Aura Microwave Limb Sounder (MLS) ozone profile data record – characteristics, quality and applications

A presentation for the 2016 meeting of the Committee on Earth Observation Satellites (COES) Atmospheric Composition Virtual Constellation (AC-VC)

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Photograph by ISS astronaut Ron Garan

Fundamentals of the Microwave Limb Sounding approach

- MLS views the atmosphere "edge on", scanning its field of view from 0 – 90 km

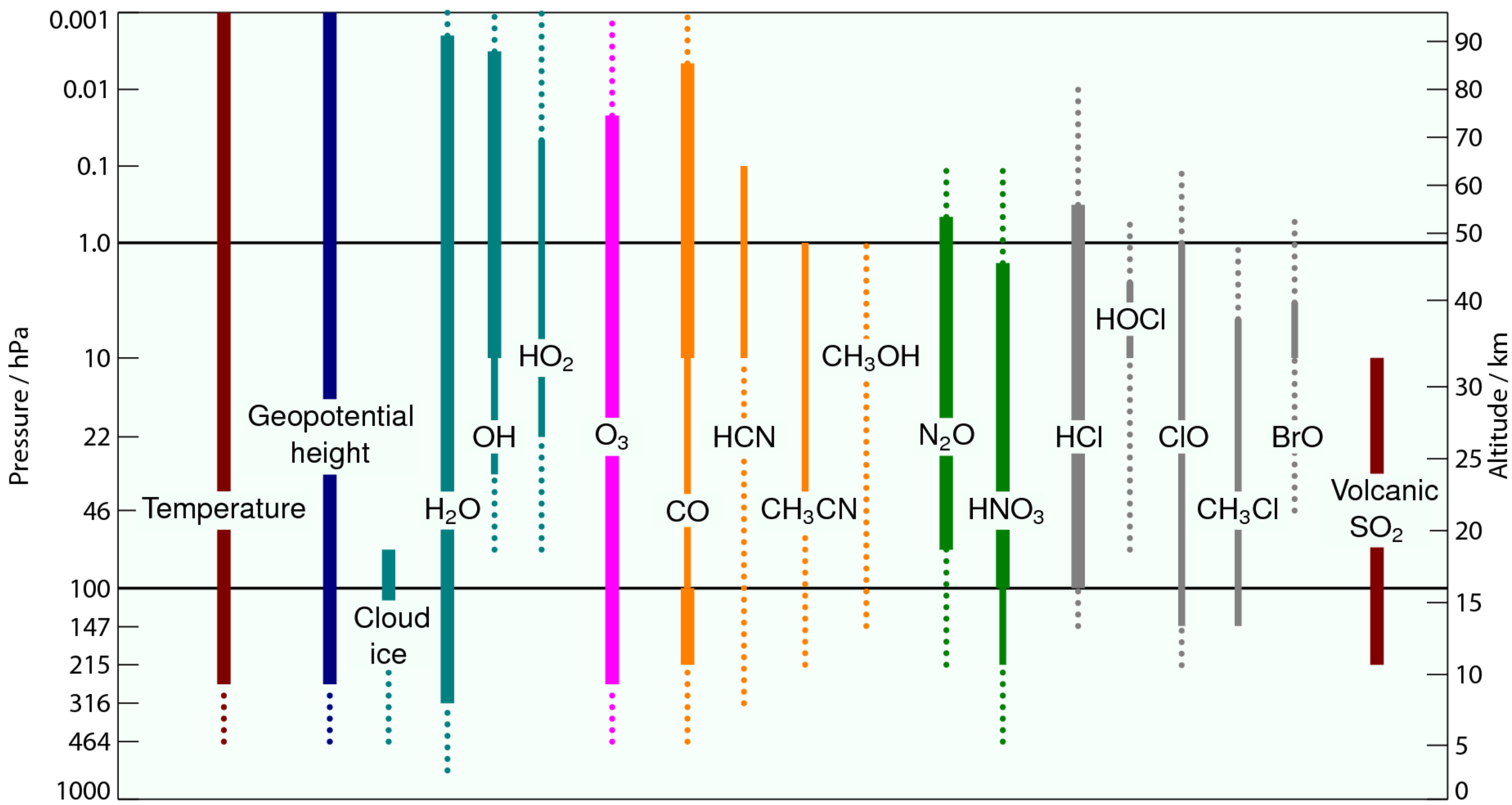
+ The vertical scan enables good (2–5 km) vertical resolution
+ The long atmospheric path length enables good signal to noise
+ The long (millimeter scale) observing wavelength enables measurements to be made in the presence of aerosol and all but the thickest clouds
+ Pressure broadening of spectral lines enables excellent measurement of limb tangent pressure, reducing dependence on spacecraft pointing knowledge

