Release 2 data products from the Ozone Mapping and Profiler Suite (OMPS) Limb Profiler

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ABSTRACT

The OMPS Limb Profiler (LP) was launched on board the NASA Suomi National Polar-orbiting Partnership (SNPP) satellite in October 2011. OMPS-LP is a limb-scattering hyperspectral sensor that provides ozone profiling capability at 1.5 km vertical resolution from cloud top to 60 km altitude. The use of three parallel slits allows global coverage in approximately four days. We have recently completed a full reprocessing of all LP data products, designated as Release 2, that improves the accuracy and quality of these products. Level 1 gridded radiance (L1G) changes include intra-orbit and seasonal correction of variations in wavelength registration, revised static and intra-orbit tangent height adjustments, and simplified pixel selection from multiple images. Ozone profile retrieval changes include removal of the explicit aerosol correction, exclusion of channels contaminated by stratospheric OH emission, a revised instrument noise characterization, improved synthetic solar spectrum, improved pressure and temperature ancillary data, and a revised ozone climatology. Release 2 data products also include aerosol extinction coefficient profiles derived with the prelaunch retrieval algorithm. Our evaluation of OMPS LP Release 2 data quality is good. Zonal average ozone profile comparisons with Aura MLS data typically show good agreement, within 5-10% over the altitude range 20-50 km between 60°S and 60°N. The aerosol profiles agree well with concurrent satellite measurements such as CALIPSO and OSIRIS, and clearly detect exceptional events such as volcanic eruptions and the Chelyabinsk bolide in February 2013.

Keywords: Remote Sensing, Limb Scatter, Ozone Vertical Profiling, Hyperspectral, Retrieval Algorithm, Data Products.

1. INTRODUCTION

The Suomi National Polar-orbiting Partnership (S-NPP) satellite was originally designed to serve as a bridge between existing NOAA and NASA polar-orbiting environmental satellites and future National Polar-orbiting Environment Satellite System (NPOESS) missions, and to provide technology demonstration of new or improved remote sensing instruments proposed for those missions. One component of the S-NPP payload is the Ozone Mapping and Profiler Suite (OMPS)[1], which both extends long-term ozone measurements and provides new operational capabilities. The Nadir Mapper (NM) instrument continues the global total column ozone data record begun by the Total Ozone Mapping Spectrometer (TOMS) instruments[2], and continued by the Ozone Monitoring Instrument (OMI)[3]. The Nadir Profiler (NP) instrument provides profile ozone data that are consistent with the continuous data record from the Solar Backscattered Ultraviolet instruments (Nimbus-7 SBUV, NOAA SBUV/2 series)[4].

In order to provide profile ozone data with good vertical resolution (< 3 km) and full global coverage, OMPS also includes a Limb Profiler (LP) instrument. The LP instrument uses a 2-D CCD to collect limb scattered radiance data simultaneously over a wide spectral range (290-1000 nm) and a wide vertical range (0-80 km), allowing the retrieval of ozone profiles between 10-60 km with approximately 1.8 km resolution. The LP measurement concept was originally demonstrated on the Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE)[5]. Similar missions with limb scattering measurements include the Optical Spectrograph and Infrared Imaging System (OSIRIS)[6] and the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY)[7]. Initial OMPS LP measurements began in January 2012, and a Release 1 ozone data product was released in December 2012[8].

This paper briefly describes the changes and improvements that have been implemented to create OMPS LP Release 2 data products, which were released in July 2014. There are four products represented: gridded radiance data, ancillary data, aerosol extinction coefficient profiles, and ozone profiles. We will review some relevant instrument characteristics briefly, and then describe the Release 2 data products and their quality, with emphasis on the ozone profile data.

2. INSTRUMENT DESCRIPTION

The design and key characteristics of the LP instrument have been described previously[9]. Following their terminology, we separate the spectral range of the LP sensor into three regions for discussion: UV = 290-370 nm, VIS = 370-750 nm, IR = 750-1000 nm. Figure 1 shows a schematic of the OMPS viewing geometry. Since LP views backwards along the spacecraft orbit, the tangent point of the line of sight (the point where the line of sight intersects an Earth radius vector at a right angle) is approximately 25º in latitude to the south of the subsatellite point. LP employs 3 vertical slits, where the center slit is aligned with the orbit track and the left and right slits are each separated horizontally by 4.25° from the center slit (approximately 250 km at the tangent point). Consecutive measurements are separated by approximately 125 km along-track, so that the revisit time for a given location is approximately 4 days.

