Lessons Learned from AIRS: Improved Determination of Surface and Atmospheric Temperatures Using Only Shortwave AIRS Channels

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AIRS

AIRS is a grating detector array spectrometer launched on Eos Aqua in May 2002

Provides information about surface and atmospheric temperature, water vapor and constituent profiles, and clouds

Measures upwelling radiance $\hat{R}_i$ in 2360 spectral channels i between 650 cm^{-1} and 2665 cm^{-1}

$\nu_i / \Delta\nu_i \approx 1200$ $\Delta\nu_i$ goes from 0.5 cm^{-1} - 2.2 cm^{-1}

Spatial resolution ≈ 13 km at nadir from 705 km orbit

Referred to as AIRS Field of View (FOV)

AIRS was accompanied by AMSU-A

Microwave temperature profile sounder

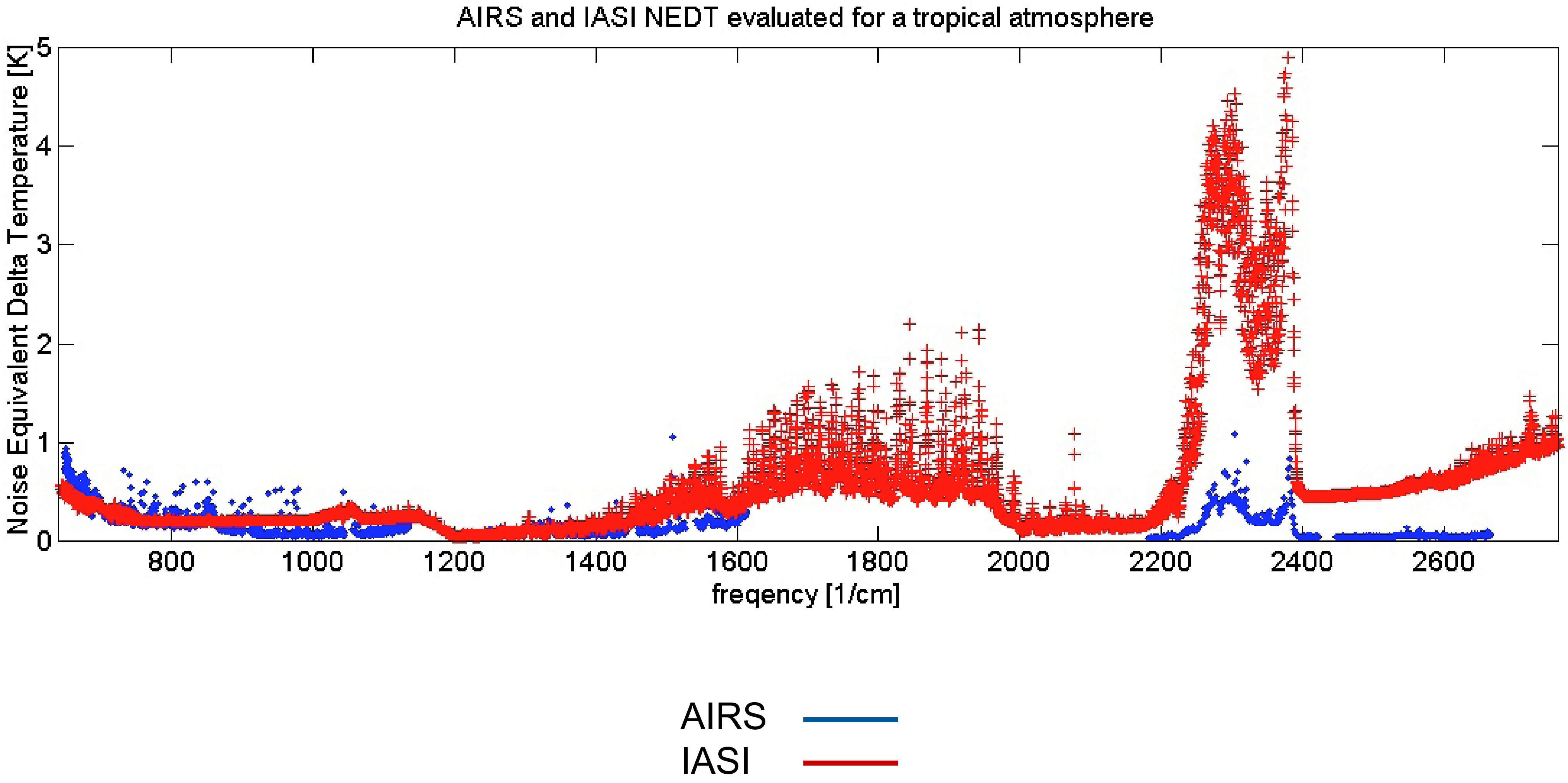
Spatial resolution ≈ 45 km at nadir

Referred to as AIRS Field of Regard (FOR)

9 AIRS FOV's fall within one FOR

AIRS was designed specifically to have very low noise at short wavelengths

IASI, a high spectral resolution IR interferometer on METOP-A, has much higher noise at short wavelengths


AIRS and IASI NEDT evaluated for a tropical atmosphere
Noise Equivalent Delta Temperature [K]
0
1
2
3
4
5
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
freqency [1/cm]
AIRS
IASI

Overview of AIRS Science Team Retrieval Methodology

Physically based retrieval system

Independent of GCM except for surface pressure - used to compute expected radiances

Uses cloud cleared radiances $\hat{R}_i$ valid for AIR FOR to determine the solution

- $\hat{R}_i$ represents what AIRS would have seen in the absence of clouds
- Derivation of $\hat{R}_i$ is updated in different steps of the retrieval process

