POLAR SCIENCE FOR PLANET EARTH

Atmospheric Responses to Solar Wind Dynamic Pressure

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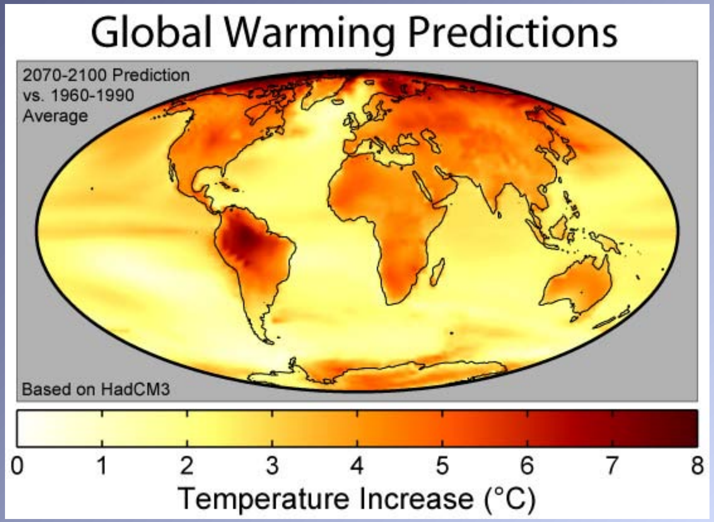
British Antarctic Survey

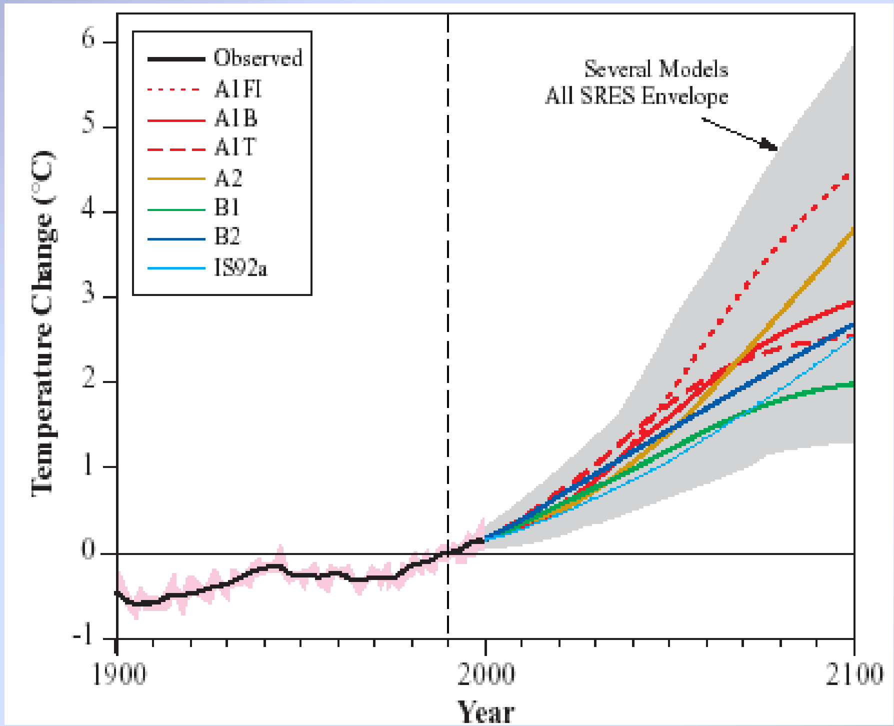
Outline

- Background: Sun-Earth Climate Connection
- Solar wind/geomagnetic activity signals with 3 examples
  - stratospheric Quasi-Biennial Oscillation (QBO)
  - the Northern Annular Mode (NAM)
  - A non-linear relationship between geomagnetic activity and the North Atlantic Oscillation (NAO)
- Possible mechanisms

Motivation: Climate Change and Global Warming

Large Uncertainty Is Associated with the Model Prediction





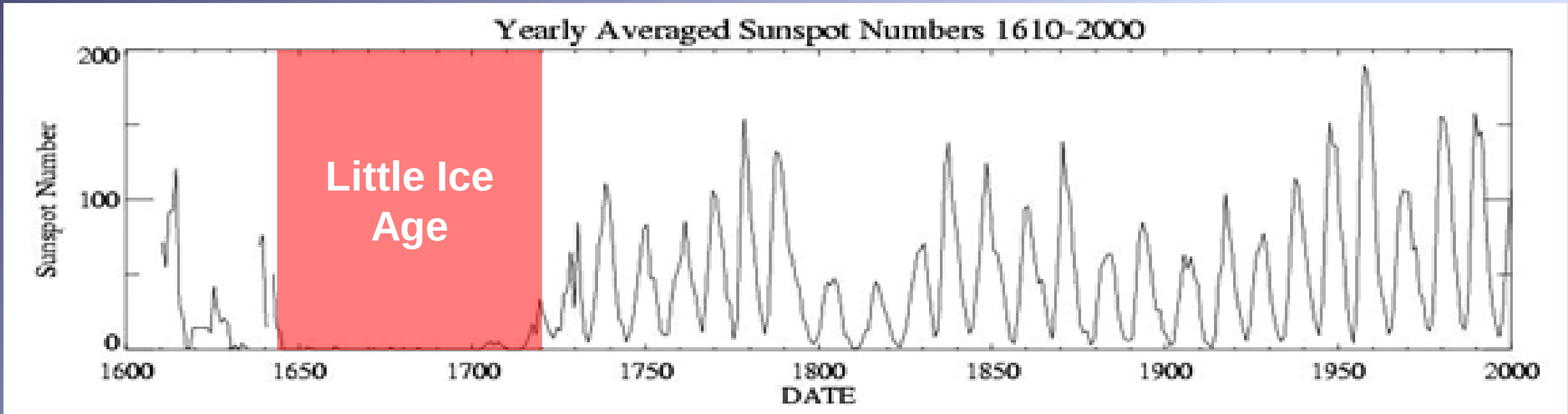
Predictions made by Intergovernmental Panel on Climate Change (IPCC)

- Reduce uncertainty
- Better understanding natural *vs* human induced changes

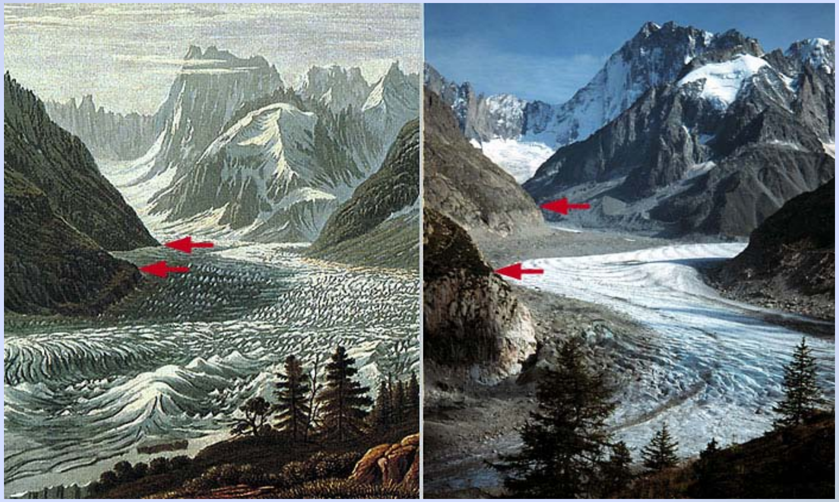
Part I:

Background: Sun-Earth Climate Connection

Natural Climate Variability



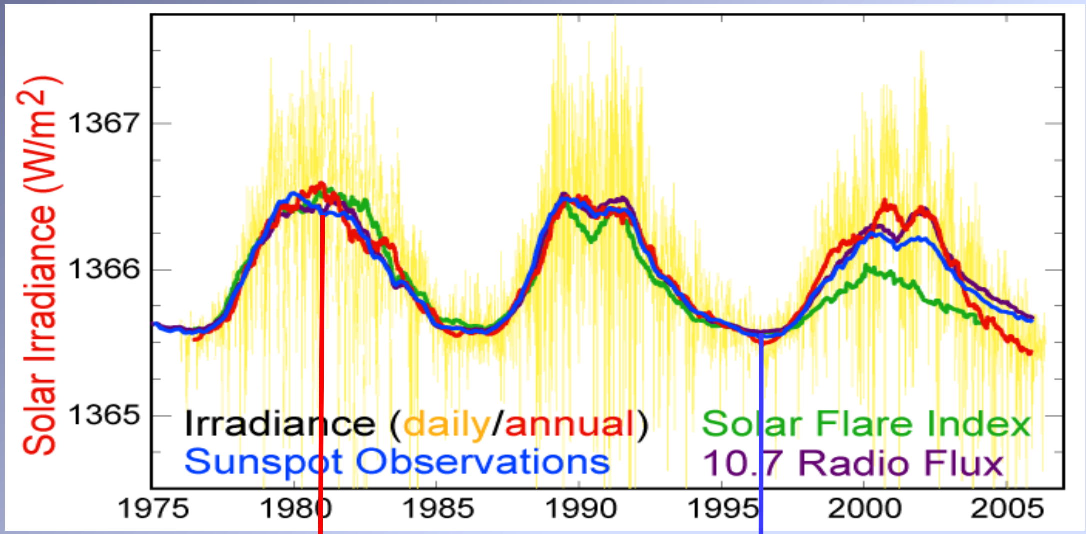
Frost Fair on the River Thames

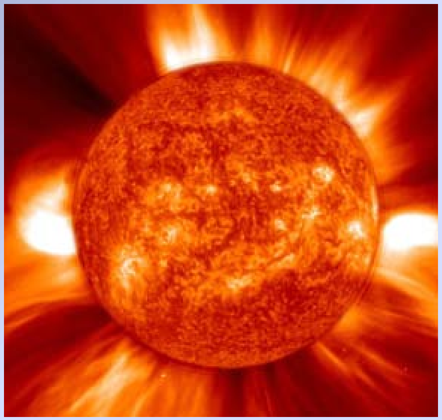


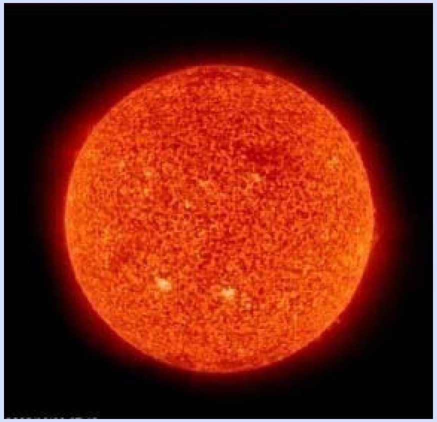
The Mer de Glace viewed from Montenvers, Mont Blanc region, French Alps, Swiss National Library

The Variable Sun

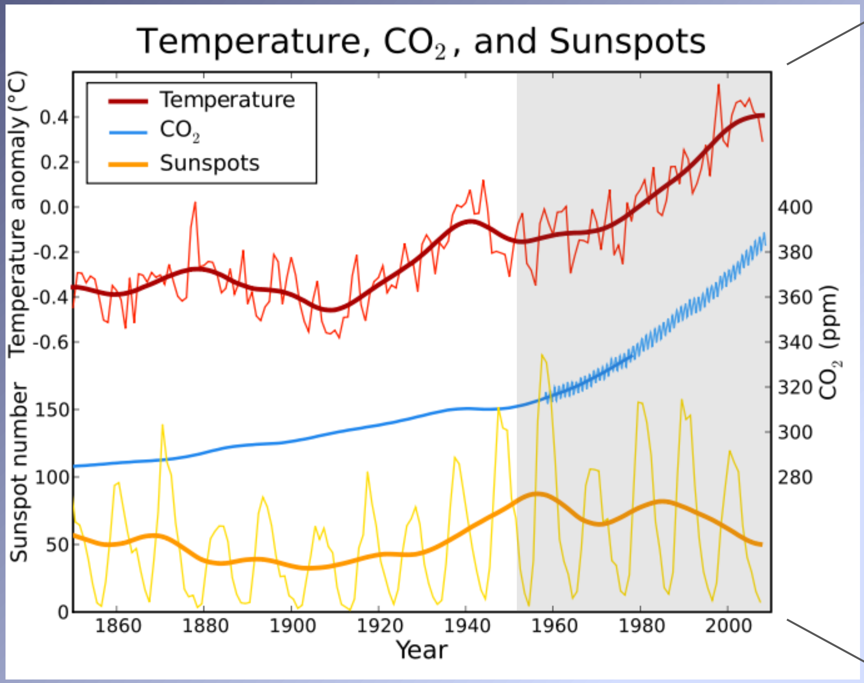
The 11-year Solar Cycle and Solar Irradiance

