Sensitivity of the atmospheric response to the specification of the UV solar cycle variation in WACCM-3.5 simulations

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TOSCA workshop, May 15, 2012

Outline

Introduction

Motivation

Results

conclusions

outlook

Observational and modeling evidence of quasi-decadal oscillations in the stratosphere and troposphere

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The magnitude of 11-yr variations in SSI in SORCE-SIM retrievals is 5-7 times greater than NRL in the UV range, and out-of-phase in the VIS range (?)

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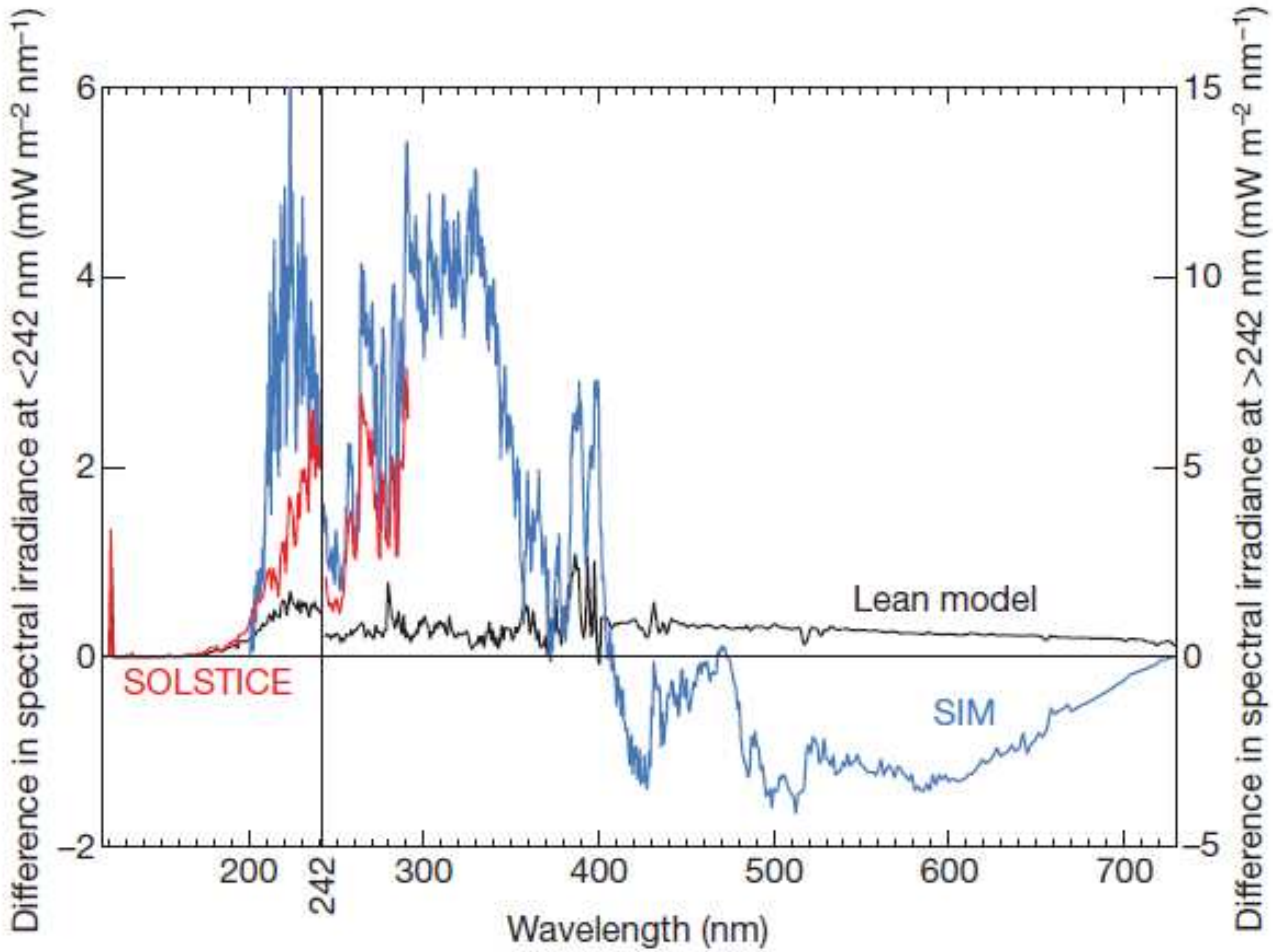
- Haigh et al., NATURE [2010]



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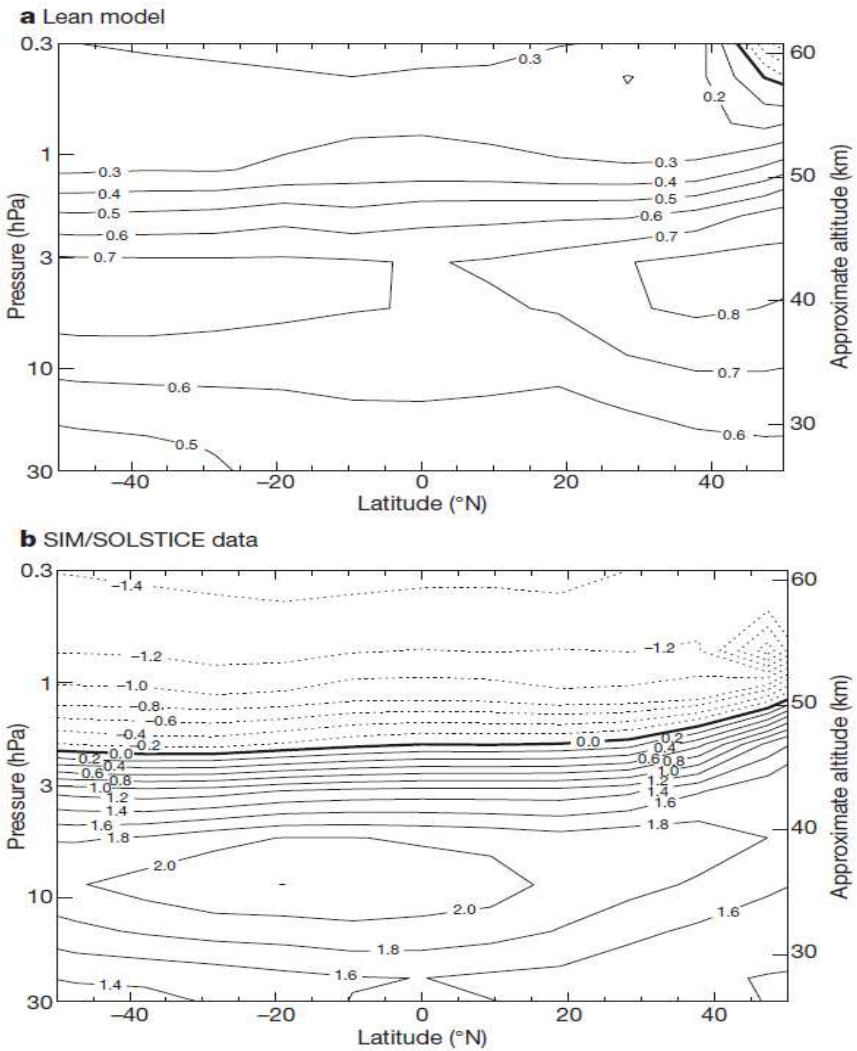
- Ozone response from Lean model and SORCE-SOLSTICE data



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Ineson and Scaife (2011) used SIM-based (200-320nm) spectrum changes (2004-2007) in MetOffice model

Problem

SORCE-SIM data only represent changes over part of a solar cycle. The semi-empirical models (e.g. Lean 2005, Krivova 2006) reconstruct variations over multiple cycles.

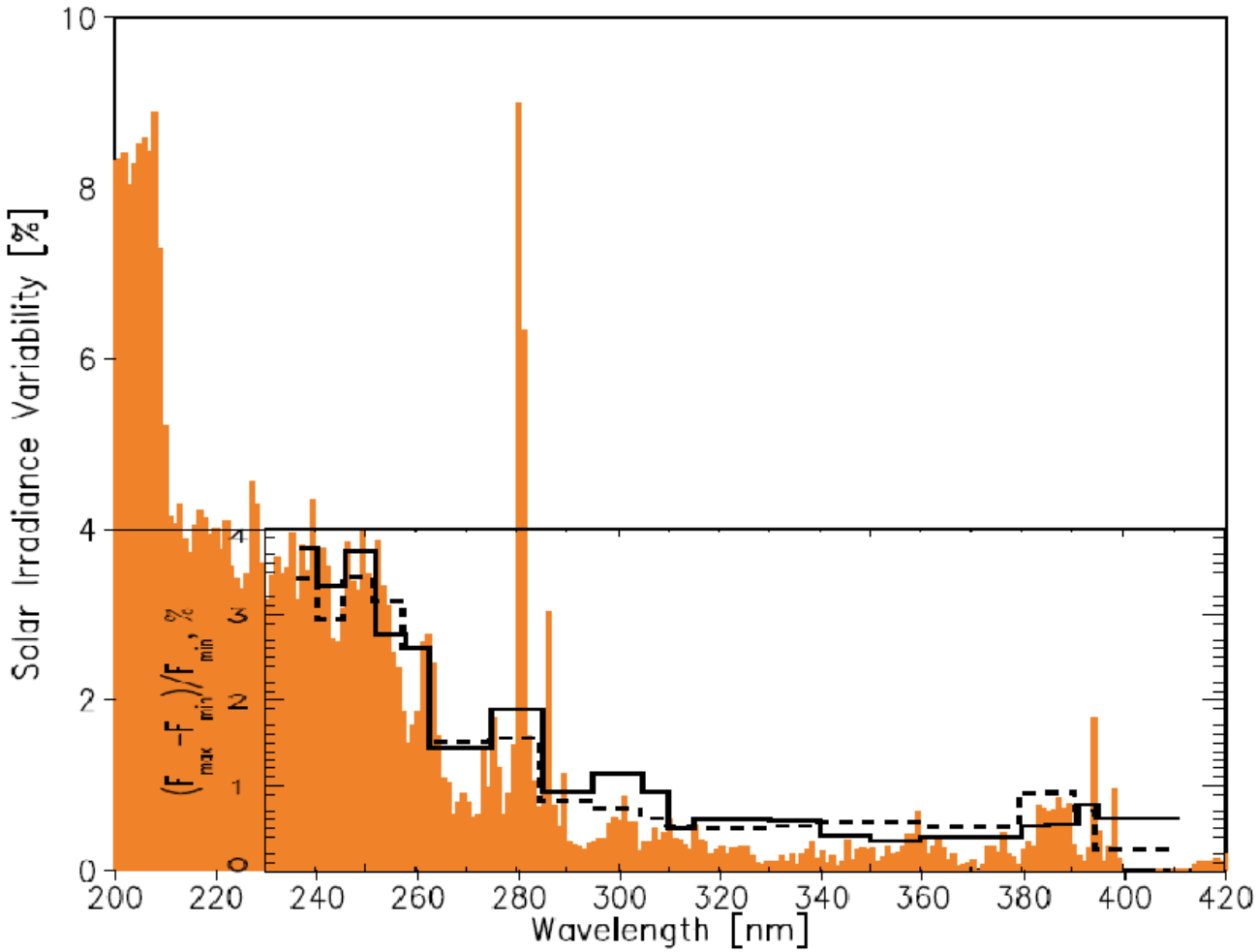
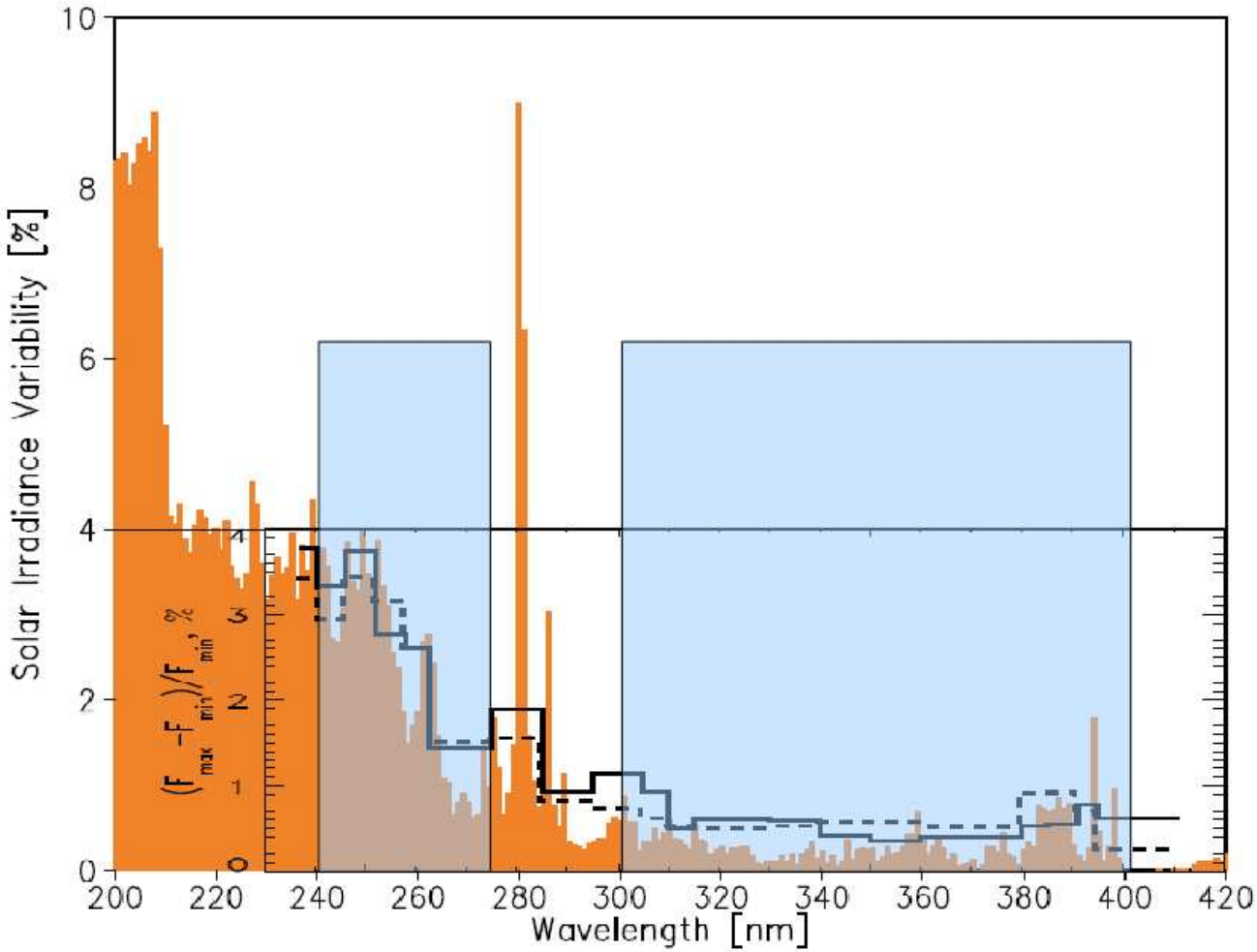


Figure: Relative 11-yr solar cycle variation in spectral solar irradiance modeled by Lean (2005) (orange bars) and Krivova (2006) (black line)



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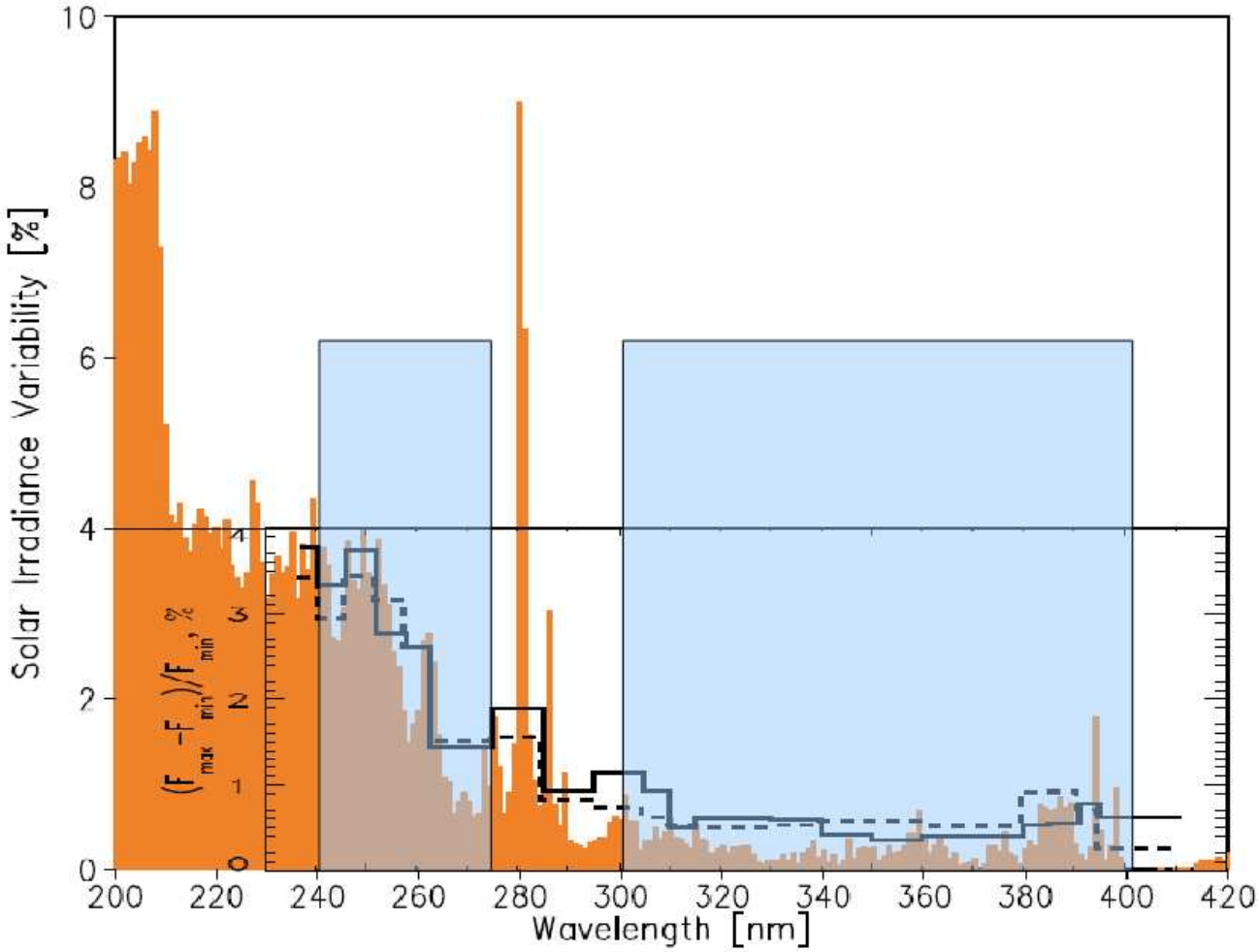

TASK: Study the sensitivity of a GCM response to uncertainty in the SSI forcing.

Model and experimental set-up

Whole Atmosphere Community Climate Model - v3.5

Model features:

- Finite-Volume dynamical core (Lin Rood 2004)
- 1.9 x 2.5 x 66 L (model top at 140 km)
- interactive chemistry (Kinnison et al., 2007)

Set-up:

- fixed solar spectral irradiance (MAX vs MIN spectra)
- climatological SSTs, no QBO, 1995-composition

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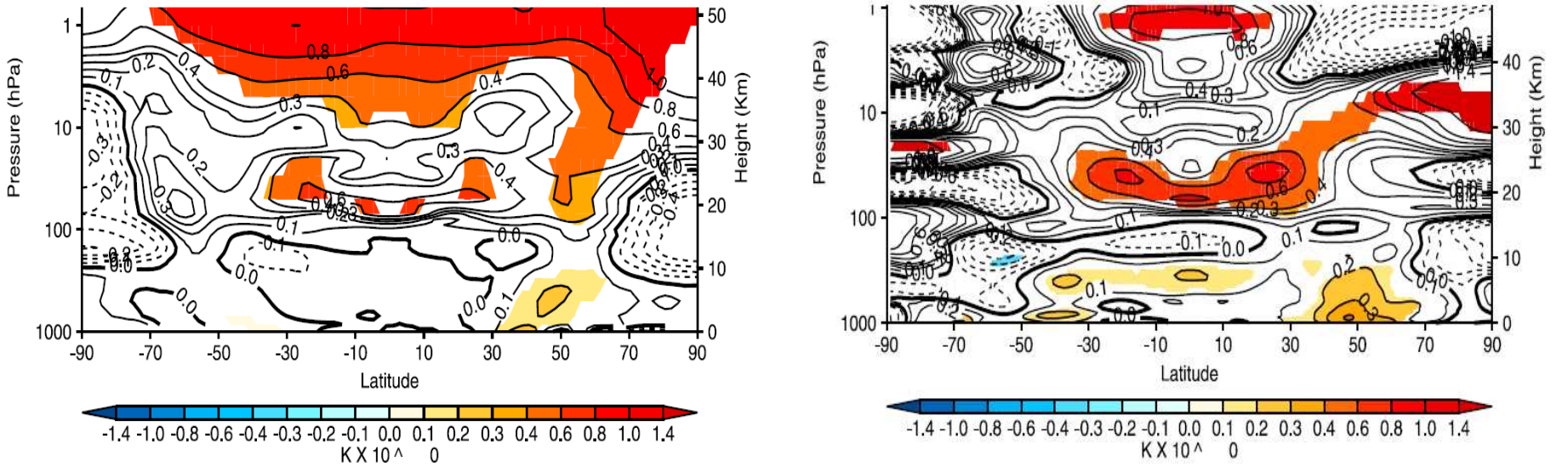

Figure: Annual mean solar (F10.7) regression coefficient in zonal mean temperature, from WACCM-3.5 (left) and ERA-40 data (right)

