Applications of the STAR Integrated Calibration & Validation System (ICVS) Monitoring System:

Long-Term Inter-Sensor Radiometric Bias Stability Assessments across SNPP, NOAA-20, NOAA-21, and Legacy NOAA/Metop AMSU-A Instruments

NOAA
Center for Satellite Applications and Research (STAR)

105th AMS Annual Meeting

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STAR/SMCD/Sensor and Calibration Branch

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ERT INC.

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2. Acknowledge very valuable ideas and support from JPSS and STAR SDR teams

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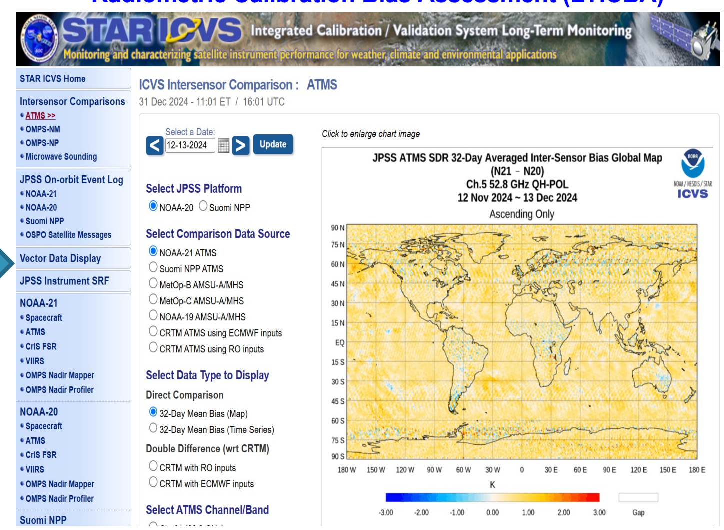
Outline

- Overview of the STAR Integrated Calibration & Validation System (ICVS) for Long-Term Monitoring (LTM), commonly referred to as ICVS
  - A portal for Long-Term Inter-sensor Radiometric Calibration Bias Assessment (LTICBA) in ICVS
- Applications of ICVS-LTICBA Products
  - Long-term inter-sensor radiometric calibration bias assessment across SNPP/NOAA-20/NOAA-21 ATMS, and SNPP ATMS vs. NOAA-19 AMSU-A
  - Long-term inter-sensor radiometric calibration bias assessments across SNPP/NOAA-20/NOAA-21 OMPS, and SNPP OMPS-NM vs. Metop-B GOME-2
  - Long-term inter-sensor radiometric calibration bias assessments across SNPP/NOAA-20/NOAA-21 CrIS, and SNPP CrIS vs. GOES-16 ABI
- Summary and Conclusions
- Acknowledgements, References and Disclaimer

Integrated Calibration & Validation System (ICVS) for Long-Term Monitoring (LTM)

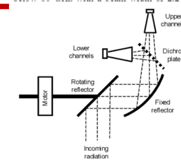
- **What does ICVS-LTM do?**
  - A web-based **ICVS Monitoring System** (named as ICVS for simplification) for Near-Real Time (NRT) and Long-Term (LT) performance of satellite instrument and data monitoring to support JPSS and legacy NOAA satellite missions
  - ICVS is an important tool to provide supplemental information about the healthy status of satellite spacecraft and instrument, the quality of instrument level 1b or Sensor Data Records (SDR) data
    - The ICVS products are used by STAR (SDR/EDR teams), OSPO, NWS, ECMWF, EUMETSAT, NASA, Air Force, NAVO, etc.
- **Key Features**
  - Currently monitoring 30+ POES satellite instruments with more than 7000 products online (https://www.star.nesdis.noaa.gov/icvs/index.php)
  - Used to evaluate ***instrument performance and Level 1b radiance/SDR*** product quality for SNPP and NOAA-20 ATMS, VIIRS, OMPS and CrIS, AMSU, AVHRR and other satellite instruments
  - **Inter-satellite radiometric bias monitoring** (https://www.star.nesdis.noaa.gov/icvs/comparison_ATMS.php, and https://www.star.nesdis.noaa.gov/icvs-beta/ (NOAA user internal access)
    - The uncertainty of SDR (TDR) data records depends not only on the calibration accuracy and LT stability of individual sensors, but also on their calibration consistency across instruments and platforms.

A Web-based Portal for Long-Term Inter-sensor Radiometric Calibration Bias Assessment (LTICBA)



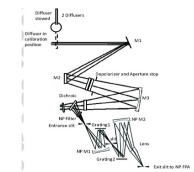
JPSS ATMS, CrIS, VIIRS, OMPS-NM, OMPS-NP, and Legacy POES AMSU-A Instruments

Advanced Technology Microwave Sounder (ATMS) is a 22-channel scanning microwave radiometer from 23.8 GHz to 183.3 GHz for observation of the Earth's atmosphere and surface.



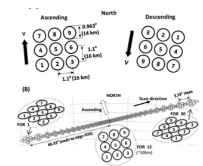
https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/D0001-M01-S01-001_JPSS_ATBD_ATMS-SDR_B.pdf

Ozone Mapping and Profiler Suite (OMPS) nadir instrument consists of two grating spectrometers (NM, NP) that measure atmospheric ozone reflected radiances in the 0.28 to 0.4 um spectral range with a spatial resolution of ~10/50/250 km for ozone concentration measurements for modeling and climate applications



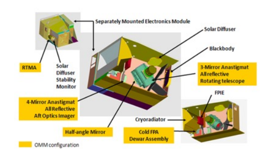
Pan. et al., 2017

Cross-track Infrared Sounder (CrIS) is a hyperspectral infrared Fourier transform interferometer with 2211 spectral channels covering the spectrum from 3.9 to 15.4um for atmospheric temperature and moisture observations for direct radiance assimilation in numerical weather prediction, temperature, moisture and trace gas retrievals.