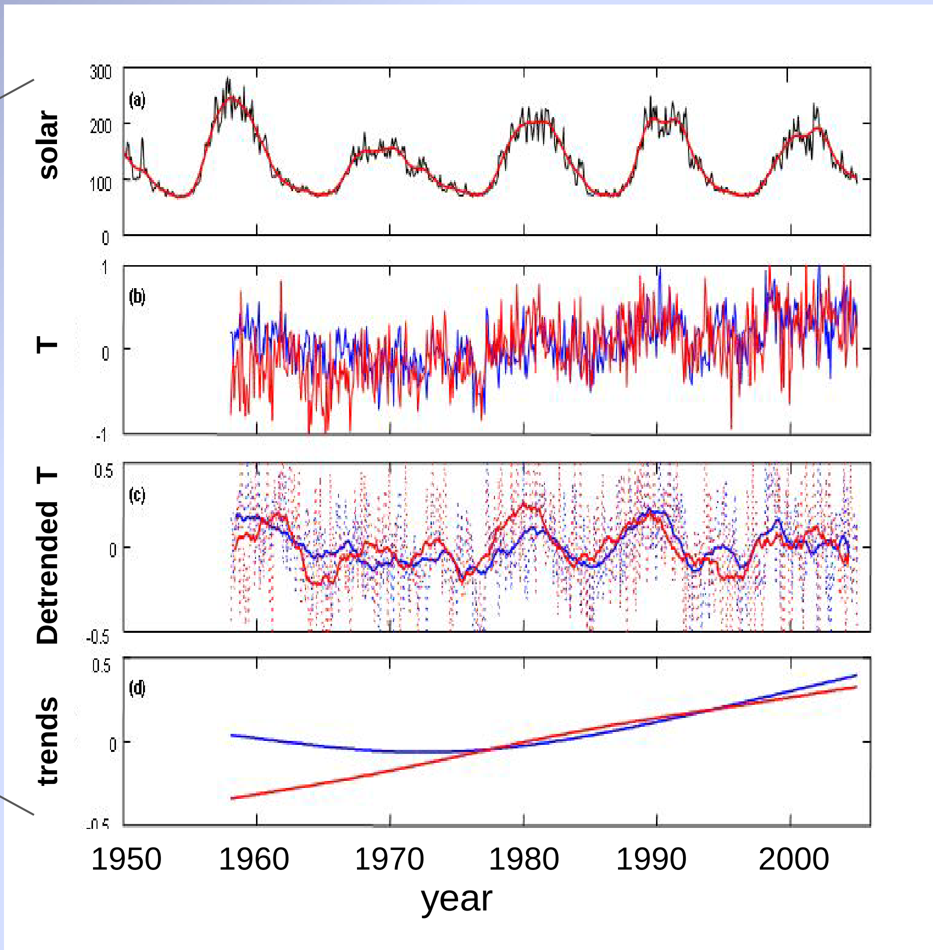



active sun


quiet sun

The Sun Affects Earth's Atmospheric Temperature

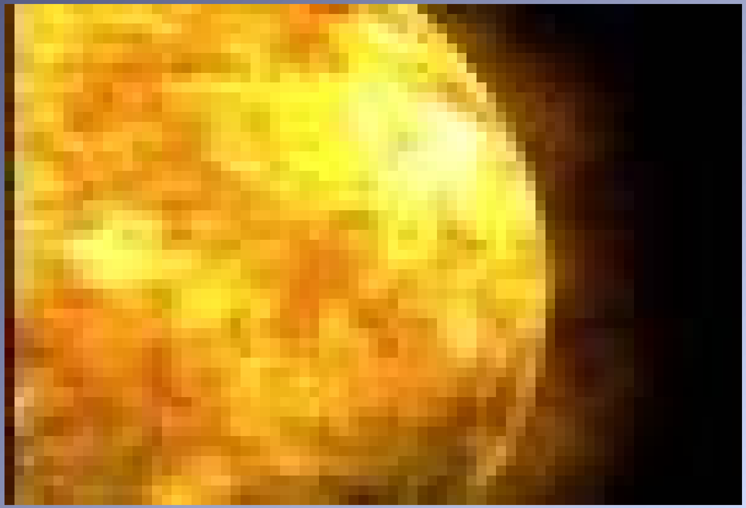




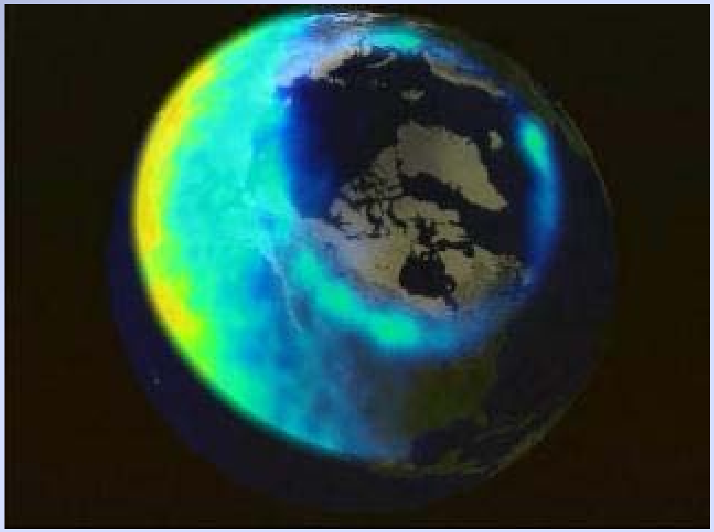
- A lot of research has been done in this area
- But it is not the focus of this talk

(Lu et al. 2007, JGR)

Solar Wind and Energetic Particles Precipitation

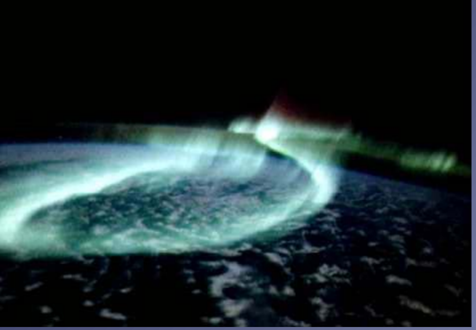


Corona Mass Ejection, most associated with proton precipitation



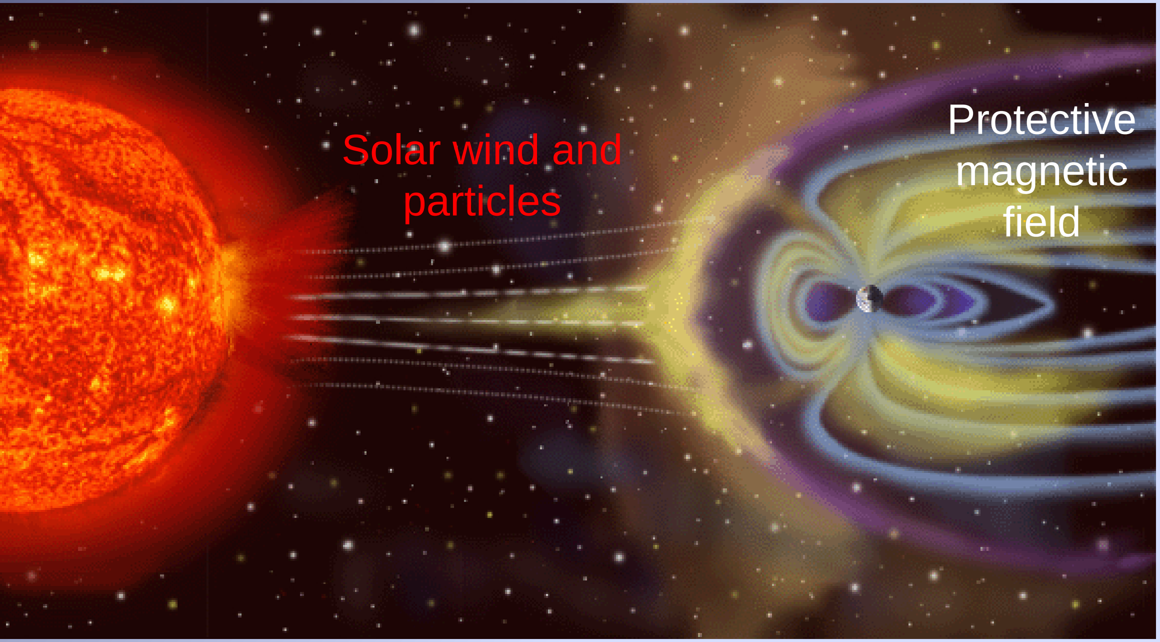
Aurora activity is caused by high speed solar wind, most associated with electron precipitation and is affect by Sun's 27 day rotational periodicity

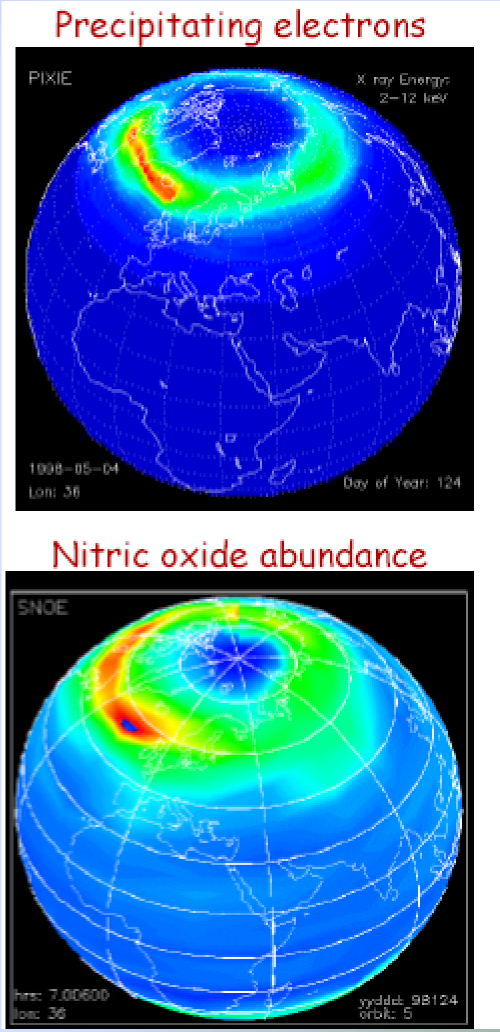
Acknowledgement: the video clips are created by and downloaded from NASA Goddard Space Flight Centre



Solar Wind and Particle Precipitation

- particles precipitate into the Earth's atmosphere
- produce ionization from 150km down to ~40 km
- generate odd nitric oxide which may destroy ozone

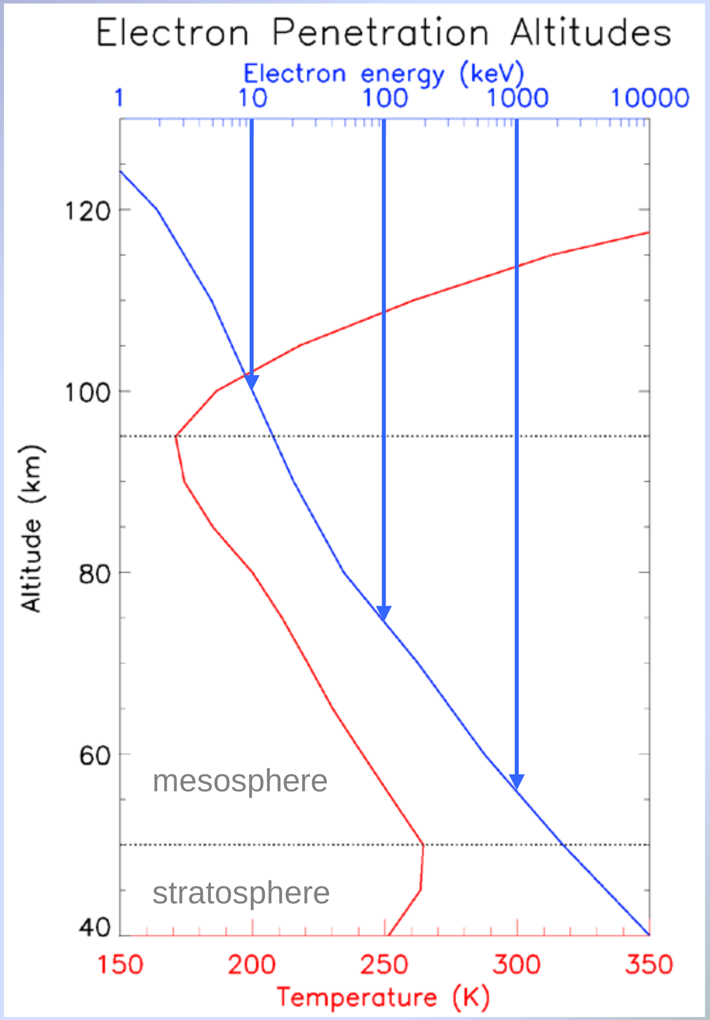


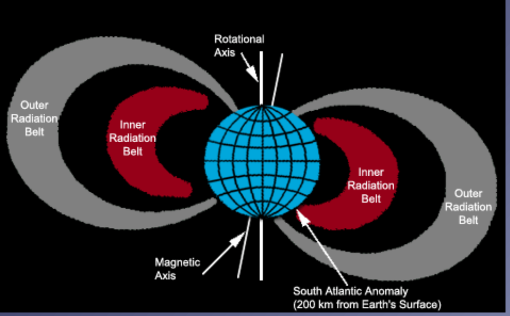


Relevance to the Middle Atmosphere

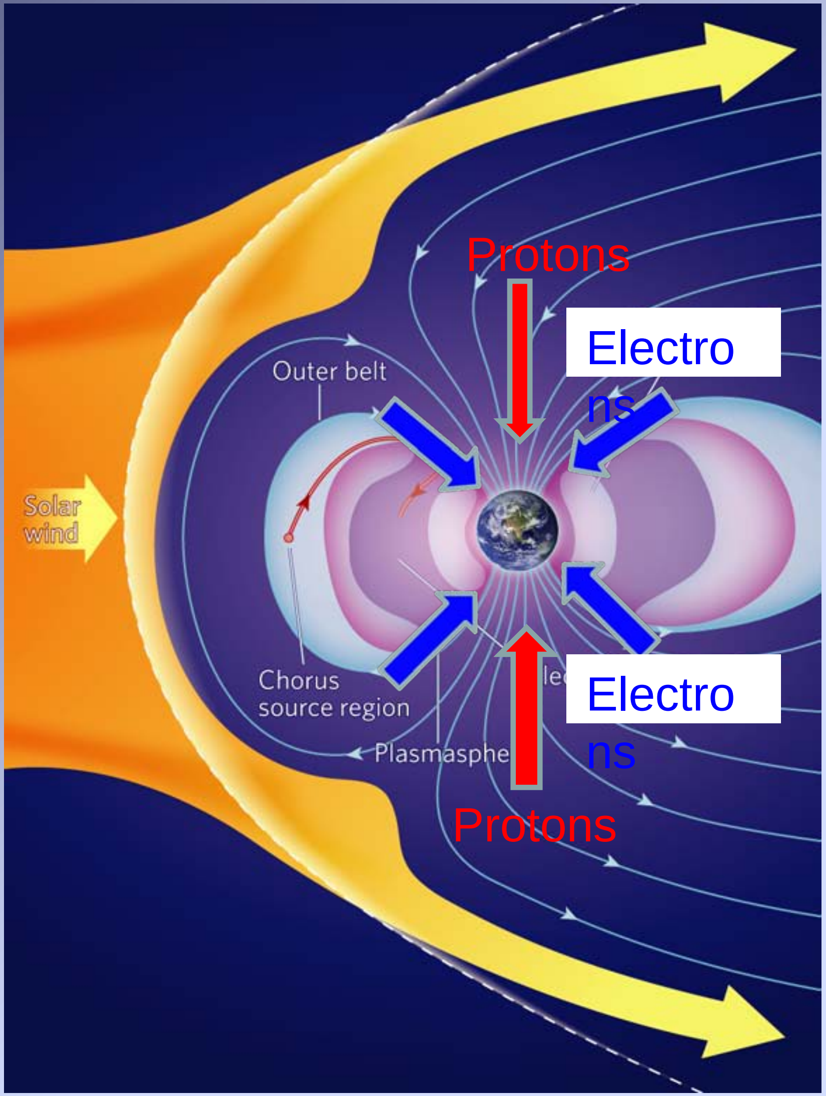
- Energetic particles can penetrate to low altitudes where they drive changes in atmospheric chemistry

- Particle precipitation from the Earth's radiation belts could be very important for communicating solar variability to the Earth's middle atmosphere [*e.g.*, Kozyra et al., AGU, 2006].





Where particle precipitation occurs?

