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Status of NOAA-20 Ozone Monitoring Profiler Suite (OMPS) Sensor Data Calibration and Evaluation

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Abstract

The Ozone Mapping and Profiler Suite (OMPS) aboard the Joint Polar Satellite System-1 (JPSS-1) spacecraft is the 2nd Ultraviolet (UV) Sensor Suite launched on November 18, 2017. Similar to the OMPS on S-NPP, the OMPS on JPSS-1 or NOAA-20 (N20) contains two advanced nadir viewing hyper-spectral instruments, Nadir Profiler (NP) and Nadir Mapper (NM), to measure the total column and vertical profile of ozone in the atmosphere globally. This paper first briefly summarizes the status of calibration to OMPS/N20 sensor data record (SDR) at NOAA, which reached provisional maturity status on April 28, 2019, then presents an initial assessment to its quality. These assessments include the (1) inter-comparison of the spectral among NOAA-20, S-NPP and TROPOMI, and (2) comparison with simulations using the radiative transfer model, TOMRAD. The major inputs of the simulations are the collocated ozone profiles from S-NPP and the total ozone amounts, which are from two different sources, i.e. NASA S-NPP and TROPOMI L2 products. The results show that most channels of OMPS/N20 meet the requirements with an accuracy below 2%. The difference of the OMPS/N20 spectral from S-NPP and TROPOMI is mainly due to the difference in observing geometry, and further studies are needed.

Keywords: S-NPP, N20, OMPS, sensor data record (SDR), inter-comparison

1. INTRODUCTION

The Ozone Mapping and Profiler Suite (OMPS) aboard the Joint Polar Satellite System-1 (JPSS-1) spacecraft was launched on November 18, 2017, the follow-on mission of the S-NPP (Suomi National Polar –orbiting Partnership) launched on 2011. On S-NPP the OMPS sensor suite consists of two advanced nadir viewing sensors, i.e. the Nadir Mapper (NM) and the Nadir Profiler (NP), as well as a limb-viewing sensor, the Limb Profiler (LP) [1]. Similar to the OMPS on S-NPP, the OMPS on N20 also contains a Nadir Profiler and a Nadir Mapper, but no Limb Profiler, to measure the radiance on the top of atmosphere, which are used to derive the total column and vertical profile of ozone in the atmosphere once a day globally. Limb Profiler measurements will resume in JPSS-2 and follow-on missions. OMPS/N20 has successfully passed the Early Orbit Checkout (EOC) and is currently in the late stage of the intensive calibration and validation phase (ICV). The Sensor Data Record (SDR) products of OMPS/N20 reached provisional maturity status on April 28, 2019 and are ready for operational validation. Like the sensor system on S-NPP[2], OMPS on N20 is calibrated to provide a baseline for monitoring both the sensor health and the key SDR attributes that matter most to the quality of the ozone Environmental Data Records (EDRs). The important SDR attributes include dark current, electronic bias, linearity, stray-light, solar fluxes, and wavelengths. A previous comparison of these characteristics of OMPS on S-NPP from the lab and orbiting sensor tests[3] showed that the orbiting nadir sensors' electronic bias, detector gain, dark smear, dark current rate, and linearity remained within 0.2% of the prelaunch values, with the biases and linearity continuing to be stable. The specifications for OMPS/N20 SDR are similar to OMPS/S-NPP.

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In general, the OMPS SDR performance depends on both the instrument performance and the SDR algorithm performance. The SDR algorithm performs the necessary processing steps to remove and correct sensor effects that are inherent to the sensor hardware, such as bias, dark current, linearity, wavelength registration and radiance calibration. The routine calibration activities to OMPS/N20 are the same as those to OMPS/S-NPP, which include the monitoring and delivery of the look-up tables associated with dark rate evolution, nonlinearity variation, stray-light contamination, NP solar and spectral wavelength shifts. This paper aims to make an initial assessment to NOAA OMPS/N20 SDR products by comparing the OMPS NP and NM spectral with those from OMPS/S-NPP and TROPOMI. In addition, we used radiative transfer model, TOMRAD, to simulate radiance of OMPS/N20 observations, which is also compared to the calibrated SDR products of OMPS/N20. Section 2 gives a brief summary of the difference of OMPS on N20 with S-NPP in spatial sampling and spectral range, as well as the data used in this paper. Section 3 shows the results of these spectral comparisons with some discussion of the causes for the difference. A summary and conclusion is given in session 4.

