UK Met Office Latest Results on PC Radiative Transfer

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Advanced High Spectral Resolution Infrared Observations,
Eumetsat 15-17 Sept 2008.

Talk Content

- IASI – current data usage and impacts
- JAIVEX – Joint Airborne IASI Validation Experiment
- HT-FRTC
- 1d-Var retrievals from ARIES and IASI
- Future work
- Conclusions

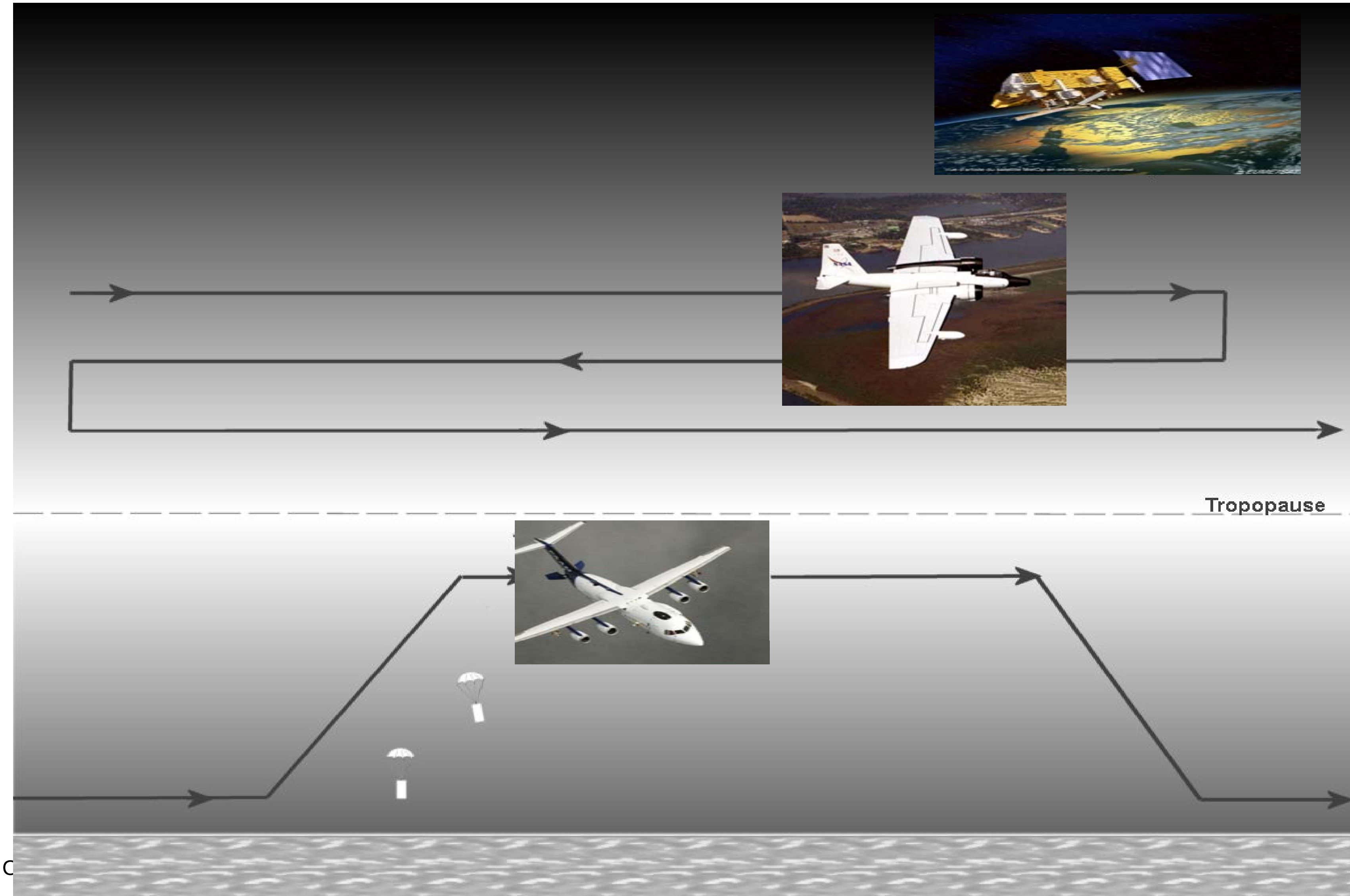
Assimilation of IR satellite sounder data

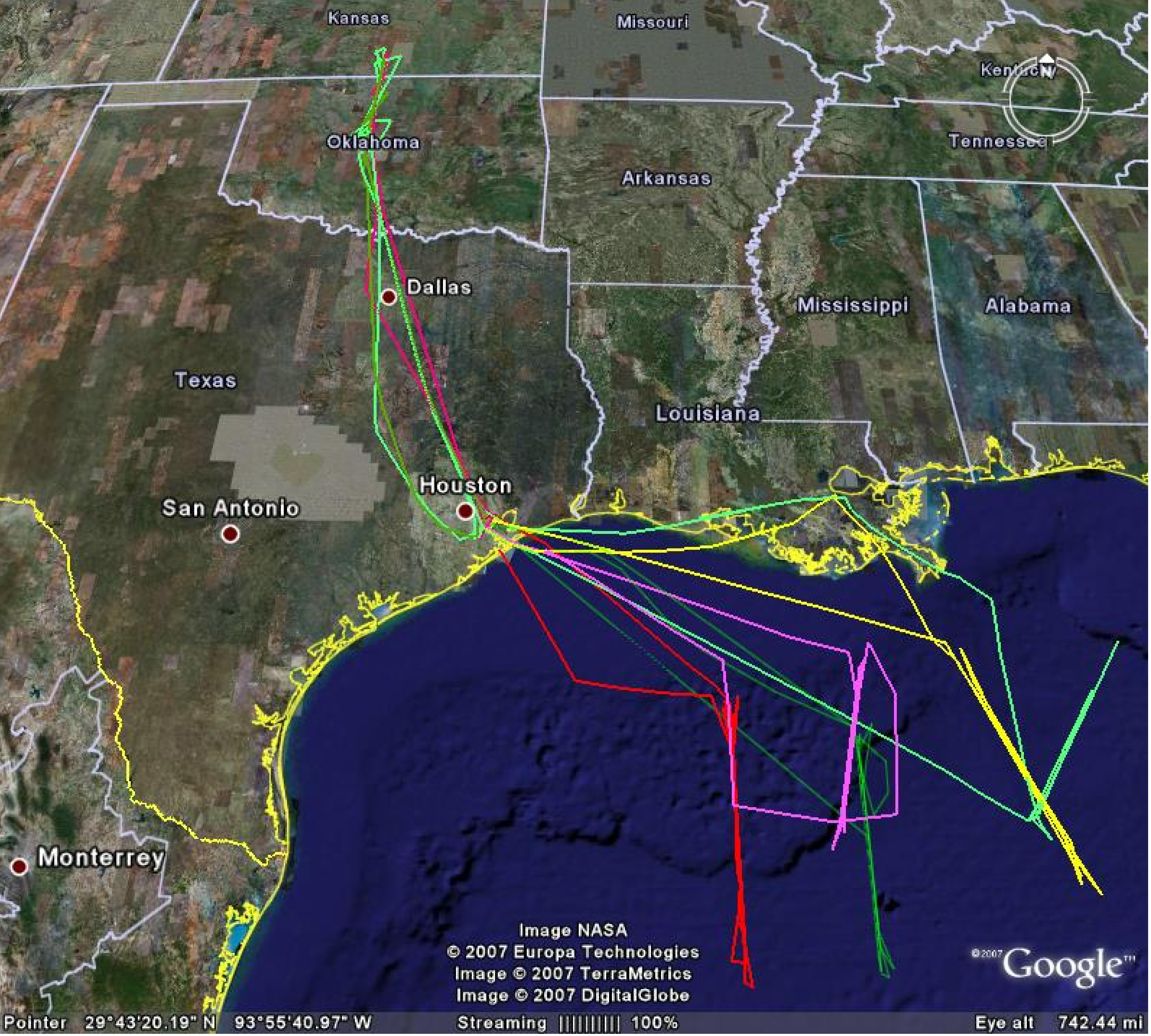
- AIRS instrument on Aqua satellite, IASI on Metop and soon CrIS on NPOESS all measure the upwelling radiance at 1000’s of wavelengths.
- The Met Office started assimilating IASI data from the Metop platform in November 2007 and trials have shown it to have a big impact on NWP skill. However, current assimilation techniques only allow 183 of the 8461 available channels on IASI to be utilised and these are only assimilated in cloud free conditions. Over land the number of channels is reduced further to around 40 that have their peak sensitivity at altitudes above 400hPa.
- Met Office and ECMWF have had difficulties assimilating water vapour channels in 4d-Var
- Currently only assimilate data over ocean in cloud free conditions.
- We would like to assimilate data over any surface (land, sea ice or ocean) and in the presence of clouds and through thin cirrus.

JAIVEX Objectives

- To validate and characterize the radiometric performance of IASI
- To validate the performance of different algorithms designed to retrieve temperature,humidity, ozone and carbon monoxide profiles from IASI spectral radiance measurements over land and ocean and under cloudy as well as clear sky conditions
- To gather a diverse set of IASI spectra with co-located airborne and in-situ observations to further the development of innovative techniques to assimilate IASI data into numerical weather prediction models, utilizing as many channels as possible, over land and ocean and under cloudy as well as clear sky conditions
- Partly funded by Eumetsat

Flight Coordination





JAIVEX Campaign

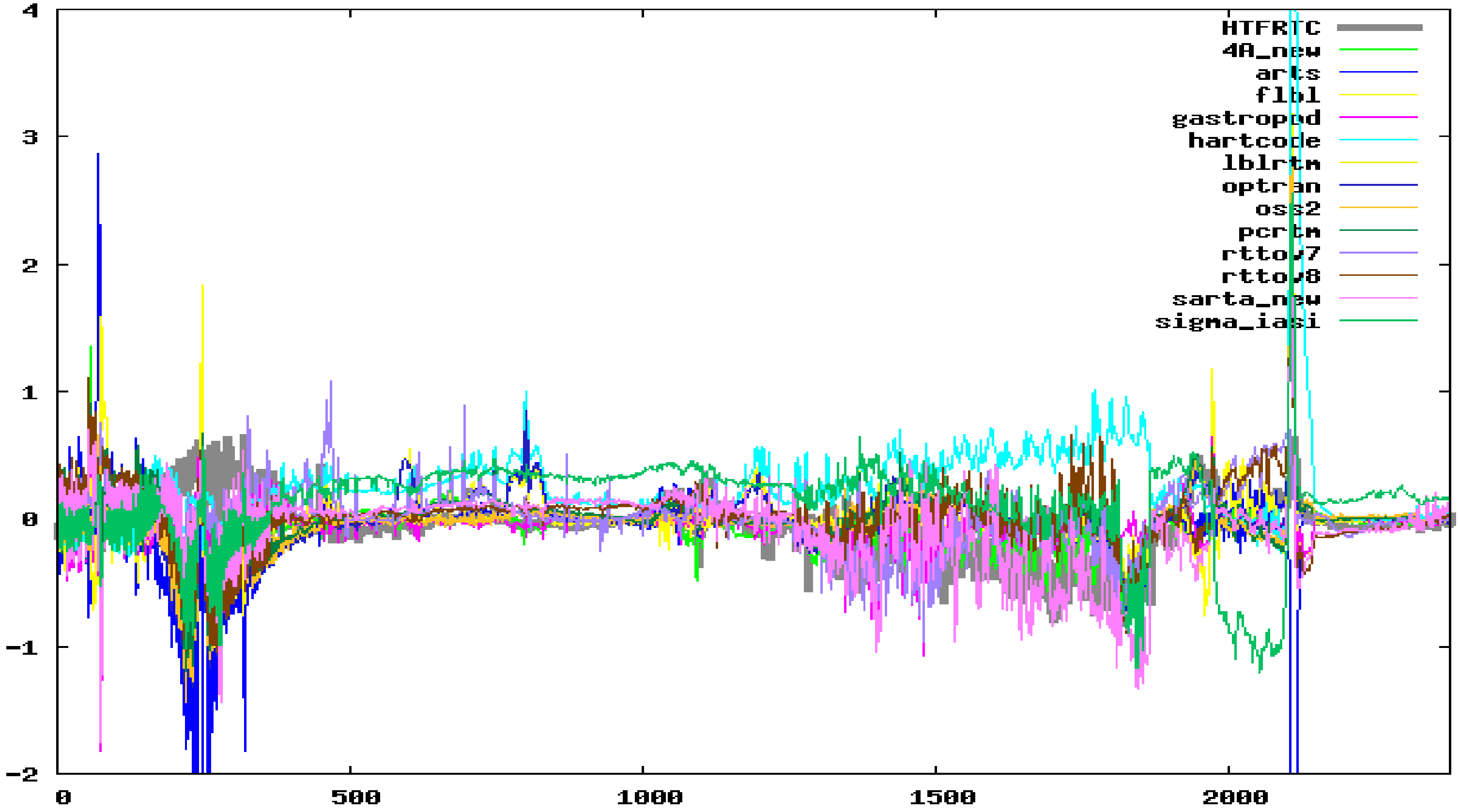
Principal Component Radiative Transfer

- The Havemann –Taylor Fast Radiative Transfer Code (HT-FRTC) has been developed:
- Benefits
  - **Fast:** computes entire IASI spectra (~8500 channels) in < 1s
  - **Accurate:** has been compared with 14 other codes and is just as good.
  - **More Information:** simulating 8500 channels means that information on surface and clouds can be assimilated plus multiple channels giving same information about temperature and water vapour structure act to reduce the noise of the measurement.

