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Solar forcing of the Earth climate: the role of the middle atmosphere-troposphere coupling

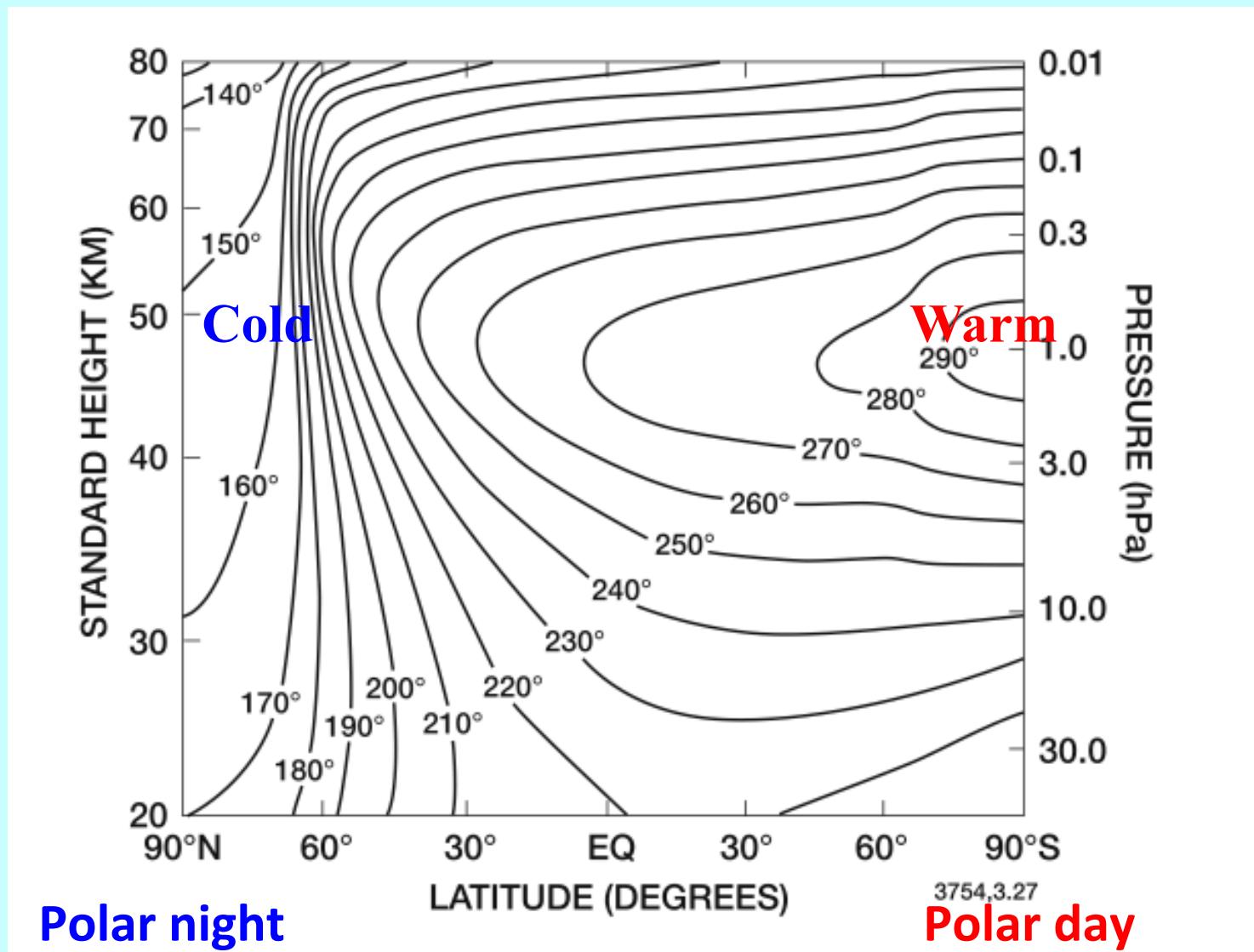
Alain Hauchecorne
LATMOS, UVSQ, CNRS



Presentation outline

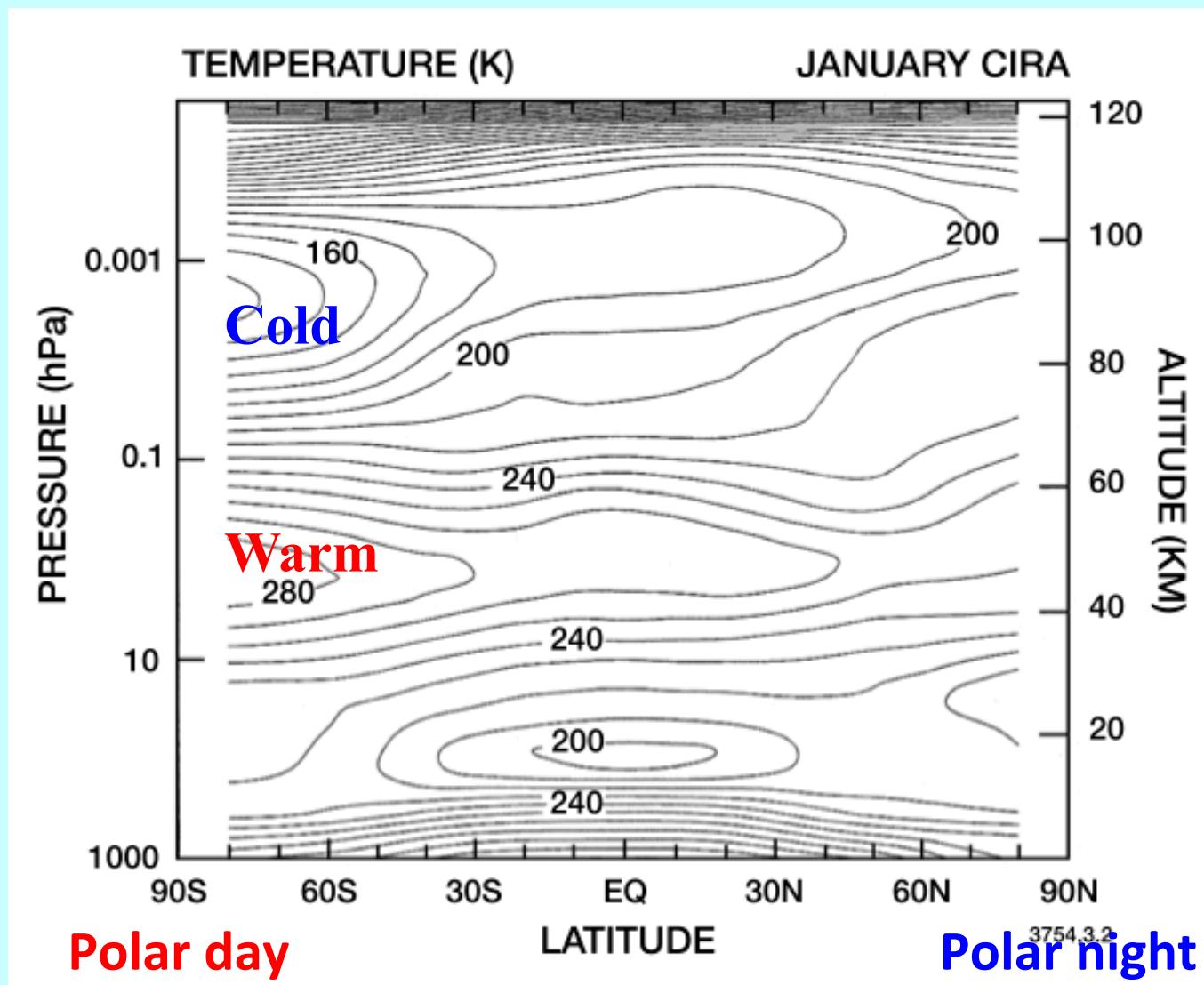
- **Fundamentals on middle atmosphere dynamics**
- **Solar variability**
- **Impact of particle precipitations**
- **Role of solar UV variability and stratospheric ozone**
- **Stratosphere-troposphere coupling and impact of 11-year solar cycle on regional climate**

Radiative equilibrium temperature



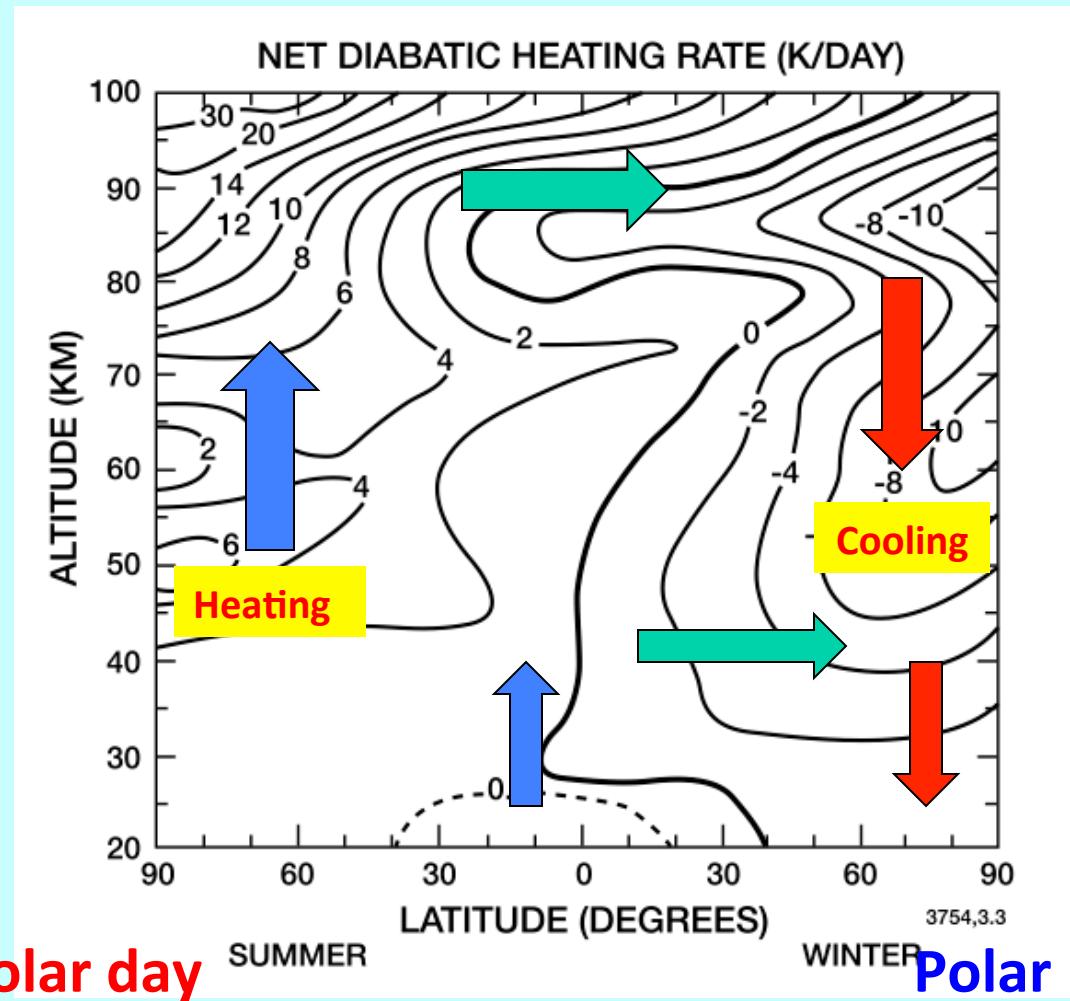
Brasseur and Solomon, 2005; computed by Fels, 1985

Observed zonal averaged temperature



Net diabatic heating and residual circulation

Diabatic heating (cooling) → vertical ascent (descent) of air
Continuity equation → meridional wind



