

*SPATIAL DISTRIBUTION OF
NORTHERN HEMISPHERE WINTER TEMPERATURES
OVER THE SOLAR CYCLE
DURING THE LAST 130 YEARS*

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- Possible connection between energetic electron precipitation and Northern Hemisphere winter surface temperatures
 - NOAA/MEPED data period 1980-2010
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BACKGROUND...

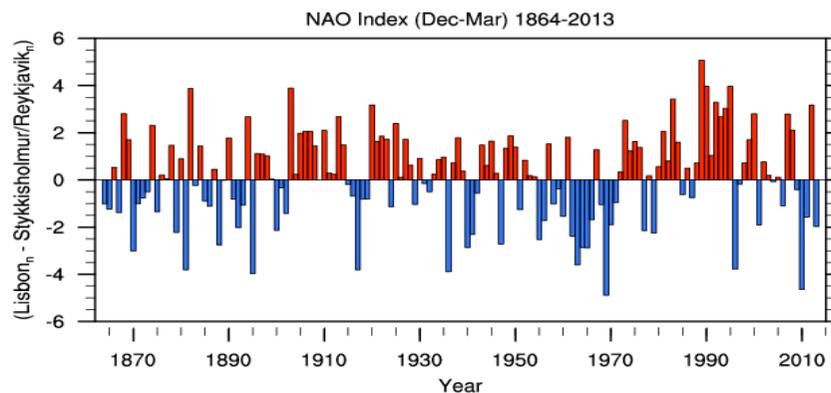
NORTH ATLANTIC OSCILLATION (ARCTIC OSCILLATION)

Normalised sea-level pressure difference between Iceland and Azores/Iberia

Closely related to the evolution of polar vortex

Strongly affects winter conditions in Europe and N. America

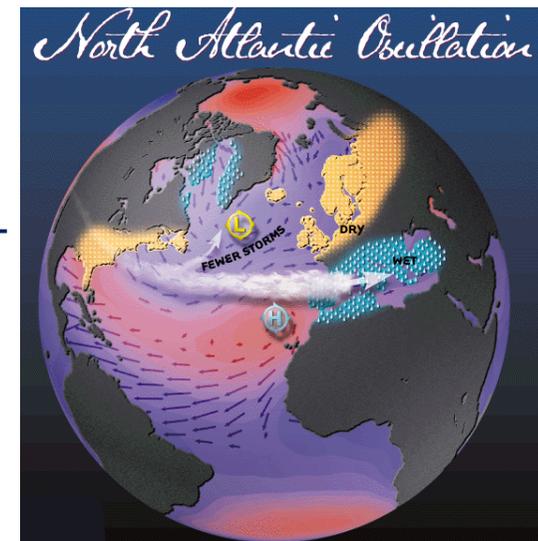
- NAO+
 - ✓ More and stronger storms cross Atlantic
 - ✓ Warm & wet in N. Eurasia and US east coast
 - ✓ Strong polar vortex
- NAO-
 - ✓ Reduced p gradient=> fewer and weaker storms
 - ✓ Dry & cold in N. Eurasia and US east coast
 - ✓ Weaker polar vortex



NAO+

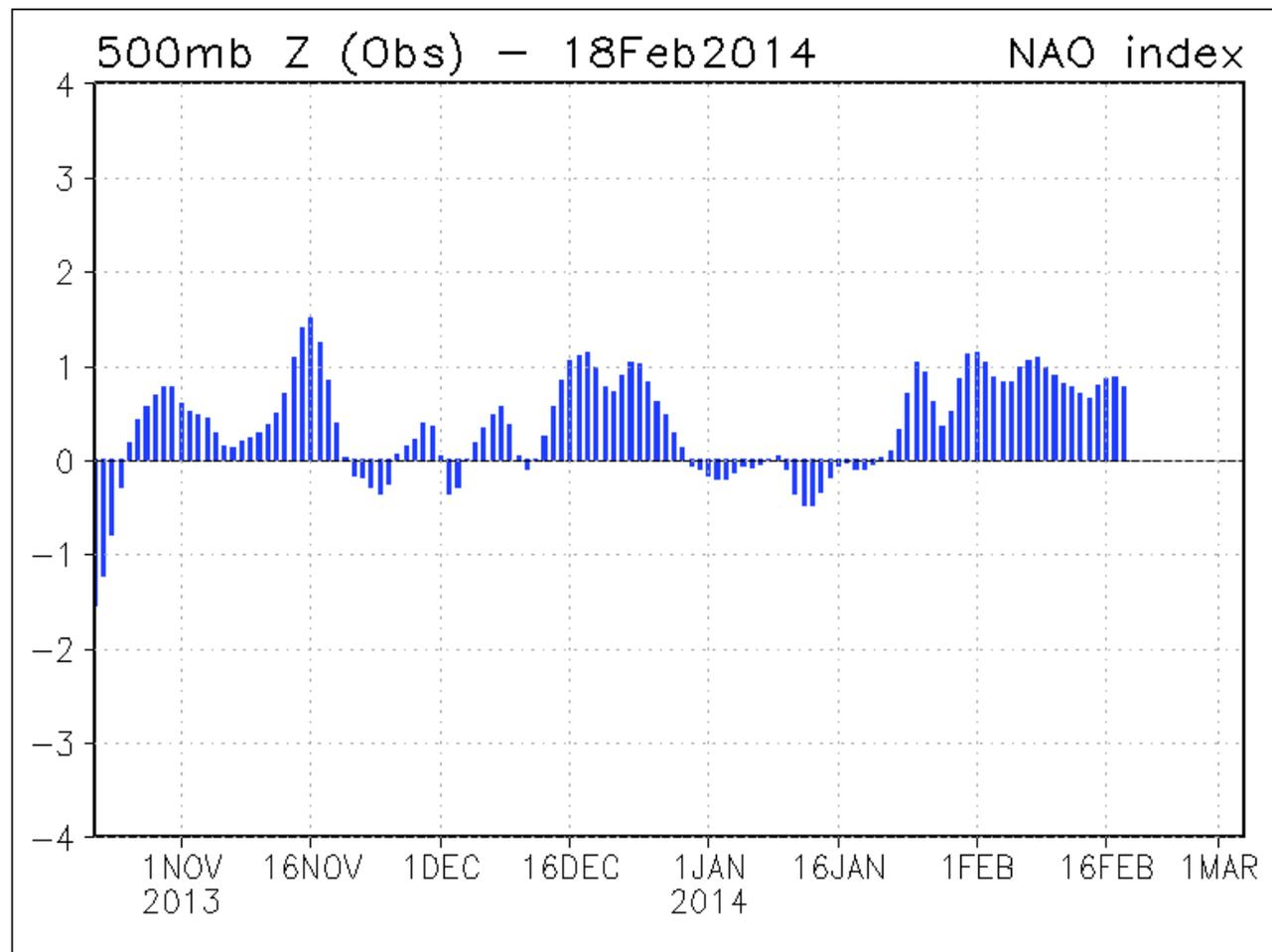


NAO-



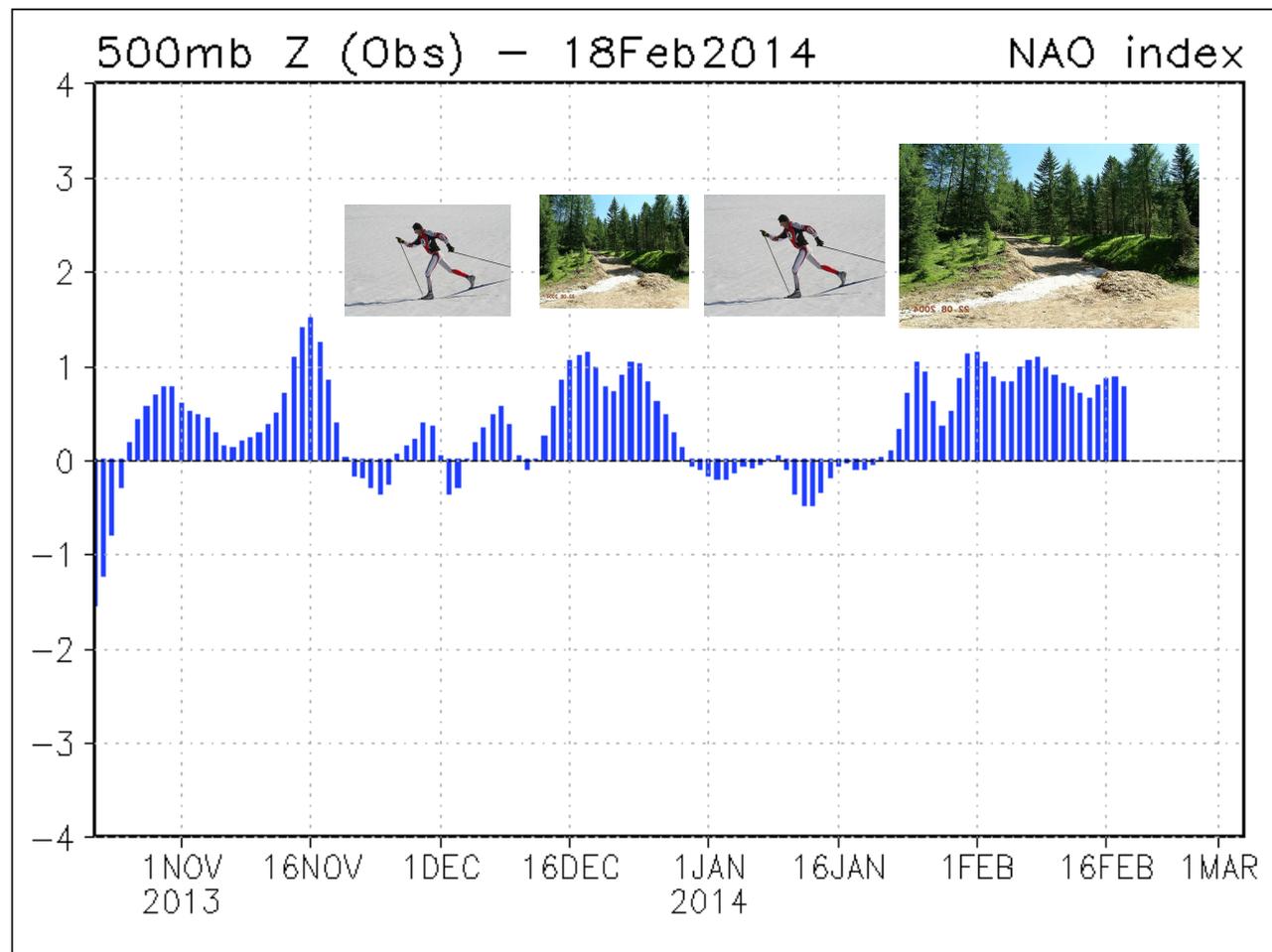
DAILY NAO INDEX AND MELTING OF SNOW IN FINLAND

- Very low snow levels in most of Finland: Two events of snow melting
- Positive NAO from Jan 21, 2014 until now

