Долговременные измерения потоков космических лучей в земной атмосфере

Стожков Ю.И., Свиржевский Н.С., Базилевская Г.А., Махмутов В.С., Крайнев М.Б., Свиржевская А.К., Логачев В.И.

Физический институт им. П.Н. Лебедева, Российская академия наук.

33 ВККЛ, ОИЯИ, Дубна, 11 – 15 августа 2014

План доклада

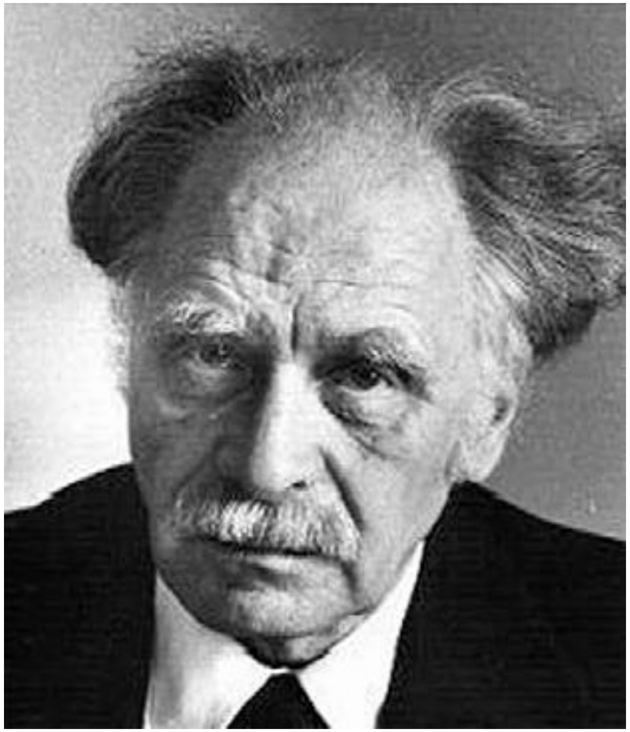
Введение

1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

Заключение

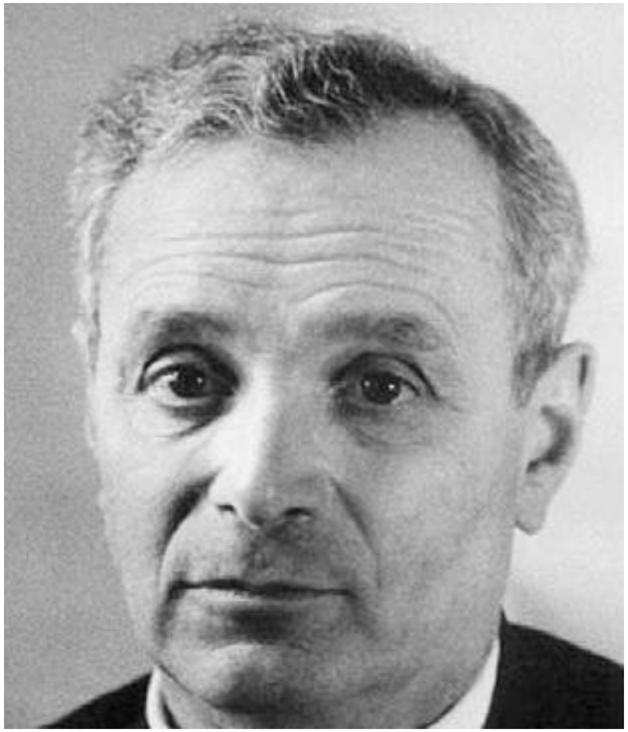
Введение

Регулярные измерения потоков заряженных частиц в атмосфере были начаты в июне 1957 г. (JGY).



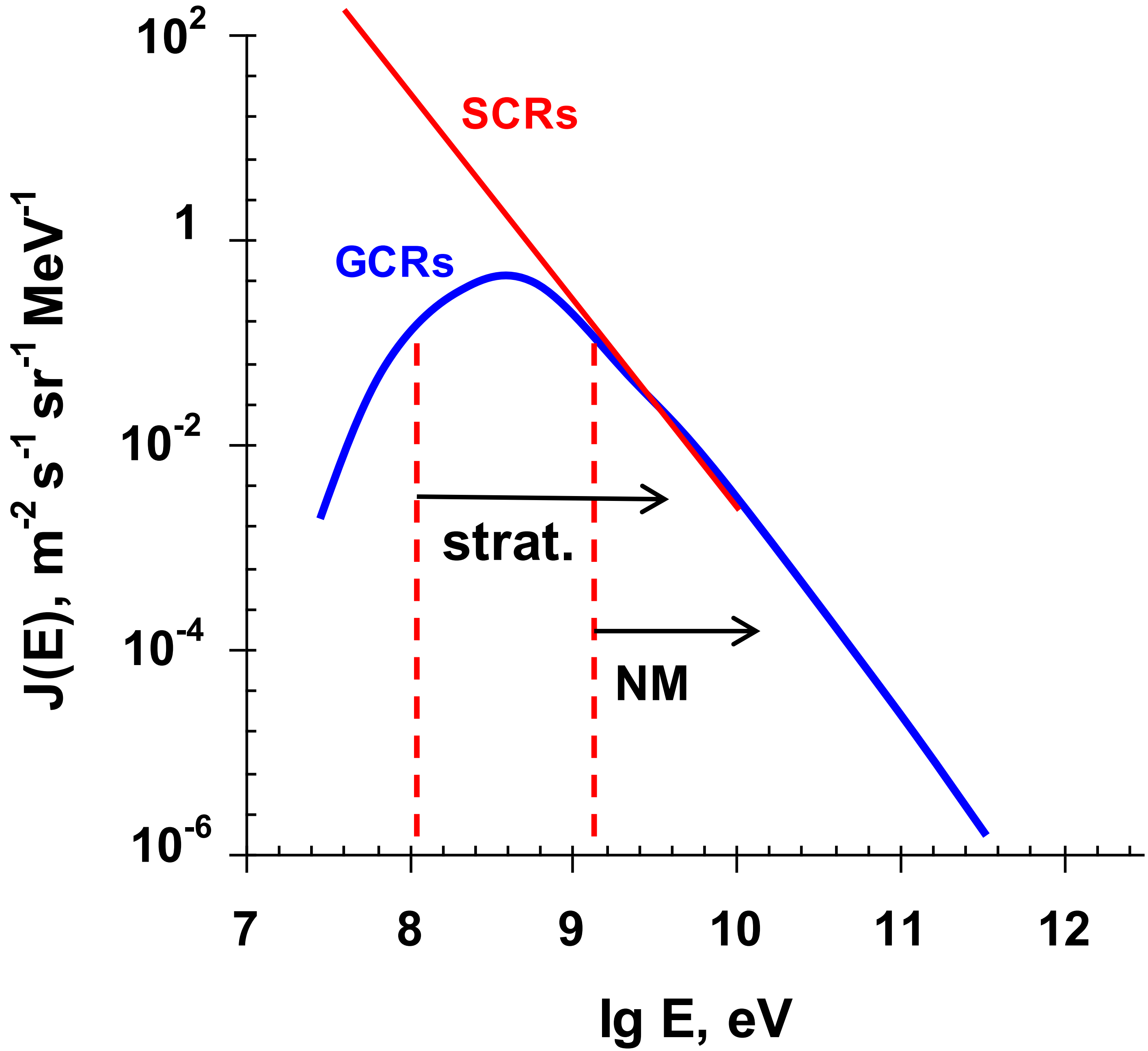
Академик С.Н. Вернов

(11.07.1910 – 26.09.1982)

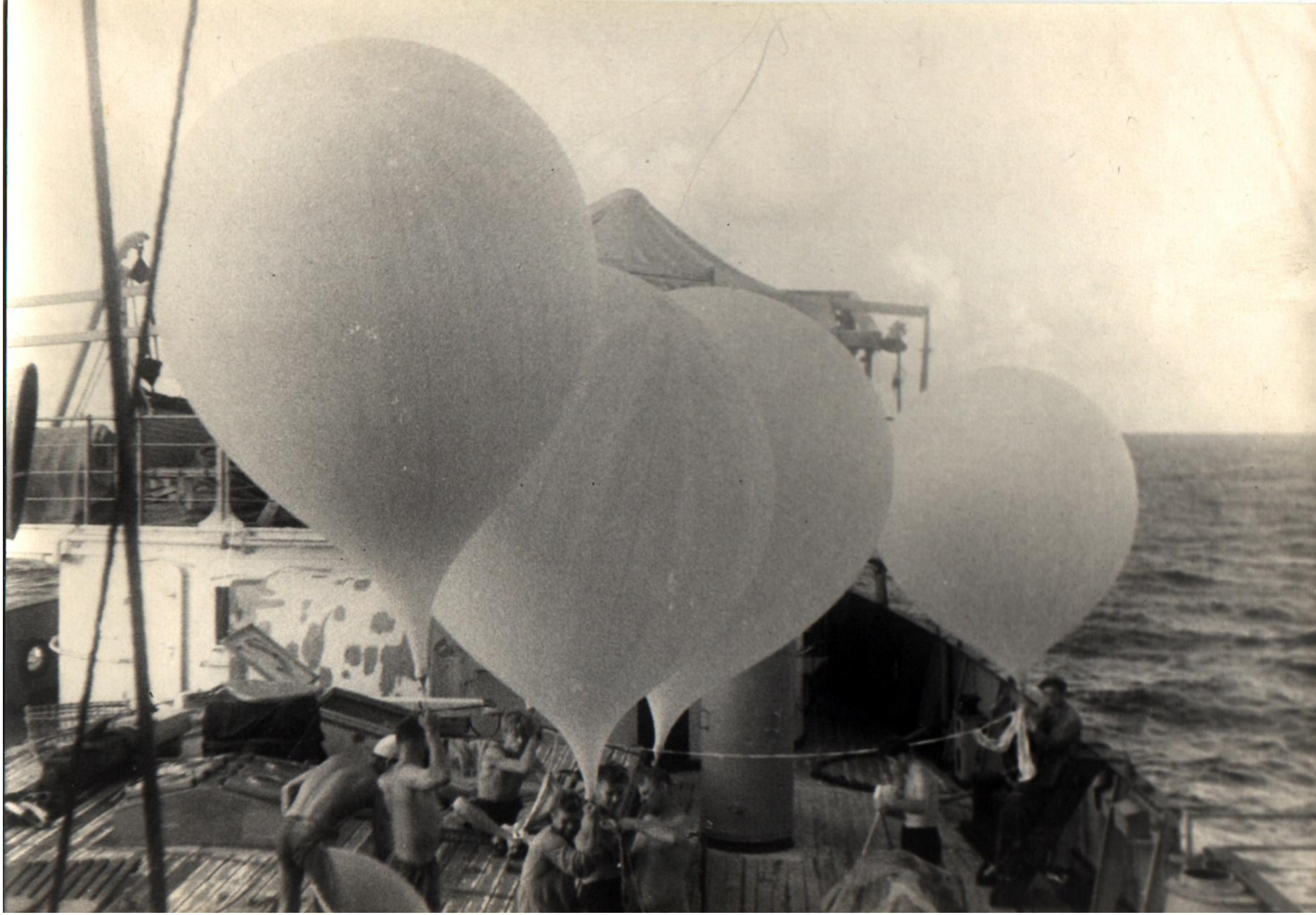


Профессор А.Н. Чарахчьян

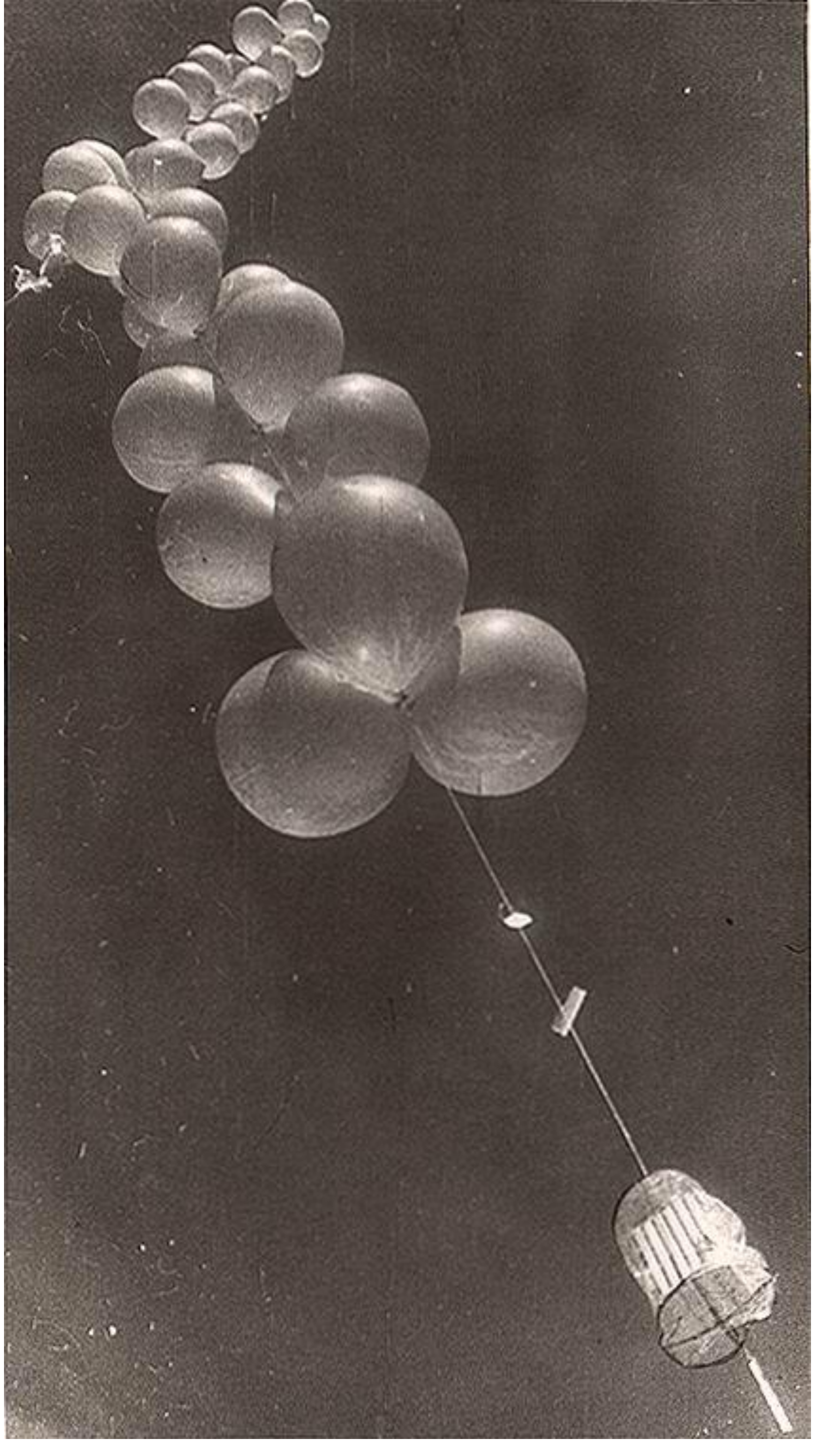
(01.11.1905 – 08.03.1981)



SCRs
GCRs
strat.
NM
10^2
1
10^{-2}
10^{-4}
10^{-6}
7
8
9
10
11
12
J(E), $m^{-2} s^{-1} sr^{-1} MeV^{-1}$
lg E, eV



India Ocean expedition, 1949



План доклада

Введение

1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

Заключение

Table 1. The sites and periods of regular measurements of CR fluxes in the atmosphere

Site of measurements	Geographical coordinates	R_c (GV)	Period of measurements
Murmansk region	67°33′N; 33°20′E	0.6	07.1957–present time
Dolgoprudny, Moscow region	55°56′N; 37°31′E	2.4	07.1957–present time
Alma-Ata, Kazakhstan	43°15′N; 76°55′E	6.7	03.1962–04.1993
Mirny, Antarctica	66°34′S; 92°55′E	0.03	03.1963–present time
Simeiz, Crimea	44°00′N; 34°00′E	5.9	03.1958–12.1961 03.1964–04.1970
Voyeikovo, Leningrad region	60°00′N; 30°42′E	1.7	11.1964–03.1970
Norilsk, Krasnoyarsk region	69°00′N; 88°00′E	0.6	11.1974–06.1982
Yerevan, Armenia	40°10′N; 44°30′E	7.6	01.1976–05.1989
Tixie, Yakutiya	71°36′N; 128°54′E	0.5	02.1978–09.1987
Dalnerechensk, Khabarovsk region	45°52′N; 133°44′E	7.35	08.1978–05.1982
Vostok station, Antarctica	78°47′S; 106°87′ E	0.00	01.1980–02.1980
Barentzburg, Norway	78°36′N; 16°24′E	0.06	05.1982, 03–07.1983
Campinas, Brazil	23°00′S; 47°08′W	10.9	01.1988–02.1991
Sea expeditions	60°00′N–70°00′S	0.1–17	1963–1987

