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* Low clouds and Cosmic Rays: possible reasons for correlation changes

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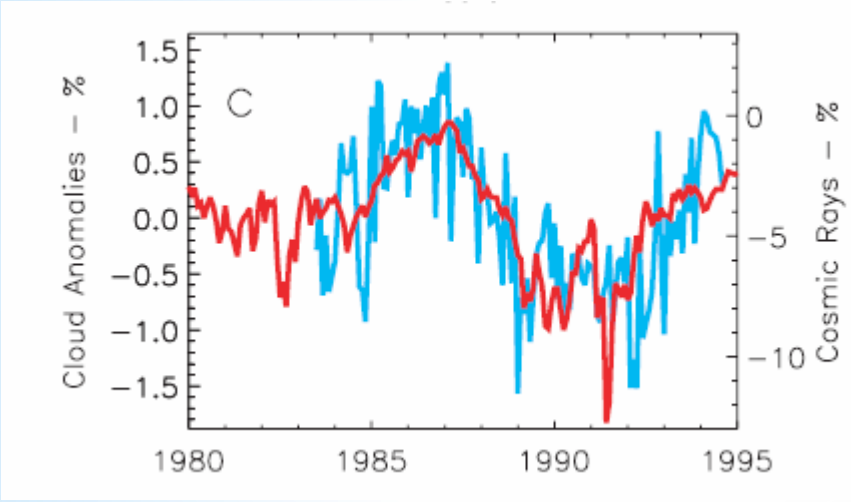
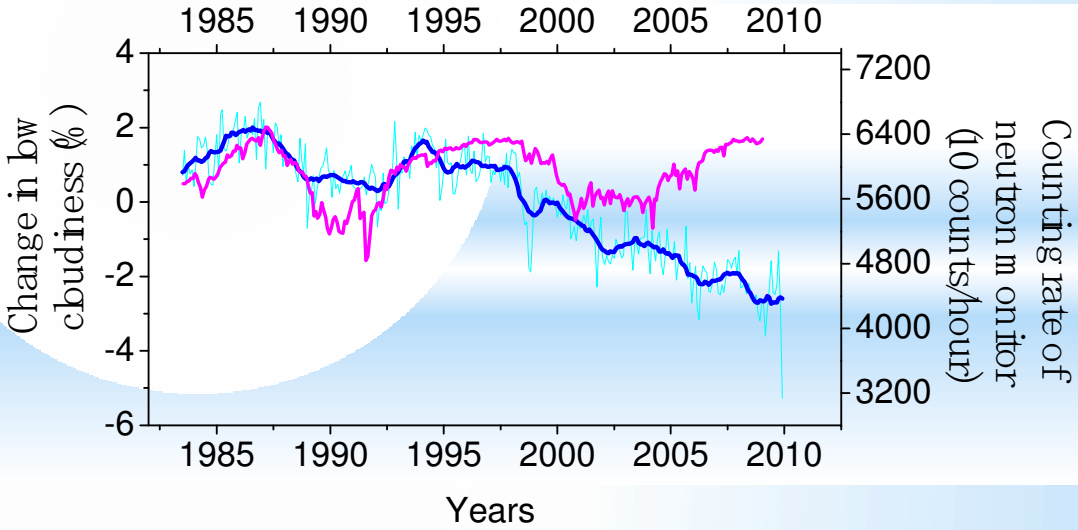
* Low cloud anomalies and variations of galactic cosmic ray intensity



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.



Globally averaged LCA (blue line) and neutron monitor counting rate (Kiel) (magenta line) according to Ogurtsov et al., 2014

The aim of this study:

- 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

*1.Cloud field formation at extratropical latitudes:

Links to the atmosphere dynamics

*Cloud types

Cloud classification on the base of **cloud bottom height** :

High level clouds, cloud bottom is higher than **6 km**:

cirrus (Ci), cirrocumulus (Cc), cirrostratus (Cs)

Middle level clouds, cloud bottom is at **2-6 km** :

altocumulus (Ac), altostratus (As)

Low level clouds, cloud bottom is lower than **2 km** :

stratocumulus (Sc), stratus (St), nimbostratus (Ns)

Vertical development clouds (all three levels):

cumulus (Cu), cumulonimbus (Cb)

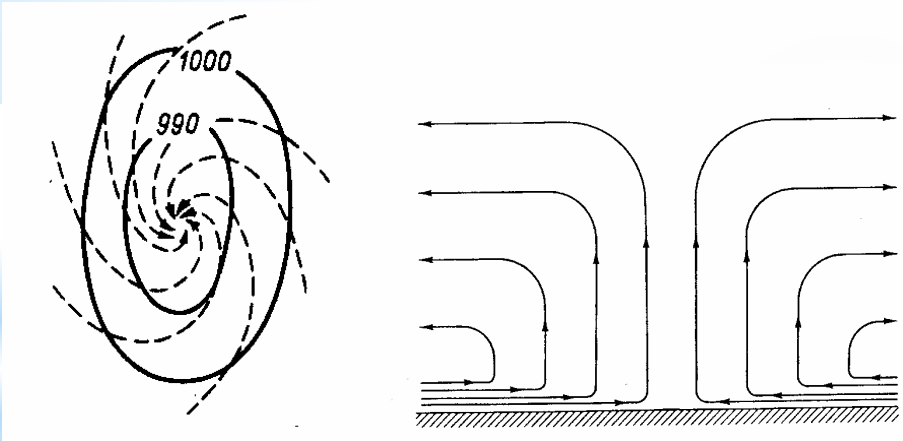
The main reason for cloud formation is vertical transport and cooling of water vapor i.e., formation of cloud field is determined by vertical movement of air

