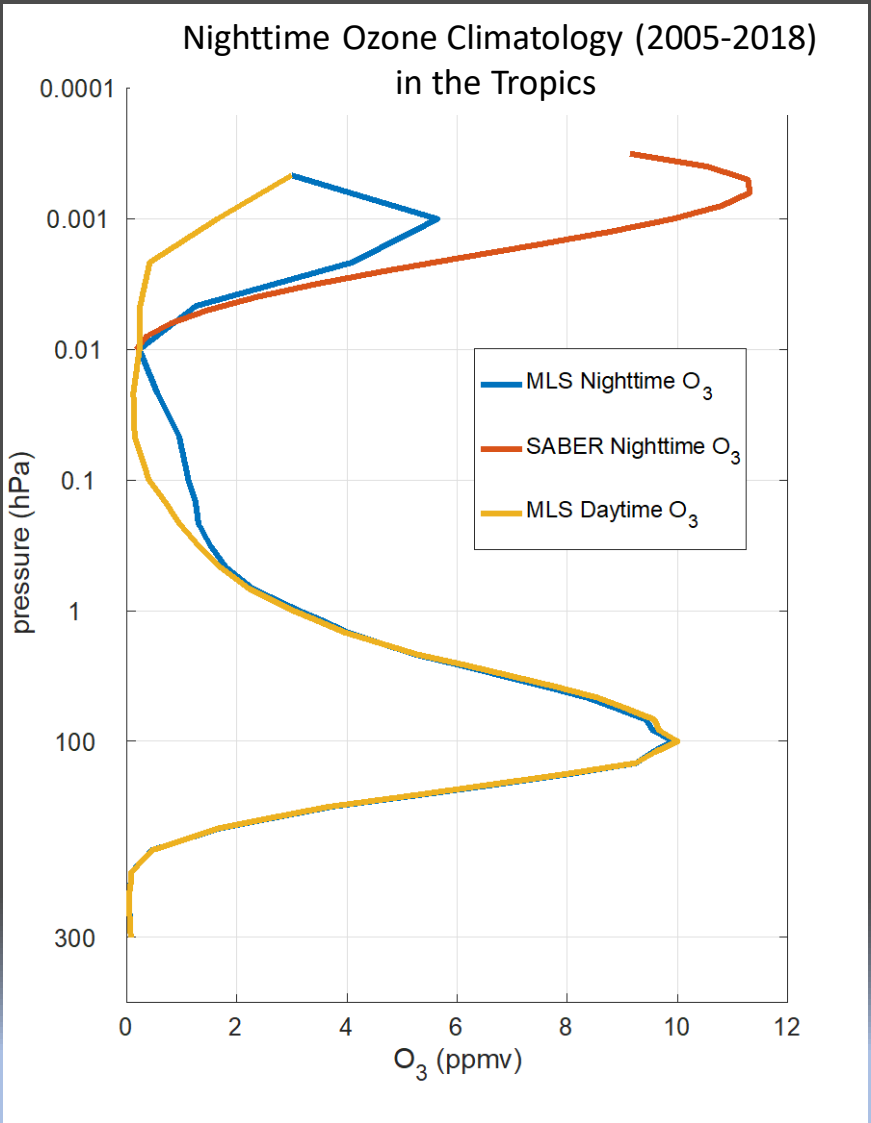
Solar Cycle Modulation of Nighttime Mesospheric Ozone as Observed by MLS

Jae N. Lee[1,2] and Dong L. Wu[2]

1. Joint Center for Earth Systems Technology, University of Maryland, Baltimore County,
2. NASA Goddard Space Flight Center

Acknowledgments : NASA Sun Climate Research
J. Yue and M. Mlynczak, N. Livesey and L. Froidevaux , M. Snow and J. Harder

