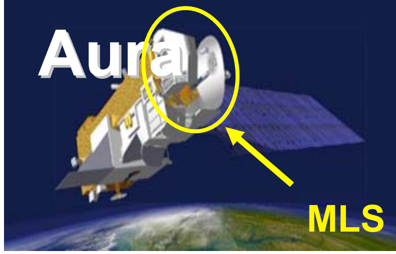

Overview of Microwave Limb Sounder (MLS) results after Aura's first year in orbit: Validation and Science

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Jet Propulsion Laboratory, California Institute of Technology

Robert Harwood, Hugh Pumphrey, Mark Filipiak, Carlos Jimenez, Cory Davis, Ian MacKenzie

School of Geosciences, The University of Edinburgh

Sep. 19-23, 2005 AVE/PAVE Meetings and Aura Validation Workshop, Greenbelt, MD

MLS milestones since 15 July 04 launch and Status Summary

Major MLS milestones

- Instrument ‘first light’. . . . . 24 Jul 2004
- Atmospheric data processing (retrievals) starts . . . . 27 Jul 2004
- Full-up science observations start . . . . 13 Aug 2004
- Production atmospheric data processing starts . . . . 30 Aug 2004
- V1.51 (first public release) data processing starts . . . . . 28 Jan 2005
- V1.51 data accessible on GSFC DAAC, starting . . . . 15 Feb 2005
- Add ‘full’ MLS V1.51 Data Quality Documents . . . . 1 Aug 2005

Status Summary

- MLS instrument & data processing systems working excellently
- All measurements for which the instrument was designed have been demonstrated over an initial, usually broad, altitude range
- All Level 2 files routinely available from GSFC DAAC + AVDC
- Validation and science results
  - > 10 cal/val papers submitted for IEEE Special Issue
  - > 7 GRL papers published + 2 submitted

EOS MLS Level 2 Data Processing Status

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Aug'04	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	31	1	2	3	4
Sep'04	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30	1	2
Oct'04	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
Nov'04	31	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
	28	29	30	1	2	3	4
Dec'04	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30	31	1
Jan'05	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Feb'05	30	31	1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
Mar'05	27	28	1	2	3	4	5
	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	31	1	2
Apr'05	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
May'05	1	2	3	4	5	6	7
	8	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	31	1	2	3	4
Jun'05	5	6	7	8	9	10	11
	12	13	14	15	16	17	18
	19	20	21	22	23	24	25
	26	27	28	29	30	1	2
Jul'05	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Aug'05	31	1	2	3	4	5	6
	7	8	9	10	11	12	13
	14	15	16	17	18	19	20
	21	22	23	24	25	26	27
	28	29	30	31	1	2	3
Sep'05	4	5	6	7	8	9	10
	11	12	13	14	15	16	17
	18	19	20	21	22	23	24
	25	26	27	28	29	30	1
Oct'05	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
	30	31	1	2	3	4	5

v1.51
v1.50
unprocessed
<90% useful
L1 problem
in progress

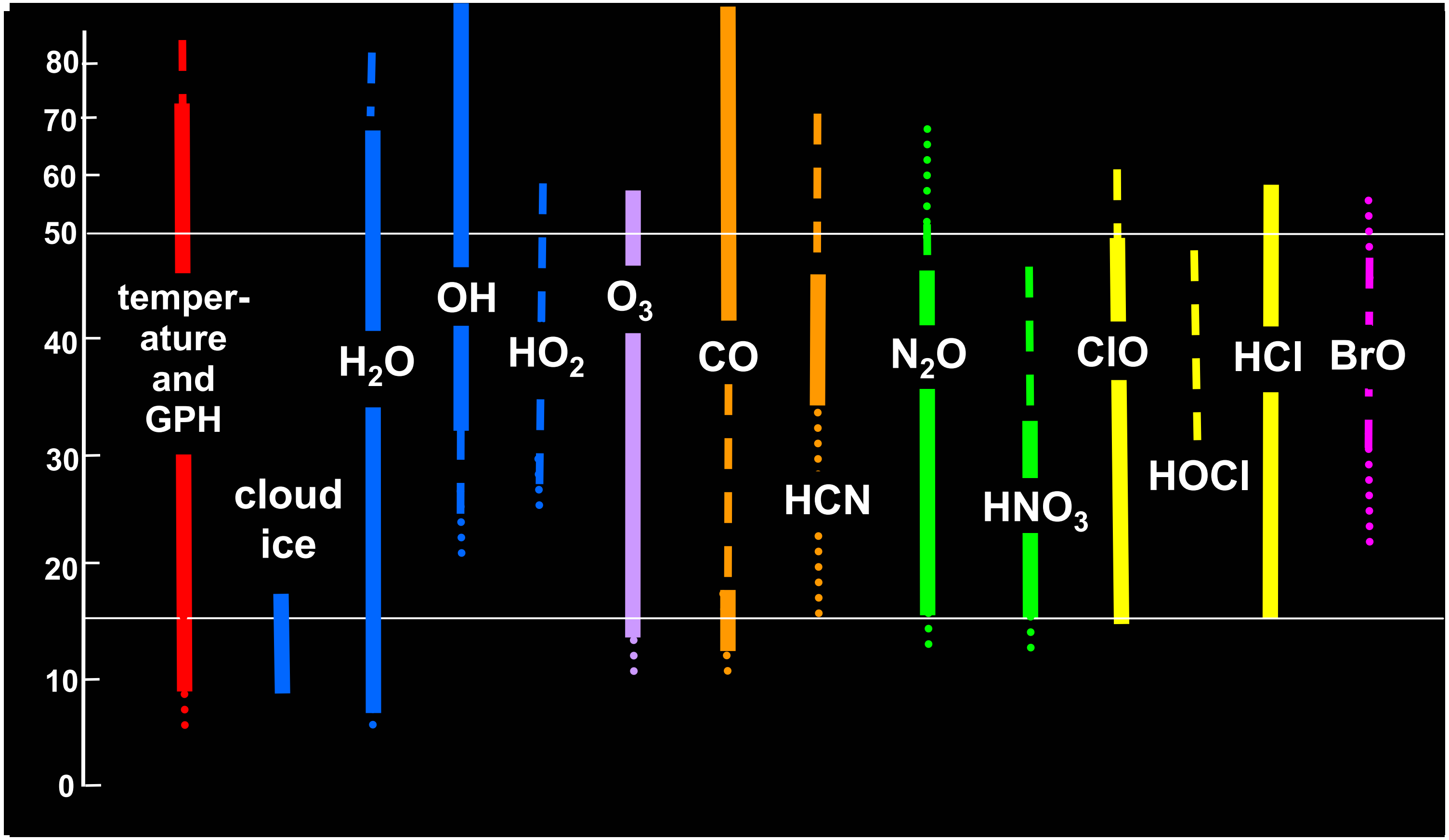
- **V1.50 has metadata error (will be reprocessed)**

