Solar Cycle Variations in Mesospheric Carbon Monoxide (CO)

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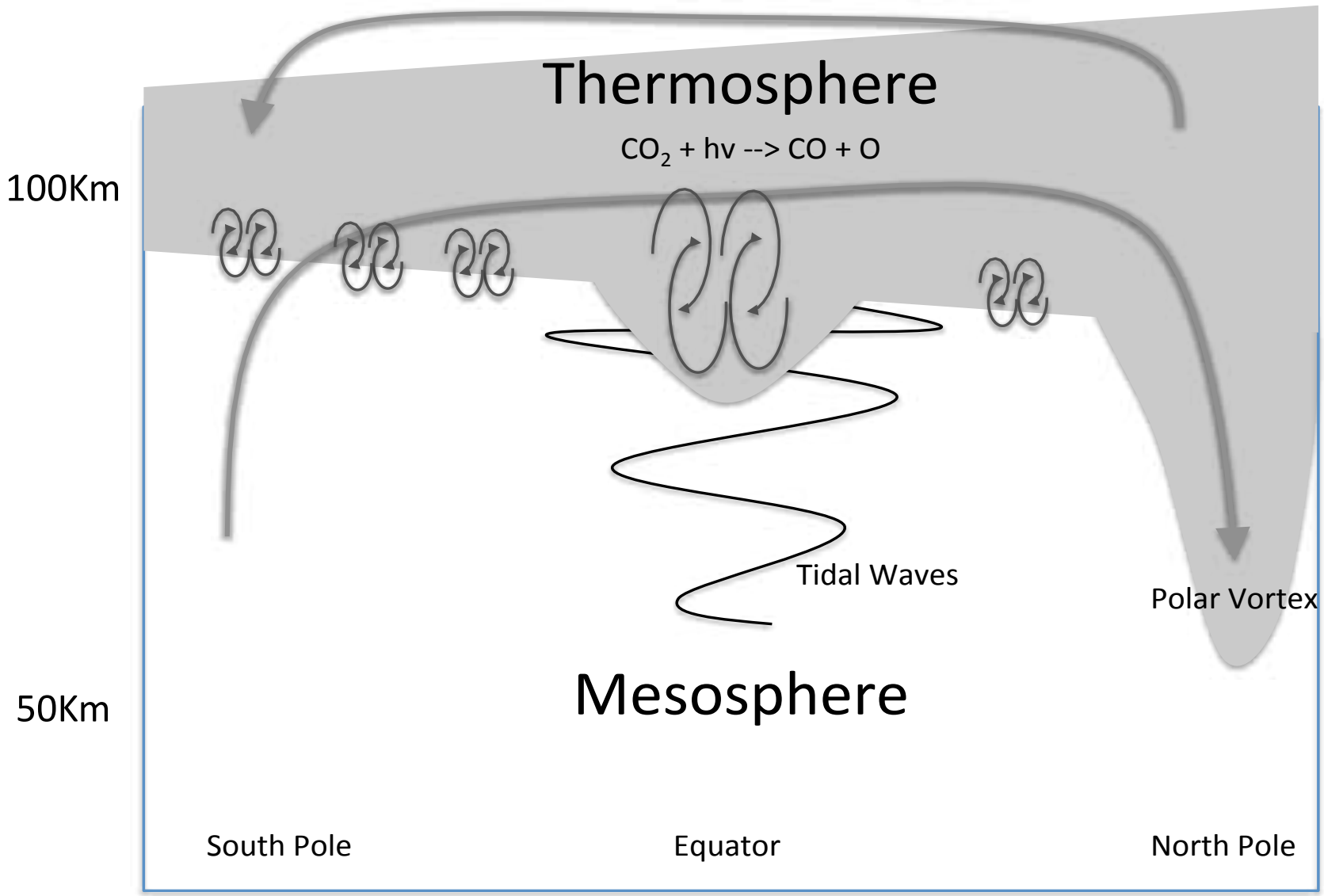
CO chemistry and transport in the middle atmosphere



Lee et al., 2018, JASTP

Major CO chemistry

- UV source: $CO_2 + h\nu \xrightarrow{J} CO + O\ (121\ nm < \lambda < 200\ nm)$

  Mesoosphere

- EUV source: $CO_2 + h\nu \rightarrow CO + O\ (\lambda < 121\ nm)$ ← This source is NOT implemented in WACCM 3.5

  Thermosphere

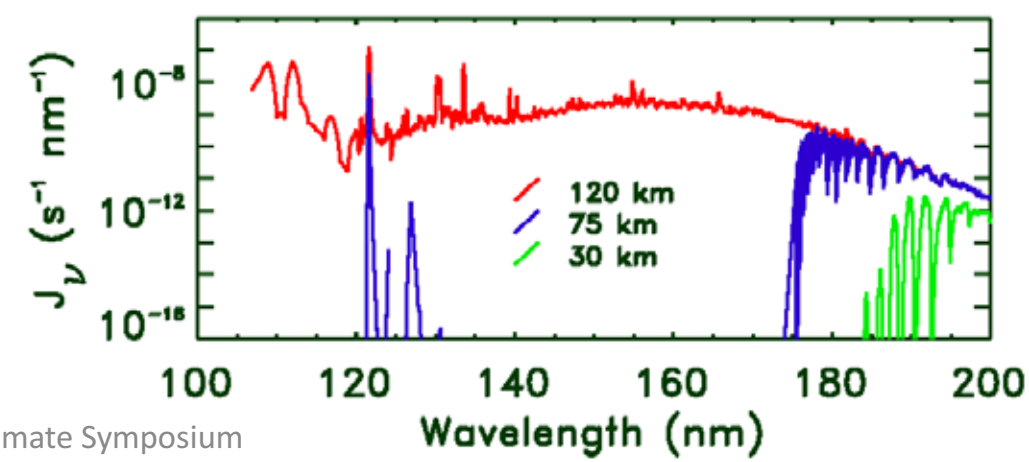
  $CO_2 + O^+ \rightarrow CO + O_2^+$

- Sinks:

  $CO + O + M \rightarrow CO_2 + M$ Thermosphere

  $CO + OH \rightarrow CO_2 + H$ Mesosphere

Minschwaner et al. (2010)



