Atmospheric (clear-sky and cloudy) and Surface Retrievals in Principal Component Space using the Havemann-Taylor Fast Radiative Transfer Code (HT-FRTC)

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IASI conference 3rd-8th February 2013, Hyeres les Palmiers

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Introduction

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Motivation

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Traditional radiative transfer models are too time-consuming to deal with modern IR hyperspectral sensors such as:

- **IASI (Infrared Atmospheric Sounding Interferometer): ~ 8000 channels**
- **ARIES ~ 5000 channels**

or SW hyperspectral imagers such as

- **AVIRIS (Airborne Visible/Infrared Imaging Spectrometer): ~ 200 channels + high spatial resolution**
- **Hyperion (SW Imaging Spectrometer): ~ 200 channels + high spatial resolution**

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HT-FRTC capabilities

The HT-FRTC uses principal components, these can be ‘line-by-line’ sensor-independent principal components

Works in the microwave, infrared and short-wave

Does treat water vapour, ozone, carbon dioxide and 50 other trace gases (LBLRTM 12.2)

Does treat any spectrally resolved surface emissivity / reflectance

Does include 20 different aerosols as well as water and ice clouds and liquid and frozen precipitation

Incorporates an exact treatment of scattering as well as the Chou-scaling approximation

Works for any sensor-height, for up and down-looking instruments (air / space borne or ground-based)

Is able to compute radiances, fluxes and transmittances

Includes the solar and lunar source and can account for spherical earth

A full hyperspectral radiance calculation takes less than one millisecond

The HT-FRTC is used in a 1D-Var retrieval system in principal component space

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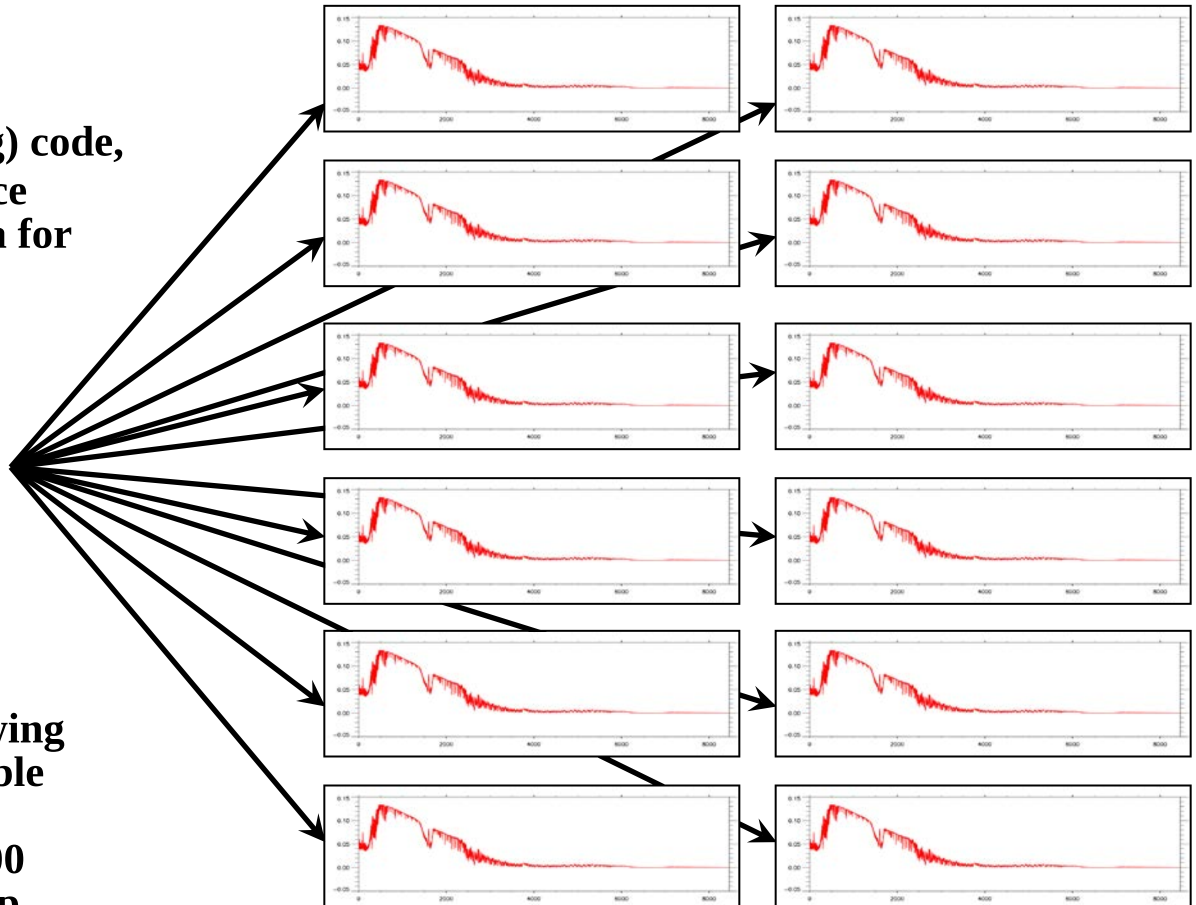
Training the HT-FRTC

Using our accurate **line-by-line** (scattering) code, simulate line-by-line radiance (/transmittance/flux) spectra for many different cases

Line-by-Line Code



This should include as many *realistic* combinations of atmospheric conditions, viewing angles and altitudes as possible

We currently use a set of 1000 ECMWF profiles for this step

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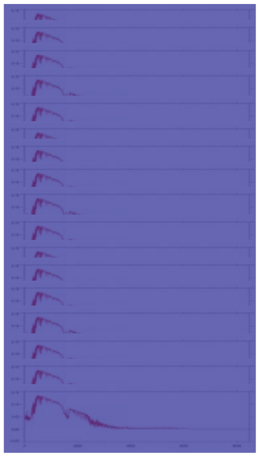
Training the HT-FRTC



n
cases

m line-by-line
frequencies

The set of all the generated radiance spectra are arranged together in a large m x n matrix

We perform Singular Value Decomposition (SVD) on this matrix to obtain the Empirical Orthogonal Functions (EOF), Singular Values (SVs) and Principle Components (PCs)

The SVD is given by $A_{mxn} = U_{mxn} \times \Sigma_{nxn} \times V^{t}_{nxn}$

EOF

Represent the basic characteristics of the sensor and atmosphere

SVs

Sorted by size, give significance of each EOF

PCs

Depend on the actual atmospheric state for each training case

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Training the HT-FRTC

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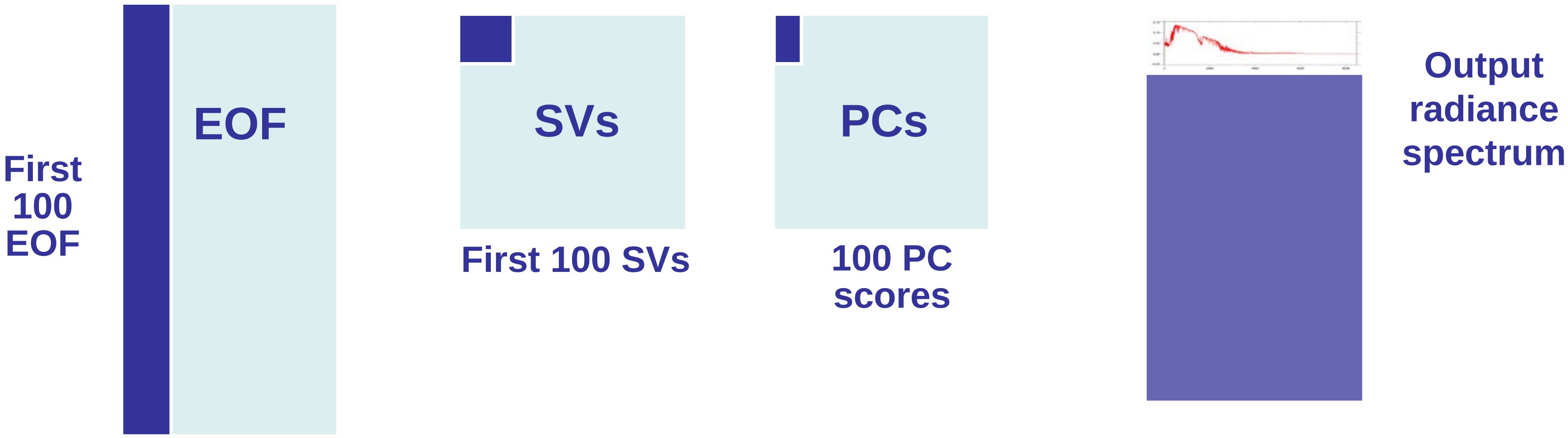
Many of the EOF and SVs can be discarded, since any atmospheric conditions can be represented almost perfectly using only a set of leading EOF, SVs and a set of PC scores

The PC scores for any given atmospheric case can be predicted by performing full line-by-line calculations at a few specific frequencies, inferred from the initial training dataset

A similar process is used to represent surface reflectances, based on a training set of 500 surfaces from the ASTER and USGS spectral libraries

We typically use 100 PCs for the radiances and 10-15 for the surface reflectances



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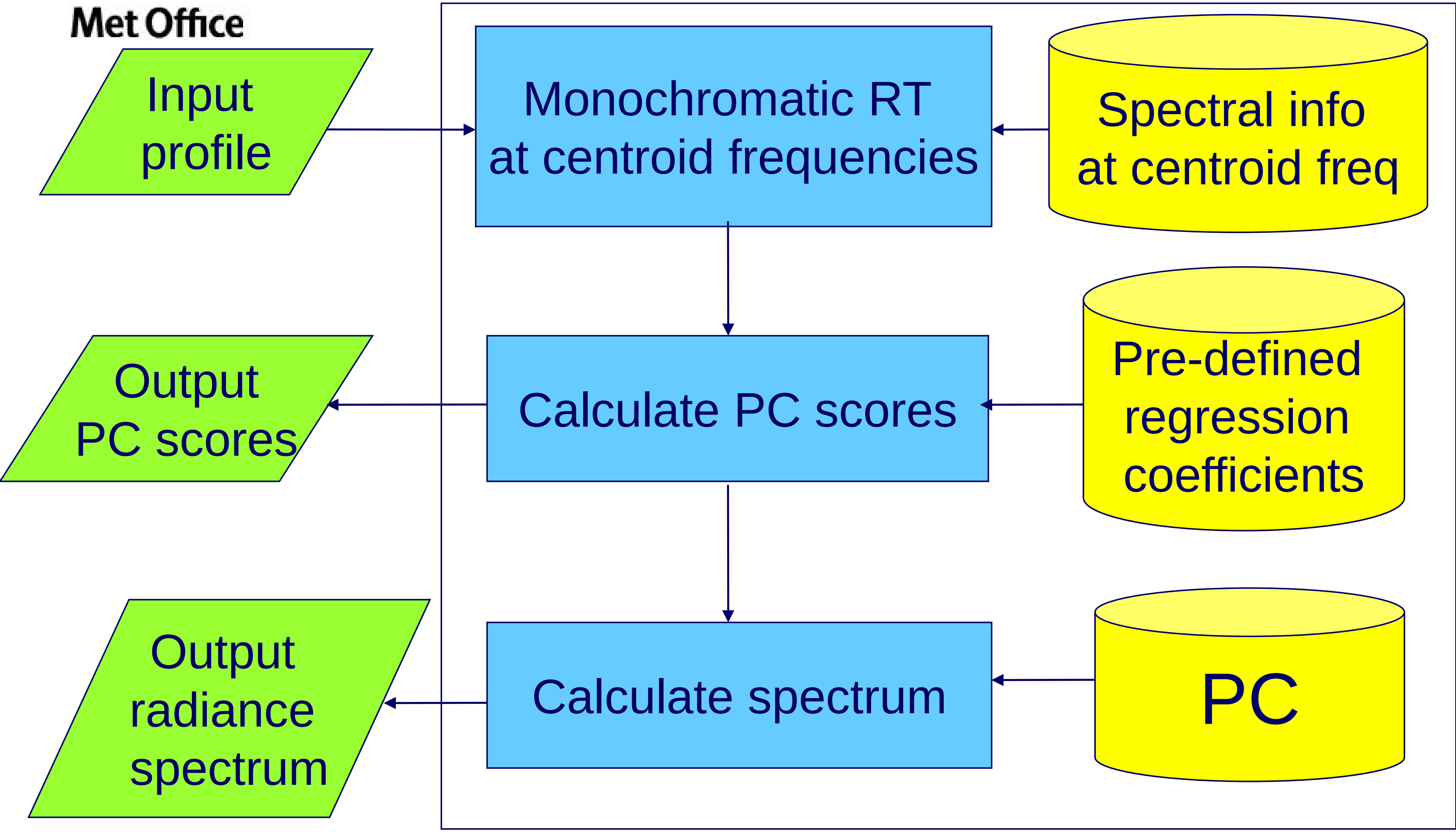
HT-FRTC fast model step