Results of model intercomparison

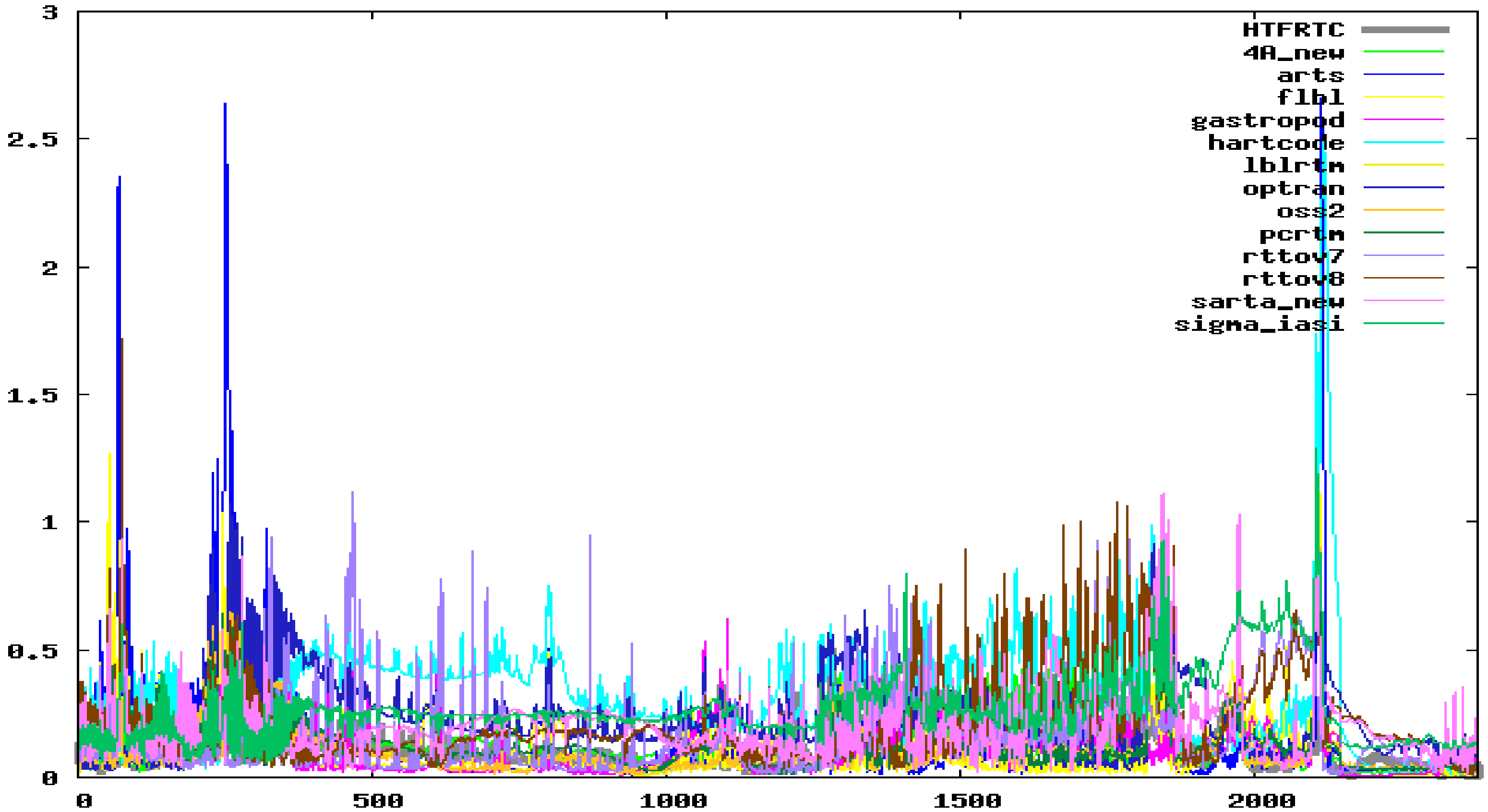
- Intercomparison of 14 line-by-line or fast
- radiative transfer models (Roger Saunders et al)
- Simulated AIRS spectra (2378 channels in IR)
- Diverse test set of 52 different atmospheric
- profiles of temperature, humidity and ozone,
- with different surface temperatures and surface
- pressures, with fixed surface emissivity 0.99, with no
- solar contribution and clear sky

Model Intercomparison : Biases



- HTFRTC based on GENLN2, Ozone variable

Model Intercomparison : STDEV



- HTFRTC based on GENLN2, Ozone variable

HT-FRTC – how does it work?

Perform Singular Value Decomposition on training set of profiles – the resulting Empirical Orthogonal Functions are fixed: They represent the basic spectral physical characteristics of gases / surfaces / aerosols / clouds and the instrument

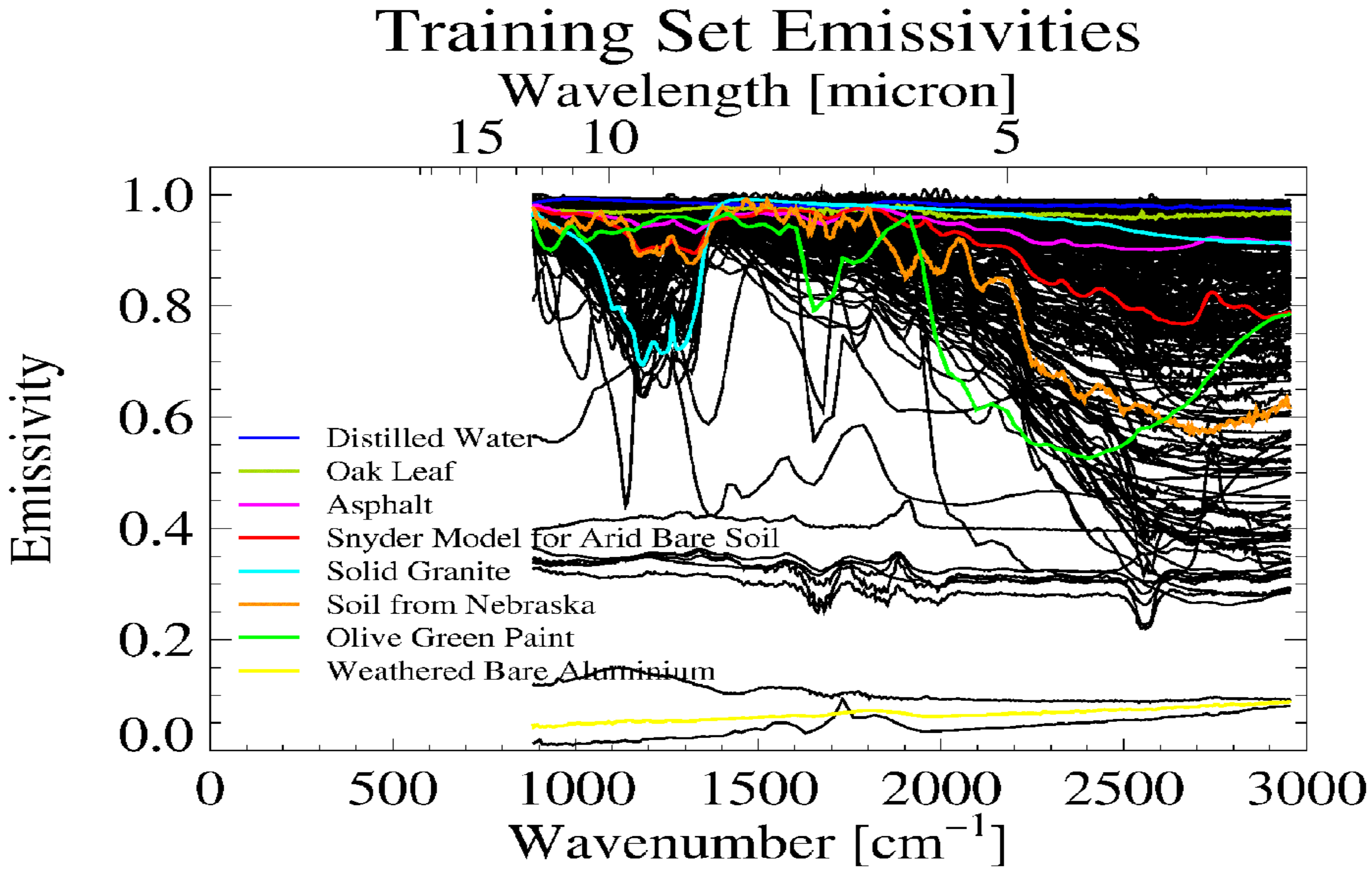
PC scores depend on the actual atmosphere state: Only they need to be re-calculated (‘Calculation *in EOF space*’) – dealing in Principal Components means by definition there are no issues with correlated errors.

So represent ~8500 channels with ~100 leading Principal Components.

How to deal with Surface Emissivity

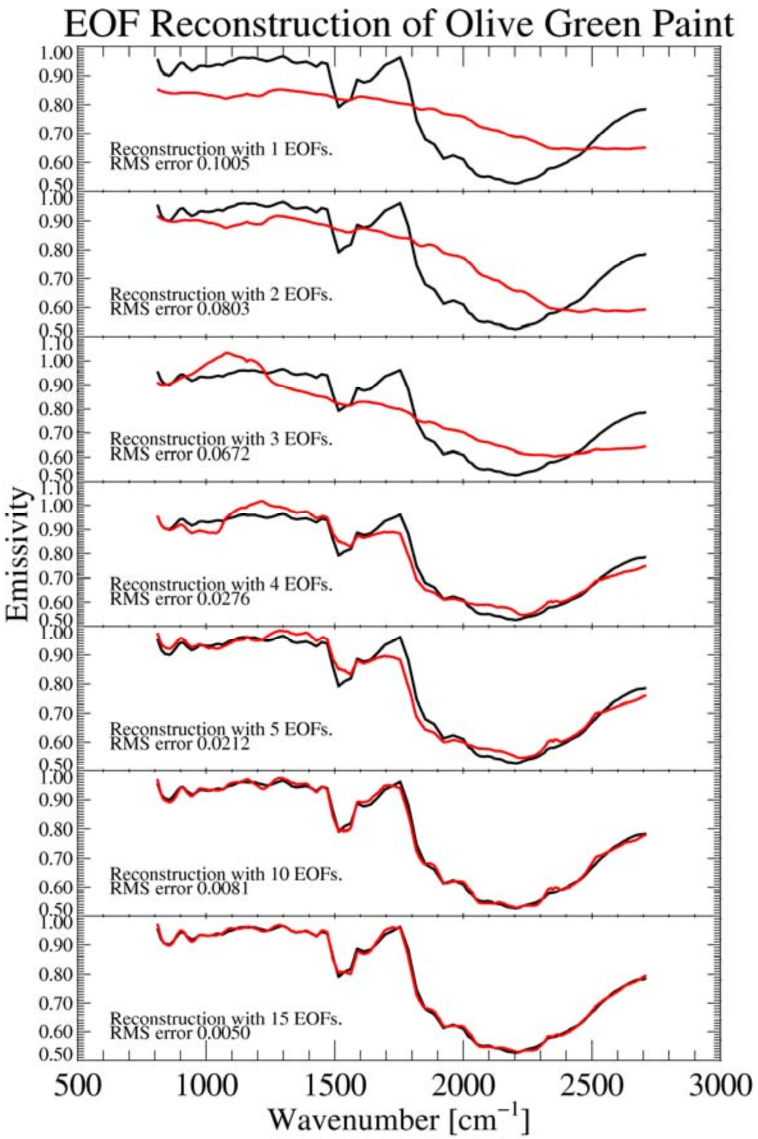
- IR sounder data in some spectral regions is sensitive to the temperature and emissivity of the surface
- Over the ocean this is well known and hence we are easily able to use data here
- Over land/sea ice/snow the emissivity is highly spectrally variable and prior information is not sufficient.

