Recalibrated MSU/AMSU/SSU Radiances for Data Assimilation in Climate Reanalyses

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NOAA/NESDIS/Center for Satellite Applications and Research

Coordination meeting on exchanging observation feedback and blacklists
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Outline

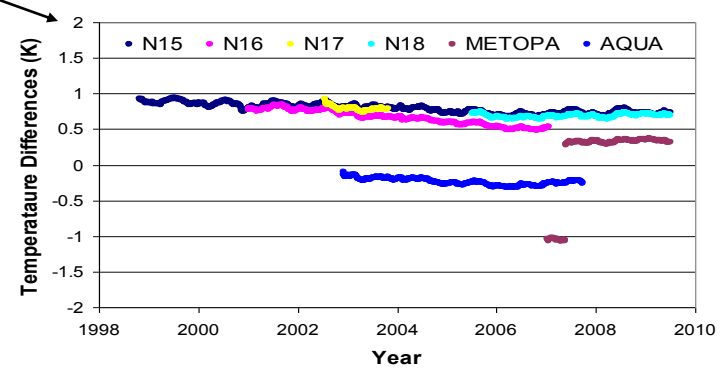
- AMSU-A bias corrections from ERA-Interim
- Recalibrated MSU Radiances for Climate Reanalysis Data Assimilation
- Recalibrated AMSU radiances for Climate Reanalysis Data Assimilation
- Recalibrated SSU radiances for Climate Reanalysis Data Assimilation
- Comparisons of MSU/AMSU/SSU time series between observations and reanalyses

Satellite Bias Corrections in Climate Reanalyses

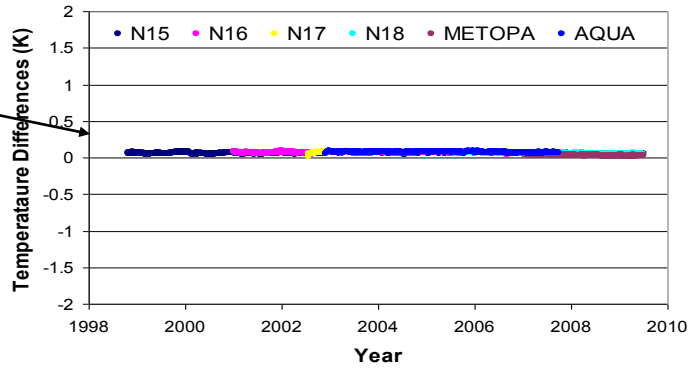
- ERA-Interim bias estimates: b
- NOAA operational calibrated AMSU-A level-1c data: y
- Departure between observations (y) and background after application of the bias correction: dy
- Background h(x): Reanalysis forecast field
- Balance equation: dy=y-h(x)-b
- dy can be ignored: b≅y-h(x)
- For global means, h(x) is identical to reanalysis, therefore, drift in b reflects

  trend differences between observation and reanalysis

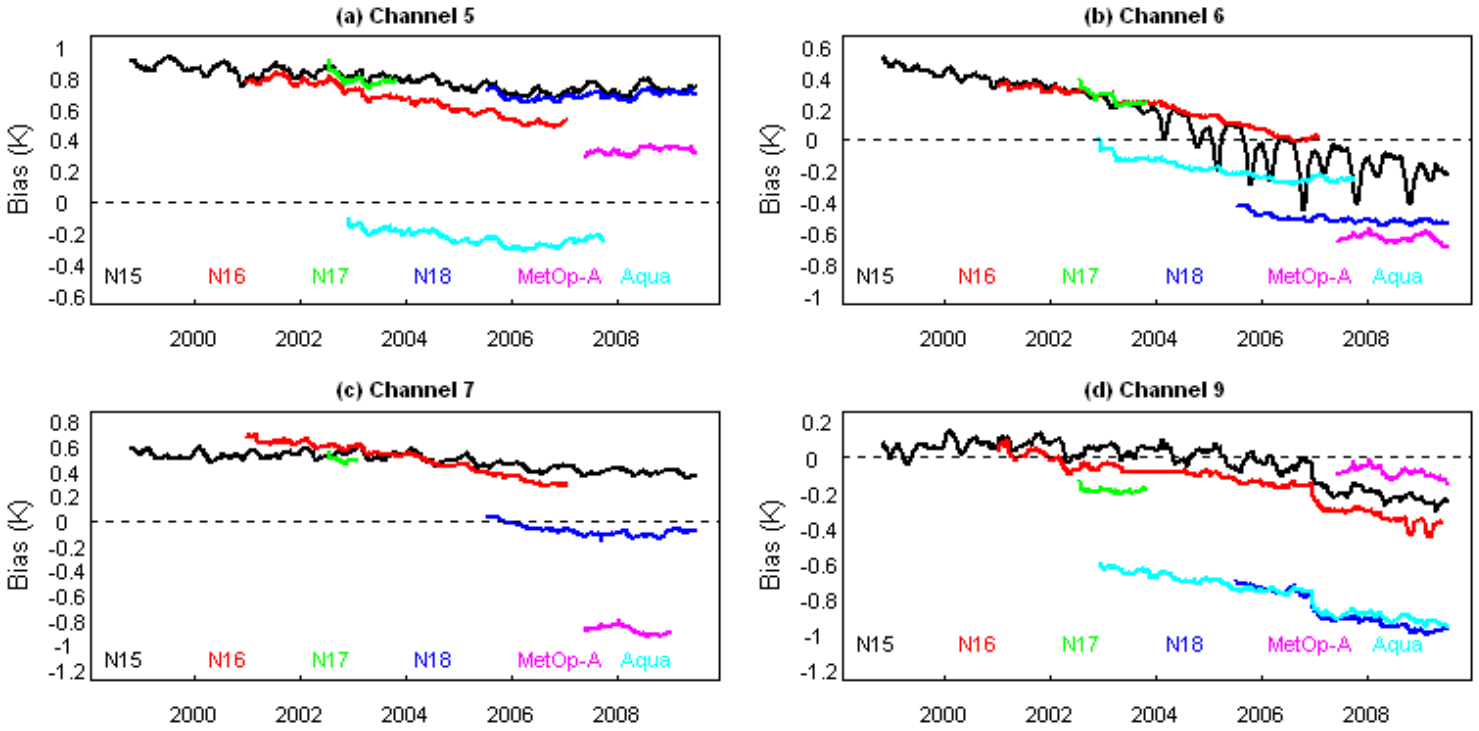
ERA-Interim b time series for AMSU-A CH5, Ocean Mean



ERA-Interim dy time series for AMSU-A CH5, Ocean Mean



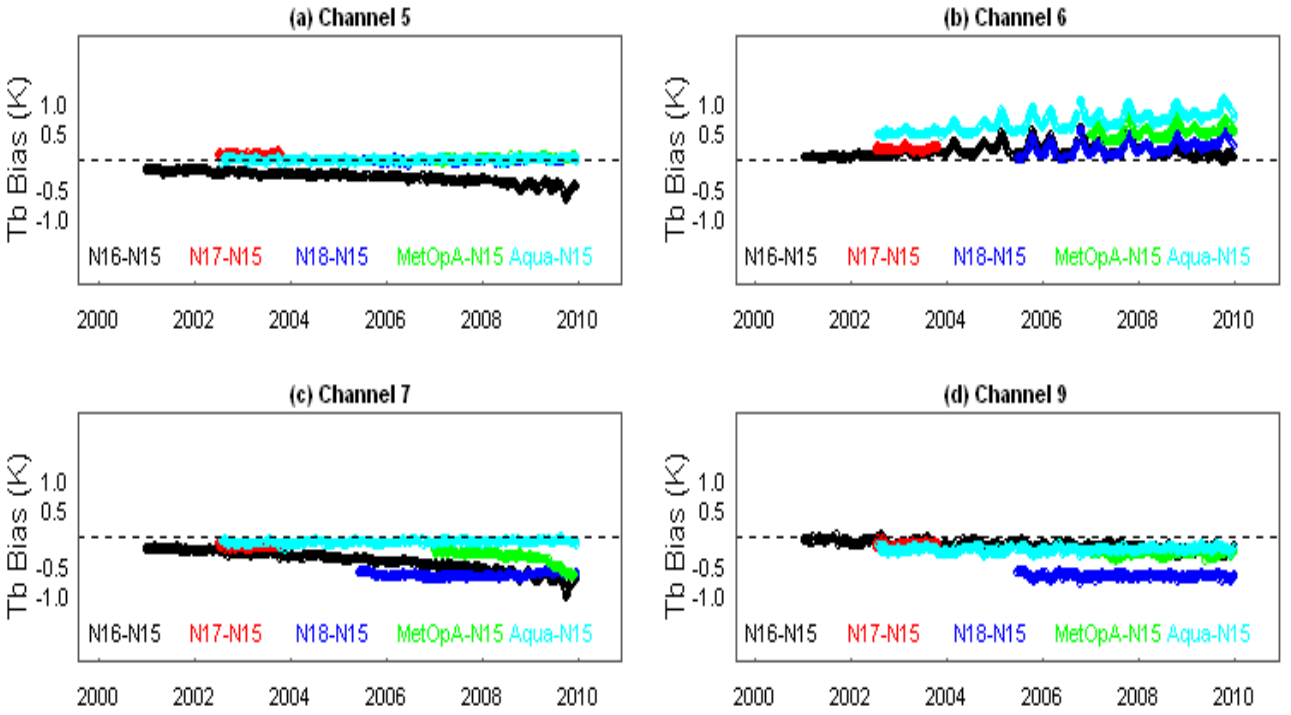
AMSU-A Bias Estimates for Different Satellites and Channels – ERA-Interim



ERA-Interim bias corrections for different AMSU channels on different satellites

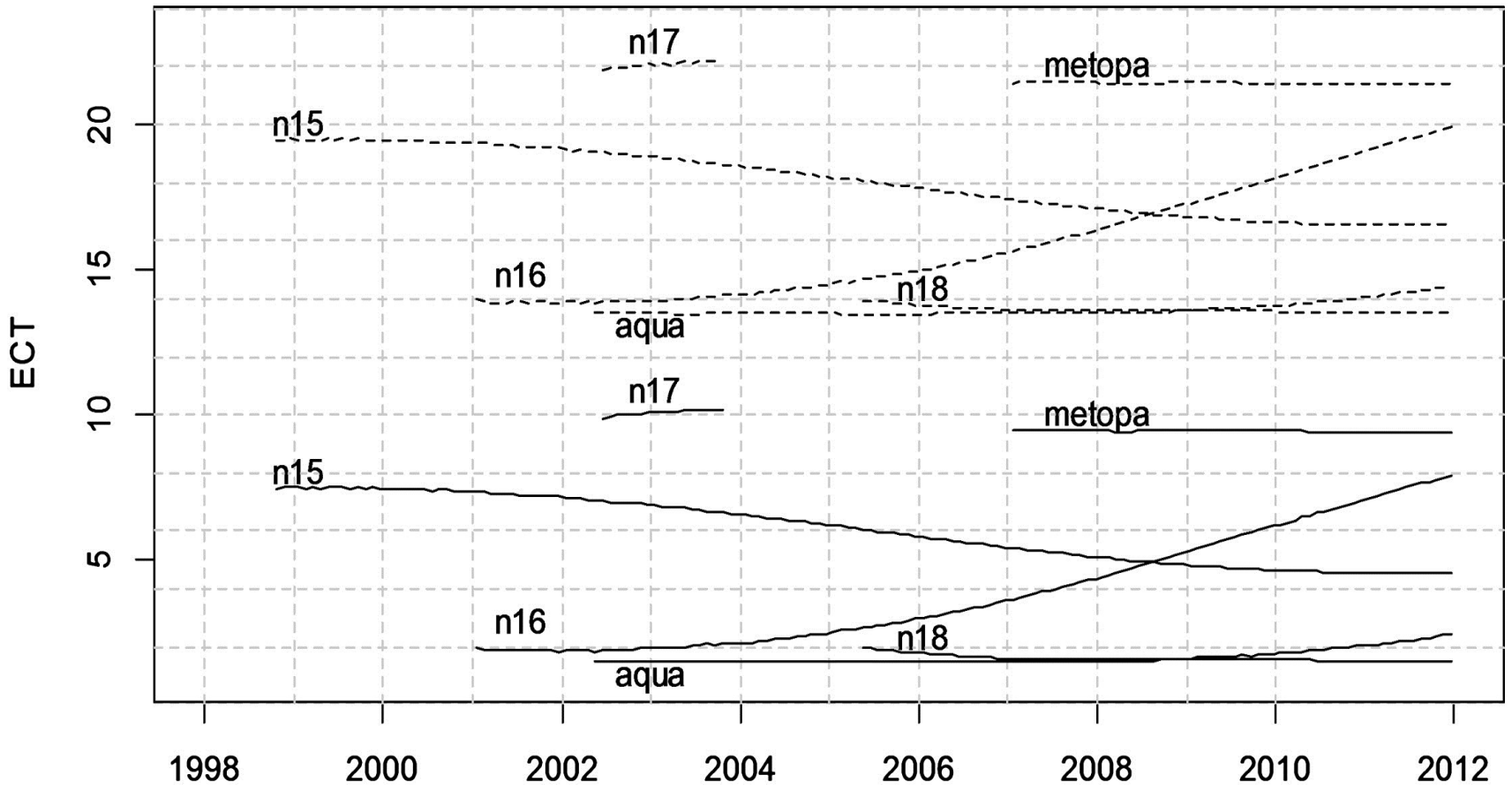
AMSU-A Inter-Satellite Biases for Operational Calibrated Radiances—STAR analysis

- Most satellite don't have relative drifts for most channels



Global mean difference time series between different satellites for different AMSU-A channels For operational calibrated radiances (plot from Zou and Wang 2011)

Satellite Orbital Drifts



Lesson #1

- Inter-satellite biases between NOAA-15 and AQUA are close to zero with no drift over time for most channels. AQUA has no orbital drifts. Suggesting AQUA and NOAA-15 radiances don't have artificial drifts over time
- Unfortunately, ERA-Interim shows large bias drifts for all AQUA channels; which was inconsistent with independent assessment
- Large bias drift on NOAA-15 channel 6 was captured.
- In summary, when satellite channels are OK, ERA-I may show bias drifts over time

Lesson # 2

- Satellite radiances don't have bias drifts for many 'good' channels, although orbits were drifting

- Drifts in the reanalysis bias correction as shown in previous slides are inconsistent with what was found in inter-satellite calibration

- How the drifted bias corrections of satellite data affect the final trends in reanalyses? Explanation required whether the final trends are consistent or inconsistent with independent satellite processing

Recalibrated MSU Observations

- Methodology: Integrated Microwave Inter-Calibration Approach (IMICA)
  Formally known as SNO (Simultaneous Nadir Overpass) Approach

- Bias removed: > constant inter-satellite biases
  > solar-heating induced temperature variability in radiances
  > calibration nonlinearity

- Current status: > Available from NOAA/NCDC CDRP website
  > http://www.ncdc.noaa.gov/cdr/operationalcdrs.html
  > Direct download

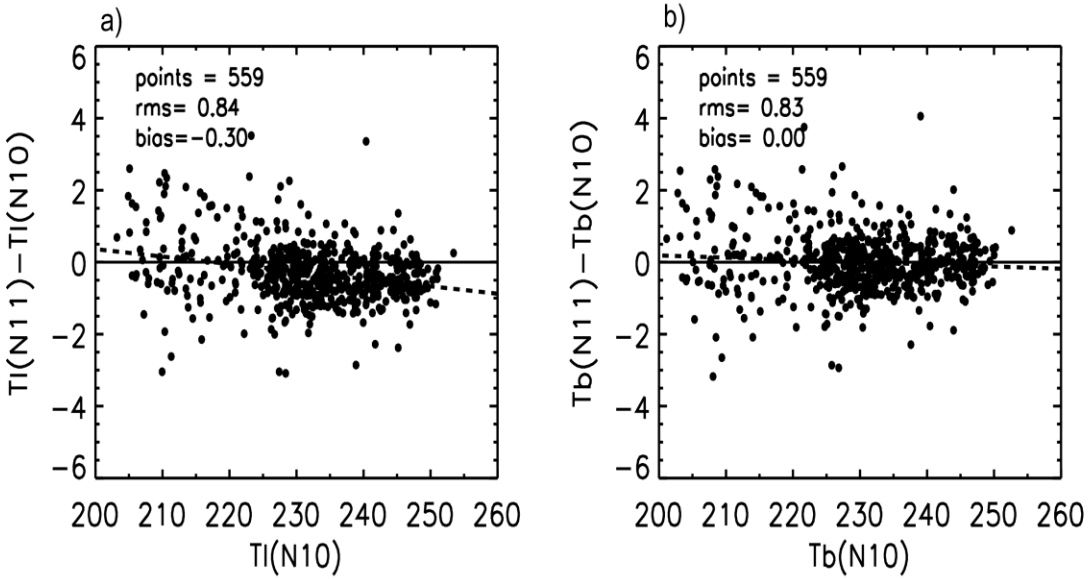
- Data Format: NetCDF

- MeteData: Processing code, C-ATBD, Maturity matrix
  all available from the website

