Assimilation of AIRS in cloudy regions

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Motivation

- IR becoming an increasingly important source of observations
  - Currently assimilate
    - AIRS + IASI (high spectral resolution)
    - HIRS (older generation)

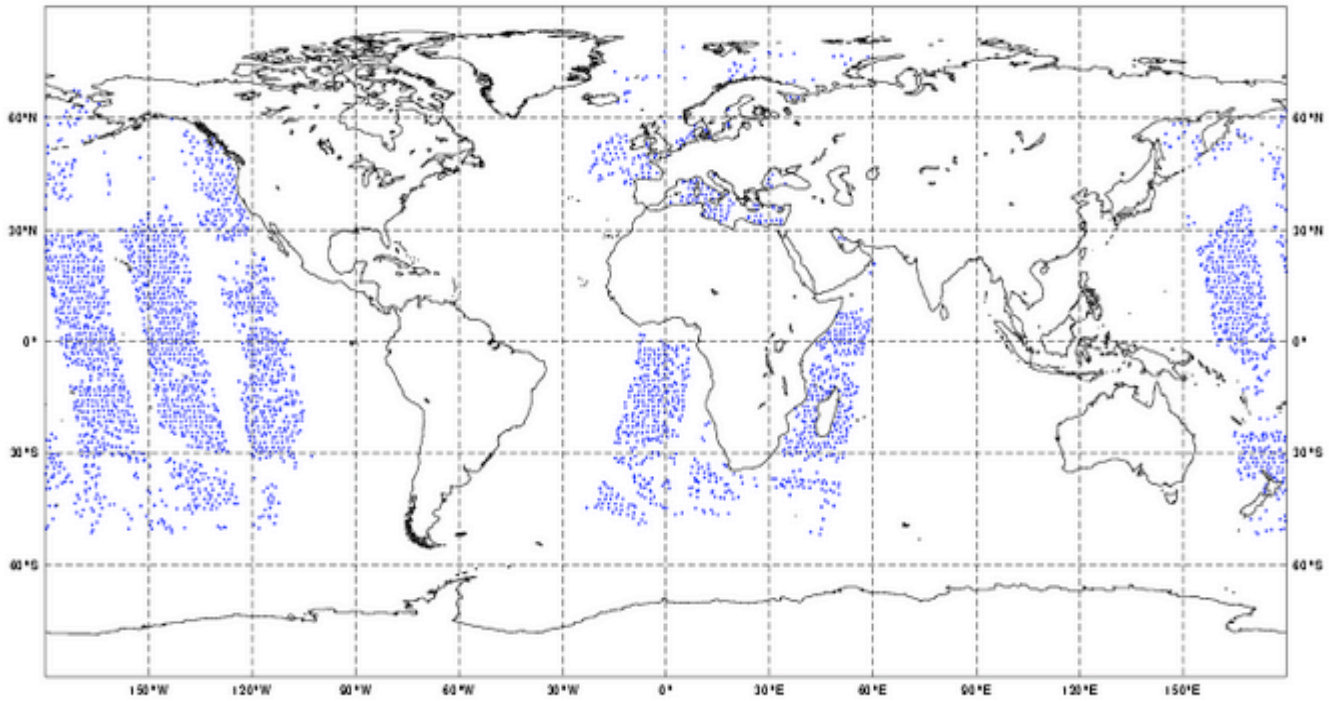
- Majority of IR soundings are affected by cloud
  - Throwing away a lot of data!

- Forecast is particularly sensitive to cloudy regions
  - Meteorologically active! (e.g. McNally, 2002, QJRMS 128, 2551-2556)

- Expect cloudy soundings to have a large impact on the analysis

Old usage of IR sounding data at the Met Office

- IR sounding data previously only assimilated in **cloud-free** areas over sea
  - Warmest field-of-view (most likely cloud-free)
  - Only ~ 5% of data used after thinning
  - Example: 8 June 2006: 3038 of 80998 AIRS observations assimilated



Approaches to cloudy IR radiance assimilation

- The dream: Full cloudy 4D-Var
  - Requires realistic cloudy radiative transfer and cloud physics in 4DVar
  - Model doesn't resolve cloud on small enough scales

- Cloud clearing
  - Reconstruct clear-sky radiances assuming *T* and *q* locally homogeneous in horizontal
  - Makes broad assumptions about homogeneity of cloud

- Reject cloud-affected channels (e.g. ECMWF)
  - Compare observations with cloud-free background
  - No information at or below cloud top

1D-Var cloud analysis technique

- Retrieve cloud parameters in 1D-Var
  - Using RTTOV: Single level “grey” cloud
  - Retrieve:
    - cloud top pressure
    - effective cloud fraction (=$N\varepsilon$) for each FOV
- Pass cloudy radiances, retrieved CTP and CF to 4D-Var
- Use cloud parameters as fixed constraints on 4D-Var radiative transfer
- Allows sounding down to cloud top

Simulation study

- Use ECMWF 60-level sampled profile dataset (Chevallier, 2001)
  - **13495 profiles** of T, q, O3, cloud liquid water, cloud ice water and surface variables
  - So far using only sea profiles (**5810**)

- Simulate cloudy AIRS BTs using RTTOV_CLD
  - Add simulated measurement errors

- Simulate model background profiles
  - Add errors consistent with Met Office B-Matrix

- Perform experiments using stand-alone 1D-Var code:
  1. Retrieve cloud parameters in 1D-Var
  2. Simulate assimilation of cloudy radiances with fixed cloud parameters: Use 1D-Var instead of 4D-Var

Limitations in cloud model

- In many cases, 1D-Var cloud model is unrealistic
  - Not (generally) single-level grey cloud
  - Cloud is generally multi-level, 3D
  - Leads to biases below cloud top

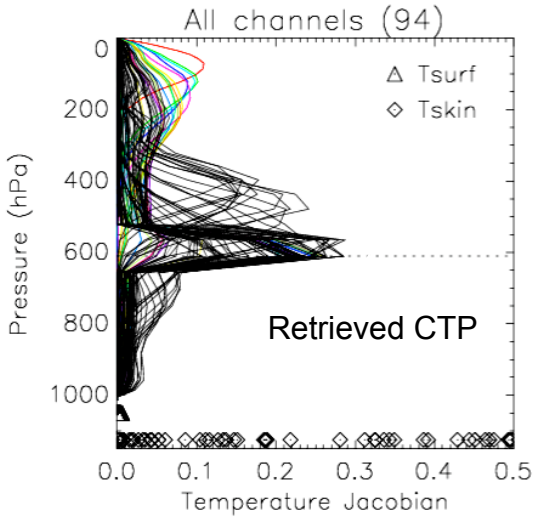
- **Solution: Remove channels most likely to be poorly modelled**