Secondary Ozone Maximum in the Mesosphere



Production

$O_2 + hv \rightarrow O + O$

$O + O_2 + M \rightarrow O_3 + M$

Loss

$O_3 + hv \rightarrow O + O_2$

$O_3 + O \rightarrow 2\,O_2$

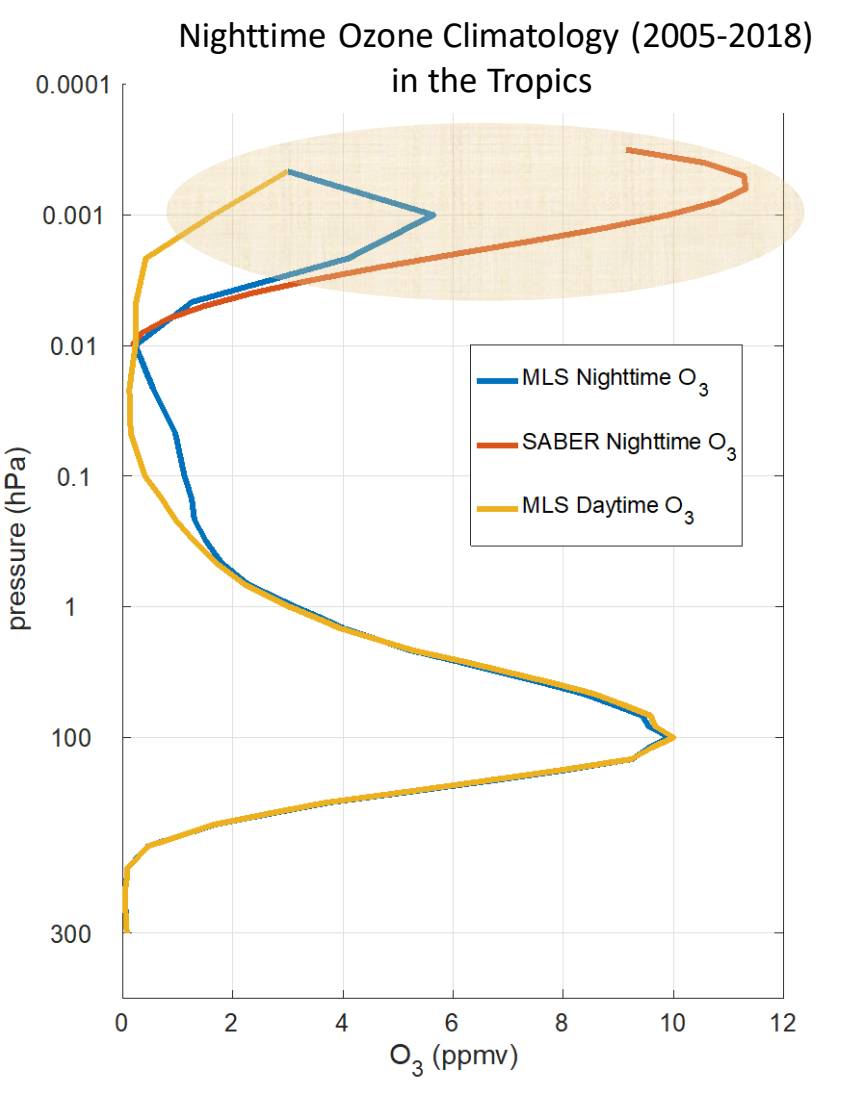
$O_3 + H \rightarrow OH + O_2$

- For mesospheric Ozone, solar radiation is important in chemistry.
- Daytime Ozone is low due to short τ
- less observation with less validation compared to stratospheric O_3

Ozone maximum in the Stratosphere

- Chemistry of NOx and HOx compounds
- Impacted by emissions of ozone depleting substances (i.e. CFCs)
- largely driven by ENSO and QBO

Secondary Ozone Maximum in the Mesosphere



Production

$O_2 + hv \rightarrow O + O$

$O + O_2 + M \rightarrow O_3 + M$

Loss

$O_3 + hv \rightarrow O + O_2$

$O_3 + O \rightarrow 2\,O_2$

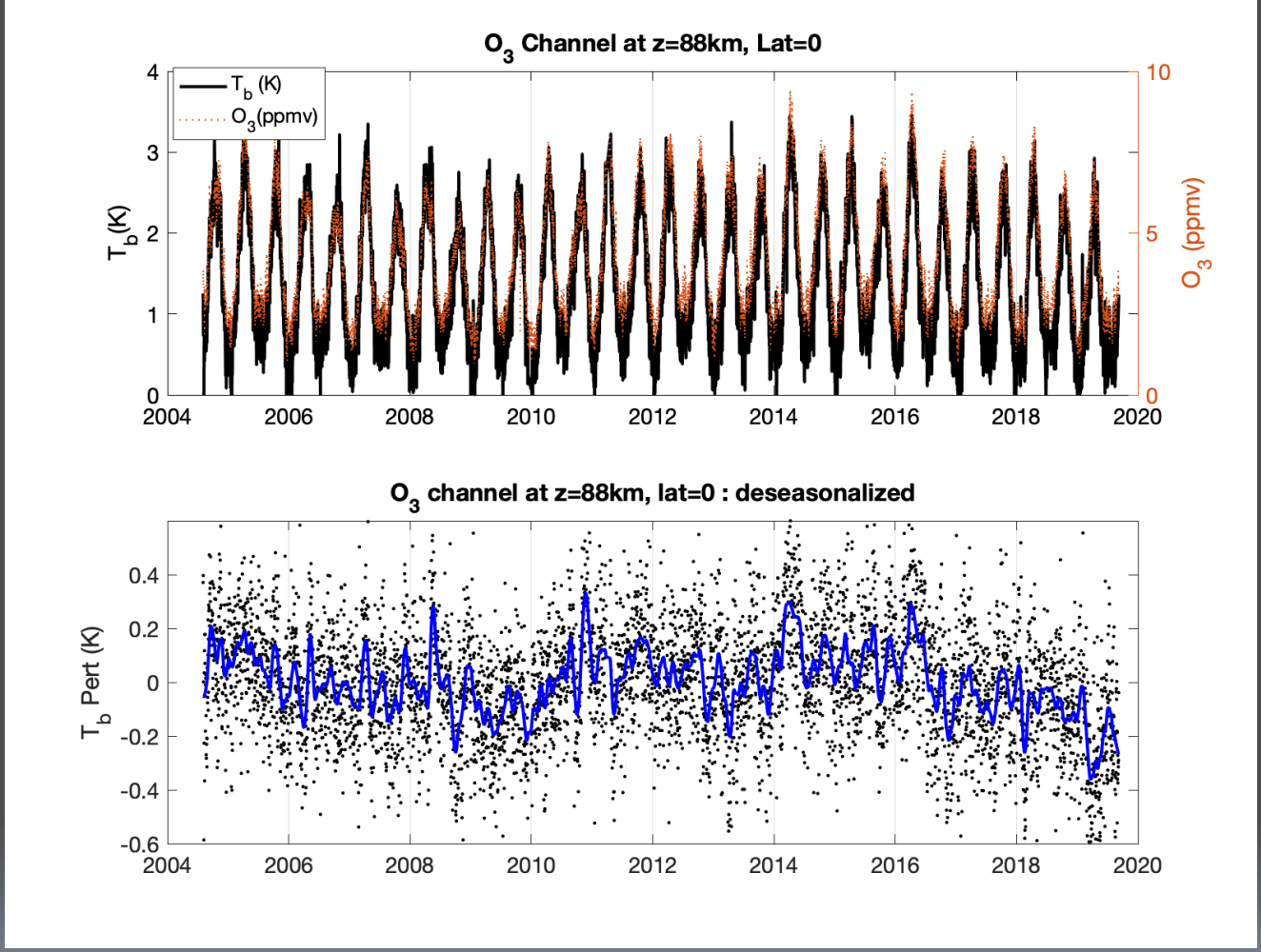
$O_3 + H \rightarrow OH + O_2$

- For mesospheric Ozone, solar radiation is important in chemistry.
- Very low Daytime Ozone due to short τ
- less observation with less validation compared to stratospheric O_3

Ozone maximum in the Stratosphere

- Chemistry of NOx and HOx compounds
- Impacted by emissions of ozone depleting substances (i.e. CFCs)
- largely driven by ENSO and QBO

