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Reference atmospheric temperature trends observed from satellites in stable sun-synchronous orbits

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I. Abstract

Atmospheric temperature time series developed from satellite microwave sounder observations has been extensively used in climate change monitoring and verifying climate model simulations of climate change. However, uncertainties exist in the satellite merged products and their resulting atmospheric temperature trends, mainly caused by diurnal sampling changes over time and instrument calibration errors. Satellite products developed by different research groups produced different atmospheric temperature trends, undermining the capability of using satellite observations in global change monitoring. Here we develop a post-millennium mid-tropospheric temperature time series from continuous observations by advanced microwave sounders onboard satellites only in stable sun-synchronous orbits, including Aqua, MetOp-A, S-NPP, and NOAA-20. Such observations have high radiometric stability and do not experience diurnal sampling changes over time, allowing us to develop merged time series from multiple satellites with an accuracy better than 0.01 Kelvin per decade in trend detection. This accuracy in trend detection exceeds the measurement stability requirement of 0.02 Kelvin per decade given in GCOS (2016) for deep layer atmospheric temperature time series. With such high accuracy, the resulting time series can be used as a reference measurement of climate variability and trends in atmospheric temperatures. The warming rate from this time series for the atmospheric layer between surface and 10 km is 0.23±0.13 Kelvin per decade during the period from 2002 to 2020. This reference measurement is expected to help reconcile differences in climate trend comparisons among different satellite products and between climate model simulations and satellite observations during the post-millennium periods. It may also be helpful in the development of atmospheric temperature time series with a better accuracy for satellites before the millennium when used as a reference.

II. Characteristics of Satellite Microwave Sounder Instruments in Stable Sun-synchronous Orbits

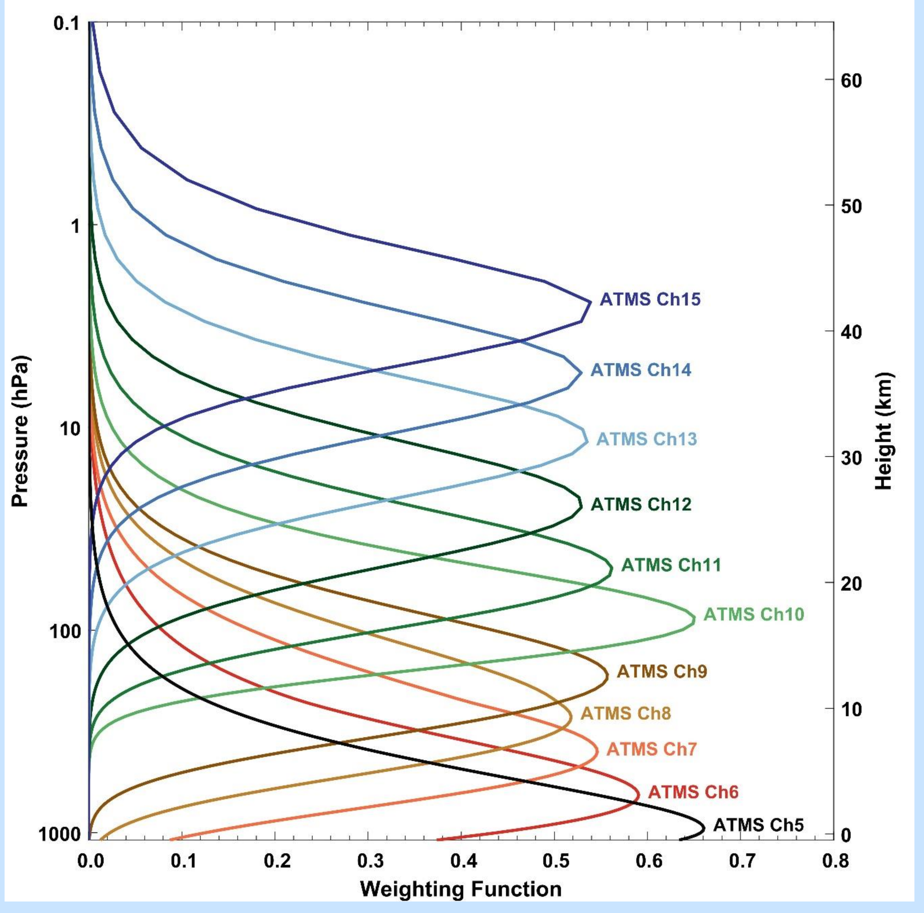


Figure 1 Weighting functions of ATMS. The AMSU-A weighting functions are the same as those of the ATMS counterpart channels.

