INFRA-RED SOUNDERS
Part 2: Results Using AIRS Version 5

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Workshop on Applications of Remotely Sensed Observations in Data Assimilation

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Objectives of AIRS/AMSU

Provide real time observations to improve numerical weather prediction

- Could be $\hat{R}_i$ (used by NCEP, ECMWF) or T(p), q(p) (used by Robert Atlas)
- 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
  - Using soundings or radiances only in clear cases limits utility of the data

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
- Must not contain systematic data gaps in certain regions

Error estimates and quality flags provide options for use in either weather or climate applications

Version 5 quality flags are based on fixed error estimate thresholds

The user can assign different quality flags as they see fit

Generation of Empirical Error Estimates δX_i

This step is done after physical retrieval is otherwise completed

Methodology used for $\delta SST, \delta T(p), \delta W_{tot} / W_{tot}$ **is identical**

Uses 16 internally computed values of convergence tests Y_j (13 in V5 AO)

Thresholds of 12 Y_j terms are used in Version 4 quality control

δX_i, error estimate for X_i, is computed according to

$$\delta X_i = \sum M_{ij} Y_j$$

Determination of M_{ij}

Use profiles with “truth”

$$\Delta X_i = \left| X_i - X_i^{TRUTH} \right|$$

Each profile now has $\Delta X_i, Y_j$

M_{ij} found which minimizes RMS $\left| \delta X_i - \Delta X_i \right|$

M_{ij} generated using all September 29, 2004 cases in which IR retrieval is accepted

ECMWF taken as “truth” to provide ΔX_i

M_{ij} tested on January 25, 2003 - used once and for all

Same basic approach is used for $\delta \hat{R}_i, \delta q(p)$

Methodology Used for V5 Quality Control

Temperature Profile T(p)

Define a profile dependent pressure, p_g, above which the temperature profile is flagged as good - otherwise flagged as bad

Use error estimate $\delta T(p)$ to determine p_g

Start from 70 mb and set p_g to be the pressure at the first level below which $\delta T(p) >$ threshold for n (currently = 3) consecutive layers

Temperature profile statistics include errors of T(p) down to p = p_g

Sea surface temperature SST

Flag SST as good if $\delta SST < 1.0K$

Total precipitable water W_{tot}

Flag W_{tot} as good if $\delta W_{tot} / W_{tot} < 0.35$

Clear column radiance $\hat{R}_i$

Flag $\hat{R}_i$ as good if $\delta \hat{R}_i < 0.9K$ in brightness temperature error units

Thresholds for T(p) - Computation of p_g

P_g is the highest pressure at which $\delta T(p) > \delta(p)$ for 3 consecutive levels

$\delta(p)$ is defined at 3 pressures: $\delta(70\,\text{mb}), \delta(p_{surf/2})$, and $\delta(p_{surf})$

$\delta(p)$ is linearly interpolated in ln p between these 3 values

Separate threshold values for $\delta(p)$ are set for non-frozen ocean and for land/ice

Version 5 uses Standard thresholds optimized for weather and climate simultaneously

We have done forecast impact experiments with other thresholds: Medium and Tight

Table 1

Temperature Profile Thresholds (K)

	Ocean			Land/Ice		
	δT_{70}	δT_{mid}	δT_{surf}	δT_{70}	δT_{mid}	δT_{surf}
Standard	1.75	1.25	2.25	2.25	2.0	2.0
Medium	1.75	1.0	1.75	1.75	1.0	2.0
Tight	1.75	0.75	1.75	1.75	0.75	1.75

Quality Flags for Accepted Retrievals

QC = 0 (Best)	QC = 1 (Good)	QC = 2 (Do not use)
Use for data assimilation	Use for Level 3	

Temperature Profile

Version 5
QC T(p) = 0 if $p \le p_g$
QC T(p) = 1 over land if $p \ge p_g$ and $p_g \ge 300\,\mathrm{mb}$
QC T(p) = 2 otherwise (QC never = 1 over ocean)

Version 4
QC T(p) = 0 within three distinct pressure ranges if ad-hoc individual tests are passed
QC T(p) = 1 for $p \ge 500\,\mathrm{mb}$ if mid-tropospheric temperature test is passed - both land and ocean
QC T(p) = 2 otherwise

Land skin temperature, emissivity - same for Version 5 and Version 4

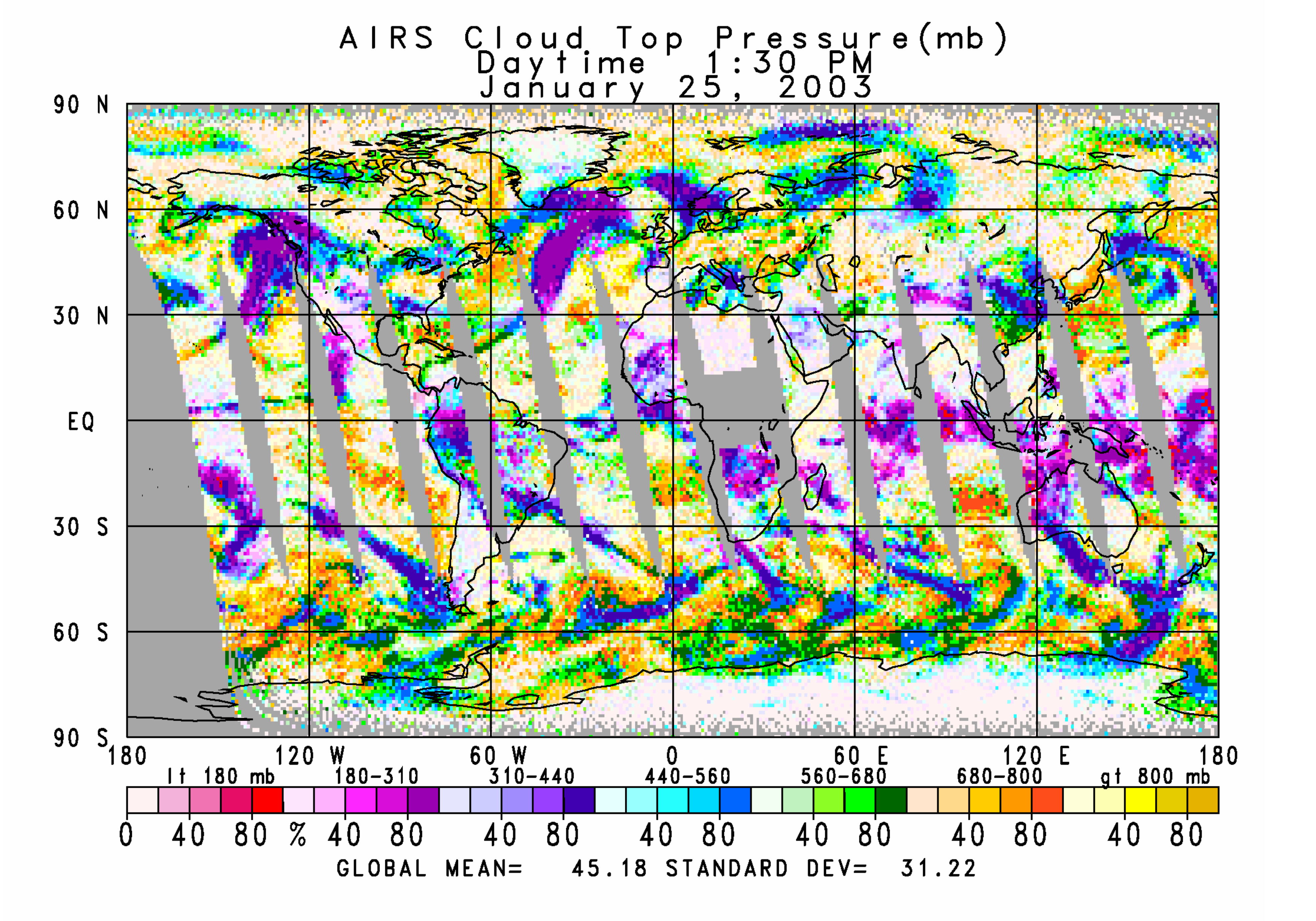
QC = 1 if QC surf air = 1
QC = 2 otherwise

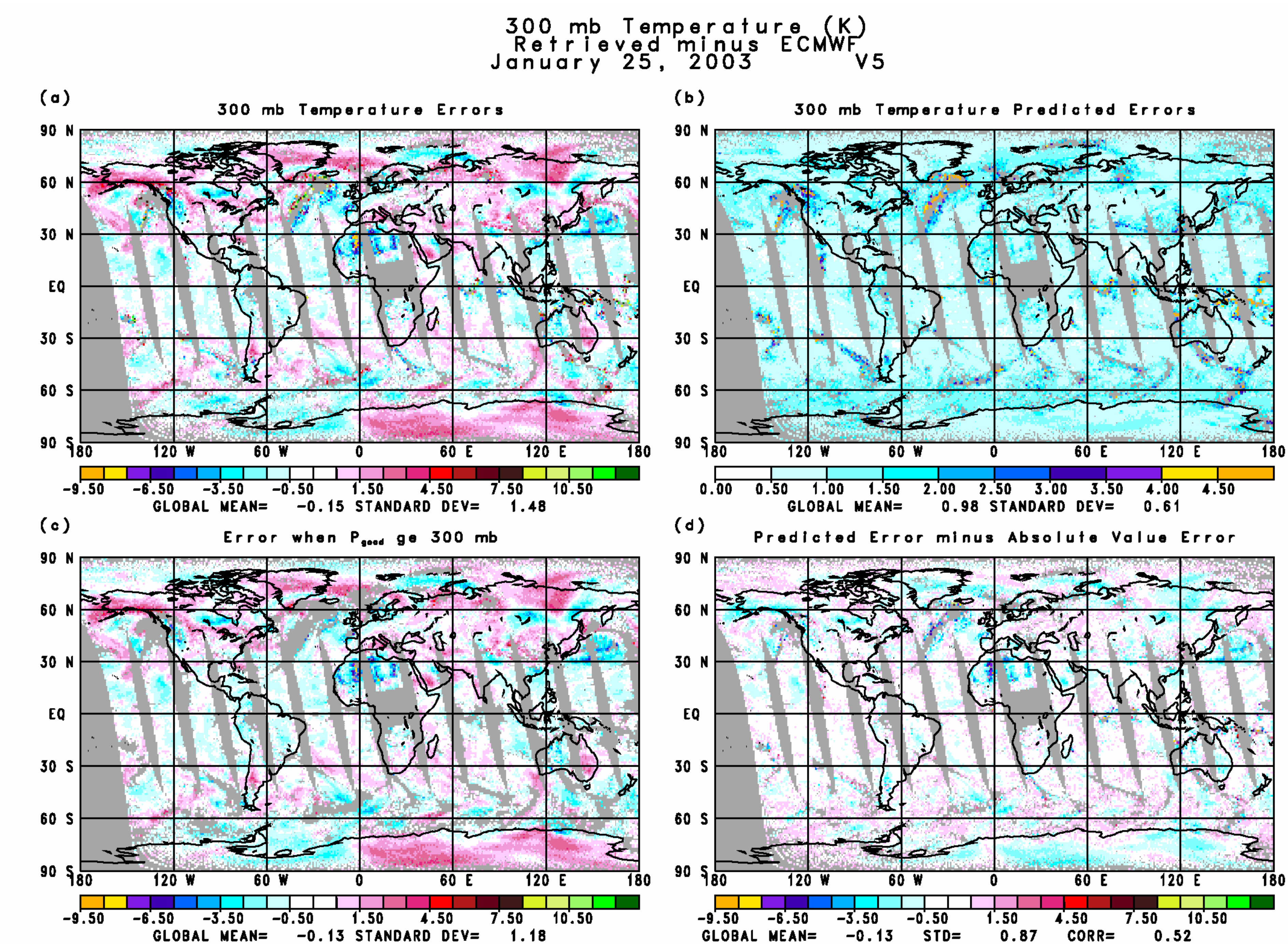
Sea surface temperature - same for Version 5 and Version 4

