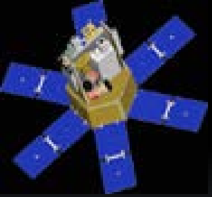

Vertical Profile of the Solar Cycle Signal in Middle-atmospheric OH and the Implications on Ozone

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Background

• During the 11-year solar cycle, the total solar irradiance (TSI) varies by only ~0.1%. However, the relative changes in UV is much larger.

• OH, produced through photolysis in UV, is expected to be affected by the solar cycle (SC).

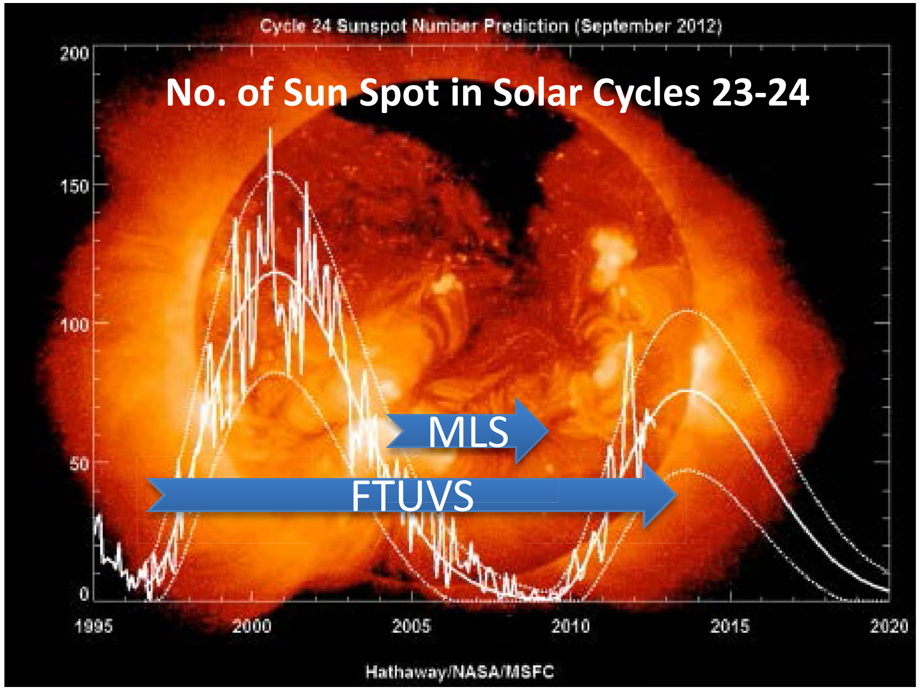
$$H_2O + h\nu \rightarrow OH + H \quad (Mesosphere)$$

$$O_3 + h\nu \rightarrow O(^1D) + O_2 \quad (Stratosphere)$$

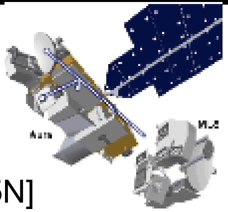
$$O(^1D) + H_2O \rightarrow 2\ OH$$

- The variability in OH and the related HO_x (OH, H, HO_2) chemistry affects the variability in middle atmospheric O_3 (through HO_x catalytic reaction cycles).

- We have extracted the OH SC signal using 15-year ground-based data. The 5-year MLS OH show similar trend *[Wang et al., 2013, PNAS]*.



Review — Solar Cycle Signal in OH Observations



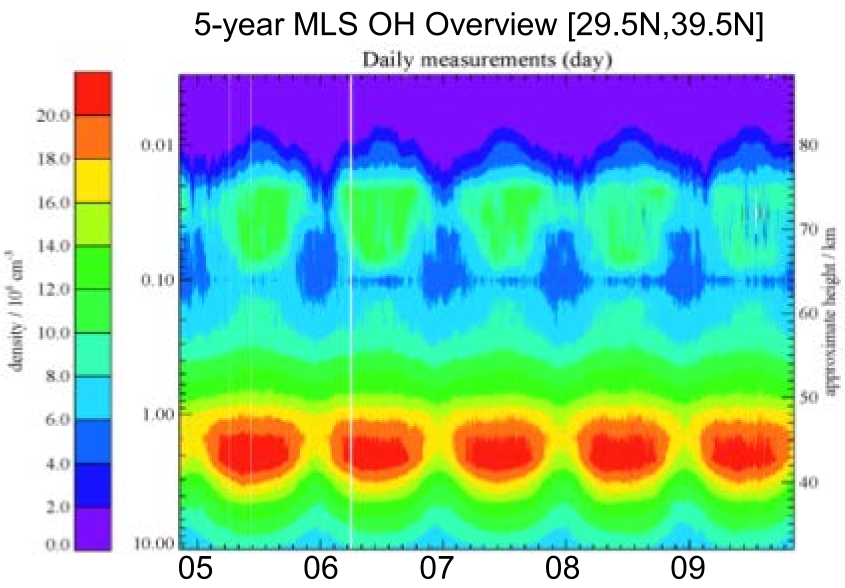
Aura/MLS (Microwave Limb Sounder) OH

— 2.5 THz module: 32 – 0.0032 hPa (~90% of total OH)

— Available data: Aug 2004 to Dec 2009

— Future data: 30-day in 2011, 2012, (2013, ……)

[Pickett, 2006, 2008; Wang et al, 2008; Canty et al., 2006]



