Satellite data assimilation at NCEP

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Data Assimilation Context

- Data assimilation attempts to bring together all available information to make the best possible estimate of:
  - The atmospheric state
  - The initial conditions to a model which will produce the best forecast.

Data Assimilation Context

- Information sources
  - Observations
  - Background (forecast)
  - Dynamics (e.g., balances between variables)
  - Physical constraints (e.g., $q > 0$)
  - Statistics
  - Climatology

Data Assimilation Context

- Must build data assimilation system within context of :
  - Observing system
  - Data handling system
  - Forecast model
  - Computational resources
  - Available knowledge about observations and statistics
  - Human resources
  - Verification and monitoring system

Atmospheric analysis problem (theoretical)

$$J = J_b + J_o + J_c$$

$$J = (x-x_b)^T B_x^{-1}(x-x_b) + (K(x)-O)^T(E+F)^{-1}(K(x)-O) + J_C$$

J = Fit to background + Fit to observations + constraints

- x = **Analysis**
- x_b = **Background**
- B_x = **Background error covariance**
- K = **Forward model (nonlinear)**
- O = **Observations**
- $E+F = R$ = **Instrument error + Representativeness error**
- J_C = **Constraint term**

Basic Assumptions (violated)

- Data (forecast and most observations) are unbiased
  - Radiosonde and others commonly biased
  - All forecast models have significant biases.
  - Satellite observations biased - but corrected.
- Observational errors normally distributed
  - Moisture errors not normally distributed because moisture cannot be < 0 or >> saturation.
- Background error uncorrelated to observational errors
  - May be true if not using retrievals
  - Representativeness error likely correlated

Solution Algorithm

- Solve series of simpler problems with some nonlinear components eliminated
- Outer iteration, inner iteration structure
- Outer iteration
  - QC
  - More complete forward model
- Inner iteration
  - Preconditioned conjugate gradient
  - Often simpler forward model
  - Variational QC
  - Solution used to start next outer iteration
  - Possibly lower resolution

Atmospheric analysis problem (Practical) Outer (K) and Inner (L) iteration operators

Variable	*K* operator	L operator
Temperature – surface obs. at 2m	3-D sigma interpolation adjustment to different orography	3-D sigma interpolation Below bottom sigma assumed at bottom sigma
Wind – surface obs. at 10m over land, 20m over ocean, except scatt.	3-D sigma interpolation reduction below bottom level using model factor	3-D sigma interpolation reduction below bottom level using model factor
Ozone – used as layers	Integrated layers from forecast model	Integrated layers from forecast model
Surface pressure	2-D interpolation plus orography correction	2-D interpolation
Precipitation	Full model physics	Linearized model physics
Radiances	Full radiative transfer	Linearized radiative transfer

Data Assimilation Context

- Over 1.43B observations received per day (most satellite data – global system does not include radar radial winds).
- Over 7M observations per day used.
- Data selection and quality control eliminate many observations
- Data selection applied because of:
  - redundancy in data
  - reduction in computational cost
  - eliminate non-useful observations

Operational context

- Forecasts must complete within schedule
  - Trade-offs
    - More accurate formulation – higher resolution
    - Improved model – improved analysis
    - Enhanced physics – higher resolution
    - Etc.
- Must work everywhere – all the time
- Manual intervention should be minimal
- Both operational and research satellites used in systems
  - Geostationary and polar platforms

Satellite data

- Only the obs. term $(K(x)-O)^T(E+F)^{-1}(K(x)-O)$, directly involved in use of satellite data (and other observations).
- However, impact of the data is greatly impacted by other observation terms and background term
- This talk will concentrate on the satellite part of the observation term

Satellite data context

- One of the biggest data assimilation developments in the last 15 years was allowing the observations to be different from the analysis variables
  - In variational schemes this is done through the *K* operator
  - In OI, the same thing could be done – but was only rarely done.
  - The development allows us to use the observations as they were observed AND allows the use of analysis variables with nice properties.

Satellite data

- Satellite data differ from many conventional data in that the observations are often indirect observations of meteorological parameters
  - If x is the vector of meteorological parameters we are interested in and
  - y is the observation,
  - then $y = K(x,z)$,
    - where z represents other parameters on which the observations is dependent
    - K is the physical relationship between x, z and y

Satellite data

- Example –
  - y are radiance observations,
  - x are profiles of temperature, moisture and ozone.
  - *K* is the radiative transfer equation and
  - z are unknown parameters such as the surface emissivity (dependent on soil type, soil moisture, etc.), CO2 profile, methane profile, etc.
- In general, *K* is not invertable – thus retrievals.
  - Physical retrievals – usually very similar to 1D variational problems (with different background fields)
  - Statistical retrievals – given y predict x using regression

Satellite data context

- 3-4 D variational analysis can be thought of as a generalization of “physical retrieval” to include all types of data and spatial and temporal variability.
- To use data in 2 steps – retrieval and then analysis-- can be done consistently if K is linear and if one is very careful – but is generally suboptimal.

Satellite data context

- Key to using data is to have good characterization of *K* – forward model.
- If unknowns in *K*(x,z) – either in formulation of *K* or in unknown variables (z) are too large data cannot be reliably used and must be removed in quality control.
  - example, currently we do not use radiances containing cloud signal
- Note that errors in formulation or unknown variables generally produce correlated errors. This is a significant source of difficulty.

Satellite data context

- Additional advantages of using observations directly in analysis system
  - easier definition of observation errors
  - improved quality control
  - less introduction of auxiliary information
  - improved data monitoring

Satellite data assimilation

- Satellite observations currently used
  - Atmospheric wind vectors
    - Geostationary
    - MODIS, TERRA
  - SSM/I surface wind speeds
  - Scatterometers
  - GPS radio-occultation
  - SSM/I and TRMM precip. estimates
  - SBUV ozone profiles
  - Radiances

Satellite data assimilation

- **Satellite observations**
  - **Radiances**
    - **AMSU-A (N-15,16,18,METOP,EOS-AQUA)**
    - **AMSU-B/MHS(N-15,16,17,18,METOP)**
    - **HIRS(N-16,17,18,METOP)**
    - **AIRS(EOS-AQUA)**
    - **SSM/I – SSM/IS**
    - **GOES Sounder (1x1- 4 detectors, G-11, G-12)**
    - **Imagers (AVHRR,GOES, METEOSAT, etc.)**

Satellite data requirements

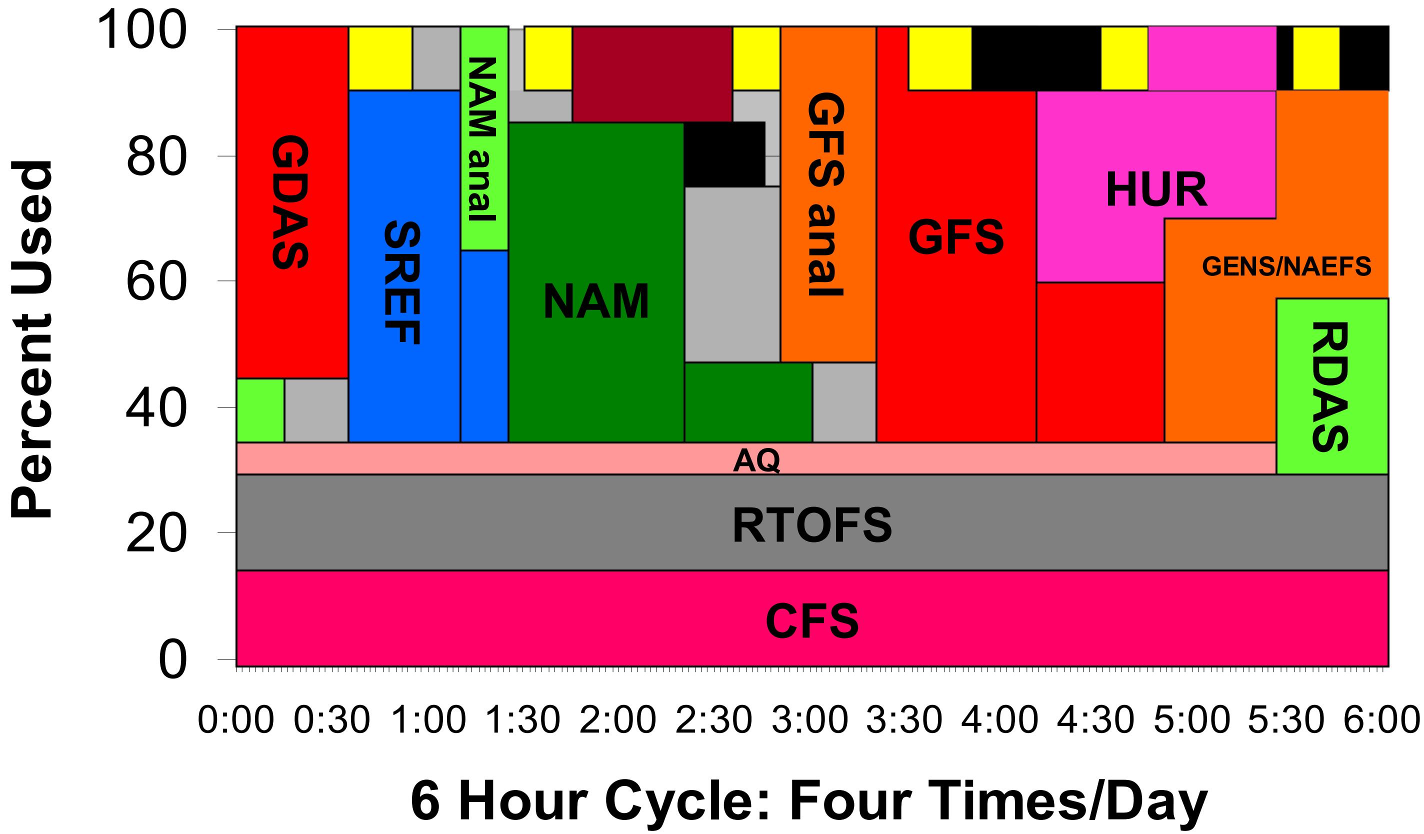
- Requirements for operational use of observations
  - Available in real time in acceptable format
  - Data files need to contain all necessary information
  - Assurance of stable data source
  - Accurate forward model (and adjoint) available
  - Quality control procedures defined (conservative)
  - Observational errors defined (and bias removed if necessary)
  - Integration into data monitoring
  - Evaluation and testing to ensure neutral/positive impact

Data available in real time in acceptable format

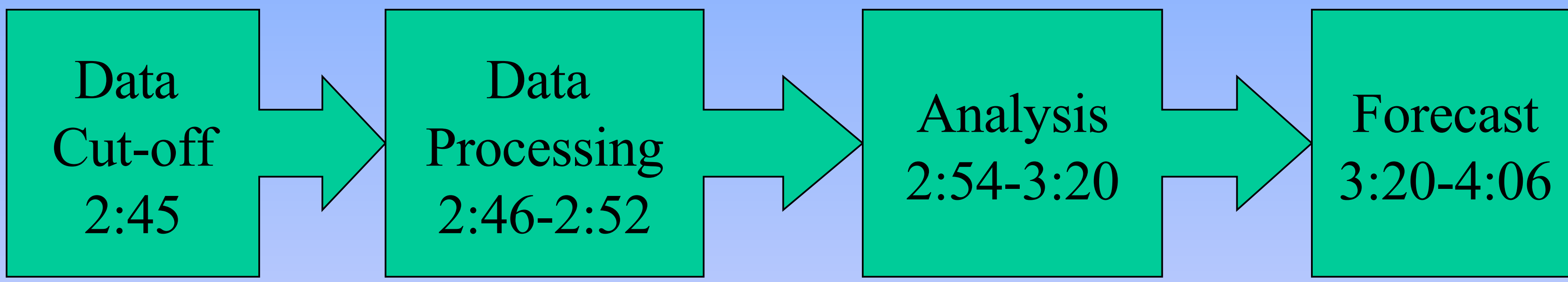
- Data formats
  - WMO acceptable formats – BUFR – CREX (not really relevent) – used by most NWP centers
  - Almost every satellite program uses a different format
  - Significant time and resources used understanding/converting/developing formats
- If data is not available in time for use in data assimilation system – not useful

NCEP Production Suite
Weather, Ocean, Land & Climate Forecast Systems

Current - 2007

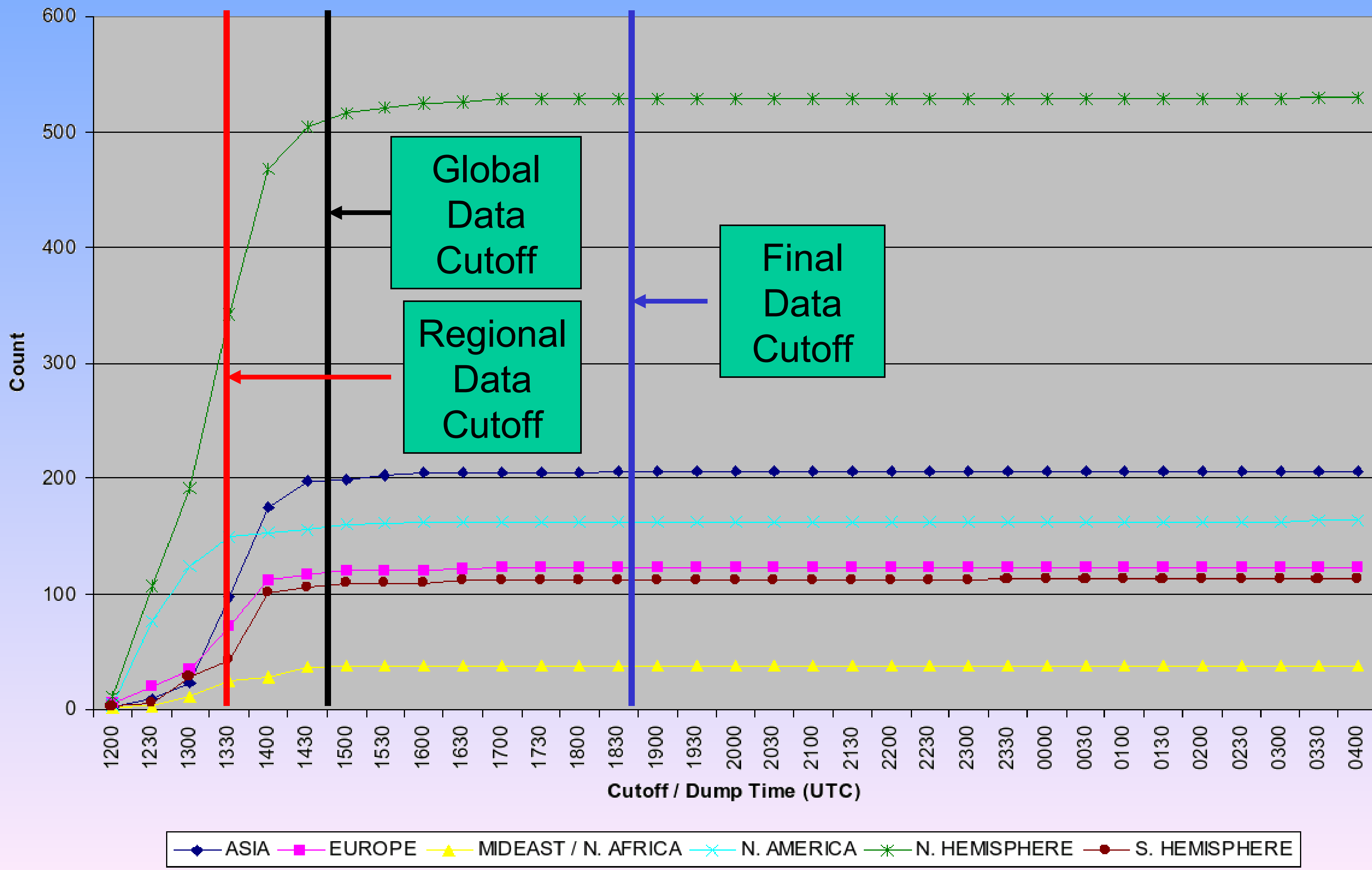


Analysis/forecast cycle

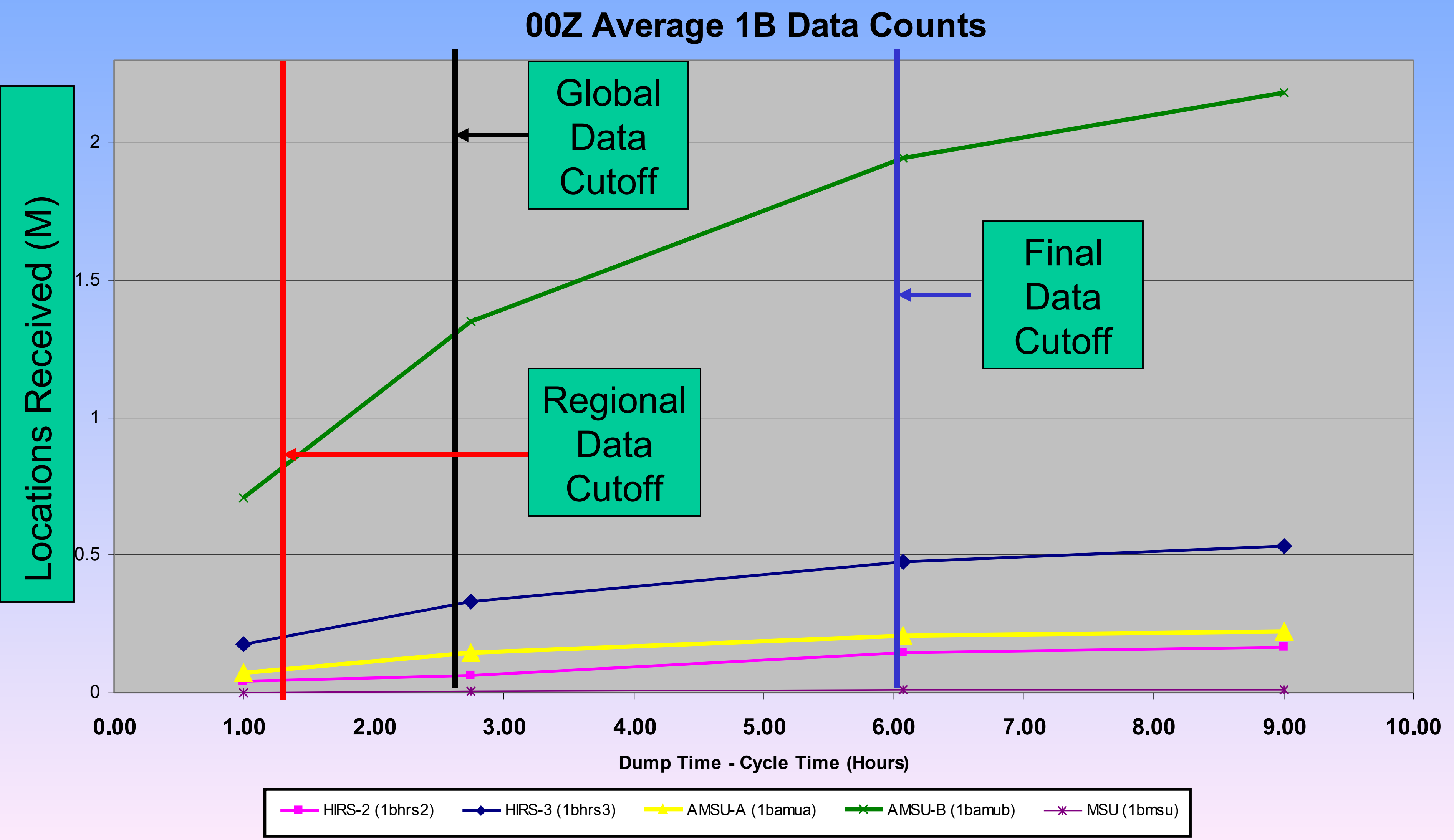


- Any data not available by cut-off will not be used
- Later catch up cycle at +6:00

