JEM/SMILES Mission

(JEM/SMILES: Superconducting Submillimeter-Wave Limb-Emission Sounder designed to be aboard the Japanese Experiment Module on ISS; Collaboration project of JAXA - Japan Aerospace Exploration Agency - and NICT - National Institute of Information and Communications Technology -)

1. Demonstration of superconductive mixer and 4-K mechanical cooler for the submillimeter limb-emission sounding in space

[Mechanical Cooler] Two-stage Stirling and J-T; 20mW @4K, 200mW @20K, 1000mW @100K; Power Consumption: <300 W; Mass: 90 kg

[SIS Mixer]
RF: 640 GHz, IF: 11-13 GHz; Junction: Nb/AlOx/Nb, ~7 kA/cm^2; Fabricated at Nobeyama RO

2. Observation on atmospheric minor constituents in the middle atmosphere

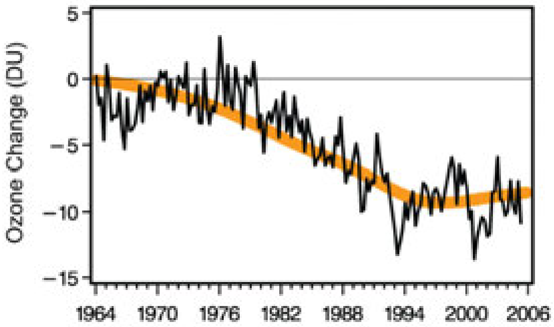
[Standard Products]

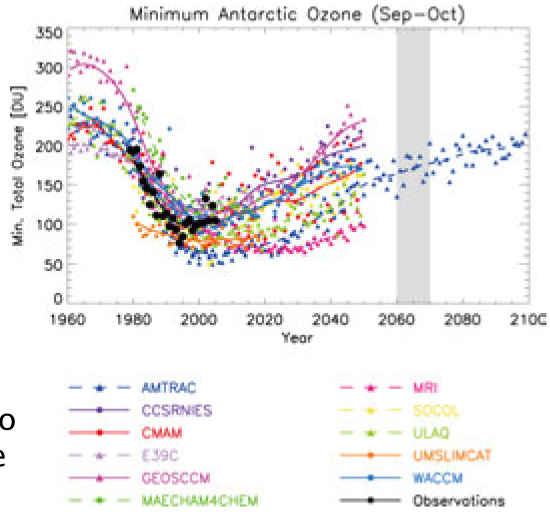
- 1 scan : O_3, HCl, ClO, CH_3CN, O_3 isotopes, HOCl, HNO_3
- Multi-scan : HO_2, BrO

[Research Products] UTH, Cirrus Clouds, volcanic SO_2, H_2O_2

2

Background: Future Ozone Layer



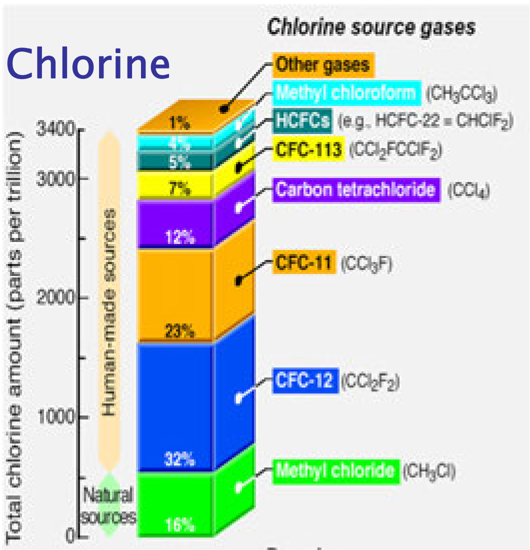


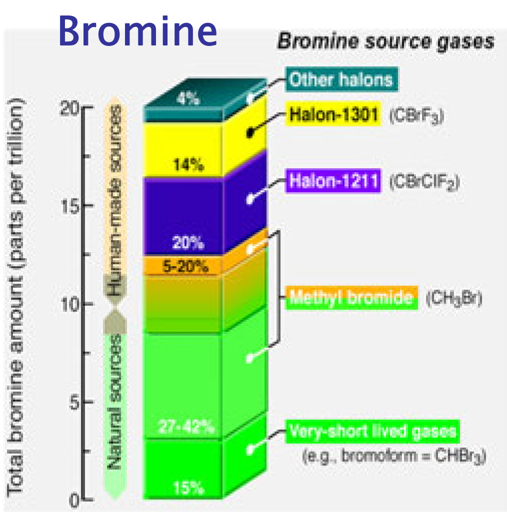
Not only in the polar latitudes, but also in the mid- and lower latitudes, ozone depletion is critical whole the globe. The recovery is estimated around 2060-2070, but there is very big uncertainty in association with the Cl and Br chemistries (WMO, 2006)

Model results for the future Antarctic ozone amount calculated from chemistry-climate models (WMO, 2006)

3

Origin of Cl and Br in the Stratosphere





Our quantitative understanding of how halogenated very short-lived substances contribute to halogen levels in the stratosphere has improved significantly since the 2002 Assessment, with brominated very short-lived substances believed to make a significant contribution to total stratospheric bromine and its effect on stratospheric ozone. (WMO Ozone Report, 2006)

4

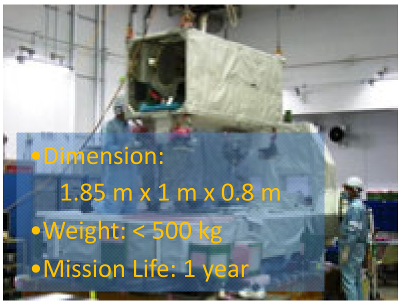
Scientific targets of SMILES

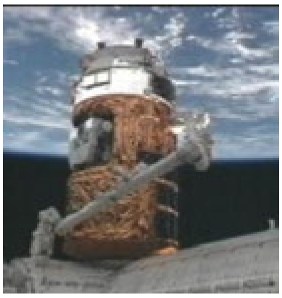
1. Inorganic Chlorine chemistry
    - ClO to HCl ratio — (O_3 trend in the US)
    - HOCl production — (O_3 trend in the LS)
    - Global ClO — (background ClO)
2. Bromine budget — (very short-lived source gas)
3. HO_x budget — (HO_x dilemma)
4. Cirrus clouds — (Het. reactions & rad. budget)
5. O_3 isotope — (mass independent chemistry)

(6. UT/LS mixing — (O_3 flux))

5

JEM/SMILES payload and status





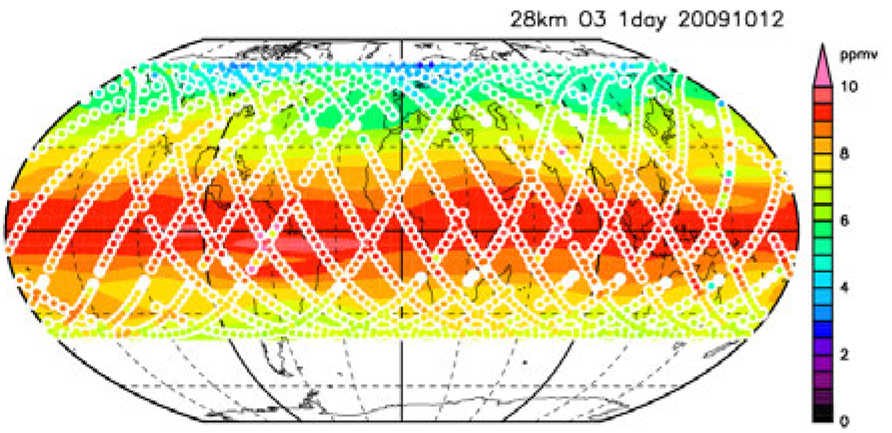
- Sep. 11, 2009: SMILES was carried by H-IIB with H-II Transfer Vehicle (HTV)
- Sep. 18: HTV was attached to ISS ; Sep. 25: SMILES was attached to JEM
- Sep. 28: The cooler reached 4K
- Oct. 12: Continuous observations started

- Apr. 21, 2010: SMILES observations have been suspended due to the failure of a critical component in the submillimeter local oscillator.
- June 5: The cooler stopped its operation due to the failure of the JEM thermal control system.
- Jan 19, 2011: JAXA officially announced termination of the normal operation (All dates in JST)

6

SMILES measurements

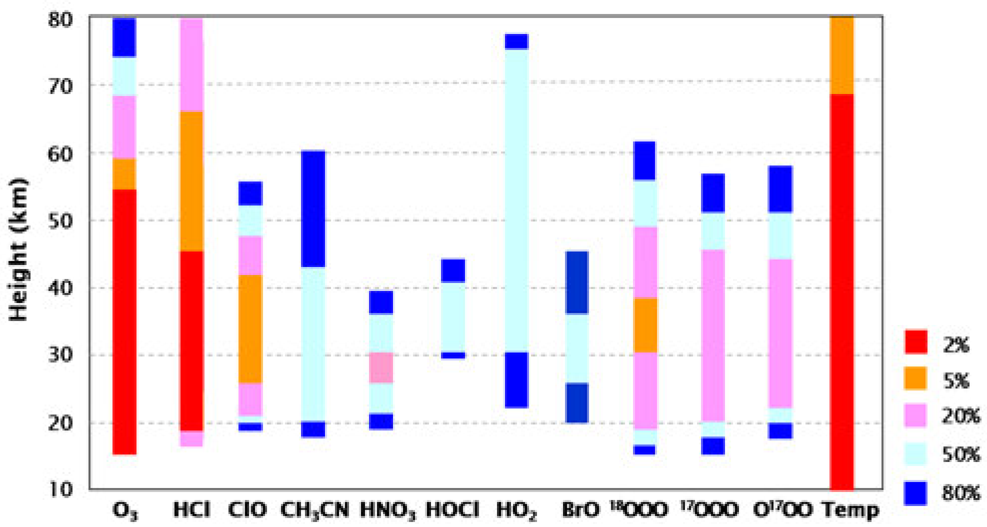
- High sensitivity in detecting atmospheric limb emission of the submillimeter wave range; Band-A : 624.32- 625.52GHz, Band-B : 625.12- 626.32GHz, Band-C : 649.12- 650.32GHz
- Vertical profiling (about 3km resolution) from ISS with latitudinal coverage of 65N to 38S; 53 sec for one sequence, about 100 points per one orbit, and about 1600 points per day.
- SMILES can measure the atmosphere at different local times because of the non-sun-synchronous ISS orbit.



Globally mapped ozone distributions at 28 km on October 12, 2009. Original observation points are plotted by white circles with observed ozone mixing ratios.

SMILES observation performance

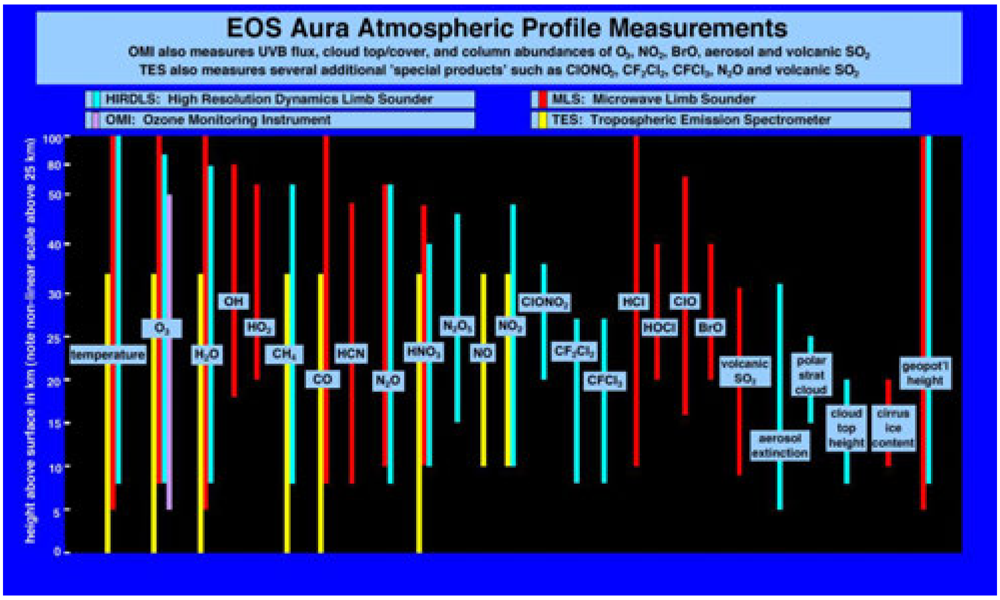
Measurements on several radical species crucial to the ozone chemistry (normal O_3, isotope O_3, ClO, HCl, HOCl, BrO, HO_2 ...)



