Fifth Workshop
Solar Influences on the Magnetosphere, Ionosphere and Atmosphere
Nessebar, Bulgaria, 3-7 June 2013

Influence of the stratospheric polar vortex on the development of solar activity effects on the lower atmosphere circulation

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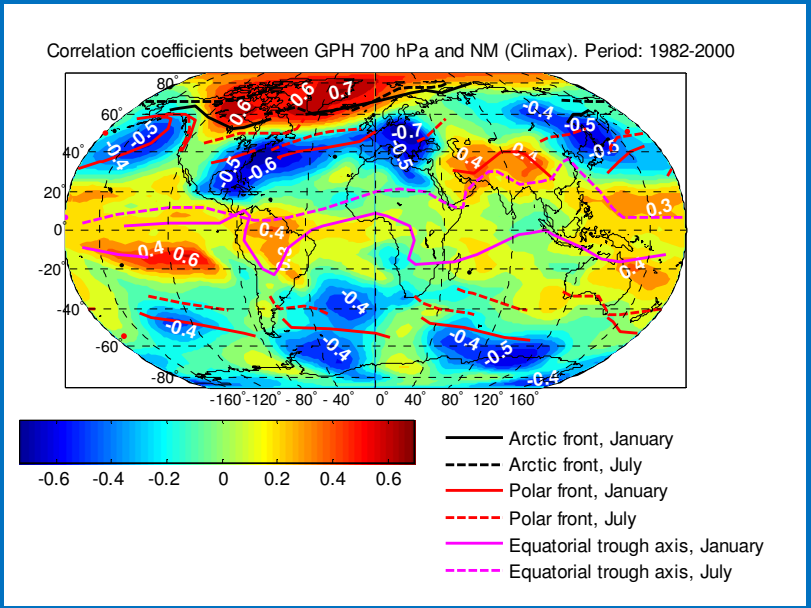
- Studies of solar-climatic relations are of significant importance to understand a variability of the Earth's climate and to forecast its future evolution.
- However, these relations reveal instability in both time and space that sometimes gives rise to doubt a reality of solar activity influence on atmospheric processes.
- The aim of this work is to study the temporal and spatial variability of solar activity effects on the troposphere circulation and possible reasons for this variability.

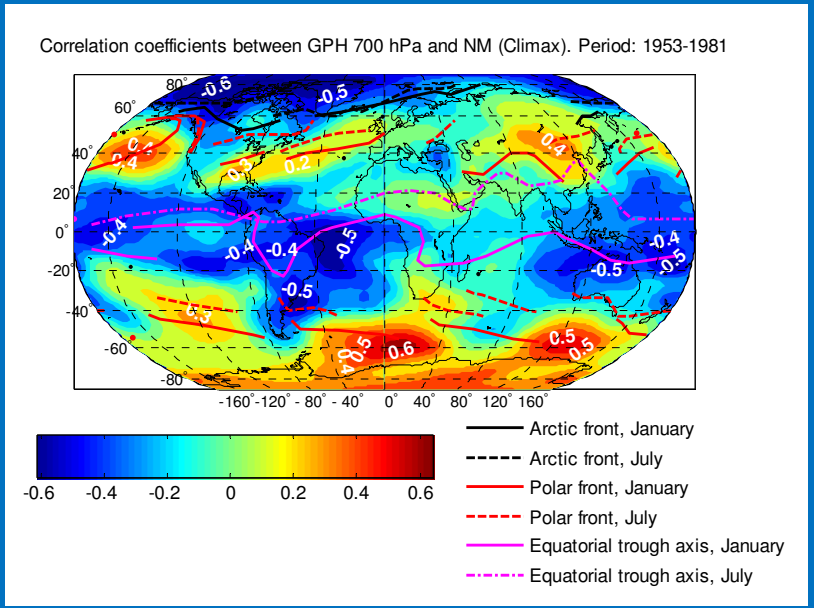
1. Temporal and regional variability of solar activity and galactic cosmic ray effects on troposphere pressure

GCR effects on troposphere pressure for different epochs of the large-scale atmospheric circulation

Epoch of increasing meridional circulation (C type) (1982-2000 rr.)



Epoch of decreasing meridional circulation (C type) (1953-1981 rr.)



GCR increase in the minima of the 11-year cycle is accompanied

↓

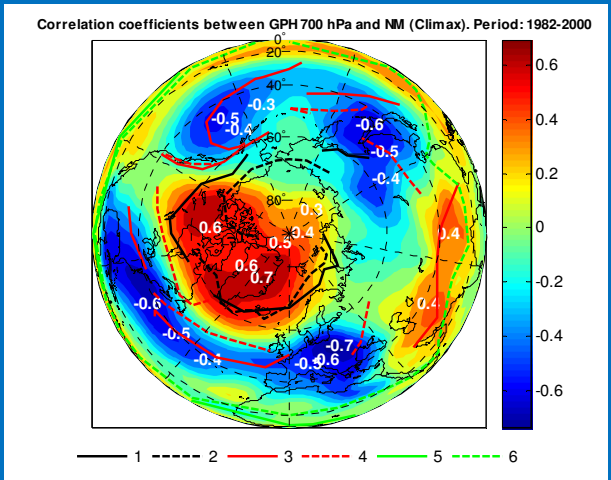
- **Intensification of near-ground Arctic anticyclones**
- **Intensification of extratropical cyclogenesis at Polar fronts**
- **Weakening of the equatorial trough**

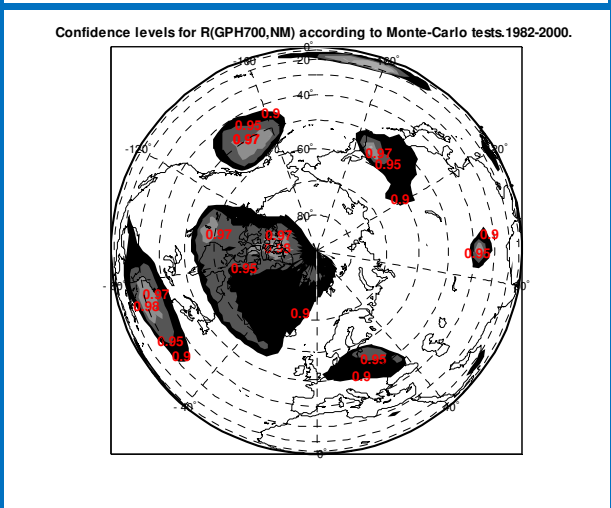
↓

- **Weakening of near-ground Arctic anticyclones**
- **Weakening of extratropical cyclogenesis**
- **Intensification of the equatorial trough**

