Past, Current, and Future NOAA Microwave FCDRs

Cheng-Zhi Zou

Center for Satellite Applications and Research, NOAA/NESDIS, College Park, MD 20740, USA

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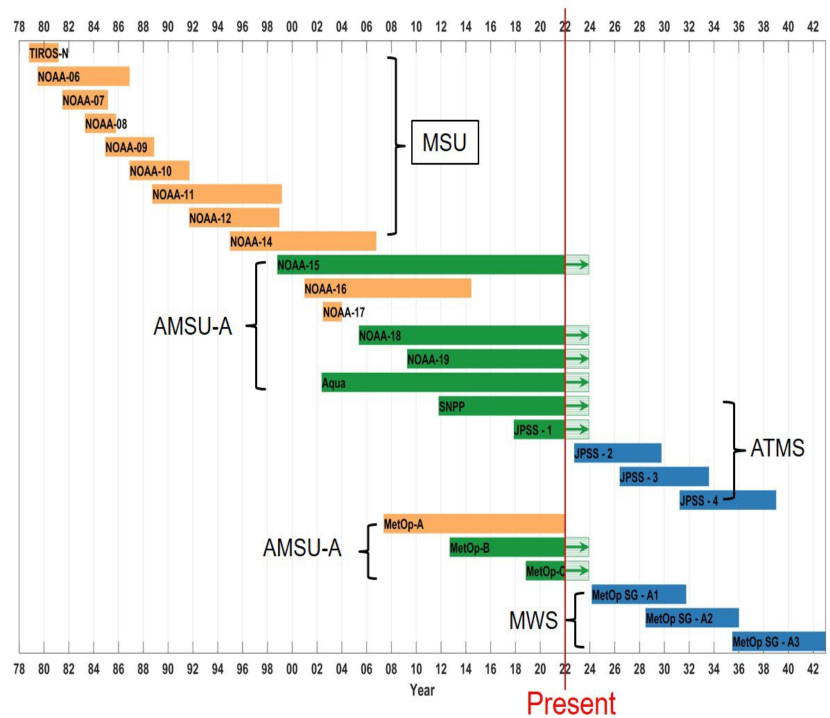
Satellite Microwave Sounder FCDR

- Involves satellite microwave sounder observations onboard NOAA, NASA, and MetOp series from 1978 to present
- MSU: 4 channels, 1978 to 2006
- AMSU-A: 15 channels, 1998-present
- ATMS: 16 channels, 2011-present and onward to the future



Satellites and instruments involved in FCDR development

MSU/AMSU-A/ATMS Channel Frequencies

MSU/AMSU-A/ATMS Channel Frequencies (Unit in GHz)

MSU	AMSU-A	ATMS
	23.8 (V), Ch1	23.8 (V), Ch1
	31.4 (V), Ch2	31.4 (V), Ch2
50.3 (V), Ch1	50.3(V), Ch3	50.3 (H), Ch3
		51.76 (H), Ch4
	52.8(V), Ch4	52.8(H), Ch5
53.74 (H), Ch2	53.595±0.115 (H), Ch5	53.596±0.115 (H), Ch6
	54.4 (H), Ch6	54.4 (H), Ch7
54.96(H), Ch3	54.94 (V), Ch7	54.94 (H), Ch8
	55.5 (H), Ch8	55.5 (H), Ch9
57.95 (H), Ch4	57.290 (H), Ch9	57.290 (H), Ch10
	57.290±0.217 (H), Ch10	57.290±0.217 (H), Ch11
	57.290 ± 0.3222 ± 0.048 (H) ,Ch11	57.290±0.3222±0.048 (H), Ch12
	57.290 ± 0.3222 ± 0.022 (H), Ch12	57.2903±0.322±0.022 (H), Ch13
	57.290 ± 0.3222 ± 0.010 (H), Ch13	57.290±0.322±0.010 (H), Ch14
	57.290 ± 0.3222 ± 0.0045 (H), Ch14	57.290±0.322±0.0045 (H), Ch15
	89.0 (V), Ch15	88.2 (V), Ch16

Inter-calibration/Recalibration Algorithms for FCDR Development
(Zou et al. 2006, 2009; Zou and Wang 2011)

