Experience and estimation of biases in ECMWF reanalyses

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Contents

- Reanalyses in general
- Bias estimation ERA-15 and ERA40
- How successful ?
- ERA-Interim
- Conclusions

General

- Reanalyses, a sequence of atmospheric and surface conditions over a long period
- Time consistency important
- Quality of reanalyses are affected by
  - The quality of the assimilation system (model and analysis)
  - The characteristics of the observing system
    - Changes
    - Coverage and gaps
  - Boundary conditions
  - Systematic and random errors in the previous

Before reanalyses ..1

- Operational analyses were successfully used in general circulation studies especially in the Tropics and Southern Hemisphere, but due to the improving forecasting system it was
  - Difficult to study interannual variations and
  - Impossible to study climate change
- Reanalysis efforts proposed e.g by Bengtsson & Shukla (1988)

Before reanalyses ..2

- There has been an increasing need to understand trends:
  - MSU-2 data compared with ECMWF operational analyses revealed discontinuities related to major system changes by Hurrell & Trenberth (1991)
  - Upper-air temperature trends Oort & Liu (1992) GFDL data v MSU-2 and MSU-4 in good agreement, high expectations on reanalyses & trends
  - Temperature trends and inadequate spatial sampling Karl el al. (1993)
  - …

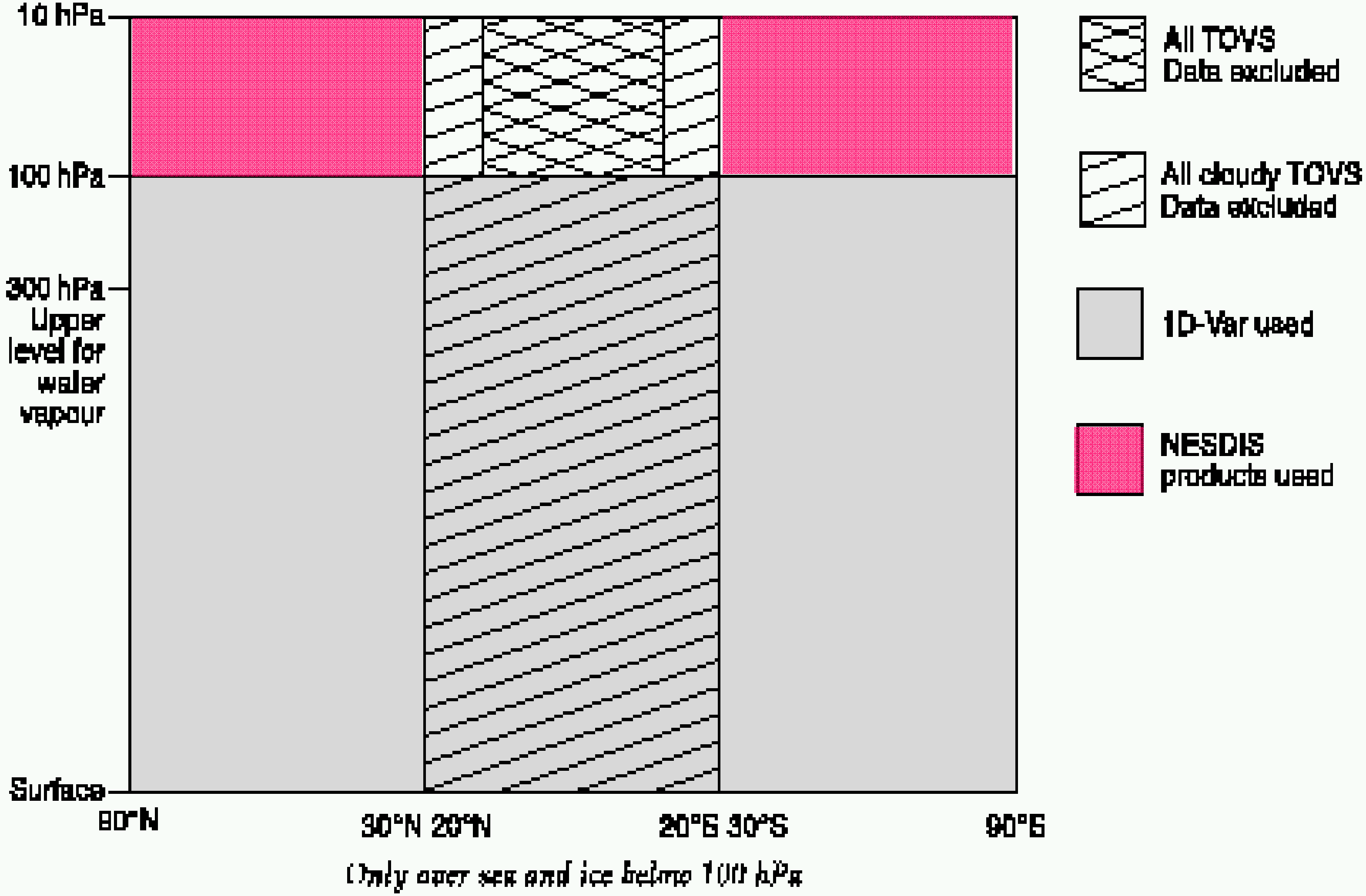
ECMWF reanalyses

ERA-15 1979-1993

- Data assimilation system
  - Model T106L31
  - Optimum Interpolation
- TOVS Cloud Cleared Radiances (HIRS/ MSU) through 1D-Var retrieval
- Bias corrections applied to satellite radiances and radiosonde heights
- ECMWF operational data the main source of conventional observations, added by COADS, FGGE, ALPEX

- NCEP Reanalysis
  - Period 1948 → and continues as Climate Data Assimilation System (CDAS)
  - NCEP reanalysis has used the original NESDIS retrievals
  - Retrievals of SSMI data have not been used
- ECMWF Operations
  - Direct assimilation of radiances started in 1996

Use of TOVS data in ERA-15



CCR bias correction in ERA-15

	ERA-15
Input radiance	Cloud Cleared and nadir corrected Radiances
Method	Static J. Eyre based on W. Smith & H. Woolf
Scan bias	Global offset with 0 at center
Air-mass dependent bias	Data selected in 5 latitude bands
	Predictors: MSU-2,3 and 4, which are unaffected by clouds
Update frequency	Monthly

ERA-15 Tropical temperature

JOURNAL OF CLIMATE

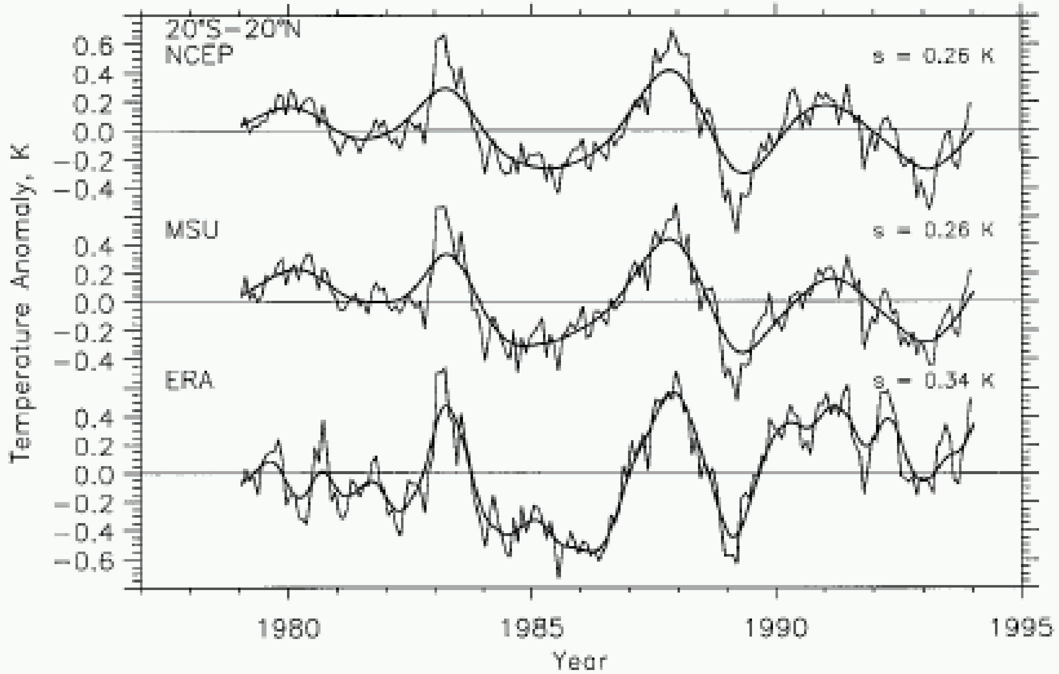


FIG. 2. Time series of the monthly mean tropical (20°N to 20°S) 2LT temperatures from NCEP, MSU, and ERA-15. The standard deviation of each is given in the insets. A low-pass smoothing spline has been fitted to the data to show the decadal variations.

Trenberth et al. (2000)

ERA-15 Tropical temperature

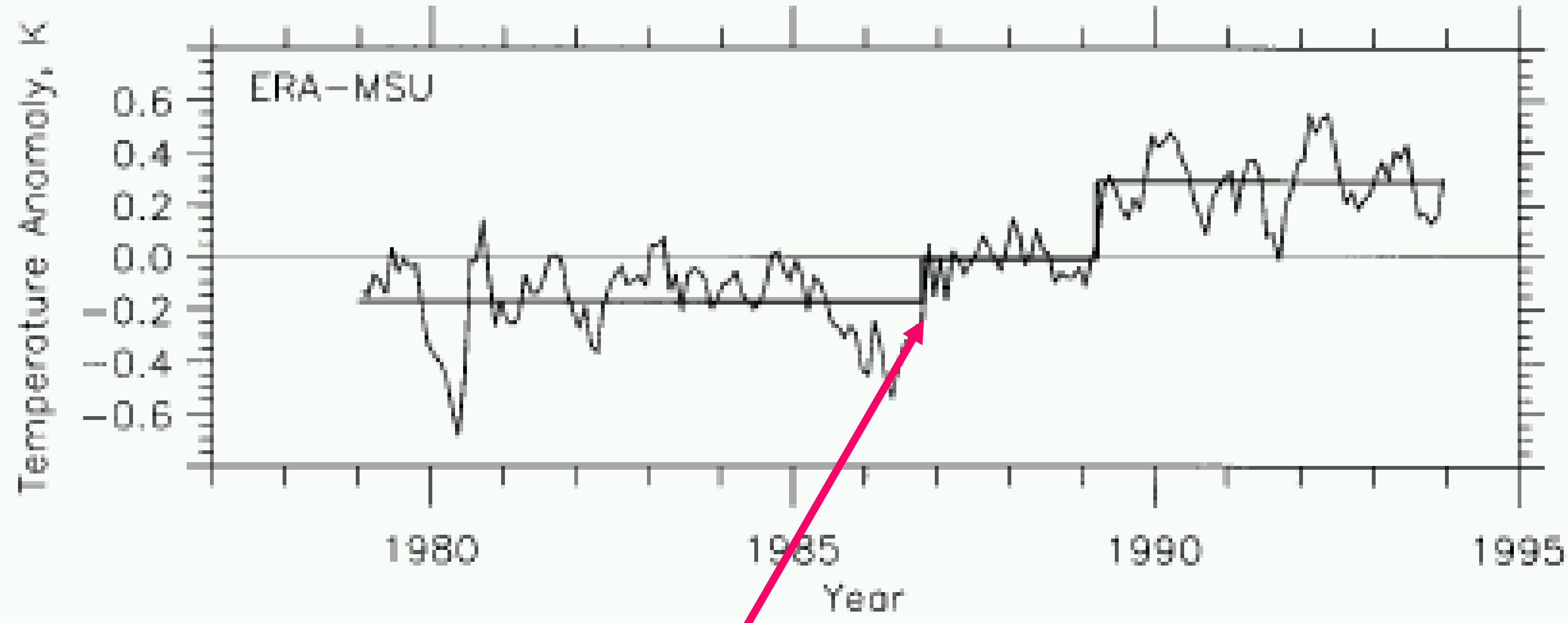


FIG. 3. Difference in time series of the monthly mean tropical (20°N to 20°S) 2LT temperatures from MSU and ERA-15, as ERA–MSU. A straight line fit has been added to the series to show the two discontinuities.

Trenberth et al. (2000)

NOAA-9 MSU-3 problem
November 1986

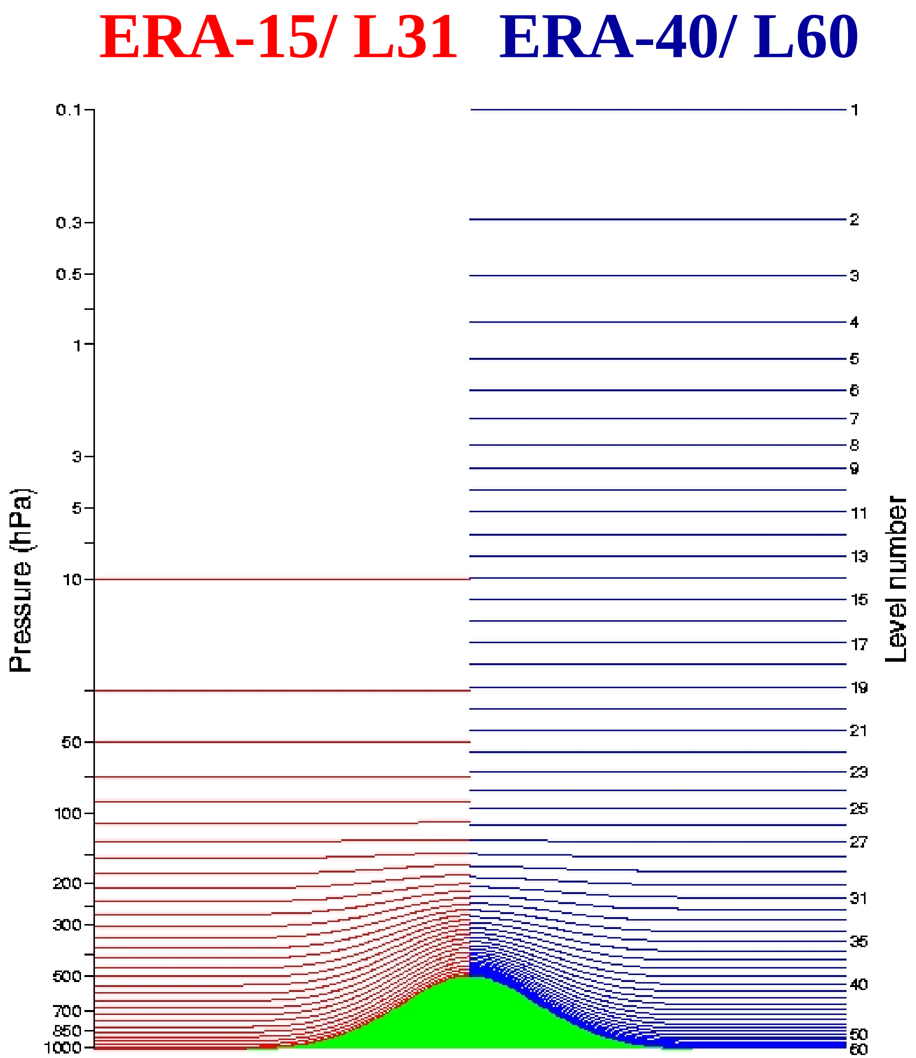
ECMWF reanalyses

ERA-40 1957-2002

ERA-15 1979-1993

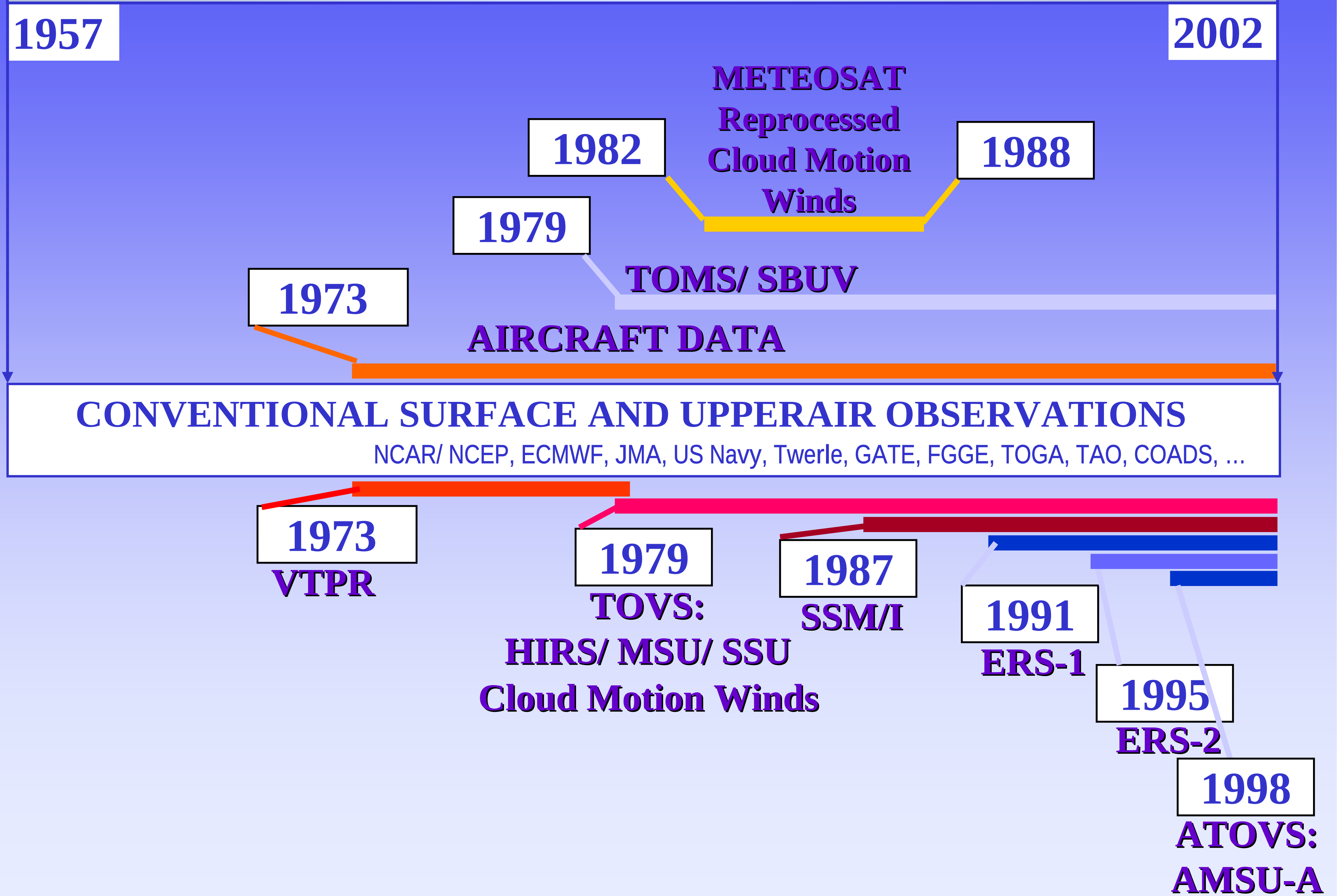
- Improved data assimilation system
  - Assimilating model T159L60
  - 3D-Var FGAT
  - Analysis of O_3
- More extensive use satellite radiances
- ERA-15 experience ➔ ERA-40 blacklist
- More comprehensive use of conventional observations
- Use of Meteosat reprocessed winds, CSR data passive
- Improved SST & ICE dataset
- Ocean wave height analysis

