

S. N. VERNOV AND STUDY OF COSMIC RAYS IN THE ATMOSPHERE

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Outline

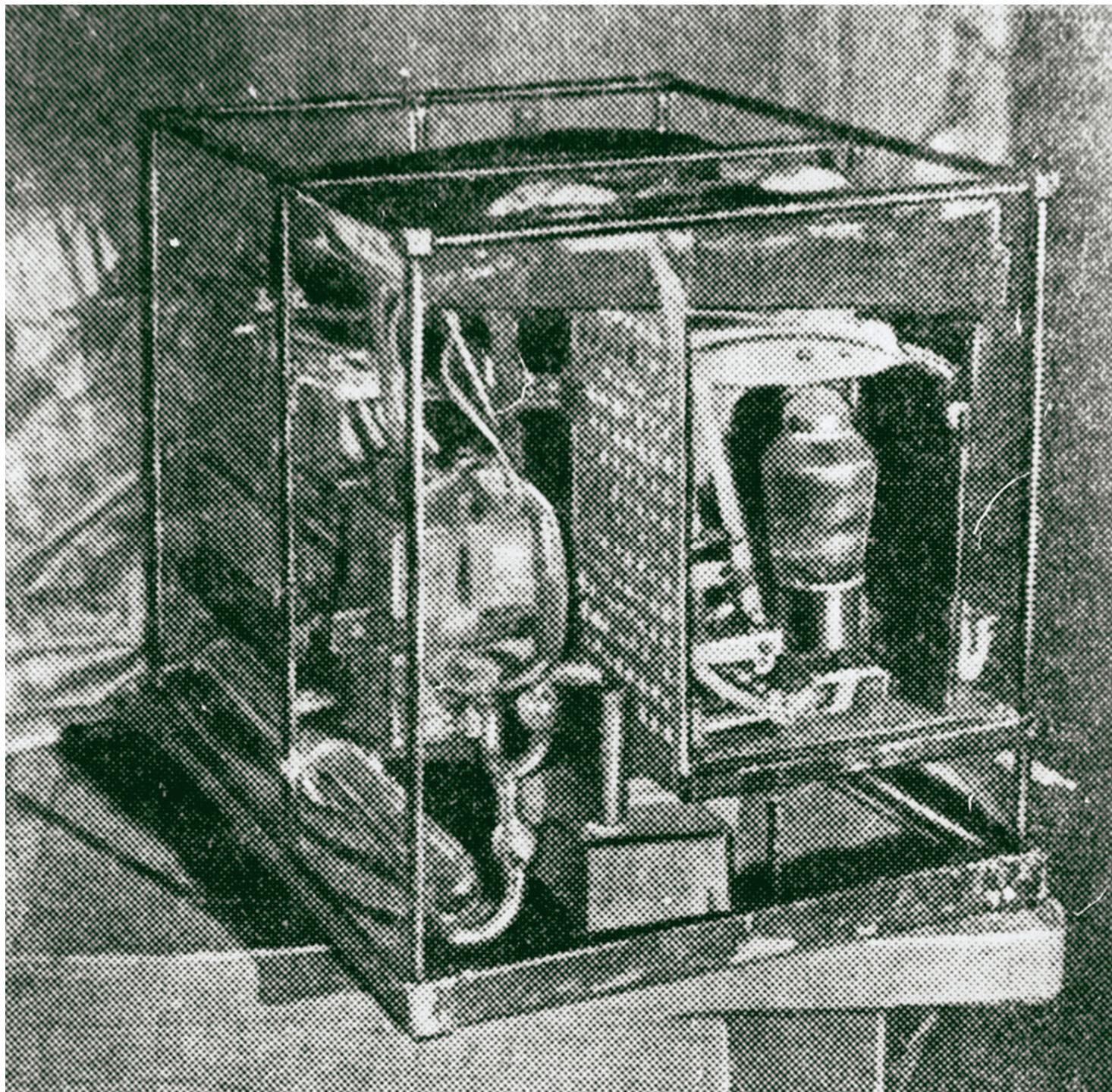
- 1. Introduction**
- 2. S.N. Vernov and cosmic ray investigations in the atmosphere before 1957**
- 3. Monitoring of cosmic ray fluxes in the atmosphere. Main results**
- 4. Cosmic rays, atmospheric electricity, and the Earth's climate**
- 5. Perspectives of regular observations of cosmic rays in the atmosphere**
- 6. Conclusion**

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Milstones of Cosmic Ray Study in the beginning of the 20th century

- 1912 – Cosmic Ray discovery by V. Hess
- 1920-1930ies – barometric and latitude effects in CR (Benade, Bowen, Clay, Compton, Johnson, Ledig, Millikan, Myssowsky, Neher, t'Hooft, Tuwim, van Alpen)
- 1935-1938 – first CR measurements made by S.N. Vernov with radiosondes at Leningrad region, Erevan, and in Indian ocean.



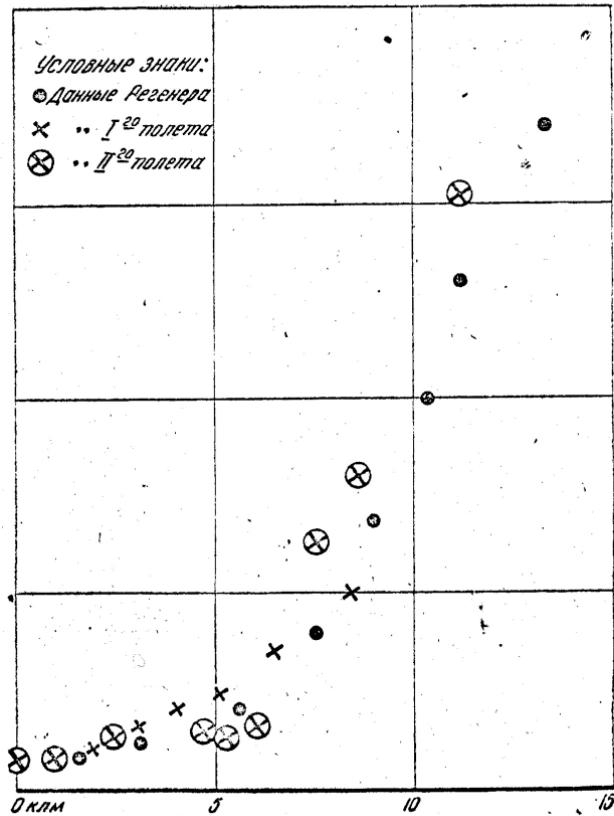


Рис. 1. Зависимость числа космических лучей, достигающих прибора по любому направлению, от высоты.

ющие вертикально идущие космические лучи, батарея на 1 400 вольт, необходимая для работы счетчиков, и нестилиамновый усилитель, приводящий в движение реле. Реле производило замыкание аподной цепи передатчика всякий раз, когда через счетчики пролетали космические частицы. Внутри прибора поддерживалась постоянная температура, что достигалось при помощи тепловой изоляции и специального терморегулятора, где источником тепла являлась реакция между кислотой и щелочью. В установке имелся барабанчик, который, производя соответствующие переключения, передавал по радио данные о высоте.

Конструкция прибора была доведена на первой Всесоюзной конференции по изучению стрatosфера в 1934 г.

В июле 1934 г. прибор был поднят на само-

летах до высоты 6 км и показал удовлетворительную работу:

Полёт установки состоялся 1 апреля 1935 г. Максимальная высота, до которой поднялся первый автостратостат, была 13 600 м. Радиолиния была непрерывной вплоть до того момента, когда один из ящичных установки шаров полета и начался спуск. Данные об интенсивности космических лучей на различных высотах сходятся с аналогичными измерениями Регенера (рис. 1). Помимо этого подъём дал новые данные об интенсивности вертикального пучка космических лучей на различных высотах (см. рис. 2). Подобного рода данные за границей пока не получены.

Вес первого типа установки составлял 18,6 кг. Для форсирования изучения космических лучей в стратосфере на различных широтах необхо-

First results of measurements of cosmic ray flux as a function of altitude in the atmosphere from the ground level up to 15 km. Observations were made in the Leningrad region in 1935.

The data were transmitted by radio.

- The Second World War interrupted the Cosmic Ray investigations. S.N. Vernov was involved in the solving of defense problems.
- He resumed CR investigations at Lebedev Physical institute where the Dolgoprudny station was established in 1946.

In 1946 the Scientific Station for cosmic ray investigations in the atmosphere was established at Dolgoprudny town, Moscow region.

Since 1986 the Dolgoprudny station bears the name of S.N. Vernov.

The station belongs to Lebedev Physical Institute of the Russian Academy of Sciences.



The main building of the Dolgoprudny cosmic ray station

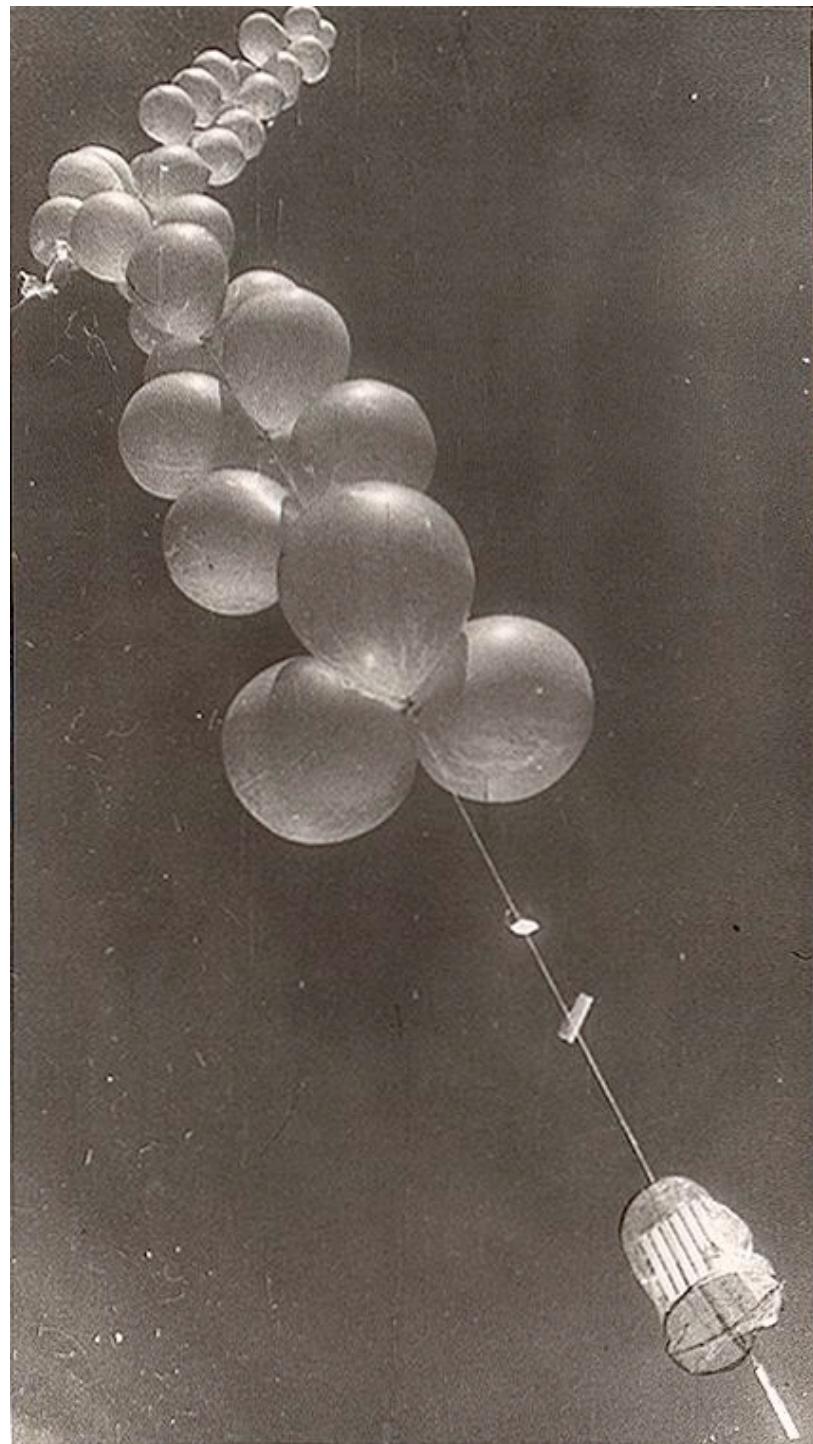
- In 1949 S.N. Vernov organized the special sea expedition from Black Sea to Far East. The main goal was the study of the charge sign of cosmic particles.



Expedition of 1949, Indian Ocean

Preparation of a radiosonde for launching. Indian Ocean, 1949.





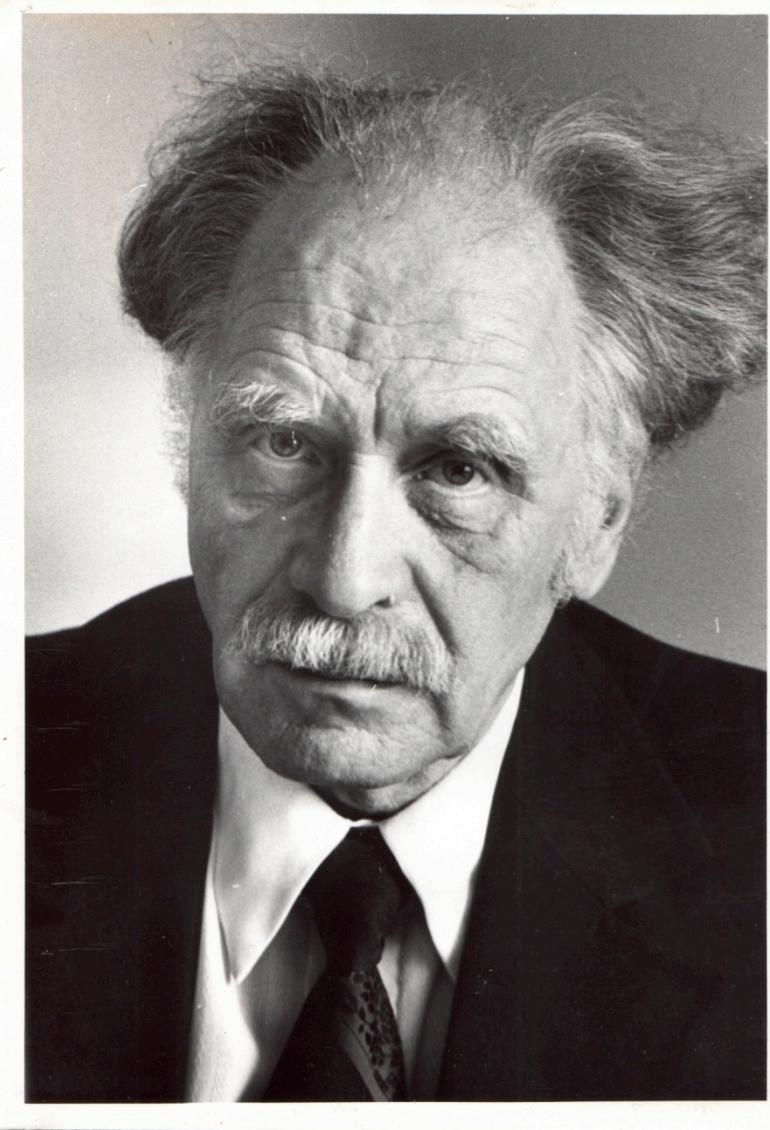
Main results obtained by S.N. Vernov and his colleagues before 1957

- Cosmic rays are charged particles, their fluxes depend on the latitude.
- East-West asymmetry of CR fluxes proves that CR particles are charged positively.
- Verification of cascade theory and CR transition effect.
- Study of different components of CRs (nuclear, muon, and electromagnetic).
- Constancy of the effective cross-section and inelasticity coefficient in the processes of interaction of protons with air nuclei ($E = 10^9 - 10^{10}$ eV).
- Scaling in the spectra of particles produced in the nuclear interactions.

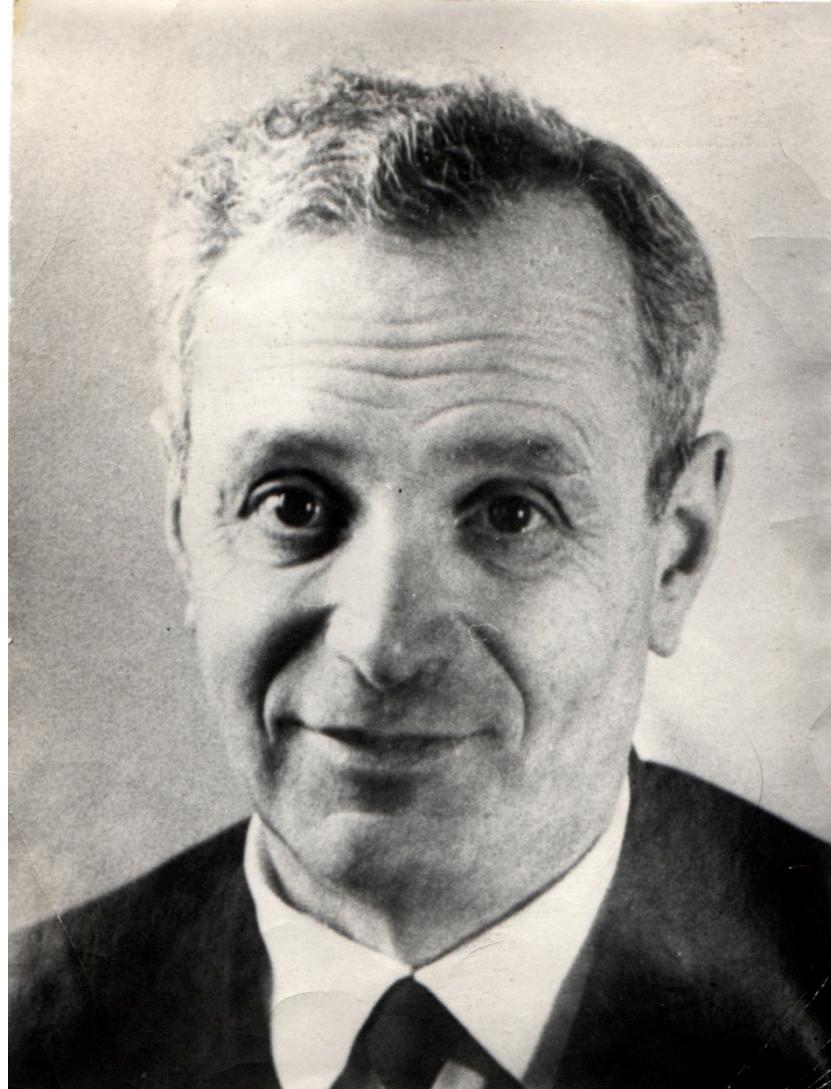
**In 1949 S.N. Vernov was awarded
with the State Prize of the first
degree for experimental
investigations of CRs in the
Earth's stratosphere.**

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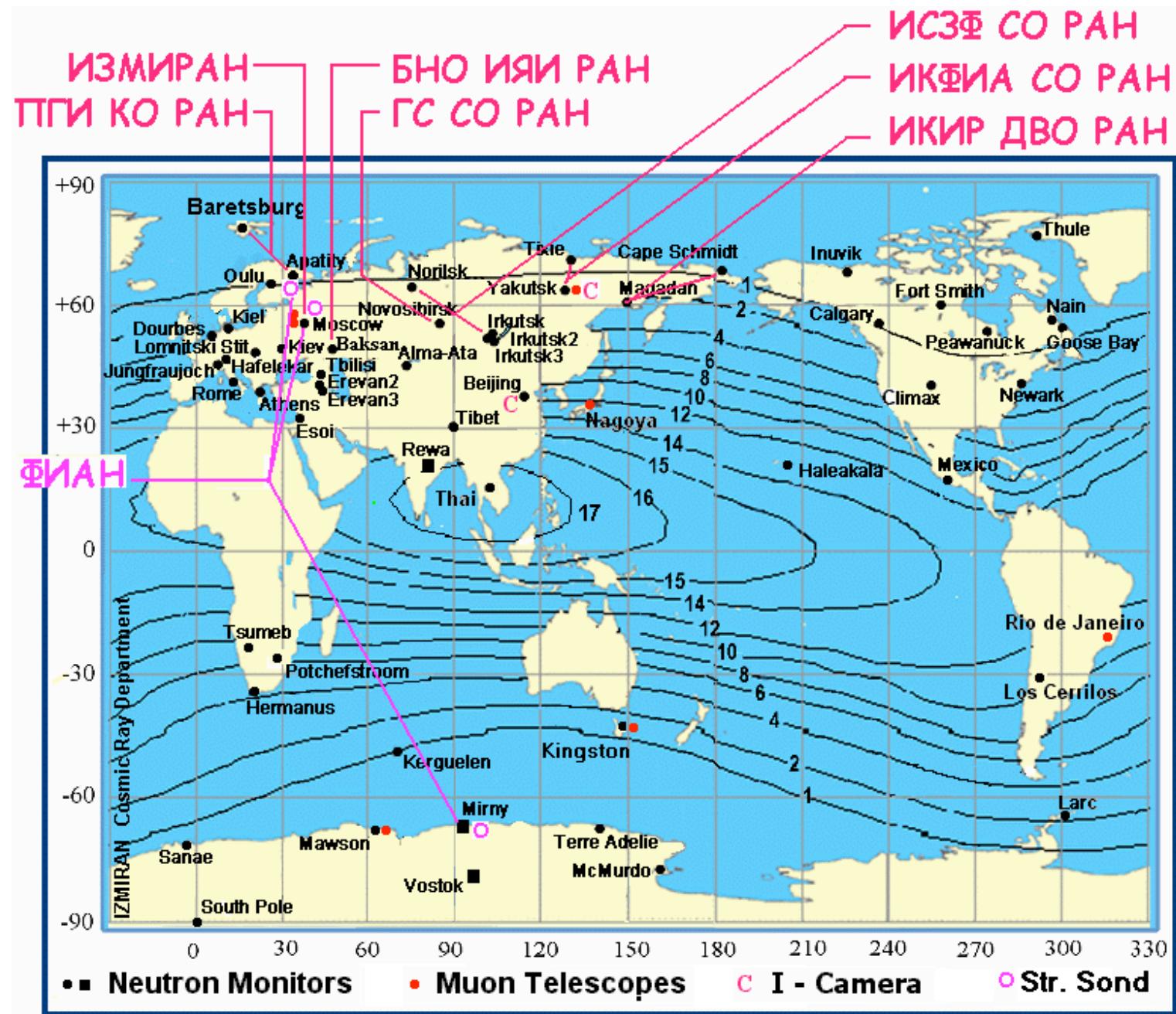


S.N. Vernov
(11.07.1910 – 26.09.1982)

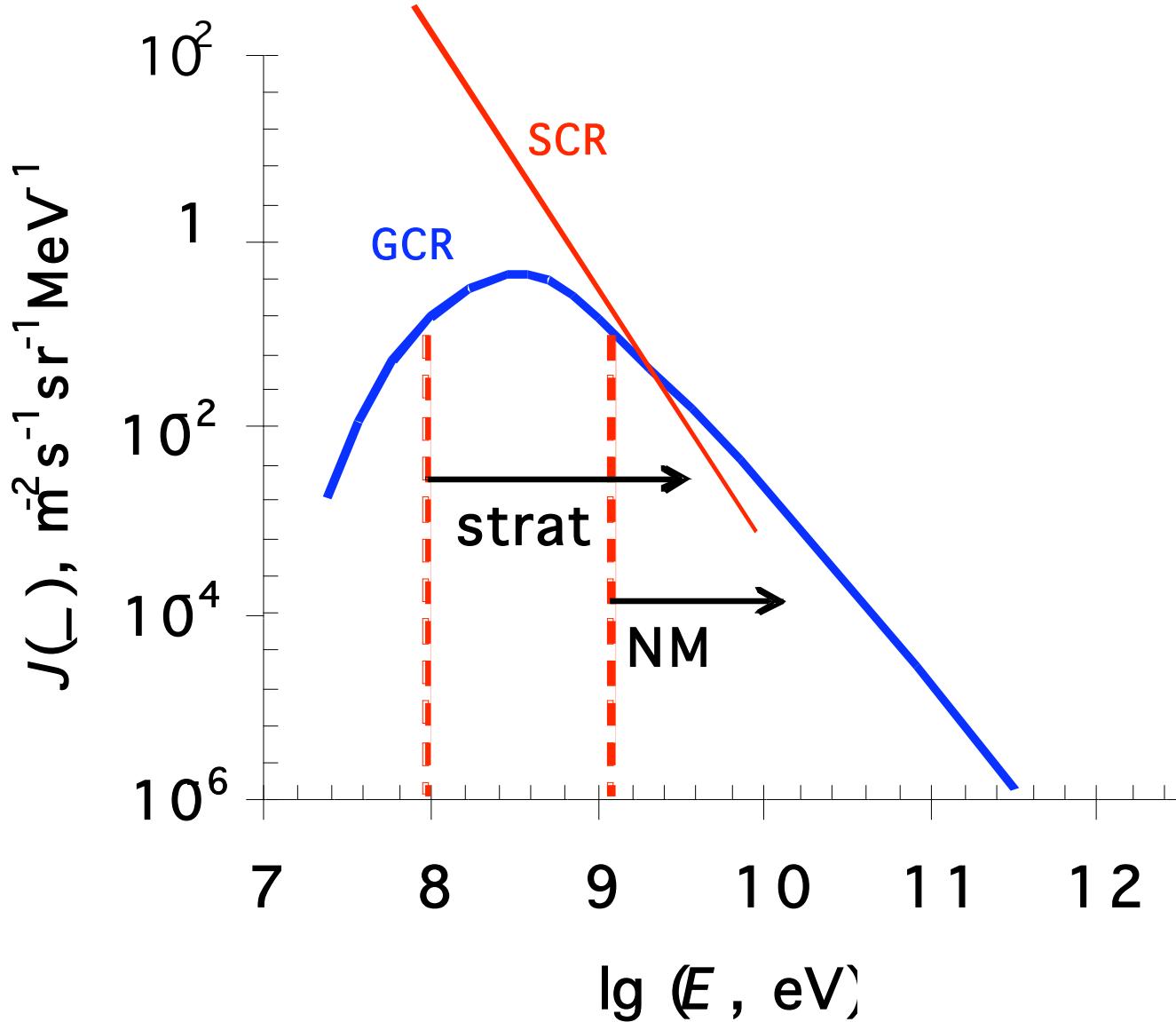


A.N. Charakhchyan
(1.11.1905 – 8.03.1981)

