Further evidence of solar cycle variability in middle atmospheric ozone and the importance of incorporating solar spectral irradiance in atmospheric modeling

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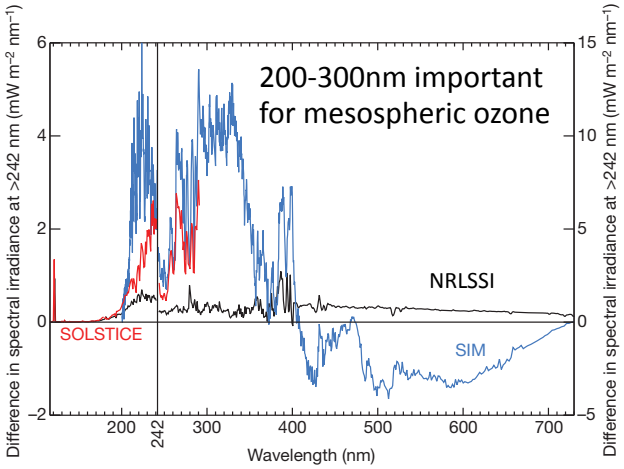
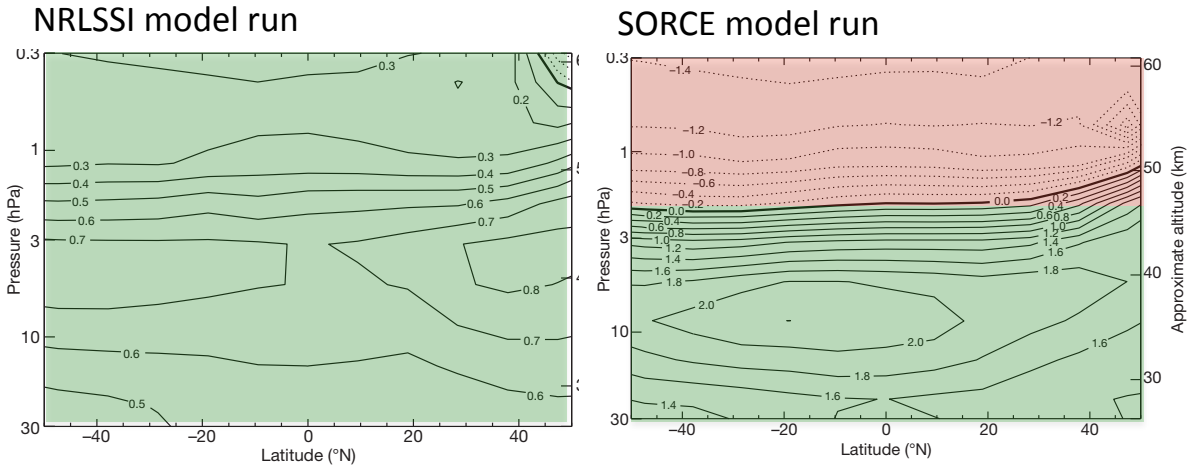
It all started with Haigh et al. *Nature 2010*

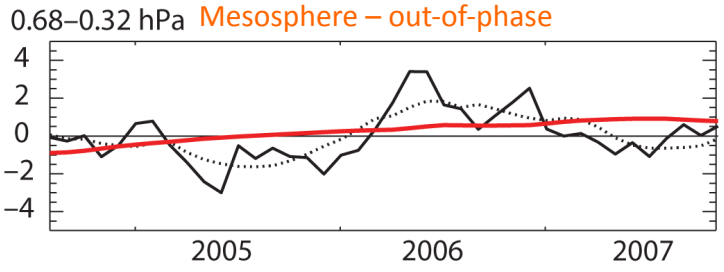
SSI influence study using a 2-D (latitude-height) radiative-chemical-transport model of the atmosphere (IC2-D).

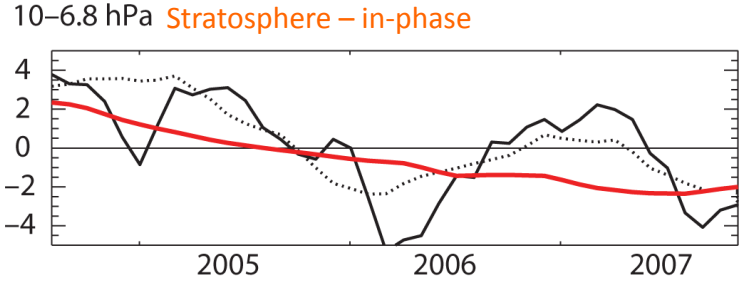


Modeled ozone response (max-min)



MLS ozone regression





Decreased ozone at solar max.

Deseasonalized monthly mean
Trend from 4-component regression
Solar component

C:\LASP documents\2010\11_november\AGU2010\IllustratorDocs\MLS_Haigh.ai

Merkel et al. 2011

GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L13802, doi:10.1029/2011GL047561, 2011

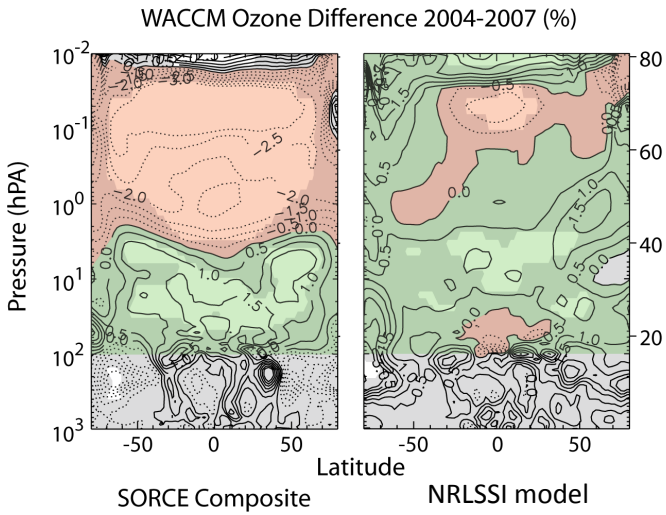
WACCM

3-D fully coupled chemistry, radiation and dynamics global model.

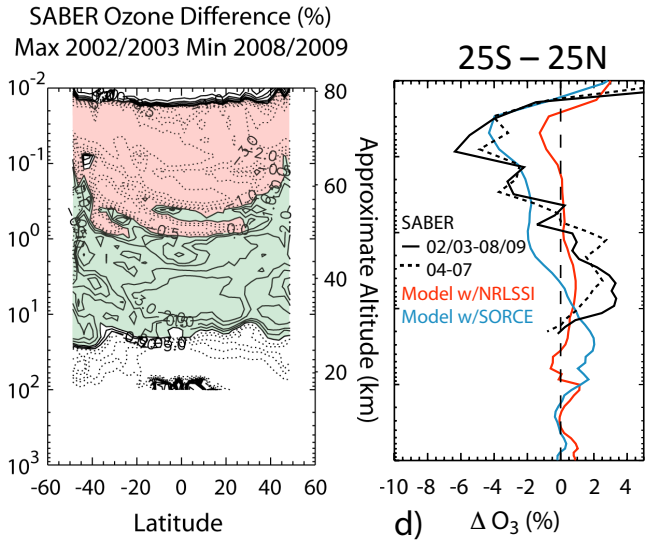
TIMED/SABER

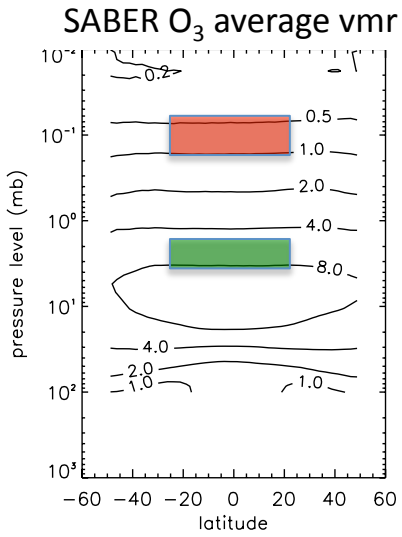
O_3 emission measurements from the 9.6µm channel – Version 1.07

Simulate Irradiance Changes in WACCM

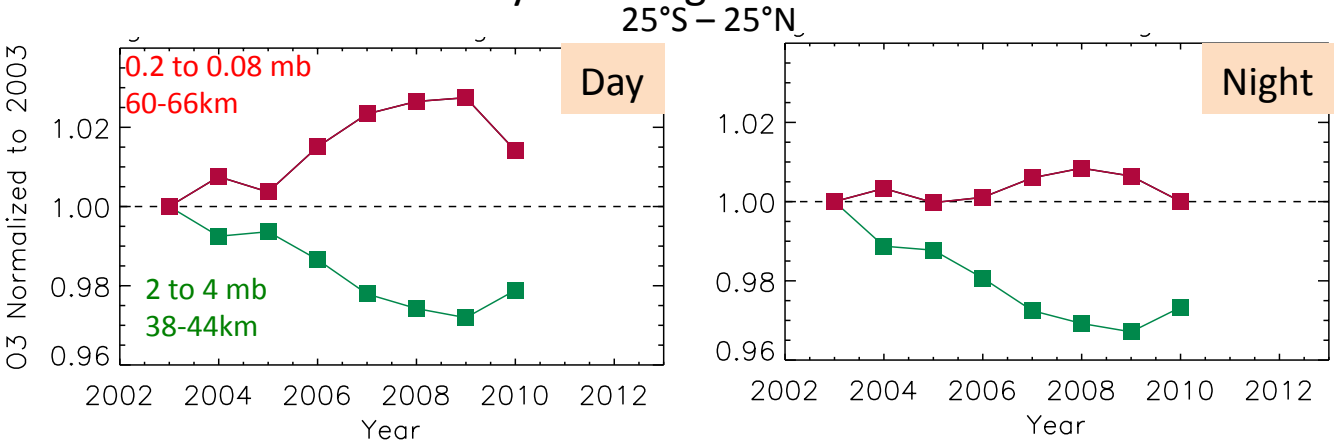


Compare Simulations with SABER Observations





SABER ozone: 2-yr running annual zonal mean trends



Descending phase of SC23

SSI Solar Forcing and Earth Atmospheric Response

Understandably, this discovery revitalized the irradiance and atmospheric modeling communities. Lots of recent modeling activity!