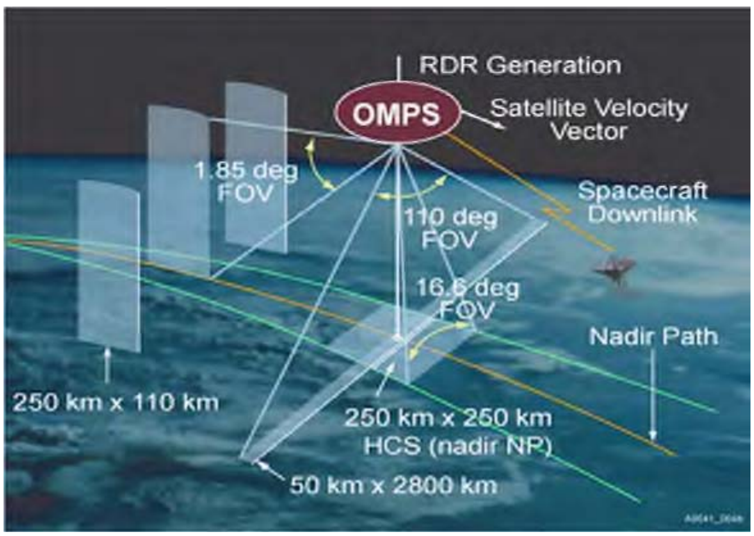

Figure 1: A schematic of the fields of view for the 3 OMPS sensors.

Each slit uses two apertures (large and small) simultaneously to accommodate the variation in signal between high altitude (lowest intensity) and low altitude (higher intensity). Short and long integration time samples are also interleaved within a single measurement interval. Thus, four separate radiance samples are available for each pixel. In addition, the LP optical design leads to variations in spectral and spatial registration (also known as “smile”) across the CCD.

3. DATA PRODUCTS

3.1 Gridded Radiances

Since most retrieval algorithms are designed to operate on a uniform spectral and altitude grid, we create a Level 1 gridded radiance product (L1G) for this purpose. For Release 2, we now select the single sample at a given pixel that has the best signal-to-noise ratio without being saturated. Different priority schemes are used for UV data and VIS-IR data. Next, the data are transformed to a fixed rectangular grid using bilinear interpolation[10]. Finally, the L1G radiance values are selected to ensure the use of data from a single aperture for each wavelength[9].

The on-orbit wavelength registration of the LP instrument shows systematic variations on the order of ~0.2 pixels that are correlated with sensor temperature variations[9]. This represents wavelength changes of ~0.2-0.3 nm in the

UV region, increasing to ~5 nm in the IR region as the LP resolution changes. We have addressed these variations for Release 2 by creating two orthogonal correction functions, one applied to intra-orbit variations and the other one applied to seasonal variations. These corrections improve the accuracy of the L1G radiances when they are interpolated to a fixed wavelength grid.

The long distance from the S-NPP spacecraft to the tangent point location on the Earth's limb (approximately 3300 km) means that accurate knowledge of the LP instrument pointing is needed to determine the proper altitude registration for radiance data. Multiple techniques have been used to evaluate and quantify absolute offsets in the prelaunch pointing[9]. For Release 2, the adjustments applied for the left, center, and right slits were revised to be 1.45 km, 1.75 km, and 2.60 km respectively. In addition, an intra-orbit tangent height adjustment is now applied, with a maximum shift of approximately 300 m at the northern terminator of each orbit.