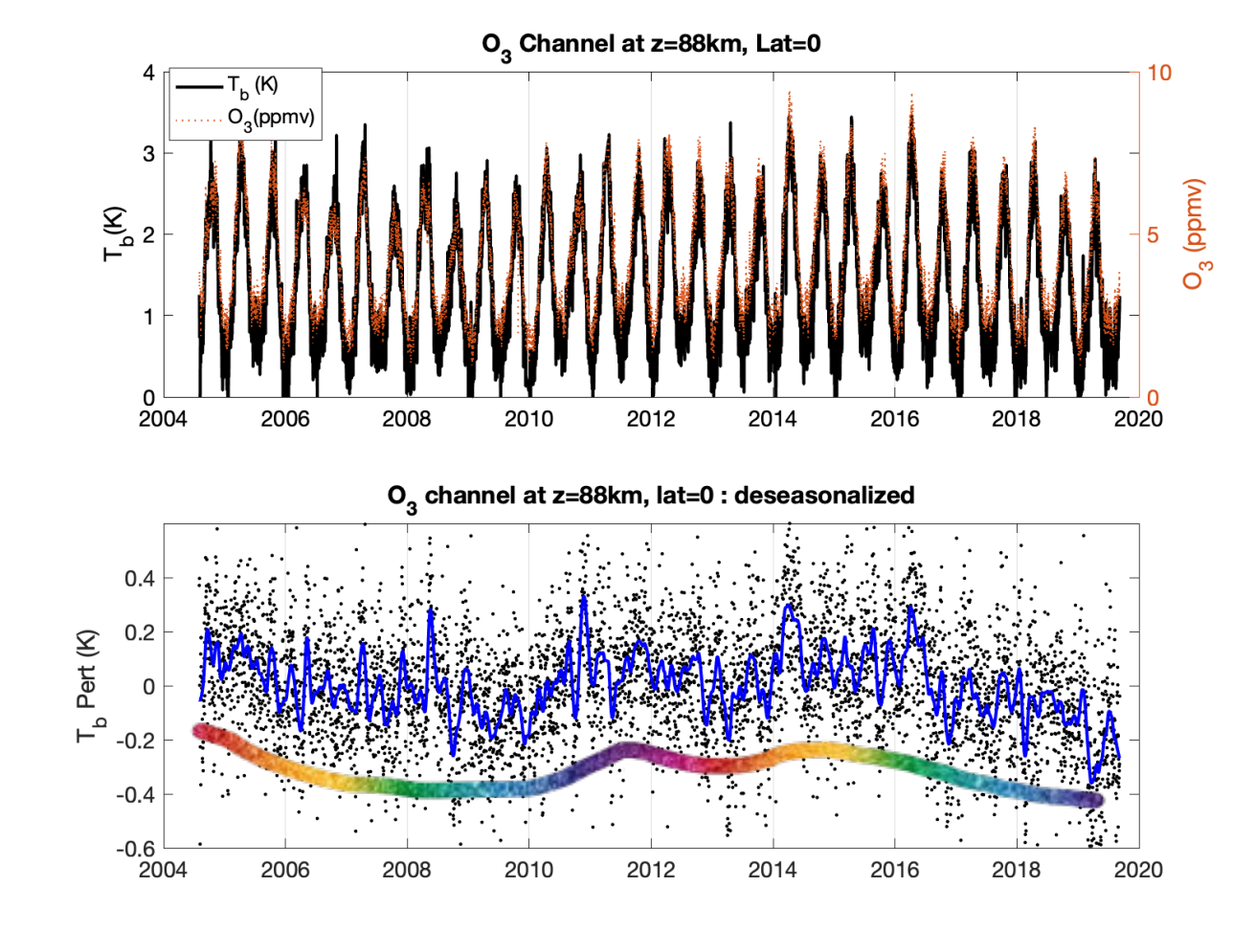
Feasibility of mesospheric Ozone data at secondary Ozone maximum



- 15-years measurement of MLS nighttime mesospheric Ozone data with MLS radiance in 235.71 GHz at 88 Km
- Both data show similar semi-annual cycle

