The impact of solar spectral variability on middle atmospheric constituents

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Overview

Modeling the Earth's atmospheric response to solar variability over descending phase of SC23

- Modelling study using NCAR's WACCM (Whole Atmosphere Community Climate Model).
- Compare and contrast to model results when forced with different solar estimate from the:
  Naval Research Laboratory SSI model (NRLSSI, Lean et al. 2005)
  SORCE (Solar Radiation and Climate Experiment) SSI observations.
- Response of the photochemistry in the middle atmospheric when forced by different distributions of solar spectral irradiance (SSI).
- Compare modelled ozone response to observations

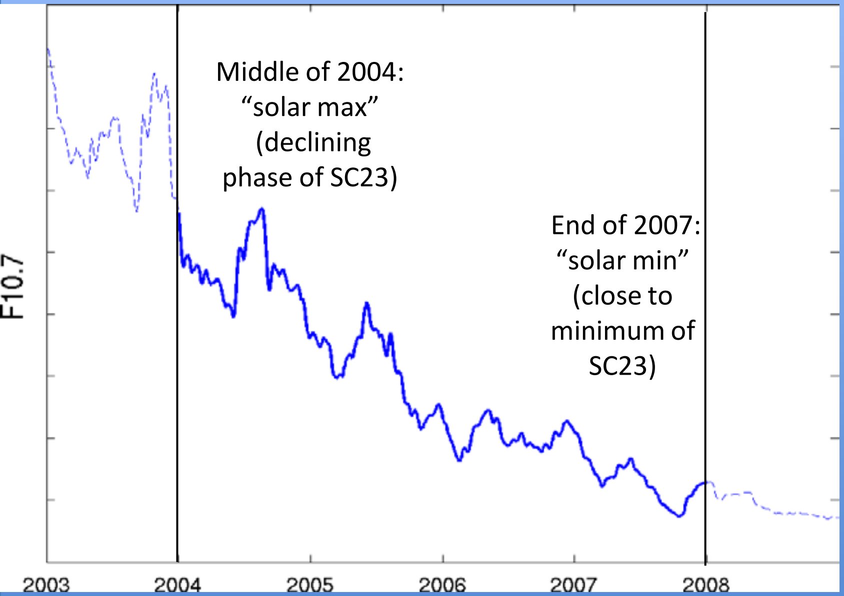
Solar Spectral Irradiance Variability over SC23

SORCE-SIM measurements from 2004 through 2007 show very different spectral distribution (in-phase with solar cycle in UV, out-of-phase in VIS and NIR)

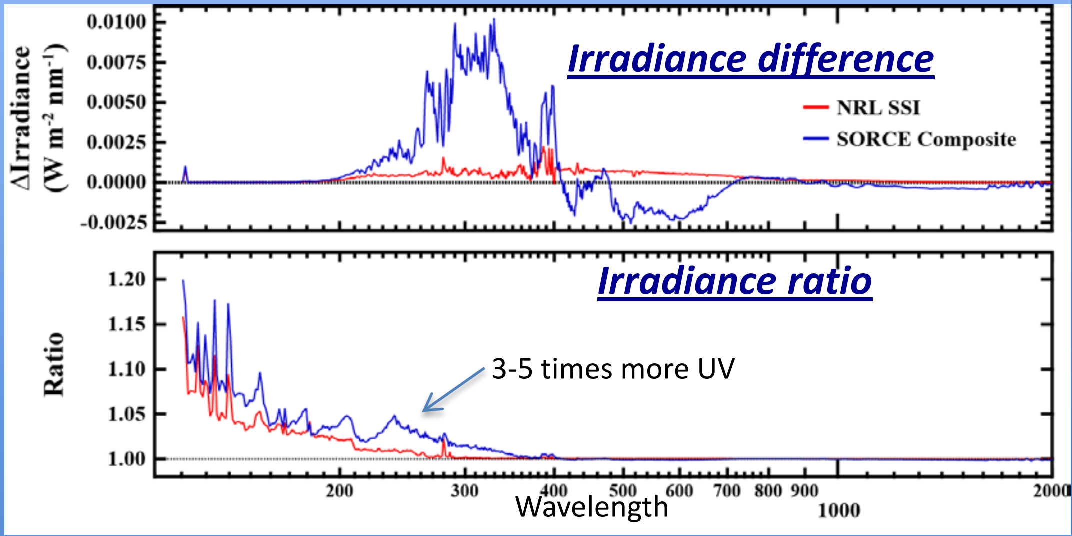
SORCE Irradiance Data (Harder et al., 2009)

NRLSSI Irradiance Data (Lean et al., 2005)

Time series of F10.7cm solar flux



2004(Active Sun) - 2007(Quiet Sun)