Model levels



Levels added

Observing Systems in ERA-40

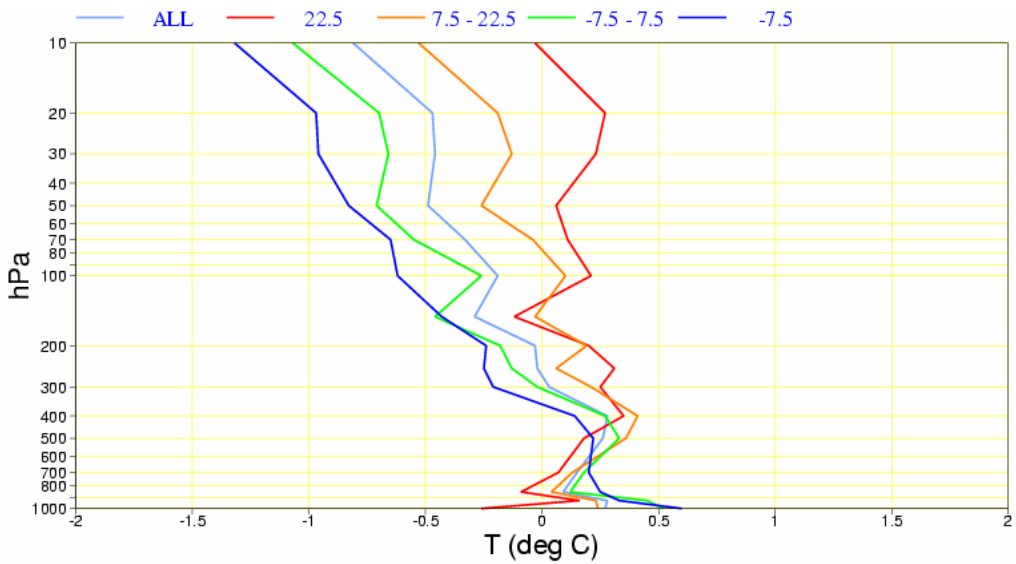


Handling of biases in ERA-40

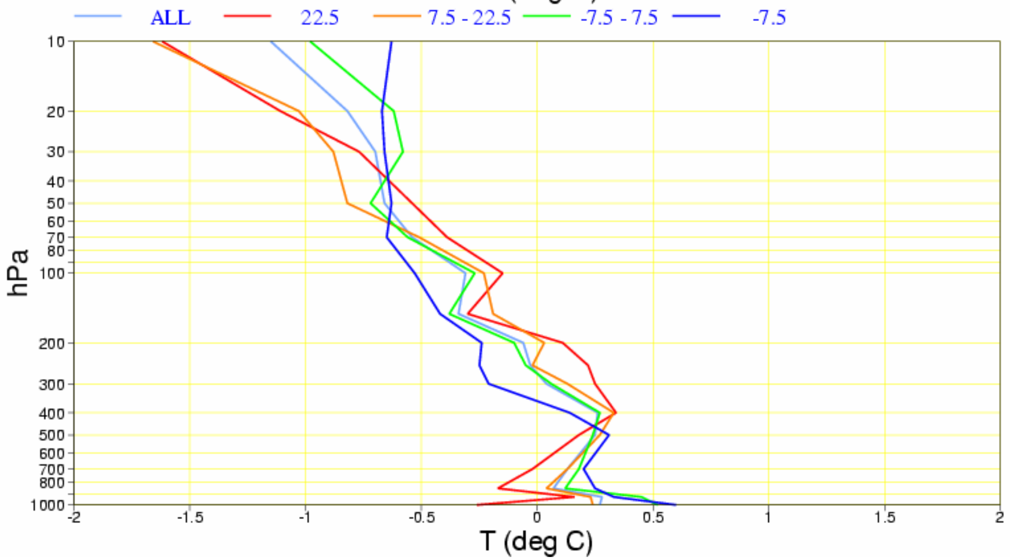
- Radiosonde temperature biases 1980 onwards (Andrae et al. 2004)
- VTPR, TOVS, SSMI and ATOVS radiances
- ERS scatterometer wind bias correction

Radiosonde temperature bias, OB-FG
(4 solar elevation angle intervals and the mean)
all year 1994, South West Canada

Uncorrected



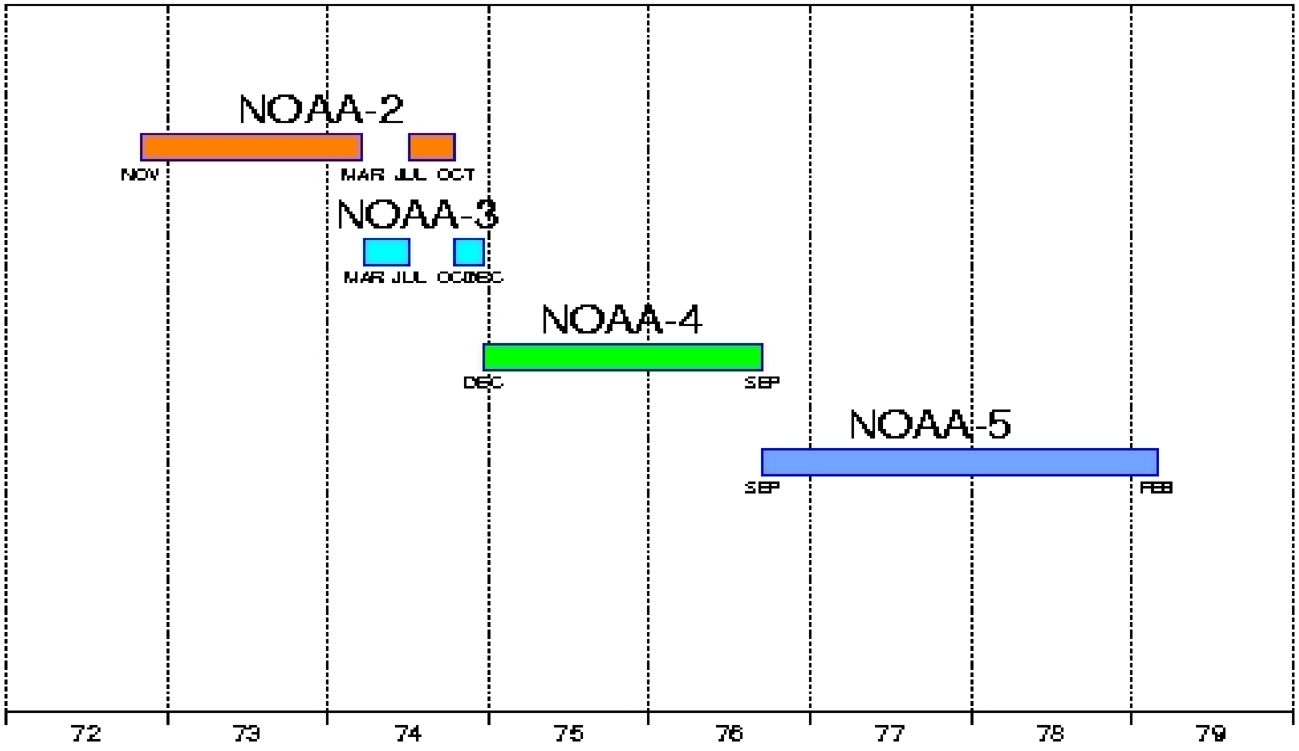
Corrected

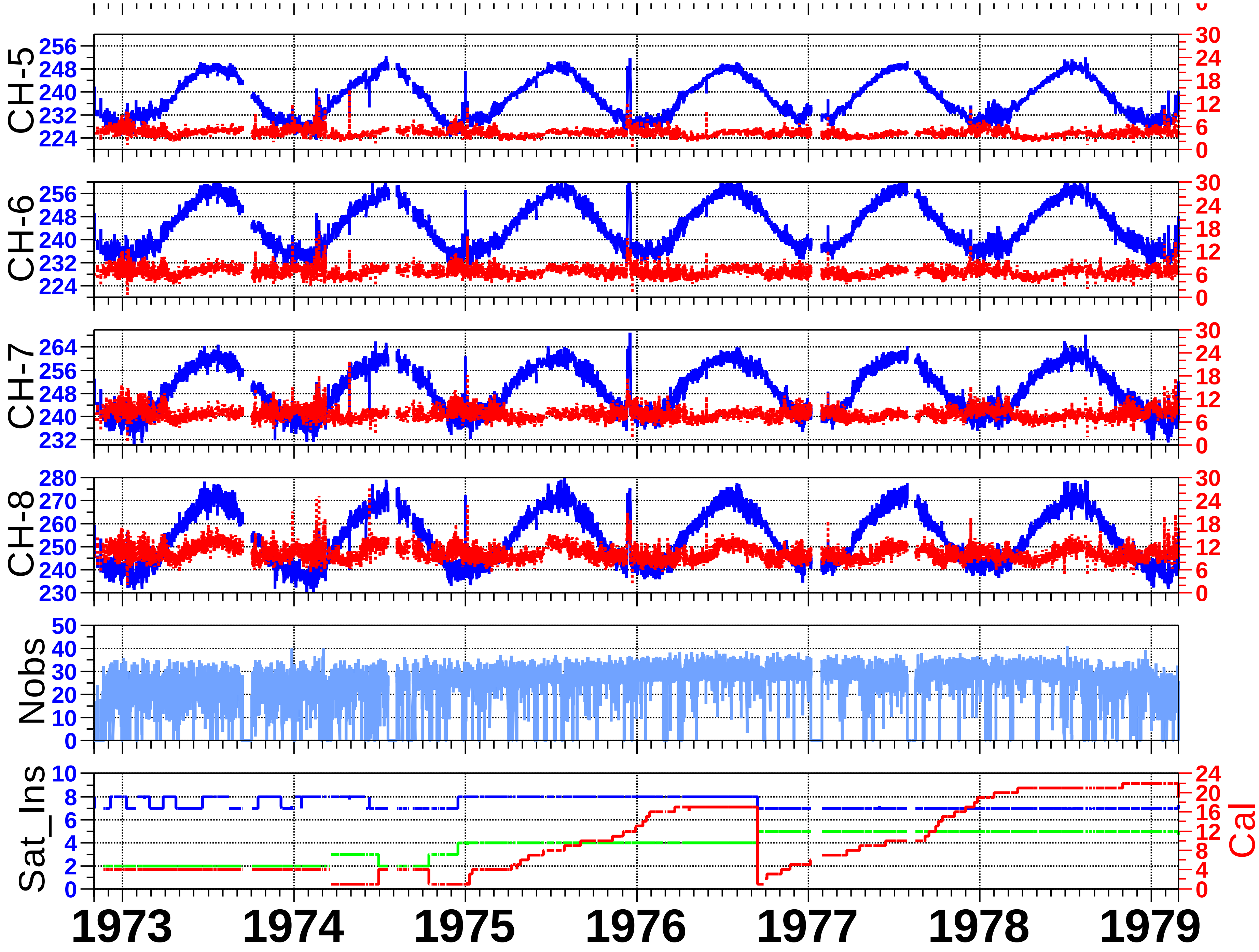


Use of radiances in ERA-40

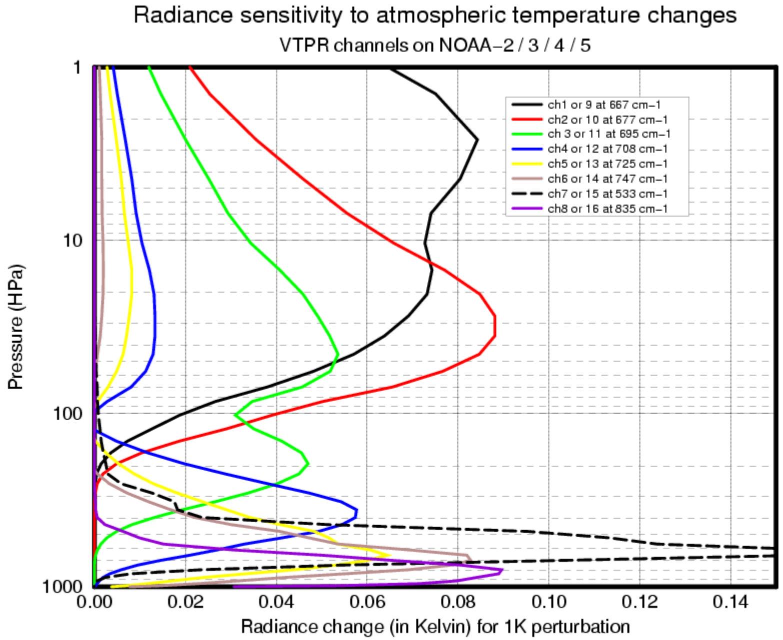
- VTPR 8 channel IR sounder instrument
  PAOBs, bogus observations (BOM) from cloud imagery
- TOVS 3 sounder instruments
  HIRS 20 channel IR
  MSU 4 channel MW
  SSU 3 channel IR
- SSMI 7 channel MW imager
- ATOVS 3 sounder instruments
  HIRS 20 channel IR
  AMSUA 20 channel MW
  AMSUB 5 channel MW