World-wide network of Cosmic Ray stations



CR energy spectrum



The sites of CR measurements in the atmosphere

1. Olenya, Apatity (Murmansk region)

$R_c = 0.5 \text{ GV}$ 1957 – present time

2. Dolgoprudny (Moscow region)

$R_c = 2.4 \text{ GV}$ 1957 – present time

3. Mirny Observatory (Antarctica)

$R_c = 0.04 \text{ GV}$ 1963 – present time

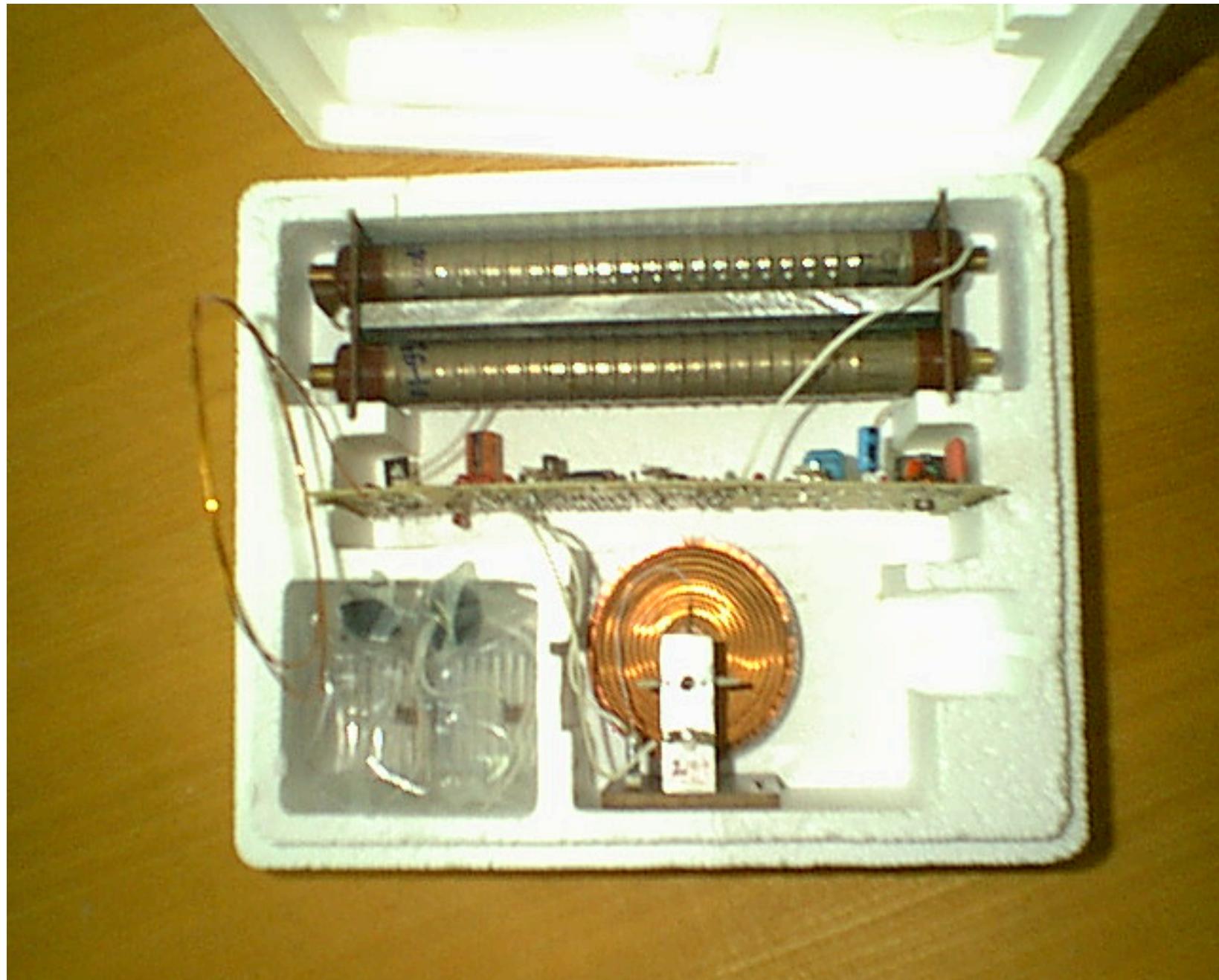
4. Alma-Ata

$R_c = 6.7 \text{ GV}$ 1962 – 1990

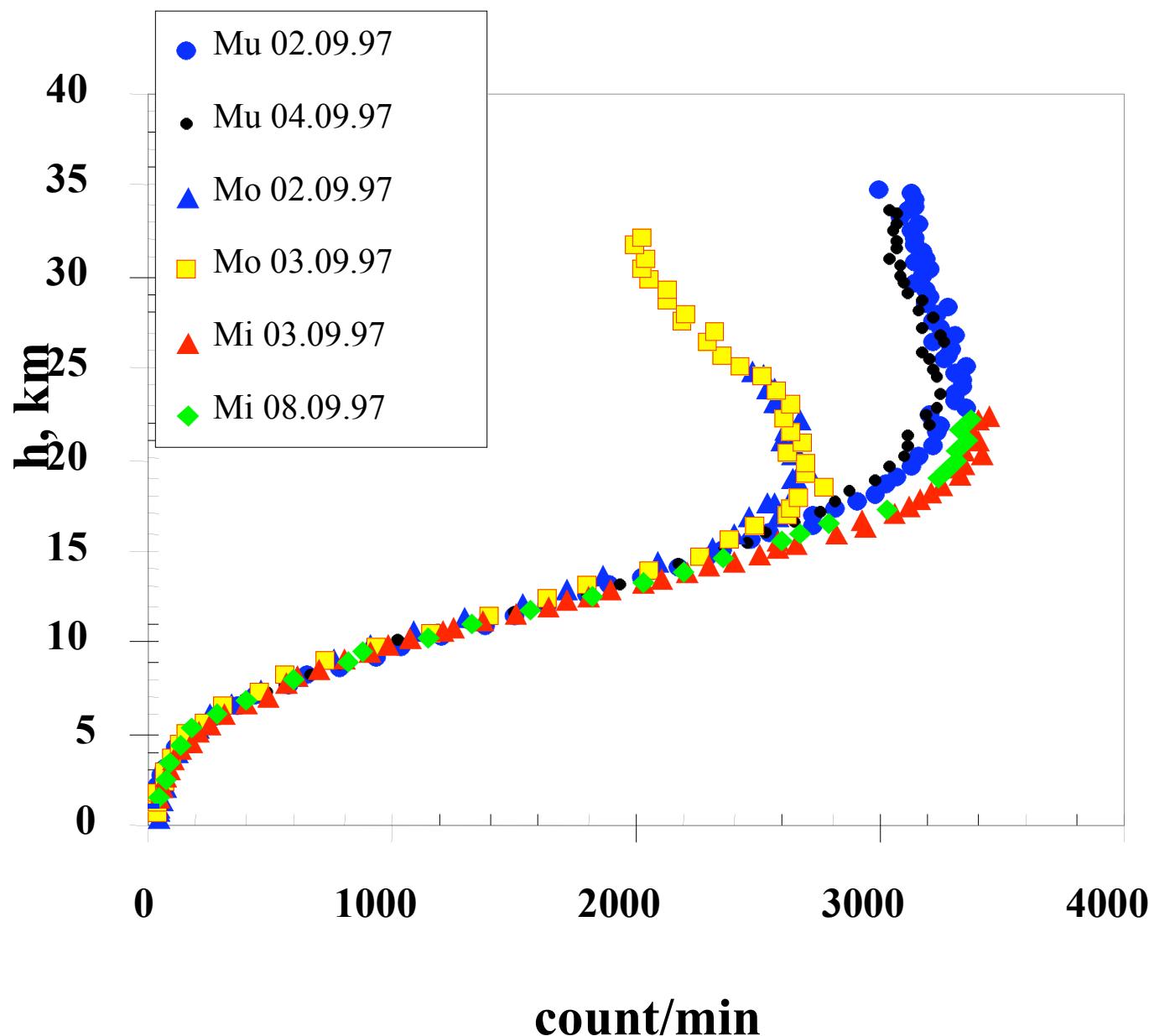
5. Latitude surveys

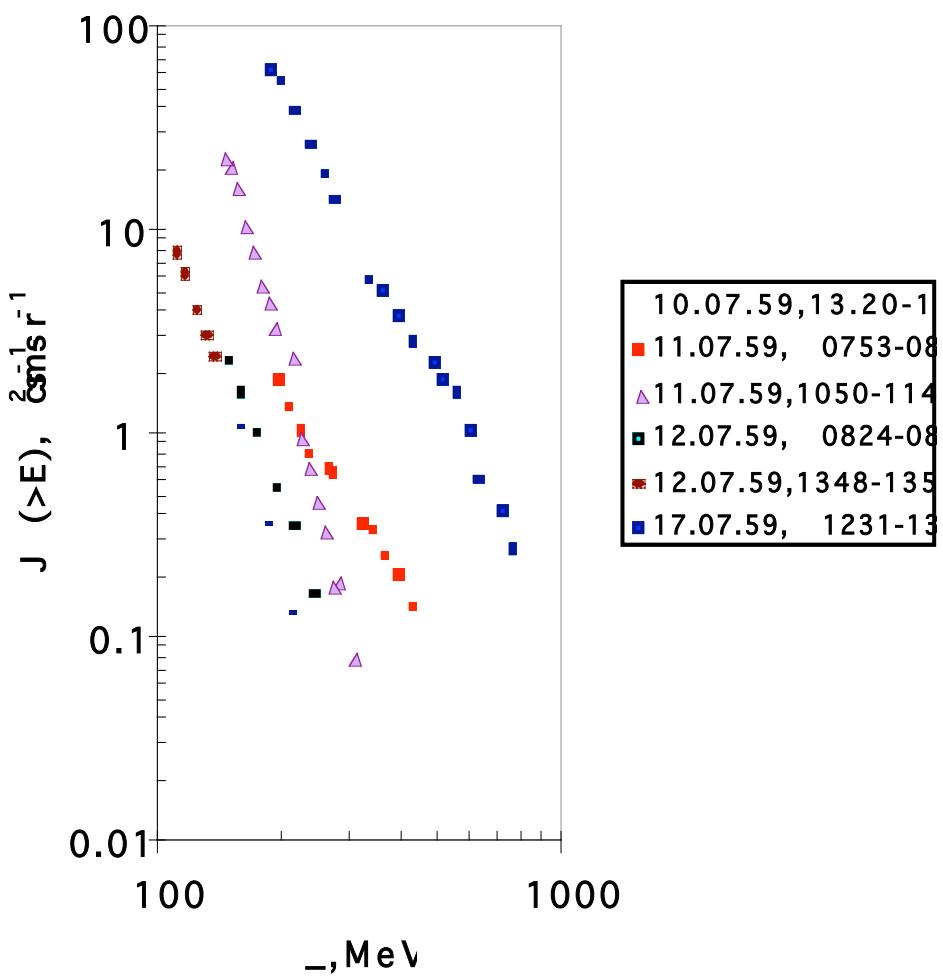
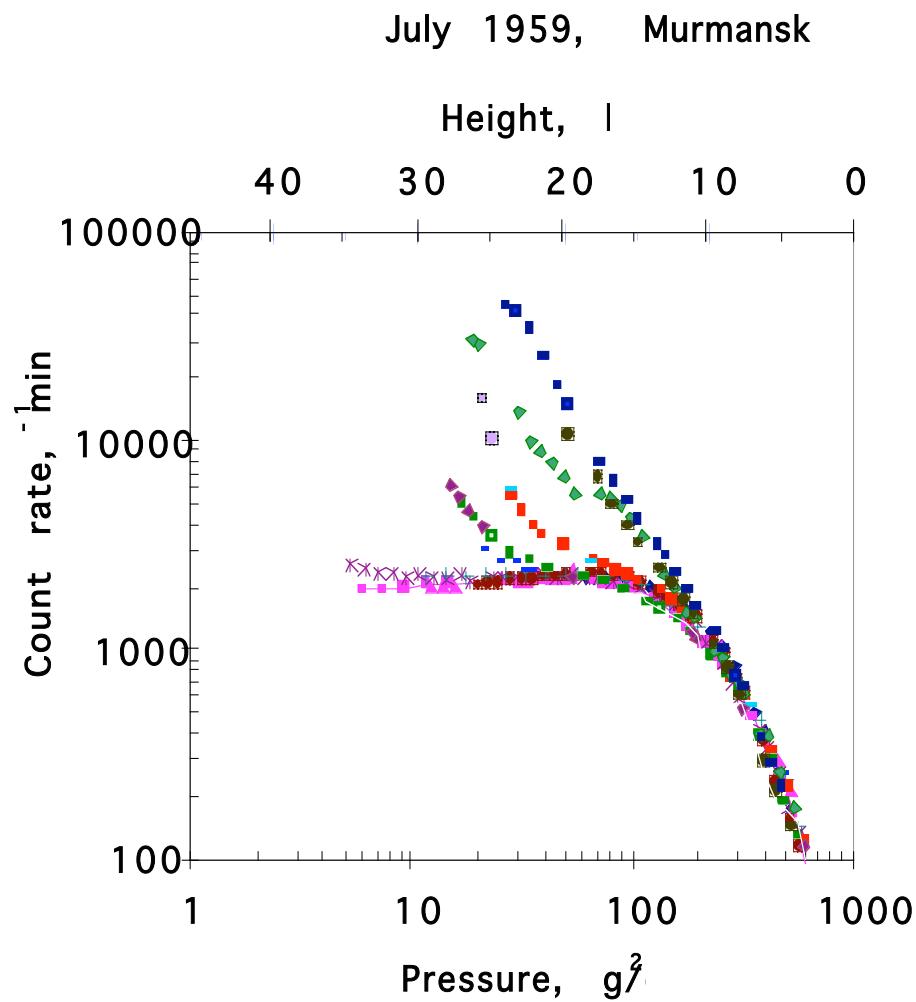
$R_c = (0.04 – 17) \text{ GV}$ 1963 – 1987

Radiosonde for CR measurements



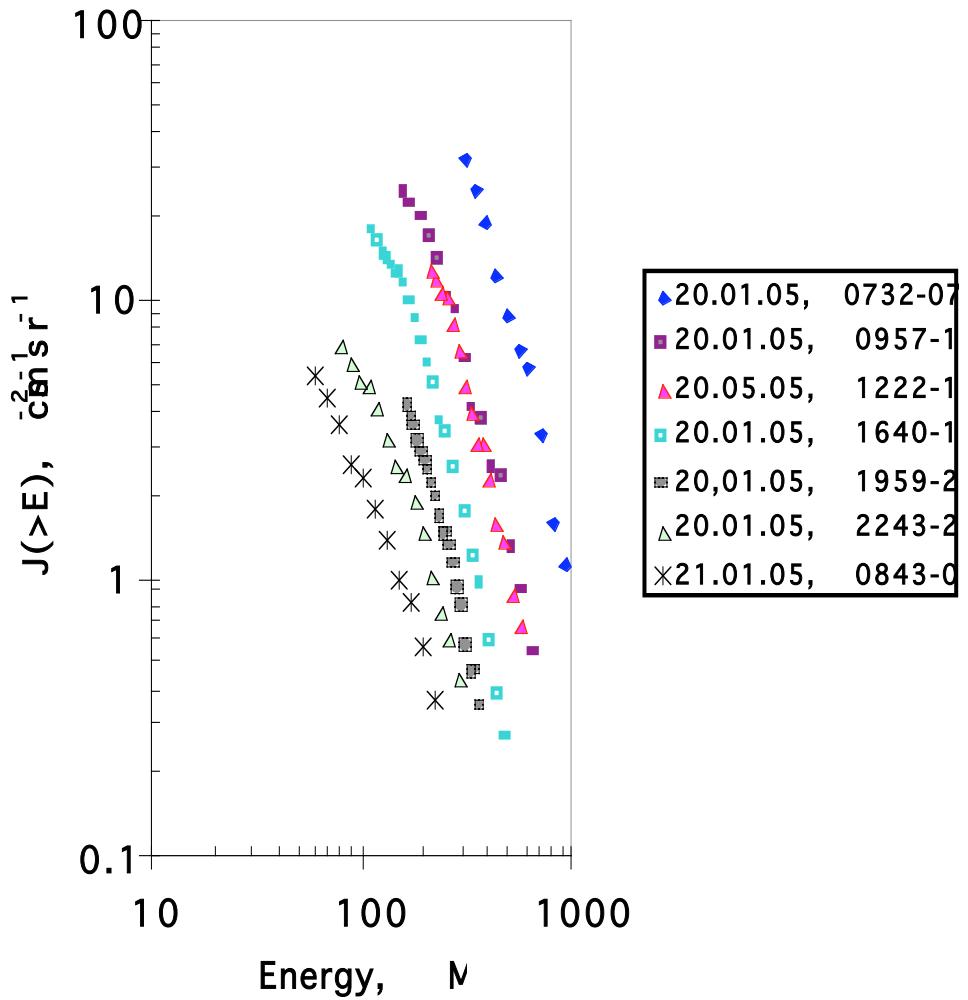
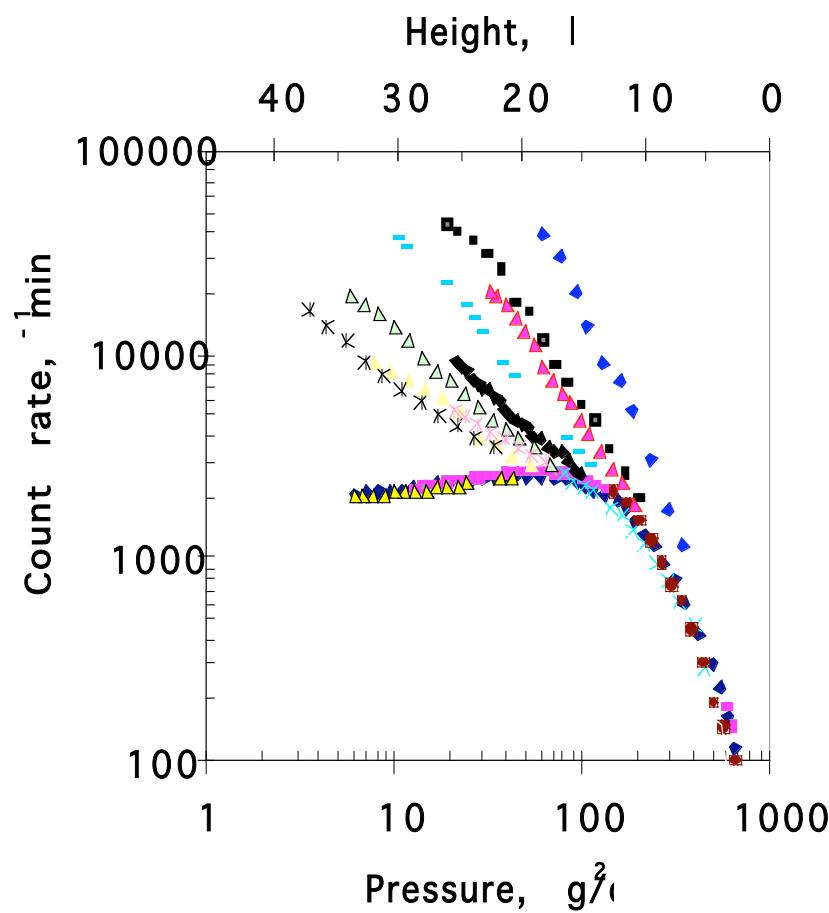
Cosmic ray fluxes in the atmosphere



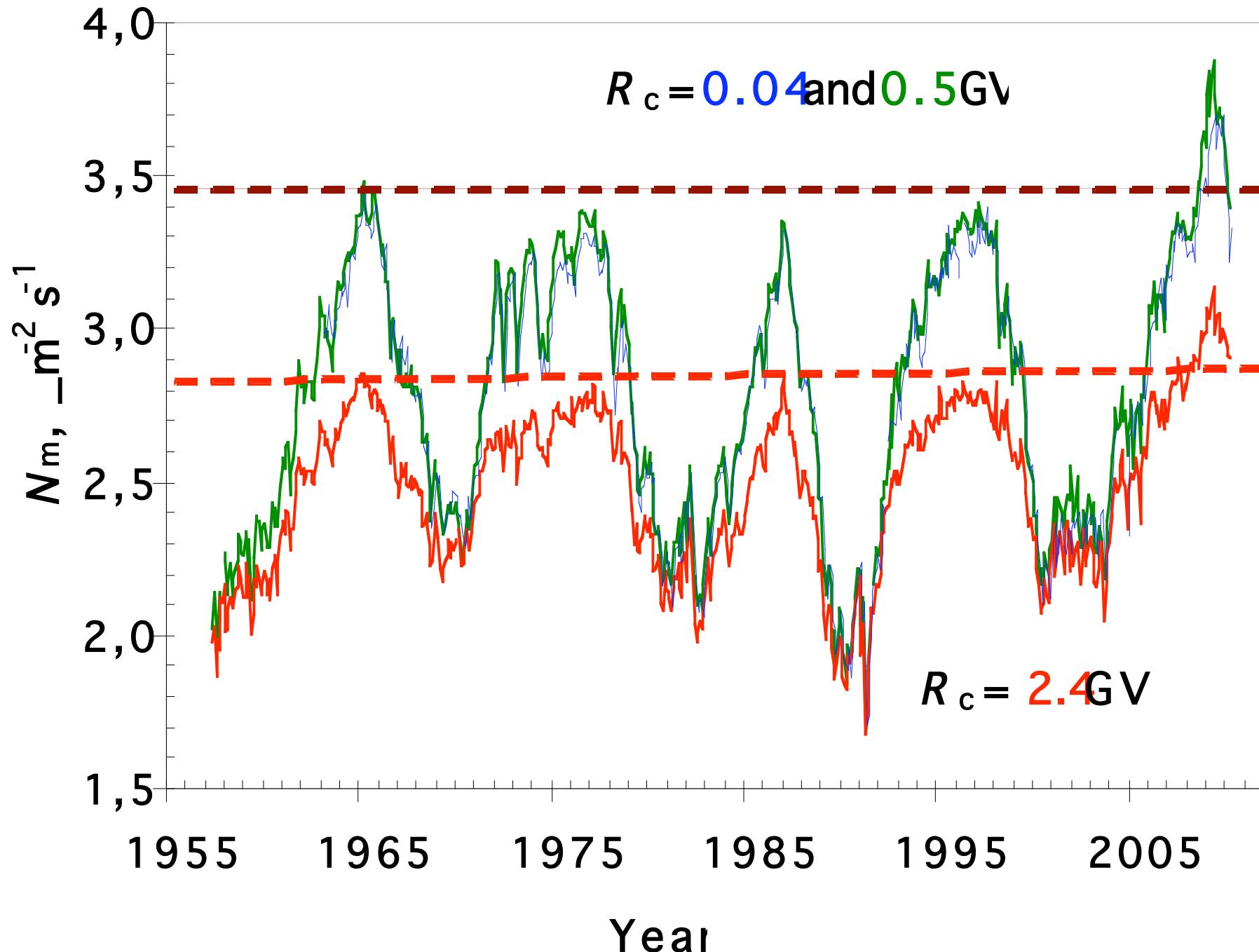


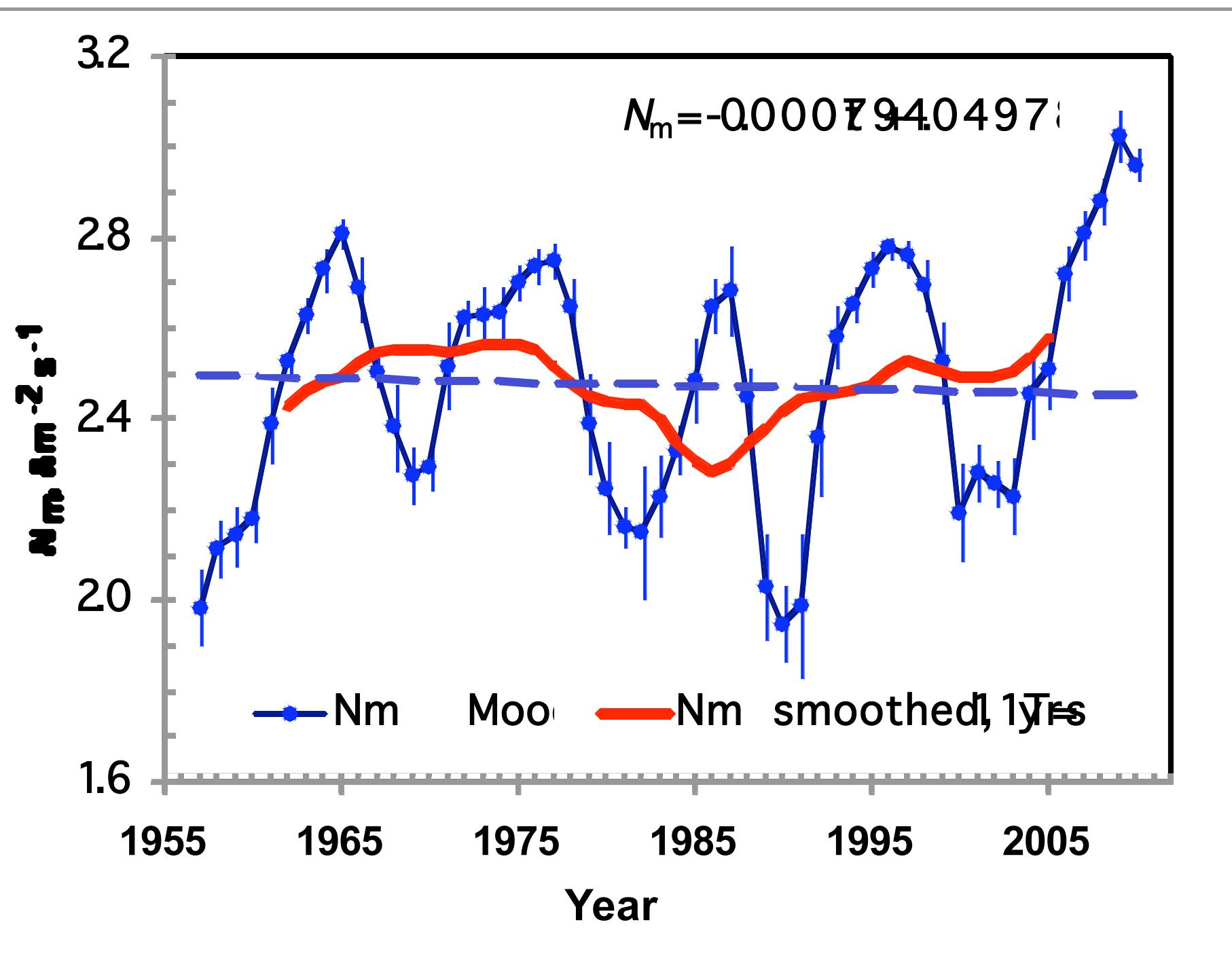
Solar energetic particle events of 9, 14, and 16 July 1959. Left panel – count rate of radiosondes vs. atmospheric pressure (height). Right panel – energy spectra of solar protons. Measurements were made at the northern polar latitudes during 9 – 17 July 1959.