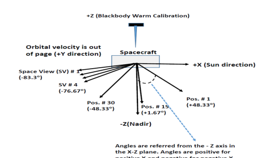
https://www.star.nesdis.noaa.gov/jpss/documents/UserGuides/CrIS_SDR_Users_Guide1p1_20180405.pdf

Visible Infrared Imaging Radiometer Suite (VIIRS) is a filter based scanning radiometer that covers 0.4 to 12um spectrum to acquire high spatial resolution (375m/750m) imagery and supporting > 26 products including visible and infrared imaging of hurricanes, detection of fires, smoke, and atmospheric aerosols. VIIRS geolocation also serve as truth for the other instruments



https://www.star.nesdis.noaa.gov/jpss/documents/AMM_All/VIIRS_SDR/Provisional/VIIRS_USERS_GUIDE_TechReport142FINAL_cc_rdlnCmts_cc_020192013.pdf

Advanced microwave sounding unit (AMSU) is a 15-channel microwave radiometer to measure microwave radiation from the atmosphere in the range from 23.8 GHz to 89 GHz to perform atmospheric sounding of temperature and moisture levels.

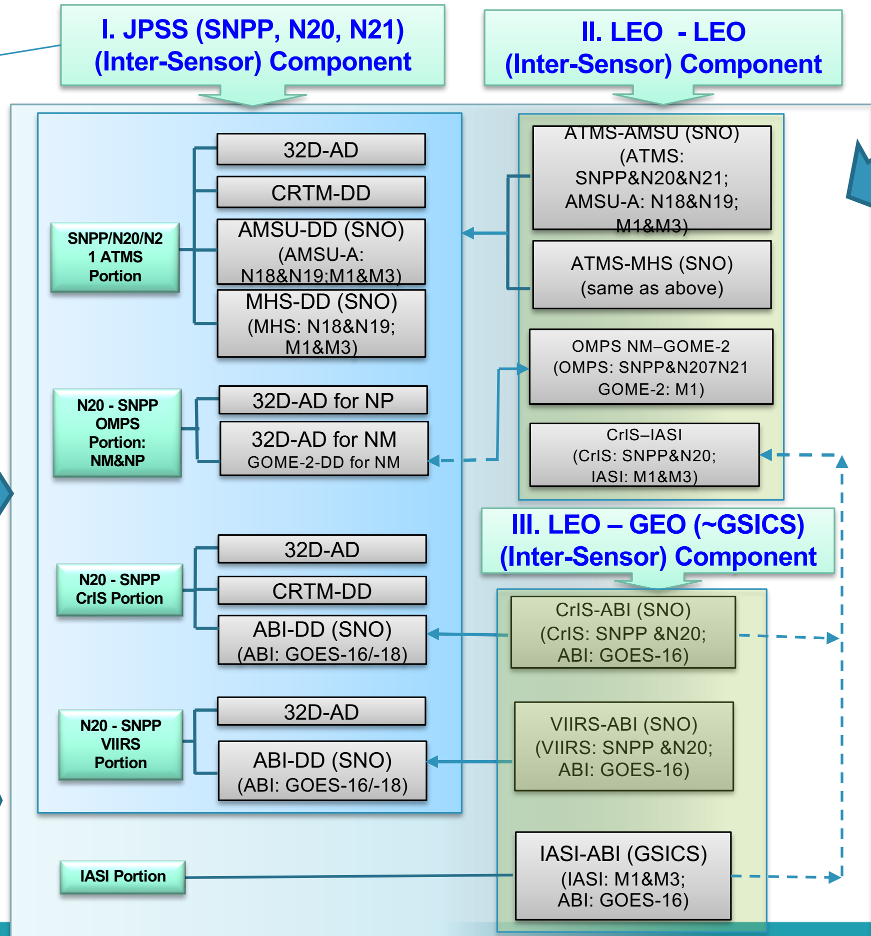


(T. Mo., 1999)

(Part of the contents here are revised from Cao et al., 2022 AMS presentation)

A Portal for Long-Term Inter-sensor Radiometric Calibration Bias Assessment (LTICBA) in the ICVS

*Inter-sensor comparison function across SNPP/N20/N21 is not listed in the LEO&LEO inter-sensor component to highlight its significance in the LTPAP-IRD system



Combining Four Methods:

1) CRTM-DD (Clear skies)
2) 32D-AD (Yan et al., 2021): All channels (32-day global average)
3) Simultaneous Nadir Overpass (SNO) (Cao et. al., 2004): Limited channels and regions
4) Sensor-DD via SNO

Inputs:
SDR/TDR data from Sensors onboard the SNPP, N20, N21, Legacy NOAA and Metop-B/C AMSU-A, GOES-16/18, and GNSS RO atmospheric sounding data

JCSDA Community Radiative Transfer Model (CRTM)

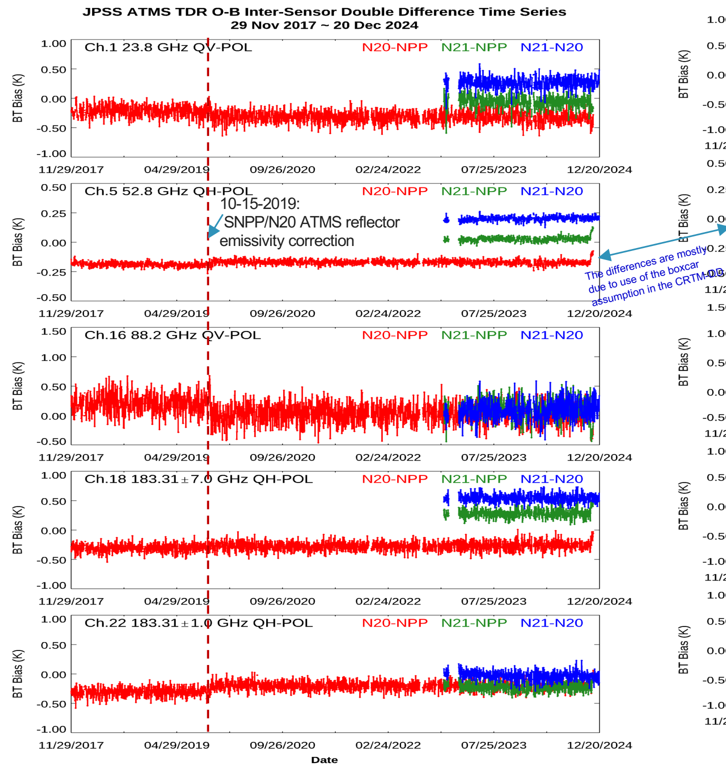
Outputs:
LT time series of inter-sensor radiance differences and standard deviations (SNPP/N20/N21; LEO-LEO; LEO-GEO)

