Response of the middle atmosphere to short-term solar irradiance variability during different Quasi-Biennial Oscillation phases

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Outline

1. Comparison different SSI data sets using 1D modeling
2. 3D (SOCOL) simulations
3. Sensitivity analysis for the different solar cycle and QBO phases
4. Conclusion
5. Outlook

Motivation

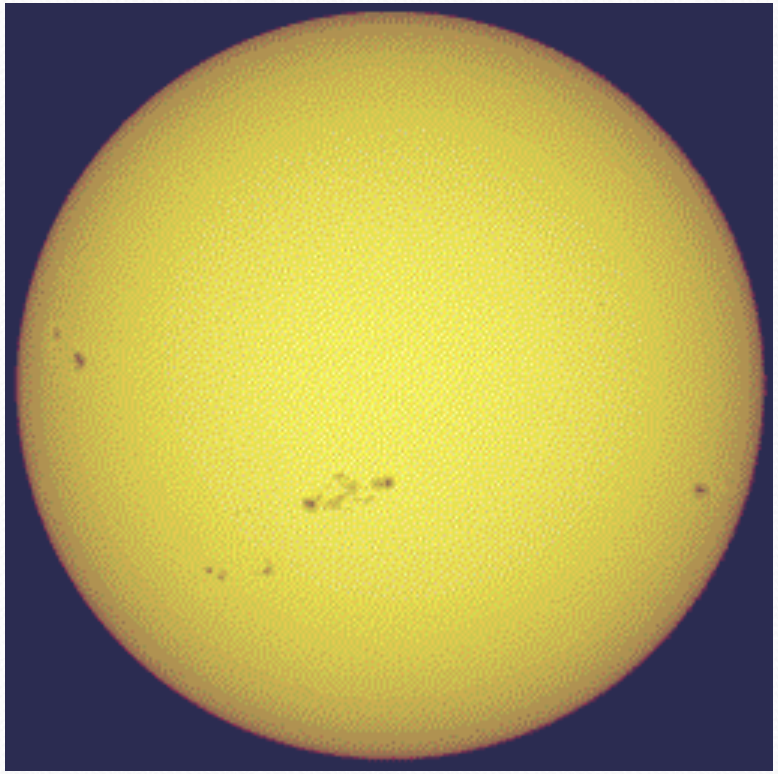
Model ⟷ Observations

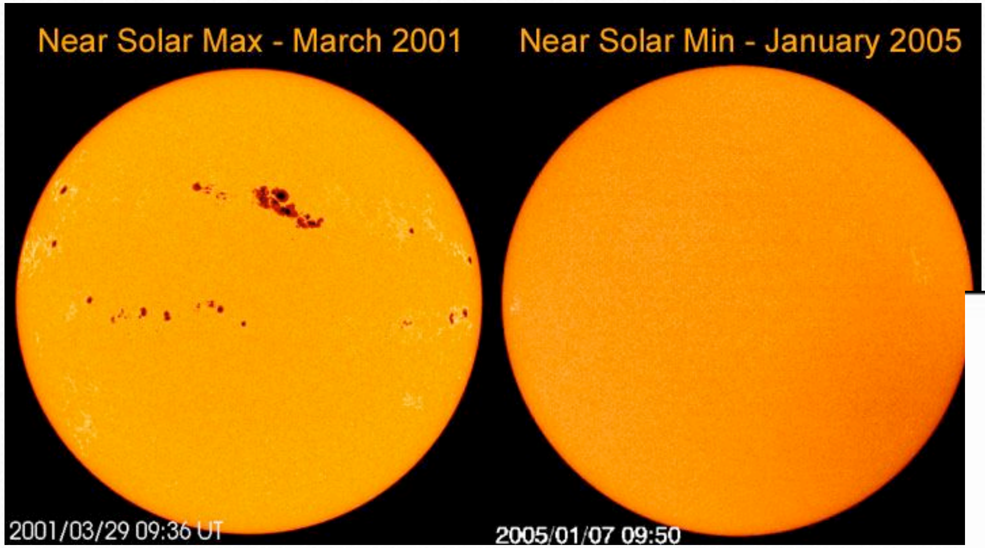
For 11 years cycle the agreement cannot be qualified as successful

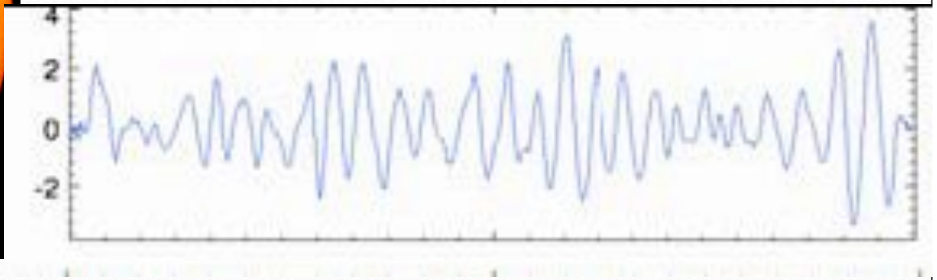
Why?

Now we have only 25 years satellite observations?

Way of solution?







Comparison different SSI

Which data sets should be used for 3D modeling???

Satellite data

Don't need in any assumptions for reconstructing (It is more robust data)

Quality of the data changes with time (degradation)

Reconstructed data

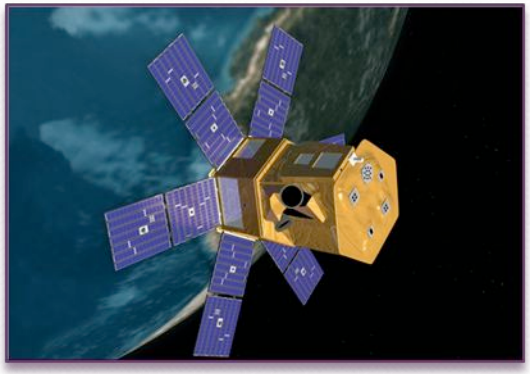
More convenient for analysis (no gaps)

Have to be sure in our assumptions for the reconstruction

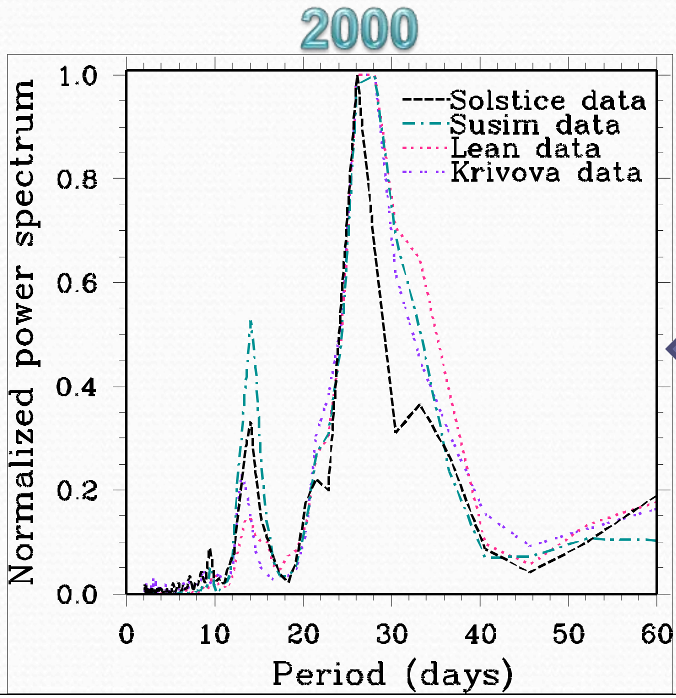
Data

Observed data

UARS
(SUSIM, SOLSTICE)

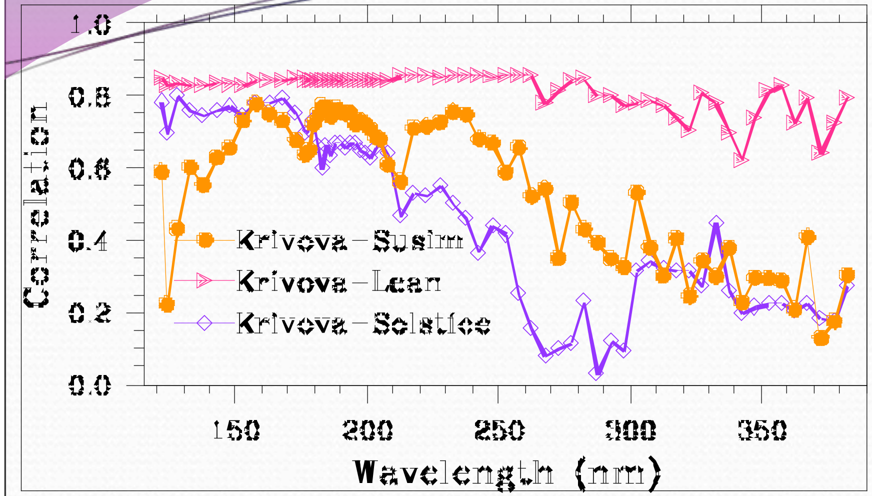


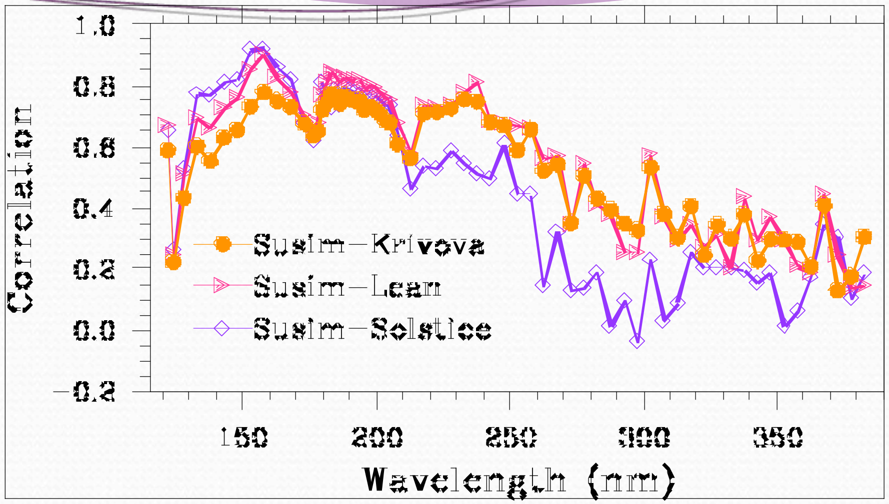
Simulated data Lean (2005), Krivova(2009)



It's possible to see that solar rotational cycle dominated in all of the spectra.

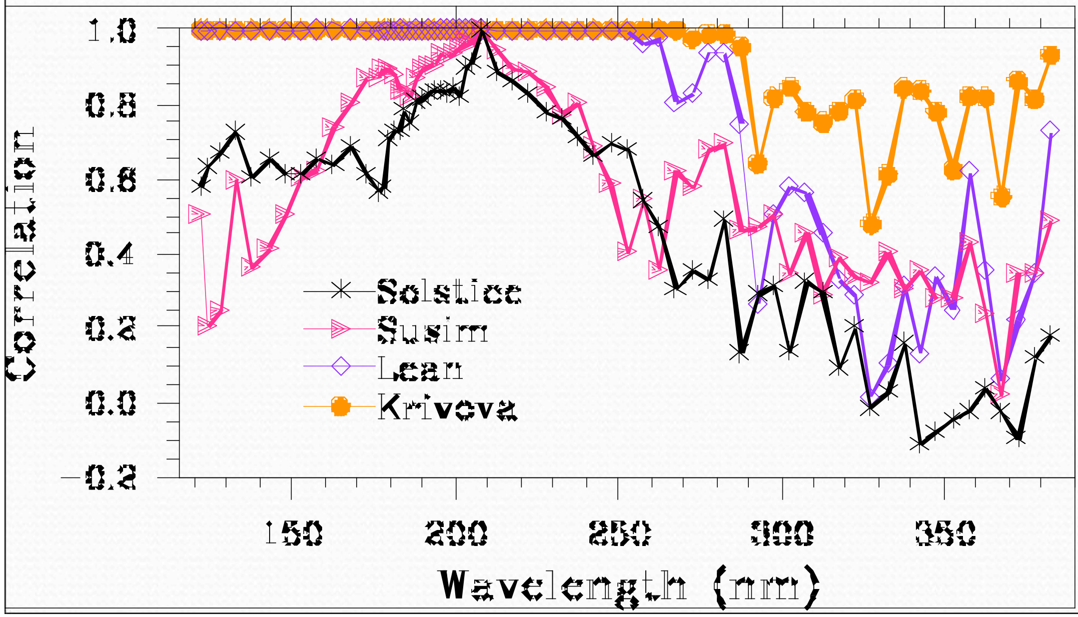
Correlations for SSI for 2000





Krivova spectral irradiance data for 2000
121 -400 nm

Susim, Solstice, Lean spectral irradiance for 2000 (121 -400 nm)



Irradiance for 2000 at 205 nm

Irradiance for 2000 at
121 -400 nm

1D RCPM Model

Input:
solar spectral irradiance,
some initial data(albedo, CO_2....)

