A Status Report to NASA Headquarters

Of the OMPS Science Team Evaluation

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Executive Summary

OMPS, the Ozone Mapper Profiler Suite, consists of two nadir sensors, the subject of this report, and a limb profile sensor. The Total Column mapper (TC) provides data to produce the total column ozone EDR, while the Nadir Profiler (NP) provides data to produce the nadir ozone profile IP. This report details the work performed by the NPP OMPS Science Team in their evaluation of the nadir sensors and ozone products. The OMPS Science Team was also charged with determining the suitability of using OMPS data for retrieving SO_2 (both volcanic and boundary layer) and cloud Optical Centroid Pressure (OCP).

This Executive Summary lists the major findings of the Science Team. The body of the report restates each major finding, followed by a detailed explanation and discussion as to how the Science Team arrived at them.

The OMPS EDR Algorithm

- The Nadir Mapper (TC) EDR product generated in IDPS lacks the maturity and stability of NASA's current OMPS product.
- The IDPS product still contains significant implementation problems leading to degraded product performance.
- The IDPS OMPS algorithms input data from other, unvalidated SNPP sensors. Consequently, errors are difficult to quantify, or to even identify.
- The multi-mission, long-term ozone data record has been established using NASA's Version 8 ozone retrieval algorithm. The Nadir Mapper and Nadir Profiler IDPS products are generated from older, independent algorithms that are inconsistent with Version 8 products.

Sensor Characterization

- The Nadir Mapper and Nadir Profiler sensors are performing within their pre-launch specification and are capable of measurements that can be used to generate dataset of high enough quality for climate/global change research.

OMPS SDR Products

- IDPS no longer produces a calibration data product. The TC and NP sensor calibrations are maintained using calibration data processed in the Ozone PEATE. Since the Science Team is indirectly responsible for sensor calibration, we did not evaluate this aspect of the products.
- The quality of the OMPS science SDR product remains poorer than what NASA typically uses in generating its ozone products. Many of the errors are small and difficult to identify because the IDPS environment is ill-suited for controlled investigation and tests.
- The SDR algorithms are difficult to debug and maintain. As a consequence, few of the necessary code changes have been implemented to date. The algorithms lack modularity and the flexibility needed to deal with sensor performance problems and future enhancements in sensor operations.

OMPS EDR Products From Science Team

- The Science Team, working with the PEATE, has implemented the most recent NASA retrieval algorithms on a research basis using, as input, their research SDRs.
- Comparisons between the Science Team/PEATE research TC EDR and OMI indicate that, under the right conditions and with compatible algorithms, the OMPS TC sensor is quite capable of providing data to extend the long-term total column ozone data record.
- Comparisons between the research NP EDR and MLS indicate a high quality data set capable of continuing the SBUV2 data record.
- Investigations by the Science Team's SO_2 group have shown that volcanic and anthropogenic SO_2 can be retrieved from OMPS TC spectral measurements to meet the two goals in their proposal: to provide NRT SO_2 data for aviation hazard mitigation and to continue the long-term SO_2 EDR over the globe.
- The Science Team's OCP group is continuing to work with other members of the team to further characterize, understand, and reduce the impact of the diffuser interference features and other sensor effects on cloud pressure retrievals.

Data Production in the IDPS Operational Environment

- The Science Team found that the system managed by the JPSS Ground Project to process SNPP data (IDPS) is ill-matched to the production of climate data records, where science-driven development and data quality are more important than the tight configuration control and processing integrity needed for operational processing.
- The system is not well-suited to immature algorithms and processes, such as with any new mission and especially with a new sensor design (OMPS). The process of "working out the kinks" needs to occur in a system where rapid prototyping and allowance for failure are the norm.
- The time necessary to implement calibration corrections, bug fixes, and other changes in the operational (IDPS) system is excessively long.
- Traceability/provenance is a major issue concerning IDPS-generated products. It is a challenge to replicate offline the products generated in the operational system.
- The IDPS system has no capability to reprocess data, a fundamental requirement for creating (and maintaining) the high-quality datasets needed for climate/global change studies.

Path forward

- Formalize the role of the OMPS science teams to make them responsible for creating OMPS science data products that are consistent with heritage UV remote sensing products.
- Merge the roles of the Ozone PEATE and heritage data processing systems (e.g. OMIDAPS) to form an integrated processing, archiving, and distribution group for OMPS, OMI, TOMS, and other UV remote sensor products.
- Resolve command and control issues for the OMPS sensors so that NASA retains its current influence over the measurements made by the Suite.

A Status Report to NASA Headquarters Of the OMPS Science Team Evaluation

Richard McPeters, Colin Seftor, and the NASA NPP OMPS Science Team

1 Introduction and Background

This report details the work performed by the NPP OMPS Science Team in their evaluation of the Ozone Mapping and Profiler Suite (OMPS) nadir sensors and products. The Total Column mapper (TC) provides data to produce the total column ozone EDR while the Nadir Profile sensor (NP) provides the ozone vertical profile Intermediate Product (IP).

The OMPS nadir sensors are designed to provide operational retrievals of total column ozone and ozone profile while, at the same time, continuing the long-term total column ozone and ozone profile record begun by the heritage Total Ozone Mapping Spectrometer (TOMS) and Solar Backscattered UltraViolet (SBUV and SBUV/2) series of sensor systems flown on NOAA and NASA satellites. While utilizing the same backscattered ultraviolet retrieval techniques as those instruments, the OMPS sensors rely on modern CCD detectors similar to OMI's. While providing many advantages over the old phototube-based sensors, CCD measurements present their own set of challenges.

The Science Team has incorporated their experience not only with TOMS and SBUV/2 but with OMI in their analysis of the performance of the OMPS nadir system, paying particular attention to whether OMPS measurements of total column ozone and ozone profile can be used for climate/global change studies. Specifically, the OMPS Science Team was charged with evaluating the performance of the OMPS nadir system to determine:

1) whether the performance of the OMPS nadir sensors provided data of high enough quality for use in climate/global change studies;

2) whether the operational TC EDR was of high-enough quality to be used for climate/global change studies and to extend the over 30 year dataset of total column ozone developed using data from the heritage TOMS and OMI sensors;

3) whether the operational NP IP was of high-enough quality to be used for climate/global change studies and to extend the over 30 year dataset of nadir profile ozone developed using data from the heritage SBUV and SBUV/2 sensors;

4) the suitability of OMPS TC data for developing an SO_2 product for use in climate/global change studies and to extend the SO_2 dataset developed from the heritage TOMS and OMI sensors; and

5) the suitability of OMPS TC data for developing an Optical Cloud Pressure (OCP) product for use in the total column ozone and ozone profile retrievals, for climate/global change studies, and to extend the OCP dataset developed from the heritage OMI sensor.

1.1 Special circumstances of OMPS data production

Two events took place during the course of the Science Team's work that significantly impacted the development of the OMPS system and, therefore, their efforts. First, responsibility for the development of the OMPS limb system, designed to take high vertical resolution ozone profile retrievals, was transferred from NOAA to NASA. Second, the joint NOAA/DOD NPOESS Project was dissolved and, in its place, the civilian Joint Polar-orbiting Satellite System Project was created. These changes created two significant pre-launch issues concerning development of the OMPS system:

1) Although OMPS consists of 3 sensors (the limb sensor with its own telescope and optics, plus two nadir sensors that share the same telescope and much of the same optics), the control and operation for each occurs through a single central processing and electronics unit, the Main Electronic Box (MEB). While full responsibility for the OMPS limb sensor and operations was transferred to NASA early in the program, responsibility for the OMPS nadir sensors remained with NOAA and the JPSS Project Office.

2) Due to funding constraints within the NPOESS program, the development of an effective OMPS nadir calibration process, including the creation and testing of the calibration arm of the SDR algorithm, was not complete by the time of transition between the NPOESS and JPSS program. The loss of the contractor support for the NPOESS/OMPS system during the transition further exacerbated the problem.

The NASA OMPS Science Teams and the Ozone PEATE worked closely with the JPSS Ground and Flight Project offices to resolve the difficulties these issues presented. The result was a special group called the OMPS Science Operations Center (SOC) which is tasked with operating the OMPS Nadir sensors and maintaining their calibration. The OMPS SOC, which is funded by the JPSS Ground Project, is co-located with the Ozone PEATE and shares personnel. We provide more details below.

1.1.1 OMPS Nadir operations

The sensor Suite ConOps was designed so that science data are collected simultaneously by the Limb and Nadir sensors. Calibration data, sensor checkout data, and other diagnostic data are collected through Limb-only or Nadir-only measurements that require a high degree of coordination between sensors. The SOC and PEATE teams are responsible for developing a coordinated operations schedule for the Suite to accomplish the NASA and NOAA measurement objectives for OMPS. In addition, the teams jointly developed and use flight table generation and delivery tools to maintain the 3 sensors in their proper command and control configuration at all times. Not only has this combined operations team reduced the risk of operations errors, it has saved resources that would have resulted from duplication of effort at separate NOAA and NASA teams.

1.1.2 OMPS Nadir Calibration

The OMPS Earth-view (science) SDR algorithms convert raw sensor data into calibrated radiances using externally-supplied calibration coefficients. These coefficients are derived from analysis of pre-launch test data and from post-launch calibration data obtained during dedicated measurements. The original NPOESS-era design had an independent Calibration SDR algorithm performing calibration data analysis and automatically generating updated coefficients. The JPSS Ground Project agreed with an OMPS Science Team 2010 assessment of this system:

1) The structure of the code developed for calibrating the Nadir sensors (the SDR calibration algorithm) was not modular. As a result it was difficult, if not impossible, to test and validate

individual components of the algorithm, or to identify and correct for problems in coding or implementation.

2) The code was very inflexible. Changes in the operation of the sensor concerning how measurements are taken, which are often needed to account for unforeseen issues arising with the sensor post-launch, could not easily be handled, or could not handled at all, by the operational algorithms.

3) The automatic or semi-automatic nature of the IDPS calibration process meant there was little opportunity to influence or modify sensor calibrations should the process malfunction or not proceed as planned. Such a scenario was considered likely due to lack of testing.

Consequently, the Ground Project allowed the OMPS SDR Team (NOAA and NASA combined) to pursue alternate approaches to maintaining Nadir sensor calibration. The selected method involves the use of the OMPS SOC to process calibration data independent of the IDPS algorithm, and to provide calibration updates to the IDPS processing system via the JPSS Ground Project.

During the initial post-launch checkout of the OMPS Nadir sensors the SDR Team confirmed that the standard operational calibration sequence was inadequate for maintaining sensor calibration. The resulting operations changes, which had been recommended by the NASA OMPS Science Team, caused calibration data processing at IDPS to cease. The last calibration data processed there was from February, 2012. All calibration data collected subsequent to that date has been processed exclusively by the Ozone PEATE using an independently developed SDR algorithm. The PEATE also processes its own version of science SDRs and EDRs. The OMPS SOC uses results from all products to generate calibration inputs for the IDPS processing of OMPS Nadir science data.

