GI3.4 - Calibration and validation of Earth satellite measurements

D847 | EGU2020-11607

The Use of Radiative Transfer Modeling to Compare Radiances from Different Instruments

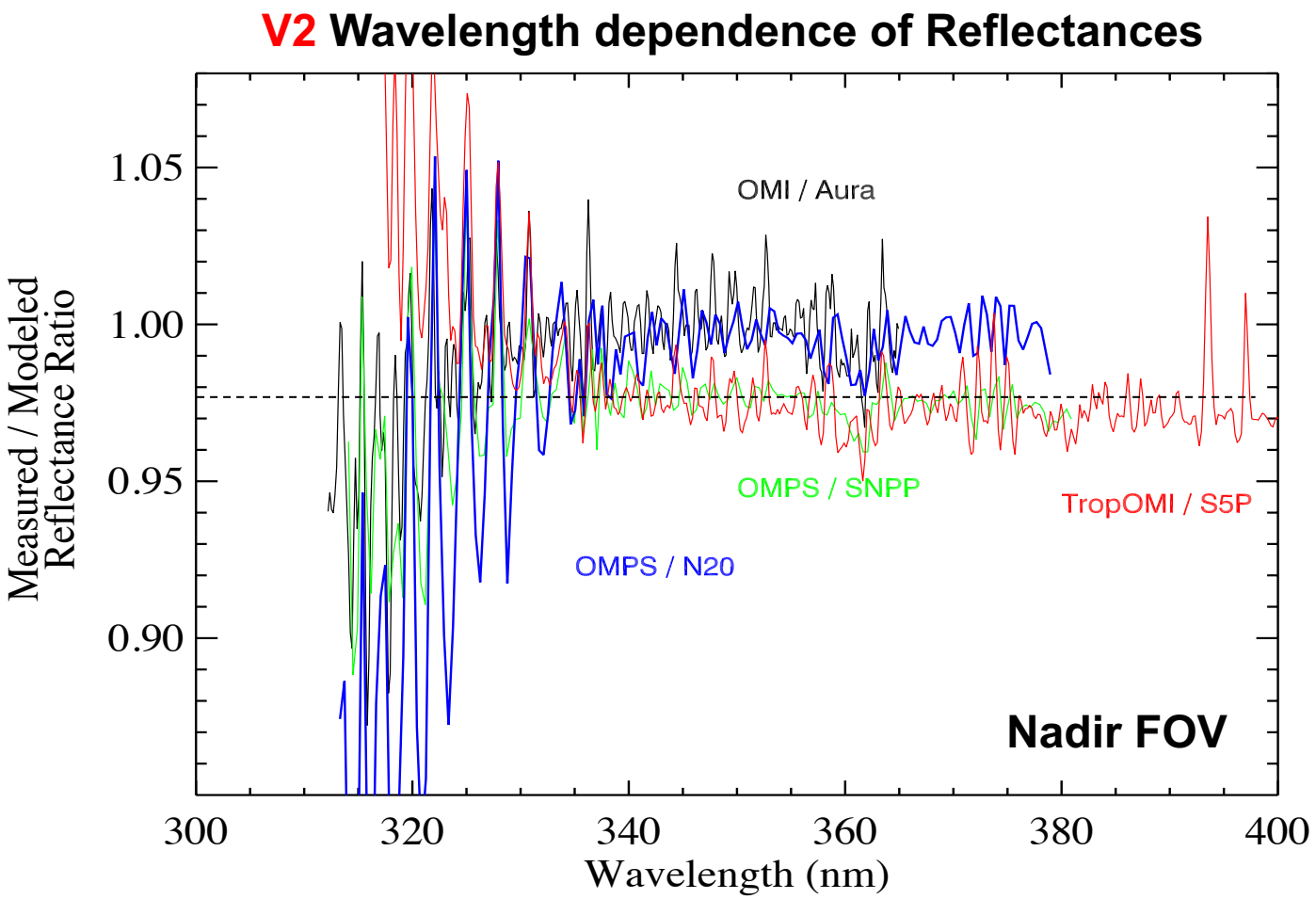
Colin Seftor[1], Glen Jaross[2], Leslie Moy[1], Natalya Kramarova[2], Eun-Su Yang[1]
[1]Science Systems and Applications, Inc, [2]NASA Goddard Space Flight Center

Summary

- The use of a radiative transfer model calculations can be used as a transfer standard to compare measurements made from two different instruments
  - This technique (which we call DRCM, for Dual Residual Comparison Method) mitigates differences between the instruments and the viewing conditions of the measurements
- As an example, we've used DRCM in combination with other analysis methods to investigate the calibration of the newest version (V2) of the TROPOMI dataset that was just released to the cal/val group for evaluation
  - We compared it to the currently released version of the S-NPP OMPS
- Our comparison indicates that there are still calibration issues present in the TROPOMI data
  - This example demonstrates the utility and usefulness of the DRCM technique