3.2 Ancillary Data

The LP forward radiative transfer model requires temperature and pressure profiles that extend up to 80 km for the calculation of simulated radiances. In addition, while the LP ozone retrieval provides number density profiles *vs*. altitude as its standard product, ozone mixing ratio *vs*. pressure profiles are also created for the convenience of users. This step requires reference atmosphere temperature and pressure profiles corresponding to the time and geolocation of each LP measurement. For Release 2, we now use the Np collection data set produced by the NASA Global Modelling Assimilation Office (GMAO) Goddard Earth Observing System Model-5 (GEOS-5) Forward Processing for Instrument Team (FP-IT)[11]. These data are provided on 42 pressure levels up to 0.1 hPa (~62 km), at 0.5° latitude x 0.625° longitude horizontal resolution, and at 3-hour temporal intervals. Each of these values represents improved sampling and coverage compared to Release 1 data. Since the FP-IT Np spatial grid is denser than the LP sampling, we identify the nearest grid point to the tangent point location of each event, and then linearly interpolate the closest temperature and pressure profiles to the observation time. For the forward model, we extrapolate the temperature profile up to 80 km using a constant lapse rate of -1.5 K/km for simplicity, then generate the corresponding pressure profile assuming hydrostatic equilibrium. We note that these data are only supplied for user reference, and do not represent a product derived from LP measurements.

The ancillary data built from GEOS-5 pressure and temperature profile data are generally very consistent with MLS measured profiles when interpolated to the same time of day and geographic location. Figure 2 shows a comparison of zonal average pressure profiles for four cardinal days in 2013 (March 21, June 21, September 21, December 21) over the latitude range 60°S to 60°N and the altitude range 10 km to 60 km. Pressure differences are generally less than ±2%, with some larger differences in December. Temperature differences on these dates (not shown) are generally less than ±5 K, with small pockets of larger differences on each day.

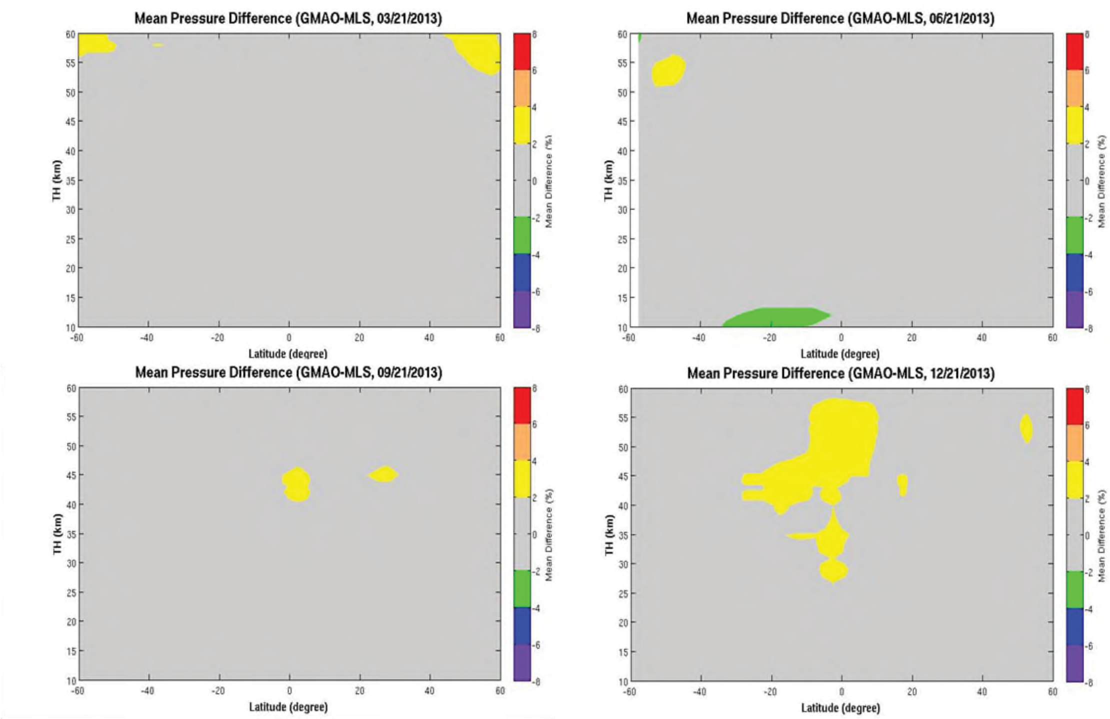

Figure 2: The daily zonal mean differences between GMAO and MLS pressure profiles. *top left* = March 21, *top right* = June 21, *bottom left* = September 21, *bottom right* = December 21. Gray areas indicate pressure differences less than ±2%.

