SOME ASPECTS of COSMIC RAY MODULATION

Yuri Stozhkov

**P.N. Lebedev Physical Institute of the Russian Academy of Sciences,
Leninsky Prospect 53, 119991 Moscow, Russia
stozhkov@fian.fiandns.mipt.ru**

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Outline

Introduction

1. Long-term CR modulation and its peculiarities in present.
2. CRs in the outer heliosphere and where CR modulation is over?
3. Unusual behavior of solar activity in the beginning of the 21-st century.
4. Some information on the climate and what we expect in the nearest future?

Conclusion

Introduction

The data on galactic cosmic ray (CR) fluxes measured in the Earth's atmosphere at polar (northern and southern) and middle latitudes during the period of about 50 years are presented.

These data show long-term modulation processes in the several 11-year solar activity cycles. Minimum and maximum periods of cosmic rays at 1 a.u. are discussed and comparison with the data obtained at the spacecraft of Voyager – 1 and Voyager – 2 in the outer heliosphere is made.

The analysis of solar activity in the previous solar cycles gives the proof that the 24th solar cycle will be very low. It is possible that we meet new grand solar activity minimum, like Maunder one in 1645-1715.

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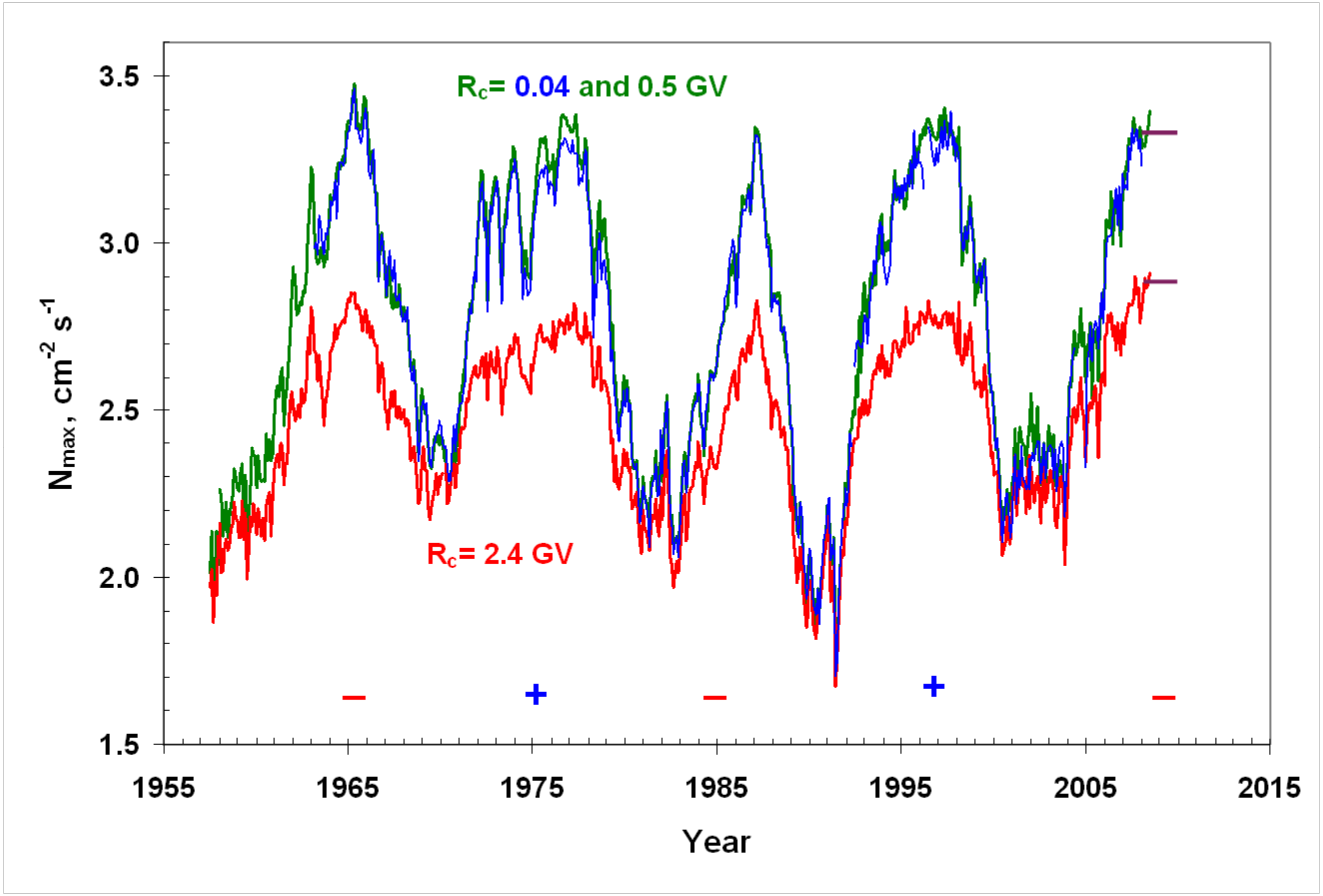
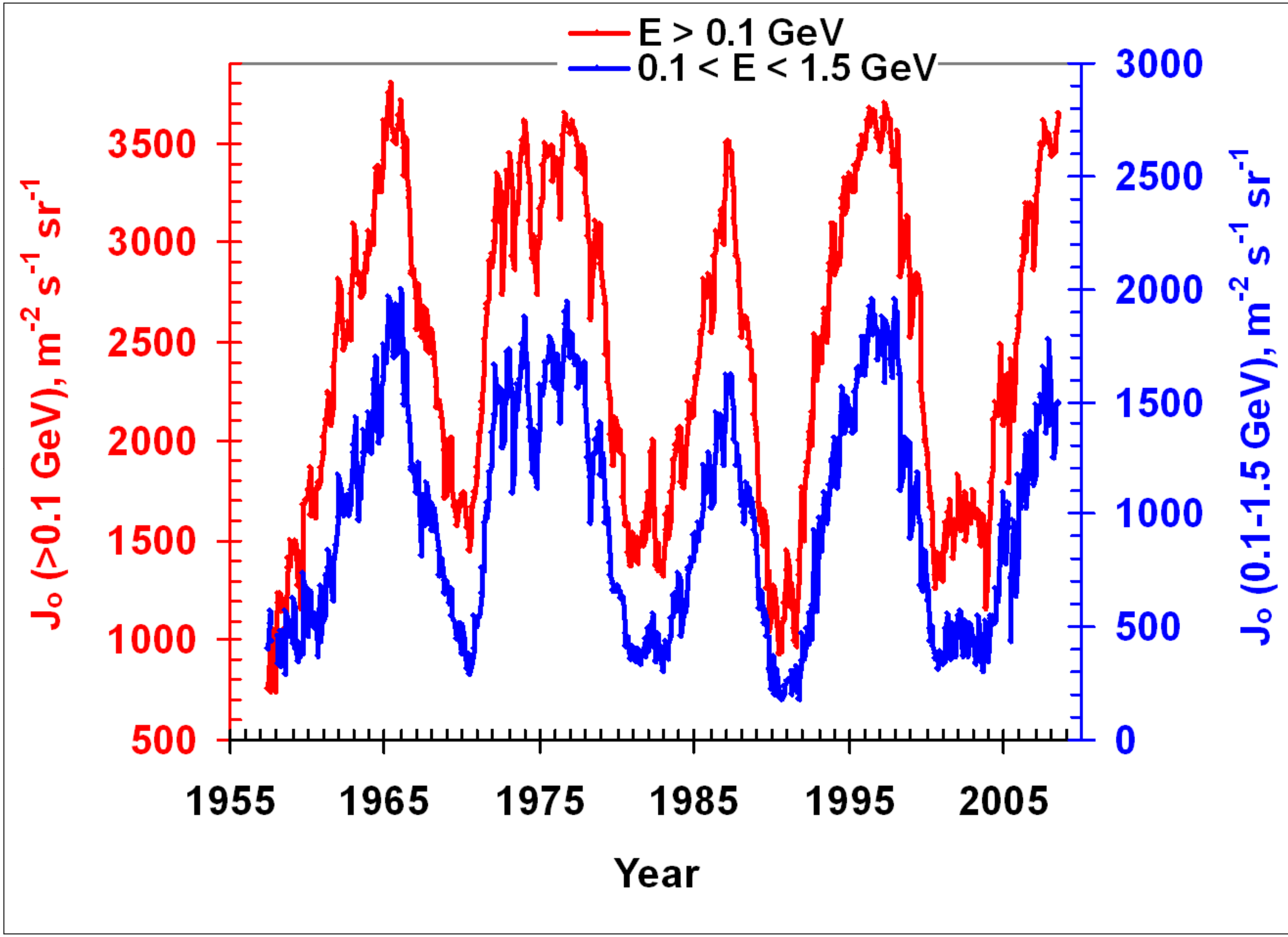
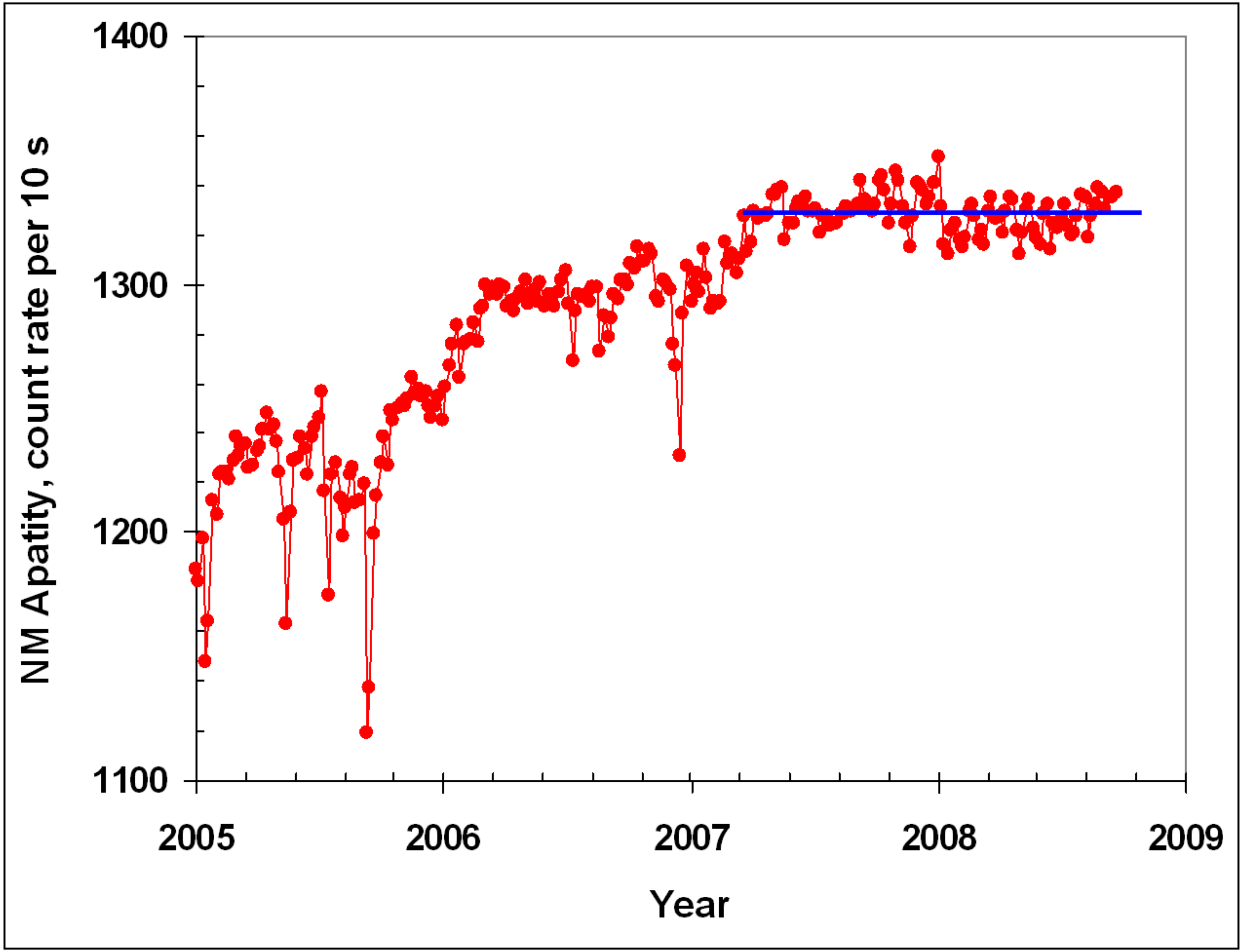


Time dependence of CR flux at the maximum of absorption curve in the atmosphere N_{max} (monthly averages) obtained at the northern polar latitude (R_c = 0.5 GV, green curve), southern polar latitude (Mirny station, Antarctic, R_c = 0.04 GV, blue curve), and at middle northern latitude (R_c = 2.4 GV, red curve). Brown horizontal bar is expected CR flux. The signs (+, -) denote the phase of polar solar magnetic field in the northern hemisphere.



Time dependence of the flux of primary cosmic particles falling on the top of the atmosphere J_o (monthly averages) obtained from the measurements of charged particles in the atmosphere.



Count rate of NM Apatity (R_c = 0.6 GV, 5 day averages). Blue horizontal bar shows constant cosmic ray flux (E.V. Vashenyuk data).