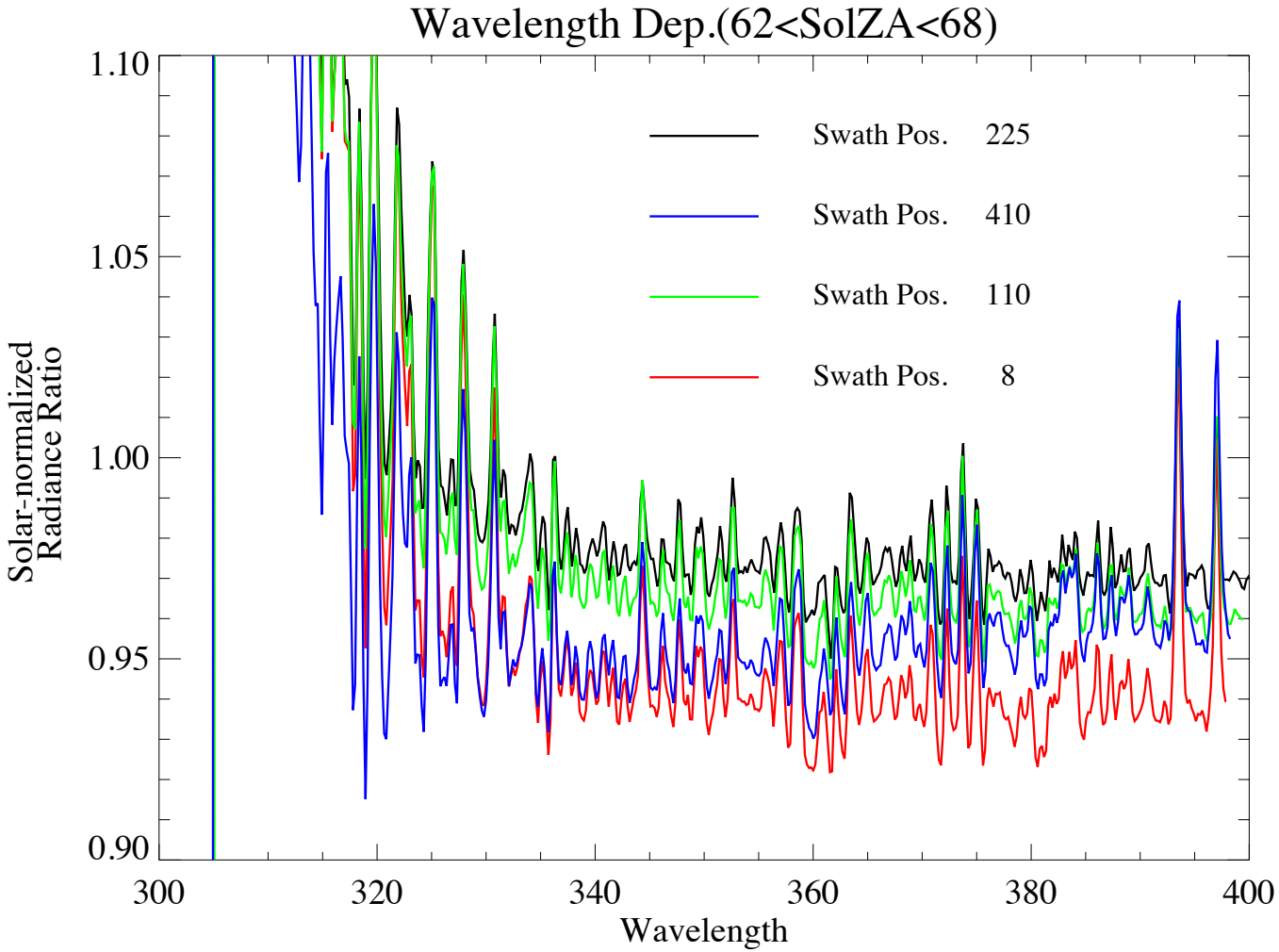
We first looked at a comparison of ice reflectances

- We compared the TROPOMI reflectances for Band 3 with those from other instruments and from results utilizing an ice radiance model that included the ice BRDF
- The reflectances indicated an offset of approximately 2% to the model results and from OMI and N20 OMPS
  - A similar offset seen in S-NPP OMPS, as shown at right, was subsequently corrected for in the current version of the dataset
- A small “step” in the TROPOMI wavelength dependence is seen at ~331 nm
  - Results are not trustworthy shortward of 330 nm due to ozone absorption.



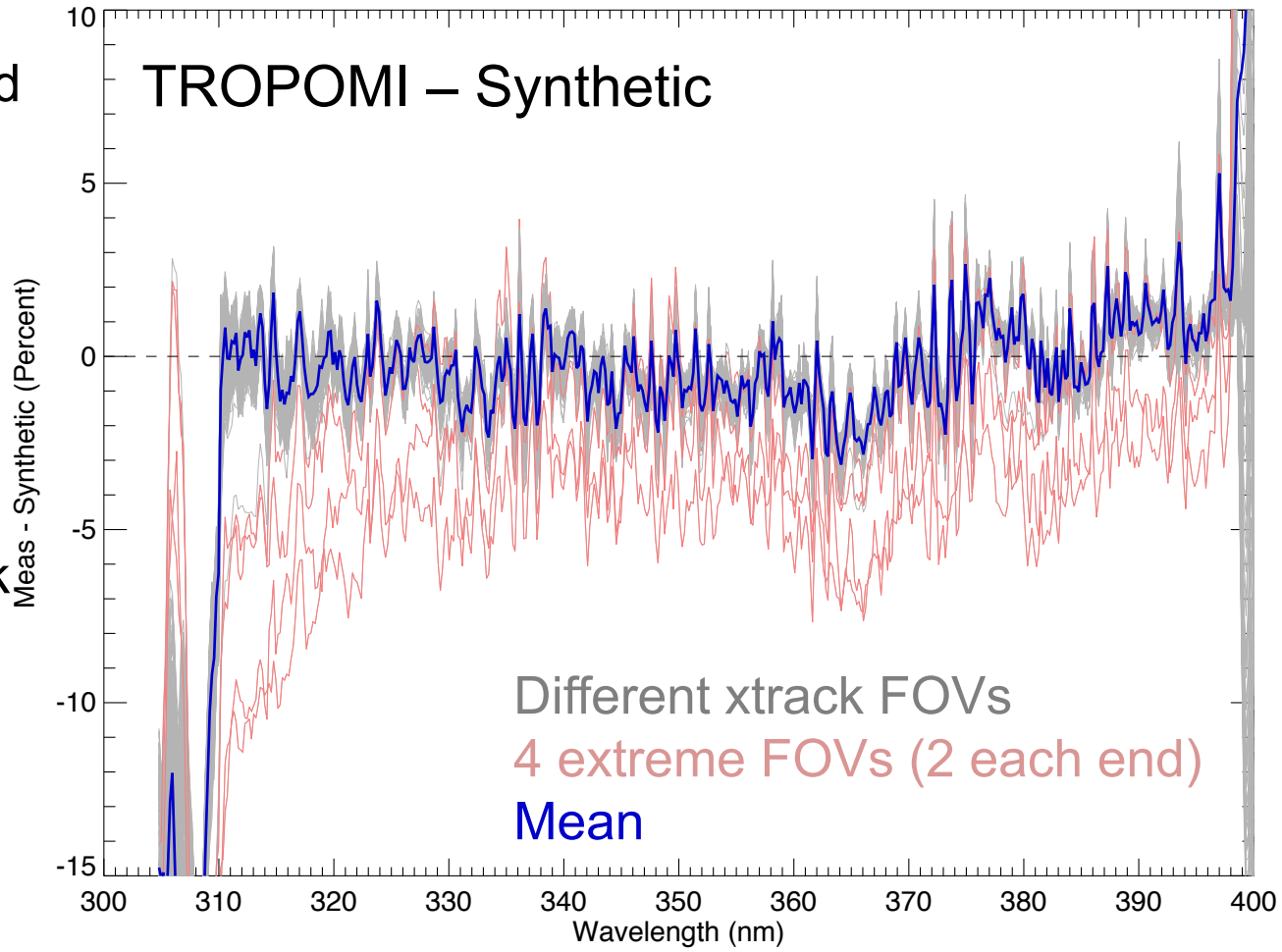
This analysis also showed that TROPOMI has a cross-track dependence

- We now show the difference between TROPOMI Band 3 reflectances and model results for different fields-of-view (FOV)
- A definite dependence of FOV indicates that this issue exists in the current V2 dataset
- The question is, does this dependence come from the radiances, the irradiances, or both?



