Aura Microwave Limb Sounder Validation Status, Issues, Plans

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Validation-related papers (recent work): Aura MLS data

Temperature and GPH	*Schwartz et al.*
H_2O and relative humidity	*Read et al.* (upper troposphere) *Lambert et al.* (stratosphere / mesosphere)
N_2O	*Lambert et al.* (same paper as stratospheric H_2O)
O_3	*Livesey et al.* (upper troposphere, same paper as UT CO) *Froidevaux et al.* (mainly stratosphere) *Y. Jiang et al.* (comparisons with sondes and ground-based lidar)
CO	*Livesey et al.* (upper troposphere, same paper as UT O_3) *Pumphrey et al.* (stratosphere / mesosphere)
HCl	*Froidevaux et al.*
HNO_3	*Santee et al.*
ClO	*Santee et al.*
BrO	*Kovalenko et al.*
OH, HO_2	*Pickett et al.*
Cloud ice	*Wu et al.*
Various products	*Manney et al.* (non-coincident validation; θ vs equivalent lat. coordinates)

Validation-related papers (recent work): Aura MLS data

Other related recent manuscripts (non-MLS-team lead)	*Boyd et al.* (**strat./mes. O_3** ; versus ground-based microwave data) *Petropavlovskikh et al.* (**O_3 column**; AVE campaigns, CAFS data) *Yang et al.* (**O_3 trop. column**; using MLS and OMI O_3 data) *Schoeberl et al.* (**O_3 column**; OMI - MLS & model for finer horiz. resolution) *Feng et al.* (**O_3** ; data assimilation) *Stajner et al.* (**O_3** ; data assimilation) *Vömel et al.* (**H_2O** ; versus cryogenic frostpoint hygrometer data) *Nedoluha et al.* (**H_2O** ; versus ground-based + HALOE data) *Barnes et al.* (**H_2O** ; versus Raman lidar) *Connor et al.* (**ClO** ; versus ground-based microwave data, Antarctica) *Considine et al.* (**O_3**, **HCl**, **H_2O** ; non-coincident validation) *Lary and Aulov* (**HCl** ; space-based data intercomparison) *Coffey et al.* (**Aura HNO_3, HCl, N_2O, H_2O** ; versus airborne FTS data)
In progress (later work)	**HCN**: *Pumphrey et al.* **HOCl**: *Froidevaux/Kovalenko et al.* **SO_2**: *Read et al.*

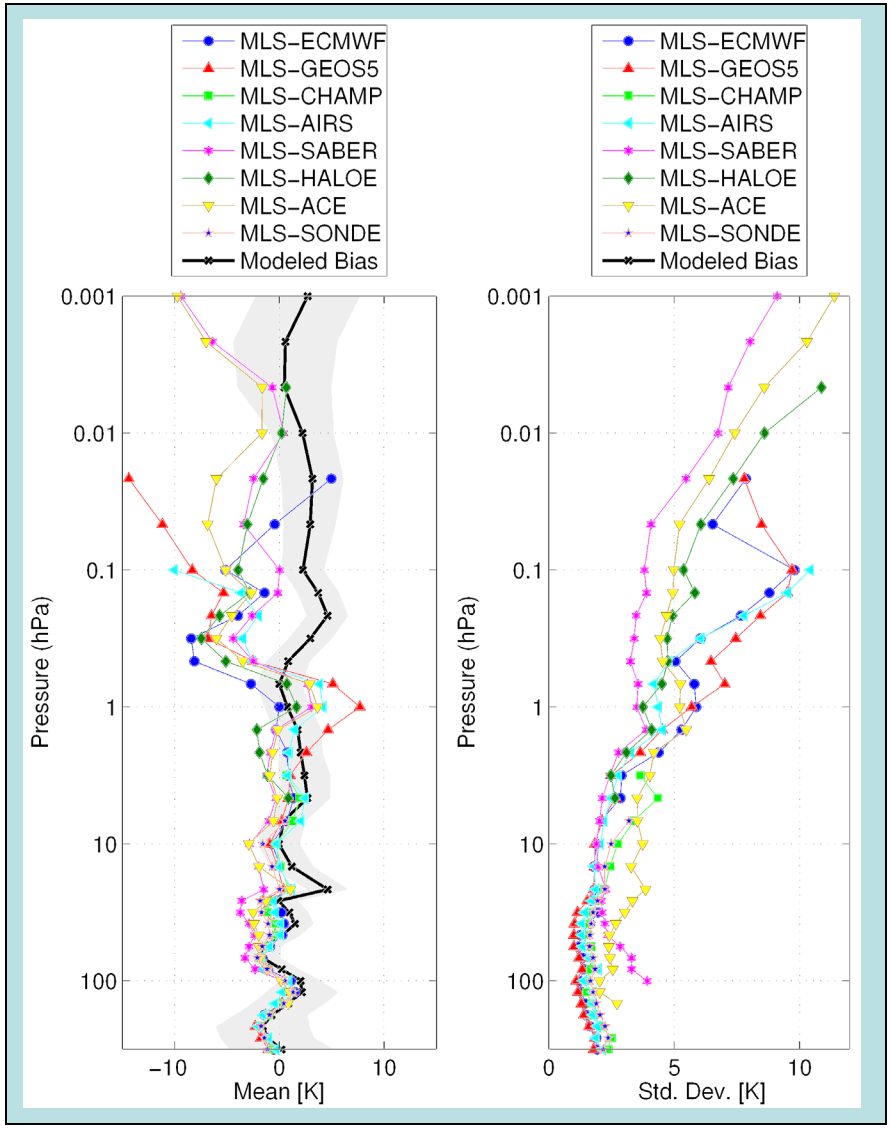
Note: Several other MLS-validation-related papers were published before the JGR special issue (2007) submissions (see refs. in special issue papers).

Temperature & GPH: Status/Issues /Plans (M.Schwartz)

Recommended range: 316 - 0.001 hPa

- Global mean temperature differences between MLS and correlative data have systematic vertical structure (~3K max. effect).

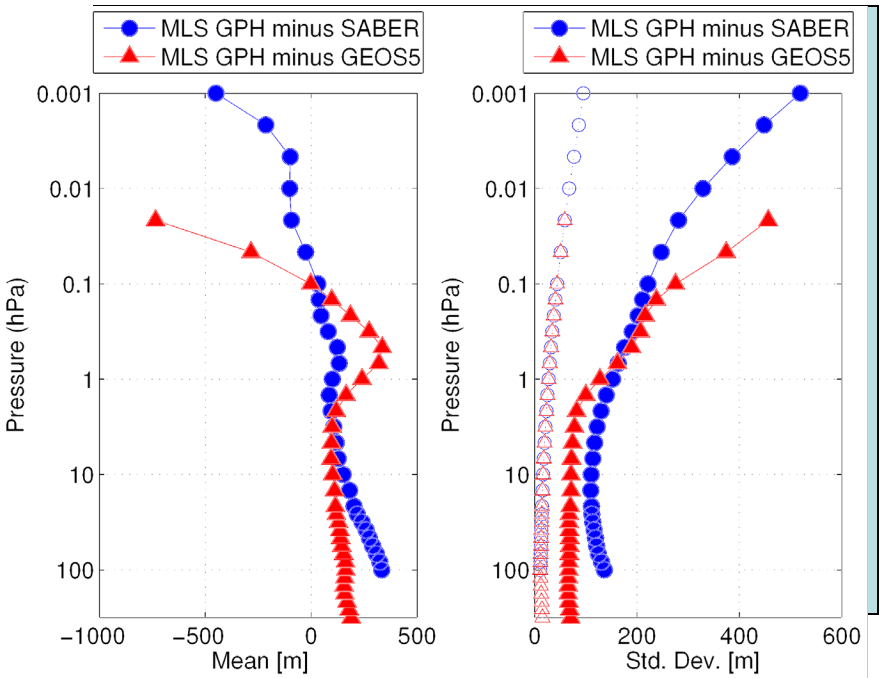
- Simulation of "gain compression" (MLS amplifier nonlinearity) effect [black "modeled bias" line in Figure] suggests that correction of radiances for this effect may improve agreement in the troposphere and lower stratosphere



Temperature & GPH: Status/Issues /Plans (M. Schwartz)

Recommended range: 316 - 0.001 hPa

- MLS 100 hPa GPH is typically 100-250 m higher than GEOS-5 at high latitudes and 0-200 m higher at low latitudes.
- Biases at lower pressures reflect the biases of MLS temperatures.
- MLS minus GEOS-5 100 hPa GPH has dropped by 40-50 m/yr.