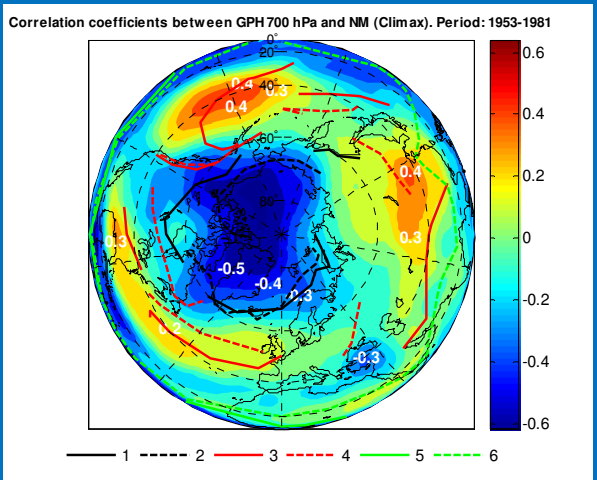
Veretenenko and Ogurtsov, Adv.Space Res,2012;

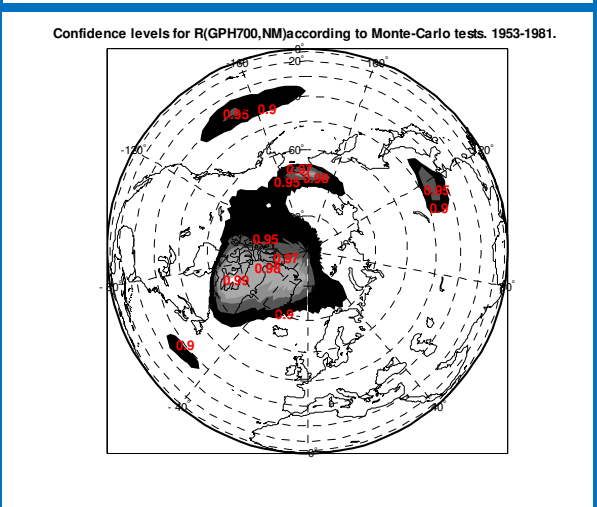
Epoch of increasing meridional circulation (1982-2000)





Epoch of decreasing meridional circulation (1953-1981)

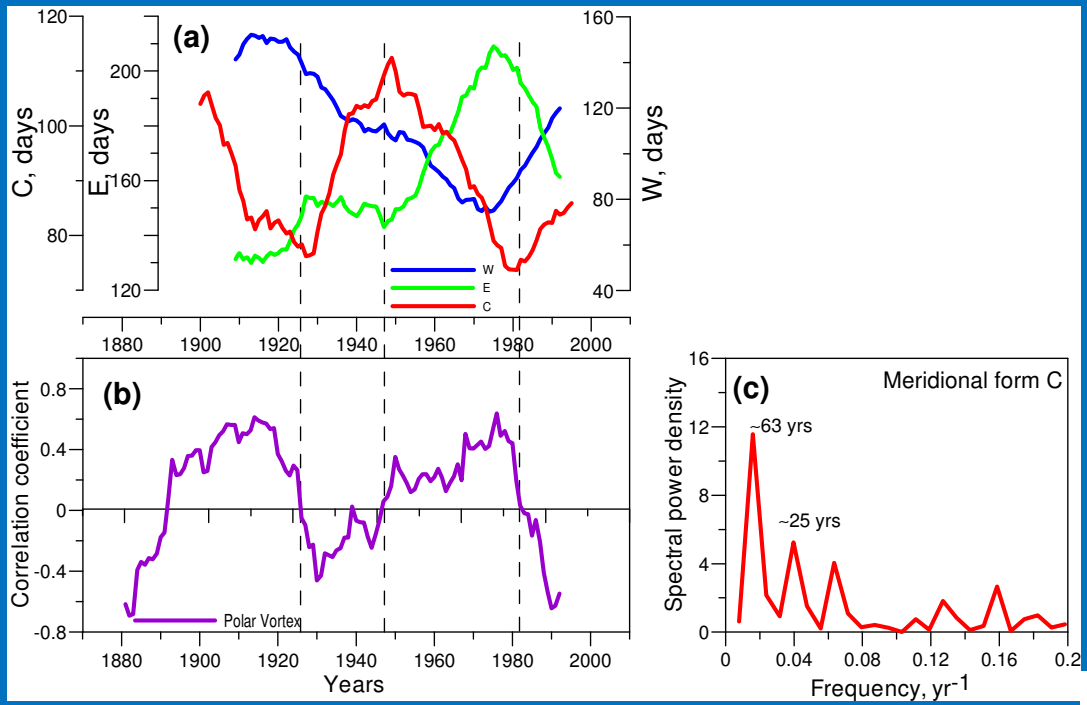




Most statistically significant correlation coefficients between troposphere pressure and GCR are observed:

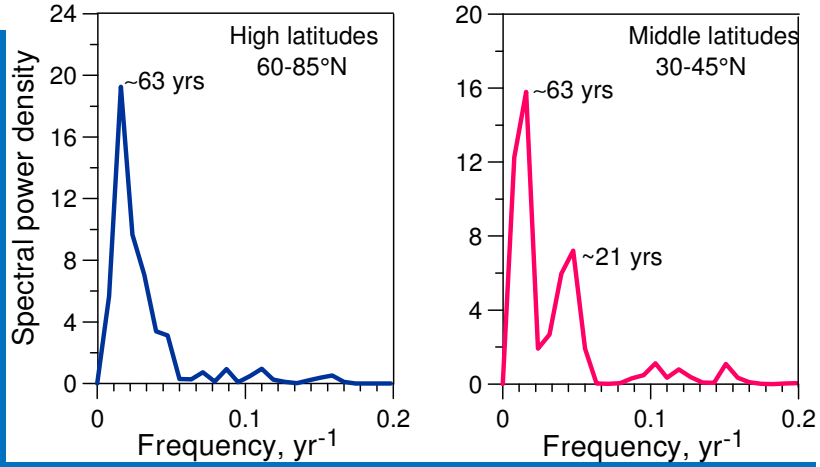
- In the high-latitudinal area (independently of the time period)
- at Polar fronts (Polar frontal zones) at middle latitudes in the periods of increasing meridional circulation.

Time variation of SA/GCR effects on troposphere pressure and the evolution of the large-scale atmospheric circulation



Time variations of the correlation between troposphere pressure at high/middle latitudes and sunspot numbers reveal a pronounced **~60-year periodicity**.

Reversals of the correlation sign at high latitudes occurred in the **1890s**, the early **1920s**, **1950s** and the early **1980s**



The **reversals of the sign** of SA/GCR effects coincide with the **changes in the evolution of the large-scale meridional circulation** (the form C according to Vangengeim-Girs classification).

