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Effects of Solar Proton Events on the development of cyclonic activity at extratropical latitudes

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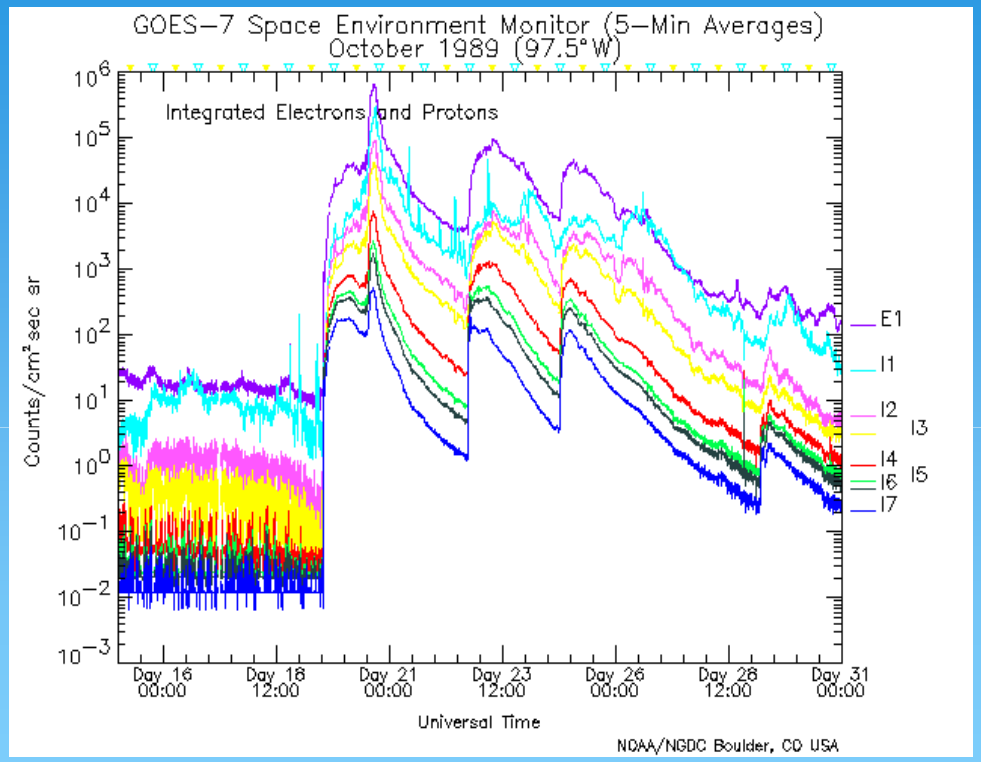
Solar Proton Events



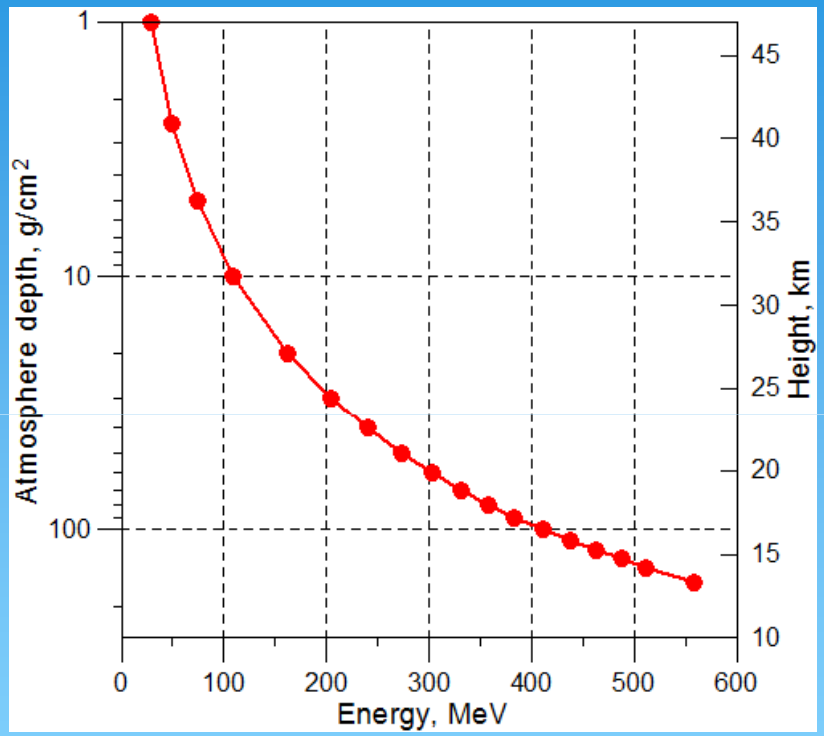
SPE series started on 19 October 1989.

Protons: *I1 – E > 1 MeV; I2 – E > 5 MeV; I3 – E> 10 MeV ; I4 – E> 30 MeV ; I5 – E > 50 MeV ; I6 – E> 60 MeV ; I7 – E> 100 MeV* . Electrons: *E1– E > 2 MeV* .

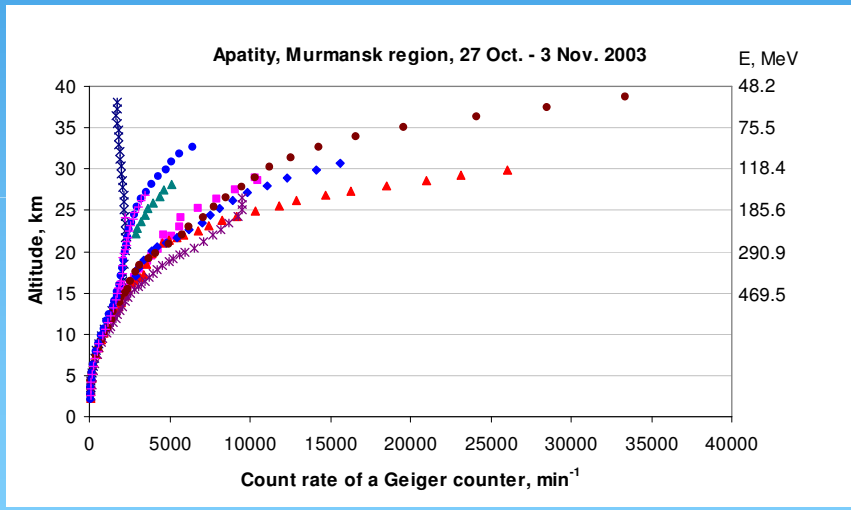
Solar energetic particles with energies from 1 MeV to 10 GeV (solar cosmic rays) are sporadically observed in the near Earth space as a sharp increase of charged particle fluxes against the background of galactic cosmic rays (GCRs).

Low-energy solar cosmic rays (E < 100 MeV) can be measured only by spacecraft devices.