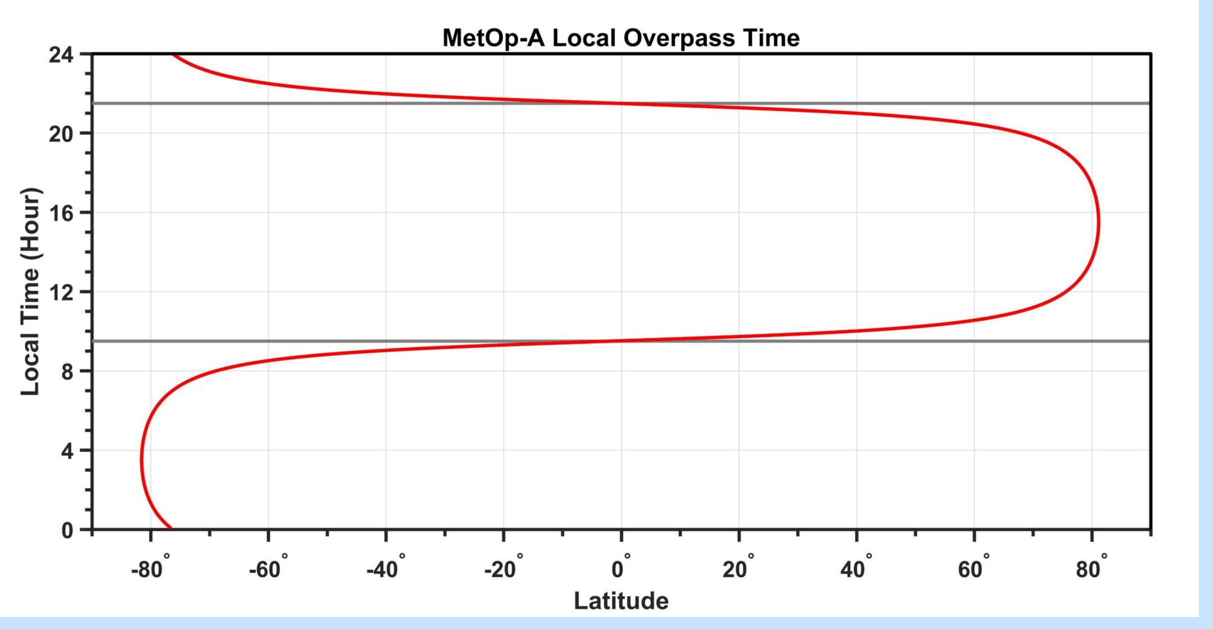


Figure 2 Local overpass time at different latitude for MetOp-A. The local overpass time is the same in a latitudinal belt.

