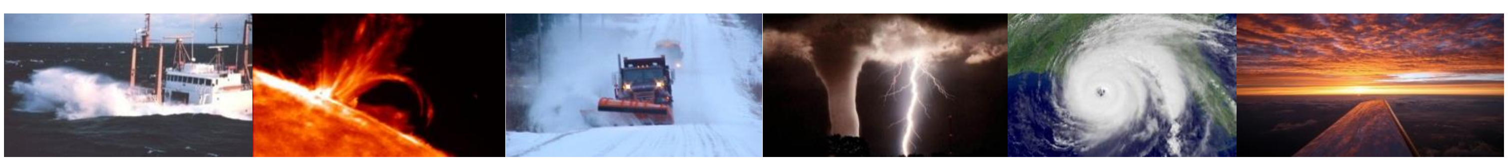
Assimilation of satellite data for meteorology

Presented by John Derber
National Centers for Environmental Prediction

ECMWF Seminar
September 8 - 12, 2012



"Where America's Climate, Weather, Ocean and Space Weather Services Begin"

Presentation Outline

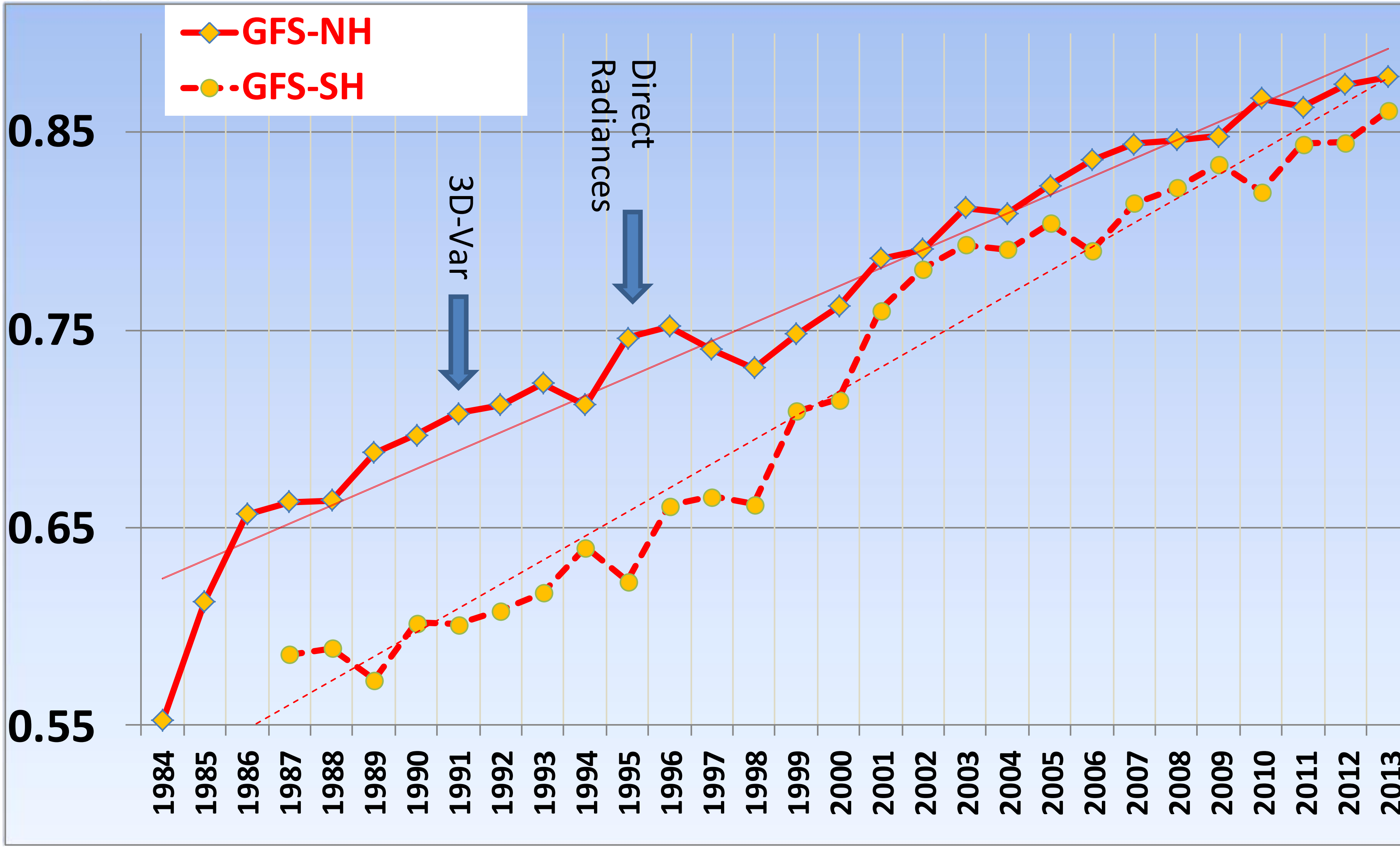
- Some history for use of satellite data and data assimilation

- Data assimilation basics

- Additional considerations for satellite observations

- Challenges

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation



History

- Early experiments indicated positive impact of use of satellite retrievals in DA systems.   Some positive operational impacts.
- By late 1980's, results were much more mixed among operational and research centers.

- J. Eyre presentation in ECWMF Seminar on "Recent Development in the Use of Satellite Observations in NWP", 3-7 Sept 2007 gives more complete history

