Atmospheric Chemistry Products from the Ozone Mapping and Profiler Suite (OMPS): Validation and Applications

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with contributions from the NOAA and NASA OMPS S-NPP Teams

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Outline

• Instrument Overview and Performance
• Nadir Mapper Daily Global Products
  – Climate-quality Total Column Ozone (climate, monitoring, assimilation, UV Index)
  – UV-absorbing Aerosol Index (smoke, dust, volcanic ash)
  – Atmospheric SO2 for Hazards and Air Quality (volcanic warnings, forecasts, inventories, campaigns)
• Nadir Ozone Profile Products
  – Ozone vertical profiles for middle and upper stratosphere (monitoring, assimilation)
  – Solar Mg II index and spectral variations
• Limb Ozone Profile Products
  – High vertical resolution stratospheric Ozone profiles (Antarctic Ozone Hole monitoring, assimilation, climate)
  – High vertical resolution stratospheric Aerosol profiles (monitoring, transport)
• Research Products
Abstract

The Ozone Mapping and Profiler Suite (OMPS) is designed to make measurements of scattered solar UV and visible radiance with three separate CCD detectors. The measurements contain information on atmospheric ozone and other trace gases. This talk reports on the performance of the instruments and the validation of the ozone products with particular attention to their ability to provide atmospheric chemistry products for use in ozone monitoring, air quality and aviation hazard applications. The OMPS measurements are well on the way to being fully validated with on-board calibration system performing as desired and thorough characterizations of stray light, wavelength scale shift, throughput degradation, non-linearity and dark current to provide models to correct for these effects. The Version 8 Ozone Profile and Total Ozone Algorithms used to create the earlier parts of the corresponding records have been adapted to produce similar products from OMPS measurements. The Version 8 Total Ozone Algorithms produces residuals used by a Linear Fit SO2 retrieval algorithm. Comparisons with NOAA-19 SBUV/2 and EOS Aura OMI products show excellent consistency. The OMPS Limb Profiler products are advancing with improved modeling and better estimates of stray light and pointing errors.
Each instrument can view the Earth or either of two solar diffusers; a working and a reference.

The instruments measure radiance scattered from the Earth’s atmosphere and surface. The detectors are 2-D CCD arrays with one spectral and one spatial dimension.

They also make solar measurements using pairs of diffusers. Judicious operation of working and reference diffusers allows analysts to track the diffuser degradation. The solar measurements also provide checks on the wavelength scale and bandpass. The instruments regularly conduct their internal dark and nonlinearity calibration sequences and have completed a full three years of solar measurements.
OMPS
Ozone Mapping & Profiler Suite
Global daily monitoring of three dimensional distribution of ozone and other atmospheric constituents.
Continues the NOAA SBUV/2, EOS-AURA OMI and SOLSE/LORE records.

Nadir Mapper (NM)
Grating spectrometer, 2-D CCD
110 deg. cross track,
300 nm to 380 nm spectral,
1.1nm FWHM bandpass

Nadir Profiler (NP)
Grating spectrometer, 2-D CCD
Nadir view, 250 km cross track,
250 nm to 310 nm spectral,
1.1 nm FWHM bandpass

Limb Profiler (LP)
Prism spectrometer, 2-D CCD
Three vertical slits, -20 to 80 km,
290 nm to 1000 nm

The calibration systems use pairs of working and reference solar diffusers.
Comparison of NASA-derived and NOAA-derived solar diffuser measurement trends for the OMPS Nadir Profile sensor. NASA estimates include (a) correction for wavelength shifts determined independently and (b) correction for solar activity determined using the Mg II proxy and associated scale factors for each wavelength. NOAA estimates are calculated by simultaneously solving for diffuser trends, wavelength shift and solar activity represented by three separate terms in a multiple regression fit. Both sets of results agree well and the instrument shows excellent stability with throughput degradation less than 0.5%/Year even for the shortest channels for the reference diffuser measurements.
OMPS Aerosol Index overlays on VIIRS RGB

ozoneaq.gsfc.nasa.gov/omps/blog/

False color Aerosol Index data (with varying scales) plotted over VIIRS RGB.

Top Right: Dust from deserts over Africa and the Middle East.
Bottom Right: Haze/smoke from agricultural burning over India.
Bottom Left: Smoke from wild fires in Australia.

Notice the capability of OMPS to retrieve aerosols over clouds.
High-Spatial-Resolution Capabilities of OMPS

The image on the left shows a false color map of the OMPS effective reflectivity (from a single Ultraviolet channel at 380 nm) over the Arabian Peninsula region for January 30, 2012 when the instrument was making a set of high-spatial-resolution measurements with $5 \times 10 \text{ km}^2$ FOVs at nadir. The color scale intervals range from 0 to 2 % in dark blue to 18 to 20 % in yellow. The image on the right is an Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) Red-Green-Blue image for the same day.