Status as of 9/16/2005

- **MLS SIPS sized & funded to process 60% of L1 data to L2 for first year. Achieved more than this.**
- **MLS SIPS recently upgraded to process 100% of new data to L2 (+ some reprocessing).**

Approximate Useful Vertical Range Expected for MLS V1.5 Data Products

be familiar with MLS 'data quality document' before using data

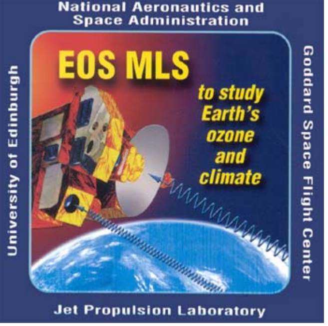


Dashes indicate that averages are generally needed for useful precision

Dots indicate goals that may be demonstrated in V1.5 with further work

- will have some wider ranges in Version 2 (e.g., mesosphere O_3)

Day-night differences currently required for BrO, HO_2, and OH below ~30 km



MLS: Atmospheric Science

Overall Science Objectives of MLS

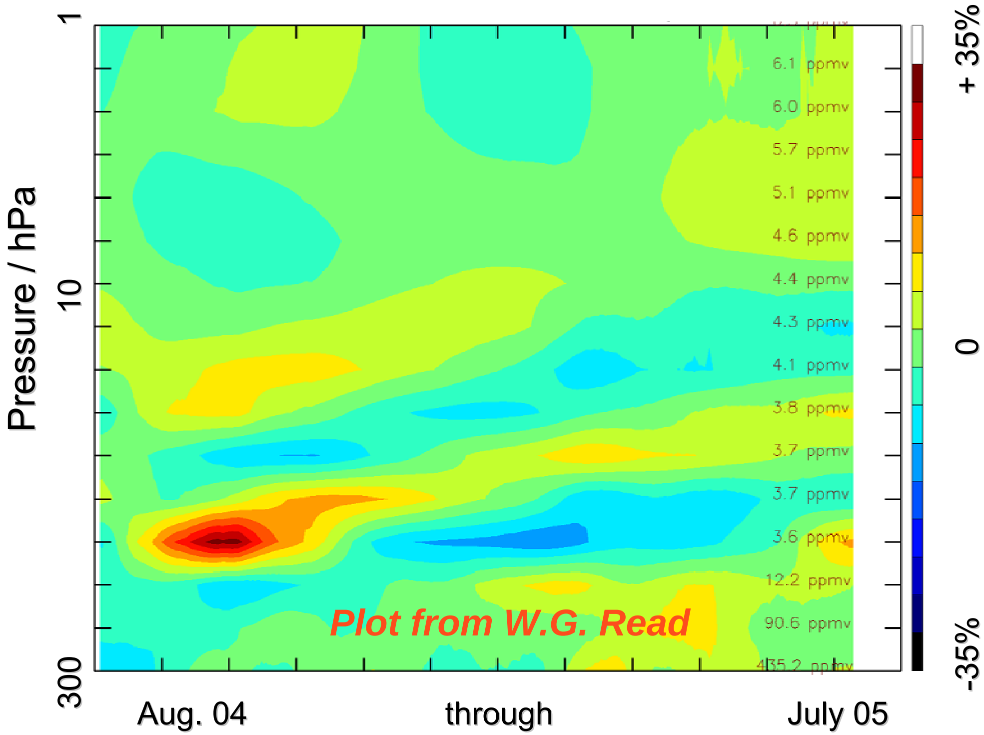
Fall under NASA's Strategic Plan

Objective 1.1: ' To understand how Earth is changing, better predict change, and understand the consequences for life on Earth.'

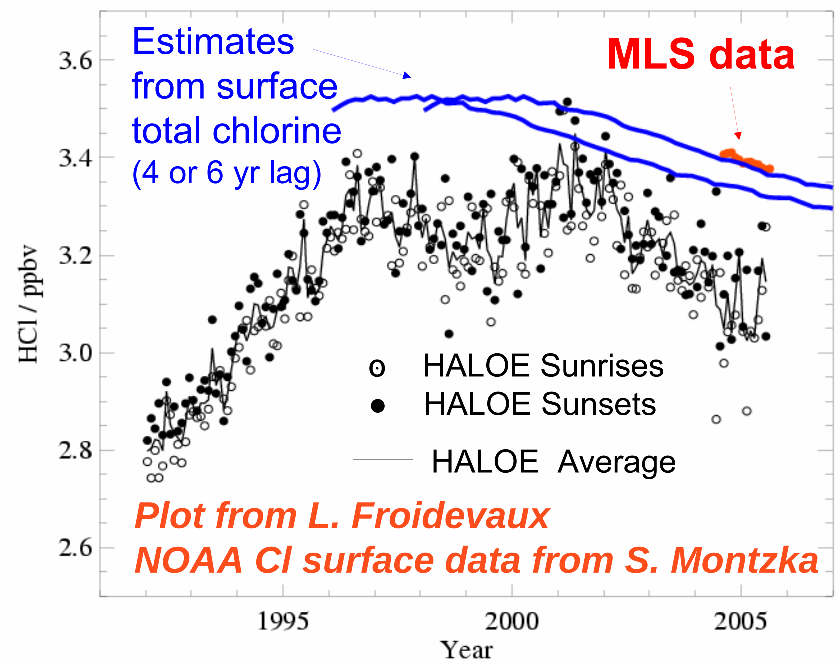
- **Track ozone-destruction chemistry during period when ozone layer may start to recover**
  - especially track chlorine & bromine chemistry, resolve issues in hydrogen chemistry
- **Understand coupling between composition and climate**
  - especially via water vapor in the upper troposphere
- **Quantify aspects of pollution in the upper troposphere**
  - via ozone, CO, cloud, and other data