Energetic SPEs (E > 90 MeV)



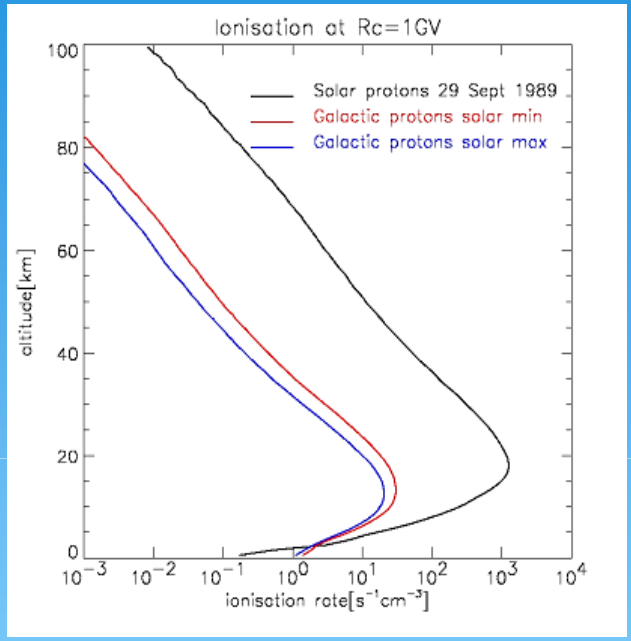
SPEs with energies 100-500 MeV may penetrate down to **the stratosphere heights** (from ~32 to ~15 km) and they are suitable for observation on balloons.

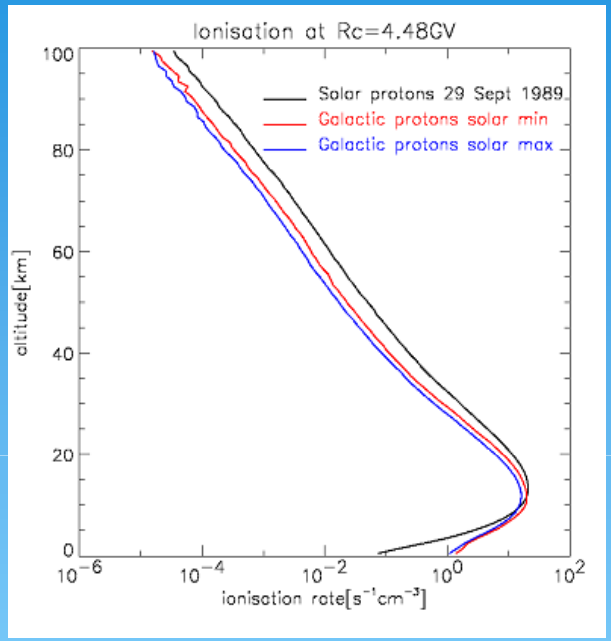


Cosmic ray fluxes measured during different balloon flights in October-November 2003 (Bazilevskaya, Adv. Space Res.,2005)

Solar protons with energies 100-500 MeV lose their energy mainly through ionization. Protons with E > 500 MeV participate in nuclear interactions producing secondary particles. Secondary neutrons may reach the ground level and be recorded by neutron monitors. Such SPEs are called Ground Level Enhancements (GLEs).

Ionization effects of Solar Proton Events

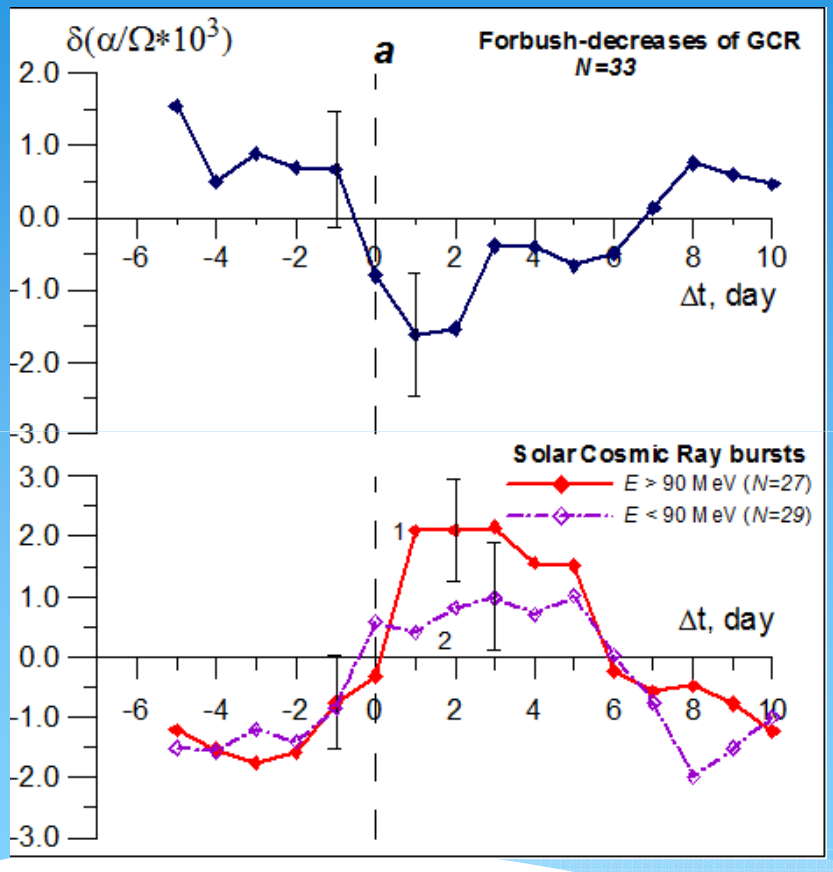




Bern Model: http://cosray.unibe.ch/~laurent/planetocosmics
Desorgher et al., AOGS 2004

Ionization by SPEs is most pronounced **at polar latitudes**. Contribution of powerful SPEs in atmosphere ionization at the same altitudes may exceed that of GCRs by several orders.