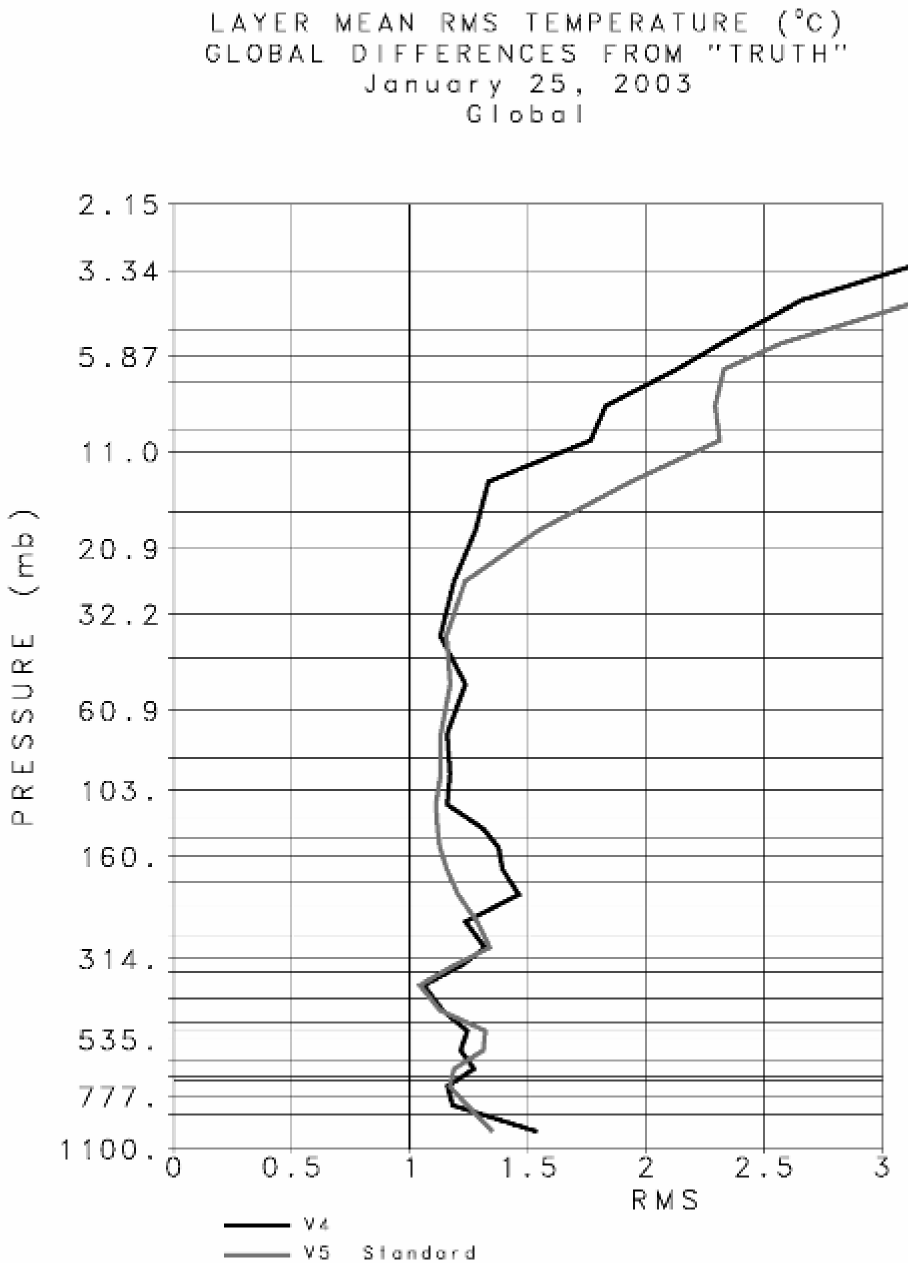
QC = 0 if tight test is passed
QC = 1 if standard test is passed

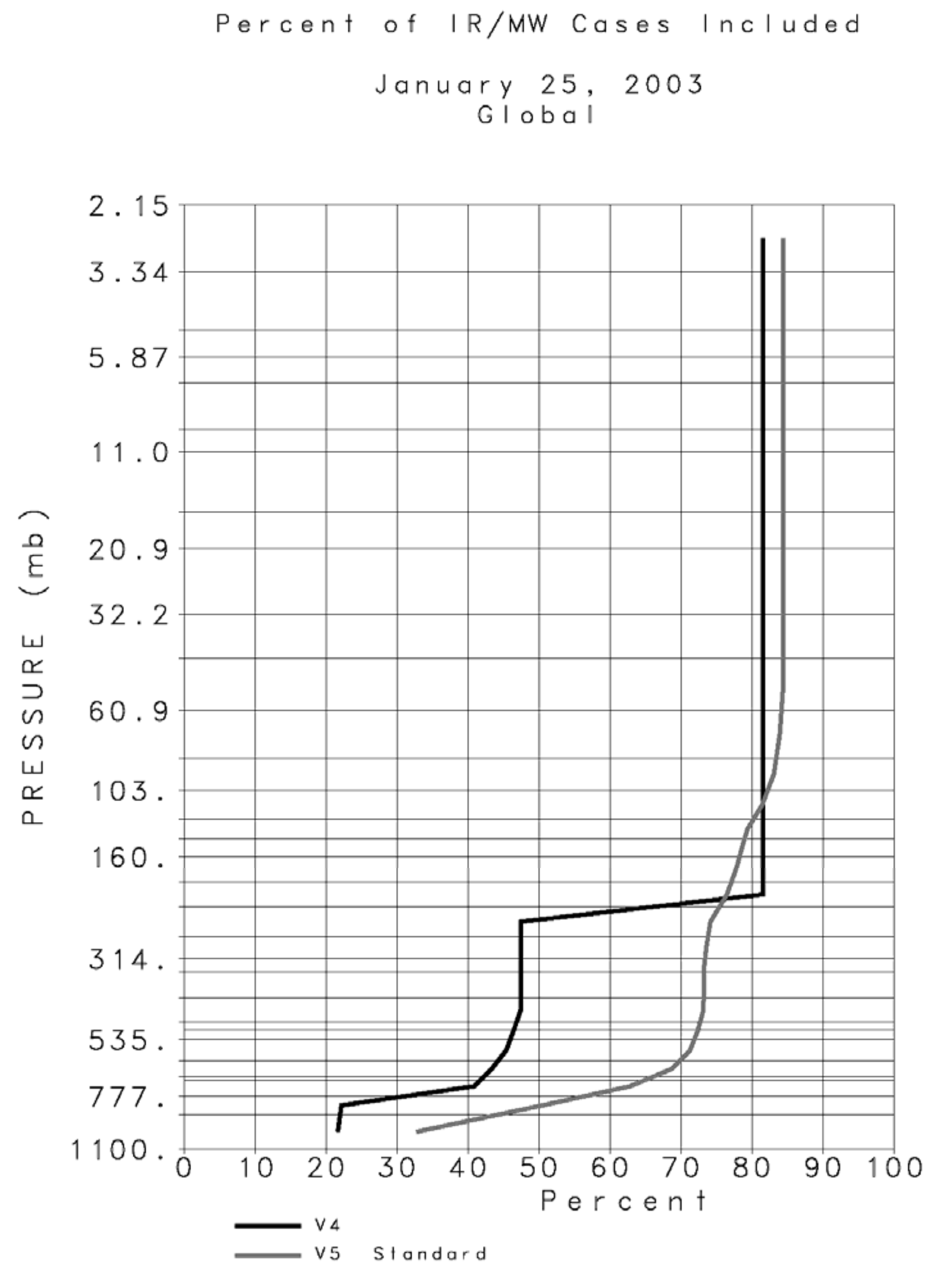
Constituent test

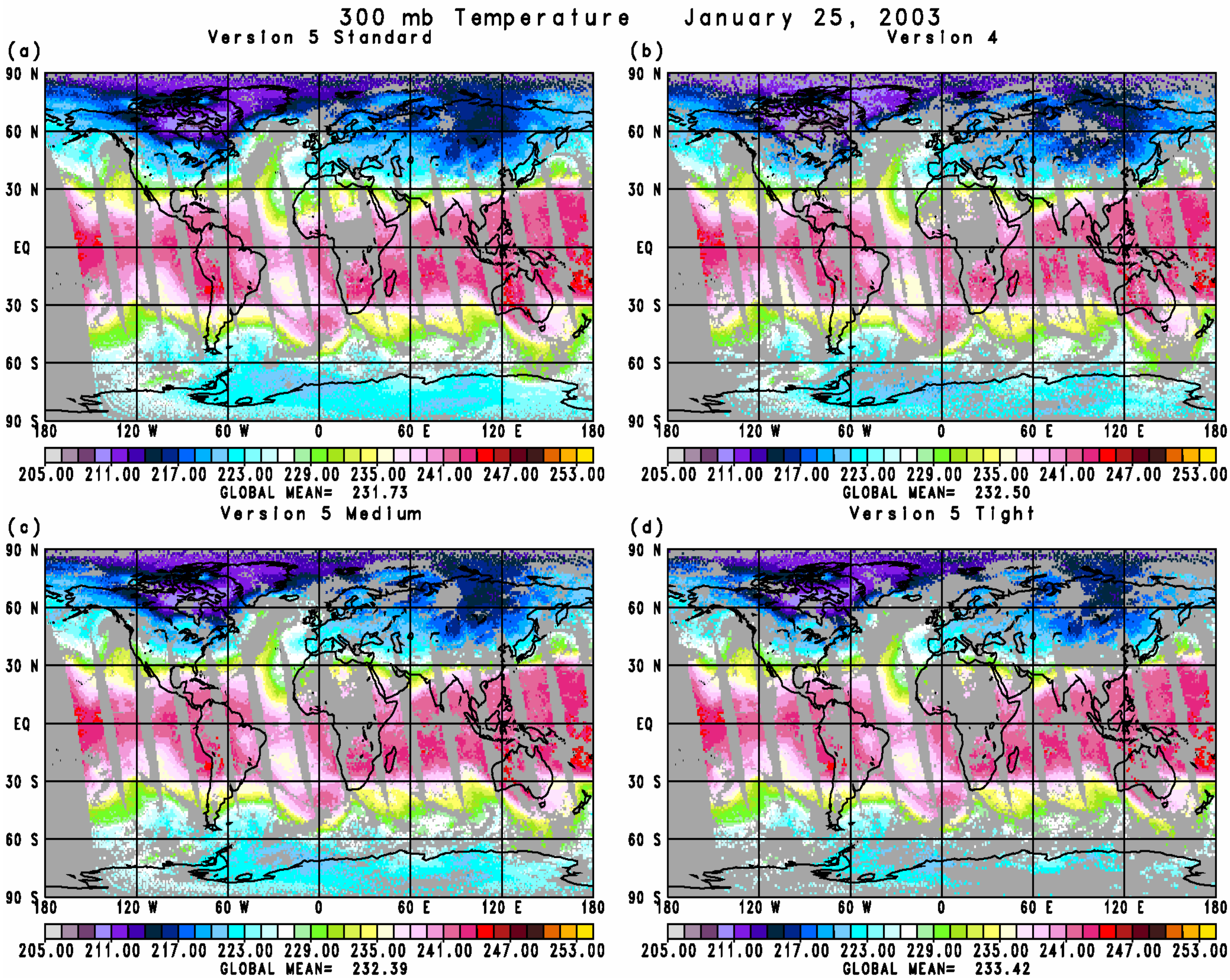
Passed if $\delta W_{tot} / W_{tot} \le 0.35$ in Version 5
Passed with ad-hoc test in Version 4
QC q(p) = 2 if constituent test fails, QC q(p) = 0 or 1 if constituent test is passed
QC q(p) = 0 only if QC T(p) = 0


AIRS Cloud Top Pressure(mb)
Daytime 1:30 PM
January 25, 2003
90 N
60 N
30 N
EQ
30 S
60 S
90 S
180
120 W
60 W
0
60 E
120 E
180
lt 180 mb
180-310
310-440
440-560
560-680
680-800
gt 800 mb
0 40 80 % 40 80 40 80 40 80 40 80 40 80 40 80
GLOBAL MEAN= 45.18 STANDARD DEV= 31.22

