Assimilation of Advanced Infrared Sounder Observations at the Met Office

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Talk Outline

- Assimilation of AIRS radiances
  - What have we done so far at the Met Office?
- The next step
  - How do we fully and efficiently exploit the data?

But first the headlines…..

AIRS is now Operational!

- AIRS data was assimilated operationally at the Met Office for the first time on 26th May 2004.
- A positive impact is being seen

AIRS in the News!

"It is one of the most exciting leaps forward in forecasting we have ever made.?"...The key to greater accuracy lies in the use of data from Nasa's *Aqua* satellite, which gathers more detailed information on temperature and atmospheric pressure and water vapour than has ever been available before.

The Times, June 21st 2004

Assimilation AIRS Observations at the Met Office

Assimilation of Observations into NWP

We need to minimise the cost function, *J*:

$$J = (\mathbf{x} - \mathbf{x}_b)\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b)^T + (\mathbf{y}[\mathbf{x}] - \mathbf{y}_{obs})(\mathbf{O} + \mathbf{F})^{-1}(\mathbf{y}[\mathbf{x}] - \mathbf{y}_{obs})^T$$

Background Penalty **Observation Penalty**

$\mathbf{x}_b$ is the background state vector
B is the background error covariance
$\mathbf{y}_{obs}$ is the observed radiances
O+**F** is the observation plus forward model error covariance
x is the state being minimised and **y**[**x**] is the radiance corresponding to that state

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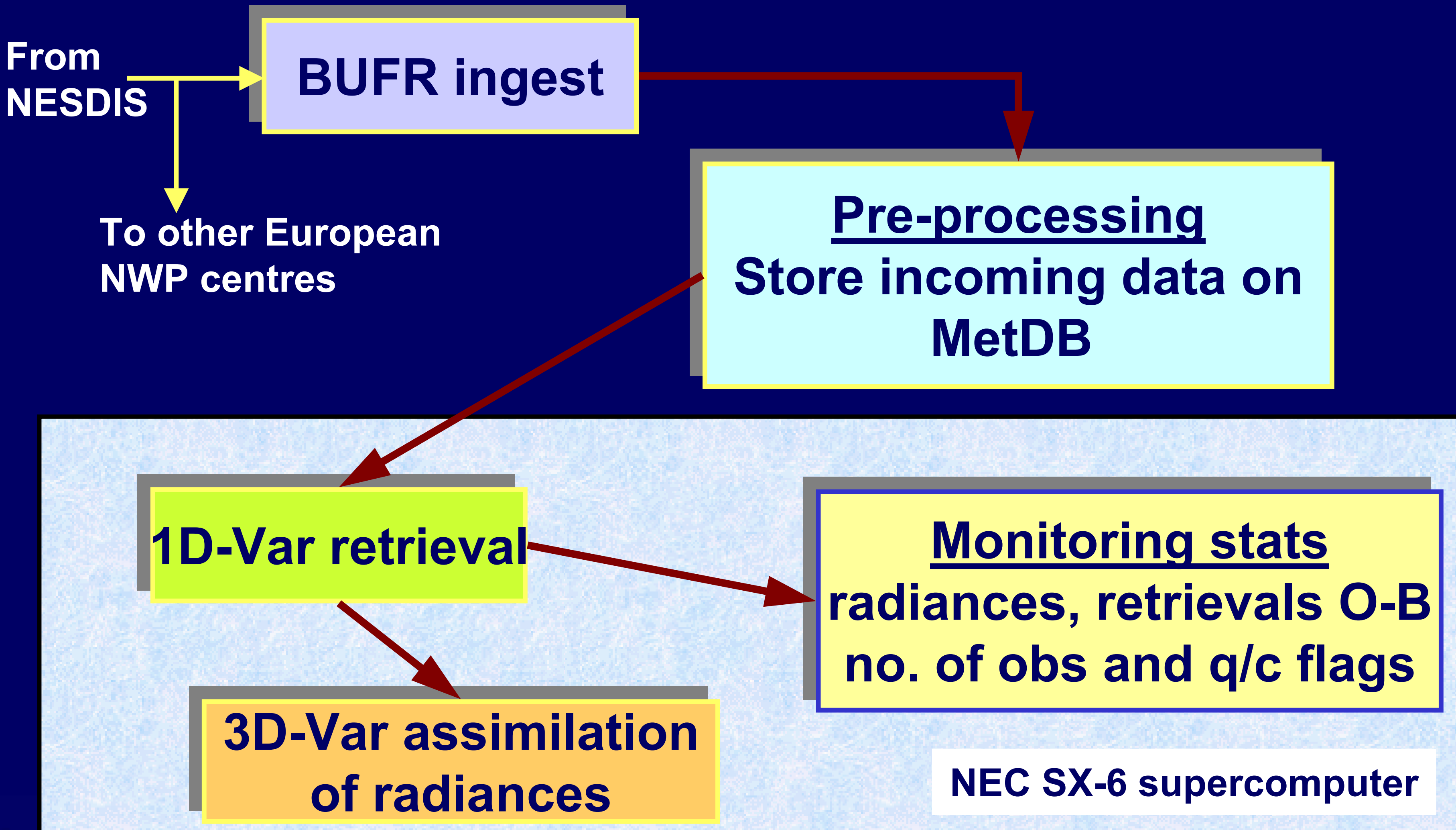
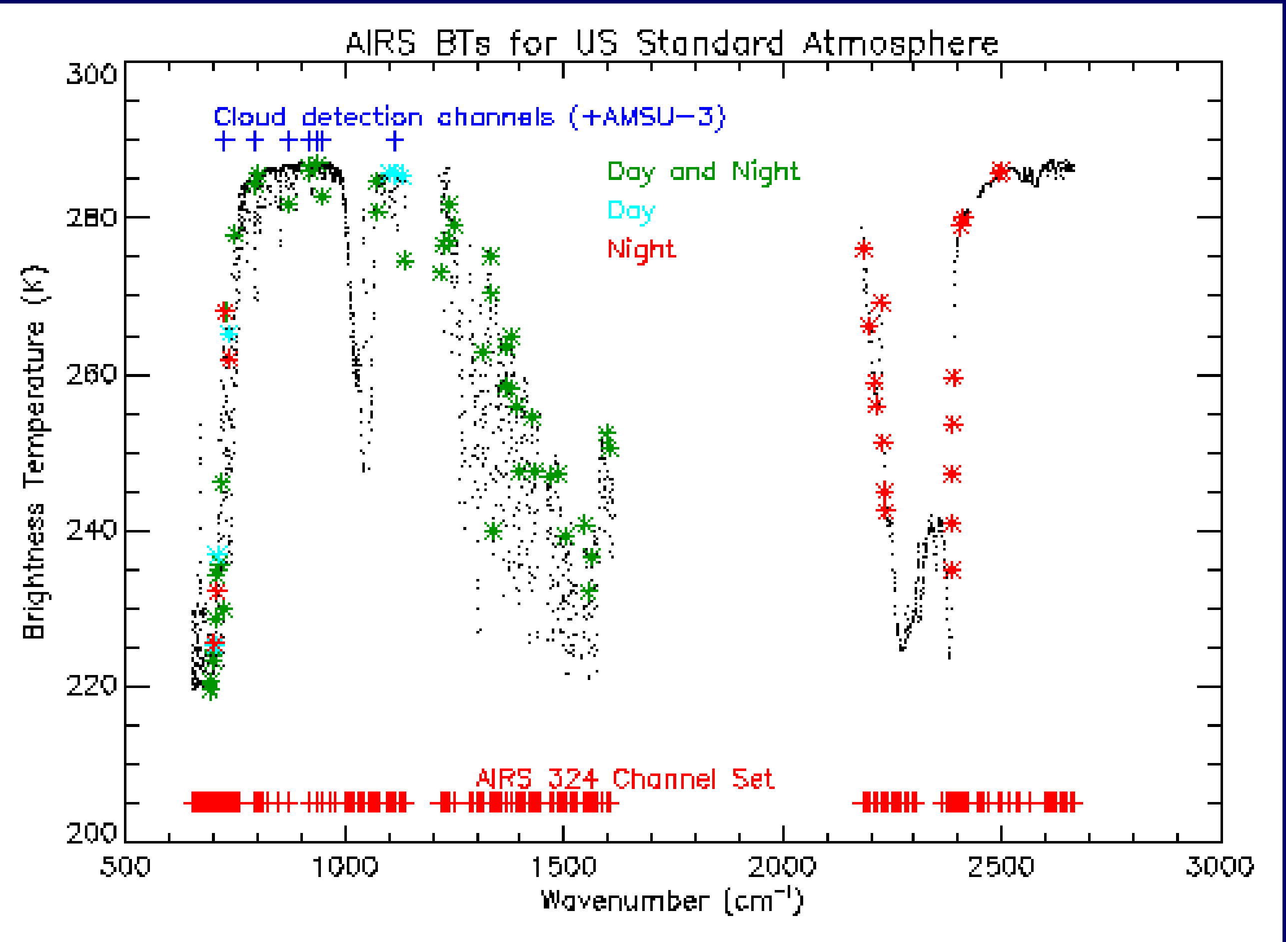
AIRS data processing at the Met Office



NRT AIRS Data from NESDIS used at the Met Office

- 324 Channels (BUFR dataset)
- One AIRS FOV for every other AMSU FOV (there are 9 AIRS FOVS/AMSU FOV)
  - Also AMSU-A and HSB auxiliary data
- AIRS reconstructed radiances are also being transferred routinely.

Channel Selection



- 324 AIRS channels supplied
- Assimilate a subset of 45 (day) or 60 (night)
- Choose those with highest impact on degrees of freedom for signal (Rodgers, 1996)
- Exclude channels (137 in all) that:
  - Have a large contribution from above the model top
  - Are significantly affected by ozone
  - Have less robust Jacobians
  - Are noisy

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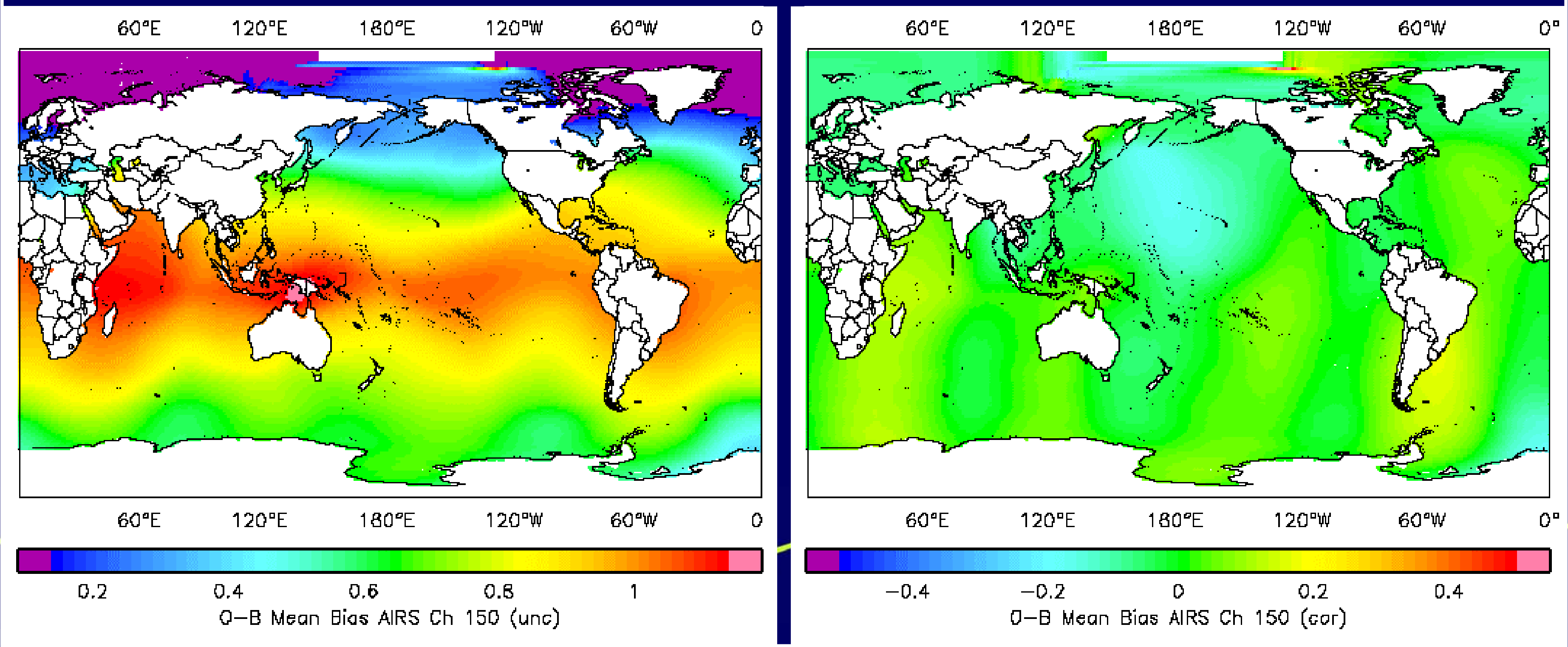
Bias Correction

