# Influence of solar variability on terrestrial atmosphere through stratosphere

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# Summary

- Introduction
- The solar variability
- Some words about the Earth's atmosphere
- Simulations and results

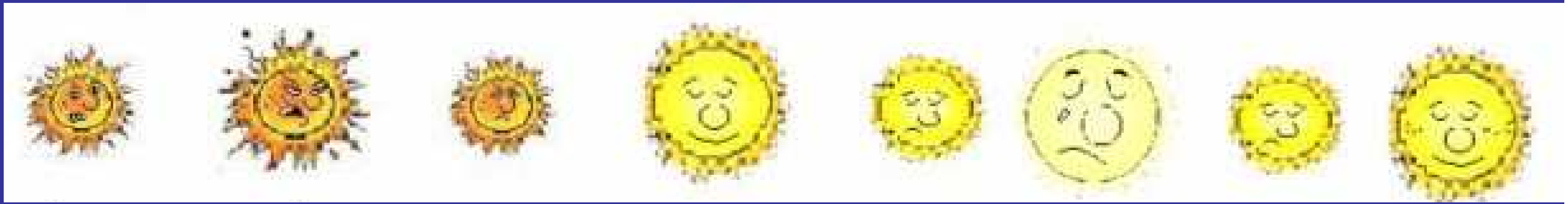
# Introduction

- Understanding and quantifying the natural variability of climate on decadal and centennial scales is a necessary condition to predict future climatic changes.

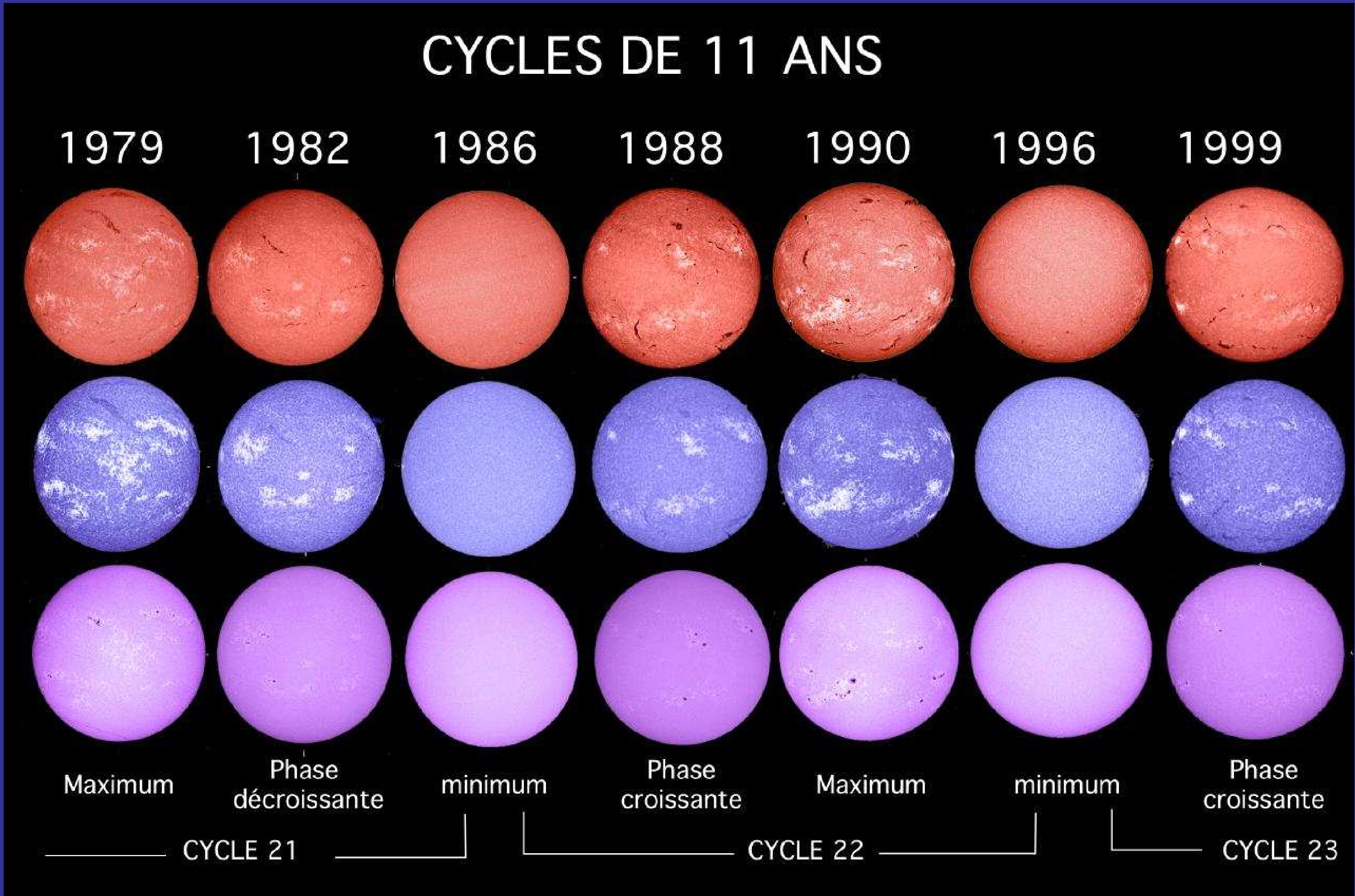
- The question of the influence of solar activity comes back regularly in the debate of climatic changes.

- Correlations between solar variability proxies (TSI, $L_{cycle}$, $N_{sunspot}$, [isotopes],…) and atmospheric variables (T, large scale circulation, cloud cover…) [Hoyt & Schatten (1997), Gleisner & Thejll (2003), Lohman et al. (2004)]
  - GIEC -> strong positive feedback
  - Amplification mechanism unsolved
  - No general consensus

# The solar variability

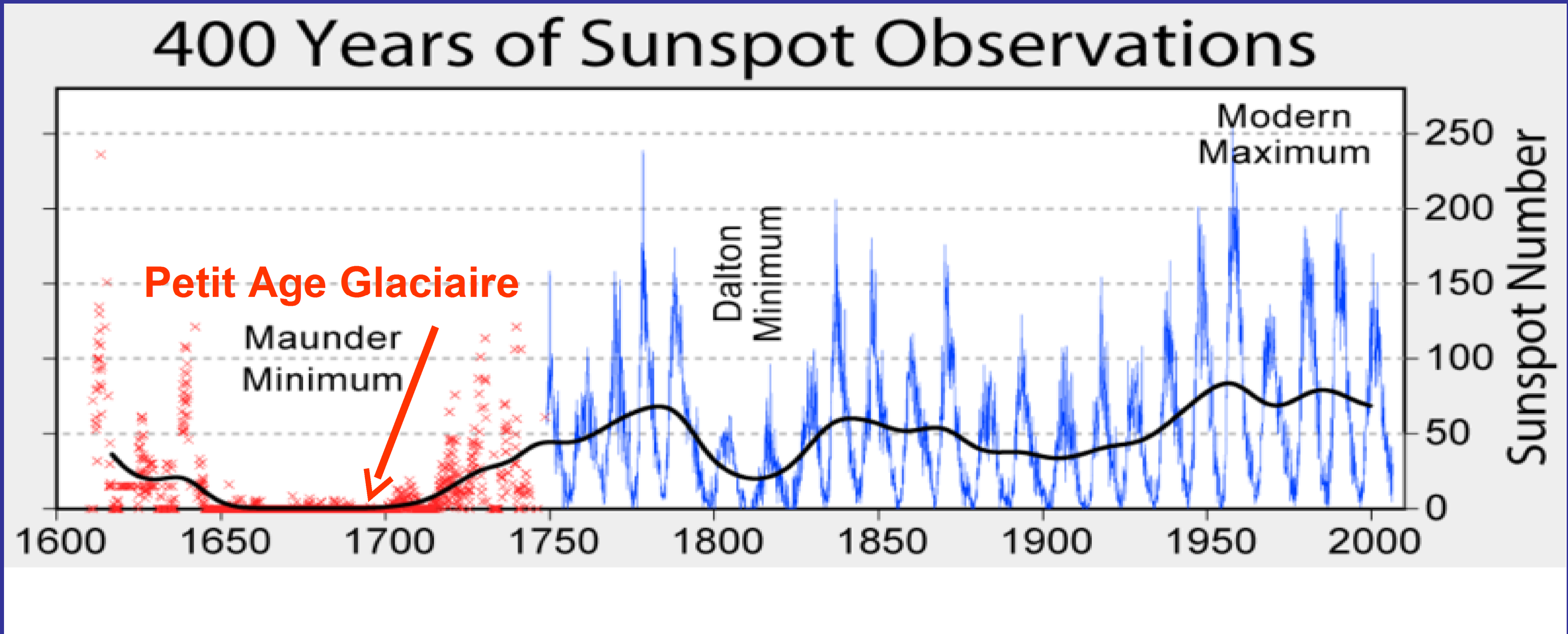


# A changing solar surface



# The 11-year cycle

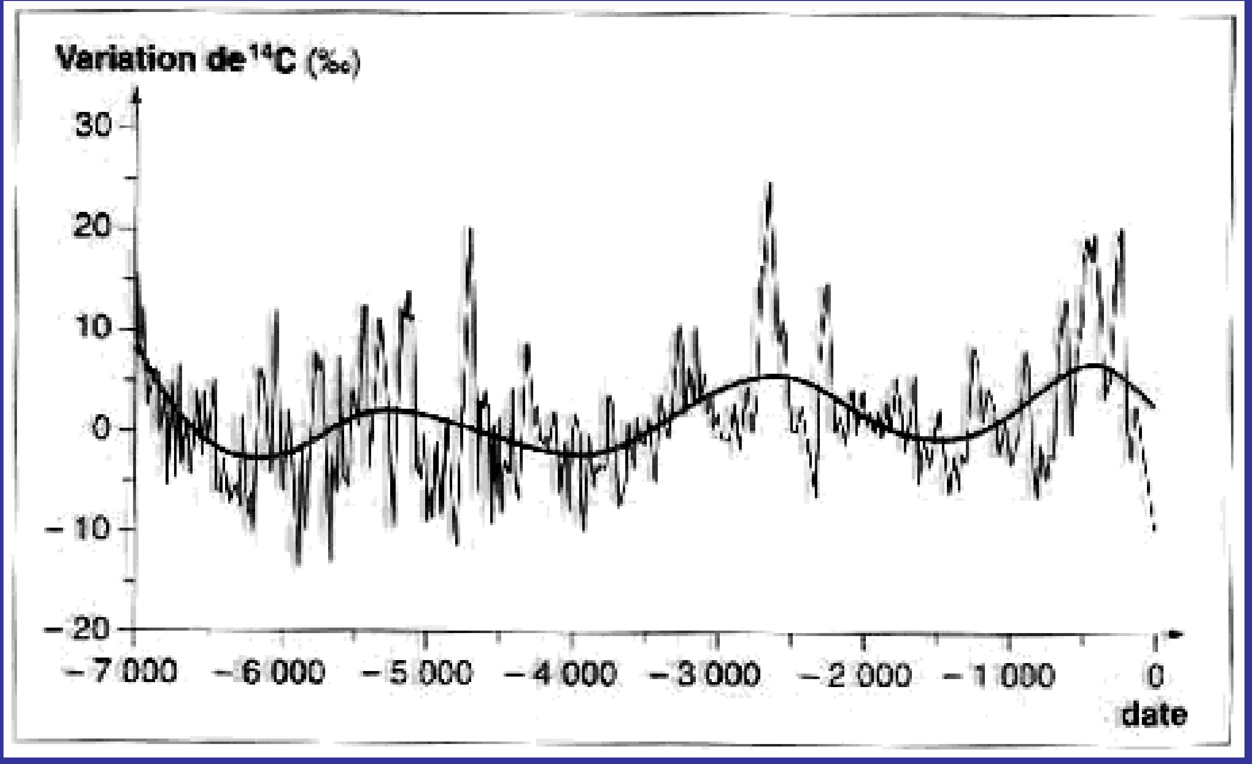
- Periodicity of sunspot emergence
  - Every 11 years on average
  - Duration between 8 and 13 years and variable amplitude
  - Schwabe cycle (Heinrich Schwabe : 1789-1875)
  - In fact, magnetic cycle of about 22 years = Schwabe cycle : duration for pole polarity coming back to its initial state



# Other cycles

- Gleissberg (1958) : 90 years
- Suess : 200 years
- Hallstattzeit : 2300 years

| MINIMUM | BEG. | END |
|---|---|---|
| OORT | 1010 | 1050 |
| WOLF | 1281 | 1347 |
| SPORER | 1411 | 1524 |
| MAUNDER | 1645 | 1715 |
| DALTON | 1795 | 1830 |