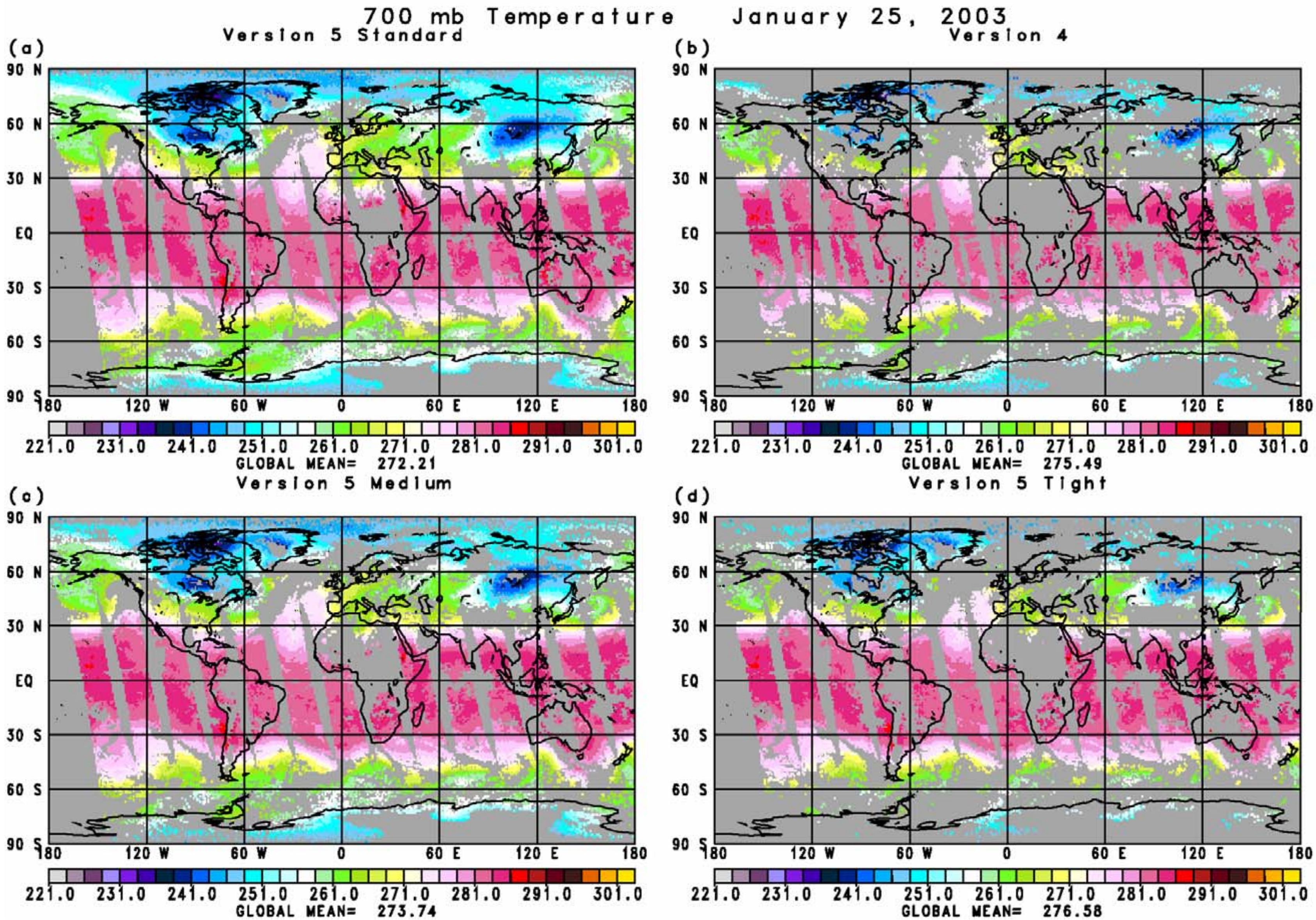

300 mb Temperature (K)
Retrieved minus ECMWF
January 25, 2003 V5
(a)
300 mb Temperature Errors
GLOBAL MEAN= -0.15 STANDARD DEV= 1.48
(b)
300 mb Temperature Predicted Errors
GLOBAL MEAN= 0.98 STANDARD DEV= 0.61
(c)
Error when P good ge 300 mb
GLOBAL MEAN= -0.13 STANDARD DEV= 1.18
(d)
Predicted Error minus Absolute Value Error
GLOBAL MEAN= -0.13 STD= 0.87 CORR= 0.52


LAYER MEAN RMS TEMPERATURE (°C)
GLOBAL DIFFERENCES FROM "TRUTH"
January 25, 2003
Global
PRESSURE (mb)
2.15
3.34
5.87
11.0
20.9
32.2
60.9
103.
160.
314.
535.
777.
1100.
0
0.5
1
1.5
2
2.5
3
RMS
V4
V5 Standard

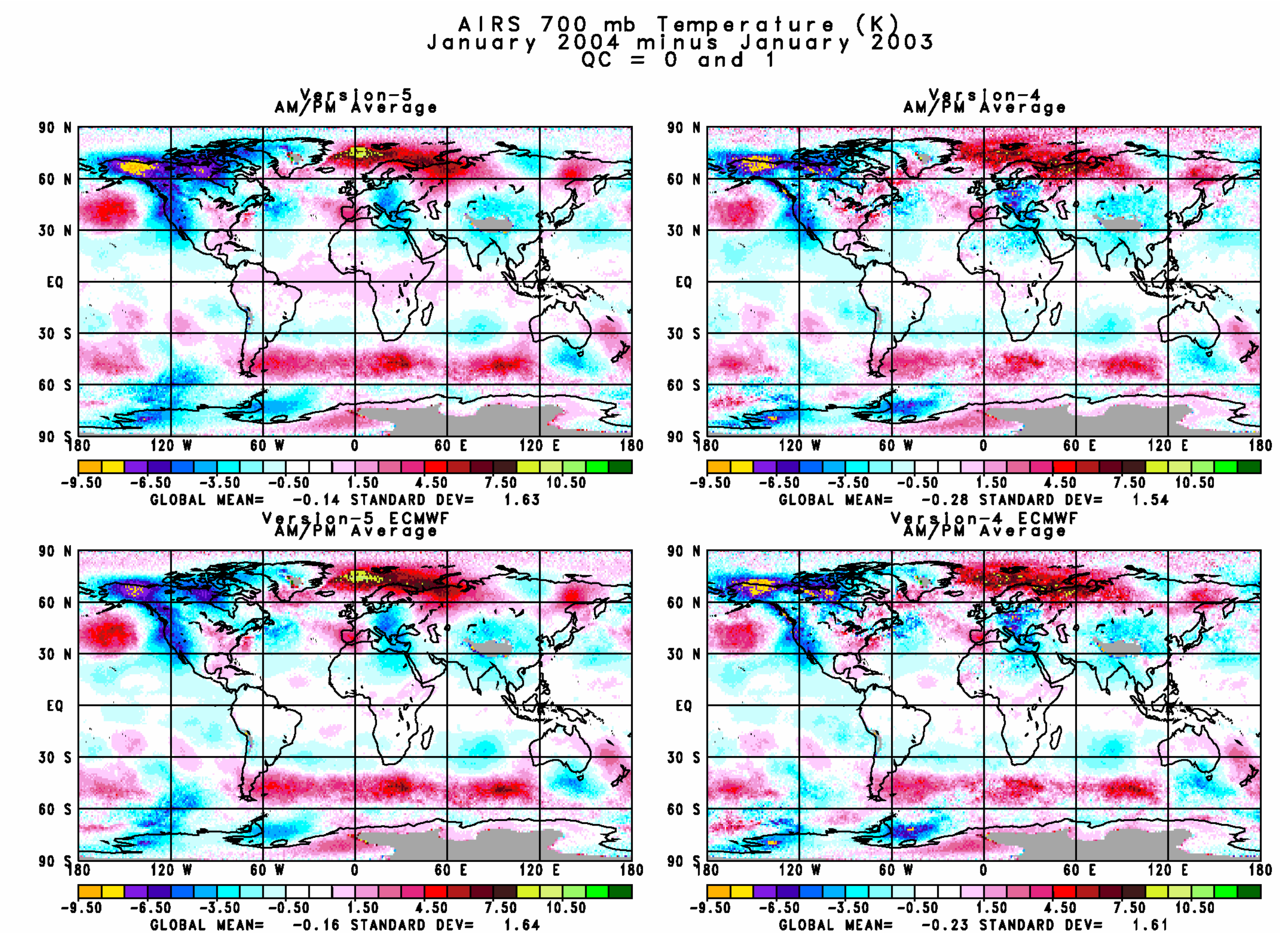

Percent of IR/MW Cases Included
January 25, 2003
Global
PRESSURE (mb)
2.15
3.34
5.87
11.0
20.9
32.2
60.9
103.
160.
314.
535.
777.
1100.
0
10
20
30
40
50
60
70
80
90
100
Percent
V4
V5 Standard



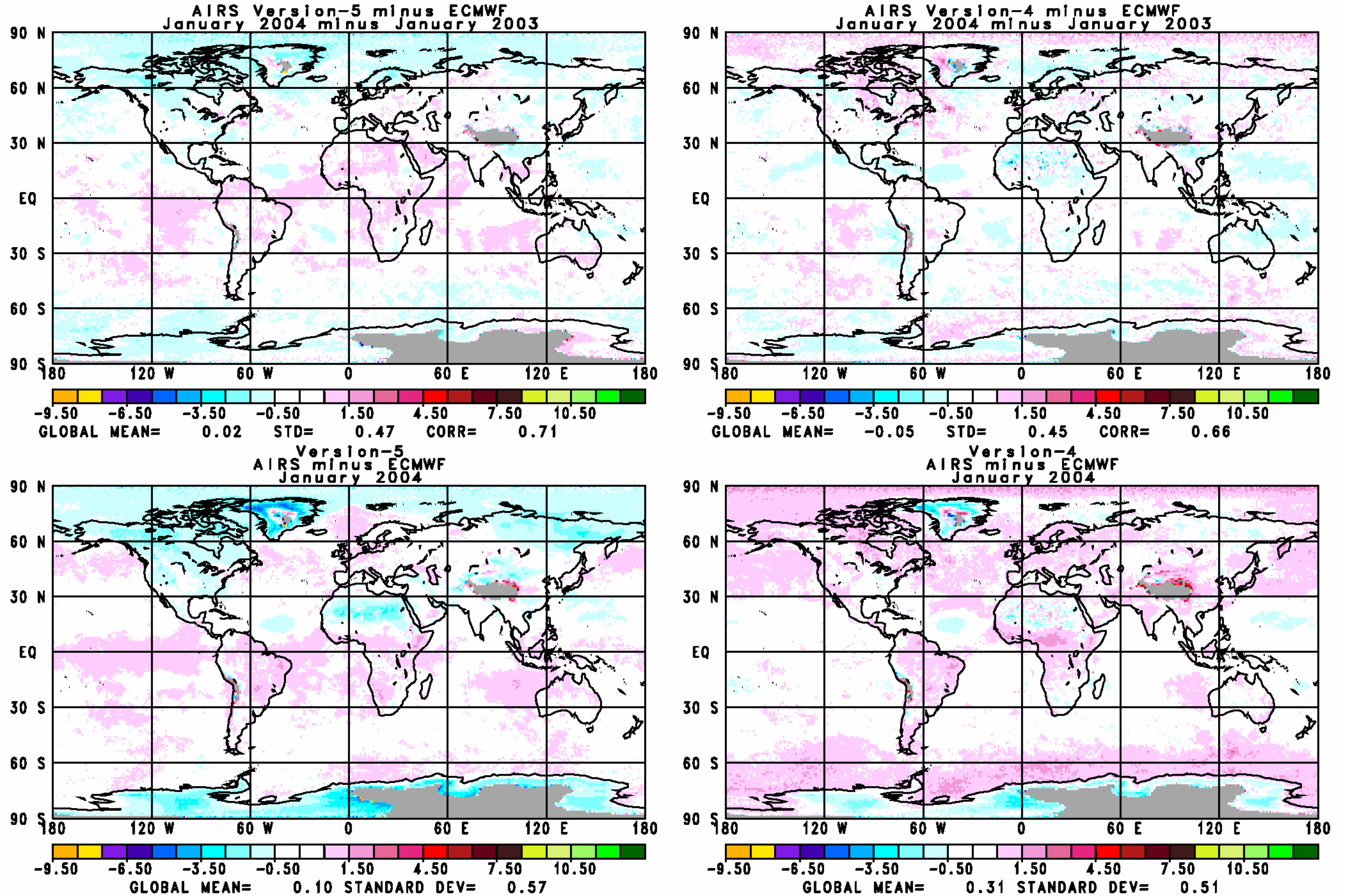
300 mb Temperature January 25, 2003
(a)
Version 5 Standard
GLOBAL MEAN= 231.73
(b)
Version 4
GLOBAL MEAN= 232.50
(c)
Version 5 Medium
GLOBAL MEAN= 232.39
(d)
Version 5 Tight
GLOBAL MEAN= 233.42
90 N
60 N
30 N
EQ
30 S
60 S
90 S
180
120 W
60 W
0
60 E
120 E
180
205.00 211.00 217.00 223.00 229.00 235.00 241.00 247.00 253.00