Basic steps

- Initial cloud clearing produces $\hat{R}_i^0$ - based on statistical initial guess using observed radiances R_i
- Sequentially determine surface parameters, T(p), q(p), O_3(p), CO(p), CH_4(p), using $\hat{R}_i^0$
  - Each step uses its own set of channels
- Generate error estimates δT(p), δq(p) and use for Quality Control (QC)

Retrieval system can be used with AIRS/AMSU radiances or in "AIRS Only" mode without AMSU radiances

Goddard DISC had been analyzing AIRS/AMSU data using AIRS Version-5 algorithm

- Retrievals are near real time
- Analyzed data from September 2002 through the present

AIRS Science Team Version-6 algorithm will become operational in late 2011

Objectives of AIRS/AMSU

Provide real time observations to improve numerical weather prediction via data assimilation

Could be R_i (used by NCEP, ECMWF) or T(p), q(p)

Accuracy of $\hat{R}_i$, T(p), q(p) degrades slowly with increasing cloud fraction

There is a trade-off between accuracy and spatial coverage

- Assimilation of soundings or radiances only in clear cases limits utility of the data
- Assimilation of poorer quality retrievals can degrade forecast skill

Provide observations to measure and explain interannual variability and trends

Must provide good spatial coverage but also be unbiased

Can be less accurate than needed for data assimilation

Use of AIRS product error estimates allows for QC optimized for each application

- Tighter QC is better for data assimilation
- Looser QC is better for climate applications

Significant Improvements in AIRS Retrieval Methodology

Improvements in AIRS Version-5

Improved radiative transfer parameterization accounts for effects of Non-Local Thermodynamic Equilibrium (non-LTE)

Allows for complete use of 4.3 μm CO_2 sounding channels to determine T(p)

Following theoretical considerations:

R_i for 15 μm CO_2 channels are used only for cloud clearing coefficients

Gives clear column radiances $\hat{R}_i$ for all channels

$\hat{R}_i$ for 4.3 μm CO_2 channels are used to determine temperature profile T(p)

This allows for accurate T(p) soundings under more difficult cloud conditions

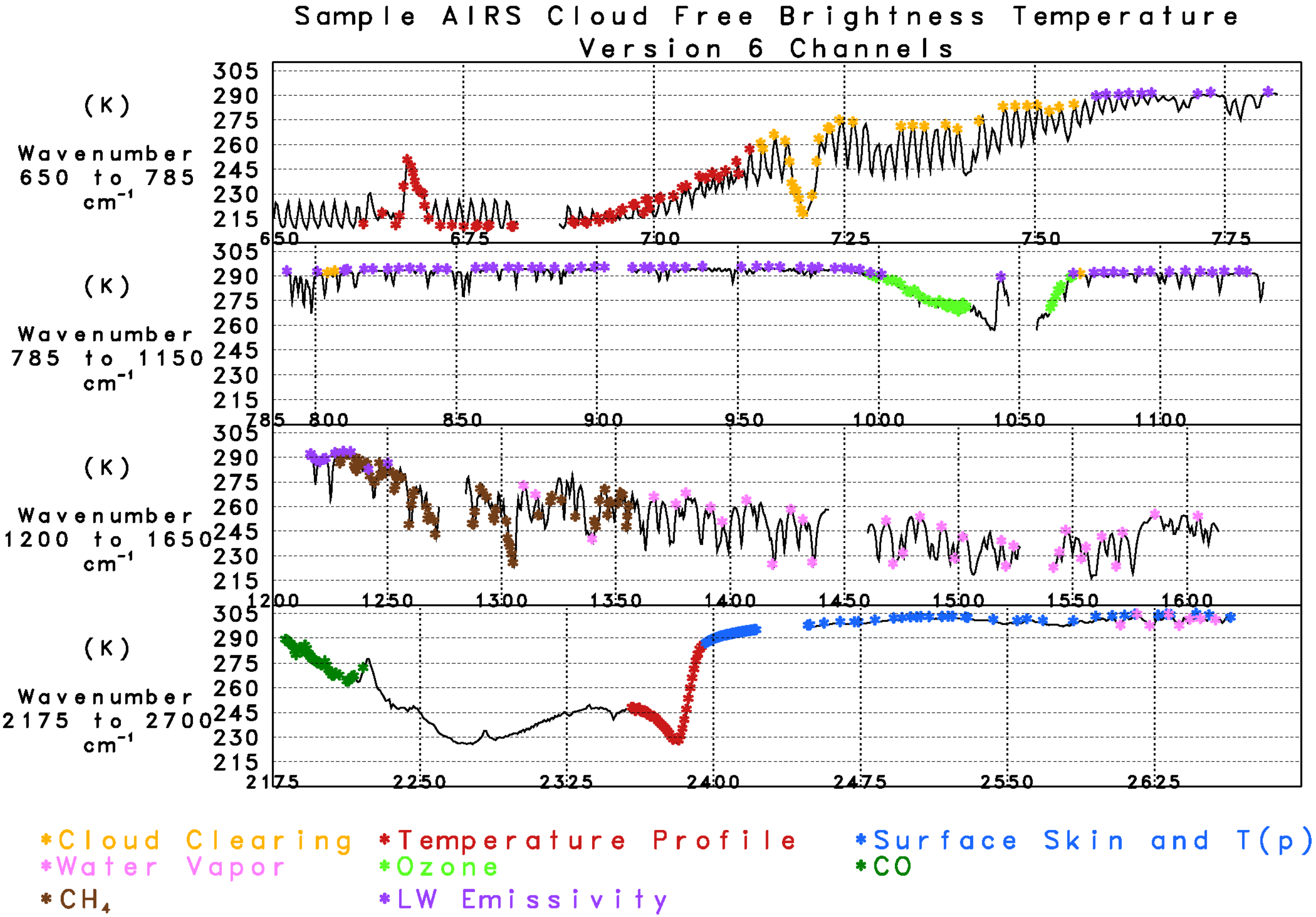
Further improvements in Version-6

Only shortwave window channels are now used to determine T_{skin} , shortwave surface spectral emissivity $\varepsilon_{SW}(\nu)$, and bi-directional reflectance $\rho_{SW}(\nu)$