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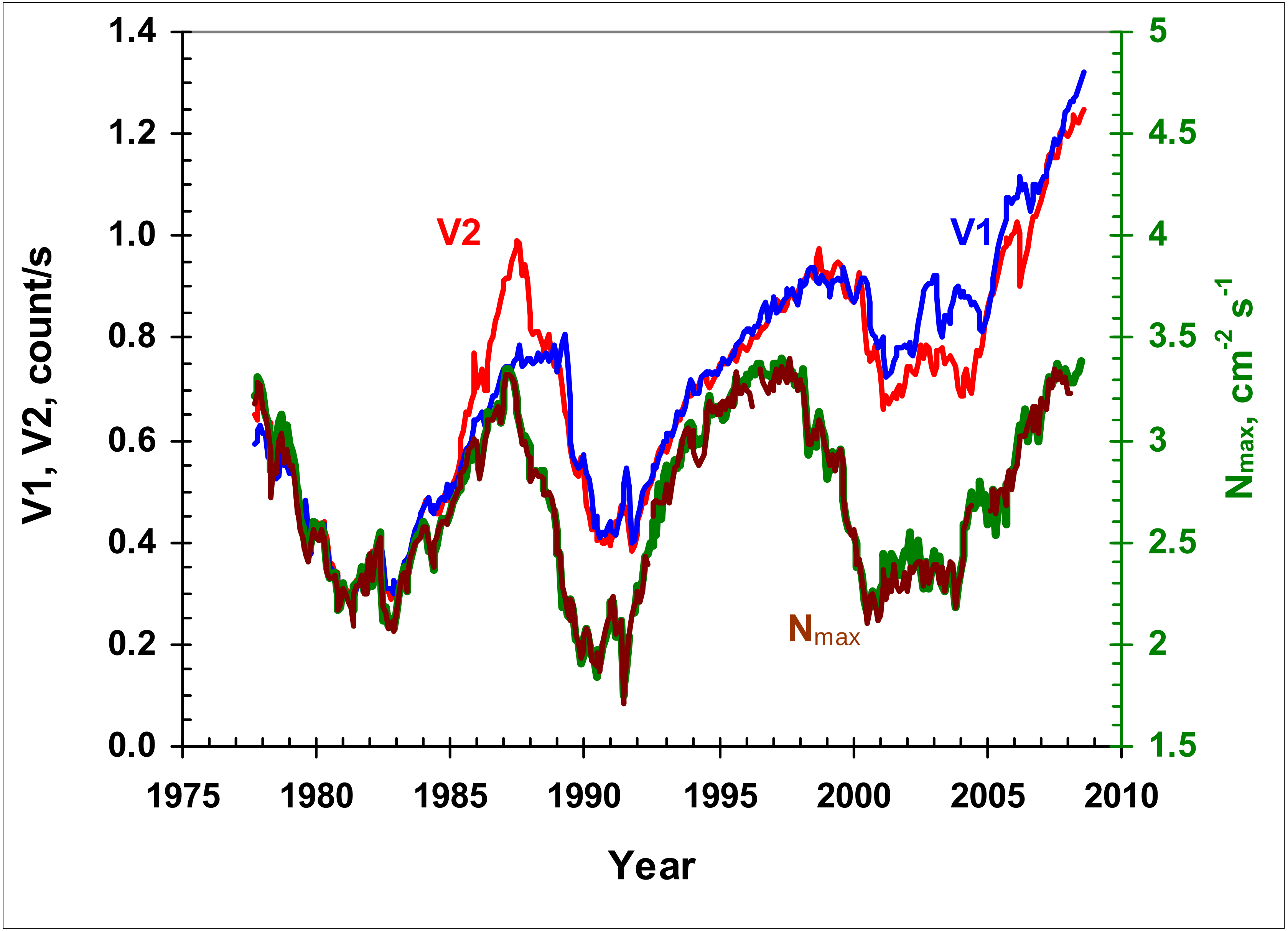
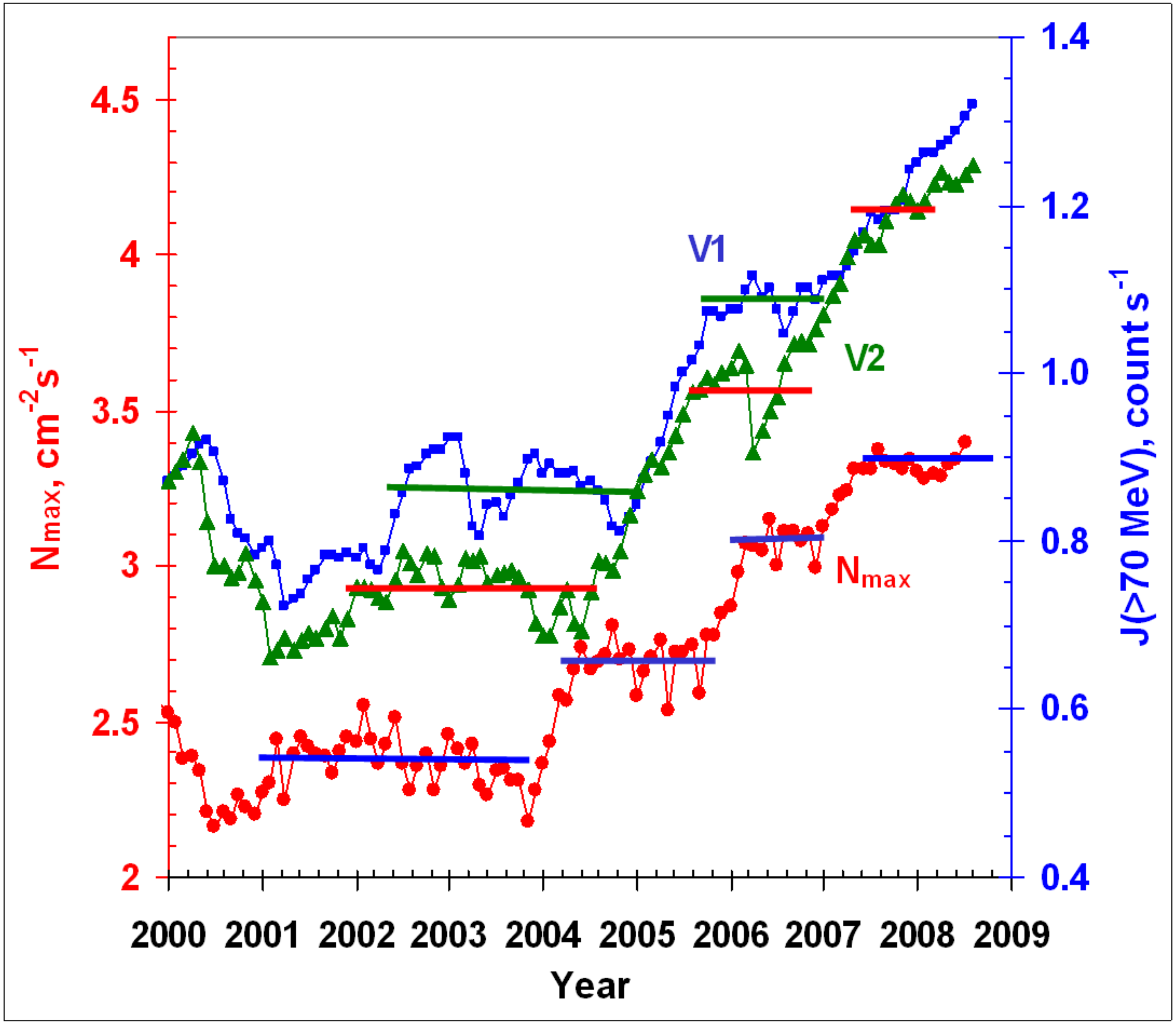
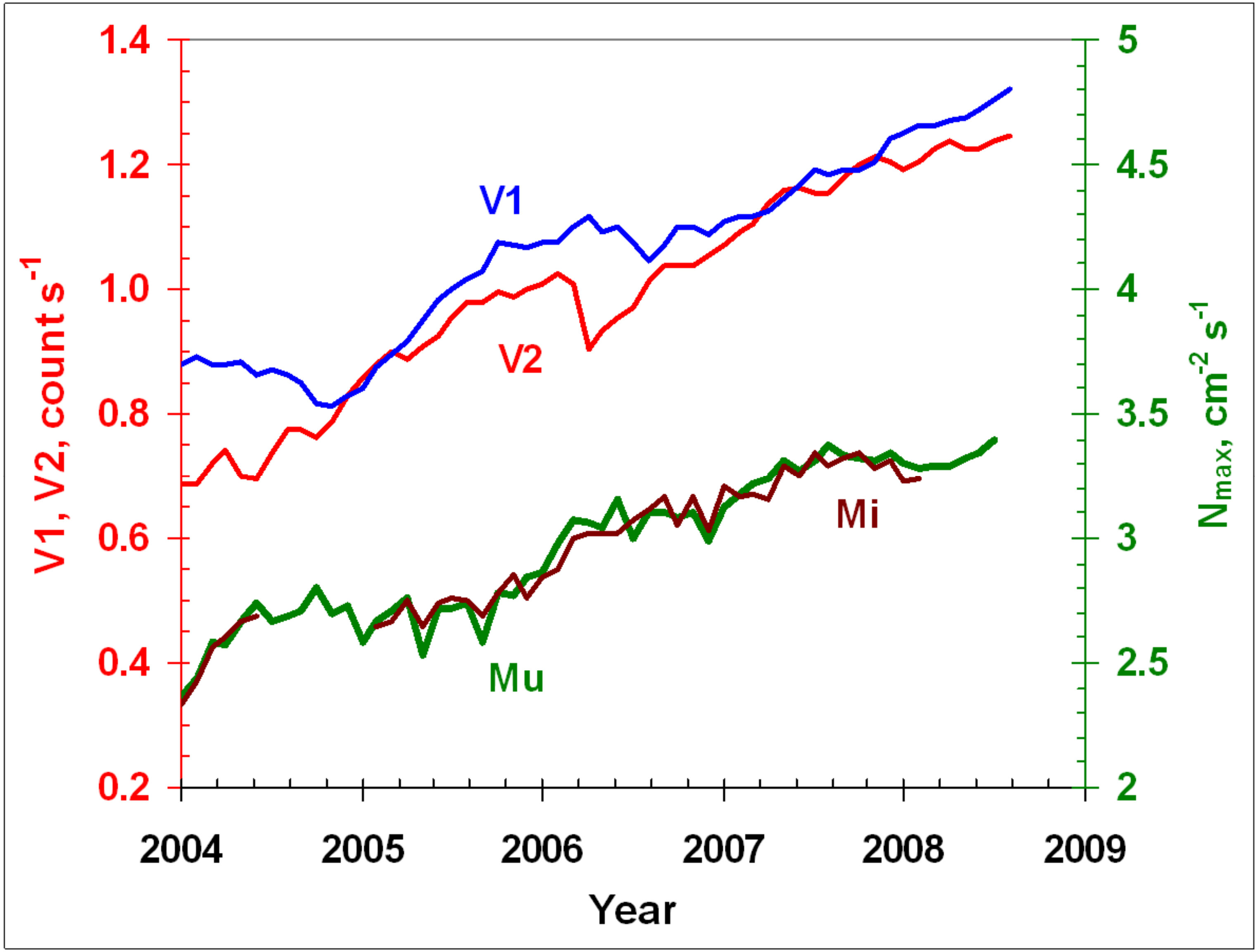


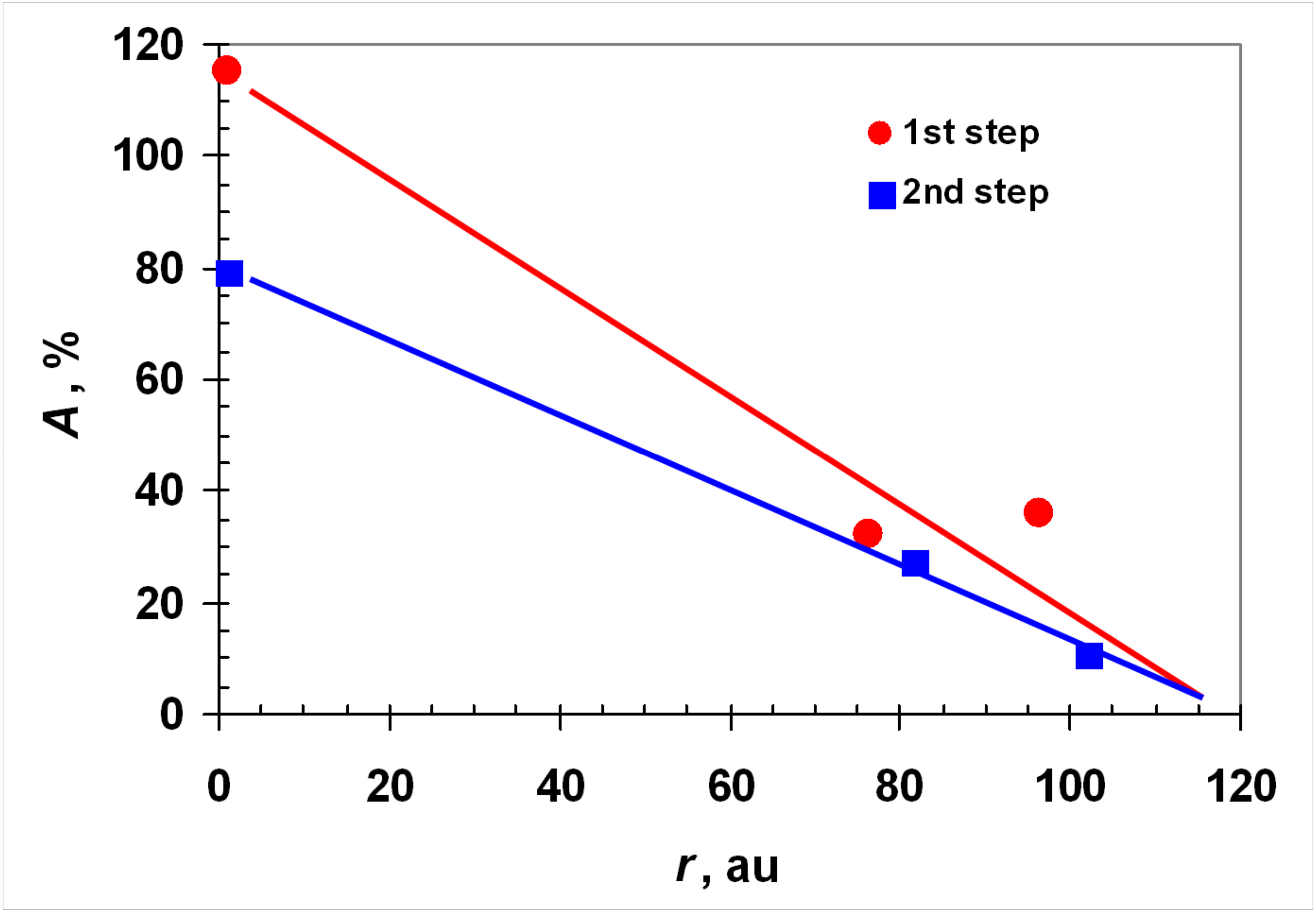
Time dependences of CR fluxes, obtained in our experiment in northern and southern polar regions at 1 a.u. and in the heliosphere from 1 a.u. up to ~ 107 a.u. (V1 and V2 data, E_p > 70 MeV)).