Lee and Wu [2020] , *JGR, in review*

Feasibility of mesospheric ozone data at secondary ozone maximum

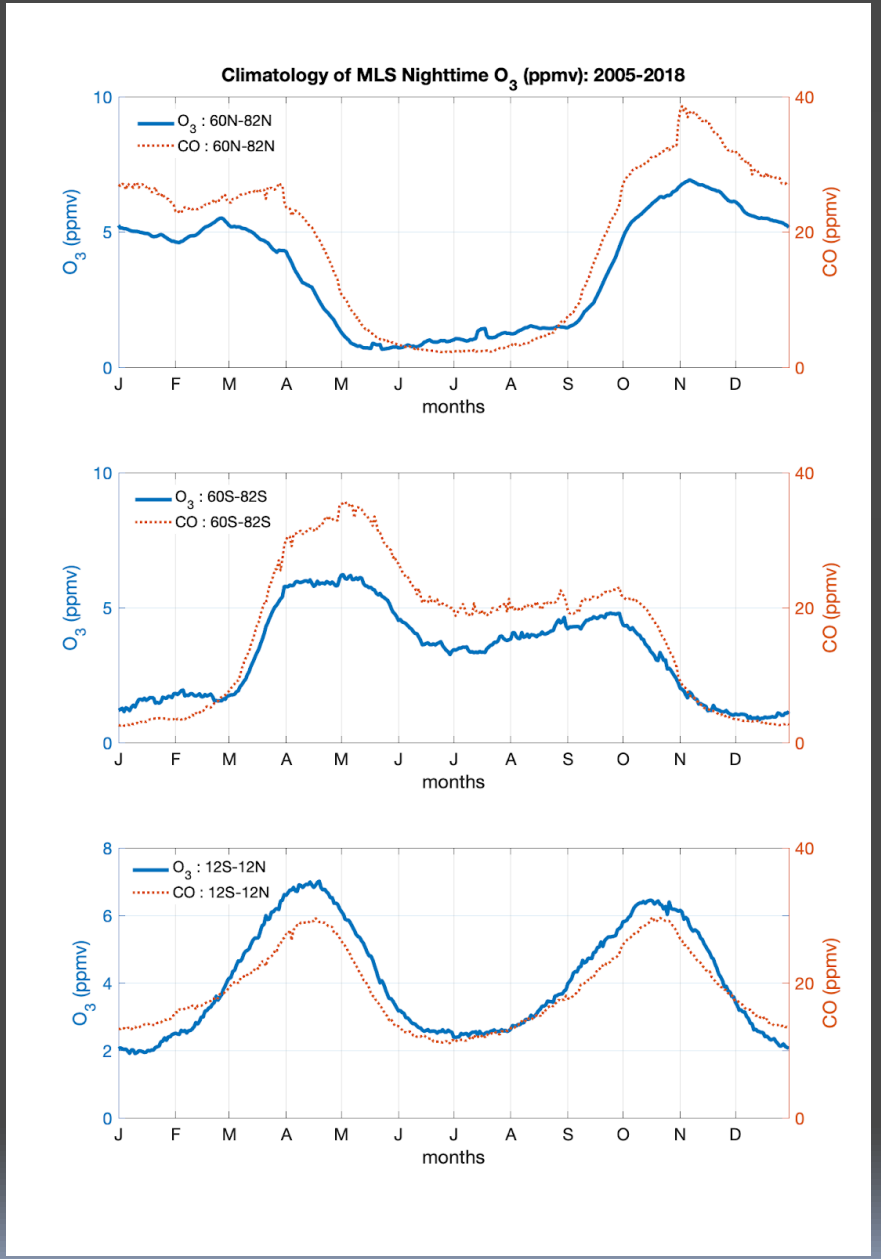


- 15-years measurement of MLS nighttime ozone data is compared with MLS radiance in 235.71 GHz at 88 Km
- De-seasonalized time series of radiance shows inter-annual variation comparable to 11-yr solar cycle
- Validated that MLS ozone at this level (0.002hPa) contains useful information

Seasonal Climatology of Mesospheric Ozone (and Carbon Monoxide) in 2005-2018 at 0.002 hPa

- Seasonal variations of MLS nighttime ozone and nighttime CO are very similar

- Maximum amount in local winter
- Minimum amount in local summer
- Semi-Annual Oscillation (SAO) are present
- Secondary peaks at local spring in high latitudes
- Equally dominant peaks in the tropics