$\hat{R}_i$ in longwave window channels are used in a subsequent retrieval step to determine $\varepsilon_{LW}(\nu)$ given T_{skin}

This provides accurate surface soundings under more difficult cloud conditions

Version-6 also has other improvements compared to Version-5



Sample AIRS Cloud Free Brightness Temperature
Version 6 Channels
(K)
Wavenumber 650 to 785 cm⁻¹
Wavenumber 785 to 1150 cm⁻¹
Wavenumber 1200 to 1650 cm⁻¹
Wavenumber 2175 to 2700 cm⁻¹
305
290
275
260
245
230
215
650
675
700
725
750
775
785
800
850
900
950
1000
1050
1100
1200
1250
1300
1350
1400
1450
1500
1550
1600
2175
2250
2325
2400
2475
2550
2625
*Cloud Clearing
*Temperature Profile
*Surface Skin and T(p)
*Water Vapor
*Ozone
*CO
*CH4
*LW Emissivity

Methodology Used for T(p) Quality Control

Version-5

Define a profile dependent pressure, p_{best}, above which the temperature profile is flagged as good - otherwise flagged as bad

Use error estimate $\delta T(p)$ to determine p_{best}

Start from 70 mb and set p_{best} to be the pressure at the first level below which $\delta T(p) > \text{threshold } \Delta T(p)$ for 3 consecutive layers

Temperature profile statistics include errors of T(p) down to $p = p_{best}$

Version-5 used $\Delta T(p)$ thresholds optimized simultaneously for weather and climate : $\Delta T^{standard}(p)$

Subsequent experience showed $\Delta T^{standard}(p)$ was not optimal for data assimilation (too loose) or for climate (too tight)

Use of new tighter thresholds $\Delta T^{tight}(p)$ resulted in retrievals with lower yield but with RMS errors ≈1K