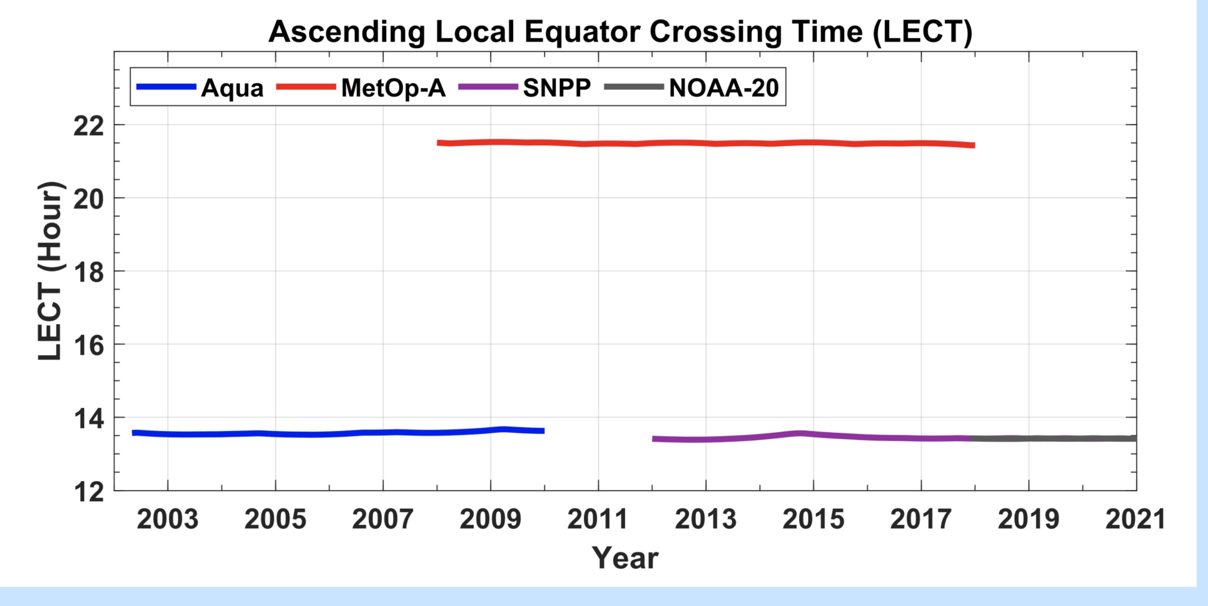


Figure 3 Ascending Local Equator Crossing Time (LECT) for MetOp-A (red), Aqua (blue), Suomi National Polar-orbiting Partnership (S-NPP [purple]), and NOAA Joint Polar Satellite System-1 (NOAA-20 [gray]) polar-orbiting satellites. The descending LECT is 12 h apart from the ascending LECT. The data periods used in this study are 08/2002–12/2009 for Aqua, 01/2008–12/2017 for MetOp-A, 01/2012–12/2020 for S-NPP, and 01/2018–12/2020 for NOAA-20. The S-NPP time series is overlaid by NOAA-20 during their overlapping period.

- ➢ **For Aqua, MetOp-A, S-NPP, and NOAA-20, diurnal drifting errors do not exist because they are in stable sun-synchronous orbits**
- ➢ **Calibration drifting errors can be determined by comparing two instrument observations in stable sun-synchronous orbits**