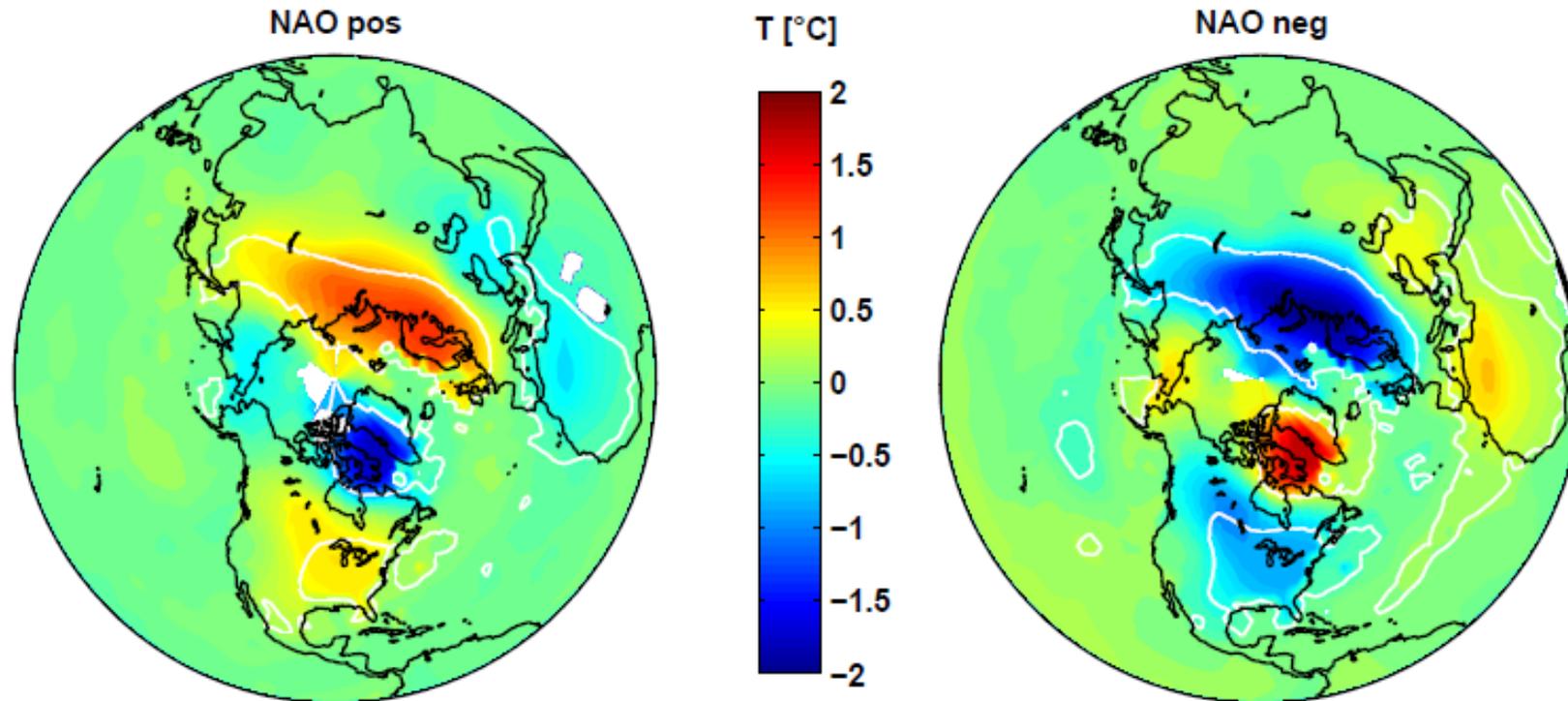


DAILY NAO INDEX AND MELTING OF SNOW IN FINLAND

- Very low snow levels in most of Finland: Two events of snow melting
- Positive NAO from Jan 21, 2014 until now



NAO AND WINTER SURFACE AIR TEMPERATURES (SAT)



Winter monthly surface air temperature anomalies during (left) positive NAO and (right) negative NAO.

White lines represent 95% confidence levels. Data gaps represent temperature grids with more than 5% of the data points missing.

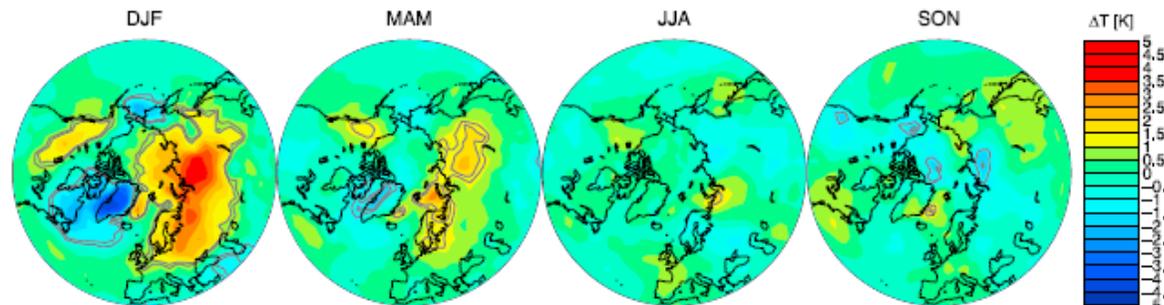
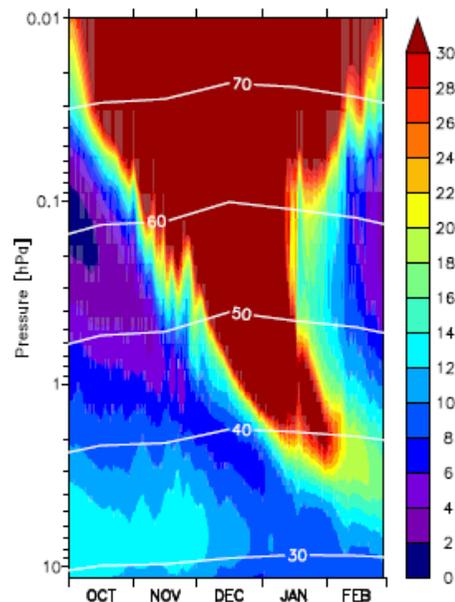
BACKGROUND...

GEOMAGNETIC EFFECT ON WINTER NAO

Several studies have indicated a relation between **geomagnetic activity and winter time tropospheric circulation and temperature** [Bochnicek et al. (1999); Thejll et al. (2003) Rozanov et al. (2005); Seppälä et al. (2009); Baumgaertner et al. (2011)].

Particle precipitation can cause dramatic changes in the upper atmospheric chemistry, **producing NO_x**. During polar winter NO_x can descend down to stratosphere and affect ozone balance, which can modulate stratospheric and tropospheric circulation [Randall et al. (2005); Funke et al. (2006); Seppälä et al. (2007)]

Particle precipitation leads to the **strengthening of the polar vortex**, which is also connected to the North Atlantic oscillation (or northern annular mode) [Baumgaertner et al. (2011)].

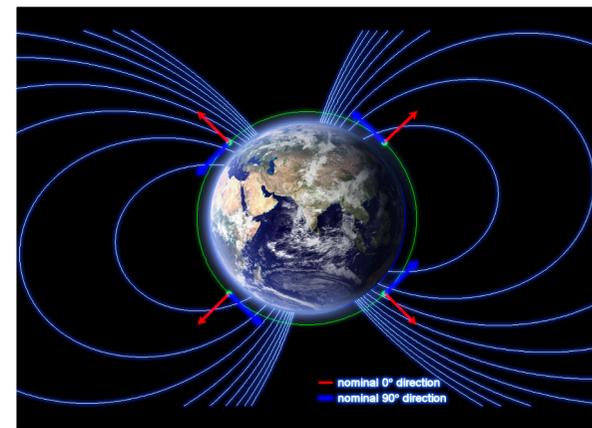
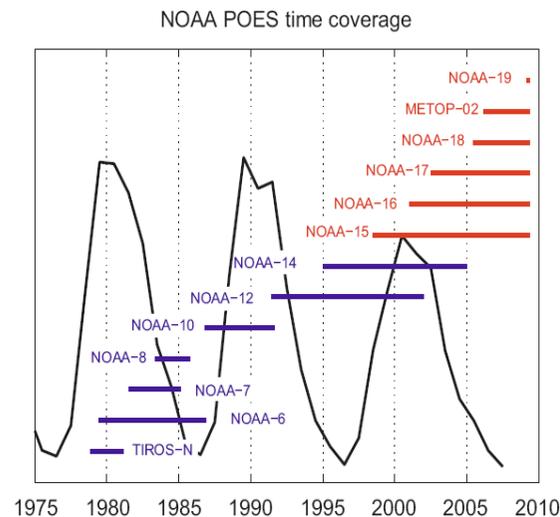
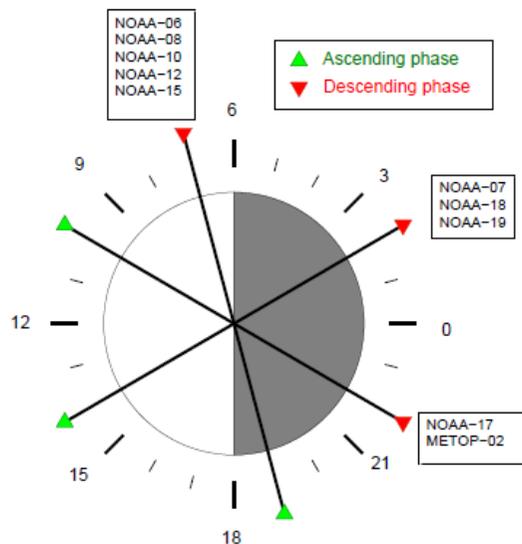


Seppälä et al. (2009), JGR

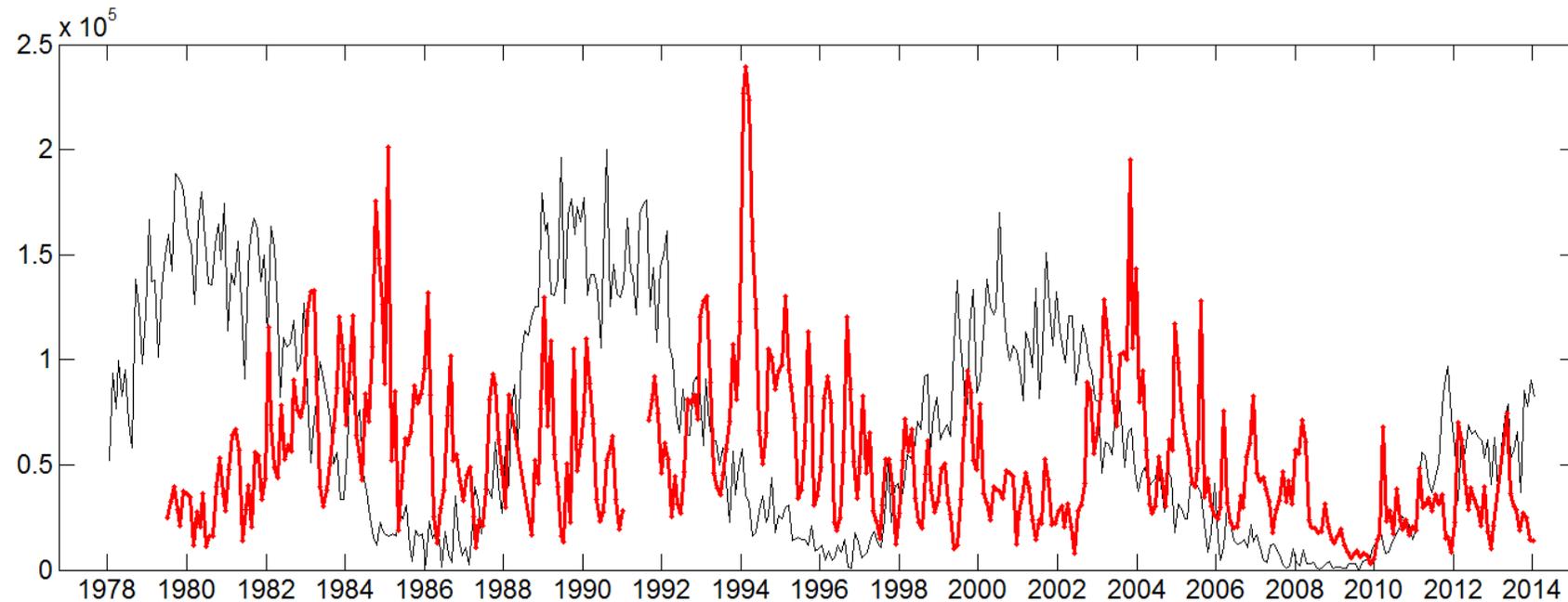
Baumgaertner et al. (2011), ACP

NOAA/MEPED: ENERGETIC ELECTRON PRECIPITATION (EEP)

- Corrected and recalibrated MEPED data [Asikainen and Mursula, 2011, JASTP; Asikainen et al., 2012, JGR; Asikainen and Mursula, 2013, JGR]
- Sun-synchronous polar orbits at 850km altitude
- Same LT-sector (Dawn-Dusk) with NOAA-06, 08, 10, 12 and 15
- Continuous time series for years 1980-2010
- MEPED 0°-telescope points roughly radially away from the Earth (detect precipitating particles at high latitudes).