Performed much better when used in data assimilation experiments

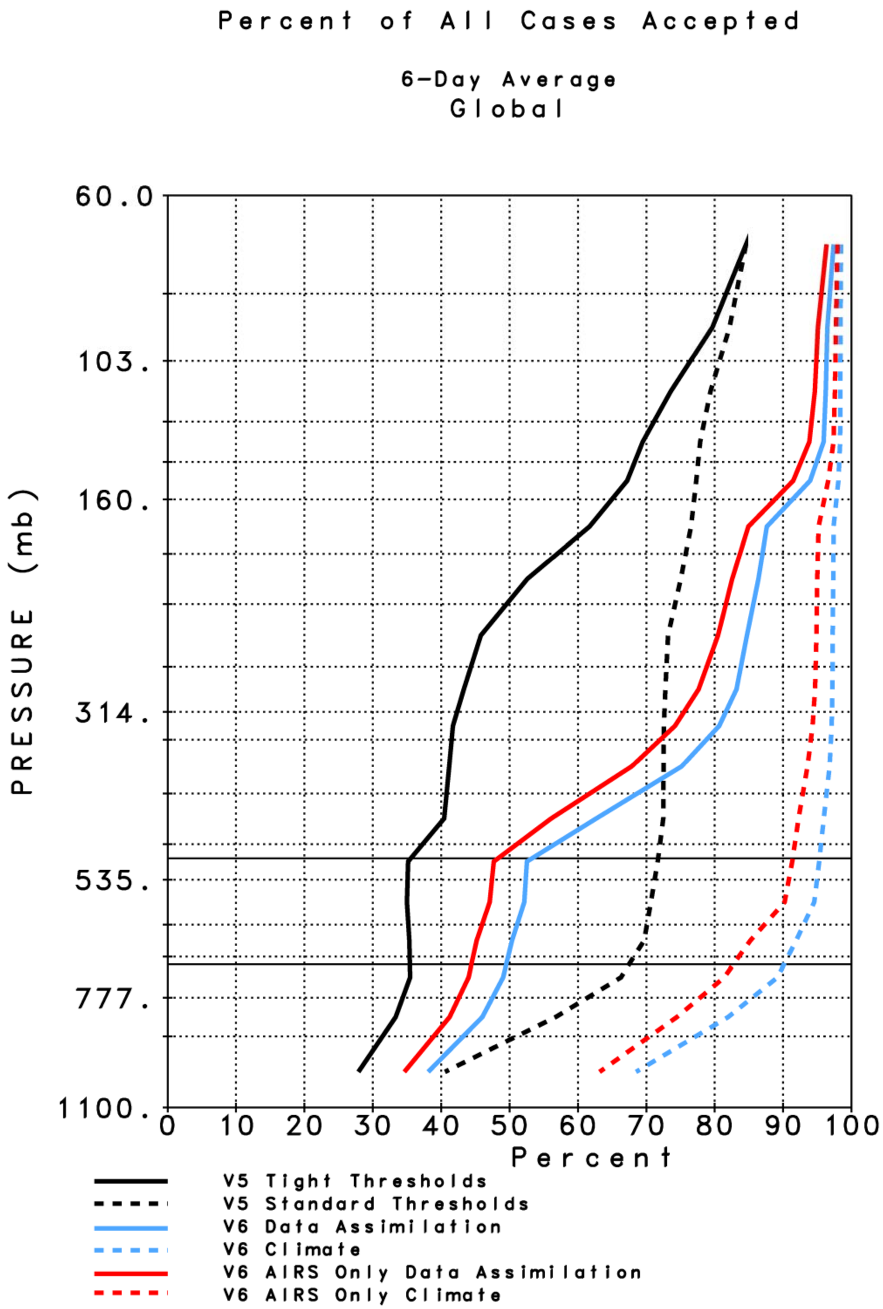
Version-6

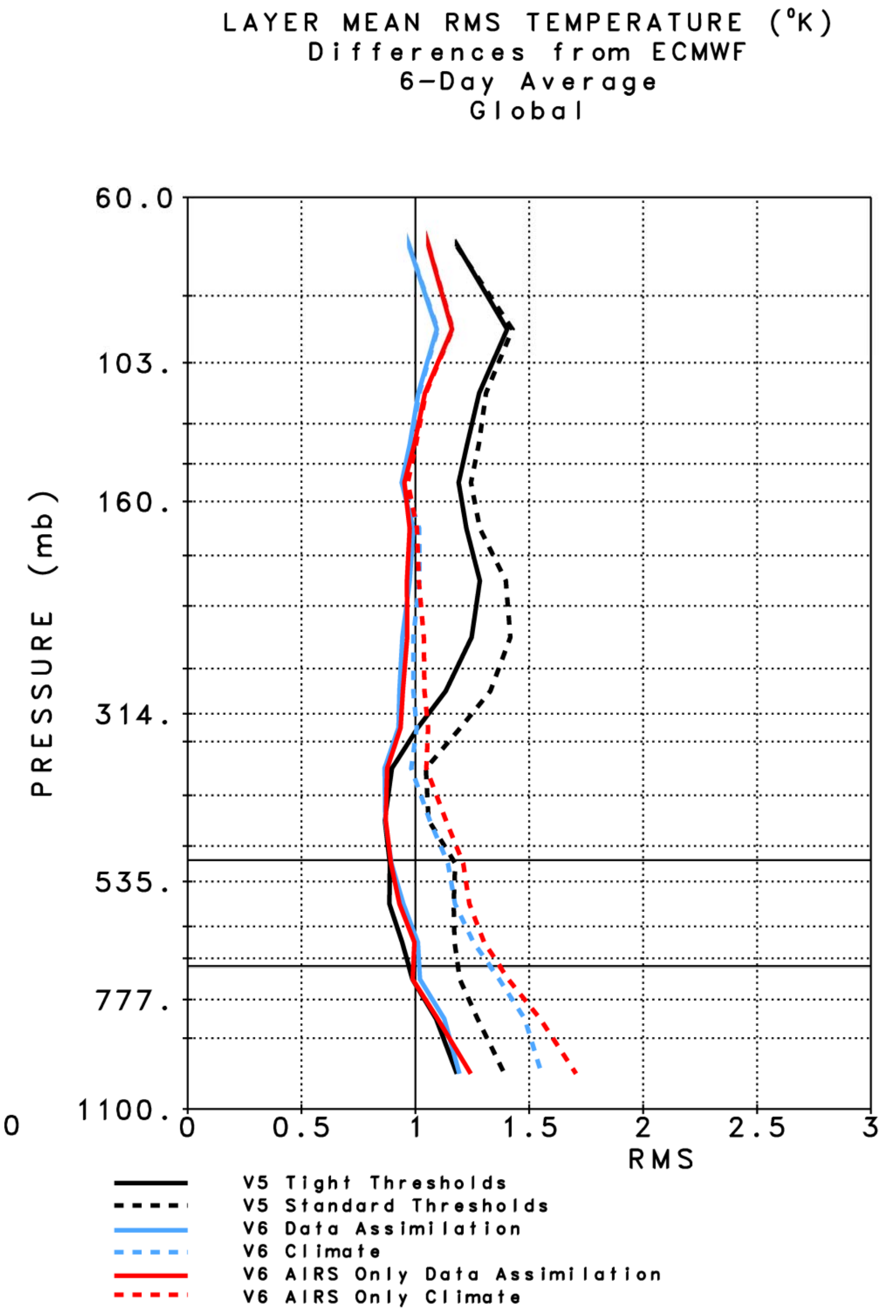
QC is analogous to Version-5 but has tight thresholds $\Delta T_A(p)$ for data assimilation and loose thresholds $\Delta T_C(p)$ for climate applications

ΔT_A thresholds define p_{best} and ΔT_C thresholds define p_{good}

ΔT_A thresholds designed to give RMS errors ≈1K

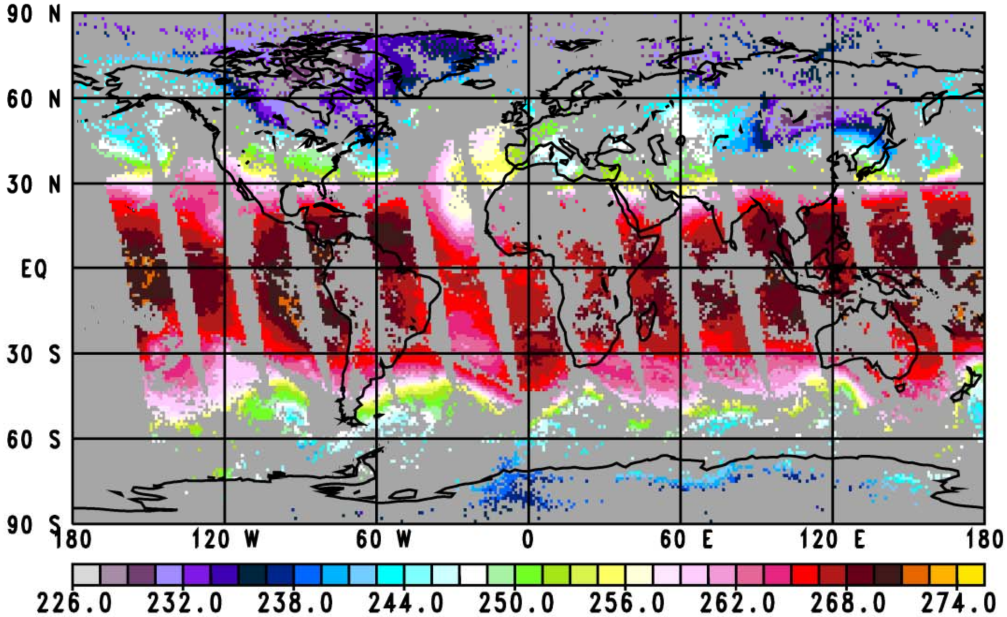
ΔT_C thresholds are used to generate level-3 gridded products