- **Future Validation Plans**

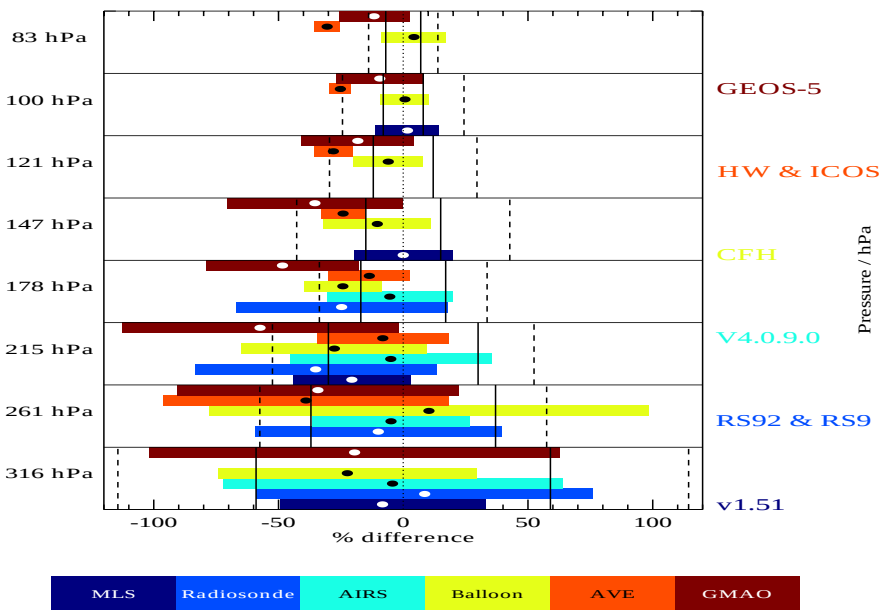
- Comparisons of MLS and lidar temperature in the MLT.
- Continued analyses of latitudinal, seasonal, and longer-term variations.

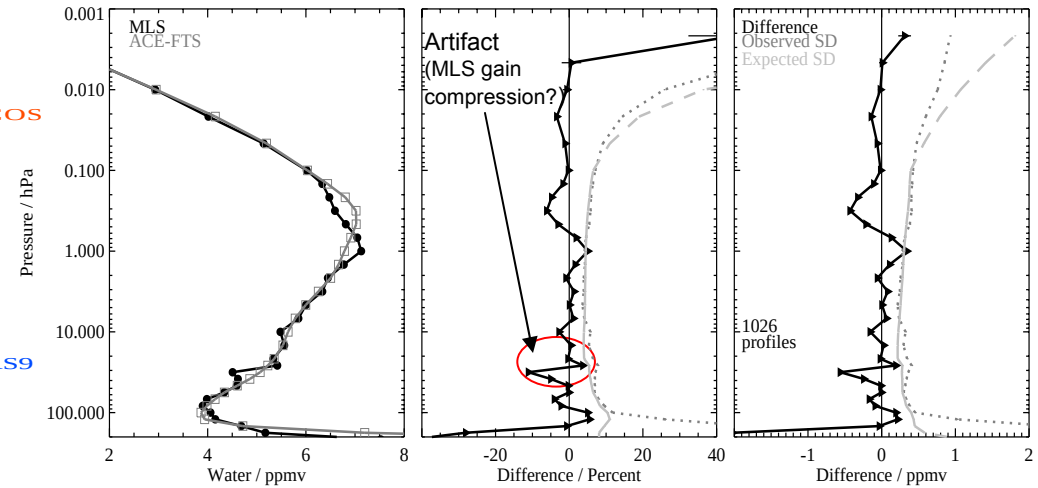
- Temperature and GPH do not require special campaigns for validation.

H_2O and RHi: Status

(W. G. Read / A. Lambert)

Recommended range: 316 - 0.002 hPa





MLS (v2.2) compared to ACE-FTS

Summary of MLS v2.2 comparisons

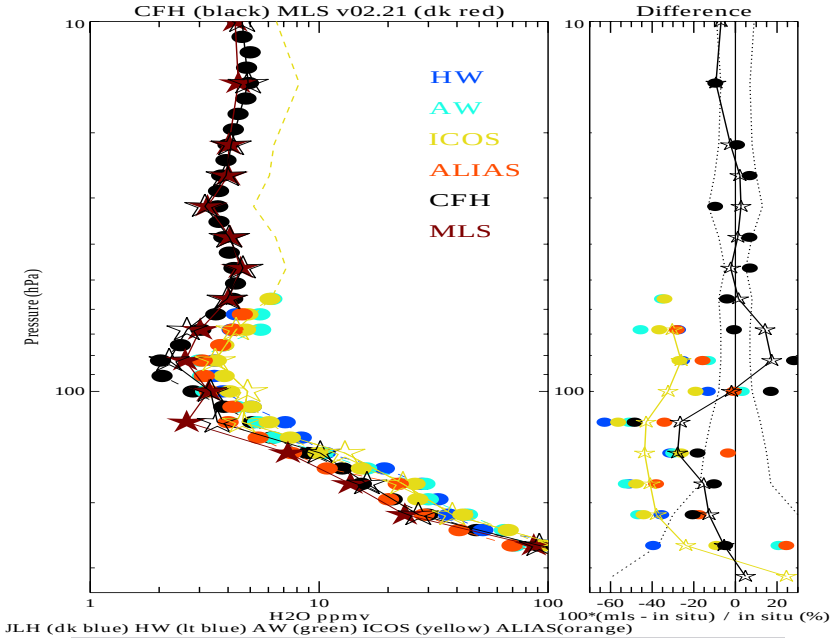
- Aura MLS shows agreement within systematic error estimates with most remote sensors and some in situ instruments.
  - Generally within 5-10 % of ACE-FTS; a 5-10 % wet-bias compared to HALOE.
- Relative humidity with respect to ice is derived from H_2O and T.
  - Up to 20% bias versus AIRS; worse than for H_2O but within combined H_2O and T systematic errors.

H_2O and RHi: Issues / Plans (W. G. Read / A. Lambert)

Recommended range: 316 - 0.002 hPa

➢ Issues

- Kink (caused by gain compression?) in H_2O profile at 26/32 hPa.
- 25% dry bias relative to CFH and Vaisala at 178 and 215 hPa (larger than predicted from systematic error analysis).
- Moist bias for H_2O mixing ratios > 500ppmv.



CR-AVE WB57, CFH and MLS H_2O

➢ Future Validation Plans

- More studies of latitudinal, seasonal, and longer-term variations.
- Comparisons with AIRS v5.
- More comparisons with CFH and Vaisala RS92 in upper troposphere.

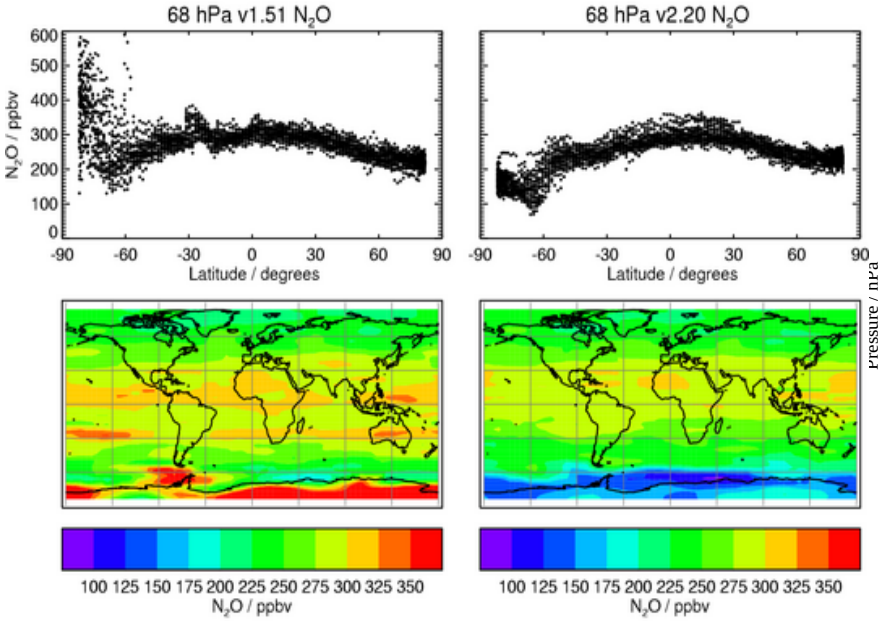
➢ Special Needs

- Resolution of differences between WB57 hygrometers and CFH.