Chiodo et al., 2012

Time-slice experiments

Experiment Name	solar forcing	length
NRL-sMIN	solar MINIMUM from Lean (2005), SC 21-24 ave	20 yy (1 spinup)
NRL-sMAX	solar MAXIMUM from Lean (2005), SC 21-24 ave	20 yy (1 spinup)
sMAX*[300-400]	solar MAXIMUM from Lean (2005) + 1%[300-400]	20 yy (1 spinup)
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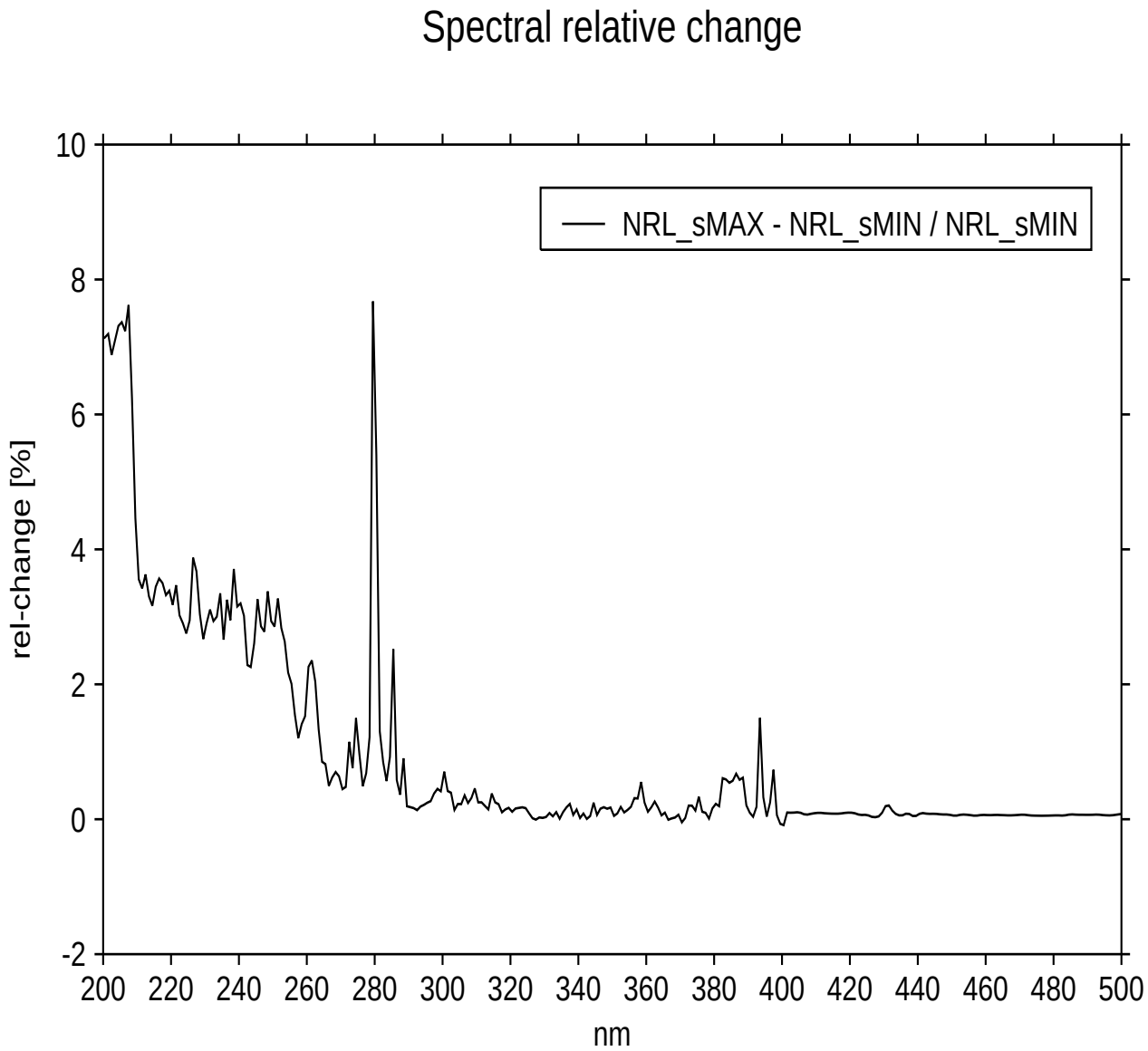

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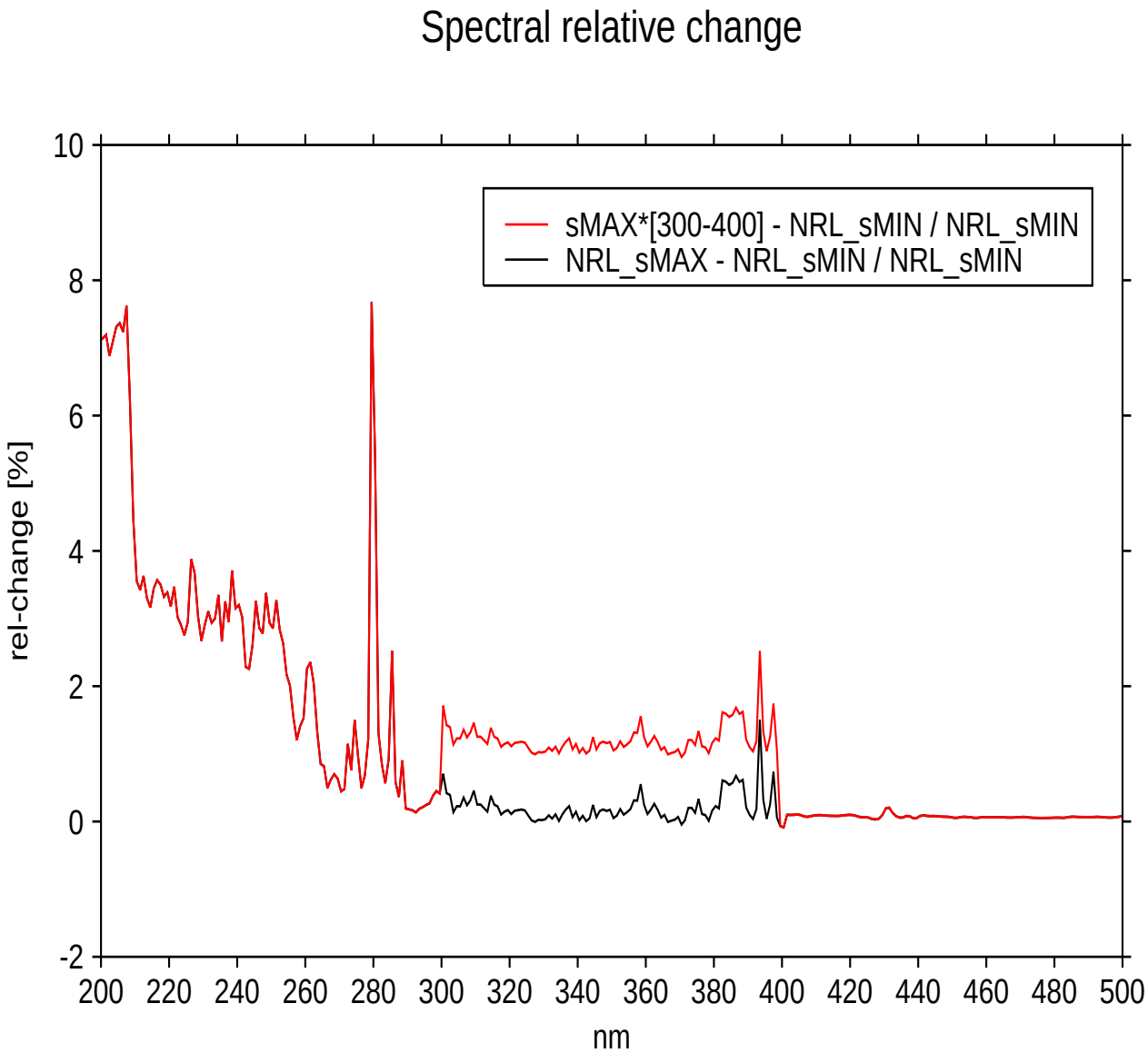

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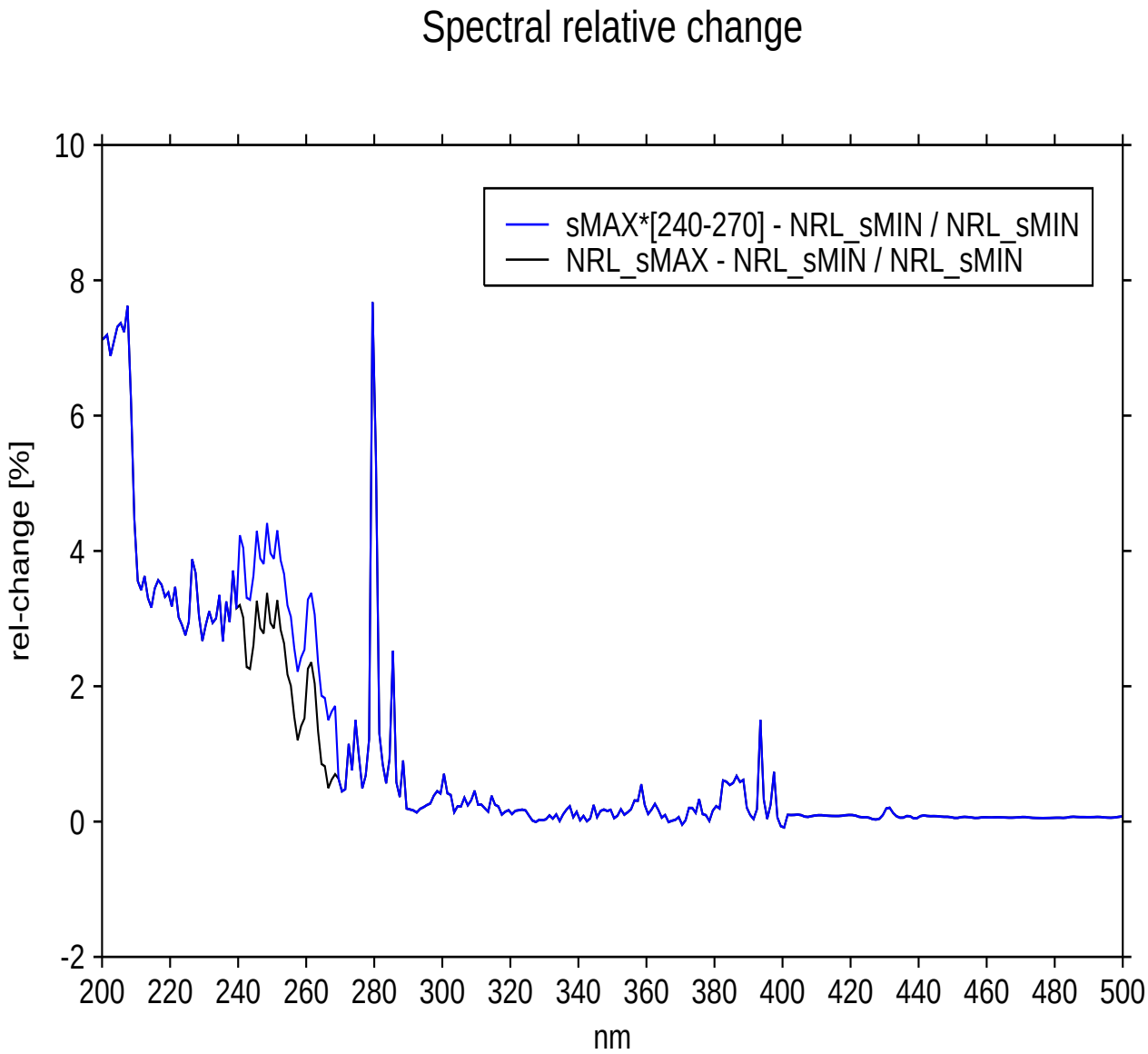

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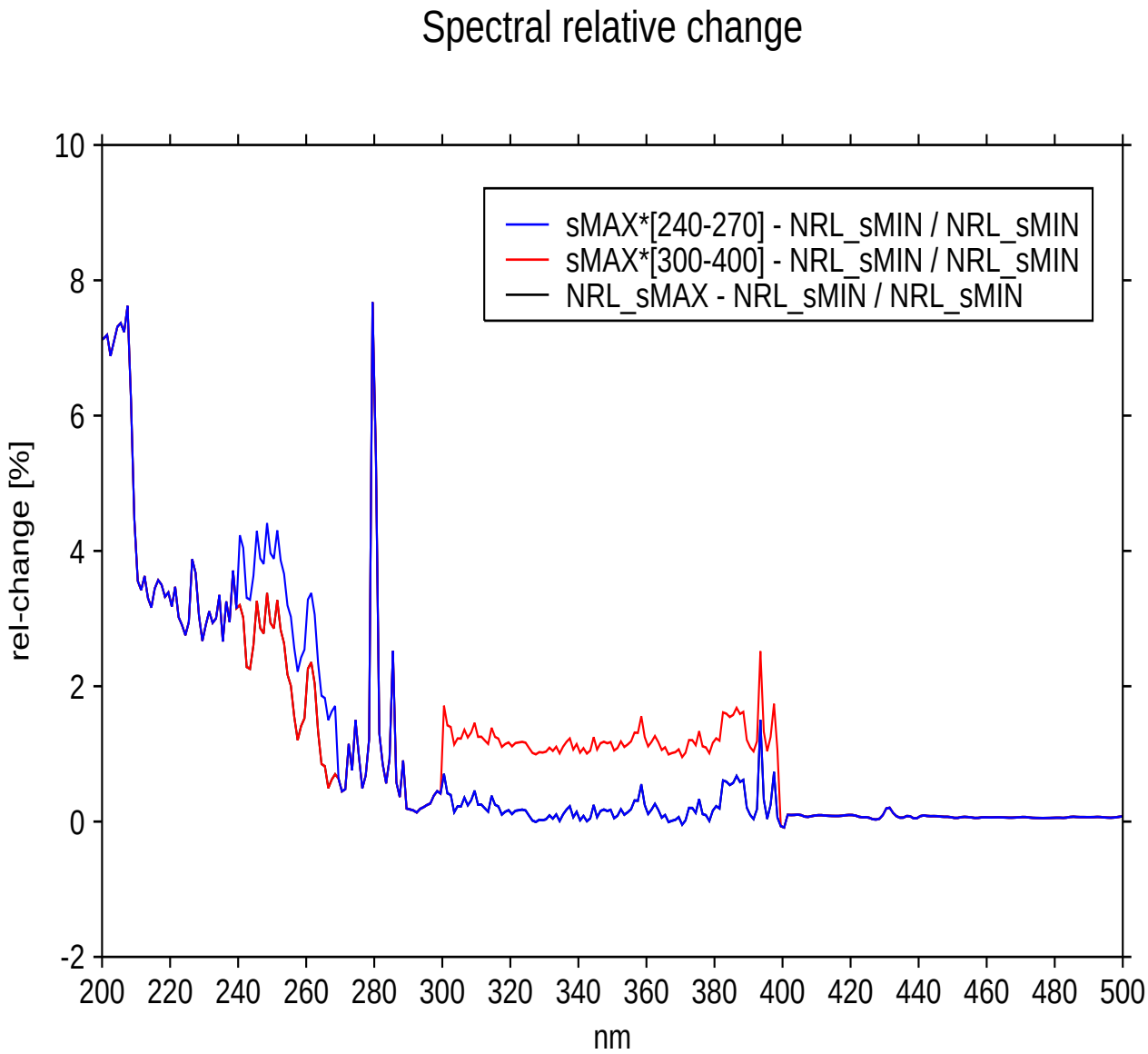

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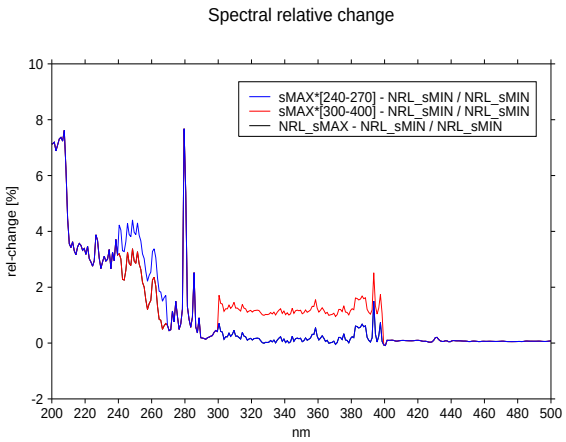
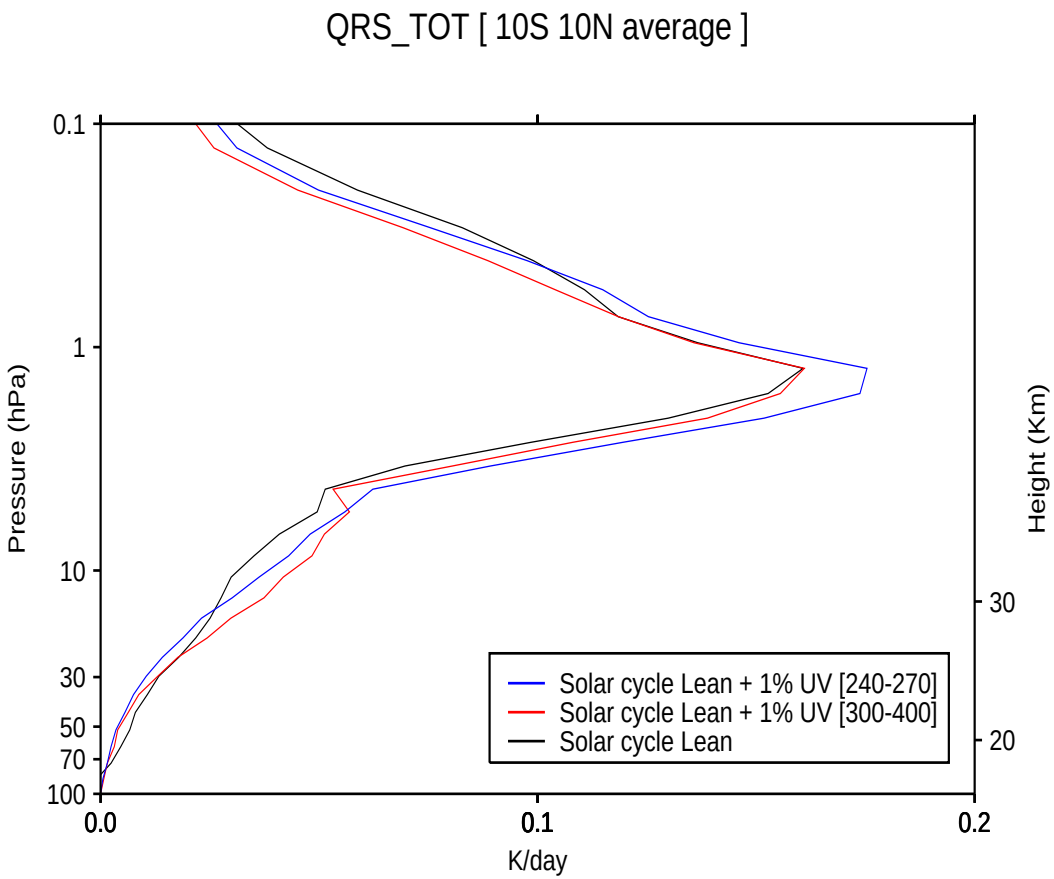


TABLE 1*b*. Summary of Spectral Data

Interval	min[a]	max[b]	$p(H_2O)$[c]	$k(H_2O)$[d]	k(droplets)[e]	$p(CO_2)$[f]
1	0.200	0.245	0	0	1	0
2	0.245	0.265	0	0	1	0
3	0.265	0.275	0	0	1	0
4	0.275	0.285	0	0	1	0
5	0.285	0.295	0	0	1	0
6	0.295	0.305	0	0	1	0
7	0.305	0.350	0	0	1	0
8	0.350	0.700	0	0	1	0
9	0.700	5.000	0.505	0.002	2	0
10	0.700	5.000	0.210	0.035	3	0
11	0.700	5.000	0.120	0.377	3	0
12	0.700	5.000	0.070	1.950	3	0
13	0.700	5.000	0.048	9.400	3	0
14	0.700	5.000	0.029	44.600	4	0
15	0.700	5.000	0.018	190.000	4	0
16	2.630	2.860	0	0	4	1.00
17	4.160	4.550	0	0	4	0.64
18	4.160	4.550	0	0	4	0.36

300-400 nm : 1 full band in radiation code (2 partial)
240-270 nm : 1 full band in radiation code (2 partial)

Radiative response



- Peak in SW-heating occurs at 45 km

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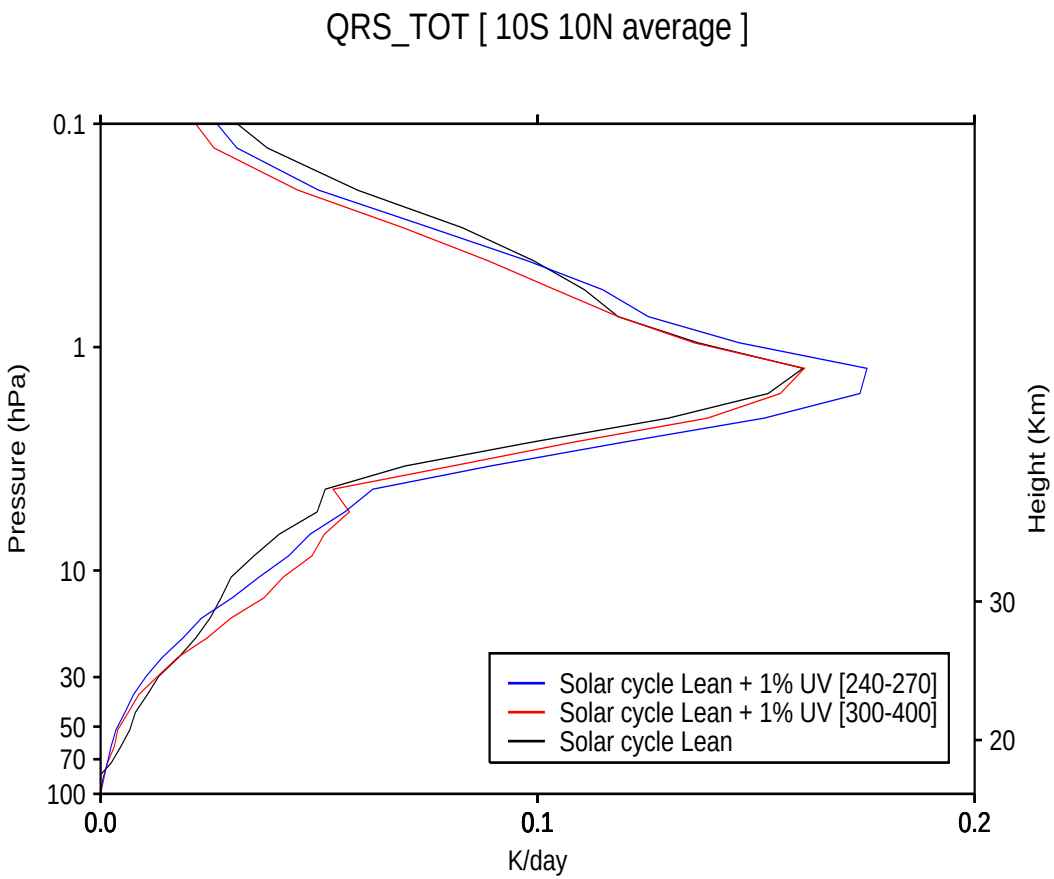