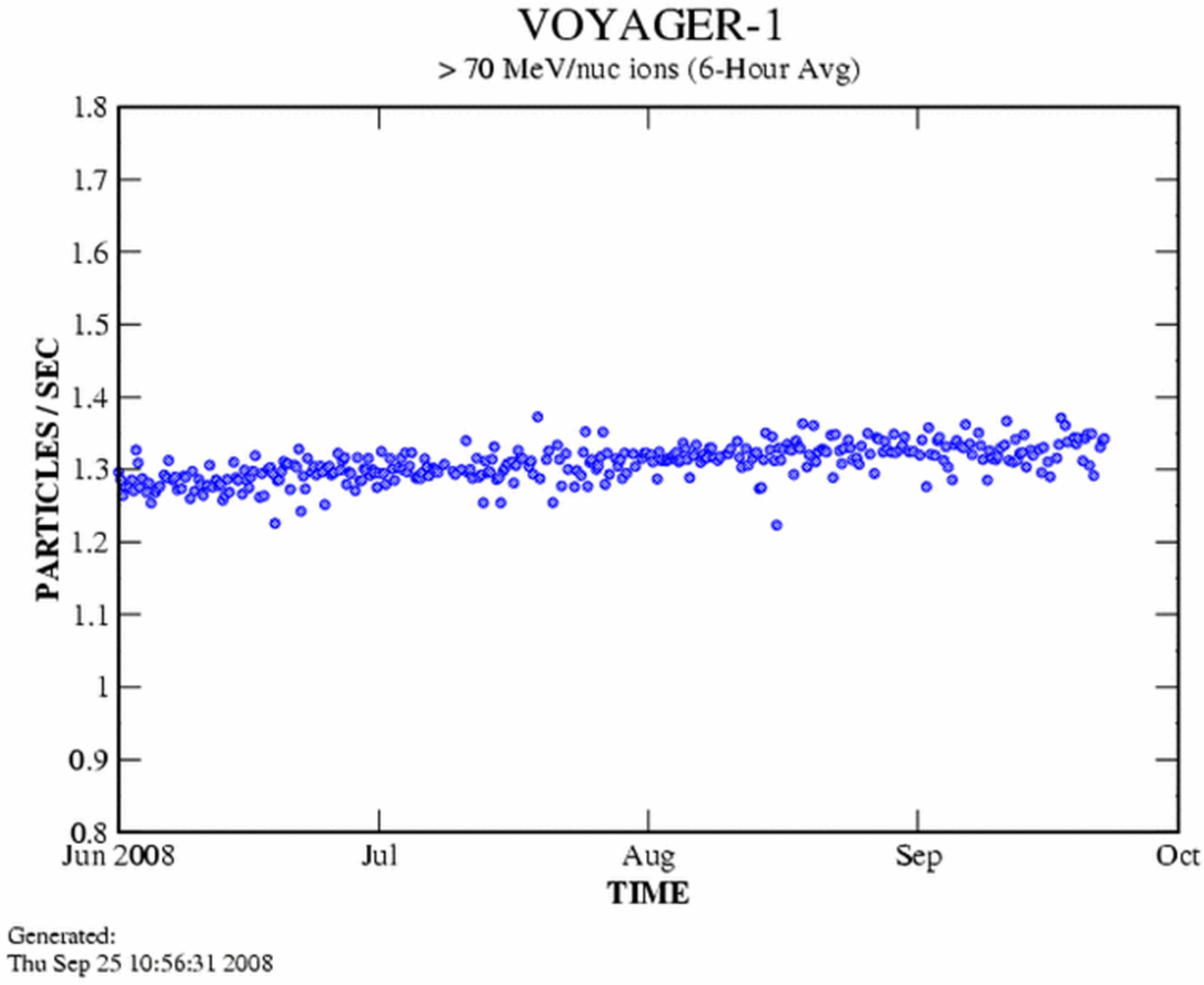
Step-like changes of CR fluxes near the Earth (red points) and in the outer heliosphere (green triangles and blue squares). Horizontal bars show the periods when CR fluxes were almost constant in time.



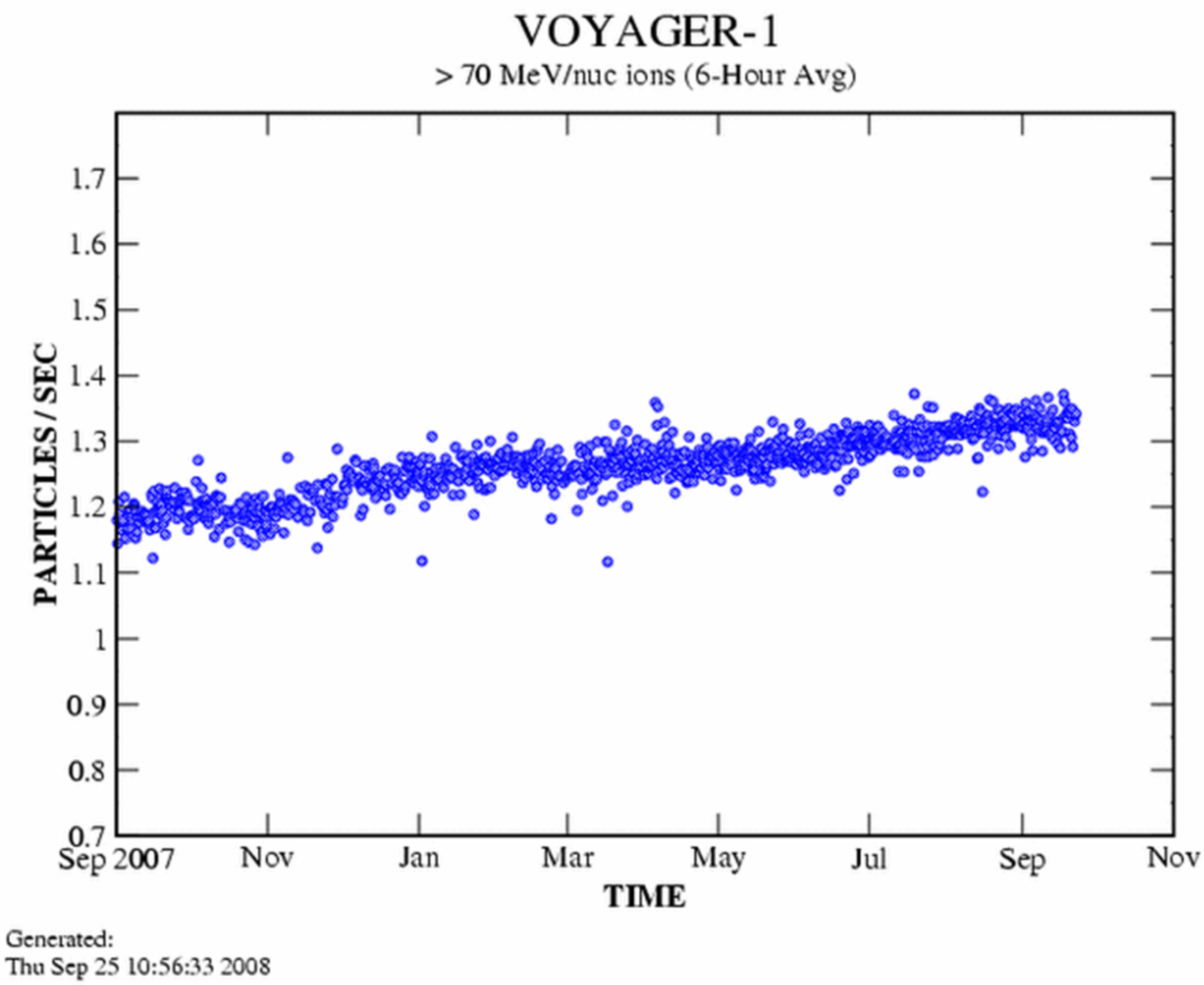
Time dependences of CR fluxes observed in the atmosphere and outer heliosphere in recent time in detail.



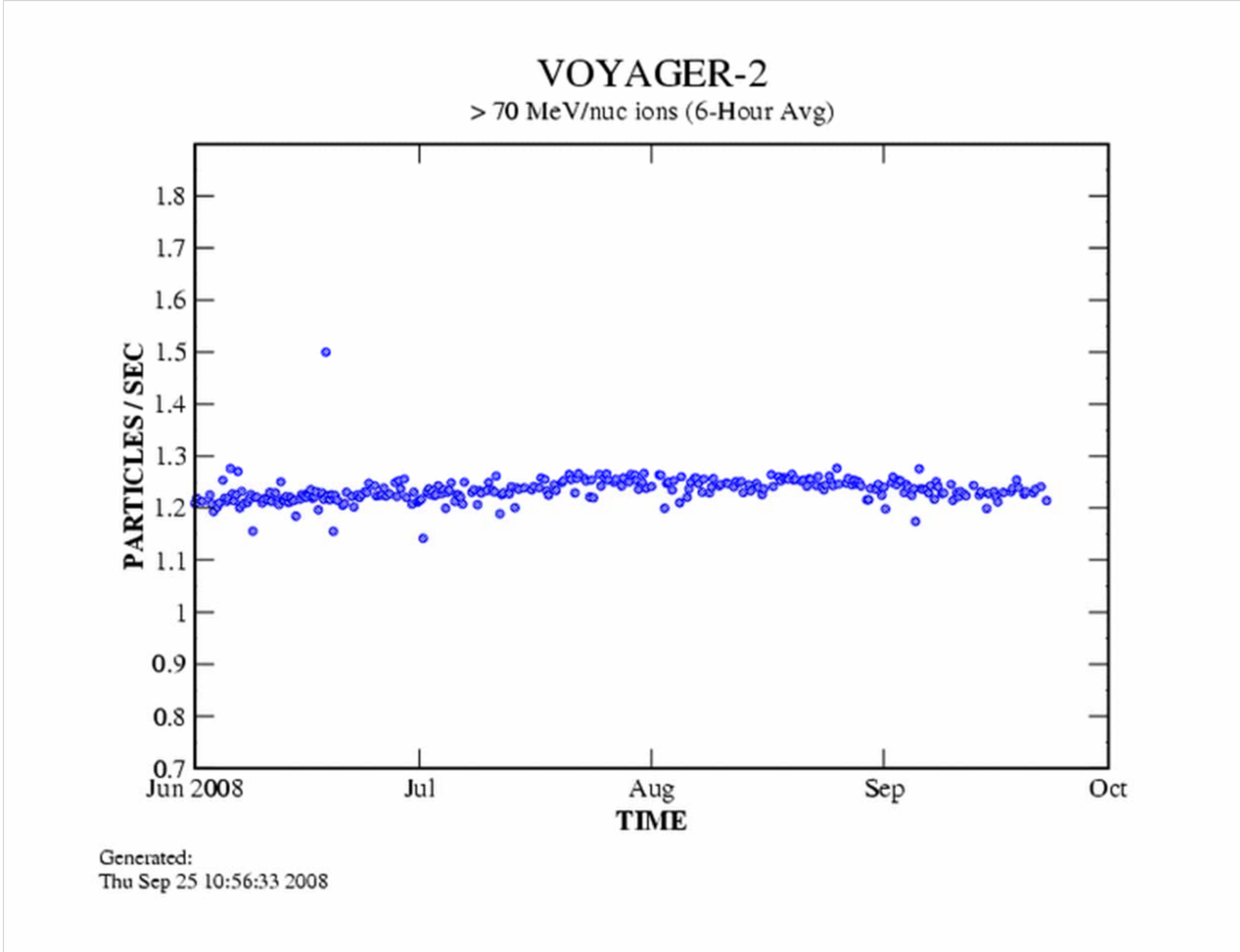
The amplitudes of step-like changes at 1 a.u. and in the outer heliosphere.