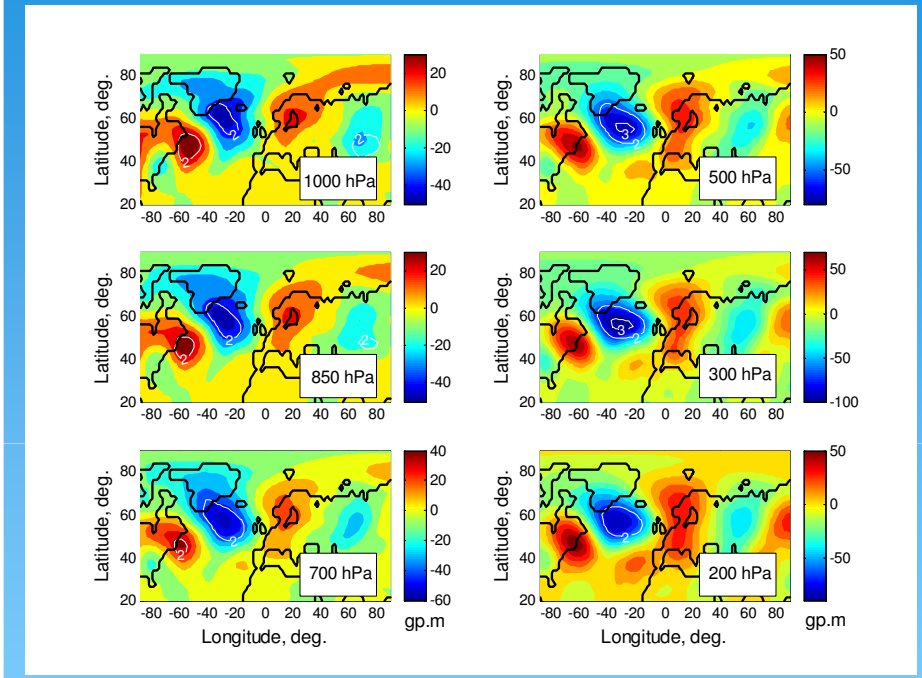
Results of previous studies: energetic SPE effects on zonal circulation intensity



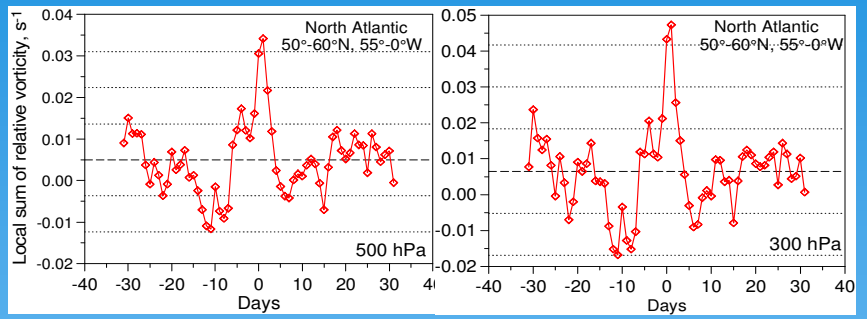
Veretenenko and Pudovkin, Geomagn. Aeron., 1993

Statistically significant response of zonal circulation intensity in the troposphere (500 hPa level) was detected **only for SPEs with energies more than 90 MeV** (red line)**.**

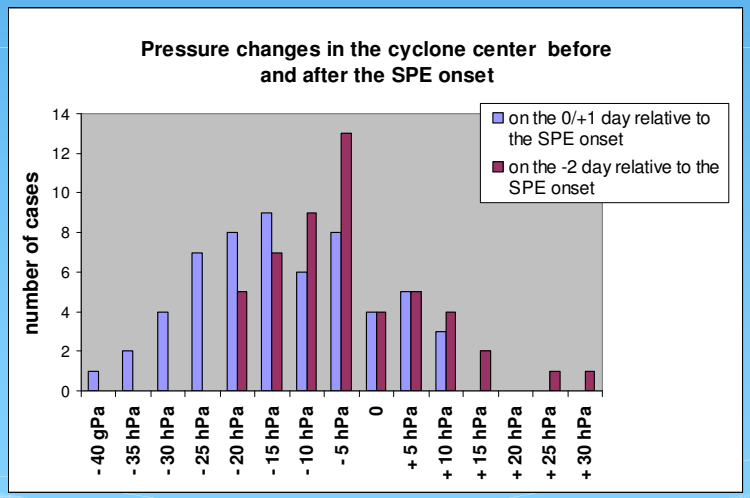
Results of previous studies: energetic SPE effects in the North Atlantic area



- Lowering of pressure levels in all the troposphere near the south-eastern coasts of Greenland



- Increase of cyclonic vorticity



- Intensification of cyclone deepening

Previous studies revealed **a significant intensification of cyclonic activity** in **the North Atlantic** area on the days following SPEs with energies above 90 Mev

(Veretenenko and Thejll, JASTP,2004; Adv. Space Res., 2005, Geom. Aeron., 2008).

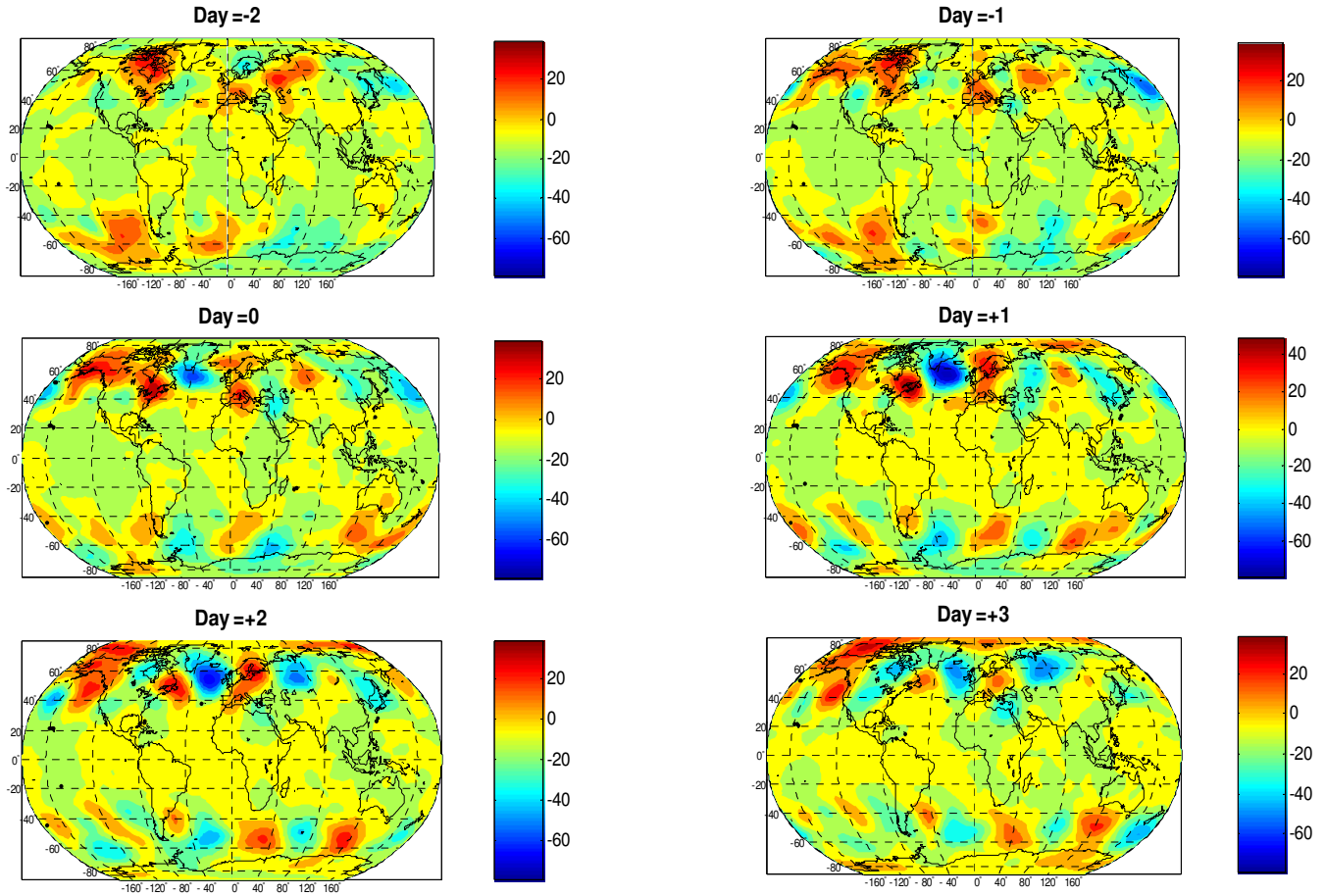
The aim of this work:

- to study variations of cyclonic activity at extratropical latitudes associated with energetic SPEs (E > 90 MeV) both for the Northern and Southern Hemispheres

Data used:

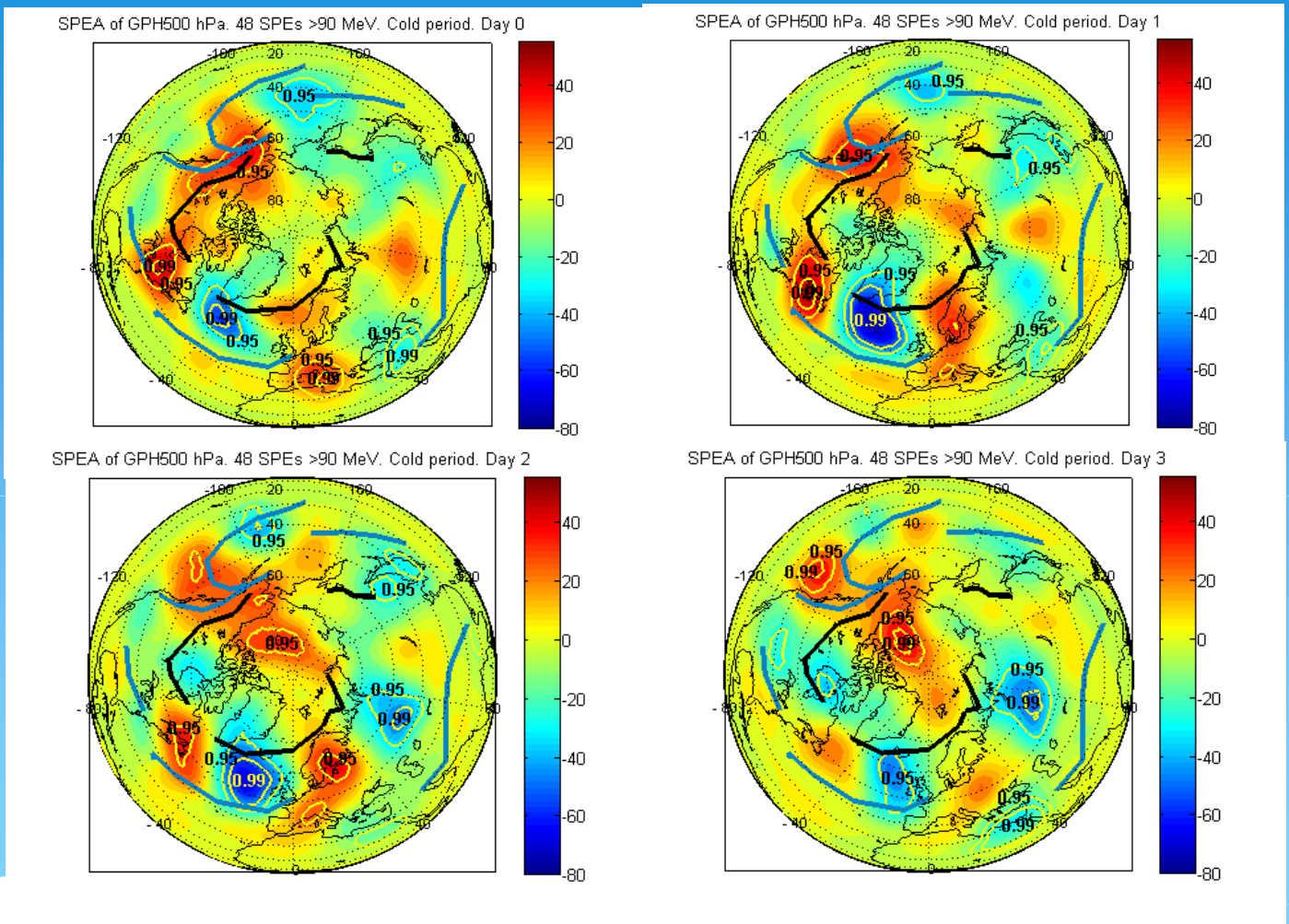
- Daily values of geopotential heights of the pressure level 500 hPa (GPH500) according to NCEP/NCAR reanalysis data (Kalnay et al., 1996)
- The set of 48 isolated Solar Proton Events, with energies > 90 MeV, in October-March 1980-1996 for the superposed epoch analysis (SPEA) according to catalogues by Logachev (ed.), 1990, 1998

Mean changes of pressure in the lower atmosphere associated with SPEs in October-March