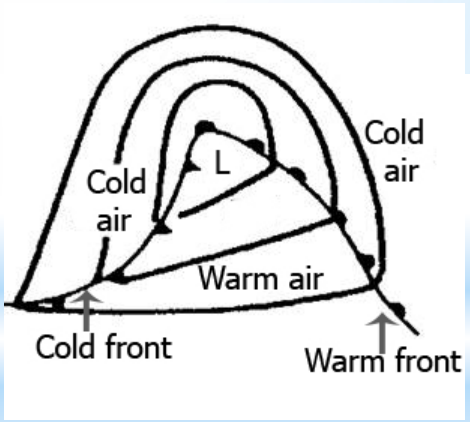
* Cloud formation at middle latitudes

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

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

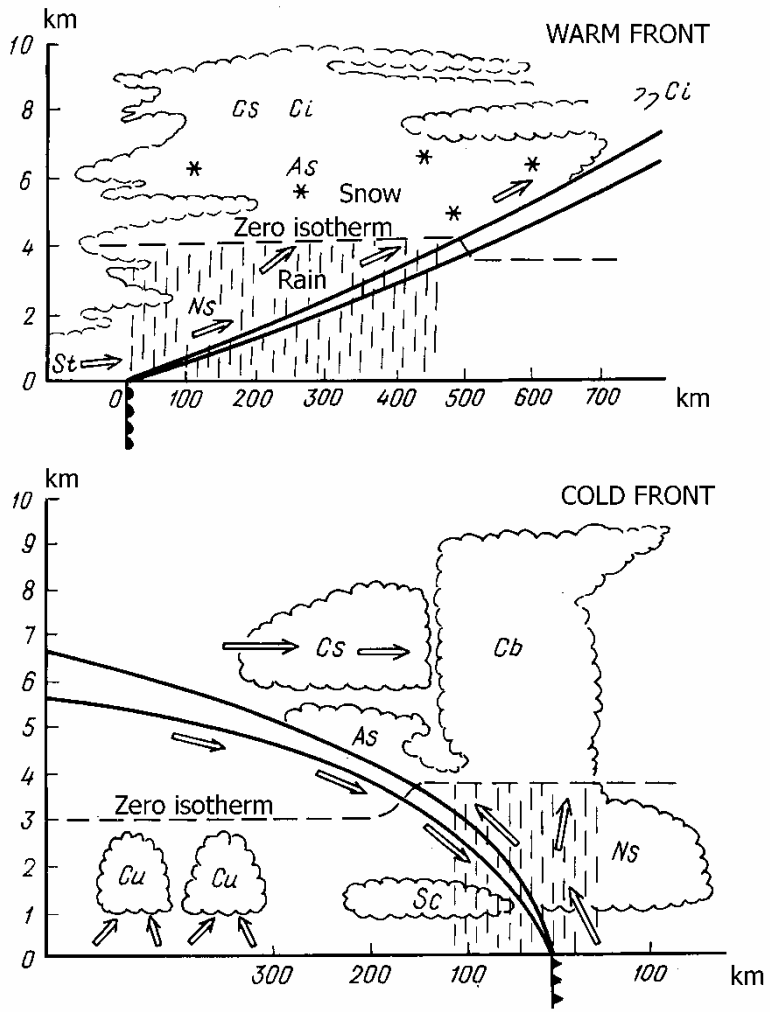
Vertical air movements in mid-latitudinal frontal cyclones





- *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

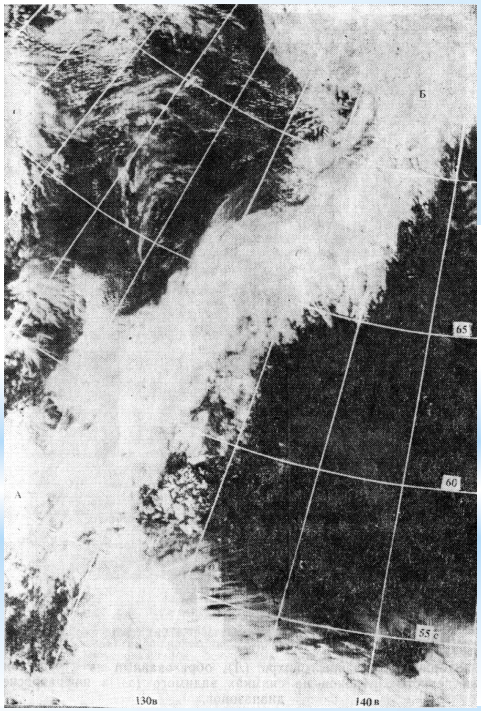


Cloud systems of warm (top) and cold (bottom) fronts (Khromov and Petrociants, Meteorology and climatology, 1994)

