ISKRA – 2017

ПРОНИКНОВЕНИЕ КОСМИЧЕСКИХ ЛУЧЕЙ В ДИНАМИЧЕСКУЮ МАГНИТОСФЕРУ И ИХ ВЛИЯНИЕ НА АТМОСФЕРУ

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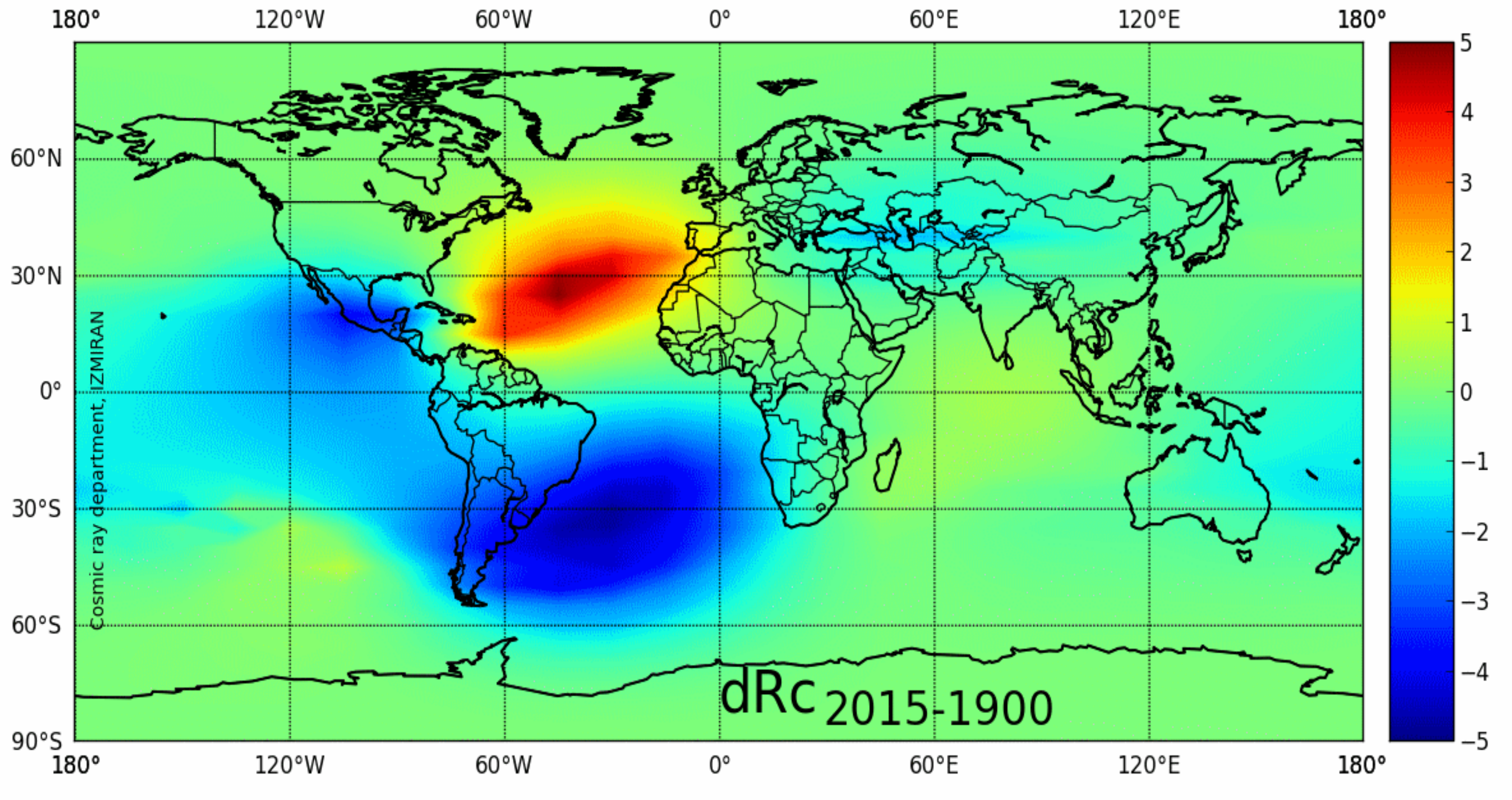
Changes in the distribution of vertical planetary geomagnetic cutoff rigidity of the era of 2015 with



Digital and graphical results of calculations can be found at

ftp Server Magnetosphere Effect. (user name : anonymous)

Accounting for the penumbra region

Excluding the effects of the atmosphere. For the primary spectrum, for example, J (R) = aRγ, the effective stiffness of geomagnetic cutoff is determined from the equation:

$$\int_{R_{eff}}^{R_H} J(R)dR = \int_{R_S}^{R_H} g(R)J(R)dR \cdots \Rightarrow \quad \boxed{R_{eff}^{\gamma+1} = R_H^{\gamma+1} - (\gamma+1)\int_{R_S}^{R_H} g(R)\cdot R^{\gamma}dR}$$

In the case of the primary spectrum is not dependent on energy ("white" or "flat")

$$\boxed{R_{eff} = R_H - \int_{R_S}^{R_H} g(R)dR}$$

Into account the atmosphere. In this case the communication functions in the penumbra W (R) = cRη, the effective stiffness of geomagnetic cutoff is determined from the equation:

$$\int_{R_{eff}}^{R_H} W(R,h)\cdot \delta J / J(R)\cdot dR = \int_{R_S}^{R_H} g(R)\cdot W(R,h)\cdot \delta J / J(R)\cdot dR$$

$$\boxed{R_{eff}^{\gamma+\eta+1} = R_H^{\gamma+\eta+1} - (\gamma+\eta+1)\int_{R_S}^{R_H} g(R)\cdot R^{\eta+\gamma}dR}$$

