The assimilation of AIRS radiance data at ECMWF

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Key elements of the AIRS assimilation system

- Assimilation algorithm
- Cloud detection
- Bias correction
- Observation errors
- Data selection

The 4DVAR assimilation algorithm

Raw (i.e. unprocessed) **radiances** are assimilated **directly** in to the 4DVAR analysis system, which finds the trajectory of atmospheric states that best minimizes a cost or penalty function

$$J(x) = (x - x_b)^T \mathbf{B}^{-1}(x - x_b) + \sum_i (y_i - \mathrm{H}[x_i])^T \mathbf{R}^{-1}(y_i - \mathrm{H}[x_i]) + Jc$$

Fit to the background

Fit to the observations

Other constraints

Subject to the additional implicit hard constraint that the atmospheric states follow the model equations

$$\forall i, x_i = \mathbf{M}_{0 \to i}(x)$$

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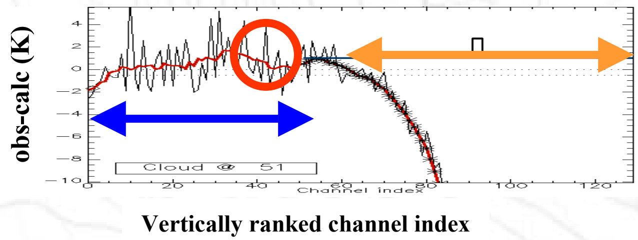
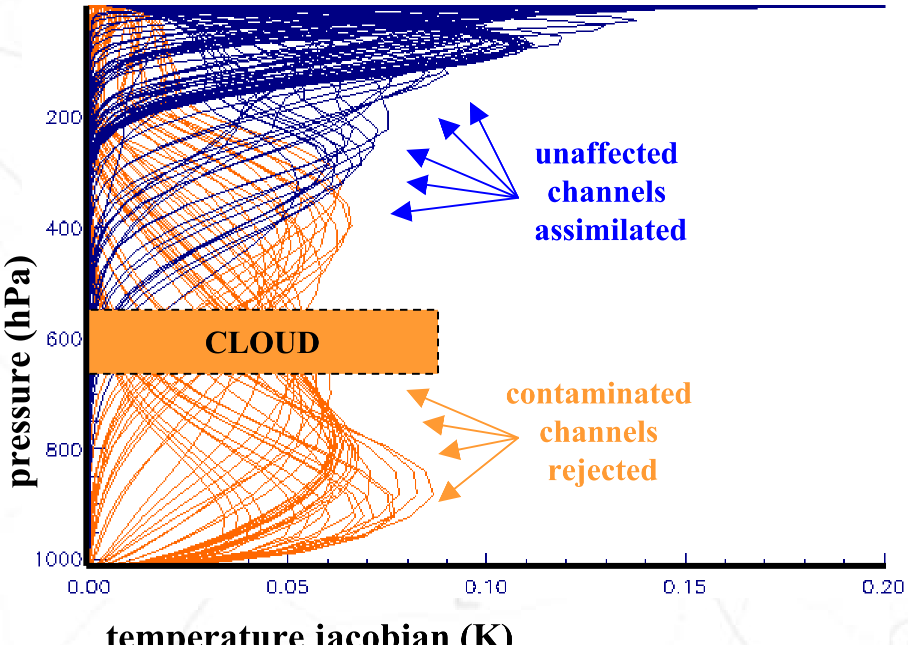
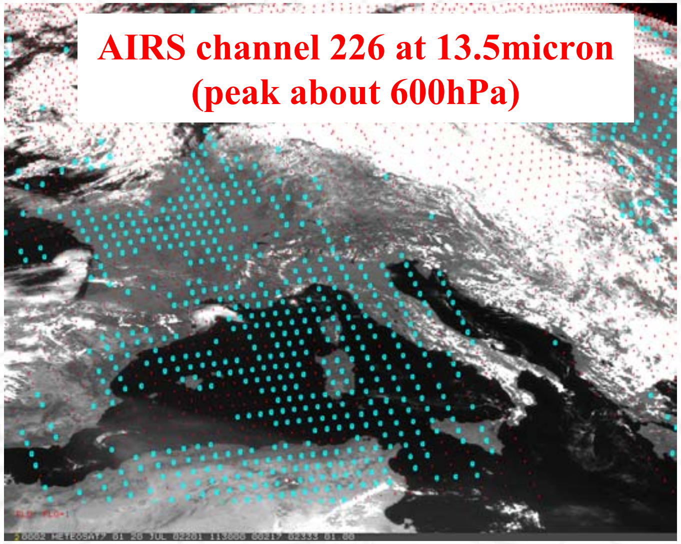
Cloud detection scheme for AIRS (IASI / CrIS)

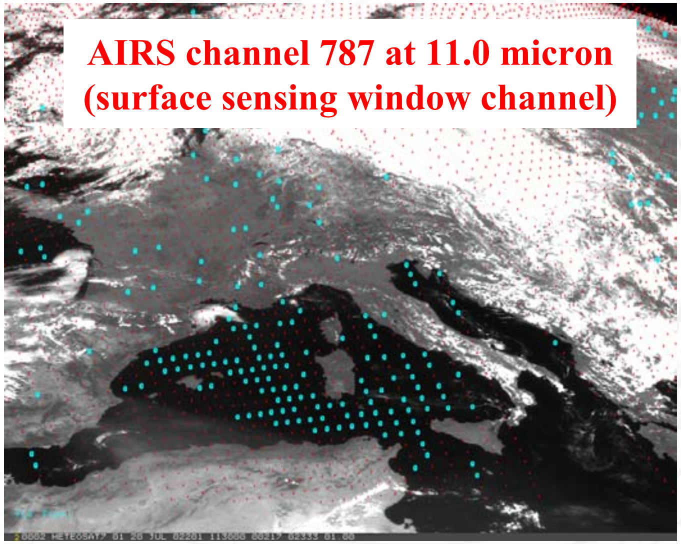
A simple pattern recognition algorithm is applied to departures of the observed radiance spectra from a computed clear-sky background spectra.



This identifies the characteristic signal of cloud in the data and allows contaminated channels to be rejected

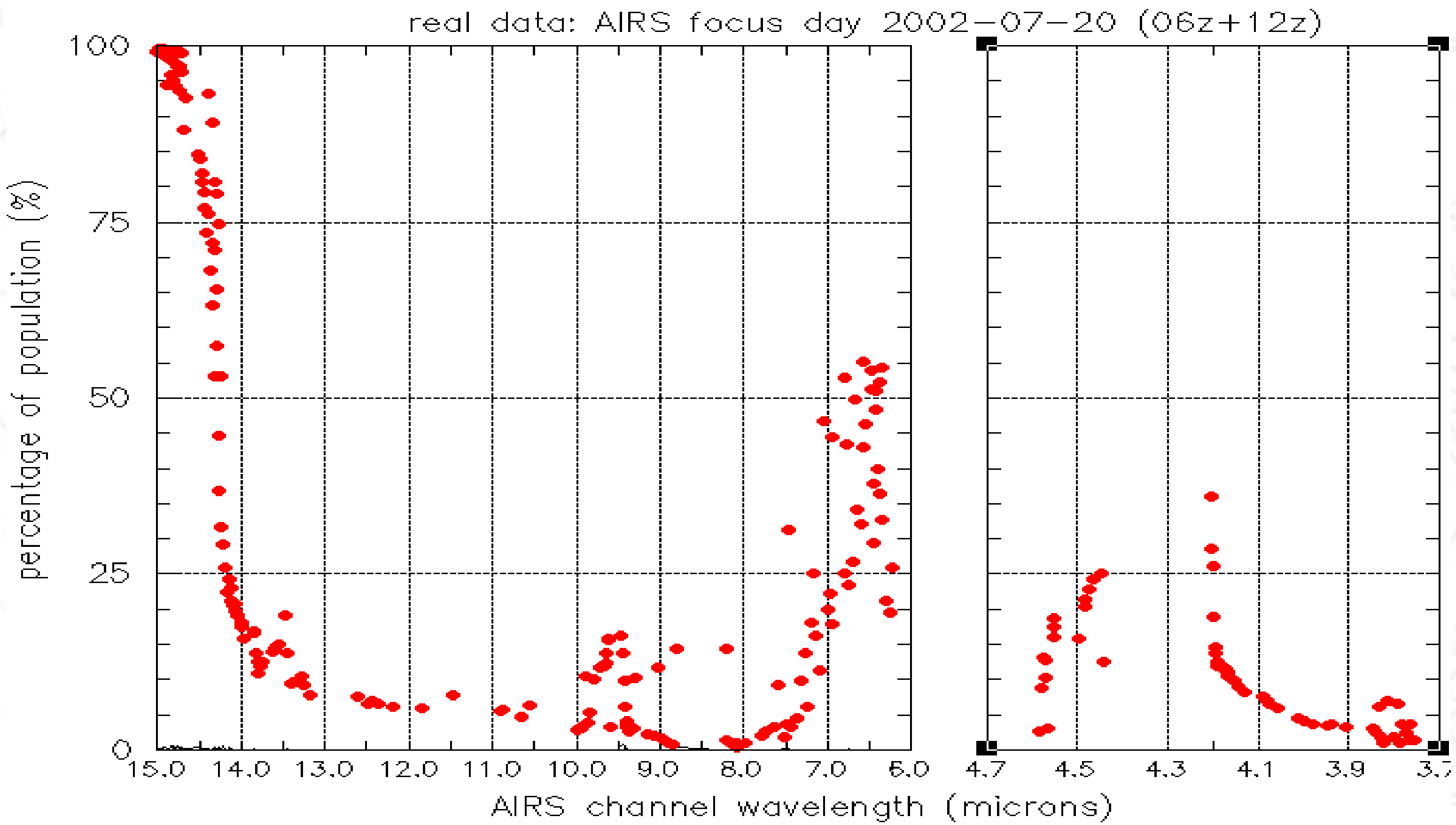






Cloud detection scheme for AIRS (IASI / CrIS)