Surface Emissivity



PC Representation of surface emissivity

- Within HT-FRTC we represent the spectrally variable surface emissivity in terms of 10-15 Eigenvectors that capture the key variability in the emissivity spectra



Met Office

Couple HT-FRTC to 1d-Var

1st 100 PCs of Obs spectra

Havemann-Taylor Fast Radiative Transfer Code
Works in PC space

1d-Var

Prior info – NWP fcst

Output profiles of:
- Temp(z)
- Wat Vap (z)
- Ozone (z)
- Surf Temp T*
- 15 Emissivity PC scores

1d-Var – minimization of the cost function

x = atmospheric state
T(z), q(z), O3(z), T*, E(PCs)

y = observations
Represented as PCs of the Radiance spectra

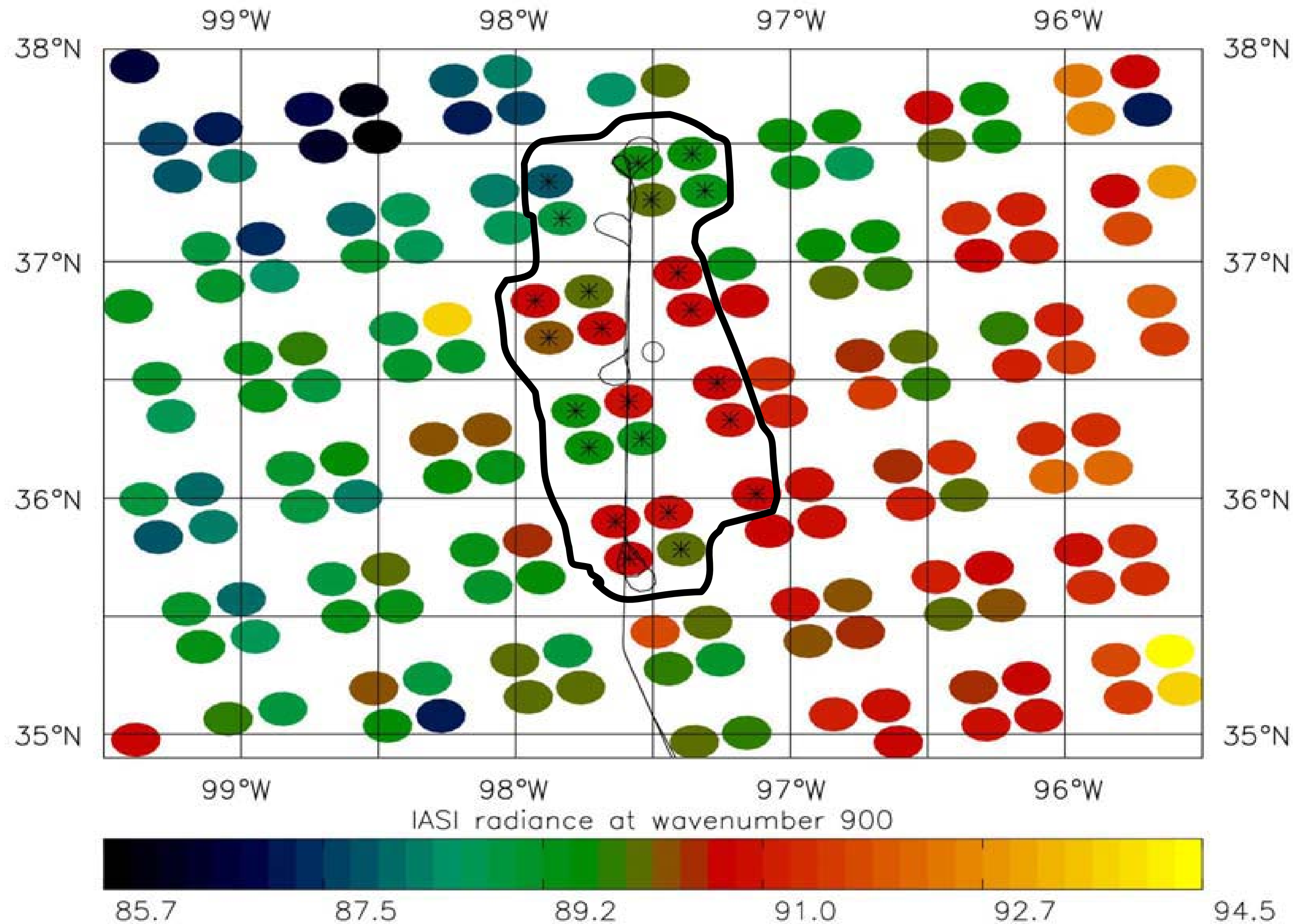
$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x_0})^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_0}) + (\mathbf{y}-\mathbf{y}(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}-\mathbf{y}(\mathbf{x}))$$

B = Error covariance of Background profile – extended to include a block matrix with the error covariances of the surface emissivity PC scores

R = Error covariance of measurements – extended to include the error covariances of the sum of the observational and model errors in Principal Component Space

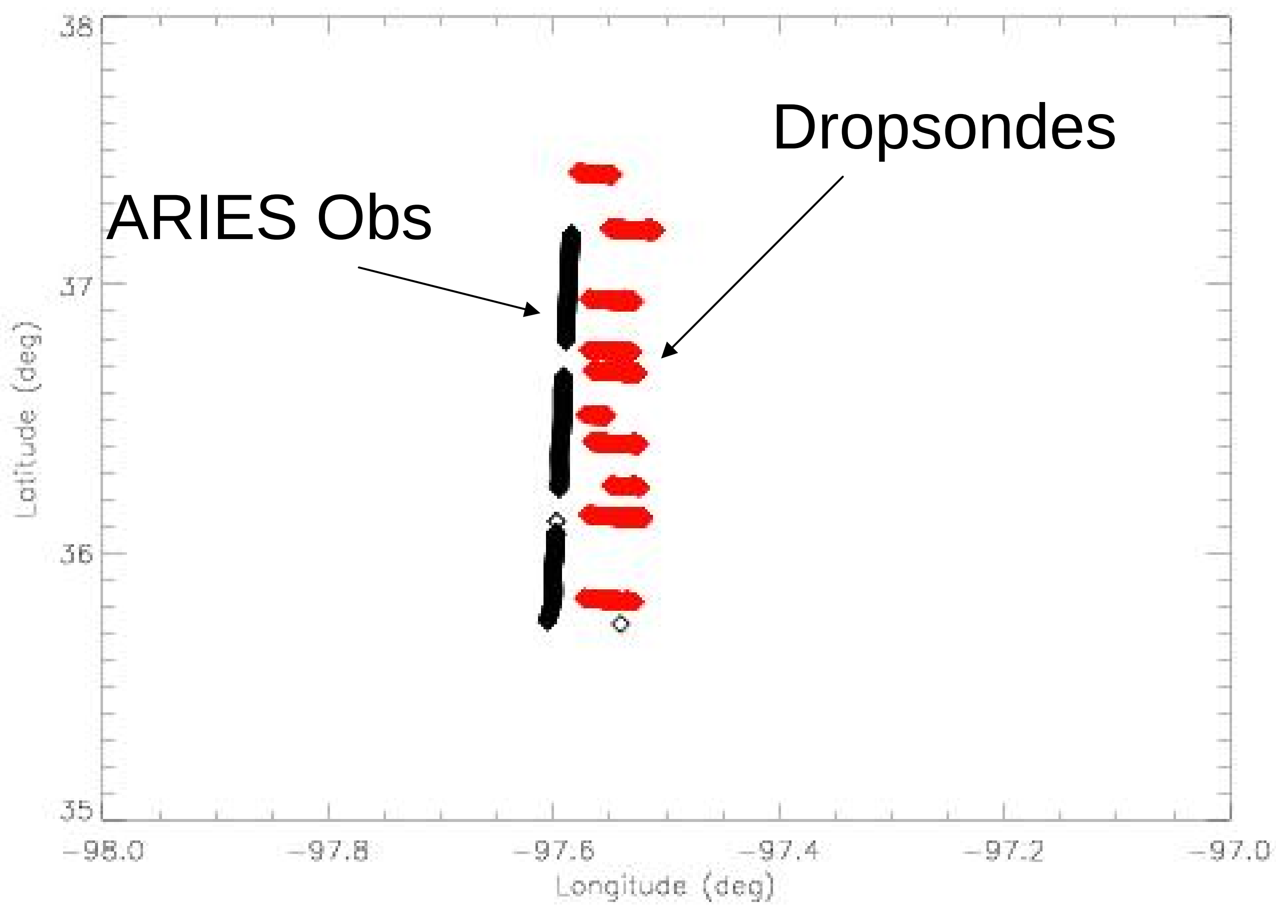
Flight B284 18/19 Apr 2007 ARM Site – Night time.

- Low level run at 3000ft, Emissivity and Surf temp retrieval using upwards and downwards views with ARIES interferometer.
- Profile from 3000ft to 35,000ft measuring T, q, O3, CO , aerosols etc.
- Run at 35,000ft coordinated with WB-57 and IASI overpass, dropped 11 dropsondes.
- Will show 1d-Var results using ARIES data gathered at 35,000ft – using 4948 channels from ARIES represented as their PCs.
- Will show 1d-Var results using IASI data – all 8461 channels represented as their PCs.

