The EOS Microwave Limb Sounder (MLS) Experiment

A summary presentation emphasizing the EOS MLS Scientific Objectives, Measurements and Data Products

prepared by Joe Waters
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An updated copy of this presentation, and more information on the MLS experiments can be found on the MLS web site: http://mls.jpl.nasa.gov.

An Overview of the EOS MLS Experiment, available on the web site, is good starting point for more information on EOS MLS.
**EOS Microwave Limb Sounder (MLS)**

**EOS MLS is an experiment on NASA’s Aura satellite to begin observations in 2004**

**Its overall objective is to provide information for:**

- Determining if stratospheric ozone chemistry is recovering as expected
- Improving knowledge of processes that affect climate variability
- Helping understand ozone and pollution in the upper troposphere

**MLS data are complementary and supplementary with those from the other Aura instruments: HIRDLS, OMI, TES**

- Together these instruments provide a comprehensive suite of information for helping understand atmospheric global change.
**EOS MLS Scientific Objective**

**Determining if Stratospheric Ozone Chemistry is Recovering**

- Are stratospheric chlorine and ozone chemistry responding to regulations as expected?

- Will ozone recovery be delayed by climate changes?
  - cooling of lower stratosphere
  - increase in stratospheric H₂O
  - changes in circulation

- Will Arctic, because of climate change, experience severe denitrification that could lead to increased ozone depletion?

- Do we adequately understand chemistry and transport in the stratosphere at all altitudes and latitudes?

- How will volcanoes affect recovery?

- MLS stratospheric measurements to address these questions:
  - HCl, ClO, BrO, OH, HO₂, O₃, HNO₃, H₂O, N₂O, temperature, HOCl, SO₂, geopotential height

**UARS MLS HNO₃, ClO, and O₃**

Note: ClO is a form of chlorine that destroys ozone (O₃); chemistry on ‘frozen’ HNO₃ (at T<195K) enhances ClO.
• How do feedback mechanisms involving upper tropospheric H₂O affect climate variability?

• What are the atmospheric processes that control upper tropospheric H₂O abundances?

• How do sea surface temperature variations affect upper tropospheric H₂O (and thus climate)?

• How do lower stratospheric H₂O and O₃, and possibly Arctic vortex variations, affect climate?

• MLS upper tropospheric and lower stratospheric measurements to address these questions:

  H₂O, cirrus ice, temperature, O₃, and the ‘tracers’ CO, HCN, N₂O
Helping Understand Ozone and Pollution in Upper Troposphere

EOS MLS Scientific Objective

• What is the global distribution and variation of $O_3$ in the upper troposphere?

• What are the dominant sources of upper tropospheric $O_3$?

• How is regional pollution related to global upper tropospheric pollution?

• How might increases in upper tropospheric $O_3$ and other pollutants affect global air quality?

• MLS upper tropospheric measurements to address these questions:
  $O_3$, CO, HCN, CH$_3$CN - and $N_2O$ as tracer to identify air masses of stratospheric origin
EOS MLS Measurement Capability

Solid lines indicate useful individual profile measurements; those for lower stratospheric ClO and upper tropospheric HCN apply to enhanced conditions. Dashed lines indicate that averages are generally needed for useful precision.

- All measurements are made simultaneously and continuously – both day and night
- Measurements can be made in the presence of cirrus and dense volcanic aerosol
- Limb scan, calibration, vertical profile every 1.5° (165km, ~25s) along the suborbital track
- Retrieved profile standard vertical grid is 6 per decade log pressure (~2.5 km in UTLS)
  A few products - most notably UTLS H₂O, cloud ice, maybe temperature - will also be retrieved at 12/decade.
EOS MLS Geophysical Data Products and Files

• Files contain value and precision for each datum
  – Also include diagnostic quantities, and ancillary information such as: time, lat, lon, local solar time & zenith angle, line-of-sight angle w.r.t. north
  – Vertical coord is atmospheric pressure

• Level 2 files
  – Contain individual retrievals, equally-spaced along orbit for normal operation
  – A separate daily file for each standard data product (~2 MByte each)
  – Analogous to UARS ‘L3AT’ files