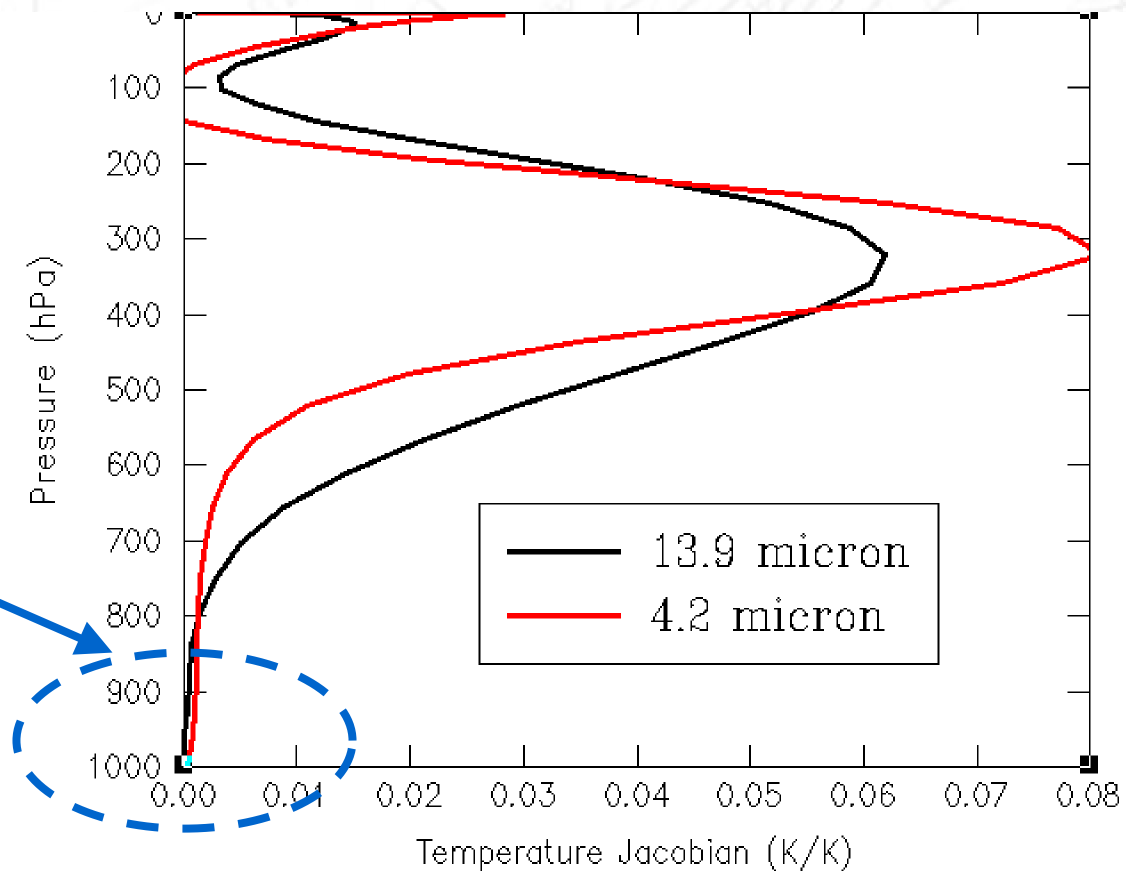
The probability of a channel being flagged clear falls off very rapidly with its depth of penetration into the troposphere.



Cloud detection scheme for AIRS (IASI / CrIS)

Shortwave channels are sharper than similarly peaking long-wave channels,

… but have long tails to the surface that increase the sensitivity to low clouds



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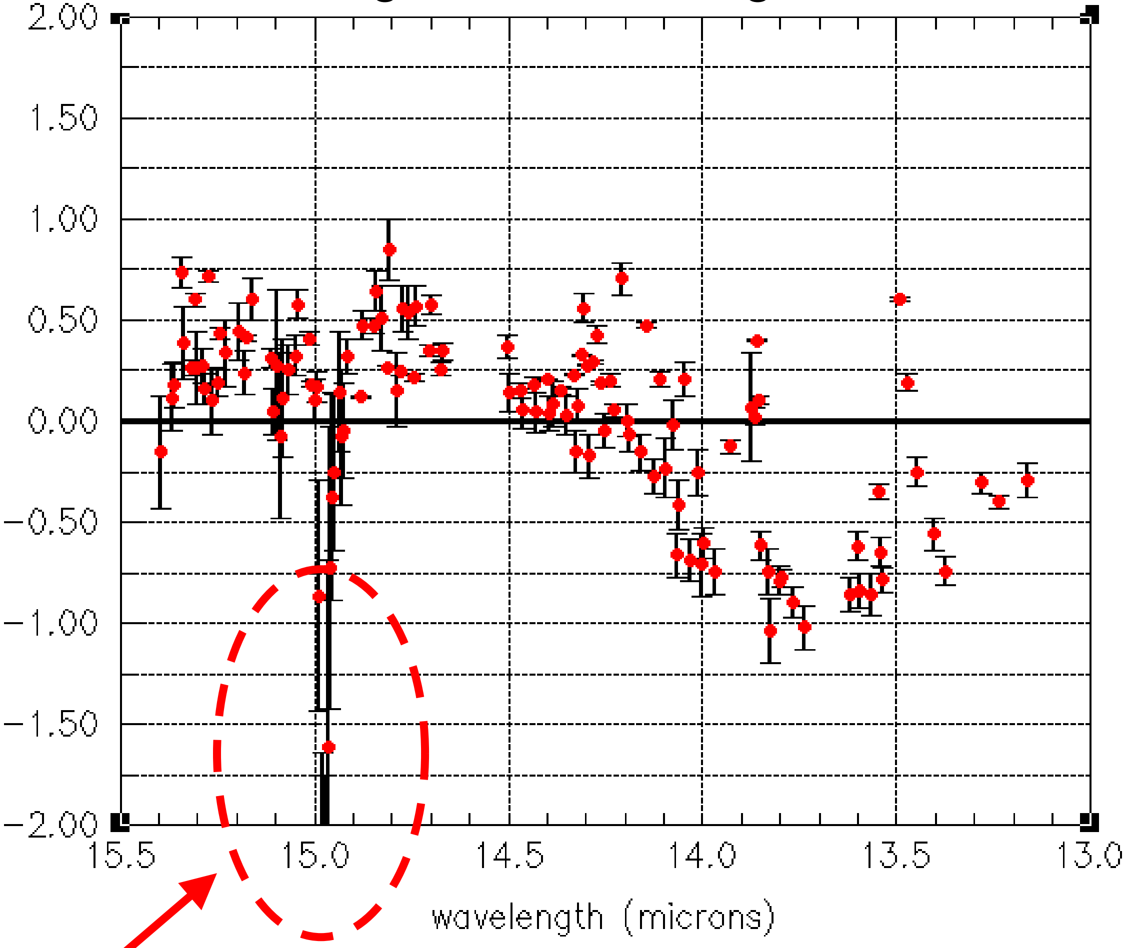
Bias Correction

Most of the AIRS channels display small biases (O-B) without a large dependence on air-mass, scan position or time (compared to the random signal).

These have been corrected with a very simple static and "flat" bias correction (i.e. a single number per channel)

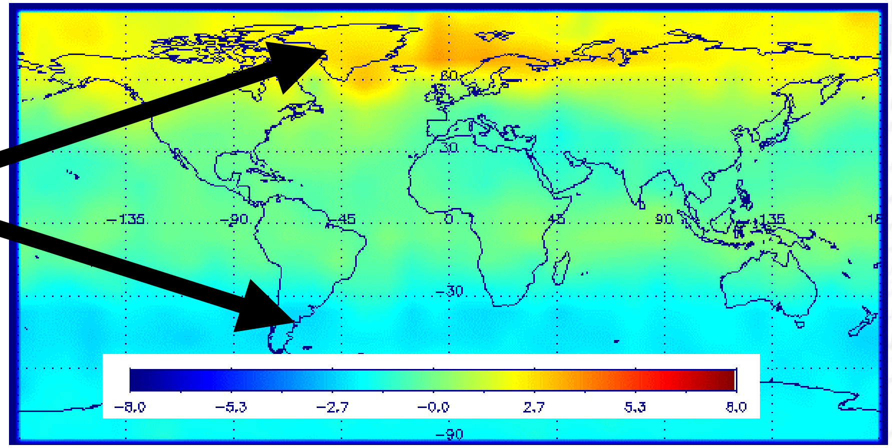
Bias and bias variation (K) for the AIRS Long-wave sounding band



This is NOT true for the upper stratospheric sounding channels of AIRS

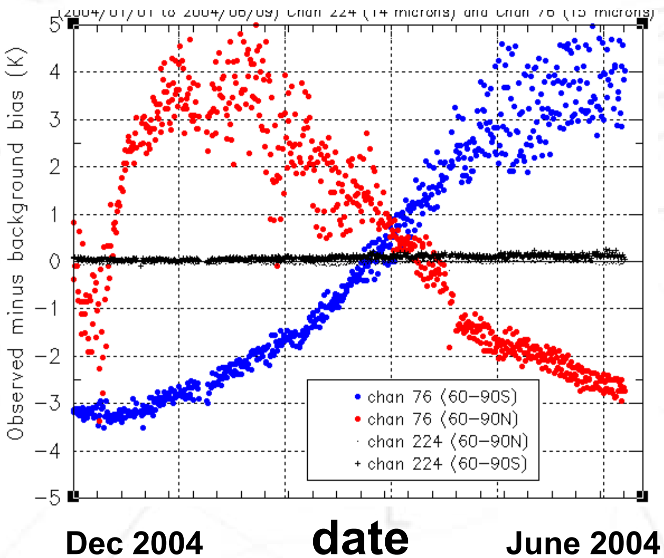
Biases in Upper Stratospheric Channels

Systematic errors in the model upper stratospheric temperatures give **apparent air-mass dependent biases**

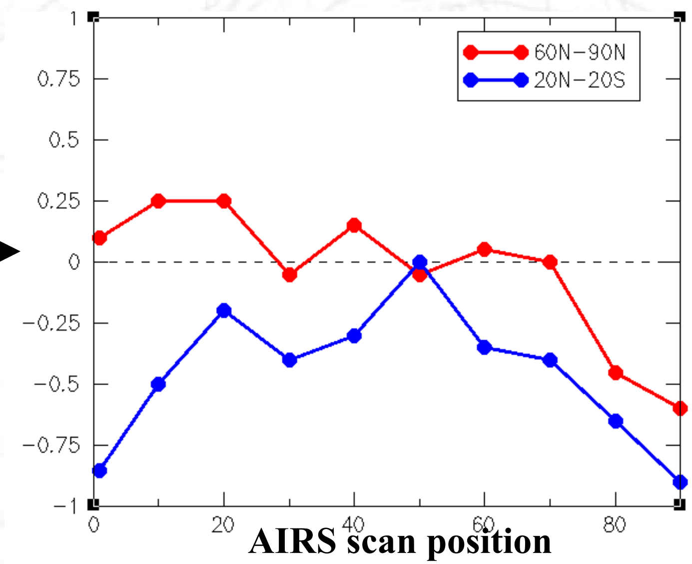


AIRS channel-75
(stratopause/mesosphere)

Seasonal dependence of bias (K)



Systematic errors in the model **lapse rate** give **apparent scan dependent biases** (symmetric and asymmetric !)



