The upcoming OMPS/LP mission

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5th Limb Workshop
Helsinki, Finland
Nov 16-19th, 2009
The upcoming OMPS/LP mission

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The Ozone Mapping Profiler Suite

- Mission goal
  - To continue US commitment to monitor global ozone: horizontal and vertical distribution within the Earth's atmosphere. Continue TOMS/OMI/SBUV/SAGE
  - Secondary products: stratospheric aerosol, cloud top, NO$_2$(?), BrO (?)

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**Ozone trends**

- **SAGE I**
- **SAGE II**
- **HALOE**

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**Stratospheric Aerosol**

From L. Thomason LaRC
NPOESS Preparatory Project (NPP)
National Polar-orbiting Operational Environmental Satellite System

- NPP is joint mission between IPO (NOAA / NASA / DoD) and NASA
  - Conceived as “bridge” mission for NASA, risk reduction for IPO
  - Presently, much more of an operational aspect due to delays
- 5 sensors:
  - VIIRS (MODIS)
  - CrIS (AIRS)
  - ATMS (AMSU)
  - OMPS (OMI, SOLSE-LORE)
  - CERES

Sun-synchronous orbit
Altitude of 825 km
13:30 ascending orbit
Spring 2011 launch
70 to 85 km

-40 to -25 km

125 km x 110 km x 3 km

Designed and built by Ball Aerospace
### OMPS specifications

<table>
<thead>
<tr>
<th></th>
<th>Nadir Total column</th>
<th>Nadir profiler</th>
<th>Limb profiler</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heritage</strong></td>
<td>TOMS, OMI</td>
<td>SBUV, OMI</td>
<td>SOLSE/LORE, OSIRIS, SCIAMACHY, SAGE III</td>
</tr>
<tr>
<td><strong>Spectral Range</strong></td>
<td>300 - 380 nm</td>
<td>250 – 310 nm</td>
<td>290-920 nm</td>
</tr>
<tr>
<td><strong>Spectral FWHM</strong></td>
<td>1.0 nm</td>
<td>1.19 nm</td>
<td>1.5 - 40 nm (prism)</td>
</tr>
<tr>
<td><strong>Field of Regard</strong></td>
<td>110 x 0.3 deg</td>
<td>16.7 x 0.3 deg</td>
<td>500kmx125kmx110km</td>
</tr>
<tr>
<td><strong>CCD pixel Field Of View (FWHM)</strong></td>
<td></td>
<td></td>
<td>Elevation: 1.3-1.5 km Azimuth: 3 km</td>
</tr>
<tr>
<td><strong>Revisit time (days)</strong></td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><strong>Cell Size: Horizontal Vertical</strong></td>
<td>50kmx50 km at Nadir</td>
<td>250 kmx250km 5 km</td>
<td>125kmx250km (3 slits) 1 km</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>15 DU or better</td>
<td>7% (at 1 mb)</td>
<td>10% (15 - 60 km) 20% (UTLS)</td>
</tr>
<tr>
<td><strong>Precision</strong></td>
<td>3 DU+0.5% or better</td>
<td>10% (at 30 mb)</td>
<td>3% (15-50 km) 10% (UTLS, 50-60km)</td>
</tr>
<tr>
<td><strong>Long-term Stability</strong></td>
<td>1% over 7 years</td>
<td>2% over 7 years</td>
<td>2% over 7 years</td>
</tr>
</tbody>
</table>

Mass 68 kg, Power 108 W, Data rate 165 kbps, Sensor Size 35 x 54 x 56 cm
Geo-locations of tangent point (TH=25km) over 5 days period.