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

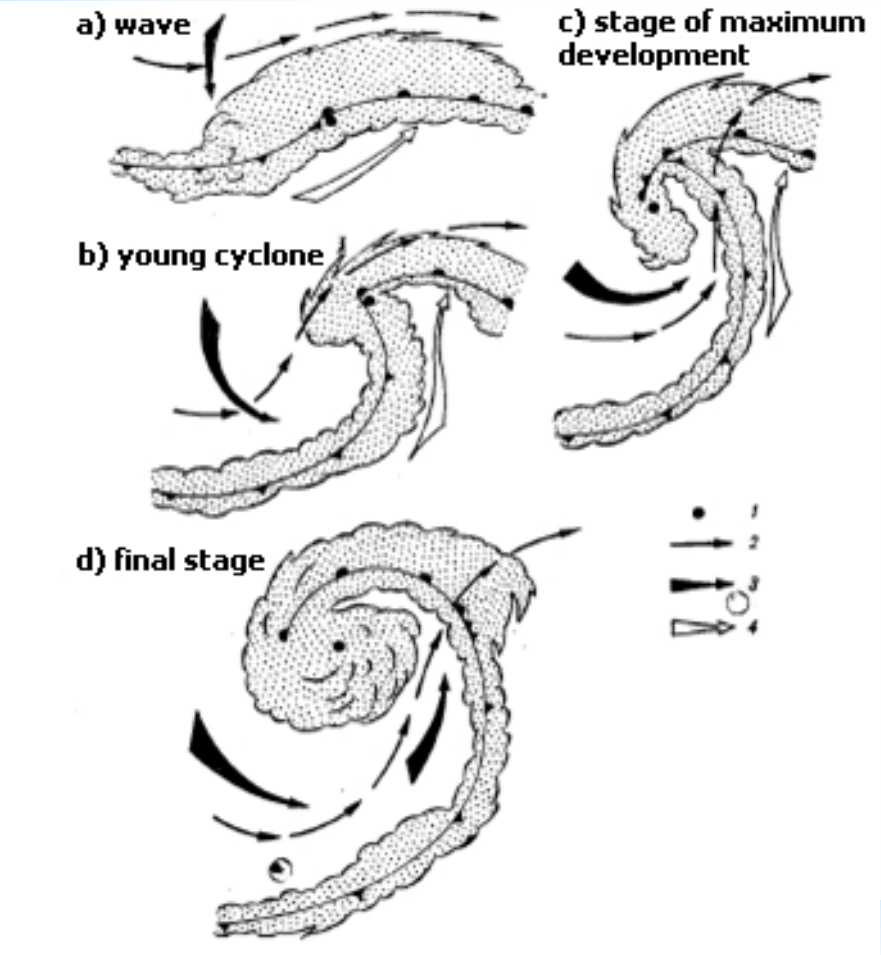
Predominant cloud types:

- ***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



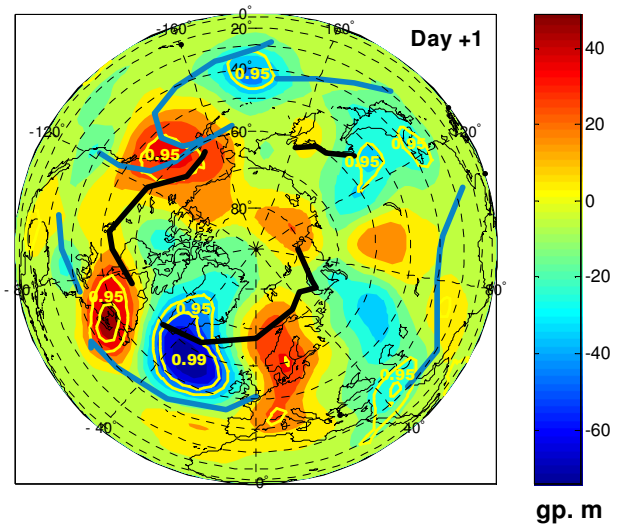
Cloud system of a frontal cyclone at different stages of its evolution (Vorobjev, Synoptic meteorology, 1991).

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

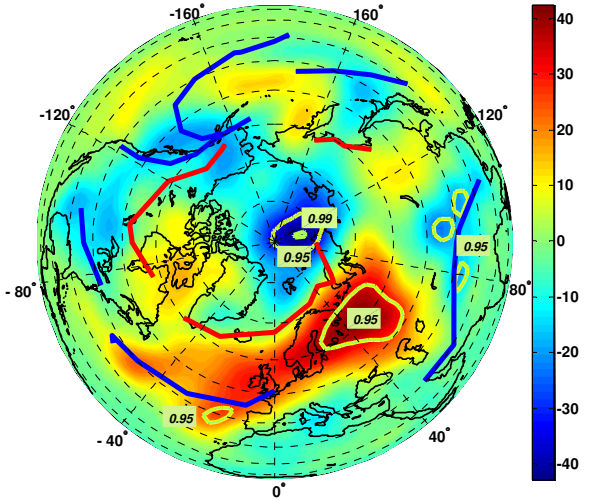
Extratropical cloud vortex in the Northern hemisphere, A – the center of the vortex (*Vorobjev, Synoptic meteorology, 1991*).

*2. Influence of cosmic rays on the development of extratropical baric systems

* Cosmic ray effects on baric system evolution: day-to-day time scale

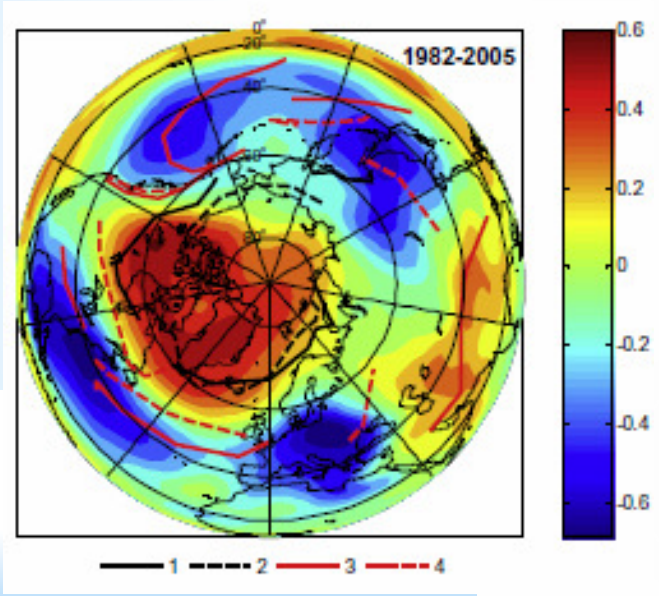


Solar Proton Events (energy of particles E > 90 MeV):
Intensification of cyclones at the Arctic front near Greenland
(Veretenenko and Thejll, J.Phys.:Conf.Ser., 2013)



Forbush decreases of GCR:
Weakening of cyclones and **intensification of anticyclones** at Polar fronts
(Artamonova and Veretenenko, Adv.Space Res., 2014)