Error estimation for the mid-latitude case based on the single scan measurement

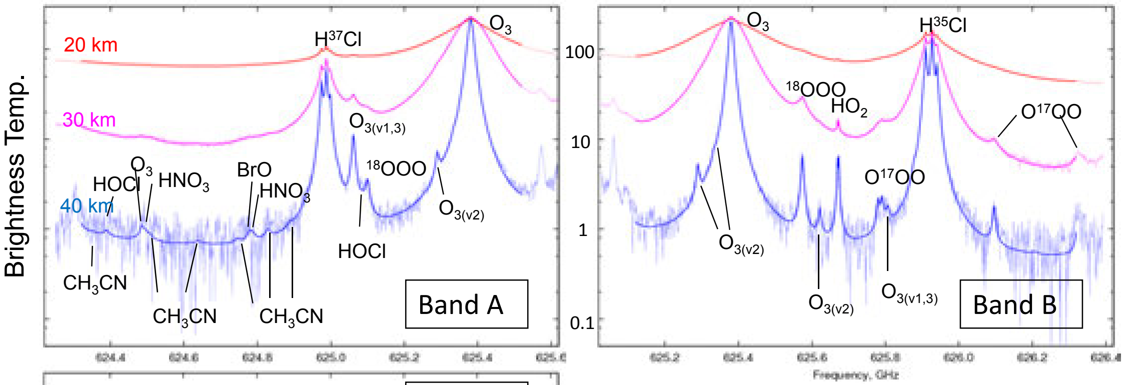
Cf. EOS Aura measurements

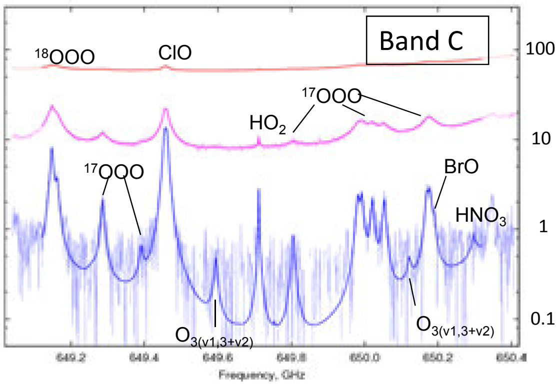
EOS-Aura launched in July 2004



9

Typical day-time spectra

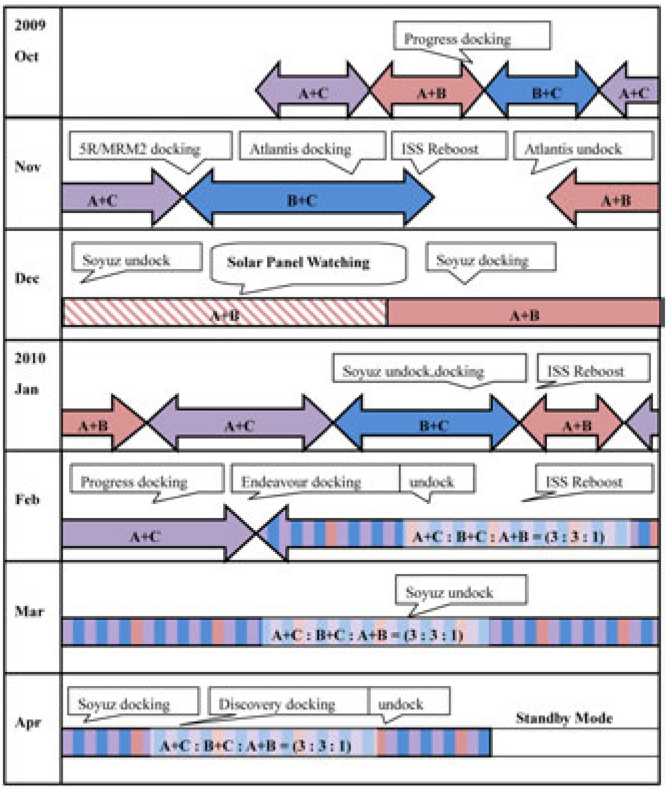




Observed spectra are in thin lines and fitted spectra are in thick lines

10

Status of SMILES observation



Two bands out of the three are used

Operational Level 2 products

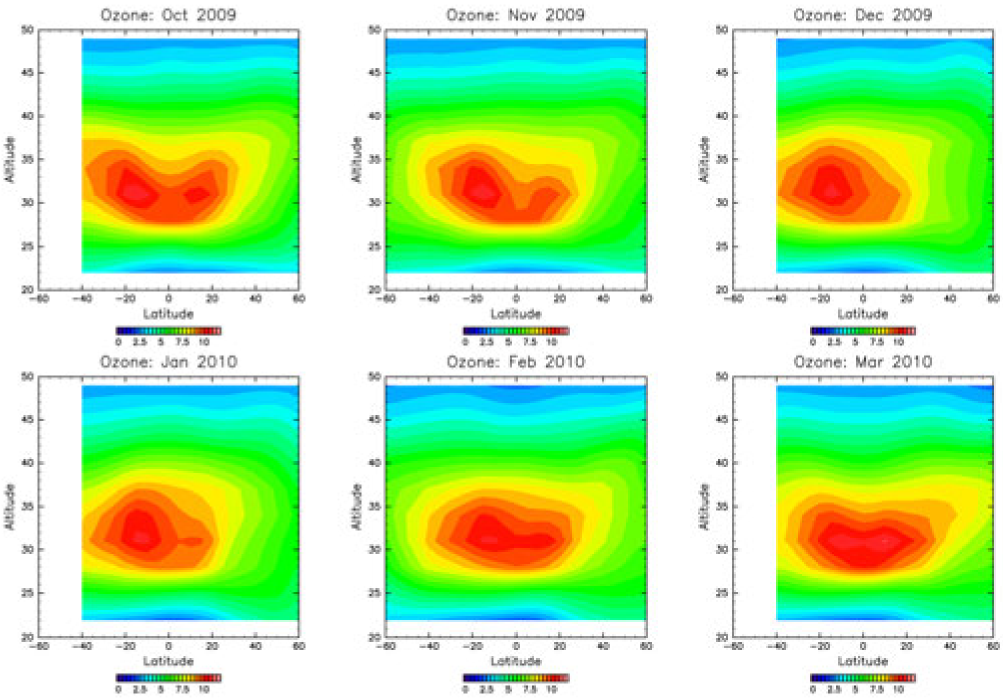
- v1.0 (005-06-0024): for retrieval test (2010/01/23 released)
- v1.1 (005-06-0032): for mapping test (2010/04/19 released)
- v1.2 (005-06-0150): algorism update I (2010/09/15 released)
- v1.3 (006-06-0200): algorism update II (2011/03/02 released)
- v2.0 (007-08-0300): major update (2011/10/04 released)
- v2.1 (007-08-0310): improvement in HOCl (2012/01/16 released)
  - Public release (2012/03/05)
- v2.2 (007-09-0400): algorithm update
- v2.3 (007-09-0402): minor update
- v2.4 (008-11-0502): a priori profile update

http://smiles.isas.jaxa.jp/access/indexe.shtml

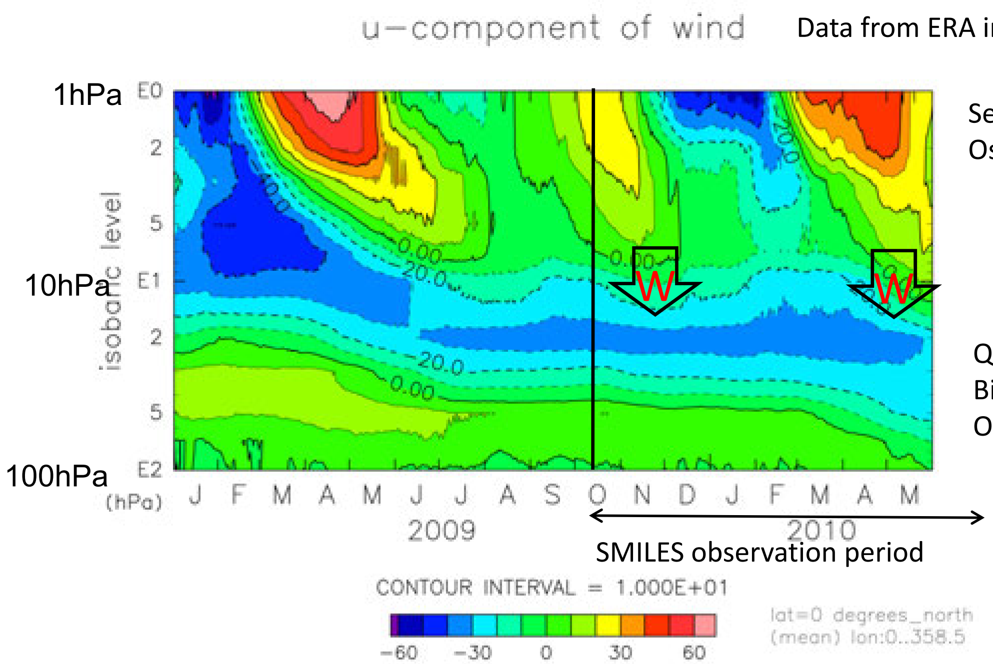
General pictures during the SMILES observation period:

i) seasonal evolutions in the equatorial latitudes
ii) a stratospheric sudden warming in Jan 2010

Seasonal evolution of ozone

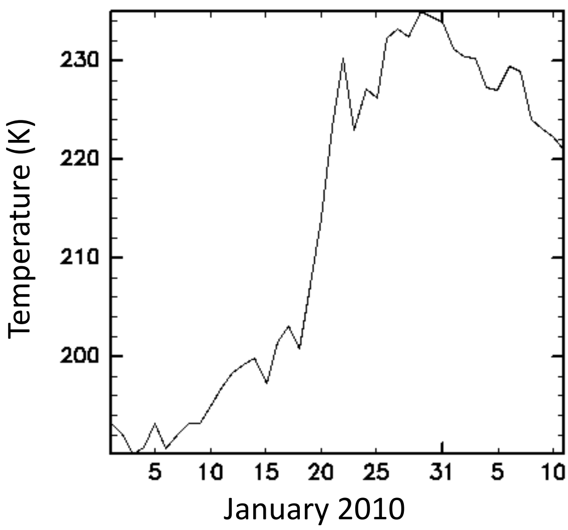


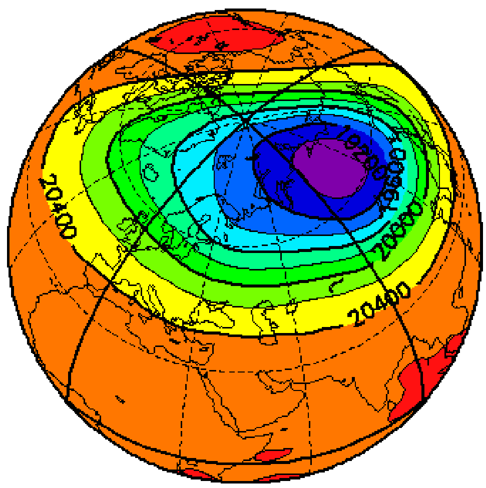
Time-height section of zonal wind (EQ)



A stratospheric sudden warming in January 2010

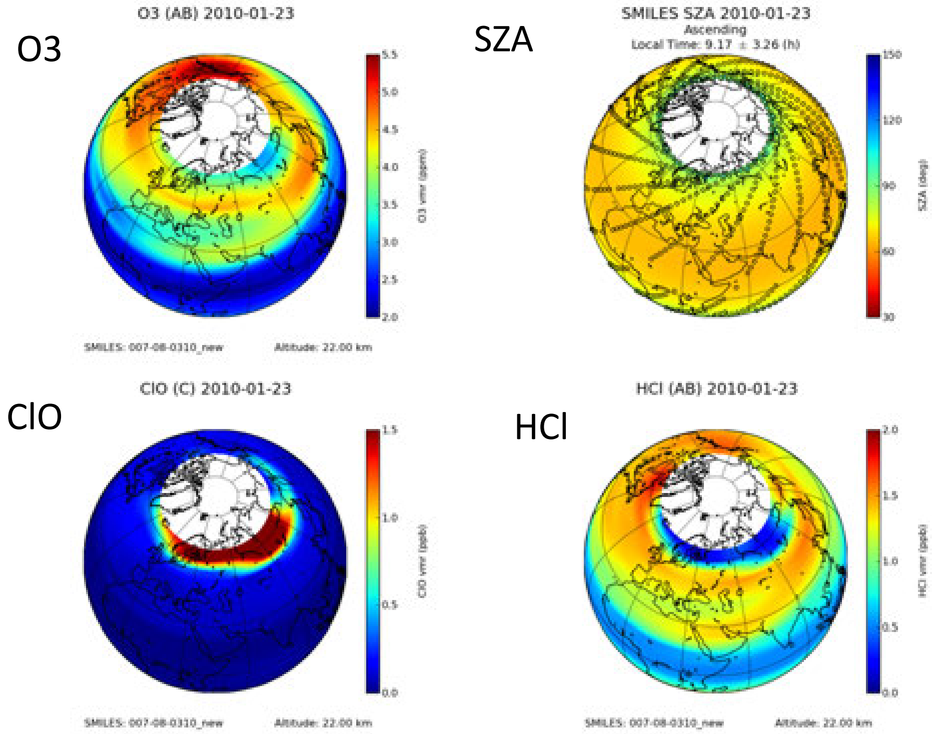
NP temperature at 10hPa





GP height field at 50 hPa on January 23

Time evolution in January 2010



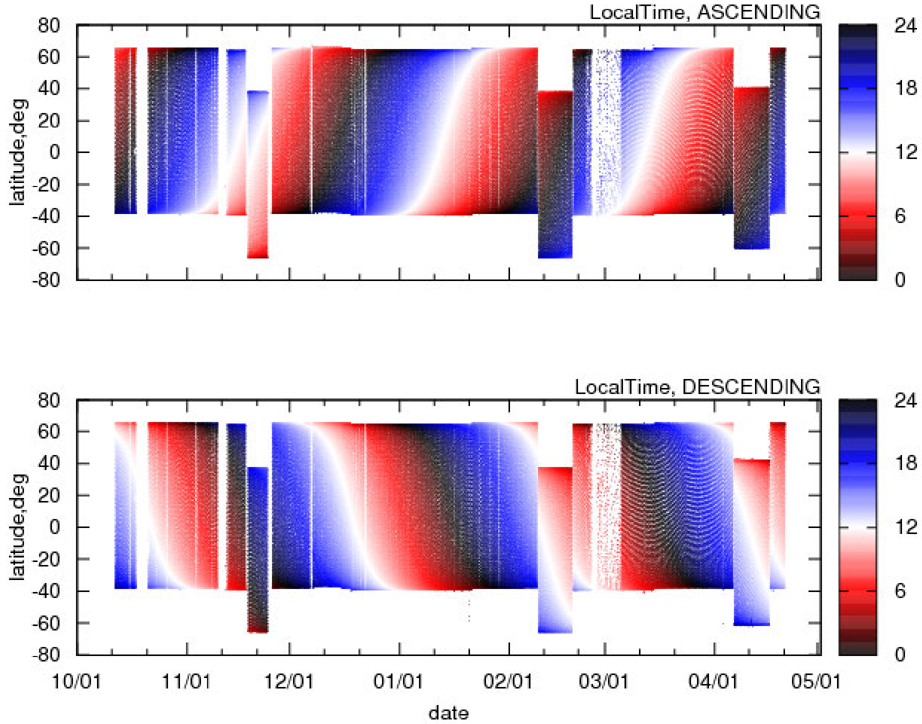
17

Diurnal ozone variations in the stratosphere revealed in observations from the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) onboard the International Space Station (ISS)

by Sakazaki et al.
(accepted, JGR)