Percent of All Cases Accepted
6-Day Average
Global
PRESSURE (mb)
60.0
103.
160.
314.
535.
777.
1100.
0 10 20 30 40 50 60 70 80 90 100
Percent
V5 Tight Thresholds
V5 Standard Thresholds
V6 Data Assimilation
V6 Climate
V6 AIRS Only Data Assimilation
V6 AIRS Only Climate


LAYER MEAN RMS TEMPERATURE (°K)
Differences from ECMWF
6-Day Average
Global
PRESSURE (mb)
60.0
103.
160.
314.
535.
777.
1100.
0 0.5 1 1.5 2 2.5 3
RMS
V5 Tight Thresholds
V5 Standard Thresholds
V6 Data Assimilation
V6 Climate
V6 AIRS Only Data Assimilation
V6 AIRS Only Climate

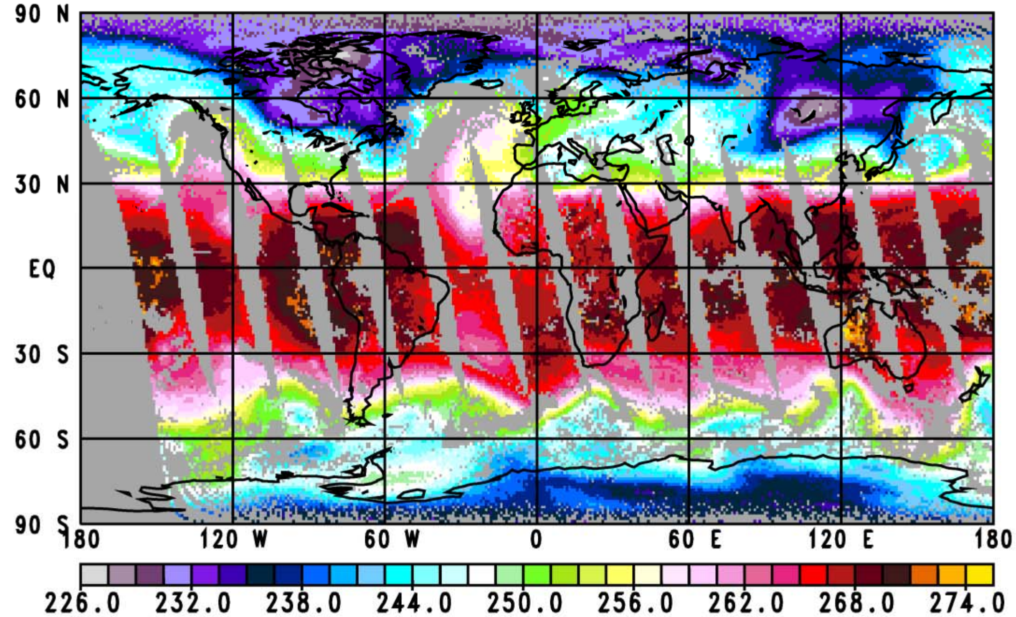
500 mb Temperature January 25, 2003

Version-5 Tight QC



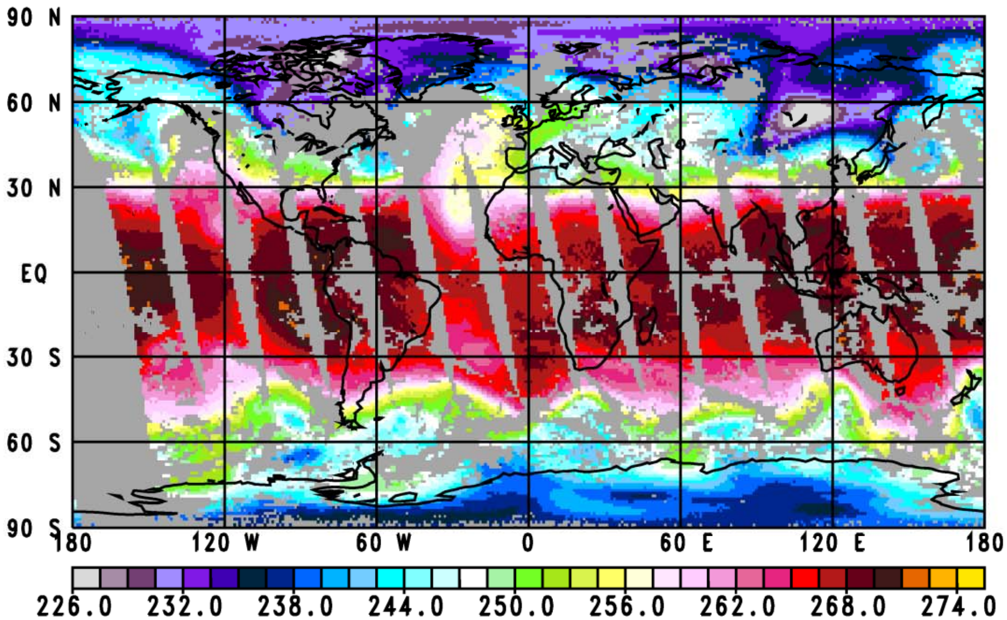
GLOBAL MEAN= 260.95

Version-5 Standard QC



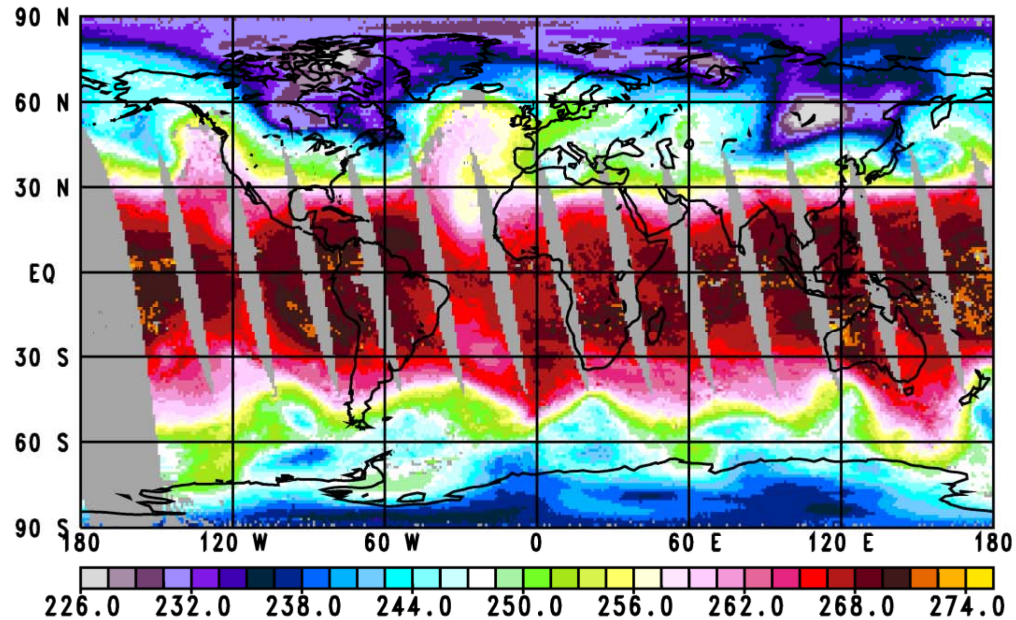
GLOBAL MEAN= 256.94