We looked at solar flux first to determine what is causing the reflectance difference

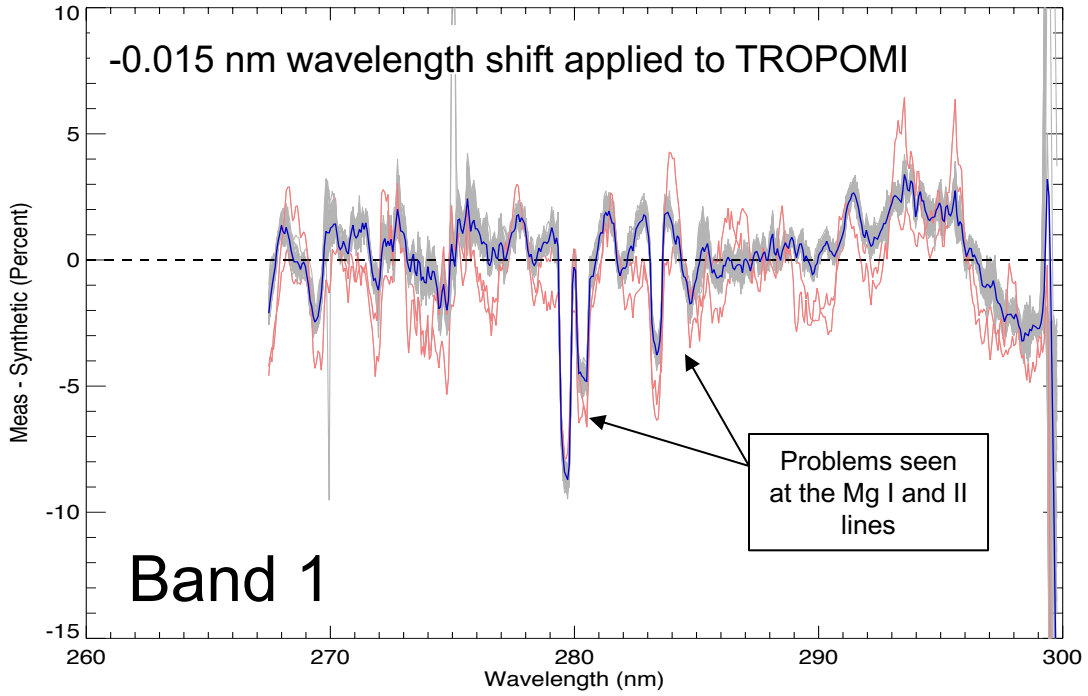
- In order to determine this, we looked at the In the plot on the right, we compare their corrected Band 3 solar flux to a synthetic solar flux*
  - The synthetic solar flux was convolved with the appropriate TROPOMI bandpasses
- Except for the extreme FOVs the mean differences are within 3% for wavelengths < 395nm
- For all but the farthest off-nadir FOVs (those shown in pink), we see only a minimal cross-track dependence in the solar flux.
- The mean solar flux is well calibrated
  - The TROPOMI cal/val team adjusted it to the S-NPP OMPS solar flux, see https://doi.org/10.5194/amt-2019-488

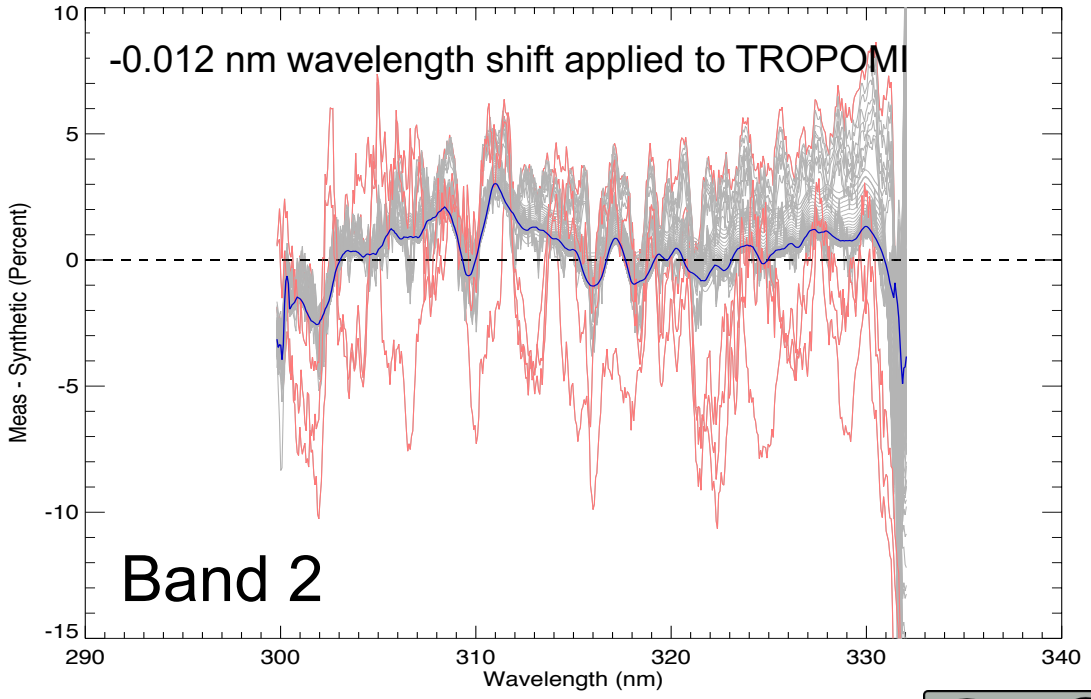


*Dobber, M., R. Voors, R. Dirksen, Q. Kleipool, and P. Levelt (2008), "The high-resolution solar reference spectrum between 250 and 550 nm and its application to measurements with the Ozone Monitoring Instrument, **Sol. Phys.**, 249, 281-291, doi: 10.1007/s11207-008-9187-7.