- Biases vary with scan angle
- Biases vary with "air-mass"
- Biases are channel dependent

- Air-mass bias predictors
  - brightness temperature
  - 200-50 hPa thickness
  - 850-300 hPa thickness

16 January - 15 February 2003, AIRS channel 150 (692.8 cm^{-1} / 14.4 μm)



Variational Cloud Detection

(English, Eyre & Smith, 1999)

Attempt to determine the probability of having a clear field of view given the observed radiances and the NWP background profile

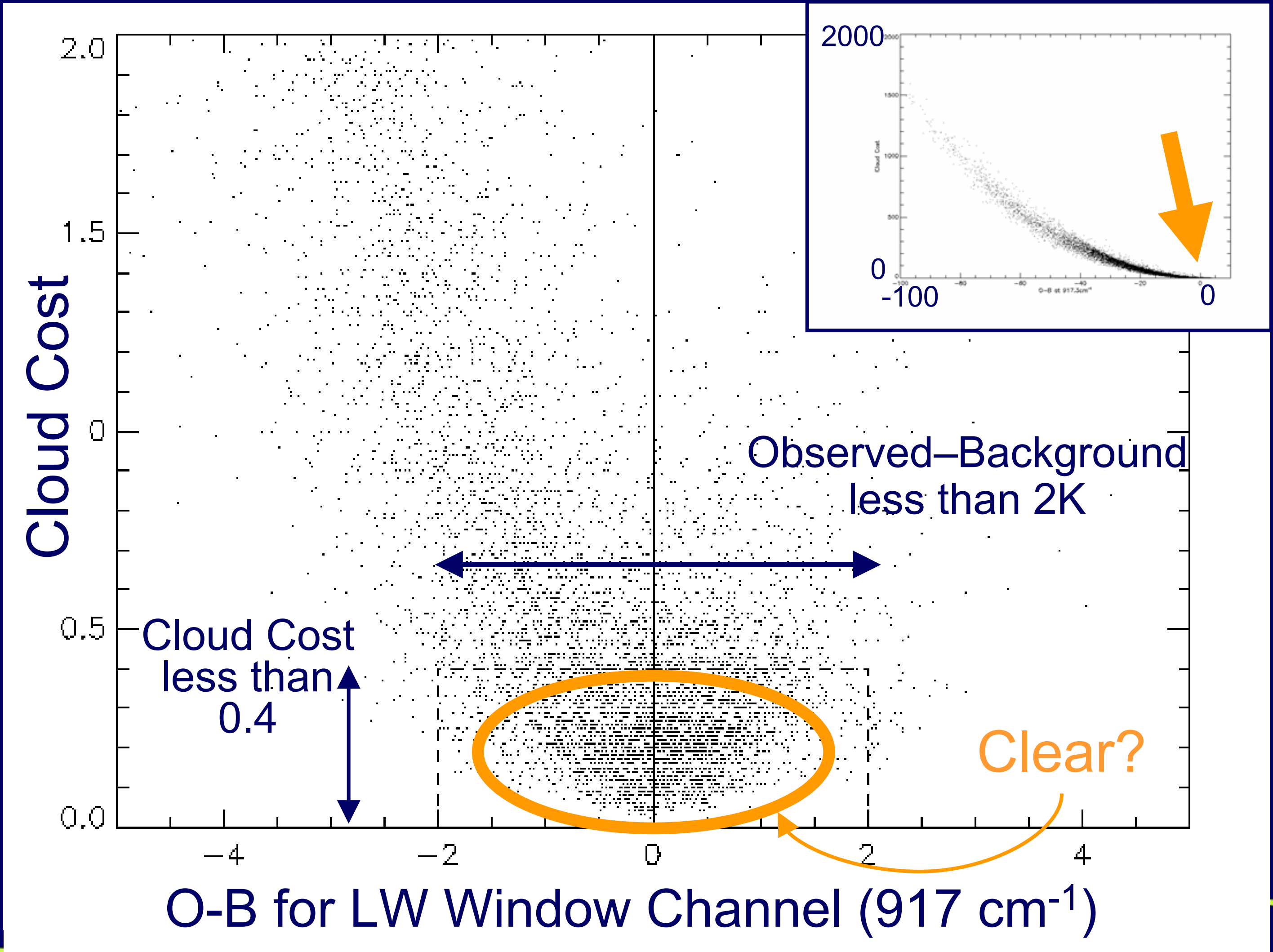
$$
\begin{aligned}
J &= -\mathrm{Ln}\{P(\mathrm{clear} \mid \mathbf{y}_{\mathrm{obs}}, \mathbf{x}_{\mathrm{b}})\} \\
&= -\mathrm{Ln}\{P(\mathbf{y}_{\mathrm{obs}} \mid \mathbf{x}_{\mathrm{b}}, \mathrm{clear})\} - \mathrm{Ln}\{P(\mathbf{x}_{\mathrm{b}} \mid \mathrm{clear})\} - \\
&\qquad \mathrm{Ln}\{P(\mathrm{clear})\} - \mathrm{Ln}\{P(\mathbf{y}_{\mathrm{obs}} \mid \mathbf{x}_{\mathrm{b}})\} - \mathrm{Ln}\{P(\mathbf{x}_{\mathrm{b}})\} \\
&\sim \tfrac{1}{2}(\Delta\mathbf{y})^{\mathrm{T}}\{\mathbf{H}(\mathbf{x}_{\mathrm{b}})^{\mathrm{T}}\mathbf{B}\mathbf{H}(\mathbf{x}_{\mathrm{b}}) + \mathbf{R}\}^{-1}(\Delta\mathbf{y}) + \mathrm{Const.}
\end{aligned}
$$

$$\Delta\mathbf{y} = \mathbf{y}_{\mathrm{obs}} - \mathbf{y}(\mathbf{x}_{\mathrm{b}})$$

Clouds are flagged when J exceeds a threshold

In addition if O-B for chan 787 less than -2K flagged as cloudy

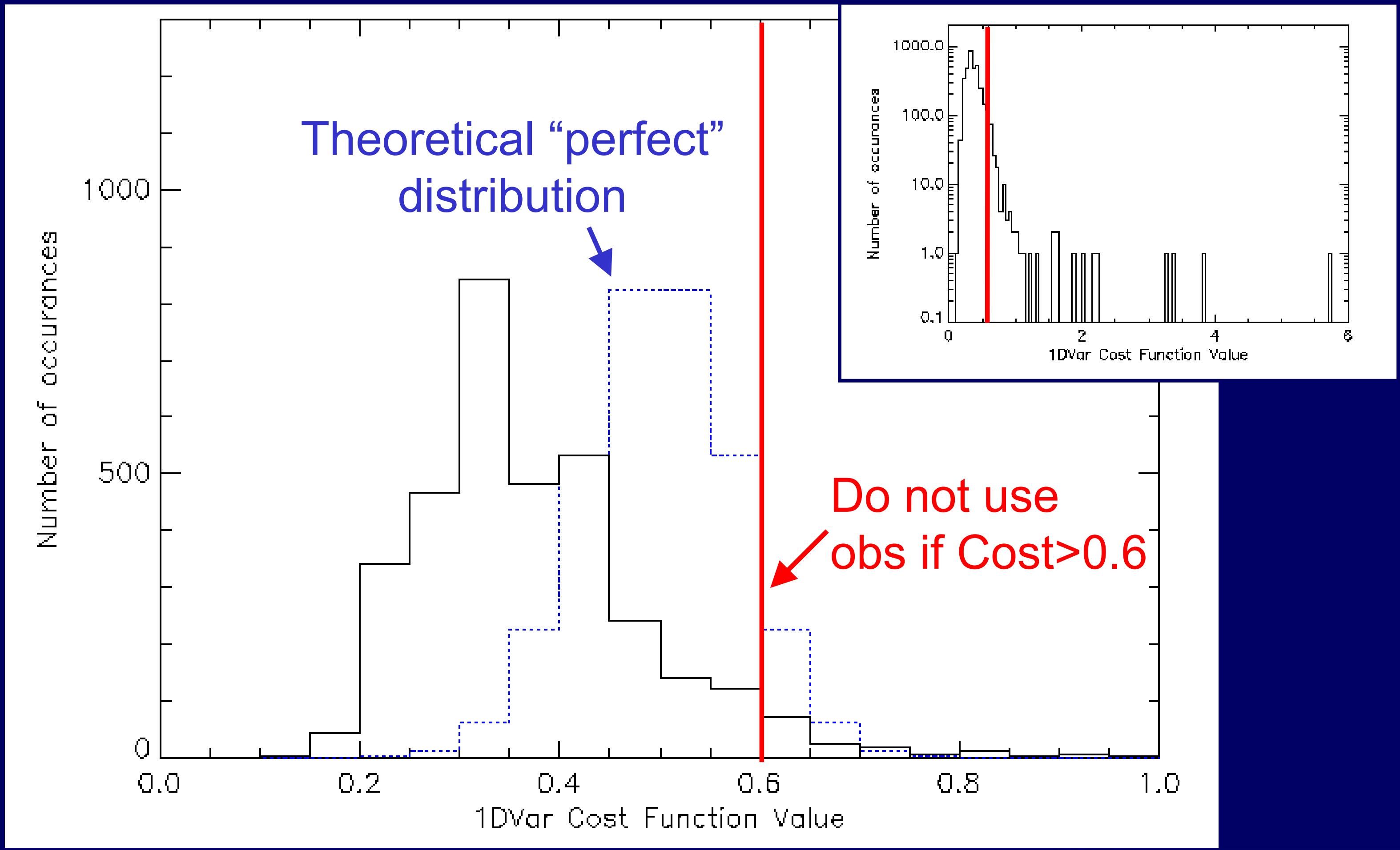
Variational Cloud Detection



Cloud Cost:
Attempt to determine the probability of having cloud in the field of view, given the observed radiances and the NWP background profile (English, Eyre and Smith, 1999)