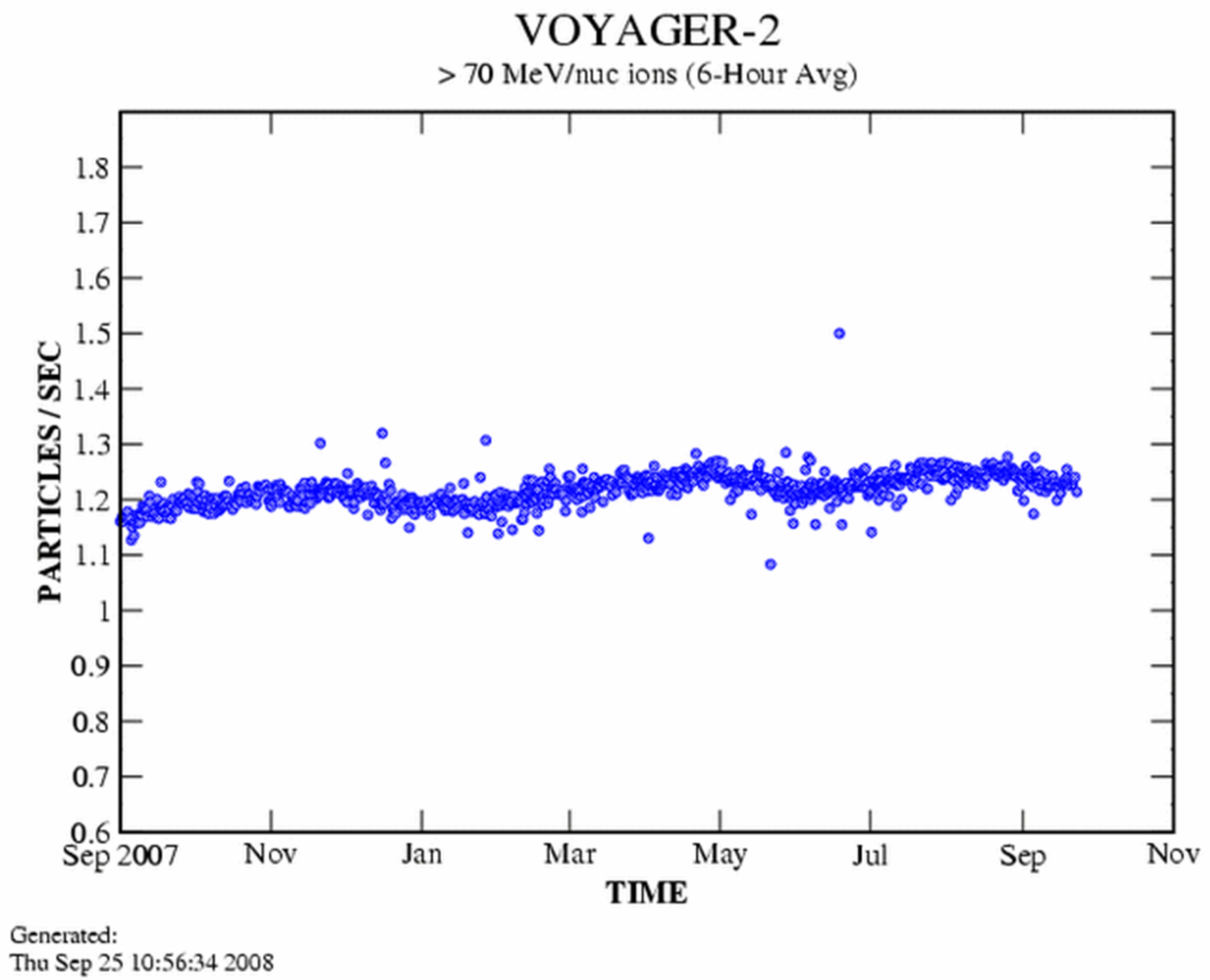
Cosmic ray flux (particles with E > 70 MeV/n) measured with V1 spacecraft at *r* ≈ 107 a.u. and λ ≈ 34^{o} N (http://voyager.gsfc.nasa.gov/cgi-bin/recent.pl)



Cosmic ray flux (particles with E > 70 MeV/n) measured with V1 spacecraft at $r \approx 107$ a.u. and $\lambda \approx 34^o$ N (http://voyager.gsfc.nasa.gov/cgi-bin/recent.pl)



Cosmic ray flux (particles with E > 70 MeV/n) measured with V2 spacecraft at $r \approx 87$ a.u. and $\lambda \approx 28^{o}$ S (http://voyager.gsfc.nasa.gov/cgi-bin/recent.pl)



Cosmic ray flux (particles with E > 70 MeV/n) measured with V2 spacecraft at *r* ≈ 87 a.u. and λ ≈ 28º S (http://voyager.gsfc.nasa.gov/cgi-bin/recent.pl)

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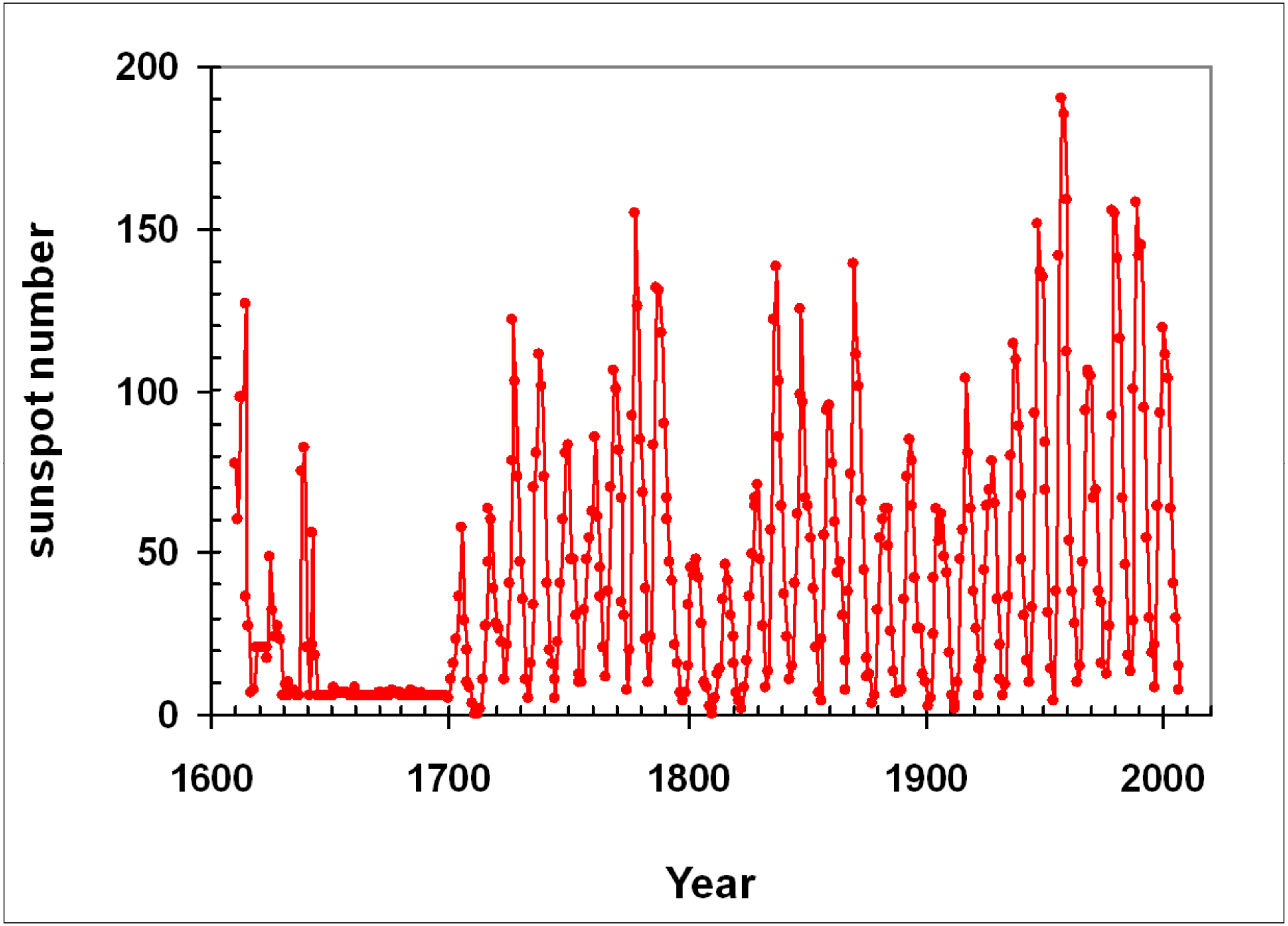
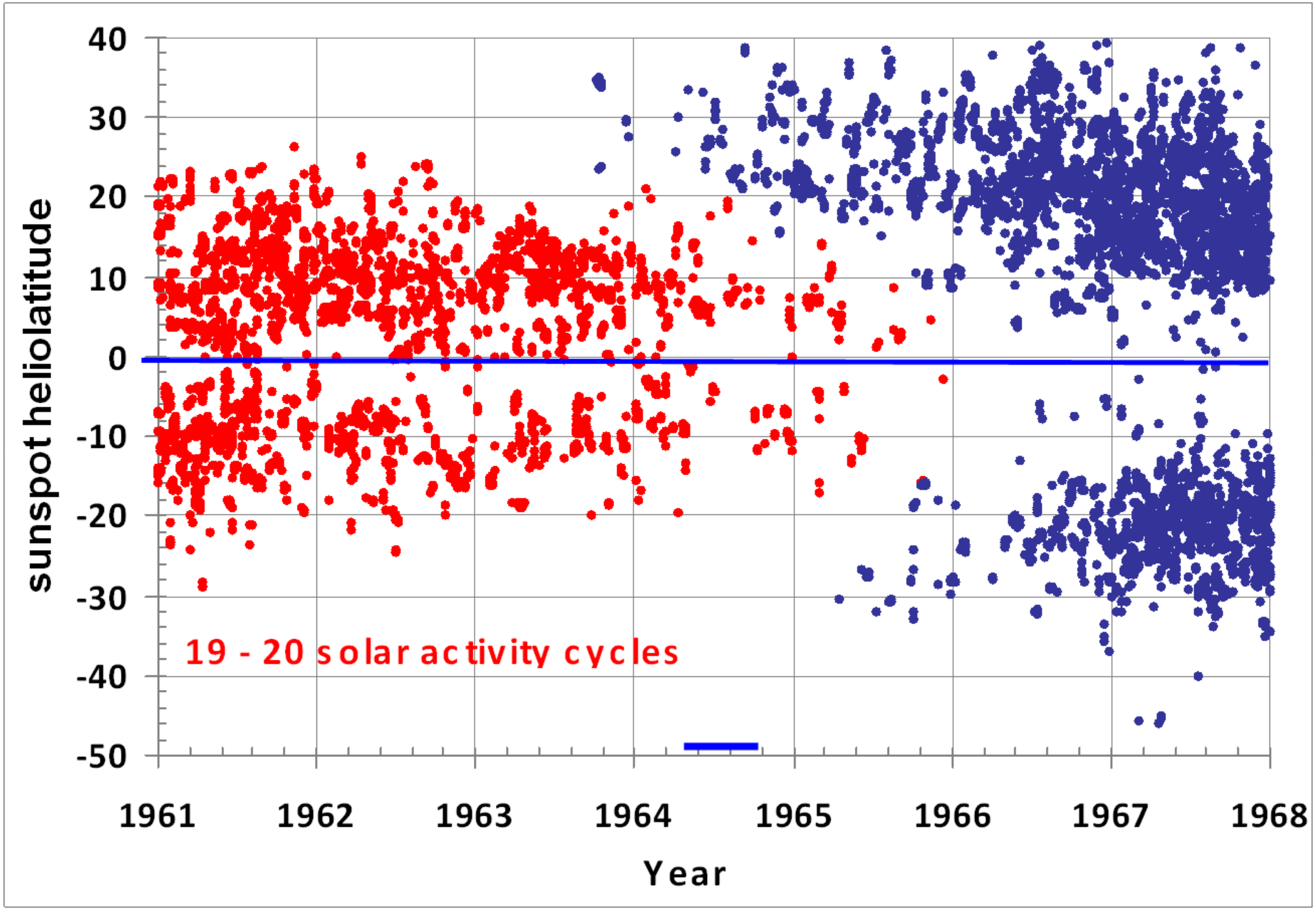
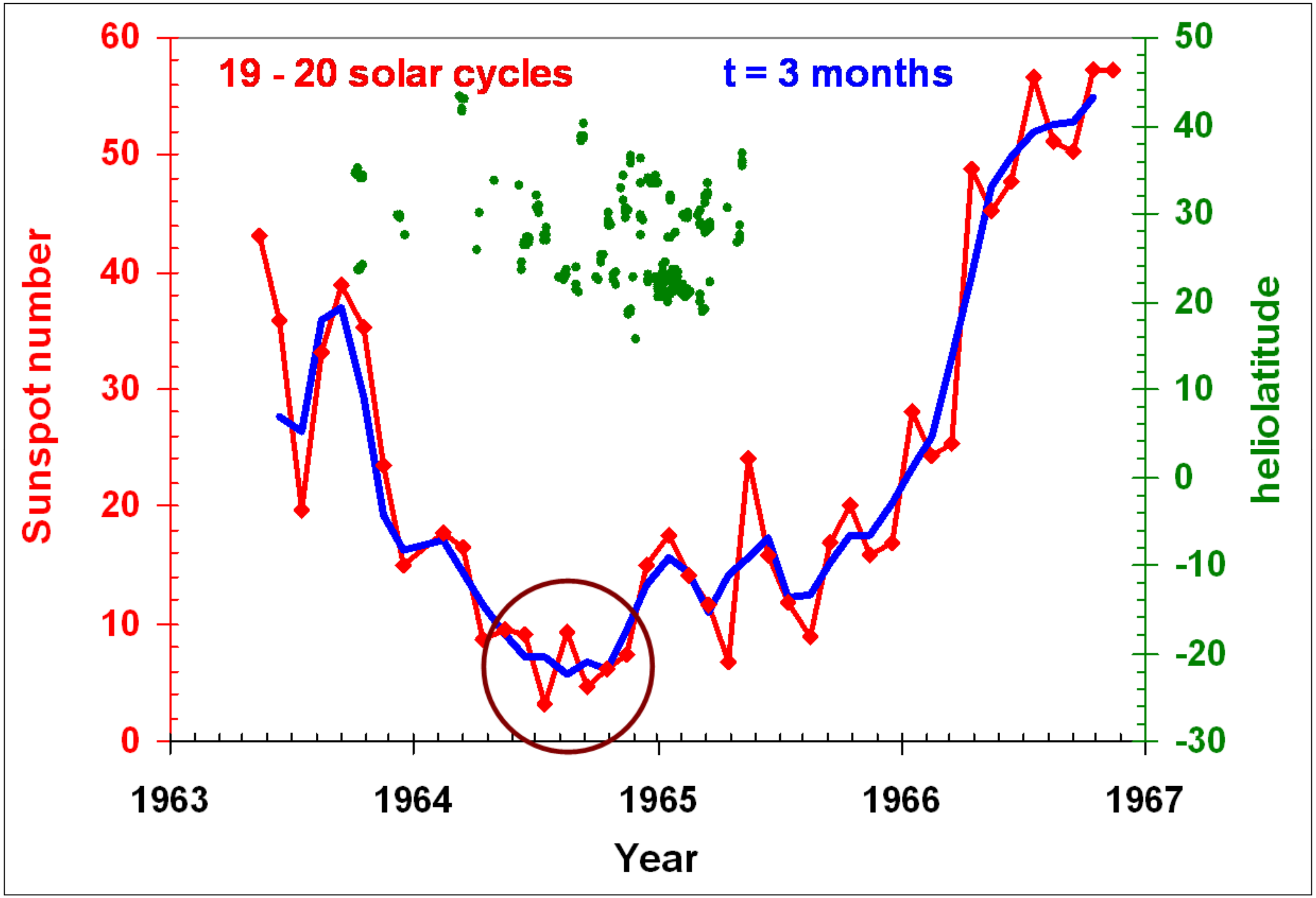