3.3 Aerosol Extinction Coefficient Profiles

OMPS LP retrieves aerosol extinction coefficient profiles at five wavelengths (nominal values 514, 526, 674, 748, 865 nm), using the Release 1 retrieval algorithm[10]. The only change made for Release 2 processing was to decouple the aerosol retrieval from the UV ozone retrieval, which had almost no effect on the extinction coefficient results. Initial comparisons of LP Release 2 aerosol profiles with contemporaneous data sets such as CALIPSO and OSIRIS are good, with average differences on the order of 10%. The temporal sampling and geographic coverage of LP aerosol data has also proven valuable in characterizing major events, such as the Chelyabinsk bolide in February 2013[12] and the Nabro (January 2012) and Kelut (February 2014) volcanic eruptions.

Figure 3 shows a series of weekly average zonal mean extinction profiles at 748 nm over the location of the Kelut eruption (8°S). During the first week after the eruption, the extinction profile is uniformly increased up to 20-21 km. Over the following six months, a distinct maximum develops that gradually rises in altitude from 19 km to 22 km. We interpret this behavior to indicate changes in the composition of the volcanic plume over time, as the initial ash discharge falls out and the emitted SO_2 is converted to sulfate aerosols.

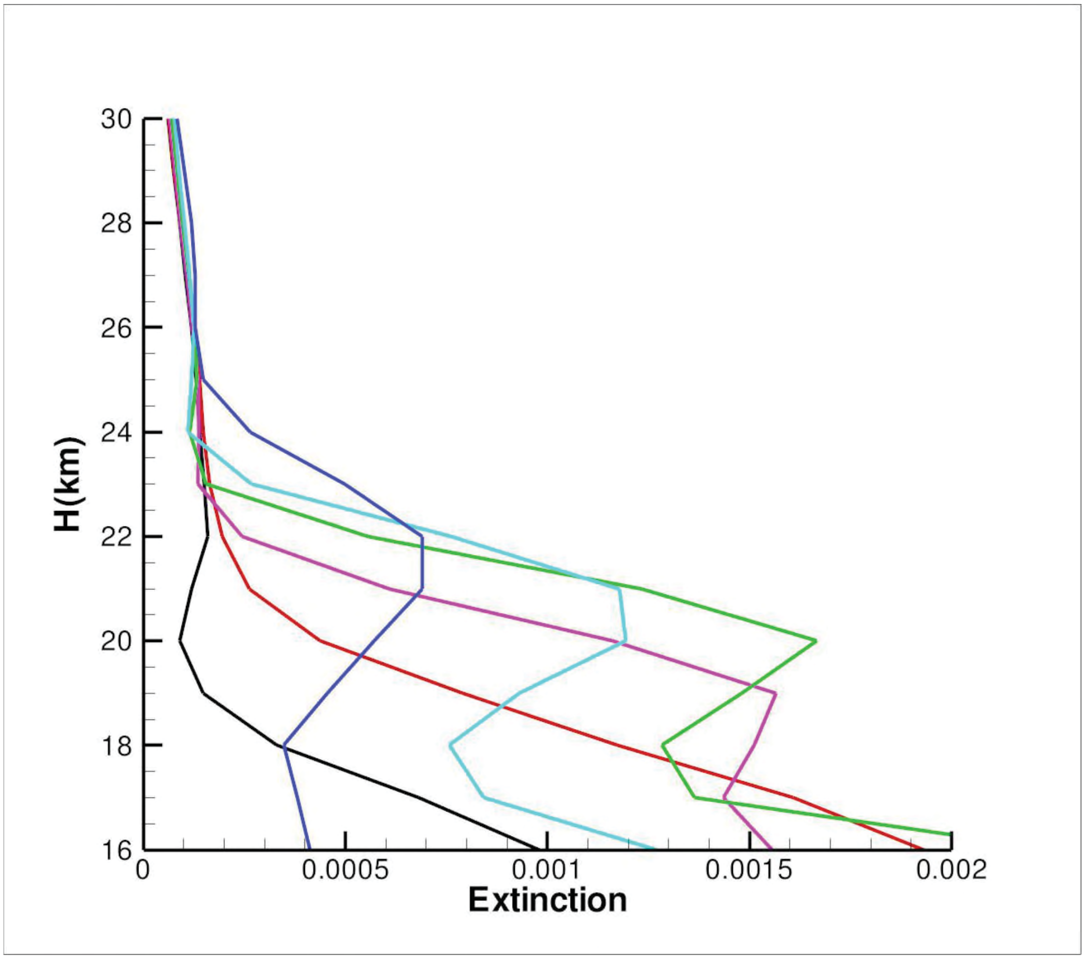

Figure 3: Zonal mean profiles of 748 nm aerosol extinction at 8°S. *Black* = 7-13 February 2014 (prior to Kelut eruption). *Red* = 14-20 February 2014 (1 week post-eruption). *Purple* = 28 February – 6 March 2014. *Green* = 30 March – 4 April 2014. *Turquoise* = 5-9 May 2014. *Blue* = 10-15 August 2014.

3.4 Ozone Profiles

LP Release 2 ozone profiles are created using a revised version of the Release 1 ozone retrieval algorithm[10]. The retrieval process uses a pair formulation at UV wavelengths (referenced to 353 nm) to reduce sensitivity to assumed pressure profile errors, and a triplet formulation at VIS wavelengths (referenced to 510 nm and 674 nm) to also reduce the sensitivity to aerosols. Both retrievals also use altitude-normalized radiances to remove the impact of absolute calibration errors and diffuse upwelling radiation (e.g. surface reflection, clouds). Further discussion of additional instrument-level uncertainties such as South Atlantic Anomaly (SAA) particle hits on the CCD, residual stray light, and tangent height registration is given elsewhere[9].