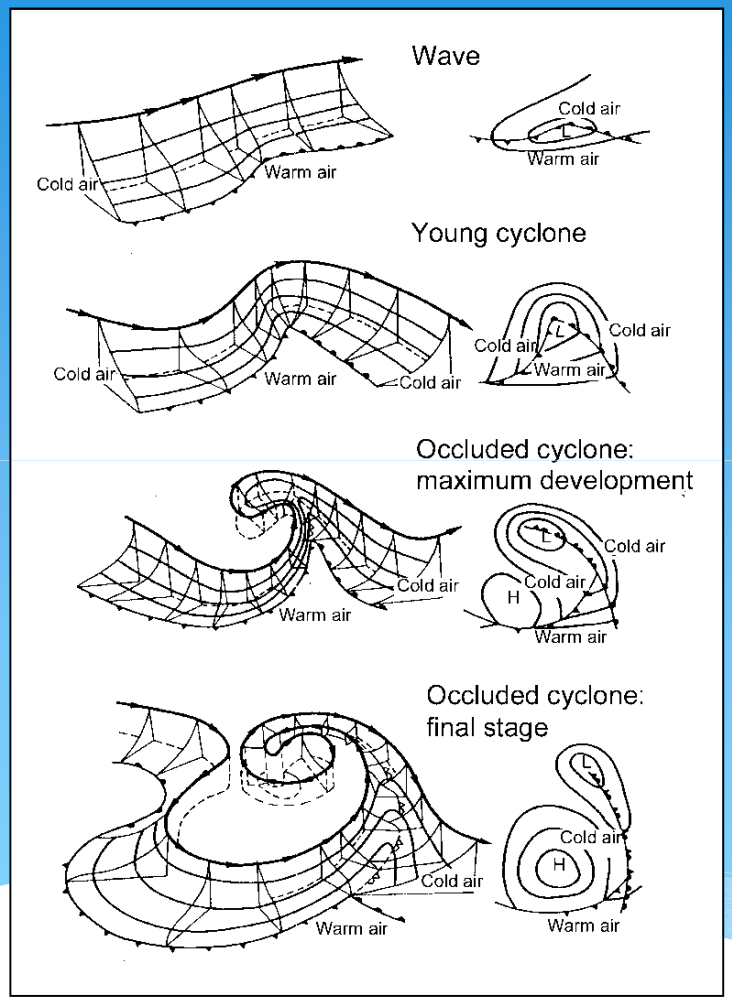
Superposed epoch analysis of GPH500 deviations from the mean level over the period ±10 days relative to the event onsets for 48 SPEs (October-March, 1980-1996).

SPE effects on pressure in the Northern hemisphere



Pressure starts sharply decreasing near the Greenland coasts just on the day of the SPE onset. The minimum of pressure is observed on the next day. Then SPE effects start weakening.

Evolution of extratropical frontal cyclone

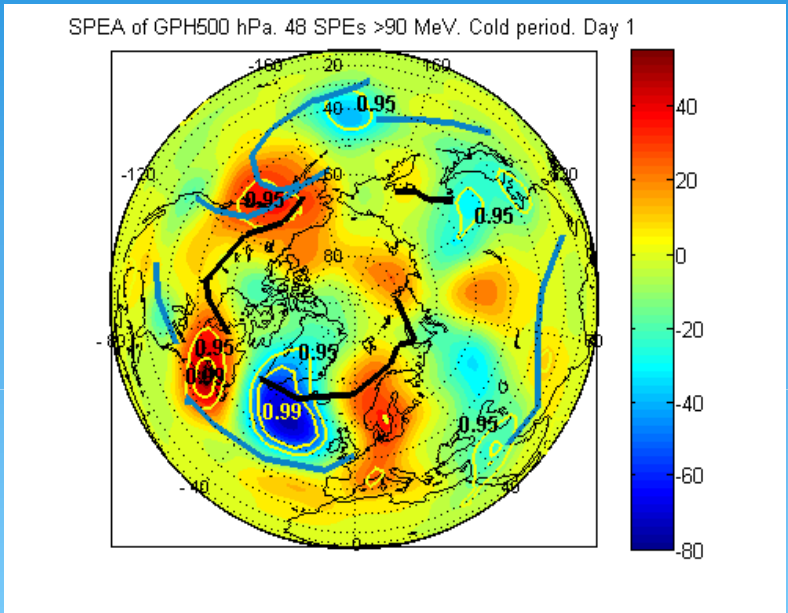


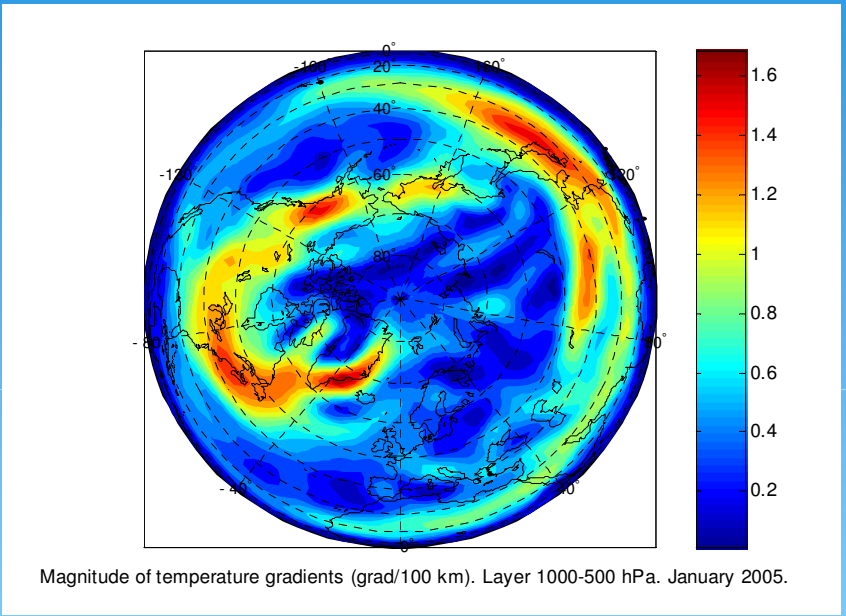
Vorobjev, Synoptic meteorology, 1991

All the stages of the evolution of a frontal cyclone at middle latitudes are closely related to atmospheric fronts.

Extratropical cyclones arise, develop at cold fronts and these fronts move together with cyclones.

Pressure variations associated with SPEs and climatic atmospheric fronts in the Northern hemisphere



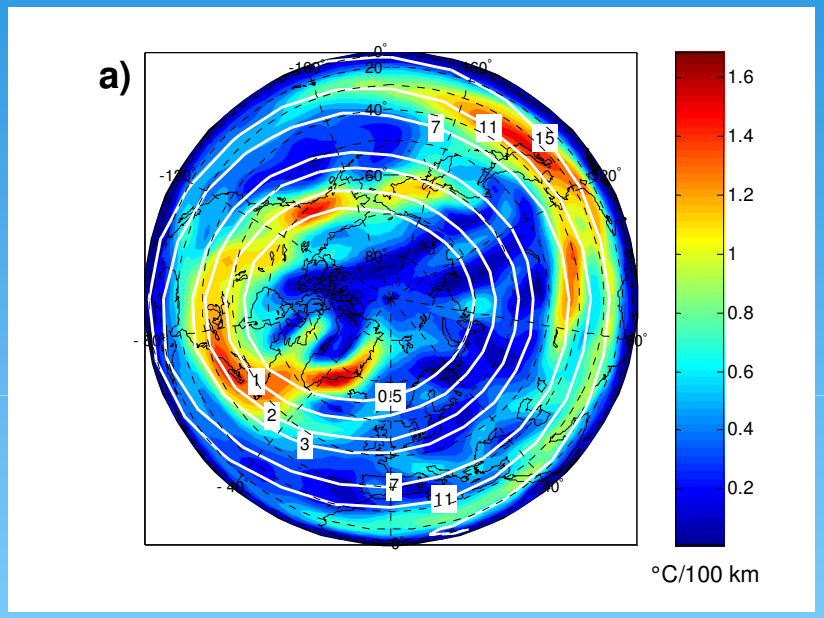


Magnitude of temperature gradients (grad/100 km). Layer 1000-500 hPa. January 2005.