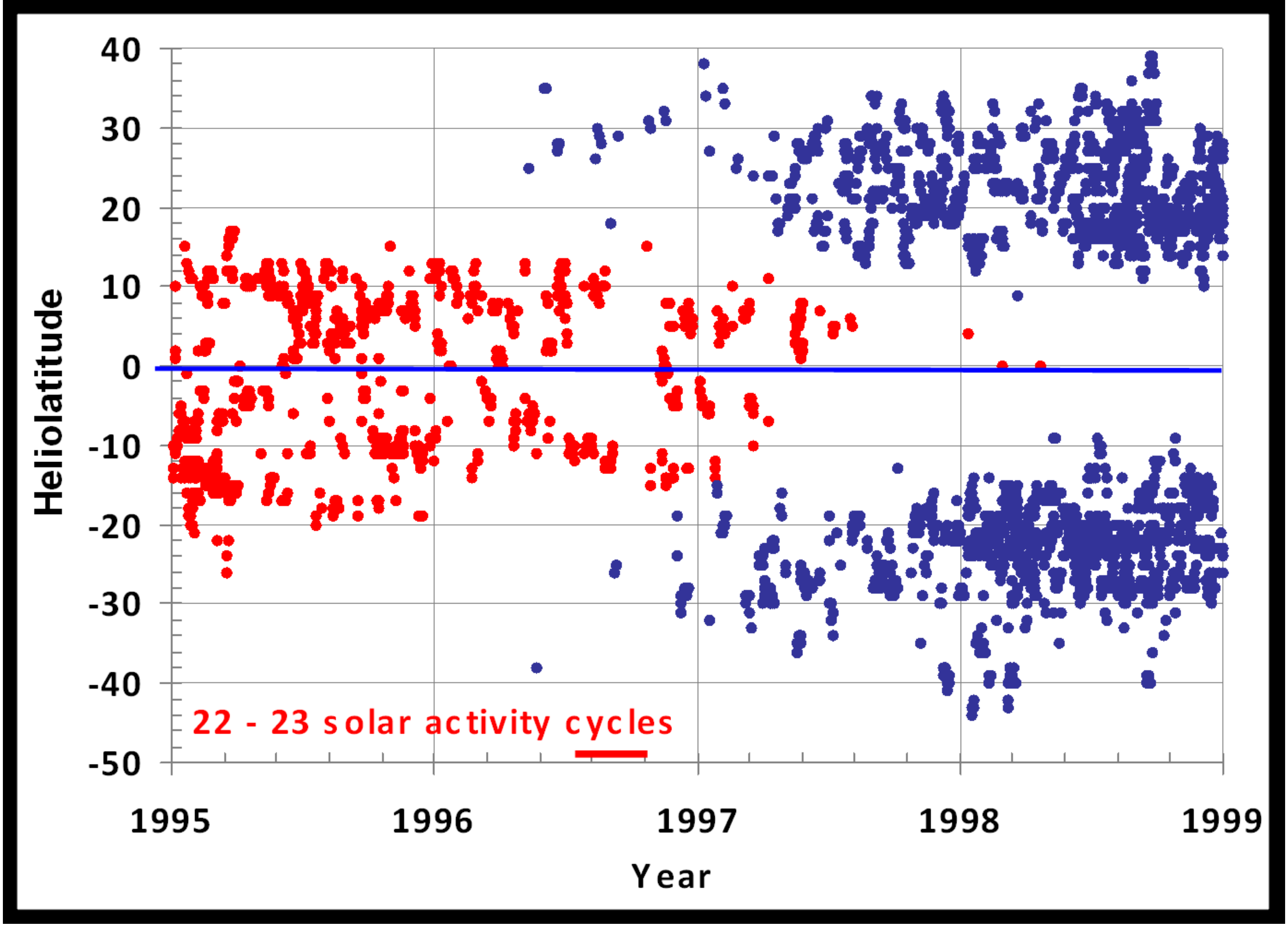
Time dependence of solar activity (Douglas V. Vogt, Kenneth H. Shatten. Group Sunspot Number: A new Solar Activity Reconstruction, Solar Physics, 179, No. 1, pp. 189-219 (1998); http://sidc.oma.be/index.php3).



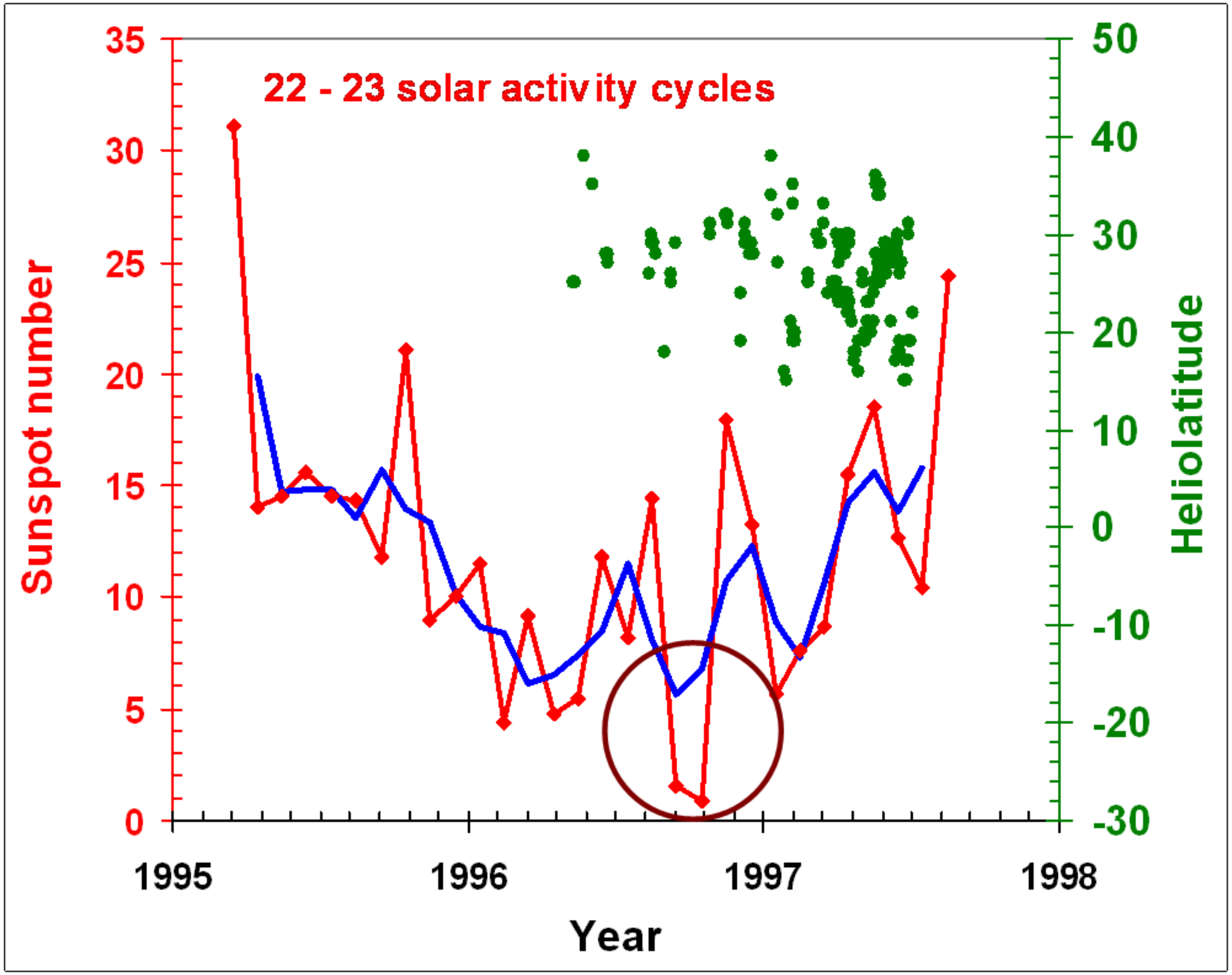
Heliolatitudinal distribution of sunspots during the end of 19th and the start of 20th solar cycles (1961 – 1967).



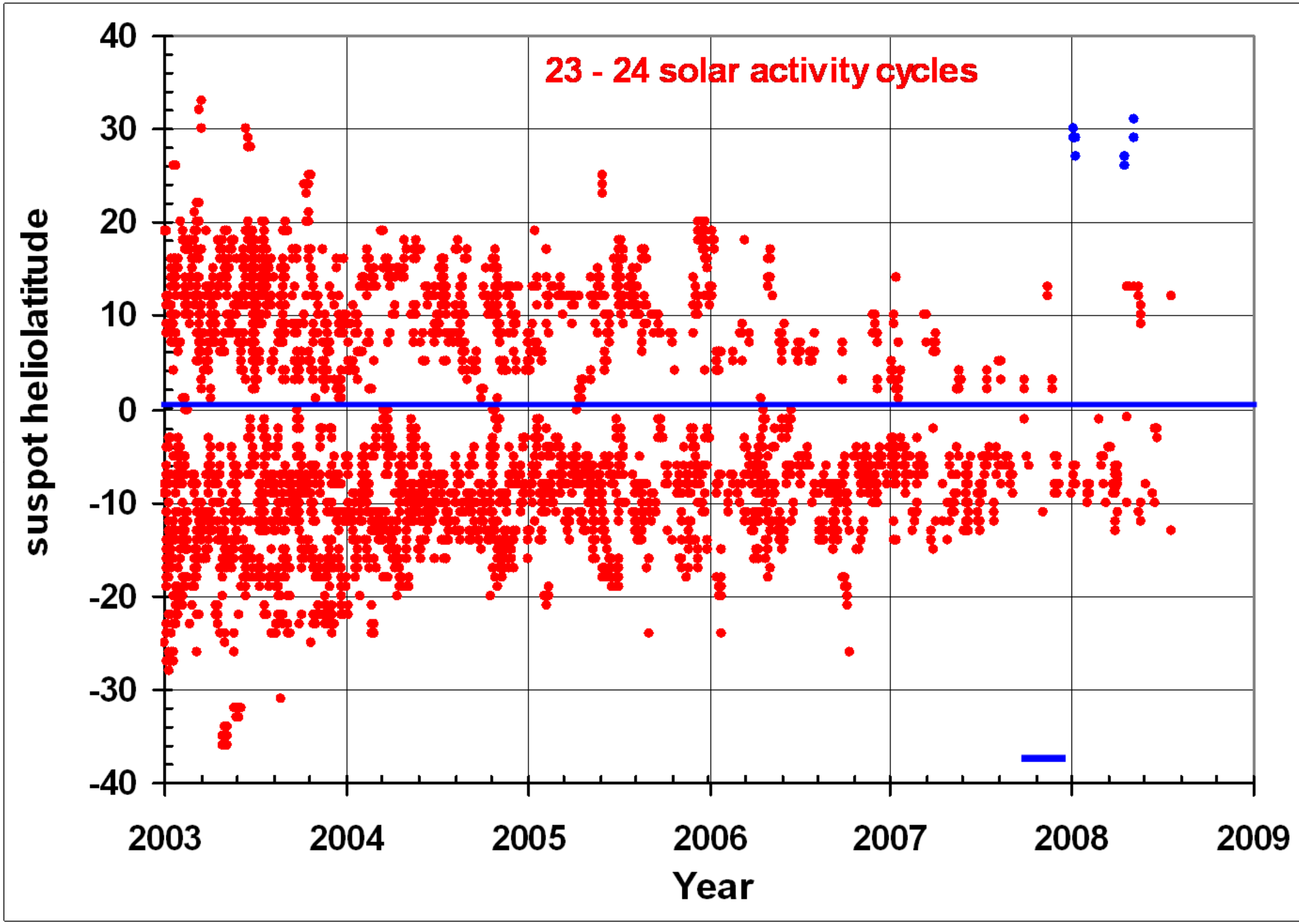
Monthly averages of sunspot numbers in 1963 -1966 (red points and curve; smoothed data with 3 months, blue curve). Heliolatitudes of the sunspots of the 20th solar cycle (green points and left vertical axes). Brown circle shows the solar activity minimum period.



