Updated trends of the stratospheric ozone vertical distribution in the 60S-60N latitude range based on the LOTUS regression model

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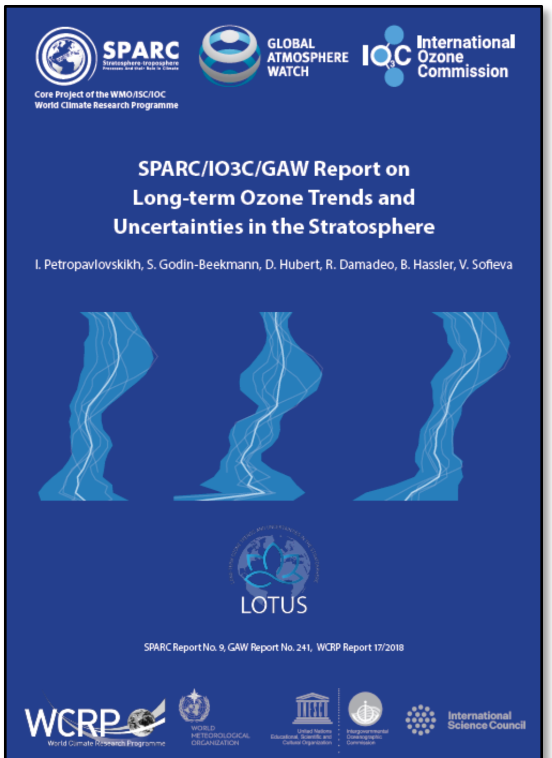
In Memoriam Will Ball

SPARC LOTUS Activity

Coordinators: I. Petropavlovskikh, S. Godin-Beekmann, D. Hubert, R. Damadeo, B. Hassler, V. Sofieva



SPARC/IO3C/GAW Report (2019)
https://www.sparc-climate.org/activities/ozone-trends

Objectives

Evaluate long-term ozone profile trends from satellite and ground-based time series

Comparison to CCMI ozone profile trends

Contribute to the WMO Ozone Assessments

1st phase (2016 – 2018)

- Selection of the LOTUS regression trend model
- Ozone trends from merged satellite data and combined trends error bars
- Comparison with ground-based data and CCMI derived trends
- Contribution to WMO Ozone Assessment 2018
- LOTUS 2019 report

LOTUS 2nd Phase

2nd phase (2019 – 2022)

- Seasonal trends (Szelag et al., 2020)
- Regional trends (Sofieva et al., 2021)
- Updated trends based on the LOTUS regression model
- Contribution to the WMO Ozone Assessment 2022

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Merged satellite ozone records

Data used in LOTUS19

Data set	Satellite instruments	Ozone representation	Latitude coverage and resolution	Altitude coverage and vertical sampling	Temporal coverage
SBUV MOD v8.6 (NASA) https://acd-ext.gsfc.nasa.gov/Data_services/merged/index.html	BUV, SBUV and SBUV-2 on Nimbus 4, 7 and NOAAs 11, 14, 16, 17, 18 ,19	Mixing ratio on a pressure grid	80S–80N, 5 deg	50–0.5 hPa, 15 layers (from ~6 to ~15 km)	01/1970 – 12/2016
SBUV COH v8.6 (NOAA) ftp://ftp.cpc.ncep.noaa.gov/SBUV_CDR	SBUV and SBUV-2 on Nimbus- 7 and NOAAs 9, 11, 16, 17, 18, 19		80S–80N, 5 deg	50–0.5 hPa, 15 layers (from ~6 to ~15 km)	01/1978 – 12/2016
GOZCARDS v2.20 https://gozcards.jpl.nasa.gov	SAGE I v5.9_rev, SAGE II v7, HALOE v19, Aura MLS v4.2		90S–90N, 10 deg	215–0.2 hPa, 6 or 12 levels per pressure decade (~3 km)	01/1979 – 12/2016
SWOOSH v2.6 https://data.noaa.gov/dataset/dataset/stratospheric-water-and-ozone-satellite-homogenized-swoosh-data-set	SAGE II v7, HALOE v19, UARS MLS v5, SAGE III v4, Aura MLS v4.2		90S–90N, 10 deg (also 5 and 2.5 deg)	316–1 hPa, 6 or 12 levels per pressure decade (~3 km)	01/1984 – 12/2016
SAGE-OSIRIS-OMPS LOTUS ftp	SAGE II v7, OSIRIS v5.10, OMPS-LP USask 2D v1.0.2	Number density (anomaly) on an altitude grid	60S–60N, 10 deg	10–50 km, 1 level per km	10/1984 – 12/2016
SAGE-CCI-OMPS http://www.esa-ozone-cci.org/?q=node/167	SAGE II v7 , OSIRIS v5.10, GOMOS ALGOM2s v1, MIPAS IMK/IAAv7, SCIAMACHY UB v3.5, ACE-FTS v3.5/3.6, OMPS-LP USask2D v1.0.2		90S–90N, 10 deg	10–50 km, 1 level per km	10/1984 – 07/2016
SAGE-MIPAS-OMPS v2 https://www.imk-asf.kit.edu/english/304_2857.php	SAGE II v7, MIPAS IMK/IAA v7, OMPS-LP NASA v2.5, ACE-FTS v3.5/3.6		60S–60N, 10 deg	6–60 km, 1 level per km	10/1984 – 12/2016