Gravity wave filtering by zonal wind

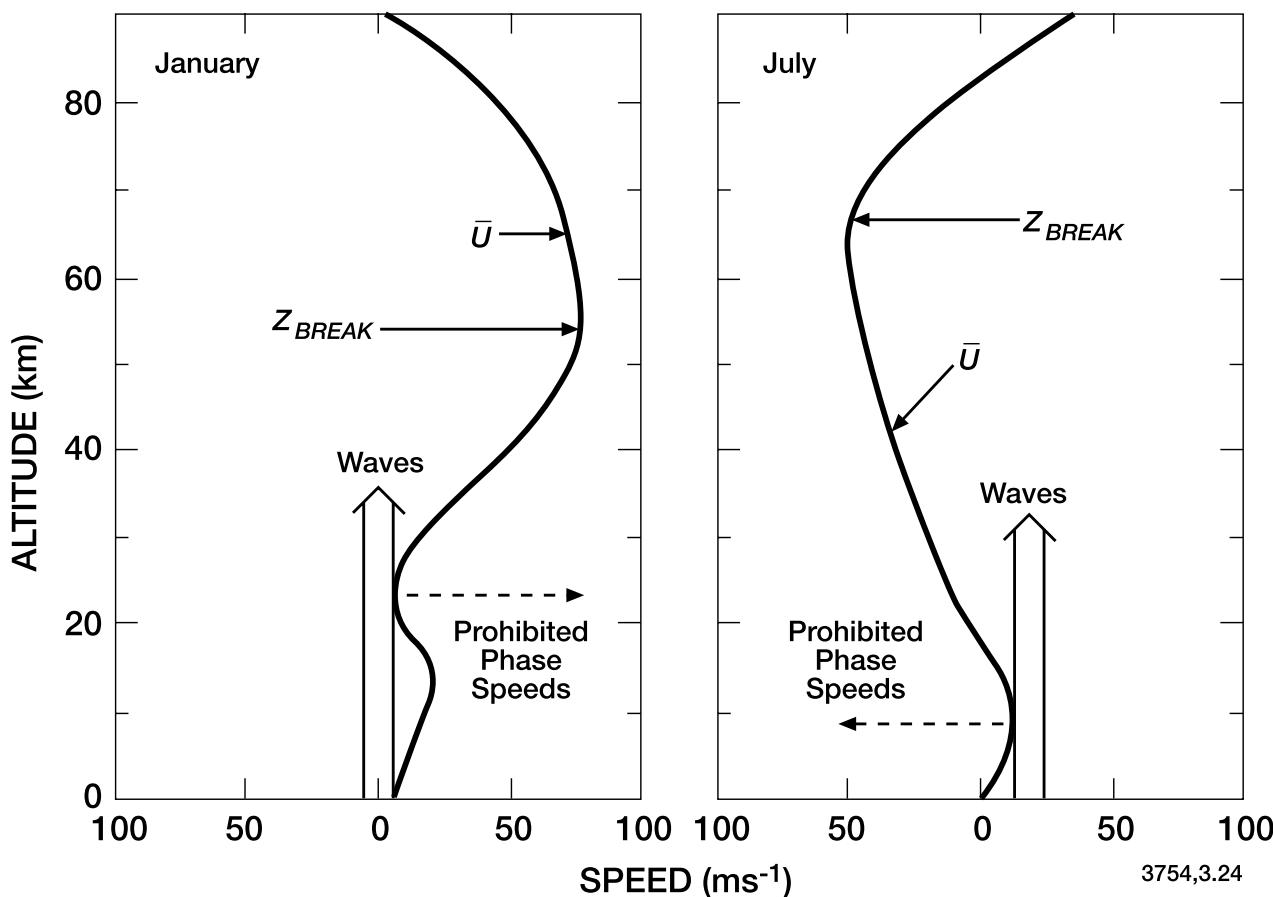
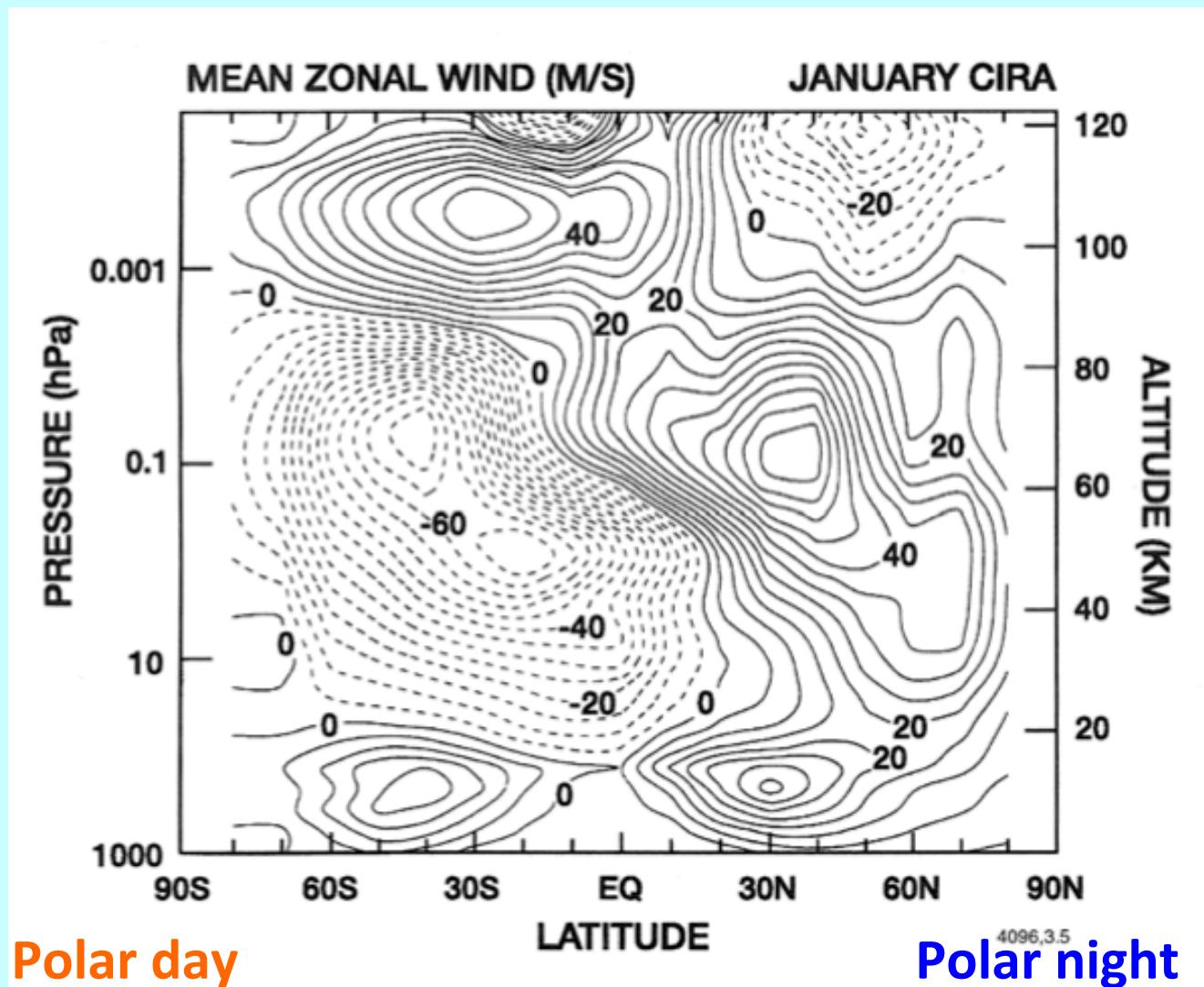
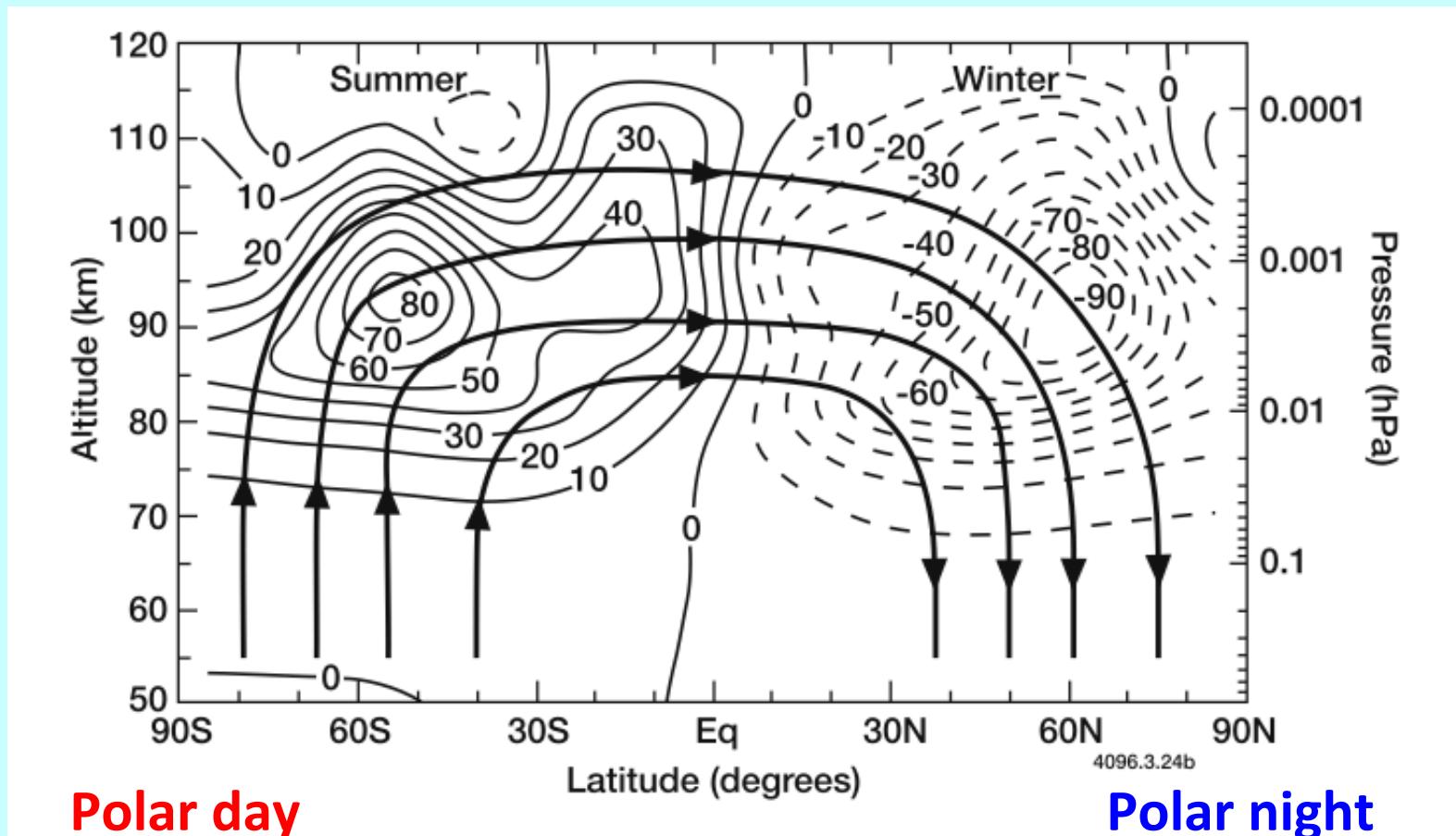


Figure 3.11. Approximate altitude profiles of the mean zonal winds in winter (left panel) and summer (right panel). The permitted phase speeds for the propagation of gravity waves and their breaking levels are also shown. Adapted from Lindzen (1981).

Zonal wind



Schematic mesospheric circulation



Solar-atmosphere link: possible mechanisms

Photochemistry effect

- Production of O_3 by solar UV flux

Radiative effect

- Bottom-up: Heating of the surface by total solar irradiance
- Top-down: Heating of the stratosphere due to solar UV absorption by O_3
+ stratosphere-troposphere dynamic coupling

Particle precipitations

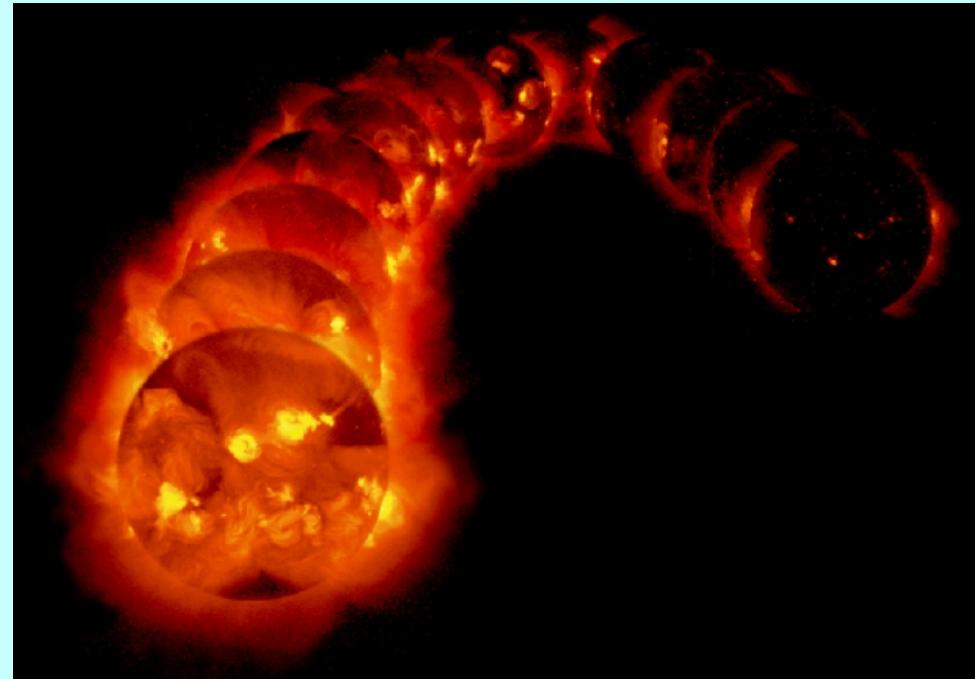
- Solar proton precipitations in auroral zone: NO_x and HO_x
- Cosmic rays modulation by solar wind: condensation
nuclei, clouds, stratospheric chemistry ?