Version-6 Data Assimilation QC



GLOBAL MEAN= 257.70

Version-6 Climate QC



GLOBAL MEAN= 257.03

Forecast Impact Tests using Version-5 T(p)

Forecast impact tests were done at GSFC using GOES-5

Ran four sets of experiments, covering different seasons and years.

January 1 – January 31, 2003
October 15 – November 19, 2005
August 10 – September 16, 2006
April 15 – May 18, 2008

Four sets of assimilations were performed for each time period

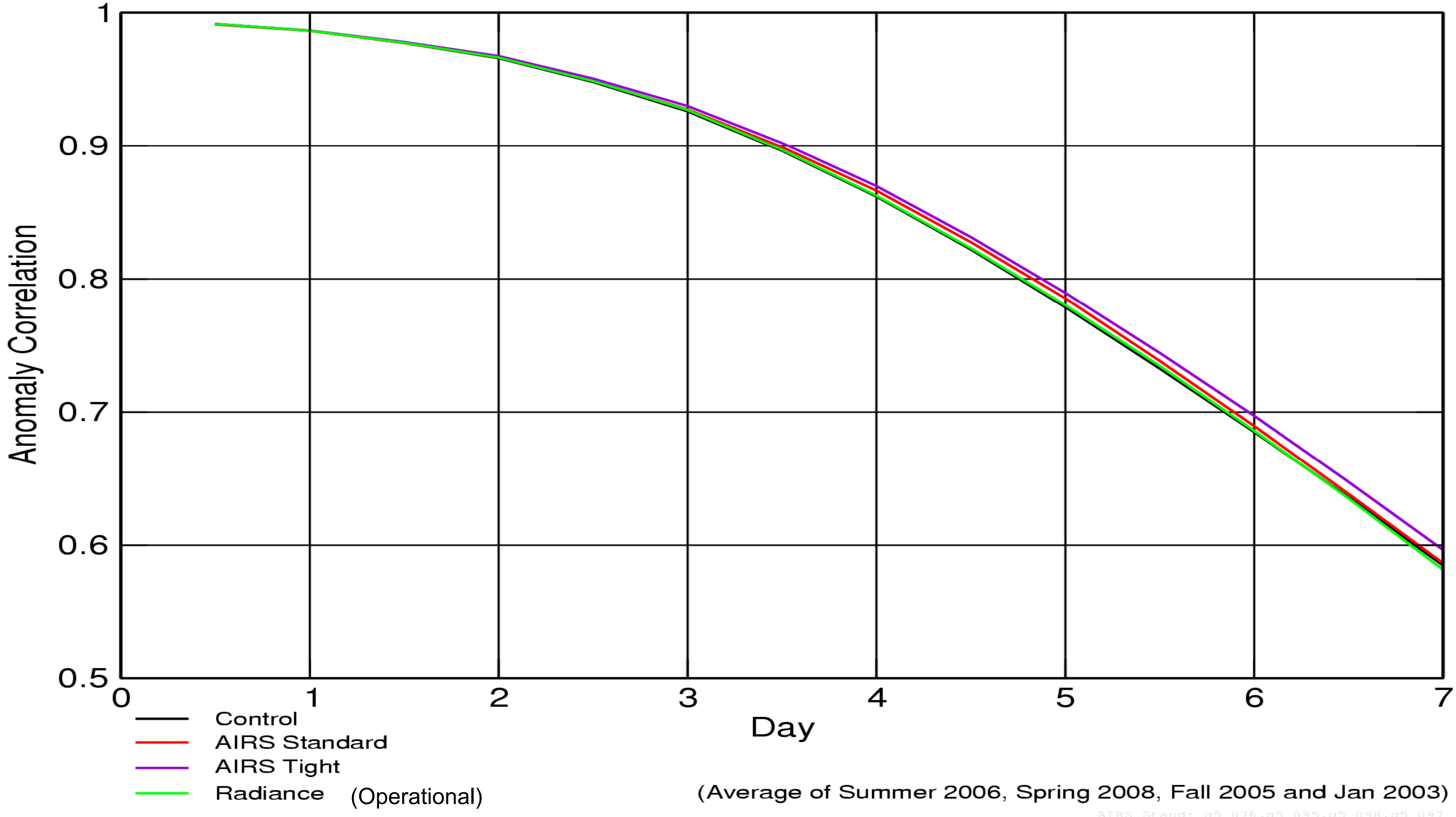
Control – uses no AIRS data but all other observations assimilated operationally
Radiance – assimilates AIRS radiances as done operationally
AIRS Standard assimilates AIRS T(p) down to p_{best} defined by standard thresholds
AIRS Tight assimilates AIRS T(p) down to p_{best} defined by tight thresholds