In LOTUS22

SAGE-MIPAS-OMPS replaced by SAGE-SCIAMACHY-OMPS

All data sets extended to 2020

New version of SBUV MOD and SBUV COH

Ground-based ozone records

Station		Latitude/Longitude	Ozone profile records	Record length
Alpine	Hohenpeissenberg	47.8°N/11.0°E	Ozonesonde	1966-2020
			Lidar	1987-2020
	Payerne	46.8°N/6.9°E	Ozonesonde	1968-2020
			Microwave	2000-2020
	Zugspitze	47.40N/11.0°E	FTIR	1995-2020
	Arosa	46.7°N/9.7°E	Umkehr	1956-2020
	Jungfraujoch	46.5°N/7.9°E	FTIR	1995-2020
	OHP	43.9°N/5.7°E	Umkehr	1984-2020
			Lidar	1985-2020
			Ozonesonde	1991-2020
Mauna Loa		19.5N°/155.6°W	Umkehr	1984-2020
			Lidar	1993-2020
			Microwave	1995-2020
Hilo		19.7°N/155.1°W	Ozonesonde	1982-2020
Lauder		45°S/169.7°E	Umkehr	1987-2020
			Lidar	1994-2020
			Ozonesonde	1986-2020
			Microwave	1992-2016
			FTIR	2001-2020

Homogenized sondes in most stations

New version of Umkehr data (Petropavlovskikh et al., 2021)

The LOTUS regression model

Maintained by University of Saskatchewan, freely available at https://arg.usask.ca/docs/LOTUS_regression/index.html

Main proxies: QBO, ENSO, sAOD, F10.7cm SC, independent linear trends before 1997 and after 2000