Sun images

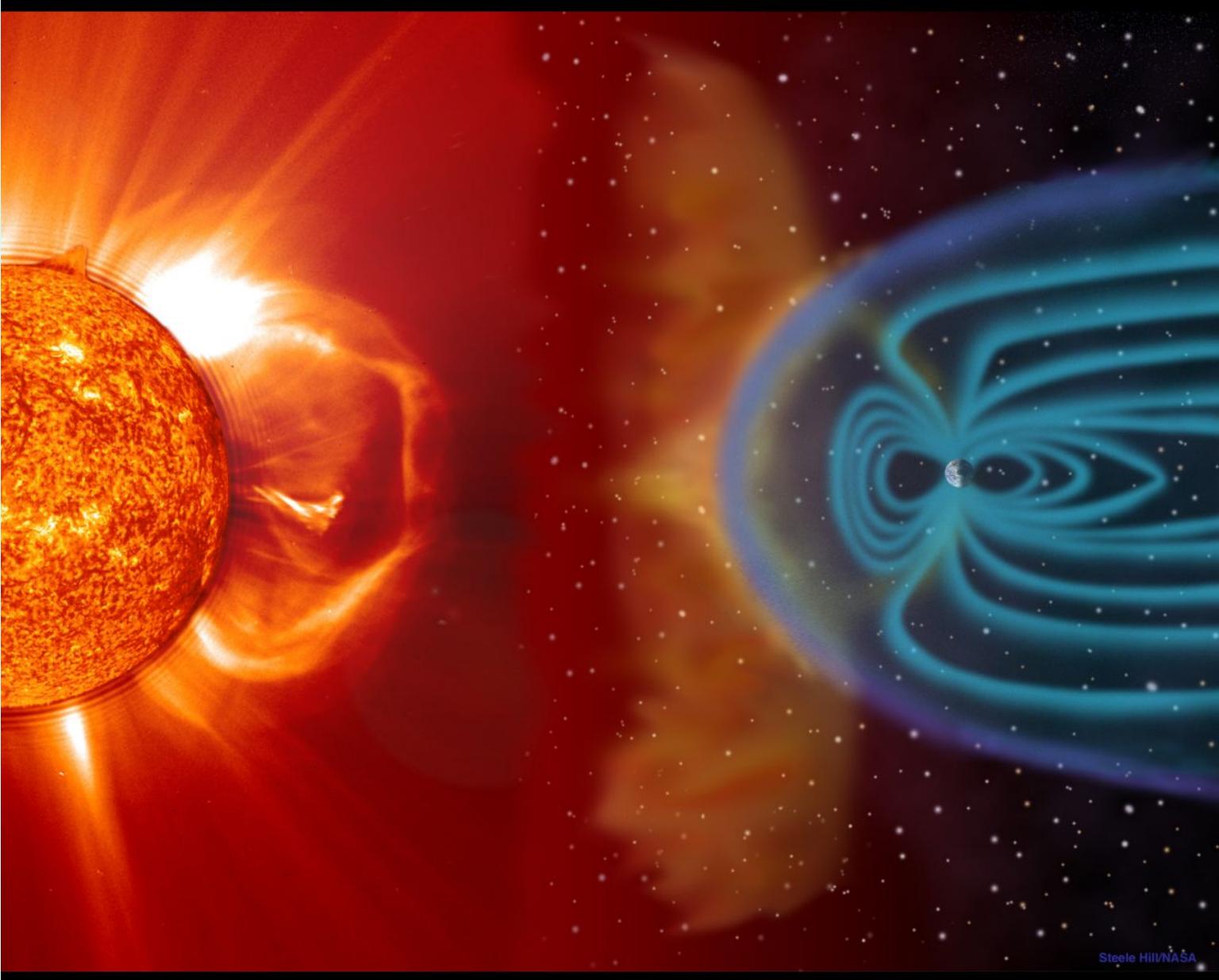
Visible (400 to 600 nm)



X Ray (0.1 to 10 nm)



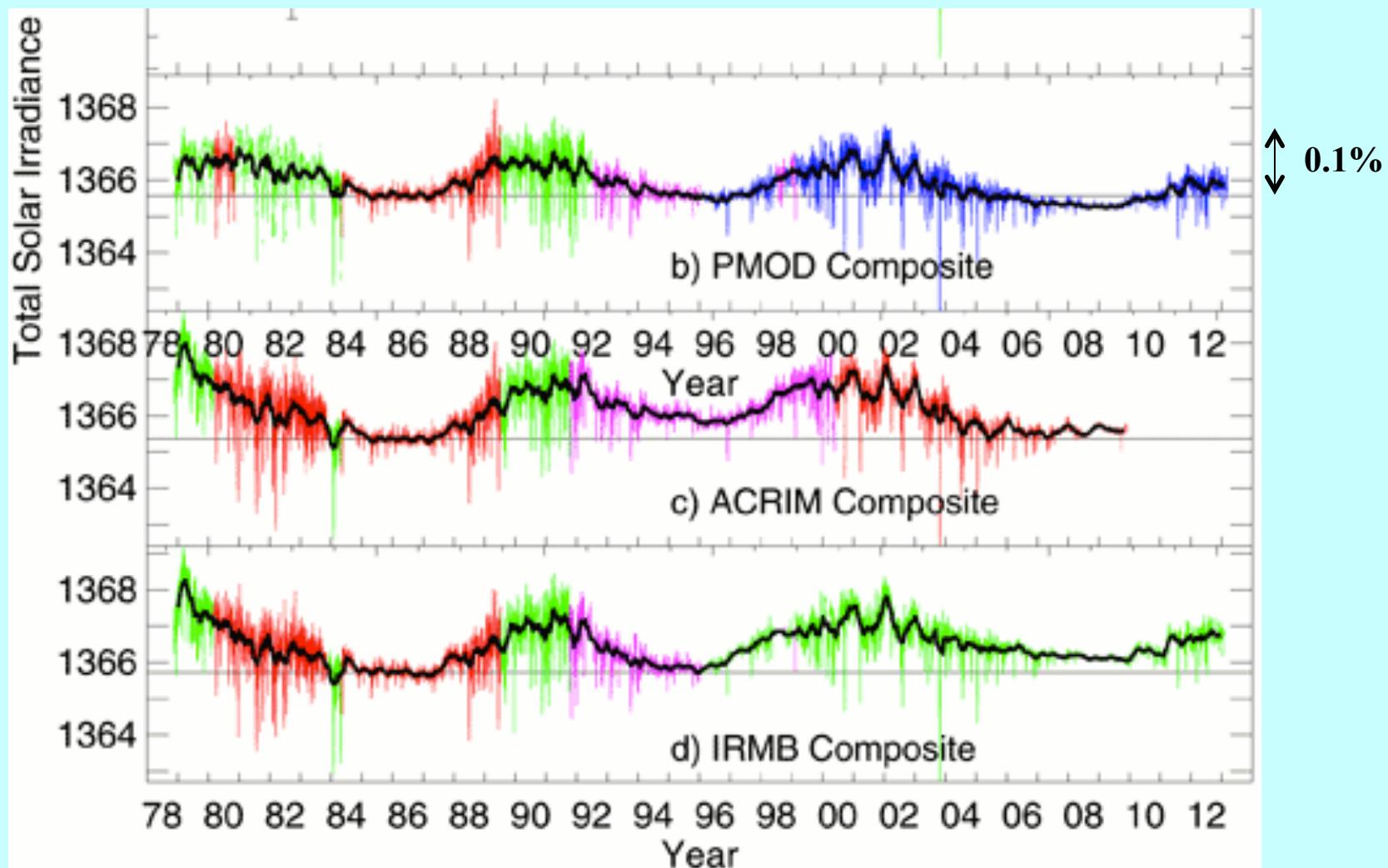
Coronal mass ejection



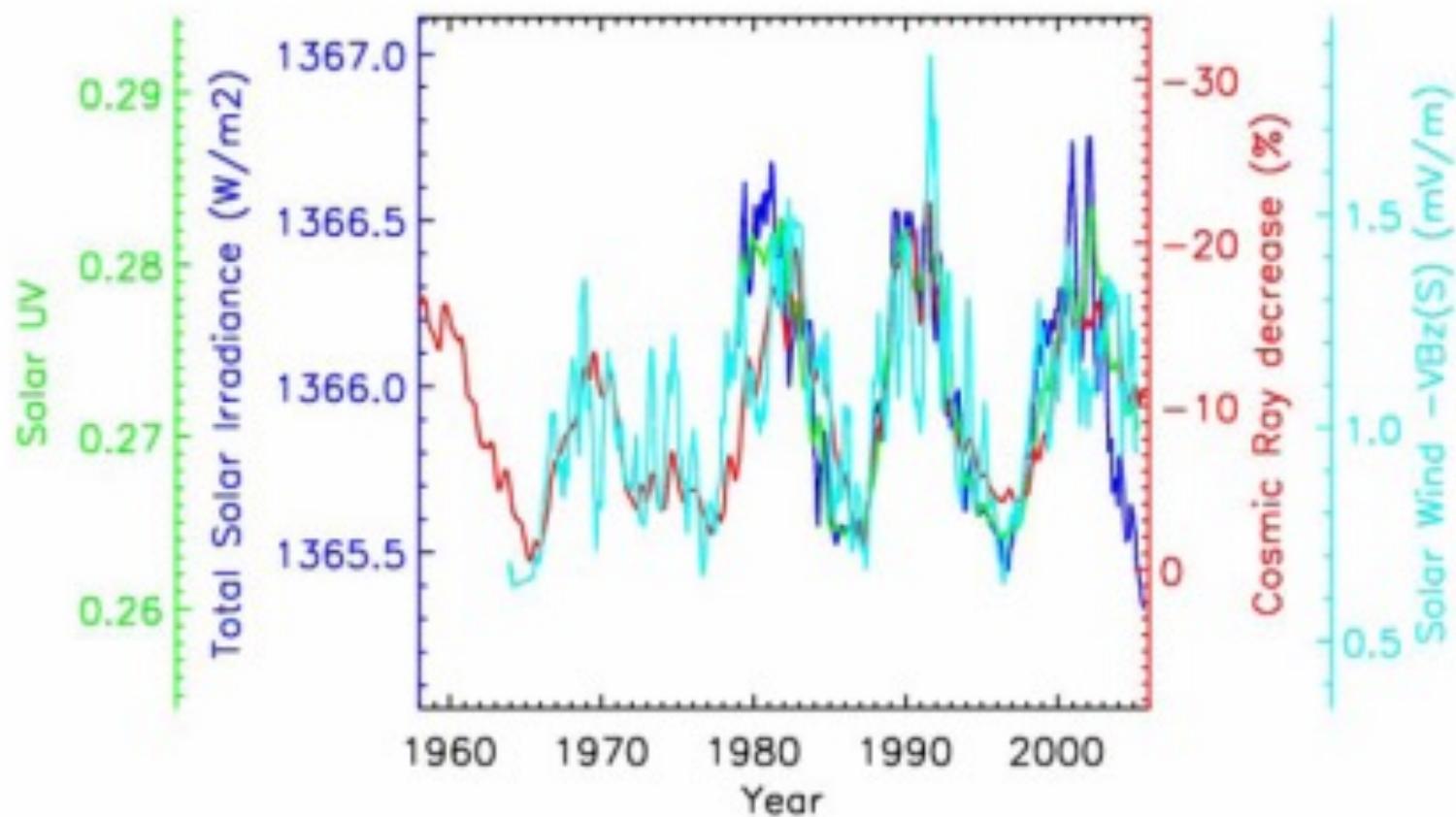
Steele Hill/NASA



Total Solar Irradiance



Solar vectors influencing Earth's Environment: TSI (blue), UV component (green), Cosmic rays (red), Solar wind (light blue).



Adapted from J. Haigh et al., 2005

Energy arriving at the top of Earth's Atmosphere.

UV ~5-10%

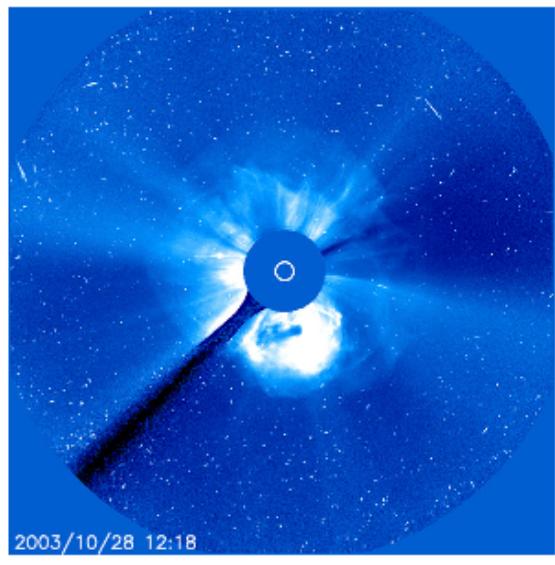
• Total Solar Irradiance	1360 W/m ²
• TSI over Solar Cycle (0.1%)	1.36 W/m ²
• Solar Wind (10 ³ eV)	~10 ⁻⁴ W/m ²
• Precipitating Particles (10 ⁴ eV)	~10 ⁻⁵ W/m ²
• Galactic Cosmic Rays (10 ⁸ eV)	~10 ⁻⁵ W/m ²

Solar Variability requires **AMPLIFICATION** to affect climate.