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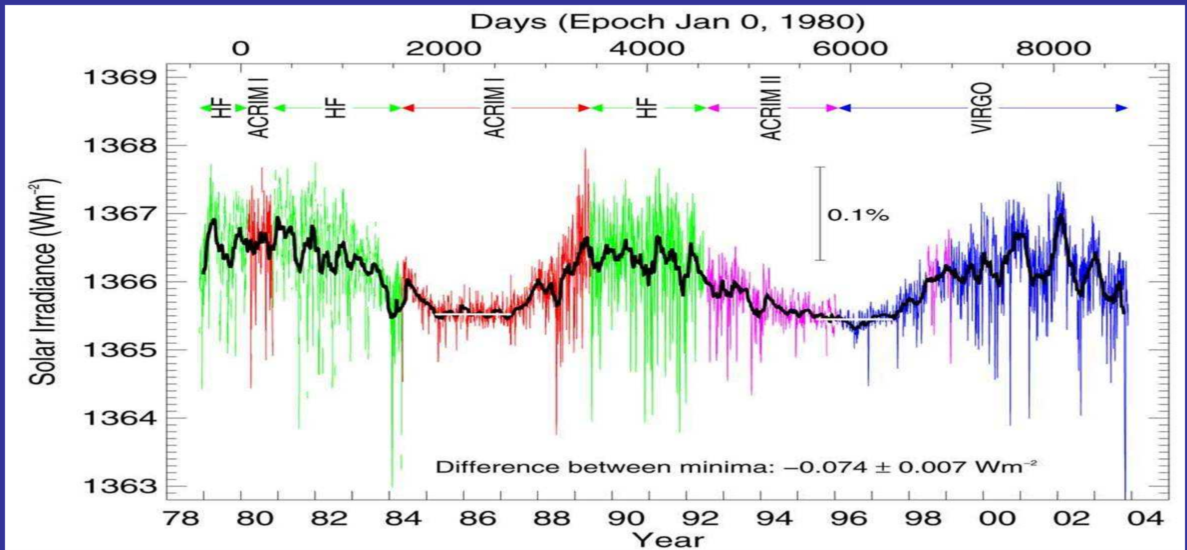
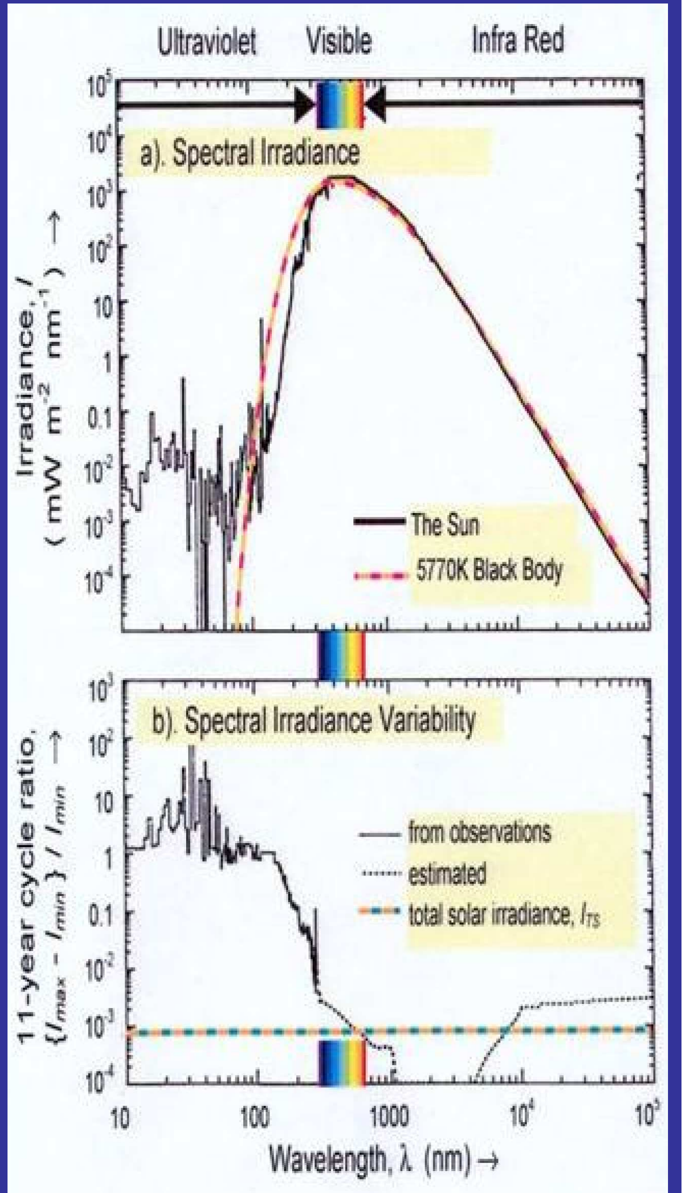
# Variation of the solar irradiance

- Variation of the solar irradiance (TSI) during the 11-year cycle : <0.1%.
  - –> Existence of process amplifying the solar cycle effects, process probably depending on the wavelength $\lambda$
  - –> $\lambda$ < 400 nm : 9% of variation during the cycle
  - –> $\lambda$ < 250 nm : 32% of variation during the cycle (Lean, 1989)

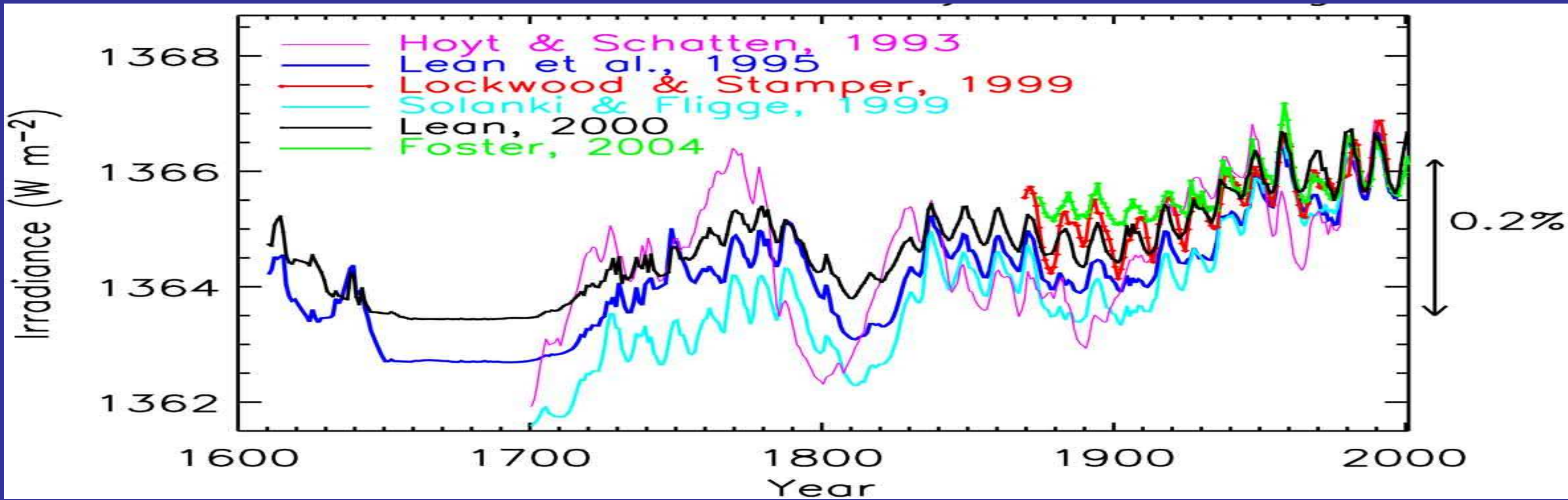


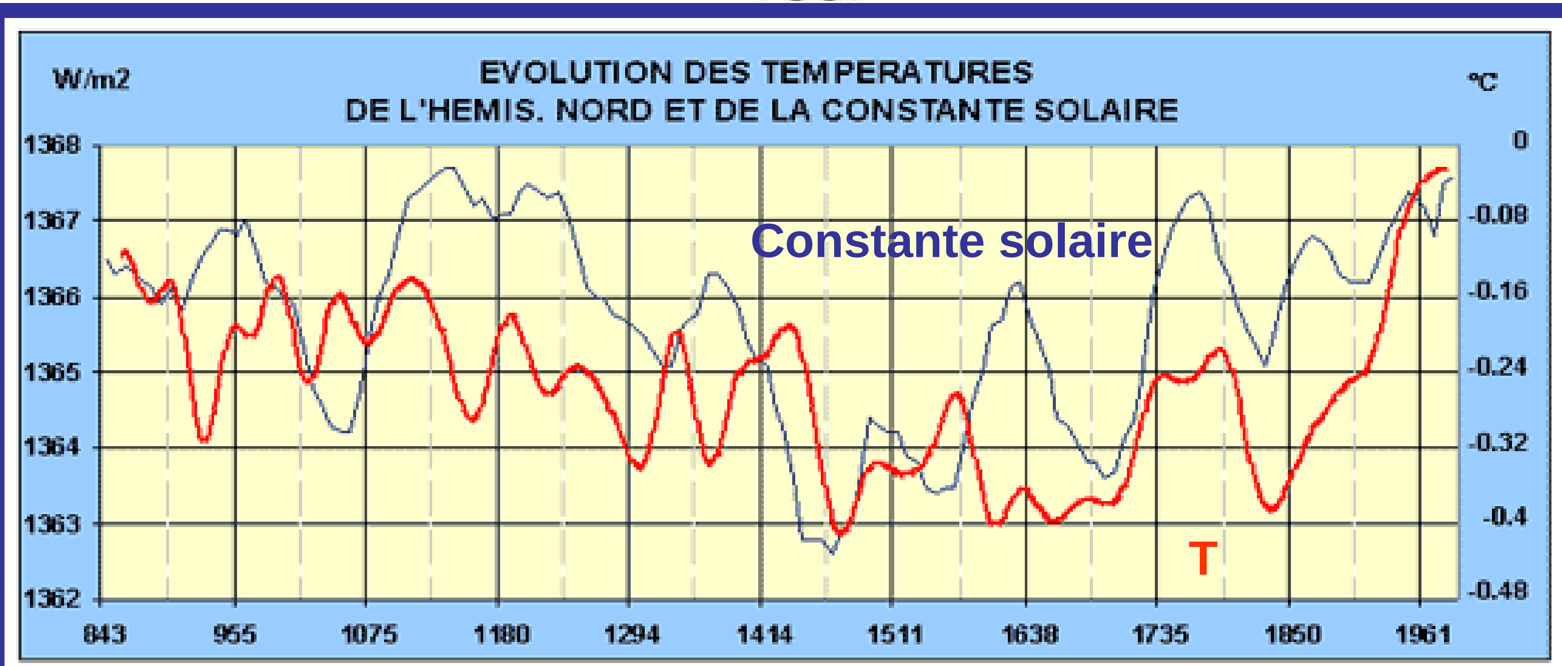

Fröhlich (2000)




Lean (1991)

# Reconstruction of the solar luminosity

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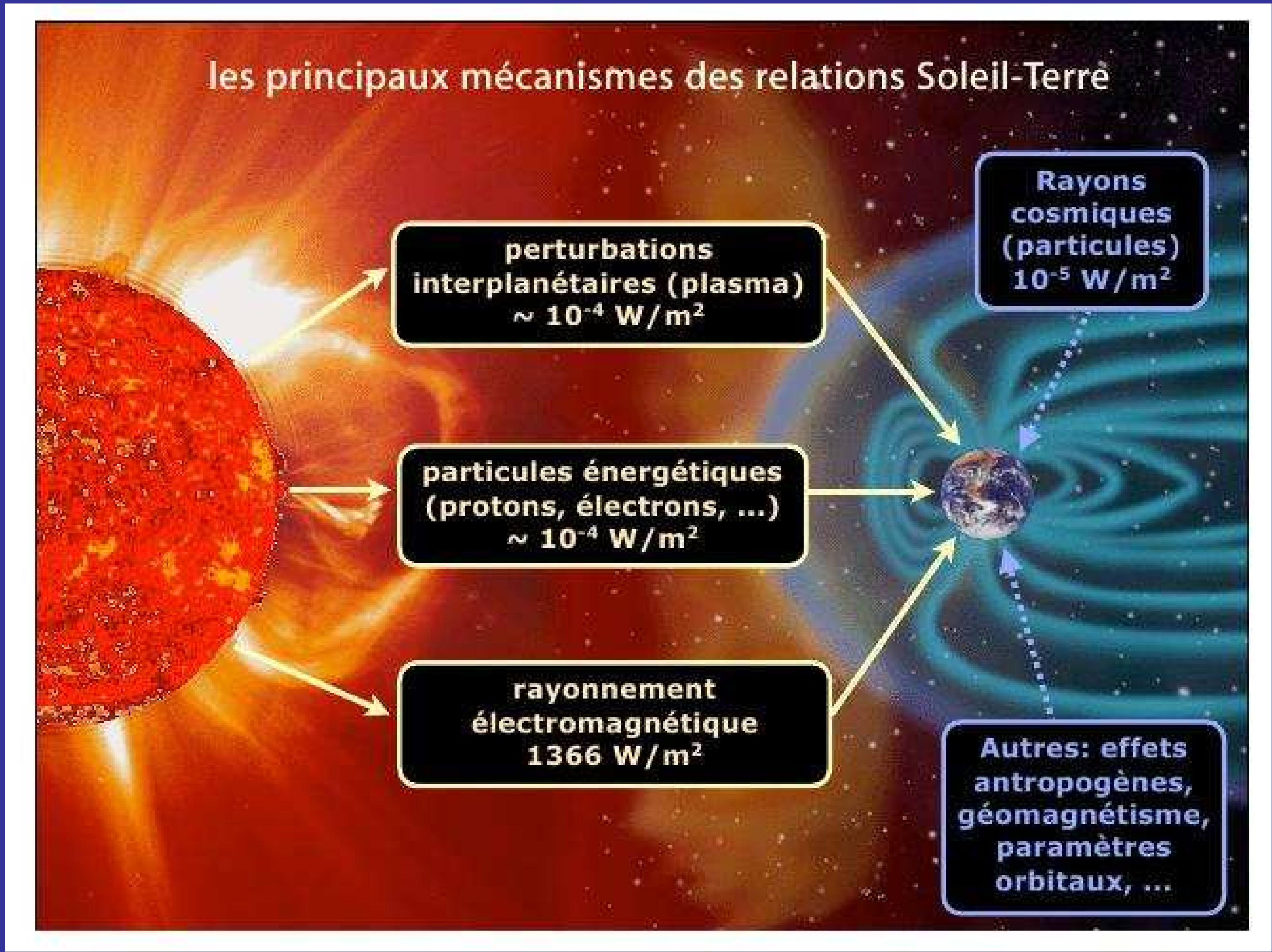
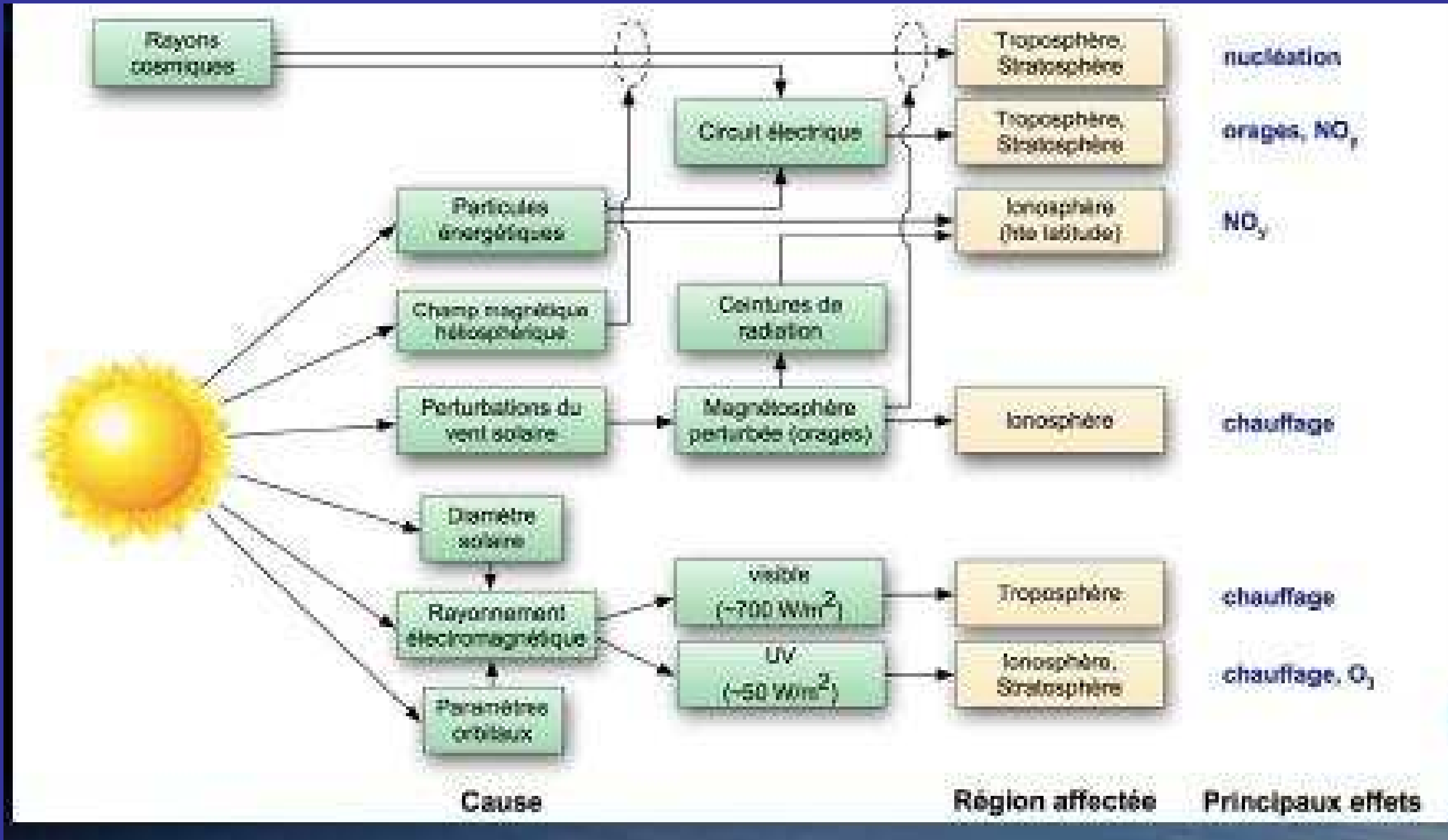
# The main mechanisms of the Sun-Earth relationship