Note: NCDC has CLASS archive of raw data for operational calibration
NCDC also has CDR archive for reprocessed radiances

Characteristics – Calibration nonlinearity

Scene temperature dependent biases due to calibration nonlinearity mostly removed



Scatter plot between NOAA-10 and NOAA-11 for their SNO matchups for before (left) and after (right) IMICA calibration

Removal of Sun-heating Induced Instrument Temperature Variability

- Theoretically, one specific value of μ exist that can completely remove instrument temperature signals:

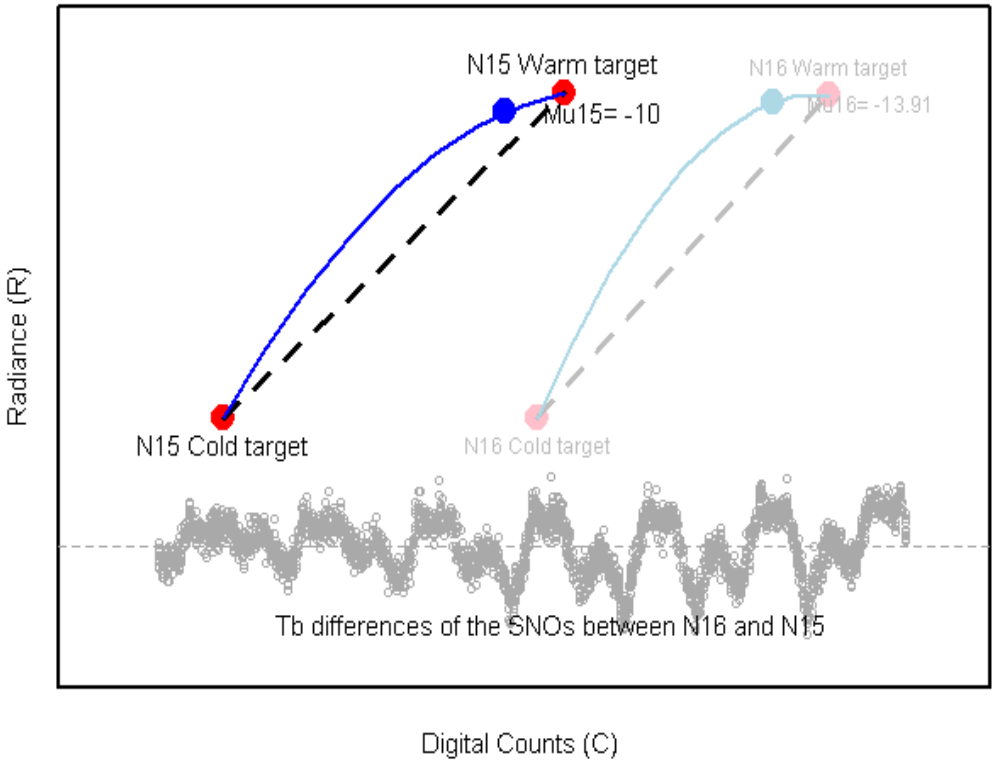
$$R = R_L - \delta R + \mu Z$$

$$\Downarrow$$

$$\overline{R'T'_w} = \overline{R'_L T'_w} + \mu \overline{Z'T'_w}$$

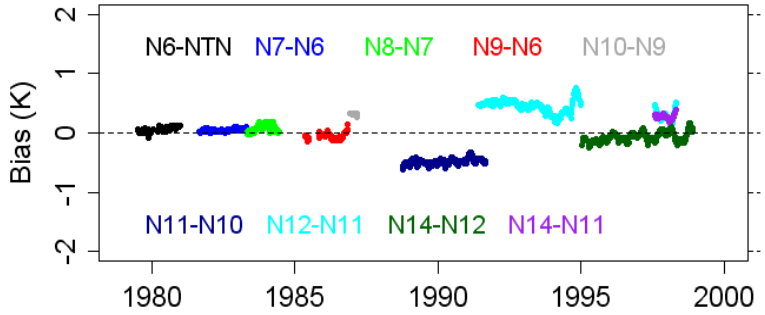
$$\Downarrow$$

$$\mu = \mu_c = -\frac{\overline{R'_L T'_w}}{\overline{Z'T'_w}}$$



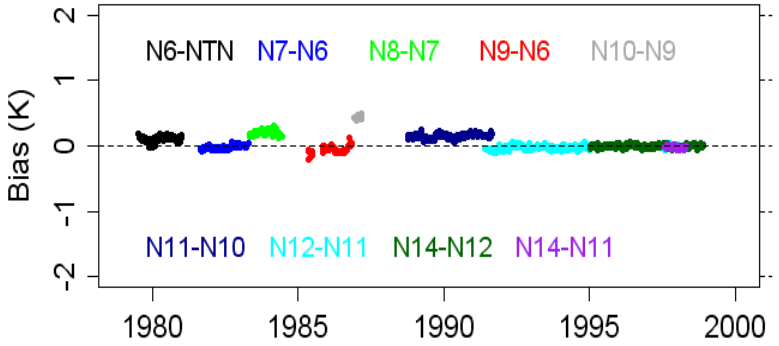
Characteristics – Solar-heating induced variability in radiances

Intersatellite biases for NOAA operational calibration (ch2 5-day and global ocean-mean)



STD=0.10K

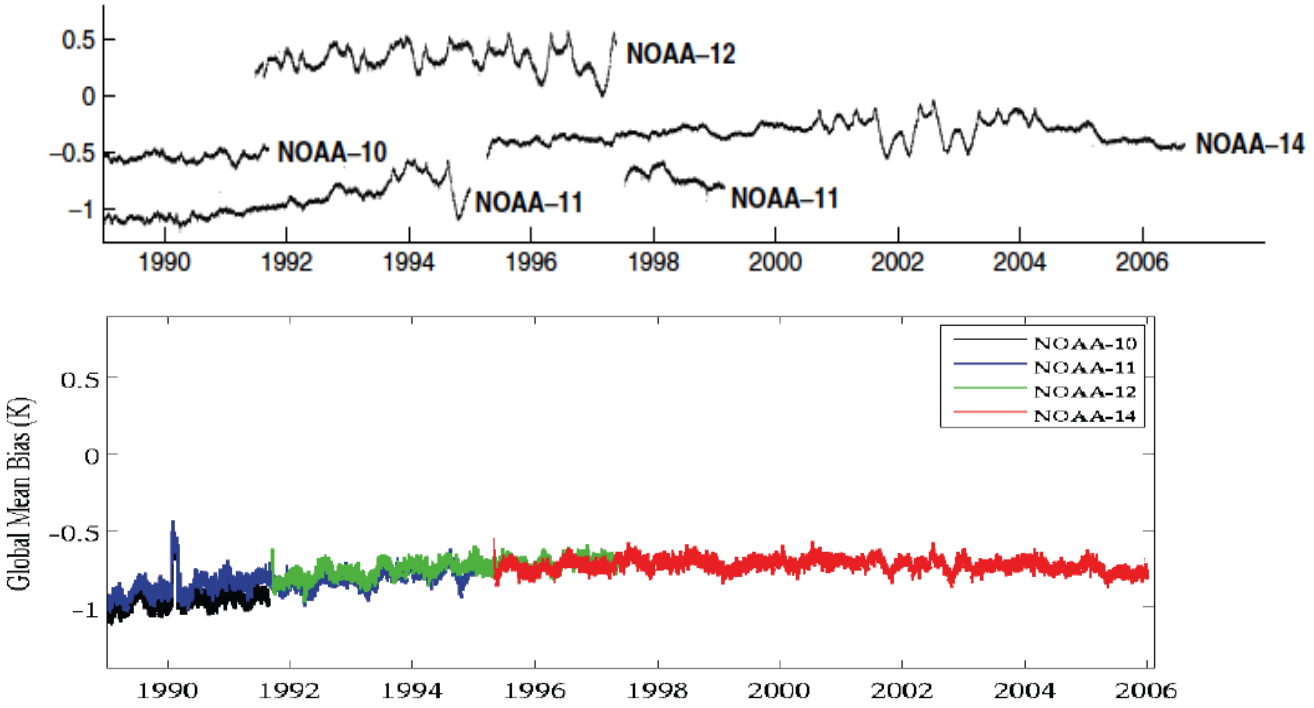
Intersatellite biases after SNO calibration



STD=0.03K

Instrument temperature variability in radiances induced by solar heating mostly removed by IMICA calibration

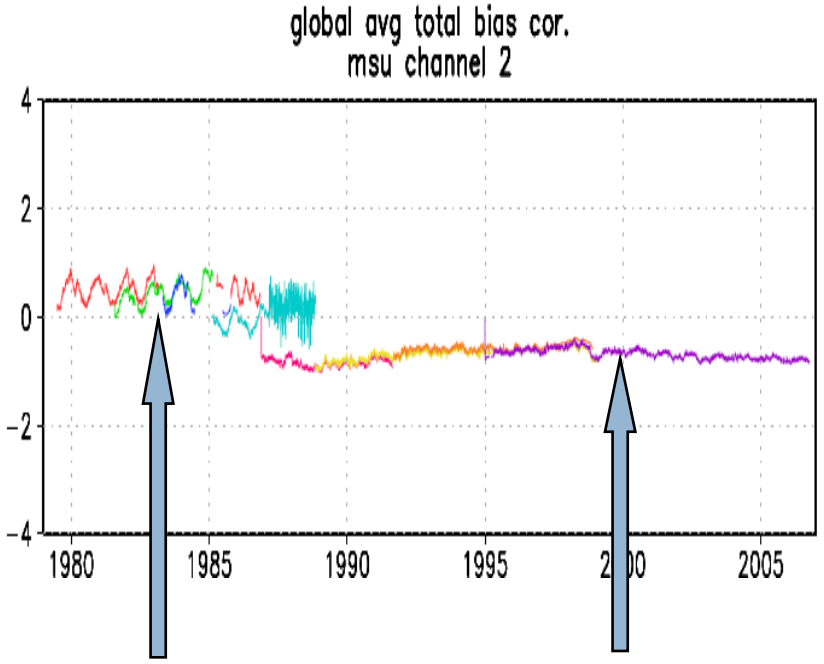
Bias Correction of Inter-Calibrated Satellite Data



Global mean 12-hourly variational bias estimates (K) for MSU channel 2 radiance data from NOAA-10, NOAA-11, NOAA-12, and NOAA-14 . The upper panel is from ERA-Interim (Dee and Uppalla, 2009) and the lower panel is from MERRA. The latter uses the NOAA/STAR SNO cross-calibrated MSU data.

MSU in NCEP CFSR

- Recalibrated MSU level-1c data were assimilated into NCEP CFSR and NASA MERRA reanalysis systems
- Bias correction pattern for recalibrated MSU data are much smoother, since instrument errors were removed before assimilation
- Need to adjust the absolute values of the recalibrated MSU/AMSU data so that the absolute value of the bias correction is close to zero



MSU Channel 2 bias correction patterns in NCEP CFSR reanalysis from 1978-2007. Recalibrated MSU data after 1987 were assimilated into CFSR (plot from Saha et al. 2010)

Available MSU Data

	TIROS-N	NOAA-6	NOAA-7	NOAA-8	NOAA-9	NOAA-10	NOAA-11	NOAA-12	NOAA-14
Available periods of data	1978.10.21-1980.12.31	1979.06.30-1983.03.05 1985.04.08-1985.07.01 1985.10.17-1986.11.15	1981.08.24-1985.02.01	1983.05.03-1984.06.20 1985.07.01-1985.10.14	1985.02.25-1988.11.06	1986.11.25-1991.09.16	1988.11.08-1995.04.10 1997.07.15-1999.02.26	1991.09.16-1998.12.14	1995.01.02-2006.10.10
Note	Channel 3 warm target issue not resolved	Channel 3 not used before 1981.01.01 due to unresolved warm target issue; 1980.06.02-06.03 not used due to poor quality	1984.03.01-03.05 not used due to poor quality	1985.09.06-09.15 not used due to poor quality	Channel 3 not used after 1987.03.05 due to miss orbits; 1985.05.16-05.31 and 1987.01.01-01.05 not used due to poor quality	All data are used	1989.12.26-12.31, 1991.07.26-07.31, 1991.08.16-08.20, 1993.09.06-09.10 not used due to missing data	1993.09.06-09.10, 1994.11.26-11.30 not used due to missing data	1995.01.02-01.05, 1996.04.26-05.05, 2001.12.21-12.25, 2004.06.11-06.15 not used due to missing data

Recalibrated AMSU Observations

- Methodology: Integrated Microwave Inter-Calibration Approach (IMICA)

- Bias removed: > constant inter-satellite biases
  > solar-heating induced temperature variability in radiances
  > calibration nonlinearity
  > Long-term drift over time on NOAA-16, and channel-7 of MetOp-A
  > Frequency shift of NOAA-15 channel 6

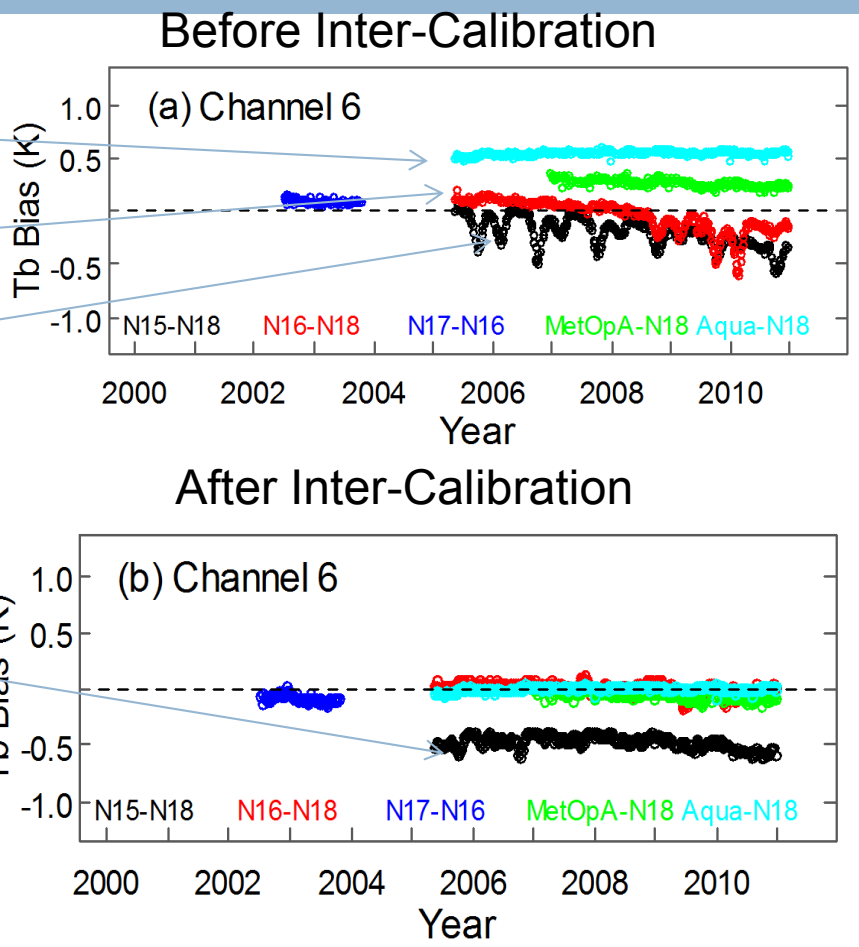
- Current status: Available from NOAA/NCDC CDRP website
  http://www.ncdc.noaa.gov/cdr/operationalcdrs.html
  Direct download

- Data Format: NetCDF

- MeteData: Processing code, C-ATBD, Maturity matrix
  all available from the website

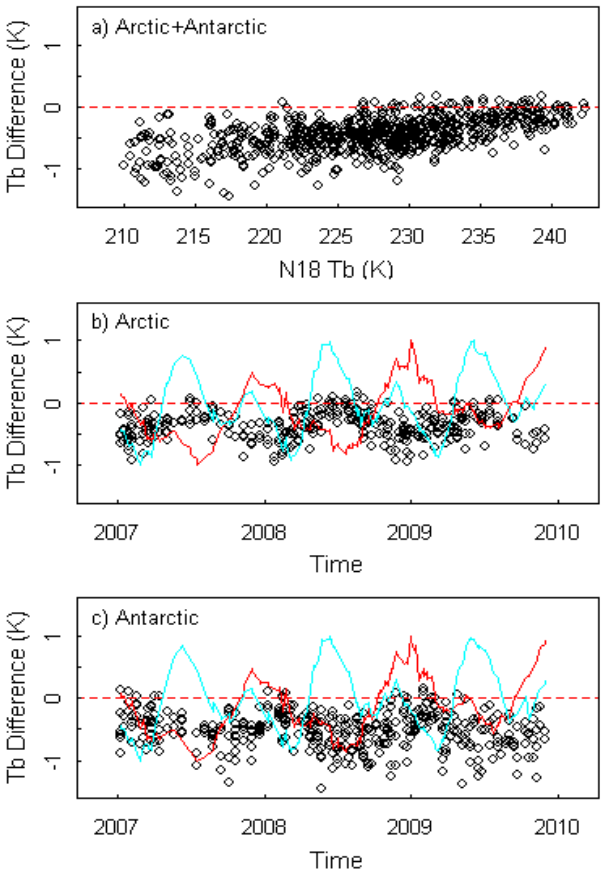
Examples of Biases Removed/Minimized

- Relatively stable inter-satellite biases (green line)
- Bias drifts over time (red line)
- Instrument temperature variability in radiances (instrument temperature dependent biases; black line)
- Biases due to channel frequency shifts black line)



