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POLAR VORTEX INTENSITY AS A MODULATING FACTOR OF COSMIC RAY INFLUENCE ON ATMOSPHERE DYNAMICS AND CLOUD COVER ANOMALIES AT MIDDLE LATITUDES

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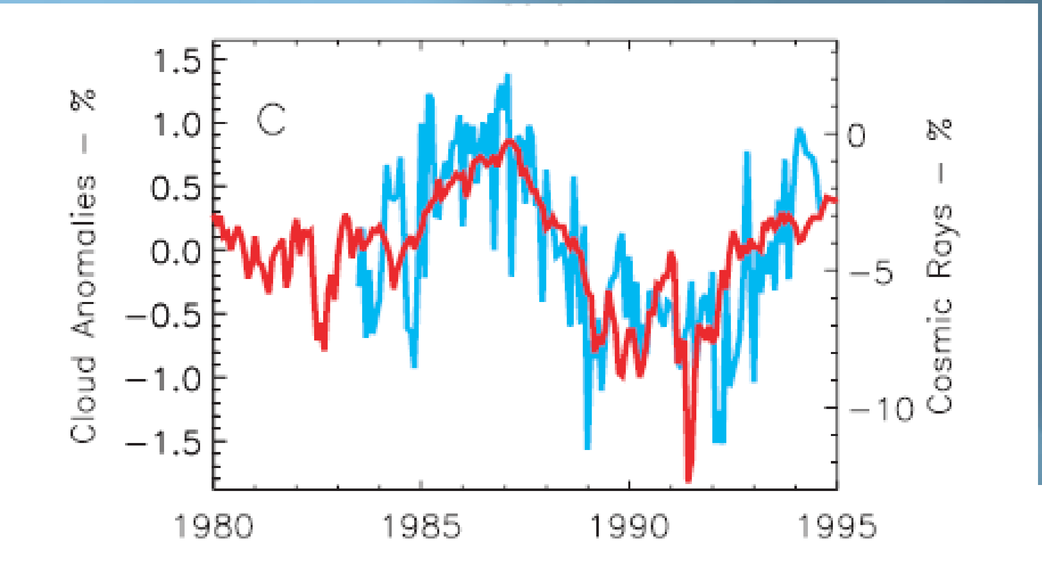
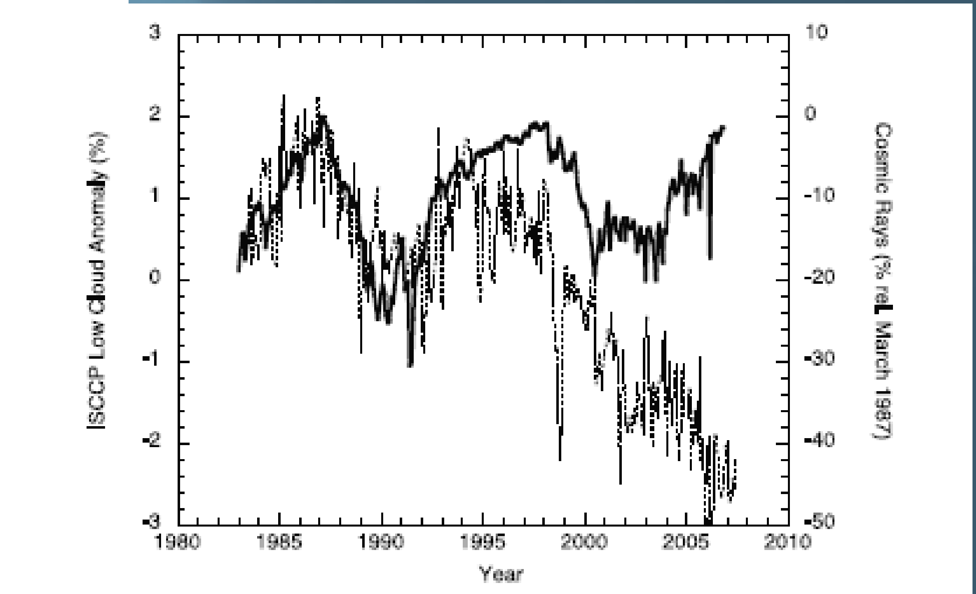
Low cloud anomalies and variations of galactic cosmic ray intensity



Marsh and Svensmark, Phys.Rev.Lett., 2000

Correlation coefficient between globally averaged low cloud anomalies (LCA) and neutron monitor (NM) counting rate (Huancayo):
R = 0.63 and *R =0.92* for the 12-month running mean (LCA data according to ISCCP-D2 for 1983-1994).

One can see a violation of relationships between LCA and NM after 2000



Gray et al., Solar influences on climate, Rev. Geophys., 2010

The aim of this work

- to consider the nature of links between low clouds and cosmic rays (LCA-GCR) observed in 1983-2000
- to consider what may be possible reasons for violation of positive correlation LCA-GCR after 2000

- **Plan**

- Links of cloud fields to troposphere dynamics
- Low cloud anomalies and pressure at middle latitudes of the Northern and Southern hemispheres
- Reversal of correlations LCA-GCR and GPH700-GCR in the Northern and Southern hemispheres
- GCR influence on cyclonic activity at the different states of the polar vortices
- Change of the polar vortex state in the period of correlation reversals

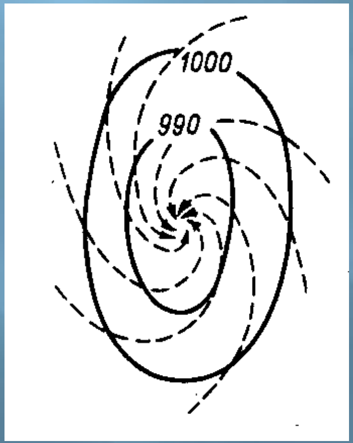
Cloud formation at extratropical latitudes

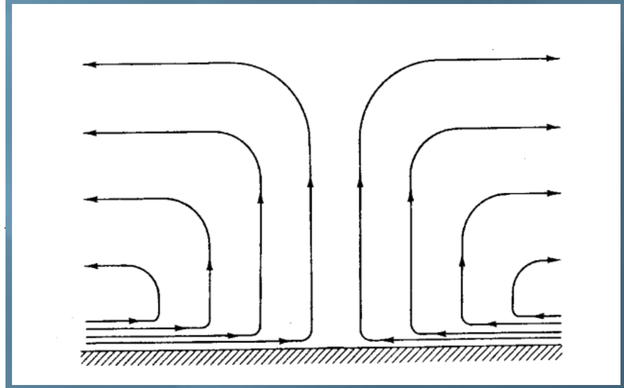
The main reason for cloud formation is vertical transport and cooling of water vapor → cloud field formation depends on vertical movements of air

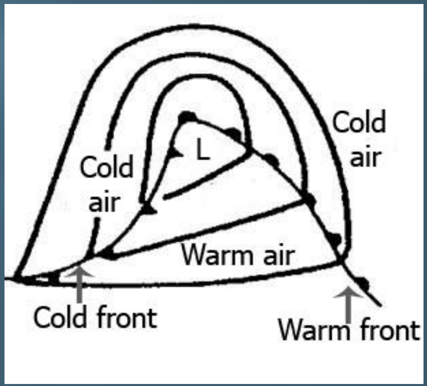
Macro-scale vertical movement of air (the horizontal scales from several hundred to several thousand kilometers) are closely related to **baric systems (synoptic objects)** :

- **Cyclones and troughs (upward movements)**
- **Anticyclones and crests (downward movements)**