↓

1-D RCPM
(radiative - convective model
with interactive photochemistry)

20 years for equilibrium

Last year

↓

Simulated neutral and ionized species → O_3, OH, electrons

Altitudes:

Ground ⟹ 100 km

(20 km ⟹ 85 km)

Solar spectrum:

Divided into

73 intervals,

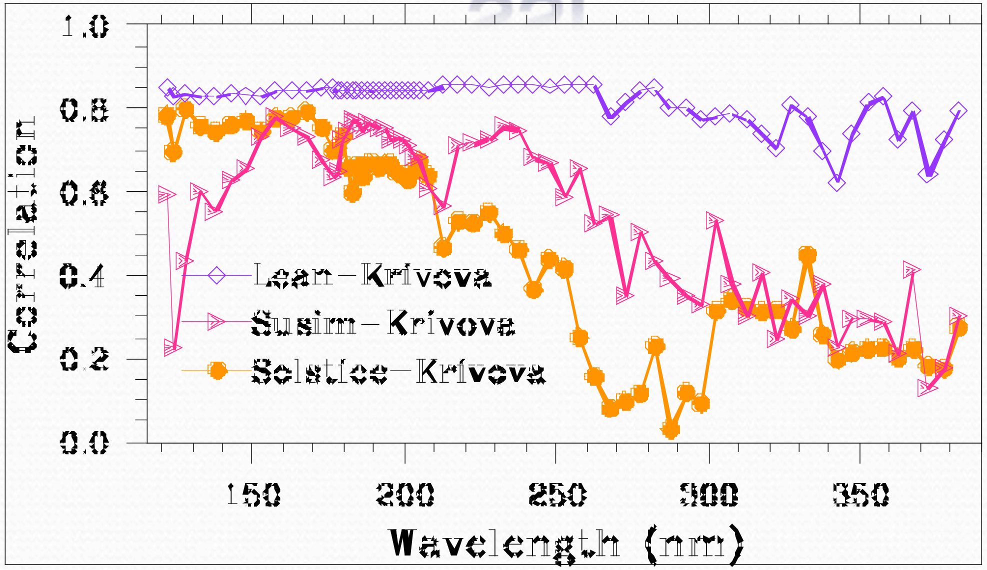
which cover

121-750 nm

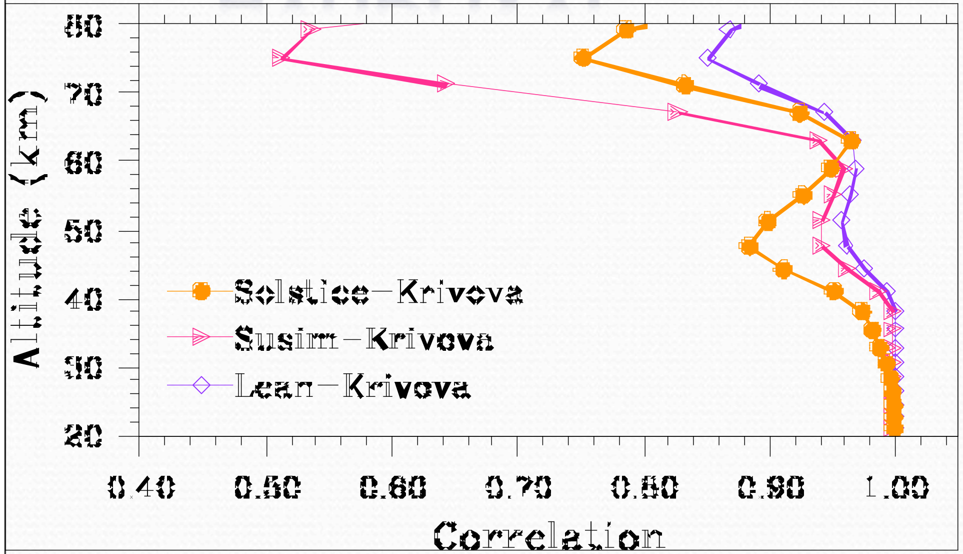
121....200......300...........500............750

Correlations of responses for 2000

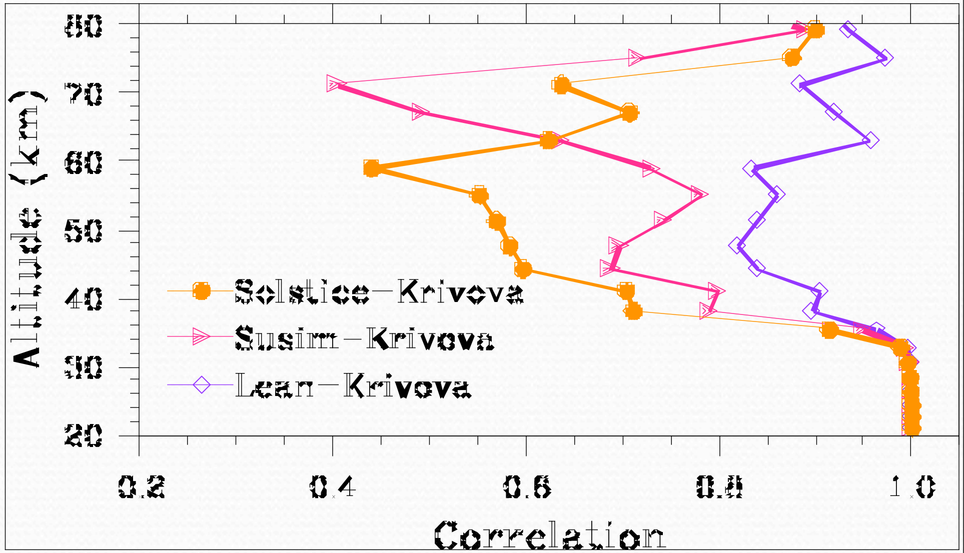
SSI



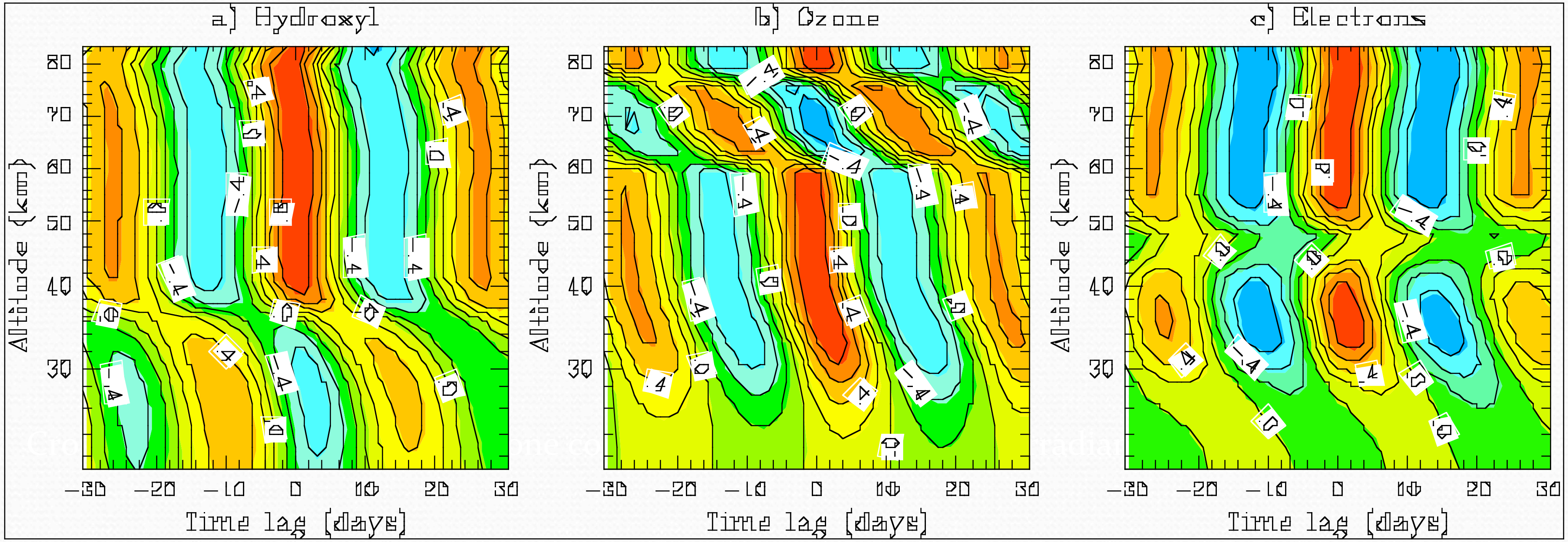
HYDROXYL



OZONE



Cross-correlation functions



Cross-correlation functions for the hydroxyl, ozone and electron concentrations versus the solar irradiance at 205 nm obtained from Lean data set.

Sensitivity

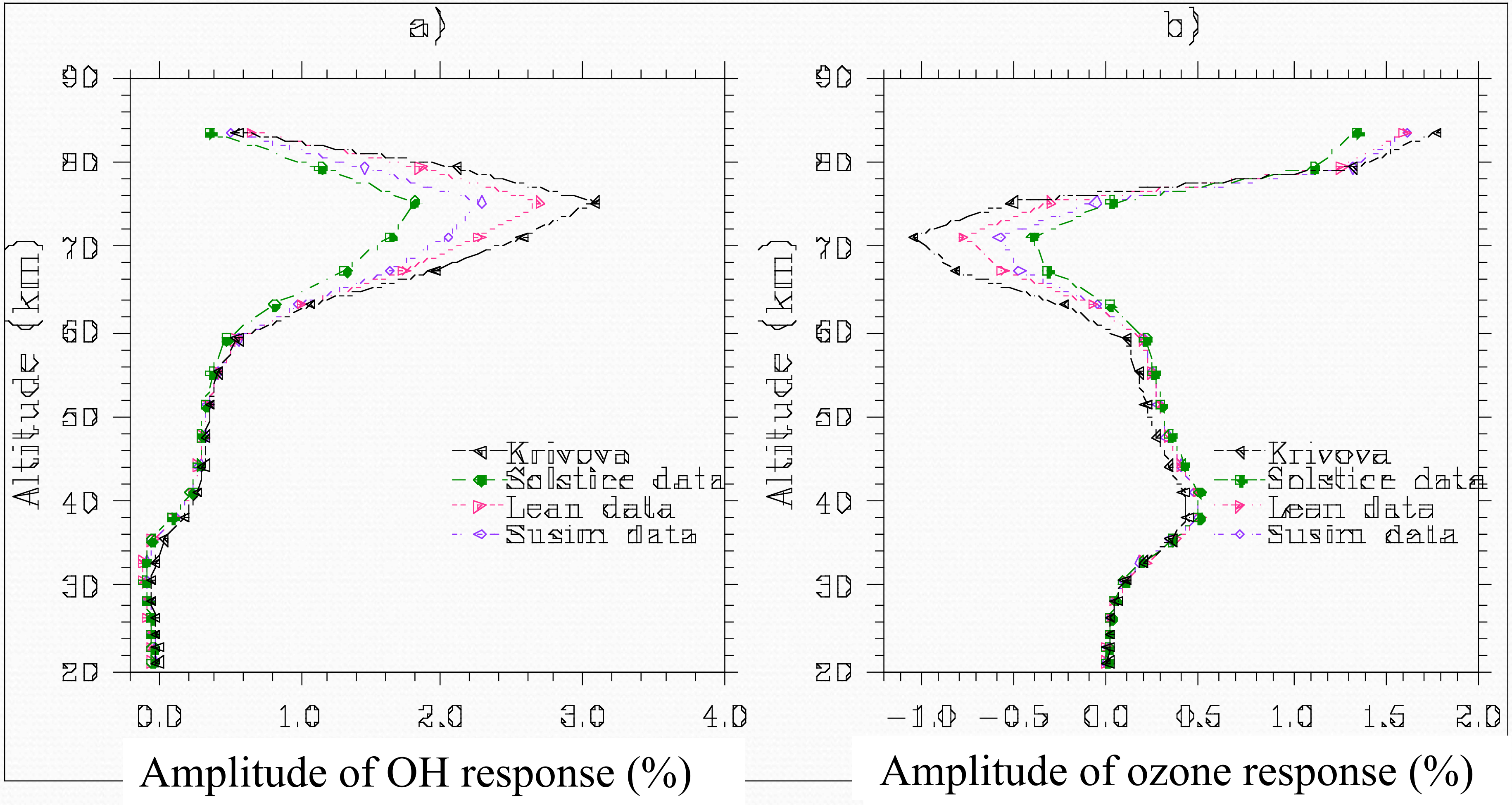
$$\Delta O_3(day,h) = \frac{O_3^{day}(day,h) - \overline{O_3}(h)}{\overline{O_3}(h)}$$

$$\Delta I(day) = \frac{I(day) - \overline{I}}{\overline{I}} \qquad I = I_{205.5nm}$$

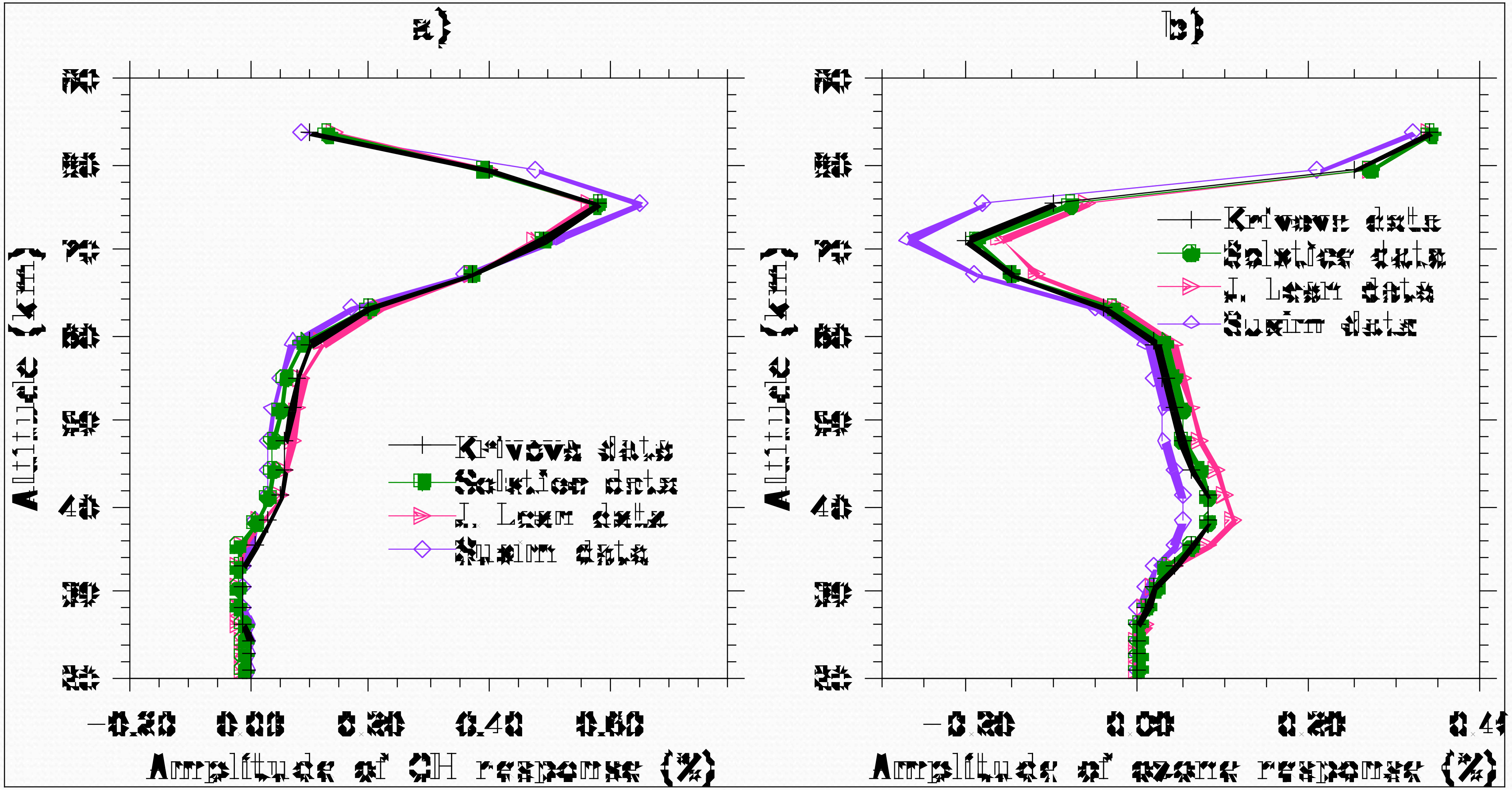
$$S(h) \leftarrow regression(\Delta O_3(day,h), \Delta I(day))$$

Sensitivity of O3 (OH,..) (%) to 1% change of 205 nm solar flux for the maximum correlation.

Sensitivities of OH and ozone for 2000



Sensitivity to irradiance at Lyman-alpha line for 2000



Sensitivity analysis application

Sensitivity analysis base on 205 nm.

- Sensitivities for different data sets are similar in the stratosphere and have a substantial difference in the mesosphere.

Sensitivity analysis base on Lyman-α.

- Sensitivities for different data sets are similar in the mesosphere and have a difference in the stratosphere.