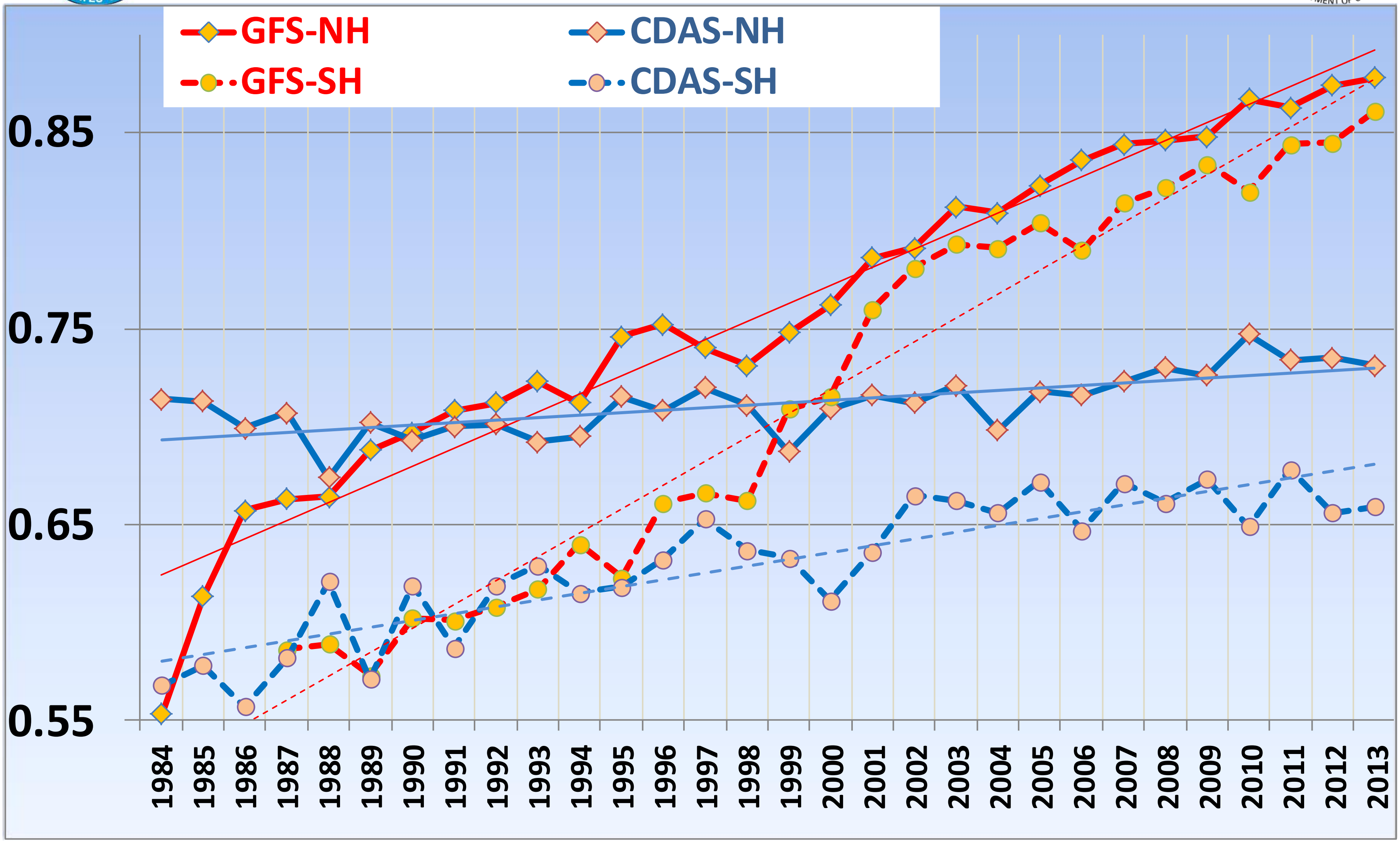
History

- Problems with satellite retrievals and use of satellite data in late 1980’s.
  – Retrievals created to make radiosonde look-alikes through the solution of ill-posed problems.
  – Correlated error introduced by retrieval process
    - Correlated error from in background (guess) used in retrieval process
    - Additional correlated error introduced by errors in retrieval process
    - Difficult to model
  – QC issues with retrievals (detecting clouds/precip)
  – Became clear that the treatment of retrievals as poor quality radiosondes, was not correct.

History

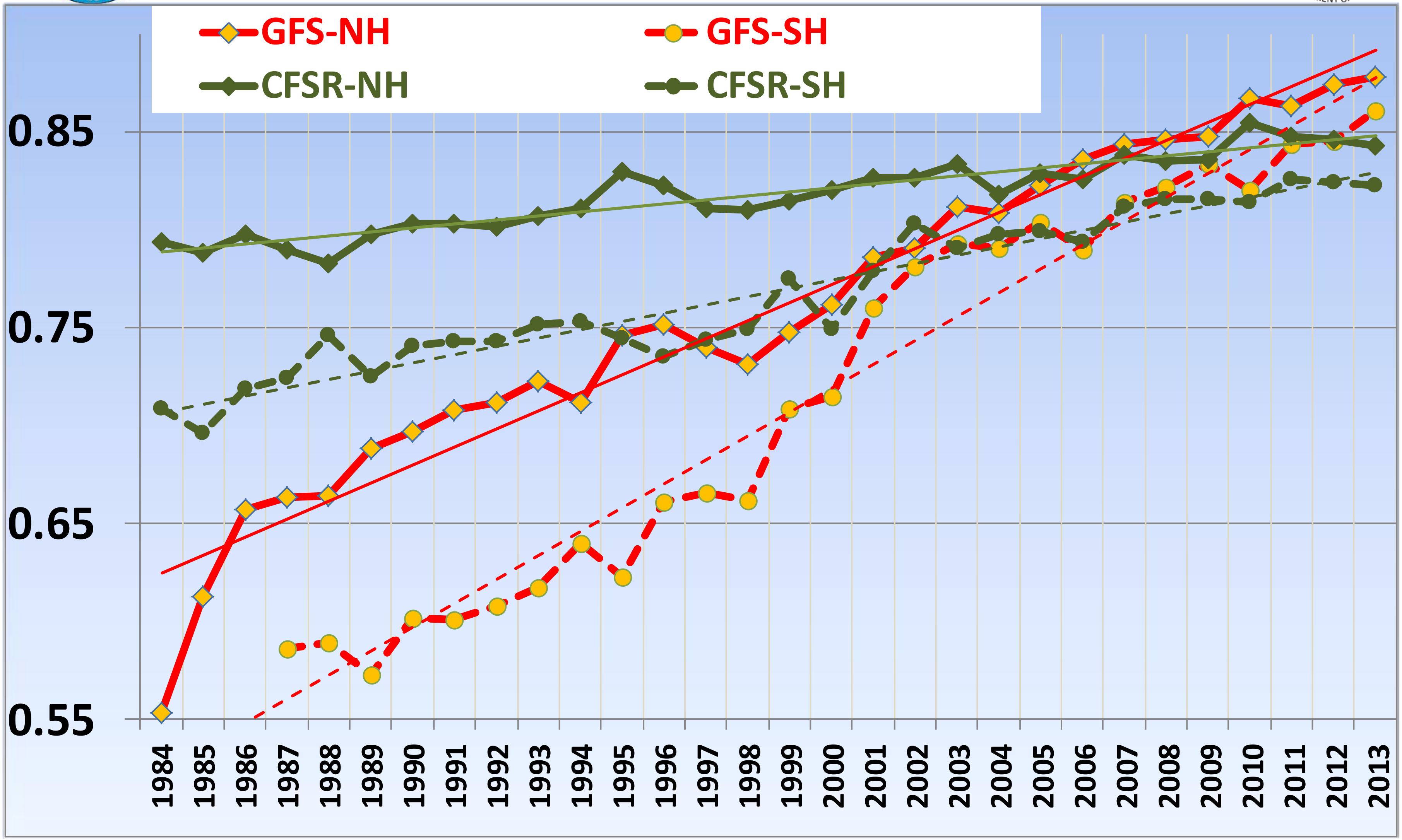
- With development of variational assimilation techniques in early 1990's possibility of directly using radiances became possibility.
  - Analysis variables do not have to be same as model variables
  - Analysis variables do not have to be same as observation variables
  - All observations used at once
- Use of satellite observations very linked to developments in data assimilation and modelling (and computing).

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation



CDAS is a legacy GFS (T64) used for NCEP/NCAR Reanalysis circa 1993.