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HT-FRTC accuracy

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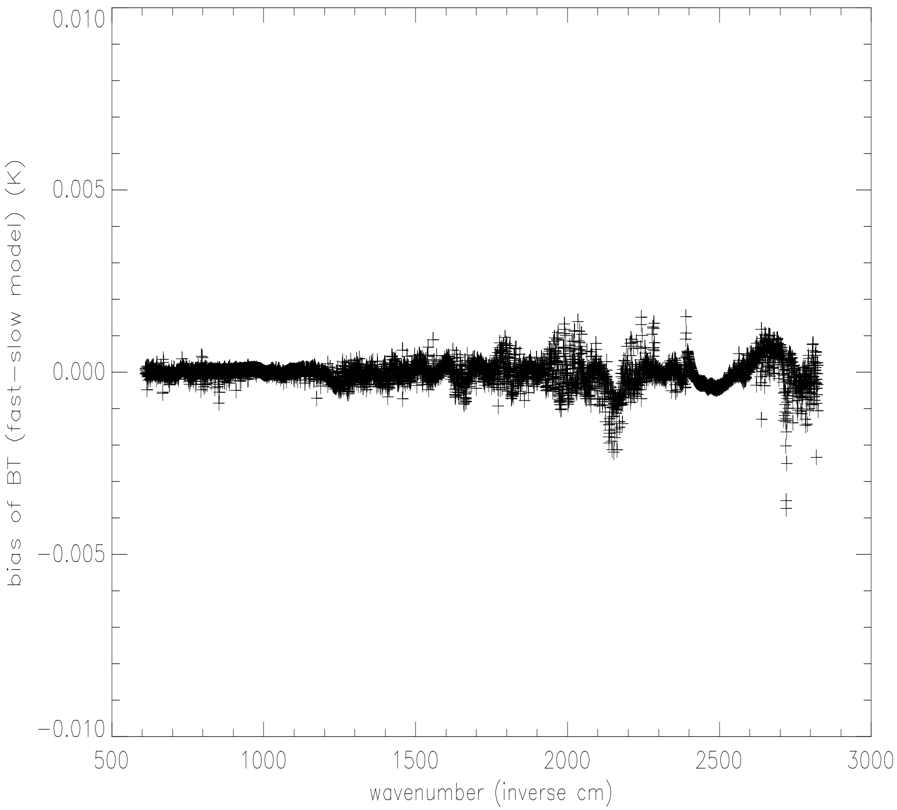
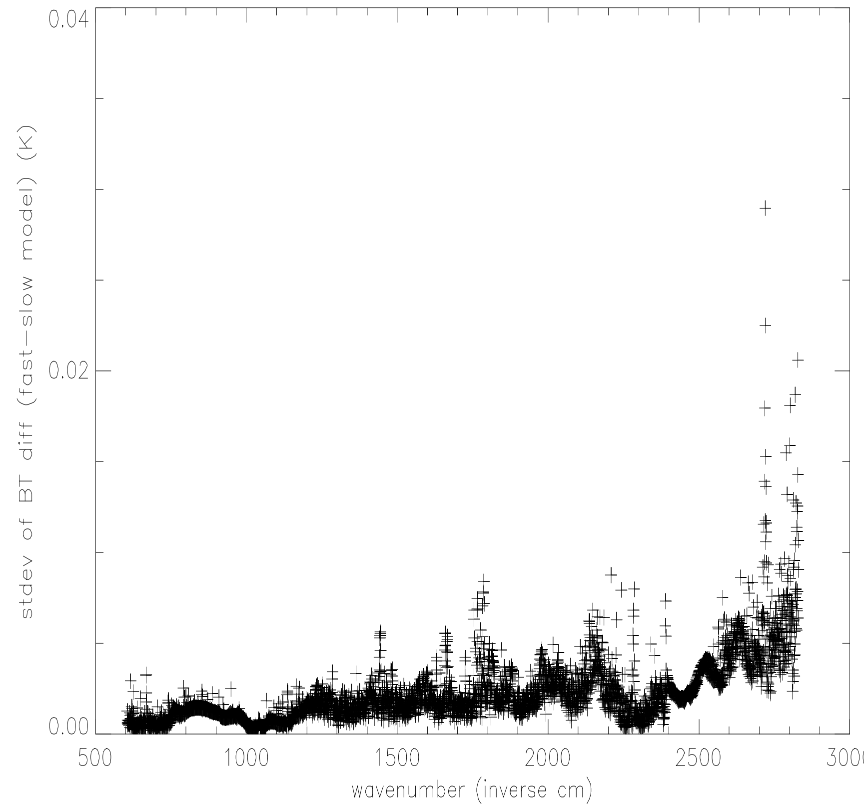
Airborne Research Interferometer Evaluation System (ARIES)





Bias and standard deviation obtained for 100 random independent ECMWF profiles.

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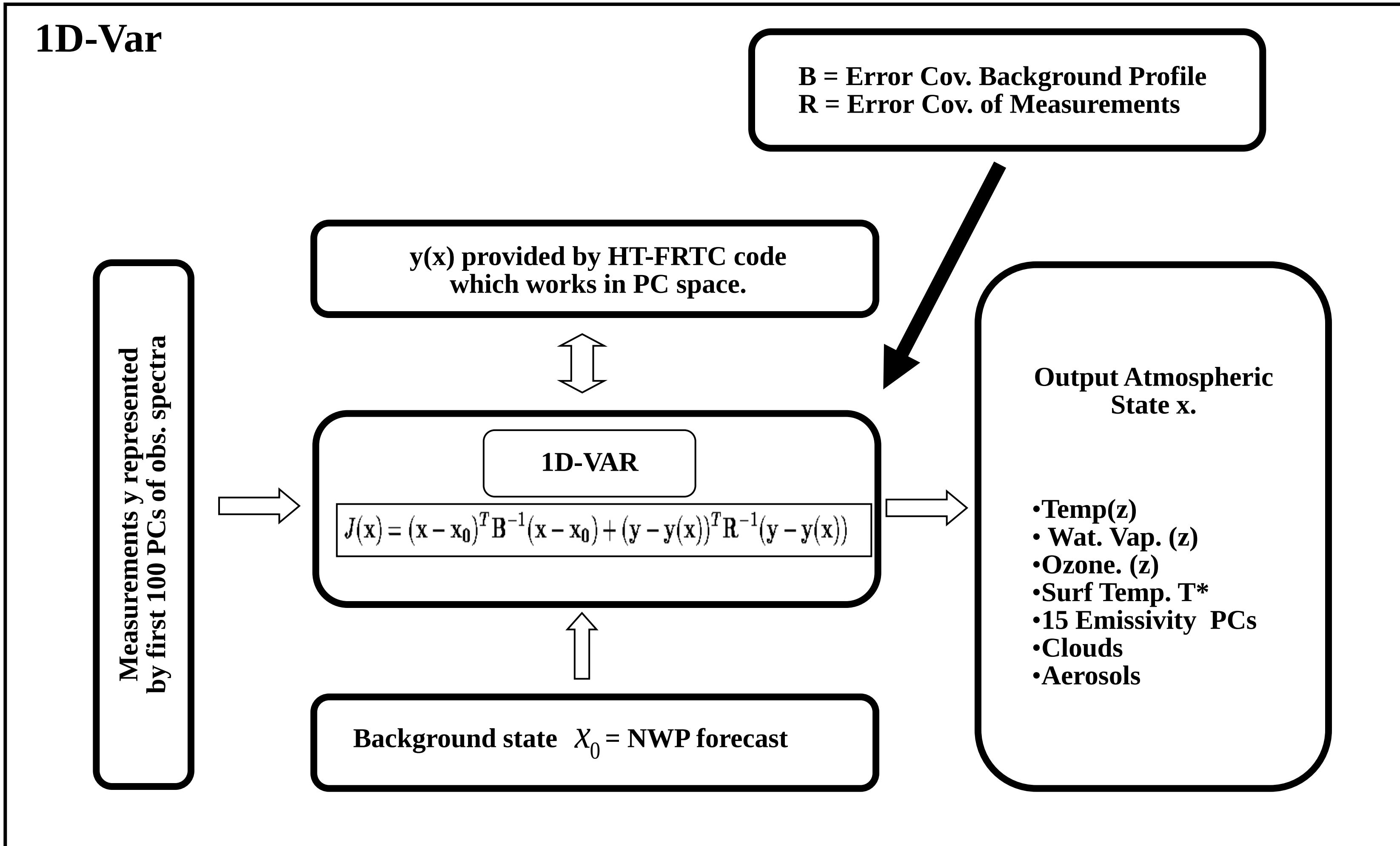
1D-Var Algorithm



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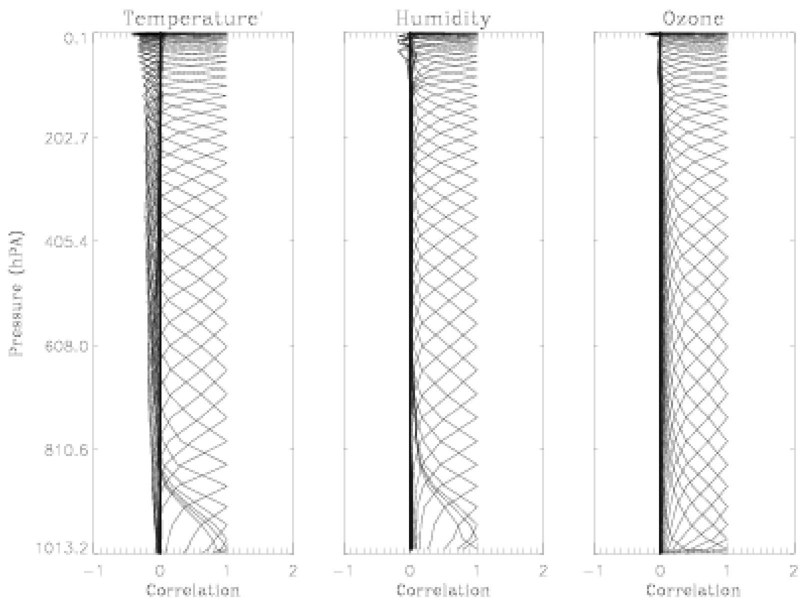
1D-Var Algorithm –
Background Error Covariance Matrices



Background error covariance matrices for temperature, humidity and ozone, from the European Centre for Medium Range Forecasting (ECMWF).

Error covariances for aerosols are not known so we approximate those by:

$$S_{ij} = \sigma^2 \exp\left(-\alpha \left|\ln(p_i) - \ln(p_j)\right|\right)$$

where P_i and P_j denote pressure levels.

No cross-correlations between state variables apart from temperature and surface temperature.