Day 1  Day 2  Day 3  Day 4  Day 5

Tracks are shown for the 3 slits.
OMPS Limb Profiler description (1)

- Specifically designed for ozone retrieval: Spectral dispersion uses a prism, with highest spectral resolution in Hartley/Huggins (1nm) and lower in Chappuis (10nm)
- Uses 4 separate gains to contend with high dynamic range across FOV
- All gains, all slits imaged onto a single CCD array focal plane
- Only download a fraction of CCD array, due to downlink rate limitations

Spectral resolution

FWHM (nm) vs. Wavelength (nm)
OMPS Limb Profiler description (2)

Level 1 products:
- Calibrated, height registered, geolocated, straylight removed radiance profiles

Level 2 products:
- Ozone profile
- Aerosol profile
- Aerosol size (1 moment)
- Cloud top height
- Effective surface albedo

2 gains, 2 integr, Sample Table, Straylight
Sensor characterization

• **Laboratory measurements**
  - Spectral and angular registrations
  - Spectral bandpasses, angular FOV
  - Absolute radiometric coefficients (radiance, irradiance)
  - PSFs (straylight)
  - Linearity
  - Goniometry (effect of diffuser incidence angle)

• **On-orbit calibration (solar diffuser)**
  - Weekly irradiance: wavelength calibration
  - Dark current on dark side

• **Instrument model**
  - To be used during operations to do troubleshooting
  - To be used to generate synthetic data
Generic output (one per orbit, 14 times a day)

Similar curtain files for aerosol, aerosol size, cloud top, effective surface albedo

Will be posted on NASA website, with latency of a few days (aka TOMS). HDF formatted files
Retrieval algorithm main concepts

Ozone retrieval:
• contrast highly absorbing channels with weaker absorbing channels (pairs in UV, triplets in Chappuis)
• $I_0$ reference

• Clouds: jumps in radiance profiles
• Aerosol: non absorbing channels
• Albedo: matching data and model in 35-45 km
Sensitivity to ozone

Sensitivity to aerosol
Sensitivity of ozone retrievals to surface reflectance, aerosol, NO$_2$, TH registration
Straylight

Straylight (red=30%)

Downloaded pixels

Short integration

Long integration

Core

Wings

Ghost
Retrieval algorithms

- Mainstream
- Direct Optimal Estimation
- Spectral fitting
- Two dimensional retrieval

Preprocessing → Retrieval

Ozone profile (trop-60km)
Aerosol extinction profile (15-35km)
Aerosol size (1 moment)
Cloud Top height
Effective scene albedo
Troposphere Vortex
Forward modeling and instrument model

• Forward models
  1. University of Arizona Gauss Seidel Radiative Transfer model: spherical SS, MS along tangent point vertical
  2. VLIDORT (Discrete ordinates): same SS as above, MS source term
  3. SASKTRAN: pending

• Instrument model
  1. To simulate main functions of instrument (radiance to counts, projection $[\lambda, TH]$ into CCD array coordinates, noise, straylight, smear, dark current, …)
  2. To generate synthetic CCD array focal planes to be used for module and end-to-end testing
VLIDORT as alternate RT model

VLIDORT (version 2.4RT) is a pseudo-spherical vector RT discrete ordinate model (typically 8 discrete ordinates). Plane-parallel scattering

- Integrate Source Function along Line of sight:
  \[ I_1 = I_2 \cdot T_{12} + S_{12} + M_{12}, \quad I_2 = I_3 \cdot T_{23} + S_{23} + M_{23} \]
- \( T_{12} \) = Transmittance along LOS segment from point 2 to point 1.
- \( S_{12} \) = Single scatter source term, segment 2\(\rightarrow\)1. (SS, no surface contribution).
- \( M_{12} \) = multiple scatter source term, segment 2\(\rightarrow\)1. (Surface included).
- \( T_{n-1,n} \) and \( S_{n-1,n} \) unchanged: Fully linearized (profile Jacobians)
- \( M_{n-1,n} \) to be provided by VLIDORT

\[ M_{n-1,n} = f(SZA_n, Az_n, Vert_n, s_n) \]

Function \( f \) is determined by running VLIDORT at a series of node points to establish 2 LUTs (Down and Up welling). Trilinear interpolation is then used to evaluate \( f \) for each LOS segment

Gain: Speed and accuracy
Retrieval = 7 successive steps:

- **Step 1:** Wavelength registration
- **Step 2:** Surface reflectance
- **Step 3 and 5:** Tangent Height registration
- **Step 4:** Aerosol and Cloud top
- **Step 6:** Hartley/Huggins ozone
- **Step 7:** Chappuis ozone
Step 1: Wavelength registration:

Compare location of solar Fraunhofer lines data vs model, along a CCD pixel row.