2 Evaluation of the OMPS EDR algorithms

2.1 The TC EDR algorithm

The operational algorithm used for the TC EDR product is an enhancement of NASA's Version 7 total column ozone retrieval algorithm. The Version 7 algorithm first calculates a quantity known as the effective cloud fraction using the measured radiance at the non ozone-absorbing 380 nm wavelength to characterize the effect of clouds on the measurement scene. An initial estimate of the total column ozone amount is then determined by comparing measured radiances at 317 and 331 nm to a table of radiances calculated using a fixed set of ozone and temperature profiles; the effective cloud fraction previously calculated, along with information on cloud pressure and the location of snow and ice obtained through climatological databases, are used to account for the effects of clouds and snow/ice on the retrievals. The initial estimate is then adjusted to account for the actual ozone profile shape using the sensitivity of the 312 nm wavelength to profile shape at higher path lengths. Finally, an adjustment to account for the presence of aerosols is made. Studies of the effect of UV absorbing aerosols on ozone retrieval have shown that the error in ozone is linearly related to a quantity known as the aerosol index, which is simply the difference between the radiance measured at 380 nm and the radiance calculated at 340 nm using the reflectivity calculated at 380 nm. A linear correction is therefore applied based on the retrieved aerosol index.

Enhancements incorporated into the operational OMPS algorithm were designed to take advantage of the availability of co-located measurements from other sensors onboard the NPP satellite and the hyperspectral capability of the OMPS sensor.

The temperature profiles from CrIS are used to correct for the use of fixed temperature profiles in the initial estimate, the cloud pressure determined from VIIRS replaced the use of a climatological cloud pressure, and ozone profile information from the OMPS limb sensor retrieval was used to correct for profile shape effects instead of the sensitivity to profile shape errors at 312 nm.

To reduce the effects of sensor noise, retrievals of ozone are performed for 4 different sets of wavelengths, with the retrievals from each set being averaged together. The wavelength sets chosen for a given measurement depend on the sensitivity of the wavelengths to the initial estimate of the ozone amount using 317 and 331 nm and to the path length of the measurement. For larger initial estimates of ozone and for longer paths through the atmosphere, wavelength sets less sensitive to ozone absorption are used to ensure that the radiances traveled to the surface.

Operationally, the EDR algorithm follows a two-step process. In the first step, an intermediate product is generated using climatological information. It essentially is a retrieval using Version 7 of the NASA retrieval algorithm, enhanced by averaging retrievals from 4 set of wavelengths, with each set determined from its sensitivity to ozone absorption along with the path length of the measurement. The other S-NPP sensors that need an estimate of ozone for their retrievals then use this intermediate product. Once the retrievals from the other sensors are performed, corrections based on the information needed from those retrievals are applied to the intermediate product.

2.1.1 Status, maturity, and quality

Even though the operational EDR algorithm was based on a mature, stable version of NASA's total column retrieval algorithm, the enhancements designed to improve its performance do not have nearly the same level of maturity. And, as described in Section 5, the Science Team uncovered many problems with the implementation of the code, along with problems with the implementation of enhancements to the base algorithm, that severely affect the quality of the EDR product generated using it.

Another issue is that the long-term total column ozone record used for climate/global change studies is based on retrievals using Version 8 of NASA's algorithm. Inconsistencies that the Science Team discovered between the enhanced Version 7 algorithm used operationally and the Version 8 algorithm would introduce inconsistencies into, and hence degrade, the long-term record.

2.2 The NP EDR algorithm

The operational algorithm used to produce the NP Intermediate Product is Version 6 of the algorithm NASA developed for use with the SBUV/2 series of sensors. It should be noted that the ozone profile product is technically designated an Intermediate Product (IP) rather than an Environmental Data Record EDR) because it is not a mission required product.

2.2.1 Status, maturity, and quality

Because NASA's long-term ozone profile data record is based on retrievals using Version 8 of this algorithm, the Science Team did not evaluate the maturity or quality of the product from this Version 6 algorithm. Instead, the Science Team worked with members of the ozone PEATE to institute a research processing stream to retrieve ozone profiles from the PEATE's SDRs using Version 8 of the algorithm to determine if an NP product of sufficient quality could be made for climate/global change studies. Results of this work are presented in Section 5.

3 Sensor Characterization

As described above, the Science Team has been routinely analyzing the performance of the nadir sensors and providing calibration results to IDPS for implementation in the operational system. Our analysis of the diagnostic and calibration data indicates that both sensors are performing within their pre-launch specifications and are therefore capable of measurements that can be used to generate dataset of high enough quality for climate/global change research. However, because of the more stringent accuracy requirements to produce products such as SO_2 and OCP, more work is needed to provide the necessary sensor characterization needed.

Our analysis indicated that:

1) Both nadir sensors are performing consistently and are stable.

2) Data from the TC sensor indicates no degradation, while data from the NP sensor indicates that a small amount (~1% over one year) of radiometric degradation may have occurred. More study is needed, but if confirmed, this degradation can easily be accounted for.

3) The flight calibration process developed before launch was not adequate to provide the optimum data set needed to characterize and calibrate both nadir sensors, particularly for products other than total column ozone and ozone profile. The Science Team therefore recommended changes to the operational calibration sequence to provide data needed to provide improved sensor characterization and calibration.

We provide details of the ST's analysis below.

3.1 Data stability

In order to provide data that can contribute to a long-term data record, the OMPS sensors must be stable or correctable. The Science Team's analysis of the first nine months of OMPS data has shown these sensors to be unusually stable. We give two examples.

Figure 1 shows the residuals of the linearity measurements from the Nadir Profiler (the residual is the difference between the measured signal and the linearity applied. The figure indicates that not only is the linearity of the signal stable over time, but that our knowledge of the linearity is within ± 0.2% over the entire dynamic range of the sensor.

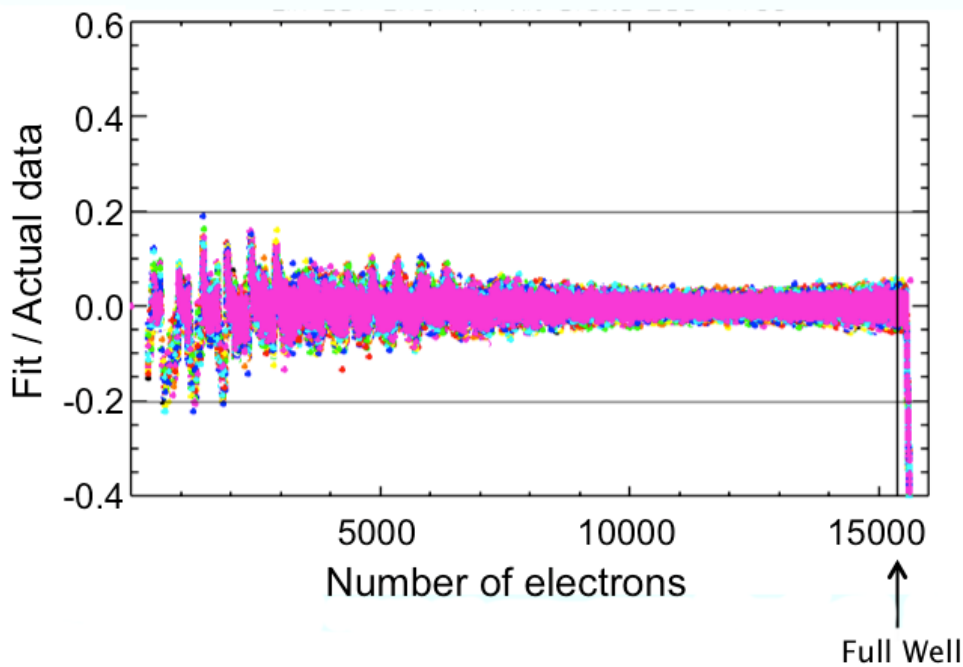

Figure 1: A plot of the ratio between the fit from a model of the linearity and the actual data shows that the linearity is stable to within the 0.2% requirement over the whole range of signal levels.

Figure 2 shows the time dependence of solar flux measurements taken over the first year of the mission at 317 nm (for TC) and 270 nm (for NP). These measurements are representative of those at other wavelengths.

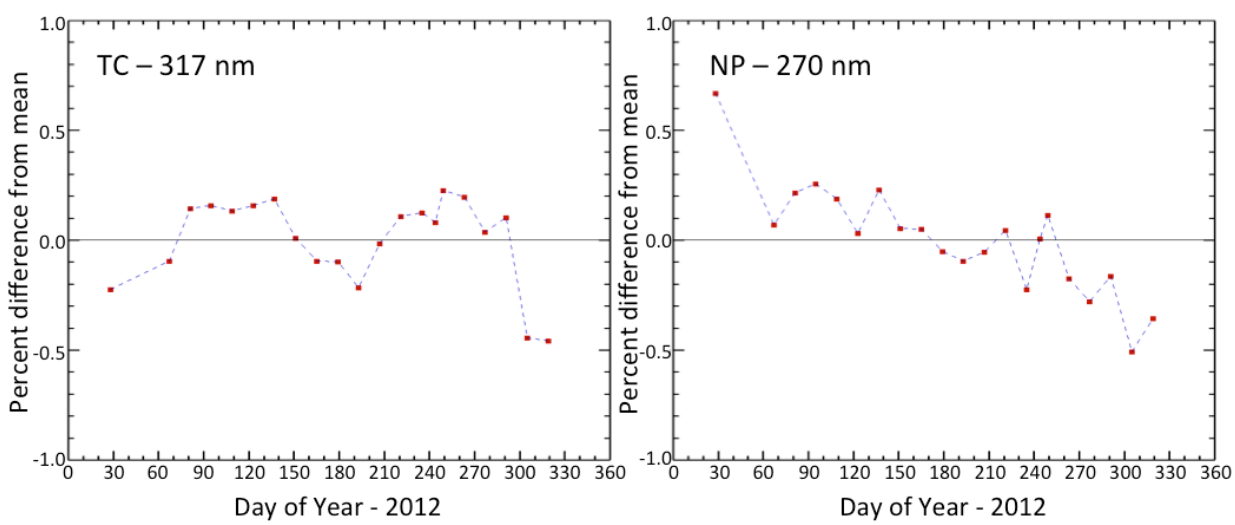

Figure 2: The plot on the left shows the ratio of the solar flux measurements for one wavelength of the TC sensor with the mean measurement for that wavelength. The plot on the right shows a similar ratio for the NP sensor.

For the TC sensor, there is no indication of any degradation. For the NP sensor a degradation of 1% over the first year of measurements is indicated, possibly caused by diffuser degradation. More analysis is needed to confirm the cause of this trend. Analysis by the Science Team will indicate whether this degradation is completely due to the diffuser itself, and if not, whether the change can easily be accommodated in data processing. Based on experience with previous instruments, such instrument changes can only properly be corrected for by reprocessing the data.

3.2 Diffuser interference features

As previously mentioned, the calibration of a CCD sensor presents challenges that are different from those of heritage sensors that relied on phototube detectors. In particular, measurements off of the aluminum diffusers used to determine the solar flux exhibit interference features driven by the spatial non-uniformity caused by the diffuser surface roughness and optical path of the sensor. These features, which are on the order of the CCD pixel size, not only affect the calibration used for ozone retrievals, but they are of particular concern for retrievals such as SO_2 and OCP that are highly sensitive to calibration errors. In the discussion below we present results for the TC sensor; results for the NP sensor are similar.

The plot on the left of Figure 3 shows the ratio of two solar flux measurements taken one month apart using the central part of the diffuser. These measurements were taken using the older calibration sequence in which 3 different exposures of the diffuser were combined for each measurement.

Since the diffuser interference features are highly dependent on the viewing geometry of the diffuser, and since that geometry varies over a seasonal cycle, the ratio exhibits inconsistencies of as much as 5 percent between two solar measurements that are taken at different times along that seasonal cycle. These errors directly affect the calibration accuracy of the TC sensor.