Major goal: Support JPSS missions
Intermediate products: Wide user community

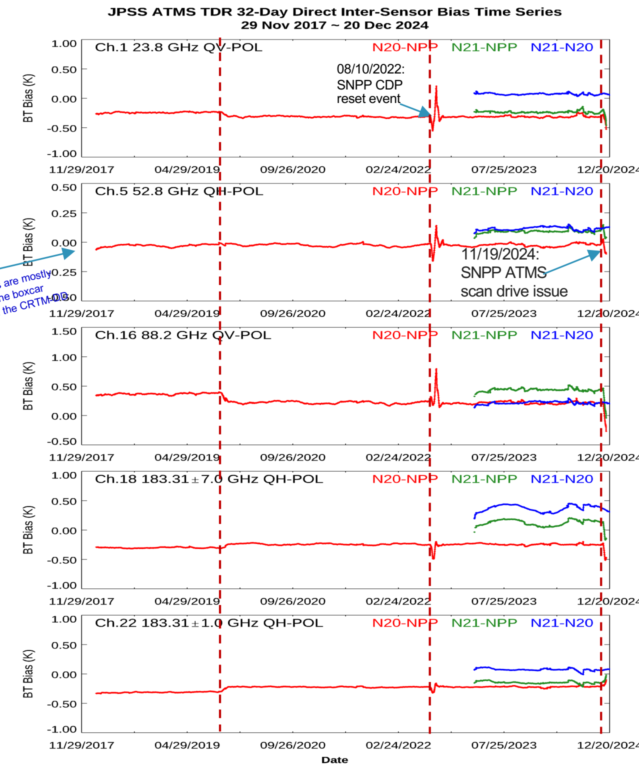
Long-Term TDR Calibration Bias Assessments for Five Channels across SNPP/NOAA-20/NOAA-21 ATMS Observations

- Figures reveal a relatively stable inter-senor radiometric calibration performance (TDR data record) across three ATMS instruments onboard SNPP, NOAA-20, and NOAA-21 satellites respectively, using the CRTM-DD and the 32-Day methods.
- Both methods capture impacts on inter-sensor biases from either SNPP spacecraft anomaly events or ATMS calibration table updates.
- For window channels (e.g., 23.8 GHz, 88.2GHz), CRTM simulations have large uncertainties (inaccurate surface emissivity). In contrast of it, the 32-Day method provides reasonable globally averaged biases for all channels.
- The results using the 32-Day method detected deficiencies in CRTM simulations for ATMS due to use of the boxcar especially in temperature sounding channels *(referred to Sun et al., 2024 IGARSS)*

(a) CRTM-DD Method (via CRTM simulations)

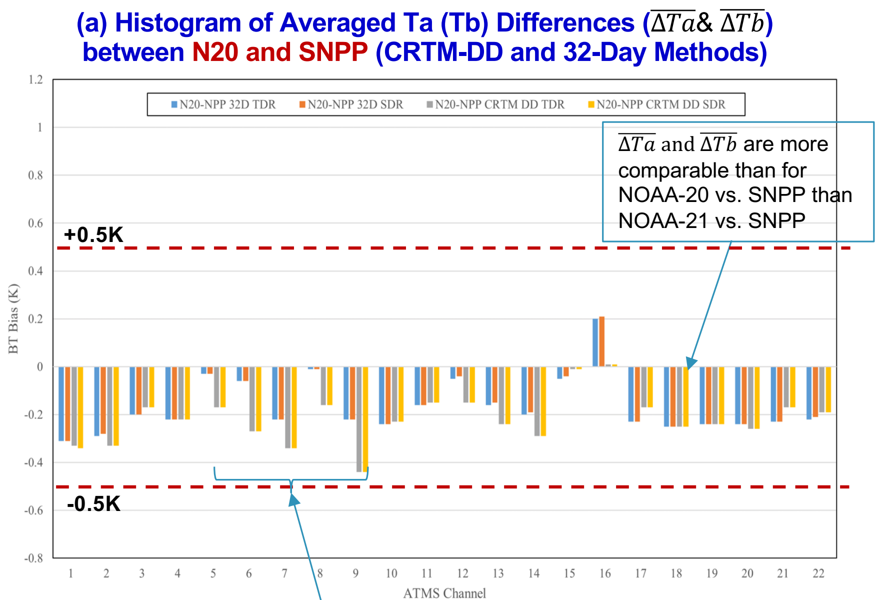


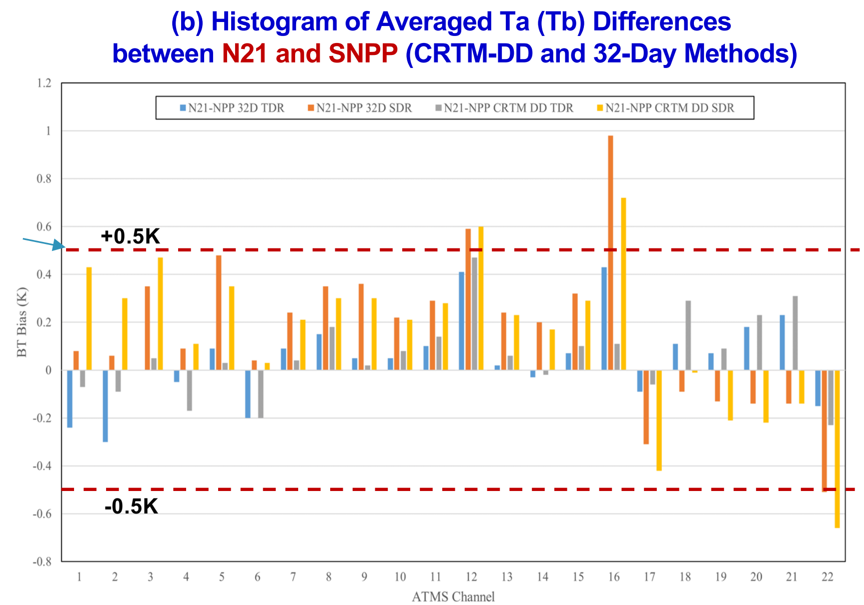
(b) 32-Day Average Method (direct data comparison)