Step 2: Surface reflectance and Cloud top height

- Compare measured radiance and modeled radiance in the TH range: 35-45 km
- Identify radiance profile sudden increases at long wavelengths
Step 4: Aerosol retrieval: extinction + 1 moment of size distribution

Normalization range

Aerosol signature

500-520

Alternative:

\[ \log[k(\lambda, H)] = a(H) \cdot \log(\lambda) + b(H) \]
Testing concepts

One step at a time

1. Test forward model vs inversion in a controlled environment: synthetic data

   Input Ozone → Forward model → Retrieval Algorithm → Retrieved Ozone

2. Test Inversion with real data proxy: SAGE III LS, OSIRIS, SCIAMACHY

   SCIAMACHY Proxy generator → Retrieval Algorithm → Retrieved Ozone

   OSIRIS

   at SAGE II locations

3. Test instrument effects

   Input Ozone → Forward model → Instrument model → Straylight decontamination → 2D-gridding Consolidation → Retrieved Ozone
End to End testing

**FM** ➔ **IM** ➔ **STr** ➔ **2D cons** ➔ **EDR**

**Slit 1**

**Slit 2**

**Slit 3**

450 synthetic LS events
Conclusion

• Launch is approaching: Spring 2011
• Numerical tools have been developed and are being tested and upgraded and tested and fine-tuned and tested...
• Codes are being integrated into operational stream (Processing speed = real time on couple of 16 processors PCs for raw to ozone / aerosol / cloud products)
• Alternatives are being implemented to be ready by launch time
• Looking forward to real data...
Back up slides
**Advanced Microwave Sounding Unit**
- Total Precipitable Water (mm)
- Rain Rate (mm/hr)
- Brightness Temperature (K)
- Cloud Liquid Water (mm)
- Sea Ice
- Snow Cover

**Atmospheric Infrared Sounder**
- Air and surface temperature
- Water vapor
- Cloud properties
- Ozone, carbon monoxide, carbon dioxide, and methane.

**Moderate Resolution Imaging Spectroradiometer**
- RGB Composite
- Cloud Optical Thickness
- Cloud Top Pressure
- Cloud Effective Radius
- Aerosol Optical Depth

**Clouds and the Earth's Radiant Energy System**
- Solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface.
Test data dataset

• 450 co-locations of a SAGE II occultation measurement with a SCIAMACHY limb scattering measurement over a one-year period.
• Forward model run with
  - ozone profile = SAGE II
  - solar view angles = SCIAMACHY
  - surface albedo = 0.15, aerosol = constant = climatology
  - atmosphere Temperature/Pressure = NCEP reanalysis
Steps 3 and 5: Tangent Height registration:

- Base: Use spacecraft state vector and attitude
- Fine tune: Use the RSAS technique with all CCD pixels around 350nm, comparing data vs model (model run with NCEP Temperature/Pressure profiles)
- Fine tune 2: Extend RSAS to wavelengths up to 500nm
## Spectral channels selection for ozone retrieval

