Solar Influences on Climate

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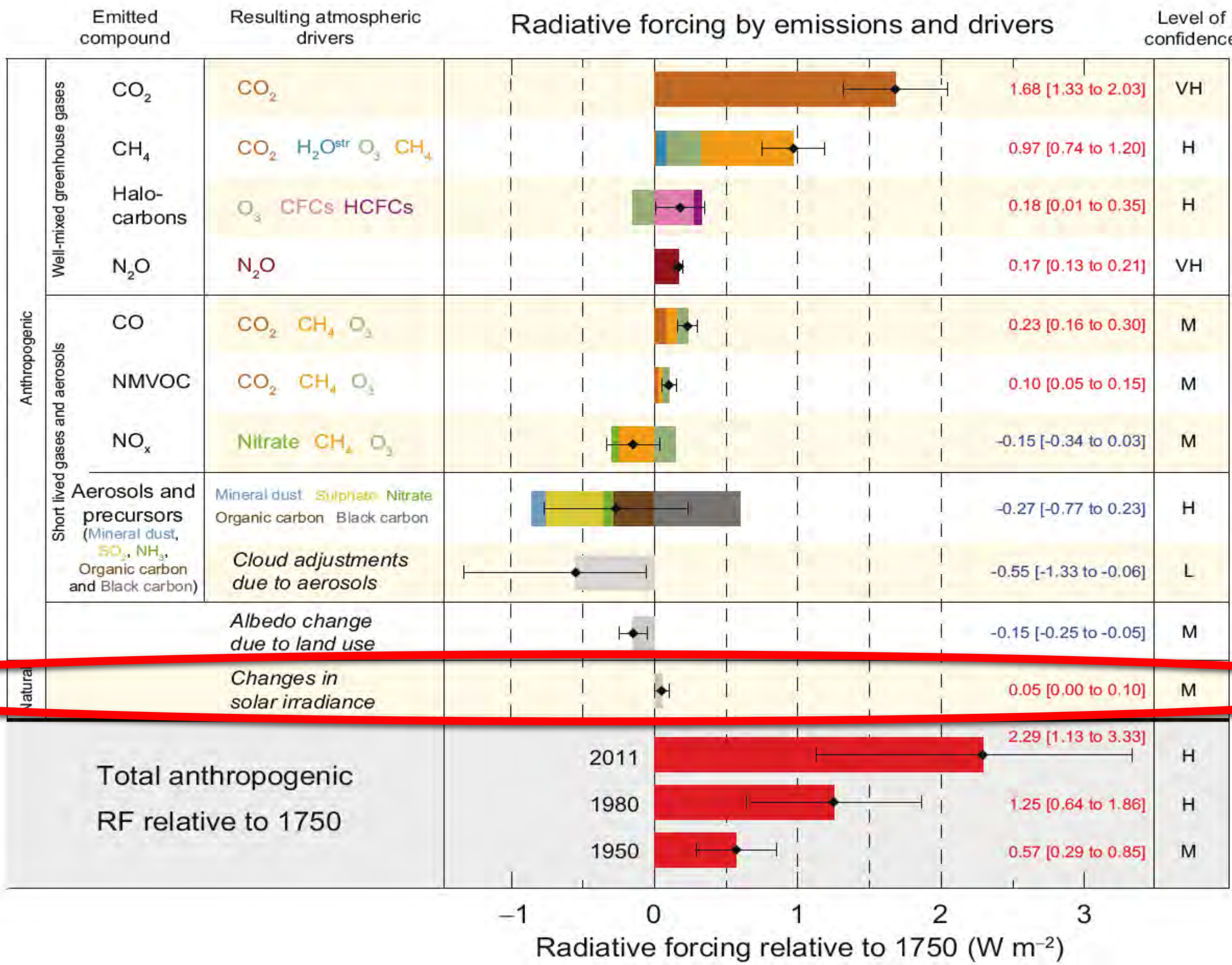
Global radiative forcing



IPCC (2013)

Changes in total solar irradiance do not contribute much to the global mean...

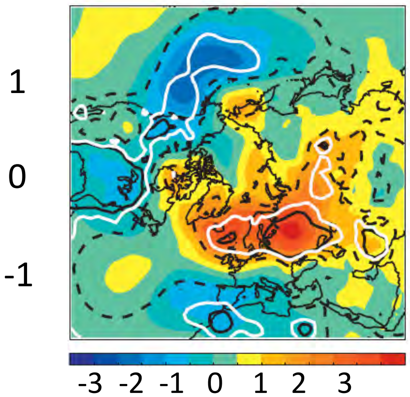
Regional Solar Forcing Contributions

Winter: DJF

ERA40/ERA-I („Obs“) Smin-Smax

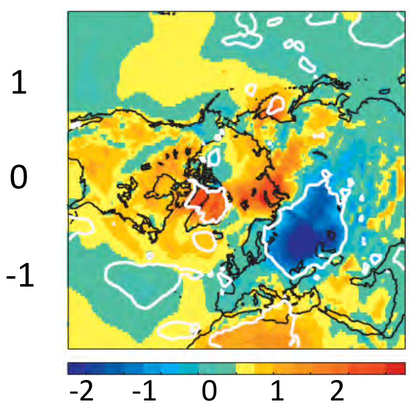
Ineson et al. (2011)

SLP (hPa)



Significant **positive NAO** signal

ST (K)



Cooling over NE America & Mediteranean region

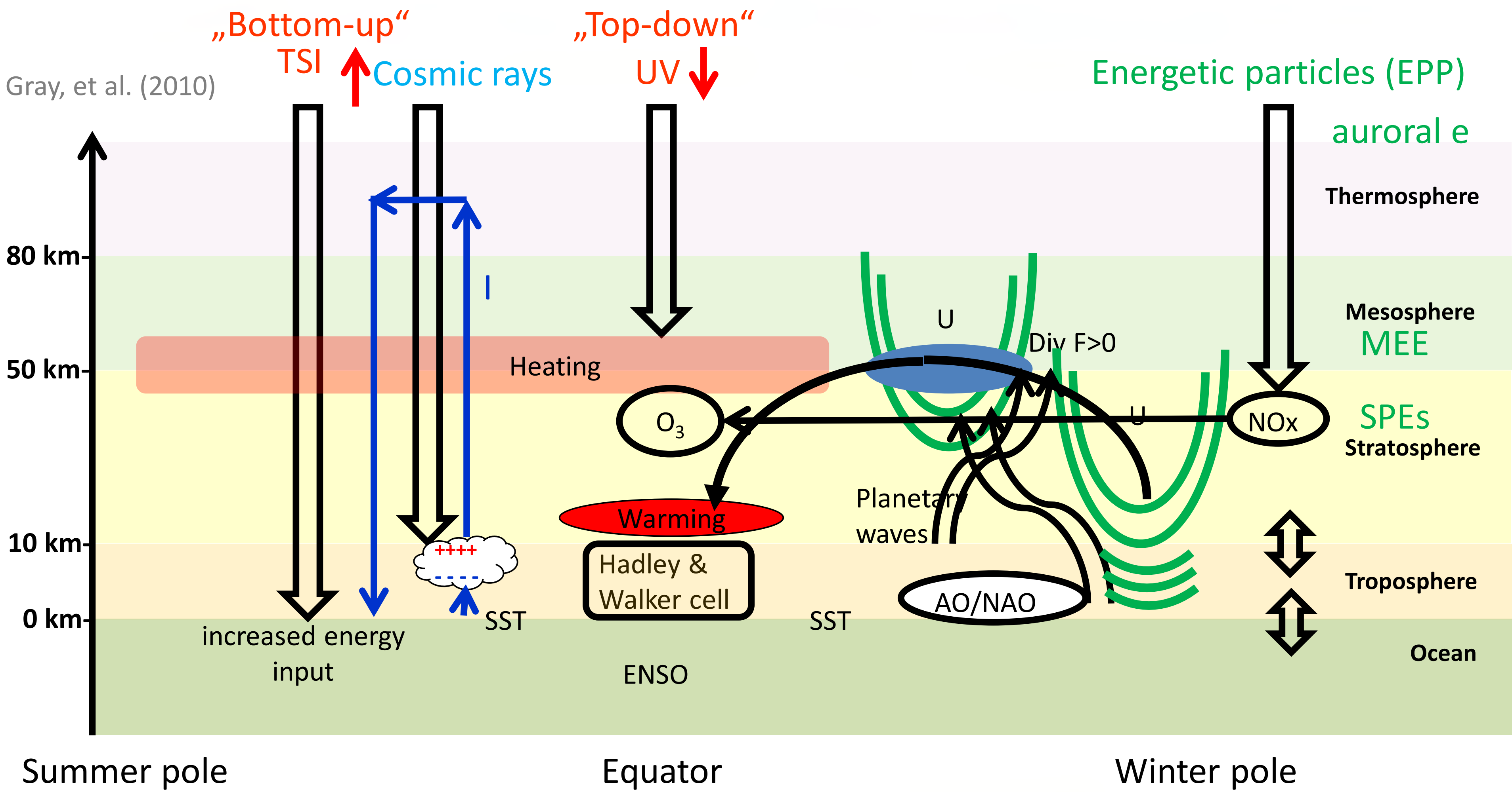
Warming over Europe

But: Significant regional contribution of solar irradiance changes, e.g. North Atlantic

Outline

- Solar variability: the complex picture
- Drivers of solar variability: what we know and what we don't know
- Solar forcing and climate impact: Recent modeling results
- Particle effects: Recent observational efforts

Solar variability: the complex picture



Questions…

- Which mechanisms (top-down, bottom-up, particles) are important for solar influences on climate?
- Can they be constrained by observations?
- What is included in current climate models to investigate solar influences on climate?