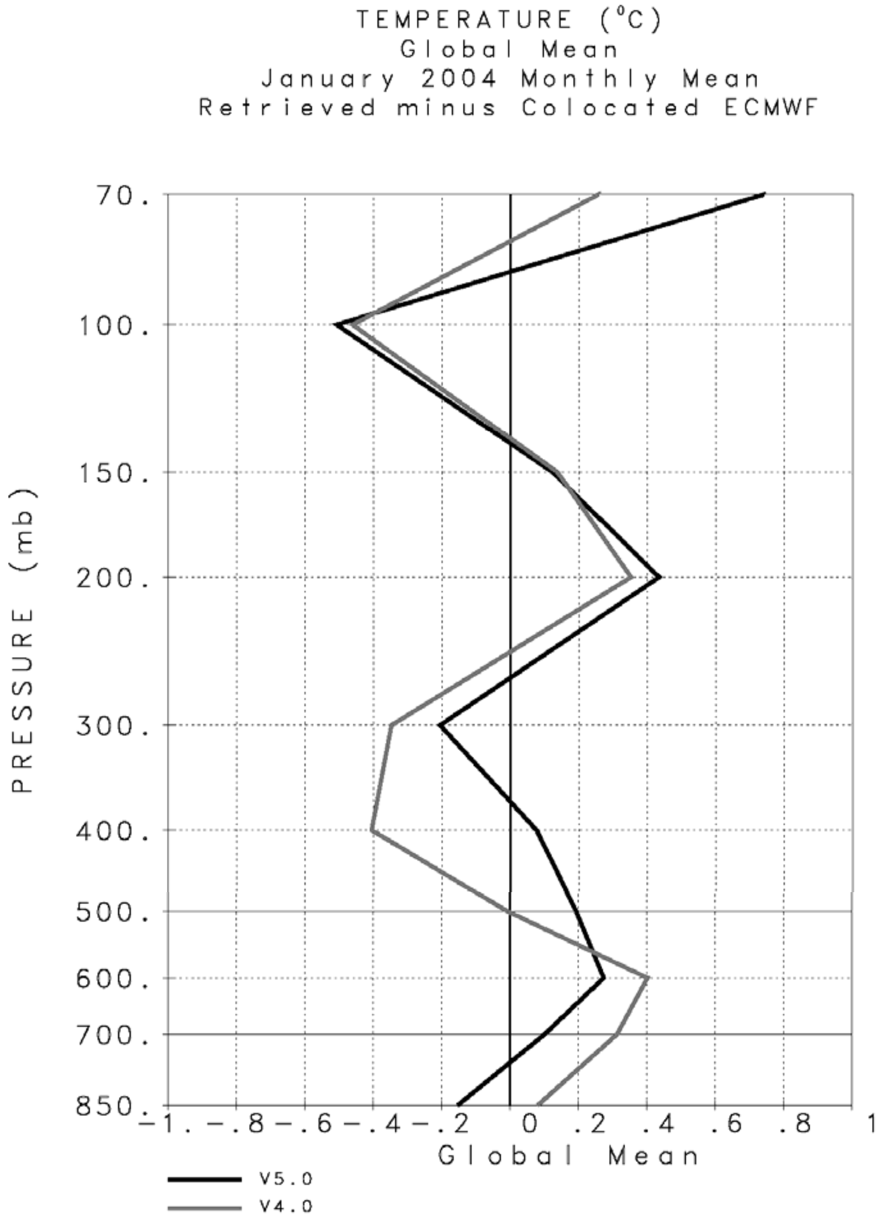


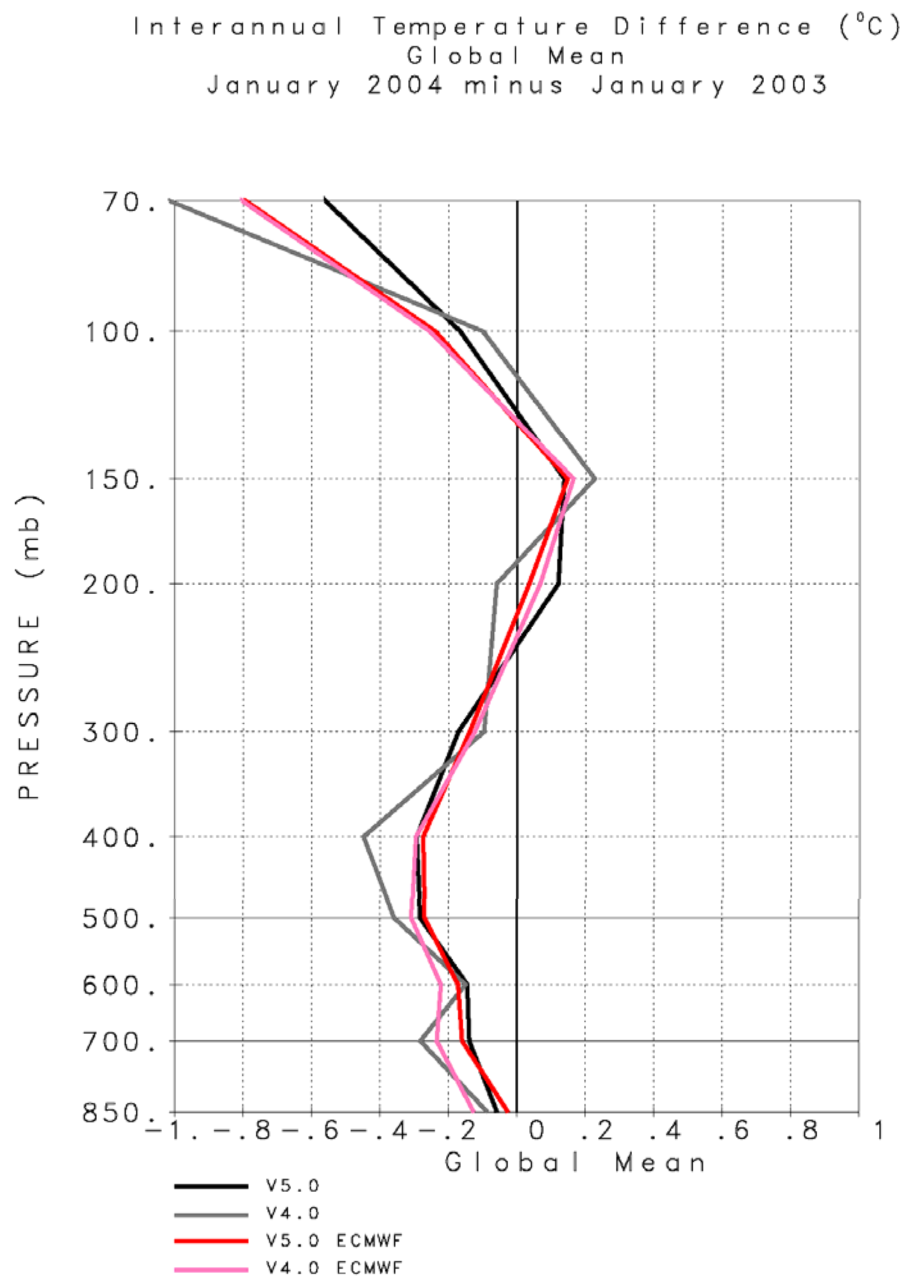
700 mb Temperature January 25, 2003
(a) Version 5 Standard
(b) Version 4
(c) Version 5 Medium
(d) Version 5 Tight
90 N
60 N
30 N
EQ
30 S
60 S
90 S
180
120 W
60 W
0
60 E
120 E
180
221.0 231.0 241.0 251.0 261.0 271.0 281.0 291.0 301.0
GLOBAL MEAN= 272.21
GLOBAL MEAN= 275.49
GLOBAL MEAN= 273.74
GLOBAL MEAN= 276.58

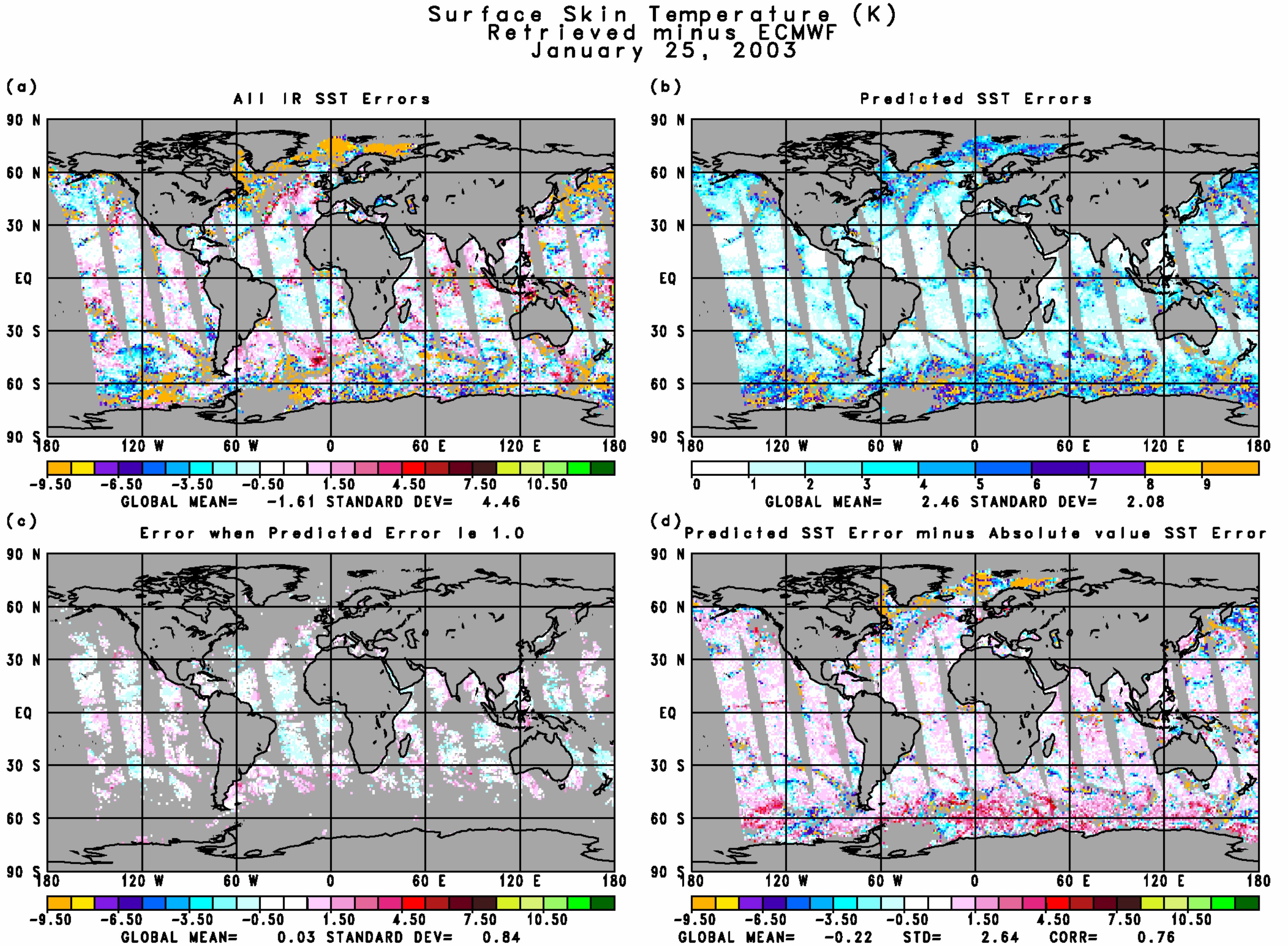

AIRS 700 mb Temperature (K)
January 2004 minus January 2003
QC = 0 and 1
Version-5
AM/PM Average
GLOBAL MEAN= -0.14 STANDARD DEV= 1.63
Version-4
AM/PM Average
GLOBAL MEAN= -0.28 STANDARD DEV= 1.54
Version-5 ECMWF
AM/PM Average
GLOBAL MEAN= -0.16 STANDARD DEV= 1.64
Version-4 ECMWF
AM/PM Average
GLOBAL MEAN= -0.23 STANDARD DEV= 1.61
90 N
60 N
30 N
EQ
30 S
60 S
90 S
180
120 W
60 W
0
60 E
120 E
180
-9.50
-6.50
-3.50
-0.50
1.50
4.50
7.50
10.50