LONG TERM EVOLUTION OF MEPED ELECTRONS

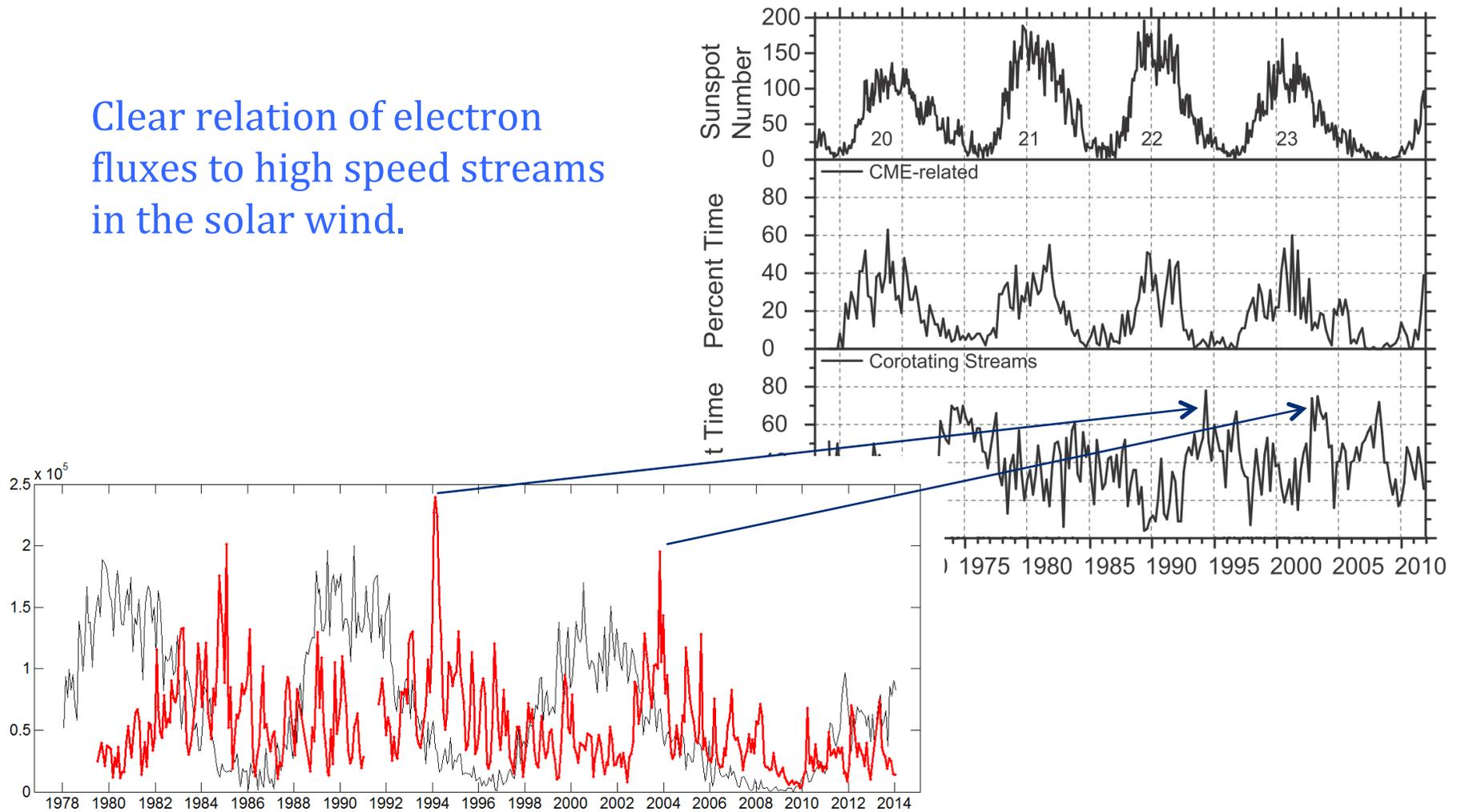


- Electron fluxes maximize fairly late in the declining phase.
- Large cycle variation !
- Interestingly the electron flux at latest solar max 2013 is even stronger than in the previous solar max at 2001. → Interesting next 2-3 years ahead.

HIGH SPEED STREAMS MOST IMPORTANT FOR ENERGETIC ELECTRONS



Clear relation of electron fluxes to high speed streams in the solar wind.



SOLAR CYCLE EVOLUTION OF EEP, GA AND SW SPEED

Two differential energy channels of MEPED:
D1 (30-100 keV) and D2 (100-300 keV).

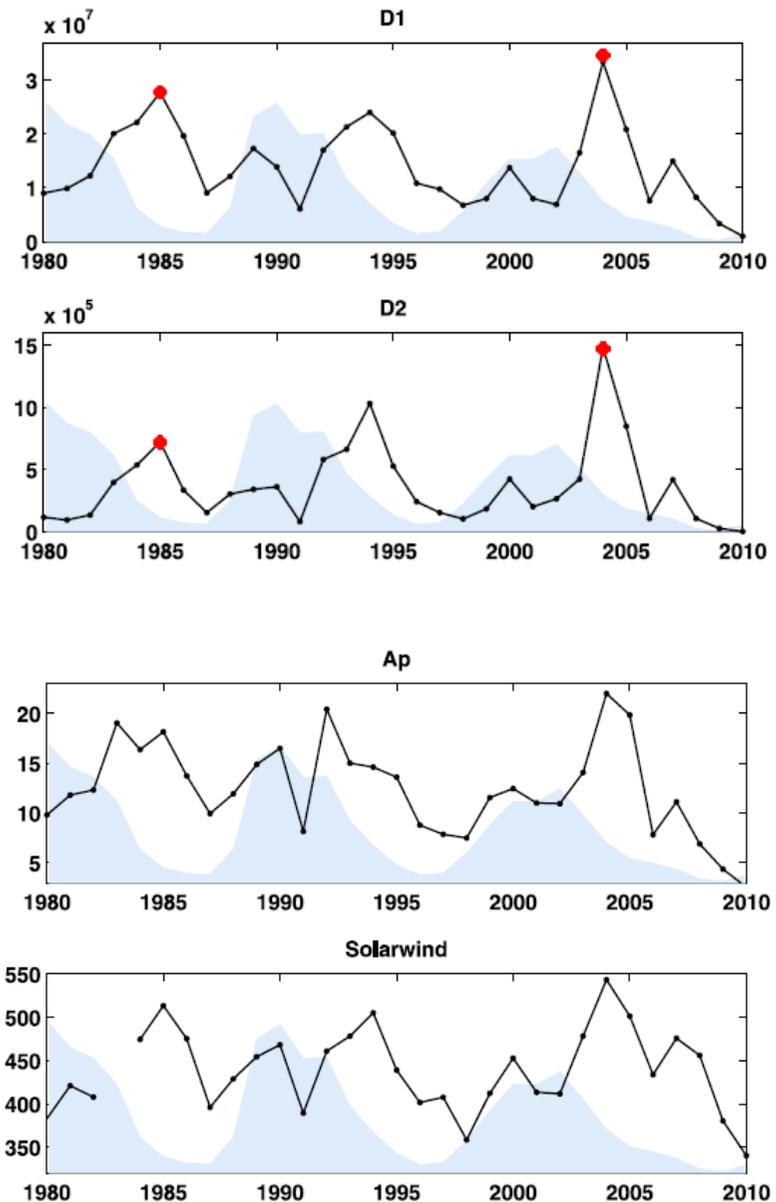
Averages over 3 winter months (Nov, Dec, Jan)

Differences in solar cycle evolution:

EEP fluxes peak later in the declining phase of the solar cycle than GA (Ap index) and covaries more closely with solar wind speed than with Ap.

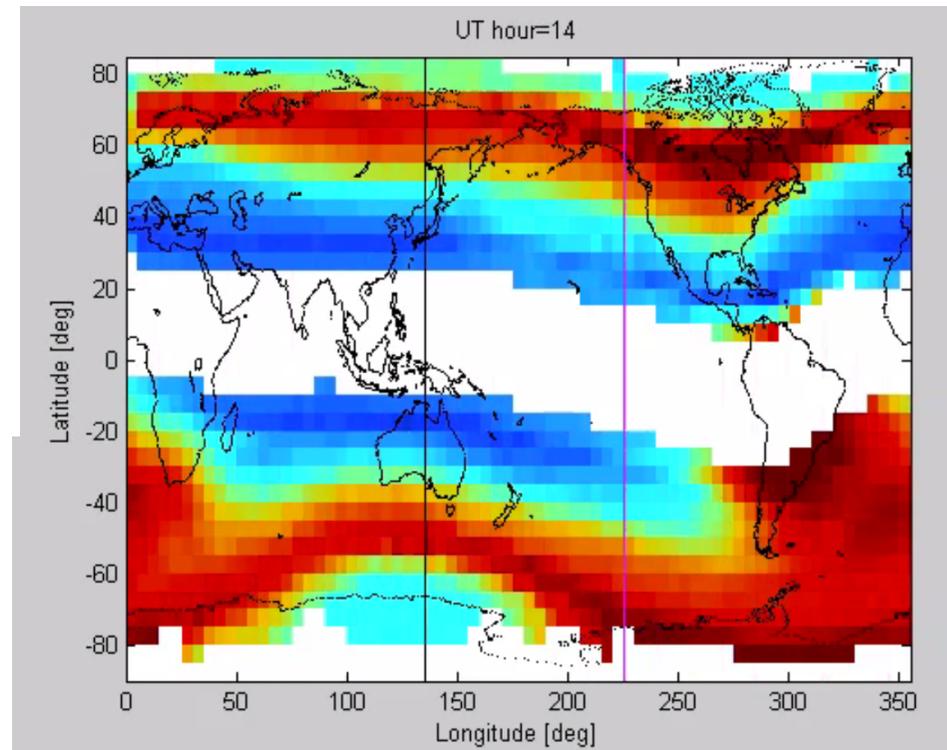
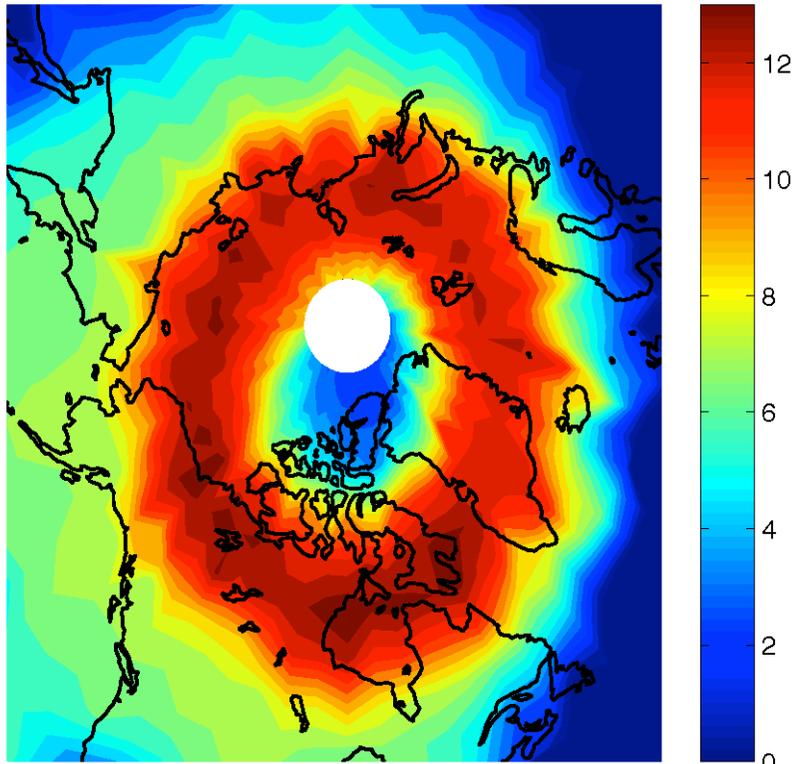
GA is produced by CMEs and HSS/CIRs !

These differences may in principle affect earlier results based on GA.