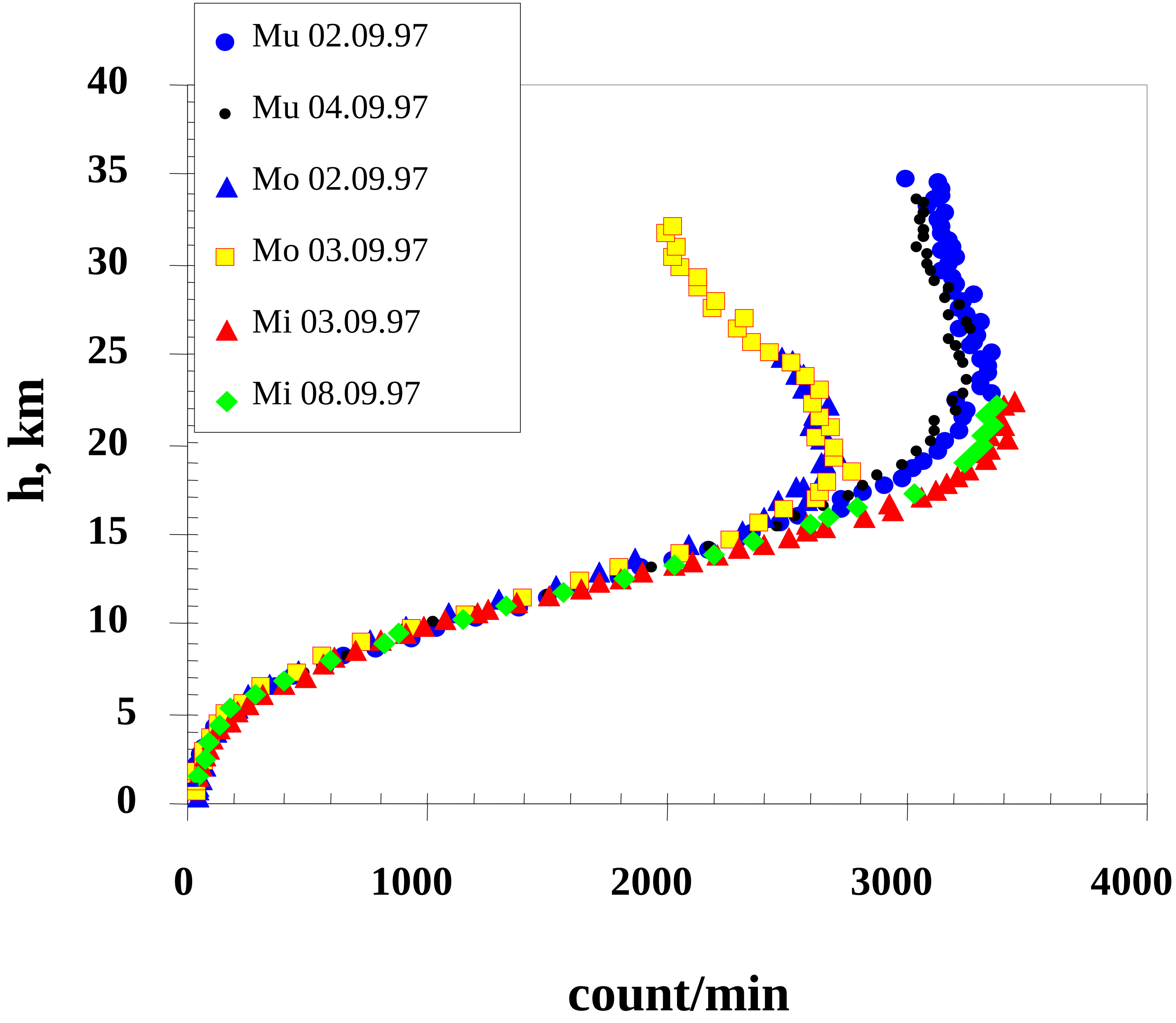
Table 1

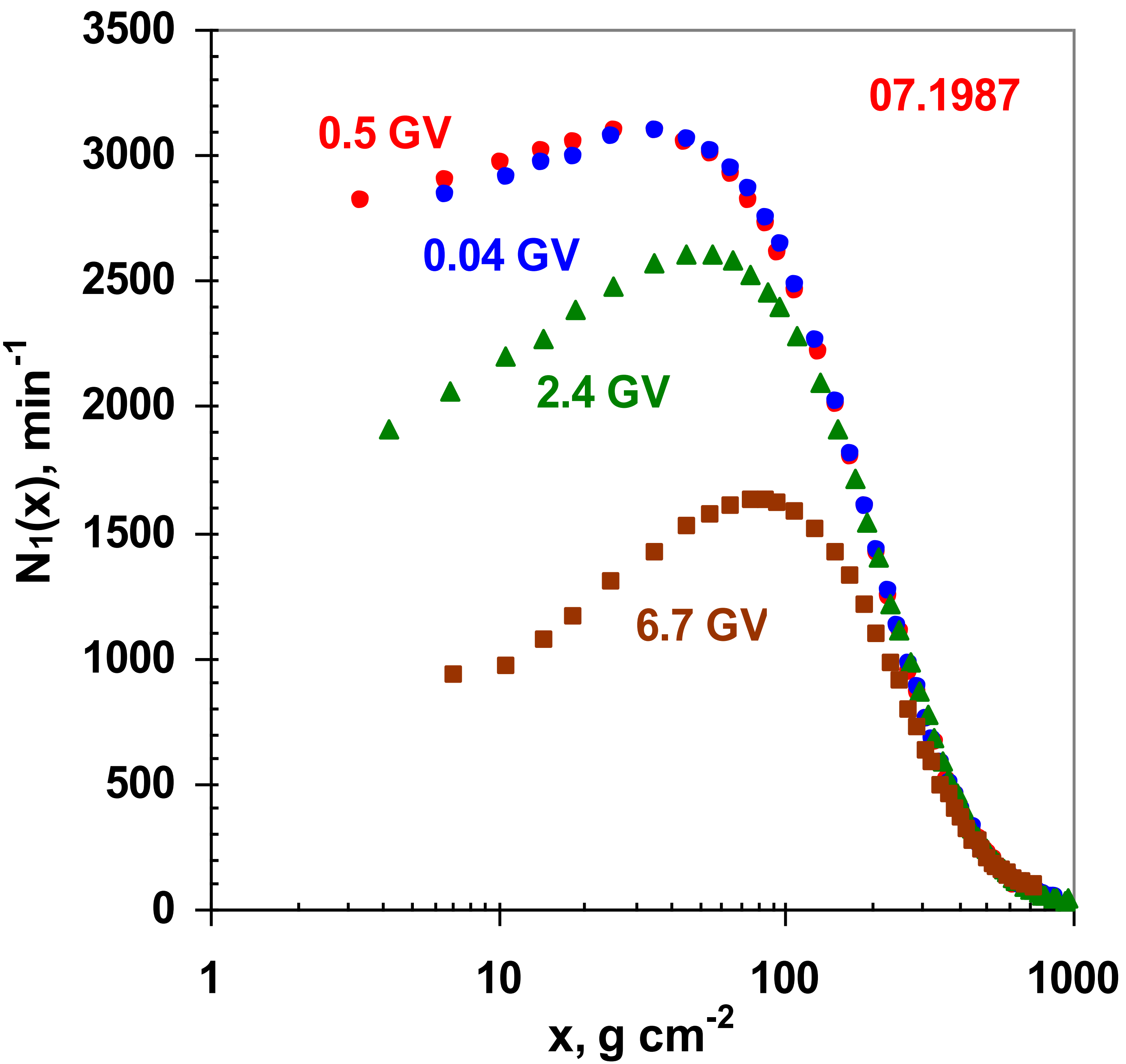
The sites and periods of measurements of CR fluxes in the atmosphere

Site of measurements	Geographical coordinates	R_c (GV)	Period of measurements
Murmansk region	67°33′N; 33°20′E	0.6	07.1957–present time
Dolgoprudny, Moscow region	55°56′N; 37°31′E	2.4	07.1957–present time
Alma-Ata, Kazakhstan	43°15′N; 76°55′E	6.7	03.1962–04.1993
Mirny, Antarctica	66°34′S; 92°55′E	0.03	03.1963–present time
Simeiz, Crimea	44°00′N; 34°00′E	5.9	03.1958–12.1961 03.1964–04.1970
Voyeikovo, Leningrad region	60°00′N; 30°42′E	1.7	11.1964–03.1970
Norilsk, Krasnoyarsk region	69°00′N; 88°00′E	0.6	11.1974–06.1982
Yerevan, Armenia	40°10′N; 44°30′E	7.6	01.1976–05.1989
Tixie, Yakutiya	71°36′N; 128°54′E	0.5	02.1978–09.1987
Dalnerechensk, Khabarovsk region	45°52′N; 133°44′E	7.35	08.1978–05.1982
Vostok station, Antarctica	78°47′S; 106°87′ E	0.00	01.1980–02.1980
Barentzburg, Norway	78°36′N; 16°24′E	0.06	05.1982, 03–07.1983
Campinas, Brazil	23°00′S; 47°08′W	10.9	01.1988–02.1991
Sea expeditions	60°00′N–70°00′S	0.1–17	1963–1987

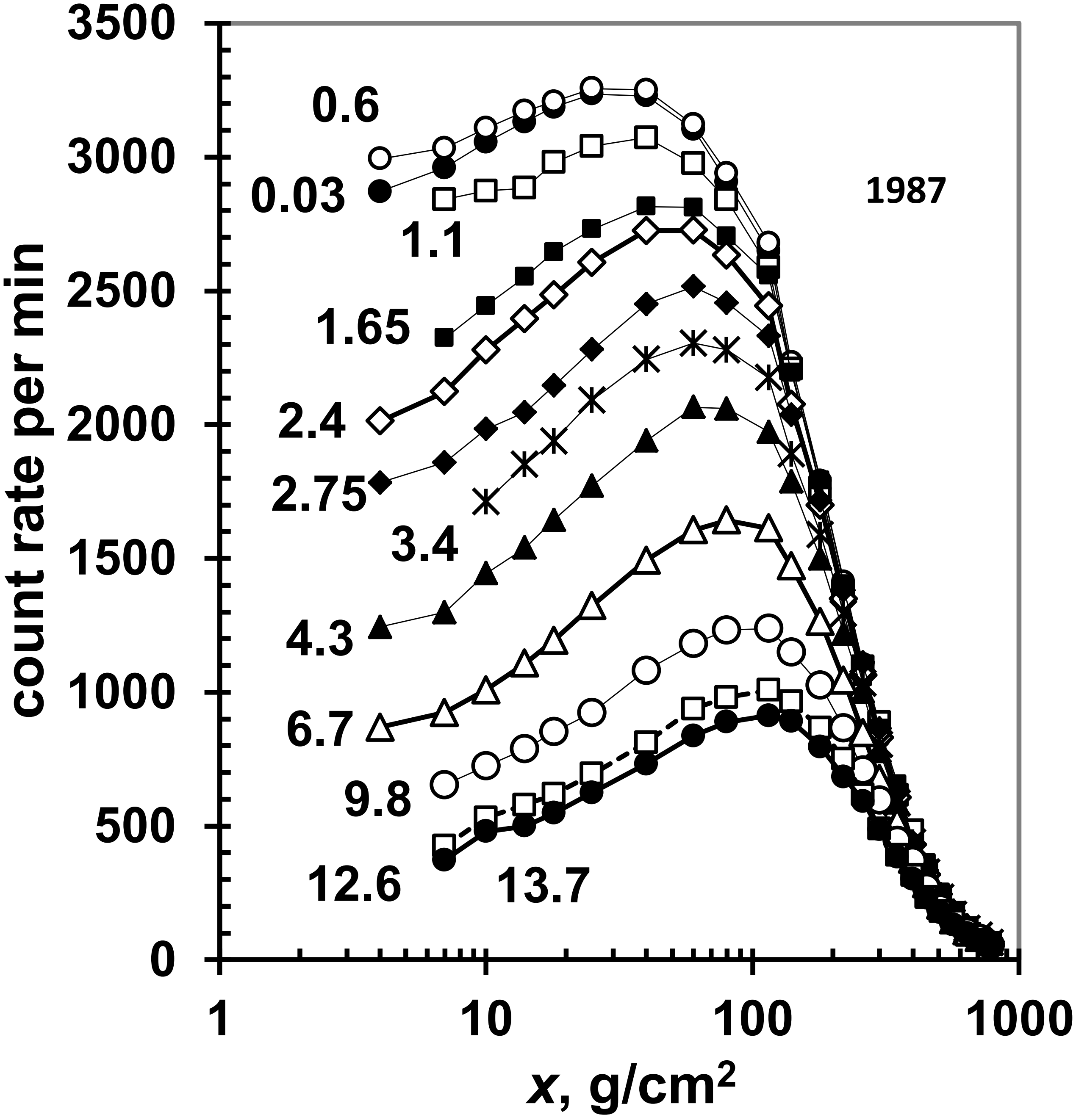
Радиозонд для измерения потоков заряженных частиц в атмосфере

Cosmic ray fluxes in the atmosphere vs altitude





3500
3000
2500
2000
1500
1000
500
0
1
10
100
1000
$N_1(x)$, min^{-1}
x, g cm^{-2}
07.1987
0.5 GV
0.04 GV
2.4 GV
6.7 GV



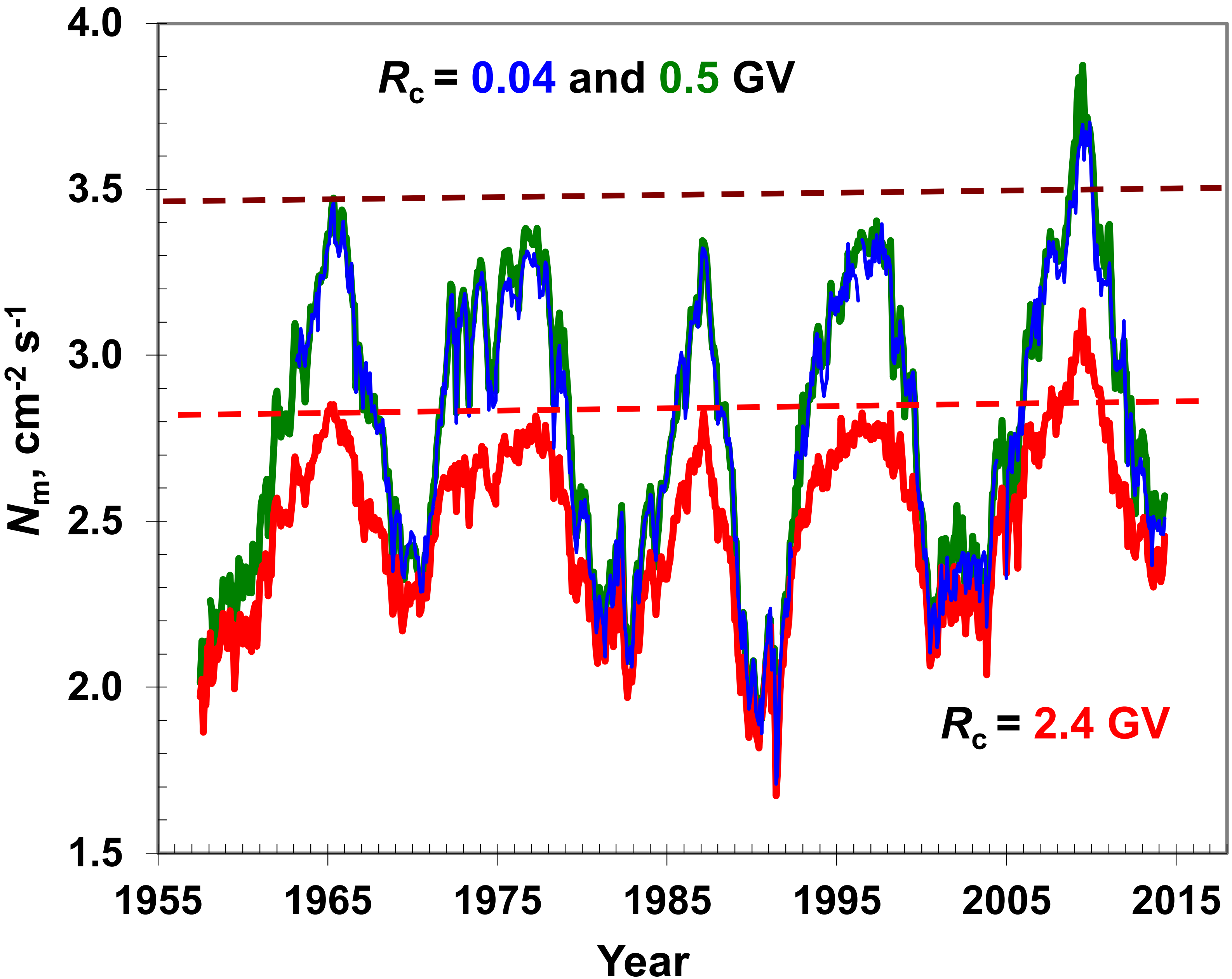
3500
3000
2500
2000
1500
1000
500
0
count rate per min
1
10
100
1000
x, g/cm2
1987
0.6
0.03
1.1
1.65
2.4
2.75
3.4
4.3
6.7
9.8
12.6
13.7

