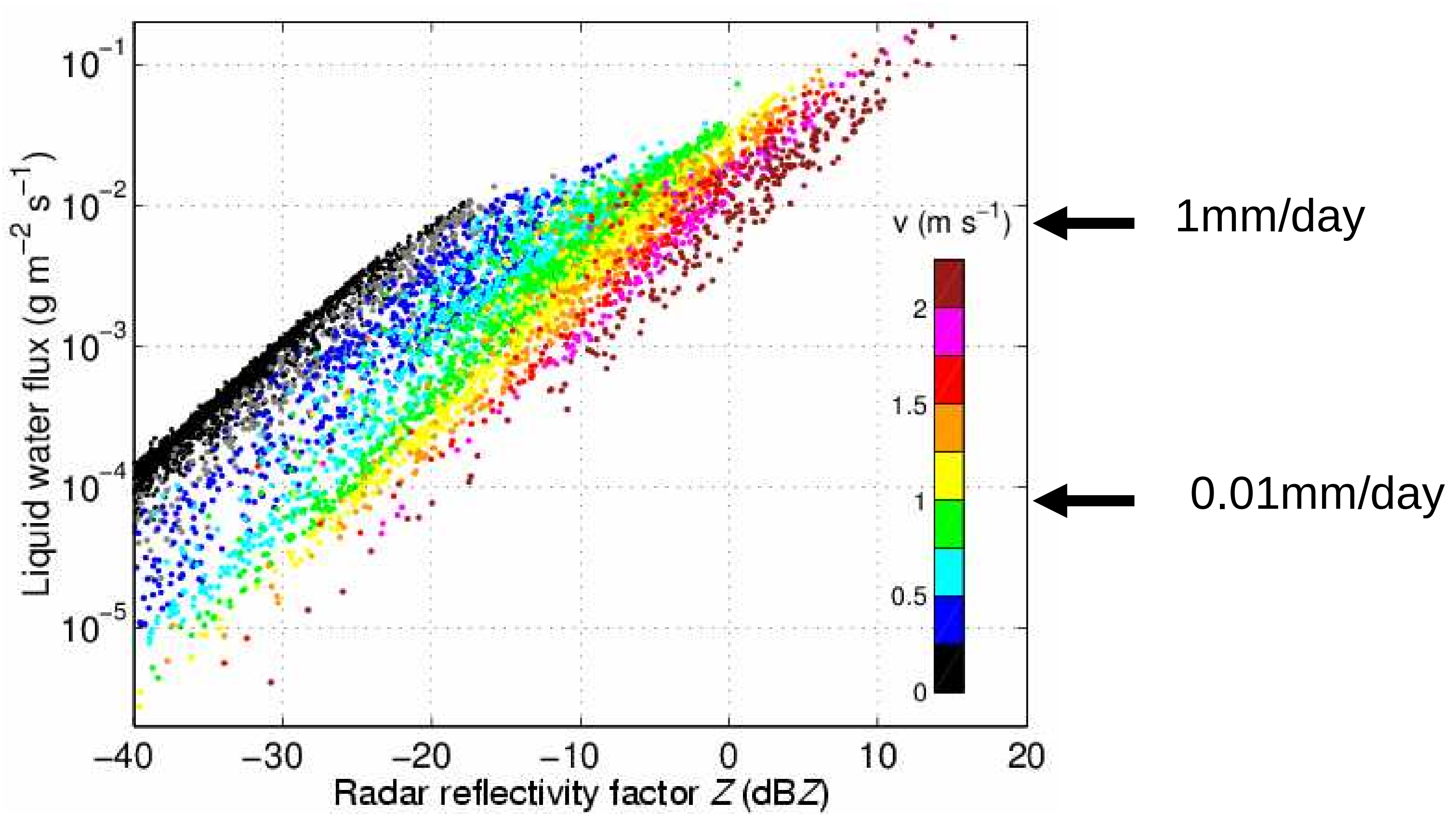
How Doppler would help lwc in presence of drizzle.