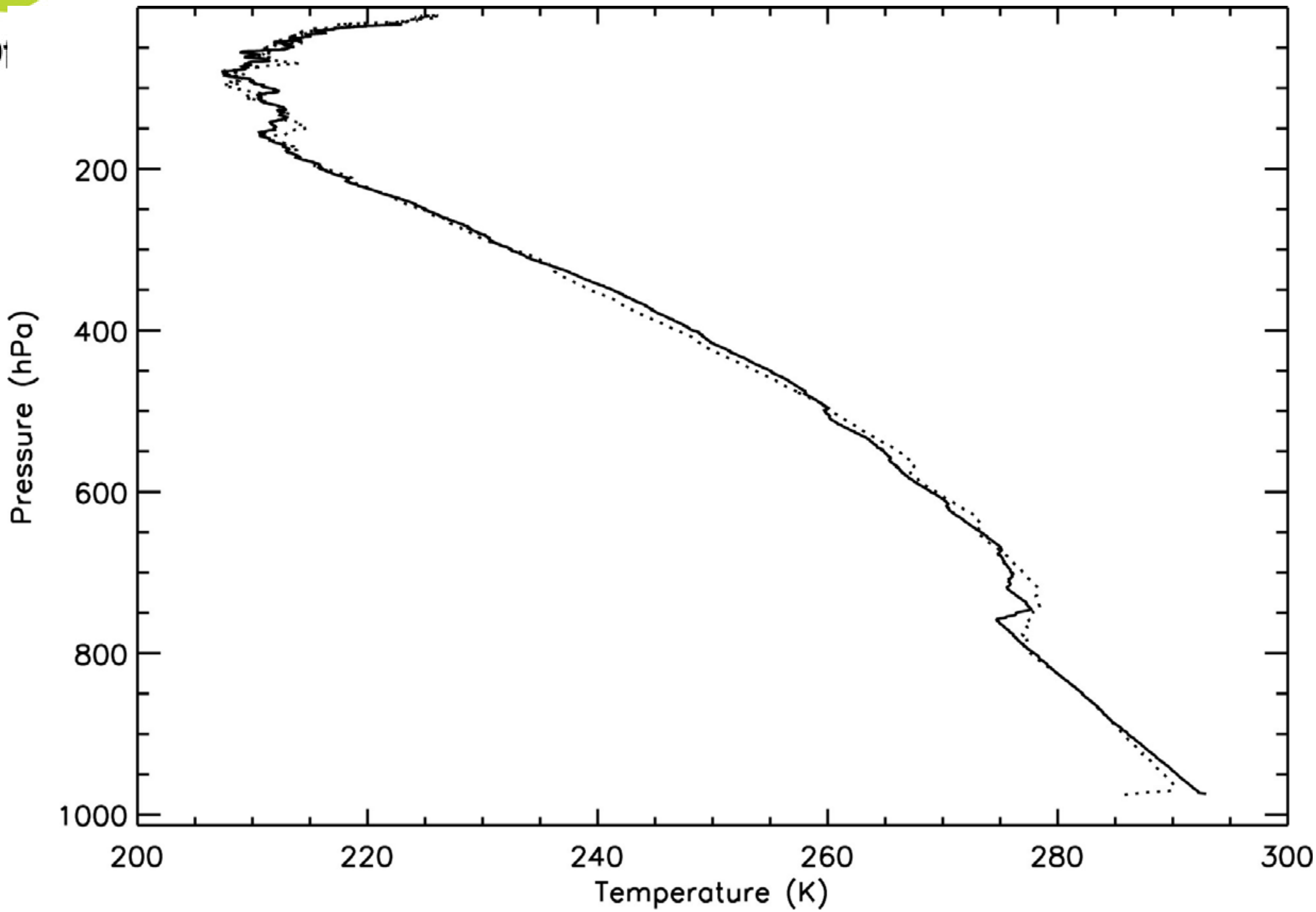


Metop overpass 0335UTC 19th April 2007

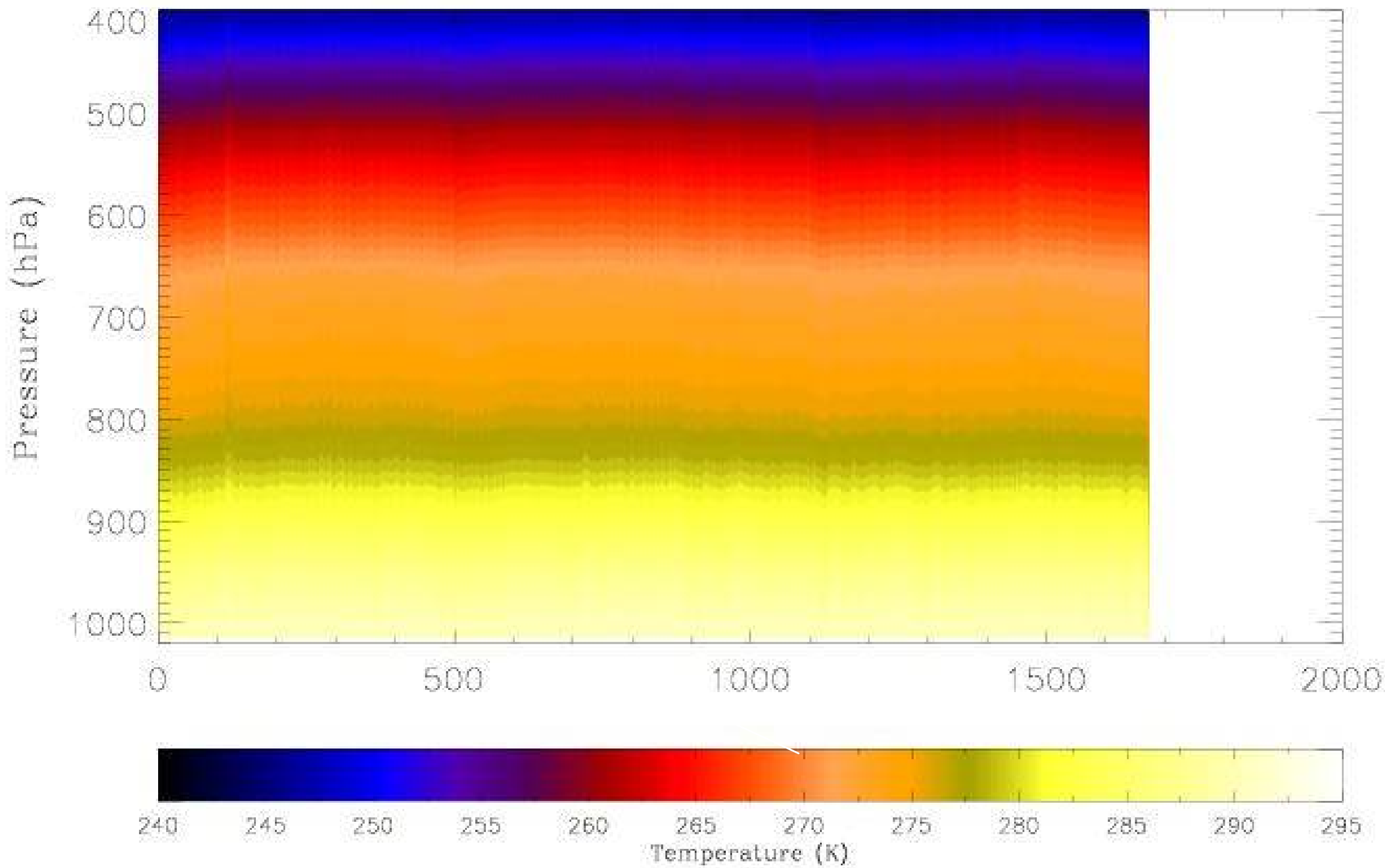
Location of observation data



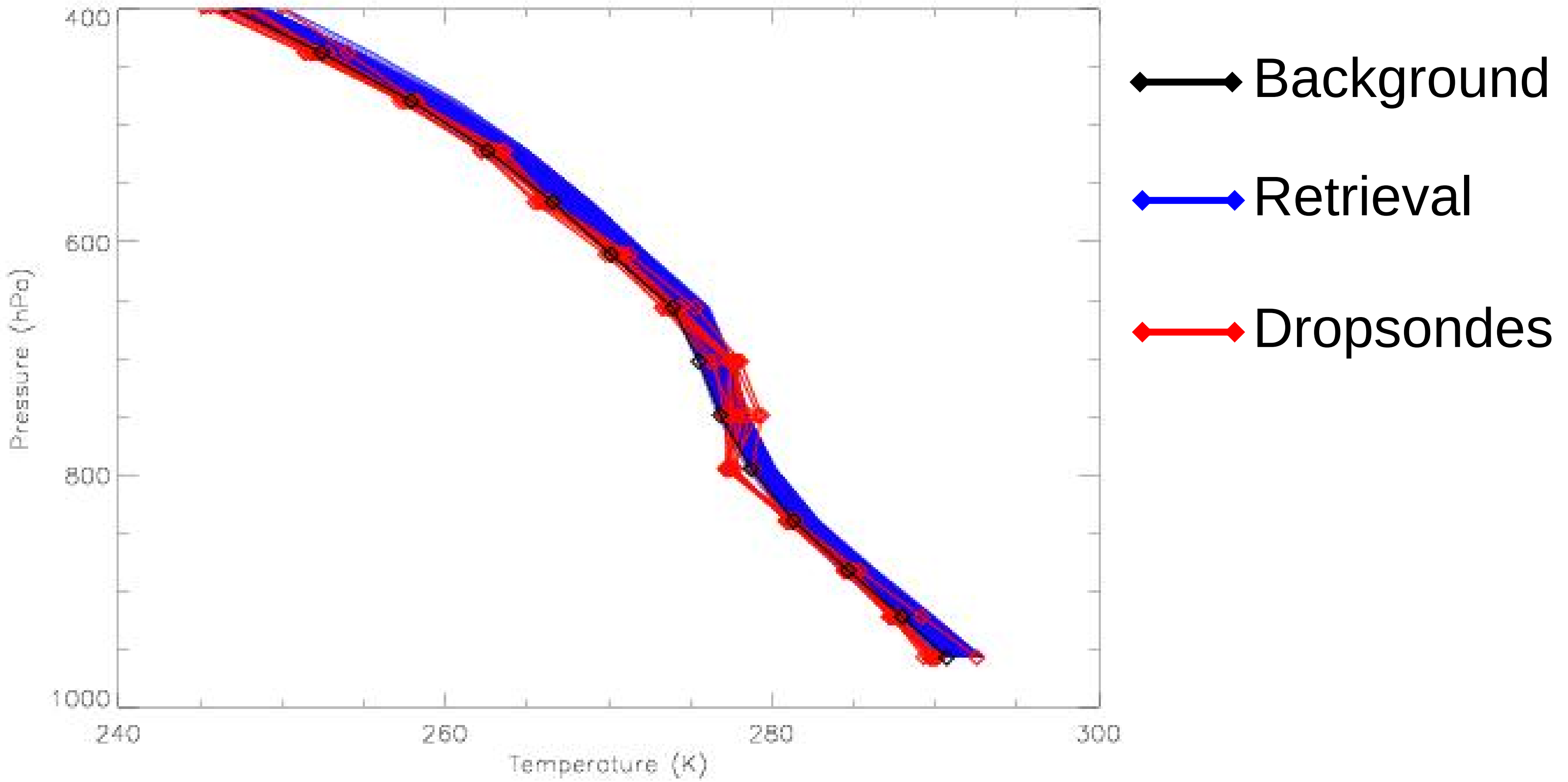
ARM Site Radiosondes - Temp



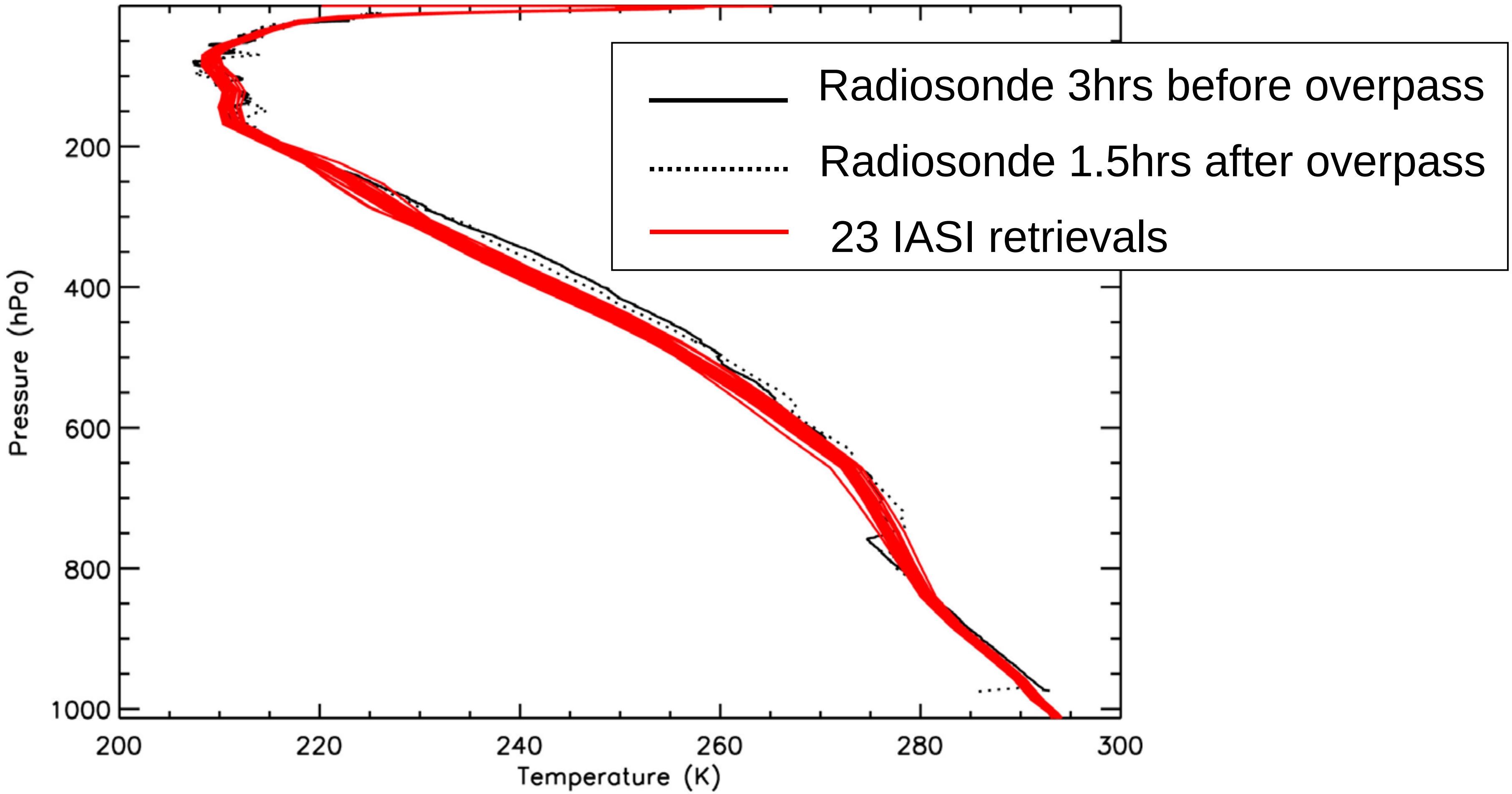
ARIES Temperature Retrieval



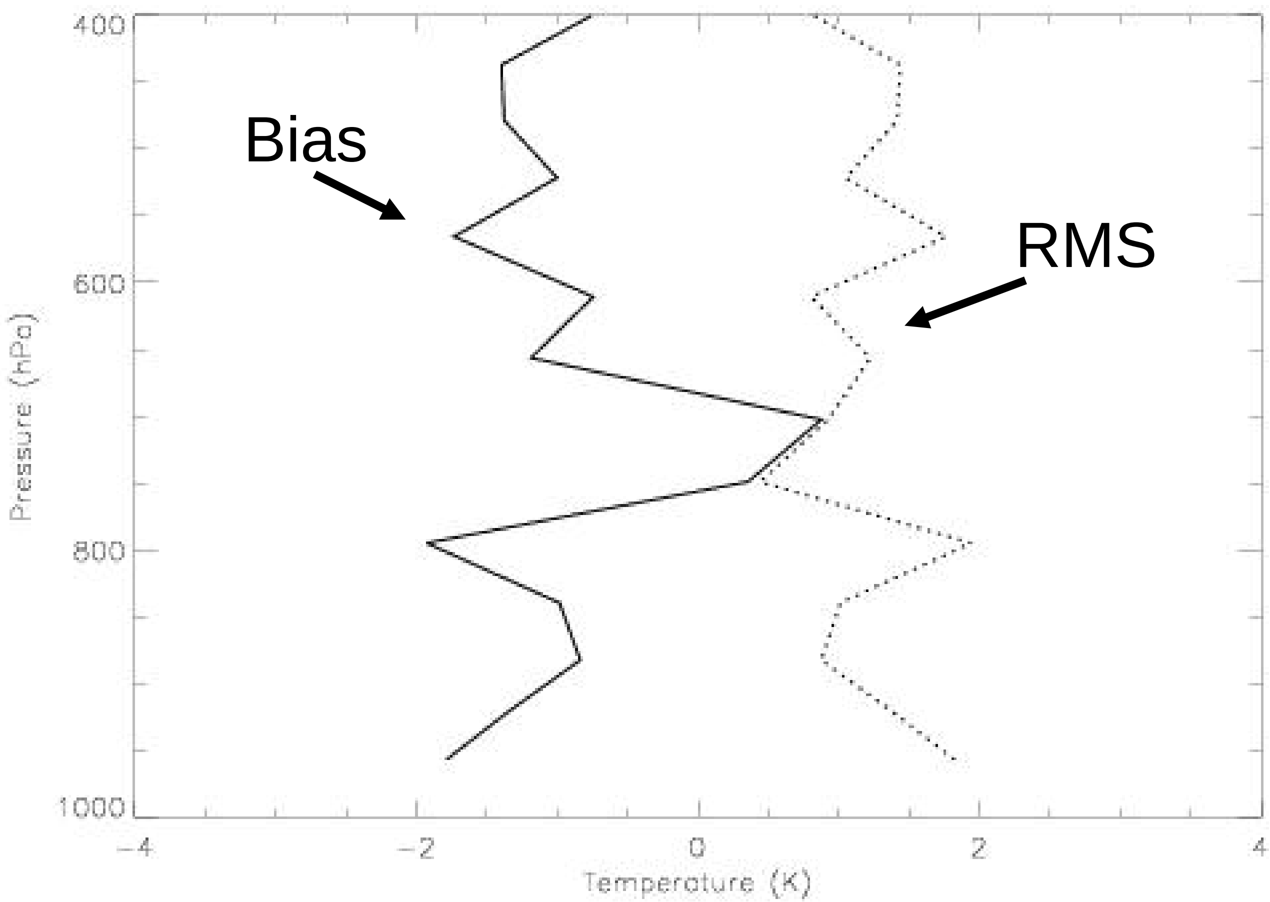
ARIES Temperature Retrieval



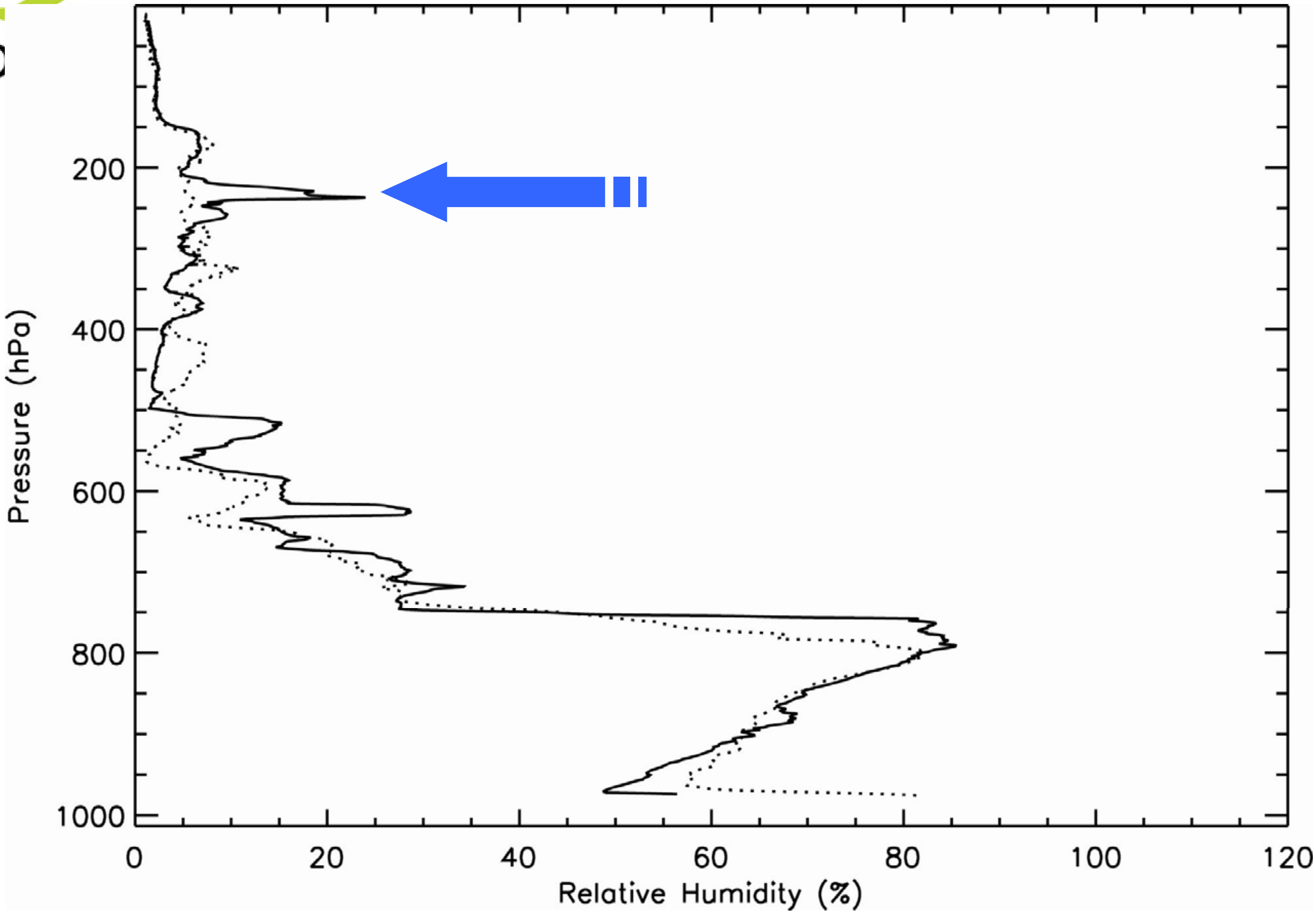
IASI – Temperature retrievals