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Results – Longwave Retrievals

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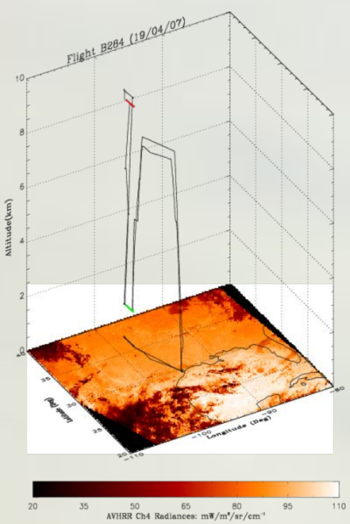
Clear-Sky LW Retrievals from ARIES

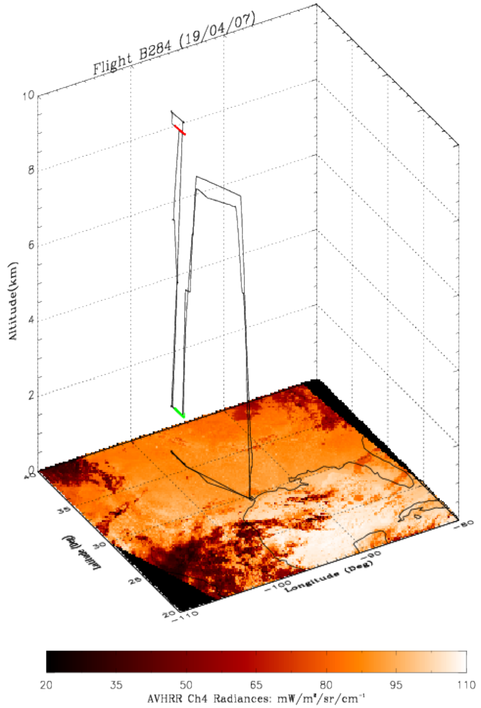
ARIES (Airborne Research Interferometer Evaluation) flies on the BAE-146 aircraft which is operated by the UK Met Office and the Natural Environment Research Council (NERC). It has about ~ 5000 channels in the 550 cm^{-1} to 3000 cm^{-1} spectral interval

Blister containing ARIES and other radiometers



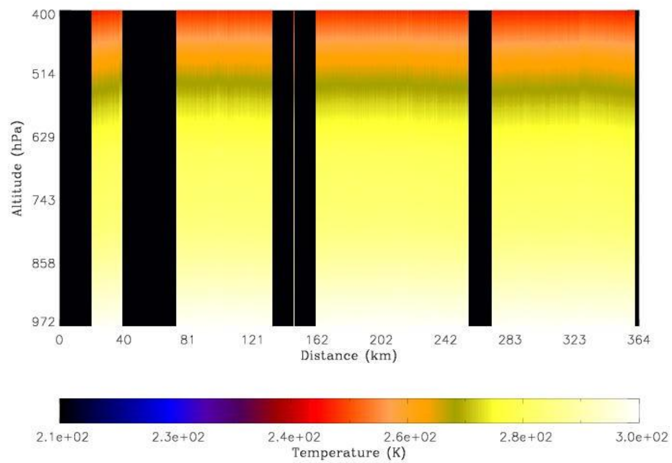
Clear-Sky LW Retrievals from ARIES

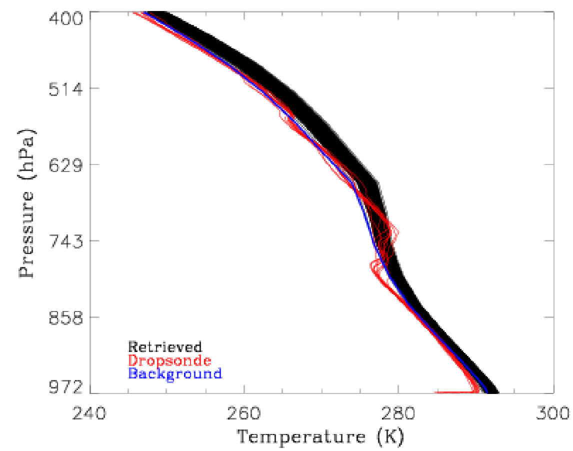
Met Office



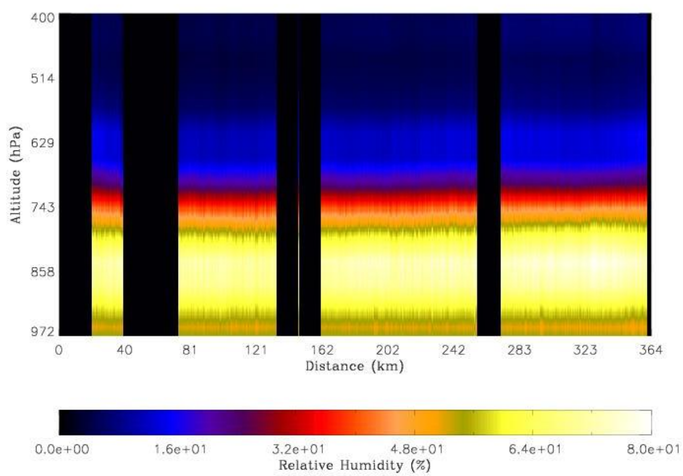
Night-Time flight B284 of JAIVEx Campaign

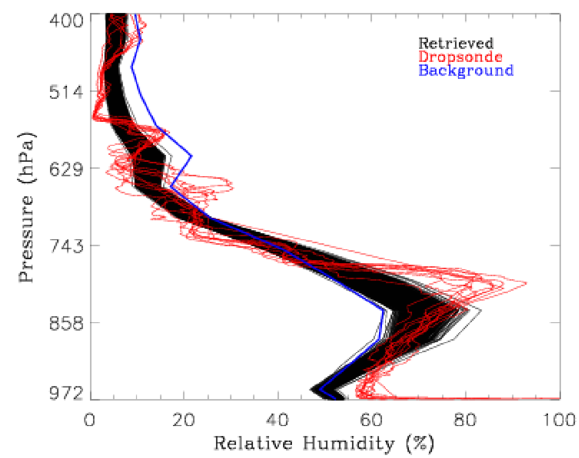
Measurements taken over the Oklahoma ARM Site





Temperature Retrievals from 1700 radiance measurements





Humidity Retrievals from 1700 radiance measurements

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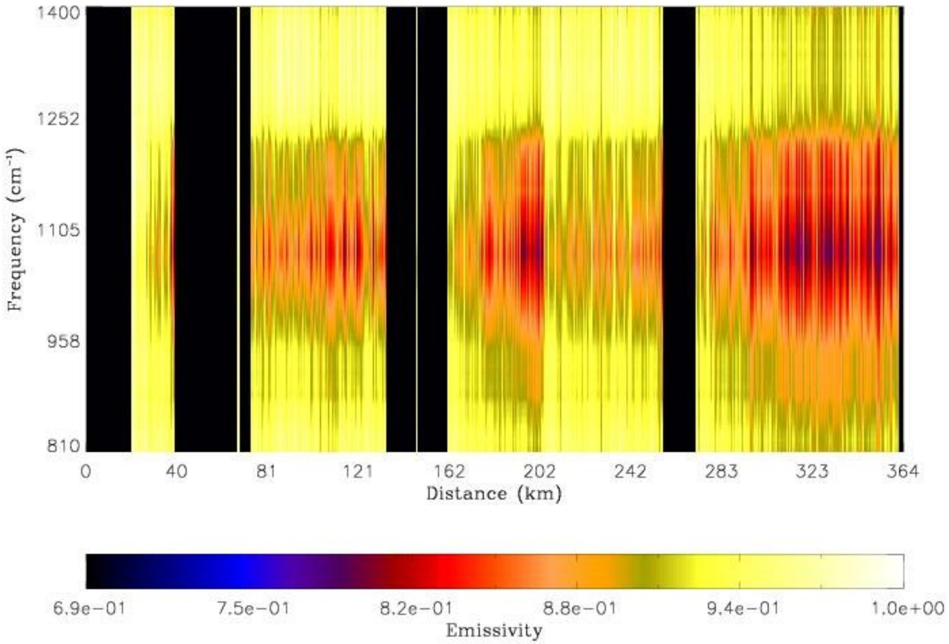
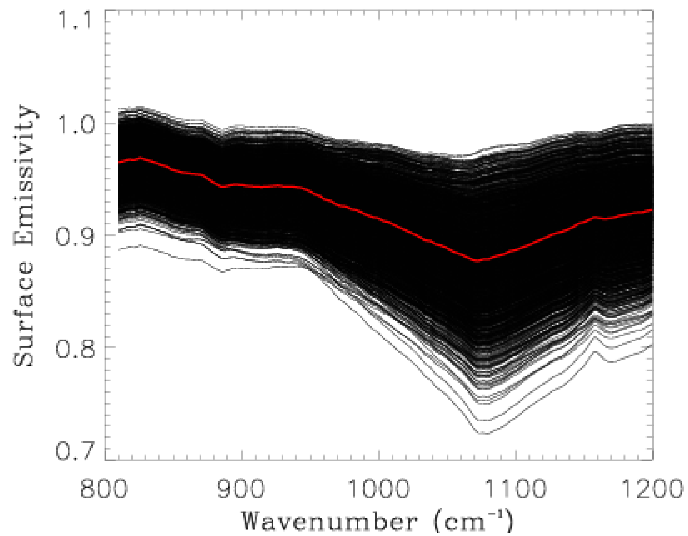
Clear-Sky LW Retrievals

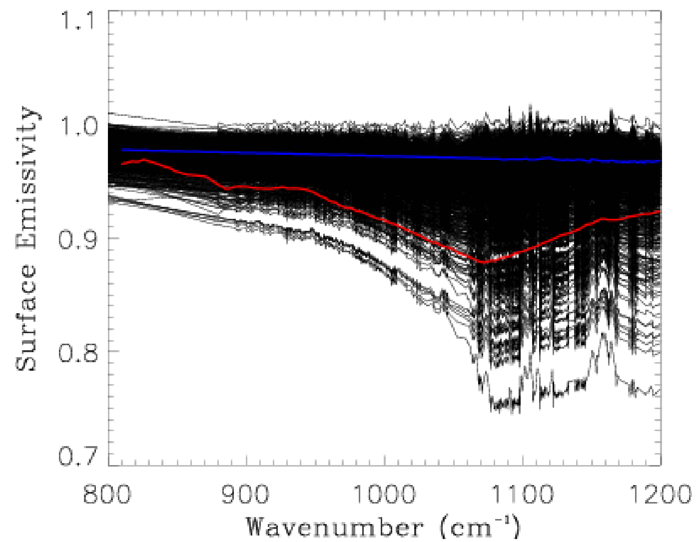


1700 surface emissivity profiles obtained from the high altitude radiance measurements.

There is a good agreement between the retrieved and the inferred surface emissivities (thanks to Stuart Newman).