FTUVS OH at Table Mountain, CA

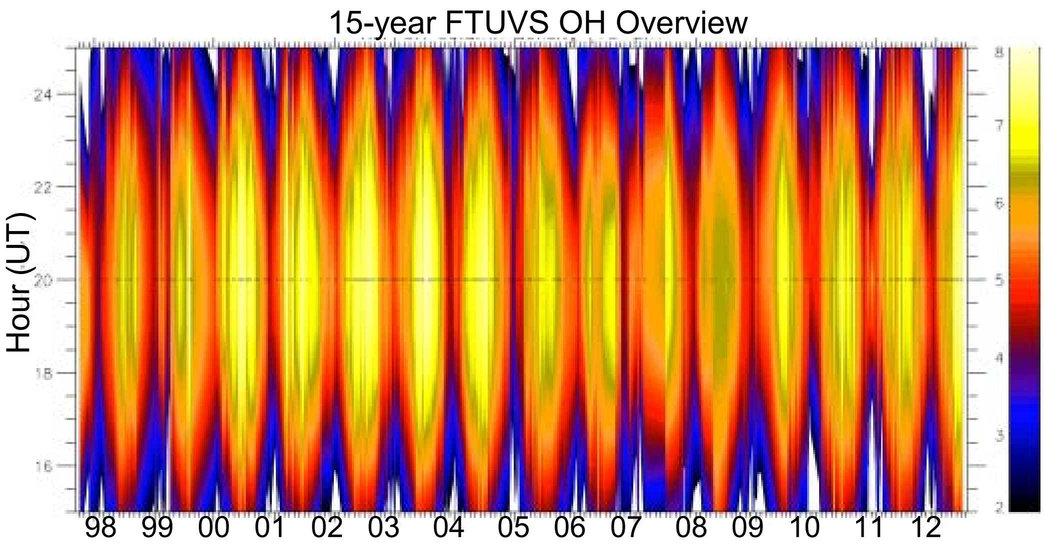
— Fourier Transform Ultra-Violet Spectrometer

— Location: TMF, Wrightwood, CA (34.4°N; ~2.3 km)

— Available data: OH column from 1997 to present

— Required condition: Clear to lightly cloudy sky

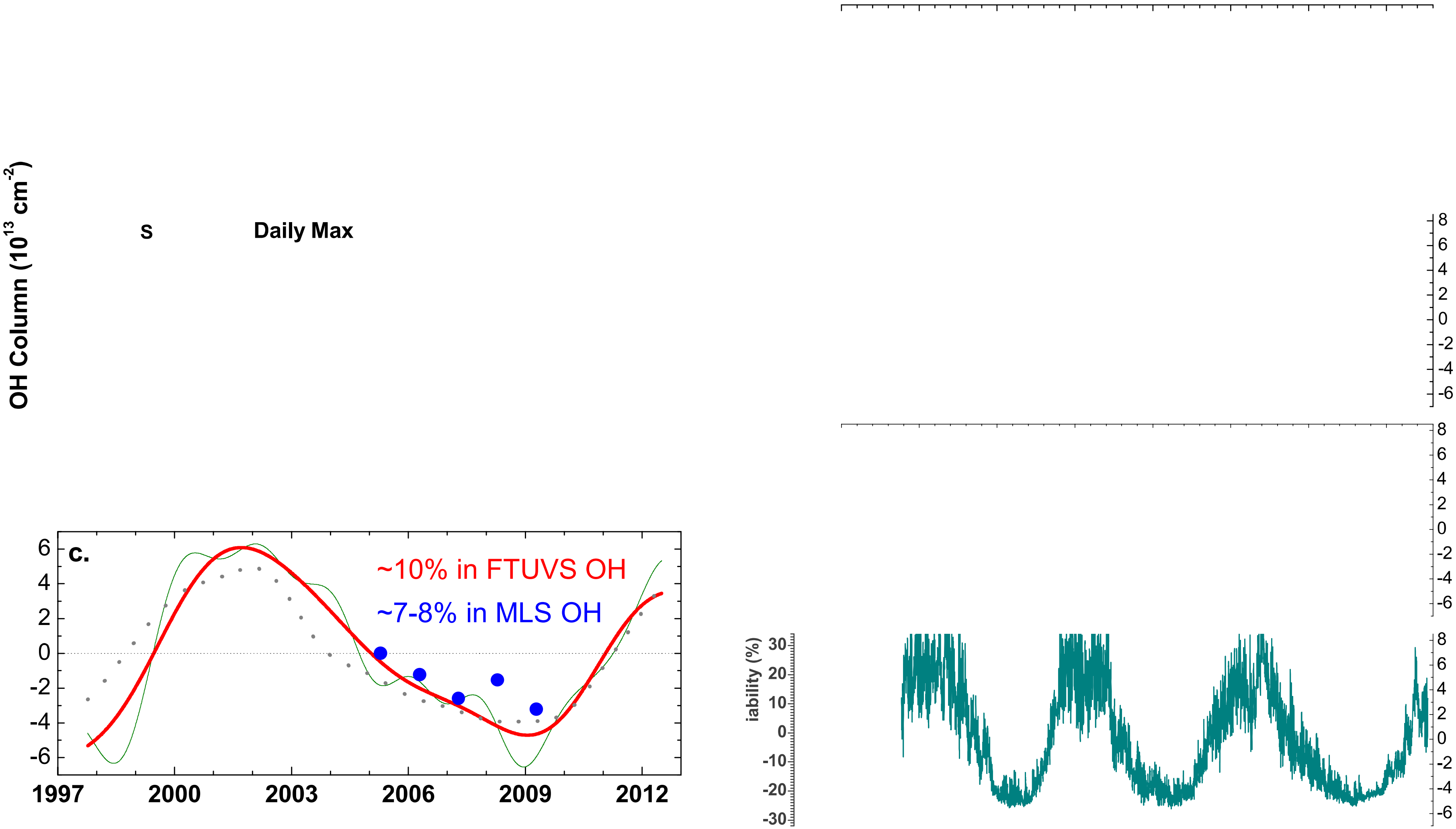
[Cageo et al 2001; Cheung, et al, 2008; Wang et al., 2008]



Major natural OH Variability

- Strong diurnal variation (SZA)
- Strong seasonal variation (SZA, source species)
- Solar cycle signal

Review — Solar Cycle Signal in OH Observations



[Wang et al., 2013, PNAS]