• Level 3 files
  – Daily maps: separate daily file for each standard data product (~4 MByte each)
  – Monthly maps: monthly file with all std products together (~50 MByte each)
  – Daily / monthly zonal means: daily and monthly files with all standard products grouped together (~1 MByte each)

<table>
<thead>
<tr>
<th>data product (alphabetical order)</th>
<th>~ useful vertical range</th>
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<tbody>
<tr>
<td></td>
<td>pressure / hPa</td>
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<tr>
<td></td>
<td>max</td>
</tr>
<tr>
<td>BrO mixing ratio</td>
<td>50</td>
</tr>
<tr>
<td>cloud ice</td>
<td>500</td>
</tr>
<tr>
<td>ClO mixing ratio</td>
<td>100</td>
</tr>
<tr>
<td>CO mixing ratio</td>
<td>300</td>
</tr>
<tr>
<td>geopotential height</td>
<td>500</td>
</tr>
<tr>
<td>H2O mixing ratio</td>
<td>500</td>
</tr>
<tr>
<td>HCl mixing ratio</td>
<td>100</td>
</tr>
<tr>
<td>HCN mixing ratio</td>
<td>300</td>
</tr>
<tr>
<td>HNO3 mixing ratio</td>
<td>100</td>
</tr>
<tr>
<td>HO2 mixing ratio</td>
<td>25</td>
</tr>
<tr>
<td>HOCl mixing ratio</td>
<td>100</td>
</tr>
<tr>
<td>N2O mixing ratio</td>
<td>500</td>
</tr>
<tr>
<td>O3 mixing ratio</td>
<td>300</td>
</tr>
<tr>
<td>O3 column in stratosphere</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>OH mixing ratio</td>
<td>50</td>
</tr>
<tr>
<td>relative humidity w.r.t. ice</td>
<td>500</td>
</tr>
<tr>
<td>SO2 (volcanic) mixing ratio</td>
<td>300</td>
</tr>
<tr>
<td>temperature</td>
<td>700</td>
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Note: CH3CN is expected to be added as a standard product.
EOS MLS Measurements

- All measurements made continuously, day and night
  - including in presence of cirrus clouds and dense volcanic aerosol

- Limb scan, calibration, vertical profile each 1.5° (25s, 165km) along the suborbital track
  - MLS views in forward direction along orbit path
  - Limb scans are synchronized to orbit, with 240 scans each orbit; scans over EQ and at symmetric latitudes in NH and SH

- Each day’s measurement coverage is shown at right
  - each cross gives the location of a limb scan and retrieved profile (line shows subsatellite path)
  - the tangent point locus during each limb scan is nearly vertical
  - Same SH coverage as NH shown here

- Vertical resolution of retrieved profiles is typically 3 km
  - there are resolution versus precision trade-offs
Annual variation of latitude range where EOS MLS measurements are in day and in night

The right vertical axis and horizontal lines give the latitude at the forward tangent point where EOS MLS makes measurements; the left axis gives their local solar time. Sampling around the orbit is in the direction from bottom to top in this figure. The unshaded or shaded regions show the progression over an annual cycle where measurements are in day or in night. The day/night boundary is defined as sunrise/sunset (over Earth’s surface) as seen from 20 km with refraction included.
EOS MLS Measurement Precision Example: tropical $\text{H}_2\text{O}$

Various $\text{H}_2\text{O}$ products at 3 km vertical resolution

Daily maps at 3, 2, 1 km vertical resolution in troposphere (and 3 km in stratosphere)

Taken from ‘EOS MLS Retrieved Geophysical Parameter Precision Estimates’ by M.J. Filipiak, which contains similar plots for all EOS MLS measurements and is available on the MLS web site (http://mls.jpl.nasa.gov).
Some features of MLS technique

• **MLS can ‘see through’ dense aerosol and cirrus**
  – Clouds/aerosol have much smaller effect than at IR, visible, UV wavelengths
  – Some cirrus signals, although optically thin, are measurable by MLS and provide unique ice information

• **Spectral lines are resolved with several channels**
  ⇒ robust data interpretation throughout stratosphere, mesosphere, and most of upper troposphere
  – Continuum emission from H$_2$O (vapor, ice, liquid) and dry air limits this aspect of robustness at lowest altitudes

