Characterizing Inter-Sensor Calibration Radiometric Biases between SNPP and NOAA-20 OMPS Nadir Profiler (NP) Sensor Data Records by Using Hybrid Methodologies*

Banghua Yan**

[1]NOAA/STAR/Satellite Calibration and Data Assimilation Branch

**Co-authors: Chunhui Pan[2], Ding Liang[3], Jingfeng Huang[3,4], Junye Chen[3,4], Trevor Beck[1], Steven Buckner[3], Xin Jin[4], and Xiaozhen Xiong[6]

2 University of Maryland/ESSIC 3 Global Science Technologies INC.
4 Science Systems and Applications, INC 5 NOAA/STAR/ SCDAB 5 NASA Langley Research Center

www.calcon.sdl.usu.edu

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Disclaimer and Acknowledgement

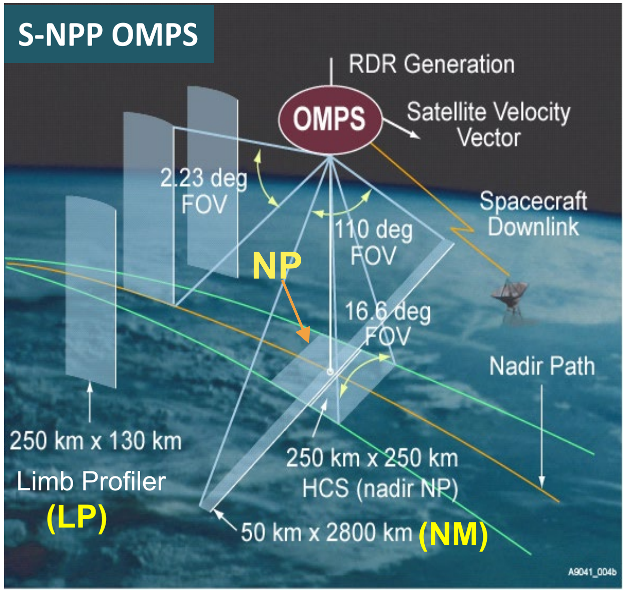
Briefing of SNPP and NOAA-20 OMPS

- **OMPS NM and NP sensors** are flying on the Suomi National Polar-orbiting Partnership (SNPP) launched in Oct. 2011 and Joint Polar Satellite Systems (JPSS)-1 (alias NOAA-20) launched Nov. 2017.
- With heritage from the NASA Backscatter UltraViolet Instrument (SBUV/2)and Total Ozone Mapping Spectrometer (TOMS), the OMPS provides ozone total column and vertical ozone profile records that continue ozone daily global records

- **Sensor Configuration**
  - 110° cross-track FOV telescope
  - Two grating spectrometers
    - » Nadir Mapper covers 300 nm to 380 nm (196 channels)
    - » **Nadir Profiler (NP) covers 250 nm to 310 nm (147 channels)**
  - 2-D CCD optical detector for each spectrometer
- **OMPS SDR Data Spatial Resolutions**
  - **SNPP NP: 1Cross-Track (CT) x 1Along-Track (AT) (250 km x 250 km)**
  - **NOAA-20 NP: 5CTx5AT (50 km x 50 km)**
  - SNPP NM: 35C x 5AT (50km x 50km)
  - NOAA-20 NM: 35CTx15AT (50km x 17km)
- **Recent improvements in SDR Products**

  (Refer to Pan et al., 2021 IGRASS Virtual Conference)
  - Solar intrusion correction
  - Solar activity adjustments
  - Off-nadir geo-location accuracy improvements

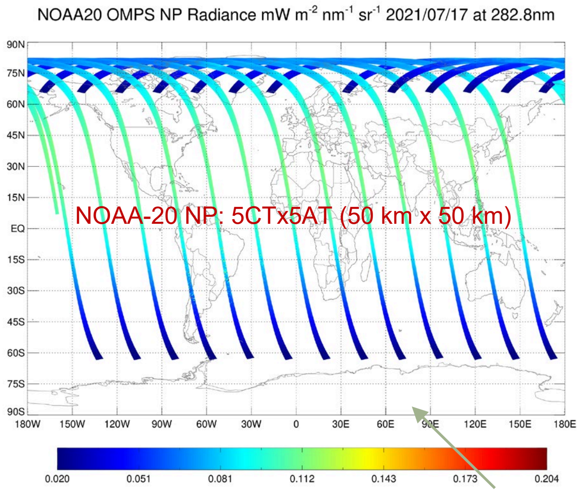
SNPP OMPS Cross-Track Geometry



- ❑ SDRs: NOAA's Comprehensive Large Array-data Stewardship System www.class.noaa.gov
- ❑ SDRs Data Maturity Matrix: https://www.star.nesdis.noaa.gov/jpss/AlgorithmMaturity.php

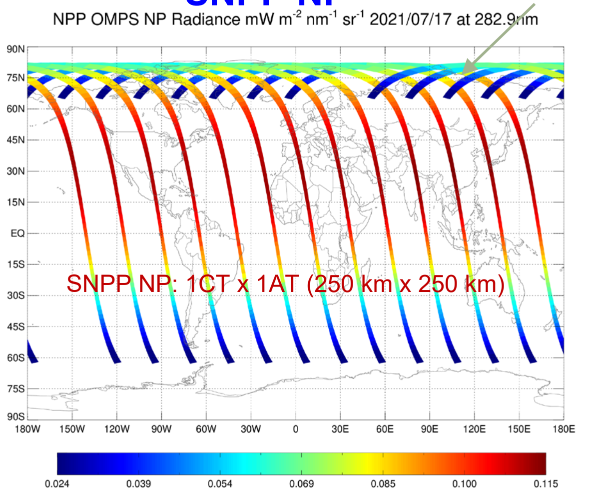
Challenge #1: OMPS NP Narrow Swath Coverage