− The long path length does effectively reduce horizontal resolution, though our "tomographic" retrieval approach reduces the impact of that

− Good vertical resolution requires a large (meter-scale) antenna

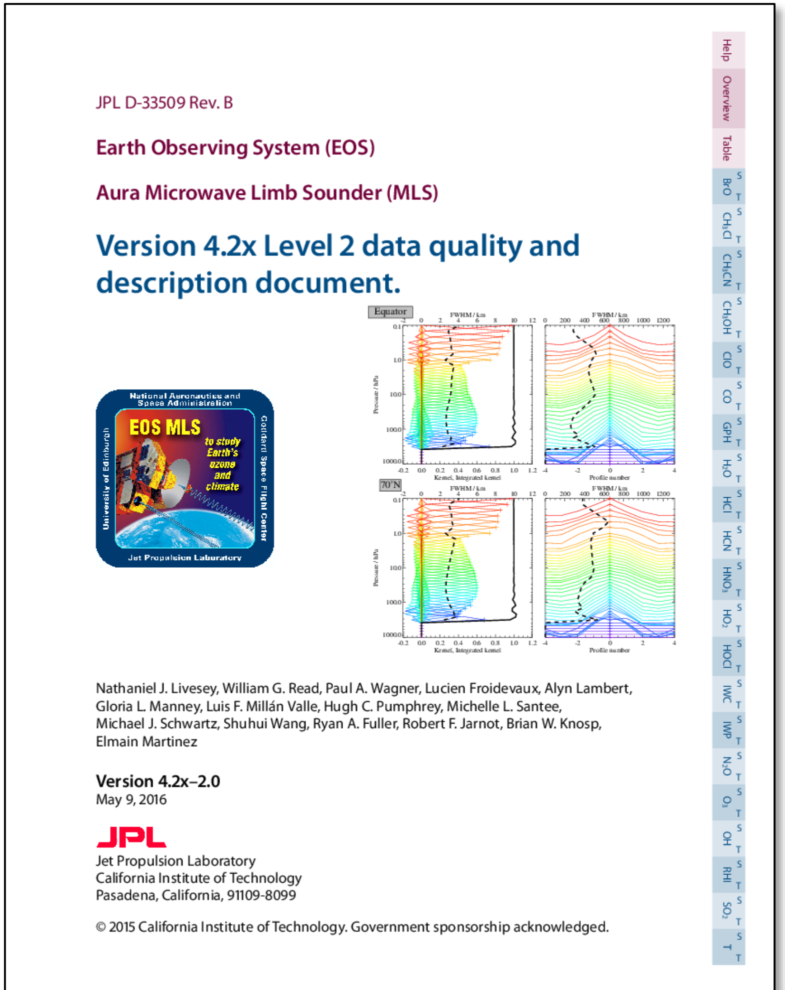
+ New technology enables significant reductions in bulkiness and power consumption

MLS measures sixteen trace gases, plus T, GPH, cloud



- Thick / thin lines show useful range in the MLS version 4 dataset. Thin lines denote where averaging is needed for a useful signal/noise. Dotted lines are goals

Users are urged to read the MLS documentation


JPL D-33509 Rev. B

Earth Observing System (EOS)

Aura Microwave Limb Sounder (MLS)

Version 4.2x Level 2 data quality and description document.

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Version 4.2x–2.0
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Table 3.18.1: Summary for MLS ozone