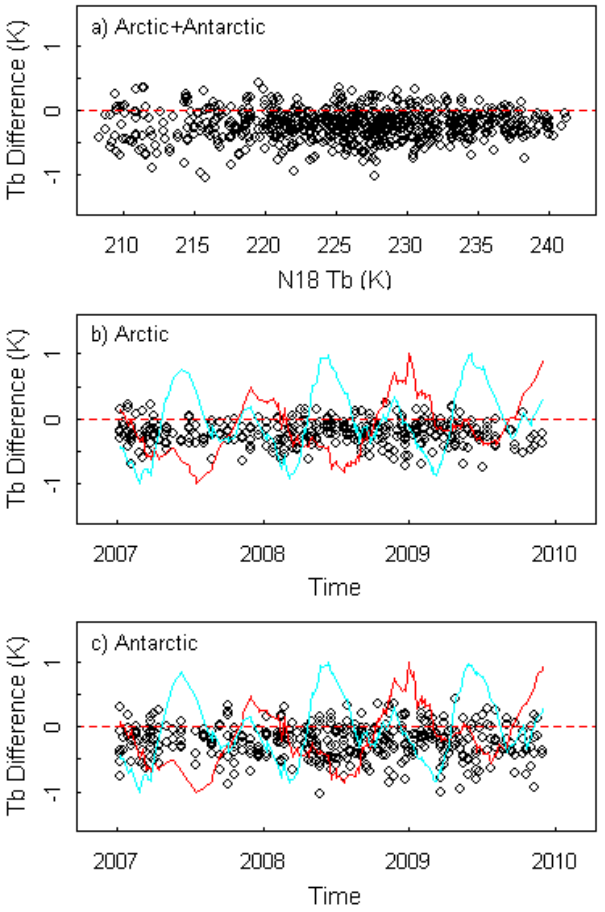
Slide courtesy of C. Zo

Calibration Non-linearity



Channel 6 of MetOp-A vs NOAA-18

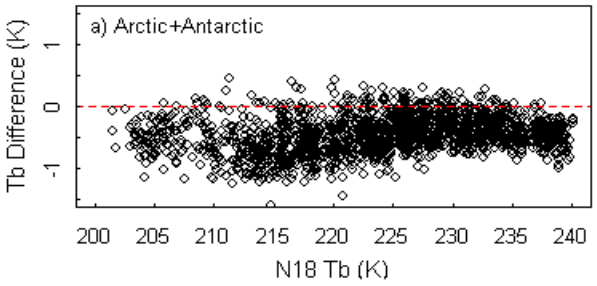
Before Inter-Calibration

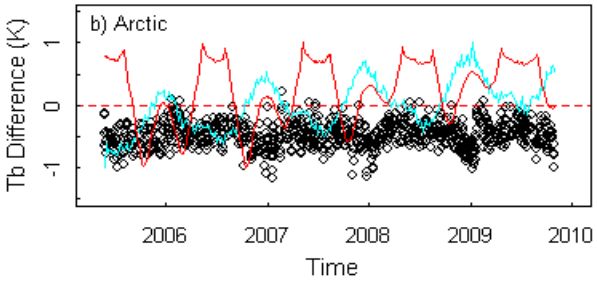


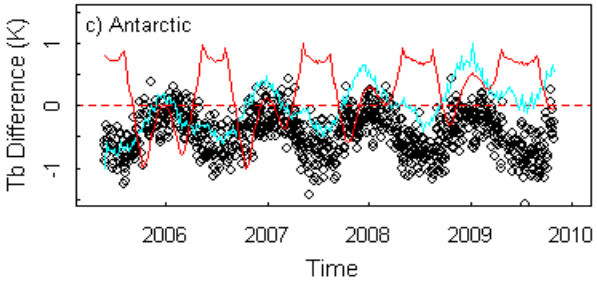
Channel 6 of MetOp-A vs NOAA-18

After Inter-Calibration

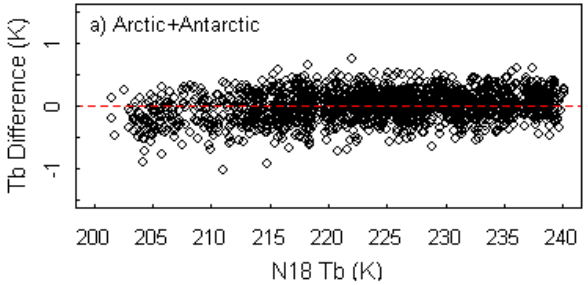
Frequency shift on NOAA-5 channel 6

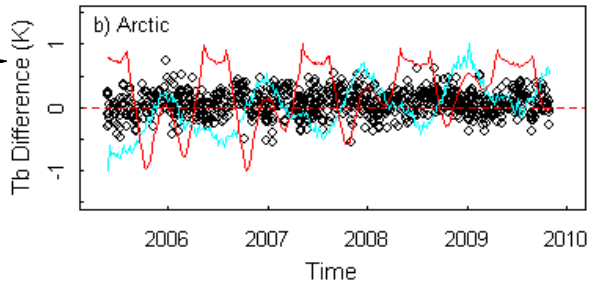


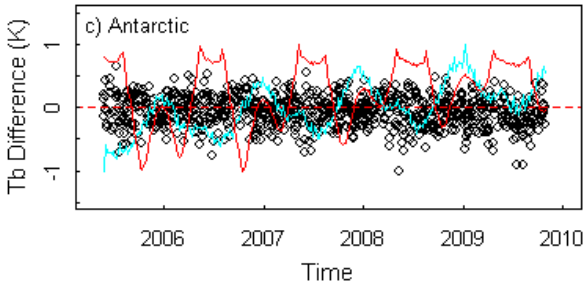




Channel 6 of NOAA-15 vs NOAA-18
Before Frequency adjustment



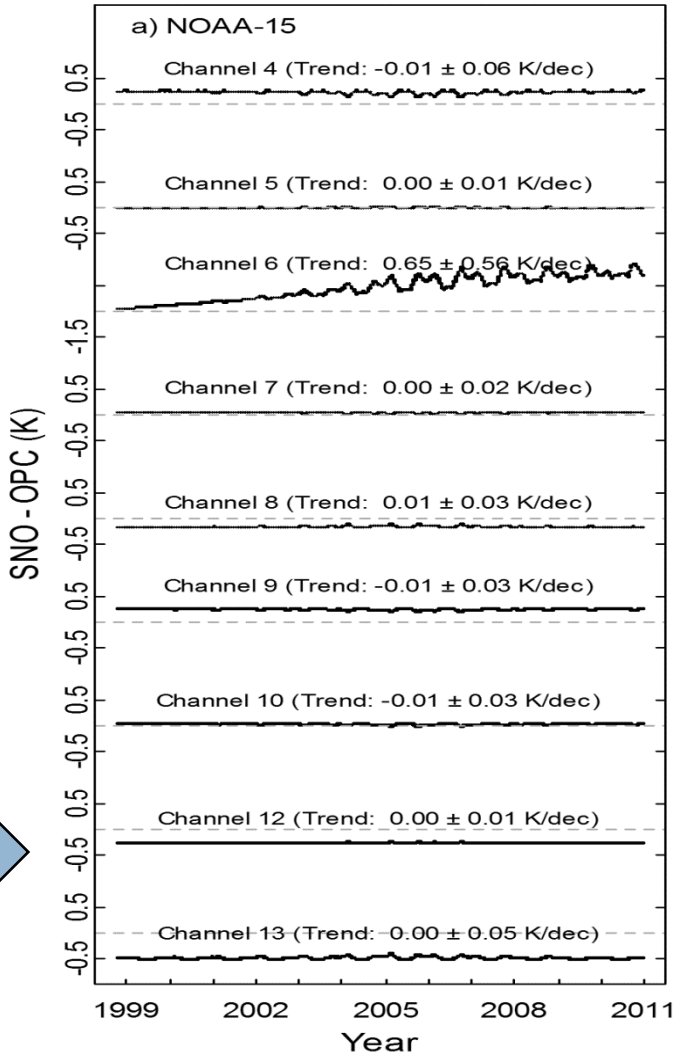




Channel 6 of NOAA-15 vs NOAA-18
After NOAA-15 Frequency adjustment

Summary of Pre-Launch Versus Post-Launch Calibrations—NOAA-15

- ERA-Interim (and also MERRA and CFSR) assimilated pre-launch calibrated AMSU-A data
- The pre-launch and post-launch calibrated data have no relative bias drifts for most channels for NOAA-15
- Suggesting that most AMSU-A channels don't have bias drifts for pre-launch calibration

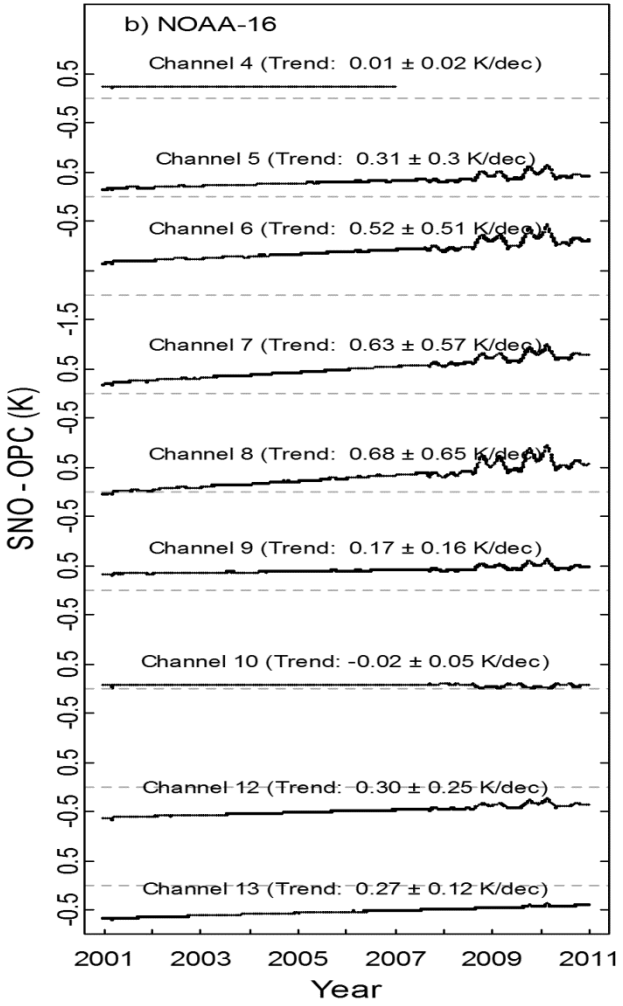


Global mean brightness temperature difference time series between pre-launch and post-launch calibrations. SNO denotes post-launch calibration using SNO method; OPC refers to pre-launch operational calibration (plot from Zou and Wang 2011)

Summary of Pre-Launch Versus Post-Launch Calibrations—NOAA-16

- The pre-launch and post-launch calibrated data have no relative bias drifts for most channels for NOAA-16
- Suggesting that most AMSU-A channels don't have bias drifts for pre-launch calibration

Global mean brightness temperature difference time series between pre-launch and post-launch calibrations. SNO denotes post-launch calibration using SNO method; OPC refers to pre-launch operational calibration (plot from Zou and Wang 2011)

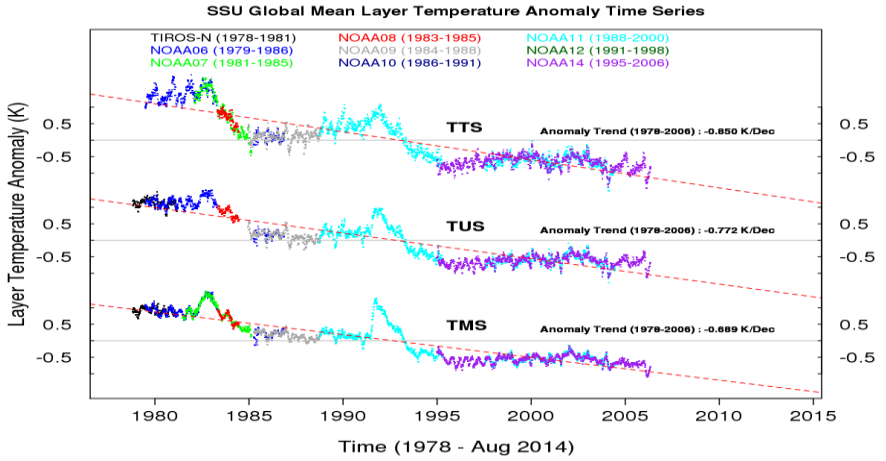


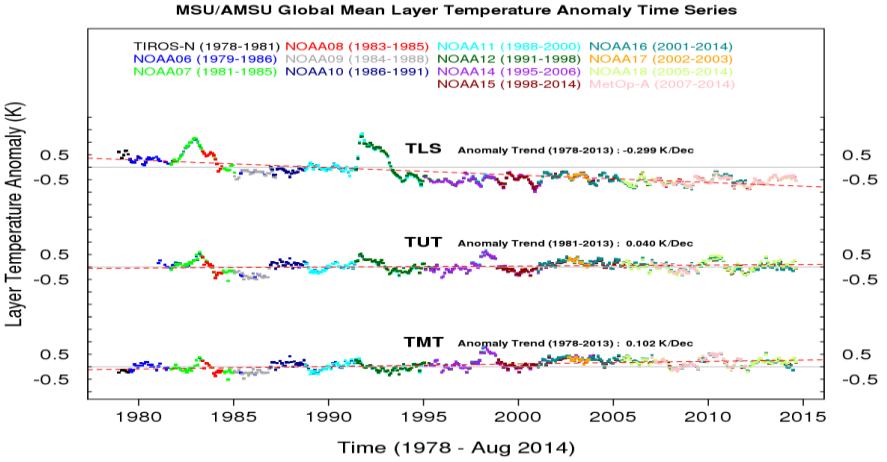
Available AMSU-A data

	NOAA-15	NOAA-16	NOAA-17	NOAA-18	METOP-A	AQUA
Available periods of data	1998.10.26-present	2001.01.01-2014.06.09	2002.06.28-2003.12.31	2005.05.24-present	2007.01.01-present	2002.05.23-present
Note	2009.01.26-01.31 not used due to poor quality	Channel 7 not used from 2002.11.16 to 11.25 due to poor quality; 2007.07.06-07.15, 2008.02.25-02.29 not used due to poor quality	2003.10.26-2003.12.31 not used due to poor quality	Channel 7 of 2005.07.26-07.31 not used due to poor quality	2007.02.16-02.20, 2007.04.21-04.25, 2007.05.01-05.05, 2007.11.21-11.25, 2008.01.16-01.20 not used due to poor quality	2002.08.06-08.10, 2003.10.26-10.31, 2003.11.01-11.05 not used due to poor quality