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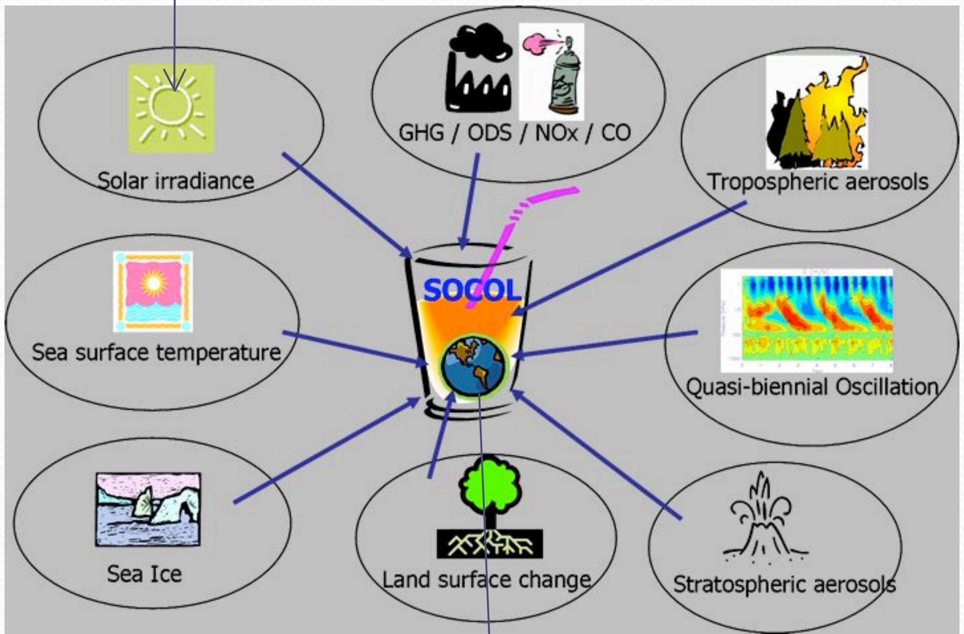
3D - SOCOL

Daily spectral solar irradiance compiled by Lean (2005) for 2000-2005



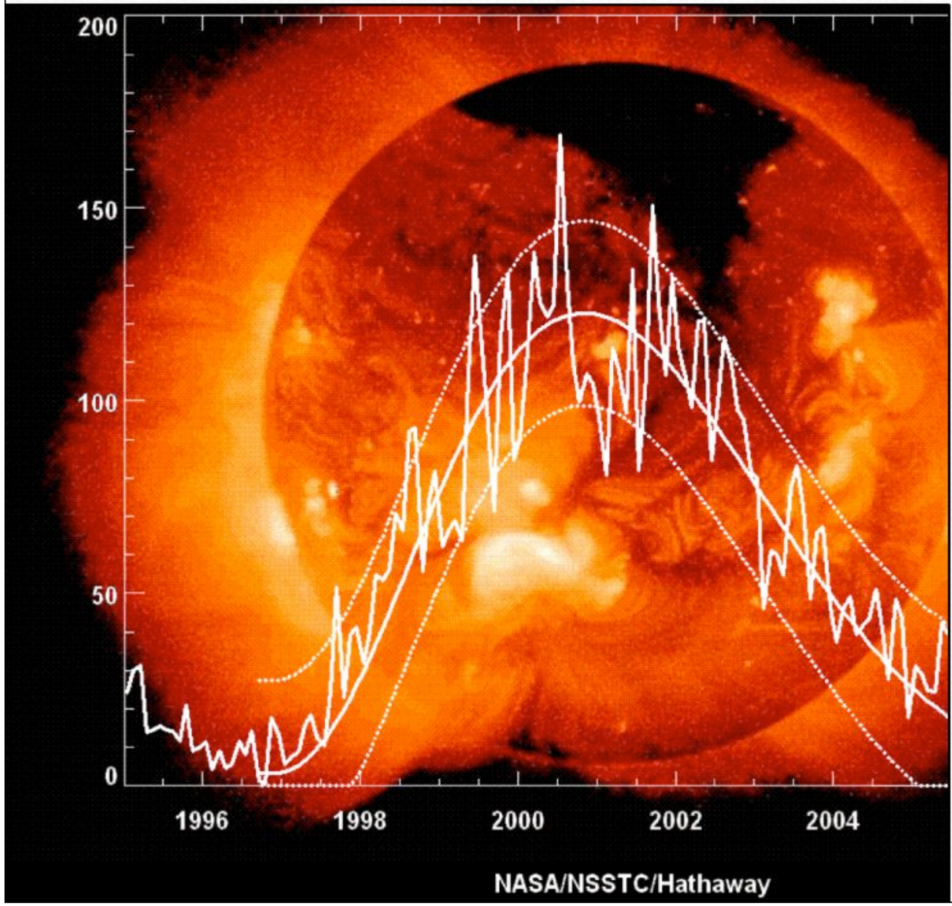
Daily response O3, OH….

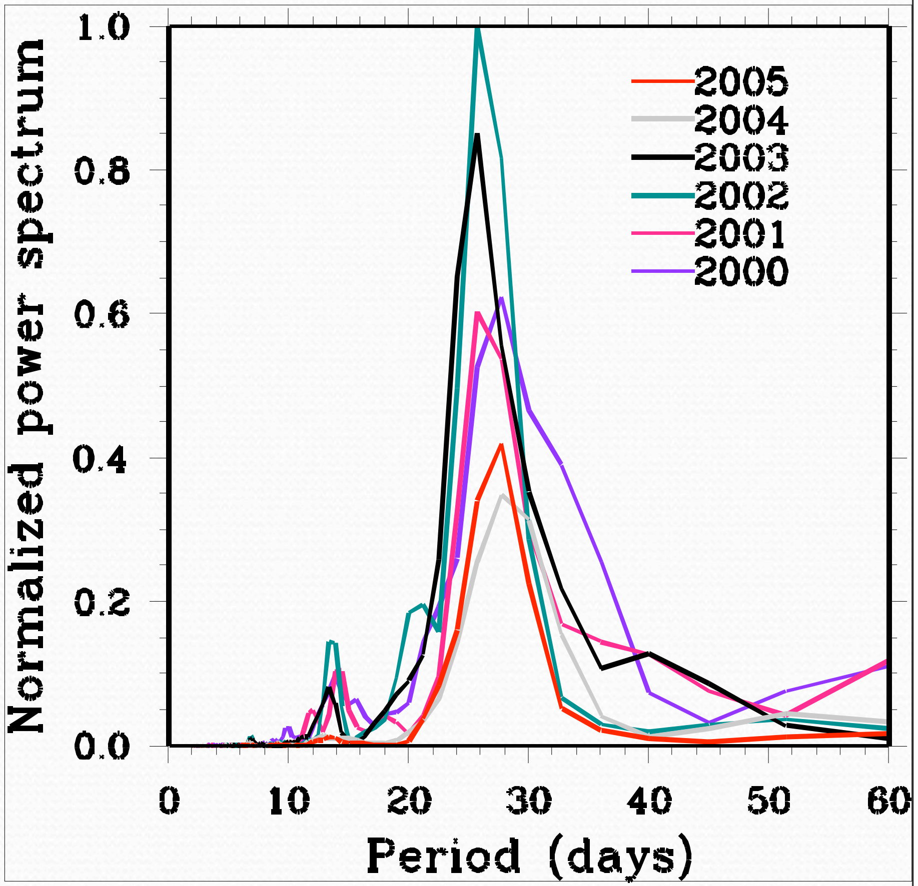
SOCOL

SOCOL description
(modeling tool to evaluate *SOlar-Climate-Ozone Links)*
General Circulation component : MA-ECHAM4 (*Manzini & McFarlane, 1998)*
Chemistry/transport component : MEZON (*Rozanov et al.,1999, Egorova et al.,2003)*
***Grid: spectral model with T30 (Gaussian grid 3.75ºx3.75º); L39 hybrid sigma-pressure* coordinate system; in the LS ~ 2 km; model top is at 0.01hPa (~80 km);**
GCM part:
Dynamics: **semi-implicit time stepping scheme with a weak time filter: Δt = 15'**
Radiation: **Δt = 2 h, adopted from ECMWF (Fouquart&Bonnel,1980; Morcrette, 1991) ;**
Heating and cooling rates are calculated every 15 min.
Gravity wave: **based on the formulation of (McFarlan, 1987), vertical propagation follows Hines(1997)**
Transport: **Semi-Lagrangian for water vapor, liquid water, and tracers (Williamson and Rash, 1994)**
Horizontal diffusion : **in the form of a hyper-Laplasian with high-diffusion sponge zone at the upper boundary(~5 km) cloud formation, convective processes, planetary boundary layer, land-surface processes**
ACTM part:
Species: **41 from O-, N-, H-, C-, Cl- and Br- families, 118 gas-phase, 33 photolysis reactions, 16 heterogeneous reactions on/in sulfate aerosol (binary and ternary solutions) and PSC particles *(Carslaw et al., 1995)***
Chemical solver : **implicit iterative Newton-Raphson scheme *(Ozolin, 1992; Stott&Harwood, 1993), Δt=2 h***
Kinetics : **JPL-1997, 2000**
Photolysis rates: **Δt = 2 h, look-up-table approach**
Transport: **Hybrid numerical advection scheme *(Zubov et al., 1999) :***
Prather scheme is in vertical direction and Semi-Lagrange scheme is in horizontal

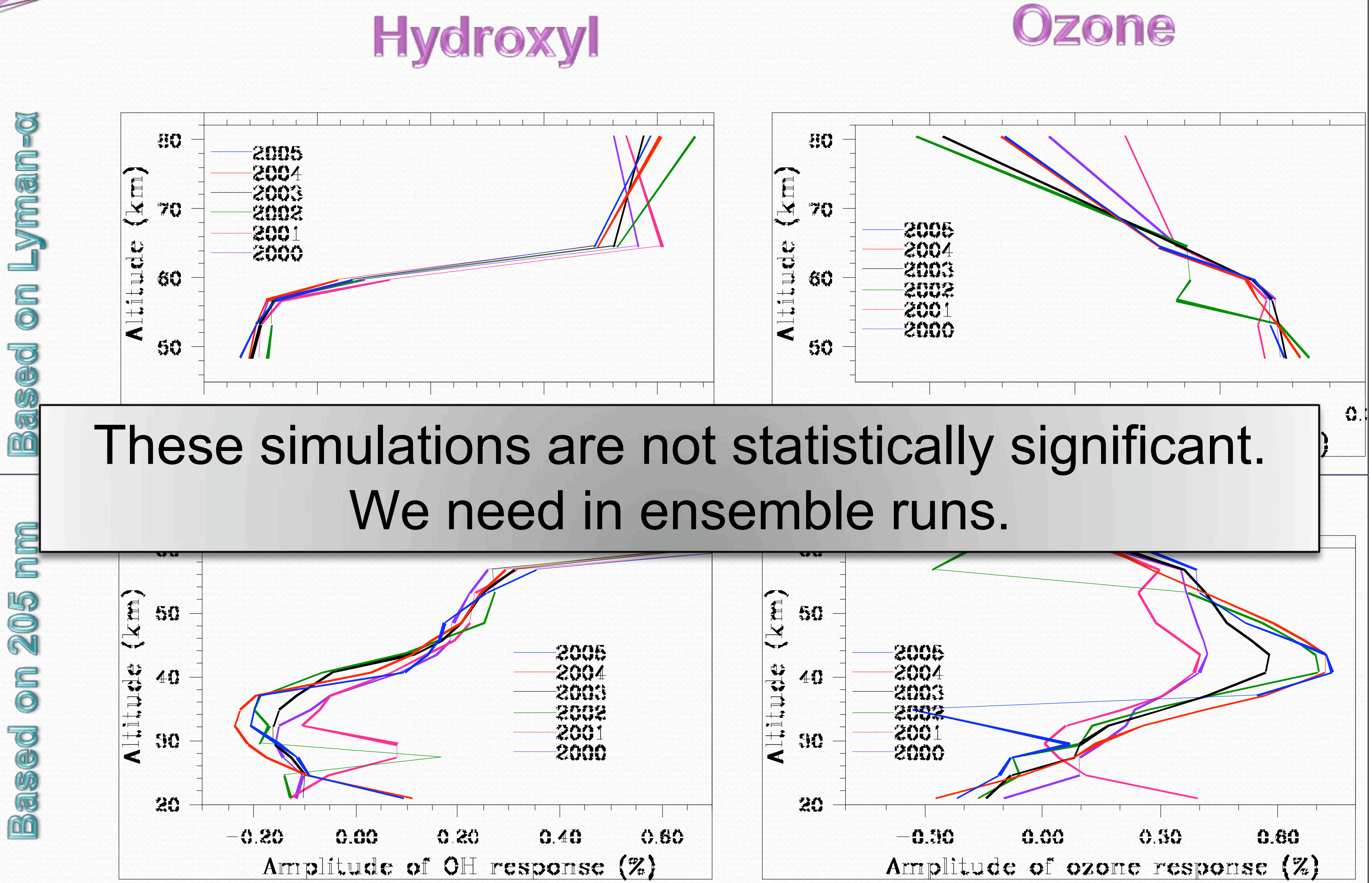
2000 – 2005 (SOCOL)

Solar rotational cycle
dominates in the spectra of each year (2000-2005)
especially for years of solar maximum (2001-2002).





SOCOL simulations (example)



These simulations are not statistically significant.
We need in ensemble runs.