a) Retrieved Surface Emissivities



b) Inferred Surface Emissivities

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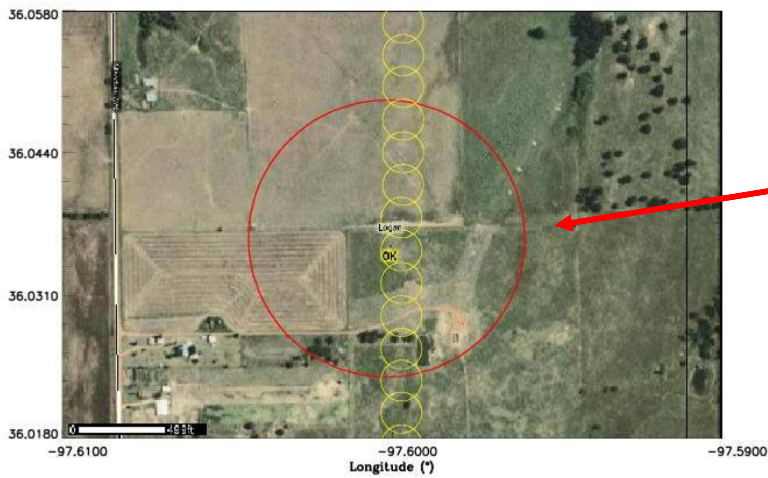
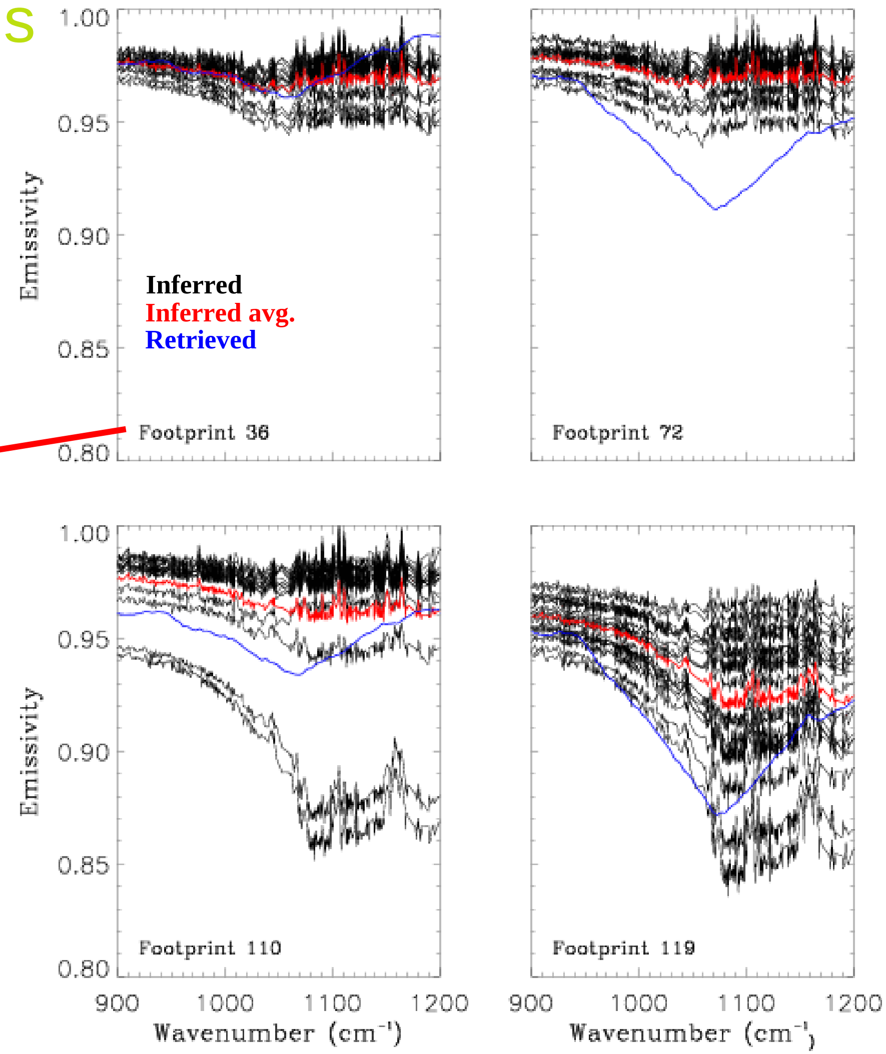
Clear-Sky LW Retrievals from ARIES



US Department of Agriculture (Web Soil Survey) 07/04/2003



- The inferred surface emissivities tend to have a much ‘flatter’ spectrum.
- Agreement between individual footprints is relatively good.

At low level the ARIES measurements have an field of view of ~50 m so we are able to resolve small features.

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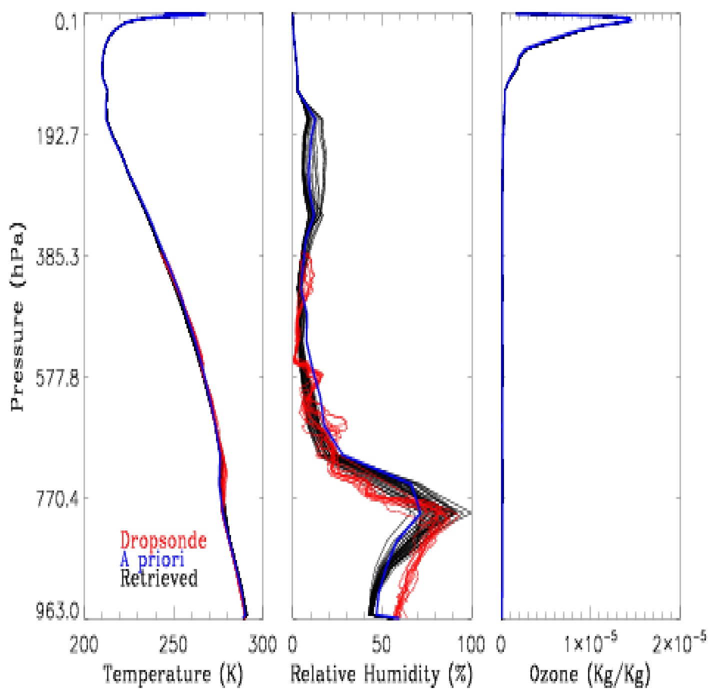
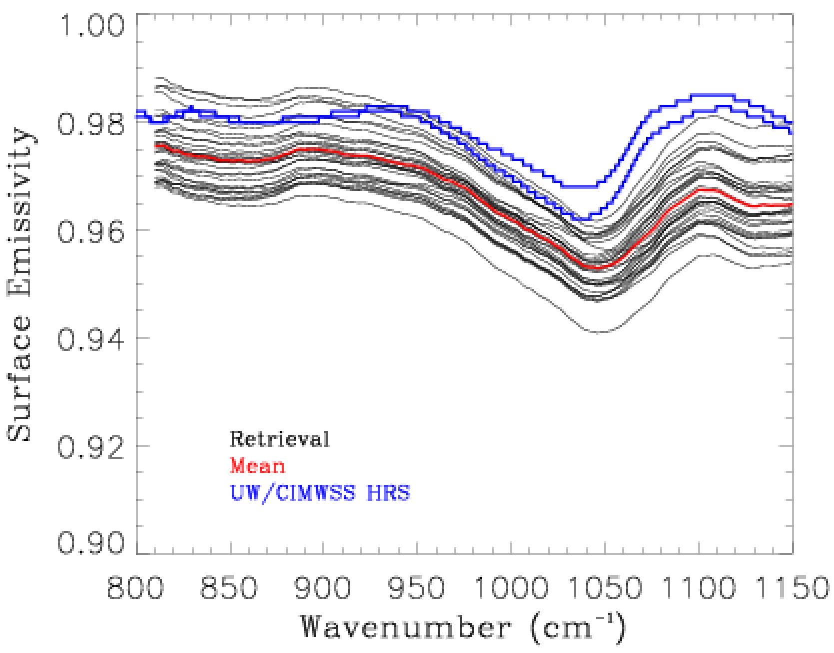
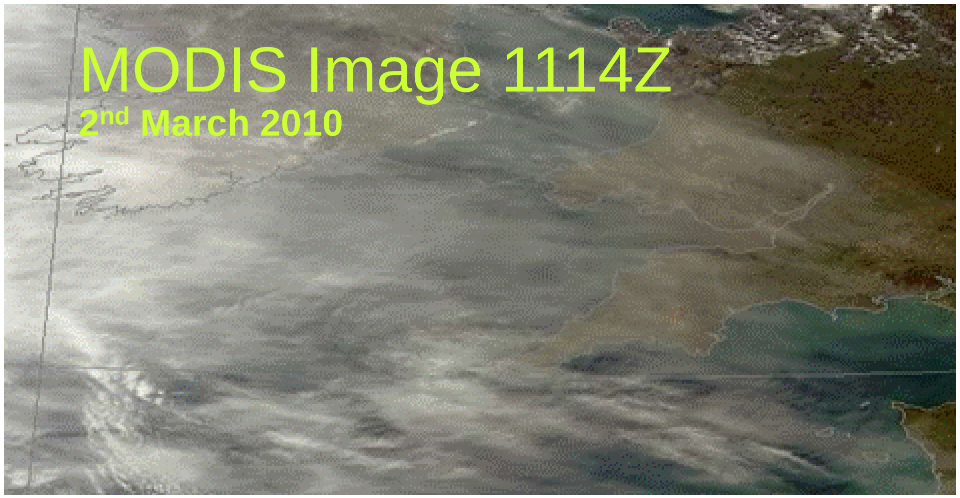
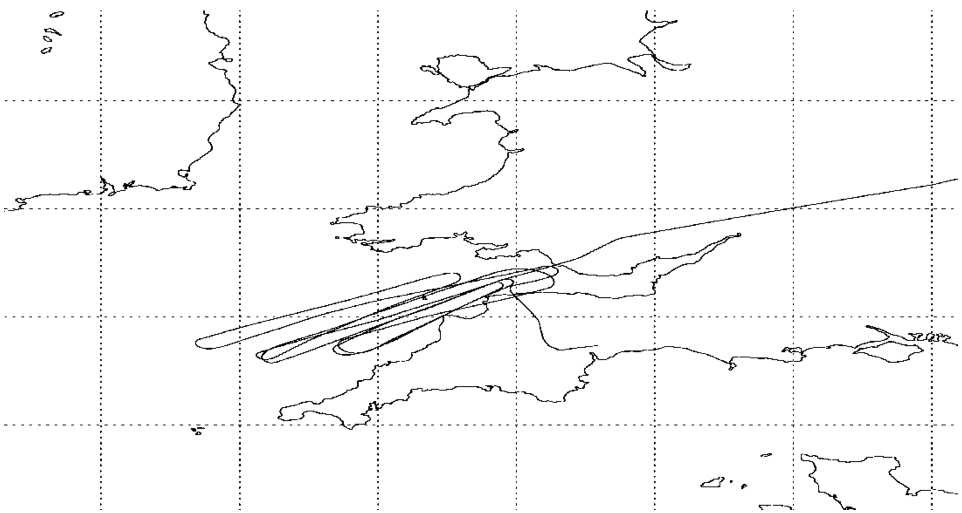
Clear-Sky LW Retrievals from IASI