Upward air movements in mid-latitudinal frontal cyclones

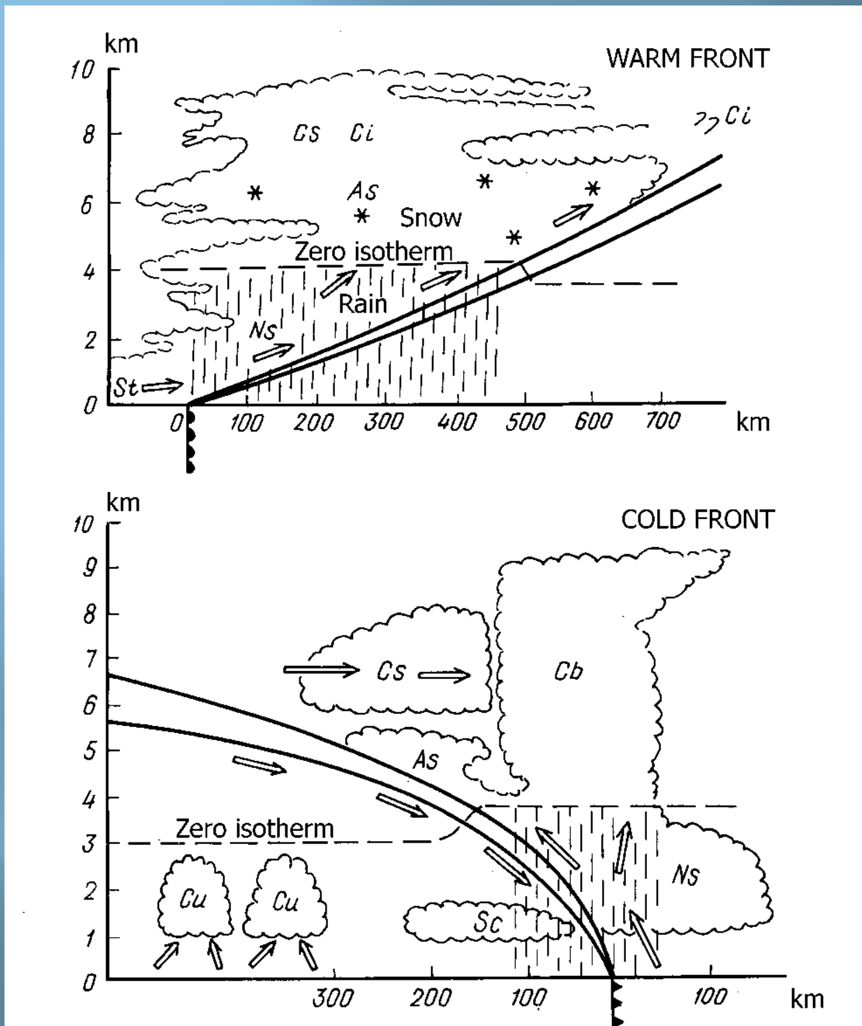






- *Upward air movement in the center of a cyclone due to convergence of air flows near the Earth's surface*
- *Regular ascending movements at cyclone fronts*

Frontal cloudiness

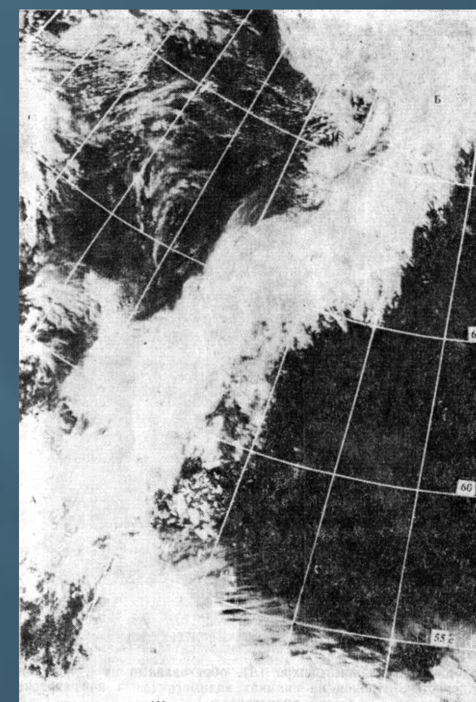


Cloud systems of warm (top) and cold (bottom) fronts (Khromov and Petrociants, Meteorology and climatology, 1994)

Regular ascending movements of air along a frontal surface result in the formation of strong systems of **stratiform clouds Ns-As-Cs**.

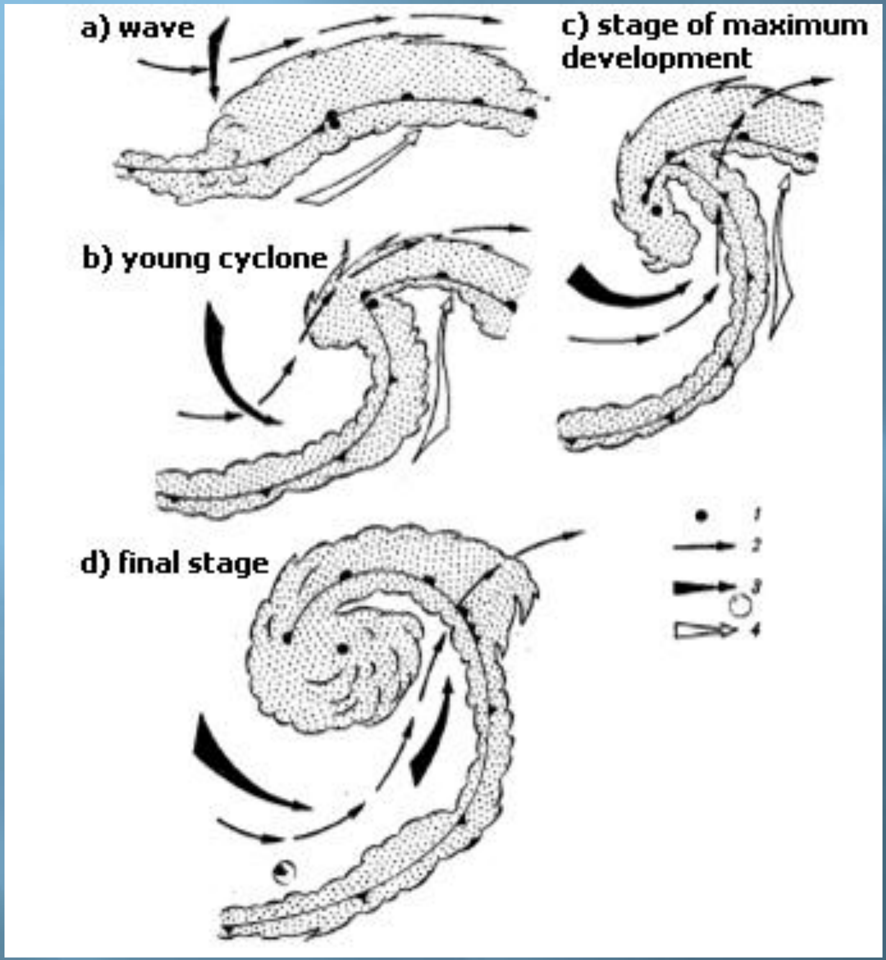
Predominant cloud types:

- ***at warm fronts***
- cirrostratus (Cs)
- altostratus (As)
- nimbostratus (Ns) – stratiform clouds with continuous precipitation
- ***at cold fronts***
- cumulonimbus (Cb) with storm precipitation and lightening



Cloud system of a cold front (Vorobjev, Synoptic meteorology, 1991)