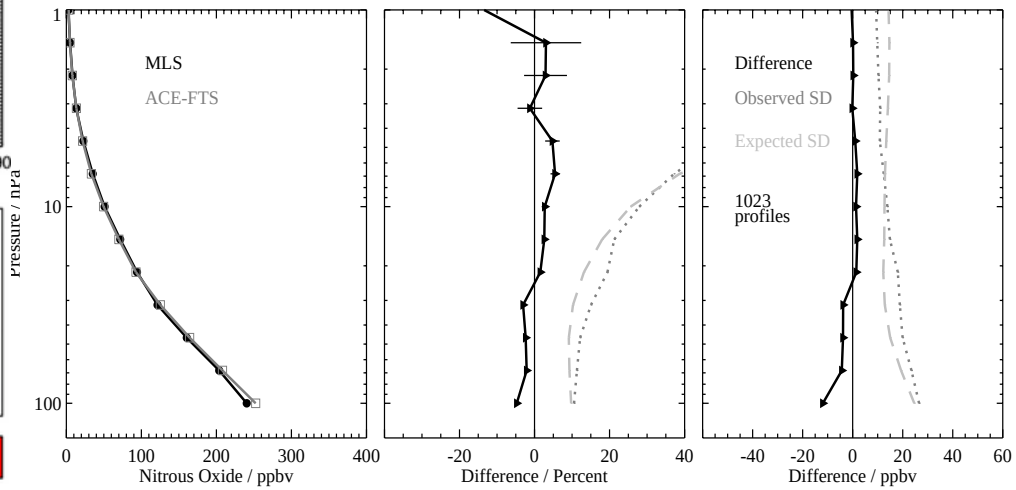
N_2O : Status

(A. Lambert)

Recommended range: 100 - 1 hPa



MLS v2.2 compared to v1.5 (September 17, 2005)



MLS (v2.2) compared to ACE-FTS

Summary

- Anomalously high values of N_2O in the Southern Hemisphere polar vortex retrieved in the v1.5 processing have been eliminated in v2.2.
- Agreement, within systematic error estimates, with most remote sensors and in situ instruments. Generally within 5-10 % of ACE-FTS.

N_2O : Issues / Plans

(A. Lambert)

Recommended range: 100 - 1 hPa

- **Issues**

- N_2O values on the 147 hPa pressure level have a large a priori influence and practically all precisions are flagged negative at this level

- May be possible to extend the retrieval of N_2O to 147 hPa using the 190-GHz measurements

- **Future Validation Plans**

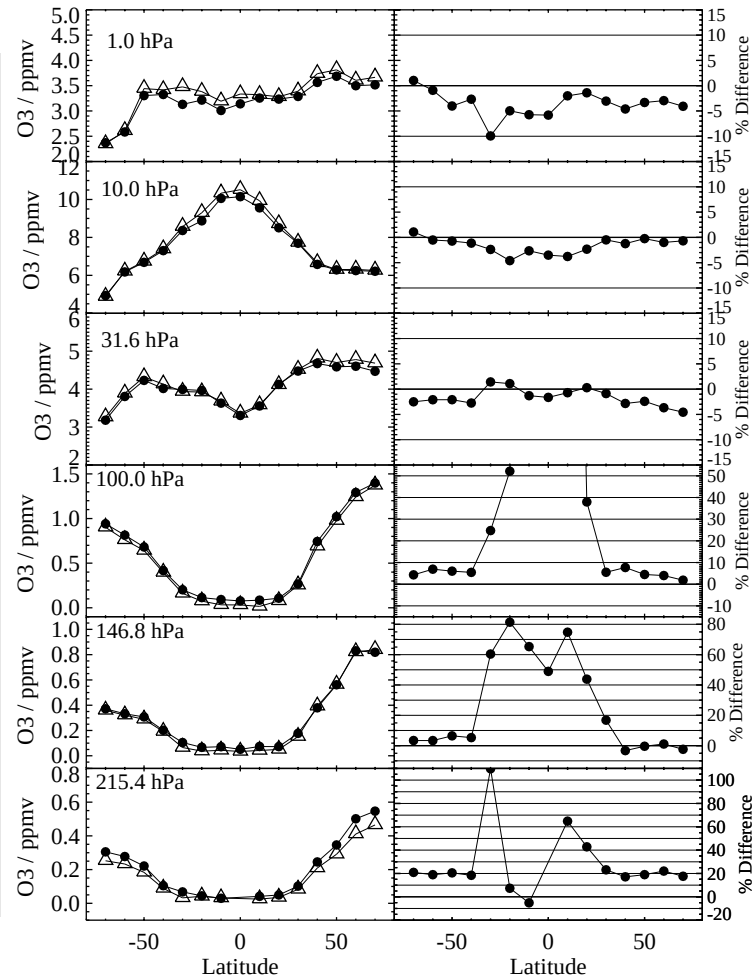
- Continue to validate against measurements by ACE-FTS, MIPAS, SMR, and ground-based (NDACC); seasonal and longer-term.

O_3: Status

(L. Froidevaux / N. Livesey)

Recommended range: 215 - 0.02 hPa

- MLS v2.2 ozone is improved overall vs v1.5.
  - slight disagreements in (v1.5) vertical gradients have now been largely rectified
  - fewer outliers in (properly screened) UT data
- Very good spatial agreement is observed versus a large set of correlative (and climatological) data sets,
  - including along-track "curtain distributions" versus aircraft lidar profiles.
- Limited comparisons versus time (seasonal, year-to-year) - so far.



MLS and SAGE II averaged coincident O_3 profile distributions versus latitude

O_3: Issues / Plans

(L. Froidevaux / N. Livesey)

Recommended range: 215 - 0.02 hPa

➢ Issues

- There is some evidence of a high (~ 20%) MLS bias at 215 hPa.
  > seen in MLS versus SAGE II, ozonesondes, TMF tropospheric lidar, and PAVE DIAL, although not readily observed versus INTEX-B DIAL/FASTOZ O_3 or AVE NOAA O_3.
  > Systematic bias of more than 1% in strat. O_3 column is not consistently observed (e.g., versus sondes or SAGE II); worth further investigation.
- Reducing MLS scatter (especially in UTLS) would be desirable.

➢ Future Validation Plans / Needs

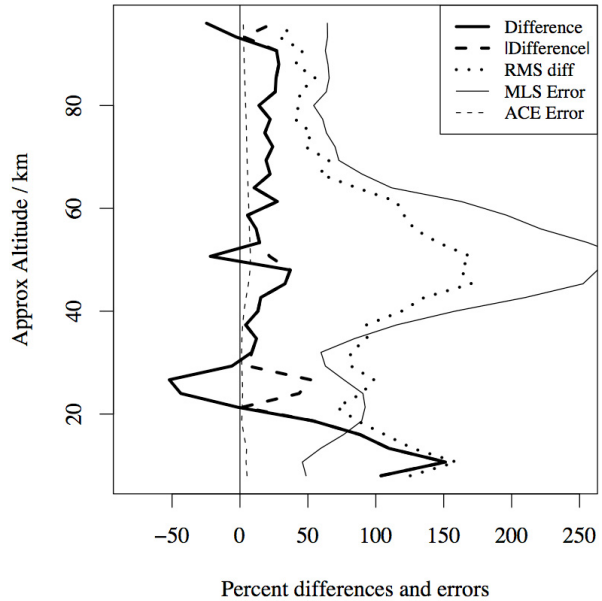
- More studies of UT ozone data / biases / morphology (e.g., using MOZAIC correlative data) + use more complete v2.2 dataset
- More seasonal, longer-term studies + "connection" to earlier time series