Updated used for LOTUS (v0.8.0) version

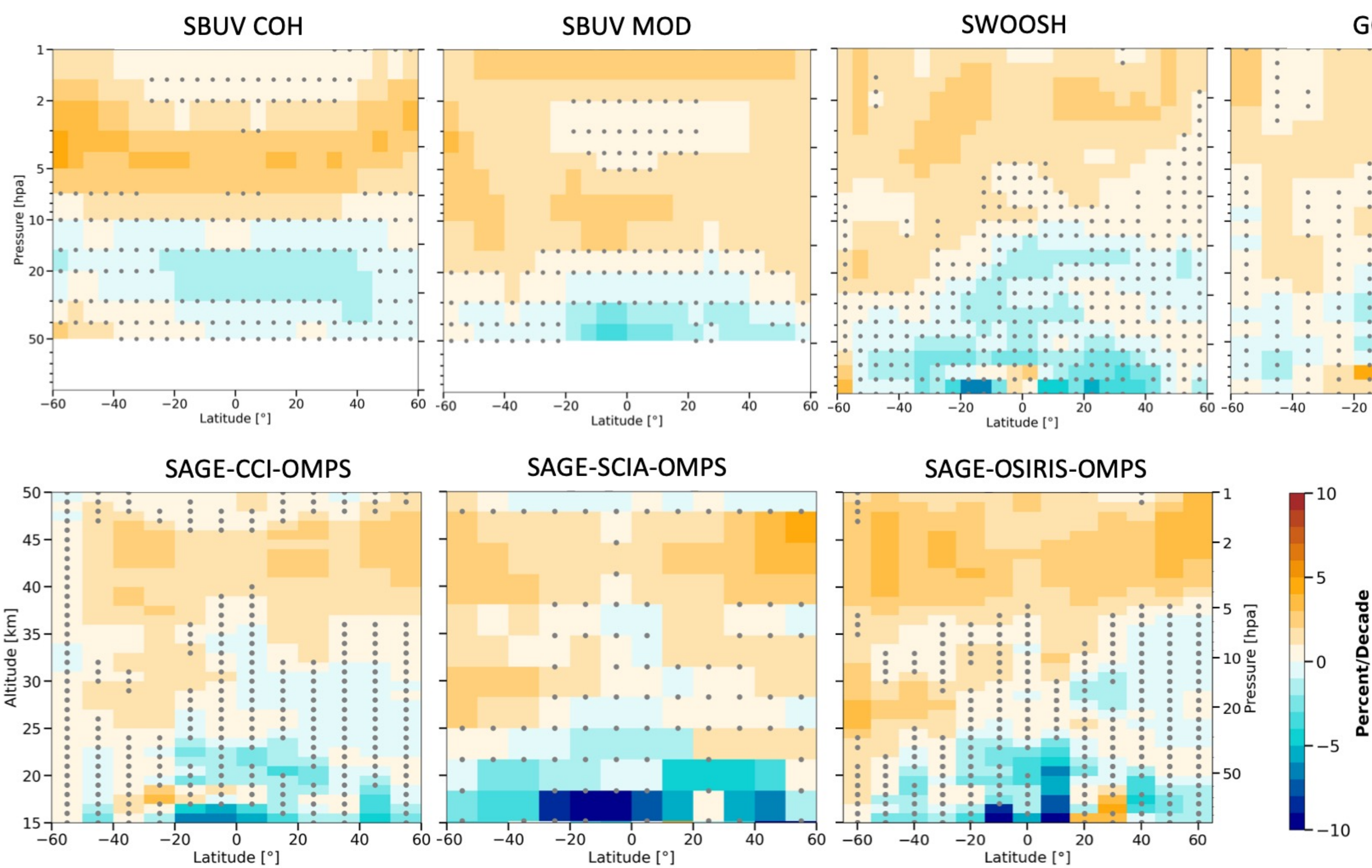
$$y(t) = A.\mathrm{QBO}_1(t) + B.QBO_2(t) + C.ENSO(t) + D.sAOD(t) + E.Solar(t) + F.Linear_{pre}(t) + G.Linear_{post}(t) + H.C_1(t) + I.C_2(t) + J.C_3(t) + \varepsilon(t)$$