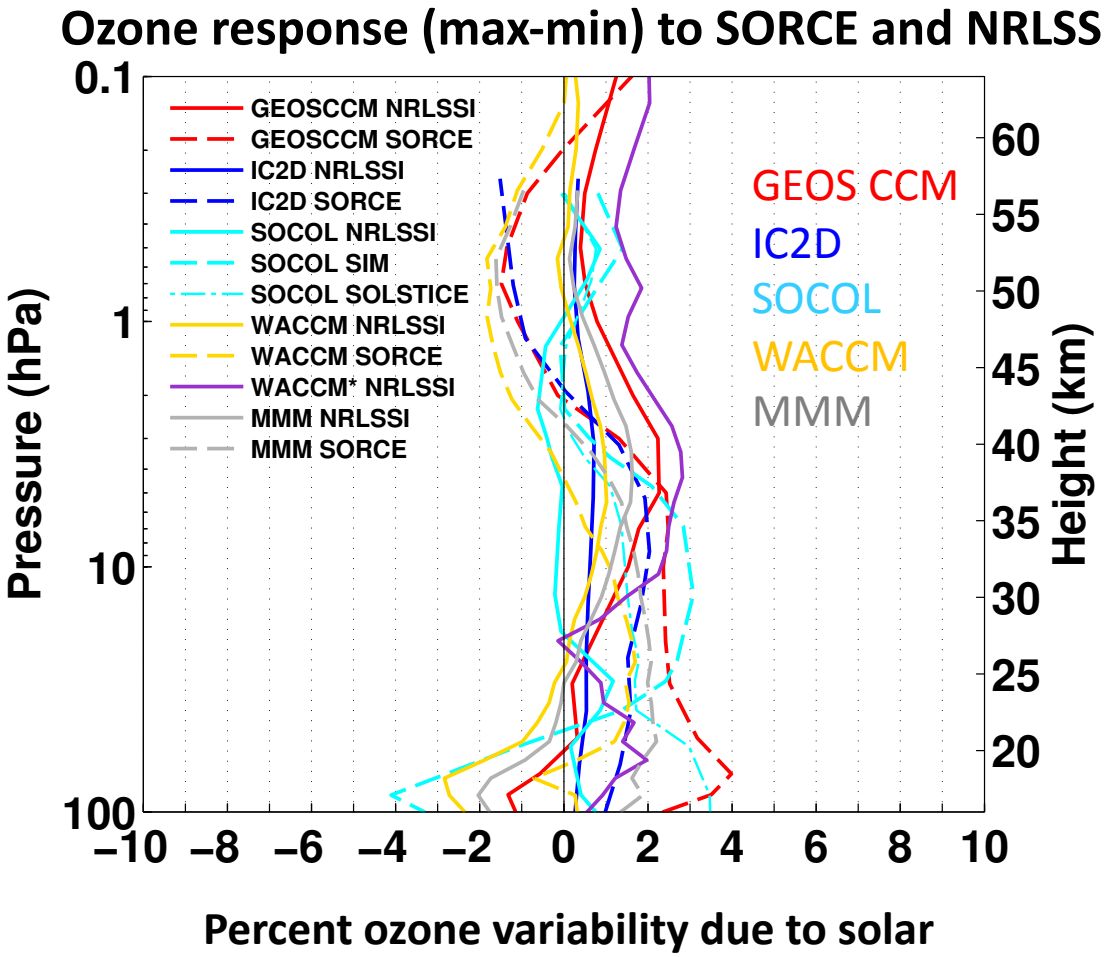
Author	Reference	Model/Topic
Haigh *et al.*	Nature, 2010	IC2D model/SC Ozone
Cahalan *et al.*	GRL, 2010	GISS ModelE/Trop. Temp.
Merkel *et al.*	GRL, 2011	WACCM/SC ozone & TIMED SABER
Ineson *et al.*	Nature Geosci., 2011	HadGEM3/NAO
Oberländer *et al.*	GRL, 2012	EMAC-FUB/Strat. temp
Swartz *et al.*	ACP, 2012	GEOS CCM/ Strat. Ozone & temp
Wang *et al.*	PNAS, 2013	WACCM/MLS & grnd based hydroxyl
Shapiro *et al.*	JGR, 2013	SOCOL/SC response
Wen *et al.*	JGR, 2013	GISS ModelE/Temp. response
Ineson et al.	(in preparation)	HadGEM3/NAO/CMIP5 study, Maunder Minimum response

Modeling studies focusing on SSI implications:

- Photochemistry
- Radiative response
- Circulation - NAO
- "Top down" vs "Bottom up"

Compiled Modeling Results

In the Ermolli et al. 2013 *ACP* paper, Katja Matthes (GEOMAR, Germany) compiled the results of these modeling studies.



Questions and Debate

Now there is suggestive evidence of this surprising SC signal in mesospheric ozone measurements that you can only get if more UV variability is incorporated into atmospheric models. Lots of questions and debate.

Solar questions:

- Integrity of the SORCE dataset (Degradation corrections?)
- Why do previous measurements at these wavelengths disagree with SORCE?
- Can we use a solar spectrum scaled by a variability proxy (TSI, MgII, Lyman α, F10.7) as a standard to characterize the sun in atmospheric models?
- Do all wavelengths vary the same way as TSI?
- How good do the solar measurements need to be? Gaps in timeseries?
- Does this variability only pertain to SC23-24 or has it been there all along?

Atmospheric questions:

- Integrity of the ozone measurements. Why haven't we seen this signal before?
- Why is the mesospheric signal out of phase with solar cycle and different than stratospheric ozone?
- Is this a special solar cycle? Is it in previous measurements?
- What does this mean for the modeling community? Is a SSI proxy good enough for atmospheric modeling studies? Are we missing important SC variability?

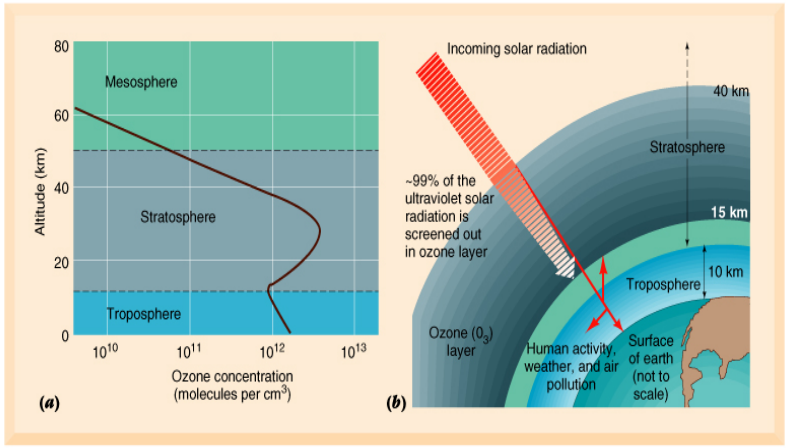
Interesting Conundrum

- The modelers - want the solar physicist to give them something to put in their models. Most models have been upgraded to included SSI on a daily cadence.

- The solar physicist - want the modelers to tell them how good they need to measure the Sun.
  - Good enough is different depending on the model, atmospheric region studied, type of model (photochemistry, radiative).

- Work in progress: We are having a workshop next month with the NCAR folks to discuss this very thing.