➢ Challenging to validate profiles under "cloud-flagged" conditions

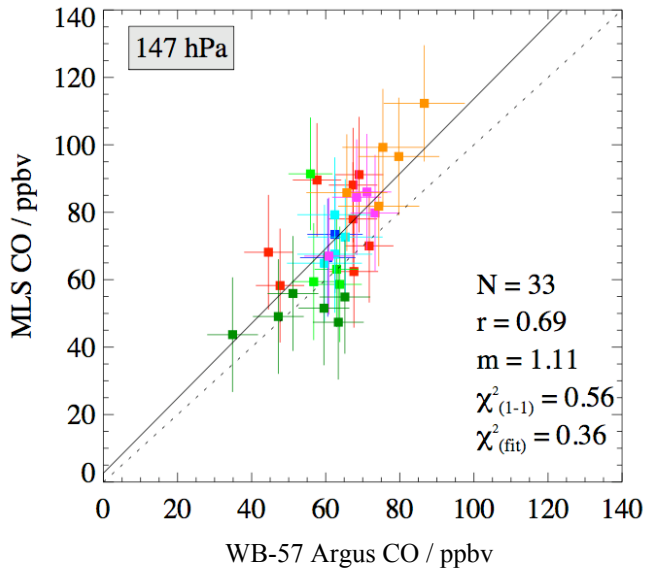
CO: Status / Issues / Plans

(H. Pumphrey / N. Livesey)

Recommended range: 215 - 0.005 hPa



Summary of MLS/ACE-FTS stratospheric & mesospheric CO comparisons



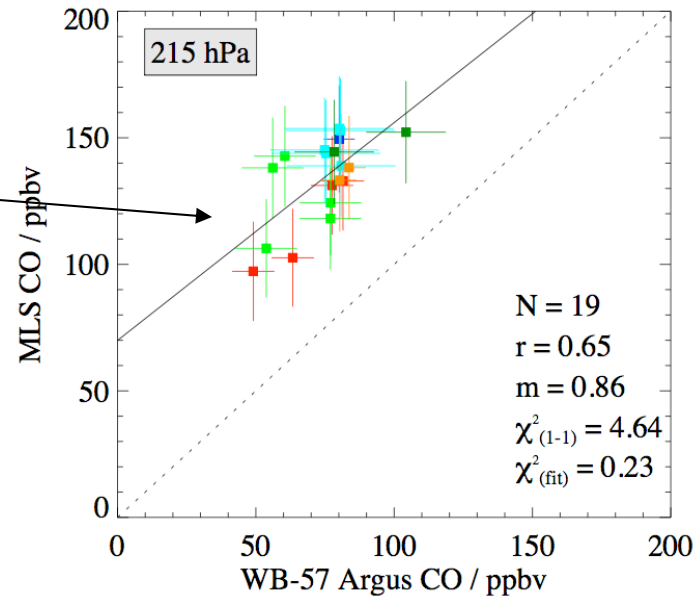
Summary of MLS / WB-57 Argus UT/LS CO comparisons

- Geographical and seasonal variations in MLS CO look robust overall
- MLS shows a ~25% high bias in the mesosphere vs. ACE (larger bias vs. SMR)
- Same comparisons show ~ -50% MLS bias in strat. (where abundances are small)
- Comparisons to *in situ* data in UT/LS show agreement at 100 and 147 hPa within the precision and ~30% systematic error estimates
- Systematic factor of 2 high bias at 215 hPa (somewhat outside systematic errors)

CO: Status / Issues / Plans (H. Pumphrey / N. Livesey)

Recommended range: 215 - 0.005 hPa

- Understanding and mitigation of the ~2x high bias at 215 hPa is the highest priority
- Extending retrievals to lower in the atmosphere is also a priority goal
- Characterizing remaining impact of thickest clouds on MLS UT/LS CO is also part of our future plans



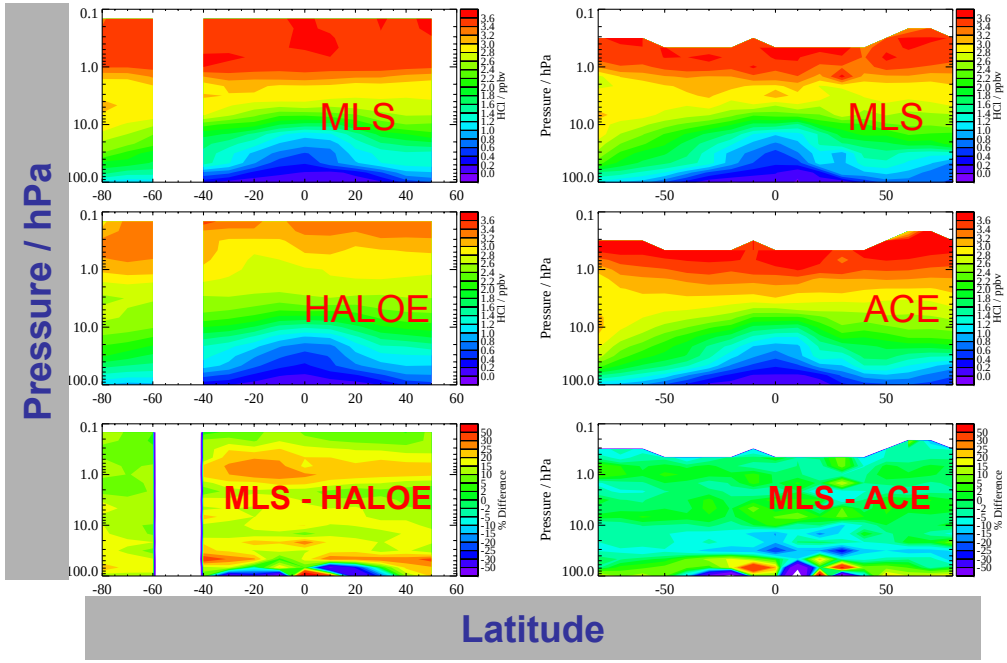
- **Future Validation Plans**
  - Long-term stability validation in mesosphere (e.g., vs. ground based)
  - Continued comparisons with MOZAIC data (UT) and further campaigns
  - Comparisons with MOPITT, TES, AIRS CO (different vertical resolutions and ranges of the observations complicate these studies)
- Challenging to validate UT CO statistically (or enhanced values) with campaigns
- Continued access to MOZAIC data will be very valuable

HCl: Status

(L. Froidevaux)

Recommended range: 100 - 0.15 hPa

- MLS HCl fields compare well, overall, with the distributions from ACE-FTS and HALOE
- However, MLS HCl > HALOE HCl by ~10-15% (bias), marginally within systematic error estimates
- Some discrepancies in latitudinal variations exist vs HALOE in upper stratosphere and lower mesosphere



HCl: MLS coincidences vs HALOE and ACE-FTS
2005, Jan. - March averages and percent diffs.

- Temporal decrease in HCl monthly means confirms expected changes, based on reductions in chlorine source gases (CFCs,…)
- Full reprocessing of v2.2 HCl dataset is needed to pursue time series analyses using a consistent dataset (due to shutdown of MLS band 13 after mid-Feb. 2006)

HCl: Issues / Plans

(L. Froidevaux)

Recommended range: 100 - 0.15 hPa

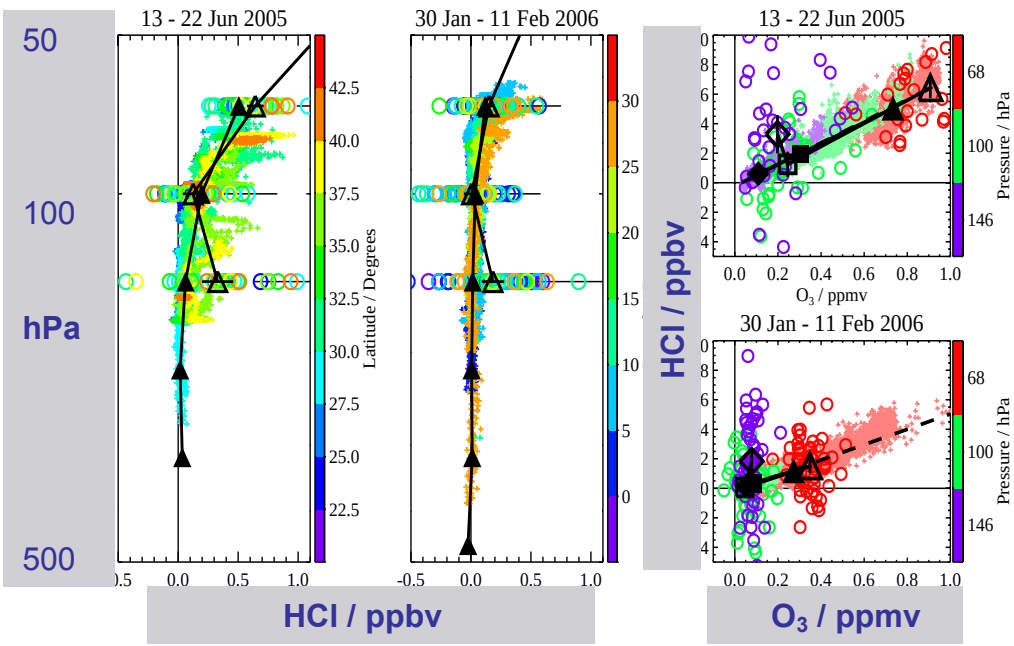
➢ Issues

- Some discrepancies in MLS vs HALOE strat. HCl
- Comparisons vs NOAA CIMS HCl (WB-57, AVE campaigns)