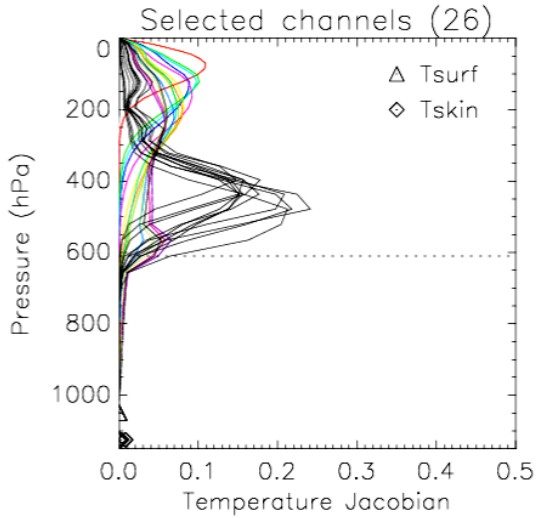
- Simple automatic channel selection:
  - Reject all channels peaking below retrieved cloud top
  - 10% of weighting function area allowed below cloud top
  - Channel selection carried out for each sounding

Example cloudy weighting functions ($\partial B_i/\partial T_i$)

Mid-level cloud

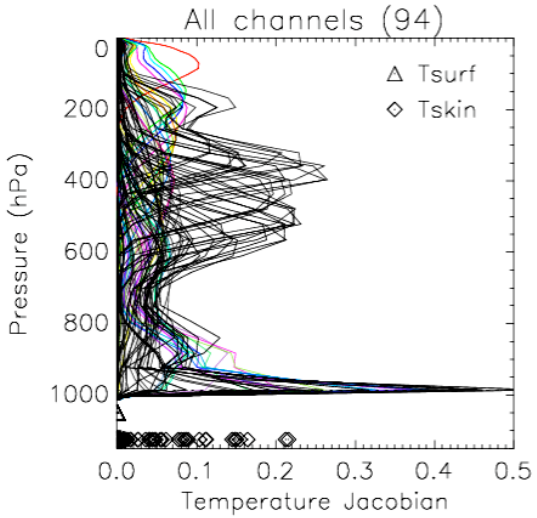