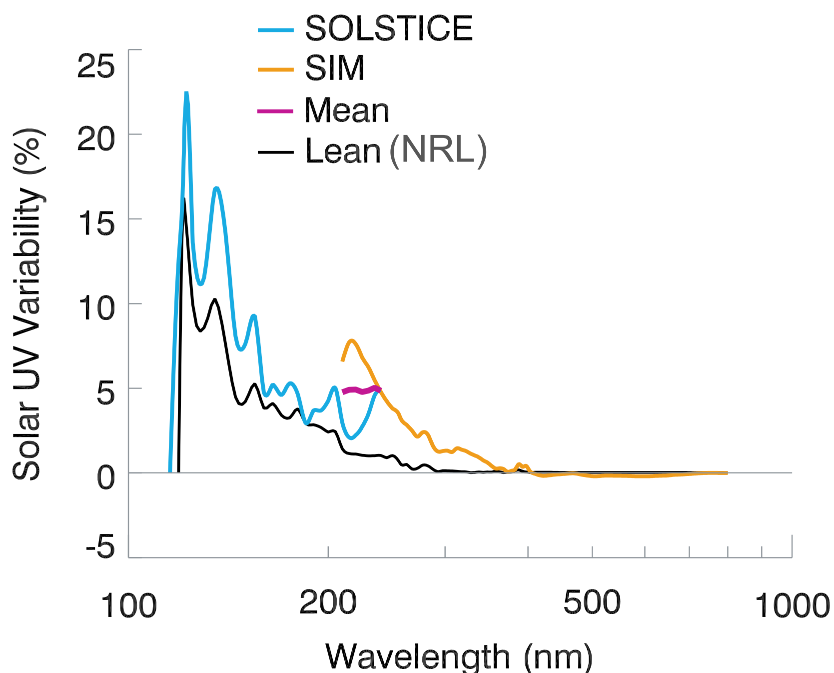
Model Simulations

Assuming the middle atmospheric HO$_x$ chemistry is well represented, **solar flux (Solar Spectral Irradiance)** used in models is a crucial factor determining the modeled solar cycle signal in OH.

- NRL SSI based on observations during past solar cycles *[e.g., Lean, 2000]*

  Other modeled SSI based on measurements *[e.g.,Woods and Rottman, 2002; Marsh et al., 2007; Austin et al., 2008]*

- Recent satellite (SORCE) observations of SSI variability during Solar Cycle 23 appear to be surprisingly larger than that of NRL. *[e.g., Haigh et al., 2010]*

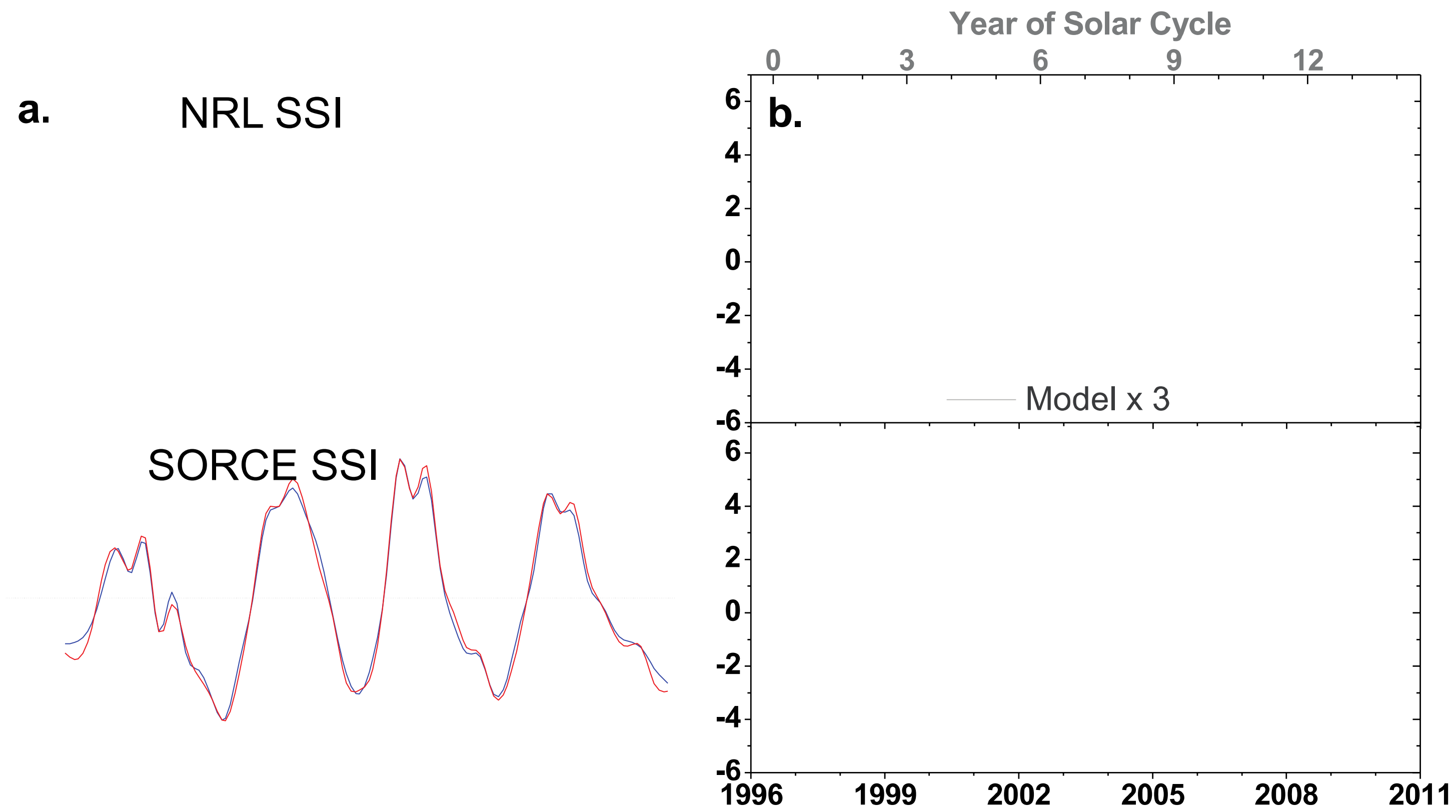


Solar Stellar Irradiance Comparison Experiment (SOLSTICE) — 115 – 300 nm

Spectral Irradiance Monitor (SIM) — 200 – 2700 nm

- We use SORCE (SOLSTICE + SIM) SSI variability during 2004 – 2007.
- Using Mg II as proxy, we scale the SSI variability back to solar max in Jan 2002.