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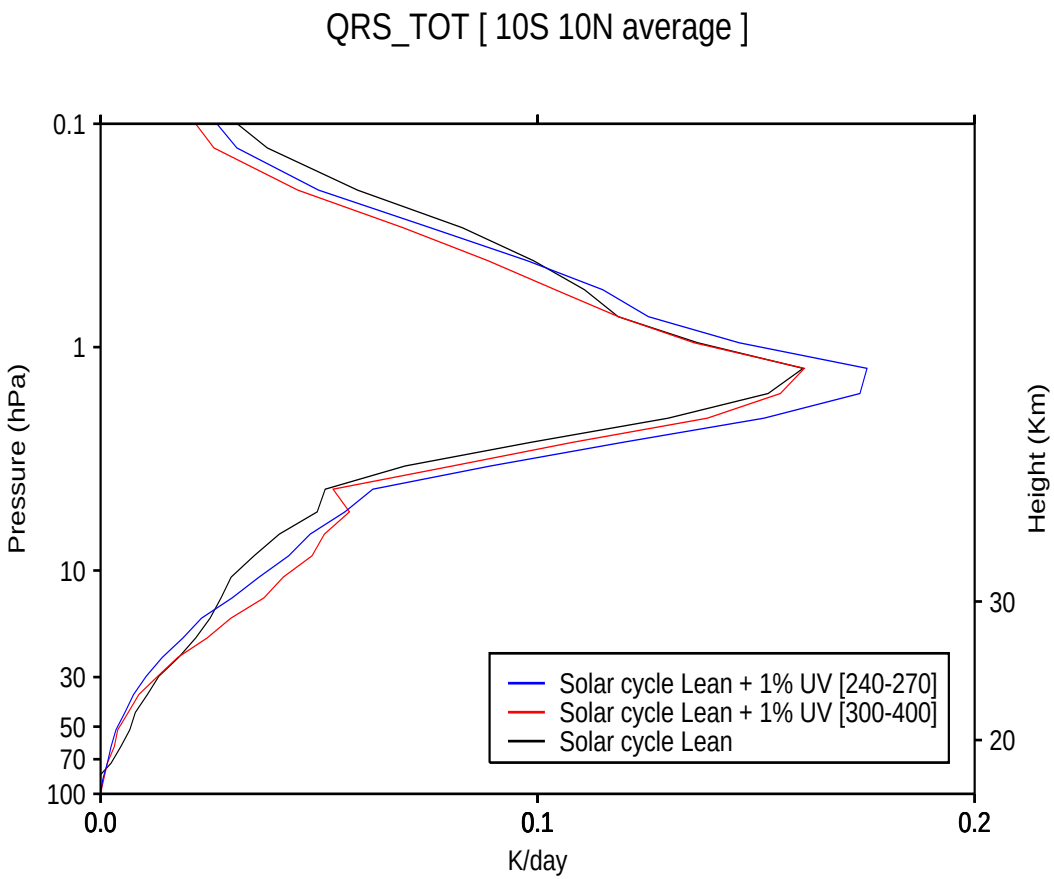

- Peak in SW-heating occurs at 45 km
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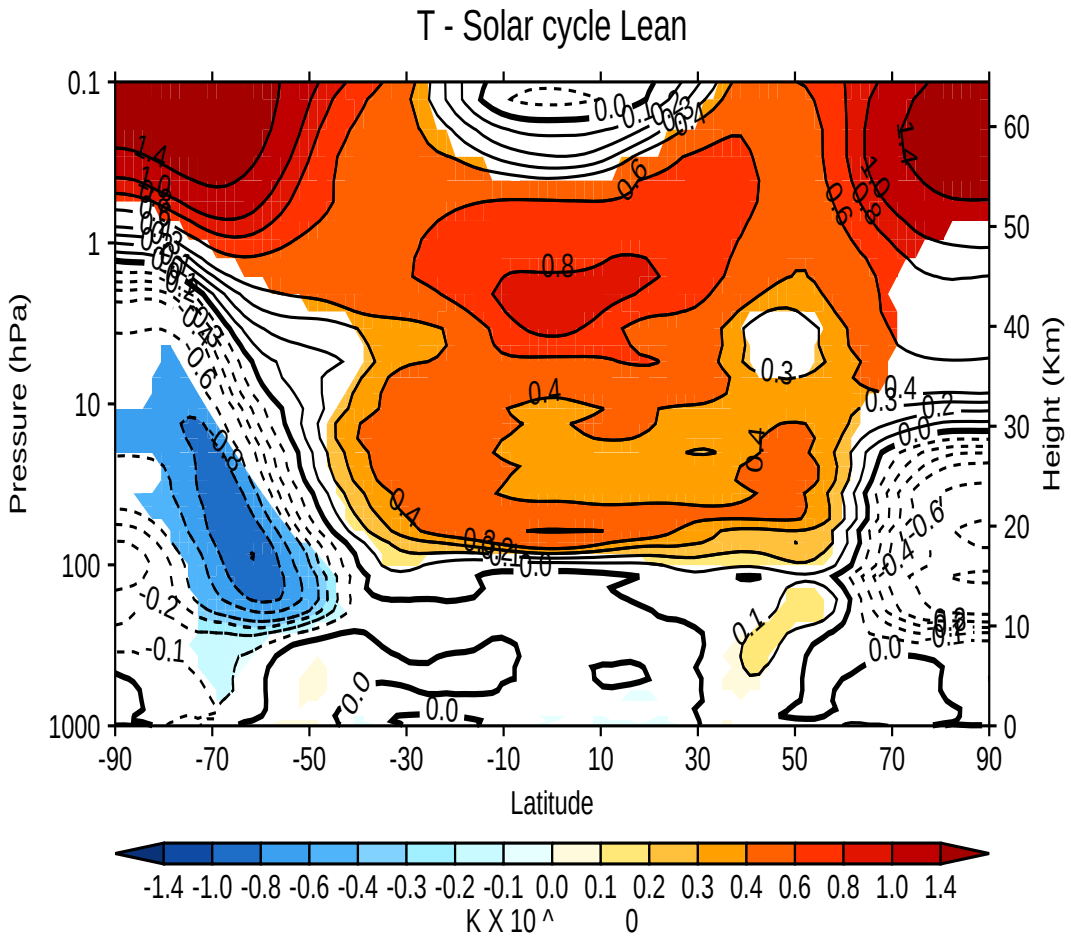
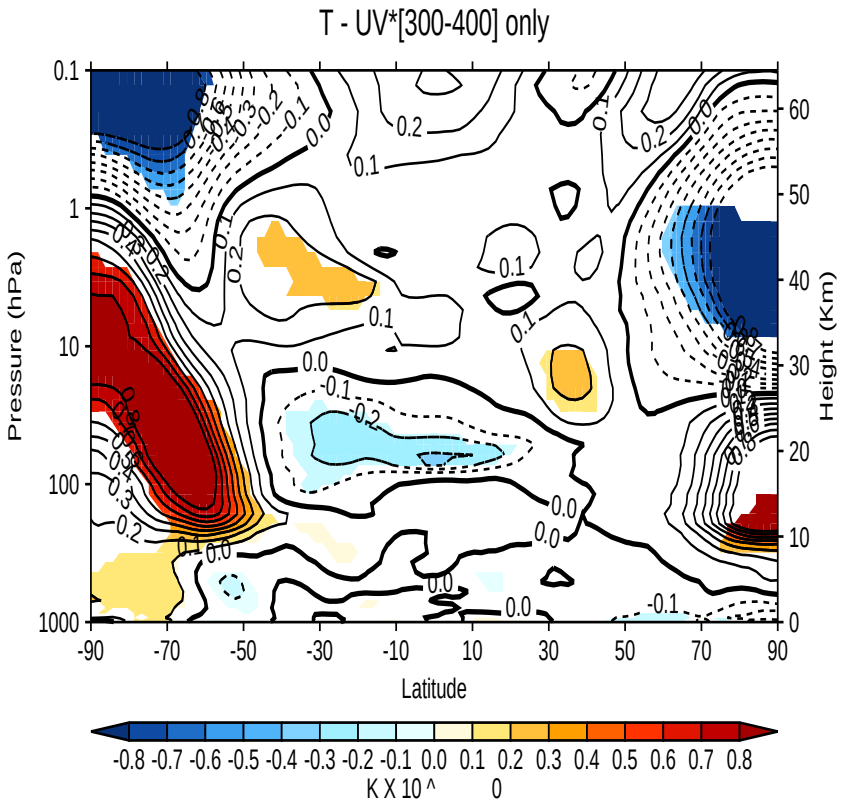
- More SW-heating in the middle and upper stratosphere if [240-270] radiation is enhanced

Solar cycle response in zonal mean temperature



Impact of 1% change of solar radiation on temperature

SC Lean+UV[300-400]



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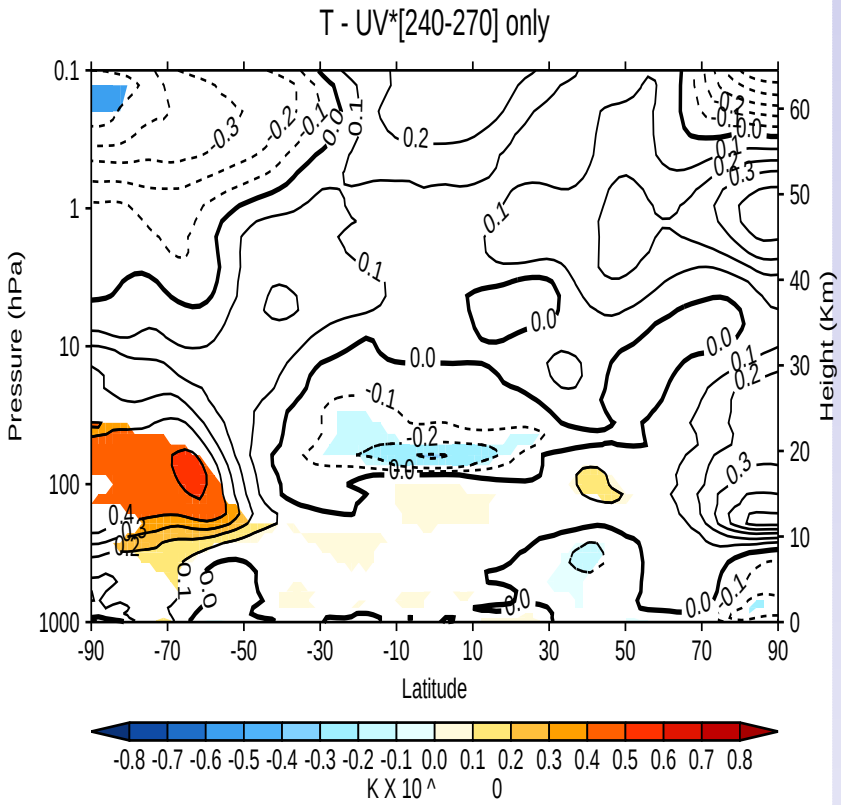
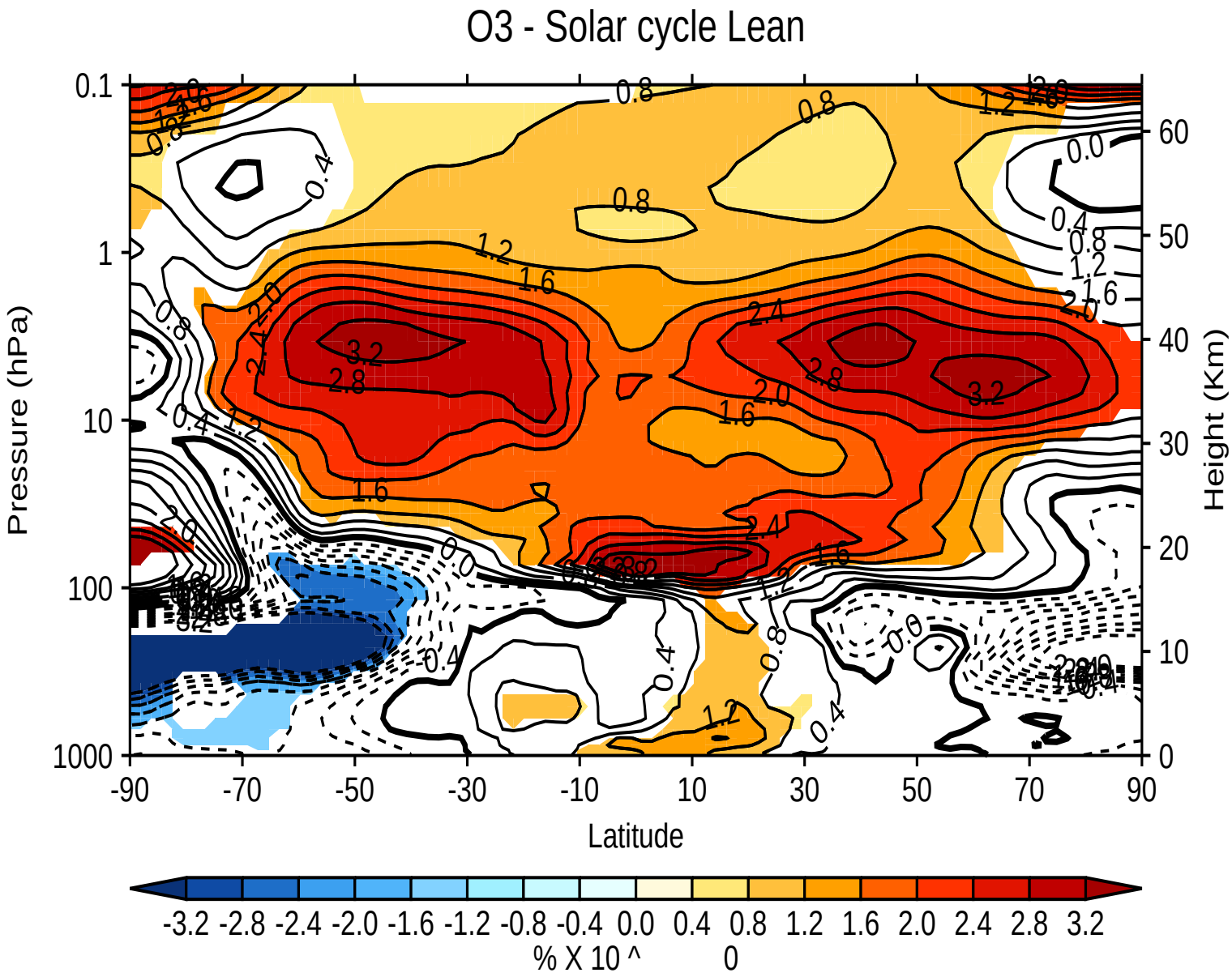


Solar cycle response in zonal mean ozone



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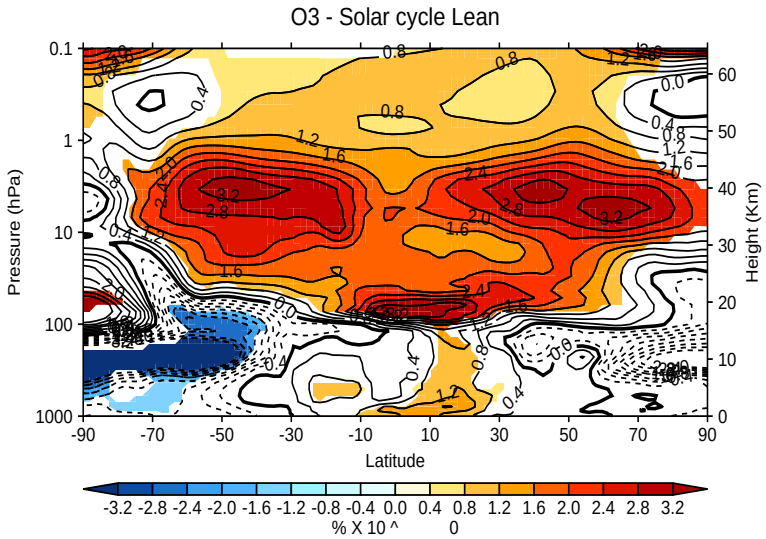

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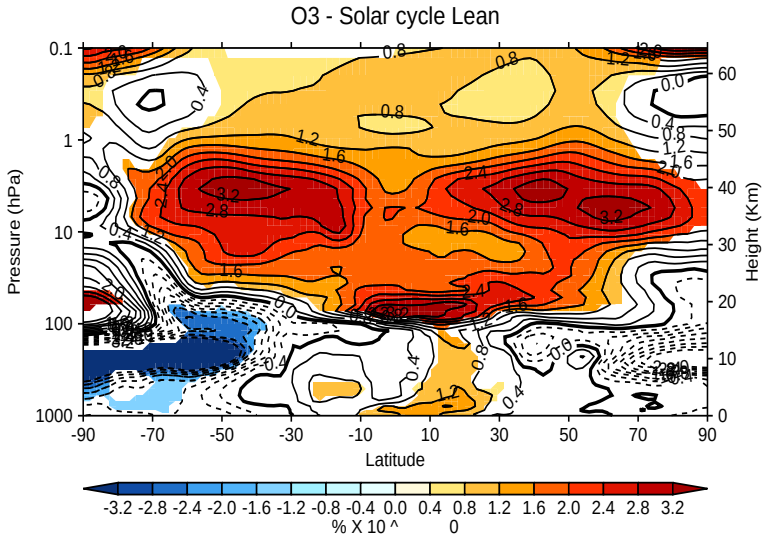
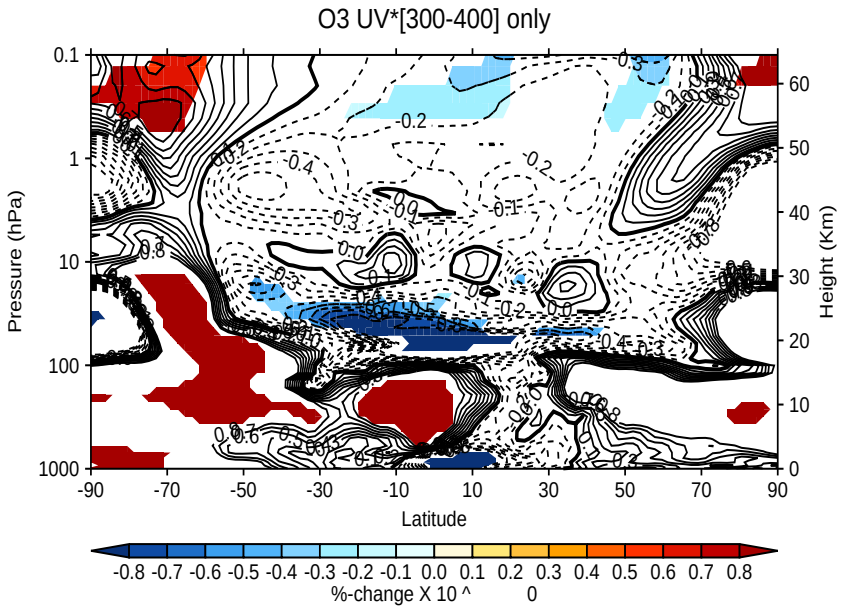


UV + [300-400]



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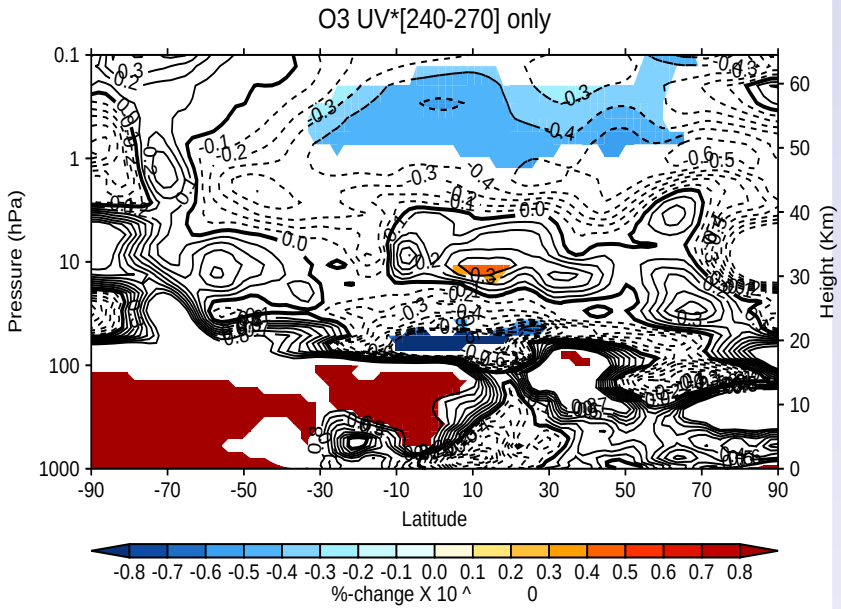

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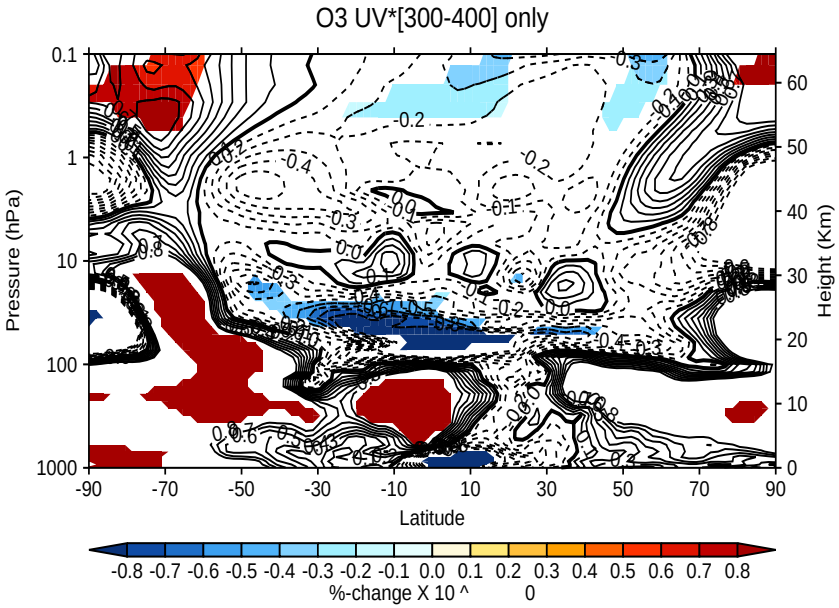

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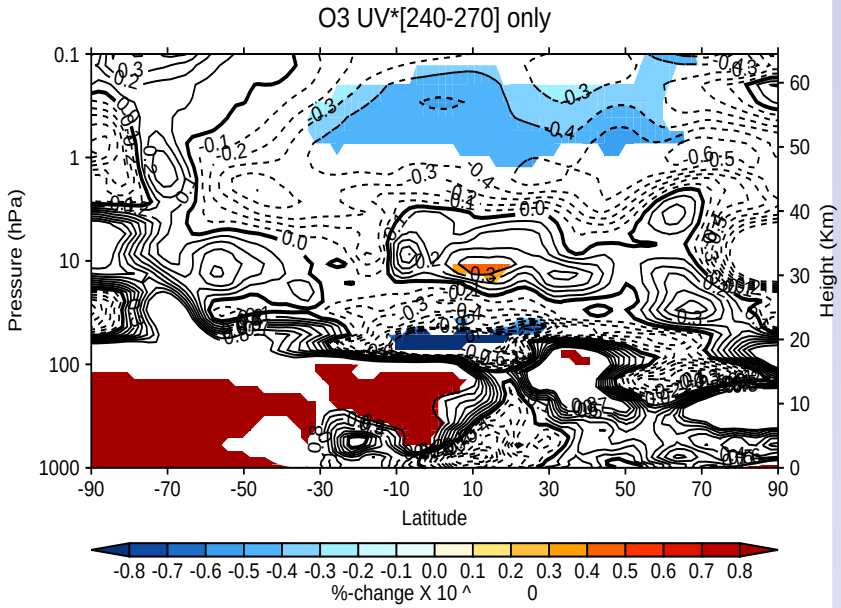