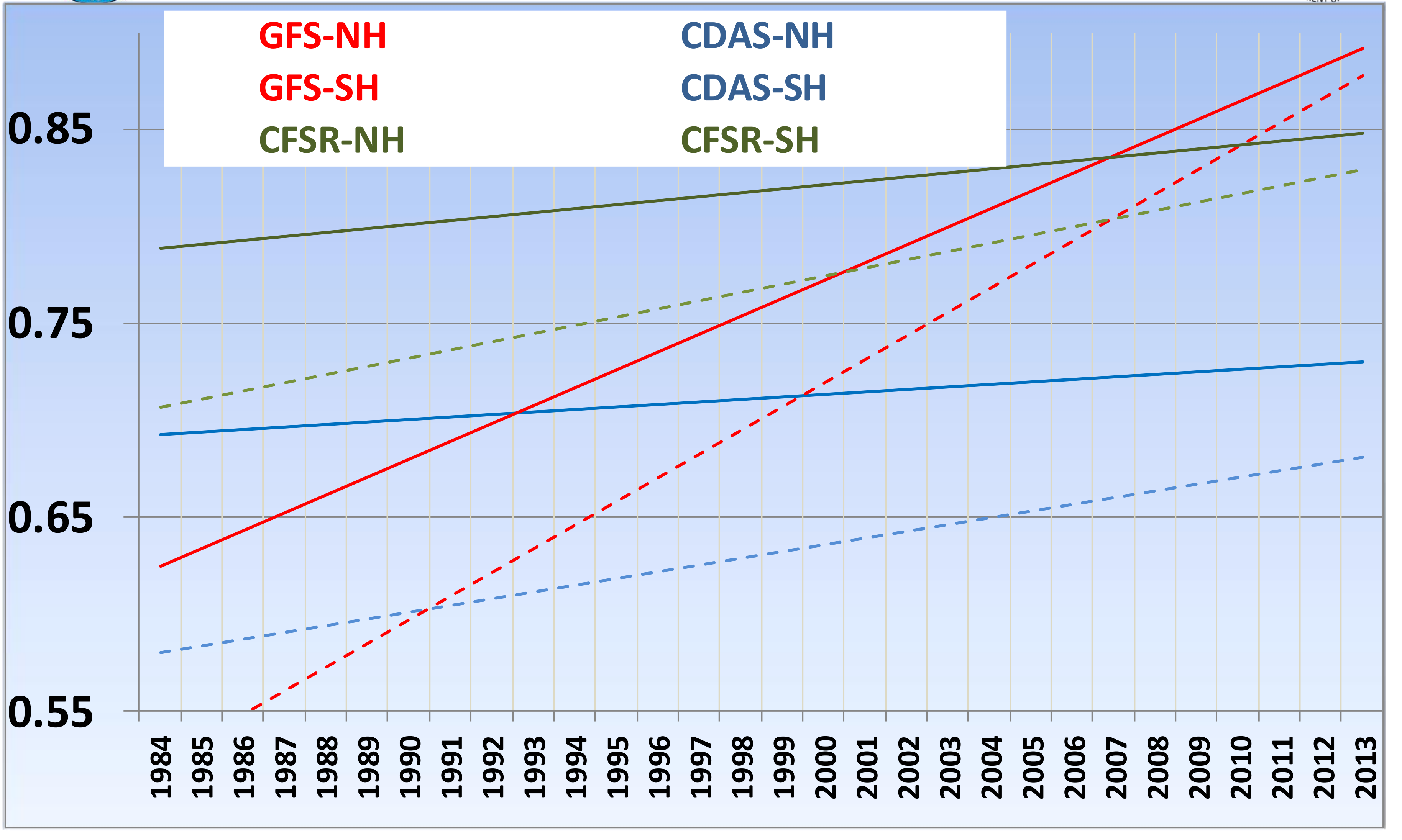
Annual Mean 500-hPa HGT Day-5 Anomaly Correlation



.

CFSR is the coupled GFS (T126) used for reanalysis circa 2006.

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation



CDAS is a legacy GFS (T64) used for NCEP/NCAR Reanalysis circa 1995.
CFSR is the coupled GFS (T126) used for reanalysis circa 2006.

Data Assimilation

- Bayesian:
  - What is the probability of atmospheric state, x, given observations, y_o?
  - Evaluate: $P(x|y_o) = P(y_o|x).P(x)/P(y_o)$

- Variational(VAR):
  - What is the most probable atmospheric state, x, given observations, y_o?
  - To maximize $P(x|y_o)$, maximize: $\ln\{P(x|y_o)\} = \ln\{P(y_o|x)\} + \ln\{P(x)\} + \text{constant}$
  - If PDFs are Gaussian and no biases, then minimize a penalty (or cost) function,

$$J[x] = \tfrac{1}{2}(x-x_b)^T B^{-1} (x-x_b) + \tfrac{1}{2}(y_o-H[x])^T (E+F)^{-1} (y_o-H[x])$$

Data Assimilation

- Physical retrievals and variational assimilation both use similar penalty functions
  - Physical retrievals – 1D
  - Atmospheric assimilation 3 or 4D
  - Possibly different background errors
  - Physical retrieval with same background as assimilation can be made same as direct use of radiances with proper specification of observation error (also assume linearity of RT model). Must transfer non-sparse retrieval error covariance matrix to analysis.
  - Quality control and bias correction also best done in radiance space

Data Assimilation

- Look at the penalty function more closely

$$J[x] = J_b \text{ (fit to background) } + J_o \text{ (fit to observations)}$$

$$J[x] = \tfrac{1}{2}(x-x_b)^T B^{-1} (x-x_b) + \tfrac{1}{2}(y_o-H[x])^T (E+F)^{-1} (y_o-H[x])$$

- Can have third term J_c (fit to constraints)
  - E.g., moisture > 0, conservation of mass, etc.

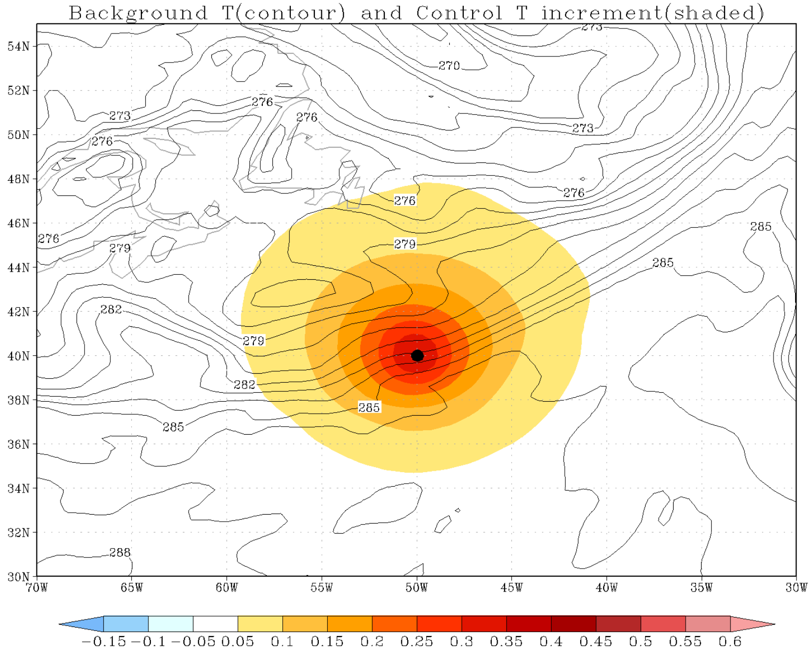
- More details in Lorenc presentation

Data Assimilation

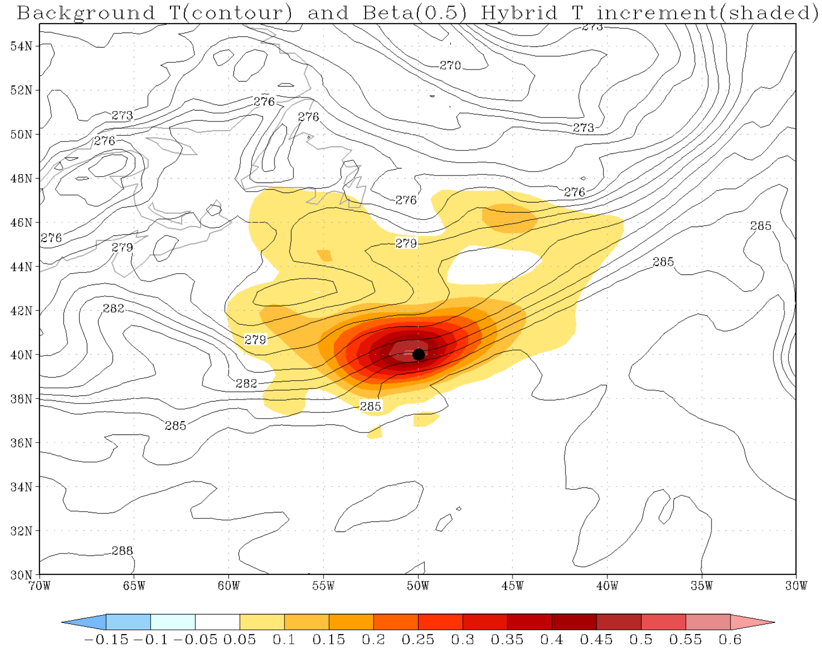
- Background term $(\frac{1}{2}(x-x_b)^T B^{-1} (x-x_b))$
  - x is analysis variable
    - Does not have to be same as model variables, but must be able to convert to model variables.
  - x_b is the Background term
    - Usually short term forecast
    - Can have as much (or more) information in it as observations
    - Quality of forecast model and previous analysis is important! (Mahfouf presentation)
  - Background error covariance
    - Determines how information is distributed spatially and among analysis variables (Lorenc and Bormann presentations)
    - Situation dependent errors area of current significant development