EEP SPATIAL DISTRIBUTION

Precipitating oval electron I1 in logarithmic scale 1994



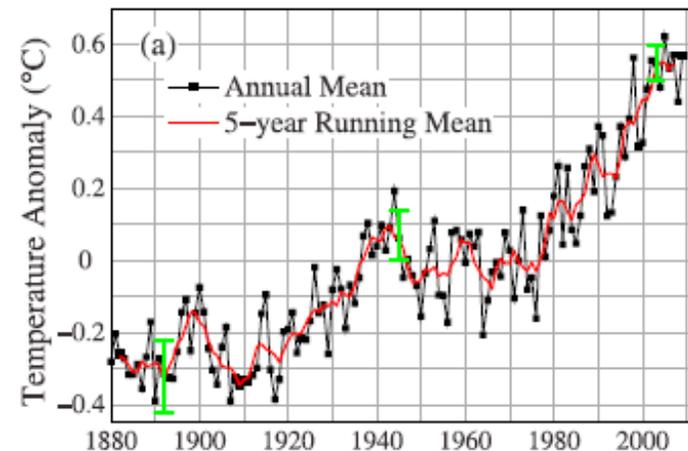
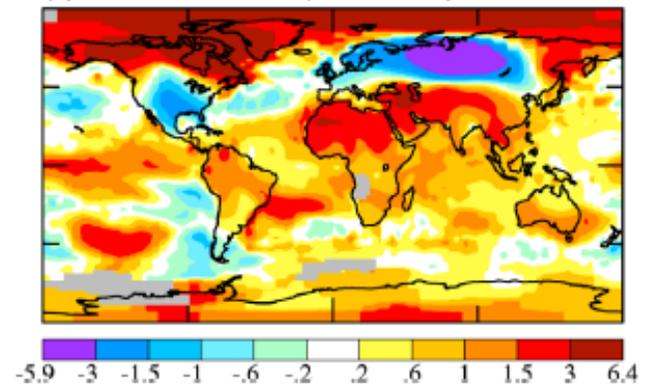
SURFACE AIR TEMPERATURE (SAT) ANOMALIES

Temperature data is presented as gridded **monthly temperature maps in 5°x5° (2°x2°) boxes** of latitude and longitude since 1980 (1880) (Nasa GISS temperature record).

Constructed from ground station data of the Global Historical Climatology Network (GHCN), from Hadley Centre analysis of sea surface temperatures (HadISST1) for 1880-1981 and from satellite measurements of sea surface temperature from 1982 onwards (Optimum Interpolation Sea Surface Temperature Version 2, OISST.v2).

Temperature anomalies are calculated as monthly anomalies from the climatology period (1951-1980) in each grid box.
(In the longer term studies we used 31-year running anomaly).

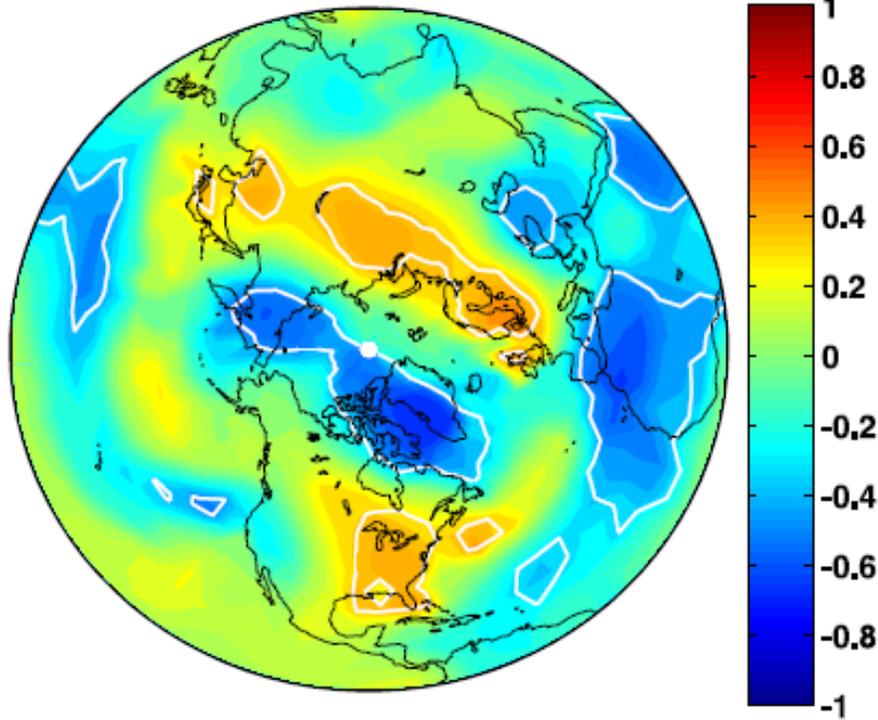
(b) Dec-Jan-Feb 2010 (2nd warmest) 0.67



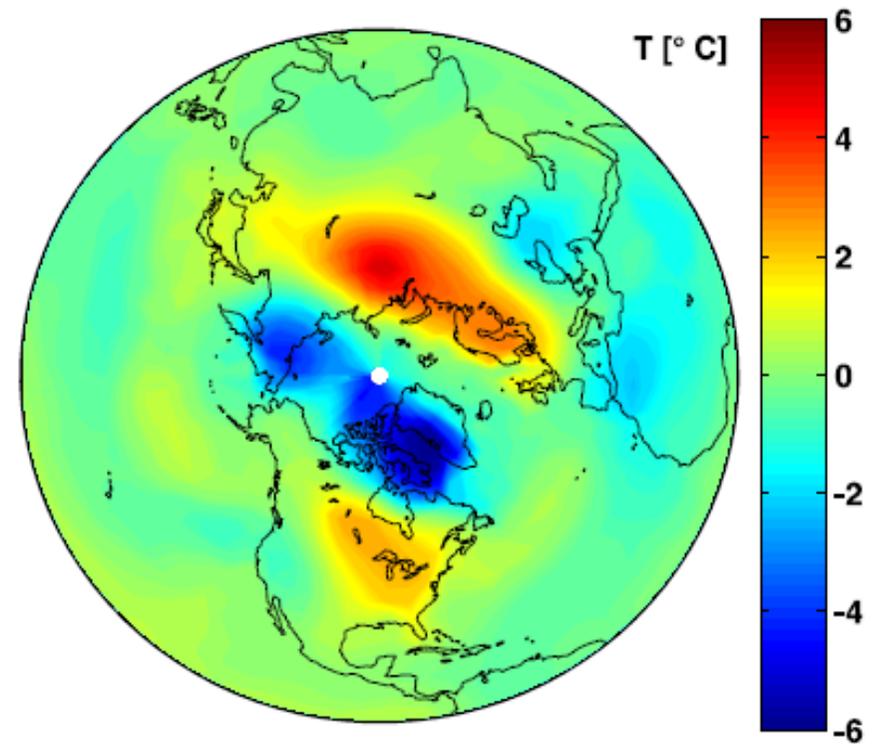
Hansen et al. (2010), Rev. Geophys

NAO AND WINTER SAT IN 1980-2010

Correlation



Range of SAT variation



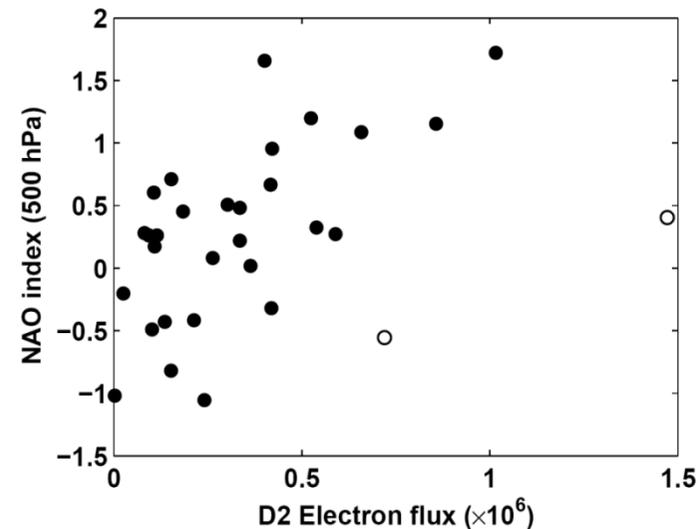
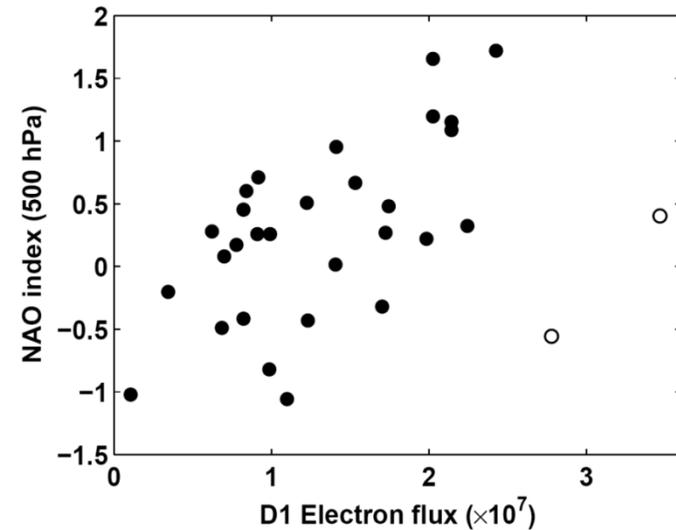
NAO AND EEP

Correlations between NAO index and D1 ($cc=0.44$, $p=0.015$) and between NAO index and D2 (0.44 , $p=0.031$) are significant.

Excluding winters with unprecedently strong SSW event (1985 and 2004; open circles) yields significantly stronger correlations ($cc=0.64$, $p<0.001$) between NAO index and D1, and ($cc=0.65$, $p<0.001$) between NAO index and D2.

p-values were obtained by bootstrapping the residuals with 1000 resamplings, shuffling the harmonic phases of the samples and calculating the fraction of those shufflings with correlation larger than original.

The same procedure was also used to calculate the p-values for EEP and SAT in each grid box.



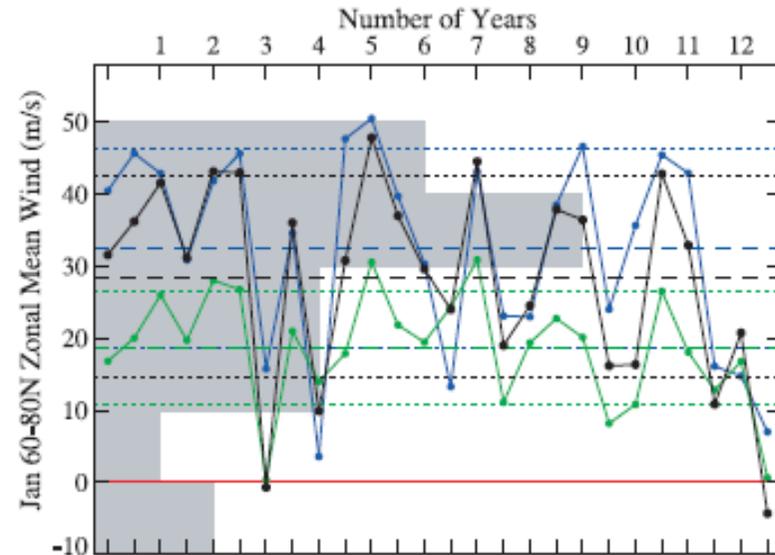
SUDDEN STRATOSPHERIC WARMING (SSW)

Sudden stratospheric warmings dramatically change overall circulation in the stratosphere and can **slow down the polar vortex**.

Weak vortex signal can propagate down to troposphere and **turn NAO more negative**.

For SSWs to show in mean winter conditions it has to be strong and persistent.