1D-Var Cost Distribution

No. of occurrences

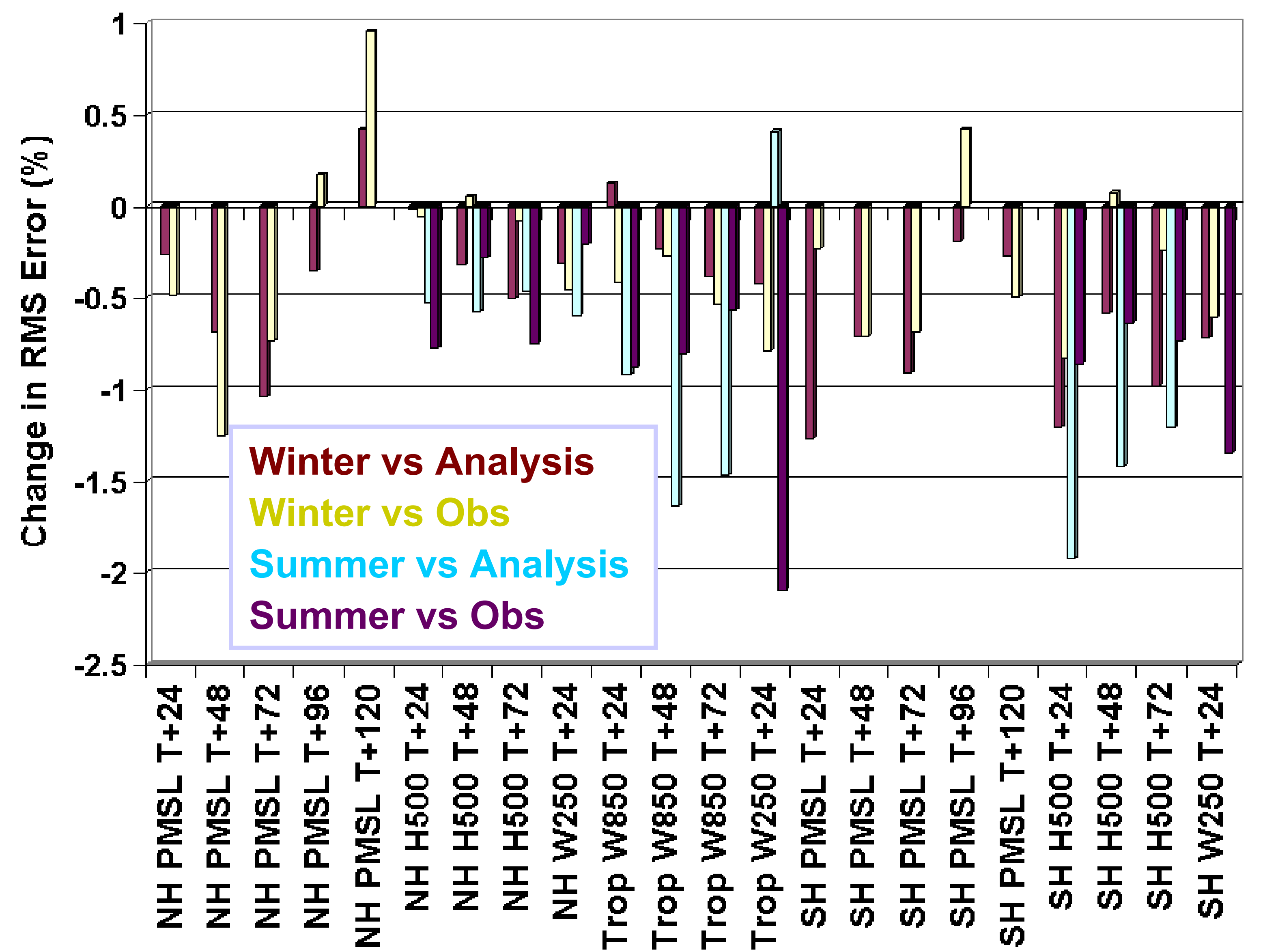


1D-Var Cost Function Value

Initial AIRS Assimilation Trials

- 16th December 2002 - 13th January 2003 and 1st - 21st July 2003.
- Headline verification score is NWP index
  - We saw improvements in this index of 0.4% when verified both versus observations and analysis in the winter trial. (The PMSL verification in the summer trial was not working correctly, so there is not a meaningful score for this period).