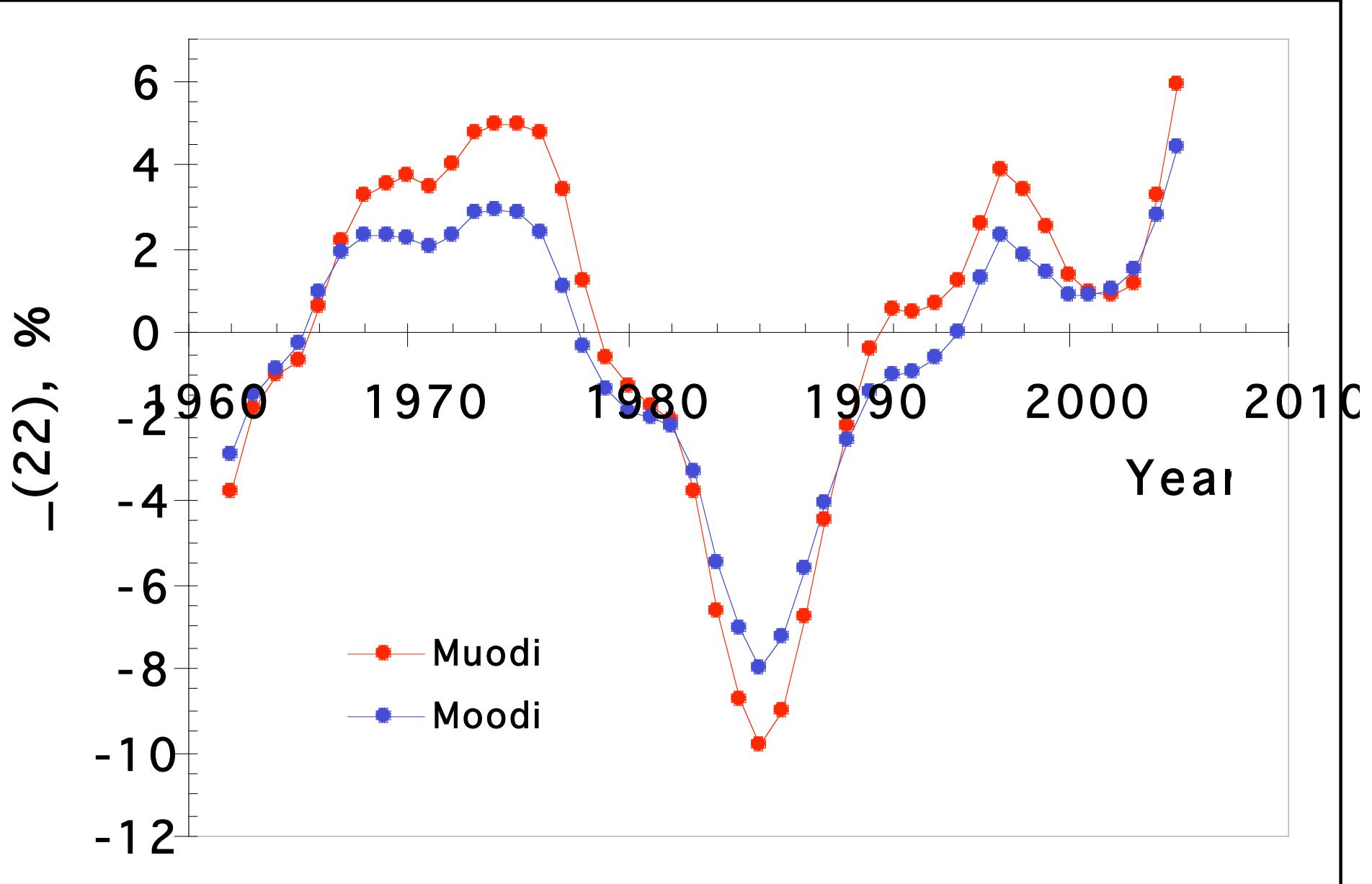
20 January 2005, Murmansk

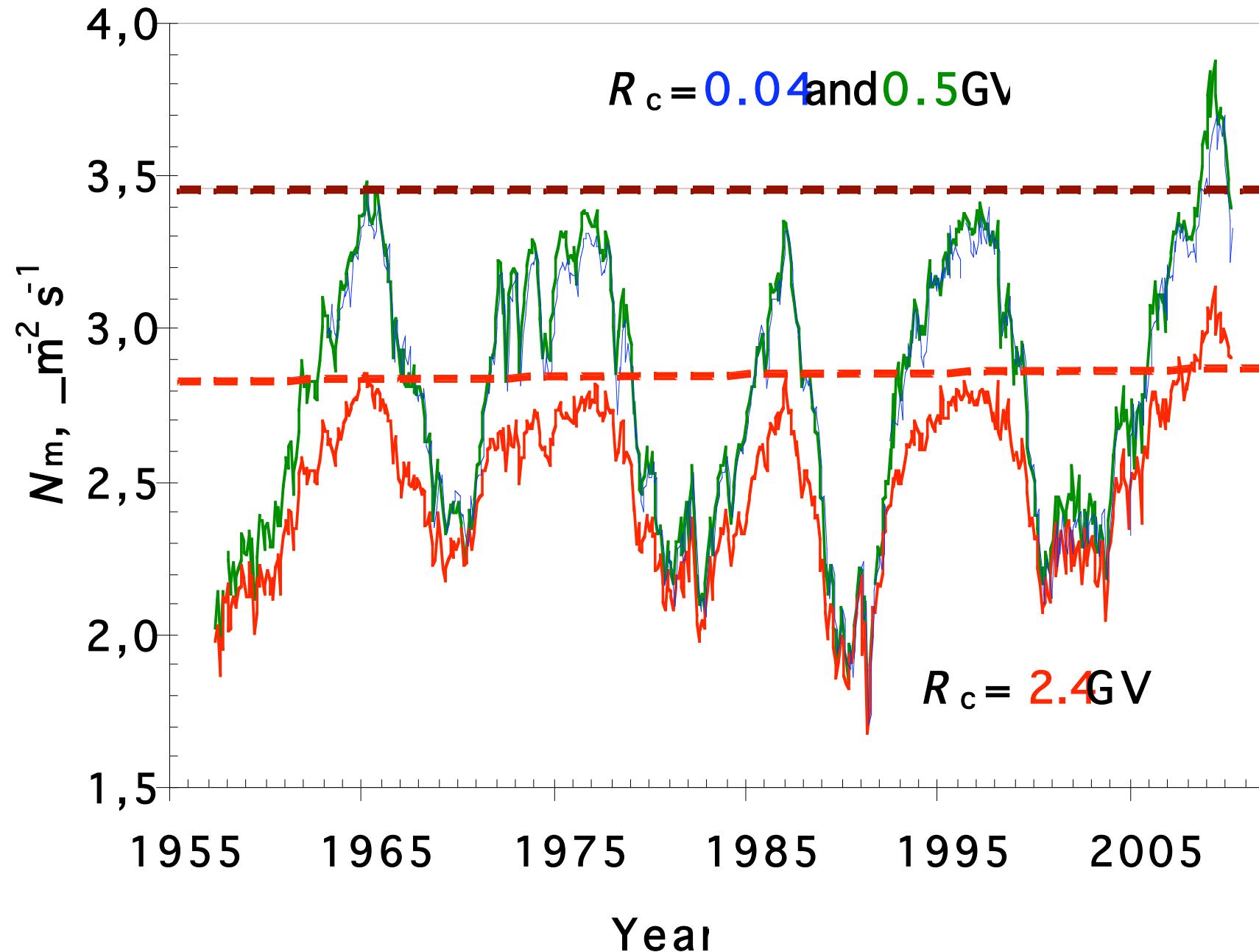


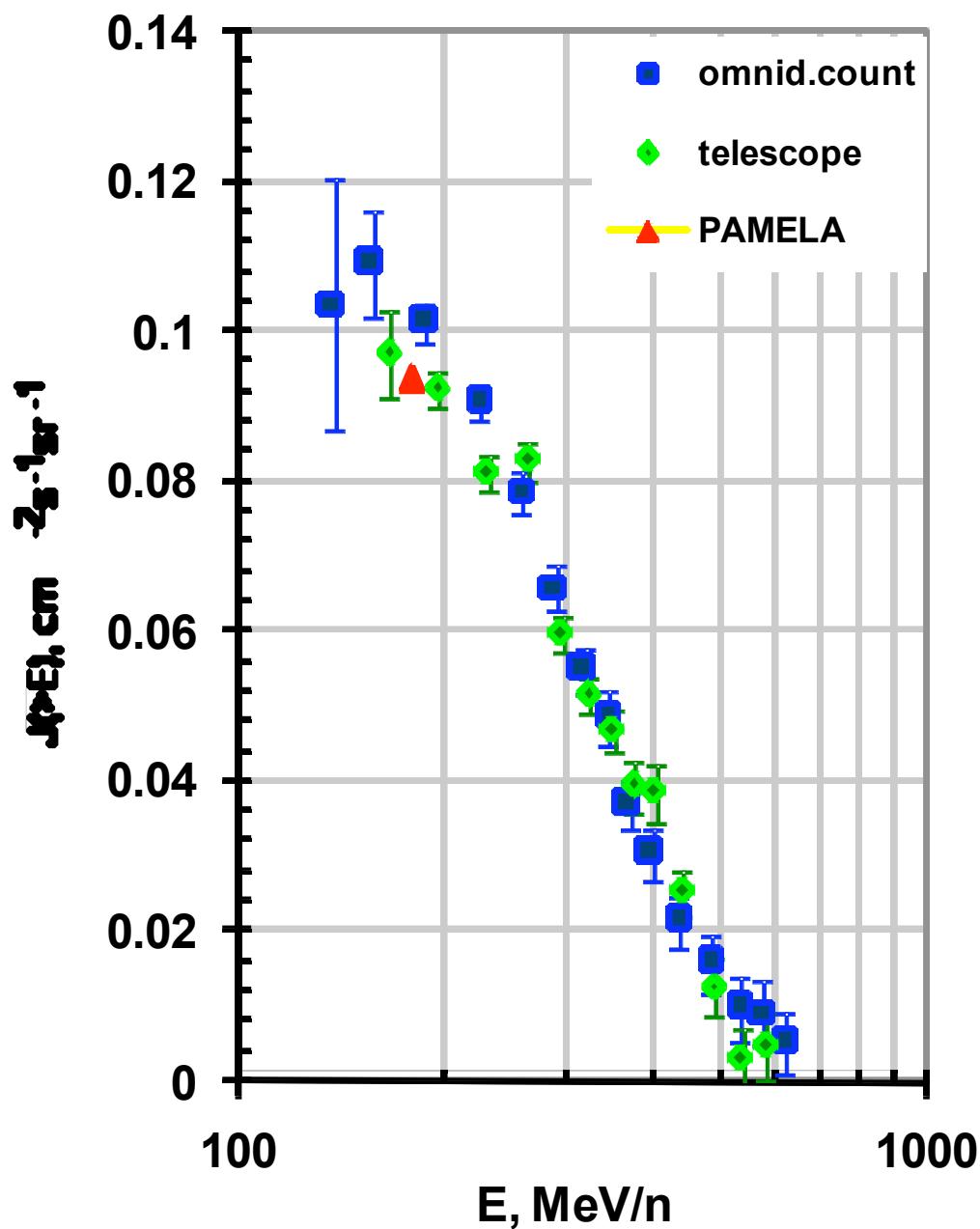
Solar energetic particle event of 20 January 2005. Left panel – count rate of radiosondes vs. atmospheric pressure (height). Right panel – energy spectra of solar protons. Measurements were made at the northern polar latitudes during 20-21 January 2005. Up to now, 112 solar energetic particle events were recorded in the stratosphere by our group.

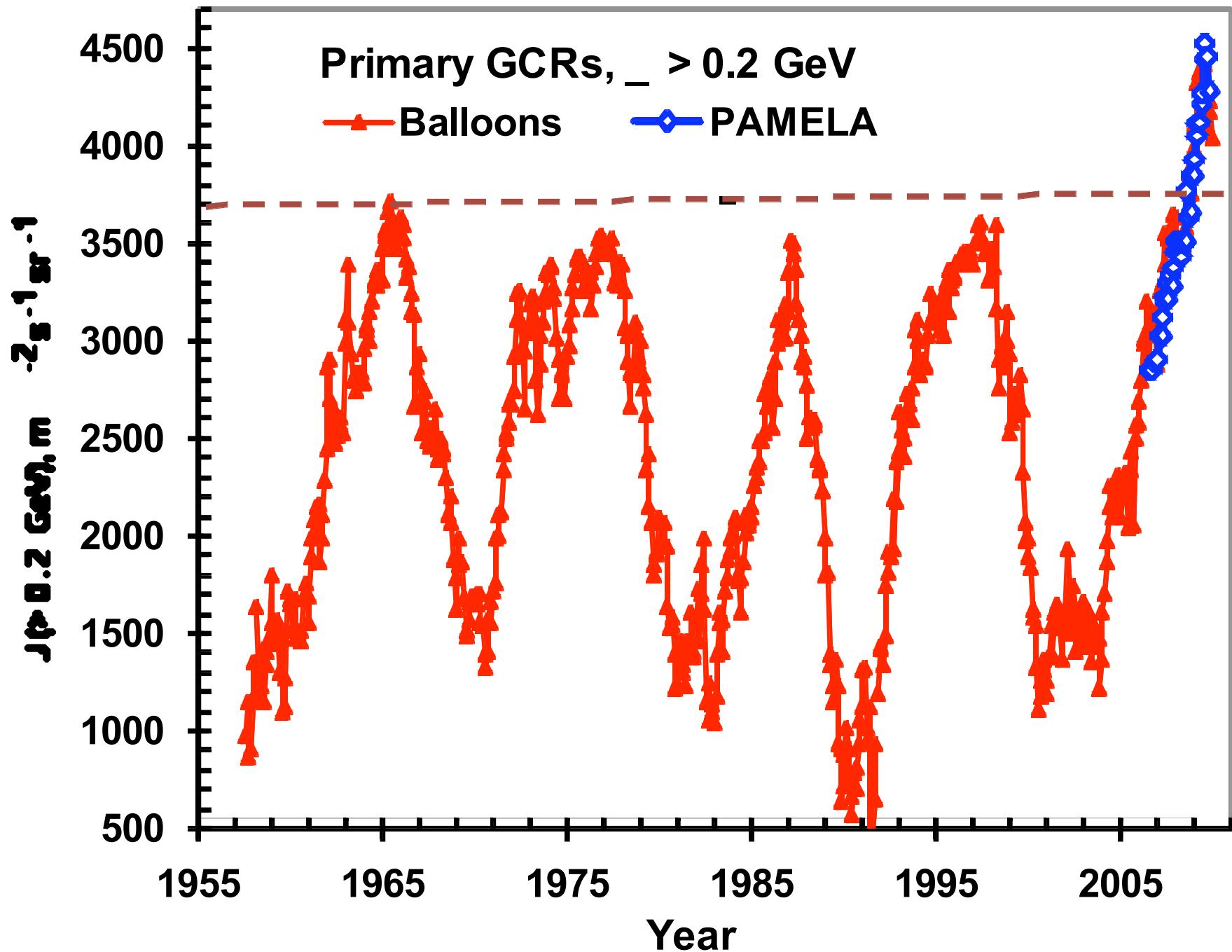


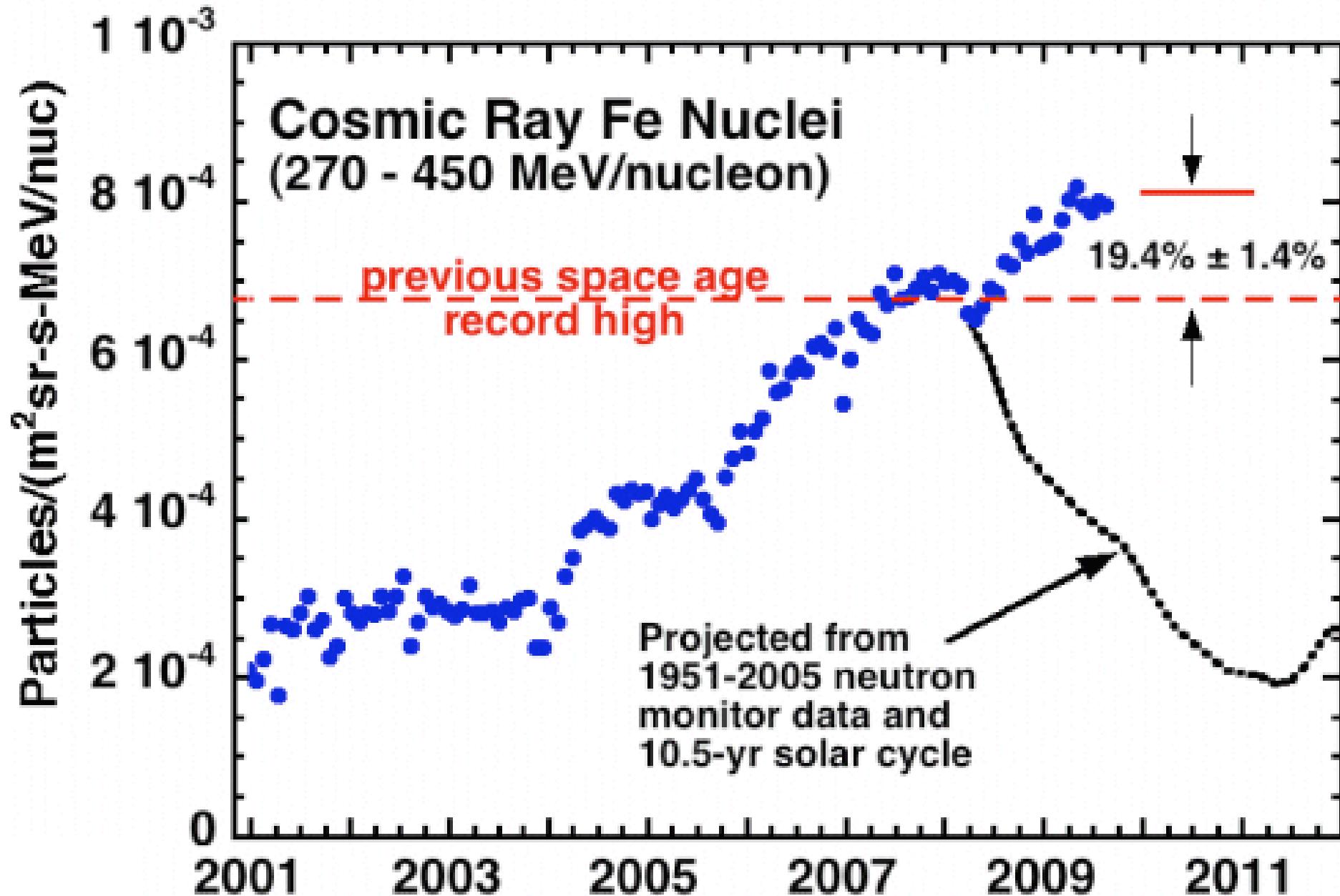




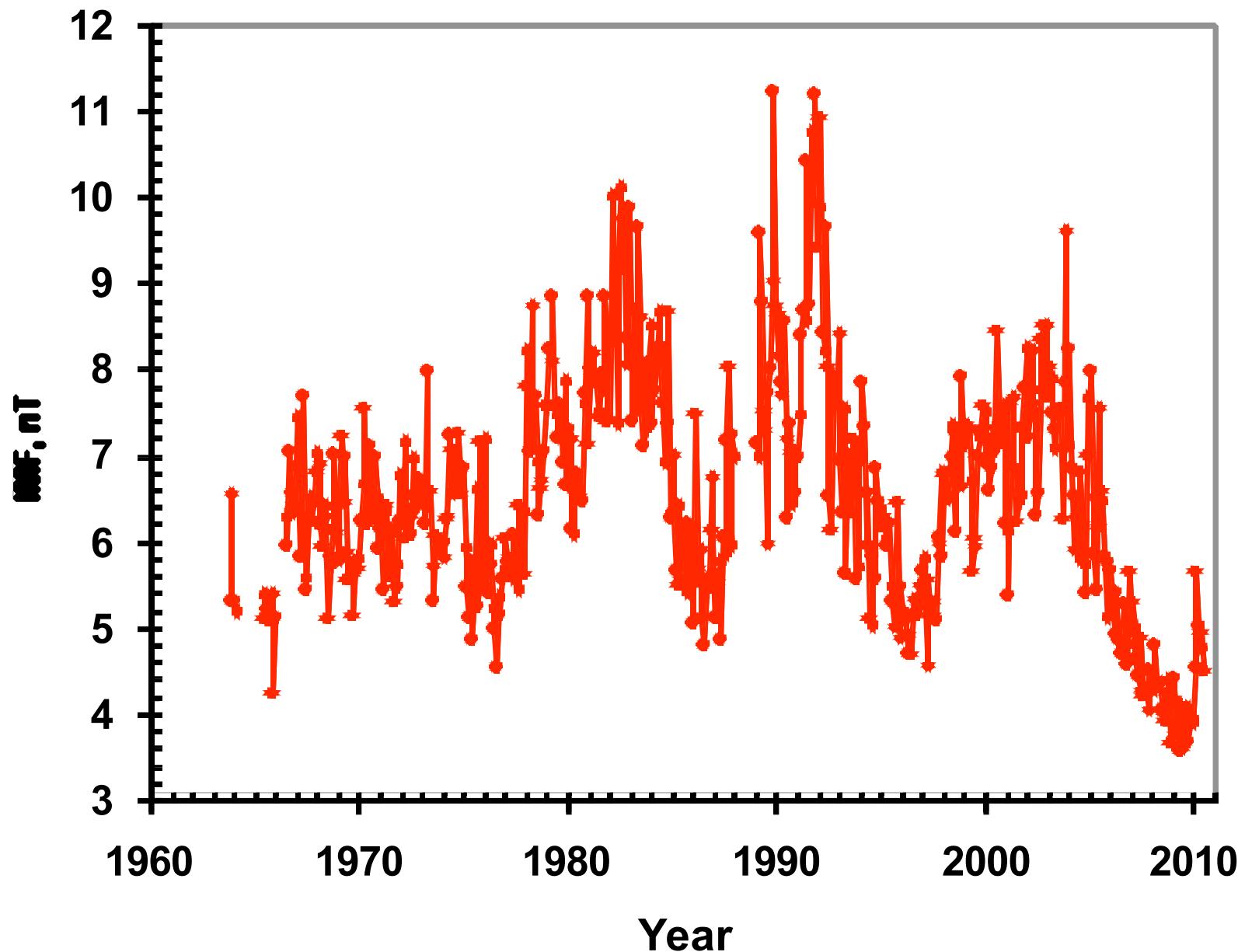






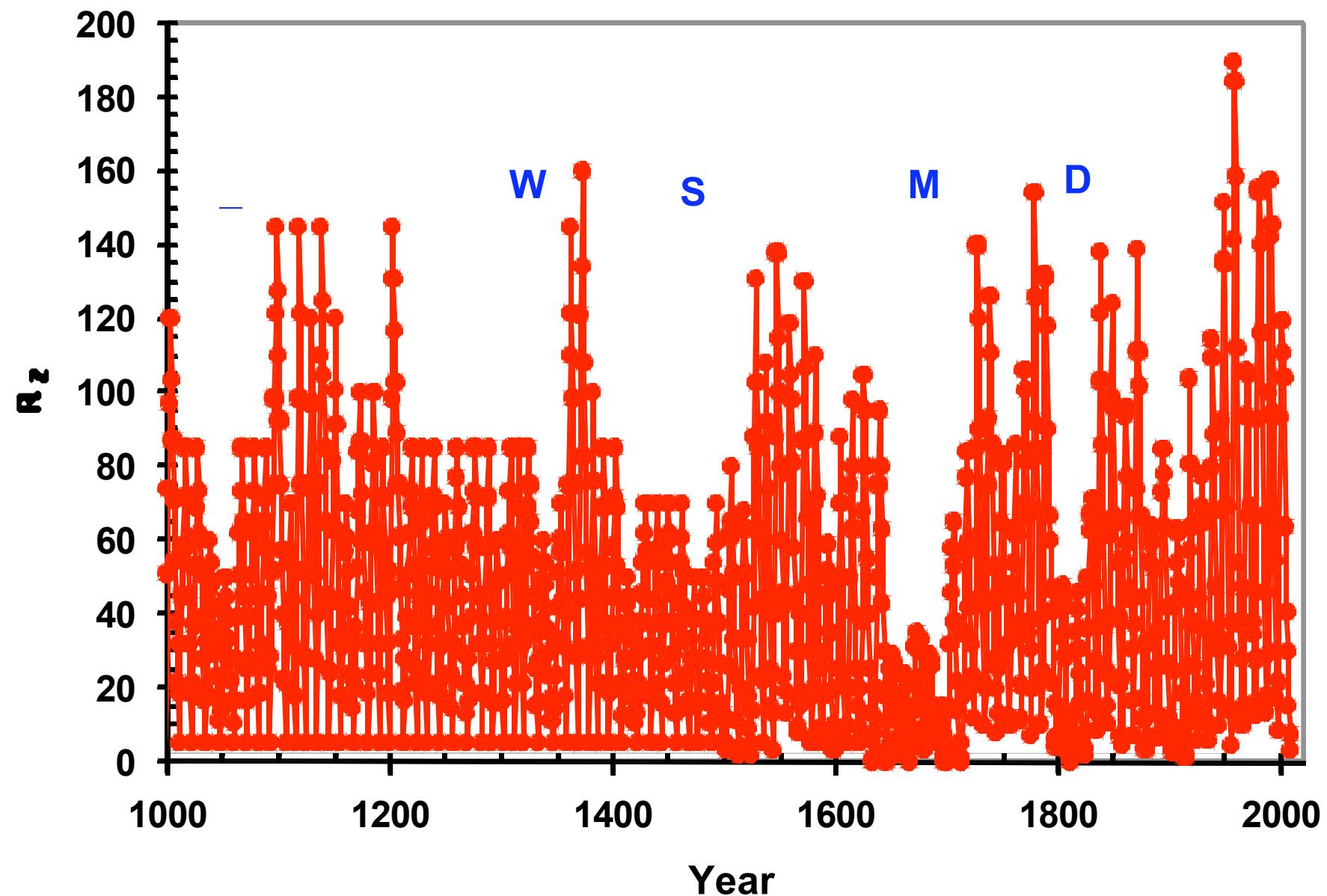


Energetic iron nuclei counted by the Cosmic Ray Isotope Spectrometer on NASA's ACE spacecraft reveal that cosmic ray levels have jumped 19% above the previous Space Age high.



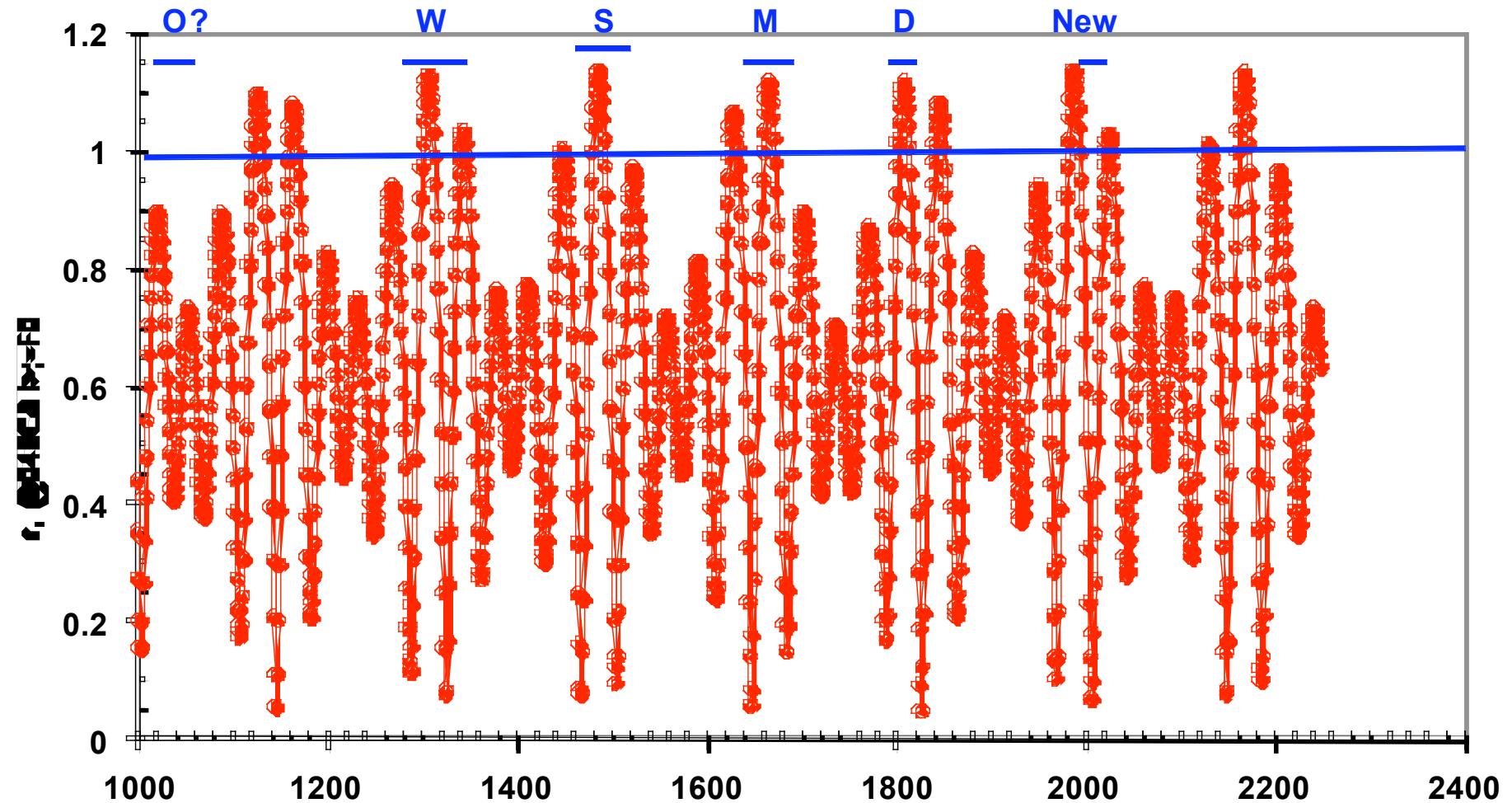
<http://omniweb.gfsc.nasa.gov/>

<http://spaceweather.com/>

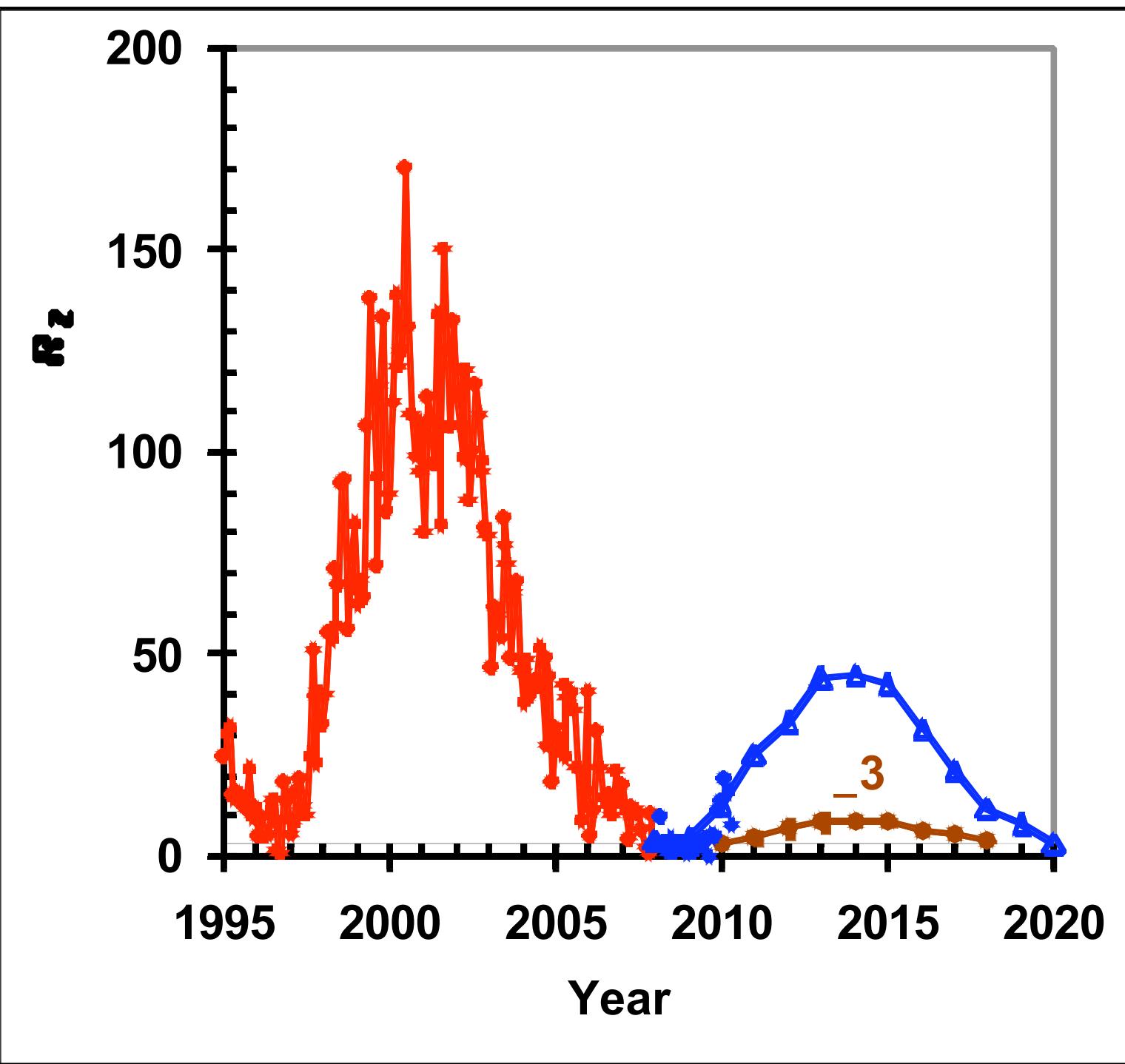


Shove D.J. Sunspots cycles, Stroudsburg, Hutchinson Ros. Publ., 1983

- 1280 – 1350 – Wolf minimum
- 1415 – 1540 – Schpoerer minimum
- 1620 – 1720 – Maunder minimum
- 1790 – 1835 – Dalton minimum
- 2007 – 2010 and later –
a new long-term minimum



Position of the Sun centre relative to the centre of mass of the solar system
(external planets without Jupiter)



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Energy fluxes

Solar irradiation

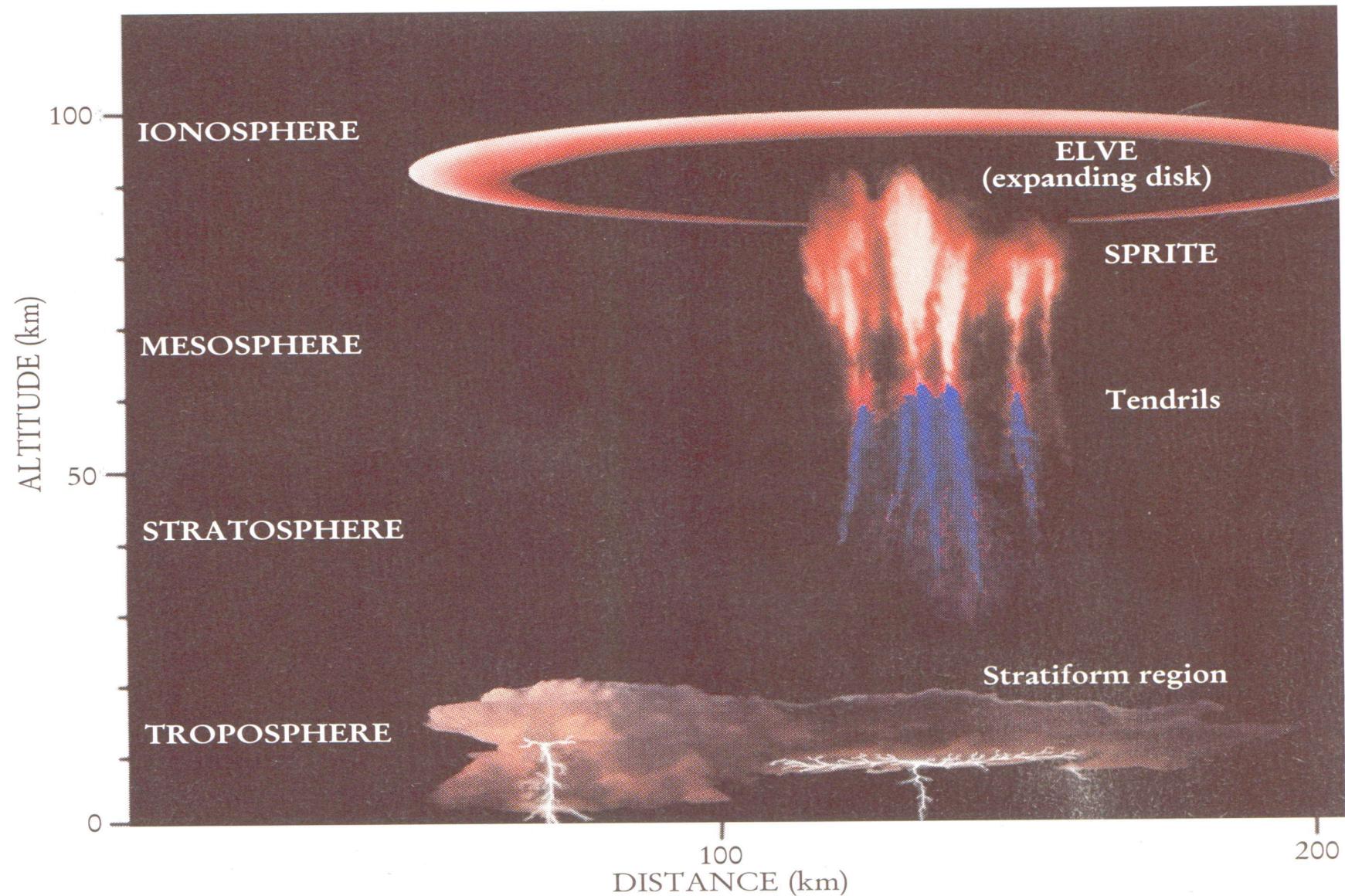
$$\approx 1.36 \cdot 10^3 \text{ W/m}^2$$

Galactic CRs

(particles with energy $E > 0.1 \text{ GeV}$)

$$\approx 10^{-5} \text{ W/m}^2$$

Sprites and elves triggered by the ground-to-cloud lightning (Lyons W.A., et al., 2000, EOS, v. 81, 373).