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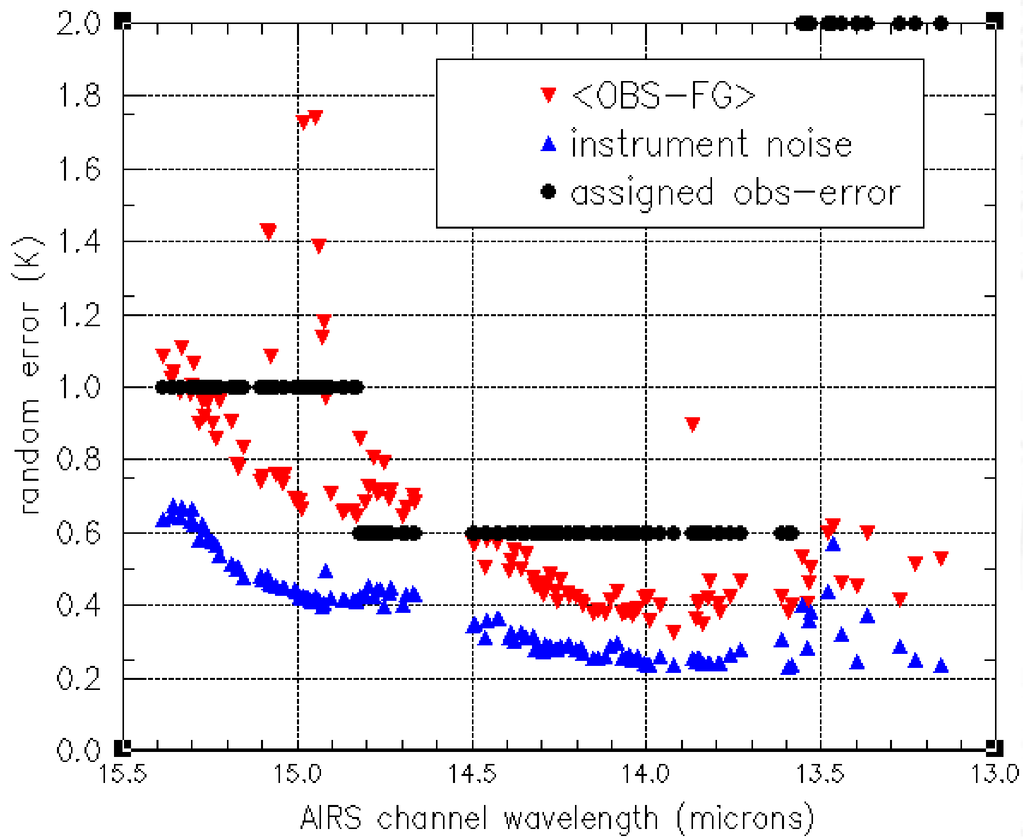
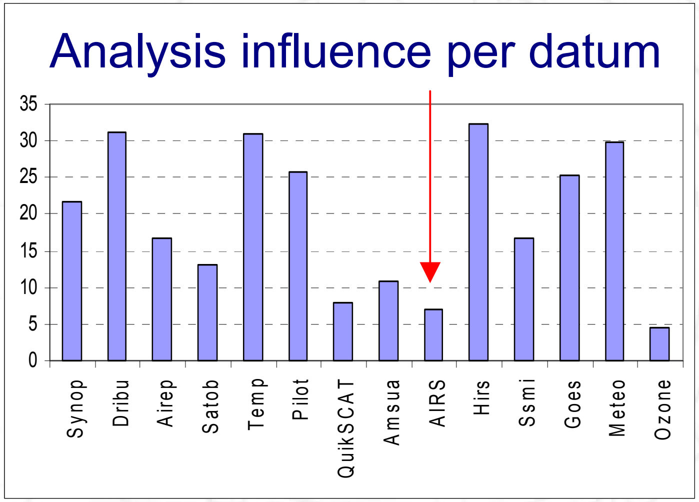
Observation errors

Radiance errors for the AIRS have been set to conservative levels to offset any potential problems due to assuming no inter-channel correlation or correlations between adjacent soundings.



$$influence = \frac{\partial Hx_a}{\partial y_i}$$

(From Cardinali et al.2004)



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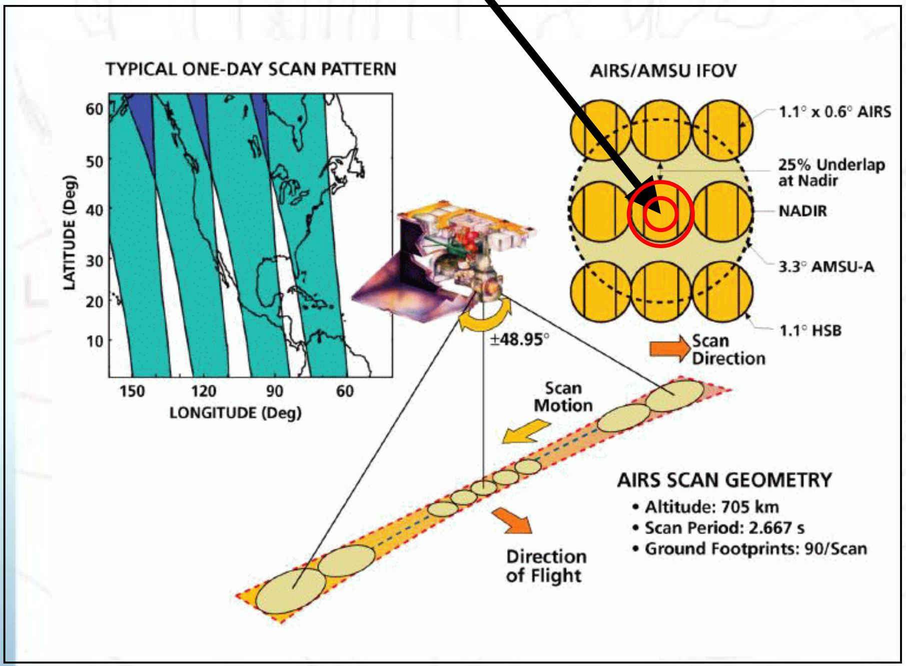
AIRS near-real-time data for NWP

1 spot out of 9

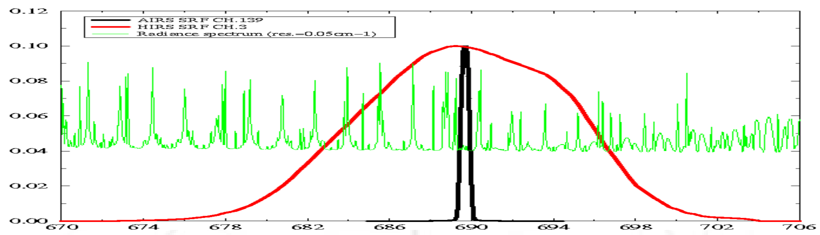


Specifications

Infrared Spectral Coverage	3.74 - 4.61 µm 6.20 - 8.22 µm 8.80 - 15.4 µm
Spectral Response	.
Spectral Resolution	l/Dl>1200 nominal
Spectral Sampling	Dl/2
Integrated Response (95%)	±1 Dl
Wavelength Stability	0.05 Dl24 hours
Wavelength Knowledge	0.01 Dl
Spatial Coverage	.
Scan Angle	±49.5° around nadir
IFOV	1.1°
Measurement Simultaneity	>99%
Sensitivity (NEDT)	0.14 K at 4.2 µm 0.20 K from 3.7 - 13.6 µm 0.35 K from 13.6 - 15.4 µm
Radiometric Calibration	± 3% absolute error
Power / Mass	256 W / 166 kg
Lifetime	5 years

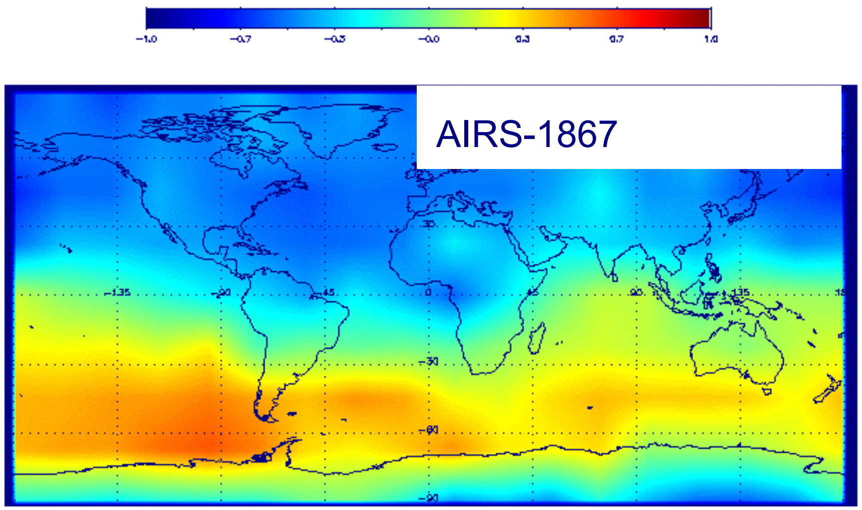
Visible Spectral Coverage	0.41 - 0.44 µm 0.58 - 0.68 µm 0.71 - 0.92 µm 0.49 - 0.94 µm
Spatial Coverage	.
Scan Angle	±49.5° around nadir
IFOV	0.185°
SNR @ Albedo = 0.4	>100
Polarization	<5%

324 out of 2378 channels

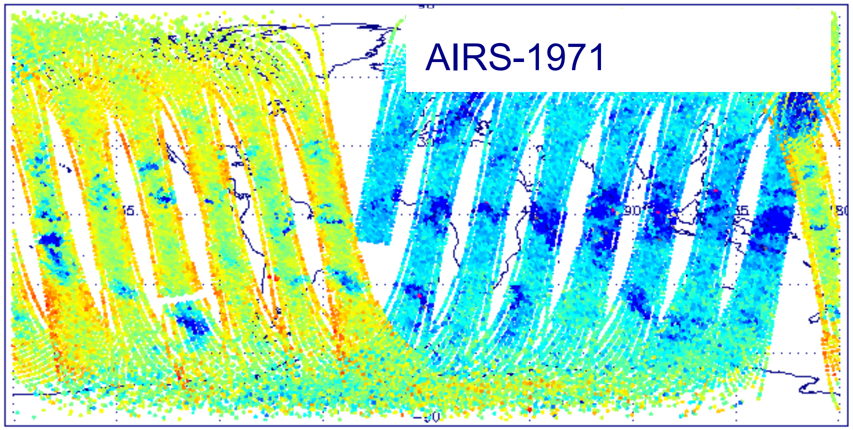


AIRS channels NOT used (i.e. blacklisted)

- Channels with a strong air-mass dependent bias (e.g. due to a gas not well modelled in RT)



- Channels with a strong day-night dependent bias (e.g. due to solar / non-LTE effects not modelled in RT)



• No surface sensing channels are used over land surfaces

The impact of AIRS

- Full operational system

- Single instrument experiments

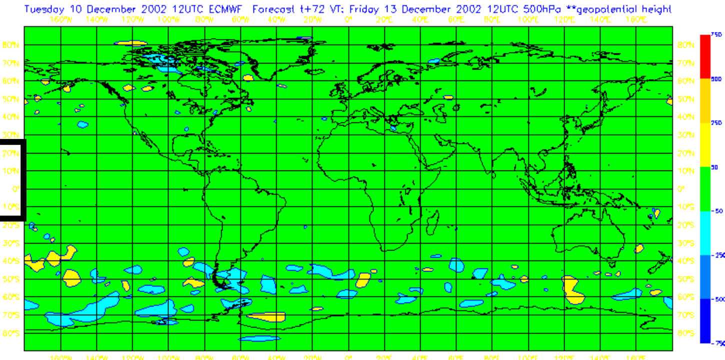
- Other applications

AIRS impact on the NWP analysis / forecast

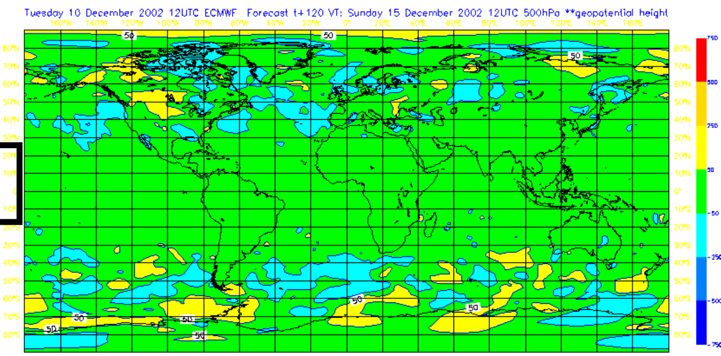
The assimilation of AIRS radiances shows a small but consistent positive impact on the analysis and forecast quality in all areas