The OMPS Nadir Mapper instrument is very stable, extremely flexible, and has excellent SNRs.
Near-Real-Time OMPS SO$_2$ Product

NPP/OMPS
Orbits 10253 & 10252 -- 10/19/2013 - 10/20/2013

Eruption of Kliuchevskoi Volcano (Kamchatka, Eastern Russia)
10/19/2013

Orbit: 10253
Low-res

Orbit: 10252
Hi-res

SO$_2$ column 5 km [DU]
SO2 estimates for the Mount Kelud eruption

Top Right: NASA OMPS product
Bottom Right: NOAA OMPS product
Bottom Left: NASA OMI product

Indonesia volcano eruption closes three international airports
OMPS NM measurements can be used to make state-of-the-art SO₂, NO₂ and Aerosol retrievals for air quality and hazard applications. Examples below are for Asia for 10/20/2013 (top) & 10/23/2013 (bottom).
Chasing Orbit Comparisons to SBUV/2

Approximately every 12 days, the orbital tracks for the NOAA-19 and S-NPP spacecrafts align and allow comparisons of products for similar locations with small viewing time differences. The top figure shows convergence of the orbital paths.

Products and residuals from the same retrieval algorithms for SBUV/2 and OMPS NP can be compared directly. The bottom figures show ozone amounts for nine layers for the two Version 8 retrievals with the top left for the lowest layer and the bottom right for the highest layer.

Additional monitoring plots provided at http://www.star.nesdis.noaa.gov/icvs/prodDemos/proOMPSbeta.O3PRO_V8.php show that the ozone profile differences are consistent with the initial measurement residuals computed relative to the first guess profiles.
Comparisons between application results for assimilated SBUV/2 and OMPS NP products at NCEP.

OMPS products are provide in NRT in BUFR files from NDE.
Multiple Linear Analysis of NP Solar Measurements for the Working Diffuser

- **Wavelength Shift Effects < 1%**
- **Solar Activity Effects < 1%**
- **Instrument and Working Diffuser Degradation**

*Retrieval Channel Locations*
The OMPS Limb Profiler has 1-KM reporting and 3-km vertical resolution.

Comparison of OMPS Total Column Ozone and Limb Profile Ozone, by C. Seftor, NASA GSFC
Outside and Inside the Antarctic Ozone Hole
Research Products

• Combined UV/IR Ozone Profile retrievals (OMPS+CrIS)
  – Simple top+bottom approach in operations -- TOAST product
• Global UV reflectivity (OMPS NM)
• UV Cloud Optical Centroids (OMPS NM)
• Column NO2 for Air Quality (OMPS NM)
• Combined UV/Visible Aerosol retrievals (OMPS+VIIRS)
• Tropospheric Ozone Estimates (Total Column - Limb, DCC)
• Polar Mesospheric Clouds (OMPS NM)
• Polar Stratospheric Clouds (OMPS LP)
• Stratospheric Rocket Plumes and Meteor Plumes (OMPS LP)
• Stratospheric NO2 Profiles (OMPS LP)
• Upper atmosphere Temperature/Pressure profiles (OMPS LP)
Summary & Conclusions

• The on-board monitoring systems are providing good characterizations of the time-dependent changes.

• The heritage Version 8 algorithm products are more than capable of continuing the Climate Data records and provide continuation of SBUV/2 records. The Linear Fit SO2 algorithm provides good estimates by using the Version 8 residuals.

• The Limb Profiler products are progressing and are achieving high-vertical resolution performance for ozone and aerosol profiles.

• We are just beginning to explore the real-time applications for the OMPS aerosol products.

• Additional products are in the research queue.
Support Acknowledgement

• The implementations at NOAA of the Version 8 algorithms for use with OMPS were supported by the NCDC Climate Data Record Program and the JPSS Program. The implementations at NASA were supported by the MEASURES Program and the OMPS S-NPP Science Team.