План доклада

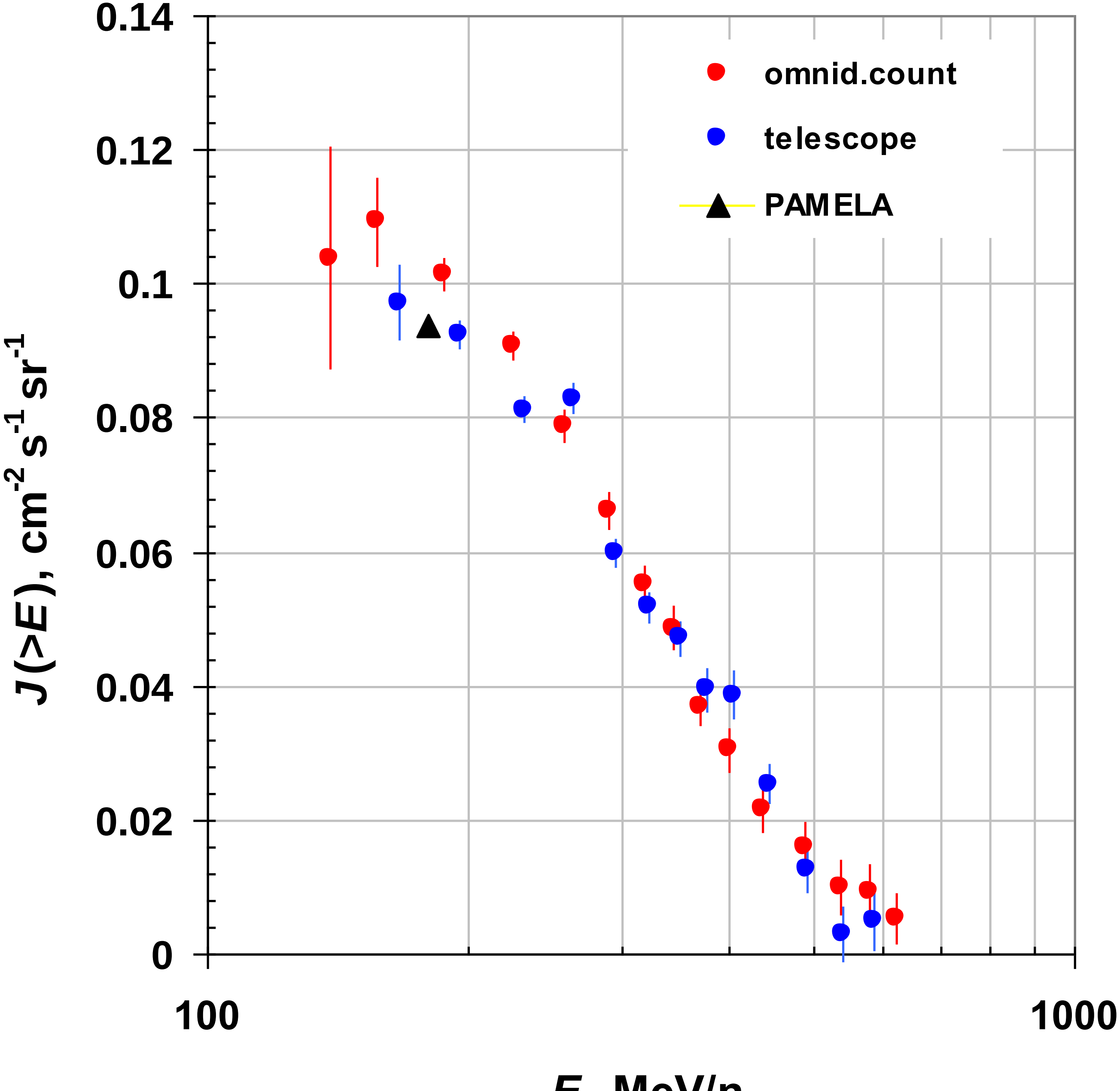
Введение

1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения потоков ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

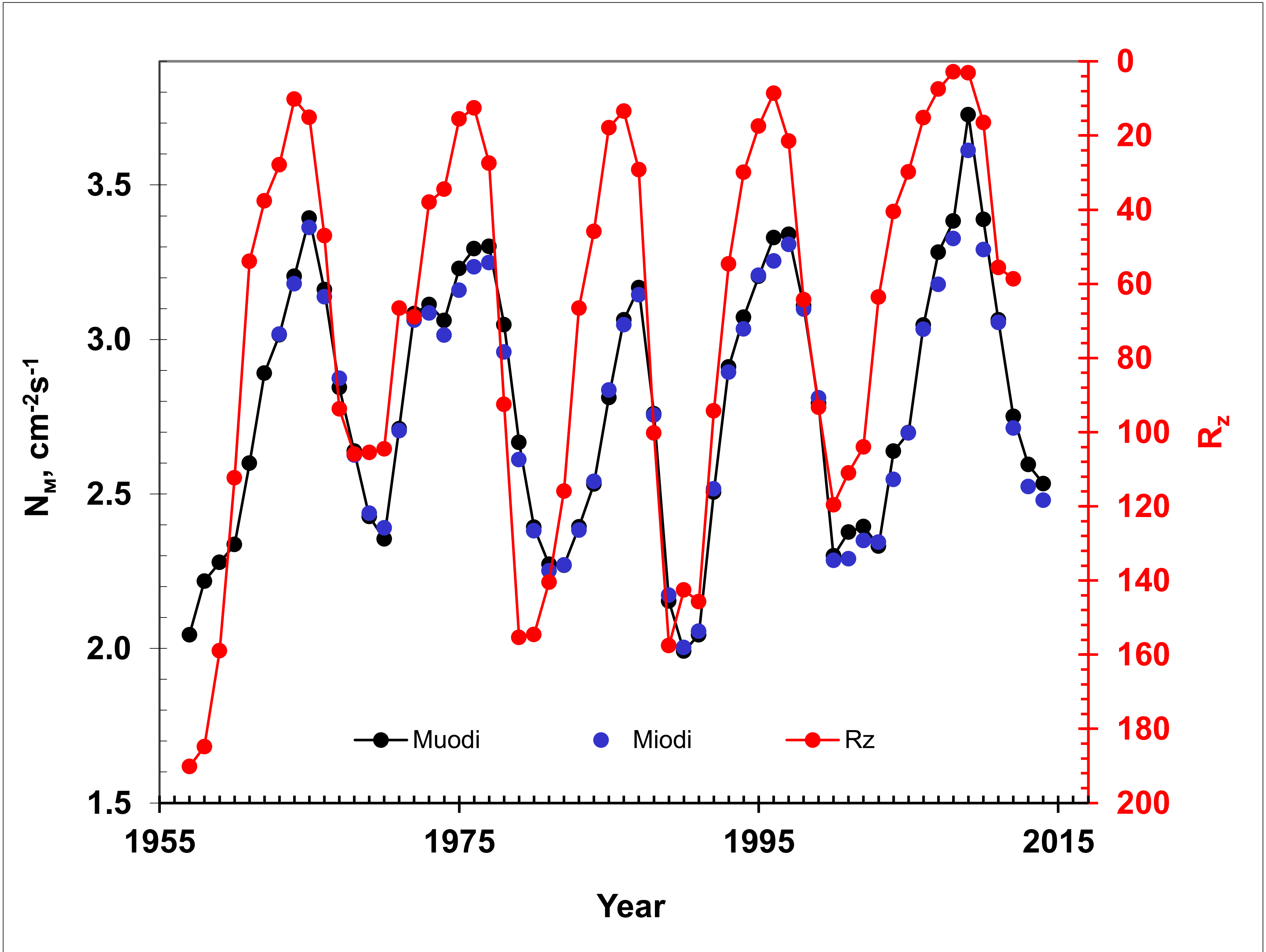
Заключение



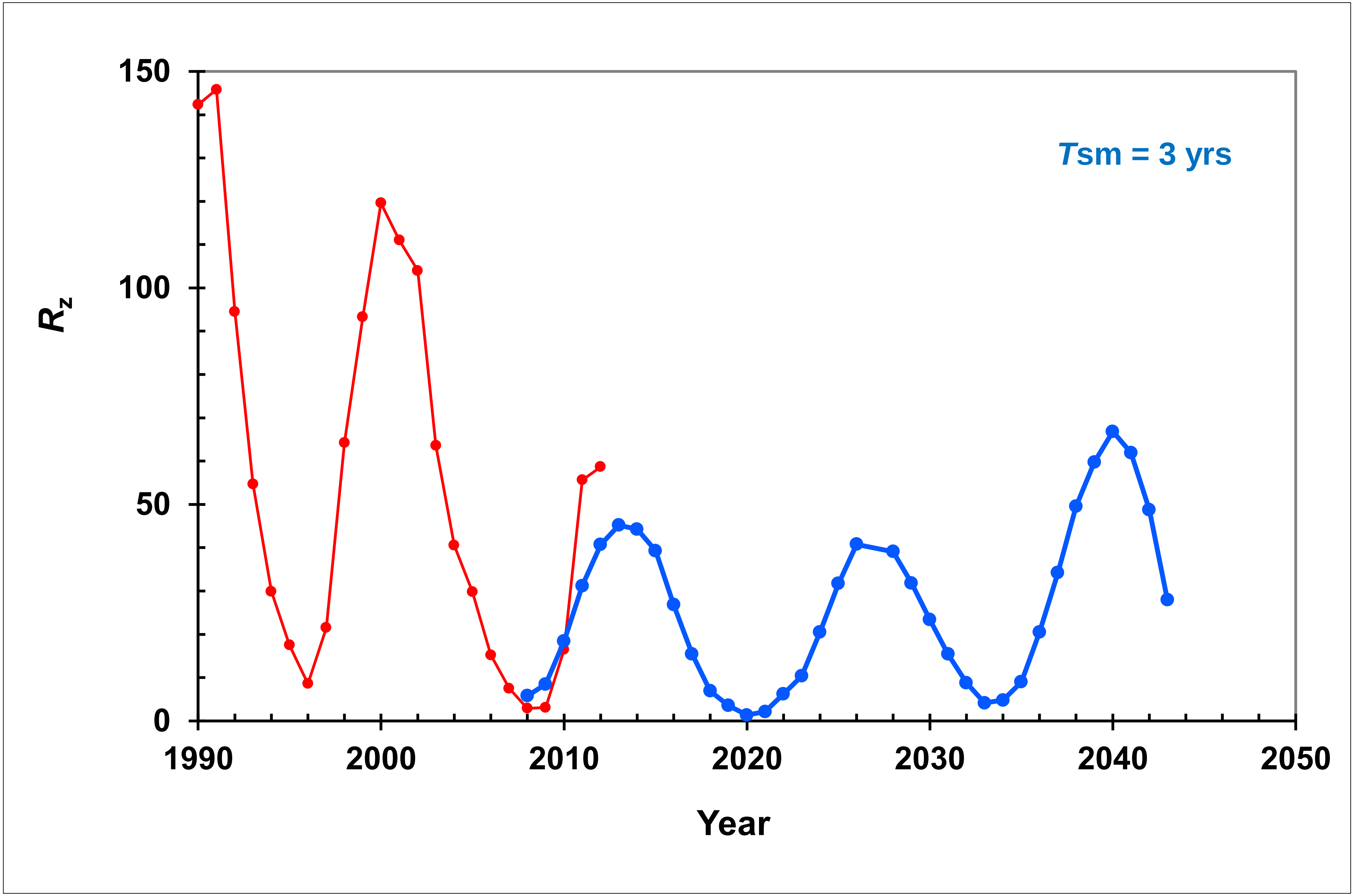
R_c = 0.04 and 0.5 GV
R_c = 2.4 GV
N_m, cm^{-2} s^{-1}
4.0
3.5
3.0
2.5
2.0
1.5
1955
1965
1975
1985
1995
2005
2015
Year



0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
100
1000
J(>E), cm-2 s-1 sr-1
E, MeV/n
omnid.count
telescope
PAMELA



N_M, $cm^{-2}s^{-1}$
3.5
3.0
2.5
2.0
1.5
1955
1975
1995
2015
Year
0
20
40
60
80
100
120
140
160
180
200
R_z
Muodi
Miodi
Rz



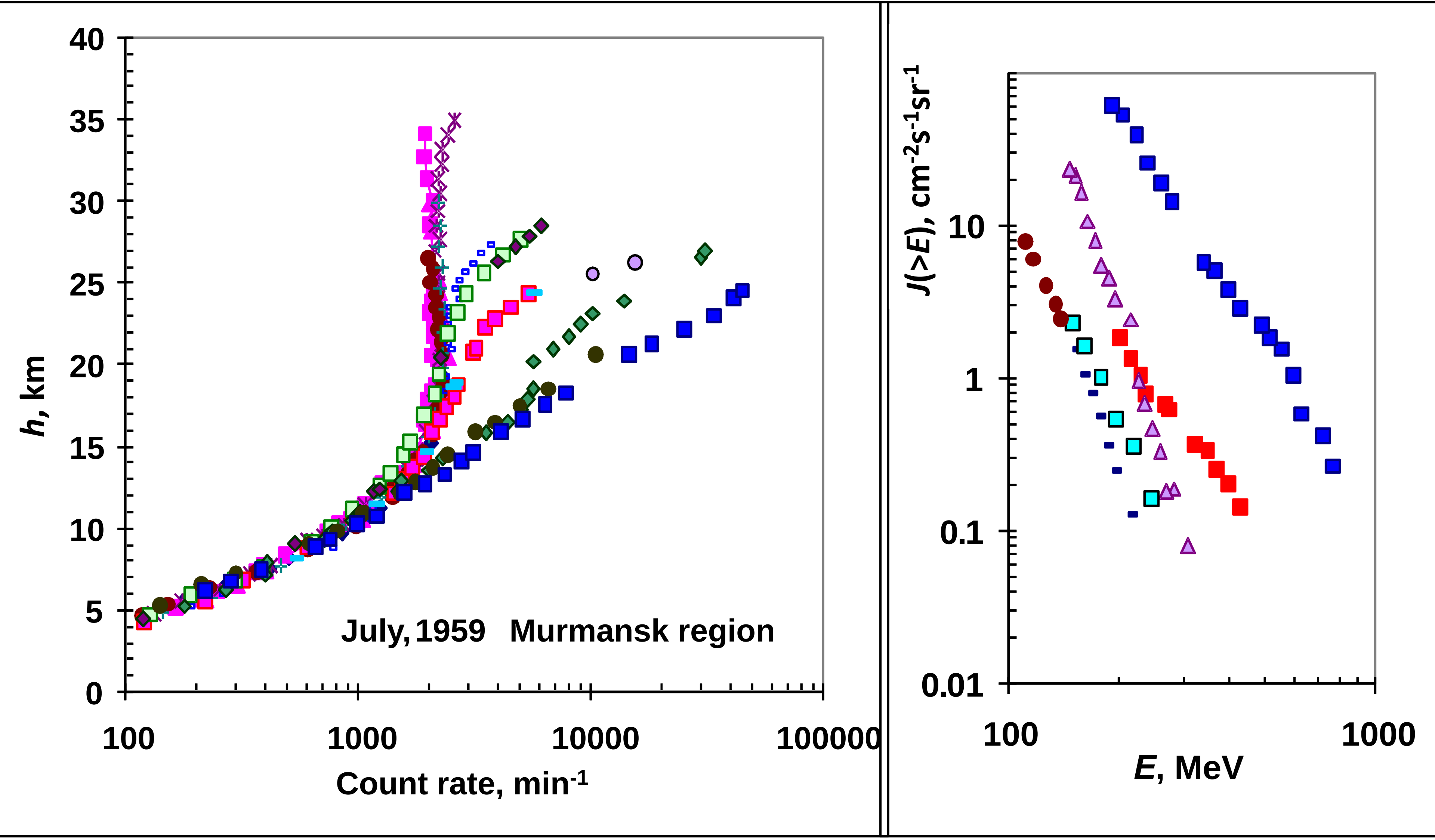
Tsm = 3 yrs
150
100
50
0
R_z
1990
2000
2010
2020
2030
2040
2050
Year