Reduced forecast errors (at all ranges)

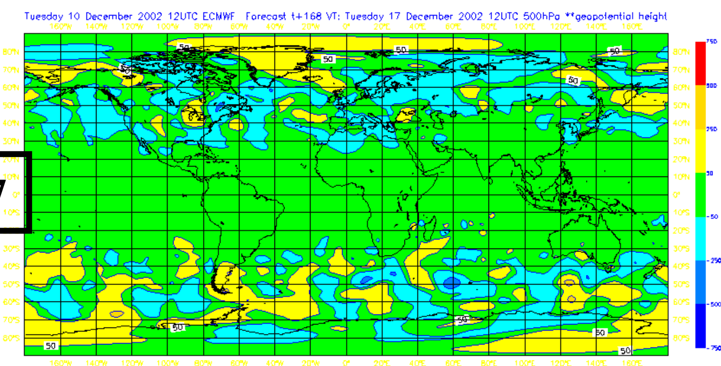
Day-3



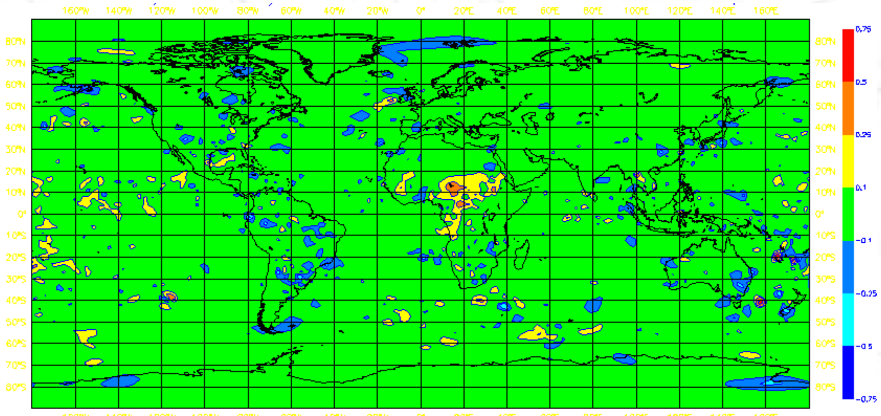
Day-5



Day-7



Reduced analysis increments (at many remote radiosonde locations)



The impact of AIRS

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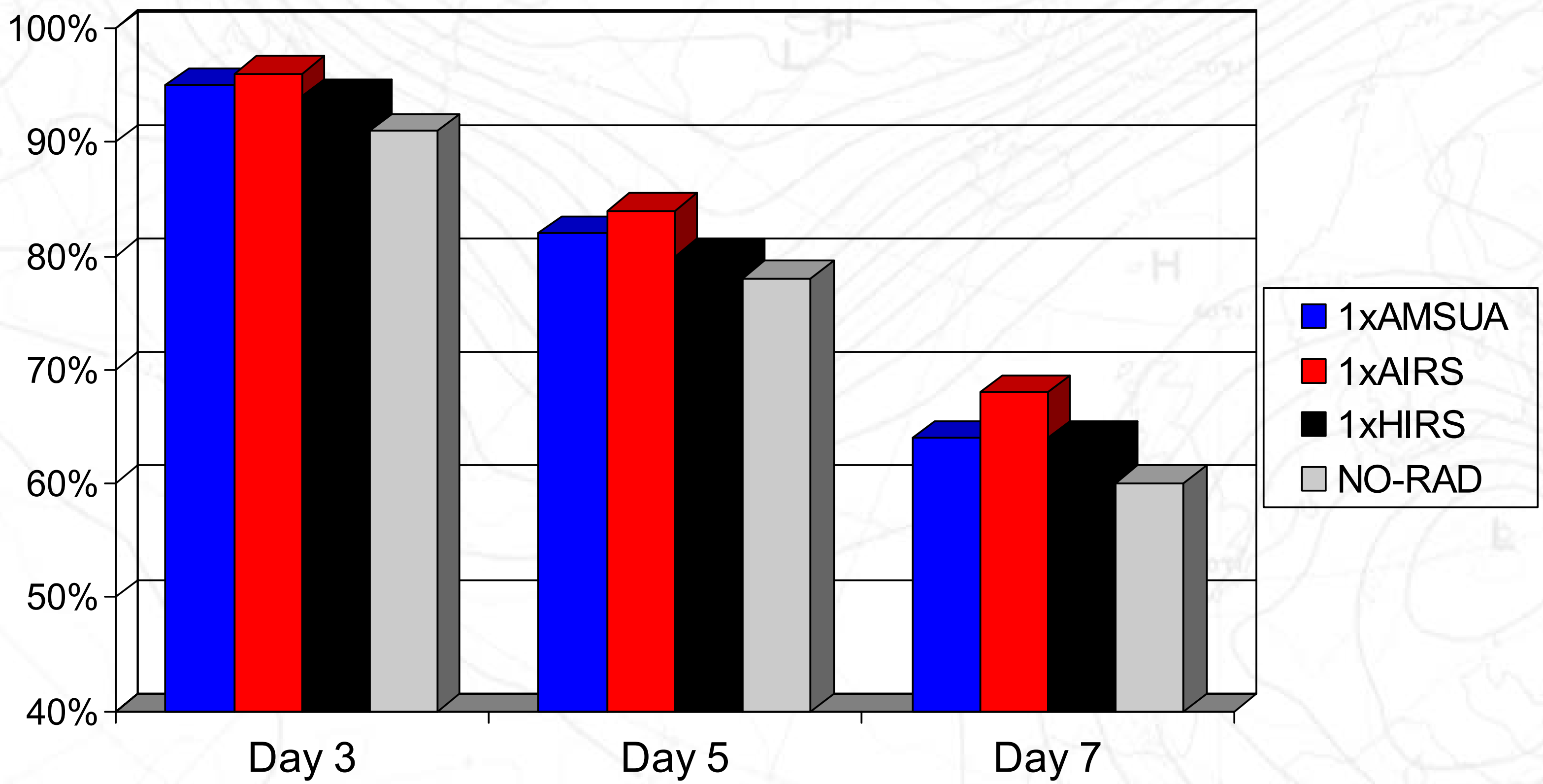
Current ECMWF operational satellite data

- AQUA AIRS
- 3xAMSUA (NOAA-15/16/17) + AQUA AMSUA
- 3 SSMI (F-13/14/15)
- 2xHIRS (NOAA-16/17)
- 2xAMSU-B (NOAA-16/17)
- 5xGEOS (Meteosat-5/7 GOES-9/10/12)
- MODIS/TERRA winds
- QuiKSCAT
- ENVISAT Altimeter / ASAR
- SBUV
- ENVISAT OZONE

Impact of individual sounding instruments on forecast quality

Anomaly correlation of 500hPa height for the **Southern Hemisphere**
(average of 50 cases summer and winter 2003 verified with OPS analyses)



The impact of AIRS

- Full operational system

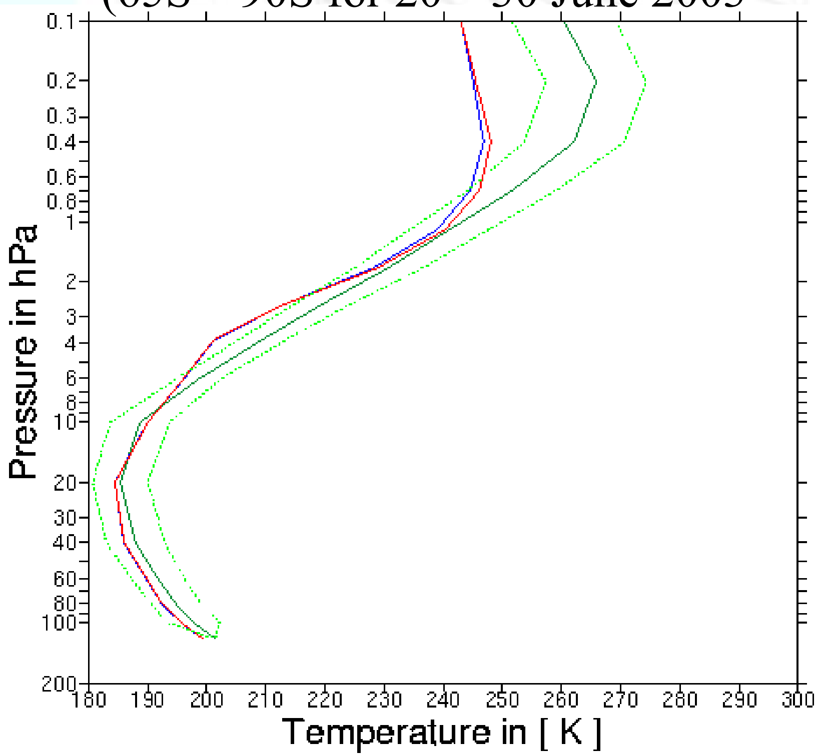
- Single instrument experiments

- Other applications

AIRS information in the stratosphere / mesosphere

ECMWF analysis fit to MIPAS temperature retrievals (not assimilated)