• The OMPS Limb Ozone Profile retrieval development and validation is primarily the work of the NASA OMPS S-NPP Science Team.
Useful OMPS Resources

• Instrument Description and Recent Publications
  – Dittman et al., 2002, “Nadir Ultraviolet Imaging Spectrometer for the NPOESS OMPS,” SPIE 4814. DOI:10.1117/12.453748

• Operational Algorithm and Algorithm Theoretical Basis Documents and Status Briefings
  – http://star.nesdis.noaa.gov/jpss/ATBD.php
  – http://www.star.nesdis.noaa.gov/star/meetings.php

• Monitoring
  – http://www.star.nesdis.noaa.gov/icvs/prodDemos/proComparison.php
  – http://www.star.nesdis.noaa.gov/icvs/status_NPP_OMPS_NM.php

• Data Sets
  – http://www.nsof.class.noaa.gov/saa/products/welcome

• Direct Broadcast Programs
  – http://directreadout.sci.gsfc.nasa.gov/?id=software
Additional Product and Validation Examples
Comparison of TACO (OMPS and CrIS) with TOAST (SBUV/2 and TOVS/HIRS)

Combined products use UV retrievals for the stratosphere and IR retrievals for the Troposphere
Sensitivity of the 305-nm (left) and 600-nm (right) channel limb radiances to layer ozone changes for 1-km layers for a 40º SZA and mid-latitude 325-DU profile. Each curve gives the ratio of changes in the limb radiance for a given tangent height to changes in the ozone amounts as a function of altitude. The changes in the natural log of both quantities are used to give a % radiance change / % ozone change interpretation to the results. The orange curve with the highest peak for 305-nm is for the 45-km tangent height case.
Limb Aerosol Extinction Retrievals

Dust from the Russian Chelyabinsk Meteor

From a talk by Nick Gorkavyi
The Meteor Skybelt has a vertical depth of about 5 km, a width of about 300 to 400 km, a density of about 1 particle per cc. Total particulate mass within the skybelt is estimated to be 40-50 metric tons.
Will products from OMPS (NOAA’s new generation of ozone monitoring instruments) measurements continue the past Ozone CDRs with adequate fidelity? This talk will present the following results:

The on-board calibration systems are functioning as designed and are identifying changes in the optical throughput and dark current with high accuracy.

Validation of the SDRs and EDRs showed good stability but identified areas where improvements were needed. Adjustments and models to apply corrections have been created to reduce errors from stray light and wavelength scale variations to acceptable levels and are progressing into the operational product processing system.

Offline processing with the heritage Version 8 algorithms creates products with good consistency with existing elements of the Ozone CDRs. These algorithms are moving down the pipeline for operational implementation.

The figure on the right compares daily averages (in Dobson units) for total ozone products over a latitude x longitude box in the equatorial Pacific Ocean for December 2014. The black line and symbols are the results from the Version 8 algorithm applied to the NOAA-19 SBUV/2 measurements and the red line and symbols are for the same algorithm applied to S-NPP OMPS measurements. They show good agreement. The other colors are for total ozone values from a variety of instruments and algorithms.
The Ozone Mapping & Profiler Suite (OMPS) was launched on the Suomi National Polar Partnership (S-NPP) satellite on October 28, 2011. The OMPS is the next generation of operational ozone sensors for NOAA. Its products will replace existing ones from the Solar Backscatter Ultraviolet (SBUV/2) instruments.

NOAA/NESDIS has provided validation and analysis of the Total Column and Nadir Profile operational ozone products from the Interface Data Processing Segment (IDPS) to justify their advance to Provisional Maturity. This will be applied retroactively to the products as of March 1, 2013. Findings presentations & ReadMe files are provided with the products at CLASS.

The two figures on the right compare the OMPS Limb Profiler and Nadir Profiler ozone profiles for September 6, 2012. They show the zonal mean mixing ratios at pressures from 100 to 1 mbars versus Latitude. The Limb data has been smoothed vertically to be similar to the Nadir resolution. Refinements of both products are continuing. (Limb Profiler data and figures are from the NASA OMPS NPP Science Team.)

Significance: The OMPS instruments provide the measurements to continue monitoring atmospheric ozone.
Taco Umkehr Layer Analysis
Optical throughput change < 1%

Reference        Working

NP

NM
Pacific Box Comparisons

• Product statistics and cross-track variations are monitored in an uneventful region of the globe extending from 20°S to 20°N and 100°W to 180°W.

• The following figures each show four weekly means for May 2014 versus cross-track view position.

• The highly repetitive patterns are produced by cross-track channel biases.

• These will be removed by soft calibration adjustments using the Calibration Factor Earth tables.
Current Total Ozone Product Deficiencies

The figures show weekly averages for June 2014 for a latitude/longitude box in the equatorial Pacific. The horizontal axes are cross-track position. These patterns are repeatable and will be removed with soft calibration adjustments.

The wavelength quadruplet chosen for the SO₂ index is too sensitive to calibration uncertainties. This leads to a large number of false positives.