Electrical phenomena in the atmosphere: lightning, sprites, etc.

Electric charge of the Earth

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

Electric field near the Earth's surface

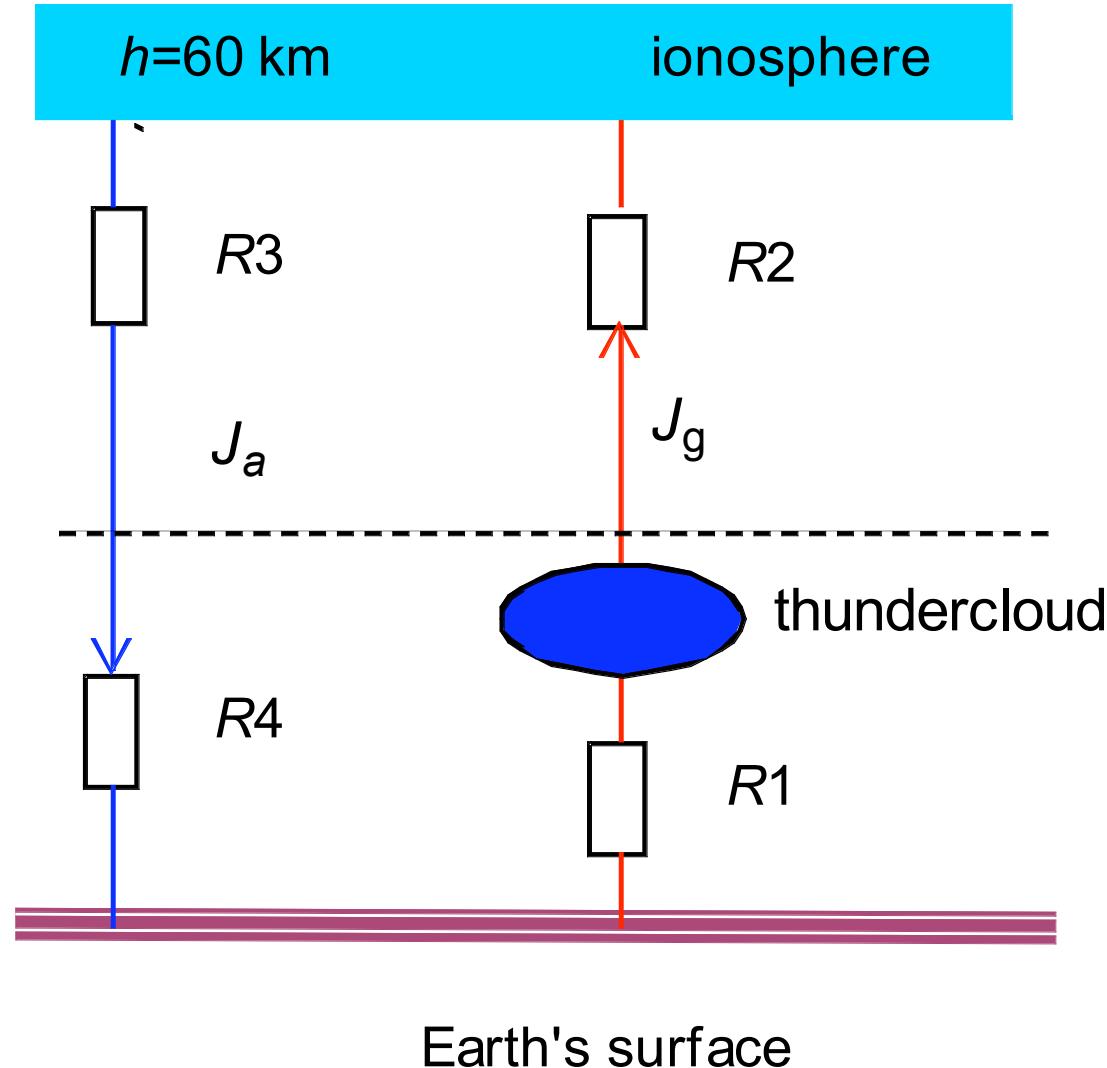
$$E \approx 130 \text{ W/m}$$

Electric current in the atmosphere

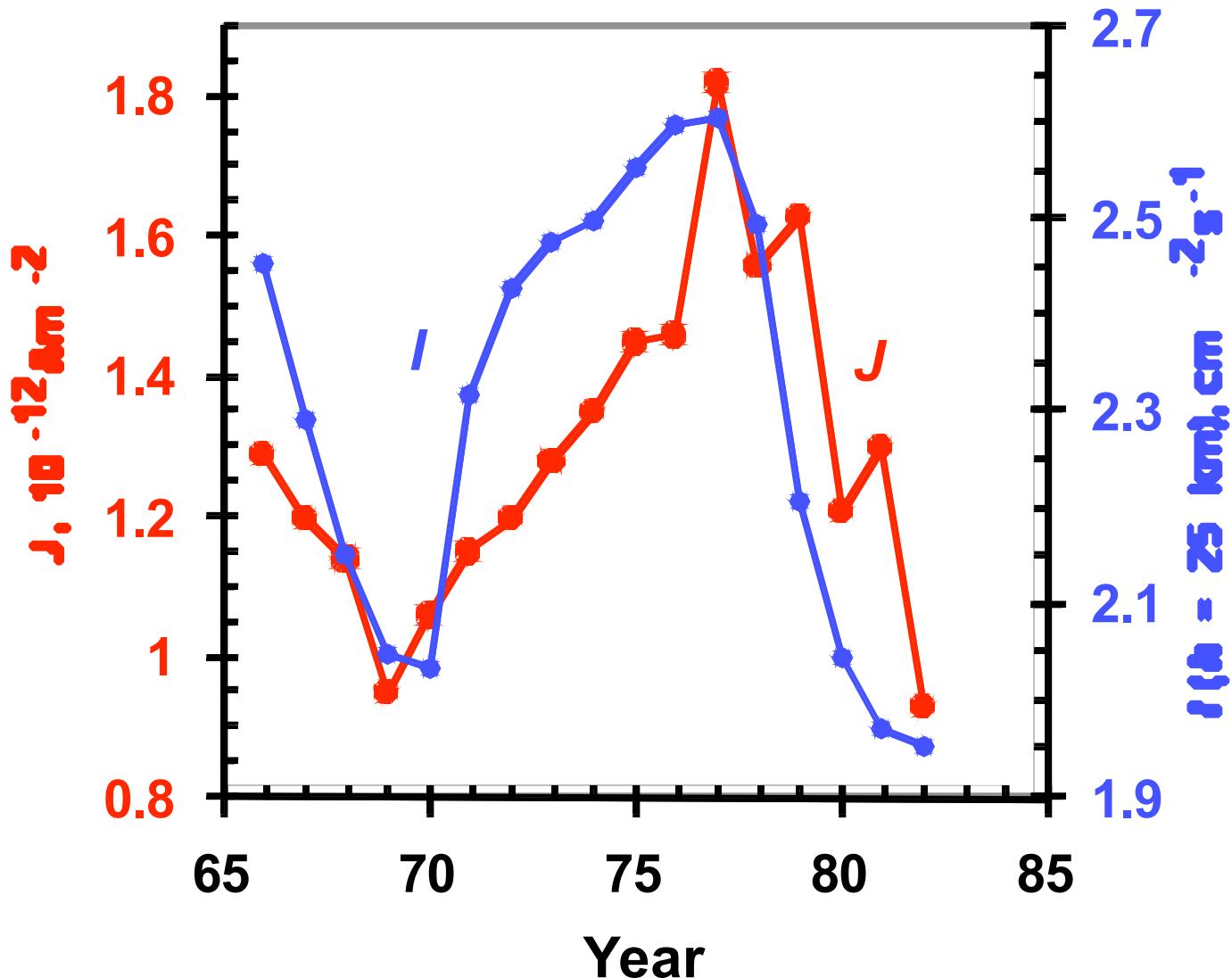
$$J \approx 10^{-12} \text{ A/m}^2$$

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

Global electric circuit

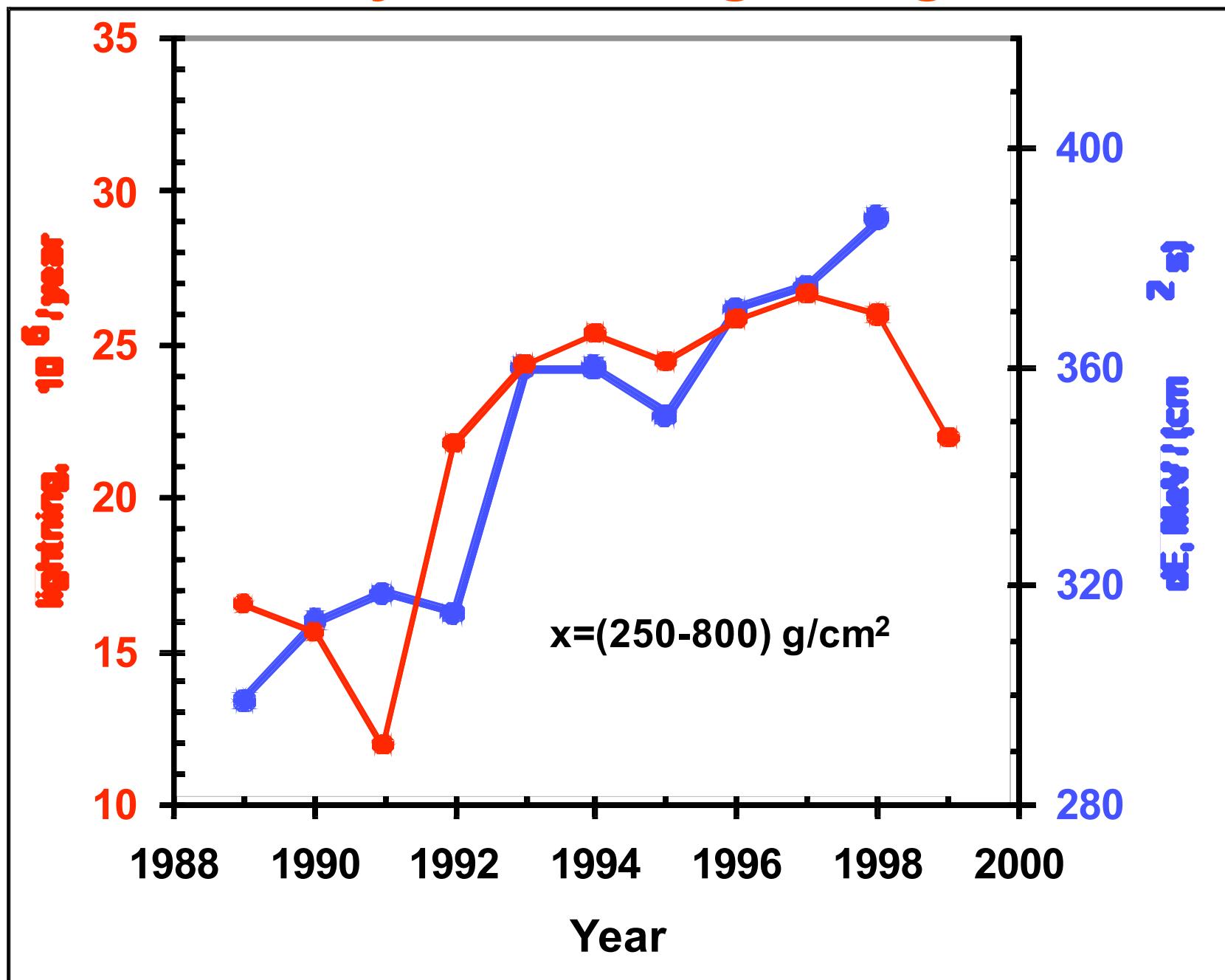


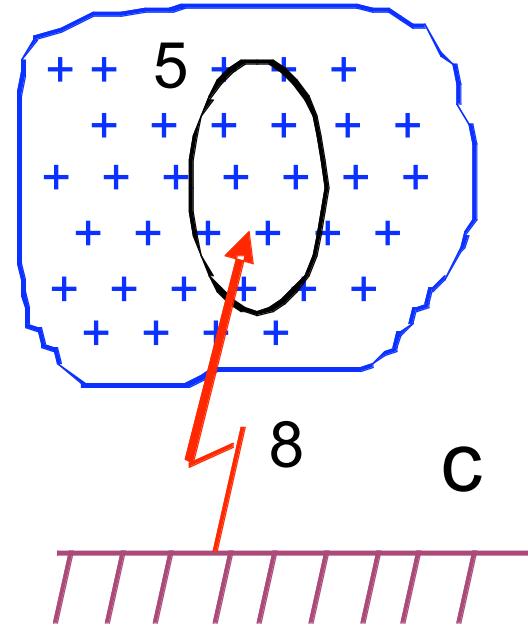
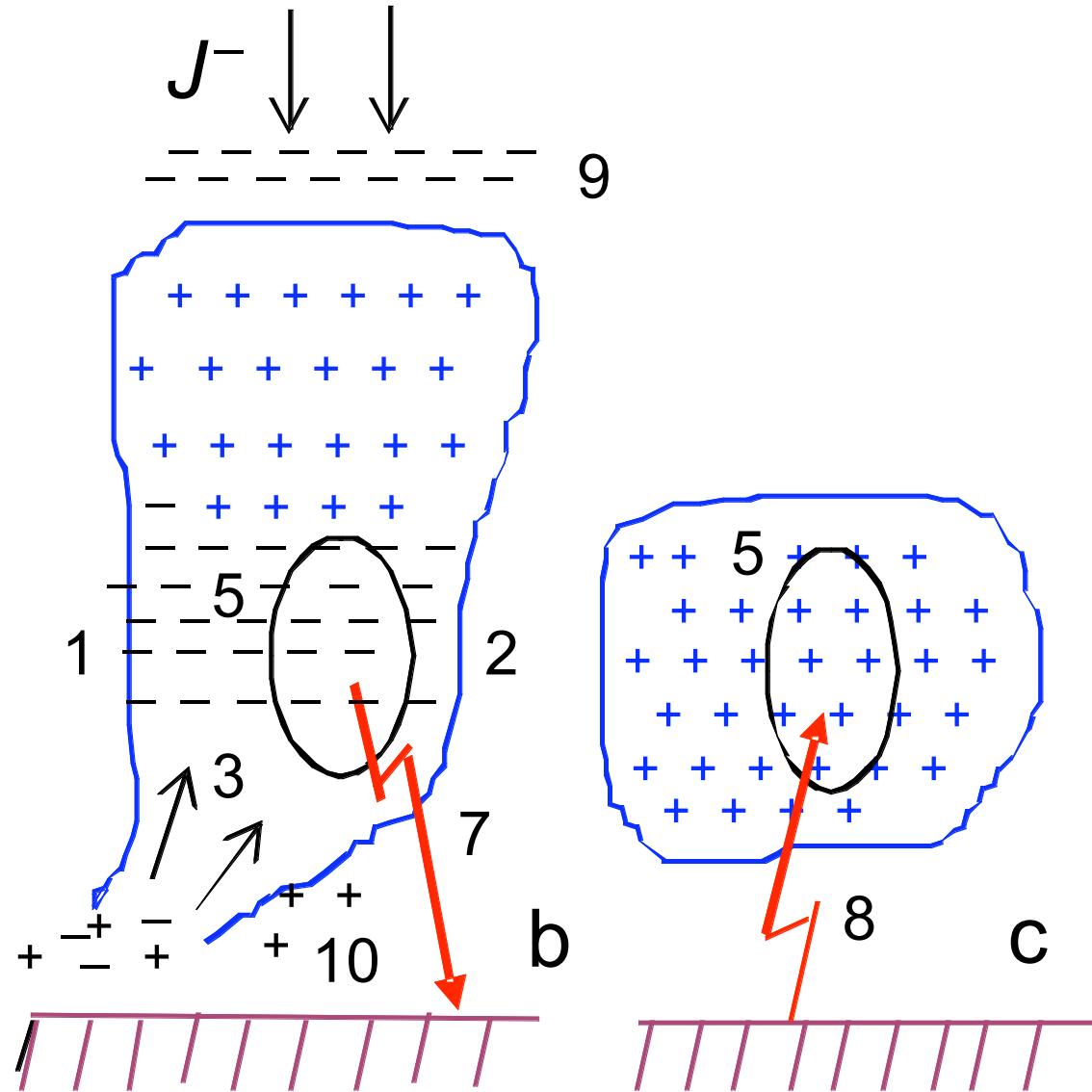
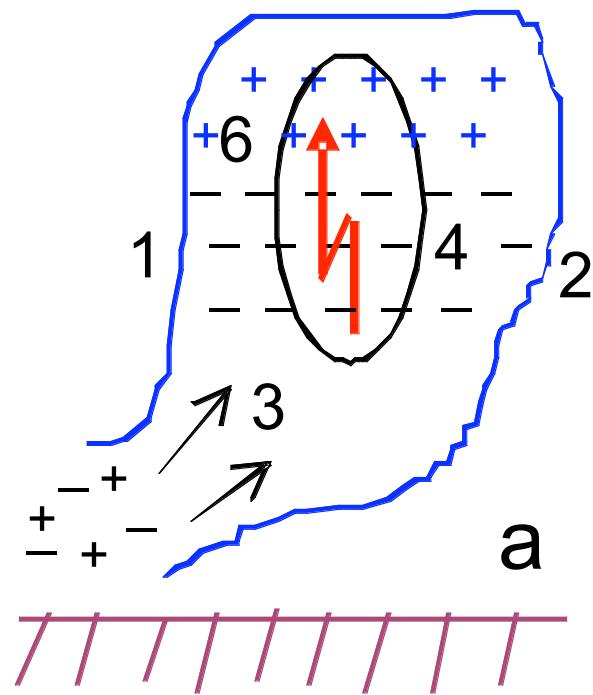
Cosmic ray flux (I) and atmospheric current (J)