- Lower-tropical stratosphere (20 km): Less ozone if UV+ (240-270) and UV+ (300-400)

Solar cycle response in zonal mean ozone

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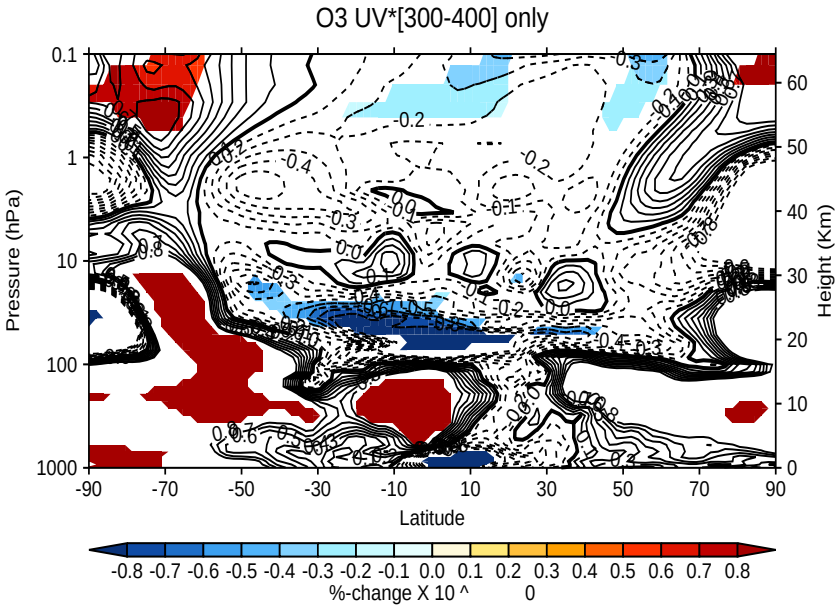

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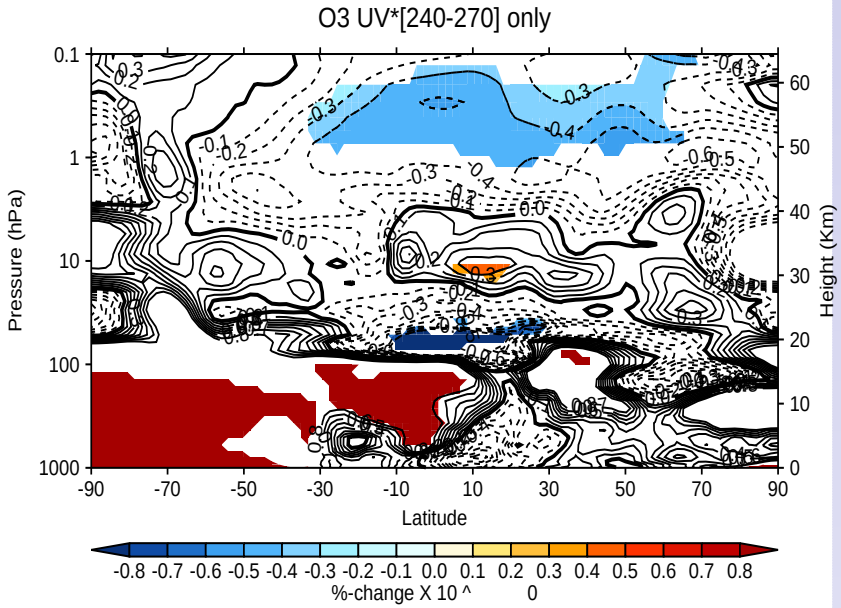

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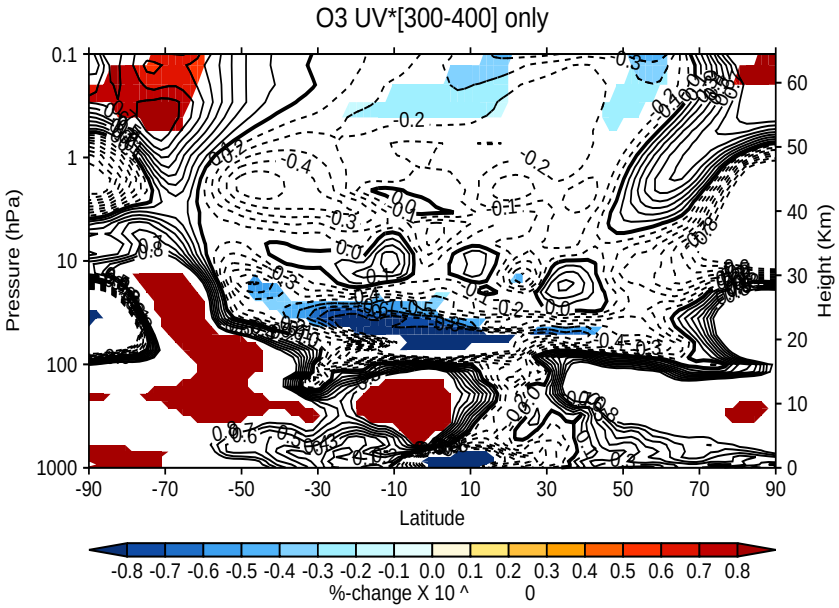

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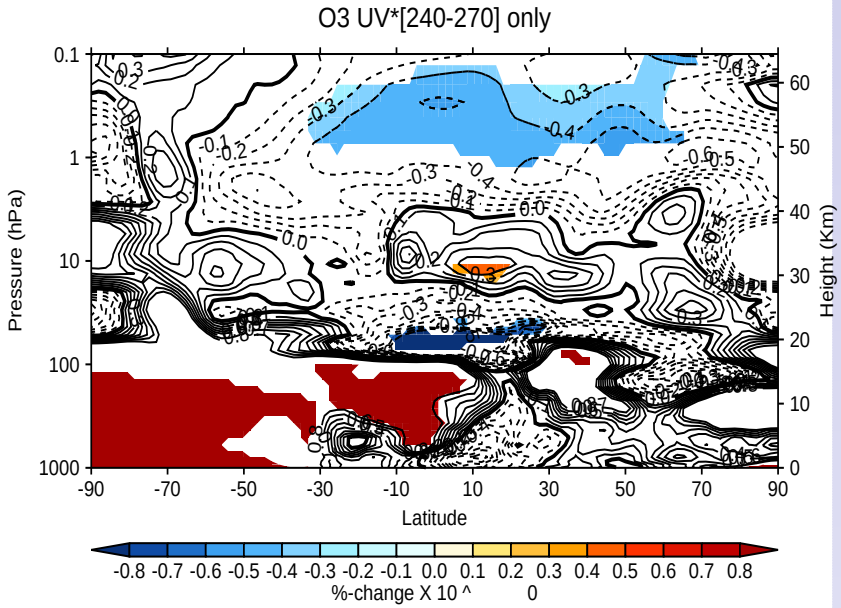


- Lower-tropical stratosphere (20 km): Less ozone if UV+ (240-270) and UV+ (300-400)
- Middle stratosphere (30 km): More ozone if UV+ (240-270)
- Upper stratosphere and lower mesosphere (40-50 km) : Less ozone if UV+ (240-270) and UV+ (300-400)
  Less O3 possibly compensates more SW-absorption = less warming?

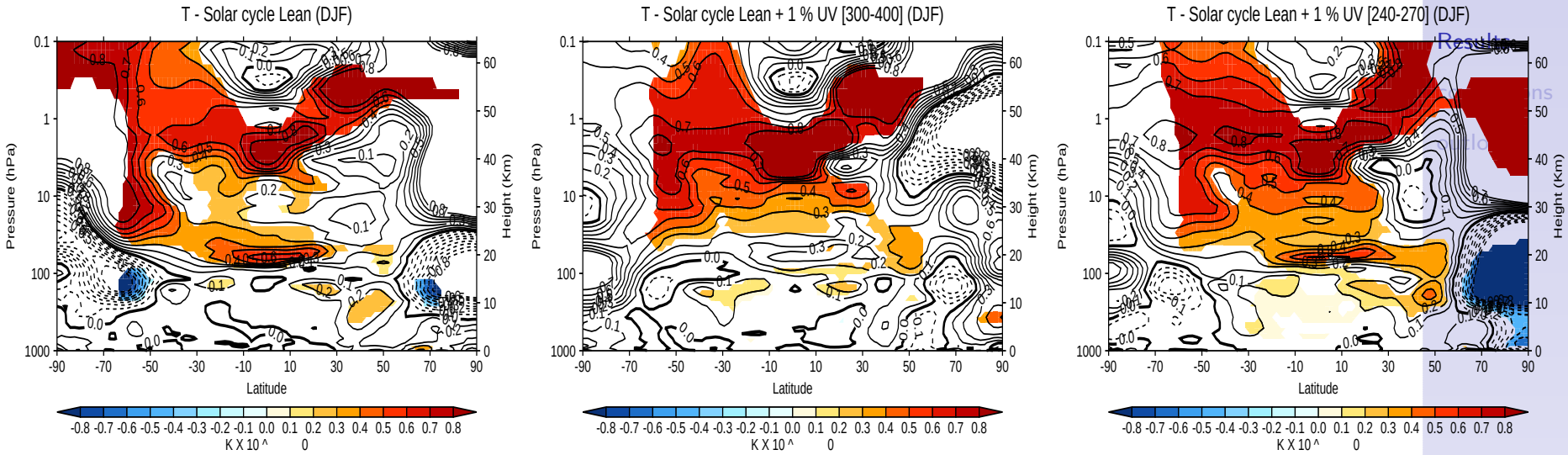
Seasonal solar cycle response in temperature

Boreal winter: DJF

SC Lean

SC Lean + UV [300-400]

SC Lean + UV [240-270]



- Strong warming at 20 km over the equator is mostly produced during boreal winter in NRL-sMAX, along with NH polar cooling.

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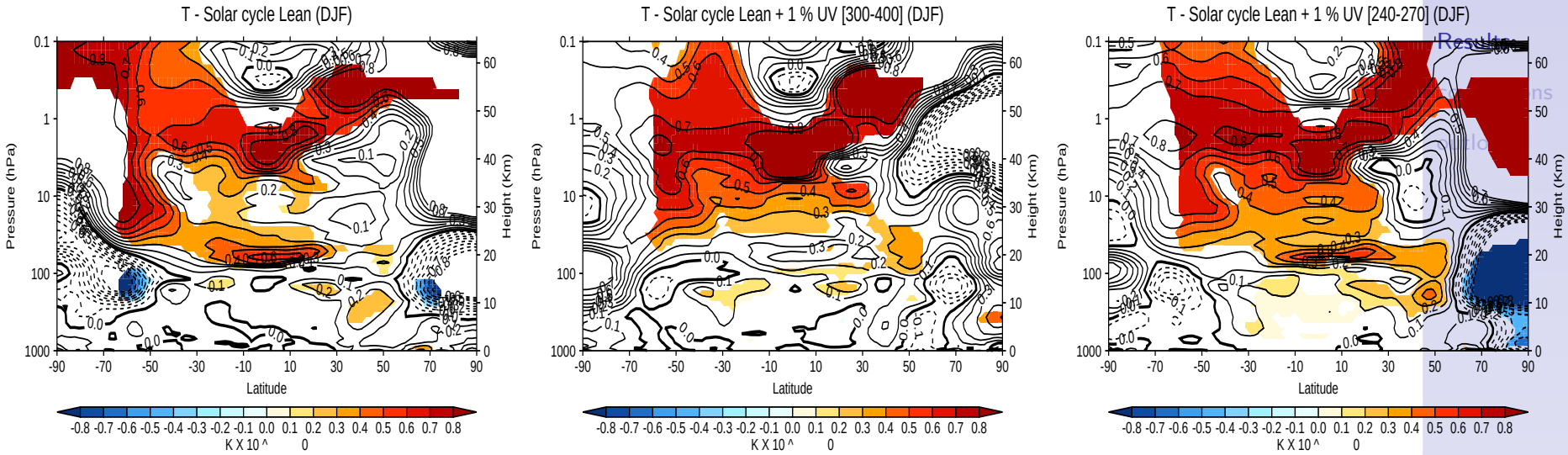

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- A similar (though stronger) pattern is also simulated if UV+ [240-270].

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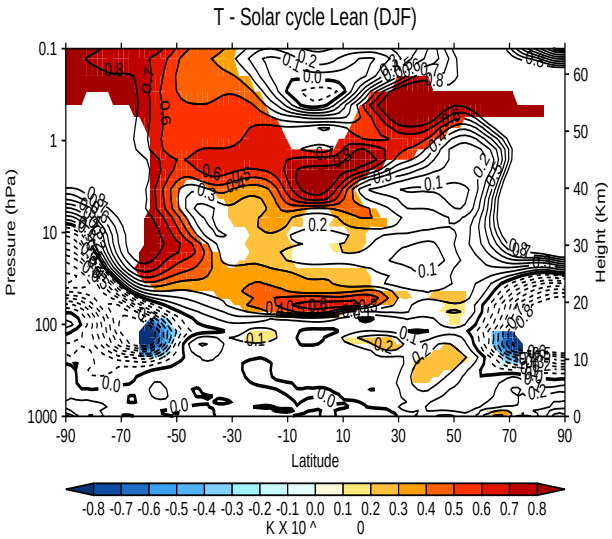
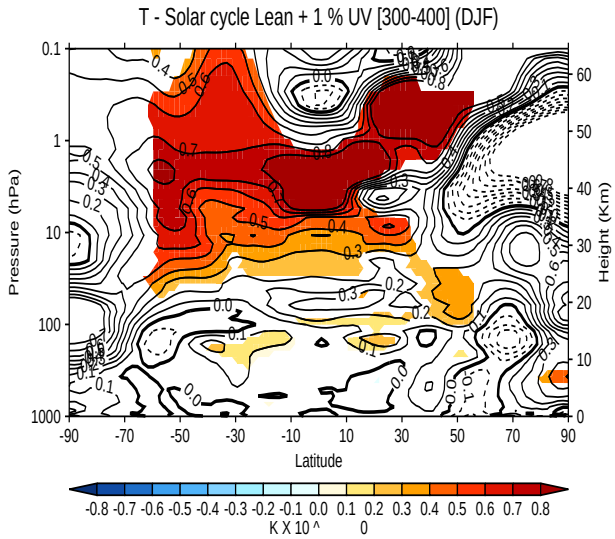
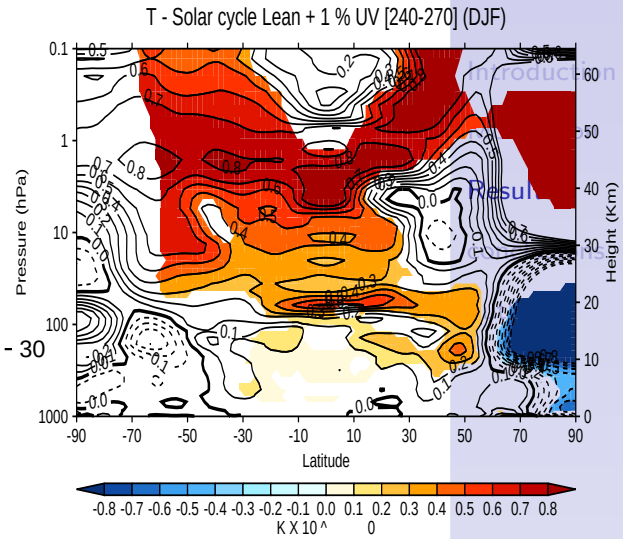
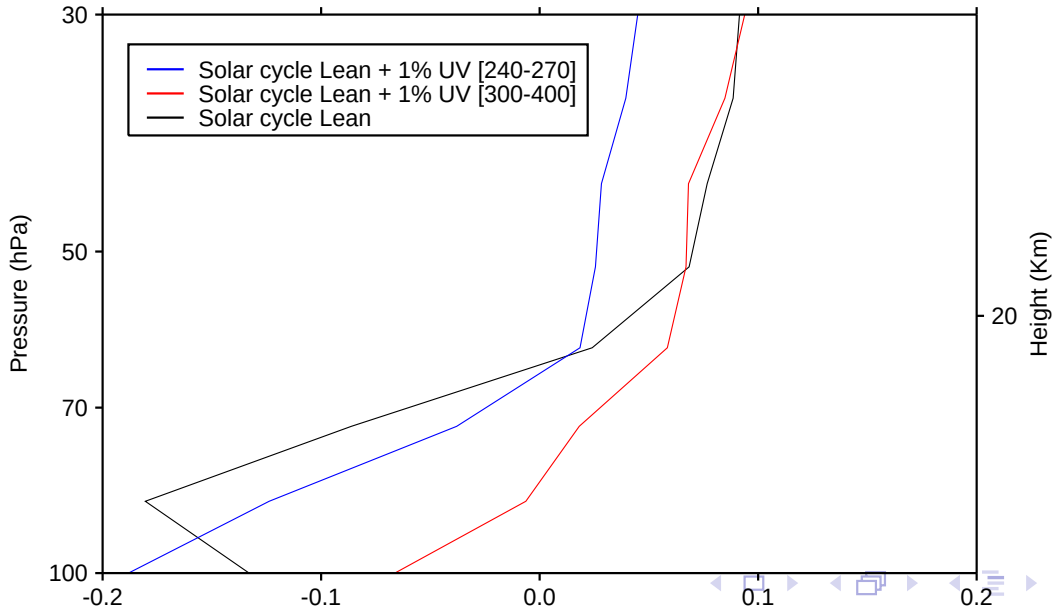