Single Temperature Observation

Static Covariances



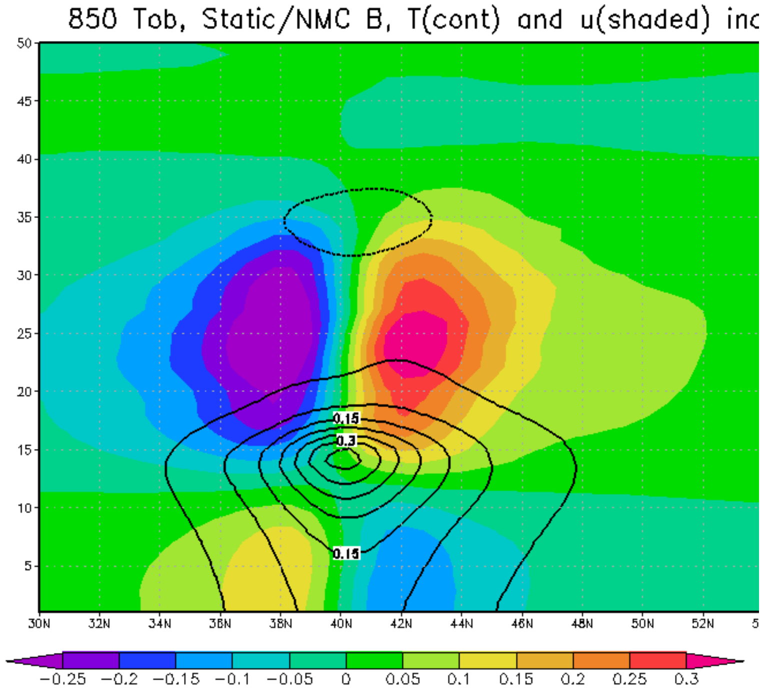
Situation Dependent Covariances



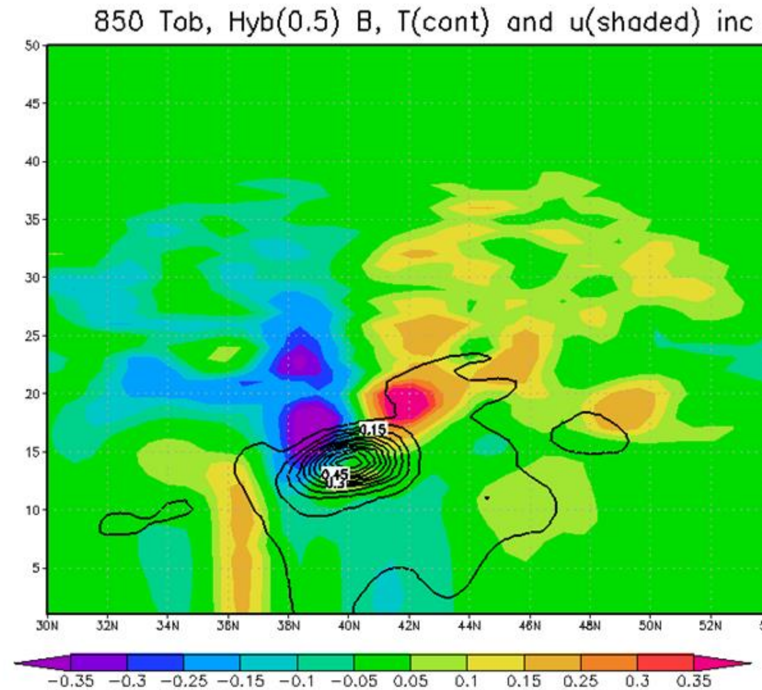
Single 850mb Tv observation (1K O-F, 1K error) – Color
Contours – Background Temperature field

Single Temperature Observation

Static Covariances



Situation Dependent Covariances



Single 850mb Tv observation (1K O-F, 1K error) cross-section – Color Shading u increment, Contours – Temperature increment

Data Assimilation

- Observation term $(\frac{1}{2}(y_o-H[x])^T(E+F)^{-1}(y_o-H[x]))$
  - y_o is vector of all observations used
    - All observations used at once
    - Important to know instrument characteristics (Klaes and Bell presentations)
  - H is forward model
    - Transforms from analysis variable to observed variable
    - May include forecast model to get to observation time (4D-var)