- Fitted coefficient : seasonal dependence added

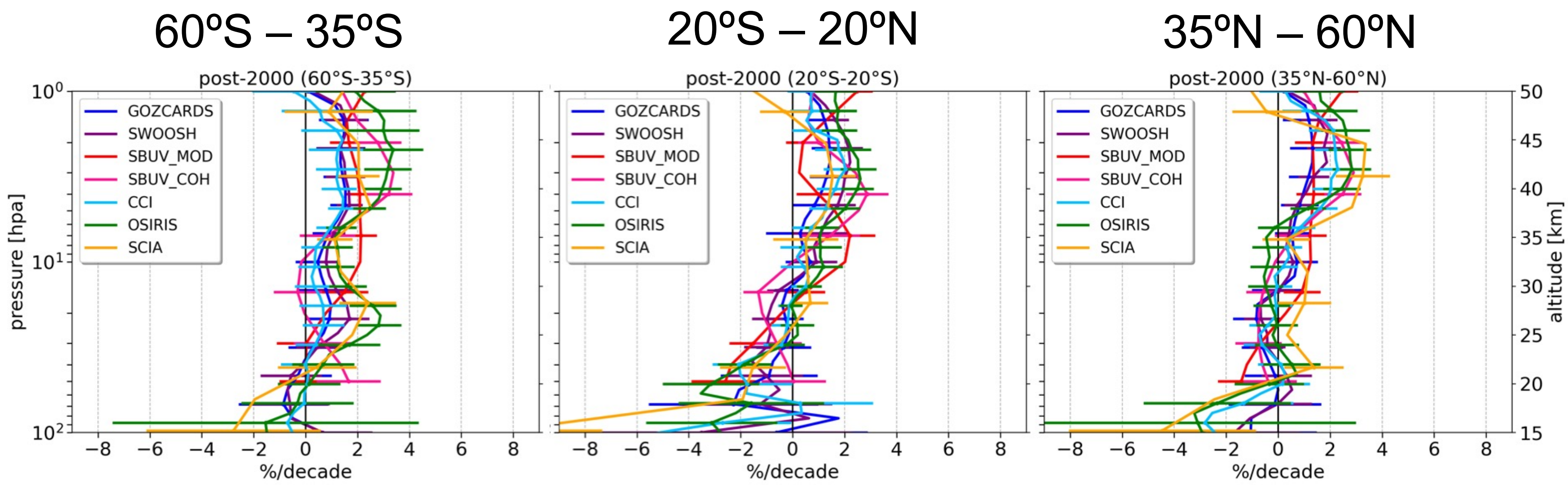
$$\beta_k(z,t) = \beta_{k0}(z) + \sum_{i=1}^{2} \beta_{k1i}(z) sin\left(\frac{2\pi it}{12}\right) + \sum_{i=1}^{2} \beta_{k2i}(z)\, cos\left(\frac{2\pi it}{12}\right)$$