In the newer solar calibration sequence proposed by the Science Team, up to 23 individual exposures are collected and subsequently averaged. Since the interference features are highly dependent on the viewing geometry, and since the viewing geometry changes slightly for each exposure, the use of 23 rather than 3 exposures serves to reduce the amplitude of the interference structure. A plot of the ratio between the two newer solar measurements is shown on the right of Figure 3. The inconsistencies between the two measurements are greatly reduced. The OMPS Nadir operational calibration sequence was permanently modified to increase the number of solar exposures based on these Science Team findings.

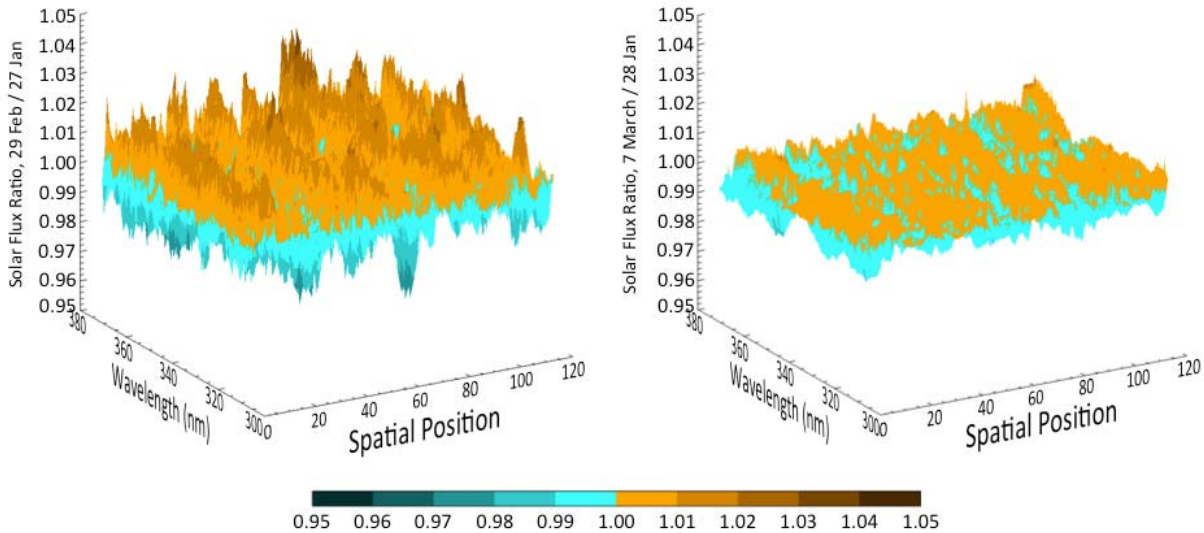

Figure 3: Ratios of solar flux measurement taken using different calibration sequences. On the left, the nominal pre-launch sequence using 3 exposures for each measurement was used. On the right, a sequence using 23 exposures for each measurement was used. The effects of diffuser interference features are greatly reduced in the modified sequence, which has since been adopted for used by NOAA-STAR.

We note that, although the new calibration sequence serves to reduce the effect of these features, the results indicate that they were not completely eliminated. For retrievals such as those for SO_2 and OCP, which are more sensitive to small calibration effects than the retrieval of ozone, they still are a factor that affects how well those retrievals perform, and the Science Team is actively engaged in investigating methods to further mitigate the effects.

We also note that the Science Team recommended, and JPSS Flight Project approved, the use of a Quasi-Volume Diffuser (QVD), which does not exhibit diffuser interference features, for the OMPS sensors that will fly on JPSS-1.

3.3 Normalized radiance calibration

3.3.1 OMPS TC sensor

In order to validate the calibration of the normalized radiance (radiance divided by the irradiance, or solar flux), the Science Team used comparisons with the MLS sensor flying on Aura. Assuming that the ozone and temperature profiles measured by the well-validated MLS sensor are accurate, co-located MLS measurements made during June 2012 were input, along with the viewing conditions of the OMPS sensors, to a radiative transfer code. The normalized radiances thus calculated represent what OMPS should have measured if the MLS profiles are accurate. These calculated values were then compared with the normalized radiances actually measured by the OMPS TC sensor.

Figure 4 shows, on the left, the comparison of measured normalized radiances to calculated radiances averaged for a latitude band from 20 degrees south to 20 degrees north for the nadir cross-track position. Only low reflectivity scenes (less than 0.10) were used to avoid clouds and their effects.

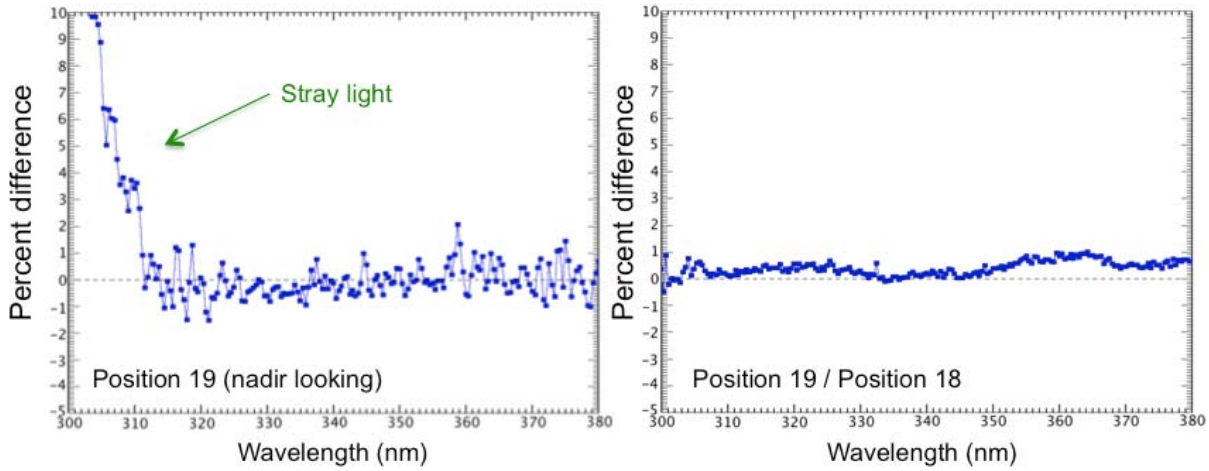

Figure 4: The left plot shows a comparison of normalized radiances calculated using MLS ozone and temperature profiles co-located with OMPS retrievals using the OMPS viewing conditions for cross-track position 19. The average is over 20 degrees south to 20 degrees north latitude for June. In the right plot, the difference for position 18 is subtracted from position 19.

A large deviation between calculated and measured NRs is seen shortward of 310 nm increasing with decreasing wavelength. This deviation is consistent with pre-launch measurements of stray light for the TC sensor. Any measurements using wavelengths below 310 nm therefore need to be corrected for stray light. Also, a peak-to-peak variation of about 2% can be seen wavelength-to-wavelength. However, when the same difference for scan position 18 is subtracted from scan position 19, the variation, along with the stray light signal, is greatly reduced. This leads to the conclusion that the variation is not noise but a physical effect not accounted for in the radiative transfer calculation (most likely Raman scattering). Once such physical effects are accounted for, the agreement between calculated and measured NR values is well within 1%, meeting the pre-launch requirement.

The behavior of the TC sensor at the outer (far off nadir) scan positions is examined in Figure 5. Using the same technique as before, measured and MLS-calculated values of the normalized radiances are shown for different cross-track positions, all with the comparison at position 18 subtracted. The comparisons show good agreement out to position 4 and 33, but at the very outermost positions (positions 1 to 3 and 34 to 36), significant differences begin to manifest themselves.

First, although the difference for cross-track position 18 is subtracted, structure is still seen in the far off-nadir positions because physical effects such as Raman scattering are different than those at position 18 and are therefore not fully accounted for. Second, a roughly linear dependence with wavelength can be seen. This dependence can be corrected through “soft” calibration techniques developed for heritage sensors. It should be noted that similar problems with retrievals at far off-nadir positions have been seen in the heritage sensors as well. Differences at these positions can be due to a number of reasons, possibly including a problem with representing the larger field-of-view at far off-nadir in the radiative transfer calculation. Since, unlike with the heritage sensors, the OMPS FOV can be varied, the Science Team plans to use this feature to further study far off-nadir issues affecting all of these sensor systems.

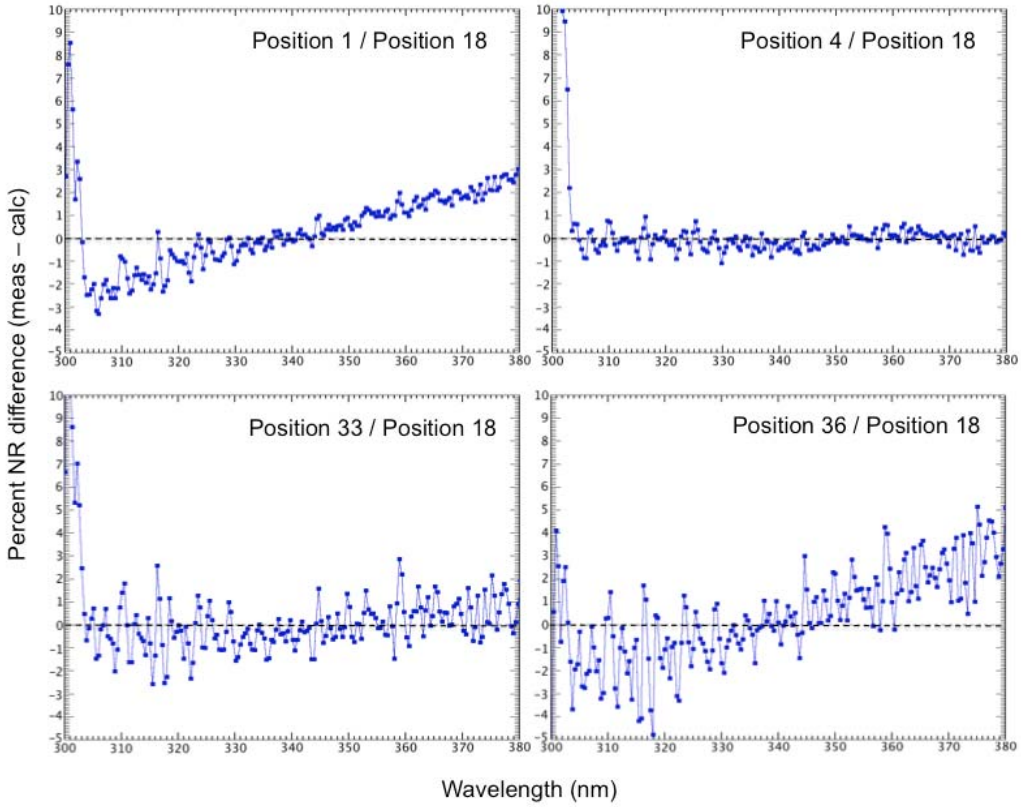

Figure 5: Similar comparison to Figure 4 for different cross-track positions. Although the difference for cross-track position 18 is subtracted, structure is still seen in the far off-nadir positions because physical effects such as Raman scattering are different than those at position 18 and are therefore not fully accounted for.

3.3.2 OMPS NP sensor

An analysis similar to that described for the TC sensor was performed for measurements from the NP sensor, with the results shown in Figure 6. Because of the large FOV (200 km x 200 km) for the NP measurement, the radiative transfer code was run 30 separate times using the viewing conditions of the 30 co-located (6 across-track by 5 along-track) FOVs of the TC sensor and then averaged together. Also shown in the figure, for the longer wavelengths, is the comparison of the averaged 30 measured radiances with the averaged calculated normalized radiances. *(Note that because the shorter wavelengths measured by the NP sensor are affected by particle effects in the South Atlantic Anomaly (SAA), matchups in this area were not included in the analysis.)*

For the NP sensor, the overall difference between measured and calculated NR values clearly increases from longer to shorter wavelengths. Much of this difference, along with the structure seen in the comparison, can be attributed to stray light issues. The comparison shows reasonably good agreement with pre-launch estimates of the stray light. This analysis, along with others, will be used to eventually correct for stray light effects. The large peaks near 280 nm are known to be caused by Raman scattering into the Magnesium Fraunhofer lines there that is not included in the radiative transfer calculation.