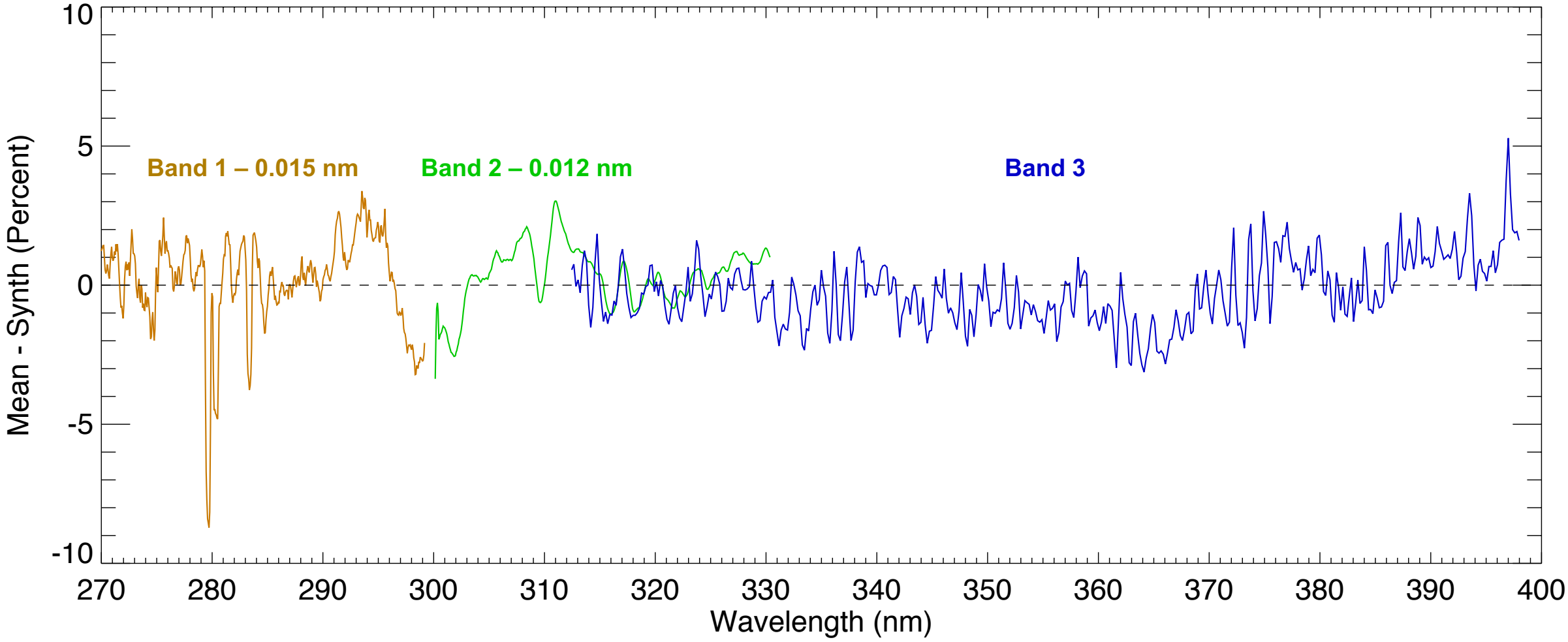
We also analyzed the Band 1 and Band 2 TROPOMI solar flux measurements

- Band 1 is, for the most part, well-calibrated with little cross-track dependence
  - A wavelength shift of -0.015 nm was needed to minimize the difference with synthetic flux
  - Problems seen at both the Mg I and II lines
- The Band 2 comparison shows larger deviations between measured and synthetic flux and a larger cross-track dependence
  - A wavelength shift of -0.102 nm was needed to minimize the measured/synthetic difference





The average solar flux for all 3 bands show that, for the most part, it is not causing the reflectance problem



We then looked at the radiances by comparing them to radiances from SNPP OMPS

Because TROPOMI and OMPS Orbits are within 3-5 minutes local equator crossing times, we can directly compare the radiances, provided we with some corrections account for differences between the two:

Spatial:

Issue: OMPS has 36 cross-track FOVs (50x50 km at nadir), TROPOMI has 450 FOVs, 7 km cross-track x 3.5 km along-track (actually, 448 for Band 2 and 77 for Band 1)

Solution:
1) Average all TROPOMI measurements that occur within a given OMPS FOV.
2) Further average into latitude bands

Spectral:

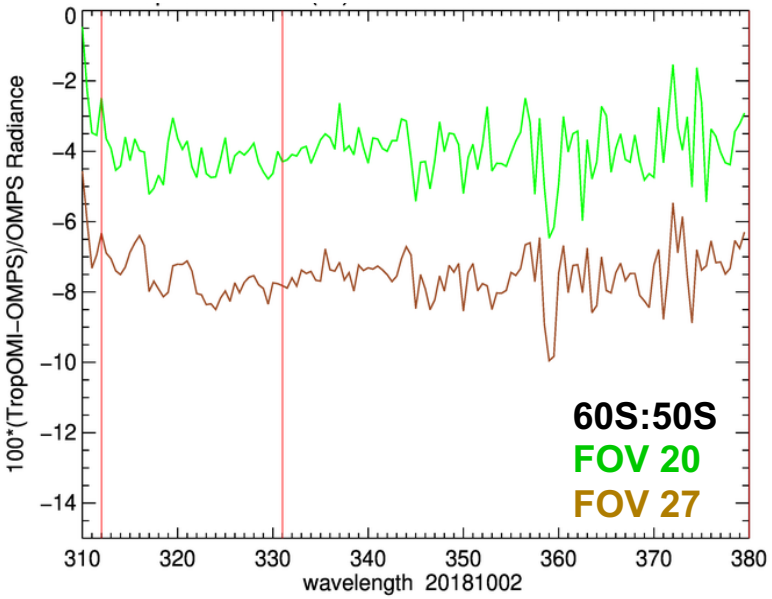
Issue: OMPS provides measurements every 0.4 nm, with a bandpass of 1.0 nm, while TROPOMI provides measurements every 0.2 nm with a bandpass of 0.5 nm.