Microwave Limb Sounder (MLS) on Aura: 1 year of continuous new views of the stratosphere

Tropical H_2O variations

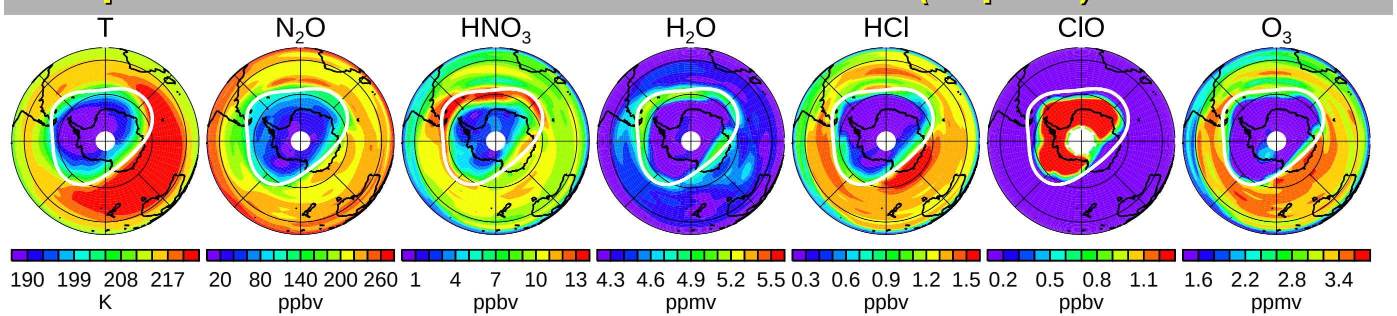


HCl variations at 50-60 km



New views of ozone-related chemistry

Maps for lower strat. Antarctic winter 2005 (Sep. 12) for θ = 520K



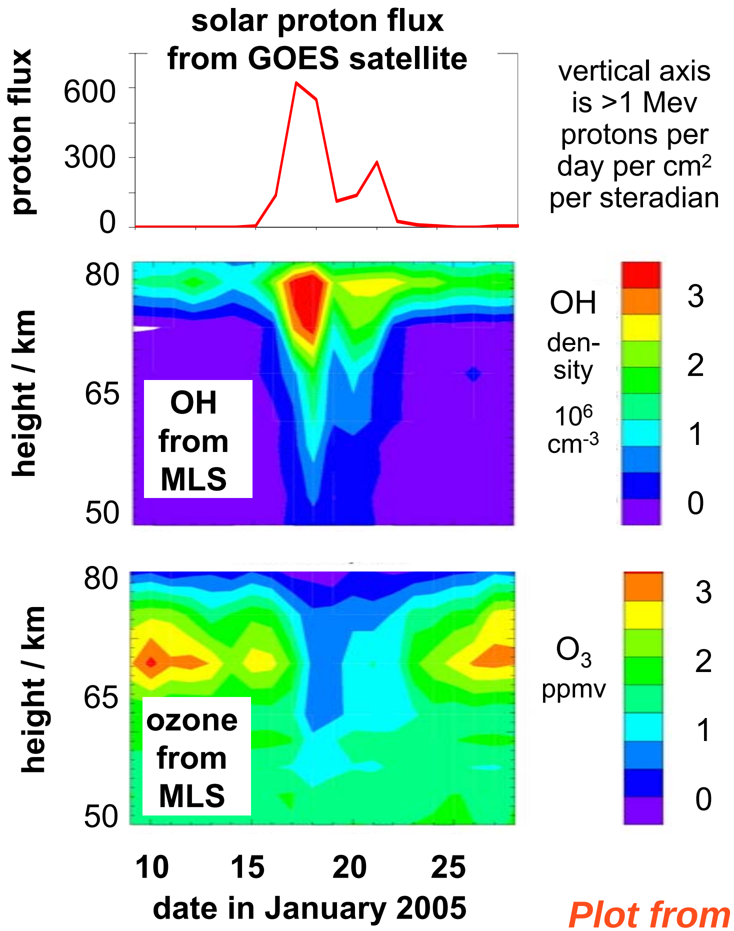
Plot from M.L. Santee

See also MLS talk on winter 04 / 05 ozone loss.