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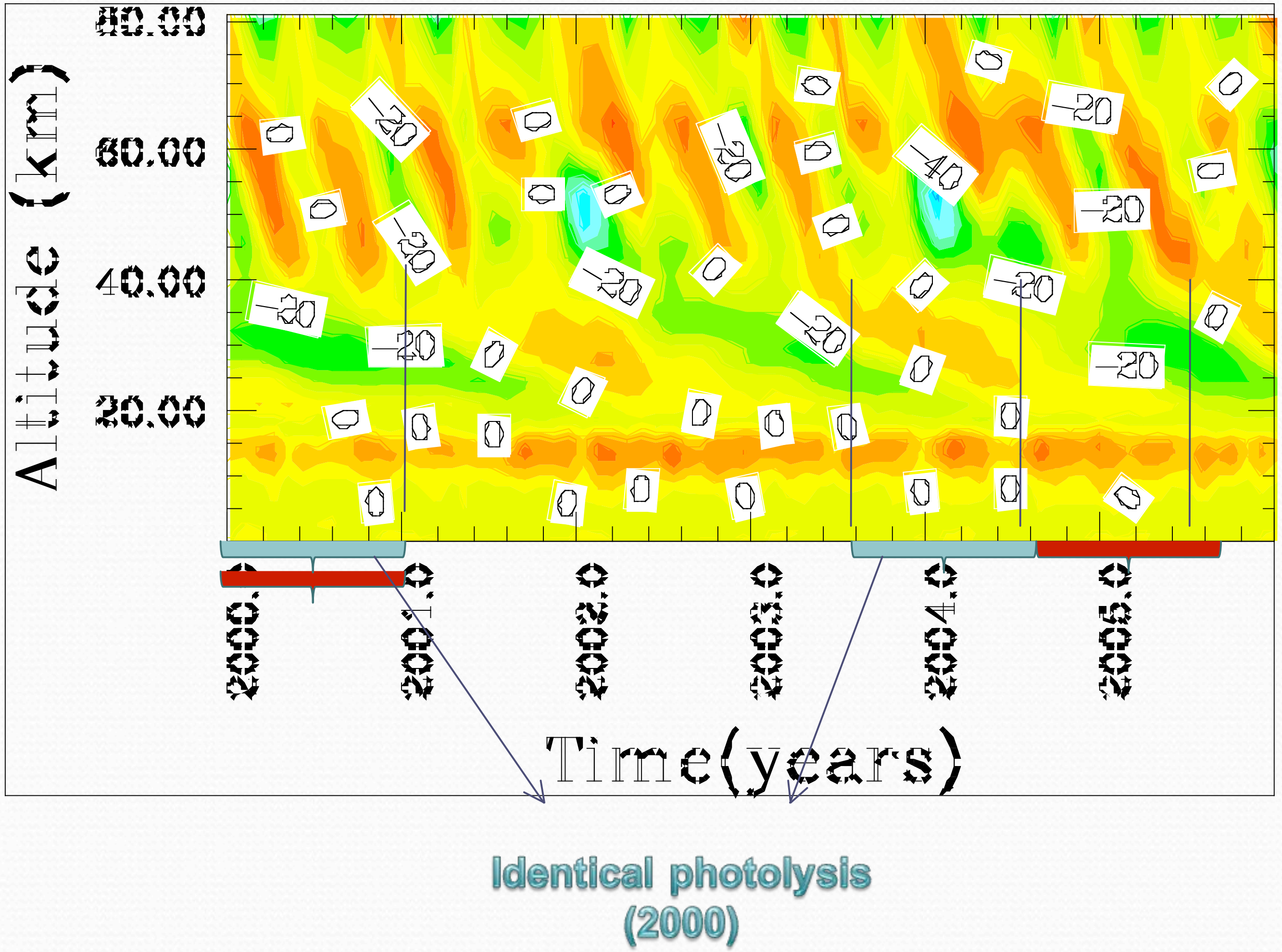
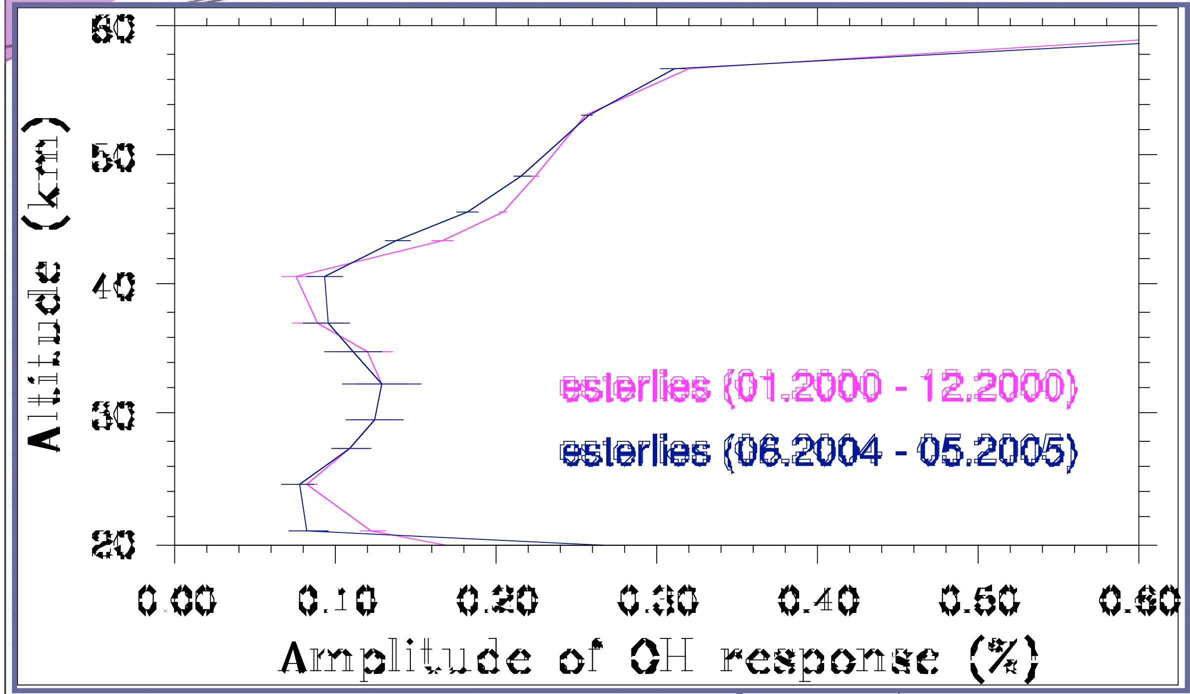
QBO

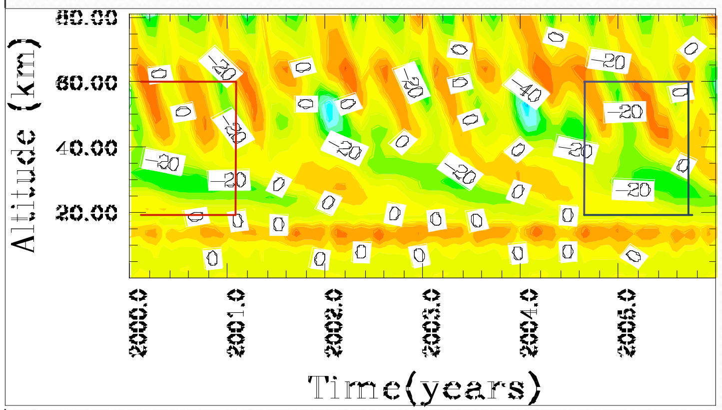
The response of some atmospheric species to short-term solar variability can be affected by internal variability of the atmosphere itself (e.g. QBO).

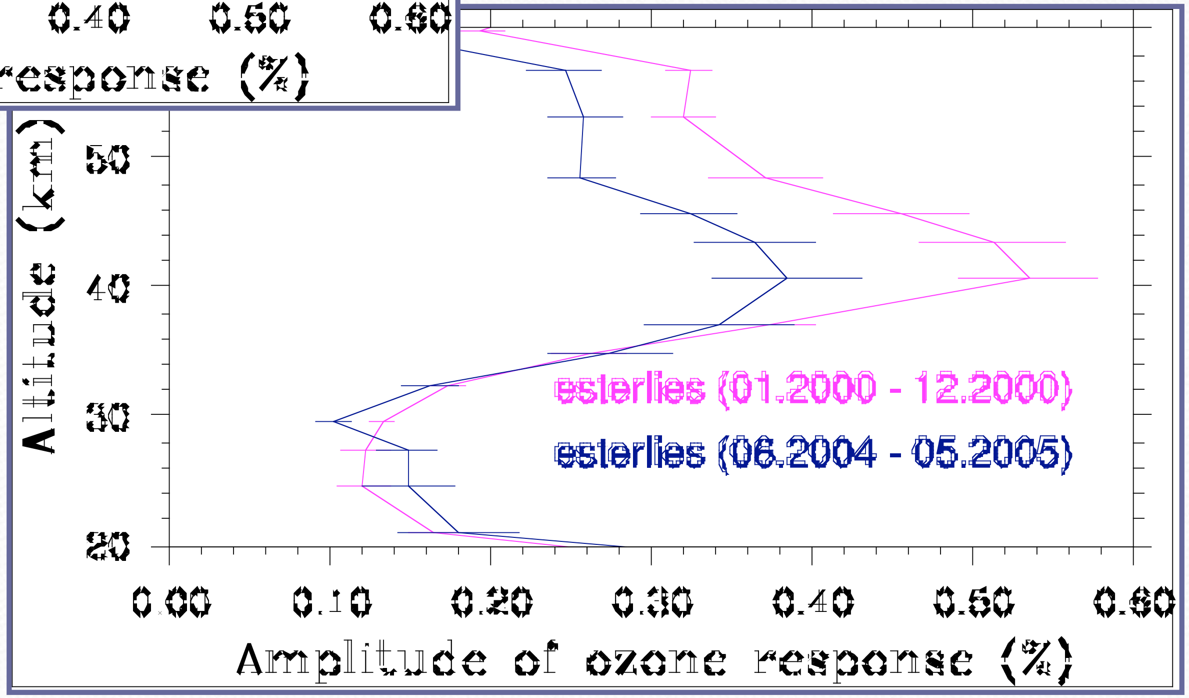


Comparison (solar min and max)

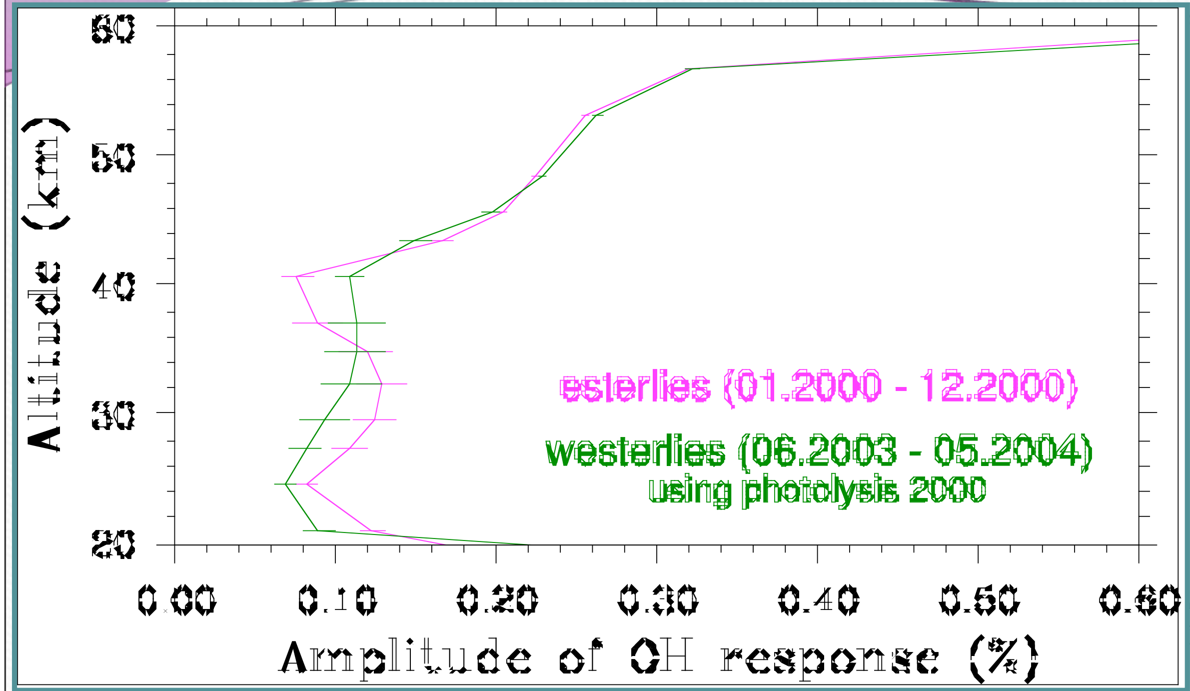


Two ensemble runs
(10 members)
Both for esterlies
01.2000 – 12.2000 – solar max
06.2004 – 05.2005 – solar min