Accounting for the penumbra region

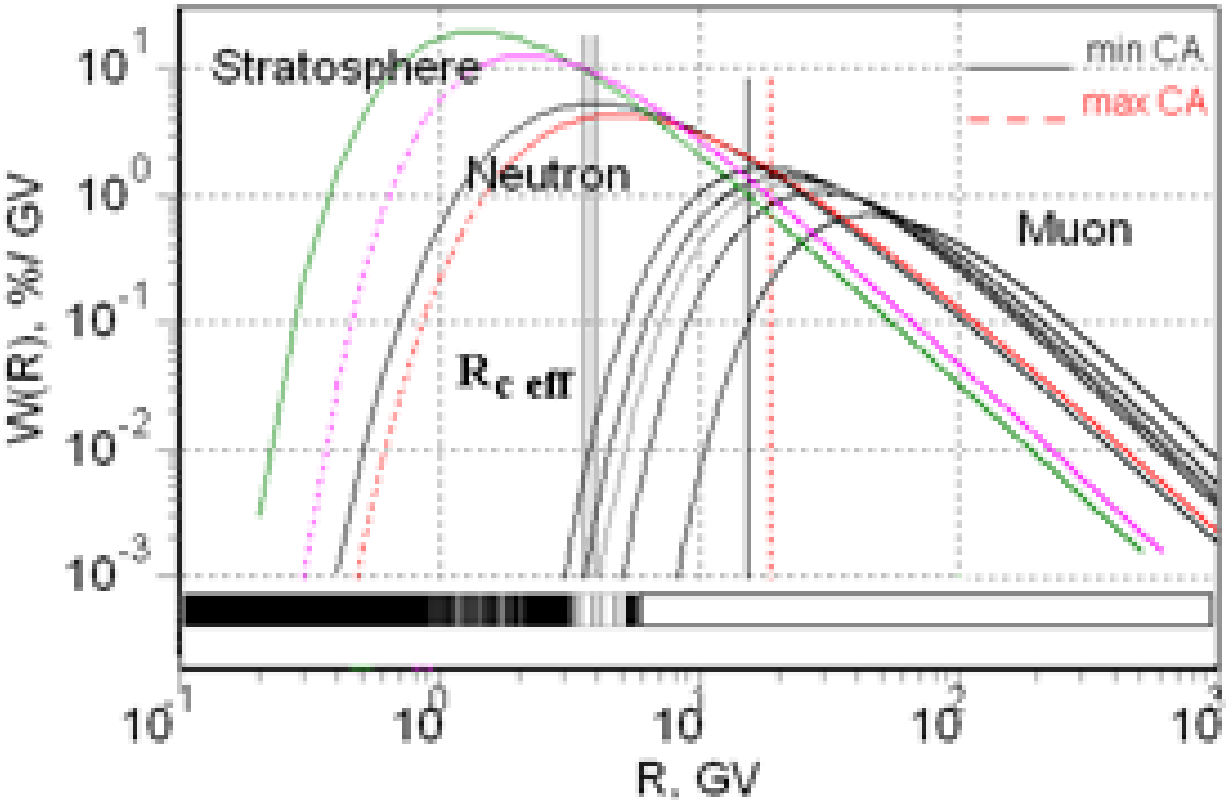
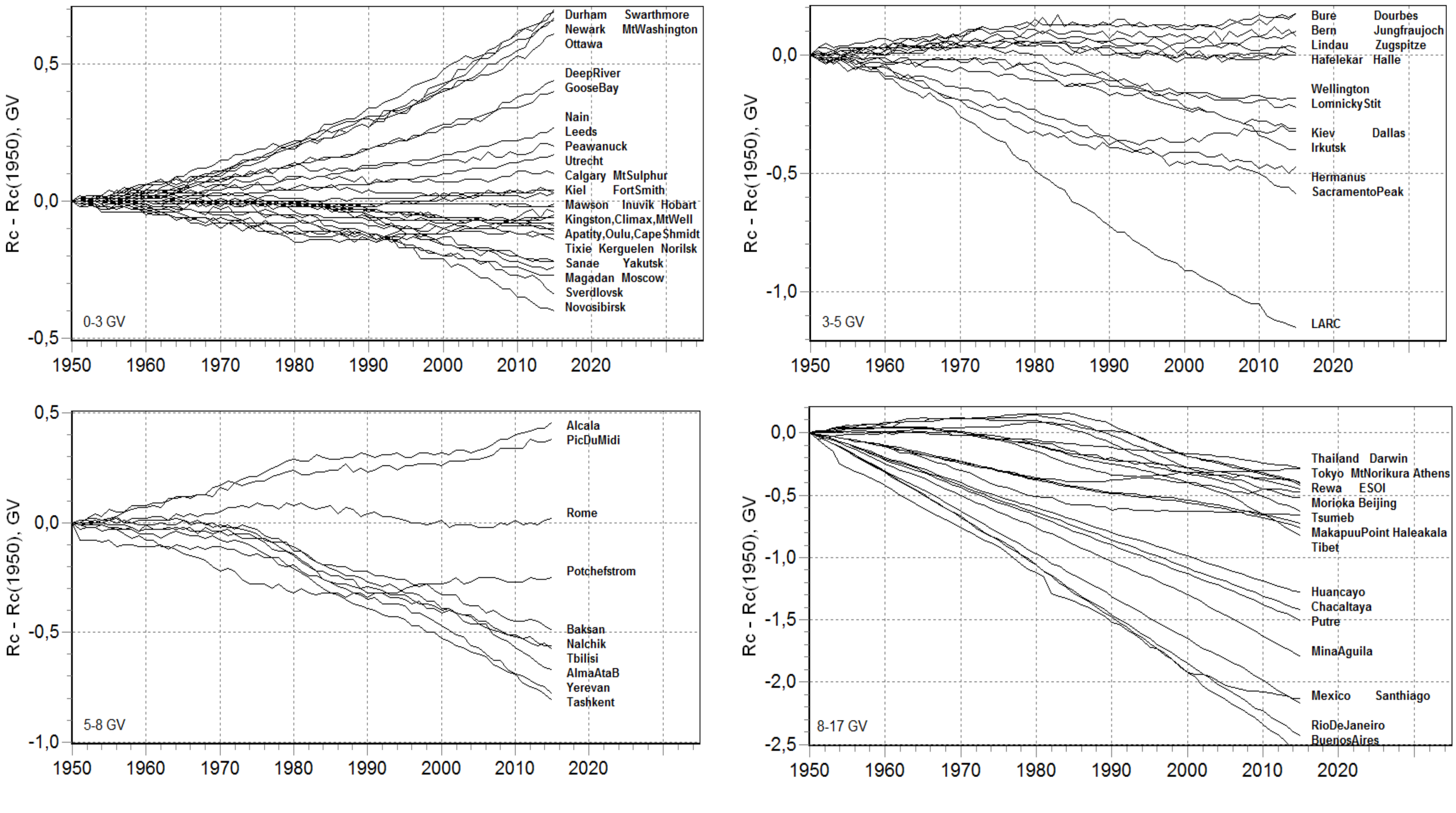


Illustration methodology for assessing the effective stiffness of circumcision to account penumbra of cosmic rays.

Changes of vertical geomagnetic cut off rigidity



Changes of vertical geomagnetic cut off rigidity for 4 groups of the CR stations relatively to the epoch 1950 (in the approach IGRF and flat spectra of CR variations)

We consider how galactic and solar cosmic rays (CR) influence on the physics and chemistry of the Earth's atmosphere and atmospheric processes:

1. Through nuclear reactions of primary and secondary CR with air and aerosol matter accompanied by formation of many unstable and stable cosmogenic nuclides, especially C-14 (radiocarbon) and Be-10.

2. Through generation in the atmosphere of secondary relativistic electrons and EAS (Extensive Atmospheric Showers) playing a crucial role in atmospheric electric field phenomena: thunder-storms, discharges, the Earth's electric charge balance.

3. Through air ionization influences on the low ionos-phere and radio wave propagation, as well as on the formation of clouds and influence on long-term global climate change, and wheat production and prices.

4. Through chemical reactions induced by interactions of CR with air atoms including production of nitrates and influence on ozone layer.