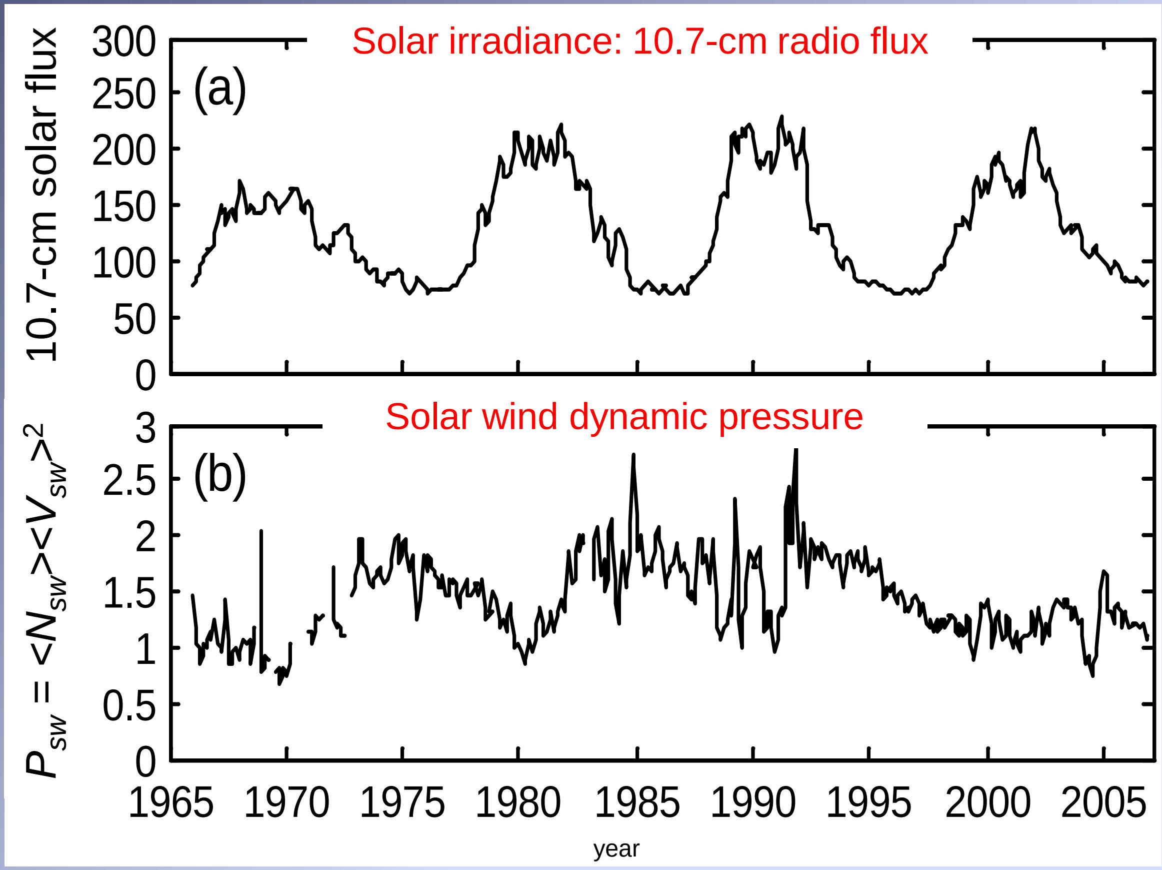


- Electrons tend to hit at mid- and high-latitudes
- Protons tend to fill the whole of the polar cap
- The effect of solar wind is mainly on the polar regions
- So the effect is more likely to be regional rather than global

Part II:

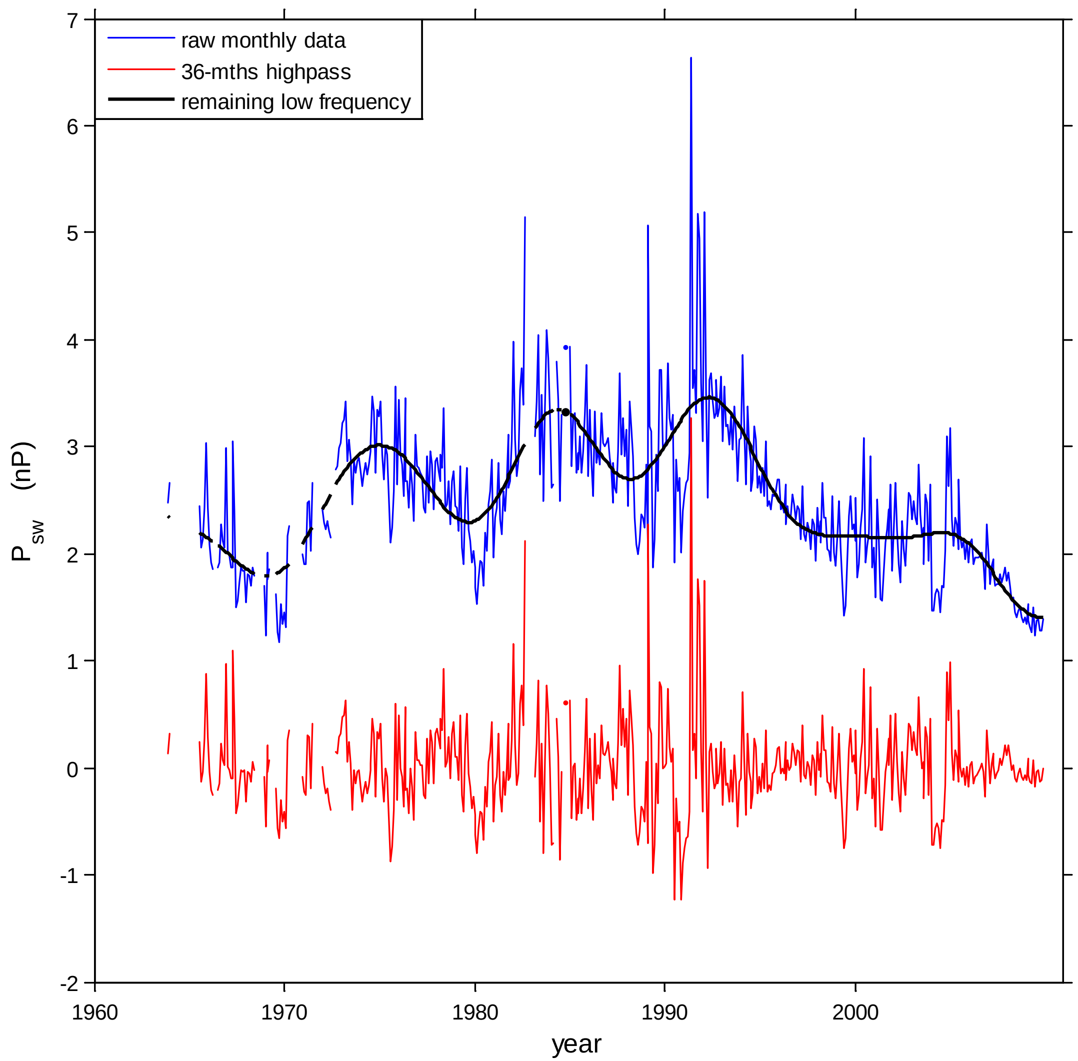
Detecting solar wind signals in the atmospheric circulation variables

SW Dynamic Pressure *vs* the11-year Solar Cycle

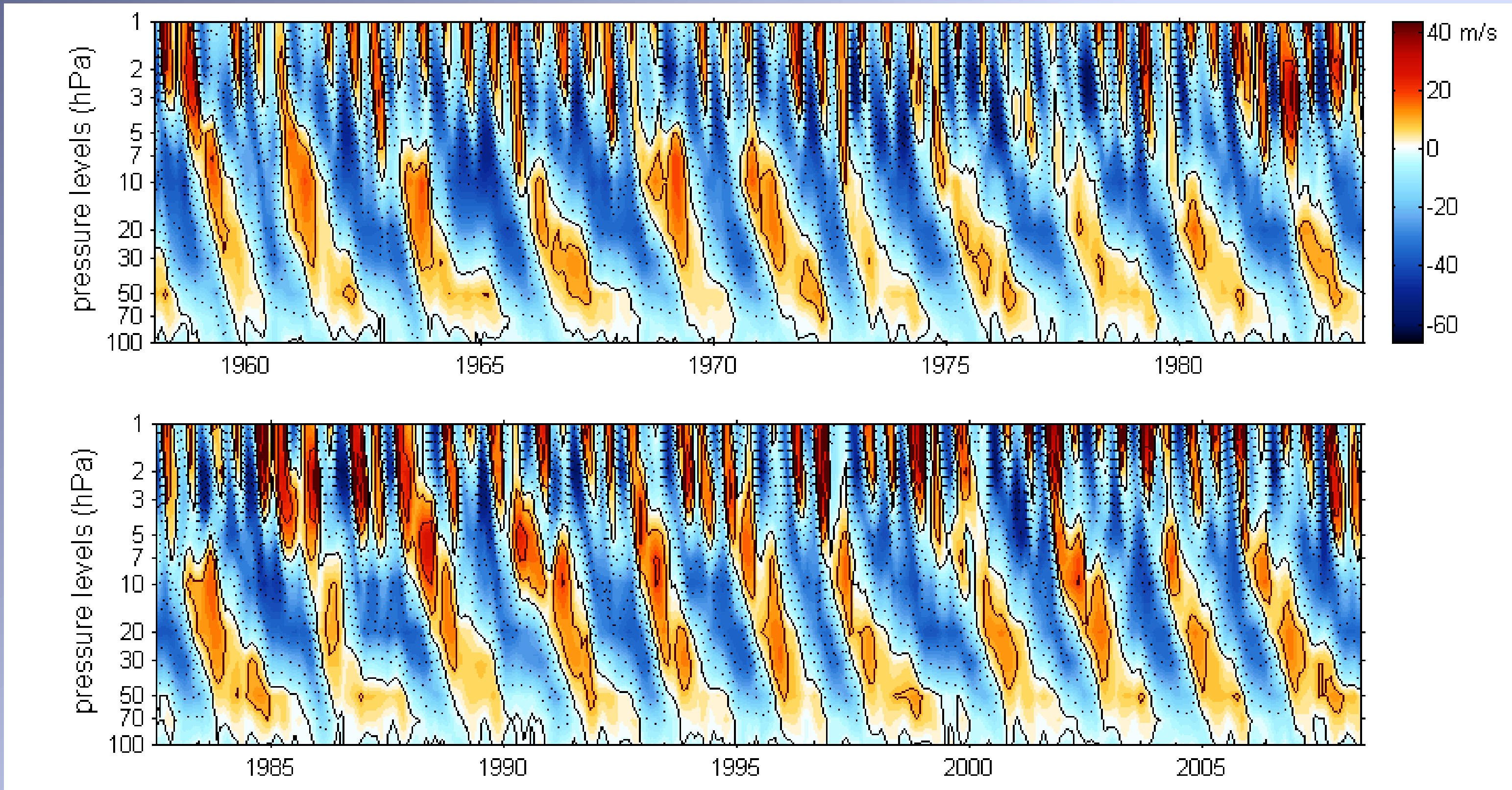


- SW dynamic pressure is not correlated with the 11-yr solar cycle since ~1990
- They tend to be anti-correlated before 1985

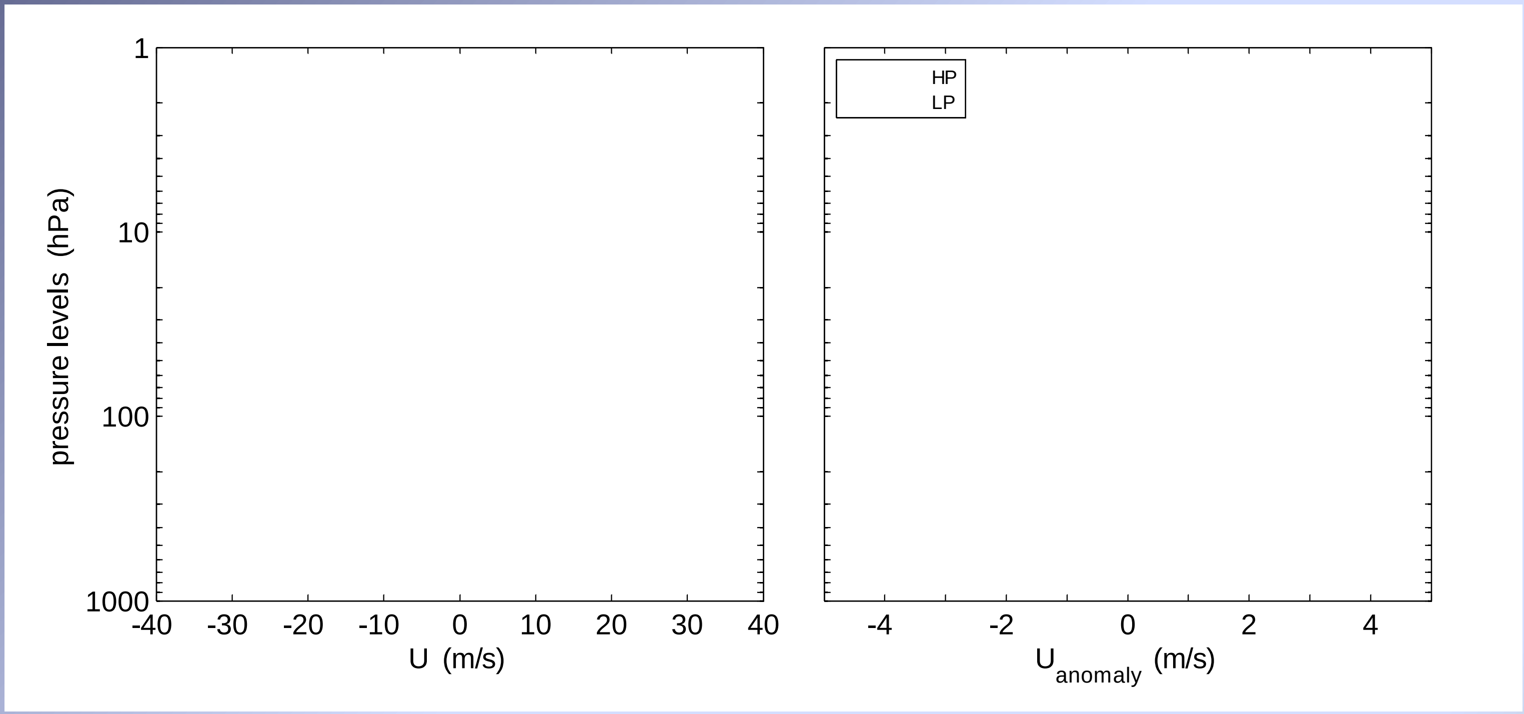
A 11-year Solar Cycle *within* Solar Wind Dynamic Pressure



Example 1: Solar Wind Signal in the Stratospheric Quasi-Biennial Oscillation (QBO)