План доклада

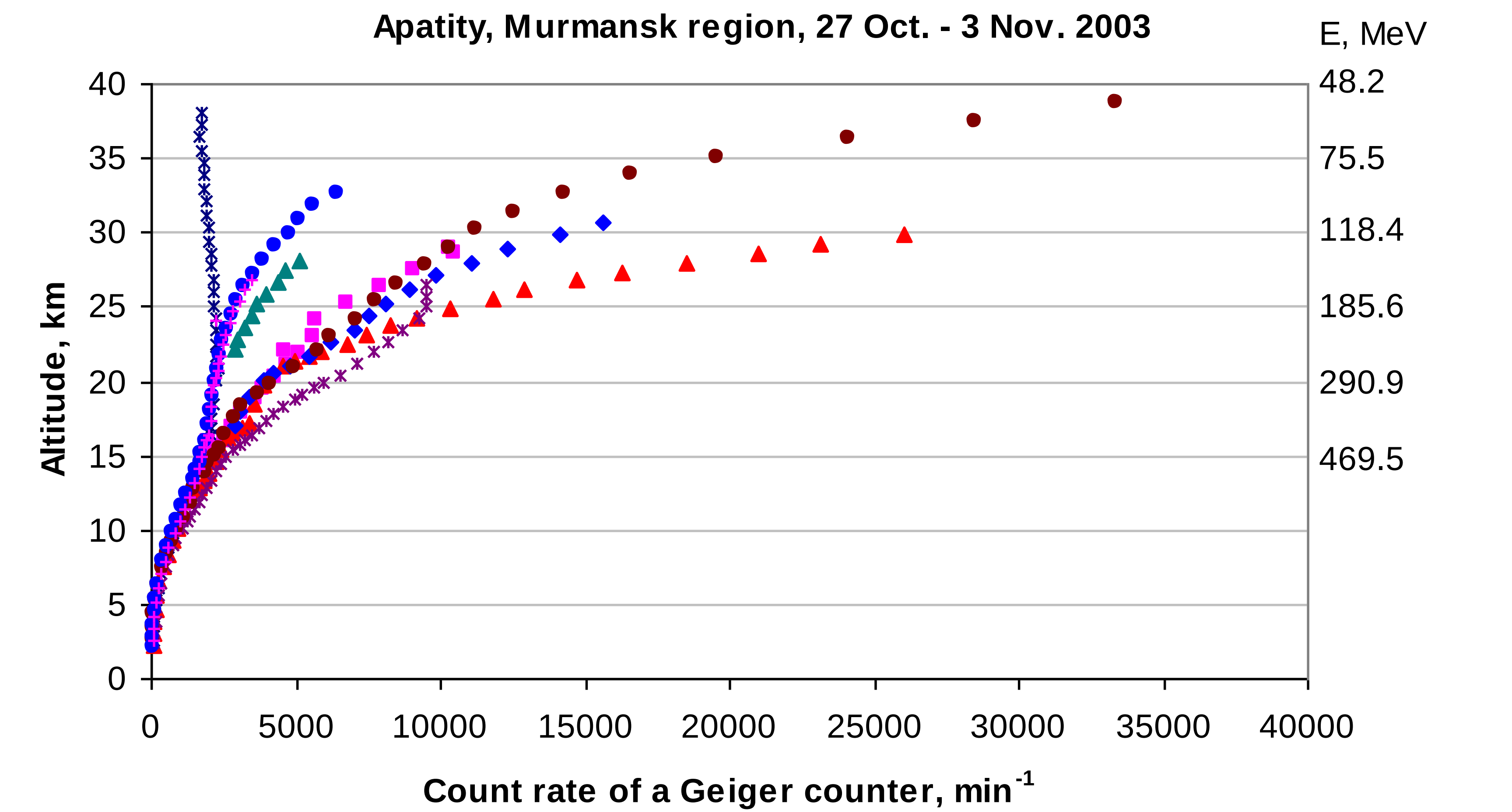
Введение

1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

Заключение

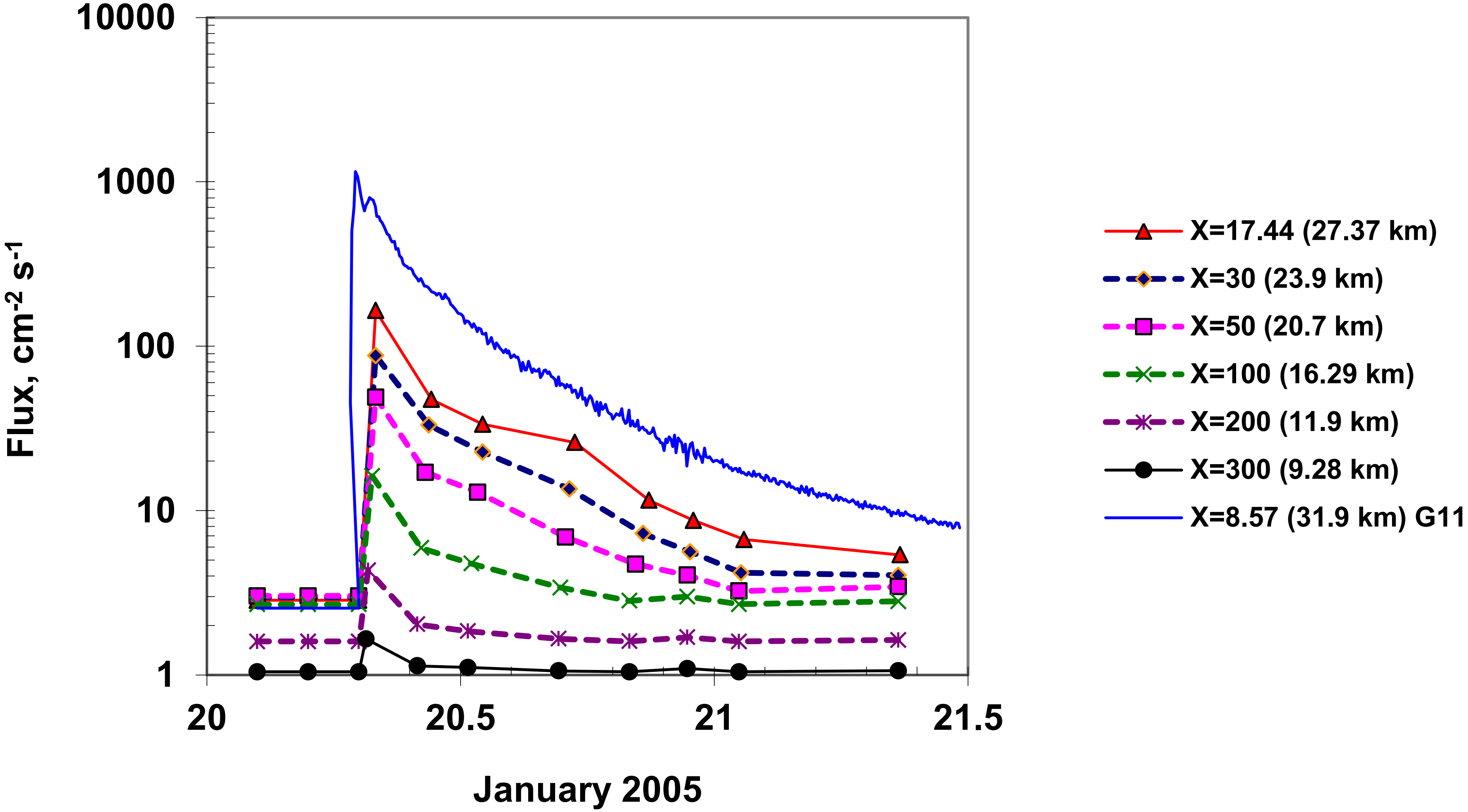


Solar proton events 9, 14 and 16 July 1959: left panel – altitudinal dependences of charged particle fluxes; right panel – energy spectra of solar protons. The measurements were made at the northern polar latitude (R_c = 0.5 GV) in the period of 9 – 17 July 1959.

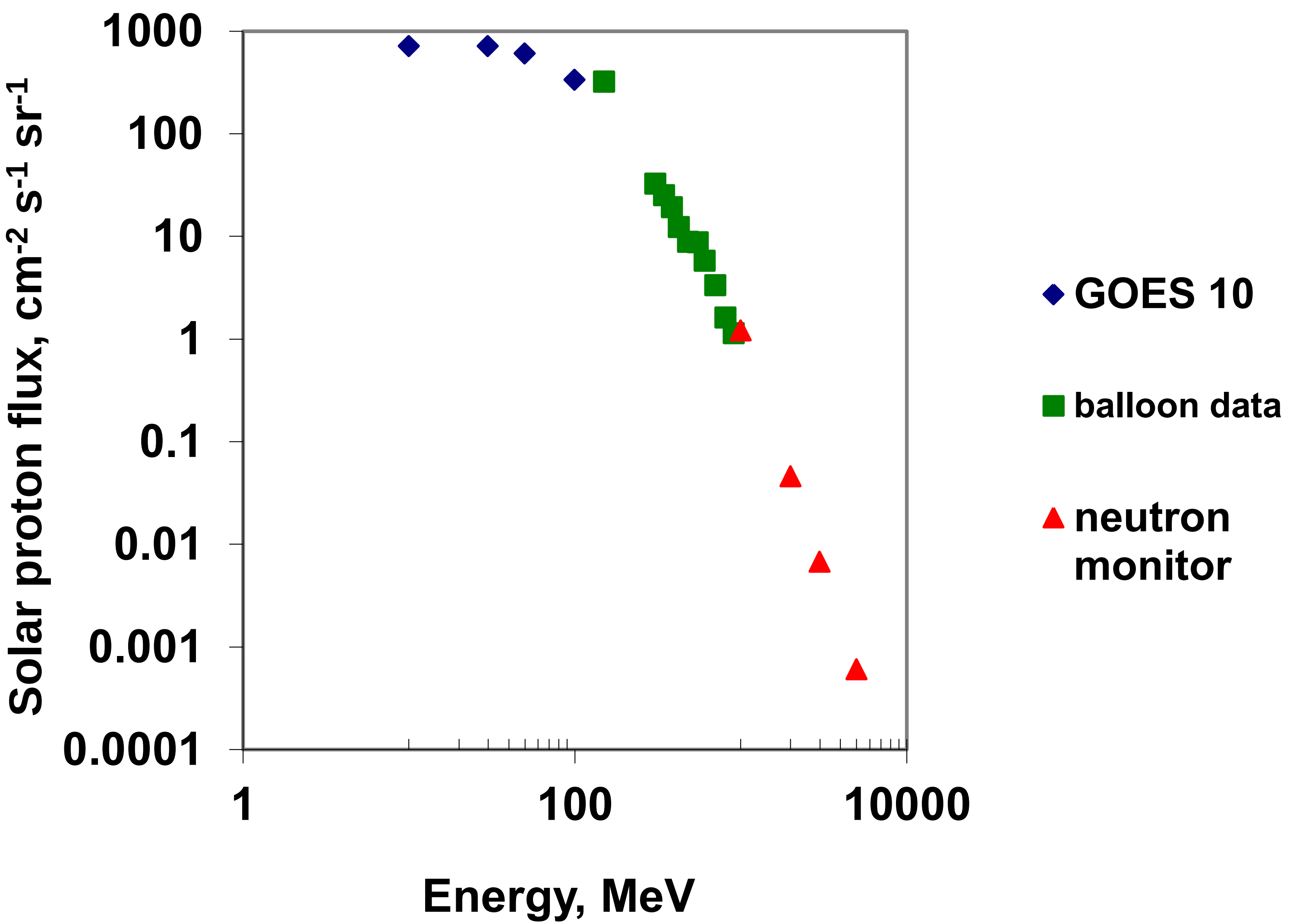


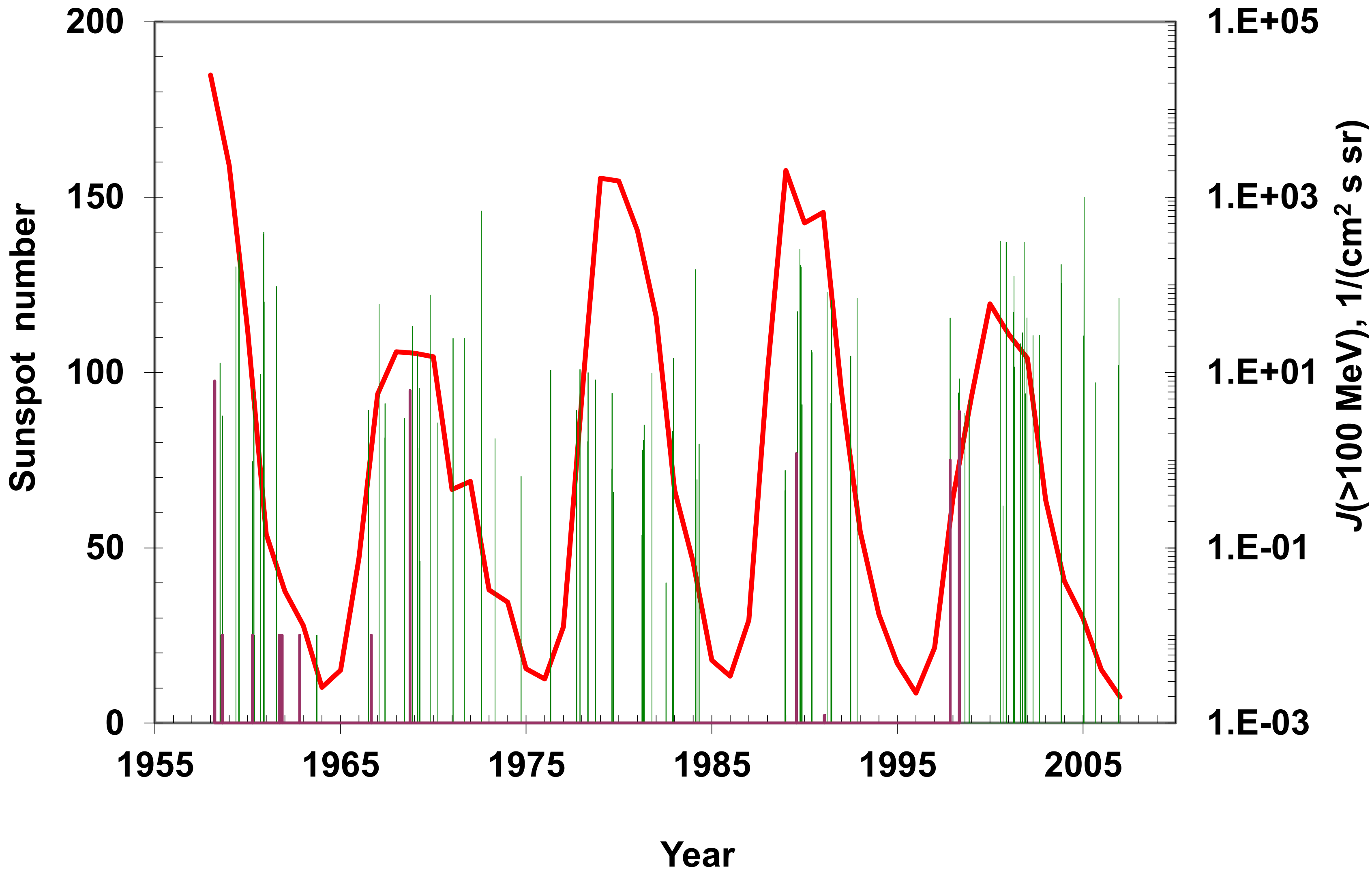
Intrusion of SEPs into the polar atmosphere. Right axis shows the energy of protons penetrating down to a given altitude. The protons with E < 500 MeV are just absorbed in the atmosphere due to ionization loss.