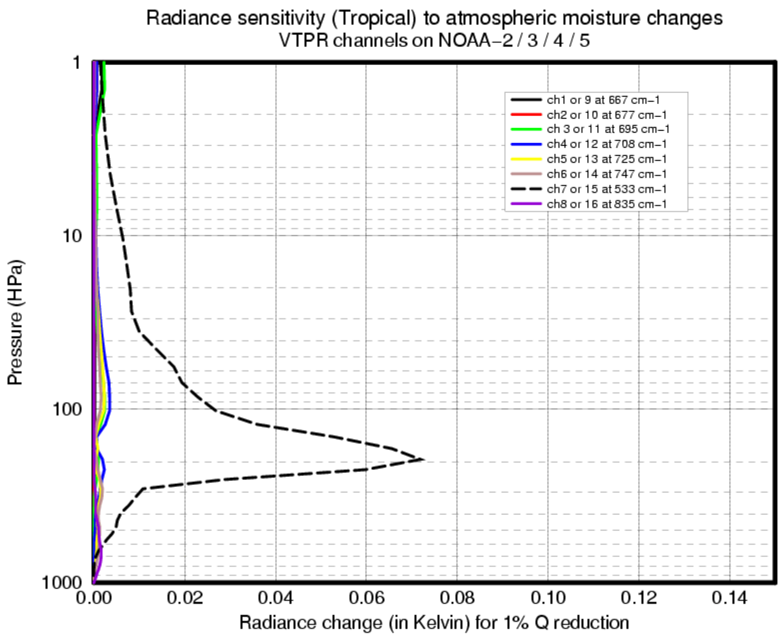
ERA40 - OBSERVING SYSTEM: VTPR




CH-5
CH-6
CH-7
CH-8
Nobs
Sat_Ins
Cal
1973
1974
1975
1976
1977
1978
1979

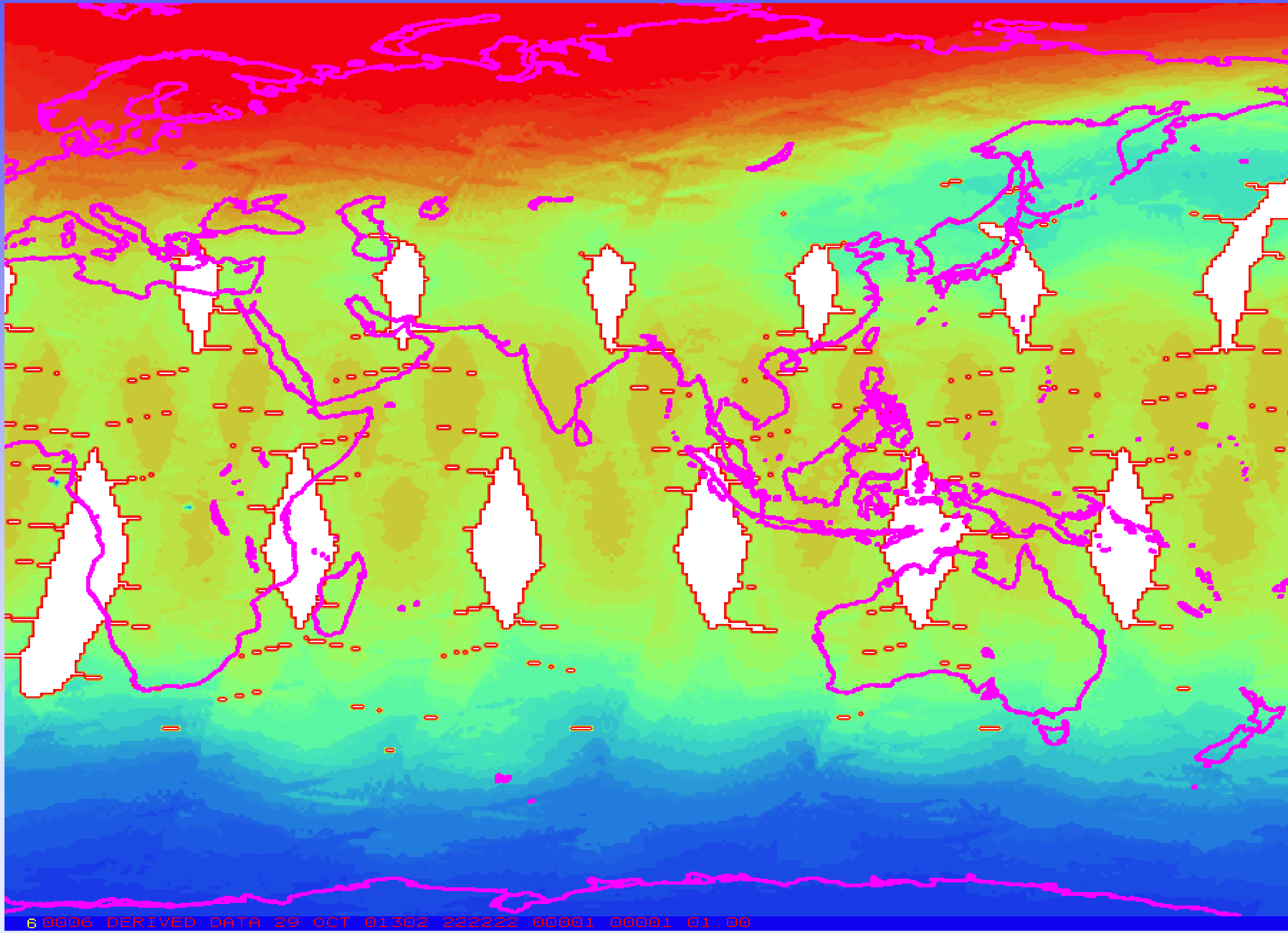
VTPR Radiance Sensitivity



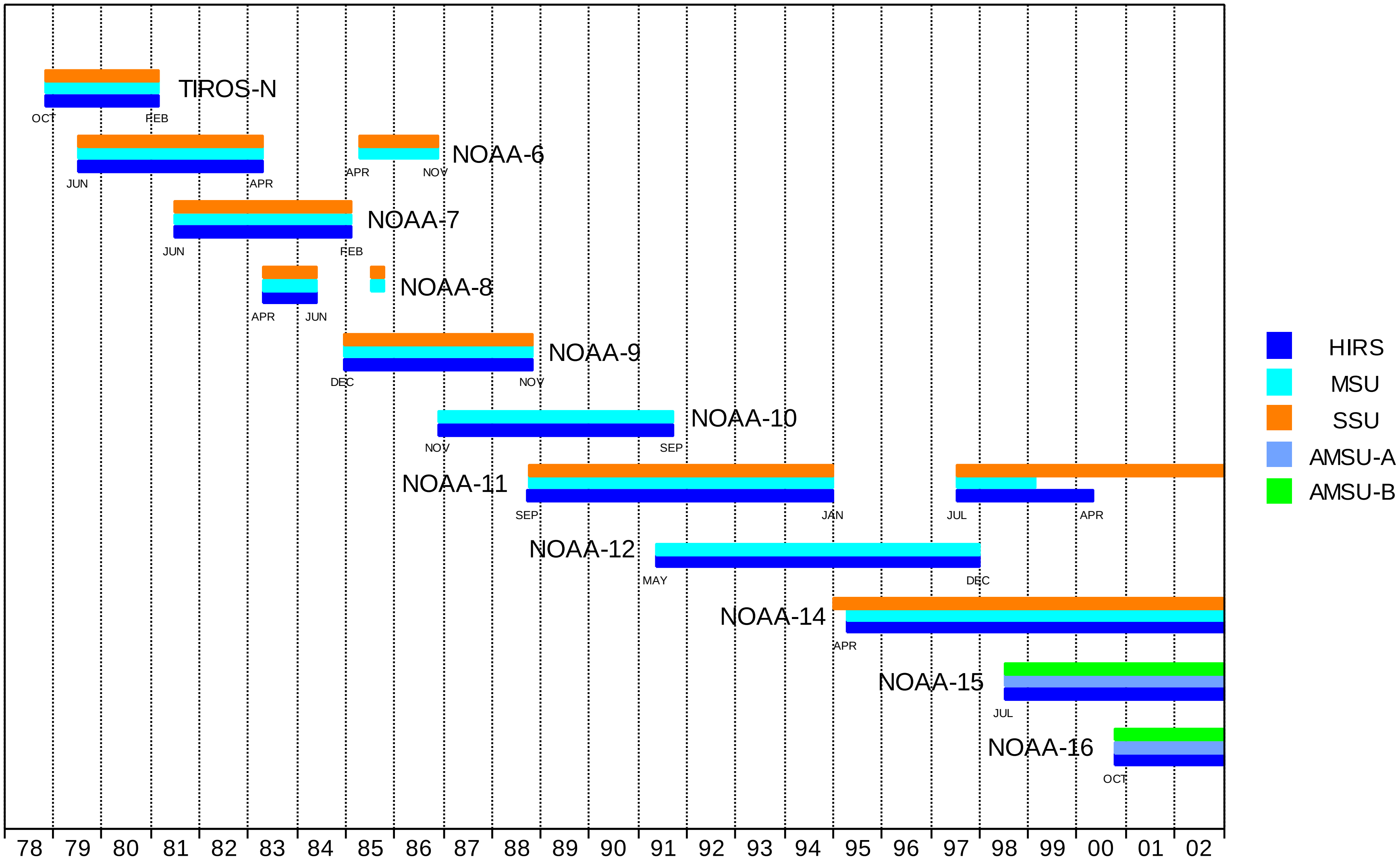


Temperature **Humidity**

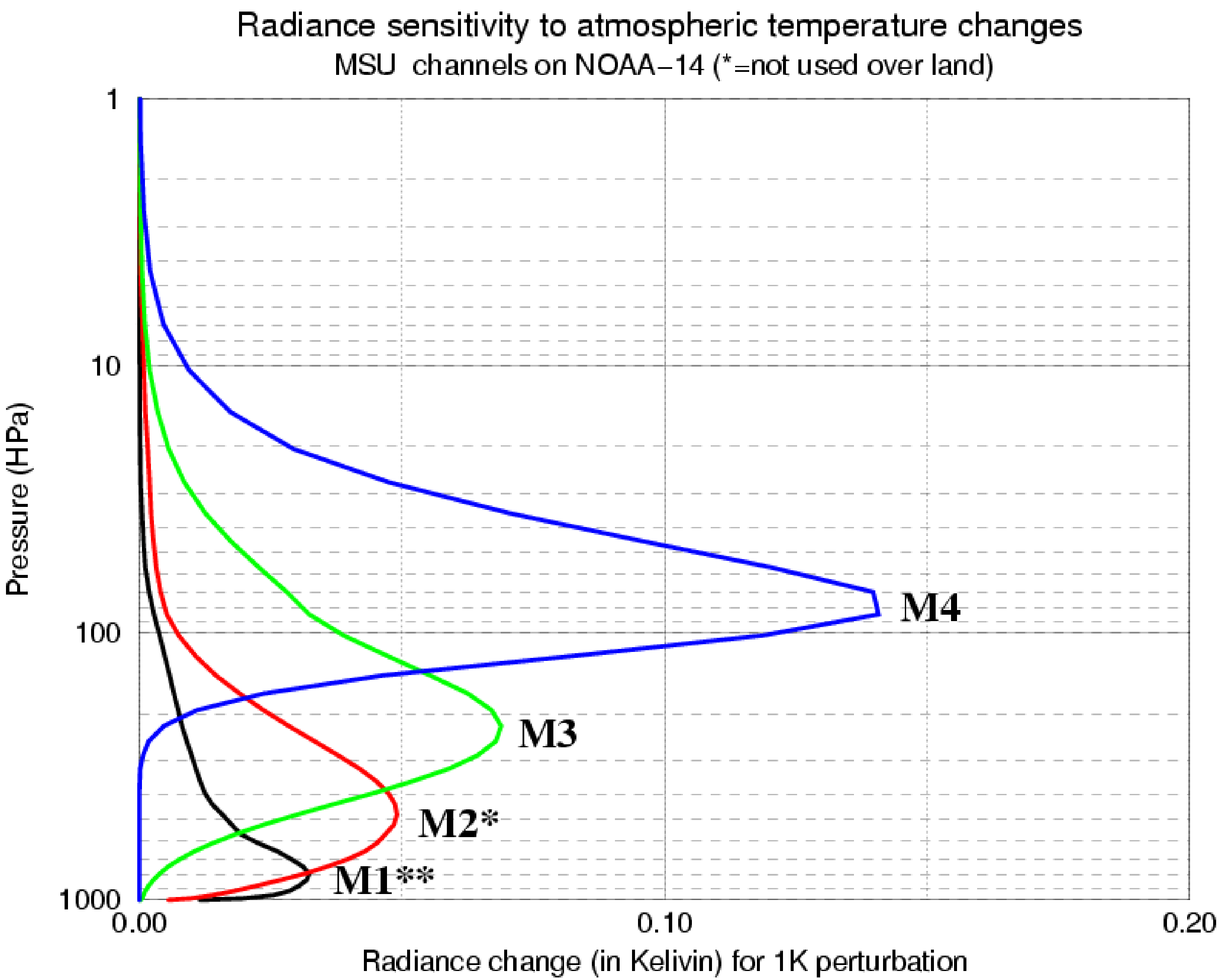
Image created from VTPR CH 2 for all orbits on 28/12/1972



TOVS/ATOVS satellite data 1978-2002

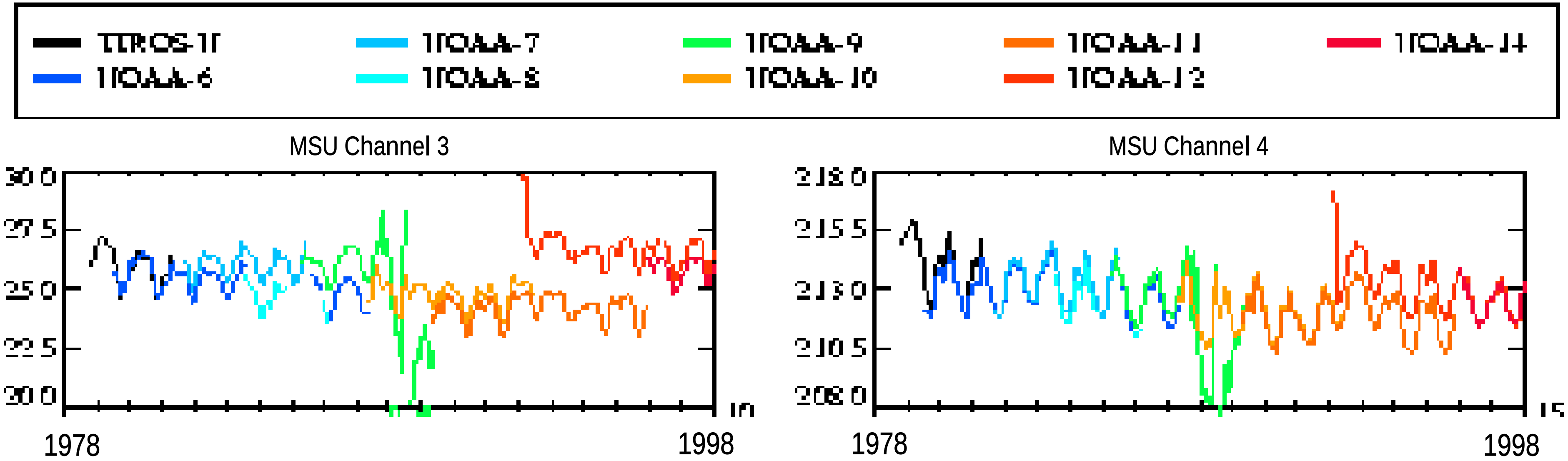


Hernandez et al. (2004)



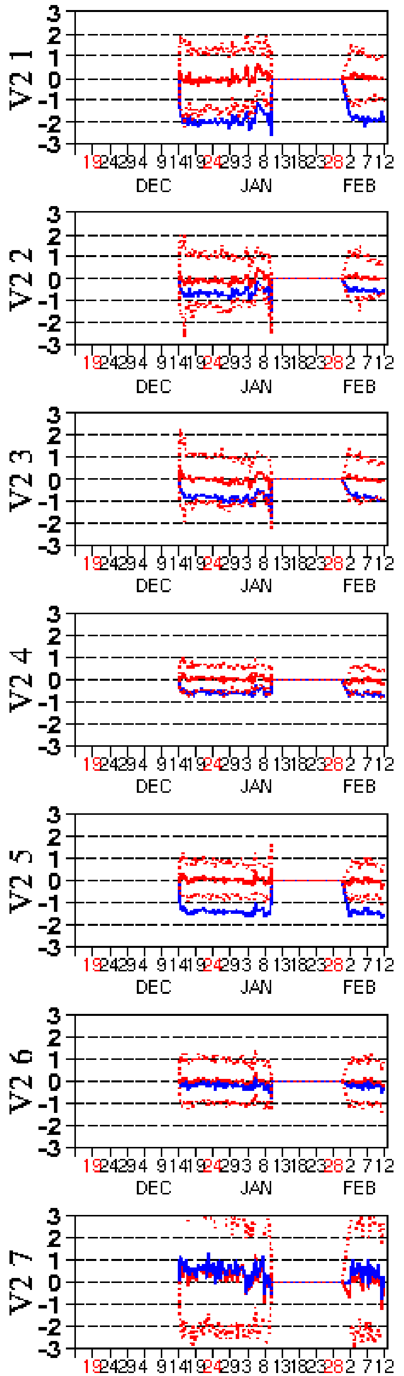
Radiance sensitivity to atmospheric temperature changes
MSU channels on NOAA−14 (*=not used over land)
Pressure (HPa)
1
10
100
1000
0.00
0.10
0.20
Radiance change (in Kelivin) for 1K perturbation
M4
M3
M2*
M1**

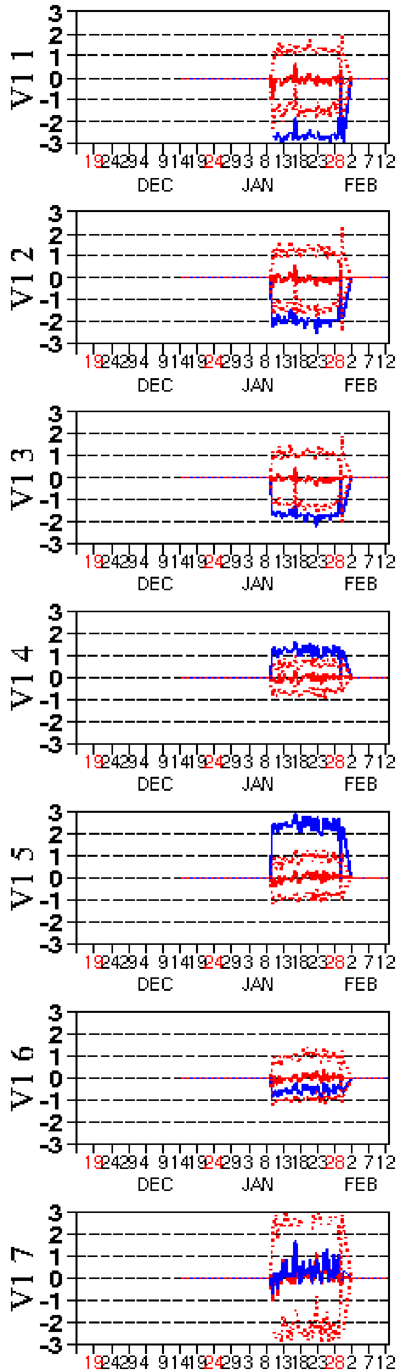
(John Bates, Darren Jackson)



VTPR/ TOVS/ ATOVS bias correction

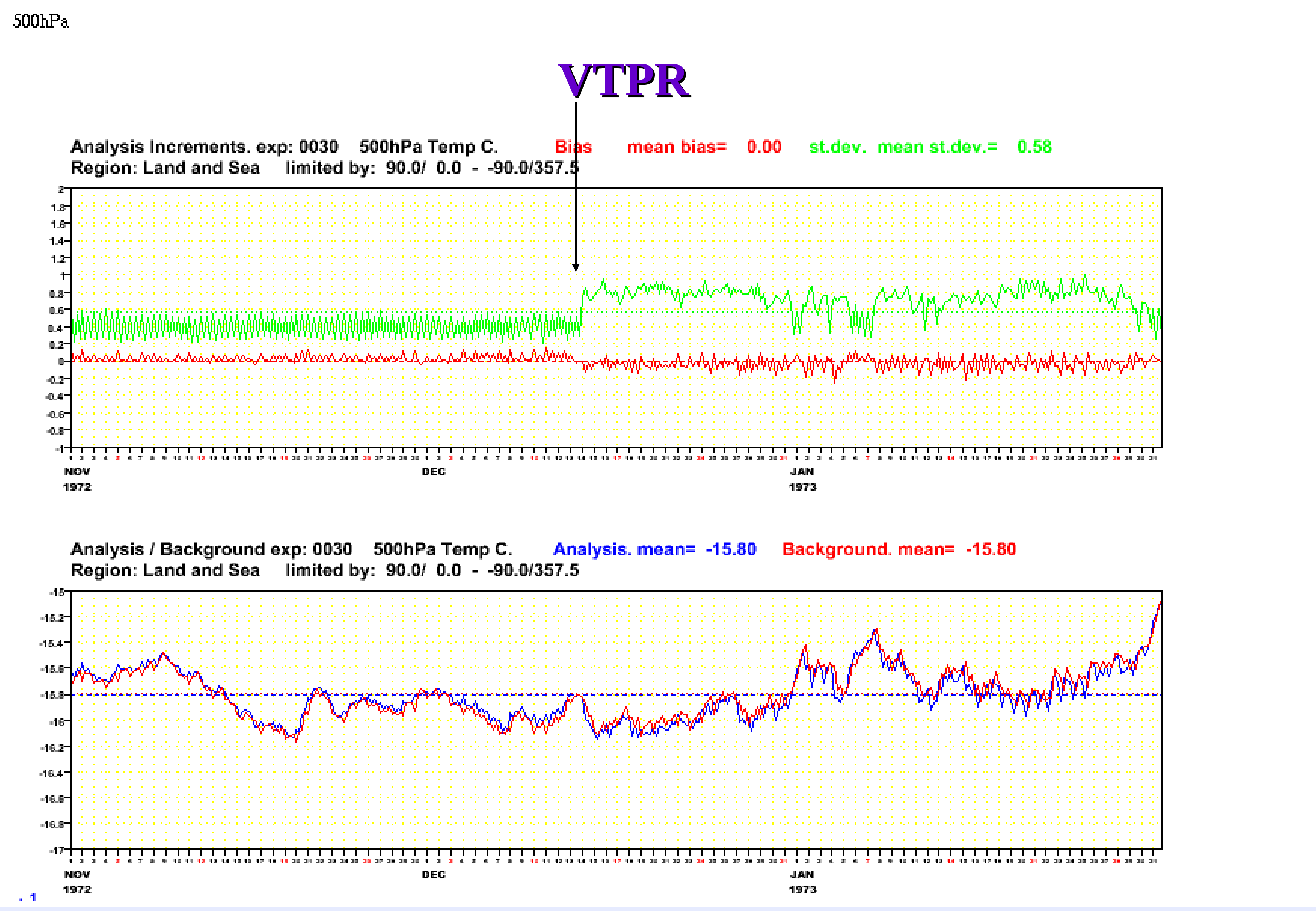
	ERA-40
Input radiance	Level-1c calibrated at ECMWF from Level-1b
Method	Static B. Harris & G. Kelly
Scan bias	18 latitude bands
Air-mass dependent bias	Predictors: Model values DZ(1000-300)hPa DZ(200-50)hPa T_{skin} and TCWV
Update frequency	Once per satellite life time or after a jump in instrument based on about two week statistics