- Z , LWC and V computed from ASTEX cloud spectra.
- V < 0.5m/s. (black) – good Z-LWC relatioship
- LWC scale structure smaller than 10km.



How Doppler could help to measure drizzle rates

- Z and drizzle rate computed from ASTEX cloud spectra.
- Need Doppler accurate to 0.5m/s.
- Drizzle structures are smaller than 10km.

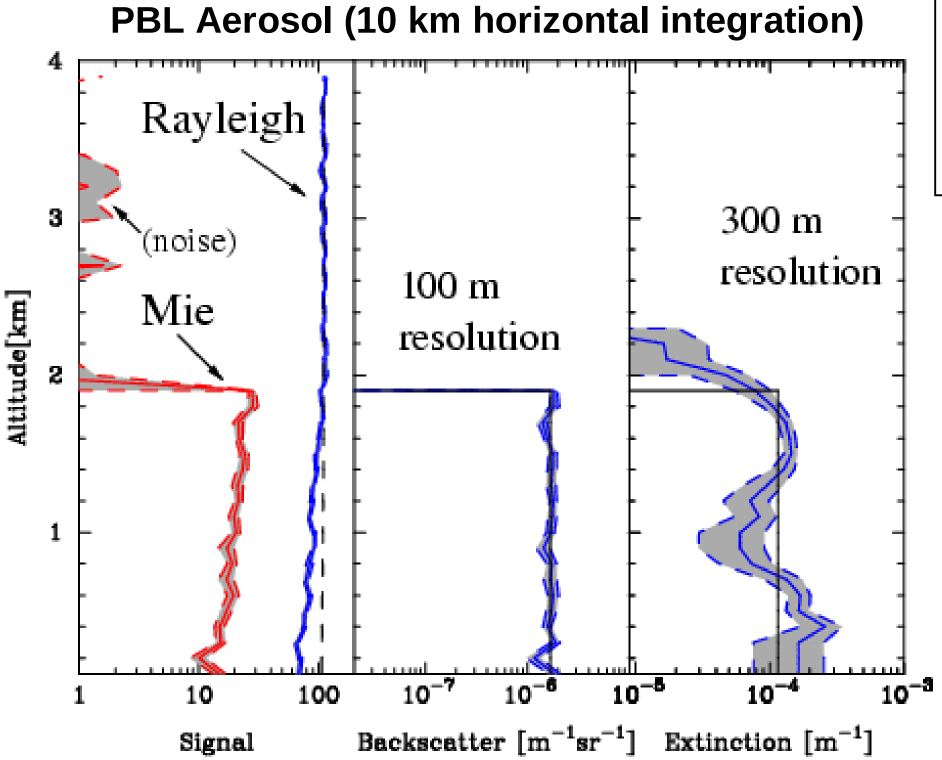


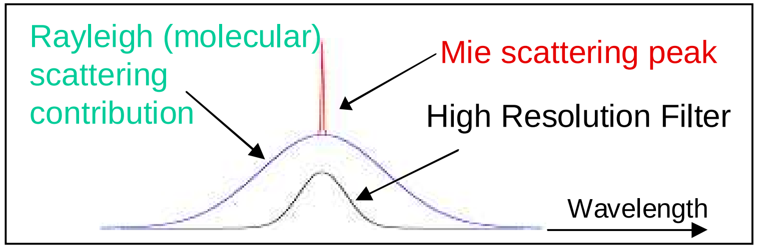
Lidar in Space.

Calipso > 90 publications!
$\beta \approx ND^2$
Lidar detects clouds and aerosols – but need to correct for attenuation.
Lidar at 1064 and 532nm: at 532 also detect molecular. Cross polar.
Lidar sees many high ice clouds missed by CloudSat.