Courtesy Dudok De Wit

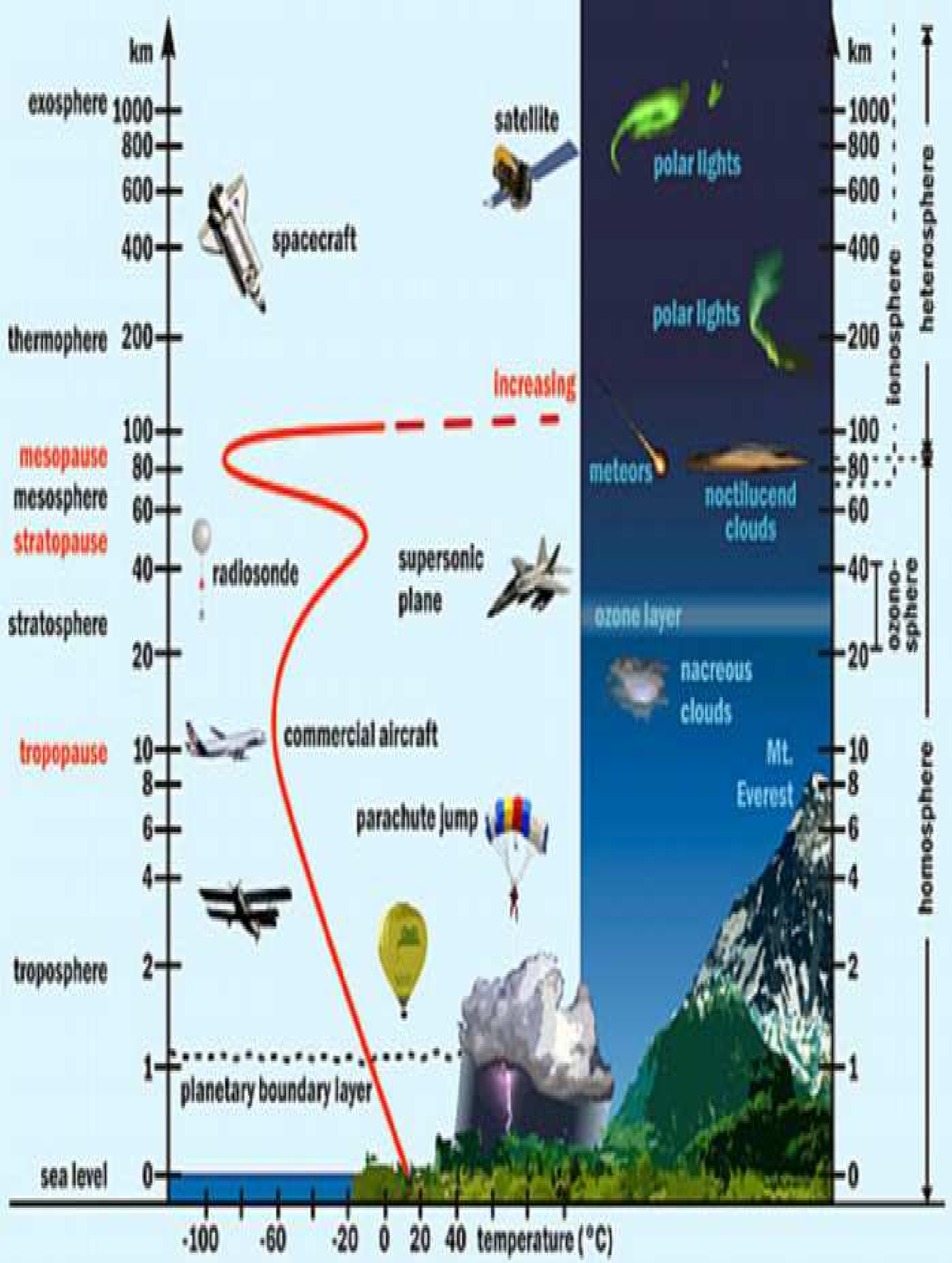
# Nothing is simple…



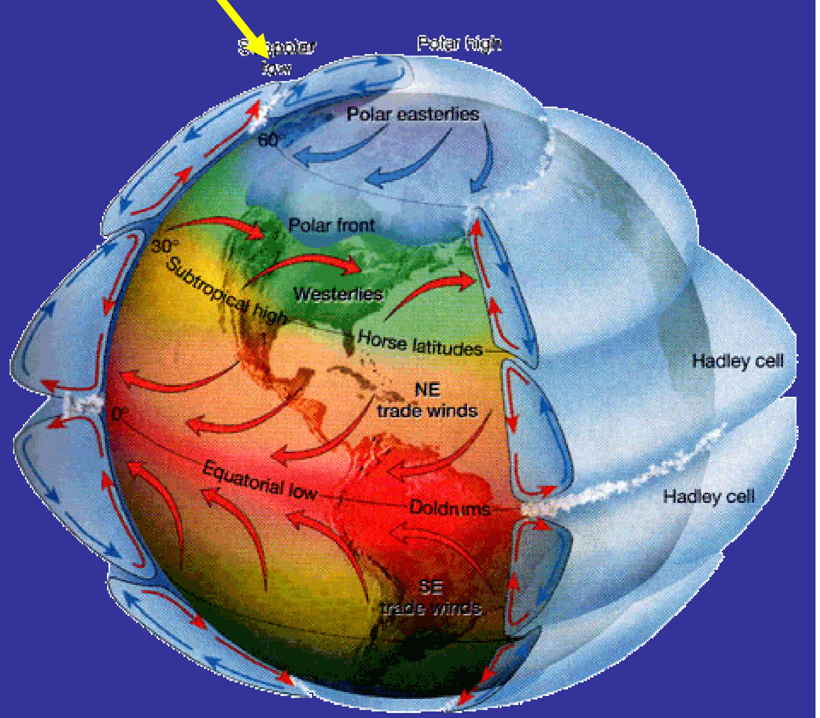

Courtesy Dudok De Wit

# Some words about our Earth's atmosphere

# The atmosphere and the general circulation




Polar Jet-stream

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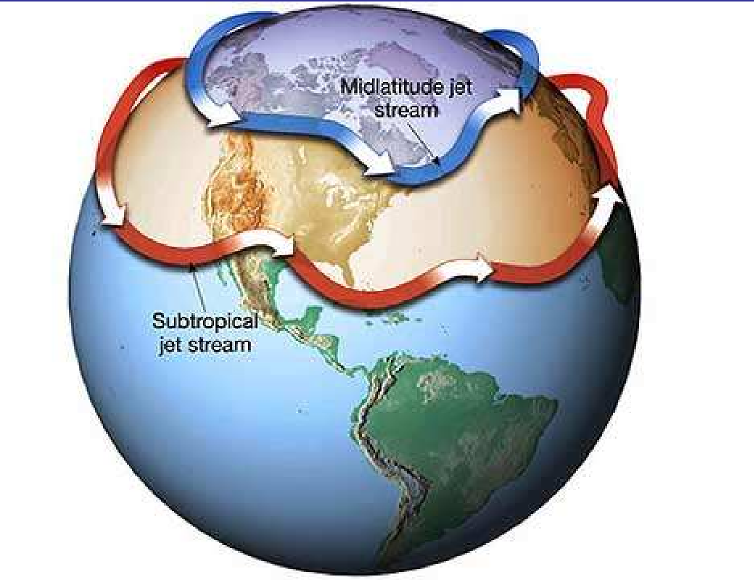
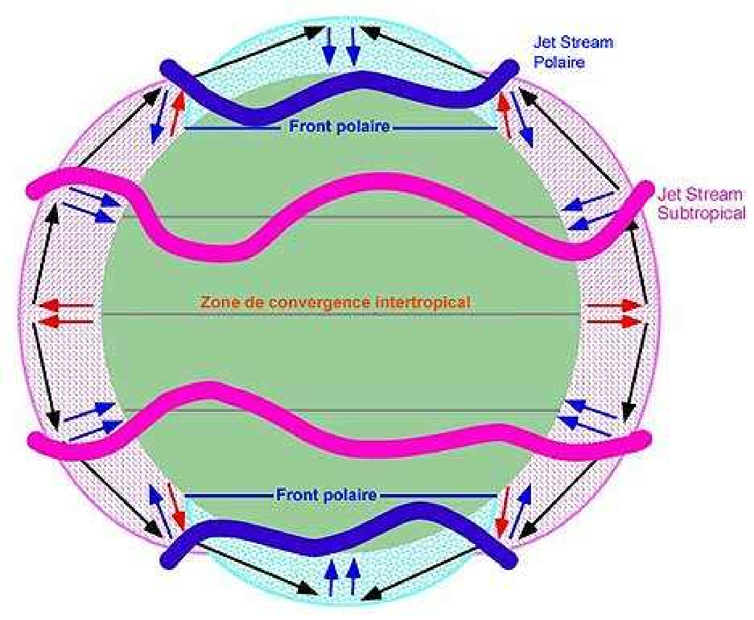
# The polar vortex

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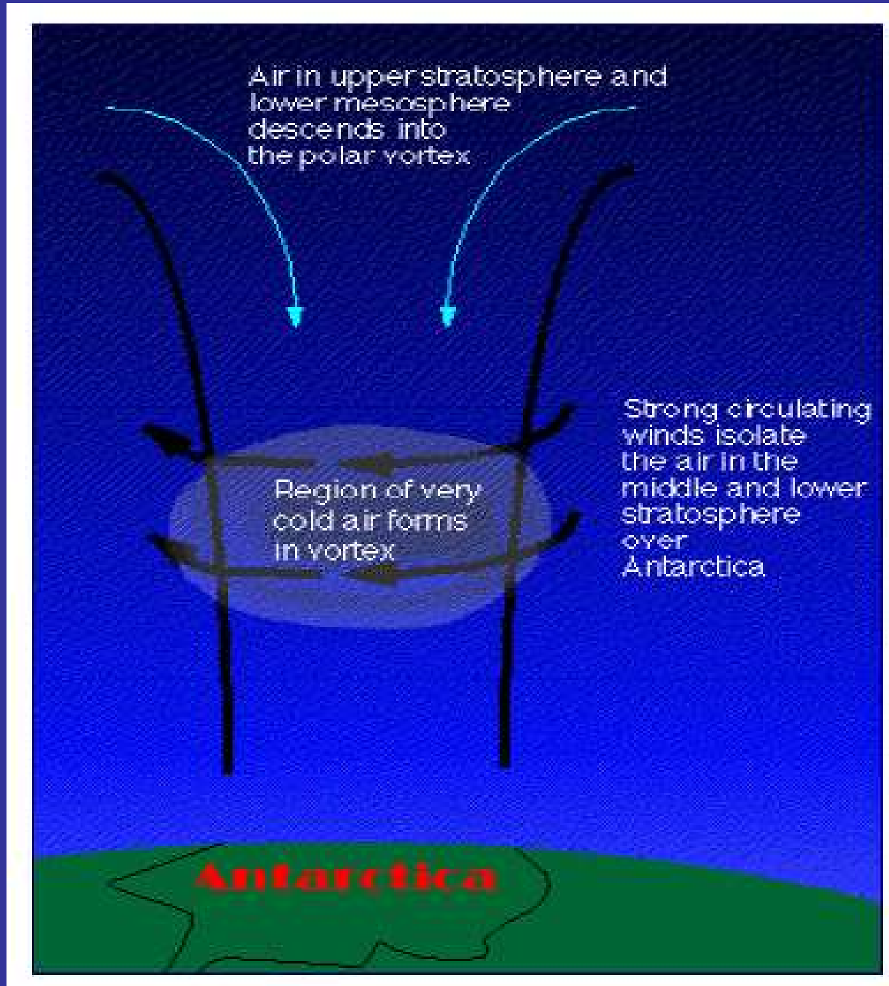
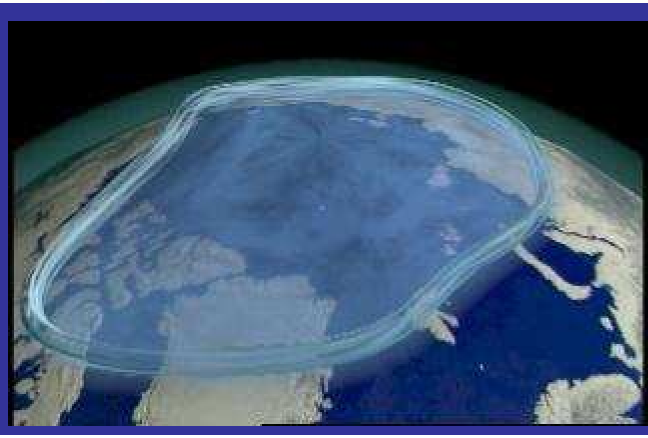
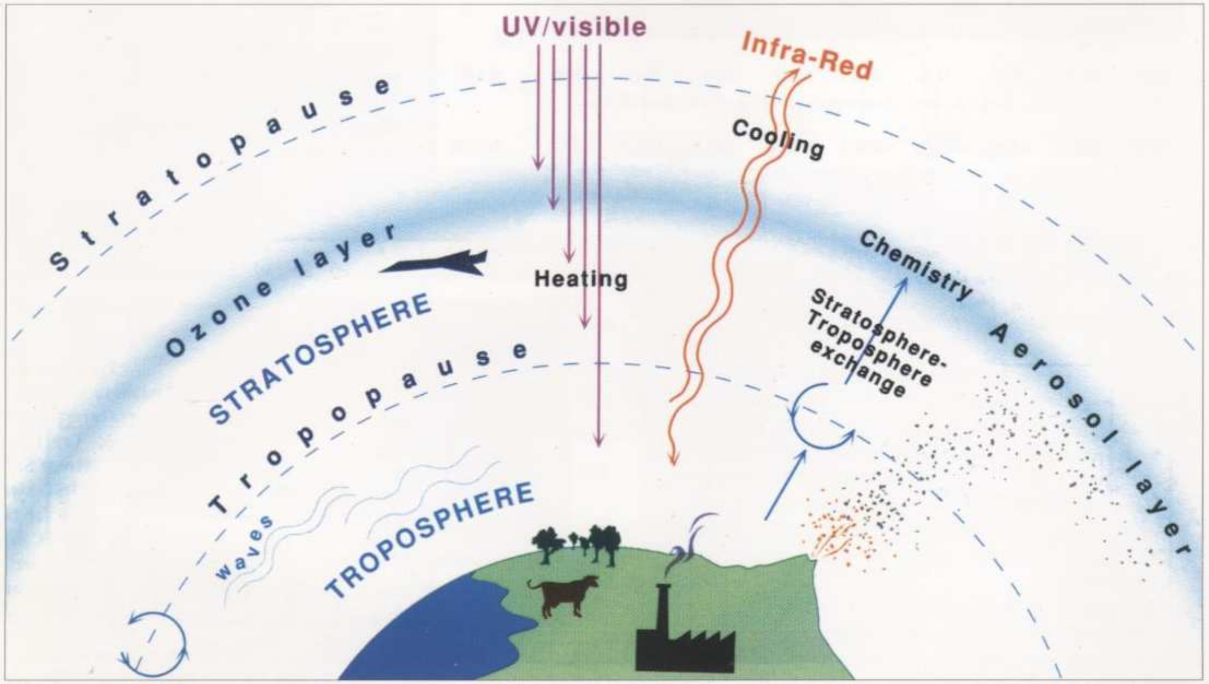