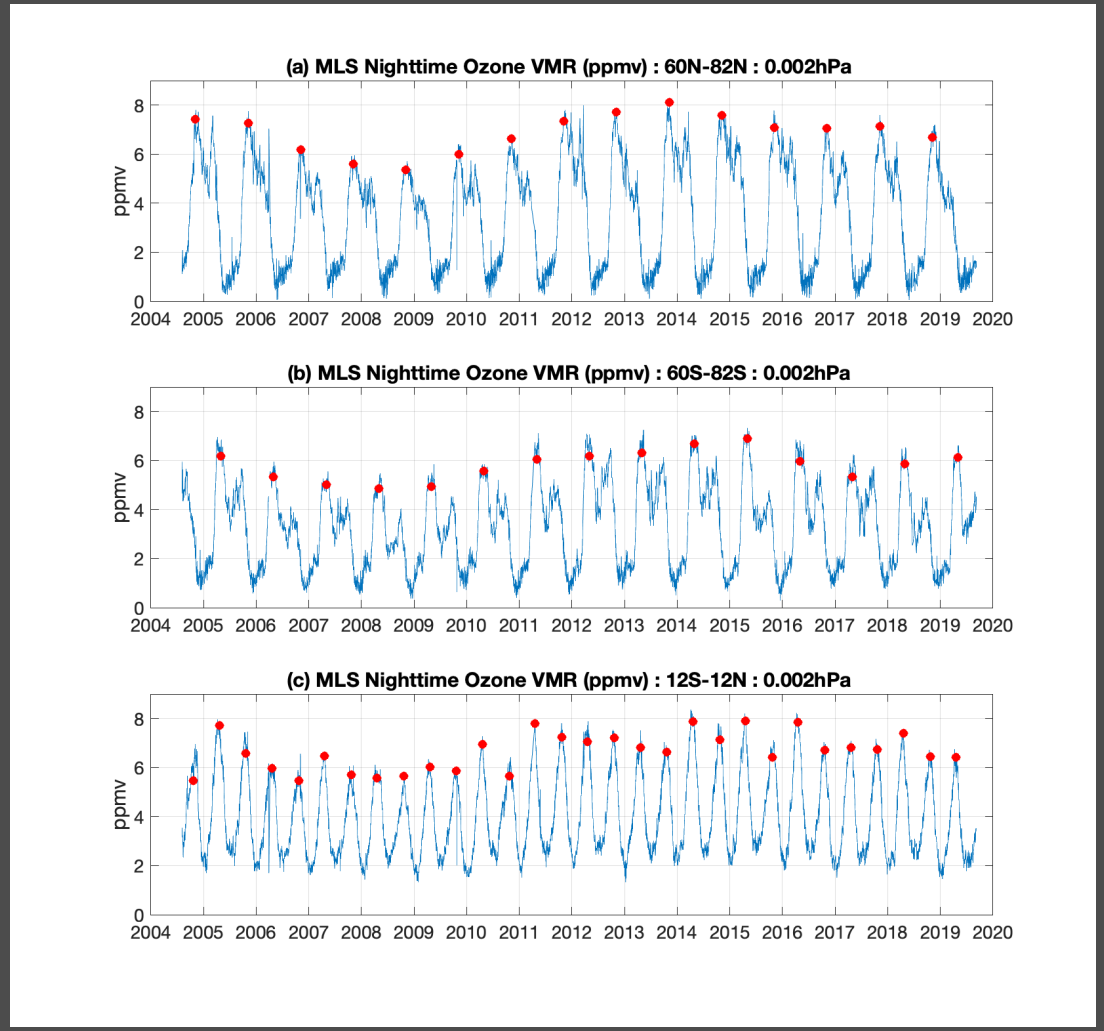


NH

SH

Tropics

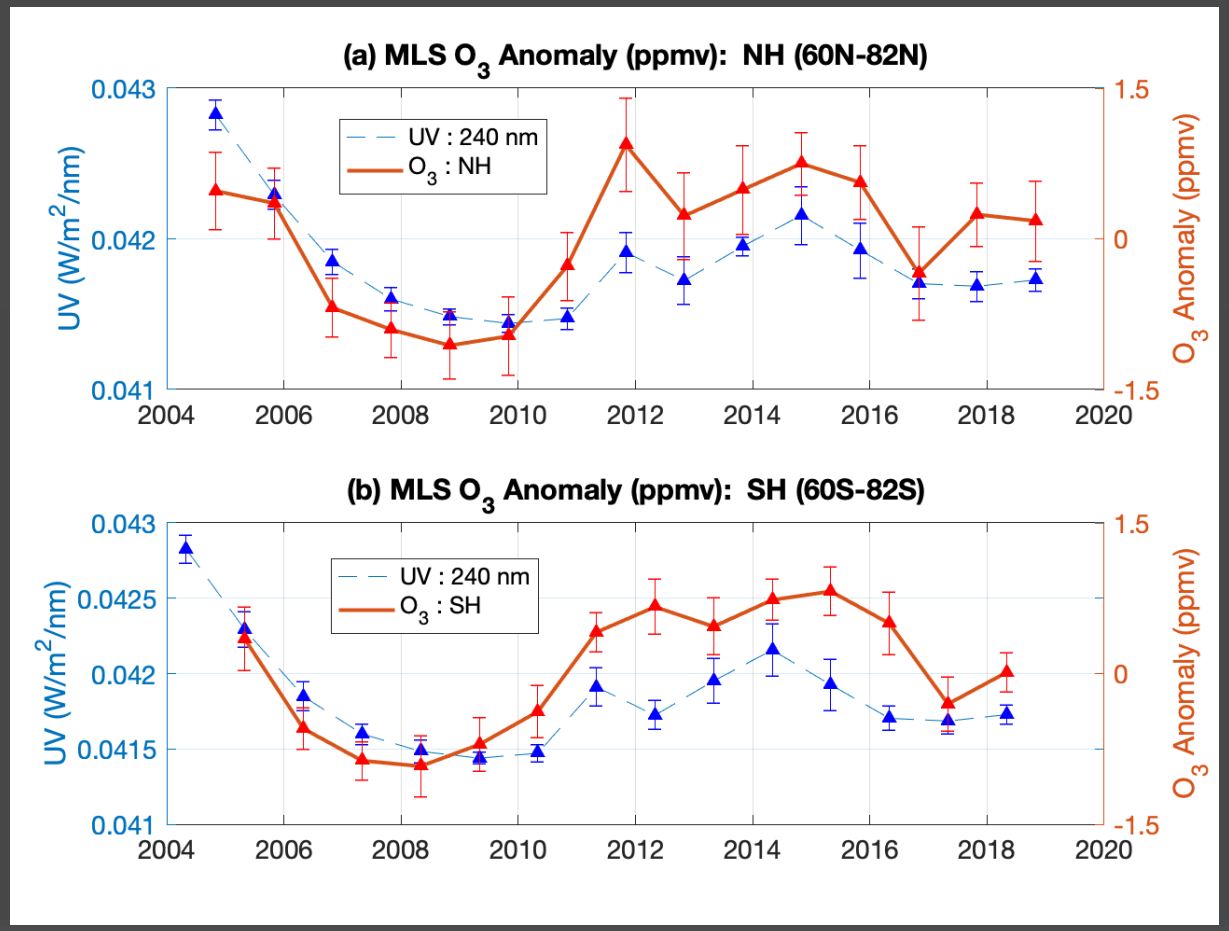
Inter-annual variation of MLS nighttime mesospheric Ozone at 0.002 hPa



- 15-yrs of MLS nighttime ozone data shows ~ 20% of inter-annual variability associated with 11-year solar cycle in high latitudes.

Lee and Wu [2020], *JGR, in review*

Solar cycle variation of nighttime mesospheric ozone at 0.002hPa



SC 23 SC 24

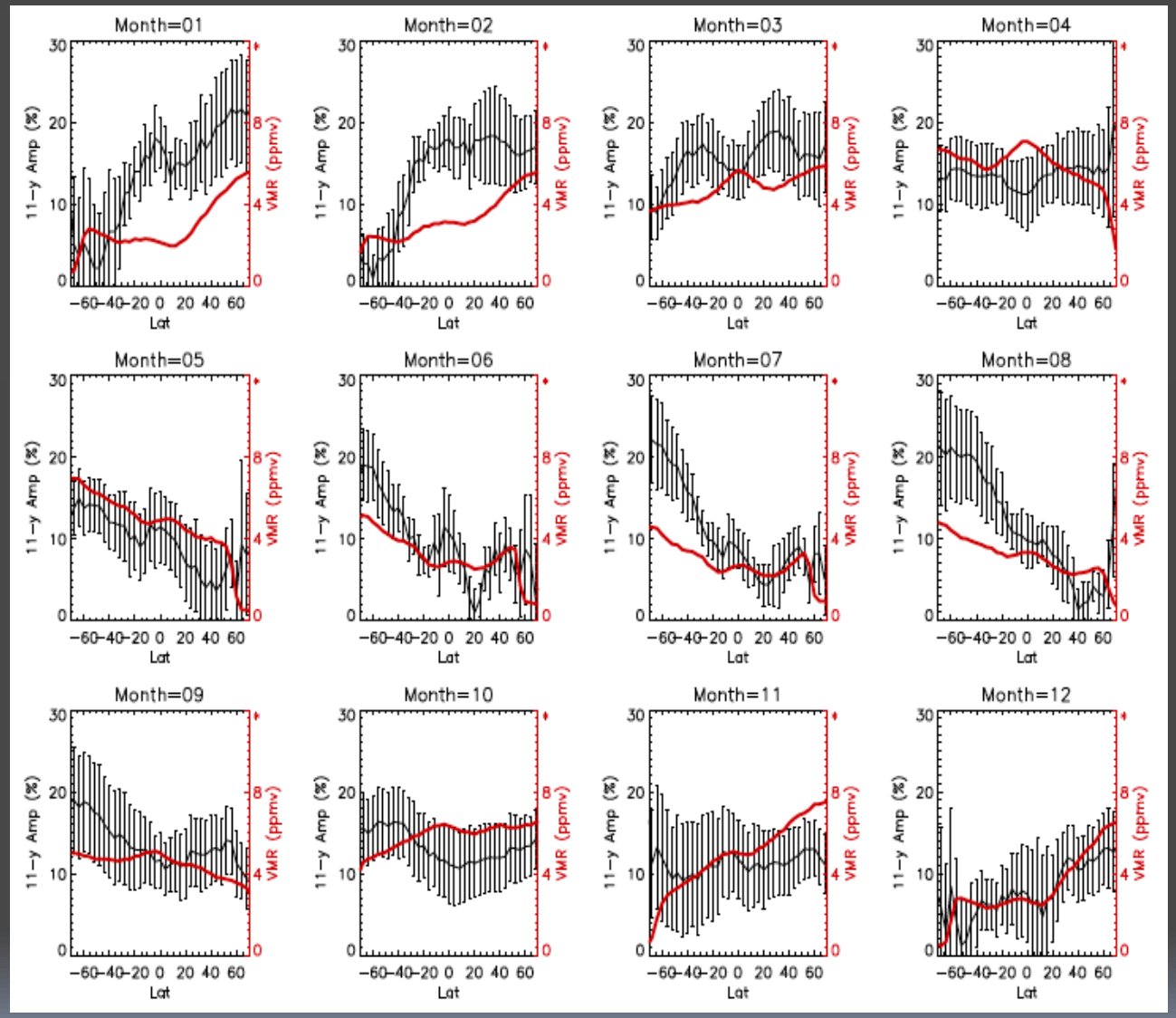
- MLS nighttime Ozone local winter anomaly is overlaid with SOLSTICE measured UV
- Nighttime ozone shows in-phase variation with UV at 240 nm
- ~20% of solar cycle variation
- While nighttime ozone increases with UV in the upper mesosphere, lower mesospheric ozone is expected to be decreased