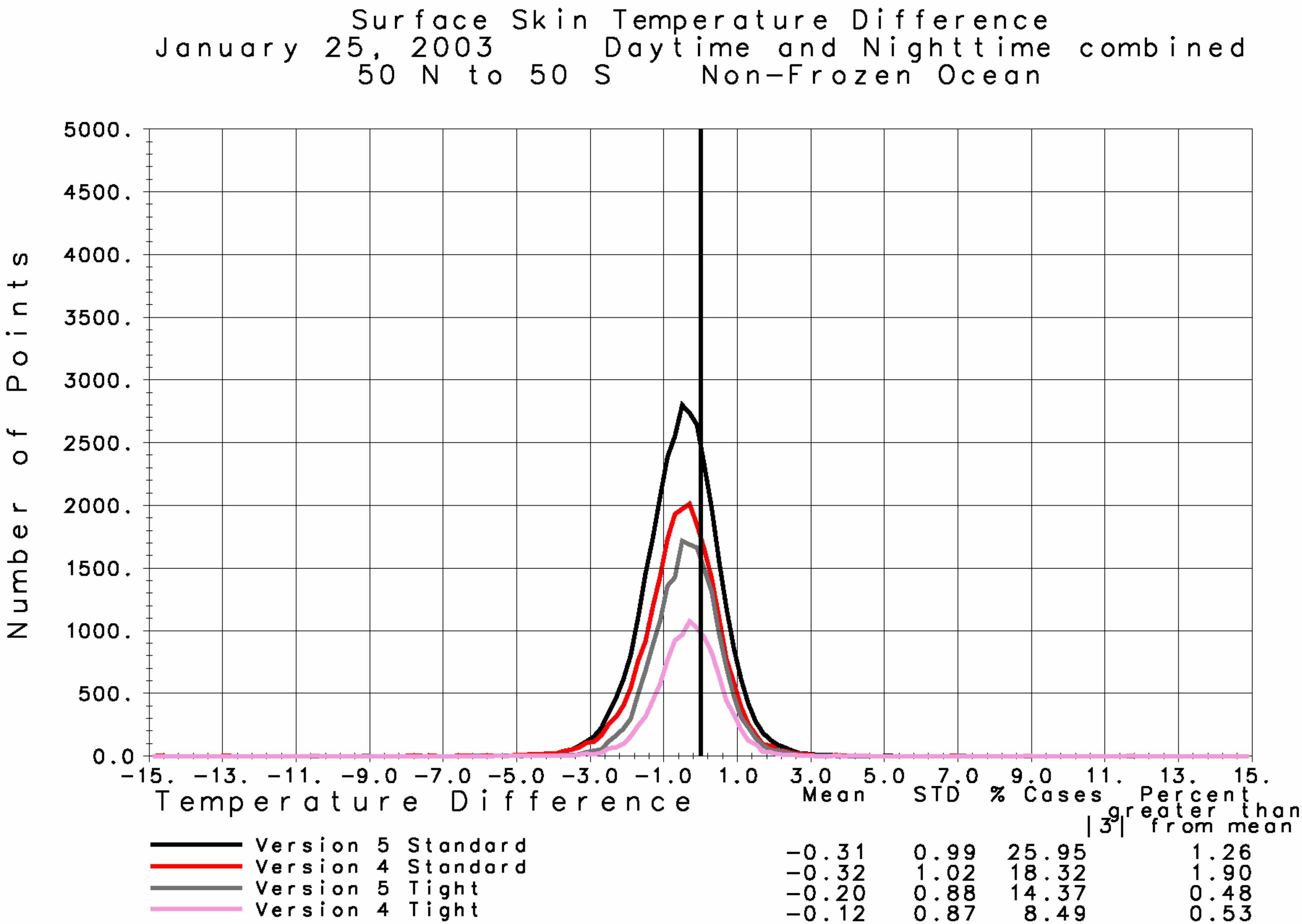
700 mb Temperature (K)
QC = 0 and 1

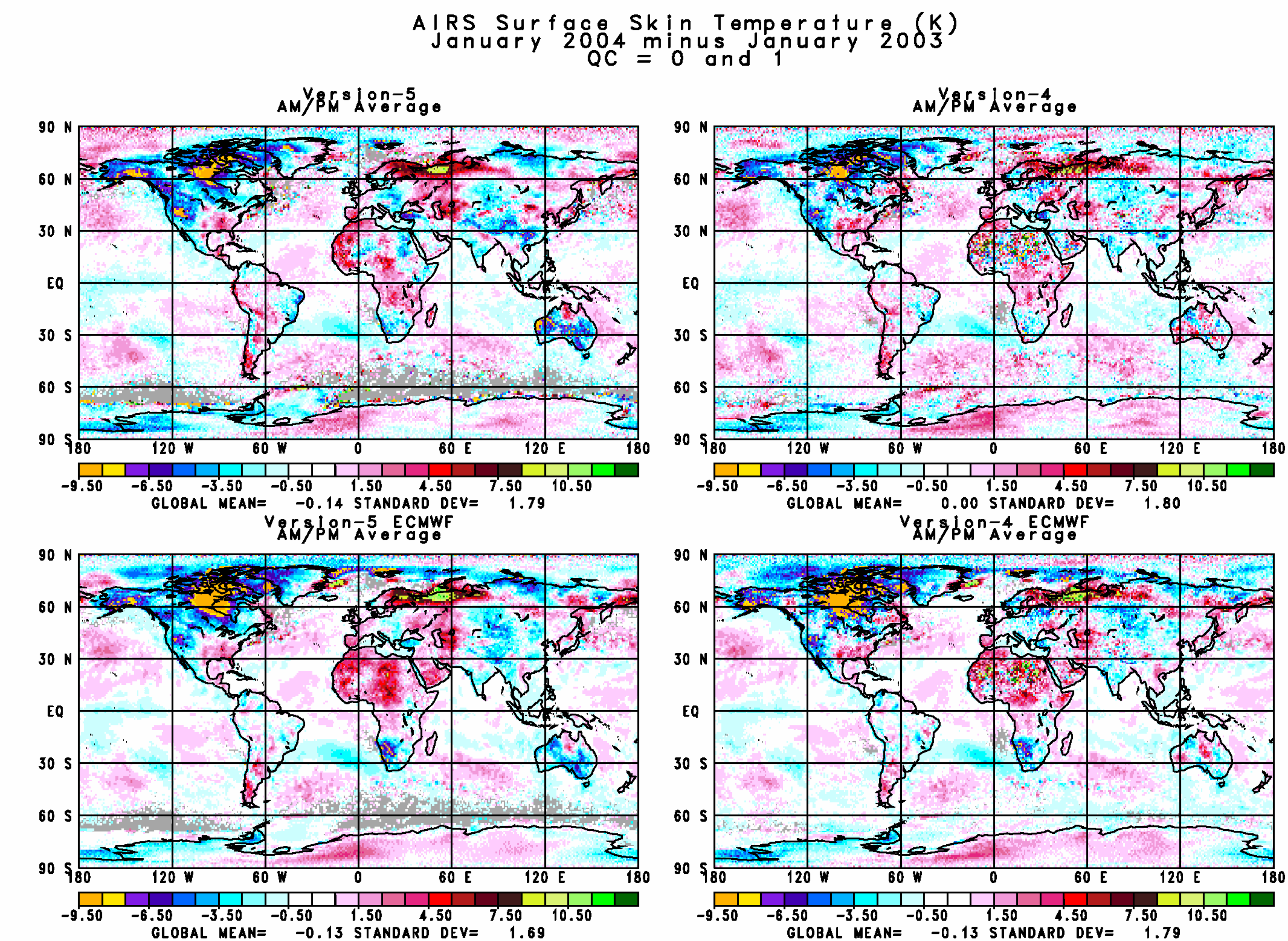



TEMPERATURE (°C)
Global Mean
January 2004 Monthly Mean
Retrieved minus Colocated ECMWF
PRESSURE (mb)
70.
100.
150.
200.
300.
400.
500.
600.
700.
850.
-1. -.8 -.6 -.4 -.2 0 .2 .4 .6 .8 1
Global Mean
V5.0
V4.0

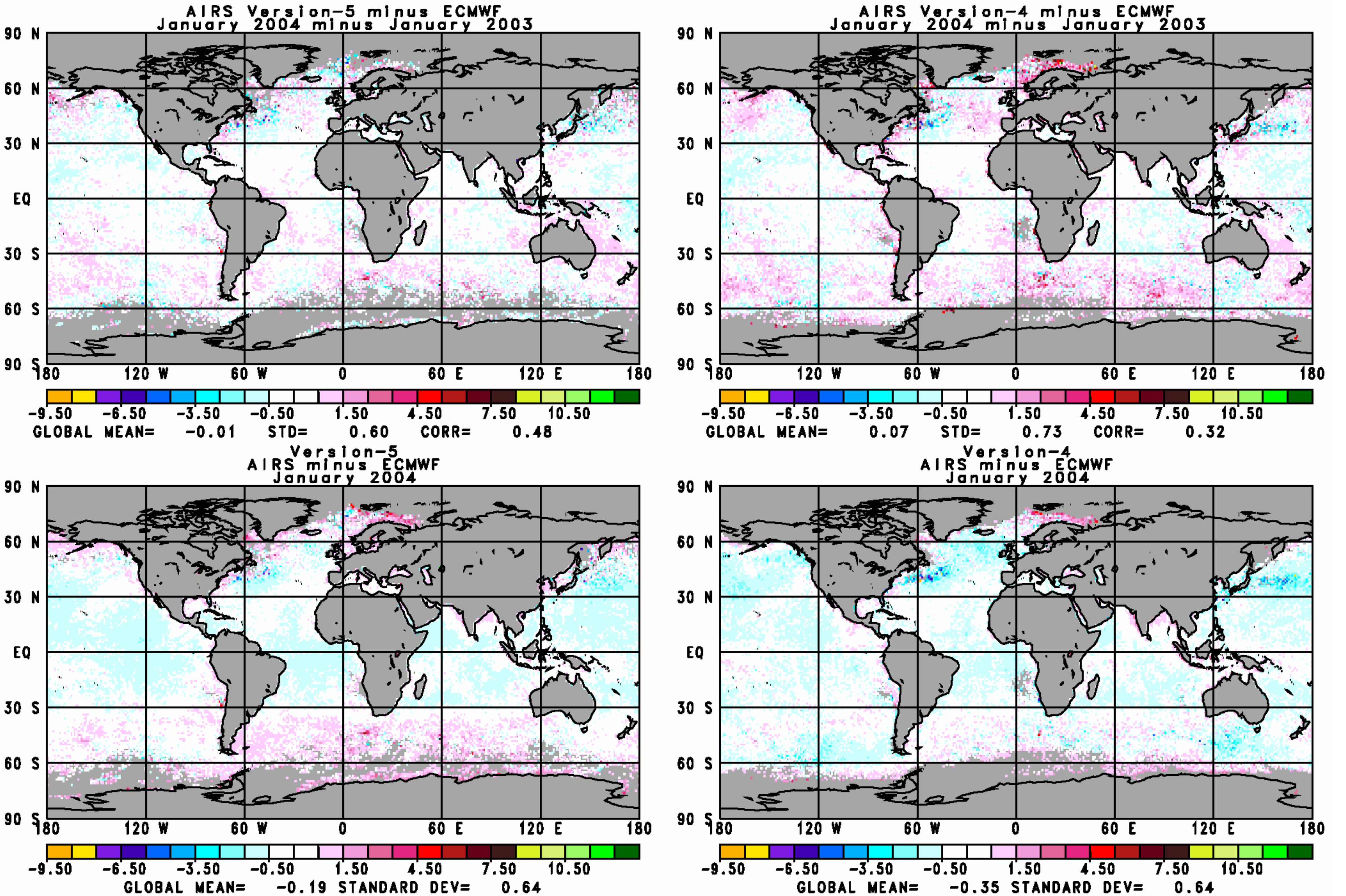

Interannual Temperature Difference (°C)
Global Mean
January 2004 minus January 2003
PRESSURE (mb)
70.
100.
150.
200.
300.
400.
500.
600.
700.
850.
-1. -.8 -.6 -.4 -.2 0 .2 .4 .6 .8 1
Global Mean
V5.0
V4.0
V5.0 ECMWF
V4.0 ECMWF


Surface Skin Temperature (K)
Retrieved minus ECMWF
January 25, 2003
(a)
All IR SST Errors
90 N
60 N
30 N
EQ
30 S
60 S
90 S
180
120 W
60 W
0
60 E
120 E
180
-9.50 -6.50 -3.50 -0.50 1.50 4.50 7.50 10.50
GLOBAL MEAN= -1.61 STANDARD DEV= 4.46
(b)
Predicted SST Errors
0 1 2 3 4 5 6 7 8 9
GLOBAL MEAN= 2.46 STANDARD DEV= 2.08
(c)
Error when Predicted Error le 1.0
GLOBAL MEAN= 0.03 STANDARD DEV= 0.84
(d)
Predicted SST Error minus Absolute value SST Error
GLOBAL MEAN= -0.22 STD= 2.64 CORR= 0.76


Surface Skin Temperature Difference
January 25, 2003 Daytime and Nighttime combined
50 N to 50 S Non-Frozen Ocean
Number of Points
5000.
4500.
4000.
3500.
3000.
2500.
2000.
1500.
1000.
500.
0.0
-15. -13. -11. -9.0 -7.0 -5.0 -3.0 -1.0 1.0 3.0 5.0 7.0 9.0 11. 13. 15.
Temperature Difference
Version 5 Standard
Version 4 Standard
Version 5 Tight
Version 4 Tight
Mean STD % Cases Percent greater than |3| from mean
-0.31 0.99 25.95 1.26
-0.32 1.02 18.32 1.90
-0.20 0.88 14.37 0.48
-0.12 0.87 8.49 0.53


AIRS Surface Skin Temperature (K)
January 2004 minus January 2003
QC = 0 and 1
Version-5
AM/PM Average
GLOBAL MEAN= -0.14 STANDARD DEV= 1.79
Version-4
AM/PM Average
GLOBAL MEAN= 0.00 STANDARD DEV= 1.80
Version-5 ECMWF
AM/PM Average
GLOBAL MEAN= -0.13 STANDARD DEV= 1.69
Version-4 ECMWF
AM/PM Average
GLOBAL MEAN= -0.13 STANDARD DEV= 1.79
90 N
60 N
30 N
EQ
30 S
60 S
90 S
180
120 W
60 W
0
60 E
120 E
180
-9.50
-6.50
-3.50
-0.50
1.50
4.50
7.50
10.50

Sea Surface Temperature (K)
QC = 0 and 1



Clear Column Radiances Error Estimates $\delta\hat{R}_i$

$$\hat{R}_i = \bar{R}_i + \sum_{j=1}^{9} \eta_j \left(R_{i,j} - \bar{R}_i \right)$$

