# Experience with bias correction at CMC

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and

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Environnement Canada
Centre météorologique canadien

Environment Canada
Canadian Meteorological Centre

# Outline

Bias considerations related to:

- TOVS (AMSU-A+B), SSM/I
- GOES, AIRS
- Ground-based GPS
- COSMIC, SAC-C, CHAMP

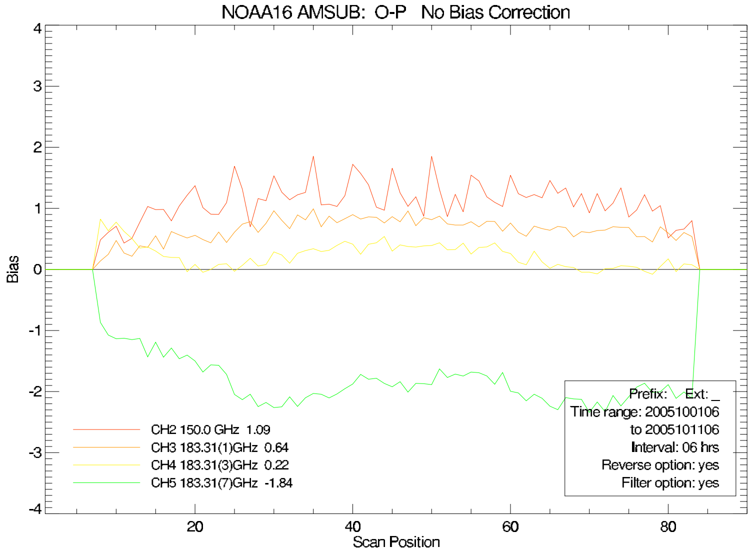
# AMSU-A-B

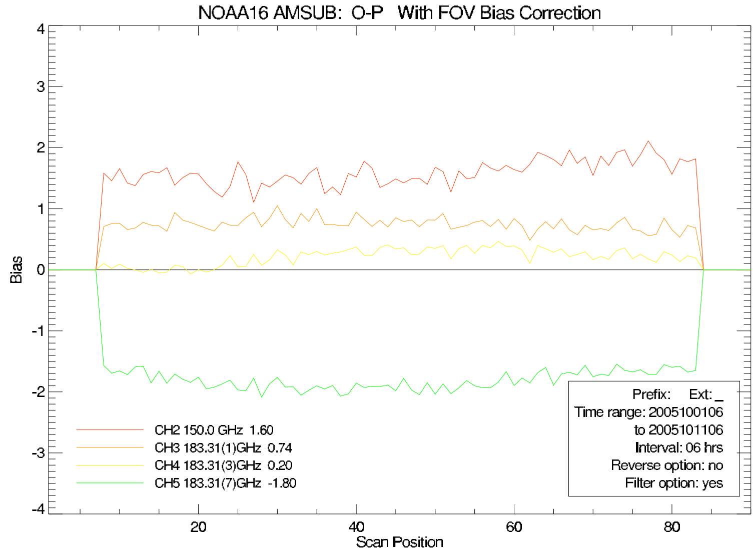
**Two-step correction**:

- Scan position: a global constant for each position. May be asymmetrical. Extreme view angles may be screened out.
- Air-mass global correction with 2 predictors:
  - * 300-1000 hPa thickness
  - * 50-200 hPa thickness