Inter-sensor biases across 3 ATMS' observations are within ±0.5K

Mean Radiometric Differences at 22 Channels across 3 ATMS' Observations: CRTM-DD and 32-Day Methods-Based Histograms

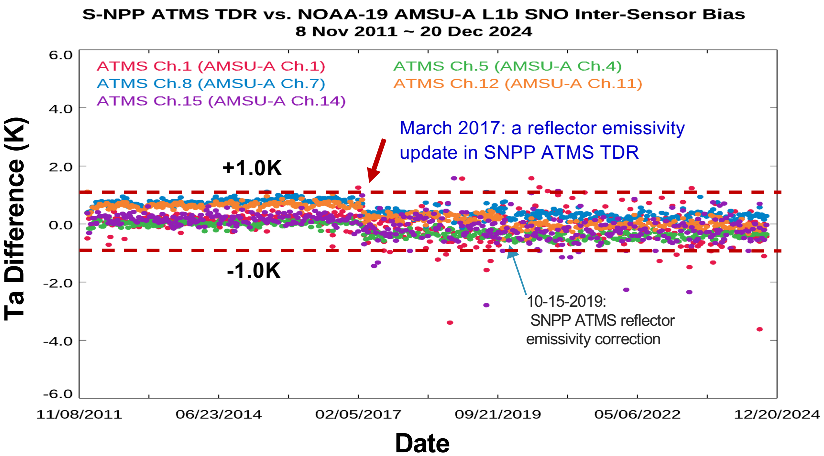




- The results using two methods show some differences, especially at window channels (CRTM simulation uncertainties) and part of the temperature sounding channels, partially due to the use of boxcar assumption in the CRTM simulations for ATMS (*refer to Sun et al., 2024*)
- Antenna temperatures (TDR) and brightness temperatures (SDR) from 3 ATMS's observations are in a good family, where the mean differences $\overline{\Delta Ta}$ and $\overline{\Delta Tb}$ are within ±0.5K for majority of 22 channels, which are confirmed using two methods.
- $\overline{\Delta Ta}$ and $\overline{\Delta Tb}$ are more comparable than for NOAA-20 vs. SNPP than NOAA-21 vs. SNPP
  - ATMS TDR and SDR data have slightly different calibration accuracies, which is clearly observed in the N21-SNPP inter-sensor histogram

Long-Term Calibration Bias Assessments across SNPP ATMS and NOAA-19 AMSU-A Observations

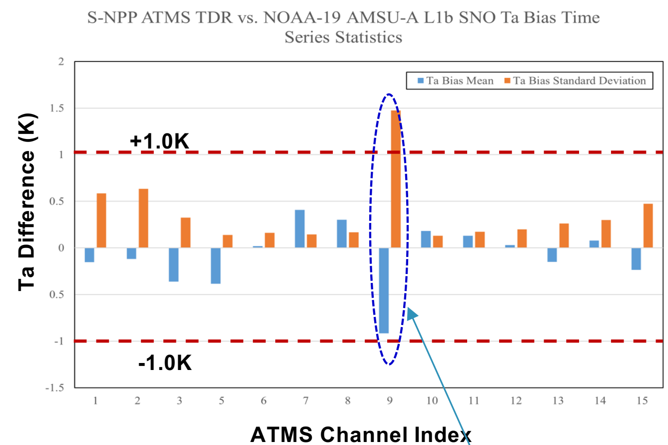
(a) Time Series of Ta Differences between SNPP ATMS and N19 AMSU-A (SNO Method)



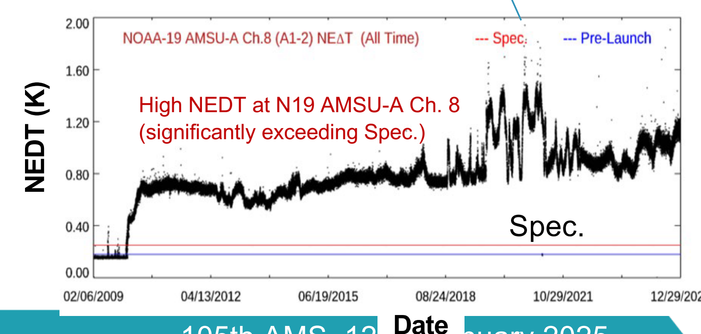
14 ATMS-AMSU-A Overlapped Channels

ATMS (AMSU-A) Channel Index	Frequency (MHz)	ATMS (AMSU-A) Nadir Pol.
1(1)	23800	QV(QV)
2(2)	31400	QV(QV)
3(3)	50300	QH(QV)
5(4)	52800	QH(QV)
6(5)	53596±115	QH(QH)
7(6)	54400	QH(QH)
8(7)	54940	QH(QV)
9(8)	55500	QH(QH)
10(9)	57290.344 (f_0)	QH(QH)
11(10)	f_0±217	QH(QH)
12(11)	f_0±322.2±48	QH(QH)
13(12)	f_0±322.2±22	QH(QH)
14(13)	f_0±322.2±10	QH(QH)
15(14)	f_0±322.2±4.5	QH(QH)

(b) Histogram of Ta Differences: Mean and Standard Deviation (05/01/2017 ~ 10/31/2024)