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$TH_{NORM}$ (Doublet)</td>
<td>65 km</td>
</tr>
<tr>
<td>$TH_{NORM}$ (Triplet)</td>
<td>45 km</td>
</tr>
<tr>
<td>Doublet $\lambda_0$</td>
<td>355 nm</td>
</tr>
<tr>
<td>Triplet $\lambda_L$</td>
<td>500 nm</td>
</tr>
<tr>
<td>Triplet $\lambda_R$</td>
<td>680 nm</td>
</tr>
<tr>
<td>Wavelengths used in UV (nm)</td>
<td>289.3 289.8 290.3 290.9 291.4 292.0 293.1</td>
</tr>
<tr>
<td></td>
<td>293.6 294.2 294.7 295.2 295.8 296.5 297.0</td>
</tr>
<tr>
<td></td>
<td>297.6 298.2 298.8 299.4 300.0 300.6 301.2</td>
</tr>
<tr>
<td></td>
<td>301.8 302.4 303.0 308.9 309.5 310.1 310.8</td>
</tr>
<tr>
<td></td>
<td>311.6 318.0 318.7 319.4 320.2 320.9 321.7</td>
</tr>
<tr>
<td>Wavelengths used in visible (nm)</td>
<td>522.8 526.3 549.9 554.3 572.1 576.9 602.5</td>
</tr>
<tr>
<td></td>
<td>608.1 613.4 619.624.8 630.9 637.4 643.4 649.7</td>
</tr>
</tbody>
</table>
Steps 6 and 7: ozone retrieval

• Method relies on Doublet/Triplet

• Doublet/Triplet measurement vectors used in Optimal Estimation
Comparison Retrievals vs Inputs

Forward model

RSAS

Aerosol extinction

Ozone retrieval

Mean offset = 46.8 m
StDev = 46.1 m

mean bias 513
STD 513
mean bias 746
STD 746
mean bias 1006
STD 1006

Mean Bias (%)
EDR testing with OSIRIS proxy radiances

Ozone retrievals

200 LS events close to SAGE II

Typical ozone and aerosol retrievals
EDR testing with SCIAMACHY proxy radiances

Ozone retrievals

Aerosol retrievals

120 LS events close to SAGE II
Three main EDR methods:

1. Mainstream: CCD data, 2D gridding, 4 gain consolidation

2. Direct Optimal Estimation: operate directly on ensemble of CCD pixels

3. Spectral fitting: DOAS on both data and model
<table>
<thead>
<tr>
<th>Wavelength range (nm)</th>
<th>Altitude range (km)</th>
<th>Useage</th>
</tr>
</thead>
<tbody>
<tr>
<td>290-295</td>
<td>50-60</td>
<td>Ozone</td>
</tr>
<tr>
<td>295-300</td>
<td>47-53</td>
<td>Ozone</td>
</tr>
<tr>
<td>300-305</td>
<td>43-53</td>
<td>Ozone</td>
</tr>
<tr>
<td>305-315</td>
<td>38-45</td>
<td>Ozone</td>
</tr>
<tr>
<td>315-325</td>
<td>28-38</td>
<td>Ozone</td>
</tr>
<tr>
<td>340-360</td>
<td>whole FOV</td>
<td>RSAS, Straylight</td>
</tr>
<tr>
<td>360-500</td>
<td>whole FOV</td>
<td>Straylight</td>
</tr>
<tr>
<td>500-520</td>
<td>10-50</td>
<td>Aerosol, albedo</td>
</tr>
<tr>
<td>525-675</td>
<td>10-50</td>
<td>Ozone</td>
</tr>
<tr>
<td>660-680</td>
<td>10-45</td>
<td>Aerosol, albedo, cloud top</td>
</tr>
<tr>
<td>740-750</td>
<td>10-45</td>
<td>Aerosol, albedo, cloud top</td>
</tr>
<tr>
<td>840-860</td>
<td>10-45</td>
<td>Aerosol, albedo, cloud top</td>
</tr>
<tr>
<td>900-920</td>
<td>10-45</td>
<td>Aerosol, albedo, cloud top</td>
</tr>
<tr>
<td>960</td>
<td>10-30</td>
<td>Cloud top</td>
</tr>
<tr>
<td>All wavelengths</td>
<td>25, 30</td>
<td>Wavelength registration</td>
</tr>
</tbody>
</table>
Present performance assessment

Input Ozone Forward model

Retrieval Algorithm Retrieved Ozone

SCIAMACHY Proxy generator

OSIRIS at SAGE II locations

Retrieved Ozone

Input Forward model

Instrument model

Straylight decontamination

2D-gridding Consolidation Retrieved Ozone