Contents

- **1. Nuclear reactions of cosmic rays in the Earth's atmosphere and production of cosmogenic nuclides**
- **2. Cosmic ray Influence on atmospheric electric field and thunderstorms, Global Earth's charge and global electric current**
- **3. Cosmic ray Influence on the chemical processes in the atmosphere and formation of nitrates and influence on ozone layer**
- **4. Cosmic ray influence on planetary cloud-covering and long-term climate change**

1. Nuclear reactions of cosmic rays in the Earth's atmosphere and production of cosmogenic nuclides

- 1.1. Cosmogenic nuclides and vertical mixing of elements in the Earth's atmosphere; local cosmogenic coupling functions
- 1.2. The planetary mixing in the atmosphere, variations in planetary cosmogenic nuclides production rate and planetary coupling functions

$$q_i\left(R_c,h,t\right)=\sum_Z \int_{R_c}^{\infty} D_Z\left(R,t\right)dR\sum_l \sum_k \int_0^{E(R)} M_l\left(R,Z_l,E_l,h\right)\sigma_{ilk}\left(E_l\right)N_k\left(h\right)dE_l$$

$$M_i\left(R,h,t\right)=\sum_Z \sum_l \sum_k \int_0^{E(R)} M_l\left(R,Z_l,E_l,h\right)\sigma_{ilk}\left(E_l\right)B_Z N_k\left(h,t\right)dE_l$$

$$Q_i\left(R_c,h_o,t\right)=T_{iv}^{-1}\sum_Z \int_{R_c}^{\infty} dR \int_{t-T_{iv}}^{t} D_Z\left(R,t\right)M_{Zi}\left(R,h_o,t\right)dt$$

$$M_{Zi}\left(R,h_o,t\right)=\int_0^{h_o} dh\sum_l \sum_k \int_0^{E(R)} M_{Zl}\left(R,Z_l,E_l,h\right)\sigma_{ilk}\left(E_l\right)N_k\left(h,t\right)dE_l$$

$$W_{iZR_{co}}\left(R,h_o\right)=D_{Zo}\left(R\right)M_{iZo}\left(R,h_o\right)/Q_{io}\left(R_{co},h_o\right)$$

$$Q_{ip}\left(R_{cp},h_{op},t\right)=\left(4\pi T_{ip}\right)^{-1}\int_{t-T_{ip}}^{t} d\tau \int_{-\pi/2}^{\pi/2} \sin\theta d\theta \int_{0}^{2\pi} d\varphi Q_i\left(R_c(\theta,\varphi,\tau),h_o(\theta,\varphi,\tau),\tau\right)$$

$$R_c(\theta,t)=R_c(\theta,0)M_p(t)/M_p(0)$$

$$W_{ip}\left(R,h_{opo}\right)=D_o(R)M_{ip}\left(R,h_{opo}\right)/Q_{ipo}$$

$$d\,N_{ip1}(t)/dt=Q_{ip}\left(R_{cp}(t),h_{op}(t),t\right)-\left(\lambda_i+\lambda_{12}\right)N_{ip1}(t)+\lambda_{21}N_{ip2}(t),$$

$$d\,N_{ip2}(t)/dt=-\left(\lambda_i+\lambda_{21}\right)N_{ip2}(t)+\lambda_{12}N_{ip1}(t).$$

H-bombs explosions, generation of radiocarbon, and estimation of parameters of the elements exchange model; influence on global environment

$$Q_p(t) = Q_{av}\left(1 + A\Delta t\,\delta(t - t_o)\right)$$

$$N_A(t) = N_{Ast}\left[1 + \frac{\lambda\lambda_1 A\Delta t \exp\left(-\lambda(t - t_o)\right)}{\lambda_2\left(\lambda + \lambda_{FA}\right)}\left(\lambda_{AF}\exp\left(-\lambda_2(t - t_o)\right) + \lambda_{FA}\right)\right]$$

$$N_F(t) = N_{Fst}\left[1 + \frac{\lambda_1 A\Delta t \exp\left(-\lambda(t - t_o)\right)}{\lambda_2}\left(1 - \exp\left(-\lambda_1(t - t_o)\right)\right)\right]$$

$$N_{A\max} = N_{A\mathrm{st}}\left(1 + \lambda A\Delta t\left(N_{\mathrm{st}}/N_{A\mathrm{st}}\right)\right) = N_{A\mathrm{st}}\left(1 + 9.98\times 10^{-3} A\Delta t\right)$$

Application to USSR and USA H-bomb explosions in 1962

- $$9.98\times10^{-3}A\Delta t\approx0.9,\qquad A = 90.2$$

$$6.83\times10^{9}\ \text{atom}\ {}^{14}\text{C.cm}^{-2}\qquad 7.48\times10^{7}$$

$$\lambda_{AF}=0.145\ \text{year}^{-1},\quad \lambda_{FA}=1.66\times10^{-3}\ \text{year}^{-1}$$

$$t_{\max F}=t_{o}+48.3\ \text{years}=2010.3\ \text{years}$$

$$N_{F\max}=N_{F\text{st}}\left(1+5.31\times10^{-3}A\Delta t\right)=N_{Fst}\left(1+0.479\right)$$

The basic equations for the 5-reservoir model

$$dN_A(t)/dt = Q_p(t) - (\lambda + \lambda_{AM} + \lambda_{AB})N_A(t) + \lambda_{HA}N_H(t) + \lambda_{MA}N_M(t)$$