• **Accurate and stable calibration**
  – **Upper limit** of 0.02% change in UARS MLS antenna reflectivity over 5 years in orbit - this is thought to be dominant contributor to overall calibration degradation, and similar performance expected from EOS MLS
  – Composition measurements can be ‘self-calibrated’ (to ~1%) from temperature

• **Heritage from UARS MLS (and balloon SLS, balloon OH)**
  – More than 250 MLS-related peer-reviewed scientific publications to date (updated list available on MLS web site, http://mls.jpl.nasa.gov)
  – EOS MLS has broader spectral coverage & finer spatial sampling than UARS
The EOS MLS Instrument

• Heterodyne radiometers operating in 5 broad mm/submm bands
  – 118 GHz radiometer: primarily for temperature and tangent pressure reference
  – 190 GHz radiometer: primarily for H₂O and HNO₃
  – 240 GHz radiometer: primarily for O₃ and CO
  – 640 GHz radiometer: primarily for HCl, ClO, BrO, HO₂ and N₂O
  – 2.5 THz radiometer: primarily for OH

• Advanced technology
  – Planar submm mixers
  – Integrated circuits
  – Composite materials
  – Compact gas laser for THz local oscillator and solid-state sources for GHz local oscillators

• JPL designed and developed
  – with many subsystems procured from industry

• Some overall characteristics
  – 440 kg, 530 W fully-on, 100 kb/s
  – 5-year on-orbit design lifetime
  – Ambient temperature operation
### EOS MLS Science Team

**Key ‘formal’ members, primary responsibilities, given below**
- from Caltech Jet Propulsion Laboratory (JPL), Pasadena, California
- from University of Edinburgh (UE), Edinburgh, Scotland, United Kingdom (UK)

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Role/Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joe Waters</td>
<td>JPL</td>
<td>US Principal Investigator</td>
</tr>
<tr>
<td>Bob Harwood</td>
<td>UE</td>
<td>UK Principal Investigator</td>
</tr>
<tr>
<td>Rick Cofield</td>
<td>JPL</td>
<td>Optics design, field-of-view calibration, geopotential height</td>
</tr>
<tr>
<td>Mark Filipiak</td>
<td>UE</td>
<td>CO and upper trop O₃ products, algorithm development</td>
</tr>
<tr>
<td>Lucien Froidevaux</td>
<td>JPL</td>
<td>Stratospheric O₃, HCl, and HOCl products, data trends</td>
</tr>
<tr>
<td>Robert Jarnot</td>
<td>JPL</td>
<td>Instrument Scientist, radiometric and spectral calibration</td>
</tr>
<tr>
<td>Jonathan Jiang</td>
<td>JPL</td>
<td>Cloud forward model, related research</td>
</tr>
<tr>
<td>Yibo Jiang</td>
<td>JPL</td>
<td>Level 3 mapping algorithms and validation</td>
</tr>
<tr>
<td>Nathaniel Livesey</td>
<td>JPL</td>
<td>Retrieval theory and algorithms, N₂O and BrO products</td>
</tr>
<tr>
<td>Gloria Manney</td>
<td>JPL</td>
<td>Data validation for dynamical consistency, dynamics studies</td>
</tr>
<tr>
<td>Herb Pickett</td>
<td>JPL</td>
<td>2.5 THz system, OH and HO₂ products</td>
</tr>
<tr>
<td>Hugh Pumphrey</td>
<td>UE</td>
<td>Stratospheric H₂O and HCN products, algorithm</td>
</tr>
<tr>
<td>Bill Read</td>
<td>JPL</td>
<td>‘Forward model’, upper tropospheric H₂O product</td>
</tr>
<tr>
<td>Michelle Santee</td>
<td>JPL</td>
<td>HNO₃ and ClO products, polar process studies</td>
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<tr>
<td>Michael Schwartz</td>
<td>JPL</td>
<td>Temperature product, tangent pressure measurement</td>
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<tr>
<td>Peter Siegel</td>
<td>JPL</td>
<td>Radiometer technology</td>
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<tr>
<td>Dong Wu</td>
<td>JPL</td>
<td>Cloud and ice products, related research</td>
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</tbody>
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**Additional scientists, outside the ‘formal’ MLS team, are involved in scientific analyses of MLS data**