26R3 – **WITHOUT AIRS** radiances
(65S – 90S for 20 – 30 June 2003



26R3 – **WITH AIRS** radiances
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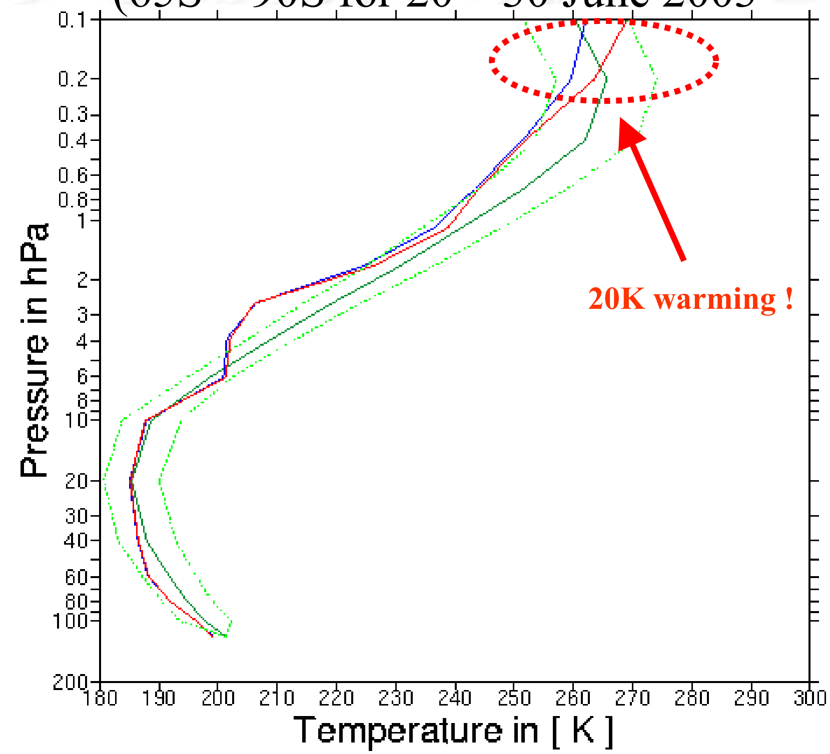
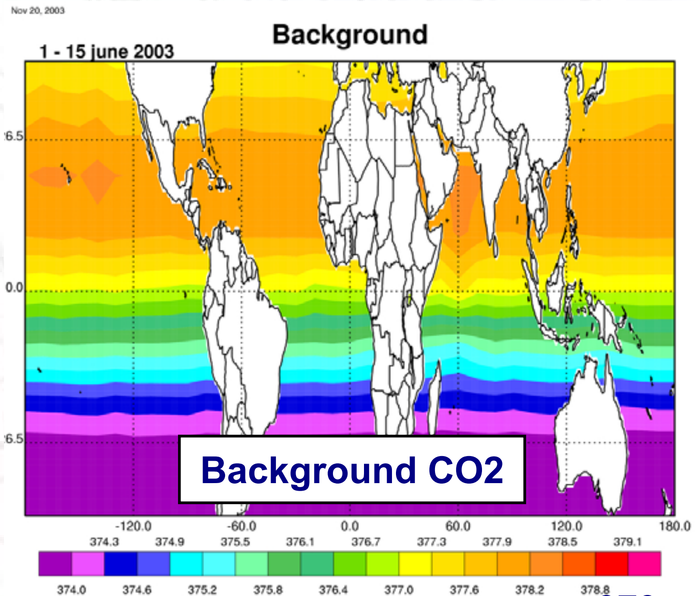
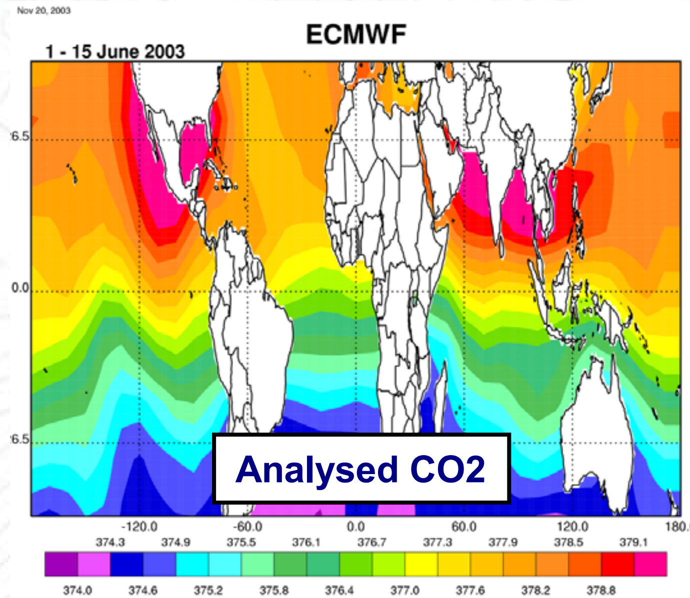


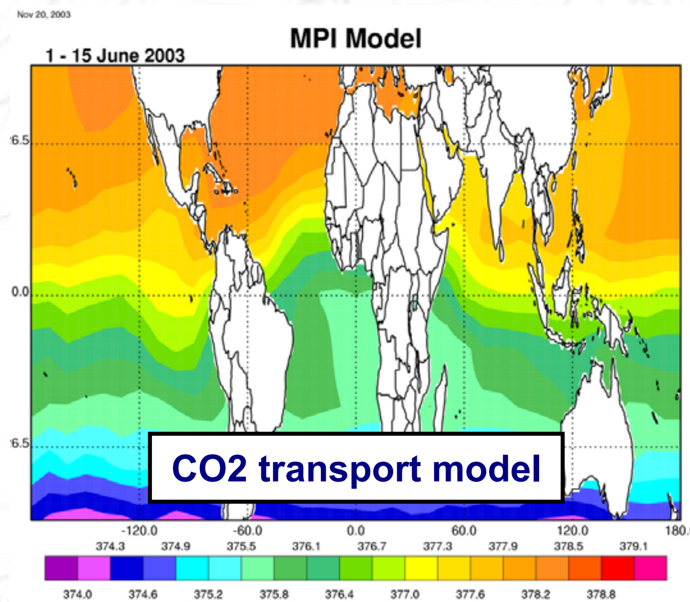
Column CO_2 estimates from AIRS assimilation



374 ppmv

379 ppmv





First half of June, tropical area: AIRS forces significant deviations from the background values.

Transport model simulations show similar variability, but there are some interesting anomalies

Summary and next steps

Summary of progress to date

- AIRS radiance data have been used in the ECMWF operational assimilation system since the **end of September 2003**.

- The AIRS assimilation system is currently conservatively tuned (in terms of observation errors and QC) and produces **modest positive impacts** on forecast skill in all areas (over a system already densely populated with other satellite data!).

- Experience with AIRS data has advanced our understanding of **cloud detection and IR radiative transfer** errors (leading to improved algorithms for AIRS and other instruments e.g. IASI and CrIS)

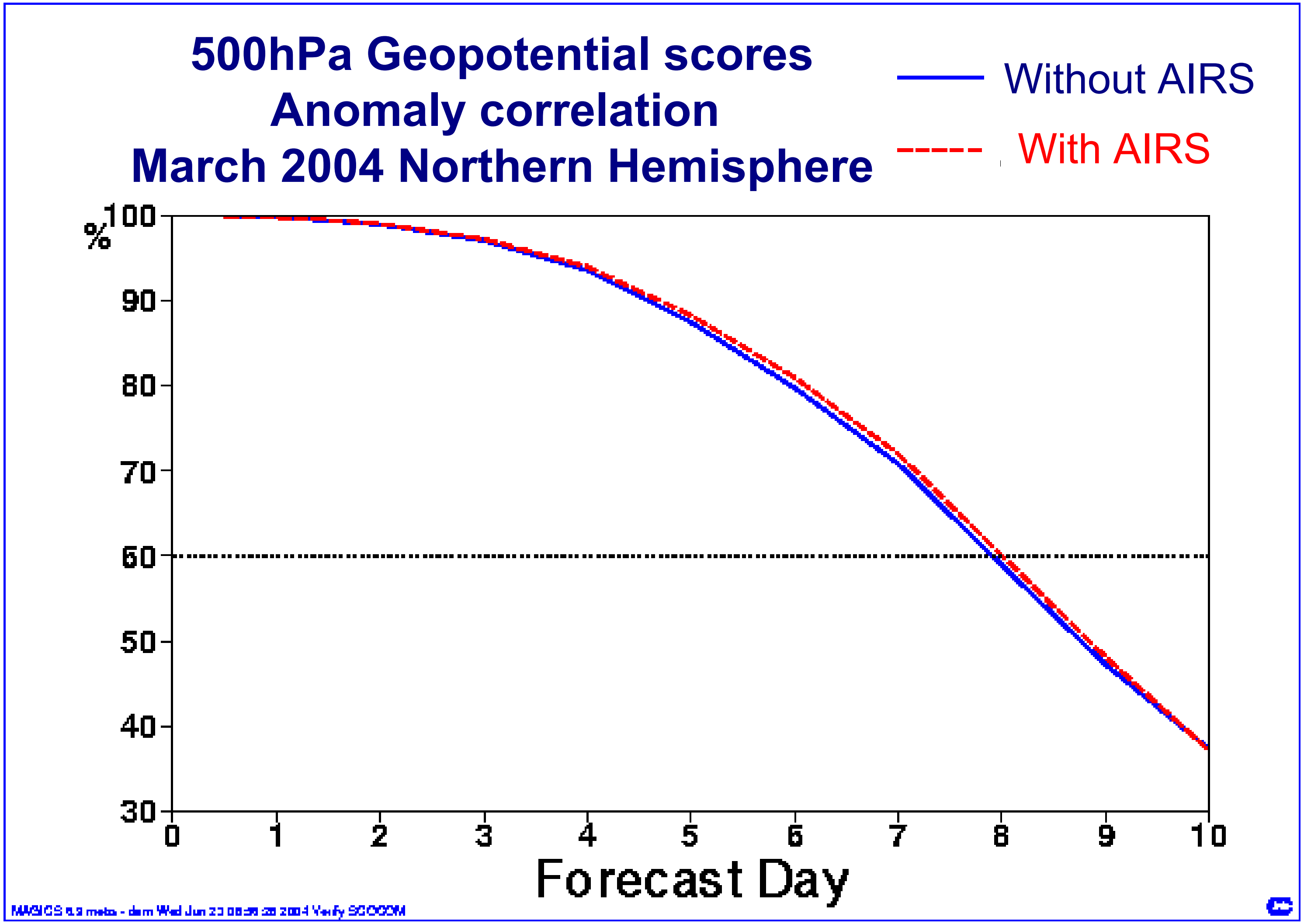
Next Steps

•Introduce a batch of scientific / technical upgrades to the operational system (bias correction / cloud detection) allowing better / more use of the AIRS spectrum.

•Investigate more efficient and sophisticated assimilation approaches (e.g. principal component or EOF analysis of spectra) for data compression and de-noising.

•Increase yield of sounding data in cloudy areas by simultaneous analysis of cloud signal (with T and Q)

Latest assessment of AIRS impact



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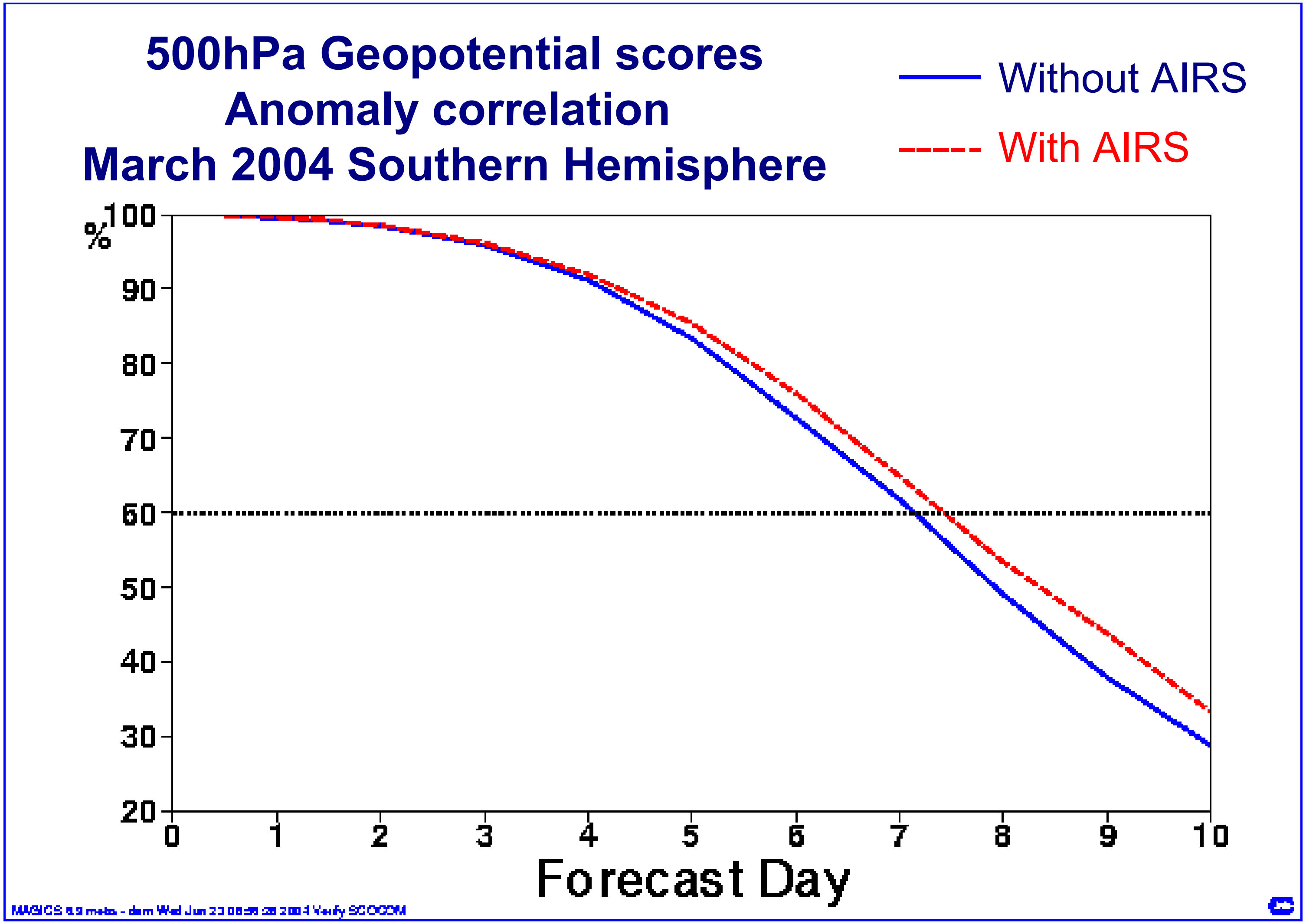