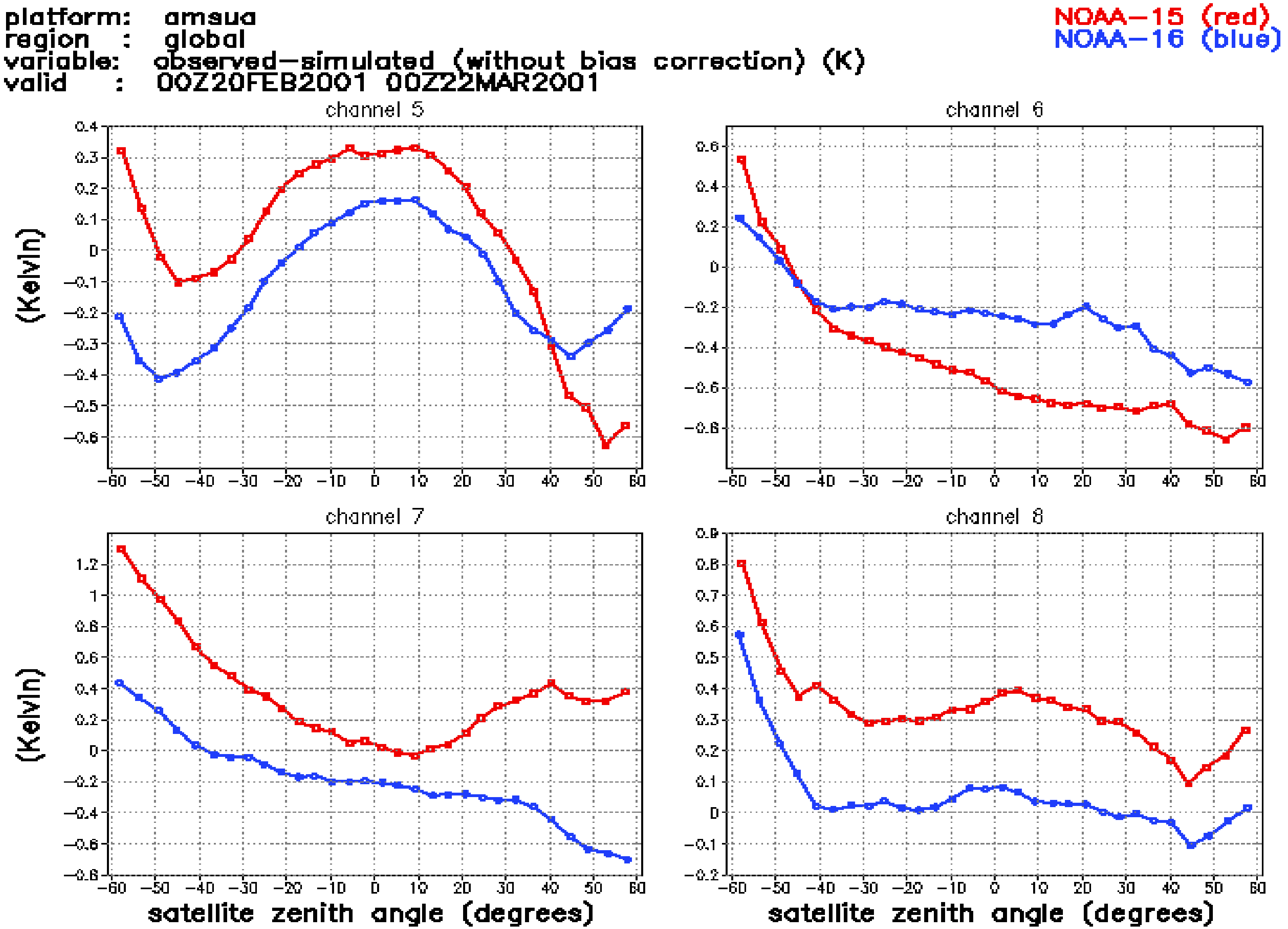
Data Assimilation

- Observation term $(\frac{1}{2}(y_o-H[x])^T(E+F)^{-1}(y_o-H[x]))$
  - E and F is the observation error and representativeness error(Bormann)
    - Correlated errors (from both terms)
    - Spatial dependence of representativeness error
  - All must be specified for all observation types
    - Radiances (Geer, Kazumori, Collard, Ruston)
      - Radiative transfer (Vidot,Karbou)
    - Principle components/reconstructed radiances (Matricardi)
    - Winds (Forsythe)
    - Radar and Lidar cloud measurements (Janiskova)
    - Wind, waves and altimetry (DeChiara and Abdalla)
    - Lidar winds (Rennie)
    - GPS RO (Healy)

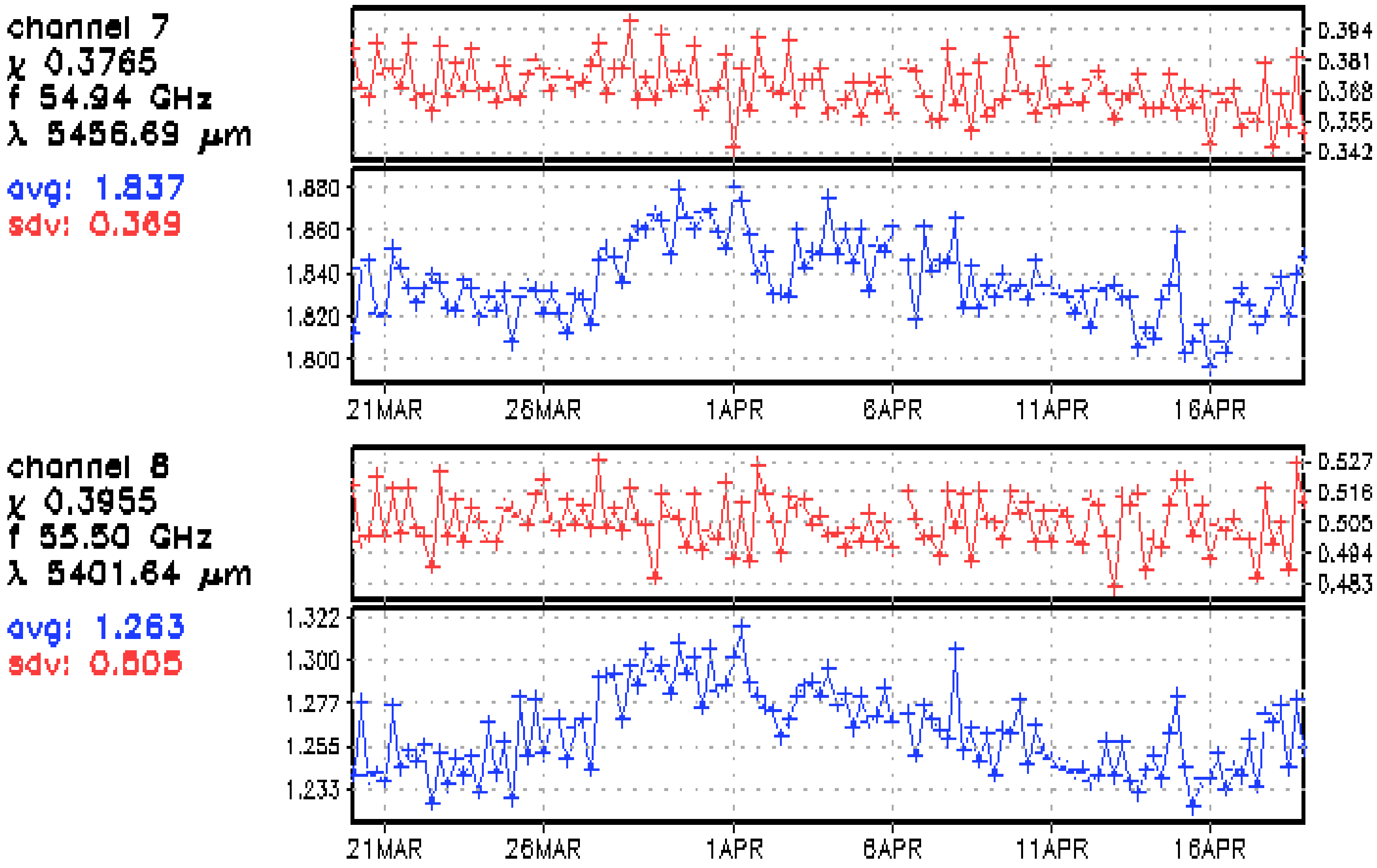
Additional considerations for satellite observations

- Bias correction
  - Equations assume that data is unbiased. Difference between observations and background not unbiased for many observations.
  - Truth is unknown
  - Sources of bias between observation and background
    - Inadequacies in the characterization of the instruments.
    - Deficiencies in the forward models.
    - Errors in processing data.
    - Biases in the background (do not want to remove from o-b).