Veretenenko and Ogurtsov, Adv. Space Res., 2012

The results obtained show:

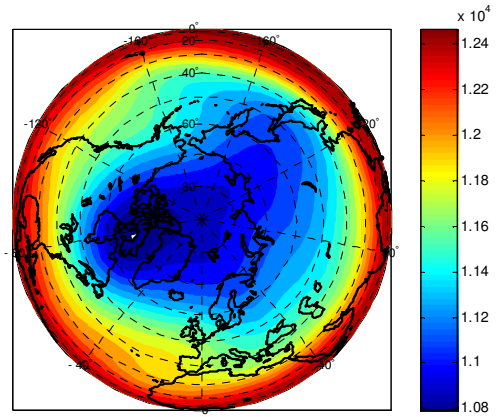
- Regional character of SA/GCR effects on troposphere pressure which is determined by climatic positions of the atmospheric fronts;
- SA/GCR effects may change the sign depending on the time period;
- The sign of SA/GCR effects seems to be determined by the evolution of the large-scale meridional circulation;
- There are long-term variations, with the period ~60 years, of the amplitude and sign of SA/GCR effects on troposphere pressure of high and middle latitudes

What processes may influence the evolution of the circulation epochs and the sign of SA/GCR effects on troposphere pressure?

2. Main elements of the large-scale circulation of the atmosphere at middle and high latitudes

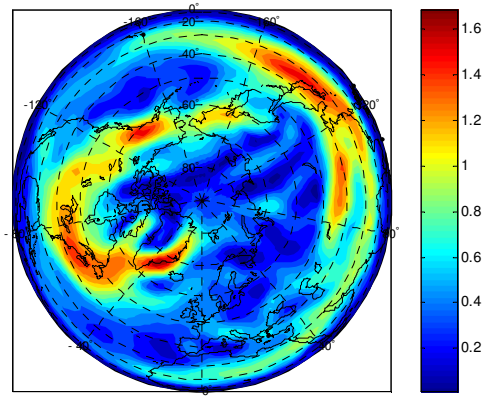
- Stratospheric polar vortex
- Planetary frontal zones
- Extratropical cyclones and anticyclones

Troposphere



GPH 200 hPa. January 2005.

Polar vortex (area of low pressure In the upper troposphere)

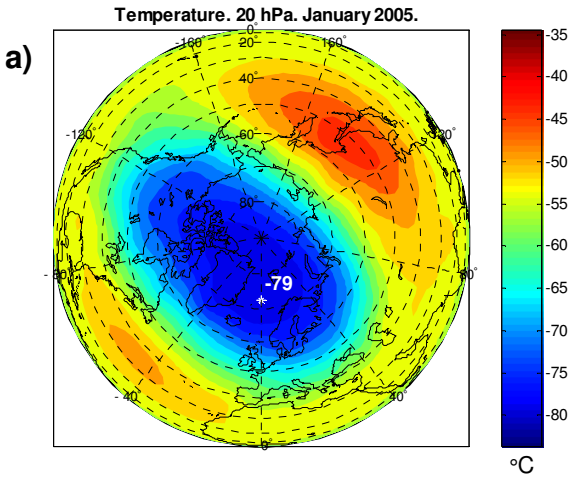


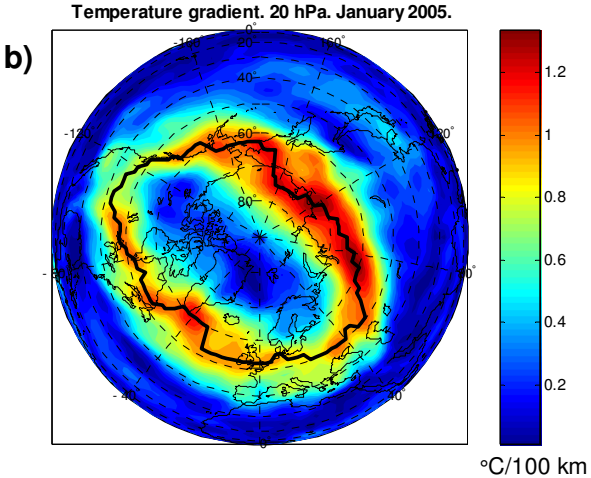
Magnitude of temperature gradients (grad/100 km). Layer 1000-500 hPa. January 2005.

Planetary frontal zones (areas of high temperature contrasts in the troposphere)

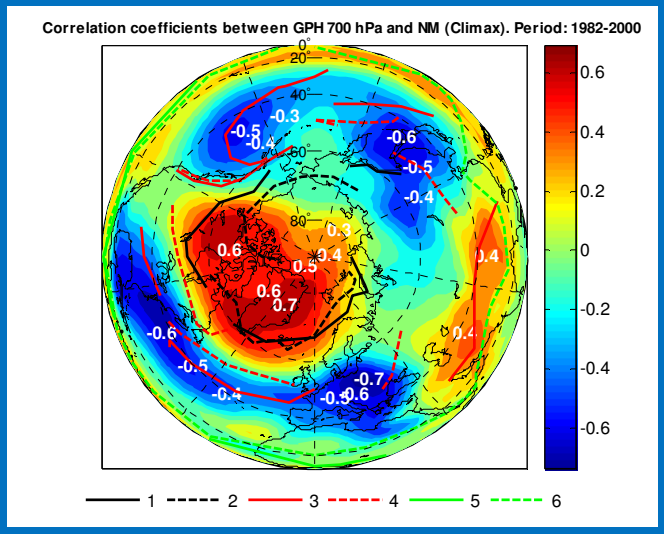
- **Polar vortex** (cyclonic circulation in the middle/upper troposphere and stratosphere at high latitudes)
- **Planetary frontal zones** (regions of high temperature contrasts in the troposphere)
- **Extratropical cyclones and anticyclones**