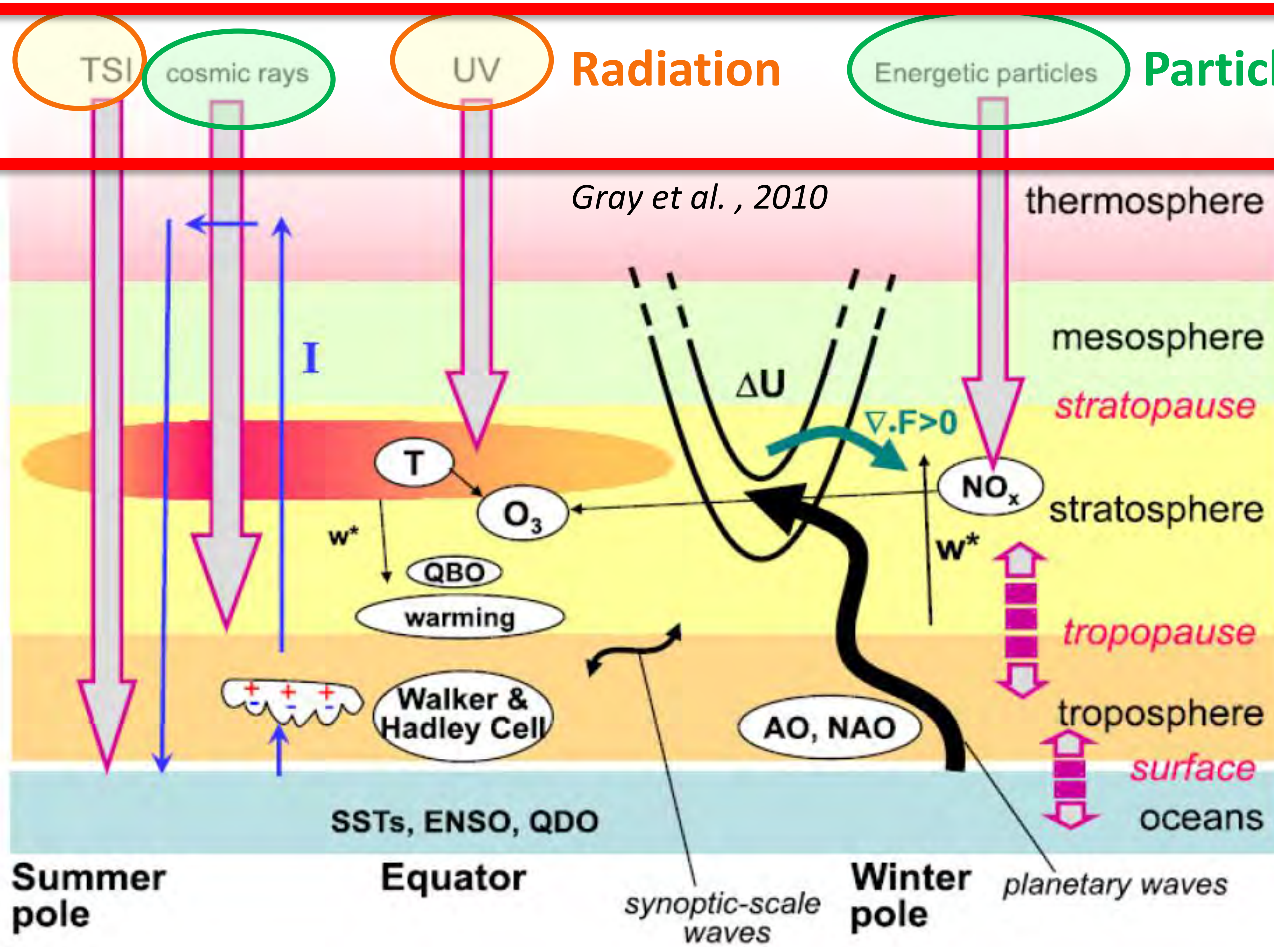
Drivers of solar variability

what we know and what we don't know…

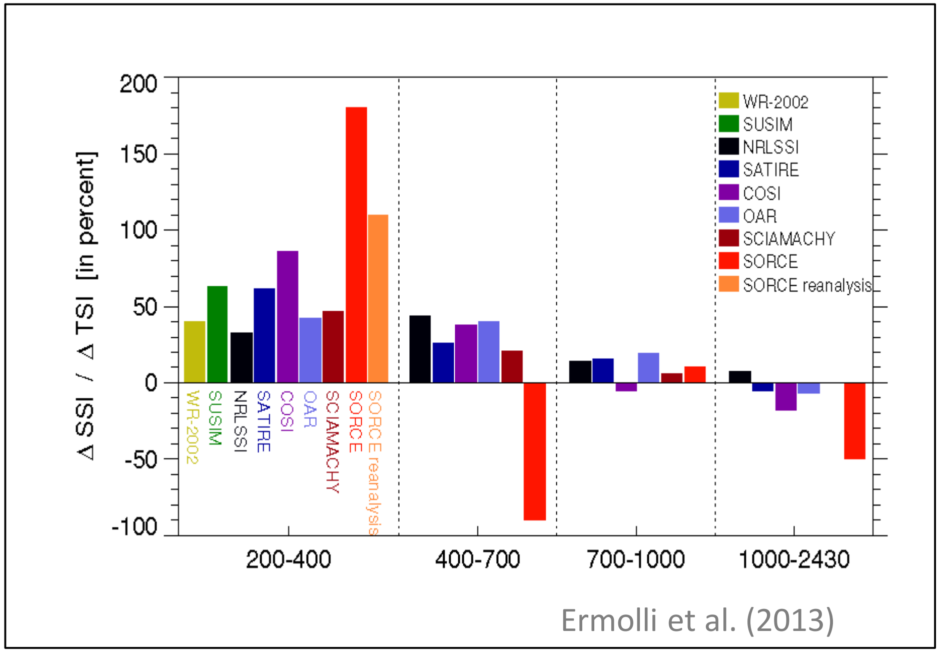
Solar drivers

Impact on dynamics & chemistry

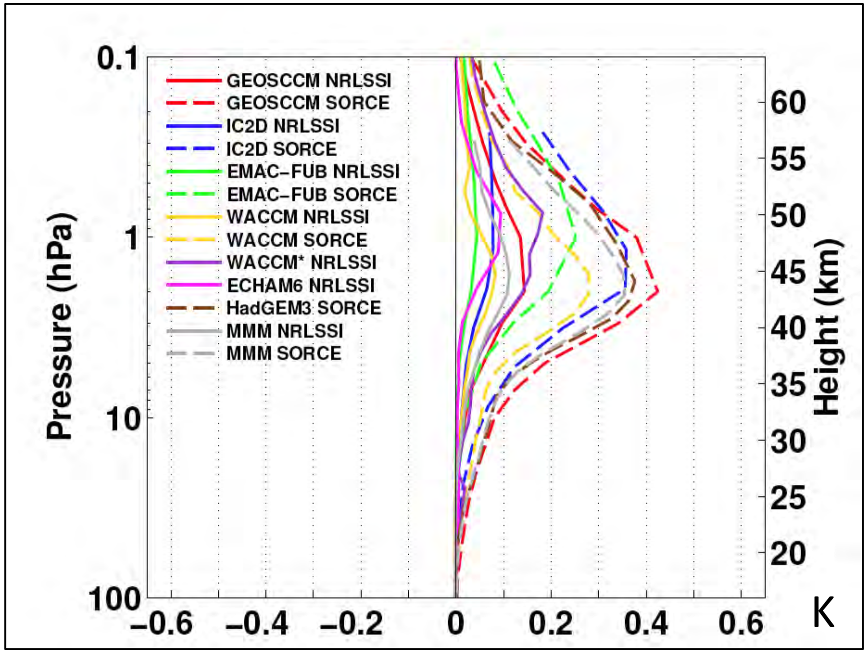
Impact on climate



SSI uncertainties and implications



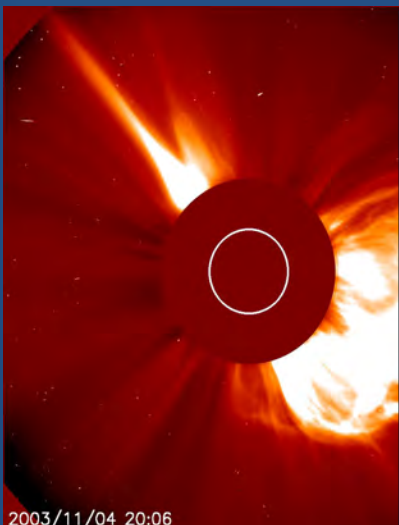
Relative contribution of the UV in (200–400nm), visible (400–700nm), near-IR (700–1000 nm) and IR (1000–2430 nm) spectral bands to the TSI change over the *solar cycle* as derived from different measurements and models.



Shortwave heating response in different models using SSI from SORCE and NRLSSI.

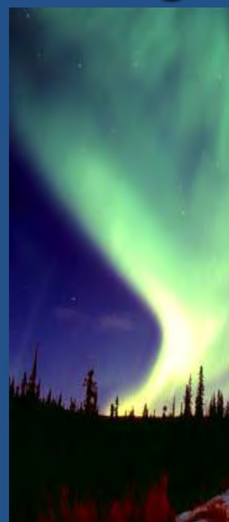
Particle sources

Solar proton events (SPE)



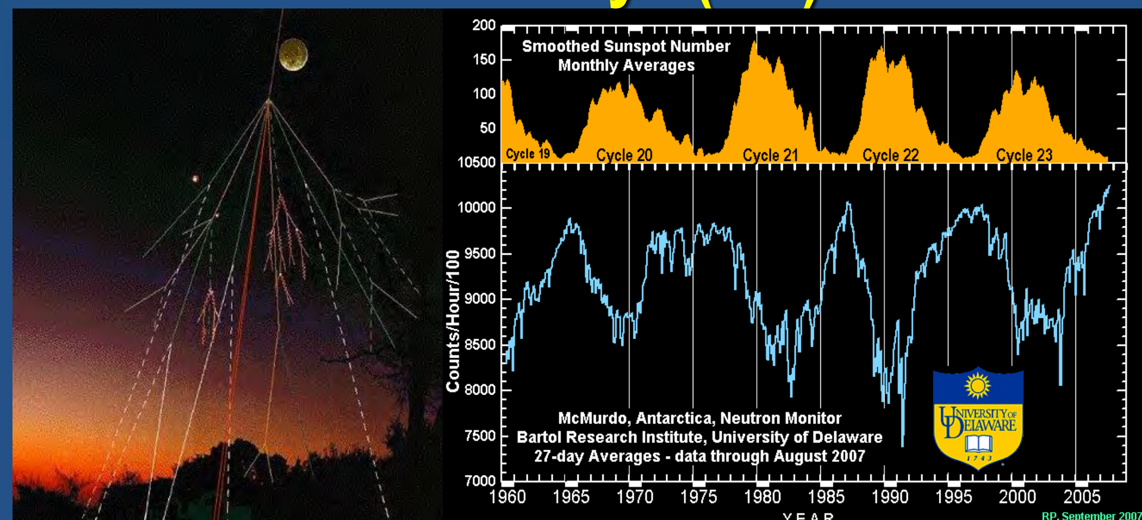
- Solar eruption
  fluxes (MeV) c
- Sporadic ever
- Maximum occ

Energetic electron precipitation (EEP)



- Geomagr
  wind caus
  trapped ir
- Continuou
- Highest ir

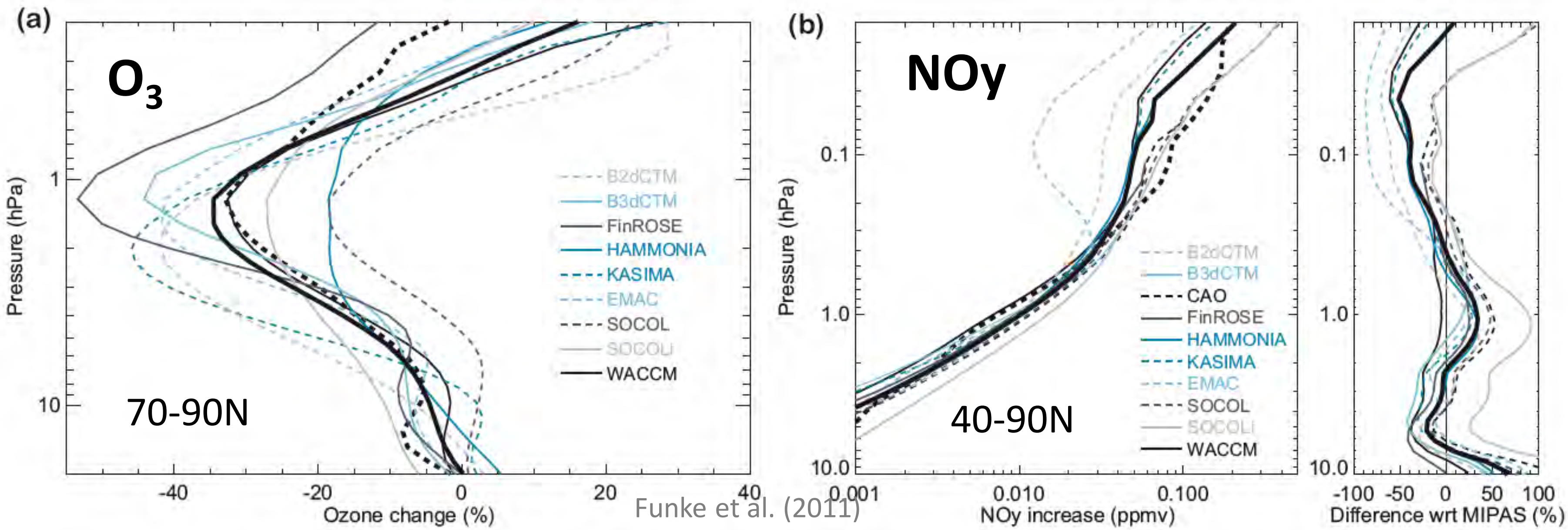
Cosmic rays (CR)



- High-energetic (~GeV) extra-solar particles (p, α) penetrate down to the surface.
- Continuous and variable process.
- Highest intensity in solar minimum (as the shielding by the solar magnetic field is lowest).