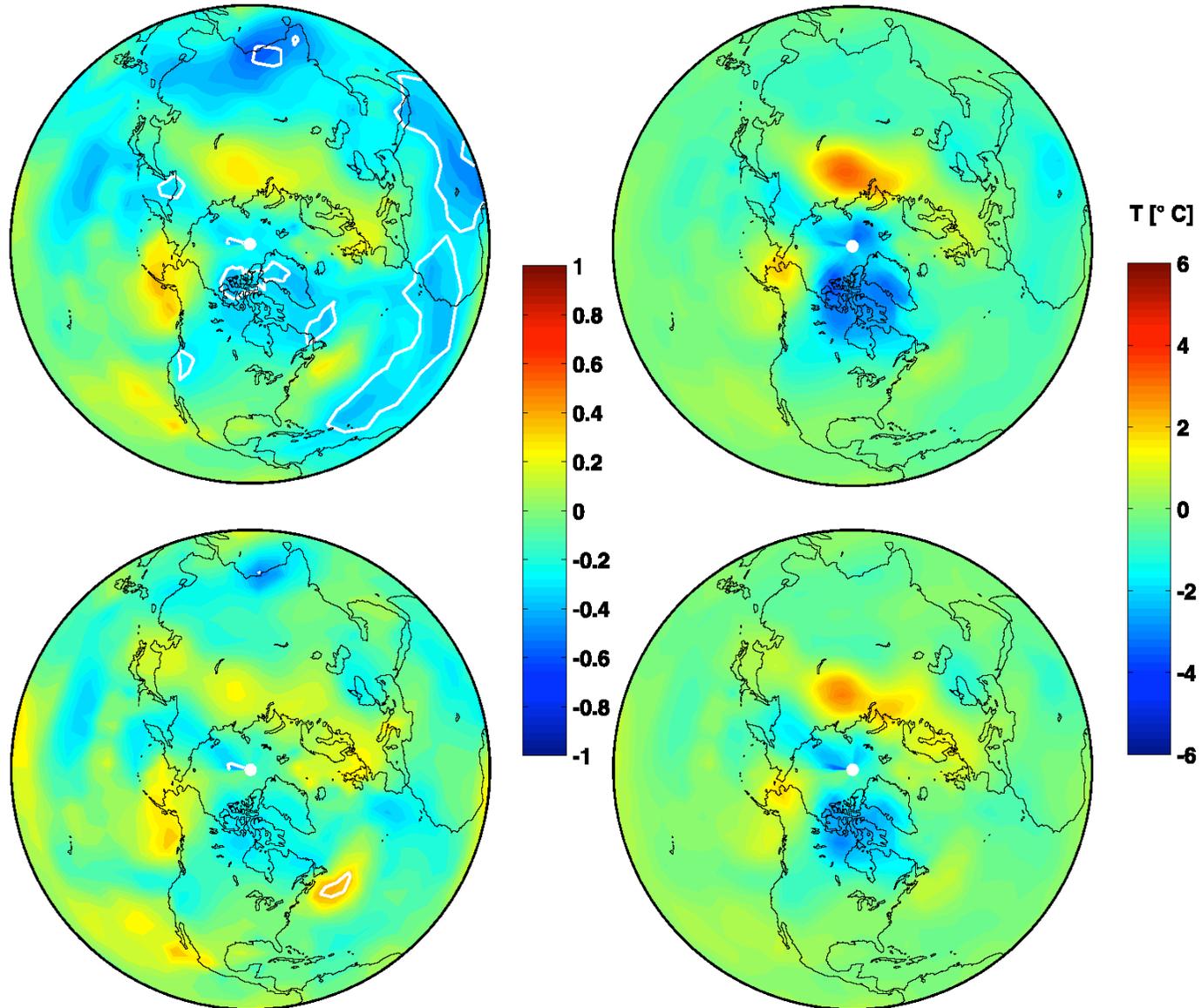
Manney et al. (JGR, 2005):
Jan mean zonal wind in 60°-80°N is
**easterly only during Winters
1984/1985 and 2003/2004.**



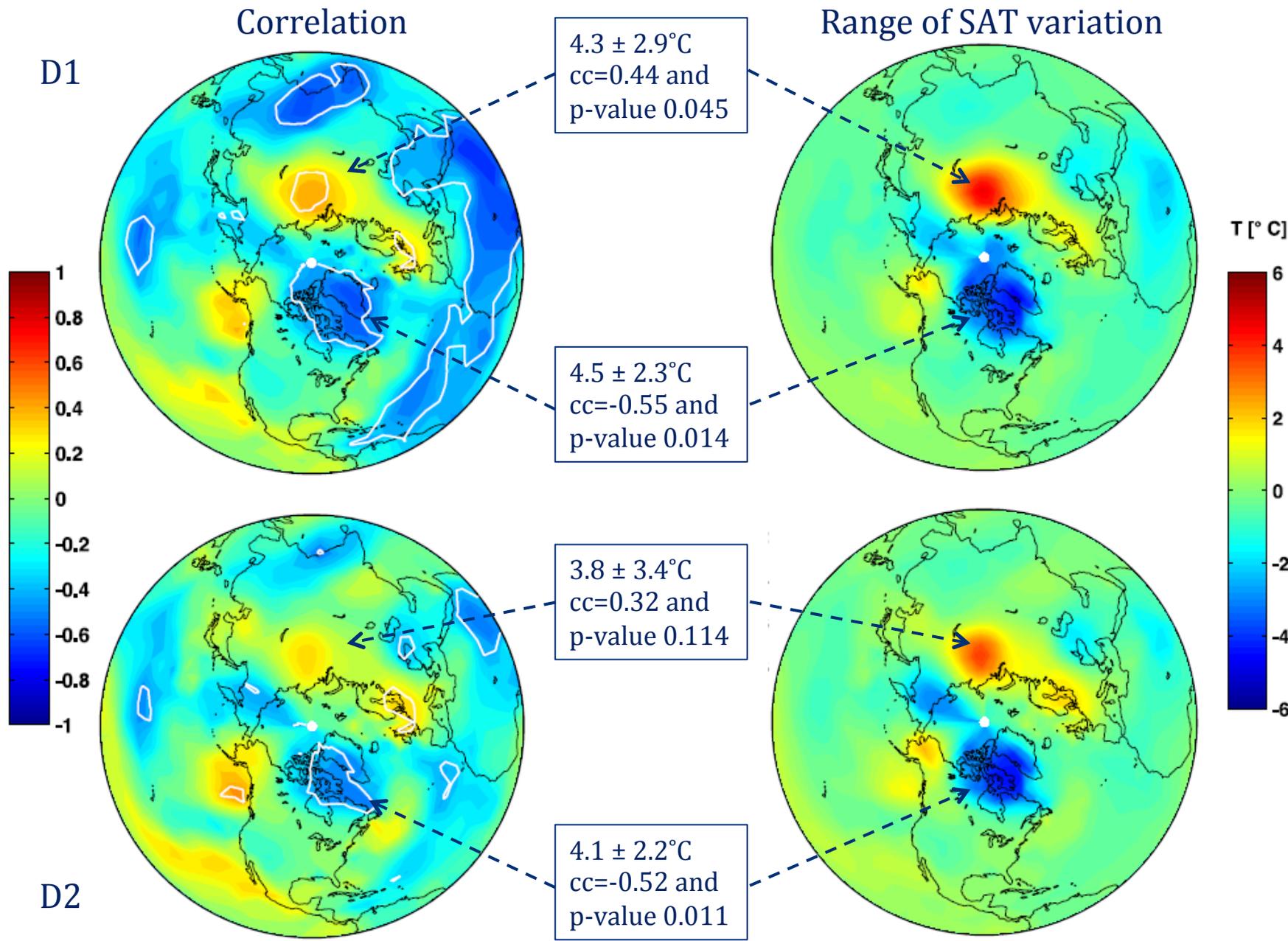
We made a similar zonal wind analysis between 60°N and 90°N at 50 hPa, by using the same (NCEP/NCAR) data for 1980–2010 and **found the same Winters (1984/1985 and 2003/2004) to be the only ones with easterly mean zonal wind in January.**

These Winters were also the only ones where the value differs from the mean January zonal wind value during 1980–2010 by more than two standard deviations.