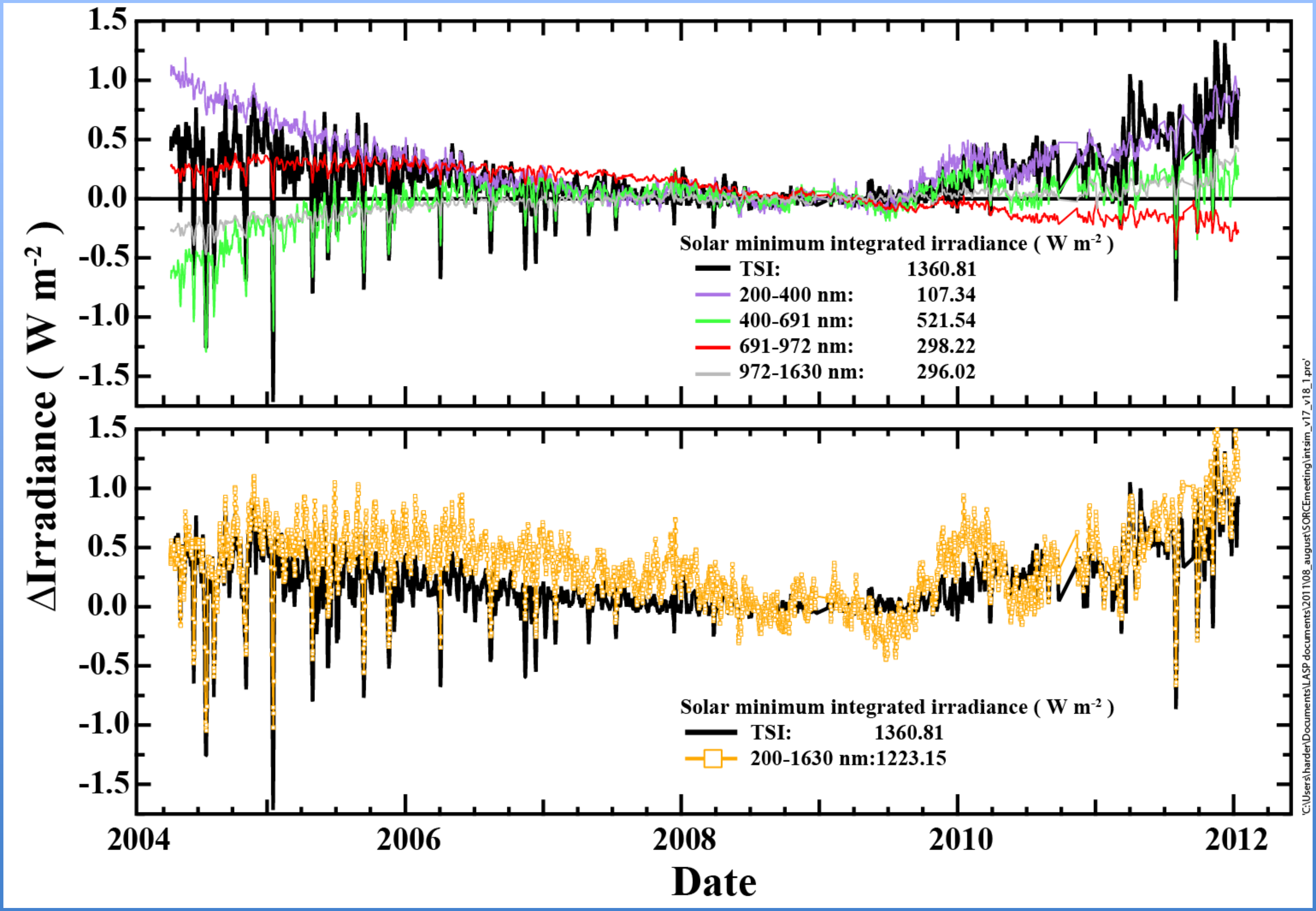
Harder et al., 2009

We compare SORCE measurements to currently accepted standard for SSI variability in climate models (NRLSSI).

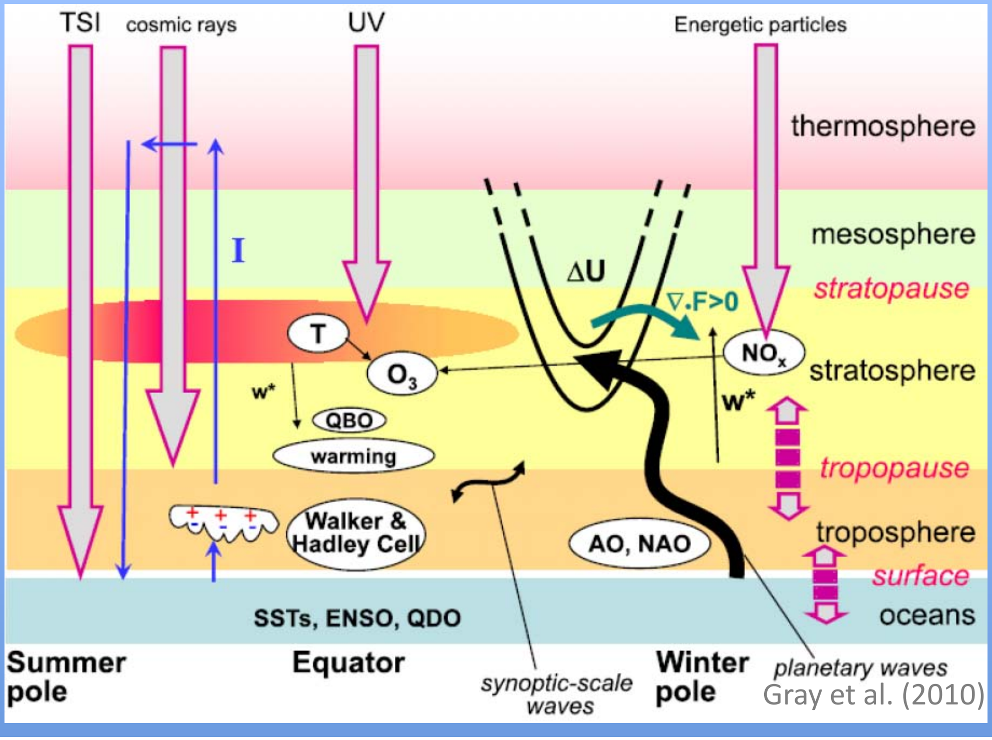
It is important to model the response and sensitivity of the atmosphere to the spectral distributions.

These model sensitivity studies will help to constrain the uncertainties in the solar measurements.. Ie. how good does the solar measurement need to be.

Solar Spectral Irradiance Variability SC23 – SC24



SSI Solar Forcing and Earth Atmospheric Response



Implications on:

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

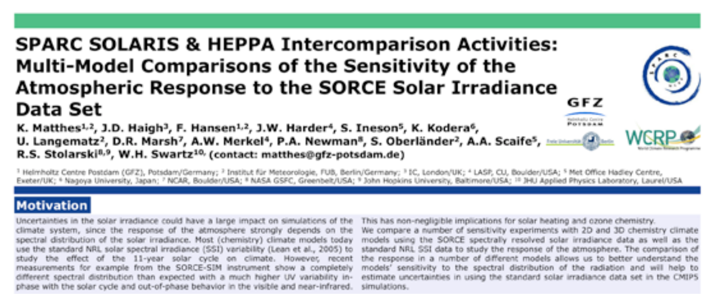
Important recent SORCE SC23 studies:

Haigh et al. 2010 – IC2D model
Cahalan et al. 2010 –GISS ModelE
Swartz et al. 2010 – GEOS-5 CCM
Merkel et al. 2011 – WACCM
Ineson et al. 2011 – HadGEM3
Oberlander et al. 2011 –EMAC-FUB
Wang et al. 2011- JPL MLS OH

SPARC-SOLARIS & HEPPA Multi-Model Inter-comparison Study

SPARC-SOLARIS Goal: Investigate solar influence on climate with special focus on the importance of middle atmosphere chemical and dynamical processes and their coupling to the Earth's surface with CCMs, mechanistic models and observations.