Understanding Mesospheric Ozone Variability

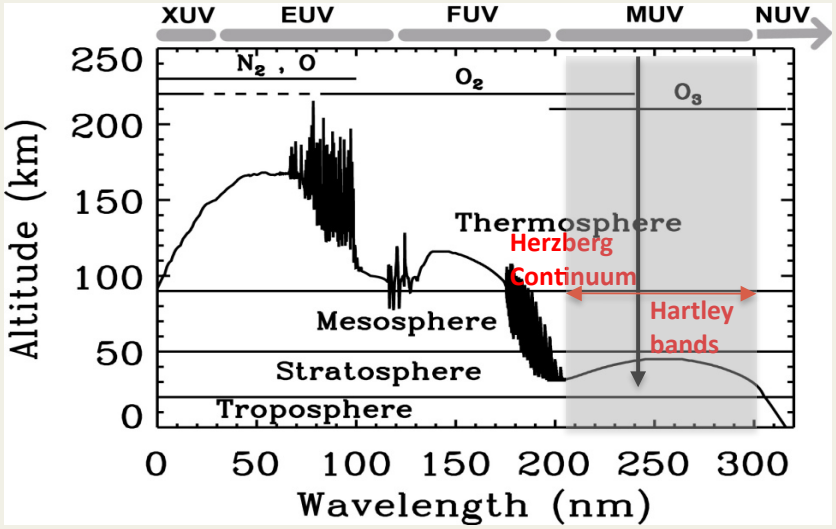


Source: Ozone concentrations from R. T. Watson, "Atmospheric Ozone," in J. G. Titus, ed., *Effects of Change in Stratospheric Ozone and Global Climate*, vol. 1, Overview, U.S. Environmental Protection Agency, p. 70. Copyright 2000 John Wiley and Sons, Inc.

Top of the atmosphere ozone~ 1% of total column

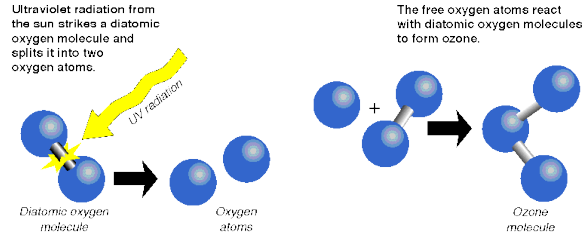
- Dominated by photochemistry.
- Photochemical lifetime is hours.
- Strong diurnal component. Local time is important for solar cycle analysis.
- More UV causes more loss of ozone at solar maximum. Loss due to photolysis and catalytic cycles with OH and H.

Mesospheric ozone influenced by the solar radiation in the 200-300nm band. (production and loss)



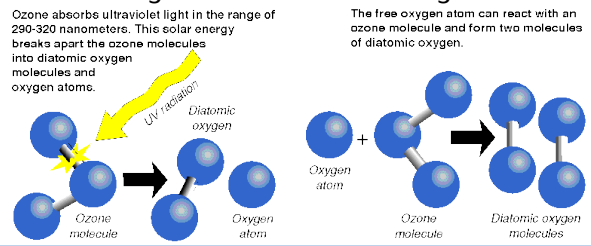
Herzberg Continuum (200-242nm)

J2 rate: O_2 Photolysis ➔ O_3 production



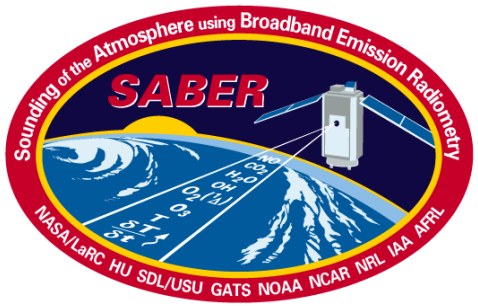
Hartley Bands (200-300nm)–

J3 rate - O_3 Photolysis ➔ O_3 loss



TIMED/SABER Ozone – 12 years of ozone data

We can now look at the ascending phase of solar cycle 24. Did the mesosphere respond?

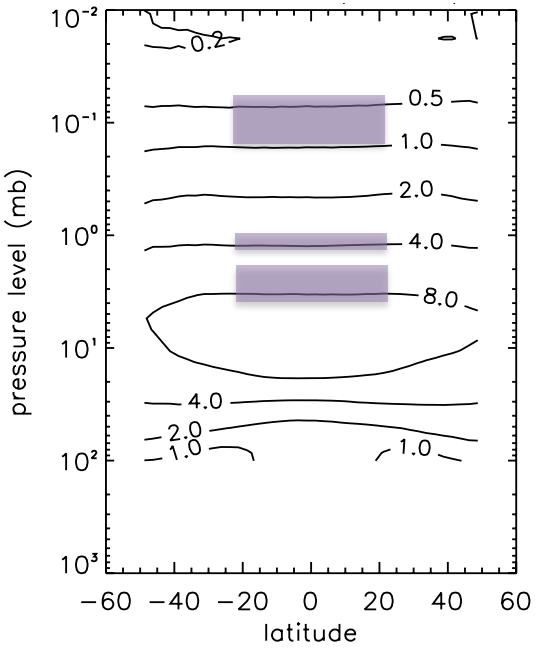


- Data now spans from 2002 – 2013 (12 years of data)
- Recently updated to Version 2 – Reprocess all results
- 9.6µm channel – O_3 emission measurements
- Version-2 data validated by A. Smith (NCAR) 2012. Known systematic bias compared to other ozone measurements. Bias is constant over time, so does not influence differences.

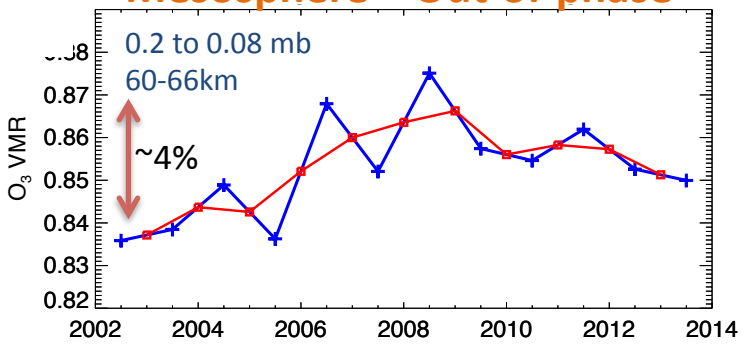
SABER Ozone Time Series – Yearly average