$$dN_B(t)/dt = -(\lambda + \lambda_{BH})N_B(t) + \lambda_{AB}N_A(t)$$

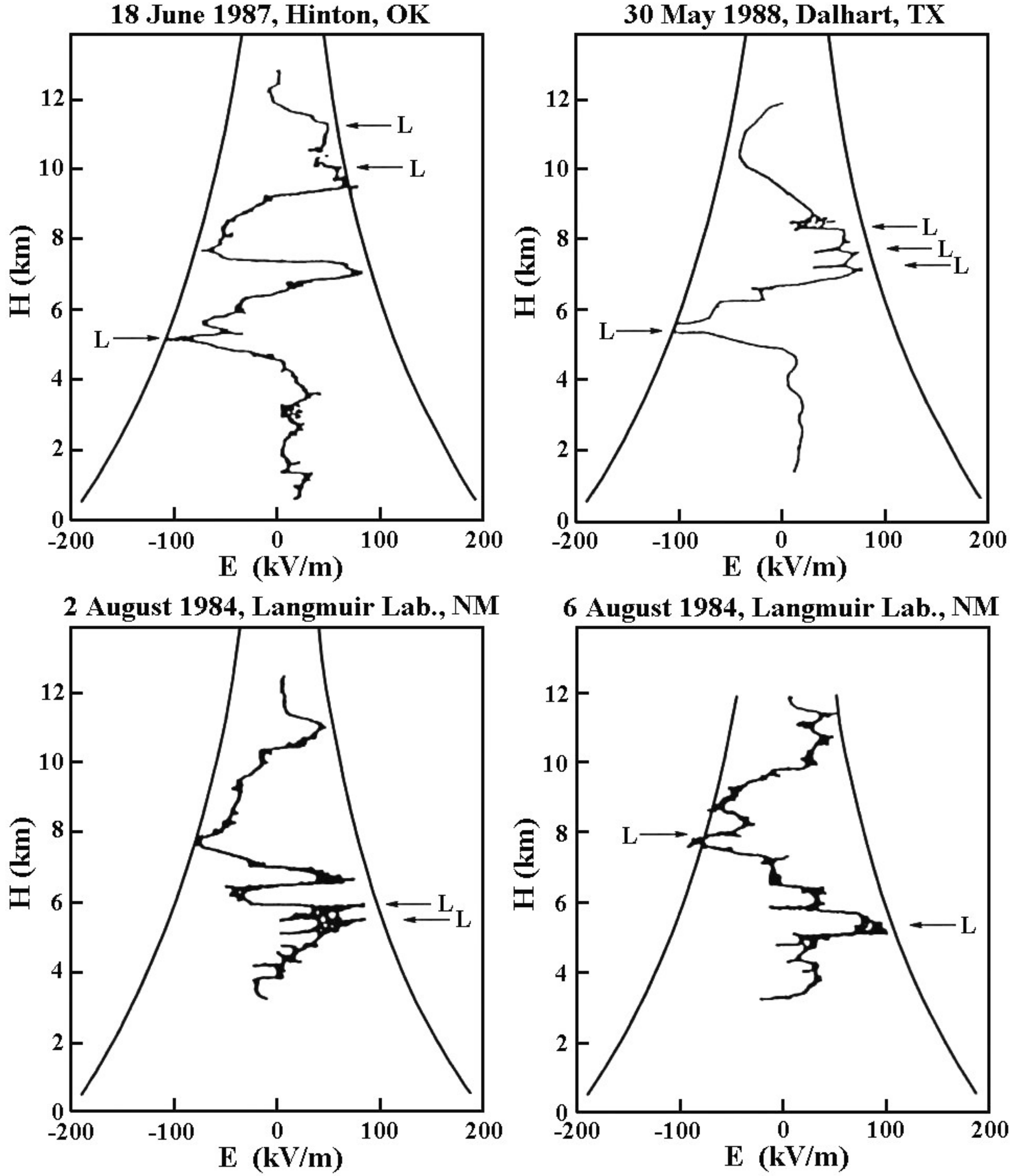
$$dN_H(t)/dt = -(\lambda + \lambda_{HA})N_H(t) + \lambda_{BH}N_B(t)$$

$$dN_M(t)/dt = -(\lambda + \lambda_{MO} + \lambda_{MA})N_M(t) + \lambda_{AM}N_A(t)$$

$$dN_O(t)/dt = -(\lambda + \lambda_{OM})N_O(t) + \lambda_{MO}N_M(t)$$

2. Cosmic Ray Influence on Atmospheric Electric Field and Thunderstorms, Global Earth's Charge and Global Electric Current

- 1. On two mechanisms of CR connection with thunderstorm discharges
- 2. Necessary conditions for atmospheric electric field discharges in the atmosphere
- 3. Measurements of atmospheric electric field, critical electric field, lightnings, and sprites

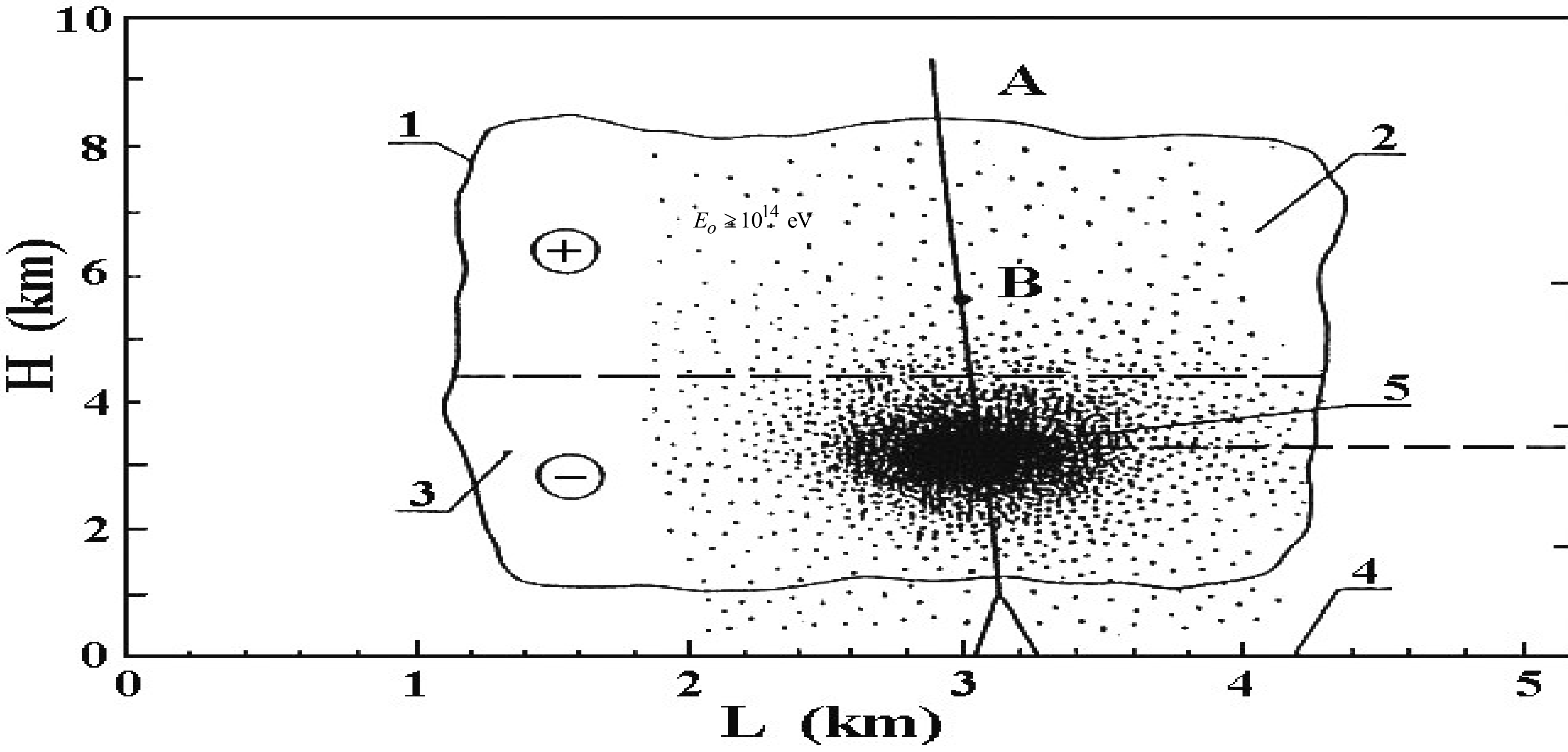

18 June 1987, Hinton, OK
30 May 1988, Dalhart, TX
2 August 1984, Langmuir Lab., NM
6 August 1984, Langmuir Lab., NM
H (km)
E (kV/m)
L