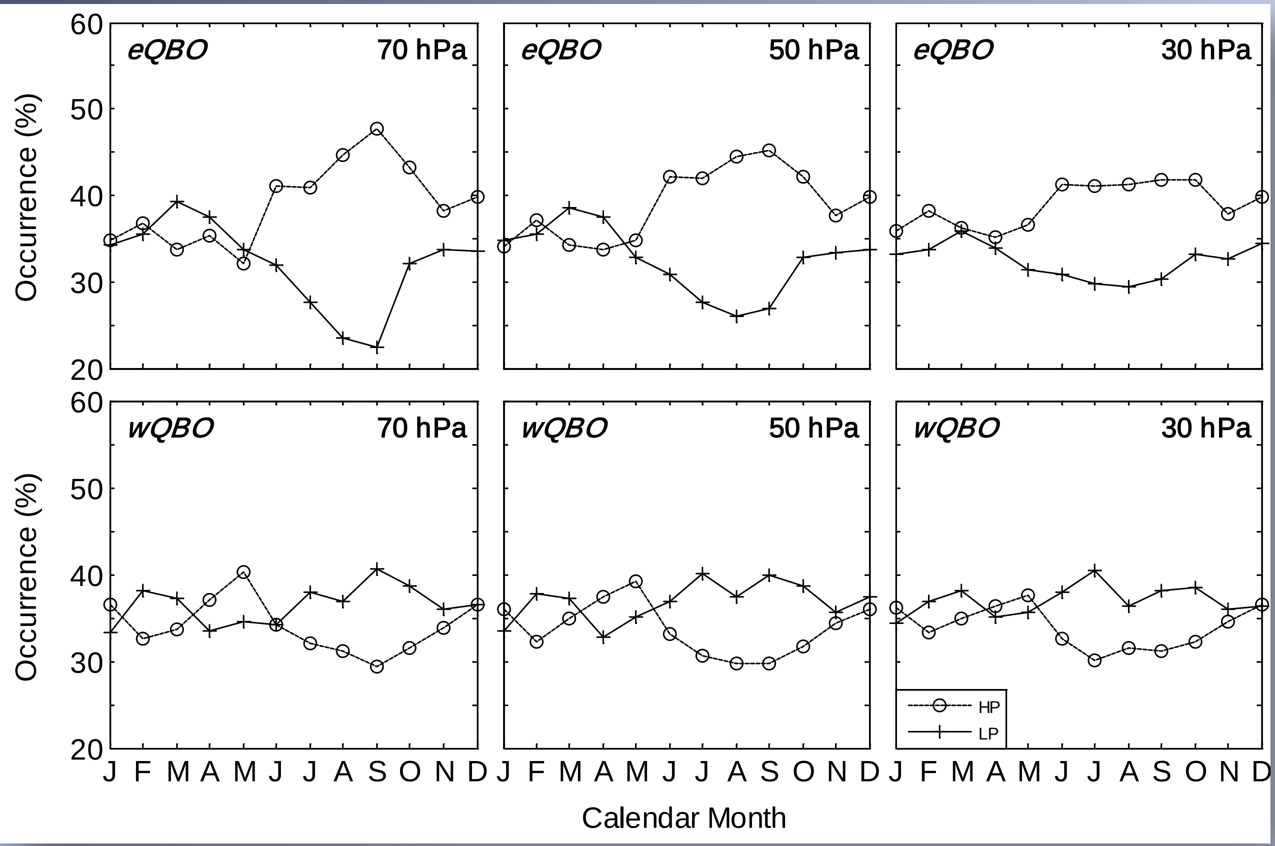


Example 1: Solar Wind Signal in the Stratospheric QBO



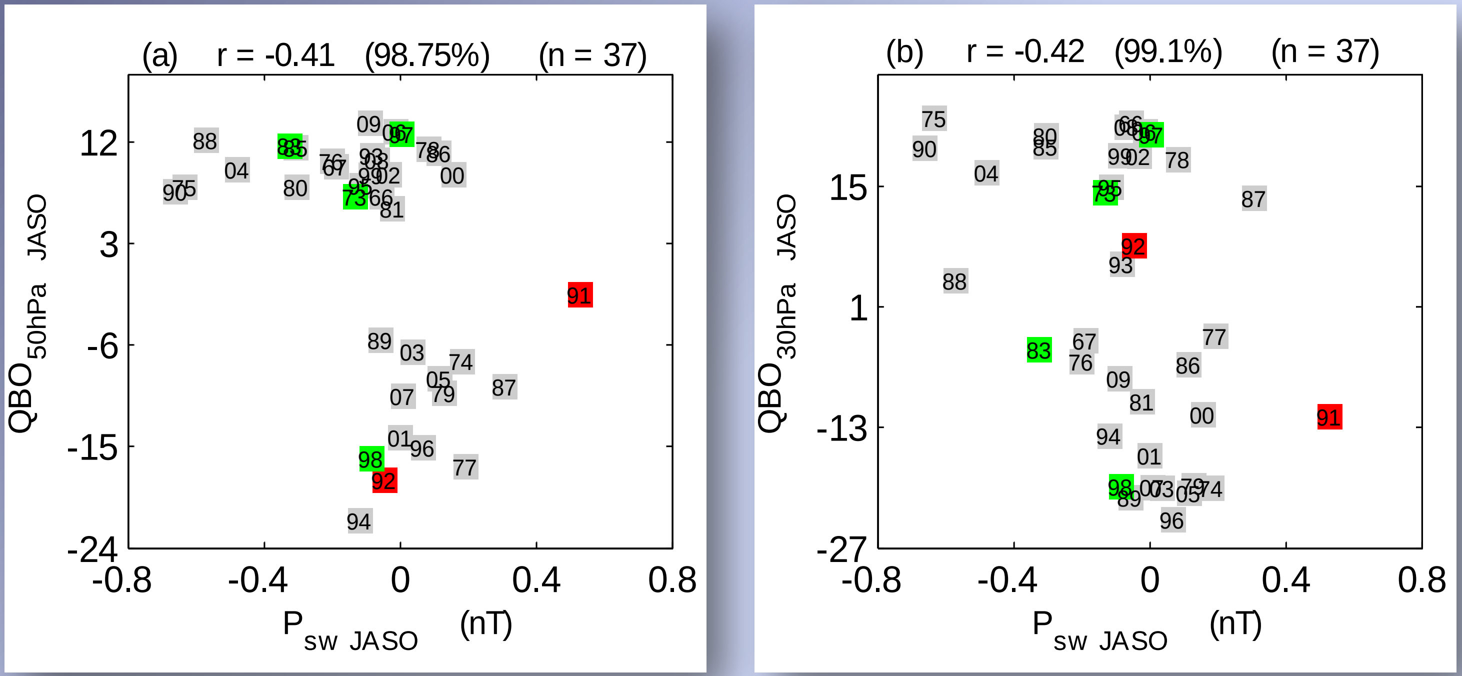
The solar wind dynamic pressure effect on the equatorial wind is of a three cell structure

Example 1: Solar Wind Signal in the Lower Stratospheric QBO



- Easterly QBO occurred more often when solar wind dynamic pressure is high
- Opposite but small effect is found for the westerly QBO

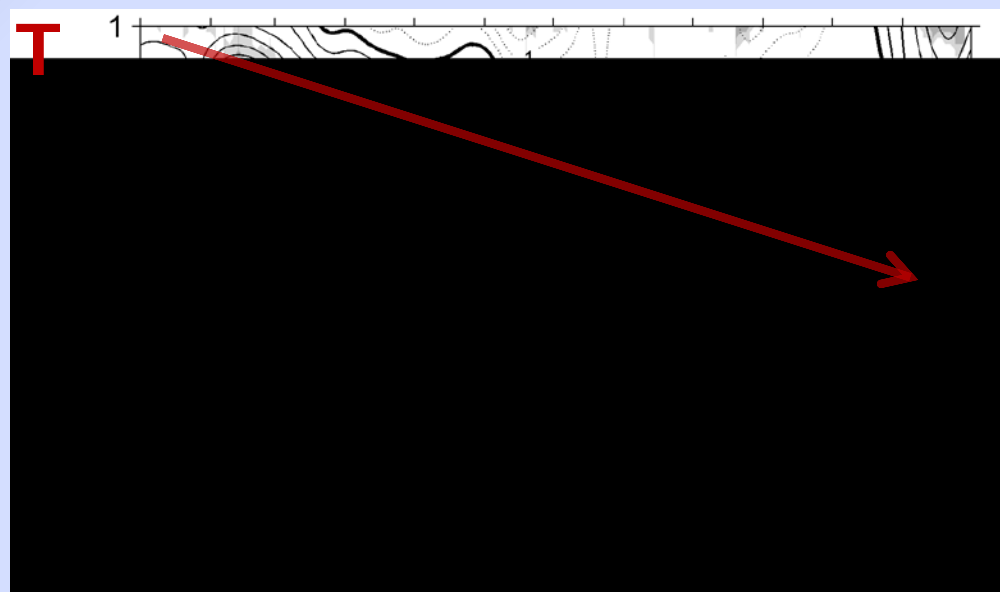
Example 1: Solar Wind Signal in the Stratospheric QBO



- Negative correlation between SWDP and QBO
- The relationship is not dominated by either ENSO or major volcanic eruption affected years

Example 1: Solar wind Dynamic Pressure Signal in the equatorial wind and temperature

- The signal is mainly associated with higher frequency component of solar wind



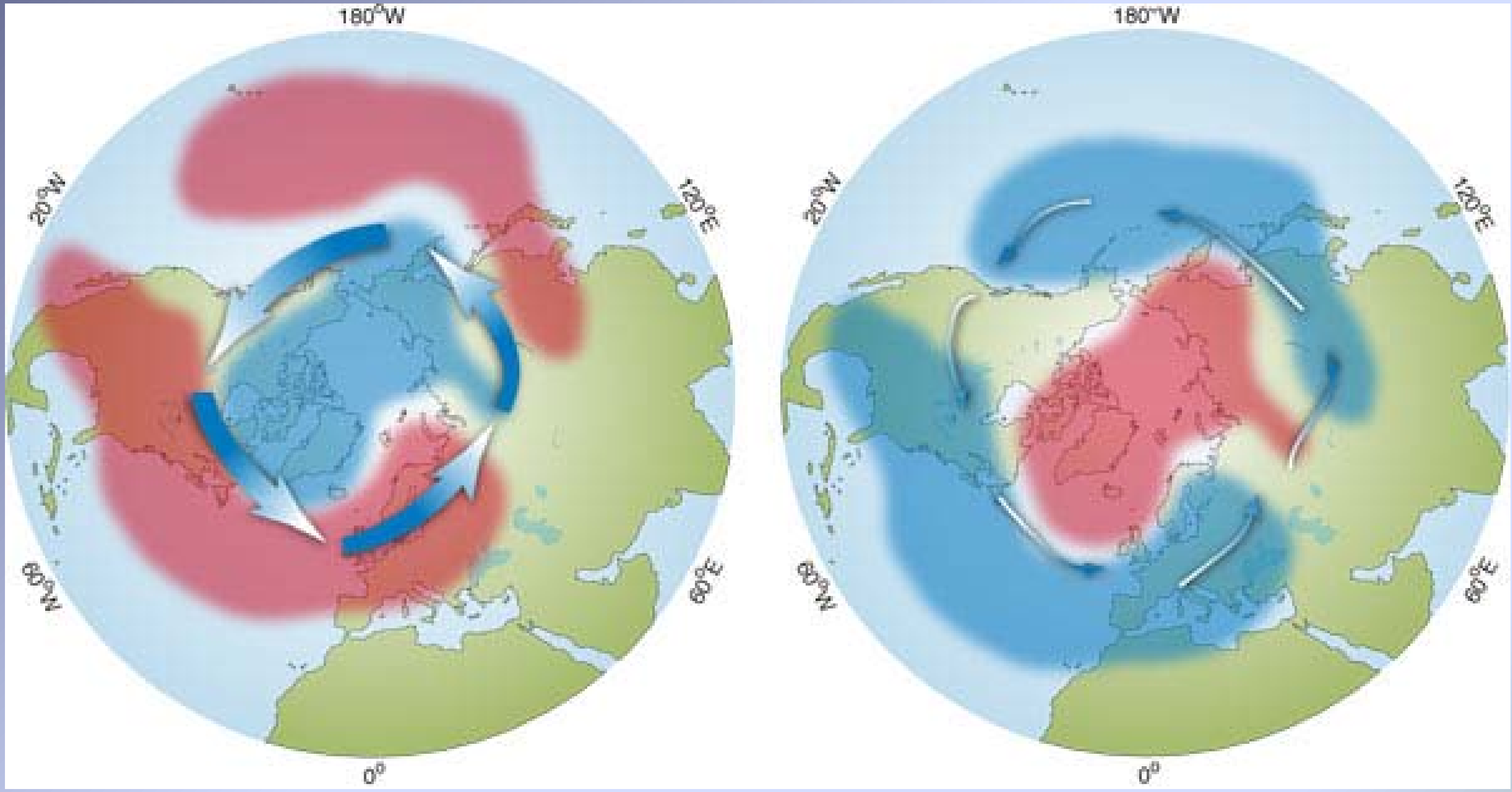
- Significant SW dynamic pressure signal in both U and T during Austral late winter and spring

- Downward decent of the signals

Example 2: Solar wind Signal in the Northern Annular Mode (NAM)

positive phase of NAM

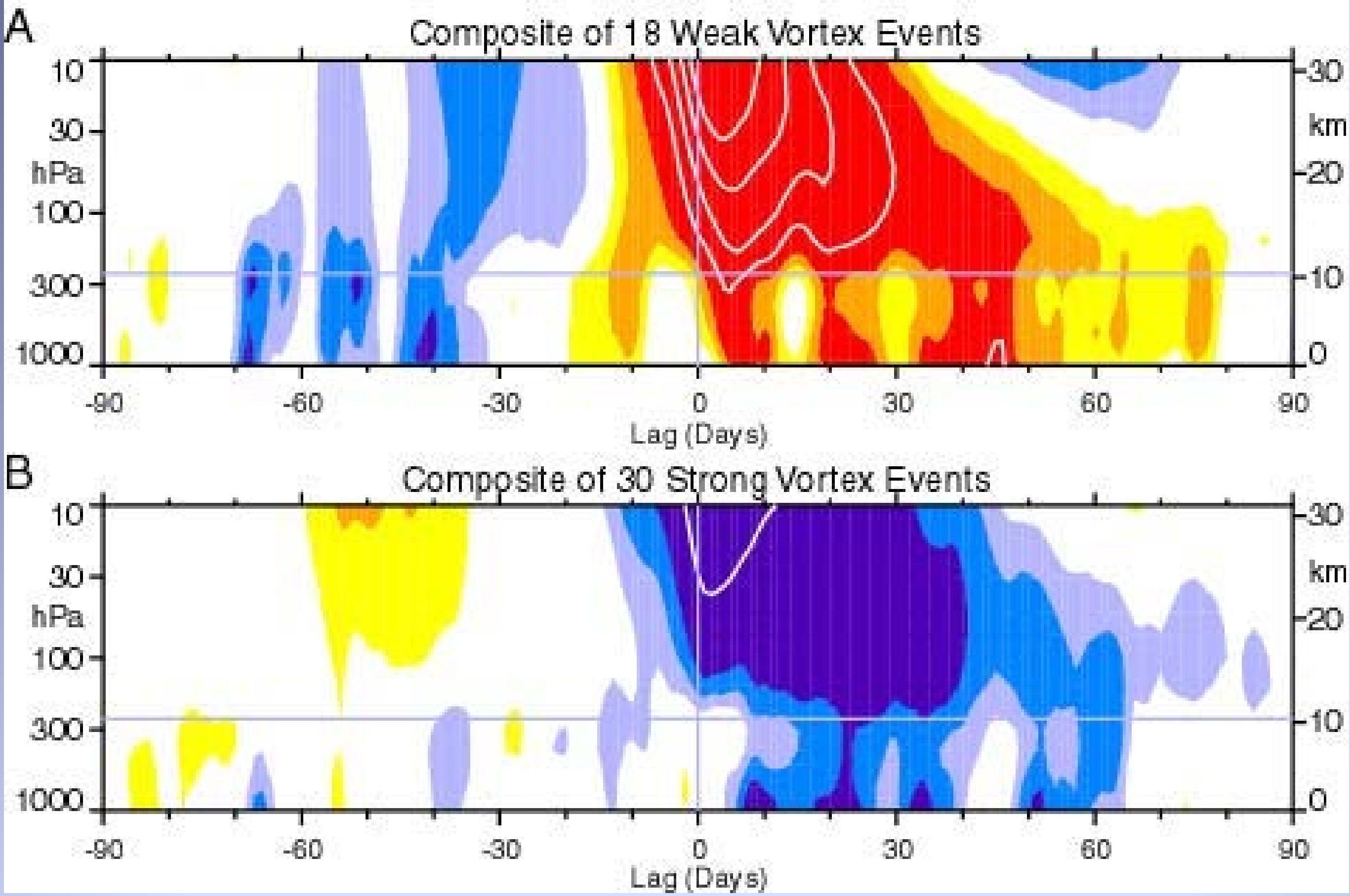
negative phase of NAM



(From Jason Goodman)