* Cosmic ray effects on baric system evolution: decadal time scale

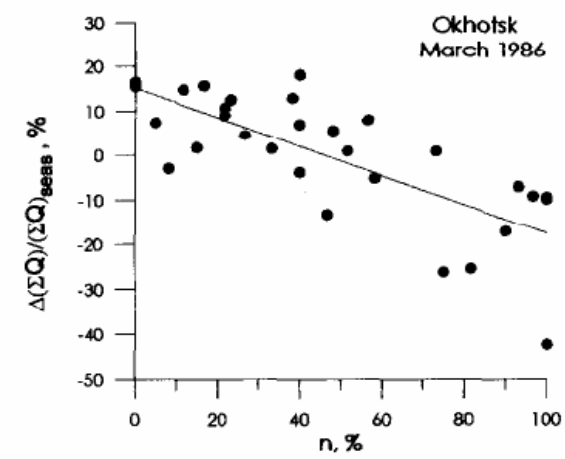


Correlation coefficients between yearly troposphere pressure and GCR intensity in the strong vortex epoch
(Veretenenko and Ogurtsov, Adv.Space Res., 2014)

Increase of cosmic ray intensity (both solar and galactic) is accompanied by **intensification of cyclonic activity at middle latitudes** both in the 11-year cycle and day-to-day time scale

This suggests a possible influence of GCR on cloud cover through changes in the evolution of baric systems

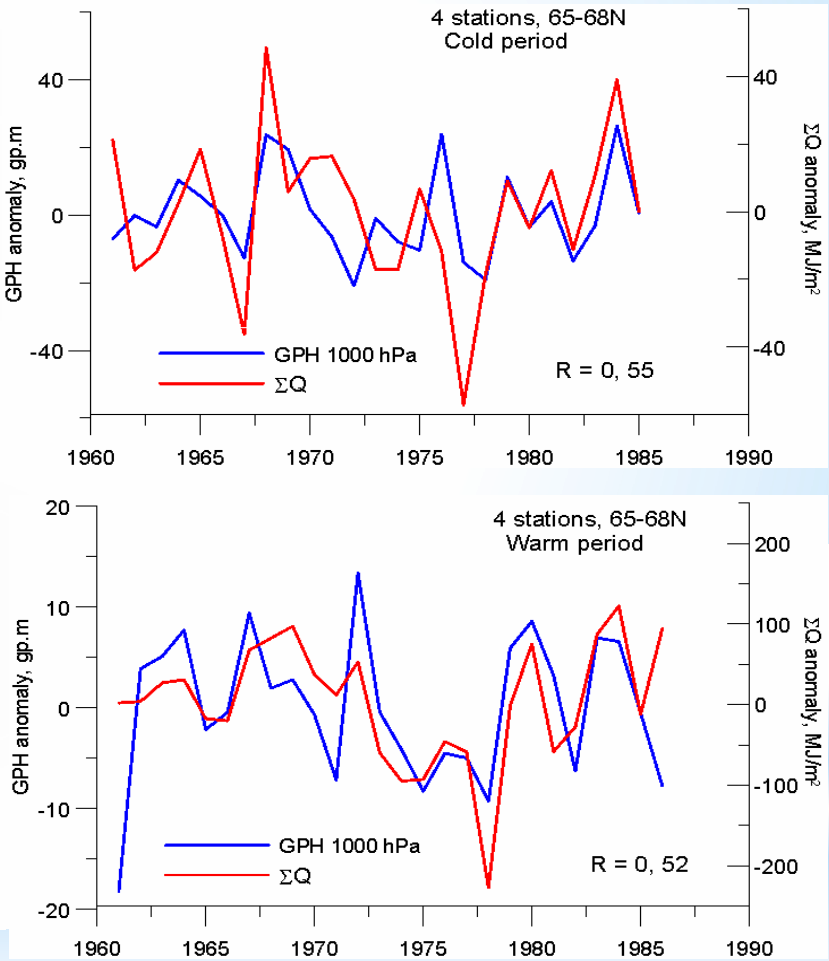
* Total radiation input and pressure variations



Total radiation (direct+ scattered) decreases with cloudiness increase

As cloud cover at extratropical latitudes is closely related to cyclonic activity, the input of total radiation correlates positively with pressure:

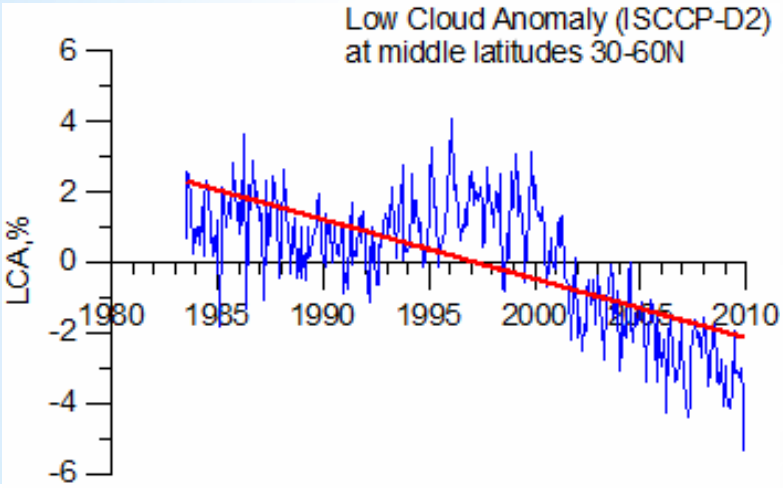
less cyclones (higher pressure) → less clouds → more radiation