- Use 26 of 94 channels

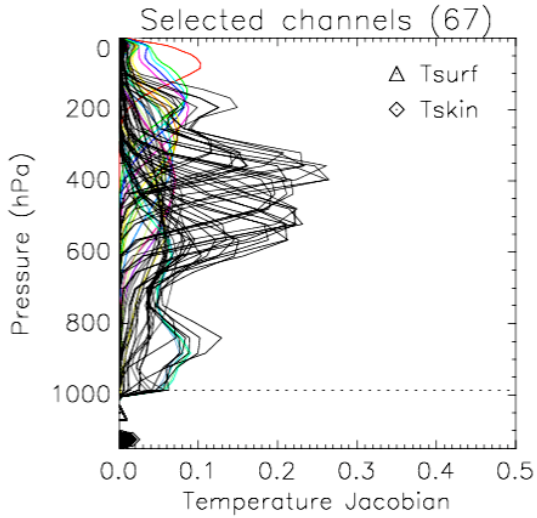




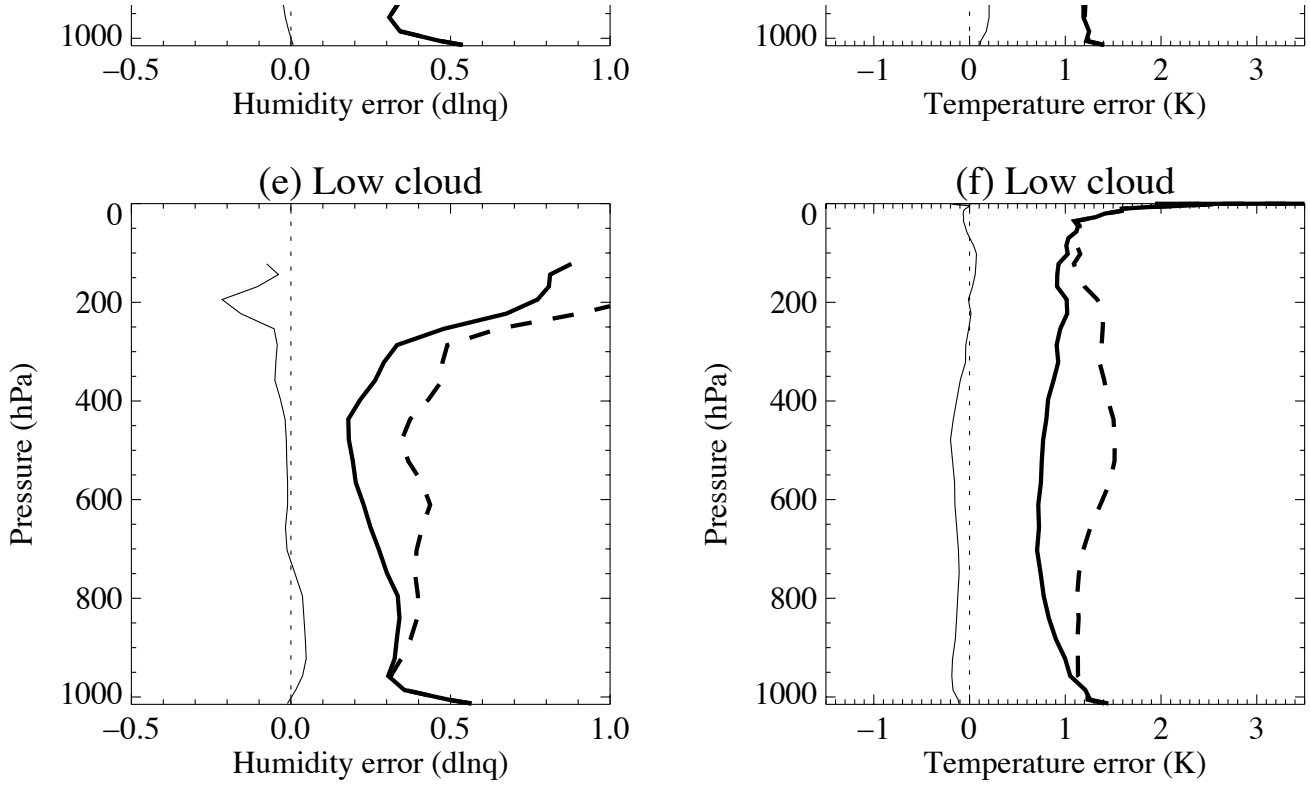
Low cloud

- Use 67 of 94 channels



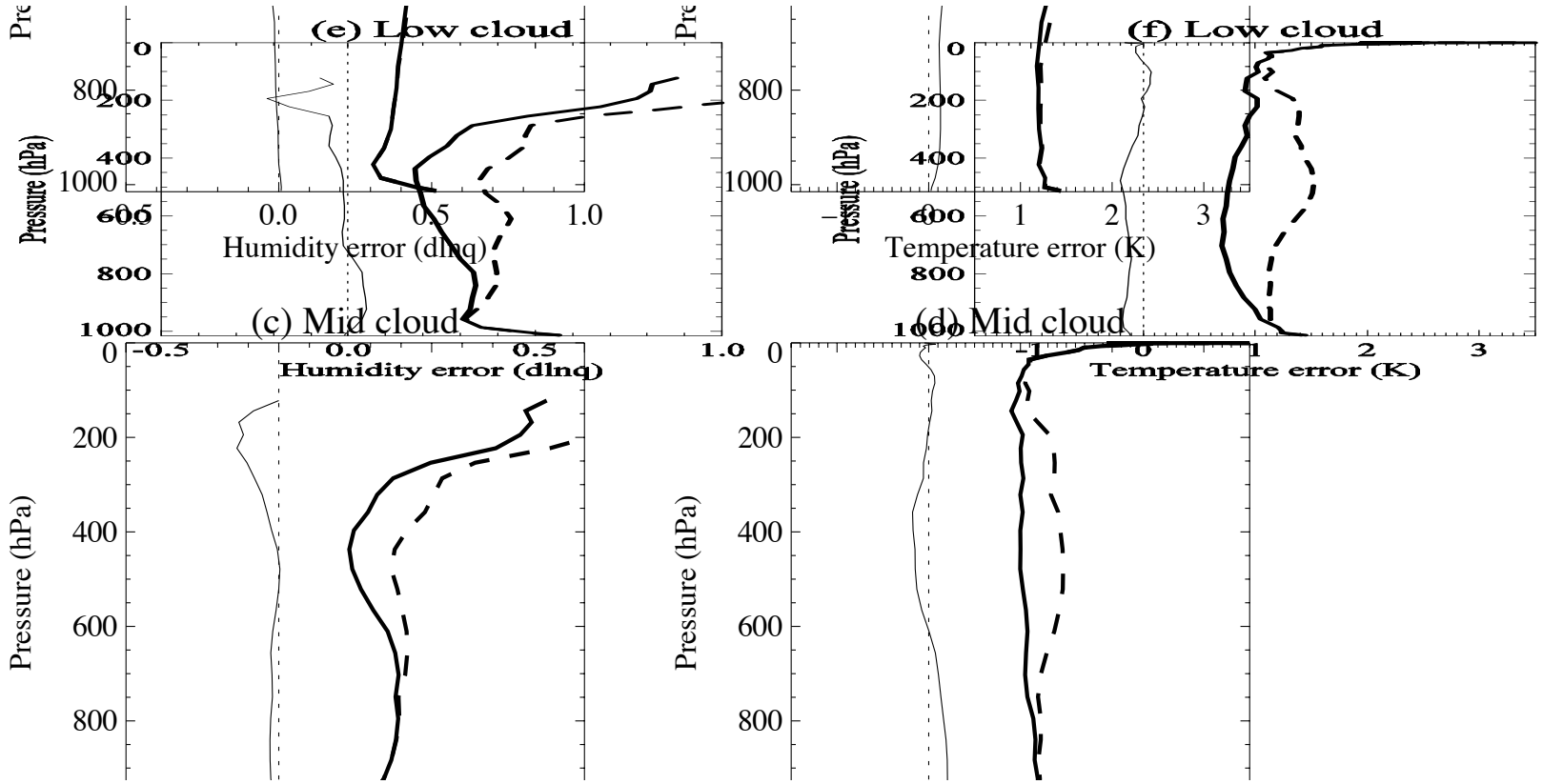


Simulated analysis errors: Low cloud cases



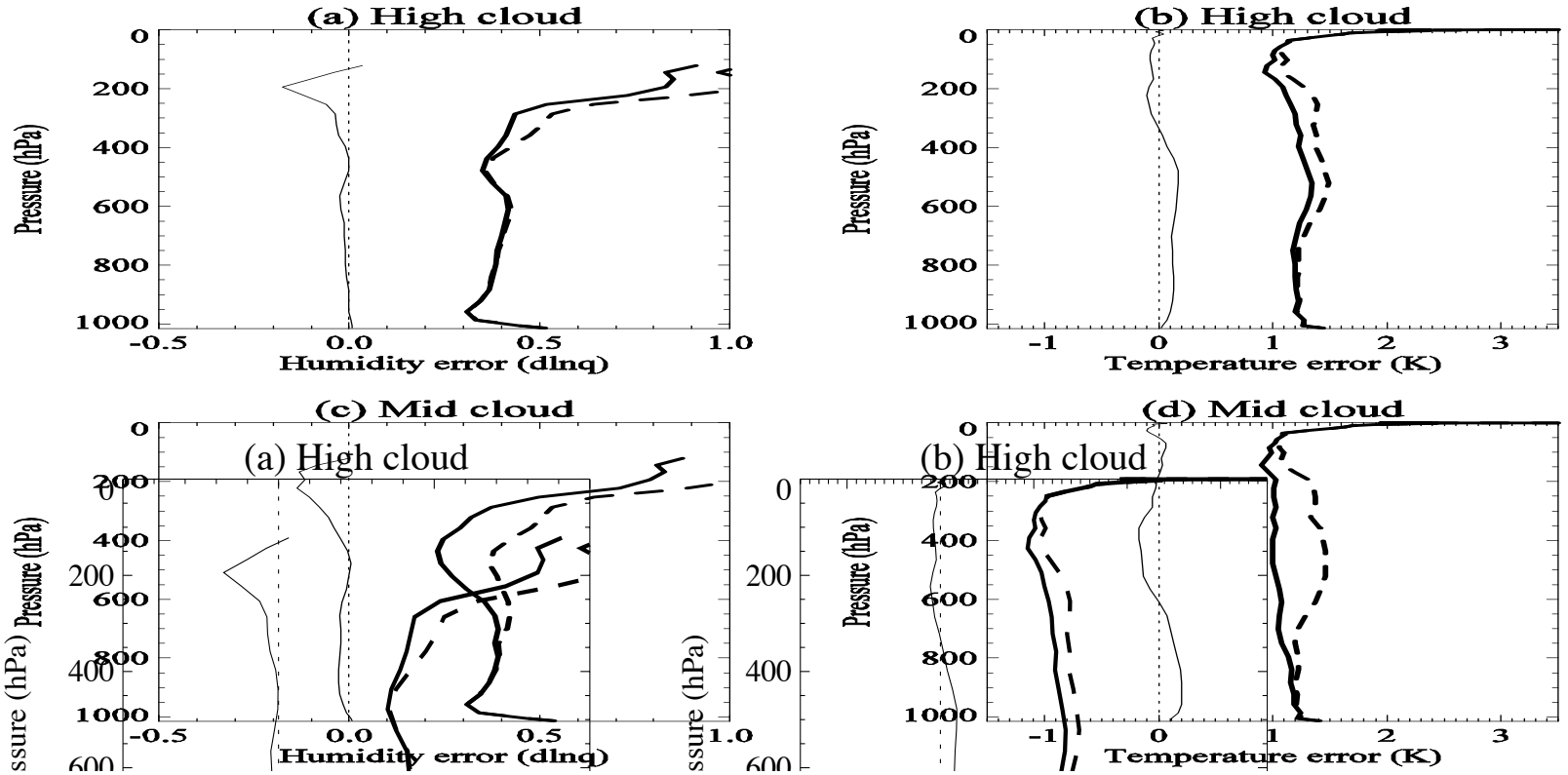
From: Pavelin, English and Eyre, 2008, *Q. J. Roy. Met. Soc.*