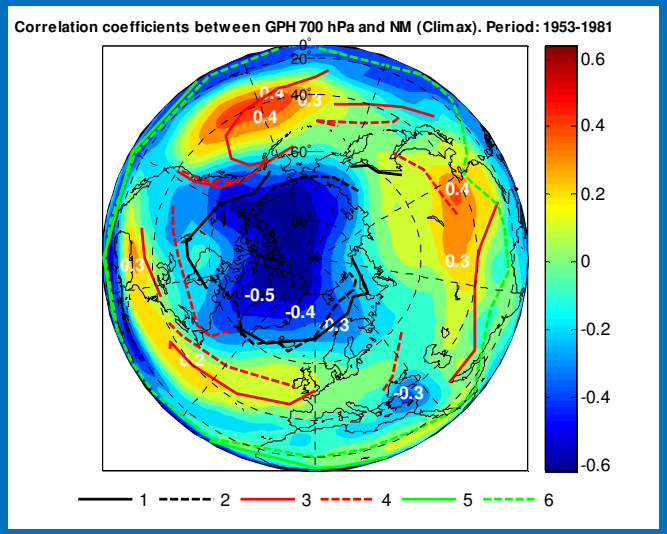
Stratosphere



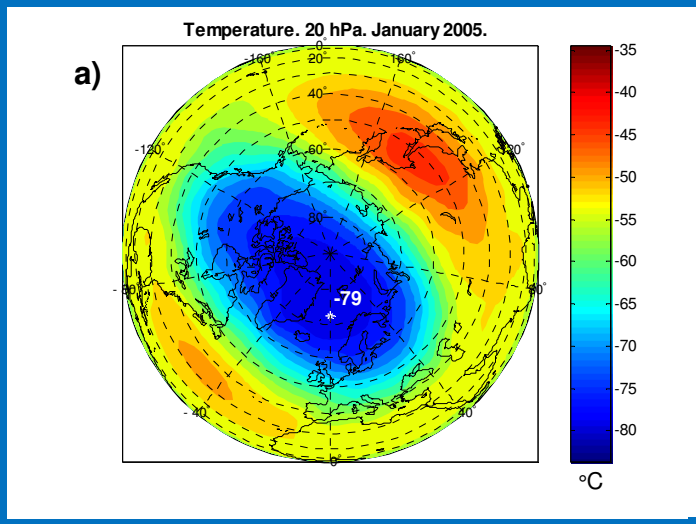


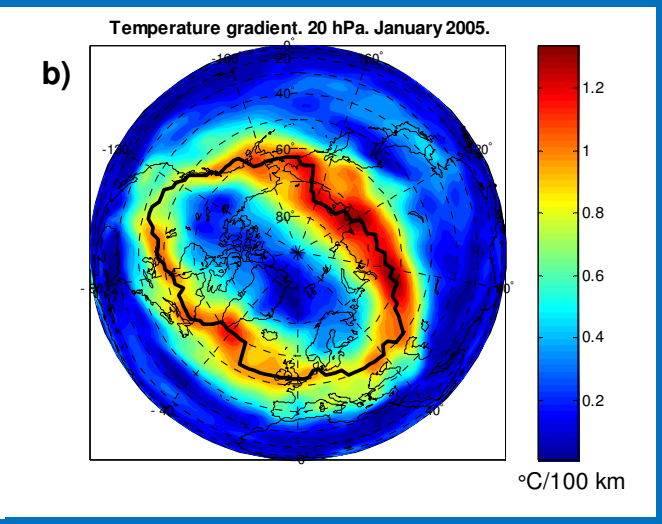
In the stratosphere the polar vortex is seen as a region of low temperature with enhanced temperature gradients at its edges.





Most significant correlations between troposphere pressure and GCR variations are associated with polar vortex area

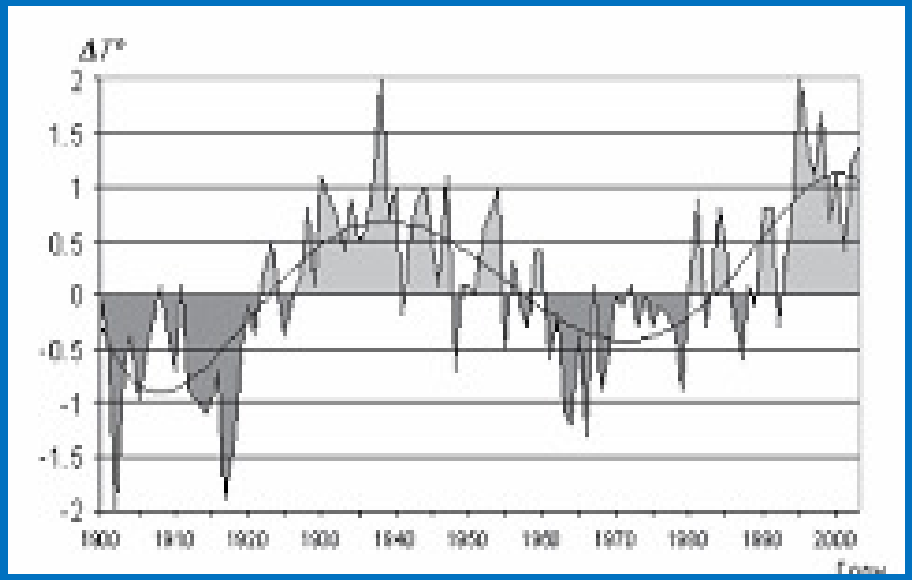




3. Temporal variations of SA/GCR effects on troposphere pressure and the vortex evolution

~60-year cycle in the climate of the Arctic and the polar vortex state

Gudkovich et al., Problems of the Arctic and Antarctic, 2009



Anomalies of mean yearly sea-level temperatures at latitudes 70-85°N in the Arctic.

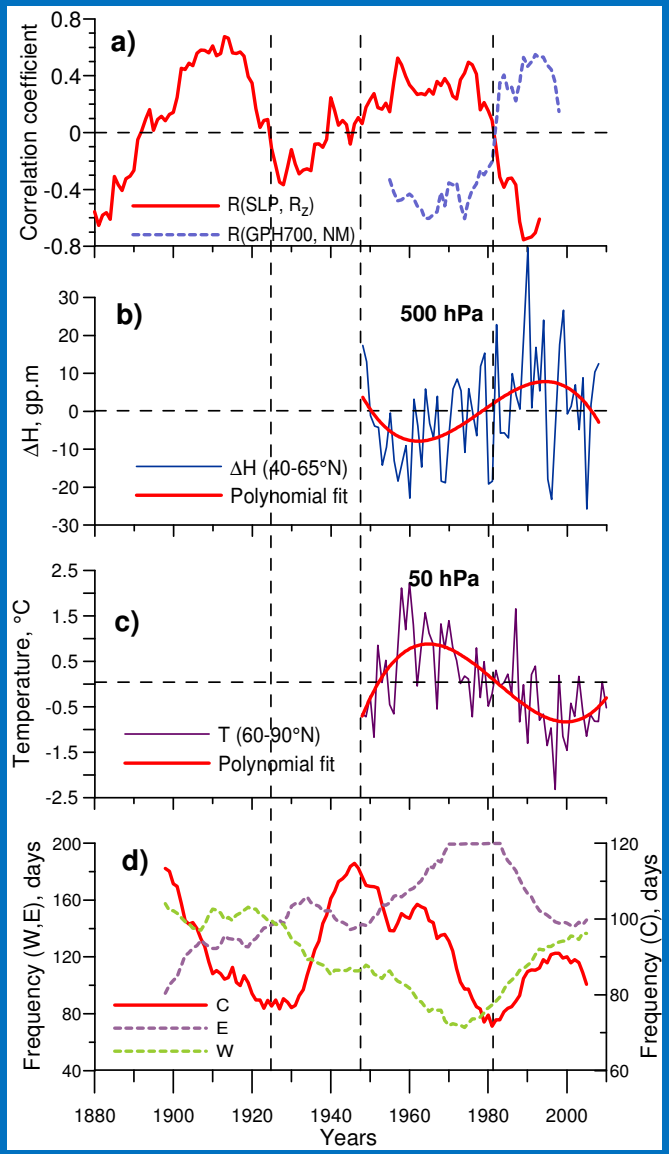
~60-year cycle in the Arctic climate manifests itself as the rotation of cold and warm epochs which is closely related to the polar vortex states:

Strong vortex → warm epoch
Weak vortex → cold epoch

The transitions between warm and cold epochs in the Arctic detected on the base of sea-level temperatures were found in the early 1920s, 1950s and 1980s

The reversals of the sign of SA/GCR effects coincide well with the transitions between cold and warm epochs in the Arctic corresponding to the different states of the vortex.