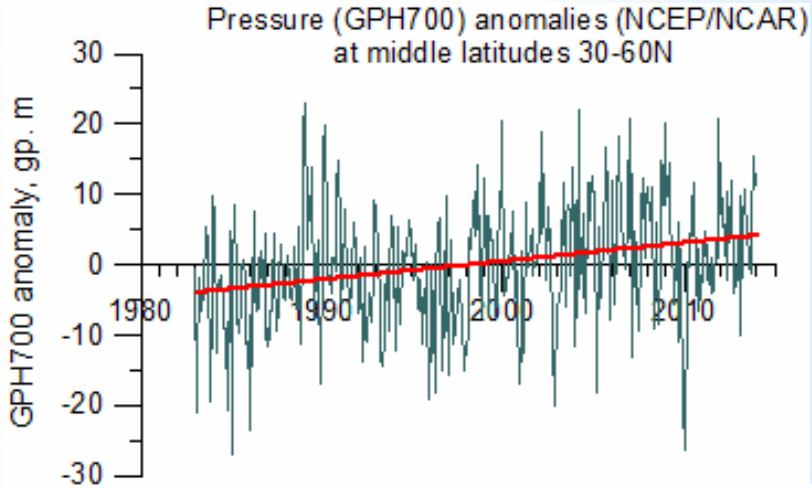


Variations of half-yearly sums of total radiation (red line) and pressure (blue line)
(radiation data according to Veretenenko and Pudovkin, JASTP, 1999)

*3. ISCCP cloud data and the atmosphere dynamics

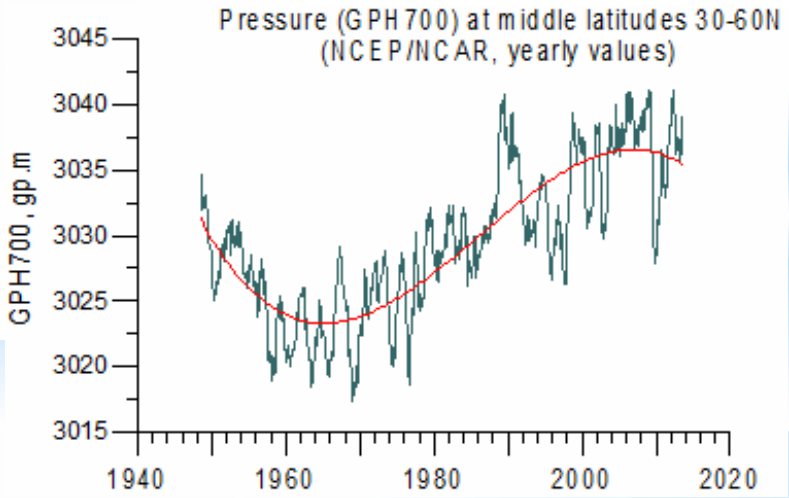
* Low Cloud and Pressure Anomalies at middle latitudes: trends



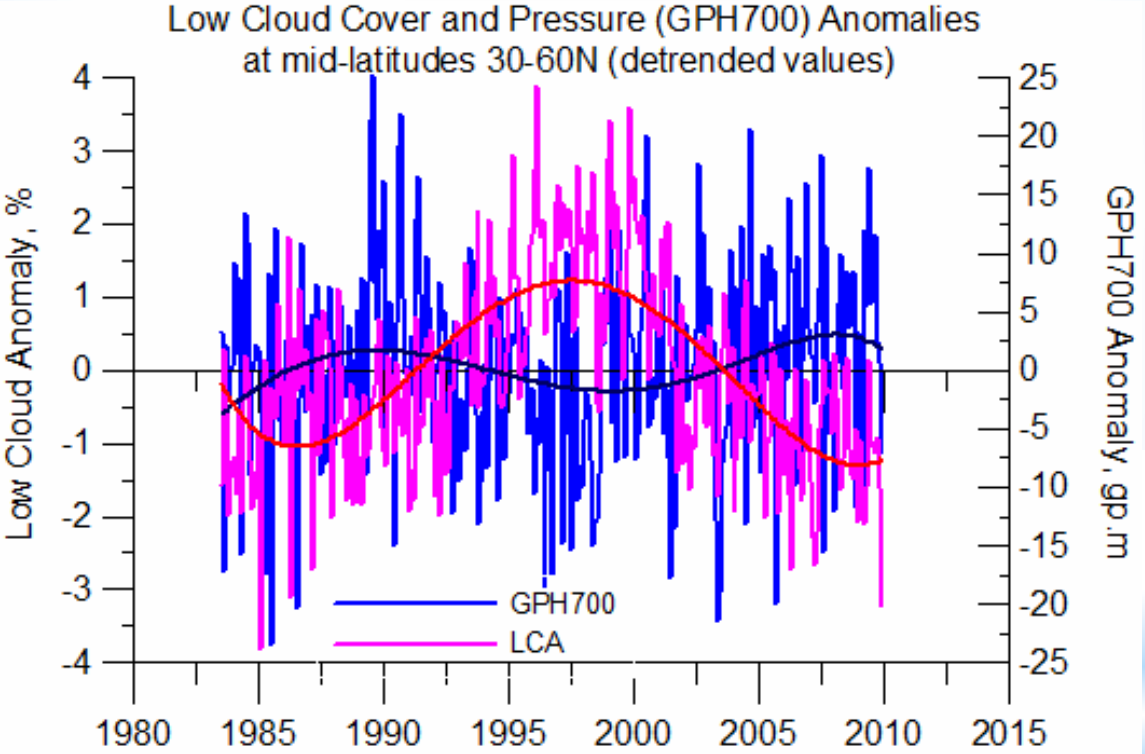


Trends in monthly values of LCA and pressure (GPH700) are opposite: In 1983-2009 **pressure gradually increased** (decrease of cyclonic activity) and **low cloudiness decreased**.

An increase of pressure at mid-latitudes is observed since 1970s.