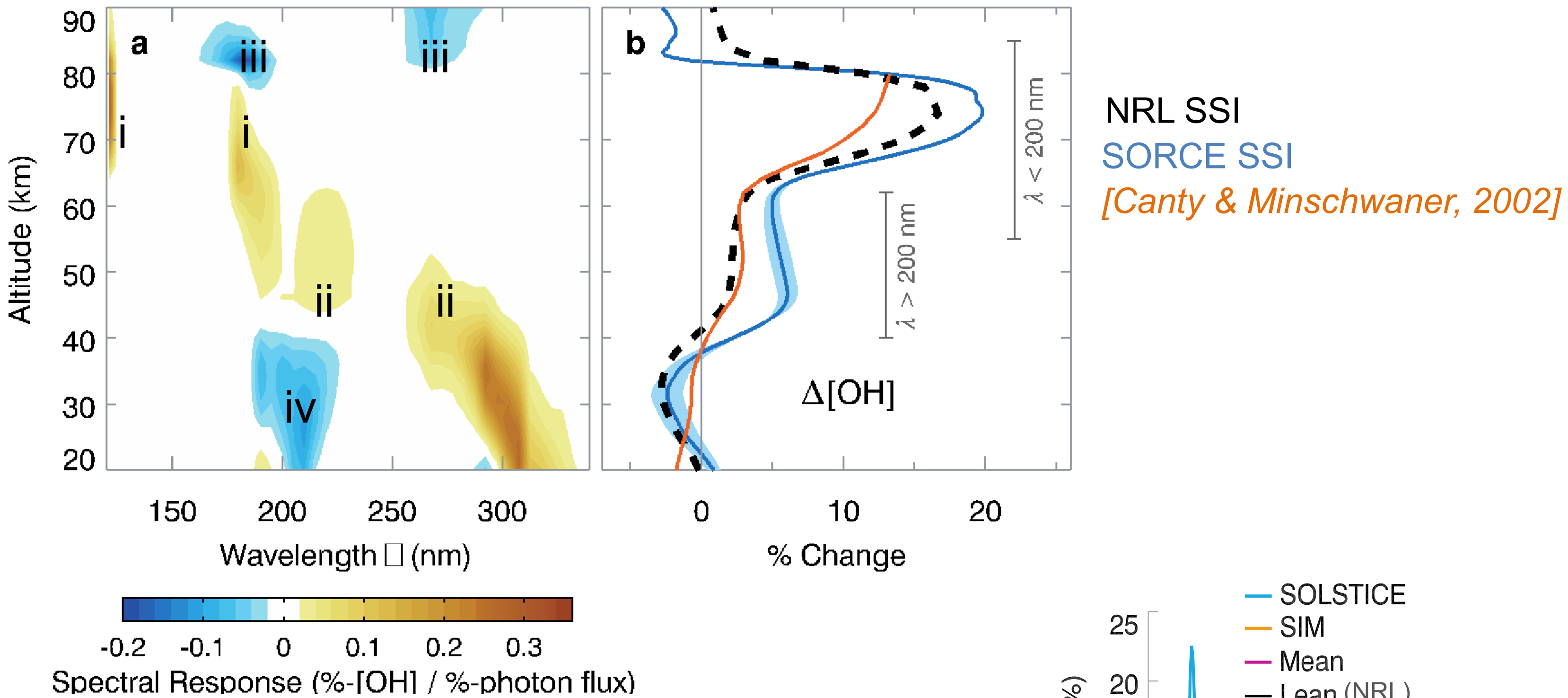
OH variability – WACCM vs. Observations

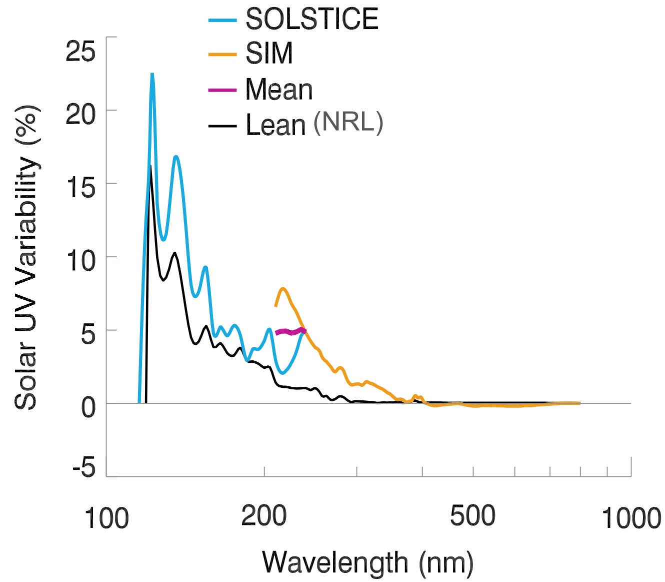


SSI used in WACCM	Modeled OH variability	Difference between model and observations
NRL	~3%	A factor of ~3
SORCE (240 nm cutoff)	~6%	A factor of ~1.5
SORCE (210 nm cutoff)	~7%	A factor of ~1.3

[Wang et al., 2013, PNAS]

OH variability – 1-D Model





i. Enhanced H_2O photolysis（< 200 nm）

ii. O (^{1}D) + H_2O → OH + O_2

Enhanced O_3 photolysis (> 200 nm)