- Use standard nonlinear instrument transfer (calibration) equation to convert counts to radiances

$$R_e = R_c + S(C_e - C_c) + \mu S^2(C_e - C_c)(C_e - C_w)$$

- Use blackbody warm target and space cold target views as end-point references

- Add linear time-varying offsets to allow inter-calibration and remove bias drift over time

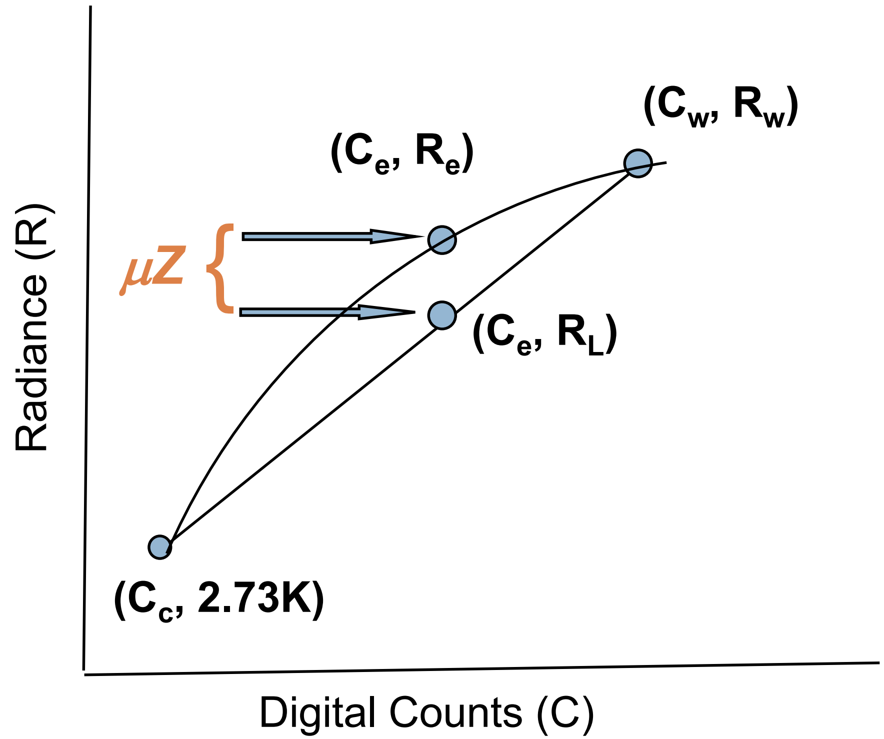
$$\delta R = \alpha + \beta(t - t_0)$$

- Allow nonlinear coefficients to change over time to remove warm target related seasonal variability

$$\mu = \mu_0 + \kappa\,(t - t_1)$$

- Time varying offsets and nonlinear coefficients were obtained using SNOs and global satellite overlap observations

- Calibration offsets and nonlinear coefficients were not allowed to change with time for reference satellites



Schematic view of calibration equation

Purpose of recalibration/Inter-calibration: to make level-1 radiances consistent with each other for different satellites

Hypothesis for Calibration Drift in MSU/AMSU-A Observations

- Possible mechanisms causing the offset changes, $\delta R = \alpha + \beta(t - t_0)$, may include:

➢ Side-lobe efficiency changes due to reflector degradation

➢ Measurement leakage when the instrument antenna switches between the earth view and calibration target views

- Changes in nonlinear coefficients, $\mu = \mu_0 + \kappa\,(t - t_1)$:

➢ Degradation in instrument amplifier's nonlinearity

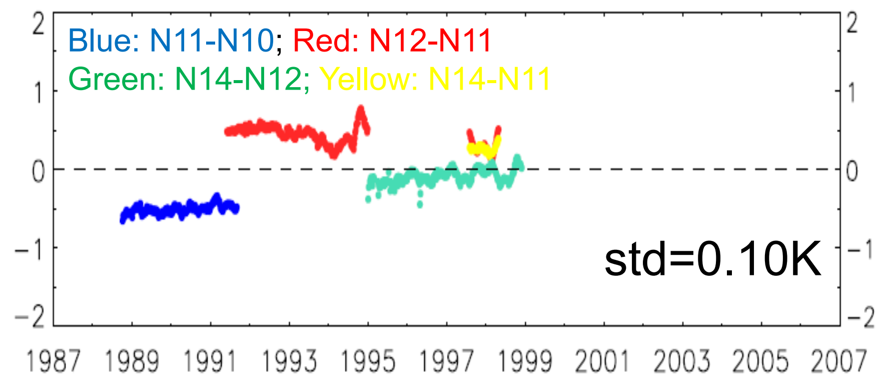
- Pre-launch calibration coefficients were not used. Calibration coefficients obtained from SNOs and global inter-satellite differences are optimal in removing inter-satellite differences