(c) N19 AMSU-A CH. 8 NEDT Time Series



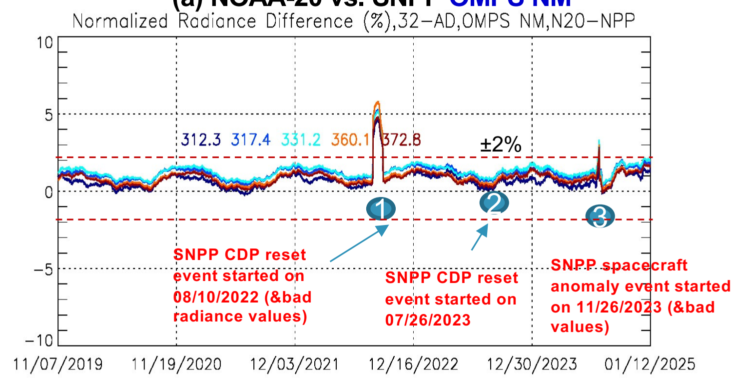
- NOAA-19 satellite was launched 02-06-2009, playing a critical role for global temperature change trends with time.
- ATMS onboard the SNPP that was launched 10-28-2011, provides a connection to assess long-term stability of NOAA-19 AMSU-A TDR data.
- Figs. (a) and (b) show time series of inter-sensor Ta biases at several channels and histogram for 14 overlapped channels: NOAA-19 AMSU-A TDR data exhibit a stable performance in comparison with SNPP ATMS data, with an exception at Channel 8 that has a NEDT exceeding specification.

Long-Term Calibration Bias Assessments across SNPP/NOAA-20/NOAA-21 OMPS NM and NP Observations

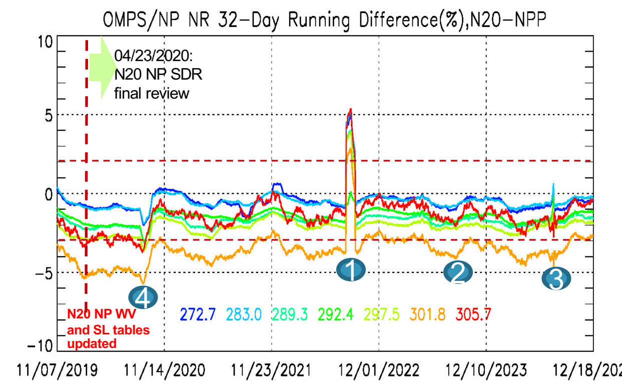
- Currently, 32-day method is a major method to assess long-terr inter-sensor biases for OMPS SDI data.
- Figs. (a) ~ (d) show time series of normalized radiance (NR) inter-sensor differences for OMPS NM and NP across SNPP, NOAA-20 (N20), and NOAA-21 (N21), usinç the 32-Day average method.
- OMPS NM and NP SDR data fron SNPP, NOAA-20, and NOAA-21, after the final JPSS review, meet the requirement (±2%), with exceptions in the events of spacecraft anomalies. Exceptions also occur at wavelengths from 300 to 305 nm for NM and 300 nm to 302 nm for NP.

Time Series of OMPS NM and NP Averaged NR Diff. (%)