Increased ozone → less UV is transmitted to lower Mesosphere → less O_2 photolysis → less O_3

Solar cycle variation and zonal mean distribution of Ozone

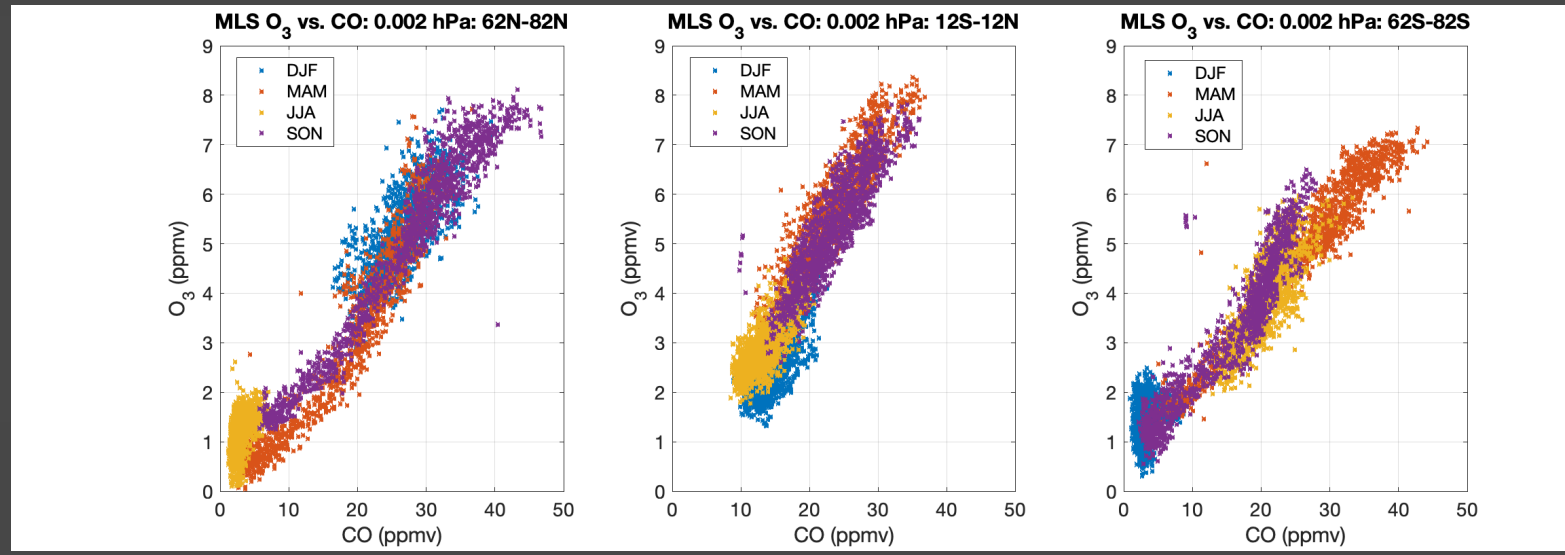
The amplitude of 11-year variation of nighttime O_3 (in percentage). Overlaid red curves are zonal mean O_3 VMR.

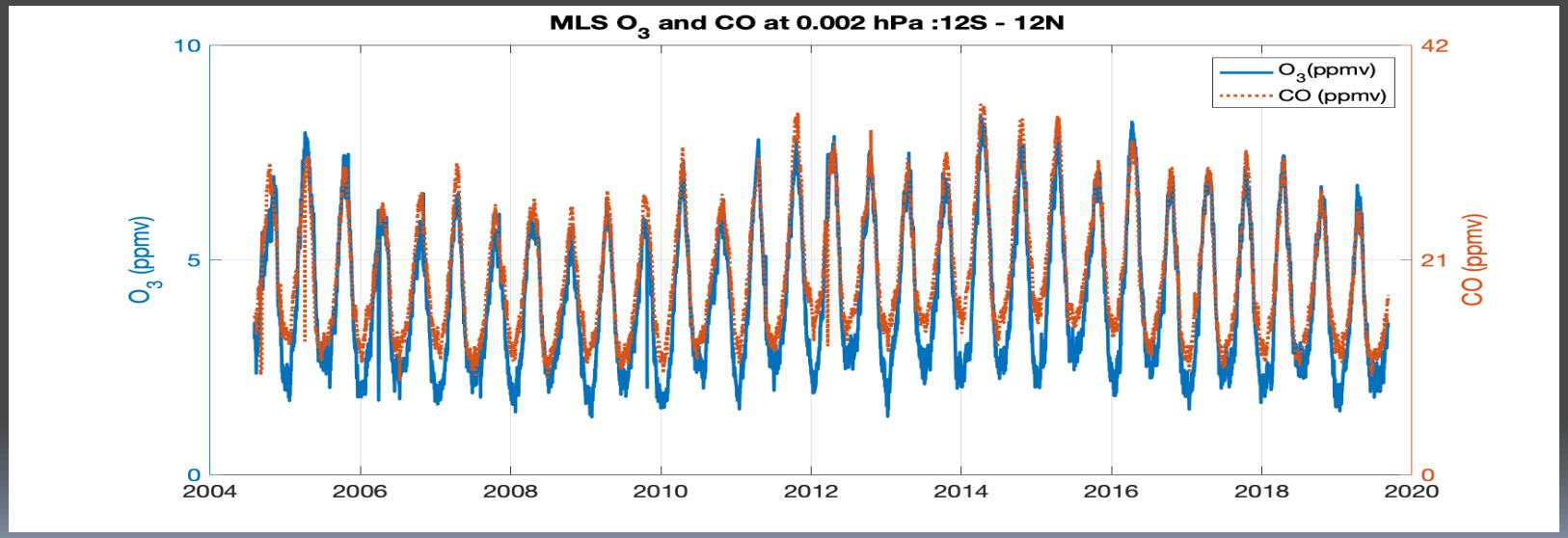
- Amplitude of solar cycle variation is not always proportional to the zonal mean ozone amount.
- Indicating dynamic control is also effective besides direct photo-chemical effect
- Spring time (March and April) tropical Ozone enhancement is due to longer lifetime of Ozone caused by low Eddy diffusion (kzz)