Charged particle fluxes in the polar atmosphere (solar and galactic cosmic rays)



Integral energy spectrum of solar protons
20.01.2005, 08 UT





Solar proton events recorded in the stratosphere. Vertical lines mark the time of event and heights of vertical ones give the solar proton intensity (protons with *E* ≥ 100 MeV). Red curve – sunspot number.

From 1958 till now 115 solar proton events were recorded in the stratosphere.

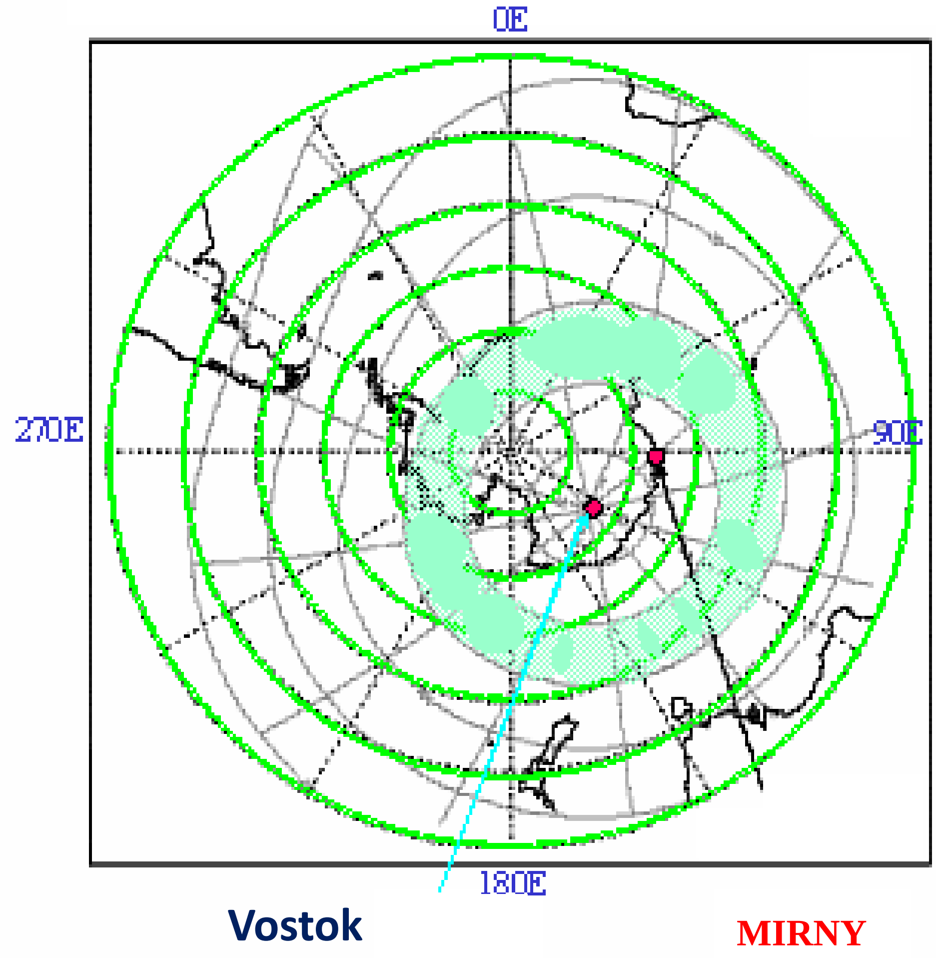
План доклада

Введение

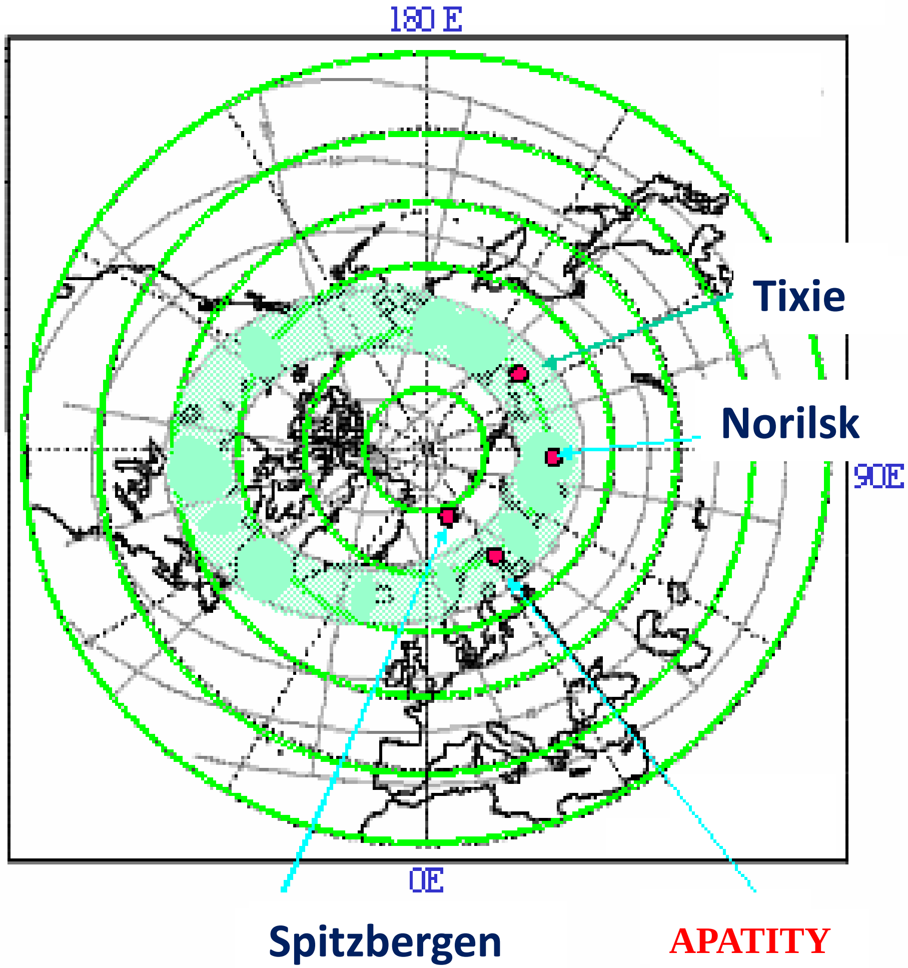
1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

Заключение

Geomagnetic Locations of Stations

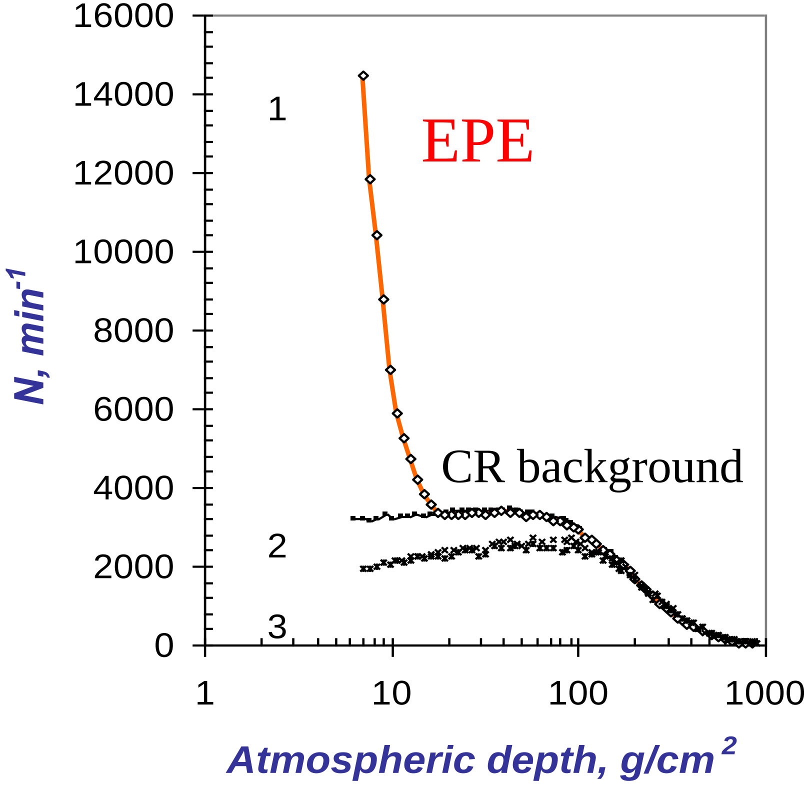


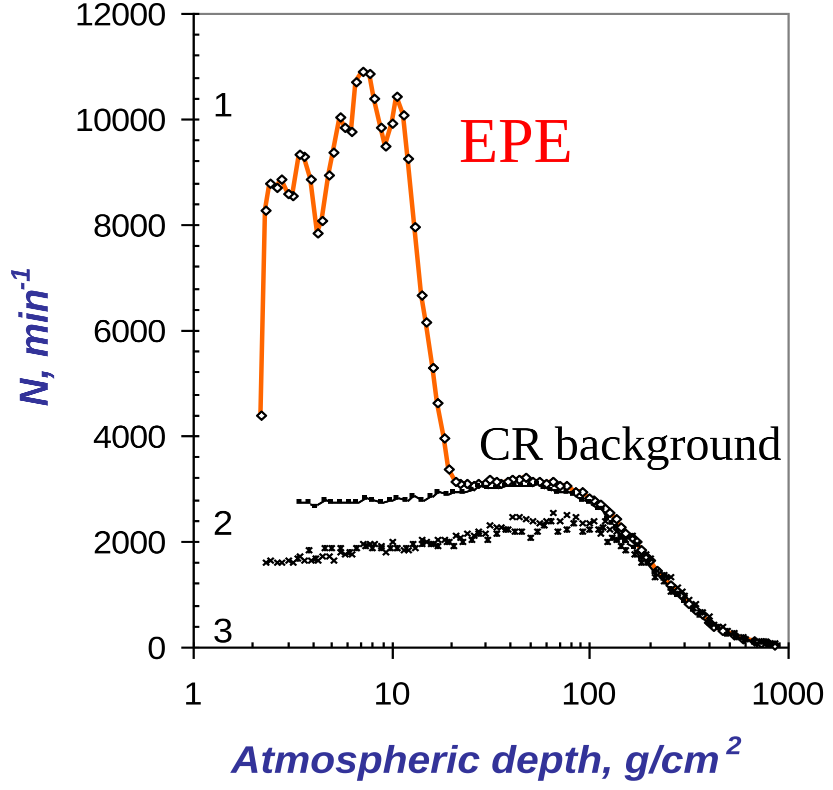
SOUTH



NORTH

Examples of electron precipitation events observed in the stratosphere





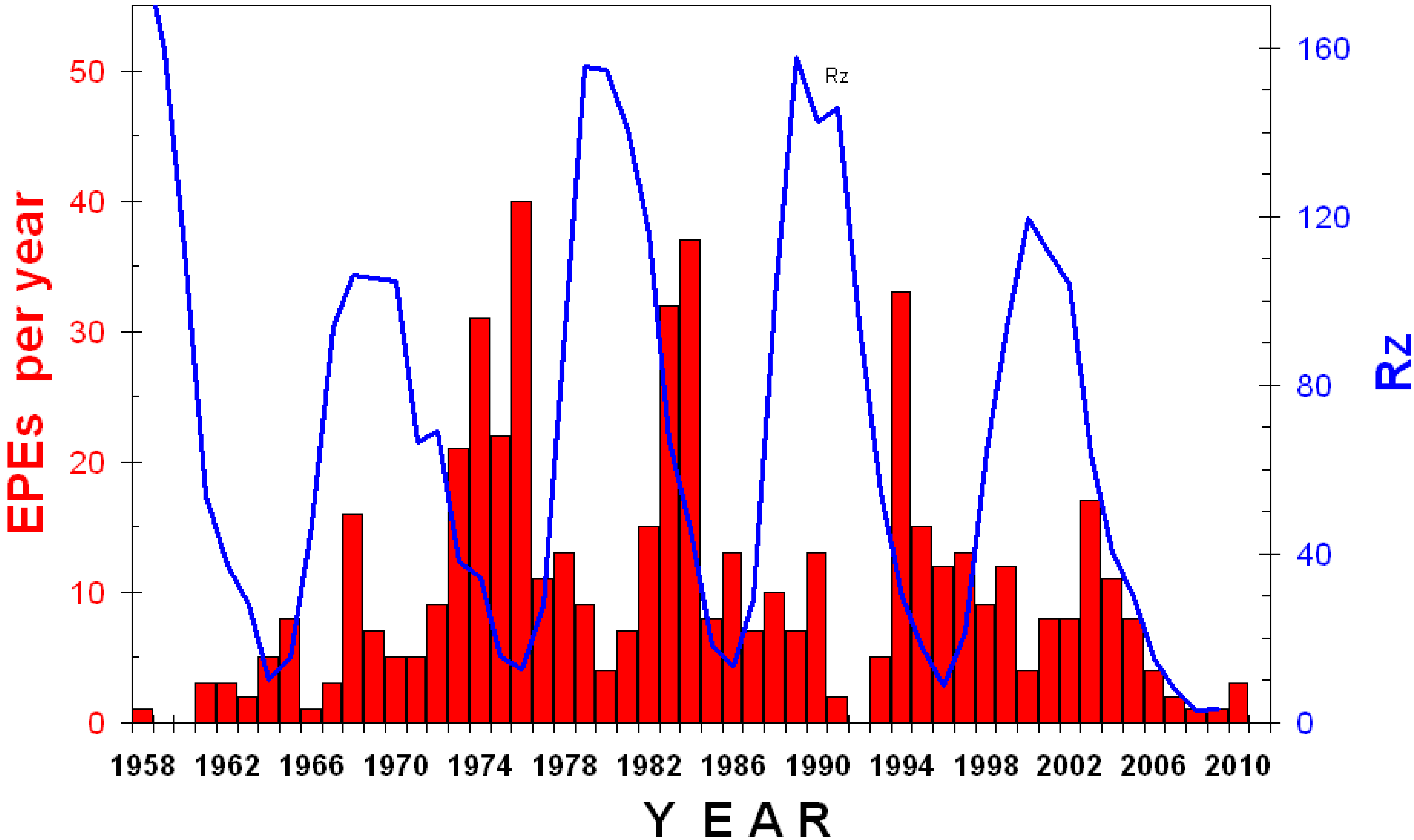
Three minute averages of count rates of single counters during (1) EPEs and (2) quiet conditions, and (3) telescopes versus residual atmospheric depth. Count rates of telescopes are multiplied by 5. On the left panel is EPE of September 26, 1997; on the right panel is EPE of October 9, 1998.