NOAA Microwave Sounder FCDR in the Past

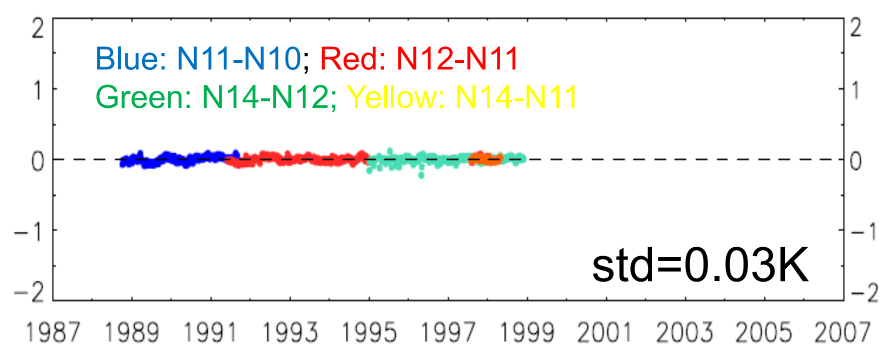
MSU FCDR; Version 1, 1978-2006 (Zou et al. 2006, 2009, 2010)

- Developed during 2003-2010 (Zou et al. 2006, 2009, 2010)
- NOAA-10 was used as a reference in the sense that its offset was assumed zero. Non-linear coefficients were resolved by recalibration algorithms
- Calibration coefficients were assumed constants for all satellites; no time-varying terms were added
- Three atmospheric channels were recalibrated; Inter-satellite differences removed; surface channel not recalibrated
- Archived and distributed by NOAA/NCEI CDR program: https://www.ncei.noaa.gov/products/climate-data-records/msu-brightness-temperature-noaa

Before Recalibration (Operational Calibration)



After recalibration using SNOs

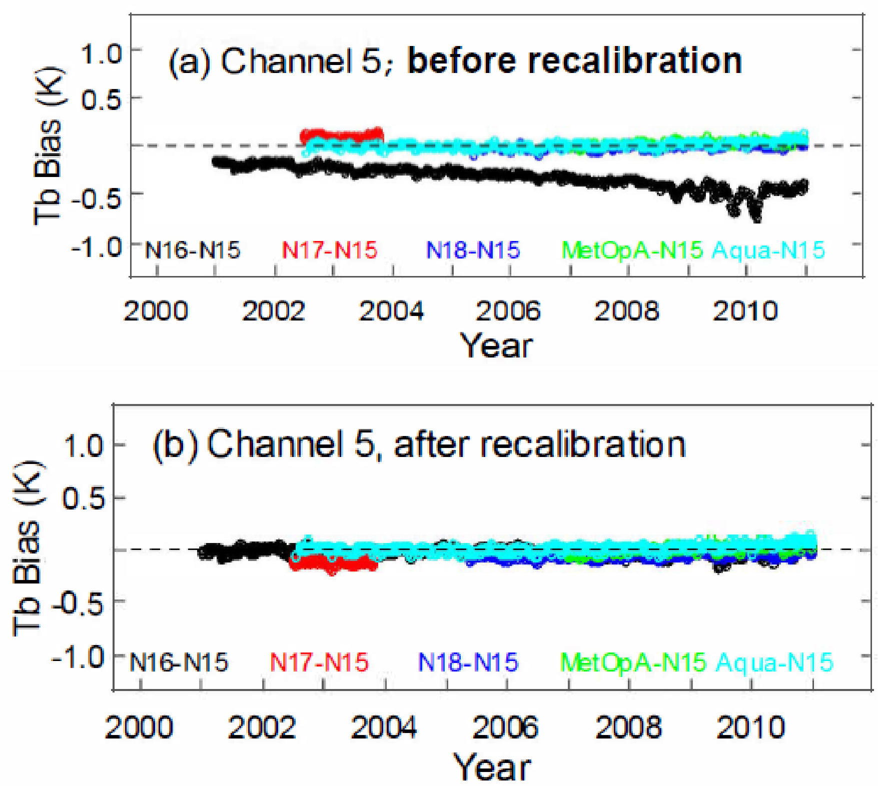


Global ocean mean inter-satellite difference time series (K) for MSU channel 2 onboard NOAA-10 to NOAA-14 (plot from Zou et al. 2009)