Small uncertainties in the calibration produce a cross-track dependence in the total ozone with satellite view angle.
Weekly 1-percentile Effective Reflectivity and Aerosol Index values, for June 2014 for a latitude / longitude box in the Equatorial Pacific versus cross-track pixel. Internal Consistency and Vicarious Calibration / Validation Generation of soft calibration coefficients (CFE) – Use Equatorial Pacific Box, Minimum Reflectivity = 4%, no aerosol, no SO2, TOz set to OMI TOz.
Time series of daily zonal mean ozone for Pacific Box

Daily equatorial Pacific mean time series of total column ozone for a variety of products from OMPS, OMI, GOME-2, and SBUV/2
Ground-Based Comparisons

Comparisons to Ground-base station Total Column Ozone estimates for matchup overpass data sets. Top right is summary for 22 Dobson stations. Lower plots are for a single well-calibrated NOAA/ESRL station at Boulder CO. Differences for OMPS and OMI products are shown.
OMPS and OMI vs Boulder Dobson, Matched daily TO3 DU, Direct Sun

Averages - Dobson DS:
311 OMPS: 301 OMI: 310

OMI = 0.96x + 11.73
$R^2 = 0.95$

OMPS = 0.96x + 1.16
$R^2 = 0.92$
Summary

• The OMPS instruments are performing well and delivering ozone products to continue the over 30-years of satellite monitoring.

• Validated nadir total column ozone and ozone profiles will be available operationally by mid-2014.

• The limb ozone profiles provide global coverage of the ozone layer with high vertical resolution.

• The OMPS measurements can be used to provide other atmospheric chemistry and composition products at good horizontal resolution.
Center Slit, OMPS Limb Ozone Profile Retrievals for one Orbit on October 22, 2013

High vertical resolution structure of the Antarctic Ozone Hole

Ozone Orbital Curtain (Center Slit - Linear Scale)
Figure Generated 2013-10-22 12:18:56
Date: 20131001 Orbit #: 9984 ST #: 0.4

Ozone Amounts in Volume Mixing Ratio, $10^{12}$ mol/cm$^3$
Current Status of NUCAPS CrIS Trace Gas Products

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<th>gas</th>
<th>Range (cm⁻¹)</th>
<th>Precision</th>
<th>Interference</th>
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<tr>
<td>UTH</td>
<td>1400-1500</td>
<td>15%</td>
<td>T(p)</td>
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<tr>
<td>O₃</td>
<td>1025-1050</td>
<td>10%</td>
<td>H₂O, emissivity</td>
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<tr>
<td>CO*</td>
<td>2080-2200</td>
<td>30%</td>
<td>H₂O, N₂O</td>
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<tr>
<td>CH₄</td>
<td>1250-1370</td>
<td>20 ppb</td>
<td>H₂O, HNO₃</td>
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<tr>
<td>CO₂</td>
<td>680-795</td>
<td>2 ppm</td>
<td>H₂O, O₃</td>
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<tr>
<td></td>
<td>2375-2395</td>
<td>2 ppm</td>
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<tr>
<td>HNO₃</td>
<td>860-920</td>
<td>40%</td>
<td>emissivity</td>
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<td></td>
<td>1320-1330</td>
<td>25%</td>
<td>H₂O, CH₄</td>
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<tr>
<td>N₂O</td>
<td>1250-1315</td>
<td>10%</td>
<td>H₂O</td>
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<tr>
<td></td>
<td>2180-2250</td>
<td>10%</td>
<td>H₂O, CO</td>
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<tr>
<td>SO₂</td>
<td>1340-1380</td>
<td>10000%</td>
<td>H₂O, HNO₃</td>
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<tr>
<td>CFCl₃ (F11)</td>
<td>830-860</td>
<td>20%</td>
<td>emissivity</td>
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<tr>
<td>CF₂Cl (F12)</td>
<td>900-940</td>
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<tr>
<td>CCl₄</td>
<td>790-805</td>
<td>50%</td>
<td>emissivity</td>
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* If sub-sampled CrIS SW is used. 15% if full resolution SW is acquired.
### Summary of products from Science Code

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<th>d.o.f.</th>
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<td>H2O,O3,N2O, emissivity</td>
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<td>H₂O</td>
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<td>4-6</td>
<td>CH4, HNO3</td>
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<td>10%</td>
<td>1+</td>
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<td>CO</td>
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<td>Volcanic SO₂</td>
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<td>50% ??</td>
<td>&lt; 1</td>
<td>emissivity H2O, CH₄, N2O</td>
<td>100 layers</td>
</tr>
<tr>
<td>N₂O</td>
<td>1250-1315, 2180-2250</td>
<td>5% ??</td>
<td>&lt; 1</td>
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