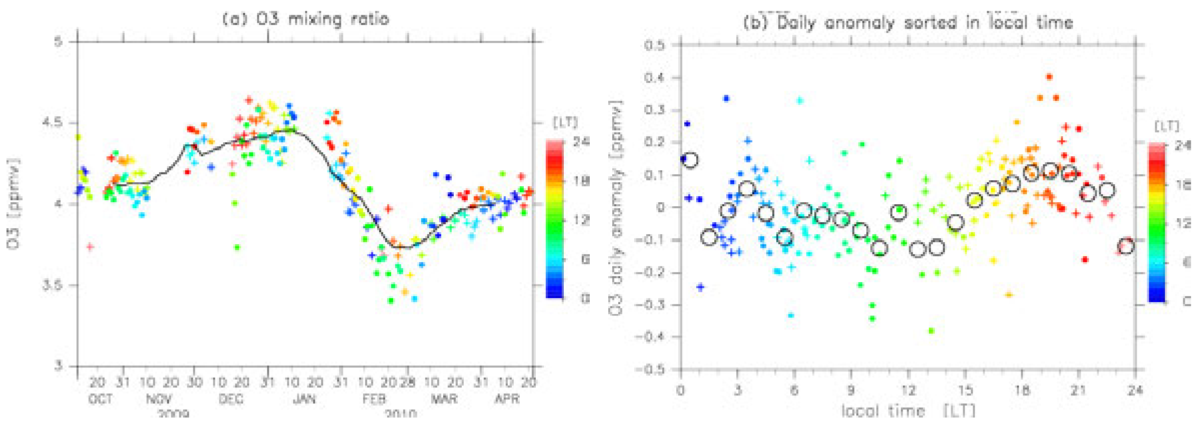
18

Local time variations



19

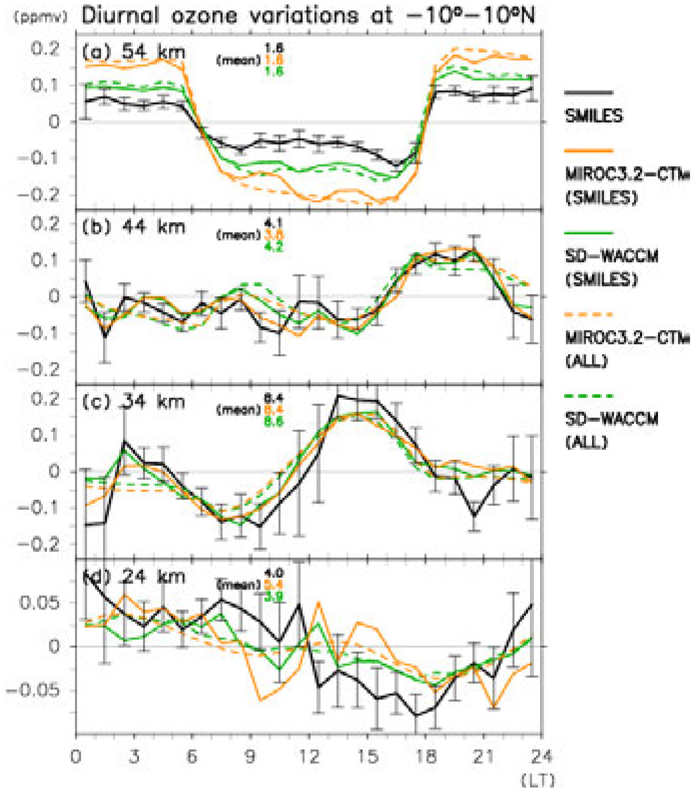
Daily time series and the residual from the 30-day running mean



Daily time series of ozone mixing ratio at the equator averaged over the longitude at an altitude of 44 km.

20

Diurnal variations averaged over 10S-10N



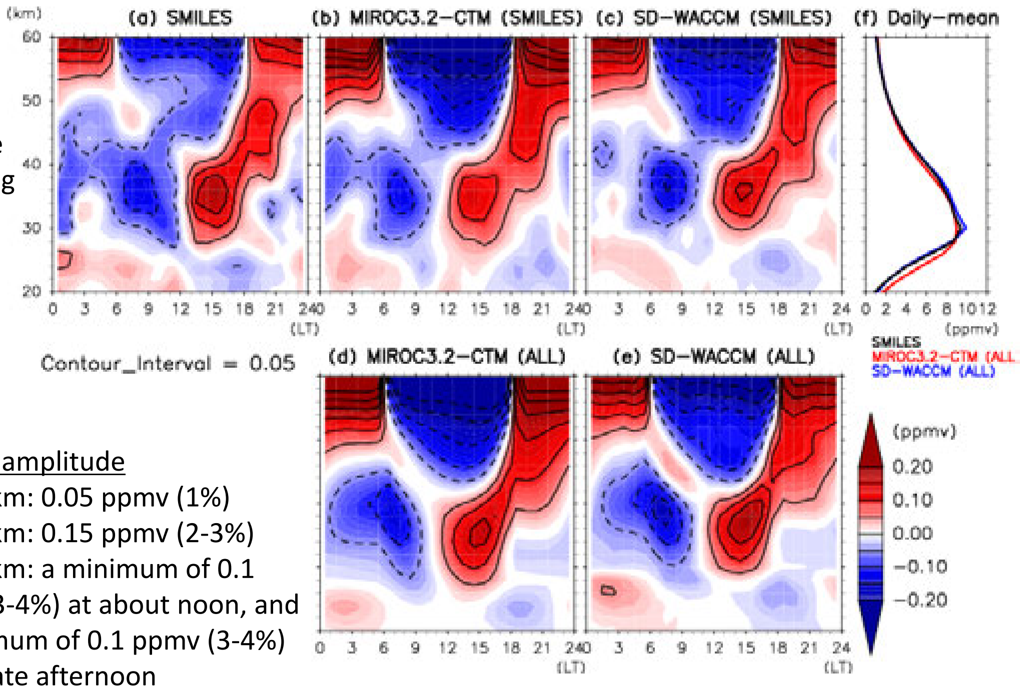
SD-WACCM

- Specified Dynamics (SD) version of WACCM
- Whole Atmosphere Community Climate Model
- Temperature and wind fields from NASA GEOS5.1 are nudged
- horizontal : 1.9°x2.5°, vertical: 88 levels (up to 140km)
- 57 species (Ox, NOx, HOx, ClOx, BrOx etc.)
- 230 chemical reactions

21

Diurnal variations in ozone

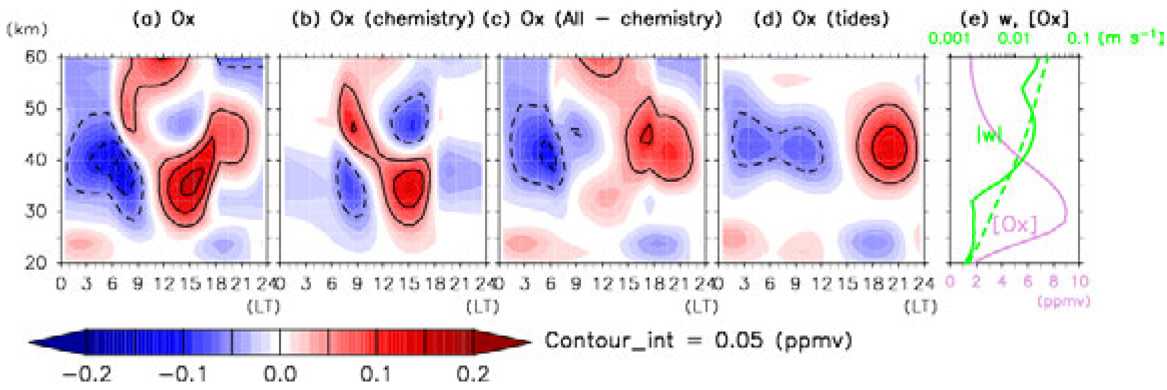
Satellite sampling



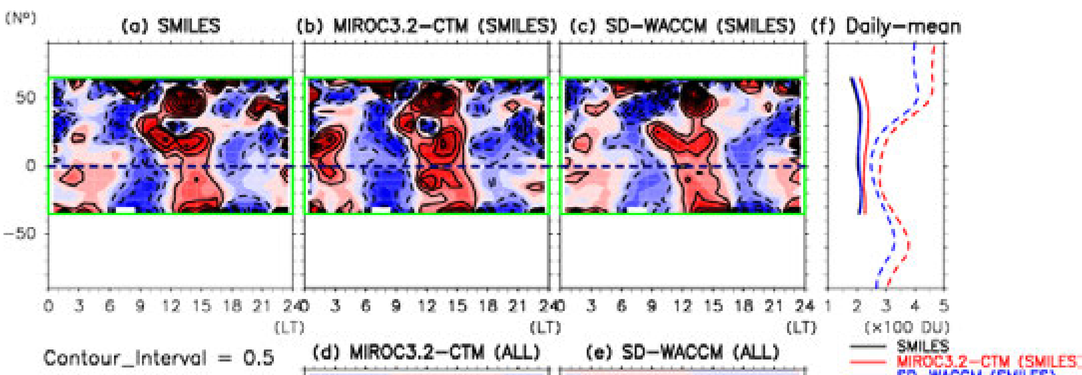
Diurnal amplitude
20–30 km: 0.05 ppmv (1%)
30–40 km: 0.15 ppmv (2-3%)
40–50 km: a minimum of 0.1 ppmv (3-4%) at about noon, and a maximum of 0.1 ppmv (3-4%) in the late afternoon

22

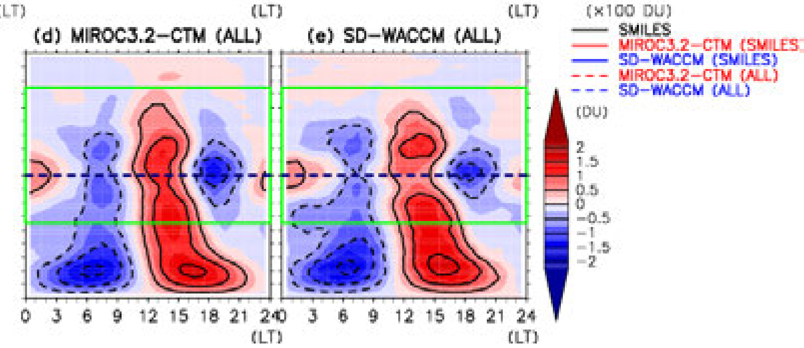
Mechanism of the diurnal variations



Diurnal variations in total ozone

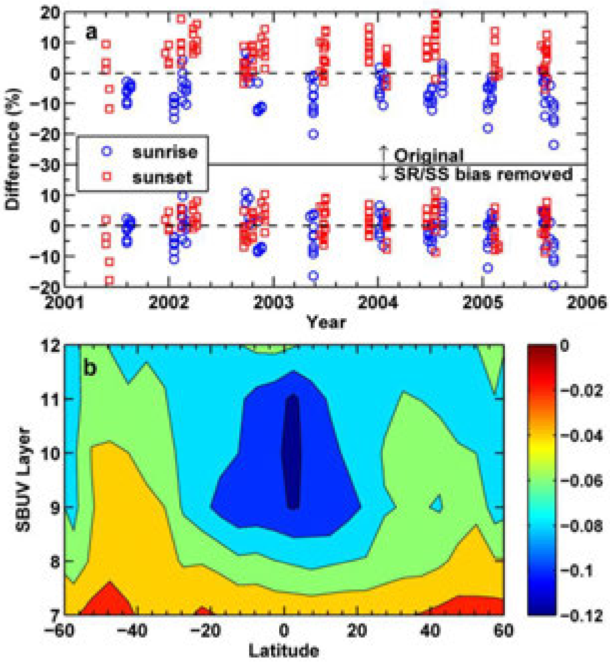


The peak-to-peak difference in total column ozone may be up to 1% over the course of a day