Solar protons: HEPPA-I

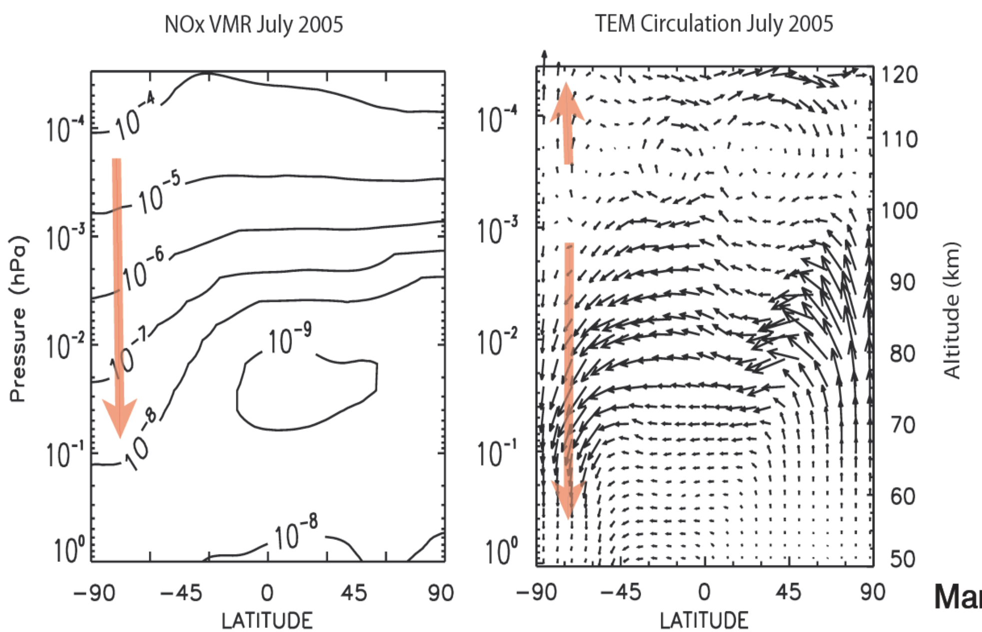
"Halloween" SPE: Comparison of modeled O_3 and NOy response to observations (MIPAS)



Funke et al. (2011)

Good representation in atmospheric models.

EPP indirect effects (auroral e)



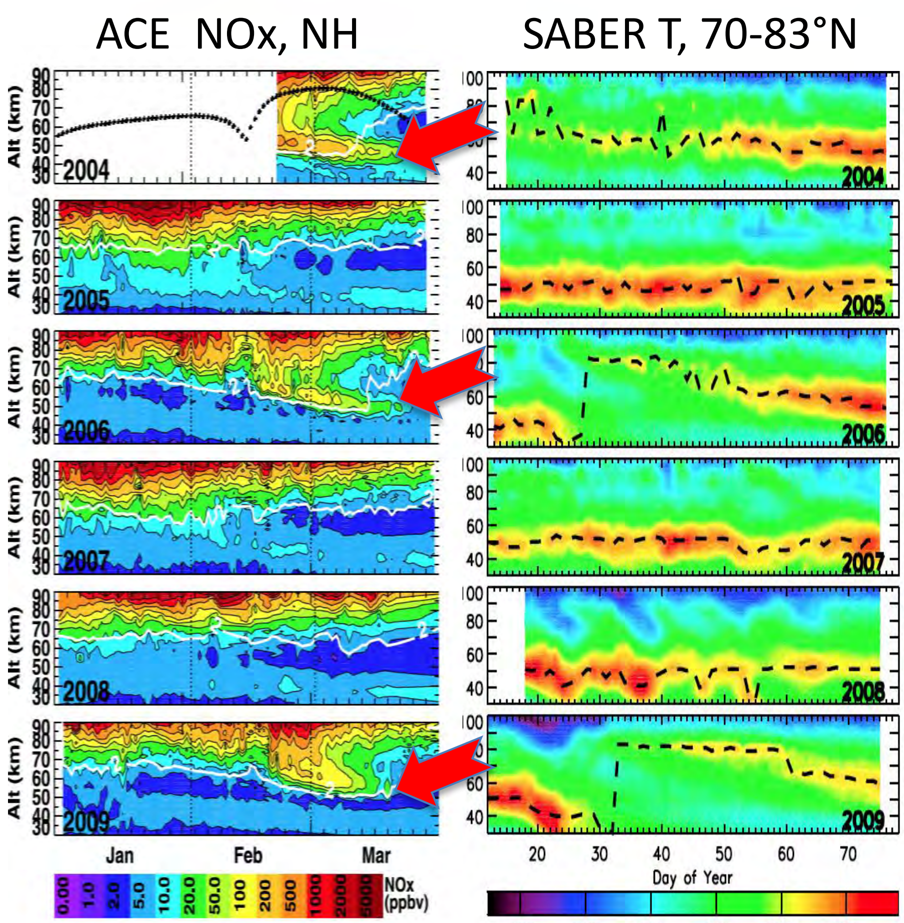
Marsh, 2011

MLT dynamics
Dominant auroral NOx source in the winter thermosphere is not connected to the middle atmosphere via TEM circulation.

NOx injection is strongly controlled by GWD scheme and MLT eddy diffusion.

Uncertainties in modeled NOx depositions and hence representation of EPP indirect effects (IE).

EPP-IE in the NH



Randall et al., 2009

Smith et al., 2009

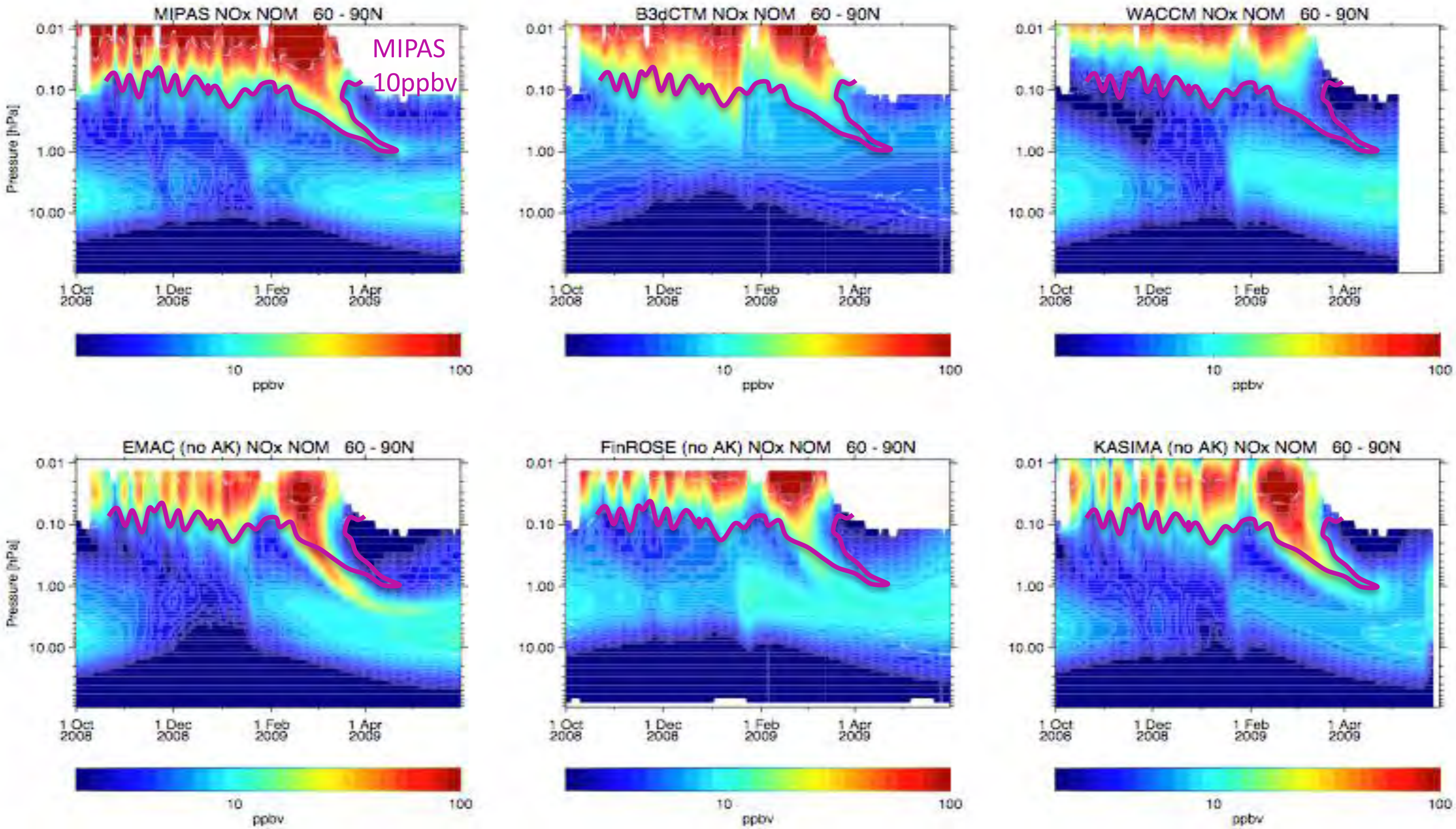
Pronounced dynamical variability in the NH related to wave activity:

Very strong EPP-IE after SSWs and associated "elevated stratopause" (ES) events.

Randall et al. 2009, Holt et al., 2013

See next talks of Anne Smith and Gloria Manney

SPARC HEPPA-II intercomparison



Models fail to reproduce NOx descent during the 2009 NH winter with SSW and associated ES event

Solar forcing: degree of understanding

"simplified" view, following the compilation of "outstanding questions" at the last HEPPA-SOLARIS workshop, Boulder 2013.

Forcing	Very good	Good	Poor	Very poor
TSI on TOA	X			
TSI on surface (SST)		X		
SSI (stratosphere)		X		
Solar protons	X			
Auroral electrons		X		
MEE/REP			X	
CR on chemistry			X	
CR on cloud formation				X

Included in CCMVal and CCMI
Included in CCMI
Not included yet (potentially to be included in CCMI Phase 2?)