Simulated analysis errors: Mid cloud cases



From: Pavelin, English and Eyre, 2008, *Q. J. Roy. Met. Soc.*

Simulated analysis errors: High cloud cases



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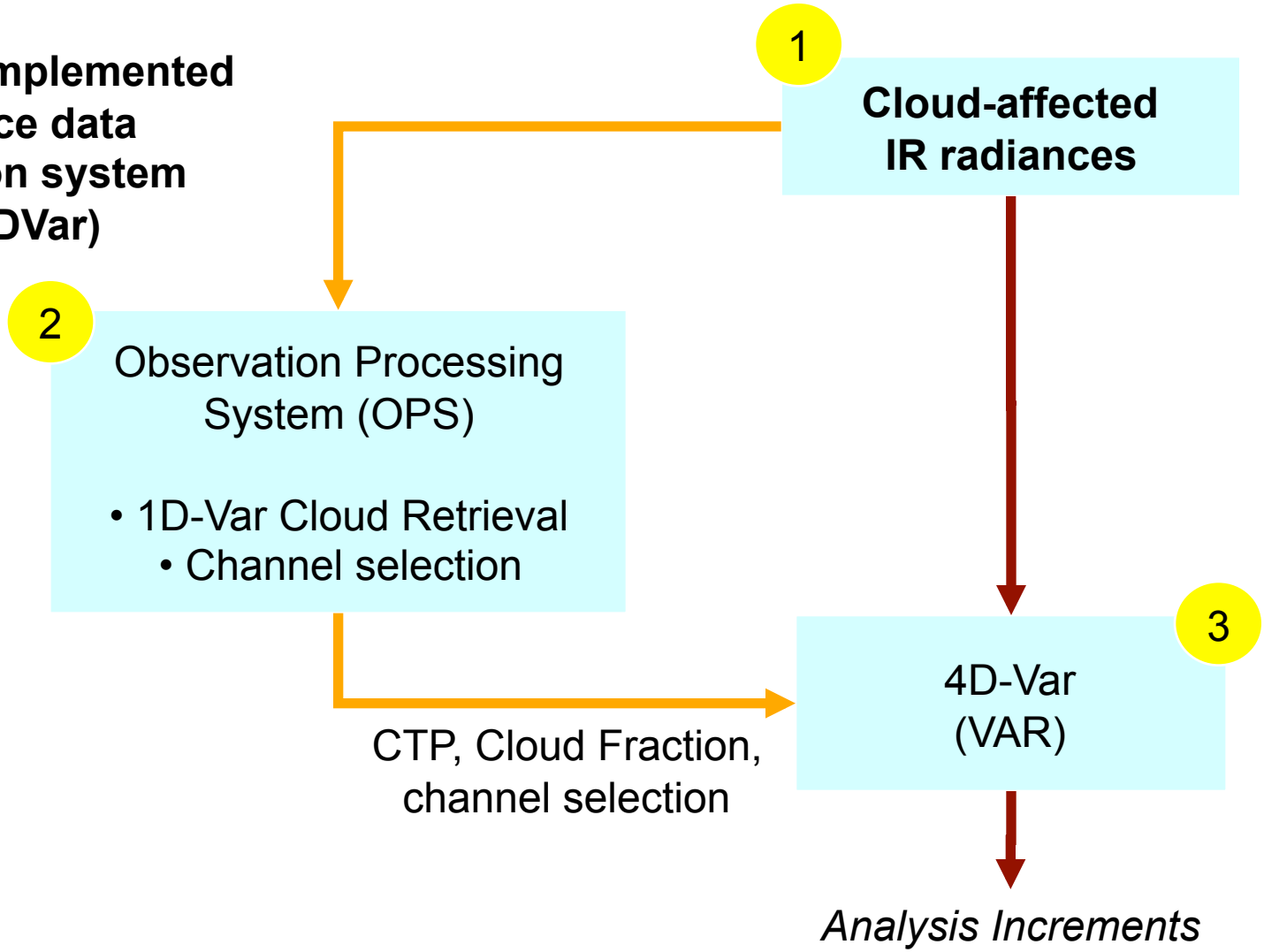
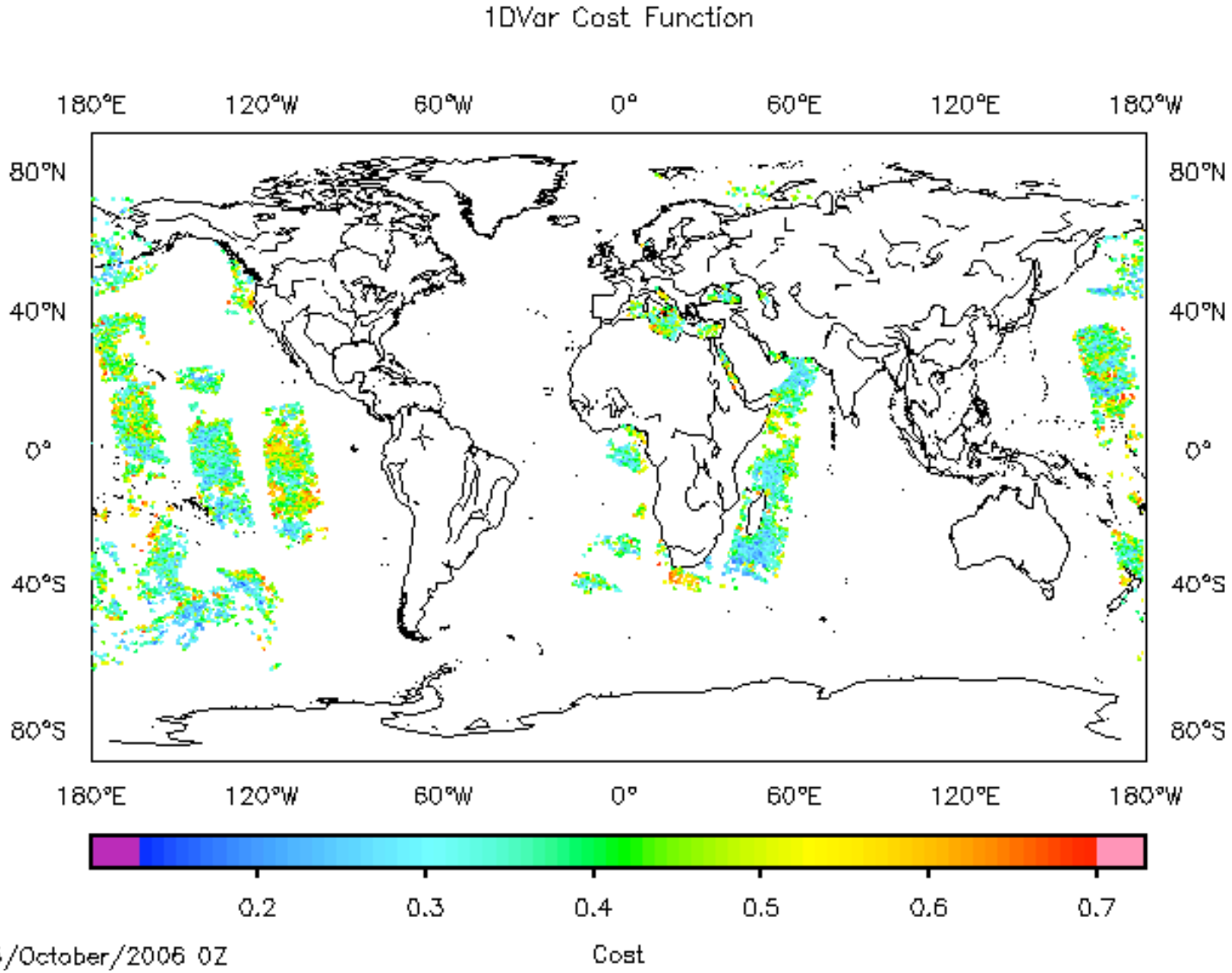
Application to real AIRS data