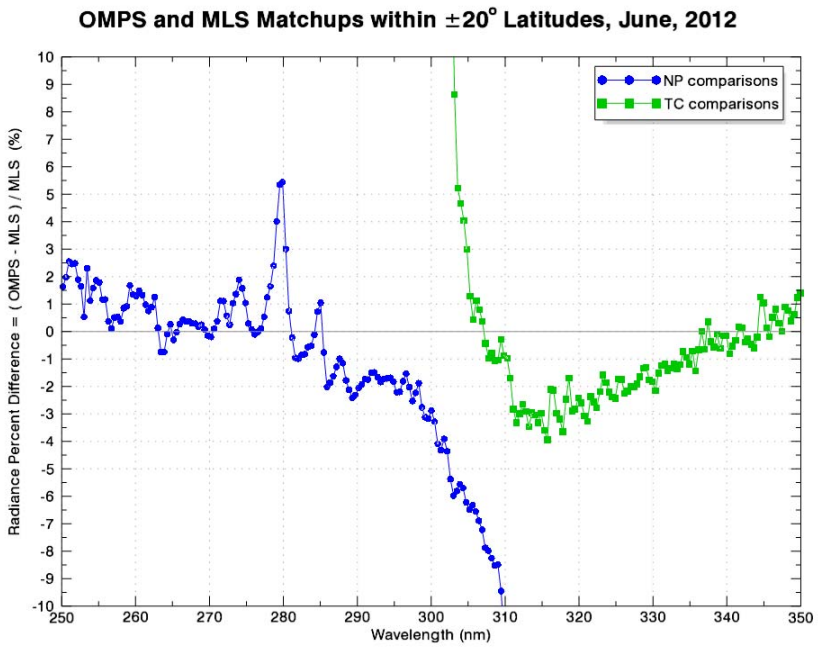

Figure 6: Comparison of radiances calculated using MLS profiles co-located with measurements from the NP sensor. The NP measurements currently consists of only one 250 km x 250 km FOV; the viewing conditions for each of 30 co-located TC FOVs (6 across-track by 5 along-track) are used in the calculation. The results show the mean difference for all of the MLS-NP matchups in June between 20 degrees south and 20 degrees north latitude outside of the SAA region.

Also of interest is the overlap region between the NP and TC sensors. While the sharp increase seen in the TC sensor from 310 to 300 nm is due to stray light, the corresponding drop in the NP sensor seen from 300 to 310 nm is currently unexplained. The Science Team plans to investigate this region further.

3.4 Geolocation

In order to properly assess the geolocation of the OMPS products, the Science Team directed the PEATE to include in the research processing stream an independent determination utilizing routines and functions from the Science Data Processing (SDP) Toolkit developed for the EOS system.

This code was used to process a set of high-resolution diagnostic data specifically taken by the OMPS nadir TC sensor to validate geolocation. This high resolution dataset, in which completely unbinned measurements were obtained from the CCD at the shortest integration time possible, provided 2.5 km cross-track by 10 km along-track fields-of-view (FOVs) at nadir. Once geolocated by the PEATE code, these measurements were used to calculate effective reflectivity, which was then mapped using the Interactive Data Language (IDL) software package using its high-resolution boundary dataset adapted from the CIA world map. Figure 7 provides an example of the results for 30 January 2012 over the Persian Gulf area.

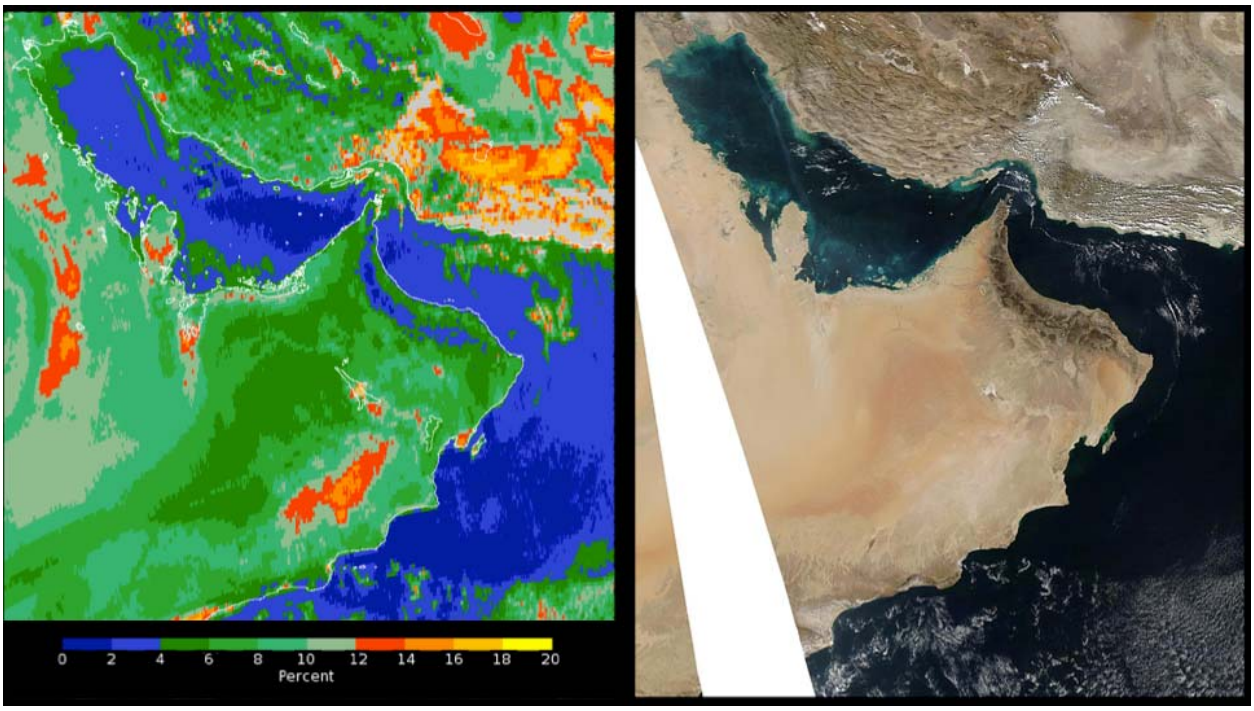

Figure 7: Geolocation of OMPS TC measurements is verified using high-resolution OMPS data (2.5 km across-track by 10 km along-track). On the left is the effective reflectivity determined using this high resolution dataset on 30 January 2012, with boundaries provided by IDL high-resolution dataset adapted from the CIA World Map database. The agreement is excellent. On the right, for comparison purposes, is an RGB image from Aqua MODIS for the same day.

The OMPS effective reflectivity calculation is shown on the left, while an RGB image from the MODIS sensor onboard Aqua is shown for comparison on the right. The effective reflectivity shows that the demarcation between land and ocean clearly follows the boundaries from the IDL database. Furthermore, comparisons between the OMPS reflectivity and MODIS RGB indicate excellent agreement between surface features seen in each image. Results like this have been used to validate the geolocation of OMPS to well within its requirement.

4 Evaluation of the OMPS SDRs

(Note: Because the TC and NP sensors are very similar, their SDR algorithms are essentially identical. We will therefore not distinguish between the two sensors in the discussion below.)

By converting instrument counts into scientifically meaningful data, the SDR algorithm provides the vital link between raw sensor measurements and the final EDR retrievals. This algorithm must not only function correctly at launch, it must also be flexible and adaptable enough to be able to account for changes in sensor performance or for changes in sensor operations throughout the lifetime of the mission. Furthermore, when applied to calibration data, the SDR algorithm serves as one of the main tools for analysis and evaluation of sensor performance.

The OMPS SDR algorithms for both the TC and NP sensors have two main components. The “Earth View” (EV) arm of the algorithm converts counts from the nominal measurements taken by the sensor into geo-located, calibrated radiances. The calibration arm of the algorithm converts raw sensor data from

the calibration operations into scientifically meaningful quantities (such as irradiance for the solar flux measurements), generates correction values needed by the EV arm (such as dark current), and provides output to monitor and track the performance of the sensors over time.

The Science Team has been evaluating the state of the OMPS operational SDR algorithms since well before launch, and their feedback and suggestions to the JPSS project office and NOAA-STAR over this time have directly shaped the current operational environment.

4.1 Calibration

As described in Section 1.1.2 and Section 3.2, the Science Team recommended prior to launch that the JPSS Ground Project not use the Calibration SDR generated in IDPS to establish or maintain OMPS calibration. One reason for this recommendation was the likelihood that the operational calibration sequence would require changes to optimize performance. Indeed, only five calibration sequences were conducted before such changes occurred. Because the IDPS calibration software requires substantial modifications in order to process the new calibration sequences, the necessary changes have not occurred at this writing.

A Science Team analysis of the original five calibration sequences confirmed the inadequacy of those measurements (see discussion in Section 3.2), but there was no evaluation of the Calibration SDR performance. Since the code is no longer used, the Science Team considered such an evaluation unnecessary.

The processing and analysis of all OMPS calibration data is now being performed using the Science Team's research SDR algorithm and processing stream, and those results are provided to the JPSS Ground Project for implementation in the EV operational processing. The NOAA-STAR OMPS team is currently studying their path forward with regards to processing OMPS calibration data in the future. The Science Team strongly recommends that NOAA-STAR continue to obtain the calibration for the OMPS Nadir sensors from NASA.

4.2 Earth View

4.2.1 Overall evaluation of SDR EV performance

Based on our analysis, the operational SDR EV algorithm, in its current state, does not produce a high-quality product. Even if all of the issues that have been discovered are eventually resolved, the lack of flexibility and modularity makes the algorithm ill-suited for effectively adapting to changes in the performance of the sensors in the future. Therefore, the Science Team concludes that the operational SDR algorithm does not now, and will not in the future, produce a product that meets the standard necessary for the generation of the high-quality EDRs needed for climate/global change studies. The research SDR developed by the Science Team should be used instead.

4.2.2 Geolocation

To validate the geolocation of data operationally processed by IDPS, the IDPS geolocation was compared to the geolocation independently calculated in the PEATE research processing stream. One example of the comparison along orbit 1828 (on 5 March 2012) for cross-track position 16 (near nadir) is shown in Figure 8.

For the most part, the comparison shows good agreement. However, spikes in the difference are seen at some locations, usually at high latitudes. These spikes represent times when definitive geolocation information was not yet available in the operational processing of the data. In these cases, the

geolocation was estimated using a “Two-Line Element” (TLE) to propagate the orbital characteristics. We note that these estimates are never updated to use definitive geolocation information, and these inconsistencies remain forever in the IDPS-generated operational dataset.