2. DATA AND METHOD

2.1 OMPS SDR Data Acquisition, Processing and the Difference between S-NPP and N20

The OMPS Nadir system has a common telescope with two grating spectrometers that provide a spectral sampling of 0.4 nm and 1-nm full-width half-maximum (FWHM) spectral resolution. The NP covers the wavelength range from 250 nm to 310 nm using 147 spectral channels for S-NPP, and two more channels are added in the two ends for N20. The NM covers 300 nm to 380 nm using 196 spectral channels for both S-NPP and N20. The two Nadir sensors not only view the backscattered UV radiances from the Earth but also the irradiances from solar and internal lamp calibration sources, all of which are recorded by the CCDs into separate Raw Data Record (RDR) outputs. A NM full frame CCD readout consists of 340 spectral columns by 740 (2 x 370) spatial rows for the NM cross-track, plus 2 x 12 serial over-clock pixels at each edge in the vertical and 2 x 20 parallel over-clock smear pixels in the horizontal direction in the middle. The OMPS NM full image frame readout size is thus 780 rows x 364 columns. To conserve the telemetry data rate during the normal operations (with Earth integration times of 7.48 s), and to provide a 3.15 deg. Nadir Mapper instantaneous field of view (IFOV) at nadir during Earth observations, the pixels in each NM column are spatially binned into 37 macropixels, including 35 cross-track spatial cells and two-binned smear macropixels (each consisting of the central 16 of the 20 smear pixels). The individual pixels on an Earth-view CCD are integrated by exposure time in the along-track spatial direction to form the required horizontal cell sizes, resulting in a resolution of 50 km by 50 km at nadir for S-NPP and 17 km by 50 km for N20. The Nadir Profiler sensor operates in a similar manner to create an RDR, except using all the NP pixels acquired to aggregate into a single cell for S-NPP and 5 by 5 macropixels for N20, thus achieving the NP cell size of about 250 km by 250 km for S-NPP, and 50 km by 50 km for N20. Figure 1 shows the difference of sampling pattern between N20 and S-NPP. For NM, the number of along-track pixels increases by 3 times in N20, i.e. from 5 to 15, and for NP there are 5 by 5 pixels in N20 corresponding to one pixel in S-NPP.

On the ground, separate OMPS SDR algorithms for NM and NP are used to convert the RDRs into the radiometrically-calibrated and geo-located spectra, which are stored into an SDR. Basically, at the system level the OMPS SDR is defined as sensor data that are: 1) time referenced and geo-referenced by parameters such as the ephemeris of the orbiting satellite, 2) Earth geo-location and/or orbit-located for remote-sensing measurements, and 3) calibrated by applying any ancillary information, including radiometric and geometric calibration coefficients. The OMPS SDR Algorithm was developed to function on the processing hardware, as well as for SDR product performance requirements. Detailed theoretical descriptions of the OMPS SDR Algorithms can be found in the OMPS SDR Algorithm Theoretical Basis Description (ATBD) documents[3, 4], and descriptions of the operational SDR Algorithms can be found from NASA documents[5, 6].

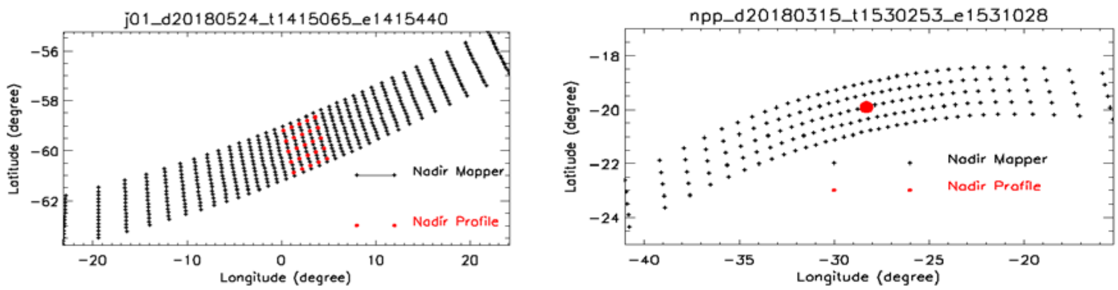

Figure 1 Sampling patterns of NM & NP for OMPS on N20 (left) and its comparison with OMPS on S-NPP (right). Red dots are for N20 and black dots are for S-NPP for one granule.