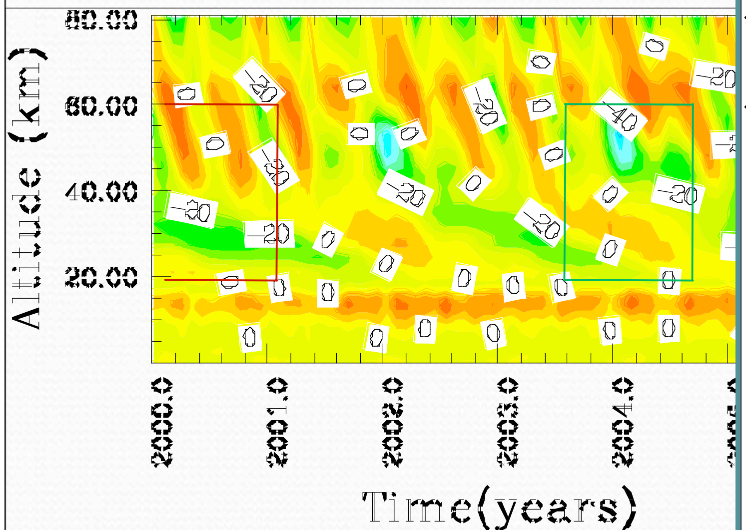


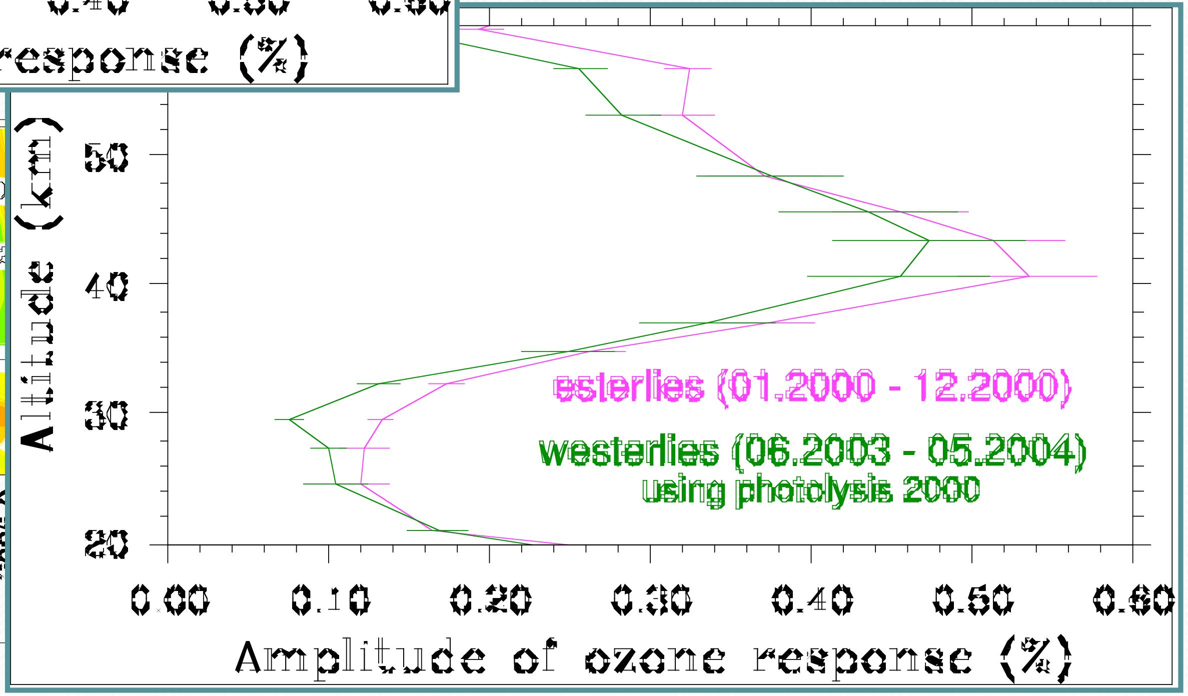


QBO phases with identical photolysis

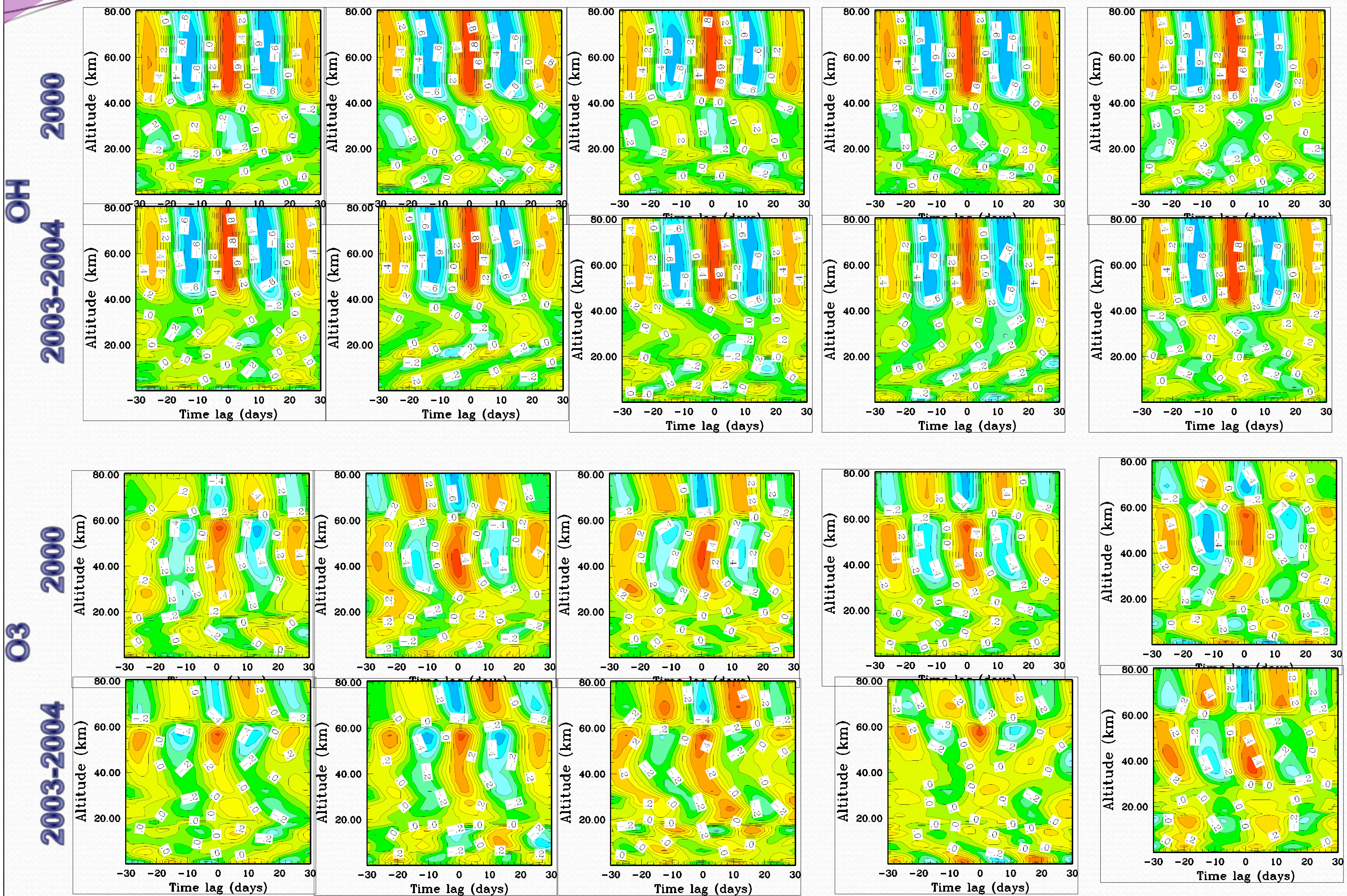


Two ensemble runs
(10 members)
Different QBO phases
Both with photolysis
01.2000 – 12.2000





Cross-correlations

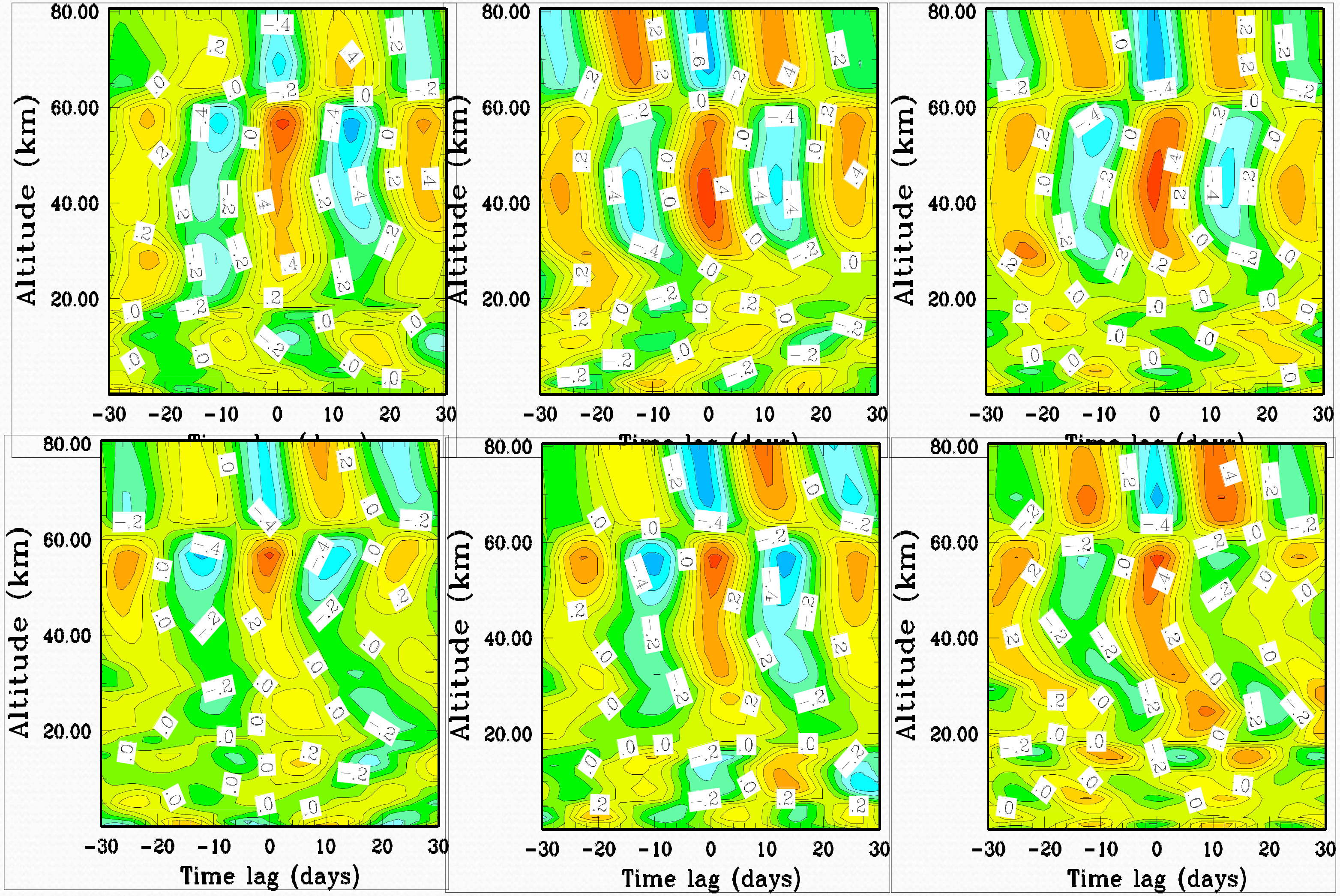


Cross-correlations

O3

2000

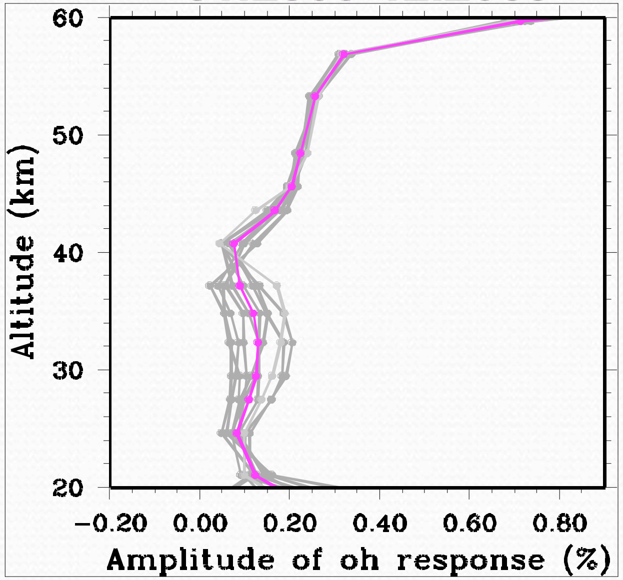
2003-2004



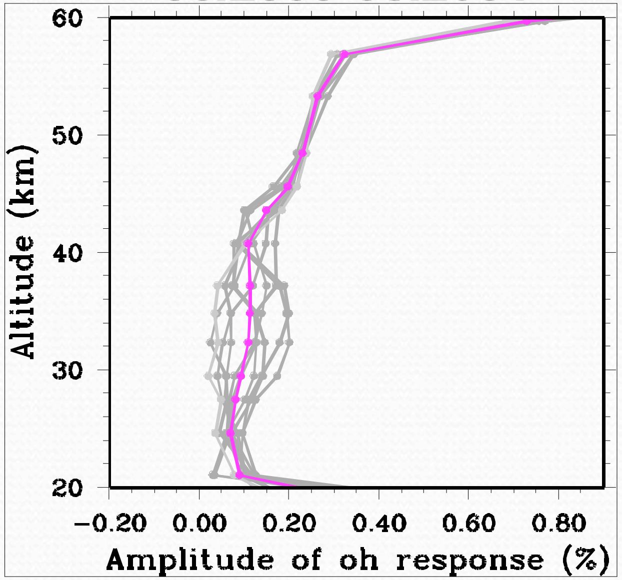
Sensitivity analysis

Esterlies

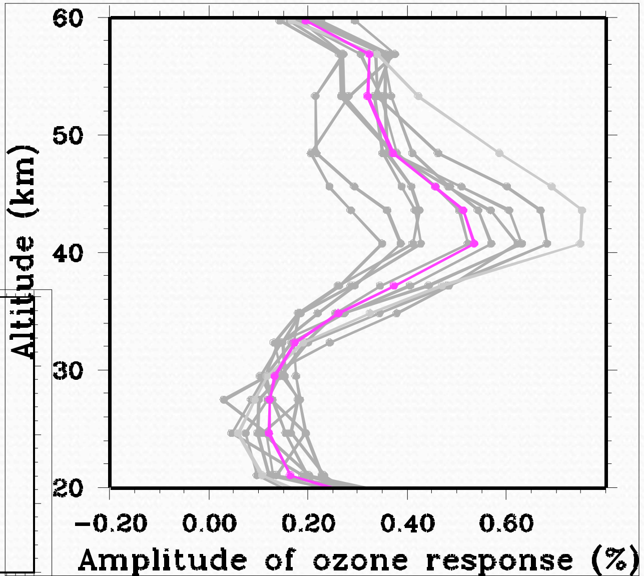
01.2000-12.2000

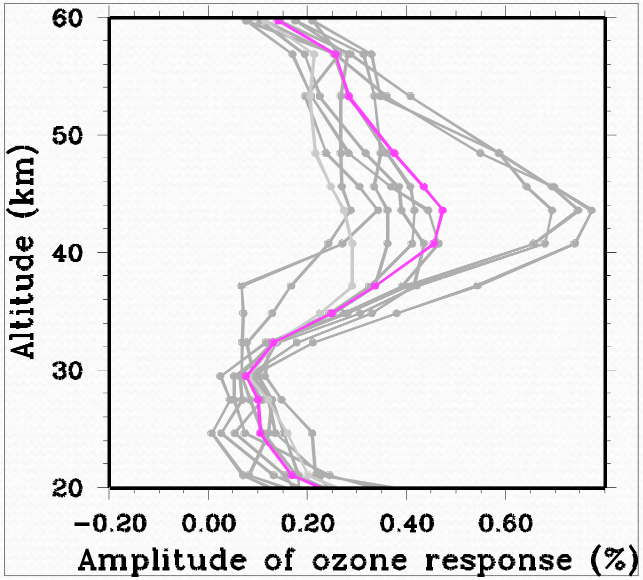


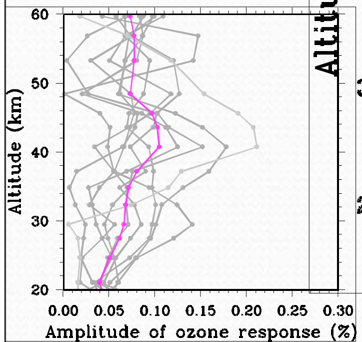
06.2003-05.2004



Westerlies







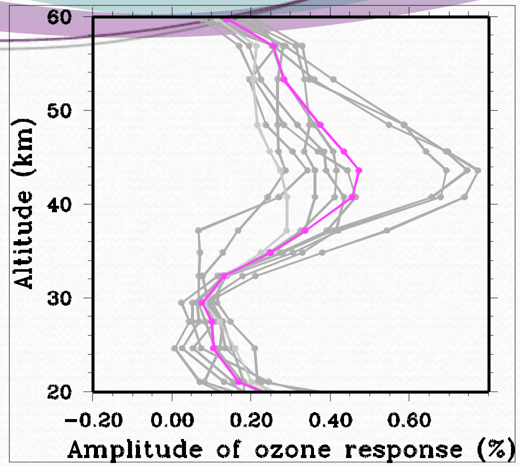
Amplitude of temperature response (K)

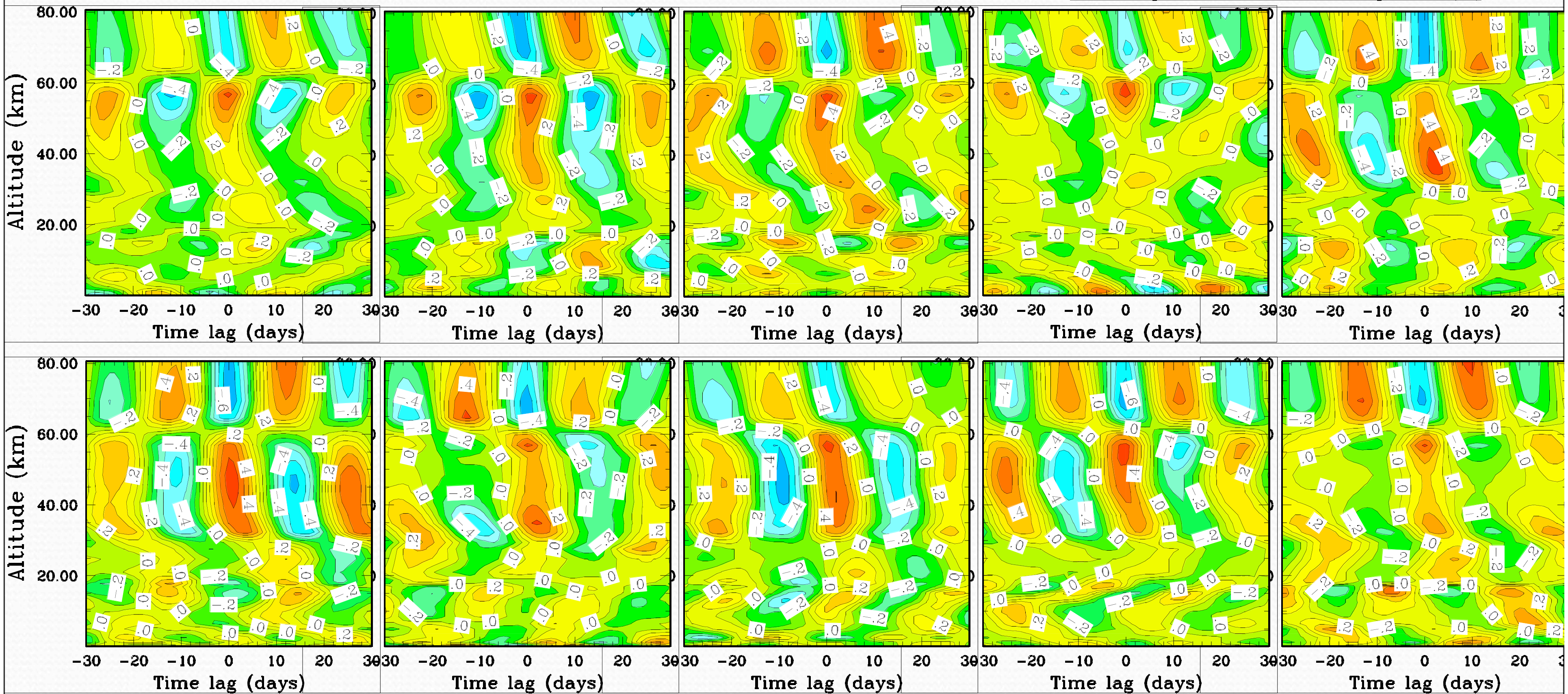
Identical photolysis (01.2000 – 12.2000)

