TESTING AND INTEGRATION OF JPSS OZONE MAPPING AND PROFILER SUITE (OMPS) ALGORITHMS USING THE ALGORITHM DEVELOPMENT LIBRARY (ADL)

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ABSTRACT

The Ozone Mapping and Profiler Suite (OMPS) consisting of three instruments, a Nadir Mapper (OMPS-NM), a Nadir Profiler (OMPS-NP) and a limb Profiler (OMPS-LP) was launched aboard Suomi NPP satellite in 2011. The instrument is also planned to be aboard JPSS satellite. The data from this instrument is processed at Interface Data Processing Segment (IDPS) built by Raytheon. The main products from OMPS include Total Column Ozone and Ozone Profile. Algorithm Development Library (ADL) framework mimics IDPS system and is used to test, troubleshoot and integrate algorithm updates. The algorithm integration team (AIT) at NOAA STAR is tasked to integrate the algorithm updates in ADL that could be simply plugged in the operational system. In this paper we will present the process in detail and will discuss the results of the latest update of V8 algorithm from V6 algorithm for OMPS Nadir Profile instrument.

***Index Terms*—** OMPS, Ozone, ADL, JPSS, Algorithm Integration

1. INTRODUCTION

The OMPS instruments measure solar radiance scattered by the Earth's atmosphere directly and solar irradiance by using diffusers. Detailed discussion of these instruments and measurements are provided in recently published papers by OMPS science team members Flynn *et al*. [1], Wu *et al*. [6], and Jaross *et al*., [5]. The OMPS-LP measurements are processed into ozone profile products by the NASA OMPS Science Team. The OMPS-NM and OMPS-NP measurements are processed into total column ozone and ozone profile products in near-real-time at the NOAA Interface Data Processing Segment (IDPS) which is also responsible for processing all other atmospheric, land and ocean products from the other sensors on board S-NPP. IDPS is built and managed by Raytheon [3][4].

The OMPS products include Earth View Sensor Data Records (SDRs) for OMPS-NM and OMPS NP, Total Column (TC) Ozone Environmental Data Records (EDRs) (OMPS-NM) and Ozone Profile EDRs (OMPS-NP). The SDR and EDR products have achieved provisional status, and new calibration parameters are in development to move them to validated status. The SDRs and the EDRs have undergone an extensive Calibration and Validation (Cal/Val) campaign to be able to achieve this status moving through the ladder of maturity levels defined by the JPSS program. This has been enabled by integrating corrections and improvements in the codes through use of the Algorithm Development Library (ADL).

2. ADL

The ADL mimics the operational system IDPS and provides a test system to enable scientists and researchers to develop algorithms on their own platforms, and provide these to Raytheon in a form that can be rapidly integrated directly into the operational baseline. The detailed ADL framework is described in Grant et al. [3]. At STAR The Algorithm Integration Team (AIT) uses ADL to test and troubleshoot errors in the existing algorithm, to integrate code changes and Look-Up Table (LUT) and coefficient table changes, and to prepare and deliver the change request package to ensure rapid transition of the desired updates into the operational system. The ADL provides a development environment that can be used to create algorithms that will plug into a JPSS Common Ground System (CGS) instantiation.

Figure 1 shows the process flow by which STAR AIT uses ADL to integrate the algorithm updates. STAR AIT has built its own configuration management (CM) system in which it retrieves the released operational versions of ADL and then creates development stream for each integration task. Depending on the test date or the GOLDEN DAY selected by the scientists, we choose the granules for the test. The next task involves gathering inputs such as Raw

Data Record (RDR) files, ancillary files, coefficient tables, Tile files, and LUTs. Some of these files are available in HDF5 format. These files are converted into binary large object (BLOB) format for ADL to process. The test runs are first made with the exact input files used in the operational system IDPS so that the baseline results can be verified. After the baseline results are verified, the updates are integrated to evaluate the effects of these updates on the products.