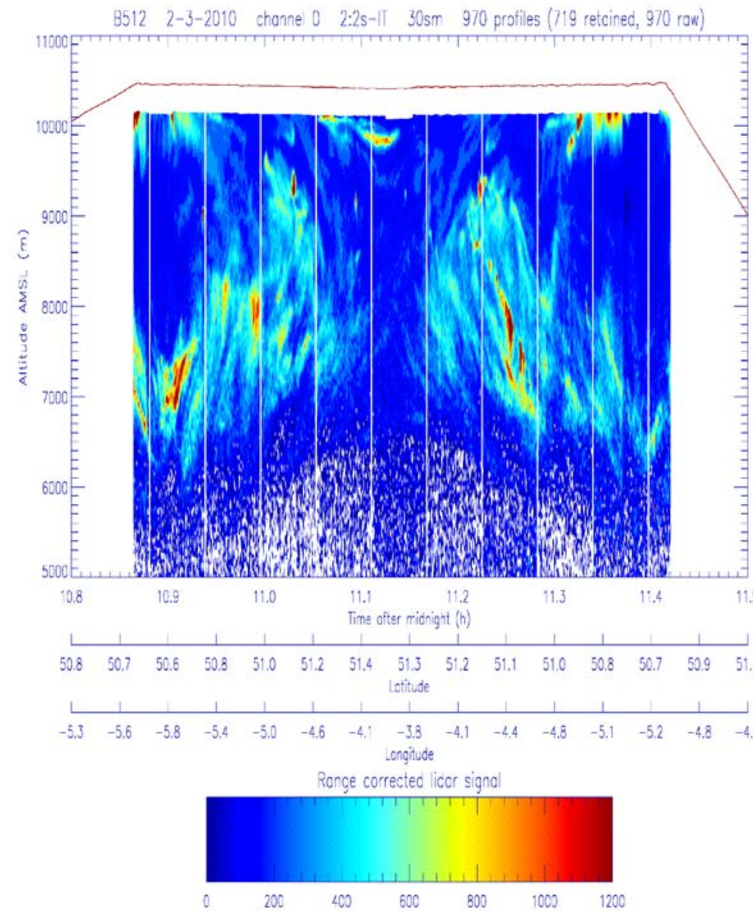




LW Cloudy Retrievals from IASI







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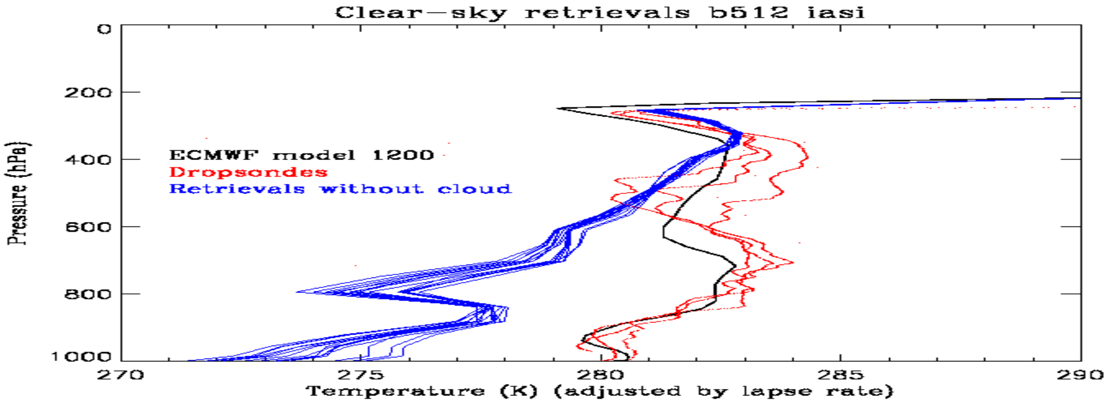
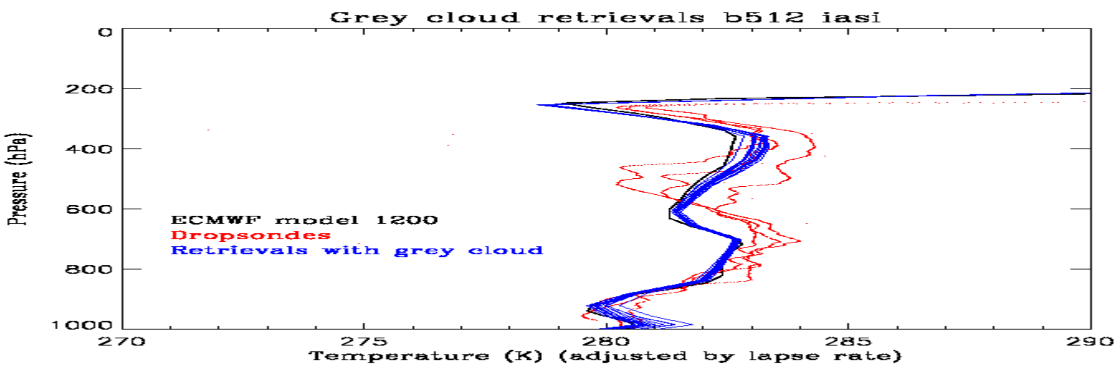
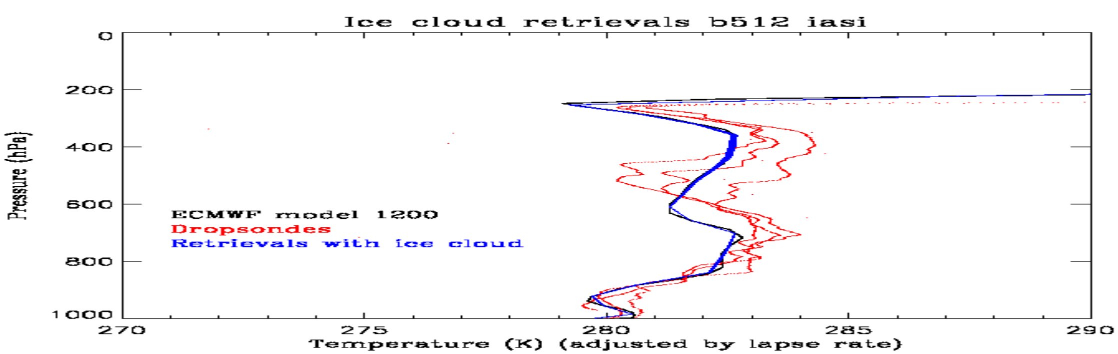
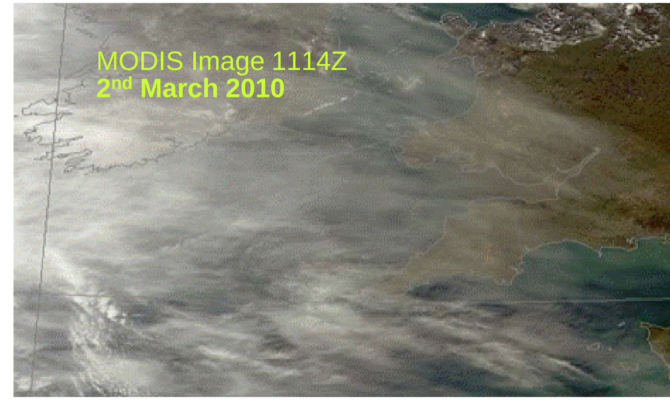
LW Cloudy Retrievals from IASI









Temperature retrievals:

clear-sky
grey cloud
ice cloud

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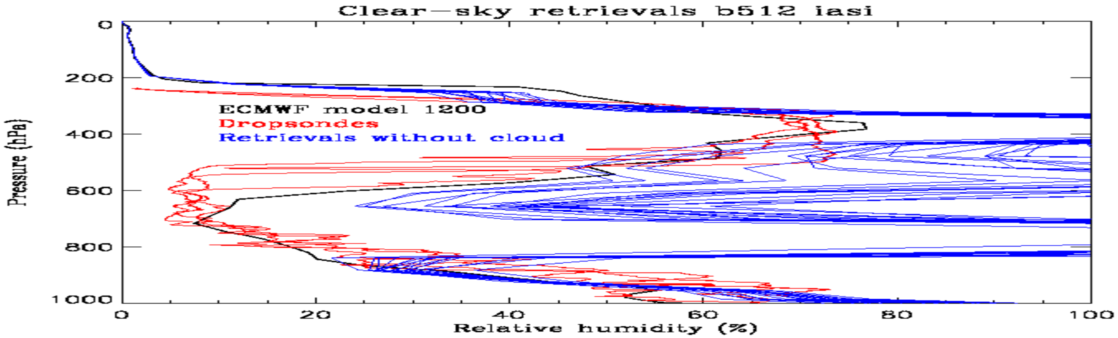
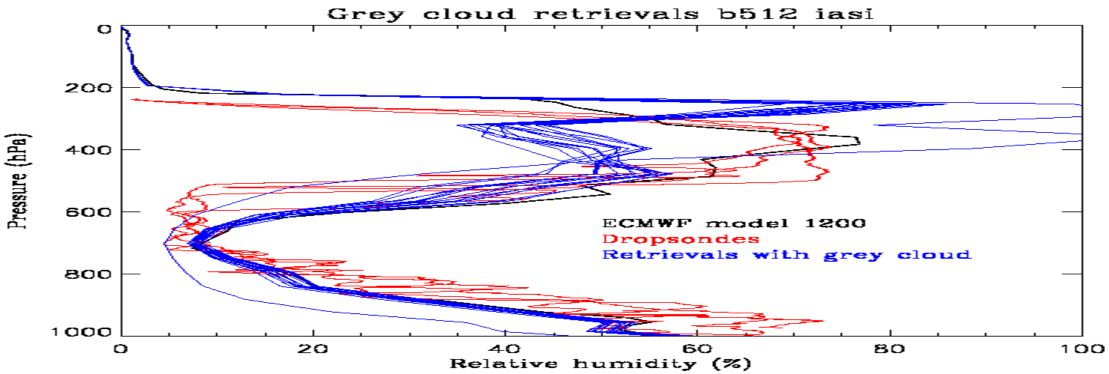
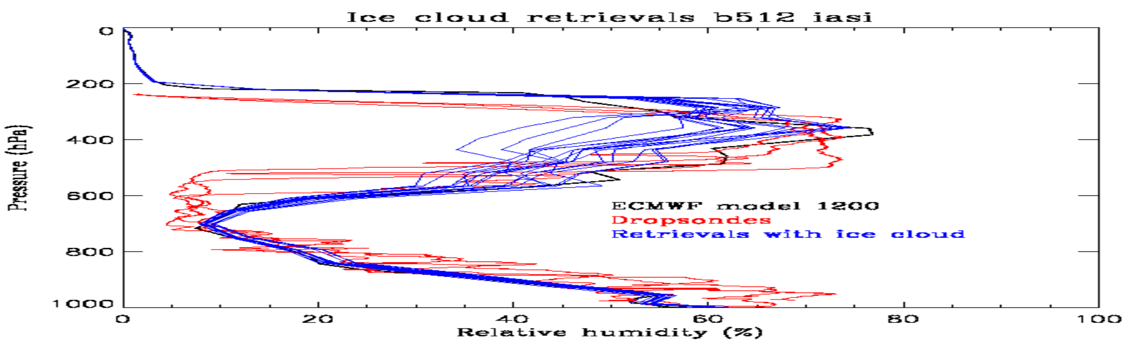
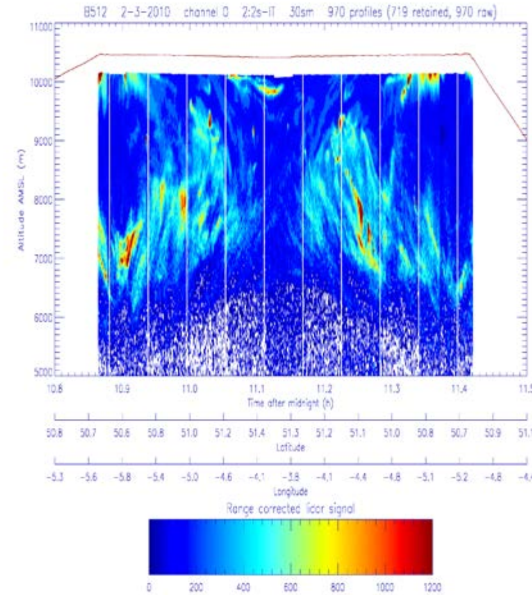
LW Cloudy Retrievals from IASI









Relative humidity retrievals:

clear-sky
grey cloud
ice cloud

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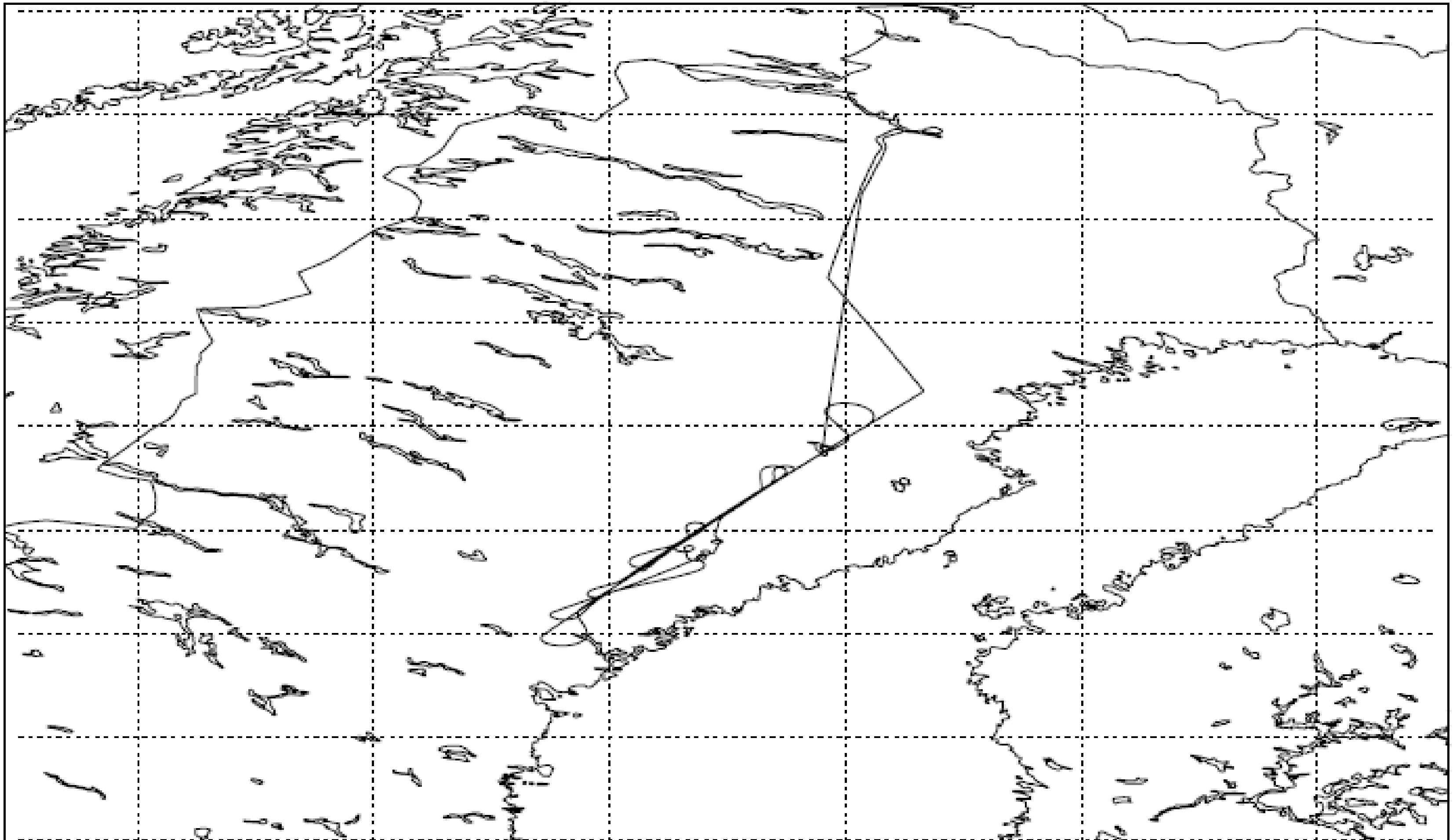
LW Cloudy Retrievals over Land from ARIES and IASI