- sAOD : GISS replaced by by GloSSAC v2

Merged satellite trends



Merged satellite ozone profile trends

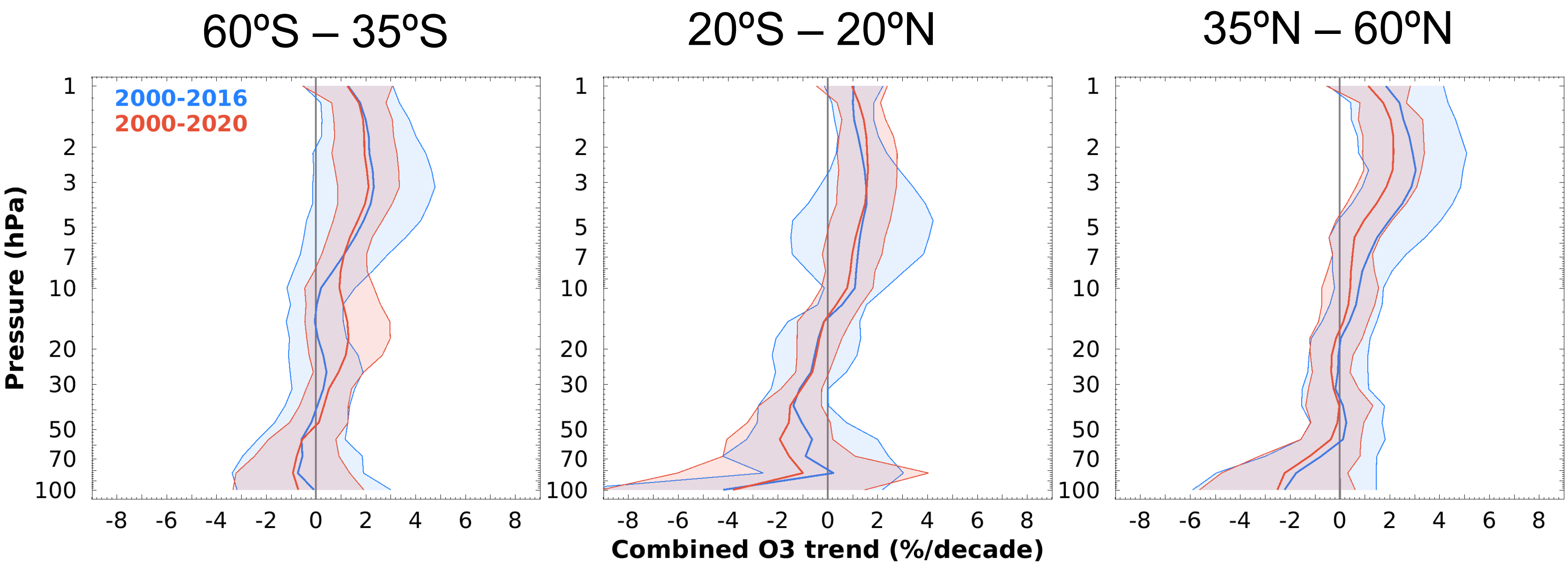


Significant positive trends in US for all records except SBUV MOD in the Tropics

Middle stratopshere: some positive trends in SH midlatitudes (SAGE-OSIRIS-OMPS, SWOOSH, SAGE-SCIAMACHY-OMPS)

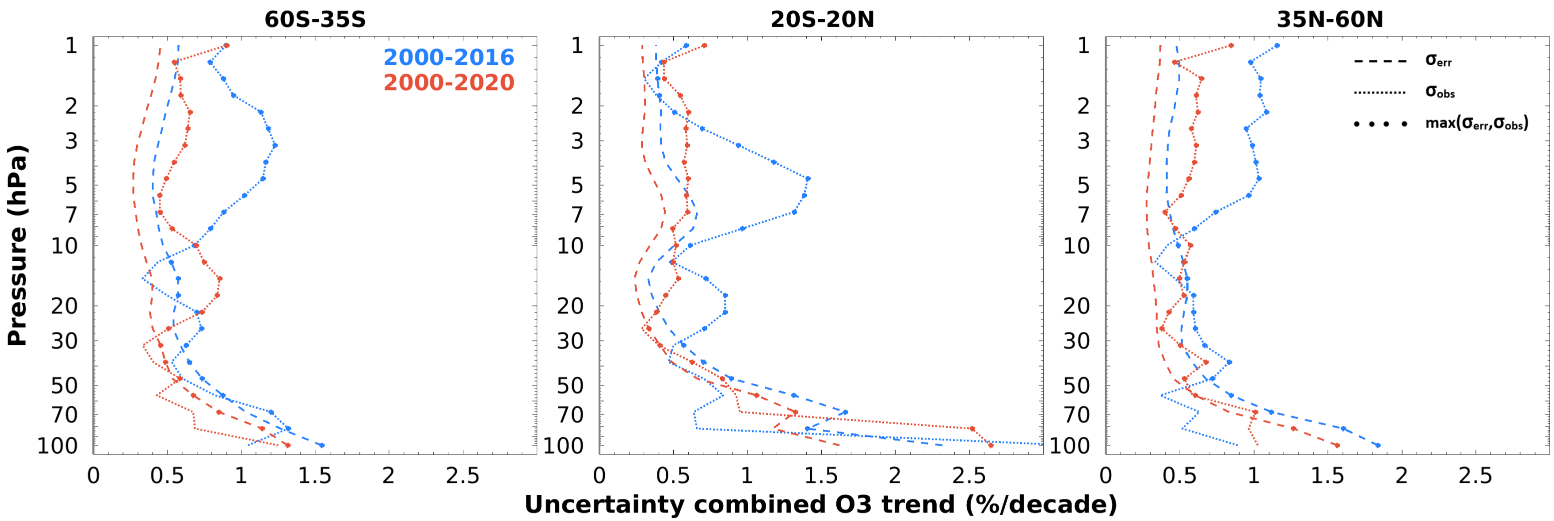
Lower stratosphere: non significant trends in the Tropics and below 20 km in NH

Combined merged satellite trends



- Generally smaller error bars in LOTUS22 compared to LOTUS19
- Positive trends in the upper stratosphere in the 3 broad latitude bands
- Similar trends in the middle stratosphere except in SH
- Negative trends in the tropics in the lower stratosphere mostly non significant