Ozone cross-correlation functions

Ozone - westerlies
06.2003 – 05.2004
Photolysis
01.2000 – 12.2000

Ozone sensitivity to 27-day solar irradiance variability





Conclusions

1. The different SSI data sets were considered
2. Sensitivities of hydroxyl and ozone to solar irradiance for different data sets are similar in the stratosphere and have a substantial difference in the mesosphere if sensitivity analysis base on irradiance at 205 nm and similar in the mesosphere and have a substantial difference in the stratosphere if sensitivity analysis base on irradiance at Lyman-alpha line.
3. Using Chemistry-climate model SOCOL sensitivity analysis for hydroxyl and ozone was made according to the conclusion 2.
4. Hydroxyl and ozone sensitivity analysis was made for different QBO and solar cycle phases
5. The hydroxyl sensitivities to the SSI changes during solar rotation cycle are almost identical for the min and max solar cycle while the ozone sensitivities to the SSI changes are different for layers higher 40 km.
6. The hydroxyl sensitivities to the SSI changes during solar rotation cycle are almost identical for the different QBO phases while the ozone sensitivities to the SSI changes are slightly different for 25 - 35 km layers.

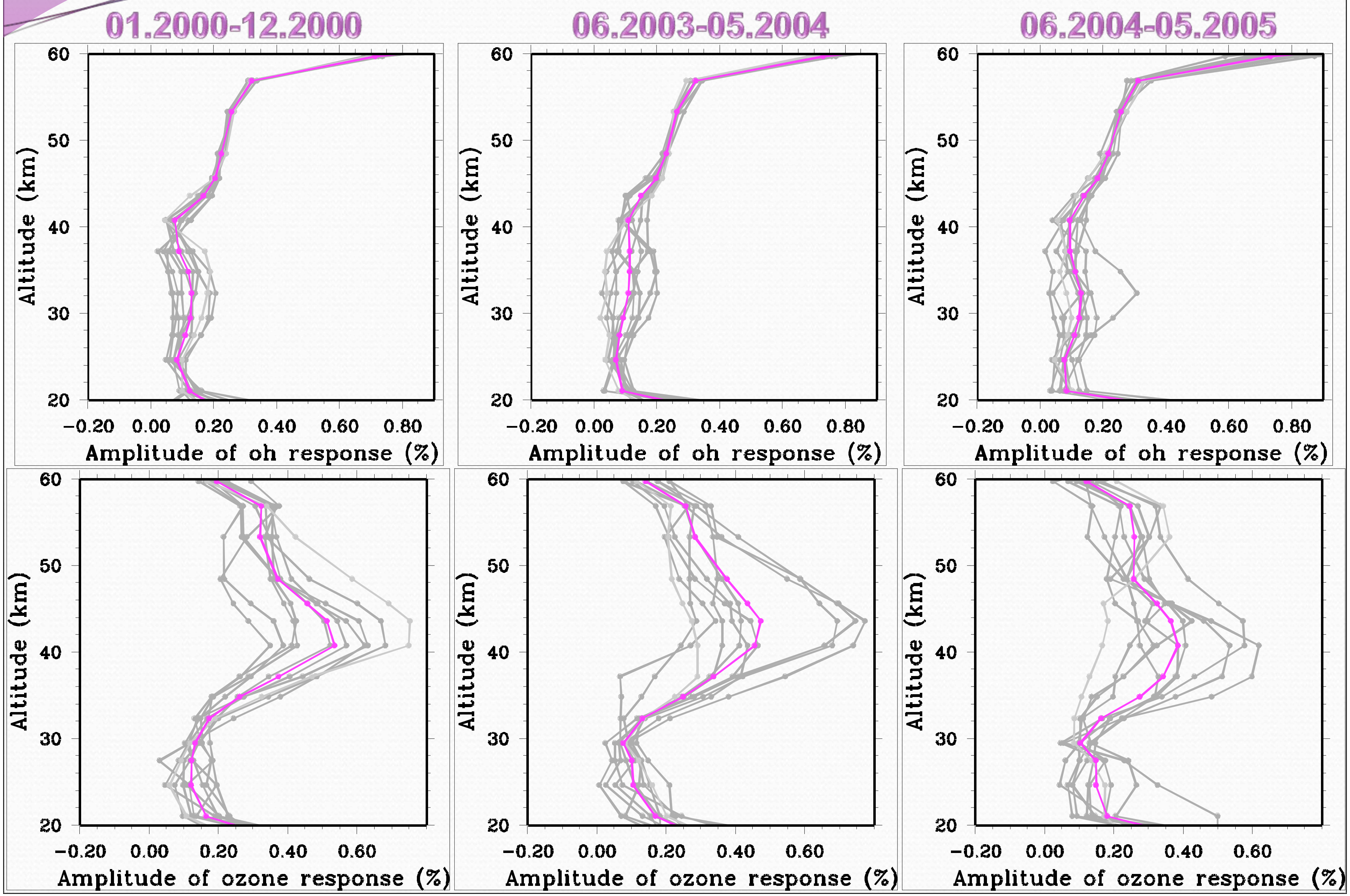
Outlook

- Investigate the temperature, water vapor and other atmospheric species responses with SOCOL
- Compare the responses with observed data (MLS, ODIN, MIPAS, SBUV, HALOE , VLF)
- Apply different methods for the calculations of the sensitivity to short-term solar variability
- Use non-linear statistical tools for the data analysis

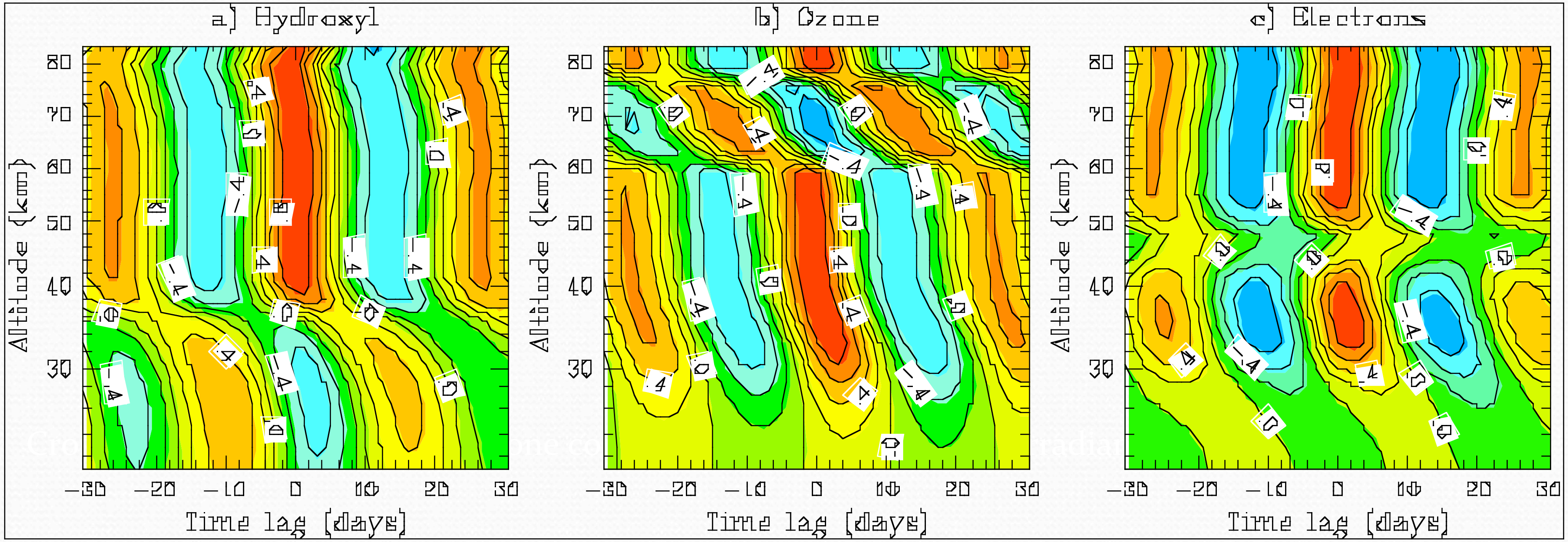
THANK

YOU!!!

Sensitivity analysis

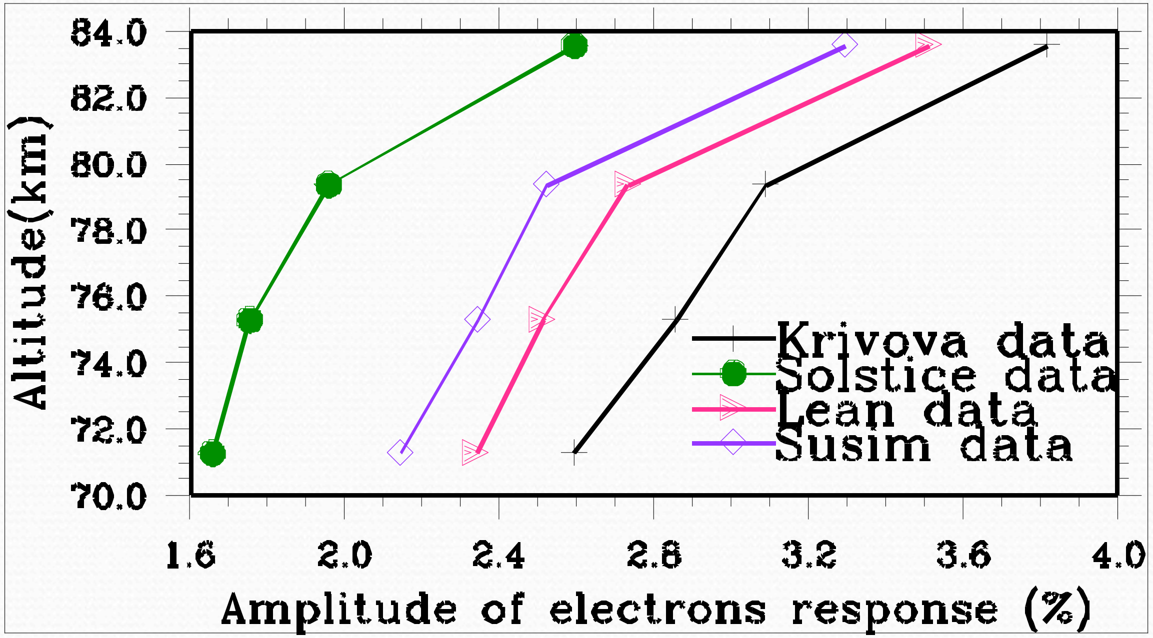


Cross-correlation functions



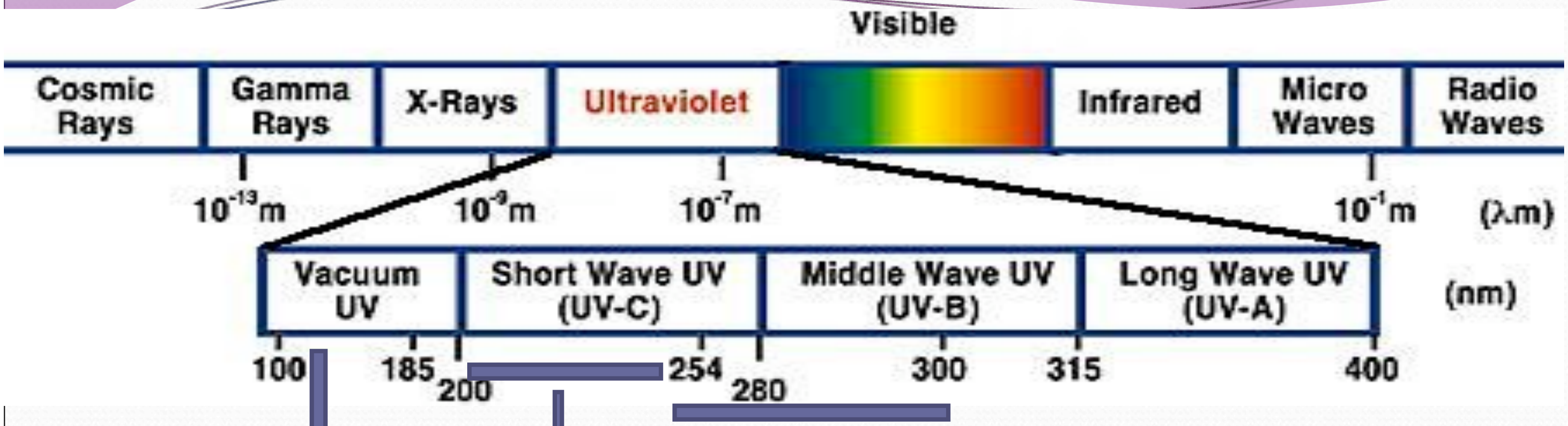
Cross-correlation functions for the hydroxyl, ozone and electron concentrations versus the solar irradiance at 205 nm obtained from Lean data set.