Solution: We convolved the TROPOMI radiances at the OMPS wavelengths using the OMPS bandpasses.

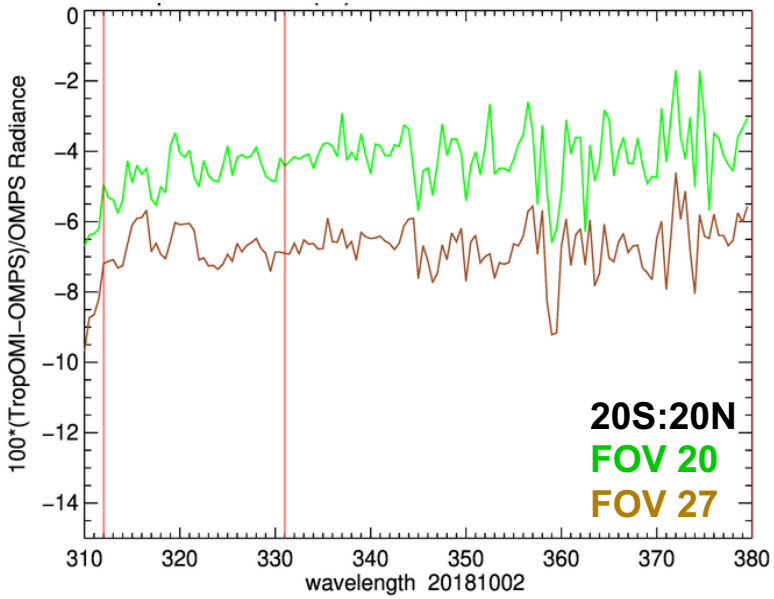
We looked at two fields-of-view for Band 3, one in the nadir (OMPS FOV 20) and one off-nadir (OMPS FOV 27)

1) TROPOMI radiances are smaller than OMPS by as much as 5%
2) Difference shows little dependence on wavelength above 320 nm.
3) Wavelength dependence varies with the 3 latitude bands below 320 nm.
4) Wavelength dependent structure exhibited in FOVs 20 and 27 is somewhat correlated implying:
   1) Not completely successful in accounting for differences in the sensor characteristics.
   2) Effects (such as Raman scattering) were not completely accounted for.