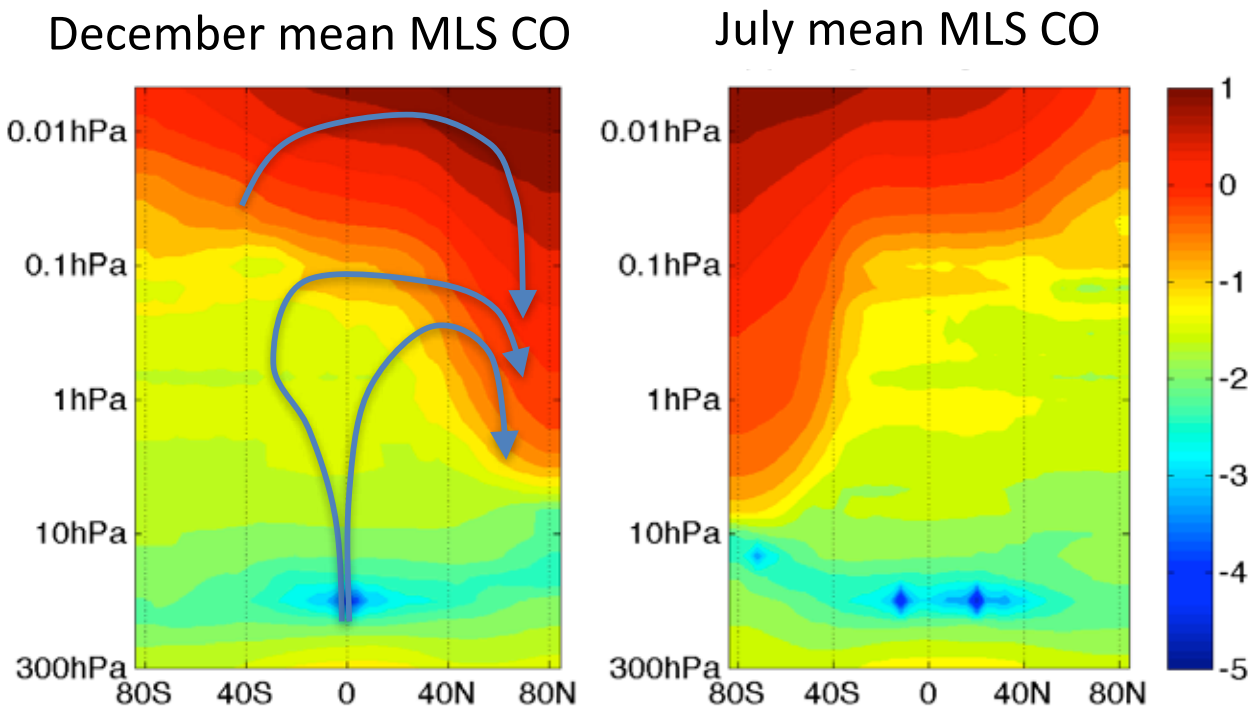
- Methane oxidation source in the stratosphere, but destroyed by OH when OH is present.

Outline

- Observed and Modeled thermospheric/mesospheric carbon monoxide (CO)

- WACCM (Whole Atmosphere Community Climate Model)/ CESM1.0.3, and model experiments on SSI

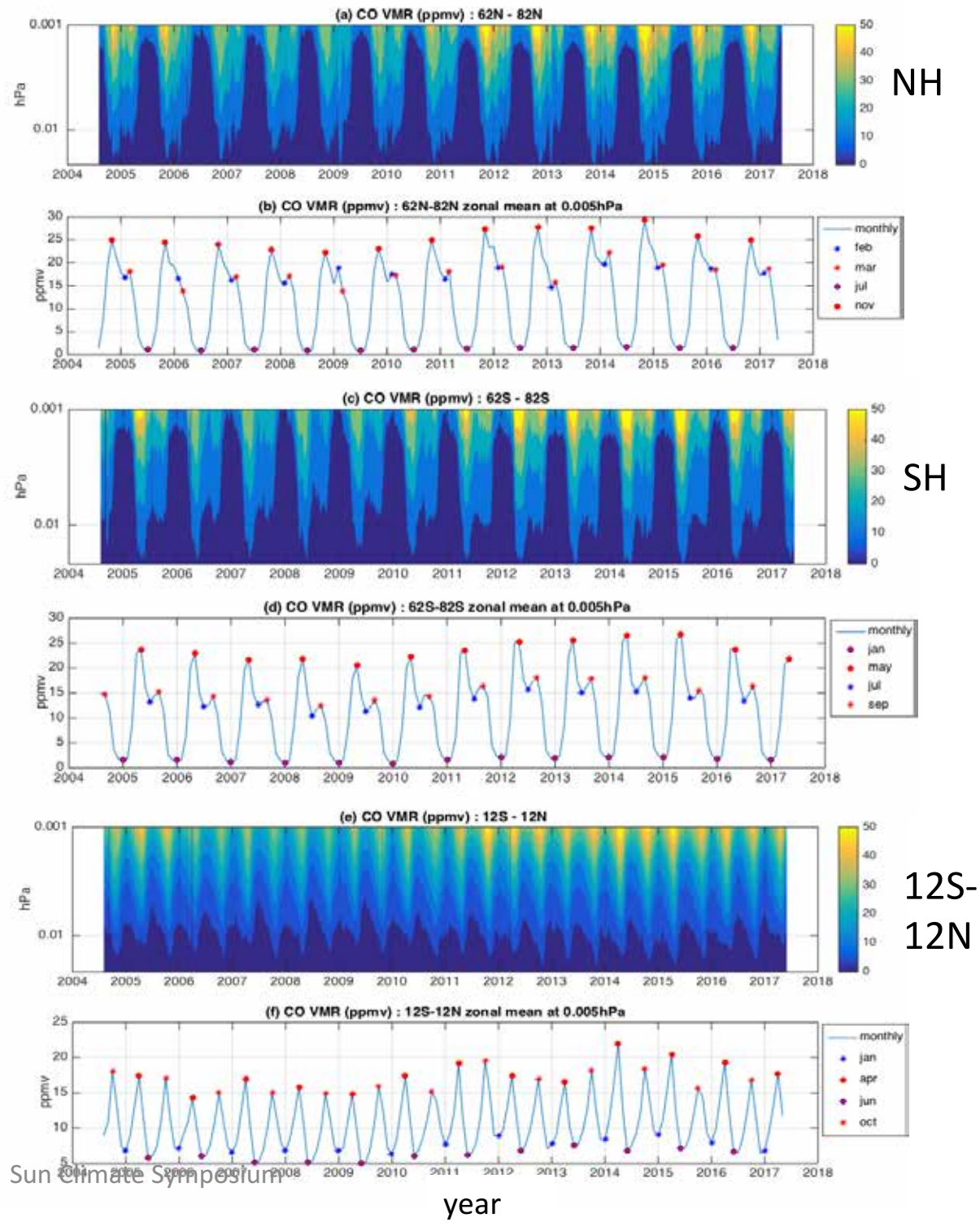
Microwave Limb Sounder (MLS) CO distribution



- Chemical and dynamical balance leads to the strong vertical gradient of CO mixing ratio with abundant CO in the mesosphere
- Decent in the polar region brings high CO from the mesosphere
- Long CO life time helps to maintain vertical and horizontal gradients
- Is there solar cycle variations in CO amount?