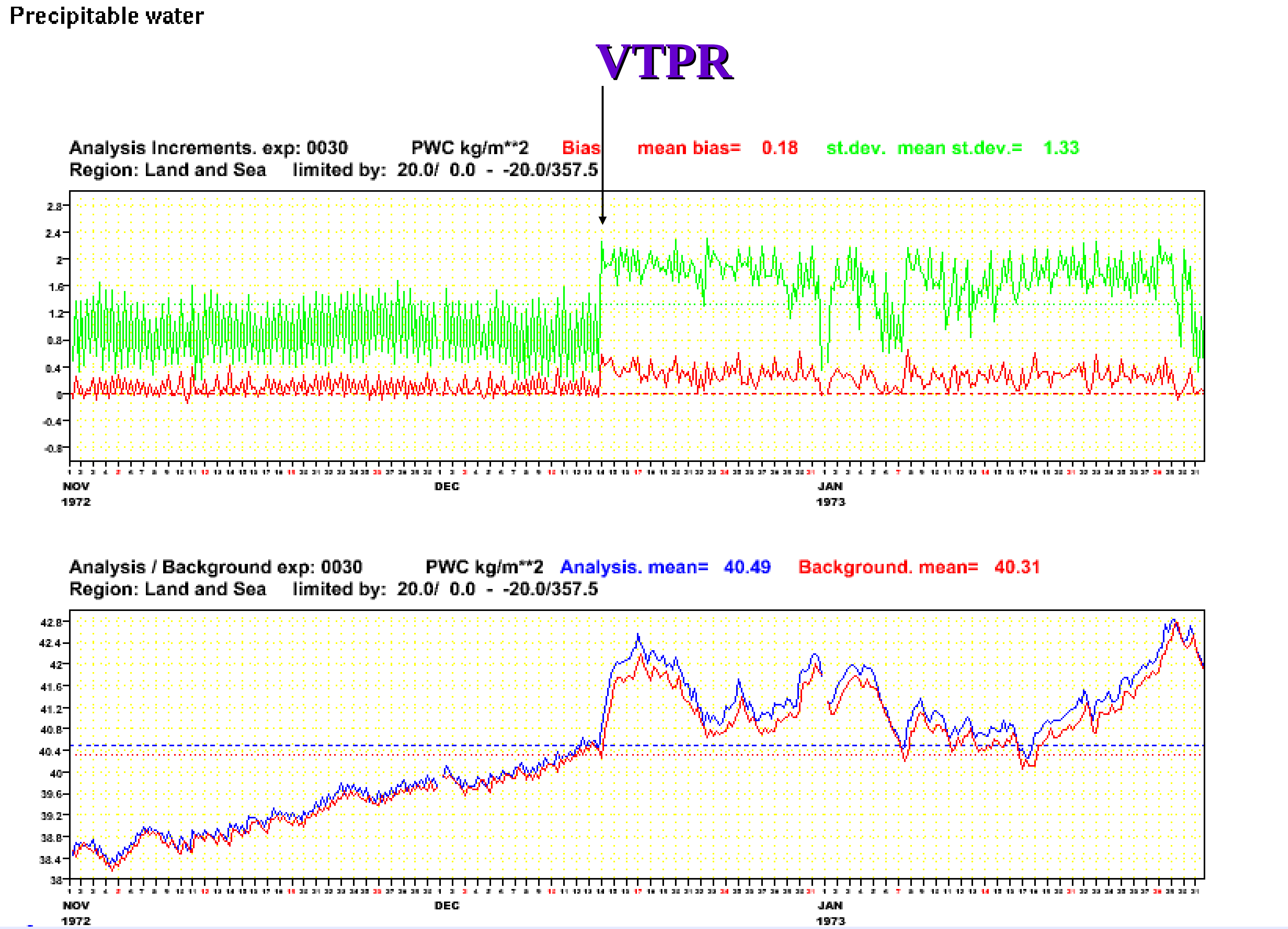


VTPR Radiance monitoring 1972/73

Analysis Increments at the start of VTPR radiance assimilation

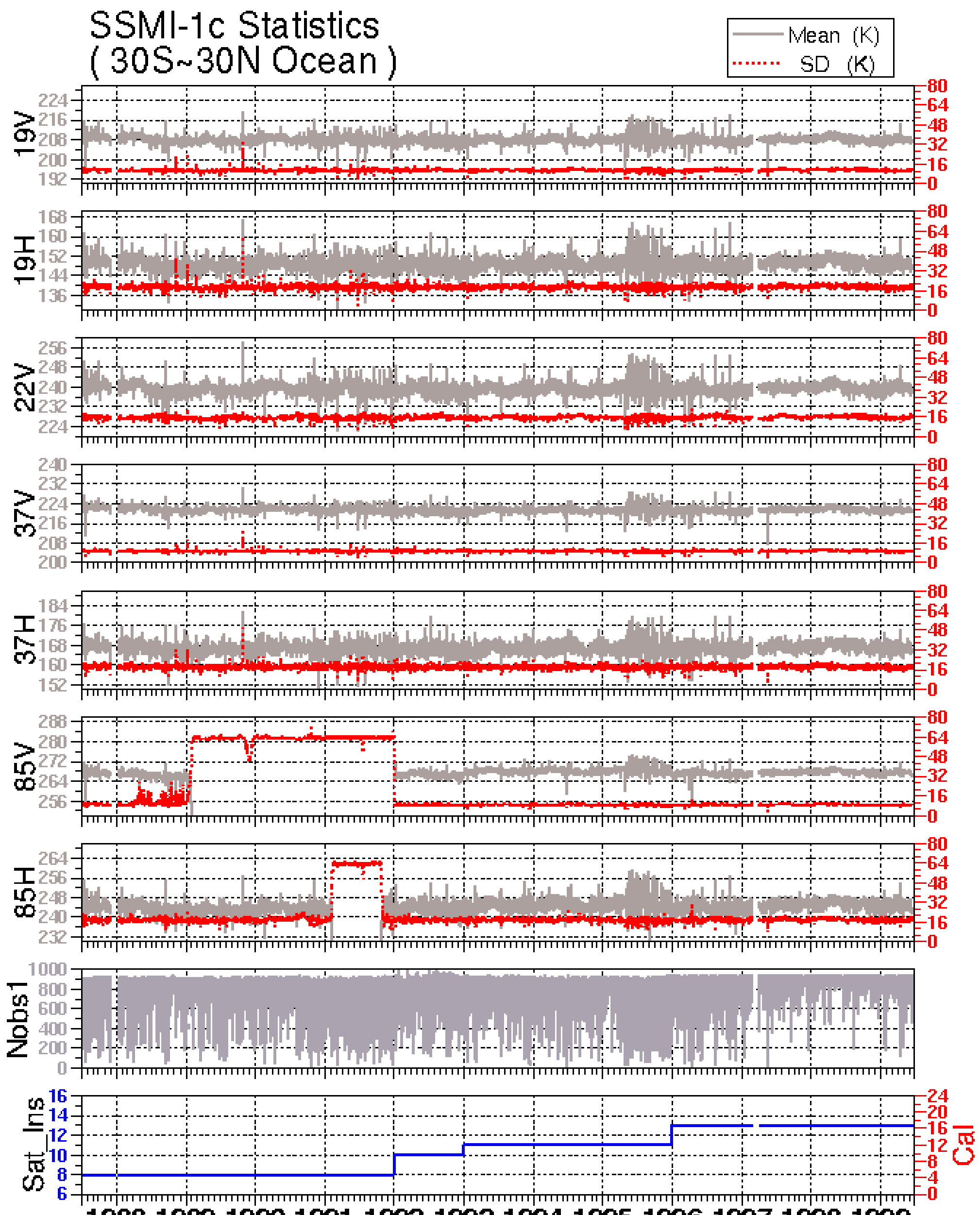


Analysis Increments at the start of VTPR radiance assimilation

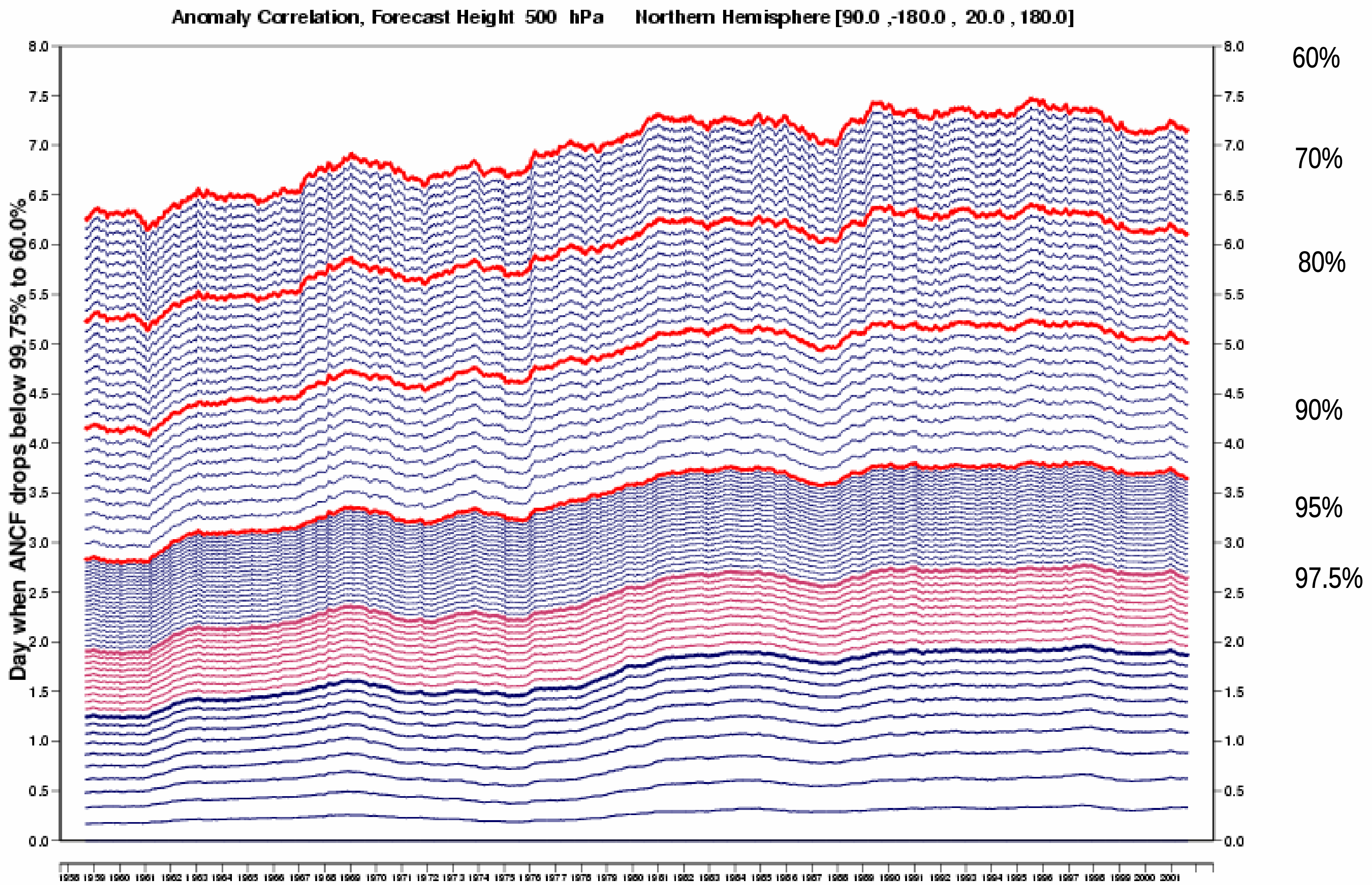


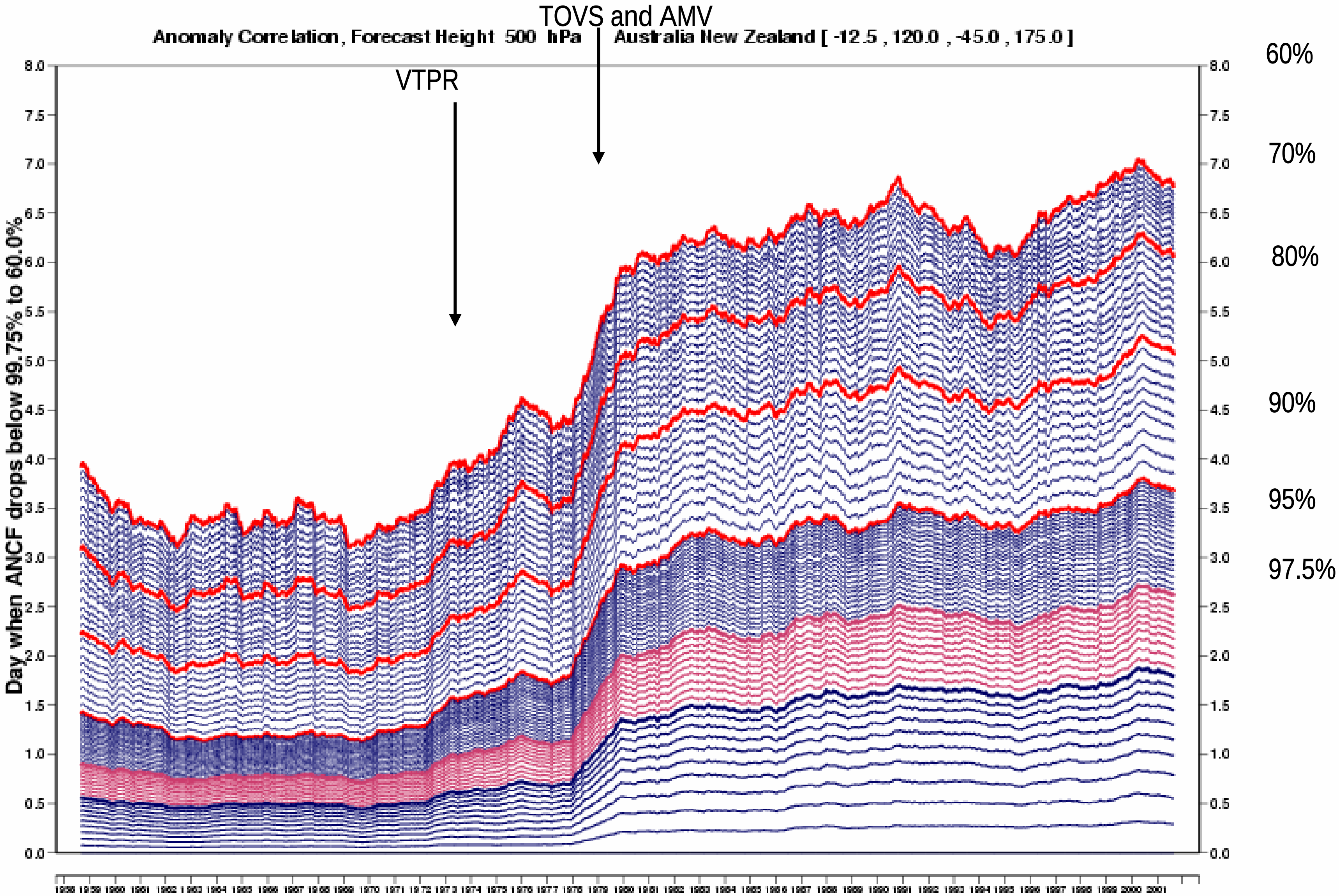
SSMI bias correction

	ERA-40
Input radiance	Calibrated Level-1c from F. Wentz →1998 and then on from ECMWF. Satellite to calibration with reference to the 1st satellite done by F. Wentz
Method	Static B. Harris & G. Kelly
Scan bias	18 latitude bands
Air-mass dependent bias	Predictors: Model values 10 m wind speed, T_{skin} and TCWV
Update frequency	Once per satellite life time or after a jump in instrument

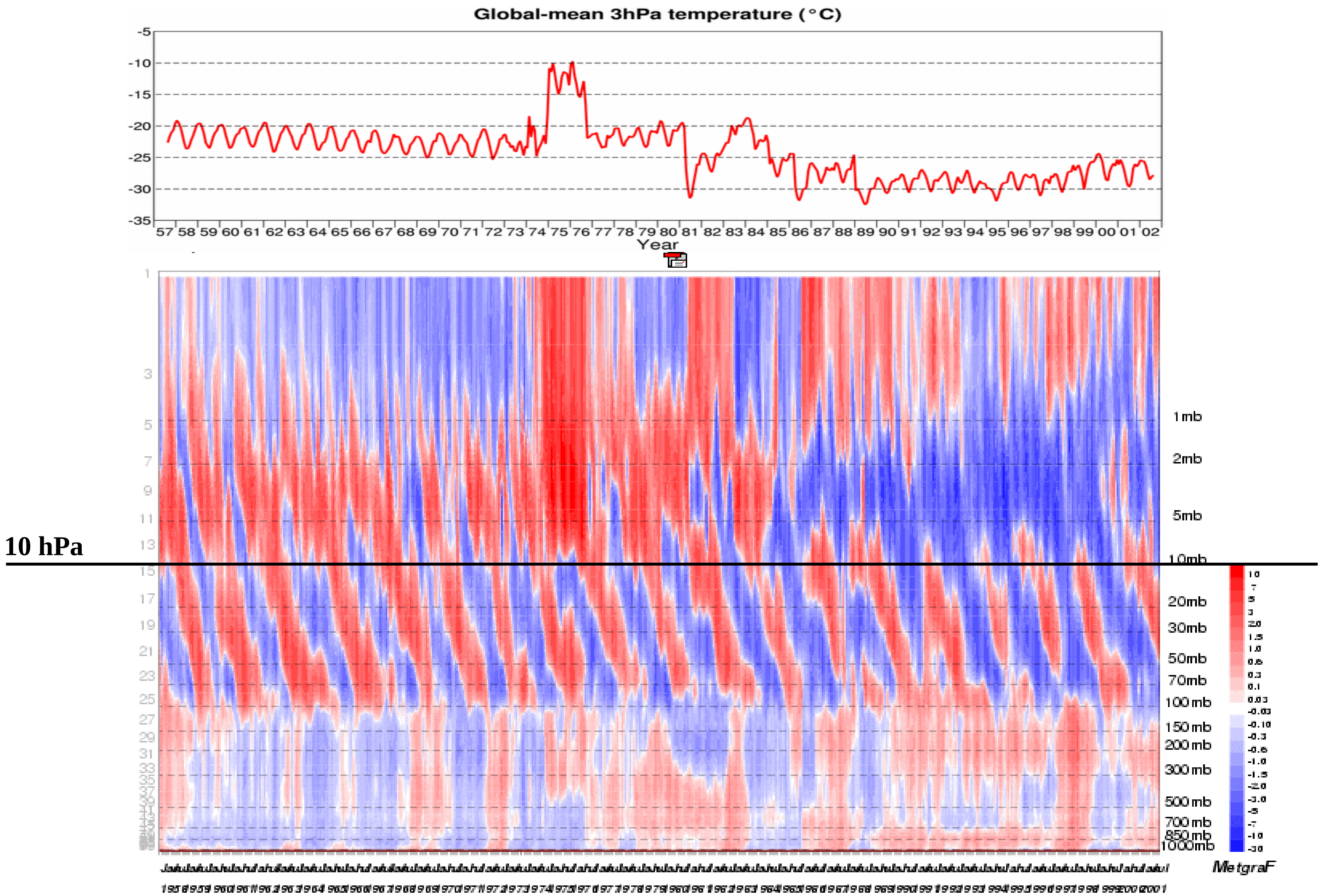

SSMI-1c Statistics
(30S~30N Ocean)
Mean (K)
SD (K)
19V
19H
22V
37V
37H
85V
85H
Nobs1
Sat_Ins
Cal
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999

How successful ?