SAT AND EEP FOR ALL WINTERS

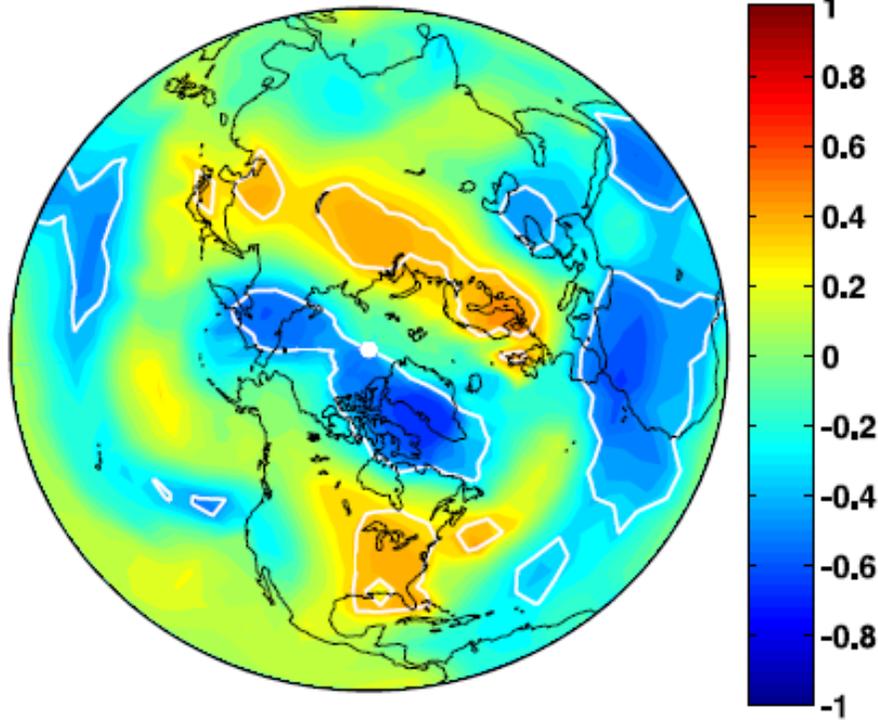


SAT AND EEP EXCLUDING THE TWO EXTREME SSW WINTERS

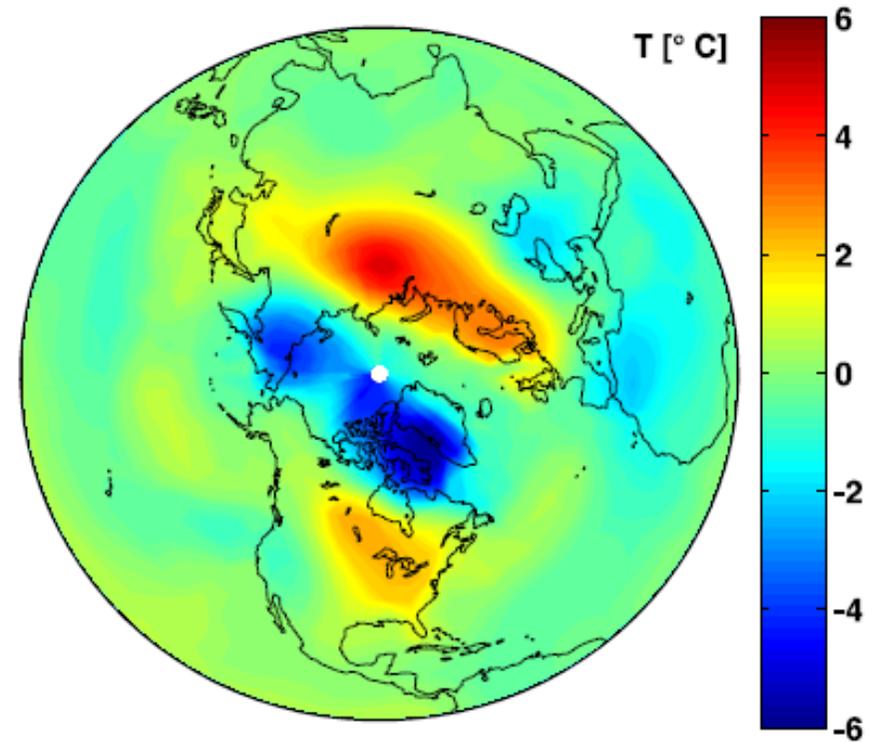


NAO AND WINTER SAT IN 1980-2010

Correlation



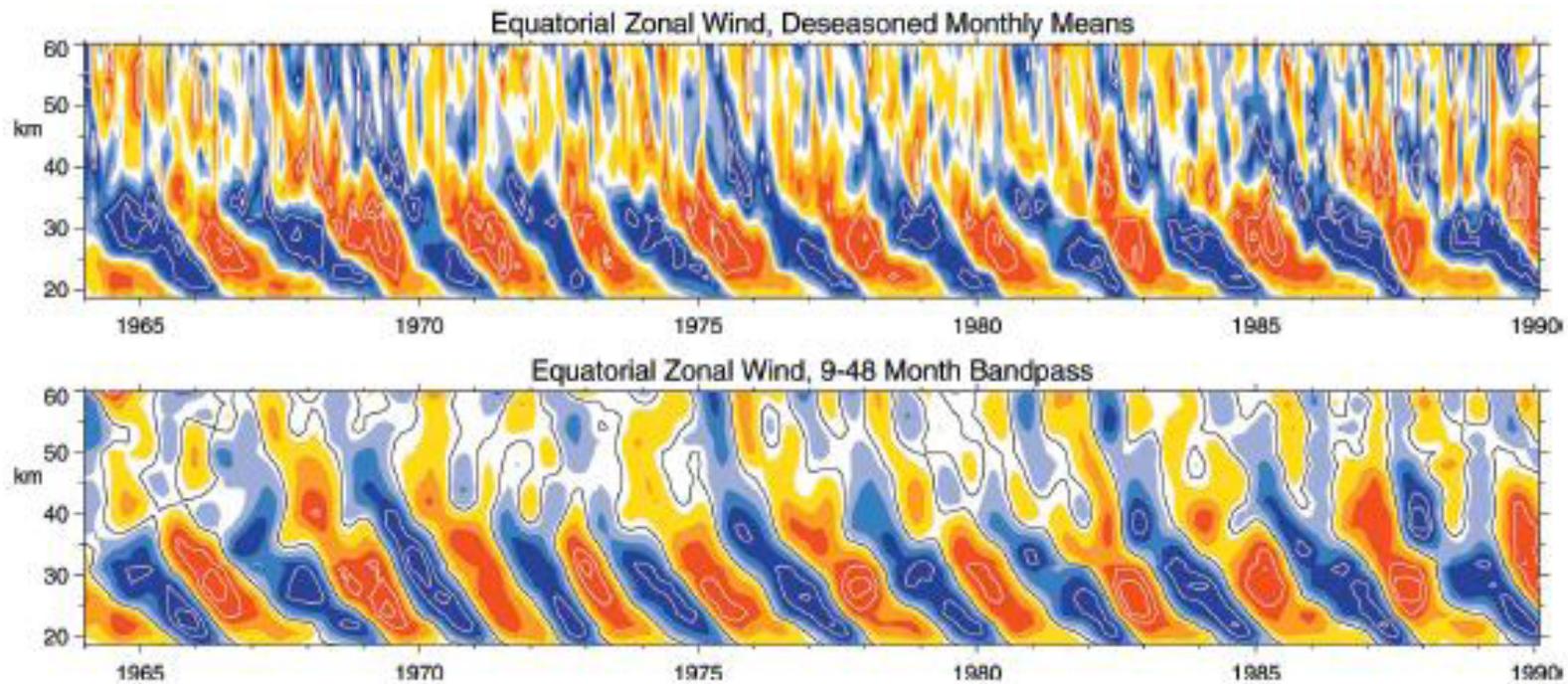
Range of SAT variation



QUASI-BIENNIAL OSCILLATION (QBO)

About 28-month oscillation in equatorial stratospheric zonal winds.

Affects the strength of the polar vortex.



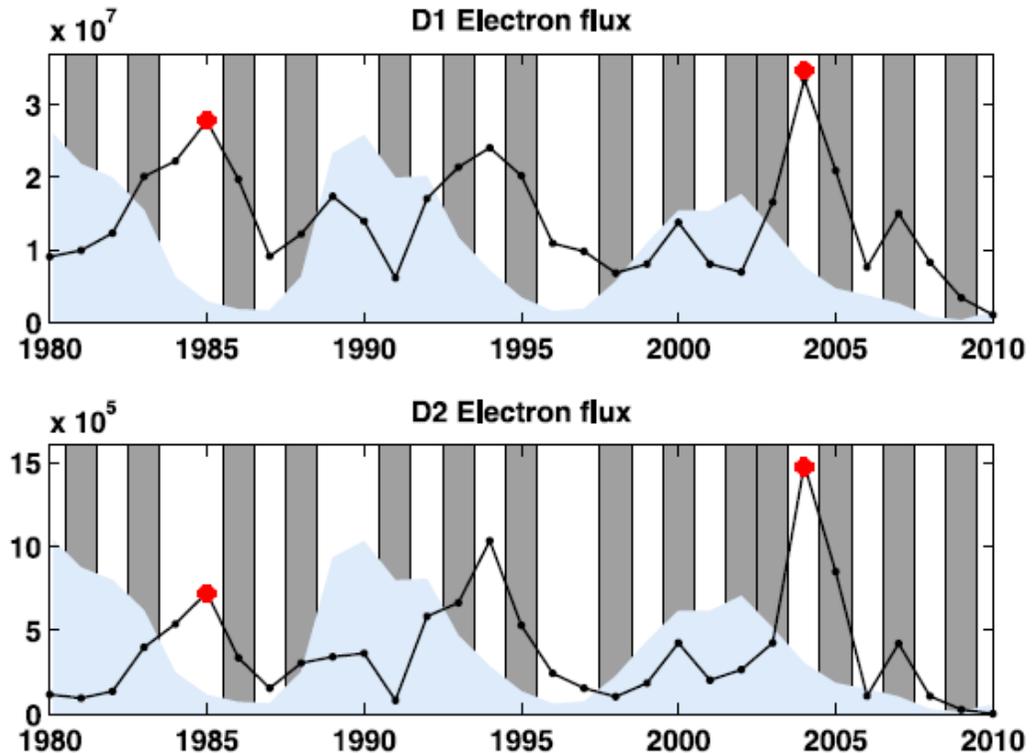
Baldwin et al. (2001), Rev. Geophys

QBO DIVISION

Averaged EEP during three winter months (NDJ) in D1 and D2 energies.

Divide Winters according to westerly and easterly QBO phase.

(3-month (NDJ) mean at 30 hPa, about 25km)

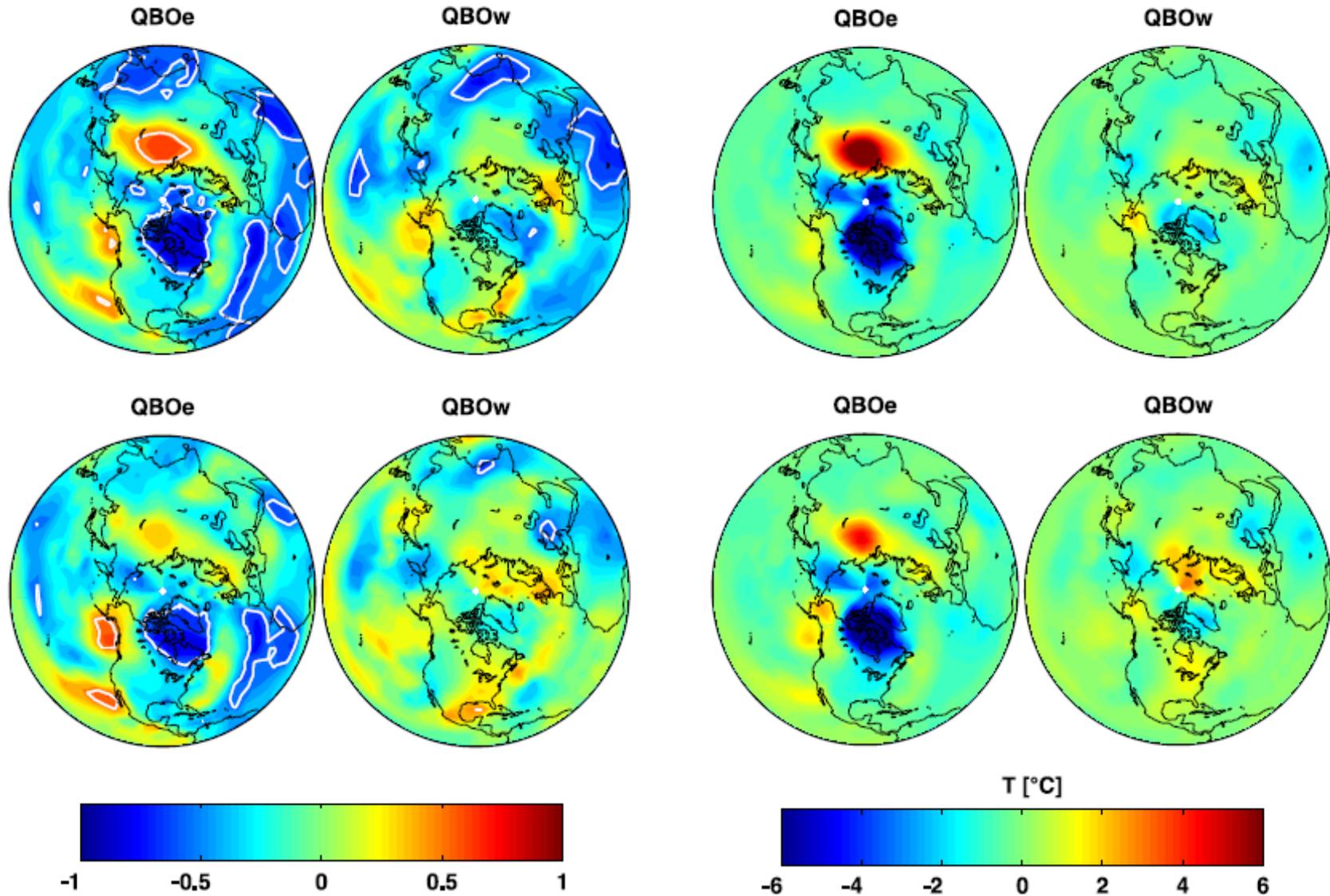


Grey bars represent winters with average QBO index being westerly, other winters being easterly.

Red circles represent the exceptional winters 1985 and 2004 of strong SSW.

Scaled sunspot numbers are indicated with light blue shading.

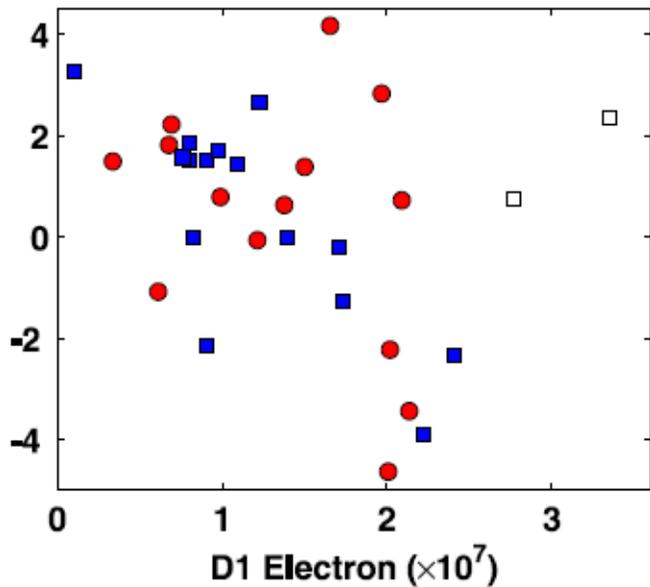
QBO PHASE SEPARATION



Baffin Island

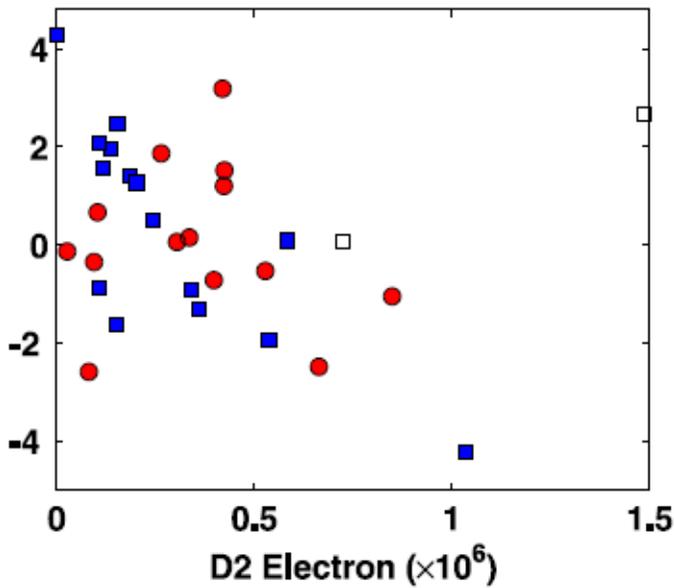
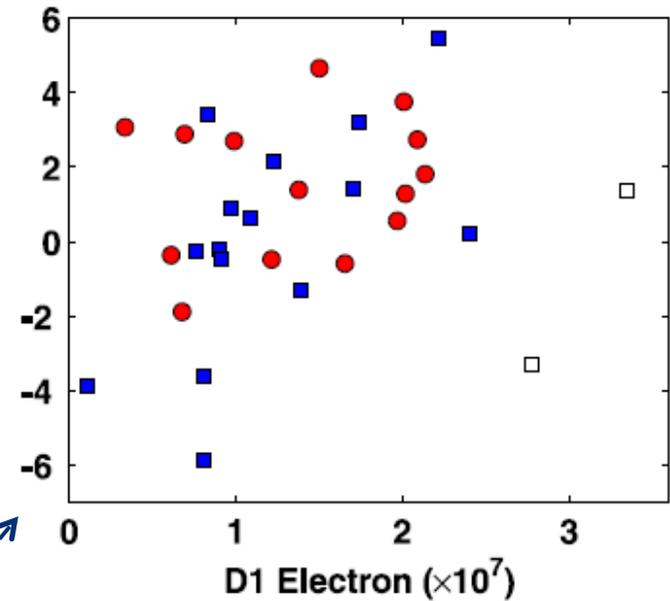
● QBOw ■ QBOe □ 1985 and 2004