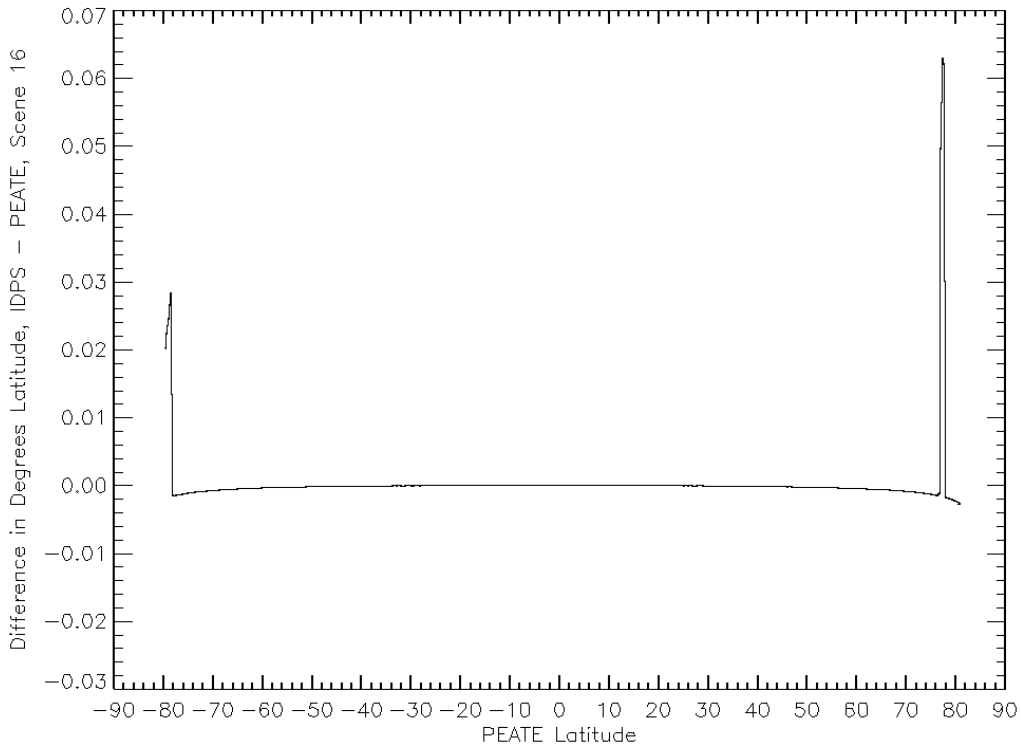

Figure 8: Comparison of the geolocation from the operational system for orbit 1828 with the geolocation from the PEATE research product. Spikes in the comparison indicate where geolocation was estimated by the operational system because definitive geolocation information was not yet available to the system.

4.2.3 Earth View: Conversion of counts to radiances

Once the EV (Earth View) arm of the SDR algorithm has performed geolocation, the basic purpose of the remaining code is to convert raw counts into calibrated radiances. In principle, this is a straightforward calculation that follows the following equation:

$$\text{Radiance} = [\text{Raw Counts} - \text{Bias} - \text{Smear} - \text{Dark} - \text{StrayLight}] \times \text{CalConst}$$

where Raw Counts, Bias, and Smear counts are directly provided by the RDR, Dark counts are updated regularly based on analysis of the dark current calibration data, the stray light correction relies upon measured scene radiances and pre-launch sensor characterizations, and CalConst is the calibration factor that converts counts into radiances.

The primary method used by the Science Team to investigate the application of the EV arm of the IDPS SDR algorithm was to compare with results obtained from the research SDR. The comparisons uncovered a number of discrepancies. While discrepancies could have been due to problems in either code, in practice they were traced to problems and issues with the operational code’s implementation of the above equation.

Figure 9 provides one example. The left plot shows a comparison of the radiances from the IDPS operational algorithm (red) and the PEATE research algorithm (black) as a function of wavelength. The radiances represent those for field-of-view (FOV) 16 for one swath from orbit 4964 (taken on 12 October 2012). This FOV is one of the most nadir-looking of the 35 cross-track FOVs. The black line in the plot on the right indicates the ratio of the two radiances. (These results are representative of those for the other cross-track FOVs.)

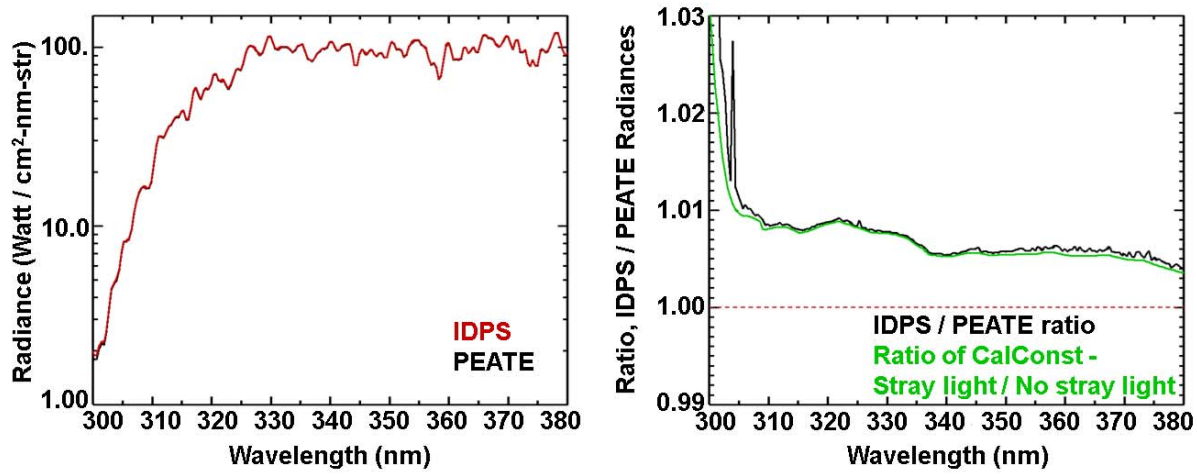

Figure 9: Comparison of the radiances determined from the IDPS operational and PEATE research SDRs. The left plot shows the radiances themselves, while the right plot shows the ratio. The difference can be seen to track the difference in CalConst used by the two algorithms.

The ratio plot on right shows that there is a clear difference between the operational and research code, especially below 305 nm. The Science Team traced the difference to the use of a different CalConst factor by the respective algorithms. The ratio of the two sets of CalConst factors as a function of wavelength, shown in green in the right plot, can be seen to closely match the ratio of the radiances. The operational code uses a set of calibration constants that assume a stray light correction has been applied to the counts, but since StrayLight is currently set to 0, this set of constants should not be applied. Once a stray light correction has been determined and applied the discrepancy will be removed, but until that time the discrepancy in the operational product will remain. The cause of the spike in the ration near 305 nm, which is due to a small inconsistency in the operational product, is currently still unknown.

Figure 10 provides a second example, where the ratio between radiances calculated from the operational and research algorithms are shown, again for FOV 16, for 3 different locations for orbit 4971 (also on 12 October 2012). Locations labeled A and C look similar to Figure 9 while, for location B, the ratio looks completely different. Further studies indicated problems with the dark and smear corrections being applied by the operational algorithm for measurements that are in the South Atlantic Anomaly (SAA). NOAA-STAR is currently investigating the issue; it currently remains unresolved.

The Science Team has also uncovered problems with the application of the dark current correction elsewhere. This correction, which is being supplied to IDPS by the Science Team through the OMPS SOC, does not appear to be correctly applied in the operational code. Members of the Science Team and SOC are working with NOAA-STAR and IDPS personnel to understand how the correction supplied by the SOC is being used within the operational code.

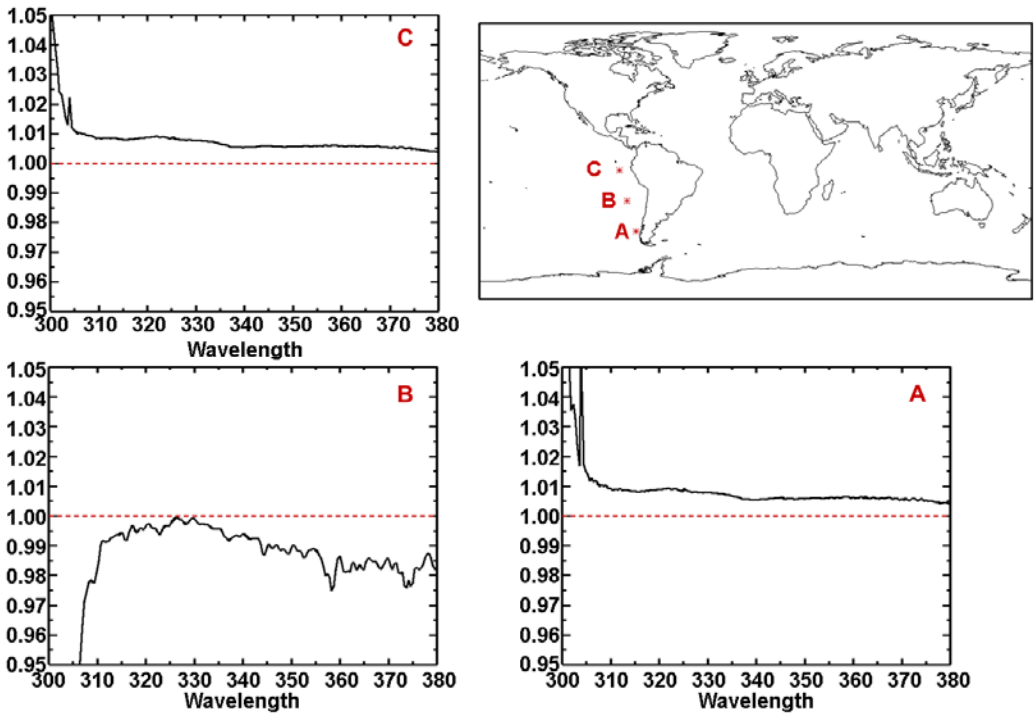

Figure 10: Ratios of the IDPS operationally calculated radiances to radiances calculated from the PEATE research algorithm for 3 different locations along one orbit. Locations A and C show a similar relationship to Figure 9, while location B is completely different. Further analysis uncovered problems with the application of the dark current and smear corrections in the SAA region.

4.2.4 Support for new products

SDR requirements for the SO_2 and OCP production are somewhat more stringent than for ozone production. Specifically, the SO_2 group has developed a direct fitting method to accurately model the radiance measurements to independently characterize wavelength registration, the spectral response functions, signal-to-noise levels, and the calibration consistency between irradiance and radiance. Furthermore, the SO_2 group has developed soft-calibration schemes to reduce the impacts of the significant stray light contamination that, at the shorter wavelength region, has not yet been corrected. The group's results validate those of the rest of the Science Team, namely that the radiance measurements of OMPS TC have been stable and consistent during its first year on orbit, providing high precision radiance data that can be used for the production of high quality ozone and SO_2 products.

The air quality and volcanic hazard science communities have made a compelling case for increased spatial resolution measurements from the OMPS Nadir Mapper instrument. Heritage UV products such as SO_2, OCP, and aerosols are of much more value when the nadir view resolution approaches 10 km rather than the 50 km provided by the IDPS SDR product. In recognition of this NOAA is modifying requirements for the JPSS-1 OMPS to provide higher resolution measurements.

Though no similar requirement is being discussed for the SNPP Nadir Mapper, that sensor is also capable of supporting high spatial resolution measurements. Figure 7 is an example of these measurements. One major impediment to routine production of OMPS SDRs at high resolution is the inability of the IDPS SDR algorithm to process these data. While the code was written with these improved capabilities in mind,

no demonstration of its performance exists. Furthermore, the IDPS SDR code is incapable of processing the multiple simultaneous spatial resolutions that are needed to support more than one high resolution EDR product. Given the lack of requirements beyond ozone for SNPP OMPS, such deficiencies are understandable. But a substantially redesigned EV SDR algorithm will be needed to support the EV measurements currently planned for JPSS-1 OMPS. We note that the NASA EV SDR code has the necessary functionality today.