Anomaly Correlation, Forecast Height 500 hPa Northern Hemisphere [90.0 ,-180.0 , 20.0 , 180.0]
Day when ANCF drops below 99.75% to 60.0%
60%
70%
80%
90%
95%
97.5%

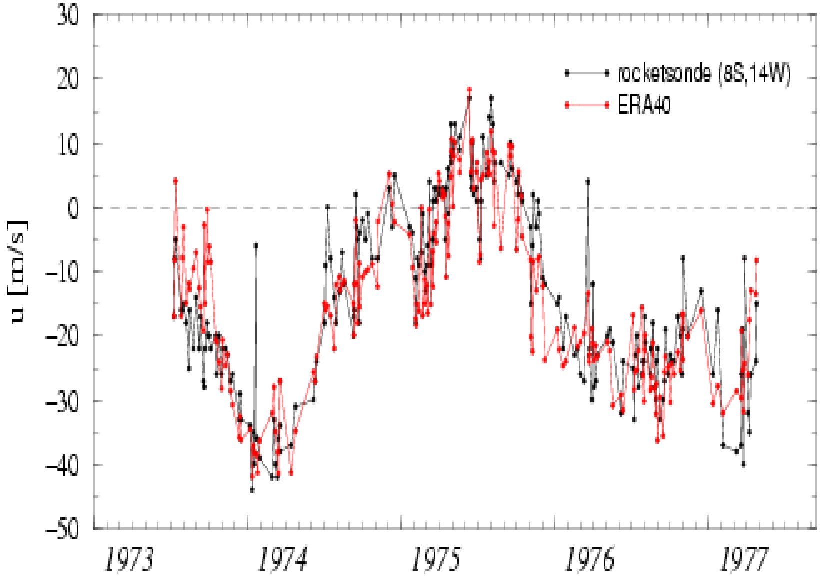


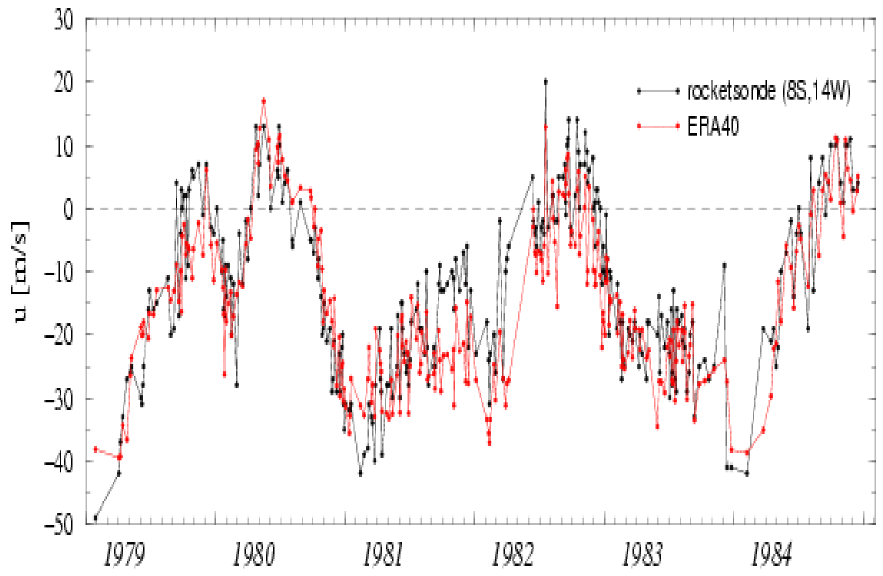
TOVS and AMV
Anomaly Correlation, Forecast Height 500 hPa
Australia New Zealand [-12.5 , 120.0 , -45.0 , 175.0]
VTPR
Day when ANCF drops below 99.75% to 60.0%
60%
70%
80%
90%
95%
97.5%



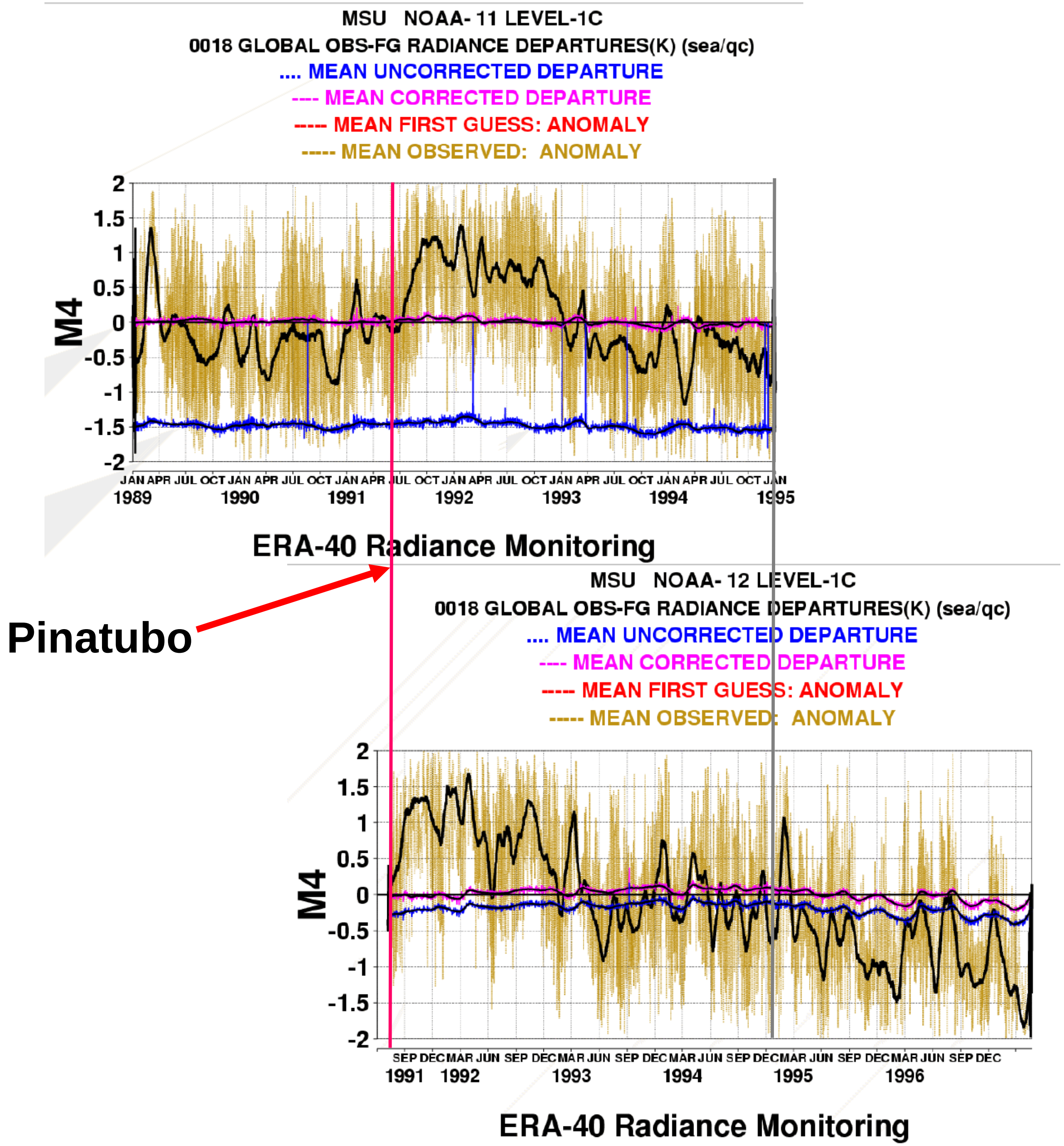
Global-mean 3hPa temperature (°C)
Year
10 hPa
1mb
2mb
5mb
10mb
20mb
30mb
50mb
70mb
100mb
150mb
200mb
300mb
500mb
700mb
850mb
1000mb
MetgraF

Ascension Island (8S,14W)
Independent rocketsonde data and ERA-40
Zonal wind at 30km



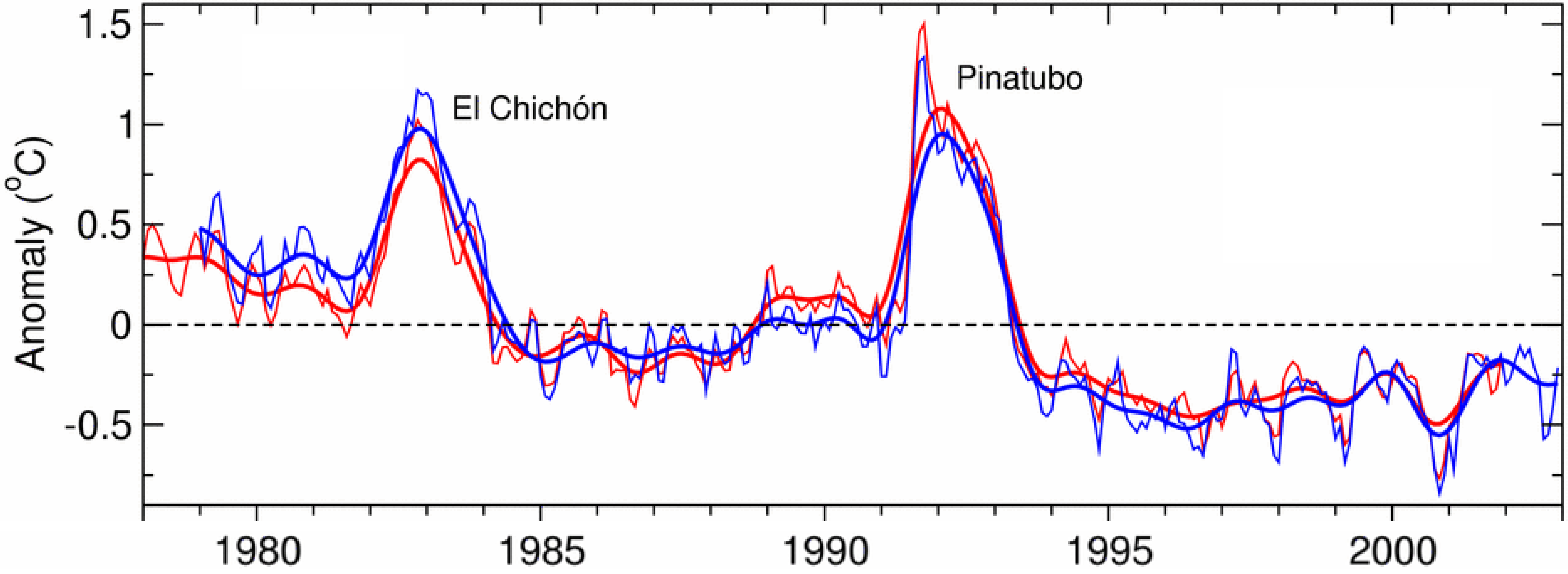


(Agathe Untch)



MSU NOAA- 11 LEVEL-1C
0018 GLOBAL OBS-FG RADIANCE DEPARTURES(K) (sea/qc)
.... MEAN UNCORRECTED DEPARTURE
---- MEAN CORRECTED DEPARTURE
---- MEAN FIRST GUESS: ANOMALY
----- MEAN OBSERVED: ANOMALY
M4
JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN
1989 1990 1991 1992 1993 1994 1995
ERA-40 Radiance Monitoring
Pinatubo
MSU NOAA- 12 LEVEL-1C
0018 GLOBAL OBS-FG RADIANCE DEPARTURES(K) (sea/qc)
.... MEAN UNCORRECTED DEPARTURE
---- MEAN CORRECTED DEPARTURE
---- MEAN FIRST GUESS: ANOMALY
----- MEAN OBSERVED: ANOMALY
M4
SEP DEC MAR JUN SEP DEC MAR JUN SEP DEC MAR JUN SEP DEC MAR JUN SEP DEC MAR JUN SEP DEC
1991 1992 1993 1994 1995 1996
ERA-40 Radiance Monitoring

Trend and variability in lower stratospheric temperature

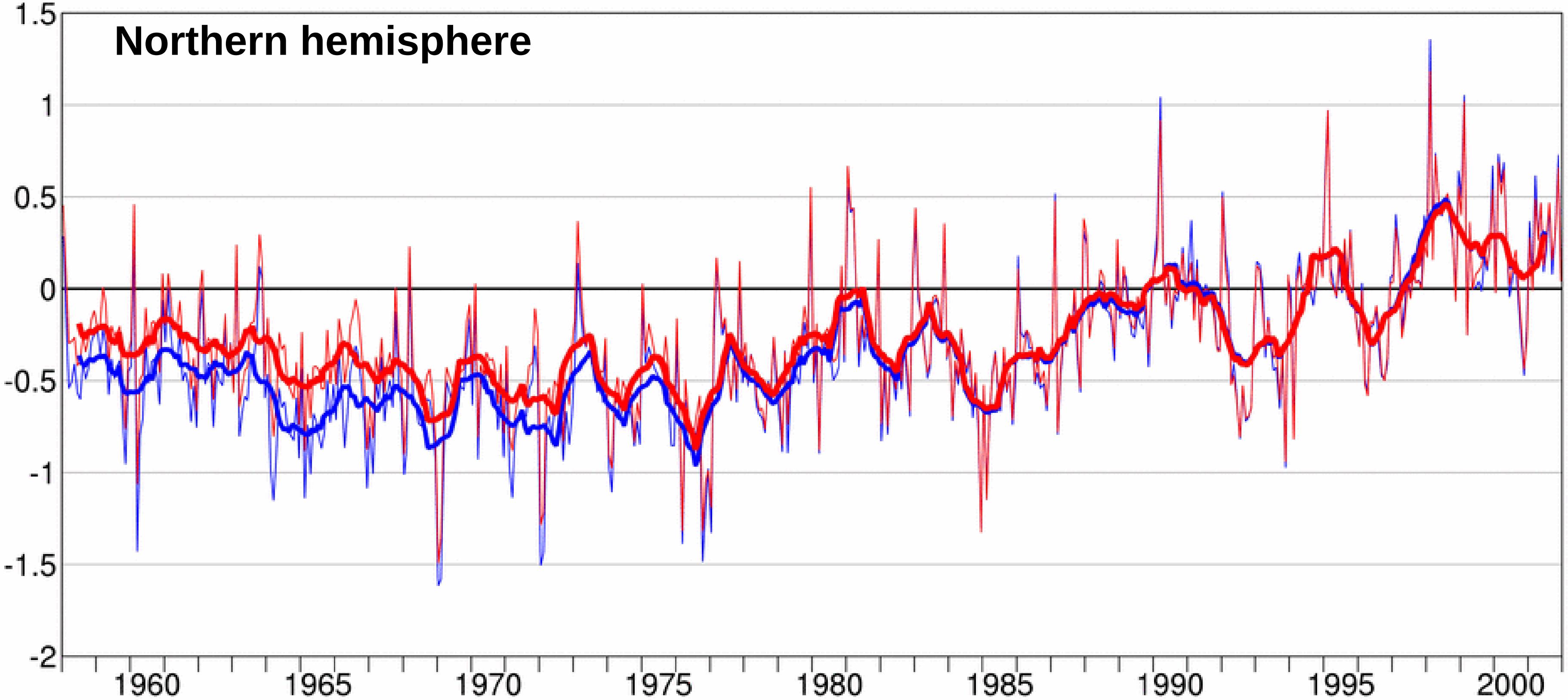


MSU-4 data analyzed by Mears et al. (2003)

ERA-40 equivalent from Ben Santer

Linear trend:	**MSU-4**	**- 0.39^{O}C/decade**
	ERA-40	**- 0.30^{O}C/decade**
	NCEP	**- 0.82^{O}C/decade**

Surface air temperature anomaly (^oC) with respect to 1987-2001



Based on monthly station data (Jones and Moberg, 2003)

Based on ERA-40 reanalysis of synoptic data

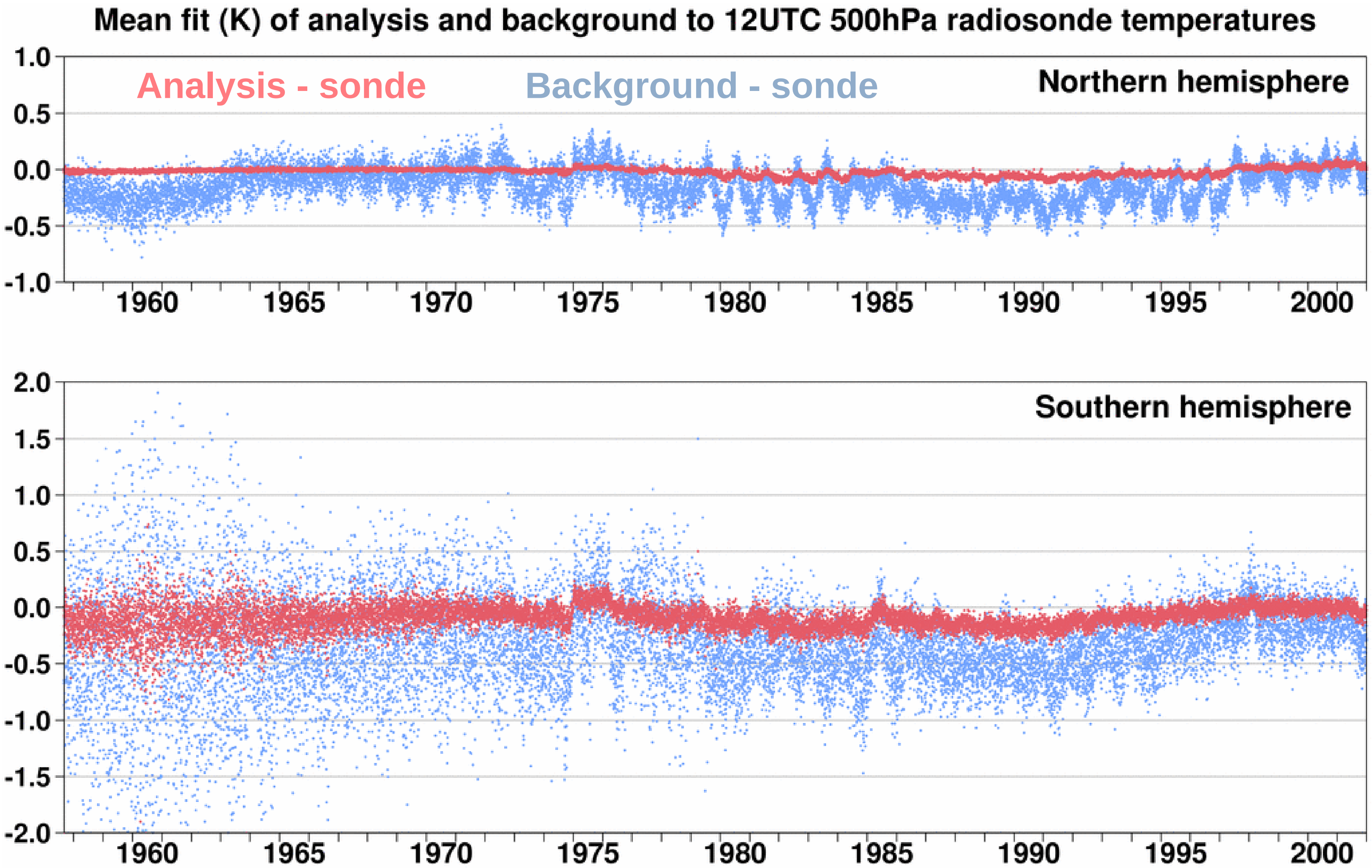
Simmons et al. (2004)

Polar regions

- **Recents trends (1985-2001) in Antarctic snow accumulation from simulations based on ERA-40 and NCEP boundary conditions agree well with the ice core measurements**

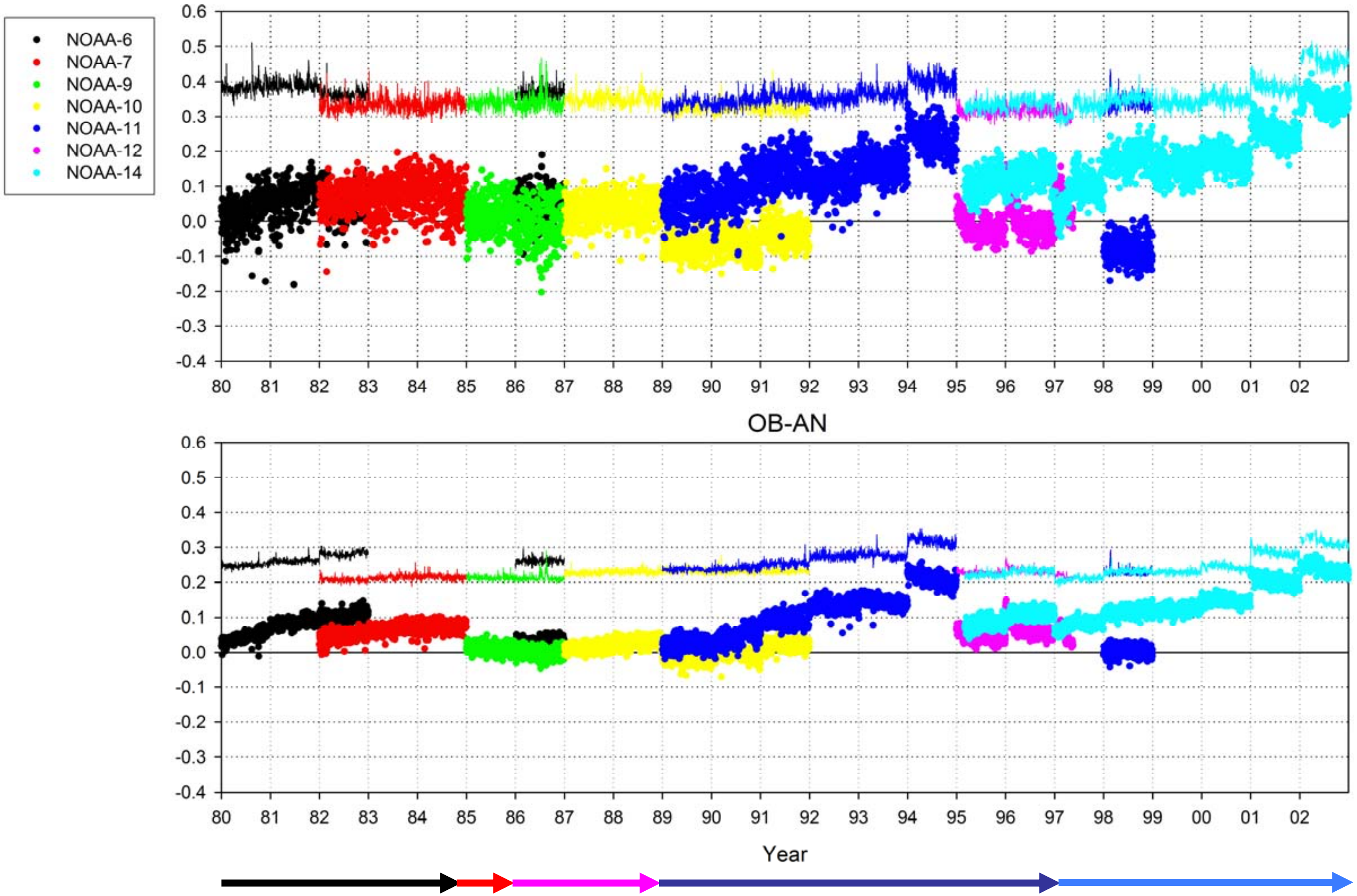
  Andrew J. Monaghan et al. (2005)