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Spectral data compression and de-noising

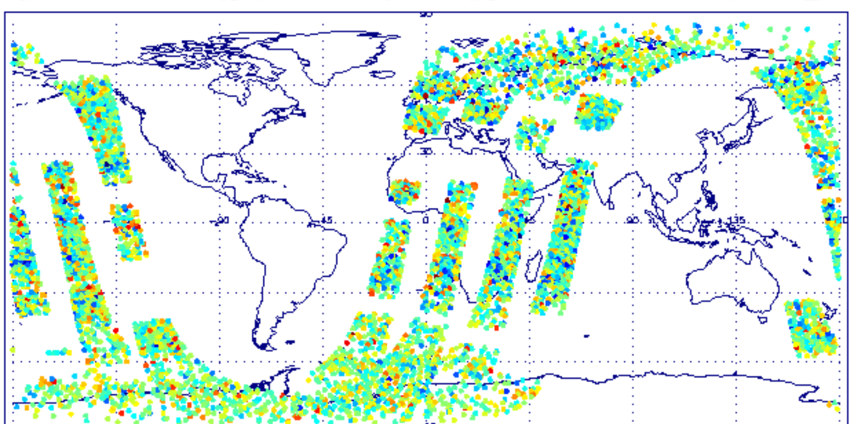
The complete AIRS spectrum can be compressed using a truncated principal component analysis (e.g. 200PCAs v 2300 rads)

$$S_i^R = \overline{S}_i + \sum_{l=1}^{N} P_l V_{l,i}$$

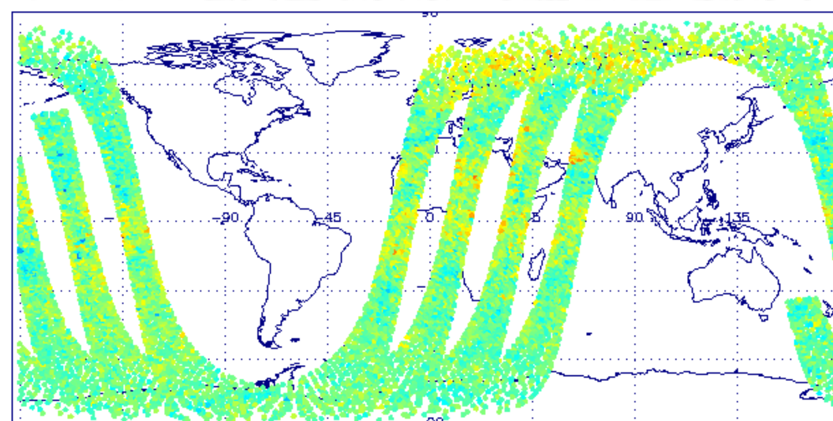
(see talk by J. Smith …)

This allows data to be transported efficiently and (by appropriate tuning of the truncation) results in a significant de-noising of the data

Observed minus computed radiance departures for real AIRS ch-123



Observed minus computed radiance departures for recon AIRS ch-123



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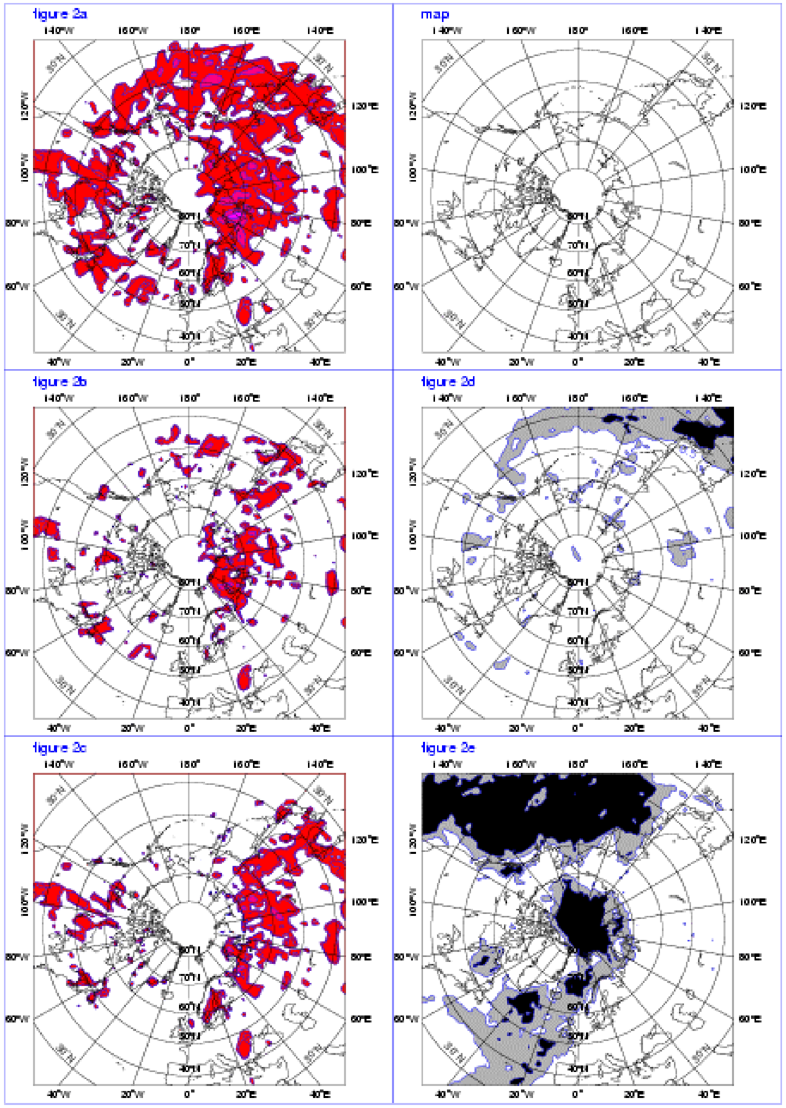
Cloud and meteorologically sensitive areas

Regions important for forecast error development can be traced using adjoint sensitivity techniques.

These sensitive areas have been found to correlate with cloud cover.

i.e. cloudy areas are very important !