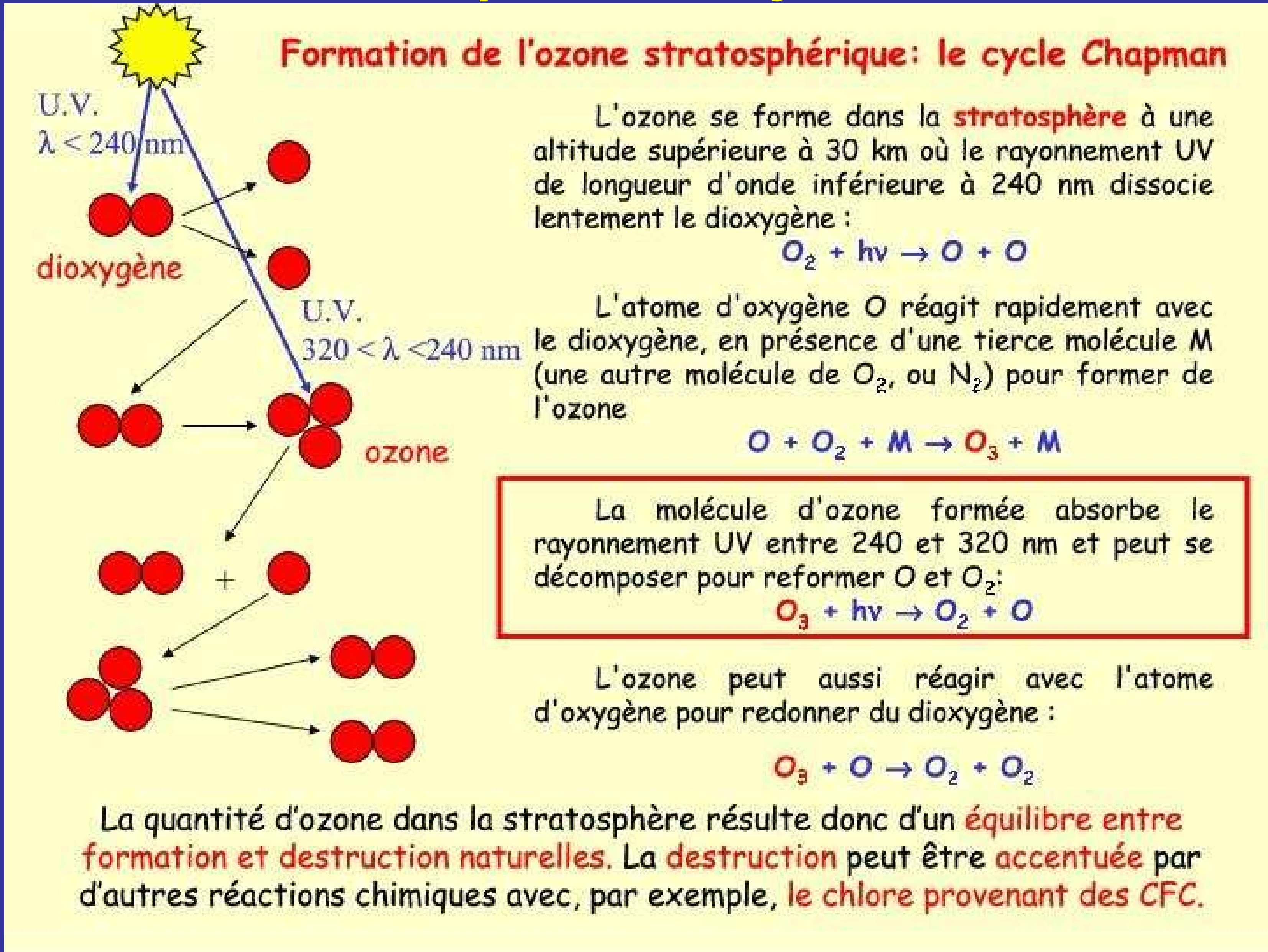
# Stratosphere and photodissociation of ozone

- Photodissociation and formation of ozone by Chapman cycle
  - –> Most of ozone is produced at low latitudes in the high atmosphere
  - –> Meridional circulation (Brewer-Dobson) => ozone also present at mid and high latitudes




SPARC: Stratospheric Processes And their Role in Climate

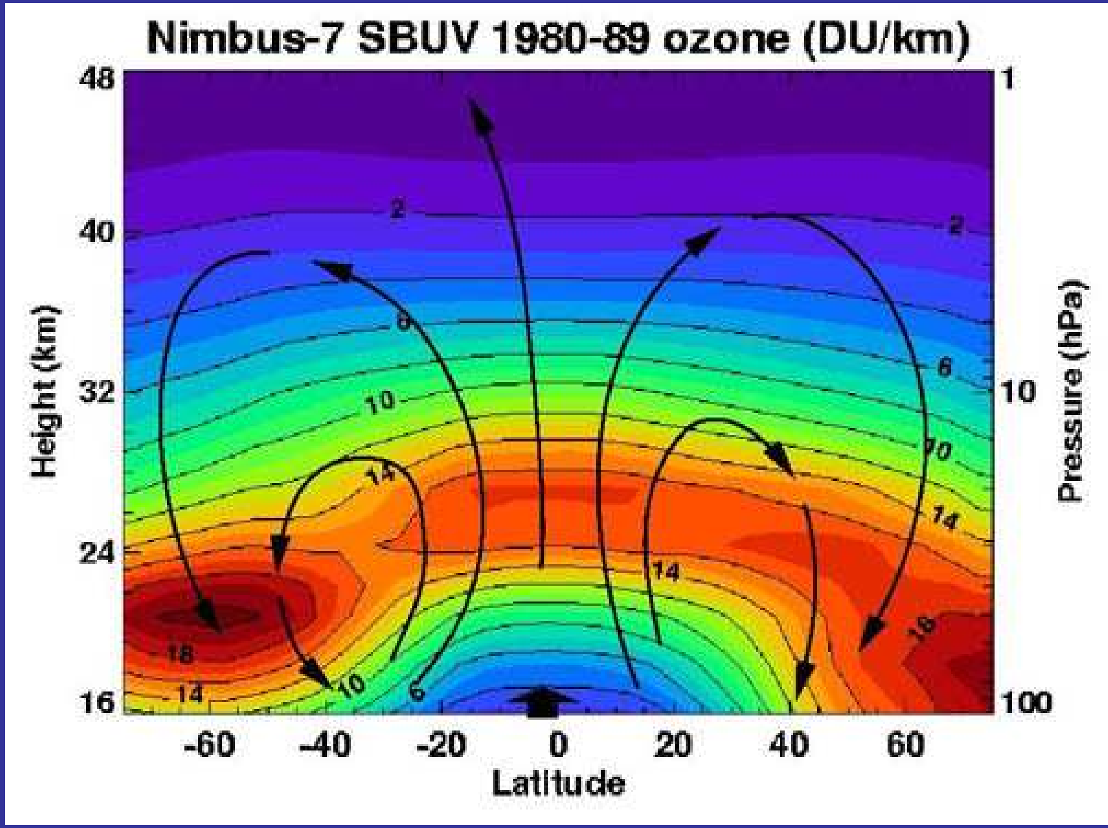
# Chapman cycle




http://perso.numericable.fr/~frgheusi/UPS/figures/chapman.jpg

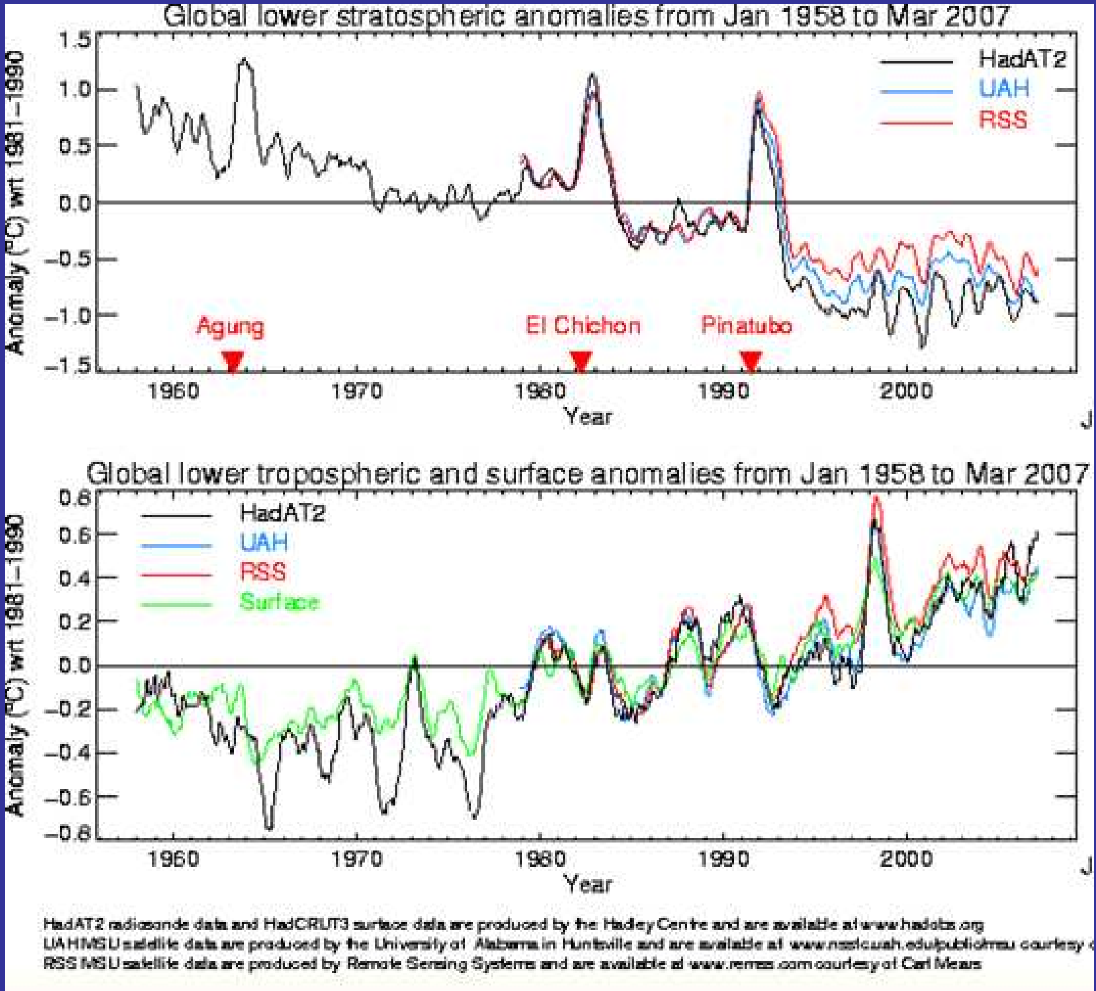
# Brewer-Dobson circulation

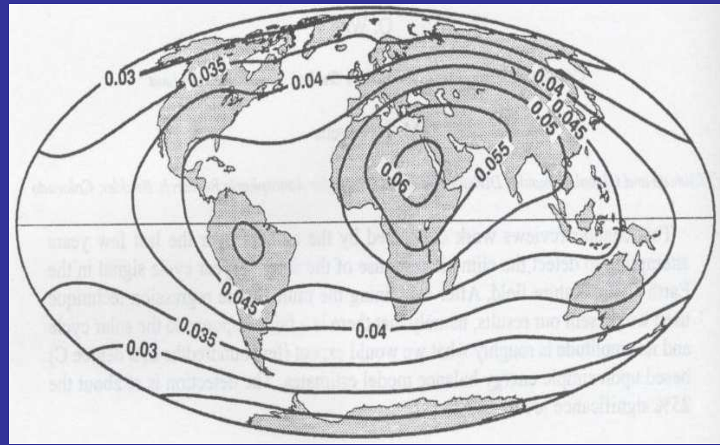
- Ozone mainly produced above tropics
- But accumulation at high latitudes
- Proposed model : Brewer-Dobson circulation
  - > slow current that redistributes the air