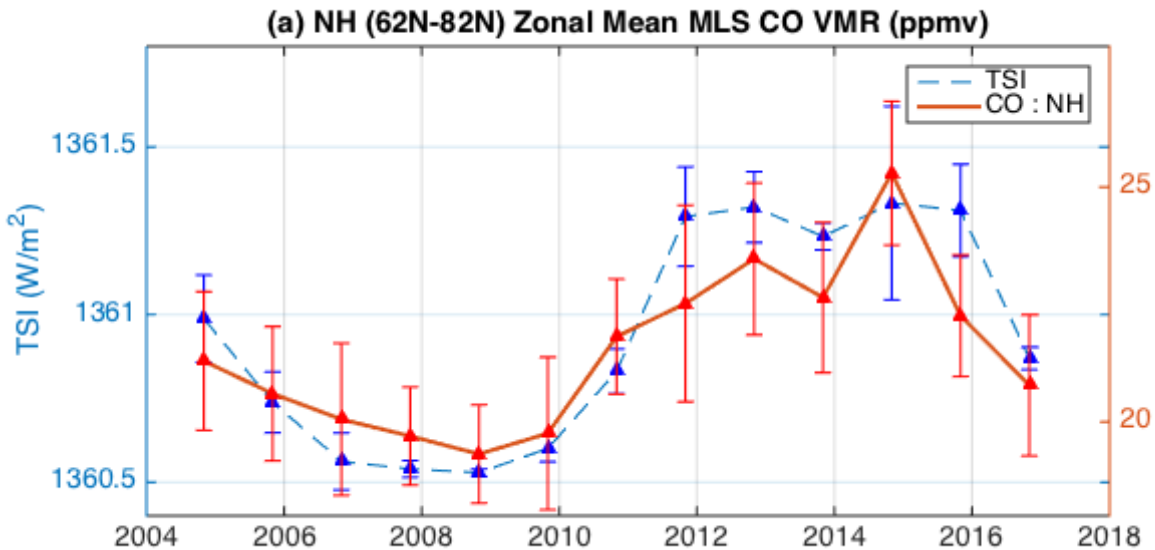
MLS CO VMR

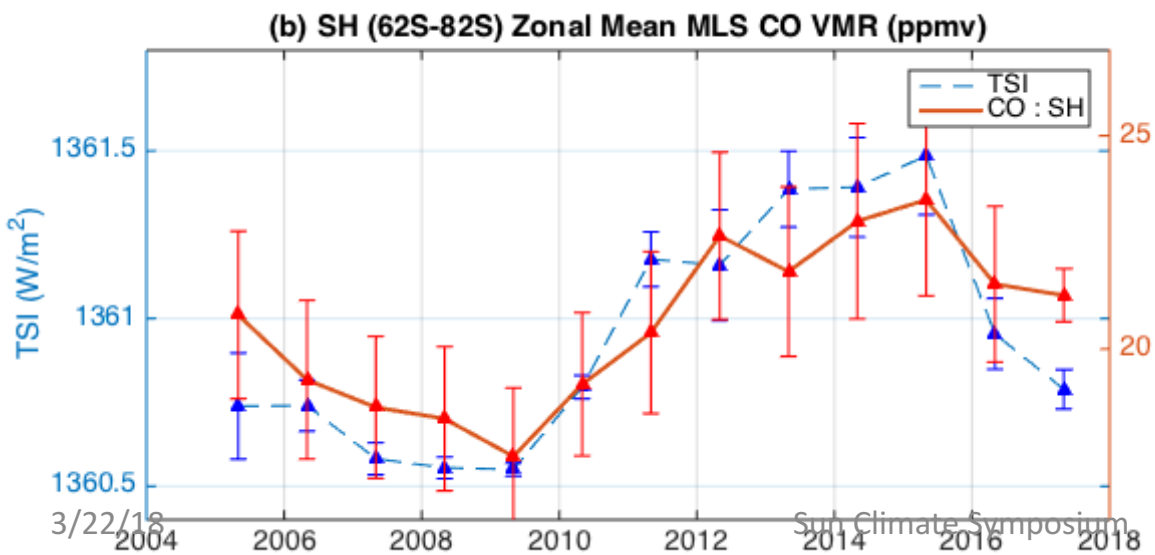
- Strong interannual variability in CO
- Large annual cycle from ~1 ppmv to ~30 ppmv in NH
- SAO in the tropics



Interannual variations of MLS CO and SORCE TSI

Winter time mean MLS CO at 0.005hPa

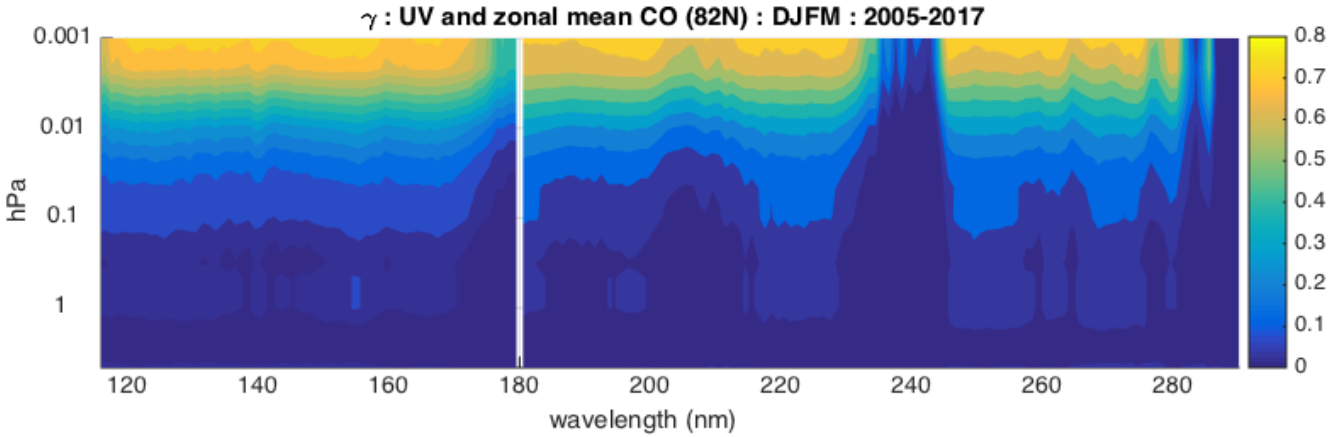




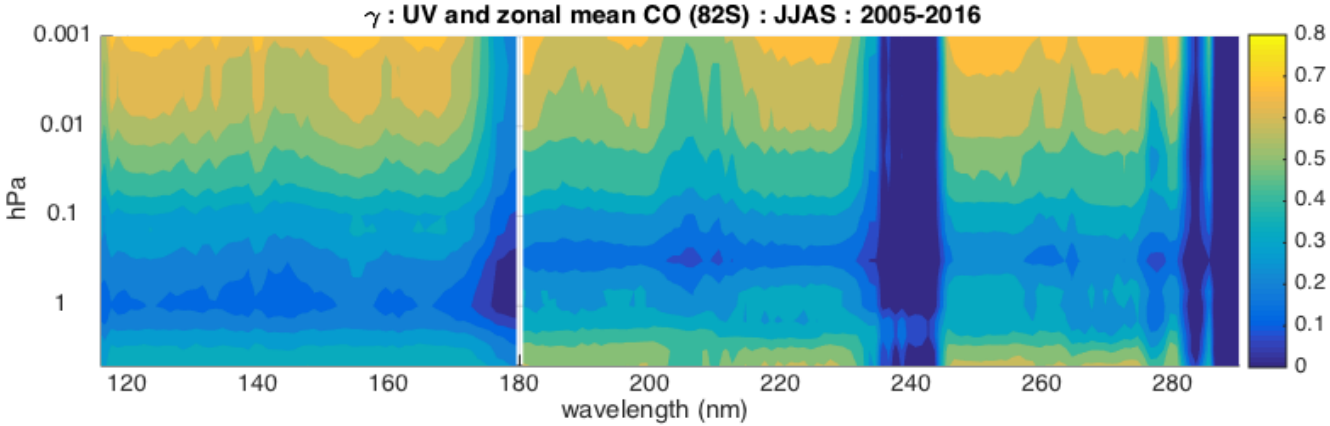
- Strong interannual variability
- ~25% increase from 20 ppmv to 25 ppmv since 2009 solar minimum
- UV variation on photolysis and transport from the low thermosphere likely play a role