iii. OH + O → H + O_3

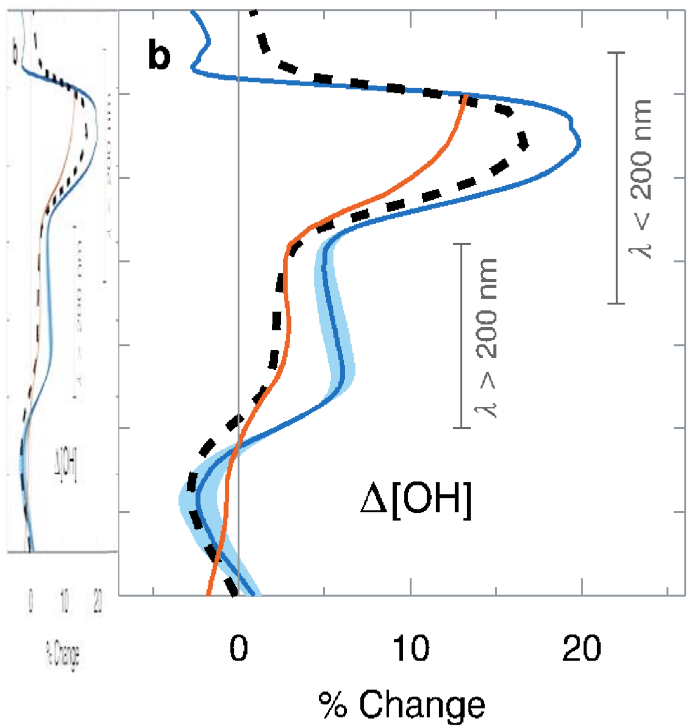
Enhanced photolysis of O_2 and O_3

iv. Shielding effect: Enhanced overhead O_3 opacity

OH variability – Vertical Profile

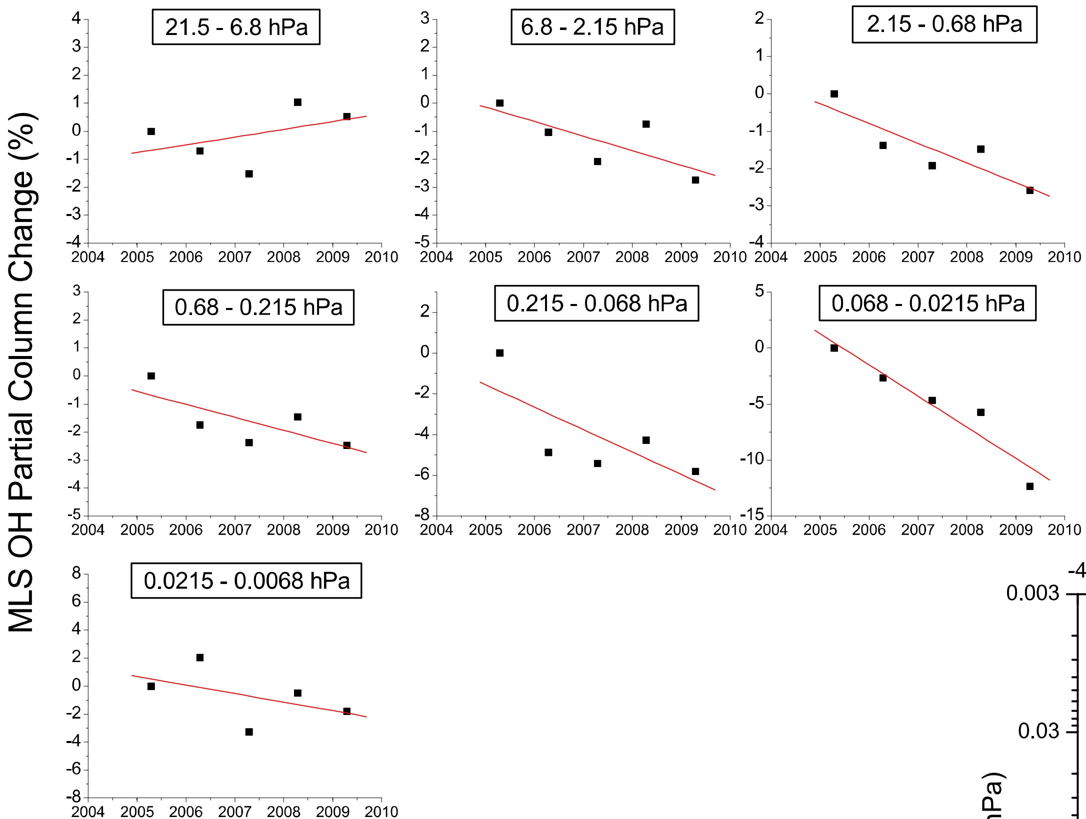
When replacing NRL SSI with SORCE SSI –

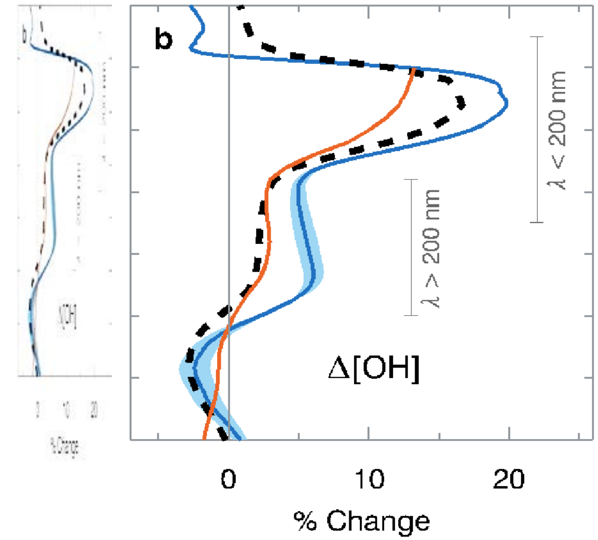
- Mesospheric OH SC signal increases by ~15% (λ < 200nm)
- Upper stratospheric OH SC signal increases by 100-200% (λ > 200nm)