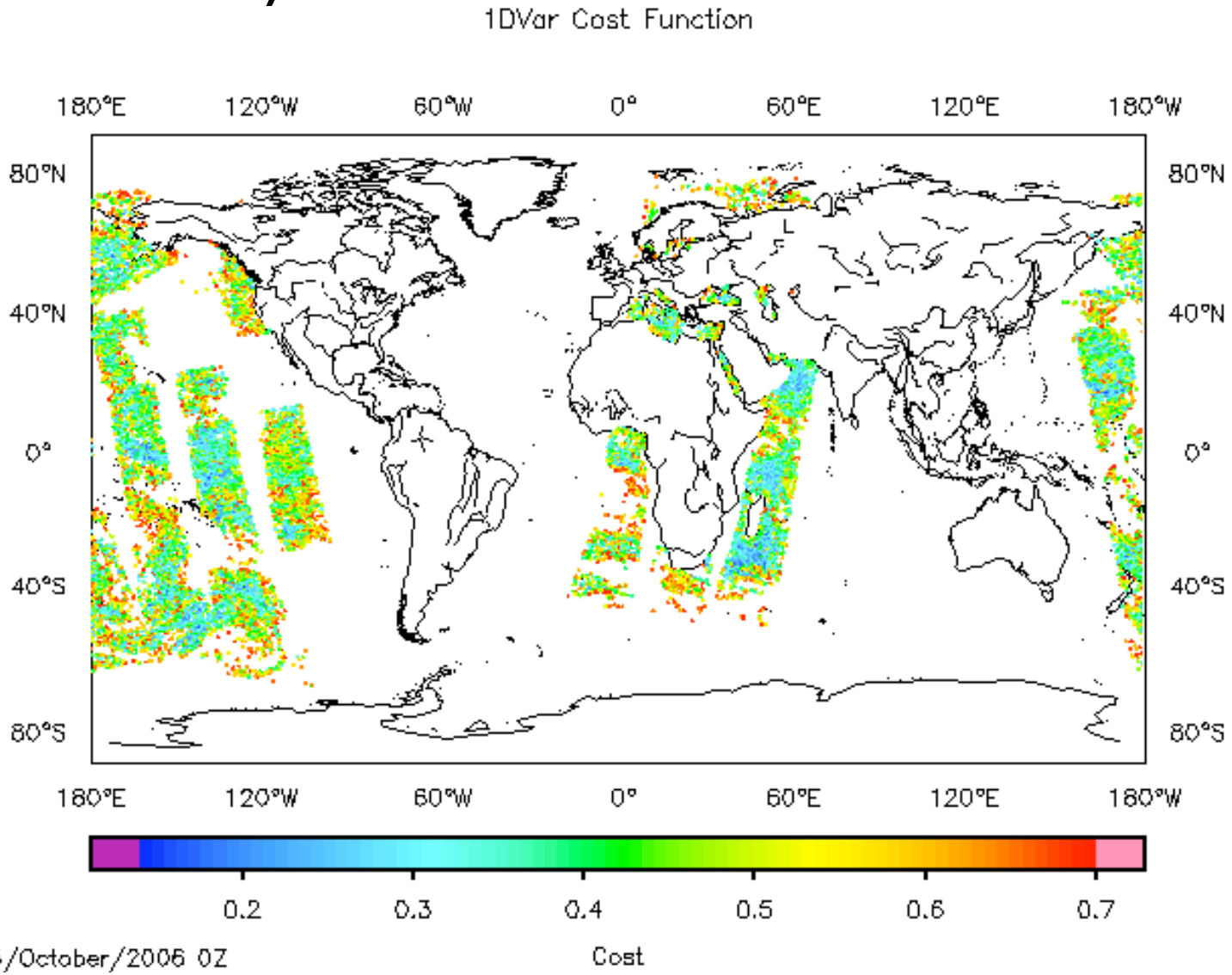
- **System implemented in Met Office data assimilation system (1DVar + 4DVar)**