Pressure / hPa	Resolution Vert. × Horiz.	Precision[a] ppmv	Precision[a] %	Accuracy[b] ppmv	Accuracy[b] %	Commen
≤ 0.01	—	—	—	—	—	Unsuitabl
0.02	5.5 × 200	1.2	300	0.1	35	
0.05	5.5 × 200	0.8	150	0.2	30	
0.1	4 × 400	0.5	60	0.2	20	
0.2	3 × 450	0.4	30	0.1	7	
0.5	3.5 × 550	0.3	20	0.1	5	
1	3 × 500	0.2	7	0.2	7	
2	3.5 × 450	0.15	3	0.2	5	
5	3 × 450	0.15	2	0.3	5	
10	3 × 500	0.1	2	0.3	5	
22	2.5 × 400	0.1	2	0.2	5	
46	2.5 × 350	0.06	3	0.2	8	
68	2.5 × 350	0.04	3–10	0.05	3–10	
100	3 × 300	0.03	15–25	[0.05 + 5%]		
150	3 × 400	0.02	5–70	[0.02 + 5%]		
215	3.5 × 350	0.02	5–100	[0.02 + 20%]		
261	3.5 × 400	0.03	5–100	—	—	Requires f
316	2.5 × 550	0.03	—	—	—	Not recon
1000 – 464	—	—	—	—	—	Not retrie

[a] Precision on individual profiles

[b] As estimated from systematic uncertainty characterization tests. Stratospheric values a *alent* percentage value quoted. 215 – 100 hPa errors are the sum of the ppmv *and percenta* values, especially for pressures from 100 to 316 hPa will be re-evaluated, but the estimates fo

The MLS “Data Quality Document” is the recommended starting point for all users

The document includes a table for each product (ozone example shown above) detailing resolution, precision and accuracy

MLS uncertainty quantification – terms and techniques

Precision: The impacts of random instrument noise on measurements

- Reported for each MLS profile, based on propagation of radiance noise through the retrieval
- These values generally agree well with estimates based on scatter in near-coincident observations or in situations of low atmospheric variability (e.g., nighttime ClO)

Resolution: The volume of the atmospheric region MLS measurements describe

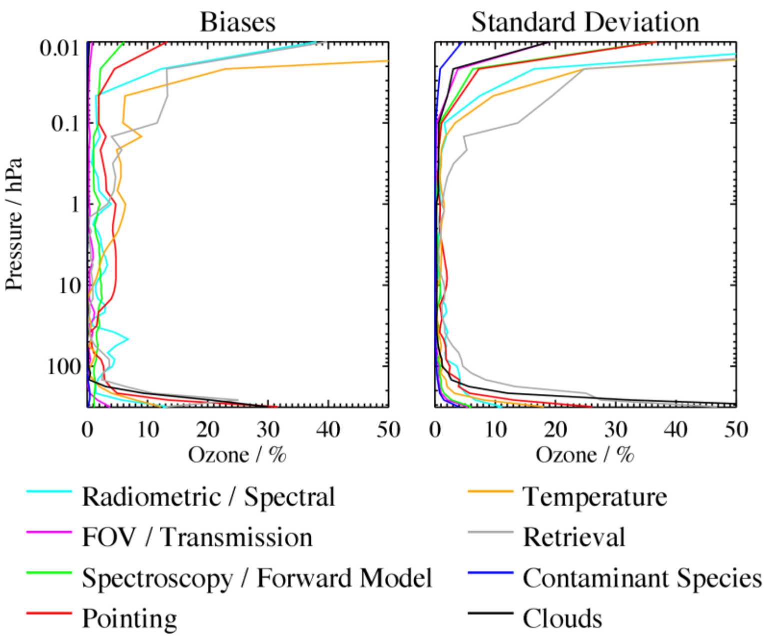
- Resolution and precision can be traded for each other, both in the retrieval calculations (e.g., by tuning smoothing parameters) and in downstream analyses (e.g., by computing a daily zonal mean or monthly map)

Accuracy: Quantifies the impact of systematic errors on the MLS observations

- In some cases these manifest as bias, other contributors lead to scaling errors
- Often additional "scatter" is introduced too (e.g., inaccurate ozone spectroscopy induces ozone-dependent errors on other species)

We have quantified impacts of ~30 error sources on a day of simulated observations