If all η_j were perfect

$$\delta\hat{R}_i^{per} = \left[\left(\sum_{j=1}^{9} \frac{1}{9} \cdot \left(1 + \sum_{j=1}^{9} \eta_j{}' \right) - \eta_j \right)^2 \right]^{1/2} NE\Delta N_i = A \ NE\Delta N_i \approx \sum_{j=1}^{9} \left[\eta_j^2 \right]^{1/2} NE\Delta N_i$$

A is the channel noise amplification factor

Larger η's (more cloud clearing) results in more channel noise in $\hat{R}_i$

If channel i does not see clouds, we set all $\eta_j = 0$ $A = 1/3$ (noise reduction)

Errors in η_j will result in additional errors in $\hat{R}_i$, which are correlated from channel to channel

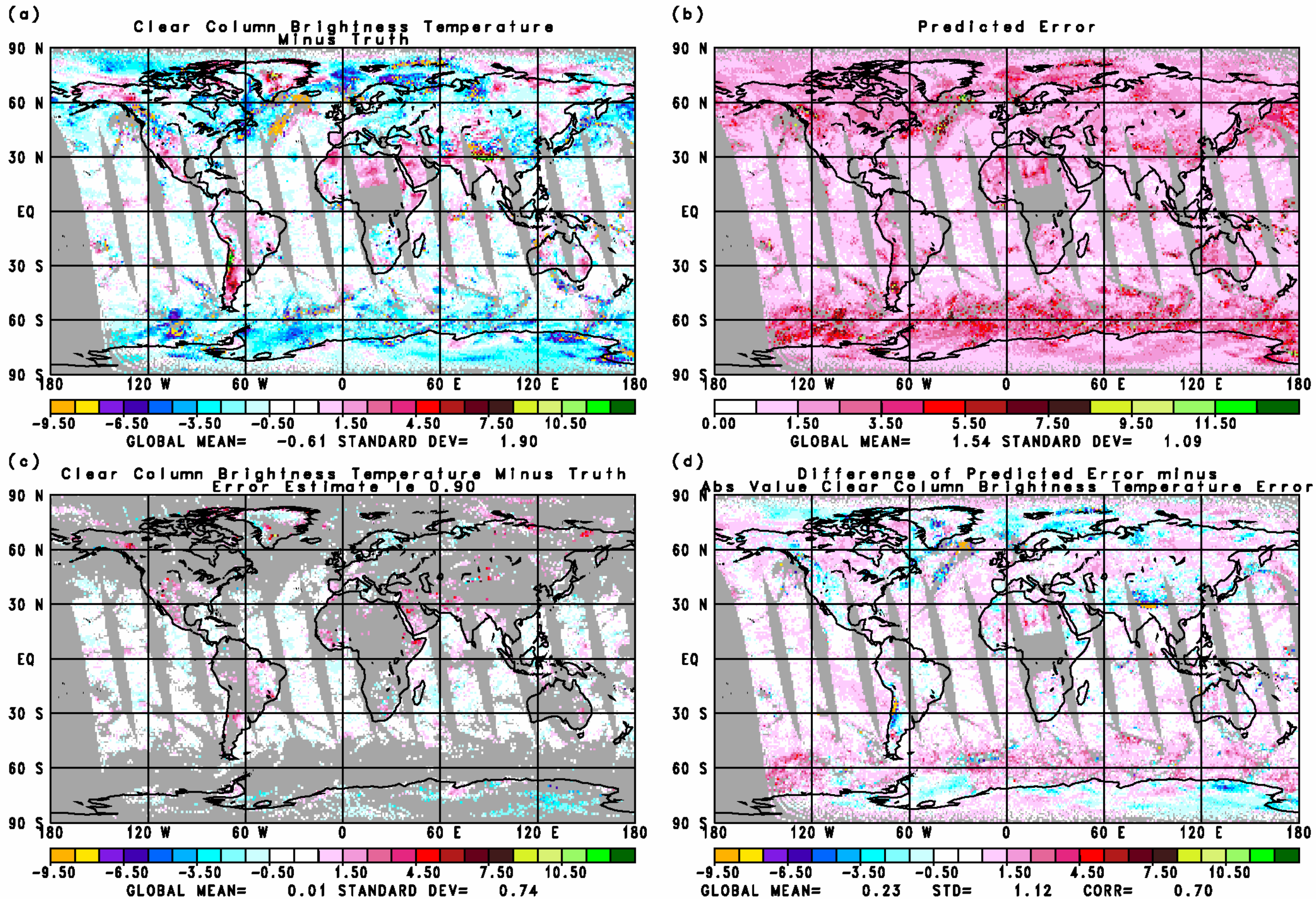
We set $\delta\hat{R}_i = \left(A \ NE\Delta N_i \right) + \left[\left(\sum_{k=1}^{6} \hat{M}_{i,k} \, \delta T(p_k) \right) \right] + \hat{M}_{i,7} \left[\delta W_{tot} / W_{tot} \right]$

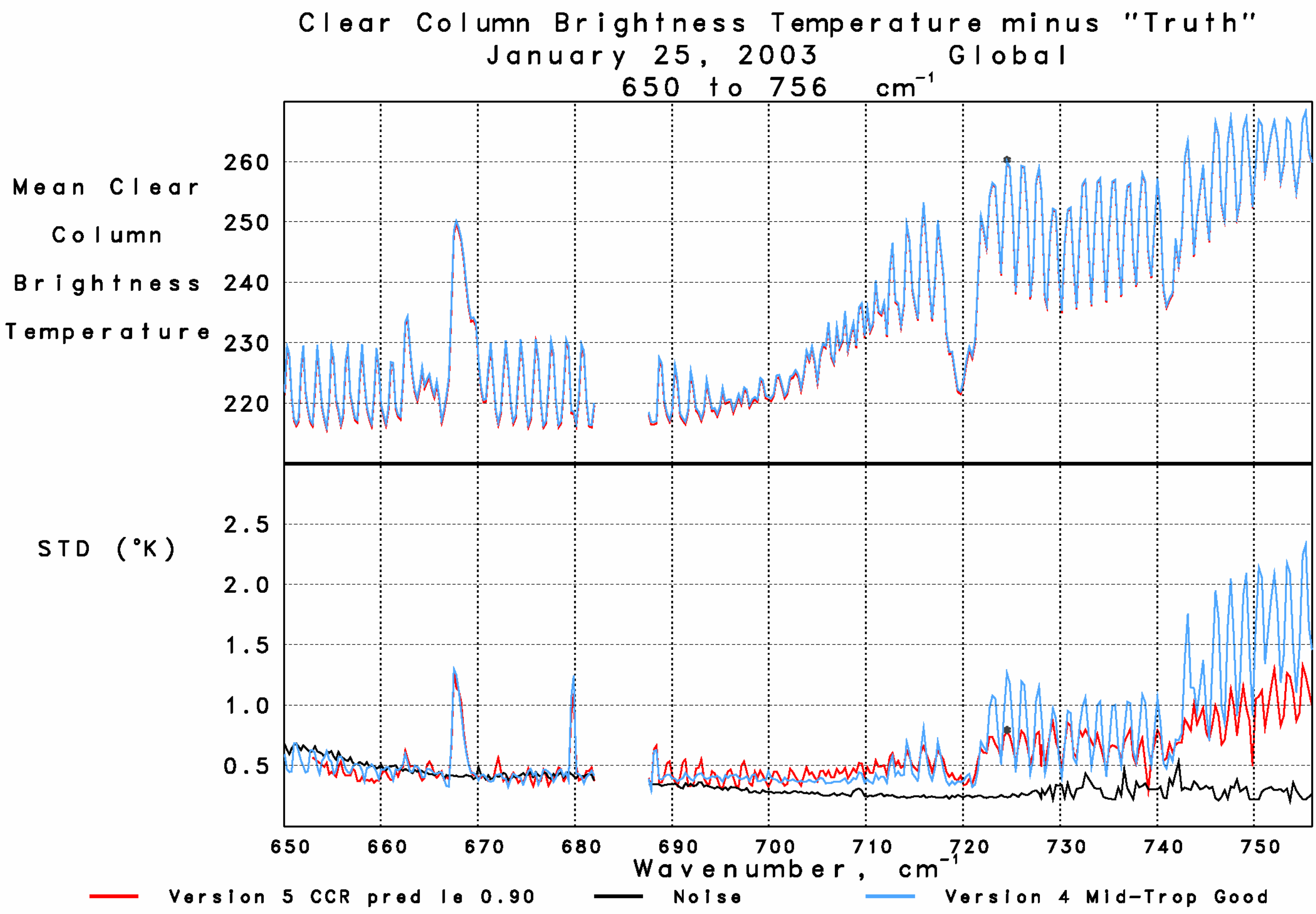
Where $\delta T(p_k)$ is the error estimate for $T(p_k)$ and $\delta W_{tot} / W_{tot}$ is the fractional error estimate for W_{tot}

Coefficients of $\hat{M}$ are generated analogously to coefficients of M

Use $R_{i,CLR}$ computed from ECMWF as $\hat{R}_i^{truth}$

Clear Column Brightness Temperature (K)
724.52 cm^{-1} Channel
January 25, 2003





Clear Column Brightness Temperature minus "Truth"
January 25, 2003 Global
650 to 756 cm-1
Mean Clear
Column
Brightness
Temperature
260
250
240
230
220
STD (°K)
2.5
2.0
1.5
1.0
0.5
650
660
670
680
690
700
710
720
730
740
750
Wavenumber, cm-1
Version 5 CCR pred le 0.90
Noise
Version 4 Mid-Trop Good

Forecast Impact Test

Experiments run with GSFC GOES-5 data assimilation system

Forecasts run at 1° x 1° resolution

Analysis using NCEP GSI analysis at 1° x 1° resolution

Data period covers January 1, 2003 - January 31, 2003

Control uses all data NCEP used operationally at that time

Assimilates all satellite data but AIRS, including Aqua AMSU radiances

Control + AIRS adds V5.0 global quality controlled T(p) retrievals

Assimilated as if radiosonde data

$\delta T(p)$ is used as the measurement error

27 independent forecasts run from each analysis

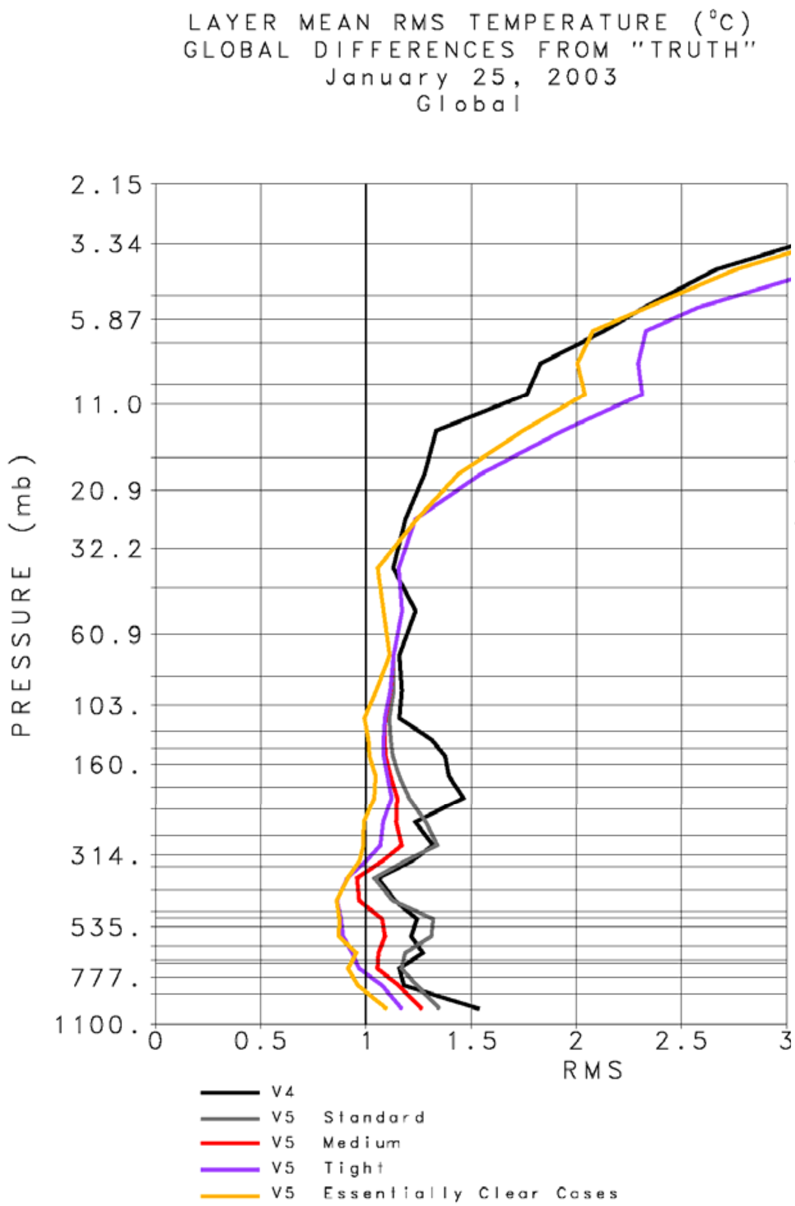
Forecasts verified against NCEP analysis