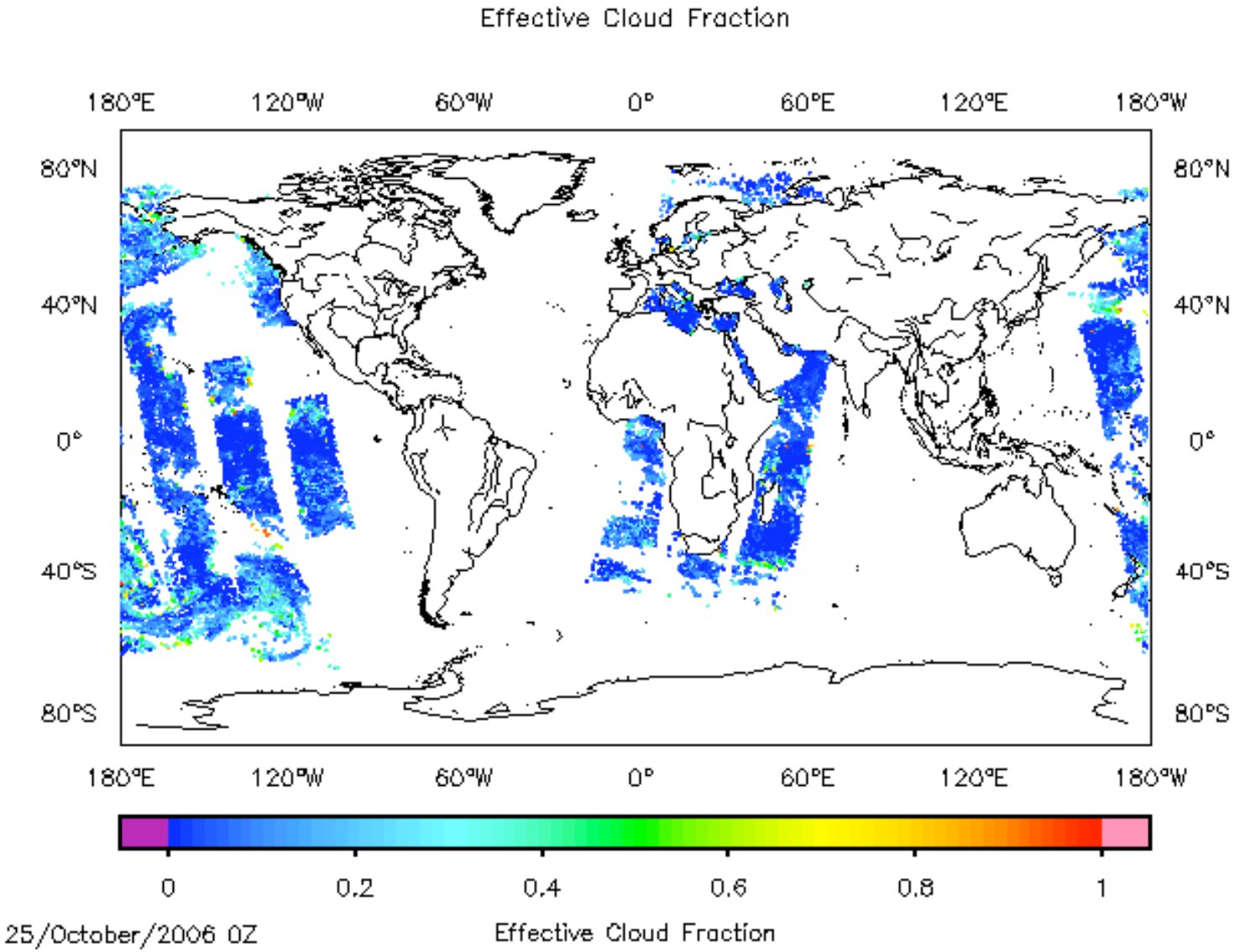
Coverage: Clear AIRS



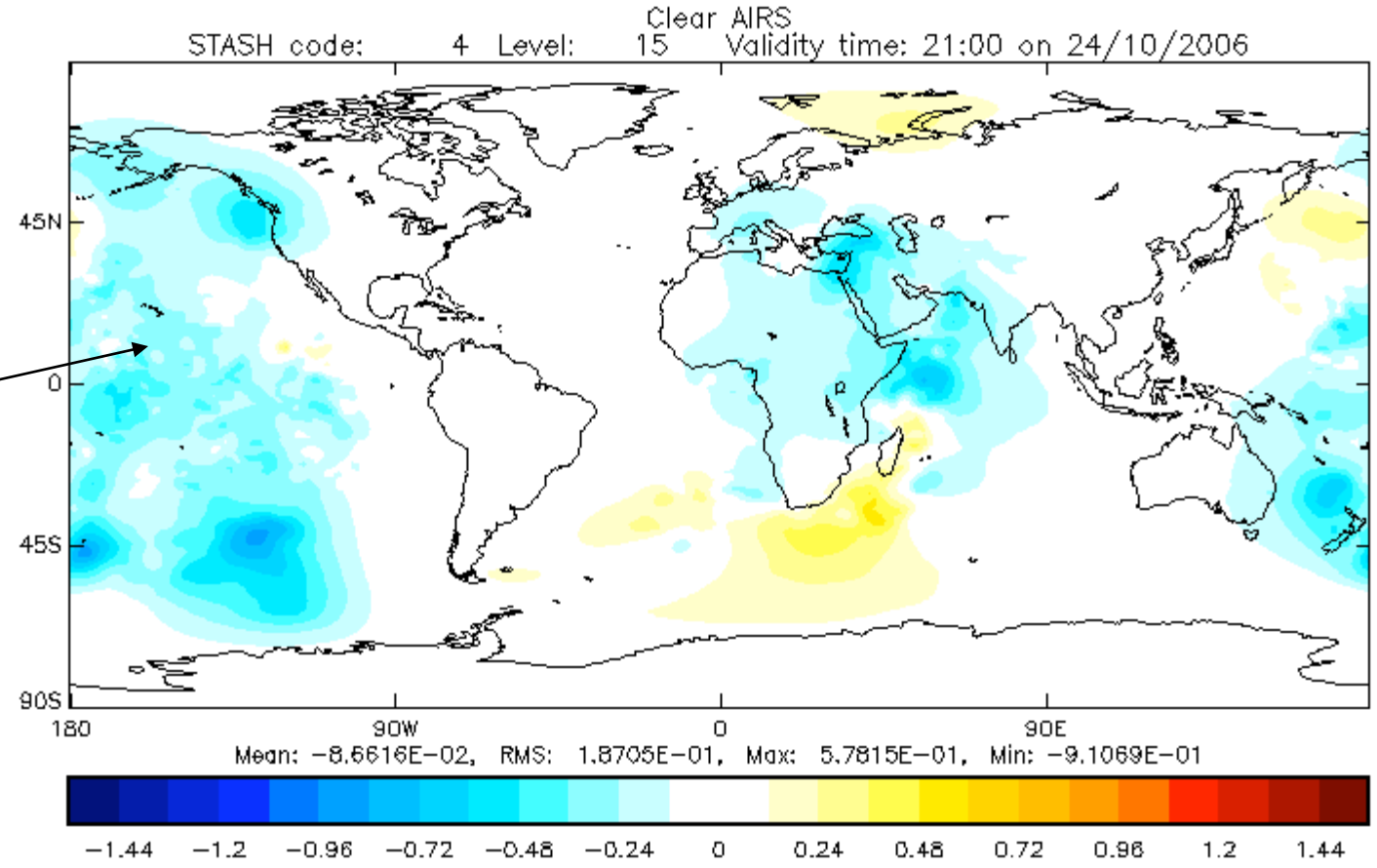
Coverage: Cloudy AIRS (~ 2 × no. of obs.)