Example 2: Solar wind Signal in the Northern Annular Mode (NAM)

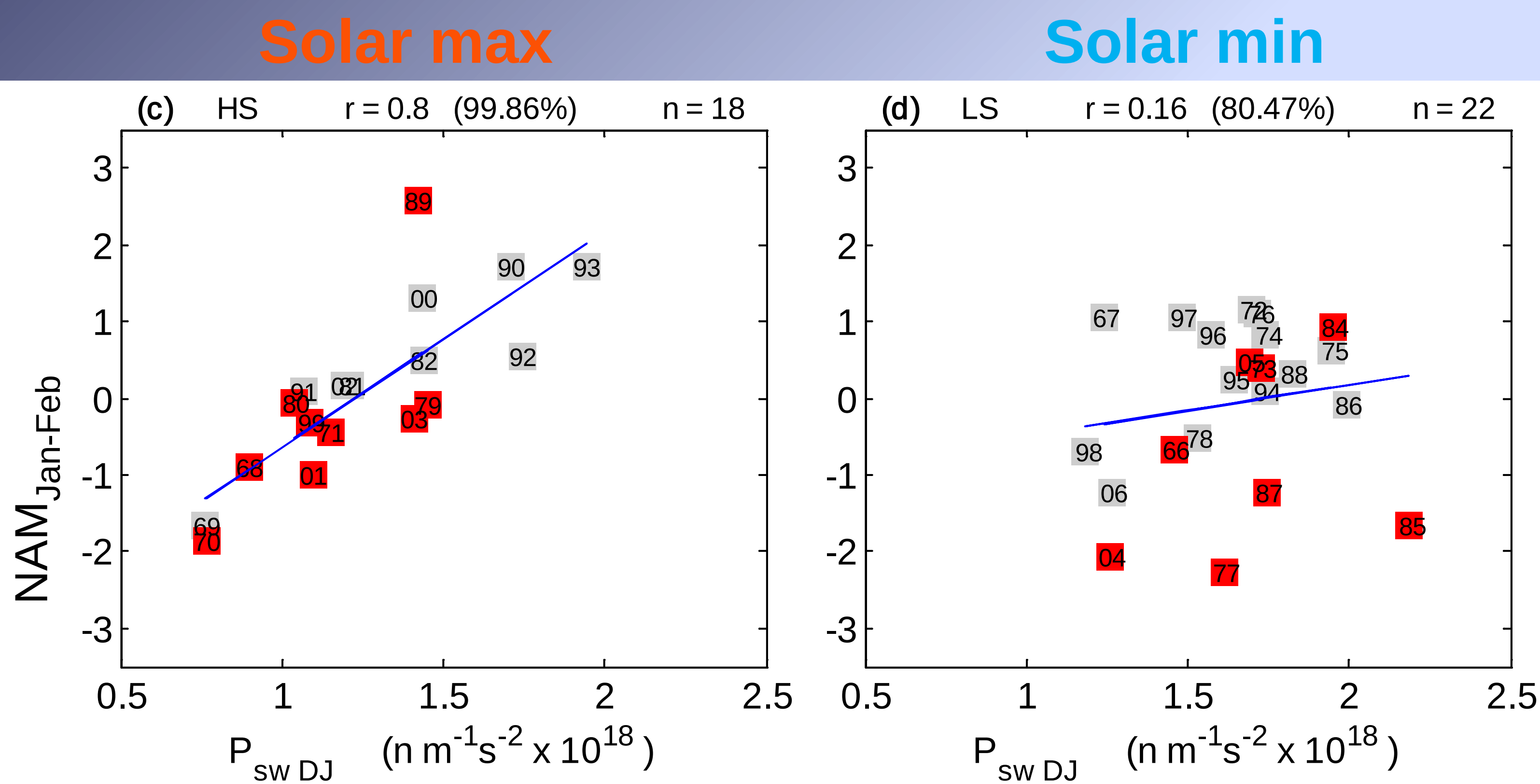
Stratosphere-Troposphere Coupling



Baldwin and Dunkerton (2001): Science.

Example 2: Linear Correlation with 200 hPa NAM

January-February mean



solar wind dynamic pressure

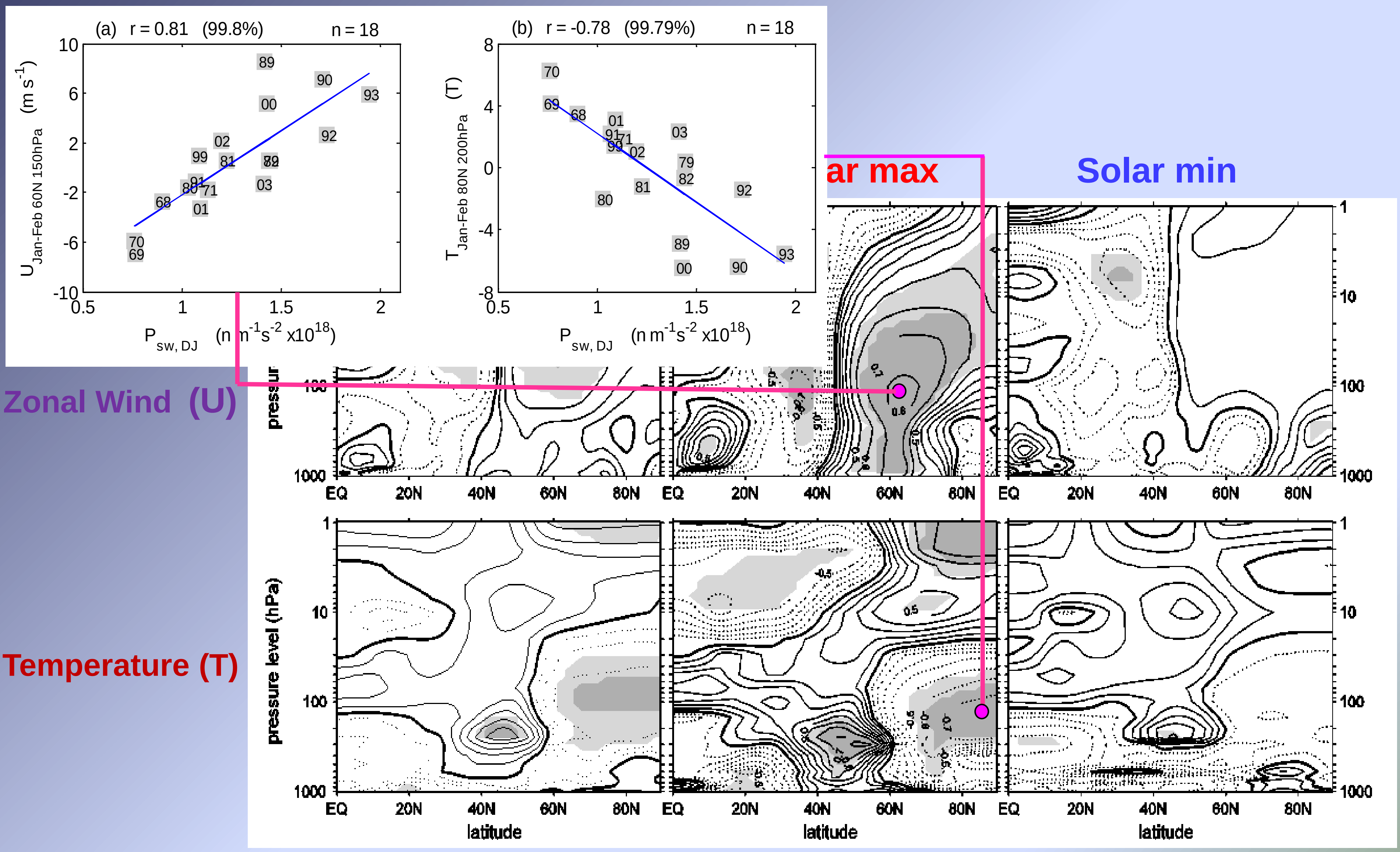
solar wind dynamic pressure

90 — years in two digital number

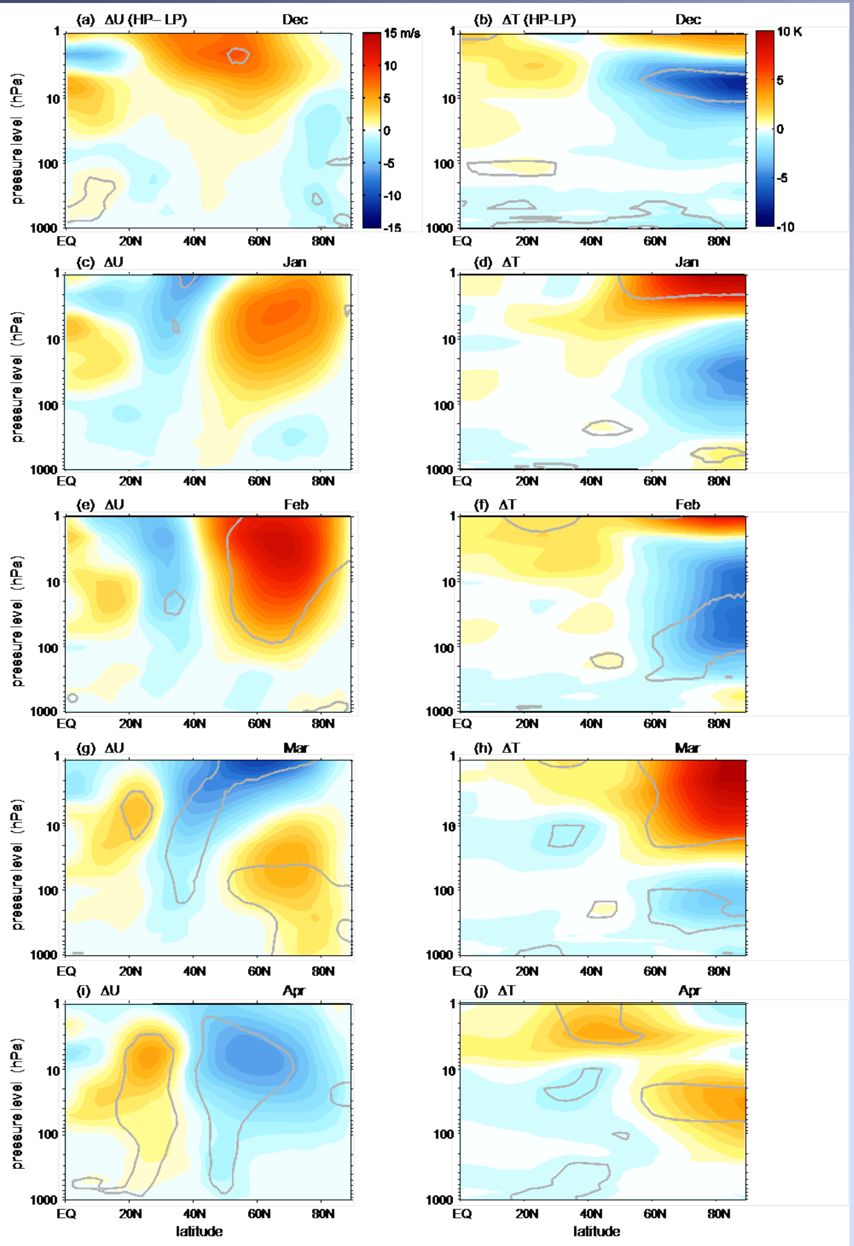
— years in which stratospheric Sudden Warming occurred