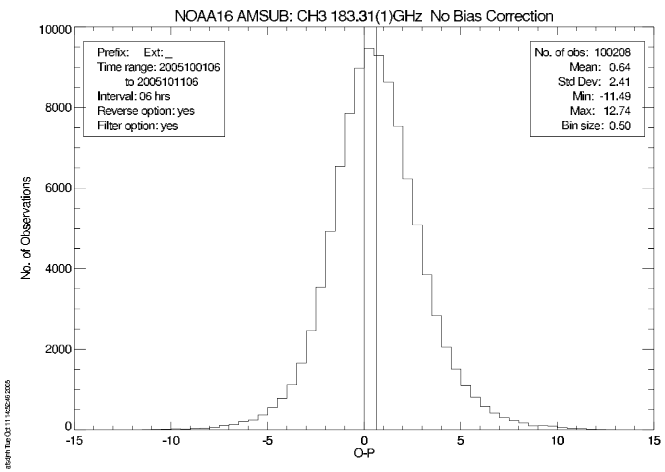
# 2-step procedure: example with AMSU-B

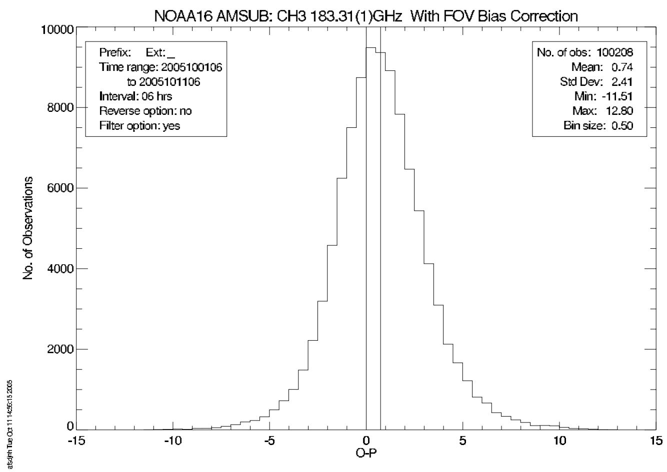
Ch 2-5 biases




Ch-3 O-P



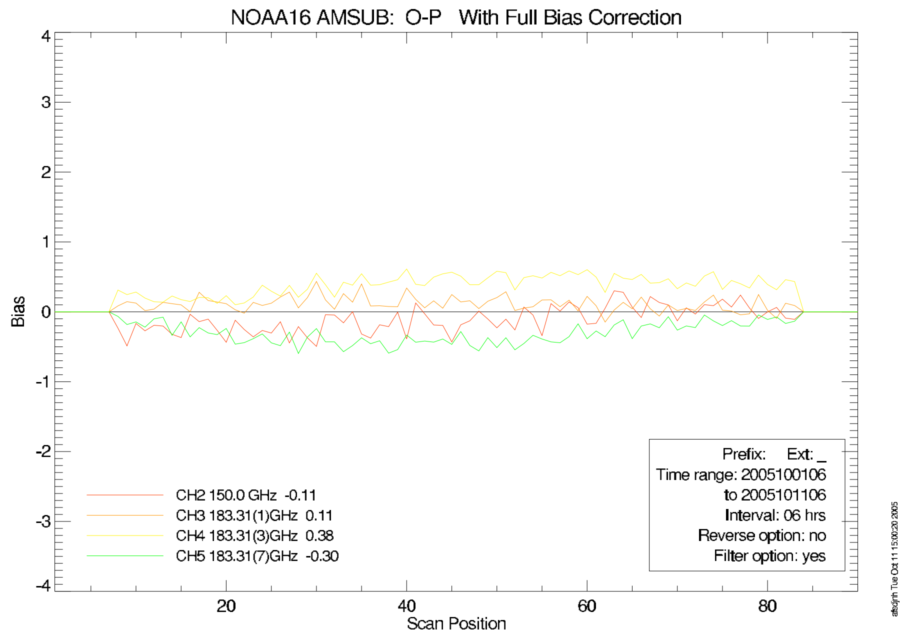




No correction

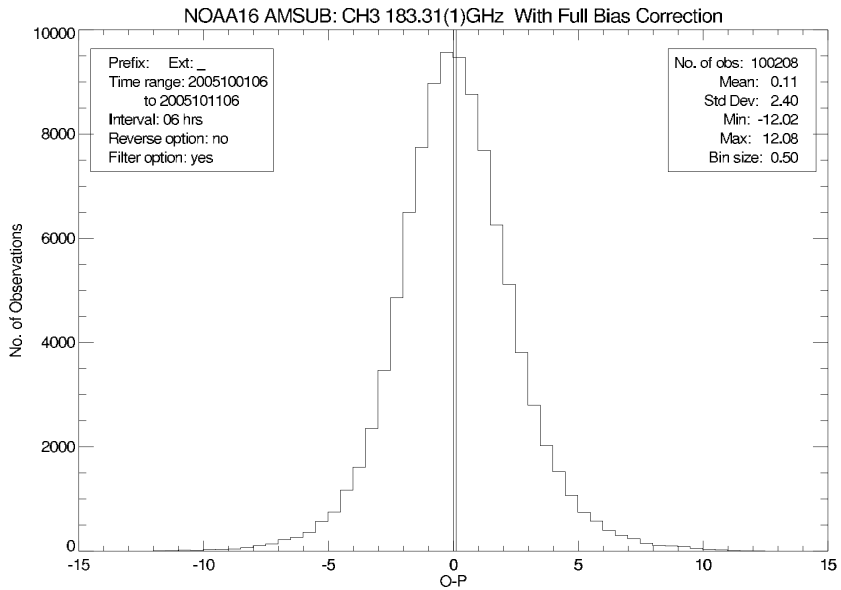
scan bias correction

# Final: after air-mass correction

## AMSU-B ch 2-5

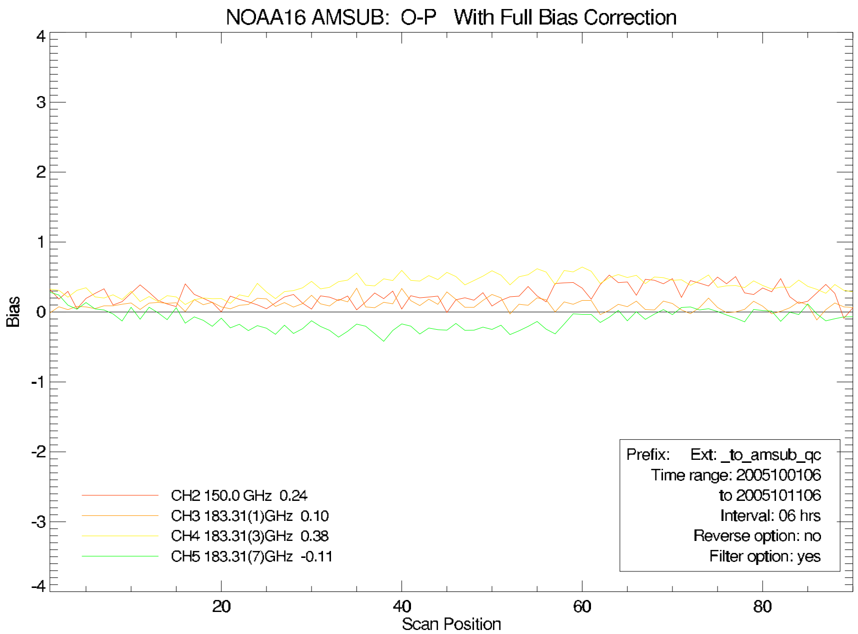



## histogram (O-P) ch 3

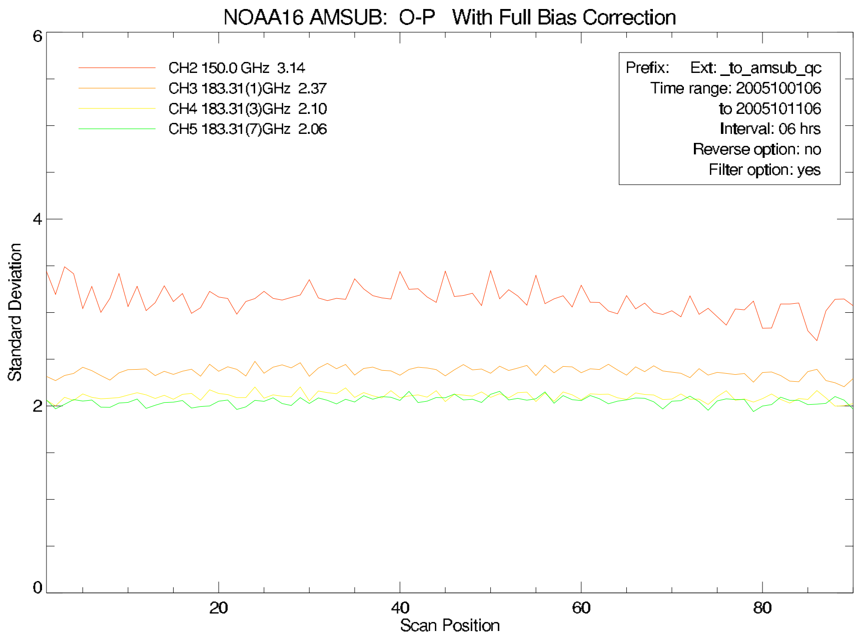


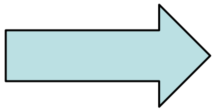
# AMSU-B bias/std – all available data

**Bias**




**STD**

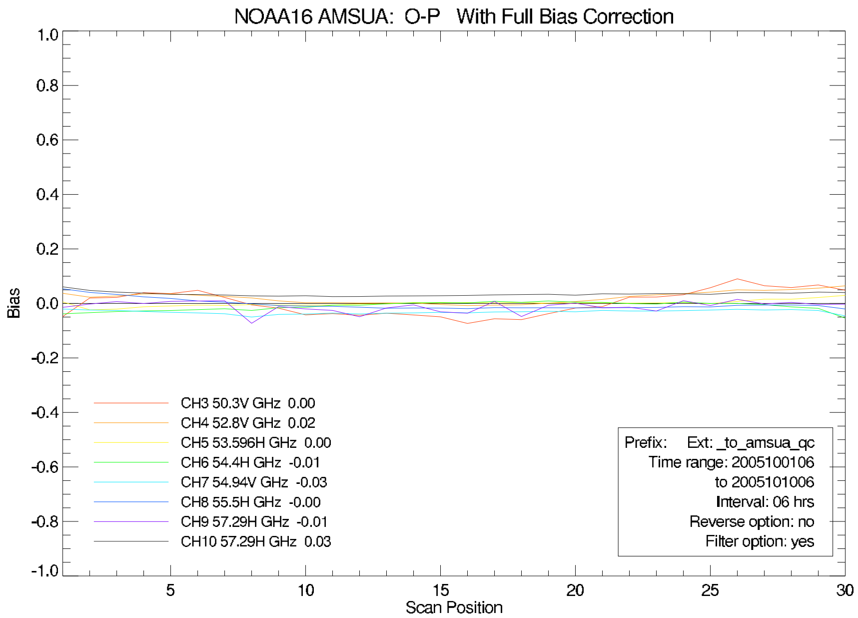


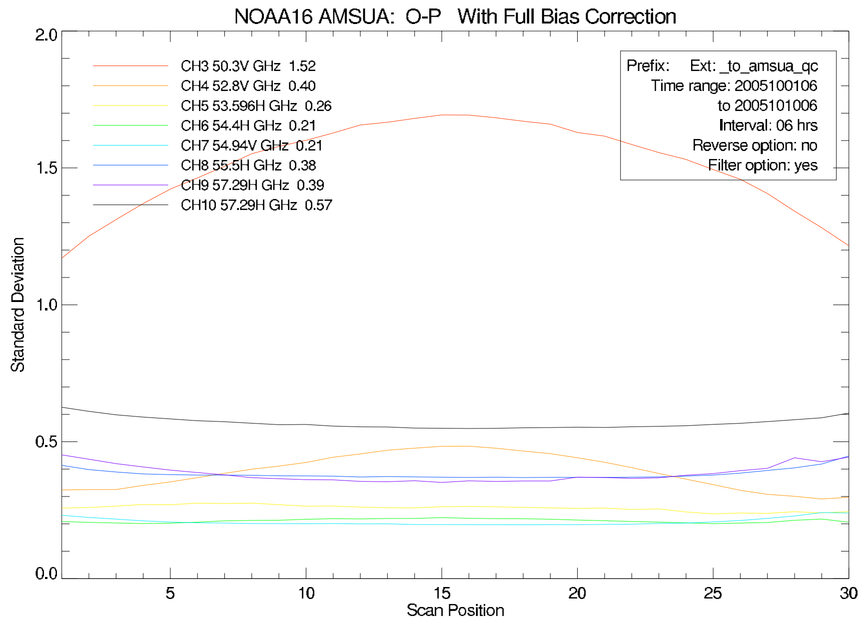
**No need to eliminate edges of scan**

# AMSU-A bias/std – all available data

**Bias**



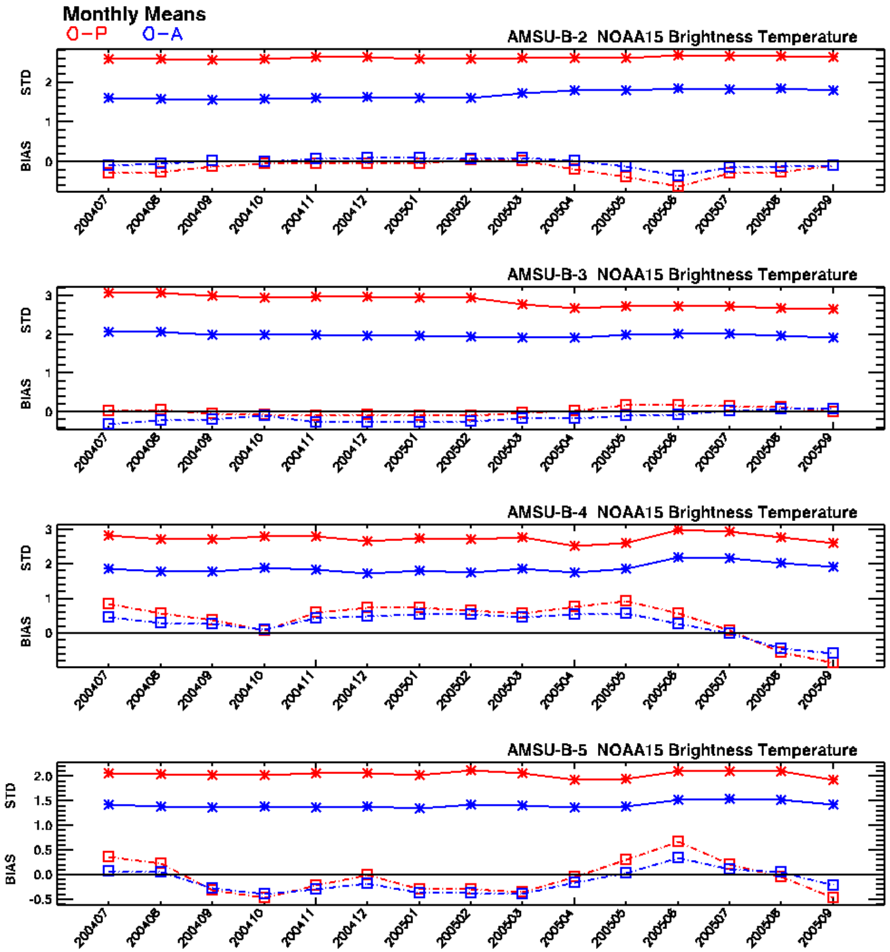

**STD**




**Some channels (5-7) could be used for all scan positions**
**Higher nadir STD for Ch 3-4 due to higher sensitivity to Ts**

# NOAA-15 AMSU-B stats: unstable instrument behavior

**Last 15 months stats**

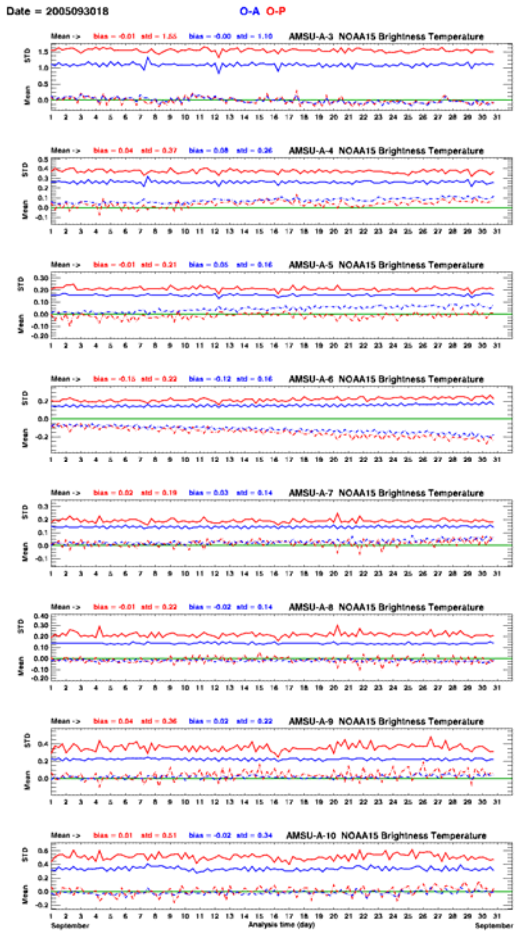


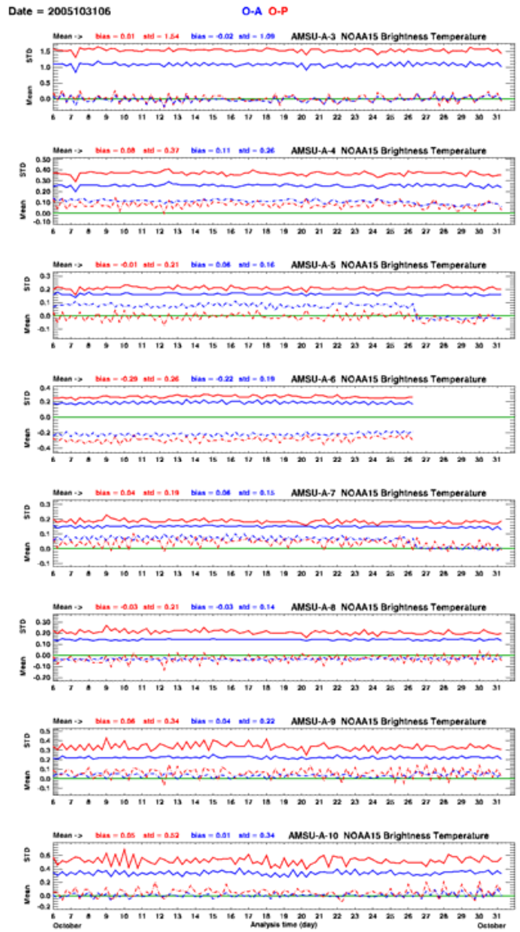

Bias correction reviewed in June 2005. This did not stabilize the bias of Ch 4-5 after that.

Significant drift also noted in AMSU-A (notably Ch 6)