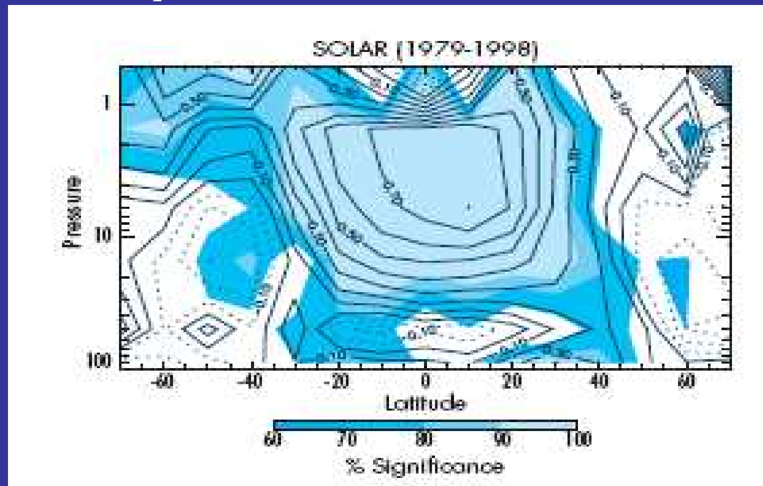
# Results and simulations

# Some literature…




Sinusoidal variation of I with an imposed 11-year variation of 0,1 % amplitude ⇒ maximum ΔT of 0.06 K [North et al., 2004]




ΔT between solar minimum and maximum from satellite measurements [Haigh et al., 2004]

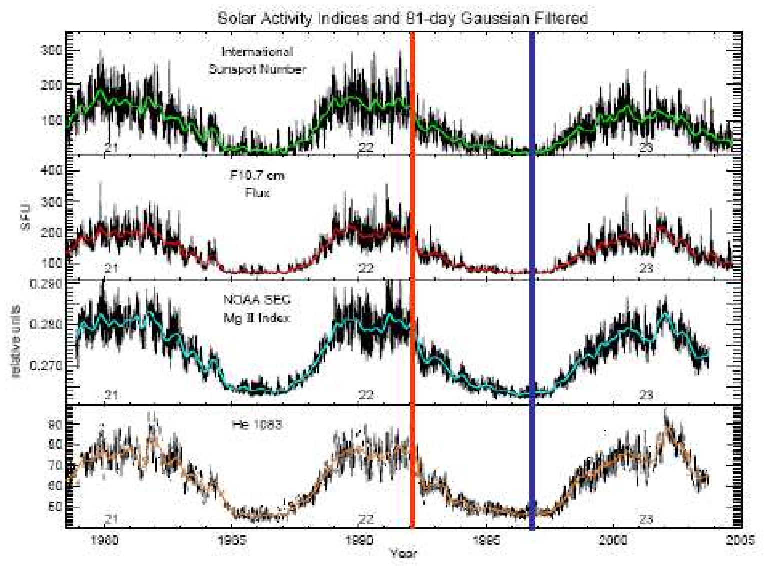
# Objectives and simulations

- LMDZ-REPROBUS = Chemistry-climate model (CCM)
  - Complete representation of dynamical, radiative and chemical process in the atmosphere and their interactions, especially feedbacks of chemical phenomenons on dynamics.
  - The solar variability is explicitly forced in the model through variations of radiative and photolysis heating rates (Lott et al. (2005), Lefèvre et al. (1994), Lefèvre et al. (1998), Jourdain et al. (2008)).
  - Other forcings (SST, sea ice, stratospheric aerosols, CFCs, GHGs, …) are constant.
  - Horizontal grid (lat x lon) : 2.5°x3.75°
  - Vertical grid : 50 levels extending from the surface to 0.07 hPa (about 65 km)

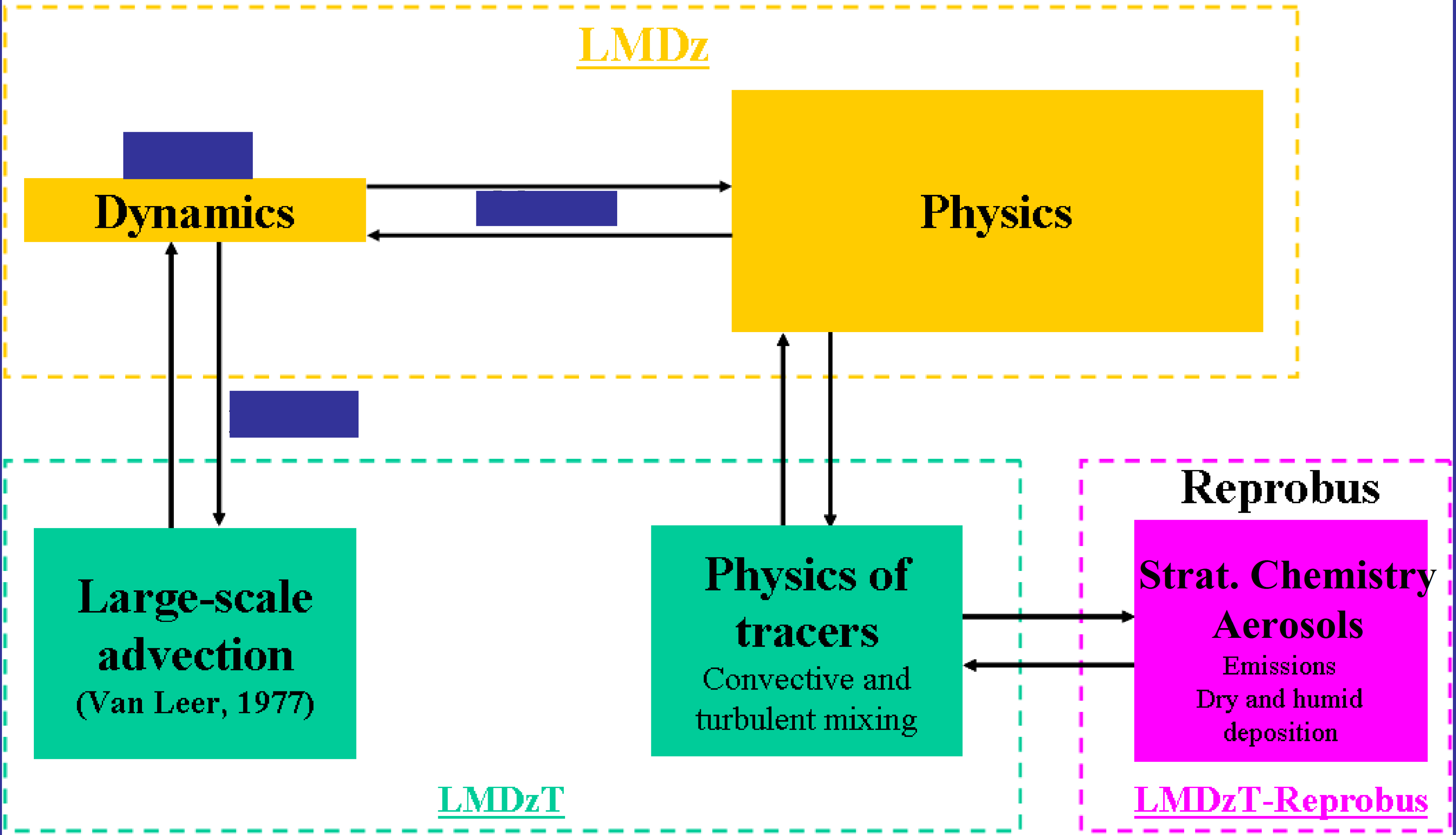
- Evaluation of the model response to the 11-year cycle
  - Experience with SUSIM/ATLAS solar fluxes
  - Solar maximum : 2 february 1992
  - Solar minimum : 10 october 1996
  - Integration of fluxes aver 2 bands :
    - 0.25 – 0.68 µm
    - 0.68 - 4 µm

- Simulations : 30 years

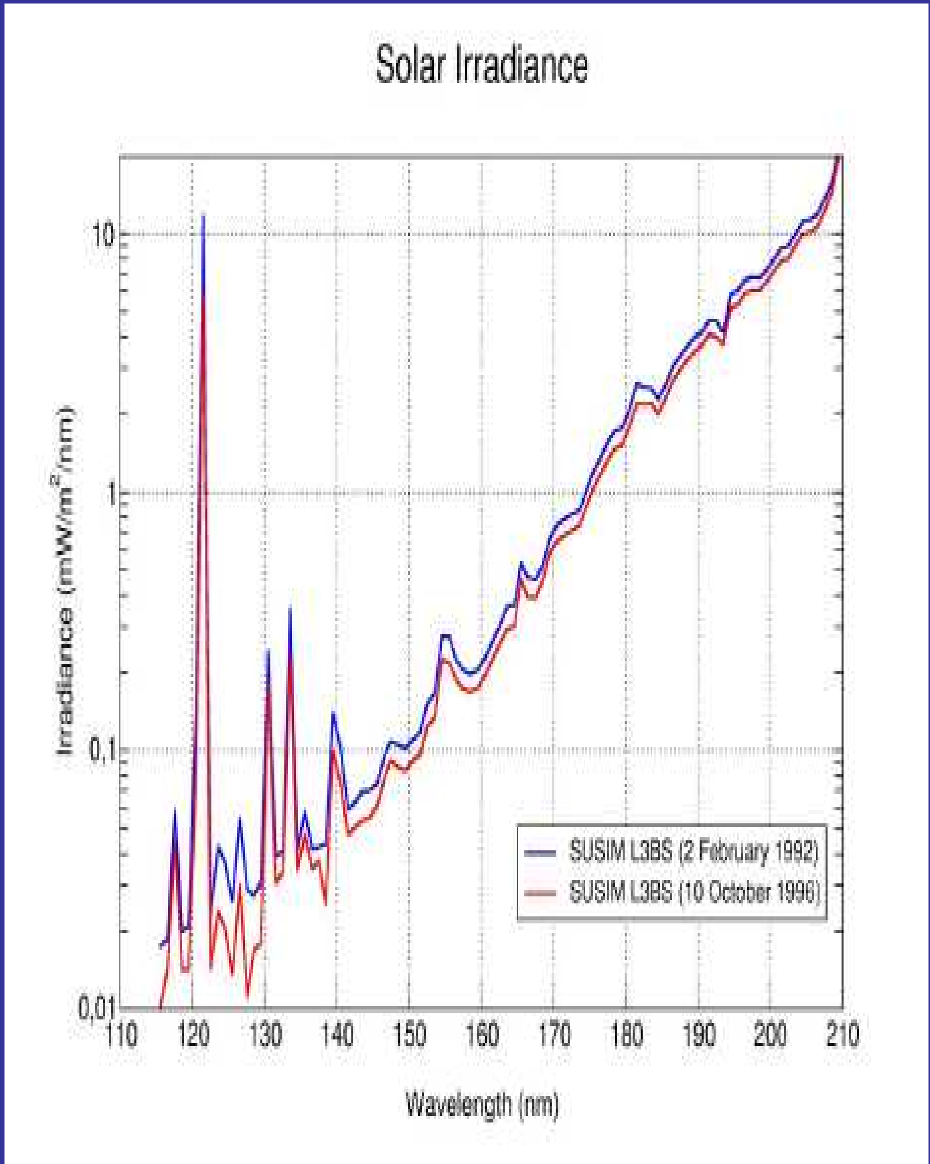
- Zonal means over 26 years (spin-up: 4 years)