Correlations with zonal-mean zonal wind and temperature

Signals in January-February mean

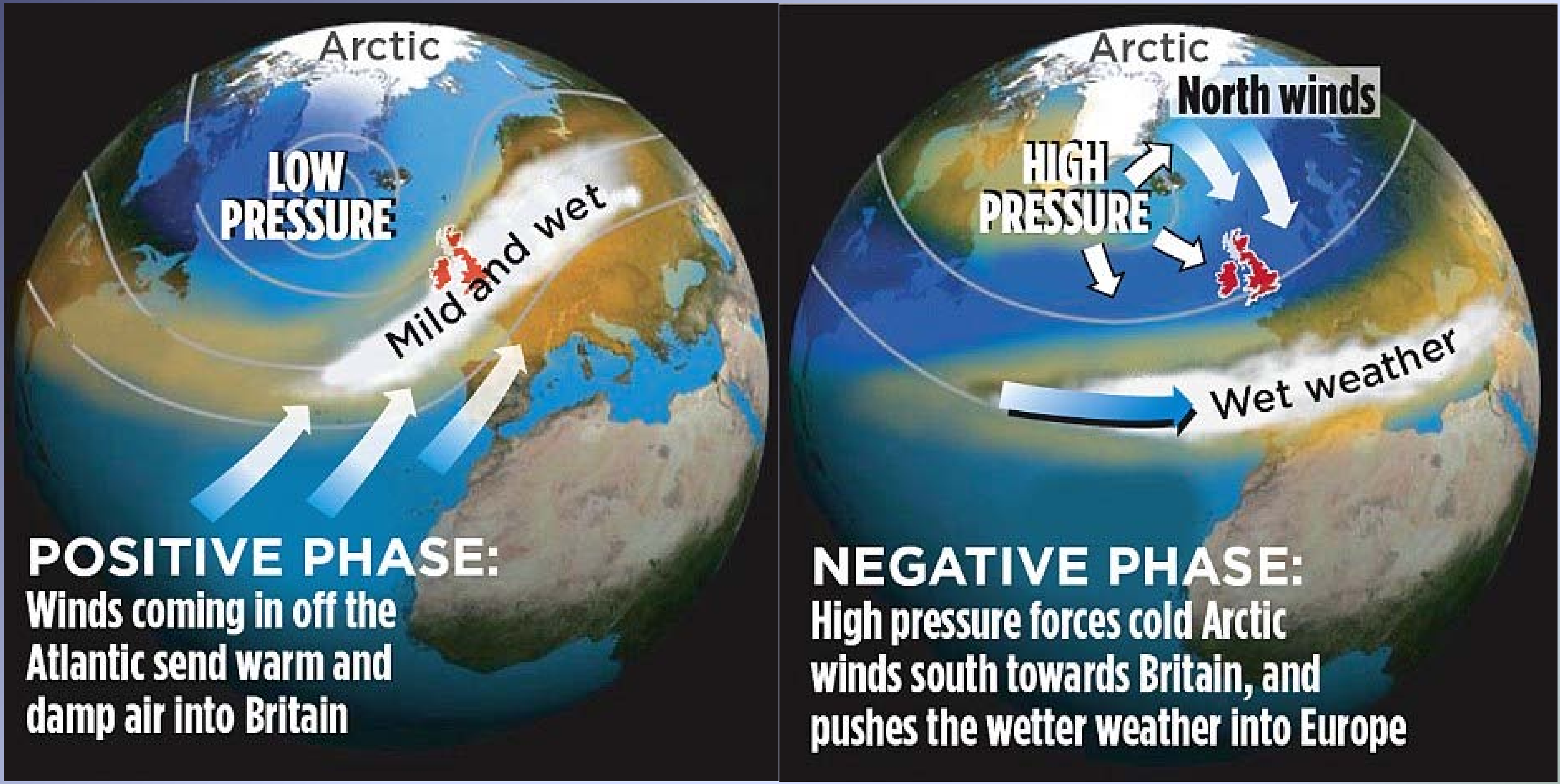


Downward progression of SW dynamic pressure signals

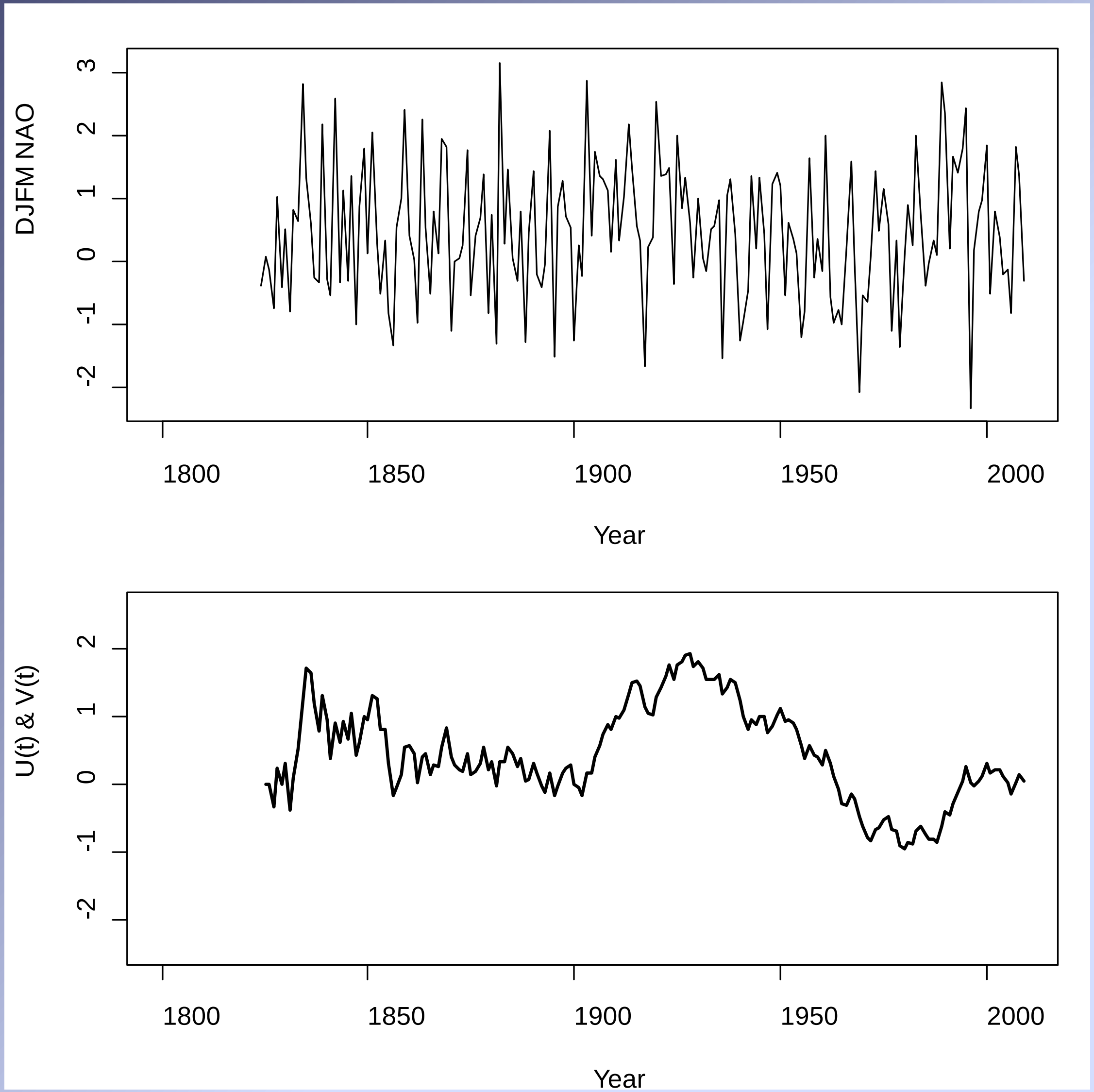


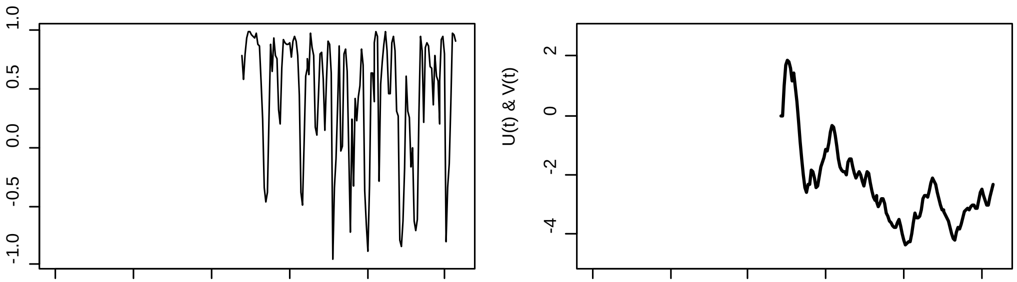
- Stronger and colder stratospheric vortex
- Poleward and downward propagation of westerly wind anomalies
- Downward movement of temperature anomalies
- Polar stratosphere is colder in mid-winter to late winter and warmer in spring

Example 3: Geomagnetic Signals in the North Atlantic Oscillation (NAO)



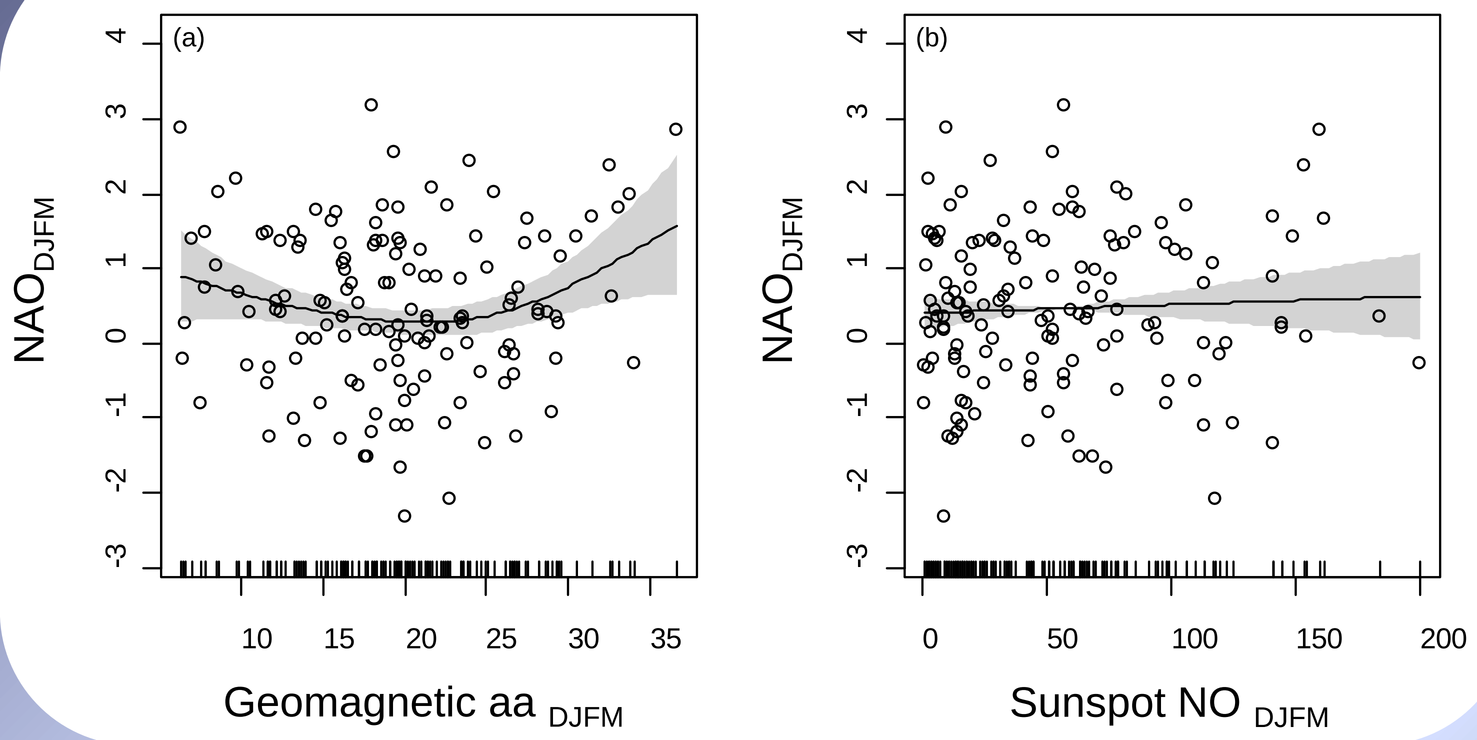
From Daily Mail Online, 28th of December, 2010


DJFM NAO
3
2
1
0
-1
-2
1800
1850
1900
1950
2000
Year
U(t) & V(t)
2
1
0
-1
-2
1800
1850
1900
1950
2000
Year