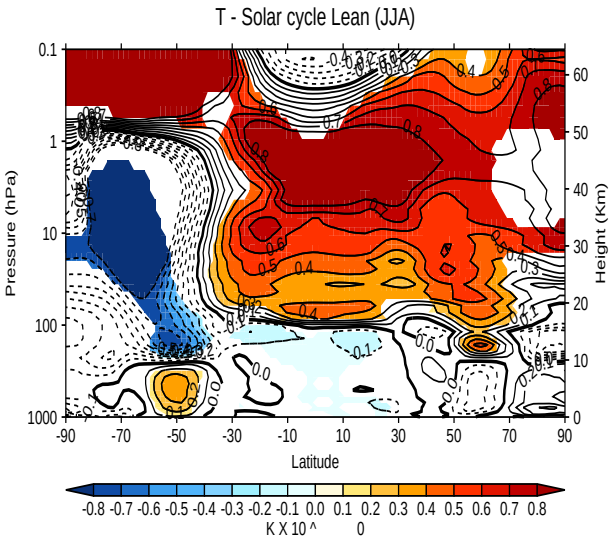


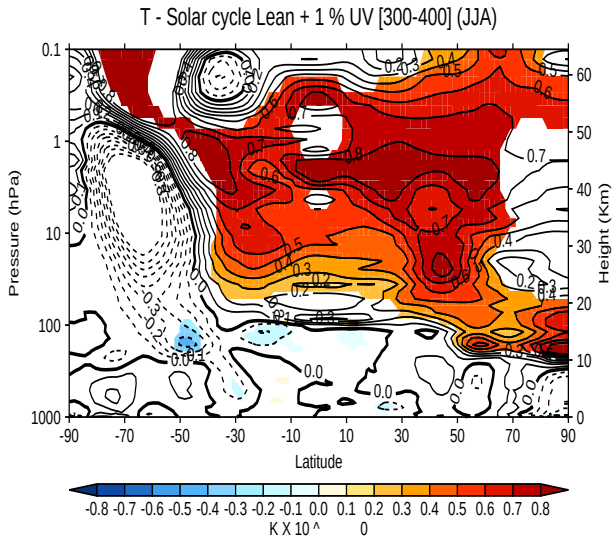


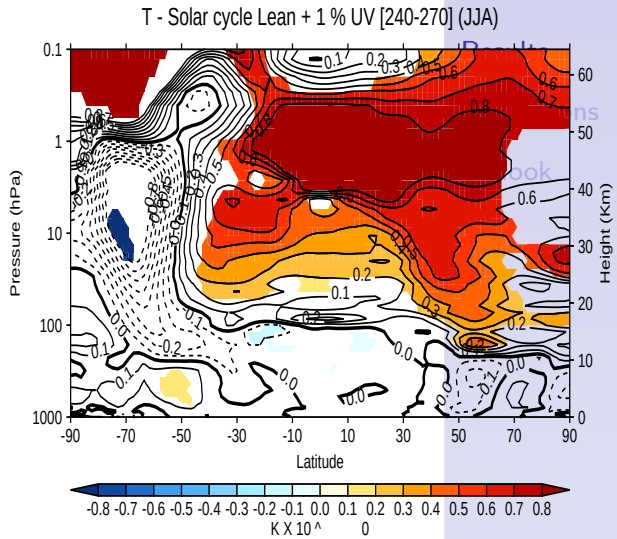
WSTAR [10S 10N] DJF



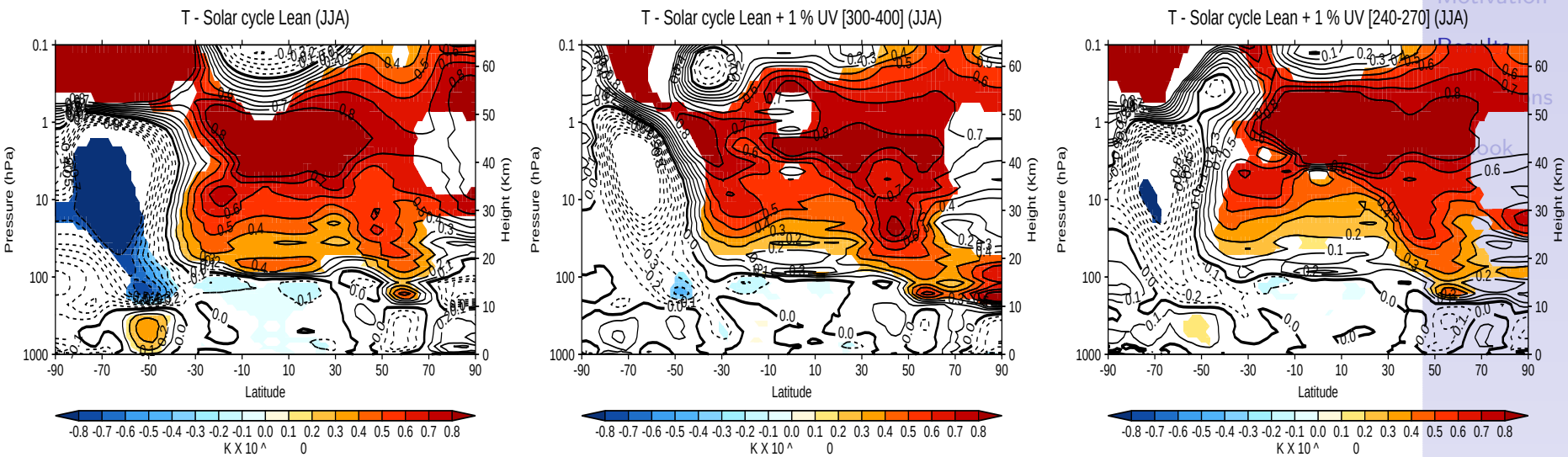
Austral winter: JJA





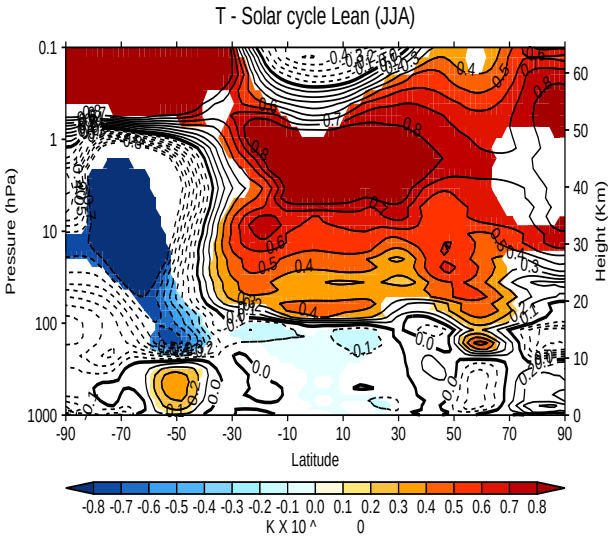


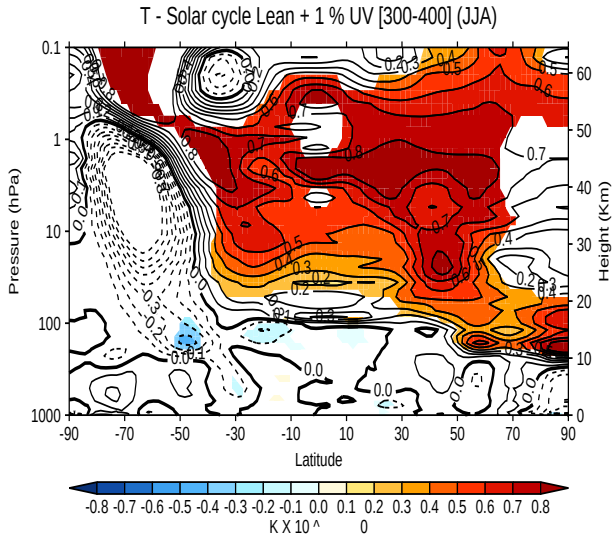
Austral winter: JJA

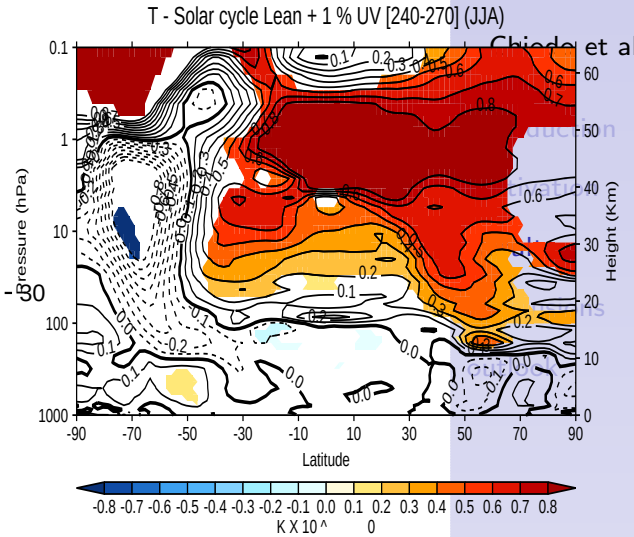


- A cooling at high and warming at low latitudes is simulated in the SH in NRL-sMAX. No such pattern is simulated if UV + [240-270] and UV + [300-400]

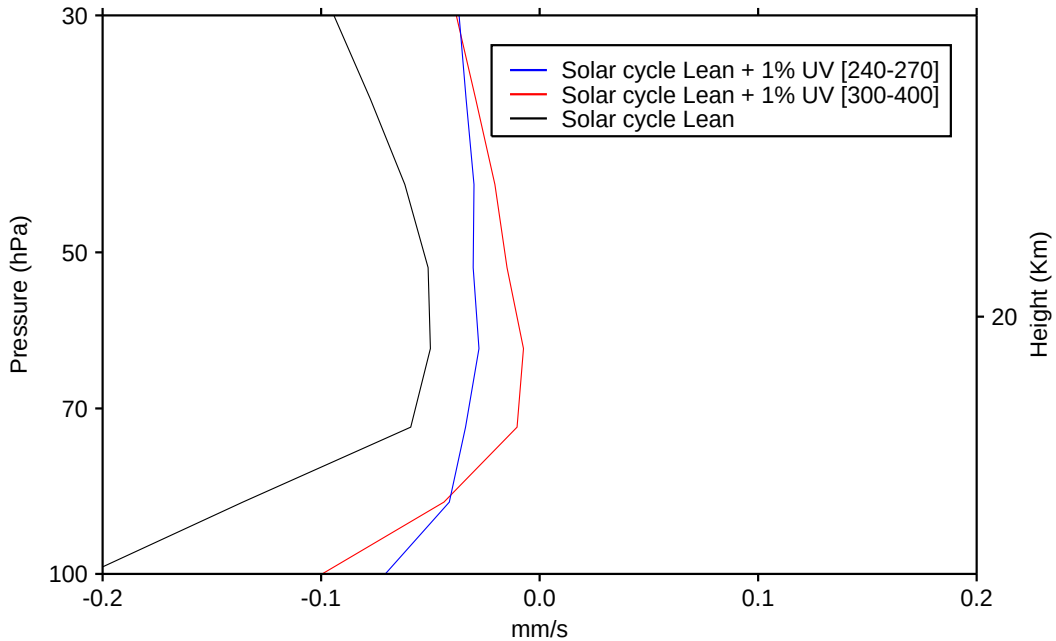
Austral winter: JJA



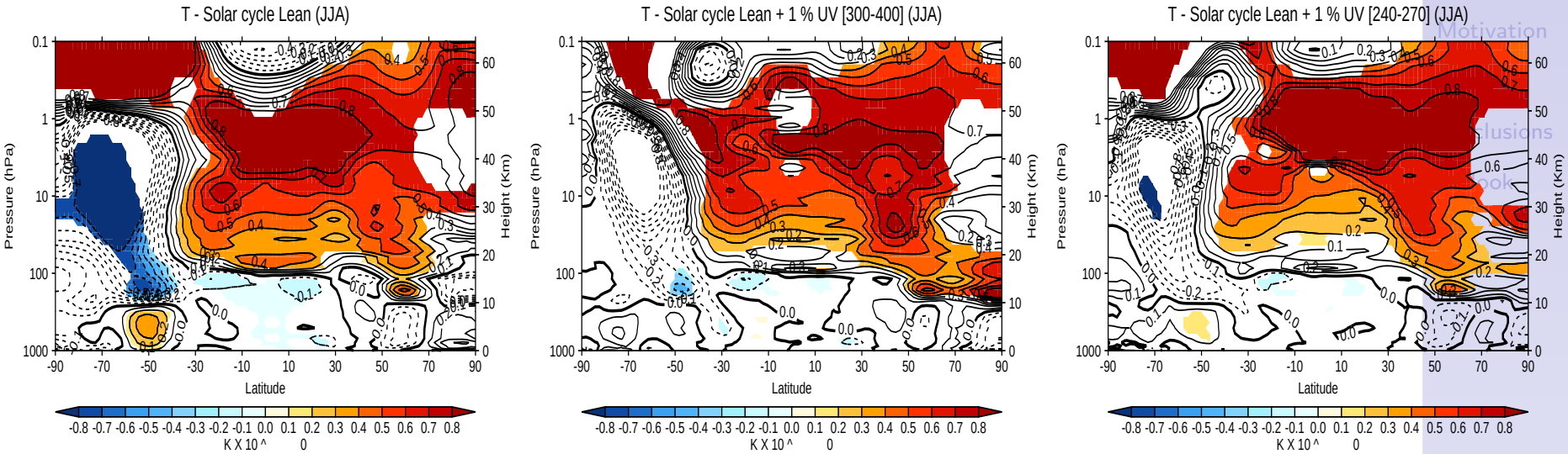




WSTAR [10S 10N] JJA



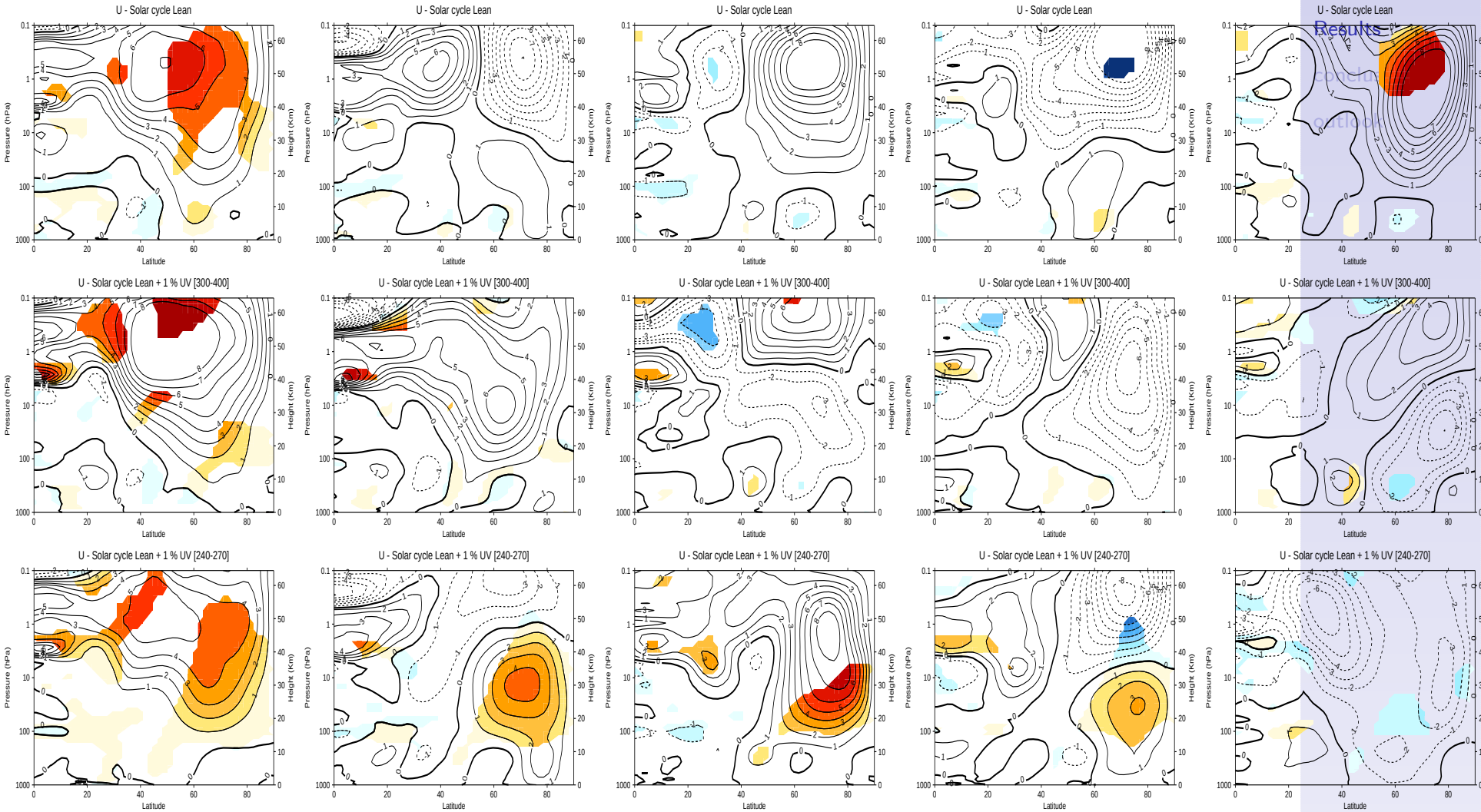
Austral winter: JJA



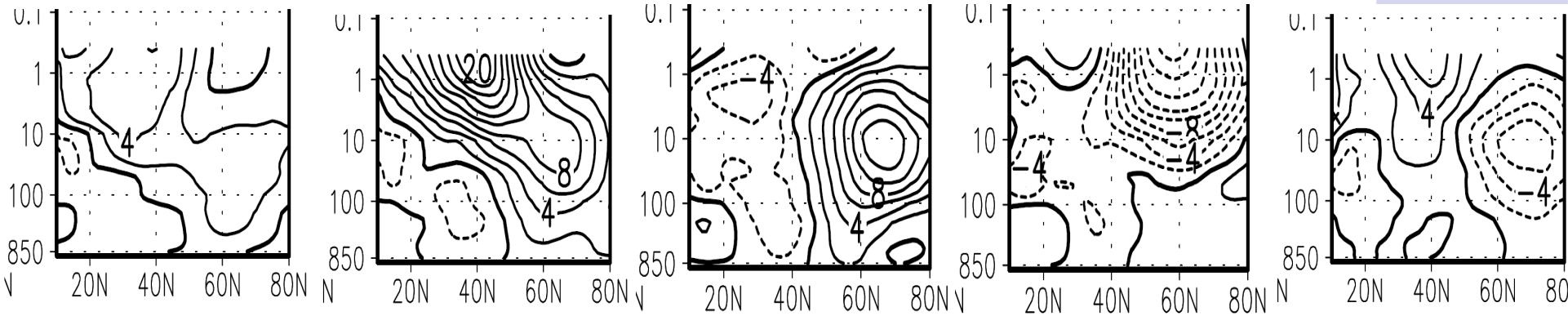
- Relative equatorial downwelling is simulated below 70 hPa in NRL-sMAX, and in UV + [240-270] compared to NRL-sMIN. Weakening of equatorial upward branch of B-Dobson circulation ?

Solar cycle response in zonal mean zonal wind in the NH

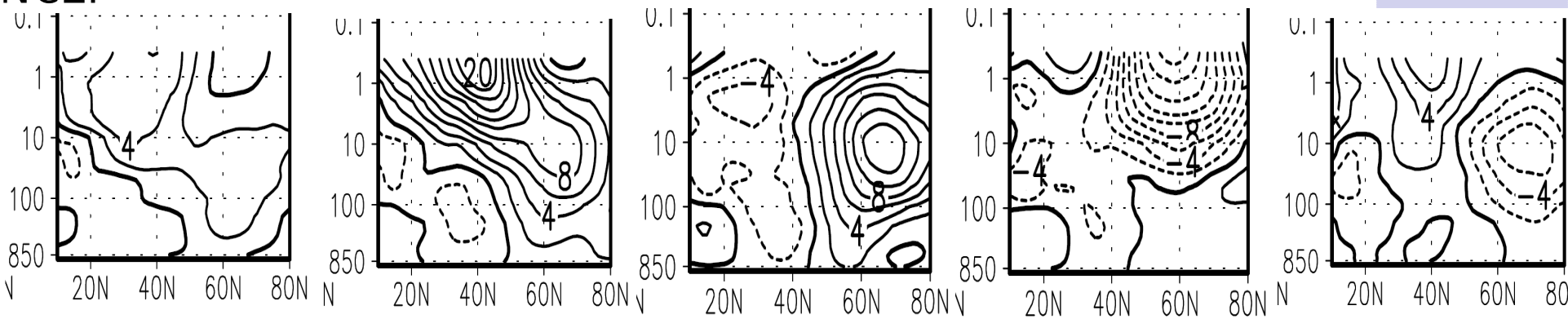
November | December | January | February | March



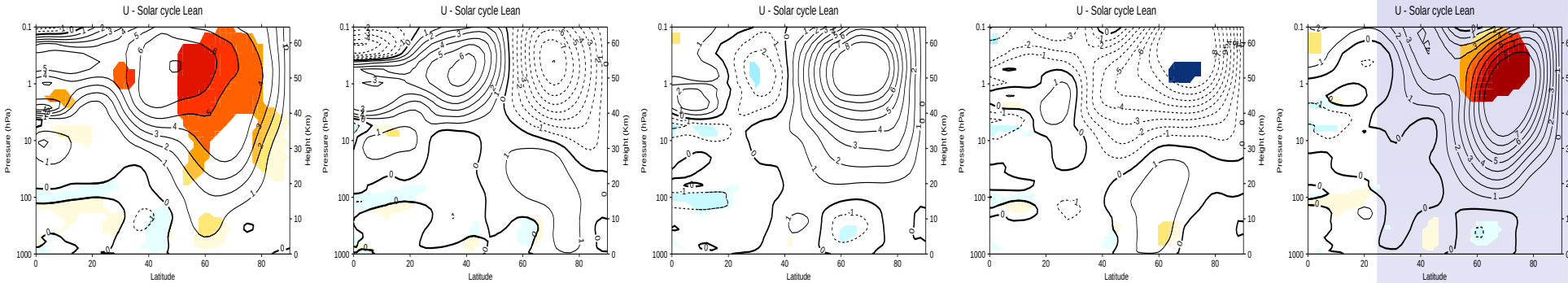
NCEP



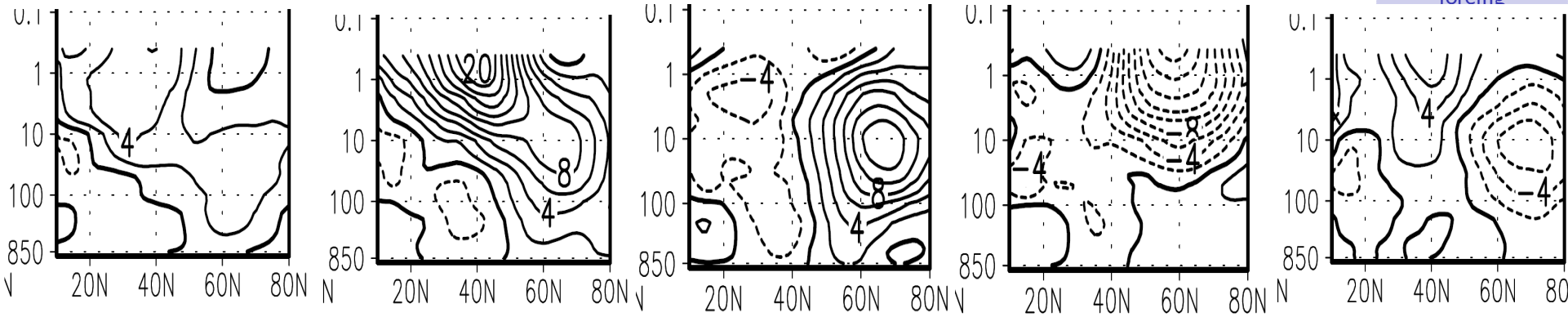
NCEP



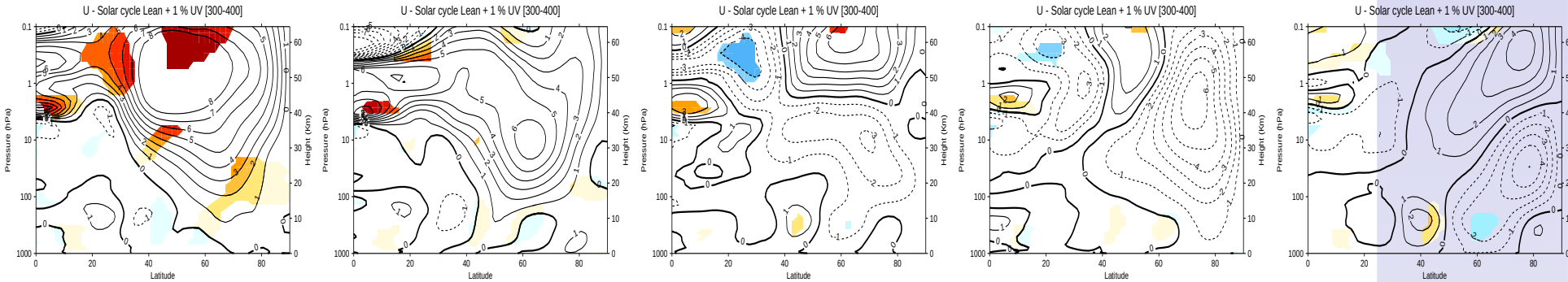
Solar cycle Lean



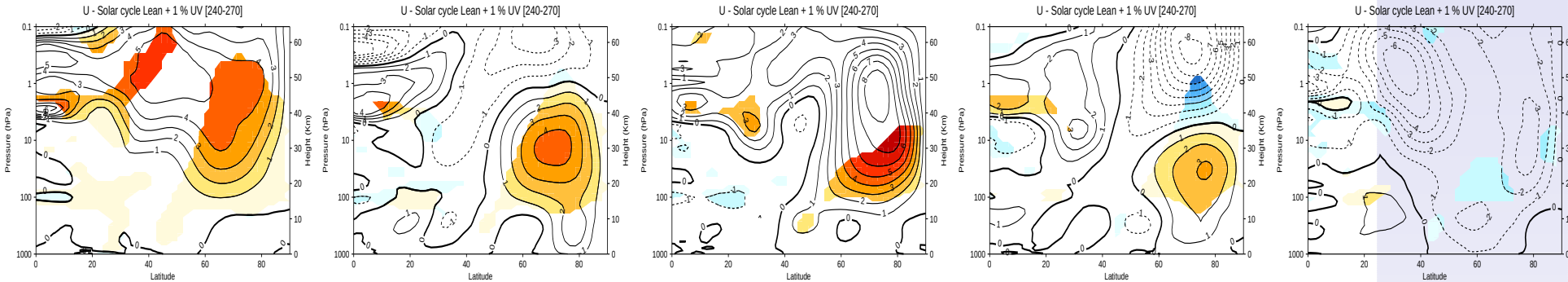
NCEP



Solar cycle Lean + UV [300-400]



Solar cycle Lean + UV [240-270]



Discussion

- The solar cycle derived from the Lean dataset (NRL-sMAX-NRL-sMIN) leads to stronger vortex in early-winter, but no clear response in the following months