500hPa temperature differences



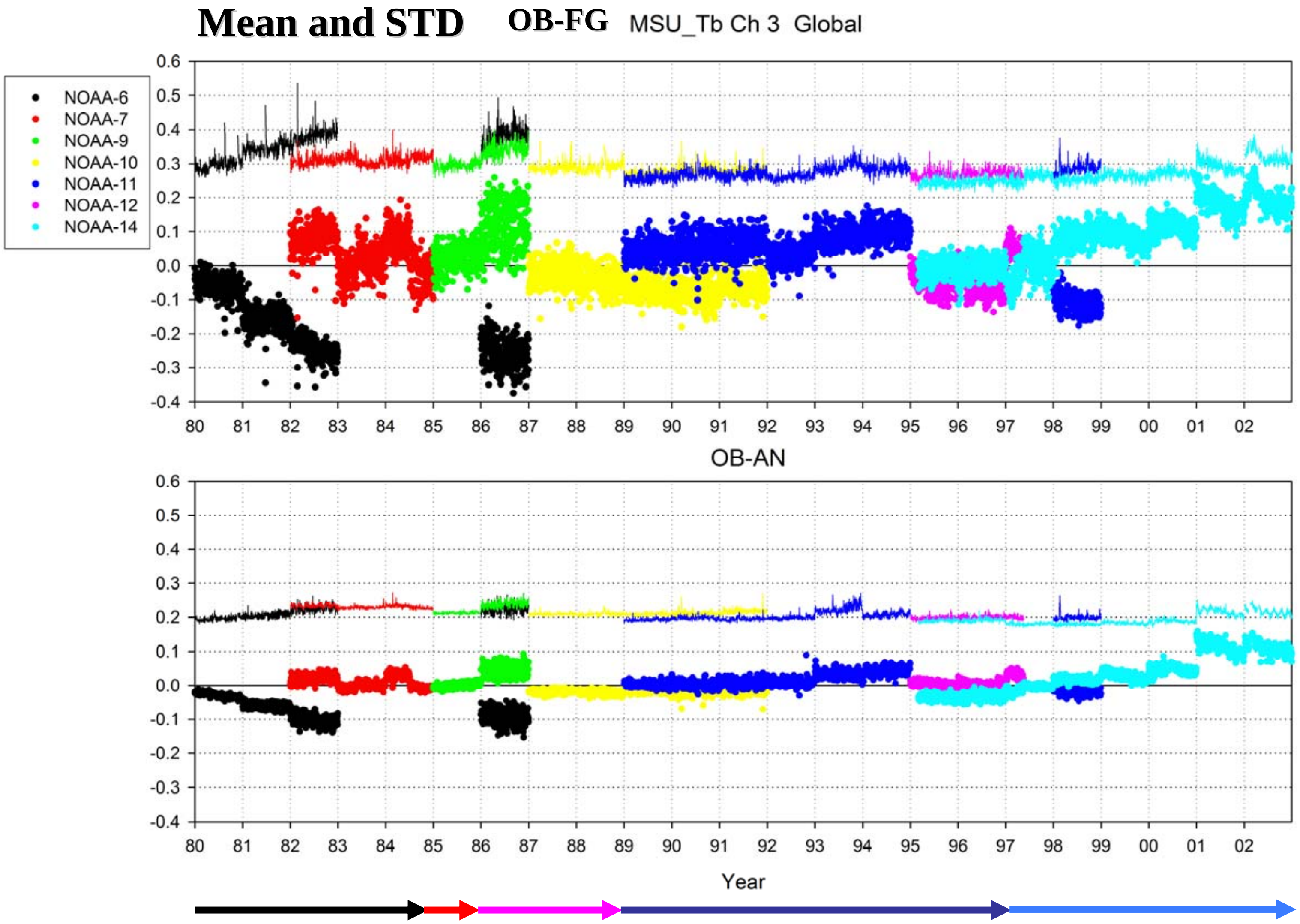
(Maximum energy contribution 700 hPa)

Mean and STD OB-FG MSU_Tb Ch 2 Global

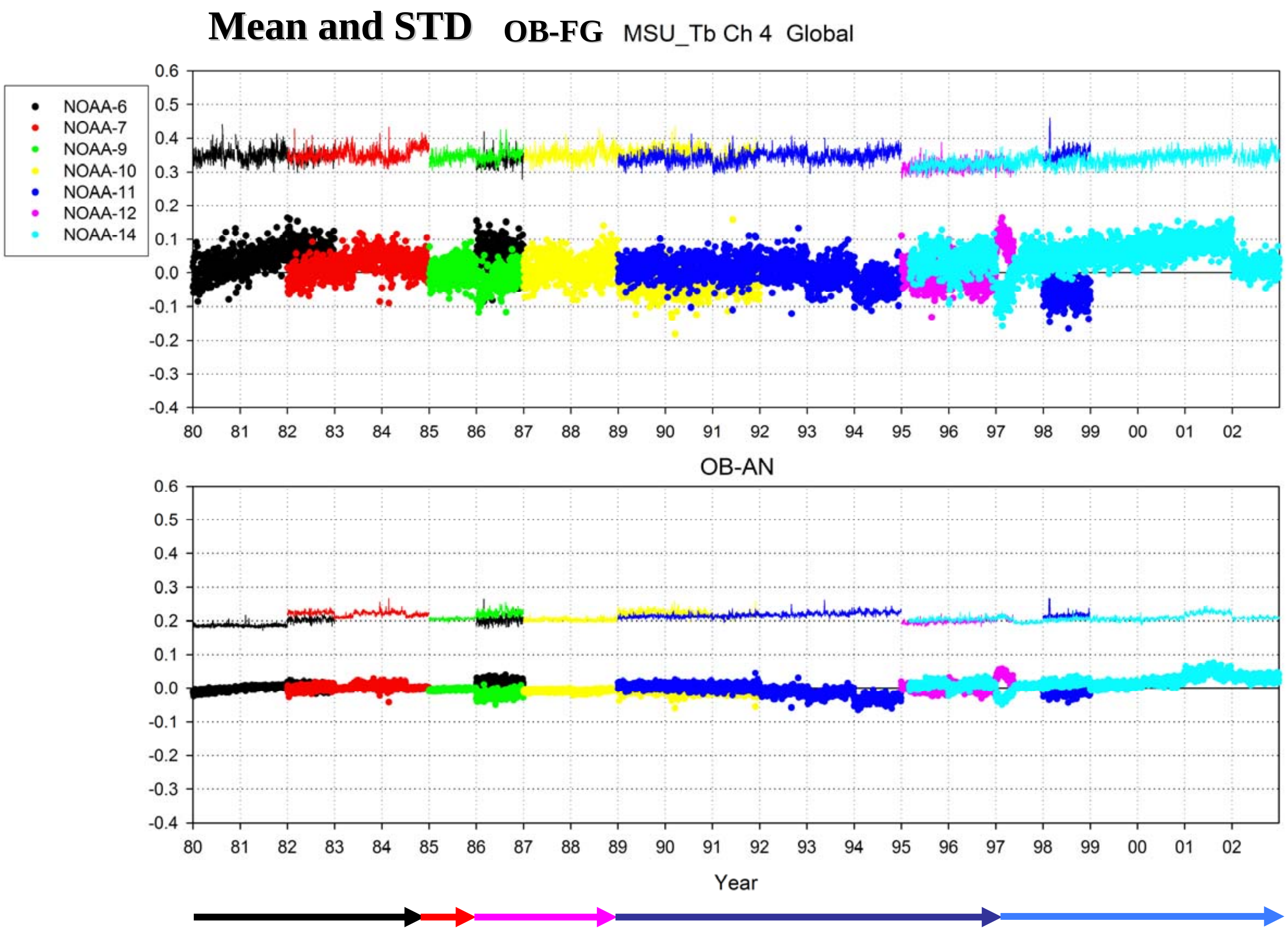


(Maximum energy contribution 300 hPa)

Mean and STD

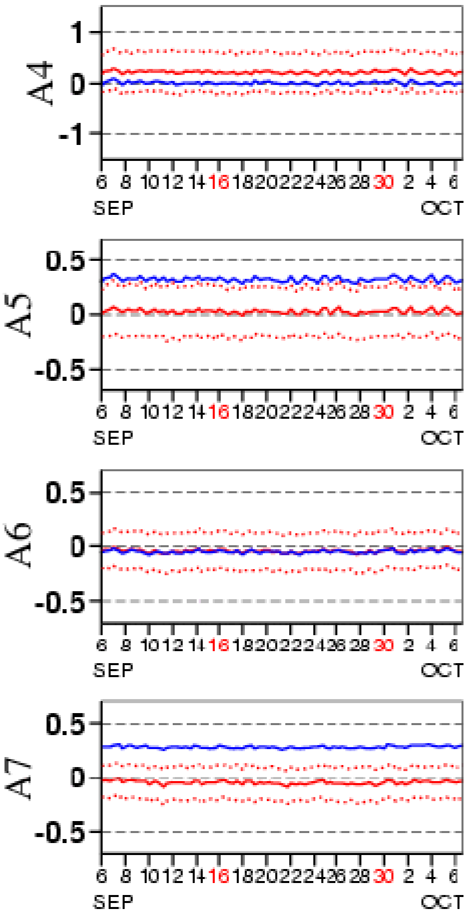


(Maximum energy contribution 90 hPa)

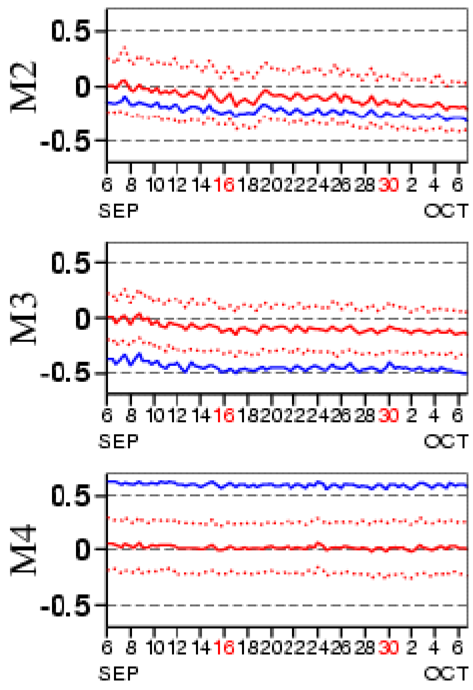


Operational monitoring 6/9/2001-6/10/2001

- Spacecraft manoeuvre causing instrument heating



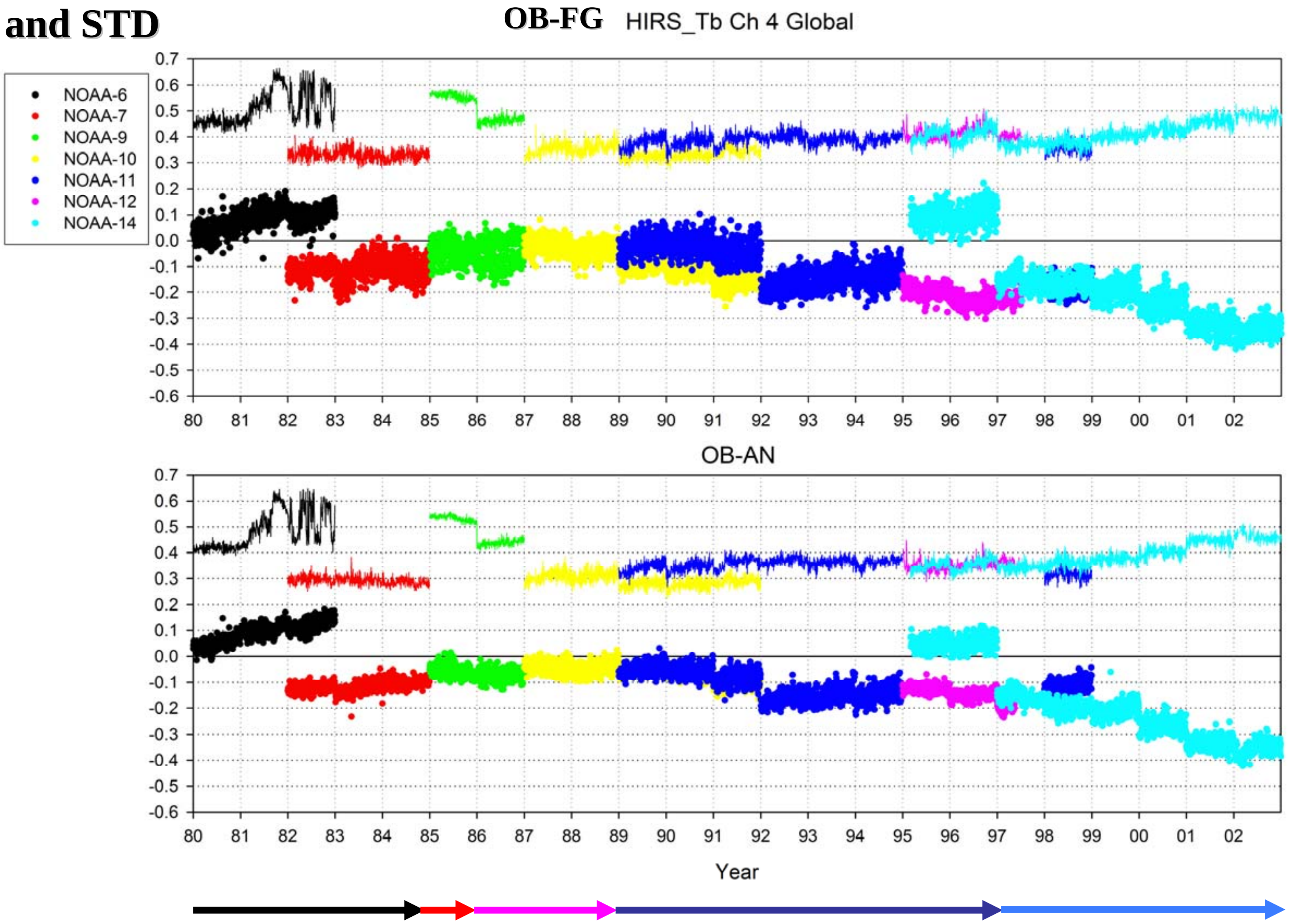
AMSU A NOAA-16



MSU NOAA-14

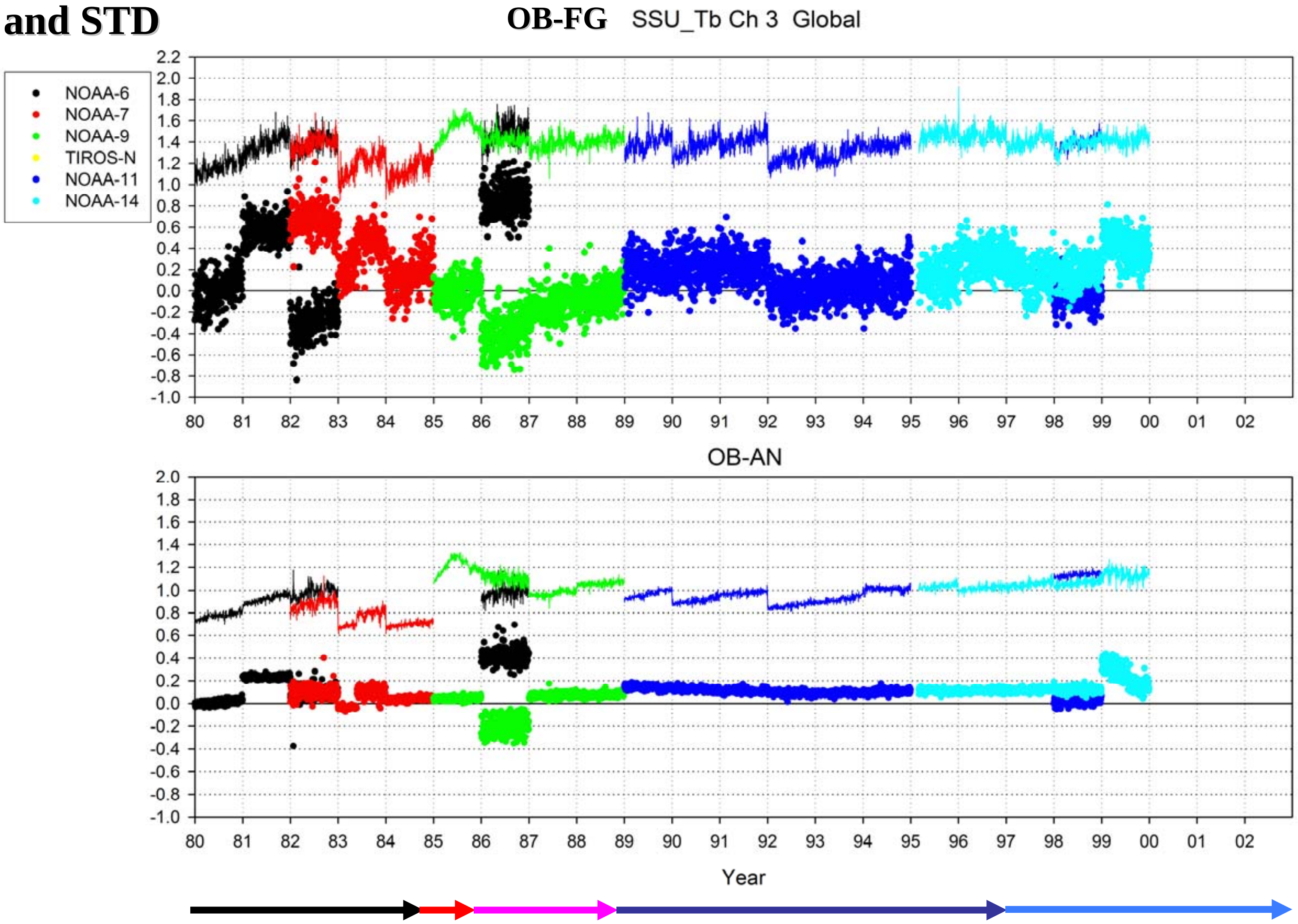
(Maximum energy contribution 400 hPa)