Solar Flares Affect Mesospheric OH and Ozone

> MLS has observed solar proton flares enhancing mesospheric OH and its resulting destruction of mesospheric ozone
  - Thanks to C. Jackman for suggesting we look for this

> Images at right show solar proton flux from mid-Jan 2005 solar flare and its resulting effects on mesospheric OH and ozone
  - Magnetic field 'funnels' protons into polar regions where effect is observed, most prominently in the polar night (Arctic data shown)
  - Expected related effects have been detected in the Antarctic and in mesospheric HO_2
  - MLS has observed 3 such (large) events since the start of the Aura mission



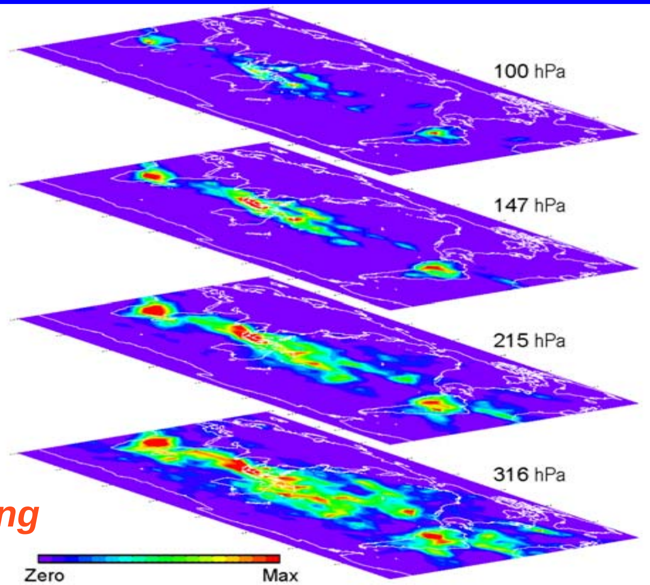
Plot from H.M. Pickett

Global height-resolved cloud ice measurements from MLS

Ice Water Content (IWC) is derived from the radiance 'residual' after accounting for all gas-phase signals

See *Wu et al.* (IEEE paper, and MLS website) for retrieval details

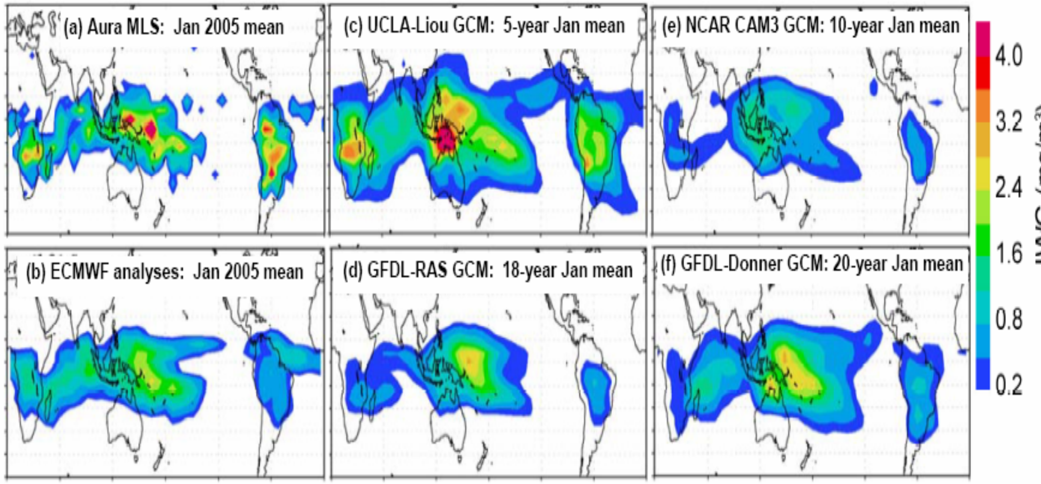
Ice Water Content: Dec. 04 average



Plot from J. Jiang

- > MLS measures average ice content
  over region of ~200x7x3 km^3
  with sensitivity ~ 1 mg/m^3 at 100 hPa
  ~12 mg/m^3 at 316 hPa.
- > MLS data at λ = 0.2 to 3 mm
  → ice particle size information
- > Data at orthogonal polarizations
  - can place constraints on ice particle alignment *(Davis, et al., GRL, 2005)*

January mean cloud ice at 150 hPa from (a) Aura MLS, (b) ECMWF analyses, (c-f) four GCMs