Sensitivity of the electron concentration



$$NO + h\nu \rightarrow NO^{+} + e^{-}$$

Experiments



First experiment
Lyman α (121-122 nm)

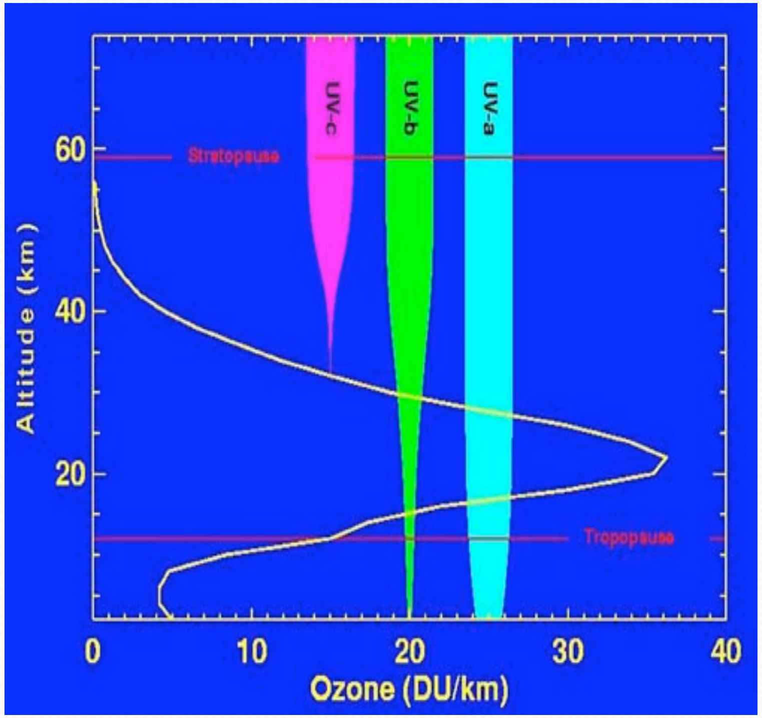
absorbed by O2 in the mesosphere

Second experiment
Herzberg continuum
(200-250 nm)

Absorption by O2 in the stratosphere and weak absorption in the mesosphere

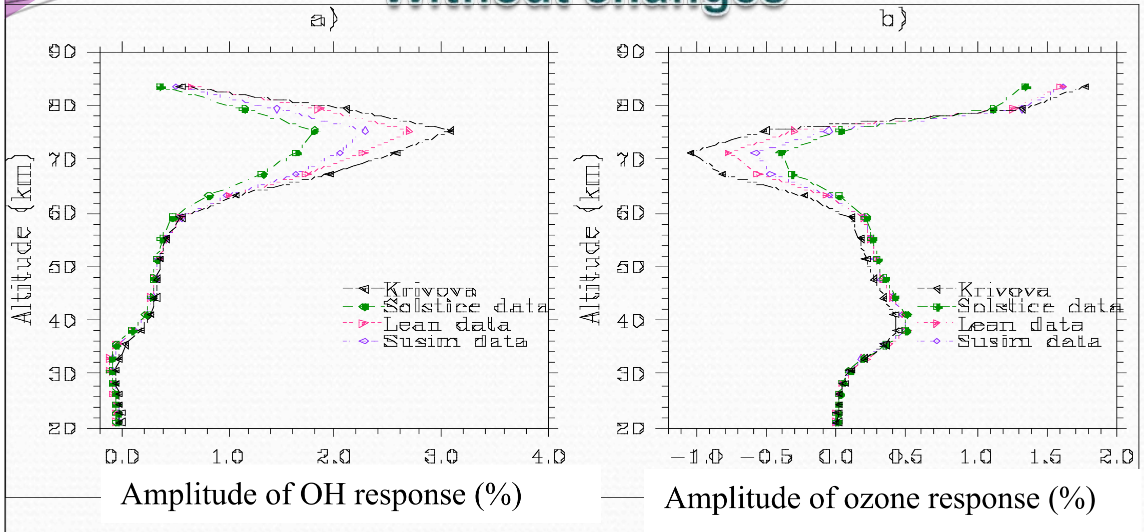
Third experiment
Hartley band
(250-300 nm)

Absorption by O3 in the stratosphere leading to the formation of O (1D).



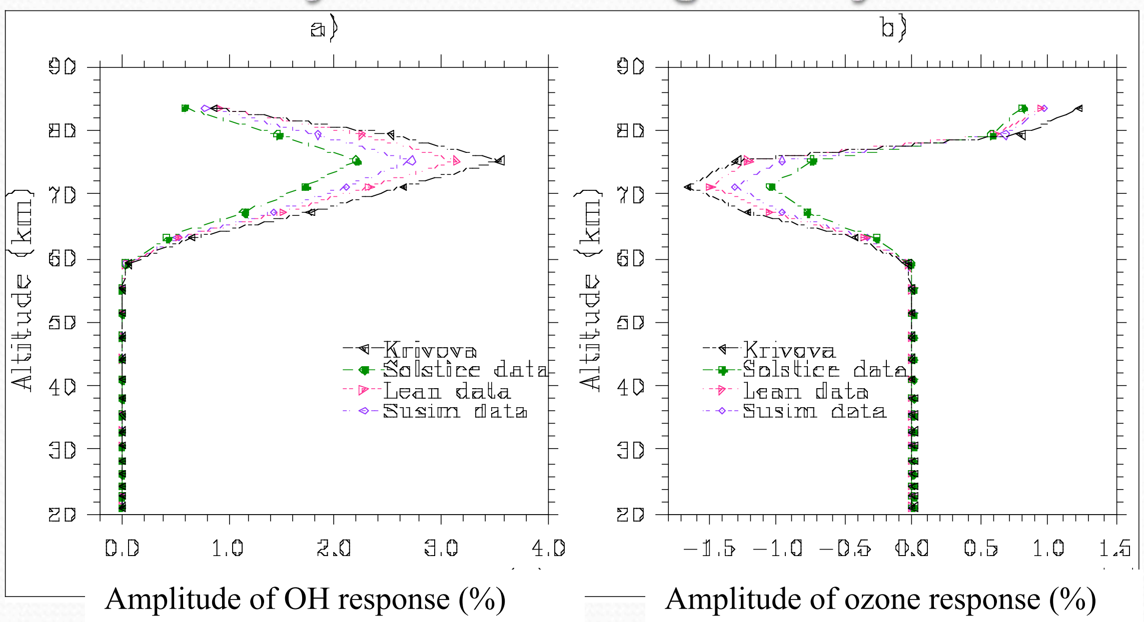
Sensitivities of OH and ozone (Lyman alpha line)

Without changes



Negative ozone and positive hydroxyl sensitivities in the mesosphere are driven by the increased photolysis of the water vapor in Lyman-alpha line that leads to increase hydrogen radicals (OH) and can be a reason for destruction of the ozone by the hydrogen radicals.

Lyman α is changed only



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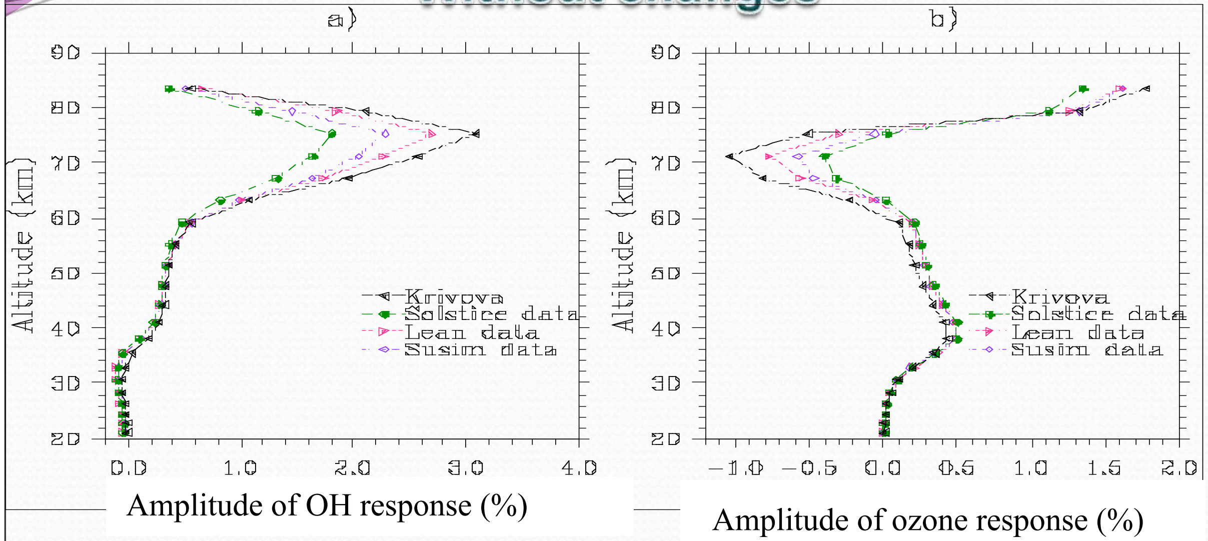
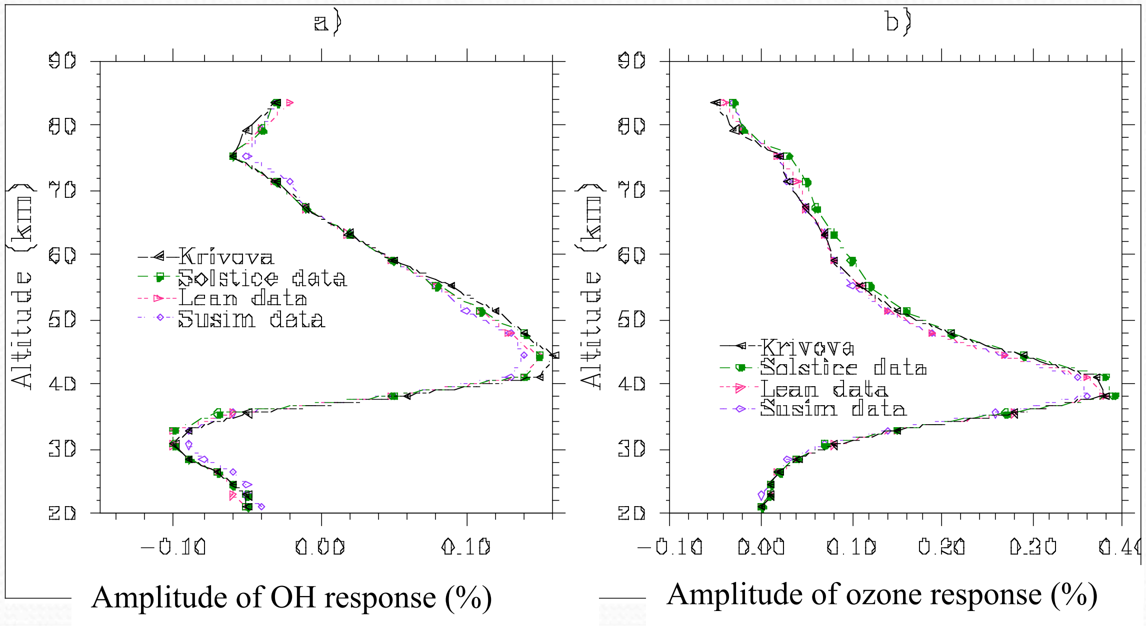
Sensitivities of OH and ozone (Herzberg continuum)

Without changes



Herzberg continuum is changed only



$$H_2 + O(^1D) \rightarrow H + OH$$

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

$$O_2 + h\nu \rightarrow O + O(\lambda < 240nm)$$

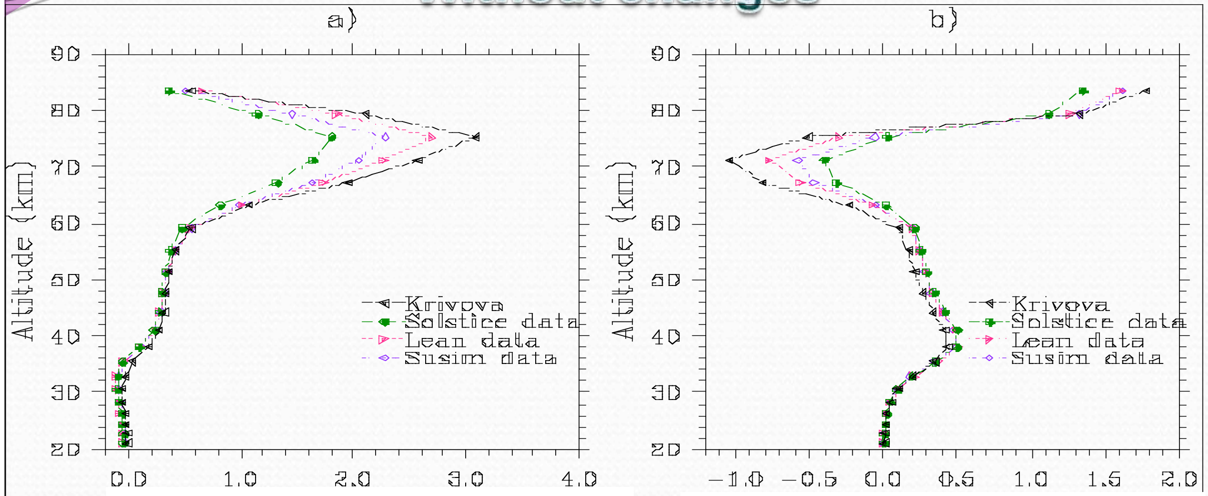
$$O + O_2 + M \rightarrow O_3 + M$$

$$O_3 + h\nu \rightarrow O_2 + O(^1D)(\lambda < 320nm)$$

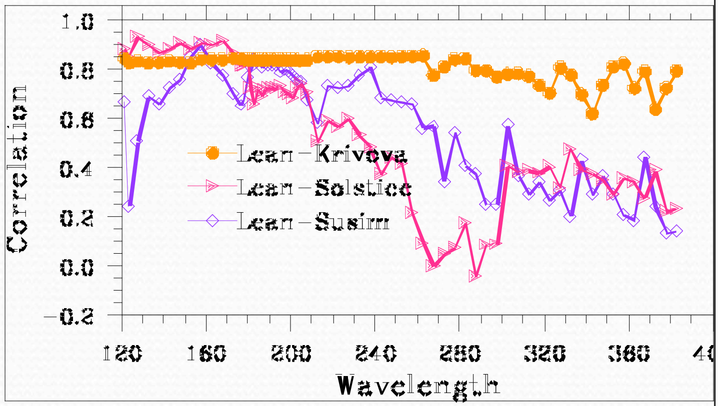
$$O_3 + O \rightarrow O_2 + O$$

Sensitivity of ozone (Hartley band (250-300 nm))