NOAA-20 NP



About 50 mins operating time difference between 2 NPs

SNPP NP



SNPP and NOAA-20 OMPS NP Daily Coverages

(Every 8 days to have entirely overlap orbits between two NPs)

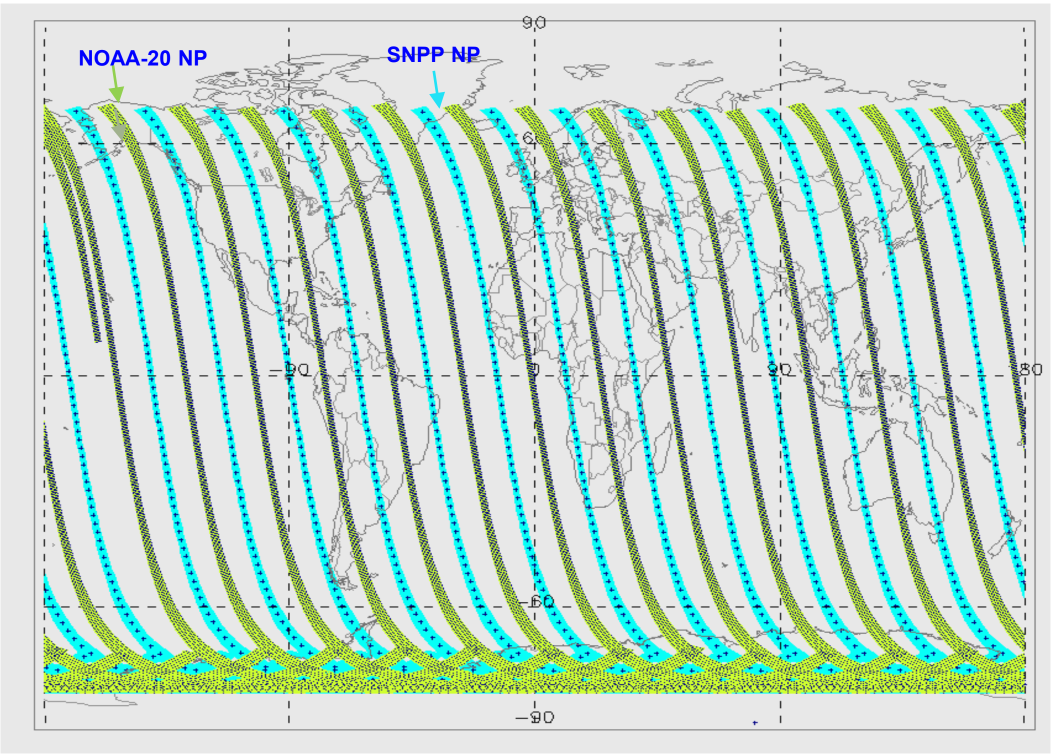
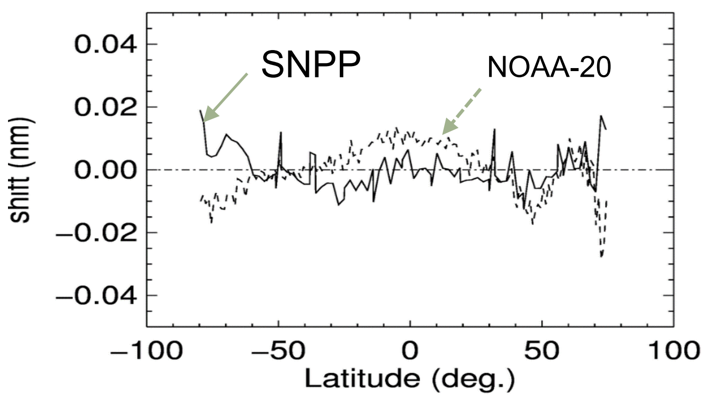


Figure Very narrow NP swath coverage of 250 km not only increases the temporal difference up to 8 days but also extremely reduces the sample size of overlapped observations between the two satellite sensors.

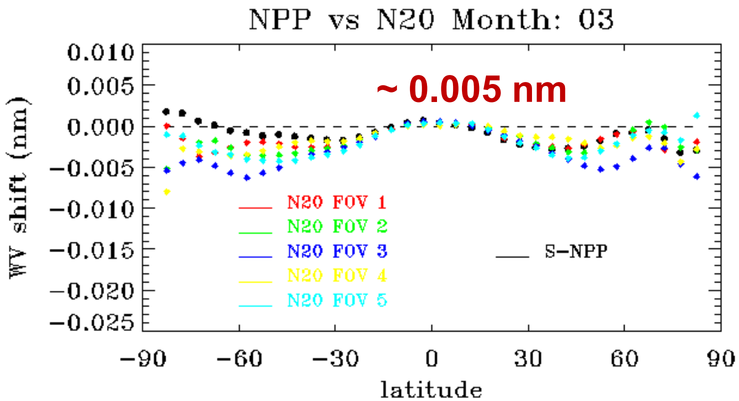
Challenge #2: Different Latitude-Dependent Radiance Wavelength Shift Pattern between 2 NPs