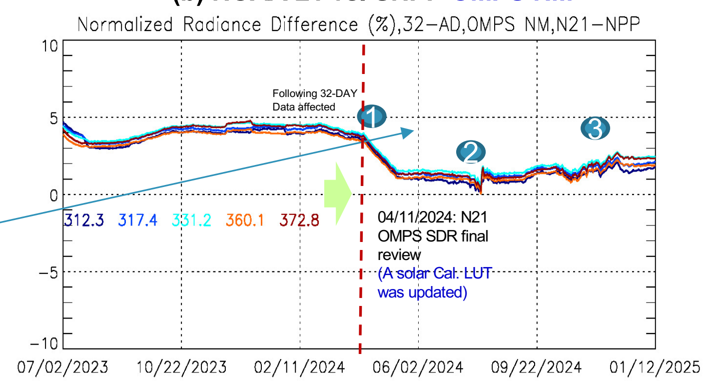
(a) NOAA-20 vs. SNPP OMPS NM



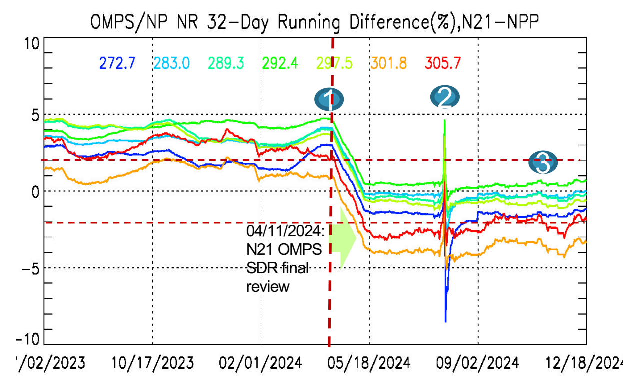
(c) NOAA-20 vs. SNPP OMPS NP



(b) NOAA-21 vs. SNPP OMPS NM



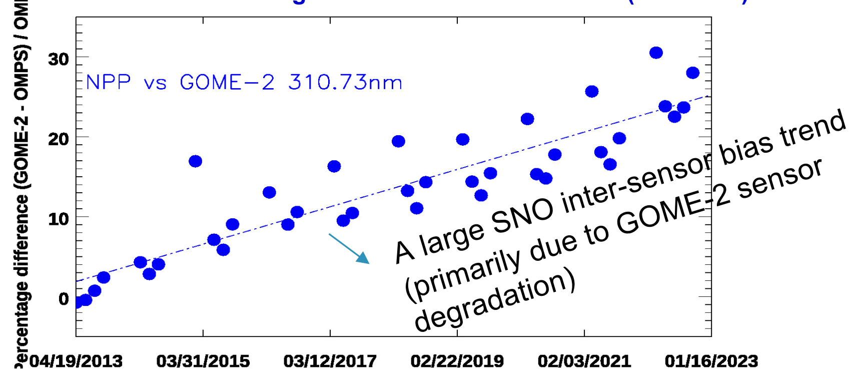
(d) NOAA-21 vs. SNPP OMPS NP



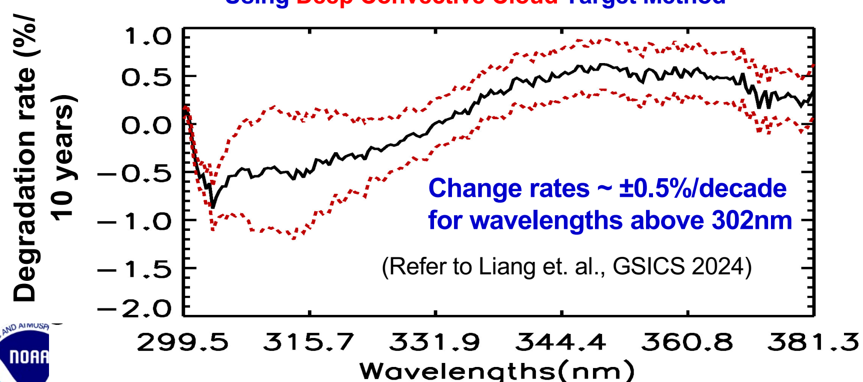
Detecting Metop-B Gome-2 Instrument Throughout Degradation

- The SNPP OMPS NM SDR data show a mission-long stability with a change rate within ±0.5% (Fig. a below)
- Conducted a long-term inter-sensor comparison analysis over ten years' data between SNPP OMPS NM and GOME-2 within the ICVS framework, by using the SNO method.
  - -The SNO-based radiometric calibration biases are obviously increased with time, with yearly increase rates from 0.7% to approximately 2.5%, depending wavelength.
  - -The gradually increased inter-sensor reflectance differences are majorly contributed to the Metop-B GOME-2

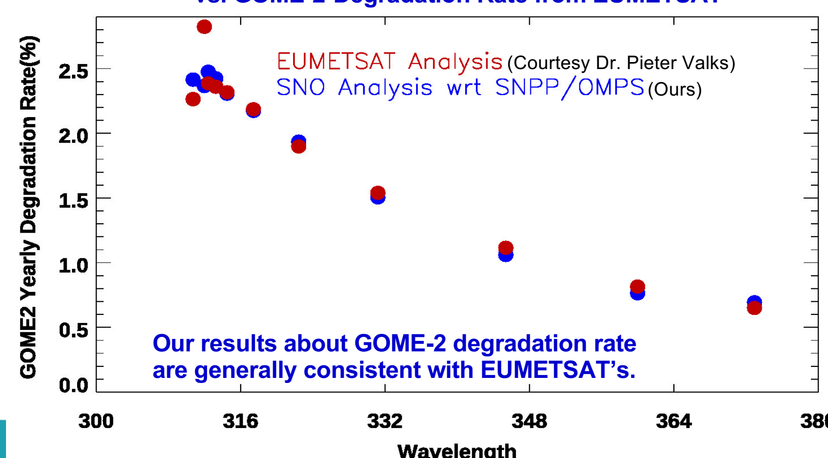
(b) Time Series of SNO-Inter-sensor Reflectance Differences (%) at 11 wavelengths from 310.73 to 372.93nm (Animated)



(a) Estimated SNPP OMPS NM Reflectance Change Rate (%/decade) Using Deep Convective Cloud Target Method

