EOS MLS: The Earth Observing System Microwave Limb Sounder on the Aura Satellite

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With input from MLS Science Team
MLS Science Team

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MLS Scientific Objectives

- Helping to understand if stratospheric ozone is recovering as anticipated
- Helping to Understand Processes that affect Climate Change
- Helping to understand ozone pollution in the upper troposphere
EOS MLS Atmospheric Measurements
(dotted lines indicate averages)
EOS Aura Atmospheric Profile Measurements

OMI also measures UVB flux, cloud top/cover, and column abundances of O$_3$, NO$_2$, BrO, aerosol and volcanic SO$_2$.

TES also measures several additional ‘special products’ such as ClONO$_2$, CF$_2$Cl$_2$, CFCl$_3$, N$_2$O and volcanic SO$_2$.

- HIRDLS: High Resolution Dynamics Limb Sounder
- MLS: Microwave Limb Sounder
- OMI: Ozone Monitoring Instrument
- TES: Tropospheric Emission Spectrometer

The diagram shows a profile of various atmospheric species and their heights above the Earth's surface, indicating the measurement capabilities of the EOS Aura Atmospheric Profile Measurements.
Pros and Cons of measuring in the microwave region

- **Pro**
  - Some species only available in this range
  - Measurements do not depend heavily on ancillary data
  - Emission relatively insensitive to temperature
  - Line widths give pressure information; precise platform pointing not essential
  - Aerosols and clouds give negligible effect
  - Radiative transfer theory relatively straightforward
  - LTE applies from ground to thermosphere

- **Cons**
  - Large Antenna needed?: hinders calibration
Heterodyne radiometers in 5 broad mm/submm bands:

- **118 GHz radiometer** primarily for T and pointing
- **190 GHz radiometer** primarily for H\textsubscript{2}O and HNO\textsubscript{3}
- **240 GHz radiometer** primarily for O\textsubscript{3} and CO
- **640 GHz radiometer** primarily for HCl, ClO, BrO, HO\textsubscript{2}, N\textsubscript{2}O
- **2.5 THz radiometer** primarily for OH

The EOS MLS Instrument
MLS: A double-sideband system
EOS MLS Spectral Coverage (folded sideband)

Blue lines correspond to 10 hPa tangent point.
Green lines correspond to 30 hPa tangent point.
Red lines correspond to 100 hPa tangent point.
Pale labels indicate redundant signals or alternate polarizations.

- Standard 25 channel filter bank
- Mid band 11 channel filter bank
- Single 0.5 GHz wide filter
- Digital Autocorrelator Spectrometer (~0.2 MHz resolution over ~10 MHz)
Arrows indicate direction of channel numbering.

Local oscillator frequencies:
R1[A/B]:11B 126.8000 GHz (lower sideband only)
R2:190 191.9000 GHz
R3:240 239.6600 GHz
R4:640 642.8700 GHz
R5[H]:275 2.5227816 THz
EOS MLS Measurement positions

Fig shows measurements taken on a typical day.

A profile is measured at the position of each dot

~3094 per day

Lats repeat each orbit

~170km spacing
To scale: profile positions and surface-tangential ray.
Satellite moves right to left along red arc at top.
Axes have origin at centre of earth, labelled in km
Blue depth=100km
**Precision and Resolution**

- Following 4 slides show some precisions
- GHz channels Beamwidth ($\alpha$ frequency)
  - vertical 1.5 to 6.5 km,
  - horizontal cross-track 3 to 13 km,
  - horizontal along-track about 400 km
- Scanning is continuous
- Best precision shown is for 3km vertical - for H2O and O3 in troposphere 2km resolution can be achieved but with loss of factor 2-3 in precision
EOSMLS

Temperature precision

Blue curve shows single profile precision assuming 3km vertical resolution

Sept 2006
EOSMLS

Geopotential Height Precision

Blue curve shows single profile precision assuming 3km vertical resolution
EOSMLS
Water Vapour
Precision

Blue: single profile precision assuming 3km vertical resolution
red: typical profile

Sept 20C
EOSMLS Ozone Precision

Blue: single profile precision assuming 3km vertical resolution

red: typical profile

Sept 2006
Milestones since launch (1)

- Launch 15 July 2004
- Instrument activation 18 July 2004
- First light 24 July 2004
- First full day of operation 3 August 2004
- Start Science mode 12 August 2004
- Reprocessing using version 1.5x of retrieval software begun 1 Jan 2005: all now reprocessed
- ver 1.5x data available at DAAC kept up to date
- Papers describing instrument in IEEE Transactions (GeoScience & RS) May 2006 (vol 44 no 5)
Milestones etc (2)

- Limited days processed with new software version (2.1), a prelude to major new version (2.2): Sept 2006
- First delivery of version 2.2 data anticipated in next few weeks
  2.2 superior to 1.51 by:
  - H2O lower into troposphere
  - HNO3 improved spectroscopy
  - CO has fixes to radiation calibration
  - HCl continuous across band 13 switch-off
- Calibration papers due March 2007
- Details of updates and data from http://mls.jpl.nasa.gov
- Please read the quality docs and contact Sci Team before using data
Retrieval

- Uses Maximum A Posteriori Probability method
- Problem is non-linear so MAP formula is used iteratively. Marquadt-Levenberg procedure needed to find minimum of the cost function
- To account for overlapping scans state and measurement vectors are blocks of about 12 profiles and scans
- Retrieval done in stages:
  Phase 1 (core) retrieves highly non-linear T, H2O. Later phases (core+R2, core+R4 etc) add in the (much more linear) mixing ratio retrievals.
Odd H and O photochemistry in the mesosphere
One day of data: 3495 profiles, 14.5 orbits
One day of data: 3495 profiles, 14.5 orbits
• 2D retrieval algorithms developed & used for EOS MLS
  - developed by Nathaniel Livesey and Bill Read [GRL, 2000]

• Improvements over 1D algorithms shown below
  - solid line is ‘truth’, crosses are 2D retrievals, dashed line is 1D
Aerosol and Cloud Effects on MLS

- **Aerosol**
  - Insignificant effect on MLS
  - See UARS MLS data at right

- **Ice Particles**
  - In absence of large (> ~100 µm) particles MLS radiances are proportional to total ice content
    - detection limit is a few mg/m³ average (over MLS FOV) ice density
    - Effect of larger particles is more complicated - and is being modeled

- **Liquid Droplets**
  - Clouds with > ~ 0.1 mg/m³ average (over MLS FOV) liquid water density will have large effect on radiances
  - MLS data *per se* cannot distinguish between water in liquid and ice forms
    - We *assume* that signals from sufficiently-cold regions are due to ice
MLS Cloud radiances

Map shows MLS track (stars) over MODIS cloud-top pressure.

Scale: $-\log_{10}(\text{Pressure / mb})$
END