**No ideal time to**
**Refresh bias correction**
**Decision to redo BC**
**Or eliminate a channel**
**Not obvious.**

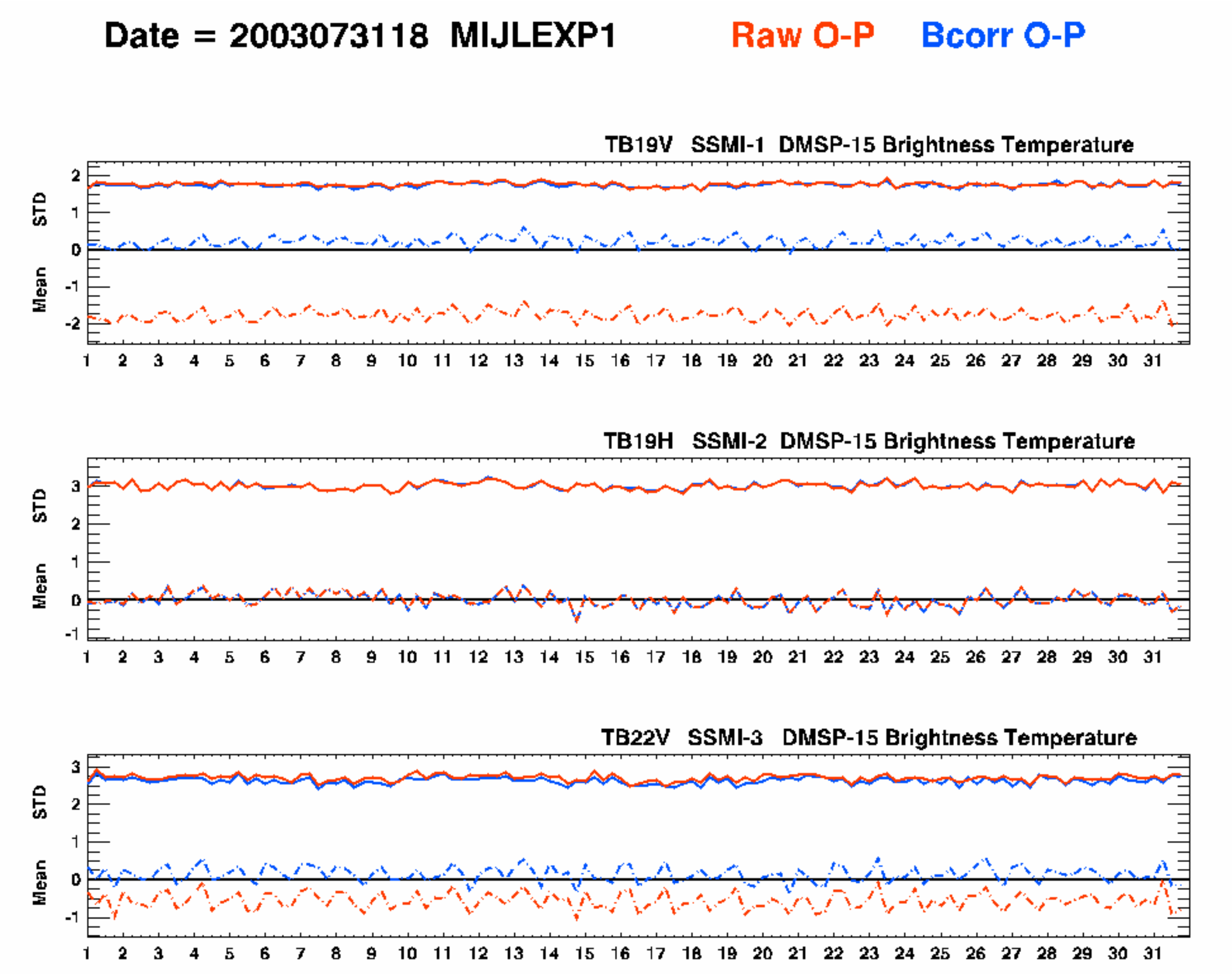
# NOAA AMSU-A stats Sep-Oct 2005



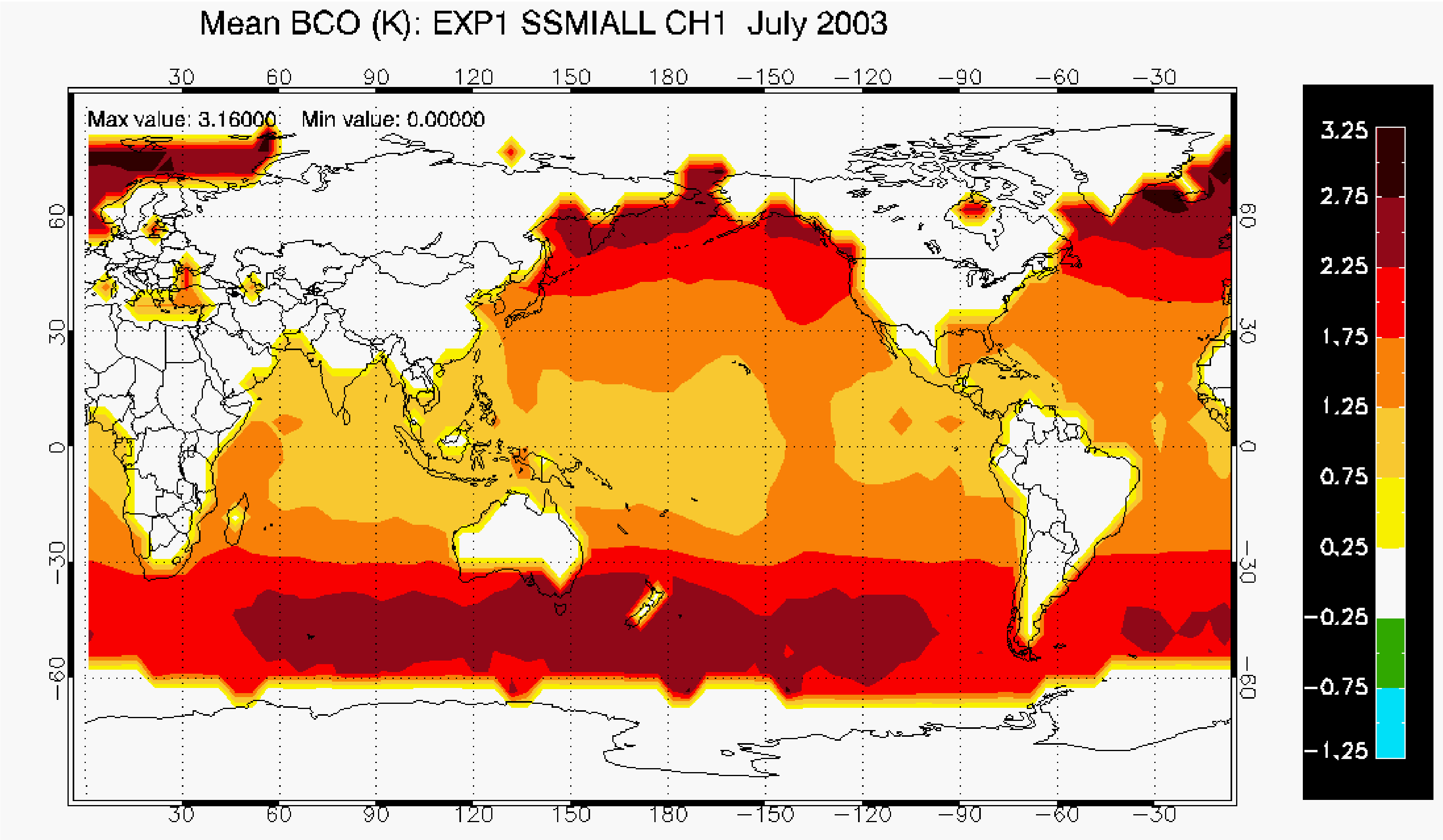

**Bias in ch 6 created a biased (O-A) in ch 5 and ch 7**

Passive monitoring of SSM/I using same processing as for TOVS. STD and bias shown for ch 1-3. Correction for scan position almost negligible (same viewing angle) except for first last ~4 scan positions.



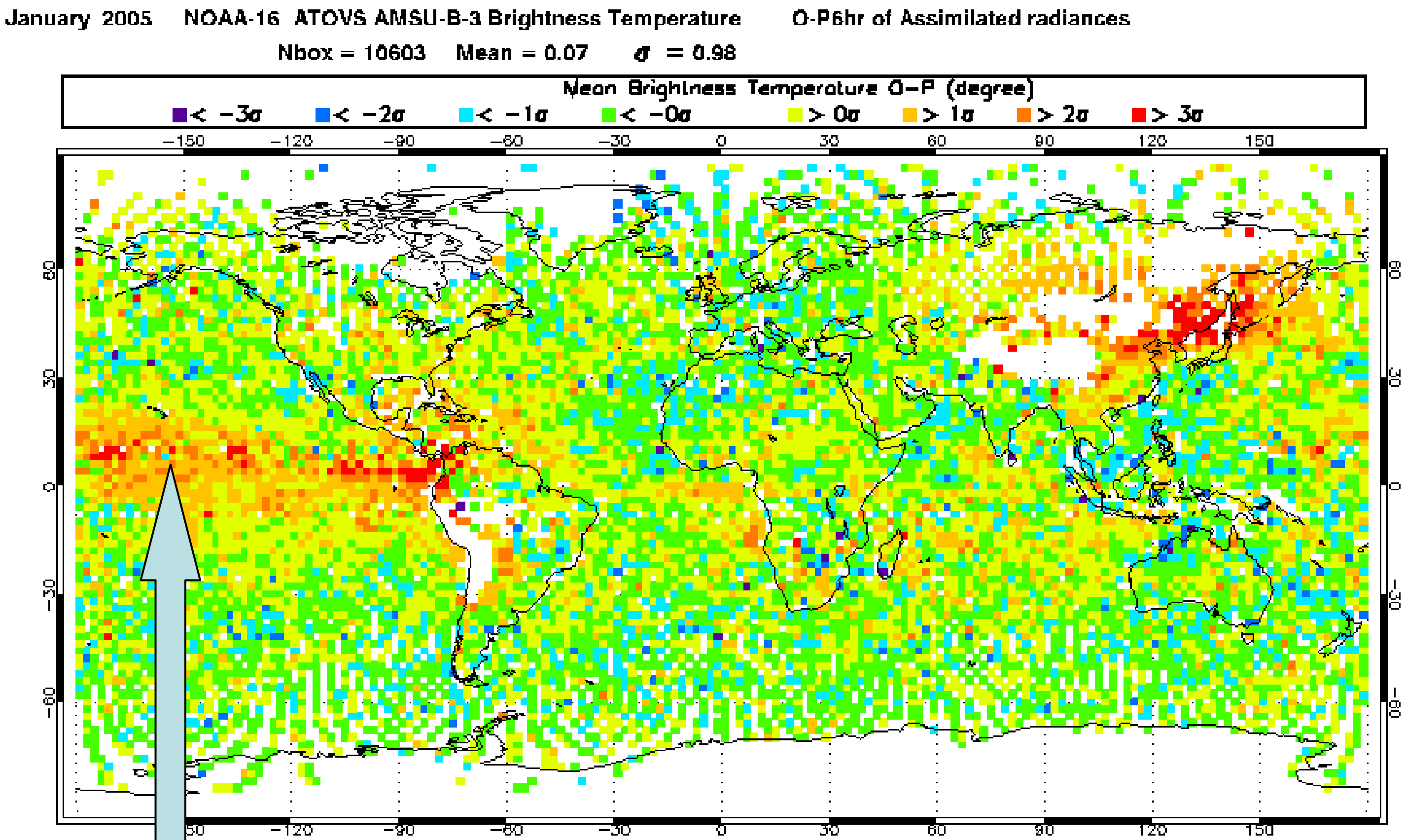
# Mean bias correction for SSM/I ch-1 for July 2003

## - Similar north-south patterns seen in most channels



# Monthly O-P: organized patterns noted

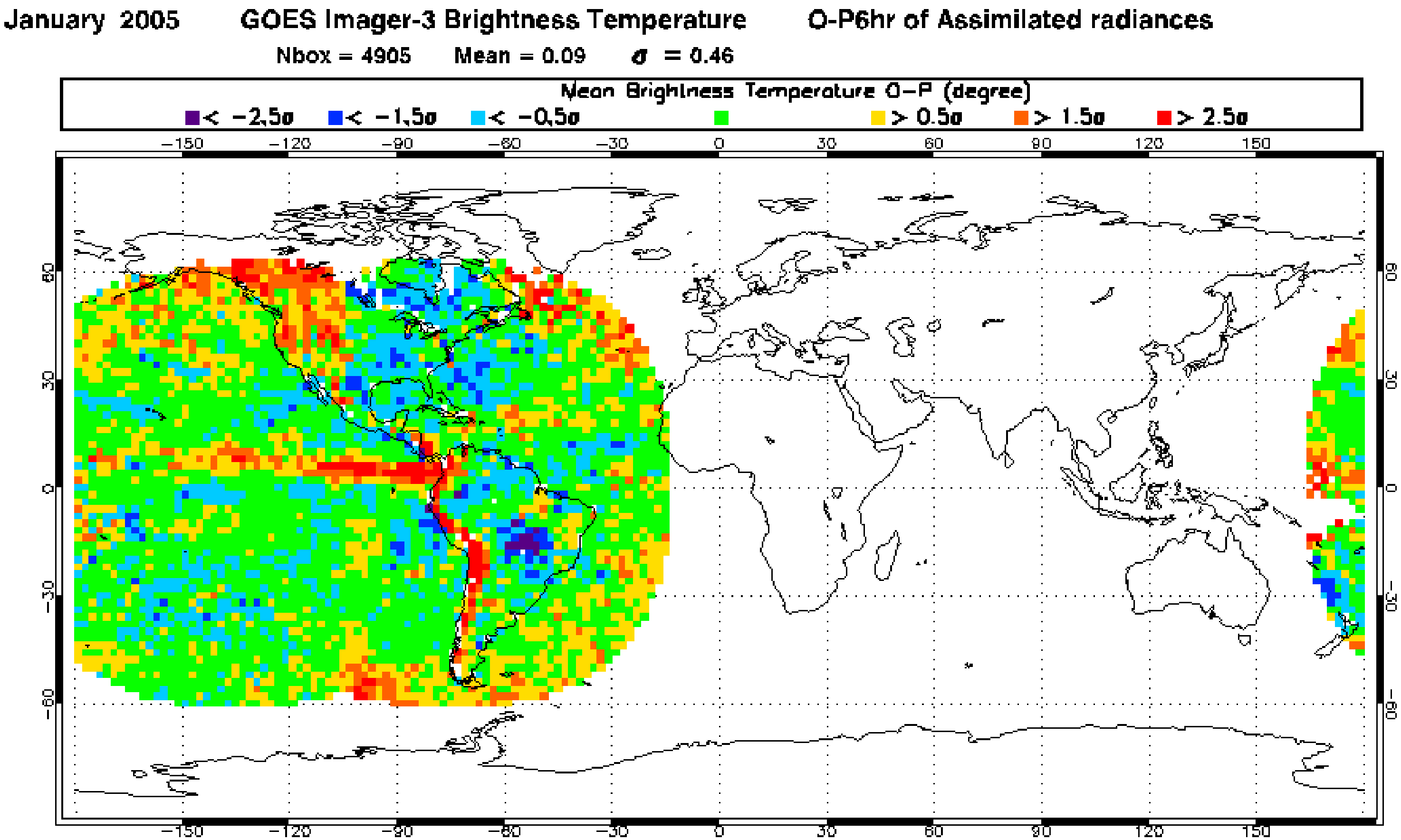
NOAA-16 AMSU-B-3 JAN 2005




Positive forcing likely due to too moist Chinese RAOBs.