  →147 hPa HCl level has high bias, and is not recommended,

  [but 147 hPa HCl may be useful at high lats.]
- Also, small notches in MLS HCl avg. profiles (mainly near 2 hPa) are systematic v2.2 artifacts

  > to be investigated further



HCl: MLS (open symbols) versus WB-57 (and ozone)

➢ Future Validation Plans

- Investigate Kiruna 2006 balloon data comparisons (potential issues/biases)

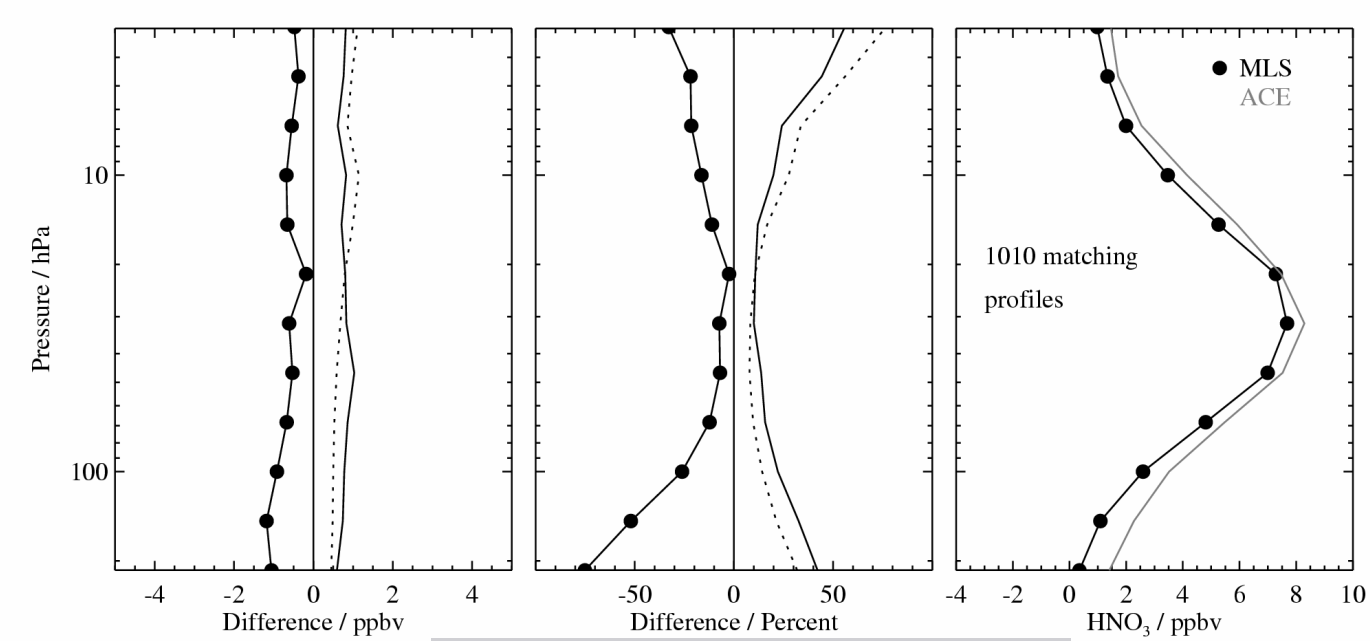
  → possibly more polar vortex validation (balloon data) need
- More studies of seasonal and longer-term variations

  > versus ACE-FTS, as well as ground-based HCl (columns / low resolution)

HNO_3: Status / Issues / Plans

(M. Santee)

Recommended range: 215 - 3.2 hPa



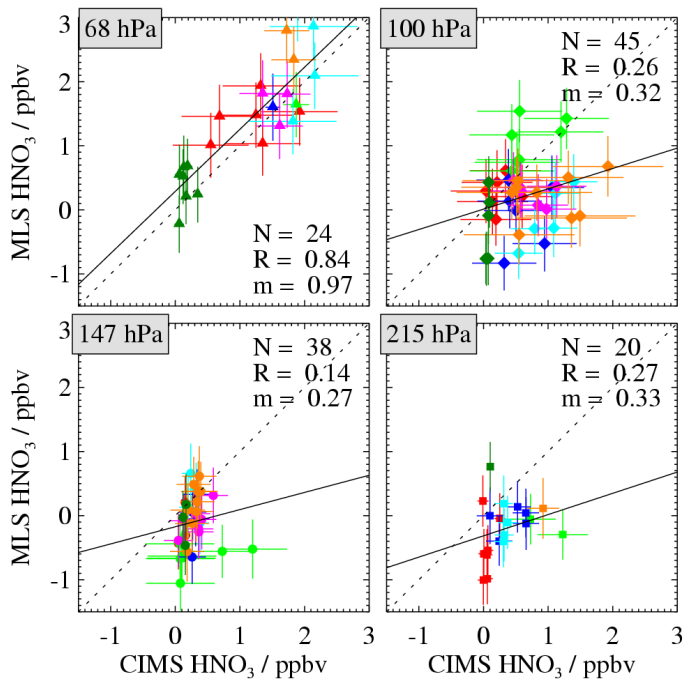
HNO_3: MLS versus ACE-FTS

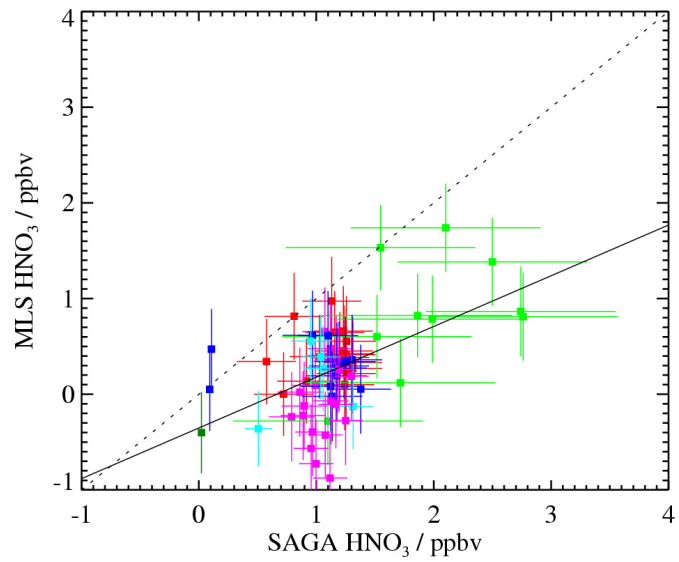
- MLS v2.2 HNO_3 is greatly improved over that in v1.5, with smoother profiles, much more realistic behavior at the lowest retrieval levels, and correction of a high bias caused by an error in one of the v1.5 spectroscopy files.
- Comparisons with correlative datasets from ground-based, balloon-borne, and satellite instruments (both infrared and microwave) show that v2.2 HNO_3 mixing ratios are low by ~ 1 ppbv (10–30%) throughout most of the stratosphere.
- MLS HNO_3 latitudinal / seasonal variations are robust.