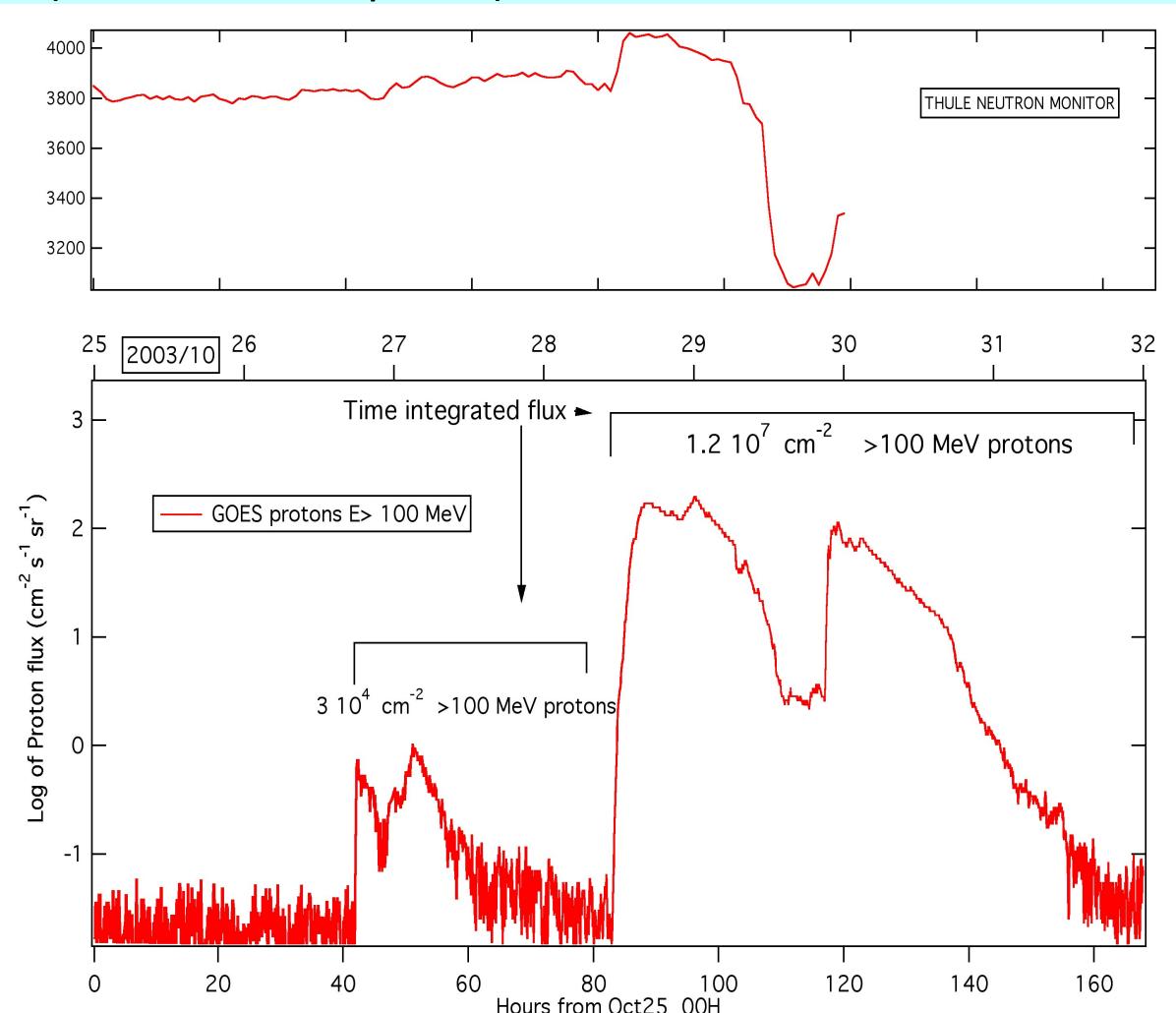
Solar Protons Observed by GOES 8

Measured in several energy intervals:

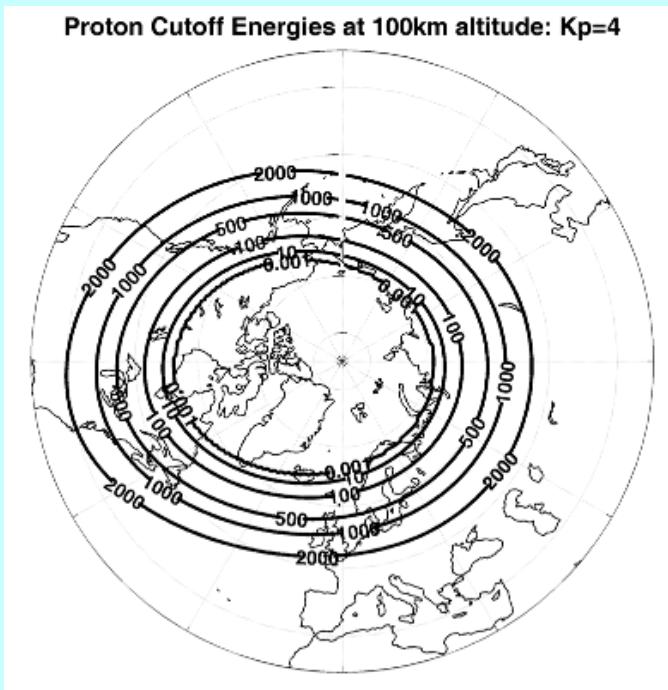
- > 1 MeV → 87 km (upper mesosphere)
- > 100 MeV → 33 km (middle stratosphere)



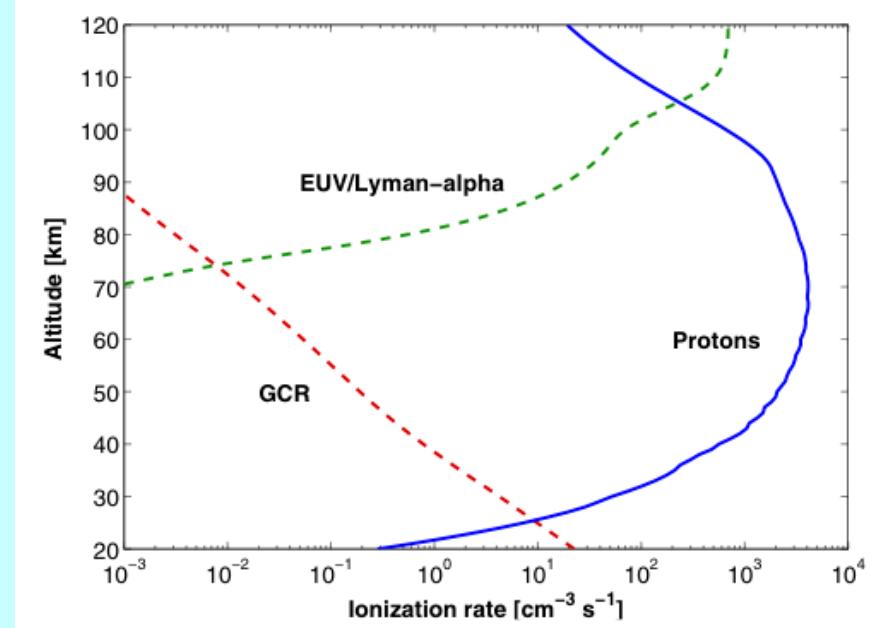
Coronal mass ejection
LASCO/SOHO



Proton cutoff energy and ionization rate



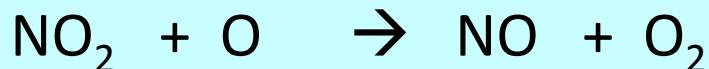
Computed ionization rate, October 29, 2003



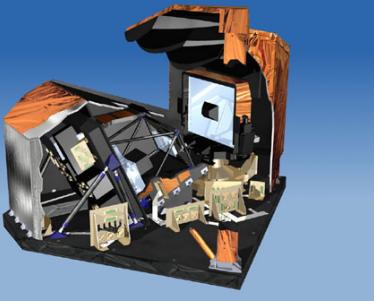
Verronen, 2006

Solar protons produce NO_x longer-term influence on ozone

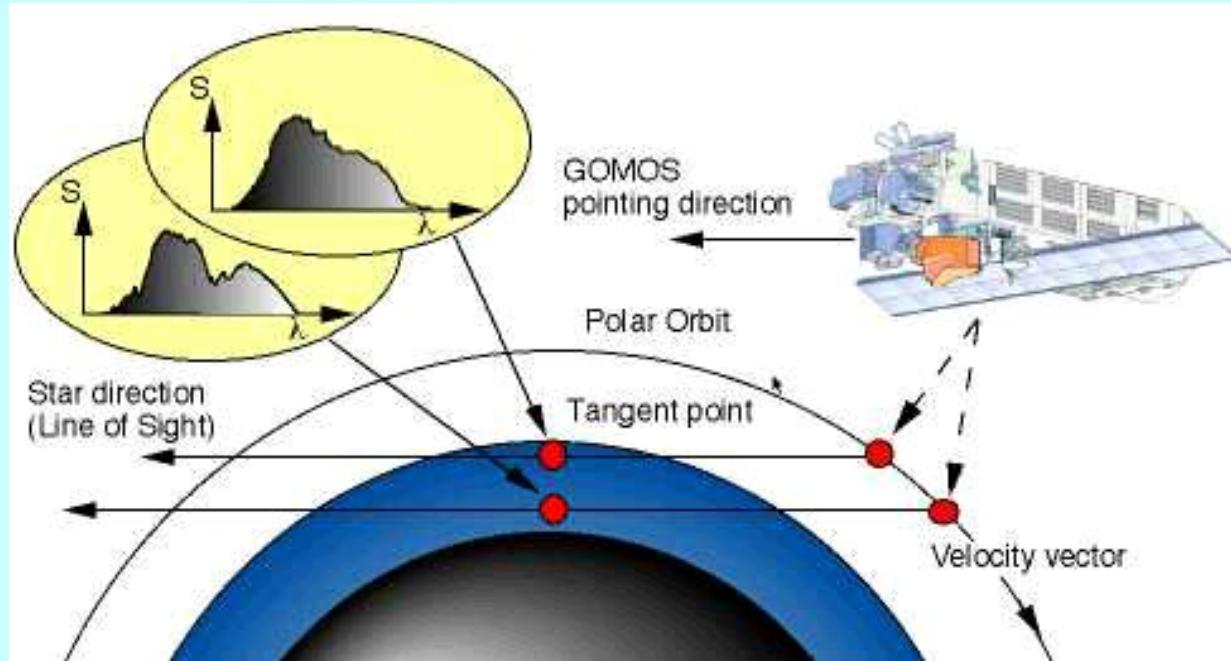
- NO_x can also cause catalytic destruction of Ozone
 - Lower mesosphere, stratosphere mechanism:



- Lifetime of ozone can be longer in low sun conditions
- Ozone chemistry (loss & production) stops at sunset



GOMOS principle



**Below 10 km
Up to 120 km**

**One star spectrum
every 0.5 s**

**Pointing information
100 Hz**

**Scintillation information
1000 Hz**

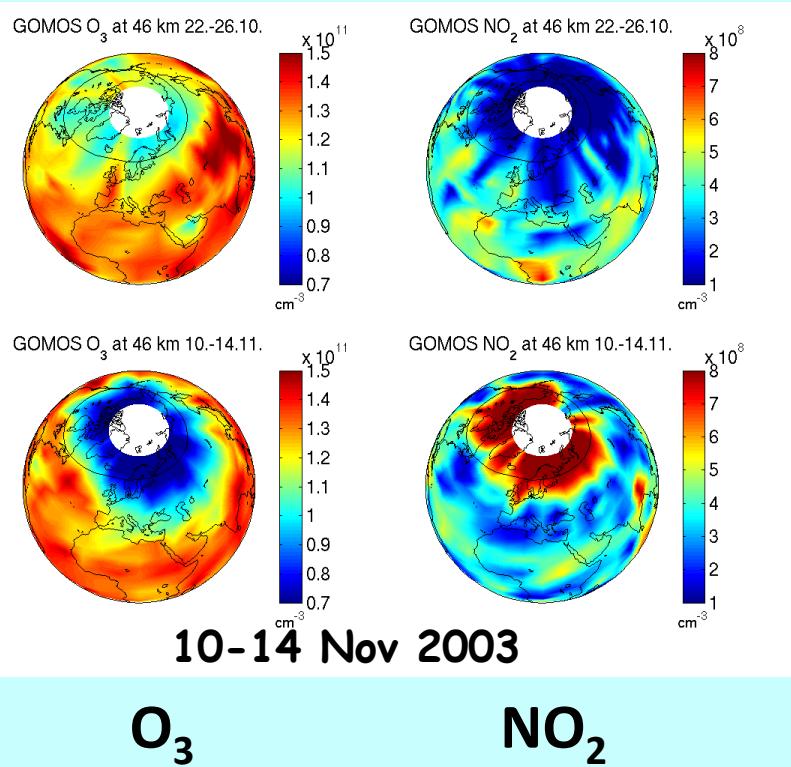
Self-calibrated instrument

Highly accurate altitude registration

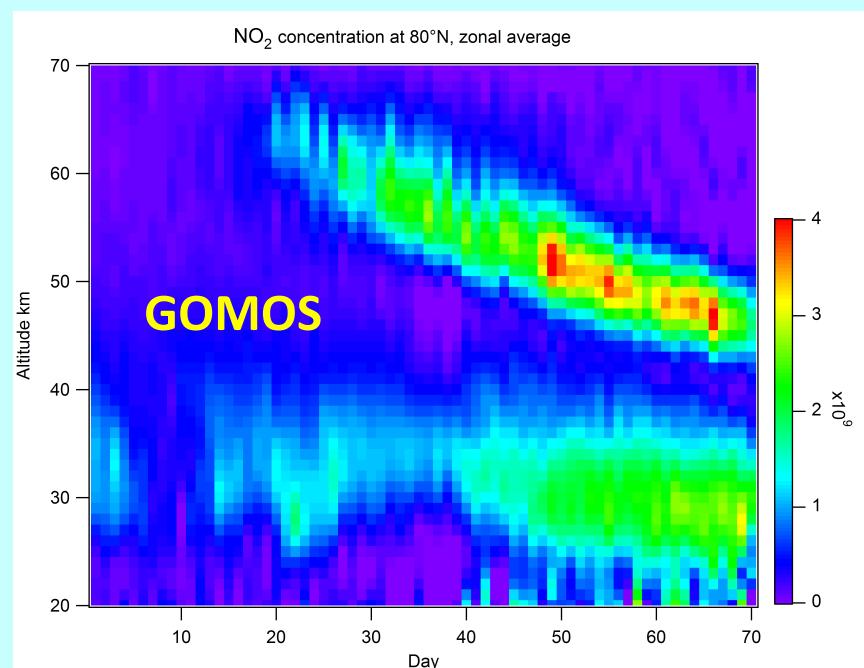
Impact of particle precipitation

- Formation of NO in the mesosphere / lower thermosphere due to energetic particle precipitaions
- NO descent in the winter polar vortex and NO₂ formation
- O₃ destruction through the NO_x catalytic cycle