- A bias in the SAGE sunrise and sunset profiles [McLinden et al., 2009]
- Orbital drift of SBUV onboard NOAA satellites [Wang et al., 2012]
- TOMS and OMI measurement local times are 1130 LT and 1330 LT

SAGE sunrise & sunset bias

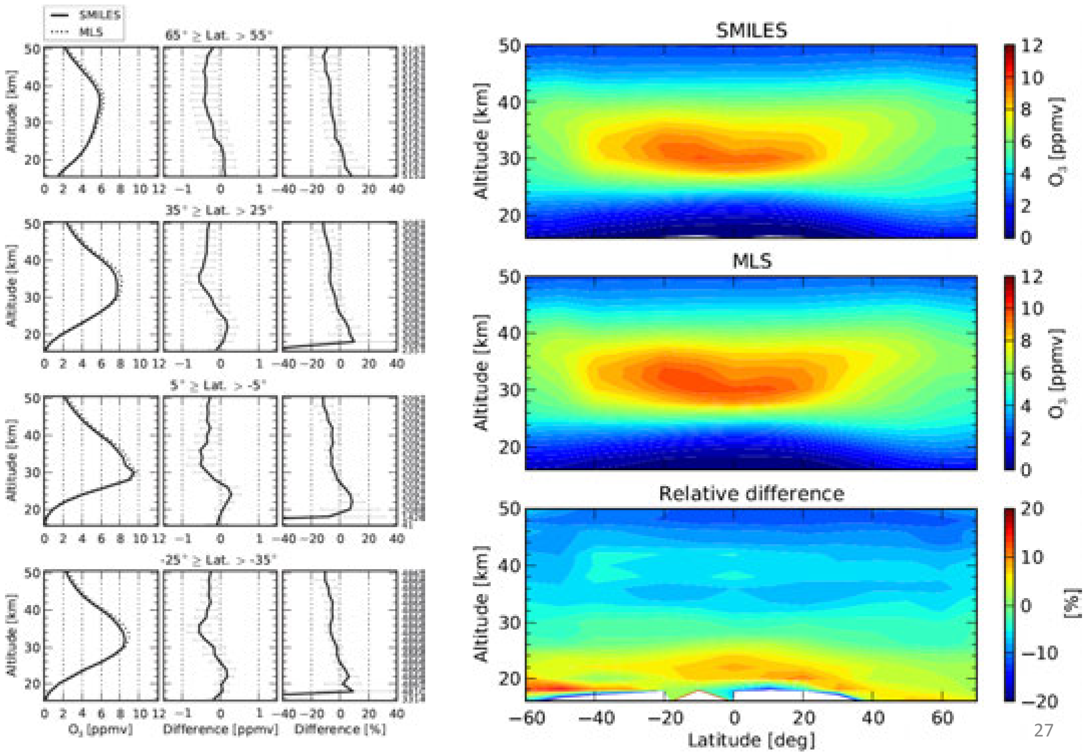


(upper) Relative difference between SAGEII and NOAA16/SBUV2 ozone partial columns in layer 10 at 0-5N before and after the sunrise/ sunset (SR/SS) bias was removed.
(lower) SR/SS bias
(McLinden et al., 2009, ACP)

Validation of ozone data from the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES)

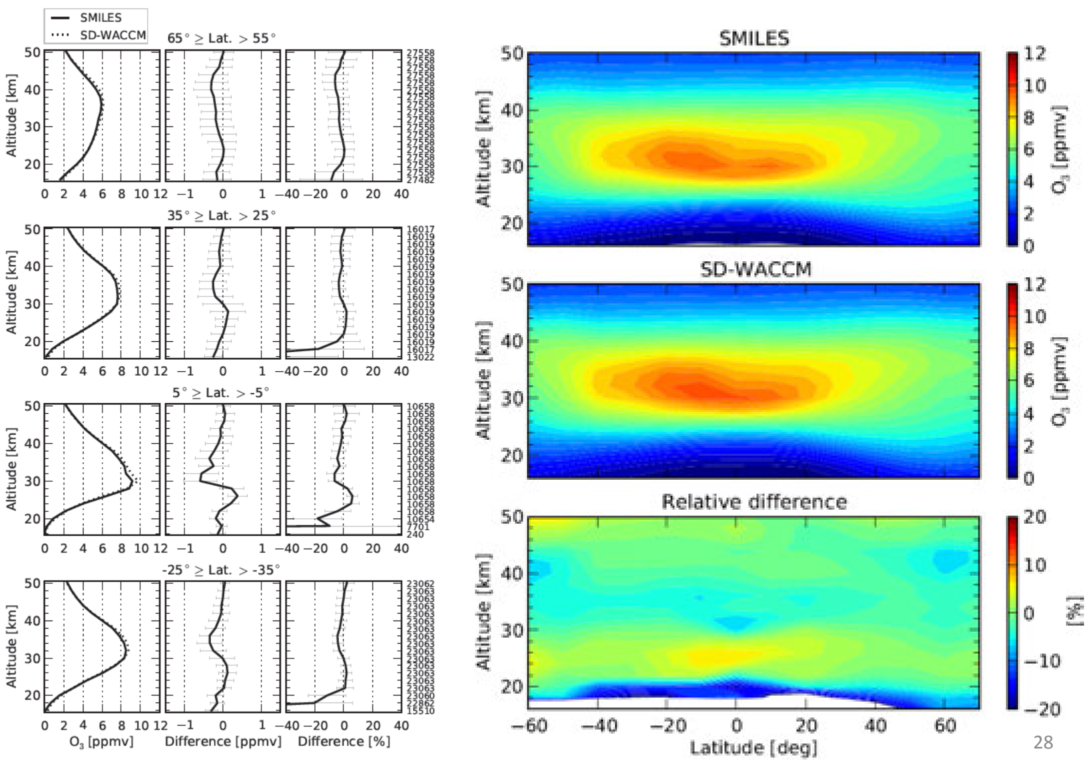
by Imai et al.
(under revision, JGR)

SMILES and MLS comparisons



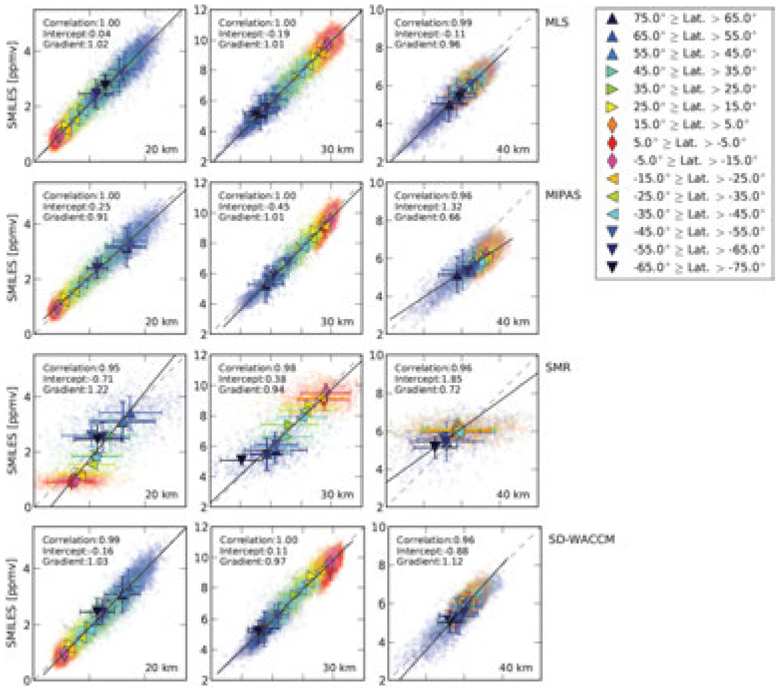
27

SMILES and SD-WACCM comparisons



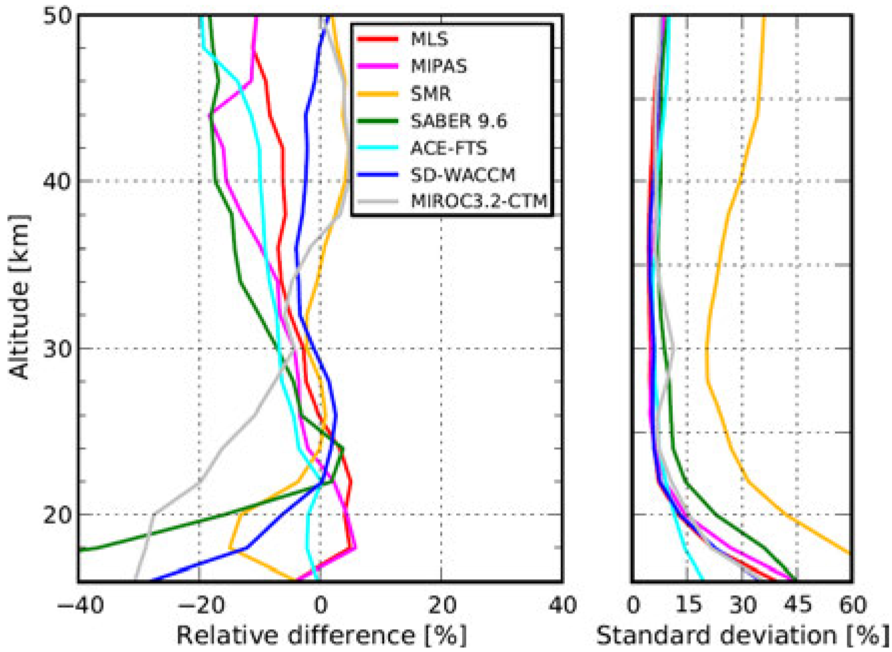
28

Variability of SMILES ozone data



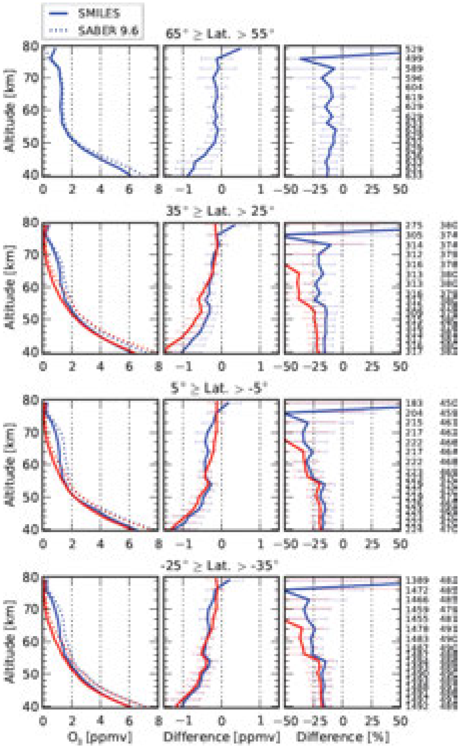
29

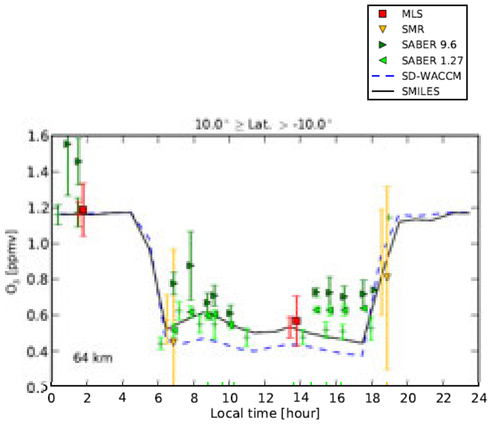
Comparisons of ozone with other data



30

Comparisons in the mesosphere



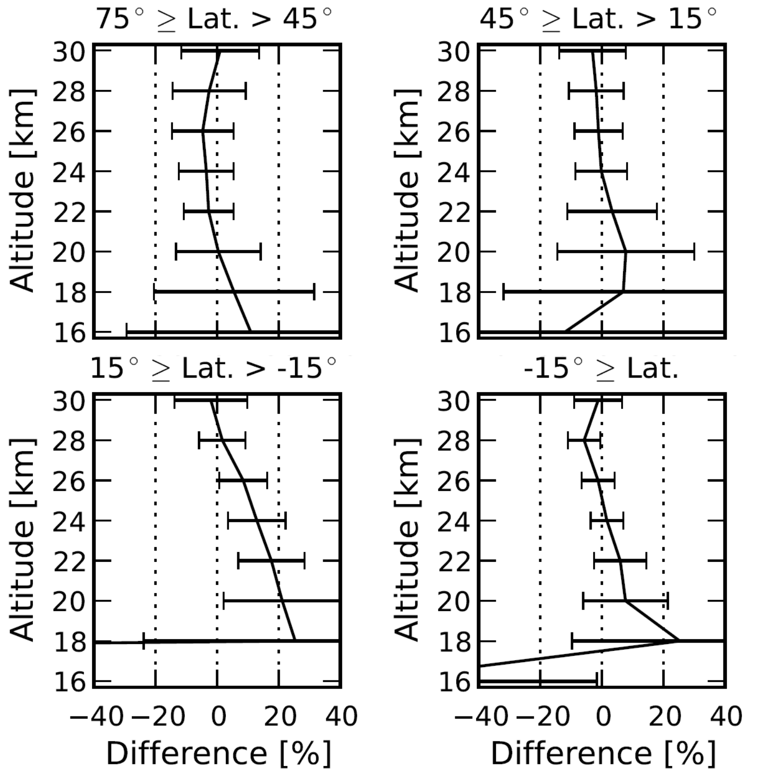


In details for the mesosphere, see Smith et al., and for the diurnal variations, see Sakazaki et al.