1.0
0.5
0.0
-0.5
-1.0
U(t) & V(t)
2
0
-2
-4

Example 3: Geomagnetic Signals in the NAO

1869-2009, all data

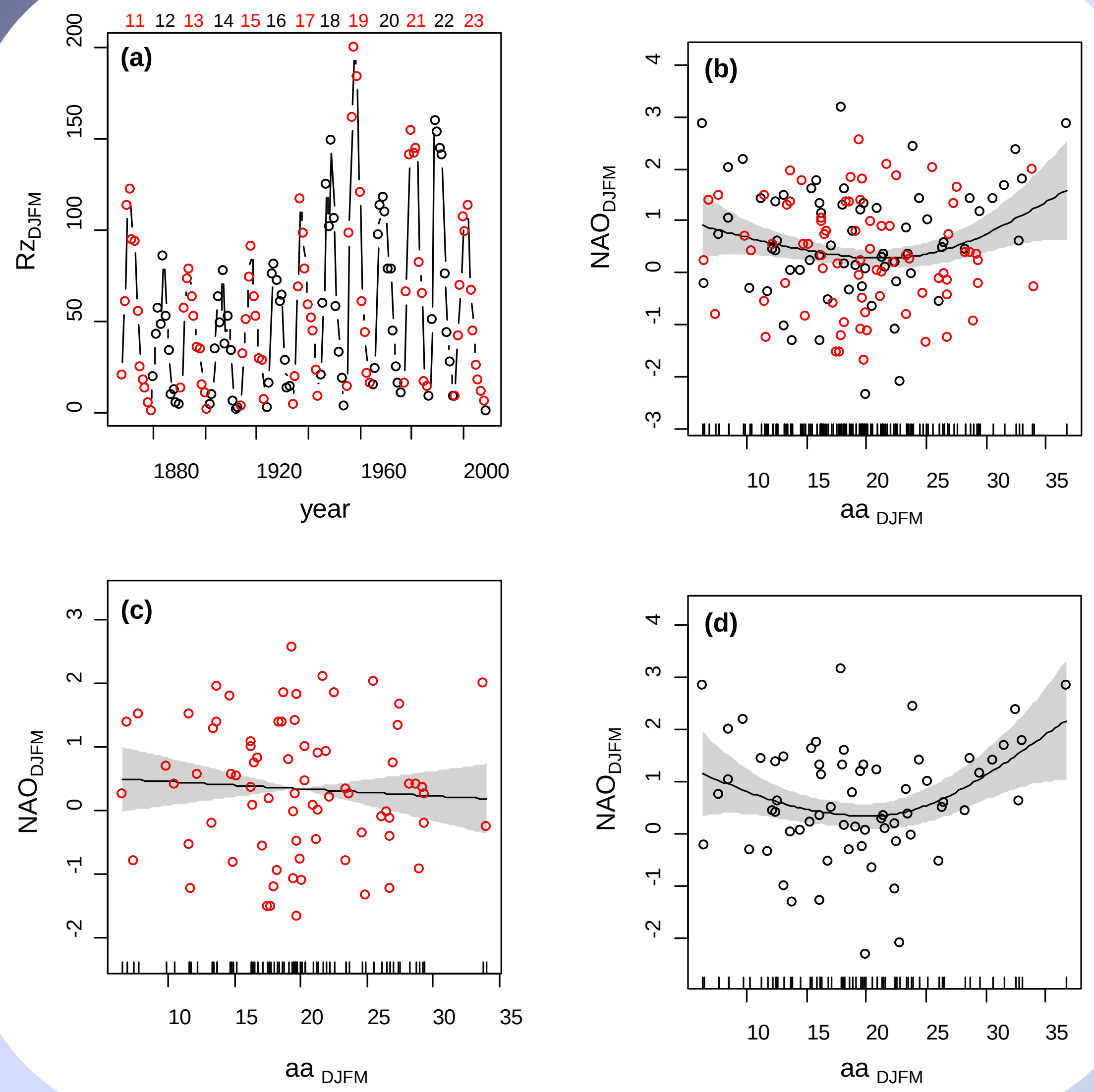


black line: General Additive Model (GAM) fitting

the shaded region: 95% confidence interval

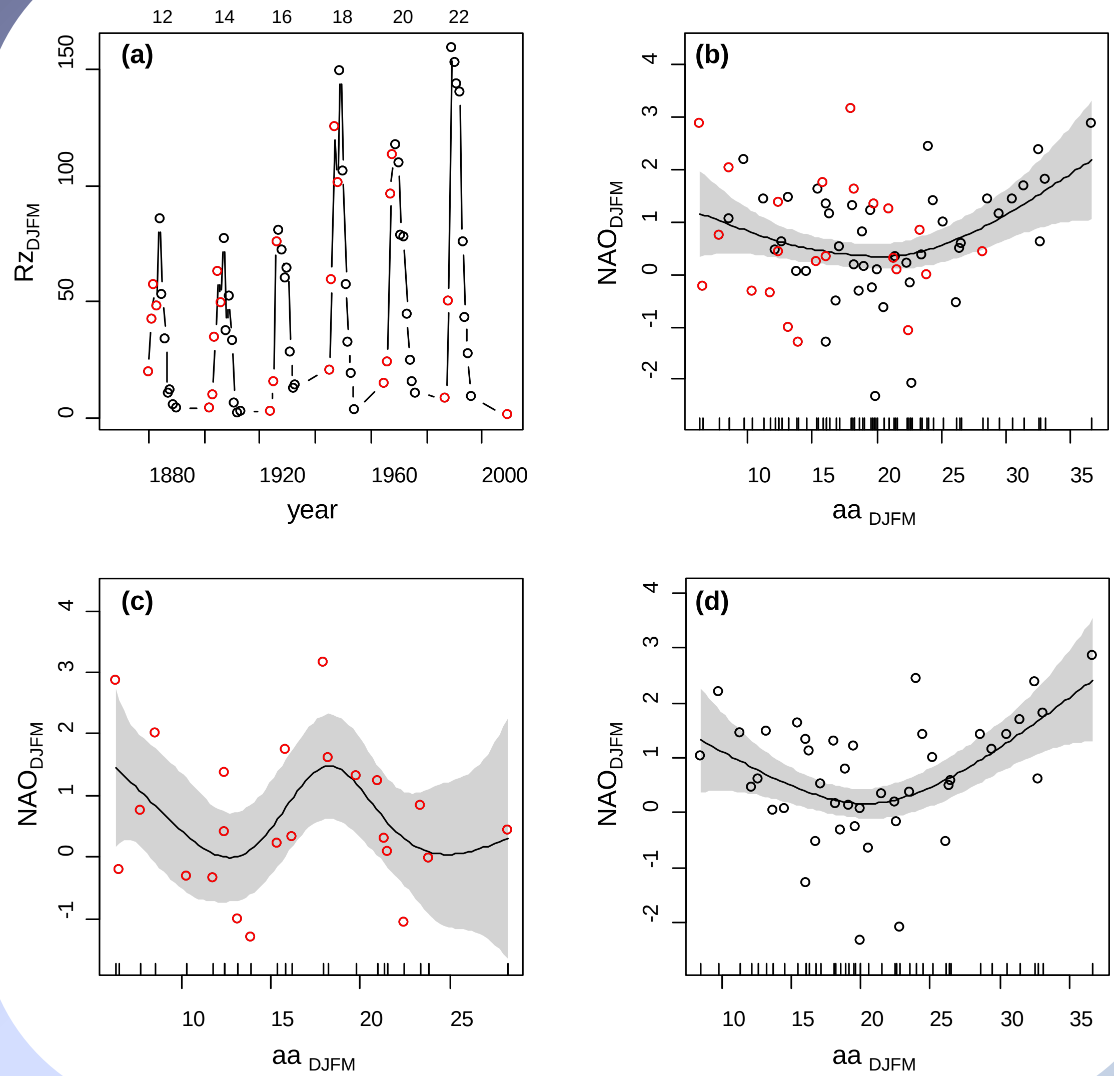
Example 3: Geomagnetic Signals in the NAO

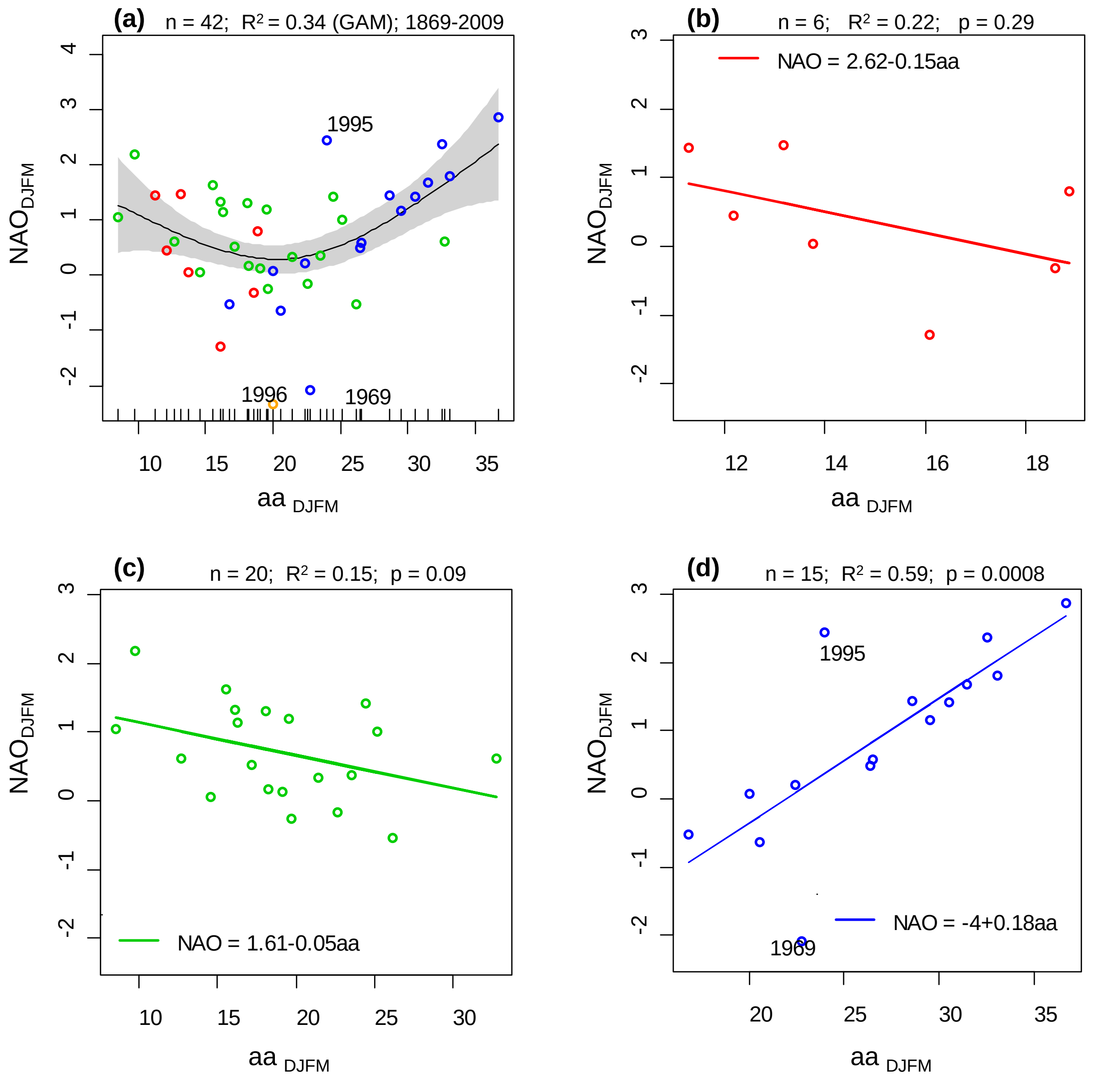
1869-2009, GAM built from odd/even numbered solar cycles

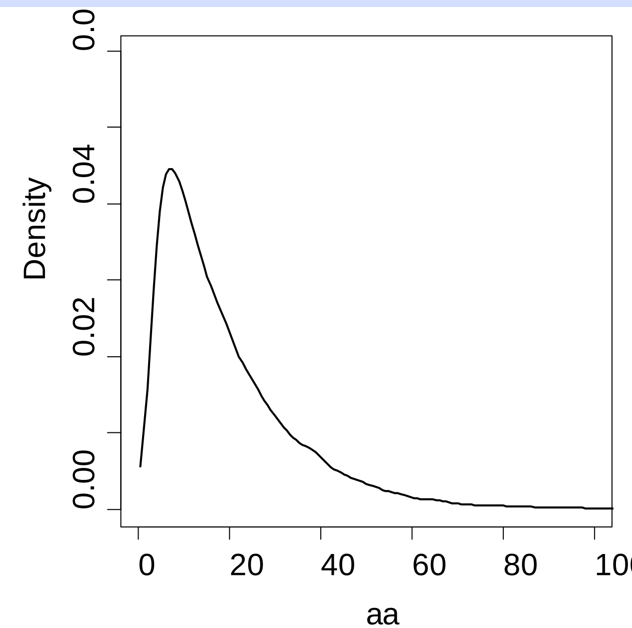


Example 3: Geomagnetic Signals in the NAO

1869-2009, the declining phase of even numbered solar cycles

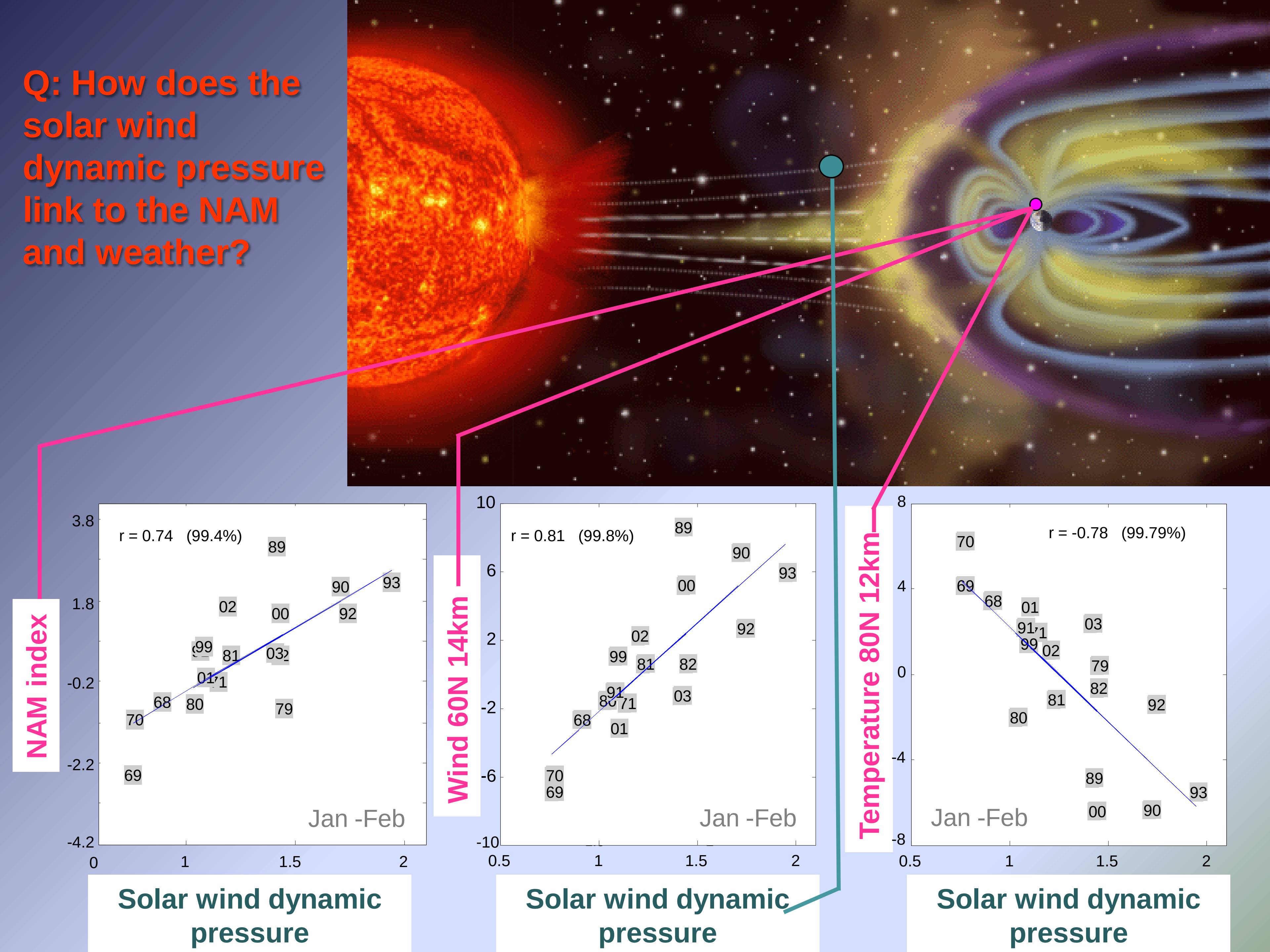



(a) n = 42; R² = 0.34 (GAM); 1869-2009
1995
1996
1969
(b) n = 6; R² = 0.22; p = 0.29
NAO = 2.62-0.15aa
(c) n = 20; R² = 0.15; p = 0.09
NAO = 1.61-0.05aa
(d) n = 15; R² = 0.59; p = 0.0008
1995
1969
NAO = -4+0.18aa
NAO DJFM
aa DJFM

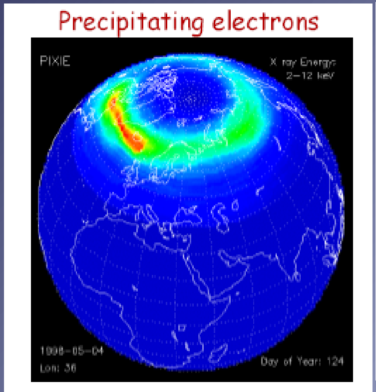

Density
aa

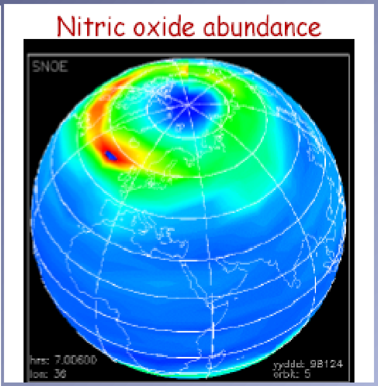
Part III:

Possible mechanisms


Q: How does the solar wind dynamic pressure link to the NAM and weather?
NAM index
r = 0.74 (99.4%)
Jan -Feb
Solar wind dynamic pressure
Wind 60N 14km
r = 0.81 (99.8%)
Jan -Feb
Solar wind dynamic pressure
Temperature 80N 12km
r = -0.78 (99.79%)
Jan -Feb
Solar wind dynamic pressure

Production of Odd Nitrogen (NOx) by Energetic Particle Precipitation (EPP)

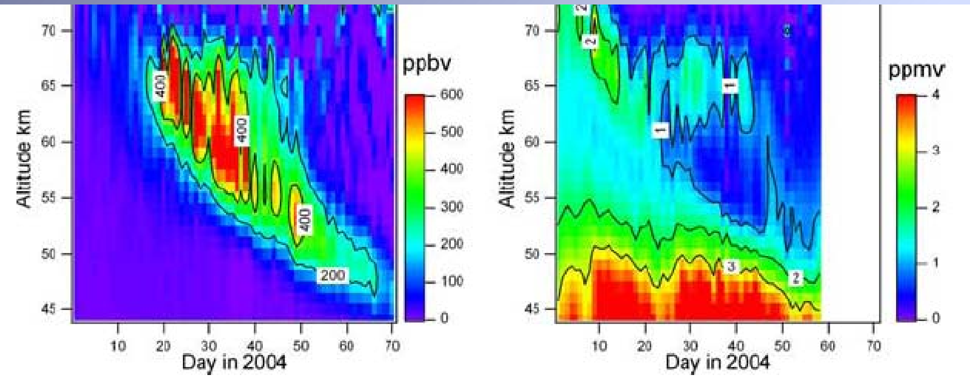




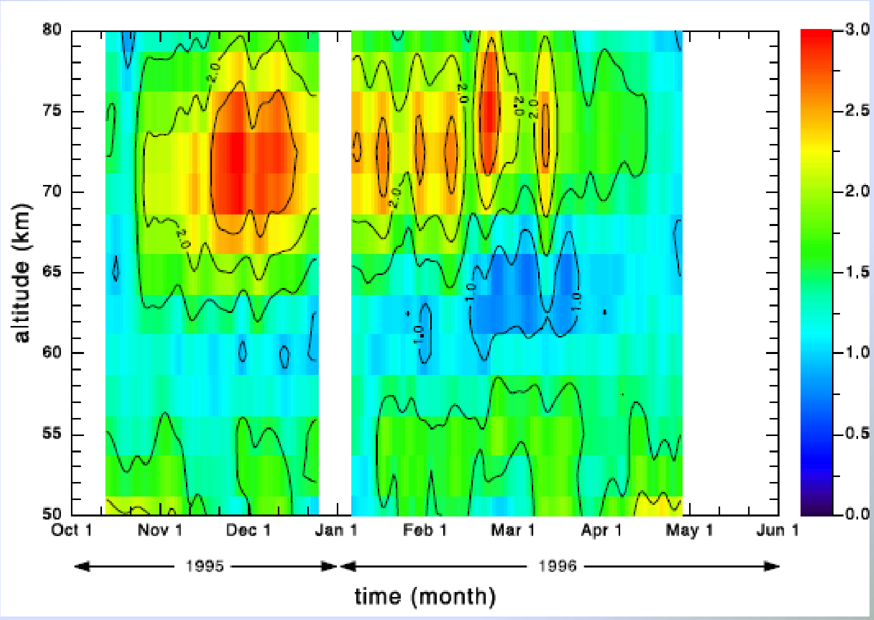
Zonal averaged mixing ratio of (left) NO_2 and (right) O_3 at 80N from GOMOS data between 1st January and 10th March 2004
Hauchecorne et al. (2007)