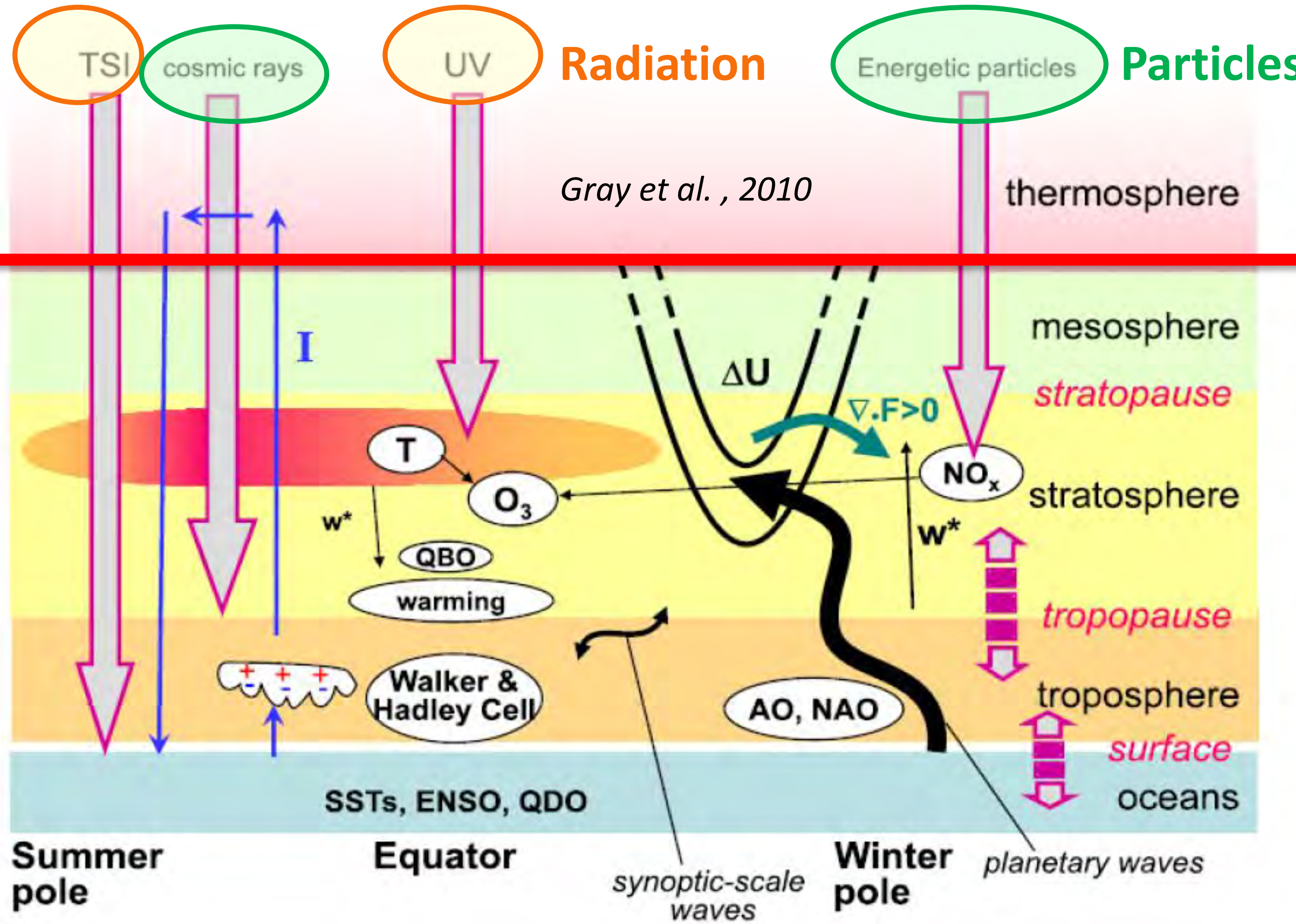
Mechanisms and climate impact

Recent modelling results

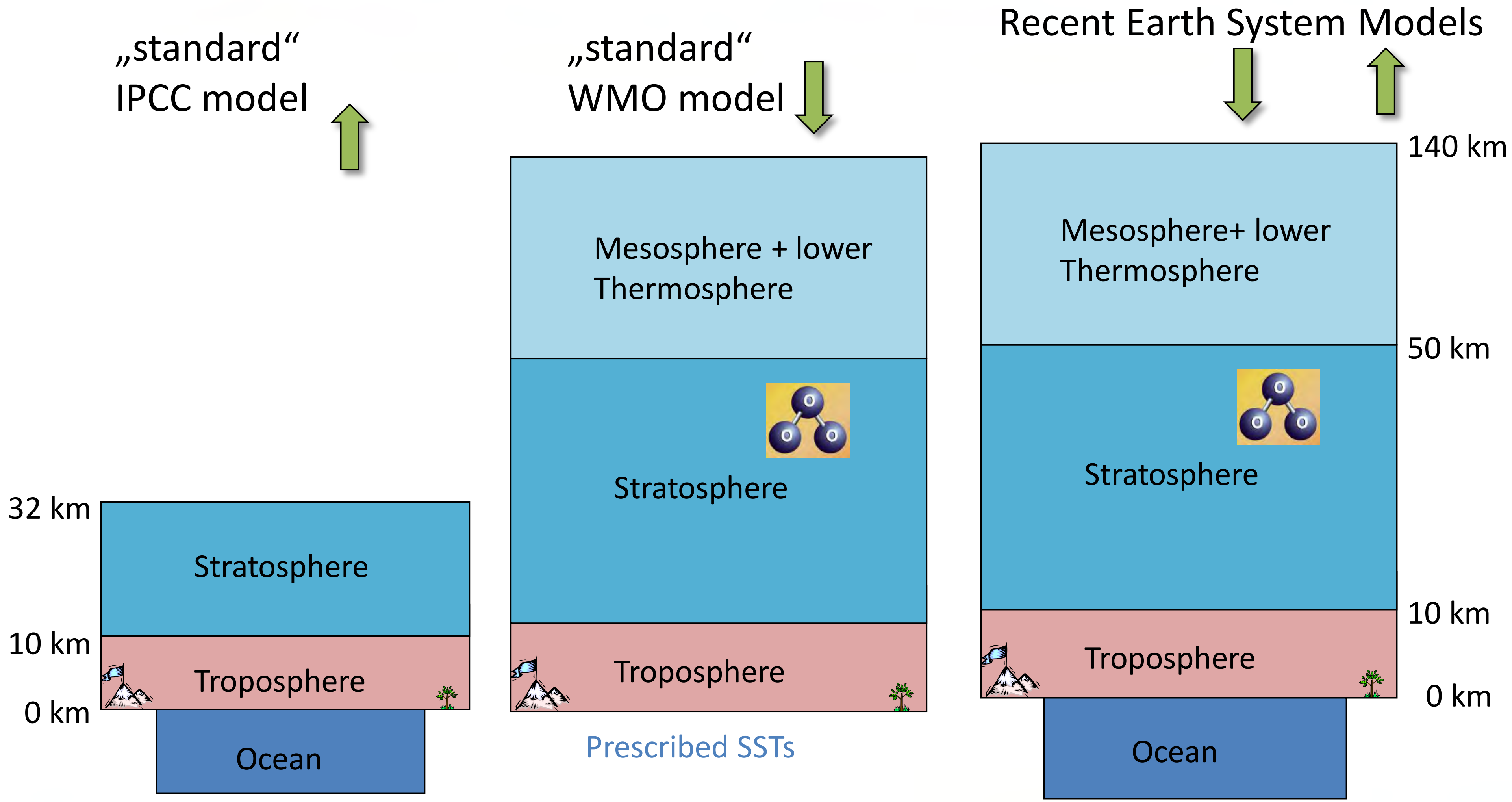
Solar forcing

Impact on dynamics & chemistry

Impact on climate



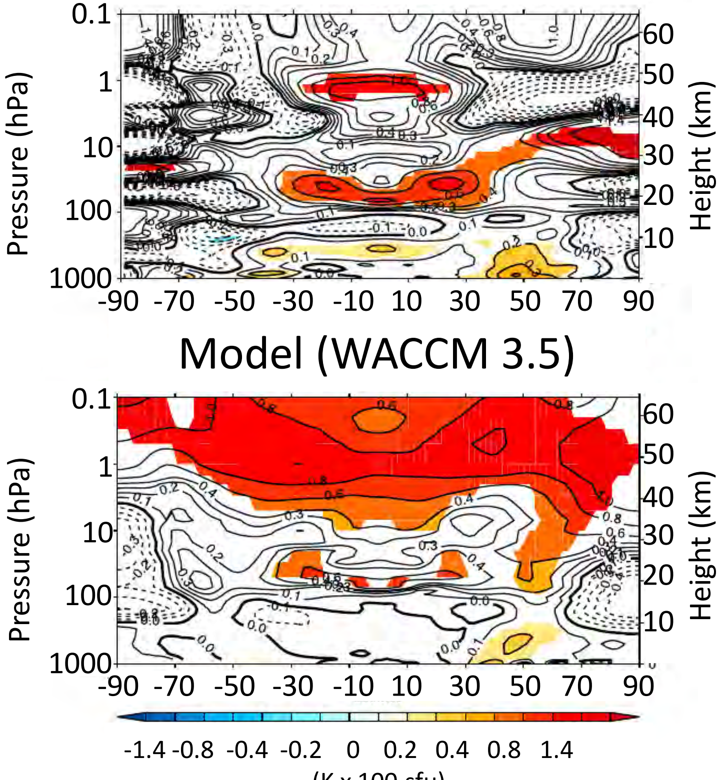
Representation in climate models



Transient CCM simulations: Stratospheric signal

Temperature (regression)

Observations (ERA-40)

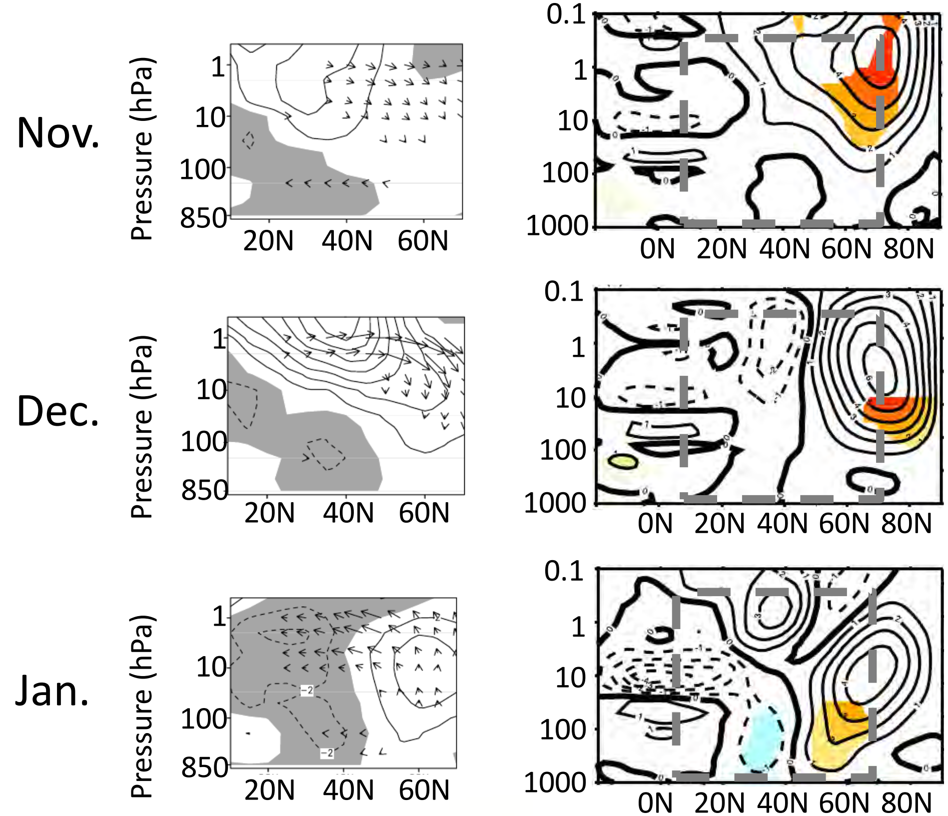


Chiodo et al. (2012)

Zonal mean zonal wind (Smax-Smin)

NCEP
Kodera & Kuroda (2002)

WACCM 3.5
Chiodo et al. (2012)



„Top-Down“ SSI induced mechanism has been reproduced in **transient CCM simulations**