Halloween Solar Proton Event 22-26 Oct 2003

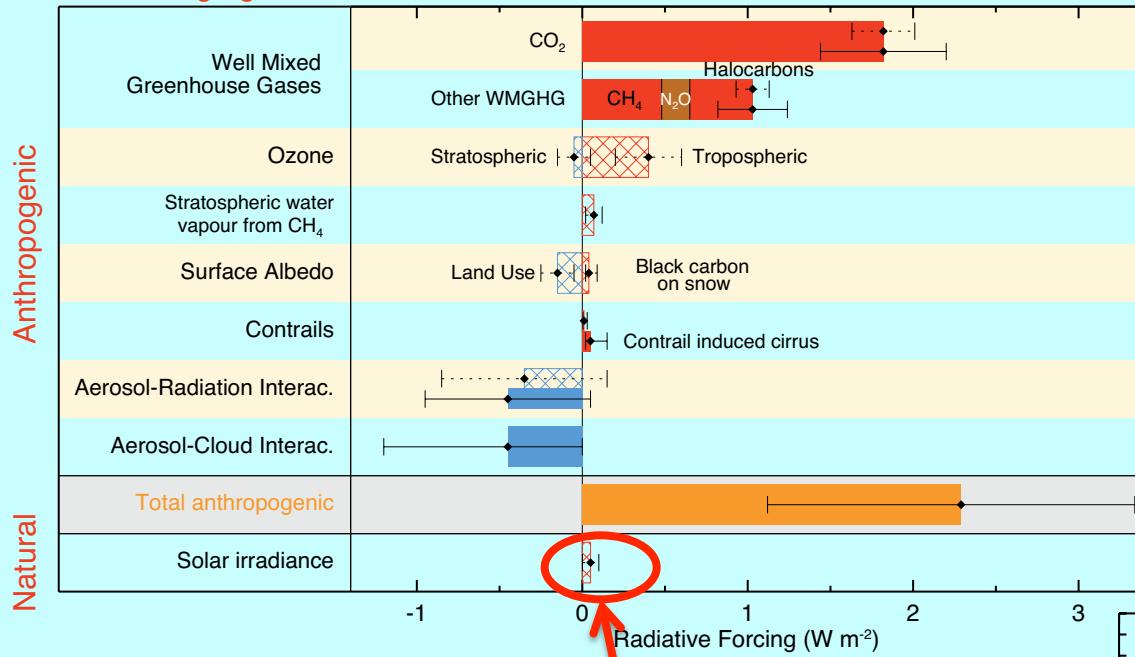


NO₂ enhancement and descent in the North polar vortex, January-March 2004

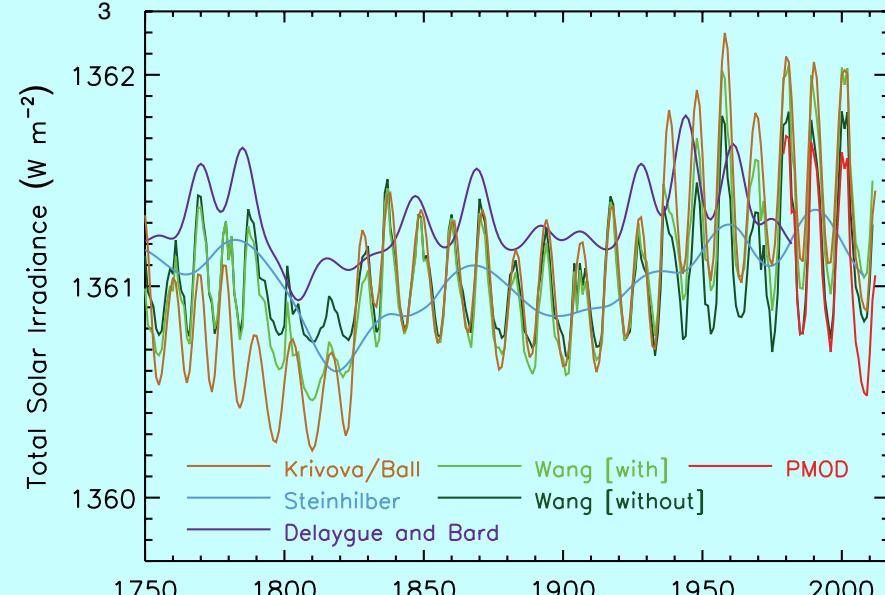


Solar forcing of the climate

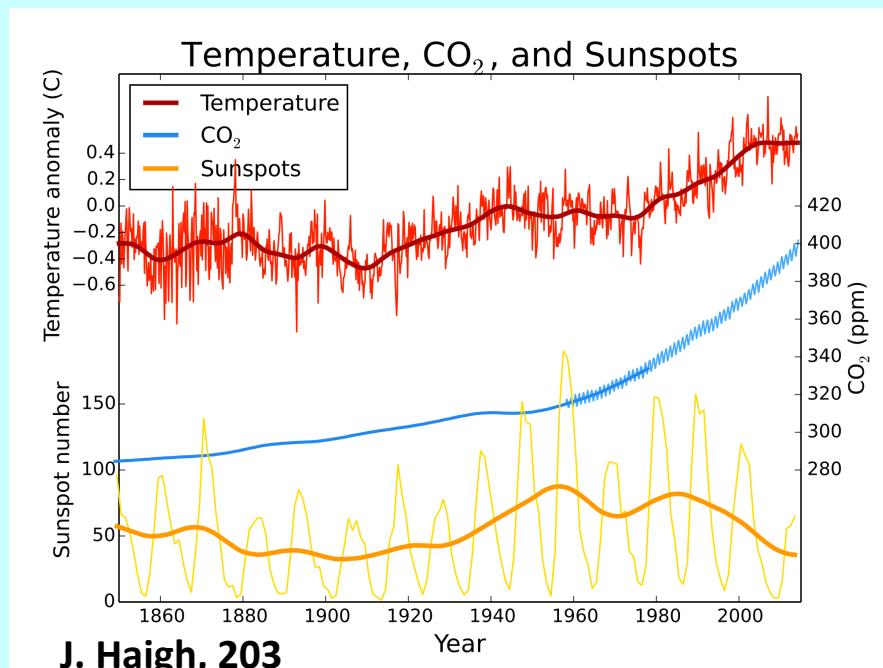
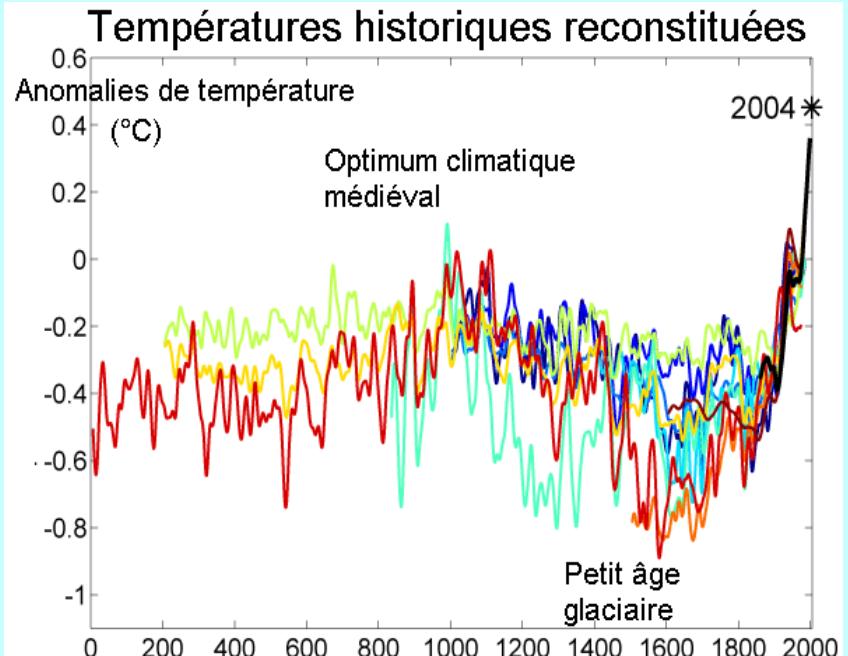
Radiative forcing of climate between 1750 and 2011
Forcing agent



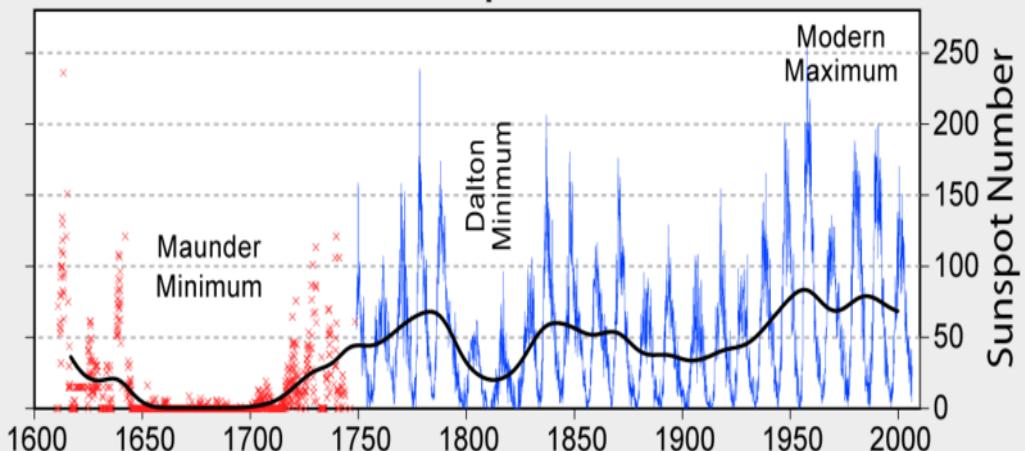
- **IPCC 2013 report: weak solar forcing of the climate at global scale**
- **Based on total solar irradiance variability smaller previously estimated**



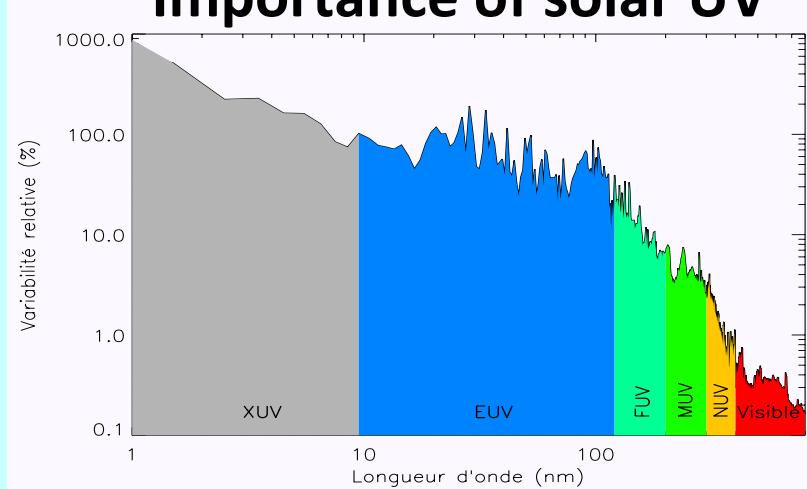
Mean surface temperature and solar activity



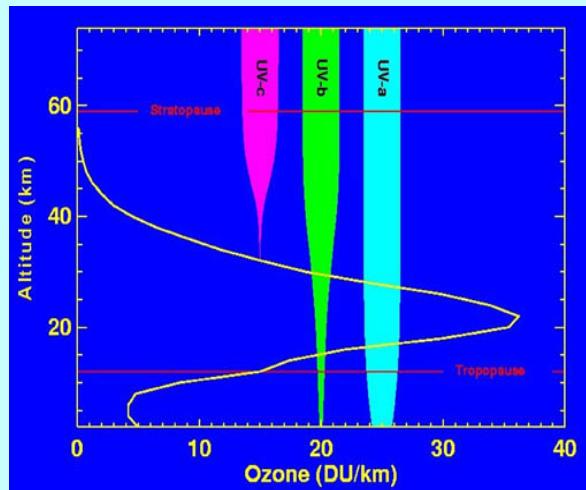
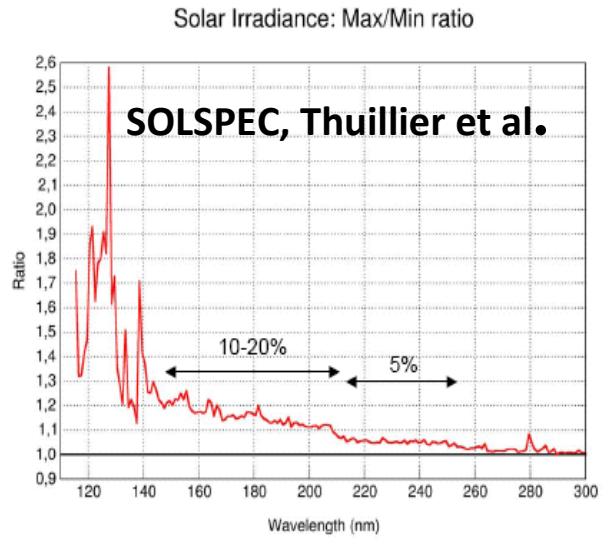
400 Years of Sunspot Observations