NOAA Microwave Sounder FCDR in the Past

AMSU-A FCDR; Version 1, 1998-Present (Zou and Wang 2011)

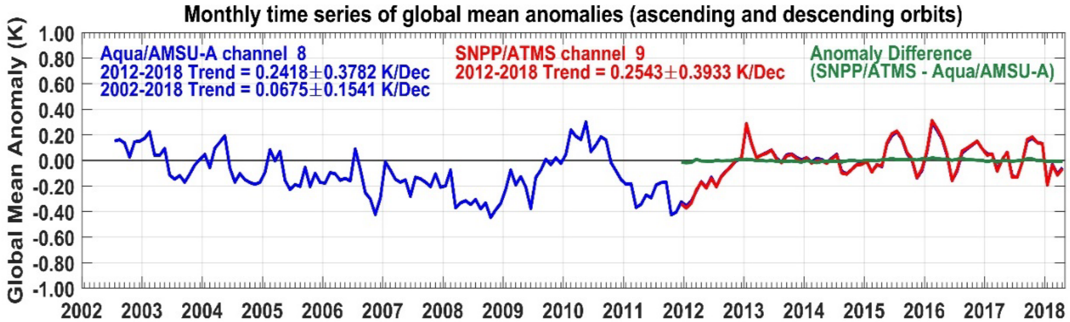
- Developed during 2010-2012 (Zou and Wang 2011)
- NOAA-15 was used as a reference in the sense that its offset was assumed zero.
- Calibration coefficients were assumed time-varying for all satellites except for the reference (NOAA-15)
- Channels 4-14 onboard NOAA-15, -16, -17, -18 were recalibrated
- Channels 1-3 and 15 were recalibrated by NOAA Ralph Ferraro's group using the same approach (Yang et al. 2020)
- Archived and distributed by NOAA/NCEI CDR program

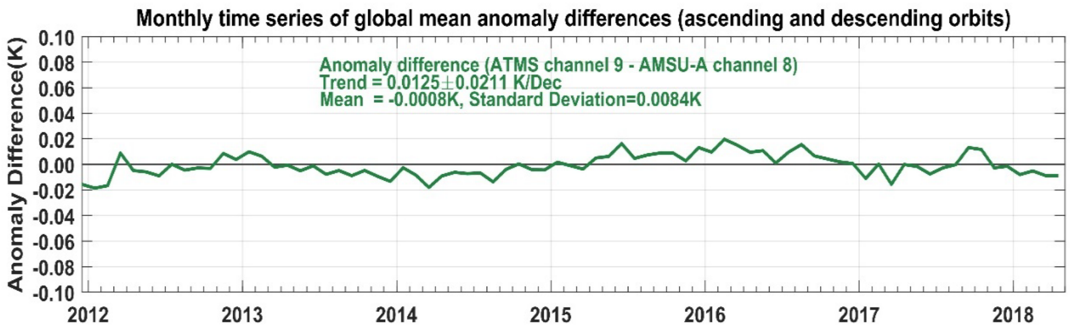


Inter-satellite differences of global ocean means for AMSU-A channel 5. NOAA-16 calibration drift and nonlinearity were removed by recalibration (Plot from Zou and Wang 2011)

Recent Understanding on Radiometric Stability In Satellite Microwave Sounder Observations in Stable Orbits (Zou et al. 2018)