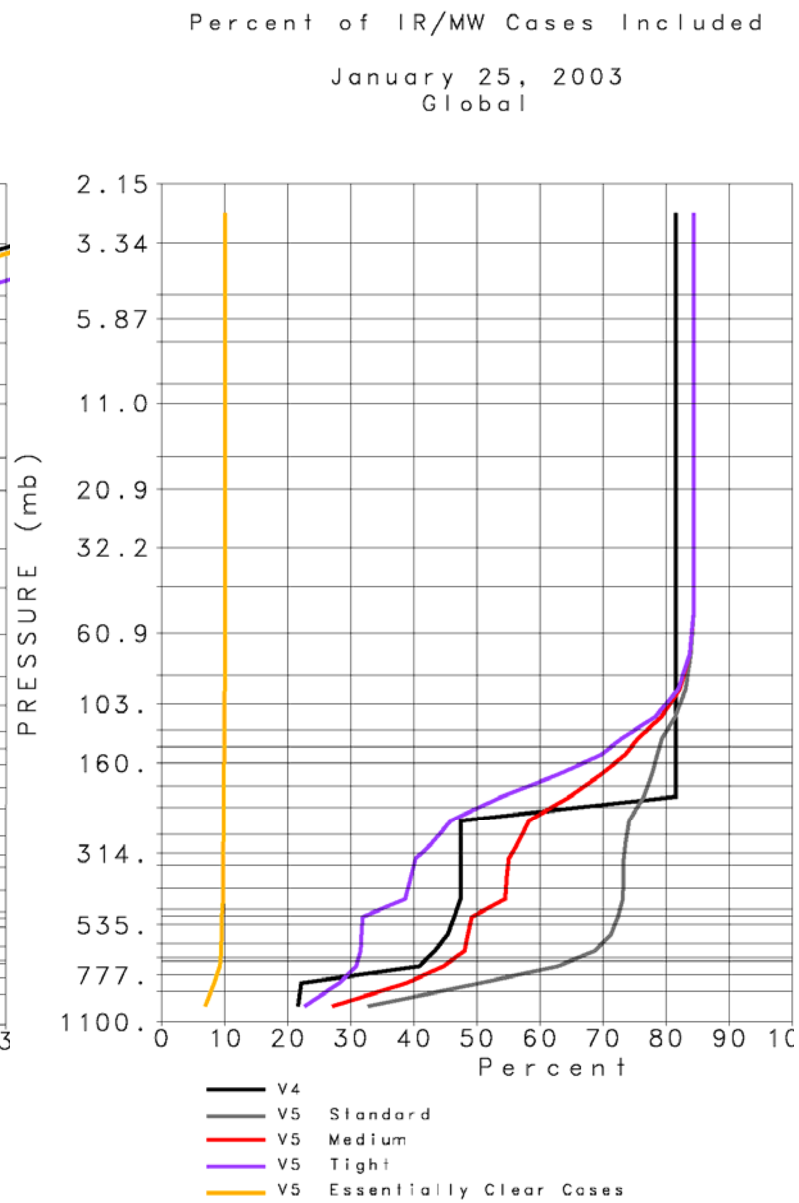
Experiment 1: Assessment of Trade-Off of Spatial Coverage and Overall Accuracy

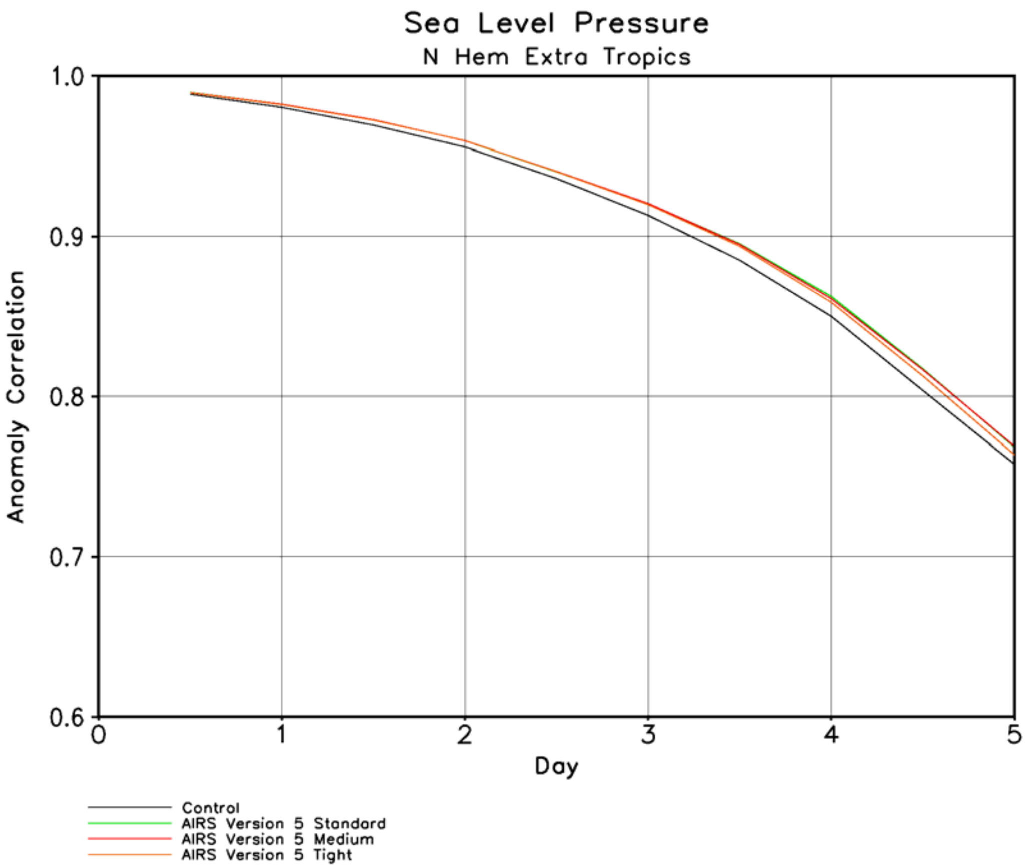
We compared forecasts from four assimilations

1a	Control
1b	AIRS V5 Standard QC
1c	AIRS V5 Medium QC
1d	AIRS V5 Tight QC

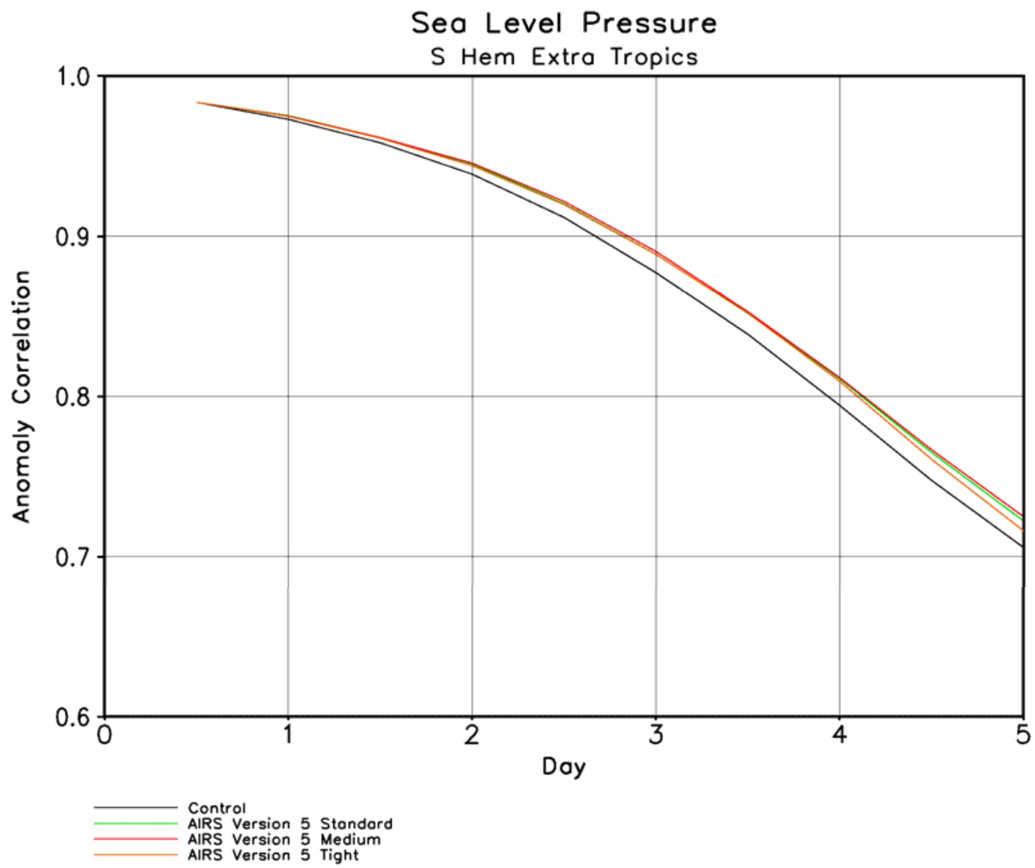
Data assimilated in all three AIRS experiments is identical, except for computation of p_g


LAYER MEAN RMS TEMPERATURE (°C)
GLOBAL DIFFERENCES FROM "TRUTH"
January 25, 2003
Global
PRESSURE (mb)
2.15
3.34
5.87
11.0
20.9
32.2
60.9
103.
160.
314.
535.
777.
1100.
0
0.5
1
1.5
2
2.5
3
RMS
V4
V5 Standard
V5 Medium
V5 Tight
V5 Essentially Clear Cases


Percent of IR/MW Cases Included
January 25, 2003
Global
PRESSURE (mb)
2.15
3.34
5.87
11.0
20.9
32.2
60.9
103.
160.
314.
535.
777.
1100.
0
10
20
30
40
50
60
70
80
90
Percent
V4
V5 Standard
V5 Medium
V5 Tight
V5 Essentially Clear Cases



Sea Level Pressure
N Hem Extra Tropics
1.0
0.9
0.8
0.7
0.6
Anomaly Correlation
0
1
2
3
4
5
Day
Control
AIRS Version 5 Standard
AIRS Version 5 Medium
AIRS Version 5 Tight



Sea Level Pressure
S Hem Extra Tropics
1.0
0.9
0.8
0.7
0.6
Anomaly Correlation
0
1
2
3
4
5
Day
Control
AIRS Version 5 Standard
AIRS Version 5 Medium
AIRS Version 5 Tight

Findings of Experiment 1

All three AIRS data assimilation experiments improved forecast skill significantly compared to the control

Northern hemisphere extra-tropics improvement in 5 day forecast skill

    3 hours for Tight QC, 5 hours for Medium QC and Standard QC

Southern hemisphere extra-tropics improvement in 5 day forecast skill

    4 hours for Tight QC, 6 hours for Medium QC and Standard QC

Medium QC performed slightly better than Standard QC, which was optimized for climate

Tight QC lost substantial impact as a result of reduced spatial coverage

We are performing more experiments to find optimal trade of accuracy and coverage for data assimilation

Experiment 2: Test of The Importance of Assimilation of Tropospheric Temperatures