EarthCARE ATLID.
β Sensitivity (Mie) is similar. 355nm wavelength:
Footprint smaller 15m (355nm - less problem with eye safety).
so less multiple scattering and less stray daylight.
High spectral resolution – separate the Mie and Rayleigh returns:
true Rayleigh return is known from the air density, so any observed reduction gives you the attenuation.
Once you correct for attenuation you have the 'lidar ratio', S: the ratio of the extinction to backscatter of the aerosol and cloud particles.

EarthCARE:High Spectral Resolution 355 nm Lidar





1. **Compare observed molecular return with expected non-attenuated value ⇨ True extinction coefficient (α) and/or optical depth (τ)**
2. **Use α to correct the attenuated backscatter (β_{OBS}) ⇨ (β_{TRUE})**
3. **Derive the true lidar ratio α/β ~ ice crystal habit and aerosol size / composition**

Additional information:

- Shape of ice particles and aerosols: from cross-polarisation channel
- Distinguish anthropogenic from natural aerosol: from cross-polarisation channel and lidar ratio

PERFORMANCE OF HSRL LIDAR.

What is the improvement in the performance because of the HSRL separation of the Mie and Rayleigh returns?

Can we distinguish aerosol and cloud more clearly?

How well can we infer lidar ratio S, and depolarisation ratio P.

Given P and S what level of aerosol discrimination is possible?

Can P and S help us to identify different types of ice particle?

Evaluation of such retrievals using a ground based or airborne HSRL?

{ESA study into this has just started}

ADDITIONAL INFORMATION ATLID + MSI

ESA study has just started

EarthCARE: Resolution of data.

Radar: Vertical resolution (Pulse length) 500m – samples at 100m
{Question how much extra information at 100m?)
Horizontal 500m.

Lidar – Vertical resolution 100m. Horizontal 100m (pulse separation)
On- board integration to 200m.

Level two products will be derived on a common grid:
Radar and lidar: 100 and 500m vertical: 1km and 10km horizontal
MSI – 500m. BBR 10km.

Typical products: Target classification, IWC and ice particle size, LWC and effective radius, aerosol type, extinction coefficients Rain and snow water content…….

SYNERGY OF RADAR, LIDAR, MSI, BBR.

Aerosol - from the lidar (unless extinguished by the cloud) and MSI.

Clouds - Radar and lidar together can give cloud particle size, better ice & liquid water content, extinction profiles etc than single instrument

From CloudSat/Calipso we know:
The lidar detects lots of high clouds not seen by the lidar.
The radar detects lots of low clouds for which the lidar is extinguished
There is a limited range of radar/lidar detection.

1. A variational technique can handle these three situation seamlessly and derive model variables (with quantified errors).
2. How much more radar/lidar overlap with the more sensitive radar?
3. How much better will retrievals be with Doppler and HSRL?

RADIATION.

We envisage two approaches to analyse the BBR radiance observed at nadir, +55deg, and -55deg from each 10km footprint:

Full 3-D approach:

1. Construct a vertical slice of cloud/aerosol properties from the narrow swath of the active instruments.
2. Use the MSI 500m resolution data to extrapolate this vertical slice to give a 3D representation over the 10km BBR footprint
3. Run 3D radiation code over this 3D scene, predict fluxes/radiances.
4. Compare with observed BBR radiances. Compute fluxes/heating rates. Compare with NWP/climate model fluxes and radiances.

CERES like ADM approach:

1. From the radar/lidar plus MSI construct a large number of 'scenes' each one having its own ADM (Angular Distribution Model).
2. For each observations use appropriate ADM to convert the observed BBR radiances to a flux.

{ESA study into this is just starting}

COMPARISONS WITH NWP AND CLIMATE MODELS.

Level 2 synergy provides the model variables full errors which can then be mapped to the appropriate model grid.

NWP – Compare on a snapshot by snapshot basis.

Build up statistics on mean values, pdfs, biases.

Skill scores: getting right cloud/aerosol in right place at the right time.

Rapid evaluation of new versions of the operational model.

TWO WAY PROCESS:These rapid evaluations will also provide timely warning of any problems with the instruments on the satellite.