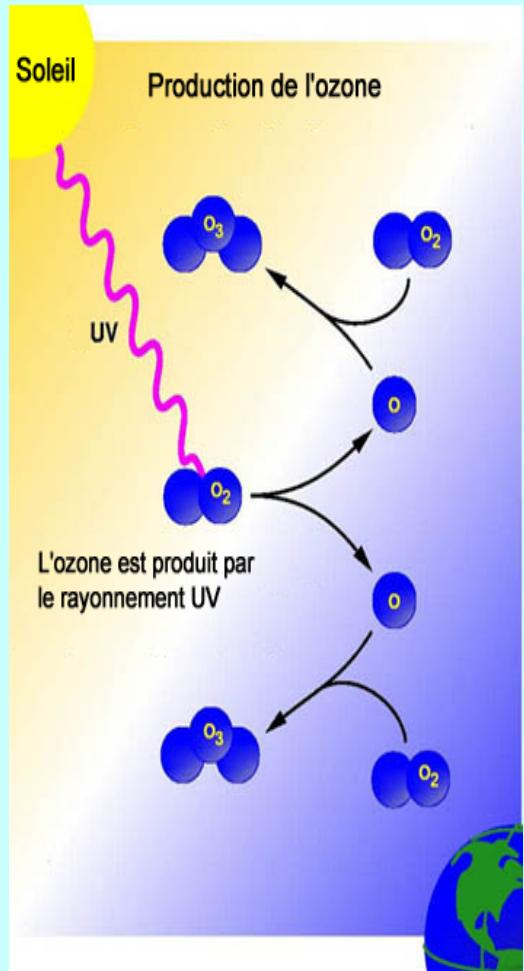
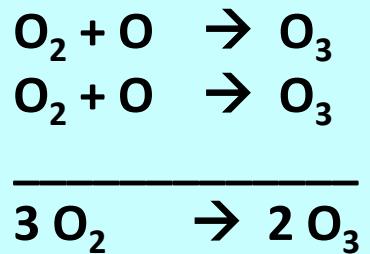
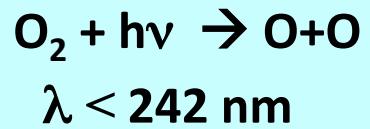
Importance of solar UV



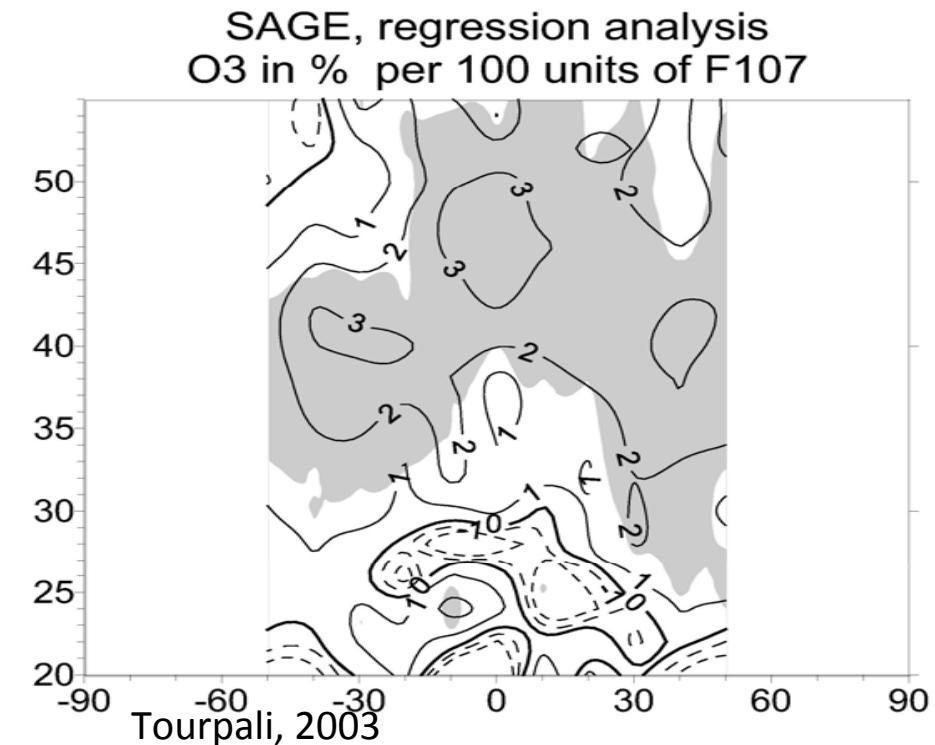
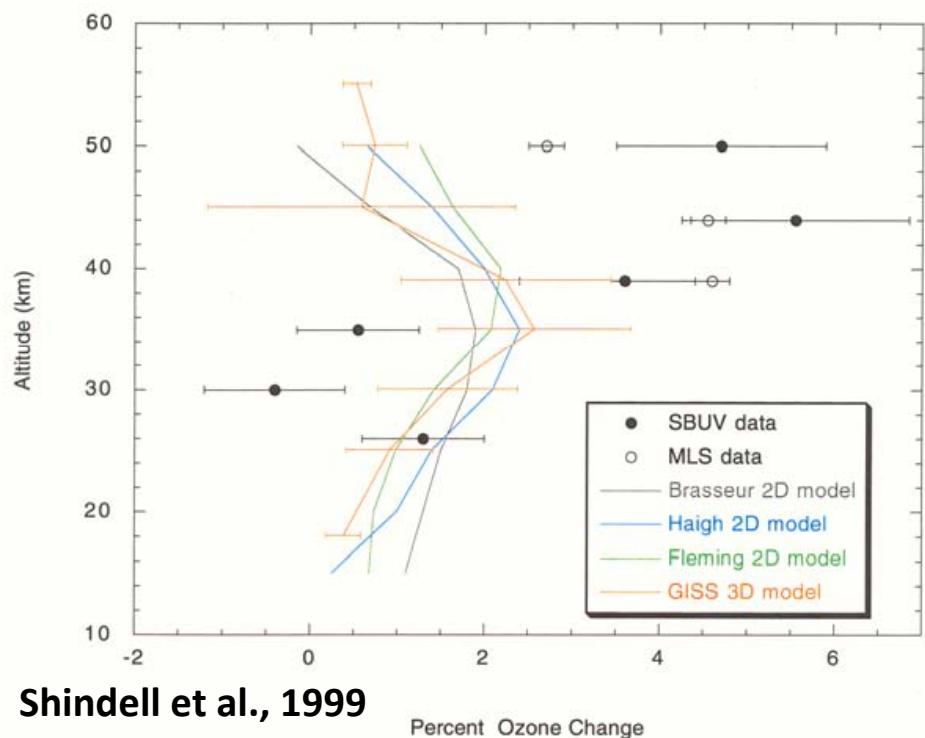
UV solar variability and ozone



Stratospheric ozone production

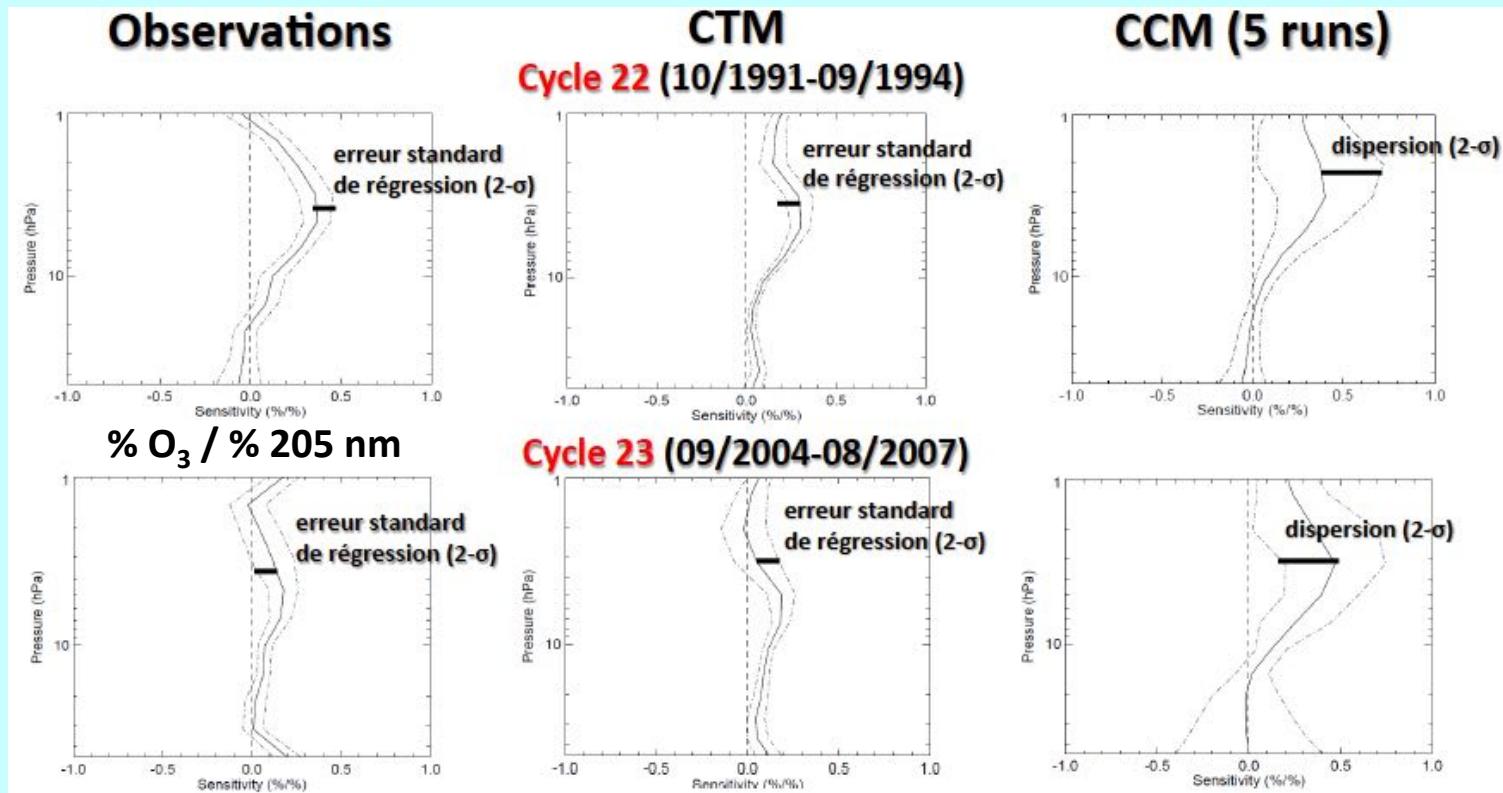


Stratospheric ozone response to 11-year solar UV cycle



2-3% ozone increase in the upper stratosphere

Stratospheric ozone response to 27-day solar UV modulation



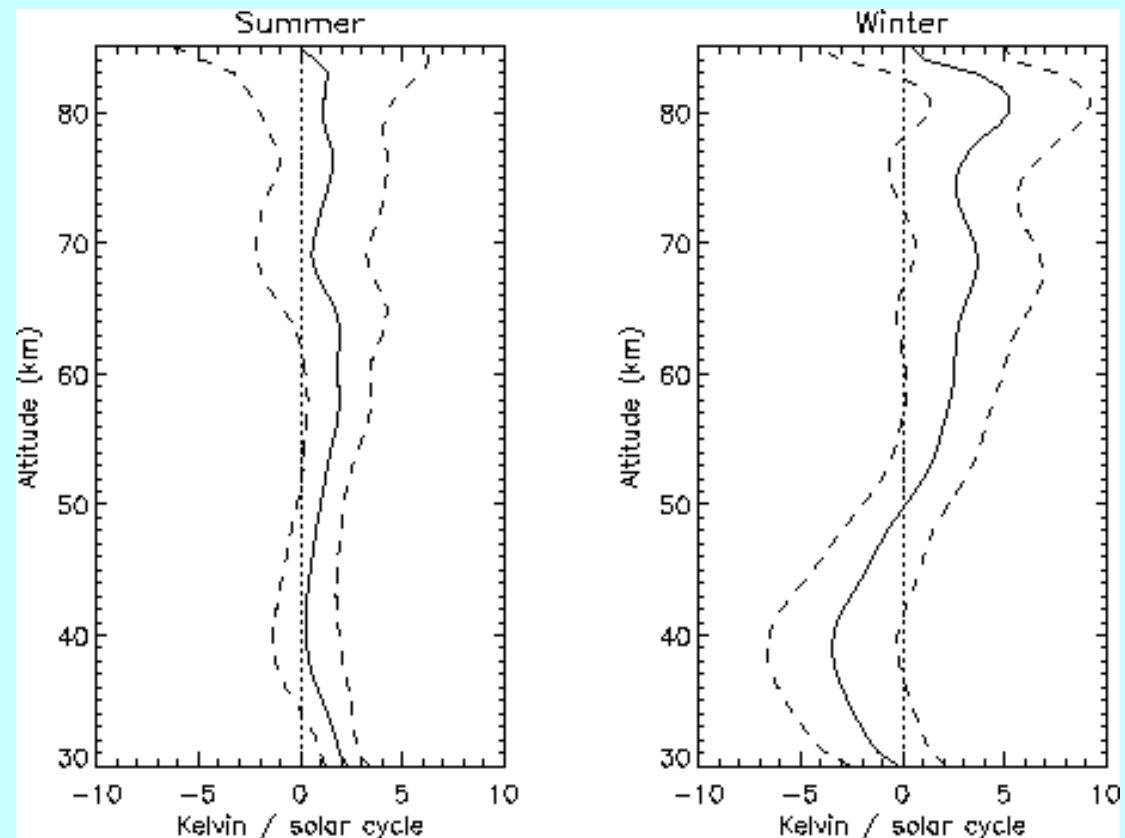
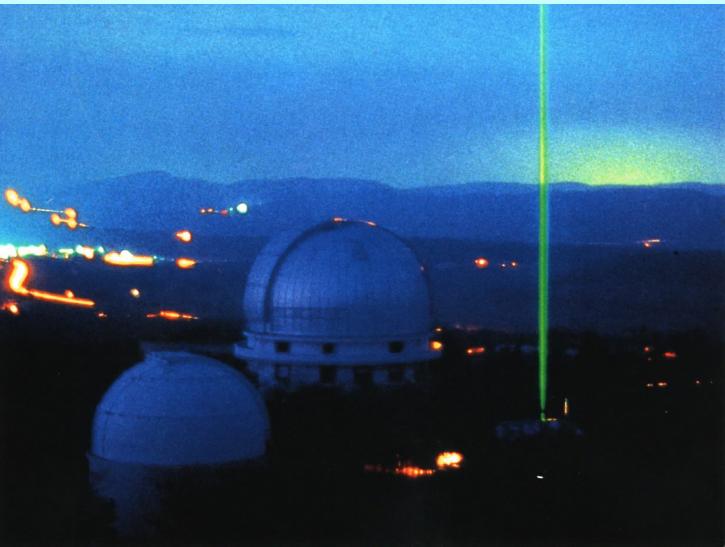
Bossay and Bekki,, 2015