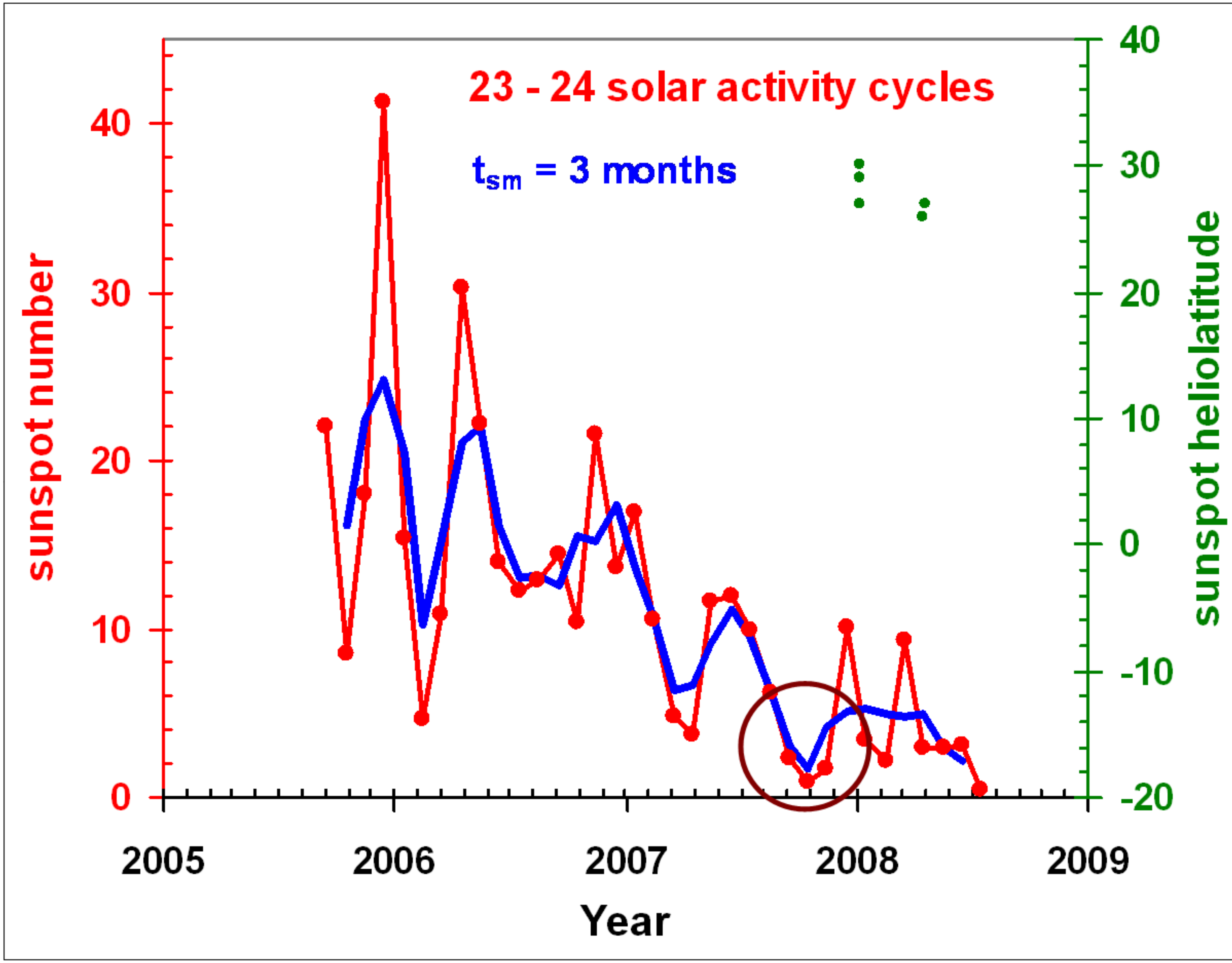
Heliolatitudinal distribution of sunspots during the end of 22nd and the start of 23rd solar cycles (1995 – 1998).



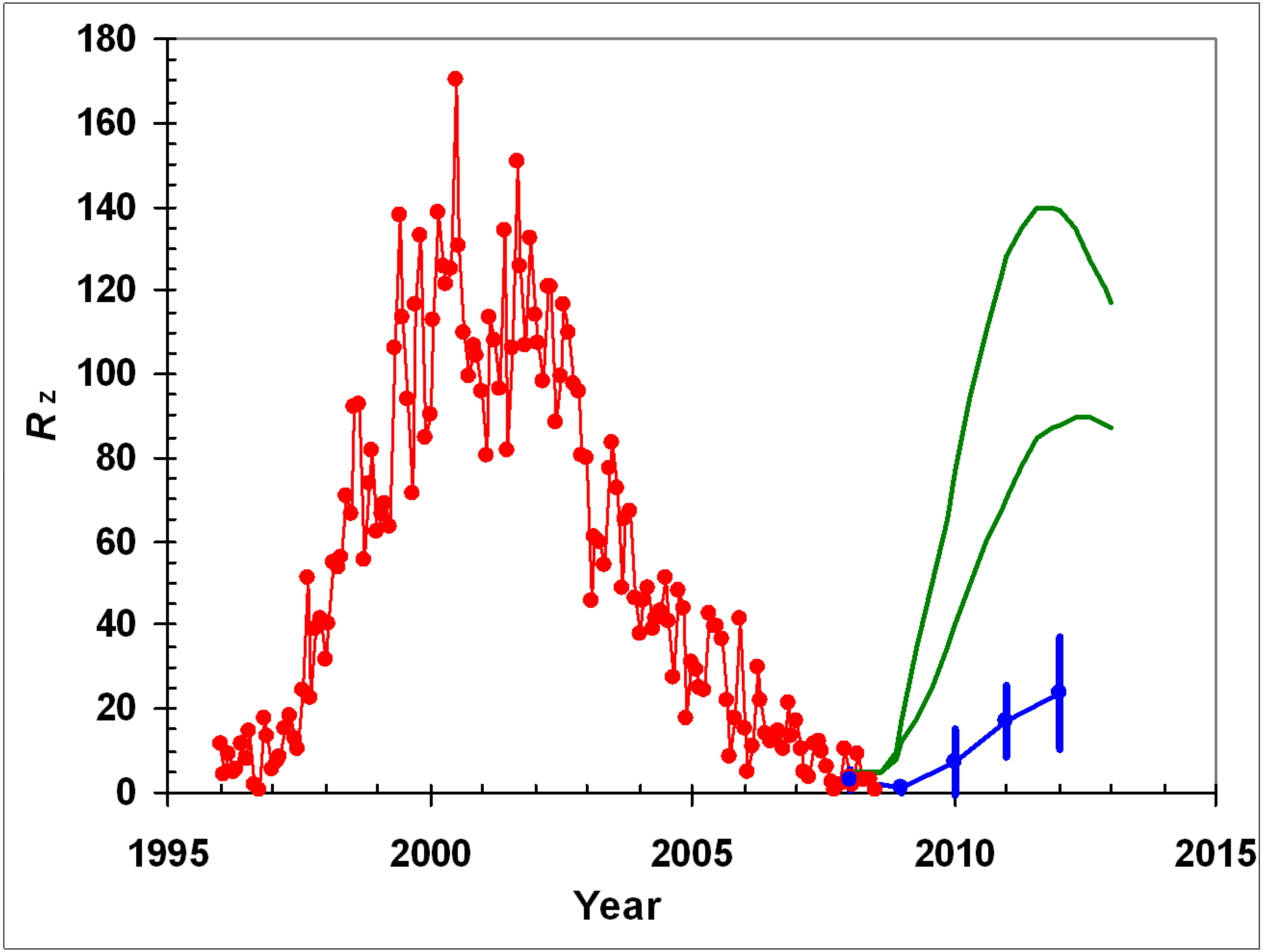
Monthly averages of sunspot numbers in 1995 -1997 (red points and curve; smoothed data with 3 months, blue curve; left vertical axes). Heliolatitudes of the sunspots of the 22nd solar cycle (green points and right vertical axes). Brown circle shows the solar activity minimum period.



Heliolatitudinal distribution of sunspots in 2003 – 2008.Blue points show the heliolatitudes of sunspots of new 24th solar cycle.



Solar activity in recent time (monthly averages, red points and curve; smoothed data with 3 points, blue curve). Heliolatitudes of sunspots of the new 24th solar activity cycle (green dots and right vertical axes).



Solar activity in 1996 – 2008 (red points), prognosis of solar activity (blue curve- this report, green curve - http://www.swpc.noaa.gov/SolarCycle/index.html).

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Conclusion

There is the influence of cosmic rays and cosmic dust on environment. Cosmic dust takes part in the cloud formation (waterdroplets of clouds grow on particles of dust). The clouds reflect part of solar irradiation back to space. Thus, the cosmic dust influences the Earth’s climate.

The observations show that the global cloud coverage was decreased to the end of 20th century but from the beginning of 21st century the increase of it is observed.

According to data of the global meteorological station network, the process of global warming that took place in the 20th century was terminated and in 21st century process of global cooling has been started.

In the mass-media the question on global warming of the Earth's climate at ~ 1°C has been widely discussed. This effect occurred in the 20th century.

As is believed, the main reason of this process is the anthropogenic influence on the atmosphere. With time this influence has to increase and the proponents of this point of view give prognosis that to the end of 21st century the global temperature *T* near the Earth's surface will increase at (1.4 – 5.8) °C. Such value of warming can give catastrophic impact on environment.

However, the climate cooling in the first half of current century is expected.

This conclusion follows immediately from the spectra analysis of the set of data on the global temperature *T* near the Earth’s surface for the period of 1880 – present time.

Let us discuss the question on climate changes in the nearest future.

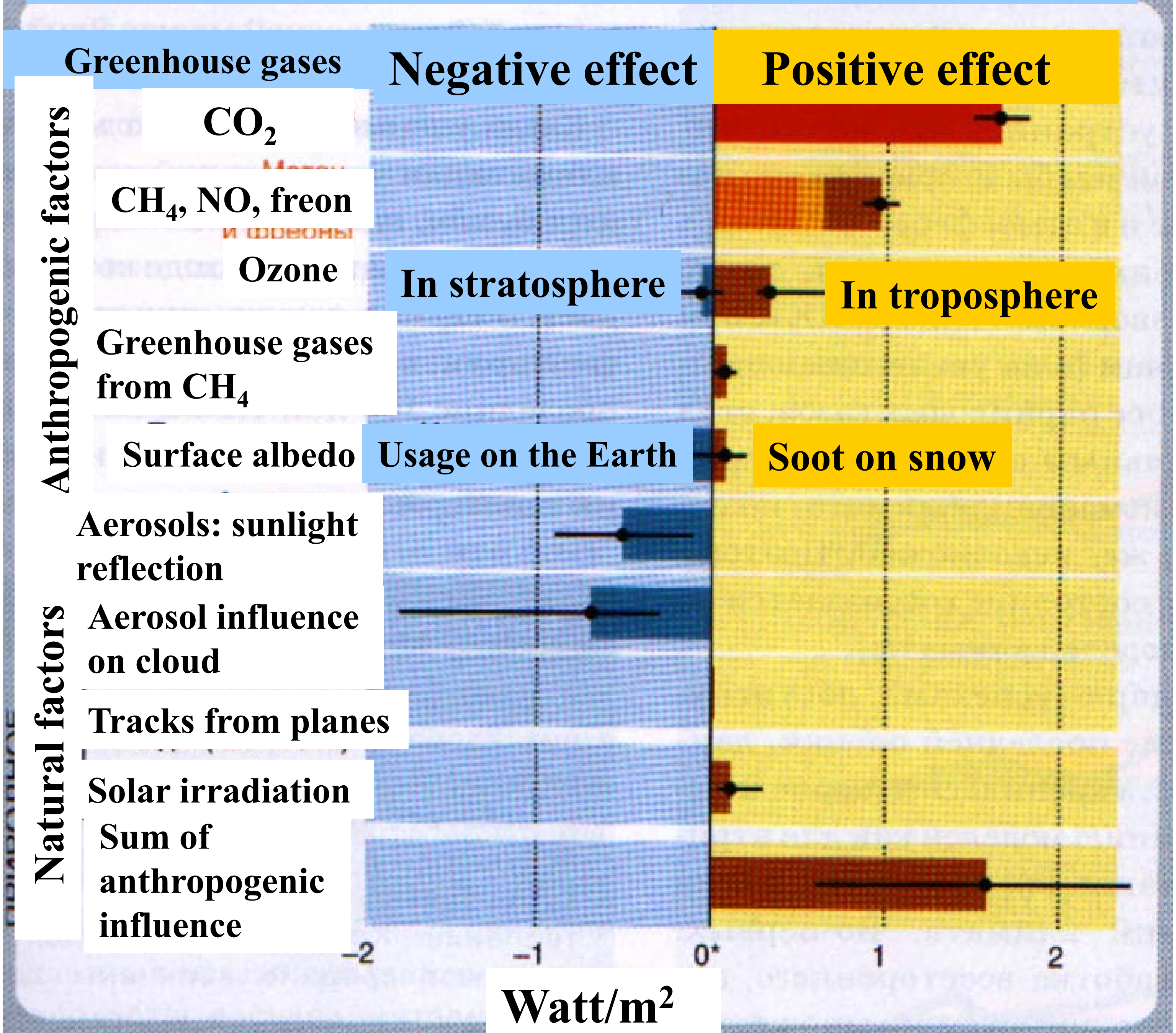
What occurs during the recent years – climate warming or cooling and what is the cause of this process?