Rawinsonde Delivery

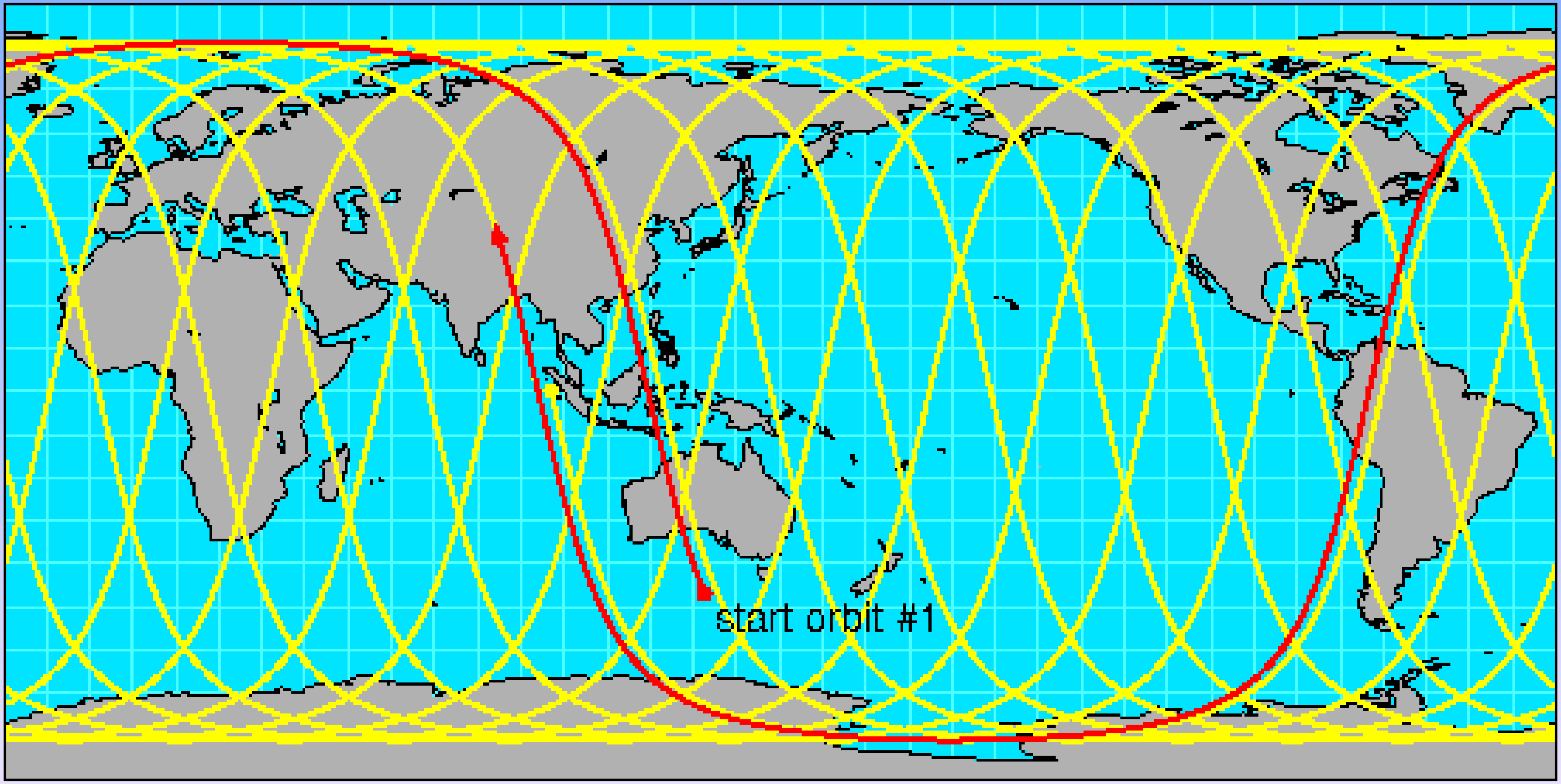


POES Data Delivery

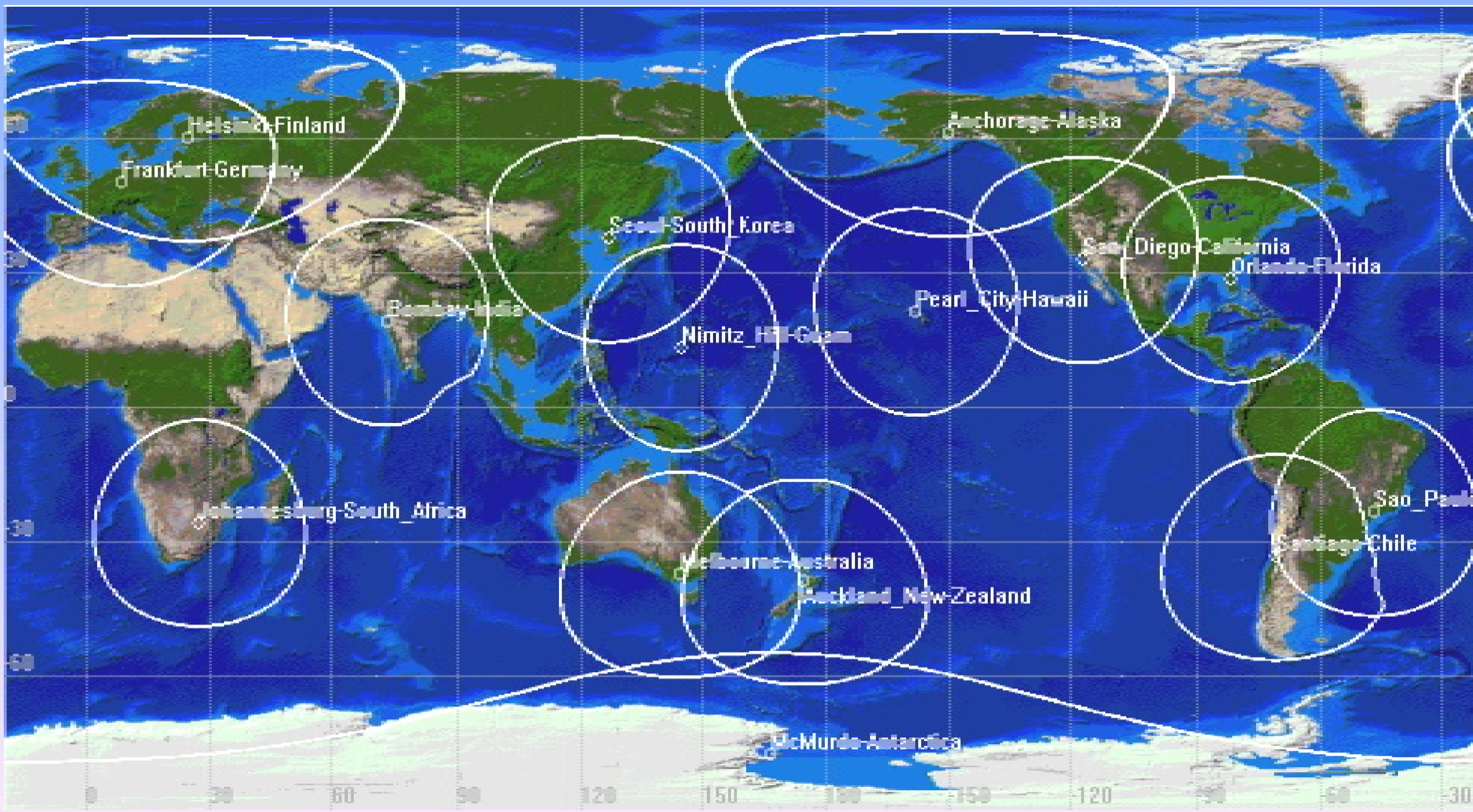


Satellite data delivery

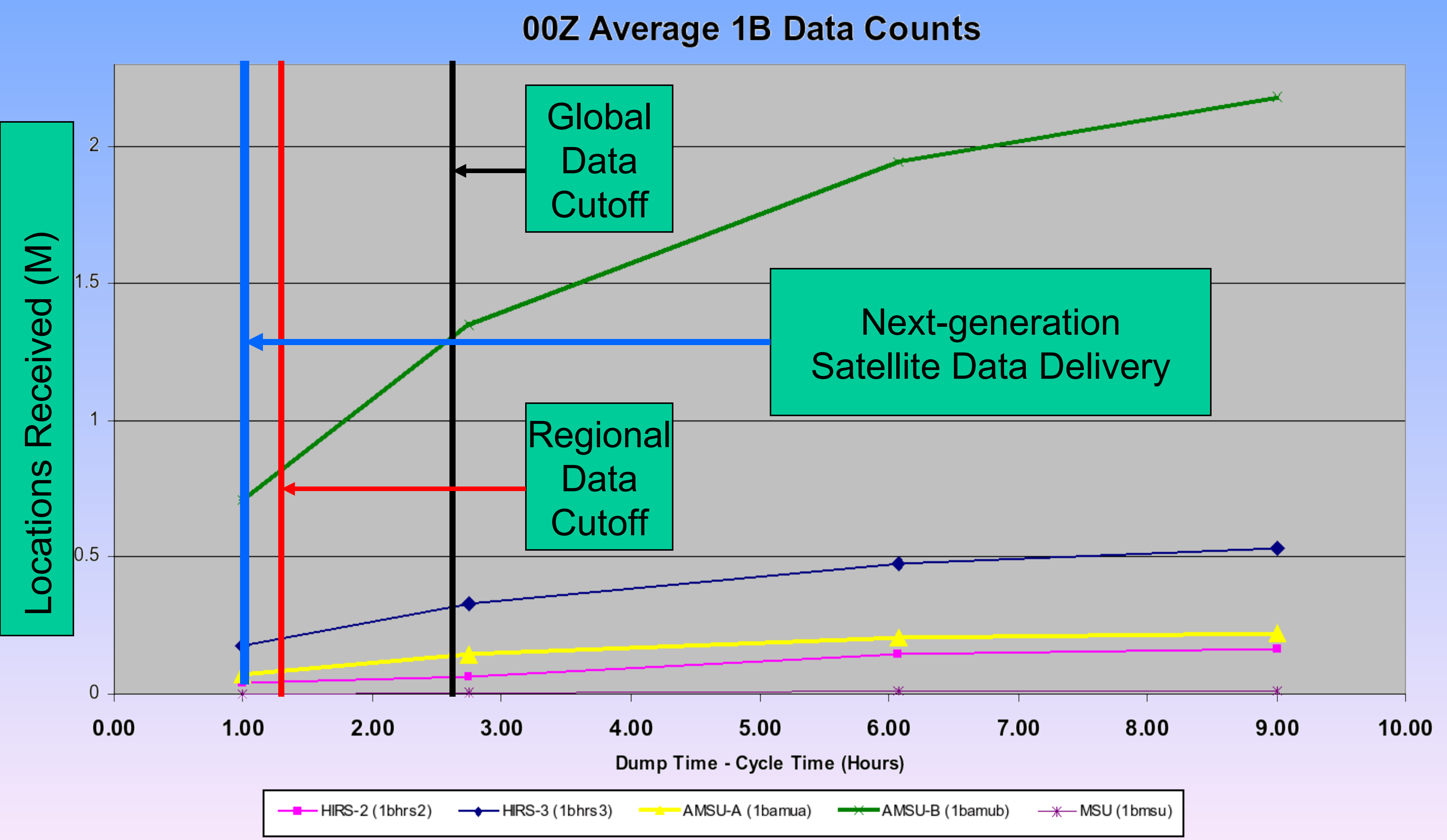
- Satellite data must wait until ground station within sight to download
- Conflicts between satellites
- Blind orbits (reduced with METOP ground station)
- Proposed NPOESS ground system (METOP currently left out)
  - **SafetyNet is a system of 15 globally distributed receptors linked to the centrals via commercial fiber, it enables low data latency and high data availability**


start orbit #1

NPOESS SafetyNetTM Architecture



POES Data Delivery



Observations

- **Availability in real time**
  - **Many research satellite programs do not want to or plan on distributing data in real time**
  - **However they want their data to be used by operational data assimilation system (Helps justify program)**
  - **Significant resources and work necessary after launch to make data available (e.g. AIRS radiances)**

Observations

- **Necessary information**
  - **To properly use the data all information necessary for the forward model should be included with the observation.**
  - **However this is often not true.**
  - **Examples**
    - **Satellite and solar azimuth angles**
    - **Satellite locations (for calculating slant paths)**
    - **Conventional station locations and elevations**

Assurance of stable data source

- Changes in data processing can result in changes in observation error characteristics
- Notification, testing and provision of test data sets essential prior to changes
- For operational satellites – situation OK
- For research satellites – means loss of control by instrument/program scientists

Forward Models

- Must be developed for each type of data.
- Improvements in forward model results in improved use of data.
- Adjoint model necessary for each forward model in inner iteration
- I will show examples for NCEP's 3D-Var system (GSI)

Forward Model
Atmospheric wind vectors (AWV)

- Convert analysis variables to u/v
- 3-D interpolation of u/v increment to observation location
- Compare to obs minus 4-D interpolation of Background

Forward Model
Surface wind speed

- Same as AWV to u/v
- 2-D interpolation of u/v to observation location
- Apply reduction factor to 10m from lowest model level
- Calculate total wind speed (including background) (note nonlinear)
- Compare wind speed to observed wind speed

Forward Model Scatterometer

- Same as AWV to u/v
- 2-D interpolation of u/v to observation location
- Apply reduction factor to 10m from lowest model level
- Compare u/v to observed u/v
- Note forward model could/should be more complex because of ambiguity in wind vectors – use backscatter directly? – difficulties in defining observational error

Forward Model
GPS radio-occultation

- Convert analysis variables to T, q, p
- Interpolate T,q and p to profiles at observation location
- Calculate either refractivity or bending angle
  - Tangent linear if inner iteration
  - Refractivity: $N = 77.6(P/T) + 3.73x10^5(P_v/T^2)$
  - Bending Angle: $$\alpha(a) = -2a\int_a^\infty \frac{d\ln n/dx}{(x^2-a^2)^{1/2}}dx$$
- Compare to observation

Forward Model Precipitation observations

- Convert analysis variables to T, q, Ps, u, v, cloud liquid water
- Interpolate T, q, u, and v profiles and Ps to observation location
- Calculate estimate of precipitation from model precipitation parameterization
  - Tangent linear of calculation – inner iteration
  - Need to upgrade to current version of model physics
  - Note when estimate of precip is negative must be set to zero
- Compare log observation to log of estimate

Forward Model
SBUV ozone profiles

- Convert analysis variables to ozone
- Interpolate ozone profile to observation location
- Integrate ozone profile over layers represented by observations
- Compare layer observations to simulated ozone observations

Forward Model Radiances

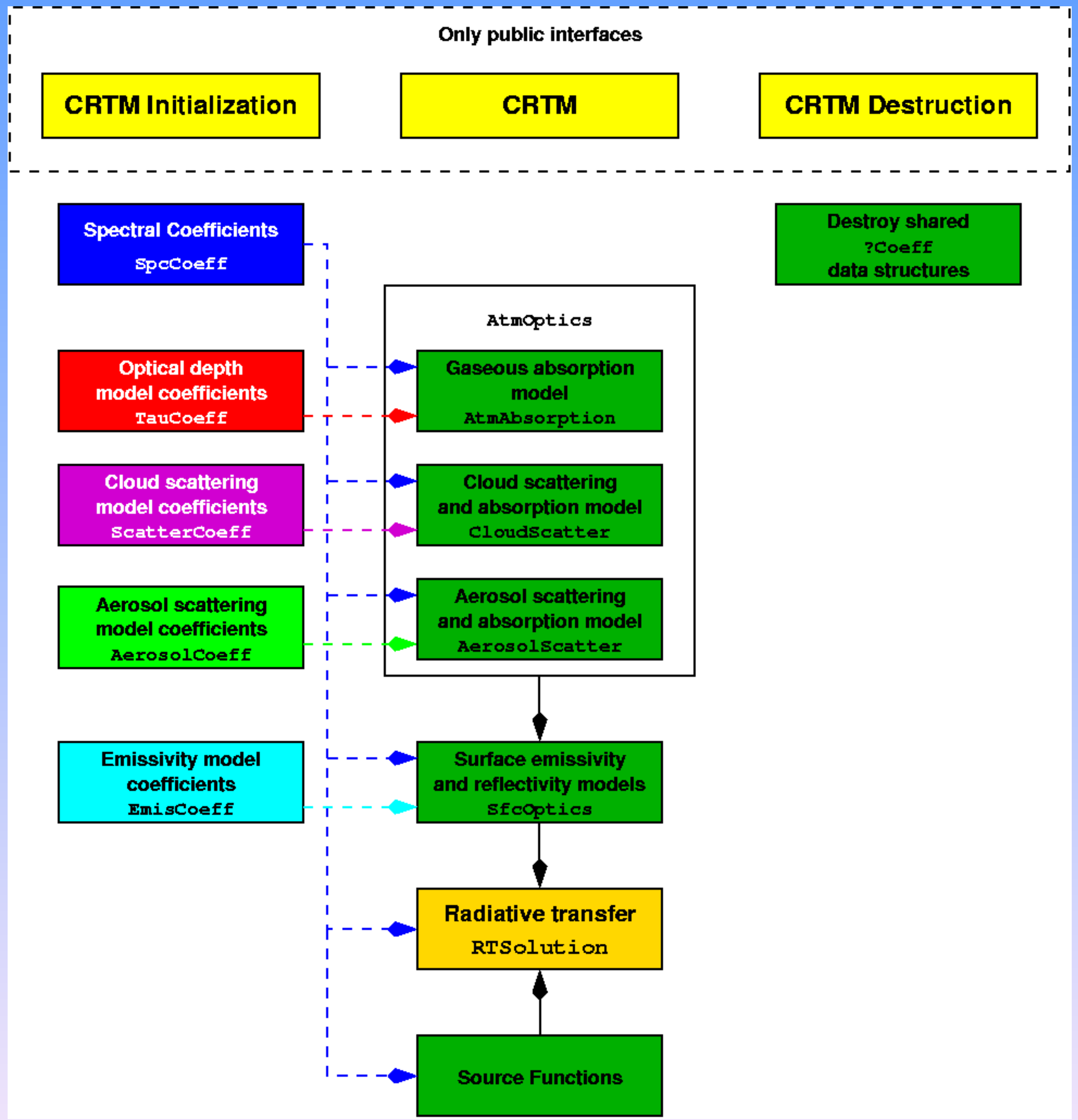
- Convert analysis variables to T, q, Ps, u, v, ozone
- Interpolate T profiles, q profiles, ozone profiles, u_1,v_1, P_s and other surface quantities to observation location
- Reduce u_1 and v_1 to 10m values
- Calculate estimate of radiance using radiative transfer model (and surface emissivity model)
  - Tangent linear of calculation – inner iteration
  - Currently simulation does not include clouds
- Apply bias correction
- Compare observation to estimate

Radiative Transfer Model

- Community Radiative Transfer Model
- The CRTM is being developed as the basis for the use of satellite data at NCEP (and other locations).
- The radiative transfer problem is split into various components (e.g. gaseous absorption, scattering etc) to facilitate independent development.
- Want to minimise or eliminate potential software conflicts and redundancies.
- Components developed by different groups can “simply” be dropped into the framework.
- Faster implementation of new science/algorithms.

Radiative transfer model

- CRTM is a fast radiative transfer function (and tangent linear, adjoint and Jacobian) (LBL codes much too slow)
  - Reflected and emitted radiation from surface (emissivity, temperature, polarization, etc.)
  - Atmospheric transmittances dependent on moisture, temperature, ozone, clouds, aerosols, CO_2, methane, ...
  - Cosmic background radiation (important for microwave)
  - View geometry (local zenith angle, view angle (polarization))
  - Instrument characteristics (spectral response functions, etc.)
  - Scattering from clouds, precipitation and aerosols



Only public interfaces
CRTM Initialization
CRTM
CRTM Destruction
Spectral Coefficients
SpcCoeff
Destroy shared
?Coeff
data structures
AtmOptics
Optical depth model coefficients
TauCoeff
Gaseous absorption model
AtmAbsorption
Cloud scattering model coefficients
ScatterCoeff
Cloud scattering and absorption model
CloudScatter
Aerosol scattering model coefficients
AerosolCoeff
Aerosol scattering and absorption model
AerosolScatter
Emissivity model coefficients
EmisCoeff
Surface emissivity and reflectivity models
SfcOptics
Radiative transfer
RTSolution
Source Functions

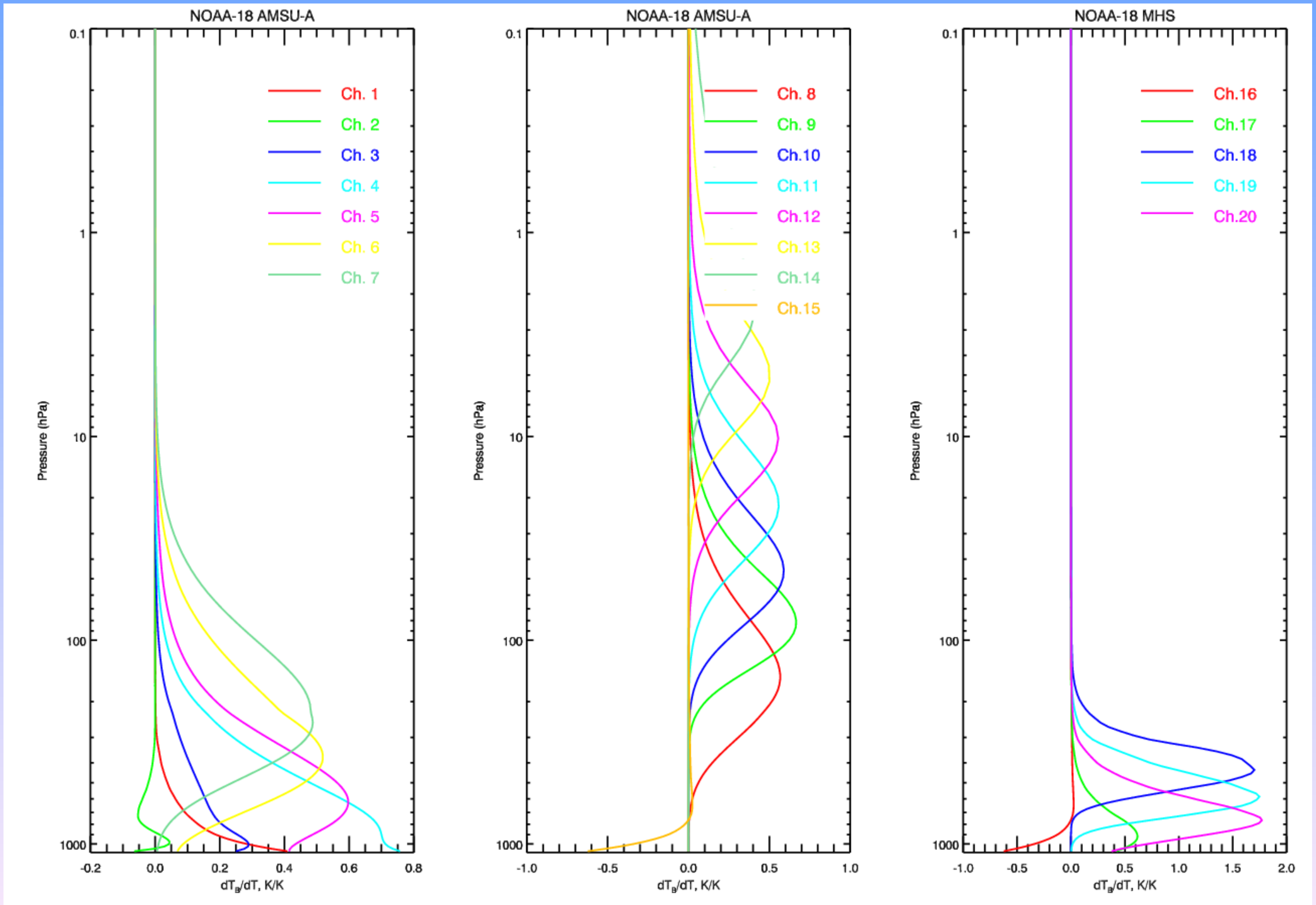
Satellite Radiance Observations

- Measure upwelling radiation at top of atmosphere
- Measure deep layers
  - IR not quite as deep as microwave
  - New IR instruments (AIRS, IASI, GIFTS) narrower, but still quite deep layers
  - Deep layers generally implies large horizontal scale