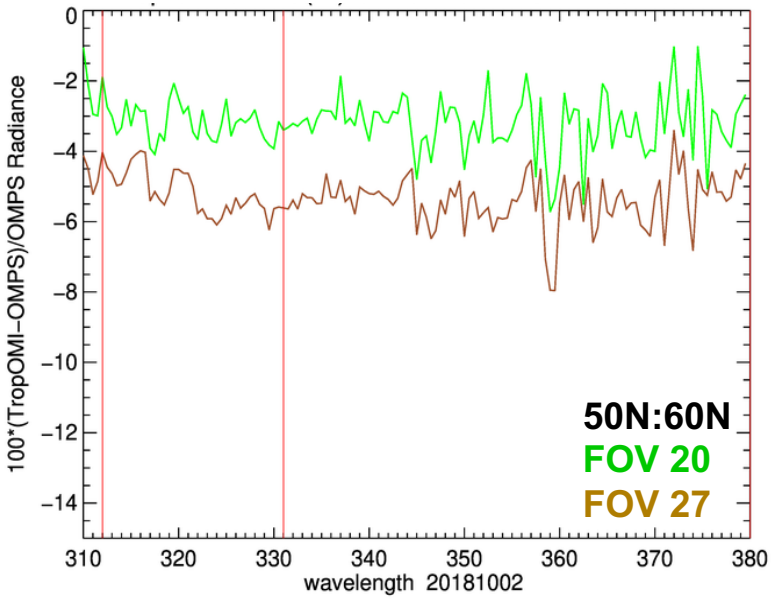
TROPOMI V2 – OMPS, % SH



TROPOMI V2 – OMPS, % EQ



TROPOMI V2 – OMPS, % NH

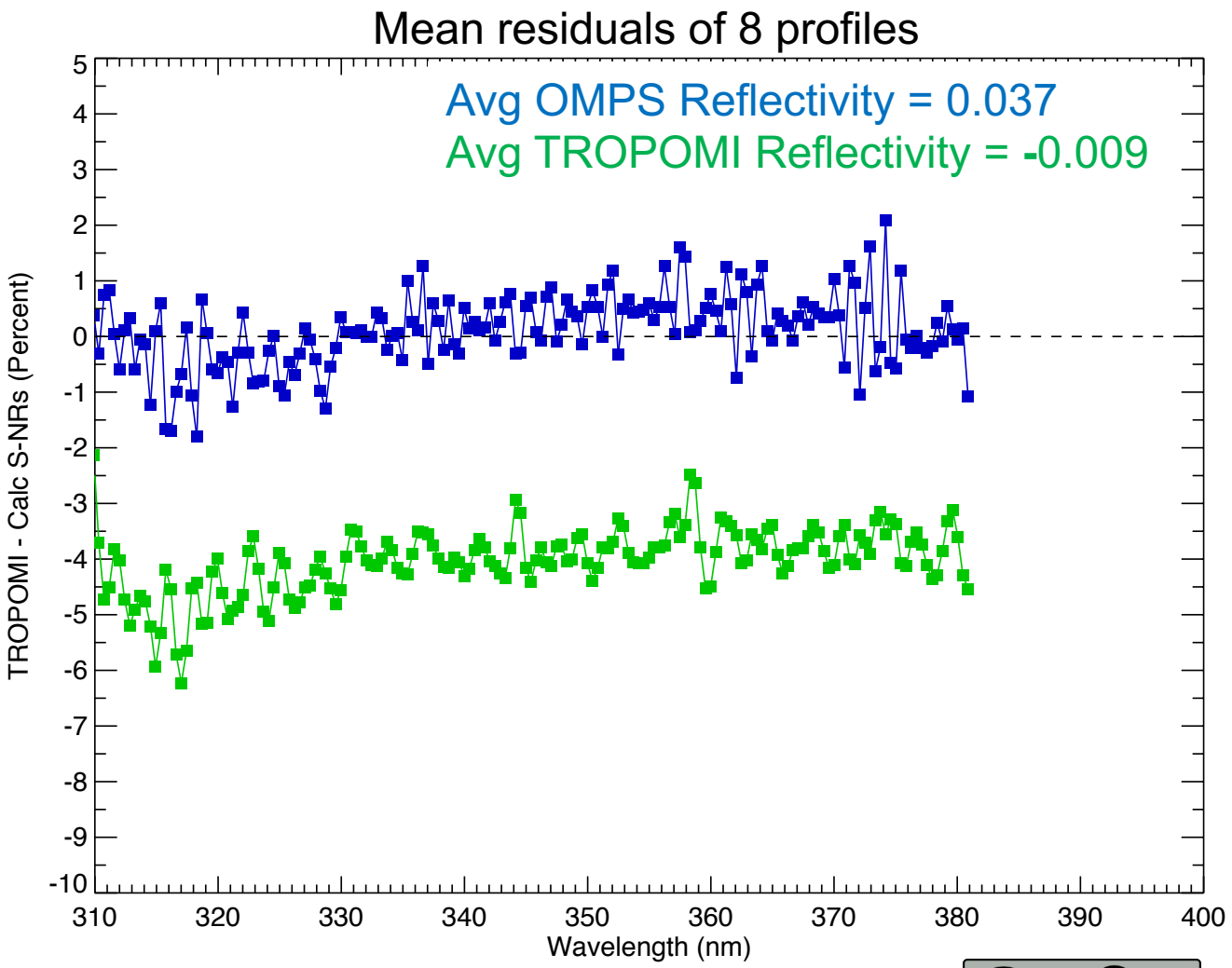


So, how do we determine which radiances are more accurate, TROPOMI or SNPP OMPS?

- This is where the DRCM method is utilized
  - We compare both sets of measurements to calculated radiances from a radiative transfer model
  - Our radiative transfer model is TOMRAD
    - Well validated and tested after decades of use
  - We picked one day (2 October 2018) to perform the comparisons
  - OMPS solar, satellite, and relative azimuth angles used (co-located)
  - Two different sets of “truth” profiles: OMPS nadir profiler sensor and MLS
    - For the MLS ozone profiles, we “swapped” the tropospheric ozone amounts for the McPeters, Labow, and Logan climatological values.
    - For the OMPS profiles, we used a climatological temperature profile.
  - Scene reflectivity
    - Lambert Equivalent Reflectivity (LER) determined from the OMPS measurements
    - This ***does*** link the RTM calculations to the OMPS measurements
    - Since we constrained this reflectivity to be < 0.05, clouds are not an issue
  - To simplify the comparison, we limit our analysis to measurements from -20 to 20 degrees latitude and over ocean.

Our residual results (Measured – Calculated sun-normalized radiances, or S-NRs) show a 4-5% difference

- Eight measurements fit within our constraints
  - The plot at right is the average difference
- OMPS residuals are within +/- 1%
- TROPOMI residuals are ~4% lower
  - 5% for wavelengths < ~325 nm
- Retrieved LER from OMPS is ~4%
  - Close to the generally accepted minimum surface LER over ocean
- Calculated LER from the TROPOMI radiances is **negative (-1%)**
  - Not only too low, but unphysical
- ***We believe this is strong confirmation that the OMPS S-NRs (and radiances) are correct while those from TROPOMI are not.***



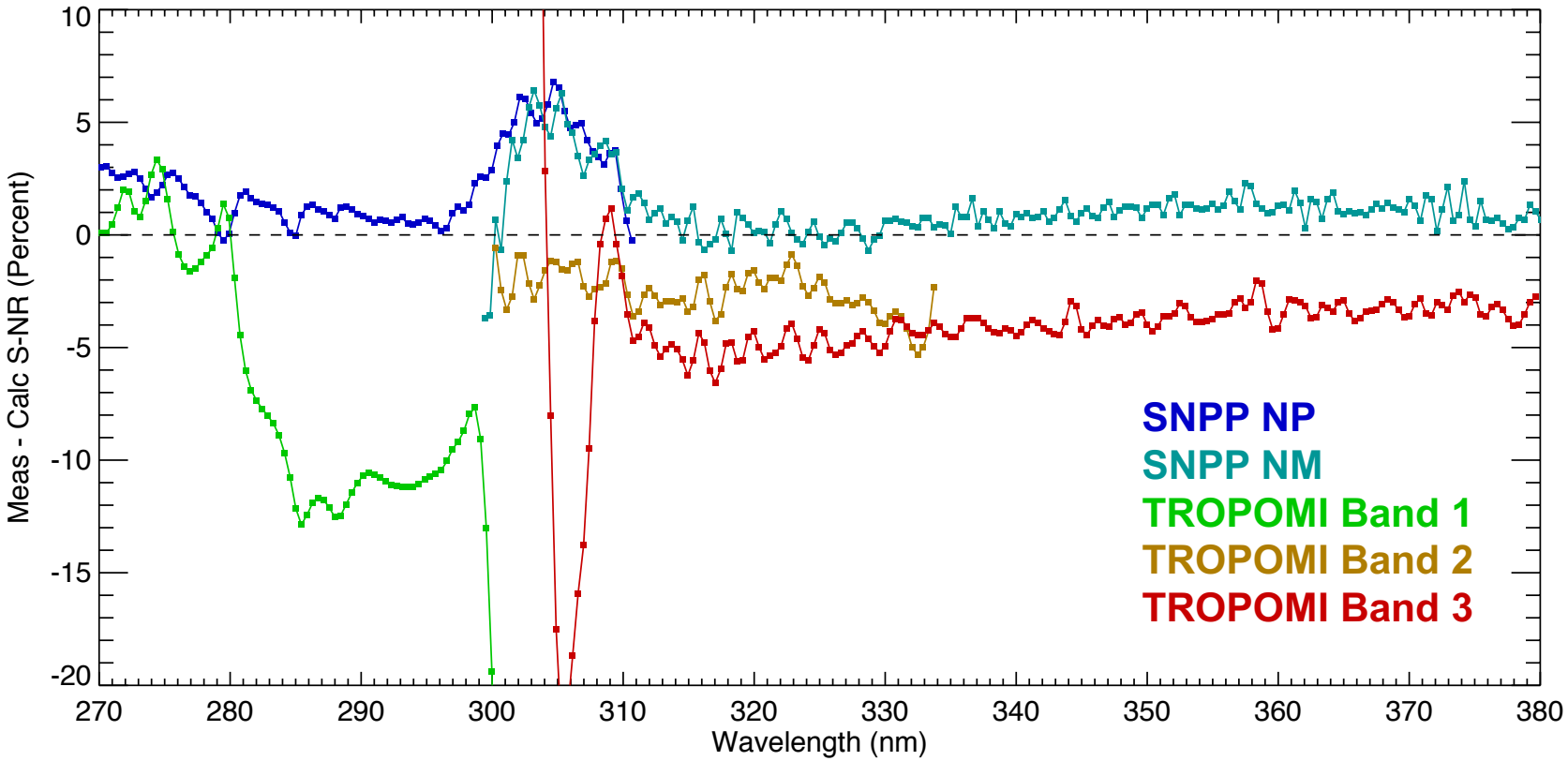
We then broadened the scope of our DCRM method to include Bands 1, 2, and 3