AIRS trial scores

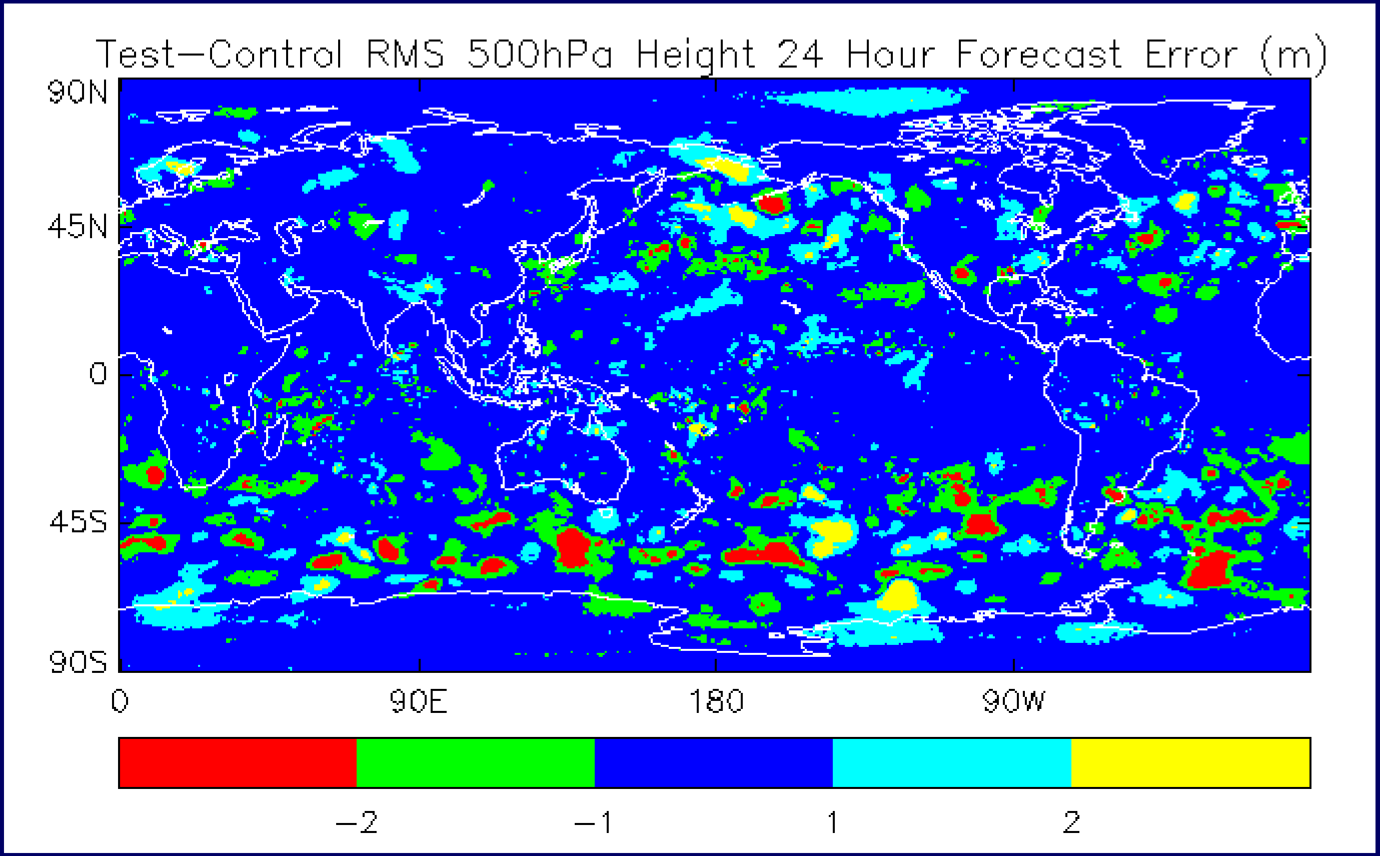


Change in Forecast Errors: 500hPa Height at 24 hours

-0.2%

-0.6%

-1.8%

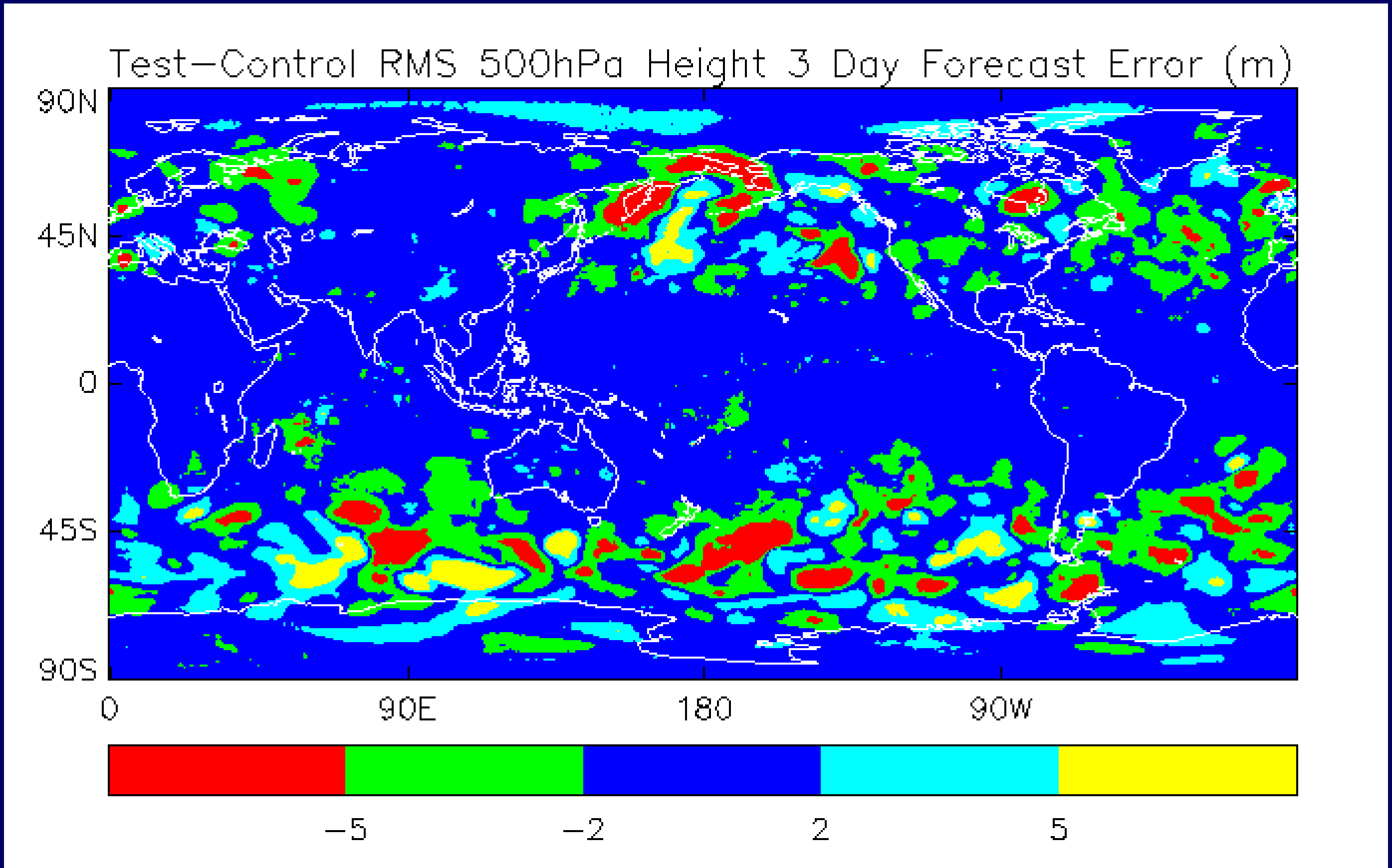


Change in Forecast Errors: 500hPa Height at 72 hours

-2.0%

-1.0%

+0.3%



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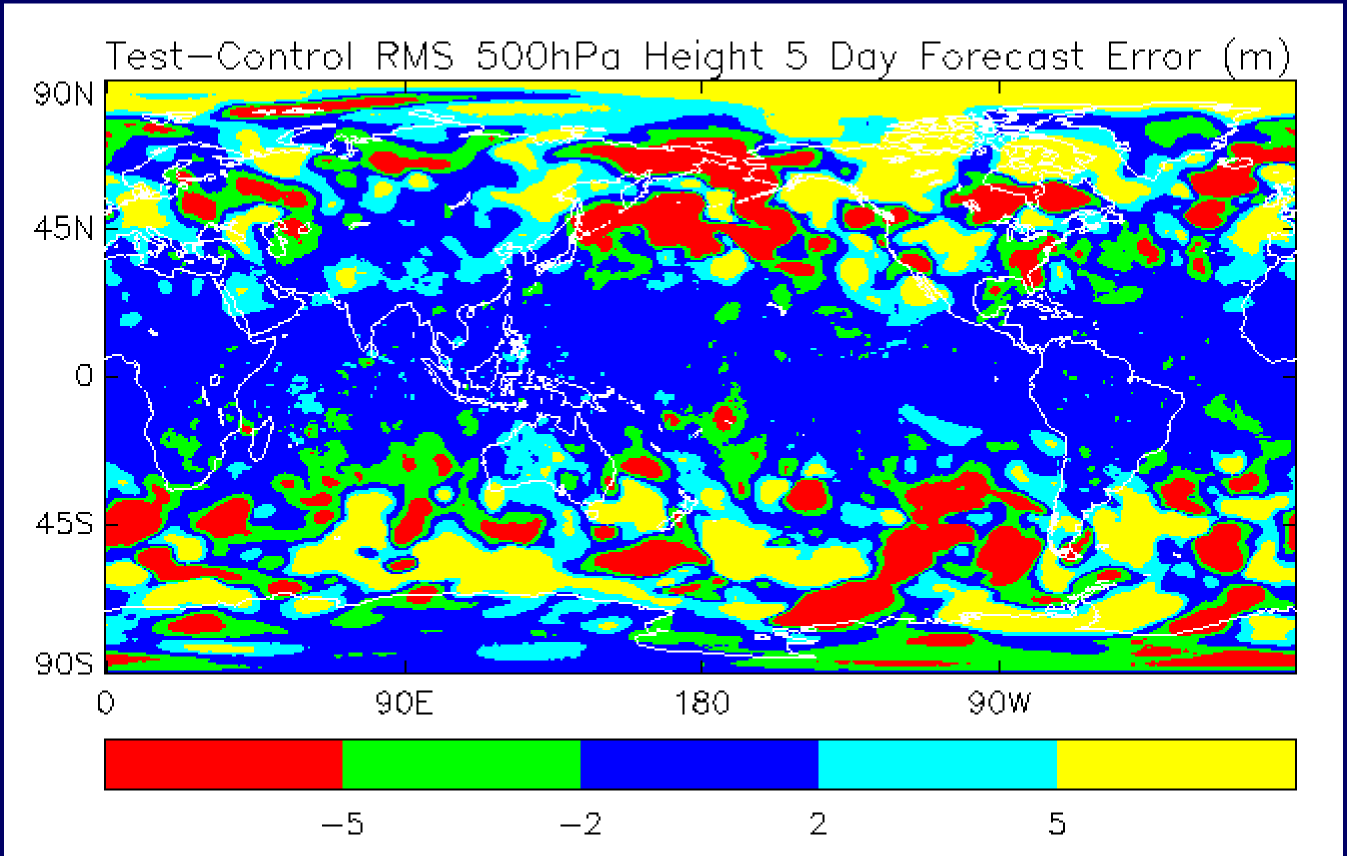
Change in Forecast Errors: 500hPa Height at 120 hours

0.0%

-1.1%

-1.1%



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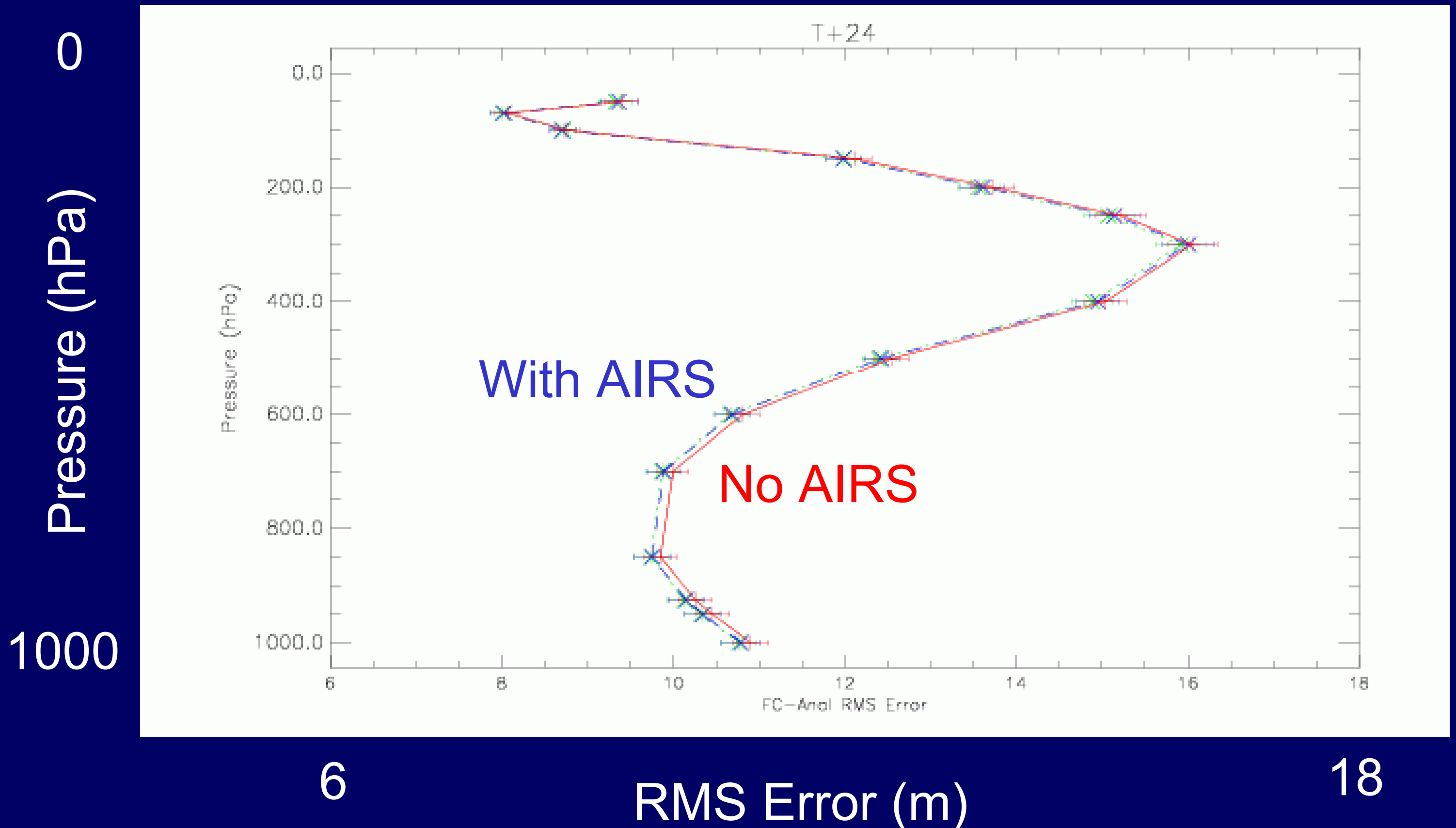
T+24 SH Height vs Analysis



A note on observation impact

- It has been noted that the addition of the Aqua AIRS to the Met Office's two-ATOVS (NOAA-15 and 16) baseline results in an impact on forecast accuracy that is greater than that achieved through the addition of either the NOAA-17 AMSU-A or the Aqua AMSU-A after thinning.
  - Implying that AIRS and ATOVS impacts are similar.
- This is very encouraging considering the conservative nature of this initial implementation.

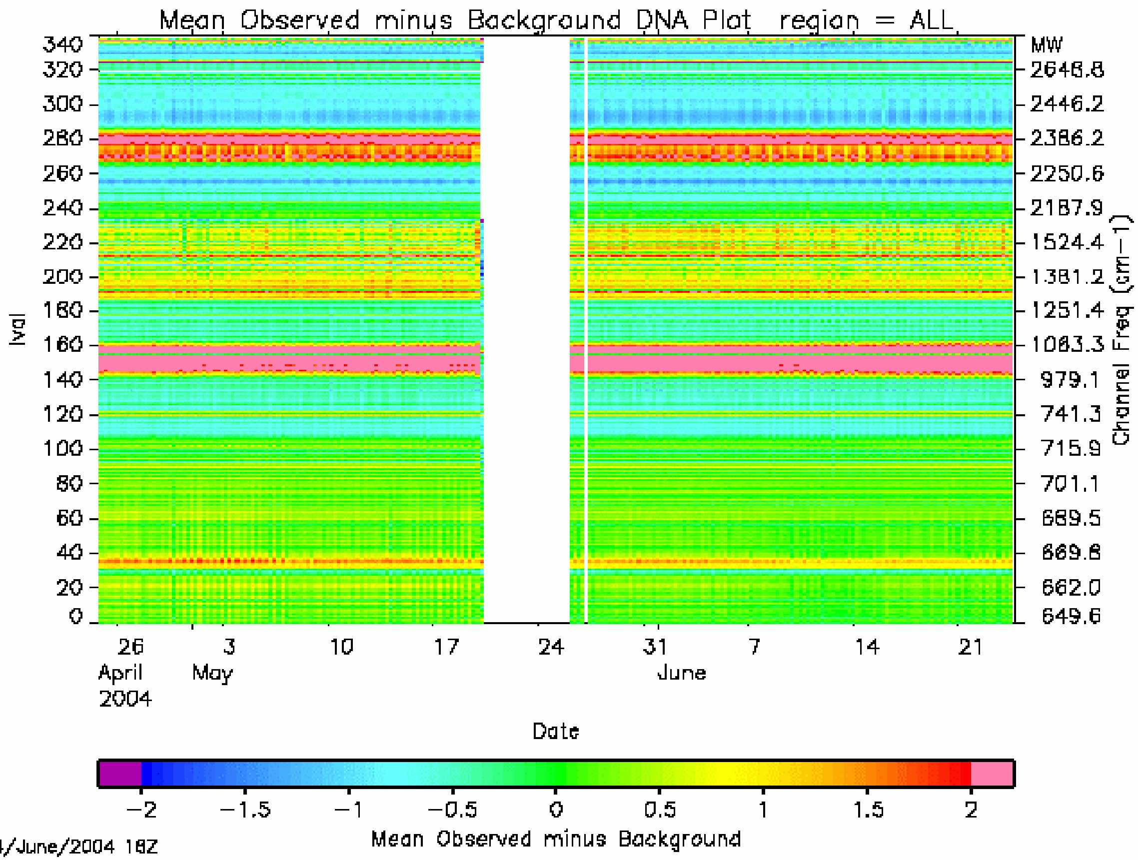
Online Monitoring

AIRS Time Series Plots

These plots are considered experimental. The Met Office accepts no responsibility for actions taken on the basis of these monitoring plots.