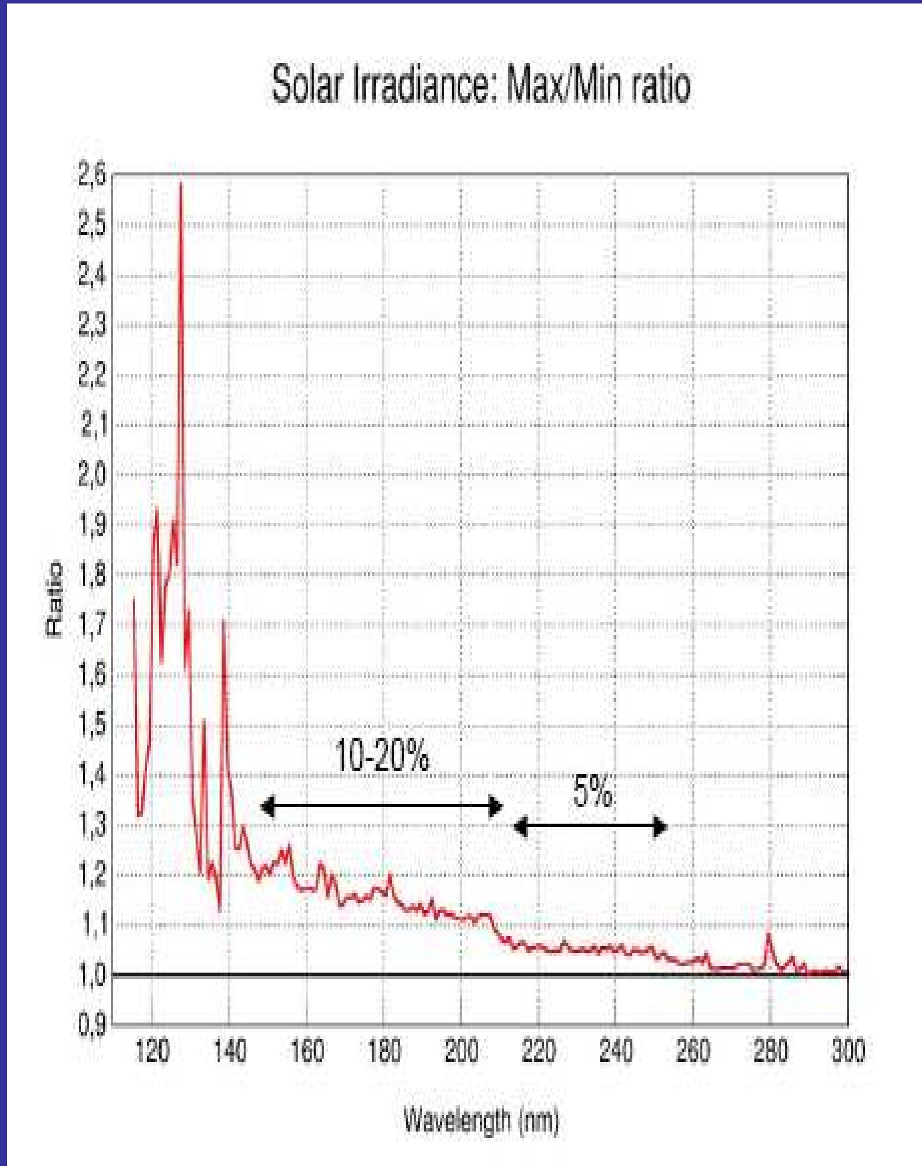


# LMDzT-REPROBUS Chemistry-Climate model

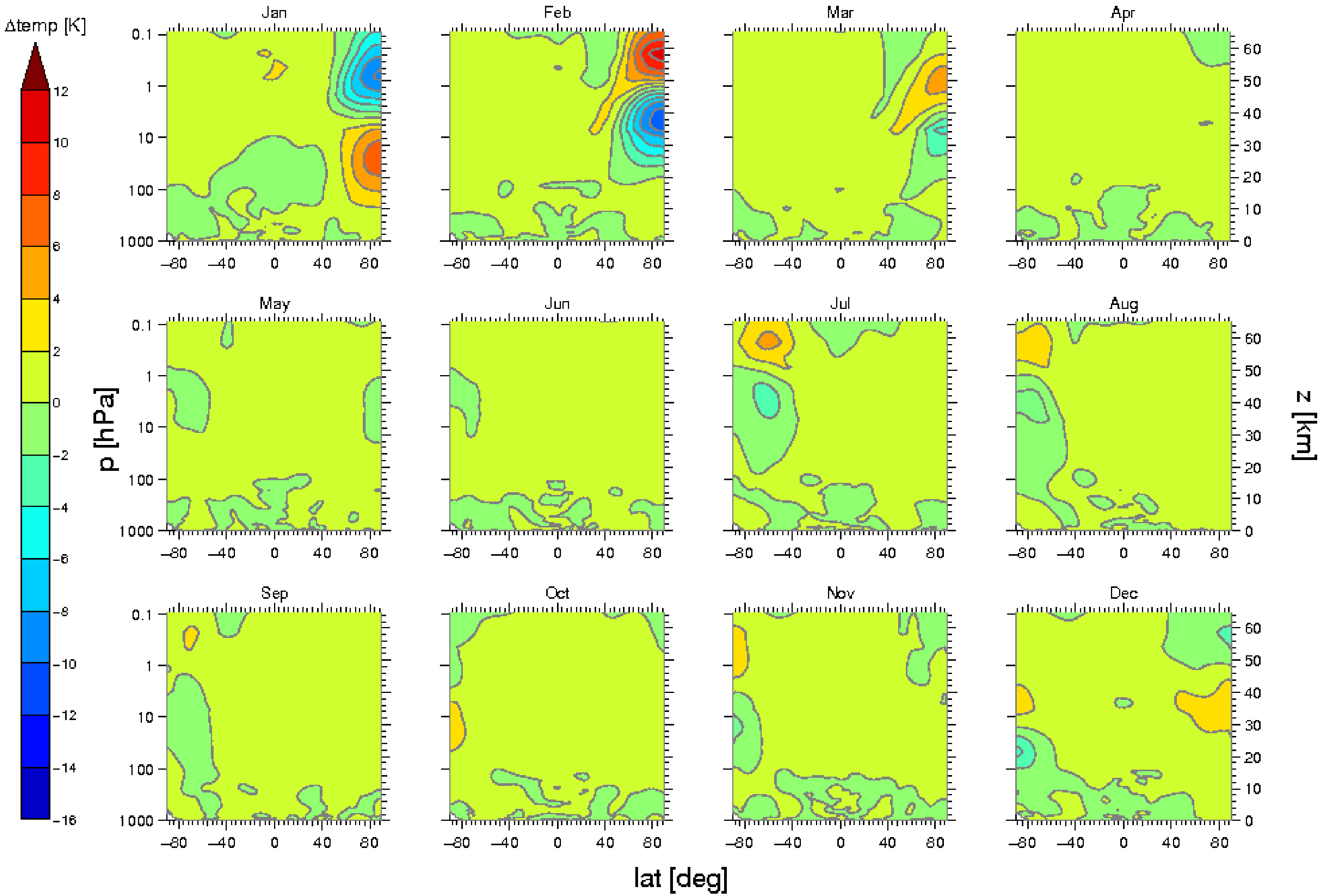


# Variation of the solar irradiance in UV for the chosen dates

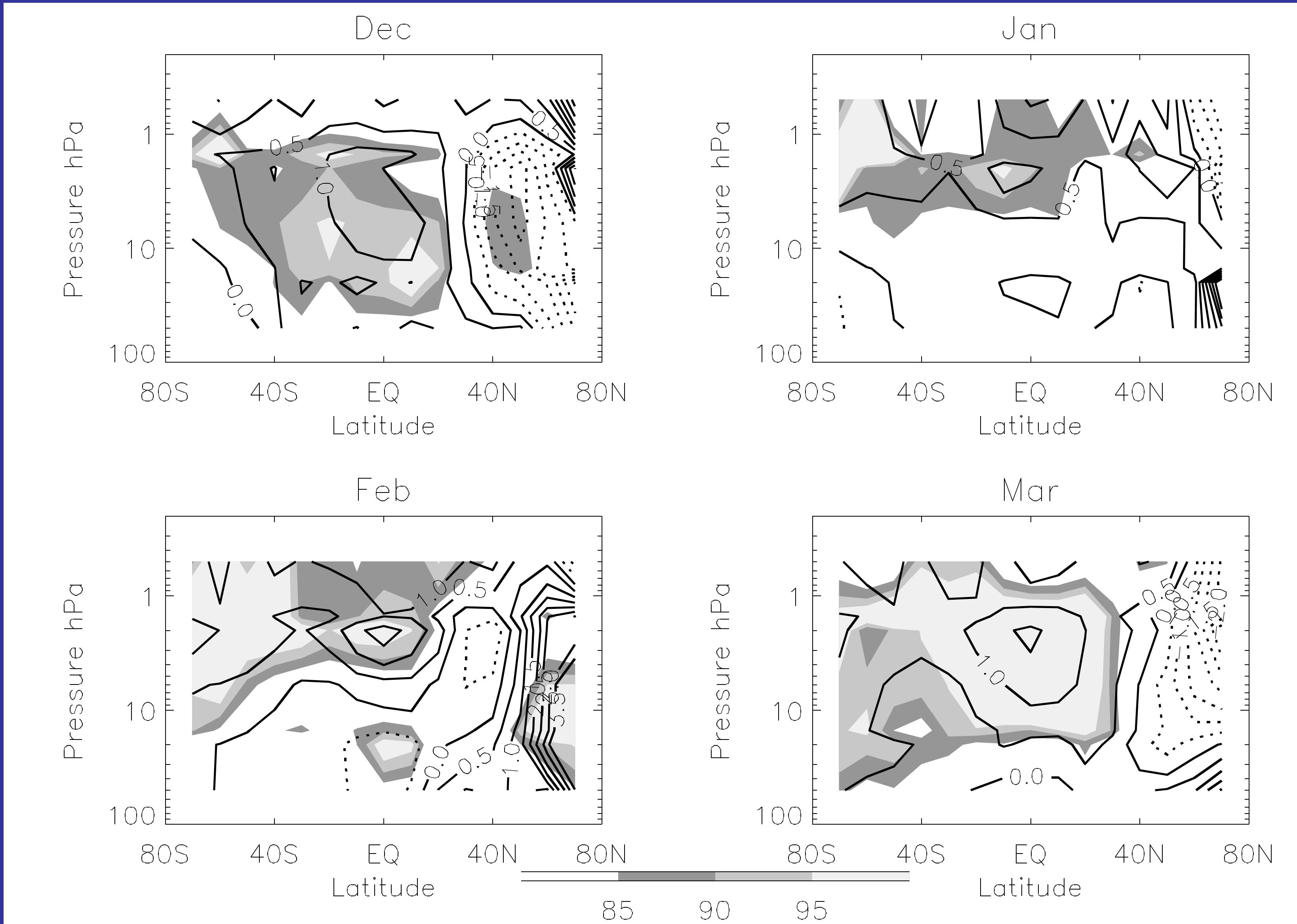


# Temperature response (model)

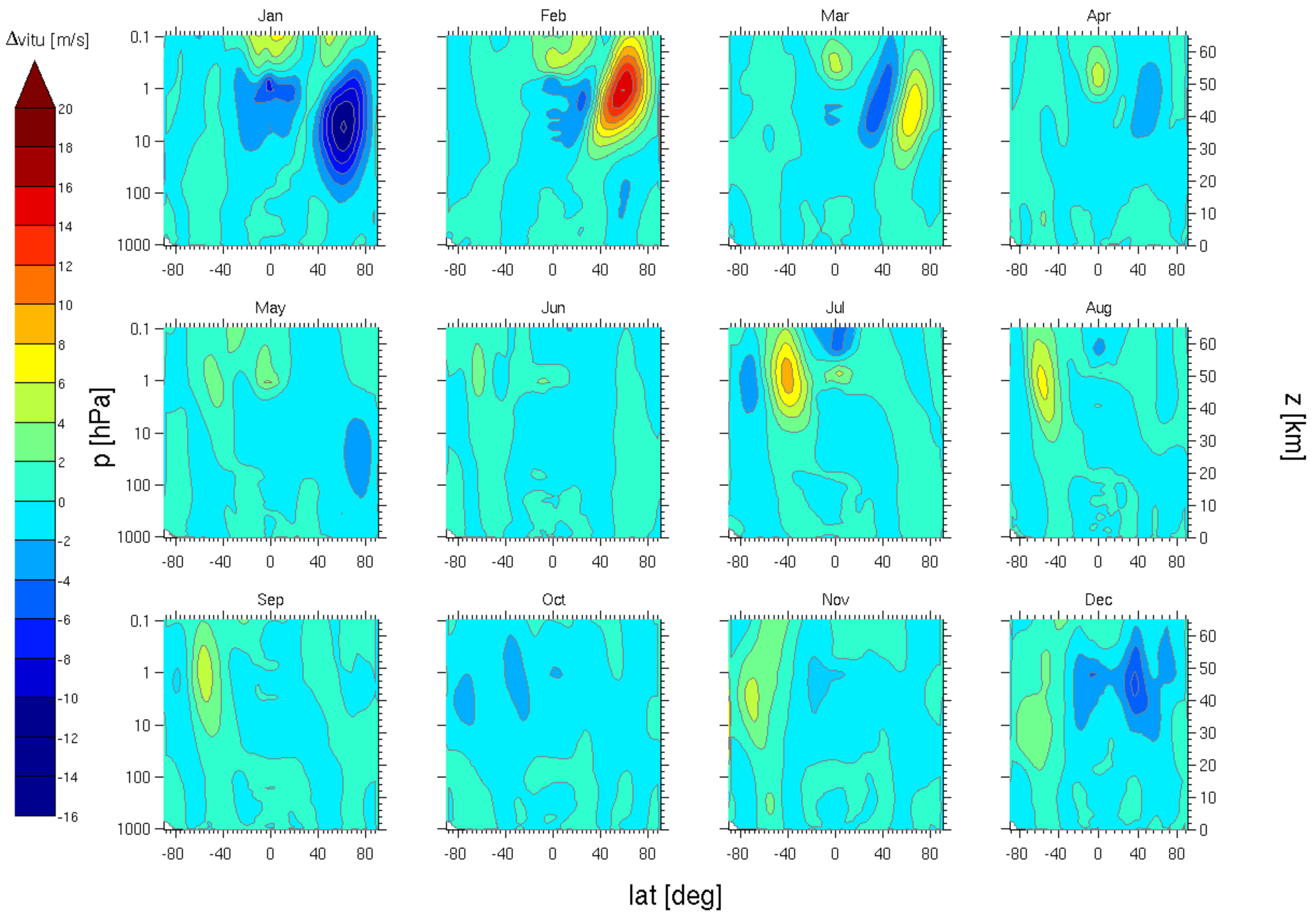


# Temperature response (SSU)

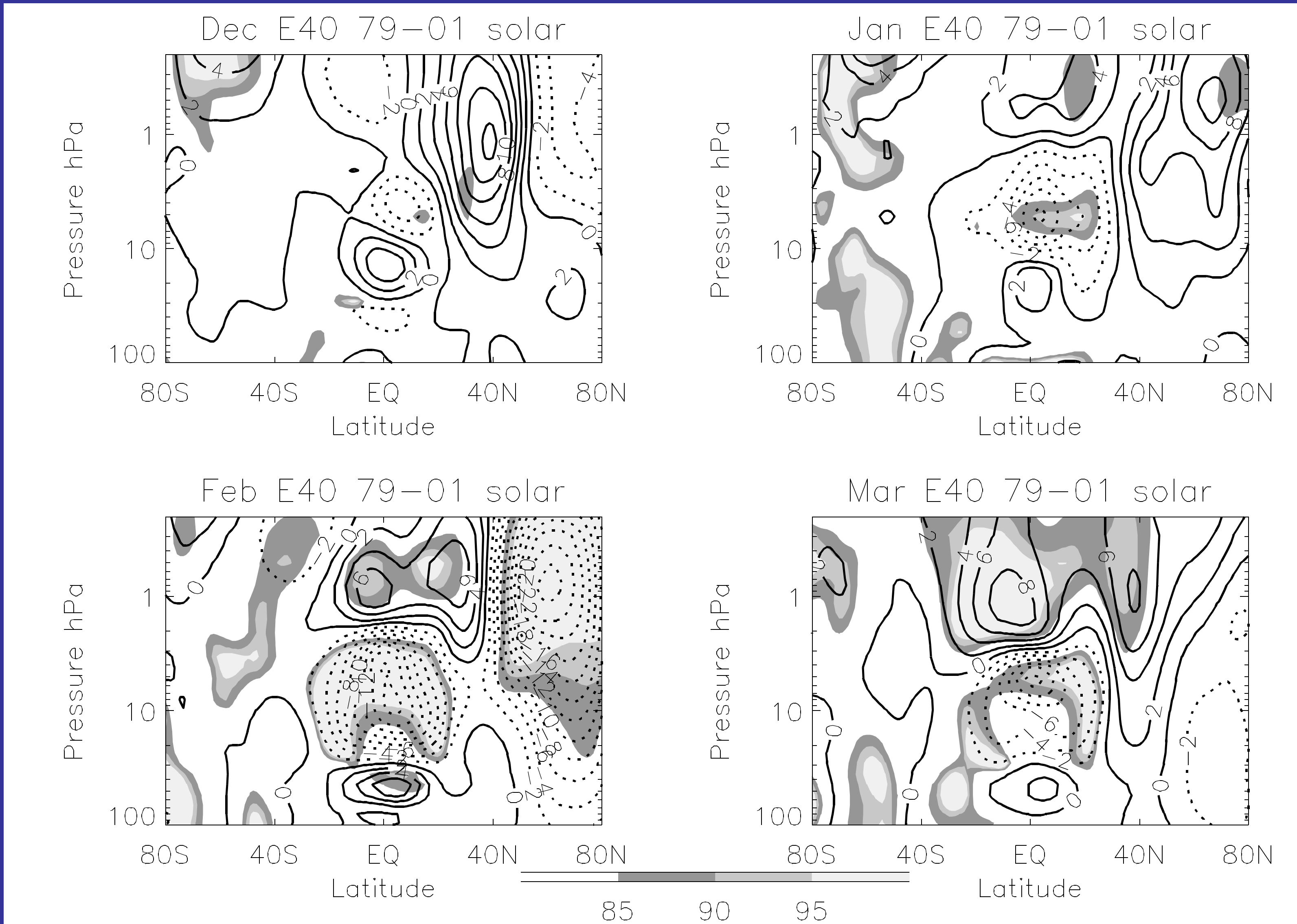



Claud et al. (2008)