A number of changes were made in the ozone retrieval algorithm for the Release 2 data product. We briefly describe the key elements of these changes in the following section.

<u>Aerosol Correction</u>. The Release 2 algorithm does not apply an explicit aerosol correction in either portion of the retrieval. For VIS wavelengths, any resulting errors are most likely to be observed in the lower stratosphere, when aerosol extinction can reduce the ozone airmass factor along the line of sight (LOS). Comparisons with Aura MLS data indicate that these errors for a single profile are substantially smaller than typical event-to-event variability. However, we have found that the ozone retrieval at UV wavelengths is particularly susceptible to the presence of polar mesospheric clouds (PMC). Although PMC exist at 80-85 km, they can affect retrieved ozone densities at

lower altitudes (down to 40 km) if they are located in the instrument LOS. We have implemented a flag to identify PMC-contaminated profiles, which are generally found in summer months at latitudes greater than 50°.

OH Emission. We found that UV ozone retrievals were producing density errors up to 5-10% at 40-55 km due to additional radiance dayglow emission from the OH band at 309 nm. For Release 2, we exclude radiance values in a 5 nm wide region surrounding this band from the retrieval to remove the error from the retrieved profiles.

Assumed Instrument Error. We found that assuming instrument errors in the covariance matrix based solely on the signal-to-noise ratio of the measurements could produce large high-frequency vertical oscillations in the retrieved ozone profiles, particularly near the upper and lower limits of the altitude range. Introducing a constant estimated error of 1% to the covariance calculation for Release 2 processing greatly reduced this problem.

High-Resolution Solar Flux. We now use a high-resolution solar irradiance spectrum that combines ATLAS-3 SUSIM data at UV wavelengths[13] and MODTRAN data at VIS-IR wavelengths[14] for forward model calculations. This change significantly improves the quality of the radiance residuals from the forward model, although the impact on the retrieved ozone profiles is quite small (~0.2%).