Satellite Reprocessed Data as a Validation Tool

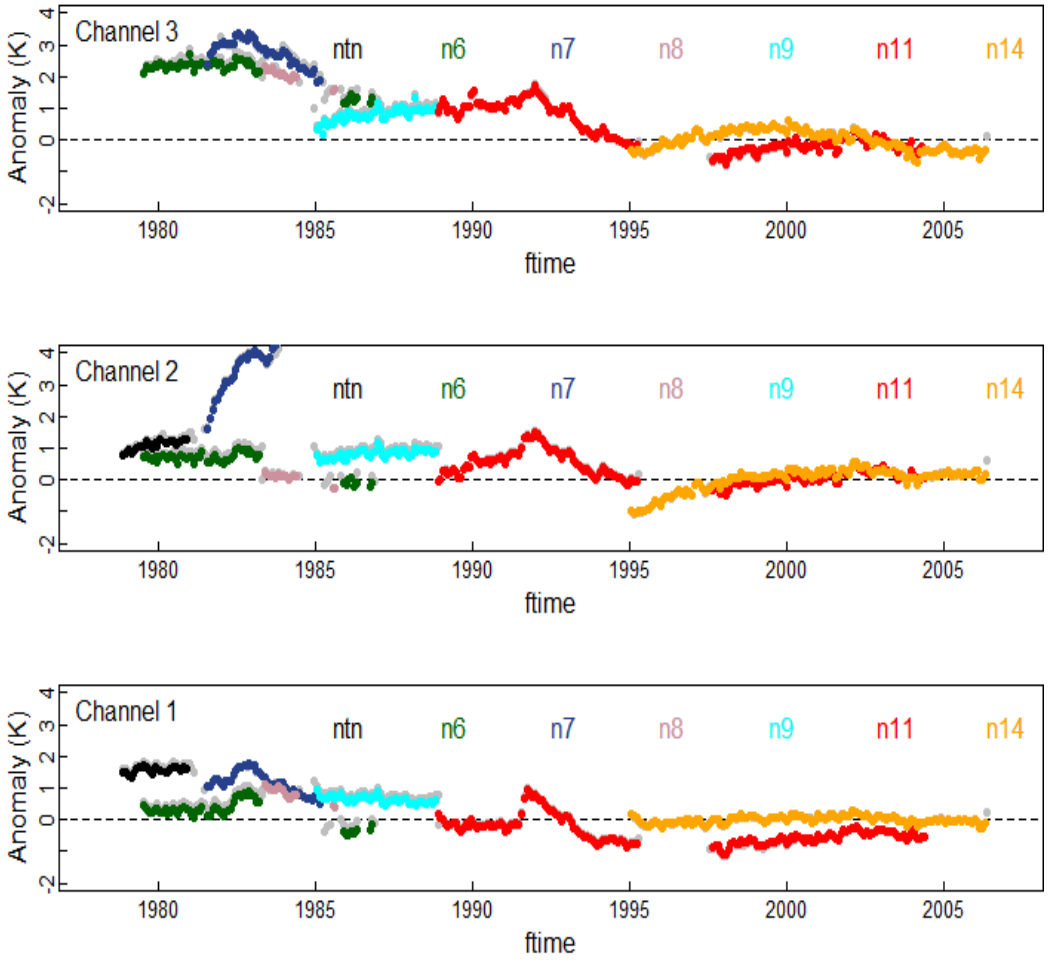
- NOAA/STAR MSU/AMSU/SSU channel based deep-layer atmospheric temperature time series
- Global monthly gridded data with 2.5 by 2.5 spatial resolution
- Well inter-calibrated and merged; inter-satellite differences minimized
- Convert reanalysis level temperatures to layer temperatures using CRTM; no weighting function variability issue
- Accurate comparison; issues maybe detected by careful examination of differences





SSU time series, Raw Radiances Data in CLASS Archive

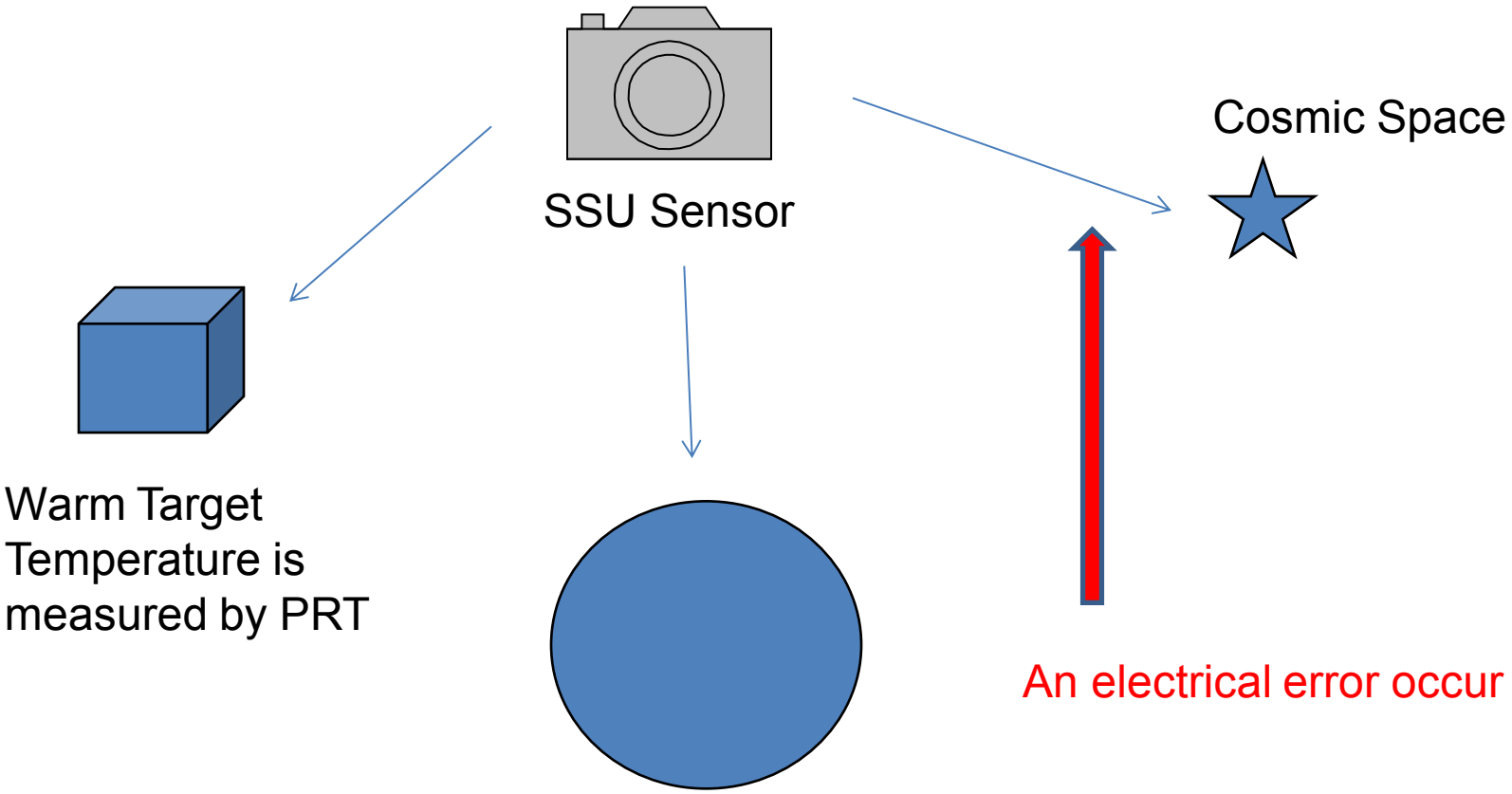
- Inter-satellite biases found in NOAA -CLASS calibration
- Need to understand how much of the biases came from level-1c calibration



Issues to deal with in SSU recalibration

- Poor documentation– lost or no record of many calibration parameters
- Quality of raw counts data
- Space view anomaly—directly affects level-1c radiances
- Blackbody target
- Gas leaking problem in the CO_2 cell→ cell pressure change
- atmospheric CO_2 variations
- limb-effect
- diurnal drift effect→ semi-diurnal tides
- Residual biases

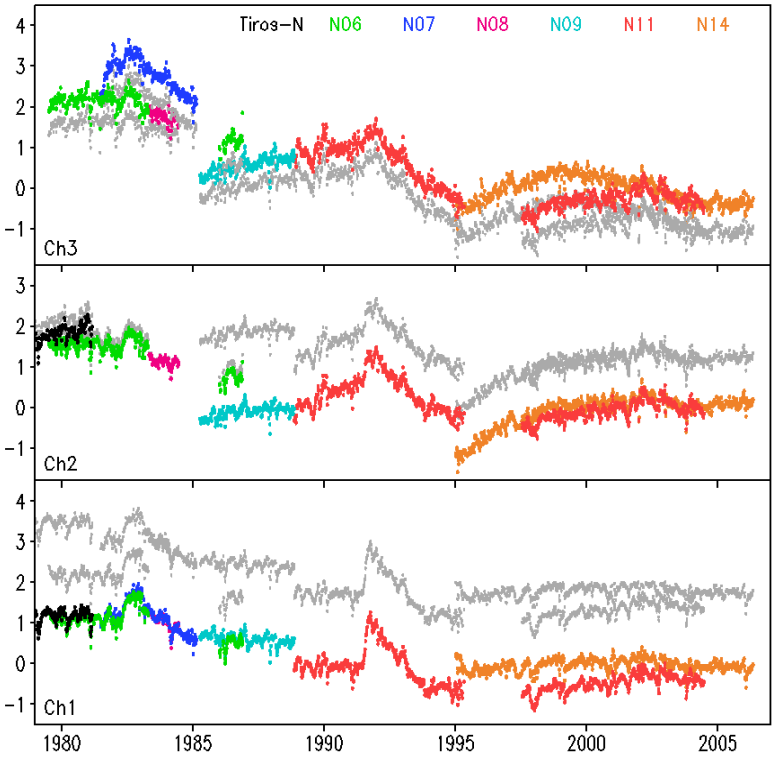
Calibration Principle of SSU Instrument



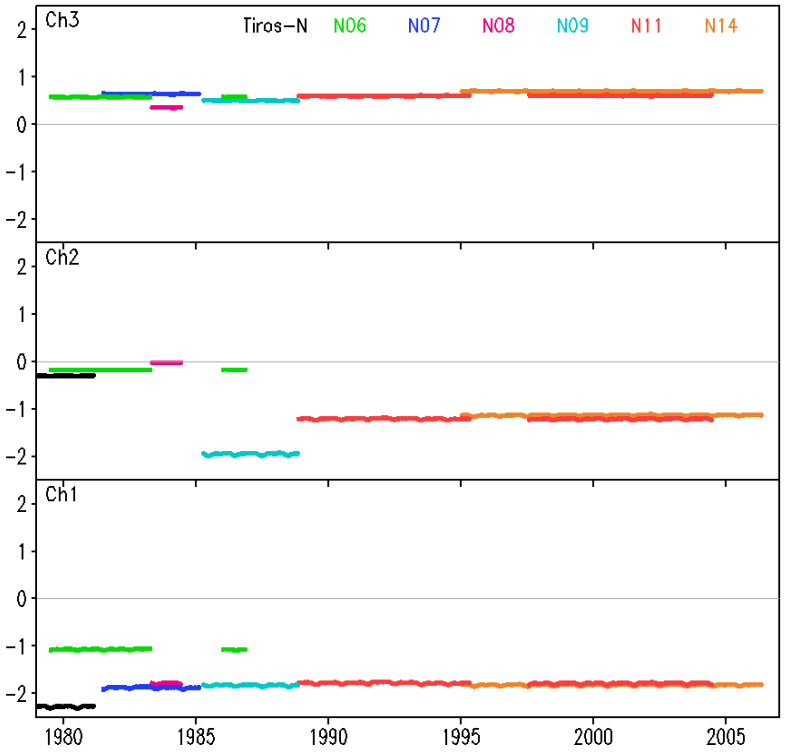
Conceptual diagram of SSU observational procedure

Recalibrated Radiances—With Space View Correction

NOAA-6 is defined as a reference

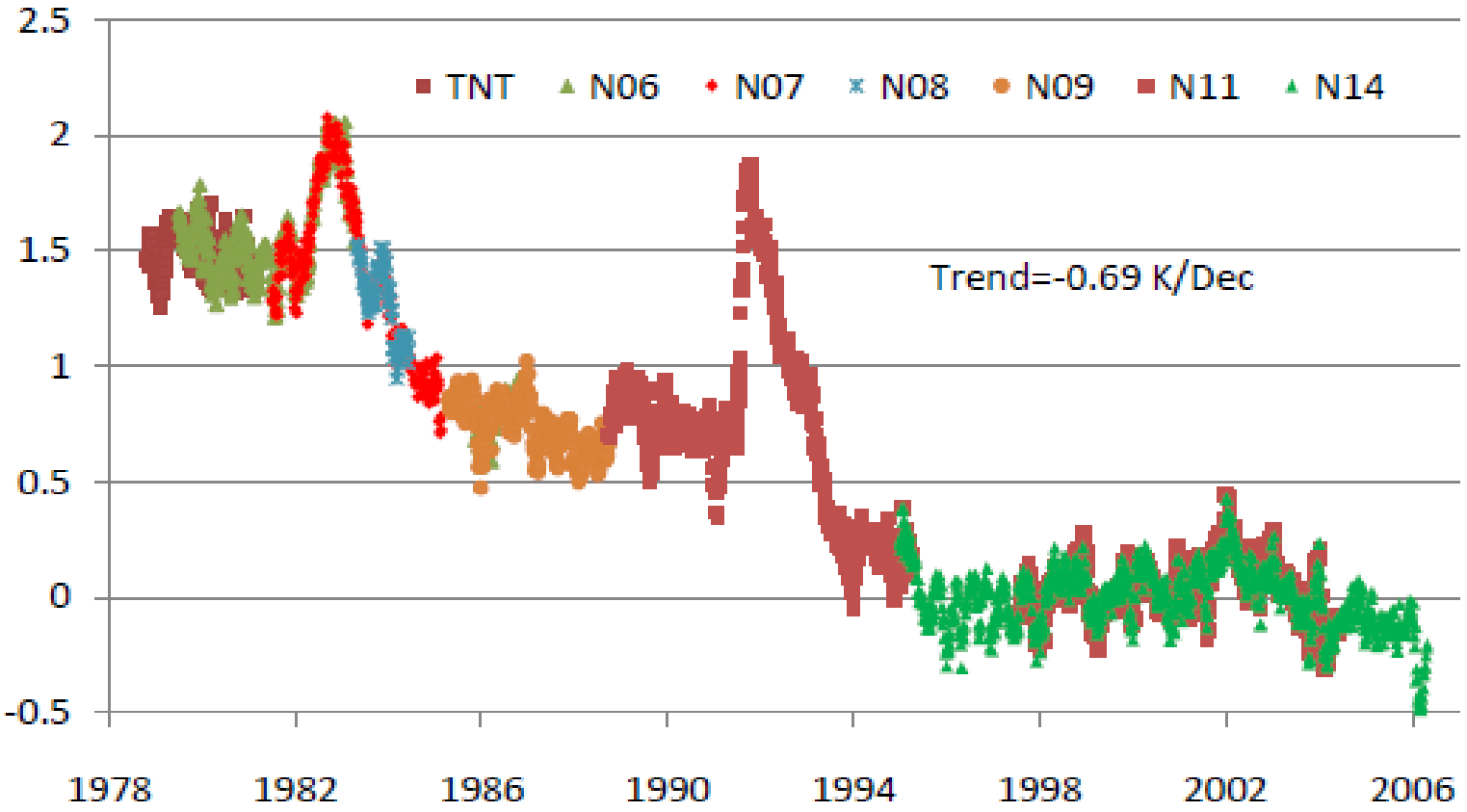


Recalibrated (color) versus operational (grey) calibrated anomaly time series



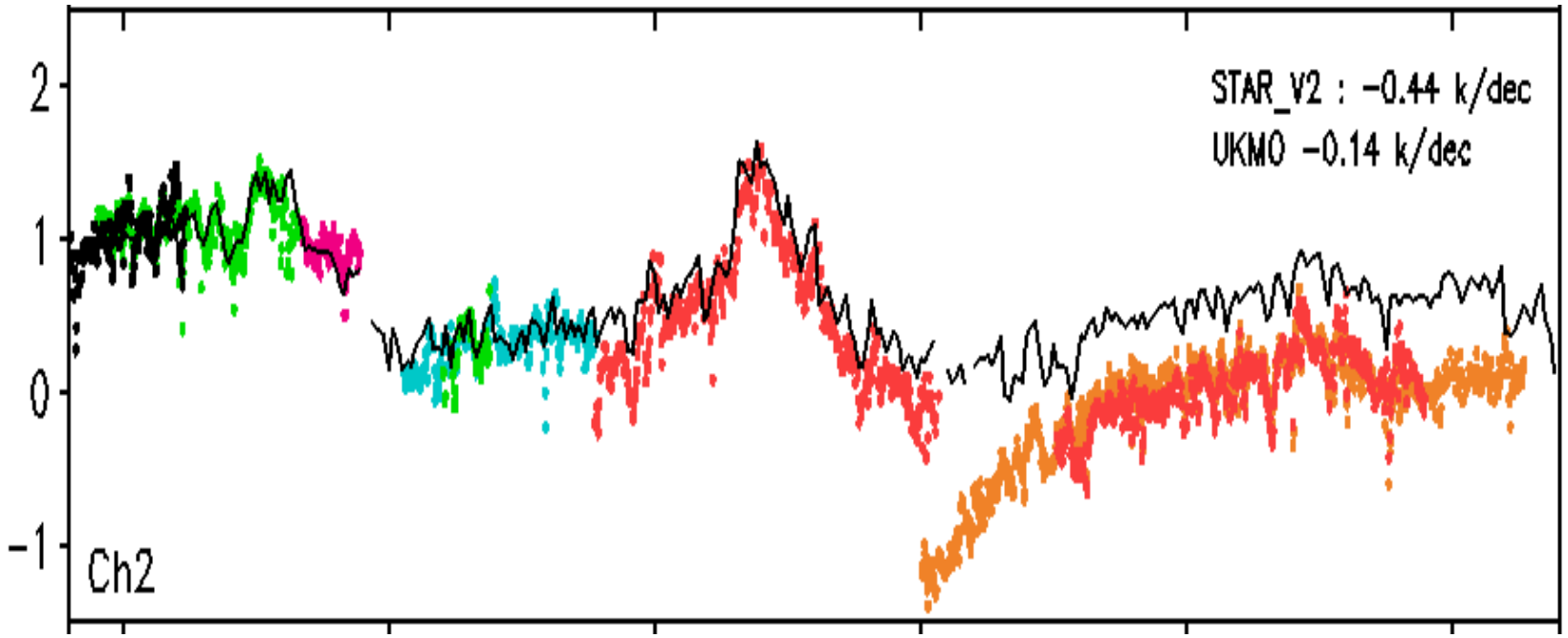
Differences between recalibration and NOAA operational calibration