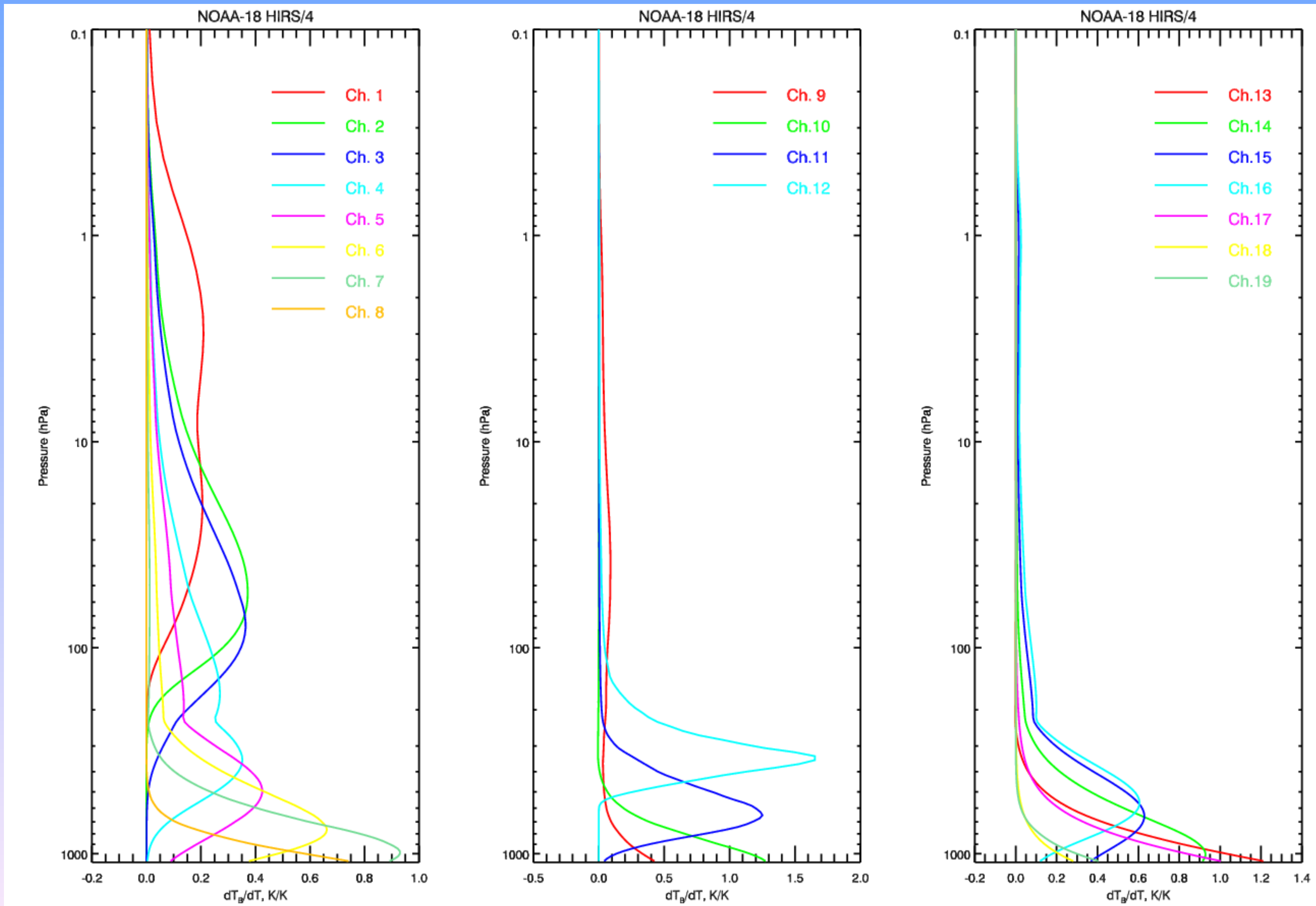
Forward model and adjoint for RT

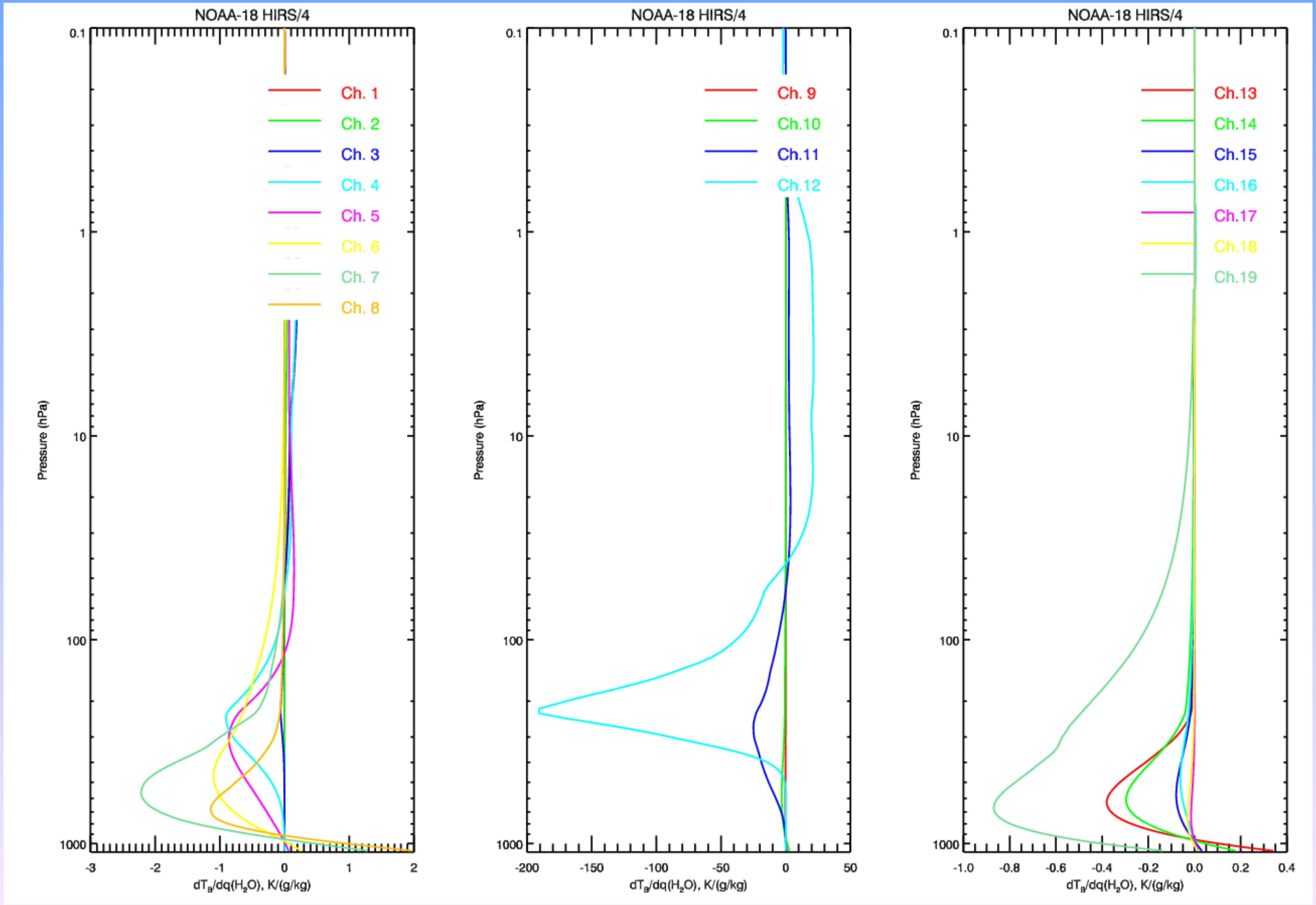
- RTTOV – CRTM two examples of fast forward models
- From CRTM get both simulated radiance and

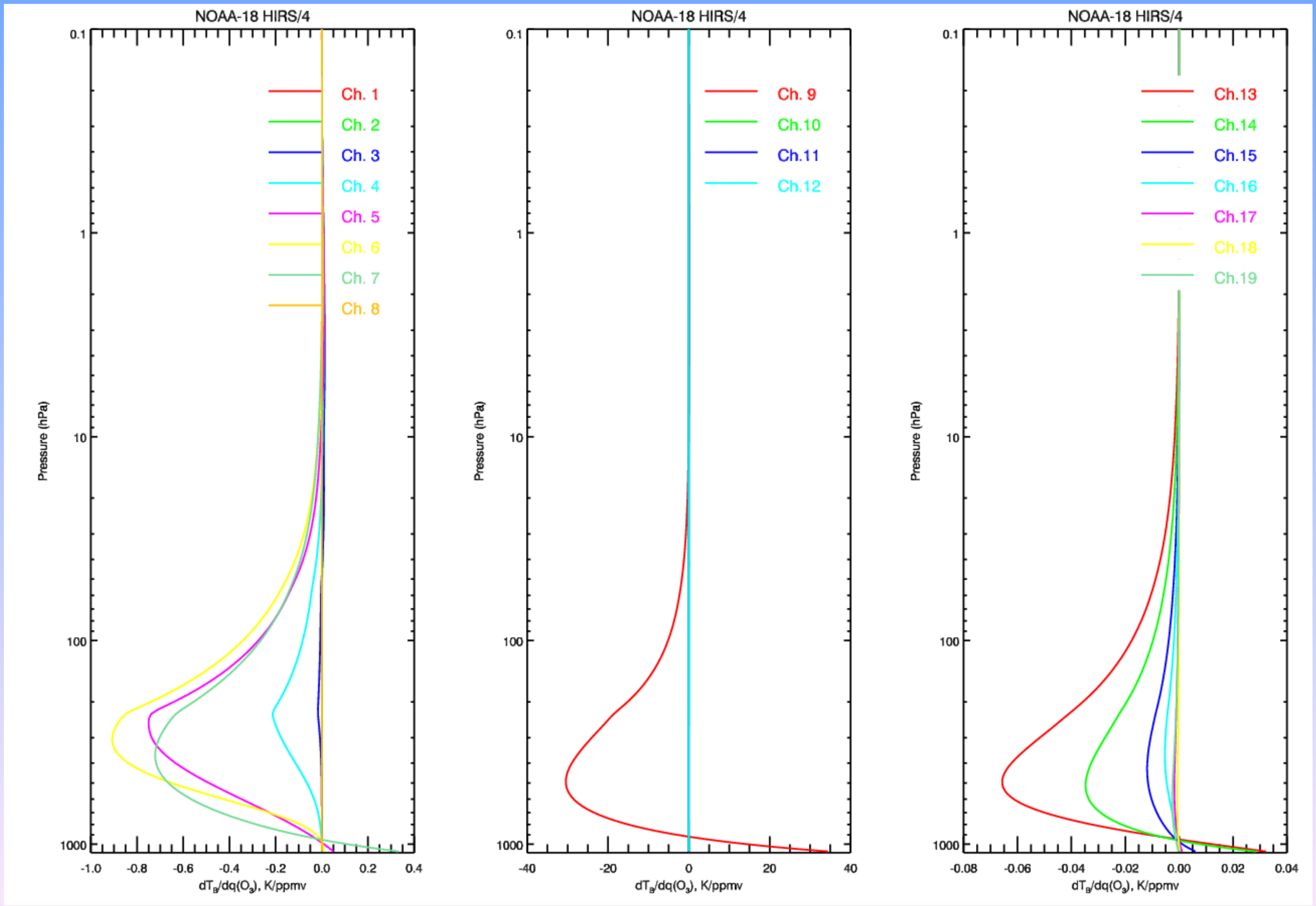
$$\frac{\partial R}{\partial T}, \frac{\partial R}{\partial q}, \frac{\partial R}{\partial q}, \frac{\partial R}{\partial O_3}, \ldots$$



NOAA-18 AMSU-A
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Pressure (hPa)
dT_B/dT, K/K
NOAA-18 AMSU-A
Ch. 8
Ch. 9
Ch.10
Ch.11
Ch.12
Ch.13
Ch.14
Ch.15
Pressure (hPa)
dT_B/dT, K/K
NOAA-18 MHS
Ch.16
Ch.17
Ch.18
Ch.19
Ch.20
Pressure (hPa)
dT_B/dT, K/K

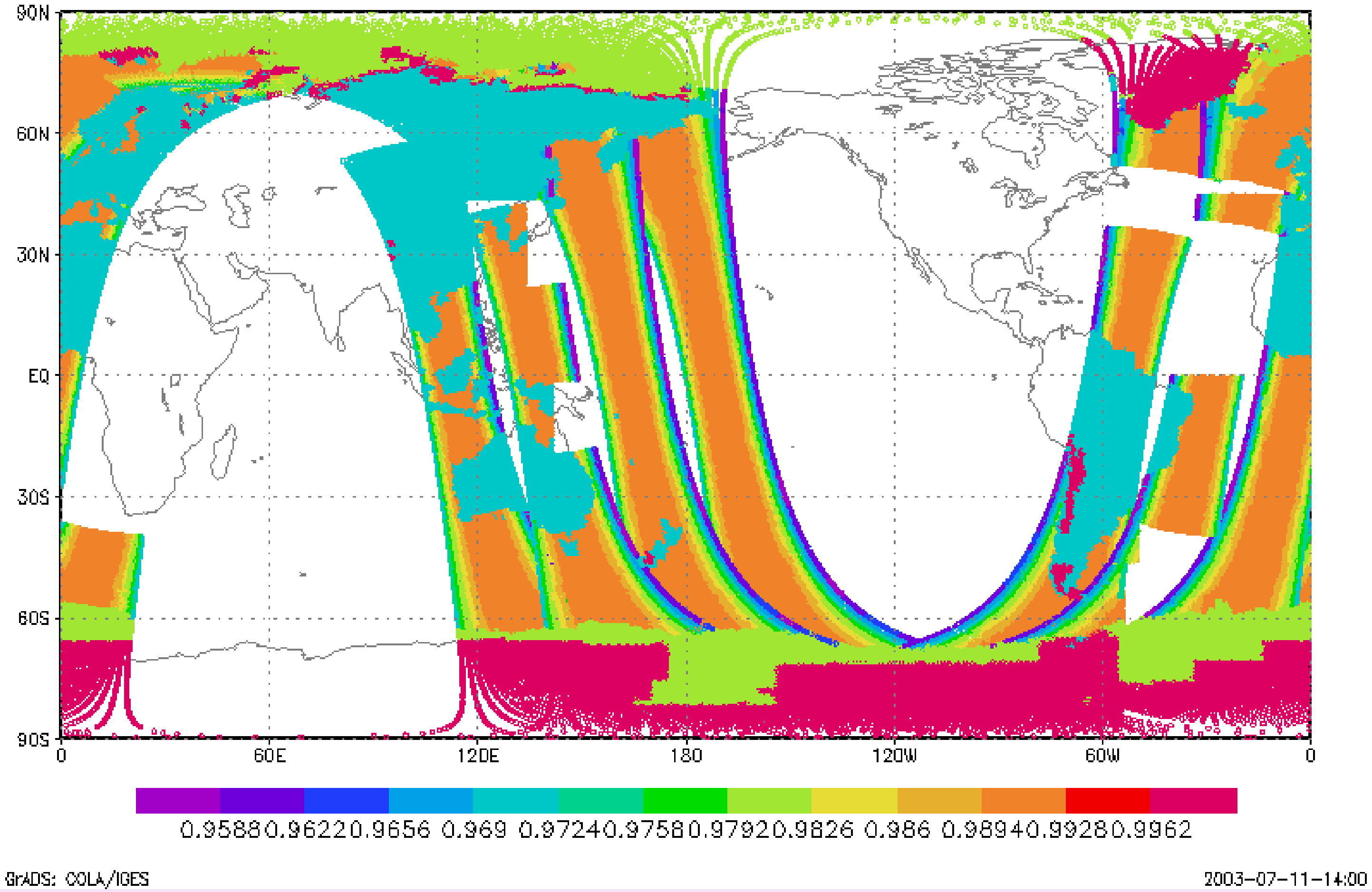

NOAA-18 HIRS/4
Pressure (hPa)
0.1
1
10
100
1000
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
dT_B/dT, K/K
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Ch. 8
NOAA-18 HIRS/4
Pressure (hPa)
0.1
1
10
100
1000
-0.5
0.0
0.5
1.0
1.5
2.0
dT_B/dT, K/K
Ch. 9
Ch.10
Ch.11
Ch.12
NOAA-18 HIRS/4
Pressure (hPa)
0.1
1
10
100
1000
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
dT_B/dT, K/K
Ch.13
Ch.14
Ch.15
Ch.16
Ch.17
Ch.18
Ch.19

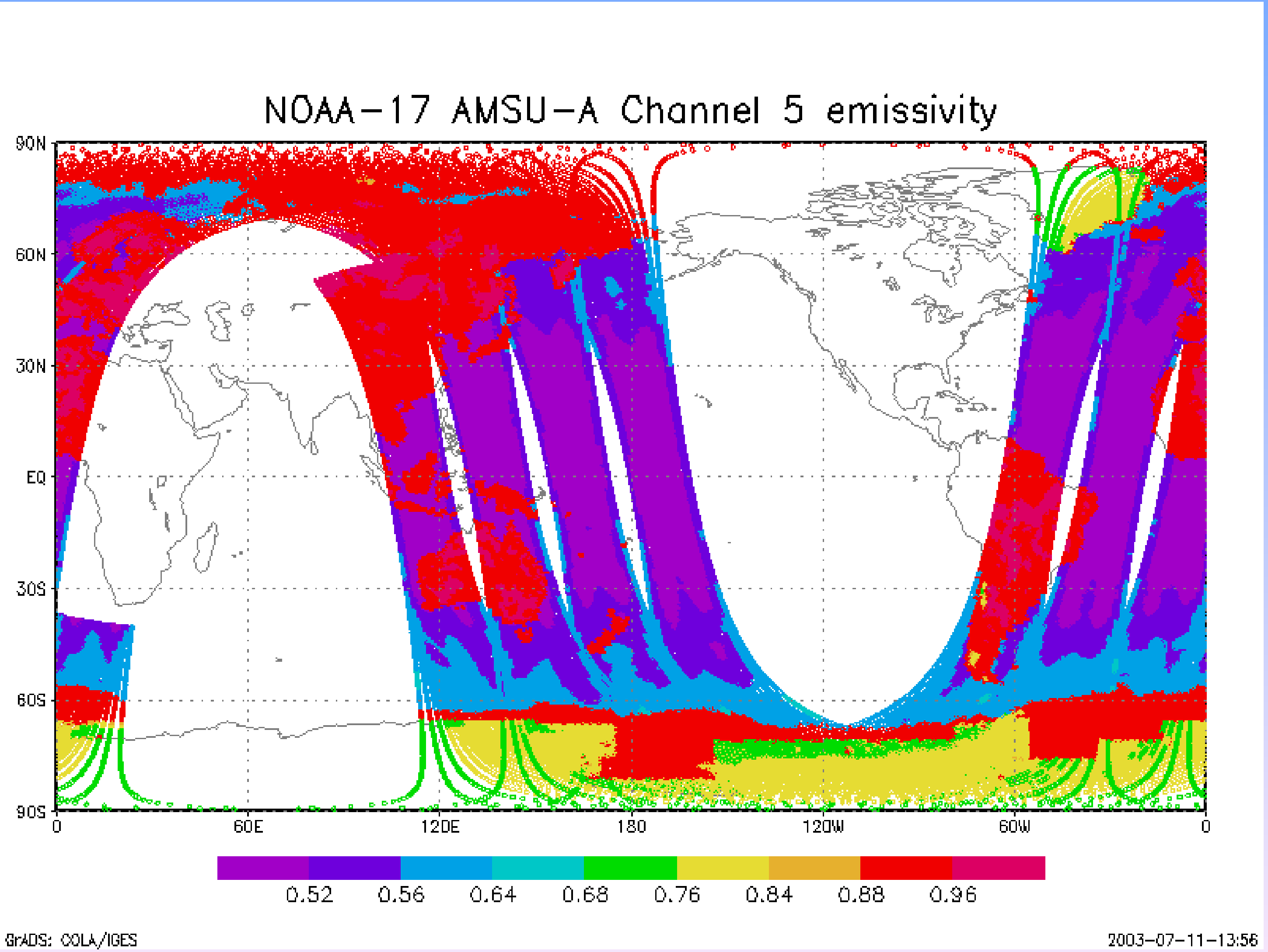

NOAA-18 HIRS/4
Pressure (hPa)
0.1
1
10
100
1000
-3
-2
-1
0
1
2
dT$_B$/dq(H$_2$O), K/(g/kg)
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Ch. 8
NOAA-18 HIRS/4
Pressure (hPa)
-200
-150
-100
-50
0
50
dT$_B$/dq(H$_2$O), K/(g/kg)
Ch. 9
Ch.10
Ch.11
Ch.12
NOAA-18 HIRS/4
Pressure (hPa)
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
dT$_B$/dq(H$_2$O), K/(g/kg)
Ch.13
Ch.14
Ch.15
Ch.16
Ch.17
Ch.18
Ch.19



NOAA-18 HIRS/4
Pressure (hPa)
dT_B/dq(O_3), K/ppmv
Ch. 1
Ch. 2
Ch. 3
Ch. 4
Ch. 5
Ch. 6
Ch. 7
Ch. 8
NOAA-18 HIRS/4
Ch. 9
Ch.10
Ch.11
Ch.12
NOAA-18 HIRS/4
Ch.13
Ch.14
Ch.15
Ch.16
Ch.17
Ch.18
Ch.19

NOAA-17 HIRS/3 Channel 8 emissivity




NOAA-17 AMSU-A Channel 5 emissivity
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0.52
0.56
0.64
0.68
0.76
0.84
0.88
0.96
GrADS: COLA/IGES
2003-07-11-13:56

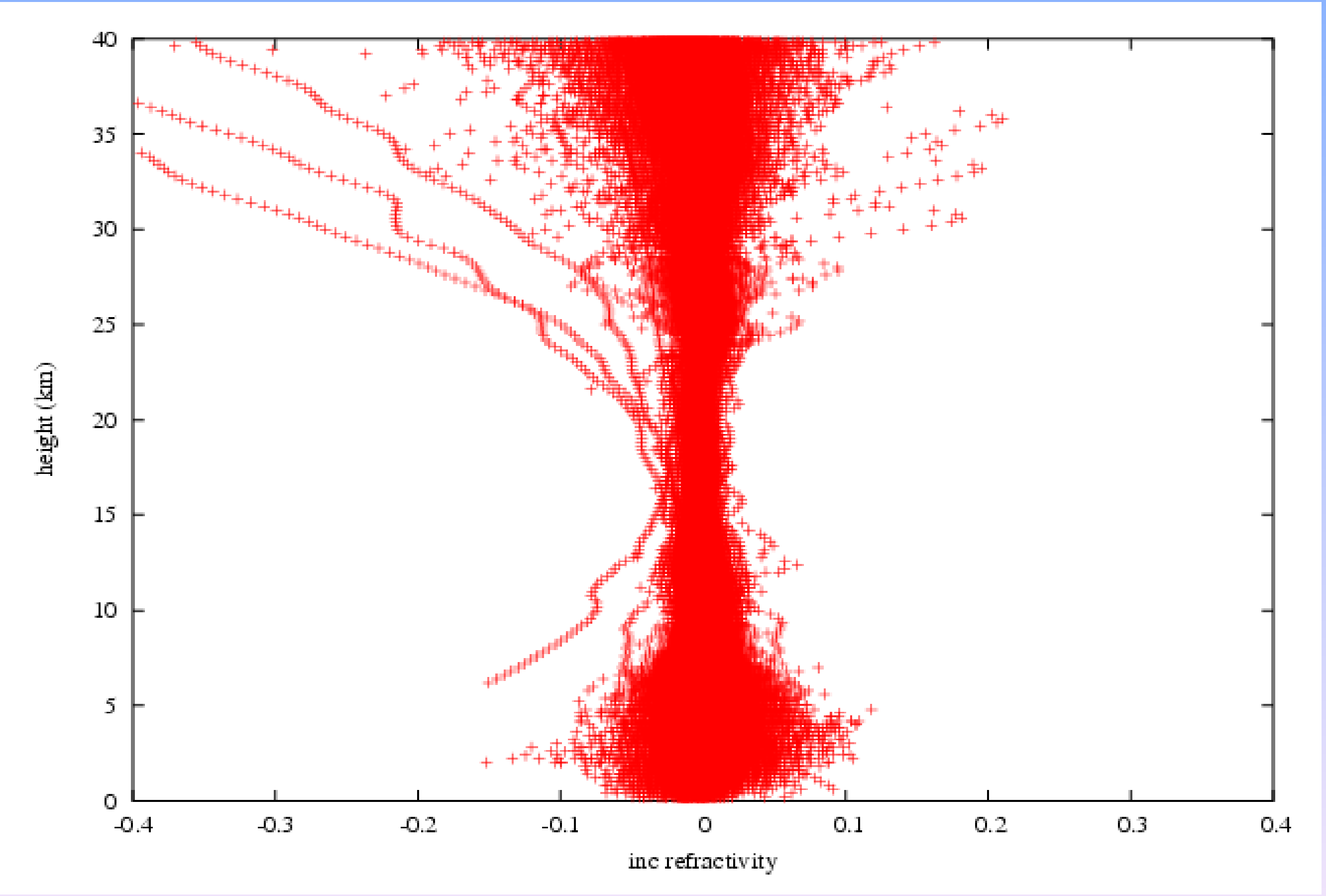
Quality control procedures

- The quality control step may be the most important aspect of satellite data assimilation
- Data must be removed which has gross errors or which cannot be properly simulated by forward model
- Most problems with satellite data come from 2 sources
  - Instrument problems
  - Inability to properly simulate observations