Photon spectra in the atmosphere and precipitating electron spectra at the top of the atmosphere

DATE	$A_{ph,o}(cm^{-2}s^{-1}sr^{-1})$	$E_{ph,o}$(keV)	B_{oe},$(cm^{-2}s^{-1}sr^{-1})$	E_{oe} (keV)
8 March 1994	31	50	2816	150
15 March 1994	798	30	5E5	48
5 April 1994	335	16	1E5	21
7 May 1994	5	34	2015	60
13 May 1994	5.5	30	3093	48

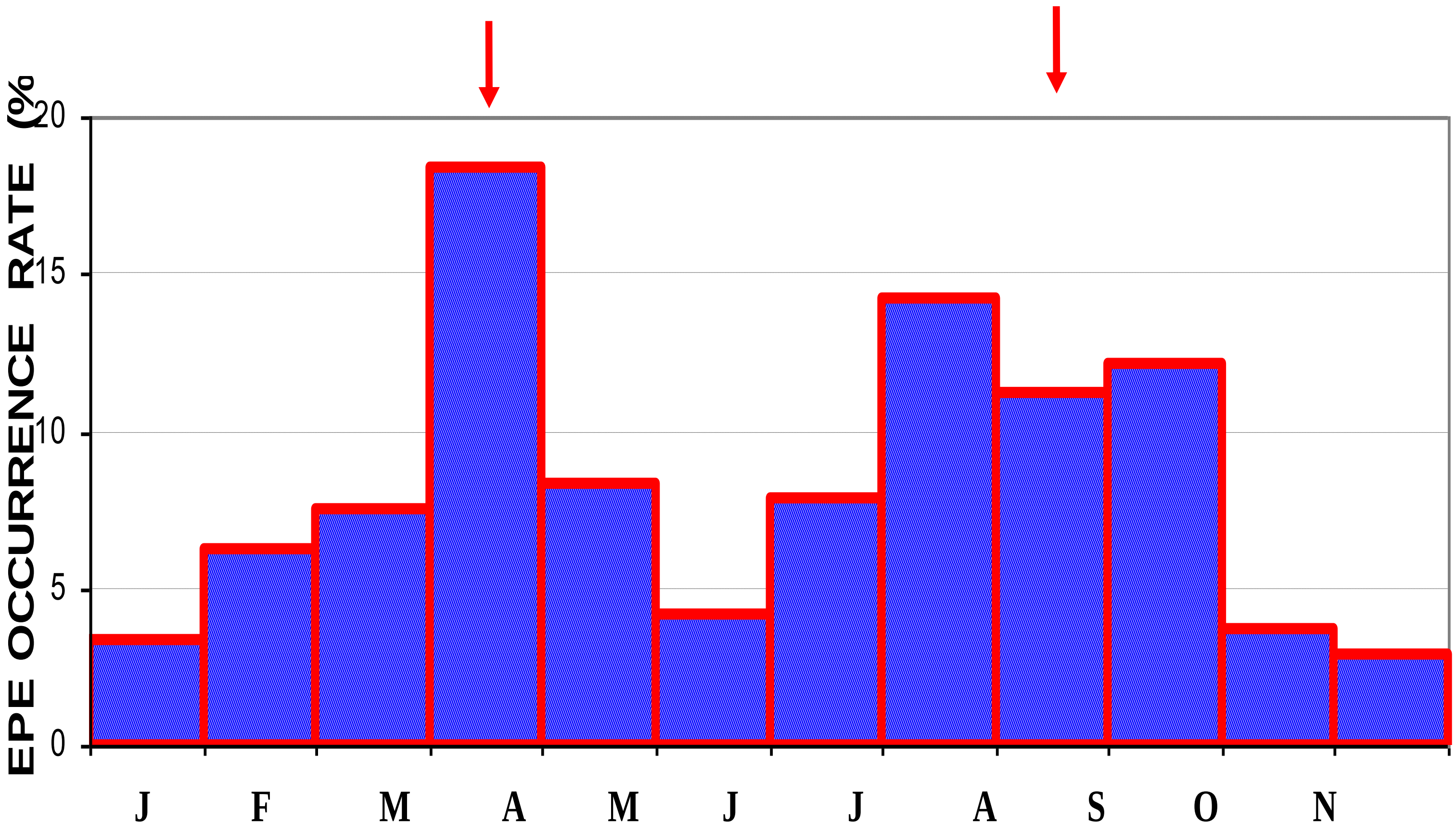
$$dN_{ph}/dE = A_{ph,o} * exp(-E/E_{ph,o}) \qquad dN_e/dE = B_{oe} * exp(-E/E_{oe})$$

EPEs observed at Murmansk polar region in 1958-2010



Yearly numbers of electron precipitation events in the Murmansk region. Sunspot number (blue curve) is given to outline the 11-year solar activity cycles.

Seasonal effect in the EPE occurrence rate.



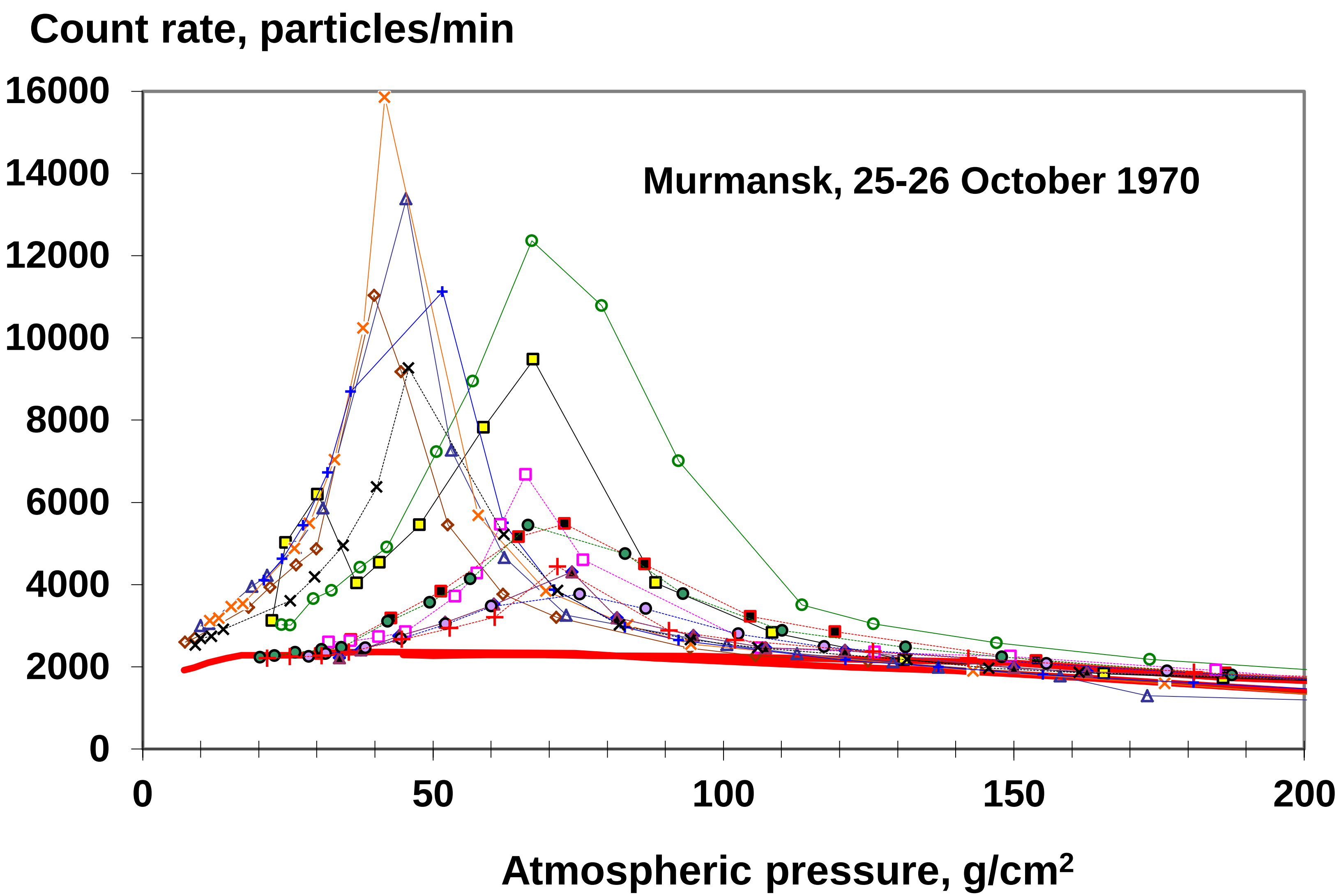
The monthly occurrence rate (in % per month) of the Electron Precipitation Events observed in the atmosphere at Olenya, Murmansk region during 1970-1987. Total number of EPEs is 240.

План доклада

Введение

1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

Заключение



On 14 October 1970 the power nuclear explosion on the Earth's surface was produced at Lobnor's poligon in China. Radioactive cloud from this explosion was recorded in the atmosphere at Murmansk, Moscow and Alma-Ata duing October and November.

The radioactive cloud was observed in the atmosphere more than 1 month. In Murmansk region the increase of count rate was in several times in comparison with natural background. For the period from 10 o'clock 25 October till 16 o'clock 26 October 14 launches of radiosounds were made (here and below the Moscow time is used). At the previous slide the data for 25 October are shown with solid curves and for 26 October - with dashed curves. The maximum of count rate was recorded at 17 o'clock 25 October and it excesses the background in 7.5 times. The particle fluxes were increased till 17 o'clock 25 October and after this time the gradual decrease of particle fluxes was observed. This gradual decrease took place up to 16 o'clock 26 October.

The maximum density of radionuclides was recorded on 25 October at the altitudes of 18 – 24 km (atmosphere pressure is 30–70 g/cm^2). During the next day the position of maximum decreased at 20–18 km.

The radioactive cloud had a flat disk form at the altitudes 18 – 24 km. This cloud had strong marked core. The cloud horizontal sizes were evaluated from wind speed in the atmosphere over Murmansk. At the altitudes of 18 – 24 km the wind speed was about 10 m/sec. The cloud was recorded about 30 hours. It gave the horizontal size of cloud along the wind direction (west – east) about 1100 km. As cloud sizes along the wind direction and perpendicular to it are formed the diffusion mechanism, it means that cloud sizes along the wind direction and perpendicular to it have to be equal approximately.

План доклада

Введение

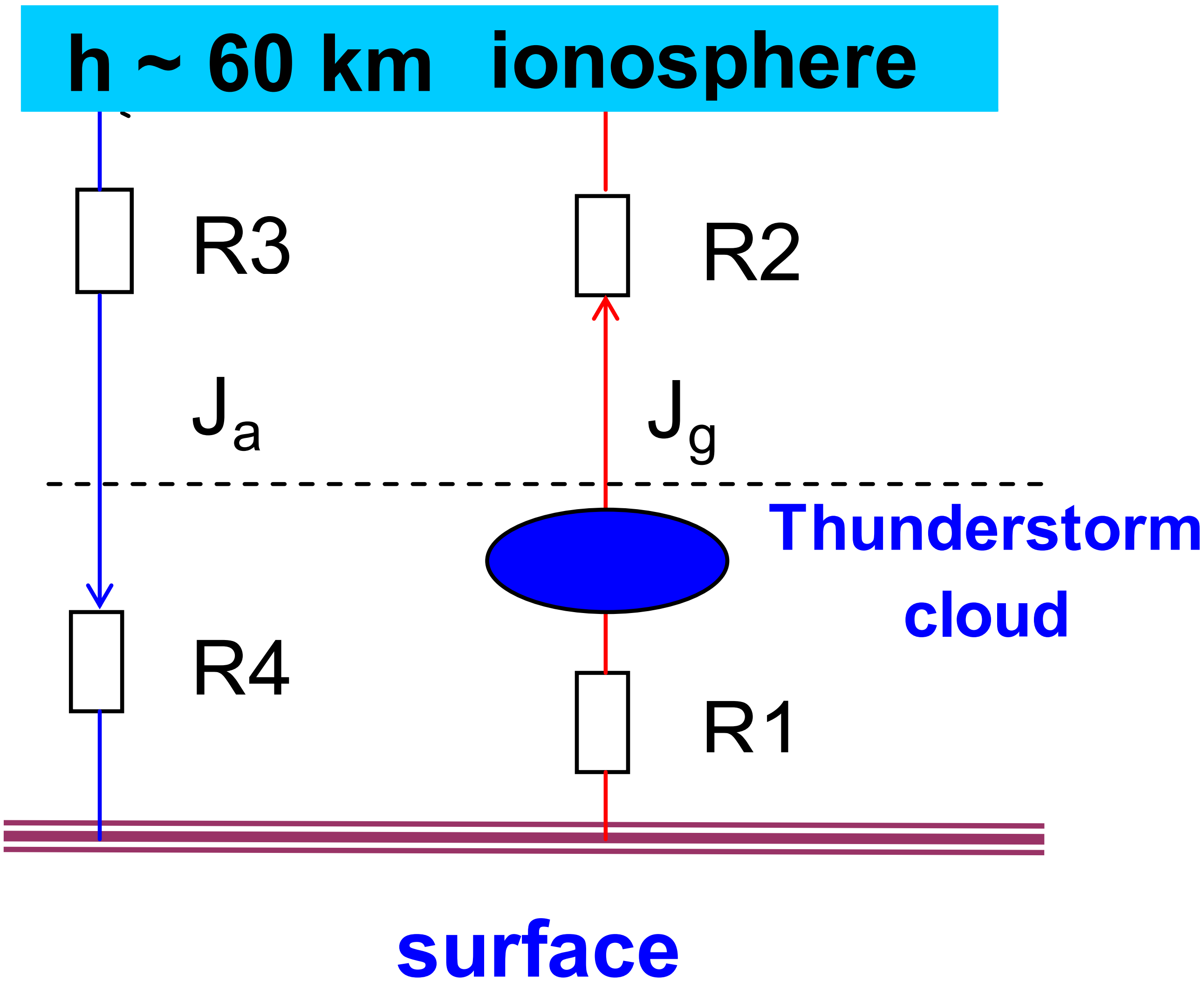
1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

Заключение

Ion production rate in the atmosphere (over globe)

Ionization source	Number of ion pairs per second
Natural radioactivity (*h* < 3 km)	$< 10^{24}$
GCRs (all atmosphere)	$\sim (10^{27} – 10^{28})$
SCRs, precipitation (polar latitudes)	$\sim (10^{26} – 10^{27})$
UV - and *X* – solar irradiation (*h* > 50 km)	$\sim 10^{28}$
Solar wind (ionosphere)	$\sim 10^{26}$
lightning (regions with thunderstorm activity, *h*<10 km)	$\sim (10^{27} – 10^{28})$

Global electric current circuit



Electrical characteristics of the atmosphere: lightning, sprites, electric current and so on.