Spectral correlation between UV and CO

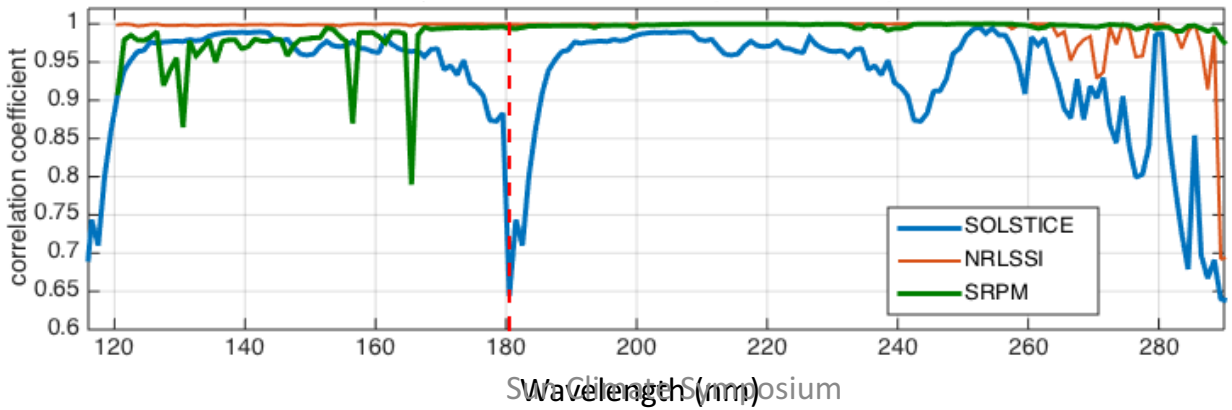
NH



SH

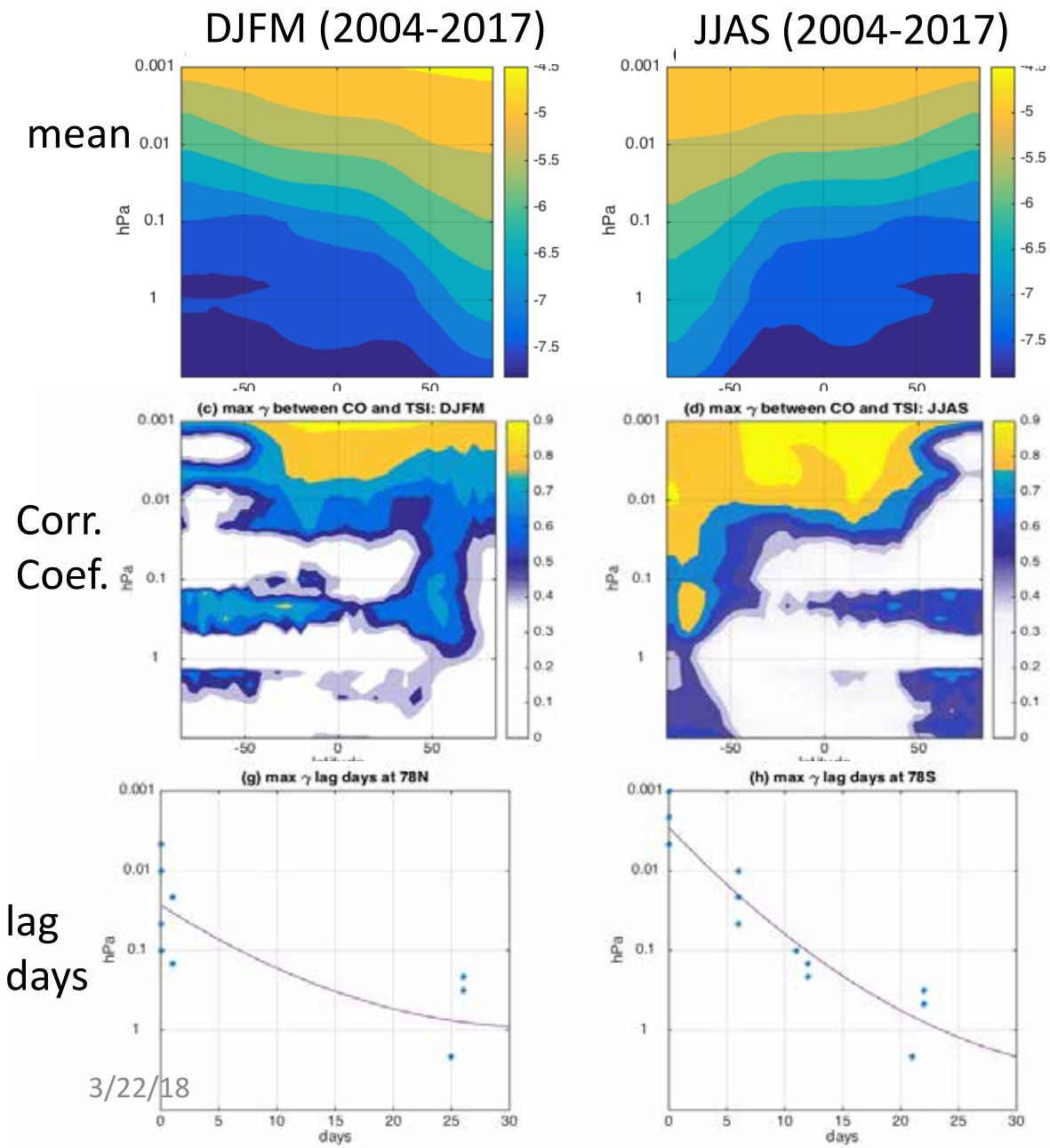


Correlation between UV and MUV (250nm-255nm)