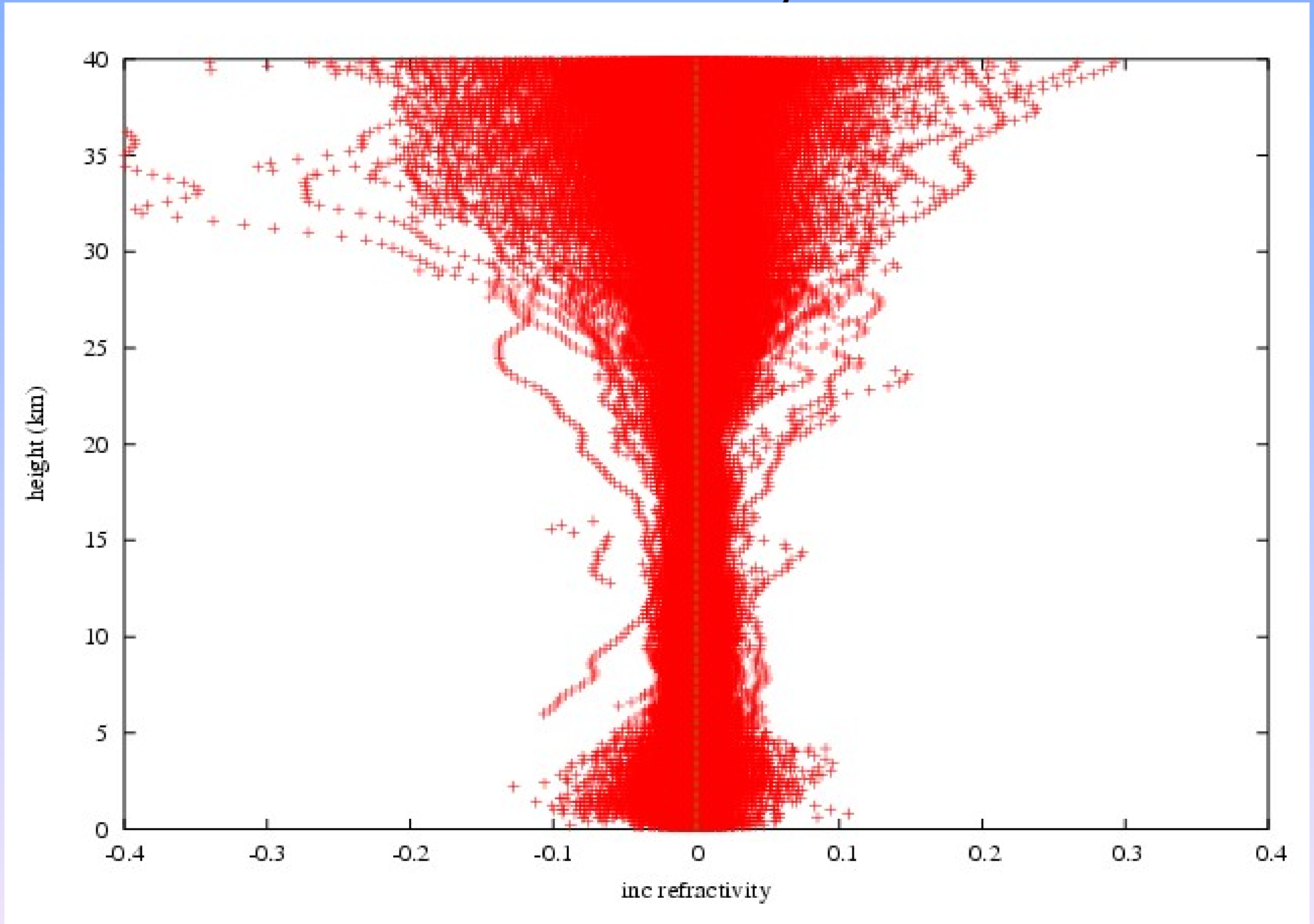
Quality Control
Major problems

- Atmospheric wind vectors
  - Improper height assignment
  - Correlated errors – more is not better
  - Bad winds
- SSM/I surface wind speeds
  - Precipitation
  - Land/ice
- Scatterometers
  - Precipitation
  - Improper ambiguity removal
  - Land/ice
- GPS radio-occultation
  - Loss of signal
  - Improper removal of ionosphere

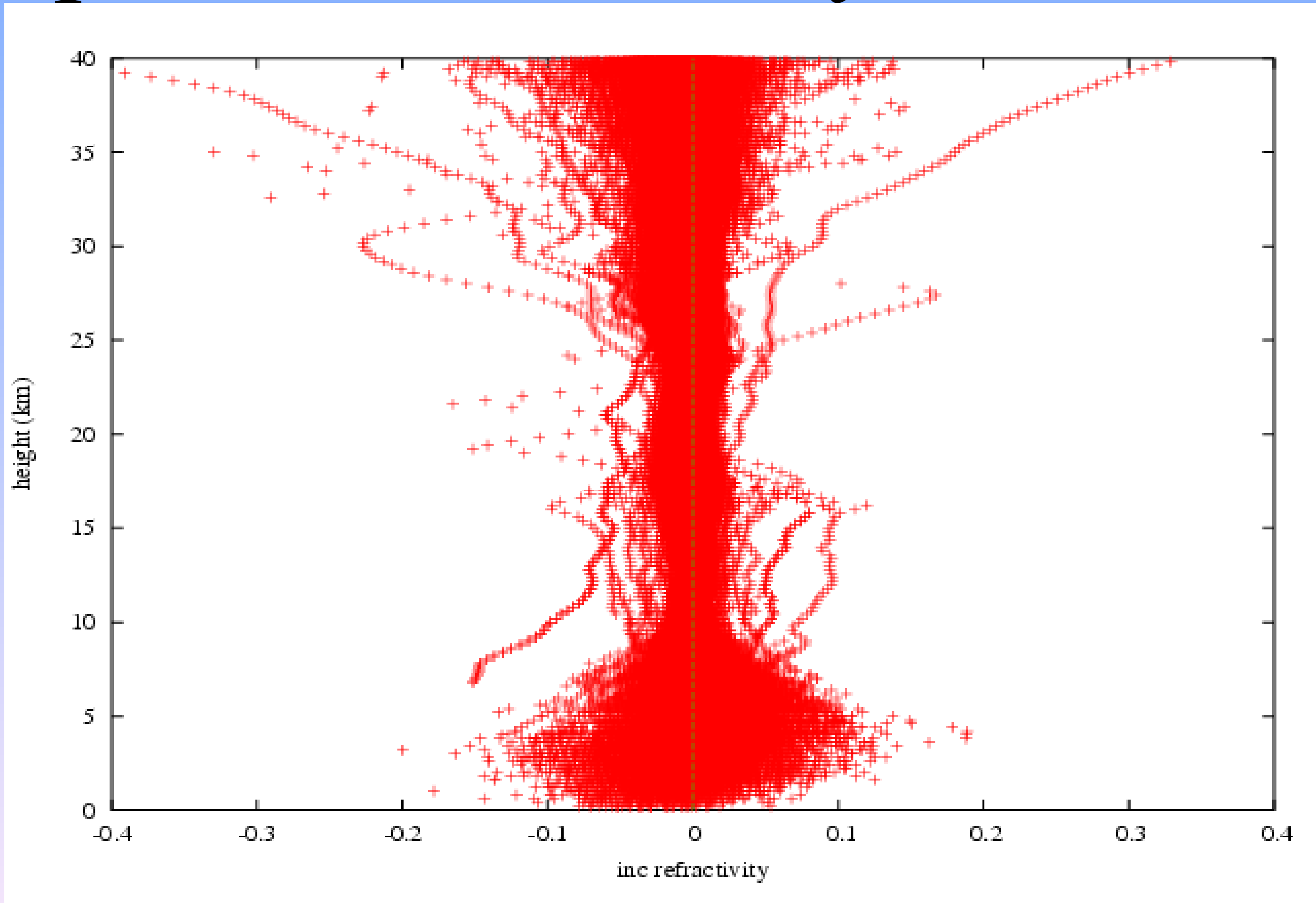
NH % refractivity difference



SH % refractivity difference

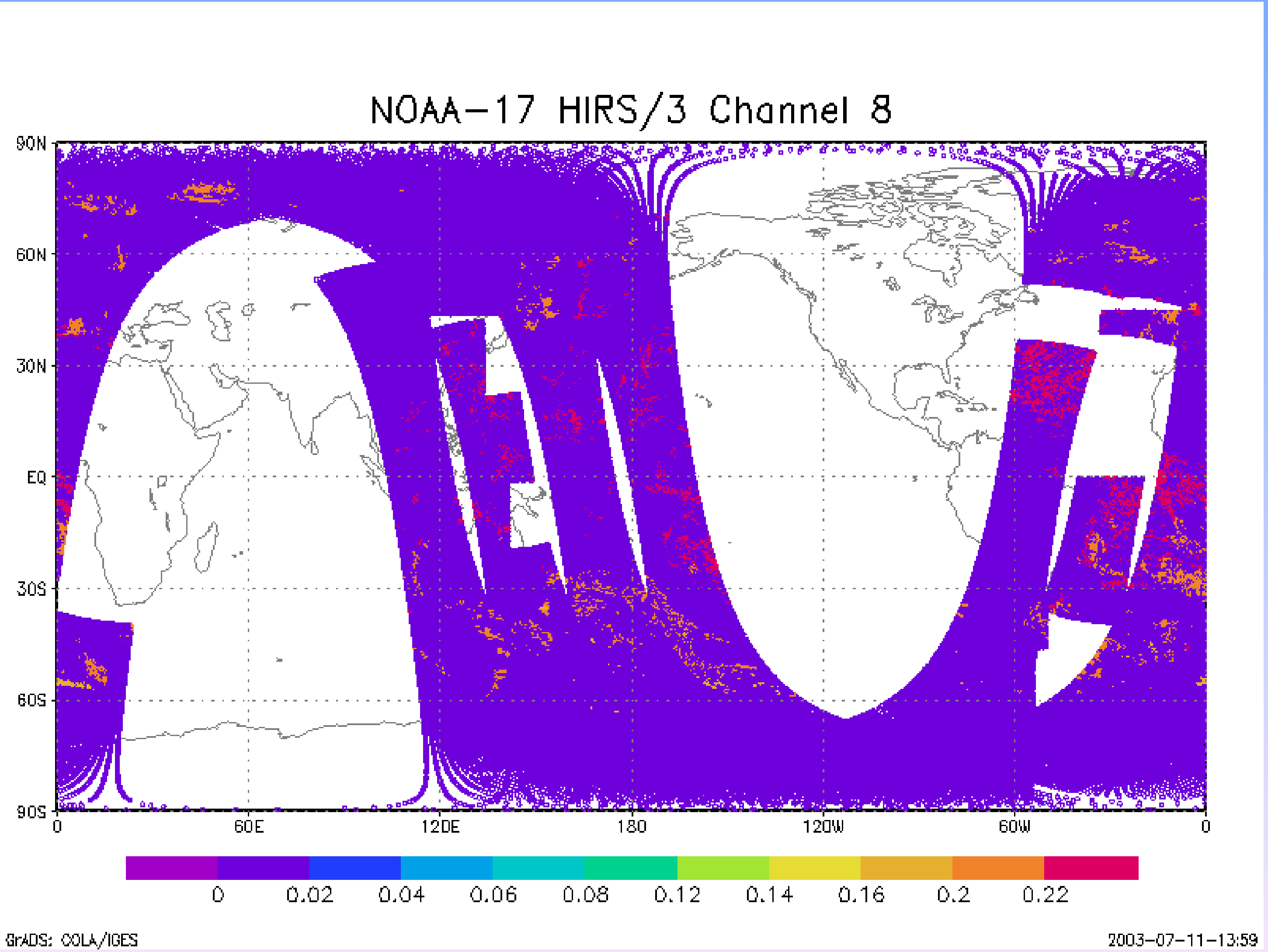


Tropics % refractivity difference



Quality Control
Major problems

- **SSM/I and TRMM precip. estimates**
  - **Bad estimates**
  - **Ice/snow**
- **SBUV ozone profiles**
  - **Bad profiles**
- **IR and Microwave Radiances**
  - IR cannot see through clouds – cloud heights difficult to determine
  - Microwave impacted by clouds and precipitation but signal from thinner clouds can be modeled and mostly accounted for in bias correction
  - Surface emissivity and temperature not well known for land/snow/ice
    - Also makes detection of clouds/precip. more difficult



NOAA-17 HIRS/3 Channel 8
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
0.02
0.04
0.06
0.08
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0.14
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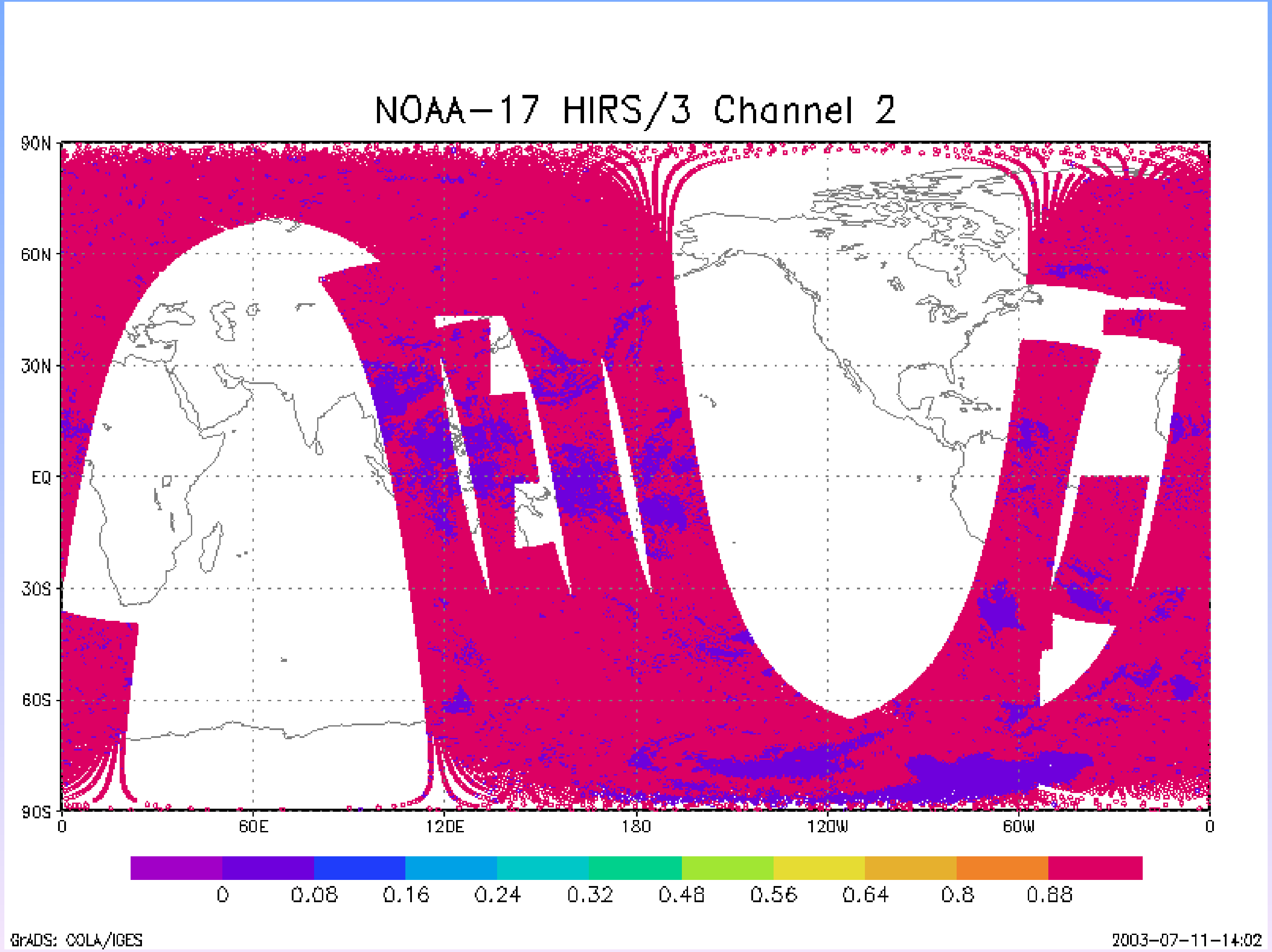
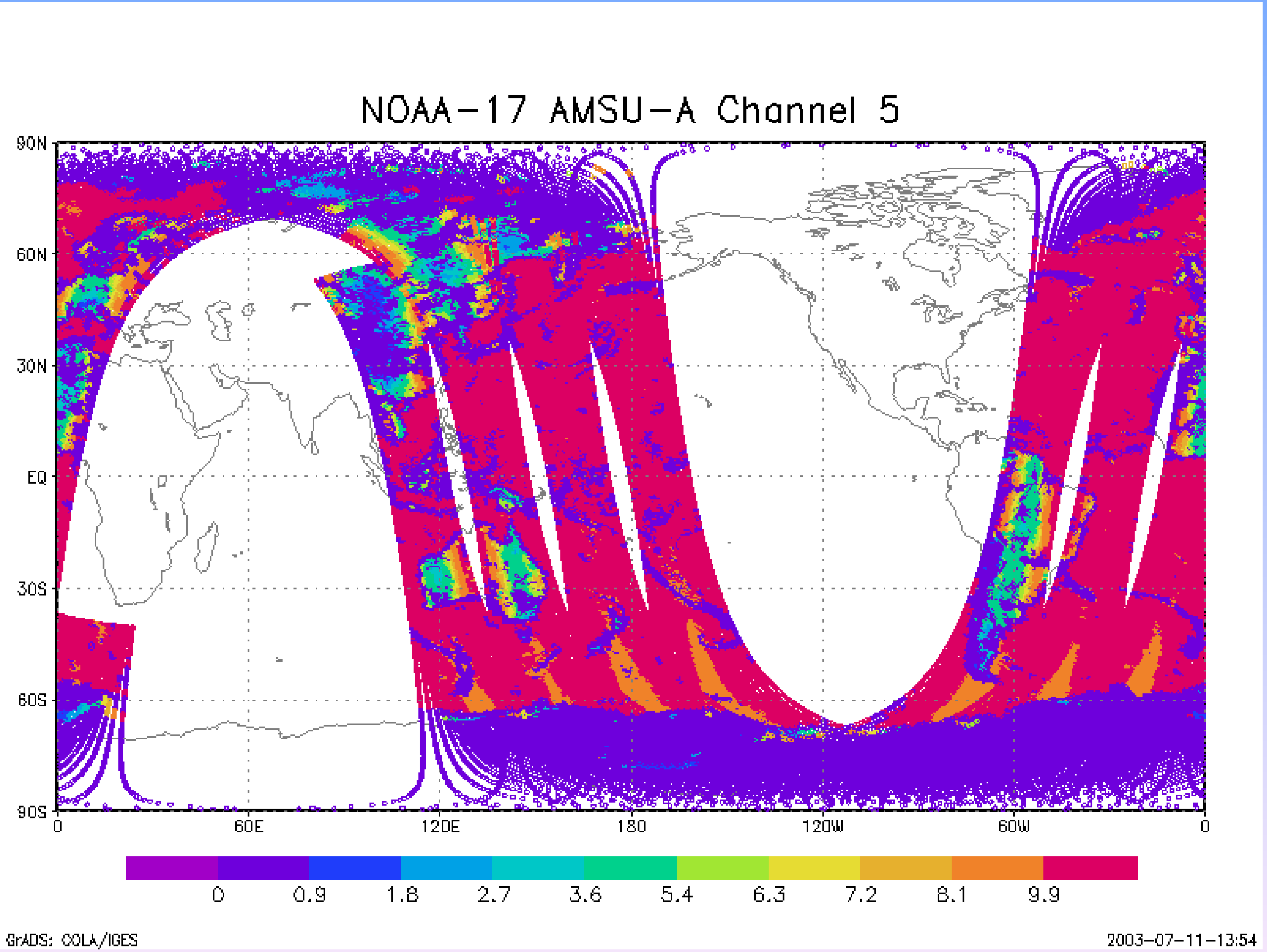
0.2
0.22
GrADS: COLA/IGES
2003-07-11-13:59



NOAA-17 HIRS/3 Channel 2
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
0.08
0.16
0.24
0.32
0.48
0.56
0.64
0.8
0.88
GrADS: COLA/IGES
2003-07-11-14:02