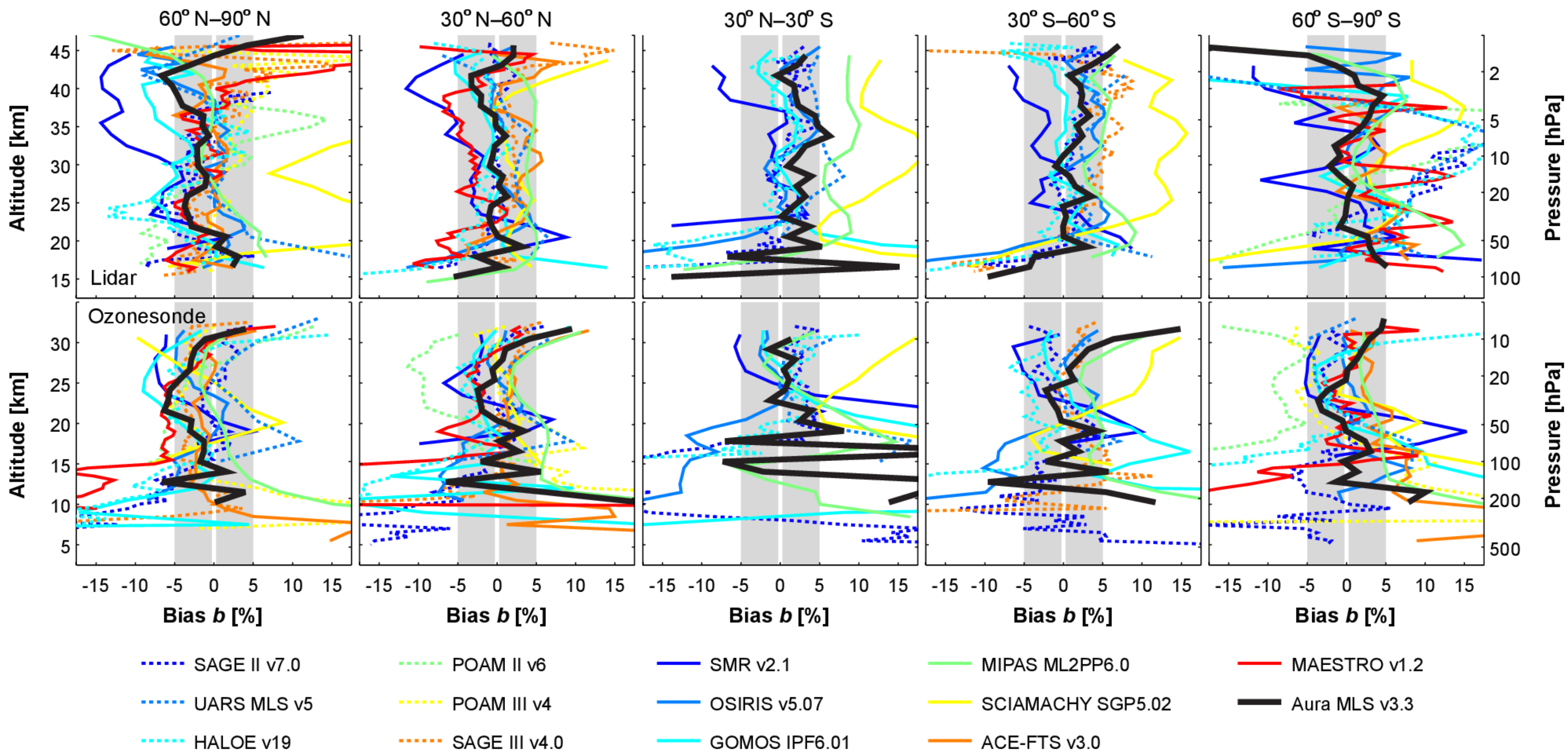
In addition we have aggregated these results into a single number, to aid those users for which that is all they wish to know