External Atmospheric Showers (EAS) generated by high energy CR particles

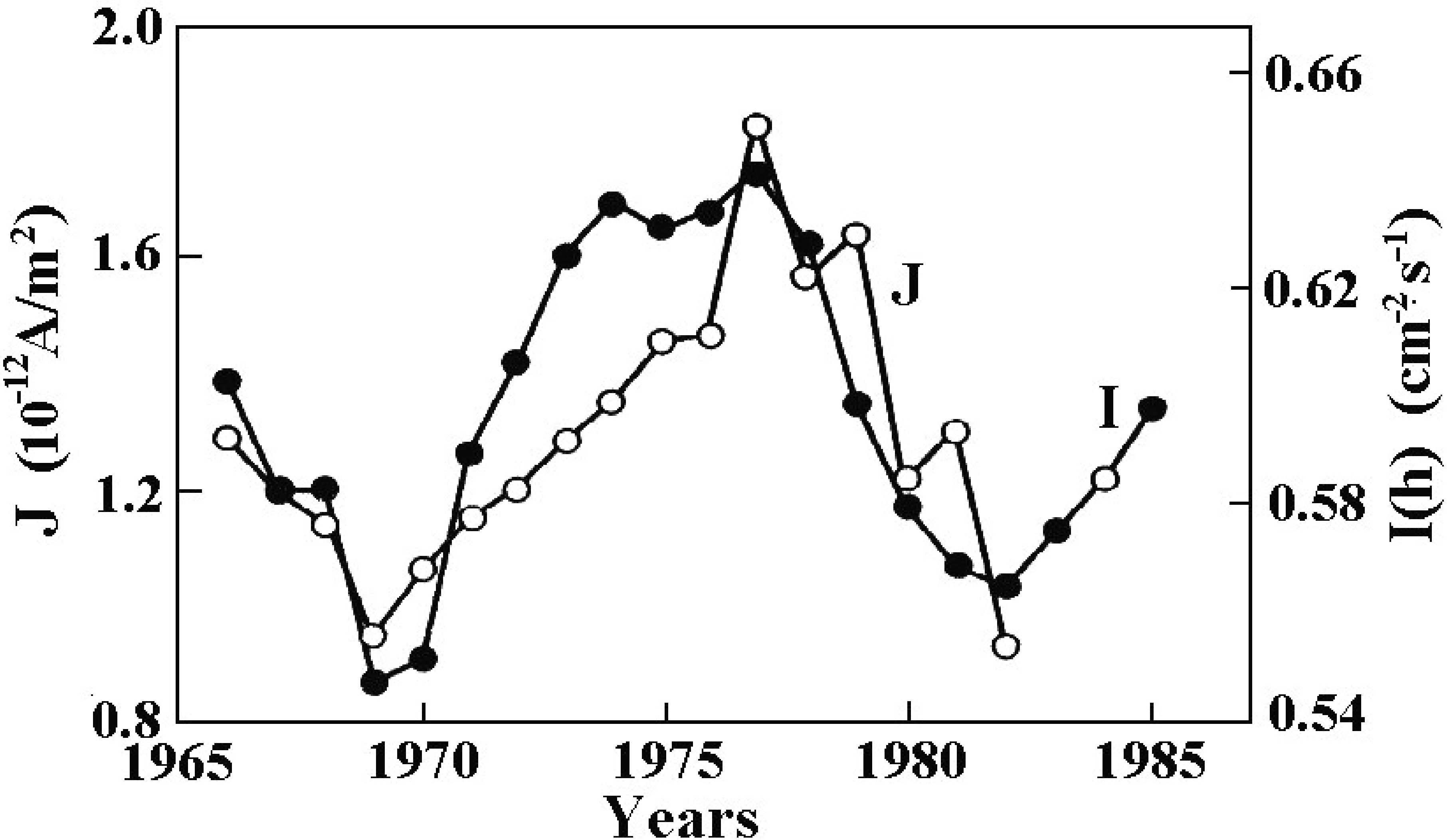
and thunderstorm discharges (Ermakov and Stozhkov, 2002, 2003)

$$X_m = 500 + 75 \times \lg\left(E_o / 10^{15}\,\mathrm{eV}\right)\ \ \mathrm{g/cm^2}$$

$E_o \geq 10^{14}$ eV $\qquad F_{\mathrm{EAS}} \approx 1300\ \mathrm{sec}^{-1}$

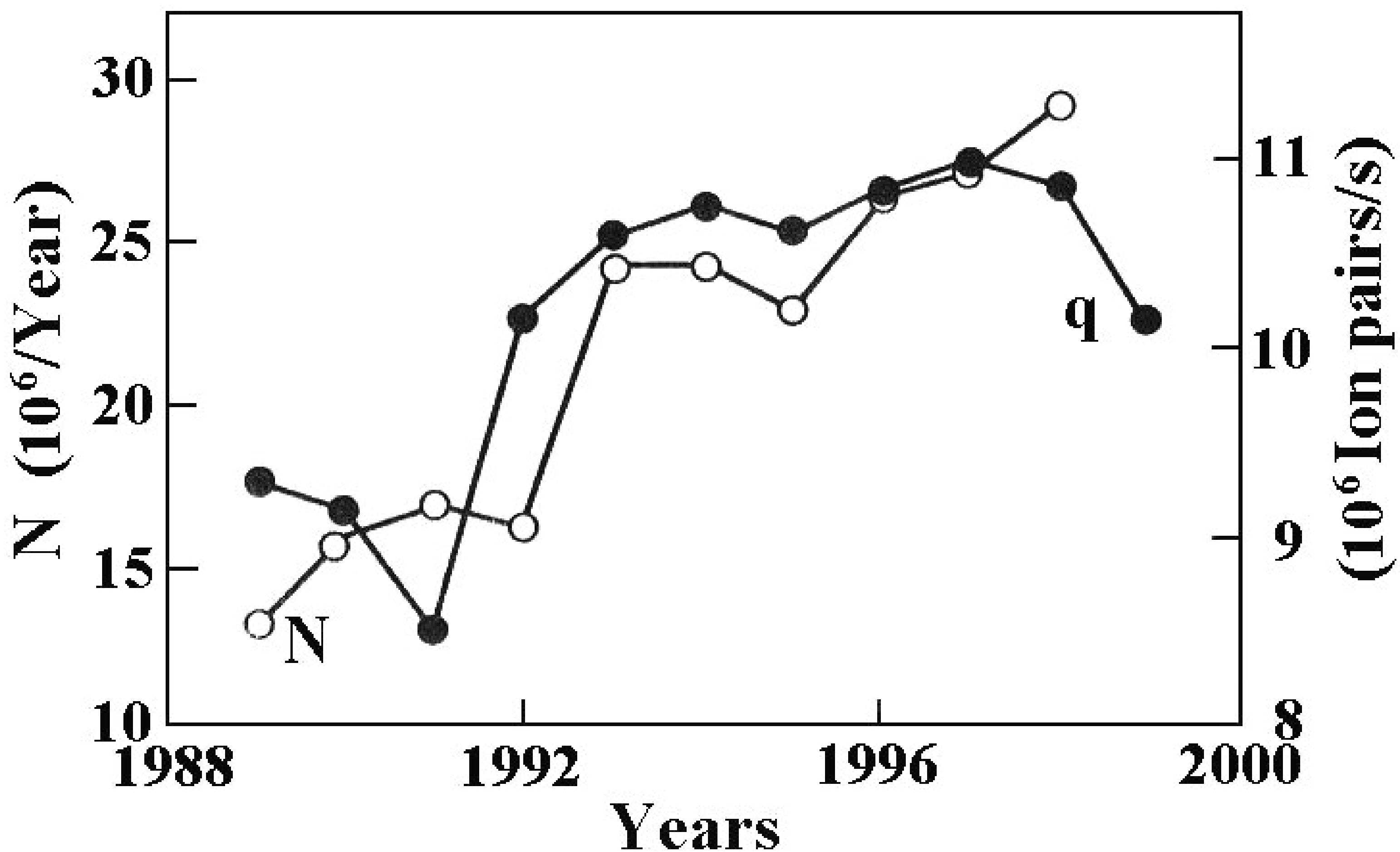


Time variations for 17 years observations of discharged electric current ***J*** (light circles) according to Roble (1985) and of CR intensity ***I(h)*** (black circles) according to Stozhkov et al. (2001).