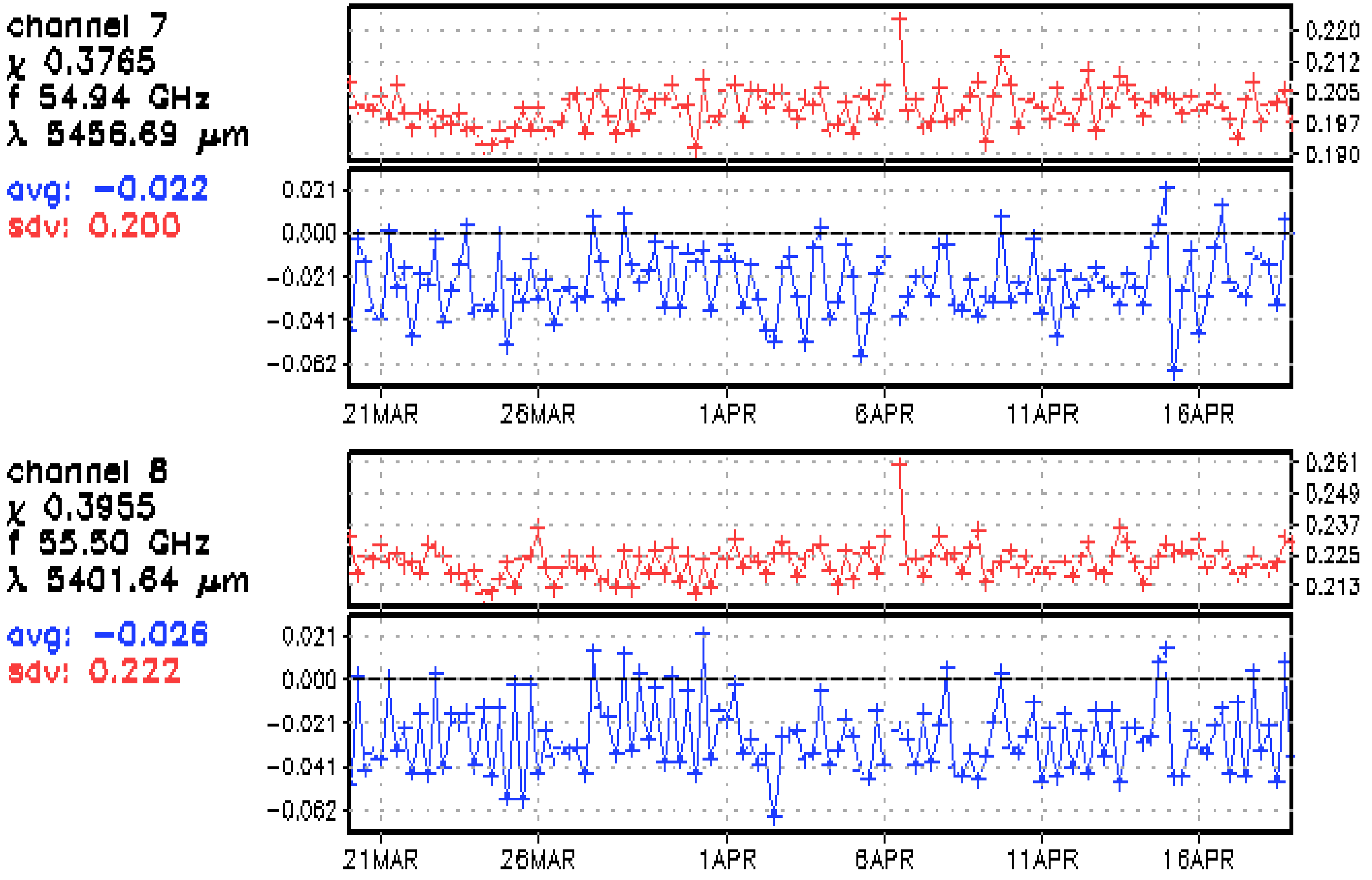
Scan dependent biases for AMSU



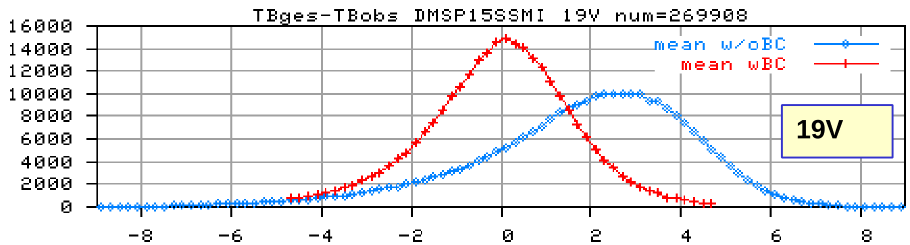
NOAA 18 AMSU-A
No Bias Correction

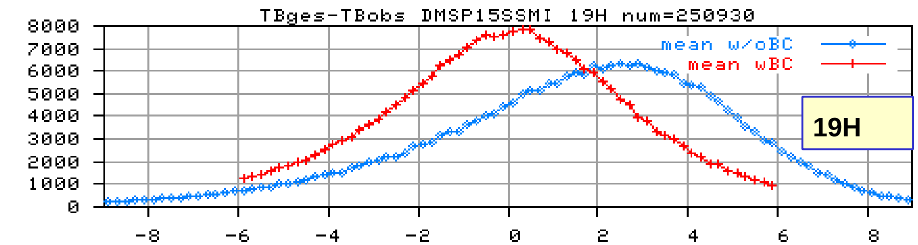


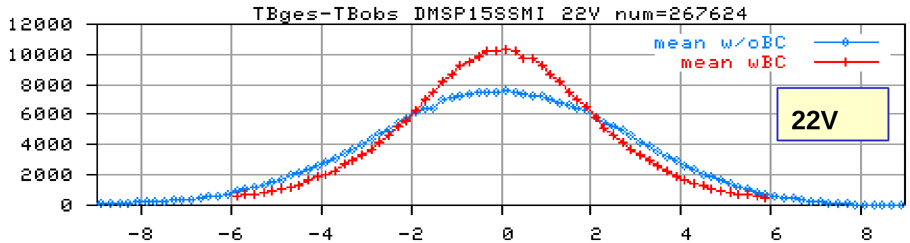
NOAA 18 AMSU-A
Bias Corrected

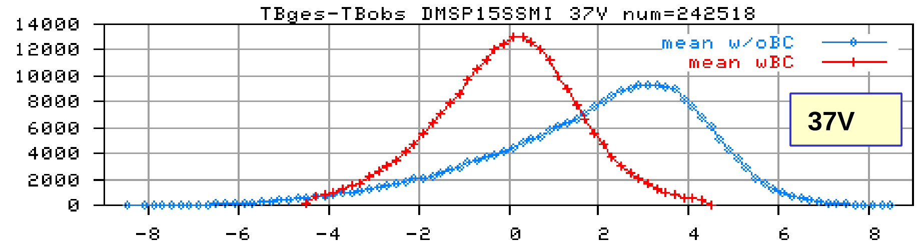


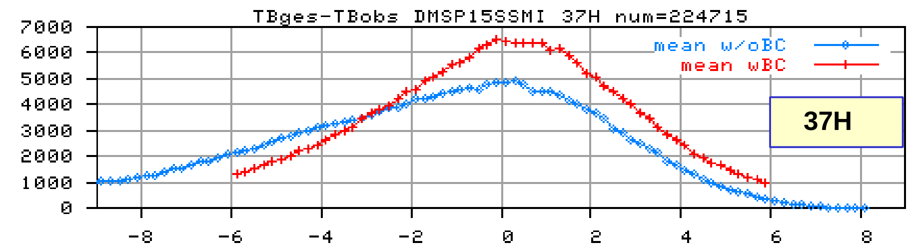
Observation - Background Histogram

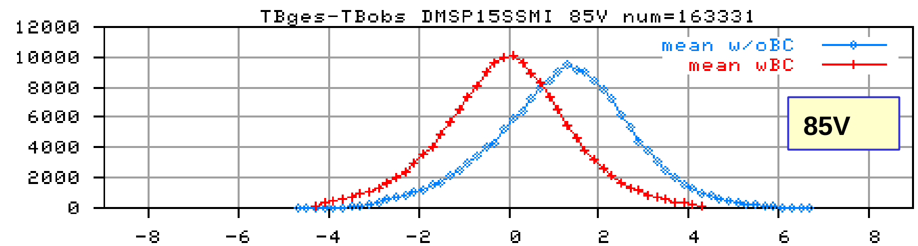


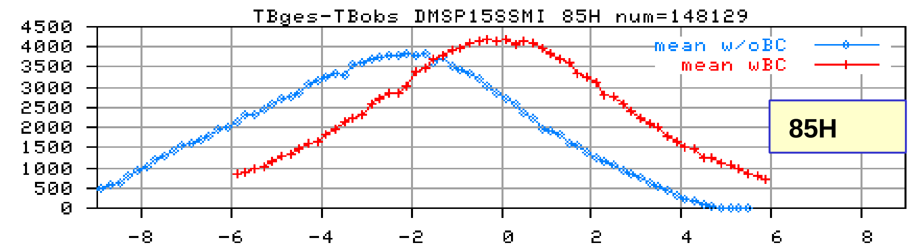












DMSP15 July2004 : 1month

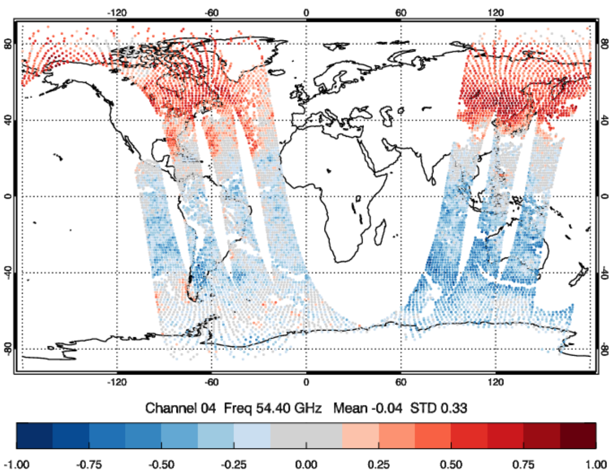
before bias correction

after bias correction

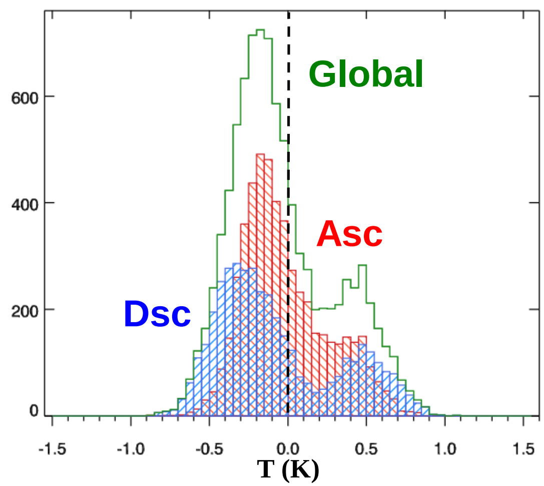
gl use 2004070200-073118(63cases)