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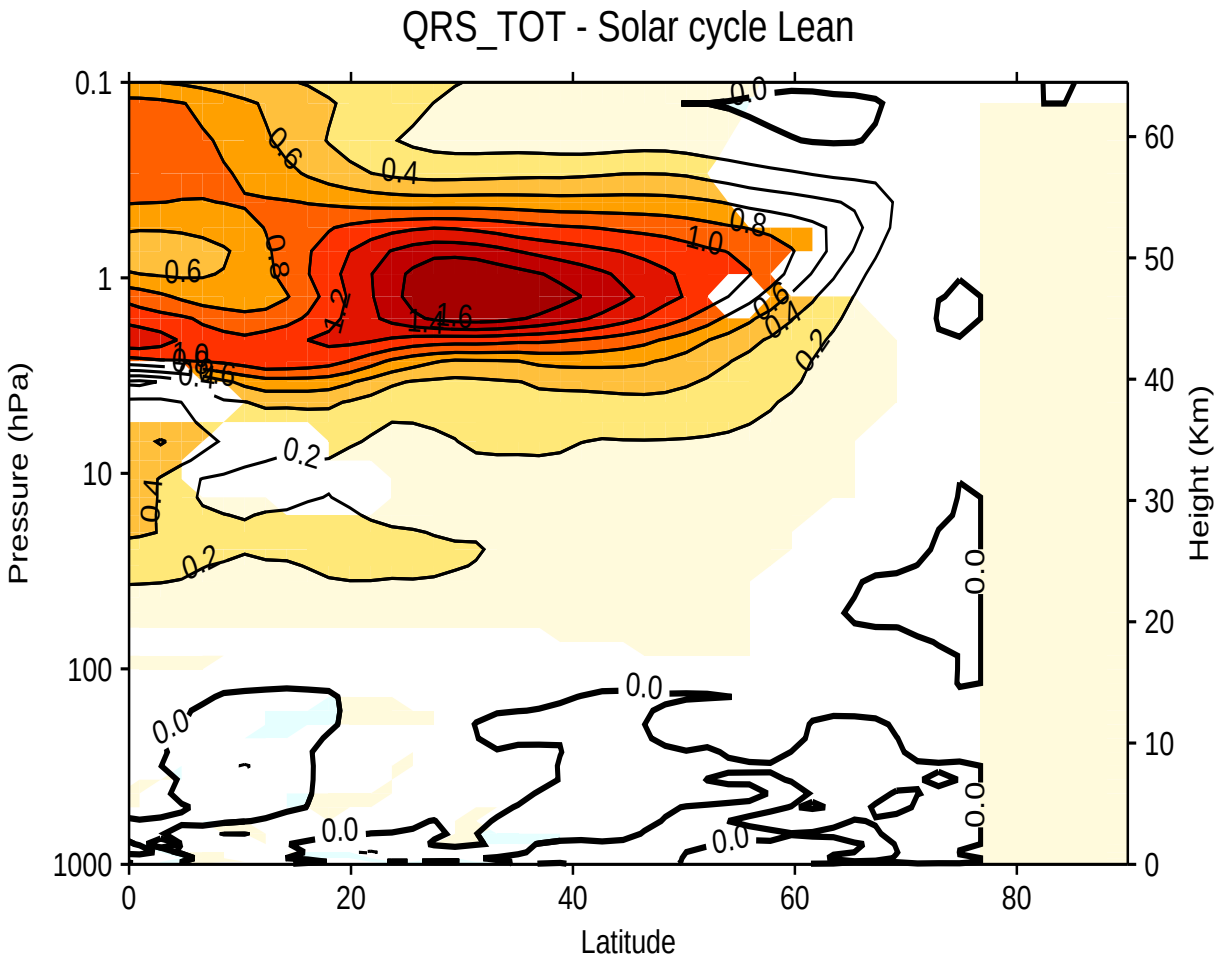
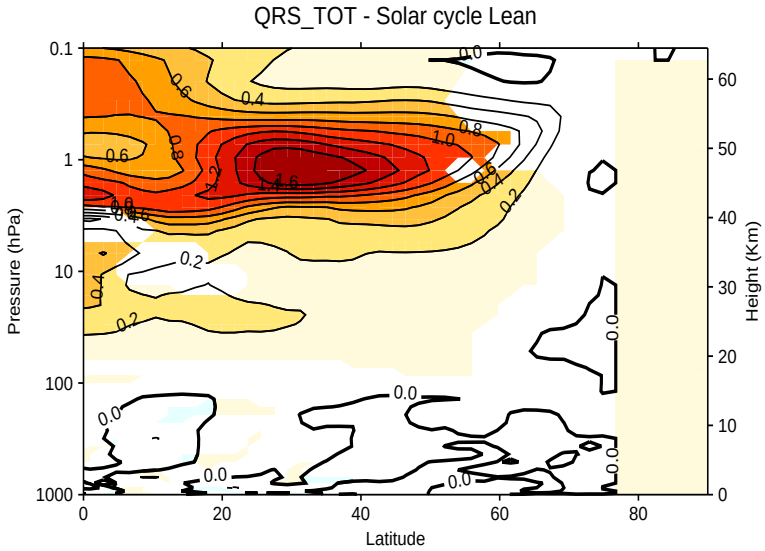
Discussion

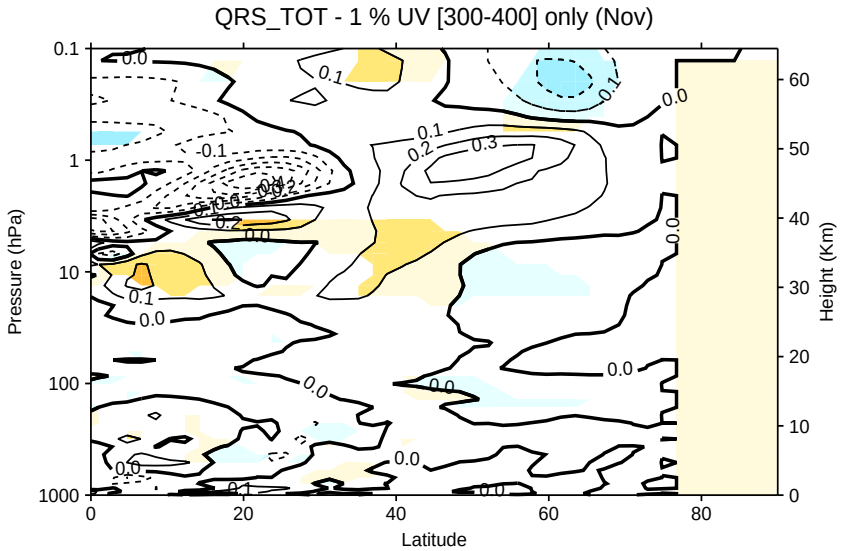
- The solar cycle derived from the Lean dataset (NRL-sMAX-NRL-sMIN) leads to stronger vortex in early-winter, but no clear response in the following months
- The increase in the [300-400] radiation leads to stronger change in the Polar vortex during early winter. A switch in sign is found in January (i.e. Weaker vortex). More realistic late winter response
- A stronger polar-vortex is simulated throughout the NH winter if the [240-270] radiation is enhanced. A switch in sign is found in March (i.e. Weaker vortex). More realistic early to mid winter response

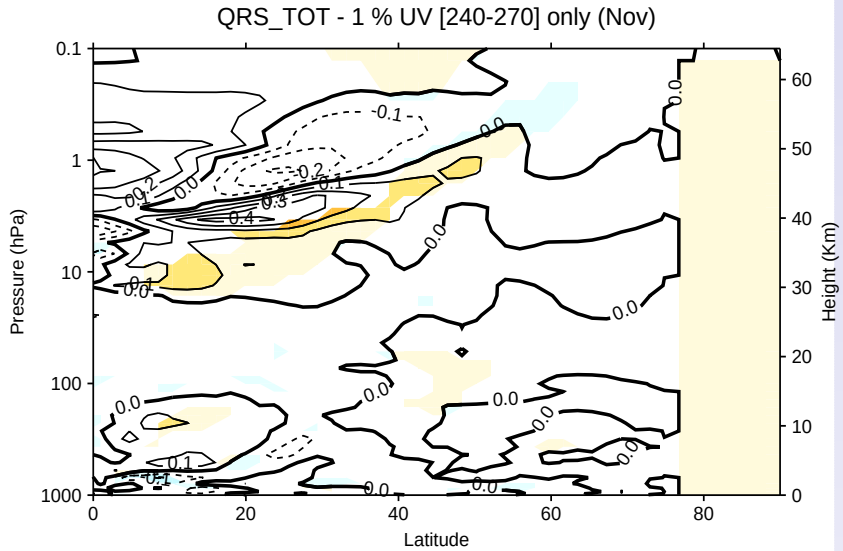
Solar cycle response SW-heating rates from Lean (NRL-sMAX - NRL-sMIN) in November





Impact of 1% radiation change in [300-400] and [240-270]





SC Lean+UV[300-400]

SC Lean+UV[240-270]

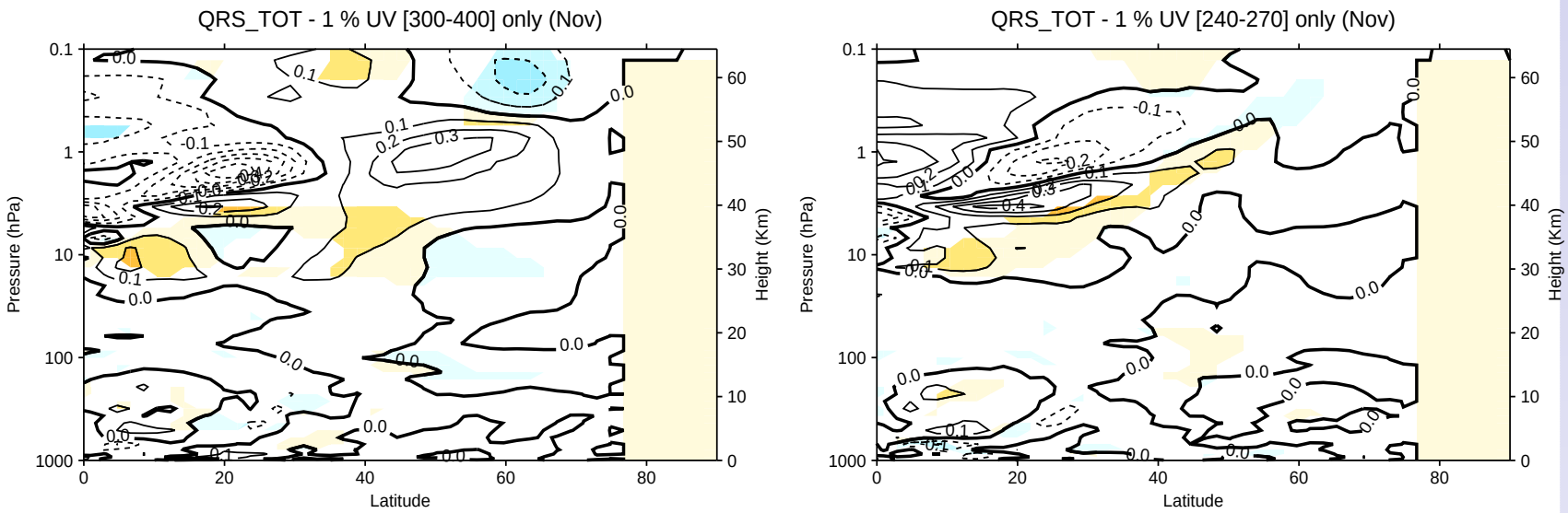
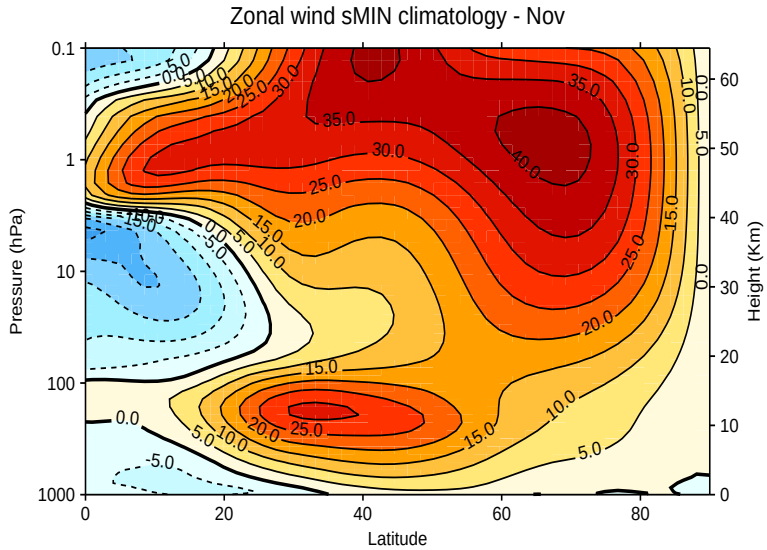
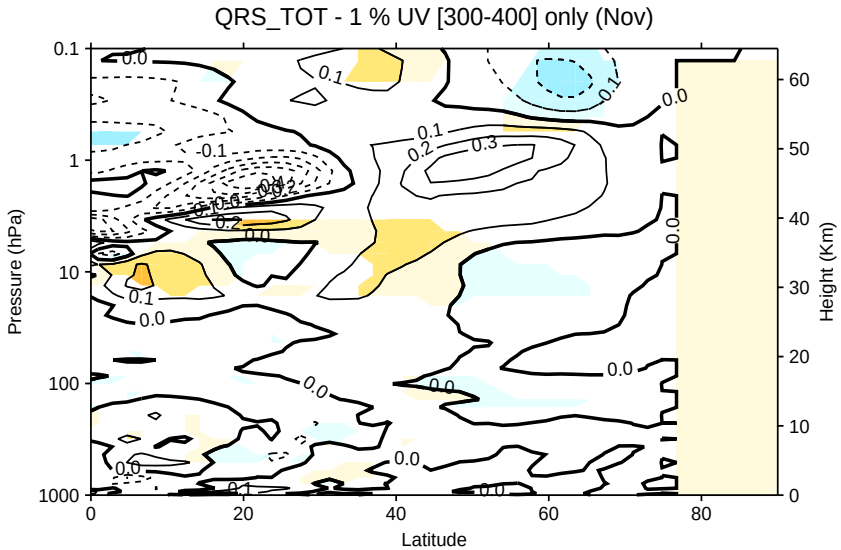


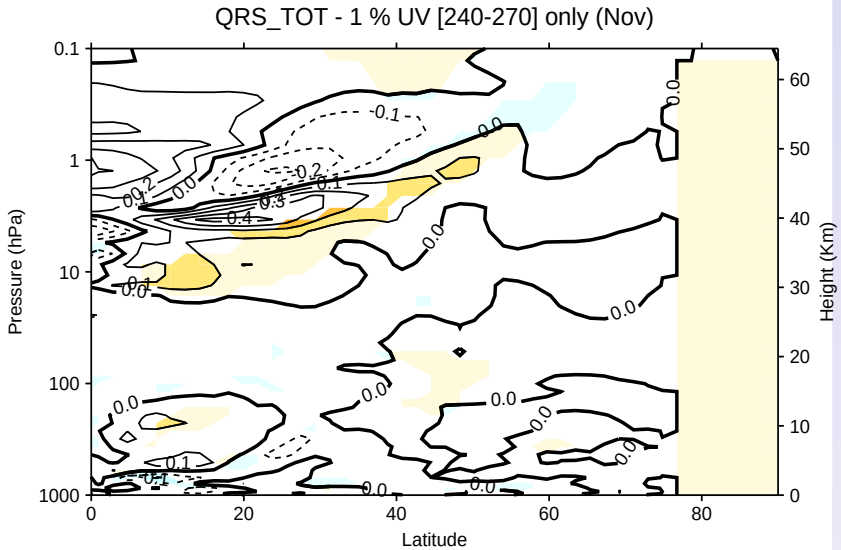
Figure: More SW-heating at 50-60N (left), and 30N (right)



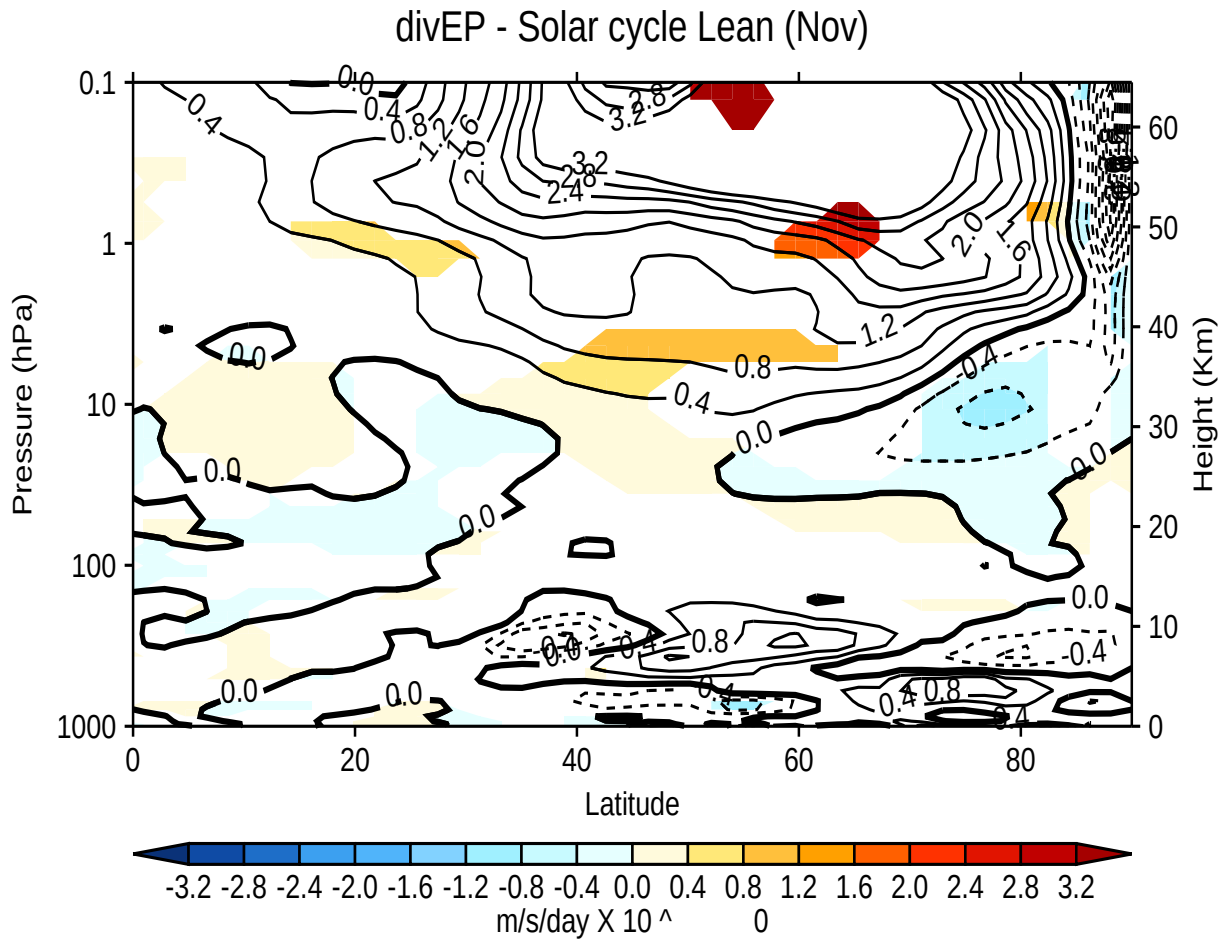
SC Lean+UV[300-400]

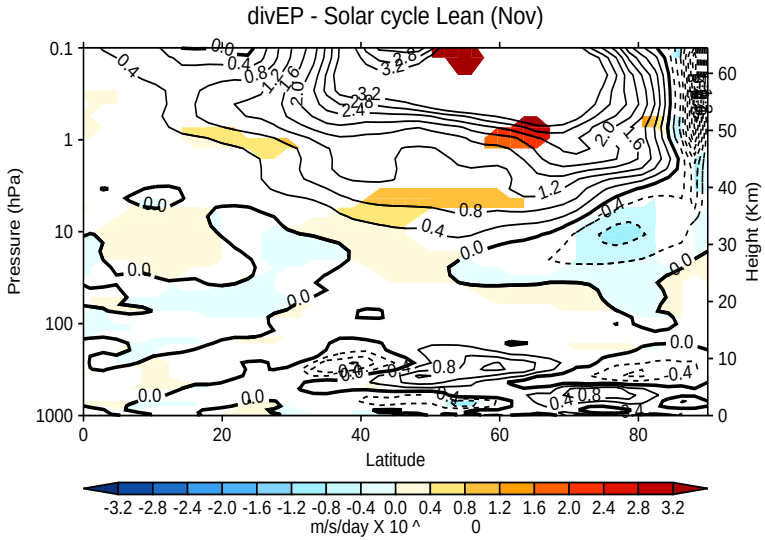


SC Lean+UV[240-270]

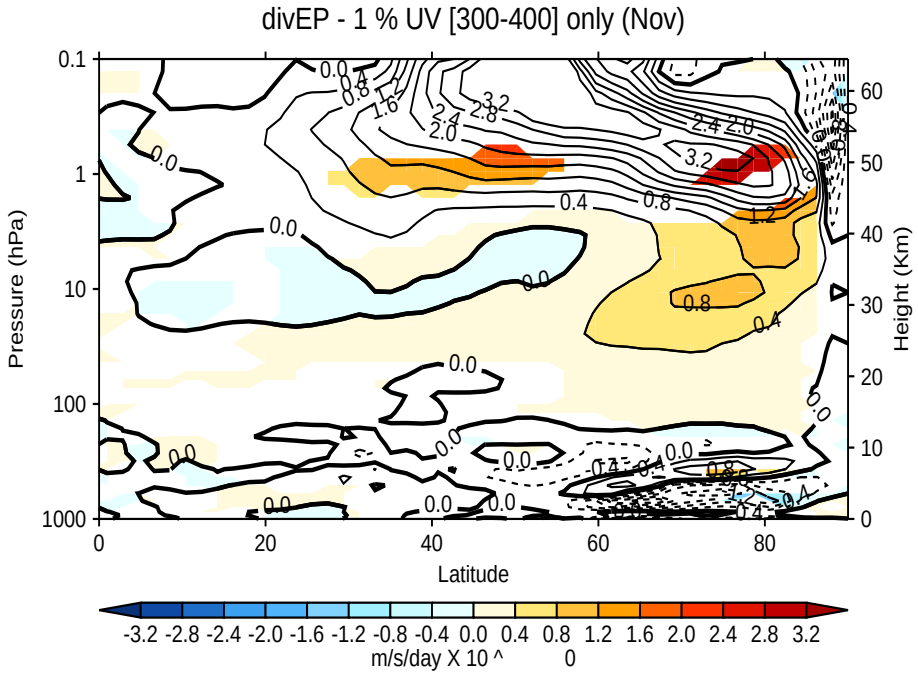


Solar cycle response in Planetary-Wave divergence (EPF-div) from Lean (NRL-sMAX - NRL-sMIN) in November [m/s/day]