Time variation of SA/GCR effects on troposphere pressure and the polar vortex evolution according to NCEP/NCAR reanalysis data



~1950-1980 – the period of a weak vortex.

- Decrease of pressure gradients between middle and high latitudes
- Increase of stratospheric temperature in the vortex area
- Weakening of the C form of meridional circulation.
- Cold epoch in the Arctic.

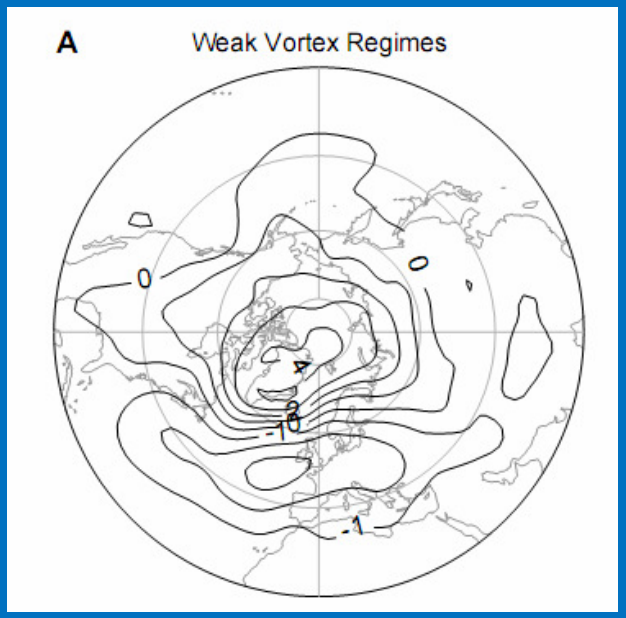
~ 1980-2010 – the period of a strong vortex

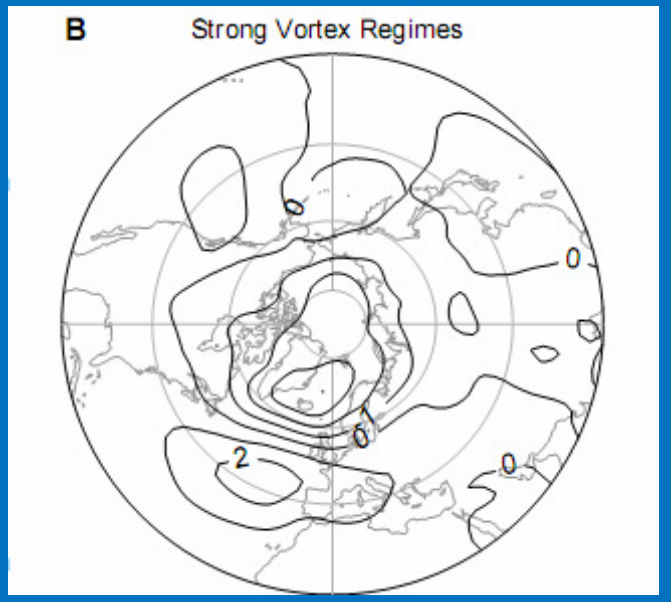
- Increase of pressure gradients between middle and high latitudes
- Decrease of stratospheric temperature in the vortex area
- Intensification of the meridional circulation C.
- Warm epoch in the Arctic.

The sign reversals of SA/GCR effects in the 1950s and 1980s correspond to the transitions between the different vortex states.

The Arctic Oscillation

The monthly NAM index (NAMI) or AO index (AOI) is defined as **the difference in the normalized monthly zonal-mean sea level pressure (SLP)** between **35°N** and **65°N (Li and Wang, 2003)**





Weak vortex (negative NAM)

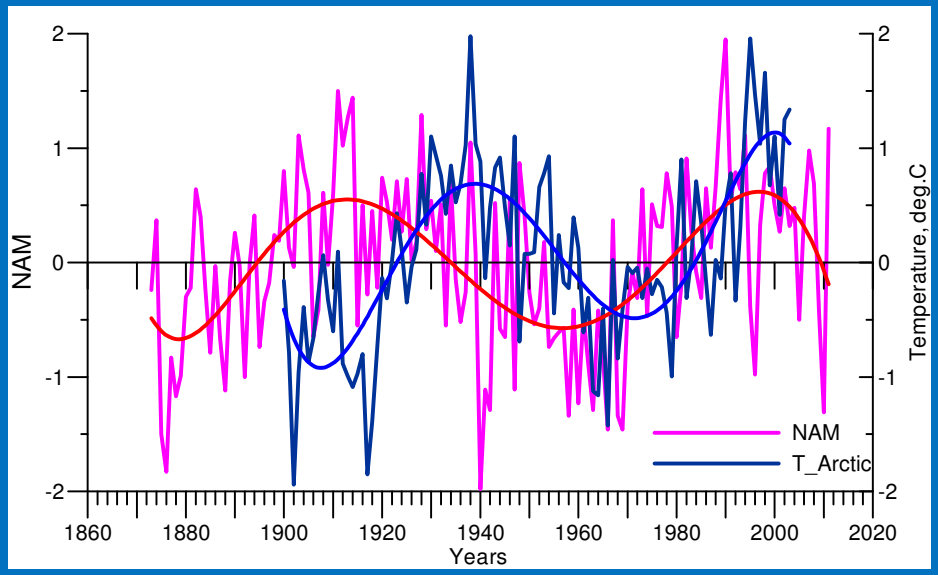
- **Positive SLP anomalies in the polar area**
- **Negative SLP anomalies at middle latitudes**

Baldwin and Dunkerton, Science, 2001

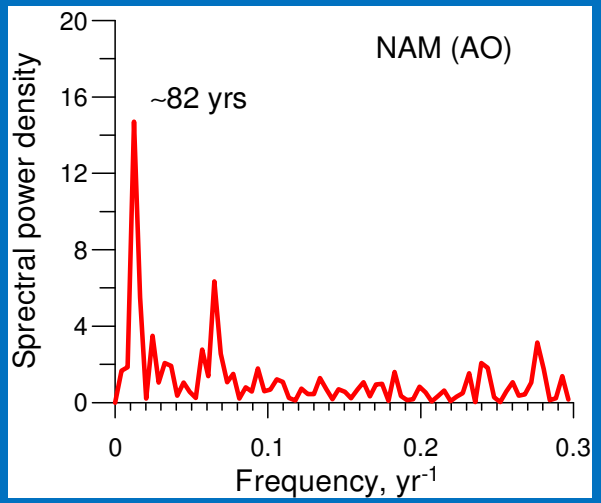
Strong vortex (positive NAM)