ESM vs. CCM vs. Observations
North Atlantic: Smax - Smin

Winter: DJF

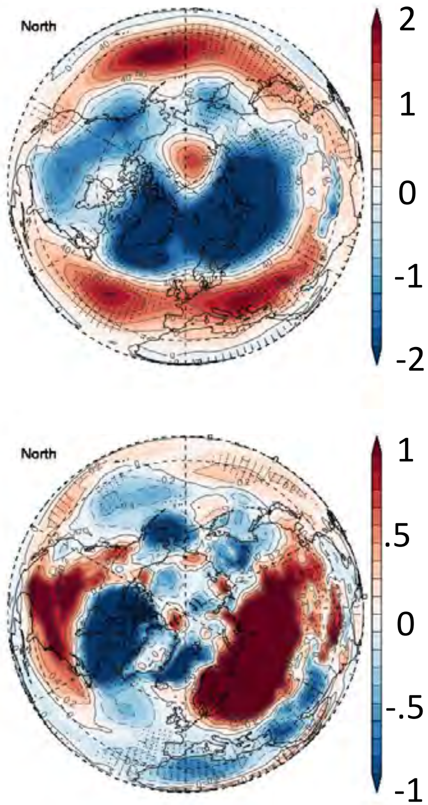
Significant **positive NAO** signal

Cooling over NE America & Mediteranean region
Warming over Europe

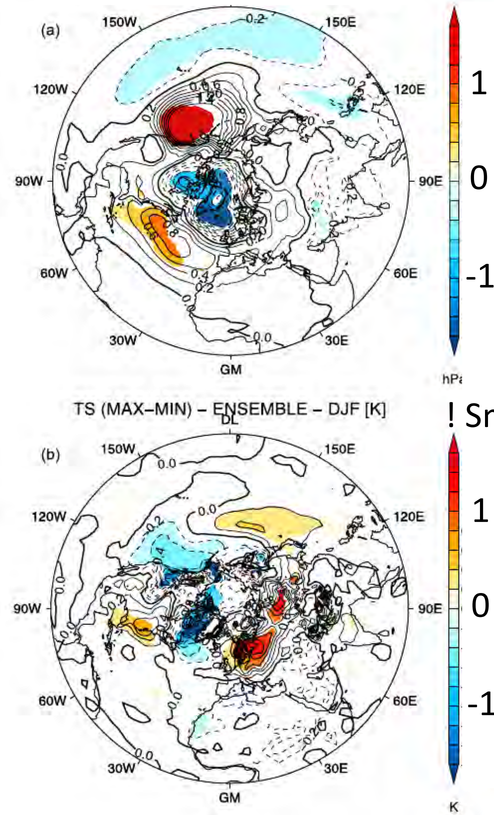
SLP (hPa)

ST (K)

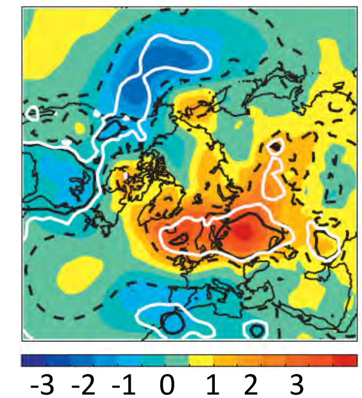
CESM (ESM)
Thieblémont et al. (2014)



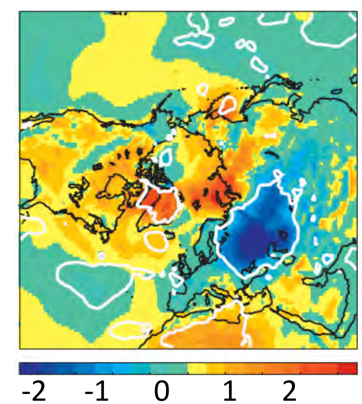
WACCM 3.5 (CCM)
Chiodo et al. (2012)



ERA40/ERA-I („Obs“)
Ineson et al. (2011)



! Smin-Smax ⇔ reversed colors !



- **Significant regional solar changes** reproduced in transient CCM simulations
- **Stronger signal with coupled ocean (ESM)** which is closer to observations

Solar Model Inter-comparison Project (SolarMIP)

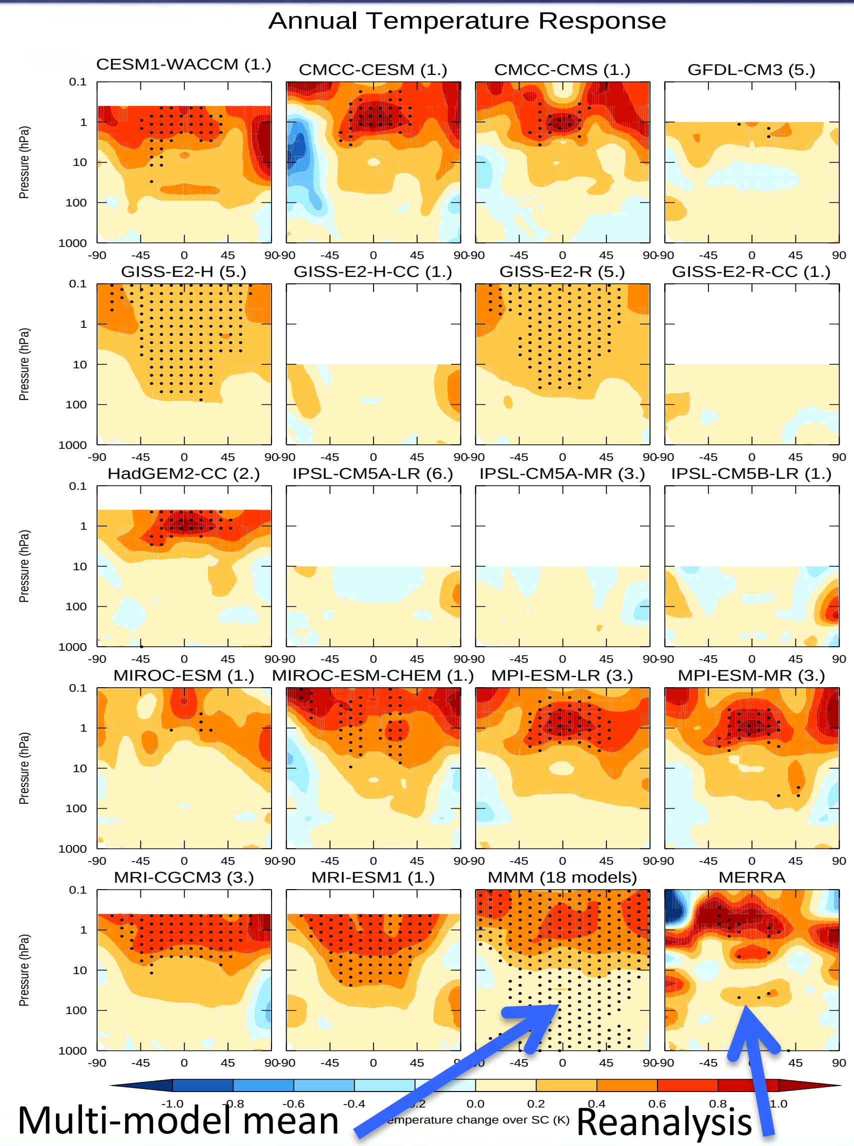
See Poster Session B

- SolarMIP compares the atmospheric and oceanic responses to the solar forcing in all the CMIP 5 models. This is done in the same way as in S-RIP.

- This figure shows the annual temperature response to a typical 11-year solar cycle, from all CMIP-5 models which resolve the stratosphere well.

- **Most models capture the observed warming at the stratopause, but few models capture the warming in the tropical lower stratosphere.**
    - Why not?

(Mitchell, Misios, Gray, Tourpali, Matthes + more)

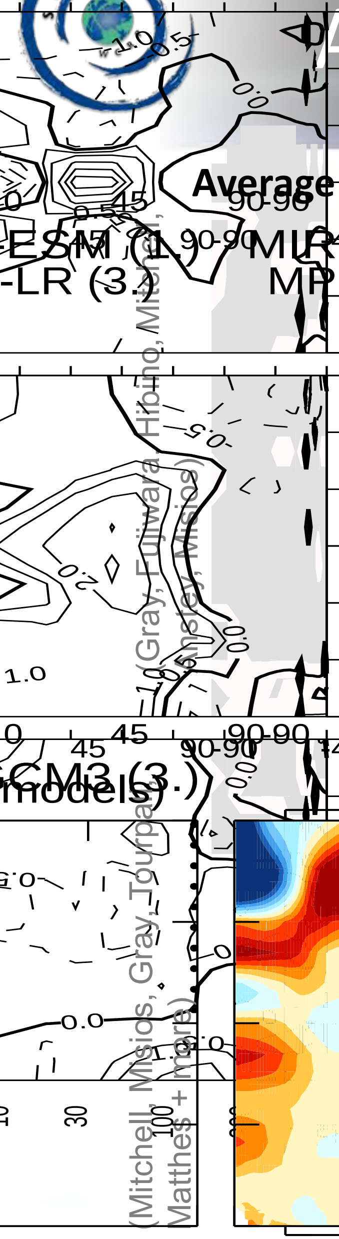


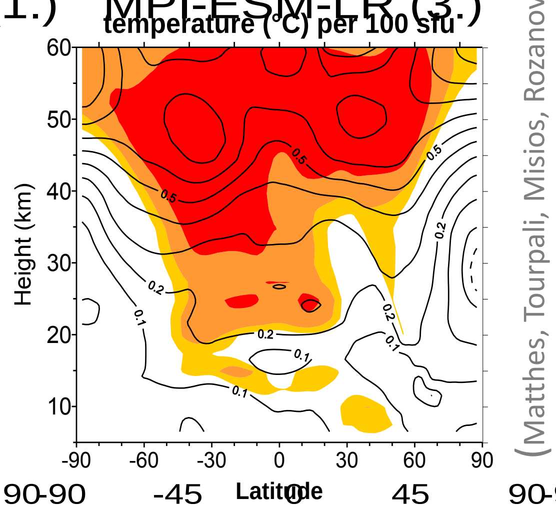
Annual Mean Solar Temperature Signal

Average 4 Reanalyses (S-RIP)

CCMVal2 Multi-Model Mean

MIROC-ESM-CHEM (1.) MPI-ESM-LR (3.) MPI-ESM-MR (3.)