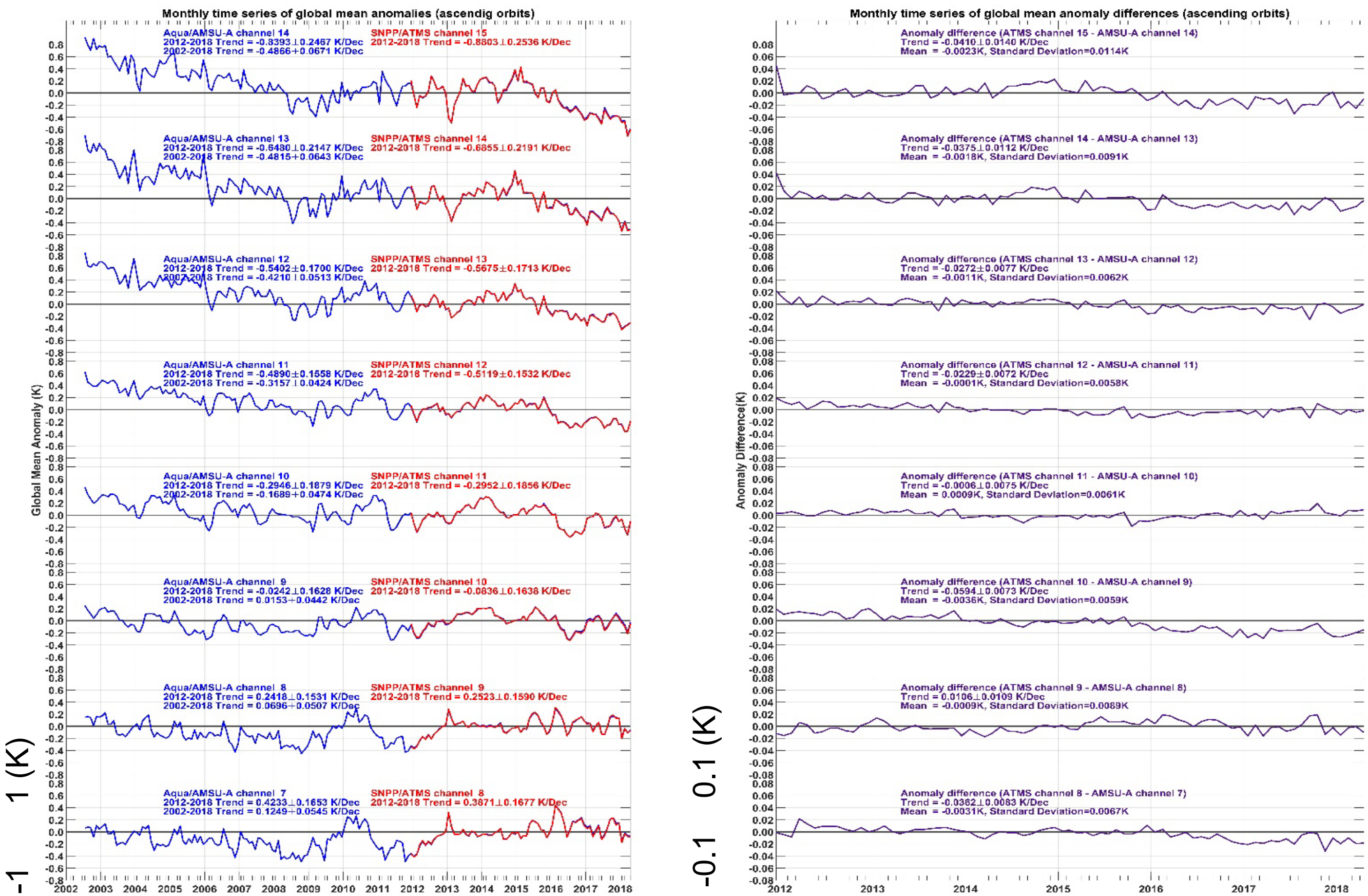
- Diurnal sampling difference is absent – diurnal sampling biases are naturally removed by satellites with stable orbits of the same overpass time
- Time series from different satellites match with each other nearly perfectly without applying any diurnal drift corrections or time-dependent inter-calibration
- Calibration drifts can be estimated quite accurately
- Small trend differences suggest near absolute stability with either instruments
- Radiometric stability within 0.004K/Year for SNPP/ATMS and Aqua/AMSU-A for all analyzed channels





Monthly global mean anomaly time series of brightness temperatures for AMSU-A channel 8 onboard Aqua (blue, top panel) versus ATMS channel 9 onboard SNPP (red, top panel) and their difference time series (green, top and lower panels). The AMSU-A and ATMS data are respectively from June 2002 and December 2011 to April 2018. The AMSU-A anomaly time series are overlaid by ATMS during their overlapping period with their differences shown as nearly a constant zero line in the same temperature scale. Amplified scale of temperature is used in the bottom panel to show detailed features in the anomaly difference time series. Both ATMS and AMSU-A data are from limb-adjusted views and averaged over ascending and descending orbits (plot from Zou et al. 2018).