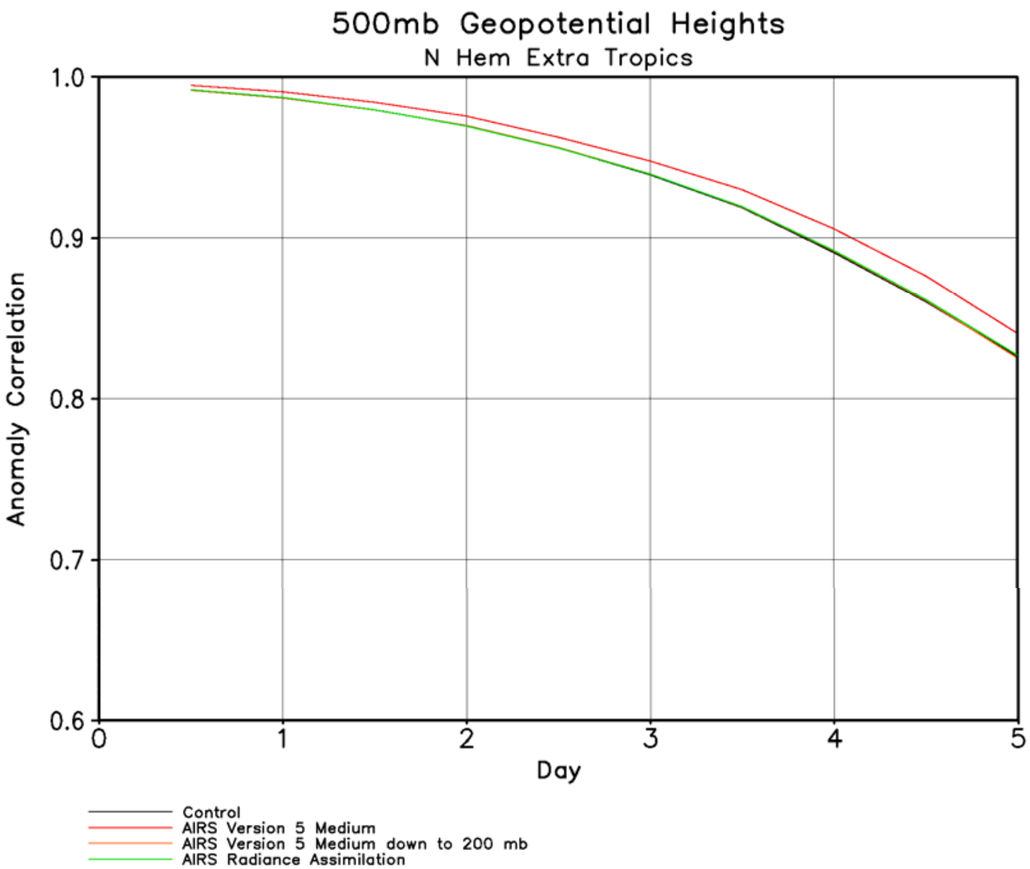
Motivation

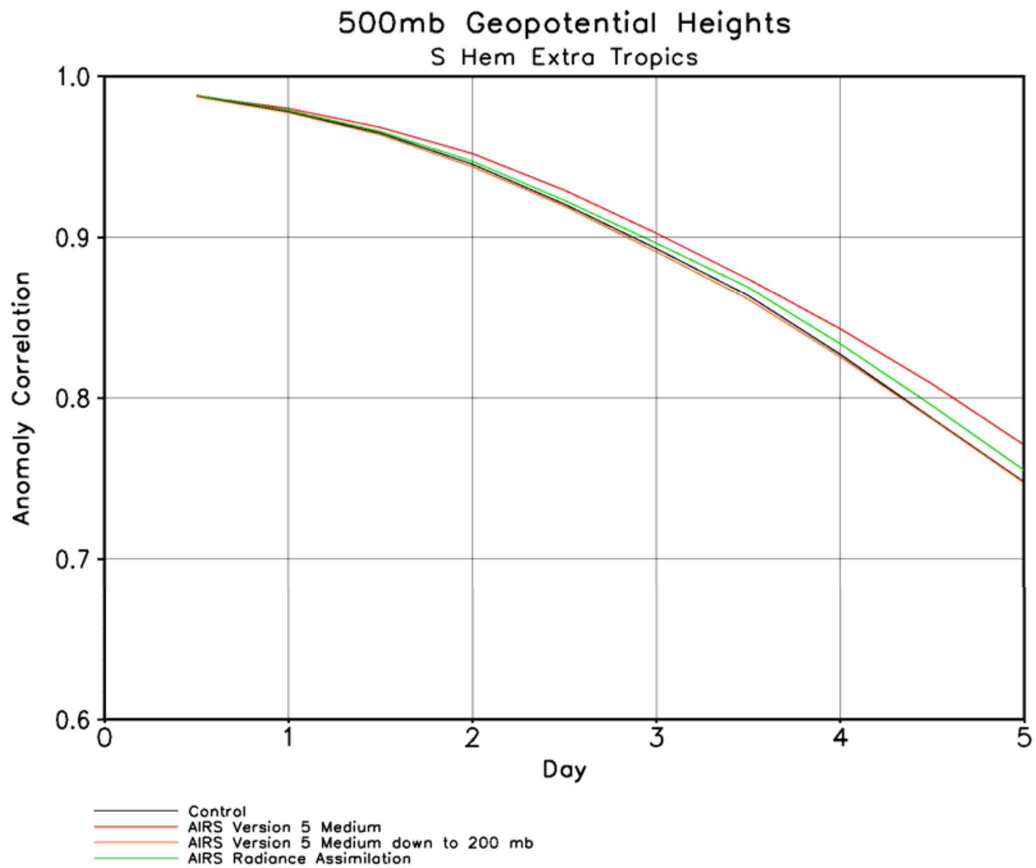
Tony McNally at ECMWF stated that most of the impact of AIRS radiances on ECMWF analysis comes from 15μm stratospheric sounding channels-claims only stratospheric information is important

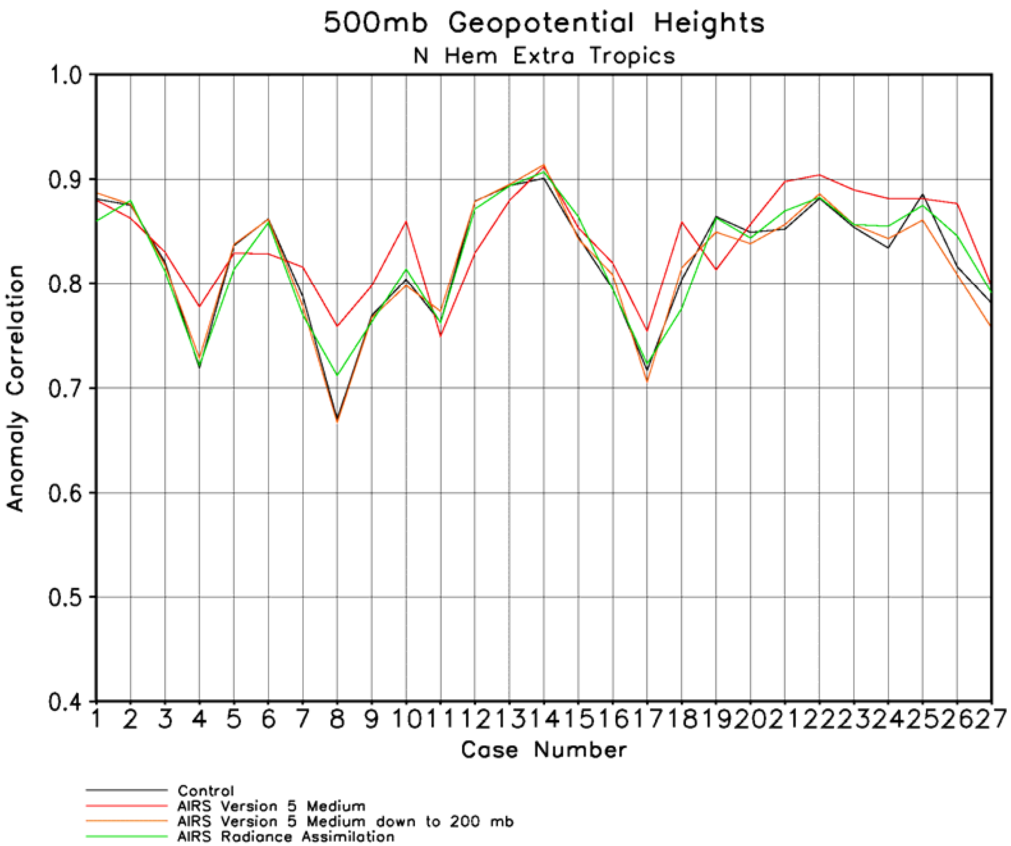
We compared forecasts from four assimilations

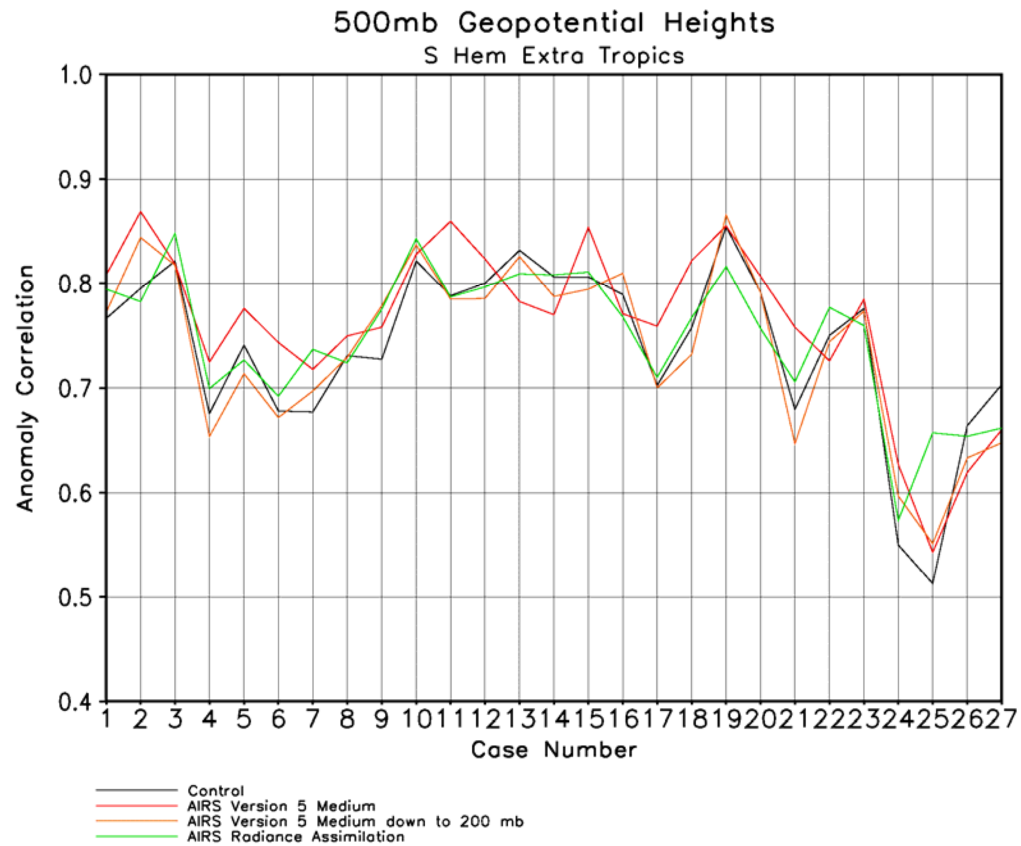
2a	Control – same as 1a
2b	AIRS V5 Medium QC – same as 1c
2c	AIRS V5 Medium QC but only down to 200 mb
2d	AIRS radiance assimilation – uses primarily stratospheric AIRS radiance information

Data assimilated in all three AIRS experiments is identical, except for computation of p_g


500mb Geopotential Heights
N Hem Extra Tropics
Anomaly Correlation
Day
Control
AIRS Version 5 Medium
AIRS Version 5 Medium down to 200 mb
AIRS Radiance Assimilation


500mb Geopotential Heights
S Hem Extra Tropics
Anomaly Correlation
Day
Control
AIRS Version 5 Medium
AIRS Version 5 Medium down to 200 mb
AIRS Radiance Assimilation


500mb Geopotential Heights
N Hem Extra Tropics
Anomaly Correlation
Case Number
Control
AIRS Version 5 Medium
AIRS Version 5 Medium down to 200 mb
AIRS Radiance Assimilation


500mb Geopotential Heights
S Hem Extra Tropics
Anomaly Correlation
Case Number
Control
AIRS Version 5 Medium
AIRS Version 5 Medium down to 200 mb
AIRS Radiance Assimilation

Findings of Experiment 2

Assimilation of AIRS temperature soundings only down to 200 mb (2c) produced no forecast impact

Most important information is coming from tropospheric temperatures in partial cloud cover

Assimilation of AIRS radiances unaffected by clouds (2d) was only slightly better than (2c)

AIRS cloud free radiances contain some tropospheric information - but is sub-optimal

Assimilation of AIRS radiances should perform better if

1) Use $\hat{R}_i$, together with error estimates

2) Do not use water vapor or ozone channels (Joanna Joiner wrote a paper on this)

Assimilation of these radiances makes problem highly non-linear

Positive impacts shown when we assimilated only AIRS T(p)

3) Make better use of AIRS 4.2 μm channels - day and night

- Perform surface parameter retrieval step before assimilation step to obtain $T_s, \varepsilon_i, \rho_i$

Allows for use of lower tropospheric sounding 4.2 μm channels

- Install new RTA that accounts for non-LTE so all 4.2 μm channels can be used

We will try experiments doing 1) and 2) in the near future

Some Planned Improvements for Version 6

Improved retrieval of ε_i, ρ_i - especially over land

Will result in better yield and higher accuracy of lower tropospheric T(p)

Higher spatial resolution retrievals

Version 5 produces 1 AIRS retrieval per 3x3 array of AIRS footprints

45 km x 45 km at nadir   150 km x 80 km at end of scan

Version 6 will produce 1 AIRS retrieval per 1 (cross track) x 3 (along track) AIRS footprints

15 km x 45 km at nadir   50 km x 80 km at end of scan

Should help retrievals, especially over land (less surface variability in FOR)

Provide stratospheric temperature soundings in overcast conditions

Possibly down to cloud level

Optimize quality flags separately for climate and data assimilation purposes

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