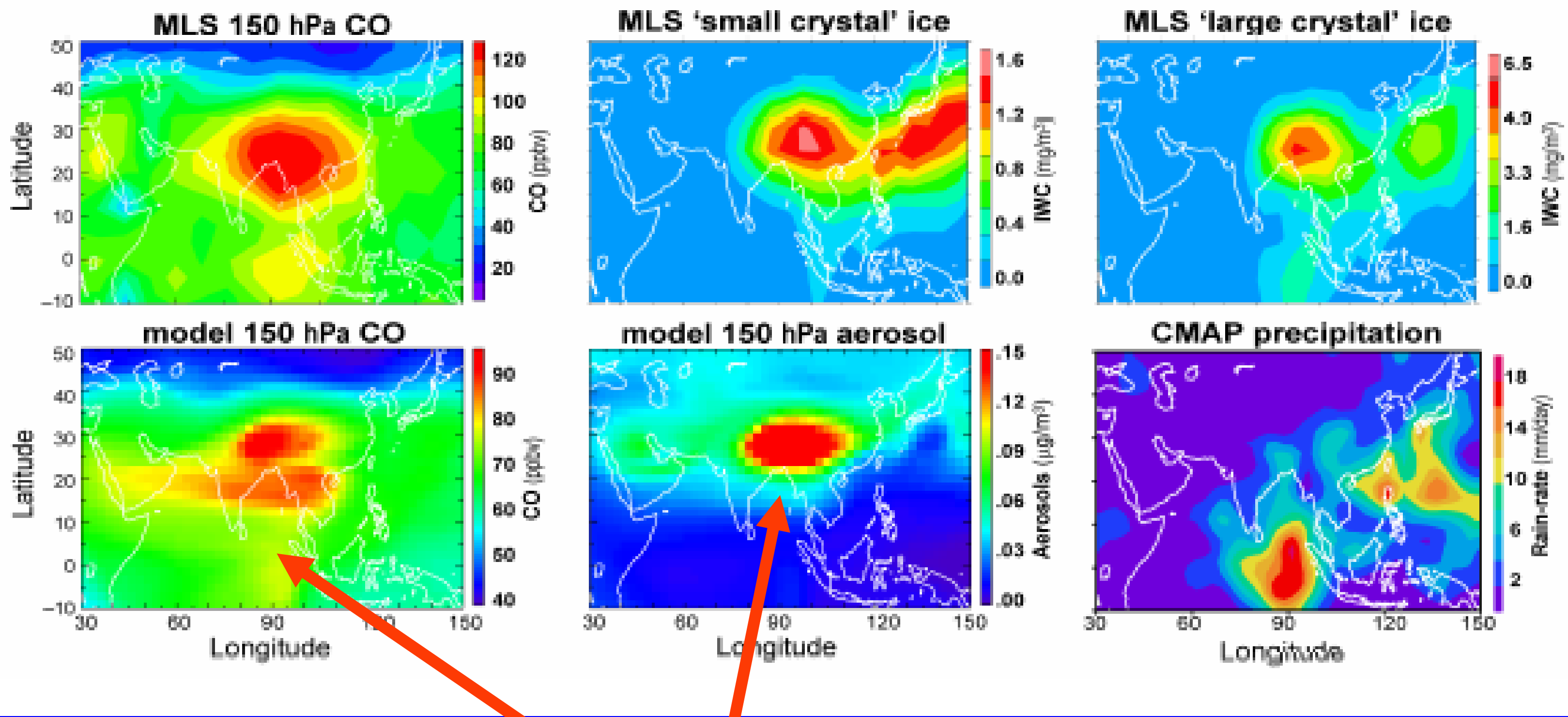


(F. Li, et al., GRL, 2005)

- > These are first-of-a-kind global comparisons of IWC versus GCMs
- > Model/model differences are at least as large as model/data differences

Relation between Cloud Ice and Boundary-Layer Pollution in the Upper Troposphere

Examples from M. Filipiak, et al., and Q. Li, et al., *GRL papers (2005)*
with 'small' and 'large' crystal ice maps added by D. Wu
(r ~ 15μm is characteristic size separating ice maps shown here)



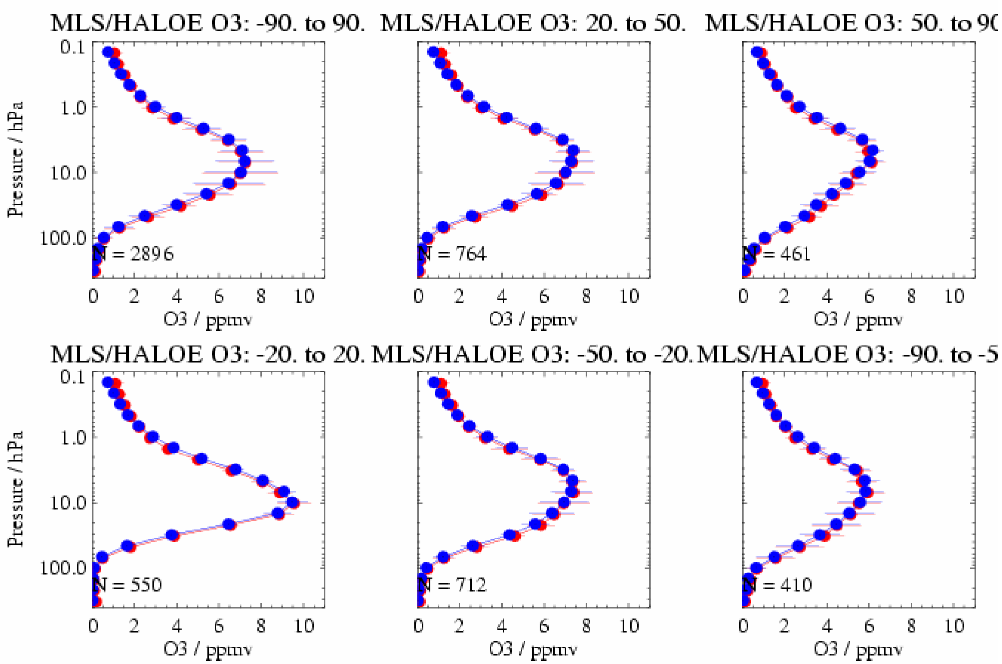
- Enhanced (Aug.-Sep. 2004) CO and aerosol are traced (by GEOS-CHEM model) to convectively/orographically-lifted anthropogenic emissions from India & China.
- Do anthropogenic aerosols contribute to co-located enhancements in cloud ice seen by MLS?
- More research on MLS cloud ice & its relationship with other parameters is in progress
- Other A-train data (CloudSat/CALIPSO) will provide more information.

MLS: Data Validation

- *Froidevaux et al.* paper (Aura special issue of *IEEE Trans. Geoscience and Remote Sensing* - also available at MLS website) discusses the MLS team's early validation results for T, O_3, H_2O, HCl, N_2O, HNO_3, CO versus other satellite data + 2004 balloon data.
- Some validation examples shown below + many more discussed at this workshop.

MLS ozone vs HALOE ozone

Mostly very good ozone comparisons with other datasets in the stratosphere; largest percentage biases are in the mesosphere and UT/LS.