Likely due to excessive mid/high trop moisture from convection scheme

# GOES E/W Ch 3 mean O-P Jan 2005

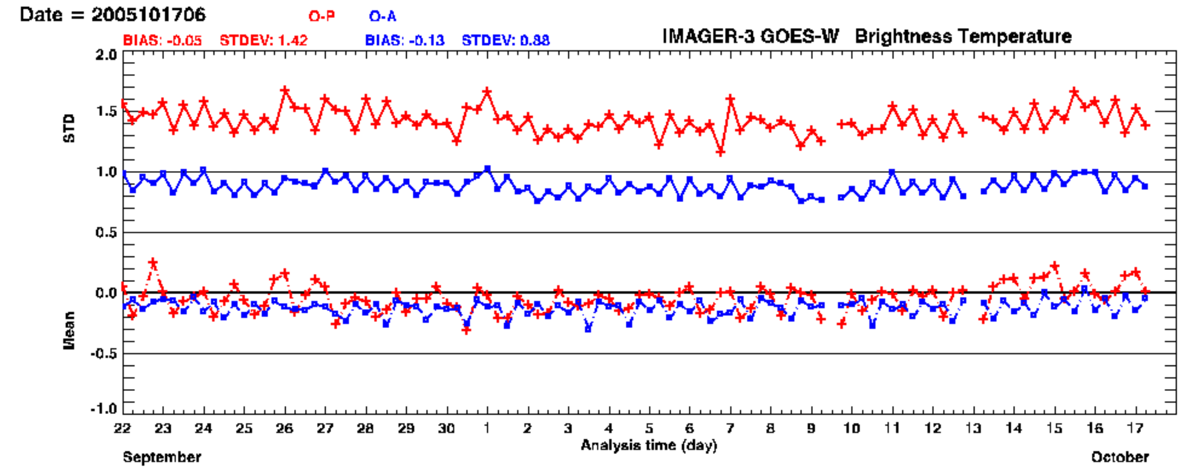



Similar drying forcing but more confined than AMSU-B in tropics

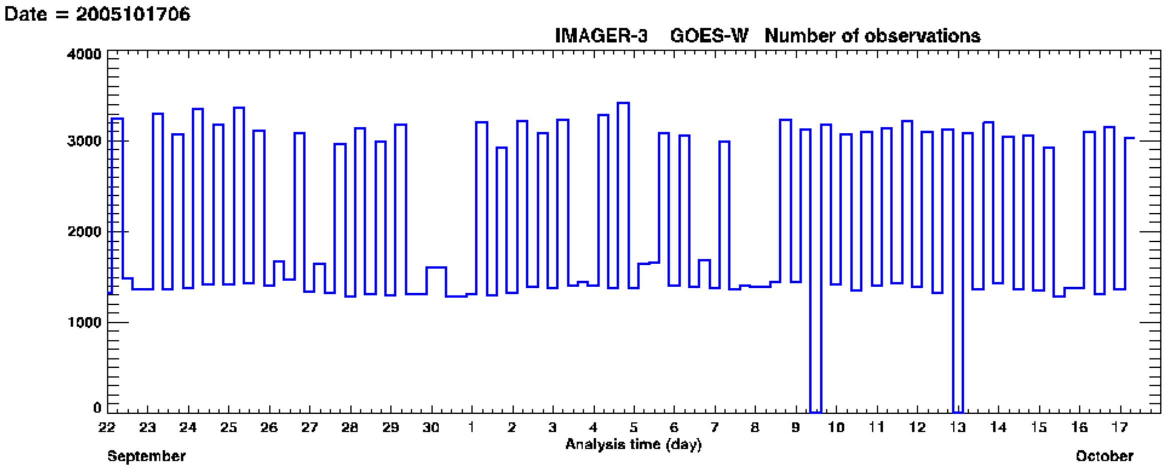
# GOES Ch 3 assimilation

**Goes 10 Sep 2005**

**bias = a $BT_O$ + b, RTM is MSCFAST**



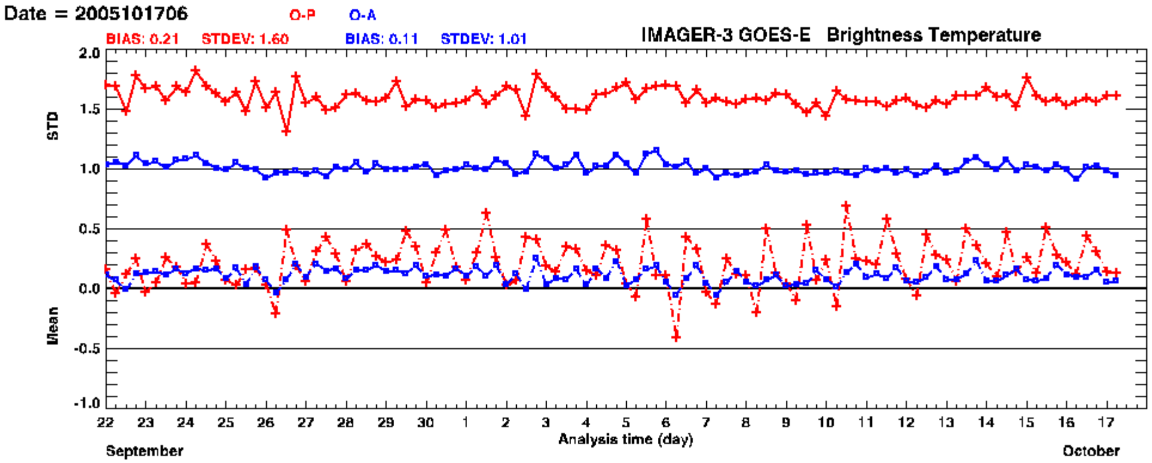

Stable stats
No screening for possible "midnight effect"
3-hr assimilation in 4D-var

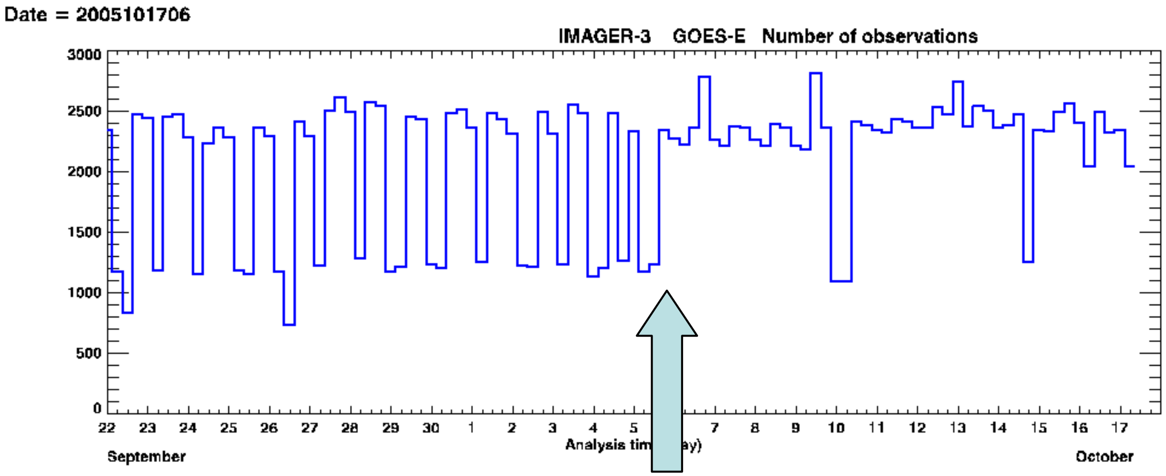



Number of samples
Varies: half/full disks

# GOES Ch 3 assimilation

**GOES-12 (EAST) 22 Sep – 17 Oct 2005**



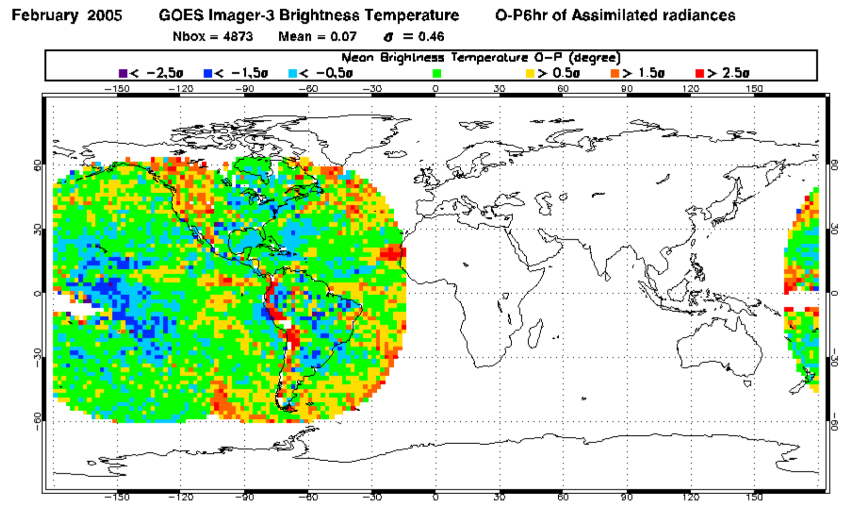



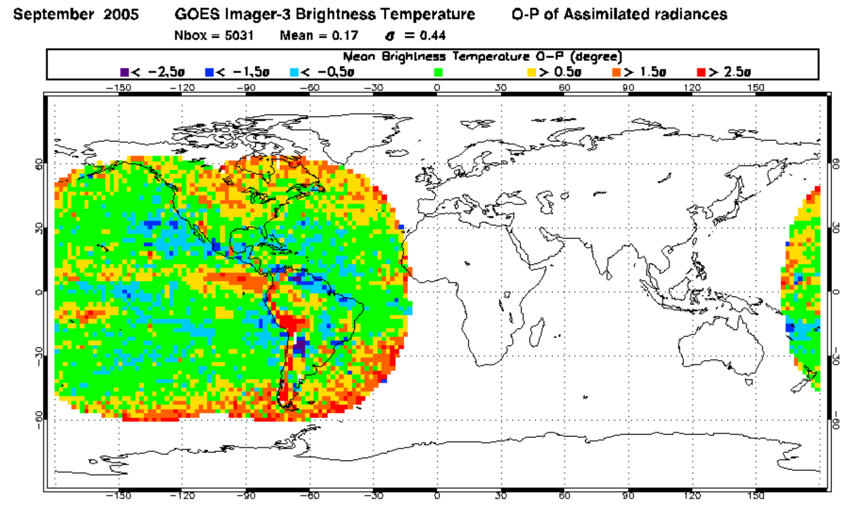

Source of bias oscillation unknown. Max typically at 12 UTC. Min at 06 UTC. Larger diurnal effect than GOES-10 (West).

More stable availability; not true for G-10

# Angular bias dependency?

**Feb 2005 mean O-P** | **Sep 2005 mean O-P σ units**




**Angular bias dependency seems present in G-12**
**View angles up to 70 deg accepted (~60 latitude)**
**Could be safer to limit at 65 deg sat-zenith**

# AIRS assimilation

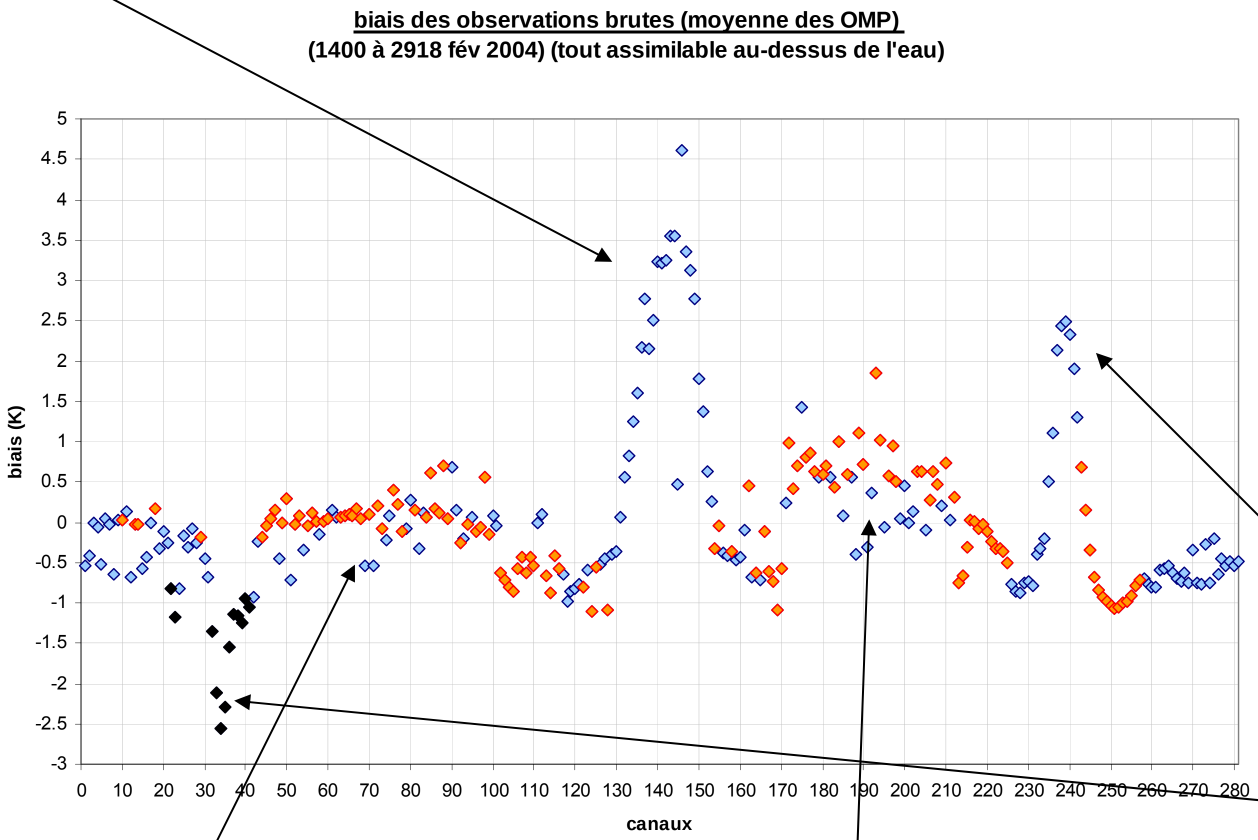
- 105 channels selected from 281 set
- Use center pixel of 3 X 3 array (warmest now available)
- Eliminate channels sensitive to ozone, peaking above model top at 10hPa, redundant surface channels, complex Jacobian shapes, with large RTM errors

Identify channels insensitive to clouds. Main criteria:

- Cloud height and emissivity from CO2 slicing. Local dtau/dp must be negligible up to 50hpa above cloud.
- Background check (+/- 3 $\sigma$)