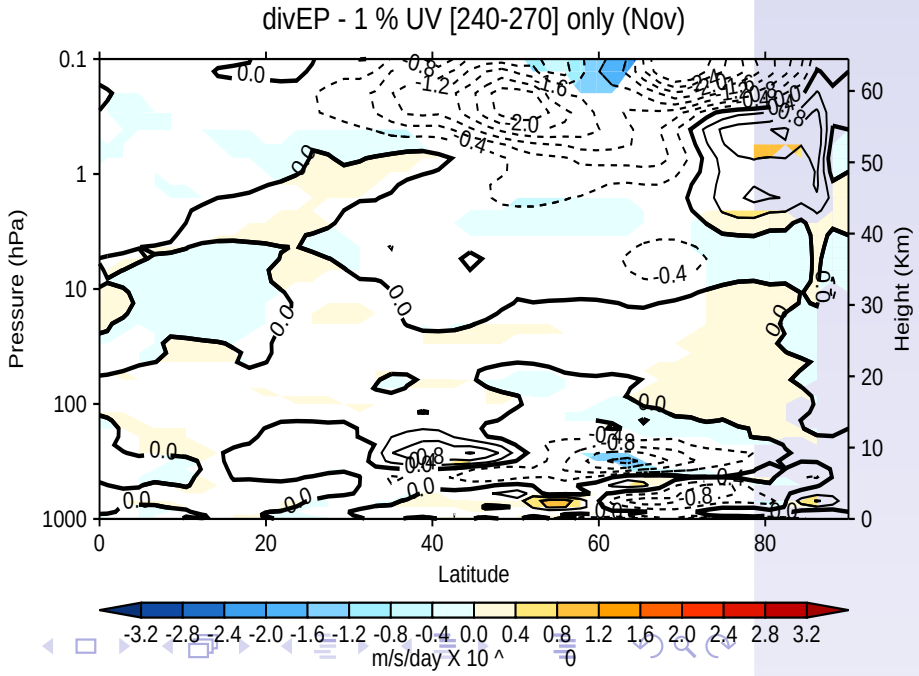




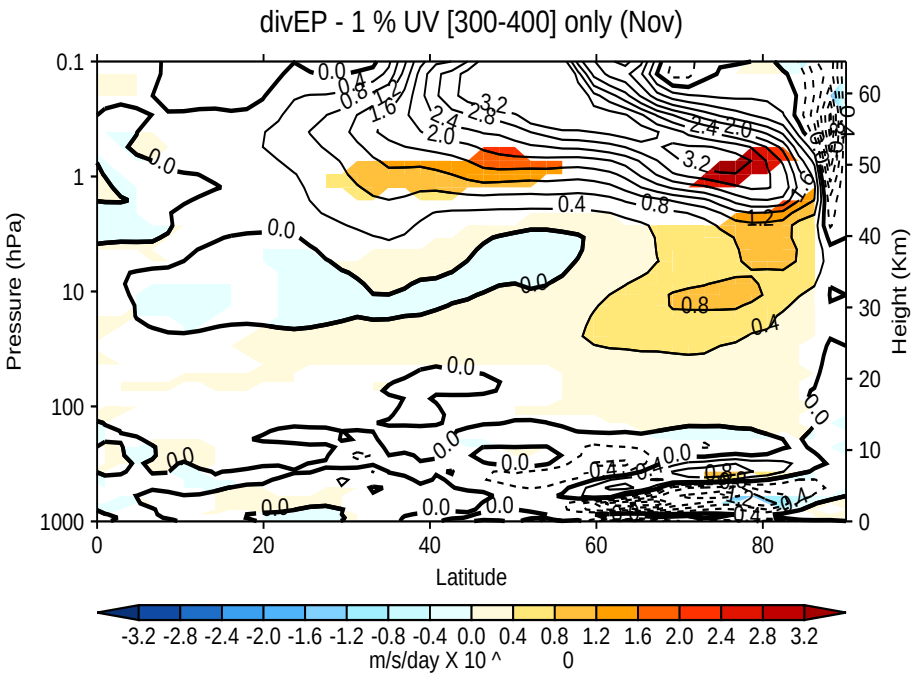
Impact of 1% [300-400]



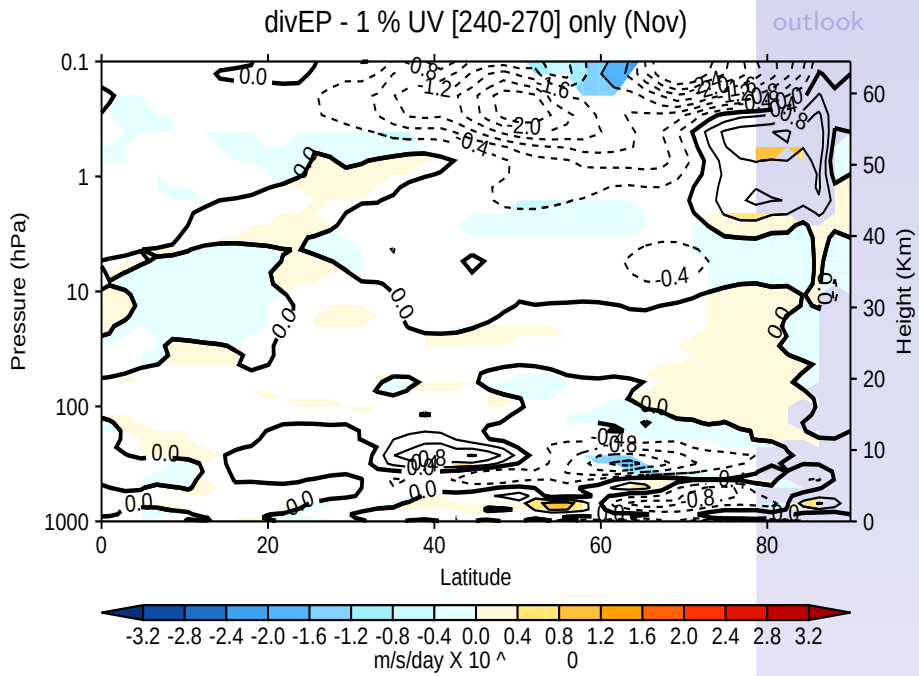
[240-270]



UV + [300-400]



UV + [240-270]



UV + [300-400]

UV + [240-270]

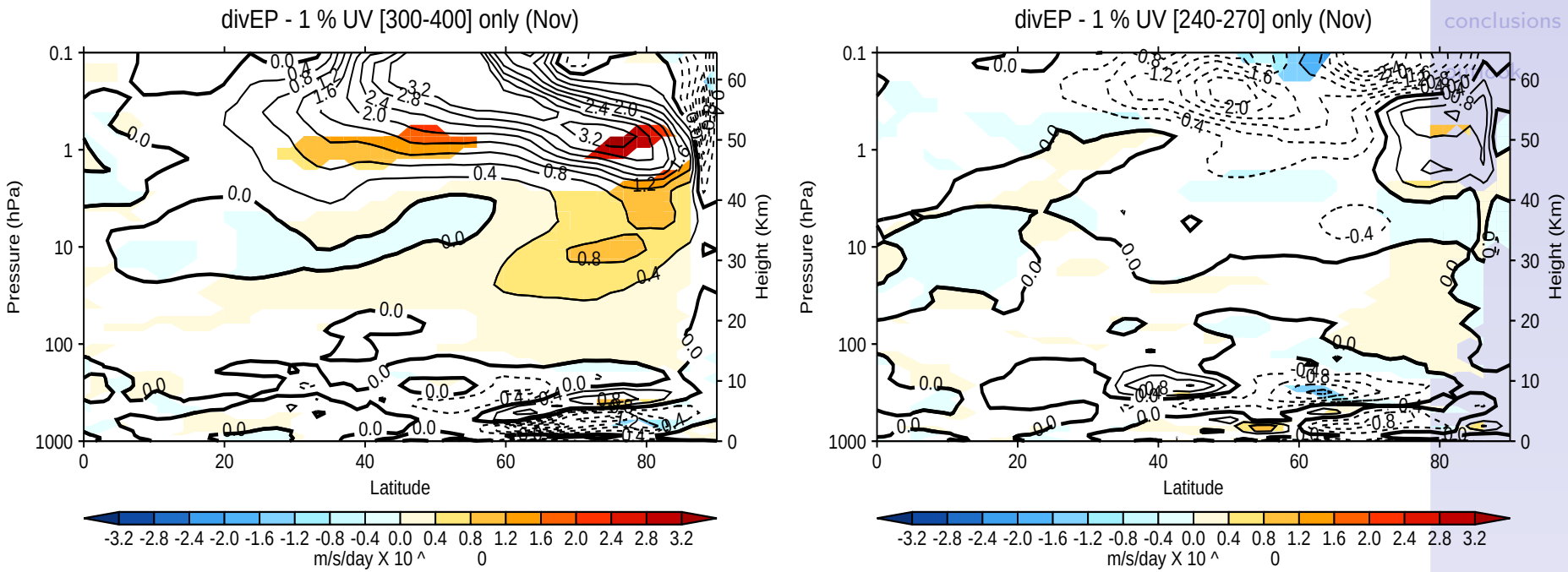
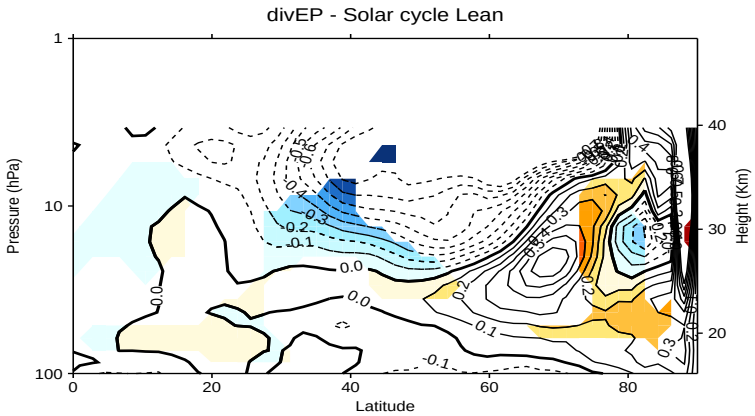
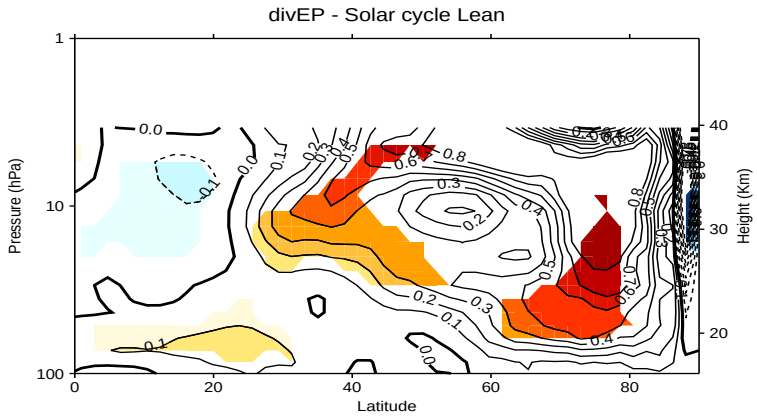
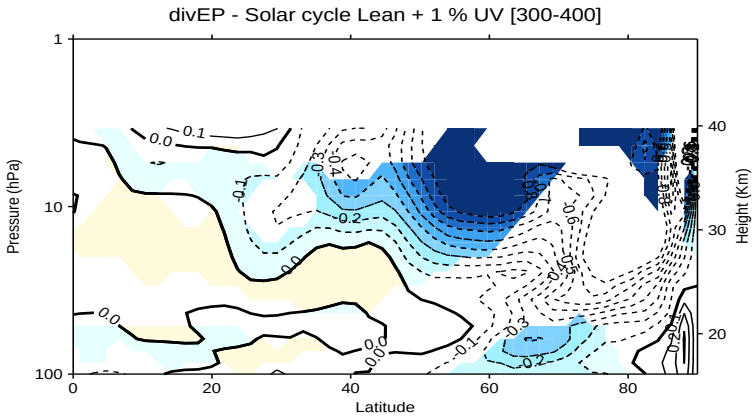


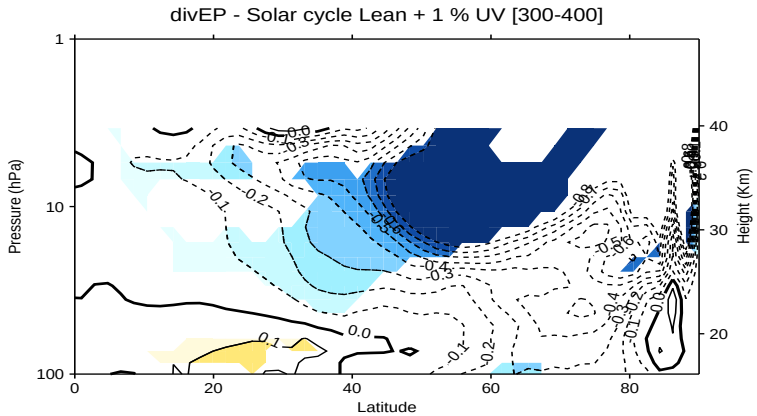
Figure: More divEP at stratopause (left), and less (right).

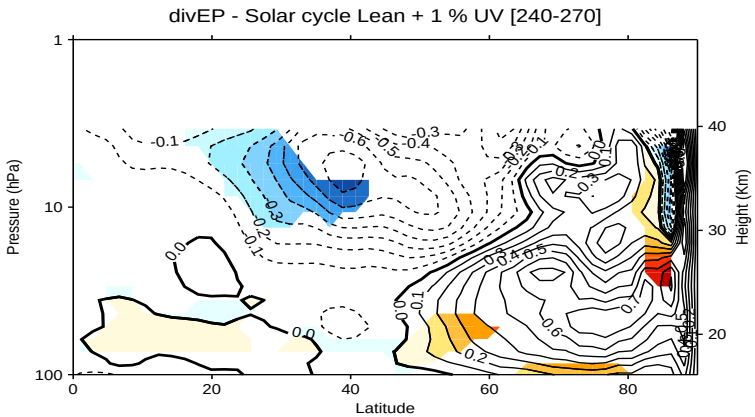
Planetary-Wave divergence changes in Dec and Jan