Tourpali, 2003

Ozone response to 27-day solar UV modulation
depends on the solar cycle

Response of temperature to solar changes 11-year time scale

OHP lidar 44°N

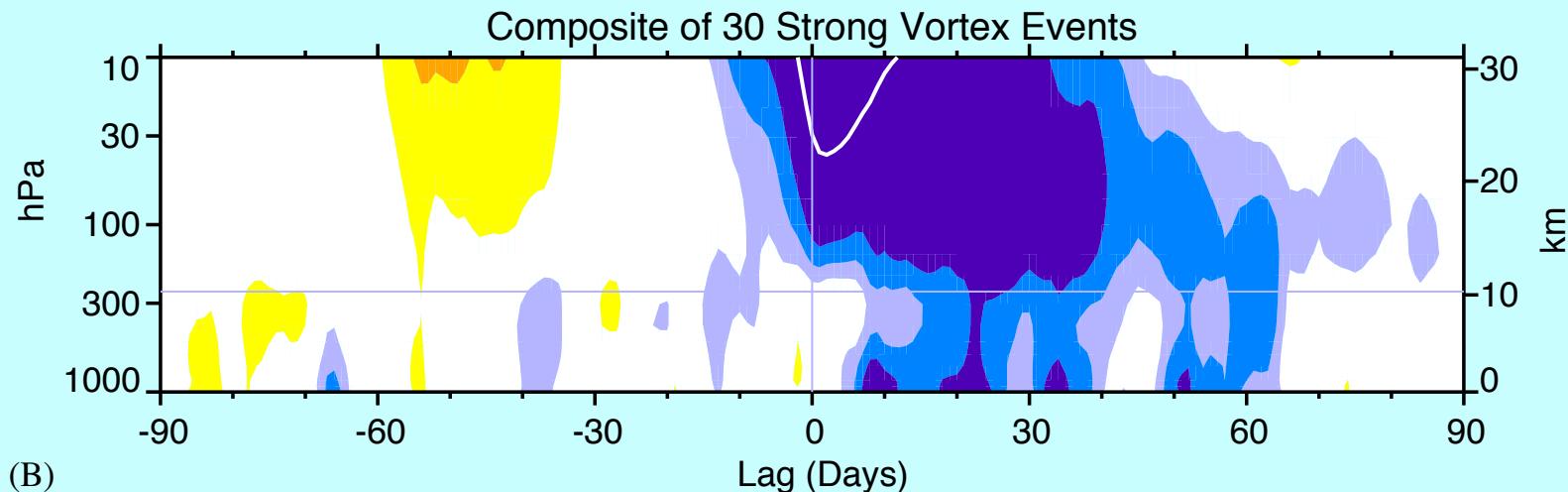
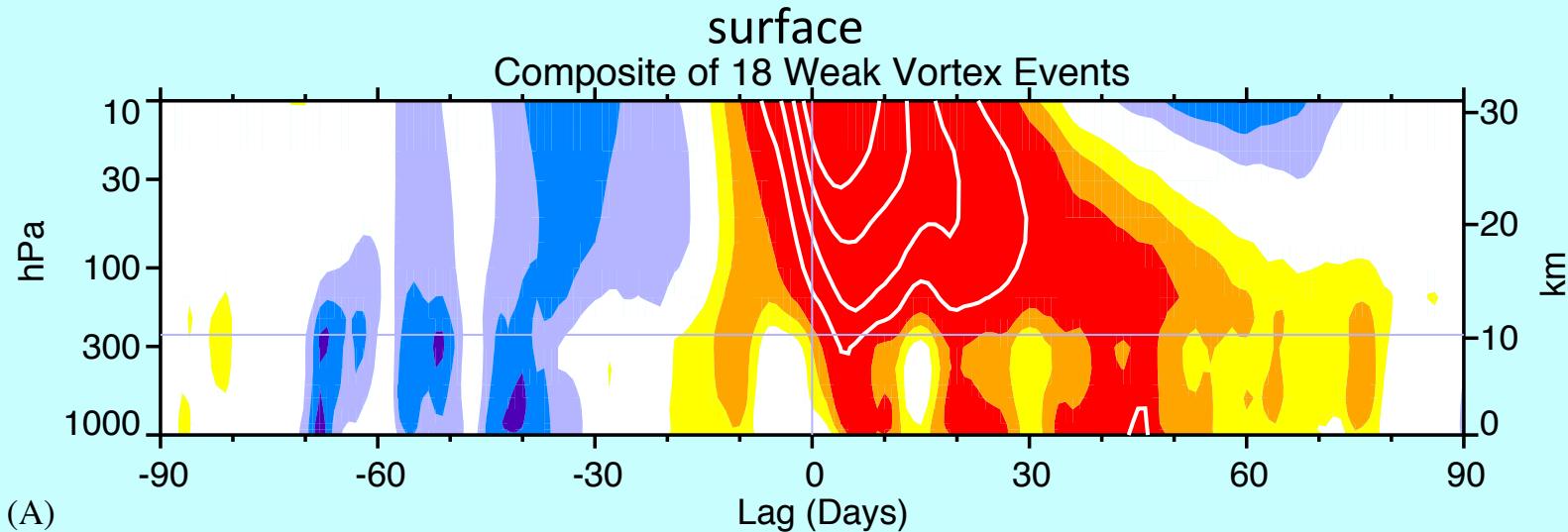


Summer

Winter

Stratosphere-troposphere dynamics coupling

Pressure and temperature perturbations generated in the upper stratosphere can propagate down to the troposphere and the surface

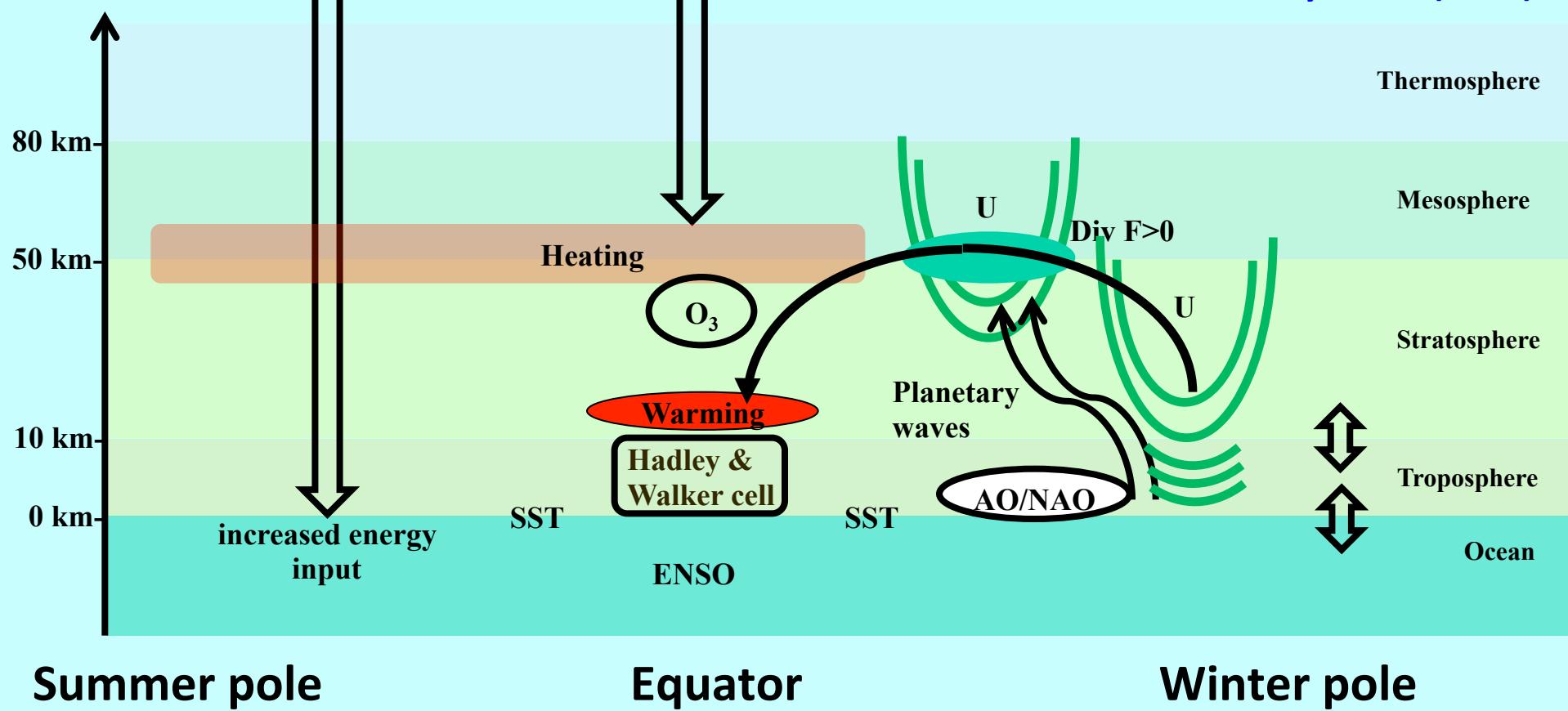


Influences of solar variability on climate: proposed mechanisms

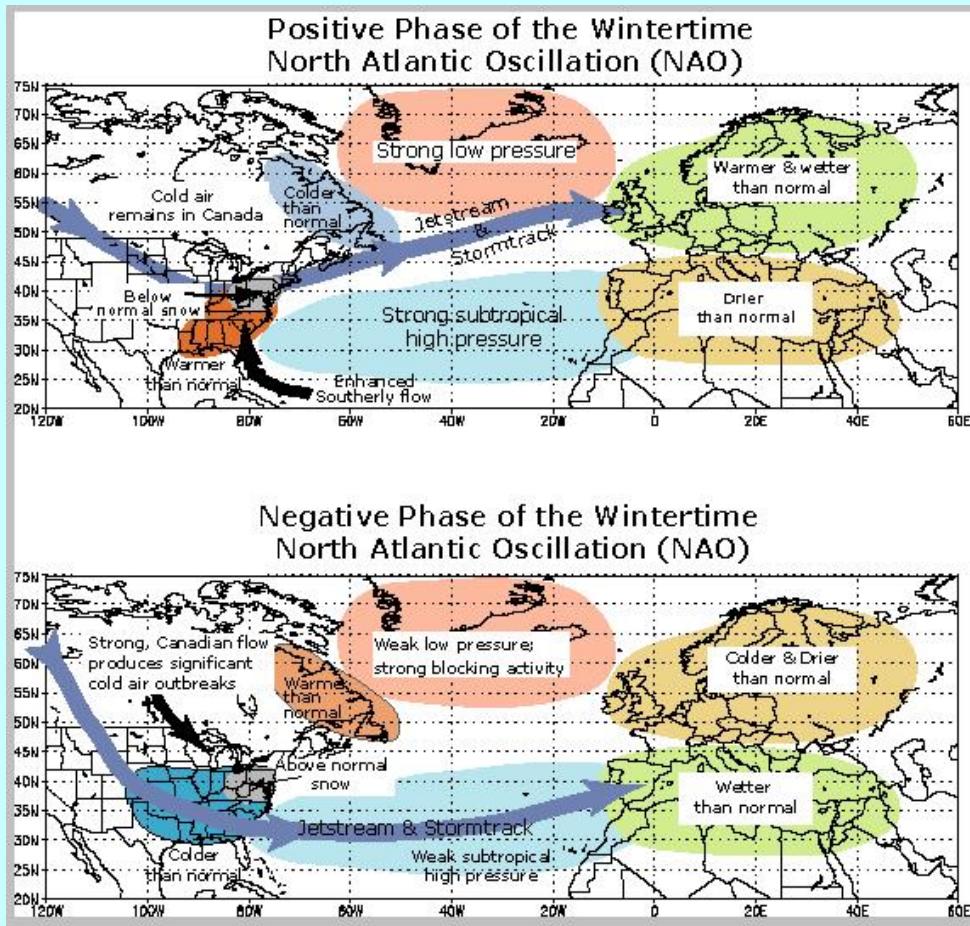
Bottom-up
TSI (0.1%)