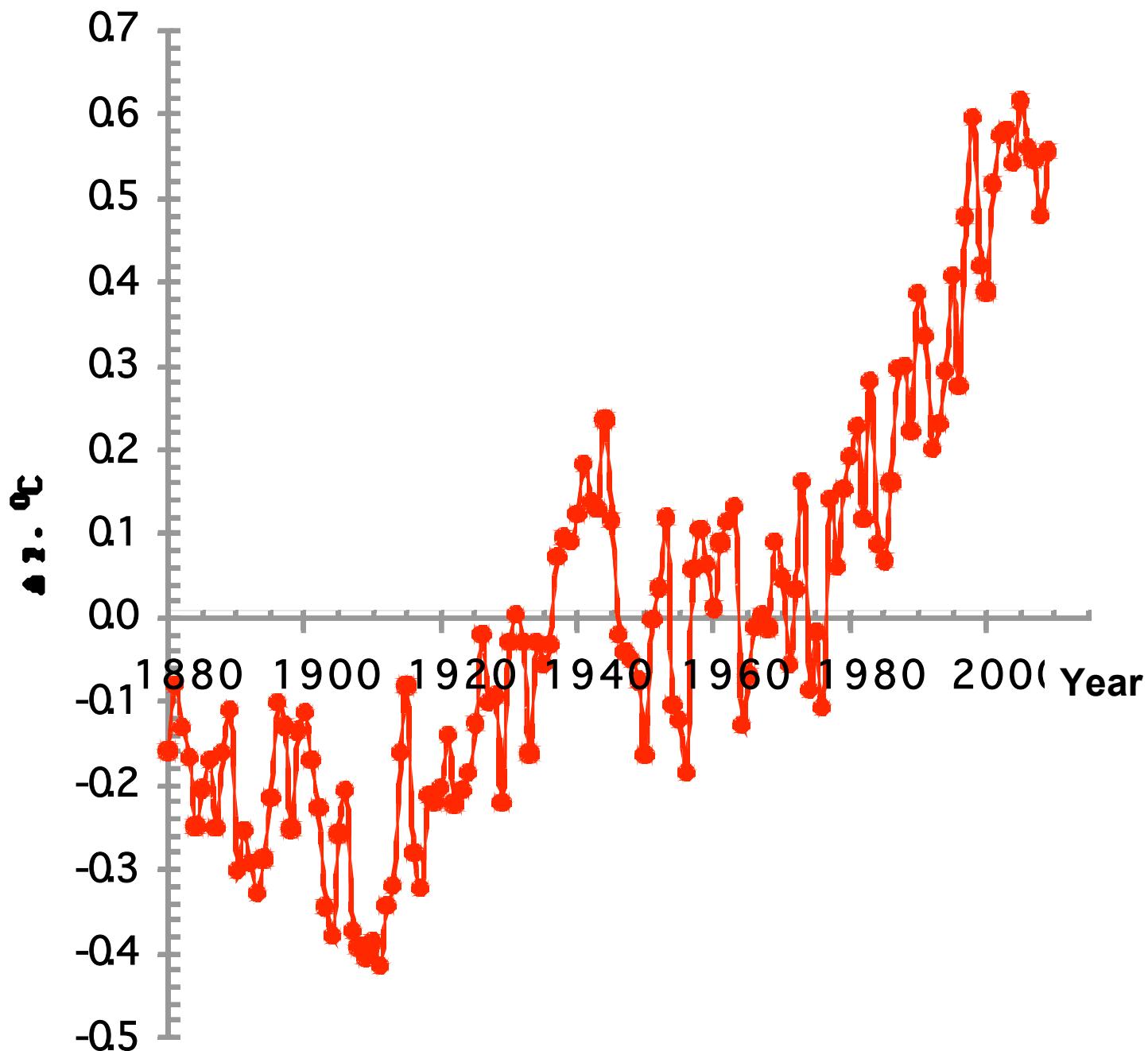


$$r(I, J) = +0.67 \pm 0.14; \quad r(J, R_z) = -0.32 \pm 0.22$$

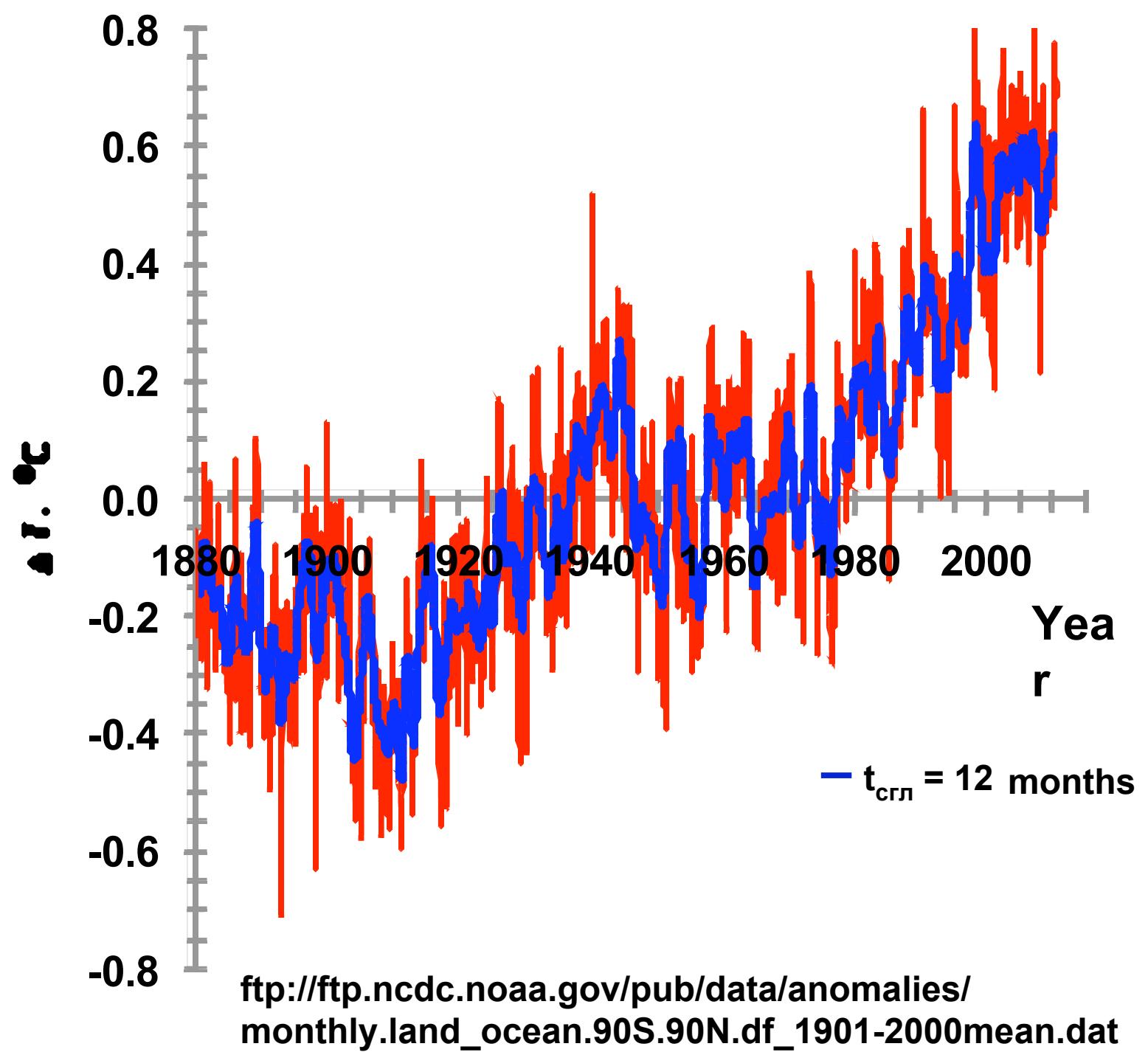
Cosmic ray flux and lightning number

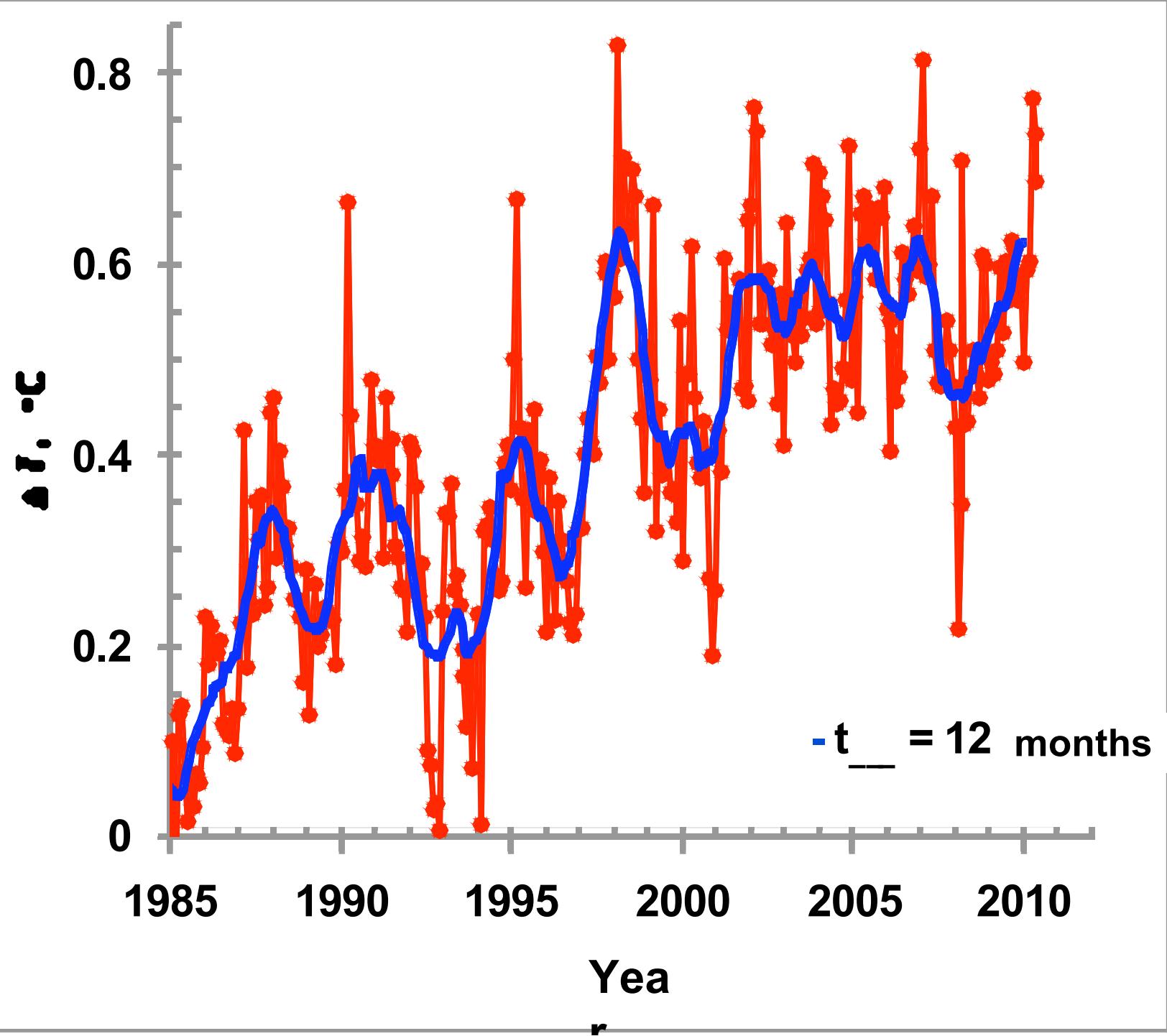




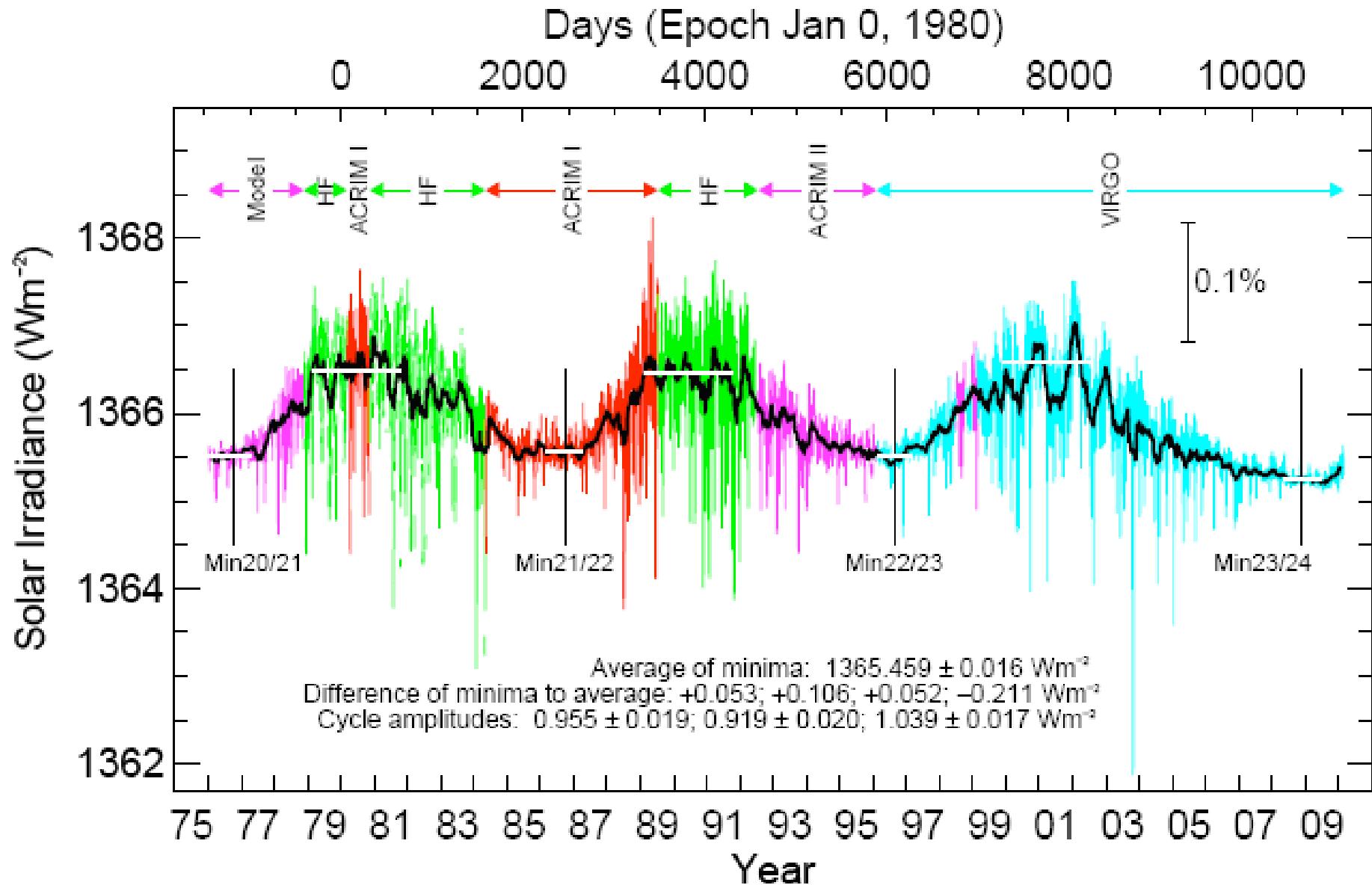


ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/annual.land_ocean.90S.90N.df_1901-2000mean.dat

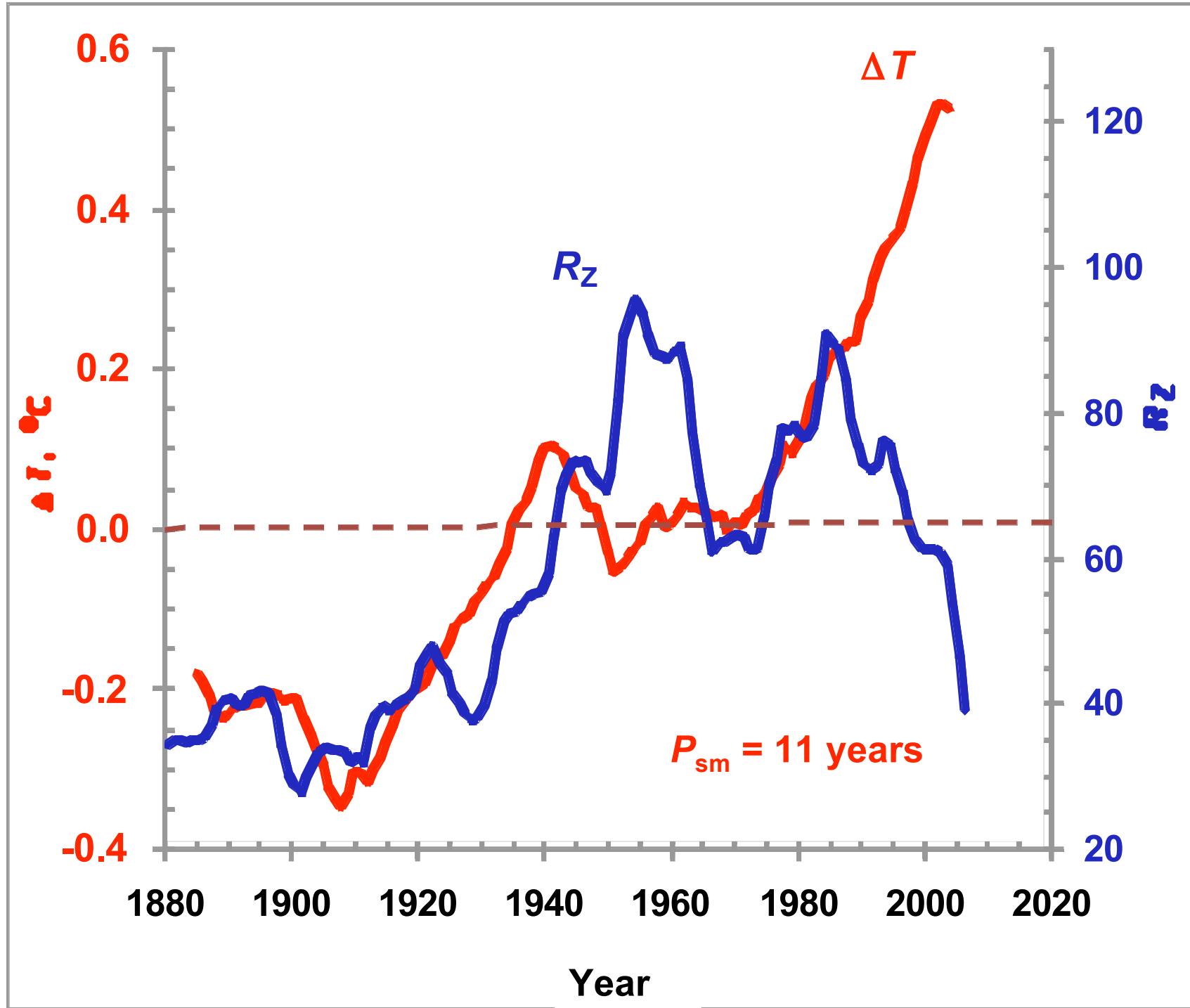




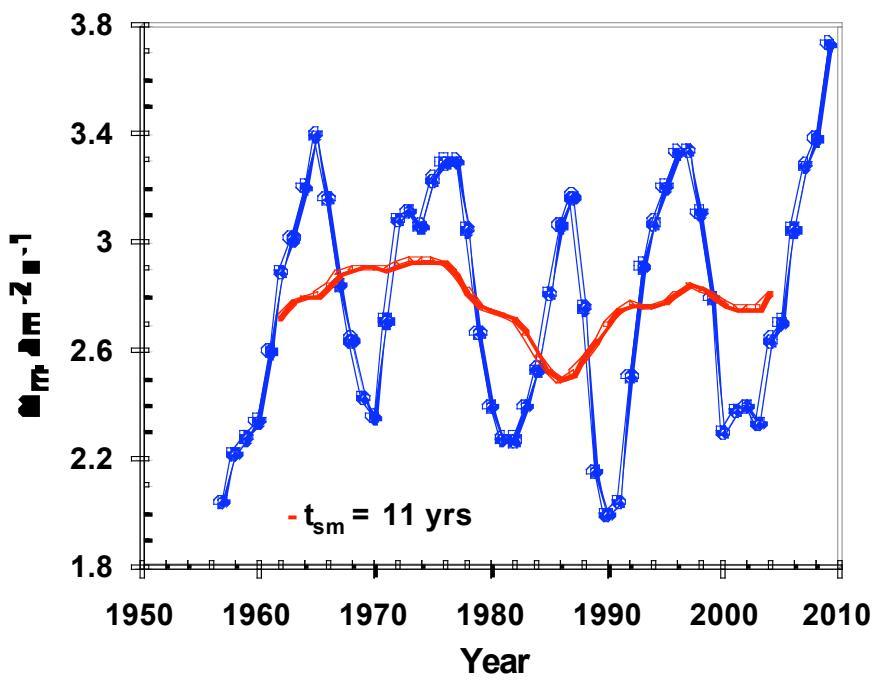
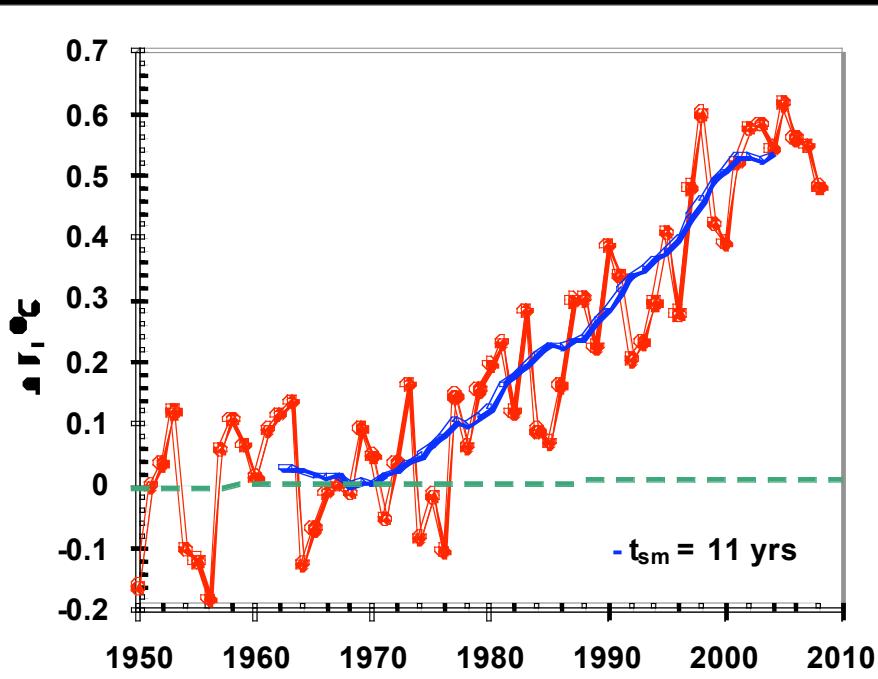
**Does our climate change because of
changes in solar luminosity?**



**Does our climate change because of
changes in solar activity?**



**Does our climate change because of
changes in cosmic ray fluxes?**



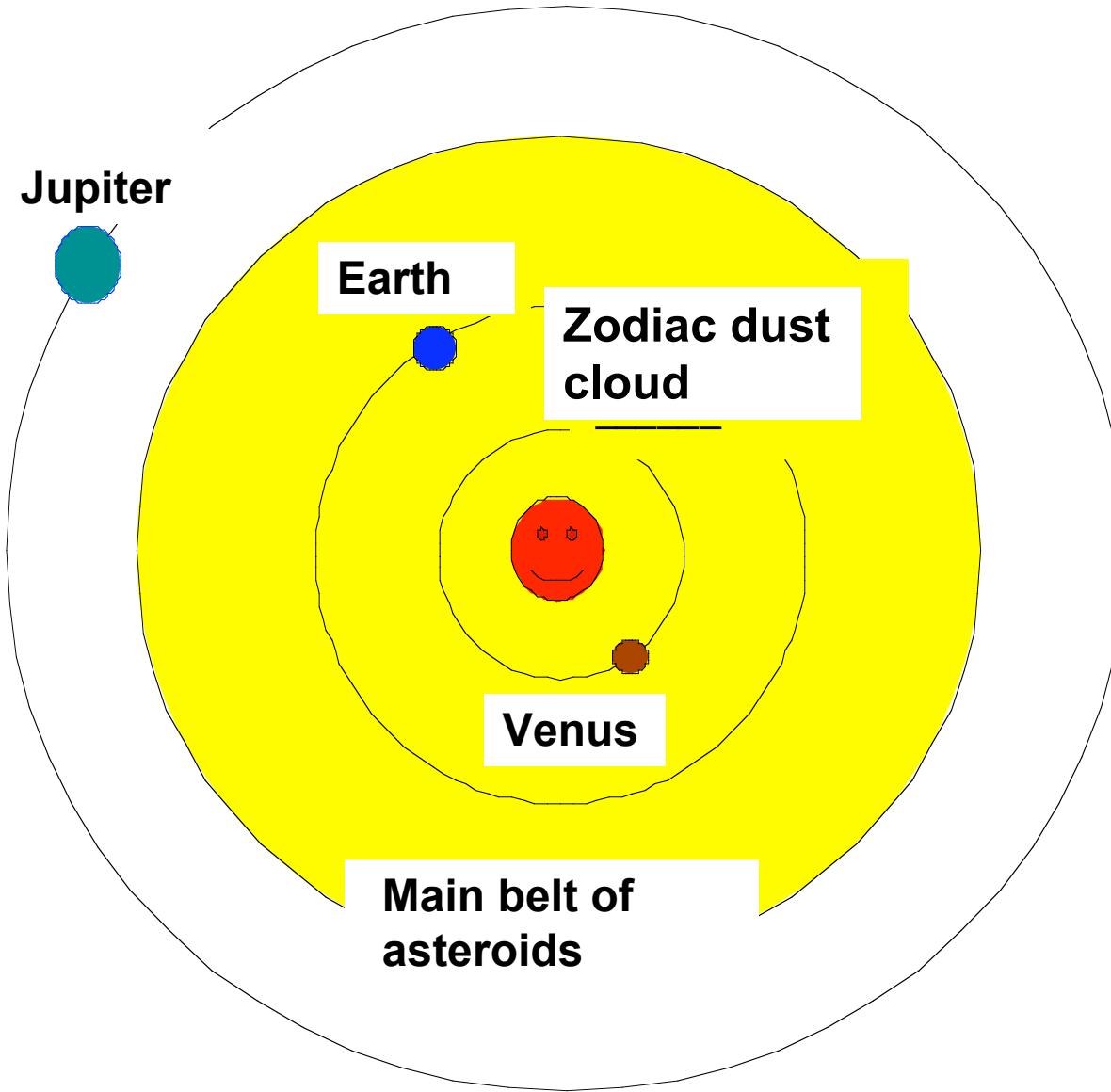
$$\frac{\pi r^2 \cdot S \cdot (1 - A)}{1.2 \cdot 10^{17} \text{ W}} + \frac{W_3}{10^{13} \text{ W}} = 4\pi r^2 \cdot \sigma \cdot T_e^4,$$

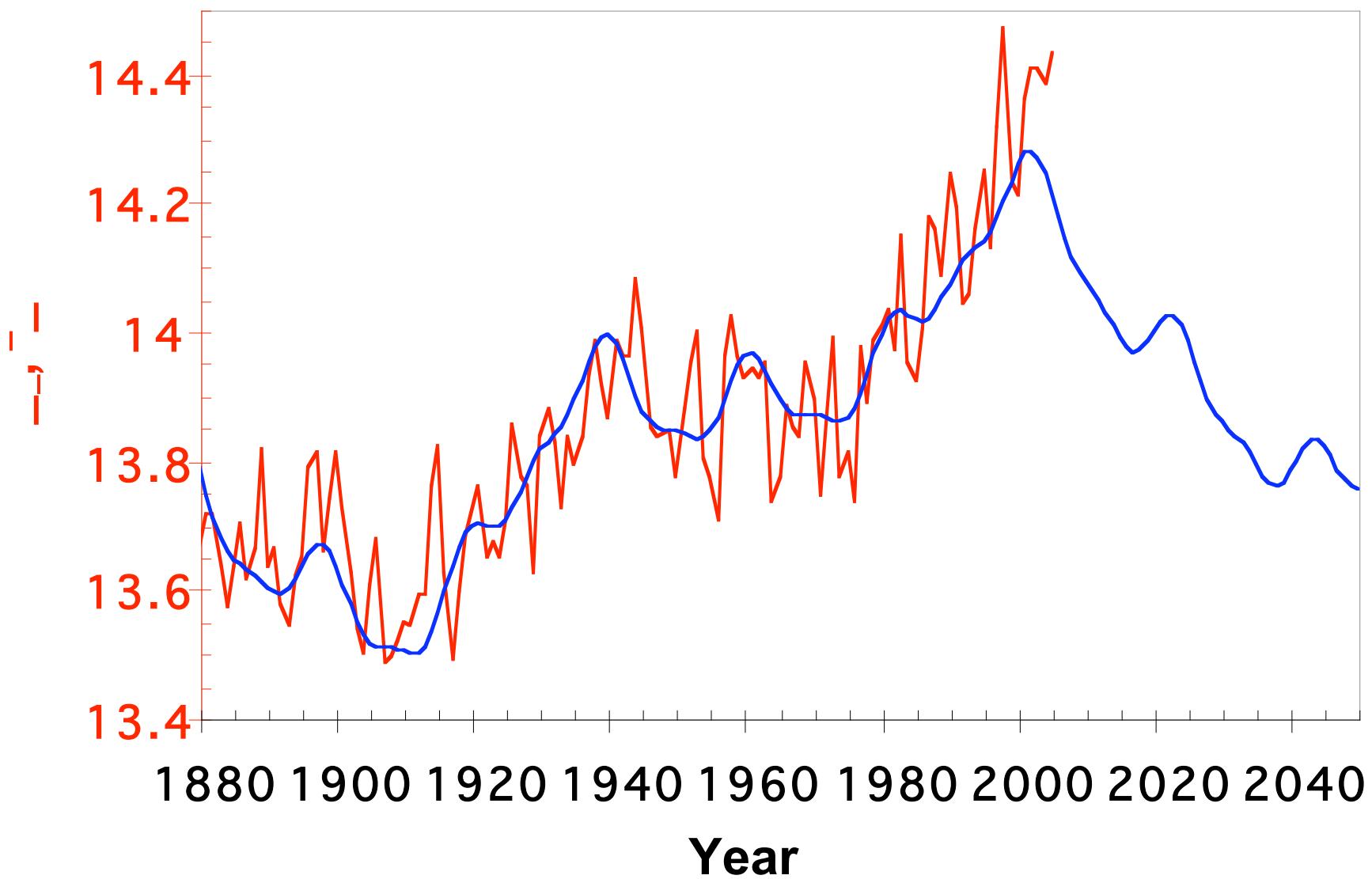
$$S \cdot (1 - A) / 4 = \sigma \cdot T_e^4$$

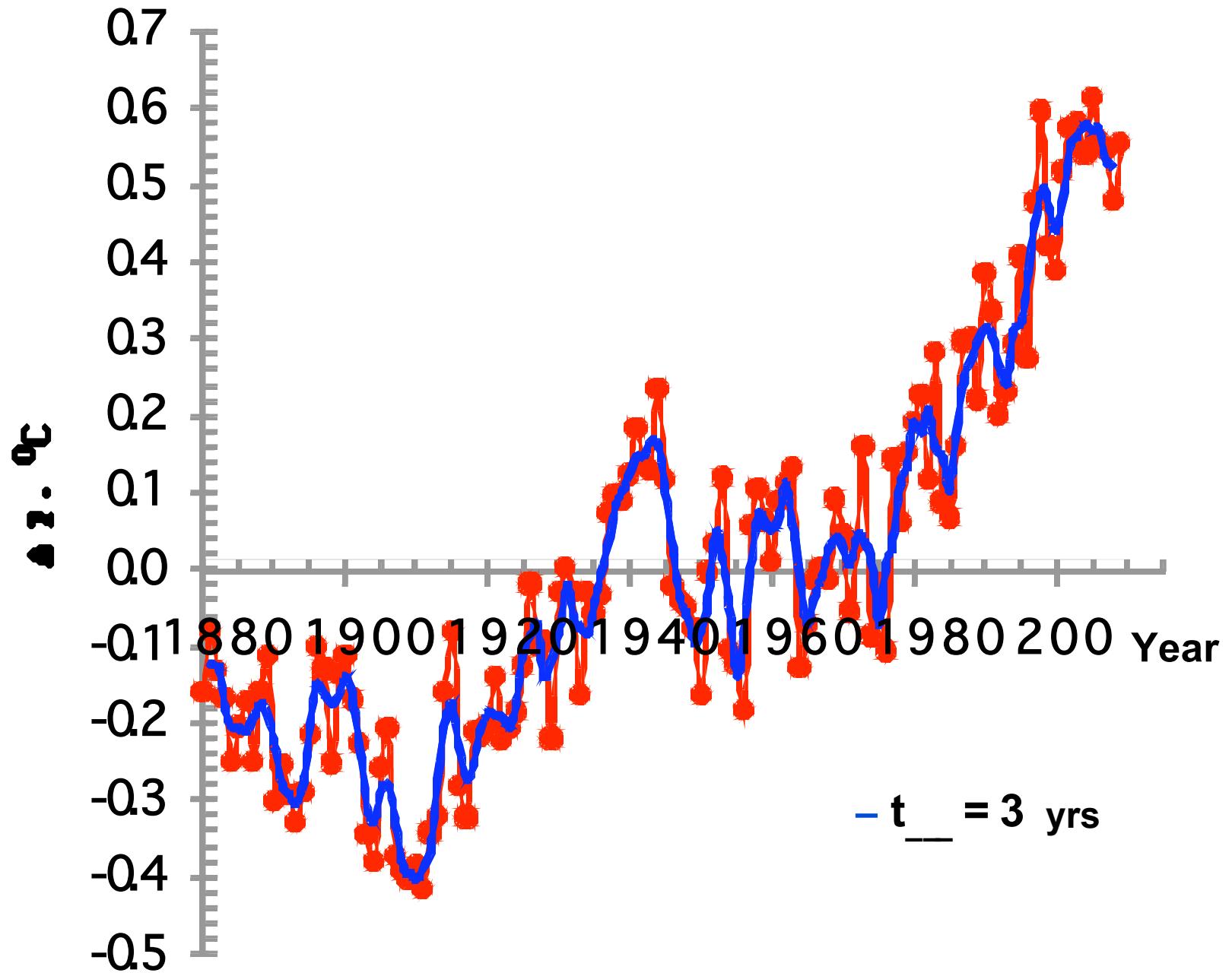
At $S = 1366 \text{ W/m}^2$, $A = 0.3$ we have

$$T_e = 254 \text{ K} = -19 \text{ }^\circ\text{C}$$

T_e – effective temperature of the climatic system (atmosphere + ocean + lithosphere)







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Cooperation of Dolgoprudny scientific station with other research organizations (present time)

- **Monitoring of CRs in the atmosphere** – PGI RAS, AARI Roshydromet, SINP MSU (Russia).
- **CRS and solar terrestrial relationships** – Mackenzie University, Sao-Paulo (Brazil), Euro-Asian University, Astana (Kazakhstan).
- **Atmospheric electricity and CRs** – Institute of experimental physics, Kosice (Slovakia).
- **Experiment CLOUD** – CERN.
- **Experiment PAMELA** – MEPhI, Moscow (Russia), Ioffe PTI, Saint-Petersburg (Russia), PAMELA collaboration (Italy, Germany, Sweden).



CLOUD in the TII experimental zone, Nov09



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Conclusion

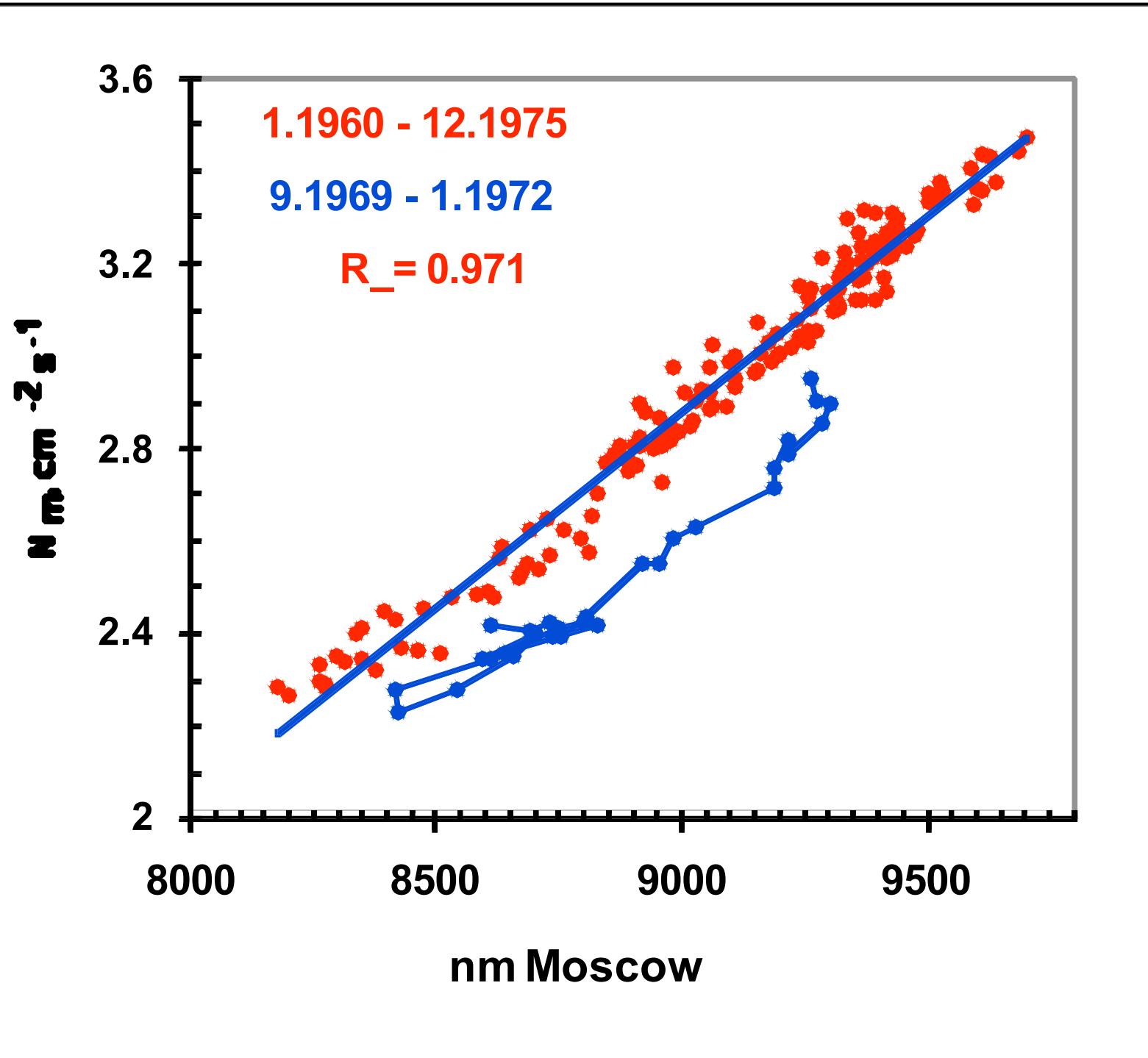
S.N. Vernov had the unique intuition for choosing the directions of scientific research. One direction started by him in 30-ies of the last century was the study of cosmic rays in the Earth's atmosphere.