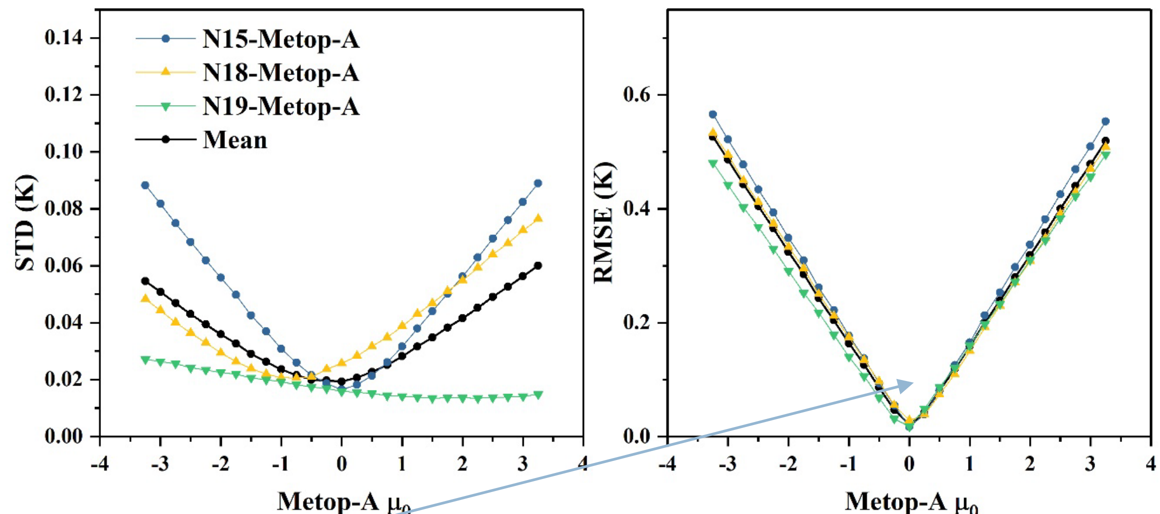
All analyzed channels



Left: Anomaly time series of Aqua/AMSU-A (blue) and S-NPP/ATMS (red) Observation
Right: Their difference time series. Radiometric stability achieves 0.004K/Year for most (plot from Zou et al. 2018).

Recalibration of AMSU-A Observations Using New Reference

- Using Integrated Microwave Inter-calibration Approach (IMICA) to recalibrate NOAA-15, NOAA-18, and NOAA-19
- Use MetOp-A as a new reference
- Optimal calibration nonlinearity and offsets were obtained that minimized inter-satellite differences



Recalibration steps (Zou et al. 2006; Zou and Wang 2011)

1) For each of the satellites, NOAA-15, NOAA-18, and NOAA-19, first choose a value for $\mu_{0,MetOpA}$ within (-3, 3) in unit of 10^{-5} (mW) $(\mathrm{sr} \cdot \mathrm{m}^2 \cdot \mathrm{cm}^{-1})^{-1}$;
2) Use SNO regressions to obtain $\delta R_{0,sat}$, k_{sat}, $\mu_{0,sat}$, *and* λ_{sat}, for the satellite;
3) Generate level-1c radiances for MetOp-A and the recalibrated satellite using the obtained calibration coefficients;
4) Compute global ocean mean time series of $T_{b,sat}$ - $T_{b,MetOpA}$ for available overlaps between the satellite pairs;
5) Change the value of $\mu_{0,MetOpA}$ and repeat steps 2, 3 and 4;
6) STOP when a minimal of the standard deviation of ($T_{b,sat}$ - $T_{b,ref}$) is found;
7) STOP when all satellites are completed.