The annual number of thunderstorm discharges ***N*** (open circles) over the territory of the USA in 1989–1998 according to Orville and Huffines (1999) and time variation of yearly average ion production rate ***q*** (black circles) in the column of atmosphere between 2 and 10 km (calculated on the basis of balloon CR measurements).

According to Stozhkov et al. (2001).



On the CR role in the equilibrium between charged and discharged global atmospheric electric currents, and in the supporting the stability of the Earth's Charge

$$J_{CR} = eI_{CR} \approx 1.6\times10^{-19}\,\mathrm{C}\times10^{4}\,\mathrm{m}^{-2}\,\mathrm{sec}^{-1} \approx 2\times10^{-15}\,\mathrm{A/m^2}$$

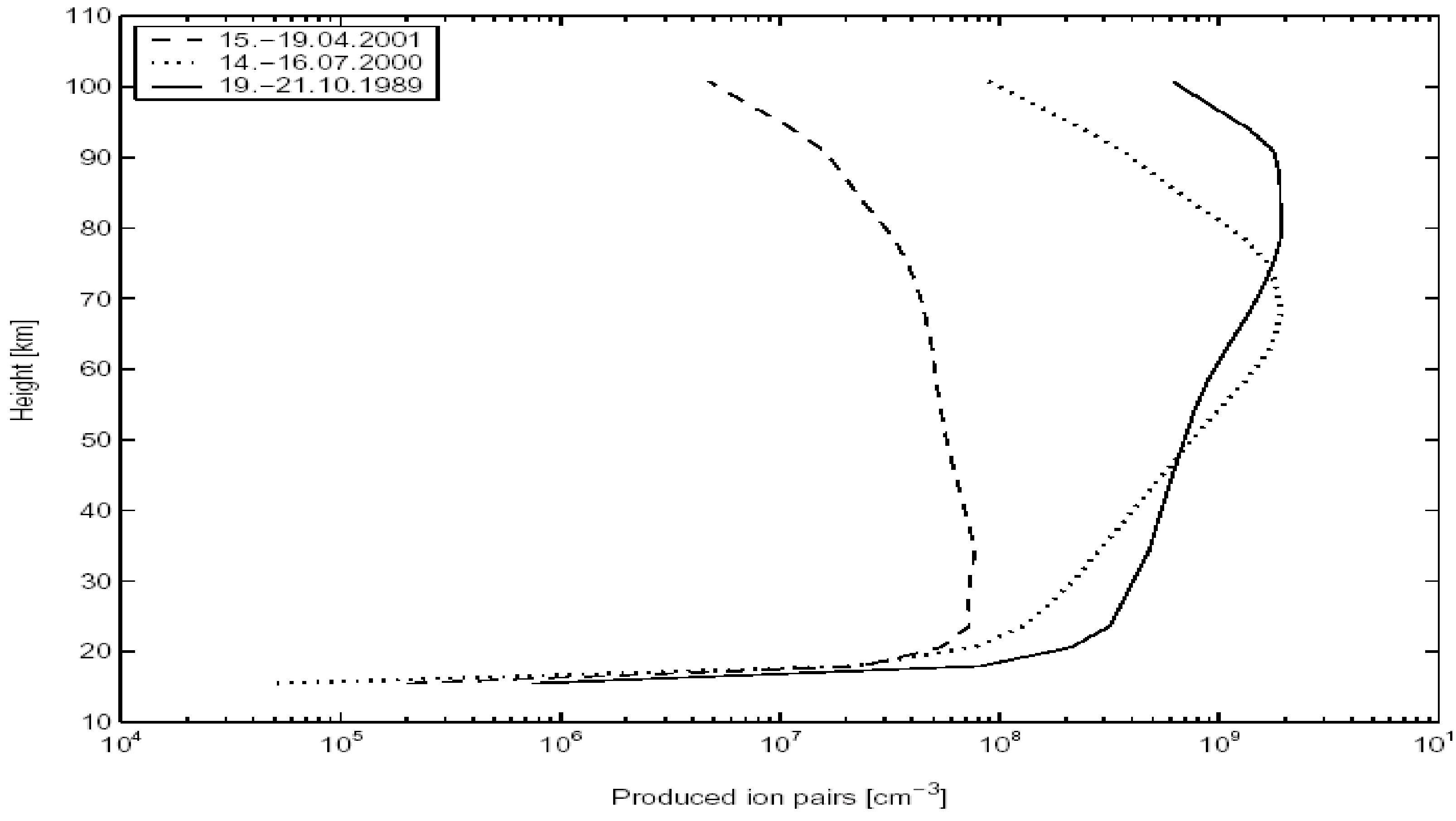
is negligible in comparison with currents caused by the global thunderstorm activity

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

From other hand, the increase of CR intensity *I* (increase of ion production rate *q*) leads to an increase of discharged global electric currents. This will mostly compensate the increasing of charged electric currents caused by increasing thunderstorms discharges frequency (caused by the same increasing of CR intensity).