Application of NWP Bias Correction for SSMIS F18

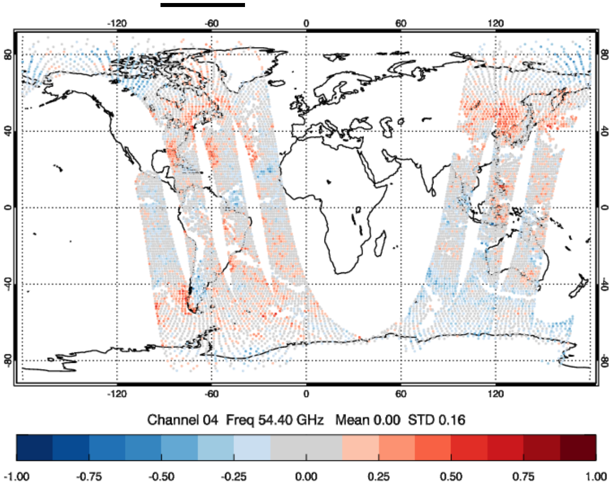
O-B **Before** Bias Correction



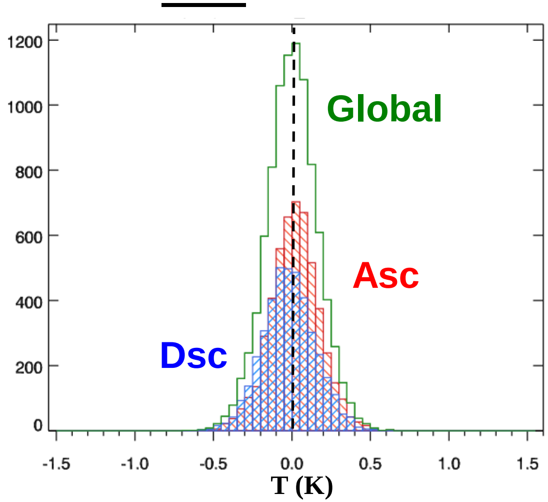
O-B **Before** Bias Correction



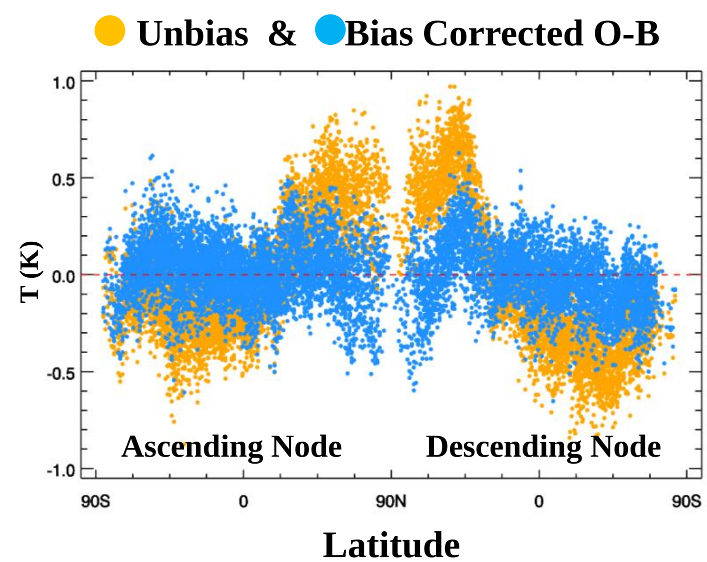
O-B **After** Bias Correction



O-B **After** Bias Correction



Using Met Office SSMIS Bias Correction Predictors



Additional considerations for satellite observations

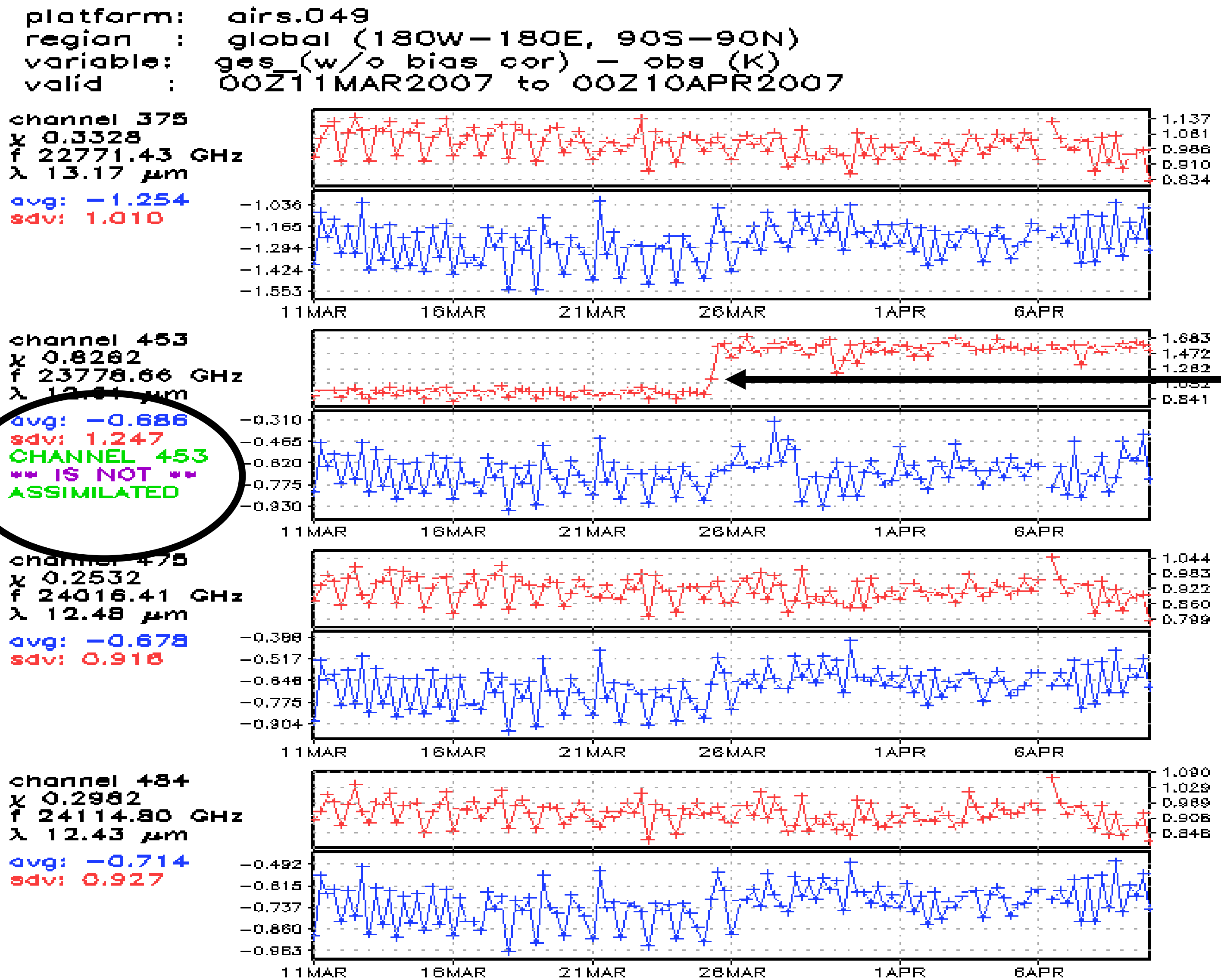
- Quality control
  - Cannot use observations which cannot be adequately modelled or contain large errors – correlated errors
  - With satellite data often made necessary by clouds/precipitation, etc. that we cannot properly model.
  - A few bad observations can do more harm than many good observations can do good. We tend to be conservative.
- Thinning or super-obbing (spatially/spectrally)
  - Trade-off between additional observations and cost
  - Can reduce correlated errors
  - Communications has been an issue

Additional considerations for satellite observations

- Data monitoring
  - Essential for the use of any observations in operational system