7-day forecasts run from each 0 Z Analysis for each experiment

The accuracy is judged against anomaly correlation of 7-day forecasts vs.
ECMWF Analysis for that time

500 mb Geopotential Heights

Global

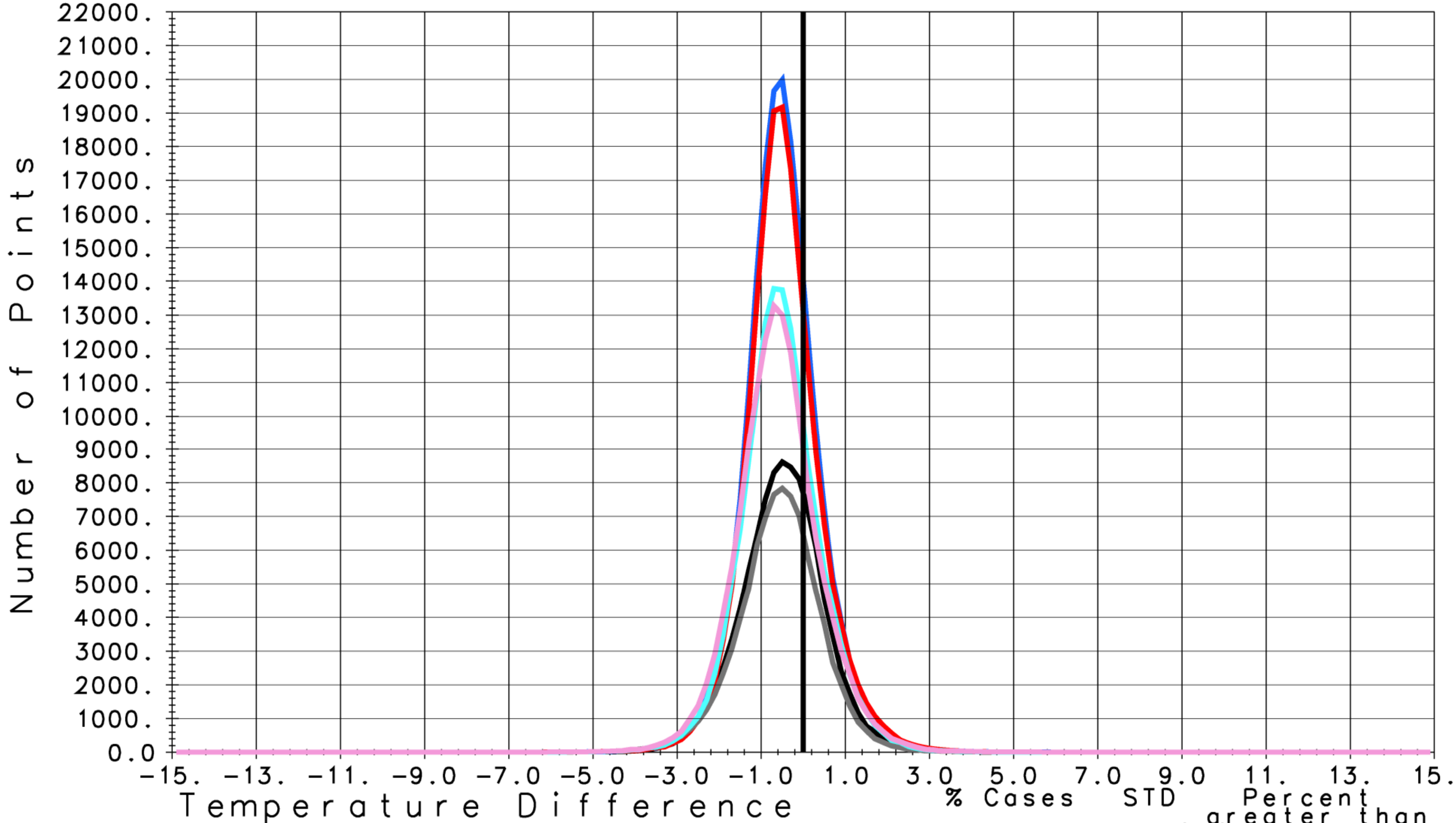


An anomaly correlation of 1.0 represents a perfect forecast

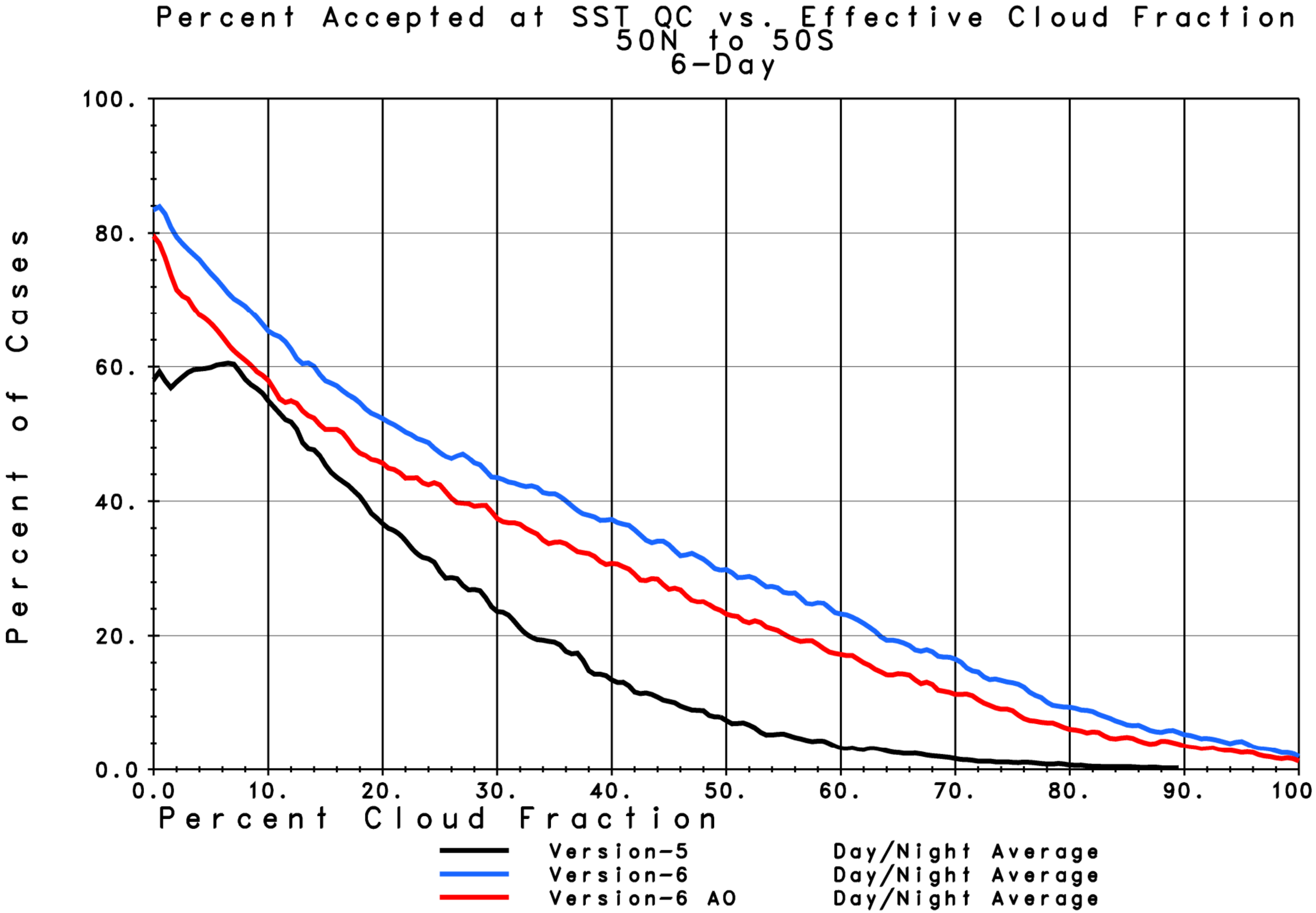
An anomaly correlation of 0.6 is the lower bound of a useful forecast

AIRS Tight improves 7-day forecast skill by about 4 hours.

Sea Surface Temperature Difference from ECMWF
6-Day
50 N to 50 S Non-Frozen Ocean



		% Cases	STD	Percent greater than |3| from mean
Version-5.0	Day	27.86	0.97	0.96
Version-6	Day	54.12	0.54	0.75
Version-6 AO	Day	50.80	0.54	0.73
Version-5.0	Night	22.42	0.96	1.55
Version-6	Night	37.00	0.59	0.96
Version-6 AO	Night	36.30	0.62	1.20


Percent Accepted at SST QC vs. Effective Cloud Fraction
50N to 50S
6-Day
Percent of Cases
100.
80.
60.
40.
20.
0.0
0.0
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
Percent Cloud Fraction
Version-5 Day/Night Average
Version-6 Day/Night Average
Version-6 AO Day/Night Average

Summary

AIRS Science Team Version-6 algorithm determines tropospheric T(p) and T_{skin} using only shortwave channels 2197 cm^{-1} – 2664 cm^{-1}. The 15 μm tropospheric sounding CO_2 channels are used only for cloud clearing (as in Version-5)

Use of only shortwave channels to determine T_s and tropospheric T(p) results in:

- "AIRS Only" retrievals that are comparable to AIRS/AMSU
  Slightly lower yield with comparable accuracy
- Improved soundings of T(p) and SST, day and night
  Improvements are larger with increasing cloud cover
- Performance during day is actually superior to performance at night
  - Higher yields and lower errors, especially at larger cloud fraction

This new approach is practical with AIRS because

- Solar radiation reflected by the surface is solved for in the surface retrieval step
- Solar radiation reflected by clouds is accounted for in the cloud clearing step
- **AIRS channels have very low noise at short wavelengths**

This approach is not practical with IASI because shortwave NEDT is too large

It is optimal for future (GEO) high-spectral resolution IR sounders to have low NEDT out to 2500 cm^{-1}. There is no need for a GEO MW sounder.

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