III. Assessment of Radiometric Stability for Aqua/AMSU-A, MetOp-A/AMSU-A, and S-NPP/ATMS

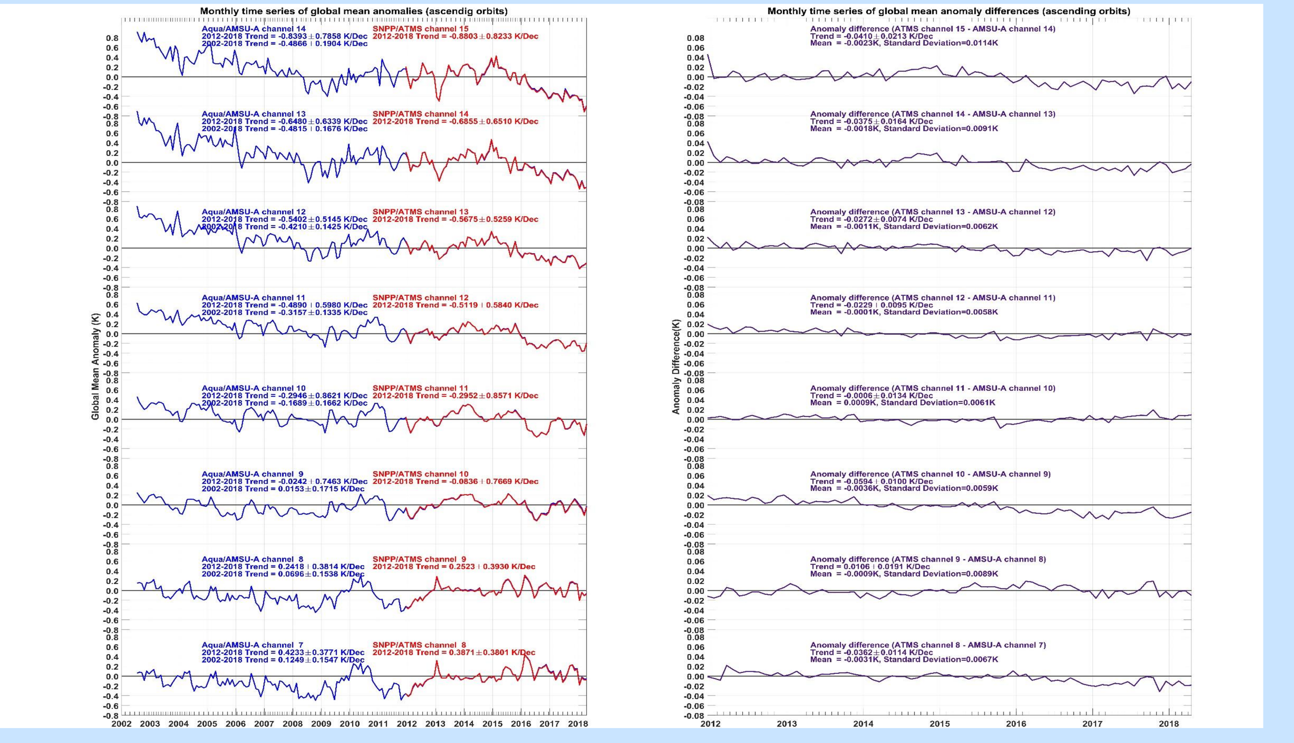


Figure 4 Anomaly time series for assessment of radiometric stability for all analyzed SNPP/ATMS and Aqua/AMSU-A channels. Monthly global mean anomaly time series of brightness temperatures for AMSU-A channels 7 through 14 onboard Aqua (blue, left panel) versus ATMS channels 8 through 15 onboard SNPP (red, left panel) and their differences (right panel) for ascending orbits. The AMSU-A and ATMS data are respectively from June 2002 and December 2011 to April 2018. The AMSU-A time series are overlaid by ATMS during their overlapping period from 2012 to 2018. Both ATMS and AMSU-A data are from limb-adjusted views. Uncertainties in trends represent 95% confidence intervals with autocorrelation adjustment.