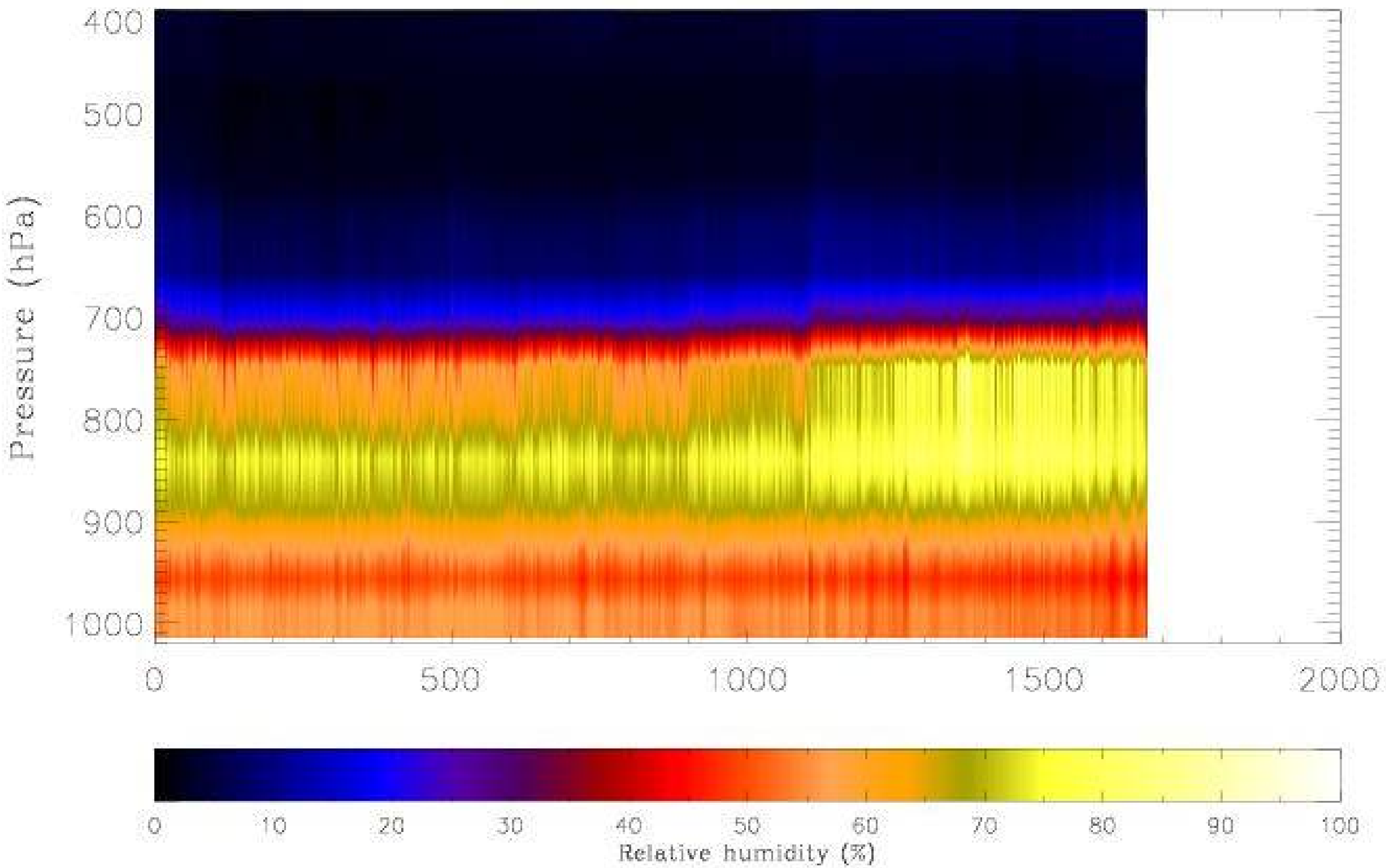
ARIES Temperature Retrieval



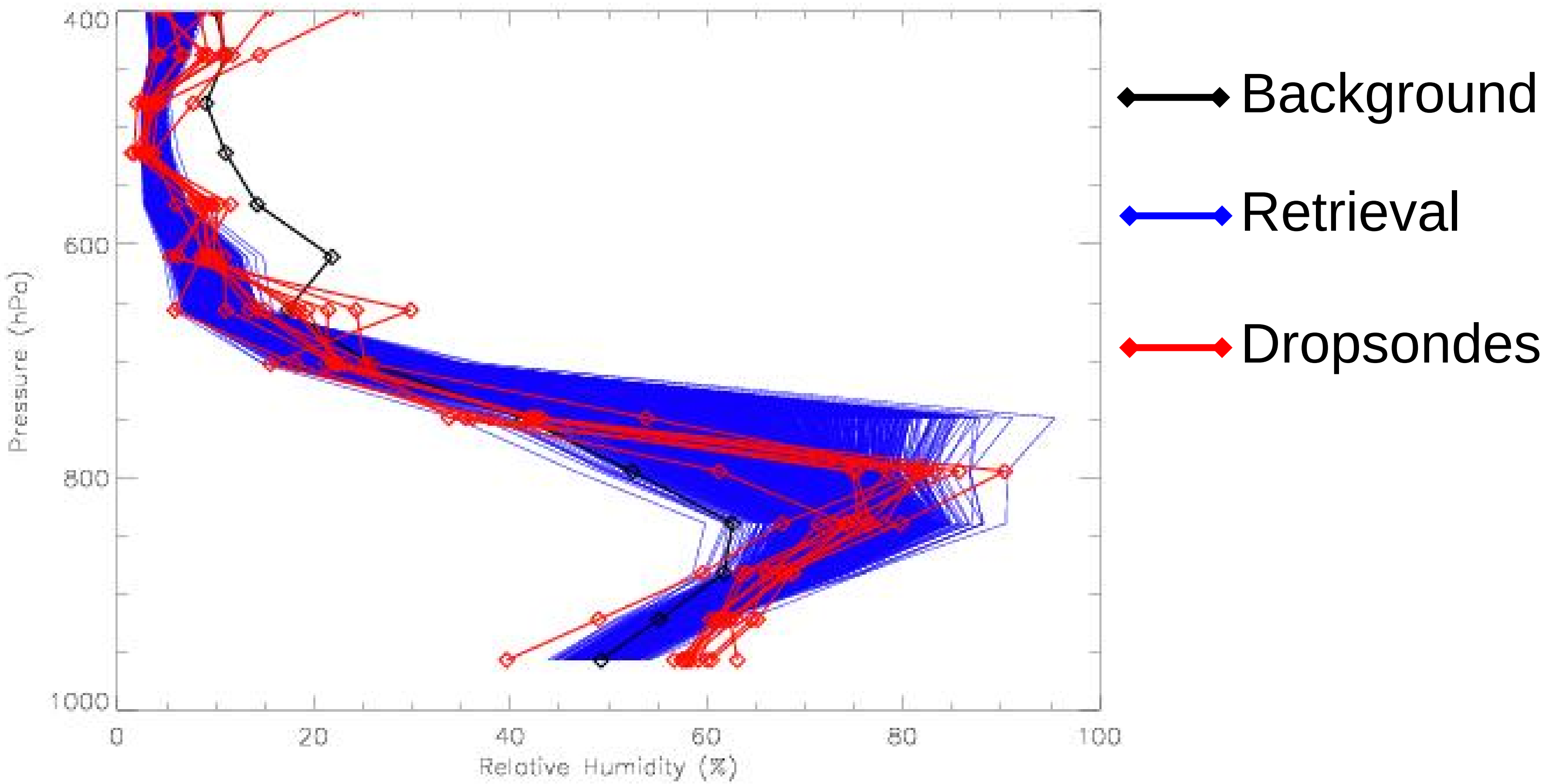
ARM Site Radiosondes - RH



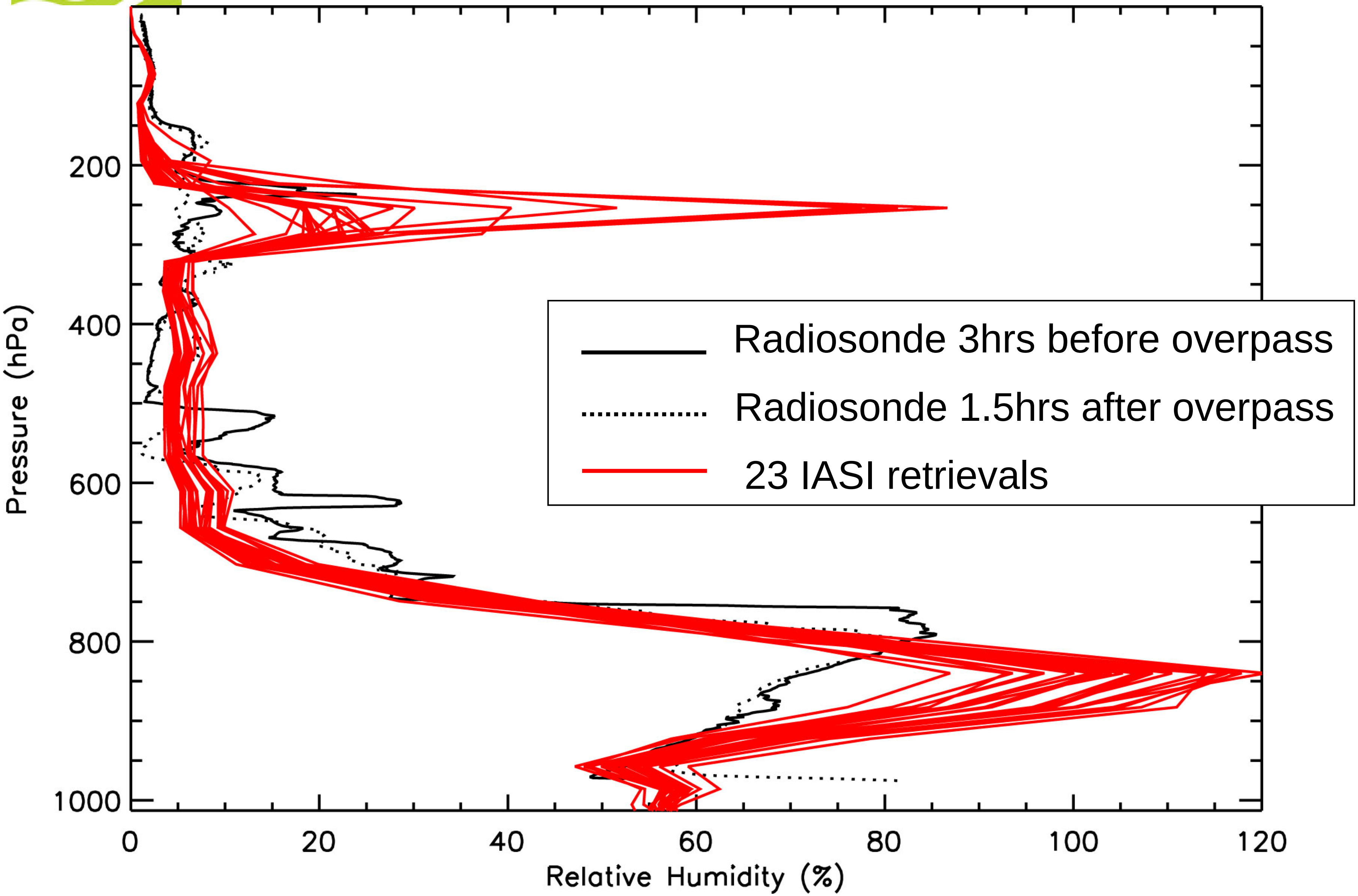
ARIES Water Vapour Retrieval



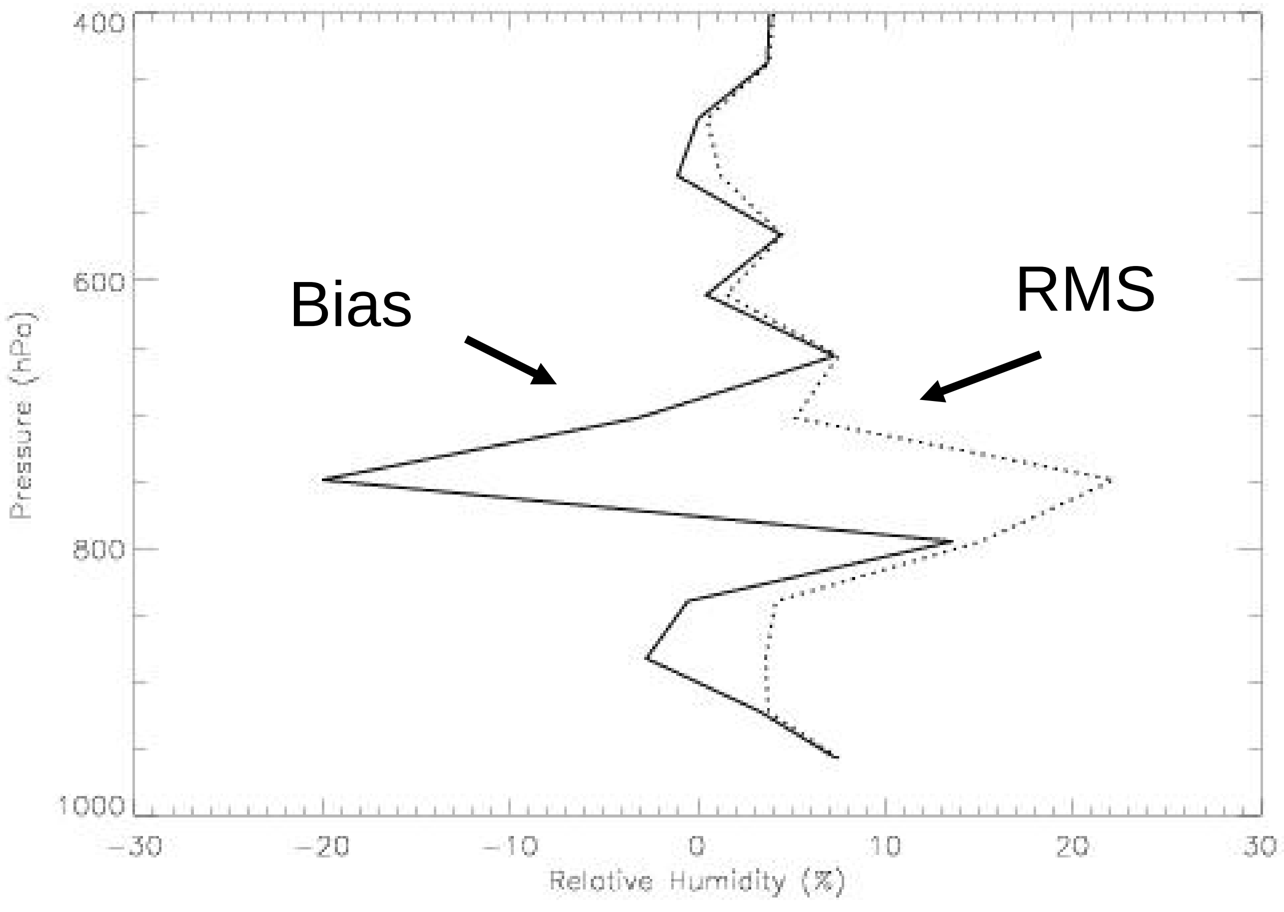
ARIES Water vapour retrieval



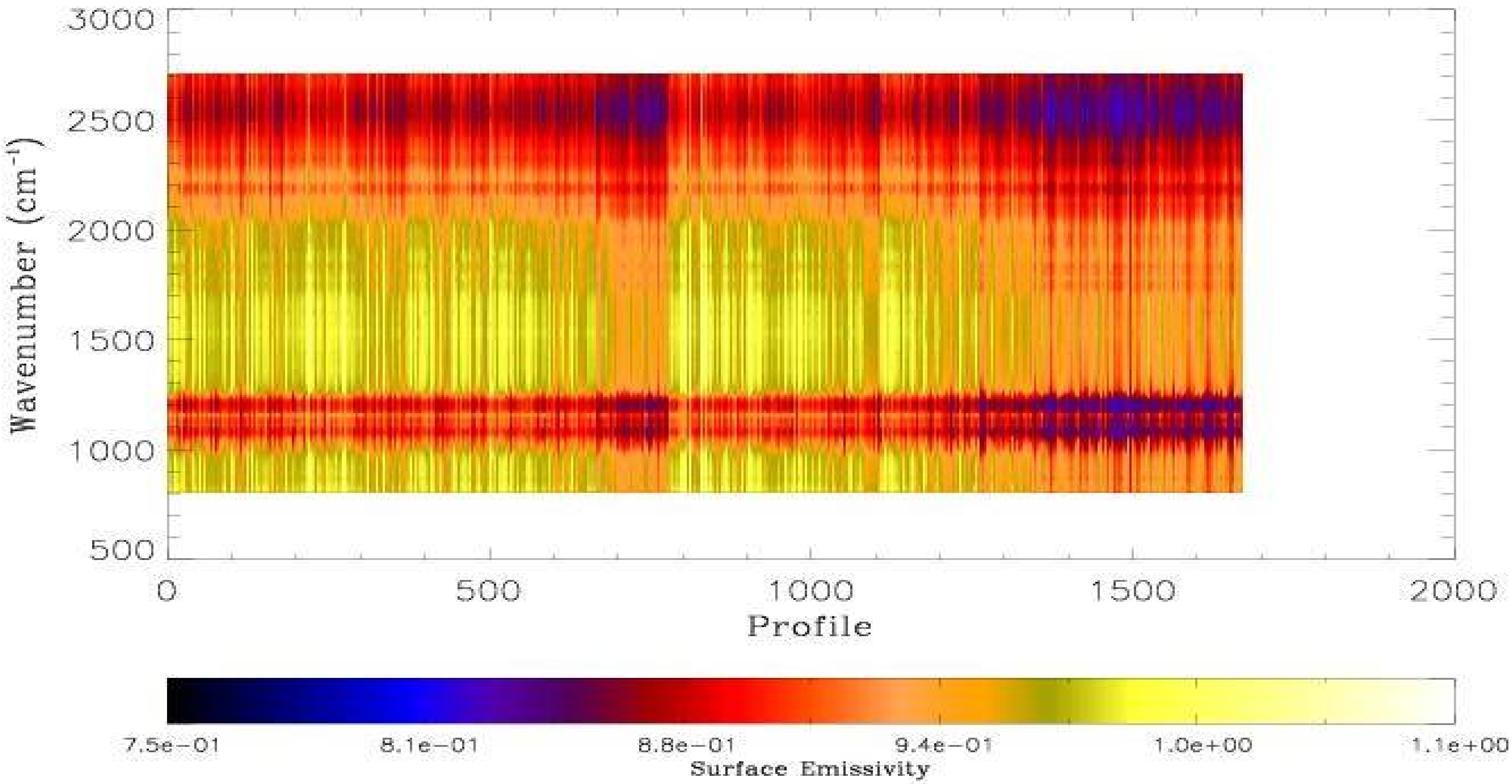
IASI- RH Retrievals



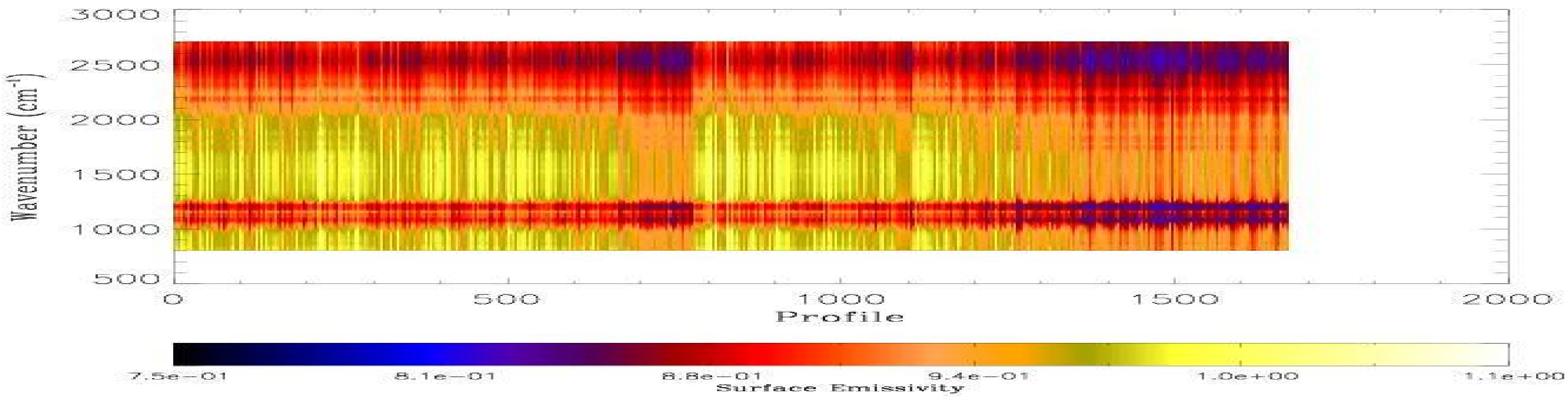
ARIES Water vapour retrieval

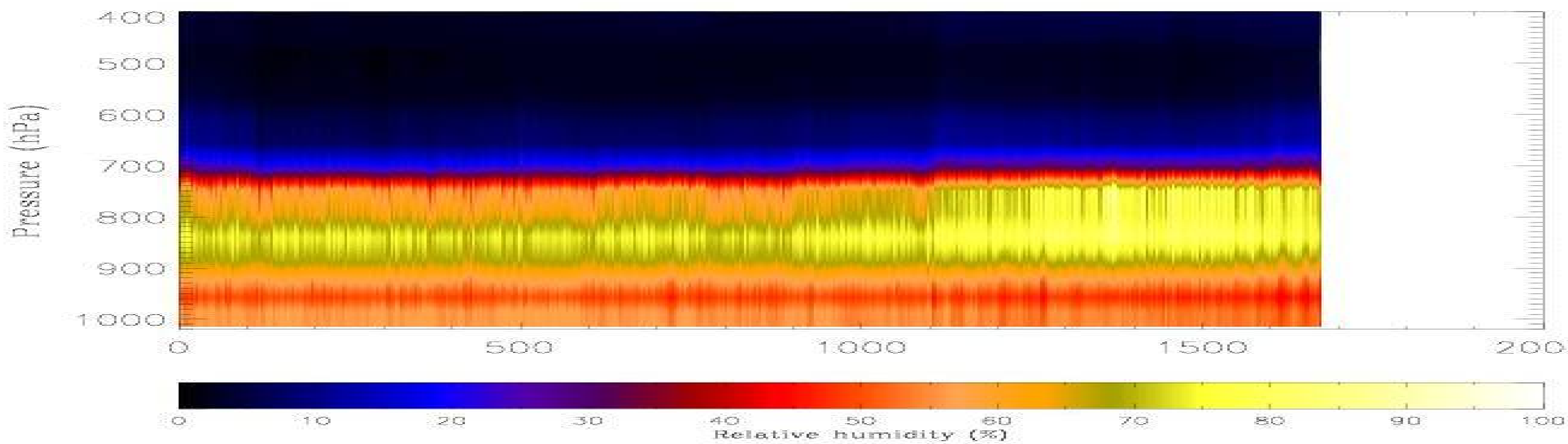


ARIES 1d-Var Emissivity Retrieval