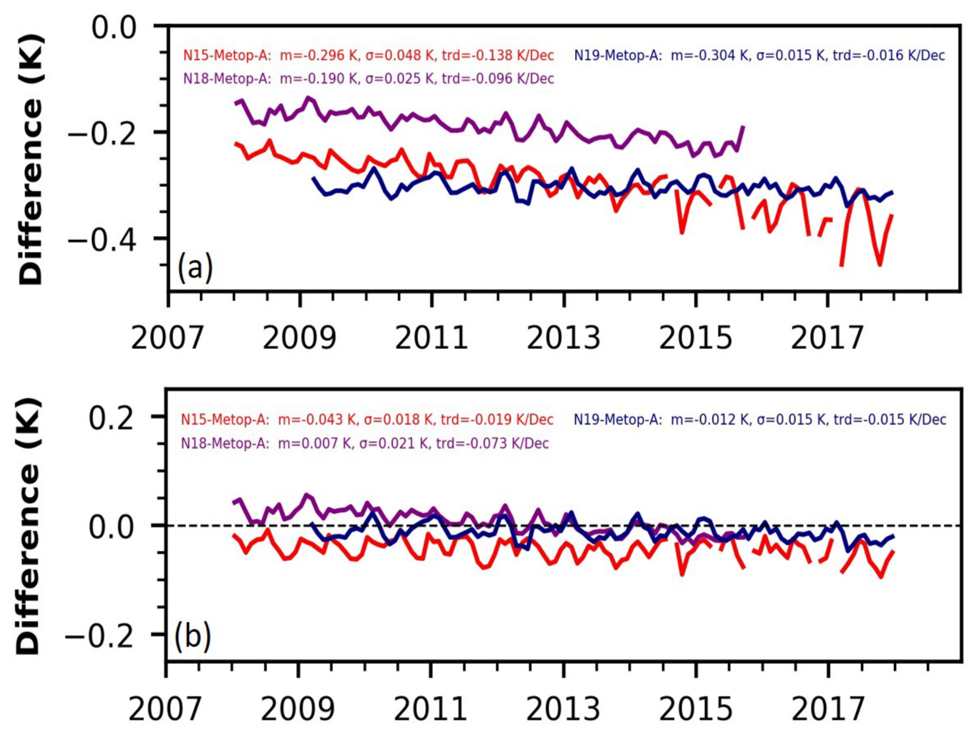
Current Status of NOAA Microwave Sounder FCDR

AMSU-A FCDR; Version 2

- NOAA-15, NOAA-19, NOAA-18 were recalibrated for channels 4, 5, 6, 9, and 10 using MetOp-A as a reference

- Calibration drifts were removed relative to MetOp-A

- Since MetOp-A is consistent with ATMS onboard S-NPP and NOAA-20 within 0.004K/Year, recalibrated NOAA-15, NOAA-18, NOAA-19 are also consistent with ATMS



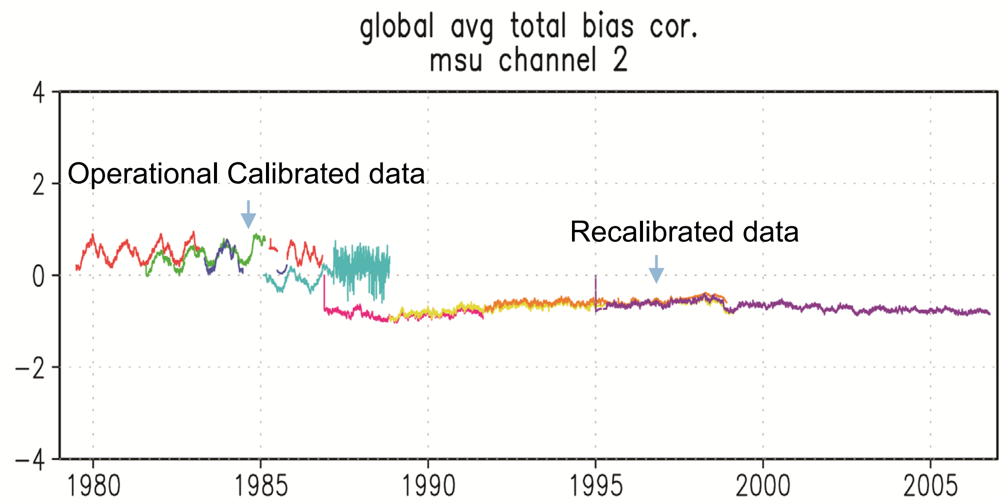
Inter-satellite differences of brightness temperatures between MetOp-A and NOAA-15, NOAA-18, and NOAA-19 for before and after recalibration

Applications of NOAA FCDRs – Input to Climate Reanalyses

- As the first case of FCDR applications in climate reanalyses, the recalibrated/intercalibrated MSU data for NOAA-10 to NOAA-14 were assimilated into the CFSR (Saha et al. 2010) and MERRA (Rienecker et al. 2011) climate reanalysis systems