2.2 Radiative Transfer Simulations

As one way to validate the calibrated SDR products, we used radiative transfer models to simulate radiance of OMPS observations. In these simulations, TOMRAD (v2.26) was used to calculate the radiance in 0.1 nm resolution, then make convolution using the NM and NP band pass respectively. Solar irradiance data is from Chance et al.(2010)[7]. To minimize the impact from the band pass difference among different sensors, only the reflectance that is normalized by the solar irradiance will be compared in the following analysis.

2.3 Data Used

The most important inputs data in the radiative transfer simulations include the input ozone profiles, the total ozone amounts, and surface reflectance. The impact of temperature to the ozone absorption is small, so the climatology of temperature profiles can be simply used. Absorptions by NO2 and SO2 needs to take into account. However, due to the lack of in-situ NO_2 and SO_2 measurement data, only the NO2 and SO2 profiles from climatology are used in the simulations. In our simulations, the collocated S-NPP NP ozone profiles are used, and two types of the total ozone amounts are used, i.e. the collocated S-NPP L2 products from NASA DESC[8, 9] and TROPOMI ozone products[10]. The closest ozone profile from S-NPP with the time difference within 1 hour from N20 was selected since N20 was just 50 minutes behind S-NPP. For the matchup with N20, the total ozone amounts of S-NPP or TROPOMI are used when their time difference from N20 is within one hour and the spatial distance is within 2 km. For simplification, the surface albedo data used was from the albedo at 331 nm in NOAA L2 EDR products without considering the change of surface albedo with wavelengths. In our comparison, N_value, which is defined as log of the normalized radiance (measured radiance/solar irradiance) with base 10 and multiplied by -100, is used.

The n20 data product algorithms are in operations through either the Interface Data Processing Segment (IDPS) implemented by Raytheon or through S-NPP Data Exploration (NDE) at Environmental Satellite Processing Center (ESPC). S-NPP data used is from through CLASS (Comprehensive Large Array-data Stewardship System) in the website: https://www.bou.class.noaa.gov/saa/products/welcome. Spectral of TROMPOI was downloaded from NASA GES DISC[11].

3. RESULTS

3.1 Comparison of N20 Spectral with S-NPP and TROPOMI

Since OMPS/S-NPP and TROPOMI align with each other, we found that the spectral of OMPS/S-NPP and TROPOMI, in general, agree quite well, except the TROPOMI spectral has large variation due to its higher spectral resolution, as shown in the three spectral in Figure 2. However, OMPS on N20 and S-NPP does not always agree with each other even though their distance is within 2 km.

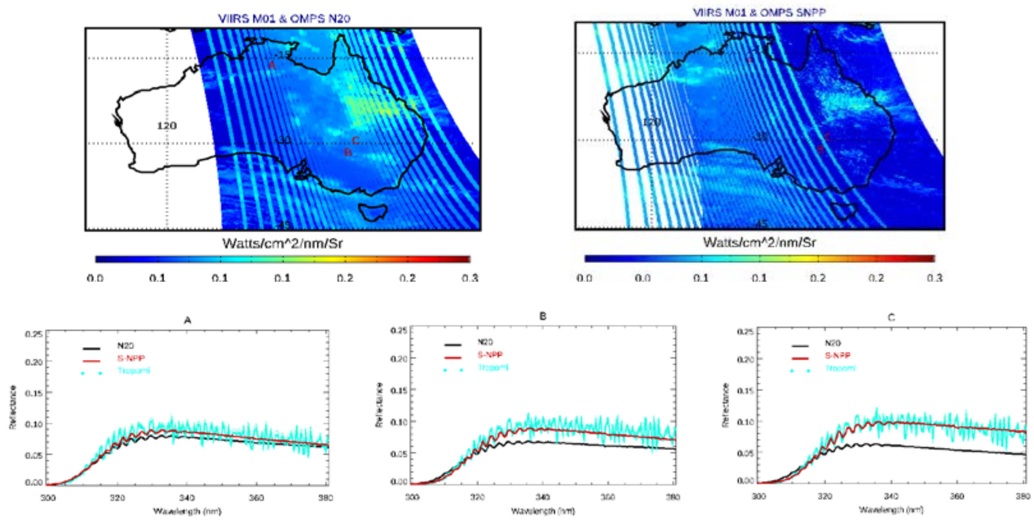

Figure 2 VIIRS Channel 1 on NOAA-20 overlaid with OMPS on NOAA-20 (upper left) and OMPS on S-NPP (upper right). Lower three panels are spectral in the three pixels A, B and C as marked in upper panels.