Correlations between Ozone and CO

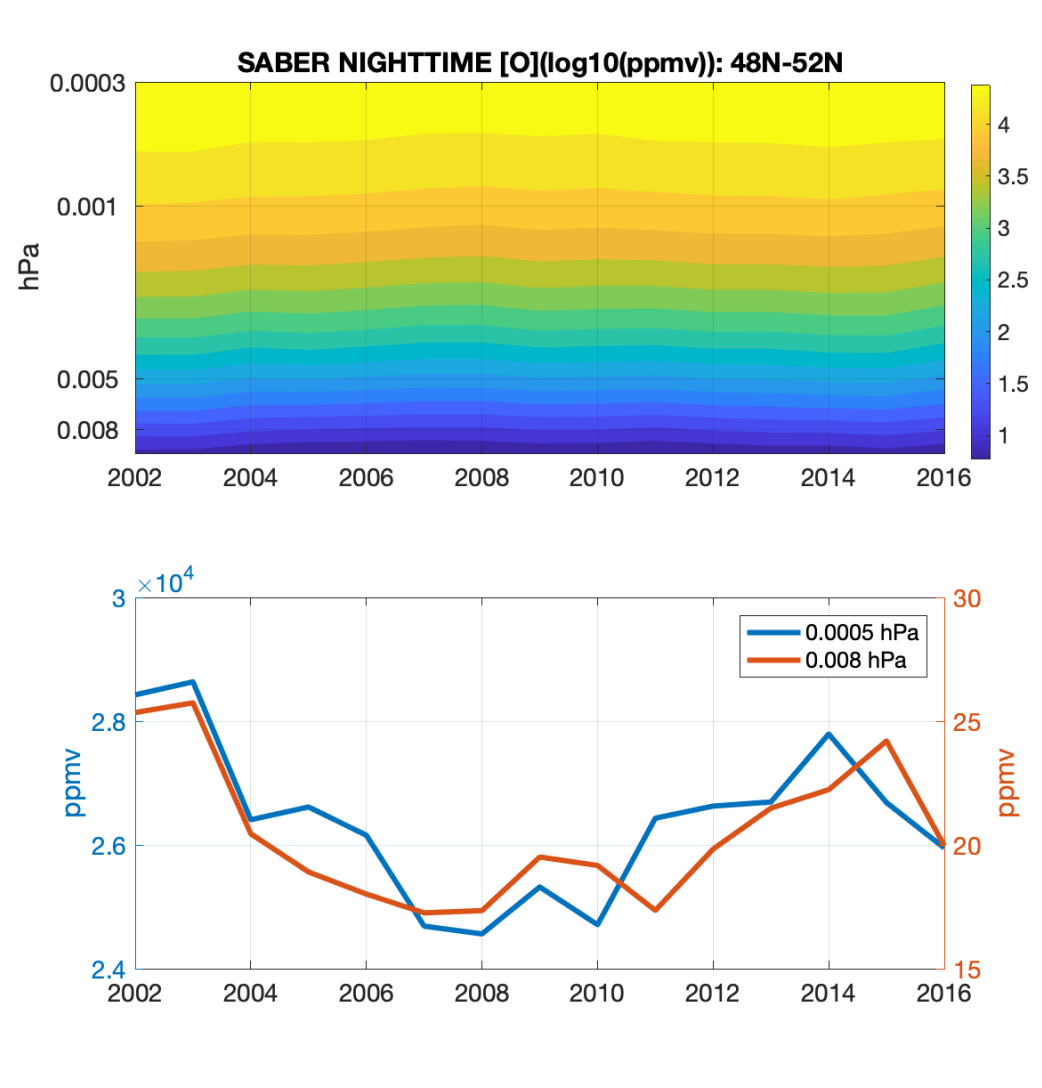
- Ozone and CO are highly correlated because both are strongly depending on UV photolysis and dynamics
- Same seasonal and solar cycle variations are expected.





- Similar SAO can be explained by Eddy diffusion (Kzz)
- High Kzz during summer induces low Ozone and CO.