Spearheaded by Katja Matthes (GFC, Institute for Meteorology, Germany)
Presented at the WCRP conference October 2011
Caveat: all the models used a slightly different experimental setup


SPARC SOLARIS & HEPPA Intercomparison Activities: Multi-Model Comparisons of the Sensitivity of the Atmospheric Response to the SORCE Solar Irradiance Data Set

K. Matthes[1,2], J.D. Haigh[3], F. Hansen[1,2], J.W. Harder[4], S. Ineson[5], K. Kodera[6], U. Langematz[2], D.R. Marsh[7], A.W. Merkel[4], P.A. Newman[8], S. Oberländer[2], A.A. Scaife[5], R.S. Stolarski[8,9], W.H. Swartz[10] (contact: matthes@gfz-potsdam.de)

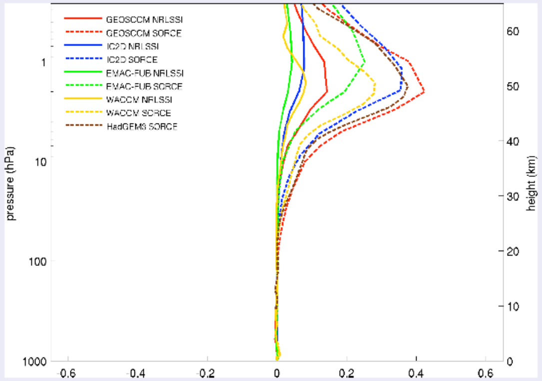
Motivation

Participating Models

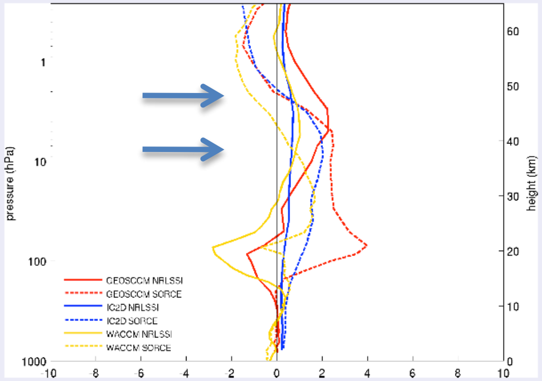
Model	Horizontal resolution	Number of vertical layers	Top level	Interactive ozone	QBO	Max & Min simulations	Length of simulation	Reference
EMAC-FUB (ECHAM5/MESSy)	T42	L39	0.01 hPa	no	no	perpetual January (NRL+SORCE)	50 yrs	Oberländer et al. (2011)
GEOS-5 CCM	2.5 x 2	72	0.01 hPa	yes	no	Annual cycle (NRL+SORCE)	25 yrs	Swartz et al. (2010)
HadGEM3 (with dynamic ocean)	1.875 x 1.25	85	85 km	no	yes (internal)	Annual cycle (SORCE-UV, full SC)	80 yrs	Ineson et al. (2011)
IC2D	9.5	29 [but only 17 for chemistry]	0.001 hPa [but only up to 0.26 hPa for chemistry]	yes	no	Annual cycle (NRL+SORCE)	670 days	Haigh et al. (2010)
WACCM3.5	1.9 x 2.5	66	6e-06 hPa	yes	yes (nudged)	Annual cycle (NRL+SORCE)	25 yrs	Merkel et al. (2011)

Tropical Profiles (25 S - 25 N)

SW Heating Rates (K/d)

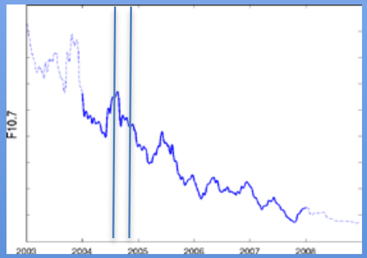


Ozone (%)

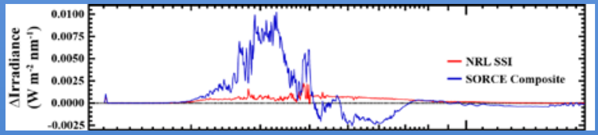


For example, our study differs by:

• Time period of max chosen:



•Source of spectra:



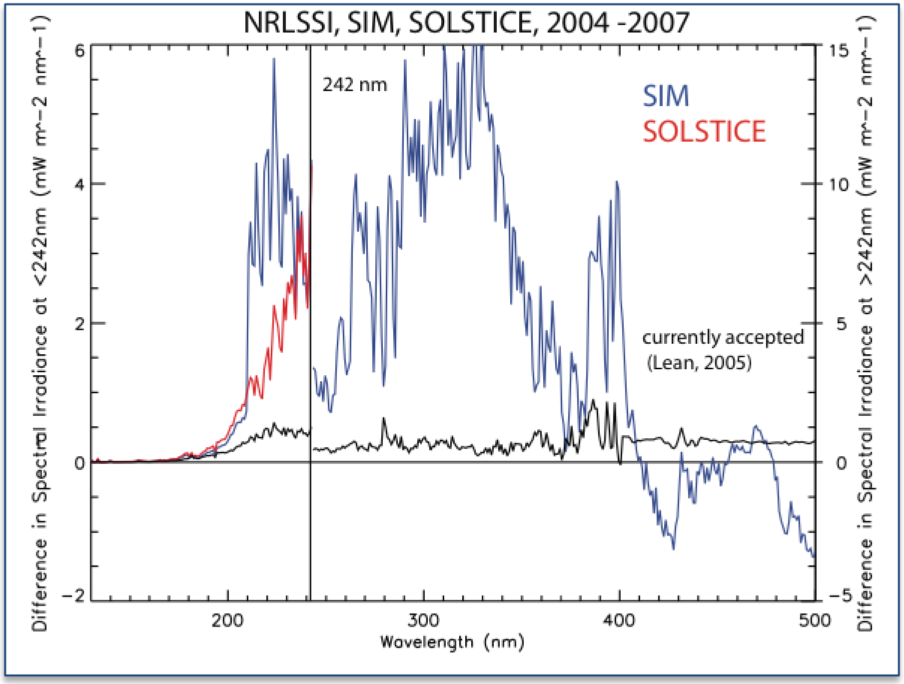
Plan to do coordinated studies with a typical solar Max (2002) and Min (2009) Spectrum to perform a number of sensitivity Experiments.

WACCM Model Simulations

WACCM is a fully coupled chemistry, radiation and dynamics global model extending from the surface to the thermosphere

Approach: Constrain model so atmospheric response is from solar forcing.