- The NP sensors present a latitude-dependent response change that contributes additional error to the SDRs (**mostly within 0.01 nm** wavelength shift)
  - Different radiometric sensitivity presents different response to the thermal loading changes within an orbit reflected by wavelengths shift
  - View footprint difference and Viewing condition difference produce different sensor response
- Analyzed the shift trend from 14-orbits wavelength change relative to a global average vs. latitudes.
  - For individual sensor, the maximum error in absolute calibration is 0.87% for the Suomi-NPP NP and 0.72% for the NOAA-20 NP.
  - A cross-sensor comparison of the two NPs finds a relatively large discrepancy in radiance. Values can be 0.3-1.2% along latitude when a relative wavelength difference between two NPs are greater than 0.01 nm
  - Figs. (a) for daily mean and (b) for monthly mean relative wavelength shifts about SNPP and NOAA-20 NP radiance

(a) Daily Mean SNPP and NOAA-20 Wavelength Shifts (Feb. 24, 2019)



(b) Monthly Mean SNPP and NOAA-20 Wavelength Shifts (animated)



Monthly mean wavelength (WV) shift difference: ~0.005 nm

Assessment Methods: Hybrid Approach

- TomRad-DD Method

(TomRad reference: Eck et. al., J.G.R., 1995)

$$\textbf{RTM-DD} = \left(\overline{O-B}\right)_{TomRad}^{NOAA-20} - \left(\overline{O-B}\right)_{TomRad}^{SNPP-20} + \left(\overline{\delta_1} - \overline{\delta_2}\right)$$

Inter-sensor calibration radiometric bias — **Simulation error**

(O: OMPS observations; B: RTM simulations)

Pros: simulation error should be mostly cancelled given a certain of sample of data

Cons: Clear skies; simulation error; time-consuming calculations;
very limited data over polar region (it might be more difficult to assess zonal mean features)

- 32D-AD Method (Yan et. al., 2021, J. RS)

$$\overline{\Delta O_{32D}^{N20-SNPP}}(i) = \overline{\Delta O_{32D}^{Cal}}(i) + \overline{\Delta O_{32D}^{Time}}(i) + \overline{\Delta O_{32D}^{Geo}}(i)$$

Use two satellite orbit repeat cycles (32 days) of data

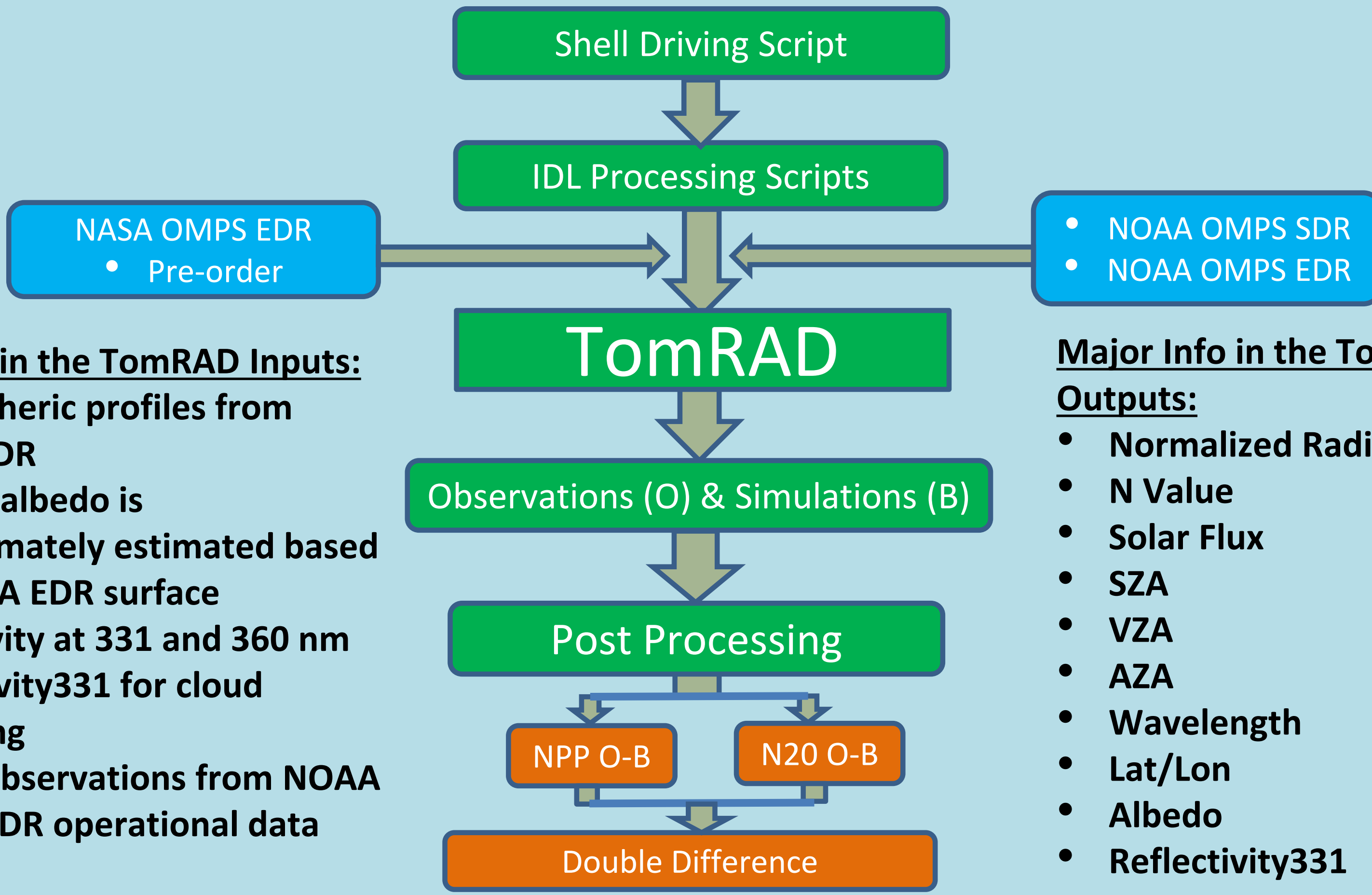
Inter-sensor calibration radiometric bias