Comparison of ozone profiles between Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) and worldwide ozonesonde measurements

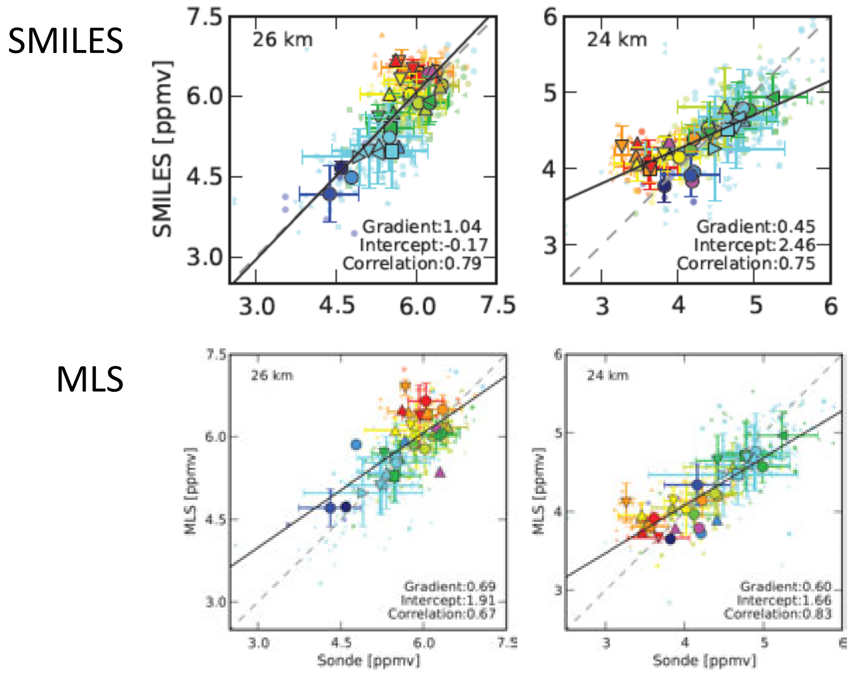
by Imai et al.
(submitted to JGR)

Comparisons with ozonesondes



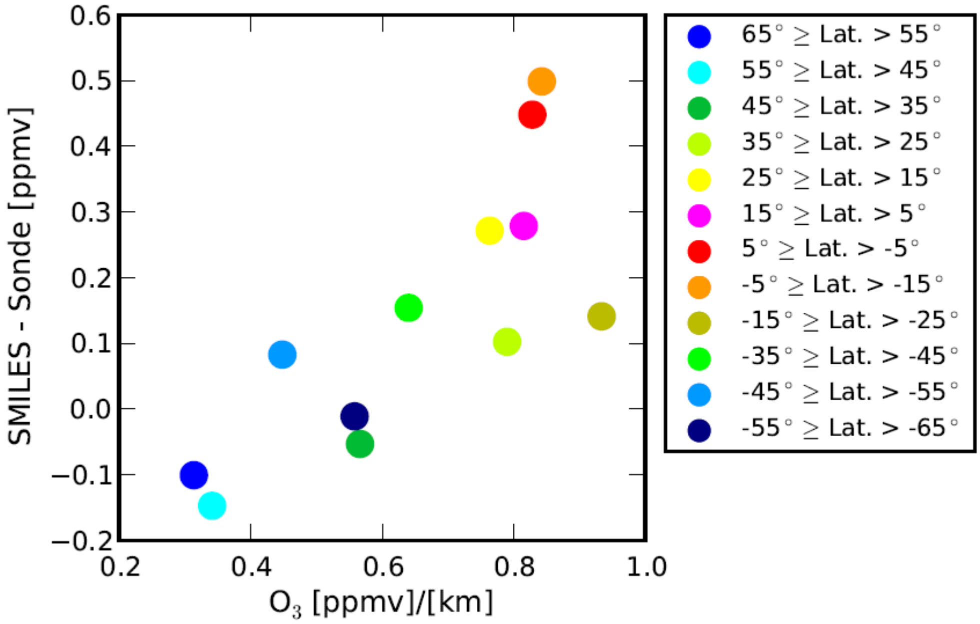
33

Latitudinal structure – SMILES & MLS

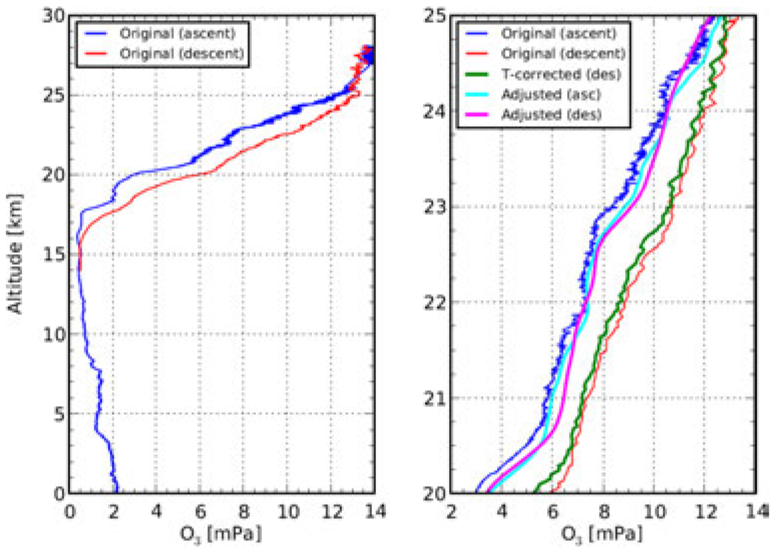


34

Relation between vertical gradient and differences (SMILES – ozonesonde)



Ozonesonde measurements with ascending and descending profiles



A time-lag correction proposed by Miloshevich et al. [2004] for humidity measurements of radiosondes

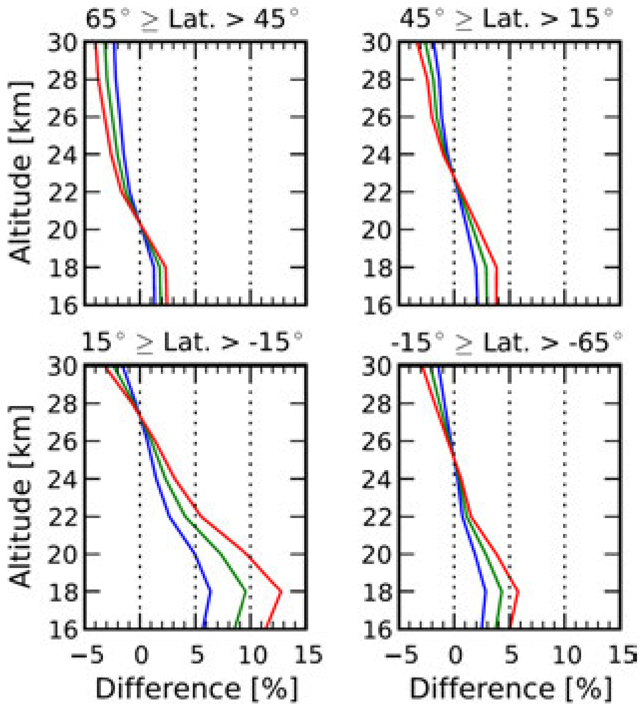
$$\frac{dX_m}{dt} = k(X_a - X_m)$$

$$X_m(t) = X_a - [X_a - X_m(t_0)]e^{-\Delta t/\tau}$$

The ozonesonde's response time is assumed to be within 20–30 s [e.g. Smit et al., 2007]), and our estimation showed response times around 28 s.

By applying this correction to the original profiles, we found a negative bias of the ozonesonde measurement more than 7% at 20 km in the equatorial latitude where the vertical gradient of ozone is steep.

Correction factors of the time-lag effect



Correction factors with response times of 20 s (blue), 30 s (green) and 40 s (red)

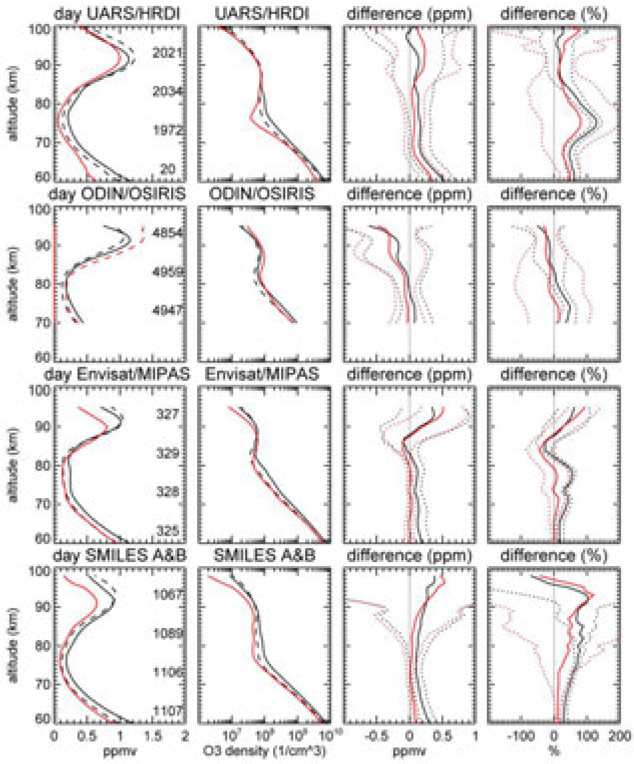
37

Satellite Observations of Ozone in the Upper Mesosphere

by Smith et al.
(under revision, JGR)