Improved uncertainties in LOTUS22



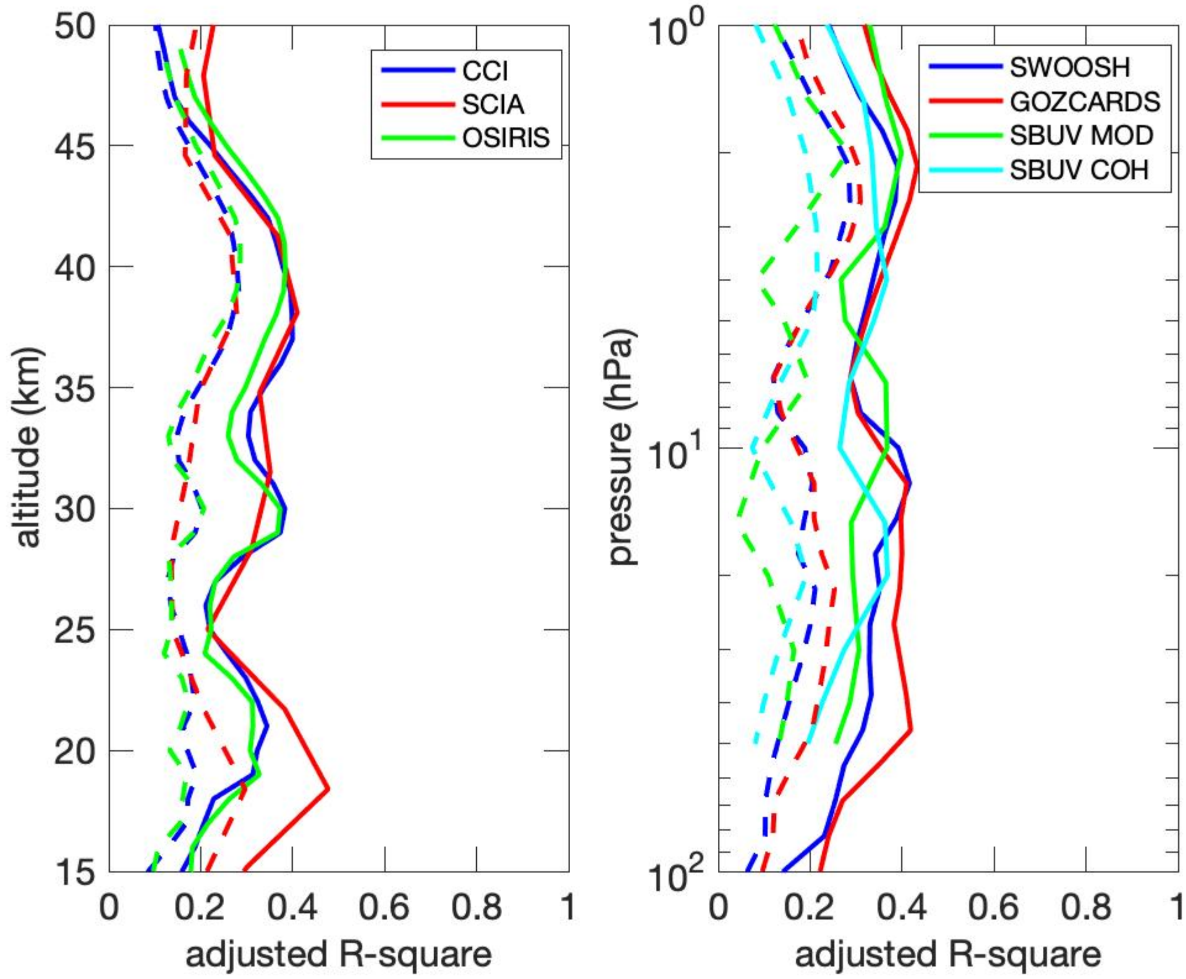
$$\sigma_{mean}^2 = max\left(\underbrace{\frac{1}{N^2}\sum_{i,j} C_{i,j}\,\sigma_i\sigma_j}_{\sigma_{err}}\ ,\ \underbrace{\frac{1}{n_{eff}}\sum_i \frac{(x_i-\bar{x})^2}{N-1}}_{\sigma_{obs}}\right)$$