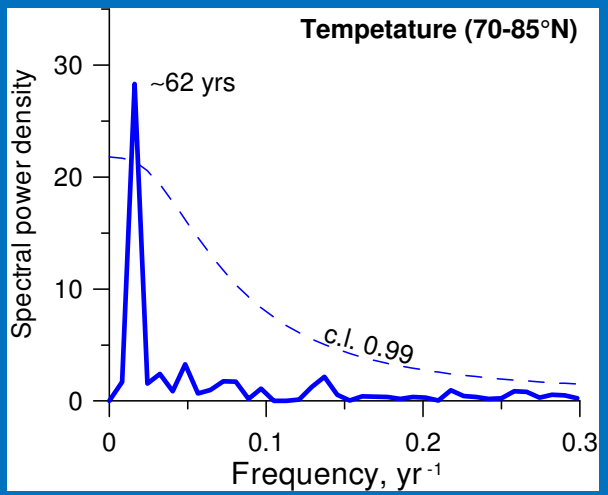
- **Negative SLP anomalies in the polar area**
- **Positive SLP anomalies at middle latitudes**

The NAM evolution and climatic changes in the Arctic



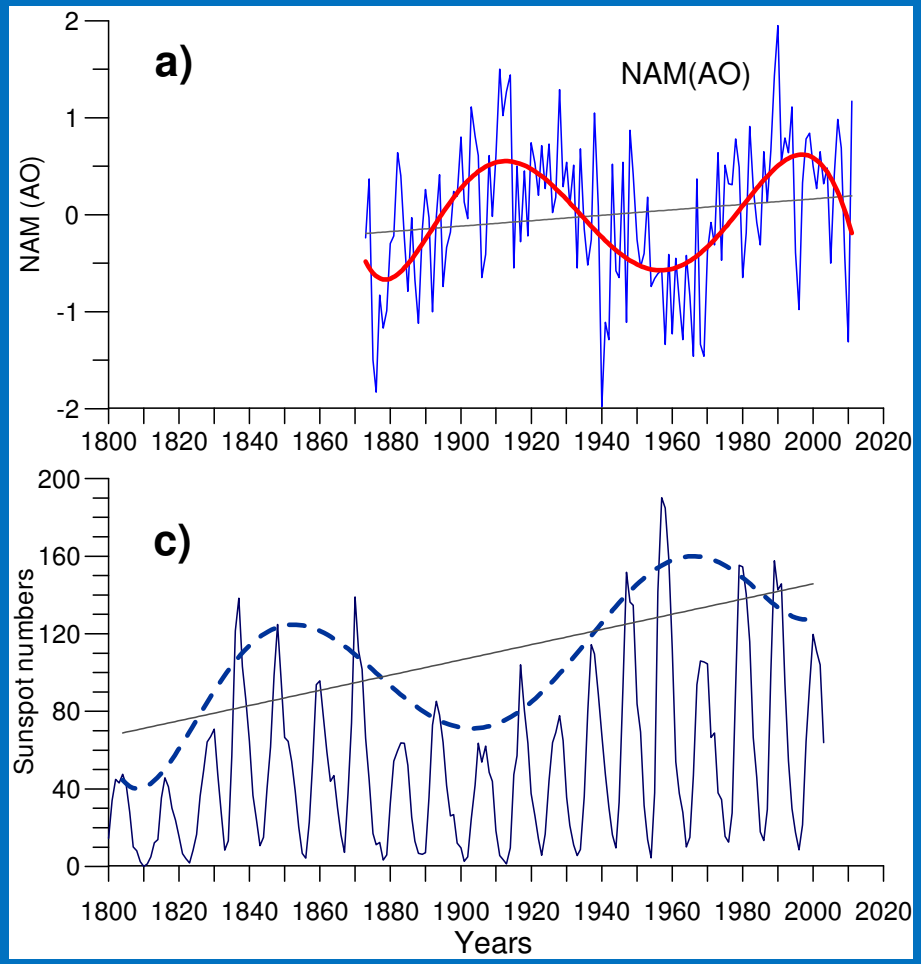
Time variations of yearly values of the NAM index (Li and Wang, 2003) and sea-level temperature anomalies in the Arctic (Frolov et al, 2009)





The NAM index: ~80-year variation
Temperature in the Arctic: ~60-year variation

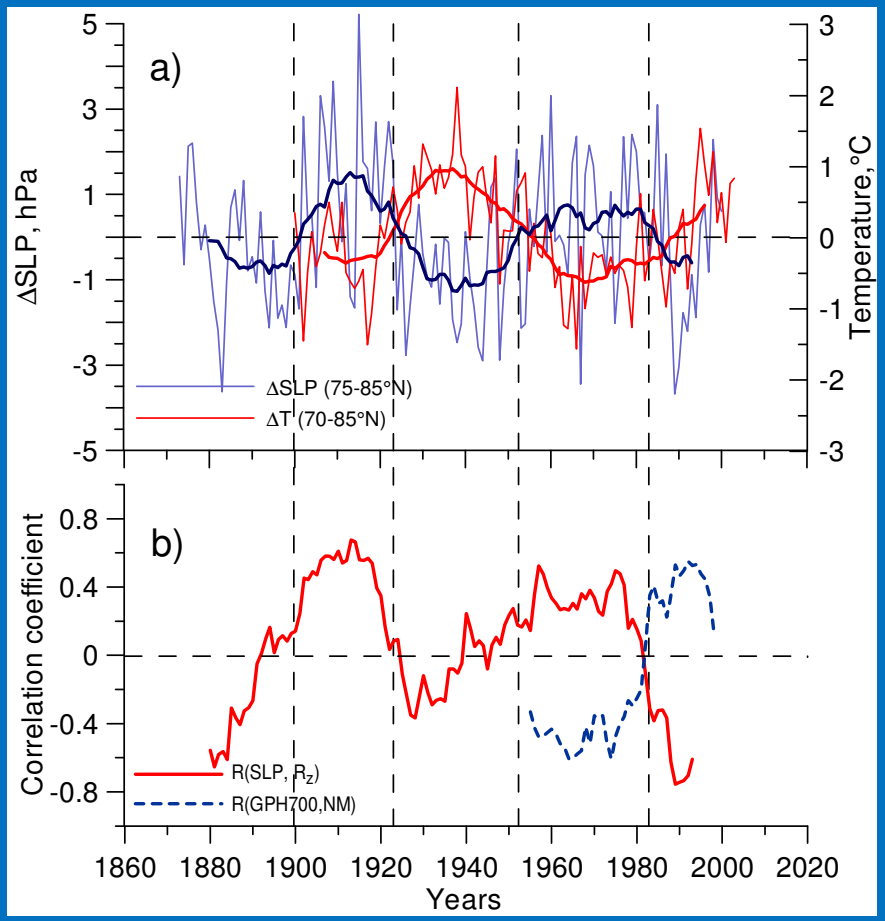
The NAM evolution and secular variations of solar activity



A comparison of this index with sunspot variations suggests a possible relationship with the secular Gleissberg cycle:

- the positive AO phase - the minimum or a descending phase of the Gleissberg cycle;
- the negative AO phase - the maximum of the Gleissberg cycle.