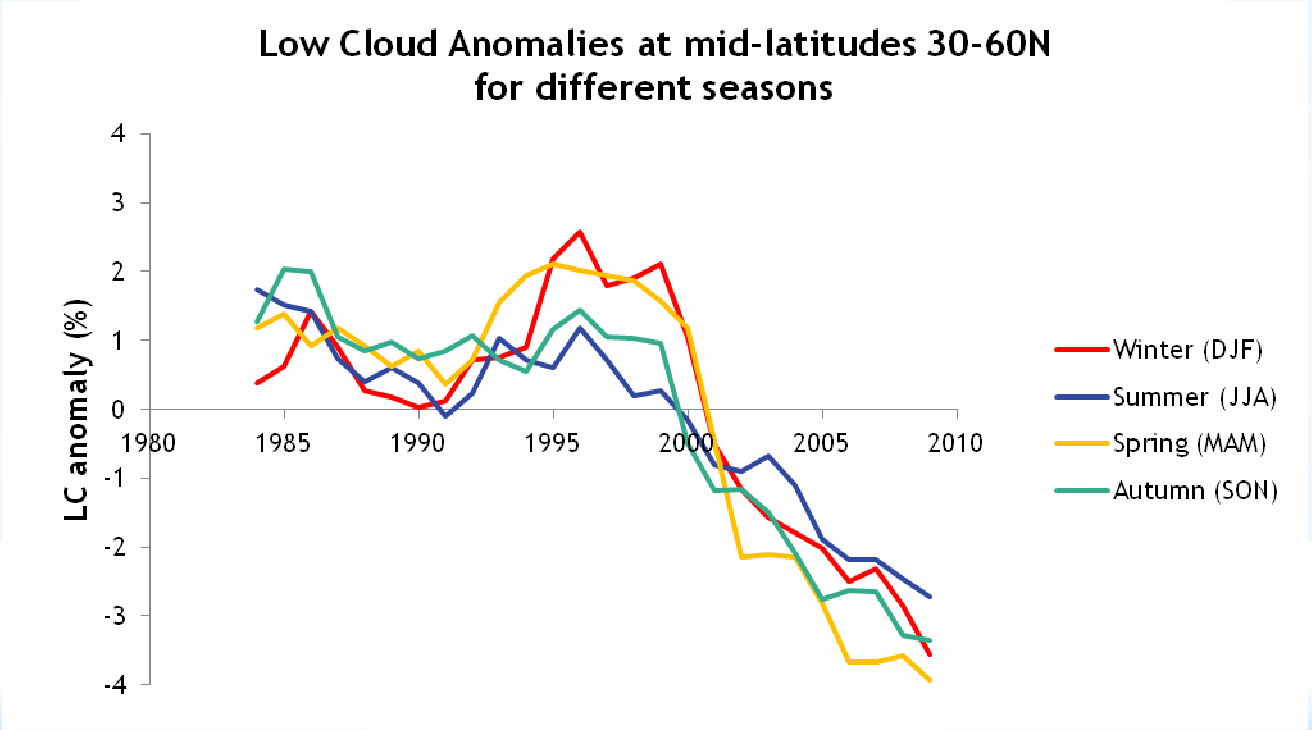


* Low Cloud and Pressure Anomalies at middle latitudes: deviations from trends



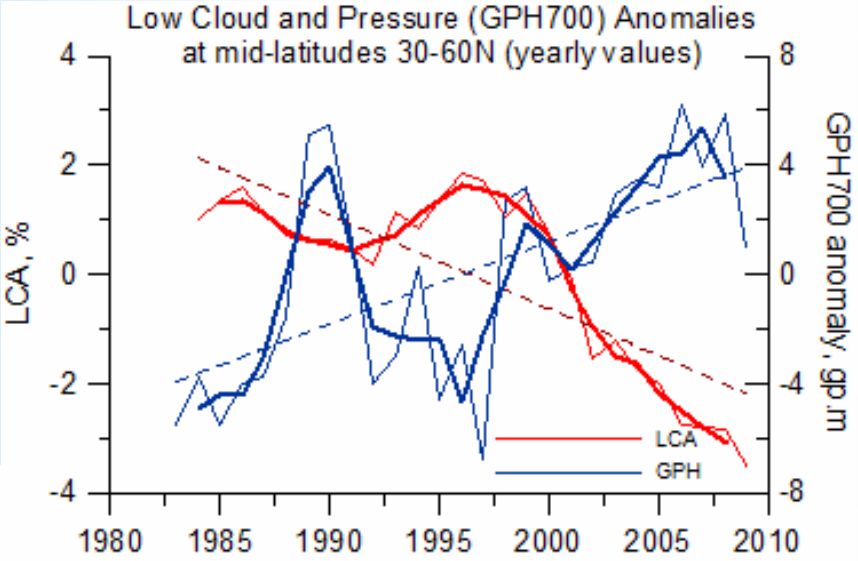
Monthly values of **Low Cloud** and **Pressure anomalies**, both the trends and the deviations from the trends, **show an opposite character**.
This indicates a close connection between cloud cover and atmosphere dynamics.