Performance of Recalibrated SSU Time Series—Channel 1

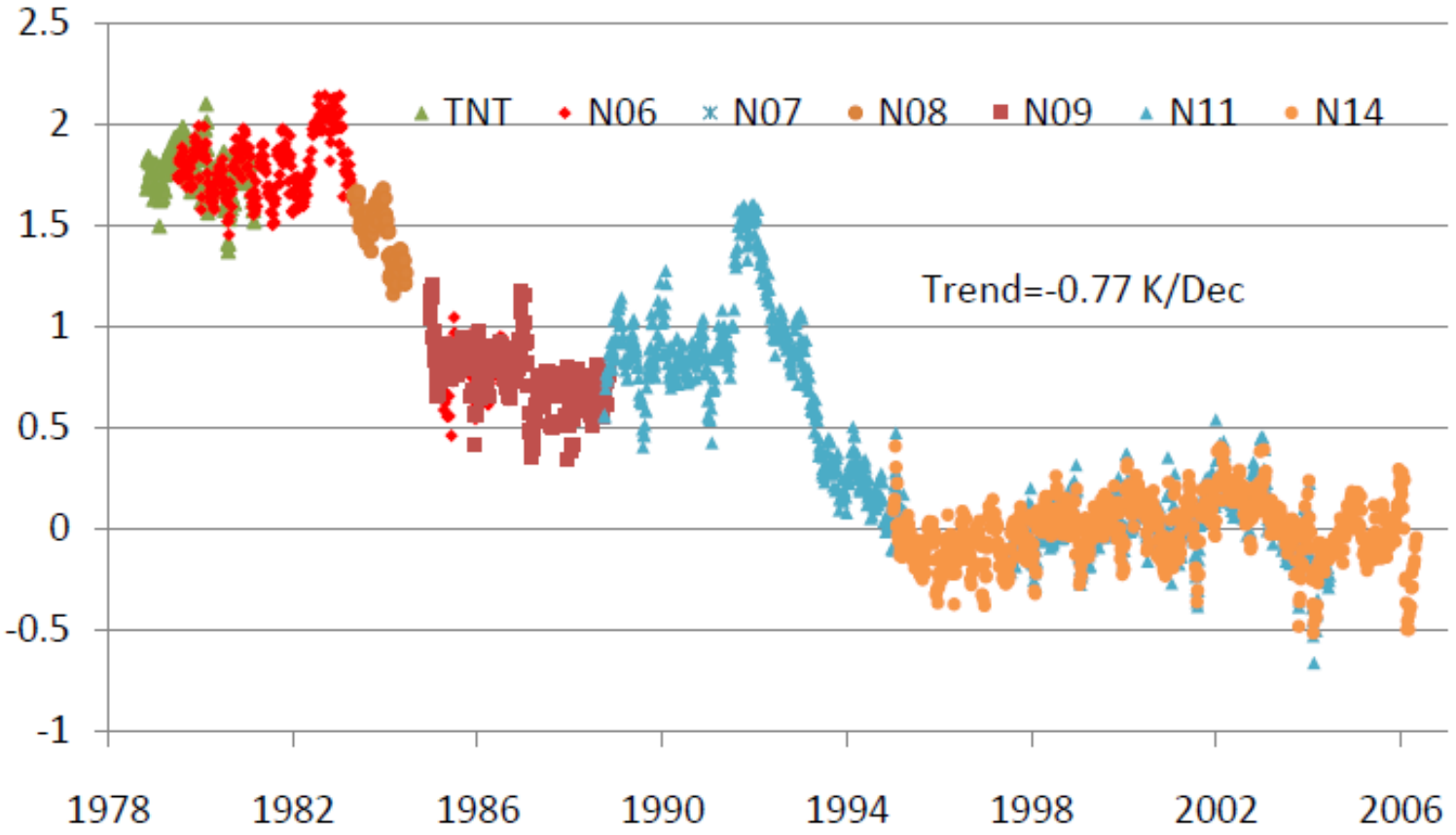


Different satellites match with each other very well, suggesting good calibration performance in every steps

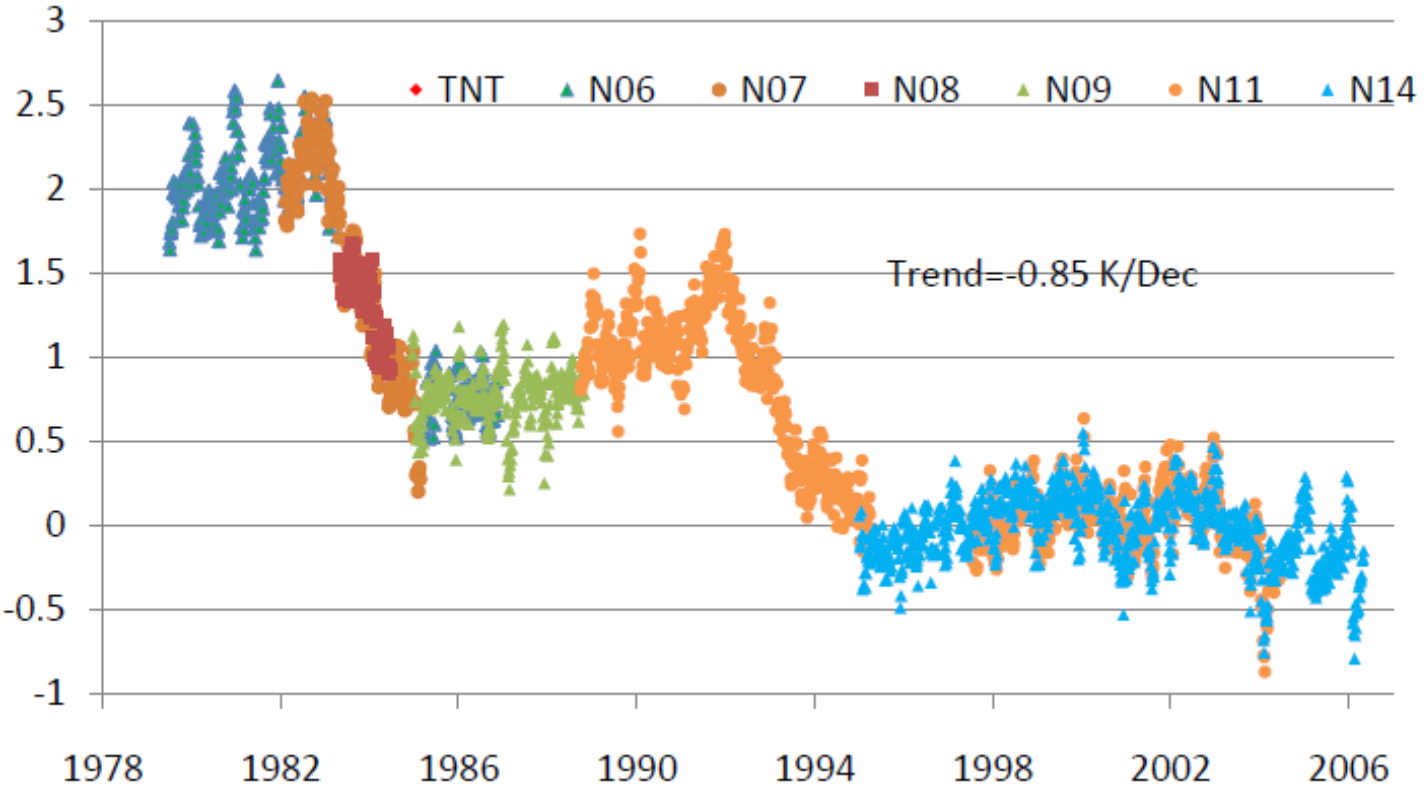
Example when adjustments were not done correctly —Channel 2



Recalibrated SSU time series—Channel 2

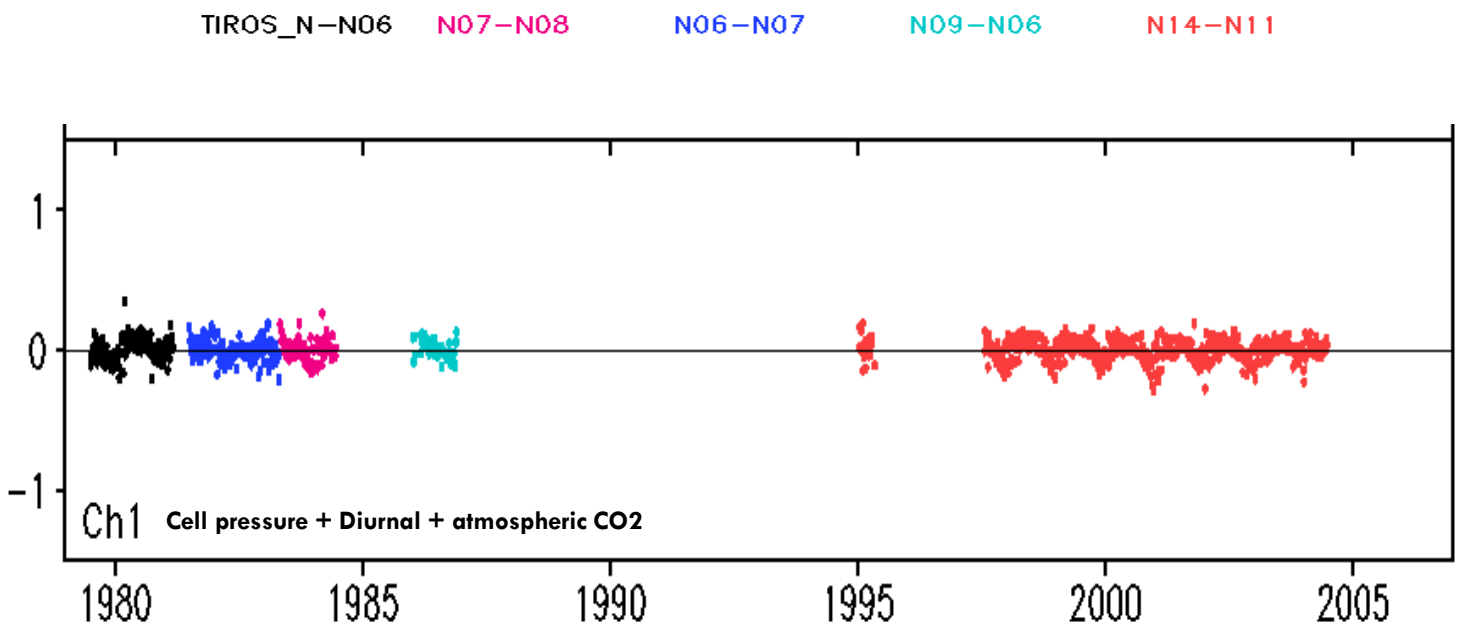


Recalibrated SSU time series—Channel 3



Inter-satellite Biases

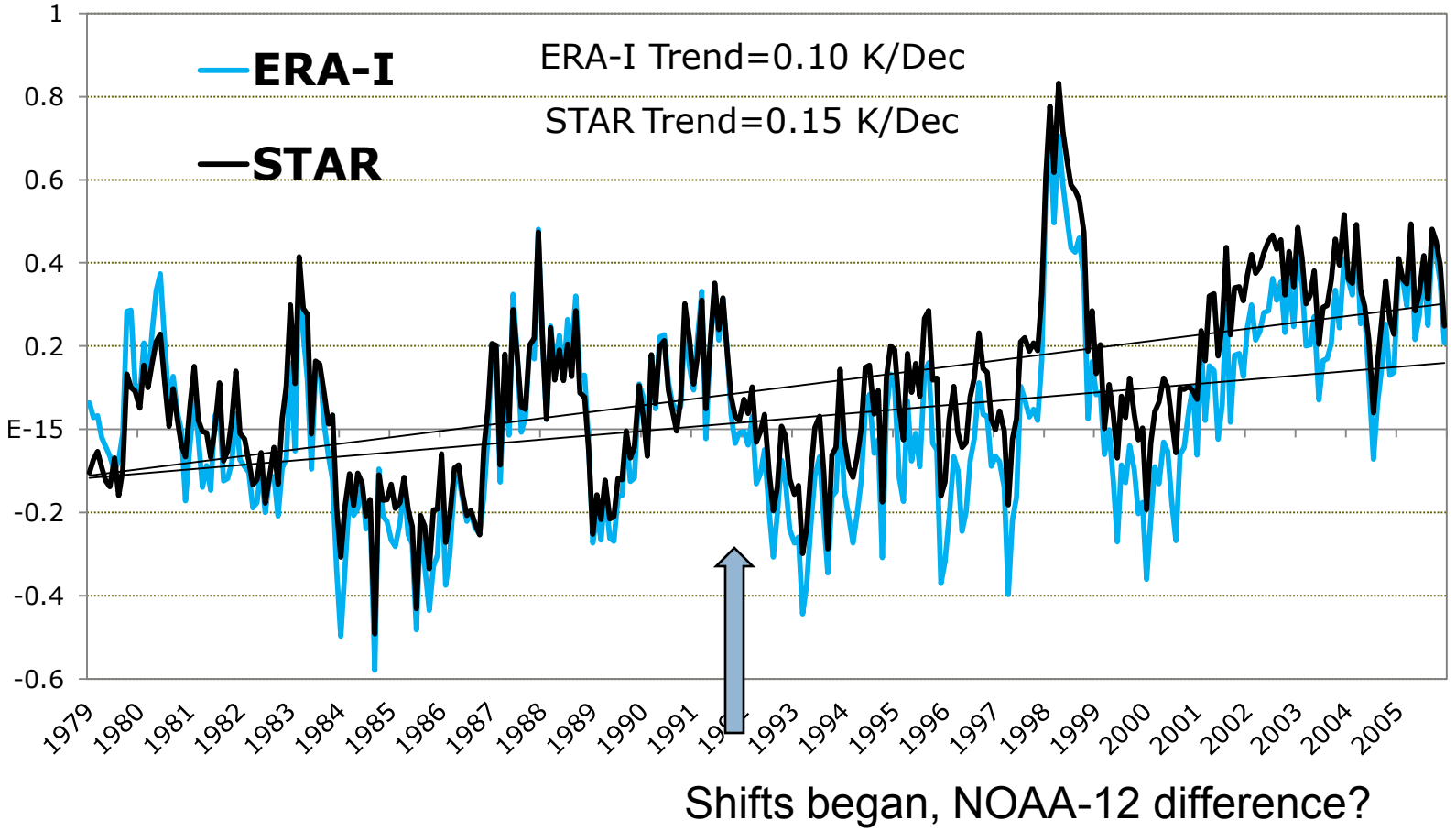
Inter-satellite biases close to zero throughout overlapping observations after all adjustment