Diurnal error (different viewing conditions)

Pros: direct radiance difference, independent of modeling simulations, computation efficient, zonal mean

Cons: 32-day of data; remaining diurnal errors at zonal means at channels above 300 nm

TomRAD based OMPS NP O-B & DD Diagram



Major Info in the TomRAD Inputs:

- **Atmospheric profiles from NASA EDR**
- **Surface albedo is approximately estimated based on NOAA EDR surface reflectivity at 331 and 360 nm**
- **Reflectivity331 for cloud screening**
- **OMPS observations from NOAA OMPS SDR operational data**

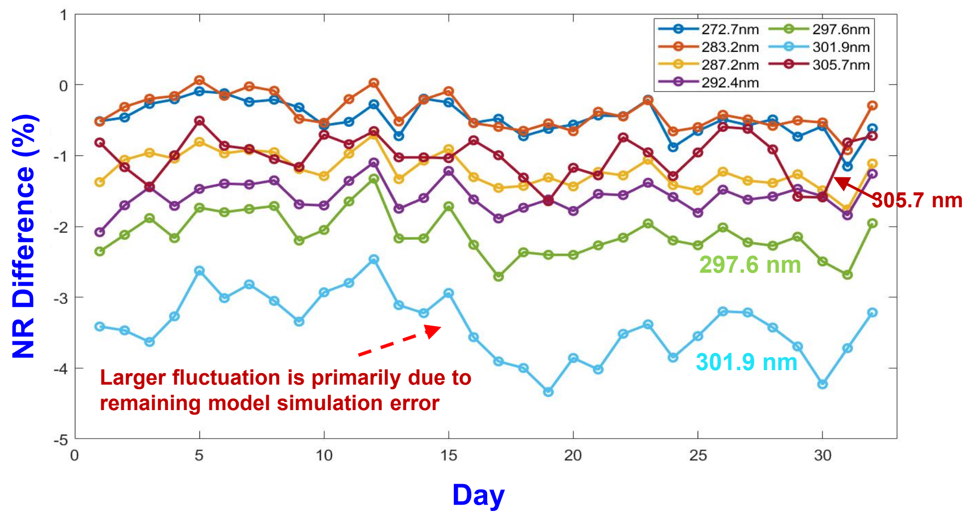
Major Info in the TomRAD Outputs:

- **Normalized Radiance**
- **N Value**
- **Solar Flux**
- **SZA**
- **VZA**
- **AZA**
- **Wavelength**
- **Lat/Lon**
- **Albedo**
- **Reflectivity331**

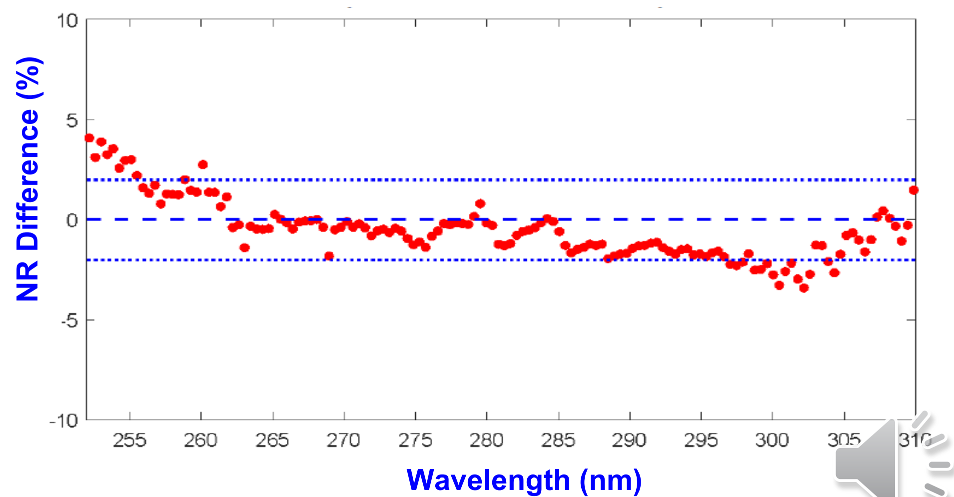
TomRad-DD: Globally Averaged Calibration Biases: NR difference % = (NOAA-20 – SNPP)*100/SNPP

- TomRad (Eck, F.; Bhartia, P.K.; Kerr, J.B., 1995) is used to simulate SNPP and NOAA-20 OMPS NP radiance covering 32 days
  - Data cover the period from December 31, 2020, to January 31, 2021
  - The ozone atmospheric profiles and surface reflectivity are from SNPP Environmental Data Record (EDR) data
- Global mean of inter-sensor normalized radiance (NR) differences (daily and 32-day averages):
  - Daily means of NR differences: Not stable due to residual RTM simulation errors (see (a))
    - The daily means at the lower sounding channels (above 300 nm) fluctuate more than those at the upper sounding channels (below 300 nm)
    - Simulation errors are relatively small for channles below 300 nm
  - 32-day averaged inter-sensor calibration biases vary primarily between -3.0% and 4.5 %, seeing (b).
    - RTM simulation errors are expected to be significantly reduced through the average of 32 days of the data due to random features