← SOLSTICE A → ← SOLSTICE B →

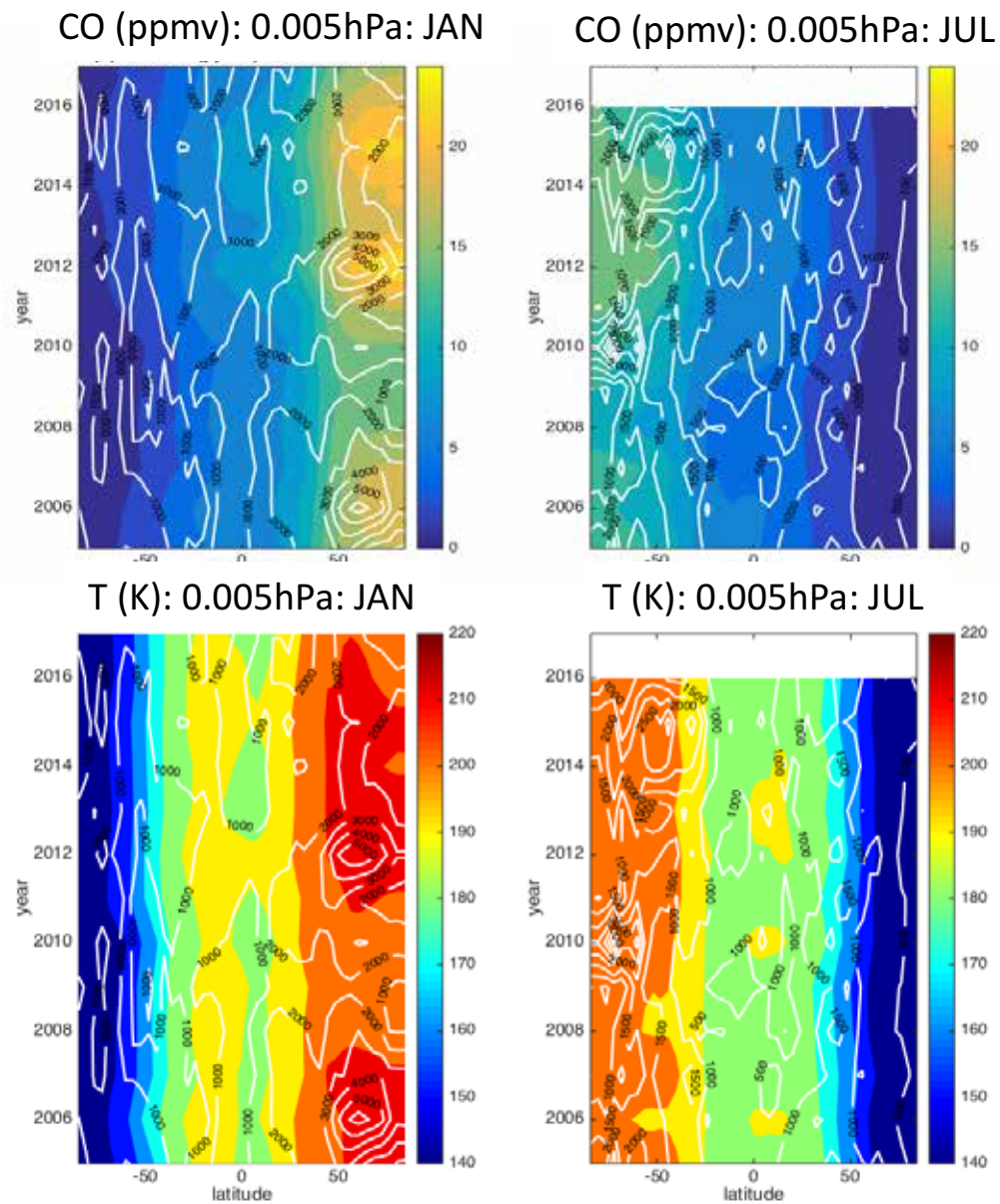
CO correlations with SORCE TSI



- Significant correlations between CO and TSI (95% level)
- Solar signal extends to upper stratosphere
- Likely from the indirect responses to the solar forcing as a result of dynamical transport
- No negative correlation suggesting that CO increase with solar irradiance
- Show consistent descent of maximum correlation in SH

Effect of Dynamics

- PW amplitude is more prominent in NH than SH.
- Higher CO amount during high solar activity years with enhanced PW activity.
- In warm and dynamic environment, more CO is present.
- Temperature shows large pole-to-pole gradient. SH winter gets ~7% less solar insolation, and is colder compared to NH.
- It is ~10K warmer in winter hemisphere during solar max years.
- Summer mesosphere is very cold with no solar signal