NOAA-17 AMSU-A Channel 5
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
0.9
1.8
2.7
3.6
5.4
6.3
7.2
8.1
9.9
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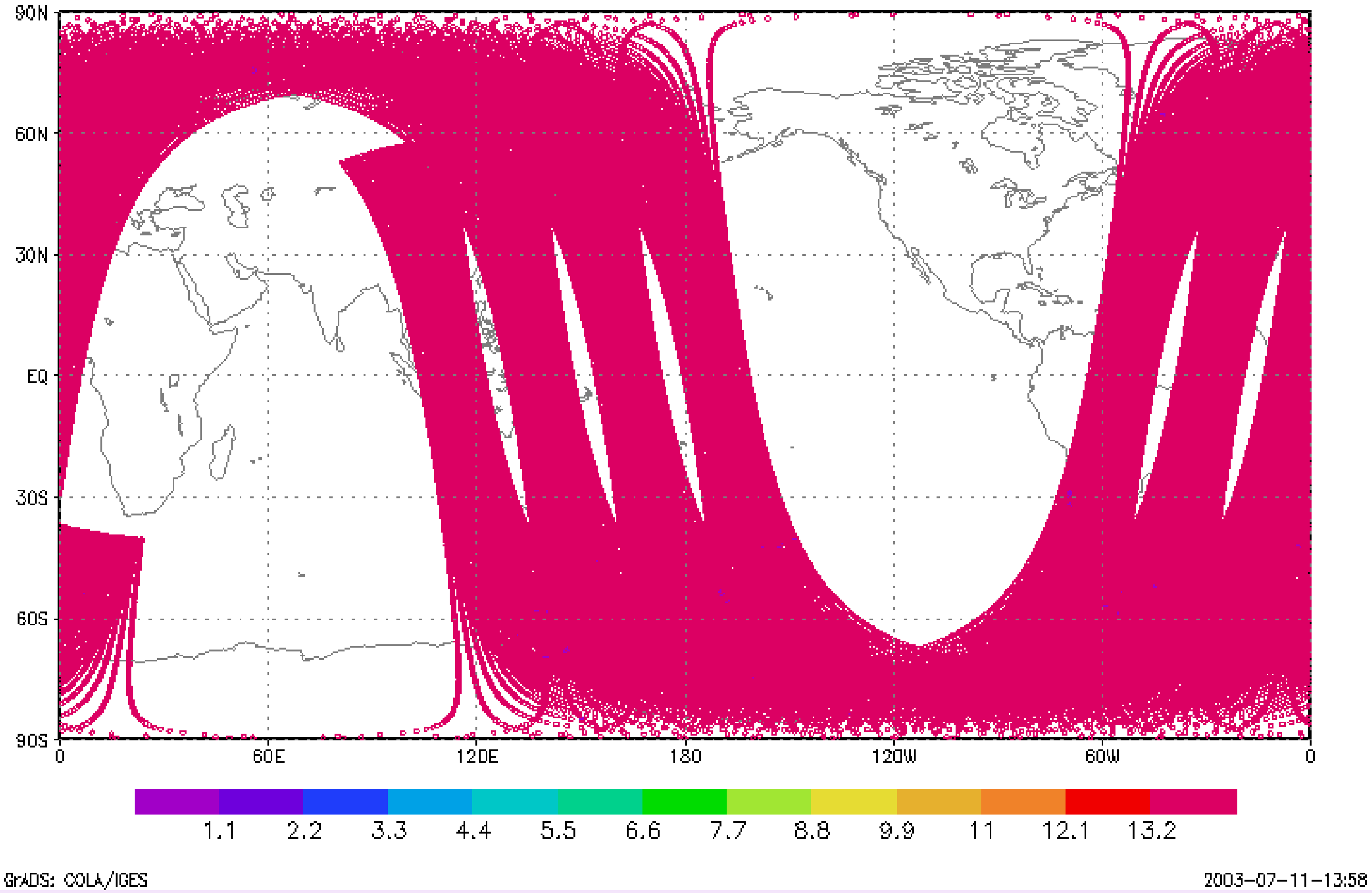
AMSU-A Channel 9



Quality control procedures (thinning)

- Some data is thinned prior to using
- Three reasons
  - Redundancy in data
    - Radiances
    - AMWs
  - Reduce correlated error
    - AMWs
  - Computational expense
    - Radiances

Observational and Representativeness error

- Essentially specifies the weight given an observation.
- Current assumption – errors are uncorrelated
  - Some error specifications (e.g., radiances) increased because of this.
- Includes instrument error, forward model error and representativeness error

Observational and Representativeness errors

- **Specified somewhat empirically.**
  - **Errors quoted by instrument developers - lower bound**
  - **Fits to observations to simulated observations – upper bound**
  - **Specification of errors can be verified with some necessary conditions in analysis system**
- **Generally for satellite data errors are specified a bit large since the correlated errors are not well known.**
- **Bias must be accounted for since it is often larger than signal**

Satellite observations

- Different observation and error characteristics
  - Type of data (cloud track winds, radiances, etc.)
  - Version of instrument type (e.g., IR sounders -AIRS, HIRS, IASI, GOES, GIFTS, etc.)
  - Different models of same instrument (e.g., NOAA-15 AMSU-A, NOAA-16 AMSU-A)

Bias Correction

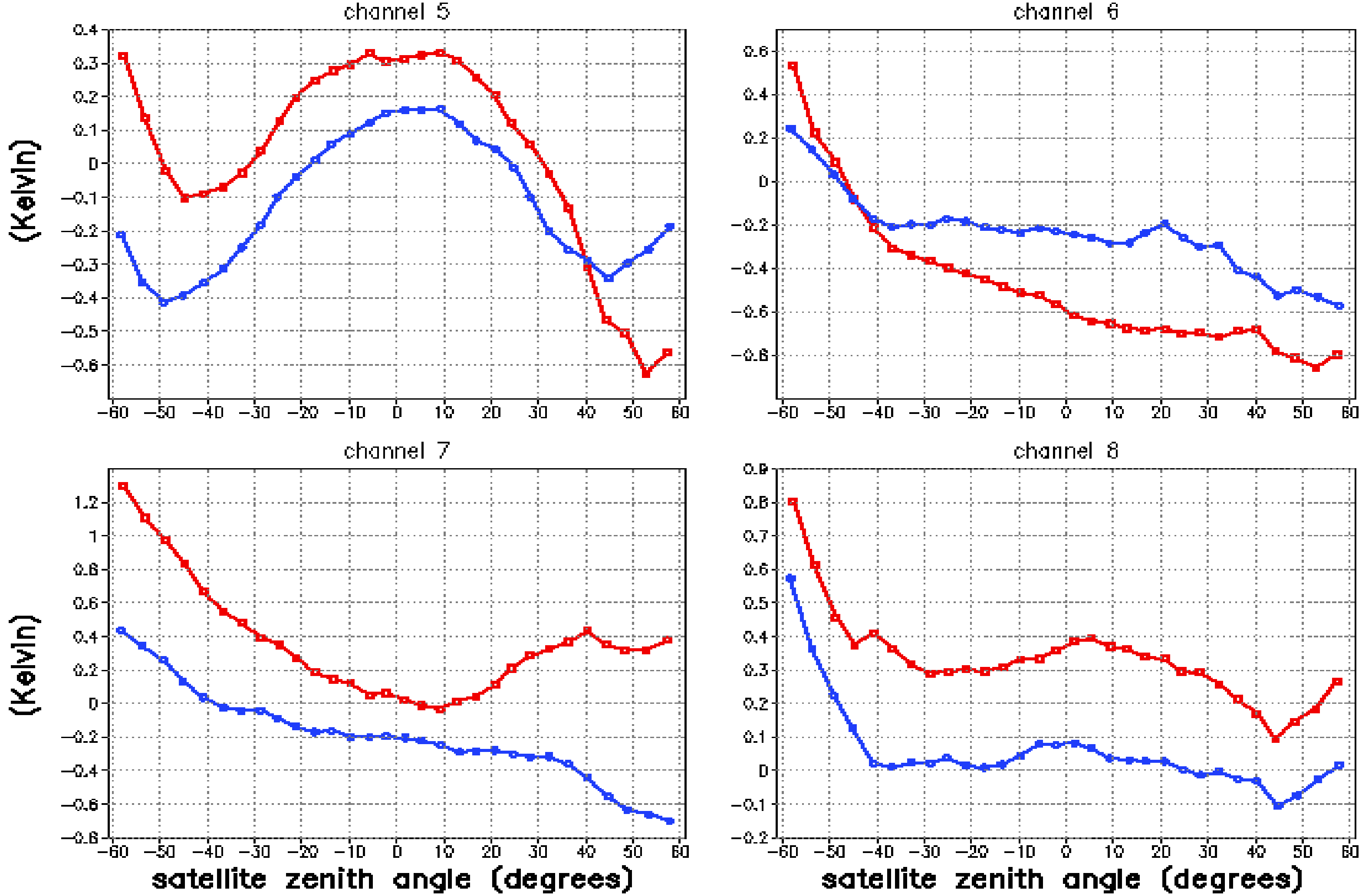
- The differences between simulated and observed observations can show significant biases
- The source of the bias can come from
  - Biased observations
  - Inadequacies in the characterization of the instruments
  - Deficiencies in the forward models
  - Biases in the background
- Except when the bias is due to the background we would like to remove these biases

Bias Correction

- Currently we are only bias correcting, the radiances and the radiosonde data (radiation correction)
- For radiances, biases can be much larger than signal. Essential to bias correct the data
- NCEP uses a 2 step process for radiances (others are similar)
  - Angle correction (very slowly evolving – different correction for each scan position)
  - Air Mass correction (slowly evolving based on predictors)

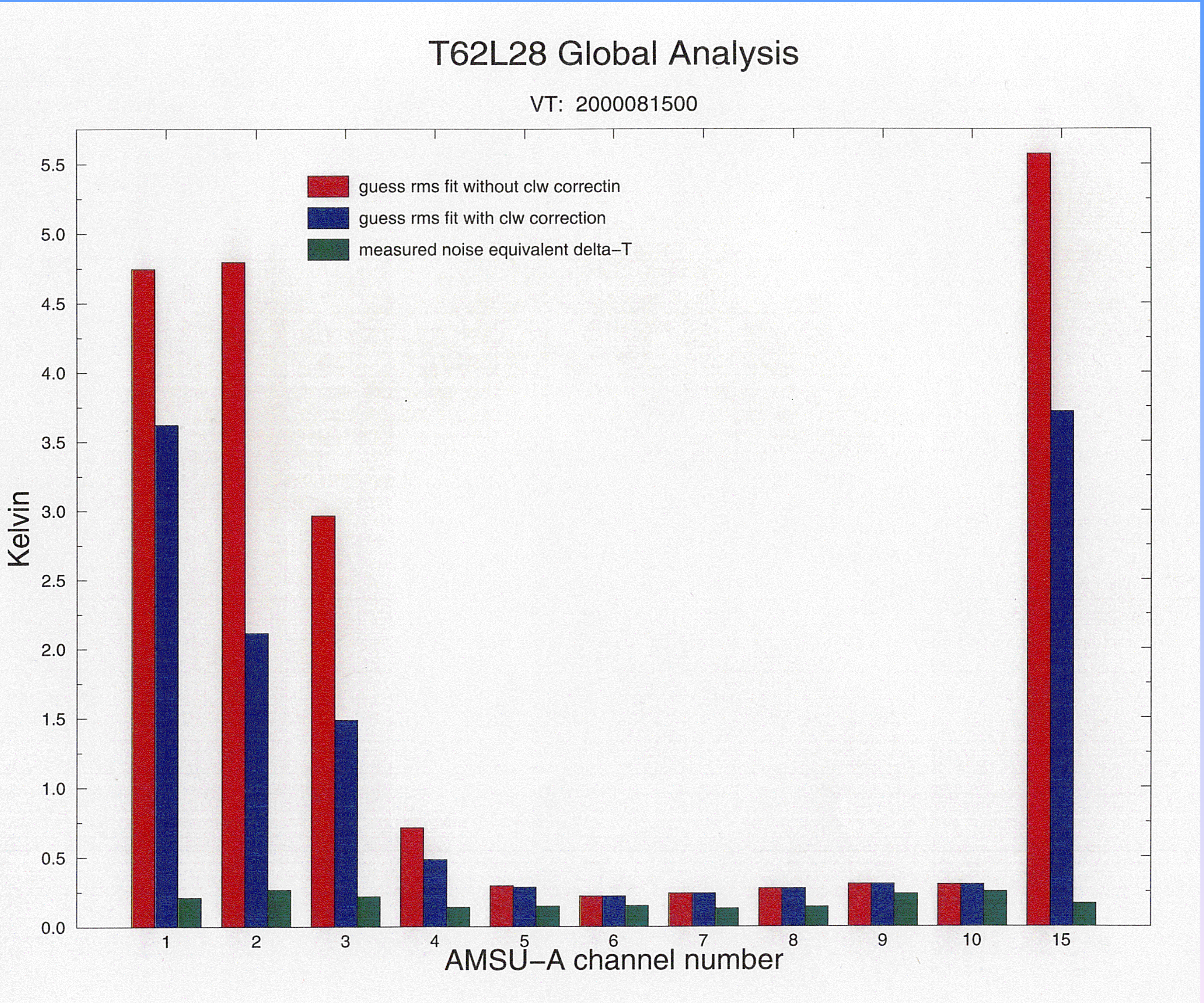
platform: amsua
region : global
variable: observed−simulated (without bias correction) (K)
valid : 00Z20FEB2001 00Z22MAR2001

NOAA−15 (red)
NOAA−16 (blue)

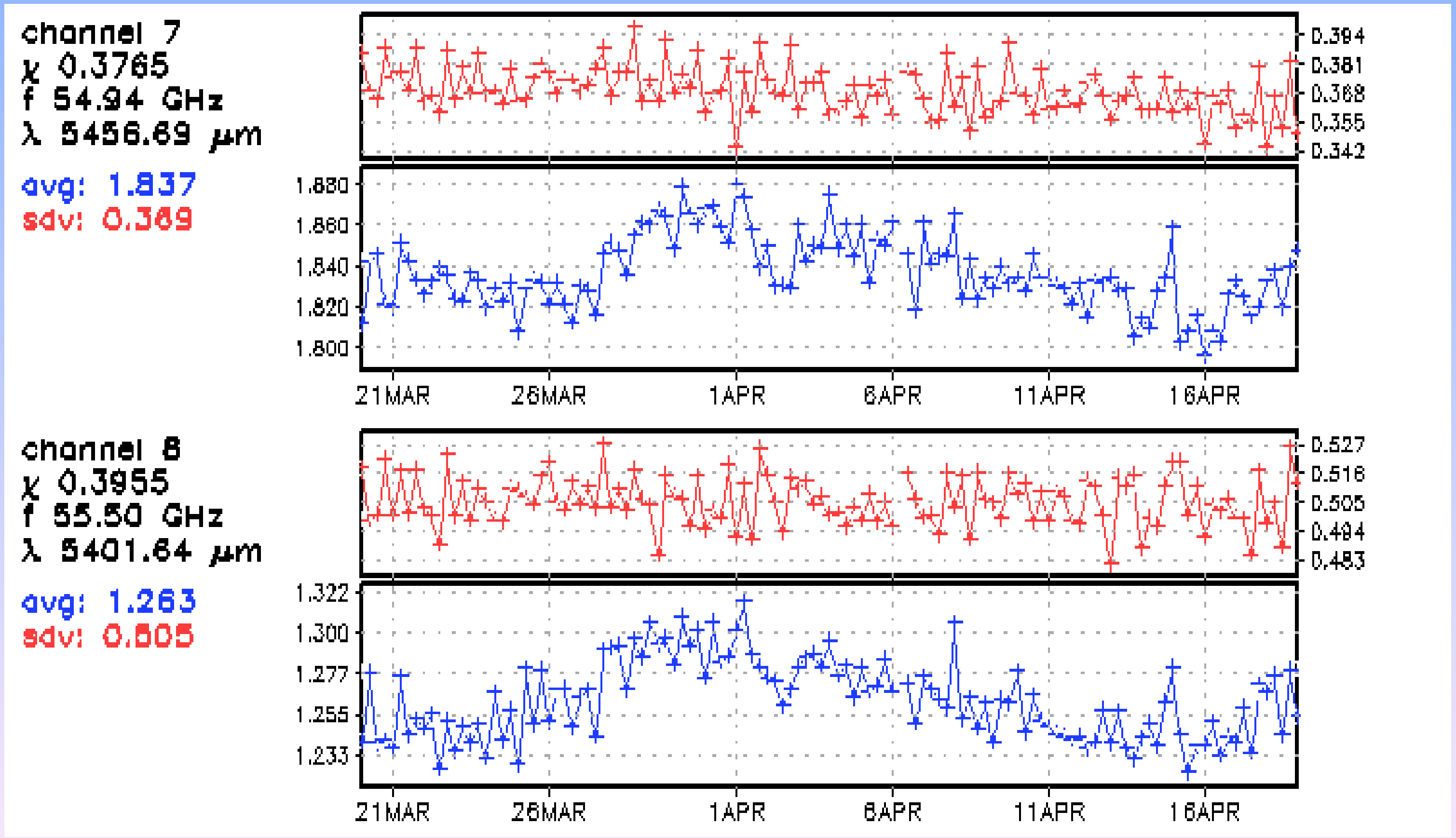


Satellite radiance observations Bias correction

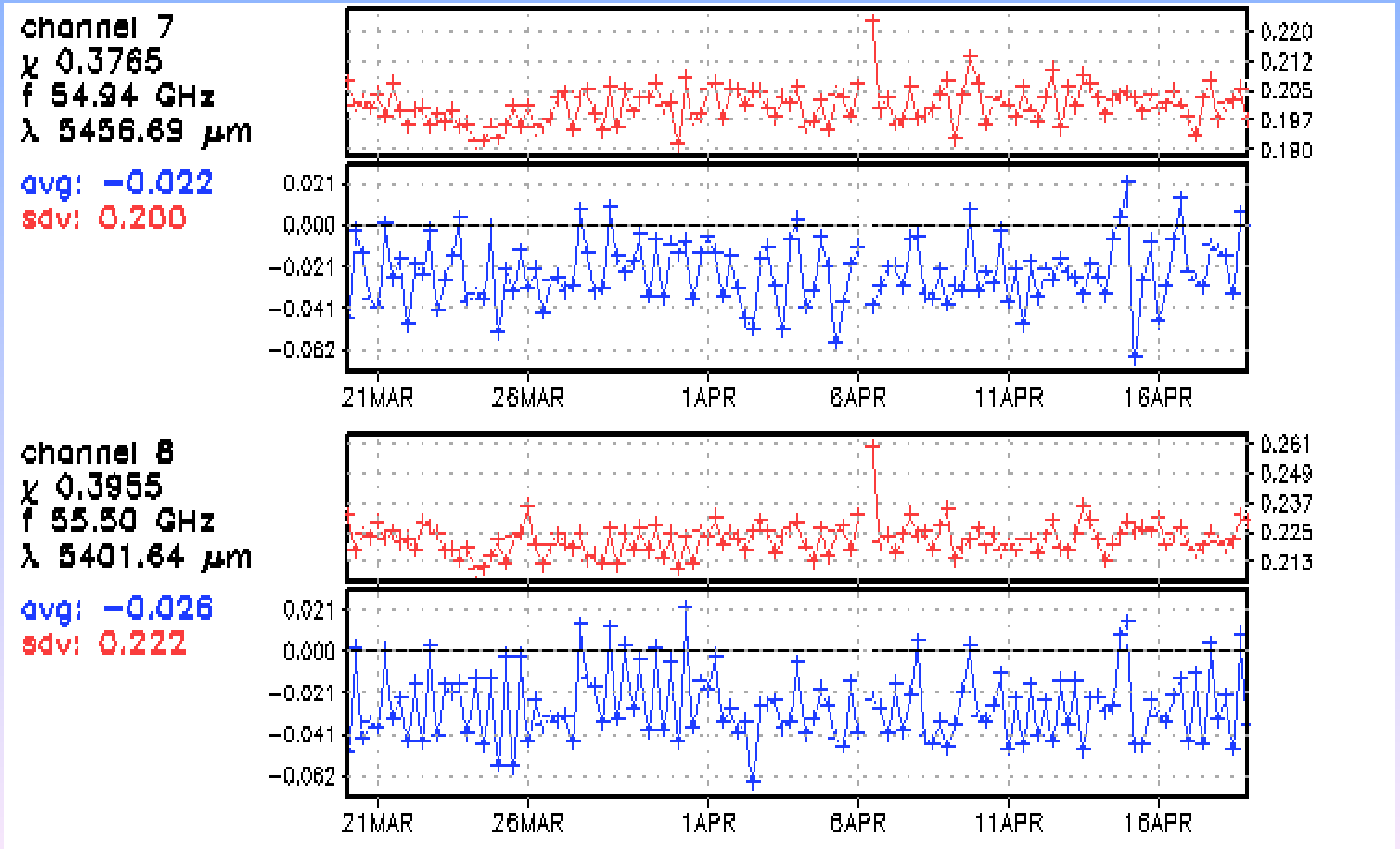
- Air Mass prediction equation for bias
  - Coefficients in equation analysis variable w/ background previous values
  - Predictors
    - mean
    - path length (local zenith angle determined)
    - integrated lapse rate
    - integrated lapse rate ** 2
    - cloud liquid water


T62L28 Global Analysis
VT: 2000081500
guess rms fit without clw correctin
guess rms fit with clw correction
measured noise equivalent delta–T
Kelvin
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
1
2
3
4
5
6
7
8
9
10
15
AMSU–A channel number