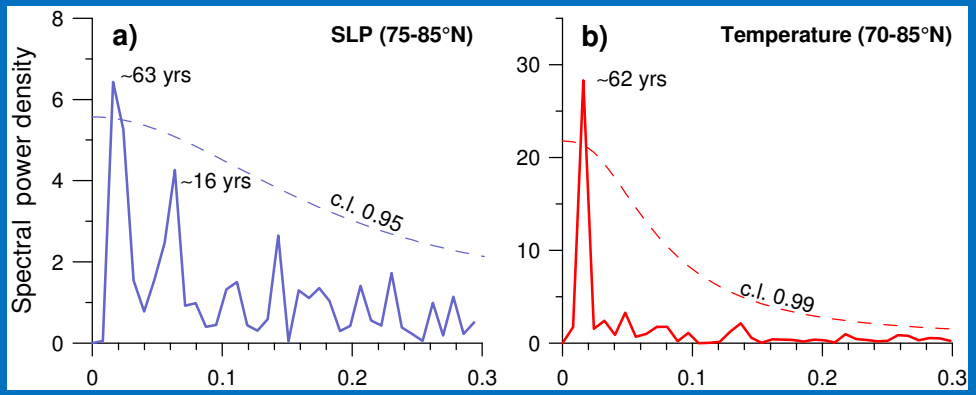
Time variation of SA/GCR effects on troposphere pressure and the polar vortex evolution according to the Arctic Oscillation



SLP and temperature anomalies in the Arctic reveal the dominant ~60-year periodicities close to a similar periodicity in SA/GCR effects

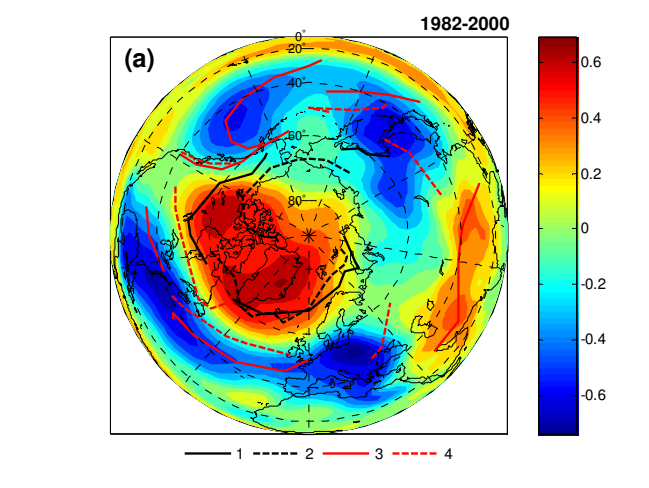
Strong vortex (negative SLP anomalies and a warming in the Arctic):
since the yearly 1980s;
~1920-1950 and before 1900
Weak vortex (positive SLP anomalies and a cooling in the Arctic):
~1950-1980 and ~1900-1920.

The sign reversals near ~1900 and ~1920 coincide with the transitions between the vortex states according to the Arctic Oscillation.



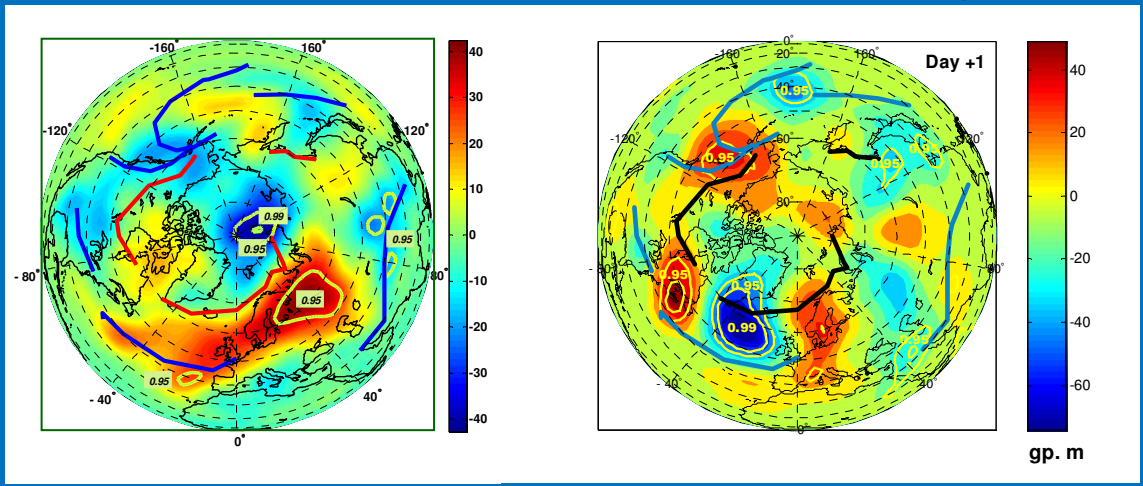
Cosmic ray effects under the strong vortex conditions

Effects of 11-year variations of GCRs



Increase of GCRs at the stage of a strong vortex is accompanied by **intensification of cyclonic activity** at Polar fronts at middle latitudes both in the 11-year cycle and a time scale of a few days

Effects of short-term variations of cosmic rays



SPEA variations of troposphere pressure for 48 events of Forbush-decreases in GCRs (left) (Artamonova and Veretenenko, Proc.Geocosmos 2012) and SPEs (>90 MeV) (right) (Veretenenko and Thejll, J.Phys.:Conf.Ser.,2013)

Thus, the **~60-year variation** of the amplitude and sign of **SA/GCR effects** on troposphere pressure seems to be closely related to the **changes of the vortex strength** and the corresponding **changes of the large-scale atmospheric circulation**

Strong vortex :

GCR increase in the 11-year cycle → intensification of mid-latitudinal cyclones and polar anticyclones

Weak vortex :