5 Evaluation of the OMPS EDRs

5.1 The TC EDR

As with the SDR evaluation, the Science Team has relied heavily on comparisons between the IDPS EDR product and its research EDR product. As noted earlier, the operational algorithm was based on the Version 7 total ozone algorithm used to process TOMS data, while the "research" algorithm was based on the latest NASA Version 8 algorithm used for OMI. By comparing retrievals from two different algorithms applied to the same OMPS data instead of comparing retrievals from two different sensors (OMPS and OMI for example), the Science Team eliminated sensor effects that would have confounded the comparison. The comparison uncovered many inconsistencies between the algorithms, but also highlighted implementation issues that lead to severely degraded performance for the IDPS EDR product.

5.1.1 Problems with the implementation of the base Version 7 algorithm

In UV ozone retrievals the effective cloud fraction does not represent the actual geometrical cloud fraction but best represents the cloud radiative transfer scattering effect. In the operational algorithm it was assumed that the effective cloud fraction was equivalent to the geometrical cloud fraction and, instead of relying on the internal calculation, used the actual co-located cloud fraction determined from VIIRS. The use of an actual cloud fraction skews the rest of the retrieval, significantly impacting the determination of total column ozone over cloudy scenes. Figure 11 shows a comparison of retrievals from the operational code and from the PEATE research processing stream. Ozone errors of 10-30 percent over cloudy scenes are common, making the actual retrieved EDR unusable. The IDPS algorithm was corrected on 15 October 2012 in a way that makes it similar to the NASA algorithm (we note that the incorrect implementation of the code was known about for two years before being corrected).

Figure 12 shows a comparison of retrievals from the corrected operational code and from the PEATE research processing stream for 11 December 2012. Although substantially improved, the comparison shows that there are still issues with the operational EDR product.

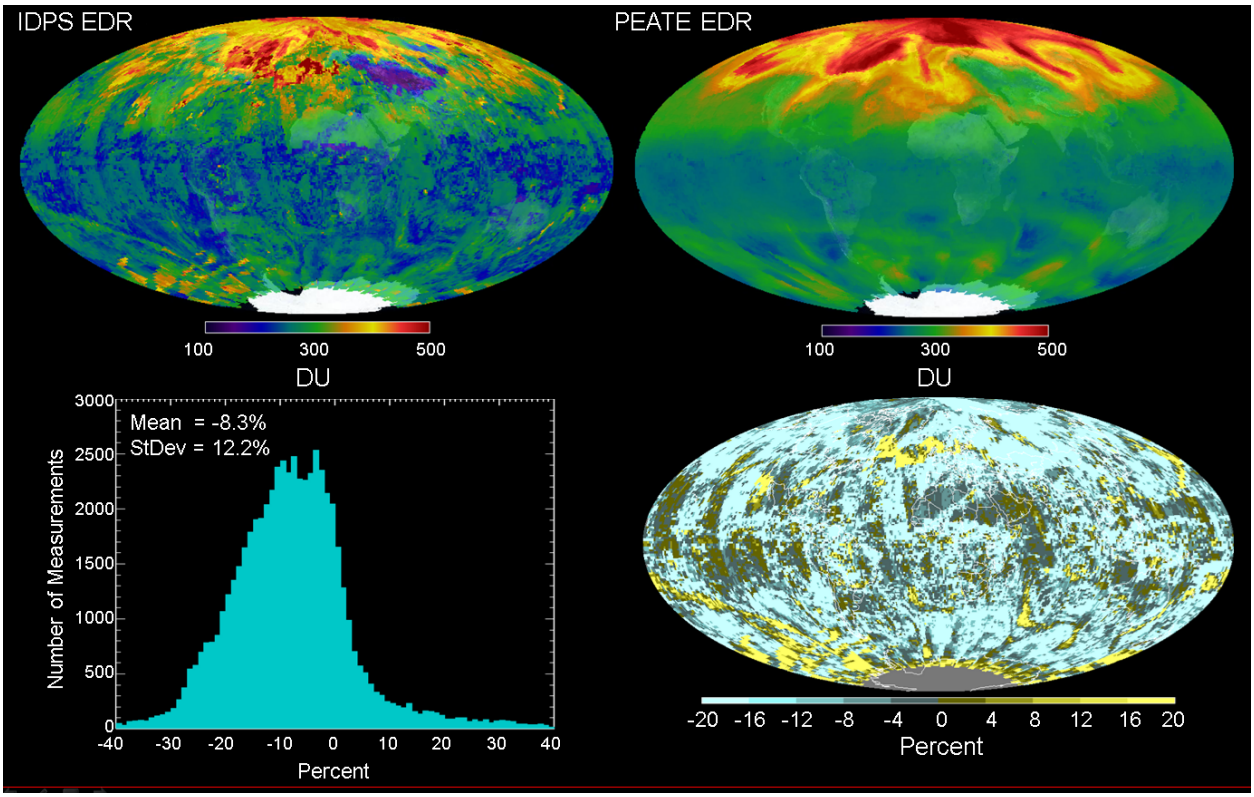

Figure 11: Comparison of the operational TC EDR retrieval for 20 April 2012 with the research retrieval performed by the PEATE using NASA's Version 8 algorithm. The differences highlight the fact that the baseline operational algorithm was initially not implemented correctly and made the operational EDR unusable.

5.1.2 Cloud pressure issue and OCP development

As stated earlier, the IDPS TC algorithm was designed to directly use the co-located determination of cloud pressure from VIIRS rather than a climatology of cloud pressure values. However, over the last decade studies on the effect of clouds on UV radiance measurements from OMI have shown that UV radiation penetrates further into a cloud than does IR radiation, and the use of IR-based cloud top pressure from VIIRS as input into UV retrievals is now known to cause both accuracy and precision errors.

For OMI, a co-located determination of a more relevant quantity known as the Optical Centroid Pressure (OCP), determined from the OMI measurements themselves, is used in the TC retrieval code. For the heritage TOMS sensors, and for the PEATE processing of the TC EDR research product, a climatology of OCP developed using OMI data is used in the retrievals. This approach will eventually be used in the IDPS product, but it is not currently.

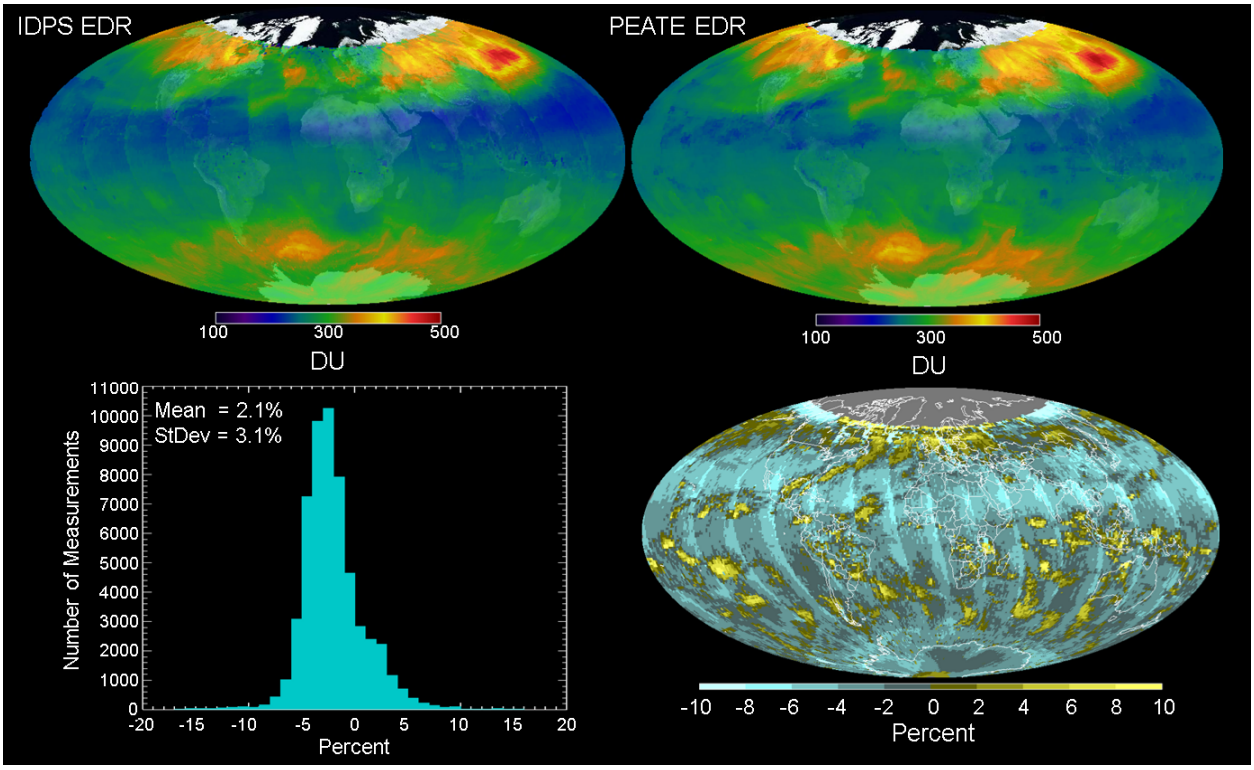

Figure 12: Comparison of the operational TC EDR retrieval for 11 December 2012 (after the implementation of the baseline code was corrected) with the research retrieval performed by the PEATE using NASA's Version 8 algorithm. Issues in the operational EDR remain at the ±3% level.

5.1.3 Use of co-located measurements from VIIRS and CrIS

Co-located retrievals of temperature, pressure, and snow/ice cover from VIIRS and CrIS are being used in the IDPS EDR retrieval before those products have been fully calibrated and validated. This leads to possible errors throughout the dataset that cannot be quantified, corrected for or, in many cases, even estimated. The continued use of the non-validated co-located products further extends the problem until each product has been declared operational and ready to be used. The variability of these inputs, irrespective of their accuracy, only complicates the difficult task of isolating OMPS retrieval issues.

5.1.4 Ozone profile shape correction

Figure 12 also shows a systematic ozone difference between the IDPS and PEATE EDRs at high latitudes / high solar zenith angles. This difference is primarily due to a difference in how profile shape effects are corrected. The operational algorithm was designed to apply a profile shape correction derived from the co-located OMPS limb sensor retrieval. Since that product is no longer available in the IDPS system, the algorithm reverts to a less accurate correction using the 312 nm profile shape sensitivity. In the NASA Version 8 algorithm used in the PEATE, the correction is similar to the original OMPS algorithm design, but it uses a set of a priori profiles instead of OMPS Limb profiles. This is the preferred approach for a new instrument whose performance is still under evaluation.

5.1.5 Overall evaluation of operational TC EDR

The performance of the IDPS operational algorithm and product has improved over time. With the incorporation of the OCP-based cloud climatology, the performance will further improve. However, the implementation of this climatology will occur no earlier than June 2013. Furthermore, the algorithm

continues to use unvalidated retrievals from the other sensors. Finally, we note that, even when all of the corrections and improvements have been made by NOAA-STAR, fundamental differences between the operational algorithm and the algorithm used to create the long-term dataset remain. Such differences will fundamentally compromise any long-term data record by introducing subtle changes in seasonal patterns and other inconsistencies. Apart from the accuracy issues already described above, the Science Team concludes that the operational OMPS TC product should not be used in climate/global change studies simply because it is generated by a different algorithm with different inputs.