Region: Global Statistic: Obs - Bgnd Redisplay Printable Version

Region = Global / Statistic = Obs - Bgnd BT

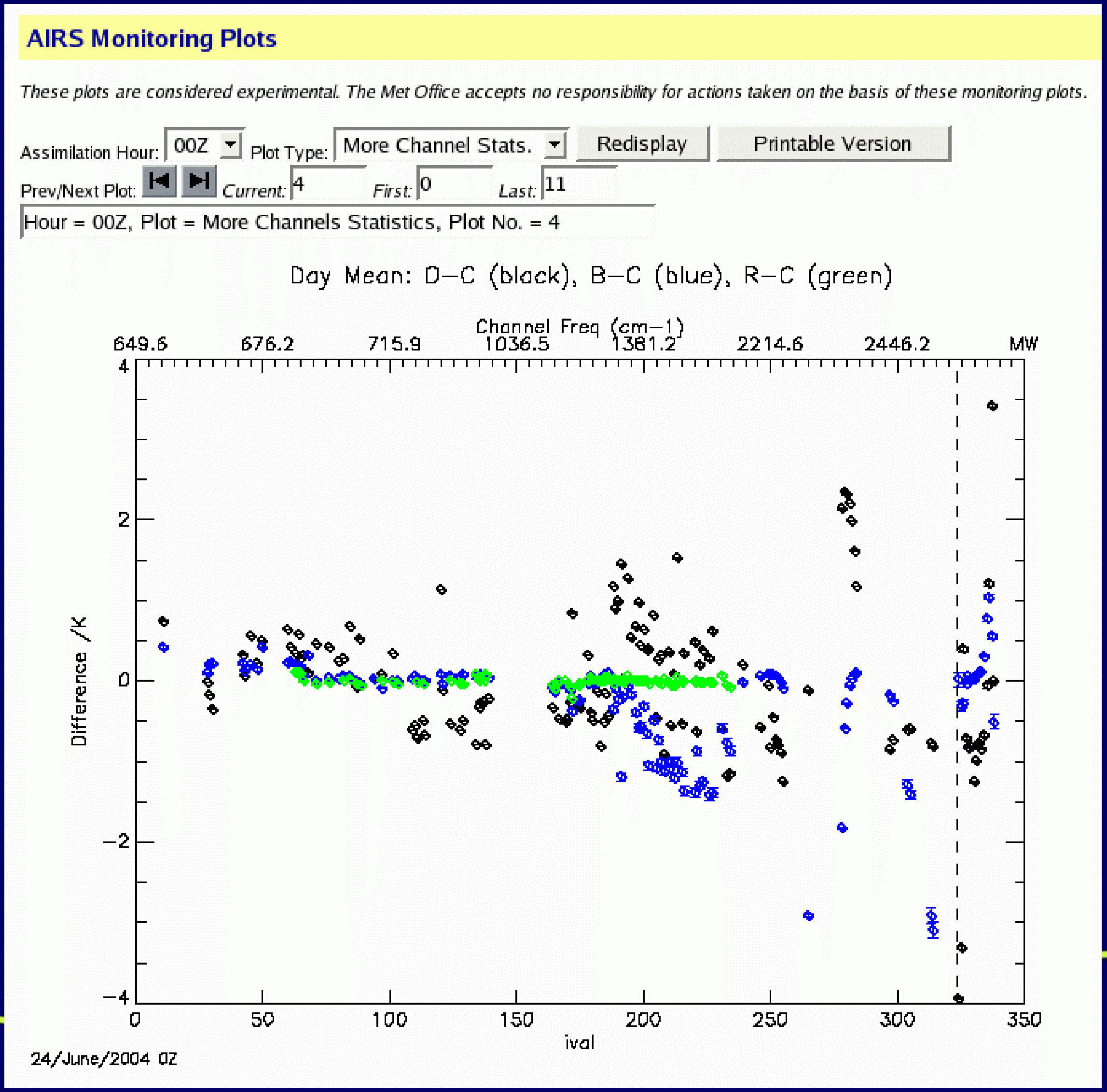


Time Series Plots:

Here mean observed-background BT differences (before bias correction).

http://www.metoffice.com/research/nwp/satellite/infrared/sounders/airs/index.html

More Online Monitoring



Spectral Plots:

Here mean daytime differences between corrected BTs and observed, background and retrieved BTs

http://www.metoffice.com/research/nwp/satellite/infrared/sounders/airs/index.html

Possible changes for next version of AIRS assimilation

- Use more channels
- Improve cloud detection
  - Revisit channel choice for cloud detection
  - AIRS visible imager data (during daytime)
- Use of advanced sounder data over land
  - Start by using channels that do not see the surface

How should we use the data most efficiently in the long term?

Main Issues (1): Cloud

- Cloud in the field of view can greatly affect our ability to use IR radiances
- Studies have show that the most important areas to measure for accurate forecasts often have cloud
- We need to identify strategies to deal with cloud
  - There is a lot of cloud information in the data that may be used.

Main Issues (2): Efficient use of channels

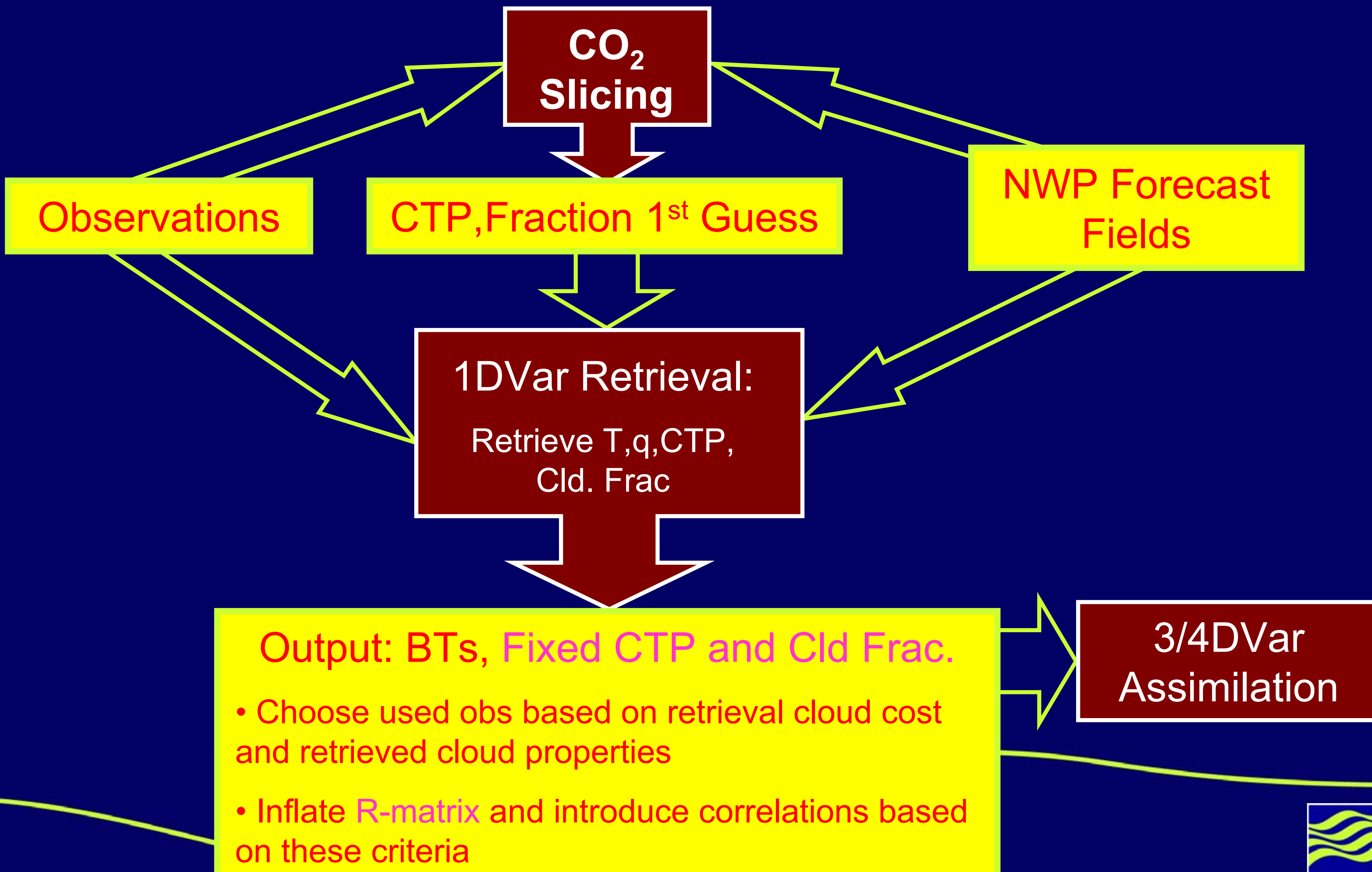
- Advanced IR sounder radiances contain a lot of information (~30pieces) …
- …but there are two orders of magnitude more channels.
- Hence there is a large amount of redundancy
- How can we use these data more efficiently?

Use of cloudy observations

One idea to for use of cloudy observations: Use 1DVar to determine where the cloud is.

- At the OPS 1DVar stage retrieve Cloud Top Pressure and Effective Cloud Fraction.
  - These are RTTOV variables that assume a grey cloud.
  - Pass the cloud parameters together with the observed radiances to Var.
  - Will need to inflate observation errors
    - May need to include error correlations and/or observation dependent errors.
  - Will need to be able to identify the situations where the technique is reliable.
- Technique is most likely to work for low stratiform cloud.

1DVar Preprocessor Flowchart



How well are we using the available channel information

The Resolution Matrix

The expected retrieved profile, $\bar{\mathbf{x}}$, and the true atmospheric state, $\mathbf{x}_T$, are related via the resolution matrix, **R**, like so:

$$\bar{\mathbf{x}} - \mathbf{x}_b = \mathbf{R}(\mathbf{x}_T - \mathbf{x}_b)$$

R is calculated by:

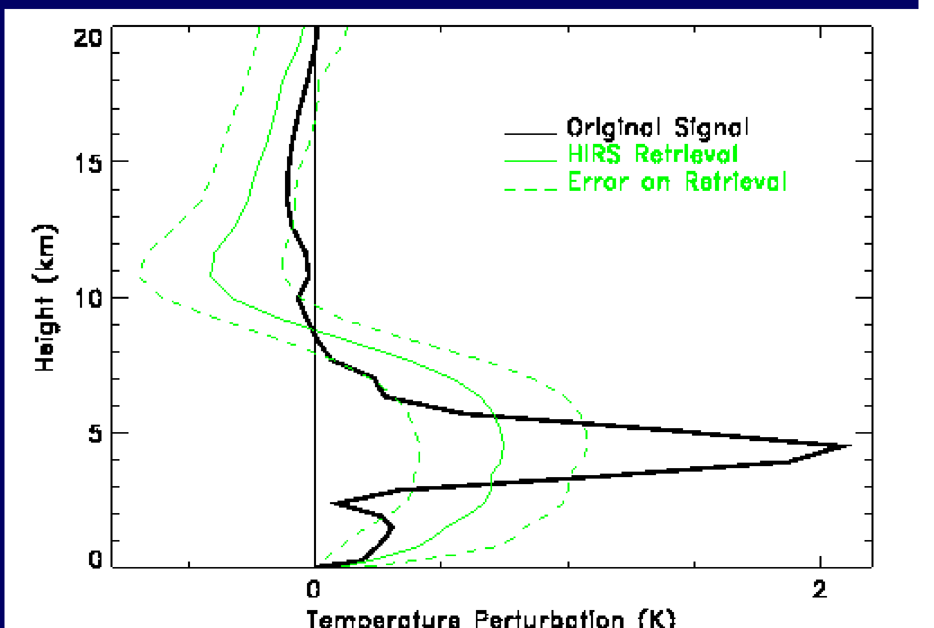
$$\mathbf{R} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{O})^{-1}\mathbf{H} = \mathbf{I} - \mathbf{A}\mathbf{B}^{-1}$$