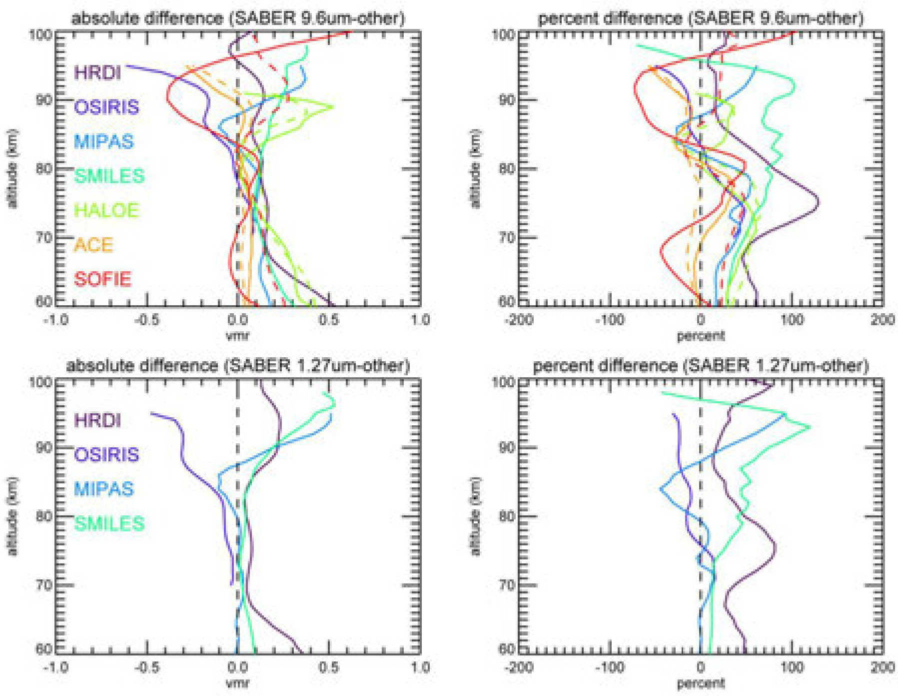
38

Profiles of daytime ozone



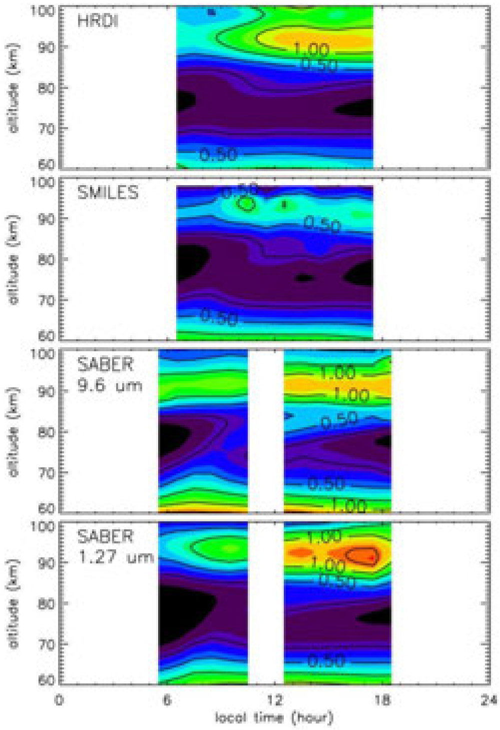
39

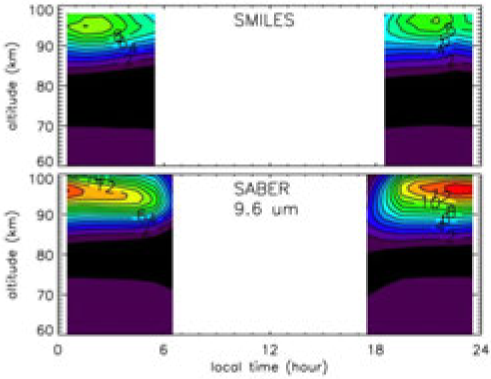
Comparisons with other satellite data



40

Diurnal variations of mesospheric ozone





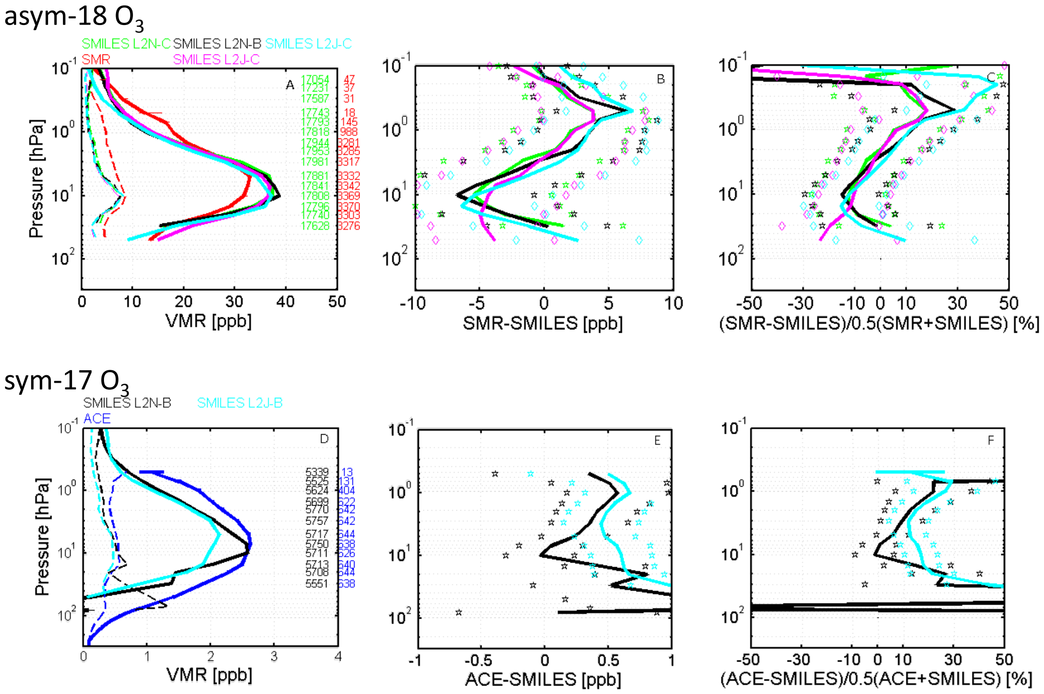
41

An intercomparison study of isotopic ozone profiles from the ACE, JEM-SMILES, and Odin-SMR instruments.

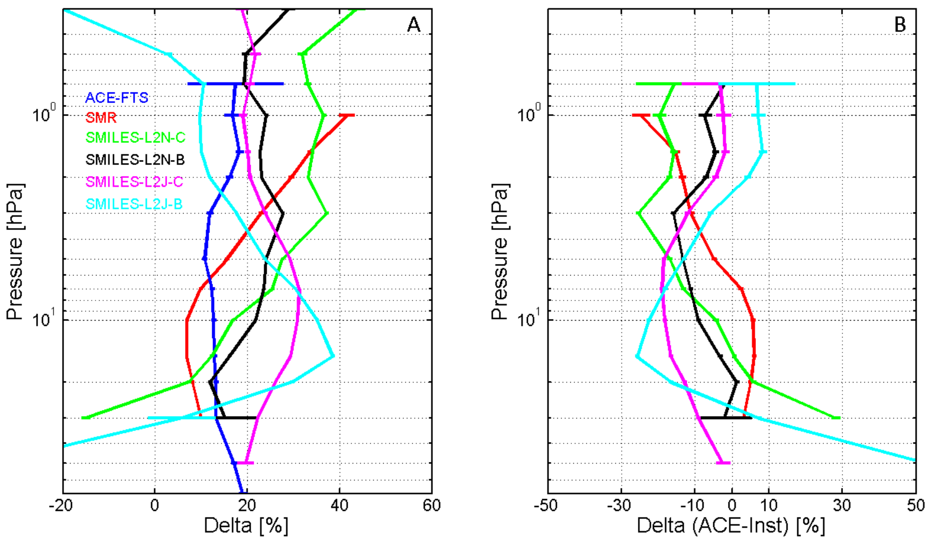
by Jones et al.
(to be submitted, JGR)

42

Comparisons for ACE and SMILES



Average asym-18 O_3 enrichment



Summary of results

				Species enrichment ± 1 sigma precision / 1 std (%)				
Platform	Reference	Altitude range (km)	Latitude coverage	Asym-18	Sym-18	Asym-17	Sym-17	$^{50}O_3$
FIRS-2	Johnson et al [2000]	25 - 35	30N - 35N, 68N	12.2 ± 1.0	6.1 ± 1.8	8.0 ± 5.2	1.6 ± 7.6	10.2 ± 0.9
ATMOS	Irion et al [1996]	25 - 40	80S - 80N	15.0 ± 6.0	10 ± 7.0			13.0 ± 5.0
Ground	Meier et al [1996]	Total column	79N	13.5 ± 4.0	11.9 ± 0.9			13.0 ± 2.7
Balloon	Haverd et al [2005]	25 - 35	35N, 65N, 68N	13.5 ± 2.7	7.7 ± 2.2			11.6 ± 2.0
Balloon	Kronkowsky et al [2001]	22 - 33	43N, 68N					7 - 11 (%)
Balloon	Mauersberger et al [2001]	22 - 34	32N, 34N, 43N, 68N					9.0 ± 0.4
Cryosampler/Lab	Mauersberger et al [1993]	25 - 35						11.8 ± 1.0
ACE		25 - 40	30N - 50N	12.3 ± 0.2/0.9	8.8 ± 0.2/0.4		9.4 ± 0.5/2.3	11.1 ± 0.2
SMILES L2N-C		25 - 40	30N - 50N	21.1 ± 0.3/11.1		17.9 ± 0.2/3.8		
SMILES L2N-B		25 - 40	30N - 50N	20.9 ± 0.1/5.8				
SMILES L2-C		25 - 40	30N - 50N	28.4 ± 0.1/2.9		23.3 ± 01./3.3		
SMILES L2-B		25 - 40	30N - 50N	29.3 ± 0.1/7.6				
Odin SMR		25 - 40	30N - 50N	11.7 ± 0.2/6.4	14.5 ± 0.4/0.3	14.5 ± 1.0/8.0*		12.6 ± 0.2

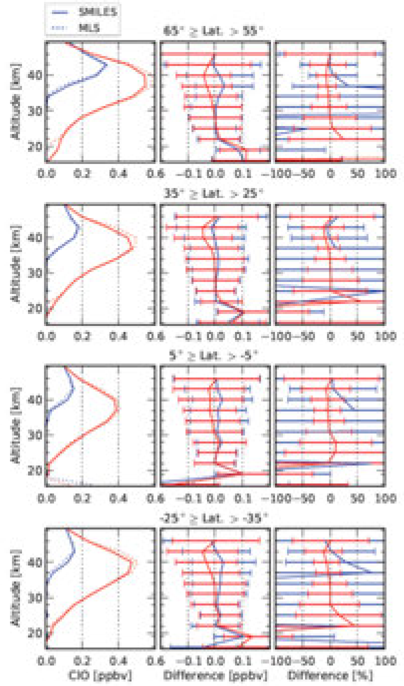
45

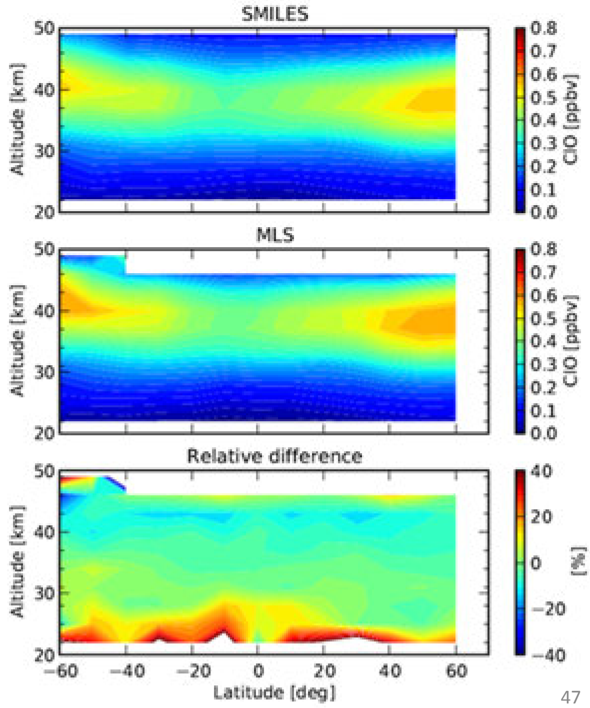
Validation of ClO data from the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES)

by Suzuki et al.
(to be submitted, JGR)