HNO_3: Status / Issues / Plans

(M. Santee)

Recommended range: 215 - 3.2 hPa



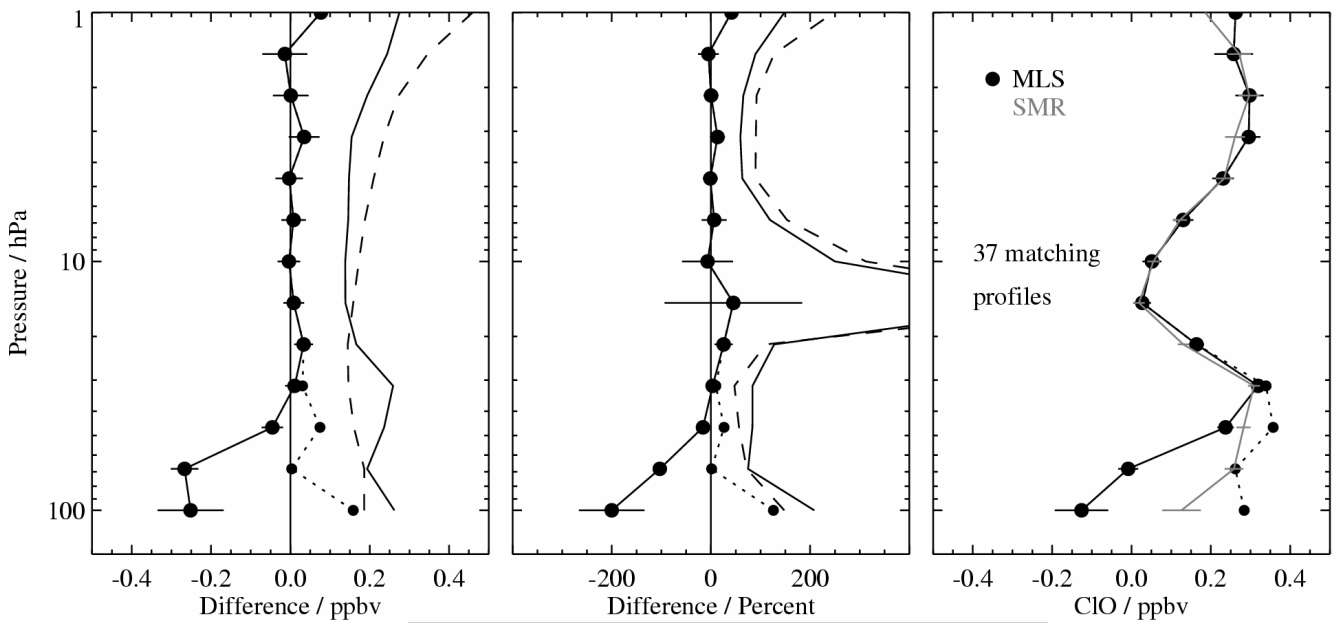


- Comparisons with in situ measurements from the WB-57 and DC-8 aircraft in the upper troposphere and lowermost stratosphere (UTLS) indicate that MLS HNO_3 values are low in this region as well, but are useful for scientific studies (with appropriate averaging)
- Future Plans: continued validation, especially of UTLS data

ClO: Status / Issues / Plans

(M. Santee)

Recommended range: 100 - 1 hPa



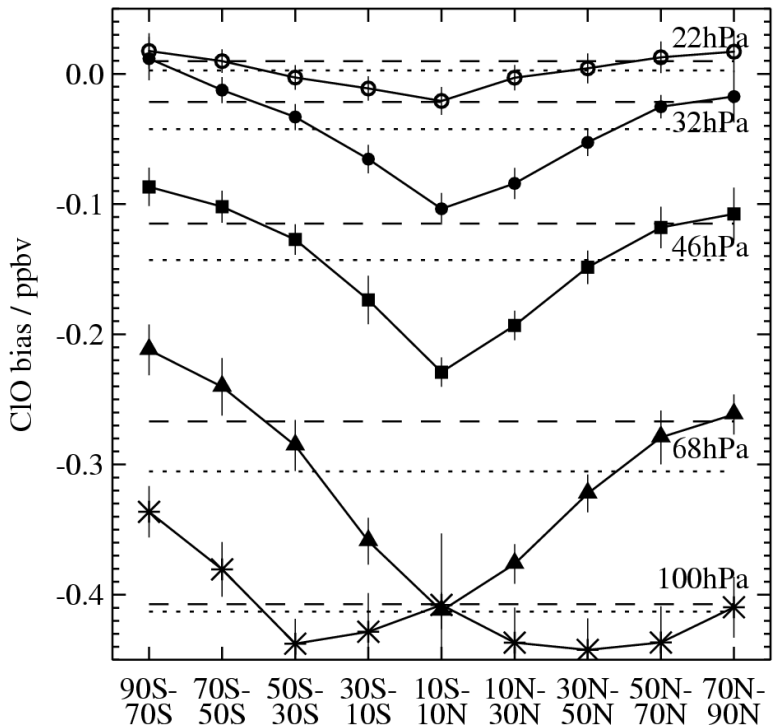
ClO: MLS versus Odin/SMR

- Comparisons with climatology and correlative measurements from a variety of different platforms indicate that both the amplitude and the altitude of the peak in the ClO profile in the upper stratosphere are well determined by MLS.
- Latitudinal and seasonal variations in lower stratospheric ClO are also robust.
- But, a substantial negative bias is present in both daytime and nighttime mixing ratios at retrieval levels below (i.e., pressures greater than) 22 hPa.

ClO: Status / Issues / Plans

(M. Santee)

Recommended range: 100 - 1 hPa



ClO bias in LS vs latitude (and pressure)

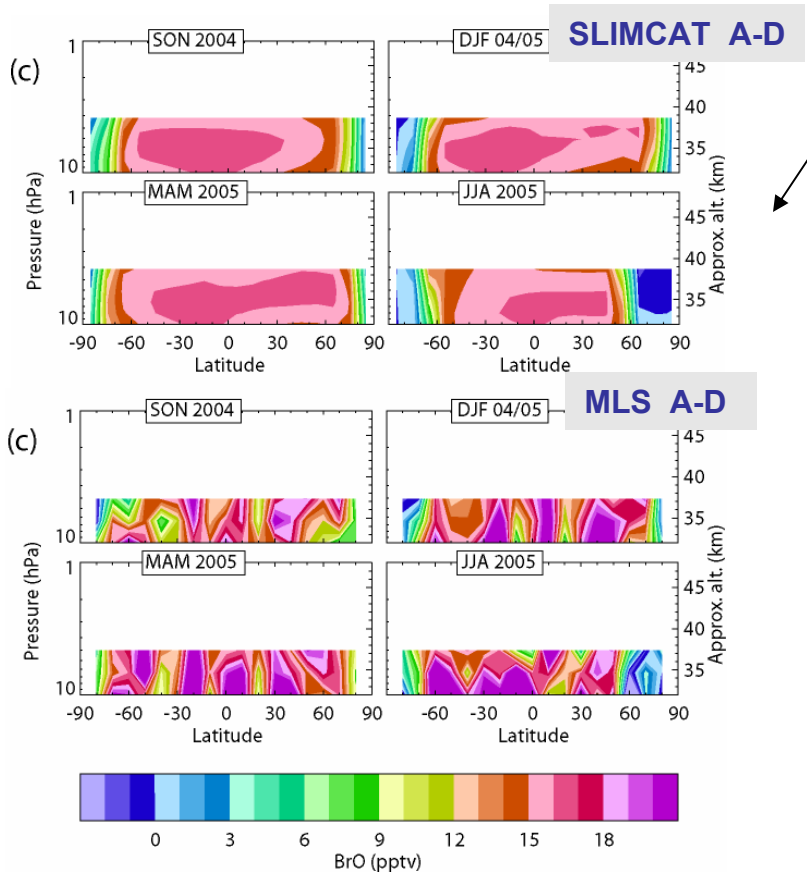
- In studies for which knowledge of lower stratospheric ClO mixing ratios to better than a few tenths of a ppbv is needed, the negative bias must be corrected for by subtracting its (avg.) estimated value at each affected level (see validation paper)
- Day-Night differences are **NOT** recommended when ClO is enhanced in the polar vortex (because of non-zero nighttime values)

- **Future Plans**
  - Mitigation of the negative bias in future MLS data versions
  - Continued validation, especially under conditions of polar ClO enhancement
  - Longer-term validation (e.g., versus ground-based microwave data)

BrO: Status

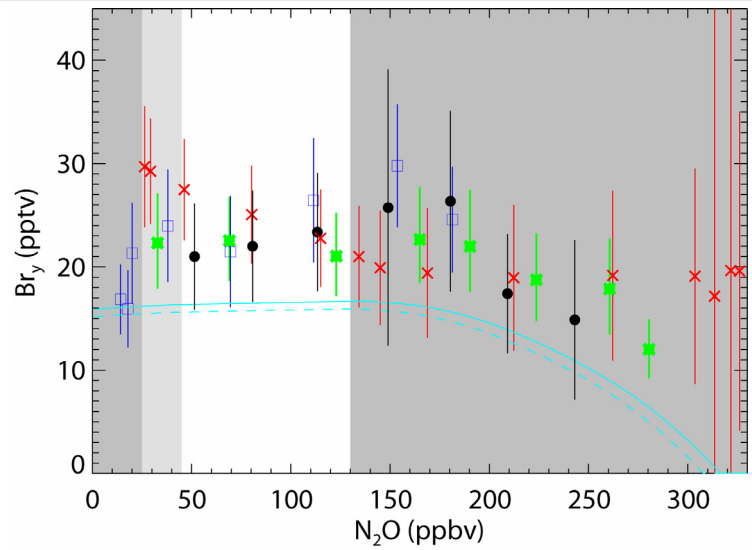
(L. Kovalenko)

Recommended range: 10 – 3.2 hPa



BrO: MLS (bottom 4 panels) and SLIMCAT model (top 4 panels) day – night (Ascend – Descend) avgs.