5.2 The NP IP

The long-term climate data record of ozone profile was generated using Version 8 of NASA's retrieval algorithm. Since the operational OMPS system uses the outdated Version 6 algorithm, the operational OMPS EDR is inherently inconsistent with that record, and the Science Team did not further evaluate the operational OMPS NP product.

5.3 Overall evaluation of PEATE TC and NP research EDRs

The Science Team has also evaluated the performance of the PEATE research EDRs, which use the PEATE research SDRs as input and which utilize Version 8 of NASA's retrieval algorithms for both the OMPS TC and NP sensors. This evaluation relies mostly on comparison with other well validated sensors. These EDRs, along with research SDRs and Level-3 datasets, are being processed by the Ozone PEATE and are being made available via the team's web site at: http://ozoneaq.gsfc.nasa.gov/omps

5.3.1 OMPS TC research EDR

This algorithm is very similar to the one used to process data from OMI and to create the long-term data record of total column ozone for the heritage TOMS sensors. Figure 13 shows a comparison of the research EDR with results from the OMI sensor for one day, 11 December 2012.

The comparison shows a small overall offset that is due to the fact that the OMPS retrievals utilize the new Brion/Daumont/Malicet ozone cross sections rather than the Bass and Paur cross sections that are still being used in the OMI retrievals. The other major difference is the fact that the PEATE research stream relies on a climatology of Optical Centroid Pressure (OCP) values while the OMI retrieval relies on co-located retrievals of OCP. Taking these two differences into account, the comparison shows excellent agreement.

Figure 14 is a comparison of the global average total column ozone retrieved from OMPS between 65 degrees south and 65 degrees north latitude with the same value for OMI. Again, after accounting for the small offset due to the difference in ozone absorption cross sections being used, OMPS shows excellent agreement over the nearly one year's worth of overlap with OMI.

The results shown in Figures 13 and 14 indicate that if compatible algorithms are used, the OMPS TC and NP sensors will be able to provide data to extend the long-term total column ozone data record.

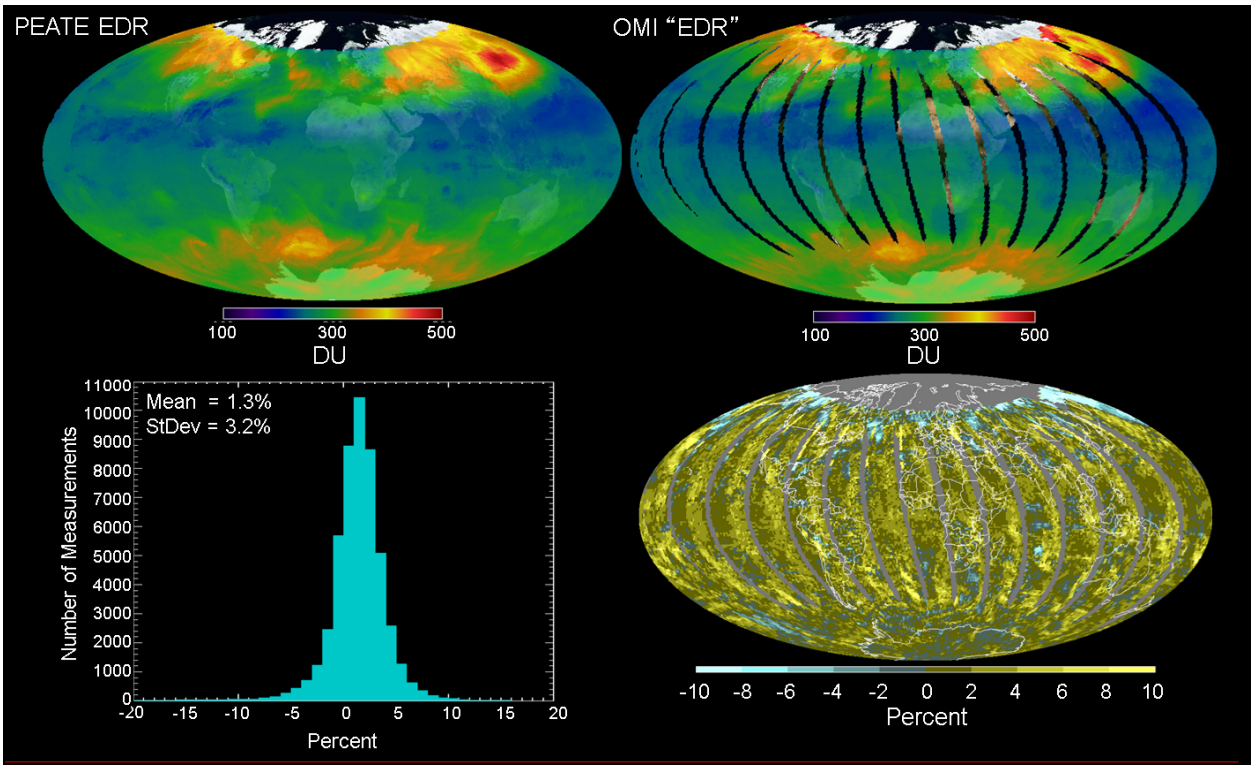

Figure 13: Comparison of OMPS research TC EDR ozone with OMI ozone for 11 December 2012. Apart from an offset due to the use of different ozone absorption coefficients, the comparison shows excellent agreement.

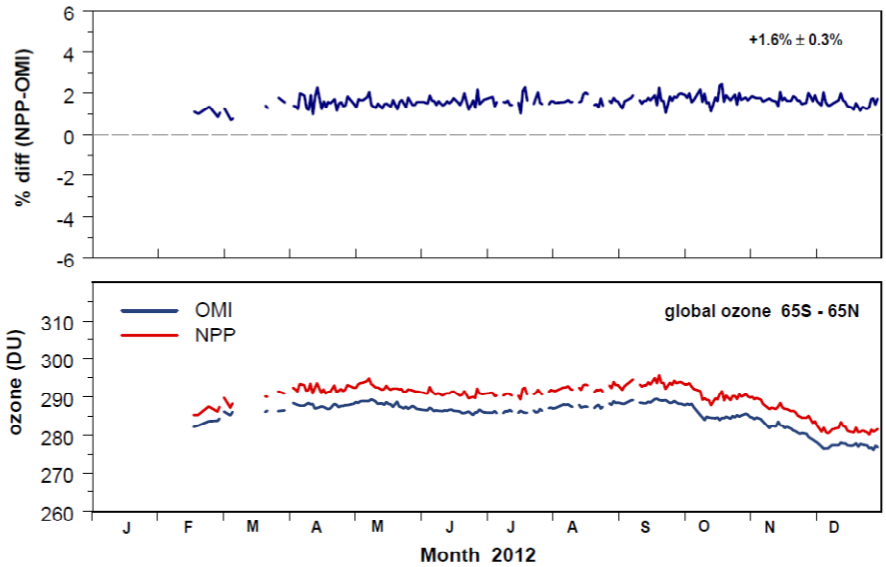

Figure 14: Comparison of the average total column ozone amount between 65 degrees south and 65 degrees north latitude for the PEATE research EDR and OMI. The comparison shows excellent agreement over the nearly one year of overlap (so far) between the two sensors.

5.3.2 OMPS NP research EDR

The NP ozone profile EDR was evaluated through comparison with retrievals from other satellites. Retrievals from the PEATE-processed NP ozone profile dataset were compared with retrievals from the concurrently flying SBUV/2 onboard the NOAA-18 satellite. Initial comparisons indicated differences that, in part, point to stray light issues remaining in the SDR radiances. A set of "soft" calibration adjustments were then determined to reduce any remaining inconsistency between the two sets of retrievals. Note that this is a standard technique to merge datasets from different satellite sensors.

Once the soft calibration adjustments were determined and applied, the resulting profile retrievals were then compared to ozone profile retrievals from the Microwave Limb Sounder (MLS) flying onboard the Aura satellite. Figure 15 shows a comparison of the average ozone profiles measured by the NP sensor for a latitude band between 20 degrees south and 20 degrees north latitude for 23 June 2012 with the average profile from MLS. A zonal mean comparison reduces errors caused by spatial match differences. The comparison shows excellent agreement. Comparisons for different days show similar results and indicate that the NP retrievals do have the potential to extend the nadir ozone profile climate data record, provided an algorithm that is consistent with that dataset is used.

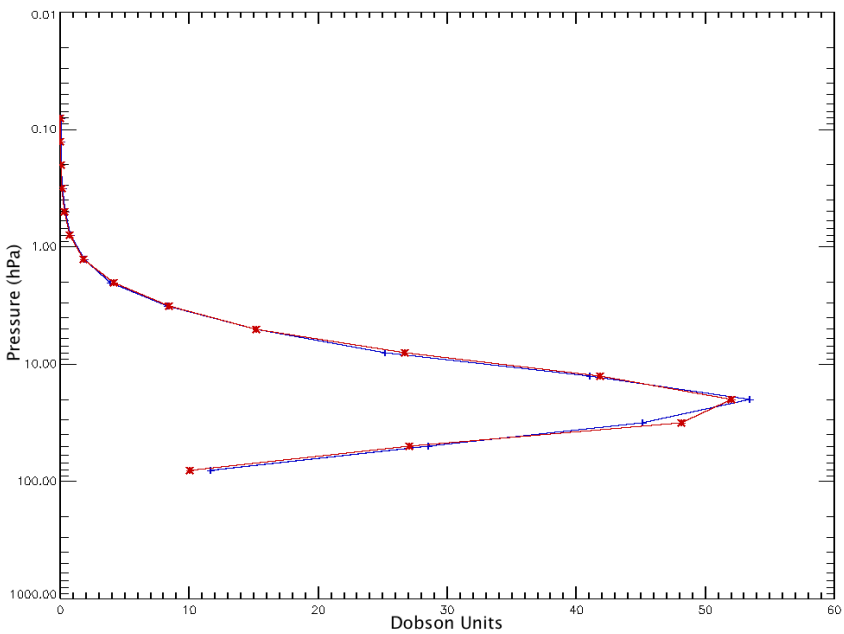

Figure 15: Comparison of the average MLS retrieved ozone profile for 23 June 2012 between 20 degrees south and 20 degrees north with the average OMPS NP profile for the same day. The integrated column ozone amount from 200 hPa to the top of the atmosphere is 235.7 DU for MLS and 236.7 DU for OMPS NP. Both the integrated ozone amount and the shape of the ozone profile show excellent agreement.

5.4 SO_2 EDR retrievals

Because the SO_2 product from OMI has proven to be a valuable addition to the scientific community, NASA has supported the development of a similar product from OMPS. The Science Team's SO_2 group has done an initial evaluation of an OMPS SO_2 science product.

5.4.1 SO_2 Algorithm Development and Processing

The Science Team's SO_2 group produces both near-real-time (NRT) and standard OMPS SO_2 products to meet the two objectives specified in their proposal: 1) to provide NRT detection and monitoring of volcanic plumes for aviation hazard mitigation, and 2) to continue the long-term sulfur dioxide EDR from TOMS and OMI.

For NRT SO_2 processing, the group implemented a linear fit algorithm; test results from this algorithm have demonstrated that OMPS TC can reliably detect volcanic SO_2 plumes, as shown in Figure 16. Note that since the linear fit SO_2 depends on the quality of the residuals at wavelengths used by the total ozone algorithm, the high quality of NRT SO_2 data (as seen in this example in Figure 16) also provides validation that NASA's total ozone algorithm running in the ozone PEATE is producing high quality ozone products. The development and testing of the NRT SO_2 algorithm has been completed and its delivery to the ozone PEATE is to be completed in January 2013. We also plan to provide to NOAA a set of SO_2 production codes to be integrated into the operational IDPS system.