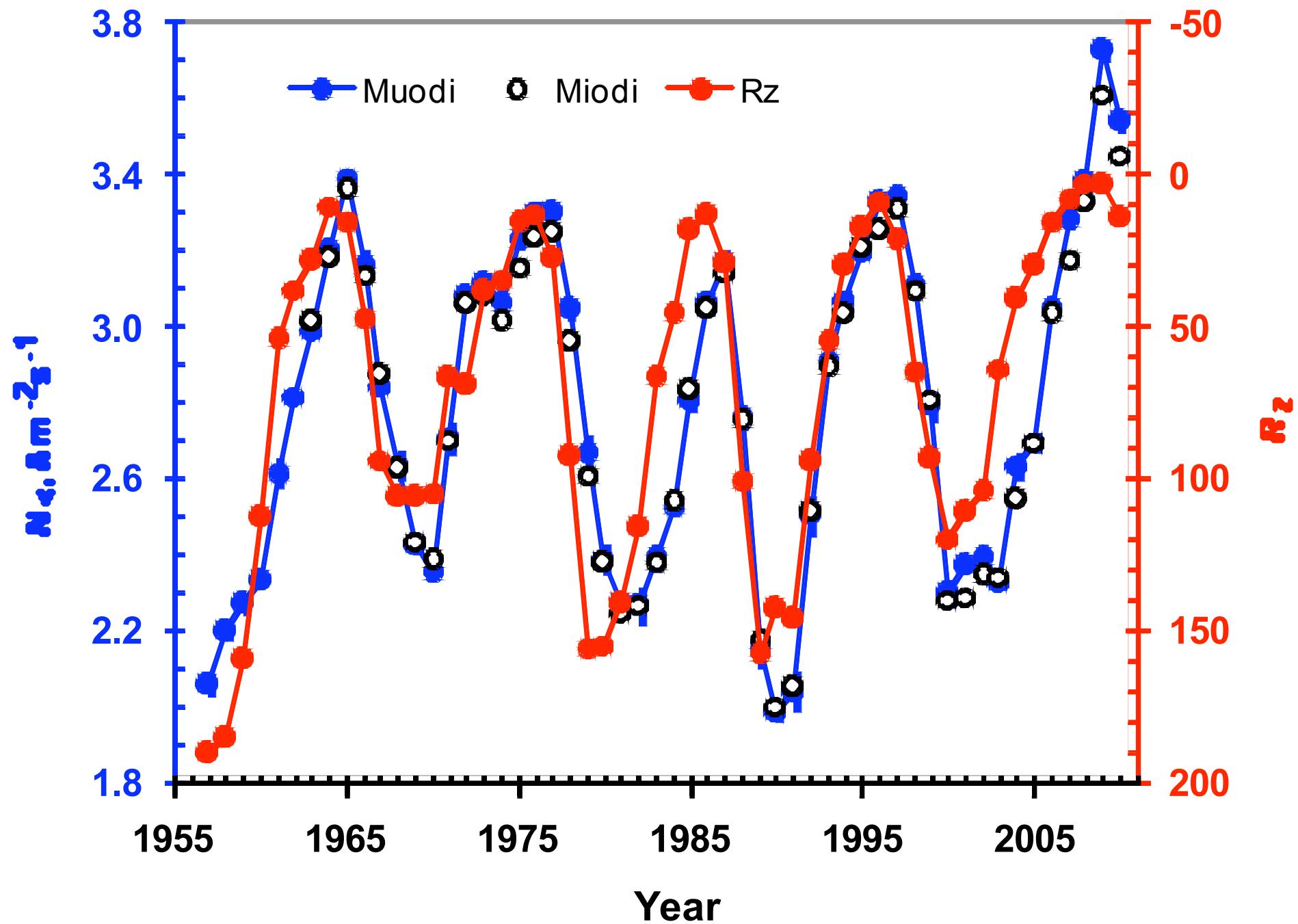
The method of regular and frequent measurements of CRs in the atmosphere gave us the fundamental knowledge on the modulation processes of CRs and its relationship with solar activity.

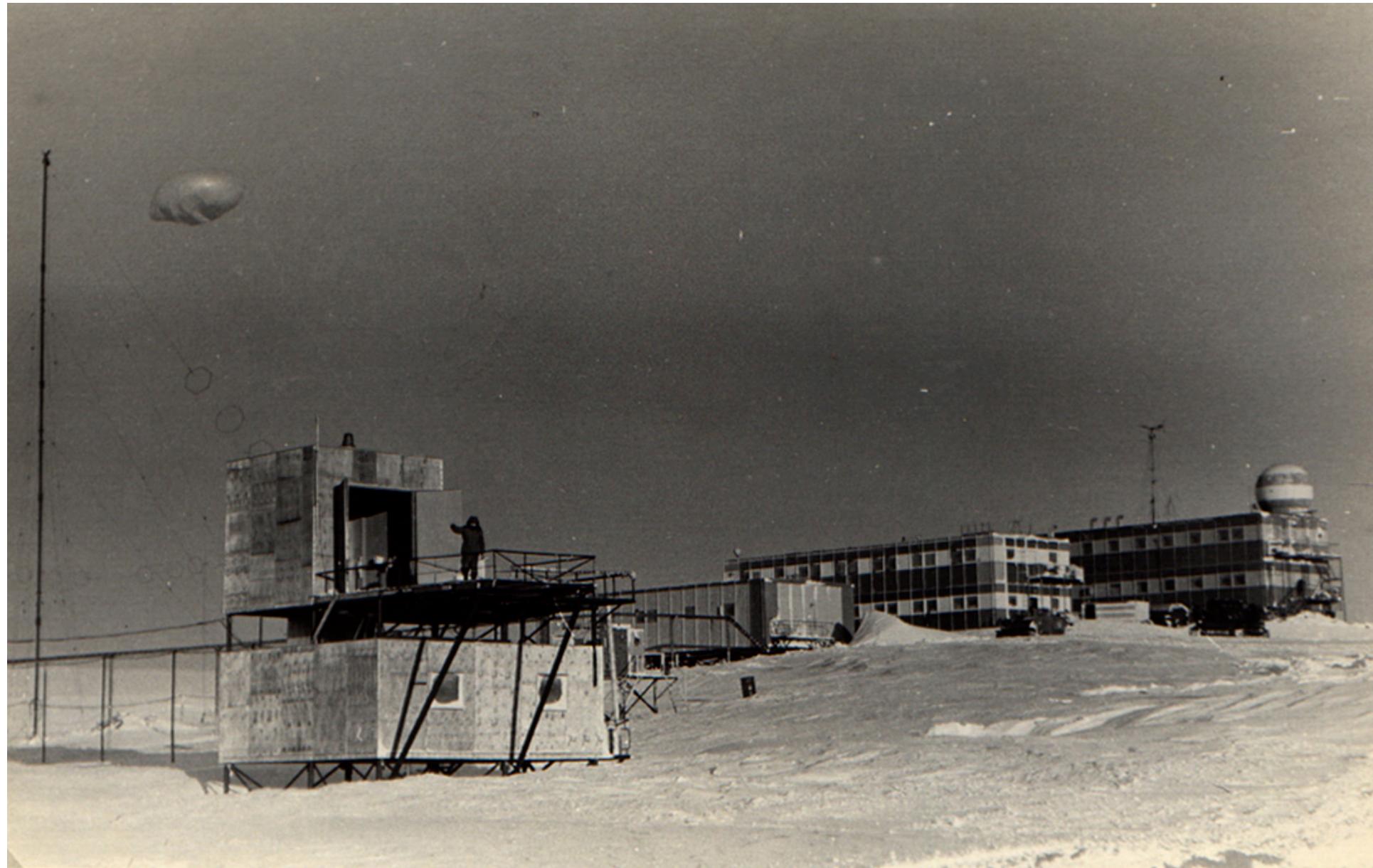
These investigations are successfully continued at present time. They have bright perspectives in the nearest future.

THANK YOU FOR ATTENTION

СПАСИБО ЗА ВНИМАНИЕ







Запуск радиозонда в Антарктиде

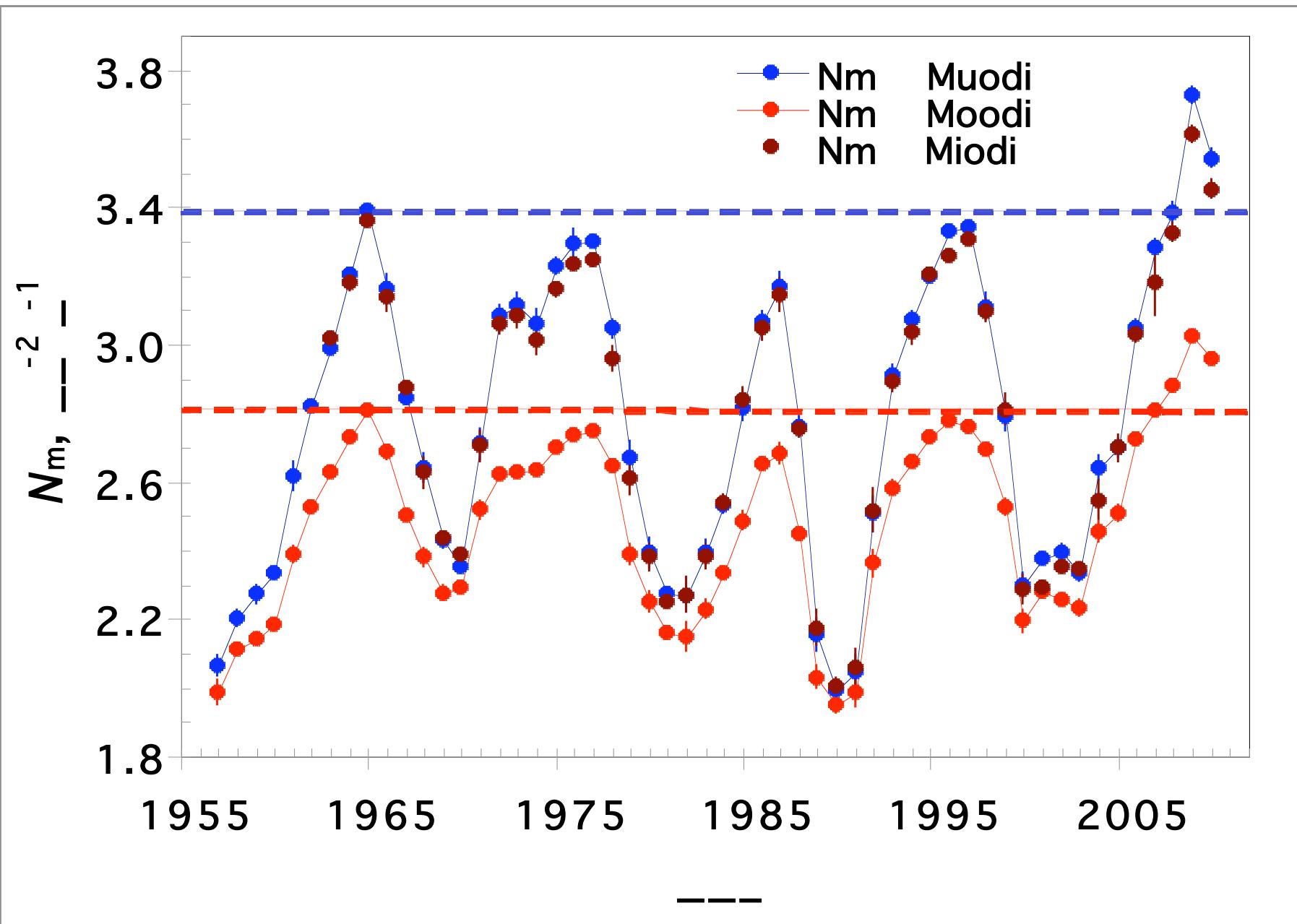
Основной задачей научных исследований на ДНС в конце 40-х годов до второй половины 50-х были изучение взаимодействий космических лучей с ядрами различных элементов, изучение состава вторичных частиц в атмосфере Земли.

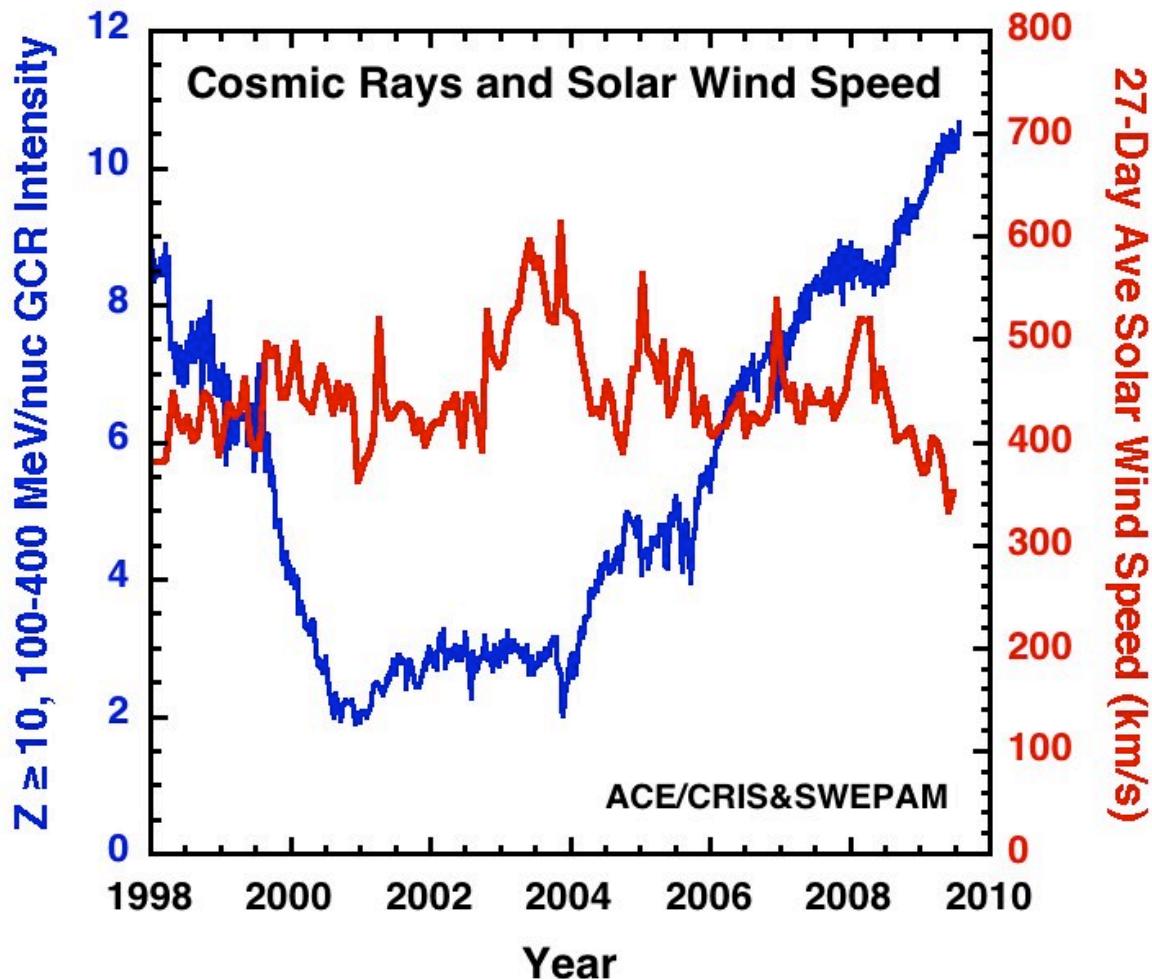
Все эти вопросы были тесно связаны с атомным проектом.

В 1957 г. С.Н. Вернов предложил проводить мониторинг заряженных частиц в атмосфере Земли.

С середины 1957 г. он вместе с А.Н. Чарахчьяном начали регулярные измерения космических лучей на высотах от уровня земли до (30-35) км. Эти измерения в северных полярных широтах, на средних широтах и в Антарктиде проводятся без перерыва до настоящего времени.

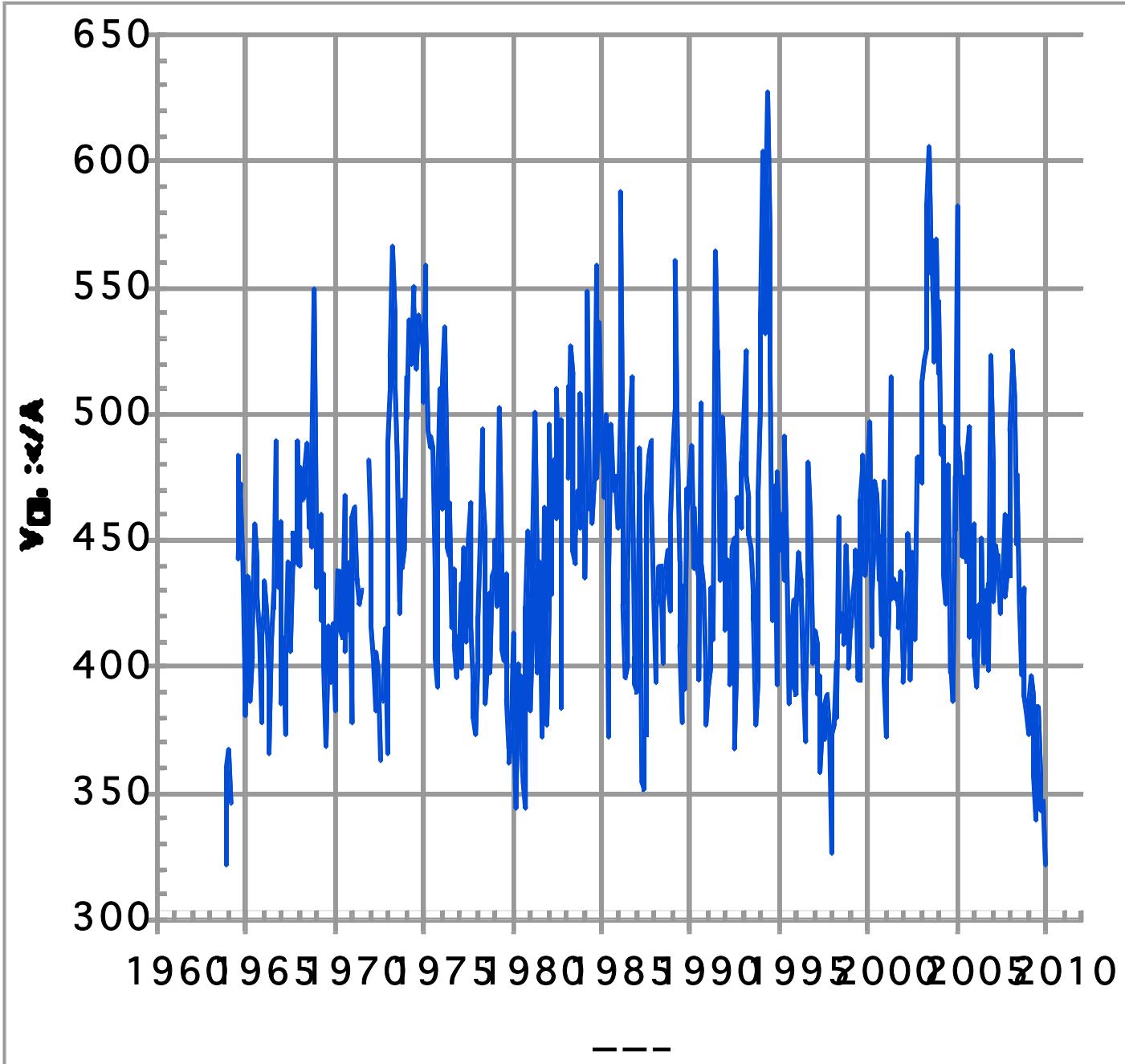
Полученные уникальные ряды данных позволили исследовать модуляцию потоков галактических космических лучей солнечной активностью в течение 5 циклов солнечной активности, в том числе впервые изучить эффекты инверсии общего магнитного поля Солнца в космических лучах.





Cosmic Ray Intensity and Solar Wind Speed

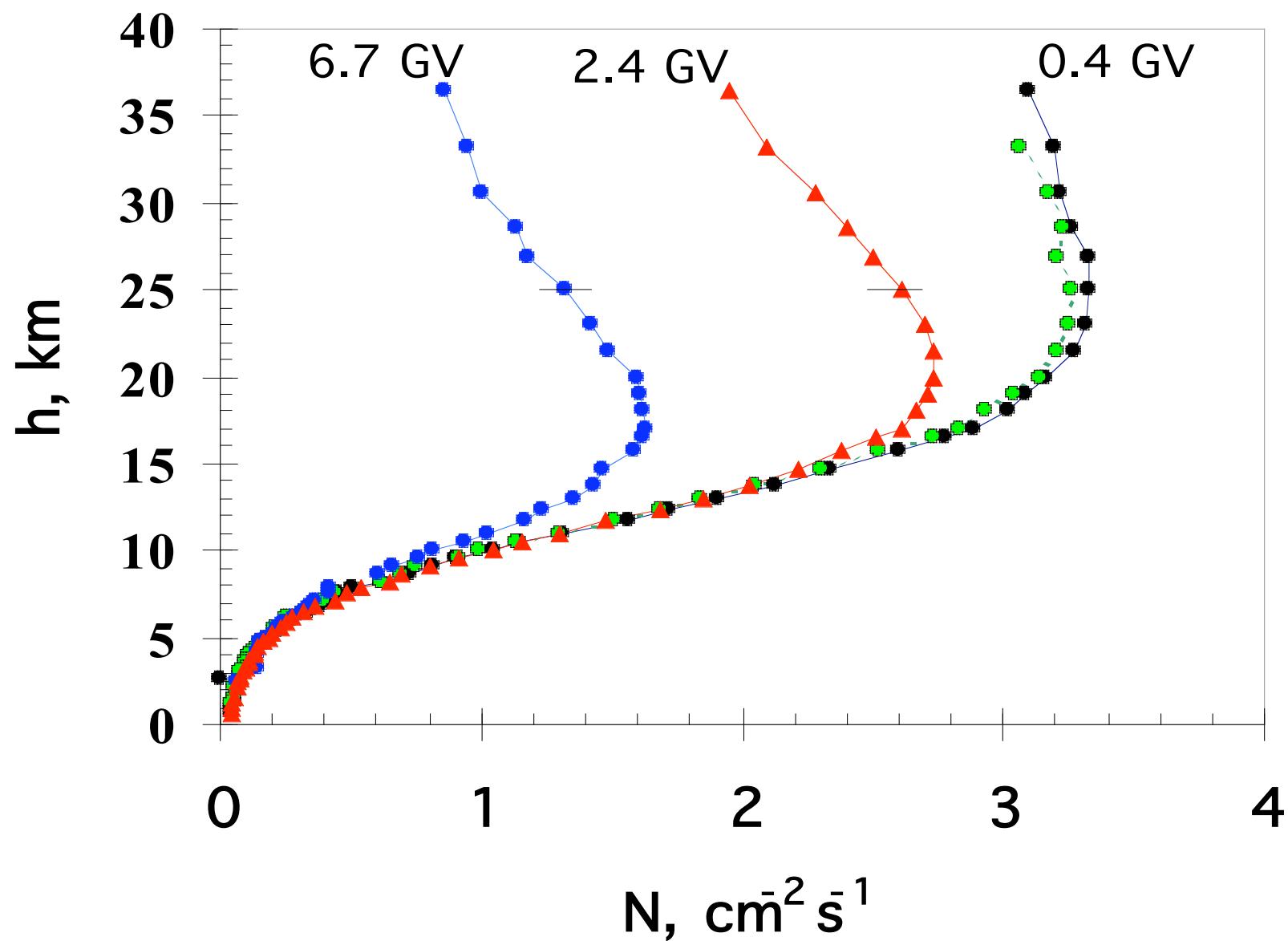
On the left hand axis are plotted 5-day averages of the 100 to 400 MeV/nucleon intensity of cosmic rays from Neon to Nickel measured by the ACE/CRIS instrument. The right-hand axis (red trace) shows the solar wind speed measured by the SWEPPAM instrument on ACE. During 2008-2009 when the cosmic rays reached record levels, the solar wind speed declined to very low levels similar to those of previous solar minima. When the solar wind speed decreases, cosmic rays encounter less resistance and they reach the inner solar system in greater numbers.

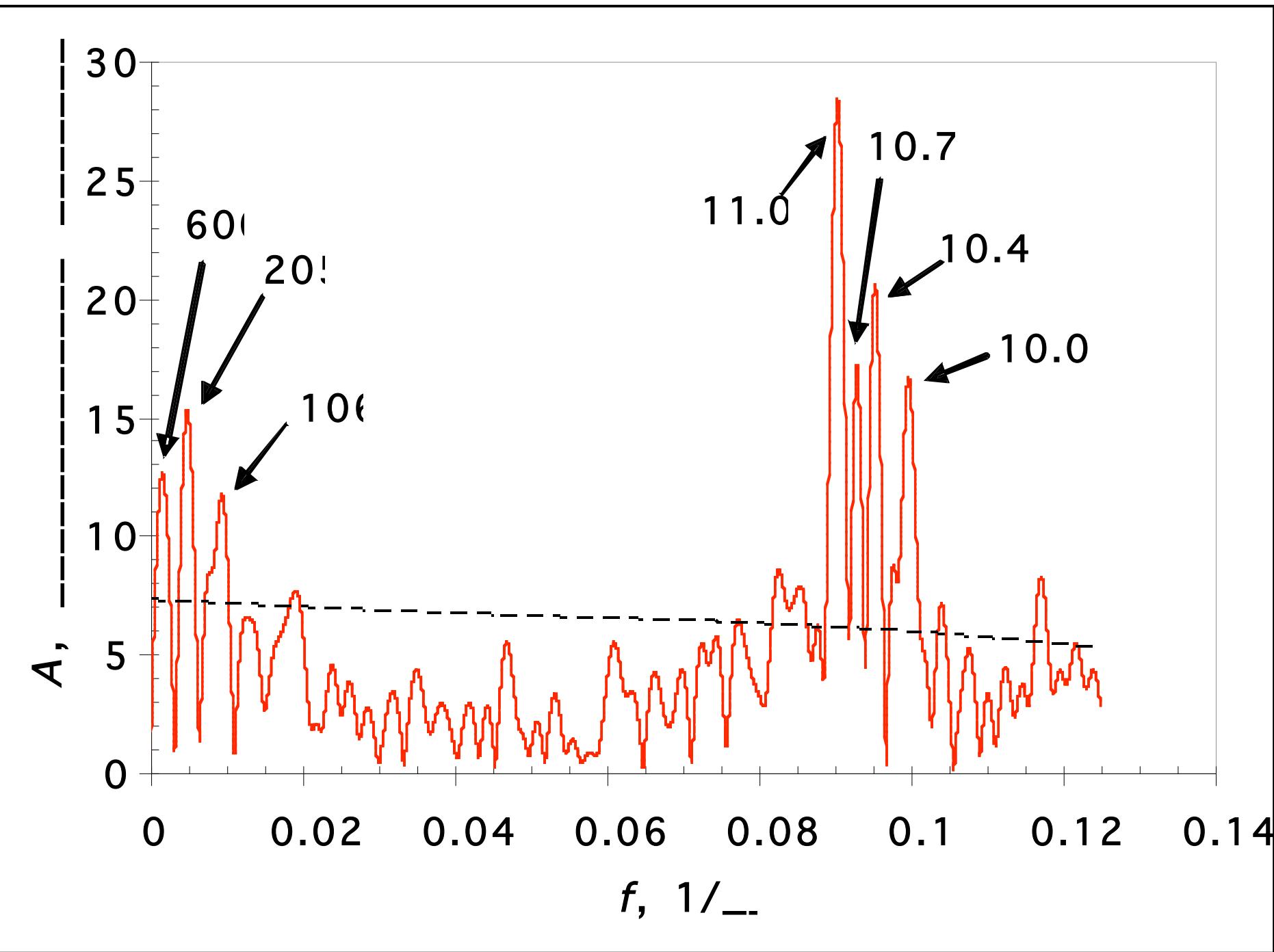


<http://omniweb.gfsc.nasa.gov/>



В 1976 г. А.Н. Чарахчьян (руководитель), Г.А. Базилевская, Ю.И. Стожков и Т.Н. Чарахчьян были удостоены Ленинской премии за исследование модуляционных эффектов космических лучей в стратосфере.