  - First step in use of data
  - Operational NWP centres frequently note problems with observations prior to data providers
  - Radiance Monitoring reports from most major NWP centers at: http://nwpsaf.eu/monitoring.html

Quality Monitoring of Satellite Data

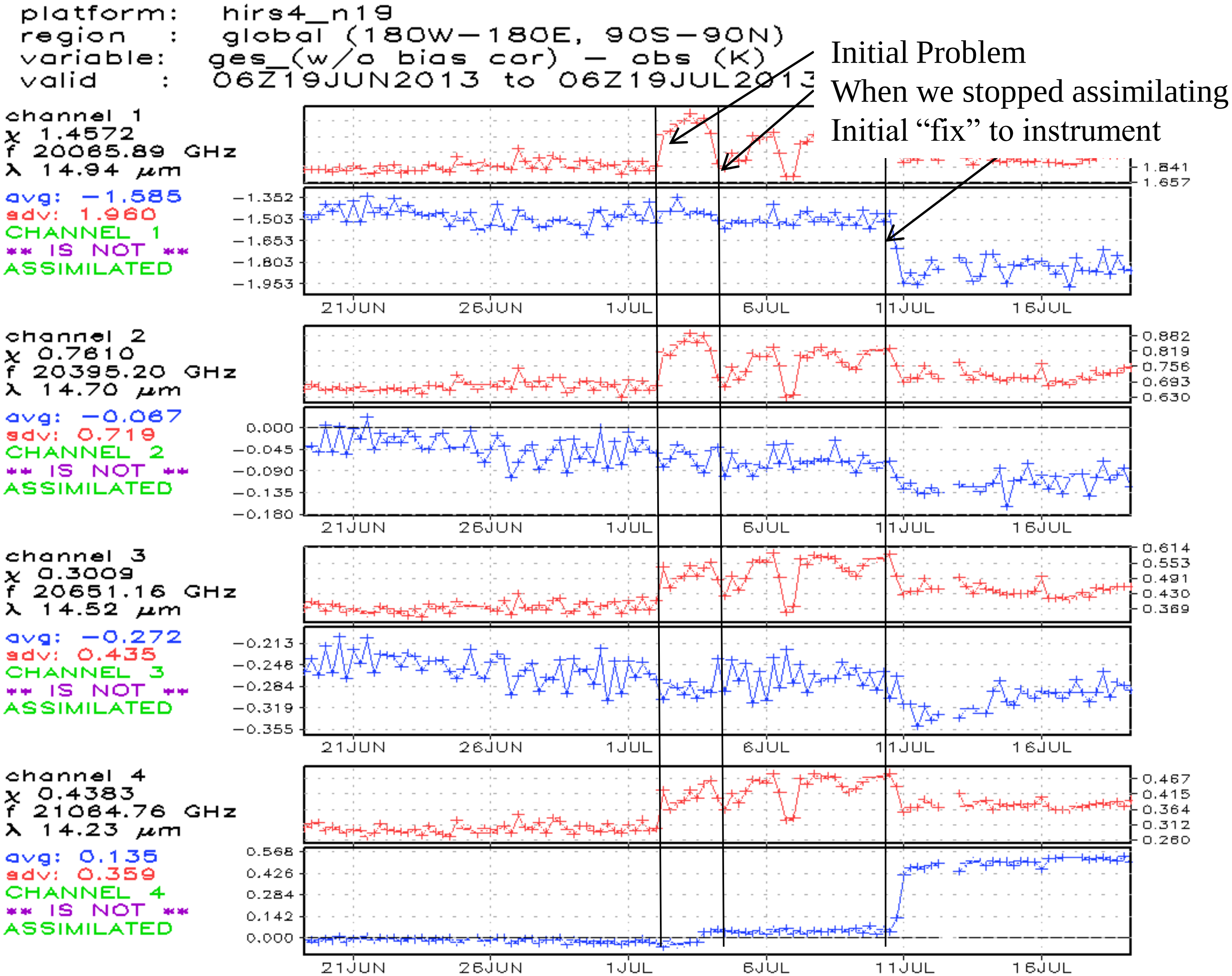
AIRS Channel 453 26 March 2007



Increase in SD Fits to Guess

Quality Monitoring of Satellite Data

NOAA-19 HIRS July 2nd 2013 – Filter Wheel Motor Problems



Challenges

- Coupled assimilation with
  - Atmospheric composition (Elbern)
  - Land surface (Candy)
  - Ocean (Johannessen)
- Convective scale assimilation (Auligne)
  - Balance issues
- Use of new observations
  - All weather assimilation (Geer and Janiskova)
  - New platforms and instruments (Eyre and Goldberg)
- Improved use of current observations (many)
  - Continual improvement of background error and specification
  - Observation error (and representativeness error)
    - Correlated errors
  - Improved forward models
  - Observation impact (McNally)
- Reanalysis projects (Bell and Dee)
  - Many uses as proxies for reality - but must be good enough