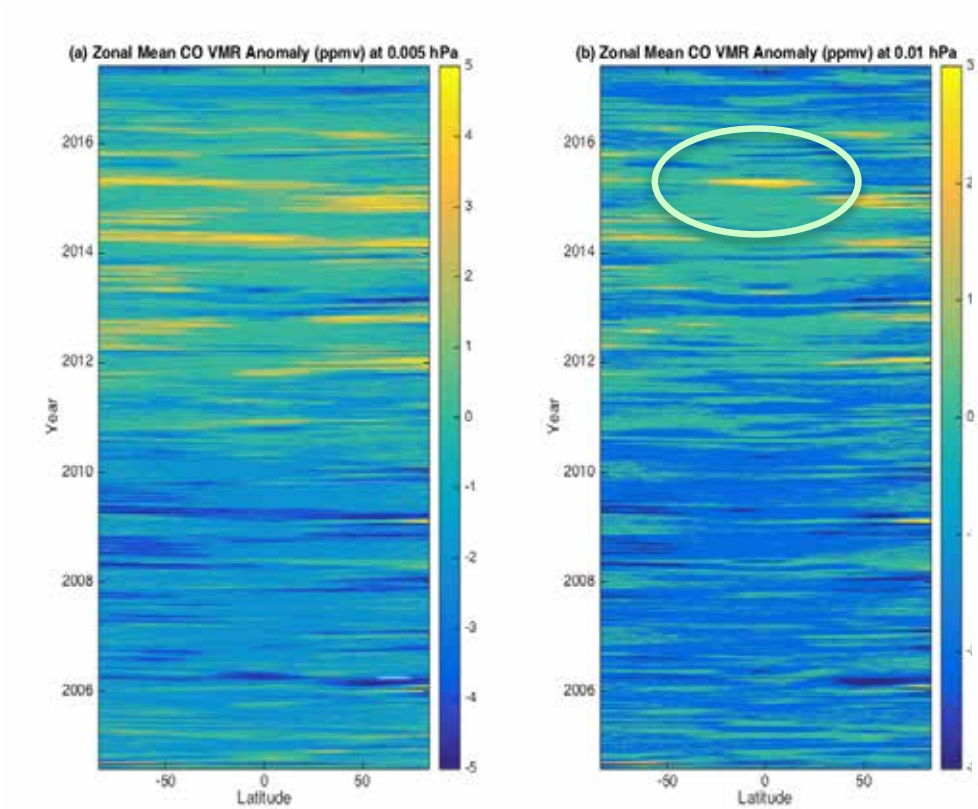


Effect of Vertical Mixing

Zonal mean CO anomaly

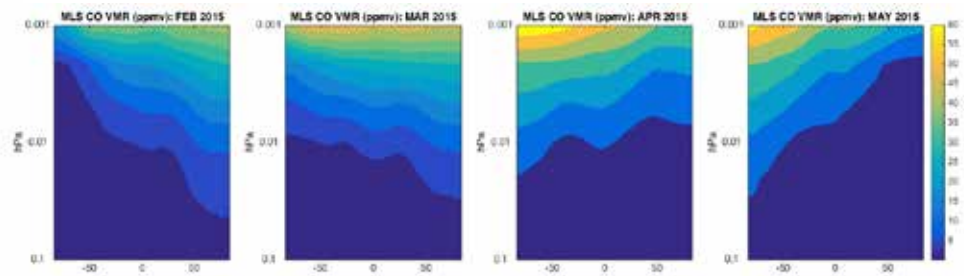
0.005 hPa

0.01 hPa

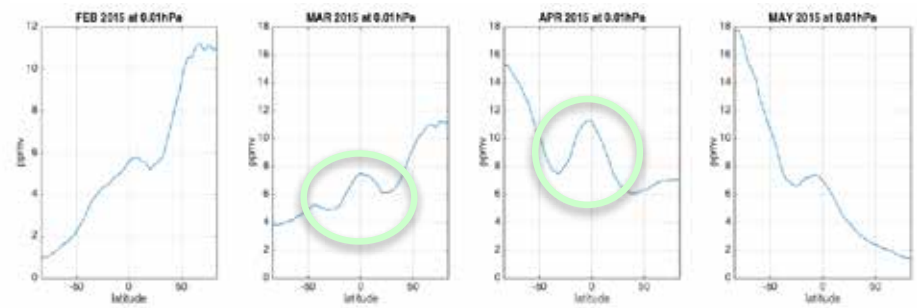


2015 spring

FEB MAR APR MAY



0.01hPa CO distribution



- CO anomaly is distributed globally but not confined to high-latitudes
- Horizontal mixing?
- Vertical mixing?

- Enhanced vertical mixing due to tidal wave and gravity wave breaking from below. Diurnal tide peaks during equinox in the tropics.

Outline

- Observed and Modeled thermospheric/mesospheric carbon monoxide (CO)

- WACCM (Whole Atmosphere Community Climate Model)/ CESM1.0.3, and model experiments on SSI
- SSI (Spectral Solar Irradiance) in SRPM and NRL models
- Modeled sensitivity to the solar-cycle forcing, compared to the value inferred from MLS and SORCE

WACCM Experiments

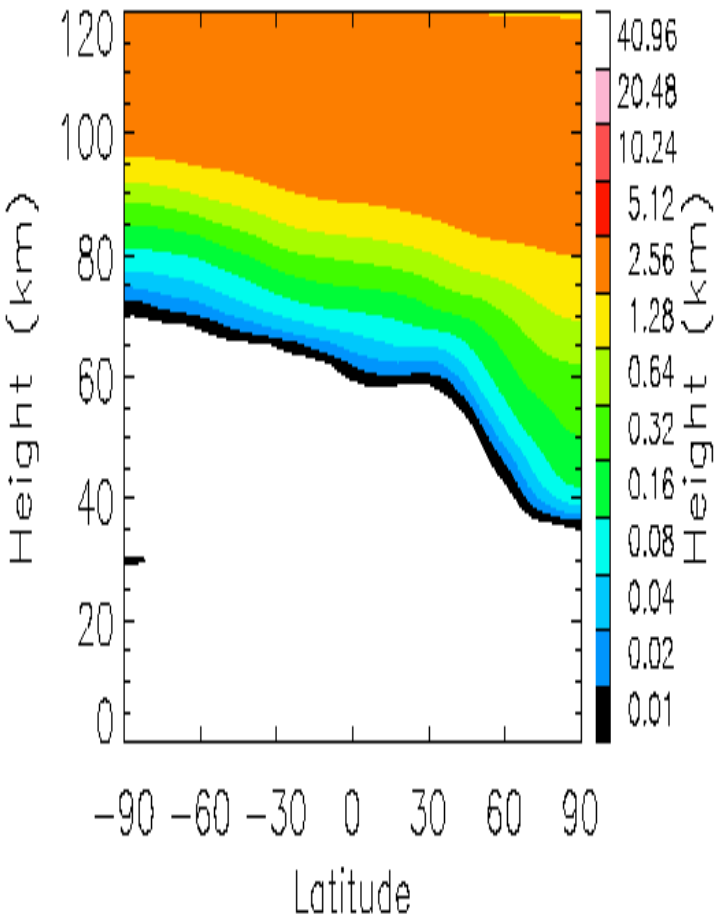
- Five (5) solar cycles (1955-2005)
- Constant and perturbed TSI
- Simulations with different SSI spectra

Experiments	TSI	SSI (>120 nm)	SSI (<120 nm)
S_const	Constant	SRPM	F10.7, Kp, Ap
S_srpm	Repeated Cycle23	SRPM	F10.7, Kp, Ap
S_nrl	Cycles 19-23	NRL	F10.7, Kp, Ap

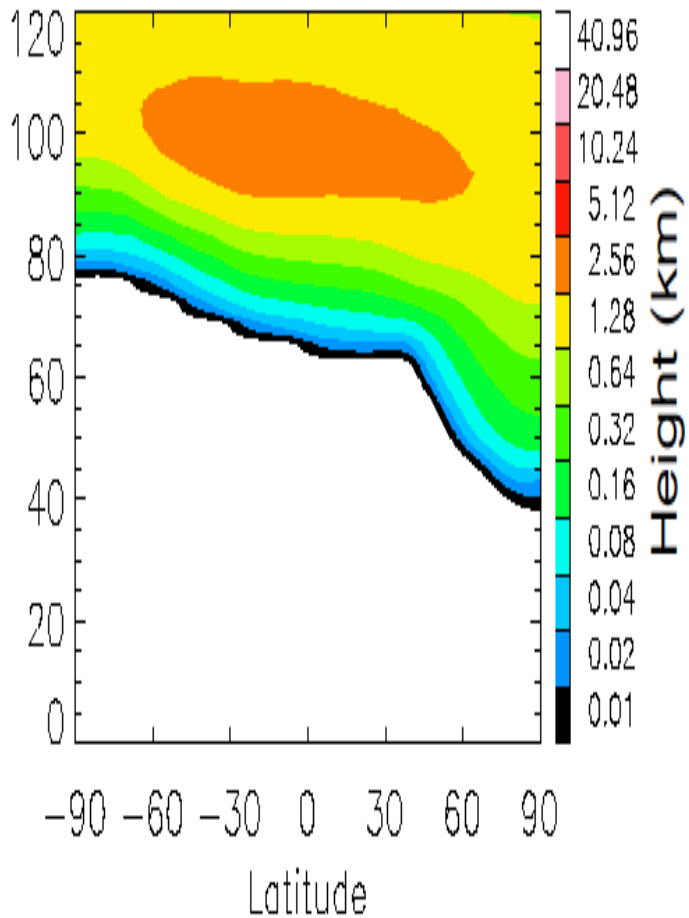
S_srpm –S_const -> remove internal variability
-> detect weak solar signals