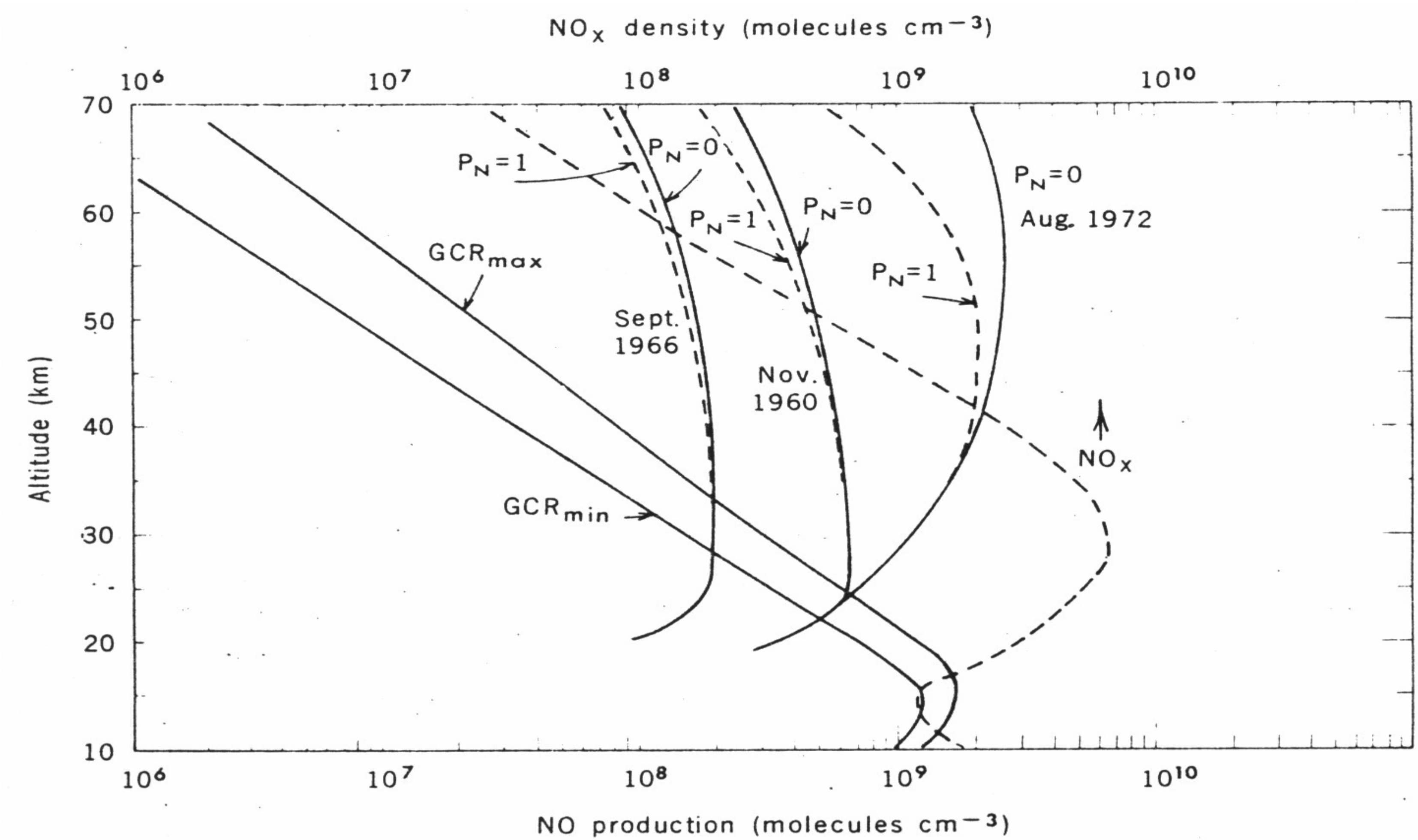
Air Ionization by CR, Influence on the Ionosphere and Radio Wave Propagation

Total ionization during GLE in October 1989, July 2000, and April 2001. According to Quack et al. (2001).

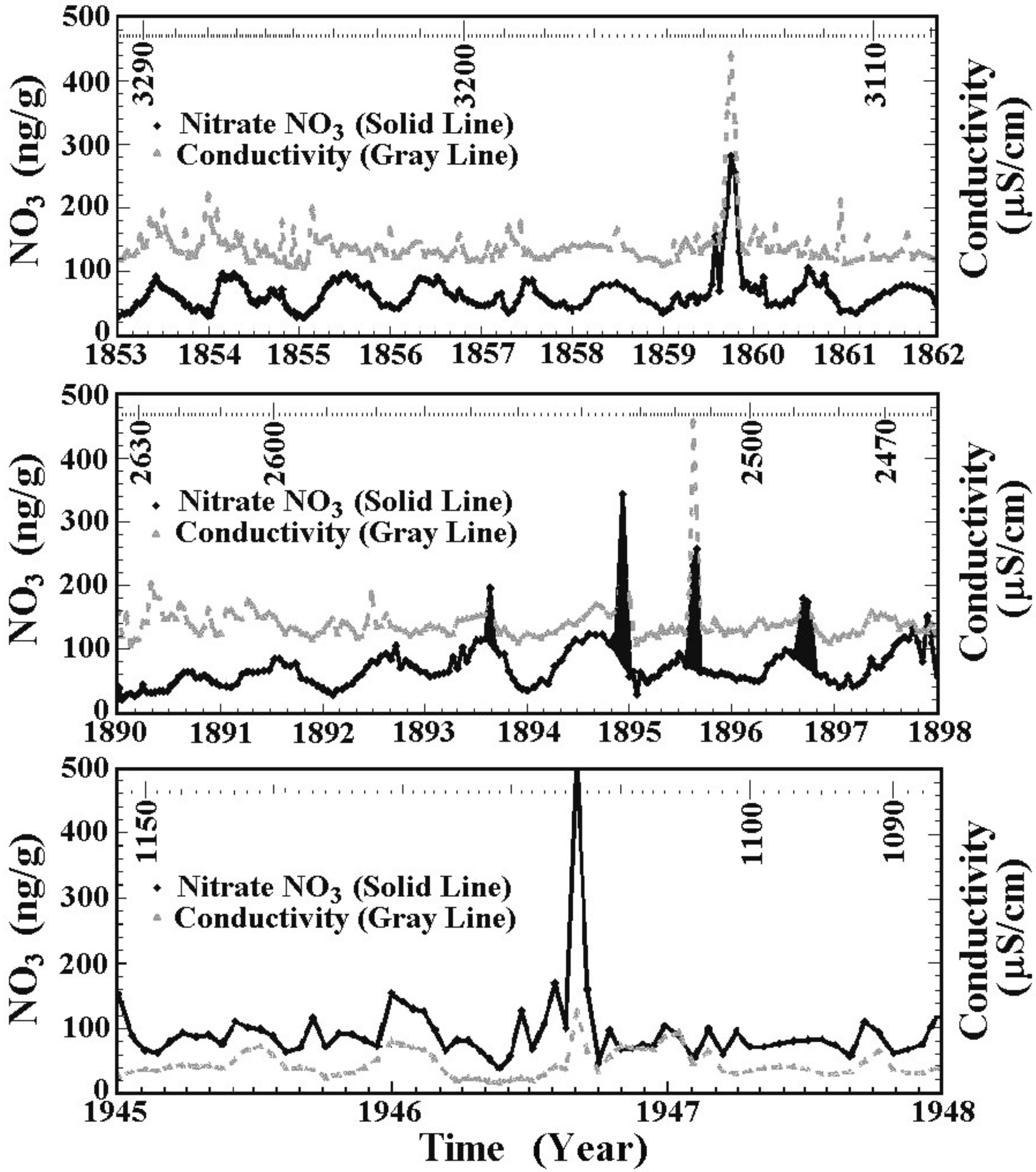


3. Cosmic Ray Influence on the Chemical Processes in the Atmosphere and Formation of Ozone Layer

- NO production by CR (Crutzen et al., 1975).