(a) Time series of Daily Mean for TomRad-DD Results (%)

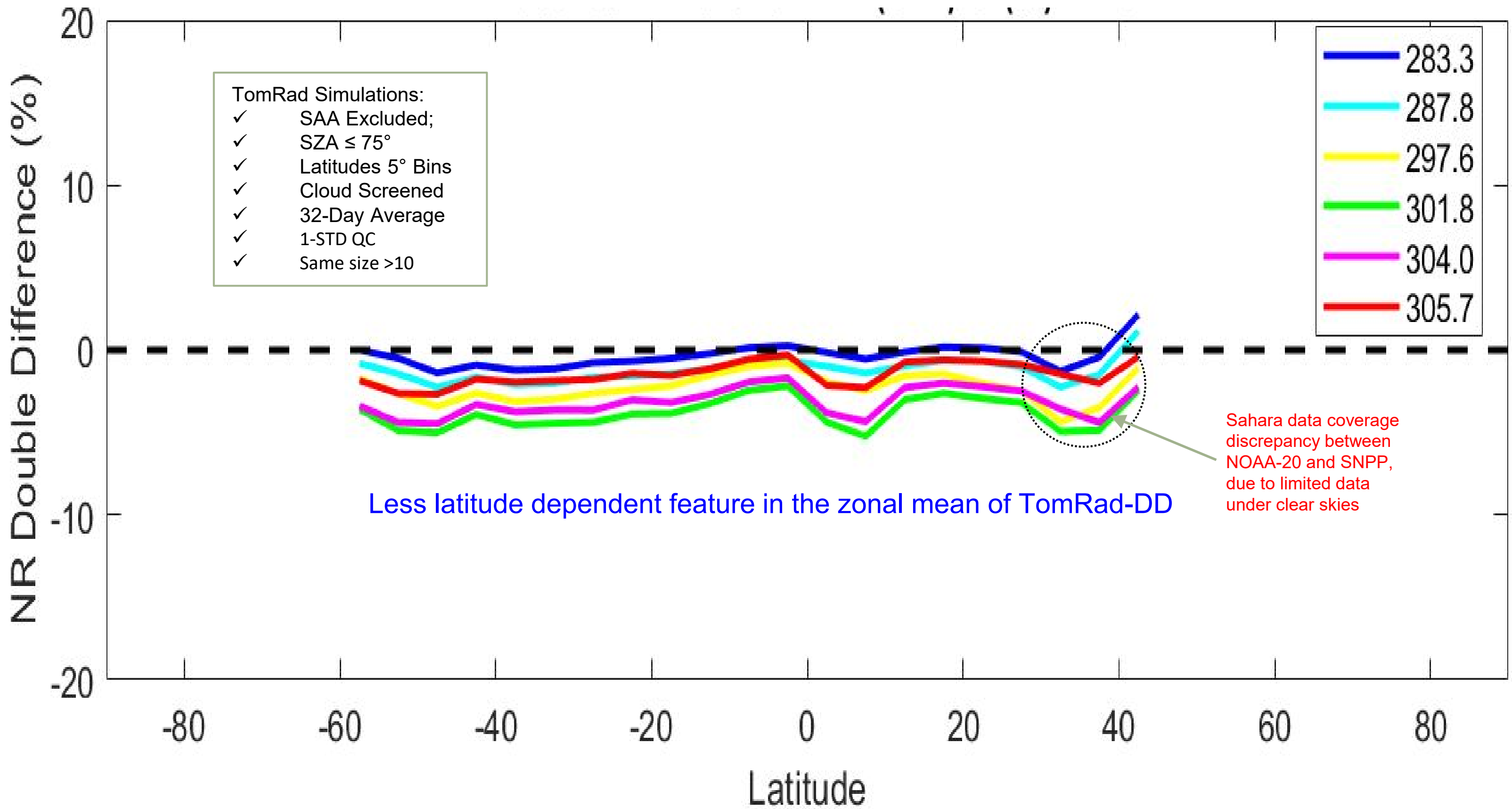


(b) 32-Day Average for TomRad-DD Results (%)



TomRad-DD: 32-Day Zonally Averaged Calibration Bias Assessment

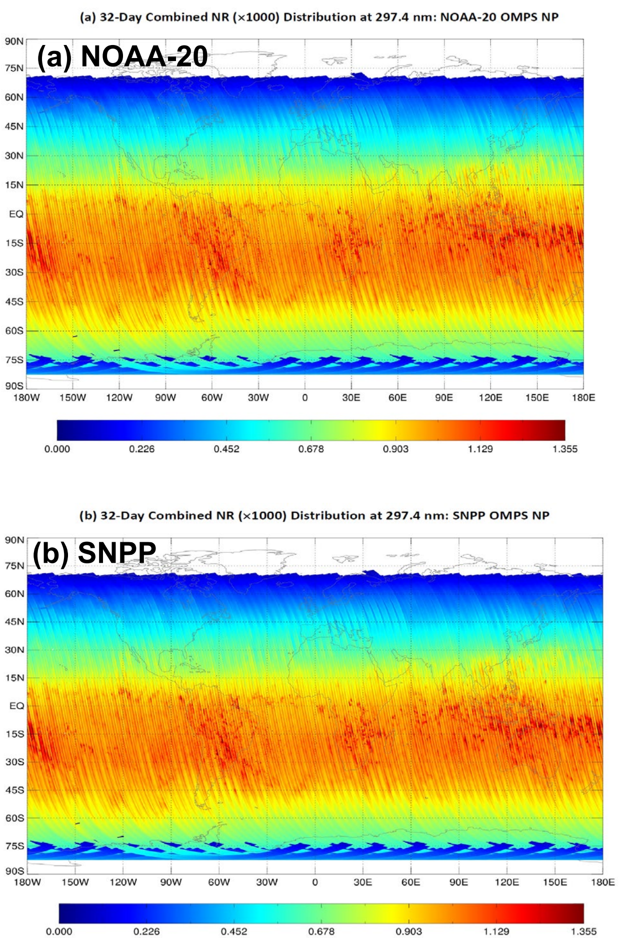
OMPS NP DD (%) (SNPP – NOAA-20): [O (SNPP) - B(TomRTM)] – [O (N20) - B(TomRTM)]*100/O_N20