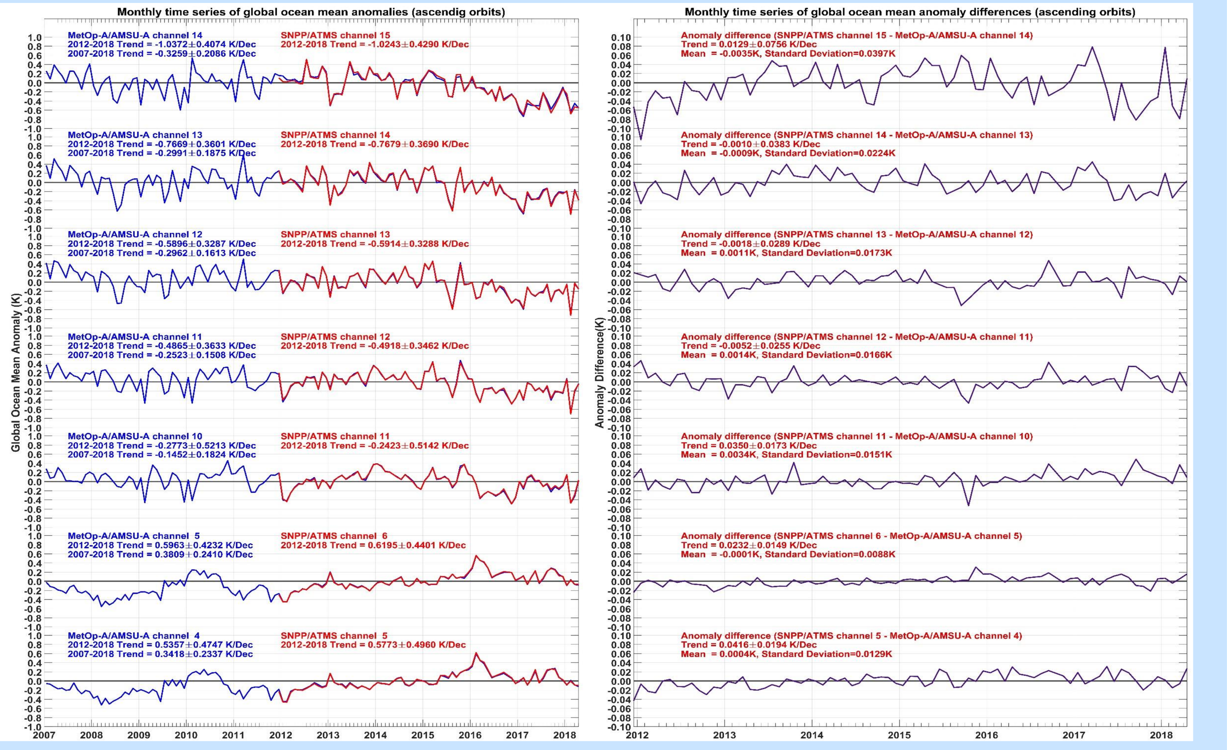


Figure 5 Anomaly time series for assessment of radiometric stability for all analyzed SNPP/ATMS and MetOp-A/AMSU-A channels. Left Panels: Monthly anomaly time series of ascending global ocean mean brightness temperatures for AMSU-A channels 4, 5, and 10 through 14 onboard MetOp-A (blue) versus ATMS channels 5, 6, and 11 through 15 onboard SNPP (red). Right Panels: Their differences. The AMSUA and ATMS data are respectively from January 2007 and December 2011 to April 2018. The AMSU-A time series are overlaid by ATMS during their overlapping period from 2012 to 2018. Both ATMS and AMSU-A data are from limb-adjusted views. Uncertainties in trends represent 95% confidence intervals with autocorrelation adjustments.

- ➢ **Aqua, MetOp-A, and S-NPP observations achieved absolute radiometric stability within 0.04 K/Decade**

IV. Development of the Reference Temperature Time Series of the Bulk Tropospheric Layer (TMT)

- **Development of Reference TMT (RFTMT) and uncertainty estimates in trend detection:**

1) **Calculate the deseasonalized anomaly time series, ascending and descending orbits separately, for each grid points; trends for the ascending and descending time series are about the same (Figure 6)**
2) **Average the ascending and descending anomaly time series to obtain the daily mean anomalies**
3) **Take MetOp-A monthly climatology as a reference and adjust the Aqua and S-NPP anomalies by subtracting a "monthly climatology" of the anomaly differences relative to MetOp-A during their overlapping periods. Adjust NOAA-20 to the adjusted S-NPP afterwards using their overlaps.**
4) **Merge together (average) the adjusted anomaly time series of the four satellites to generate a TMT time series for the entire 2002–2020 period for trend investigation (Figure 7a, RFTMT).**
5) **Uncertainty in trend detection in the merged time series is: $\delta = \frac{\Delta}{2\sqrt{N}}$ =0.012 K/Dec, where Δ (=0.033 K/Decade, Figure 7b) denotes the maximum relative drifting error, or spread of trends, and N (=2) the number of overlapping satellites.**