Период в R_z (T , годы)	600	205	106	22.13	19.96	18.35	11.06	10.76	10.49	10.02
Периоды осцилляций пар планет, годы	-	198	-	22.20	19.86	-	11.07	10.86	10.49	10.02

$$T_{10.76} \approx (T_{600} \cdot T_{11.06})/(T_{600} + T_{11.06}) = 10.86$$

$$T_{10.49} \approx (T_{205} \cdot T_{11.06})/(T_{205} + T_{11.06}) = 10.49$$

$$T_{10.02} \approx (T_{106} \cdot T_{11.06})/(T_{106} + T_{11.06}) = 10.02$$

$$T_{19.86} \approx (T_{11} \cdot T_{29})/(T_{11} - T_{29}) = 19.86$$

$$(1/T_{22}) = (1/T_{19}) - 1/(T_{178} + T_{19}/2)$$

$$T_{11.06} \approx (T_{165} \cdot T_{11.9})/(T_{165} + T_{11.9}) = 11.07$$

$$T_{\text{Ю}} = 11.86$$

$$T_{\text{С}} = 29.46$$

$$T_{\text{ЦМ}} = 178.77$$

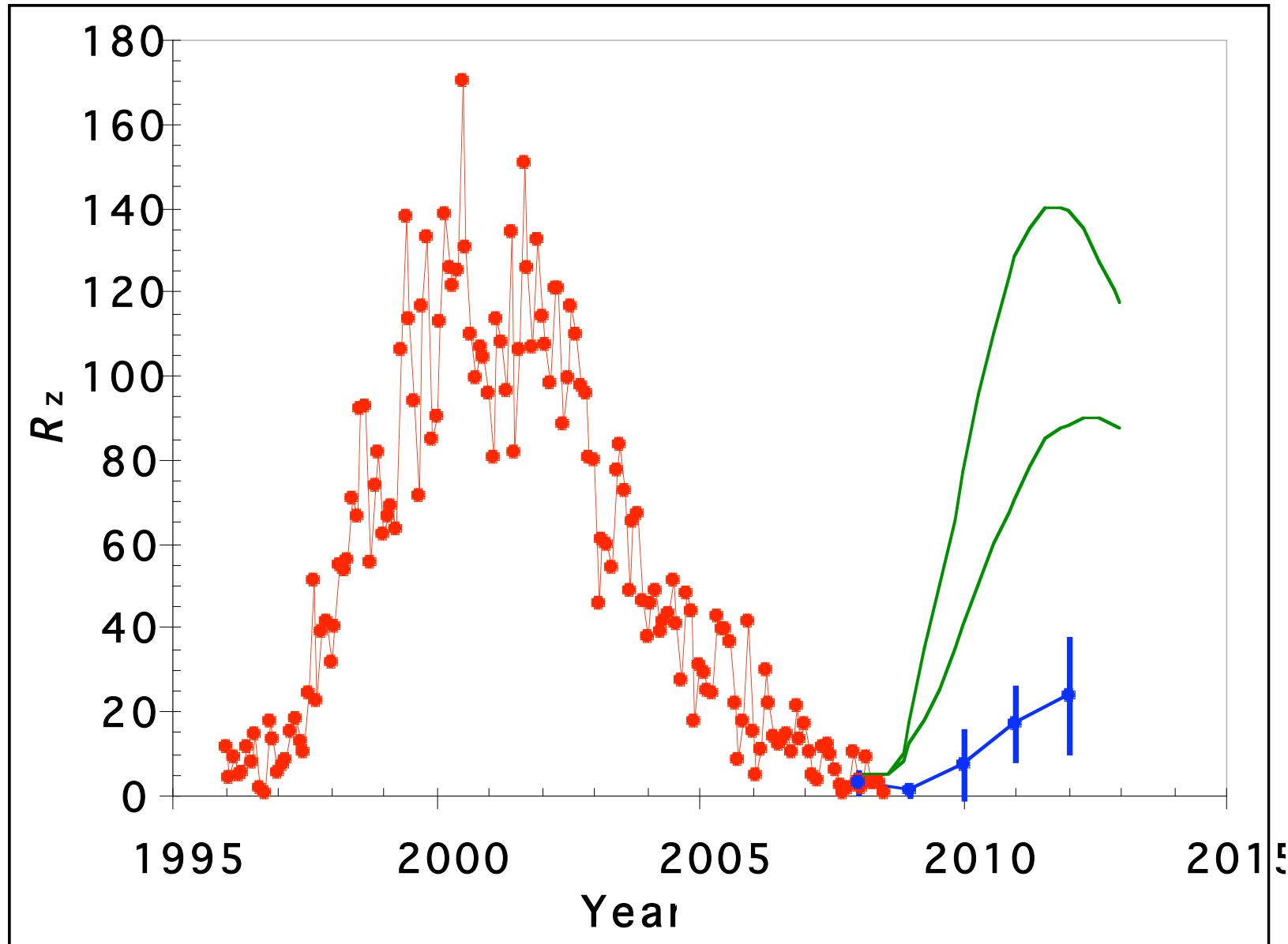
$$T_{\text{Н}} = 165.79$$

$$T_{205} \approx T_{\text{ЦМ}} + (T_{\text{Ю}} \cdot T_{\text{С}})/(T_{\text{Ю}} - T_{\text{С}}) = 199$$

$$T_{\text{ЦМ}} = 9 \cdot (T_{\text{Ю}} \cdot T_{\text{С}})/(T_{\text{С}} - T_{\text{Ю}}) = 178.67$$

$$T_{205} \approx 10 \cdot (T_{\text{Ю}} \cdot T_{\text{С}})/(T_{\text{Ю}} - T_{\text{С}}) = 199$$

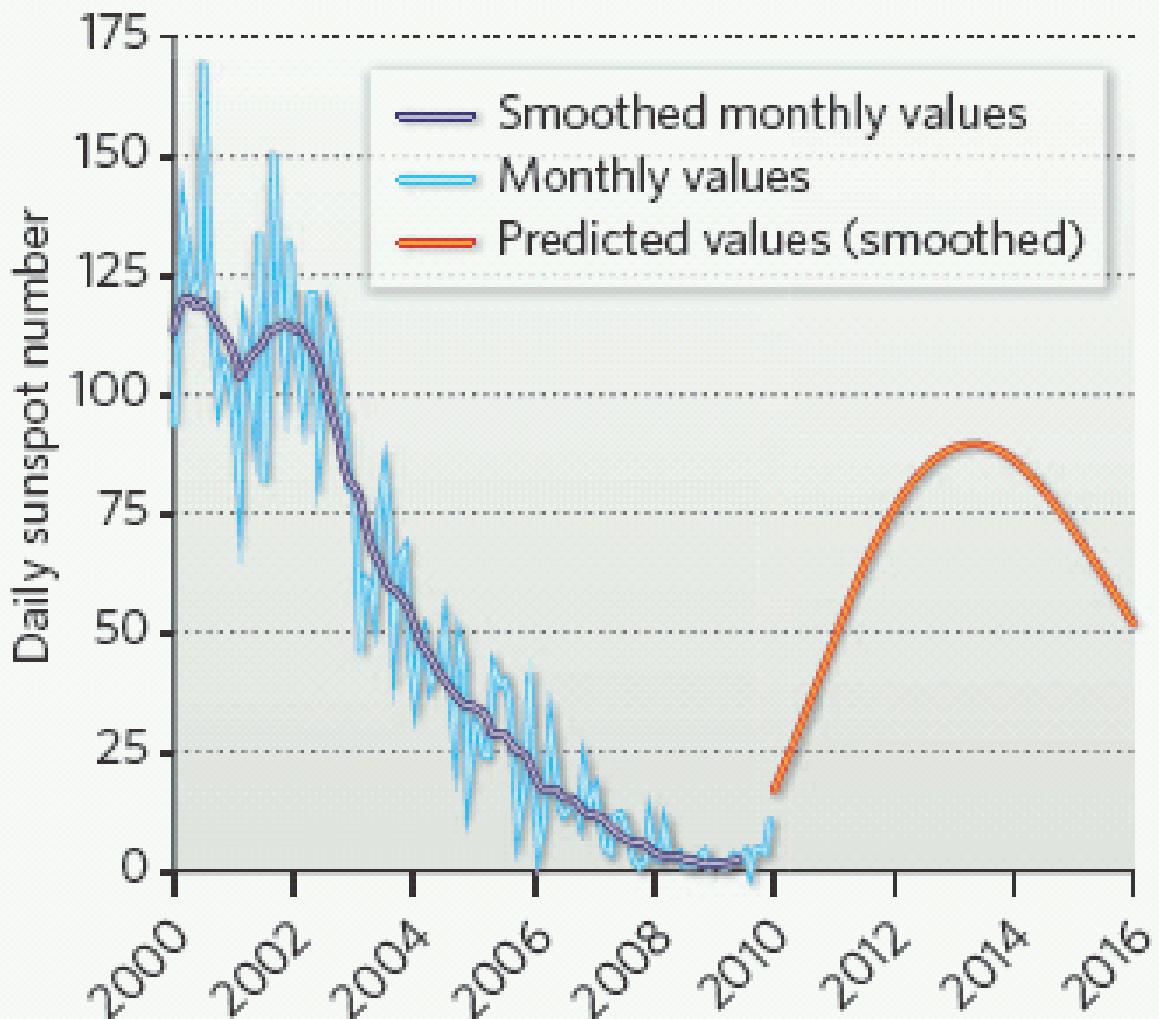
Полученные результаты указывают, что на образование солнечных пятен влияют движения планет!



Солнечная активность в 1996-2008 гг. (красные точки) и ее прогноз (синие точки – прогноз ДНС, зеленые кривые – прогноз из <http://www.swpc.noaa.gov/SolarCycle/index.html>).

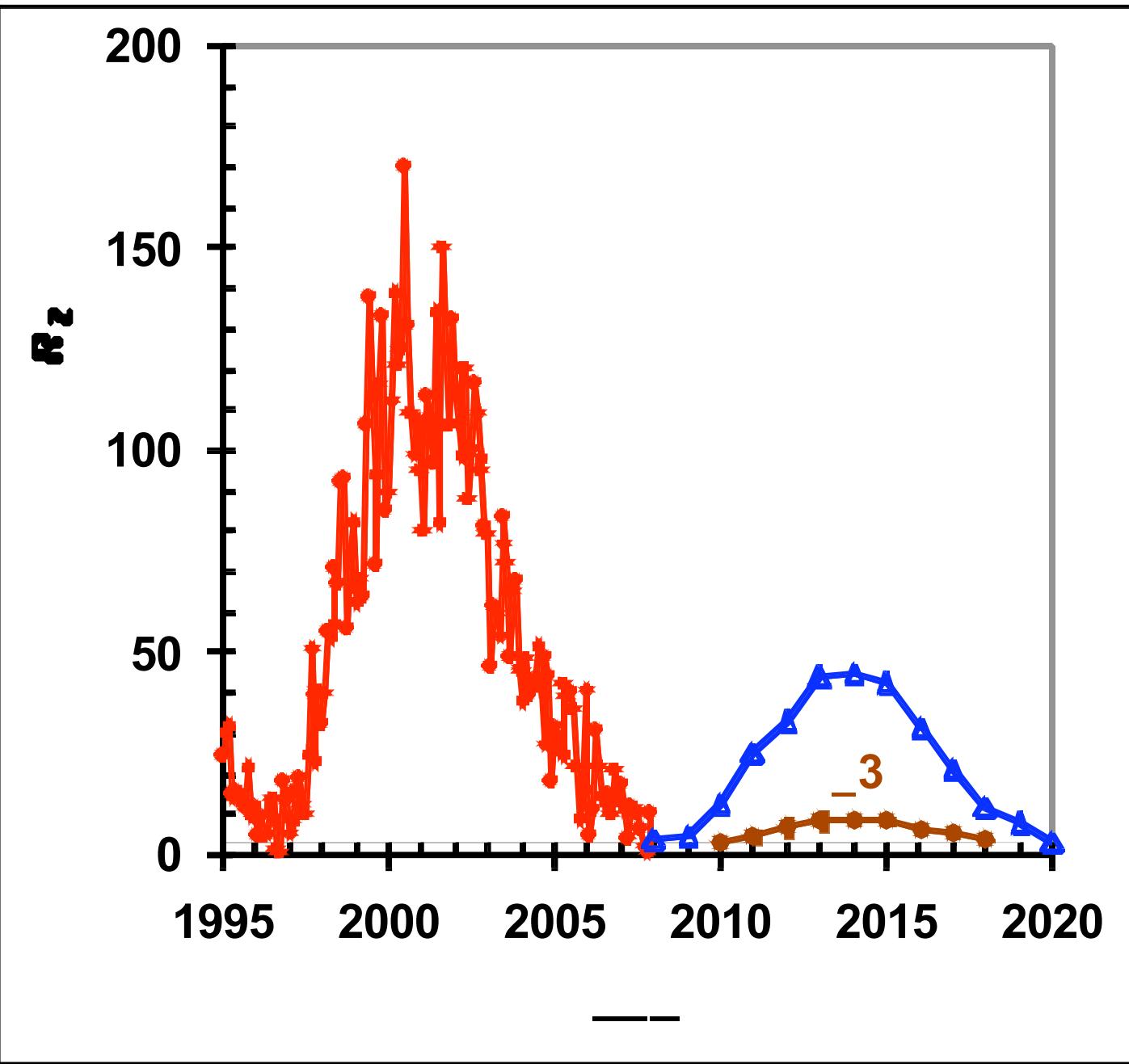
SOLAR CYCLE 24

A consensus prediction suggests that 2013 will see a maximum of 90 sunspots a day — although some researchers think that the number could go to 150 or even higher.



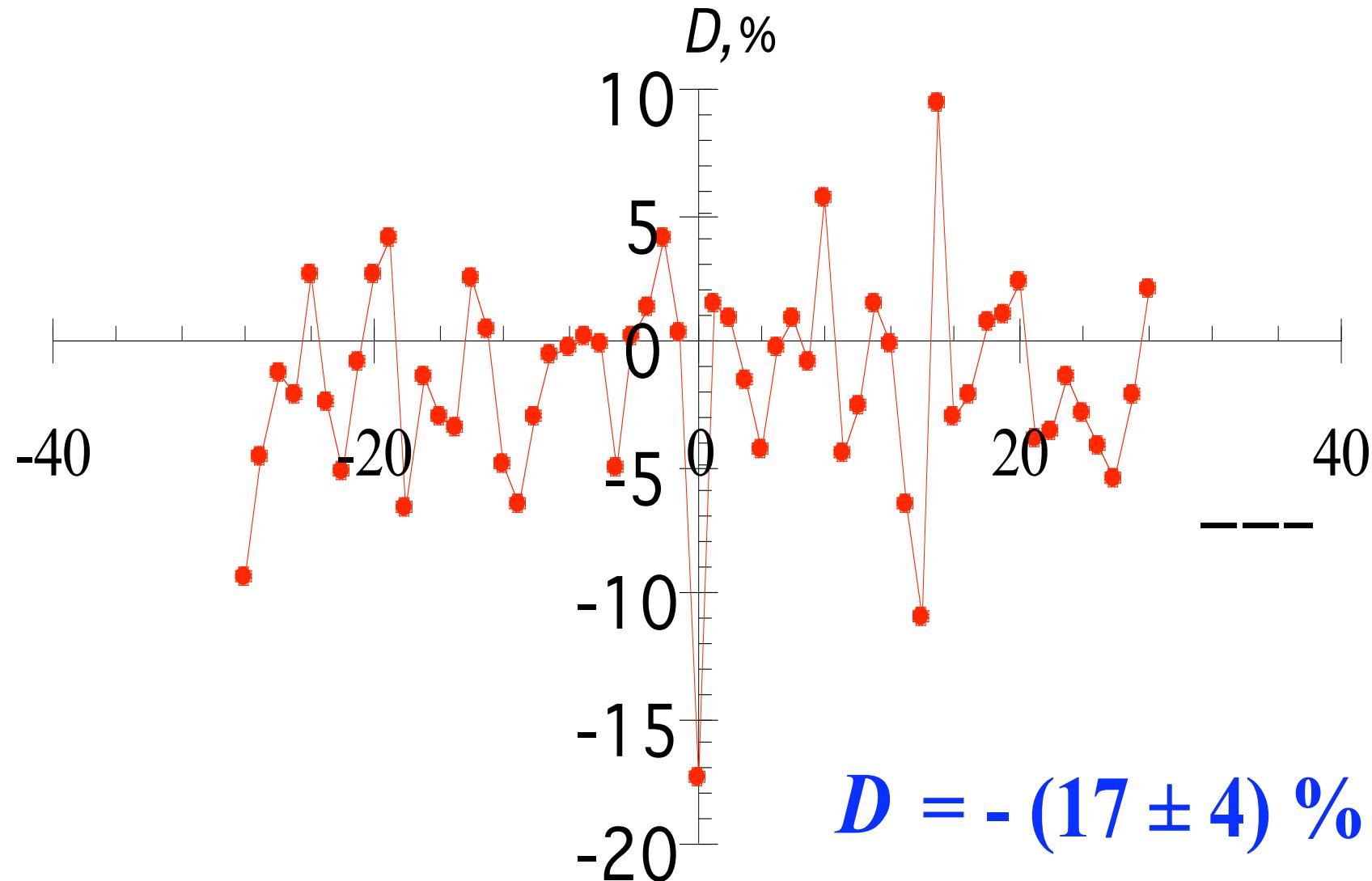
Lizzie Buchen “What will next solar cycle bring?” p. 414

NATURE|Vol 463|28 January 2010

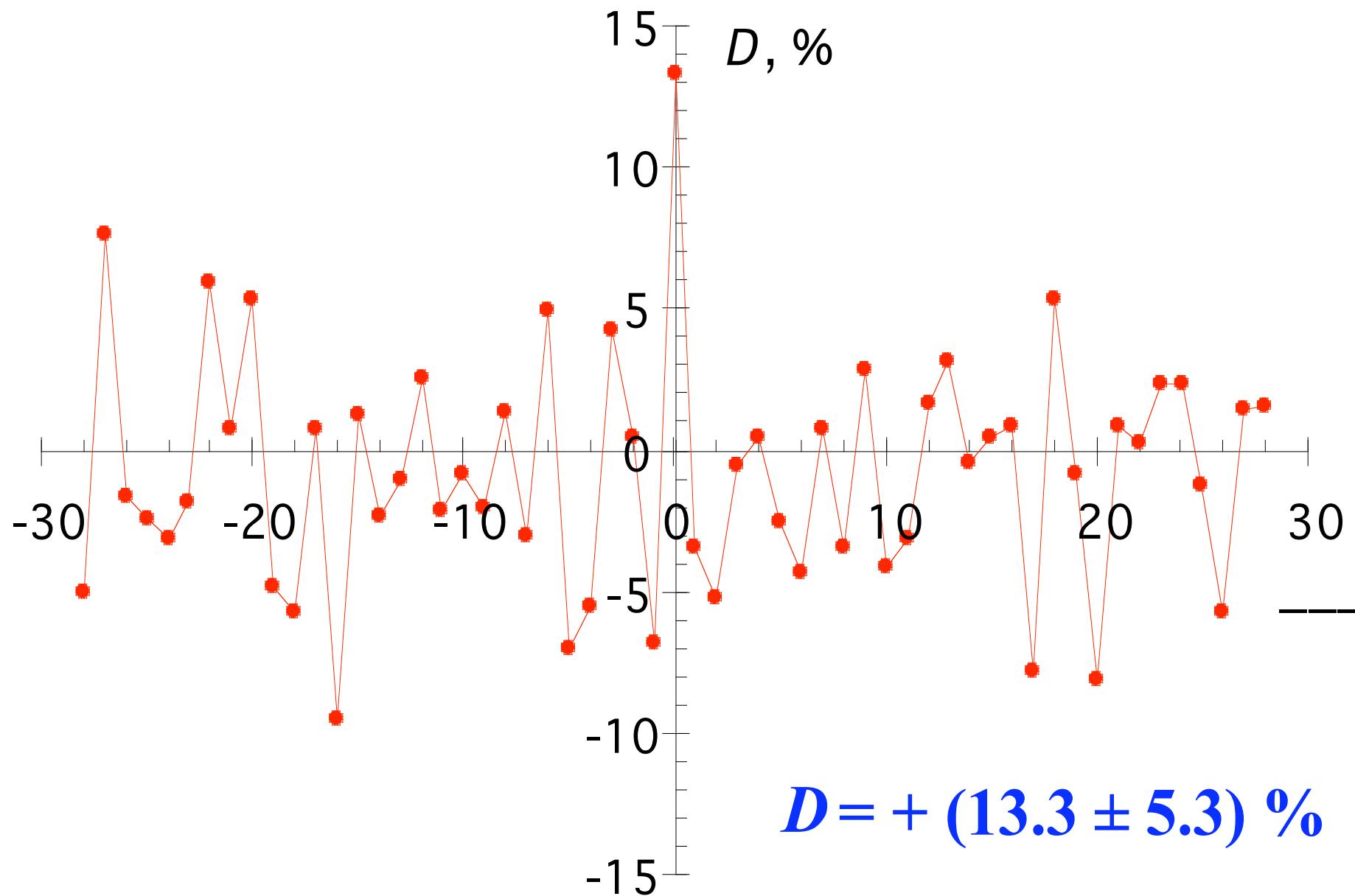


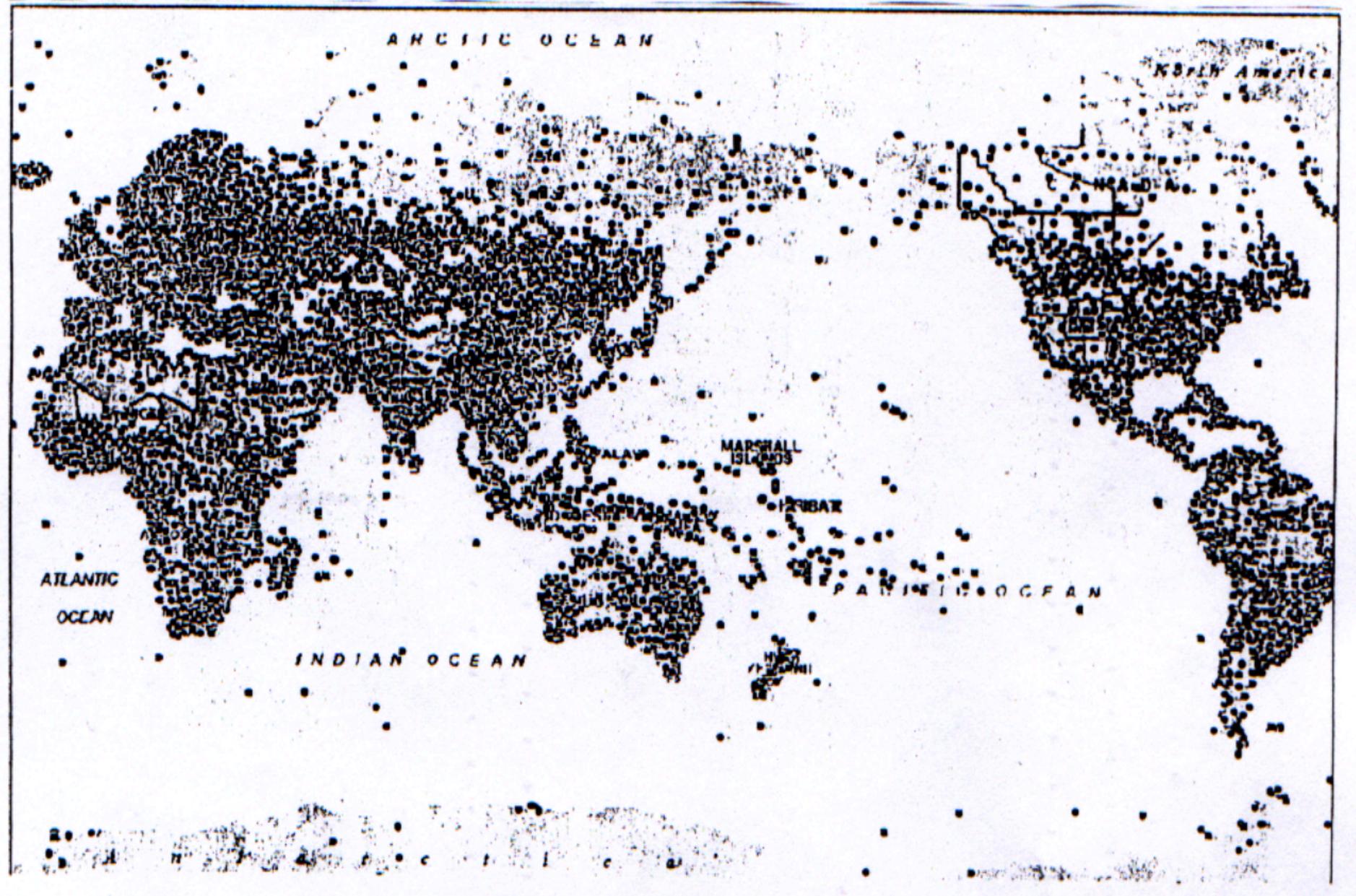
Семинар НИИЯФ МГУ 30.04.08; Proceedings of Forecasting of the Radiation and Geomagnetic Storms by networks of particle detectors (FORGES), Nor - Amberd, Armenia, 28.09- 3.10.2008

Осадки и форбуш-понижения КЛ



Осадки и СКЛ





Глобальная сеть метеорологических станций

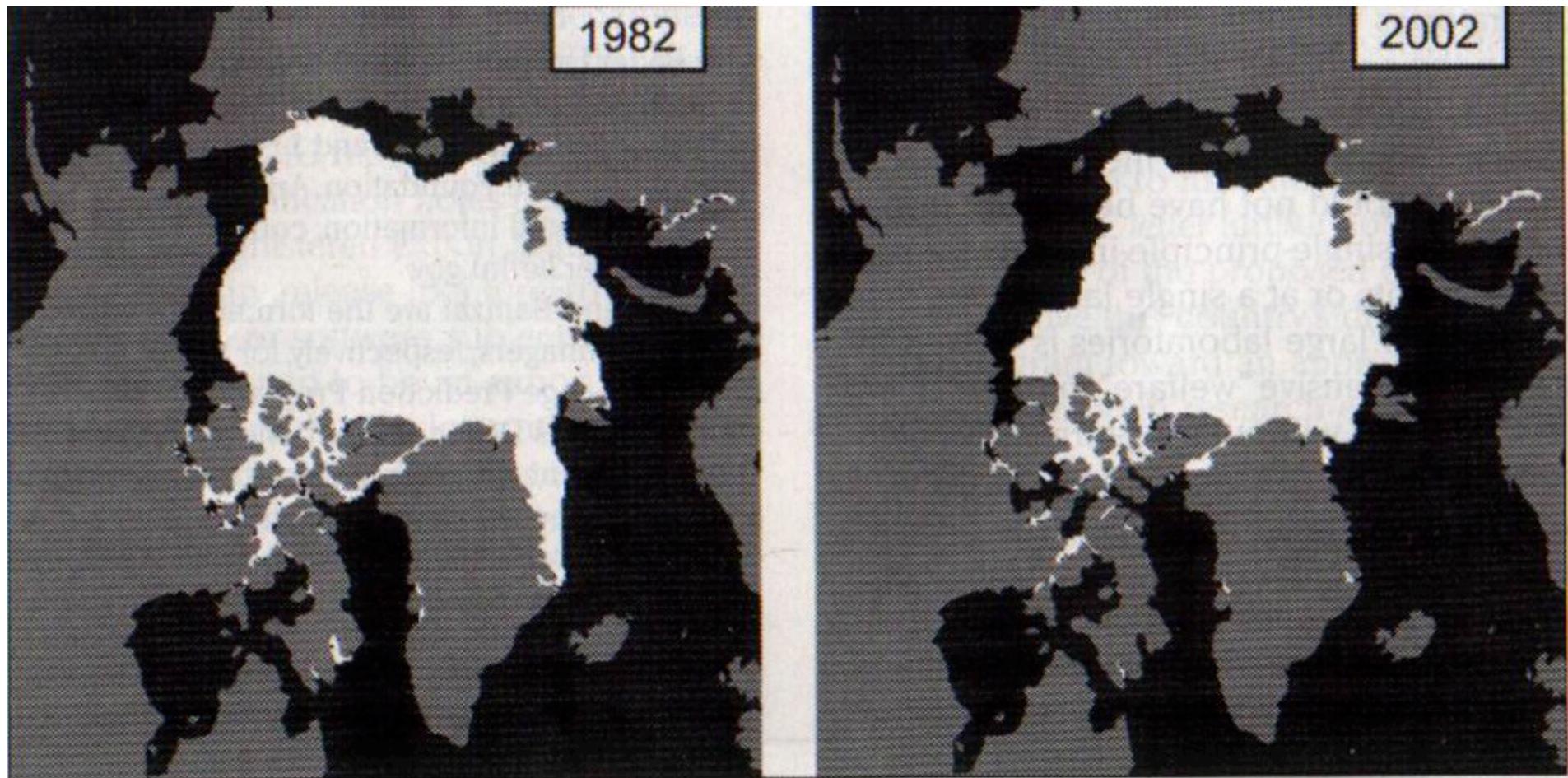
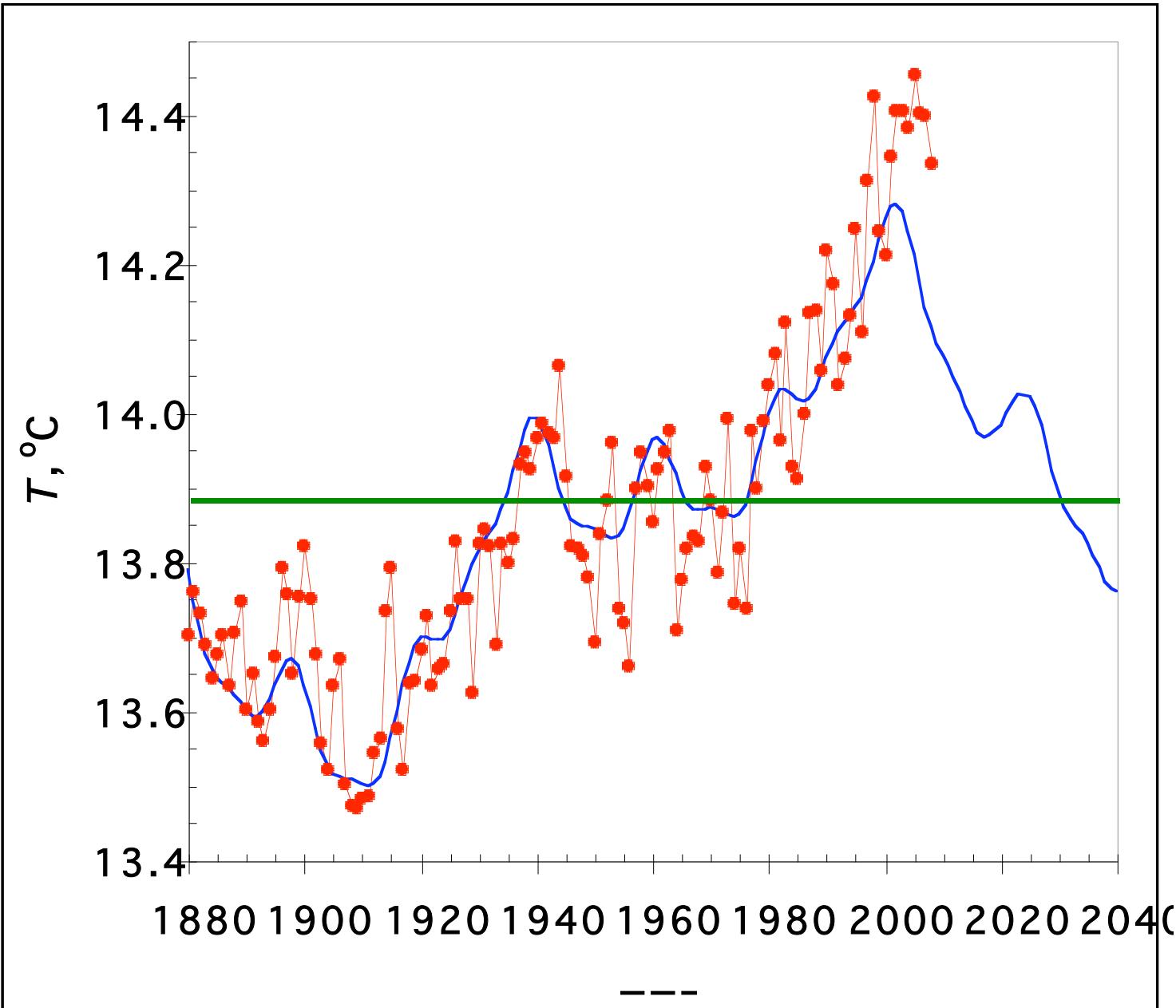


Fig. 1. Sea ice extent (white) at the end of summer in 1982 and 2002 observed with passive microwave satellite sensors. The record minimum extent was observed in 2002, but that record was nearly equaled in 2003 and 2004.



ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/annual.land_and_ocean.90S.90N.df_1901-2000mean.dat

Уравнение энергетического (теплового) баланса климатической системы Земли

$$\pi r^2 \cdot S \cdot (1 - A) + W_3 = 4\pi r^2 \cdot \sigma \cdot T_e^4,$$

где r – радиус Земли, S – солнечная постоянная, рассчитанная на удалении от Солнца в одну астрономическую единицу, A – сферическое альbedo Земли, W_3 - мощность теплового потока, поступающего в климатическую систему из недр Земли, σ - постоянная Стефана-Больцмана, T_e – эффективная (излучательная) температура климатической системы.

$$S(1 - A - k)/4 = \sigma \cdot (T_p^4 - T_e^4),$$

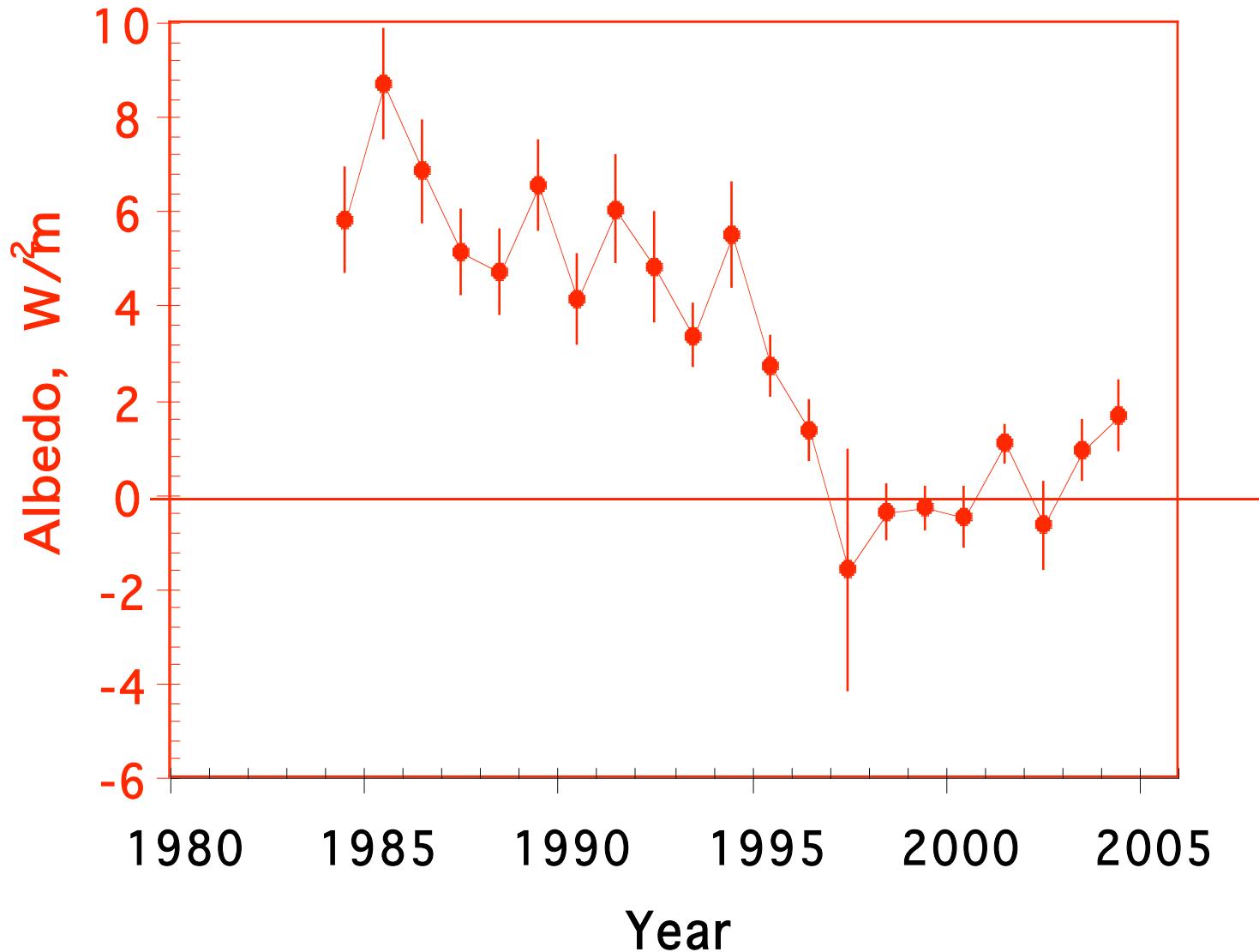
где k - коэффициент поглощения солнечного излучения атмосферой.

$$T_p^4 = S(1 - A - k) / [4\sigma(1 - (T_e^4 / T_p^4))]$$

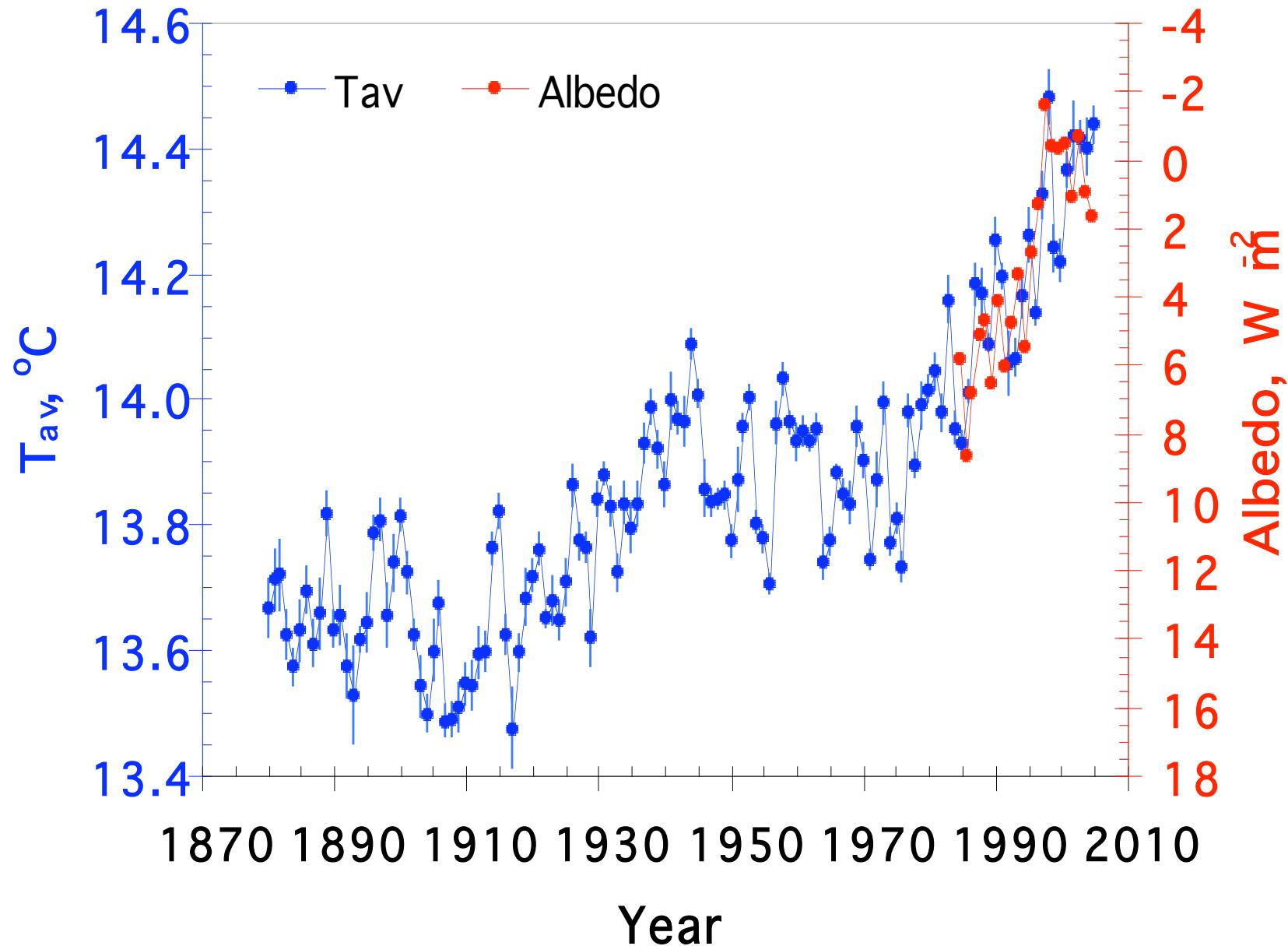
T_p зависит от S , A и k

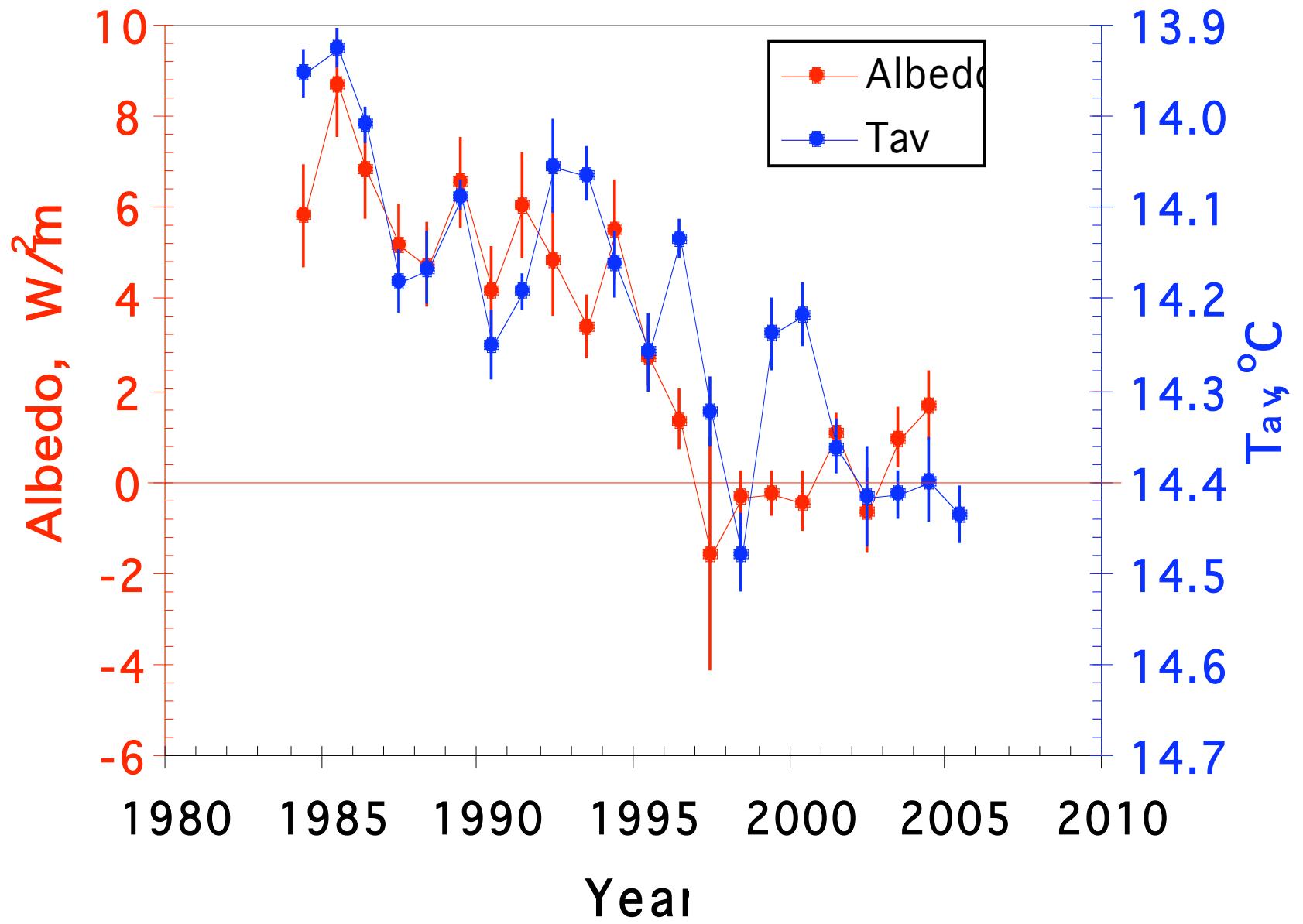
T_p (современное значение) ≈ 14 °C

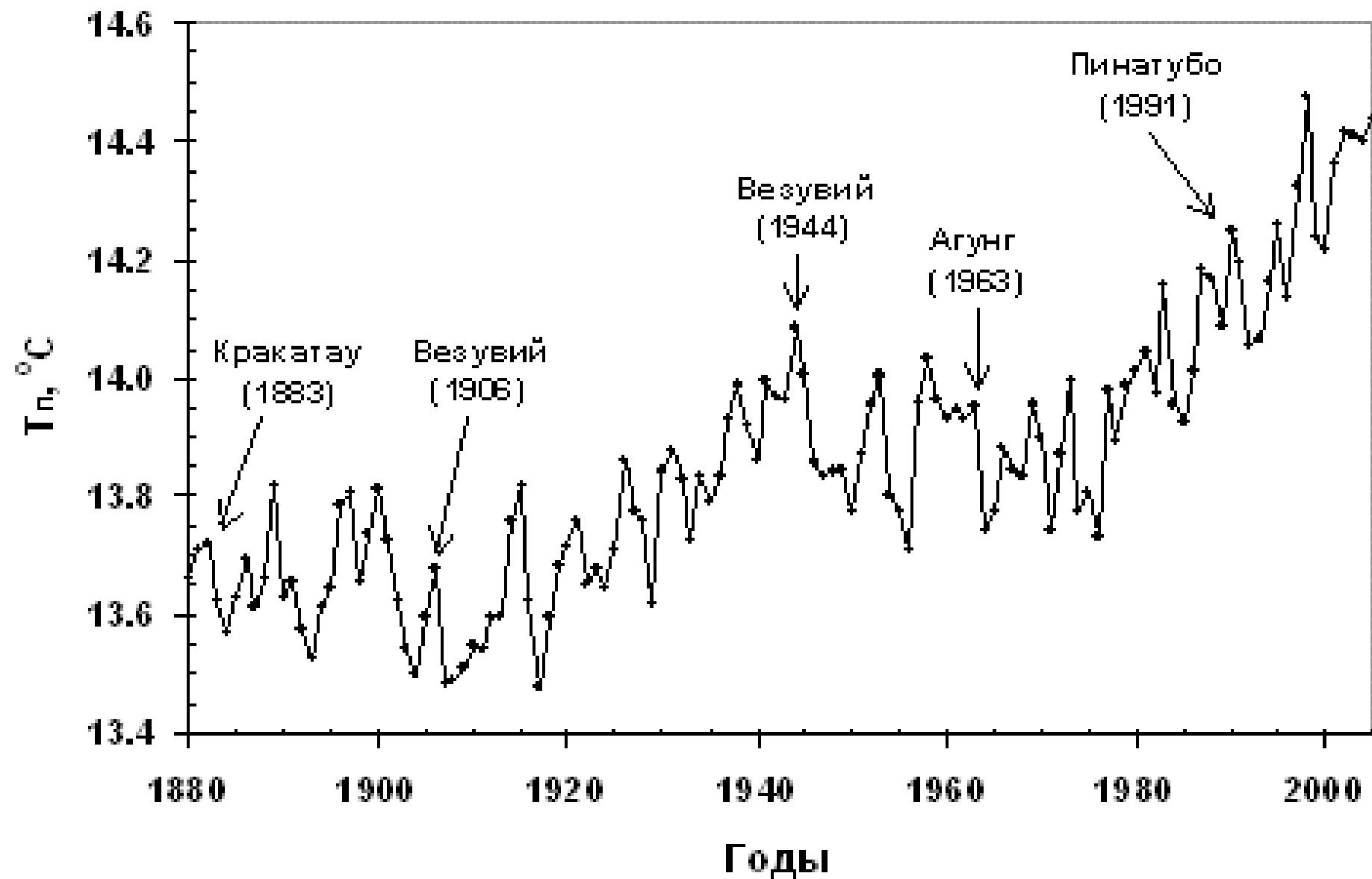
$T_p > T_e = -19$ °C

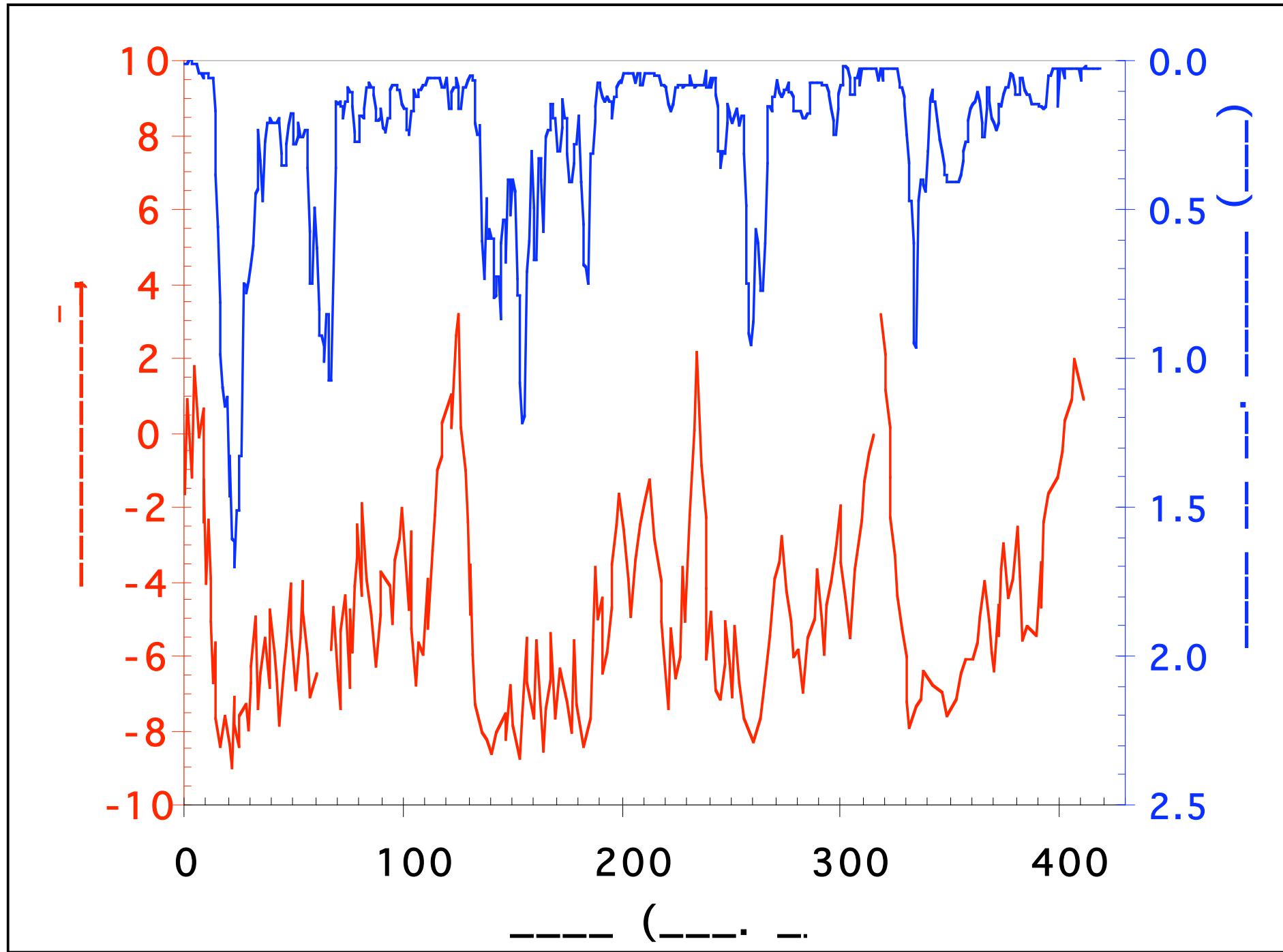


Can Earth's albedo and Surface Temperatures increase together? E. Palle et al., EOS, 2006, v. 87, No. 4, pp. 37, 43









СПЕКТР ГЛОБАЛЬНОЙ ТЕМПЕРАТУРЫ, 1880 – 2005

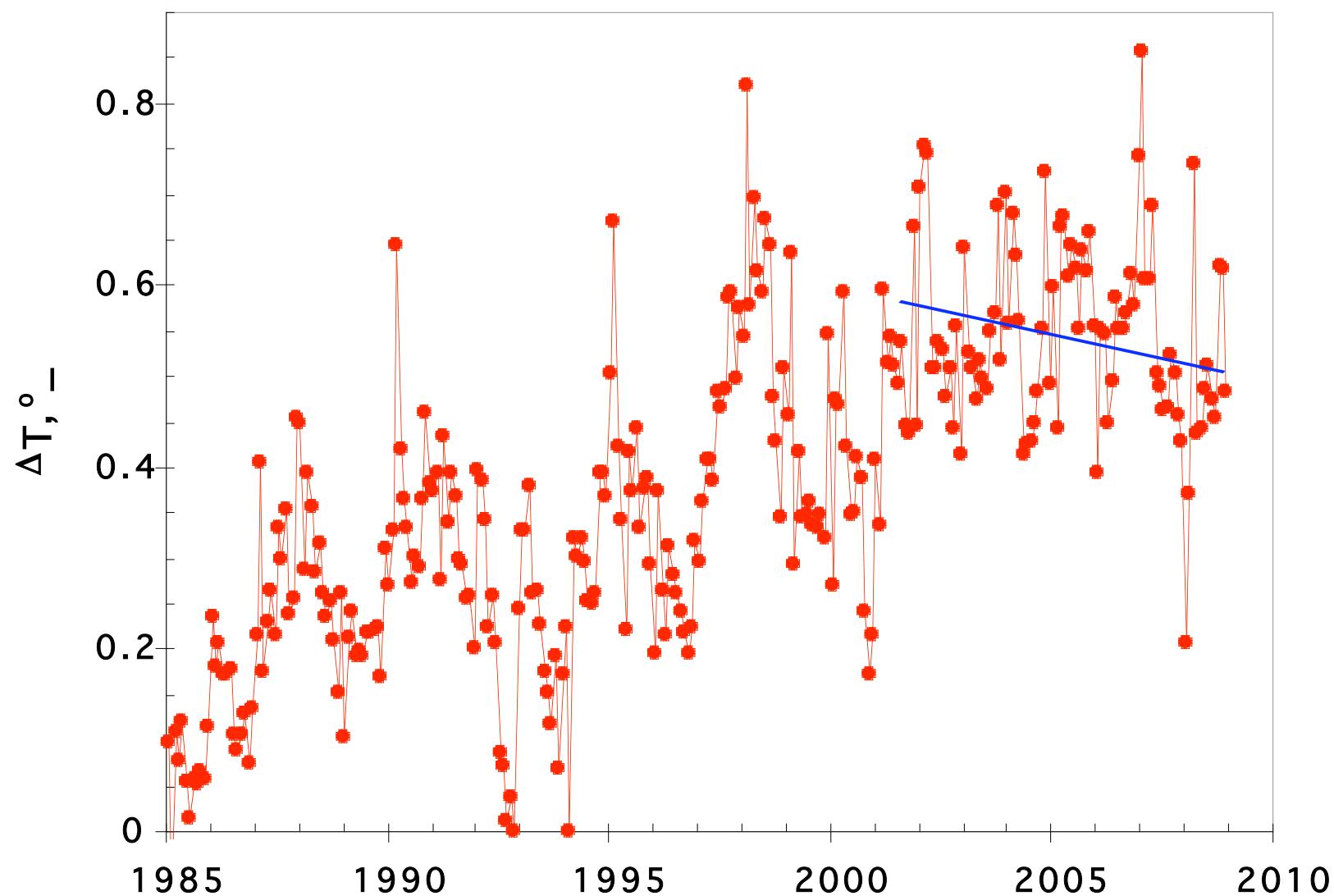
Амплитуда	Фаза	Период	УР95	УР99
.2765	125.3551	194.0357	.0671	.0831
.1567	25.2184	64.2959	.0628	.0777
.0698	18.9872	32.5329	.0564	.0698
.0724	7.8688	20.8962	.0492	.0609
.0440	11.7415	14.5267	.0404	.0500
.0352	4.8761	11.4379	.0326	.0404
.0335	4.0237	10.3881	.0289	.0358
.0350	1.8540	8.9727	.0268	.0331
.0295	.9868	8.2506	.0264	.0326
.0433	4.7750	7.5249	.0259	.0320
.0317	5.4183	6.4106	.0249	.0308
.0291	2.7896	6.0066	.0244	.0303
.0383	.8626	5.1891	.0233	.0289
.0254	3.0586	4.7491	.0224	.0278
.0214	.2731	4.2864	.0212	.0263
.0254	1.9658	3.7469	.0194	.0240
.0306	1.0311	3.6088	.0189	.0234
.0408	1.5974	3.5097	.0184	.0228
.0148	1.1290	3.3047	.0175	.0216
.0197	.0948	3.2053	.0170	.0210
.0176	.6533	2.9884	.0158	.0195
.0155	.0999	2.8968	.0152	.0188
.0158	.9208	2.5299	.0125	.0155
.0217	.7557	2.4718	.0123	.0152
.0166	1.2999	2.1457	.0123	.0152
.0178	.2413	2.0341	.0123	.0152

Выводы

Дан прогноз о наступлении нового длительного минимума солнечной активности. Вероятно максимальное значение R_z будет менее 50.

Прогноз основан на том, что солнечные пятна возникают после падения небесных тел на солнечную фотосферу.

Солнце и тяжелые планеты действуют на небесные тела при их движении к Солнцу, как гравитационные линзы.



ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/



Ключевская сопка в 1973 - 1974



Пинатубо, 12 июня 1991 г. (17.2 Мт пыли)