Comparison of N20 OMPS spectral for one pixel with one closest pixel observed by S-NPP or TROPOMI is hard because the solar zenith angles and satellite viewing angles are different, which results in the difference of the optical depth of UV lights passing through the atmosphere. One of the major difference in the optical depth is due to the Rayleigh scattering by molecules. So, in our comparison we first selected the closet pixels, then selected the spectral when the difference in channels near 360-380nm between OMPS/N20 and OMPS/SNPP is less than 2%. Use of the channels near 360-380nm is because the ozone absorption in these channels are small.

Figure 3 shows the comparison of N20 NP plus NM spectral with the S-NPP spectral. As NM on S-NPP has only 147, which is 4 less than N20, only 147 channels for NP is compared. In this preliminary analysis, we used data on April 25, 2019 and the pixels whose latitudes are below 60 degrees and the solar zenith angles are less than 80 degrees, because the signals for other pixels outside of these ranges are usually very small. Except for a few NM channels below 300 nm, we can see from Figure 3 that for most channels the mean difference is less than 2%, which meet the requirements. These a few NM channels below 300 nm are not listed in the OMPS requirement and they are not used in the ozone total amount retrieval.

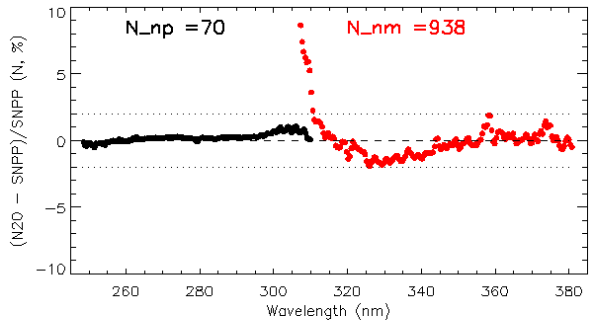

Figure 3 Comparison of N20 spectral with S-NPP spectral. Black dots are for NP channels, and red dots are for NM channels.

Figure 4 shows the comparison of OMPS/N20 NP spectral with TROPOMI band 1 and OMPS/N20 NM spectral with the TROPOMI band 3. Similar to the comparison of OMPS/N20 with S-NPP, the TROPOMI pixel closet to OMPS/N20 was selected first. Since TROPOMI has a finer spectral resolution, the spectral of TROPOMI is smoothed using 6 points for band 1 and 4 points for band 3. A linear interpolation of the TROPOMI spectral to the N20 spectral is made, as the wavelength coverage for TROPOMI band 1, 267 to 300 nm, is shorter than OMPS/N20 NP from 248 to 312 nm. As the spatial resolution of TROPOMI is 7*3.5 km while the resolution of N20 NM is 17*50 km, the mean spectral of TROPOMI of 9*3 TROMOPI pixels is used for comparison with OMPS/N20. As we did before, only those spectral with the difference in channels near 360-380nm between OMPS/N20 and TROPOMI is less than 2% are used in the statistic analysis in Figure 4. Overall, for NP, OMPS/N20 is less than TROPOMI by -3 ~ -4%, and for NM their difference varies with channels, and on average it is about -3 ~ -4%. Obviously, with a finer spatial resolution TROPOMI could see more clear pixels than OMPS, which can be a reason leading to some difference. More careful comparison by selecting the clear uniform cases will be carried out in the next step.