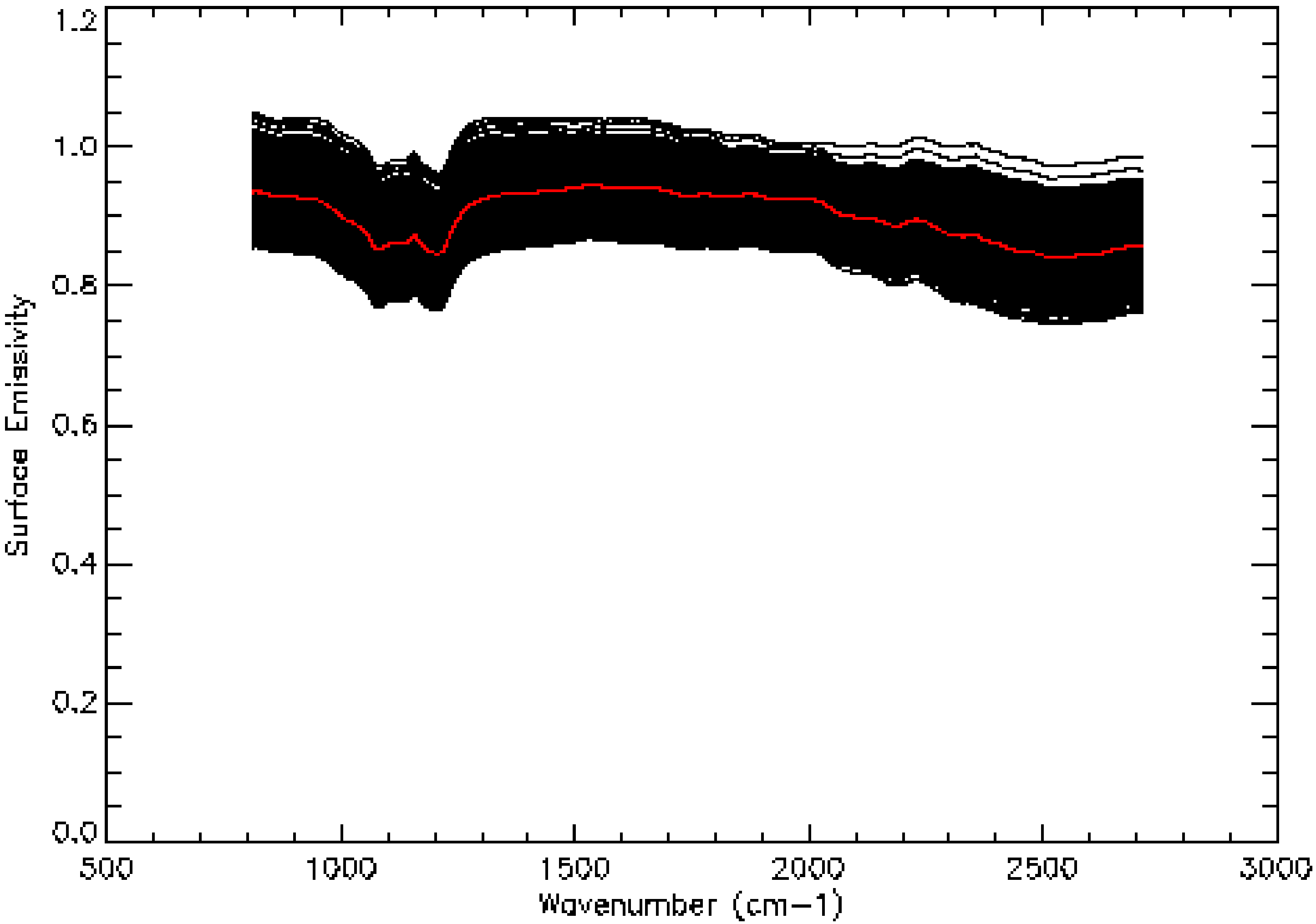


1d-Var Emissivity Retrieval





ARIES Emissivity Retrieval (2)



ARIES fov from 35,000ft is ~450m

ARIES emissivity retrievals

- Radiance leaving sea surface is

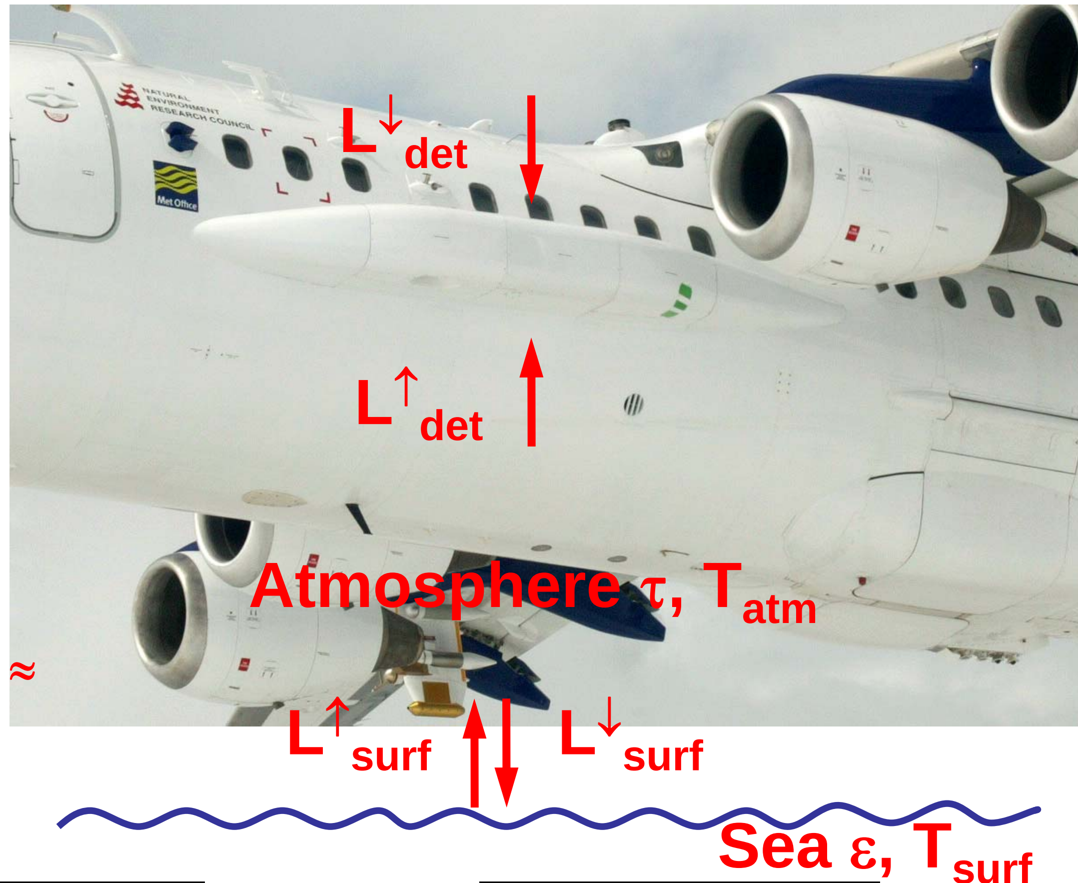
$$L^{\uparrow}_{surf} = \varepsilon B(T_{surf}) + (1-\varepsilon)L^{\downarrow}_{surf}$$

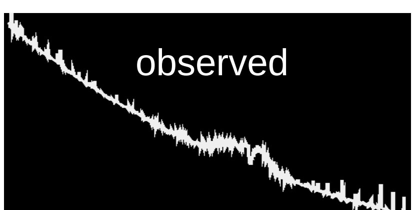
- Solve for r = (1–ε) to reproduce smooth surface radiance:

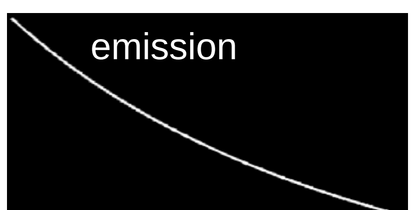
$$L^{\uparrow}_{surf} - r.L^{\downarrow}_{surf} = \varepsilon B(T_{surf})$$

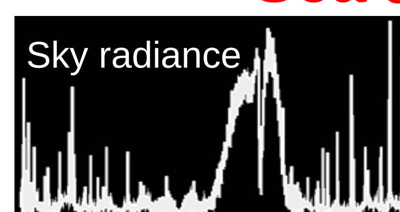
- Important to include effects of intervening atmosphere:

$$L^{\uparrow}_{det} = \tau L^{\uparrow}_{surf} + (1-\tau)B(T_{atm}) \qquad L^{\downarrow}_{det} \approx L^{\downarrow}_{surf}$$

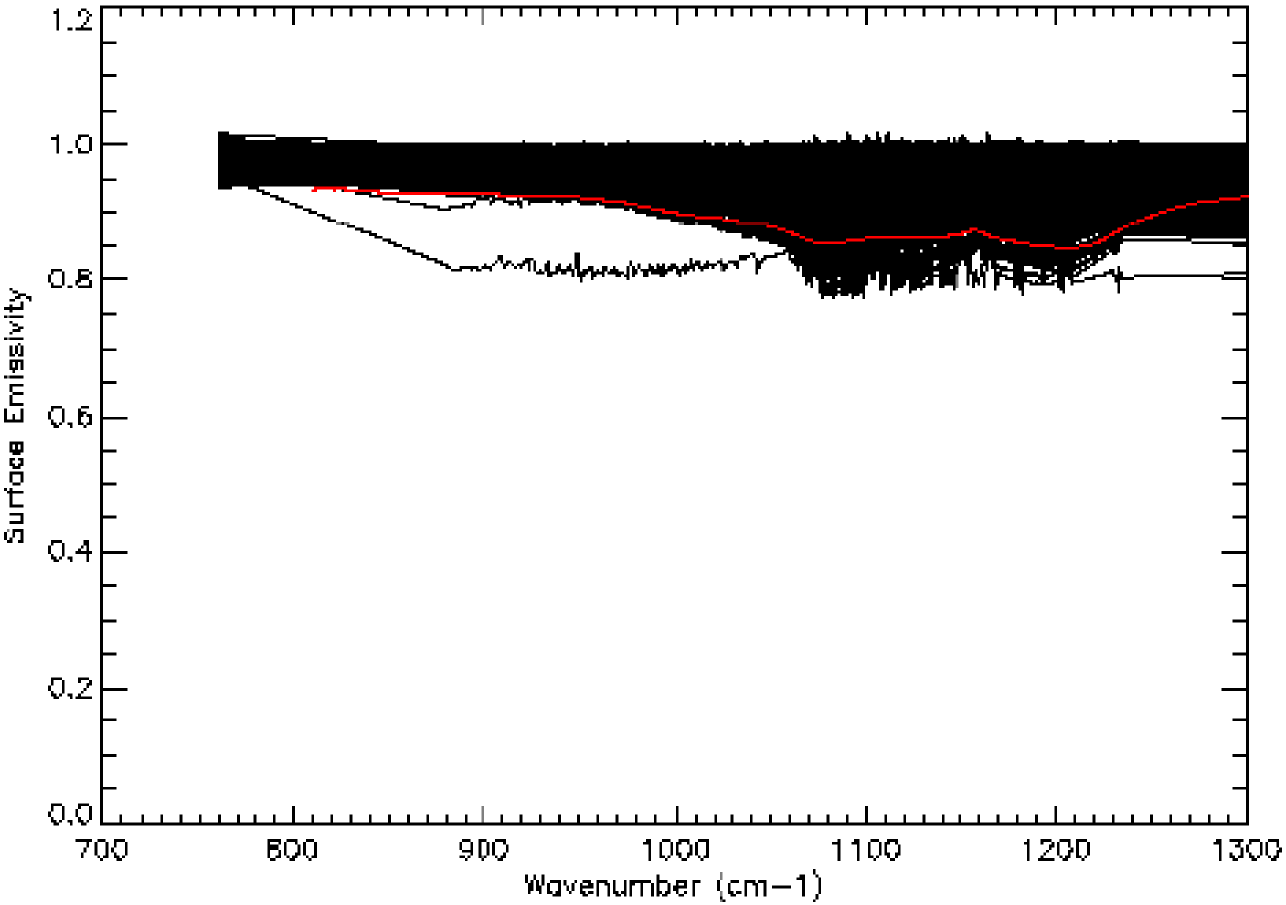








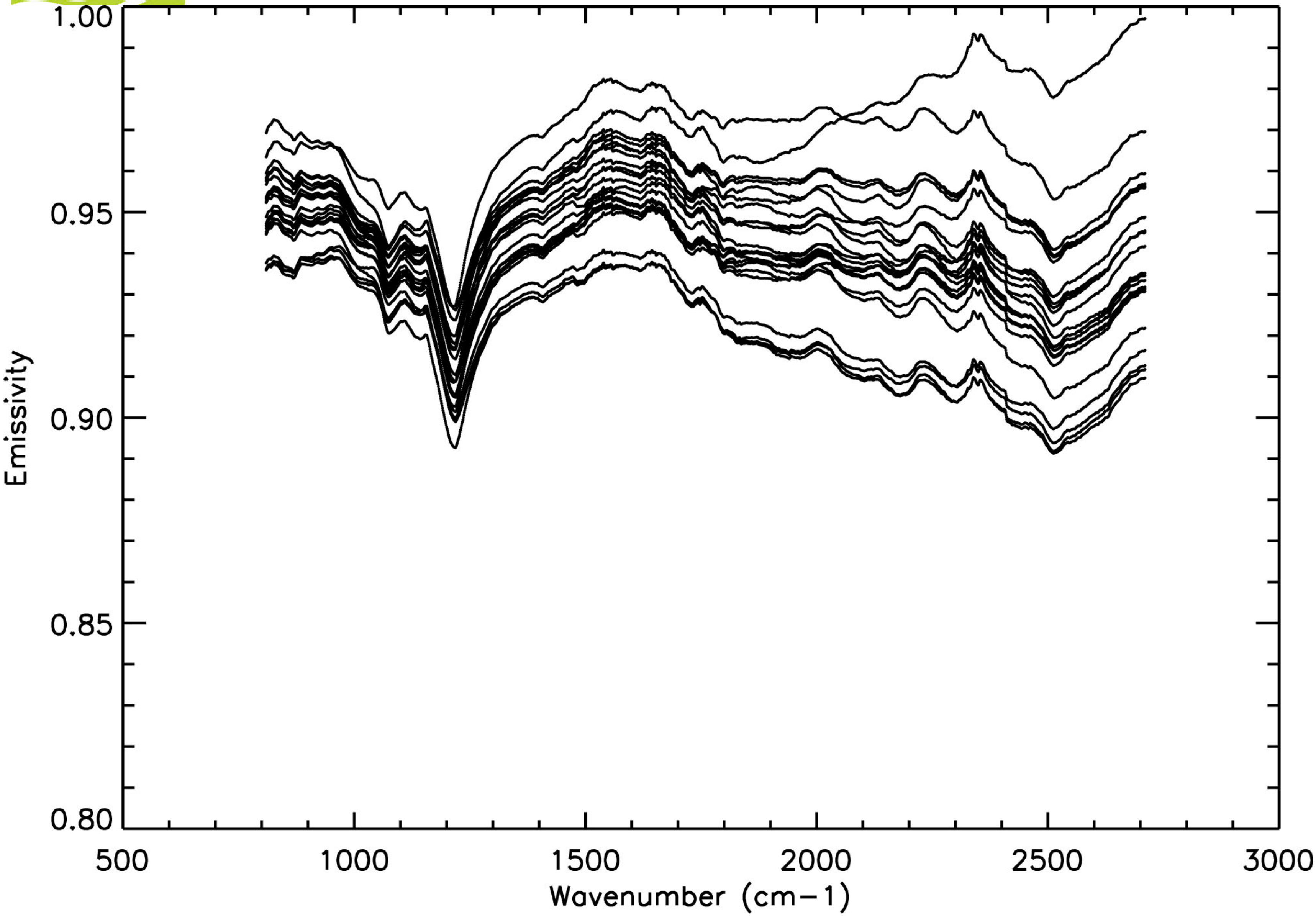
ARIES Emissivity Retrieval (3)