Top-down
UV (6-10%)

Gray, et al. (2010)



North Atlantic Oscillation (NAO)



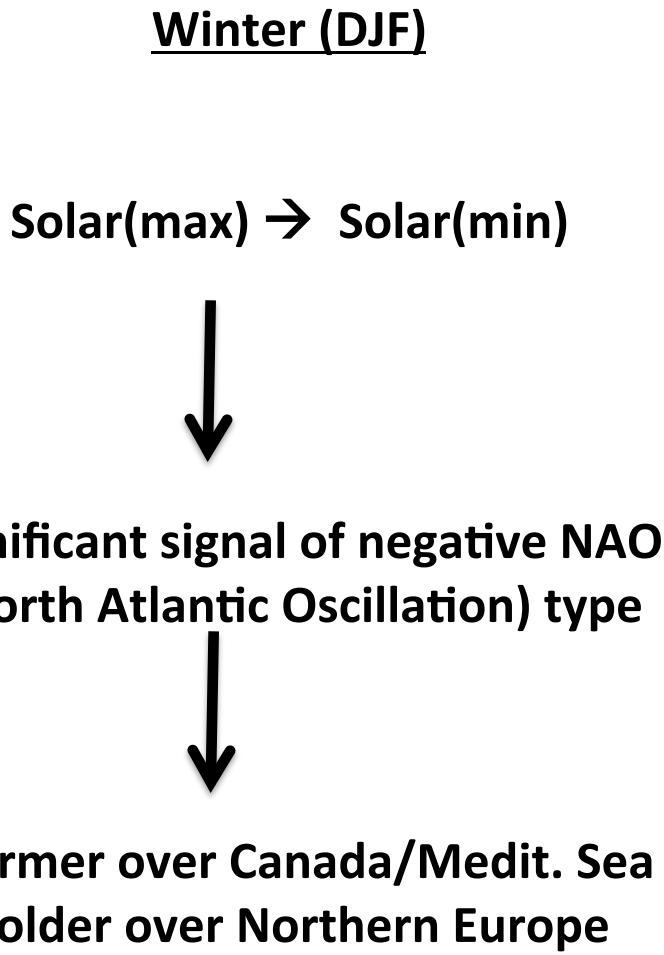
NAO positive

- Drier in Mediterranean region
- Warmer and more humid in Northern Europe

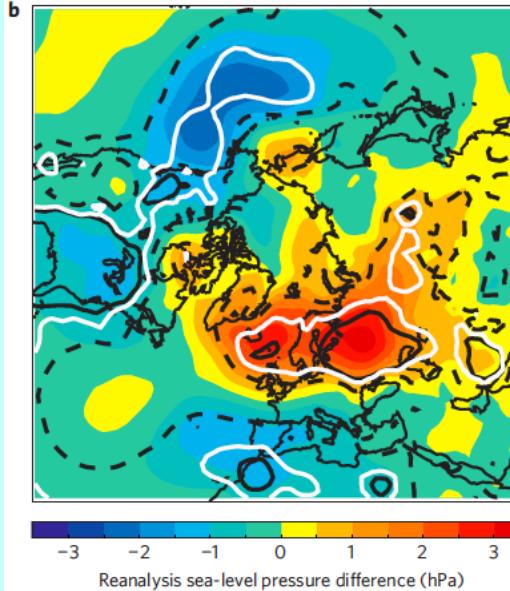
NAO negative

- More humid in Mediterranean region
- Colder and drier in Northern Europe

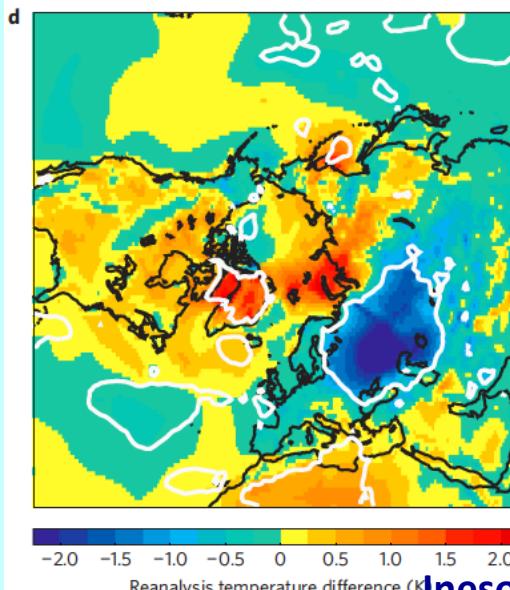
Solar regional forcing



ERA40/ERA-I: Solar(min)-Solar(max)

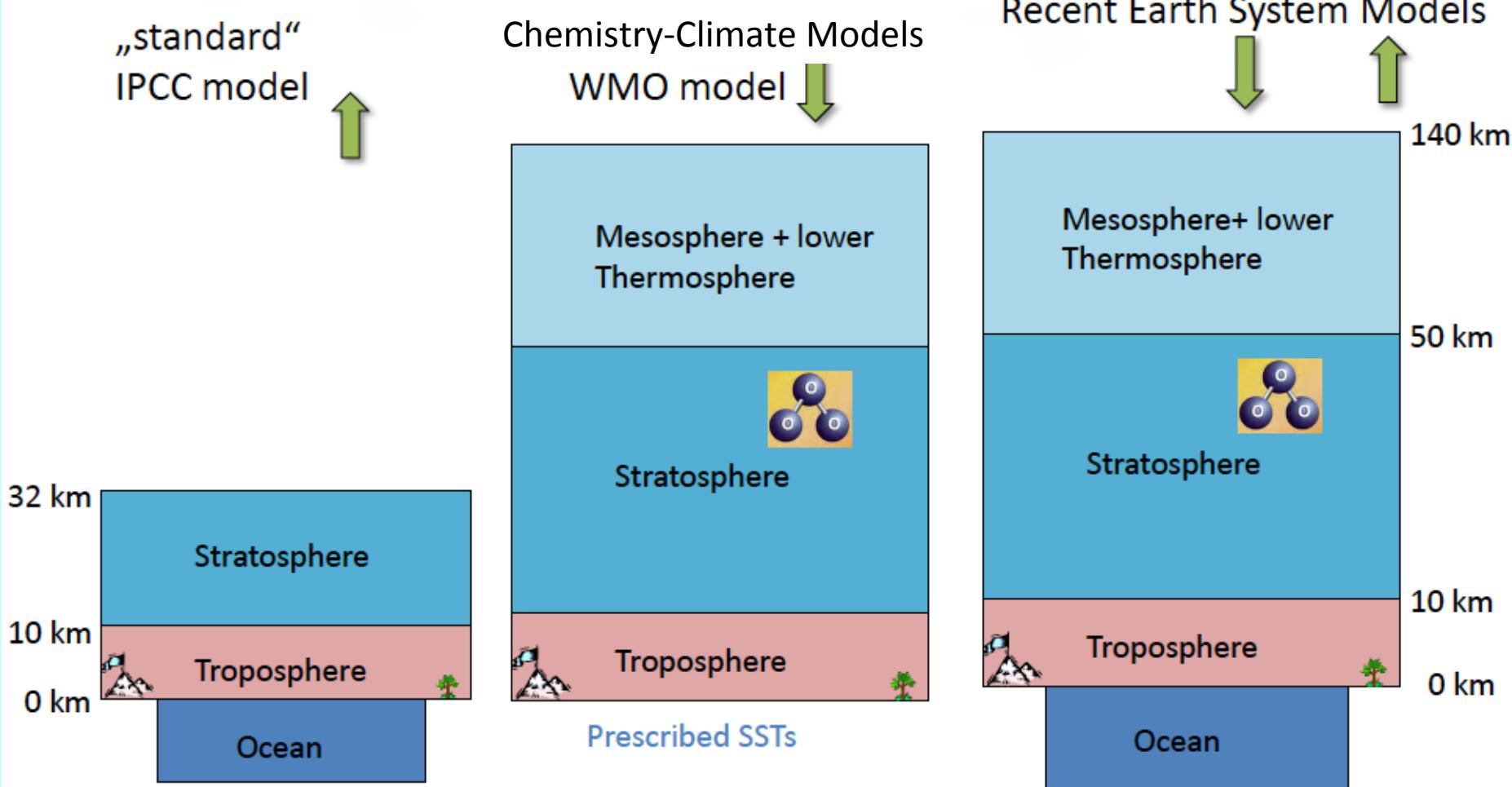


Surface P (hPa)

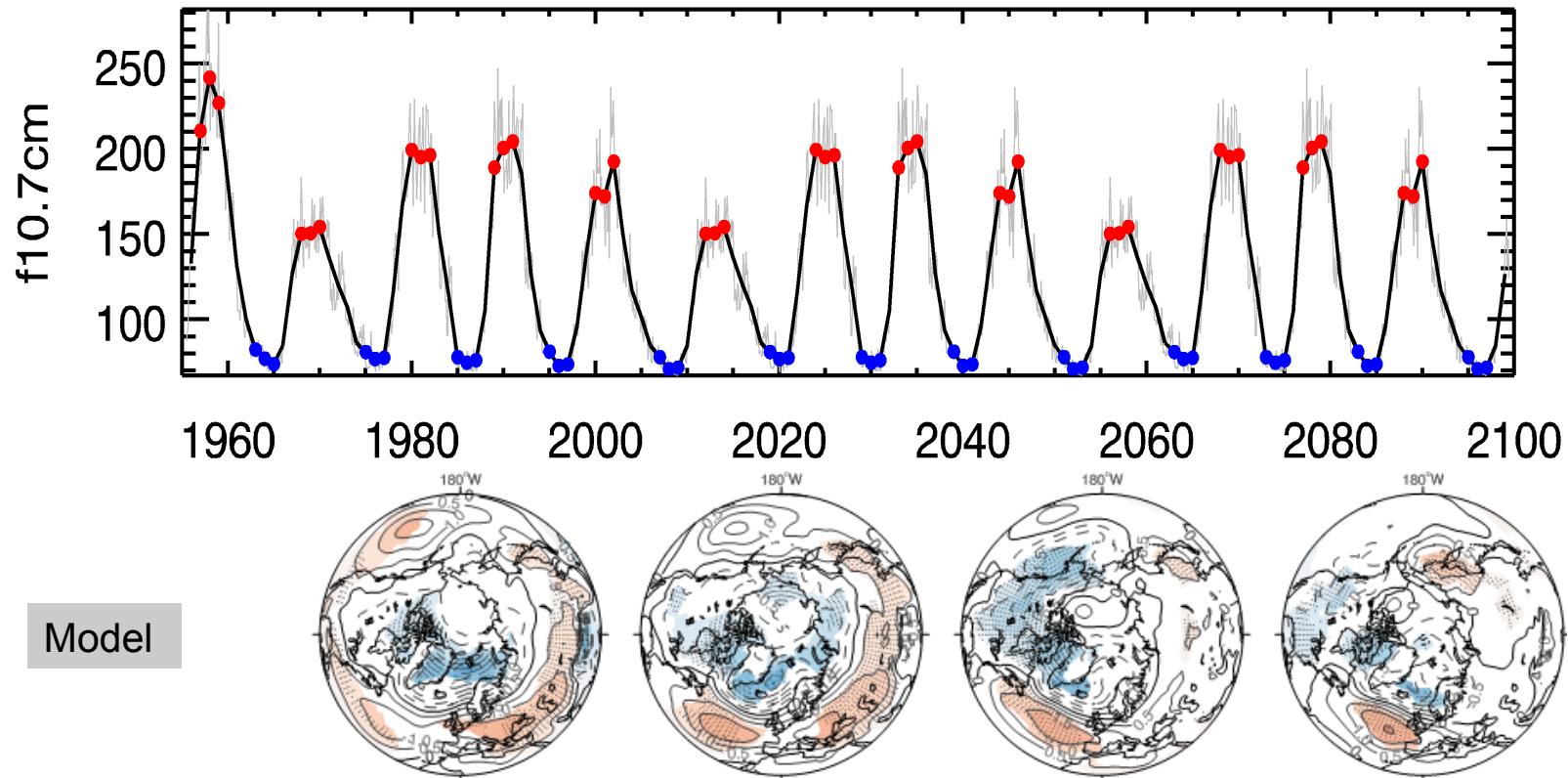


Surface T (K)

Representation of the solar forcing in climate models



Surface solar signal in winter (DJF)



- Lagged solar/NAO relationship by 1-2 years consistent with Gray et al. (2013) & Scaife et al. (2013)
- Model consistent with reanalysis

Courtesy, R. Thiéblemont, 2014

Conclusion

- Several mechanisms are involved in the solar forcing of the climate
- The middle atmosphere is sensitive to the UV and particle solar forcing.
- Solar signatures in climate variables cannot be explained by the TSI variability alone. They are similar to internal modes of the ocean-climate system (NAO, ...), indicating a possible transmission of the middle atmosphere signal via the dynamical stratosphere-troposphere coupling.
- Coupled climate models with interactive ocean and stratospheric chemistry are needed to study the Sun-climate link.
- A project on *Solar forcing of the climate at global and regional scale (mainly Europe)* will be funded by IPSL.