CLIMATE MODELS: Comparison has to be more statistical.

SIMULATOR APPROACH: Take NWP or climate model output and forward model the EarthCARE instrument responses.

DATA ASSIMILATION.

If the NWP model has a reasonable representation of the cloud/aerosol then one can consider assimilating the observations in real time.

CAL-VAL?

CALIBRATION

- Lidar - Calipso (532nm) use the molecular return. Works well.
- EarthCARE – Rayleigh via molecular return.

  Mie cross/co? Rayleigh leakage – or standard targets?
- Radar – CloudSat - off nadir ocean surface return. Works well.

Confirmed by statistical comparison with clouds over ground stations, desert targets.

- EarthCARE – same principle – sea surface return, desert targets…

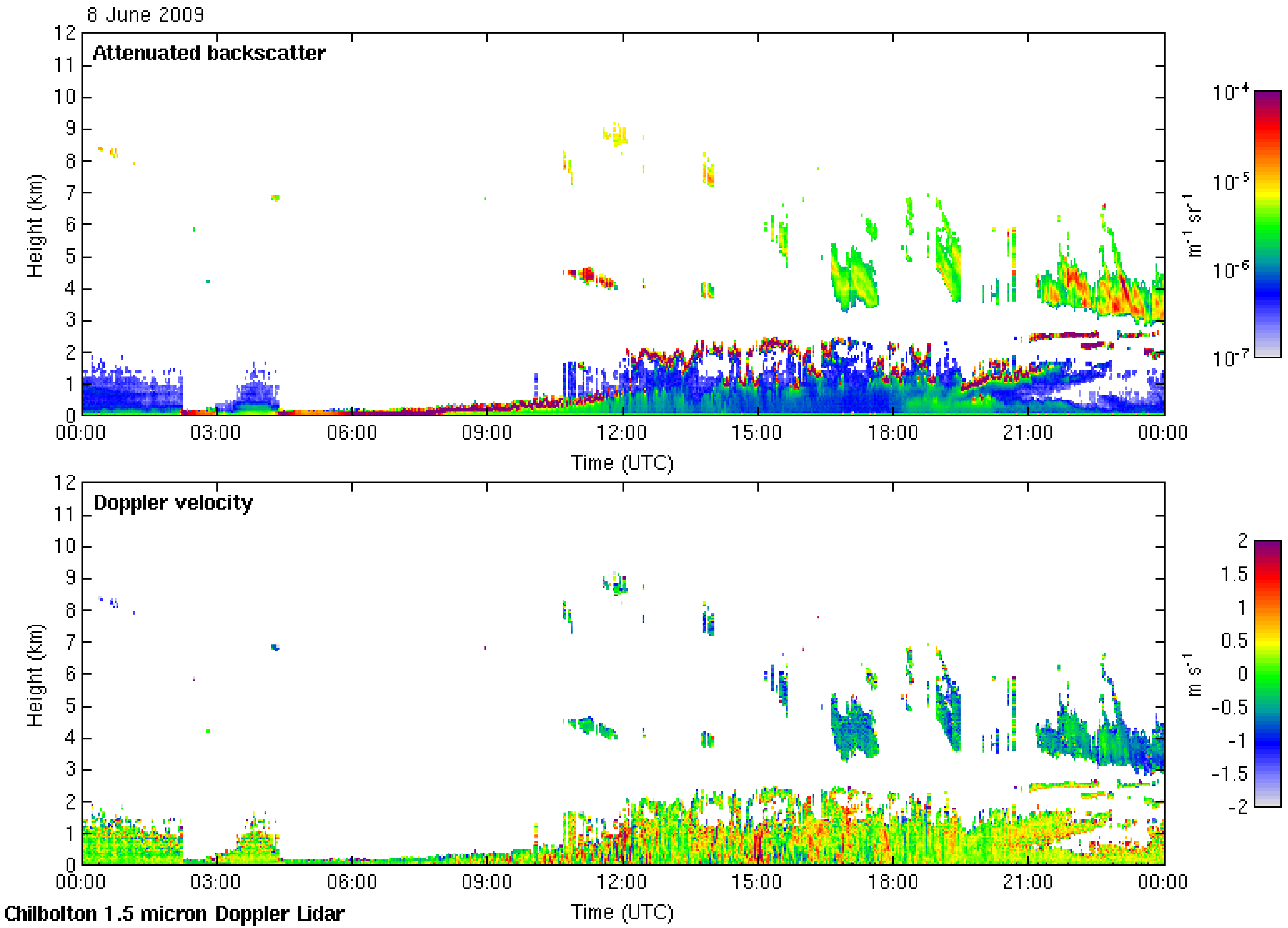
Lidar and radar have narrow swath – clouds very variable – calibration using satellite overpasses over mobile ground stations or underflying aircraft is challenging. .