Systematic error breakdown for MLS ozone

Comparisons show excellent MLS, sonde, lidar agreement

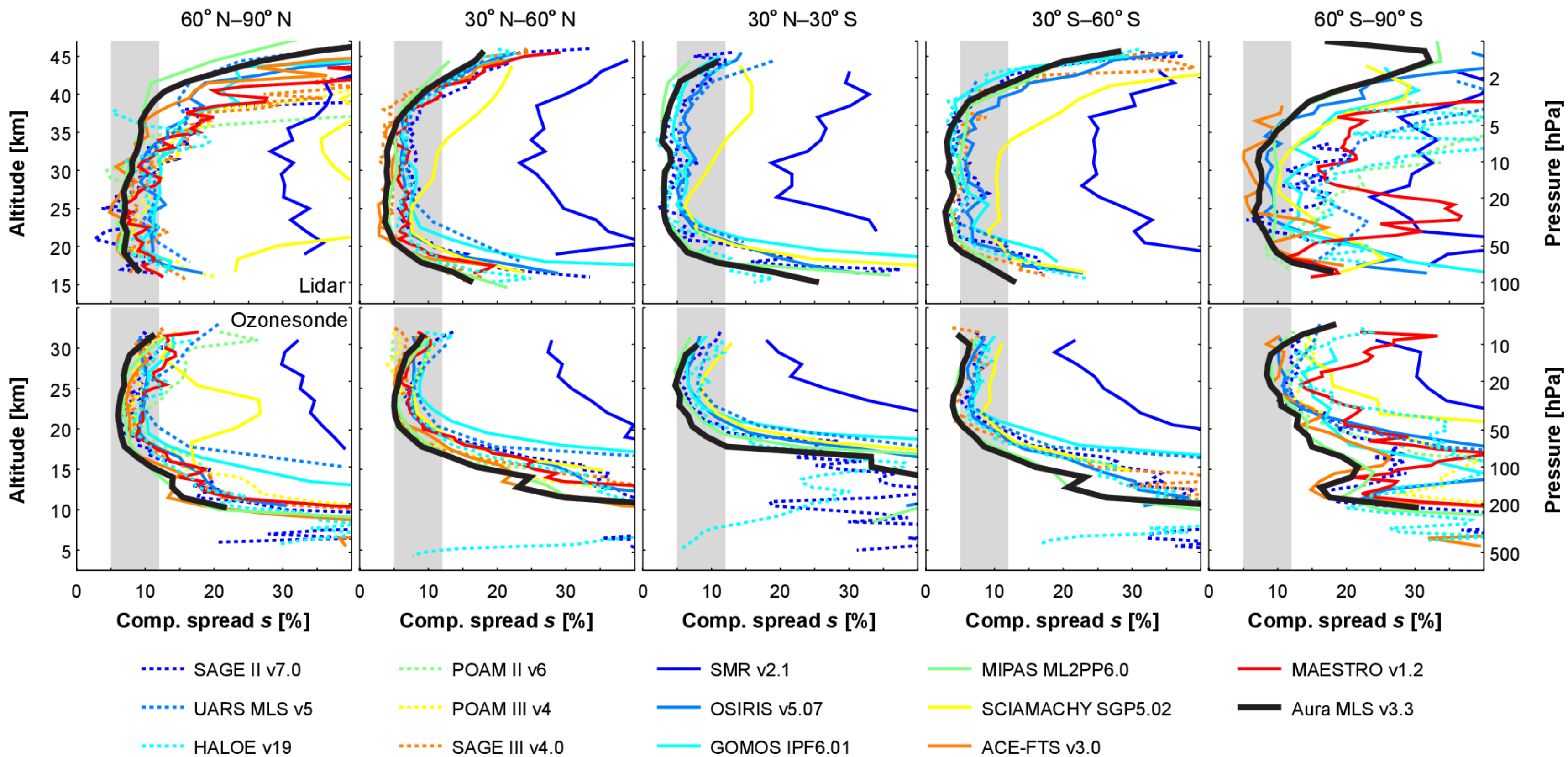
- A recently published paper [*Hubert et al.*, *AMT*, 2016] describes an extremely comprehensive comparison of ozone profiles from MLS (version 3) and 13 other limb/occultation sounders to the long-term record of sonde and ground-based Lidar profiles from multiple locations



Comparison between lidar (upper) and sonde (lower) measurements of ozone and a variety of spaceborne sensors (MLS in heavy black). Dashed lines indicate instruments that ceased operations prior to 2006.

MLS also shows low scatter compared to sonde, lidar

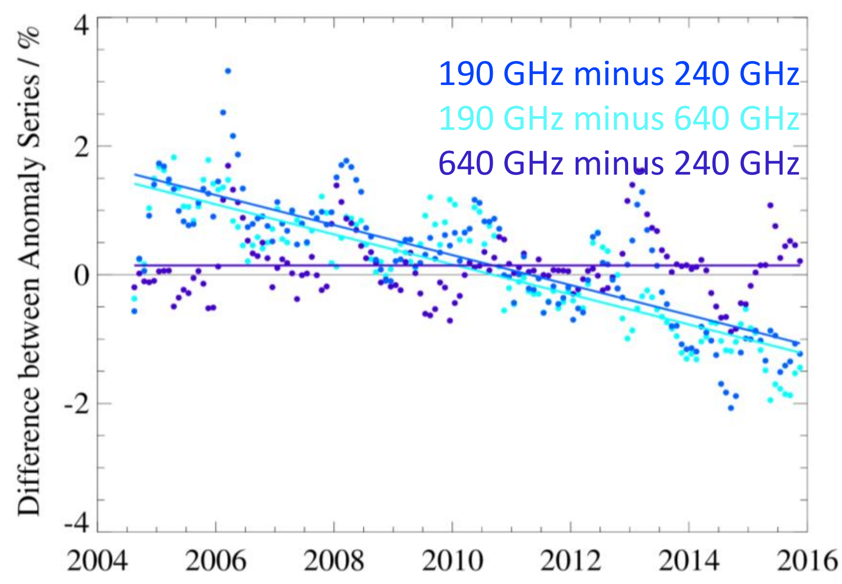
- The scatter in the MLS vs. sonde/lidar stratospheric ozone comparisons is typically within 10%, often better