According to the TomRad-DD, less latitude dependencies appear within available latitude rang in the TomRad-double differences between SNPP and NOAA-20 NP SDR. The simulation errors remain particularly in the presence of sample size discrepancies.

32D-AD Method: Globally Averaged Inter-Sensor Calibration Biases Assessment

(1) Global distributions of 32-day-averaged OMPS NP normalized radiance at 298 nm



(2) Globally averaged OMPS NP normalized radiance differences at 298 nm using the 32D-AD method

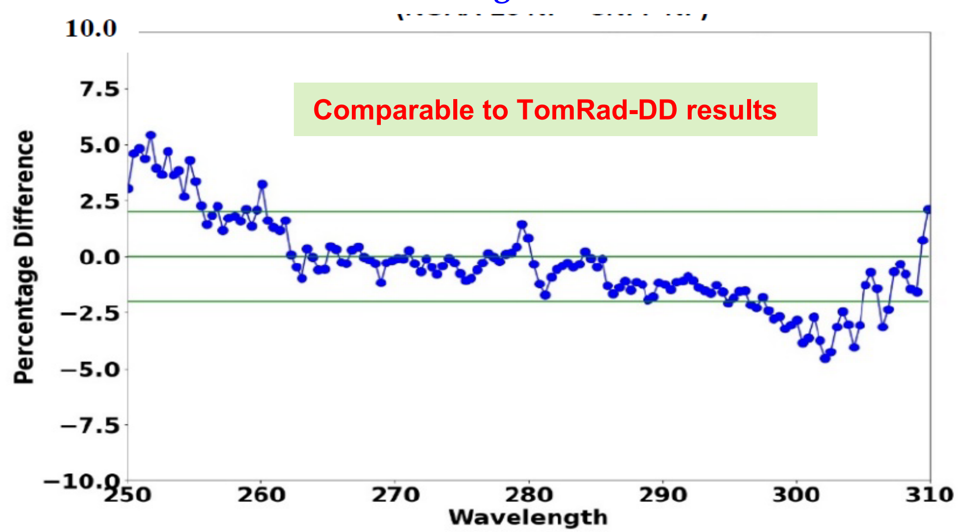
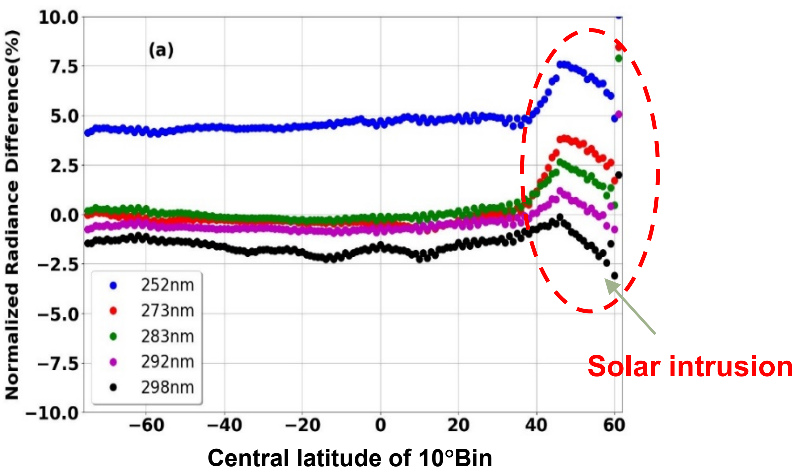


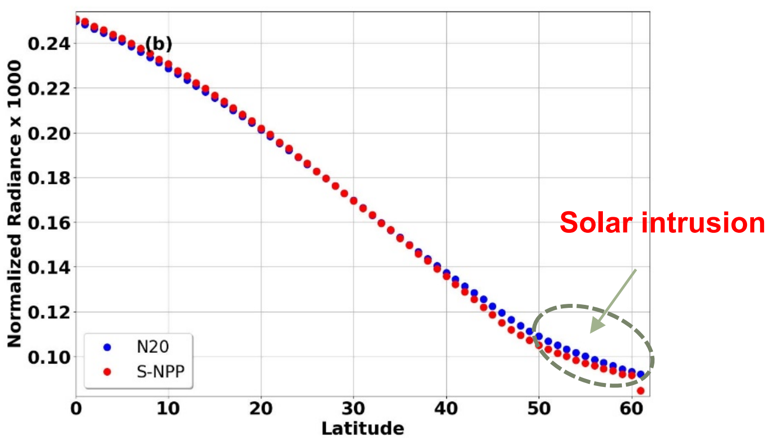
Figure (1) Global distribution of 32-day-averaged OMPS NP normalized radiance (NR) at 298 nm for NOAA-20 in (a) and SNPP in (b). (2) 32-Day averaged NP inter-sensor calibration radiometric biases at all NP channels between SNPP and NOAA-20 using the 32D-AD method, where the data cover from December 31, 2020 through January 31, 2021. The green lines in the figures represent ±2% difference.