- Green house gases held constant – Model spin up
- Time slice experiment – not transient simulation
- TSI is conserved between active cases
- Perpetual year simulations per case study
- Scaled NRLSSI spectra to SORCE variability
- Climatological SST, “Top Down” Focus



Case studies:

NRLSSI

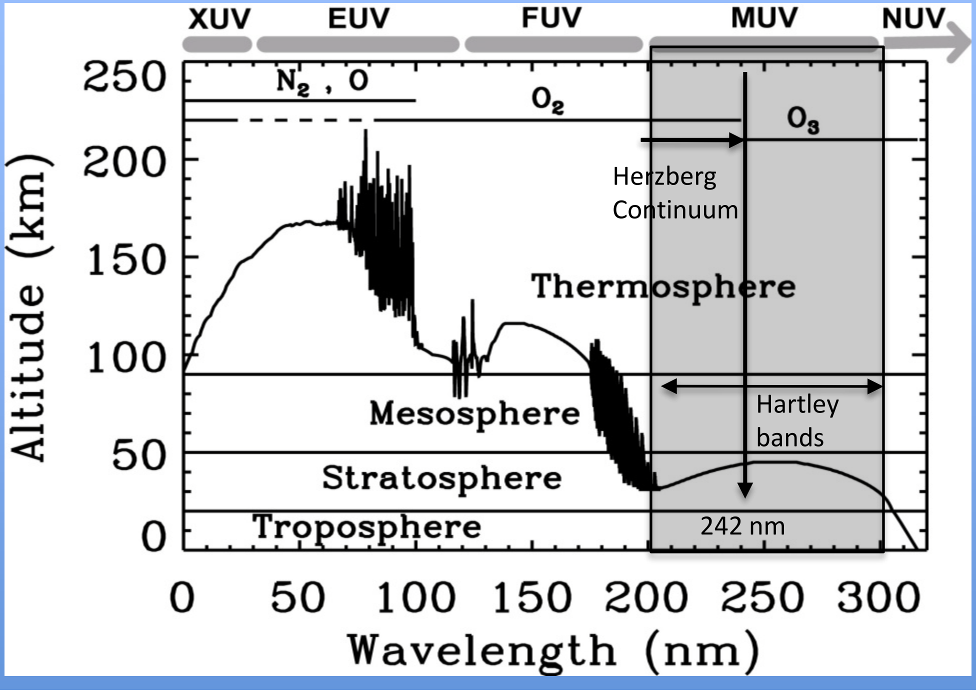
SORCE 1 – SOLSTICE < 242 nm
SIM > 242 nm

SORCE 2 – SIM > 210 nm

2.5% increase in intensity in 200-242nm band between SORCE 1 and SORCE 2.

Experimental Setup

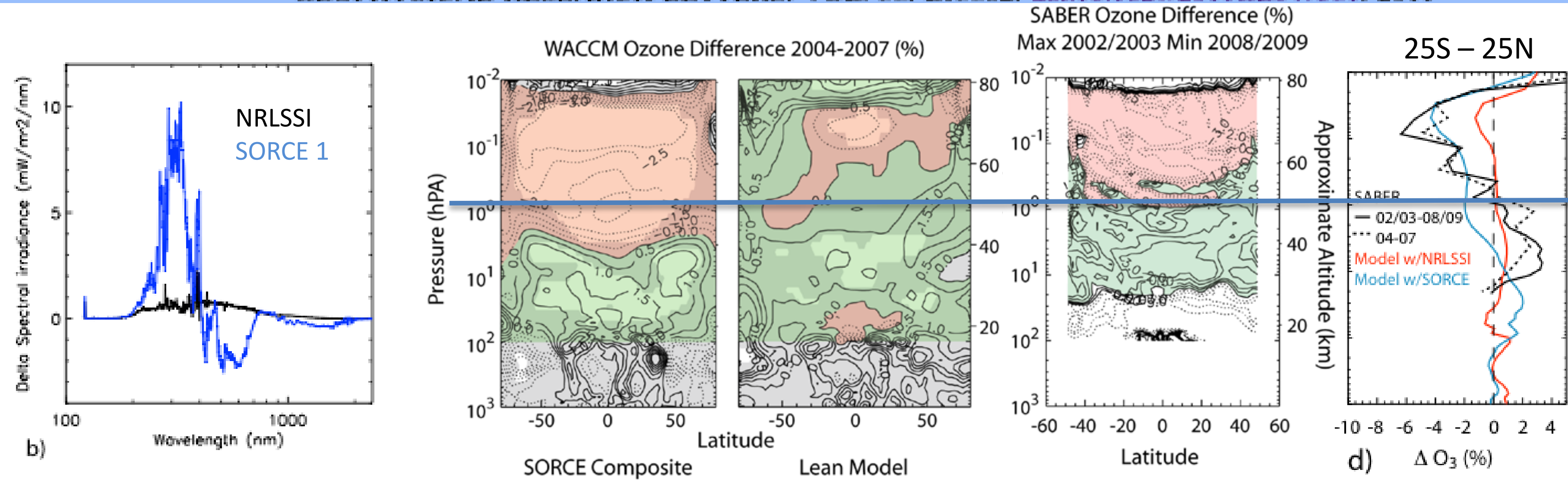
Our Focus: Photochemistry



- Any changes in the UV irradiance will modify the photo-dissociation rates and influence ozone concentrations.
- Ozone concentration in the upper and middle atmosphere is influenced by the solar radiation in the 200-300nm band. (production and loss)
  - Herzberg Continuum (200-242nm) – O_2 Photolysis – O_3 production
  - Hartley Bands (200-300nm)– O_3 Photolysis – absorption peaks 250nm

Merkel et al. 2011

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



SORCE Observations of Irradiance

Simulate Irradiance Changes in WACCM

Compare Simulations with Observations

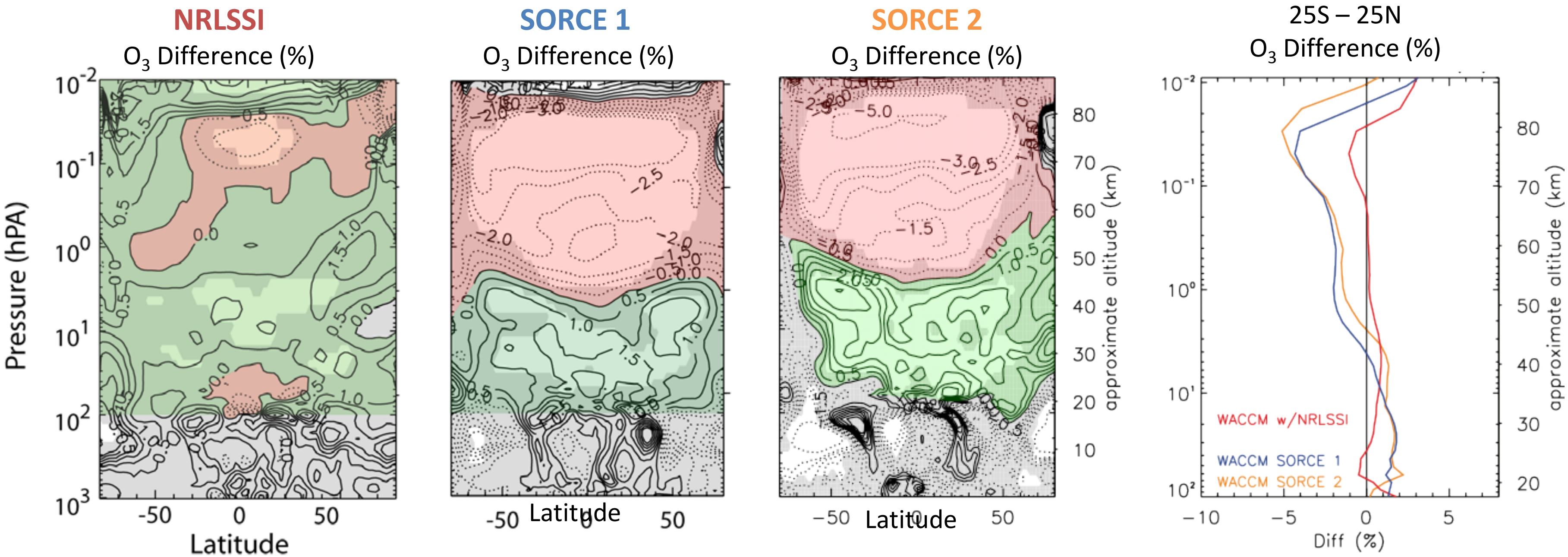
Conclusions of this study:

1) Extends and Confirms study by Haigh et al. (Nature 2010).
2) WACCM model response to increase UV variability (max-min) shows that there is increased ozone loss in the lower mesosphere at max conditions.
3) Descending SC 23 SABER ozone data supports this modeling result.

   Signal observed in two independent instrument observations (MLS).
4) Mesospheric ozone solar cycle response is sensitive to local time.

Ozone response Model Simulations

Active 2004 – Quiet 2007 (% Difference)



SORCE 1
SOLSTICE < 242 nm
SIM > 242 nm

SORCE 2
SIM > 210 nm
2.5% more intensity in Herzberg Continuum

Annual Mean Differences

(25N-25S)

Mesosphere (less O_3 at solar active) Why?

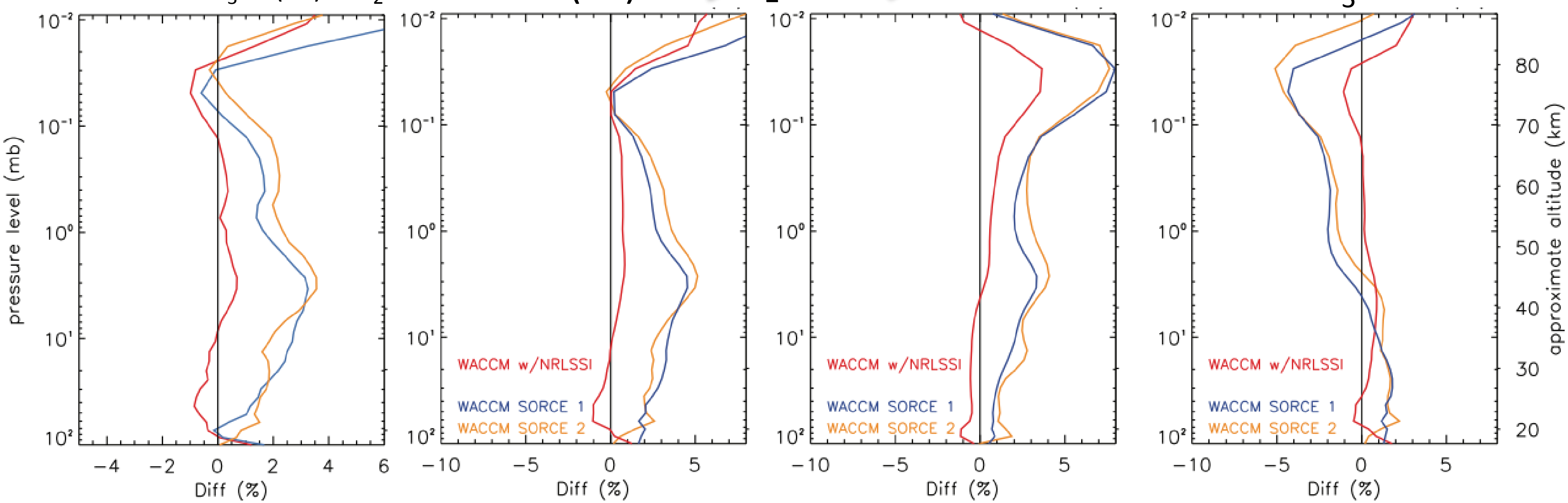
Ozone is depleted through several catalytic processes with OH and H