As for previous figure, except showing the root mean square scatter rather than the average bias.

Internal measures show excellent stability in MLS ozone

- Ozone lines are highly prevalent in the microwave spectrum and are observed in all the MLS radiometers
- The MLS algorithms generate ozone products from observations in each radiometer, notably those at 190, 240 and 640 GHz, with the 240 GHz ozone measurements reported as the “standard” MLS ozone product
- Comparisons between these largely independent observations give insights into long-term stability (small variations may arise from vertical resolution differences)
- These comparisons have highlighted a slow drift (~0.2%/year) in the 190 GHz measurements compared to the others, likely linked to observed drifts in the MLS water vapor product, also measured using the 190-GHz radiometer



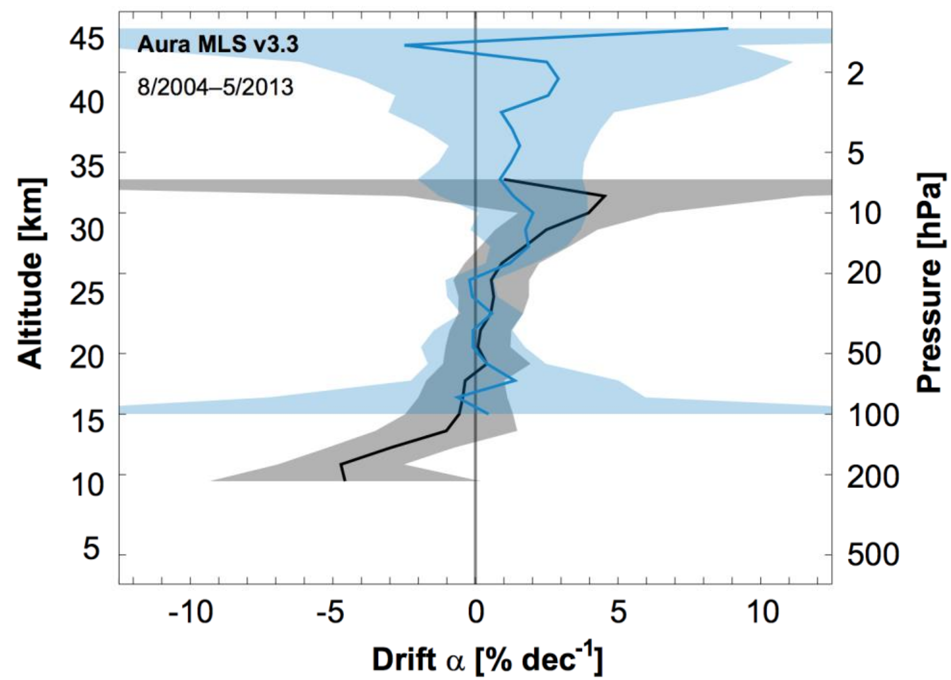
Timeseries of differences between MLS ozone products (22 hPa, 20S–20N), highlighting drift in 190-GHz product

Comparisons show MLS ozone to be “very stable”

- The *Hubert et al.* study also quantified long-term drifts between the spaceborne sensors and the sonde/lidar record

  “… We therefore conclude that Aura MLS v3.3 is stable in the entire stratosphere, certainly within 1.5%/decade (middle stratosphere) and 2%/decade (upper stratosphere).”