# Zonal wind response (model)

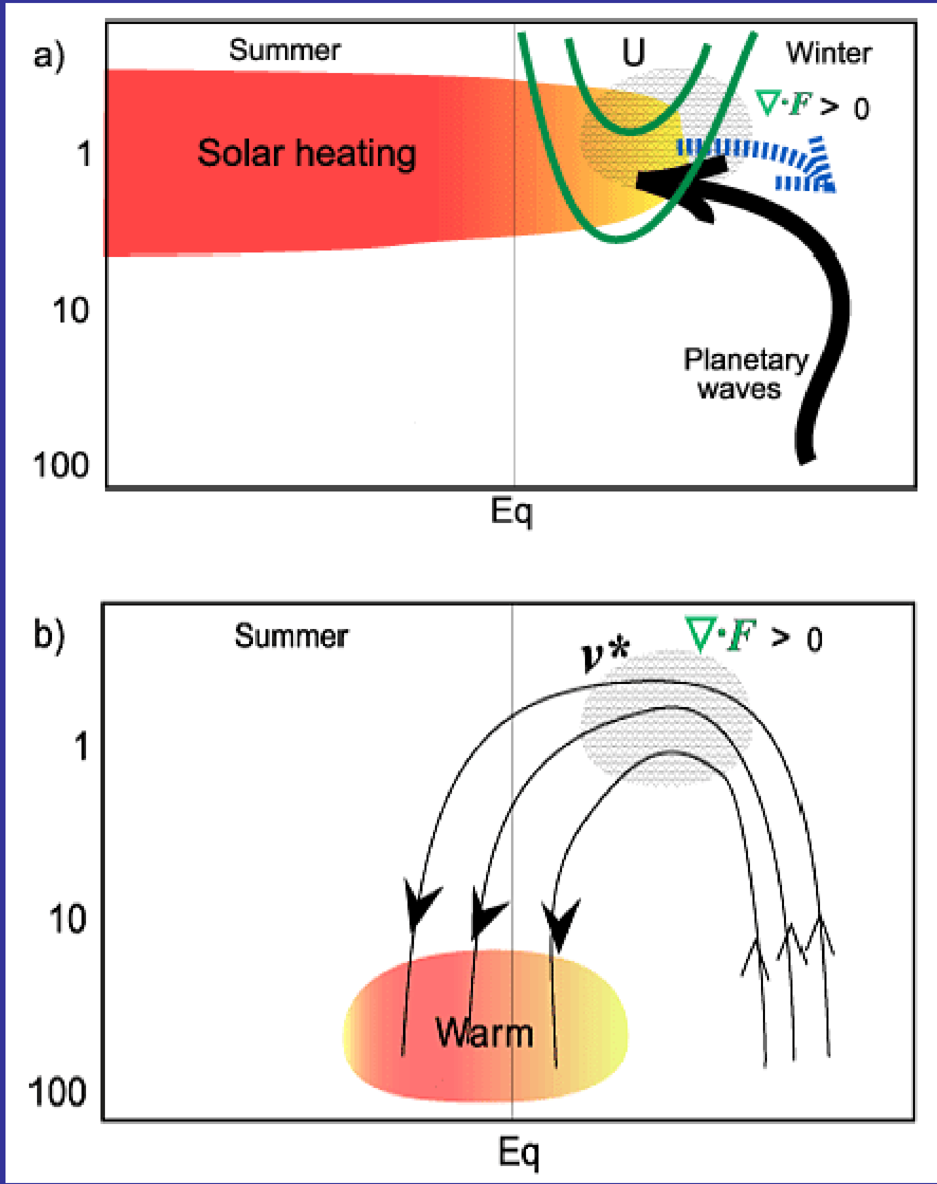


# Zonal wind response (ERA-40)




Claud et al. (2008)

# Proposition of mechanism



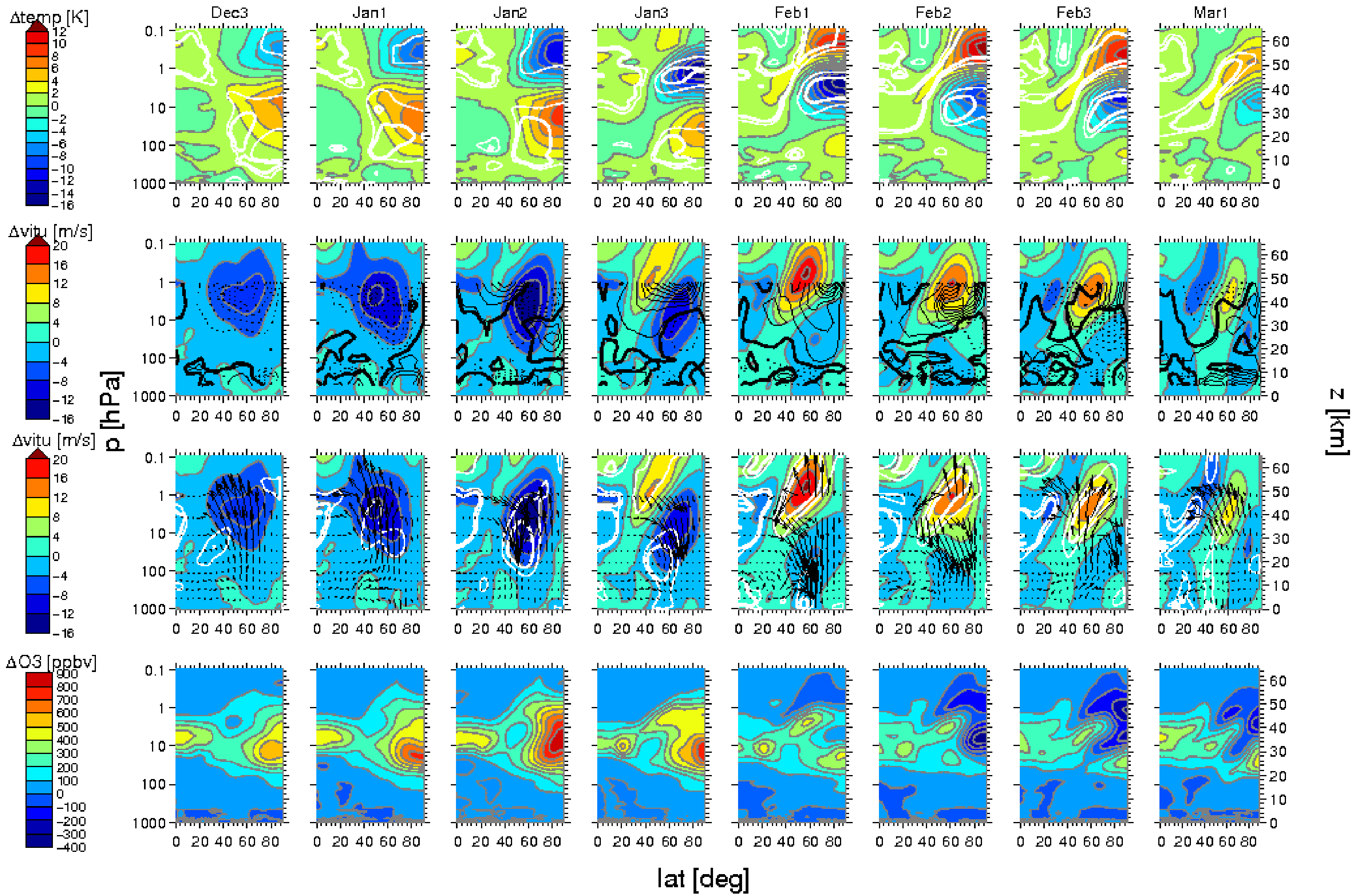

Kodera & Kuroda (2002)

1. The heating anomalies of the atmosphere due to the Sun change the strength of the the stratospheric polar jet U

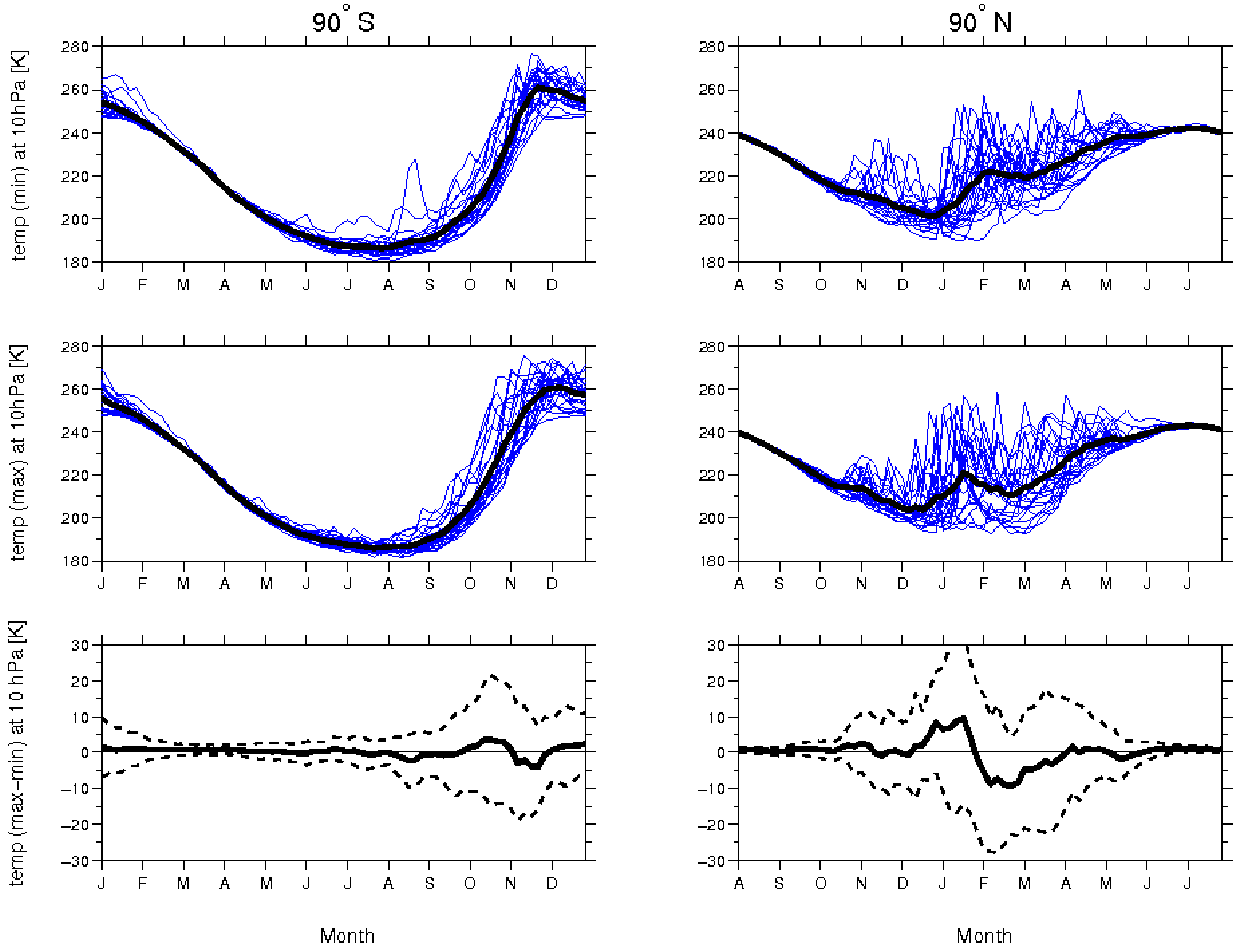
2. This influences the path of the planetary waves that deposit their zonal momentum of the side of the polar jet