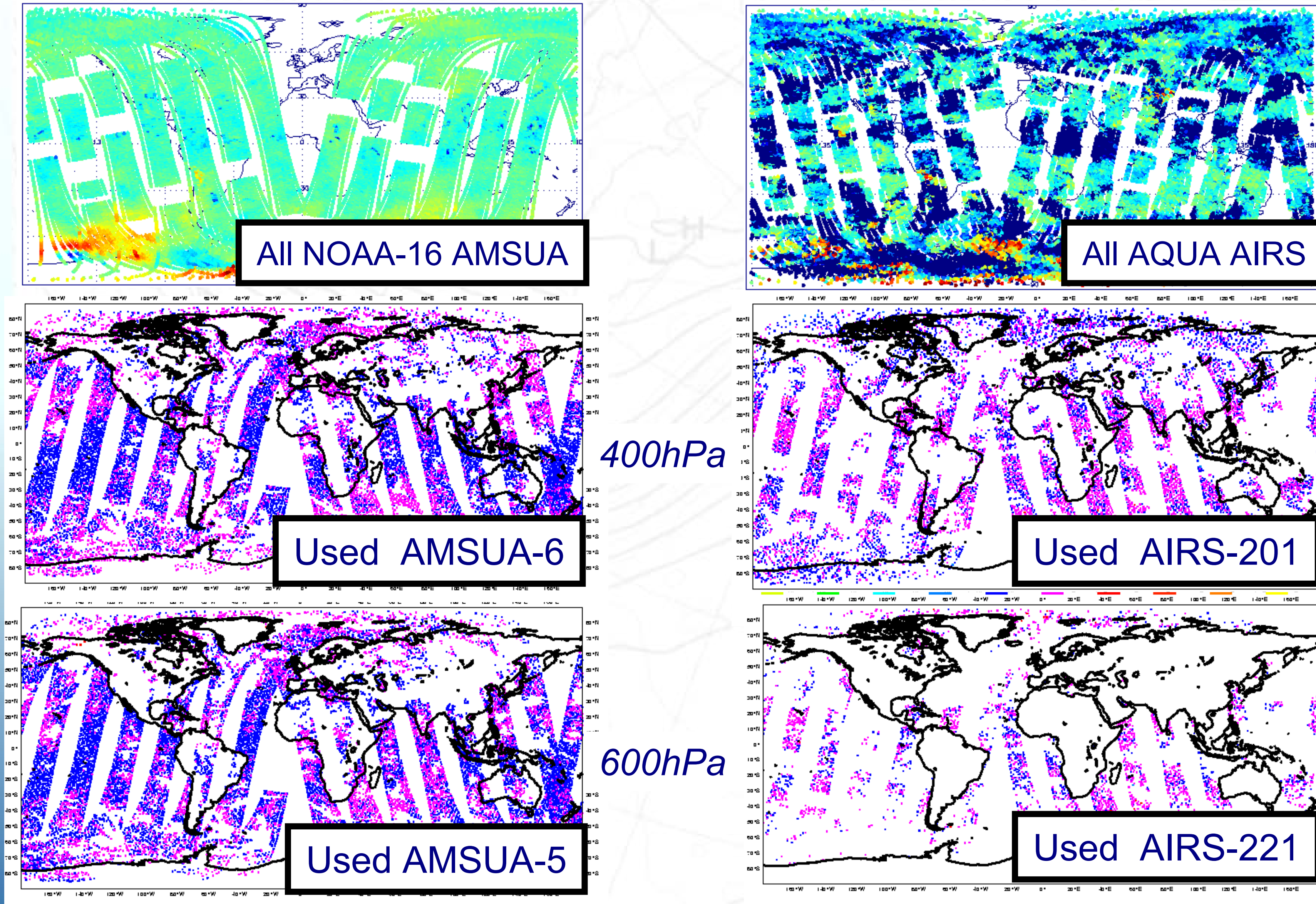
sensitivity **cloud cover**



High cloud

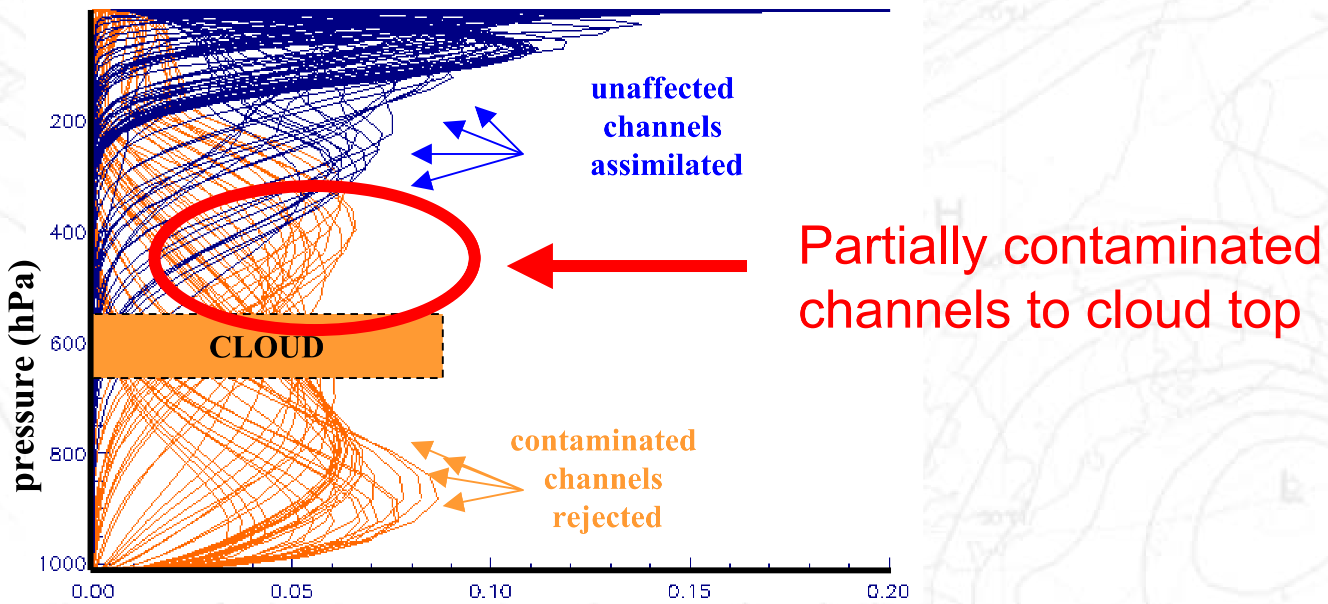
Low cloud

Data coverage: Microwave versus Infrared



Using partially cloud contaminated IR data

By introducing cloud as a *sink* variable within the analysis we hope to to explicitly take into account the contribution of the cloud to the measured radiance and use more channels down to the cloud top

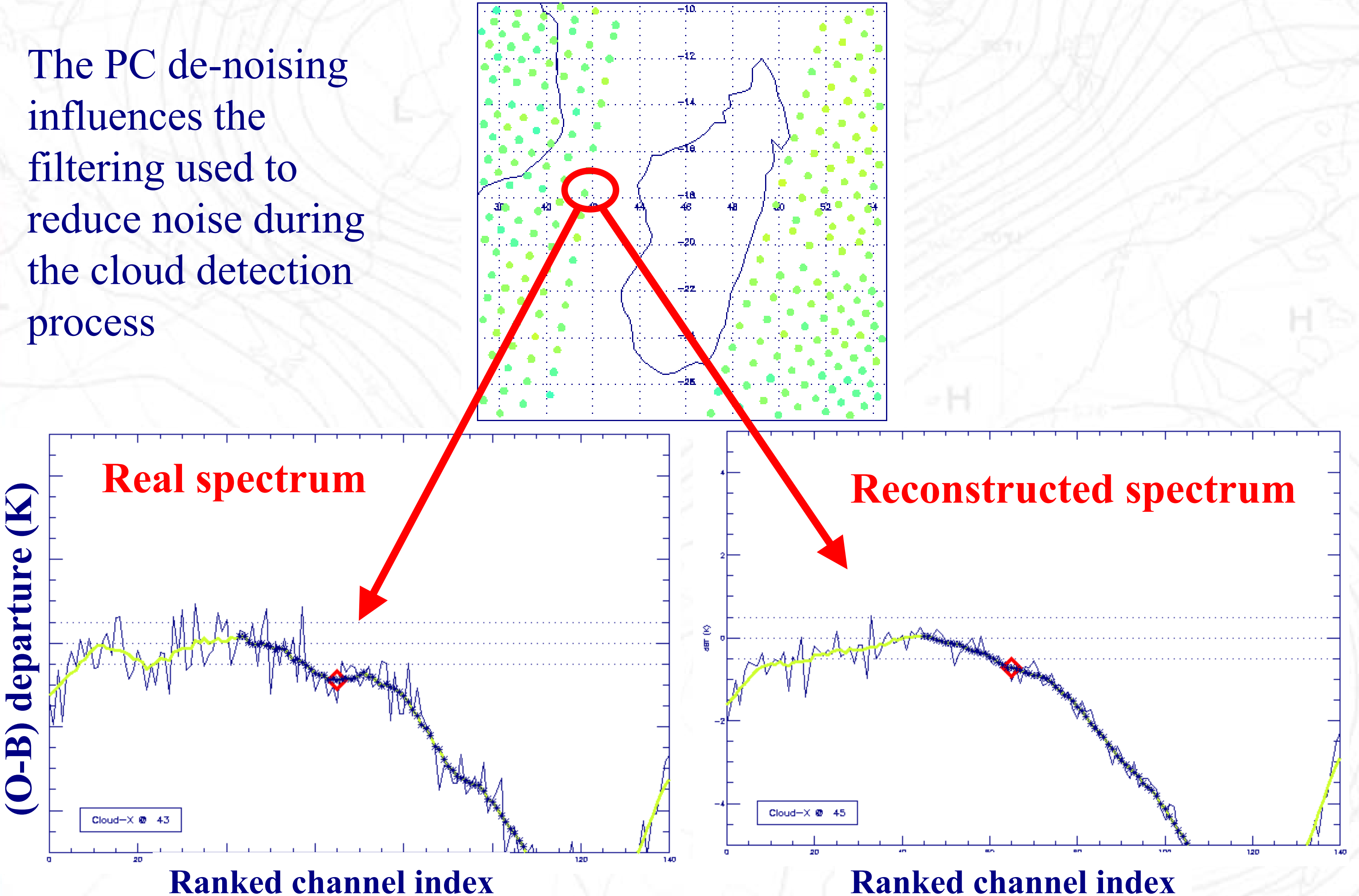


See talk by F. Chevallier for another possible approach ….

End

De-noising with 200 NESDIS principal components

The PC de-noising influences the filtering used to reduce noise during the cloud detection process

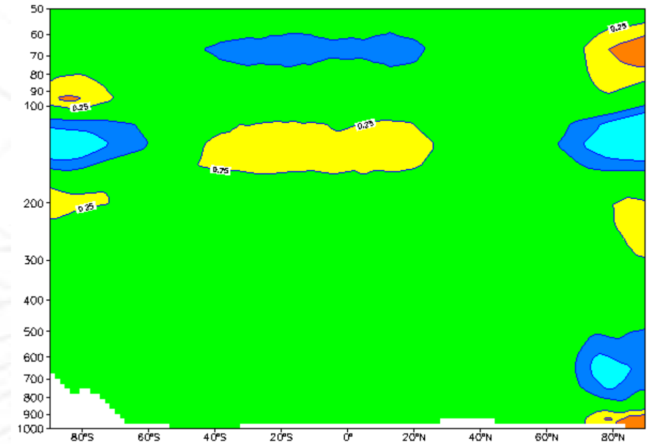


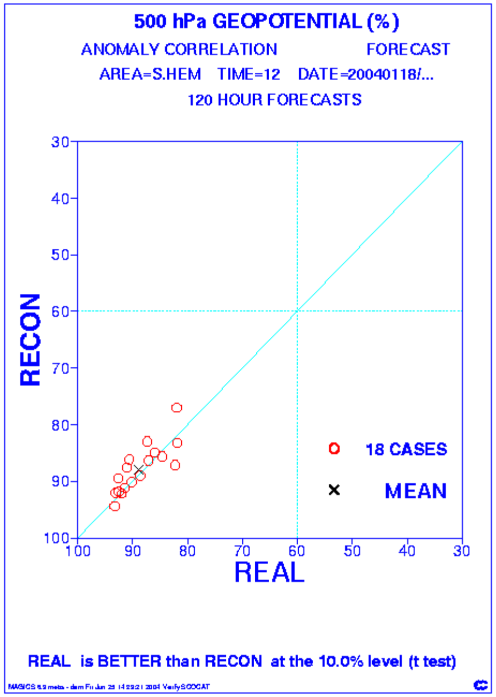
Assimilation experiments with NESDIS PC reconstructed radiances

Slightly larger stratospheric analysis increments obtained with the reconstructed (de-noised) radiances

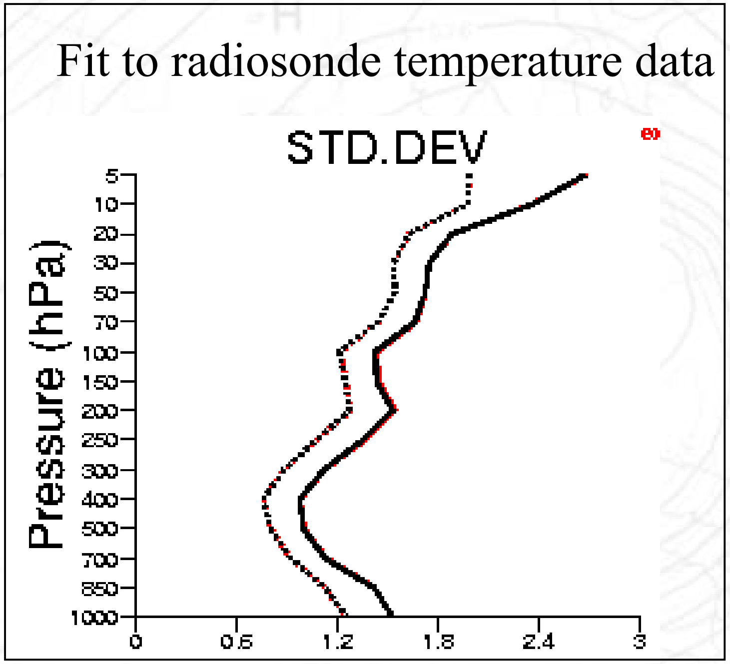
possible *organisation* of radiance signal ?