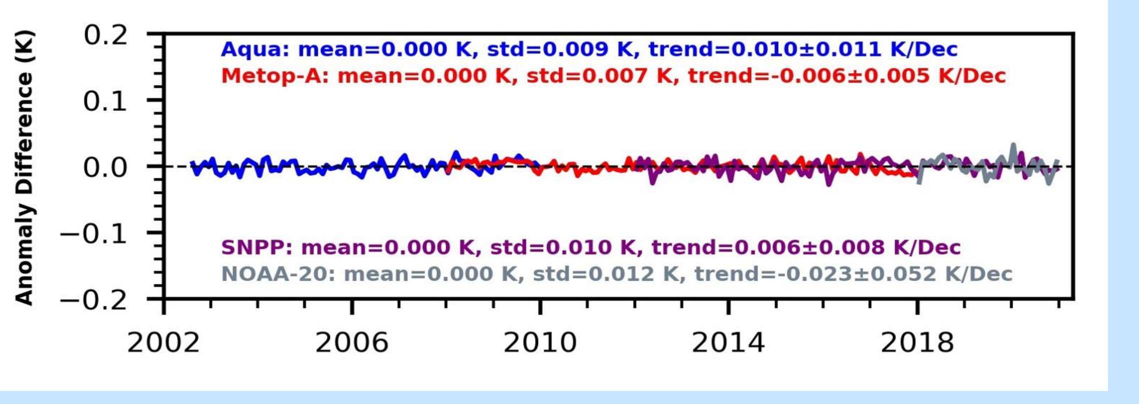
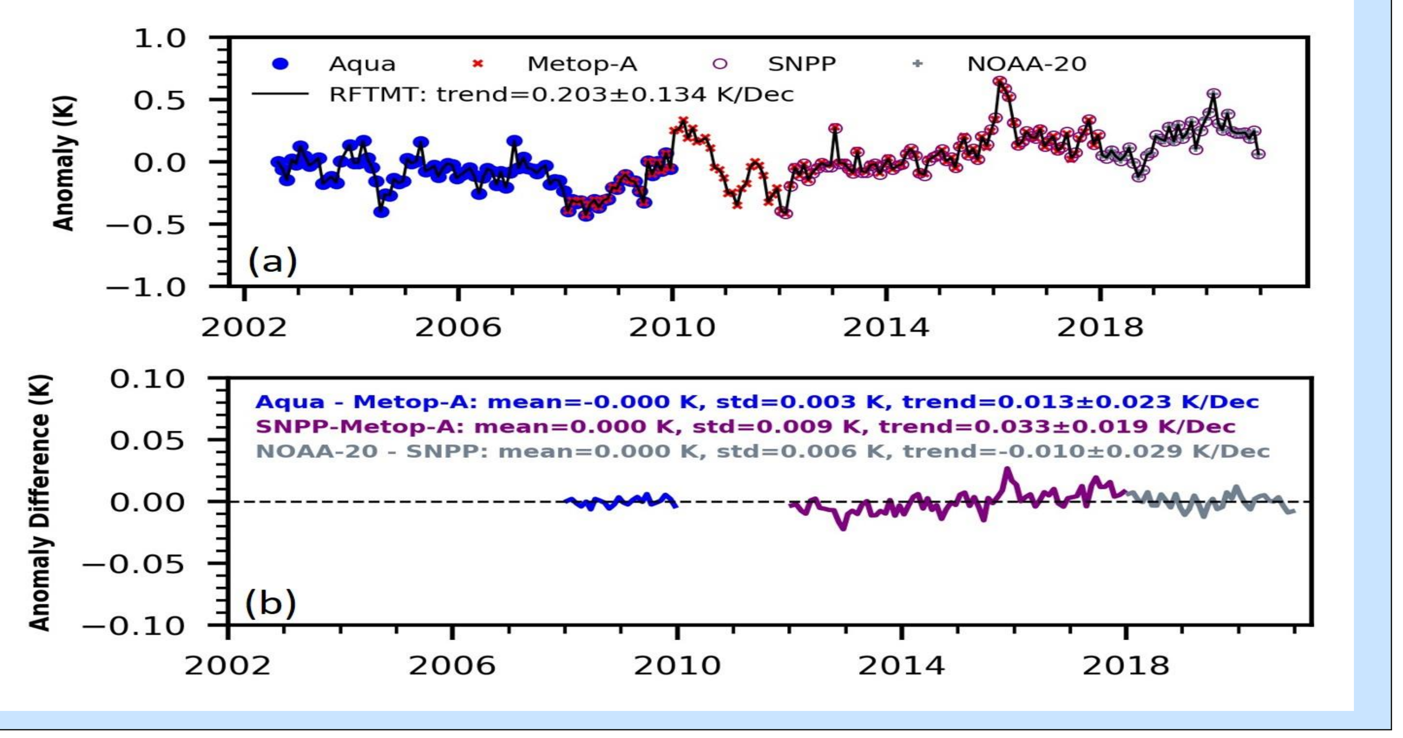


Figure 6 Global mean brightness temperature anomaly differences between ascending and descending orbits. The differences are for ascending minus descending for Aqua (blue), Suomi National Polar-orbiting Partnership (S-NPP, purple) and NOAA Joint Polar Satellite System-1 (NOAA-20, gray) and descending minus ascending for MetOp-A (red). The anomalies are relative to the monthly climatology calculated for the entire observation periods for each satellite.

Figure 7 (a) Monthly global mean temperatures in the mid-troposphere (TMT) anomaly time series from Aqua, MetOp-A, S-NPP, and NOAA-20 and the reference TMT (RFTMT) time series merged from these satellites; (b) inter-satellite difference time series before the merging. Anomalies are relative to a monthly climatology of RFTMT for the MetOp-A period from January 2008 to December 2017. Uncertainties in trend calculations represent 95% confidence intervals with autocorrelation adjustments.



The RFTMT dataset is freely available at the NOAA/NESDIS/STAR Microwave Sounding Calibration and Trend Website:
https://www.star.nesdis.noaa.gov/smcd/emb/mscat/products.php

References

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