Anthropogenic influence on climate

Anthropogenic activity produces greenhouse gases (CO_2, CH_4 , etc.). The increase of the concentrations of these gases in the atmosphere leads to the climate warming. The calculations show that for the last 100 years the thermal flux entering from the atmosphere to the Earth's surface increased at 1.6 W m^{-2}. It was due to the anthropogenic activity only.

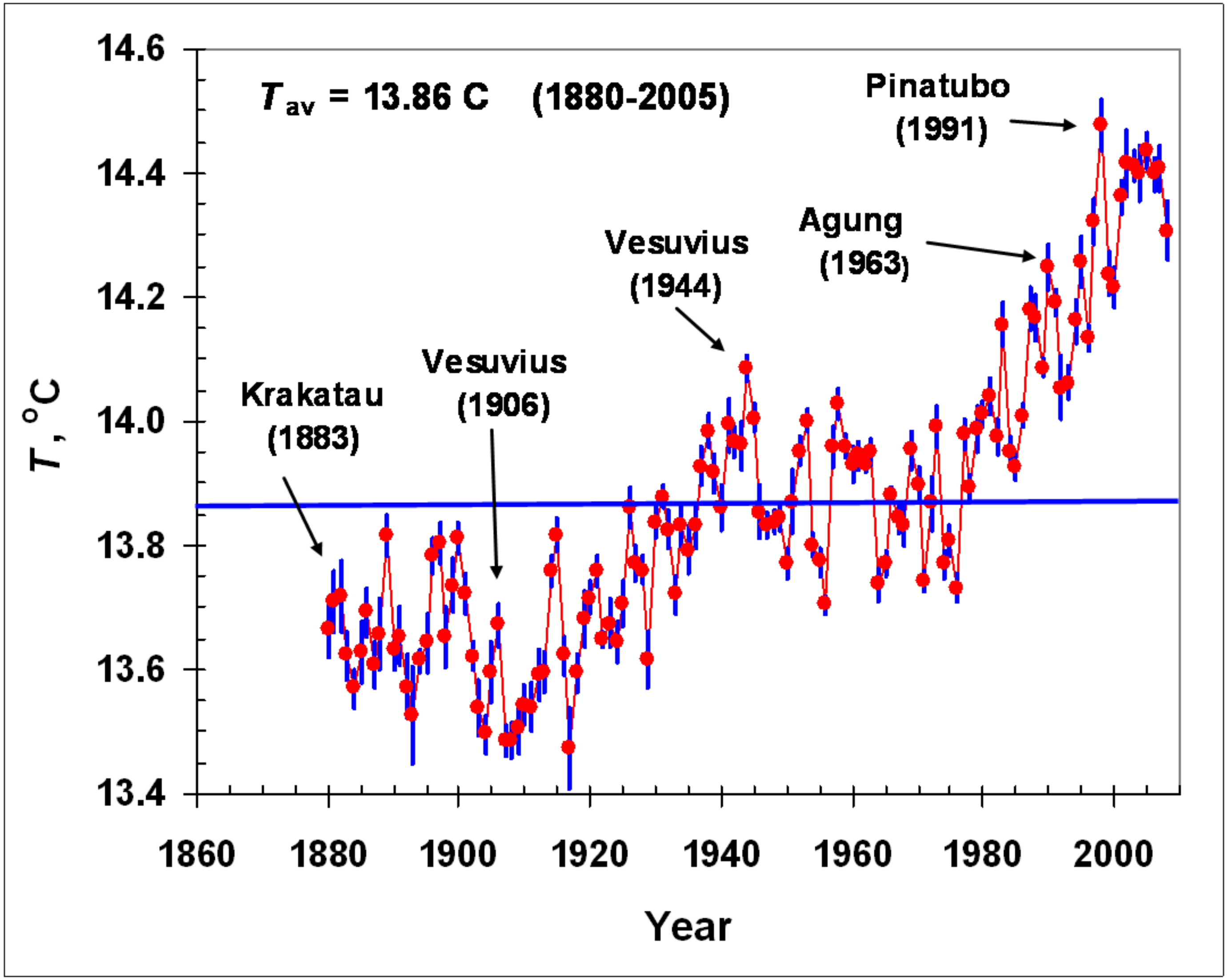
Climate system of the Earth includes atmosphere + ocean + lithosphere. From the thermal balance equation the increase of thermal flux at 1.6 W m^{-2} was not enough to increase the value of *T* at ~ 1^{o}C (to get the observed growth of *T* one needs to increase the thermal flux in ~ 10 times).

Fig.1. Radiation effect



Temperature data for 1880 – 2007

The yearly averages of global surface temperature *T* obtained at the global network of meteorological stations are presented in INTERNET (ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/global_meanT_C.all). During 20th century the climate warming at ~ 1 °C occurred. However, this process was not monotonic. In 1880-1910 and 1945-1975 small cooling of climate took place, but in 1910-1945 and 1975-1998 the warming was observed. It is difficult to explain such changes of climate by anthropogenic influence because during the period under consideration anthropogenic influence has been increased permanently.



Yearly averages of global air surface temperature *T* obtained at the global network of meteorological stations (ftp://ftp.ncdc. noaa.gov/pub/data/anomalies/ global_meanT_C.all). Blue horizontal line is the averaged temperature for 1880 - 2005. Vertical blue bars are standard errors.

Effect of dust on the Earth's climate

It is known that during ~ 2years after strato-volcano eruption the global cooling at ~ 0.2 ^{o}C was observed. In such eruptions huge amount of dust is vented to the atmosphere. This dust lives in the atmosphere about 2 years. This fact gives proof that the dust entering into the atmosphere influences the Earth's climate. It is known that waterdroplets grow on fine particles of dust and reflect part of solar irradiation back to space. So, more dust, more cloud, and cooler climate.

The dust has terrestrial or cosmic origin. From the Earth's surface the dust enters the stratosphere when strato-volcano eruptions occur. Cosmic dust falls upon the atmosphere permanently.

Cosmic dust in the Earth's atmosphere

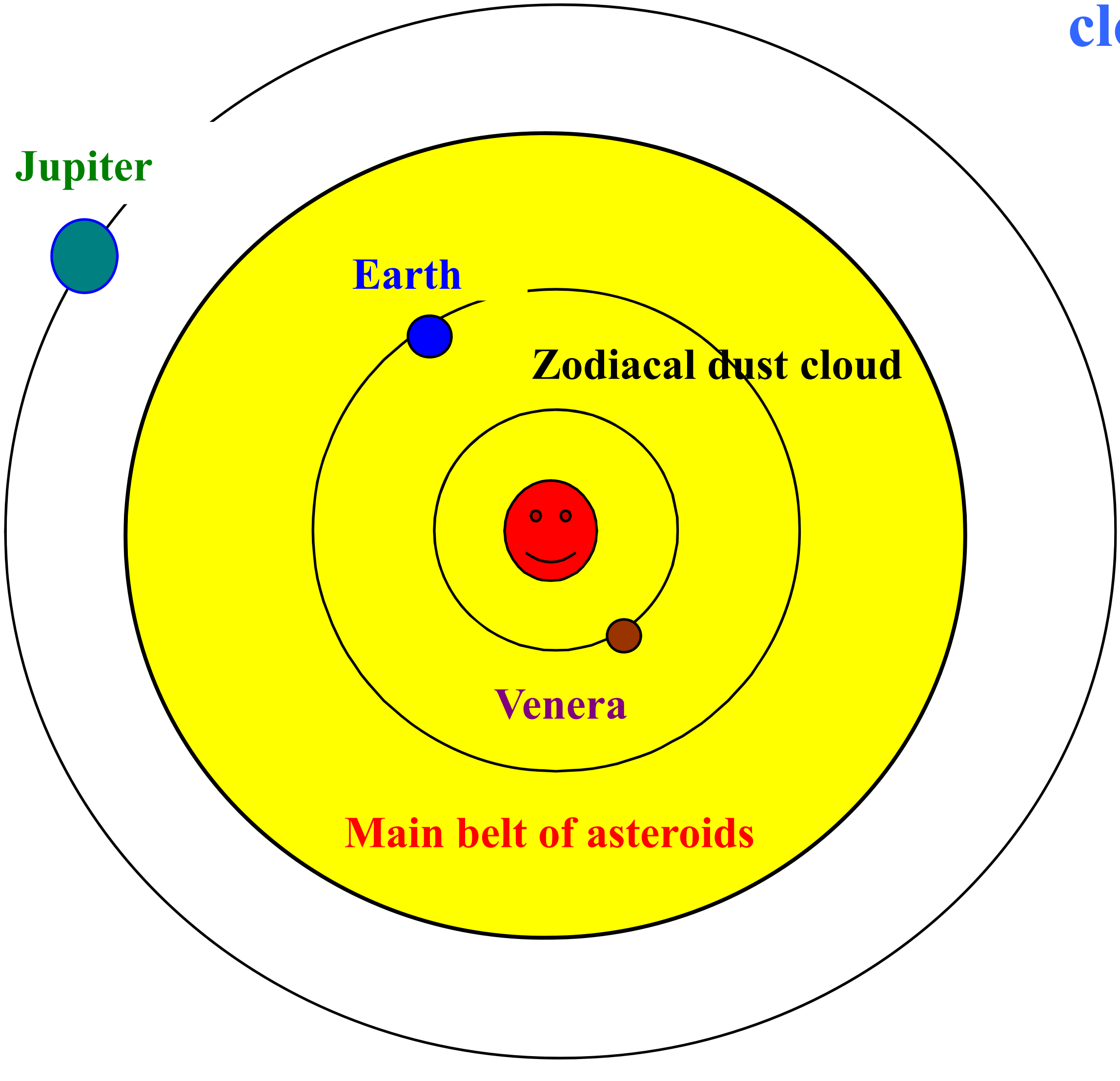
In the interplanetary space between the Sun and the Mars zodiacal dust cloud exists. The dust is concentrated to the ecliptic plane and during the yearly Earth's rotation around the Sun this dust comes to the Earth's atmosphere. Zodiacal light observed from the ground and in space proves the existence of the dust cloud.

The long-periodical comets coming to the Sun from the Oort's comet cloud in the interstellar space are the main sources of dust in the zodiacal cloud. The periods of such comet rotations around the Sun is about 200 years. In the interstellar medium the cold comets accumulate on its surface a large amount of dust and gas.

The planets influence comets moving to the Sun. They are the gravitational lenses for all flying nearby bodies including comets. Some part of comets falls on planet surfaces. Another part is deflected from the direction to the Sun. As a result, each planet modulate the value of comet flux moving to the Sun. The number of comets moving to the Sun depends on the mutual planet disposition.

At the distances from the Sun r < 2 a.u. the comets release gases and dust frozen on them during their travel in the interstellar medium. In doing so, huge gas-dust clouds are produced and zodiacal dust cloud is formed in the region between the Sun and Mars orbit.

Thus, the changes of the dust concentrations in the zodiacal cloud and changes of the Earth’s climate have to depend on the mutual planet disposition.



Zodiacal dust cloud (yellow color)

Thus, the changes of the dust concentrations in the zodiacal cloud and changes of the Earth's climate have to depend on the mutual planet disposition.