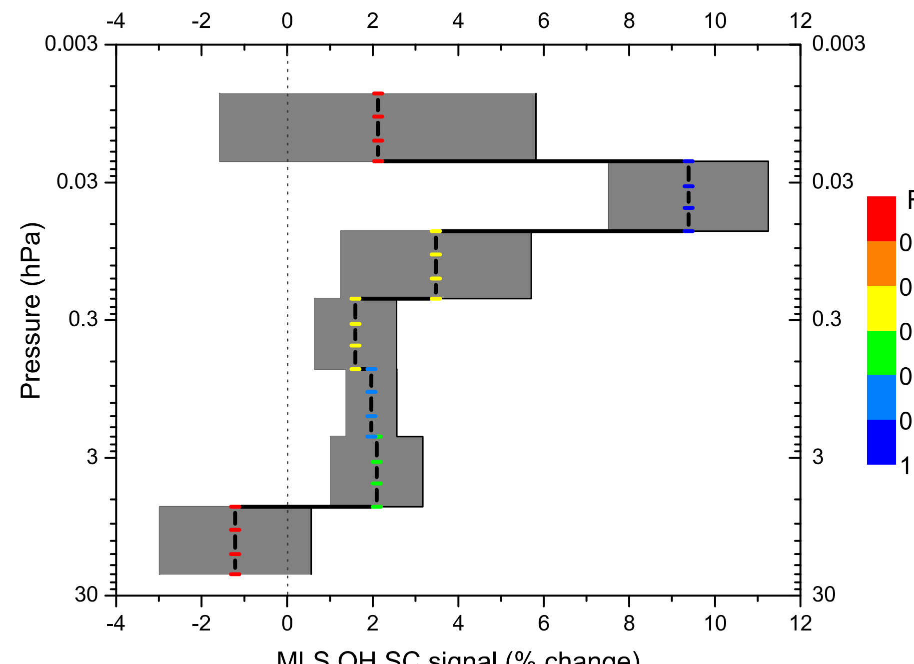


MLS Annual mean OH Variability at [29.5N, 39.5N]

OH variability – Vertical Profile (MLS vs. Model)

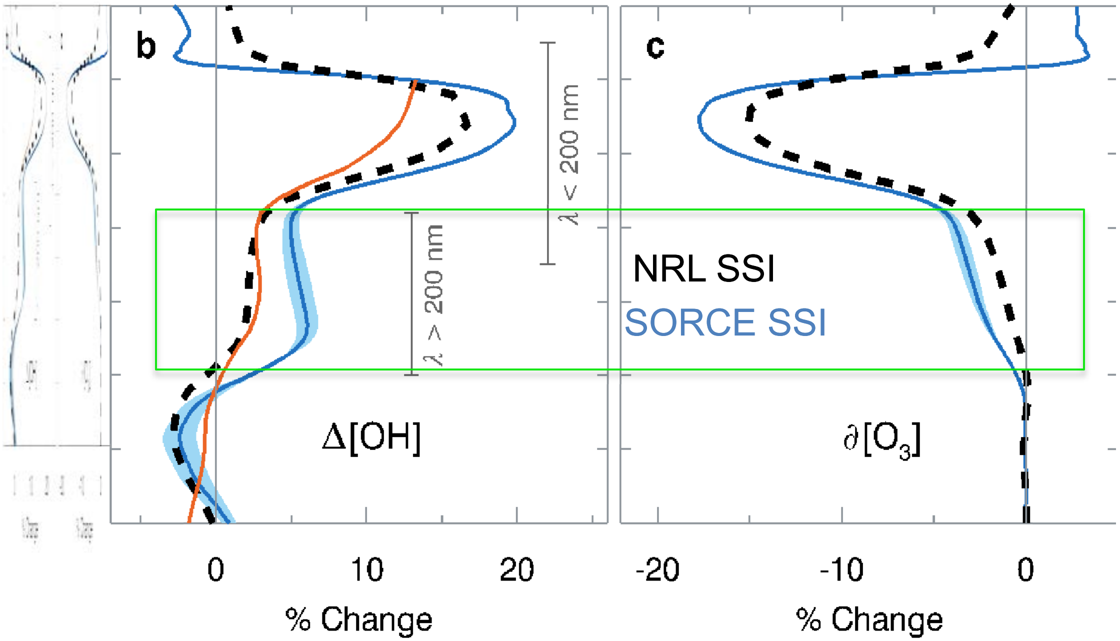






- MLS observations seem to agree better with model using SORCE SSI.
- Current MLS data record is too limited to make solid conclusions.
- More data in the future are required.

OH variability – Implications on O_3



Δ[O_3] (overall SC signal in O_3) is similar to other studies using same models

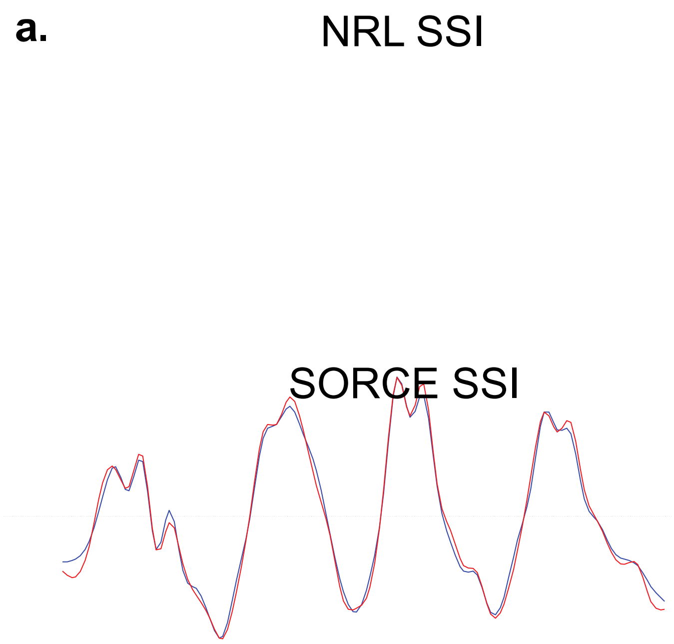
[Merkel et al., 2011; Li et al., 2012]

- Direct changes (photolysis)
- Indirect changes (O_3-destroying catalytic HO_x chemistry)
- Other possible indirect changes (e.g., T, circulation)