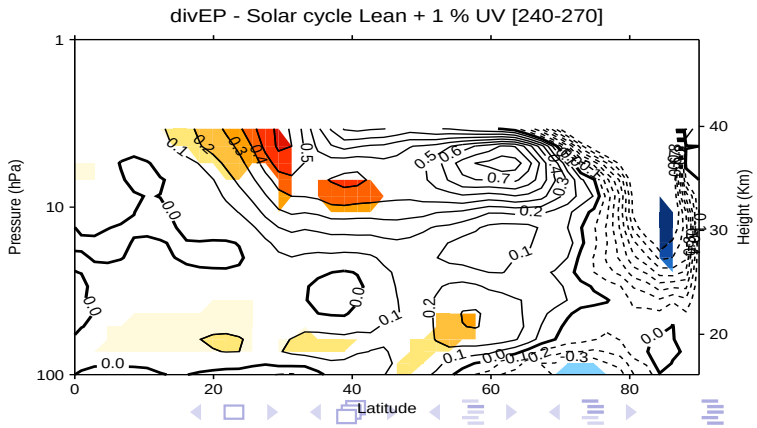


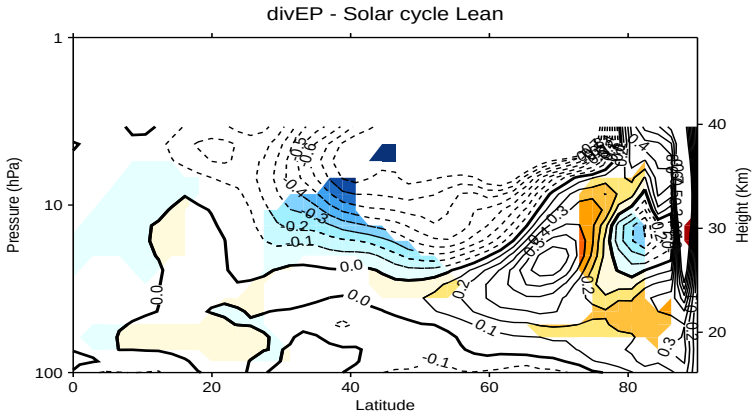


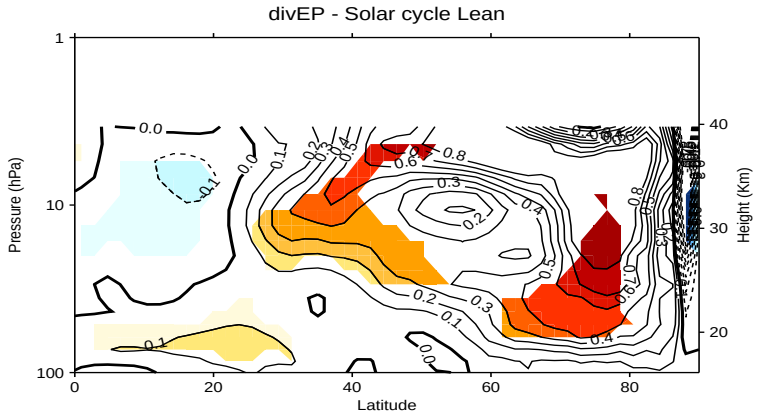


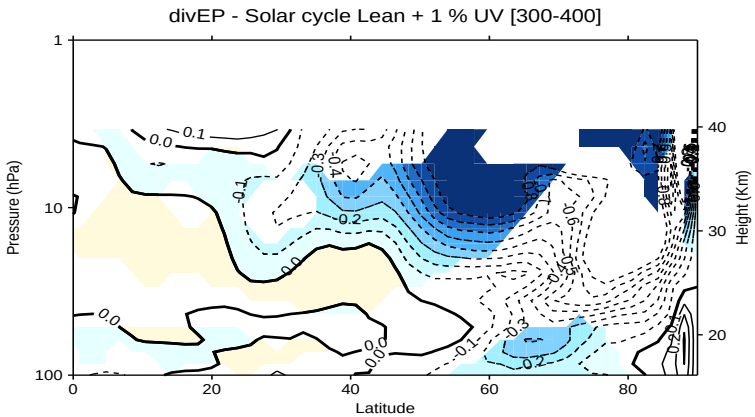


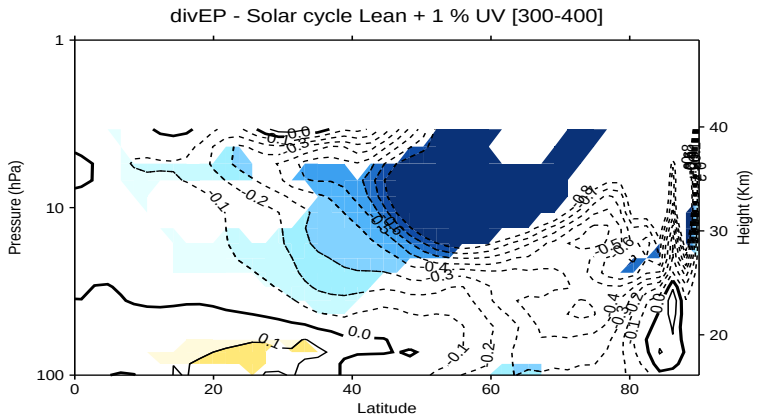


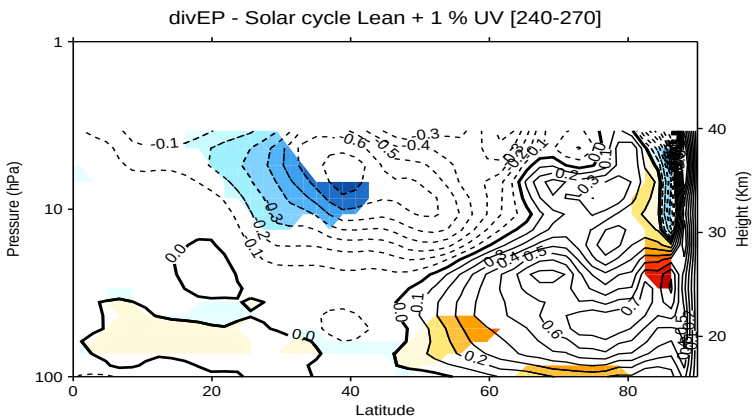


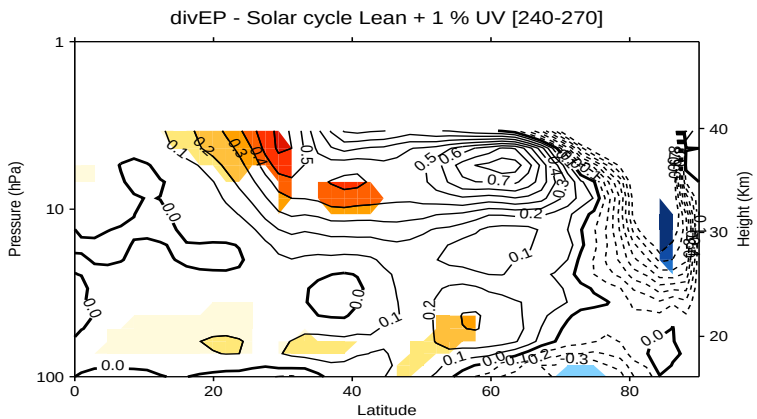

divEP - Solar cycle Lean
Pressure (hPa)
Height (Km)
Latitude


divEP - Solar cycle Lean
Pressure (hPa)
Height (Km)
Latitude

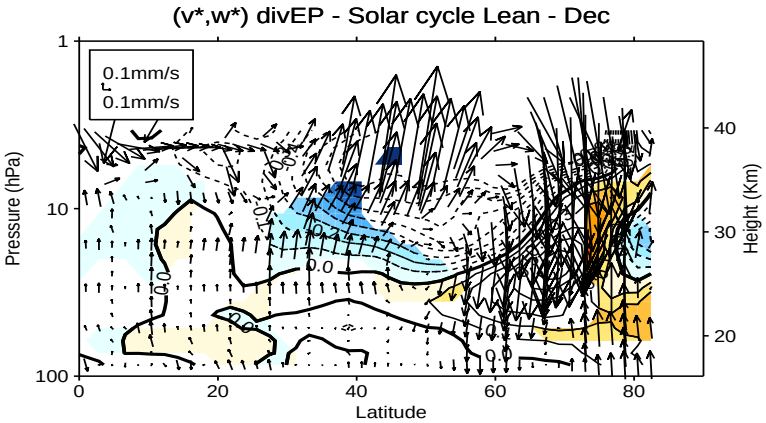

divEP - Solar cycle Lean + 1 % UV [300-400]
Pressure (hPa)
Height (Km)
Latitude

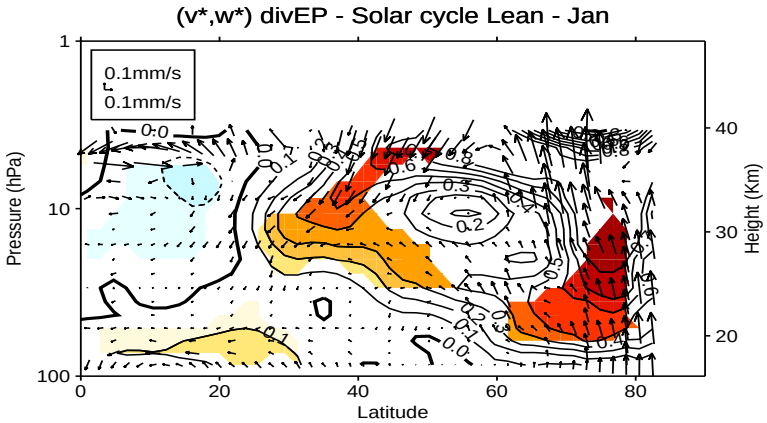

divEP - Solar cycle Lean + 1 % UV [300-400]
Pressure (hPa)
Height (Km)
Latitude

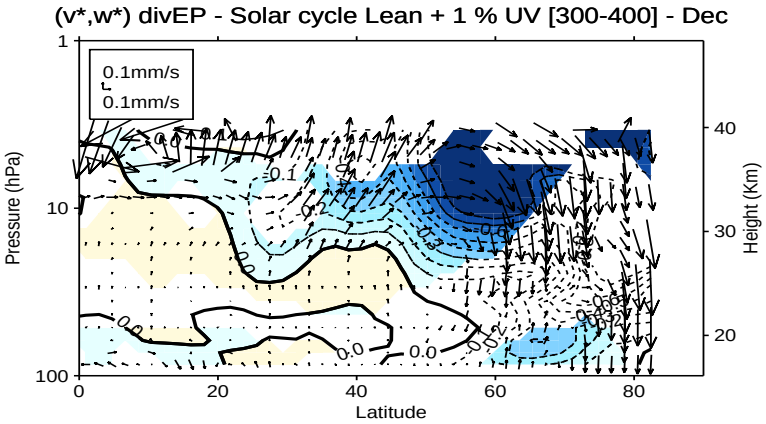

divEP - Solar cycle Lean + 1 % UV [240-270]
Pressure (hPa)
Height (Km)
Latitude

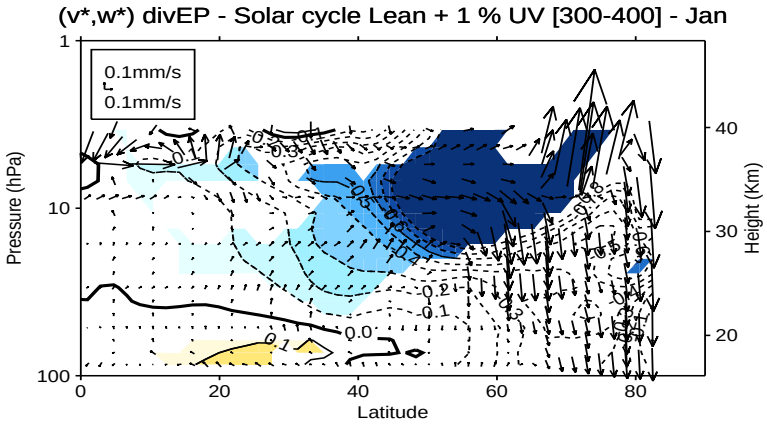

divEP - Solar cycle Lean + 1 % UV [240-270]
Pressure (hPa)
Height (Km)
Latitude

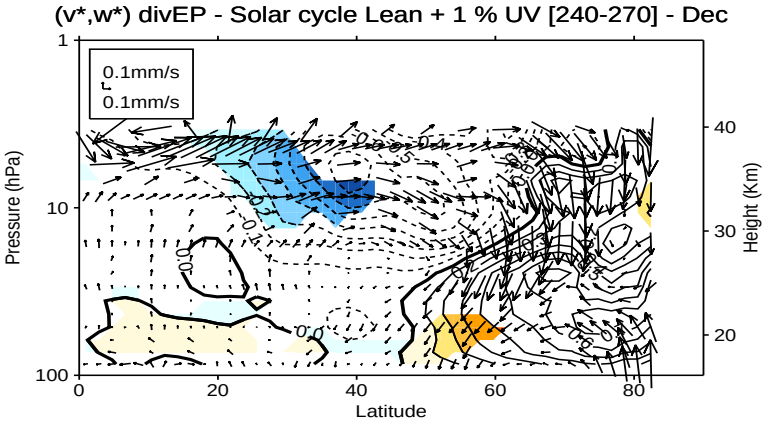
Residual circulation (v*,w*) changes in Dec and Jan

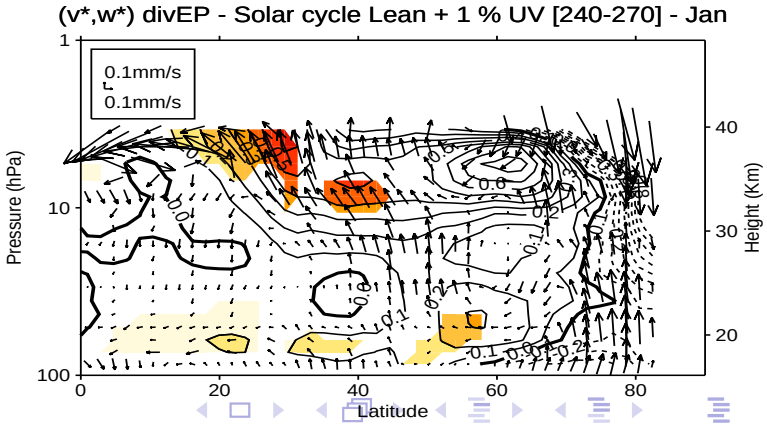


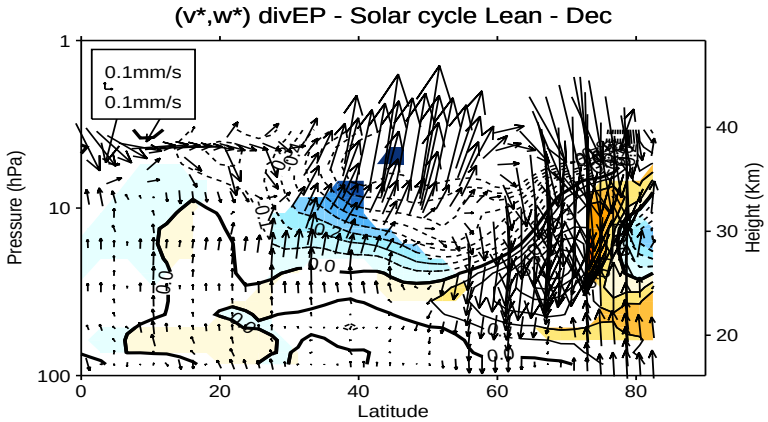


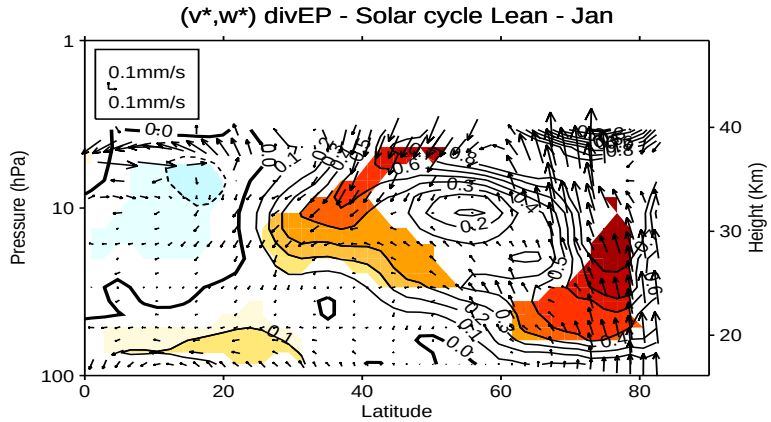


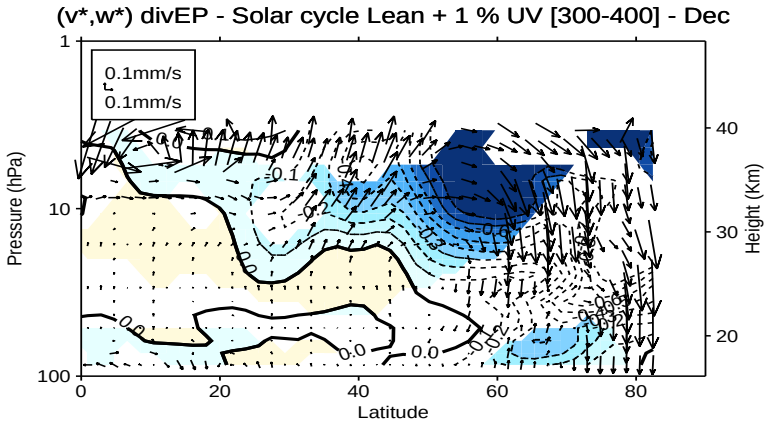


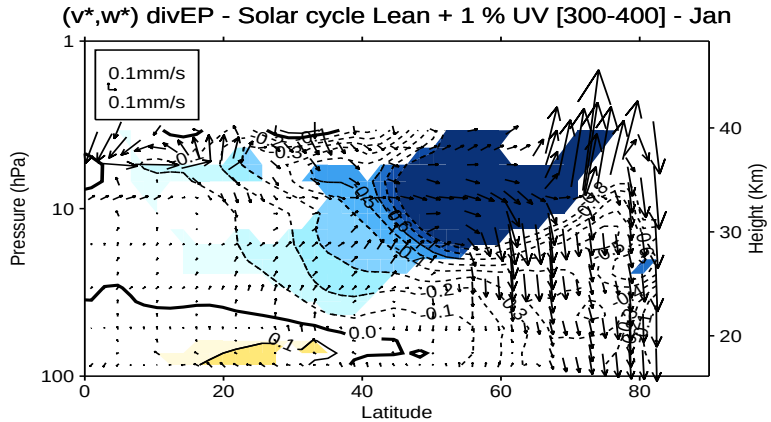


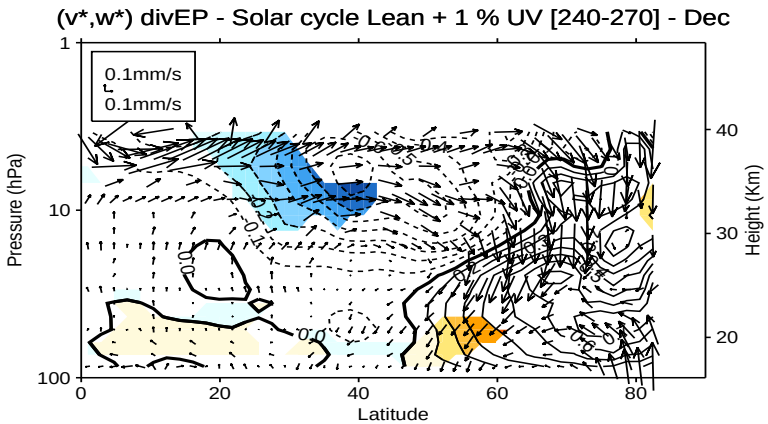


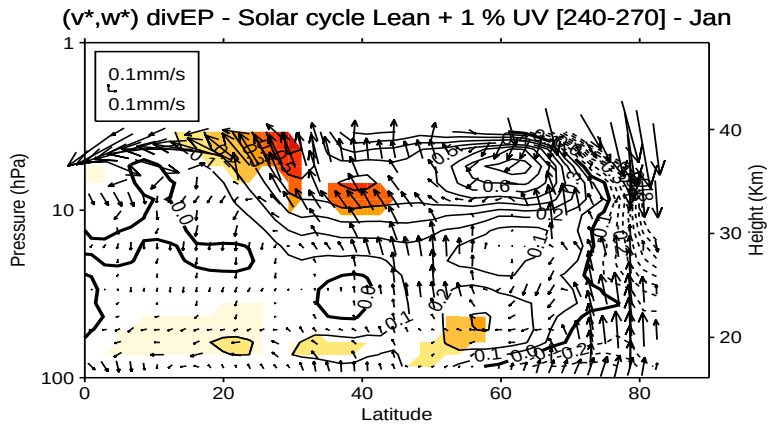

(v*,w*) divEP - Solar cycle Lean - Dec
0.1mm/s
0.1mm/s
Pressure (hPa)
Height (Km)
Latitude


(v*,w*) divEP - Solar cycle Lean - Jan
0.1mm/s
0.1mm/s
Pressure (hPa)
Height (Km)
Latitude


(v*,w*) divEP - Solar cycle Lean + 1 % UV [300-400] - Dec
0.1mm/s
0.1mm/s
Pressure (hPa)
Height (Km)
Latitude

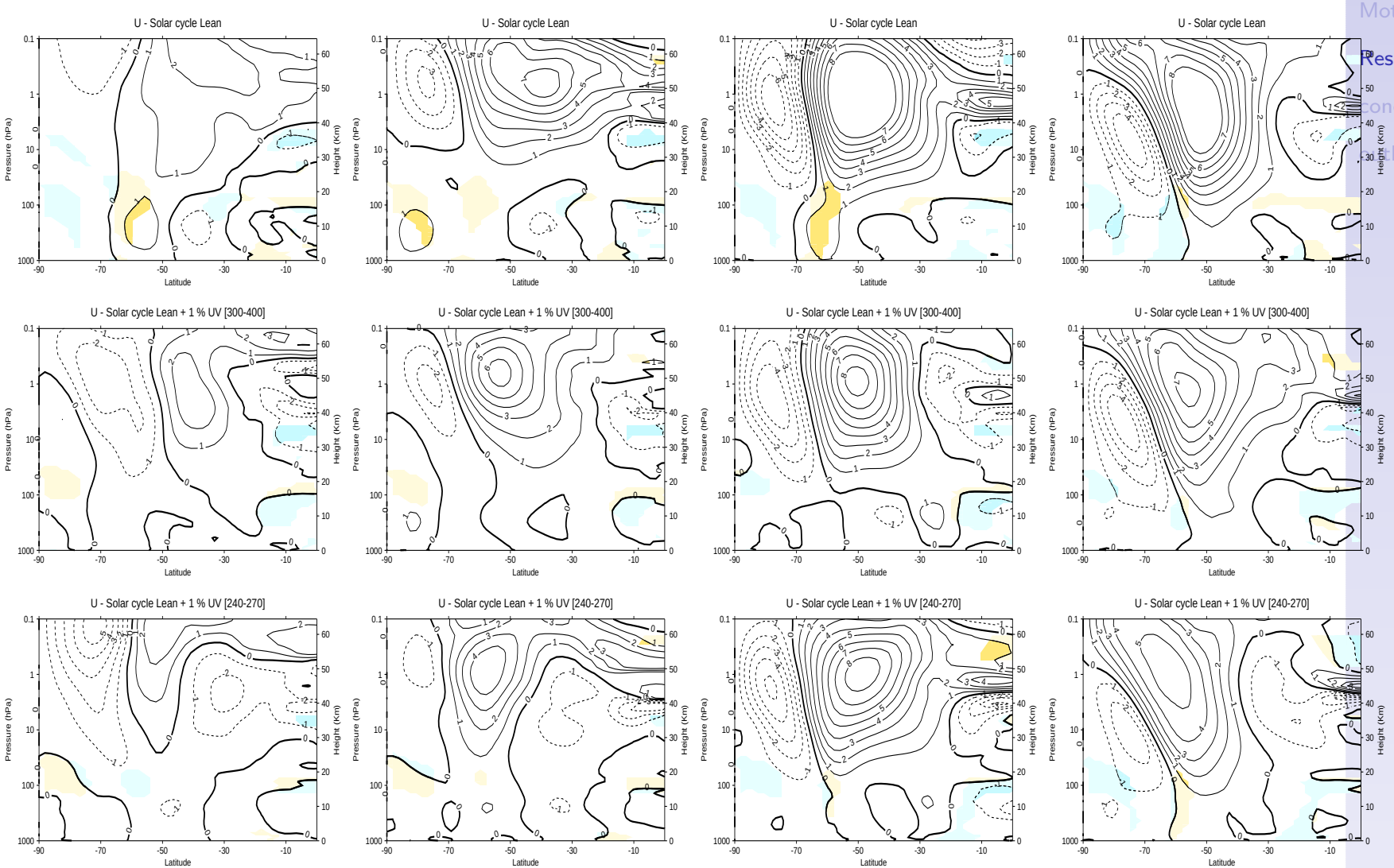

(v*,w*) divEP - Solar cycle Lean + 1 % UV [300-400] - Jan
0.1mm/s
0.1mm/s
Pressure (hPa)
Height (Km)
Latitude


(v*,w*) divEP - Solar cycle Lean + 1 % UV [240-270] - Dec
0.1mm/s
0.1mm/s
Pressure (hPa)
Height (Km)
Latitude


(v*,w*) divEP - Solar cycle Lean + 1 % UV [240-270] - Jan
0.1mm/s
0.1mm/s
Pressure (hPa)
Height (Km)
Latitude

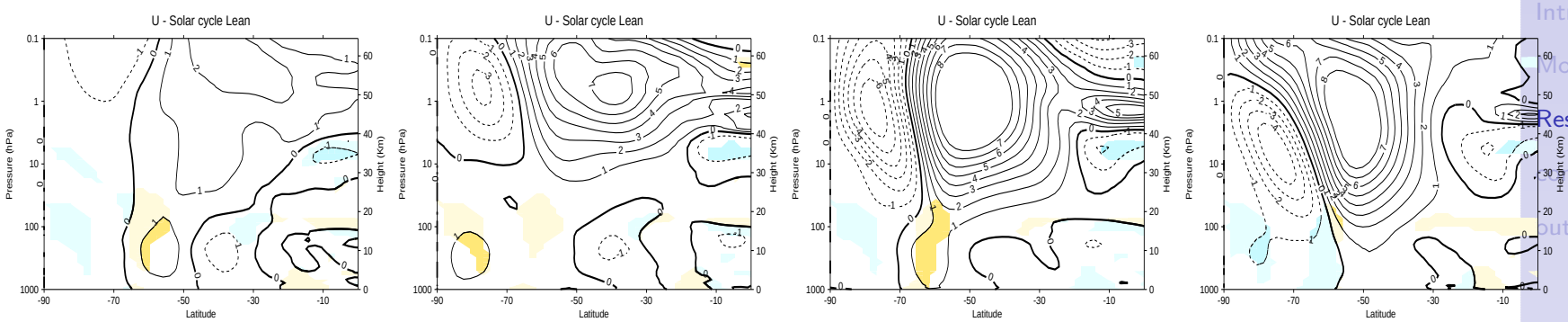
Solar cycle response in zonal mean zonal wind in the SH

June July August September

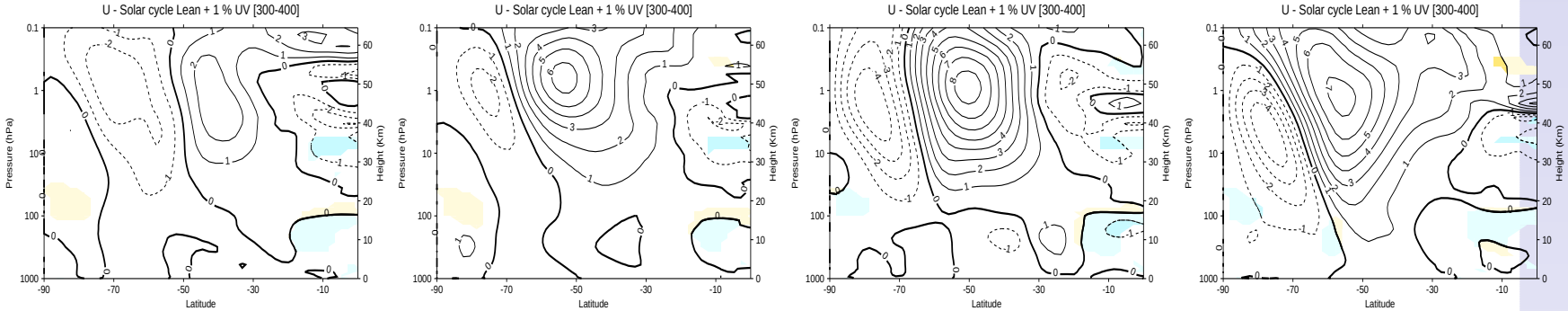


Solar cycle response in zonal mean zonal wind in the SH

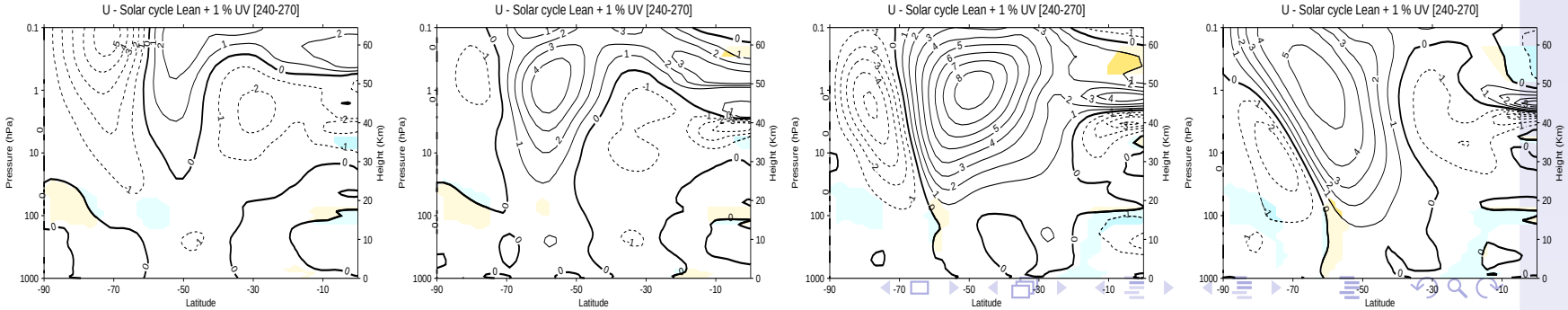
SC Lean



SC Lean + UV [300-400]



SC Lean + UV [240-270]



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- The austral polar vortex response is stronger if the model is forced with the solar cycle variation from the Lean data-set (NRL-sMAX - NRL-sMIN)
- The reason for the difference in the SH dynamical response is still unclear

Conclusions

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- The dynamical response in the boreal winter circulation is highly sensitive to the spectral distribution of solar cycle variations.
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- The response in the austral winter circulation shows less sensitivity to the idealized spectral forcing

Outlook

- Investigate the tropospheric response to the spectral forcing
- Investigate the dynamical cause for hemispheric differences in the sensitivity
- Investigate the impact of spectral solar forcing on variability (Sudden Stratospheric Warmings, blocking activity etc.)