More UV

=

More O_3 photolysis = More $O(^1D)$ = More OH = Less O_3

J3 rate $O_3 = O(^1D) + O_2$ $O(^1D) \rightarrow H_2O \rightarrow OH$ O_3



SORCE 1 – SOLSTICE < 242 nm

SIM > 242 nm

SORCE 2 – SIM > 210 nm

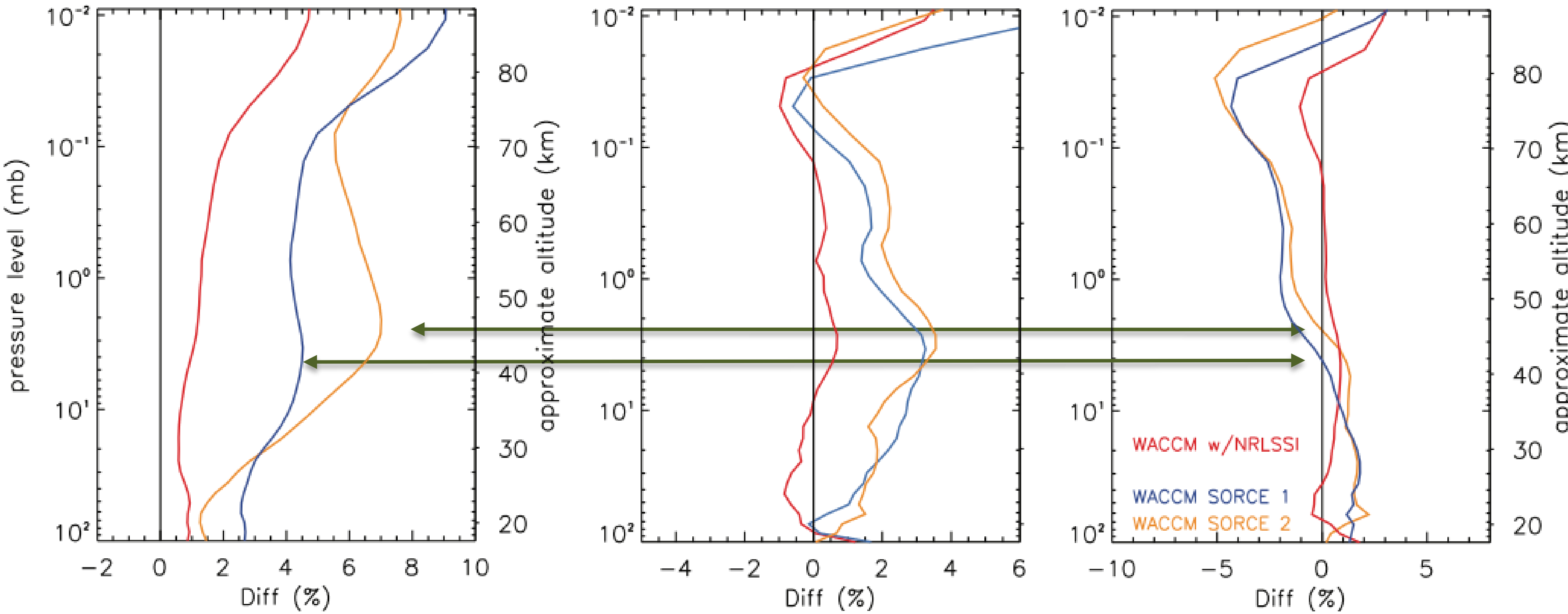
2.5% increase in intensity

Annual Mean Differences

(25N-25S)

<u>Stratosphere</u> -more O_3 at solar active

J2 rate O_2=2O photolysis　　J3 rate O_3=O(^{1}D) + O_2　　O_3



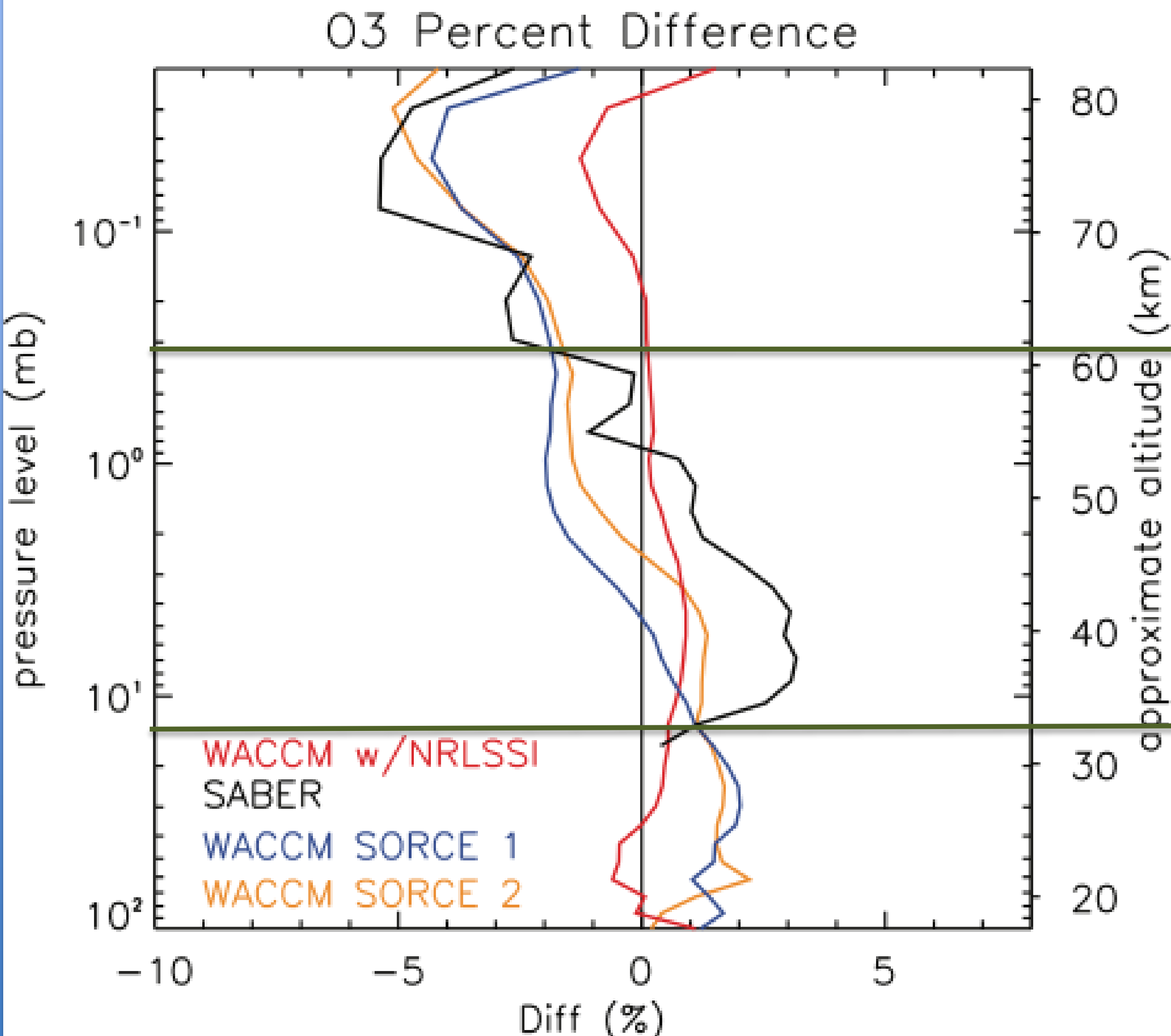
More UV radiation is transmitted to lower levels

- **Greater O_2 photolysis and thus more O_3**

- **2.5% increase in intensity in 210-242nm band**
  - **Increased J2 rate from 4.5% to 7%**
  - **Increased J3 rate from 3% to 3.5%**
- **Altitude of sign change seems to depend on both J2 and J3 rate**

Model Ozone Compared to SABER

Annual Mean Difference 25S-25N



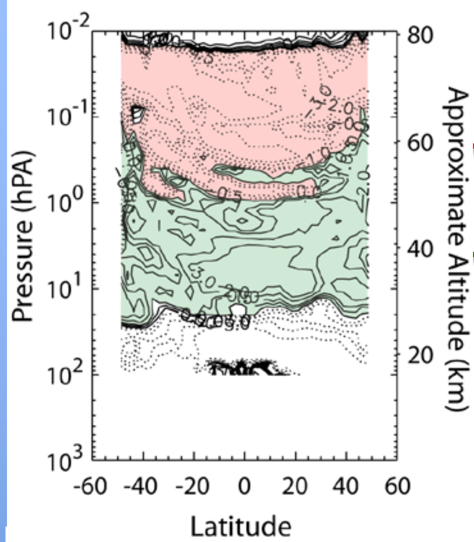
Upper Mesosphere:
Both SORCE model simulations reproduce the observations