- Improved temporal bias correction patterns were observed

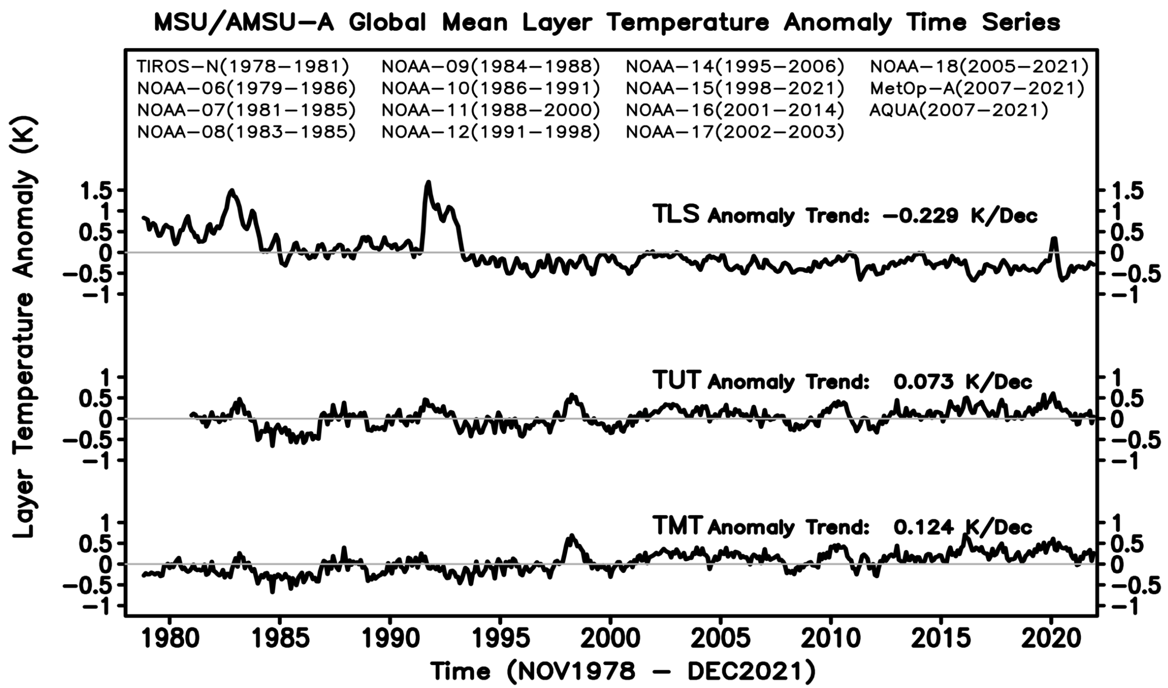
- It was speculated that this assimilation may have helped MERRA to produce a more realistic stratospheric temperature response following the eruption of Mount Pinatubo (Simmons et al. 2014)



Temporal pattern of bias corrections in CFSR climate reanalysis systems for MSU channel 2. NOAA-10 to NOAA-14 were recalibrated data by Zou et al. (2006) and TIROS-N to NOAA-9 were from NOAA operational calibration

Applications of NOAA FCDRs – Development of Mean Layer Atmospheric Temperature CDRs for Climate Change Monitoring

- MSU, AMSU-A, ATMS FCDRs were used as inputs to generate STAR version of the mean layer atmospheric temperature CDRs for climate change monitoring



Mean Layer Temperatures Time Series for Mid-troposphere (TMT), Upper-Troposphere (TUT), and Lower-Stratosphere

Future of NOAA Microwave FCDRs

- Complete AMSU-A Version 2 FCDR, including recalibrating all channels from 4 to 14 onboard NOAA-15 to NOAA-19 using MetOp-A as a reference
- Recalibrate MSU and generate its Version 2 FCDR using recalibrated NOAA-15 as a reference. Initial results suggest MSU Version 1 had calibration drifts
- Deliver the Version 2 MSU/AMSU-A FCDR to NCEI for operational archiving and distribution
- Use Version 2 MSU/AMSU-A FCDR in development of atmospheric temperature CDRs
- Recommend Version 2 MSU/AMSU-A FCDR to be used in development of future climate reanalysis systems

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URL address for data products: https://www.star.nesdis.noaa.gov/smcd/emb/mscat/products.php