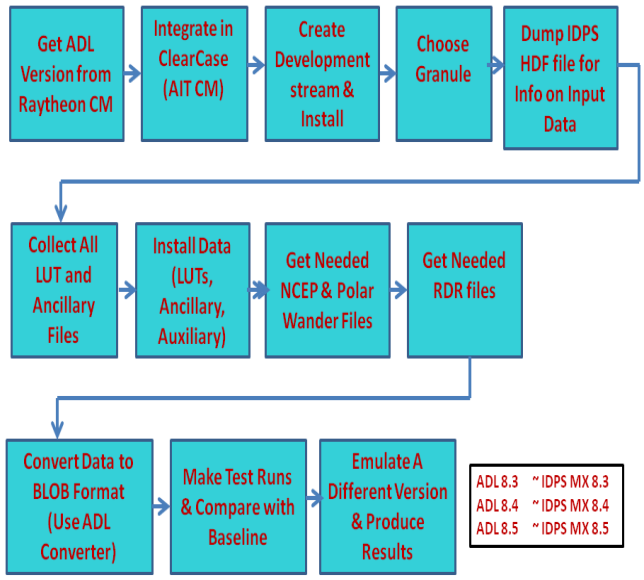

Figure 1: ADL Integration Process Flow

We have used ADL to integrate several updates to improve OMPS SDR and EDR products. These updates include fixes to bias impact on smear and radiance, impact of wavelength shift characterization, profile mixing fraction adjustment, stray light corrections, wavelength scale updates and solar irradiance spectra updates.

4. OMPS ALGORITHMS

4.1 SDR Algorithms

The OMPS Total Column SDR algorithm and OMPS Nadir Profile SDR algorithm both follow the same algorithm design method to process input from Raw Data Records (RDRs) into Sensor Data Records (SDRs). Two basic RDR types, Earth View and Calibration, are available for processing. Currently Calibration RDRs are processed on a separate system and the auxiliary data from those processing are used in used during Earth data processing to adjust the spectral and radiometric calibrations of those data. The basic components of SDR processing: signal correction, calibration analysis, and calibration application, are all automated. Intervention is required only for approving upload tables and the synchronized configuration tables used in the ground system.

The Earth View algorithms also use a number of inputs that are provided as separate tables. These include sensor parameters, initialization parameters, and a series of sample tables which describe which pixels were used for each RDR – e.g. the Solar Calibration Sample Table is a map of which pixels were used in the Solar Calibration frame observations. The tables describe the locations of smear pixels as well as observation pixels. During the mission, changes to the flight software sample tables are synchronized with the sample tables used by the ground software to maintain sampling integrity. Detail descriptions of these algorithms are available in the respective Algorithm Theoretical Basis Document (ATBD) and Operational Algorithm Description (OAD) document.

4.2 EDR Algorithms

There are separate algorithms for TC/NM IP/EDR product and NP IP product. The purpose of the TC EDR algorithm is to invert nadir radiances to TC ozone and to write the TC EDR data. Total column ozone is derived for each of the 35 50x50km FORs from triplets formed with 22 normalized radiances using the OMPS SDRs and multiple scattering tables as inputs. The TC ozone algorithm contains several validity checks for maintaining data quality. After these checks are applied, quality checks are performed to identify invalid and lower quality ozone values (outside of the [50, 650 DU] range) caused either by bad input data that passed preprocessing checks or by limitations of the ozone algorithm. Other quality checks are performed to assure the product quality.

The OMPS-NM total column ozone product provides estimates over the full sunlit Earth of total column ozone, effective reflectivity and UV absorbing aerosols (an aerosol index) each day. The measurements are binned into 35 cross-orbital-track fields of view (FOVs) onboard the spacecraft with each FOV using a specific fixed set of CCD pixels. The performance requirements for the total ozone EDR are documented and mandated by the mission planning team.