Electric charge of the Earth

$$Q \approx -600\,000 \text{ C}$$

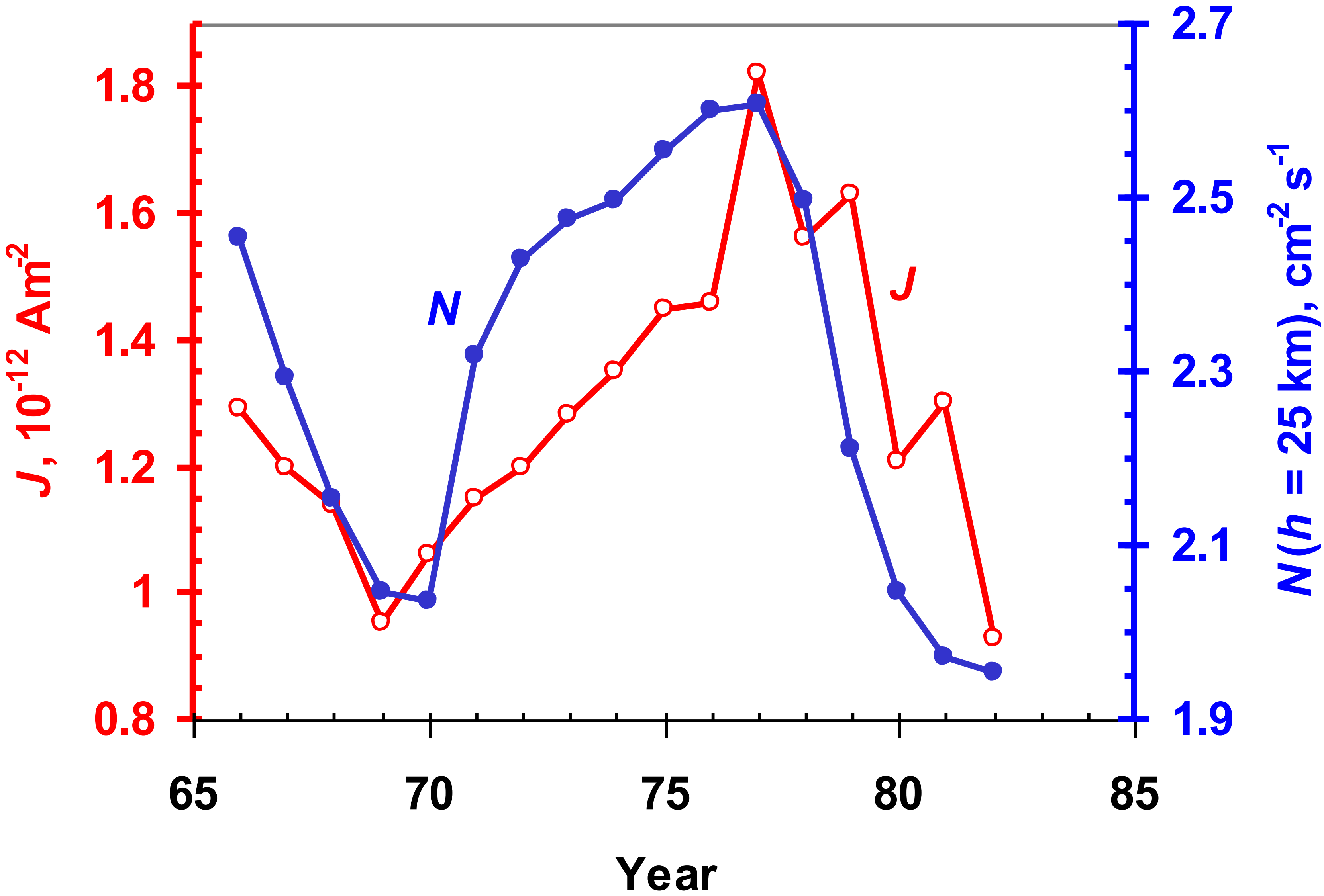
Electric field near the Earth's surface

$$E \approx 130 \text{ V/m}$$

Electric current in the atmosphere

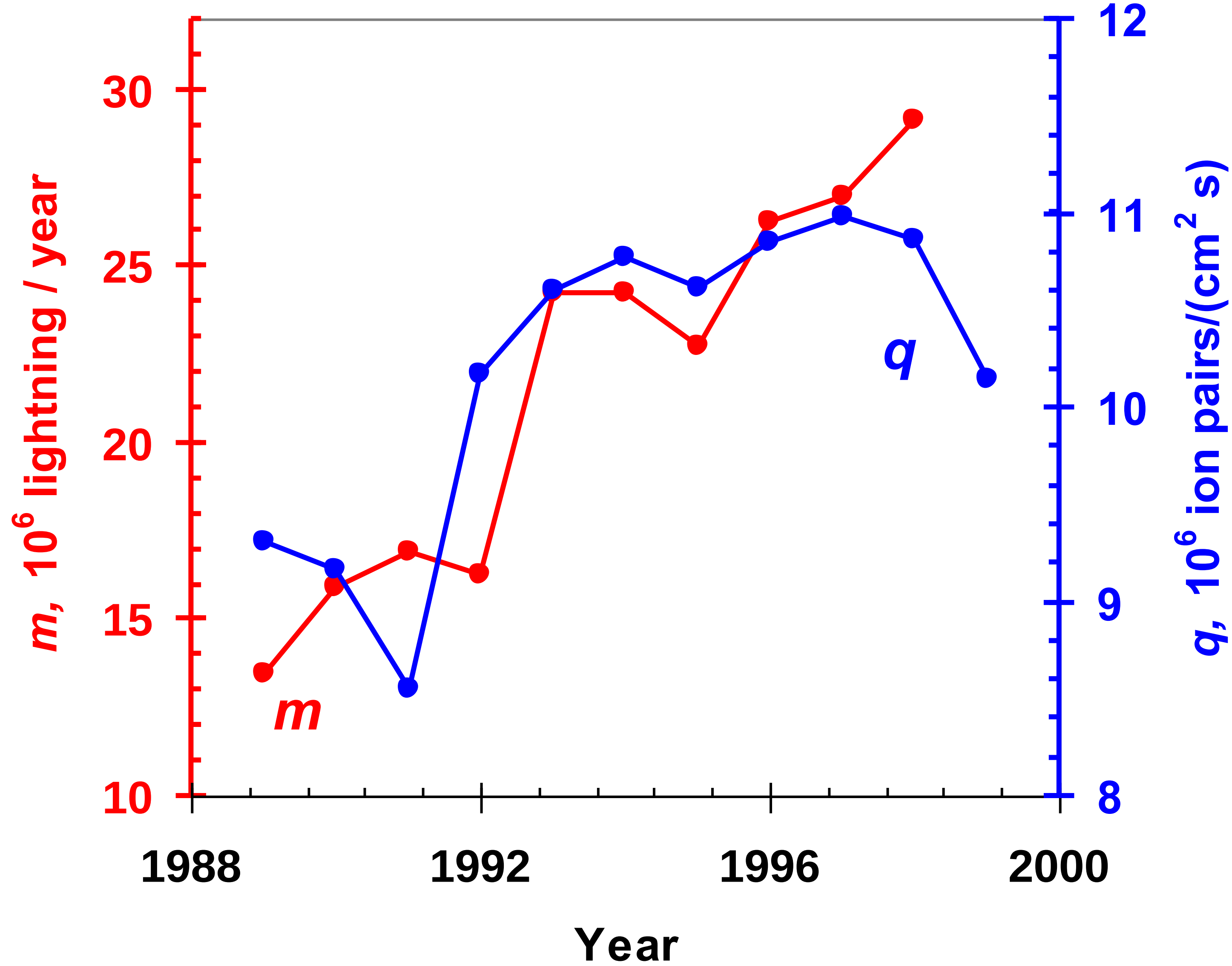
$$J \approx 10^{-12} \text{ A/m}^2$$

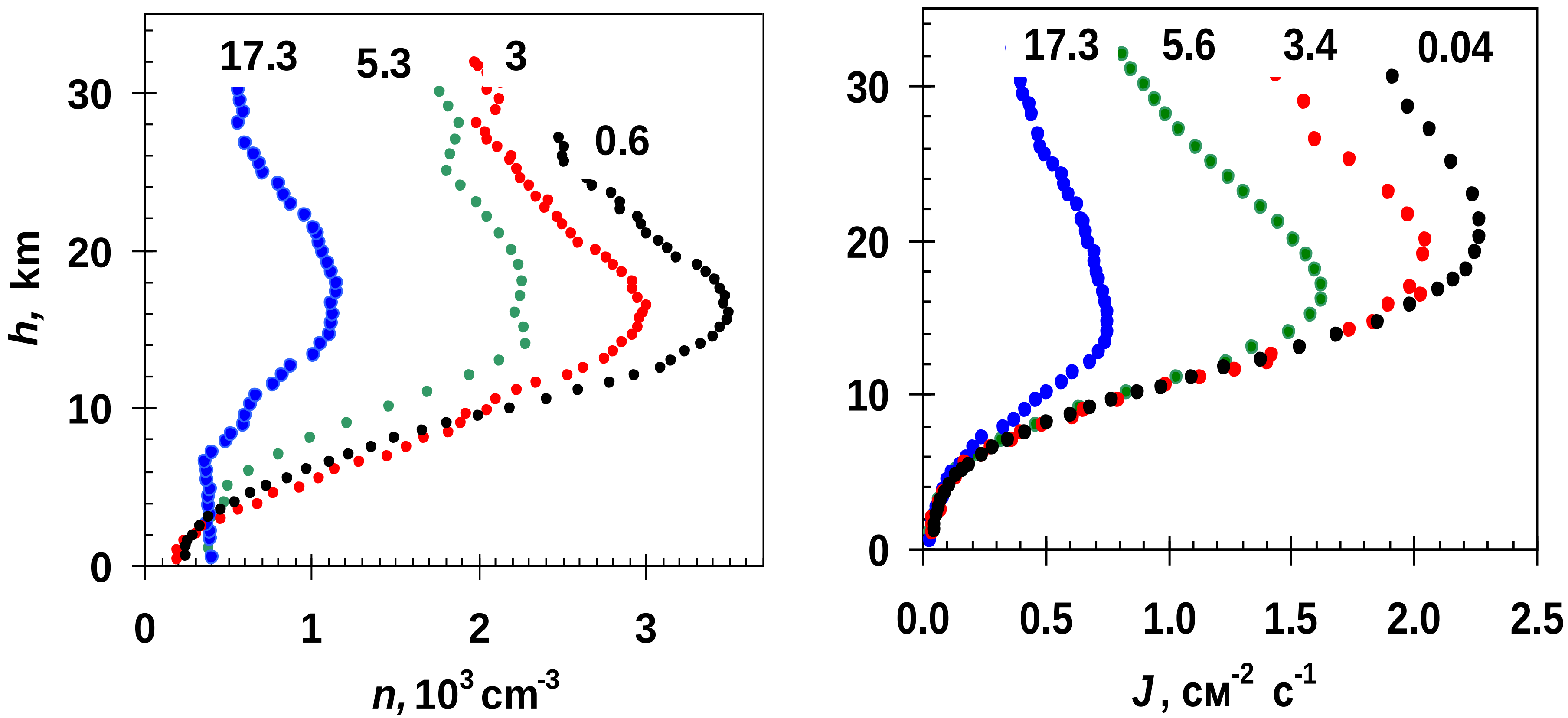
$$J_{total} \approx 2000 \text{ A}$$



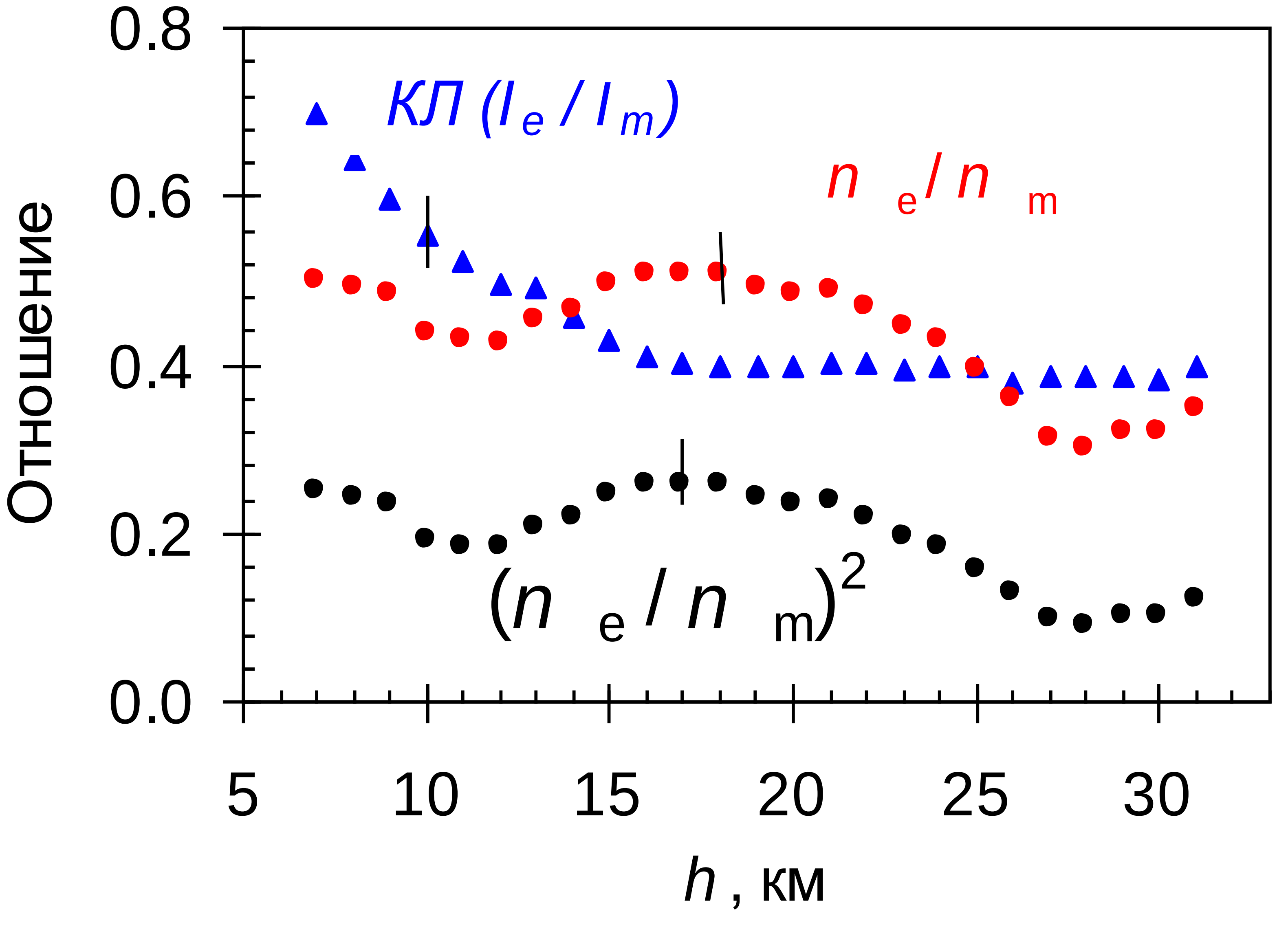
$r\ (N, J) = +\ 0.67 \pm 0.14$; $r\ (N, R_z) = -\ 0.32 \pm 0.22$

GCR flux and number of lightning




17.3
5.3
3
0.6
h, km
n, 10^3 cm^-3
17.3
5.6
3.4
0.04
J, см^-2 c^-1

$$[(n)_e / (n)_m]^2 = [(I)_e/(I)_m] \qquad [(n)_e / (n)_m] = [(I)_e/(I)_m]$$



Ion balance equation in the atmosphere

$q = \alpha \cdot n^2$ **is wrong.**

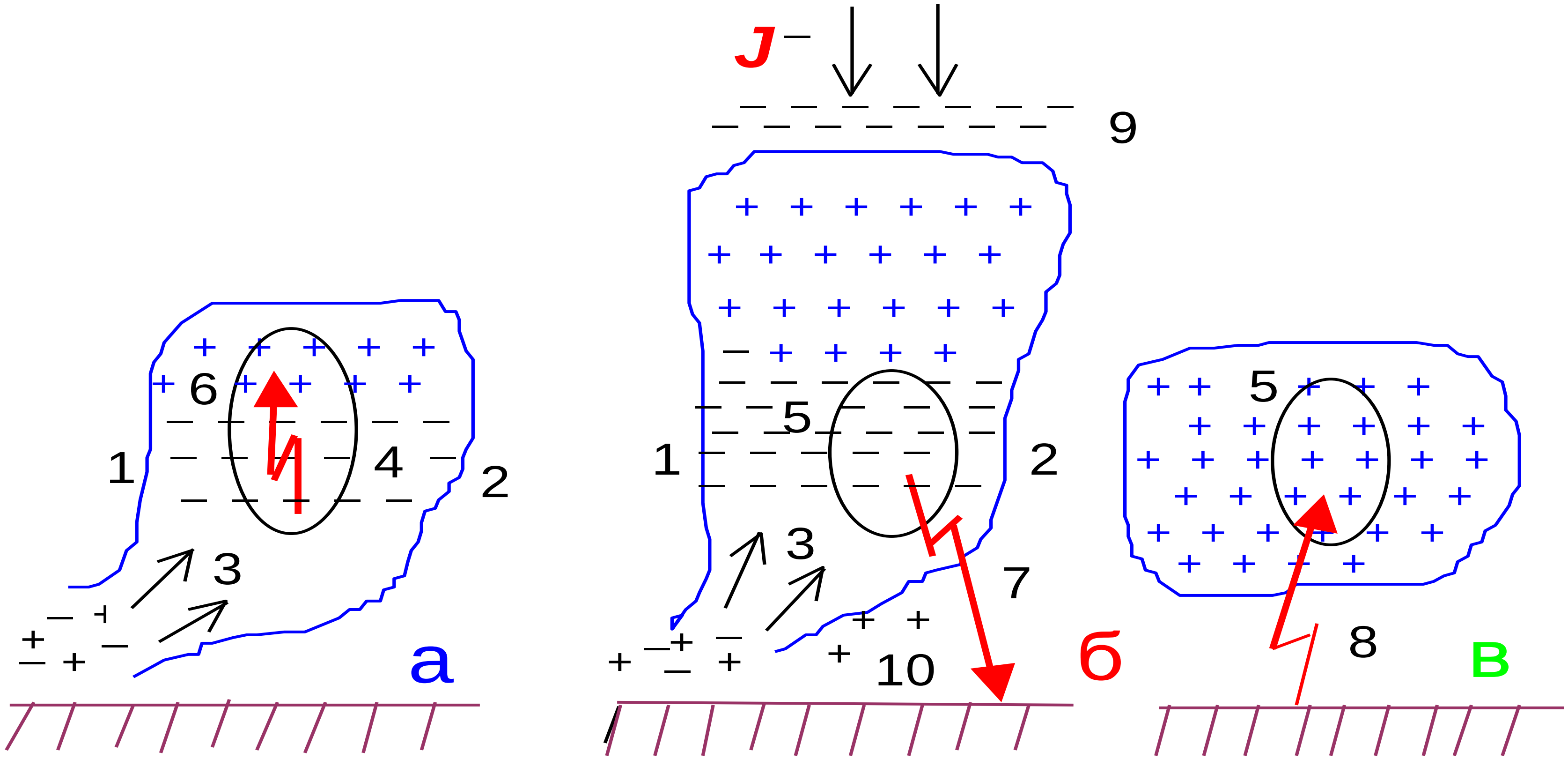
The right equation is $q = \beta \cdot n$**.**