Zonal mean of RMS analysis increments



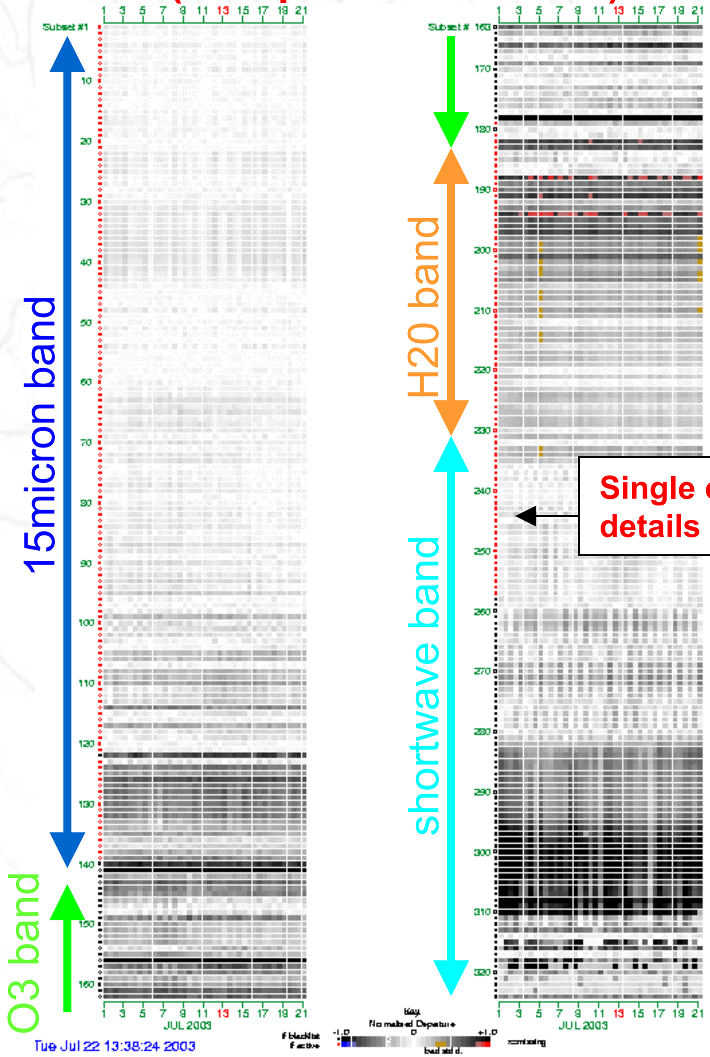


No impact on forecast quality or analysis fit to other data



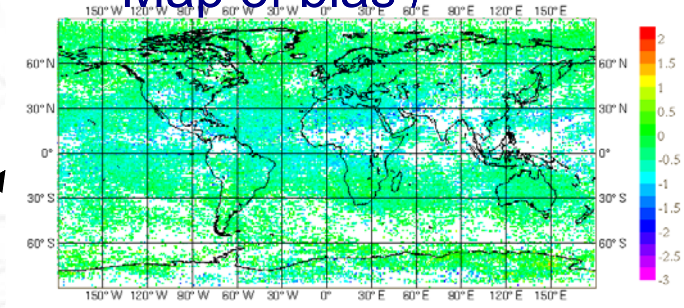
AIRS bias monitoring

All channels time series (for operational alerts)

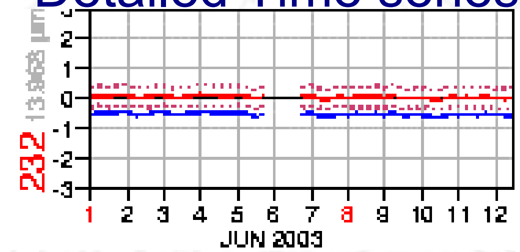


Single channel details

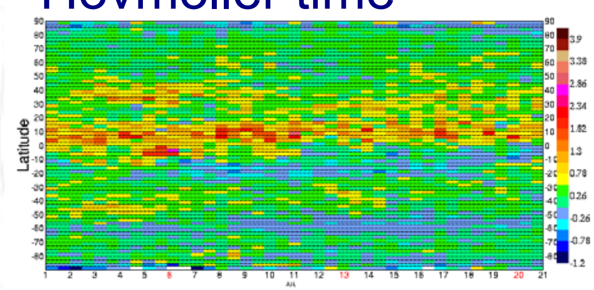
Map of bias /



Detailed Time series



Hovmoller time

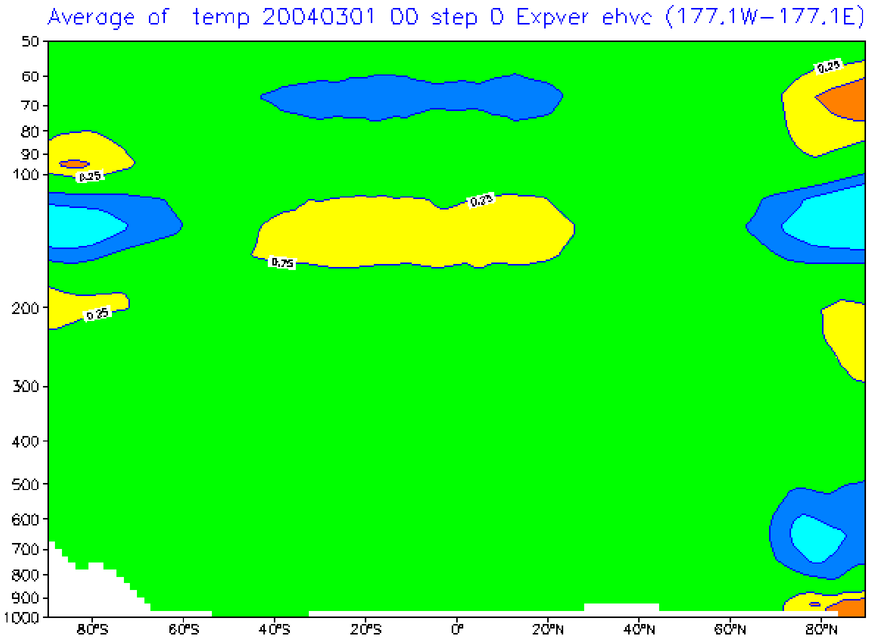


First upgrade of operational AIRS system

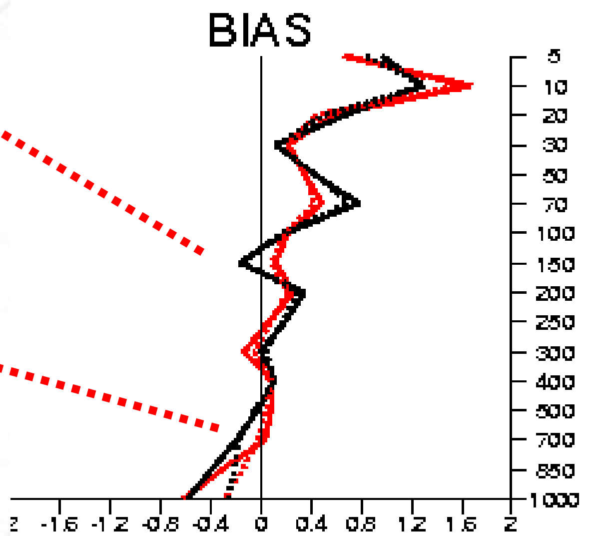
•The new *gamma* adjusted RT model reduces analysis increments and improves the mean fit of the assimilation to radiosonde data

•*gamma* is a constant factor multiplying the optical depth and translates into an air-mass dependent bias correction

Zonal mean temperature analysis changes



Northern Polar radiosonde temperature departures



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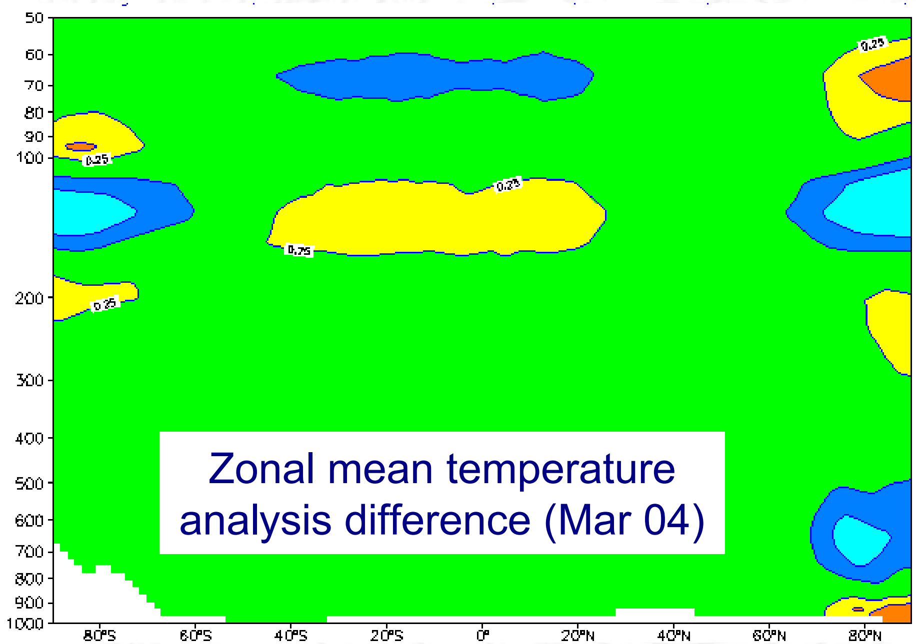
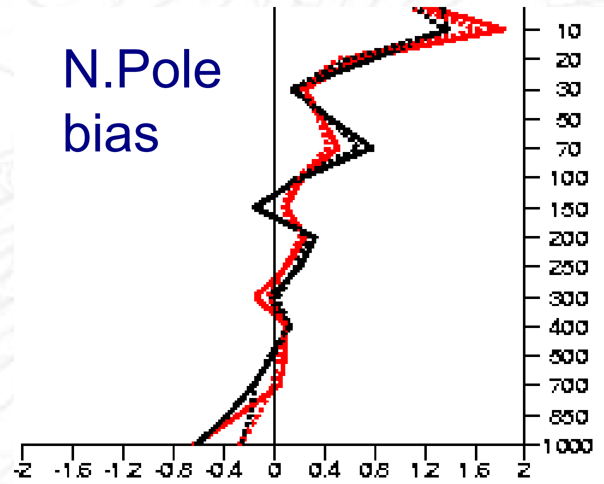
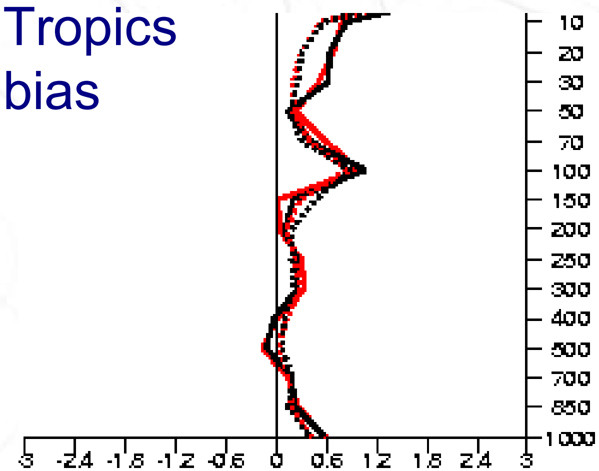


Zonal mean temperature analysis difference (Mar 04)

N.Pole bias



Tropics bias



S.Pole bias