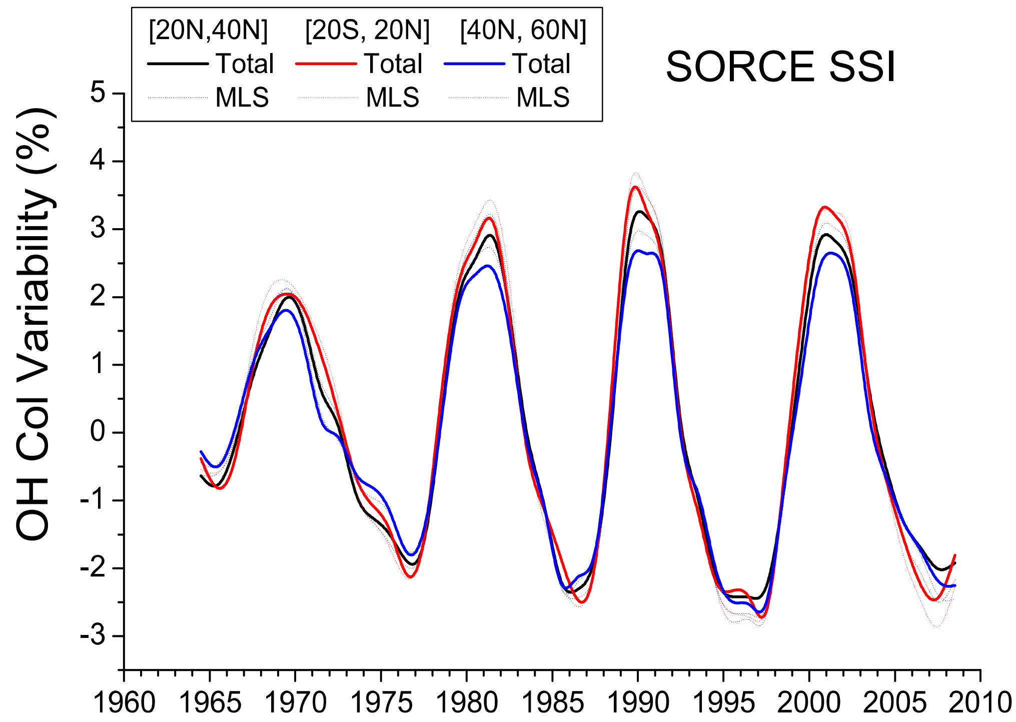
∂[O_3] Fix SSI; constrain OH changes (SC max to min) to values in (b)

- At 40 – 60 km, using Δ[OH] from SORCE SSI instead of from NRL leads to nearly doubled ∂[O_3] (*similar to what Merkel et al [2011] found in the total Δ[O_3]*)

Diurnal and Latitudinal Dependence of Solar Cycle Signal



Based on monthly mean output
(mean including both day and night)



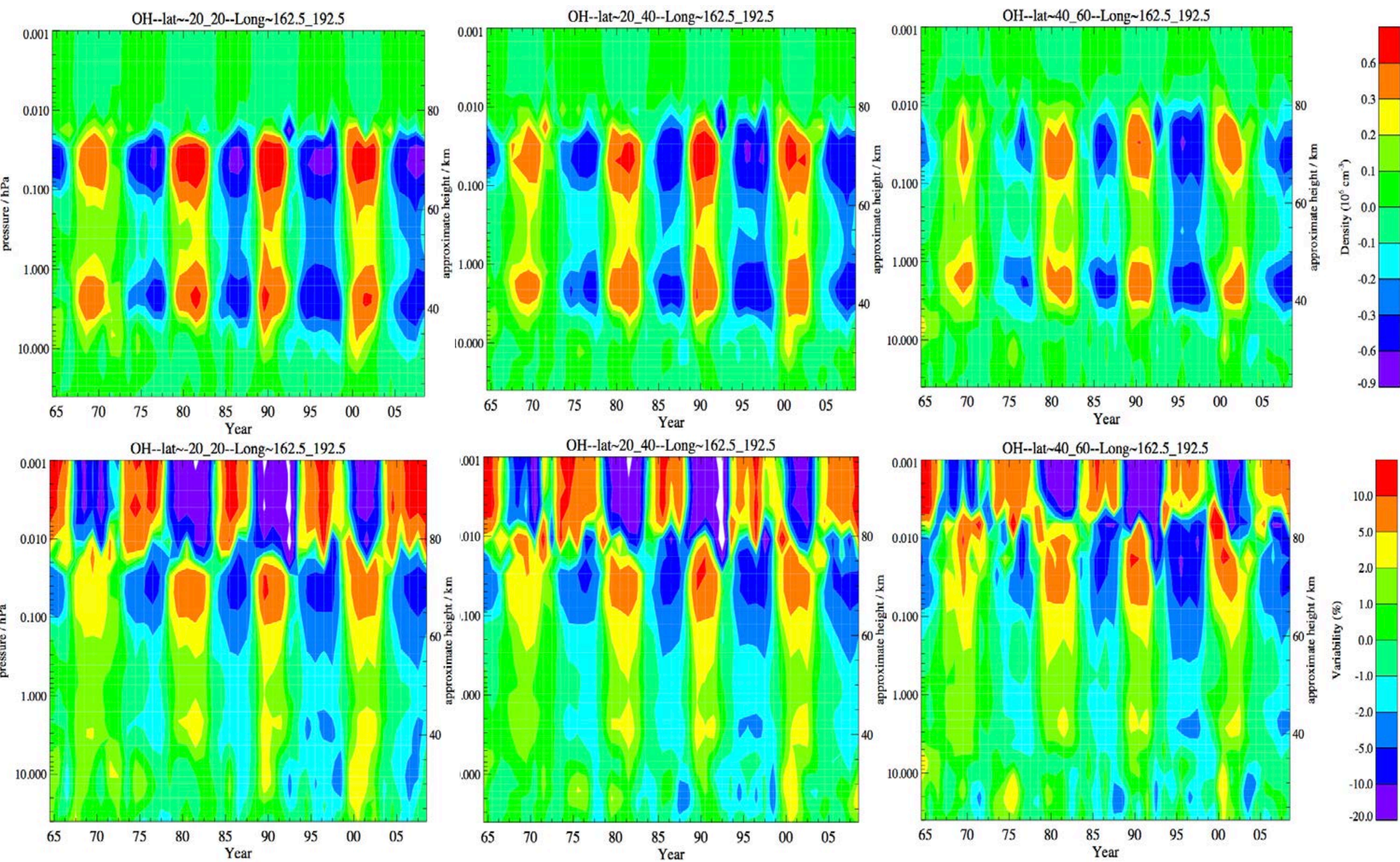
Based on Daily output at 0:00UT at longitude [162.5,192.5] (Noon ± 1hr LST)