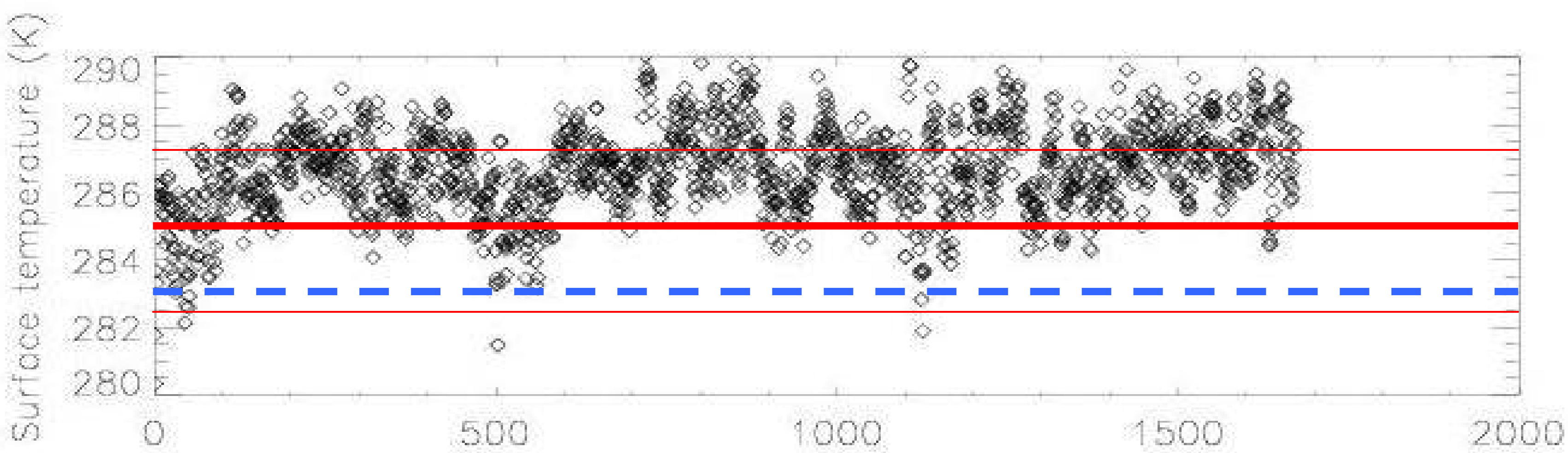
ARIES measurements
At low level have an fov 40m so able to resolve
Small features

Red line is average
Of 1601 retrievals from 35,000ft

IASI – Surface Emissivity Retrievals

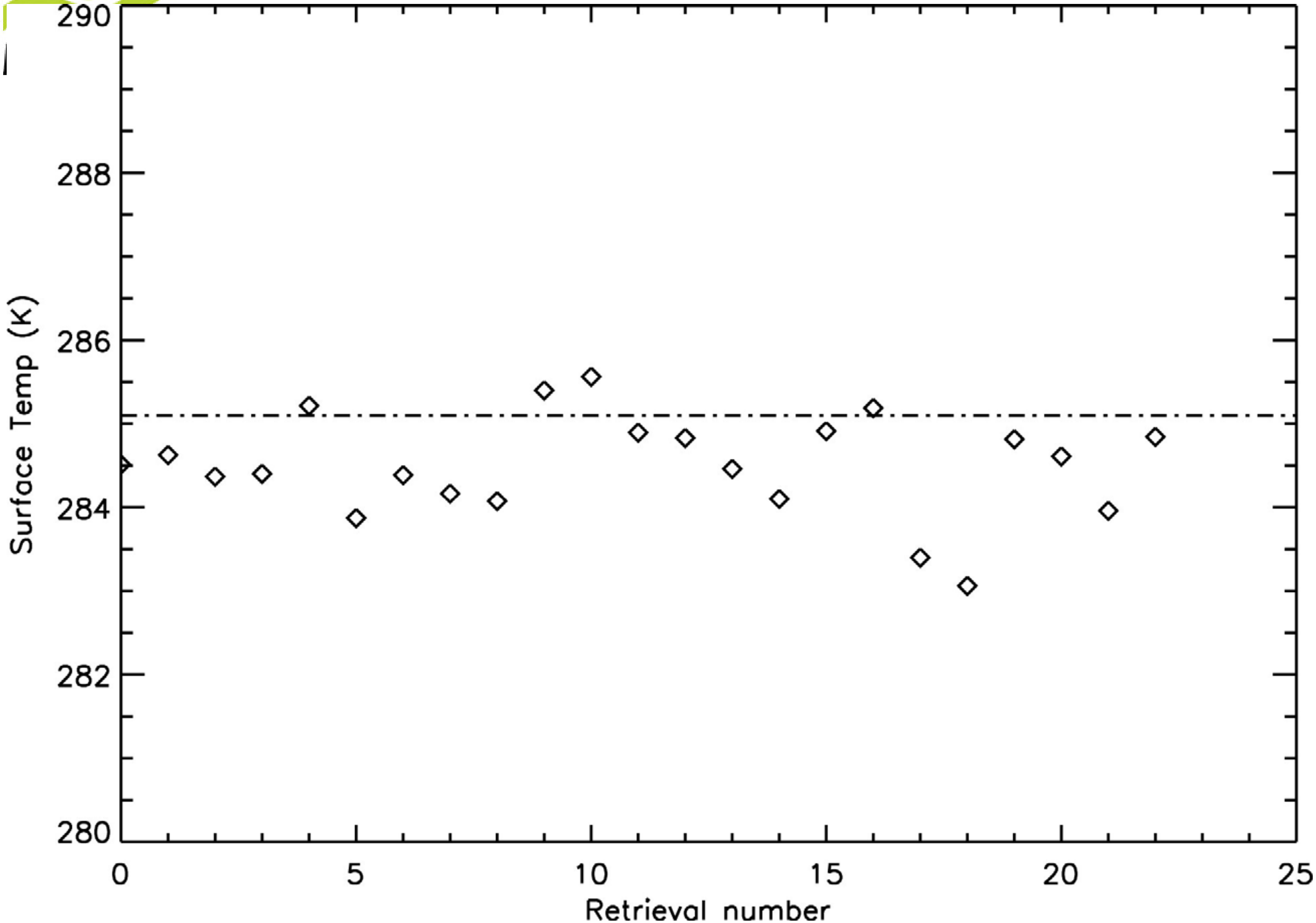


ARIES Surface Temperature Retrieval



Low level data before high level – mean +/- 1 st devn. First guess = 283K

IASI – Surface Temp Retrievals



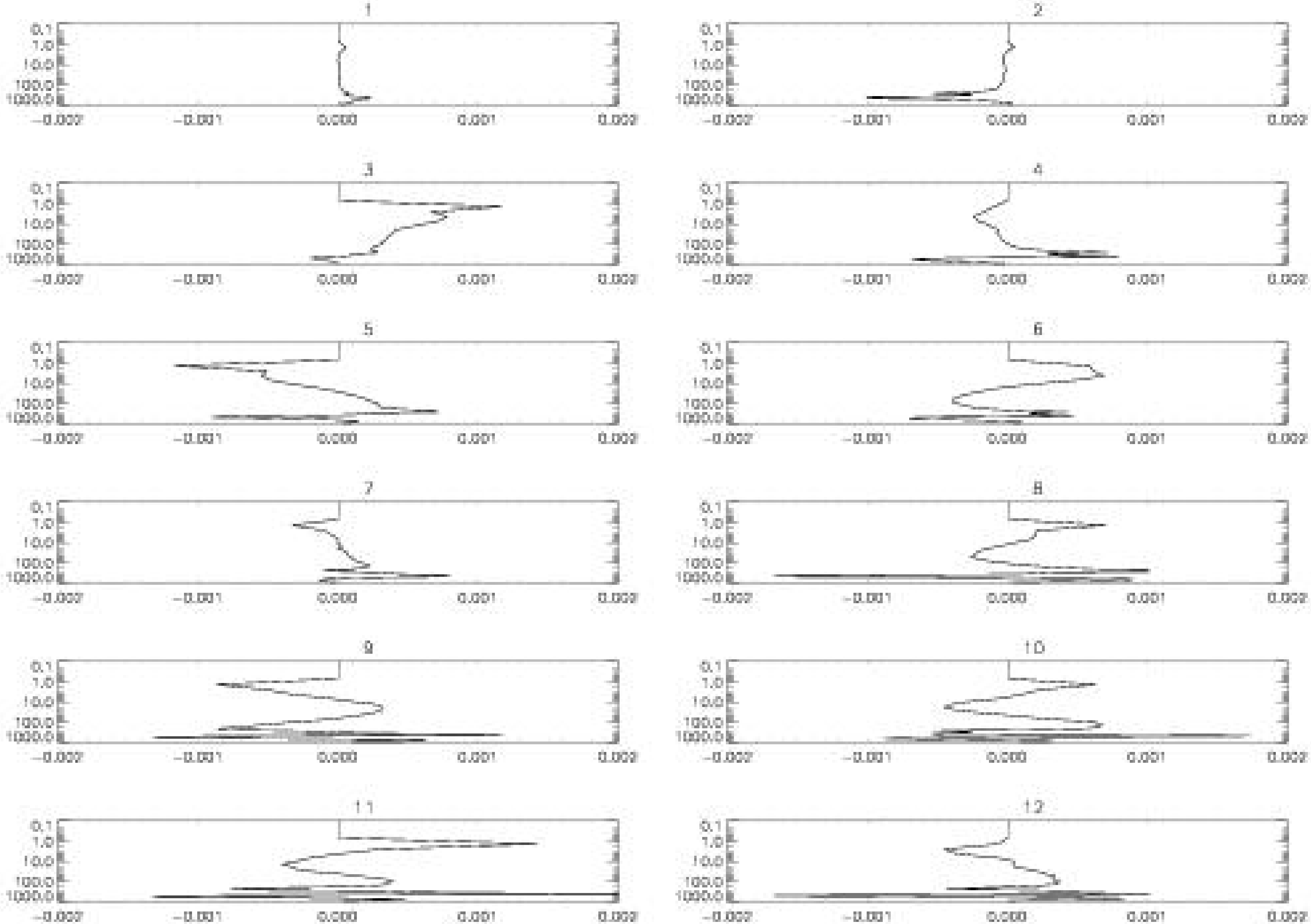
Challenges using IASI data in NWP

- Any one principal component includes information from a range of channels they are sensitive to atmospheric structure at many levels

- Therefore it follows that PC Jacobians e.g. dPC/dT will have significant vertical structure

- In an ideal world where the background error covariance matrix of the model were known exactly this would not cause any problems

- However, in reality our B matrix is not perfect and there are concerns in the NWP community about dealing with these complex Jacobians


1
2
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12
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1.0
10.0
100.0
1000.0
-0.002
-0.001
0.000
0.001
0.002

Summary

- HT-FRTC code performing well
- Successfully coupled HT-FRTC with 1d-Var Scheme – using 4948 ARIES channels and 8461 IASI channels
- Ability of BAe146 to fly low over surface allows measurement of surface emissivity and temperature and coincident drop sondes give “truth” measurements
- 1d-Var retrievals show skill in T, q, T* and Emissivity retrievals (ozone to come)
- Shows that it is possible to use hyperspectral sounder data (1000’s of channels) over any surface has the potential to significantly increase usage of AIRS and IASI data which would increase NWP skill

Future Work

As expected the retrieval is very sensitive to the background error covariance matrix – in particular the elements describing the surface emissivity eigenvectors

To date I have used all 8461 IASI channels – I need to be more selective and discard a few!

ARIES data at low level gives us an independent handle on surface emissivity – need to look at average of all ARIES low level retrievals in each IASI footprint

Need to extend data analysis to more JAIVEX cases plus others e.g. snow and sea ice, desert.

Met Office

Questions and answers