Contribution of [O] to solar cycle variation of Ozone



Production

$O_2 + hv \rightarrow O + O$

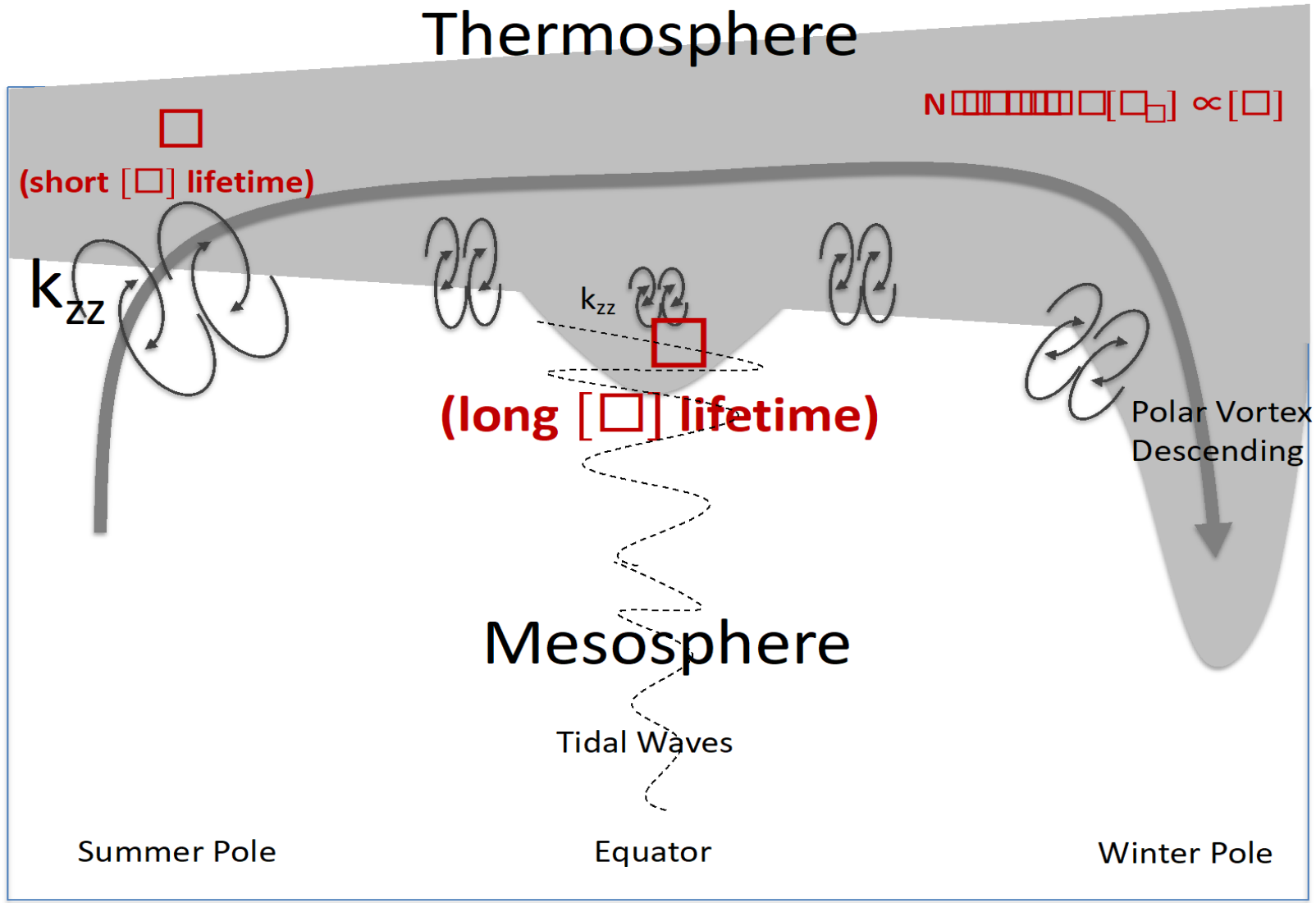
$O + O_2 + M \rightarrow O_3 + M$

Nighttime [O_3] is proportional to UV and proportional to [O]

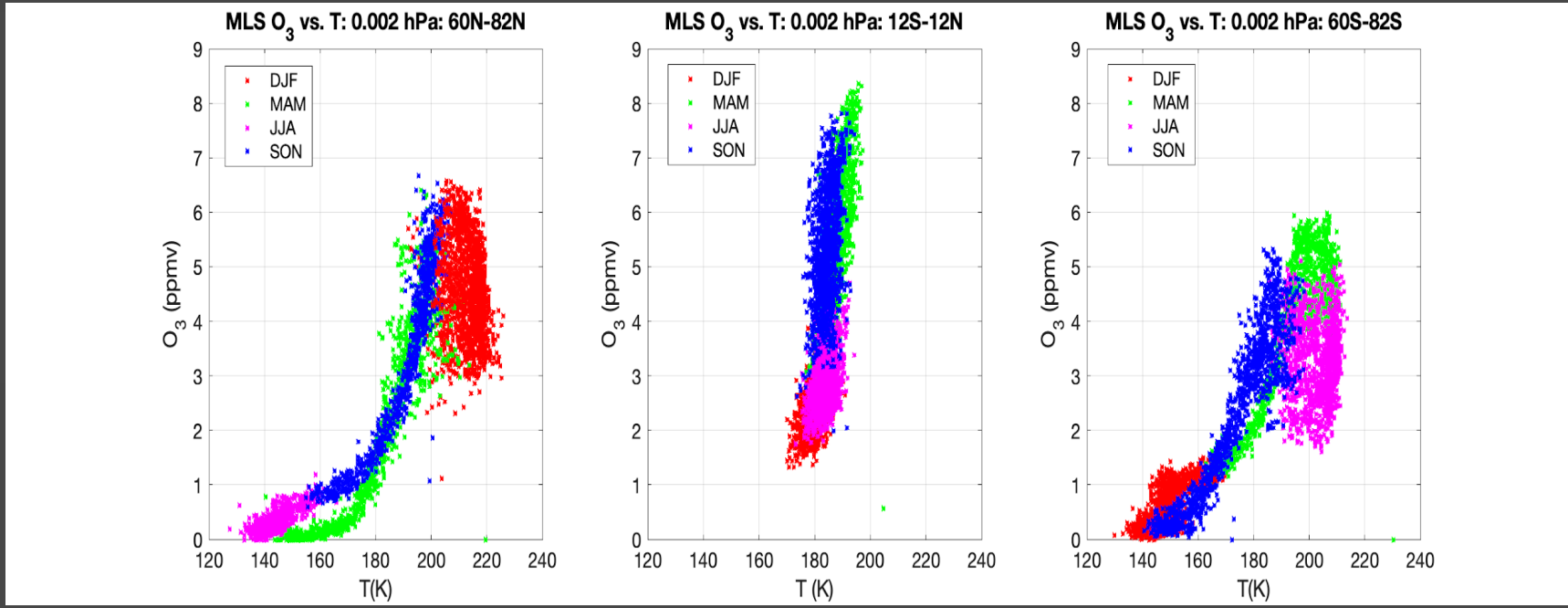
[o] variation is an important factor of mesospheric Ozone variation

- SABER derived nighttime [O] increases exponentially with height
- ~35% of solar cycle variations are nearly same at UM and LT

Summary


Thermosphere
(short [□] lifetime)
k_{zz}
k_{zz}
(long [□] lifetime)
Polar Vortex
Descending
Mesosphere
Tidal Waves
Summer Pole
Equator
Winter Pole

Correlations between ozone and temperature



Temperature dependence of nighttime ozone is not monotonously positive nor negative, indicating complex roles of temperature in ozone chemistry and middle atmosphere dynamics.

- There are apparent co-existing positive and negative correlations.
- Strong positive temperature dependence during fall (SON) is found in all three latitude bins.
- For other seasons, the temperature-ozone correlations are generally positive, except northern high latitude winter.