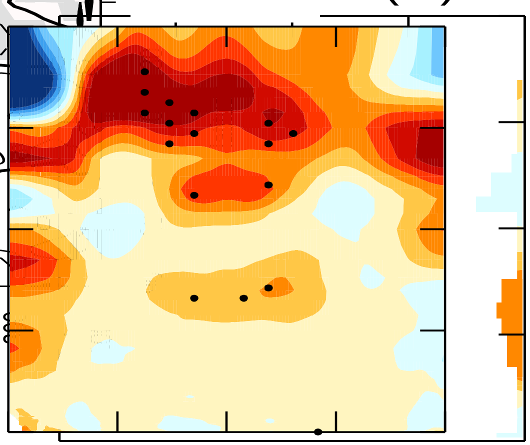


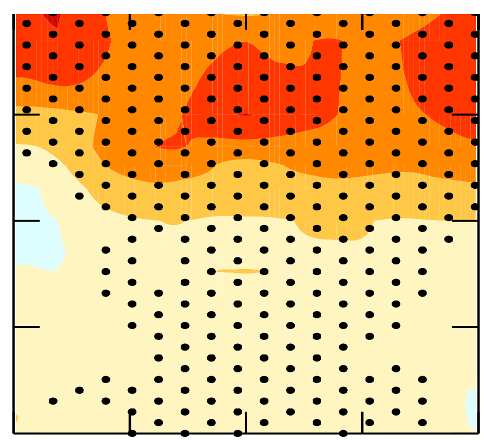


CCMVal2 and CMIP5 models capture the observed warming at the stratopause but…

MERRA

SolarMIP Multi-Model Mean

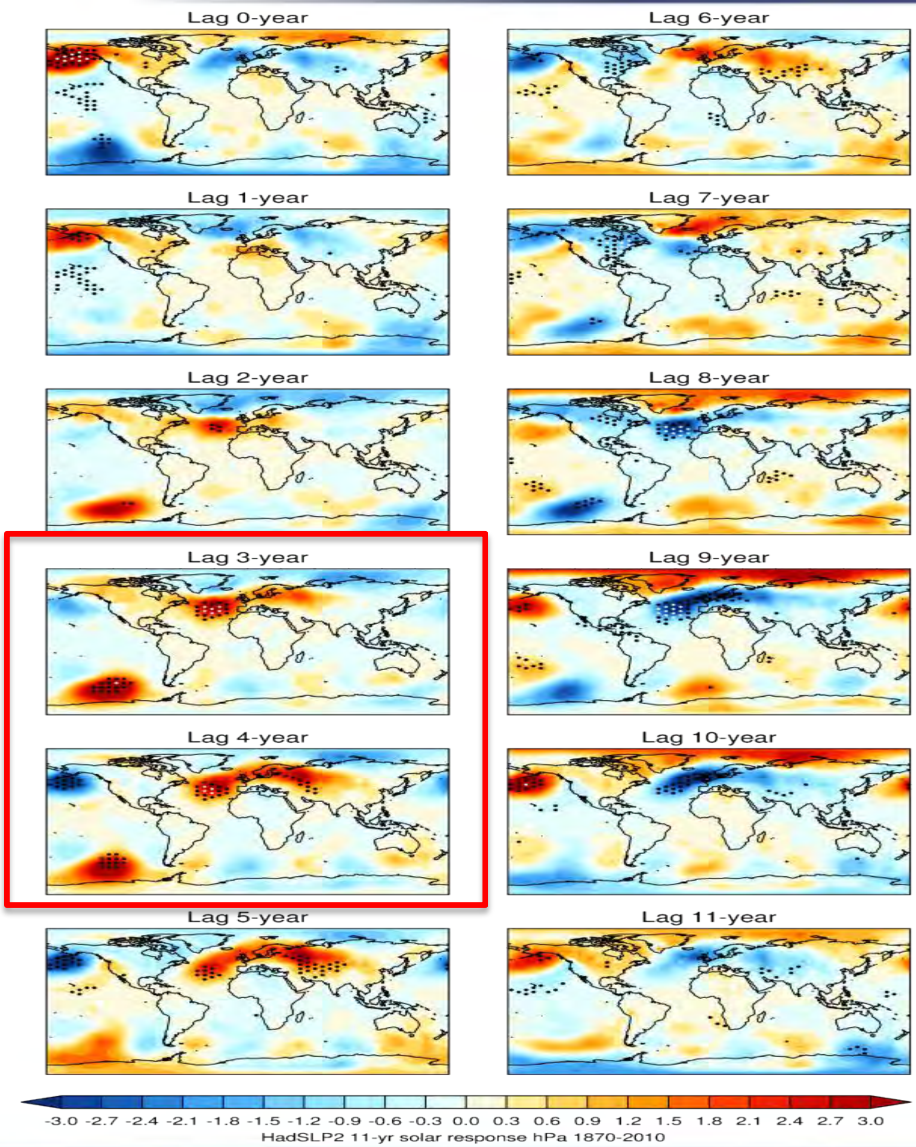




the secondary warming in the tropical lower stratosphere is only reproduced in CCMVal2 models

⇒ why?
possibly interactive chemistry…

Observed MSLP Smax –Smin signal



Estimates from a multiple linear Regression Analysis Observed Mean Sea Level Pressure 1870-2010 HadSLP2 dataset

Gray et al. JGR Dec 2013

Regression included solar, volcanic ENSO, QBO indices plus linear trend.

Plot shows different lag times i.e. surface response lags the solar index.

positive NAO-like
response at 3-4 years, suggests a solar influence over Europe.

white (black) dots: 99% (95%) stat. significance

Solar Model Inter-comparison Project (SolarMIP)

See Poster Session B

- The global surface response is dominated by the tropics.
- **In a global perspective, solar signals at the surface lag the signals in the stratosphere by about 1 to 2 years.**
- This is also true for the troposphere, and ocean responses (not shown).

(Misios, Mitchell, Gray, Tourpali, Matthes + more)

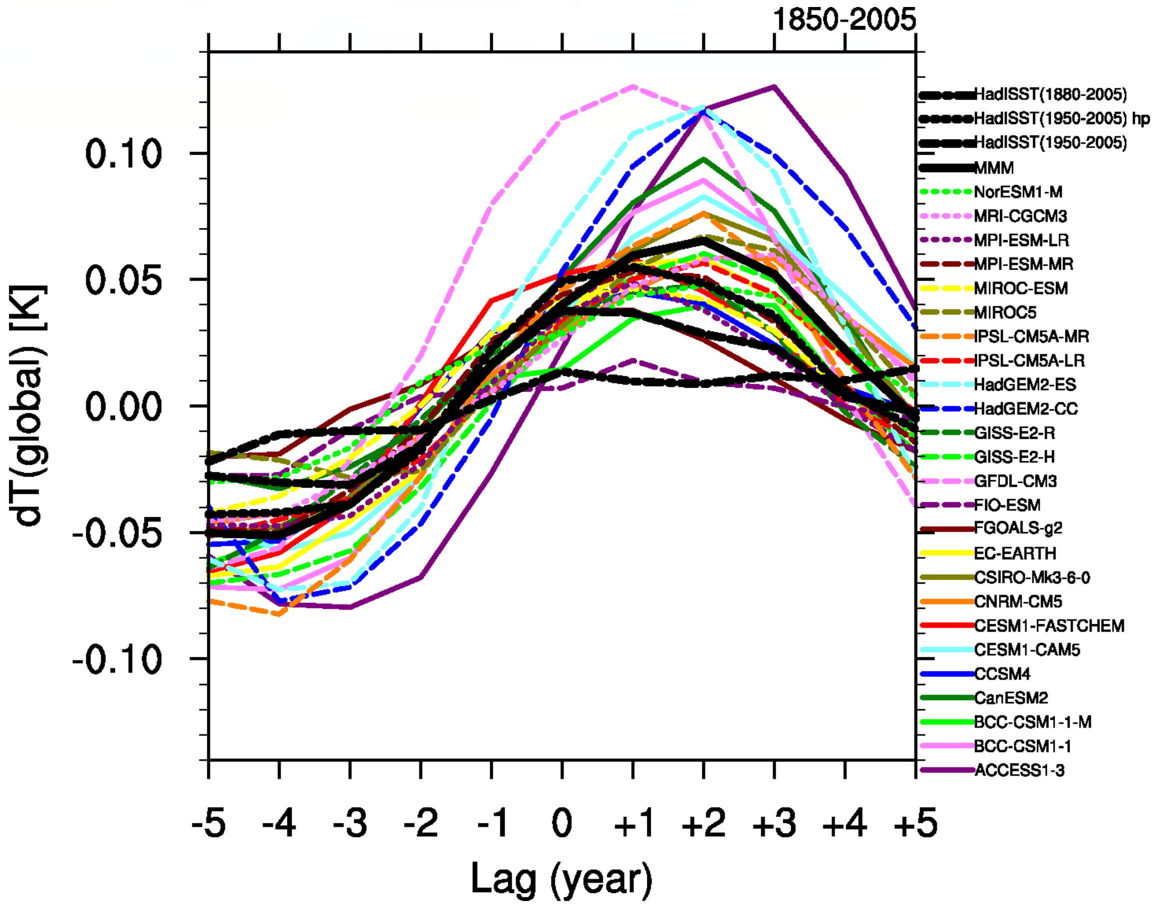
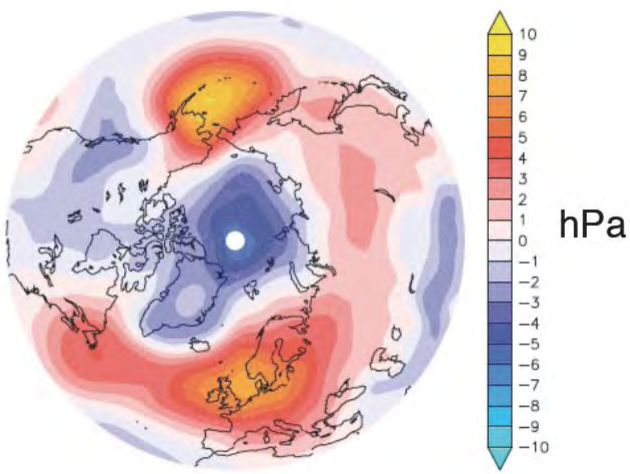


Figure Lagged global mean surface air temperature response from solar min to max for all models. The observed signals are from the HadISST reconstruction.

Surface EPP response: recent model results

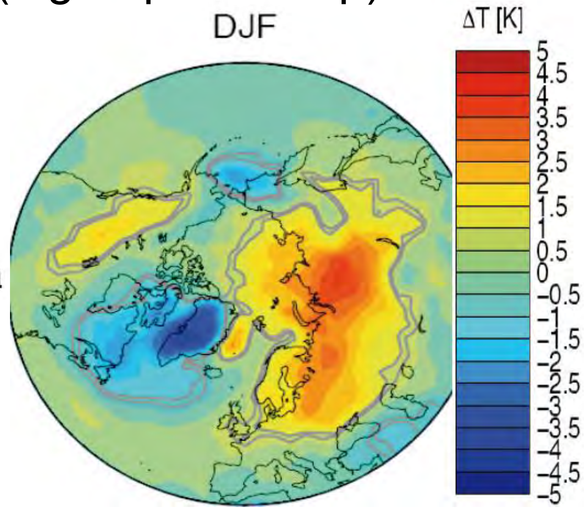
See Poster Session D

EMAC, DJF surface press. changes (EPP-no EPP), no SSW years



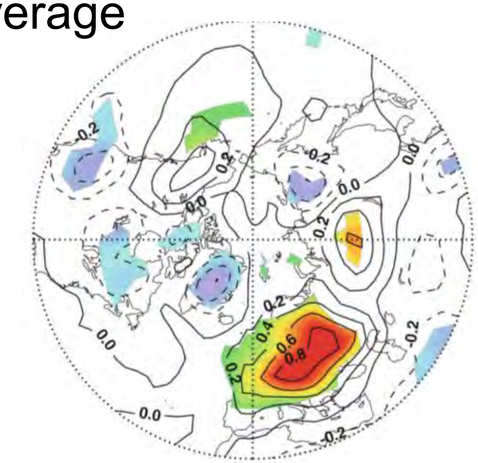
Baumgaertner et al., 2010

NCEP reanlysis, DJF surface T changes (high Ap – low Ap)