$$n_{eff} = \frac{N^2}{\sum_{i,j=1}^{N} C_{i,j}}$$

n_{eff} = 1.39 for 7 records compared to 1.34 for 6 records in LOTUS19

C_{ij}	SBUV MOD	SBUV COH	GOZCARDS	SWOOSH	SAGE-OSIRIS-OMPS	SAGE-CCI-OMPS	SAGE-SCIA-OMPS
SBUV MOD	1.00	0.90	0.60	0.60	0.60	0.60	0.60
SBUV COH	0.90	1.00	0.60	0.60	0.60	0.60	0.60
GOZCARDS	0.60	0.60	1.00	0.95	0.60	0.65	0.60
SWOOSH	0.60	0.60	0.95	1.00	0.65	0.70	0.65
SAGE-OSIRIS-OMPS	0.60	0.60	0.60	0.65	1.00	0.82	0.80
SAGE-CCI-OMPS	0.60	0.60	0.65	0.70	0.82	1.00	0.80
SAGE-SCIA-OMPS	0.60	0.60	0.60	0.65	0.80	0.80	1.00

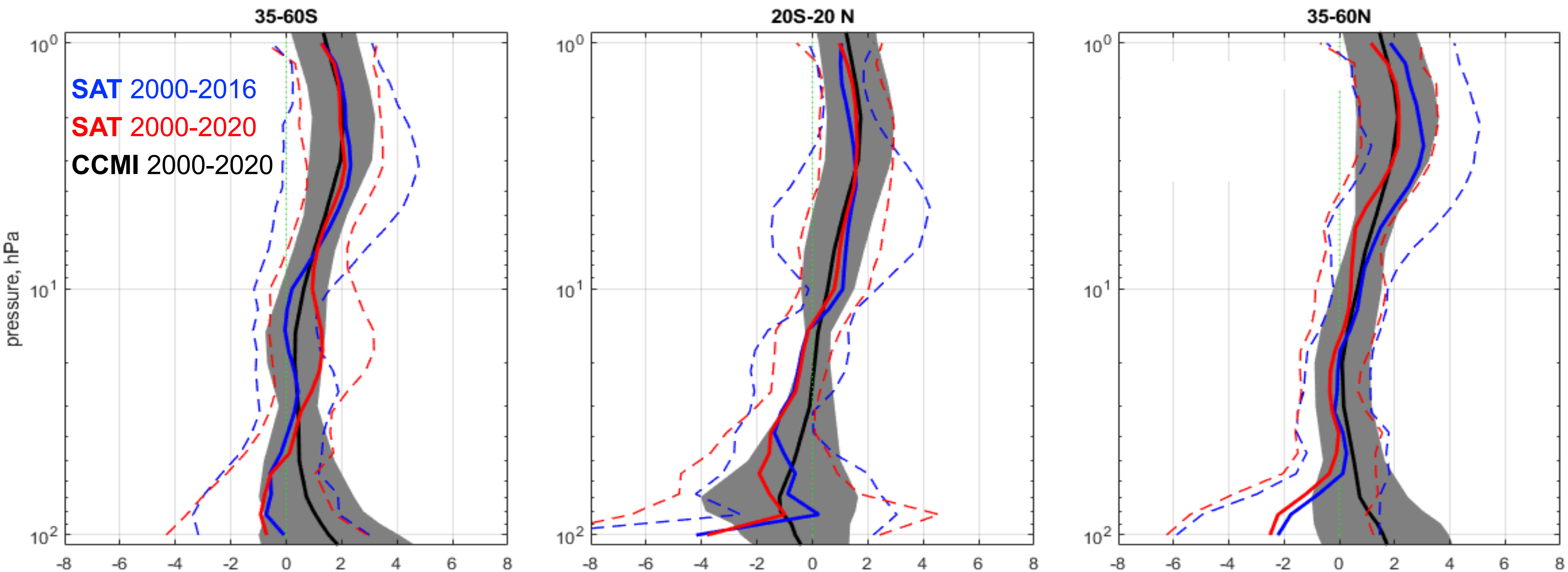
Seasonal variation of fitted coefficients