Lower Mesosphere
More modeling work is needed

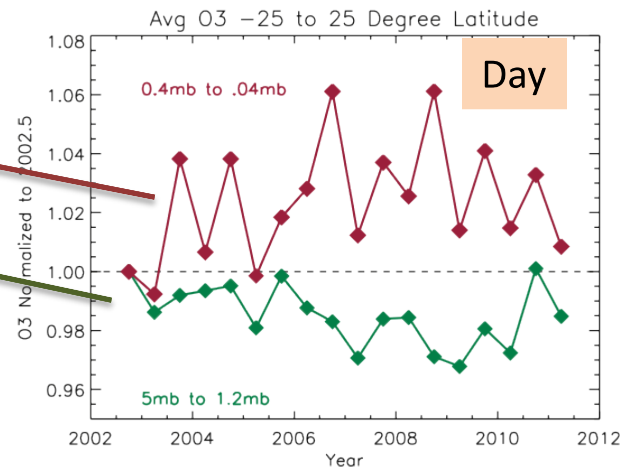
Stratosphere
More UV between 210-240nm helps reproduce the O_3 In-phase solar response

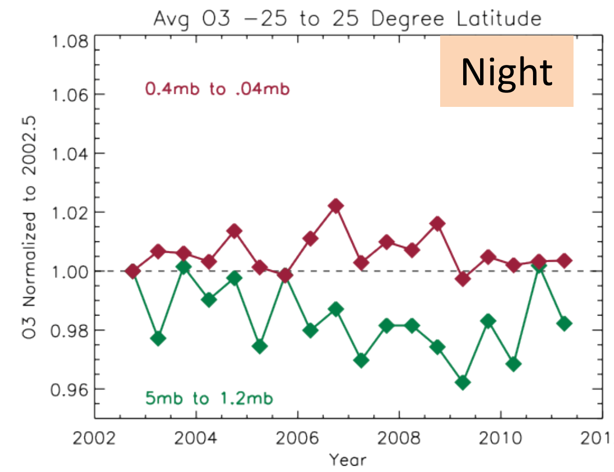
SABER Analysis – 10-years of data

SABER Ozone Difference (%)
Max 2002/2003 Min 2008/2009



6-month zonal mean trends





10 years of measurements

Just getting to the point that we can look at solar effects.

Only time will tell!

Lower Mesosphere

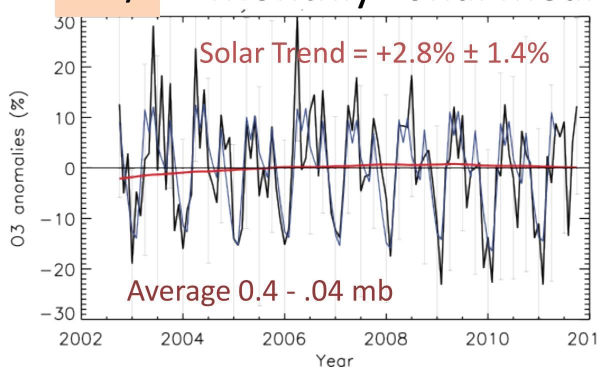
- Out-of-phase with solar cycle
- Trend in day, absent at night
- photolysis ceases at night

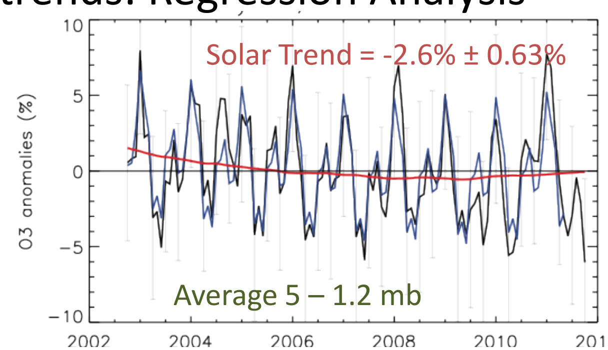
Stratosphere

- In-phase with solar cycle
- Trend similar for day and night
- Less driven by photochemistry
- Very little diurnal variation

Day

Monthly zonal mean trends: Regression Analysis





SABER Compared to HALOE

HALOE

Halogen Occultation Experiment

(Remsberg et al., 2008)

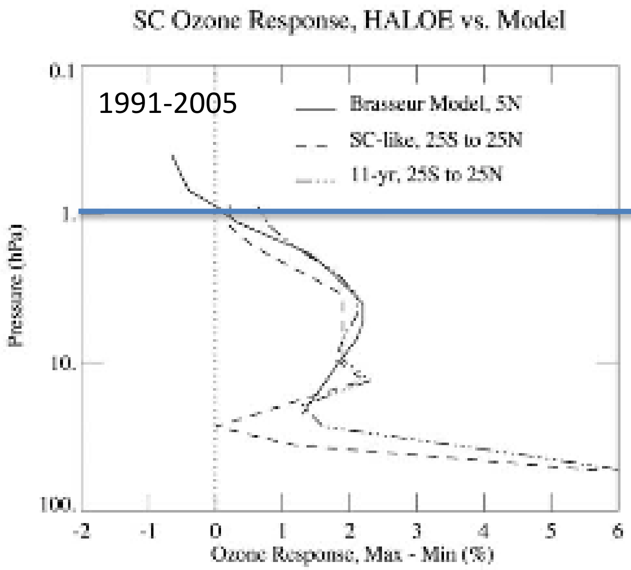
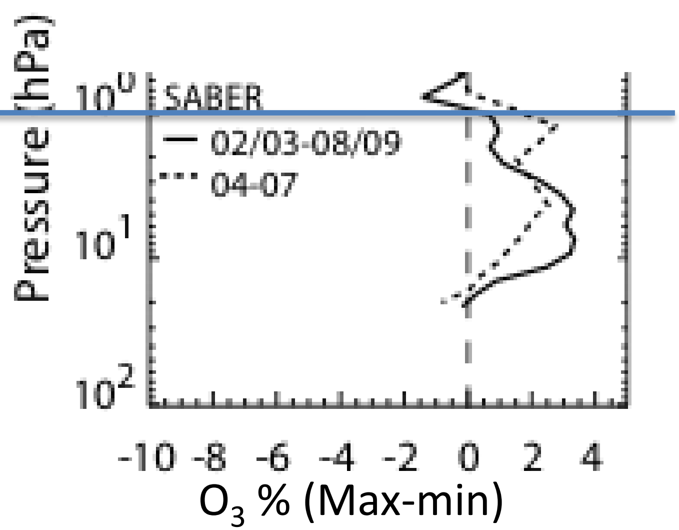


Figure 12. Profiles of the 11-year and the SC-like, maximum minus minimum responses (in percent) for the tropical to subtropical ozone from HALOE. The solid curve is the model result for 5°N from *Brasseur* [1993].