Available SSU data Period

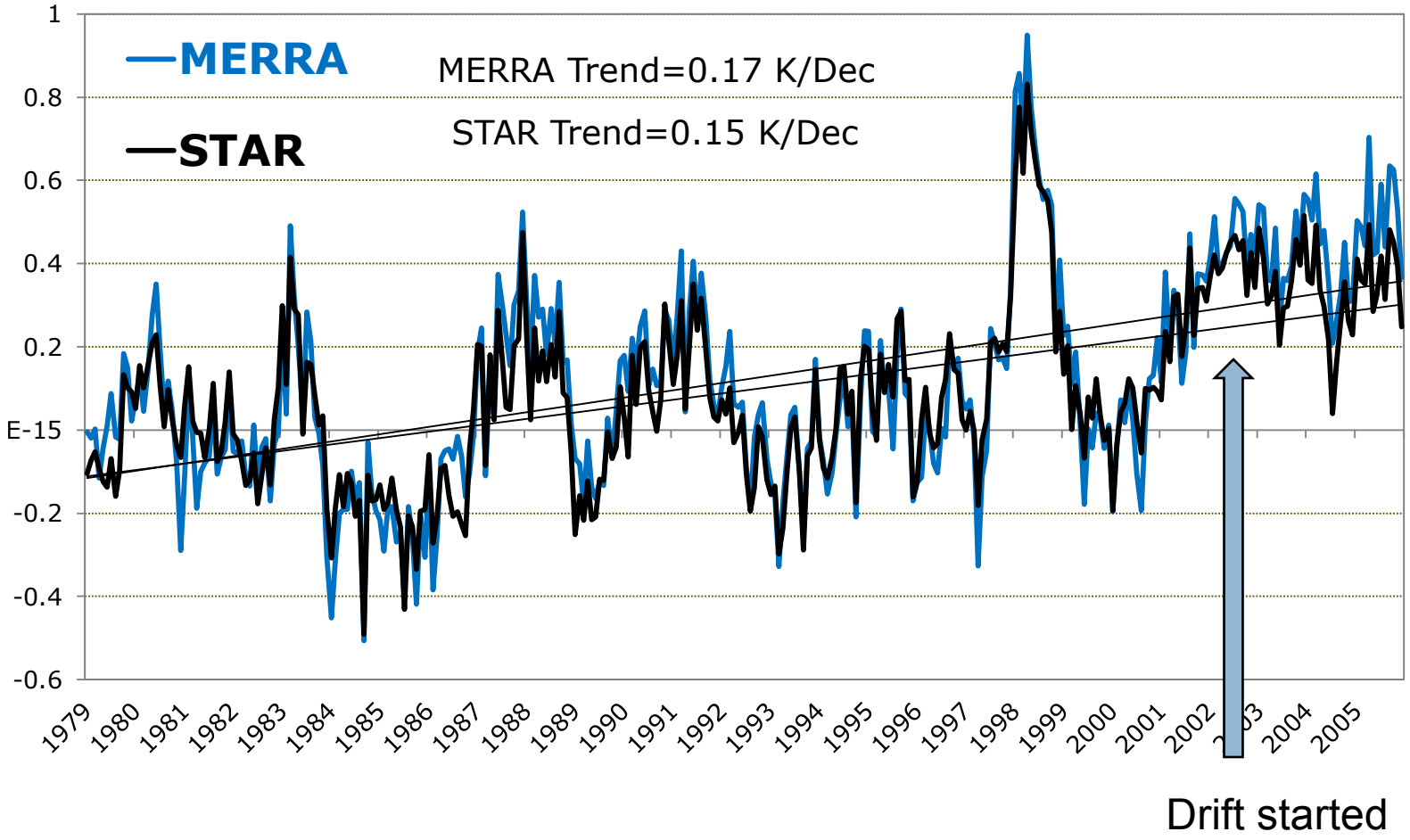
	TIROS-N	NOAA-6	NOAA-7	NOAA-8	NOAA-9	NOAA-11	NOAA-14
Available periods of data	1978.10.29-1981.02.27	1979.06.30-1983.04.17 1985.04.08-1985.07.04 1985.10.15-1986.11.17	1981.06.27-1985.02.18	1983.04.25-1984.06.21 1985.07.02-1985.10.14	1984.12.12-1988.11.07	1988.09.24-1995.04.10 1997.07.15-2004.06.16	1995.01.01-2006.05.05
Note	Channel 3 unusable	6 pentads from 1986.01.21-1986.02.19 removed due to poor quality	Channel 2 unusable for the entire period; Channel 3 from 1981.06.27-1981.12.31 not used due to poor quality	Data of the second period unusable due to poor quality	Channel 1 from 1984.12.17-1985.04.07 not used due to poor quality	6 days of data from 1988.09.24-1988.09.29 not used due to poor quality	All data are used

Trend Comparison between ERA-Interim and STAR MSU/AMSU – TMT (MSU2)



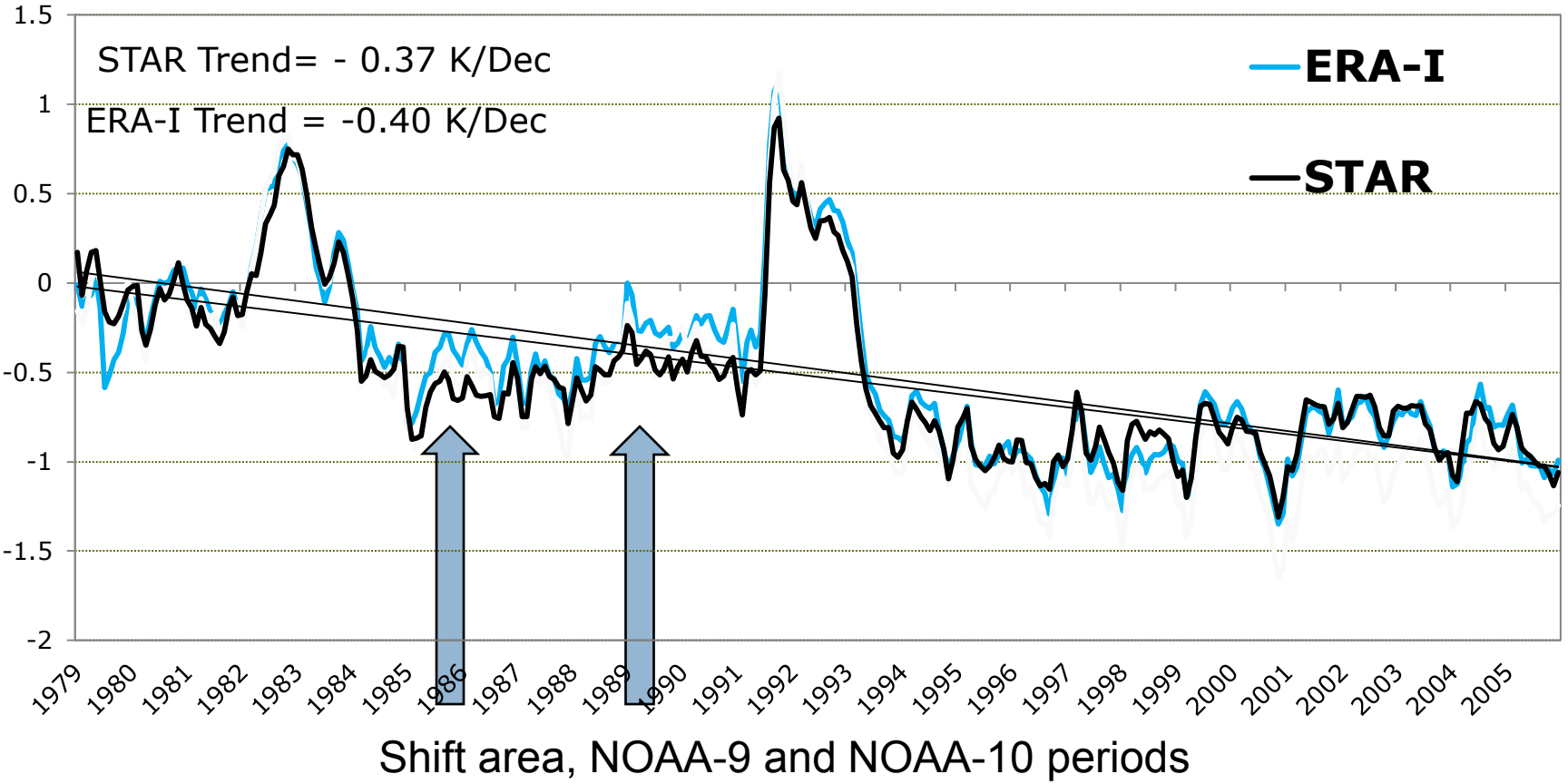
Global Mean Anomalies of Temperature of Mid-Troposphere. Different time series start from the same 1979-1982 mean so that their departures can be seen later on (plot from Powell et al. 2013)

Trend Comparison between MERRA and STAR – TMT (MSU2)



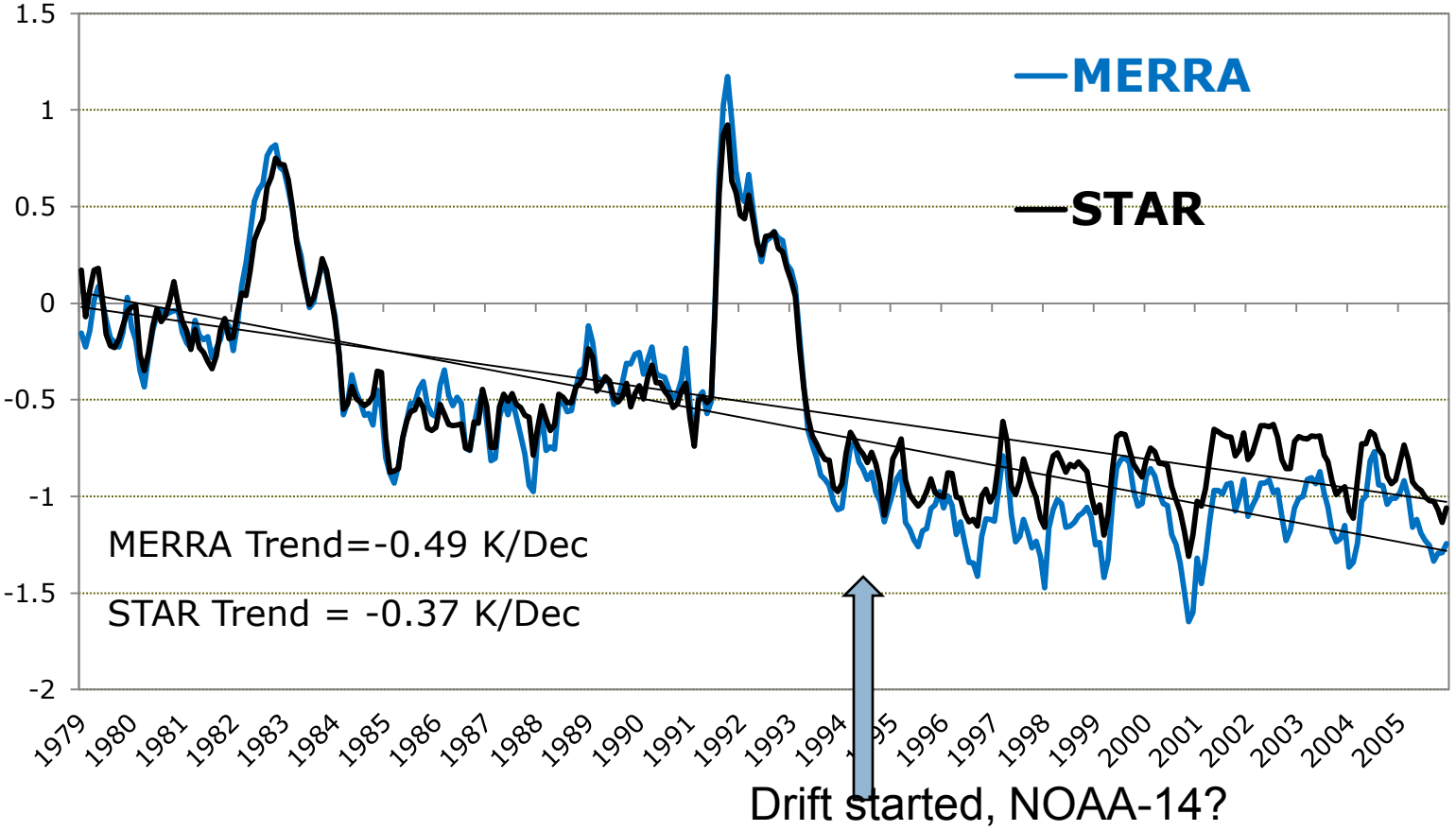
Global Mean Anomalies of Temperature of Mid-Troposphere. Different time series start from the same 1979-1982 mean so that their departures can be seen later on

Trend Comparison between ERA-Interim and STAR —TLS (MSU4)



Global Mean Anomalies of Temperature of Lower-Troposphere. Different time series start from the same 1979-1982 mean so their departures can be seen later on.

Trend comparison between MERRA and STAR – TLS (MSU4)

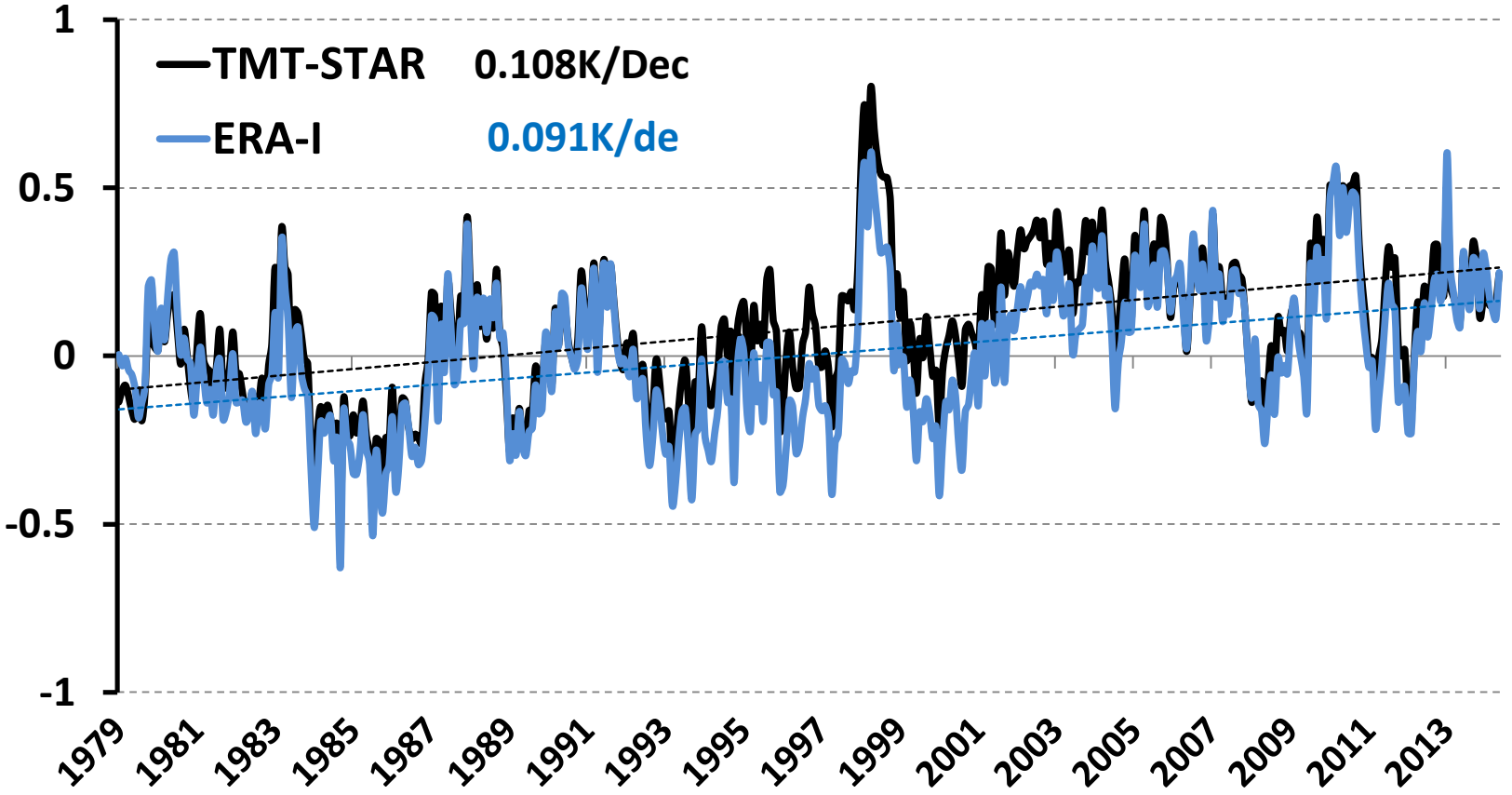


Global Mean Anomalies of Temperature of Lower-Troposphere. Different time series start from the same 1979-1982 mean so that their departures can be seen later on.