Solar Intrusion Impact on SNPP and NOAA-20 NP Inter-Sensor Calibration Bias Pattern

(a) 32-Day zonal mean NR difference (%) between NOAA-20 and SNPP NP (running 10° bin in latitude)



(b) 32-Day zonal mean NR for NOAA-20 NP (running 10° bin in latitude)



(c) OMPS NP O – B (NR Difference) with/without Solar Intrusions Correction

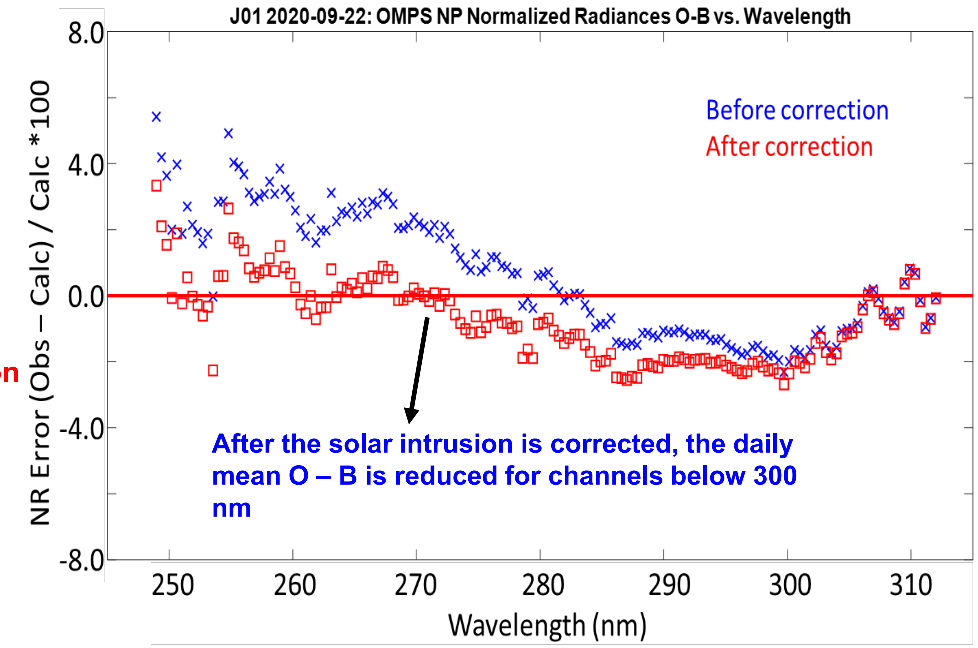


Figure (a) Zonal means of the 32D-AD for SNPP and NOAA-20 OMPS NP NR data at the channels, 252, 273, 283, 288, 292, 298 nm, which are computed at each 10° latitude running bin. In the calculations, the data beyond the SZA of 75° are removed due to a much smaller sample size. (a) Zonal means of 32D-AD over the NH between SNPP and NOAA-20 NPs at the channels, 252, 273, 283, 288, 292, 298 nm. (b) Zonal mean of NP NR at 273 nm over NH for SNPP and NOAA-20 individually. (c) Daily mean of O – B of normalized radiance (NR) for SNPP and NOAA-20 NP

Impact of Accumulated Days on Globally Averaged NR Differences between 2 OMPS NPs