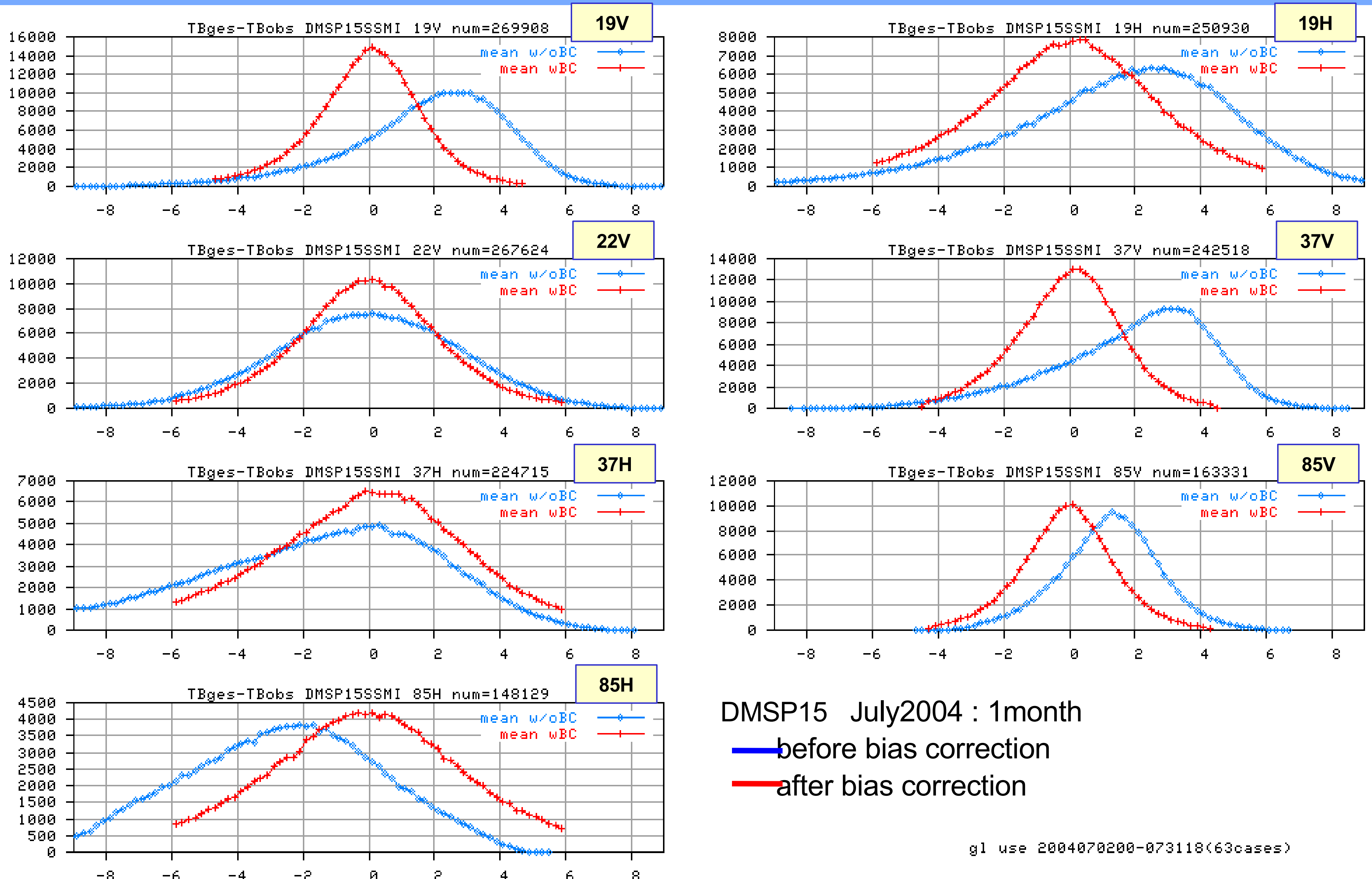
NOAA 18 AMSU-A
No Bias Correction



NOAA 18 AMSU-A
Bias Corrected



G-O histogram



DMSP15 July2004 : 1month

before bias correction

after bias correction

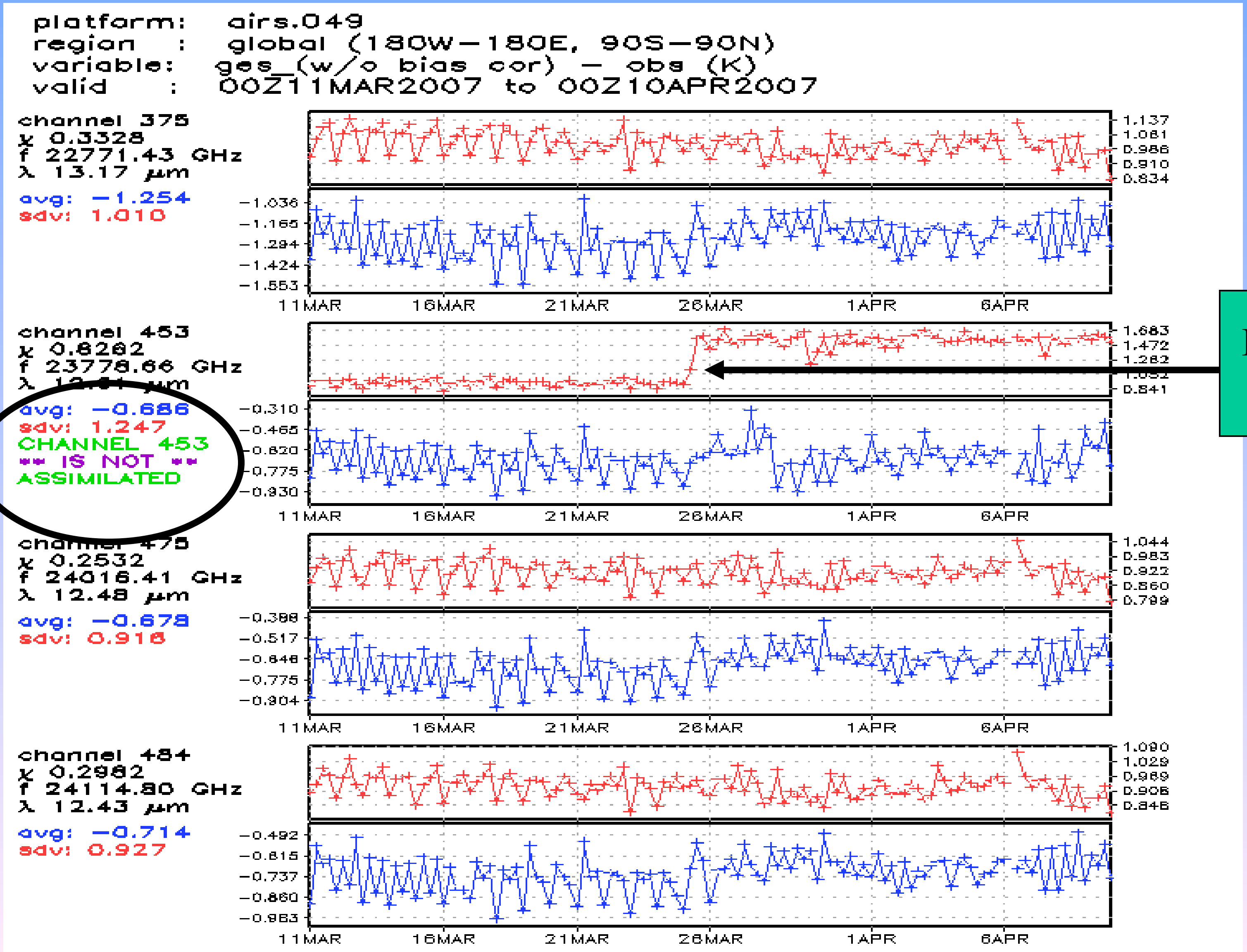
gl use 2004070200-073118(63cases)

Data Monitoring

- It is essential to have good data monitoring.
- Usually the NWP centres see problems with instruments prior to notification by provider (UKMO especially)
- The data monitoring can also show problems with the assimilation systems
- Needs to be ongoing/real time

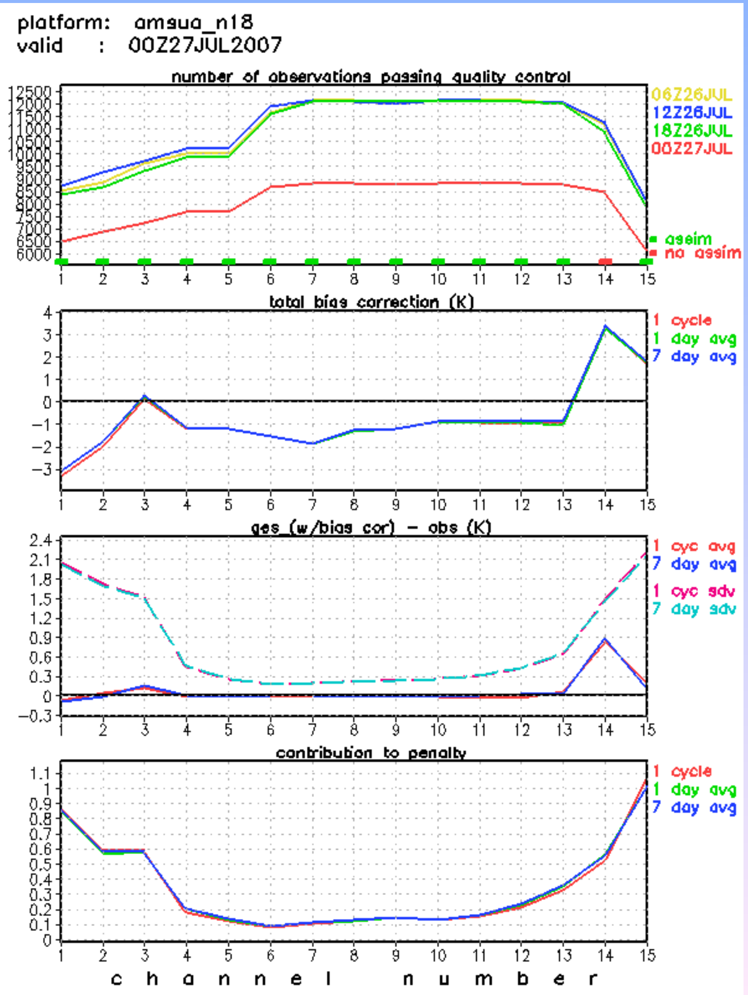
Quality Monitoring of Satellite Data

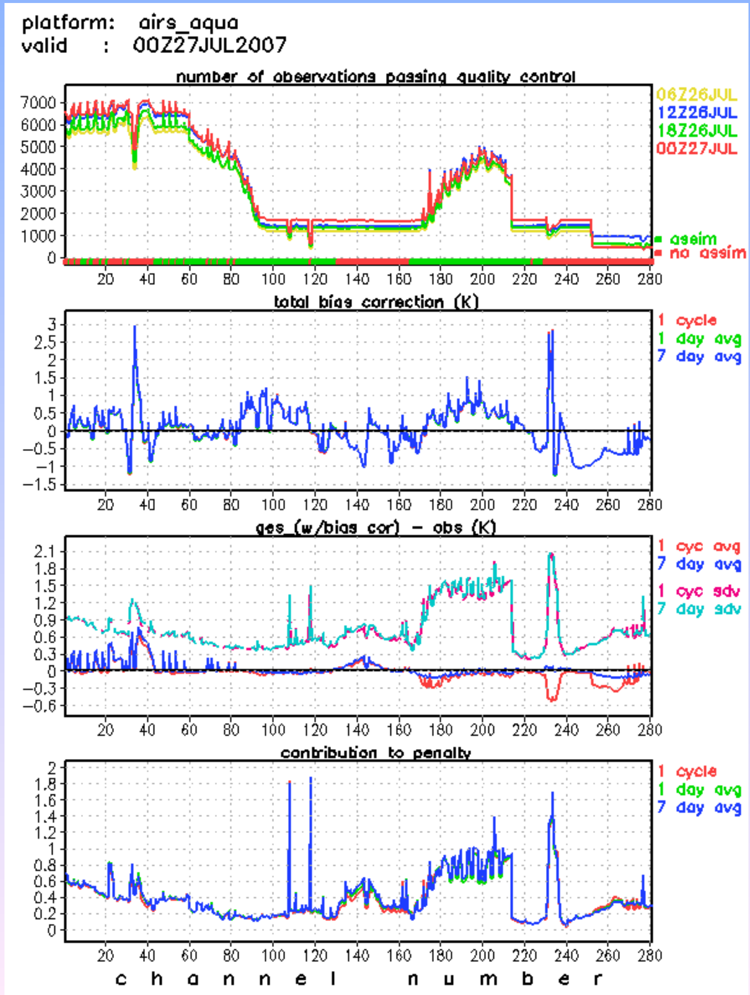
AIRS Channel 453 26 March 2007



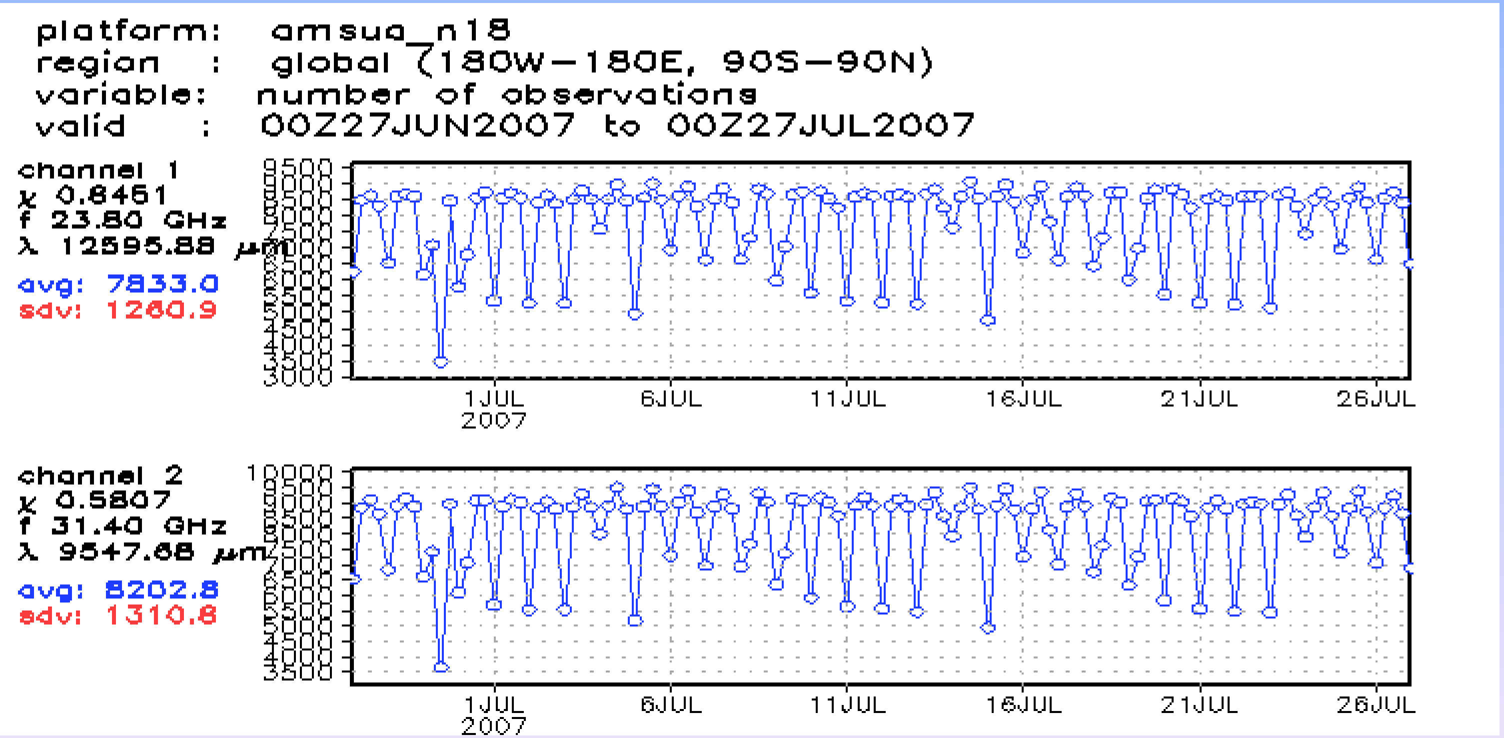
Increase in SD Fits to Guess

Summary Plots

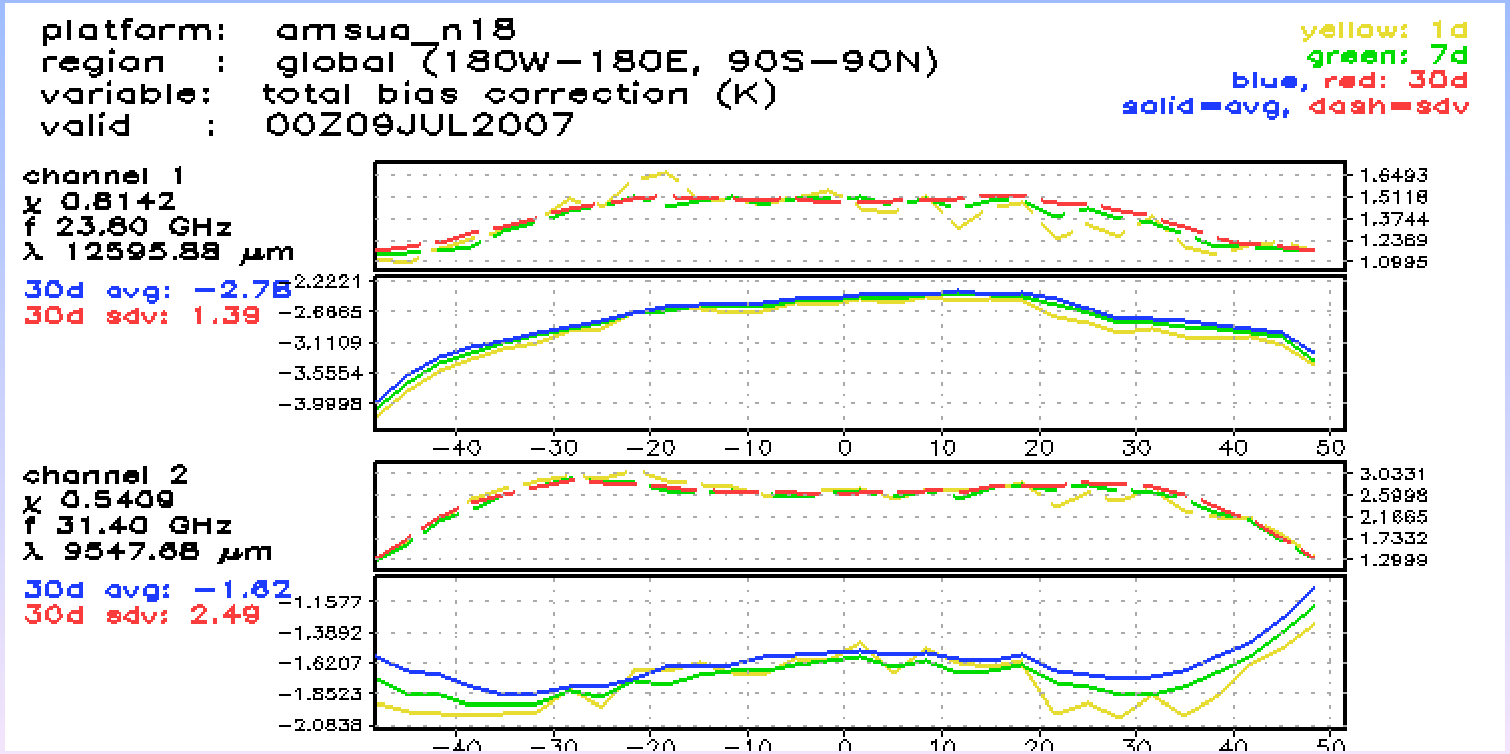




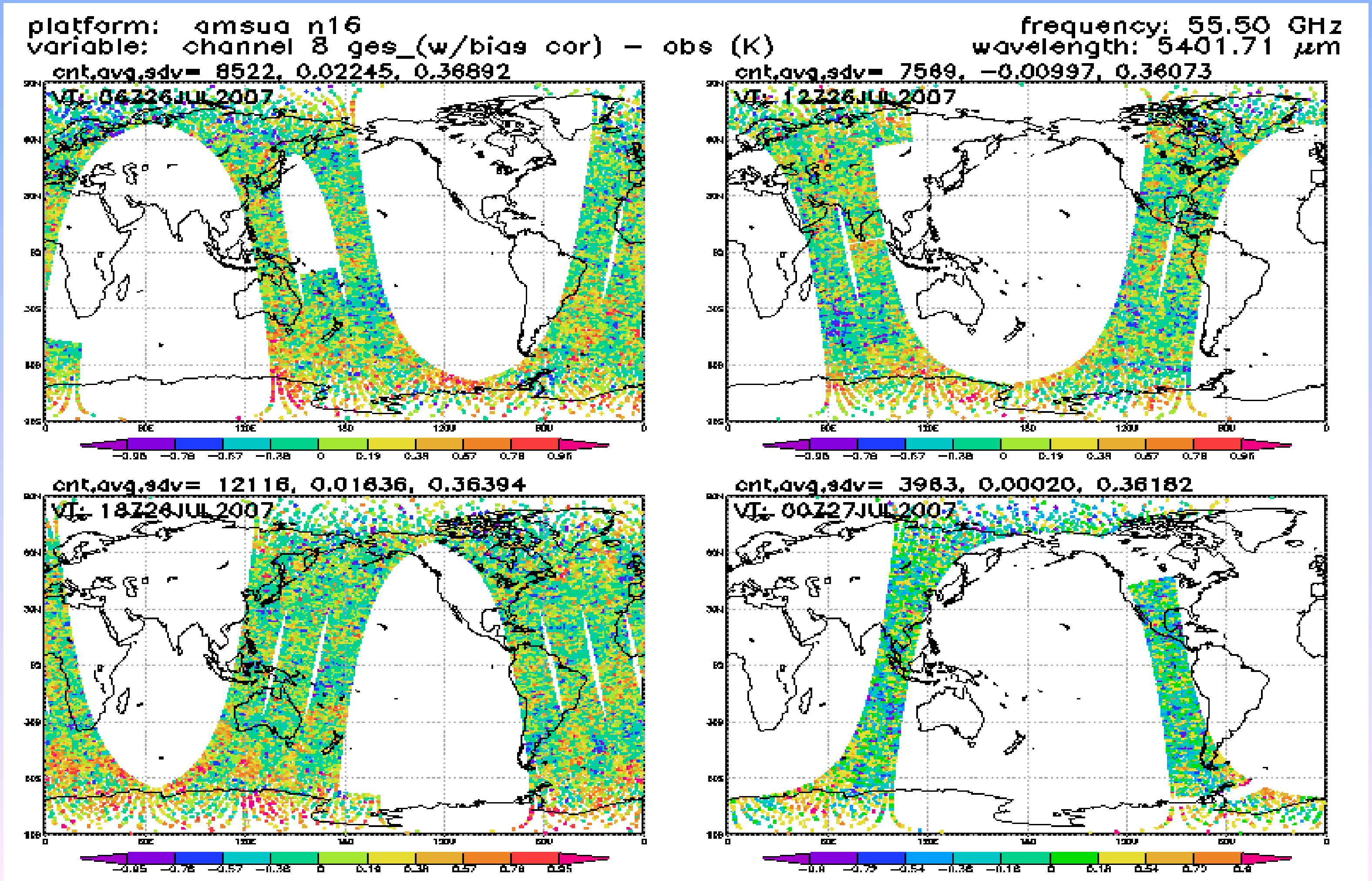
Data counts


platform: amsua_n18
region : global (180W-180E, 90S-90N)
variable: number of observations
valid : 00Z27JUN2007 to 00Z27JUL2007
channel 1
χ 0.8451
f 23.80 GHz
λ 12595.88 μm
avg: 7833.0
sdv: 1260.9
1JUL
2007
6JUL
11JUL
16JUL
21JUL
26JUL
channel 2
χ 0.5807
f 31.40 GHz
λ 9547.68 μm
avg: 8202.8
sdv: 1310.8
10000
3500