North Siberia



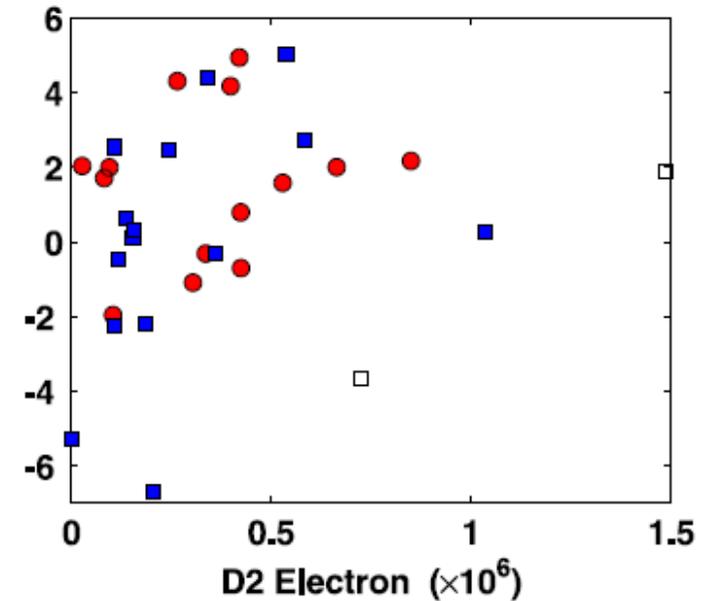
QBOe:
 $6.0 \pm 2.6^\circ\text{C}$
 $cc=-0.78$ and
 $p\text{-value } 0.002$

QBOw:
 $2.5 \pm 3.7^\circ\text{C}$
 $cc=-0.36$ and
 $p\text{-value } 0.208$



QBOe:
 $6.7 \pm 4.7^\circ\text{C}$
 $cc=0.59$ and $p\text{-value } 0.027$

QBOw:
 $0.9 \pm 2.7^\circ\text{C}$
 $cc=0.17$ and $p\text{-value } 0.540$



CONCLUSIONS SO FAR

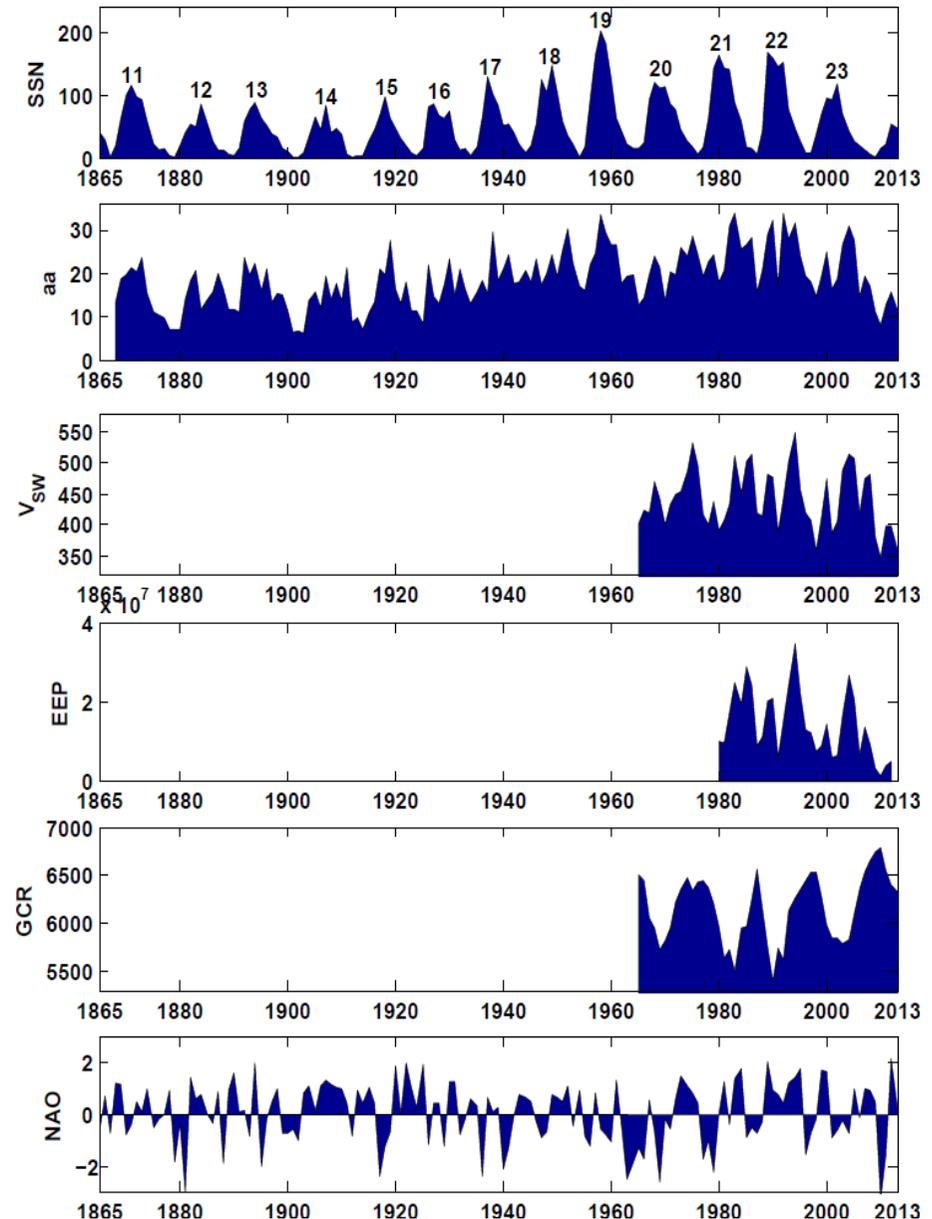
- Northern Hemisphere winter surface temperatures and associated NAO variability are positively correlated with energetic electron precipitation during the last 30 years.
 - Connection is strongly dependent on the QBO phase, so that easterly (at 30 hPa) phase enhances the NAO pattern observed earlier but during westerly phase the effect disappears almost completely.
 - Results are quite similar to those earlier obtained when using geomagnetic activity indices as proxy to EEP. (Quite similar solar cycle variation).
 - The results support the idea that high-speed solar wind streams and related energetic particle precipitation are more important than TSI/UV flux or cosmic rays in modulating Northern Hemisphere winter NAO and associated surface temperatures.
-
- V. Maliniemi, T. Asikainen, K. Mursula and A. Seppälä, QBO-dependent relation between electron precipitation and wintertime surface temperature, JGR, DOI: 10.1002/jgrd.50518, 2013

SOLAR CYCLE VARIABILITY SINCE SC 11 (1860s)

Several studies have found solar related modulation of Northern Hemisphere winter climate (NAO).

Proposed modulating drivers include total solar irradiance and UV irradiance (vary in phase with the solar cycle), galactic cosmic rays (in opposite phase with the solar cycle), geomagnetic activity, magnetospheric energetic particle precipitation (peak in the declining phase)

While the effect of the drivers in the same or opposite phase may be difficult to distinguish, **the effects of drivers with different phases can be better separated.**



SOLAR CYCLE PHASE FUNCTION

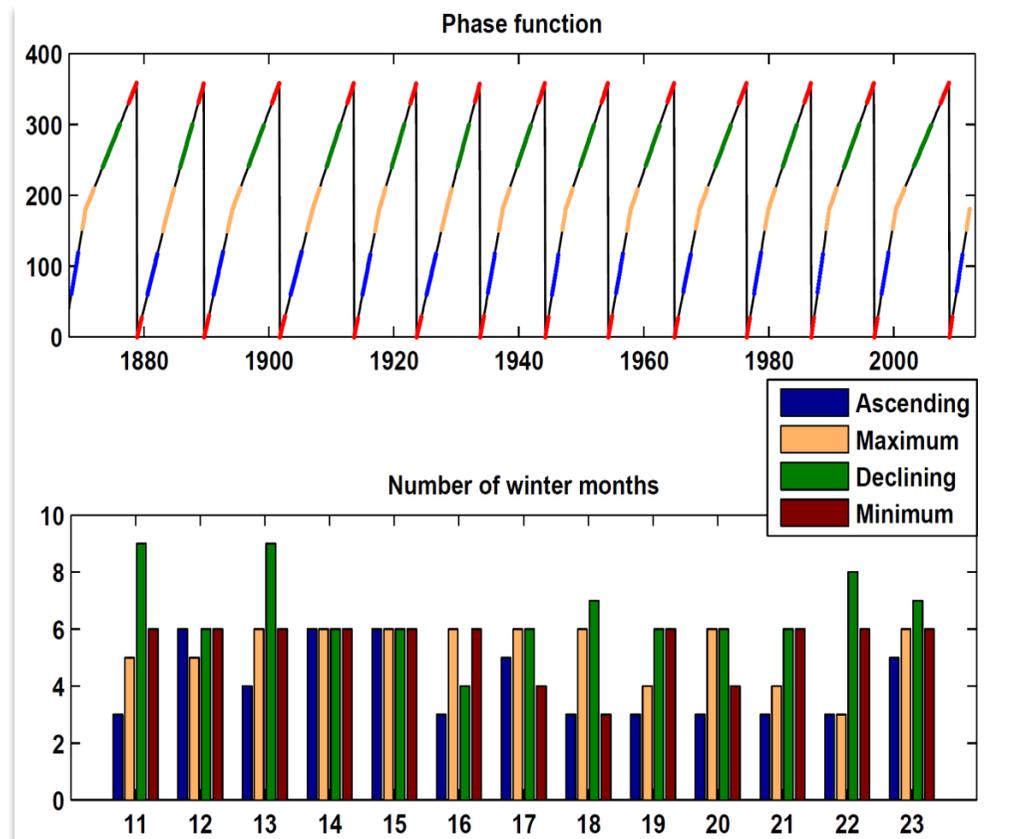
Four separate phases with a 60° wide window in the phase function (ascending phase centered at 90°, maximum at 180°, declining at 270° and minimum at 360°/0°).

Only winter months (Dec, Jan, Feb) included.

In total 53 winter months in the ascending phase, 69 in the maximum phase, 86 in the declining phase and 71 in the minimum phase.

Since cycle 16 the cycles are **asymmetric**, having longer declining phase than ascending phase (top panel).