Combined Ozone Profile. The UV ozone retrieval produces a density profile between 27.5 km and 60.5 km, while the VIS ozone profile is retrieved from cloud top up to 30-35 km, where both limits vary with each event. In order to create a single profile from these retrievals for each event, the Release 2 product limits the maximum altitude of the VIS portion to 26.5 km, and appends the entire UV portion above this altitude.

A Priori. For Release 2, the *a priori* ozone climatology now uses monthly average 10° zonal mean Aura MLS data for 2012. We interpolate the profiles from the nearest reference grid points to the time and latitude of each LP event in order to better capture spatial and temporal variability. Retrieved ozone differences from Release 1 data are generally less than ±1% below 50 km when the new *a priori* data are used.

Extensive validation studies with LP Release 2 ozone data are now underway. Figure 4 shows an example of the results obtained when we compare LP ozone data with MLS ozone data for a monthly average in February 2014. Zonal mean differences are generally less than ±10% between 100 hPa and 1 hPa over all latitudes, with some larger differences only below 60 hPa (~20 km) in the tropics. Overall, we are pleased with this performance.

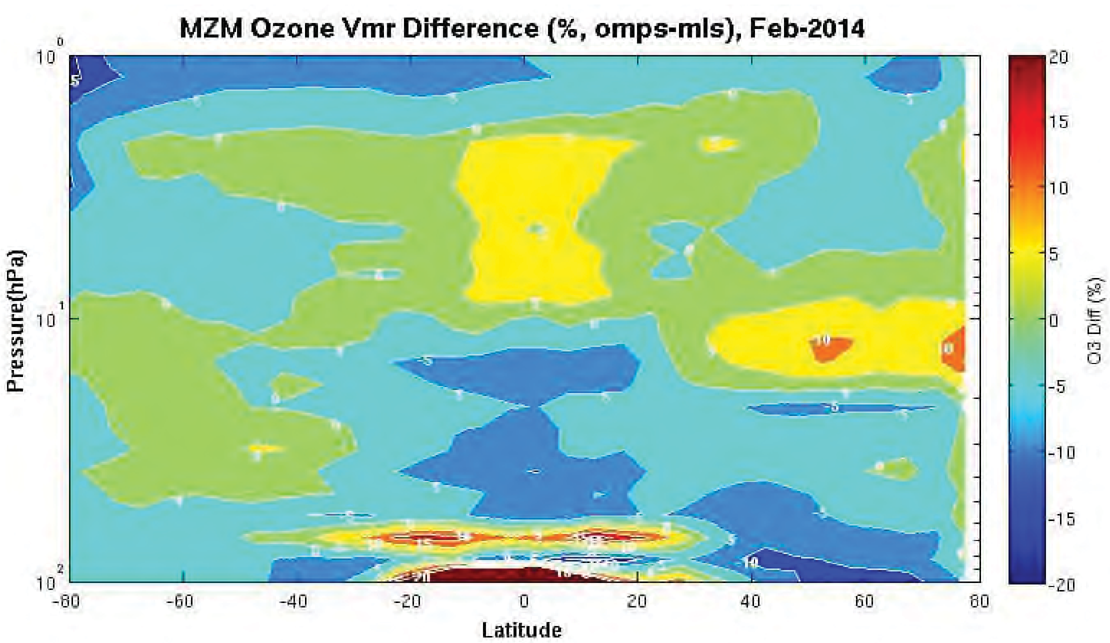

Figure 4: Difference between OMPS LP and Aura MLS monthly zonal mean ozone mixing ratio data for February 2014.

4. CONCLUSION

The OMPS LP instrument has been operating successfully since it began on-orbit measurements in January 2012. The combination of limb scattering design and a hyperspectral detector provides ozone profiles between 10-60 km with good vertical resolution and comprehensive spatial sampling. A full reprocessing of the entire mission, designated Release 2, has recently been completed and released to the public. LP data products include gridded radiances, aerosol extinction coefficient profiles, and ozone profiles. The Release 2 ozone retrieval algorithm incorporates numerous revisions that improve the quality of the ozone profiles. Comparison of LP ozone and aerosol data products with concurrent data from other satellite instruments indicates that the quality of the LP products is very good.

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