Diurnal effect: Insignificant

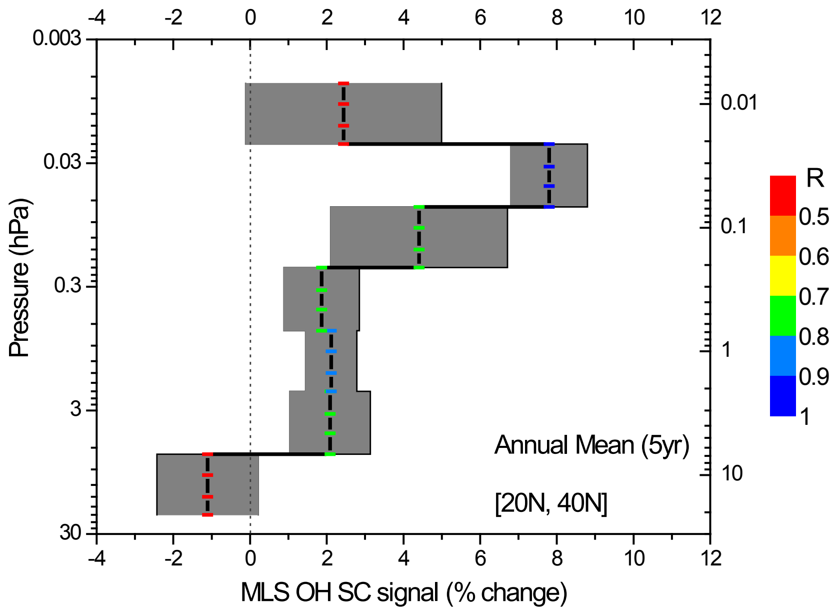
Latitudinal effect: Signal decreases with latitude

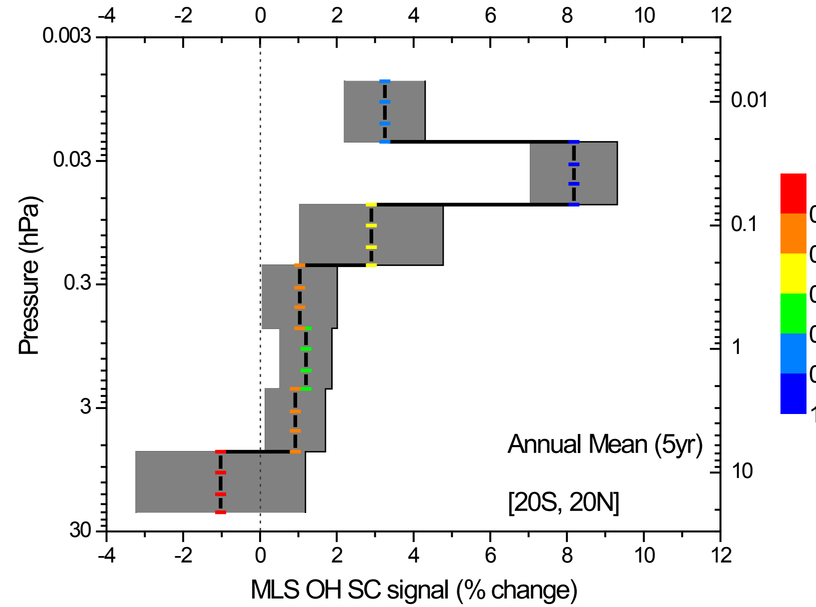
OH variability – Latitudinal Dependence

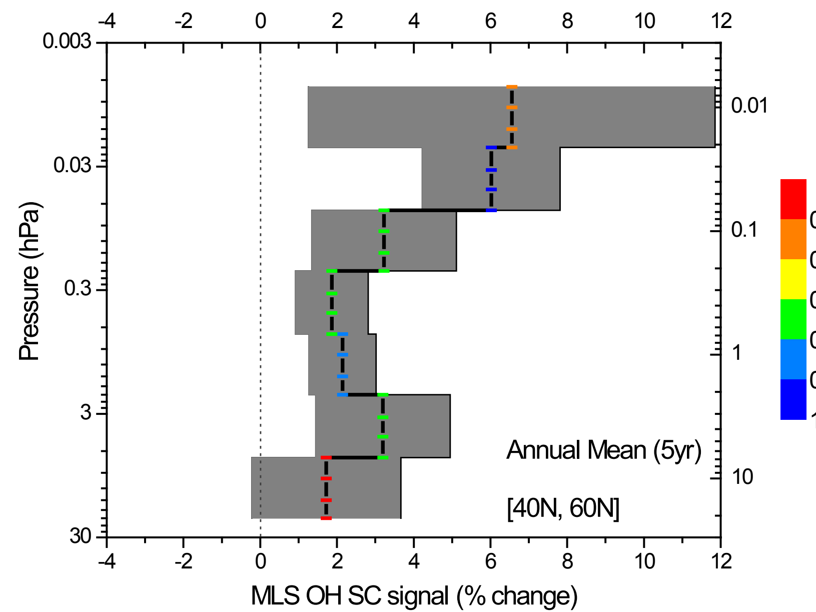
Annual mean WACCM data - Variability from all time mean



OH variability – Latitudinal Dependence







Conclusions

• Observations (Aura/MLS and TMF/FTUVS) show ~7-10% solar cycle signal in OH column. Modeled OH solar cycle signals using NRL SSI and SORCE SSI are ~3% and 6-7 %, respectively.

➔ The large discrepancy between NRL and SORCE SSI appears to be one of the dominant uncertainties in atmospheric modeling of solar cycle variability.

• We use 1-D photochemical model to understand the chemical mechanism of OH solar cycle signal:

i) H_2O photolysis
ii) O_3 photolysis
iii) shielding effect from overhead O_3

and the implications on O_3

➔ At 40 – 60 km, OH and its solar cycle variability may play a dominant role in the decadal variation in O_3 (through HO_x catalytic reaction cycles).

Continuing measurements of OH, O_3 and solar SSI, through the next solar cycle will be extremely valuable to answer the remaining questions:

- What are the causes of the discrepancies between SORCE and NRL SSI?
- Are our current understanding of middle atmospheric HO_x-O_3 chemistry complete?