Cloudiness of extratropical cyclones

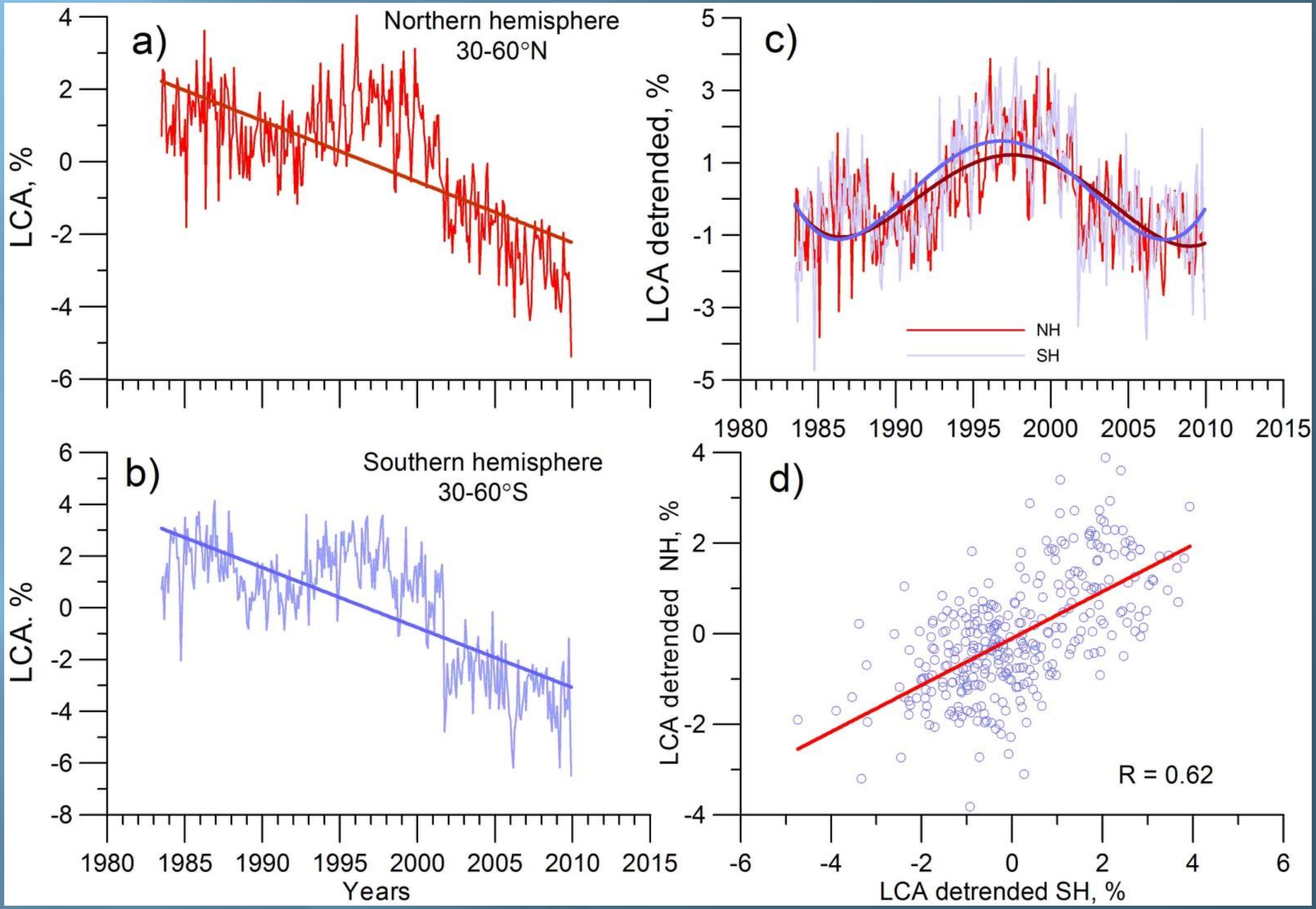


Cloud system of a frontal cyclone at different stages of its evolution (Vorobjev, Synoptic meteorology, 1991).

- **Frontal cloudiness at all stages of cyclone evolution**
- **Cloudiness in the cyclone center due to ascending air motion**

Extratropical cloud vortex in the Northern hemisphere, A – the center of the vortex (Vorobjev, Synoptic meteorology, 1991)

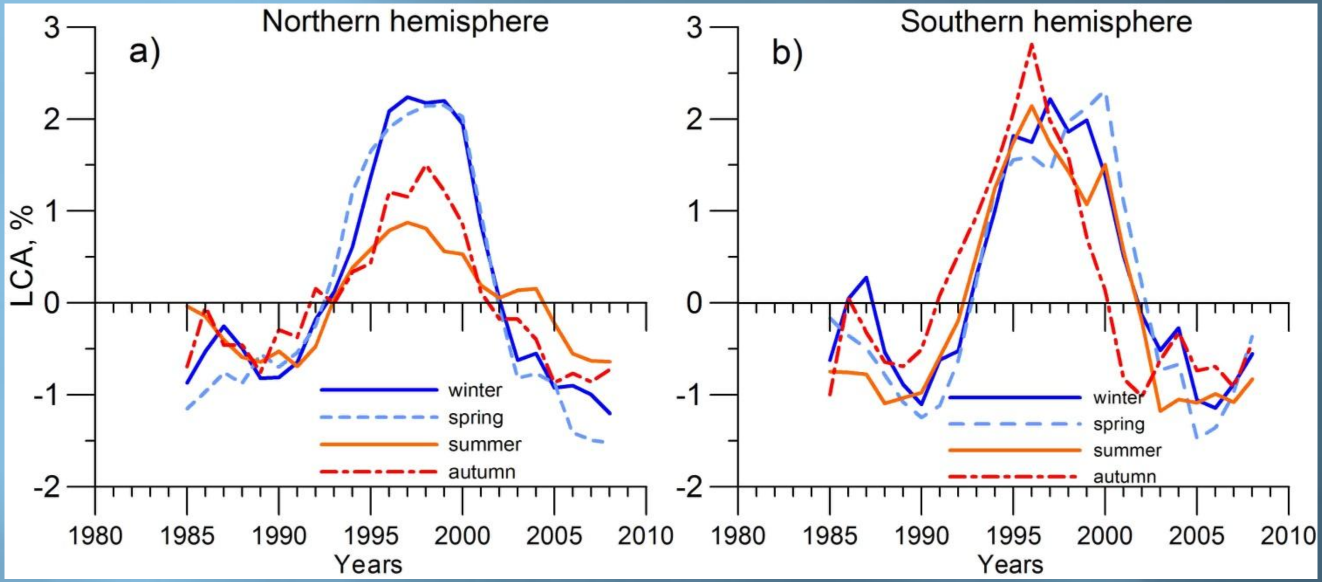
Low cloud anomalies at middle latitudes (ISCCP-D2)

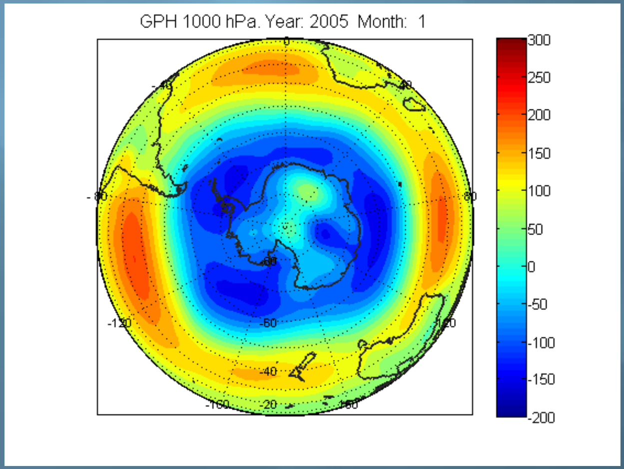


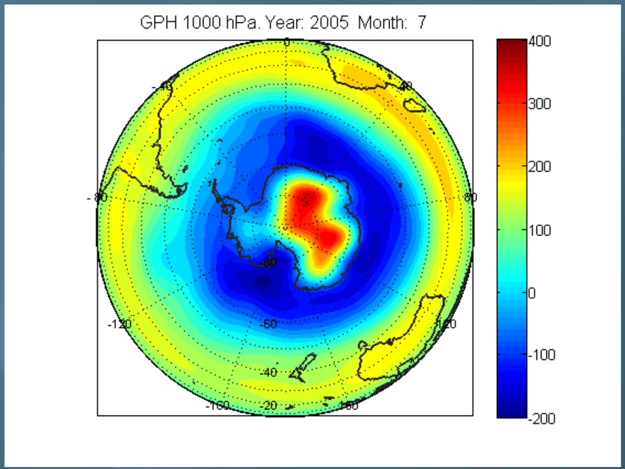
Low Cloud Anomalies at middle latitudes of the Northern and Southern hemispheres reveal a rather high correlation:

R=0.82 (no trend removal) and R=0.62 (after trend removal)

Seasonal variation of Low Cloud Anomalies







Seasonal variation of LCA is strong in the Northern hemisphere where cyclonic processes intensify in cold period.

In the Southern hemisphere cyclonic activity remains rather high during all the year

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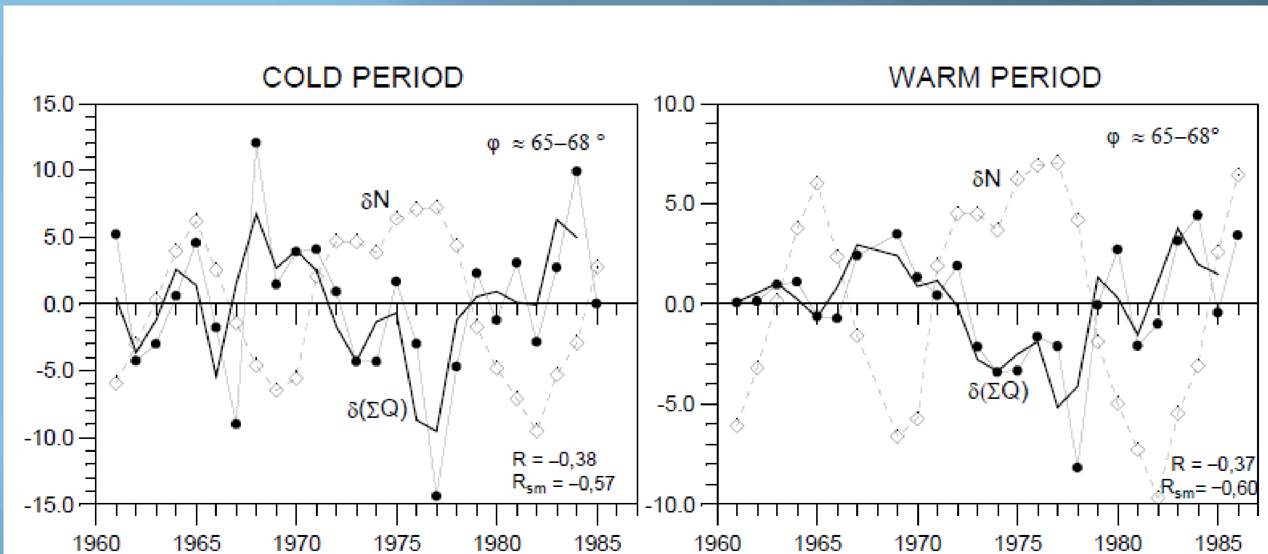
no pronounced seasonal variation in cloudiness

Seasonal dependence of LCA indicates their dynamical nature

GCR effects on cloud/radiation flux variations



GCRs seem to be an important factor influencing the input of solar radiation in the lower atmosphere (cloudiness).