Seppälä et al., 2009

SOCOL, surface temp. changes (EPP-no EPP), 1960-2010 annual average



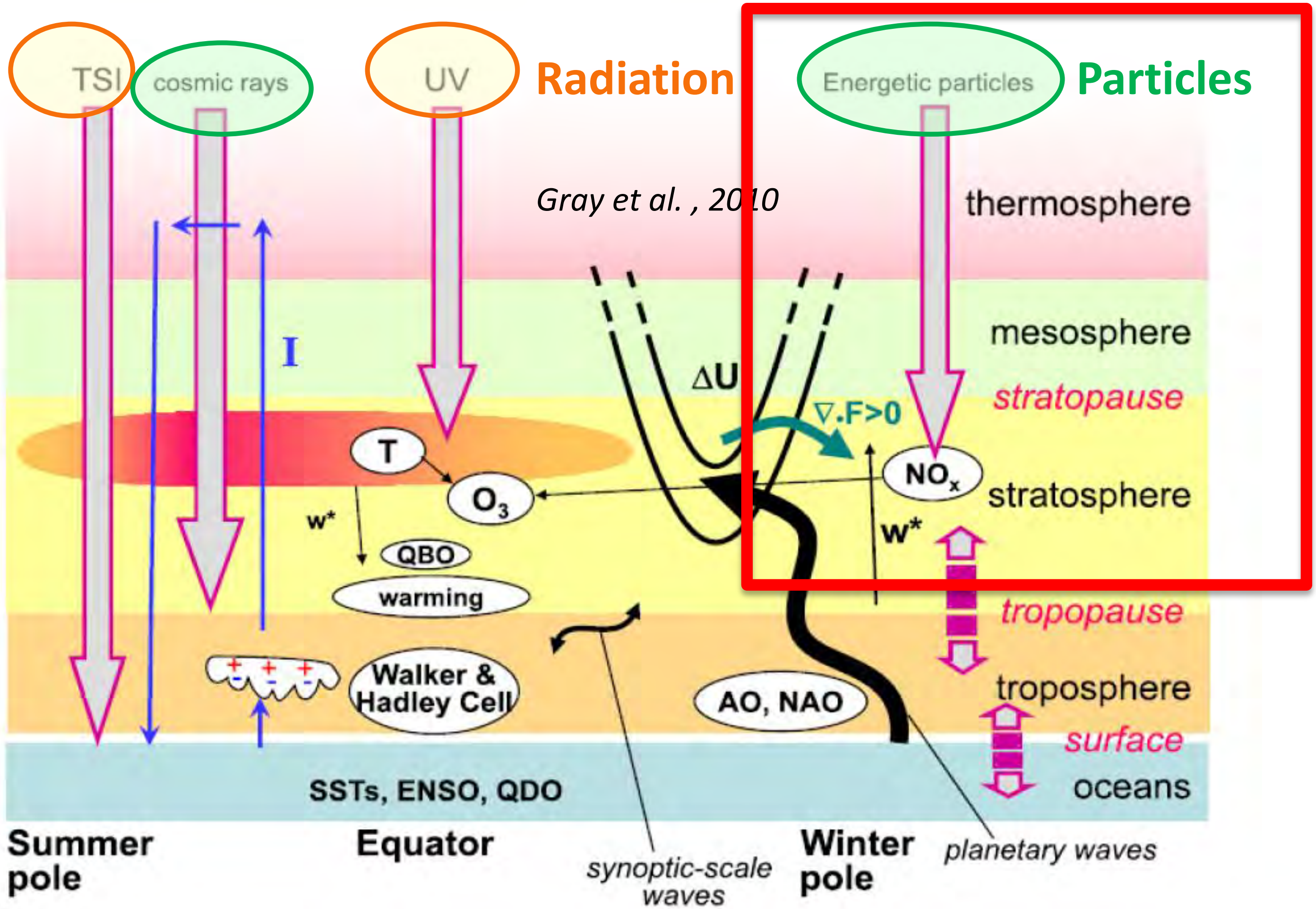
Rozanov et al., 2012

- A stronger Northern Hemisphere vortex (more positive Northern Annular Mode index) for strong geomagnetic activity.
- Mechanism still not fully understood.

Particle effects

Recent observational efforts

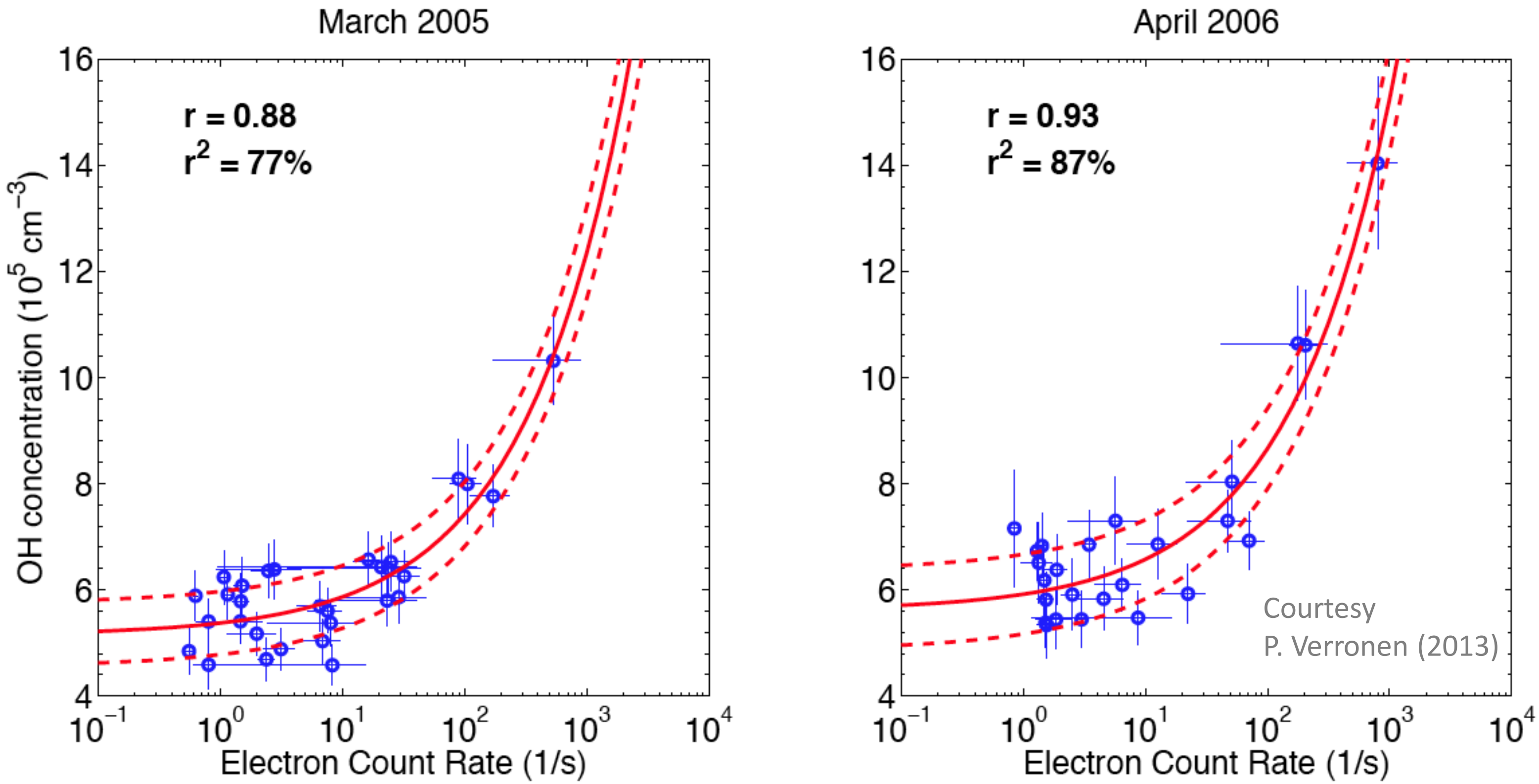
Solar forcing → Impact on dynamics & chemistry → Impact on climate



Characterization of EEP direct effects

See Poster Session D

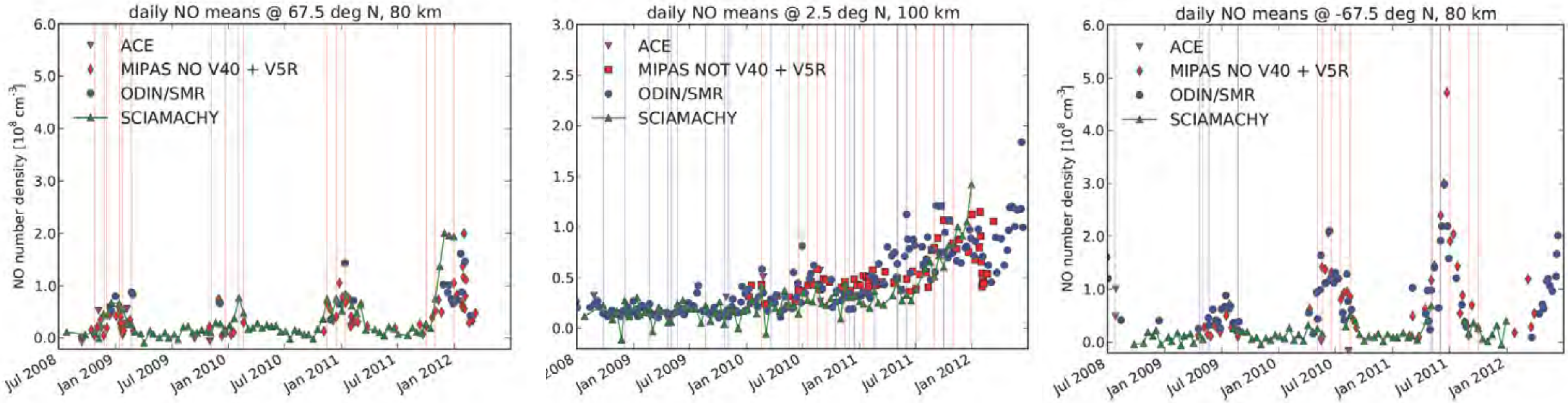
MLS OH (~75 km) versus MEPED/POES electron counts



OH as indicator for direct EEP response above ~70 km

HEPPA II: MLT NO comparisons

Courtesy: S. Bender (in preparation)

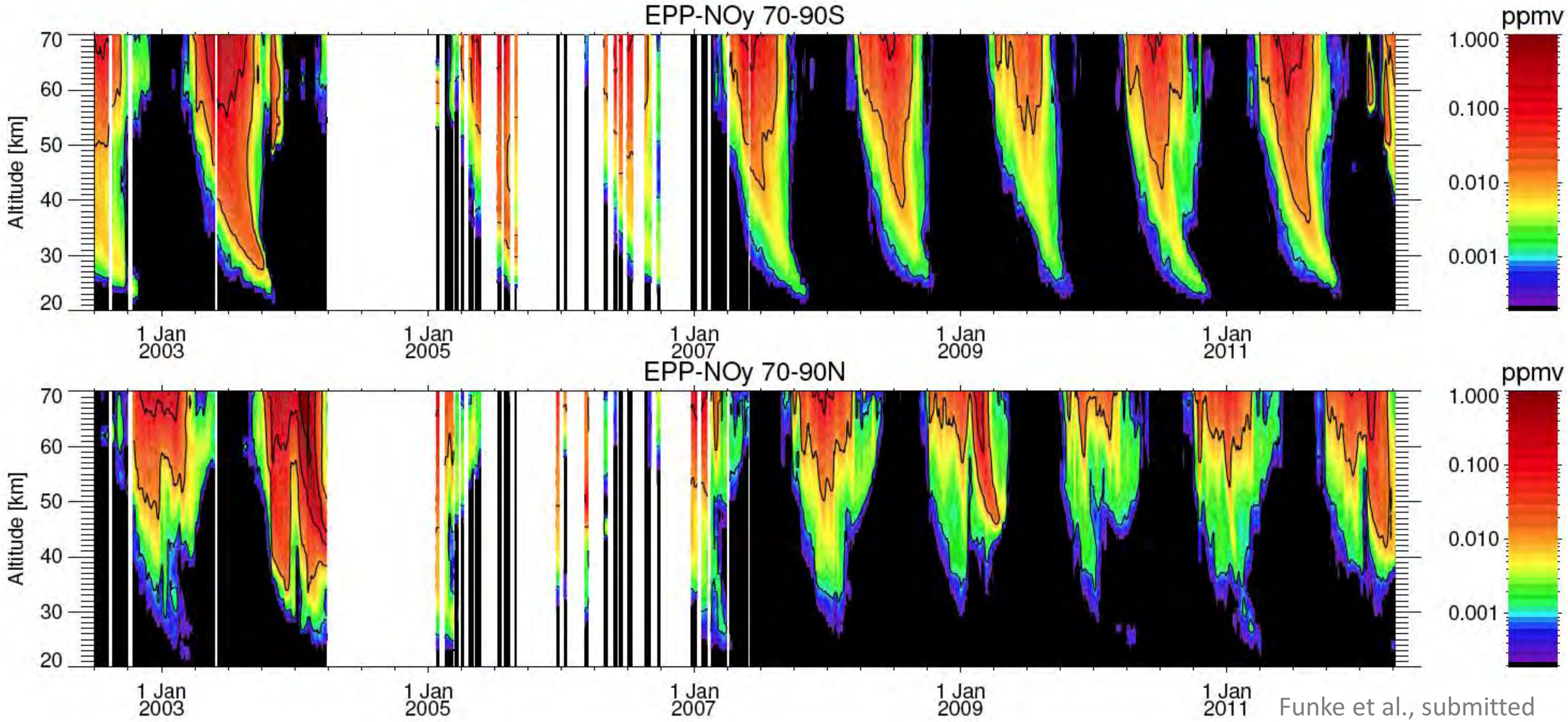


NH polar | tropics | SH polar

Good overall agreement on annual and inter-annual scales
(despite large short-term fluctuations caused by instrument precision, sampling, and geomagnetic variability)