# AIRS (O-P) bias

ozone




**281 ch set**

**Selected for assimilation**

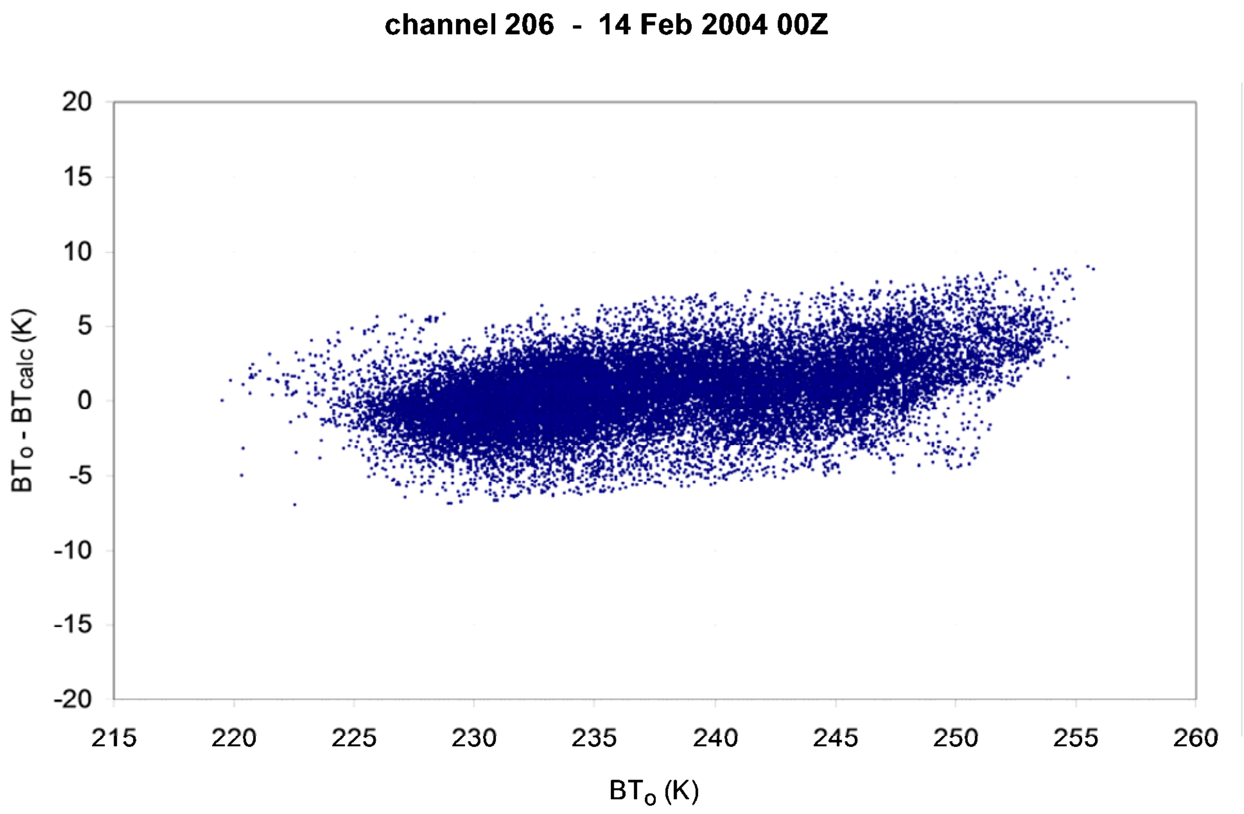
Peaks above model Top a 10 hpa

Water vapor 6.3-6.7 μ

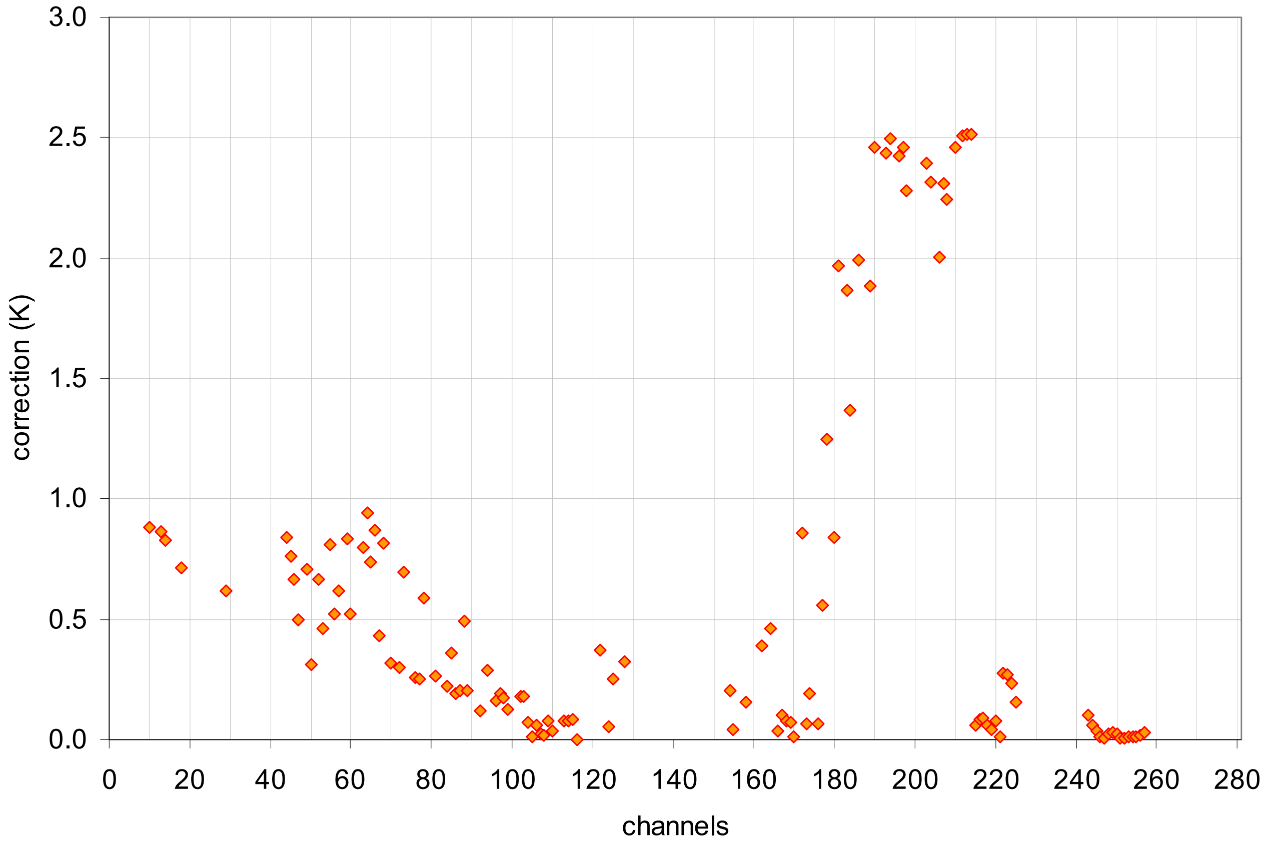
Low bias for 15 μ channels

# Example of variation of bias with observed BT

**Index 206 : AIRS 1783 (1555.6 cm-1)**



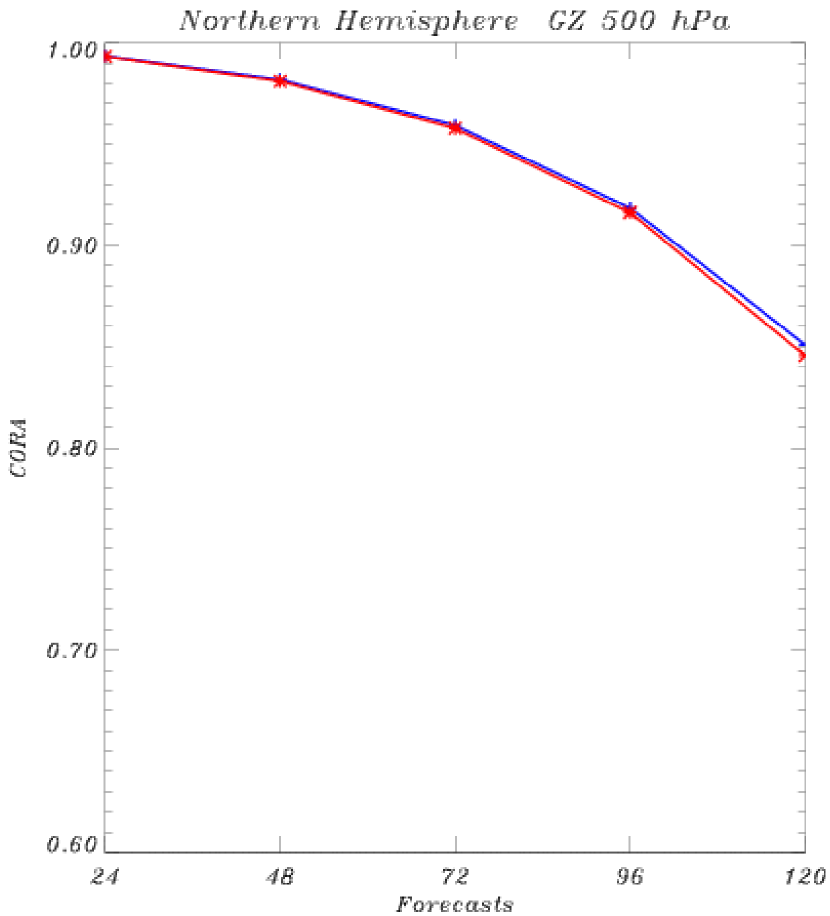
# Maximum departure (K) from flat bias ($3\sigma$)