This is also visible in the numbers of winter months in each phase during each cycle (bottom panel)

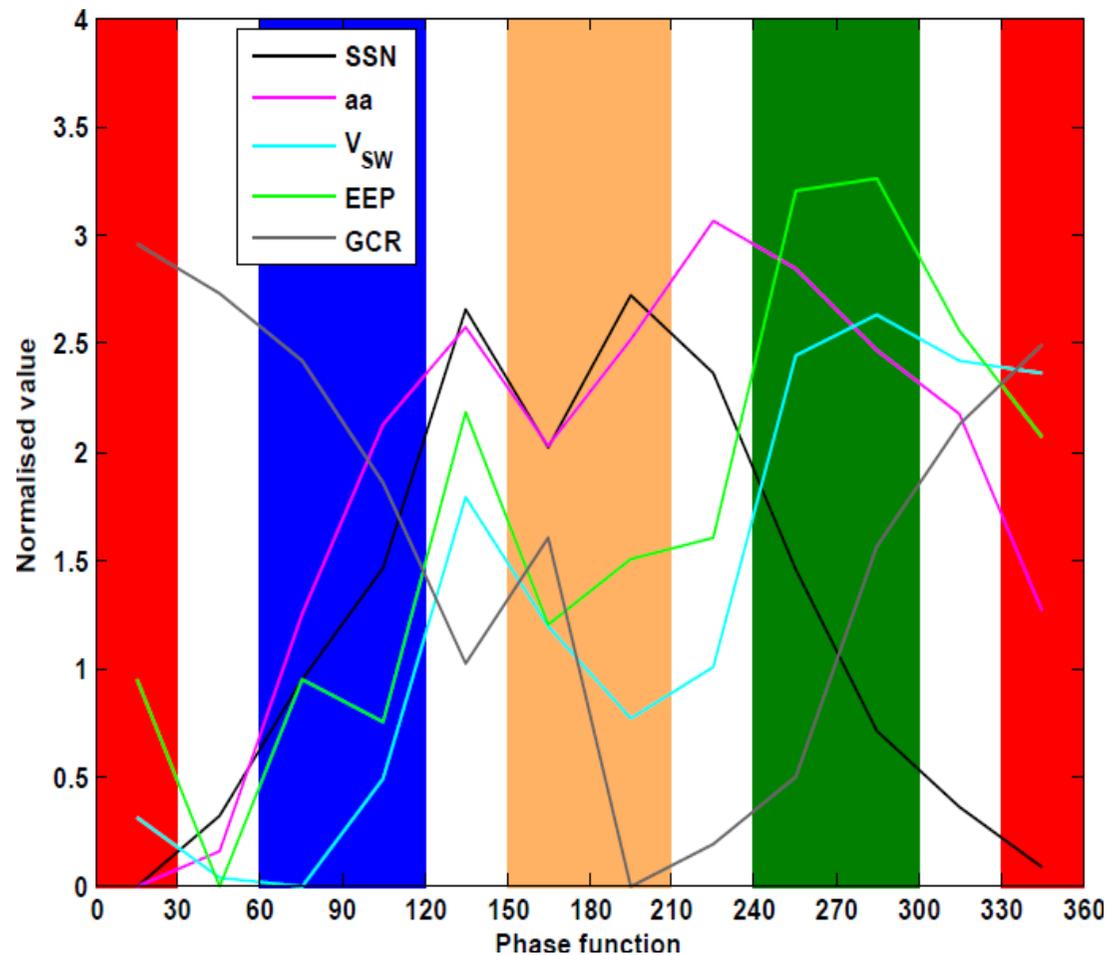


MEAN WINTER VALUES IN DIFFERENT SOLAR CYCLE PHASES

Cosmic rays are in opposite phase with the sunspot cycle.

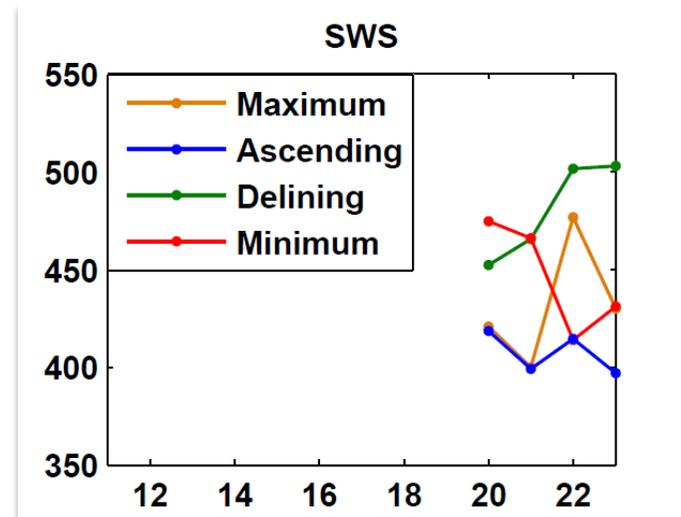
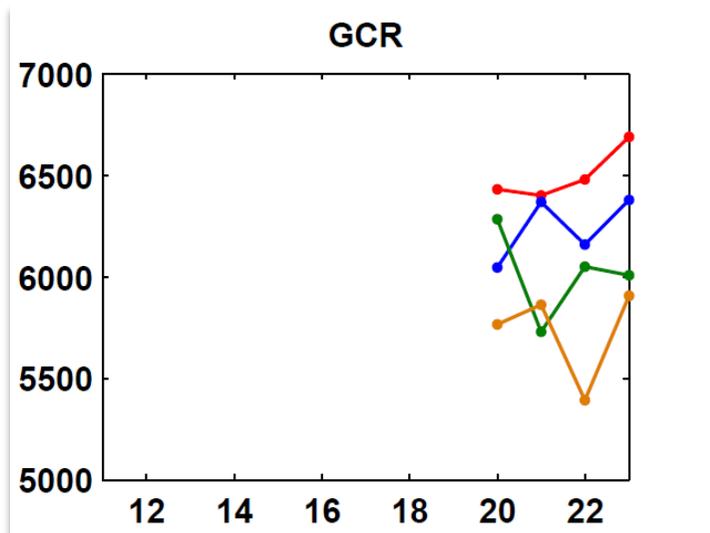
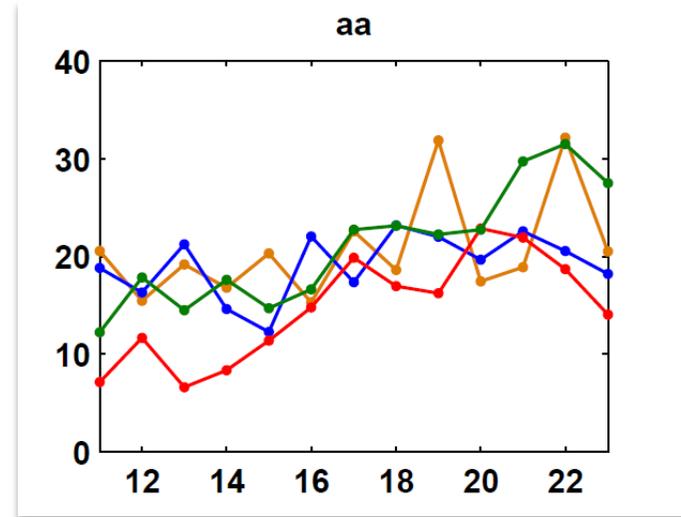
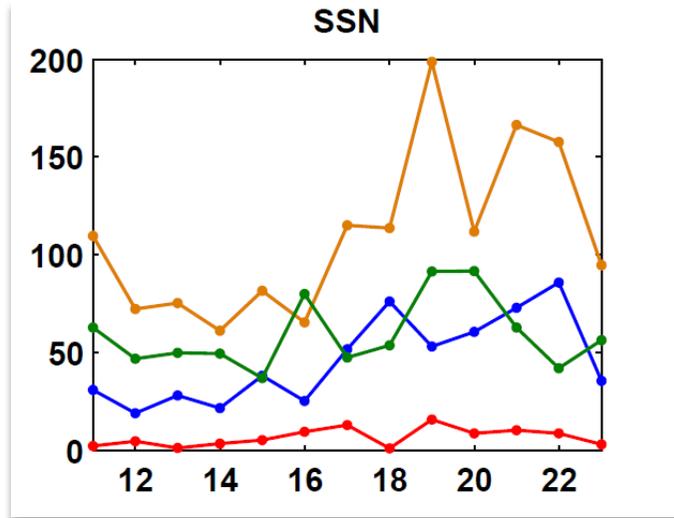
Geomagnetic activity peaks between the "maximum" and the "declining phase".

Only EEP and solar wind speed peak in the "declining phase".



VALUES IN DIFFERENT SOLAR CYCLES AND PHASES

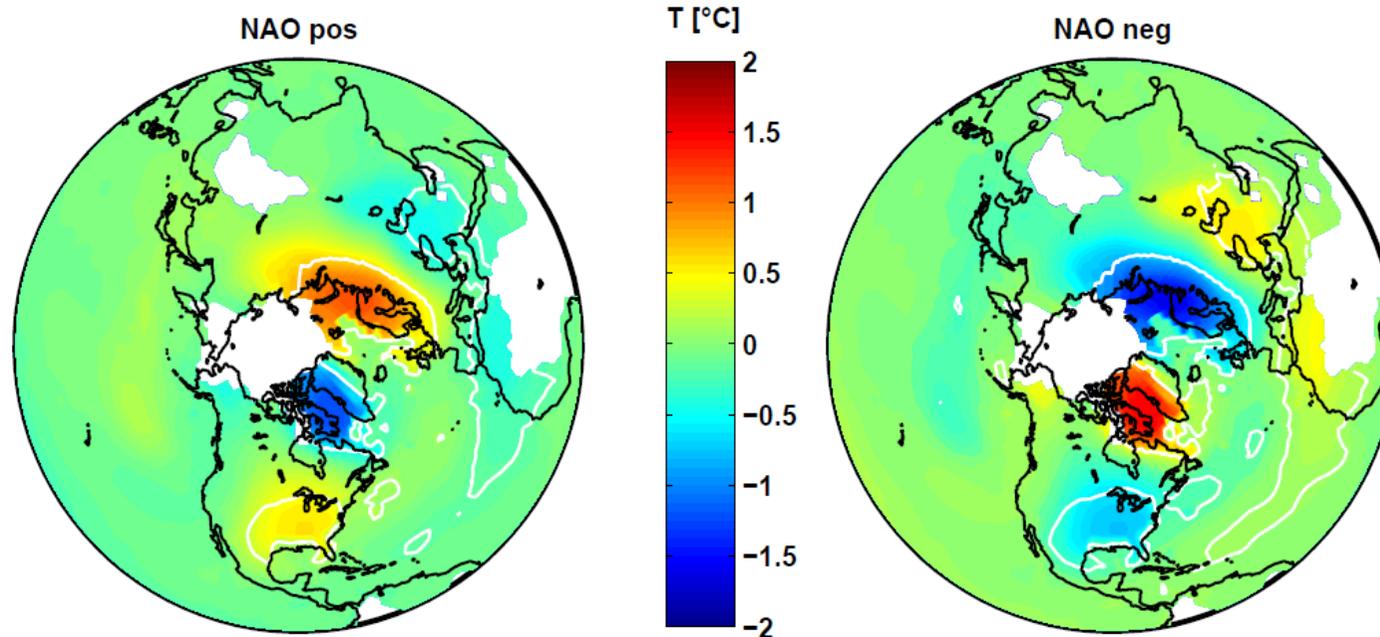
Mean winter values of sunspot number, aa index, cosmic ray flux and solar wind speed in the four cycle phases for cycles 11 to 23.



TEMPERATURE ANOMALIES DURING DIFFERENT CYCLE PHASES

- Temperature data is presented as gridded monthly temperature maps in $2^{\circ} \times 2^{\circ}$ boxes of latitude and longitude since 1880 (NASA GISS temperature record).
- Mean temperature anomalies (calculated by subtracting 31-year running mean for each month separately in each grid box) in each phase during winter months were calculated for years 1880-2009. p-values were calculated by one-sample t-test.
- **Only the declining phase produces the positive NAO temperature pattern at high latitudes with high significance.**
- **Maximum phase produces a negative NAO pattern, but with a weak significance.**

NAO IN 1880-2009



Mean winter monthly temperature anomalies during (left) positive NAO and (right) negative NAO.

White lines represent 95% confidence level. White areas denote data gaps of temperature grids with more than 5% of monthly data missing.

SUMMARY

- Northern Hemisphere winter surface temperatures and NAO variability are positively correlated with energetic electron precipitation during the last 30 years.
- Connection is strongly dependent on the QBO phase, so that easterly (at 30 hPa) phase enhances the NAO pattern observed earlier but during westerly phase the effect disappears almost completely.
- Temperature pattern resembles the pattern associated with positive phase of NAO only during the declining phase of the solar cycle .
- Declining phase produces the positive NAO for the last 13 cycles, i.e. even during the weak solar cycles around 1900 ! This supports the similar cycle evolution of coronal holes and the importance of HSS/EEP for NAO.
- The results support the idea that high-speed solar wind streams and related energetic particle precipitation are more important than TSI/UV flux or cosmic rays in modulating Northern Hemisphere winter NAO and associated surface temperatures.
- V. Maliniemi, T. Asikainen, K. Mursula and A. Seppälä, JGR, DOI: 10.1002/jgrd.50518, 2013
- V. Maliniemi, T. Asikainen and K. Mursula, Spatial distribution of Northern Hemisphere winter temperatures during different phases of the solar cycle, under review in JGR, 2014

THANKS, FOLKS !