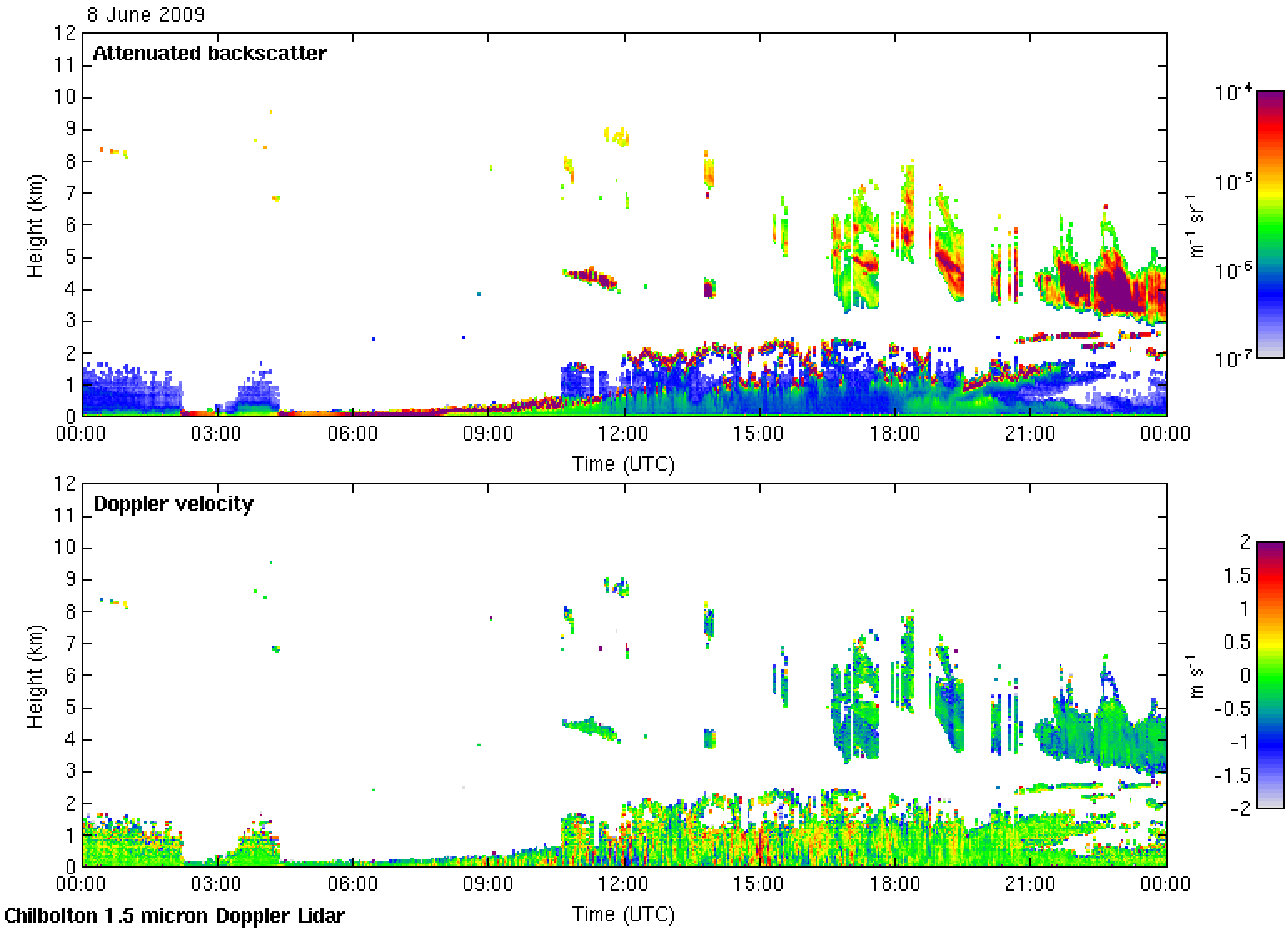
VALIDATION OF RETRIEVAL ALGORITHMS.