Recent observations provide consistent picture of MLT NO which allows to constrain the representation of EPP source region in models

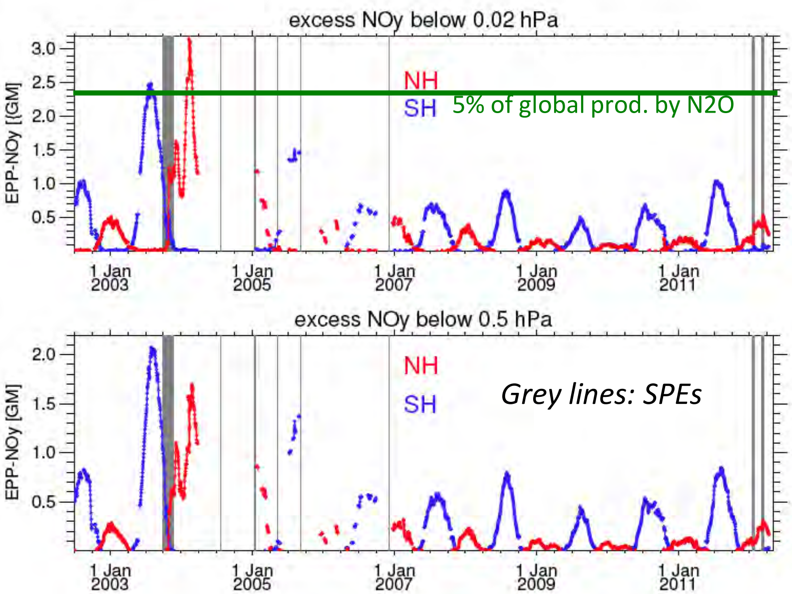
The MIPAS decadal EPP-NOy record

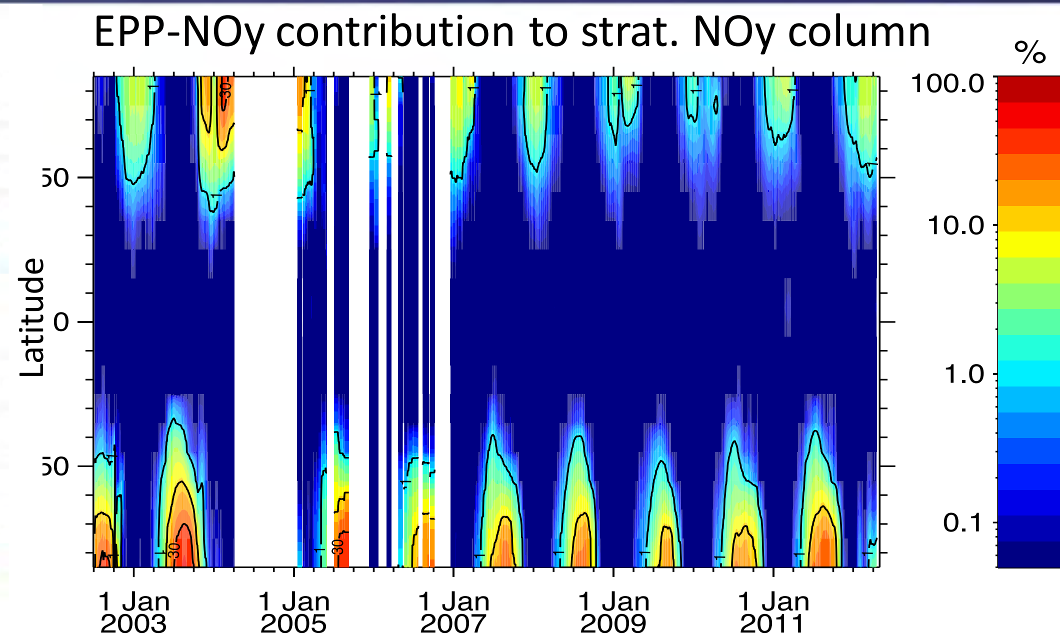


Funke et al., submitted

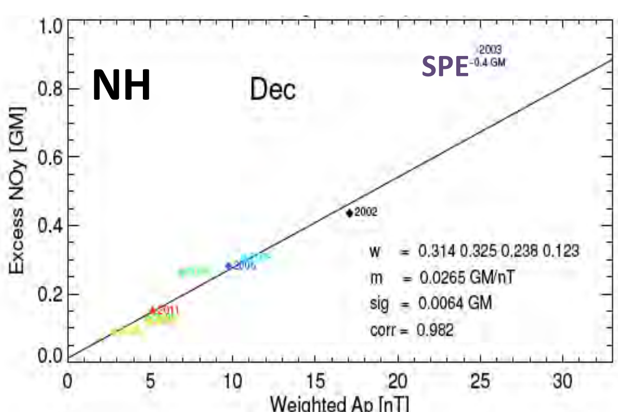
- Solar cycle variations driven by geomagnetic activity
- NH: less stratospheric EPP-NOy and more pronounced dynamical variability
- EPP-NOy down to ~25 km

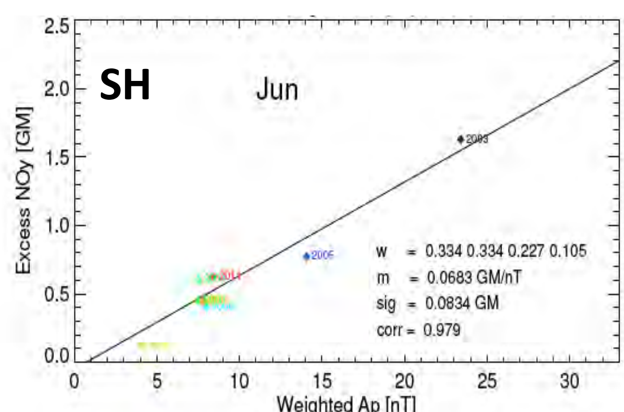
The MIPAS decadal EPP-NOy record





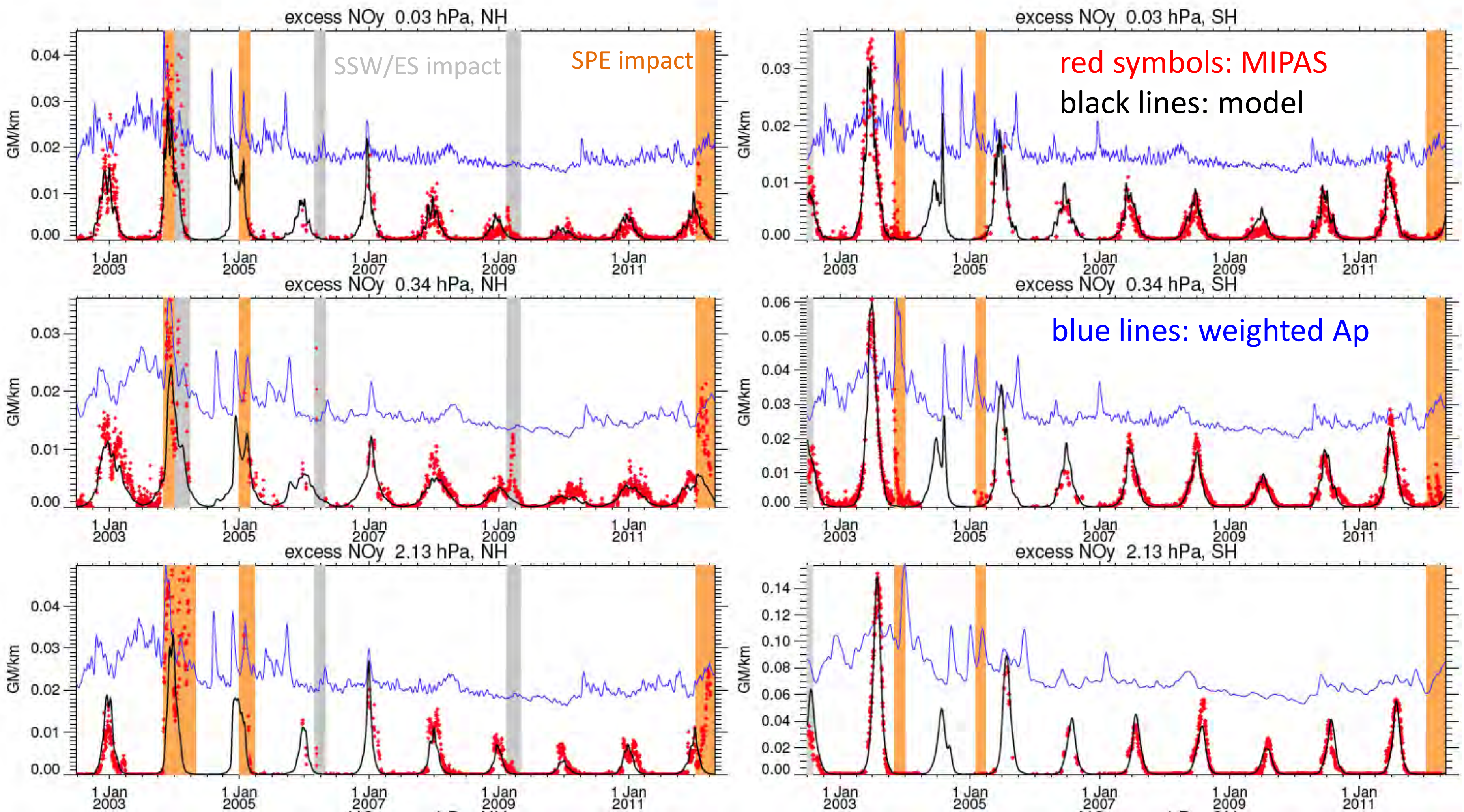
Up to 40% of strat. NOy column and 10% of global production by N_2O oxidation





High Ap correlation (except SSW/ES and SPEs)

Empirical model of EPP-NOy amounts



can be used in CCMs to constrain EPP-IE

Conclusions/Summary

- **Solar forcings: remaining issues** with SSI and particle flux observations, CR-cloud coupling still uncertain. Description of vertical coupling (EPP-IE) in the USM is challenging.

- **Interactive chemistry & ocean/atmosphere coupling** show considerable progress for studying the impact of solar variability on climate.

- **Recent transient simulations** can simulate solar signal (radiative and particles) in **reasonable agreement** with observations.

- ESMs offer the opportunity to perform **sensitivity experiments** to study **interactions between solar variability and other forcing factors**, i.e. Solar-QBO relation, North Atlantic air/sea coupling, tropical Pacific signal and ENSO aliasing.

- Progress in **constraining mesospheric and stratospheric EPP impact** by recent OH and NOy **observations**.