Equatorial average time series

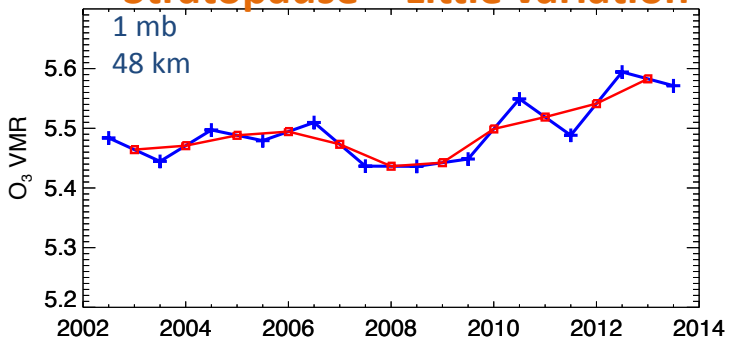
SABER O_3 Average vmr



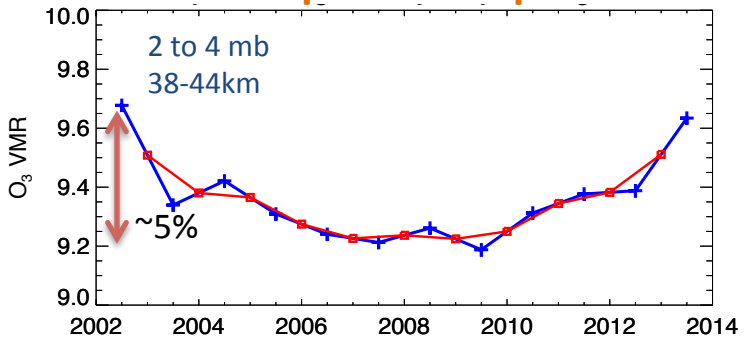
Mesosphere – Out-of-phase



Stratopause – Little variation

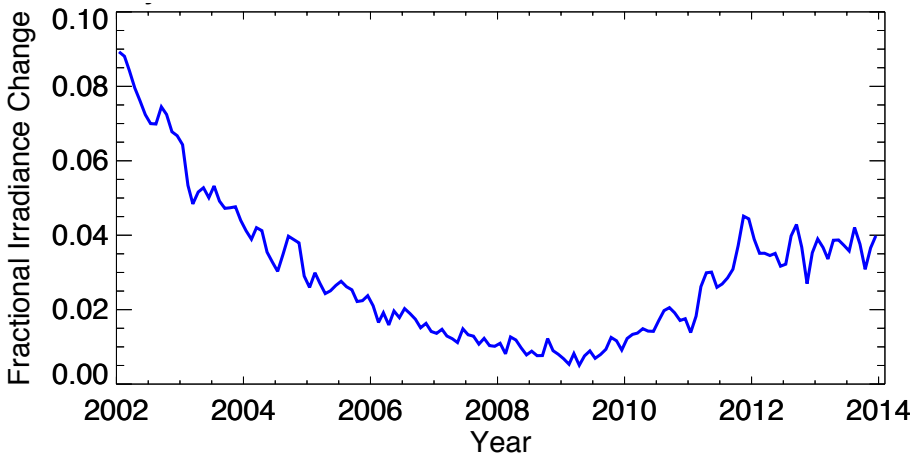


Stratosphere – in-phase



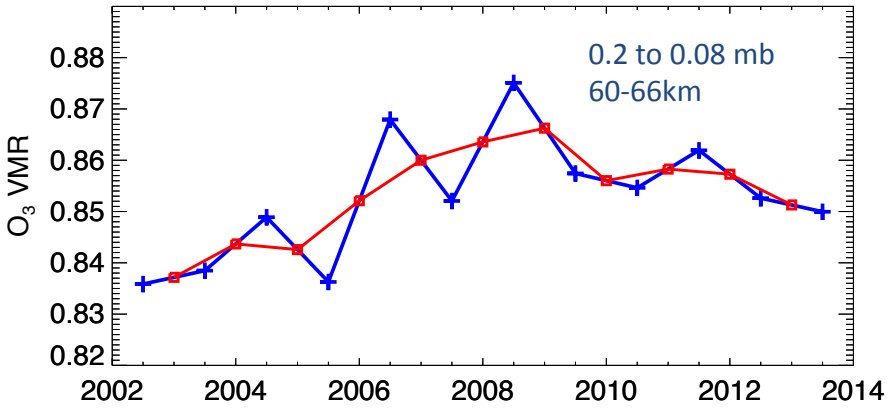
SABER Ozone Time Series

Irradiance Variability
Active Area Network -PSPT
SIM 240-260nm

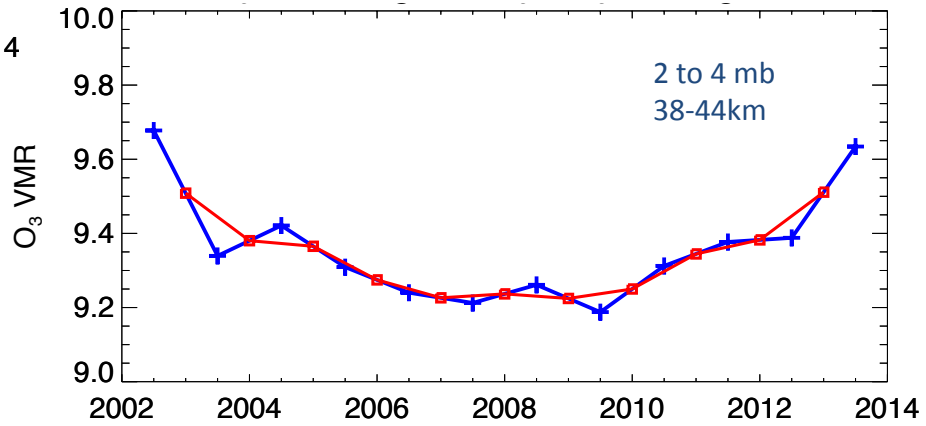


Courtesy of Jerry Harder

Mesosphere – Out of phase



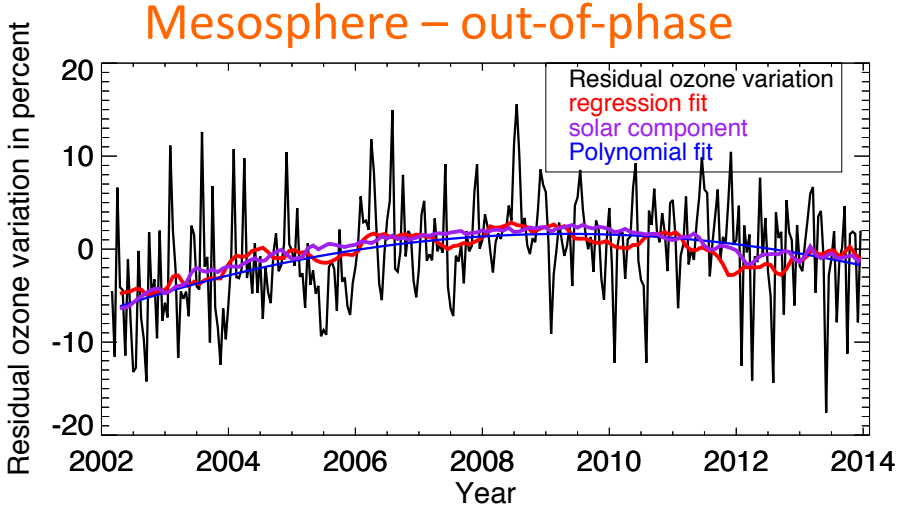
Stratosphere – in phase



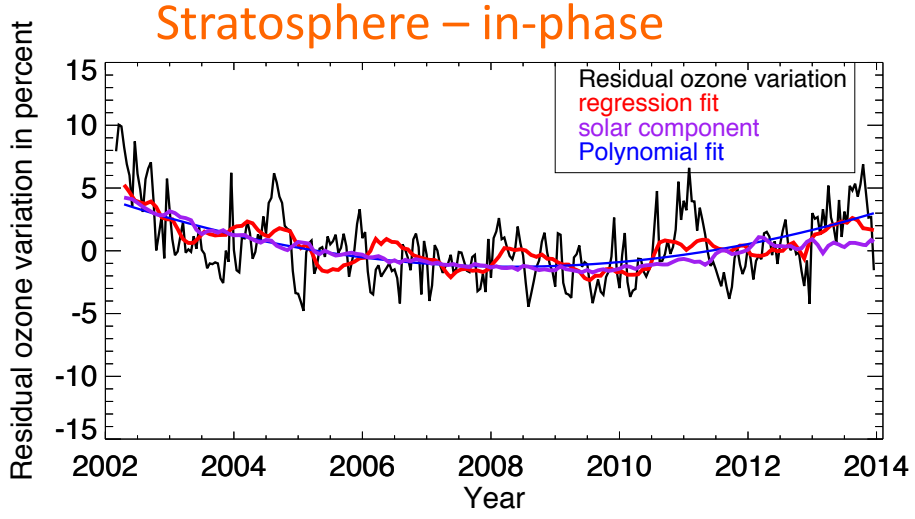
SABER Regression Analysis

4-component regression, deseasonalized time series at each pressure level.
Solar, Annual, 2-QBO