- MLS BrO [day - night avgs; Asc – Des] shows expected seasonal/latitudinal behavior - for 10 to 4.6 hPa range.
- MLS-inferred Bry falls in between the values obtained by the two published SCIAMACHY retrievals
- MLS-inferred Br_y (black) [see Figure below] is in agreement with balloon data DOAS (green) , SAOZ (blue) , and SLS-2 (red)



- MLS-inferred total inorganic bromine (Bry) = 22.1±5.5 ppt - implies VSLS contribute 6.5±5.5 ppt to Bry

BrO: Issues / Plans

(L. Kovalenko)

Recommended range: 10 – 3.2 hPa

➢ **Issues**

- Need to take day/night difference to remove BrO biases
  > investigating how to remove biases in polar winter and summer
- Continue radiance average studies to minimize biases
- Investigation of latitudinal oscillations
- Investigation of increased vertical range of usefulness

➢ **Future Validation Plans**

- Examine seasonal variations and polar abundances in more detail
- Continue comparisons versus SCIAMACHY and (on-going) balloon data

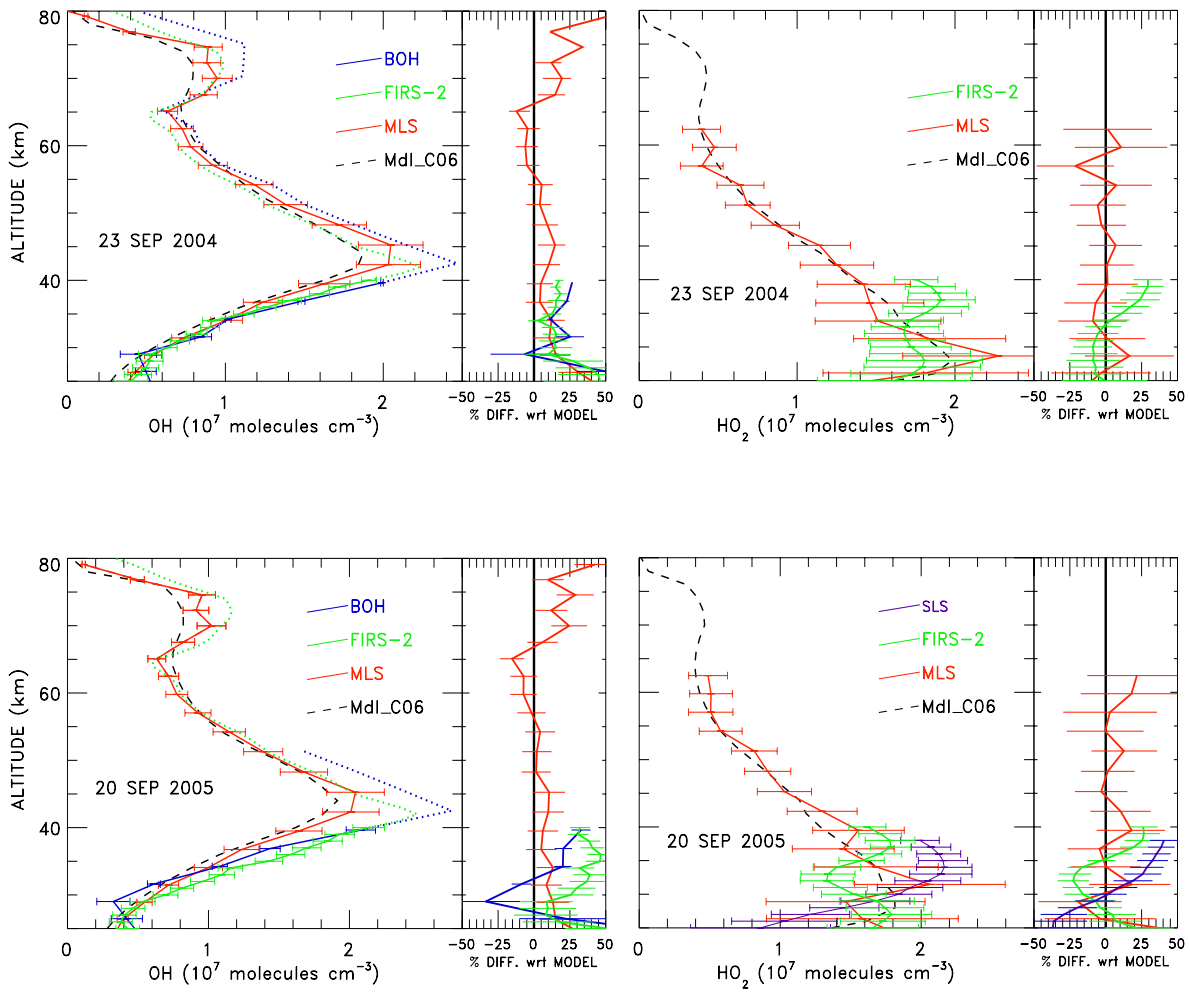
OH, HO_2: Status

(H. Pickett)

Recommended ranges: OH, 32 - 0.003 hPa ; HO_2, 21 - 0.03 hPa

- MLS (blue) is in good agreement with balloon (green, red) HO_x observations
- MLS data also show excellent agreement with models
- See *Pickett et al., GRL 2006; Canty et al., GRL 2006; and Pickett et al., JGR Special Issue*

MLS observations do not indicate a 'HO_x dilemma'

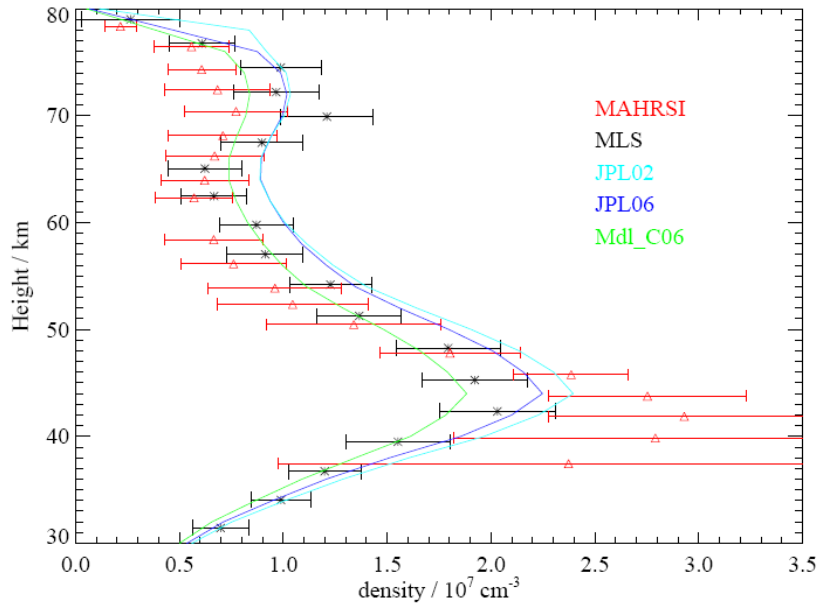


OH, HO_2: Issues / Plans

(H. Pickett)

Recommended ranges: OH, 32 - 0.003 hPa ; HO_2, 21 - 0.03 hPa

- **Issues**
- Some residual differences between ground-based, balloon-based measurements and MLS (> 2-sigma)
- MLS and MAHRSI 2-sigma errors just overlap: differences are probably statistically significant