- To encompass the wavelengths used in Band 1, we now include S-NRs from the OMPS nadir profiler (NP) sensor as well as the nadir mapper
  - Since the NP has a much larger footprint (250x250 km), we now utilize that FOV in our calculations
  - Both the OMPS nadir mapper (NM) and TROPOMI S-NRs that are contained within the NP FOV are averaged together
  - The viewing conditions of the NP are now used in the RTM calculation
  - Two different sets of “truth” profiles: OMPS nadir profiler sensor and MLS
    - For the MLS ozone profiles, we “swapped” the tropospheric ozone amounts for the McPeters, Labow, and Logan climatological values.
    - For the OMPS profiles, we used a climatological temperature profile.
  - We used the scene reflectivity determined by the NP sensor
    - Because of the large FOV, we relaxed our LER constraint to be < 0.15
  - We, once again, simplified the comparison to only include measurements from -20 to 20 degrees latitude and over ocean.
  - We switched our day of comparison to 7 August 2019 so that we could compare to results independently determined by the TROPOMI calibration team

DRCM residuals for all 3 bands*

(Avg 3 measurements, MLS profile with NP trop component used)

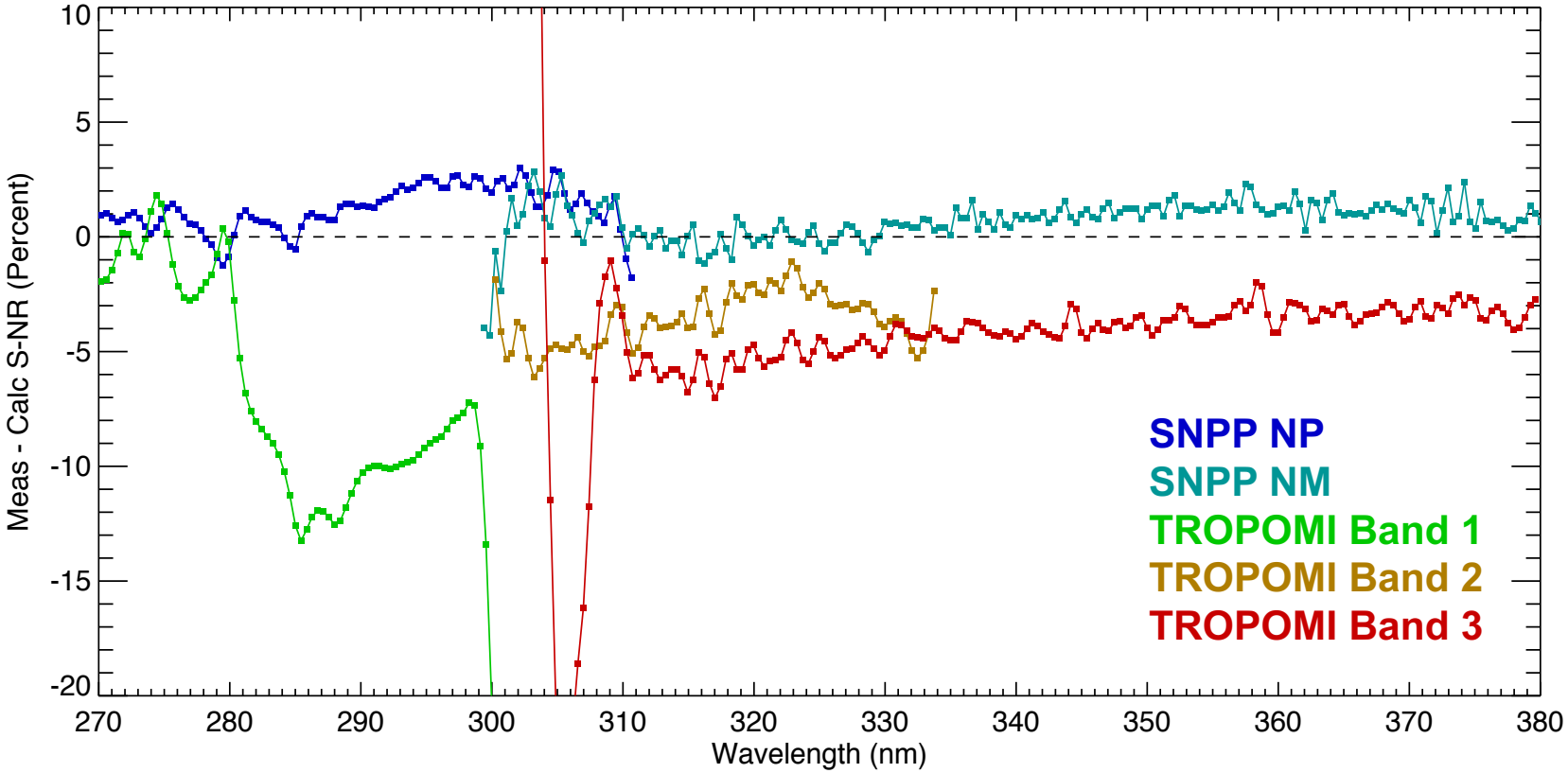
- In general, good agreement is seen between OMPS measured S-NRs and calculated S-NRs
  - "Bump" between 300-310 nm indicates difference between MLS determined total ozone amount and amount determined from OMPS
- Large differences between TROPOMI S-NRs and calculated S-NRs
  - Differences > 10% seen for Band 1