The continuation of the SO_2 EDR from Aura/OMI requires the use of full spectral measurements from OMPS. As described earlier, the SO_2 group has characterized these measurements to extract the quantitative information needed to construct forward models to accurately retrieve ozone and SO_2, as well as other geo-physical parameters. The group has also implemented correction steps specific to this instrument to reduce the impact of stray light not yet corrected for on the SO_2 retrieval. Because of the high precision of the radiance measurements of OMPS TC and successful efforts to determine a soft calibration and to reduce data artifacts, the group can now process the OMPS TC data with an advanced (ISF) algorithm that takes full advantage of the hyper-spectral measurements to produce high quality SO_2 data. In summary, both volcanic and anthropogenic SO_2 can be retrieved from OMPS TC spectral measurements. The SO_2 group has successfully achieved high quality retrievals to meet the proposal goals: to provide NRT SO_2 data for aviation hazard mitigation and to continue the long-term SO_2 EDR.

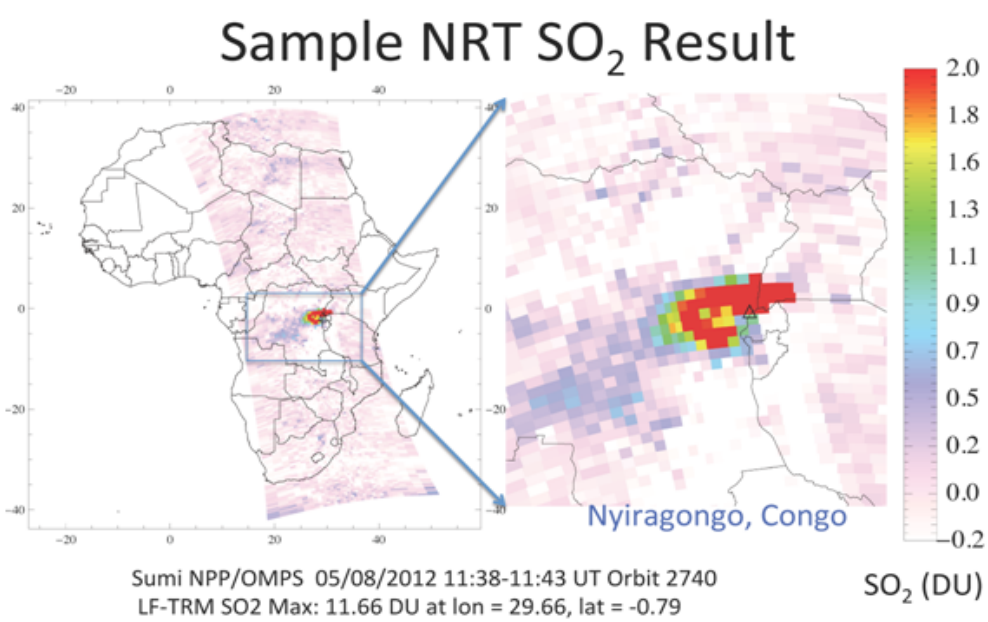

Figure 16: OMPS observation of the SO_2 plume from the eruption of Mt. Nyiragongo, Congo, on May 8, 2012.

5.5 OMPS OCP EDR retrievals

The Science Team's OCP group has adapted the OMI algorithm for use with OMPS. They are evaluating the effect of diffuser interference features, wavelength registration, etc on the accuracy and precision of OCP retrievals from OMPS and are working with the rest of the team on determining ways to reduce their impact. Once OCP retrievals have been demonstrated and validated, the OCP group will provide the algorithm to NOAA-STAR for possible incorporation into the IDPS operational ozone product generation.

Until such a capability is available, the Science Team believes, and NOAA concurs, that the OCP climatology developed using OMI data should be used. That climatology will not be implemented until, at the earliest, June of 2013. Until that time retrievals over clouds using the operational algorithm will be inconsistent with heritage sensors and the long-term dataset.

6 Producing high-quality products for climate studies in the IDPS operational environment

A summary of the contrast between the requirements needed by an operational project such as JPSS and those needed to produce high-quality products needed for climate/global change studies is contained in the Platnick, et al. white paper (Reference 1). The OMPS Science Team found several key conclusions there especially relevant to ozone and related products:

> "The JPSS organization, algorithms, and data processing requirements are designed to meet operational needs first and foremost. This results in a system capable of continuous processing with an emphasis on low latency throughput and tight configuration control. However, these attributes do not support a science-driven data enterprise. The EOS experience has demonstrated the need for a more flexible approach, including:
>
> - An ongoing commitment to on-orbit calibration/characterization, including spacecraft maneuvers incorporated into continual Level-1 algorithm updates;
> - evolving science-driven geophysical algorithms;
> - capability for data reprocessing;
> - capability for generating custom or experimental research products;
> - recognition of, and responsiveness to, a diverse set of users and their needs;
> - agility for reconfiguration and redirection of resources; and
> - communication and coordination among the instrument calibration, science, and data processing teams."

In its observation and evaluation of the JPSS project and IDPS system with respect to data from the OMPS nadir sensors, the Science Team has drawn the following conclusions that support the analysis and conclusions detailed in this white paper:

1) The time necessary to implement calibration corrections, bug fixes, and other changes in the operational (IDPS) system is excessively long. Time spans of from 6 months to 2 years have been experienced for changes related to the OMPS system. The inability to account for sensor changes and errors in a timely manner precludes the development of a consistent dataset from the operational products:

    - Errors remain in the dataset for a long time after they are discovered. Fixes for many of the errors have been identified in the operational algorithm, almost all of them months ago. Yet many (actually, most) of them have still not been fixed. Because of this, the operational products generated are not of high enough quality for climate studies

    - Sometimes changes in sensor performance/calibration can only be properly accounted for by changes in the processing code. Retrievals from the sensor are of degraded quality until the code changes are implemented and, since it takes a long time to implement the changes, the quality of the data remains degraded during this period.

    - The Science Team has found that even calibration changes that don't require code changes (changes to tables, for example) take a long time to implement. Since they don't occur very close to the actual time that the change in sensor performance was noticed, more of the dataset is of degraded quality than if the change had been made promptly.

    - The IDPS support staff are not empowered to identify and solve OMPS processing problems. Most problem resolution must come from the OMPS Cal/Val team, who has little insight into the complex IDPS system. Documentation of the operational algorithms is scant and often incorrect. Consequently it is sometimes easier to diagnose sensor anomalies than it is algorithm anomalies.

2) Traceability is a major issue concerning IDPS-generated products. Since many intermediate products are stored only in IDPS memory, stopping a production stream means losing this accumulated information. Starting up the same stream causes parts of the production to re-initialize, causing the results to be neither predictable nor repeatable.

3) For OMPS, the ability to run retrievals offline with the same results obtained operationally is highly problematic. The tools available to do this, the Algorithm Development Area (ADA) and the Algorithm Development Library (ADL), contain versions of the code that are frequently inconsistent with IDPS code. Because of this, and along with the reason stated in 2 above, it has proven difficult (if not impossible) to run in these areas using data that are consistent with the IDPS.

4) The IDPS system has no capability to reprocess data, a major requirement for creating (and maintaining) the high-quality datasets needed for climate/global change studies.

5) The IDPS processing environment is too inflexible for processing OMPS data. The rigidity of the IDPS structure means that what works for VIIRS must also work for OMPS. And while the OMPS design was based on heritage instruments, it contains many new elements whose performance is unknown. The software designer's pre-launch conception of how data will be collected is woven into the processing architecture. In several cases it is this architecture that limits our ability to fix errors and improve OMPS performance. Given the issues raised in Point 1) above, changes to this architecture are impractical.

The Science Team also fully endorses the findings contained in the "Findings and Issues Summary" report arising from the PEATEs/CARS review in November 2012 (Reference 2), many of which echo the Science Team's findings detailed above.

7 Path forward

The Platnick et al. [2011] white paper contains a set of recommendations that identify what is required to sustain or augment the NASA resource currently in place to assure the continuation of the EOS-era long-term climate/global change records into the NPP/JPSS era. The observations of the NPP OMPS Science Team, and the conclusions drawn from them, support these top-level recommendations:

1) Development of a consistent set of Level-2 and Level-3 science algorithms for use across EOS and NPP/JPSS-1 instrument records.

2) Establishment of an integrated instrument and Level-1 algorithm team.

3) Establishment of a processing group to be responsible for (re)processing, archiving, and distribution of NASA-funded instrument and science team data products.

4) Establishment of discipline-specific Validation Teams to assess the NASA-funded NPP/JPSS data records.

The work of the OMPS Science Team further supports the individual recommendations made in the white paper concerning algorithms, sensor characterization, and the production of climate-quality data records. In summary, we believe that climate-quality data products from OMPS are best produced in a processing environment similar to what is currently represented in the Ozone PEATE and in the OMI Science Investigator Processing System (SIPS). Specific recommendations include the following.

1. Transition the current NASA OMPS research products into operational products with the understanding that maintaining consistency with heritage products is of paramount importance.
2. Merge the current Ozone PEATE capabilities into a broader team responsible for creation and dissemination of discipline data products from UV remote sensors (OMPS, OMI, TOMS, SBUV, etc.). This new team would develop the product interfaces that allow science algorithms to be applied seamlessly to sensor data from multiple missions.

3. Generate NASA OMPS products starting from raw data. These data could come from IDPS RDRs, but the Ozone PEATE team currently prefers to use CADU data directly from the ground station.
4. Consider the creation of an absorbing aerosol product to complement that being produced for OMI.
5. Compete the various OMPS science product teams, but provide a single SDR product as a resource to those teams. This minimizes duplication of effort between teams, especially related to sensor performance, and places the SDR team in a clear support role. Inclusion of the Limb instrument in the SDR team will ensure that common elements of the OMPS sensors are addressed consistently and together.
6. Design all products to function with both the current 50 km resolution and an eventual 10 km resolution. This will ensure that products will transition seamlessly into JPSS-1 OMPS, and can work with a higher resolution SNPP OMPS, should that come to pass.
7. Whether OMPS flight operations are coordinated by NASA or by NOAA, ensure that a single team controls this for the Suite. NASA must retain some role in Nadir sensor flight operations because this can directly influence data quality

As discussed in Section 1 of this report, the Ozone Science Team worked with both the JPSS Project and NOAA-STAR to overcome issues related to operating, calibrating and processing OMPS data within IDPS. The general solution was to fall back on the 30 year model of cooperation followed by NASA and NOAA for handling the SBUV2 series of sensors and measurements. In this model, NASA supplies the calibration of the sensors, develops and validates the algorithms, and creates and maintains the long-term record. NOAA processes the data for operational uses, incorporating the calibration provided by NASA, and implements the algorithmic changes provided by NASA into the operational stream when it deems appropriate. While future NASA/NOAA coordination is outside the scope of this report, we note that the proposed path forward for OMPS data processing is consistent with a similar cooperative arrangement.

NOAA-STAR is currently evaluating its path forward regarding processing of OMPS data. The Science Team strongly recommends that NOAA-STAR continue to take advantage of the successful NASA/NOAA partnership developed for SBUV2 and that is currently in place for the OMPS system.

8 References

1) "White Paper on Continuity of NASA Satellite Climate and Earth Science Data Records into the NPP/JPSS-1 Era," S. Platnick, J. Gleason, P. Sellers, et al, November 2011.
2) "PEATEs/CARS Review 11-27-12 Findings & Issues Summary," from PEATEs/CARS review held at NASA HQ, November 2012.