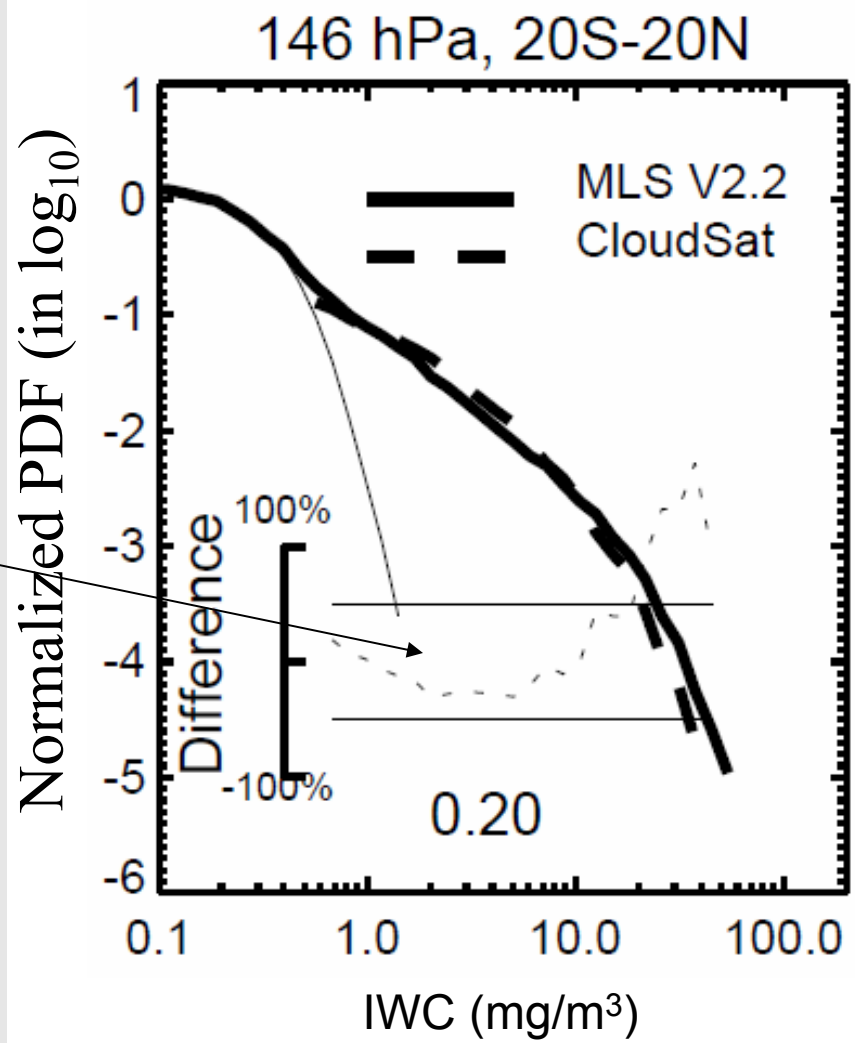
- **Future Validation Plans**
- MLS and Fall 2007 balloon flight intercomparison
- Seasonal / longer-term variations versus ground-based OH column data
- **Special Needs**
- Balloon flight with SLS, FIRS-2, BOH, and Mark-IV in Sept. 2008

Cloud Ice: Status / Issues

(D. Wu / J. Jiang)

Recommended range: 261 - 83 hPa

- **Status**
  - Ice Water Content (IWC) & Ice Water Path (IWP) are available cloud ice products in v2.2 MLS dataset
  - PDF differences of MLS - CloudSat Ice Water Content are generally < 50% in the tropics
- **Issues**
  - Uncertainties about particle size distribution and cloud inhomogeneity dominate the MLS v2.2 IWC errors
  - Difficult to validate cloud ice products
    - > particle size distribution knowledge
    - > tropics versus polar
    - > large dynamic range



Cloud Ice: Plans

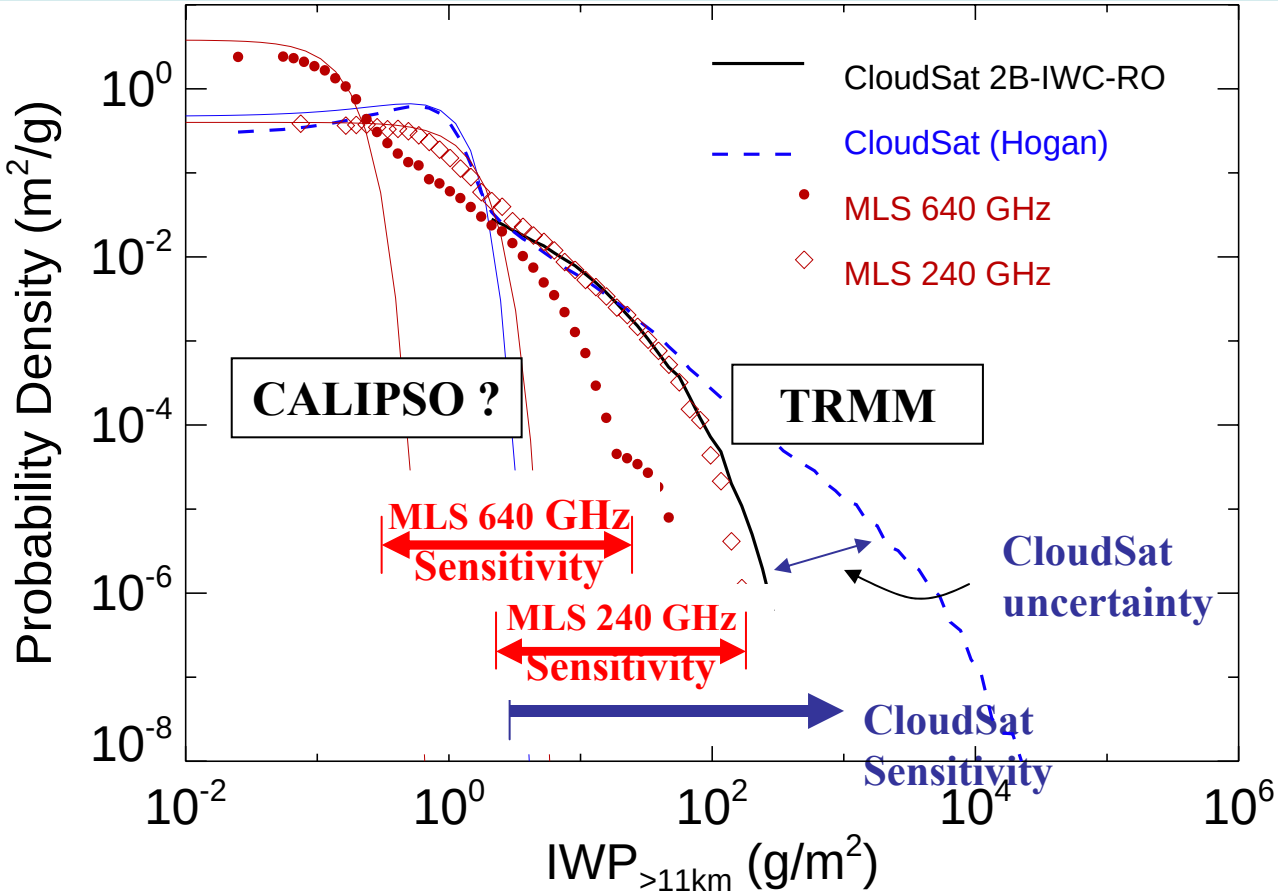
(D. Wu / J. Jiang)

Recommended range: 261 - 83 hPa

➢ Plans

- Document validation of MLS cloud fraction versus other such measurements from AIRS, MODIS,OMI…

- Also, future retrieval plans include 2-D IWC retrievals and 640 GHz cloud ice measurement investigations



➢ Goals

- Need multi-sensor agreement for cloud ice measurements
  e.g., cloud ice data for small ice particles in upper troposphere from MLS 640 GHz & CALIPSO

- Motivation: Important to constrain cloud parameterizations for GCMs (large uncertainties)

Quick Summary of Aura MLS Data Validation Status/Issues/Plans

- **Status**

- Significant improvements, overall, in new (v2.2) data version
  > e.g., bias and/or scatter reduction (e.g., T, O_3, CO, N_2O, HNO_3, BrO, HO_x)
- Validation papers document status of comparisons and error characterization
- Mostly validate spatial distributions; few temporal studies (limited by v2.2)

- **Issues / Plans**

- Specific issues depend on the product (MLS measurement system issues, need for additional validation data/studies, correlative data issues)
- We should plan to continue a variety of validation studies
  - (a) to show more robustness geographically (e.g., UT CO and O_3) or over wider vertical range
  - (b) to show more robustness over time (e.g., using more NDACC data and/or to connect back in time)
  - (c) for the less validated MLS products (e.g., HOCl, HCN)
  - (d) using improved, or more consistent, correlative data (e.g., H_2O, HO_x)
  - (e) for improved results/science, using new MLS version (e.g., for CO)