Time variation of the Earth's climate

Now we have the data on the climate changes for last 400 thousand years. These data show that climate of the Earth is steadily changed. The spectral analysis shows that in the changes of climate the following periodicities are present:

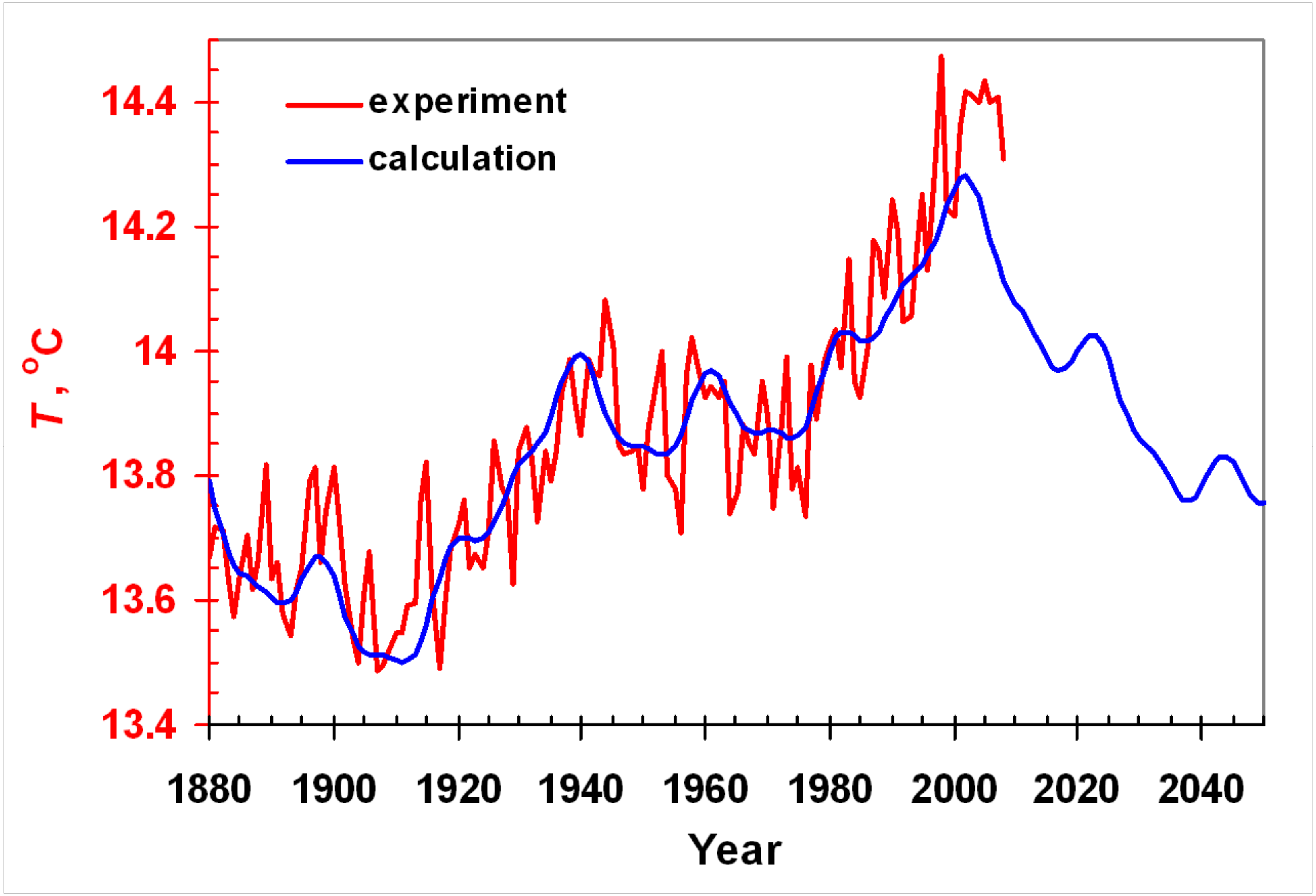
- about 100, ~ 43, ~ 21 thousand years. These periodicities are observed in the changes of the Earth's orbit characteristics. Also they are recorded in the changes of dust concentrations in the ice cores of Greenland and Antarctic.
- about 200, ~ 65, ~20, and ~ 10 years. These periodicities are present in the variations of heavy planet rotations around the Sun.

Prognosis on the cooling climate in the 1st half of the 21st century

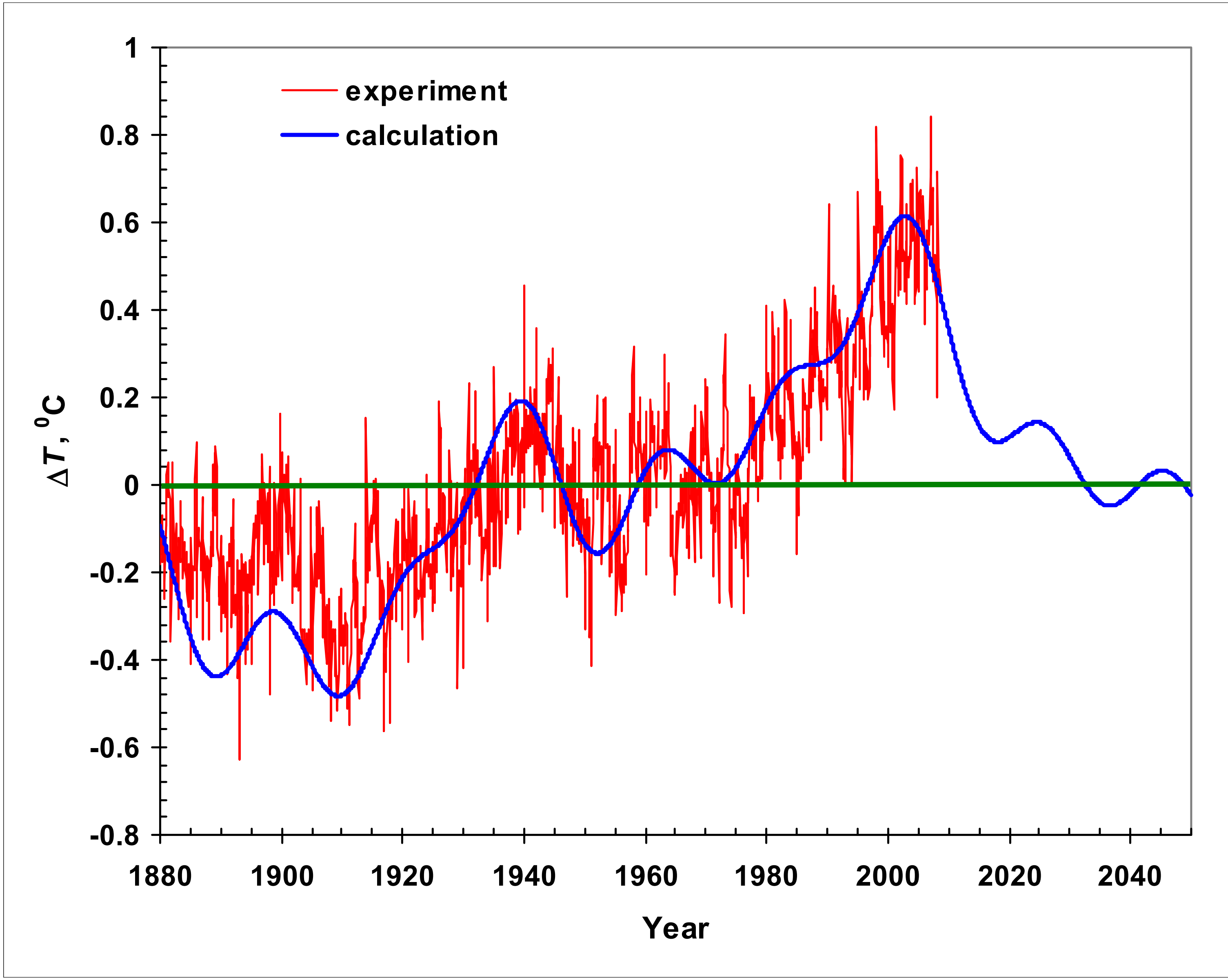
Using the data on wave amplitudes, periods, and phases obtained with spectral analysis of the temperature data for 1880-2007 (see Table) we made the prognosis on the cooling climate in the 1st half of the 21st century.

Table. Spectrum of global temperature, 1880 – 2007

Amplitude	Period	Phase
.2843	195.9135	125.0219
.1699	64.4778	25.2840
.0783	33.0765	19.3411
.0844	21.0052	7.6293
.0350	8.9727	1.8544
.0433	7.5249	4.7773
.0317	6.4106	5.4168
.0382	5.1916	0.8966
.0255	3.7469	1.9661
.0306	3.6088	1.0313



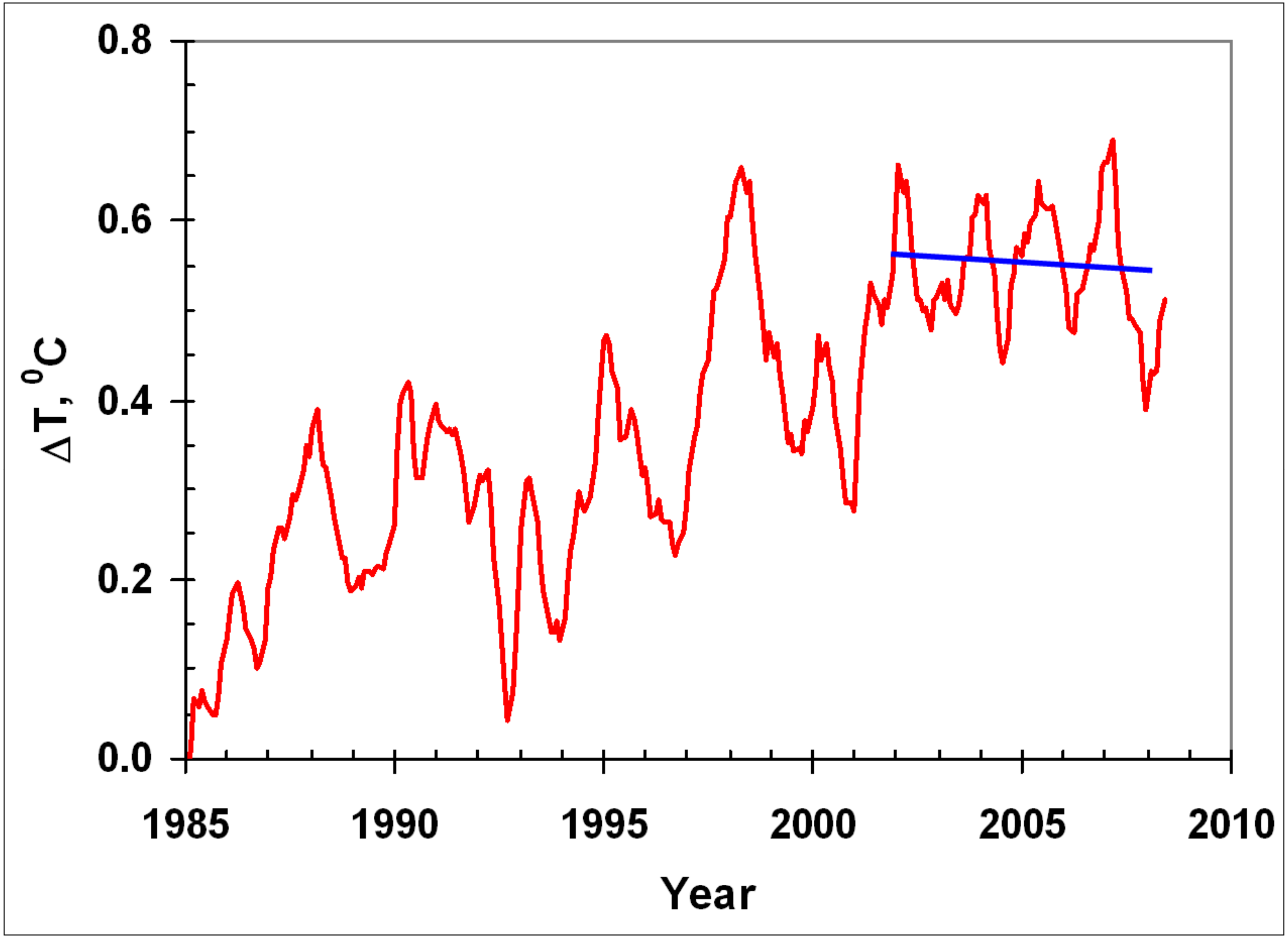
Global surface air temperature data (yearly averages, red curve) and calculated sum of the spectral lines with the periods of 196, 64, 33, and 21 years (blue curve). Prognosis is shown up to 2050.



Global surface air temperature data (monthly averages, red curve) and calculated sum of the spectral lines with the periods of 196, 64, 33, and 21 years (blue curve). Prognosis is shown up to 2050.

Is prognosis on the cooling climate justified or not?

The changes of ΔT over the globe during the period of 1985 – present time show that in the beginning of the 21st century the warming process was stopped and during the recent years the climate cooling is observed.



The monthly values of Δ*T* smoothed with 5 points (red curve). Blue straight line shows gradual decrease temperature during last years.

Conclusion

It is shown that cosmic dust influences the Earth's climate. The climate changes occurred during the last 500 hundred years were due to cosmic dust.

The mutual disposition of planets also influence climate via changes of cosmic dust concentration. The comets are the main sources of cosmic dust.

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Conclusion

- **From the middle of 2007 cosmic ray flux has a prolonged maximum near the Earth's orbit;**
- **Analysis of step-like changes observed in cosmic rays for recent years (2004-2008) shows that the modulation of cosmic particles will be over at the distances ~ (110 – 115) a.u.;**
- **It is probably that 24th solar cycle will have low solar activity level.**
- **The changes of cosmic dust concentration in the zodiacal cloud influence climate. The prediction on the cooling climate in the nearest future is made.**