Global mean of NR difference between 2 NPs: 1 day to 32 days

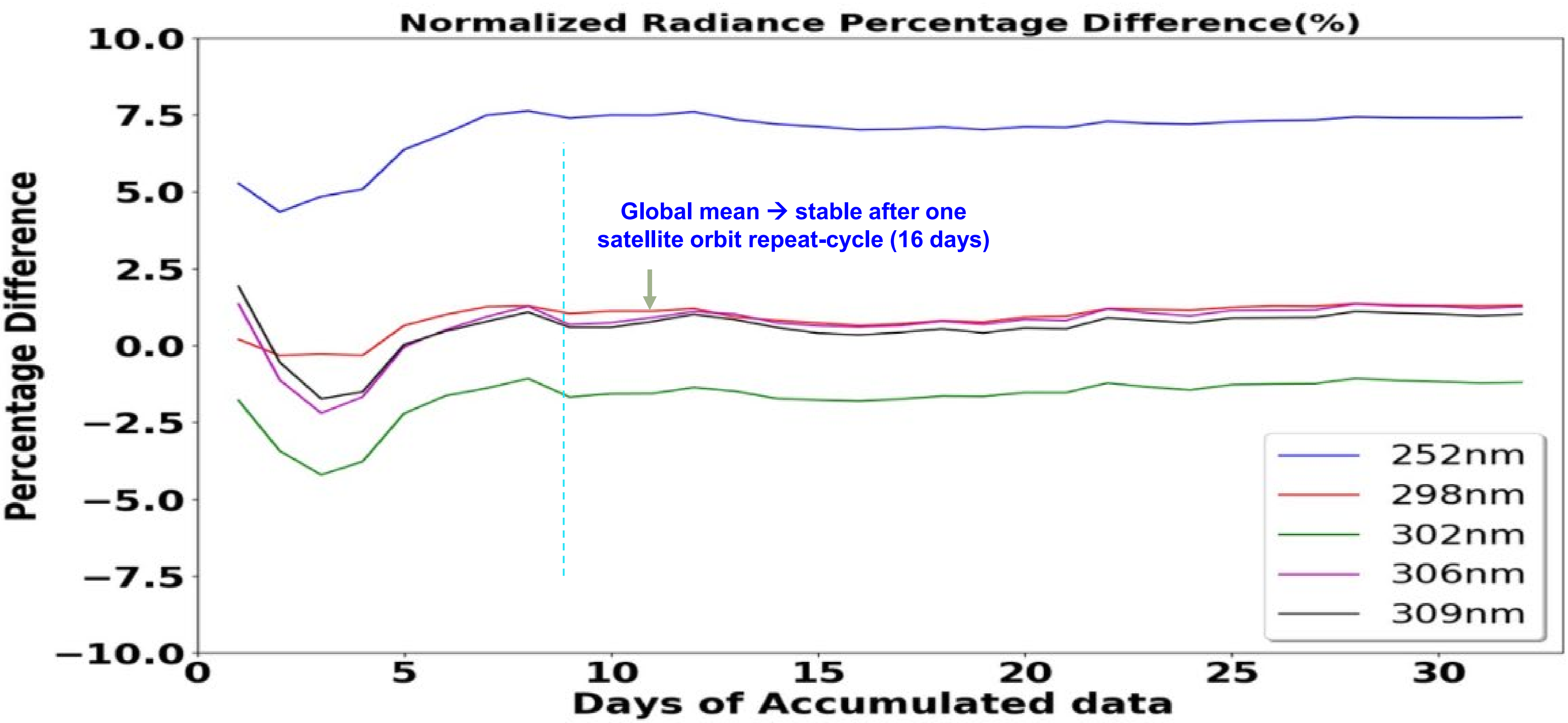


Figure Time series of the globally averaged brightness temperature differences at five OMPS NP channels between SNPP and NOAA-20, which are calculated using the data sets from one through thirty-two days with two-sigma threshold applied to the data.

Summary and Conclusions

- Both the TomRad-DD and 32D-AD methods are applied to characterize cross-sensor calibration radiometric biases between 2 OMPS NPs, demonstrating that the quality of SNPP and NOAA-20 OMPS NP radiance data at all channels generally agrees well
  - The globally averaged NP inter-sensor calibration radiometric biases are mostly within ± 2%, with exceptions for short wavelengths below 260 nm and part of wavelengths between 298 and 305 nm.
  - Impact of the radiance wavelength shift latitude-dependency is not obviously detected in the RTM-DD and 32D-AD methods.
  - Relatively large inter-sensor NR differences below 300 nm at high latitudes over the Northern Hemisphere (NH) is caused by the solar intrusion on the NOAA-20 OMPS NP SDR data.
    - A solar intrusion correction has been applied to the NOAA operational OMPS NP SDR processing stream since July 29, 2021, which was developed based on the efforts from both the NASA OMPS Group (Courtesy of G. Jaross, L-K. Huang) and NOAA STAR OMPS SDR team
- The TomRad-DD and 32D-AD methods are supplementary to each other:
  - TomRad-DD:
    - Relatively accurate given accurate inputs but poor computation efficiency
    - Not necessary use of 32 days of the data for channels below 300 nm
  - 32D-AD:
    - Relatively accurate and good computation efficiency
    - detecting solar intrusion impact
    - 32-day of the data (or 16 days of the data for global mean)
    - Not applicable for the zonal mean analysis above 300 nm due to strong diurnal error impacts
- Further investigation is still in progress to continue improving the accuracy and efficiency of the assessment methods.
  - Long-term time series of SNPP and NOAA-20 NP SDR inter-sensor biases are being implemented into the STAR Integrated Calibration/Validation System beta version (https://www.star.nesdis.noaa.gov/icvs-beta/comparison_OMPS.php; user name and pass-word required)

References

- Yan, B., M. Goldberg, X. Jin, D. Liang, J. Huang, W. Porter, N. Sun, L. Zhou, C. Pan, F. Iturbide, Q. Liu, and K. Zhang: A New 32-Day Average-Difference Method for Calculating Inter-Sensor Calibration Radiometric Biases between SNPP and NOAA-20 Instruments within ICVS Framework, in press, J. Remote Sens., 2021, doi: 10.3390/rs13163079
- Pan, C., B. Yan, L. Flynn, T. Beck, L. Wang, J. Huang, L. Huang: Recent improvements to NOAA-20 Ozone Mapper Profiler Suit Nadir Profiler Sensor Data Records**,** *IGARSS Virtual, July 12 -16 2021, Brussels, Belgium*
- Pan C., B. Yan, C. Cao, L. Flynn, X. Xiong, E. Beach and L. Zhou: Performance of OMPS Nadir Profilers' Sensor Data Records, IEEE Transactions on Geoscience and Remote Sensing, doi: 10.1109/TGRS.2020.3026586. 06 October 2020
- Yan B., C. Pan, T. Beck, X. Xiong, D. Liang, and J. Chen, G. Jaross, L. Flynn: NOAA-20 OMPS NP SDR report for validated maturity review, NOAA JPSS Science Review, April 2020, https://www.star.nesdis.noaa.gov/jpss/documents/AMM/N20/OMPS_NP_SDR_Validated.pdf.
- Pan C., Weng, F., and Flynn: Spectral performance and calibration of the Suomi NPP OMPS Nadir Profiler sensor, Earth and Space Science, 4, 737–745, 2017, https://doi.org/10.1002/2017EA000336.
- Flynn L., C. Long, X. Wu and co-authors: Performance of the Ozone Mapping and Profiler Suite (OMPS) products, J. Geophys. Res. Atmos., 119, 6181–6195, doi:10.1002/2013JD020467, 2014.

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