Averaged MLS & HALOE coincidences from Aug. 04 – July 05

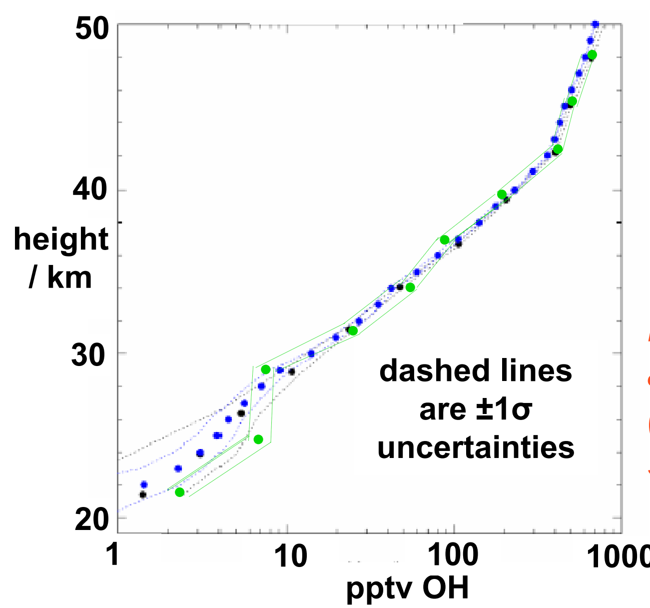
OH versus height at 34° N

black: MLS 5° ascending zonal mean centered at 34° N on 23 Sep 04

blue: Harvard SAO FIRS, and

green: JPL balloon OH

from Ft. Sumner (34° N) on 23 Sep 04



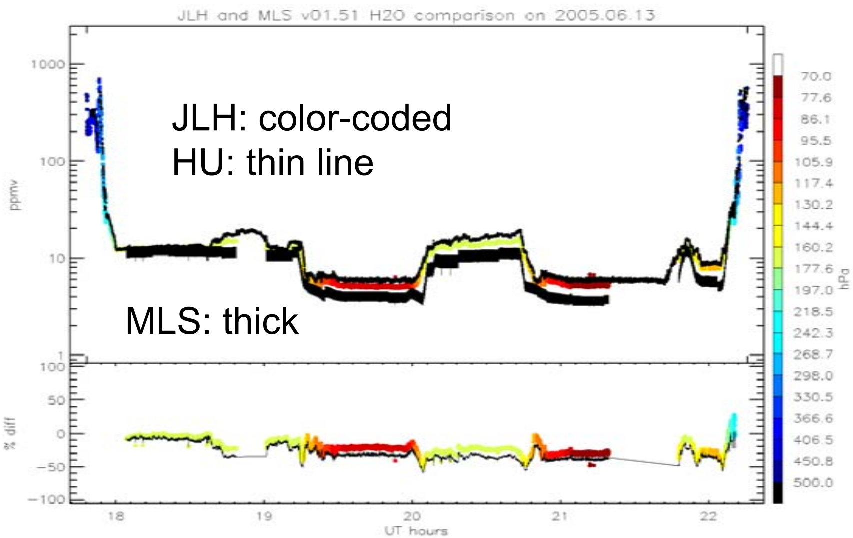
Pickett et al. (GRL, submitted)

MLS: Data Validation

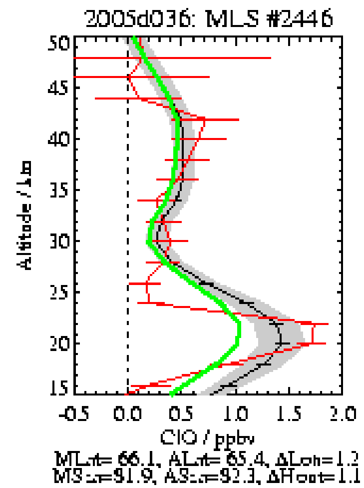
Examples of what seems to have 'worked best' in AVE and PAVE comparisons