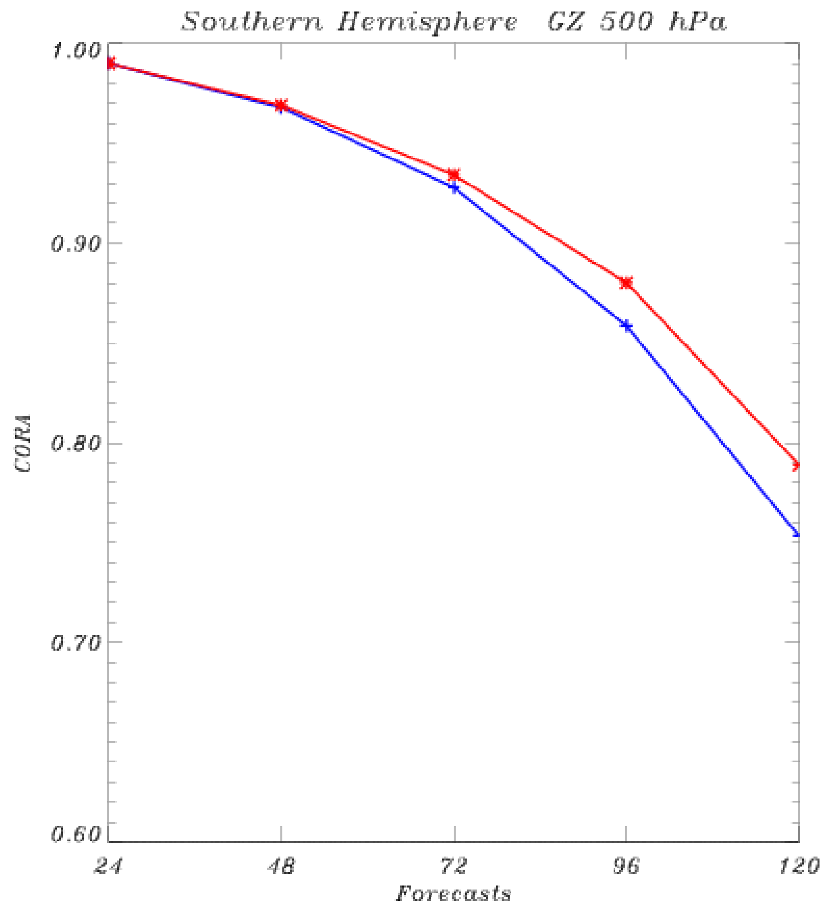



**Up to 2.5K departure from flat bias in water vapor channels.**
**These largest departures are seen in dry air masses**

# First results with AIRS assimilation (3D-Var)

CONTROL  CONTROL+AIRS   14-29 Feb 2004

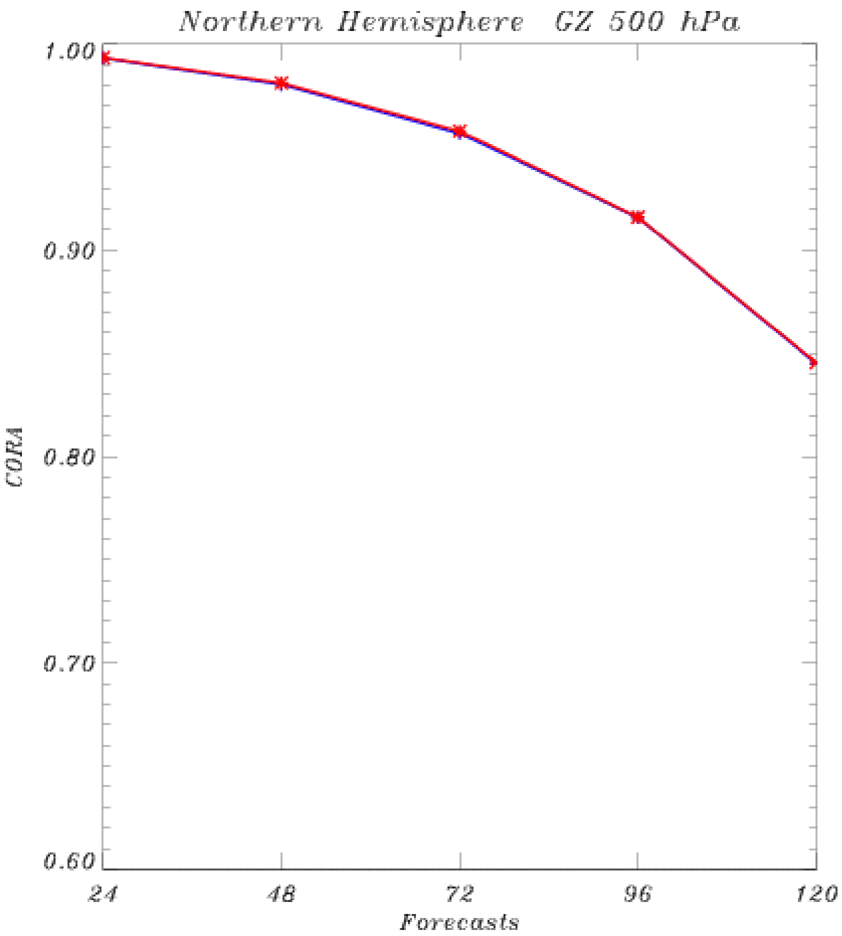


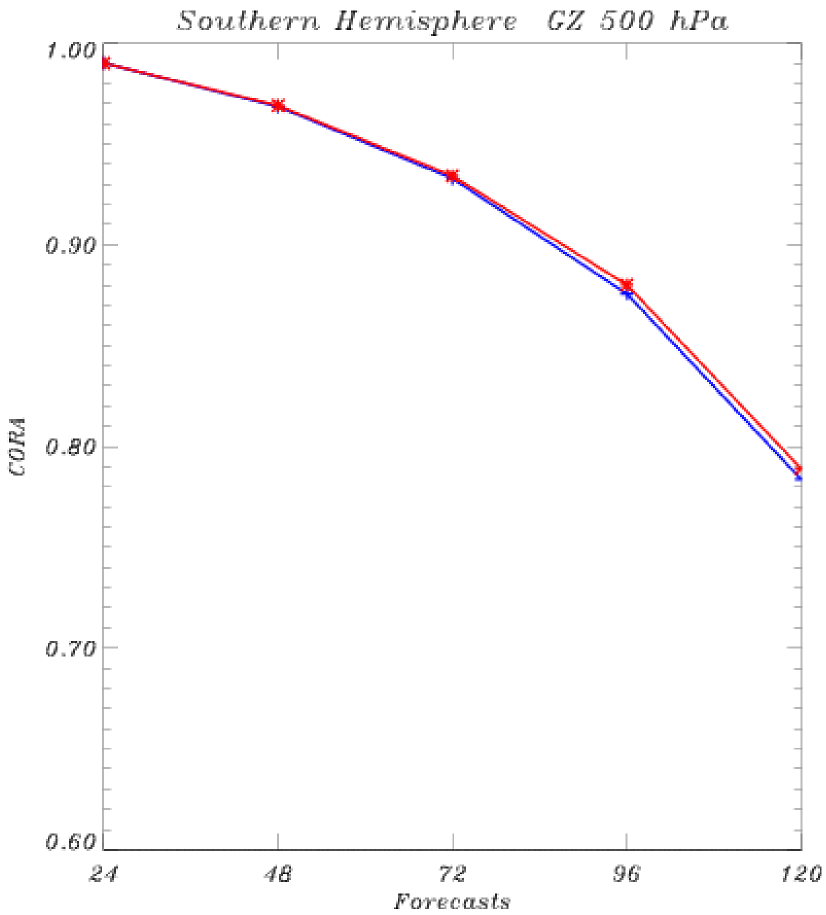




**Clear positive impact in southern hemisphere**

# Flat versus linear bias correction

**14-29 Feb 2004 assimilation**



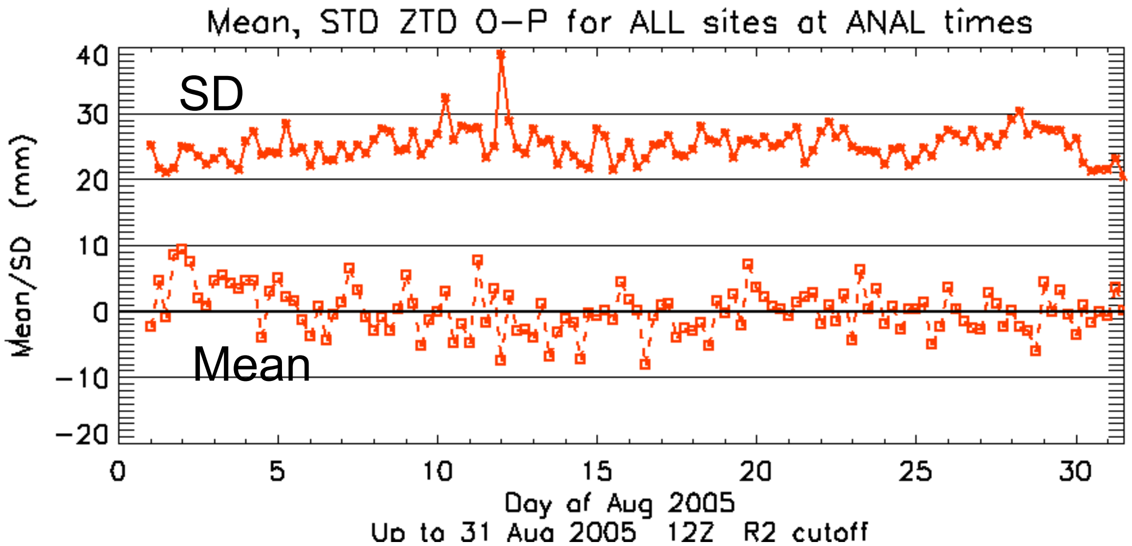

**Linear bias correction slightly superior in southern hemisphere**

# Ground-based GPS

Observation from ground-based GPS is zenith tropospheric delay ZTD (mm), a measure of signal delay due to neutral atmosphere and a function of surface pressure (Ps) and precipitable water (PW) at GPS receiver.

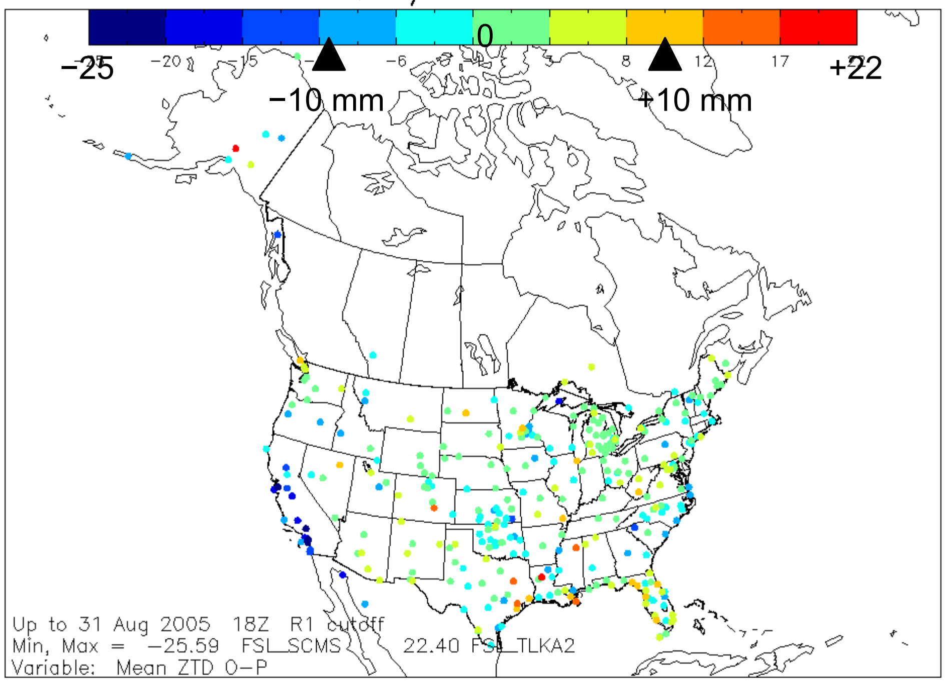
We receive since August 2004 near real time GPS ZTD observations every 30 minutes from NOAA for network of GPS receivers covering United States.

Monitor O-P for ZTD and Sfc Met ($P_s$, $T_s$, $RH_s$ (P = 6h forecast from Reg and Glb GEM). All-site ZTD bias is generally low relative to the standard deviation (SD) for a given month.

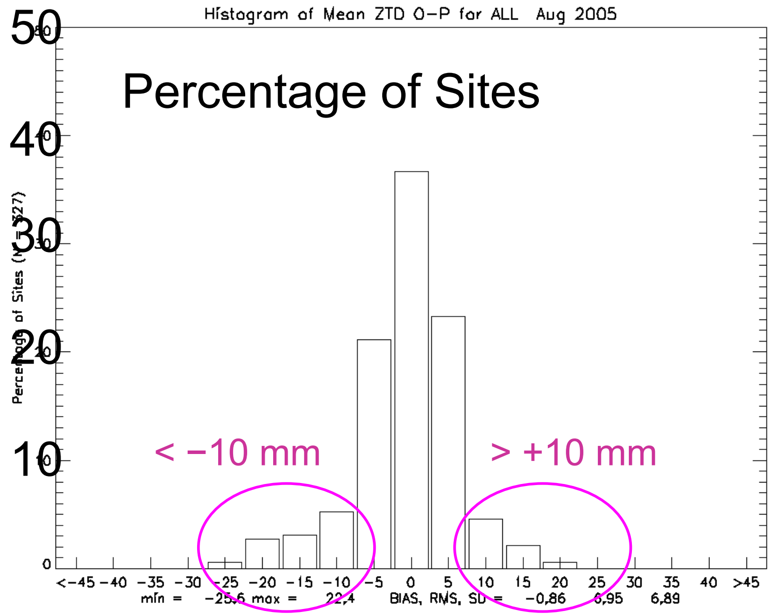


However, large monthly site-specific biases of similar magnitude to the standard deviation (SD = 10−30 mm) are noted at some locations.

Site Mean ZTD O-P (mm)




Site Mean ZTD O-P




Bias (mm)

Biases in California are similar: likely due to background error
Where site bias differs largely from that of neighbors: antenna height error likely

**Bias errors in forecast (P) ZTD** come from:

• bias errors in forecast Ps (**1 mb Ps --> 2.3 mm ZTD), PW (1 mm PW --> 6.2 mm ZTD**). Barometer present on most sites.

  • Ps bias error (< 1 mb) is small --> little contribution to larger biases

  • more relative contribution from PW bias errors in most cases

• forward operator: e.g. adjustment of model ZTD to the GPS antenna height, including errors in antenna height and inherent assumptions

•**Bias errors in observed (O) ZTD essentially come from**:

• erroneous a-priori site location information (i.e. antenna height) in estimation of ZTD.

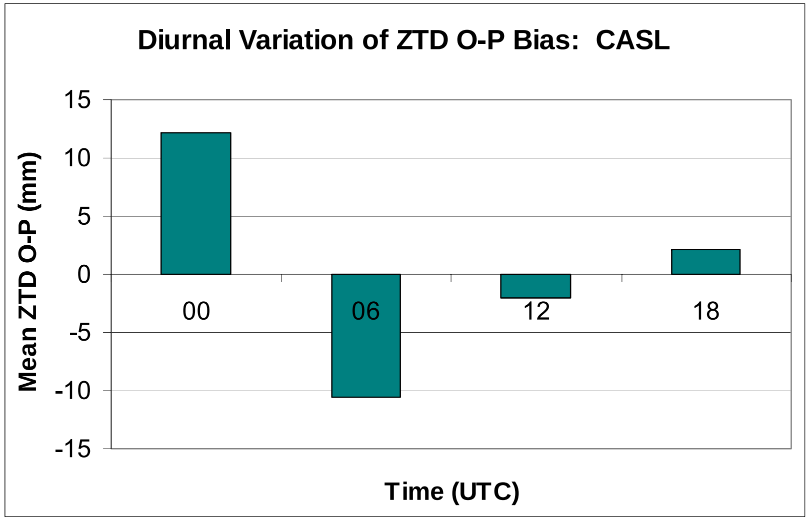
  • slight error in GPS antenna height can produce significant ZTD bias

  • such a height error recently confirmed by NOAA for site where O-P bias was significant (> 10 mm)

  • same effect found from in-house (MSC/ARMA) estimation of ZTD for selected Canadian sites

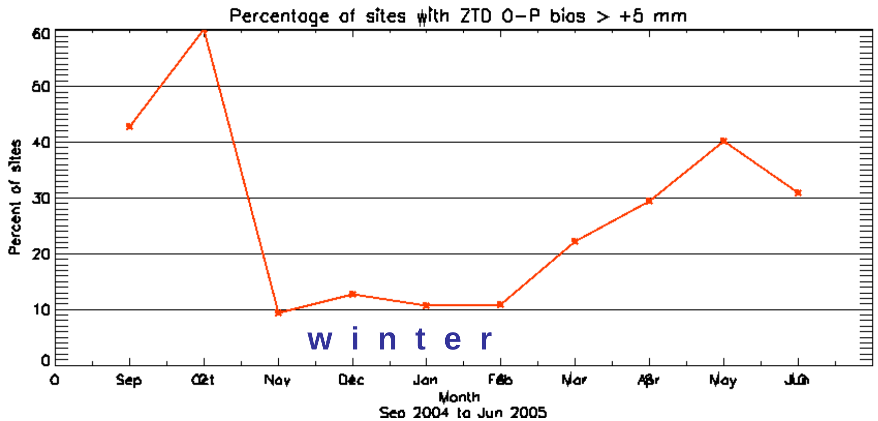
Biases appear to have constant and variable components.

The variable component produces variability of the bias at time scales of weeks to seasons. A marked diurnal variability of bias at some locations has also been noted (below, CASL station in NC).




Monthly variability of site biases:

% of (O-P) > 5 mm




Constant component --> primarily GPS antenna height issues (O)

Variable component  --> related to forecast (P) atmospheric state (PW, Ps)

# Proposed method of ZTD bias correction for data assimilation

Apply bias correction using **running-mean method**:

- compute *N*-day running mean (RM) O-P for each site
- *optional*: blacklist sites with high RM biases, e.g. > 75% of SD O-P (inform data provider for possible correction at source)
- for remaining sites, subtract RM from O to get bias-corrected observation
- <u>*N* = 10 to 31 days</u> (UK Met O uses 28 days with good results)

Also considering regression approach (O-P as a function of O or P predictors) similar to that used for TOVS, GOES radiance bias correction. Simple tests using forecast (P) ZTD, Ps, Ts as predictors show that

- global (all-site) regression is only effective for removal of variable component of bias
- **constant site-dependent component must be determined first** and removed (as opposed to e.g. TOVS where both constant and variable bias can be removed from air-mass predictors)

# GNSS Radio Occultation

- Limb-looking observation with vertical scan
- Active technology with passive satellites
- Signals from other artificial sources
- Sensitive to refraction index of air

$$n(\rho_{Air}, \rho_{WV}, T)$$

- In stratosphere: measure of temperature
- In lower troposphere: measure of vapor moisture
- Horizontal “resolution” ~300km
- Vertical resolution ~500m
- Global coverage
- Particularly dense coverage in polar regions
- All-weather. Signal traverses clouds, rain

# Outline of the principle

- Radionavigation satellites (GNSS) provide accurately known signals (in-orbit atomic clock, accuracy of few 10s of picosecond).
- Propagation takes ~0.01s
- Atmosphere & ionosphere produce delays of ~µs
- From a LEO, GNSS satellites appear and disappear through the Earth's limb (=occultation, ~500 events/receiver/day).
- Each event can be inverted to a vertical profile of refraction index.