Mean and STD



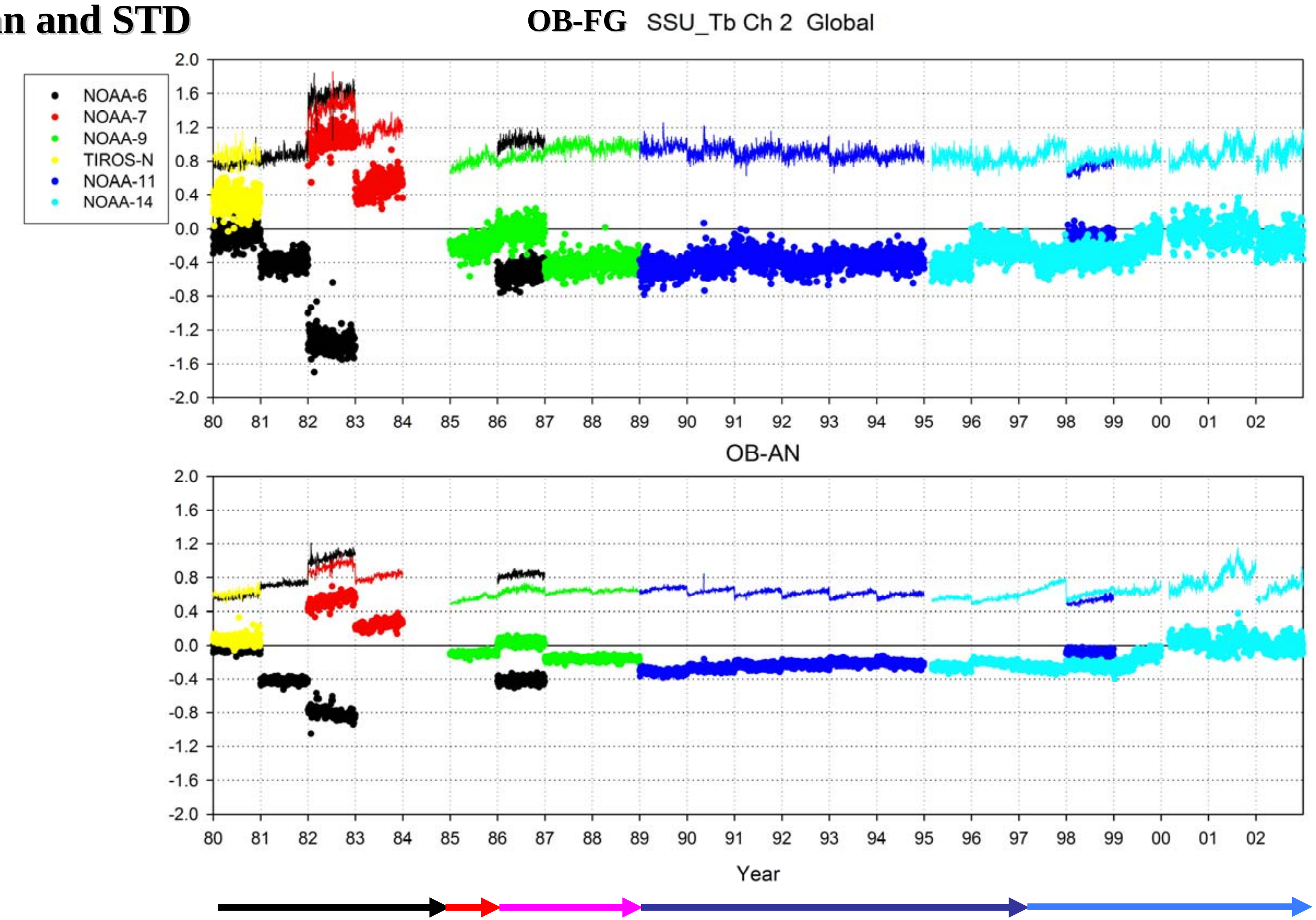
(Maximum energy contribution 1.5 hPa)

Mean and STD



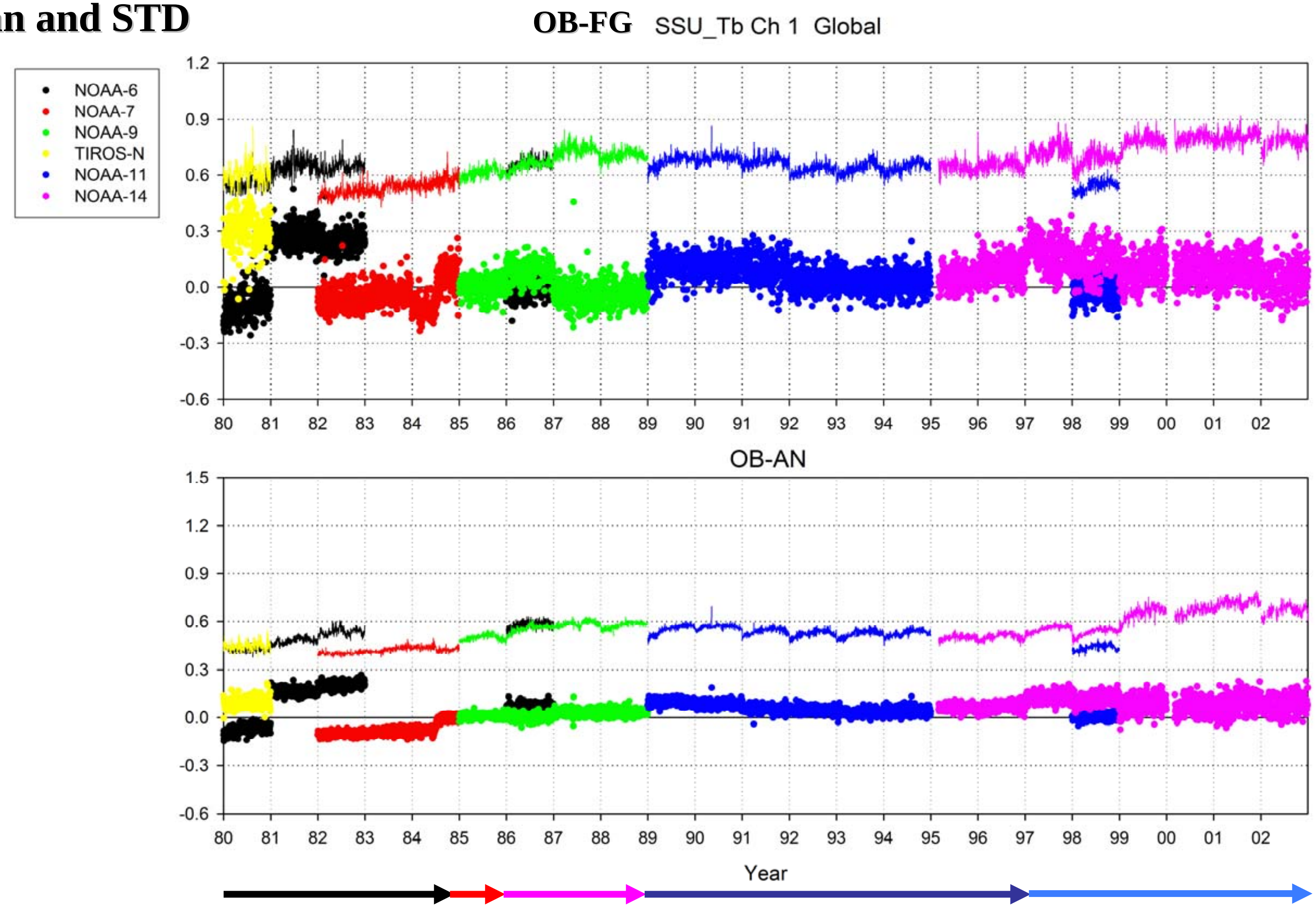
(Maximum energy contribution 4 hPa)

Mean and STD



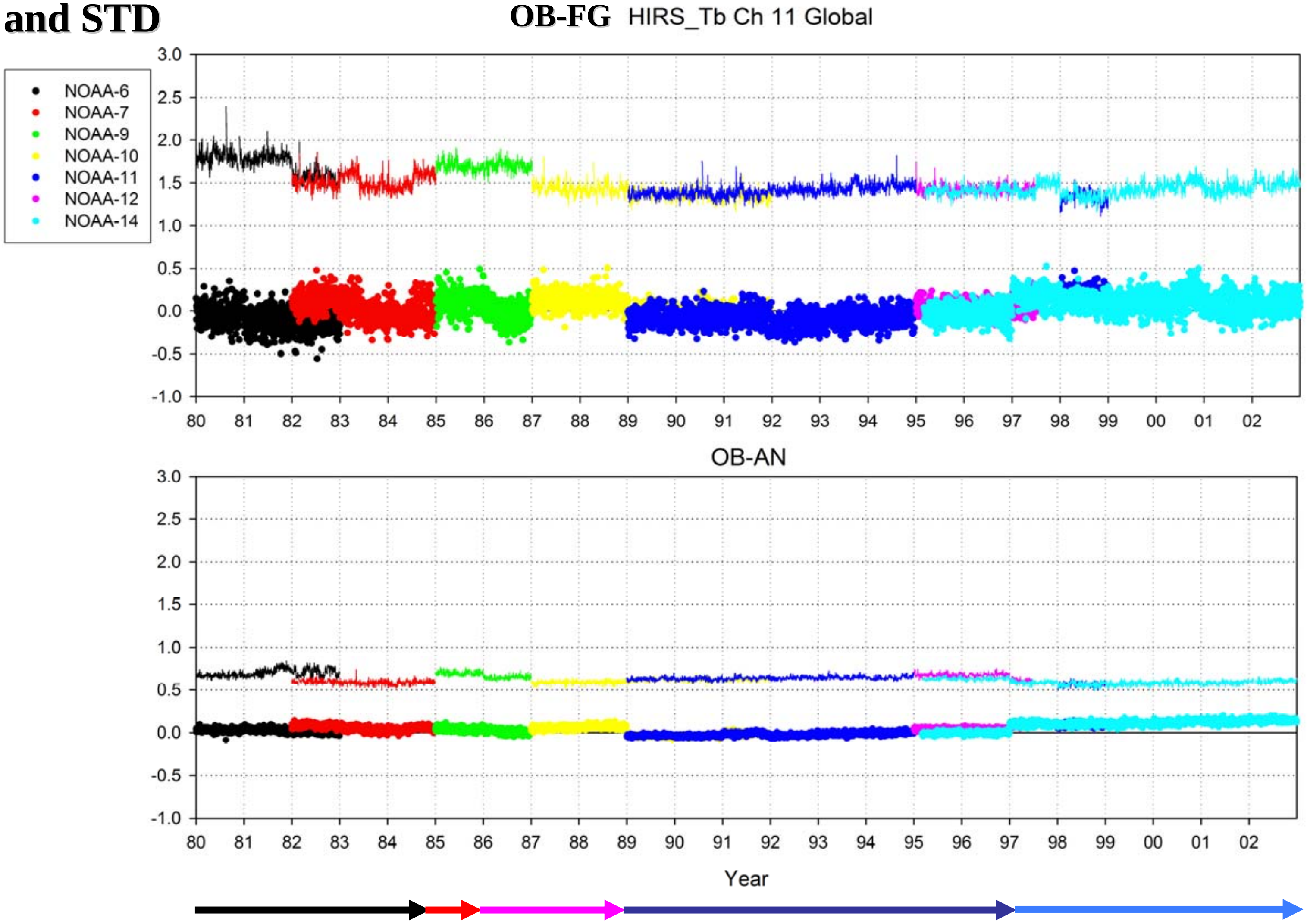
(Maximum energy contribution 15 hPa)

Mean and STD



(Maximum energy contribution 700 hPa)

Mean and STD



ECMWF reanalyses

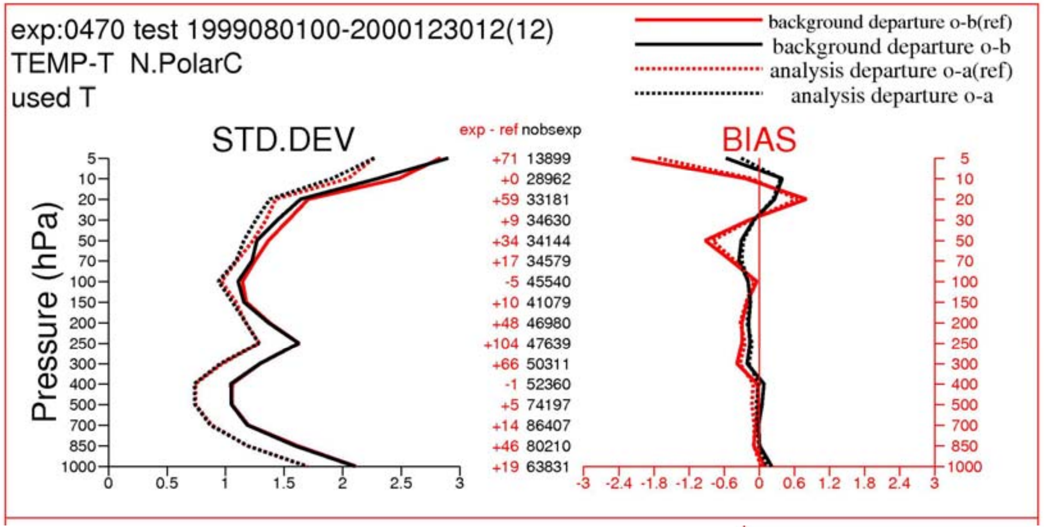
ERA-Interim 1989 → Continues as CDAS →

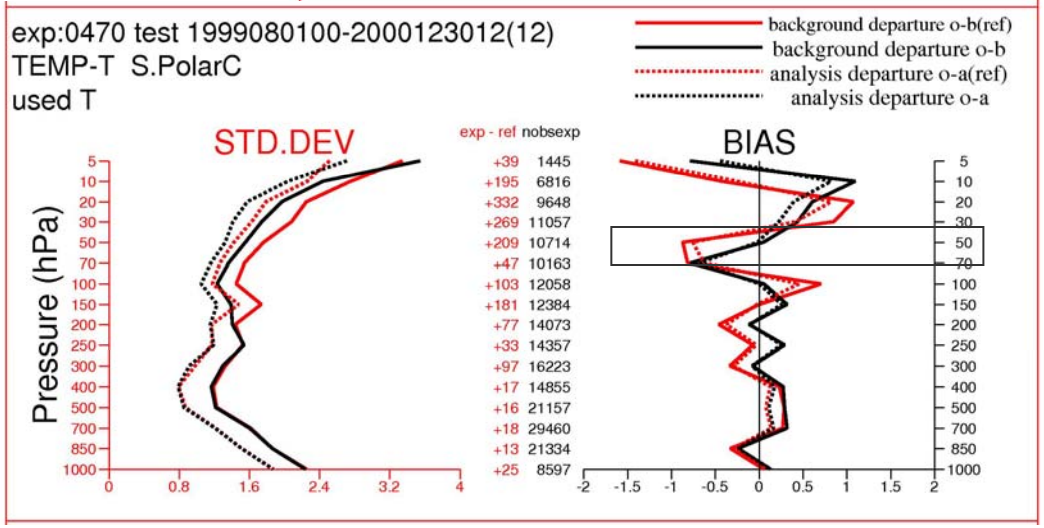
ERA-40 1957-2002

(Planned to start in Dec 2005)

- Data-assimilation system
  - T159L60 → T319L91 ?
  - Improved assimilating model CY30R1+
  - Use of 12 hour 4D-Var
  - New humidity analysis
- Satellite Level-1c radiances
  - Better RTTOV and improved use of radiances especially IR
  - Adaptive bias correction
  - Direct assimilation of SSMI radiances
  - Updating blacklist based on JRA-25 experience
- Improved use of radiosondes
  - Bias correction and homogenization based on ERA-40
- Correction of SHIP/ SYNOP surface pressure biases
- Use of reprocessed Meteosat winds and radiances 1989→
- New set of Altimeter wave height data 1991→

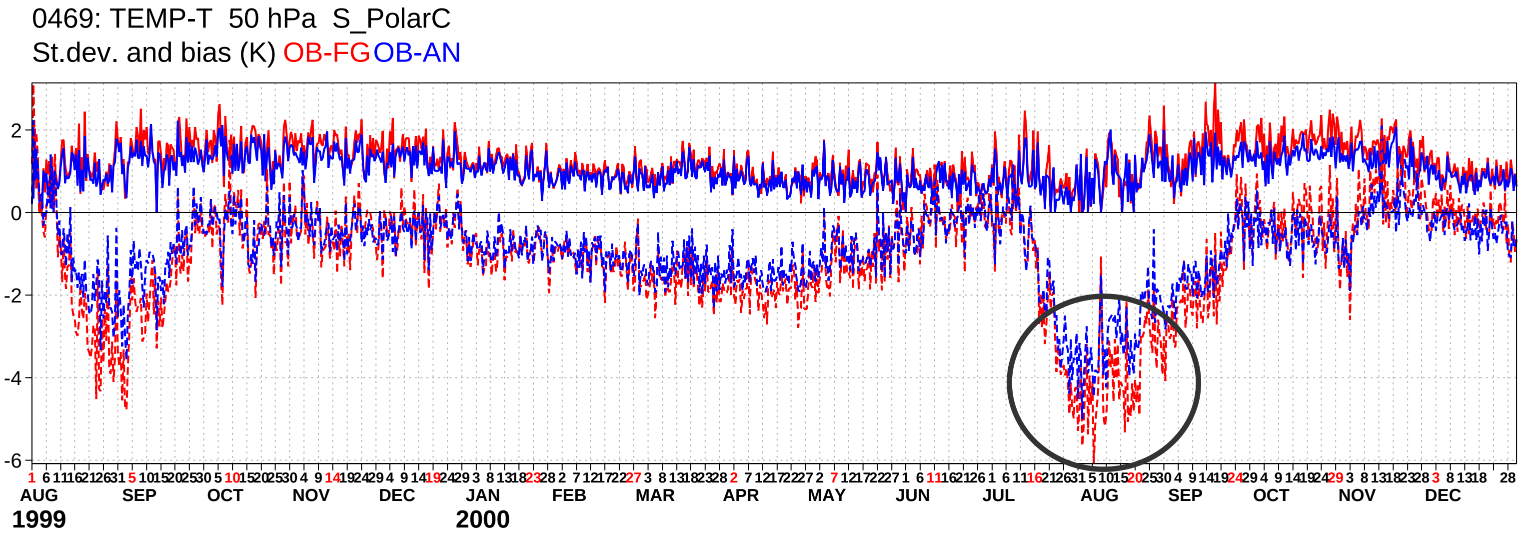
Static(Red) and Variational (Black) bias correction