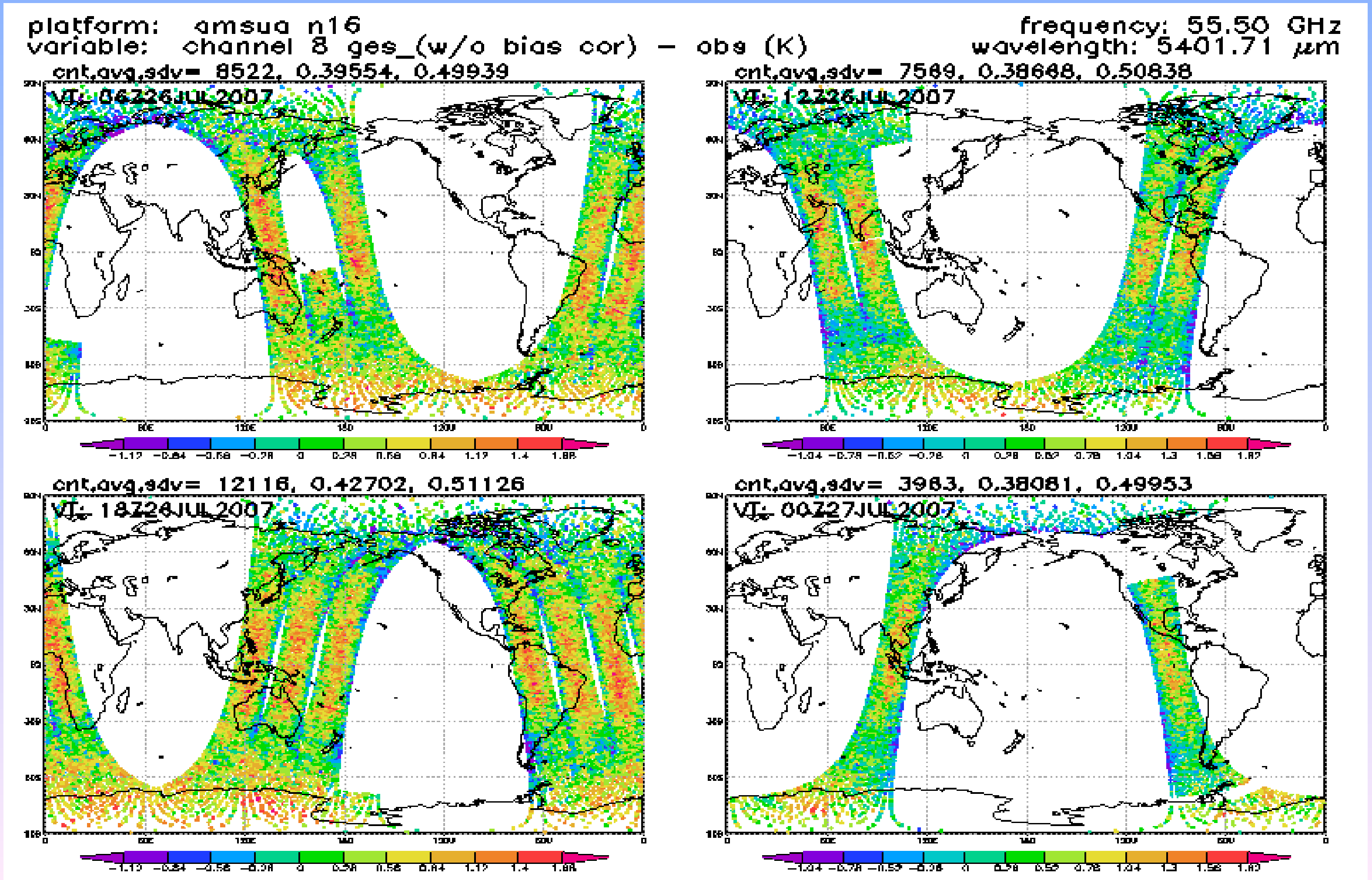
Total bias correction



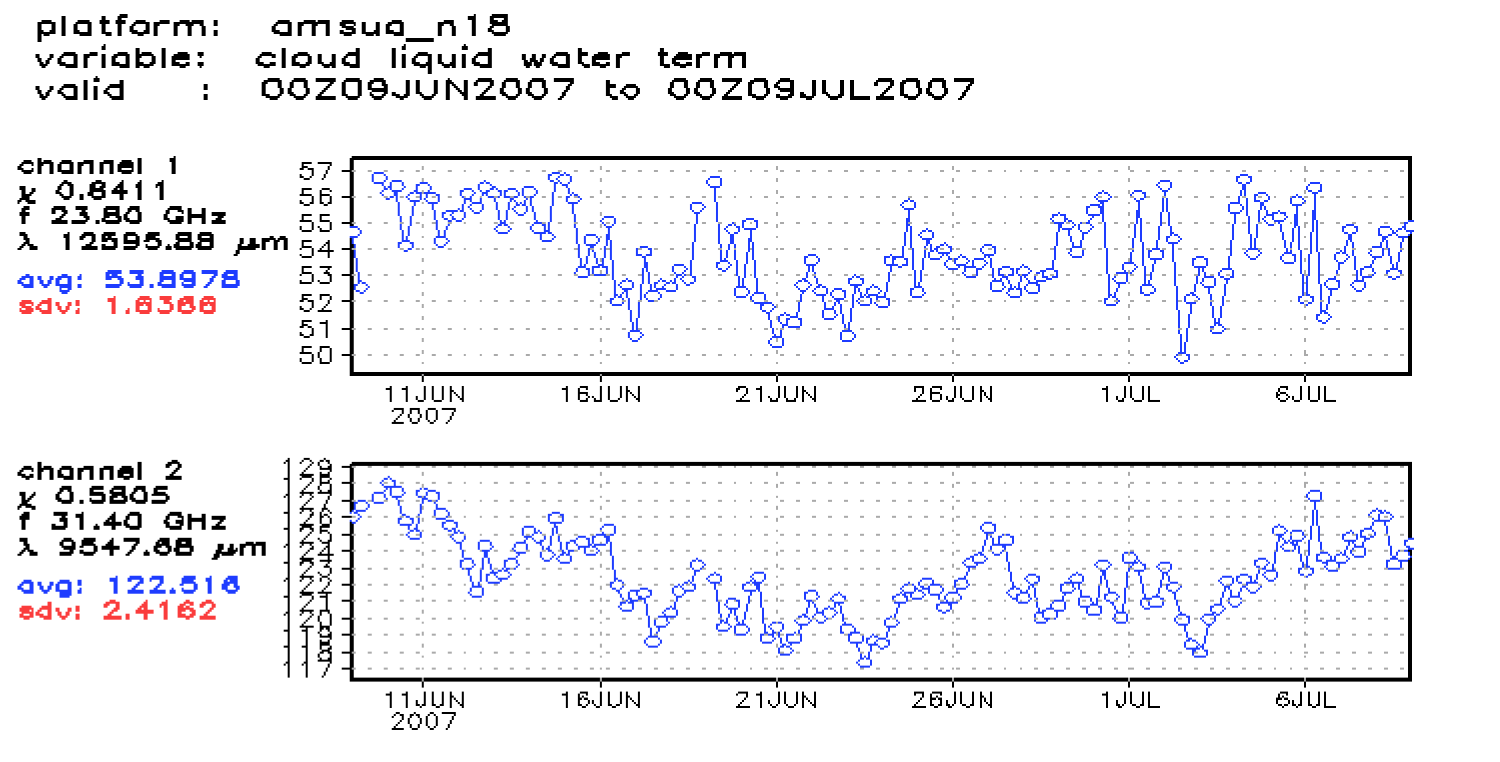
Horizontal o-g (bias corrected)



Horizontal o-g (not bias corrected)



Bias Coefficients

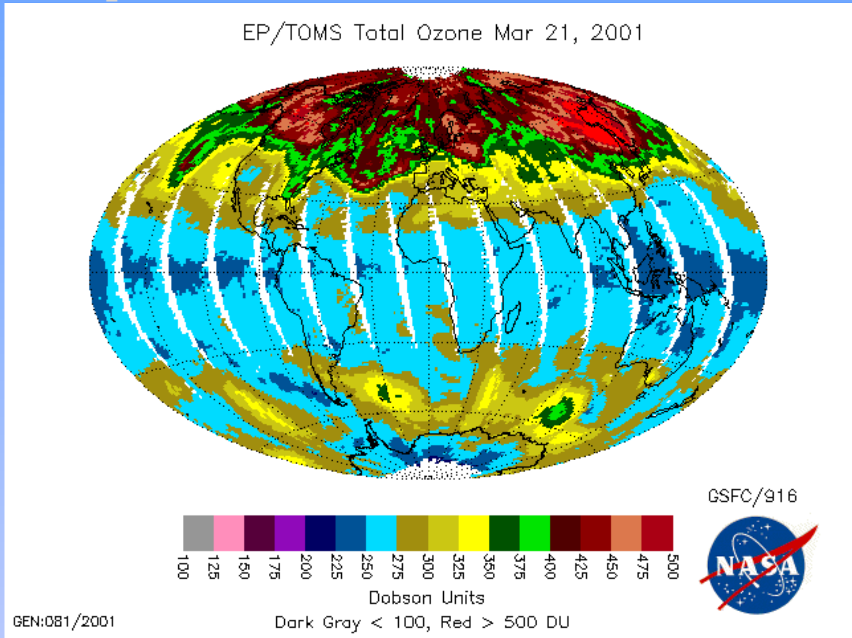


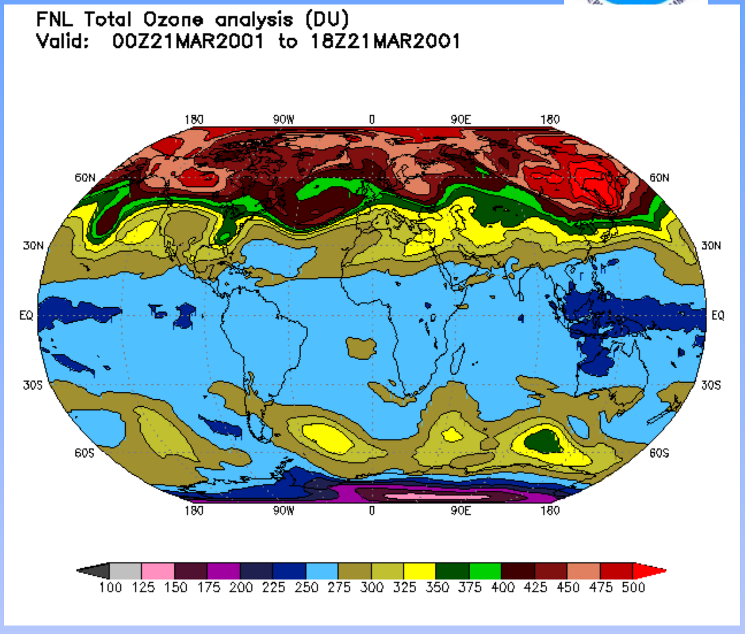
Data Monitoring

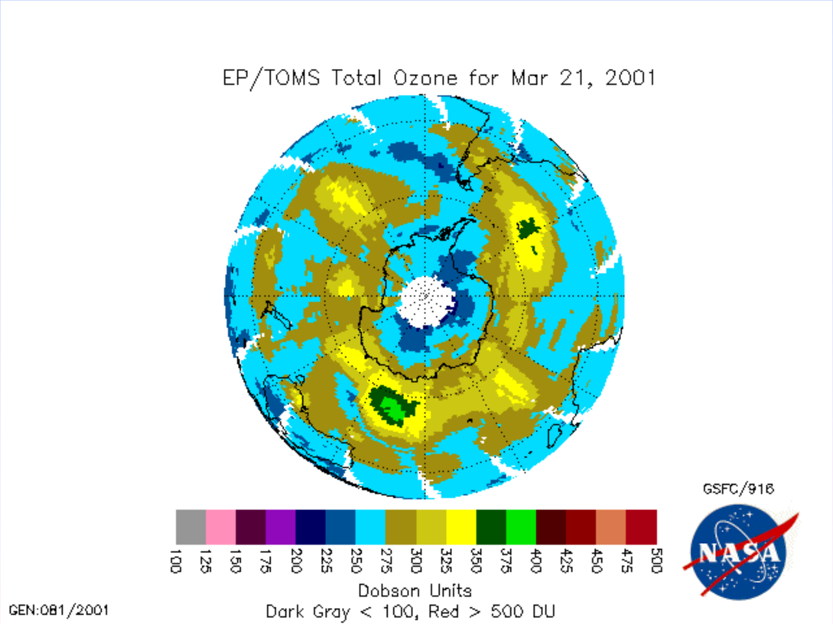
- ITSC web site listing monitoring from many centres
  http://cimss.ssec.wisc.edu/itwg/nwp/monitoring.shtml
- NCEP web site
  http://www.emc.ncep.noaa.gov/gmb/gdas/radiance/su/opr/index.html

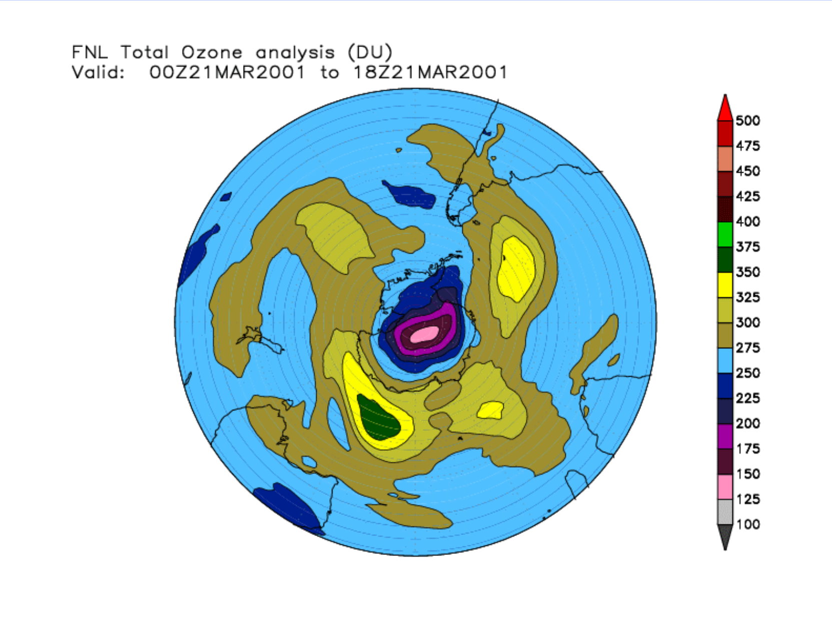
Data impact

- Satellite data extremely important part of observation system.
- Much of the improvement in forecast skill can be attributed to the improved data and the improved use of the data
- Must be measured relative to rest of observing system – not as stand alone data sets
- Extremely important for planning ($$$$)

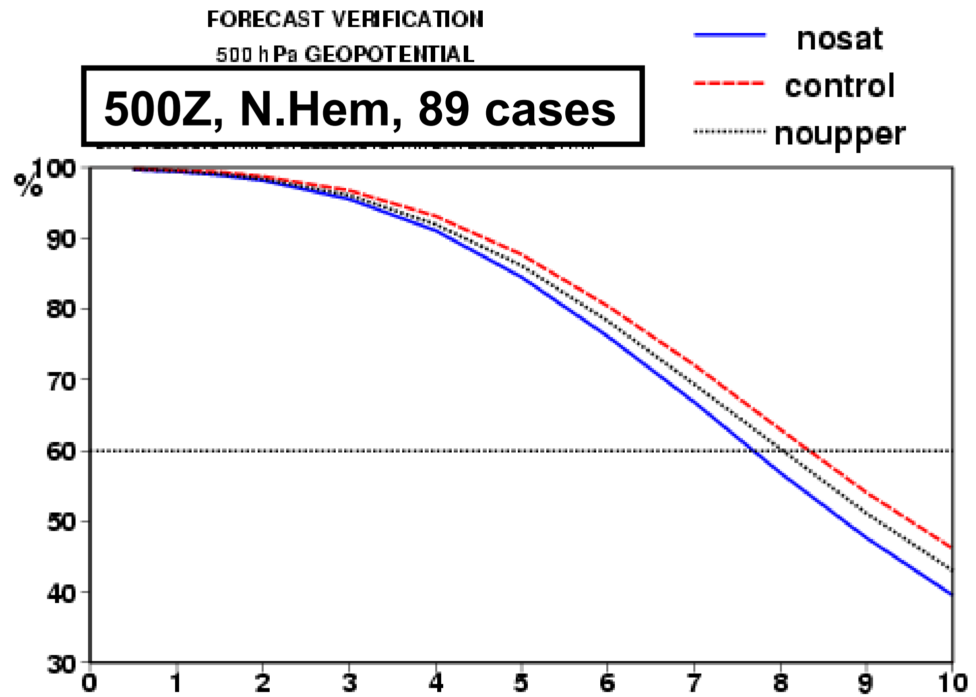

EP/TOMS Total Ozone Mar 21, 2001
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Dobson Units
Dark Gray < 100, Red > 500 DU
GSFC/916
NASA
GEN:081/2001

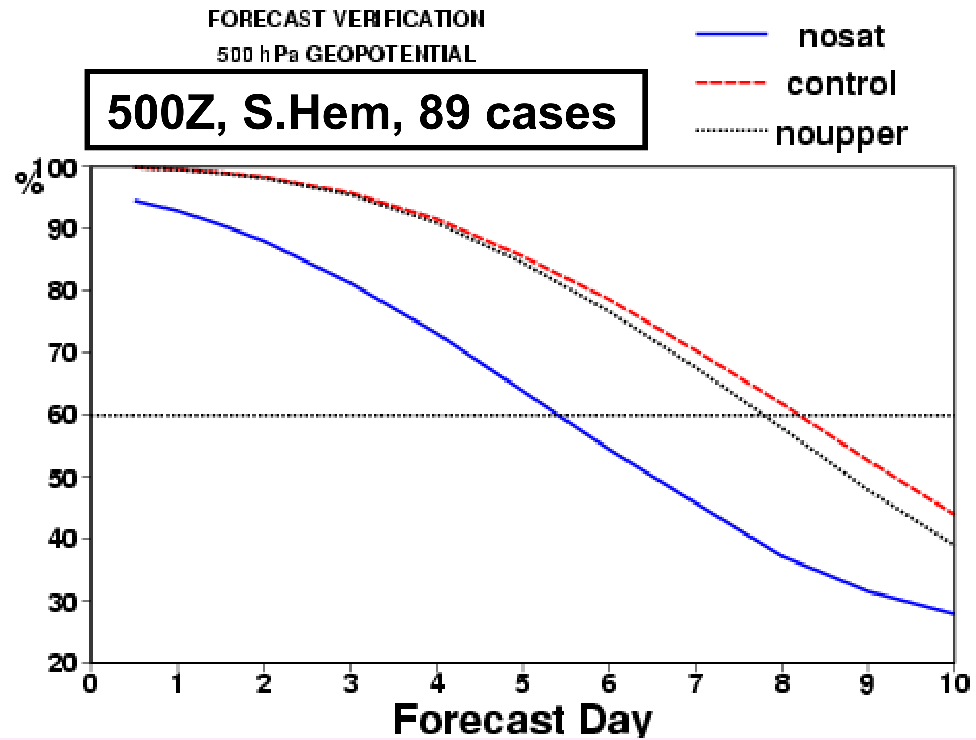

FNL Total Ozone analysis (DU)
Valid: 00Z21MAR2001 to 18Z21MAR2001
180 90W 0 90E 180
60N 30N EQ 30S 60S
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500


EP/TOMS Total Ozone for Mar 21, 2001
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Dobson Units
Dark Gray < 100, Red > 500 DU
GSFC/916
NASA
GEN:081/2001


FNL Total Ozone analysis (DU)
Valid: 00Z21MAR2001 to 18Z21MAR2001
500 475 450 425 400 375 350 325 300 275 250 225 200 175 150 125 100

Observing System Experiments (ECMWF - G. Kelly et al.)