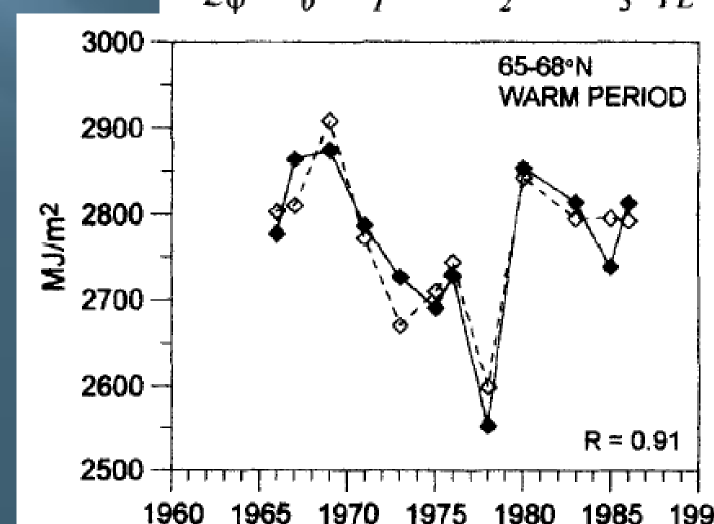
But their influence may be partly masked by other solar-related factors (flare activity, auroral phenomena)

Total, and partial, correlation coefficients between the radiation totals ΣQ in the high-latitudinal belt and different helio/geophysical factors (Neutron Monitor, AE-index of auroral electrojet activity, and solar flare intensity)

Season	Correlated values	Total correlation	Partial correlation
Warm	$\Sigma Q_{warm}, NM$	−0.37 (90%)	−0.78 (99.9%)
	$\Sigma Q_{warm}, AE$	−0.27 (–)	−0.66 (99.5%)
	$\Sigma Q_{warm}, I_{fl}$	−0.04 (–)	−0.63 (99.5%)
Cold	$\Sigma Q_{cold}, NM$	−0.40 (90%)	−0.62 (99%)
	$\Sigma Q_{cold}, AE$	−0.07 (–)	−0.27 (–)
	$\Sigma Q_{cold}, I_{fl}$	−0.02(–)	−0.50 (95%)

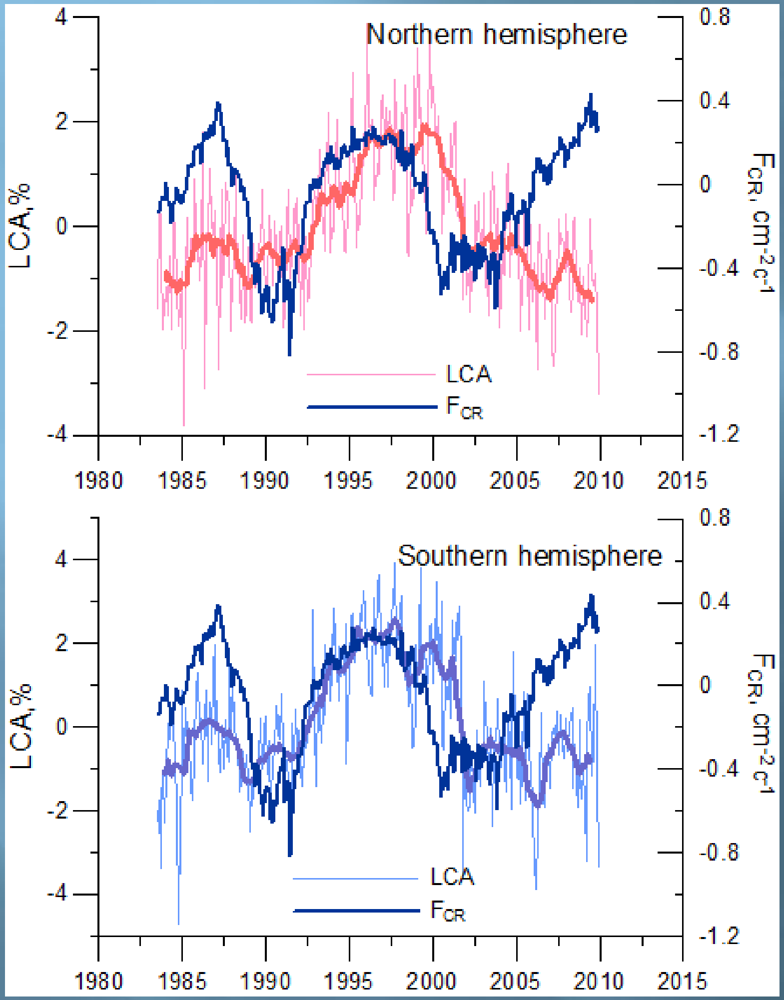
Veretenenko and Pudovkin, JASTP, 1999

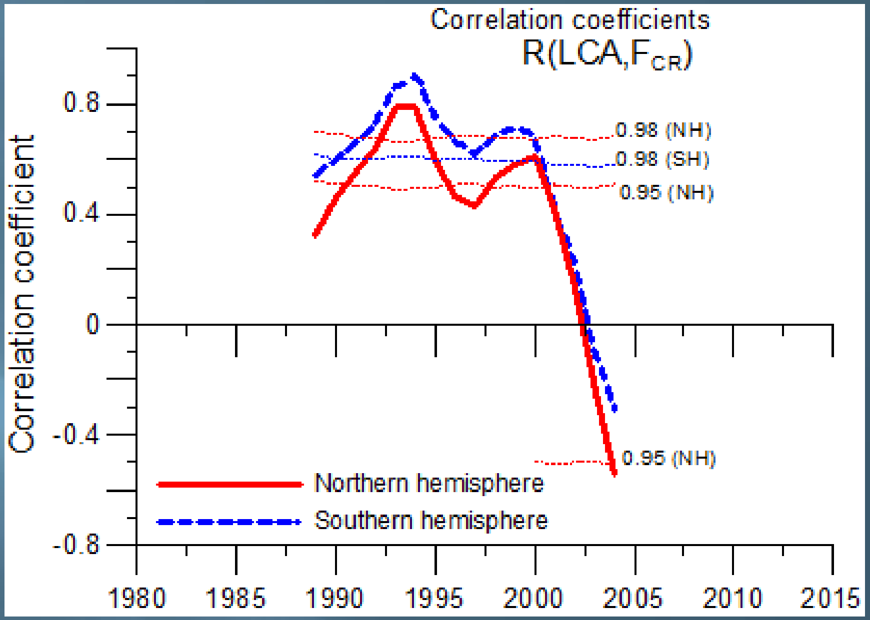
$$\Sigma Q_\varphi = a_0 + a_1 \cdot NM + a_2 \cdot AE + a_3 \cdot I_{FL}$$