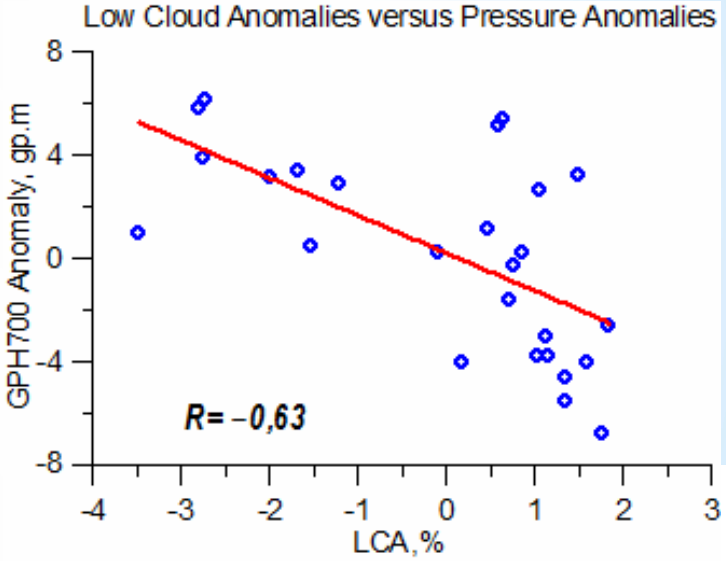
* Season variation of Low Cloud Anomaly



Season dependence of low cloudiness provides evidence for a link with cyclonic activity:
Low Cloud Anomalies reveal **highest variations in cold months** when extratropical cyclogenesis is most pronounced due to enhanced temperature contrasts in the troposphere.

* Time variation of Low Cloud and Pressure Anomaly at middle latitudes: yearly values





Negative correlation between LCA and GPH700 anomalies (yearly values):
$R = -0,63$ and $R_{sm} = -0,8$ for 3-year running mean.

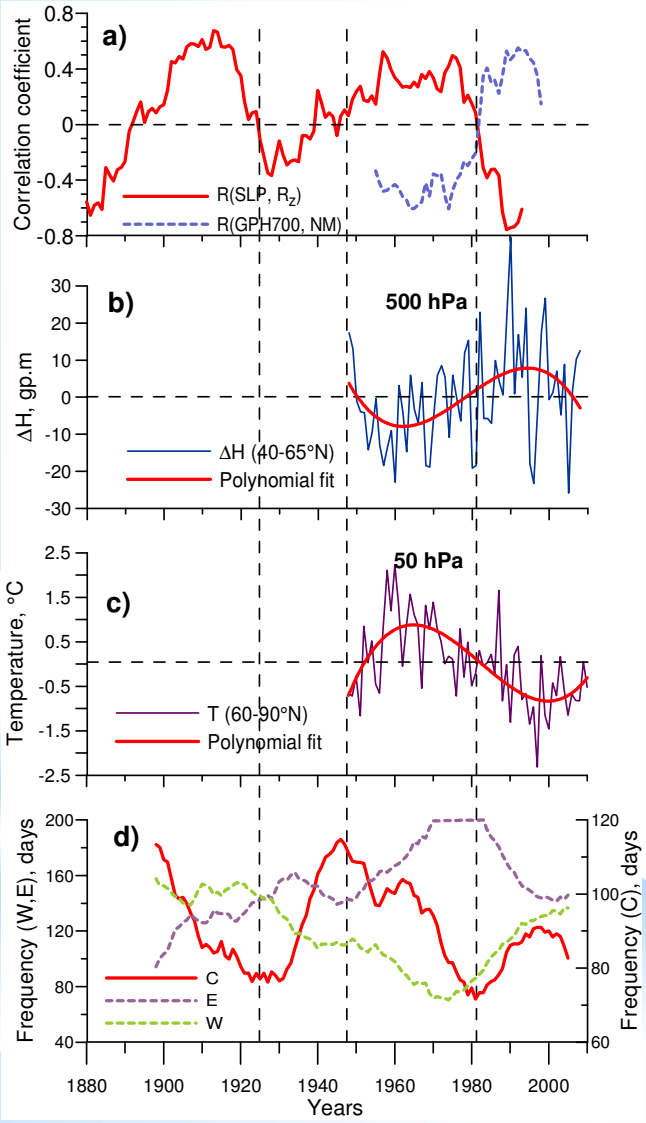
Decrease of cyclonic activity (increase of pressure)

↓

Decrease of cloudiness

*4. Time variation of links between the troposphere dynamics and cosmic rays

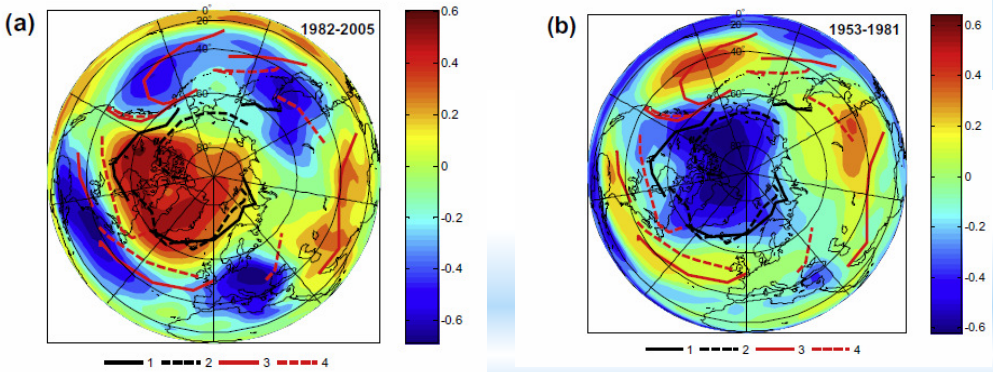
Long-term variations of Solar Activity and Galactic Cosmic Ray effects on the troposphere circulation



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

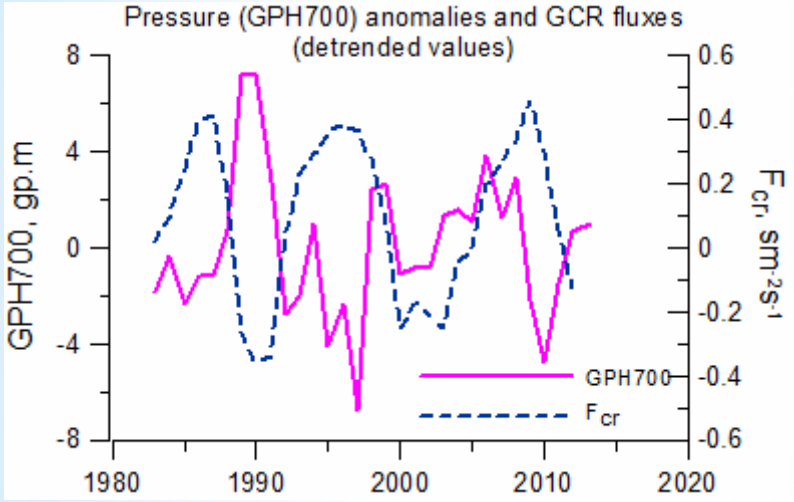
Correlation coefficients between troposphere pressure at extratropical latitudes and SA/GCR indices reveal a roughly **~60-year** periodicity.