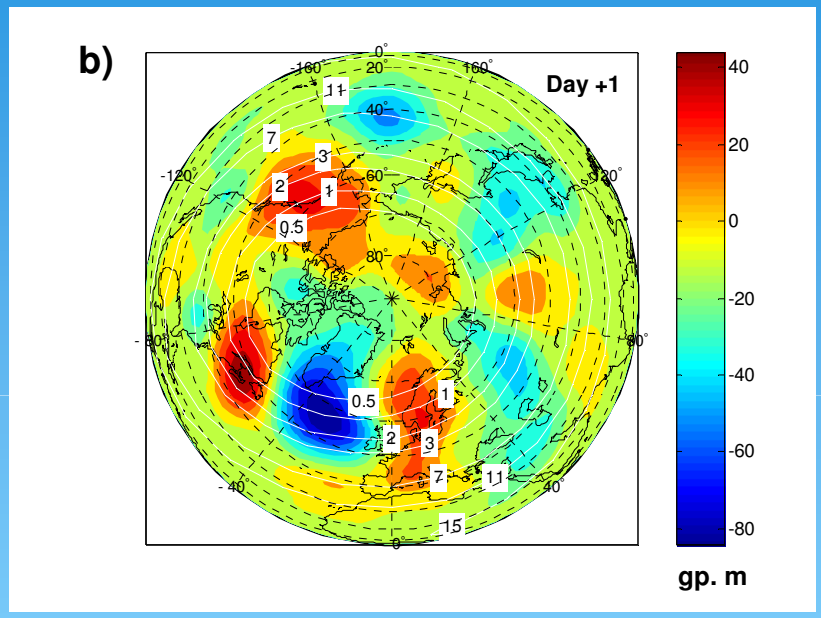
Pressure variations (both negative and positive) observed on the days following SPEs are closely related to climatic **Polar** (blue lines) and **Arctic** (black lines) **fronts** which are the areas of high temperature gradients and, then, cyclogenetic areas. So, pressure variations detected in the regions of climatic fronts provide evidence of **cyclone intensification** associated with SPEs.

Most statistically significant SPE effects are observed in the region of **climatic Arctic fronts** bounded the Arctic air mass and characterized by highest temperature contrasts . In the cold Artic mass the polar vortex (cyclonic circulation in the polar stratosphere) is formed.

Pressure variations associated with SPEs and geomagnetic cutoff rigidities in the Northern hemisphere



Magnitude of temperature gradients (layer 1000-500 hPa). January 2005

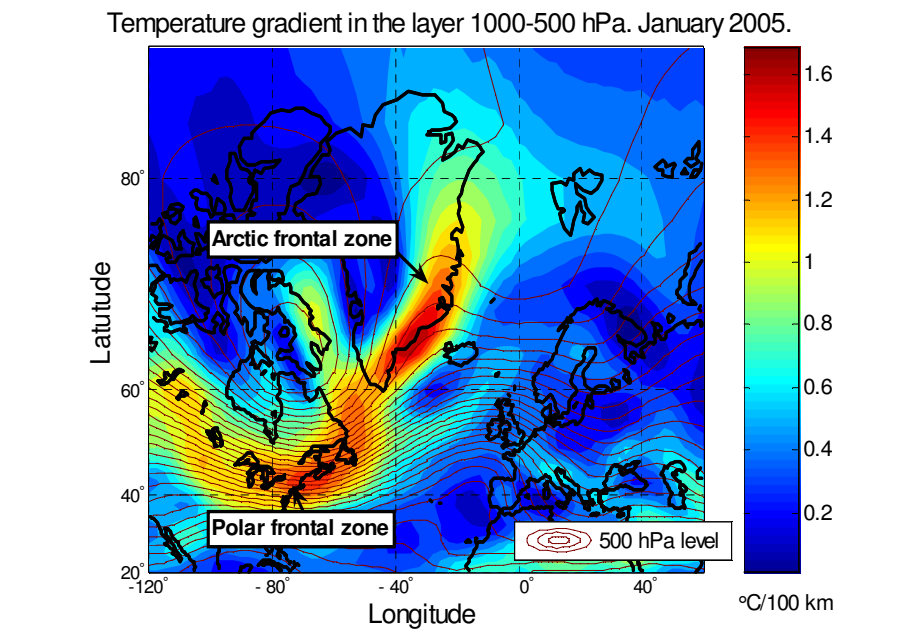


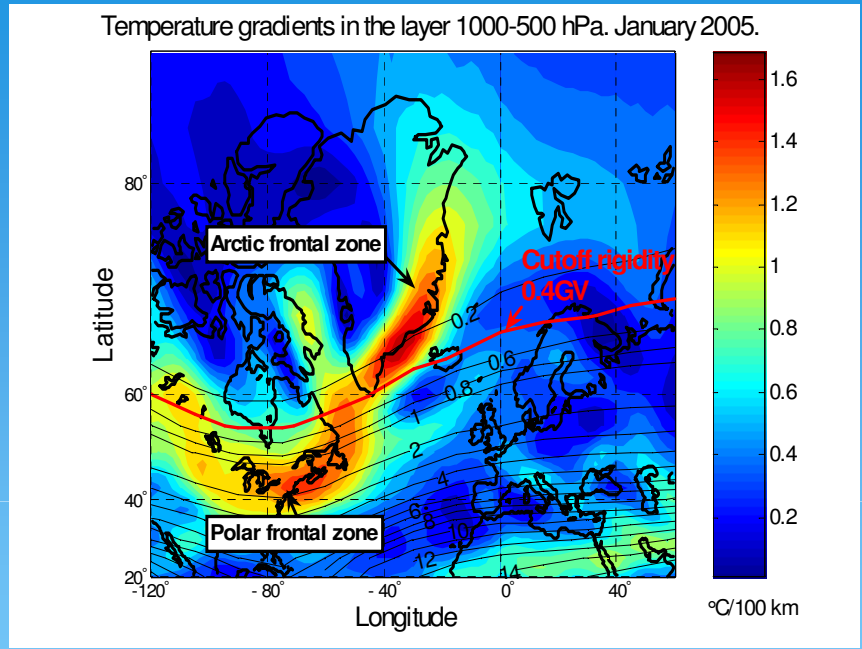
GPH500 variations on the next day of SPE onsets (48 events)

Pressure variations are most pronounced in the **North Atlantic region** and turn out to be in the area of **low geomagnetic cut-off rigidities** *R* (*R* = *Pc/Ze*, where *P* and *Ze* are the particle momentum and charge, respectively, and *c* is the speed of light). In this region *R* ≤ ~2-3 GV), i.e. cosmic particles with a broad energy range may precipitate here influencing atmospheric processes.