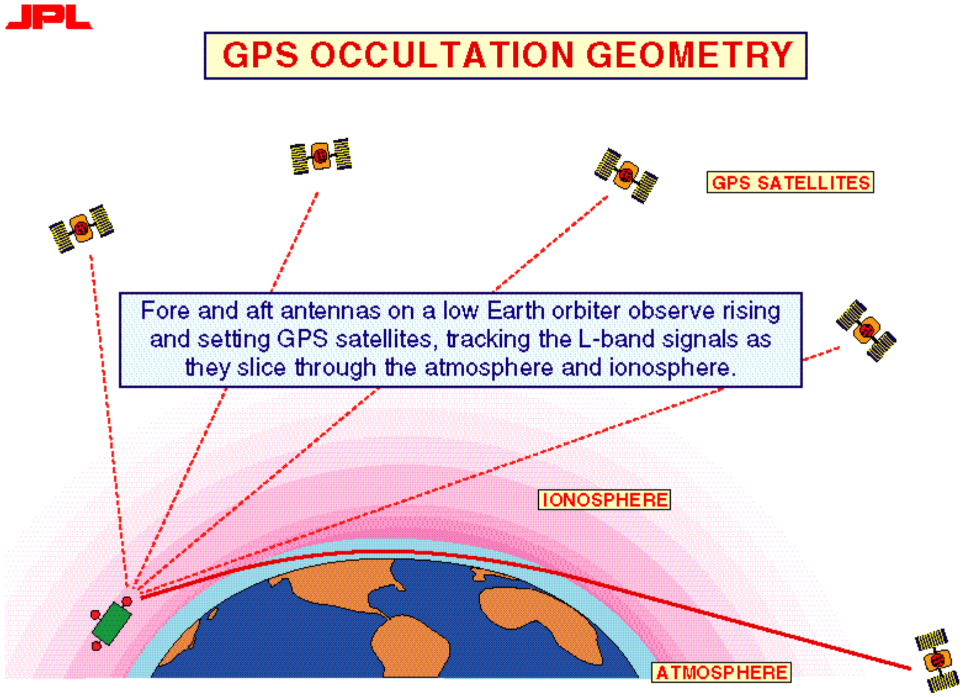



Image from JPL

# Distribution of profiles

- Typical distribution for 1 day of COSMIC data (green dots)
- Dense, very uniform worldwide coverage with few correlations
- Geographically well distributed (compare with radio sondes, red dots)
- Large density at high latitudes
- Land & ocean, all weather

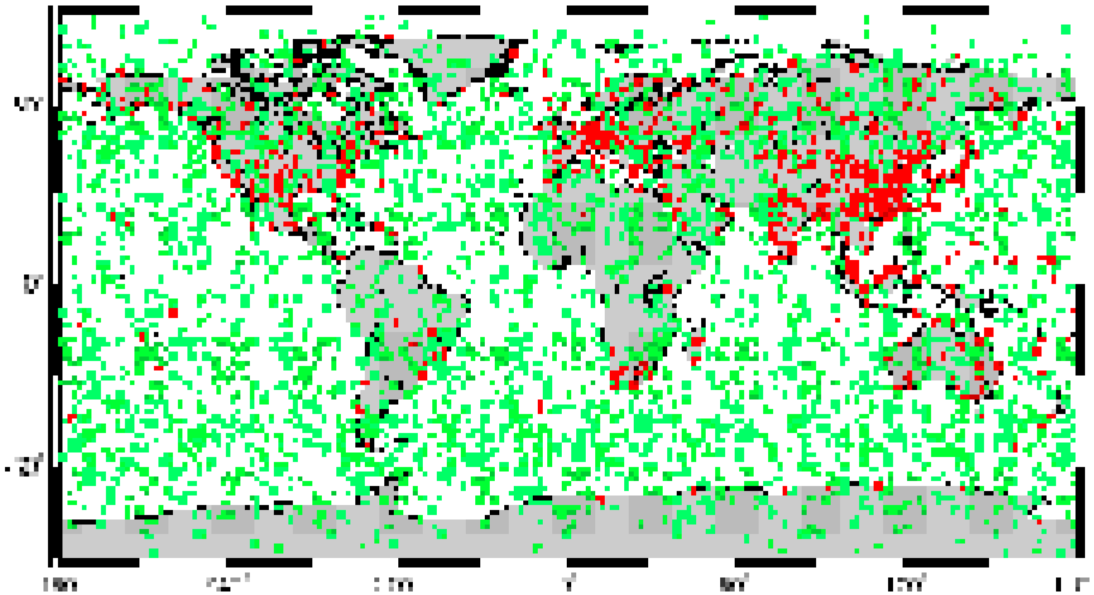


Image by COSMIC team
GREEN: Sample 1-day COSMIC soundings
RED: Radiosondes

# Orbiting Emitters & Receivers

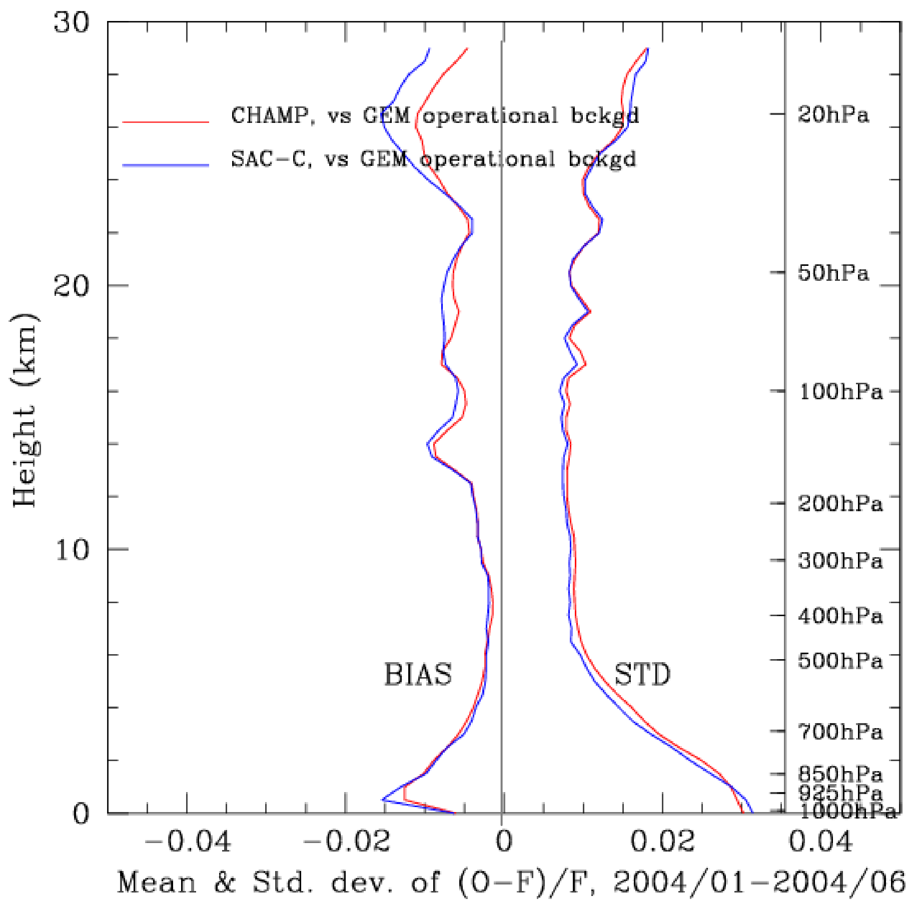
- Currently ~30 emitters (GPS) and 2 orbiting receivers (**CHAMP, SAC-C**): 300 profiles/day
- Other emitters (future missions may also consider them)
  - GLONASS (~30, but currently only ~10 operational)
  - GALILEO (~30, will be operational in 2008)
  - Others (~10, mostly geostationary)
- All current projects are focused on GPS only

| **Name** | **Number** | **Launched** | **In oper.** | **Launch date** | **Oper. commitmnt** |
|---|---|---|---|---|---|
| GPS/MET | 1 | yes | no | 1995 | no |
| OERSTED | 1 | yes | not the RO rcvr | 1999 | no |
| SAC-C | 1 | yes | yes | 2000 | no |
| CHAMP | 1 | yes | yes | 2000 | no |
| GRACE | 2 | yes | yes | 2002 | no |
| COSMIC | 6 | no | | ~2006 | Demonstr. |
| METOP | 1-3 | no | | ~2006 | Fully oper. |
| NPOESS | 1 | no | | ~2008 | Fully oper. |
| CHINOOK | 1 | no | | ~2010 | TBD |
| COSMIC II | 6-12 | no | | ~2010 | Fully oper. |

# GPSRO Observation-Model
# 1st generation inversion s/w

- Good measure above 4 km
- Negative bias below
  - a fraction is known to be data bias (partially caused by hardware & partially by inversion software)
  - Work is underway in both areas
  - Upcoming generation of receivers & inversion software expected to bring data bias consistently below 0.5%*
- Best agreement in upper troposphere & low stratosphere
- Standard dev:
  - 0.5-1% above 6km, slowly increasing with height
  - 2-3% low troposphere
  - Largest source of low-troposphere STD in the Tropics

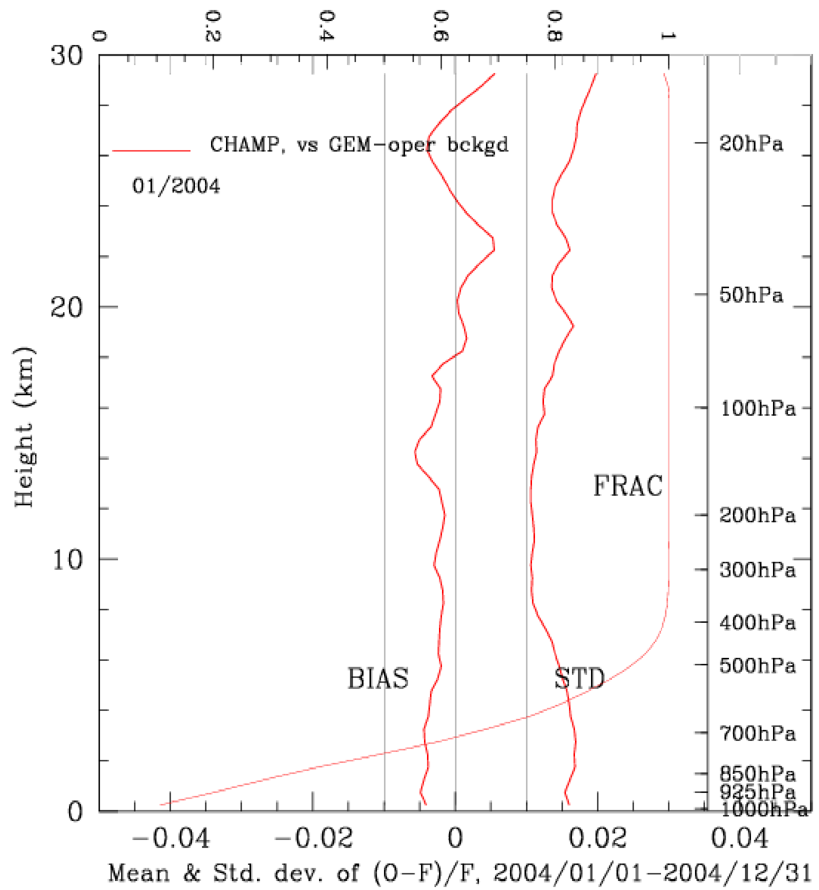
*Actual measure is refractivity. When refractivity is related to temperature, (above tropopause & polar troposphere), 0.5% translates to ~1K.




6 months data: 2004/01-2004/06
JPL inversion v1.0

# Seasonal variations
# 2nd generation inversion s/w

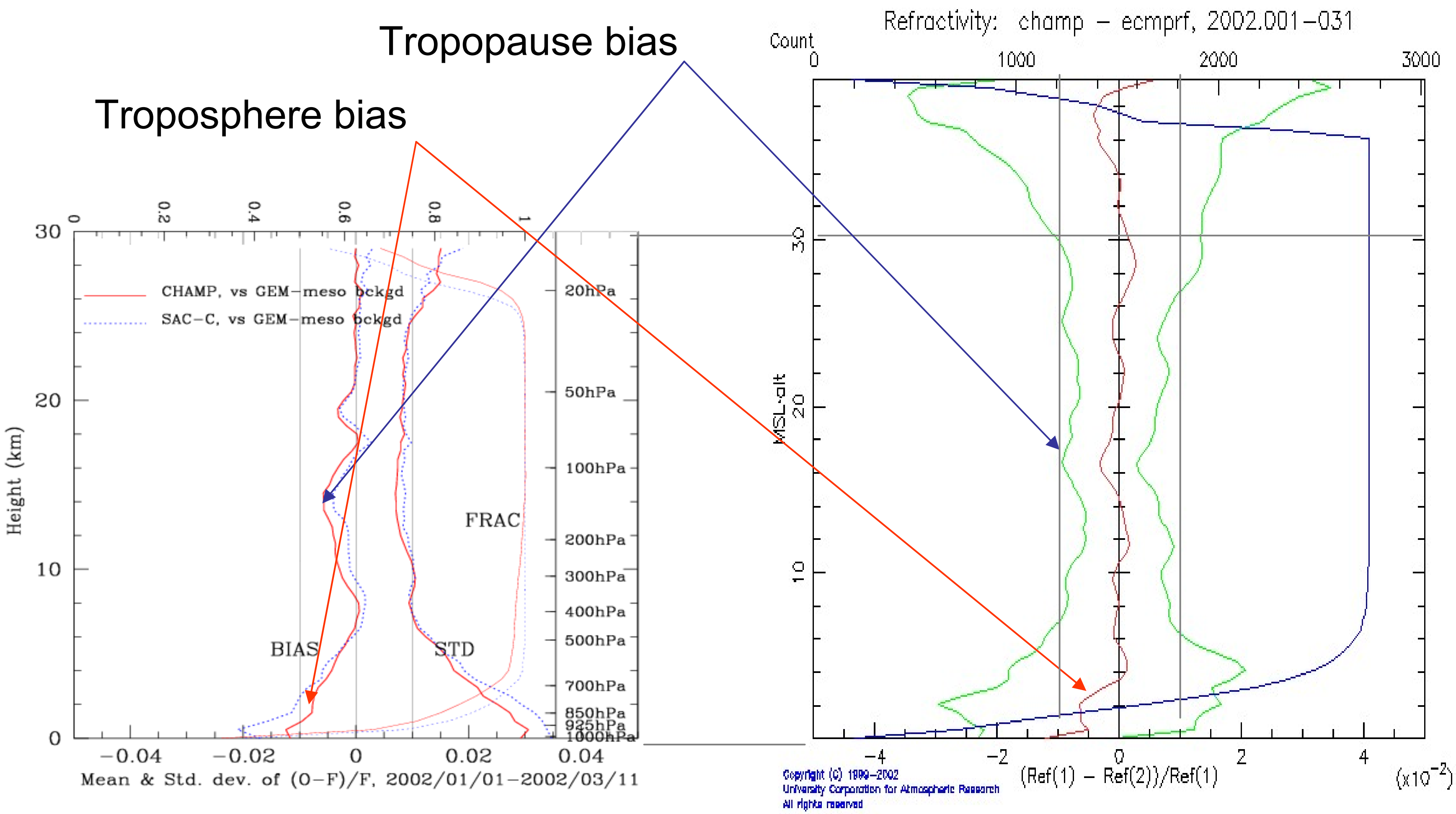
- Improvements of second generation inversion software are encouraging
- By 2006, next generation hardware in orbit, expected to further reduce low troposphere bias
- Obs-Forecast show seasonal variations attributed to forecasts
- Still two systematic biases
  - Low troposphere (much smaller with last generation inversions)
  - Around tropopause