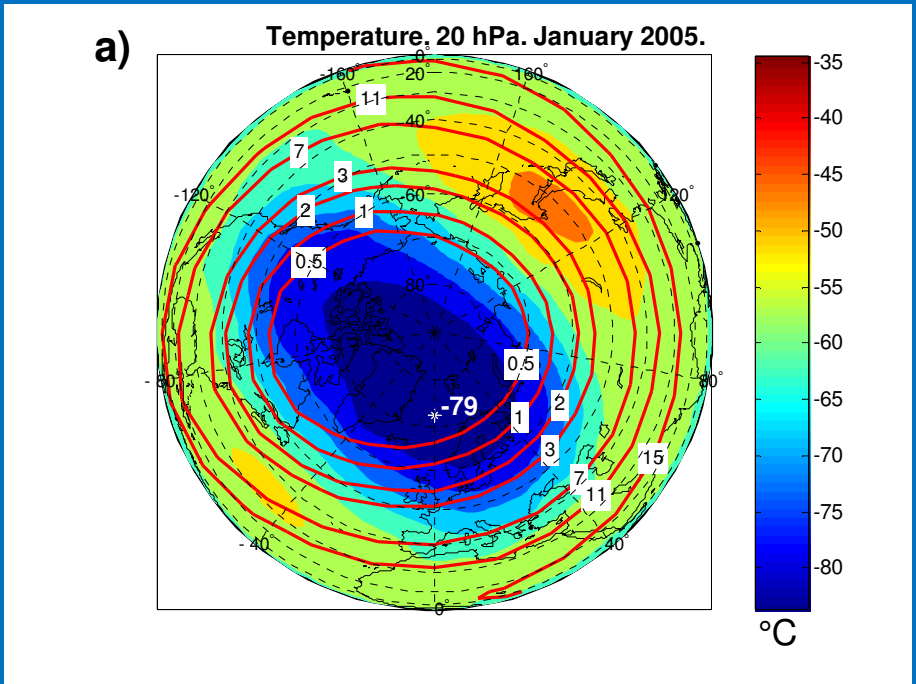
GCR increase in the 11-yr cycle → weakening of mid-latitudinal cyclones and polar anticyclones

A possible reason for the sign reversals of SA/GCR effects may be changes in the troposphere-stratosphere coupling caused by different conditions for propagation of planetary waves in the periods of a strong or weak vortex.

The polar vortex state seems to play an important part in the mechanism of solar-atmospheric links

4. Specific features of the vortex location

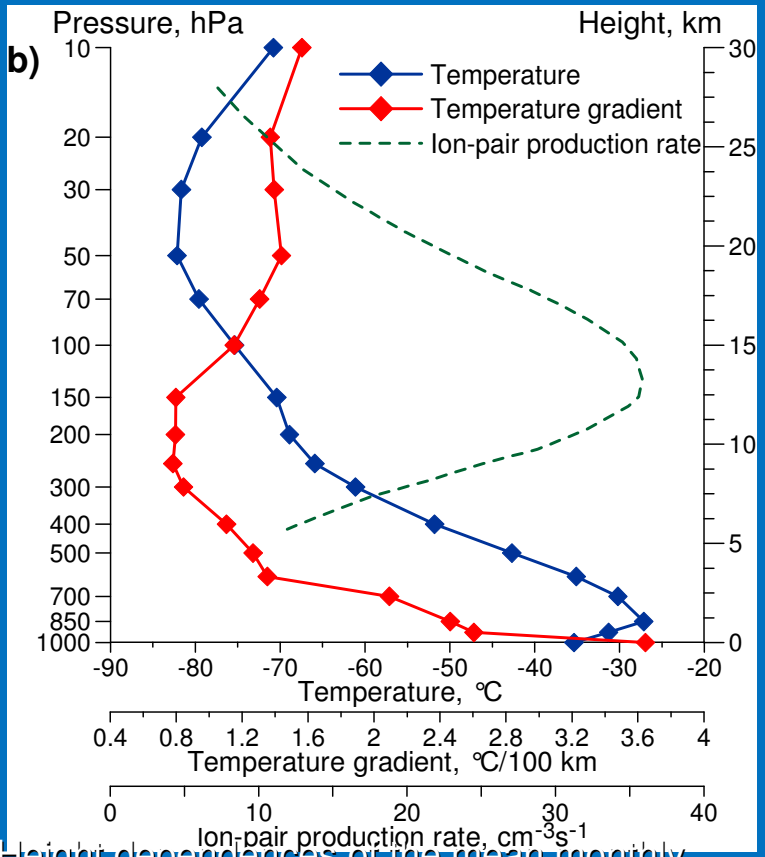
The polar vortex location and geomagnetic cutoff rigidities



The polar vortex location and vertical geomagnetic cutoff rigidities (in GV) according to Shea and Smart (1983).

The area of the vortex formation is characterized by **low geomagnetic cutoff rigidities**, so GCR particles with a broad energy range may precipitate here including the low energy component strongly modulated by solar activity. Ion production rate in the vortex area is higher compared with that at middle and low latitudes

Height dependence of the vortex characteristics and ionization rate at polar latitudes

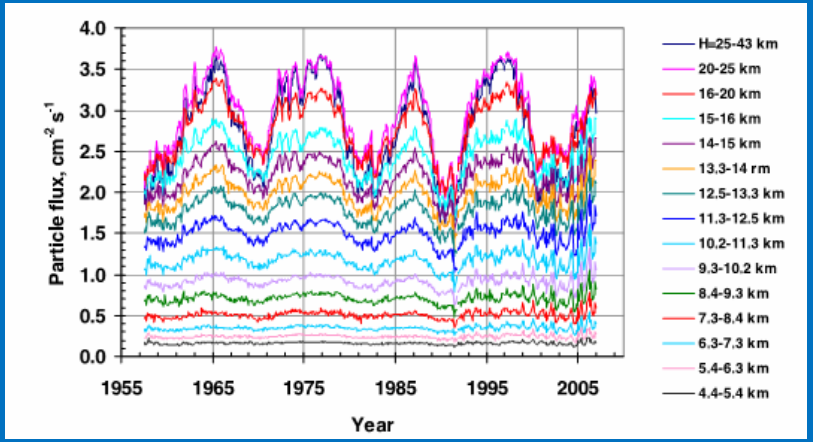


Height dependences of the mean monthly characteristics of the Arctic air mass in January 2005 and the ion-pair production rate in free air at polar latitudes (R = 0-0.6 GV) according to Bazilevskaya et al. (2008).

- The highest values of ionization due to GCR are observed in the lower part of the vortex (10-15 km) where temperature gradients at the vortex edges start increasing.

- The 11-yr modulation of GCR fluxes is the strongest at 20-25 km where the vortex is most pronounced.

Bazilevskaya et al., Space Sci. Rev, 2008



Monthly averaged fluxes of ionizing particles over Murmansk region (R =0.6 GV)

Conclusions:

- The evolution of the stratospheric polar vortex seems to play an important part in the mechanism of solar-climatic links.
- The vortex strength reveals a roughly 60-year periodicity influencing the large-scale atmospheric circulation and the character of SA/GCR effects on troposphere pressure.
- The sign reversals of SA/GCR effects on troposphere pressure (development of baric systems at middle and high latitudes) were found to coincide with the transitions between the different states of the vortex.
- Most pronounced influence of GCR variations on the development of extratropical cyclones is observed only under the strong vortex conditions.
- The vortex location is favourable for the mechanisms of solar activity influence on the atmosphere circulation involving different agents.