The NP EDR algorithm is designed to invert nadir radiances to NP ozone and to write the NP output data. The OMPS-NP IP algorithm uses data from the NP SDR, NP SDR GEO, TC SDR, TC SDR GEO, and the TC granulation of ancillary surface pressure as inputs and creates the ozone profile product. The primary data product is layer ozone

amounts in 12 layers for all solar zenith angle viewing conditions less than or equal to 80 degrees.

Ozone profiles are derived from the measured albedos using Rodgers optimum statistical inversion technique. Initial information, *a priori* is required since there is not enough information to invert the ozone profile from the measured albedos. The retrieved profile is thus constructed from both the *a priori* information and the measured albedos. The *a priori* information is sometimes referred to as "virtual measurements" because it is an integral part of the profile construction.

The ozone profile product provides estimates over the full sunlit Earth of the ozone vertical profile along the nadir satellite track each day. The performance requirements for the Nadir Ozone Profile EDR are mandated by the mission team. There is an additional long-term requirement that reprocessed products for climate data records should be stable at the 2%/decade level.

4.3 Programming Language

Both the SDR and EDR algorithms for OMPS NM and NP instruments were initially written in FORTRAN 77 and then converted to FORTRAN 90 with the interface to IDPS written in C++. Several scripting languages such as Perl, Python and shell scripts are used to make these algorithms work efficiently in the operational environment.

4.4 Algorithm Change Needs

There have been several updates for the initial algorithms in IDPS. Both SDR algorithms and EDR/IP algorithms are updated regularly for product improvements. Currently the operational TC EDR algorithm is based on the Version 7 total ozone algorithm used to process Total Ozone Mapping Spectrometer (TOMS) data, and NP EDR algorithm is based on Version 6 algorithm. Each of these products has requirements needs that has been established by the mission planning board. A set of maturity levels are formalized to check the status of the algorithm at any point of time. For OMPS, the product validation needs are established such that it should satisfy both the conditions of the requirements and would be comparable to similar products obtained from other satellite measurements as well as ground measurements. Accordingly the science team has set a goal to update the operational algorithms for both the TC EDR and NP EDR to Version 8 algorithms. We have tested Version 8 of these algorithms in ADL framework. The initial results are very promising and show improvements in the EDR products over the older versions of the algorithms. The new TC EDR also includes accurate atmospheric SO2 estimates in place of the current index values. The new algorithms are consistent with the algorithms in use for the operational SBUV/2 and GOME-2 instrument products so additional efficiency will be obtained for future maintenance and product continuity.

5. ALGORITHM UPDATE EXAMPLE: V8PRO

Currently OMPS Nadir Profile uses Version 6 algorithm in which it uses ratios of Earth radiance to Solar irradiance at a set of 12 wavelengths (at approximately 252, 274, 283, 288, 292, 298, 302, 306, 313, 318, 331, and 340 nm) with the shortest eight taken from the Nadir Profiler and the longest four from the Nadir Mapper to obtain estimates of the total column ozone, effective reflectivity, and the ozone vertical profile in 12 Umkehr Layers. (The 12 Umkehr layers boundaries are at: [0, 0.25, 0.50, 0.99, 1.98, 3.96, 7.92, 15.8, 31.7, 63.3, 127, 253, and 1013] hPa.) The radiances for the four longer wavelengths are obtained from the 25 Nadir Mapper FOVs colocated with a single Nadir Profiler FOV.