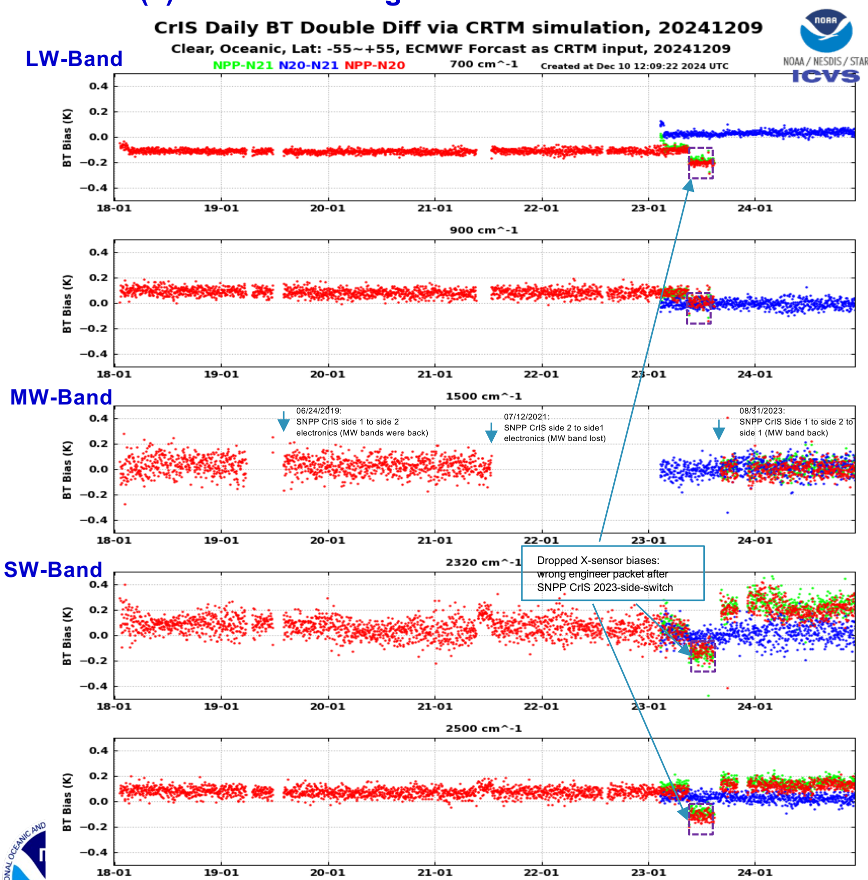


(c) SNO-Estimated Degradation Rate vs. GOME-2-Degradation Rate from EUMETSAT

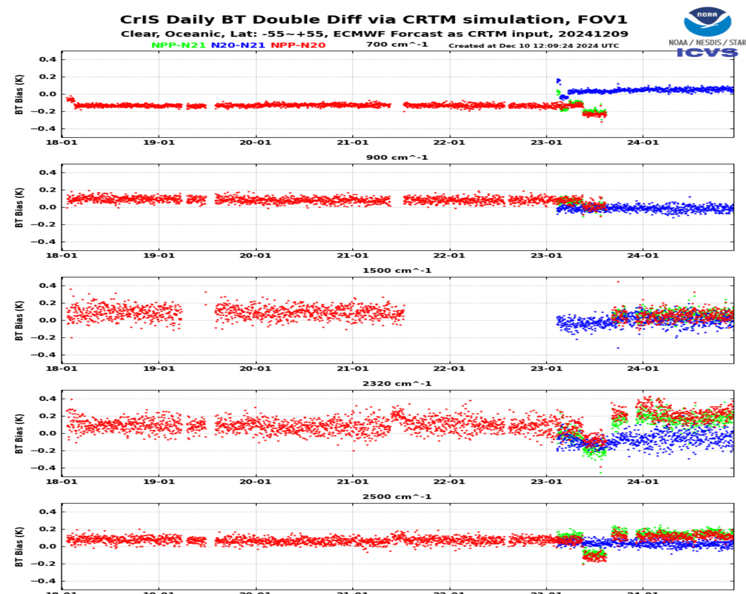


Long-Term Calibration Bias Assessments across SNPP/NOAA-20/NOAA-21 CrIS Observations: CRTM-DD

(a) All-FOV Average Inter-Sensor Biases

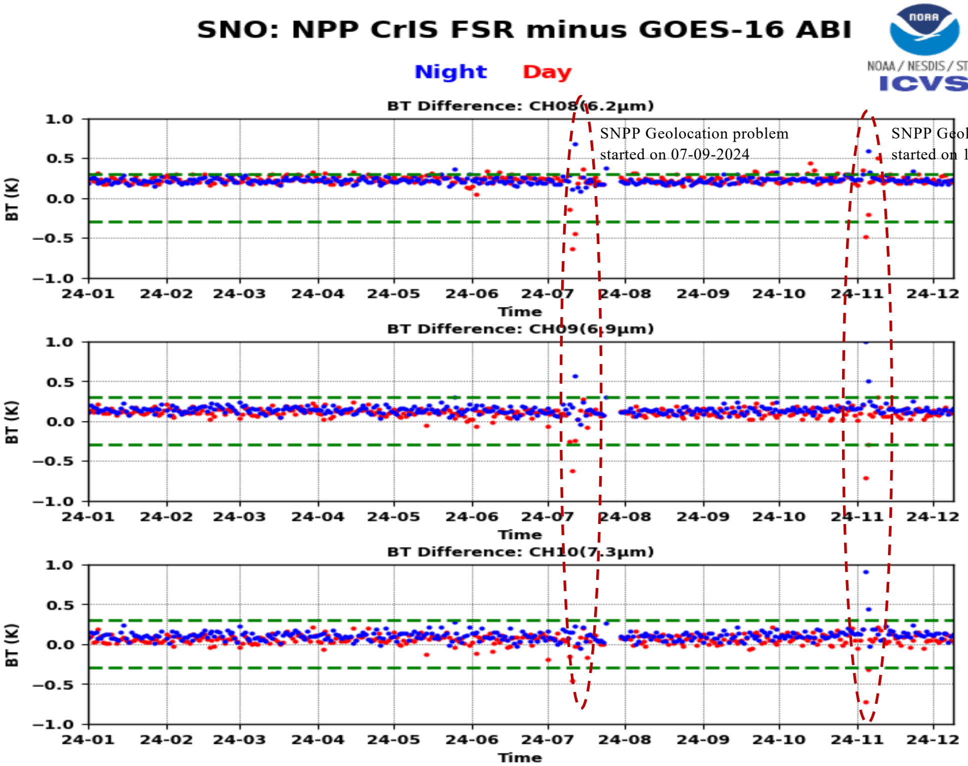


(b) Nine FOV- Inter-Sensor Biases (Animated)



- Figures reveal a relatively stable long-term inter-senor radiometric calibration performance across three CrIS instruments onboard SNPP, NOAA-20, and NOAA-21 satellites respectively, with a few exceptions.
- Capture impacts on inter-sensor biases from either SNPP spacecraft anomaly events or CrIS calibration table updates.

Detecting SNPP Geolocation Problem: via SNPP CrIS and G16 ABI Inter-Sensor Tb Differences



The first major SNPP geolocation anomaly event began at around 21:46:38 of July 09th, 2024 and finished at around 18:00 of July 16th, 2024. The second major SNPP geolocation anomaly event began at around 22:15 of Nov 02nd, 2024 and finished at around 17:00 Nov 06th 2024.