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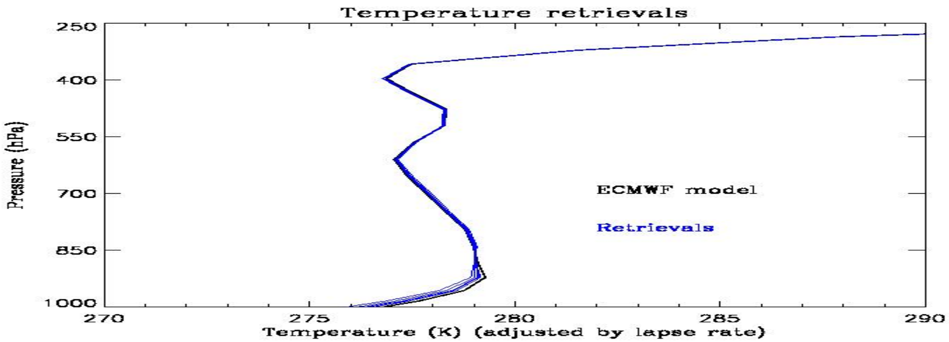
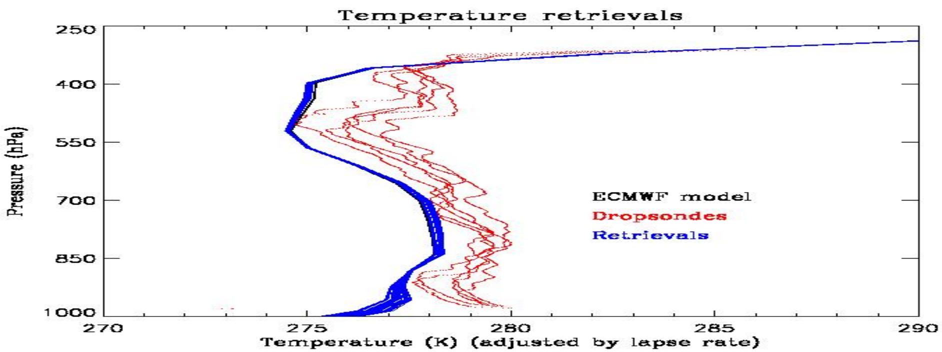
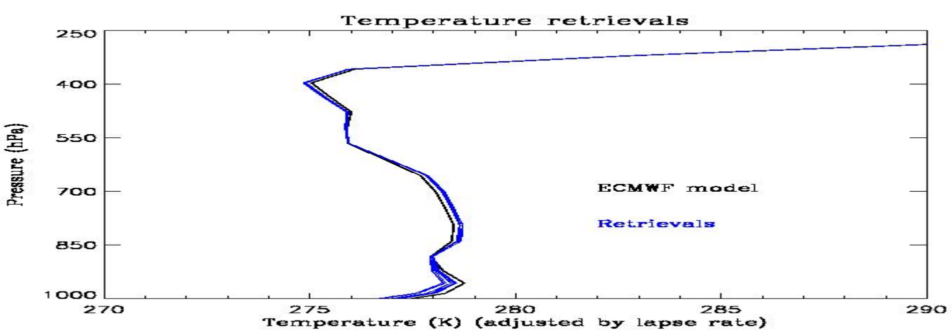
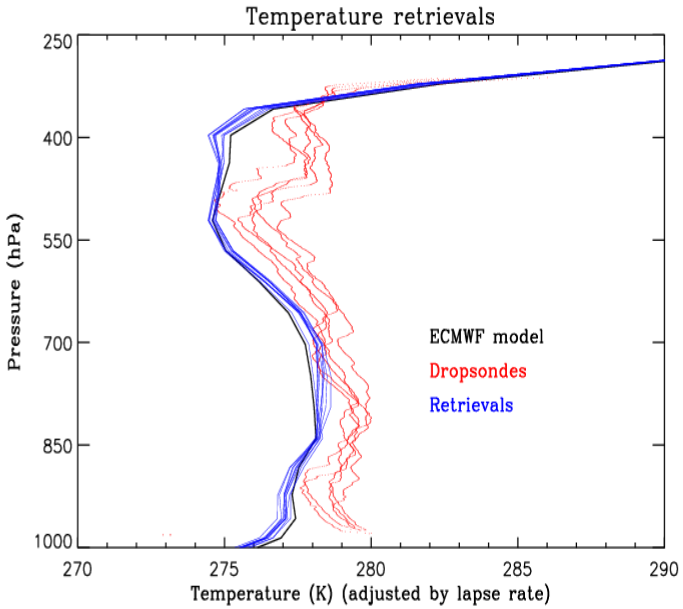
LW Cloudy Retrievals: Temperature from ARIES and IASI









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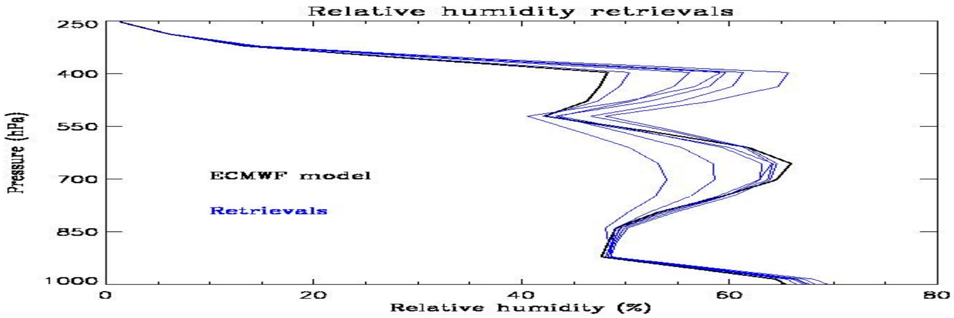
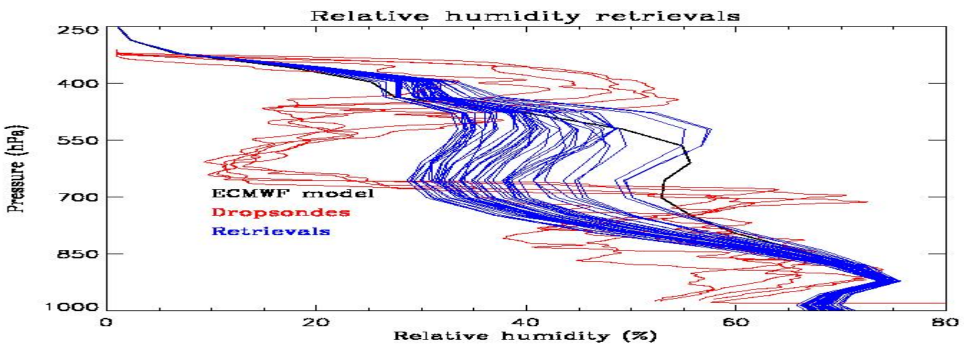
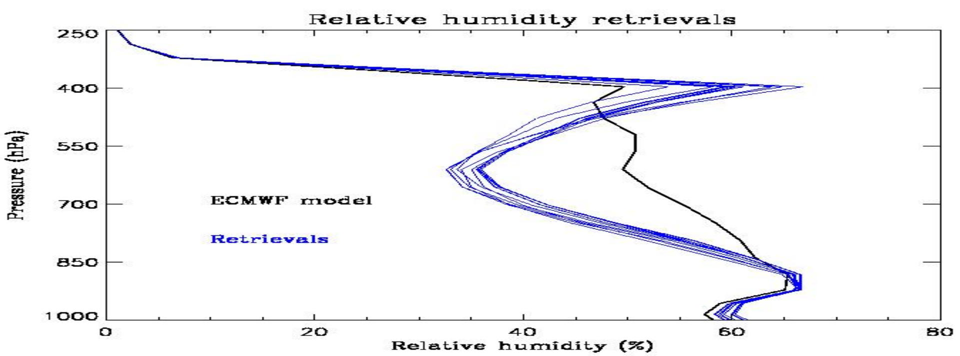
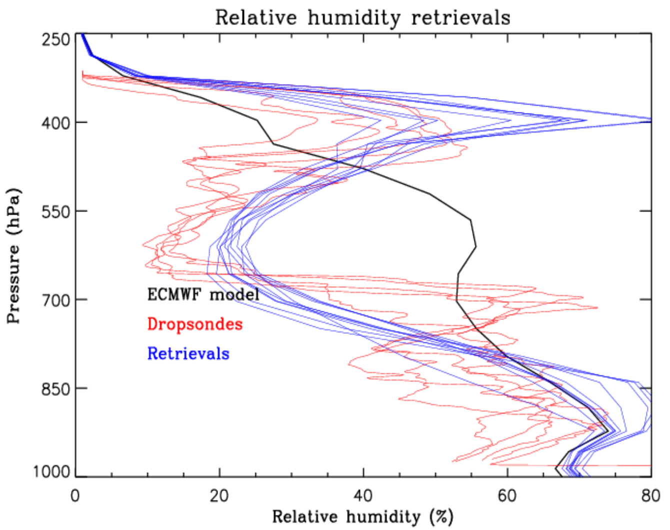
LW Cloudy Retrievals: Relative humidity from ARIES and IASI









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LW Cloudy Retrievals from ARIES and IASI: Cirrus properties

	Background values	Run 7	Run 8	Run 9	IASI
Cirrus IWC	10 mg m^{-3}	26±8 mg m^{-3}	23±14 mg m^{-3}	24±6 mg m^{-3}	20±7 mg m^{-3}
Cirrus cloud top pressure	Flight level	302±1 hPa	315±6 hPa	323±7 hPa	313±15 hPa
Cirrus cloud thickness	10 hPa (200 m)	14±3 hPa (280±60 m)	13±6 hPa (260±120 m)	18±4 hPa (360±80 m)	11±5 hPa (220±100 m)
Cirrus cloud fraction	1.00	1.06±0.03	0.98±0.04	1.01±0.03	0.96±0.05