WACCM and MLS CO for December

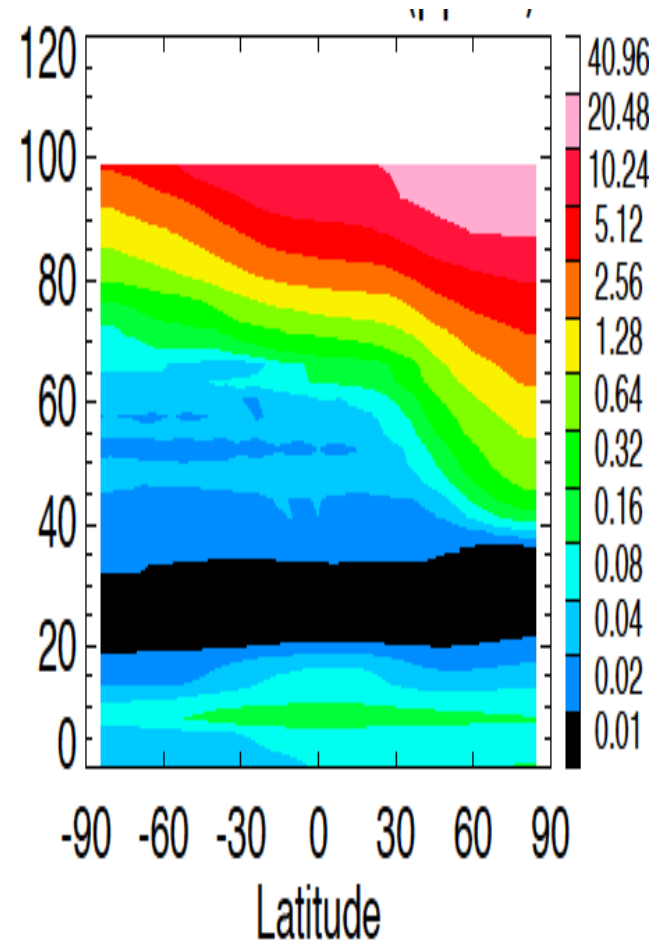
SRPM



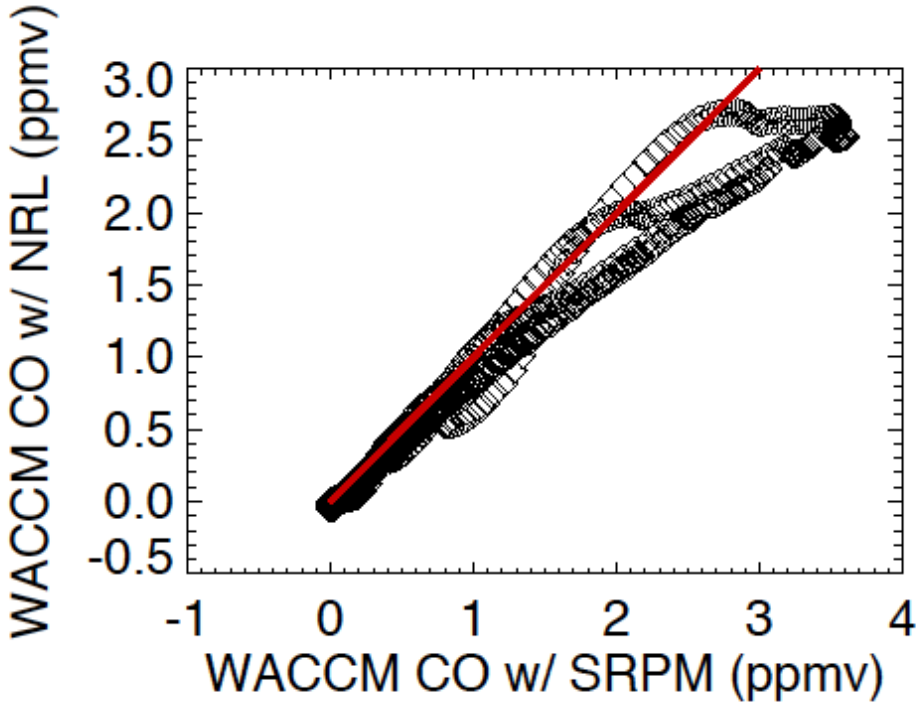
NRL

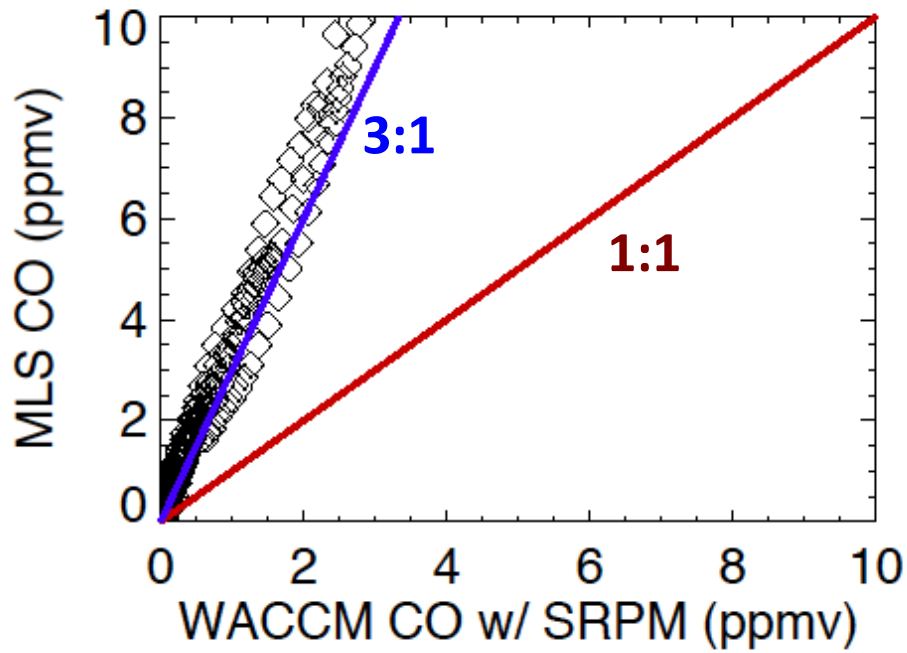


MLS



December CO VMR at heights < 90km





Lack of Chemical processes?
Lack of dynamical forcing?