NOx

ozone



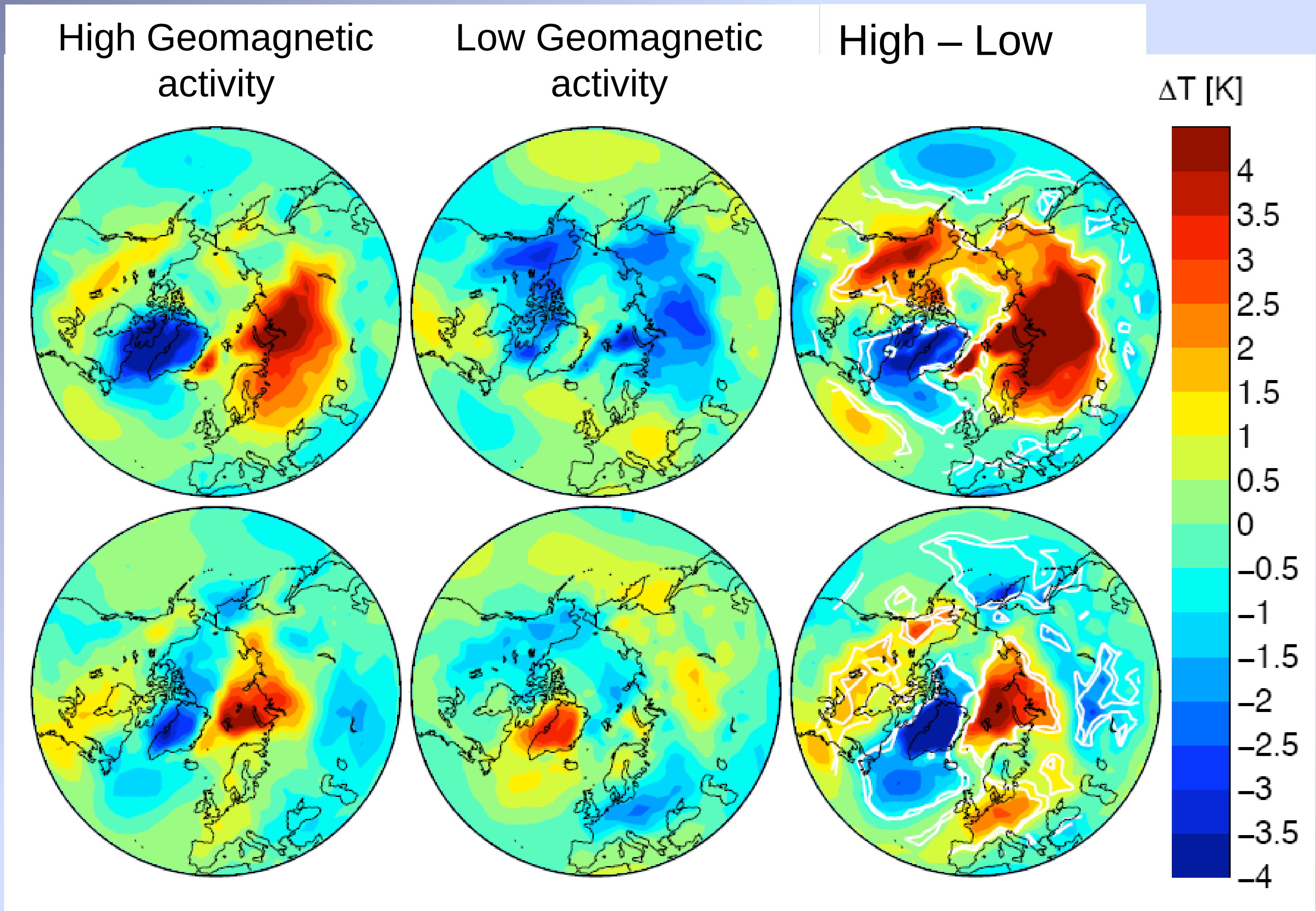
1995 1996



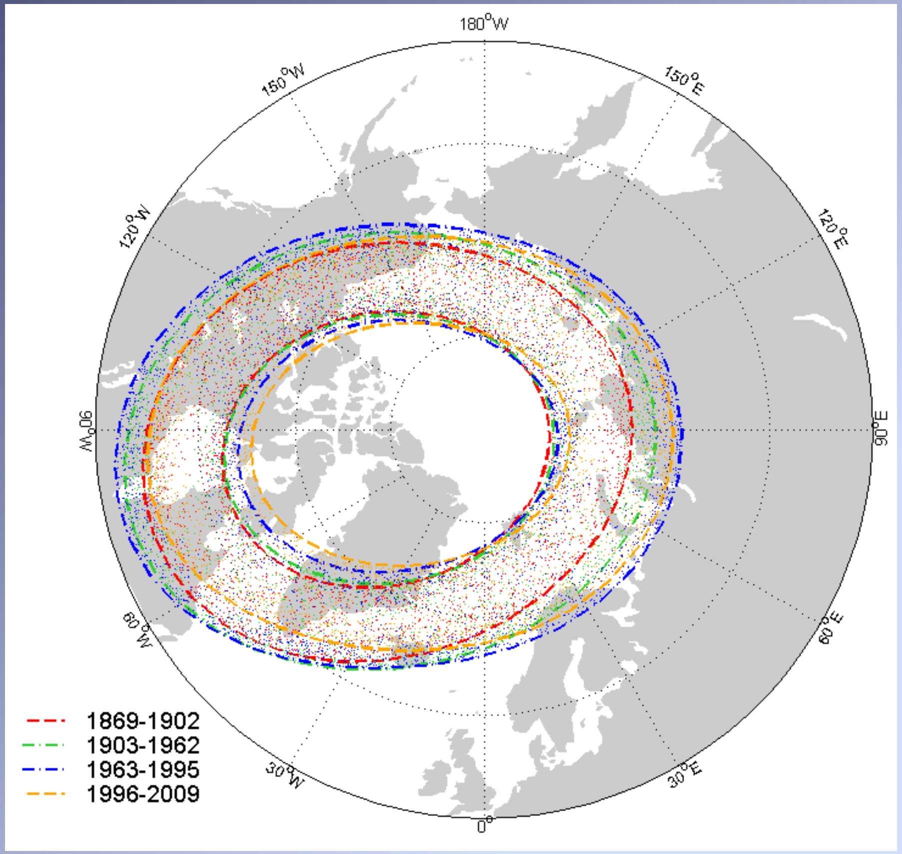
(Mixing ratio of NOx, Hartogh et al, JGR 2004)

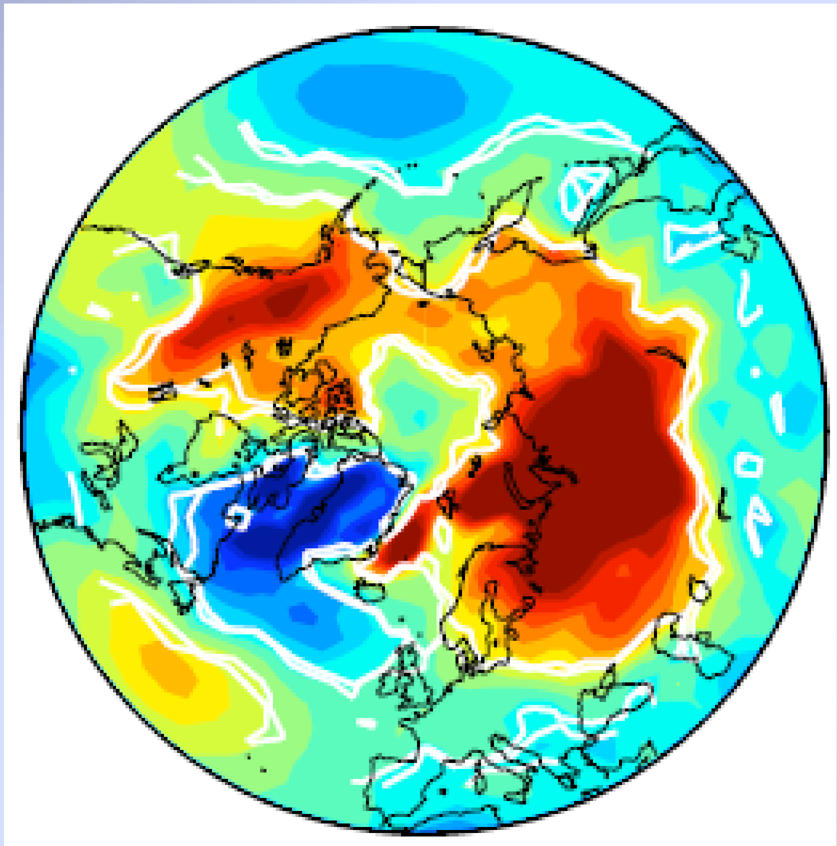
Geomagnetic Impact on surface temperature

Using ERA-40 reanalysis data to try to separate out the influence of solar UV variations and geomagnetic activity effects



What does this to do with the Aurora?

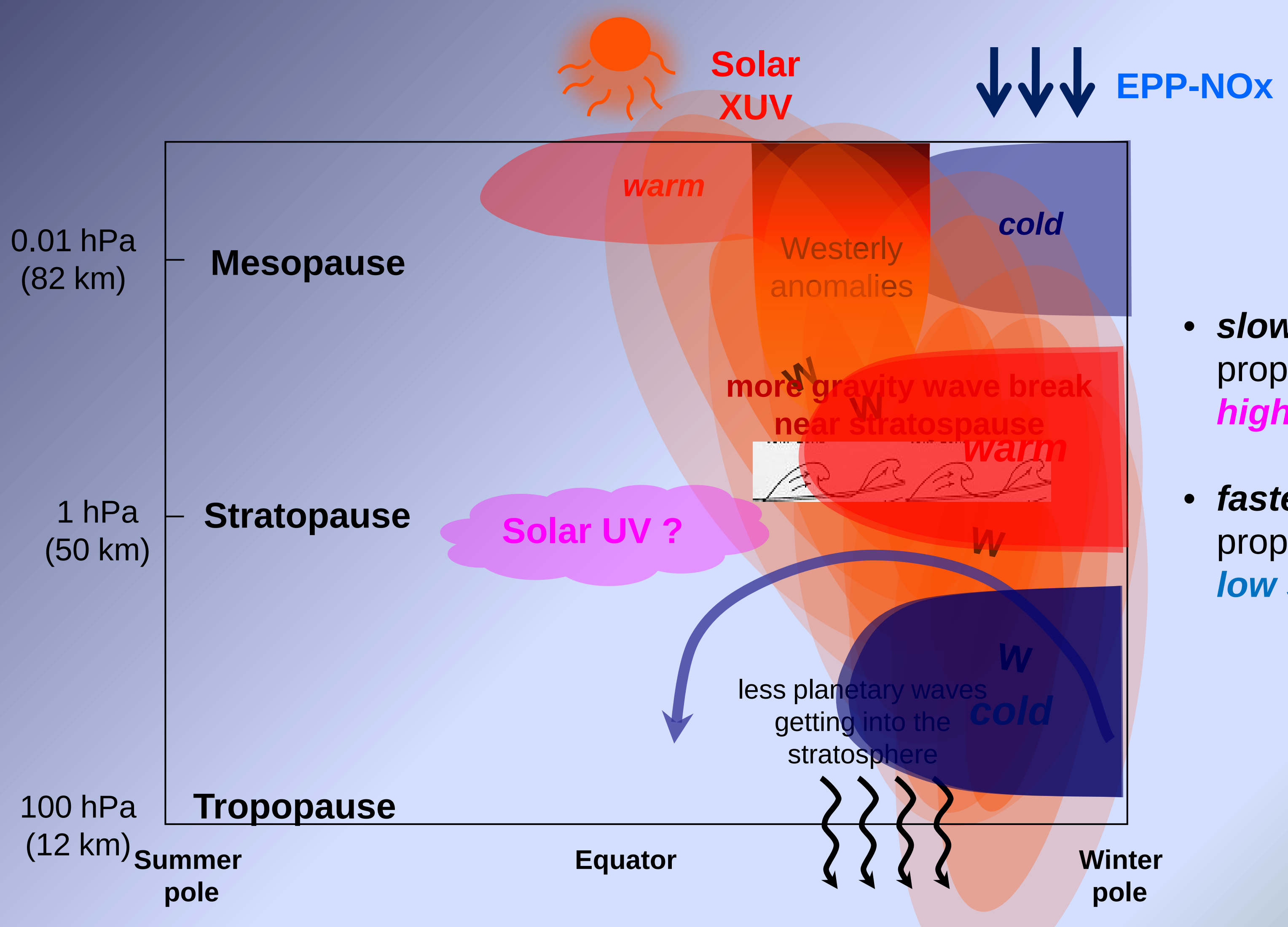




- A westward shift of the polar cell
- The signal becomes stronger at solar min and weaker at solar max

Speculative Mechanism

wave-meanflow interaction



- ***slower*** downward propagation under ***high solar activity***
- ***faster*** downward propagation under ***low solar activity***

Dynamic Characteristics of Solar Wind Disturbances

to be confirmed by GCM studies and additional measurements

Higher solar wind dynamic pressure favors the following dynamic responses:

- colder UM-LT polar region and warmer UM-LT equator region in mid-winter
- stronger westerly winds in the mesosphere sub-tropics and mid-latitudes
- less planetary waves propagating into the stratosphere from the troposphere
- slower Brewer-Dobson circulation a stronger and colder polar vortex in the lower stratosphere
- more gravity waves get into mesosphere more wave breaking near the stratopause
- breaking of gravity waves decelerates the westerly wind and creates a poleward meridional wind in the mid- to upper stratosphere a weaker, warmer polar vortex in the lower mesosphere and the upper stratosphere
- By continuity, the poleward wind induces a downward vertical wind in the polar region in late winter and spring. This downward motion is stronger in LS years than HS years due to the known effect of solar UV on the Brewer-Dobson circulation (Kodera & Kuroda 2002)

Summary