AVE campaigns

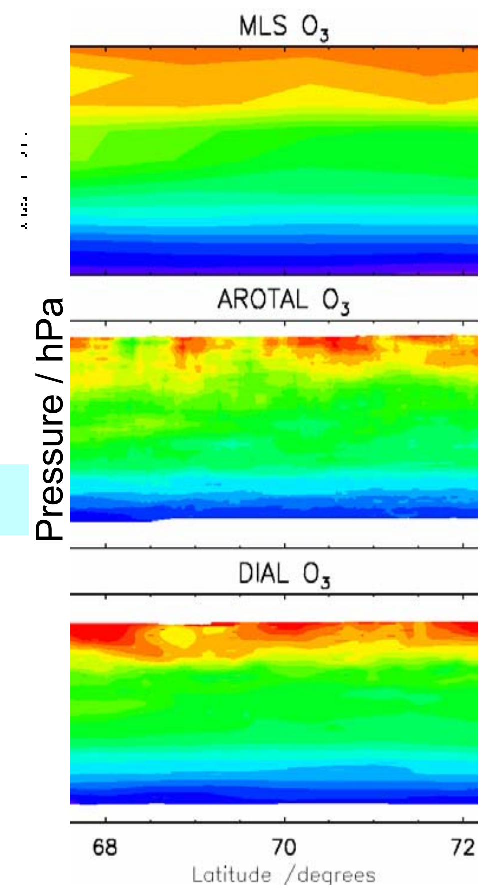
PAVE campaign



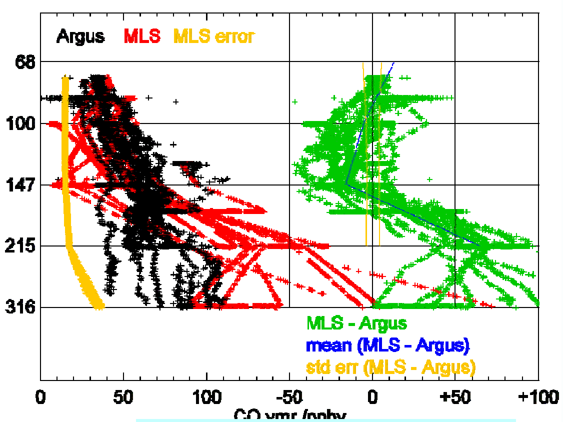
MLS & AVE H_2O



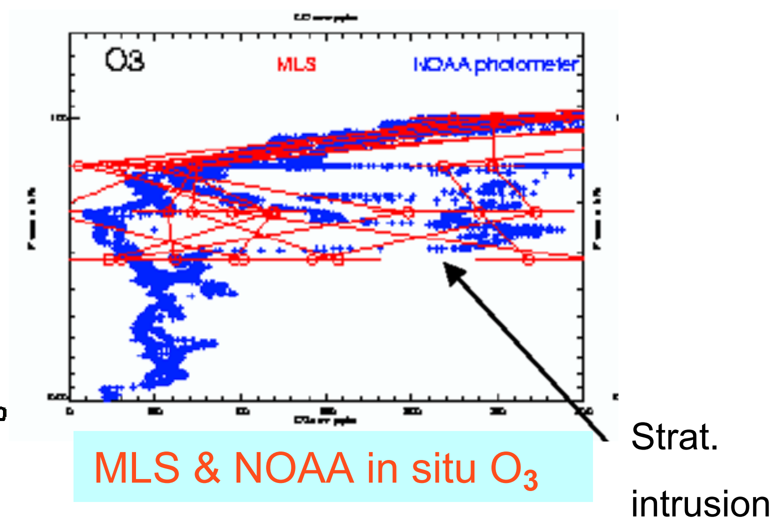
MLS & ASUR ClO



MLS & Lidar O_3



MLS & Argus CO



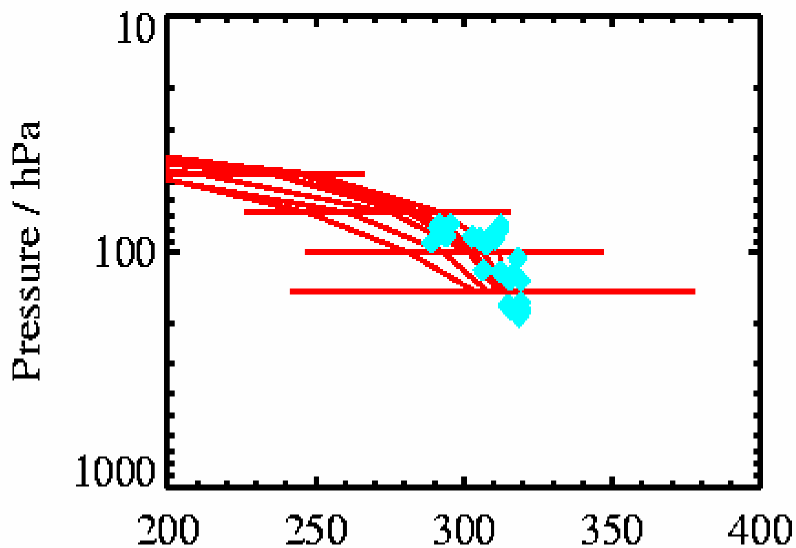
MLS & NOAA in situ O_3

MLS: Data Validation

<u>Examples</u> of what seems to be more challenging in MLS & AVE / PAVE comparisons
- can be a result of MLS noise or other issues.

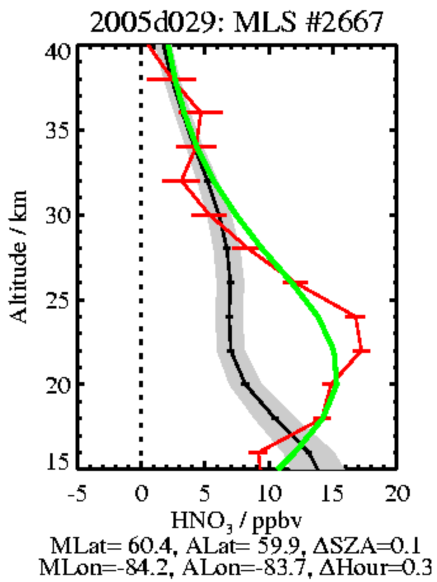
AVE campaigns

> Difficult to pull out 'small' biases (< 10-15%) in some cases
- e.g., see N_2O below (MLS noise high vs num. of comps.)
- might be true for HNO_3 and HCl also, despite some 'reasonable comparisons' (if CIMS accuracy is 25%); but tropical (pre-AVE) CIMS HCl data useful for MLS UT/LS bias.



MLS & WAS N_2O

PAVE campaign



MLS & ASUR HNO_3
Some differences are difficult to explain (so far).

Aircraft in situ data during level flight are less useful than profiles, but can 'tie in' to profiles + as calibration (e.g., in situ O_3 vs lidars) and for variability studies.

MLS V1.5 Product (recommended range / hPa)	MLS Team Lead (JPL or Univ. Edinburgh)	Datasets used in comparisons
T (316 - 0.001)	M. Schwartz	GEOS-4, CHAMP, AIRS, HALOE, ACE, SABER, radiosondes, AVE, PAVE
N_2O (100 - 0.1)	N. Livesey	ACE, Odin/SMR, MIPAS, Balloon, AVE, PAVE(ASUR)
HCN (10 - 1.4)	H. Pumphrey	Balloon data, ACE
O_3 (215 - 0.5)	STRAT / MES: **L. Froidevaux + Y. Jiang** TROP: **M. Filipiak**	profiles versus SAGE II, HALOE, ACE, POAM III sondes (profiles + columns), PAVE sondes, AVE, PAVE, [MOZAIC]
H_2O (316 - 0.1)	STRAT / MES: **C. Jimenez** TROP: **W. Read**	HALOE, SAGE-II, ACE AIRS, AVE, radiosondes, frostpoint sondes
CO (215 - 0.005)	M. Filipiak	ACE, AVE, PAVE, GEOS-CHEM, TES
HNO_3 (147 - 3)	M. Santee	UMLS, ACE, Odin/SMR, MIPAS, PAVE (ASUR), Balloon
BrO * (10 – 2)	N. Livesey	Climatology, models
OH (46 - 0.2)	H. Pickett	Balloon data, Ground-based (FTUVS) data, models
HO_2 * (22 - 0.2)	H. Pickett	Balloon data, models
HCl (100 - 0.2)	L. Froidevaux	HALOE, ACE, PAVE, Balloon data, AVE
ClO (100 - 1)	M. Santee	UARS/MLS, Odin/SMR, PAVE(ASUR)
HOCl * (22 - 2)	L. Froidevaux	Balloon data (FIRS-2), models, [ACE]
IWC (215 – 68) **SO_2** (100-10)	D. Wu / J. Jiang W. Read	MLS IWC product; statistics vs TRMM, GCMs OMI (for volcanic plume)

Notes: Products in black are a provisional data release; * means that a product requires significant averaging over most of its range.