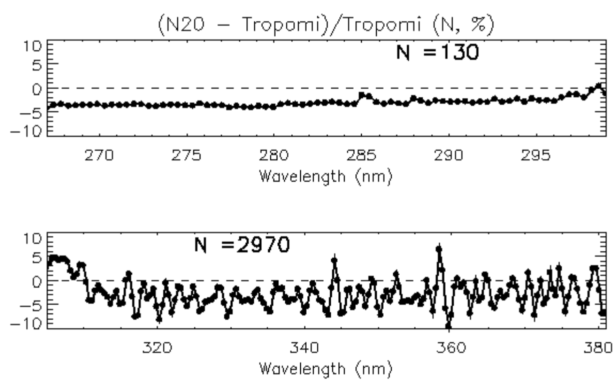

Figure 4 Comparison of N20 spectral with TROPOMI spectral

3.2 Comparison of N20 Spectral with Radiative Transfer Simulations

Figure 5 shows the comparison of OMPS/N20 spectral with the radiative transfer simulations using inputs from NASA S-NPP EDR products. TOMRAD is a fast model, however, it is still time consuming to simulate one day data using linux machine. Here we used 10 granules near west Pacific Ocean and 10 granules near the Australia. Similar to Figure 3 the mean difference is larger than 2% for a few NM channels below 300 nm. The increase of the OBS-CAL with wavelength above 330 nm, which decreases with wavelength when using N-Values as shown in Figure 5, is caused by the use of a fix surface albedo, i.e. at 331 nm, in our simulations. Use of a real albedo that increases with wavelength will alleviate this trend. Another limitation in our simulations is that we have not considered the variation of SO2 and NO2 concentrations in the atmosphere.

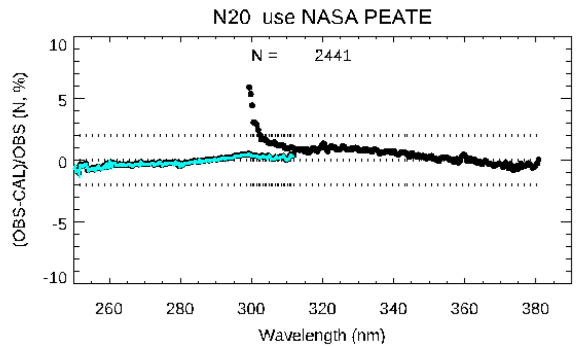

Figure 5 Comparison of OMPS N20 spectral with the simulations using inputs from NASA S-NPP EDR data. Orange line is for NP channels and black dots is for NM channels.

Similar to Figure 5, Figure 6 shows the comparison of OMPS/N20 spectral with the radiative transfer simulations that using total ozone amounts from TROPOMI. In this comparison we used the clear cases in the whole day with cases, N = 20,305. The difference in Figures 5 and 6 is very small.

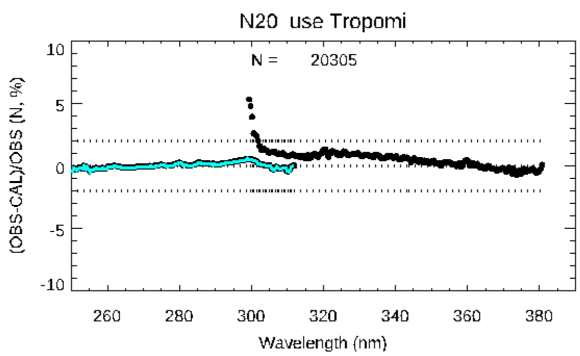

Figure 6 Same as Figure 5 but using the total ozone from TROPOMI products

4. SUMMARY AND CONCLUSION

A preliminary assessment of N20 NP and NM SDR products using one day data has been made via (1) inter-comparison of N20 spectral with the collocated S-NPP and TROPOMI spectral, and (2) comparison of N20 spectral with model simulations.

Inter-comparison of OMPS/N20 spectral with OMPS/S-NPP shows that most channels of OMPS on N20 meets the requirement with an accuracy of 2%, but the difference of OMPS on N20 with TROPOMI is a little larger. Due to the large difference in the observing geometry, such a comparison is not conclusive and need more works by selecting the clear, uniform scene and making sure the optical path is similar. In the simulations, the closest collocated S-NPP ozone profiles within one hour, and the collocated total ozone amounts within 2 km and 1 hour from two different products, i.e.(a) S-

NPP, and (b) TROPOMI, are used. The comparison of simulated spectral with OMPS SDR data also verified that most OMPS/N20 channels meets the requirement with an accuracy of 2%. These comparisons also suggest that, for desirable comparison, model simulations need to include the absorption of SO2 and NO2 as well as the variation of surface albedo with wavelength.

This study provides some insight information for NOAA-20 OMPS post-launch calibration assessment and preliminary analysis of its calibration stability and consistency with S-NPP. We will continue to use these approaches to monitor the status of OMPS and to improve the radiance calibration at NOAA in the future.

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