Sensitivity of Mesospheric CO to the Solar-Cycle

Sensitivity (%/%) at 0.005 hPa

	December 82°N	July 82°S
SRPM	345	292
NRL	392	405
MLS	~325	~510

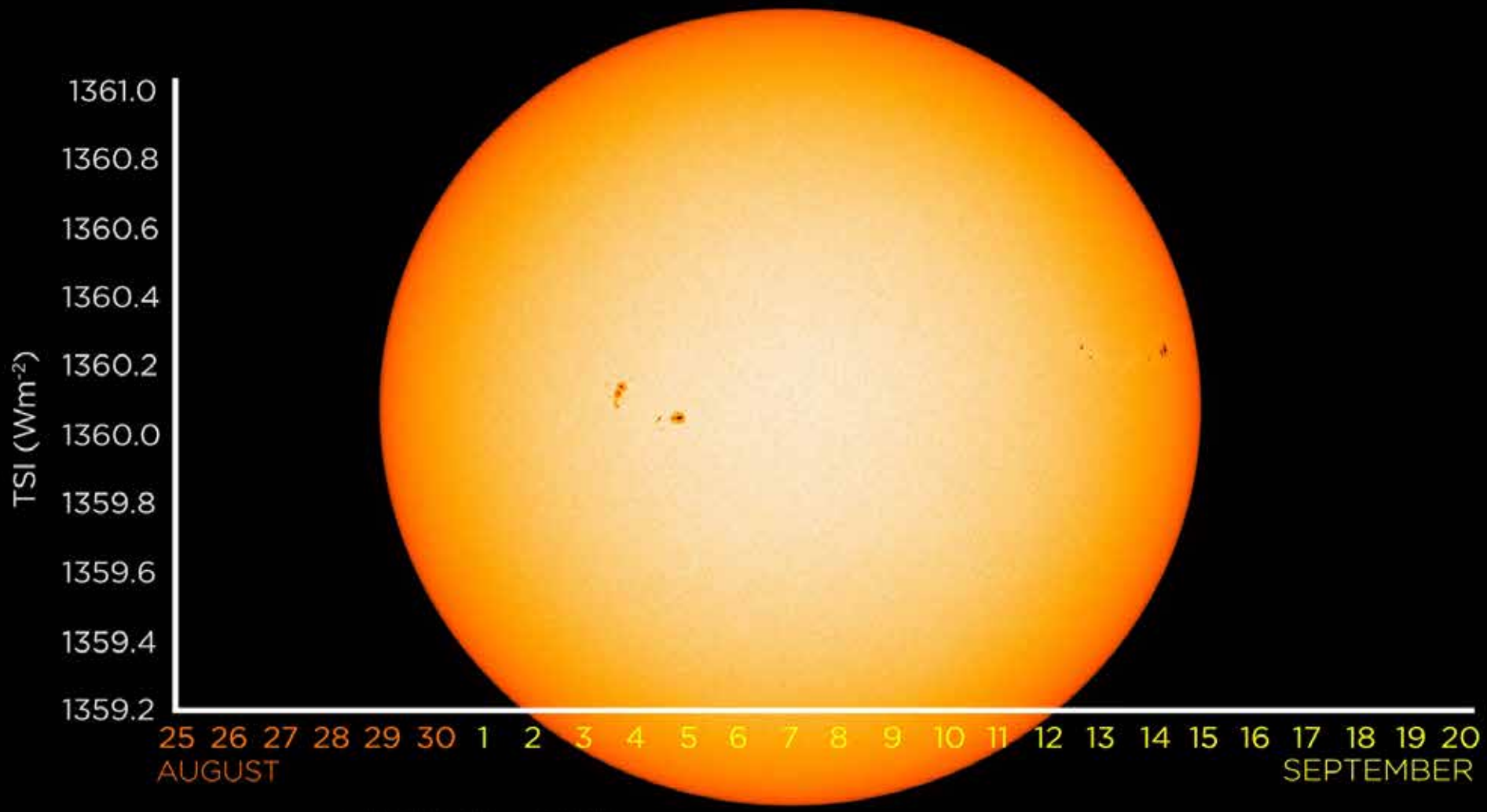
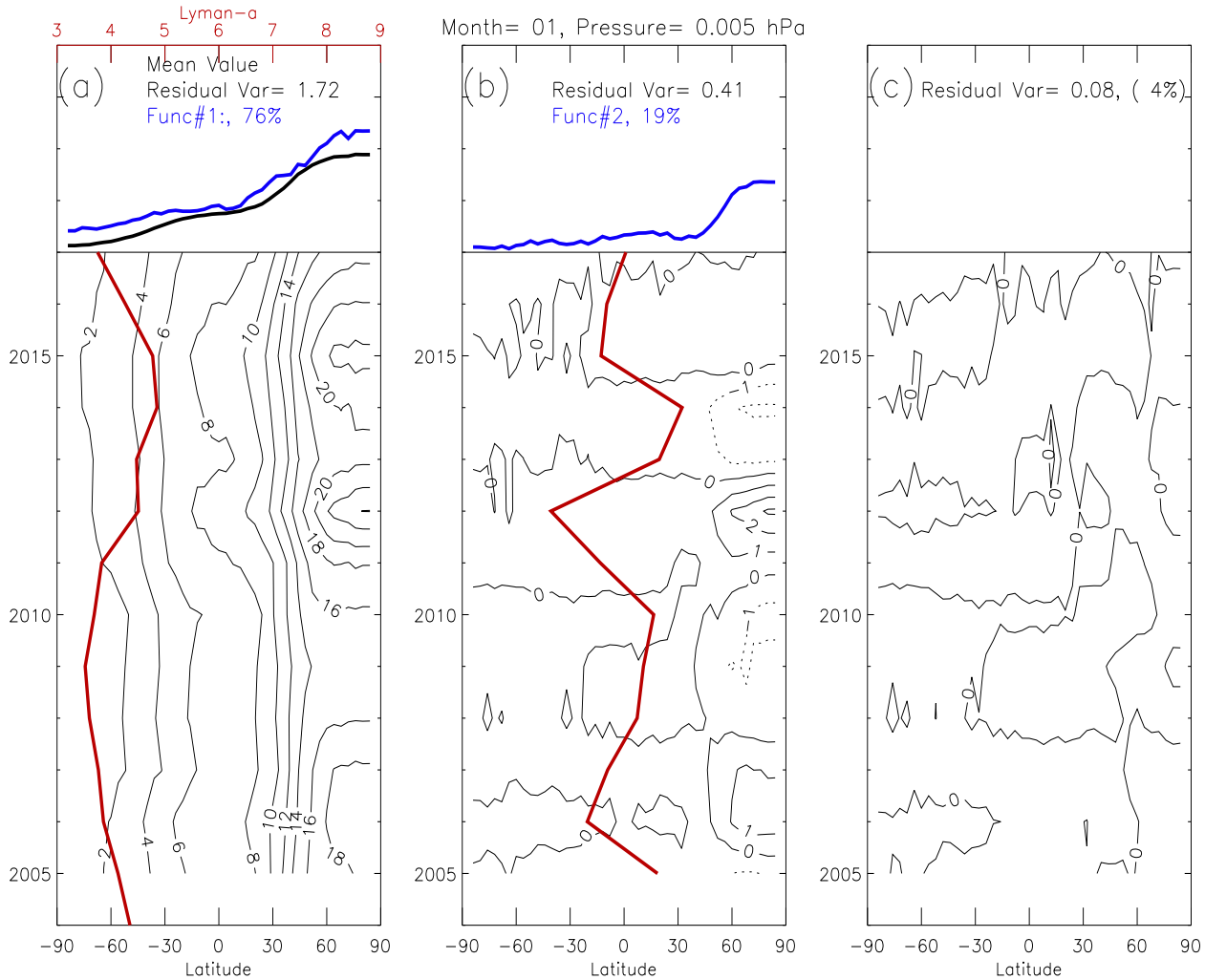
Implication for the observables:

Sensitivity * 0.1% * mean_VMR > VMR measurement error

conclusions

- Observations from Aura MLS (Microwave Limb Sounder) and SORCE showing statistically significant positive correlation between CO and solar irradiance.
- CO is in phase with solar cycle. More UV produces more CO which is transported and mixed downward.
- WACCM 3.5 simulated CO responses to the solar-cycle forcing are similar between the SRPM and NRL experiments.
- Modeled CO VMRs are substantially (~3x) lower at 0.005 hPa, compared to Aura MLS observations, due to missing EUV chemistry in this version of the model.

Sun is changing:
TSIS-1 measures Total and Spectral Solar Irradiance.



Roles of Photochemisty and Dynamics