The North Pacific is characterized by higher rigidities (*R* ~ 7-15 GV in the cyclogenetic zone near the eastern coasts of Eurasia). SPE effects are not pronounced in this region.

Peculiarities of the North Atlantic region



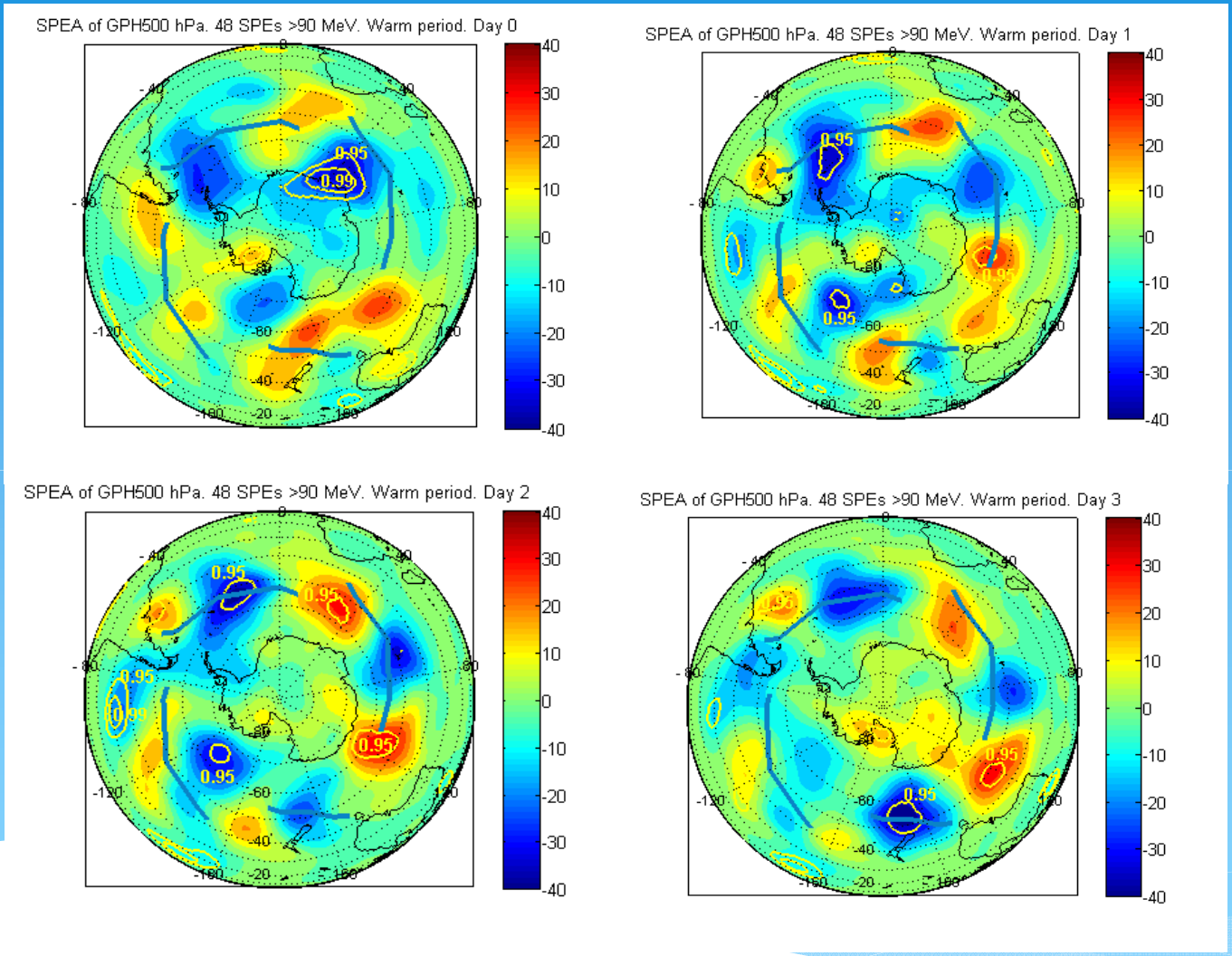


This region is characterized by **a favorable structure of the thermo-baric field** for cyclone deepening**:**

- **Divergence of isohypses** in the middle troposphere contributing to the air outflow
- **High temperature contrasts** near the Greenland coasts creating conditions for cold advection. Cold advection is known to intensify cyclonic vortices.
- **Close to the region of the Polar vortex formation.**

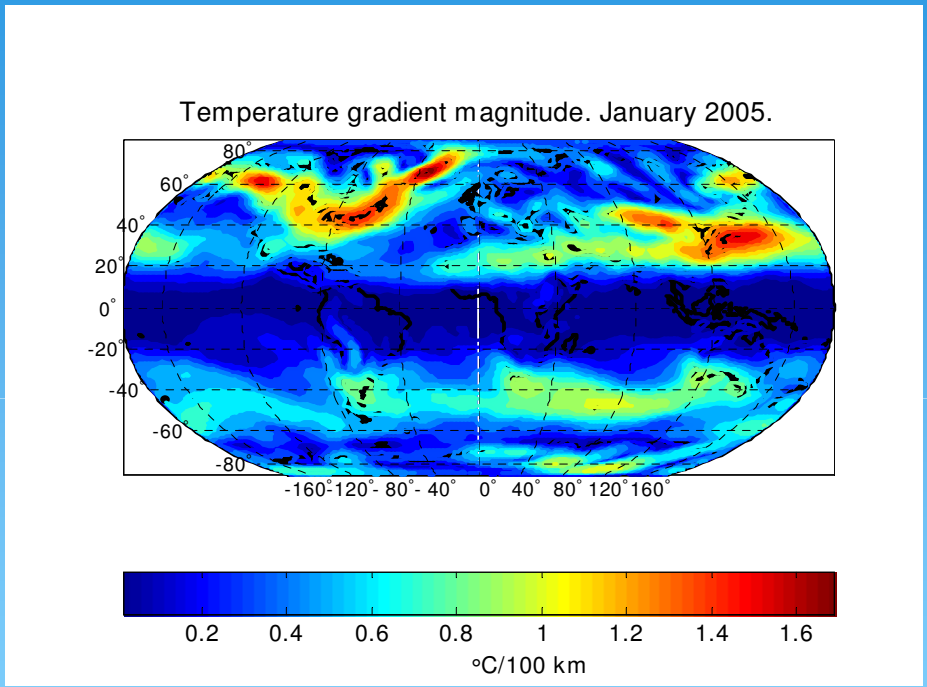
The North Atlantic region, as well as that of Polar vortex are characterized by favorable conditions for cosmic particle precipitation, with energies being ~ 90 MeV.