Residuals for all 3 bands*

(Average of 3 measurements that met criteria, **NP profile used**)

- Similar results are seen when the NP ozone profile used as input to the RTM model
  - NP retrieved profiles agree well with the SBUV/2-based MOD (Merged Ozone Dataset)
  - Better agreement with OMPS measured S-NRs is seen between 300-310 nm, which is to be expected



The TROPOMI (KNMI) calibration team (specifically, Pepijn Veefkind) has been doing a similar analysis

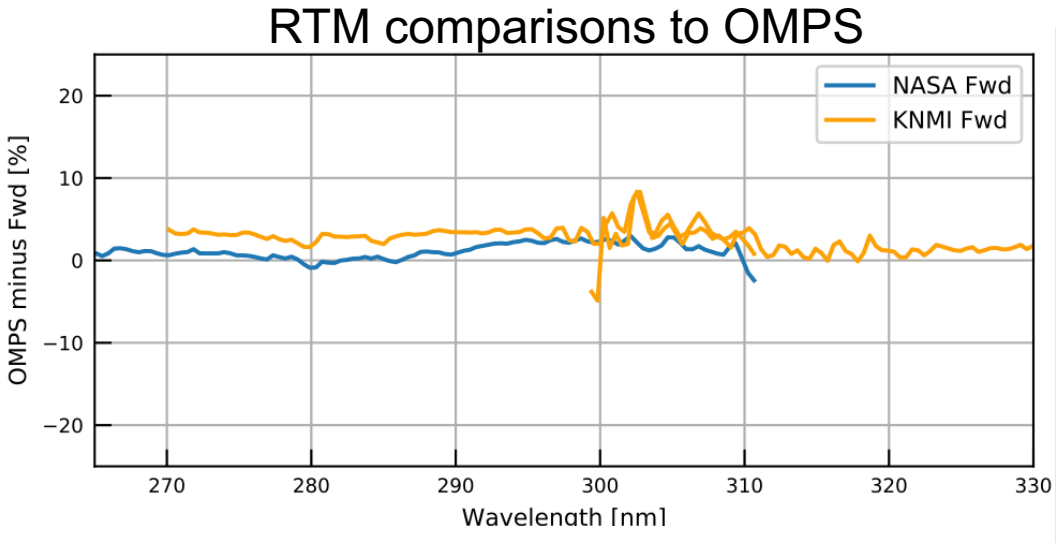
- Chose to look at on OMPS NP ground pixel on 7 August 2019
  - 25 OMPS NM ground pixel co-located with NP selected and averaged
  - Band 2 pixels are binned to Band 1 binning and concatenated in single spectra
  - TROPOMI spectra co-located with OMPS NP and averaged

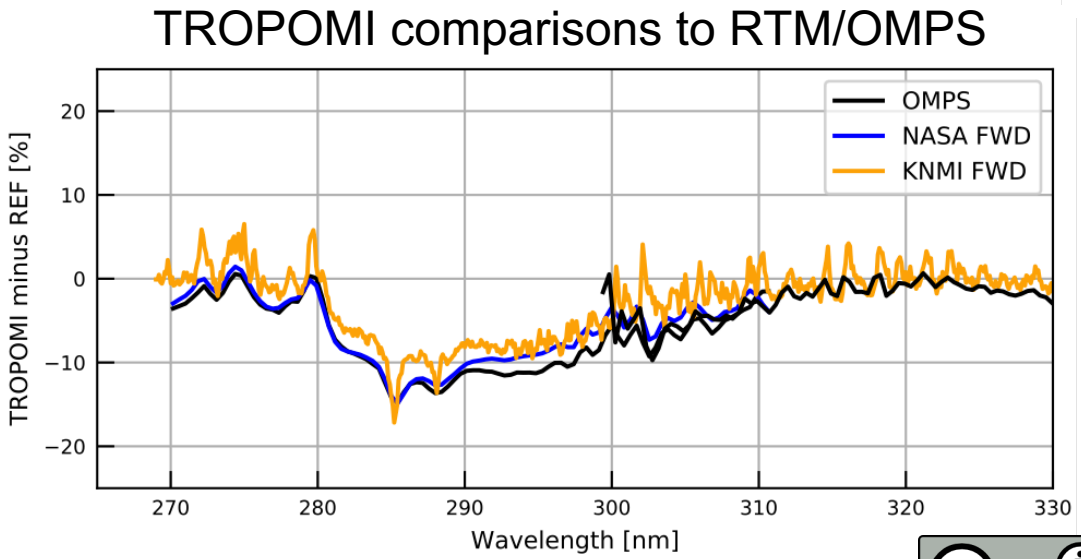
- DISAMAR forward model calculations are performed for each Band 1 ground pixel
  - Includes polarization but not Raman scattering
  - OMPS NP values are averaged and convolved with a flat-topped Gaussian
    - N-2 and FWHM-1.05 nm, n=2 and FWHM =0.85 for NM
  - Two approaches used in model
    - Ozone profile from CAMS, scaled to match OMPS L3 total ozone amount (256.7), surface albedo fitted in a small window between 328 and 330 nm
    - NP profile is used
      - Converted to VMR profile
      - Surface albedo set to 0.09132 (our retrieved LER for this measurement)

Pepijn's results for Band 1 and 2 using NP profile are quite similar to our results

- We still see some significant differences between our RTM results and those from the TROPOMI
  - Probably due to differences in model input that we haven't yet resolved
  - We are currently working (at a low priority level) to understand the differences

- Despite RTM differences, both Pepijn's (KNMI) and our (NASA) results indicate large (>10%) errors in the Band 1 radiances
  - Comparison shows difference between TROPOMI S-NRs and those from OMPS (black), from our RTM calculations (blue), and from the KNMI RTM calculations (orange)





Conclusions

- The DRCM is a useful technique for comparing measurements between different satellite instruments
  - The DRCM serves as a “transfer standard” between the measurements
  - The calibration of the instruments can then be compared and contrasted
- Comparisons of measurements between TROPOMI and SNPP OMPS were used as an example to demonstrate the techniques
  - The comparisons indicated large differences between the sun-normalized radiance between TROPOMI and OMPS
    - Larger than 10% for Band 1
    - The results confirmed that problems with the sun-normalized radiances from TROPOMI were due to issues with the radiances
    - The results were further validated by results from the TROPOMI (KNMI) validation group using a technique similar to DRCM