12 months data: 2004/01-2004/12
UCAR inversion

# Refractivity Obs-Forecast (6h)

**Results are similar in a wide class of models & data inversion procedures**

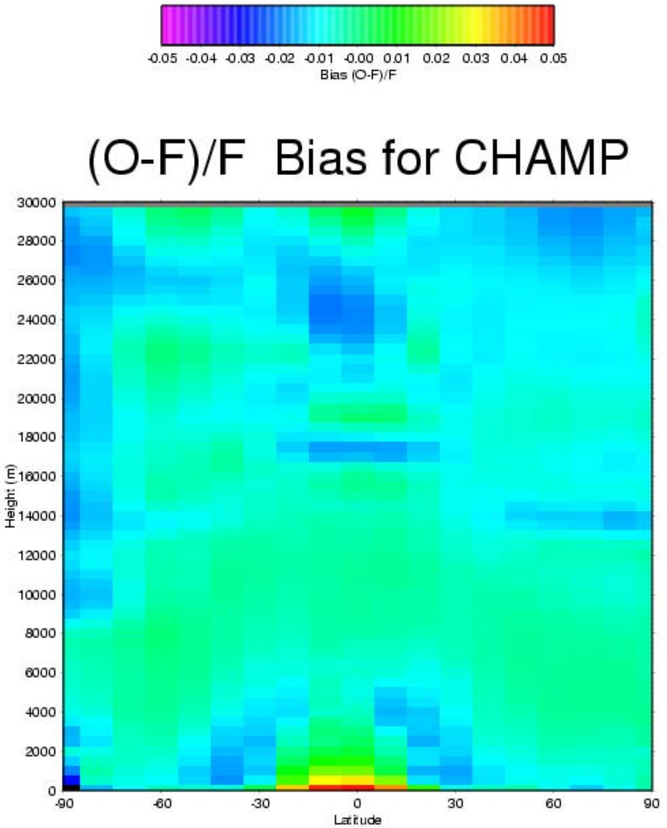


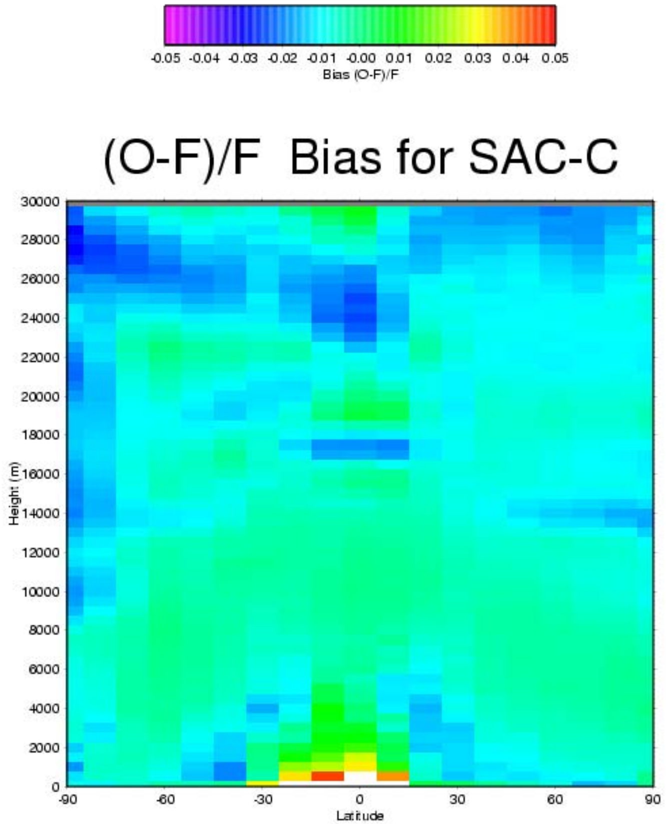

**GEM-mesoscale**

2.3 months data: 2004/01-2004/03
JPL inversion v1.0

**ECMWF** Image by COSMIC team (UCAR)
1 month data: 2004/01
UCAR inversion

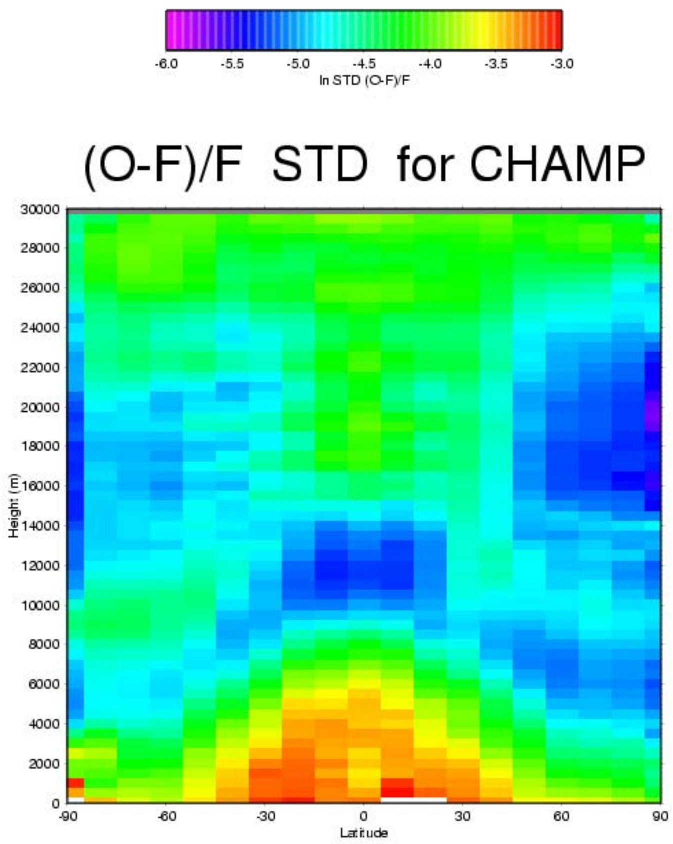
# Obs-Short Forecast bias (6h)
## height/latitude dependency

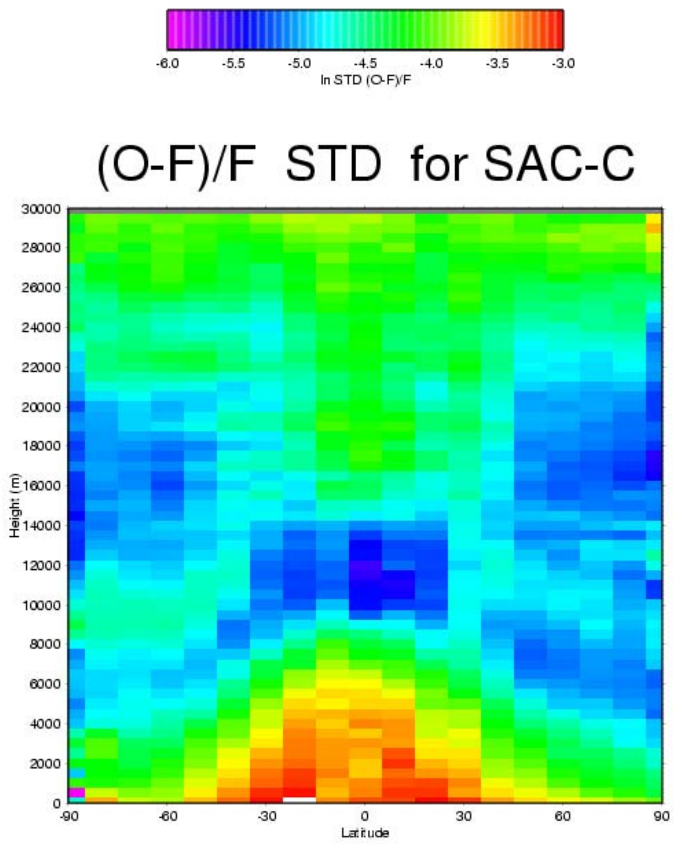



6 months data: 2004/01-2004/06
JPL inversion v1.0

# Obs-Short Forecast (6h)
## height/latitude dependency



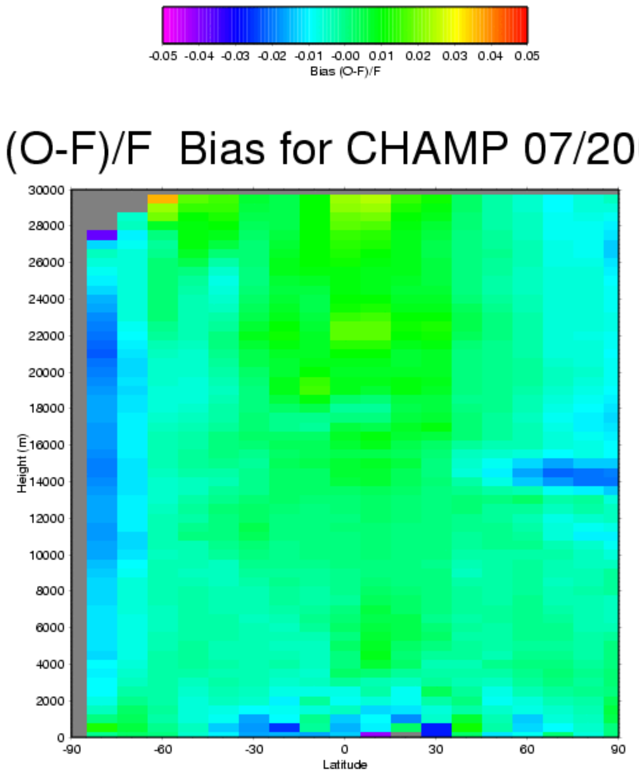




6 months data: 2004/01-2004/06

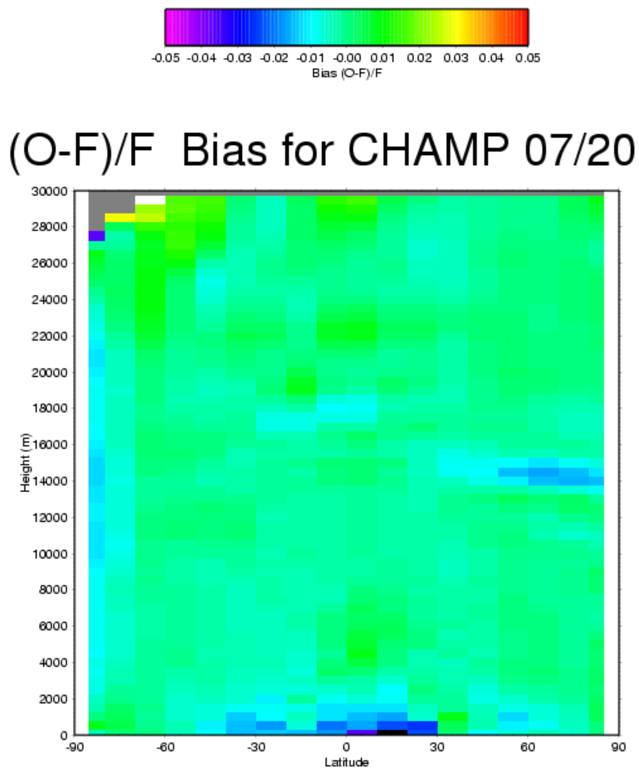
JPL inversion v1.0

# Source of bias identified: non spherical earth
## (in converting topographic height to surface geopotential)

Spherical (g constant)




Aspherical (g varies)




Effect mostly over mountains at high latitudes.
GNSS precise enough to be sensitive to neglected effect in NWP.

# Bias correction strategy

- Known data bias below 4 km. Now partially corrected during retrieval. Suspected to be a receiver hardware problem that shows when signal has traversed a region of strong gradients (large amounts of moisture).
- Also small bias around tropopause. Suspected to be model bias.
- After analyzing correlations within 1 yr of (O-P), the bias seems best represented in terms of:
  - Height (500 m resolution)
  - Latitude (10 deg bins)

# Some conclusions

- Air-mass dependent biases are much larger for MW than for IR radiances and point to RTM deficiencies.
- Removing edges of AMSU scans does not appear justified.
- GNSS appears promising as a high quality low bias data source. Ground-GPS data in comparison is more subject to biases of complex nature.
- MSC modifies his bias correction periodically. Continuous updating has its advantages and disadvantages (to be further discussed here!)
- MSC follows similar bias correction strategies to those applied at other NWP centers. Comparing monitoring statistics should facilitate the interpretation: separating model and observational bias.