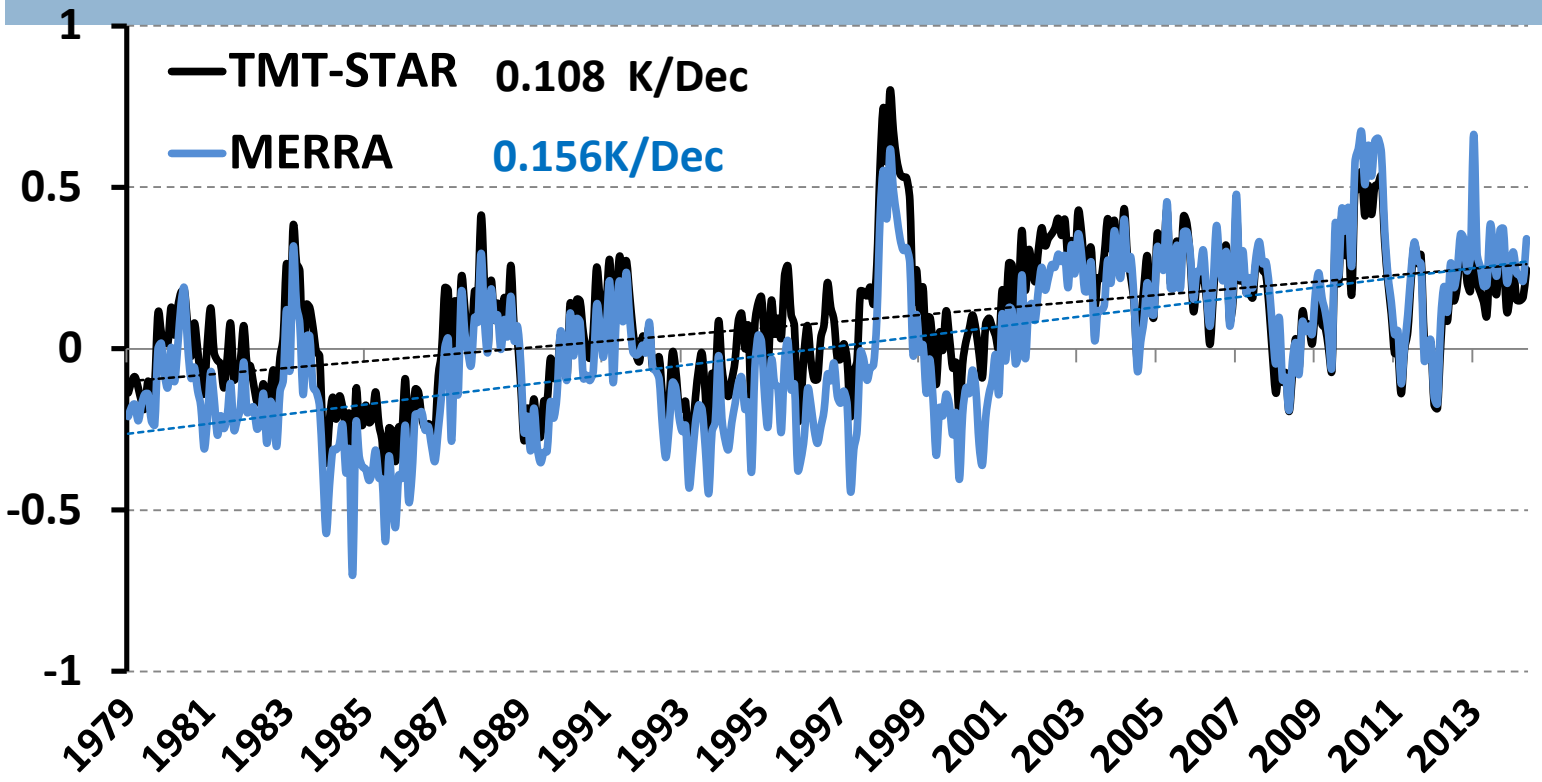
Lesson # 4

- TMT (MSU2):
  - ERA-I shifted lower 0.05-0.2K between 1992-2005
  - MERRA fitting extremely well except drifted higher 0.1K between 2003-2005
- TLS (MSU4):
  - ERA-I fitting extremely well except shifted higher 0.2-0.3K between 1985-1990
  - MERRA TLS: Fitting extremely well except shifted lower 0.2-0.3K after 1995
- TMS (SSU1):
  - Both ERA-I and MERRA shifted higher 0.5-1K after 1985; both satellite and both reanalyses may have problems
- TUS (SSU2):
  - ERA-I fitting very well except shifted higher 0.5 K between 1995-2005
  - MERAA fitting not so well and shifted higher 0.7-1K between 1995-2005
- TSM (SSU3):
  - ERA-I fitting not so well and jumped higher 1K after 1998
  - MERRA fitting not so well and jumped higher 1-2 K after 1998

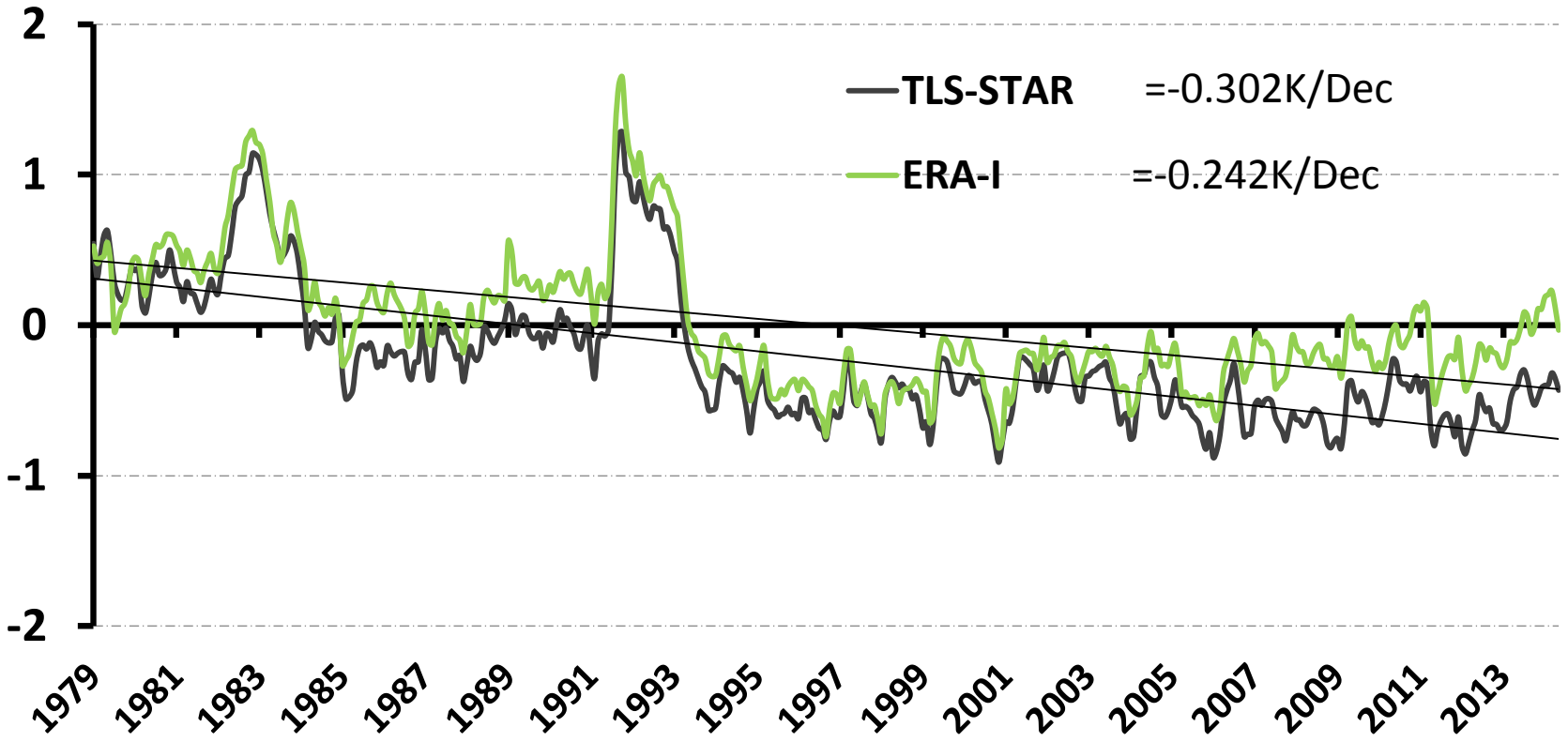
Backup slide: TMT comparisons between NOAA and ERA-I



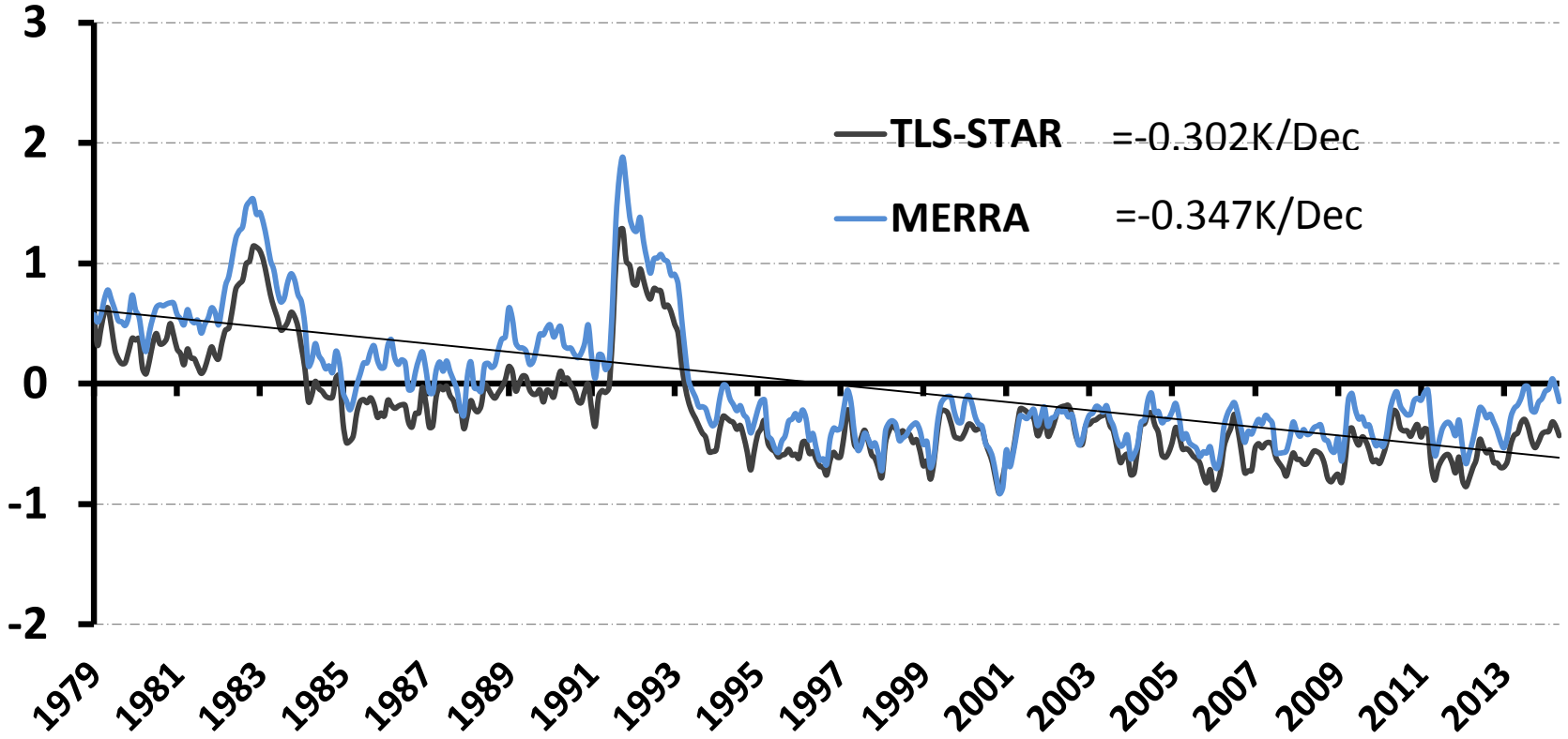
Backup slide: TMT comparisons between NOAA and MERRA



Backup slide: TMT comparisons between NOAA and MERRA



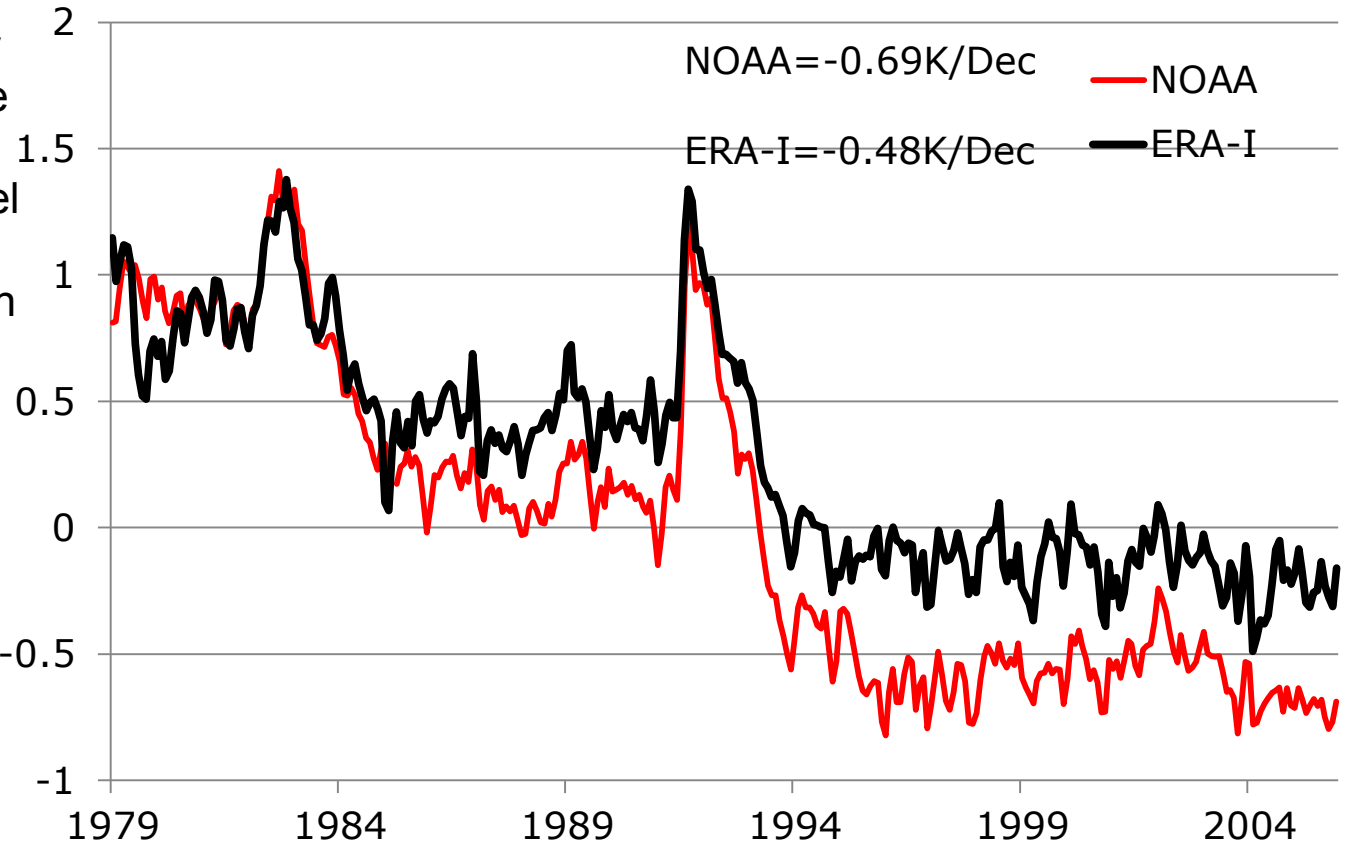
Backup slide: TMT comparisons between NOAA and MERRA



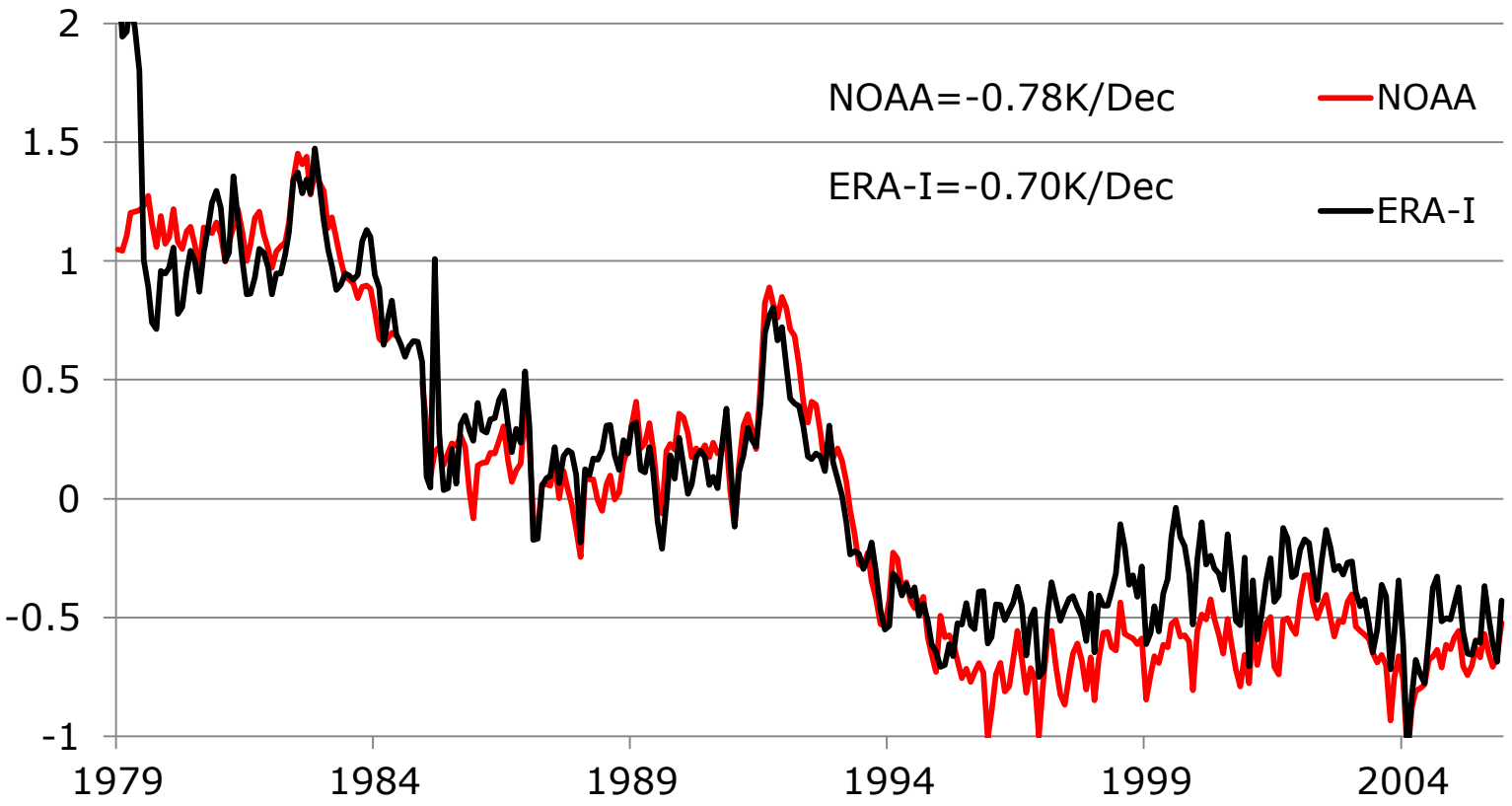
Comparison with ERA-I, Ch1

* Reanalysis layer mean temperature time series were obtained from level data using CRTM forward calculation with SSU model set up exactly the same as in the SSU processing;