SABER



➡SABER stratospheric ozone is consistent with previous measurements.

➡SABER able to resolve lower mesospheric ozone response to solar forcing.

Some measurements don't agree

Solar cycle variation of stratospheric ozone: Multiple regression analysis of long-term satellite data sets and comparisons with models

B. E. Soukharev[1] and L. L. Hood[1]

Received 22 January 2006; revised 28 June 2006; accepted 24 July 2006; published 31 October 2006.

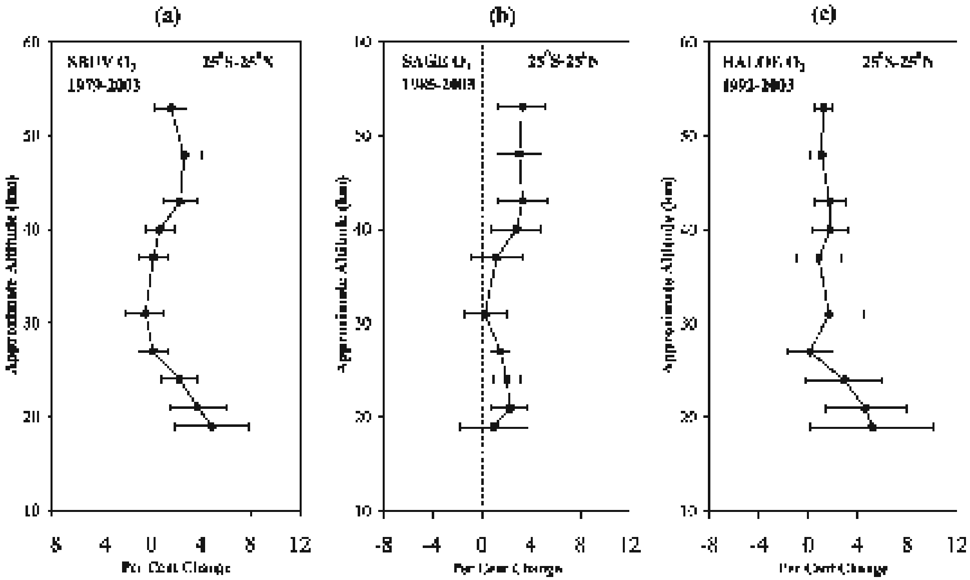
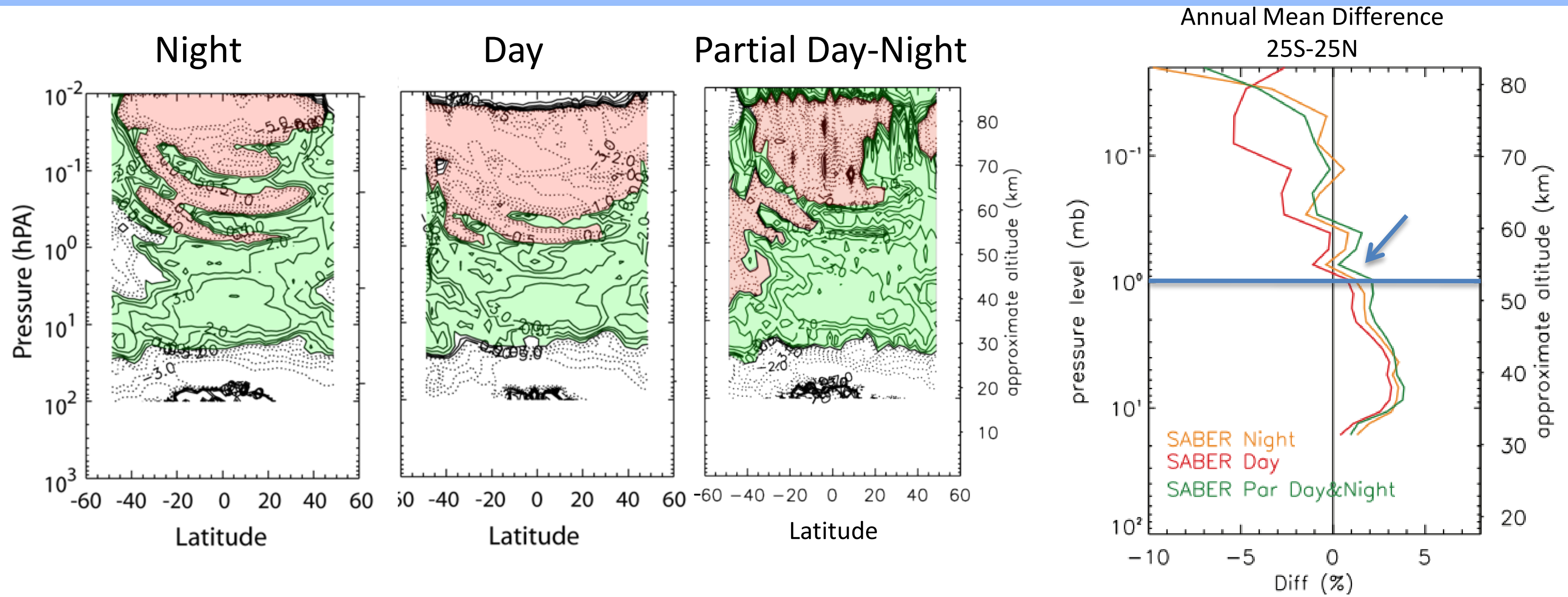


Figure 8. Solar cycle ozone regression coefficients (expressed as percent change from solar minimum to maximum) for (a) the SBUV(/2) data set, (b) the SAGE II data set, and (c) the HALOE data set. The regression coefficients were obtained by applying equation (1) to 3-month time series averaged over the 25°S to 25°N latitude band.

Question I keep asking myself.. Why have we not seen this ozone behavior in previous measurements such as SAGE II?

Occultation Measurements
Mixing of photochemistry due to local time of observation

Analyze SABER as if Occultation Experiment



When SABER is analyzed with only measurements taken at "occultation" local times:

- in-phase (positive max-min) response above 1mb
- Stratospheric response is upheld

Conclusions

- Just a 2.5% increase in intensity at UV wavelengths influences the atmospheric response. Need the best solar measurements possible in this wavelength range. Solar differences need to be resolved.
- Increase in UV helps resolve differences between modeled ozone and observations in the mesosphere.
- Mesospheric ozone response to solar cycle…Local Time Matters!
- Coordinated effort under SPARC-SOLARIS study.
- LWS proposal


"Corona Arch"
Moab, UT
Thank You