Ground based or airborne lidar/radar…. + in situ sampling by aircraft.

(e.g. airborne 355nm HSRL)

In-situ aircraft validation of satellite inferences of aerosol/cloud properties need careful justification. Sampling needs to be thought out. Satellite moves at 7km/s, swath is very narrow. Cloud decorrelation distance short. Needs v precise a/c positioning.


8 June 2009
Attenuated backscatter
Height (km)
Time (UTC)
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
10^{-4}
10^{-5}
10^{-6}
10^{-7}
m^{-1} sr^{-1}
Doppler velocity
Height (km)
Time (UTC)
m s^{-1}
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Chilbolton 1.5 micron Doppler Lidar



8 June 2009
Attenuated backscatter
Height (km)
Time (UTC)
m-1 sr-1
Doppler velocity
Height (km)
Time (UTC)
m s-1
Chilbolton 1.5 micron Doppler Lidar

MSI

- how much of a problem is the (unknown) property of the surface?
- how do we use MSI to build up 3D field from 2D slice?
- how good is this?
- is the method to examine the 10km box around the 2D radar/lidar slice and characterise the MSI 500m image?
- build up library of vertical structures associated with image from searching 2D slices in the vicinity.

How many classifications of MSI images do you have?
How far away do you search to find 2D slices with same MSI image?

NWP or climate evaluation? COSP approach?

- NWP 'easier' scene by scene
- Climate has to be more statistical

Process studies – only snapshots. No evolution.

Now have fairly well established estimates of lidar performance:

Spec: Mie 8 10^{-7} /m/sr (for 10km horiz) to 48%

- performance 40% accuracy (and at night 29%).

Rayleigh to within 15% in the BL (10km integration)

- performance 12%

Mie X-pol 2.6 10^{-6} /m/sr (for 10km horiz) to 45%

- performance 30%

Absolute calibration of the three channels now specified.

Cross talk Mie to Rayleigh 1.7% (requirement 5%) – and how constant is it?

Rayleigh to Mie 8.4% (spec 10%) etc etc.

So – in the BL how well can you estimate the backscatter from a faint aerosol, where Rayleigh is high, and how well can you Get the extinction from the reduction in the Rayleigh…..

and with what vertical and horizontal resolution?

For thick clouds with high Mie return, can you still sense the change in the Rayleigh and get the extinction and hence lidar ratio?

How much better at night?

Radar – we oversample at 100m in the vertical.

- can we really get reliable structure at <500m pulse length?

Min horizontal 500m samples.

Can get much closer to the ground than CloudSat.

Increase sensitivity over CloudSat – how many more stratocumulus and this ice clouds will we see?

- could check this by looking at current variational radar/lidar (ice) retrievals and computing the Z where we currently only have the lidar.

Radar – lidar synergy.

How much extra information from the MSI?

- need to assume v profile of temp from the forecast analysis
  what if this is wrong in high WC clouds?

What is the impact of the Doppler?

- identify drizzle in stratocumulus?
- ice falling out of (thin) supercooled cloud layers?
- resolving convective motions?