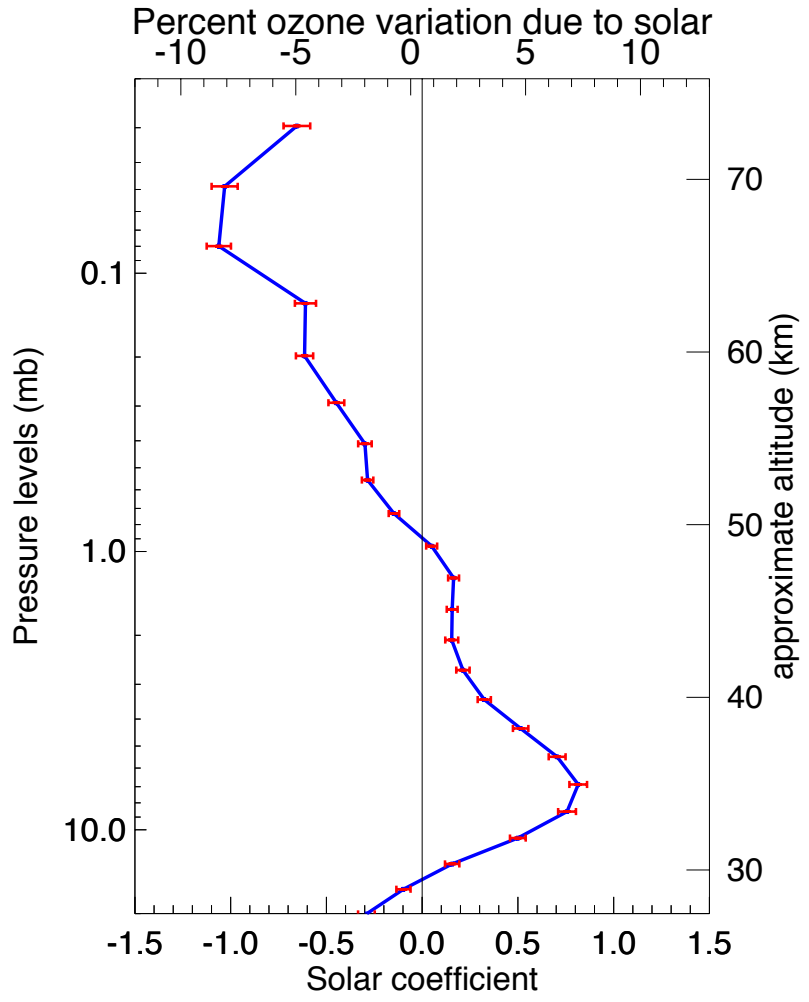
Mesosphere – out-of-phase



Stratosphere – in-phase



Solar Coefficient



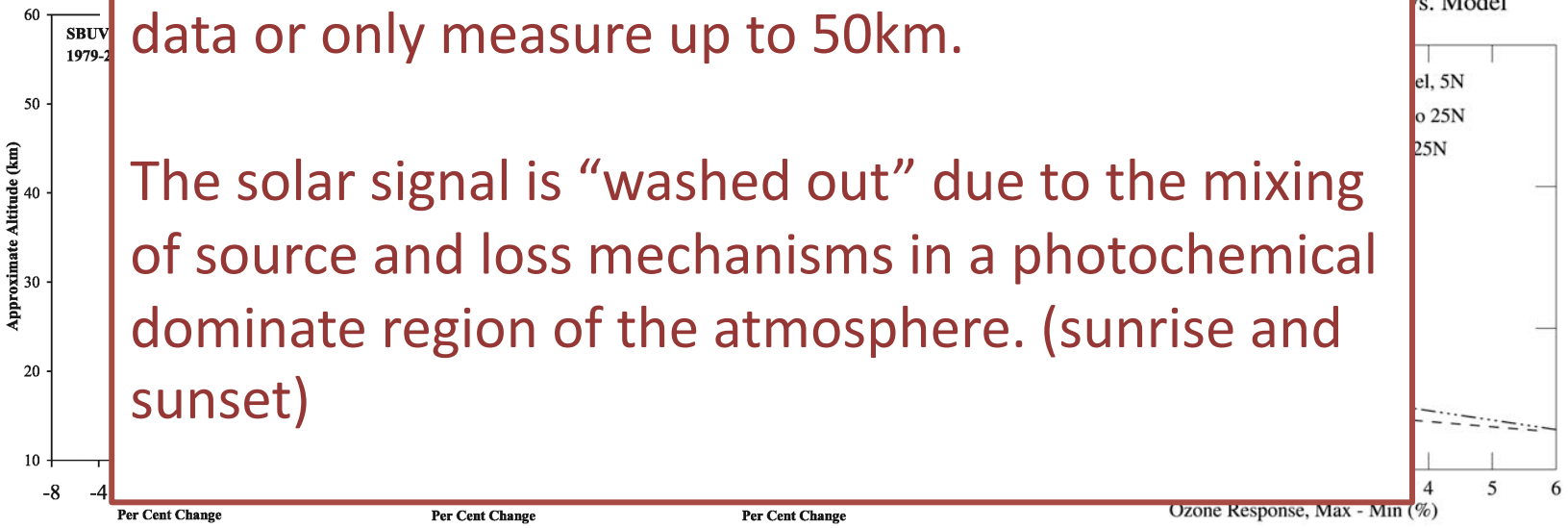
Ozone measurements in previous solar cycles

Question: Why have we not seen this mesospheric ozone behavior in previous solar cycles?

Reason

Historical ozone data comprised of occultation data or only measure up to 50km.

The solar signal is “washed out” due to the mixing of source and loss mechanisms in a photochemical dominate region of the atmosphere. (sunrise and sunset)



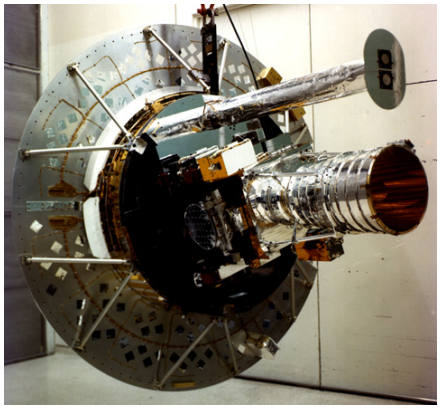
Solar Mesosphere Explorer – 1982 - 1989

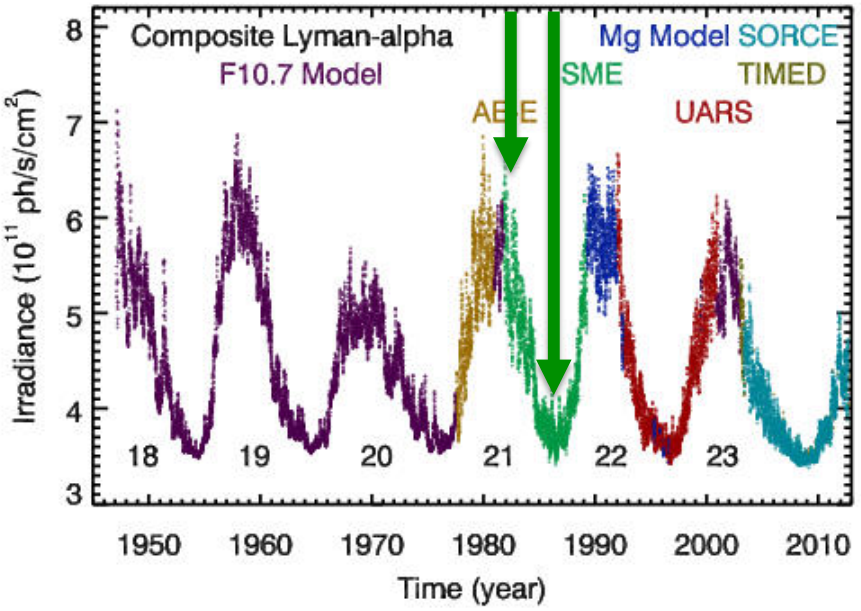
- UV ozone channel (Rusch et al. 1984)
  Solar irradiance measurements.
  (Rottman et al. 1982)

- SME covers parts of solar cycle 21-22
  - Good ozone measurements between 1982-1986

- Daytime (3pm) limb profiles of ozone with good global coverage.

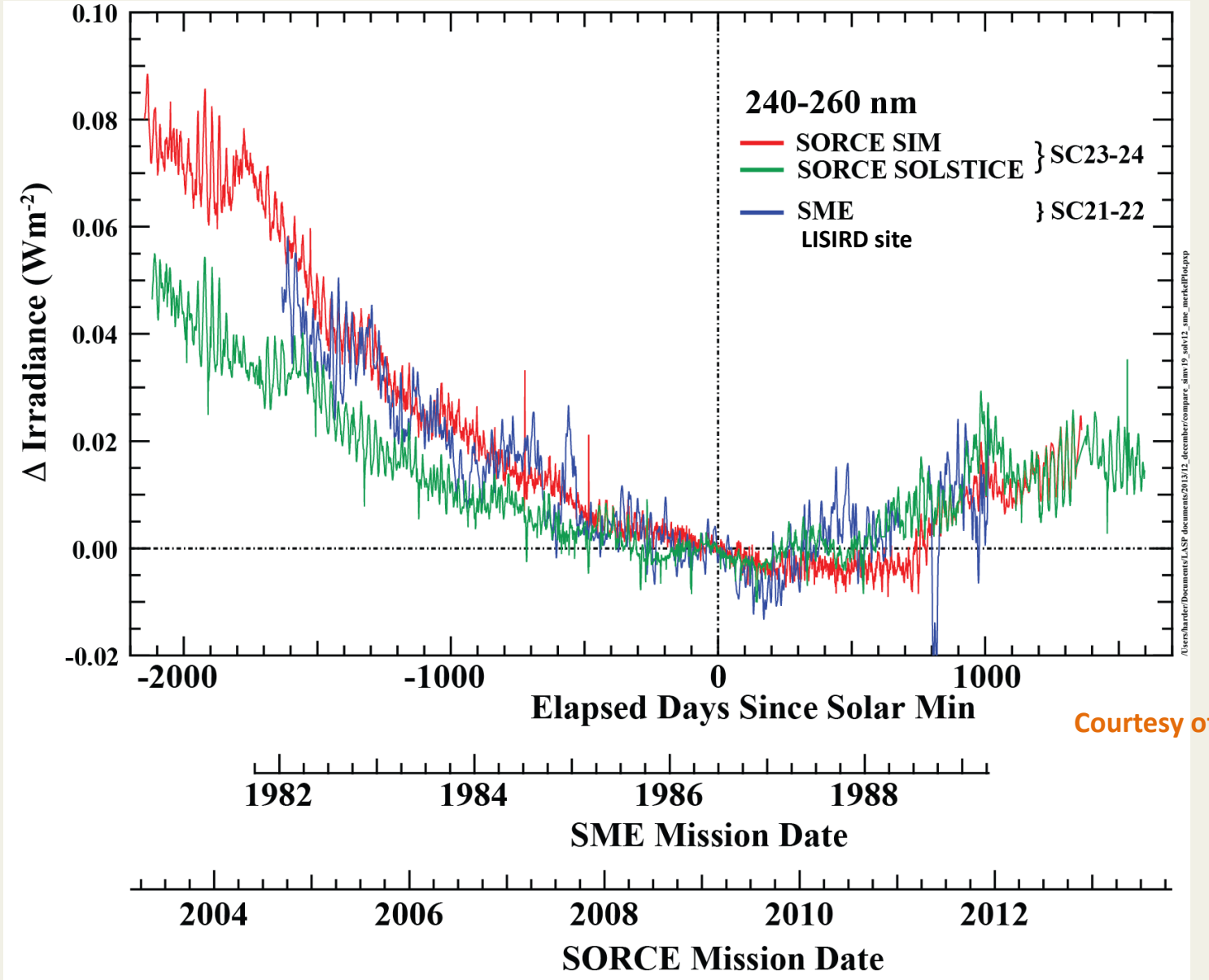
- SME ozone measurements are analyzed consistent with SABER analysis.