46

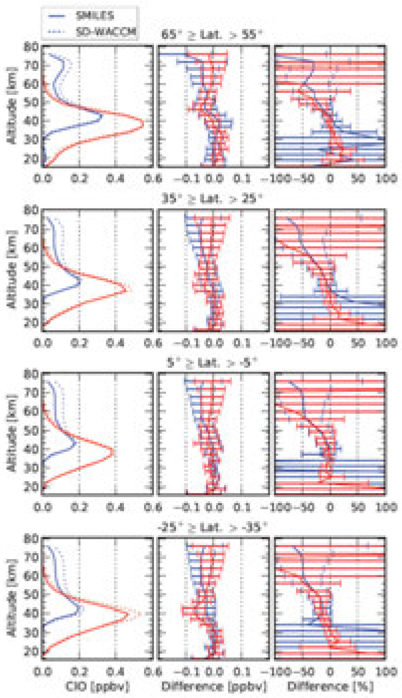
SMILES and MLS comparisons

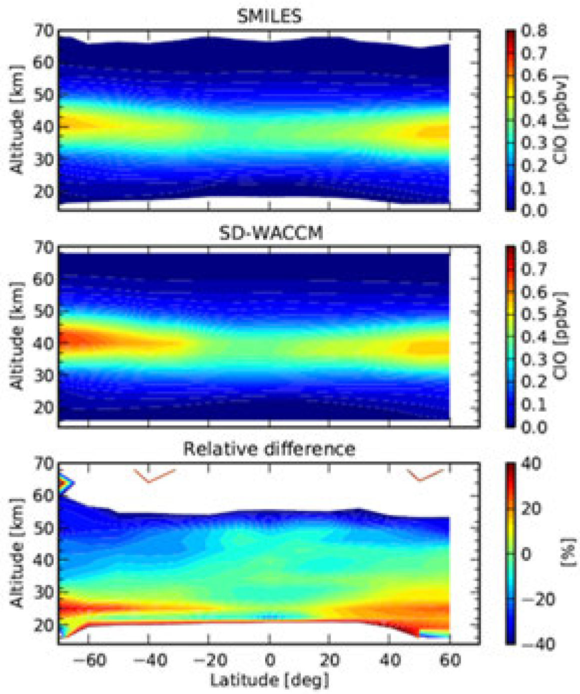




47

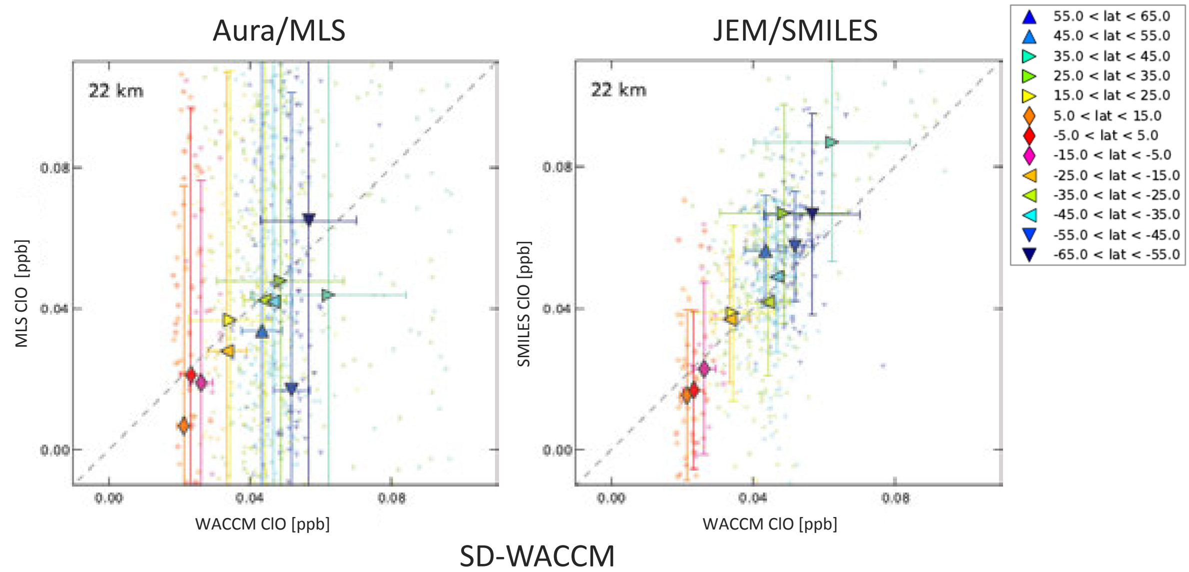
SMILES and SD-WACCM comparisons





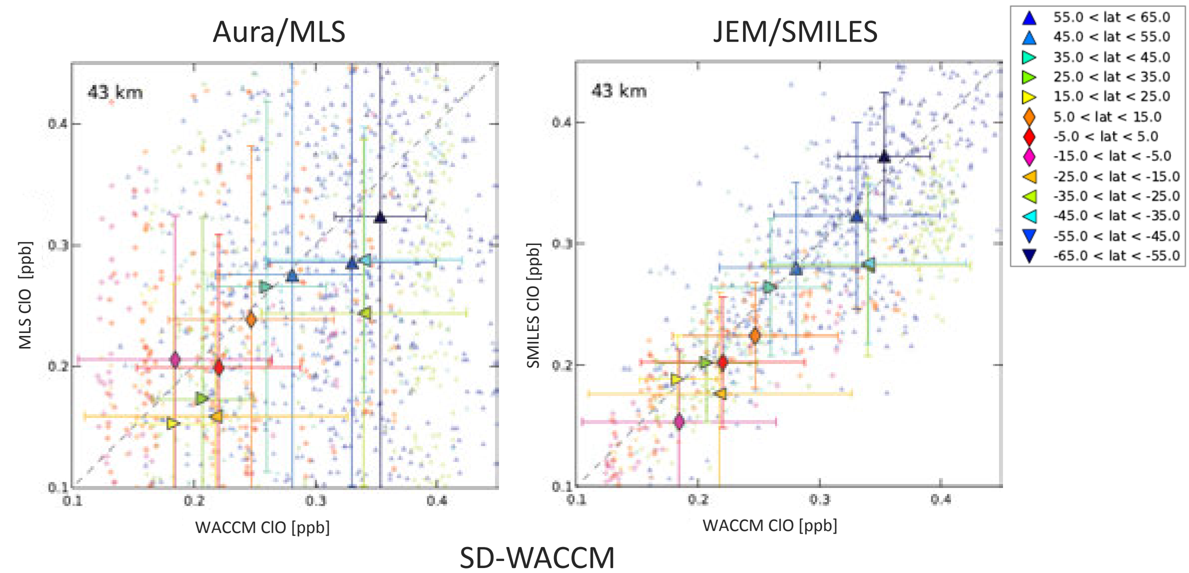
48

Comparison of SD-WACCM with MLS and SMILES - daytime ClO -



49

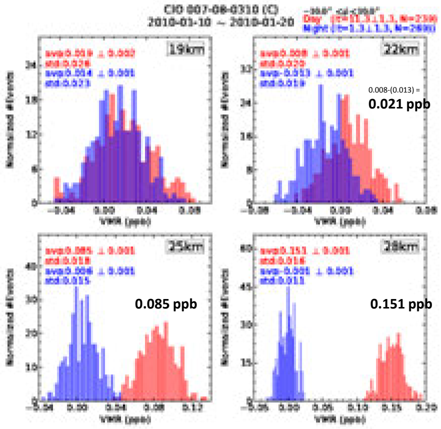
Comparison of SD-WACCM with MLS and SMILES - nighttime ClO -



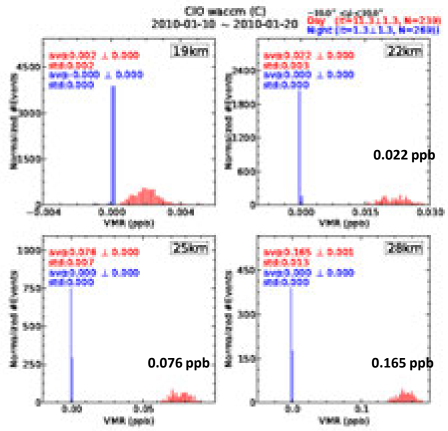
50

ClO in the Equatorial lower stratosphere

SMILES



SD-WACCM

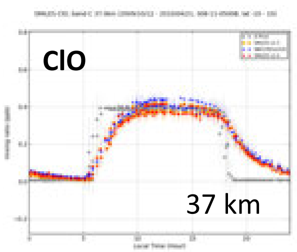


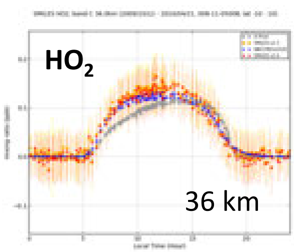
	SMILES			SD-WACCM		
	Day	Night	Day-Night	Day	Night	Day-Night
22 km	8±1	-13±1	21±2	22	0	22
25 km	85±1	6±1	79±2	76	0	76
28 km	151±1	-1±1	152±2	165±1	0	165±1

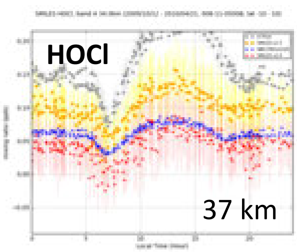
51

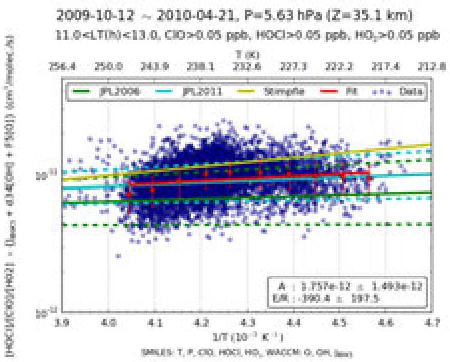
Diurnal variation of ClO, HO_2, and HOCl

Trial to verify the reaction rate of ClO +HO2 using SMILES data









$$ClO + HO_2 \xrightarrow{k_1} HOCl + O_2 \quad (1)$$
$$HOCl + OH \xrightarrow{k_2} H_2O + ClO \quad (2)$$
$$HOCl + h\nu \xrightarrow{j_3} OH + Cl \quad (3)$$

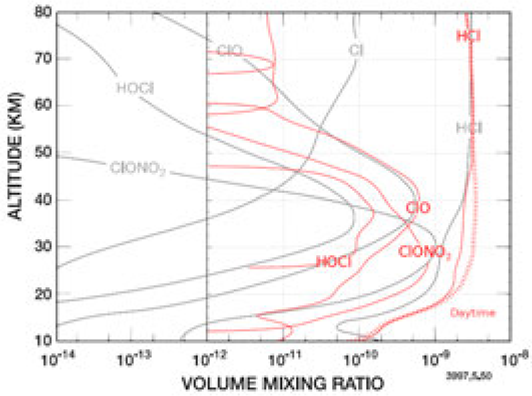
$$O + HOCl \rightarrow OH + ClO \quad (4)$$
$$OH + Cl_2 \rightarrow HOCl + Cl \quad (5)$$
$$OH + OClO \rightarrow HOCl + O_2 \quad (6)$$
$$OH + Cl_2O \rightarrow HOCl + ClO \quad (7)$$
$$OH + Cl_2O_2 \rightarrow HOCl + ClOO \quad (8)$$
$$OH + ClNO_2 \rightarrow HOCl + NO_2 \quad (9)$$
$$Cl + HOCl \rightarrow products \quad (10)$$

$$k_1 = \frac{[HOCl]}{[HO_2][ClO]}(j_3 + k_2[OH] + k_4[O])$$

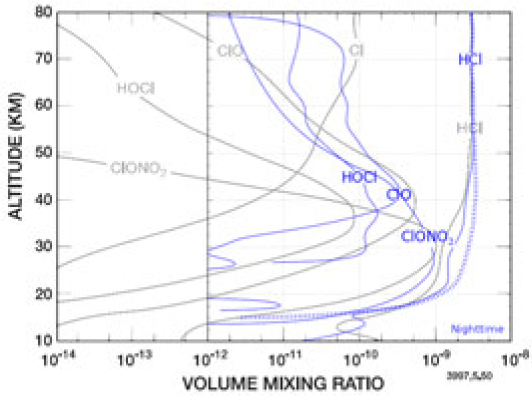
52

Chlorine partitioning in the middle atmosphere

Daytime profiles



Nighttime profiles



Brasseur and Solomon, pp.373

SMILES (+ MIPAS) can provide knowledge of chlorine partitioning in the background atmosphere based upon observations. The above figures are based on observations on October 12, 2009 at local solar noon (53N-60N) and midnight (23S-33S). ClONO2 is taken from MIPAS IMK, day 51N-57N, night 50N-54N.

53

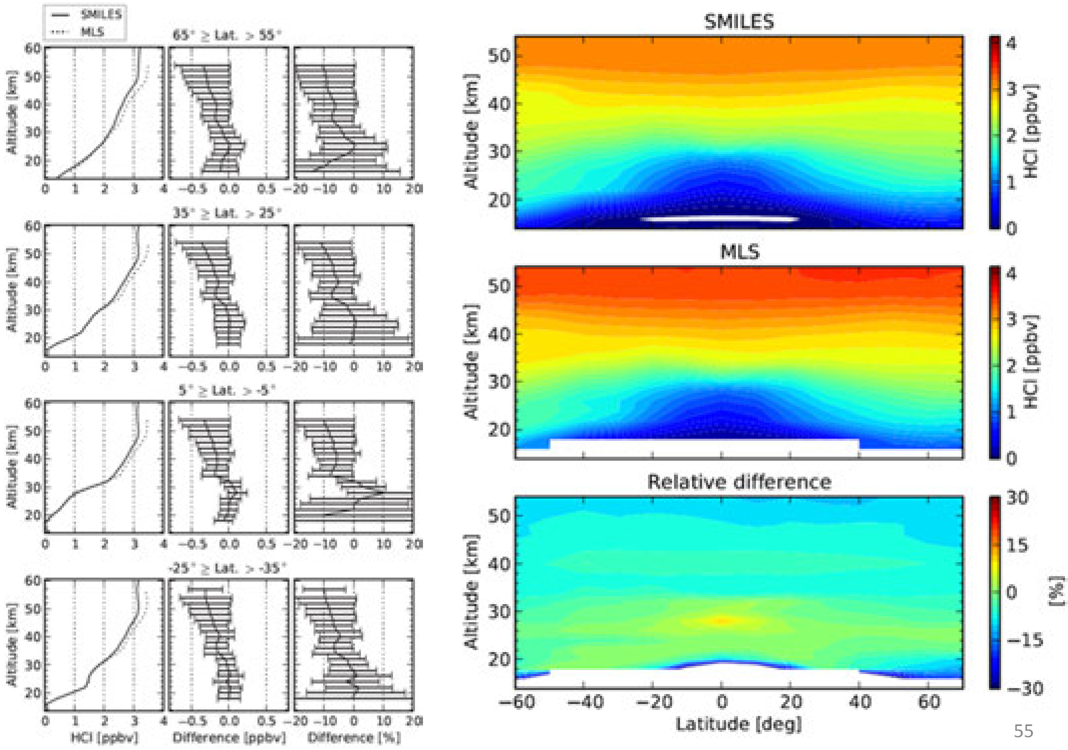
Validation of HCl data from the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES)

by Shiotani et al.