Without changes



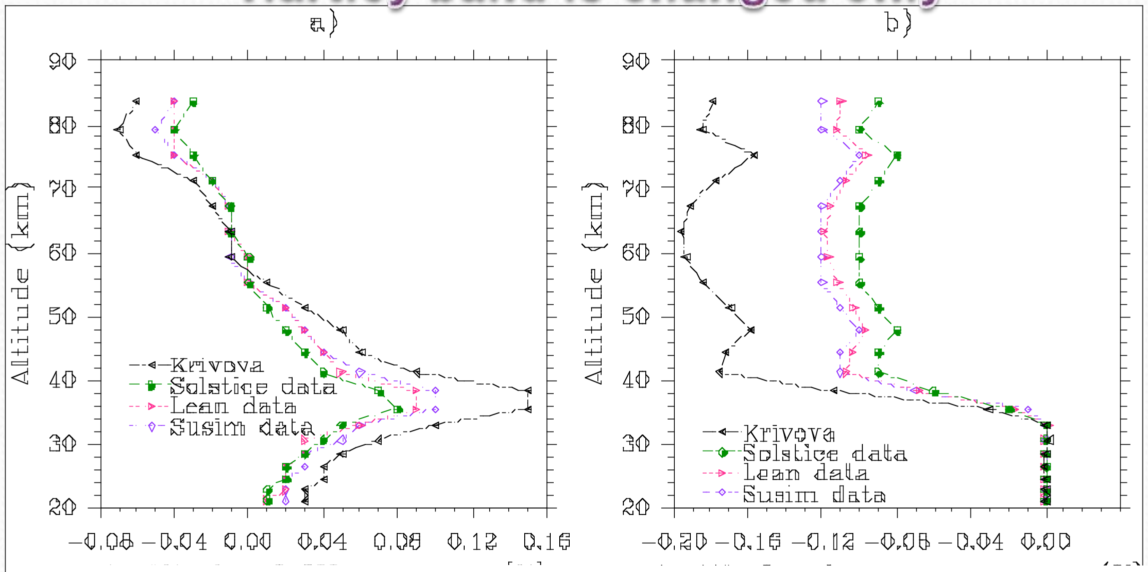
Amplitude of OH response (%) Amplitude of ozone response (%)



$$H_2 + O(^1D) \rightarrow H + OH$$

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

Hartley band is changed only



Amplitude of OH response (%) Amplitude of ozone response (%)

$$O_2 + h\nu \rightarrow O + O(\lambda < 240nm)$$

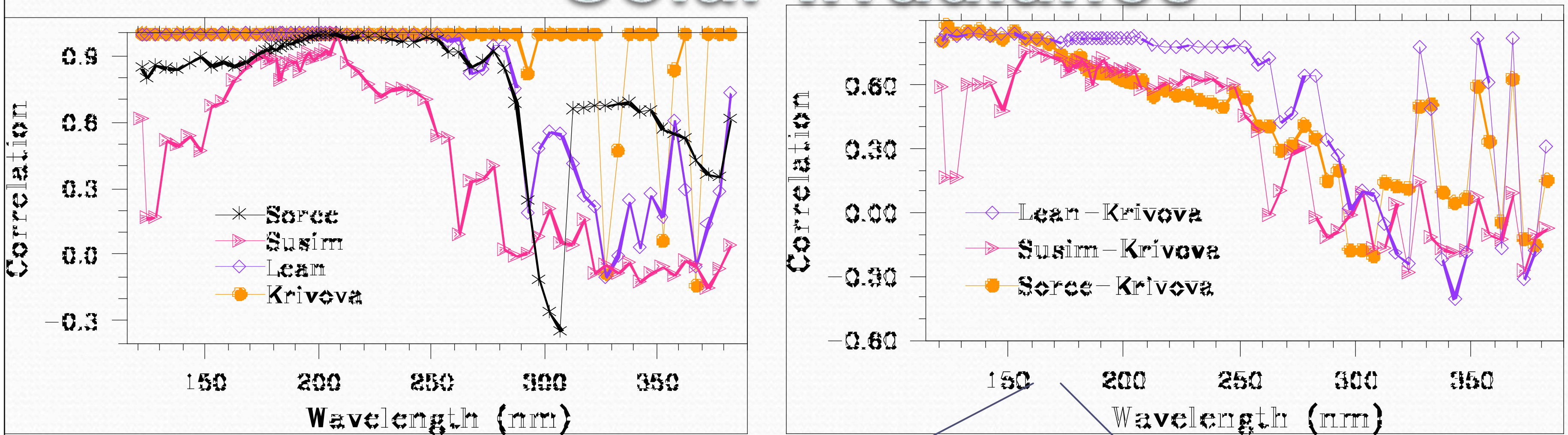
$$O + O_2 + M \rightarrow O_3 + M$$

$$O_3 + h\nu \rightarrow O_2 + O(^1D)(\lambda < 320nm)$$

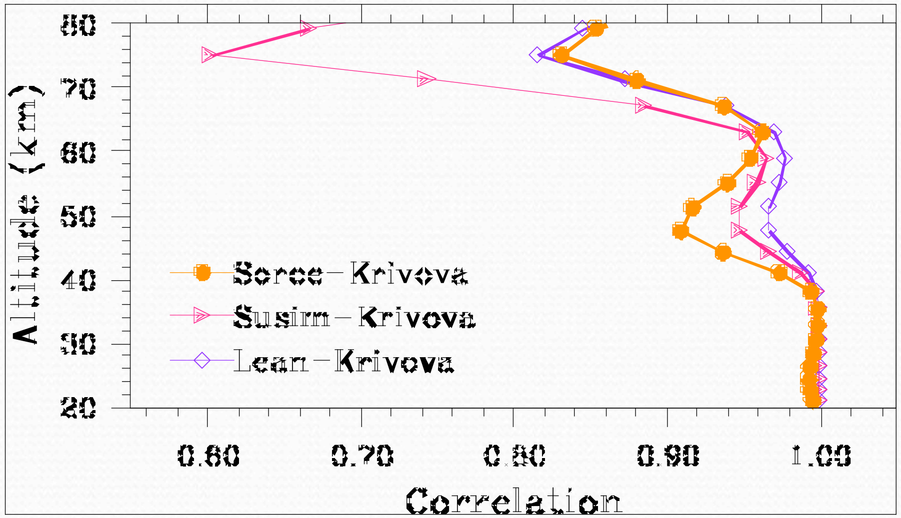
$$O_3 + O \rightarrow O_2 + O$$

Correlations (2004-2005)

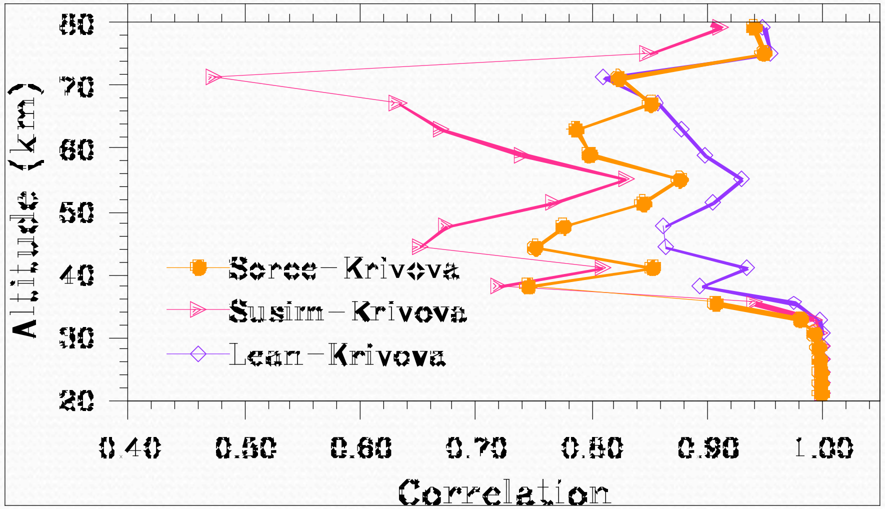
Solar irradiance



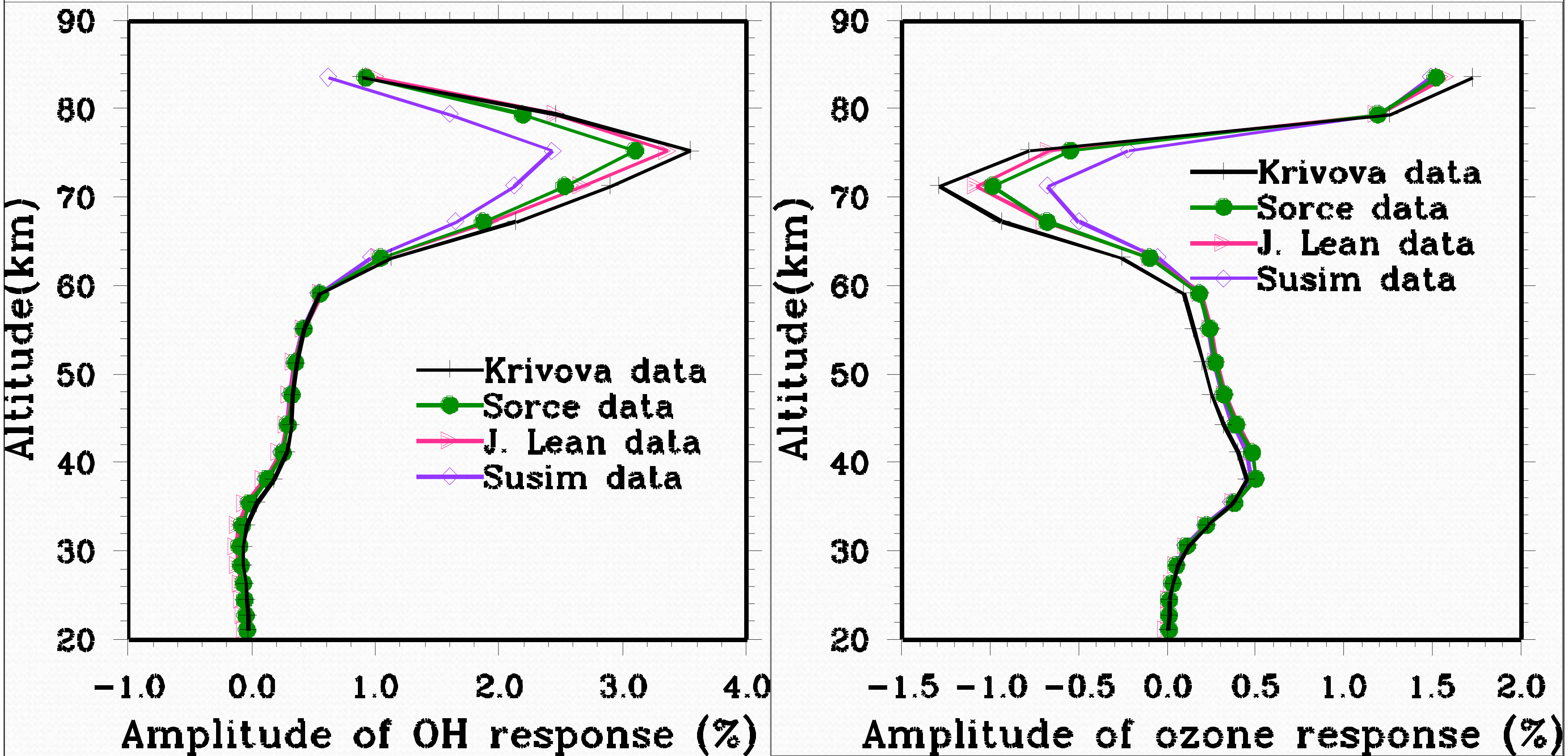
OH



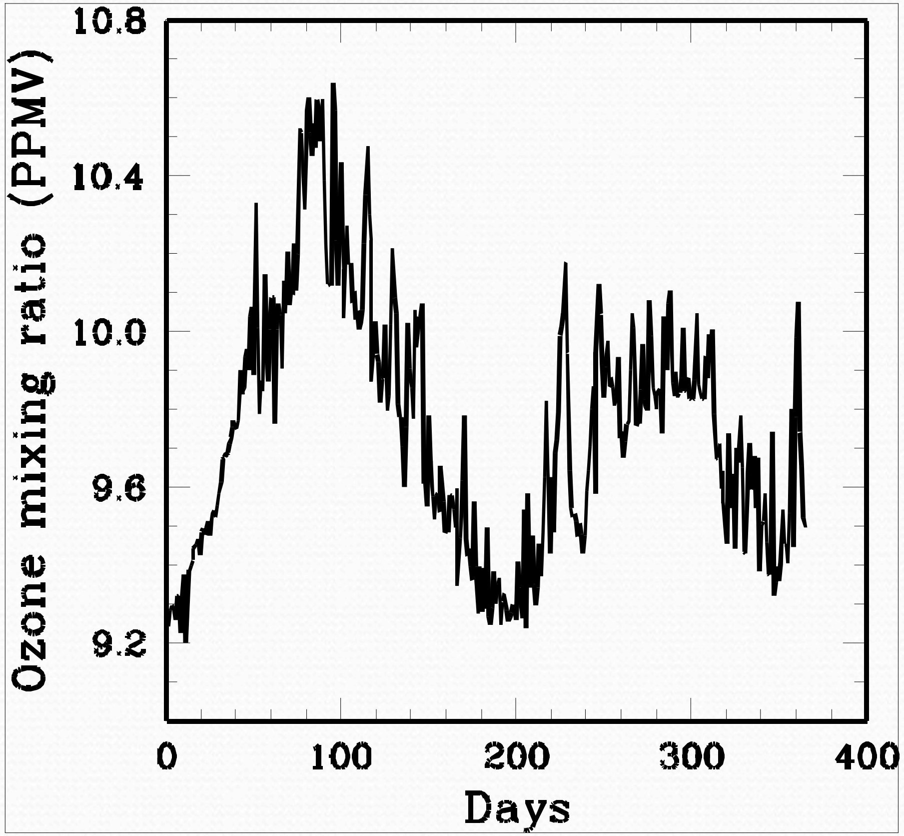
Ozone

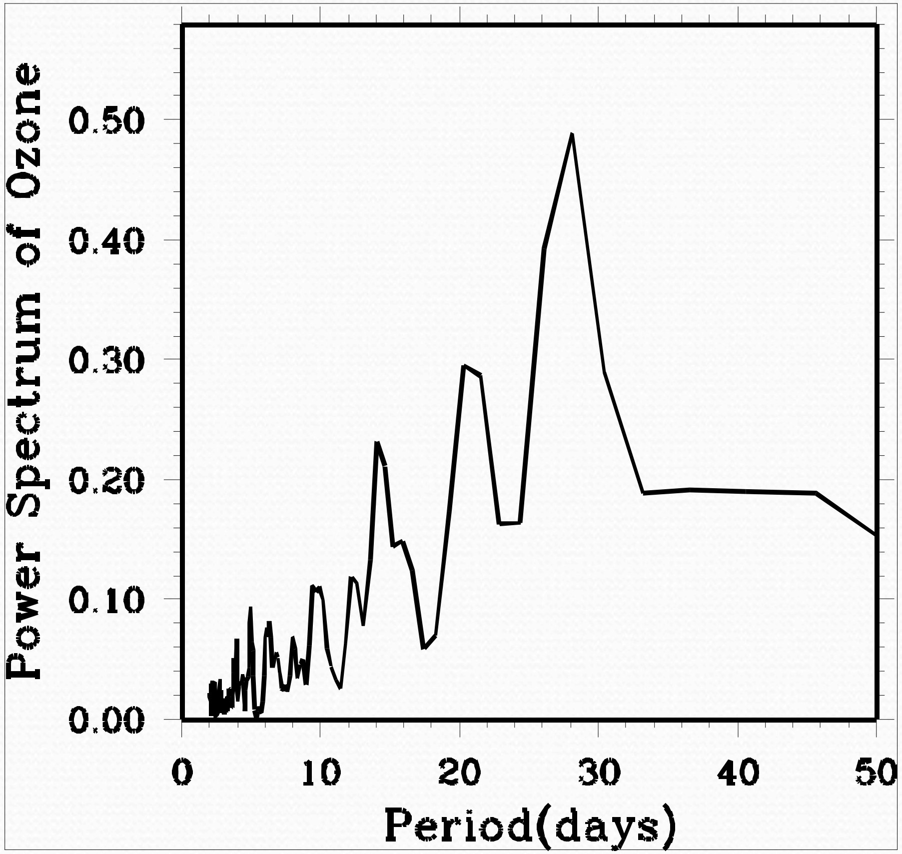


2004-2005 – Sensitivities



Observed (SBUV) ozone for 2000





Model input – 205 nm