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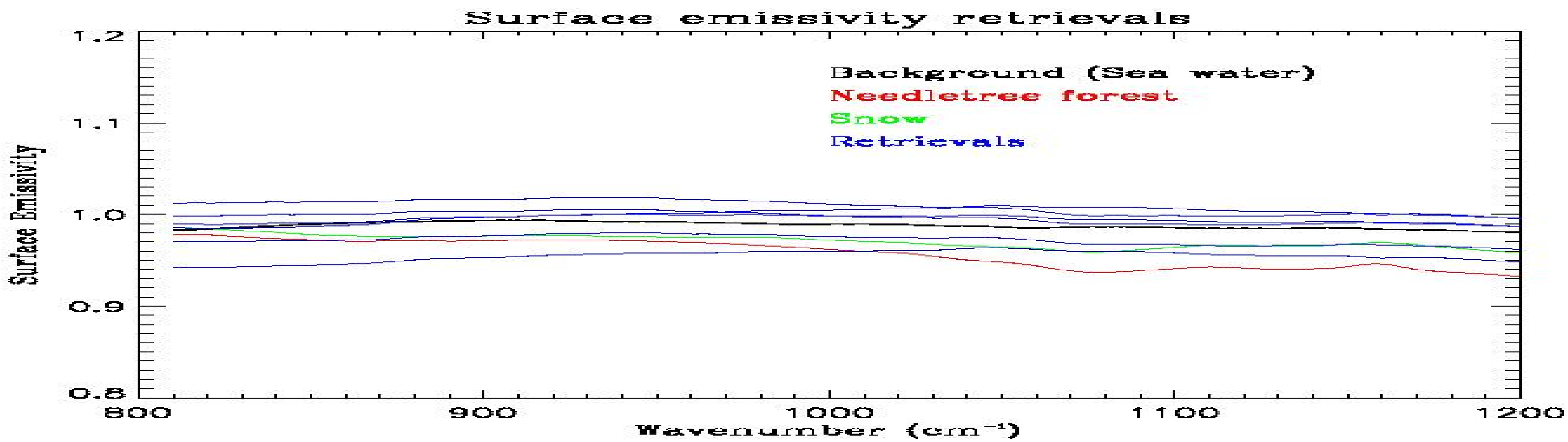
LW Cloudy Retrievals from ARIES and IASI: Surface properties



Surface temperature	Run 7	Run 8	Run 9
Background values (NWP)	275.5 K	274.9 K	276.3 K
Retrievals	274.6±0.4 K	274.3±0.8 K (IASI 274.5±0.5 K)	275.5±0.5 K

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Results – Short-Wave Retrievals

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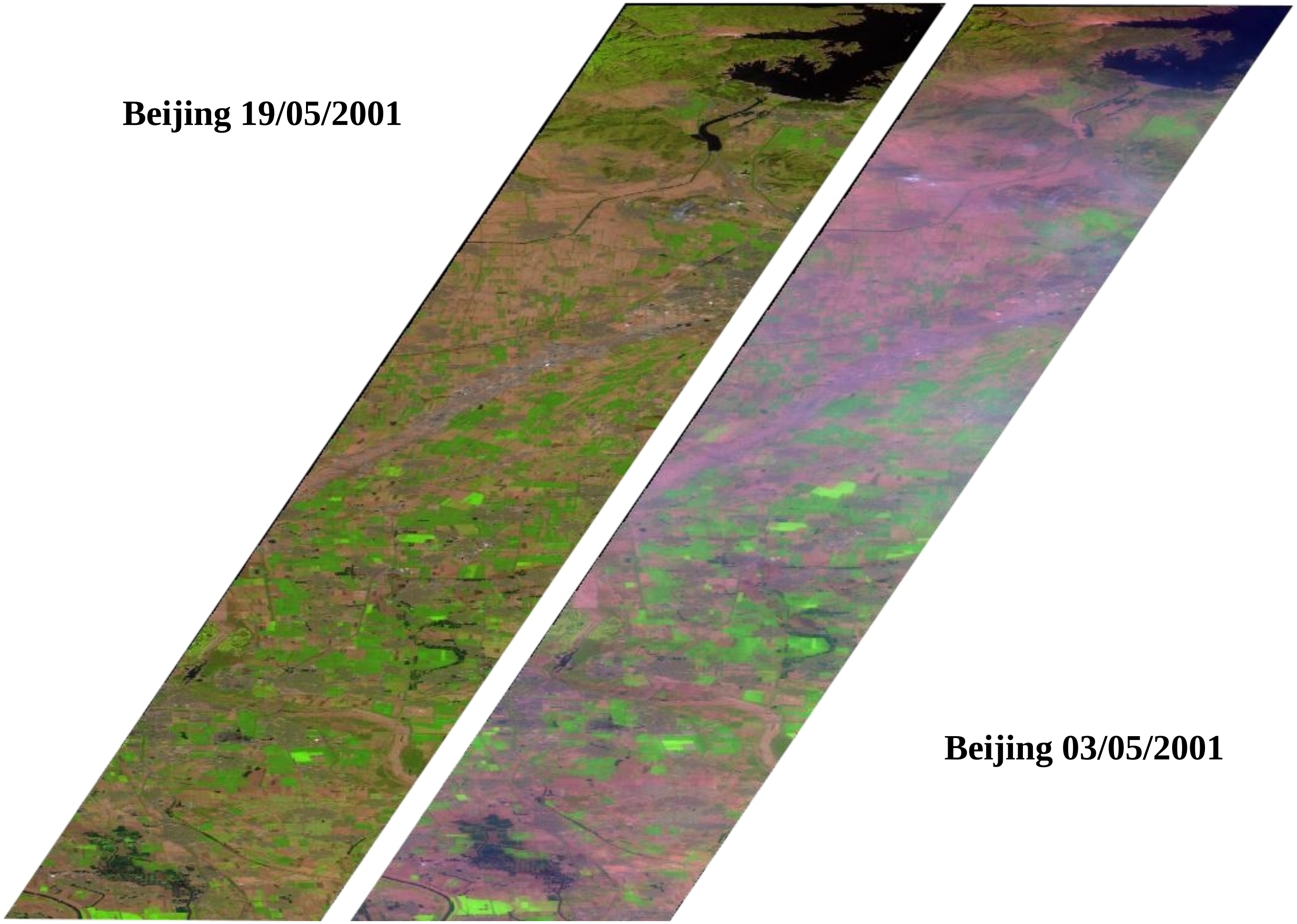
Hyperion EO1 Retrievals – Beijing

Beijing 19/05/2001



Beijing 03/05/2001

RGB False Colour Plot:

Red	: 1.6 µm
Green	: 0.8 µm
Blue	: 0.6 µm

- Soil
- Vegetation
- Water
- High Level Ice Cloud
- Water Cloud/Aerosol

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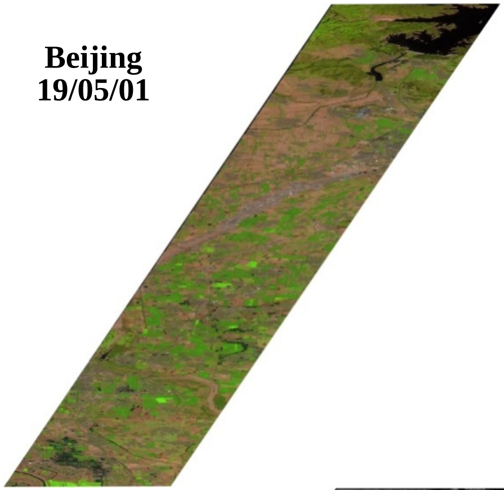
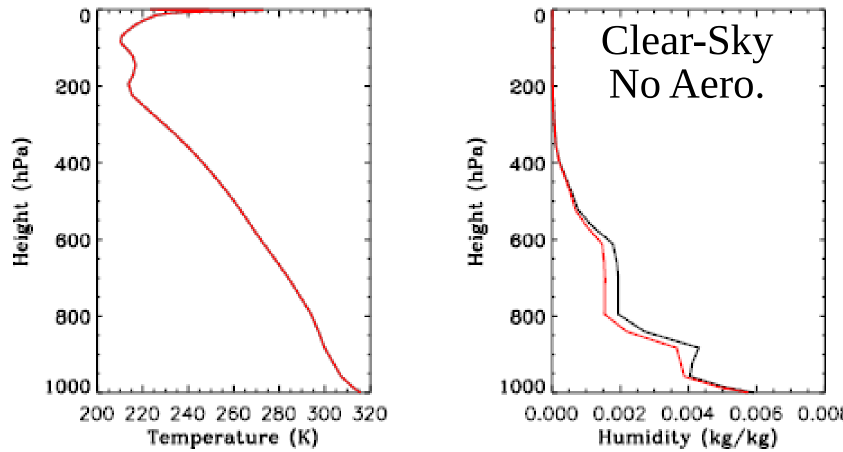
Hyperion EO1 Surface Reflectance Retrievals – Beijing – Clear Sky (19/05/01)

Met Office

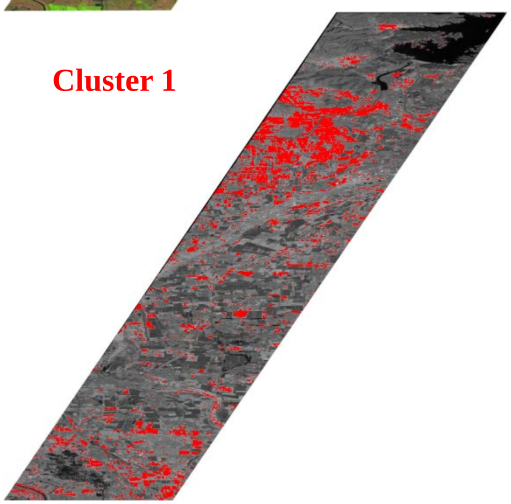
Beijing
19/05/01

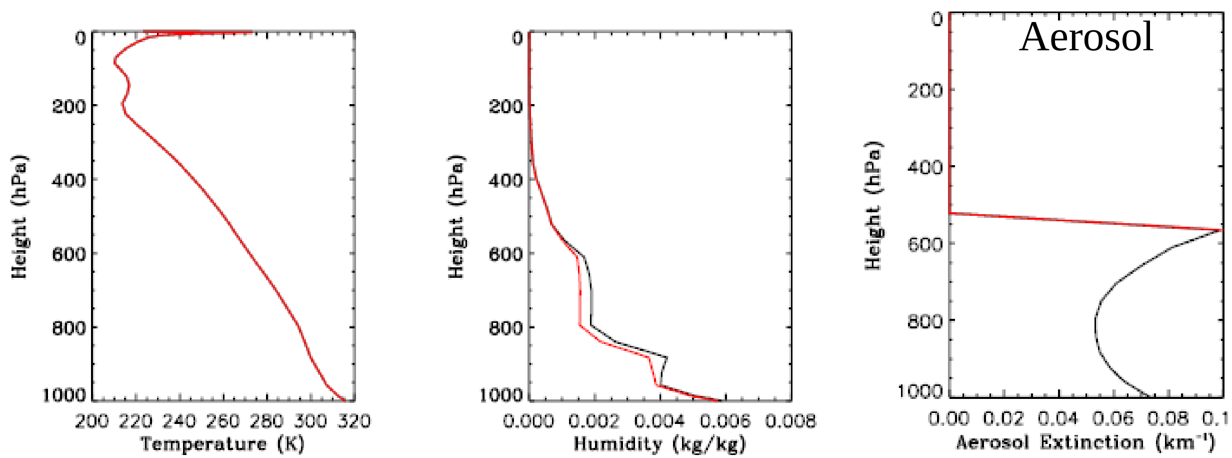




Temperature and humidity retrieved from centroid of cluster 1

Cluster 1





Temperature, humidity and aerosol profile retrieved from centroid of cluster 1. Aerosol used: Aged organic carbon