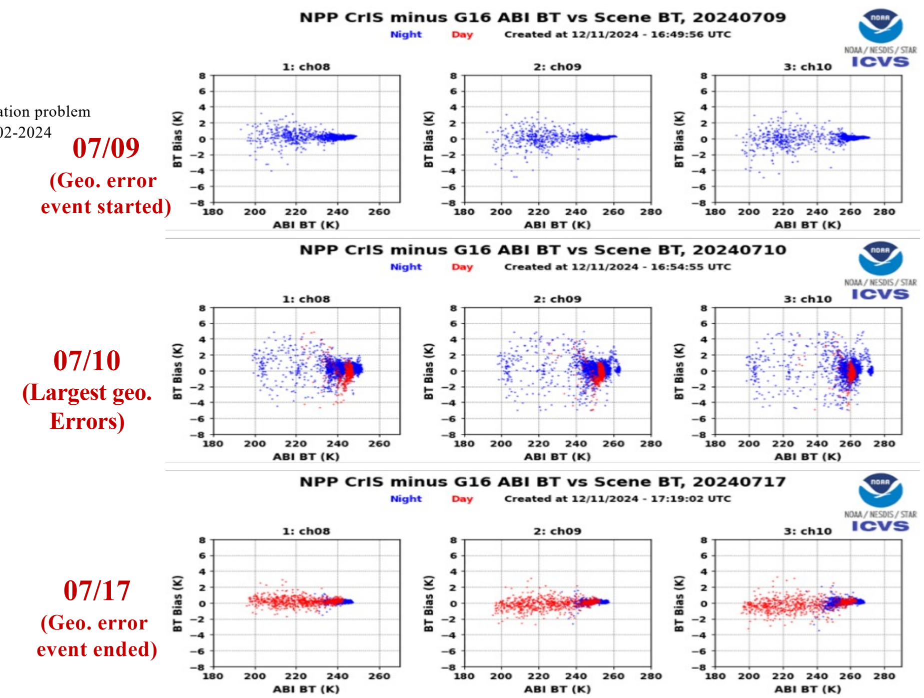


Fig. 1: the BT bias between NPP CrIS and G16 ABI water vapor bands against the scene BT on 07/09, 07/10 and 07/17, respectively.

(Note: A ML-based method is being developed to quantitatively estimate geolocation errors using CrIS and ABI SNO observations)

Summary and Conclusions (1/2)

This study has explored significant scientific values of an ICVS portal for Long-Term Inter-sensor Radiometric Calibration Bias Assessment (LTICBA), by taking advantages of four existing methods (CRTM-DD, 32-Day, SNO, Sensor-DD or SNO-DD).

- The SDR (and TDR for ATMS) data from three JPSS instruments, ATMS, OMPS, and CrIS, are demonstrated to exhibit relatively stable long-term (LT) performance during the overlapping mission period, except in cases of spacecraft anomaly events or calibration table updates (*Results related to VIIRS SDR are not included here due to incomplete computations within ICVS*)
    - The 32-Day method shows its advantage in estimating globally averaged inter-sensor biases over the CRTM-DD method for window and lower sounding channels.
    - The 32-Day method detected the deficiency of the boxcar assumption in the CRTM that is used to replace actual spectral response function in CRTM for a few microwave instruments now.

Significantly support JPSS SDR Cal./Val. missions!

Summary and Conclusions (2/2)

- In LTICBA portal, SDR (or TDR) data from ATMS, OMPS, and CrIS are used either to assess the performance of SDR data from non-JPSS instruments or to capture other anomaly events in JPSS instrument observations, e.g.,
    - The long-term stability of NOAA-19 AMSU-A TDR data across all overlapped channels (excluding Channel 8) is demonstrated through SNO-based inter-sensor biases compared to SNPP ATMS, with differences within ±0.5K. This stability supports the use of **NOAA-19 AMSU-A** data for global climate change studies.
    - A significant degradation in the sensor throughout of **Metop-B GOME-2** data at UV bands is detected, based upon SNO-based LT inter-sensor comparison results between SNPP OMPS-NM and Metop-B GOME-2.
        - The SNO-based results are generally consistent with those using GOME-2 solar and Earth radiance results from EUMETSAT (Courtesy of Pieter Valks)
    - The **geolocation errors in SNPP CrIS SDR data** due to spacecraft anomaly are captured using CrIS-ABI SNO-based inter-sensor radiometric biases.

Also benefit climate studies, Metop instrument, and GSICS users

Acknowledgements

- Thanks go to Warren Porter for his multiple years of effort in establishing the ICVS LTICBA web functions.
- Thanks go to the JPSS (Lihang Zhou) and JSTAR (Ingrid Guch) for funding support and sharing good ideas in improving the ICVS monitoring system.
- Thanks go to the EUMETSAT scientist Dr. Pieter Valks for sharing his GOME-2 degradation analysis results with us.
- Many thanks to several key teams or scientists for sharing valuable ideas and code in developing the ICVS monitoring system.
  - UMD CISESS Likun Wang (GSICS ABI-IASI SNO analysis)
  - ATMS SDR team (Flavio Iturbide, Ninghai Sun and others)
  - CrIS SDR team (Flavio Iturbide and others)
  - OMPS SDR team (Banghua Yan, Trevor Beck, and others)
  - VIIRS SDR team (Changyong Cao, Slawomir Blonski and others)
  - GOES-R team (Xiangqian Wu, Fangfang Yu and others)
  - STAR CRTM team (Quanhua Liu and others)

Several References Used in Presentation

- Yan, B.; Goldberg, M.; Jin, X.; Liang, D.; Huang, J.; Porter, W.; Sun, N.; Zhou, L.; Pan, C.; Iturbide-Sanchez, F.; et al. A New 32-Day Average-Difference Method for Calculating Inter-Sensor Calibration Radiometric Biases between SNPP and NOAA-20 Instruments within ICVS Framework. *Remote Sens.* **2021**, *13*, 3079. https://doi.org/10.3390/rs13163079
- Cao, C., Weinreb, M., and Xu, H.: Predicting simultaneous nadir overpasses among polar-orbiting meteorological satellites for the intersatellite calibration of radiometers, J. Atmos. Ocean. Tech., 21, 537–542, 2004.
- Liang, D.; Yan, B; Flynn, L.; Beck T.; other co-authors. Feasibility analysis of OMPS NM SDR data long-term stability assessment using deep convective cloud targets, 2023 IEEE International Geoscience and Remote Sensing Symposium, Pasadena, California, USA, 16 - 21 July, 2023.
- D. Liang, B. Yan and L. Flynn, "Characterization and Correction of Intersensor Calibration Convolution Errors Between S-NPP OMPS Nadir Mapper and Metop-B GOME-2," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-14, 2022, Art no. 5521114, doi: 10.1109/TGRS.2021.3134206.
- N. Sun; H. Yang; Q. Liu, B. Yan, F. Sanchez; S. Iacovazzi; X. Liang, IMPROVING THE CHARACTERIZATION OF ATMS ON-ORBT OBSERVATION BIAS USING MEASURED SPECTRAL RESPONS FUNCTION IN RADIATIVE TRANSFER MODEL , 2024 IEEE International Geoscience and Remote Sensing Symposium

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