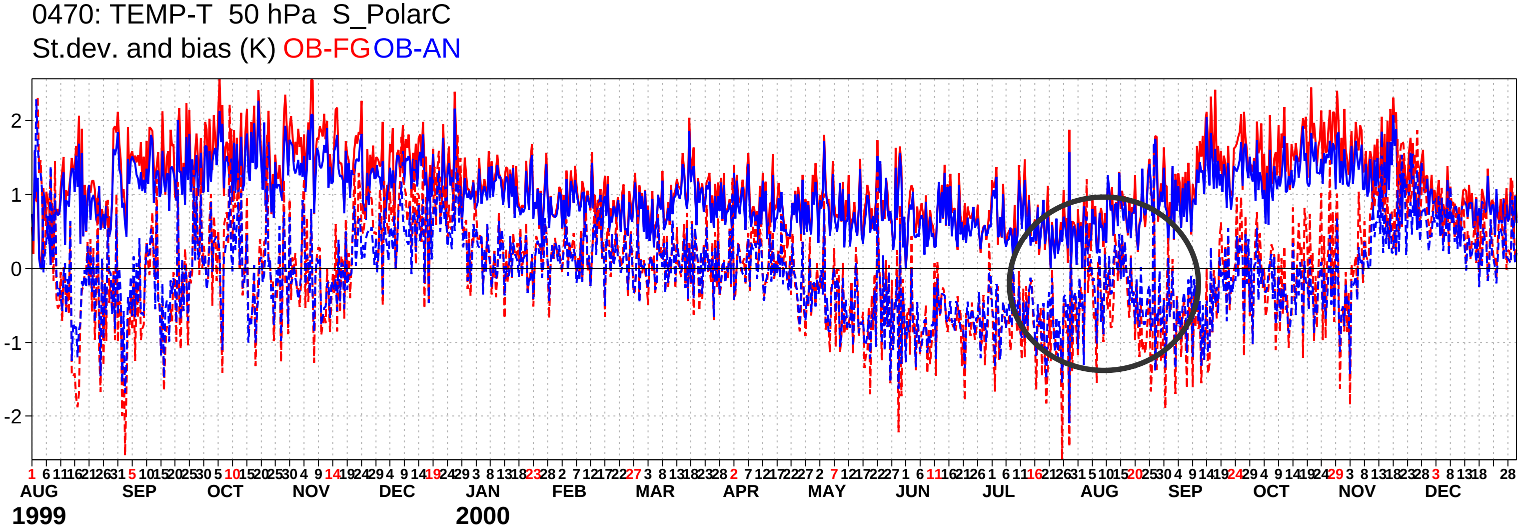


Static and Variational bias correction

Static

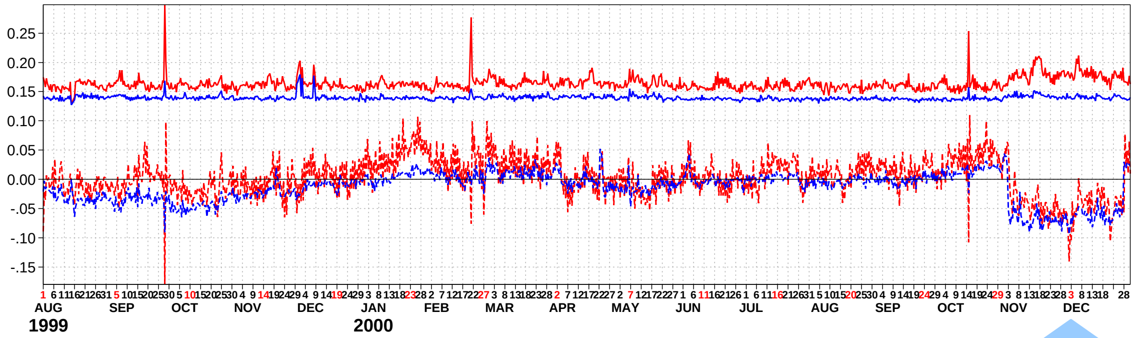


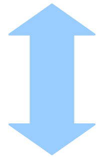
Adaptive



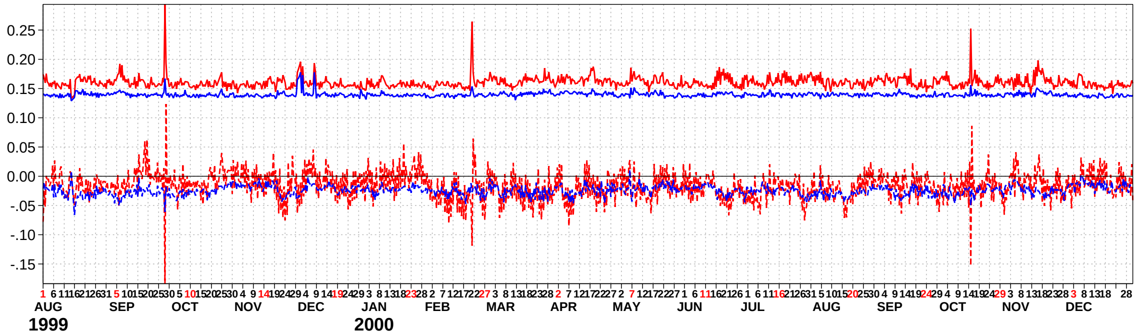
Static(Red) and Variational (Black) bias correction (Satellite Data : TOVS/AMSU-A (NOAA-15))

0469: TOVS-1C_noaa-15_AMSU-A_Tb Ch 7 Tropics
St.dev. and bias (K) OB-FG OB-AN

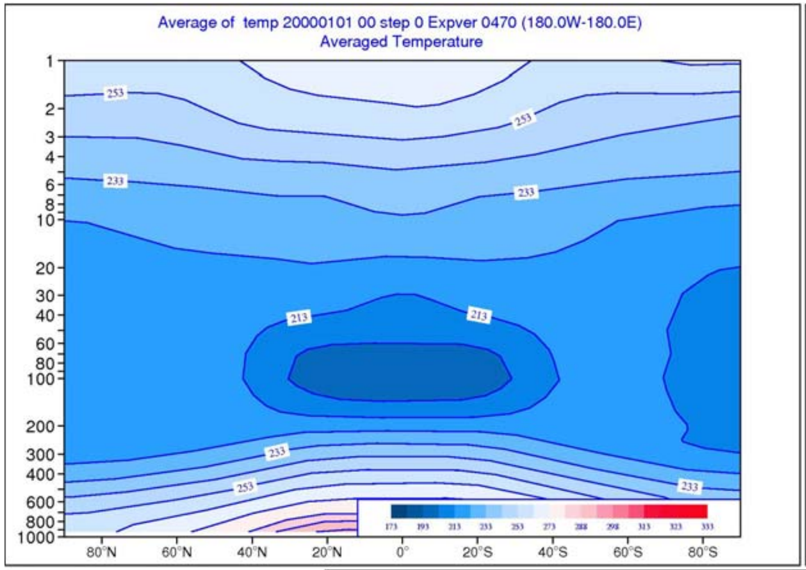




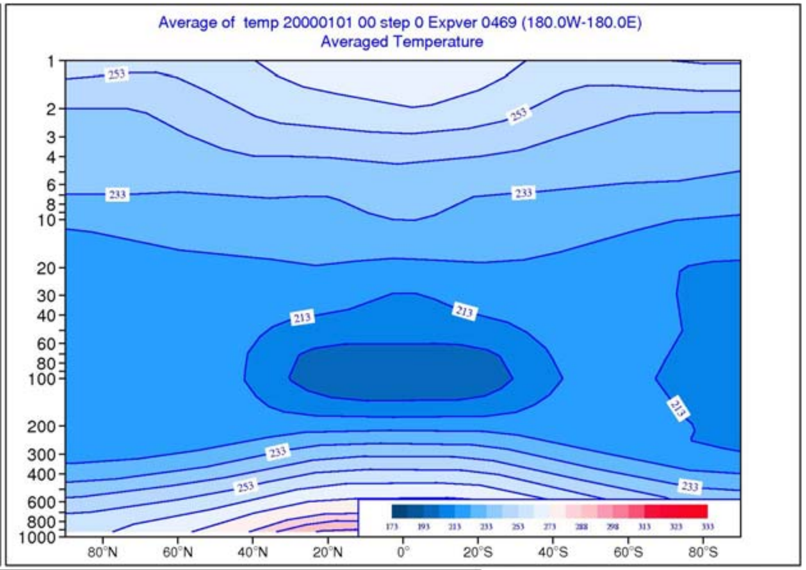
0470: TOVS-1C_noaa-15_AMSU-A_Tb Ch 7 Tropics
St.dev. and bias (K) OB-FG OB-AN

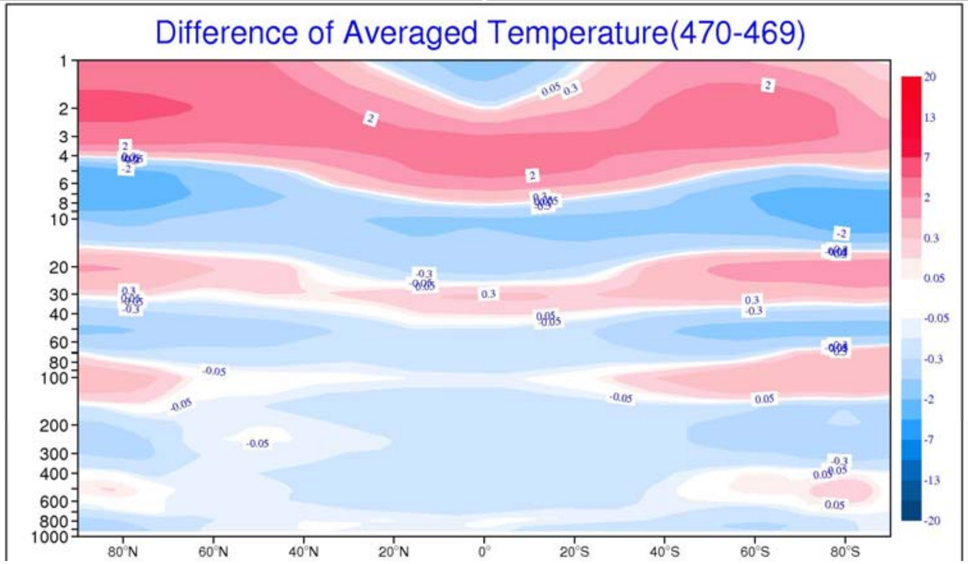


Adaptive

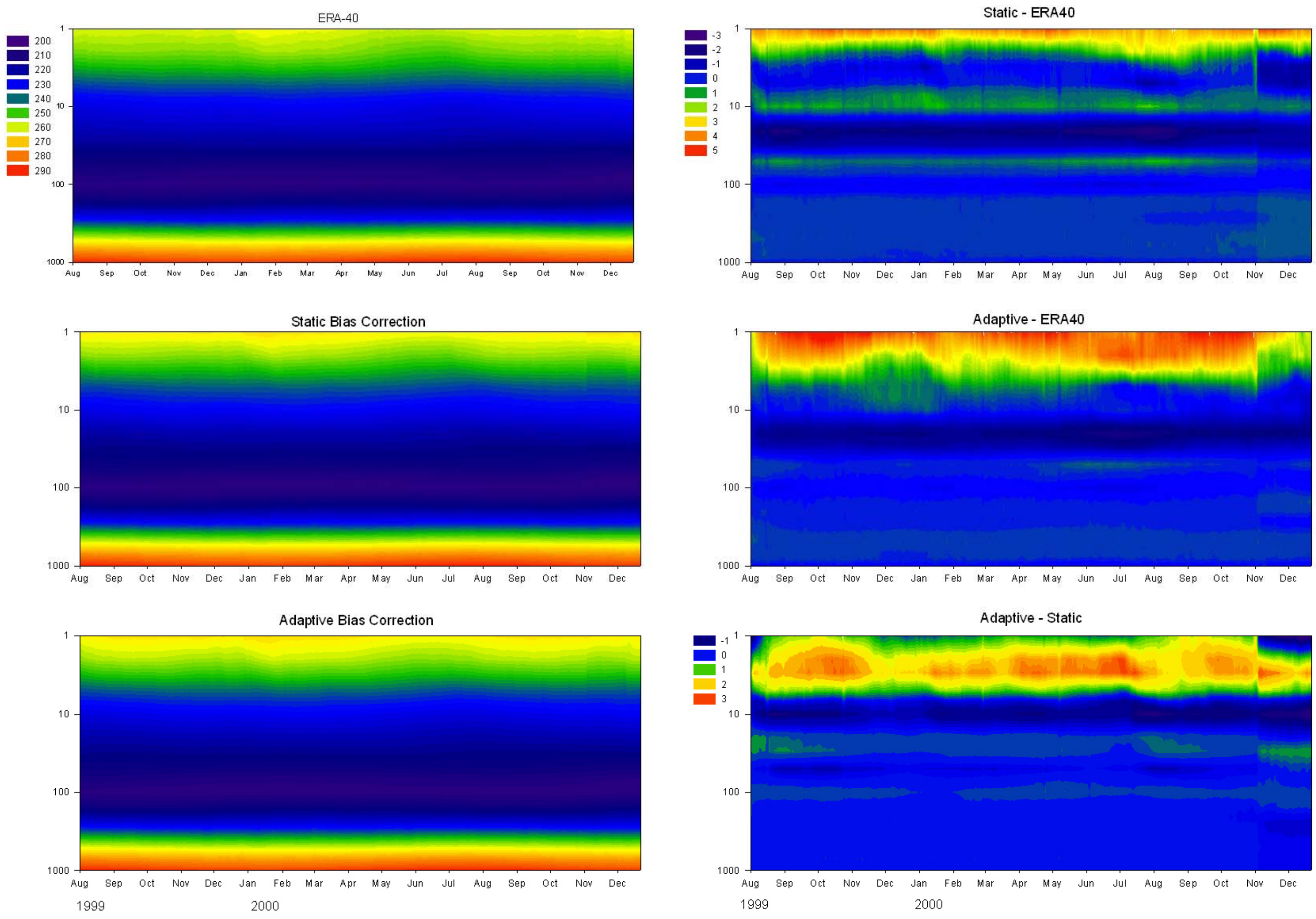


Static

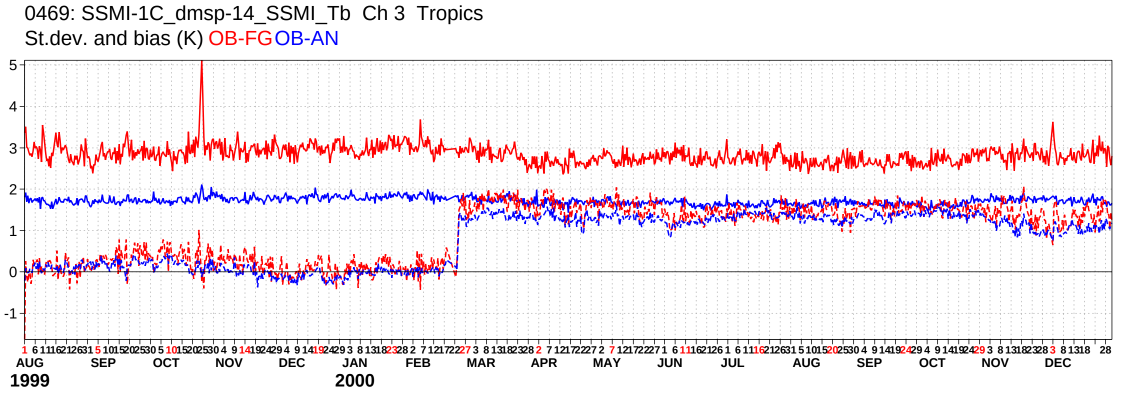


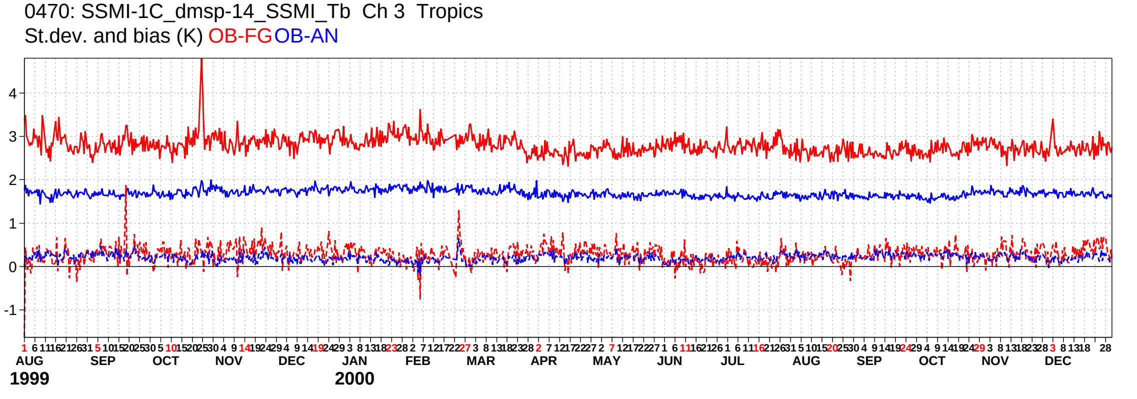


Temperature Time series (Global)

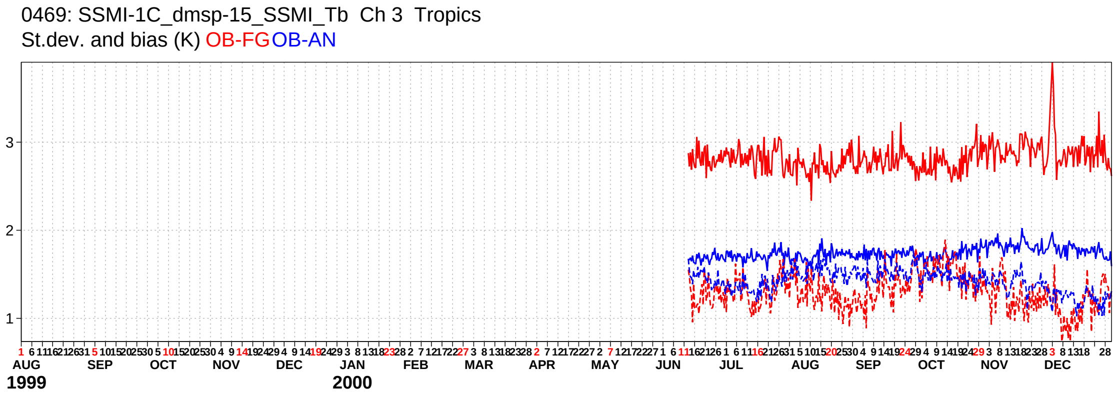


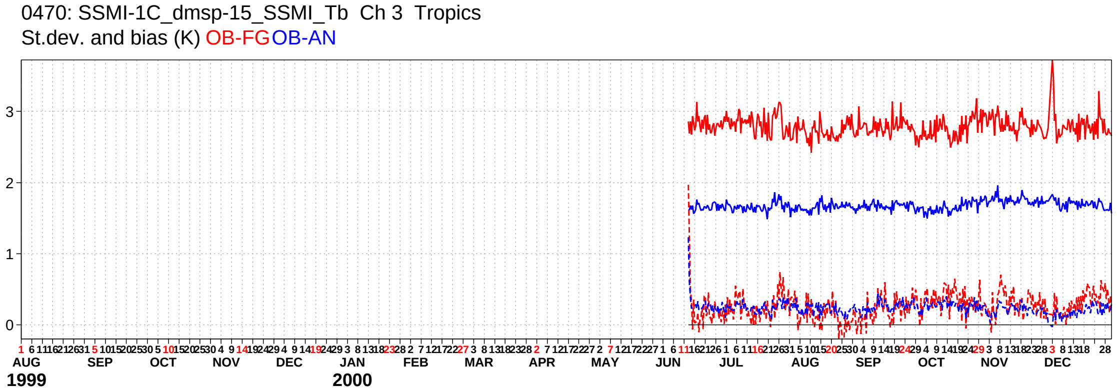
Static(Red) and Variational (Black) bias correction
(Satellite Data : SSMI)





Static(Red) and Variational (Black) bias correction (Satellite Data : SSMI)





Conclusions

- In ERA-40, for the first time, the satellite radiances been extensively assimilated over a long period
- The ERA-40 bias corrections are much more stable than in ERA-15
  - Level 1c versus CCR
  - Direct radiance assimilation, RTTOV, new bias correction predictors
- Detection of realistic climate change signals from ERA-40
- Adaptive bias correction offers many advantages
- Potential for improving the bias estimation in future reanalyses
  - Use of a longer assimilation window
  - Exploit the statistics from ERA-40 (feedback & ODB) to understand satellite biases and possible instrument drifts
  - Accounting model biases
  - Correction of biases in Atmospheric Motions Vectors ?
  - More accurate metadata from data producers
  - Integration of different bias corrections