SPE effects on pressure in the Southern hemisphere



Pressure variations in the Southern hemisphere are twice smaller than in the Northern one. They are also closely connected with the main atmospheric fronts, Antarctic (close to the Antarctica coasts) and Polar fronts (blue lines) .

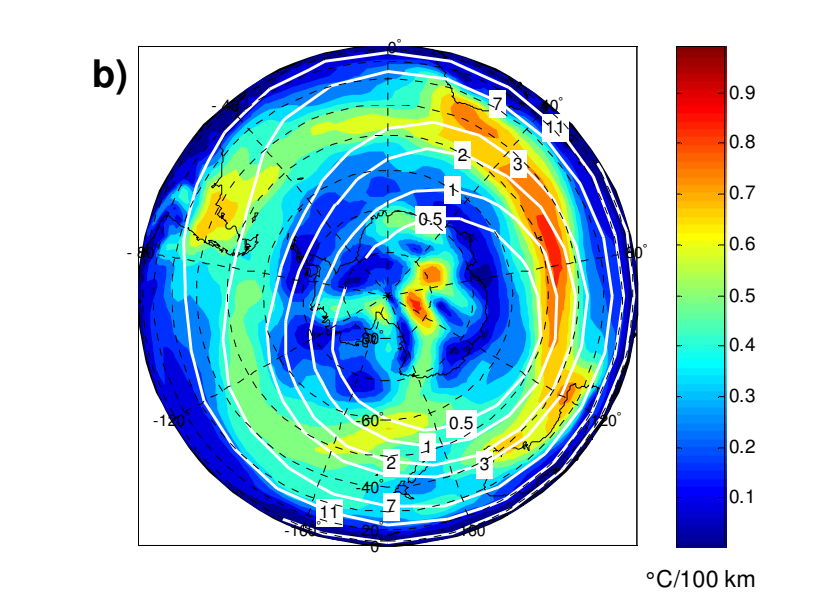
Temperature gradient distribution (cold period for the Northern hemisphere)

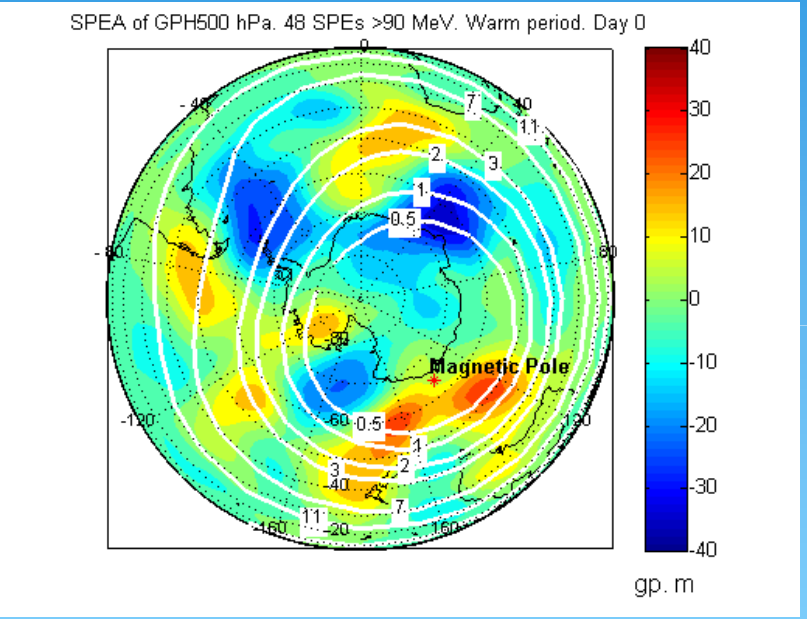


In the Northern hemisphere temperature gradients are enhanced during October-March period. This creates favorable conditions for SPE effects on the extratropical cyclone development.

In the Southern hemisphere October-March is a warm period, so temperature gradients are decreased and SPE effects are less pronounced.

Pressure variations associated with SPEs and geomagnetic cutoff rigidities in the Southern hemisphere





Similarly to the Northern hemisphere, SPE effects on the cyclone development in the Southern hemisphere are most pronounced in the area of Antarctic Polar Vortex which is in the area of low geomagnetic cutoff rigidities.

On a possible mechanism

The study show statistically significant changes in extratropical baric system development associated with SPEs having energies >90 MeV. Intensification of cyclonic activity provides evidence for the increase of temperature contrasts in the troposphere.

Problems:

- Particles with energies ~100 MeV can not penetrate down to the troposphere heights in order to influence directly cyclonic processes
- The energy of SPEs entering the stratosphere can not be comparable with the energy of the average extratropical cyclone (~10^{25} ergs/day)

Possible answers:

- Particles with energies ~100 MeV reach the heights of the Polar vortex. As the SPE effects on cyclonic activity are most pronounced at the edges of the area of its formation, this may indicate a participation of the vortex in the cyclone intensification.
- Energy supplies in the atmosphere itself are quite enough (~$8\text{-}9 \cdot 10^{28}$ ergs for kinetic energy of all the atmosphere)

So, the mechanism of SPE impact on extratropical baric systems seems to involve changes in the polar vortex and corresponding changes in the stratosphere-troposphere coupling resulting in temperature gradient enhancement in the troposphere.

Conclusions

- SPEs with energies enough to penetrate the stratosphere heights (>90 MeV) may intensify cyclonic activity at middle latitudes both in the Northern and Southern hemispheres
- Changes of baric systems on the days following the SPEs are observed in the regions of climatic atmospheric fronts (Polar and Arctic/Antarctic) characterized by enhanced temperature gradients. Most significant effects are observed close to the regions of polar vortex formation in both hemispheres .
- The effects of SPEs occurring in October-Mach are most pronounced in the Northern hemisphere compared with the Southern one due to a seasonal increase of temperature gradients
- Most significant cyclone intensification due to energetic SPEs takes place in the regions with favourable conditions, i.e. characterized by high temperature contrasts contributing to cold advection and low geomagnetic cut-off rigidities contributing to precipitation of particles with energies ~several hundred MeV. In the Northern hemisphere it is the North Atlantic region near the Greenland coasts.
- The results obtained suggest an important contribution of cosmic ray variations in the mechanism of solar activity influence on the lower atmosphere circulation