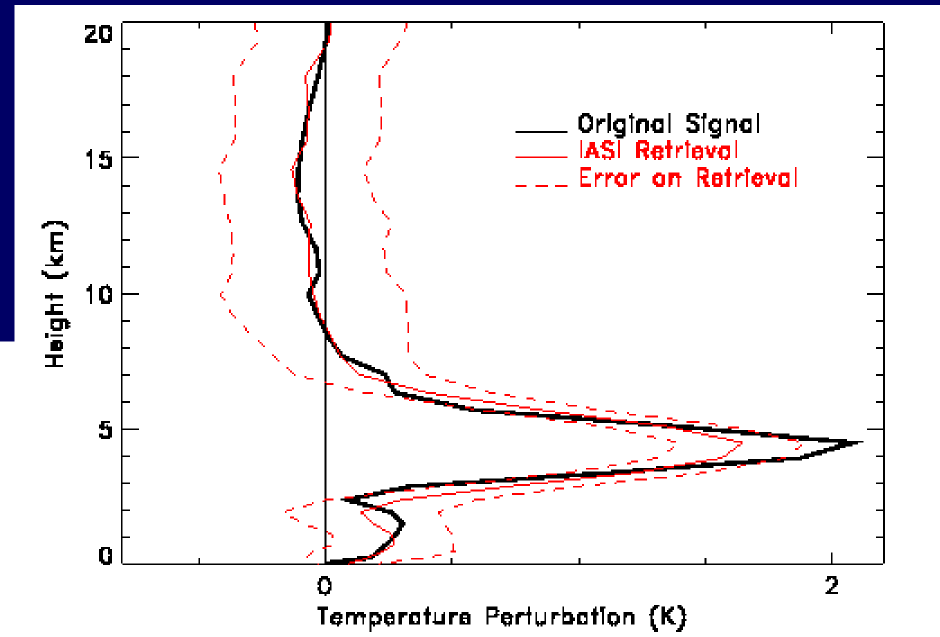
The expected deviation from $\bar{\mathbf{x}}$ is described by the propagated measurement error covariance, $\mathbf{A}_M$, where

$$\mathbf{A}_\mathbf{M} = \mathbf{A}\mathbf{H}^T\mathbf{O}^{-1}\mathbf{H}\mathbf{A}$$

Response to Important Atmospheric Structure

HIRS





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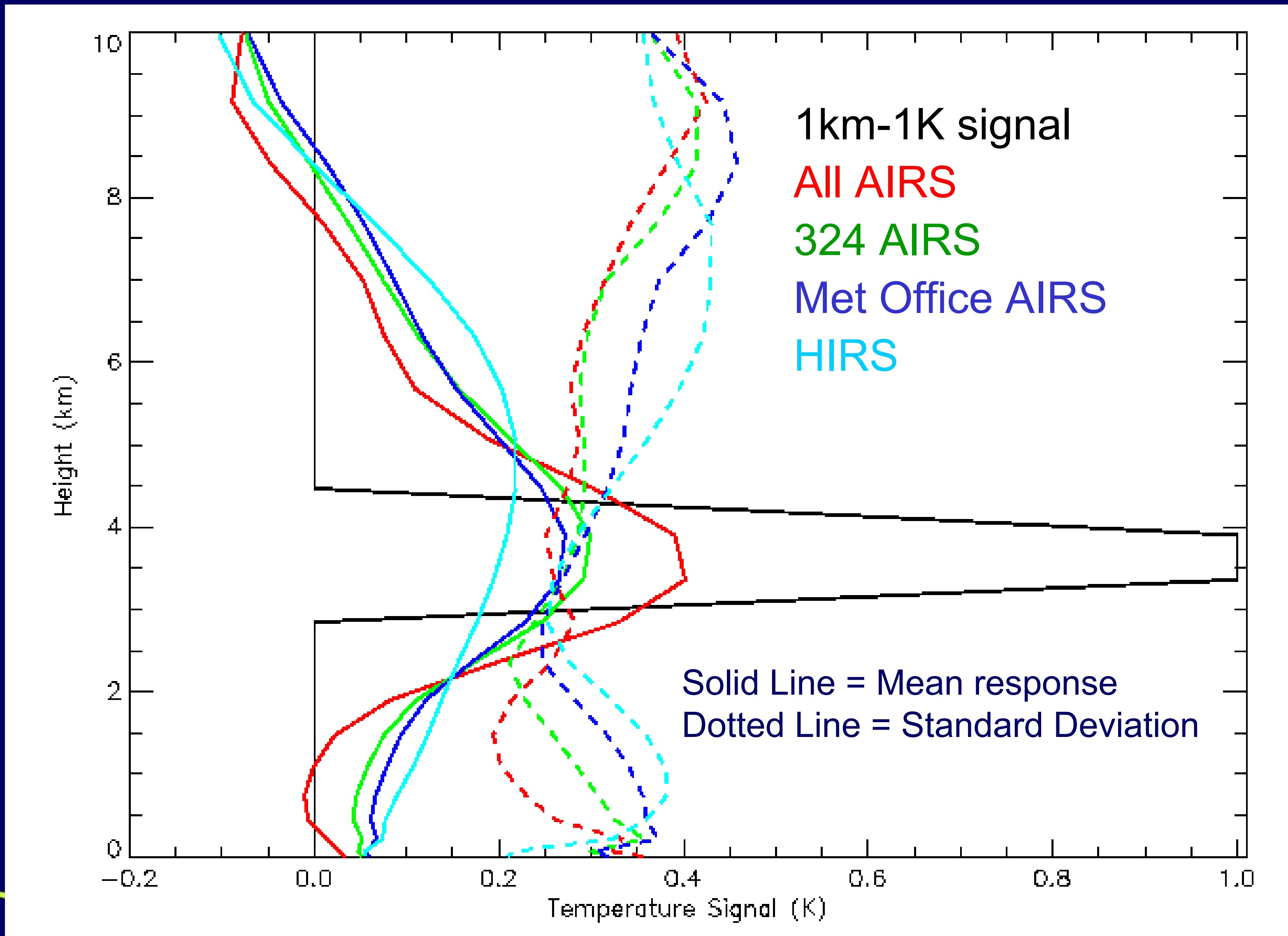
1km-1K response



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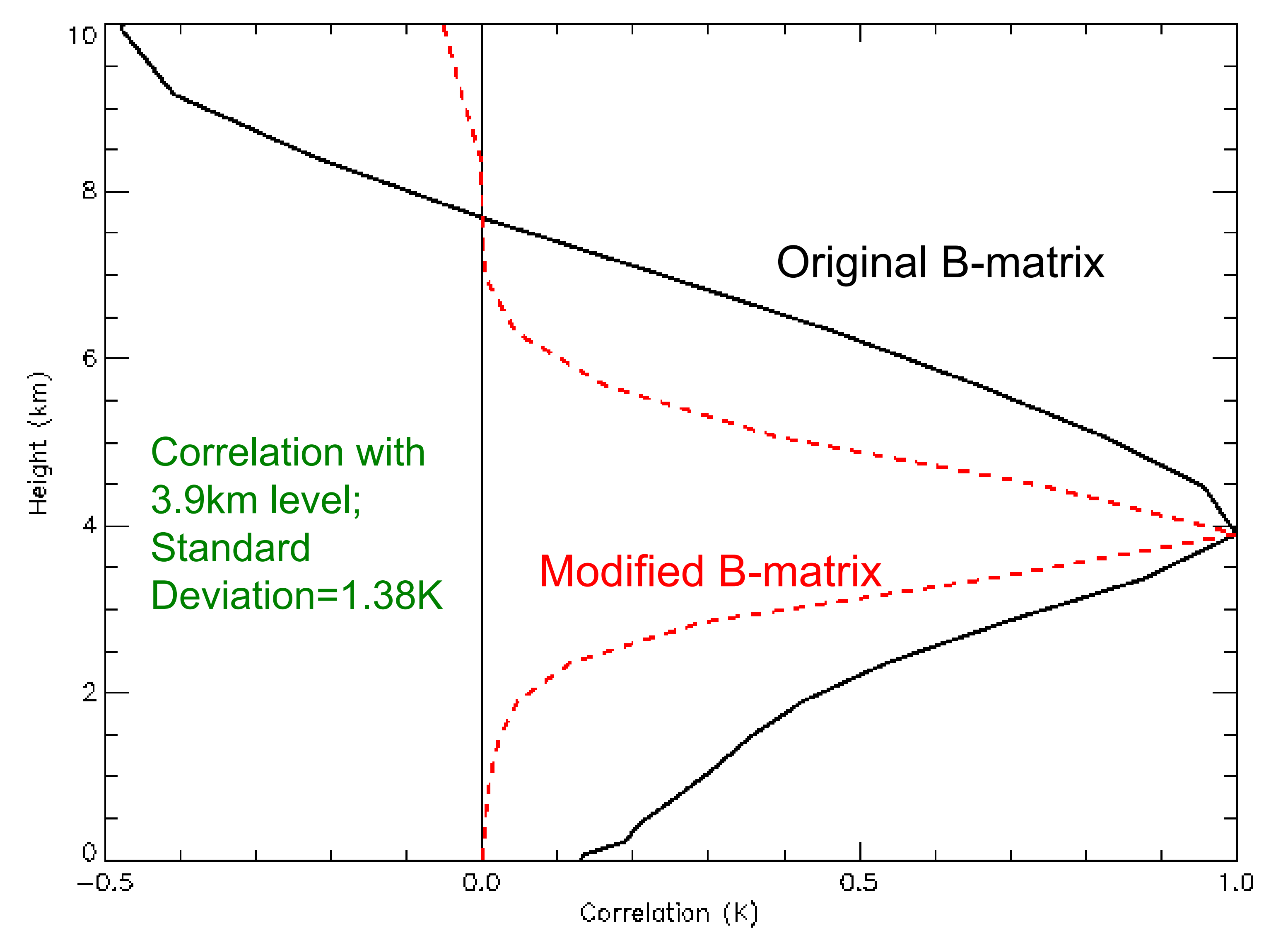
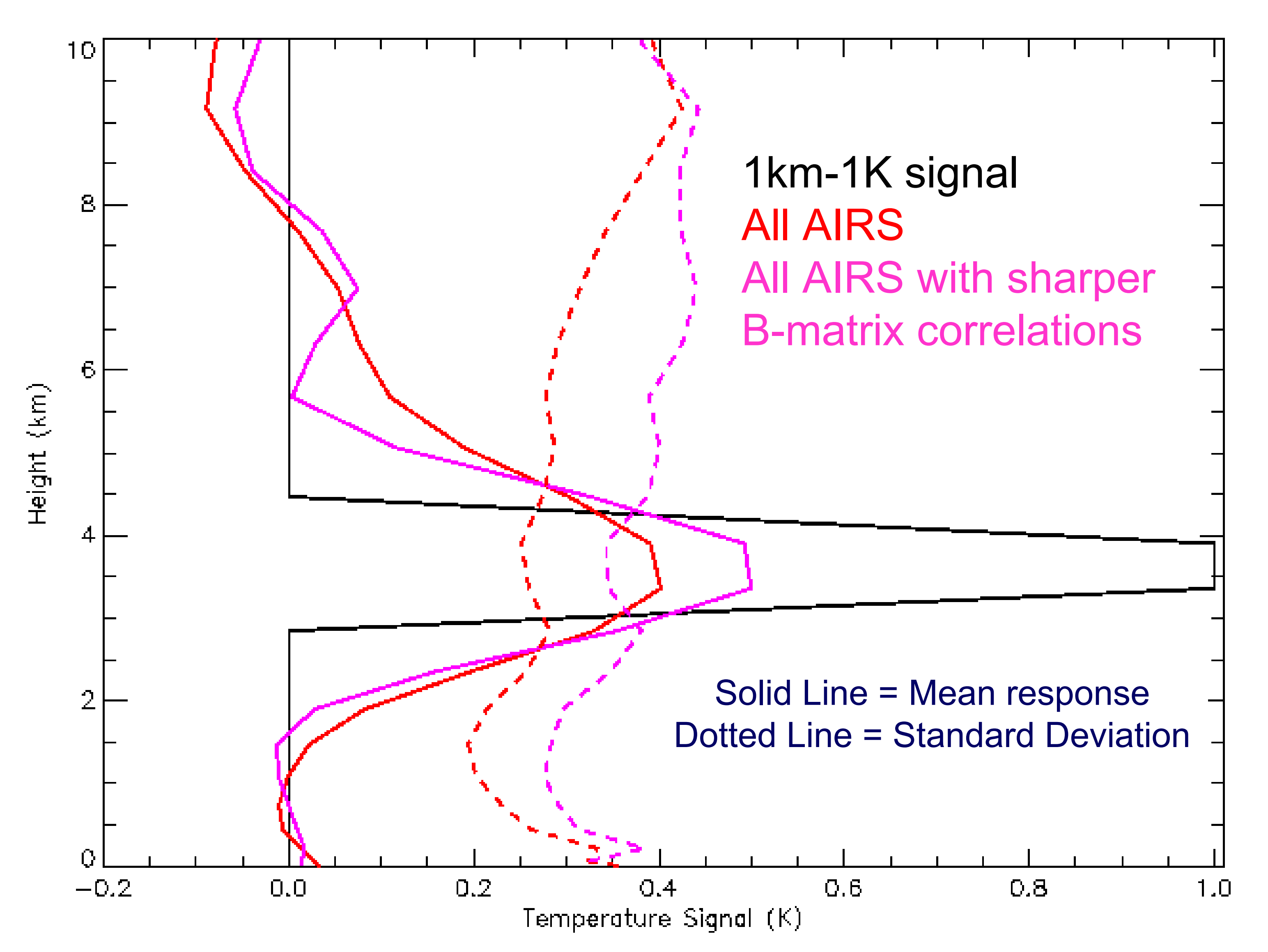
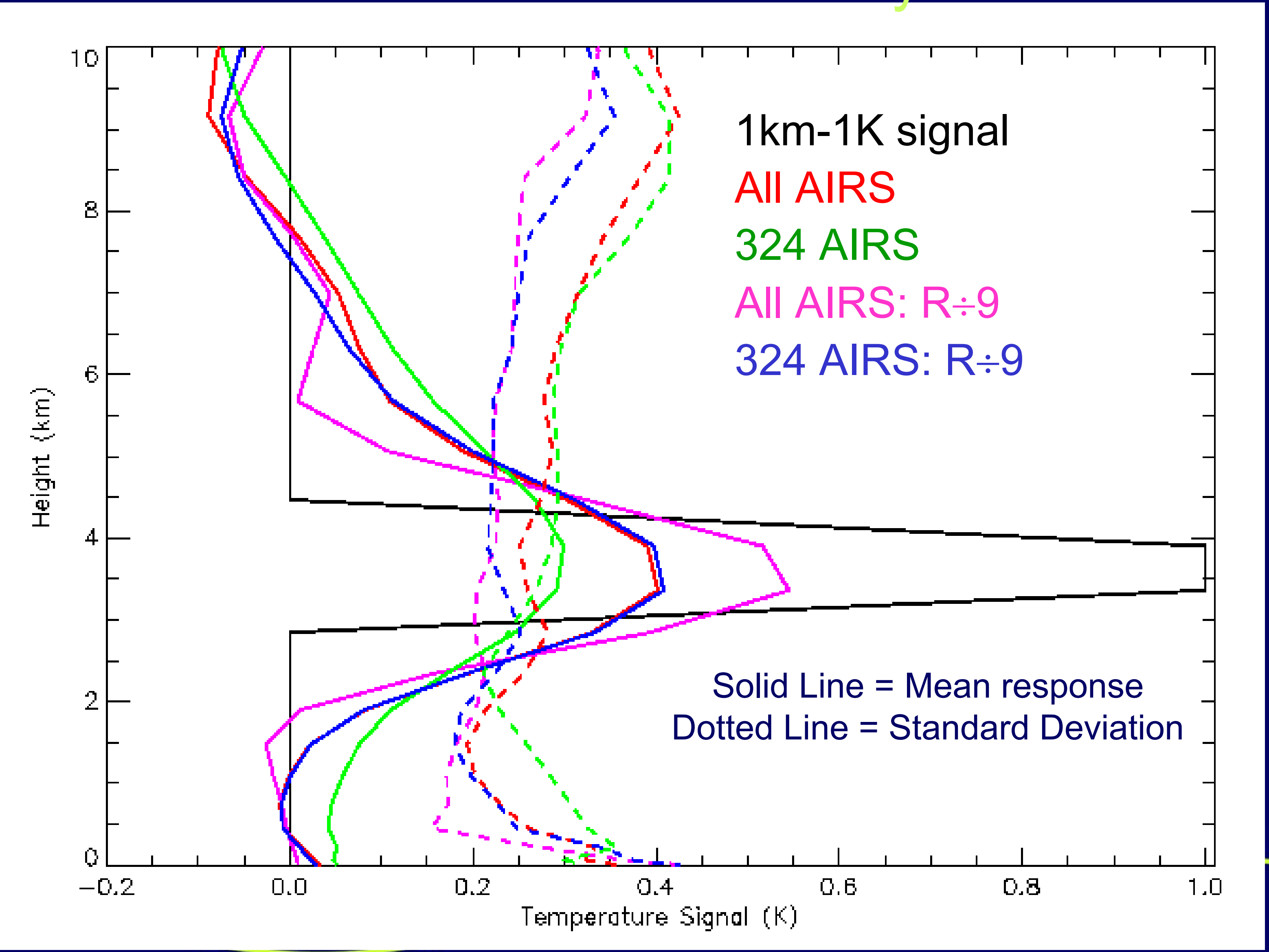
Change B-matrix