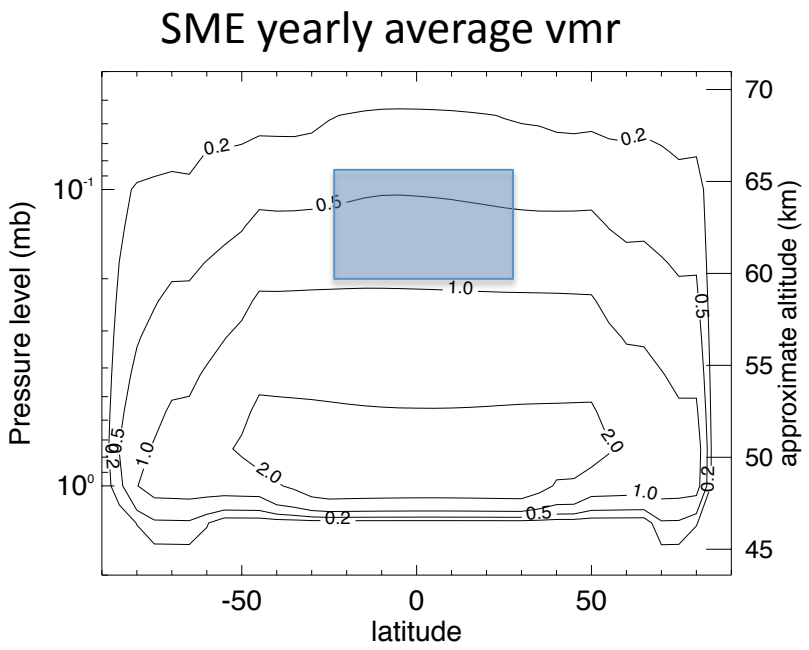
(Woods and Rottman 1997)

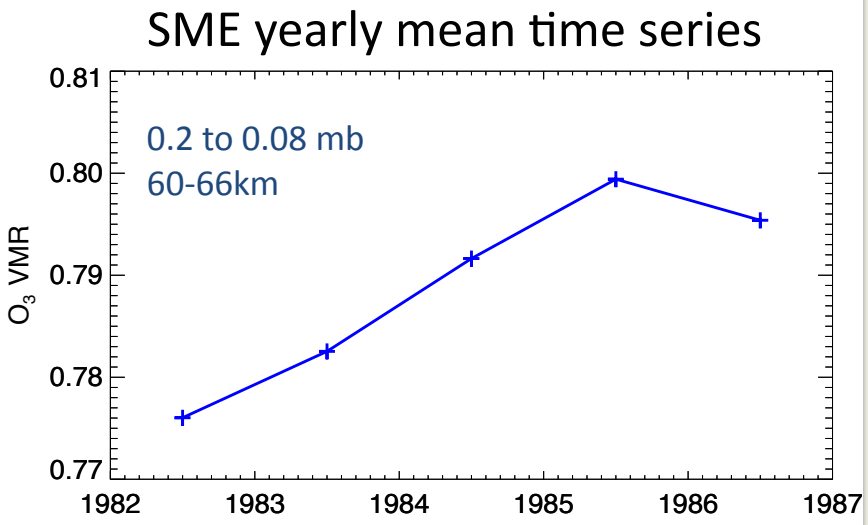
Solar Irradiance variability 2 decades apart