Veretenenko, Adv. Space Res., 2003

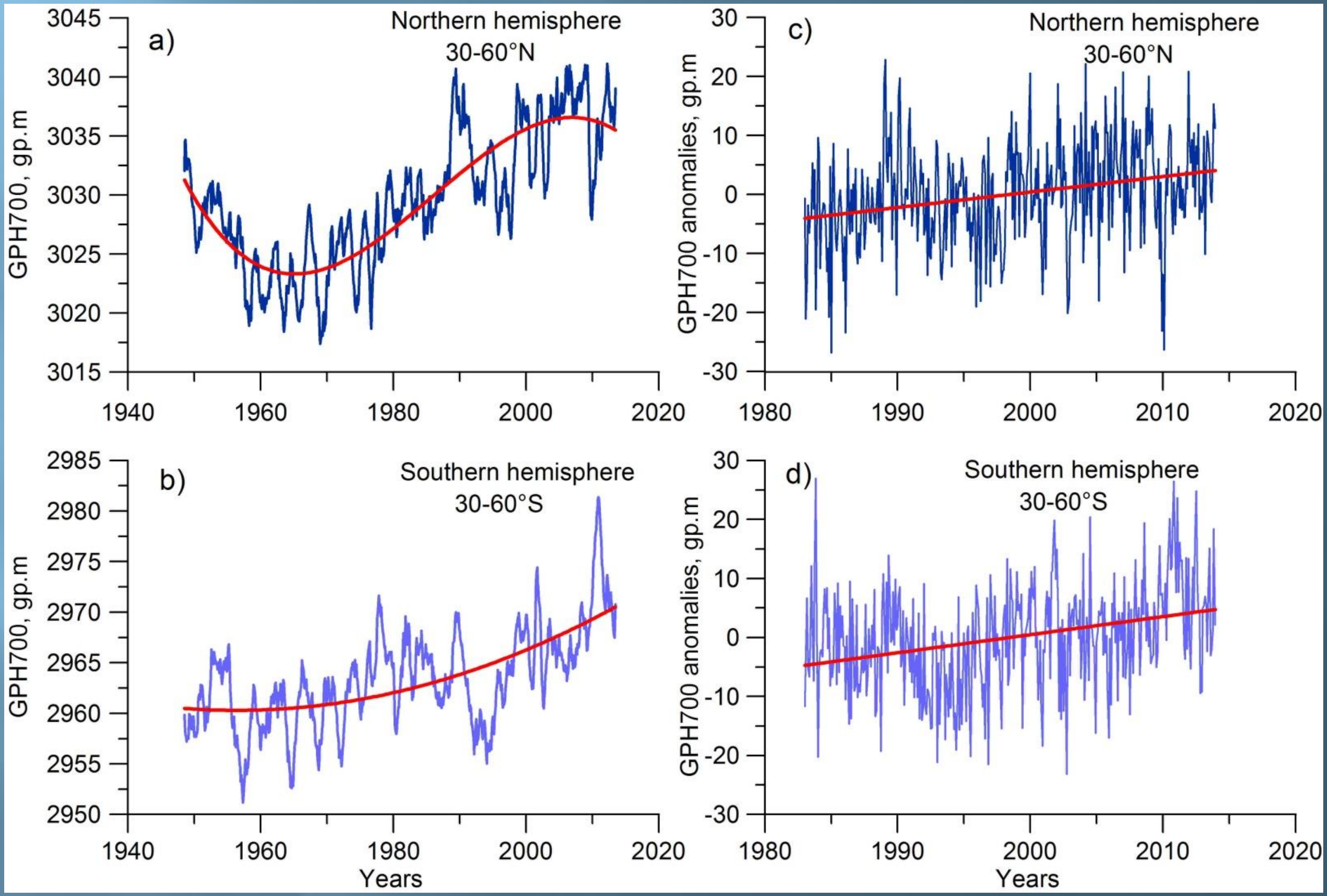
Time variation of LCA-GCR links





- **Highest correlation LCA-GCR was observed in the 1990s**
- **Correlation reversal took place after 2000 simultaneously in the Northern and Southern hemispheres**

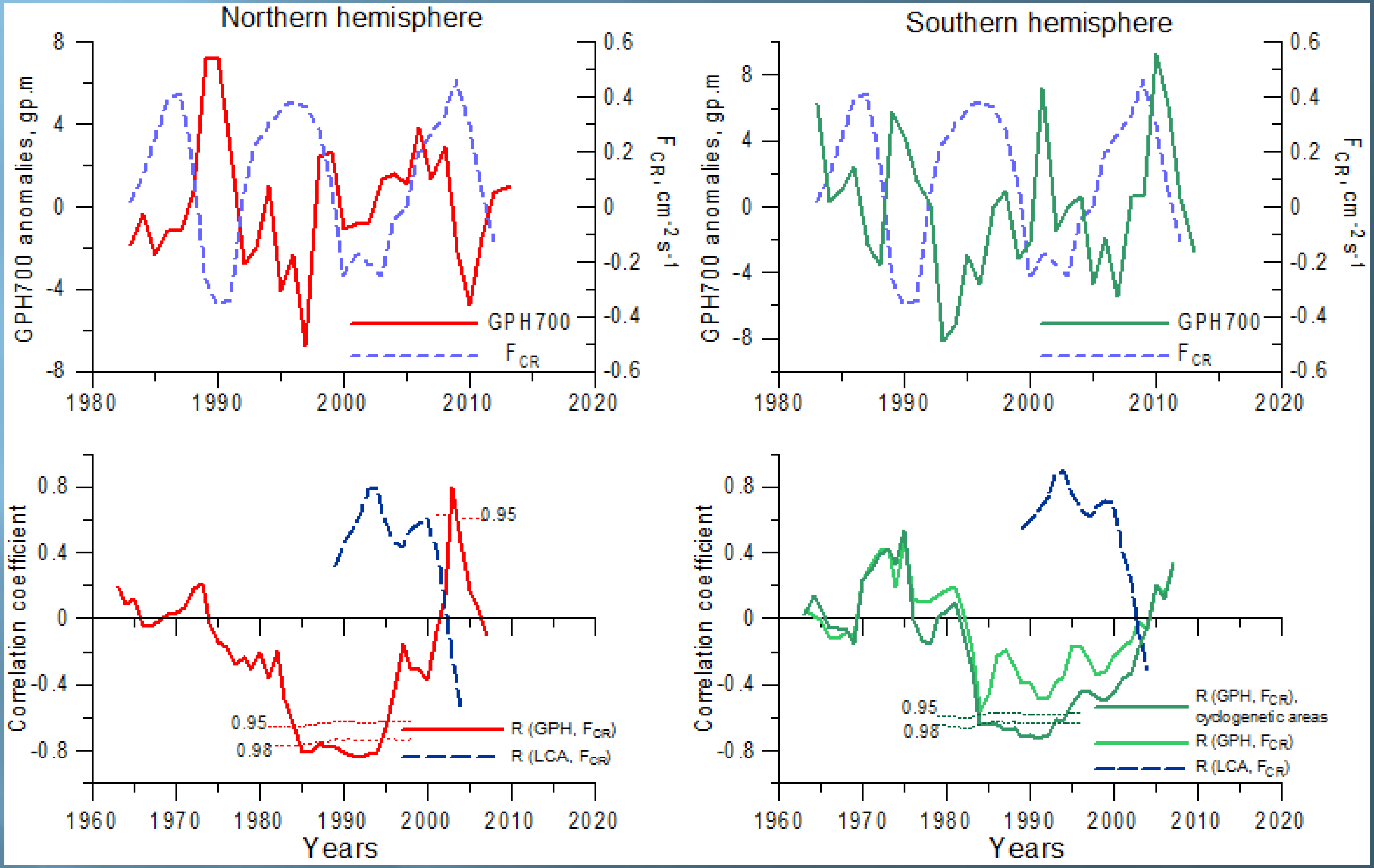
Time variation of pressure (GPH700) at middle latitudes of the Northern and Southern hemispheres



In 1983-2009 (the period of ISCCP cloud observations) pressure at middle latitudes was gradually increasing in both hemispheres.

This indicates long-term weakening of cyclonic processes $\rightarrow$ long-term weakening of low clouds

Time variations of links between pressure at middle latitudes and GCR intensity

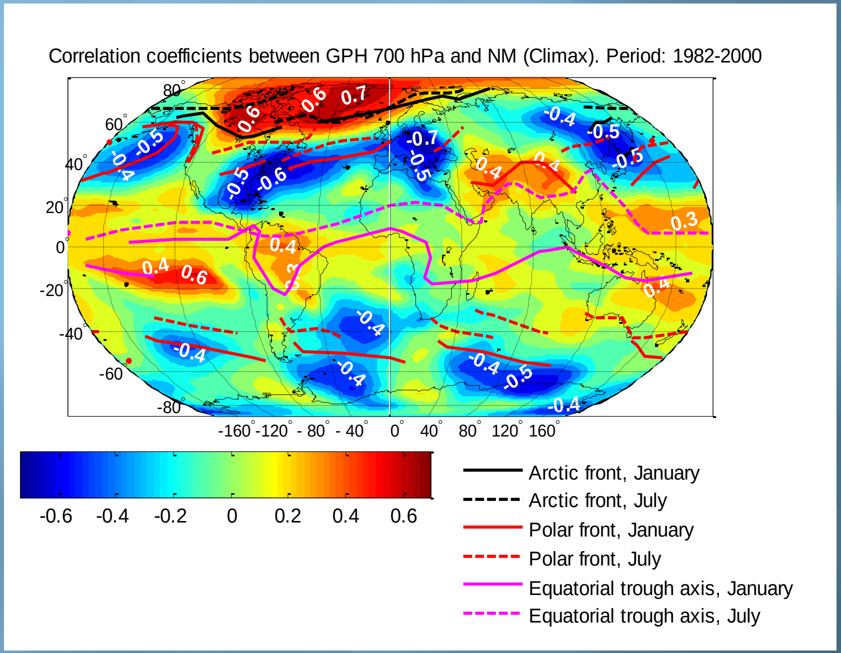


Positive correlation LCA-GCR took place in the period of negative correlation GPH700-GCR (higher GCR fluxes → deeper cyclones → more clouds)