Retrieved effective cloud fraction

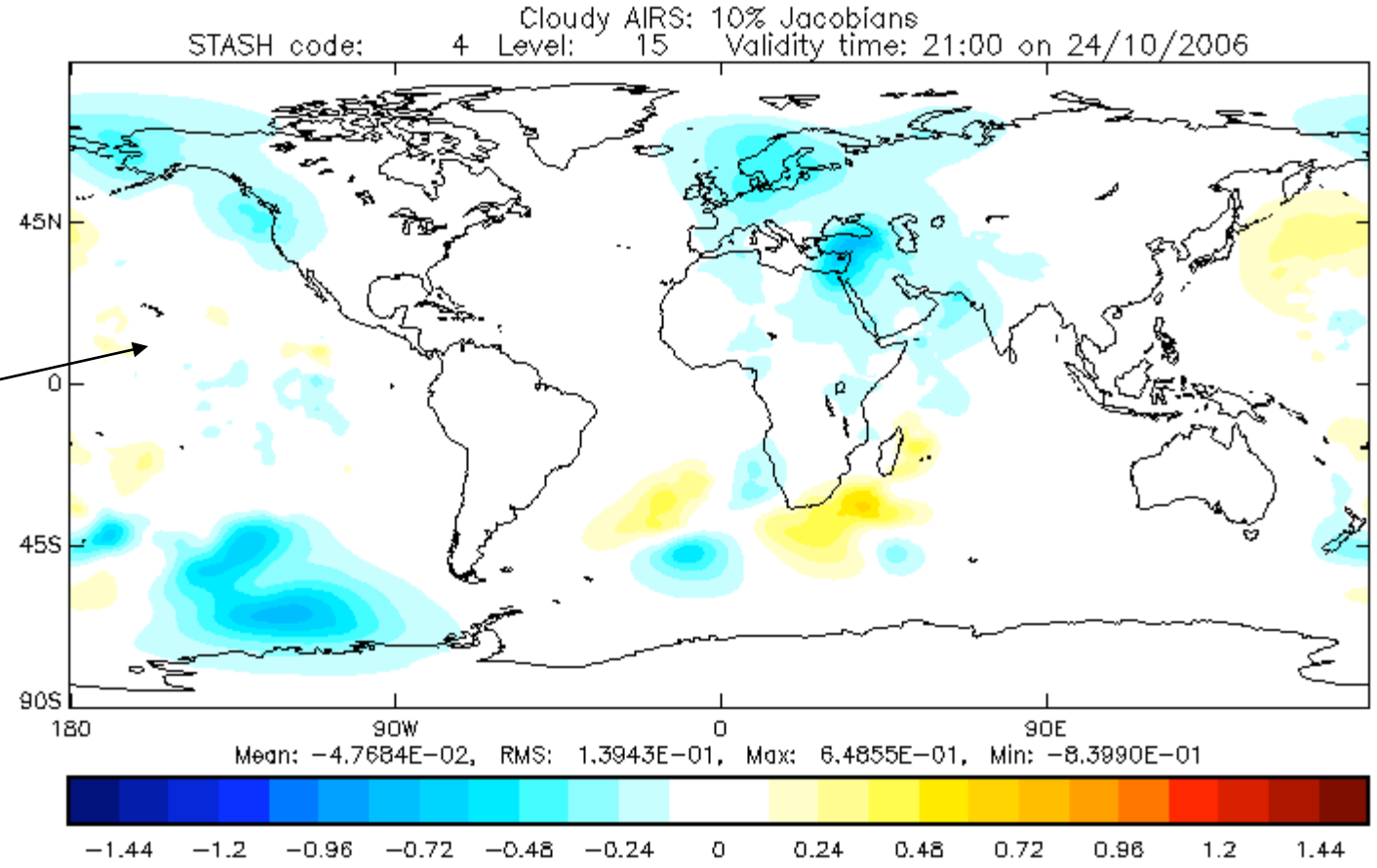


“Clear” AIRS: θ increments on level 15 of 50



Cold bias

Cloudy AIRS: θ increments on level 15 of 50

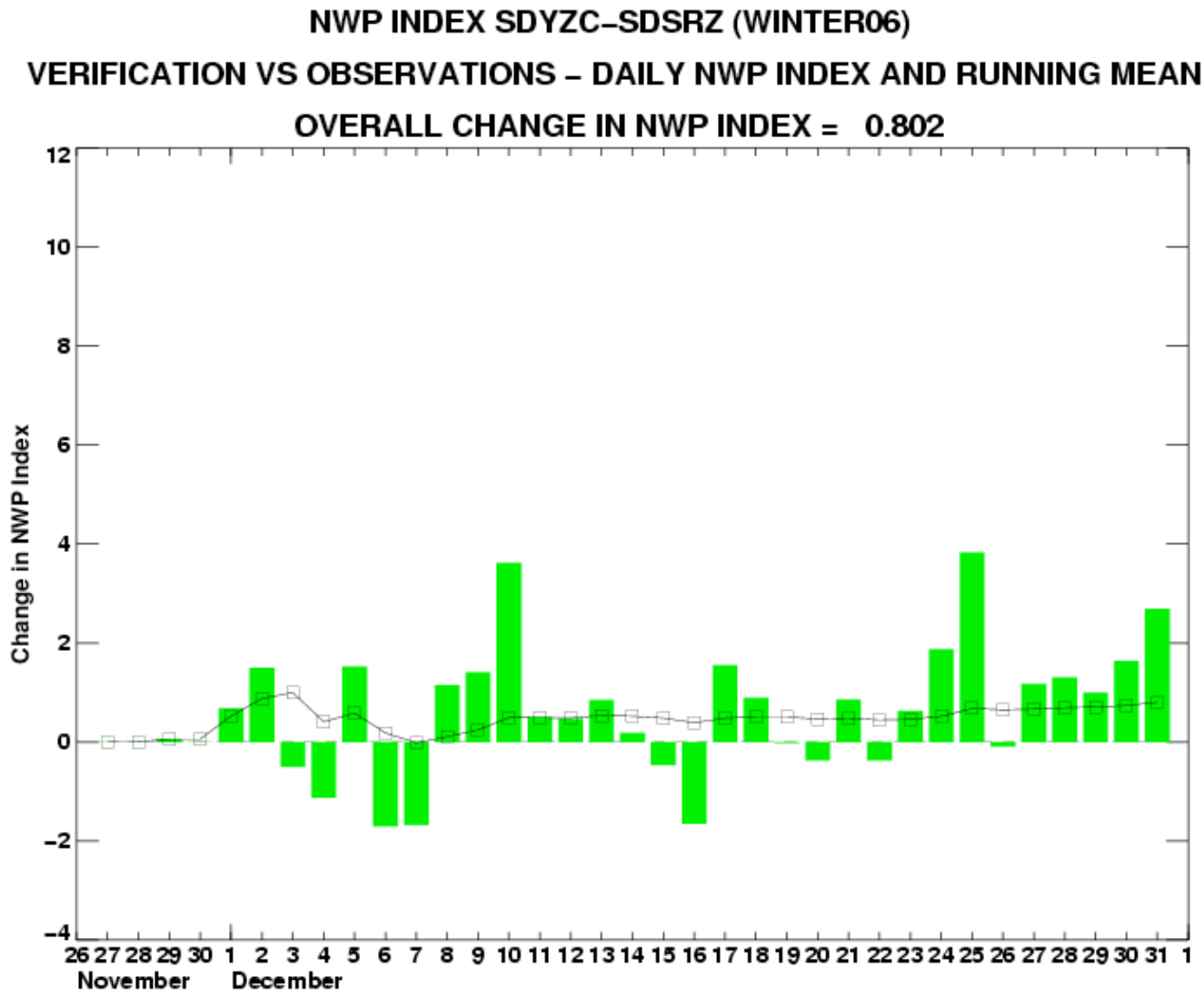


Cold bias gone

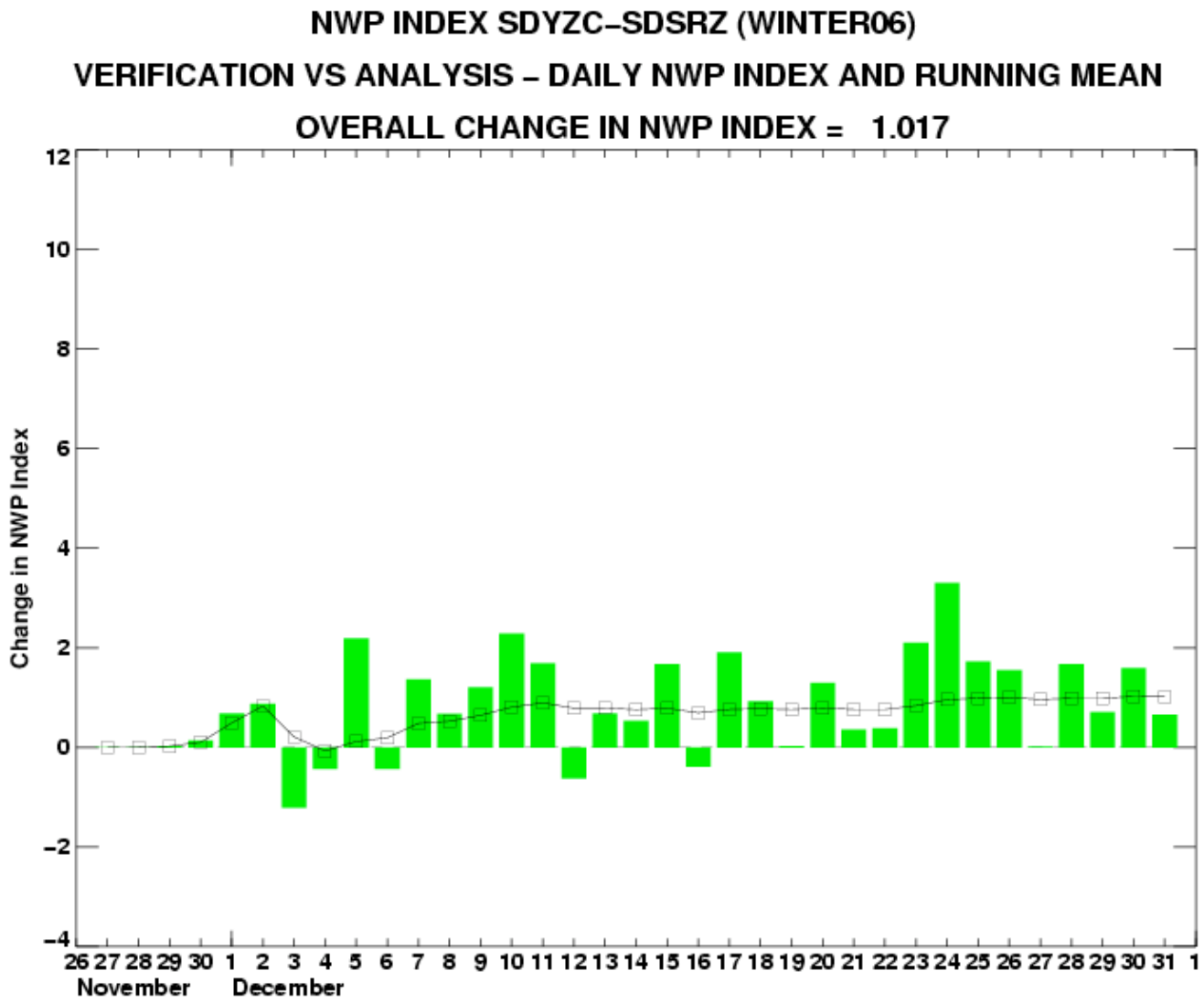
Bias Correction

- Initial trials conducted using “old” clear AIRS bias corrections
- In general, bias corrections should be re-calculated for cloudy AIRS data
- Use only channels selected above cloud when calculating BCs
  - Otherwise BCs will be contaminated by poorly-fitted cloud

Forecast impact vs. observations



Forecast impact vs. analyses



Increased cost of OPS pre-processing

- Runtime increased from 634 to 1639 sec (NEC SX8)
- No. of obs increased from 9344 to 15333
- Cloudy is 58% more expensive per ob
- Due to more iterations and extra RTTOV_K call for channel selection
- Currently be mitigated by pre-thinning (rather than post-thinning)