1km-1K response – Changing B



1km-1K response:
O+F std. dev. divided by 3



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Can improve impact of single observation by:

- Using more channels
  - RT model time is the limiting resource
    - » Advanced RT models (including EOF modelling)?
    - » Reconstructed radiances?
- Modifying B
  - Not a straight-forward task
- Reducing instrument and forward model noise
  - Reconstructed radiances?
    - » But be careful about correlations

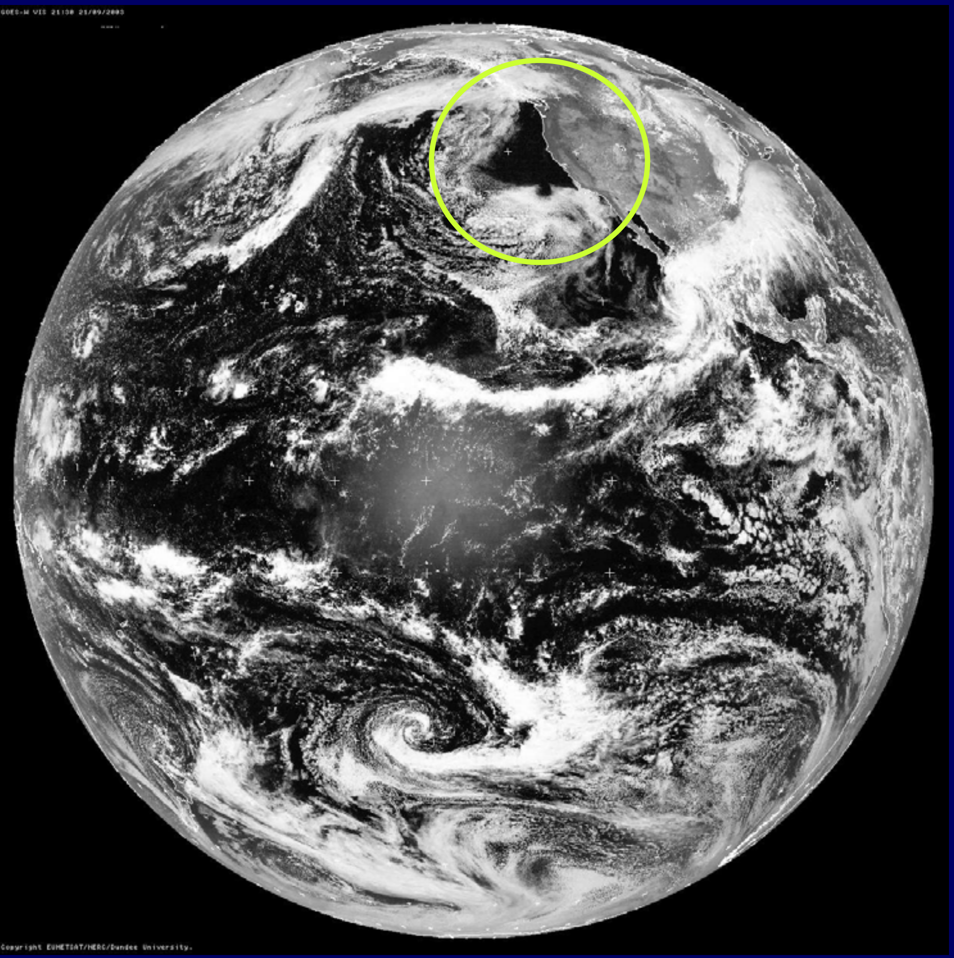
Conclusions

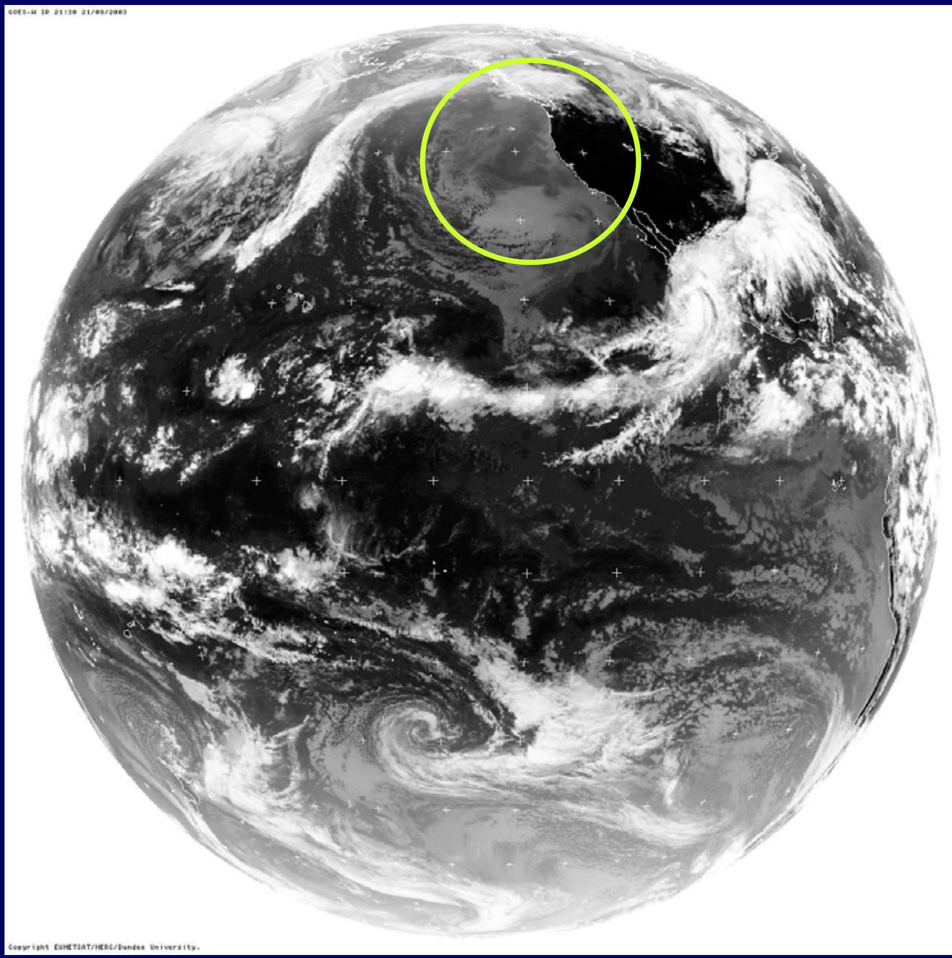
- AIRS Data has to potential to significantly improve our knowledge of the atmospheric state.
- We have implemented a conservative approach to using these data at Day-01
- Using more of the spectral information and using observations in cloudy regions are important areas for future research

Thank you for your attention!

Cloud Detection Verification (1/4):

GOES-W Images. 21/9/03 21.30Z





Focus on region of low thin cloud off western USA.