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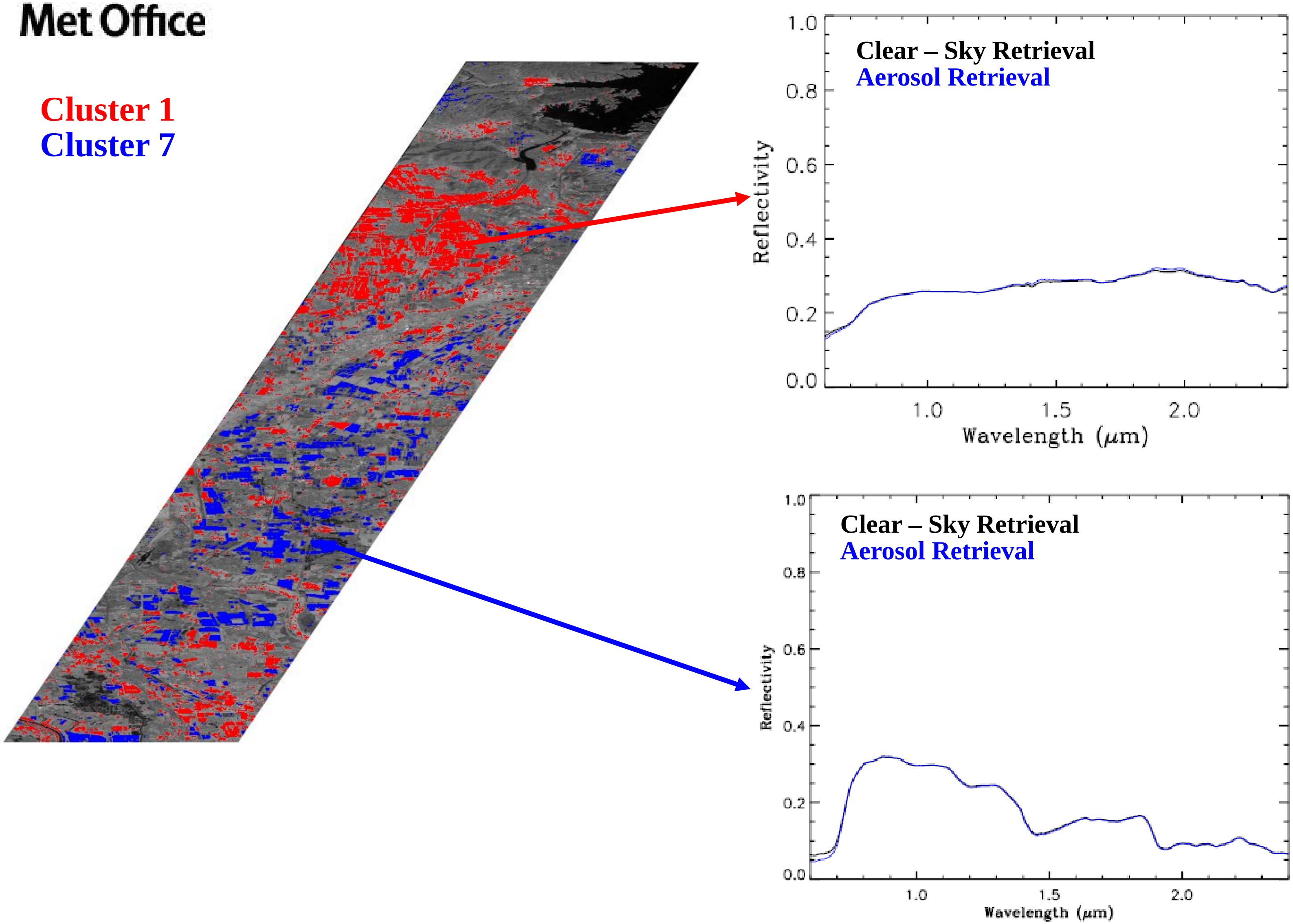
Hyperion EO1 Surface Reflectance Retrievals – Beijing – Clear Sky (19/05/01)



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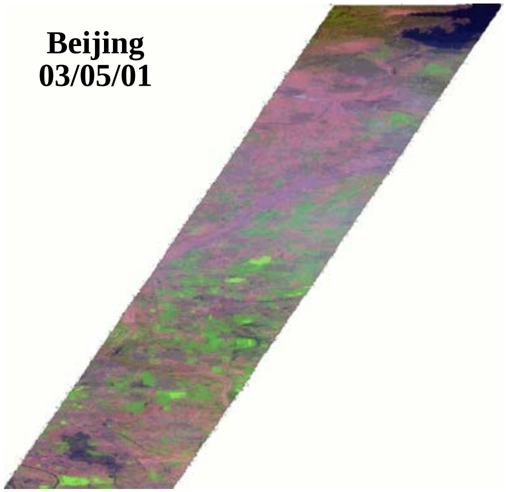
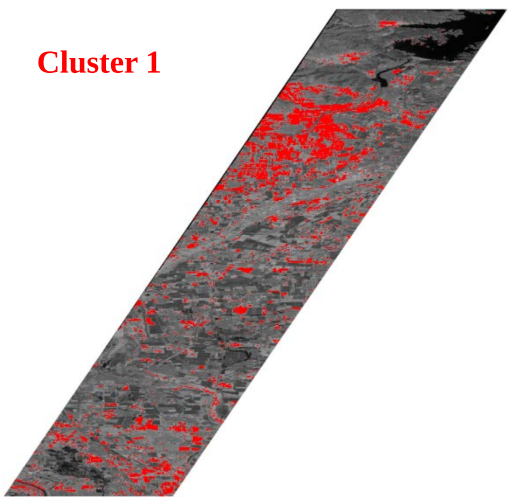
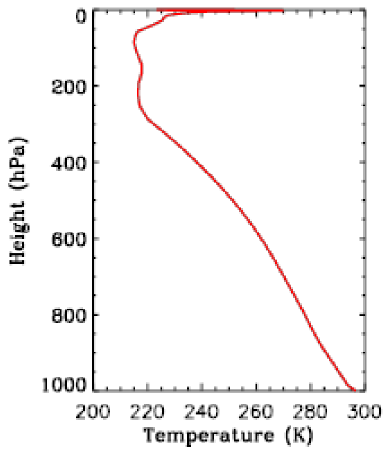
Surface Reflectance Retrievals – Beijing – Aerosol (03/05/01)

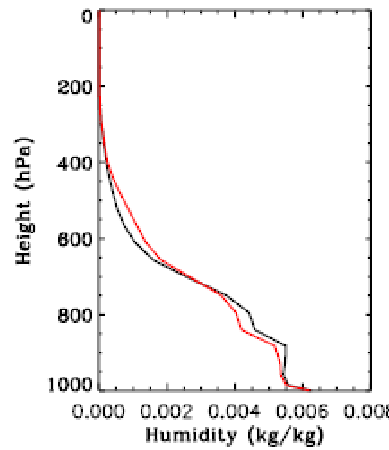
Beijing
03/05/01

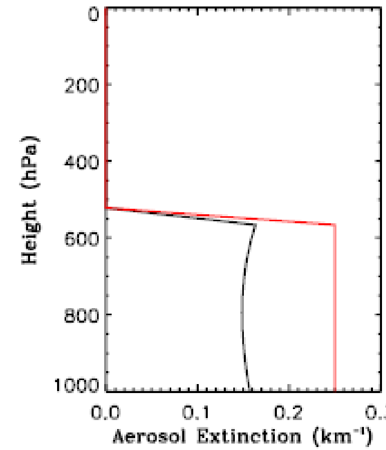


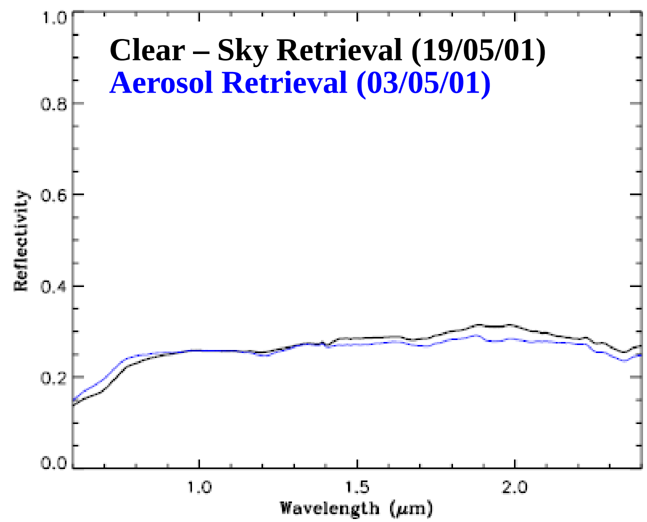
Cluster 1











Retrieval performed using ‘Aged Organic Carbon’.

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Surface Reflectance Retrievals – Beijing – Aerosol (03/05/01)

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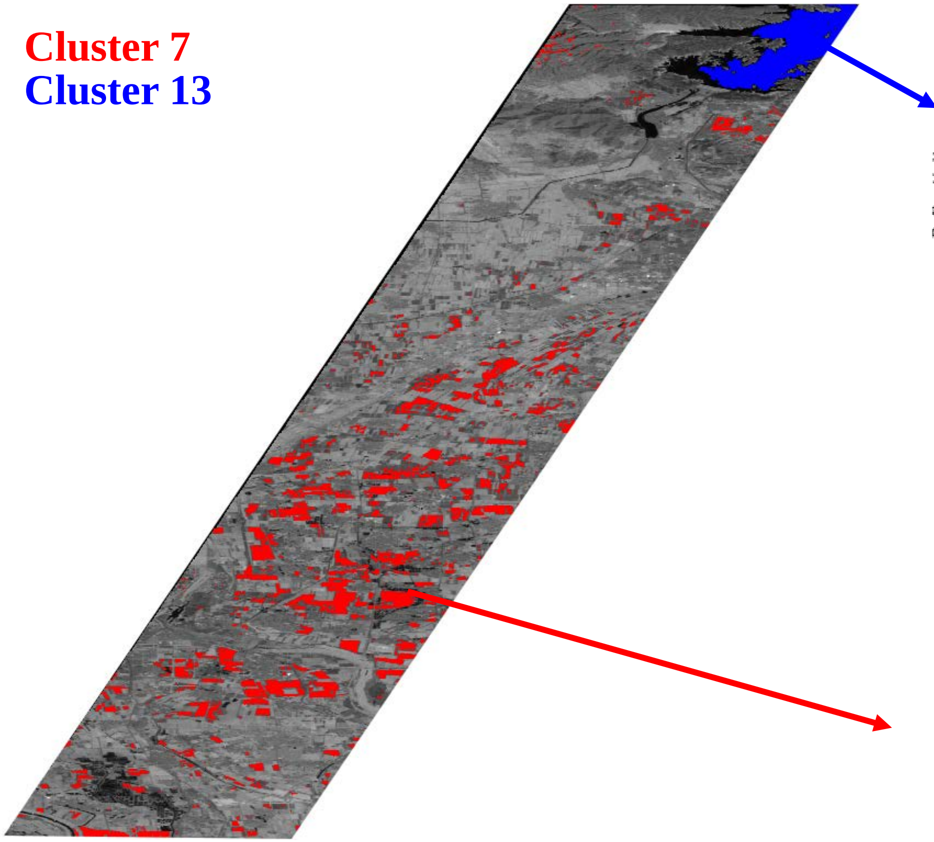
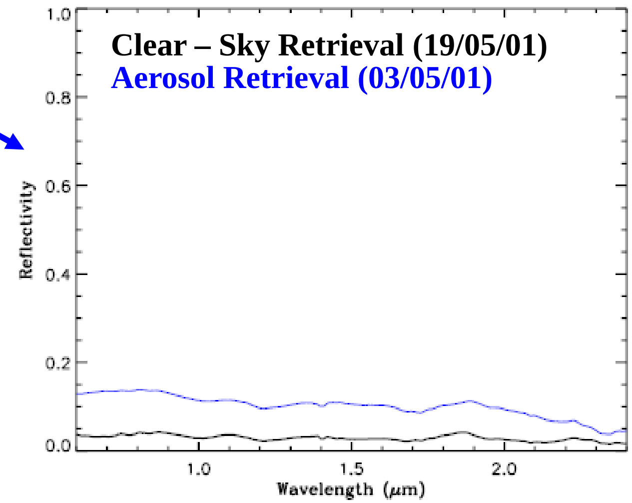
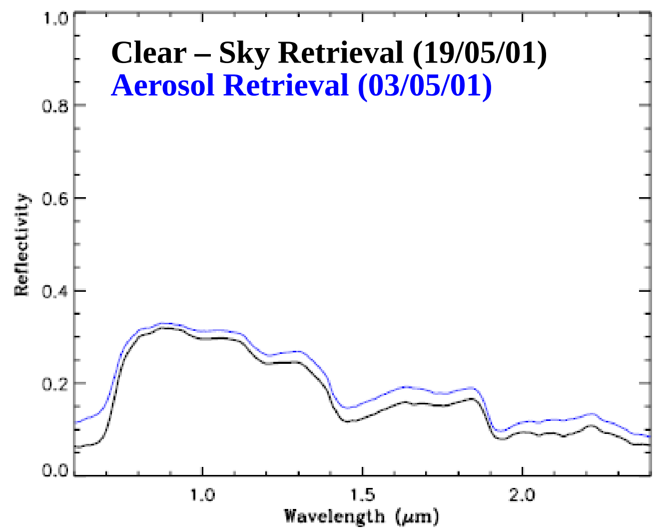
Cluster 7
Cluster 13







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Questions ?

Discussion

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