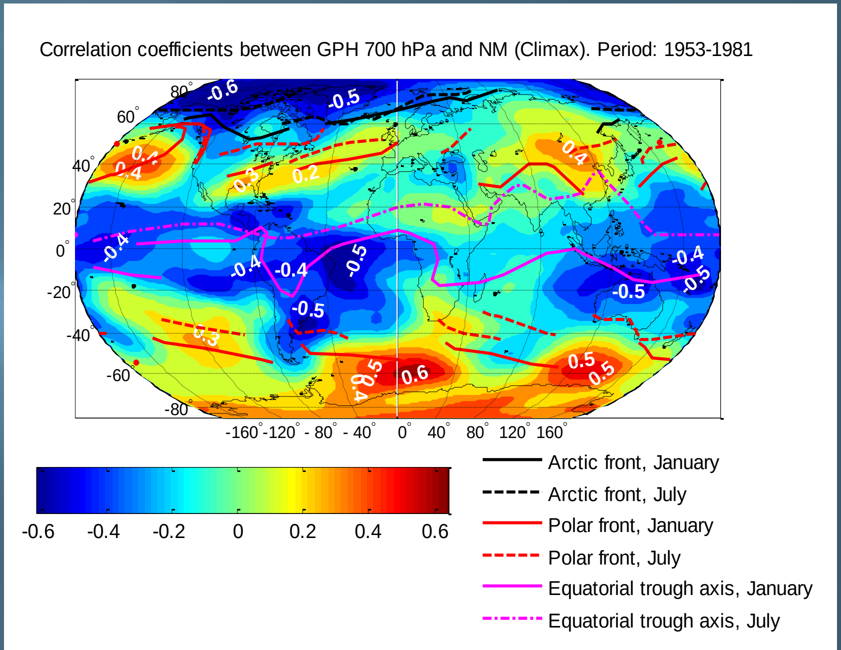
Correlation reversals of links LCA-GCR and GPH700-GCR occurred simultaneously in the early 2000s in both hemispheres.

GCR effects on troposphere pressure depending on the epochs of the large-scale circulation of the atmosphere

Epoch of increasing meridional circulation



Epoch of weakening meridional circulation

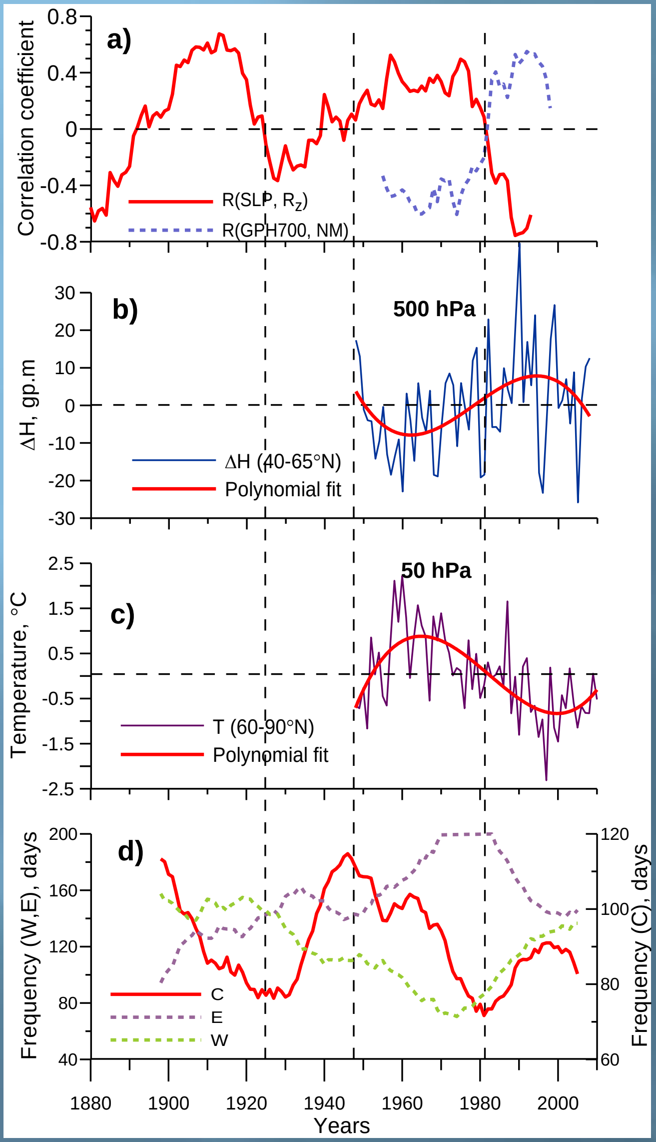


Atmosphere pressure response to GCR variations depends on time interval – epoch of the large-scale atmospheric circulation

In the period of **increasing meridional circulation** (meridional form C according to Vangengeim-Girs classification) **GCR increases** in the 11-year solar cycle are accompanied by **intensification of extratropical cyclones** at Polar fronts of middle latitudes.

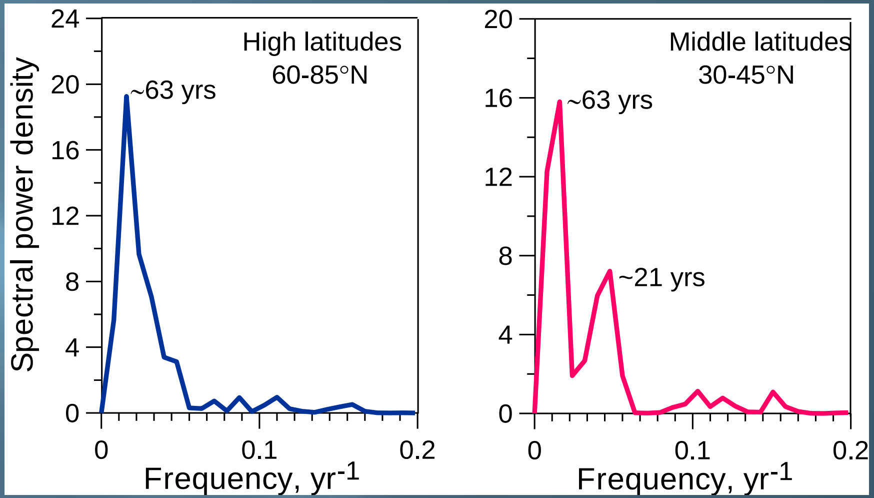
Veretenenko and Ogurtsov, Adv.Space Res,2012; Geomagn. Aeron., 2012

Long-term variations of SA/GCR effects on troposphere pressure



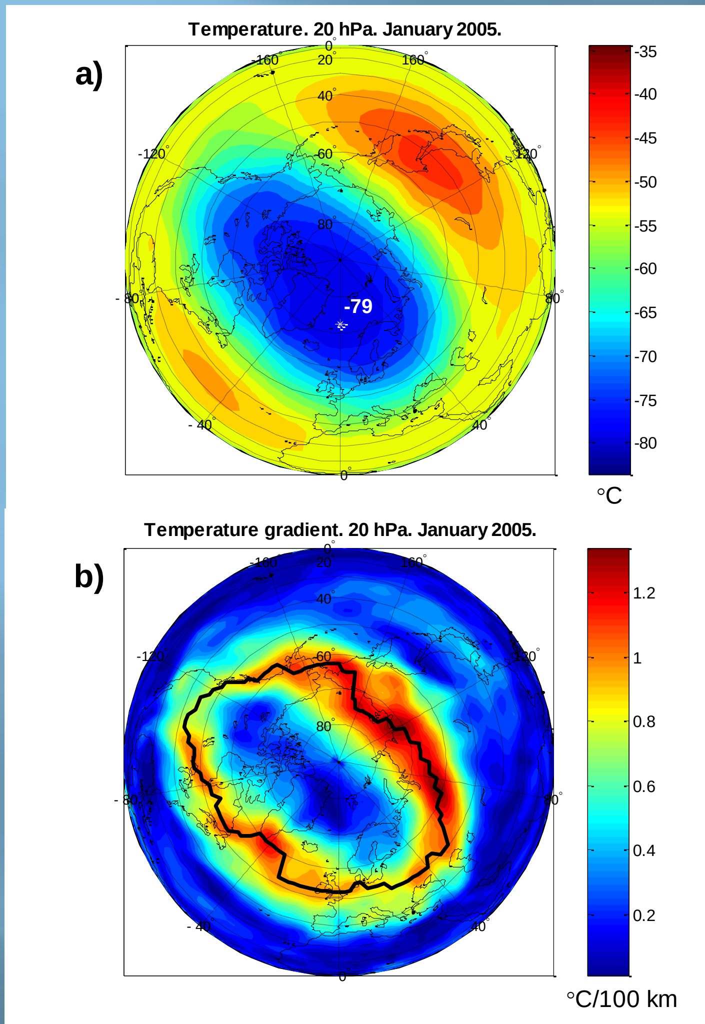
Veretenenko and Ogurtsov, J.Phys., 2013; Adv.Space Res., 2014

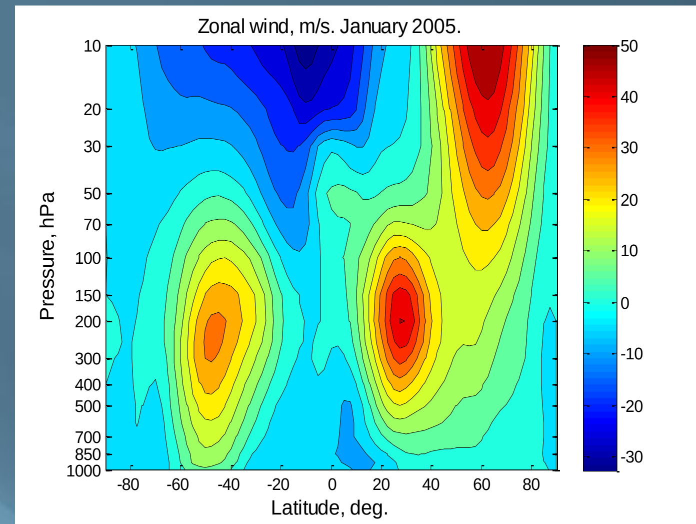
Correlation coefficients between troposphere pressure at extratropical latitudes and SA/GCR indices reveal a roughly **~60-year** periodicity.