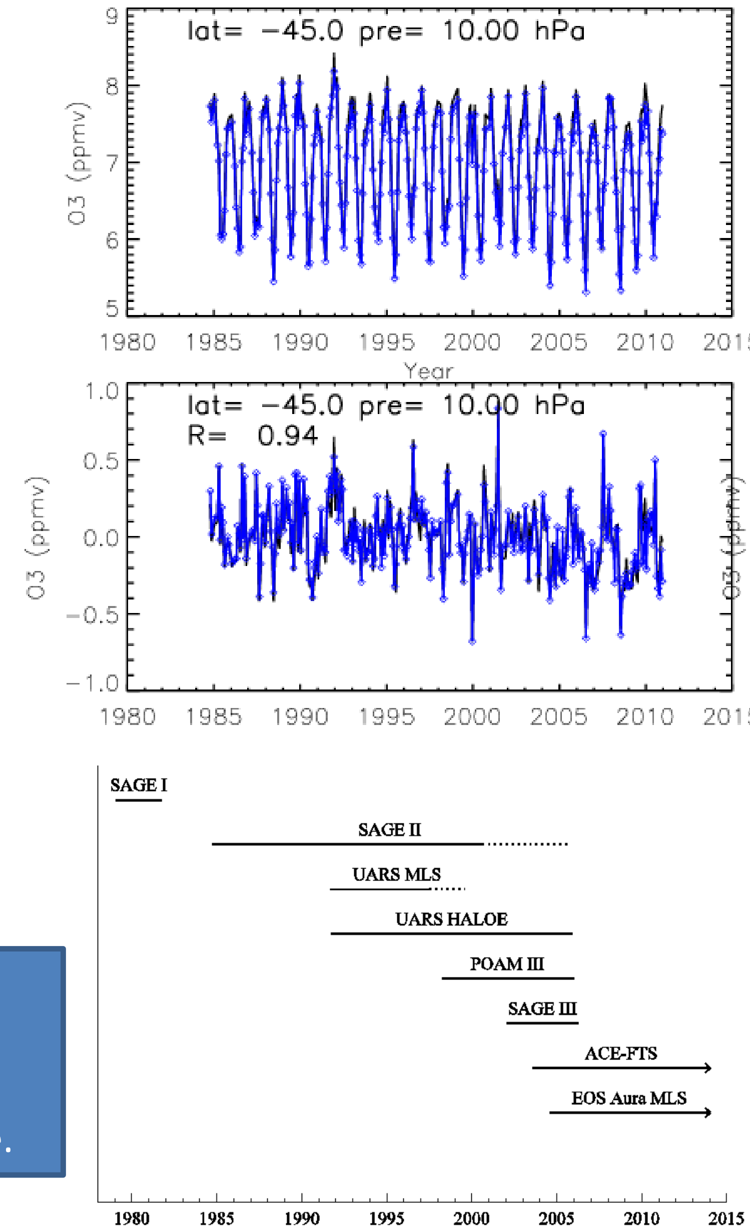
- We expect similar stability with the MLS version 4 record
- The study also discussed challenges associated with discerning clear trends in the UT/LS, given the low values and large variability



2004–2013 drifts in MLS–Lidar (blue) and MLS-Sonde (black) differences (for MLS v3). Shading is 95% confidence intervals for the drift.

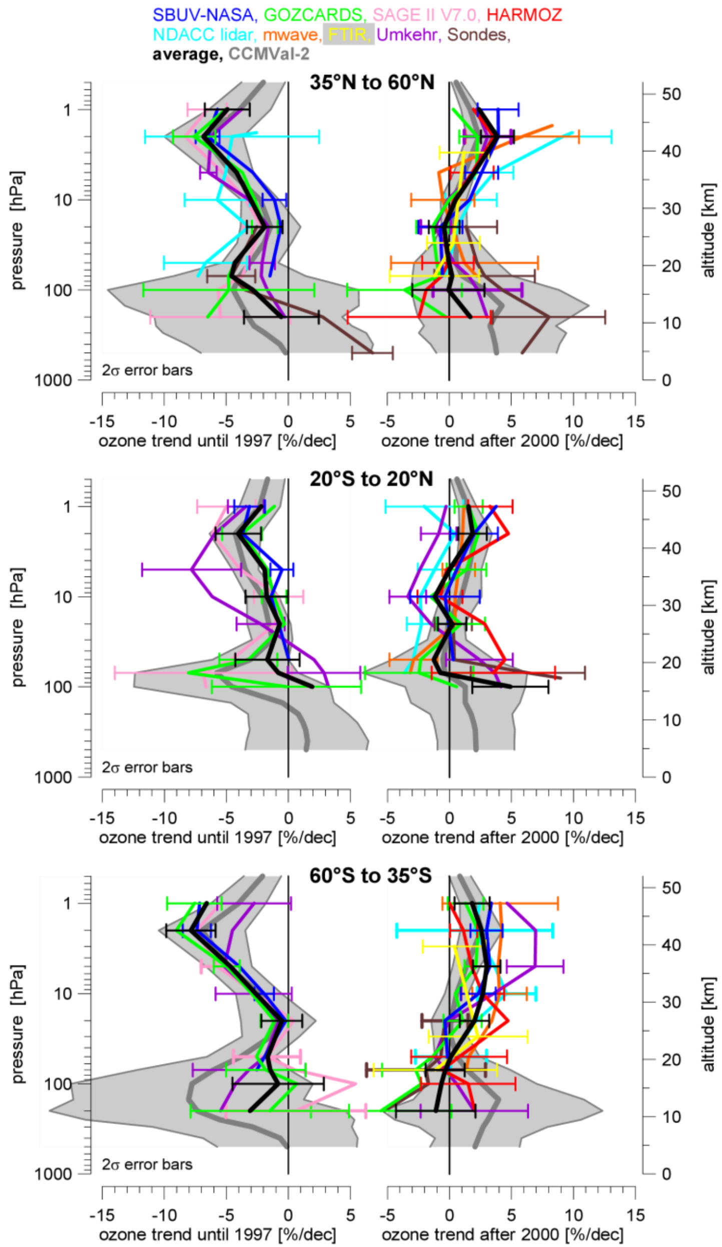
MLS ozone is central to established long-term records