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**.



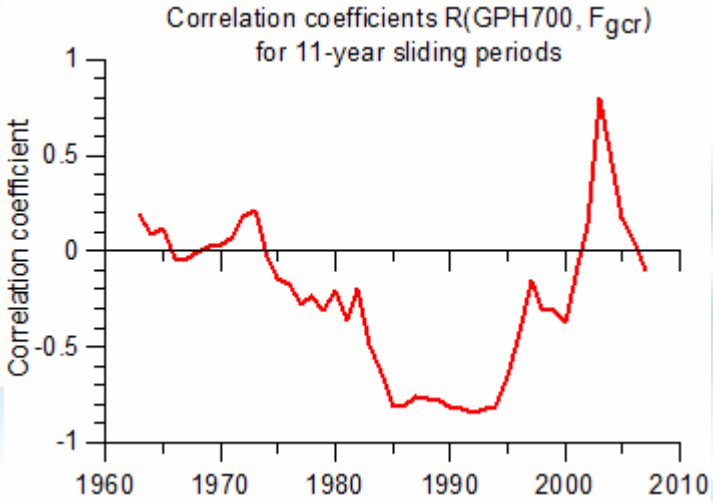
As the change of the vortex state occurred near 1980, so **the next change** may take place **after 2000**.
This may results in the **reversal of the correlations** observed in the period ~1980-2000.

* Pressure anomalies at middle latitudes and GCR intensity

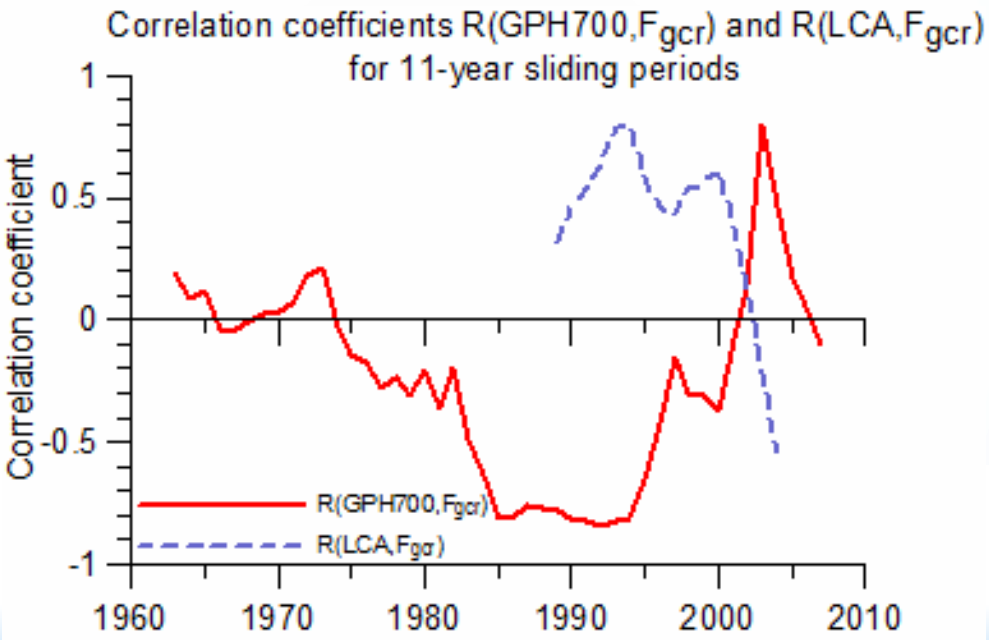


Before 2000 pressure and GCR fluxes **varied in opposite phases** implying intensification of cyclogenesis (and, thus, increase of cloud cover) with GCR increase.
In 2002-2009 we can see pressure and GCR fluxes varying in the same phase.

So, there is a strong fluctuation (a sharp increase) of the correlation coefficients *R(GHP700,CR)* in the yearly 2000s which may result from the vortex evolution to its weak state.



* Time evolution of correlations Pressure-Cloudiness-Cosmic Rays



As cloudiness at middle latitudes is closely related to cyclone activity, **a reversal of the sign of GCR effects** on the development of extratropical cyclones results in the **violation of positive correlation** between low cloud cover and GCR fluxes, observed in ~1980-2000 г.

*Conclusions

The results of this study showed:

•The link of cloud cover and GCR fluxes at mid-latitudes is not direct. It is realized through GCR effects on the development of extratropical baric systems (cyclones and troughs) which form cloudiness field.

•Positive correlation between Low Cloud Anomalies and GCR intensity in the period 1983-2000 results from positive correlation between cyclonic activity and GCR (cyclonic activity intensifies due to GCR increase) taking place under a strong stratospheric polar vortex.

•As GCR effects on extratropical baric systems change the sign with the change of the vortex state, the violation of positive correlation LCA/GCR after 2000 seems to be due to the transition of the vortex to its weak state.

• The results obtained provide evidence for an important part of the polar vortex in the mechanism of solar-atmospheric links.