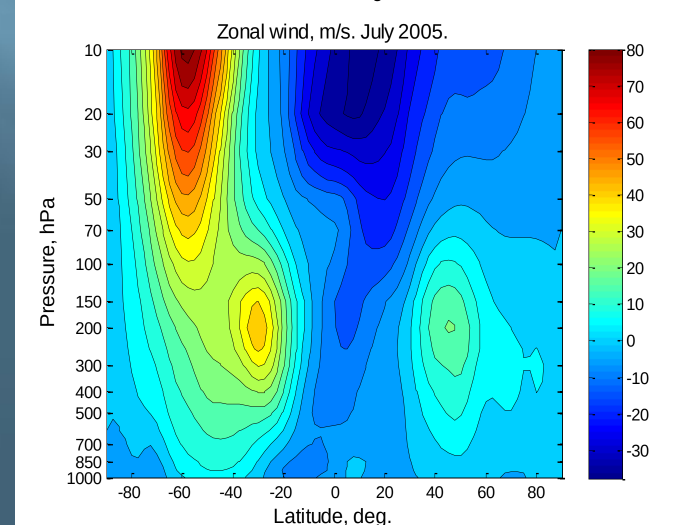


- This periodicity seems to be related to the epochs of the large-scale atmosphere circulation. In turn, these epochs may be caused by the changes of the strength of **the stratospheric polar vortex**.
- The changes of the vortex state were found in the end of XIX century, in the 1920s, 1950s and in the early 1980s (*Veretenenko and Ogurtsov, Adv.Space Res., 2014*). It was suggested that t**he following change** may take place **after 2000**

Stratospheric polar vortex



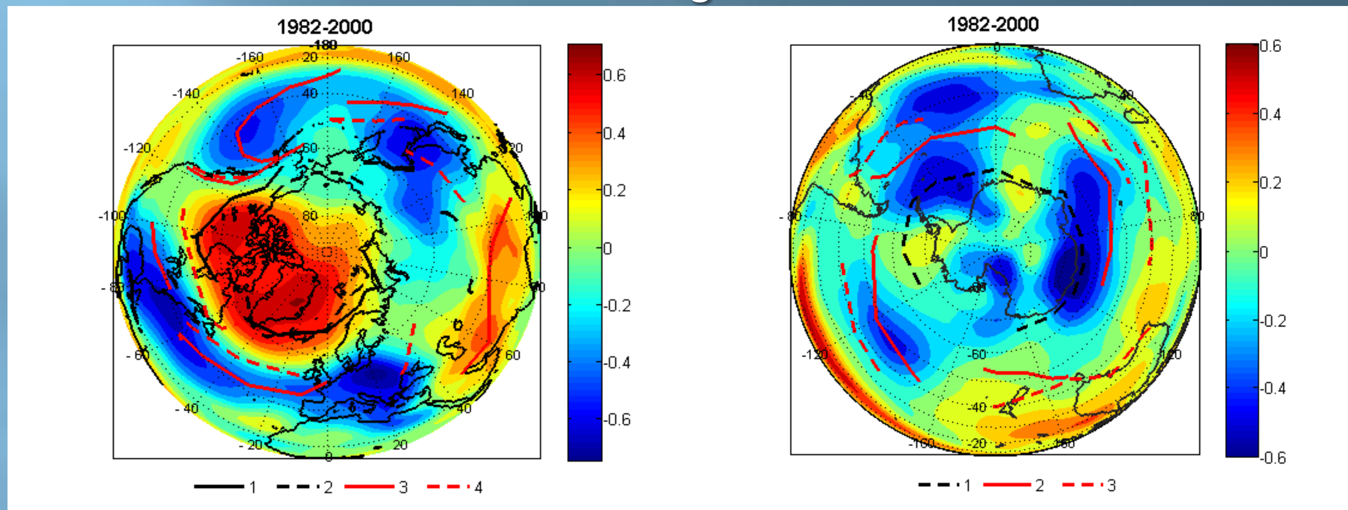




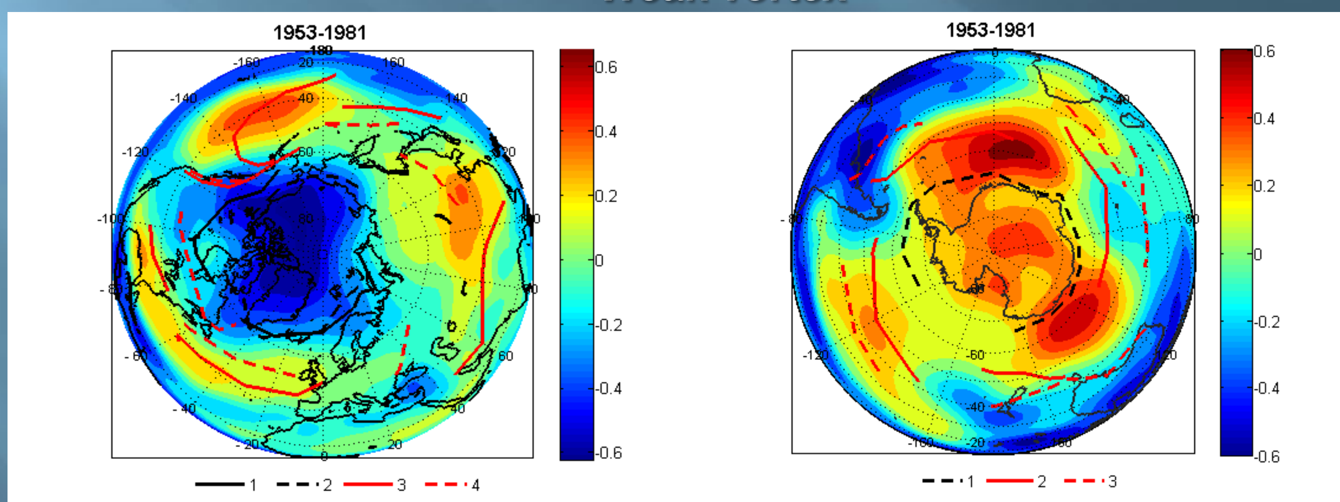
In the polar stratosphere the vortex can be seen as an area of low temperature with enhanced temperature gradients at its edges. The polar vortex intensifies in the cold half of year for a given hemisphere.

Correlation of pressure and GCR intensity under the strong and weak vortex conditions