The improved version of the algorithm which is known as V8Pro has a new set of *a priori* profiles varying by month and latitude, leading to better estimates in the troposphere and allowing simplified comparisons results to other measurement systems (in particular, to Umkehr ground-based ozone profile retrievals which use the same *a priori* data set). The algorithm has a true separation of the *a priori* and first guess. This simplifies averaging kernel analysis. Multiple scattering and cloud and reflectivity modeling are improved in this version. These corrections are updated as the algorithm iterates toward a solution. Some errors present in the V6Pro are reduced in V8Pro. These include the elimination of errors on the order of 0.5% by improved fidelity in the bandpass modeling. The V8Pro incorporates several ad hoc Version 6 algorithm improvements directly. These include better modeling of the effects of the gravity gradient, better representation of atmospheric temperature influences on ozone absorption, and better corrections for wavelength scale errors. The algorithm uses improved terrain height information and gives profiles relative to a climatological or forecast surface pressure. The V8Pro is also designed to allow the use of more accurate external and climatological data and allow simpler adjustments for changes in wavelength selection. Finally, the V8Pro is designed for expansion to perform retrievals for hyperspectral instruments, such as the Ozone Monitoring Instrument (OMI), the Global Ozone Monitoring Experiment (GOME-2) and the Nadir Profiler in the Ozone Mapping and Profiler Suite (OMPS).

5.1 V8Pro Implementation in ADL

V8Pro implementation in ADL included modification to 11 program files and a makefile in the main source directory. It also included use of 43 new program files. The coefficient table was modified with new parameters. These changes were implemented to a baseline version of the operational

IDPS algorithm. First both TC/NM earth view SDR and NP earth view SDR results were obtained. The SDR products were then used with the updated coefficient table and the updated NP IP executable to run the V8Pro instances and produce the new output. November 23, 2014 was chosen as the Golden Day for this test. The results were obtained using both V6 algorithm and V8Pro algorithm.

5.2 Evaluating V8Pro Results

Some of the preliminary evaluations of V8Pro algorithm have been made by comparing ozone profiles with the profiles from NOAA 18 and NOAA 19 SBUV instruments. Figure 2 below shows the zonal mean ozone profile information for 2 different months in different seasons. The profiles obtained from V8Pro algorithm match the ozone profiles obtained by using NOAA 18 and NOAA 19 SBUV instruments.

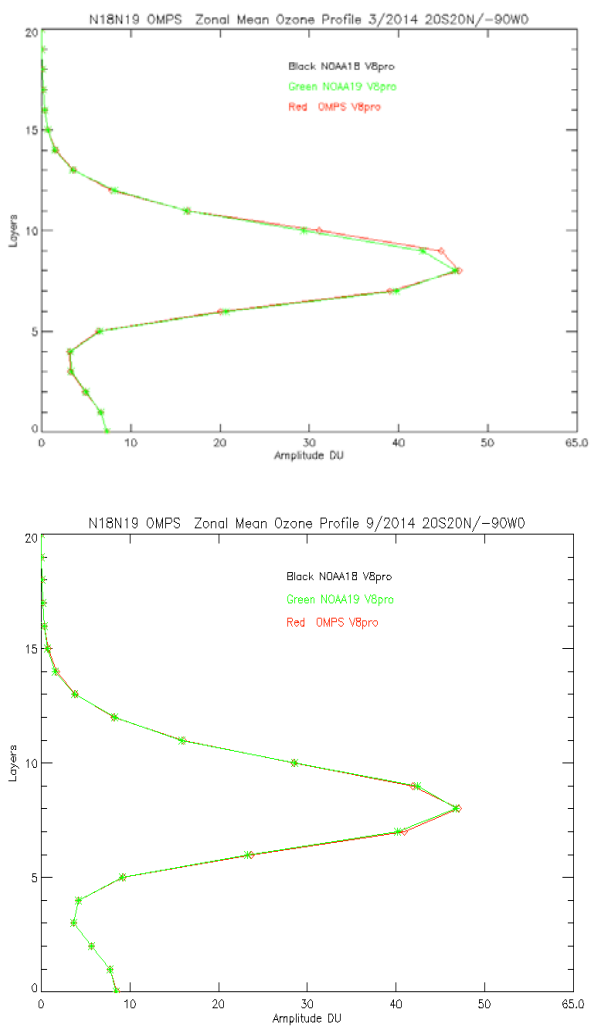

Figure 2: OMPS V8Pro Results Compared with NOAA 18 and NOAA 19

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