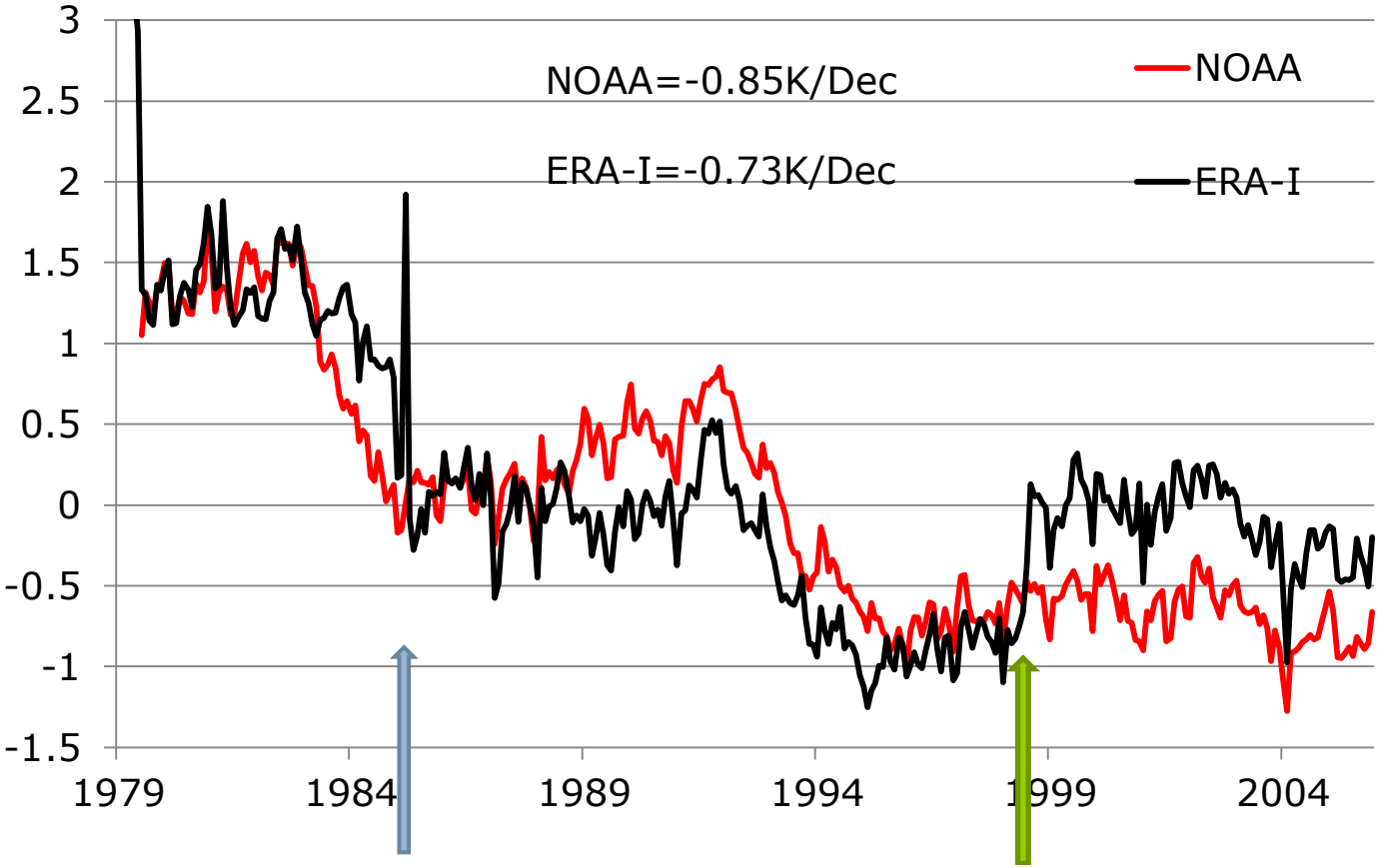
* No weighting function errors involved



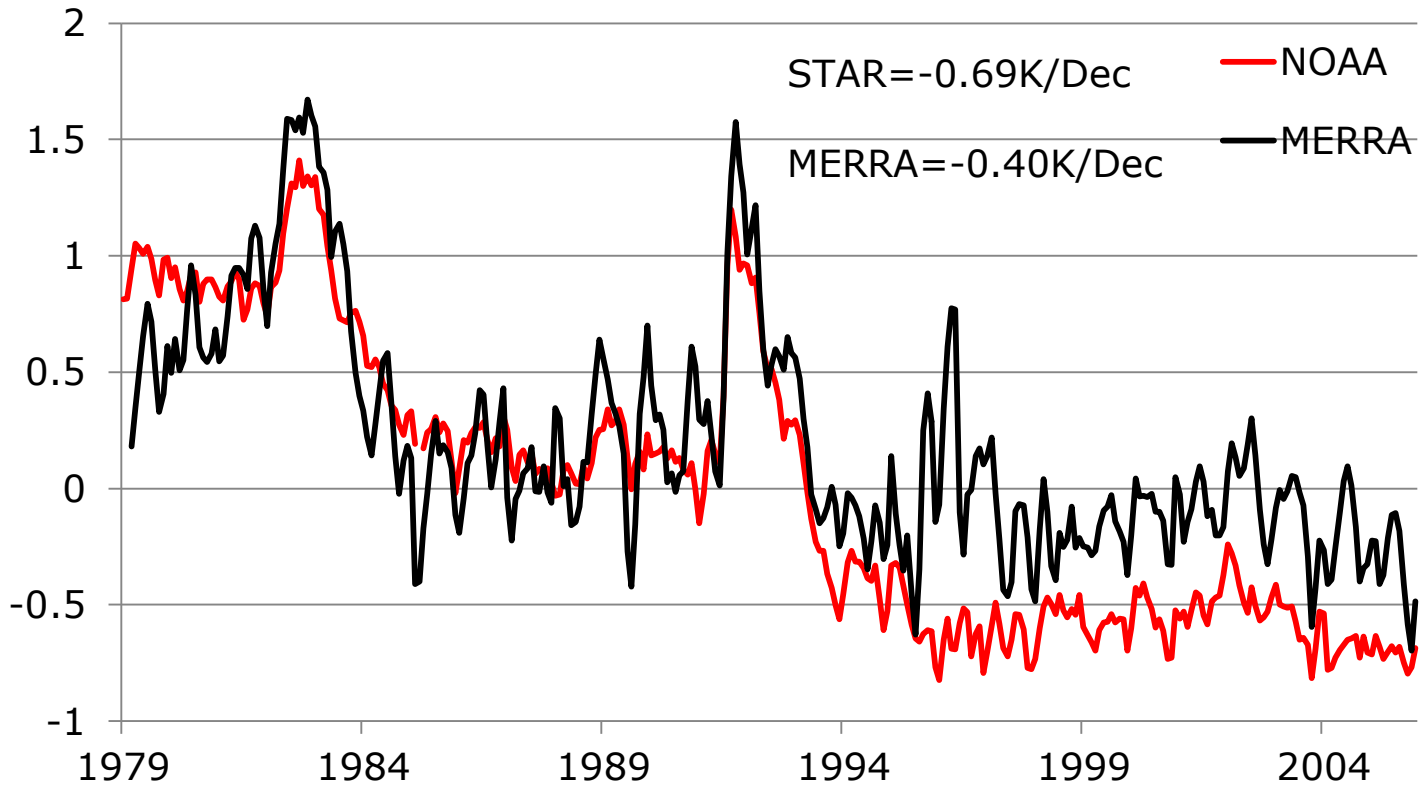
Comparison with ERA-I, Ch2



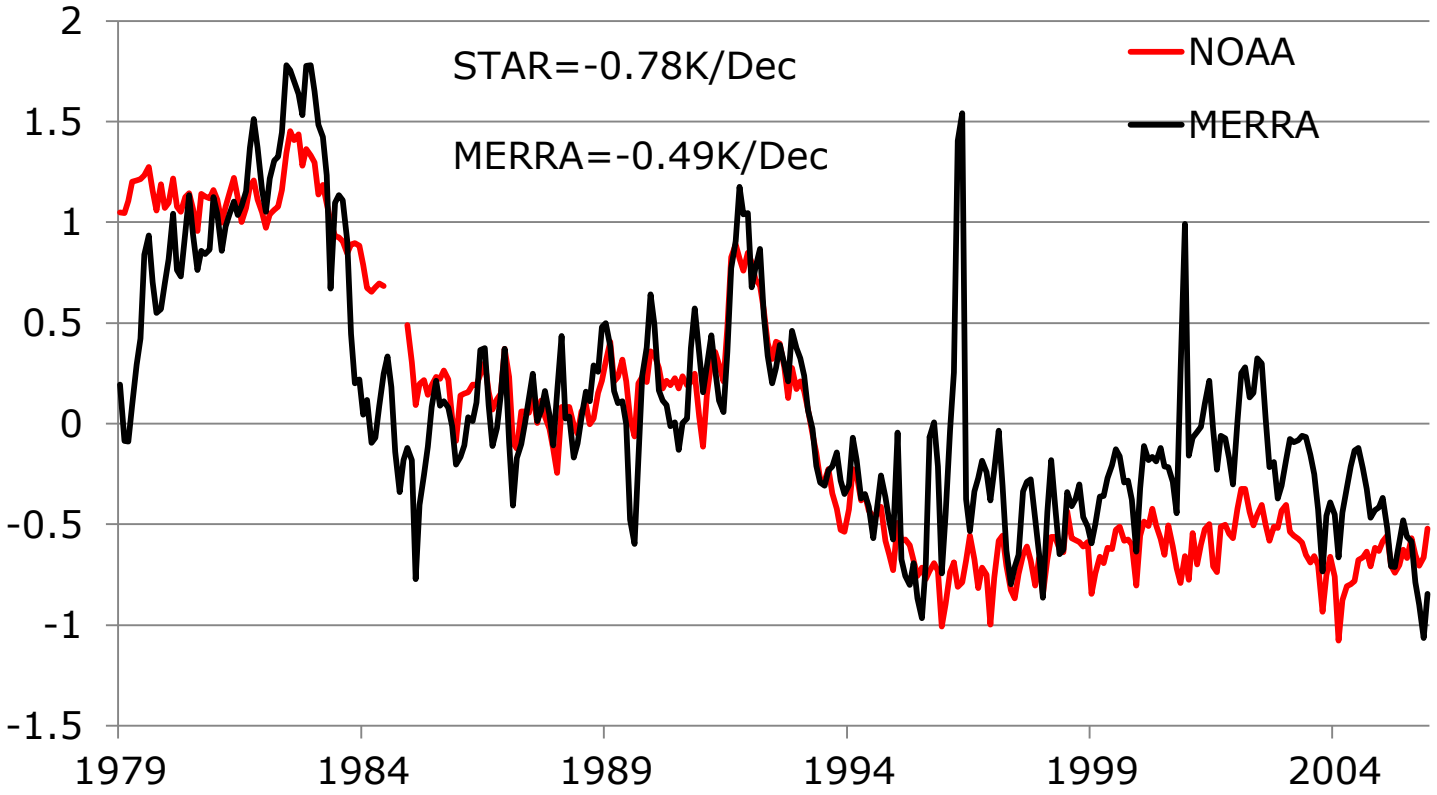
Comparison with ERA-I, Ch3



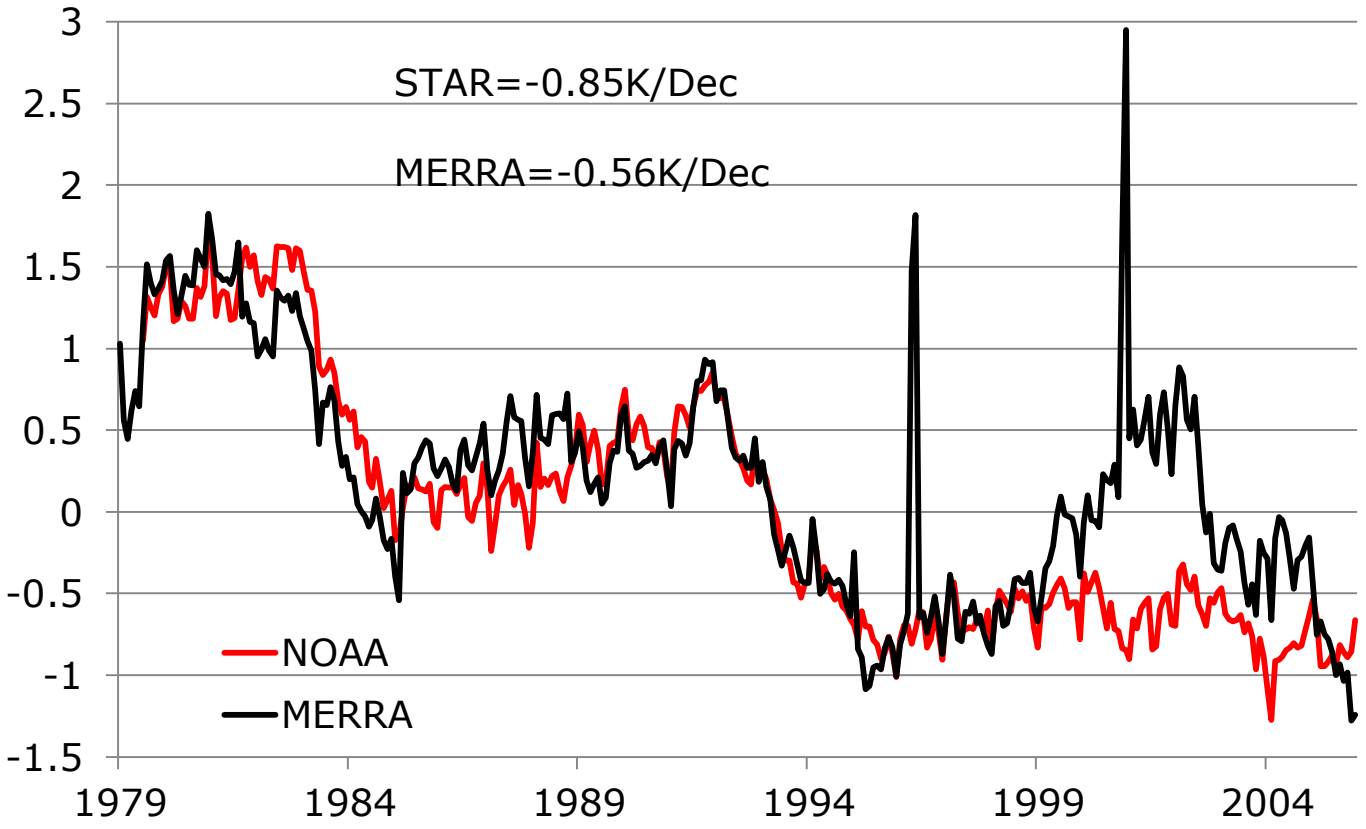
Comparison with MERRA, Ch1



Comparison with MERRA, Ch2



Comparison with MERRA, Ch3



Accessing Recalibrated MSU/AMSU Level-1c Radiance Dataset

- NCDC website:
  http://www.ncdc.noaa.gov/cdr/operationalcdrs.html
- Data name: AMSU Brightness Temperature--NOAA
  - Use Agreement, FTP, Algorithm Description, Data Flow Diagram, Maturity Matrix
- Data name: MSU Brightness Temperature--NOAA
  - Use Agreement, FTP, Algorithm Description, Data Flow Diagram, Maturity Matrix
- AMSU updated every month