Strong vortex

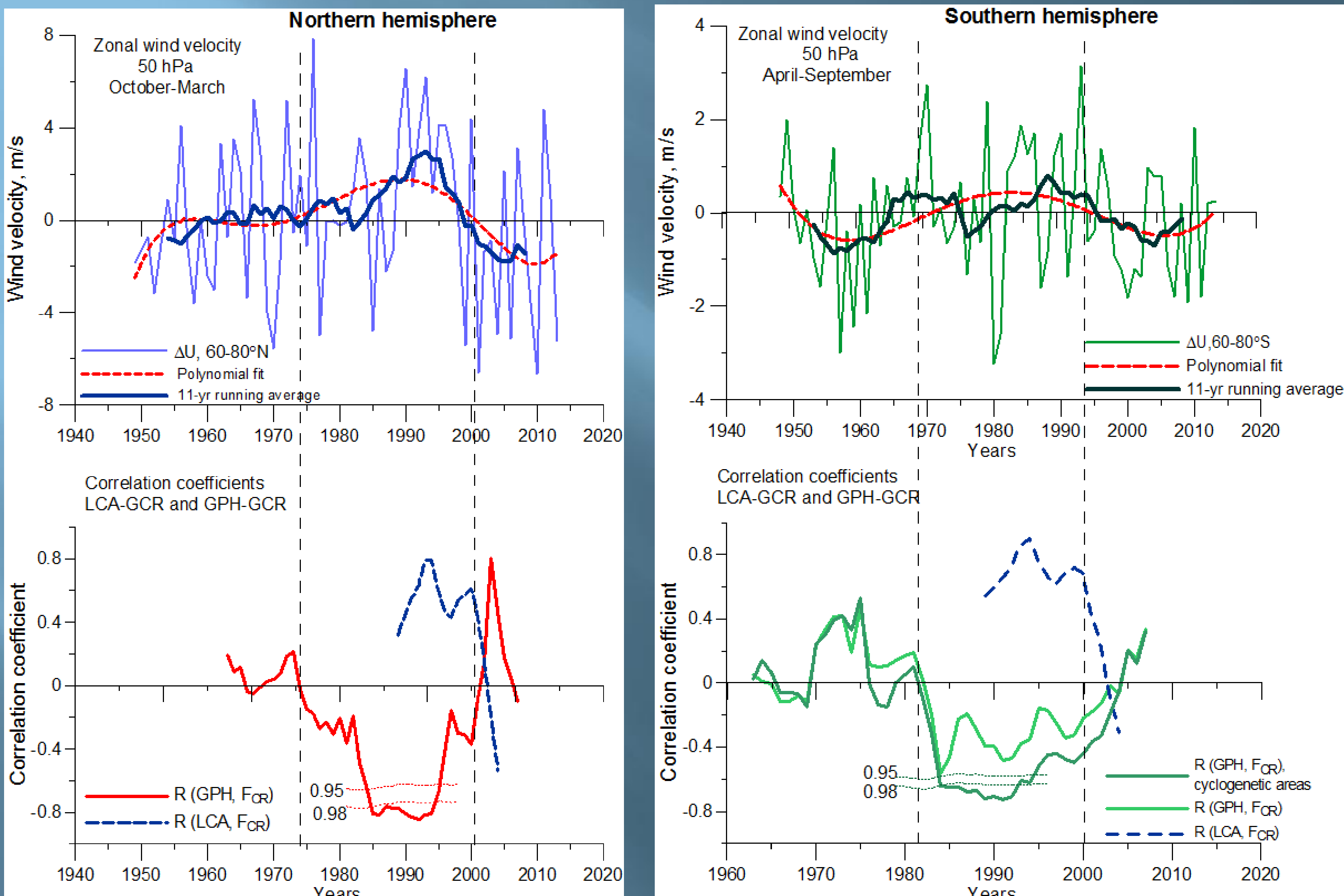


Weak vortex

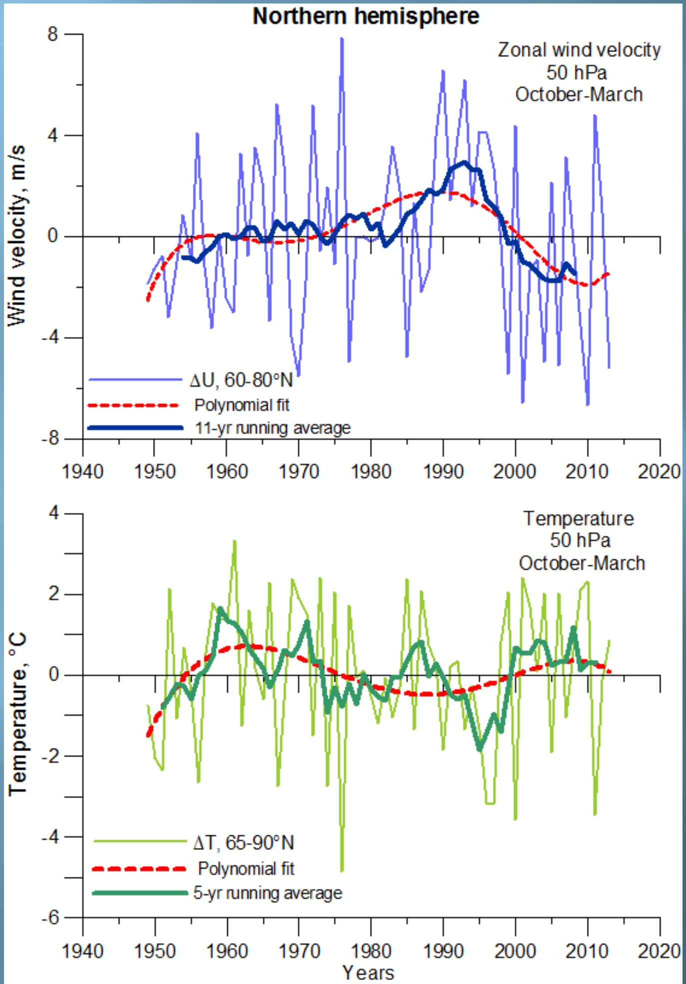


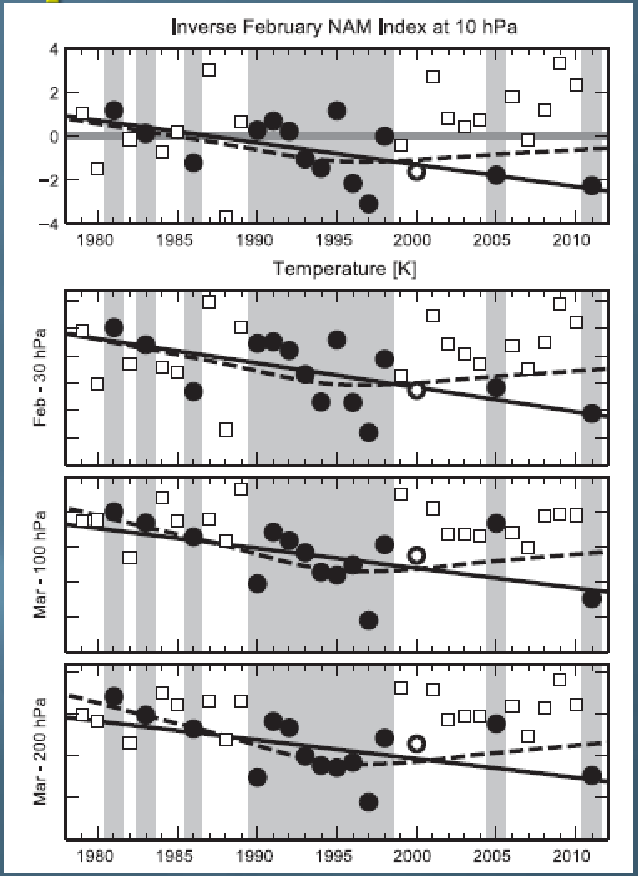
Extratropical cyclone intensification (decrease of pressure at Polar fronts) with GCR increase in the 11-yr cycle takes place only under a strong vortex.

Variations of the vortex strength and reversals of correlations LCA-GCR and GPH-GCR



Variations of the polar vortex intensity in the Northern hemisphere





Variations of NAM index and temperature in the polar cap (*Ivy et al., J.Clim., 2014*) . Black circles and gray shading show years without major SSWs.

The period of a **strong vortex** was from the late 1970s to ~2000.

- Enhancement of western winds in the polar stratosphere
- Lowering of stratospheric temperature
- Absence of major sudden stratospheric warmings (SSWs) in the 1990s (*Ivy et al., J. Clim., 2014*) .

1) In the period of a strong vortex – increase of GCR fluxes contributes to intensification of extratropical cyclones at Polar fronts of middle latitudes and Arctic/Antarctic fronts at high latitudes

↓

Cyclone intensification contributes to more intensive formation of clouds

↓

Positive correlation between low cloud anomalies and GCR fluxes from the early 1980s to ~2000 in the period of a strong vortex

2) Sharp weakening of the polar vortices in the Northern and Southern hemispheres occurred near 2000

↓

Reversal of GCR effects on cyclonic processes

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Violation of positive correlation between LCA and GCR intensity

Conclusions

- Correlation links between cloudiness at middle latitudes and GCR variations detected on the decadal time scale are due to GCR influence on the development of extratropical baric systems (cyclones, troughs) which form cloud fields.
- Positive correlation between low cloud anomalies and GCR variations in 1983-2000 results from intensification of cyclonic activity at middle latitudes of both Northern and Southern hemispheres associated with GCR increases in the 11-yr cycle. In this period the polar vortices in both hemispheres were strong, especially in the Northern one.
- Violation of positive correlation LCA-GCR occurred in the early 2000s almost simultaneously in the Northern and Southern hemispheres and coincided with a sharp weakening of the polar vortices. The changes of the vortex states seem to result in the reversals of GCR influences on the development of extratropical baric systems.
- The results obtained give evidence for an important part of the stratospheric polar vortex in solar-atmospheric links. The changes of the vortex state may be a reason for temporal variability of solar activity effects on the lower atmosphere characteristics.