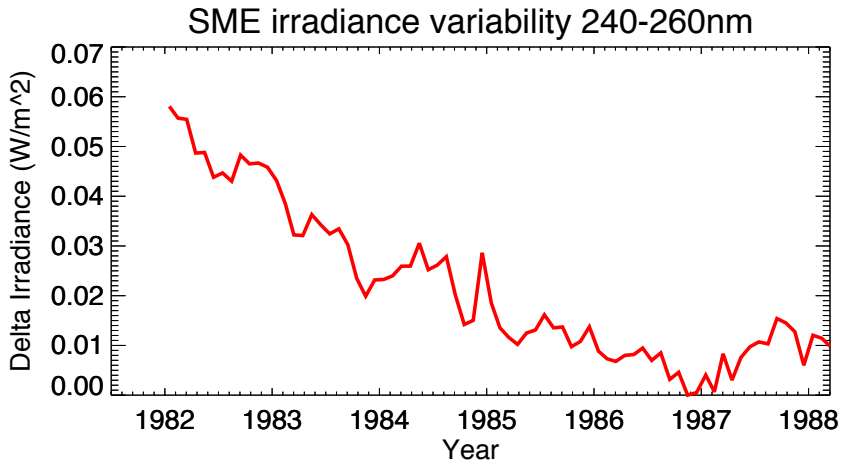


Courtesy of Jerry Harder

SME Ozone Time Series

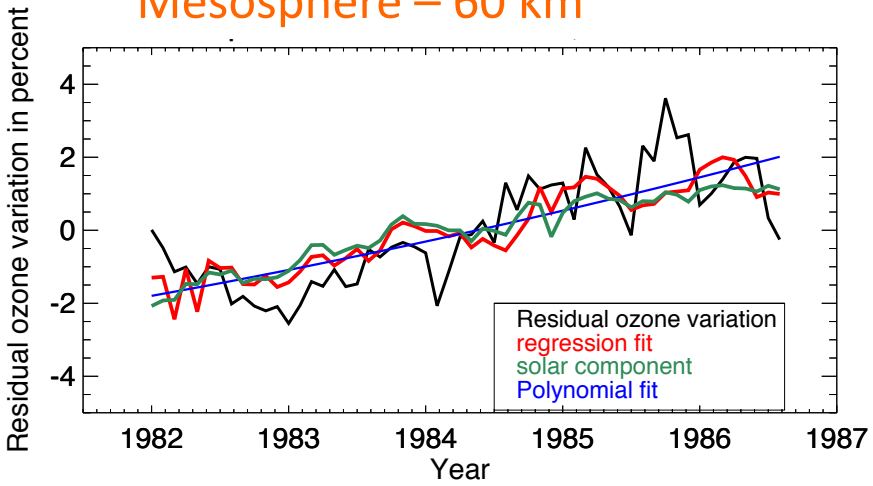




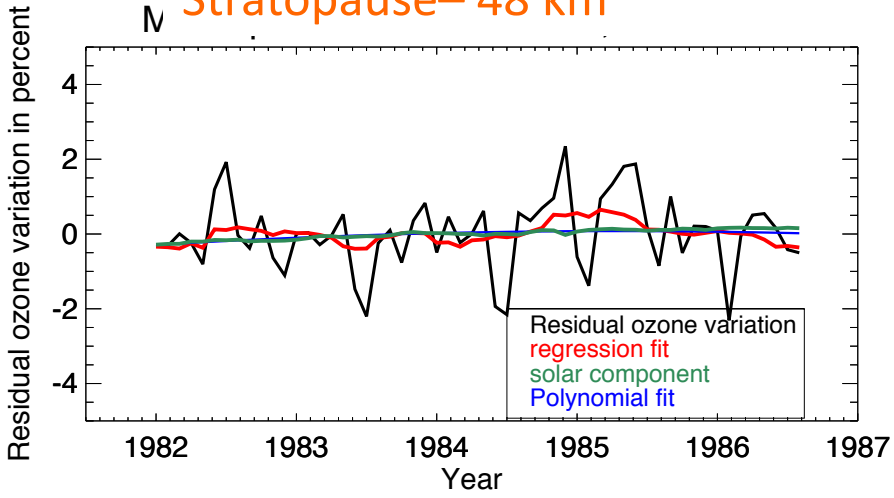


SME Regression

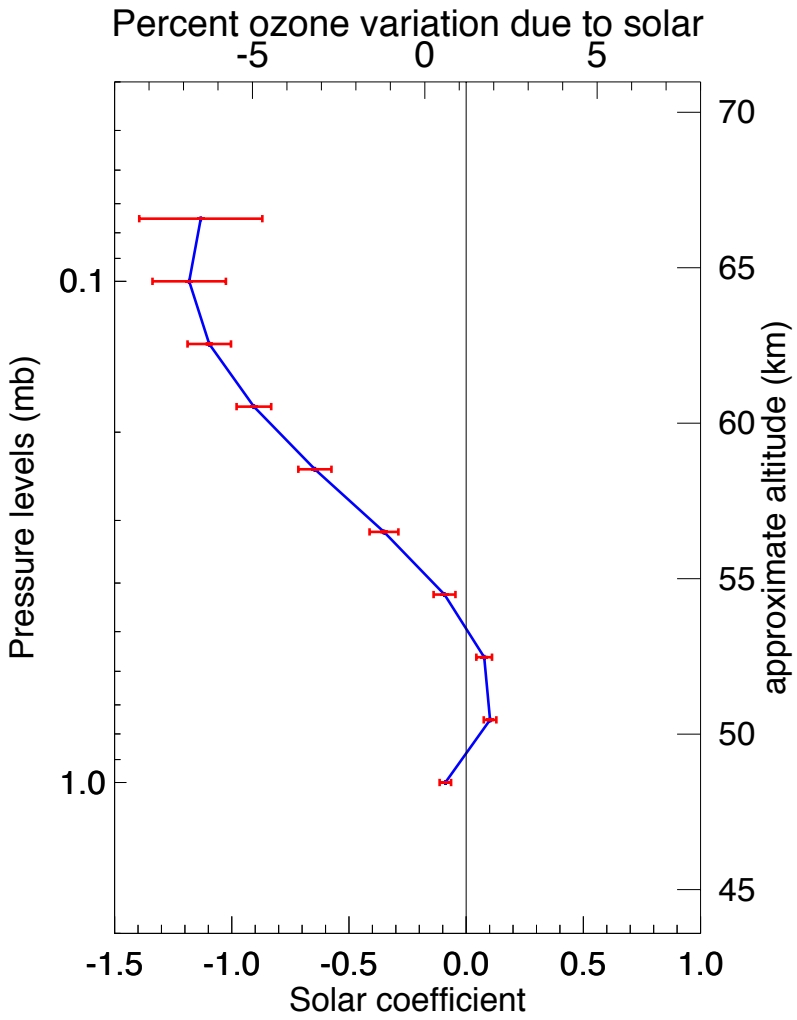
Mesosphere – 60 km



Stratopause– 48 km

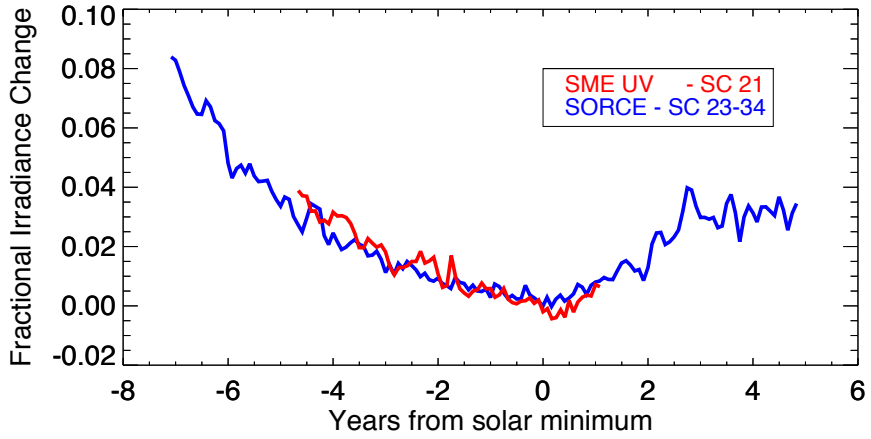


Solar Coefficient

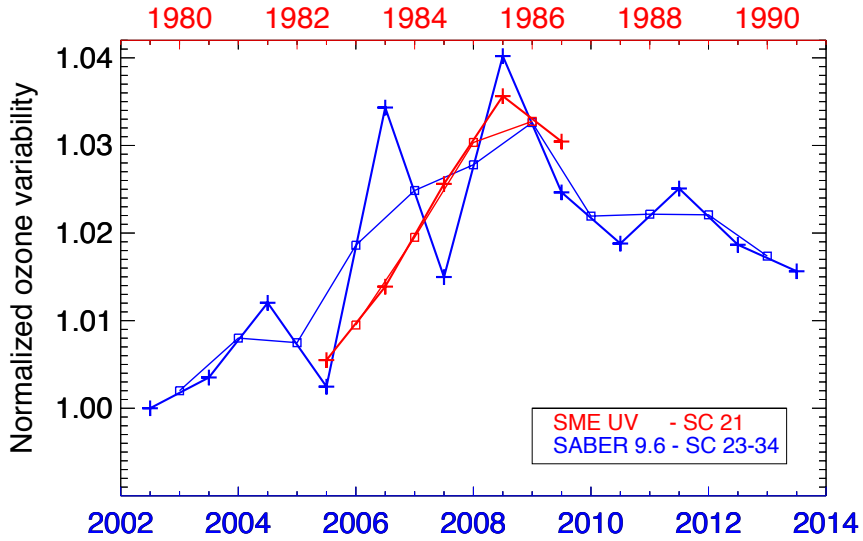


SME compared to SABER

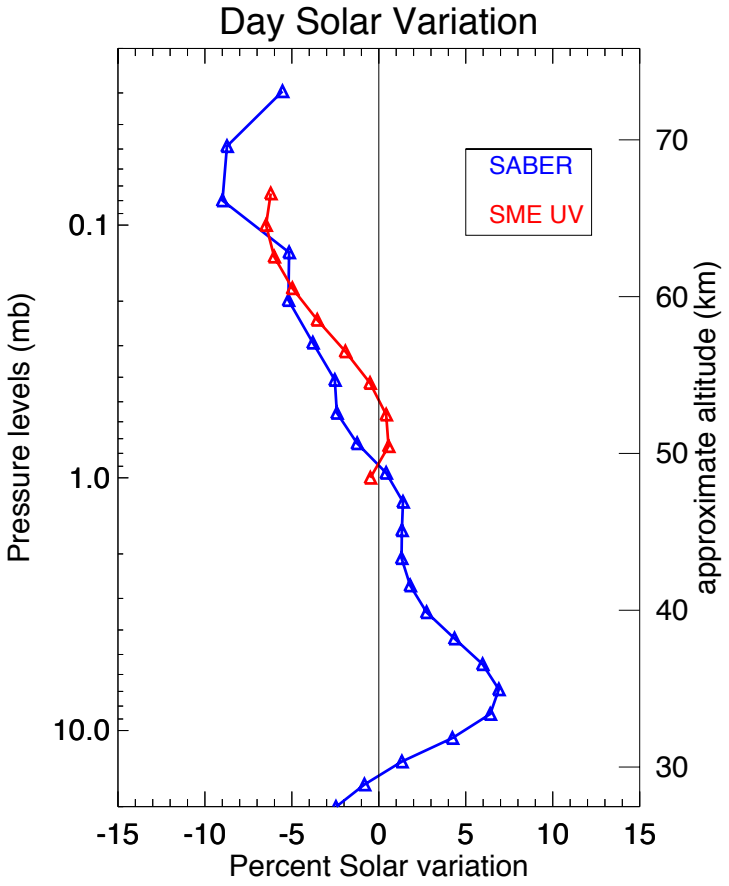
Irradiance Variability 240-260nm



Ozone yearly time series



Regression – solar component



Summary

- Suggestive evidence that UV variability in the 240-260nm range and mesospheric ozone from SC 21 are consistent with SC 23-24. Has it been there all along? Further evidence that this signal is real.

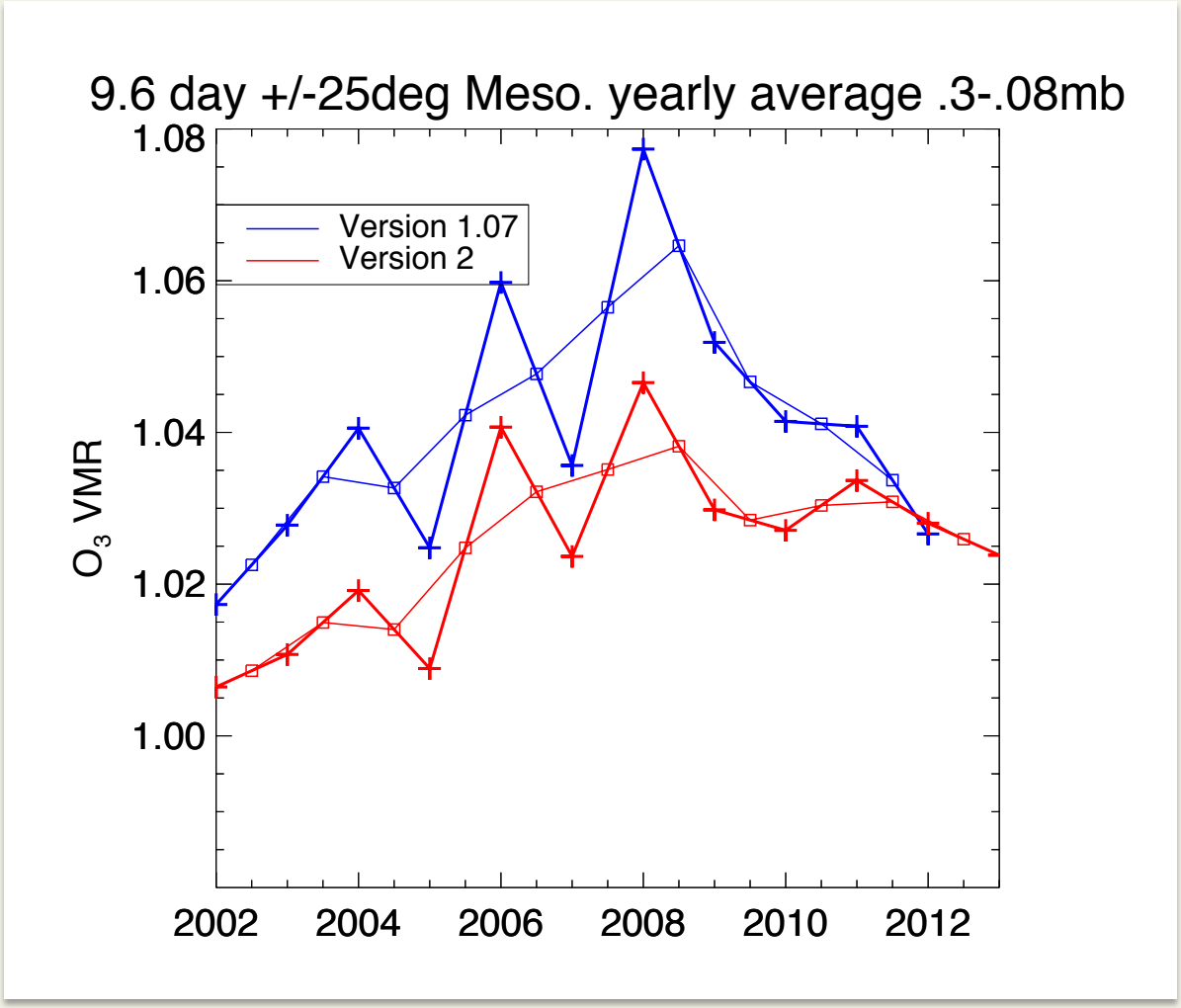
- Multiple modeling studies show that increased UV variability as observed by SORCE (both SIM and SOLSTICE) helps to resolve differences between modeled ozone and observations in the mesosphere.