q **– ion production rate**

α **– volume recombination coefficient**

β **– linear coefficient of recombination**

n **– concentration of light ions**



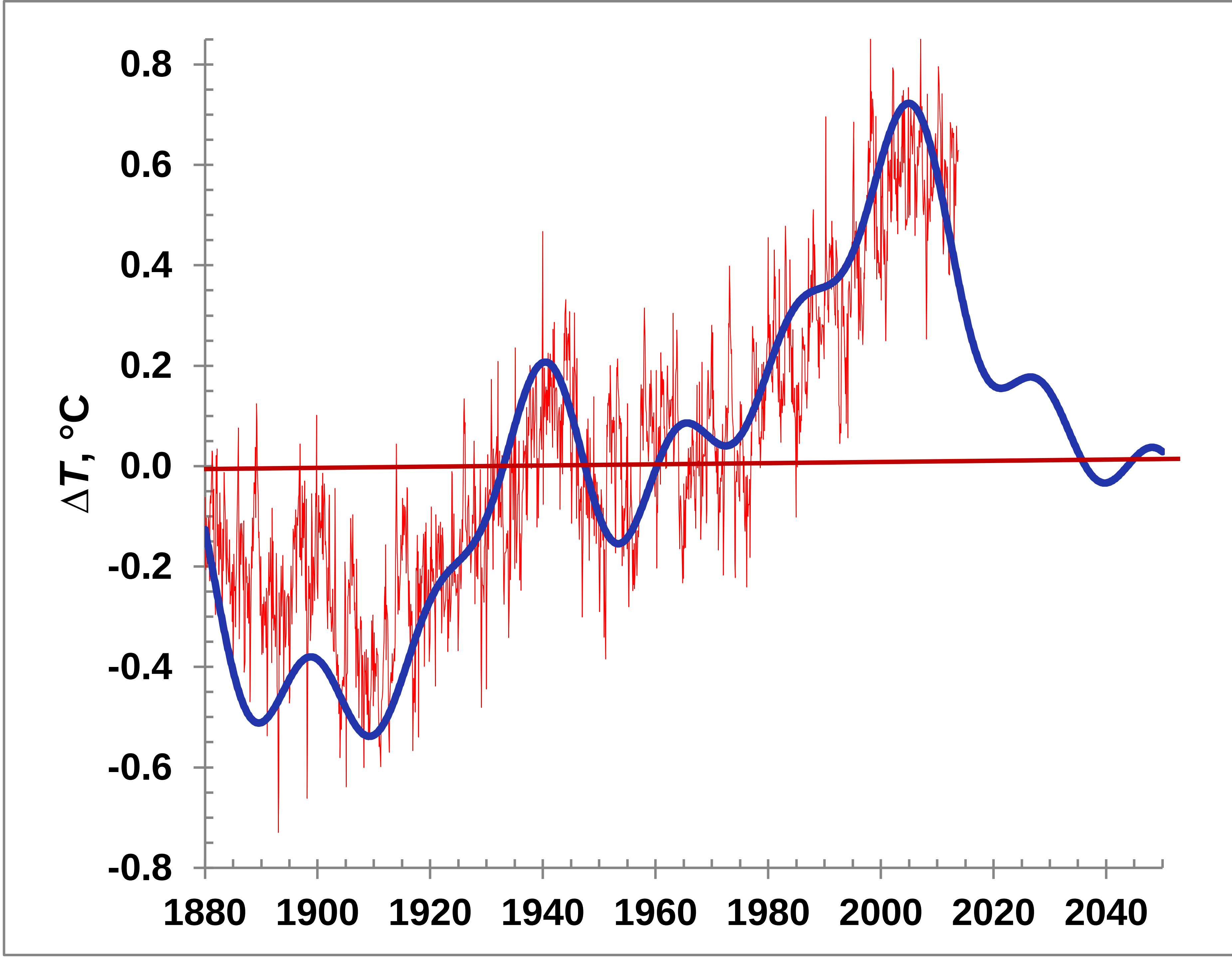
Scheme of rise, development and decay of thundercloud: a – initial phase of cloud rise; б – mature phase of thundercloud; в – decay phase; *J*⁻ - negative ion current from ionosphere to the cloud top; 1 – front of warm air; 2 – front of cold air; 3 – ascending fluxes of wet air; 4, 5 – extensive air showers produced by particles with energy $E > 10^{14}$ eV and $E > 10^{15}$ eV; 6 – intra cloud electric discharges; 7 – cloud – the Earth's surface lightning; 8 – the Earth's surface – cloud lightning; 9 – negative electric charge at the top of cloud; 10 – positive electric charge at the bottom cloud.

План доклада

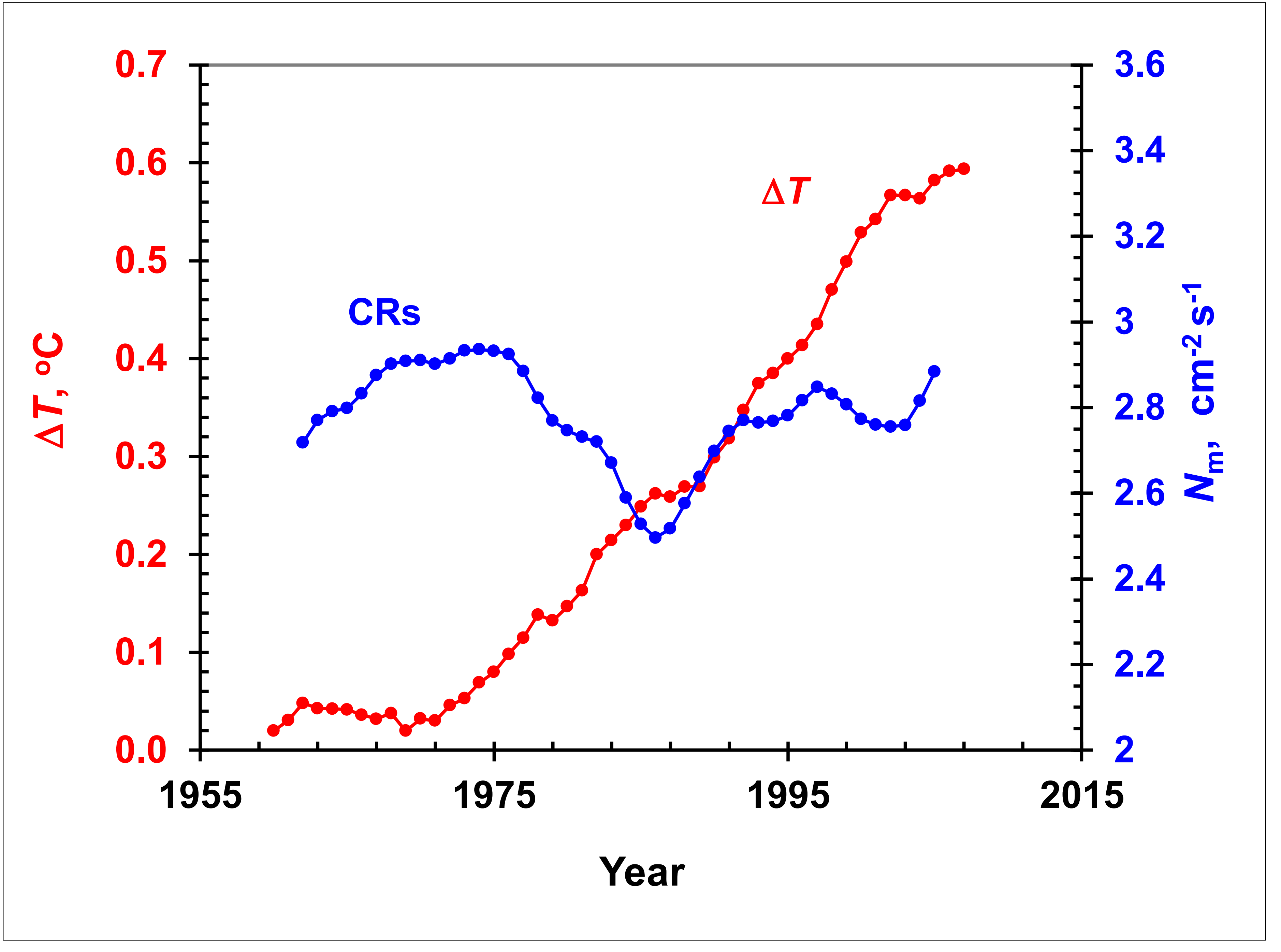
Введение

1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

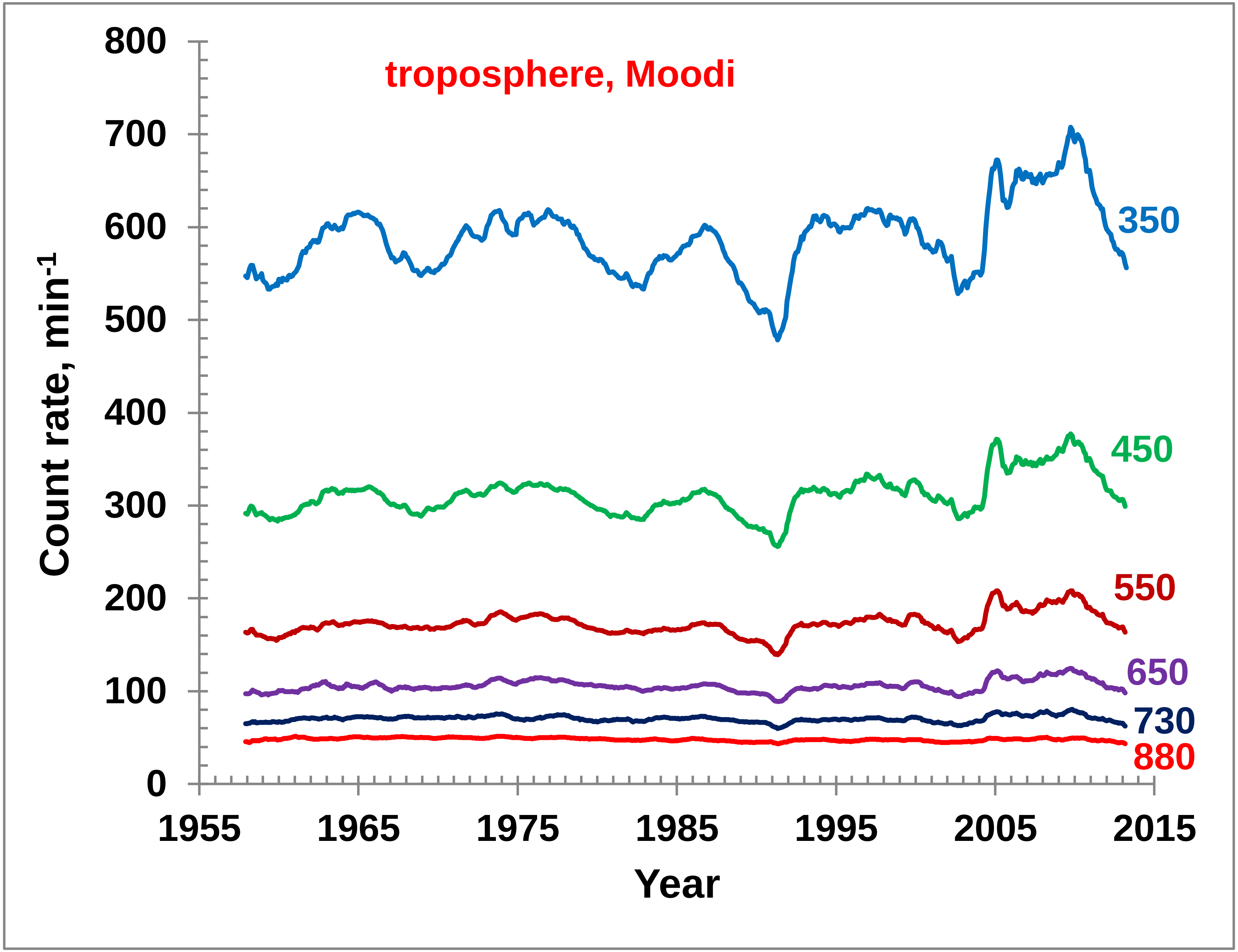
Заключение



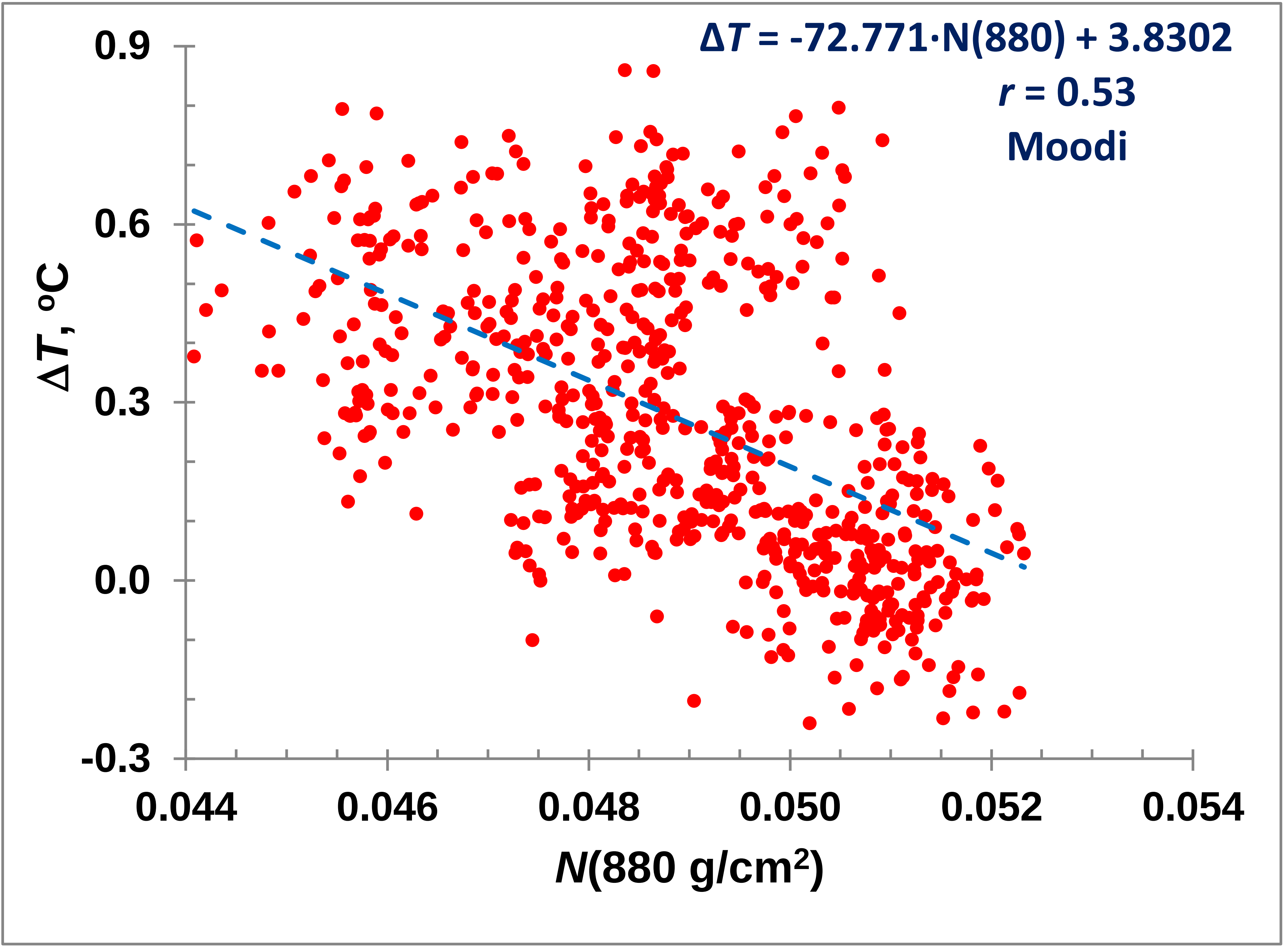
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
ΔT, °C
1880
1900
1920
1940
1960
1980
2000
2020
2040



0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
ΔT, °C
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
N_m, $cm^{-2}s^{-1}$
1955
1975
1995
2015
Year
CRs
ΔT



Cosmic ray fluxes in the troposphere at the middle latitude, R_c = 2.4 GV



ΔT = -72.771·N(880) + 3.8302
r = 0.53
Moodi
0.9
0.6
0.3
0.0
-0.3
ΔT, ºC
0.044
0.046
0.048
0.050
0.052
0.054
N(880 g/cm²)

План доклада

Введение

1. Метод регулярного зондирования потоков КЛ в земной атмосфере
2. Временные изменения ГКЛ
3. Солнечные космические лучи
4. Высыпания энергичных электронов в атмосферу
5. Радиоактивность в атмосфере
6. КЛ и атмосферное электричество
7. КЛ и климат

Заключение

СПАСИБО ЗА ВНИМАНИЕ