(in preparation)

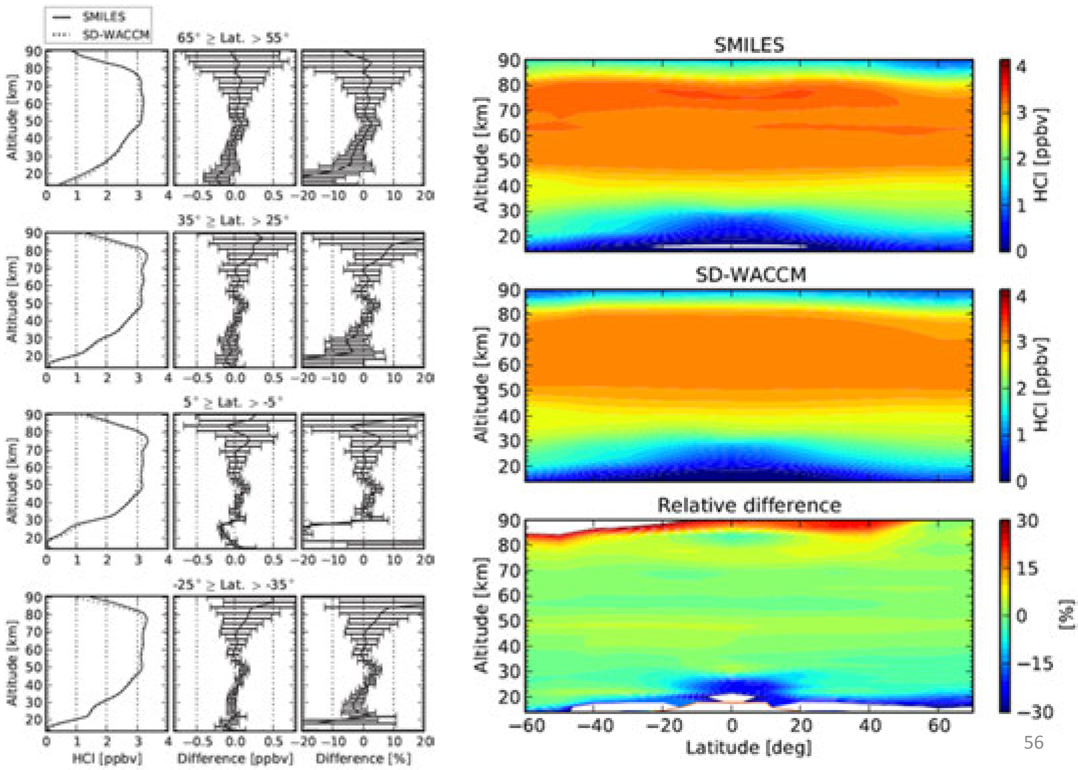
54

SMILES and MLS comparisons



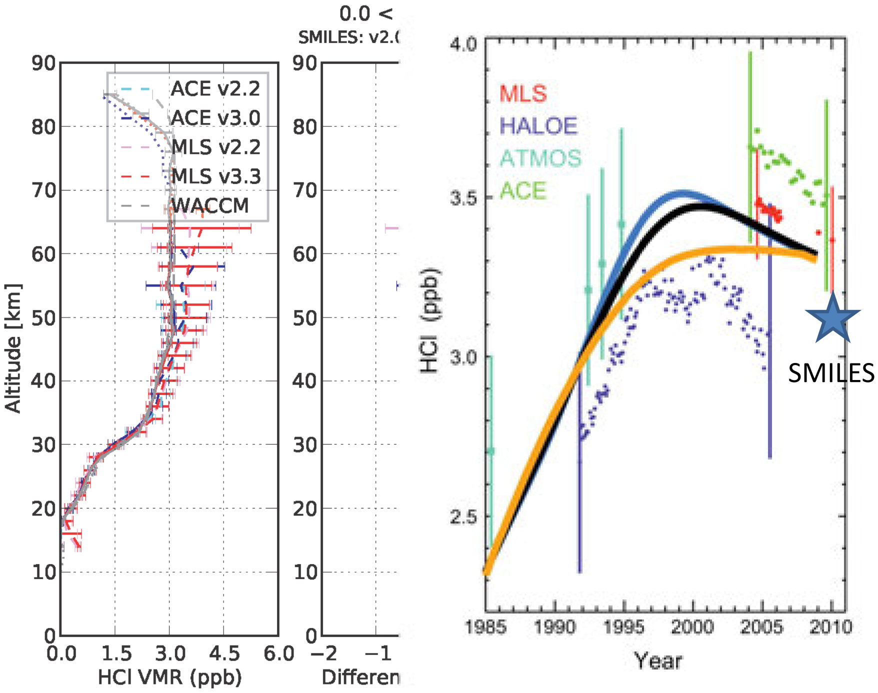
55

SMILES and SD-WACCM comparisons



56

HCl in the middle atmosphere



57

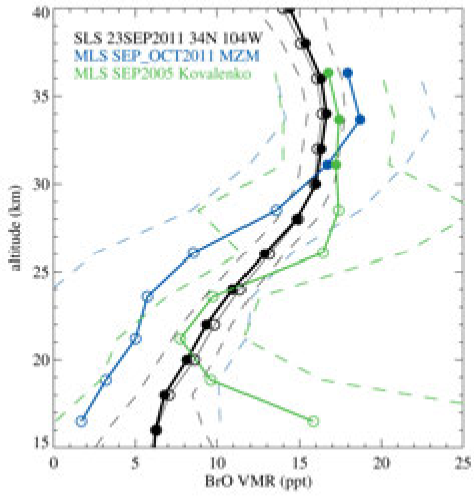
Stratospheric BrO abundance measured by a balloon-borne submillimeterwave radiometer

by Stachnik et al.
(accepted, ACP)

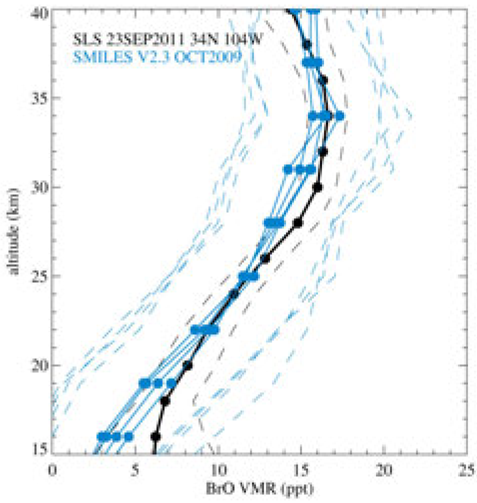
58

BrO observations

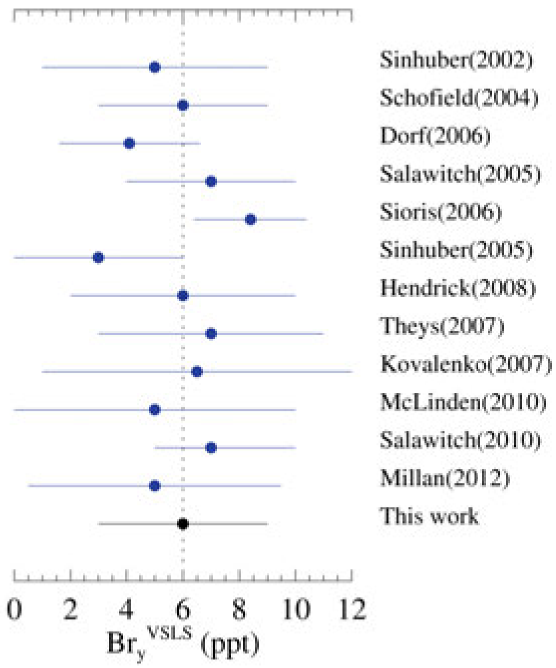
MLS



SMILES



estimations of the VSLS contribution to stratospheric inorganic bromine

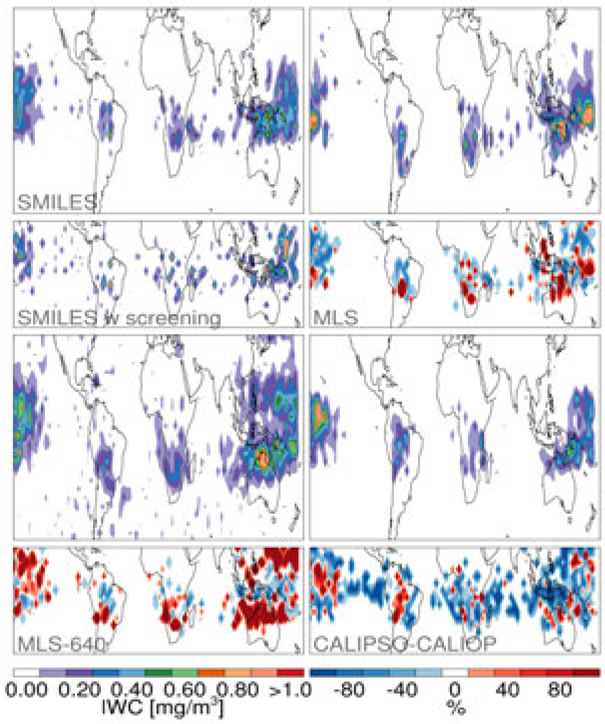


SMILES Ice Cloud products

by Millan et al.
(accepted, JGR)

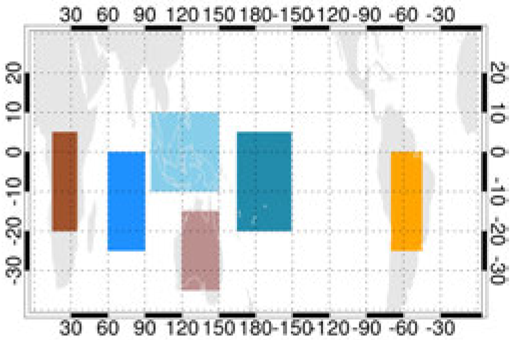
61

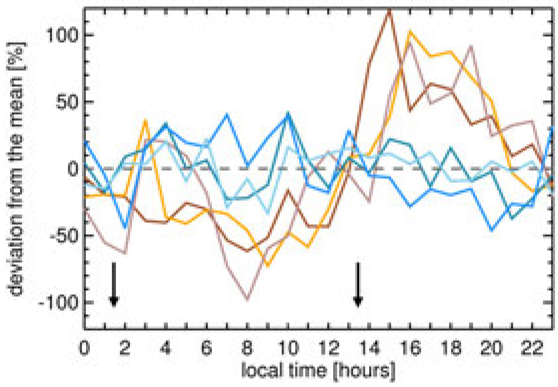
Ice water content for January 2010



62

Diurnal variation in pIWP (partial Ice Water Path)





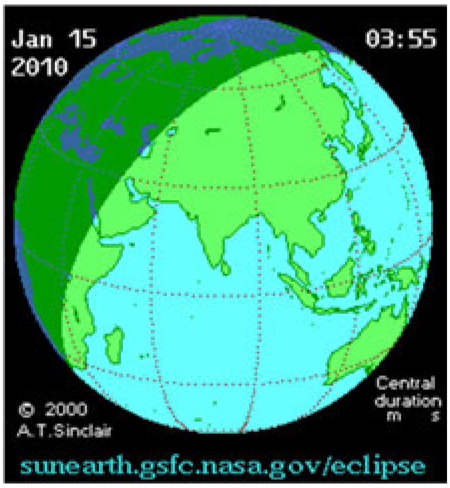
63

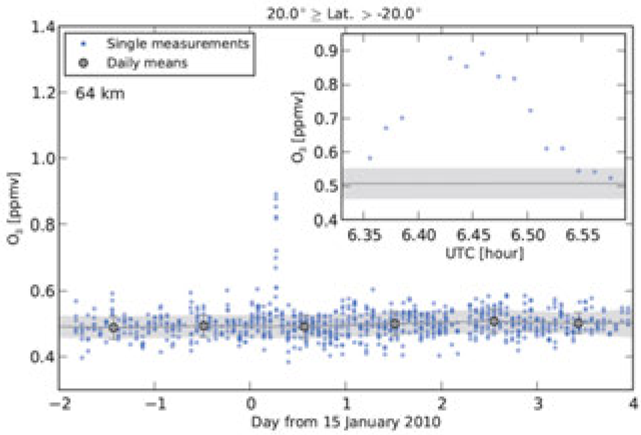
Atmospheric Response During Annular Solar Eclipse on 15 January 2010

by Imai et al.
(will be presented at AOGS 2013)

64

Solar eclipse on January 15, 2010

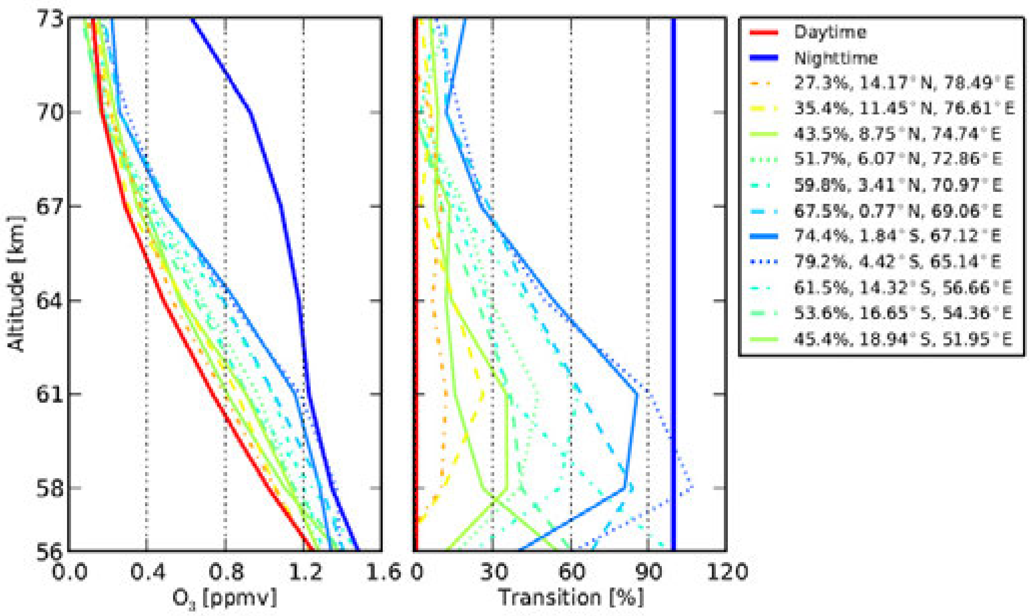




Night-time O_3 is ~1.2 ppmv at 64km

65

SMILES measurements for ozone



66

SUMMARY

- SMILES made high sensitivity measurements with lower noise than other instruments, and reasonable retrieval results are coming out.
- Diurnal variation of such as O_3, ClO and so on is one of the unique outcomes contributing to scientific issues in the middle atmosphere.
- We released the SMILES level 2 data to the science community in March 2012.

67