- Two multi-decade merged ozone profile data records incorporate MLS (both also include SAGE, UARS MLS and HALOE measurements)
- GOZCARDS (NASA, Lucien Froidevaux): Monthly ozone latitude/pressure zonal means, also for H_2O, HNO_3, HCl, ClO, CH_4, N_2O, NO, NO_2, HF
- SWOOSH (NOAA, Sean Davis): Latitude/ pressure, equivalent latitude / potential temperature means, and 3D grids. Ozone and water vapor only
- In addition, the HARMOZ project (ESA, Viktoria Sofieva) is planning to include MLS in their next version



Upper: Timeseries of 10 hPa 40S – 50S
GOZCARDS (blue) and SWOOSH (black) ozone.
Middle: As above, but for deseasonalized anomalies.
Lower: Instruments contributing to GOZCARDS ozone.

Key community studies capitalize on GOZCARDS record



Ozone trends for the periods up to 1997 (left) and after 2000 (right) from various observed data sets (lines) and CCMVal-2 model simulations (grey shading), all for selected latitude bands. Length of period depends on length of data record for each system. For CCMVal-2 simulations, the trend periods are 1979 to 1997 and 2000 to 2013. Data sets using pressure coordinates are plotted on the pressure axis, data sets using altitude coordinates are plotted on the altitude axis. Observed trends are from multi-linear regression accounting for QBO, solar cycle, volcanic aerosol and ENSO. Gray areas give multi-model average trend and ±2 standard deviation range of individual model trends from CCMVal-2 REF-B2 simulations (not including volcanos and solar cycle).

From WMO 2014 report

MLS ozone profiles – a summary

Vertical range: 261 – 0.02 hPa (approximately 9 – 75 km)

Vertical resolution: 2.5 – 3.5 km from upper troposphere to lower mesosphere, ~5 km in upper mesosphere

Horizontal resolution: 350 – 550 km along track (varies with altitude)

Region	Precision on an individual profile	"Bottom up" accuracy estimate	Typical comparison to other observations
Upper troposphere	20 – 40 ppbv	0.05 + 5%	Within 20 – 30% (sondes)
Stratosphere	60 – 200 ppbv (~2 – 5%)	200 ppbv (5%)	Within 5% (sondes, lidar)
Mesosphere	300 – 1000 ppbv	200 ppbv (10–30%)	Within 20% (SAGE, HALOE)

- Of the ~650 peer-reviewed Aura MLS-related publications, ~220 use include ozone
- Applications of MLS ozone observations for climate and related research include:
  - Identifying signs of recovery in upper stratospheric ozone (e.g., WMO 2014)
  - Ongoing characterization of polar processing and ozone loss, notably for the 2010/2011 northern hemisphere winter, arguably the first example of an Arctic "ozone hole"
  - Quantifying (in conjunction with TES) of the impact of variability in stratospheric circulation on tropospheric ozone
- More information on the MLS web site http://mls.jpl.nasa.gov/