Solid lines: Regression with SV of fitted coefficients

Dashed lines: Regression without SV of fitted coefficients

Comparison with CCMI trends

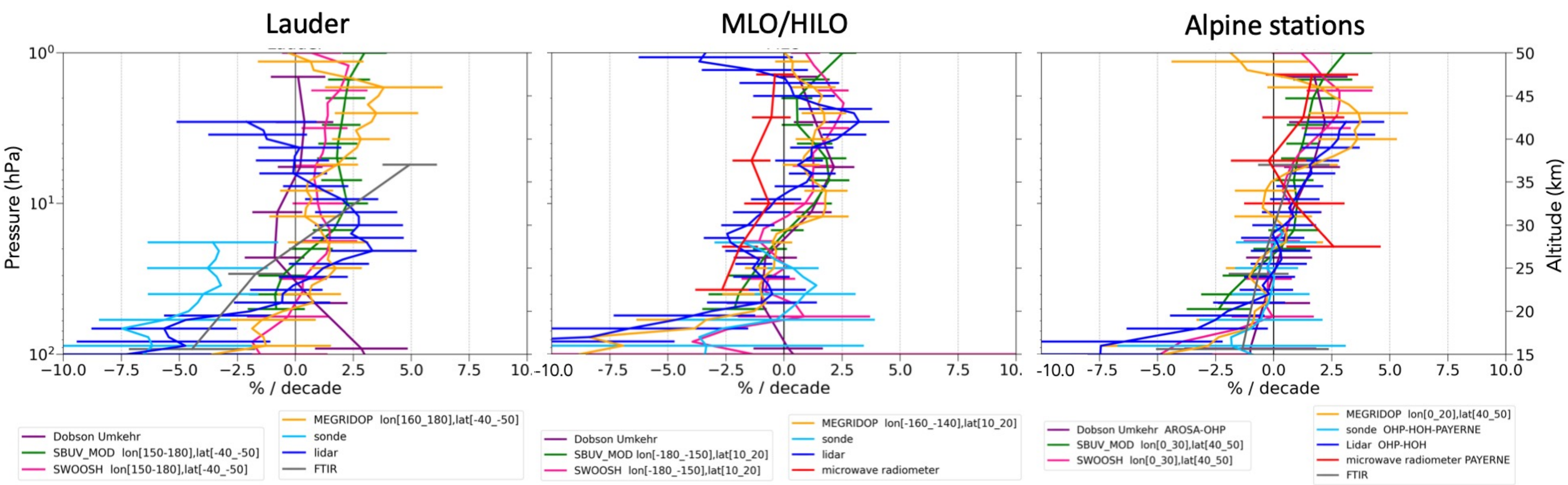


Multi-model mean and 2σ from CCMI-1 REF-2 simulations

- Good agreement with CCMI trends in middle and upper stratosphere
- Larger CCMI trends in SH and NH lower stratosphere at midlatitudes but these differences are not significant

Comparison with ground-based trends

Satellites (longitudinally resolved): MEGRIDOP, SWOOSH & SBUV MOD
GB: O3 sondes, lidar, MWR, FTIR, Umkehr



MWR
Lidar
Sondes
Umkehr
FTIR

MEGRIDOP
SBUV MOD
SWOOSH

Alpine stations:
Lidar: Hohenpeissenberg – OHP
Sondes: Hohenpeissenbeg – OHP – Payerne
Umkehr: Arosa – OHP
MWR: Payerne
FTIR: Jungfraujoch – Zugspitze

Conclusions

- Upper stratosphere: ozone recovery confirmed for all latitude bands
- Middle stratosphere: non significant ozone increase in SH, non significant ozone decrease in tropics
- Lower & lowermost stratosphere: non significant negative trends in tropics and NH
- Good agreement with CCMI trends except in LS but large uncertainties
- Reasonable agreement between satellite & ground-based trends at selected NDACC stations
- Ozone trends in the lower stratosphere need to be better constrained by e.g. using alternative coordinates and/or additional proxies
- Differences in ground-based ozone trends at NDACC stations (Lauder) need more detailed studies

Thank you!