3. The effect is to weaken the Brewer-Dobson circulation and thus to warm up the tropical low stratosphere

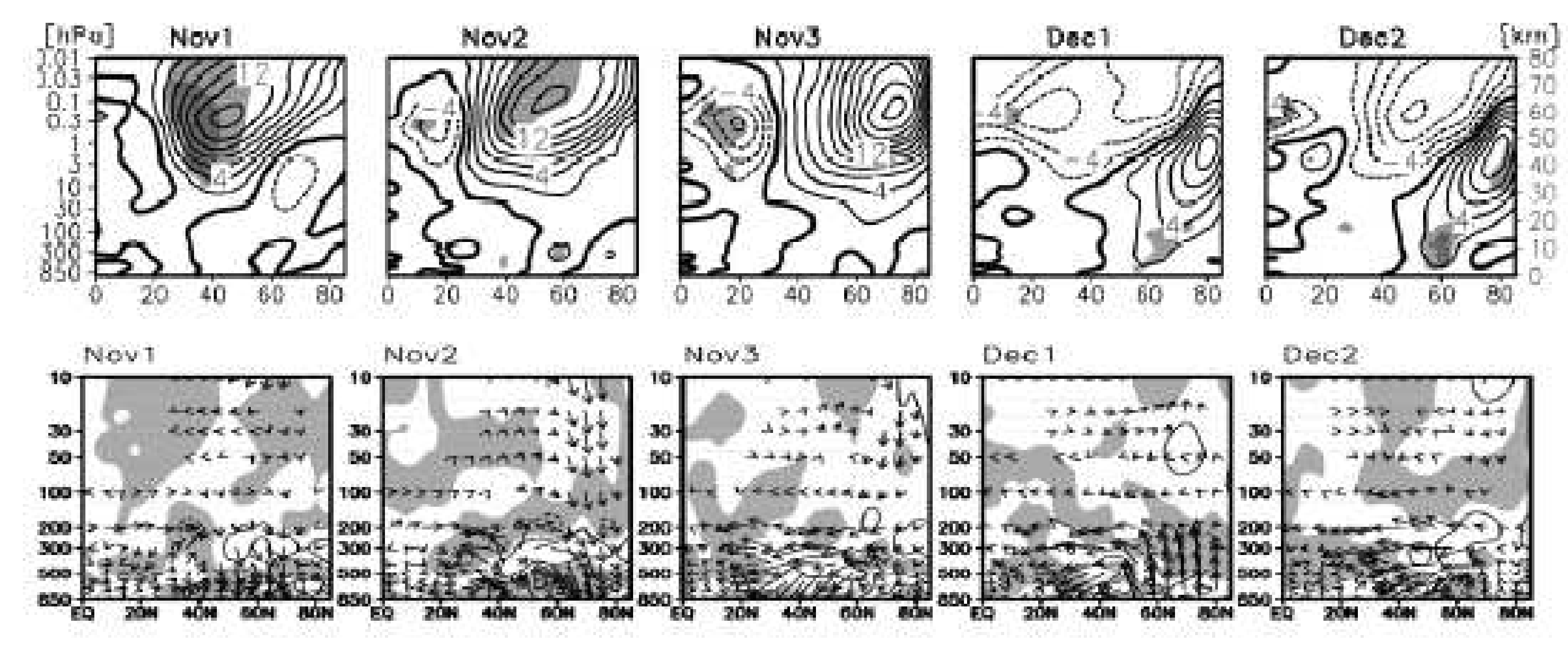
# Visualization of the planetary waves



# Sudden stratospheric warmings

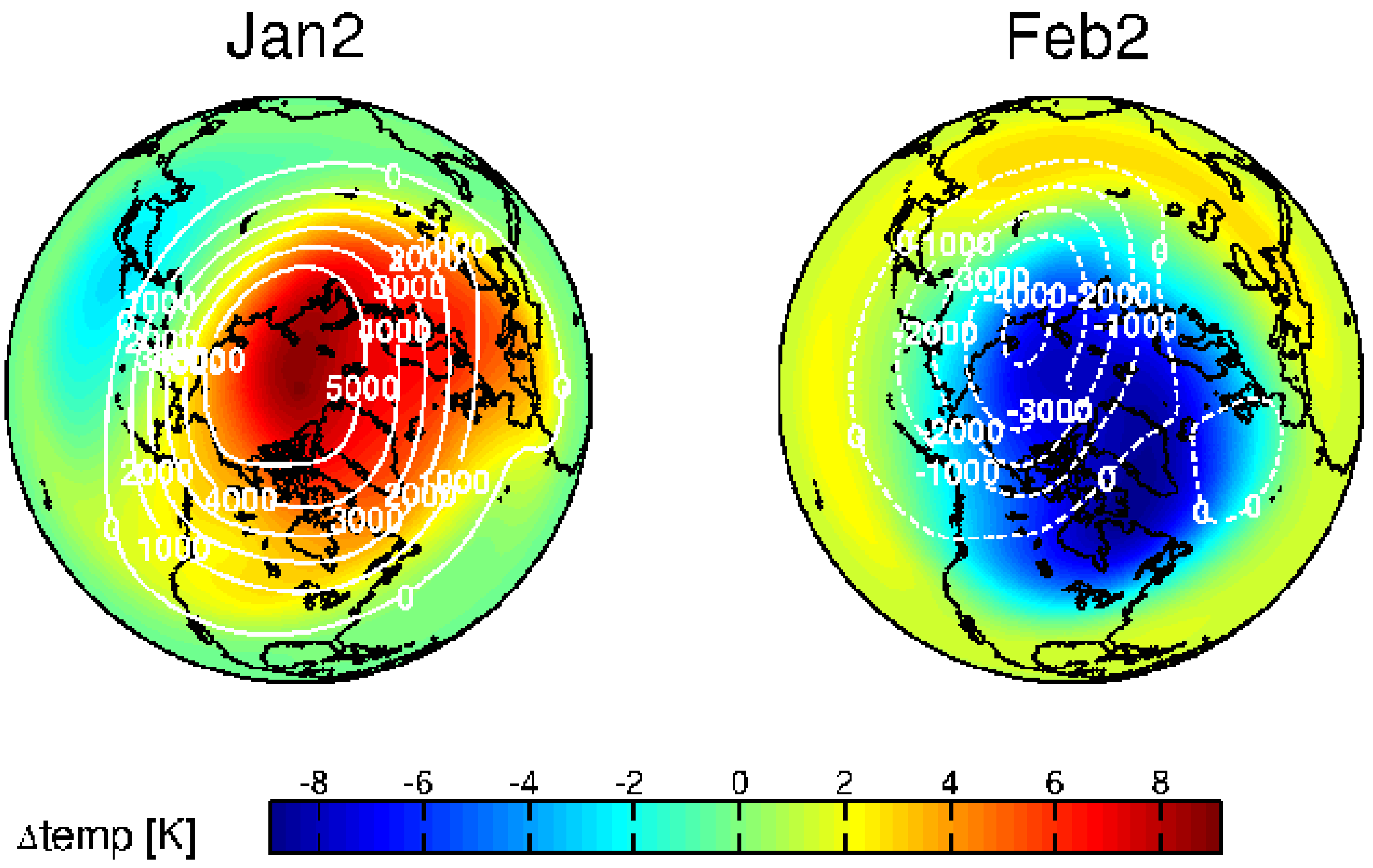


# Comparison with an other study



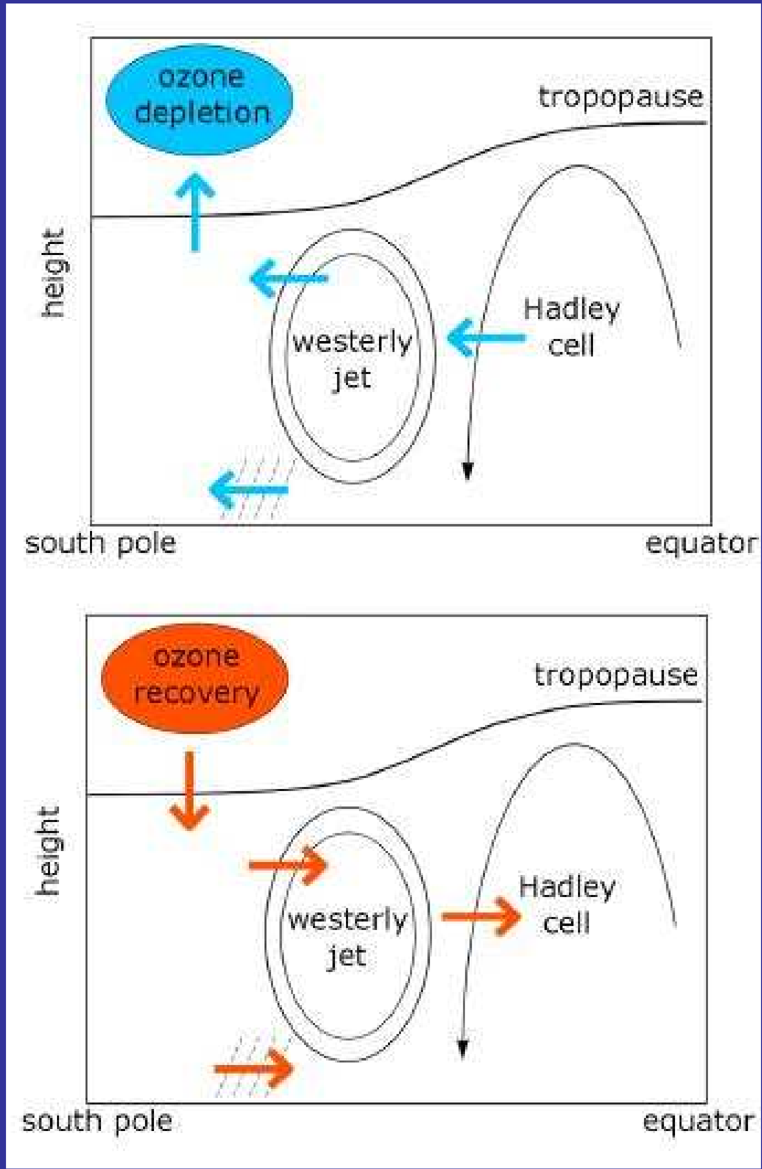

Matthes et al (2006)

# Longitudinal variation of the solar signal



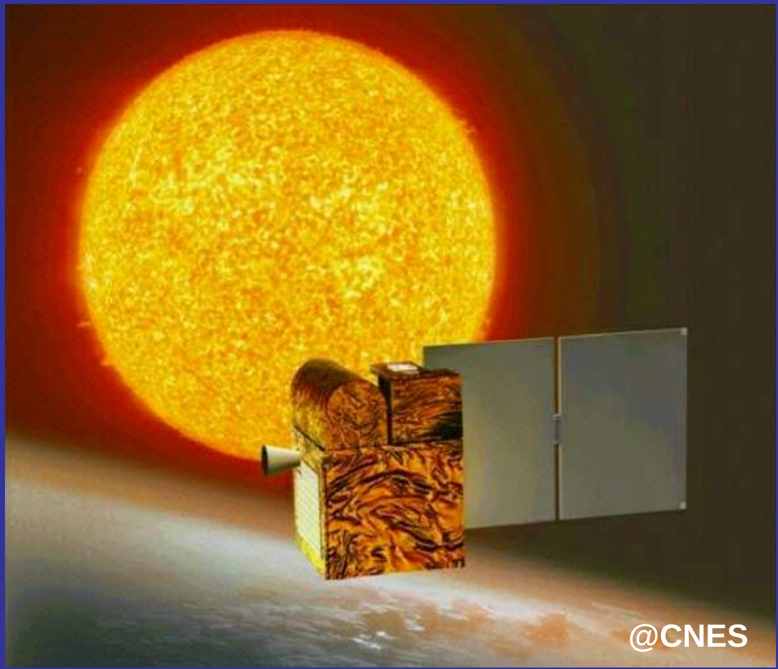
# Conclusions and perspectives

- Reinforcement of the polar vortex in winter
  - Coherence between model and observations (Claud et al., 2008) but temporal shift
  - More wave activity (Matthes et al., 2006)
  - Modulation of the Brewer-Dobson circulation (Haigh 1994, Haigh 1996, Shindell et al. 1999)
  - Polar jet affected during the night (Kodera & Kuroda 2002, Matthes et al. 2004 and 2006, Haigh & Blackburn 2006)
  - Increasing of the sudden stratospheric warmings
- Improvements of the model
  - Radiative code (SW) : 2 bands -> 6 bands
  - Extension to the high mesosphere / low thermosphere
- Analysis of the simulation with a real 11-year solar signal as imput in the model
- Simulation of the Maunder minimum
- Simulation with ocean coupling
  - More realistic influence on the climate

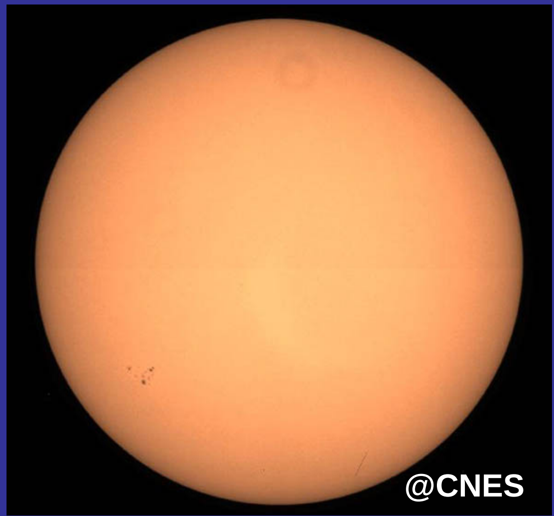



Son et al (2010)

# Future data : The PICARD mission




- CNES microsatellite launched the 15 of June 2010
- http://smsc.cnes.fr/PICARD/Fr
- Objectives:
  - Better understanding the physics and internal structure of the Sun
  - Better understanding the solar forcing on climate




- Measurements:
  - Diameter and shape of the Sun
  - Differential rotation
  - Solar irradiance and UV flux
  - Helioseismologic modes
  - W parameter (ratio between the solar luminosity variations and the diameter variations) important for the solar forcing studies

Thank you !

# References


- Claud, C., Cagnazzo, C., & Keckhut, P. 2008, JASTP, 70, 2031
- Fröhlich, C. 2000, Space Sci. Rev., 94, 15
- Haigh, J. D. 1994, Nature, 370, 544
- Haigh, J. D. 1996, Science, 272, 981
- Haigh, J. D., & Blackburn, M. 2006, Space Sci. Rev., 125, 331
- Jourdain, L., Bekki, S., Lott, F., & Lefèvre, F. 2008, Ann. Geophys., 26, 1391
- Kodera, K., & Kuroda, Y. 2002, JGR, 107(D24), 4749
- Lean, J. L. 1989, Science, 244, 187
- Lean, J. L. 1991, Rev. Geophys., 29, 4
- Lefèvre, F., Brasseur, G. P., Folkins, I., Smith, A. K., & Simon, P. 1994, JGR, 99, 8183
- Lefèvre, F., Figarol, F., Carslaw, K. S., & Peter, T. 1999, GRL, 25(13), 2425
- Lott, F., Fairhead, L., Hourdin, F., & Levan, P. 2005, Clim. Dyn., 25, 851
- Matthes, K., Langematz, U., Gray, L. J, Kodera, K., & Labitzke, K. 2004, JGR, 109, D06101
- Matthes, K., Kuroda, Y., Kodera, K., & Langematz, U. 2006, JGR, 111, D06108
- Shindell, D., Rind, D., Balachandran, N., Lean, J., & Lonergan, P. 1999, Science, 284, 305
- Son et al. 2010, JGR
- Thuillier, G., Dewitte, S., & Schmutz, W. 2006, Ad. Space Res., 38, 1792