- The UV variability is probably somewhere in between NRLSSI and SORCE, however it is apparent that the atmosphere is sensitive to this difference. When compiling SSI proxy model please consider that this type of variability in the UV matters in the mesospheric photochemistry.

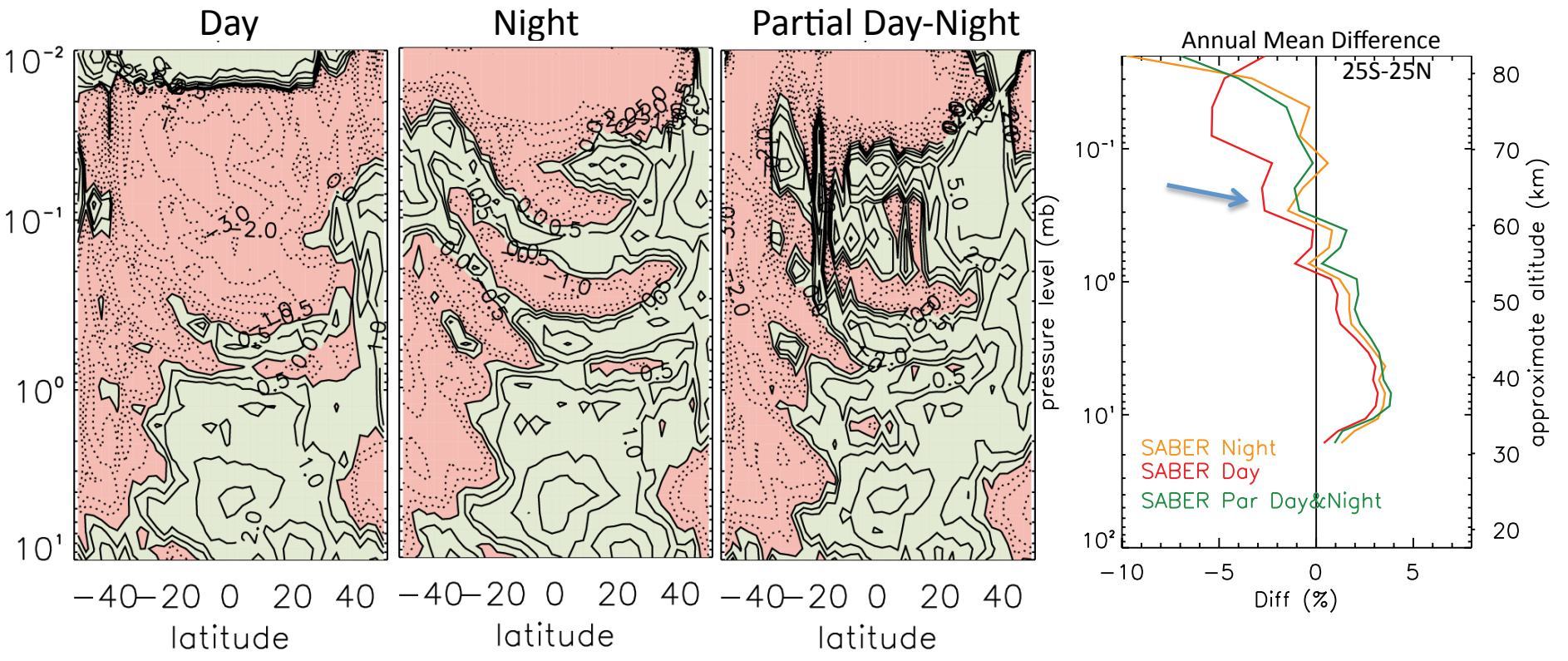
- Need to approach the issue from both directions. Atmospheric modelers and solar physicists/modelers need to work together to constrain this variability . The atmospheric modelers can perform case studies to fine tune the response to different solar variability but this can't be used to validate the solar, can only be used as a guideline. Wavelength dependent.

- Importance of the continuation of mesospheric ozone measurements in the future.

Thank You!


9.6 day +/-25deg Meso. yearly average .3-.08mb
1.08
1.06
1.04
1.02
1.00
O_3 VMR
Version 1.07
Version 2
2002
2004
2006
2008
2010
2012

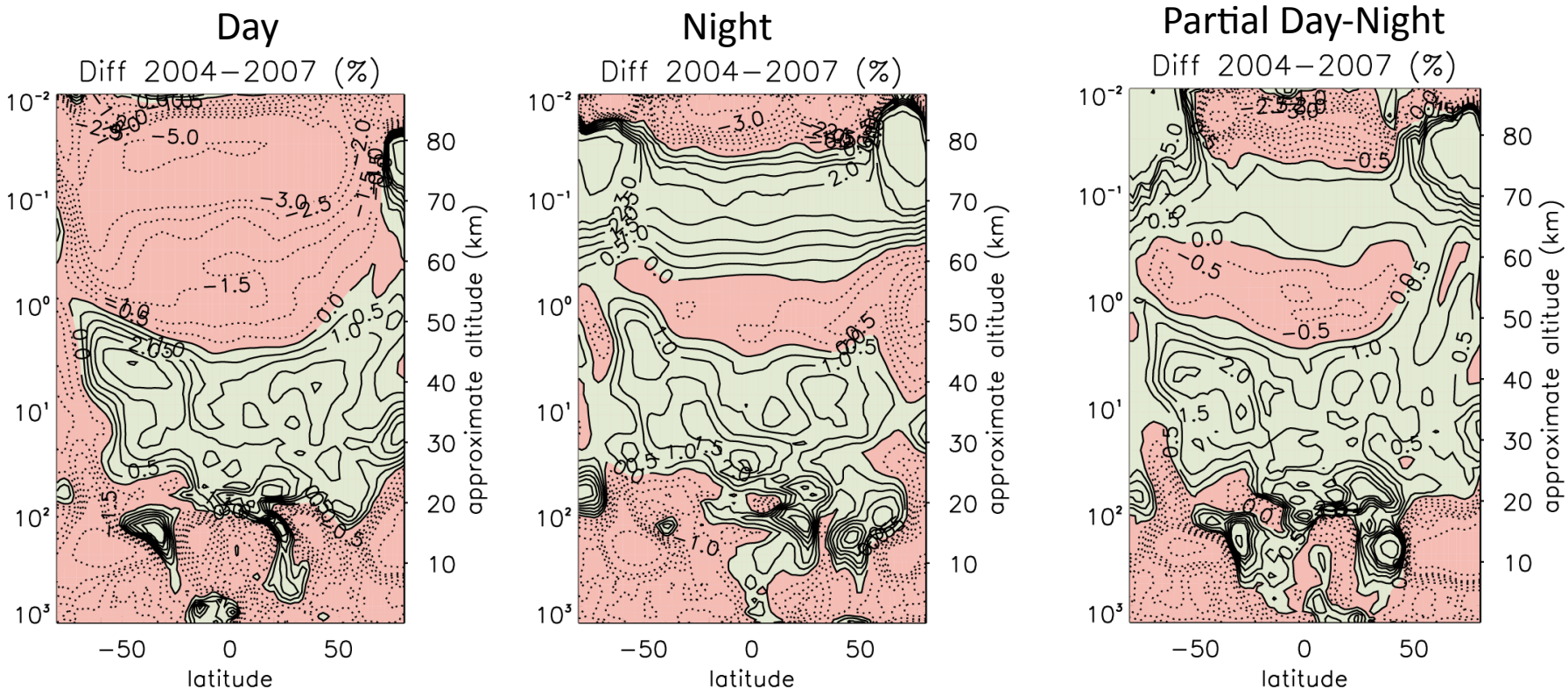
Analyze SABER as if Occultation Experiment



When SABER is analyzed with only measurements taken at "occultation" local times: Solar signal is washed out and response is more similar to night results

Analyze WACCM at Occultation local times

Modeled ozone results



When WACCM is analyzed with only measurements taken at "occultation" local times: Solar signal is washed out and response is more similar to night results.

Confirms results from SABER.