Cloud Detection Verification (2/4): AIRS Visible Imager

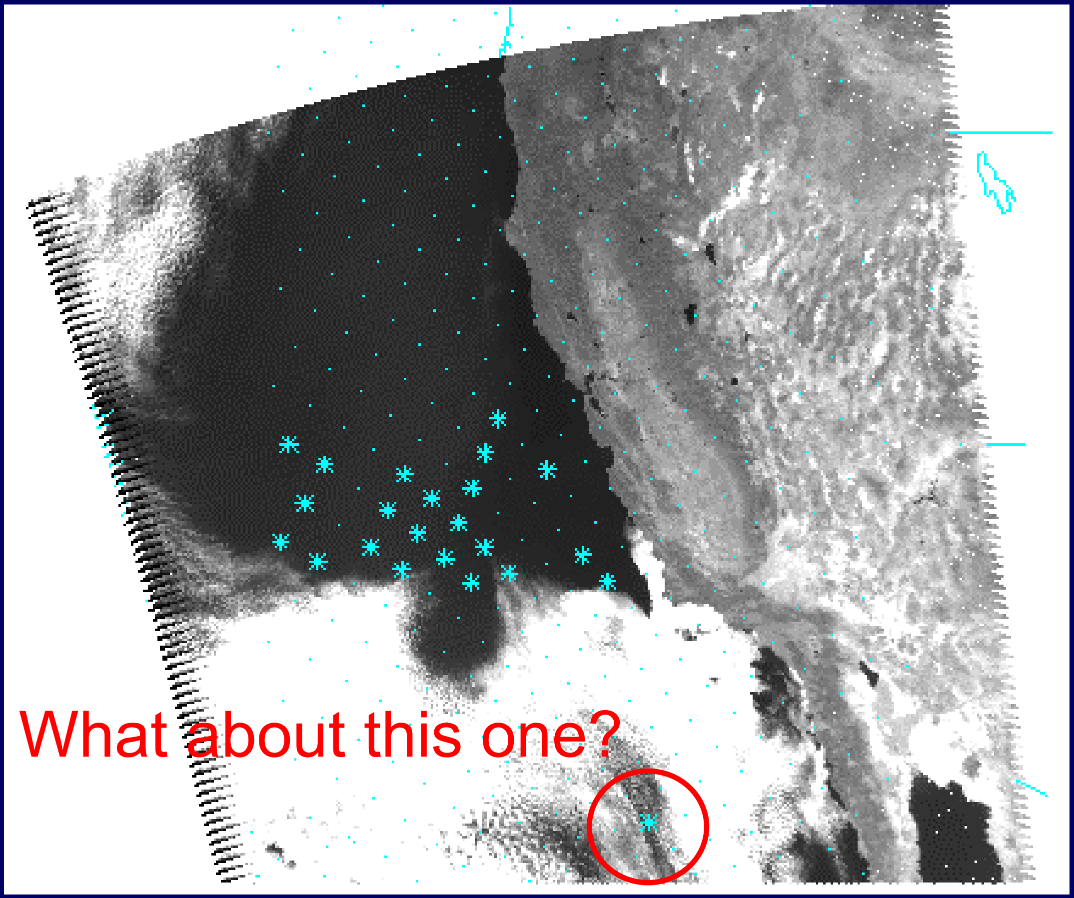
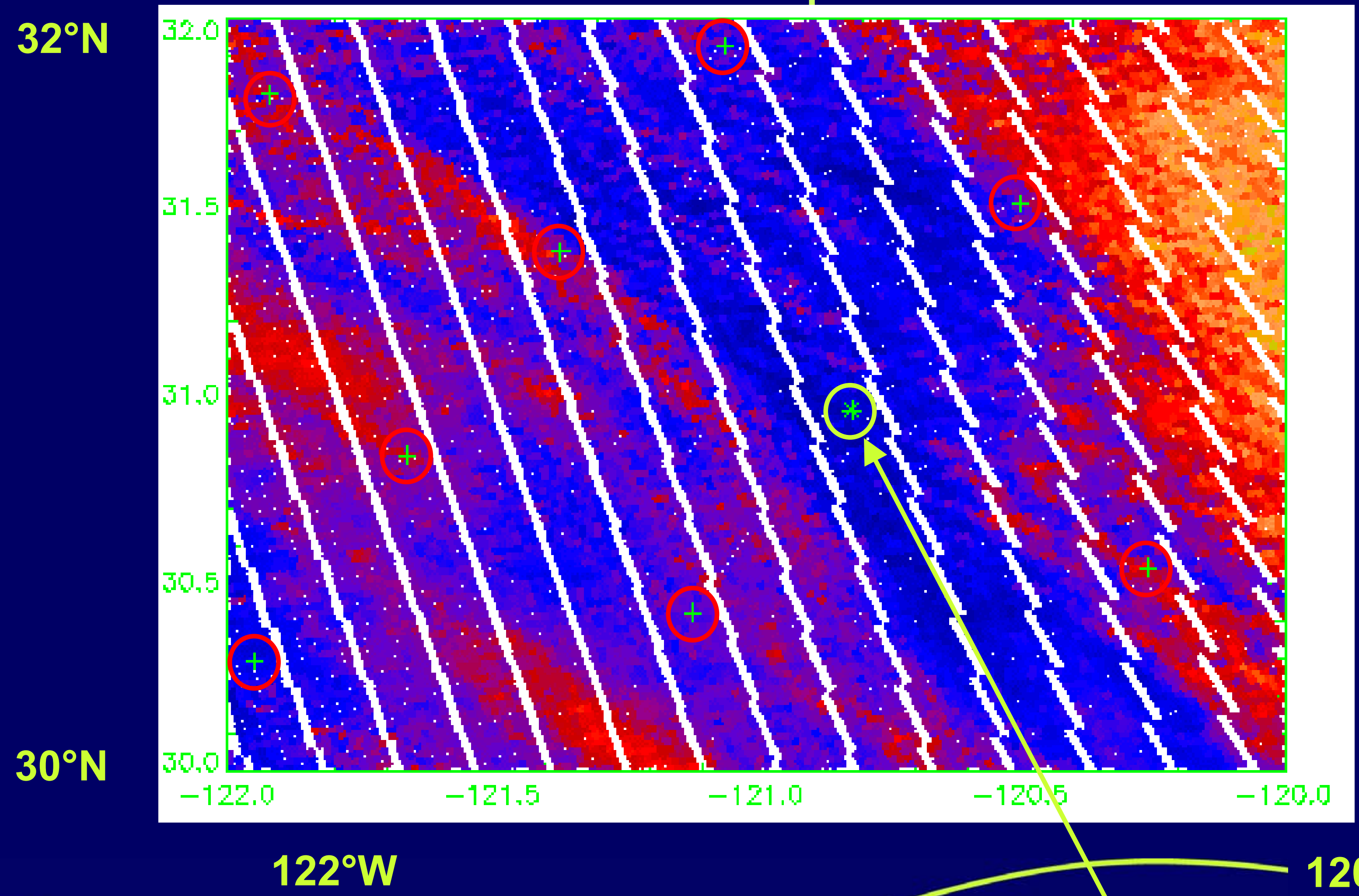


Image is AIRS Visible Imager Channel 4.
21st Sept. 2003 ~21.30Z

*=AIRS “Clear” FOV
. =AIRS “Cloudy” FOV

Cloud Detection Verification (3/4): Detail from previous slide



Blue : Low Albedo

Orange: High Albedo

Cloudy?

Clear?

Point from previous page seems to be clear

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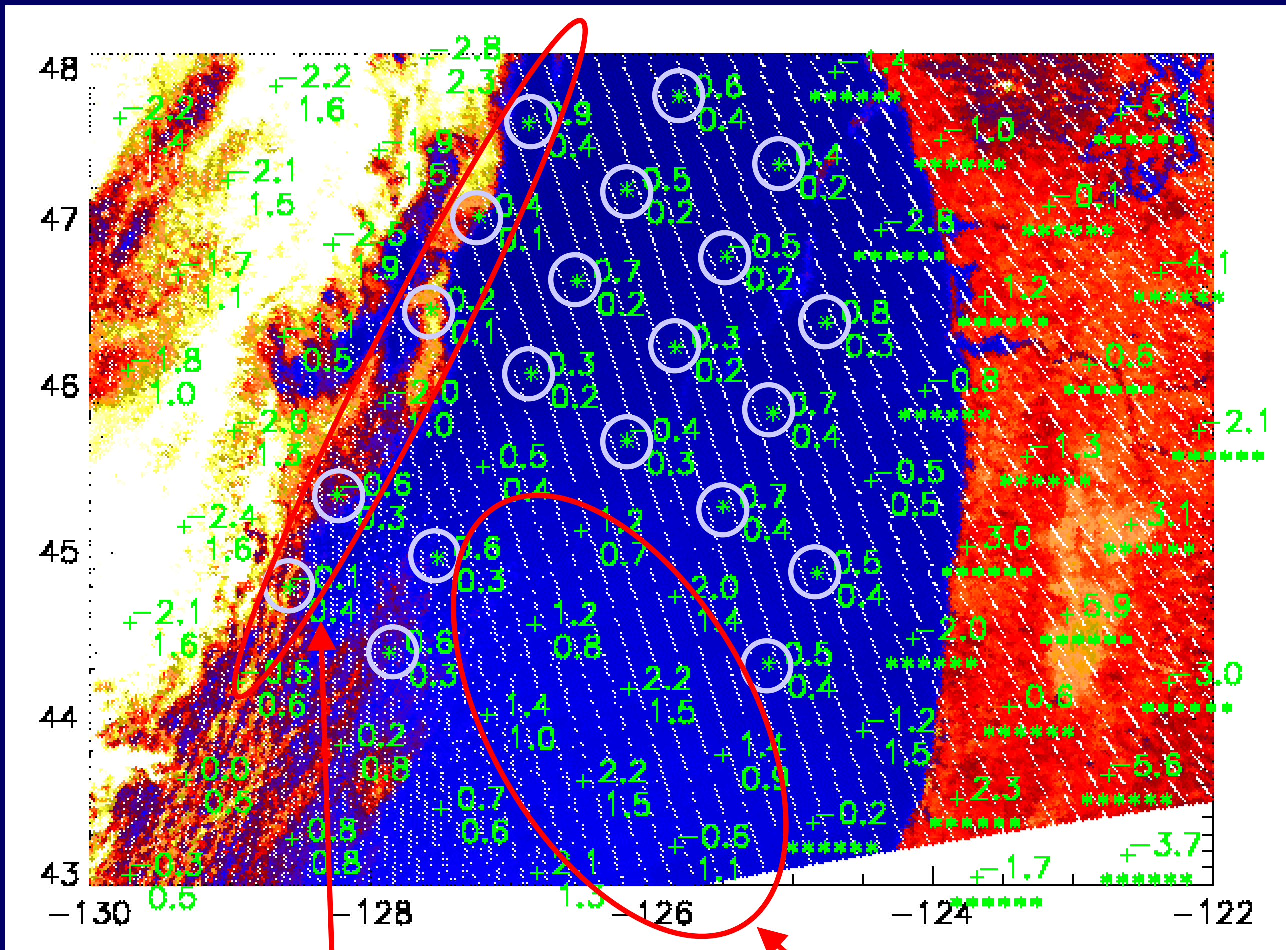
Cloud Detection Verification (4/4):

AIRS Imager, Off the coast of Washington



Top number is O-B in LW Window

Bottom number is Cloud Cost

Circled obs are designated clear

Here there are some erroneous clears on edge of thin, low cloud.

This region has high O-B: Almost certainly real SST error

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1DVar Cloud Research Strategy

- Stage 1: Using NWPSAF 1DVar, attempt to retrieve cloud properties (simultaneously with temperature, humidity etc.) from simulated radiances.
  - The radiances are simulated using RTTOVCLD and therefore the cloud optical properties are more realistic than the grey cloud assumed in the retrieval.
  - Look at the results to see where retrievals are reasonable.
    - » How will we do this QC in reality.
- Stage 2: Do a 2nd 1DVar retrieval with the cloud properties from the 1st stage fixed. This simulates the Var stage.
  - Are the results useful?