  - *New supercomputer due next year*

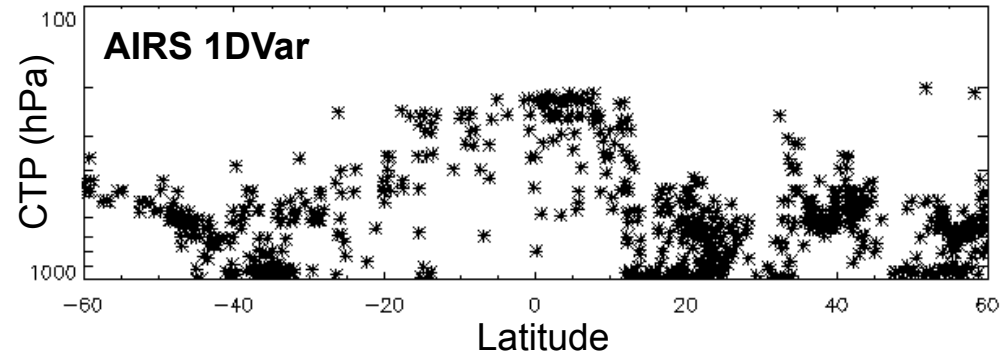
Validation of cloud retrievals

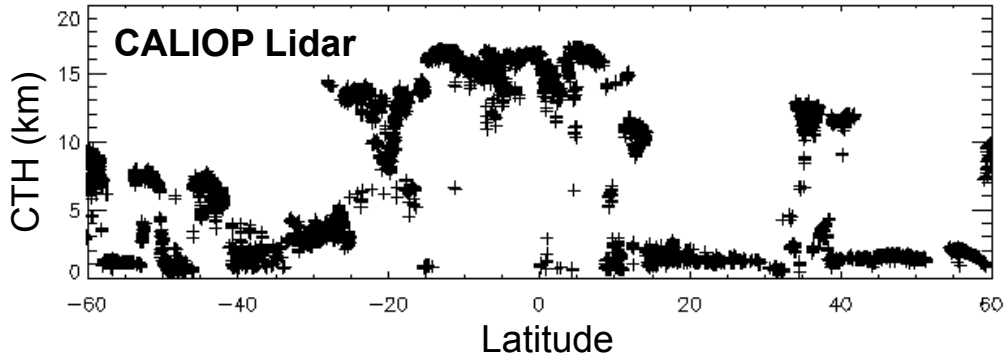
- **CALIPSO**: Spaceborne LIDAR (CALIOP)
  - Flies in A-Train close behind Aqua
  - Accurate cloud top height measurements

Preliminary, qualitative comparison

Section of one orbit

- Promising tool for validation





Summary (1)

- AIRS and IASI data currently used only in clear areas at Met Office

- 1D-Var cloud analysis has been implemented
  - Retrieve cloud fraction and cloud top pressure
  - Select assimilation channels based on CTP

- Simulation study performed well
  - Impact for low cloud similar to clear sky case
  - Also significant benefits from higher cloud

Summary (2)

- Now operational for AIRS (since July 2008)
  - Positive impact demonstrated in pre-operational trials
  - Equivalent to doubling the impact from AIRS
- Plan to implement for IASI soon

Questions and answers