MLS V1.5 Product (recommended range / hPa)	MLS Team Lead (JPL or Univ. Edinburgh)	'Validation Quality' (Low, Medium, High, Highest) and Main issues/wishes
T (316 - 0.001)	M. Schwartz	VQ = Med.; ~2K warm; oscillations; want finer vert. grid.
N_2O (100 - 0.1)	N. Livesey	VQ = Med./High; agrees with other data to ~10-20%.
HCN (10 - 1.4)	H. Pumphrey	VQ = Low; need better retrievals than V1.5 in LS.
O_3 (215 - 0.5)	**STRAT / MES: L. Froidevaux + Y. Jiang** **TROP: M. Filipiak**	STRAT: VQ = High ; some bias slope versus height. MES: VQ = Med. ; high bias needs more study. UT: VQ = Med. ; want to reduce scatter, biases.
H_2O (316 - 0.1)	**STRAT / MES: C. Jimenez** **TROP: W. Read**	STRAT: VQ = High; some oscillations; MES: VQ = Med. UT: VQ = Med./High ;some biases +want finer vert. grid.
CO (215 - 0.005)	M. Filipiak	STRAT / MES: VQ = Med.; some oscillations, biases. UT: VQ = Med.; morphology OK; high bias at 215hPa.
HNO_3 (147 - 3)	M. Santee	VQ = Med.; 20-30% bias near peak HNO_3; needs more analysis.
BrO * (10 – 2)	N. Livesey	VQ = Low; needs more analyses, better retrievals in LS.
OH (46 - 0.2)	H. Pickett	VQ = Med/High.; vs balloon. Want new retrievals for z > 60 km.
HO_2 * (22 - 0.2)	H. Pickett	VQ = Med. ; noisy, but good comparison vs FIRS-2.
HCl (100 - 0.2)	L. Froidevaux	VQ = High; HCl high vs HALOE, but close to ACE data.
ClO (100 - 1)	M. Santee	VQ = Med.; reasonable, but not many comparisons
HOCl * (22 - 2)	L. Froidevaux	VQ = Low; few comparisons; want better LS retrieval.
IWC (215 – 68) **SO_2** (100-10)	D. Wu / J. Jiang W. Read	VQ = Low/Med.; few data for abs. valid., morphology OK. VQ = Low ; no direct profile validation.

MLS: Data Validation
Some lessons learned from campaigns so far

> The AVE & PAVE campaigns have provided very interesting comparisons for MLS, despite differences/limitations in some of these (error bars, sampling scales/ranges).

- For some of the MLS data products, building statistically-significant comparisons using the aircraft data can take too many flights, given the MLS noise levels.
  - e.g., issue of MLS HNO_3 high bias near peak of profile won't be helped by aircraft.
  - accuracy of < 5-10% needed for significantly enhanced view of potential HCl biases.

- For others, like H_2O, O_3, T, several other global datasets exist for insights into potential MLS biases/issues; the aircraft data can offer useful complementary validation, and with profiles especially.

> Aircraft data can probe specific regions and times of interest (e.g., PAVE) + help resolve differences between various in situ techniques (e.g., H2O).

> There is more work to do to fully analyze the results of these campaigns
- future software versions will be used to check for any significant changes.

> The usefulness of a particular measurement for Aura validation should only be one of the aspects in future campaign payload assignments.

> A move towards more science-based validation, & science overall, is welcomed by MLS.

MLS: Data Validation
Main future priorities (not listed in specific priority order)

> High quality (<~10% accuracy) high-latitude winter balloon data

- Profiles into the mid-high stratosphere are probably more useful, for some products, than more aircraft flights, e.g., for N_2O, HNO_3, HCl. *Also useful for ACE cross-validation.*

> Reliable tropical data, especially for H_2O, are very desirable

- H_2O/O_3 sonde launches (e.g., from Costa Rica or China) are viewed quite favorably. Many profiles across tropopause desired with one consistent dataset, even if it is not totally 'bias-free'.

> MLS CO data validation could benefit most from more UT &/or LS data comparisons
Tropospheric ozone is also of interest (and not just for MLS).

- Upper tropospheric CO data are scarce (MOZAIC data may often not have right timing).
- Seek large variations in UT CO and O_3 under the MLS track:
  - Can campaign track such variations (pollution, stratospheric intrusions) to check MLS vs aircraft/sondes?
  - May be more productive than trying to get 'lots' of statistics under quiet conditions
  - Can help 'validate the science', now that 'morphology' of MLS 100 - 200 hPa data is looking reasonable (even as MLS team works to get improved retrievals).

> Impact of pollution outflows on cloud ice particle properties in the upper troposphere

- e.g., outflow off the U.S. East Coast, or off the Asian continent
  1. Need in situ data on cloud particle size distributions (in differing locations/times).
  2. Also would like ice water content (an MLS product).

  Also useful for CloudSat cross-validation.

> Future plans: Costa Rica, Guam, INTEX (still) viewed favorably overall.
Asia monsoon region would be of high interest, but more difficult / costly…

> More discussions to follow.