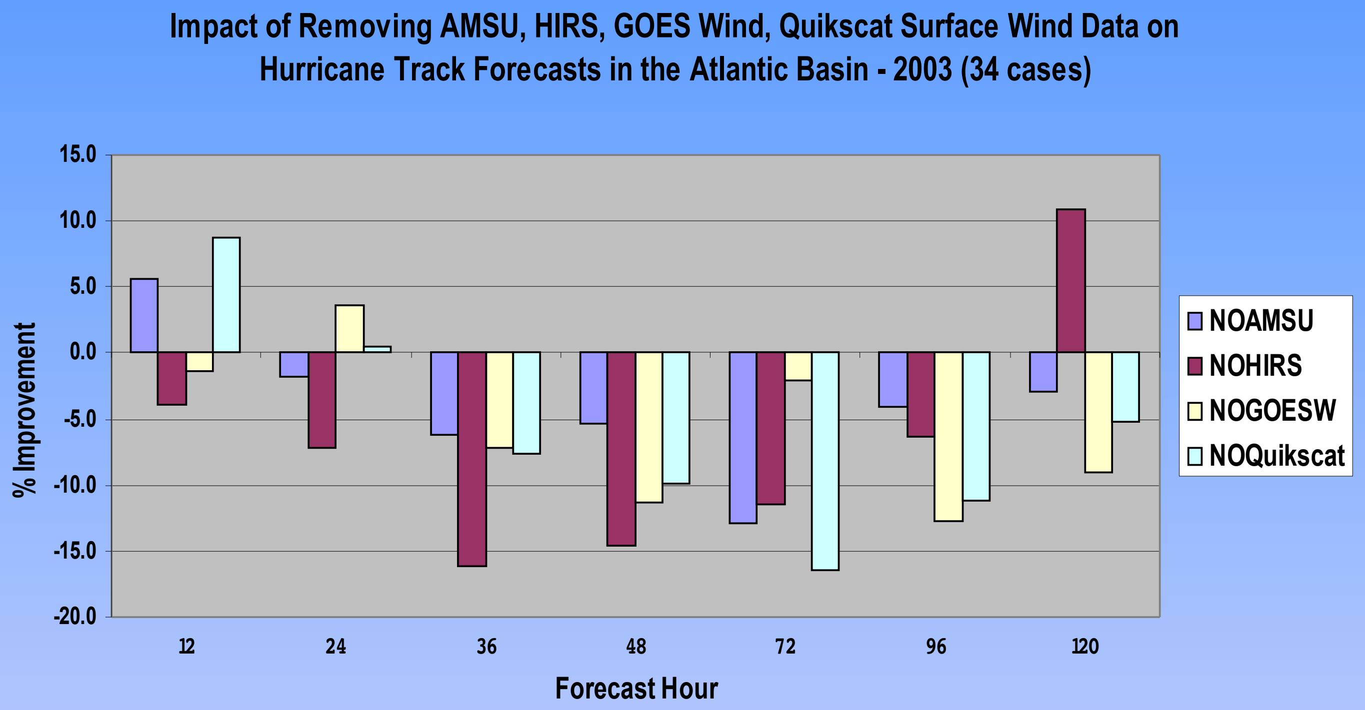




NoSAT= no satellite radiances or winds

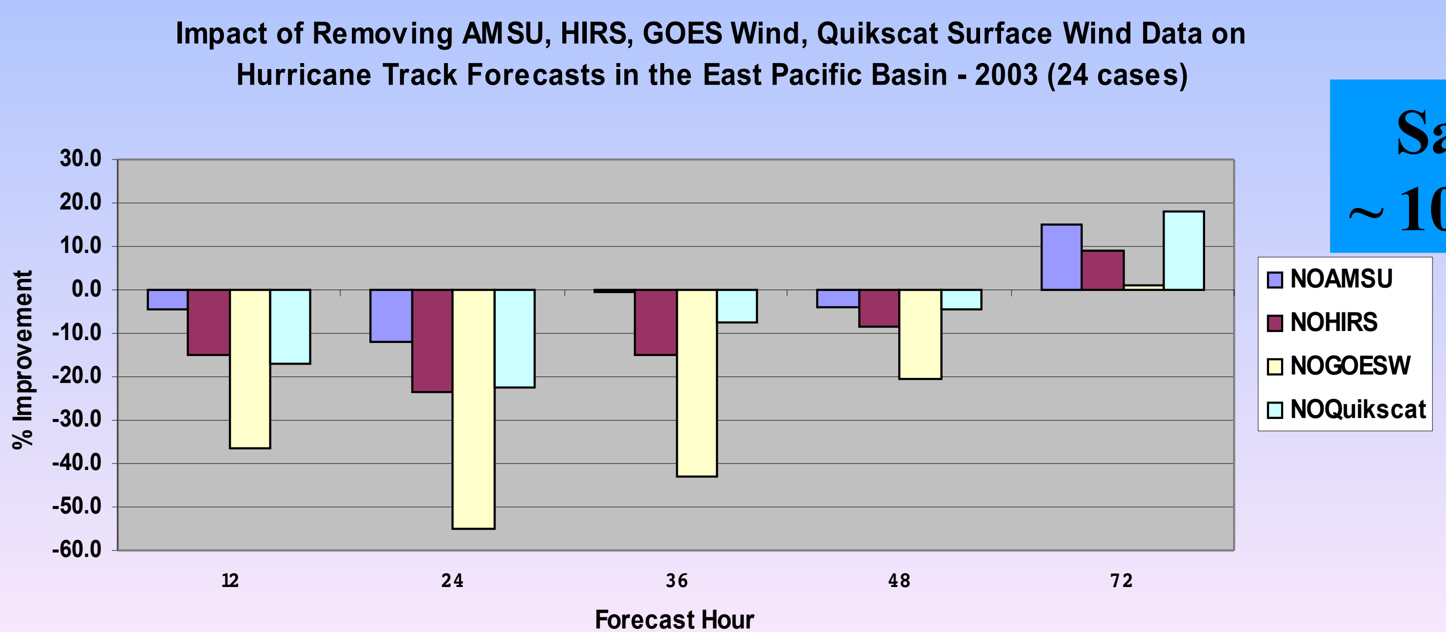
Control= like operations

NoUpper=no radiosondes, no pilot winds, no wind profilers



Jung and Zapotocny

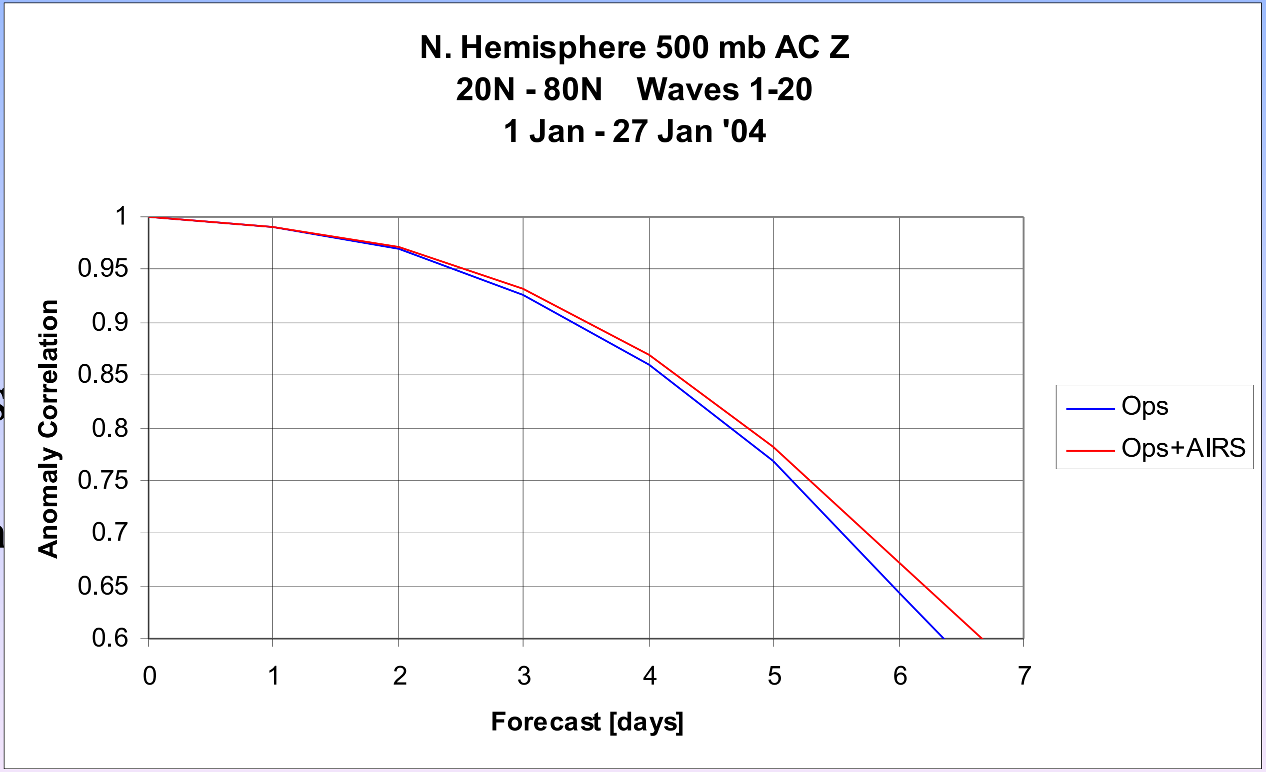
JCSDA Funded by NPOESS IPO



Satellite data ~ 10-15% impact

JCSDA AIRS Testing

- NCEP operational system
  - Includes first AIRS data use
- Enhanced AIRS data use
  - Data ingest includes all AIRS footprints
  - 1 month at 55 km resolution
  - Standard data selection procedure



Summary

- Operational data assimilation of satellite data requires:
  - Data available in real time in acceptable format
  - Necessary information in data file
  - A stable data source
  - Quality control procedures to be defined
  - Bias correction and observational errors defined
  - An accurate forward model
  - Data monitoring
  - Evaluation and testing to ensure neutral/positive impact

Additional information

- International TOVS Working Group (ITWG) – just radiances but still very useful http://cimss.ssec.wisc.edu/itwg/nwp
- NOAA POES status http://www.oso.noaa.gov/poesstatus/
- NOAA GOES status http://www.oso.noaa.gov/goesstatus/

Future

- New satellite data types/uses
  - Imagery (especially 4D) replacing AMWs
  - Use of cloud information in imager/sounders
  - New quantities – aerosols, constituent gases, surface parameters, etc.
  - Wind lidars
  - etc.

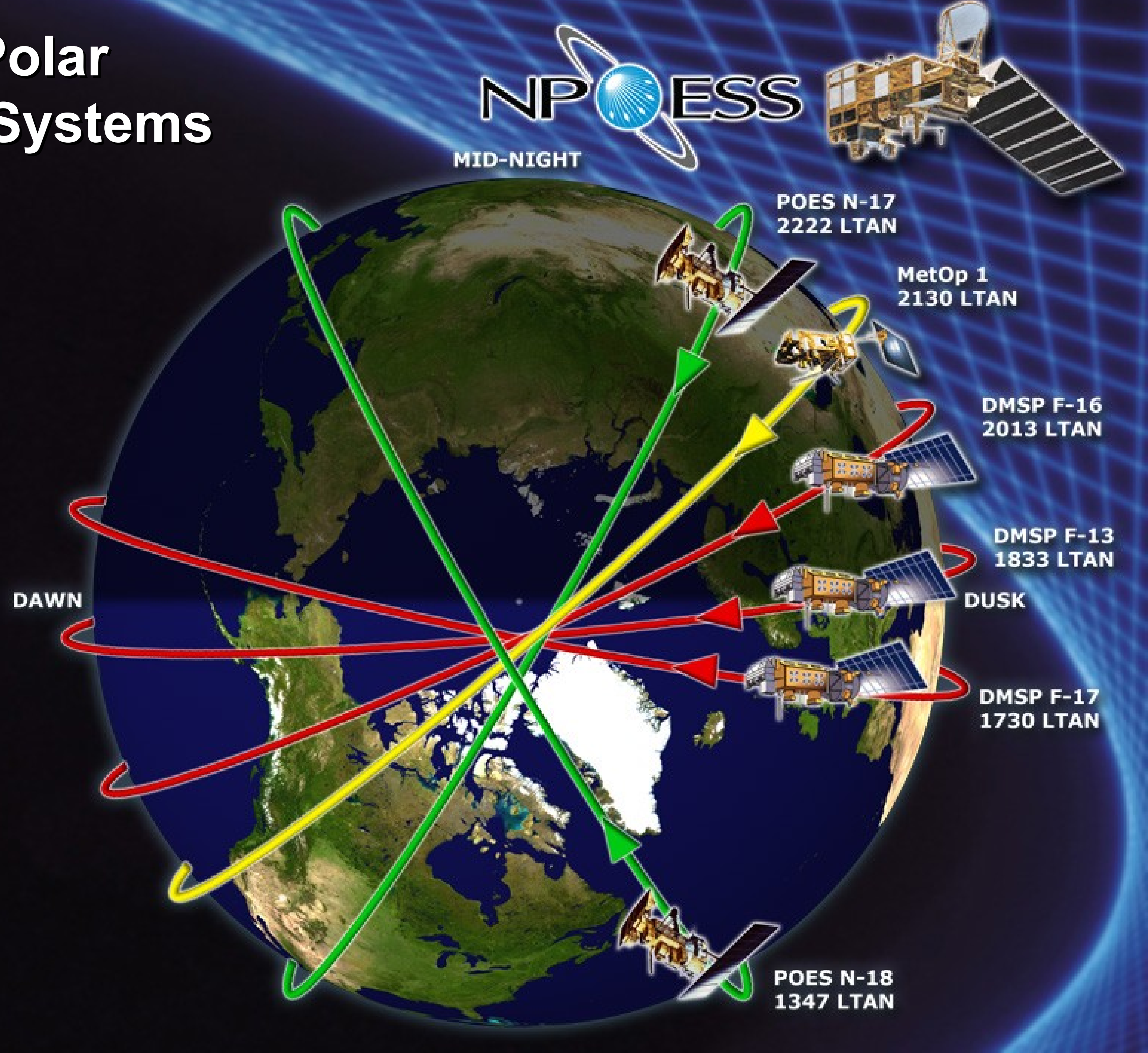
Future

- Many new "enhanced" instruments METOP/NPP/NPOESS
- Impact experiments – must be done well
  - All other observations used
  - Accuracy of:
    - Forecast model
    - Observations
    - Simulations of observations
    - Statistical formulations for errors
  - Computing Capability (Determines sophistication of assimilation techniques)

Metop-A (Metop-2)

- Launched 19 October 2006
- Instruments
  - AMSU-A (Advanced Microwave Sounding Units)
  - MHS (Microwave Humidity Sounder)
  - HIRS-4 (High-resolution Infrared Radiation Sounding)
  - IASI (Infrared Atmospheric Sounding Interferometer)
  - GOME-2 (Global Ozone Monitoring Experiment)
  - GRAS (Global navigation satellite system reciever for Atmospheric Sounding)
  - ASCAT (Advanced Scatterometer)
  - AVHRR (Advanced Very High Resolution Radiometer)

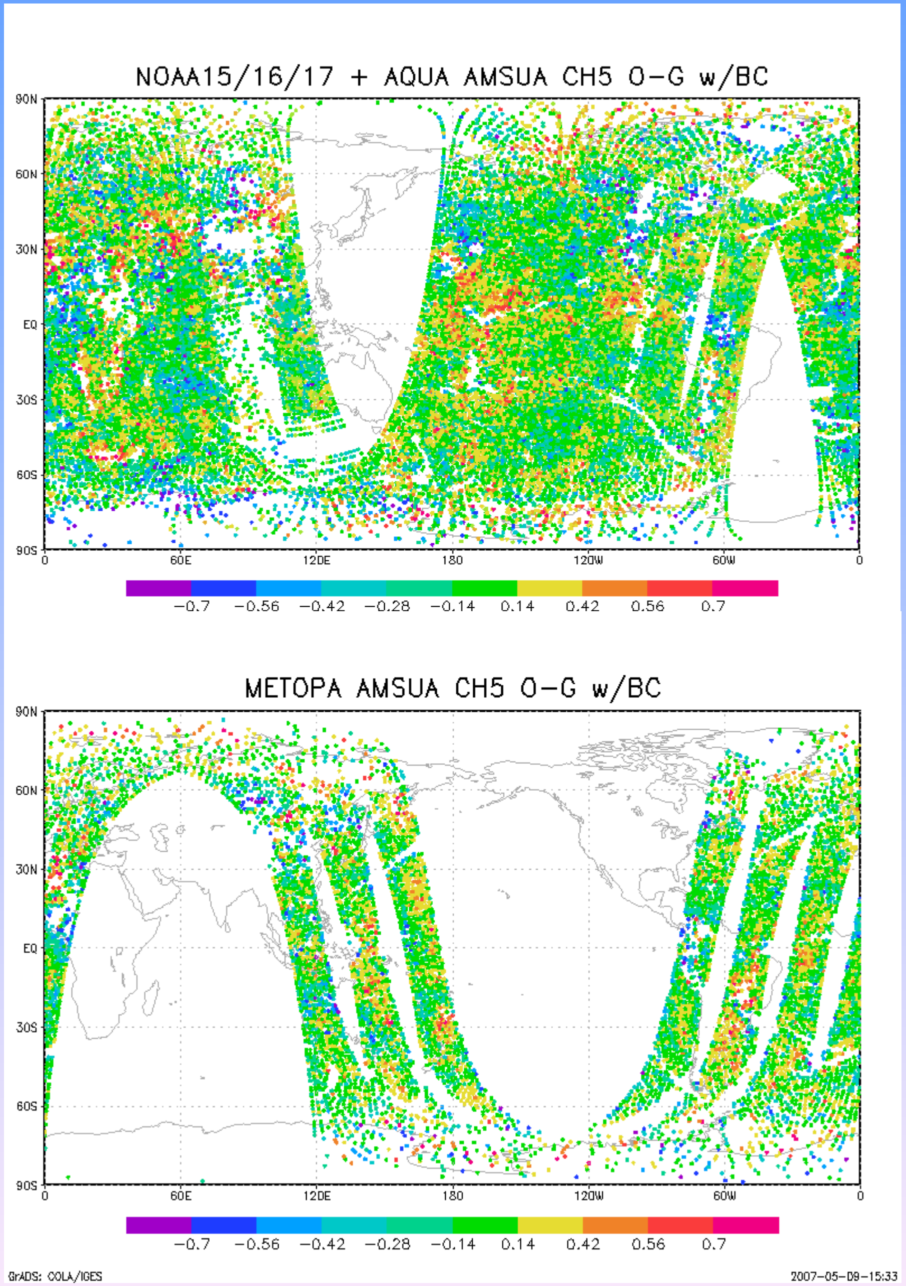
Current Polar Orbiting Systems



Metop-A (Metop-2)

- Heritage Instruments
  - AMSU-A
  - HIRS-4
  - AVHRR
  - MHS
  - Operationally using AMSU, HIRS, MHS

Operational AMSUA CH5 vs METOP



2007050812 GDAS cycle

Metop-A (Metop-2)

New instruments

- GRAS
  - GPS receiver similar to COSMIC, CHAMP, etc.
  - Usage under development – but should be similar to COSMIC (advantage of GPS-RO observations)
  - Sensitive to temperature, moisture profiles
- GOME-2
  - Measures absorption of reflected solar radiation
  - Measures O_3, NO_2, SO_2

Metop-A (Metop-2)

New instruments

- ASCAT
  - Active radar – backscatter measurement
  - 3 antenna for each swath (2 swaths)
  - Observing “same” backscatter from 3 directions
  - Find speed/direction which best fits observations
  - Impacted by clouds/precipitation
  - Directional ambiguity tough

Metop-A (Metop-2)

New instruments

- IASI
  - Produces high spectral resolution IR measurements of the atmosphere
  - Similar to AIRS except interferometer measurement more prone to correlated errors
  - Usage under development
  - Sensitive to temperature, moisture, cloud tops, surface temperature, surface emissivity, integrated O_3, CO, CH_4, N_2O
  - Clouds intercept signal

NPOESS Preparatory Project (NPP)

- Transition mission between DMSP/NOAA and NPOESS
- Major instruments from NPOESS (without improved communication)
- Still changing
- Launch date "about 2009"

NPOESS Preparatory Project (NPP)

- Instruments
  - VIIRS (Visible/Infrared Imager/Radiometer Suite)
    - Higher resolution/more bands version of AVHRR
  - ATMS (Advanced Technology Microwave Sounder)
    - Similar to AMSU-A/B – MHS (with 2 more channels)

NPOESS Preparatory Project (NPP)

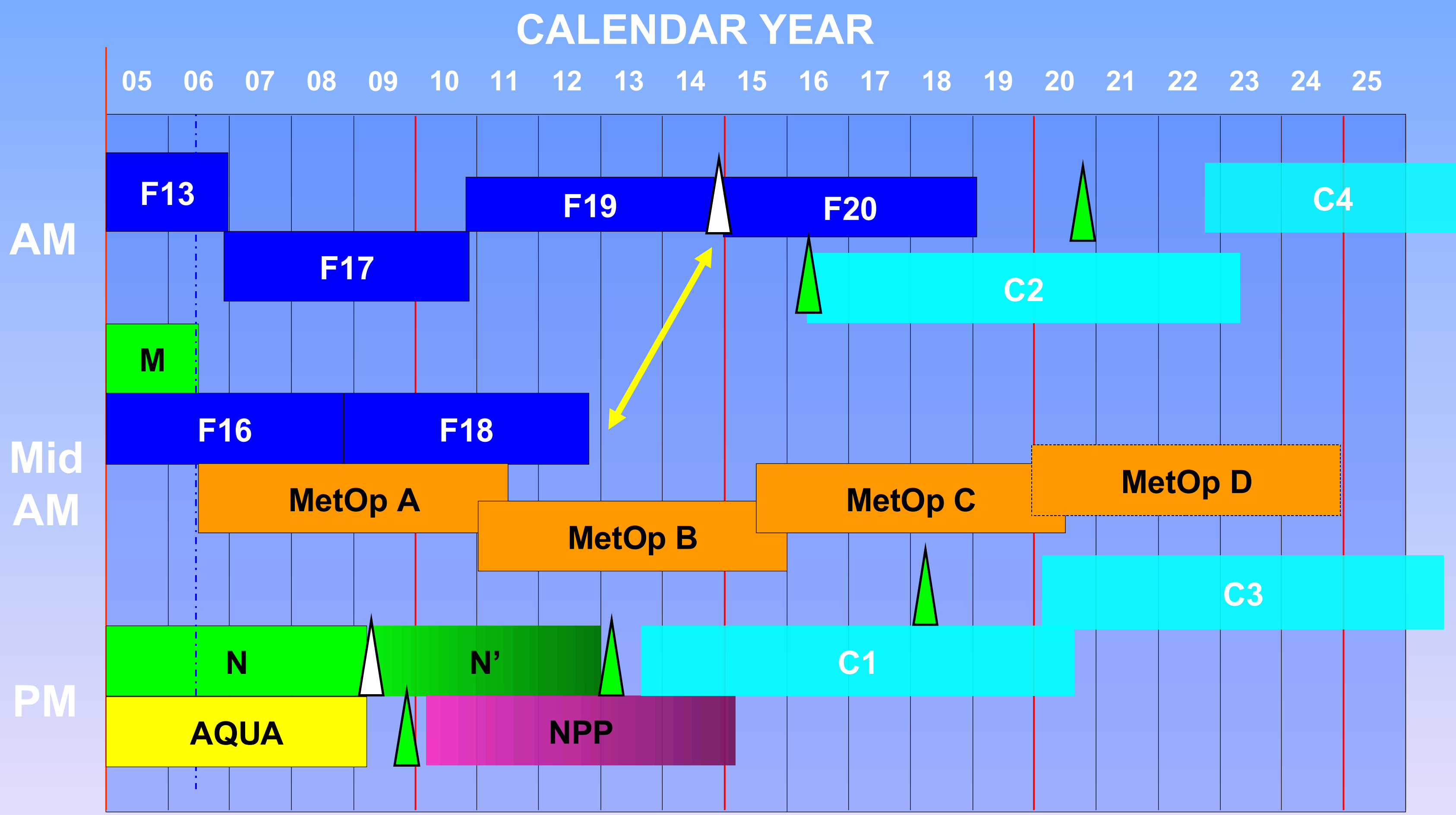
- Instruments
  - CrIS (Cross-track Infrared Sounder)
    - Interferometer based (more correlated errors?)
    - Clouds
  - OMPS (Ozone Mapping and Profiler Suite)
    - Measures along-track limb scattered solar radiance
    - Scanning instrument provides profiles of ozone

NPOESS

- National Polar-Orbiting Operational Environmental Satellite System (NPOESS)
- Contains NPP instruments +
  - Perhaps a conical scanning microwave instrument
- Troubled program – additional changes likely in my opinion

NPOESS
MetOp
09:30
NPOESS
13:30
NPOESS
17:30

NPOESS Flight Schedule



NPOESS and METOP team up to replace Heritage Systems

Future

- Rational decision process for observing system design
  - Politics and money are important for satellite data
  - How to determine relative importance for new instruments?– OSSEs?
- Tremendous volume of satellite data coming in the future from a wide variety of instruments
- Development of the proper data handling systems and models to simulate this data will be necessary

Final Comments

- The presence of satellite has virtually eliminated data voids.
- Satellite data must be used carefully because of biases or correlated errors in the data or processing.
- Still lots of work to be done
  - Difficult to even keep up with current programs
- At NCEP we currently have projects underway to use:
  - METOP IASI
  - AVHRR
  - GOES imagery
  - AMSR-E
  - SSM/IS radiances

Final Comments
(Opinion based on experience)

- For NWP, satellite radiances most important satellite observation
  - Microwave radiances more useful than IR radiances because of clouds
- More observations are not always better
- Impact of new instruments never as large as predicted by instrument advocates
  - Instruments justified based on NWP impacts
- Larger improvement usually occurs because of improvement to assimilation systems than the addition of new data

Final Comments
(Opinion based on experience)

- Most applied research in atmospheric data assimilation done at operational centers (and GSFC DAO)
- Much of expertise and knowledge is undocumented or minimally documented – papers are not the priority at operational centers
- Many opportunities to use new observations and to improve forward models for DA.
- Data assimilation is where everything comes together
  - To use new observations properly requires one to become an expert in that particular instrument
  - One must be knowledgeable on forecast model dynamics and physics to understand background errors
  - Computational techniques are necessary to improve efficiency

Final Comments
(Opinion based on experience)

- Very few satellite programs justified by their impact on data assimilation actually account for data assimilation in their program
  - Cost and time necessary to assimilate data
  - Necessary data communication and data formatting problems
  - Impact on computing resources
  - AIRS and COSMIC exceptions
- To properly provide data assimilation input to satellite programs is a huge time investment.
  - There are an infinite number of satellite meetings

Final Comments
(Opinion based on experience)

- It is great to be involved in the operational side of data assimilation – it allows you to see the data used and have an impact!