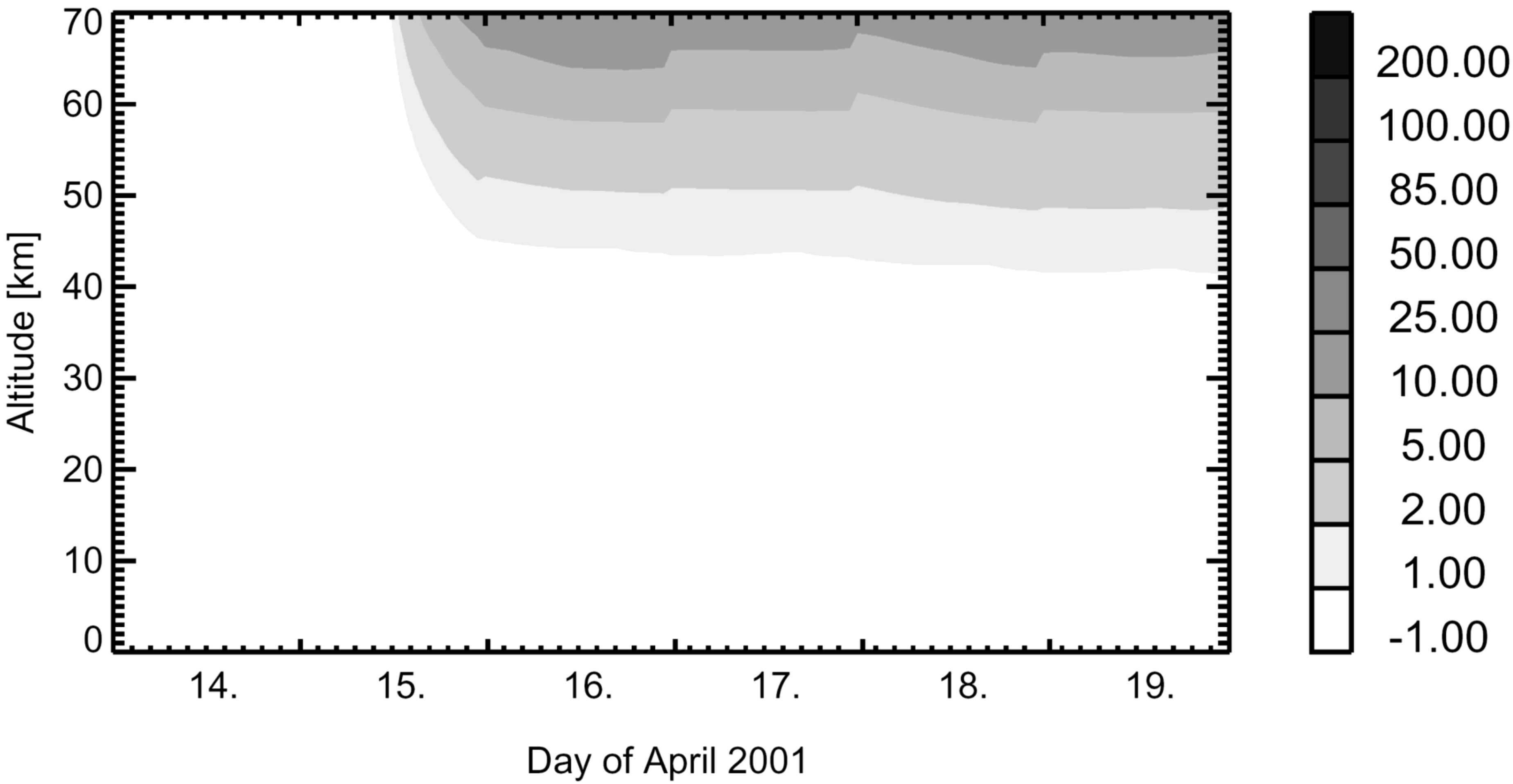
McCracken et al. (2001)



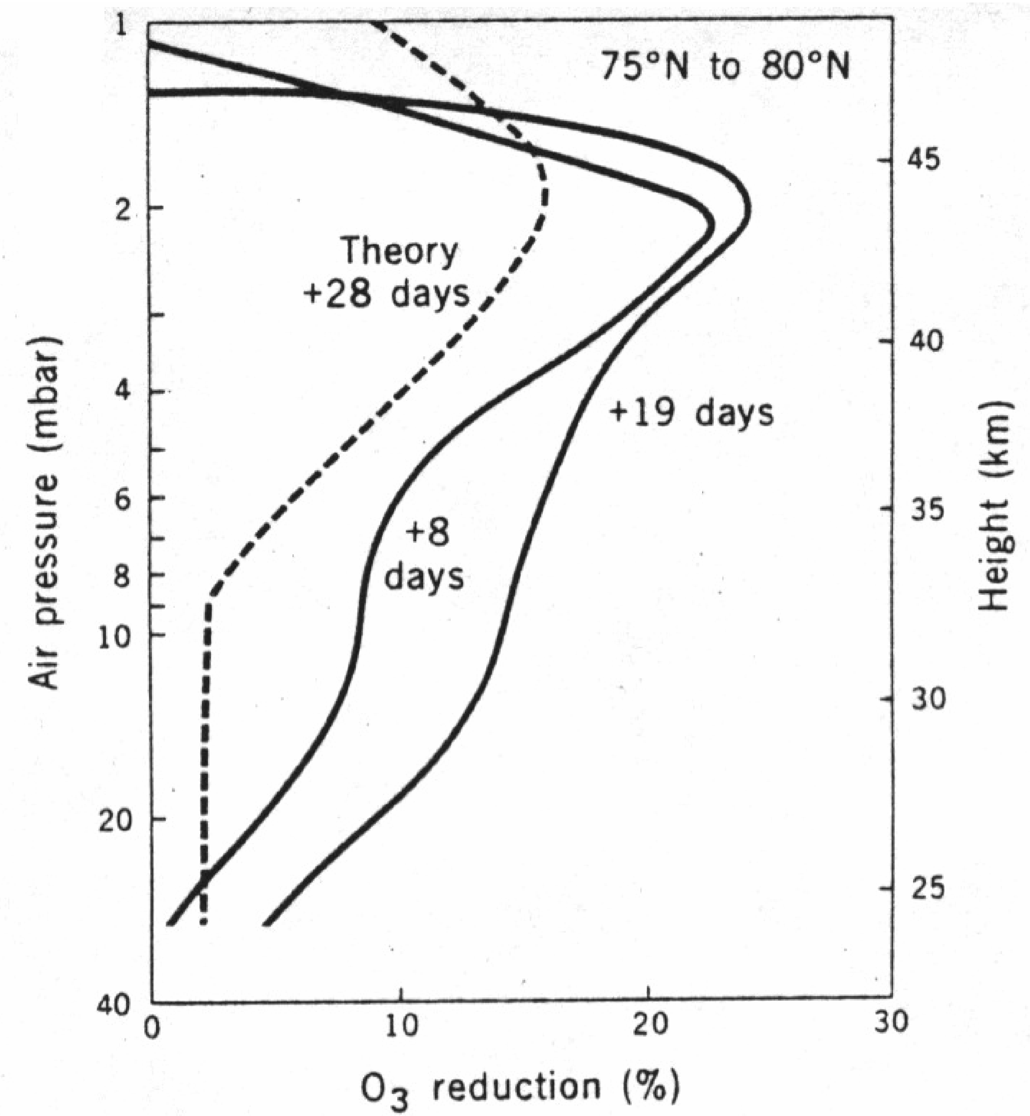
CR influence on stratospheric chemistry

Modeled of NOx during the ground level event on April 14, 2001.

According to Quack et al (2001).

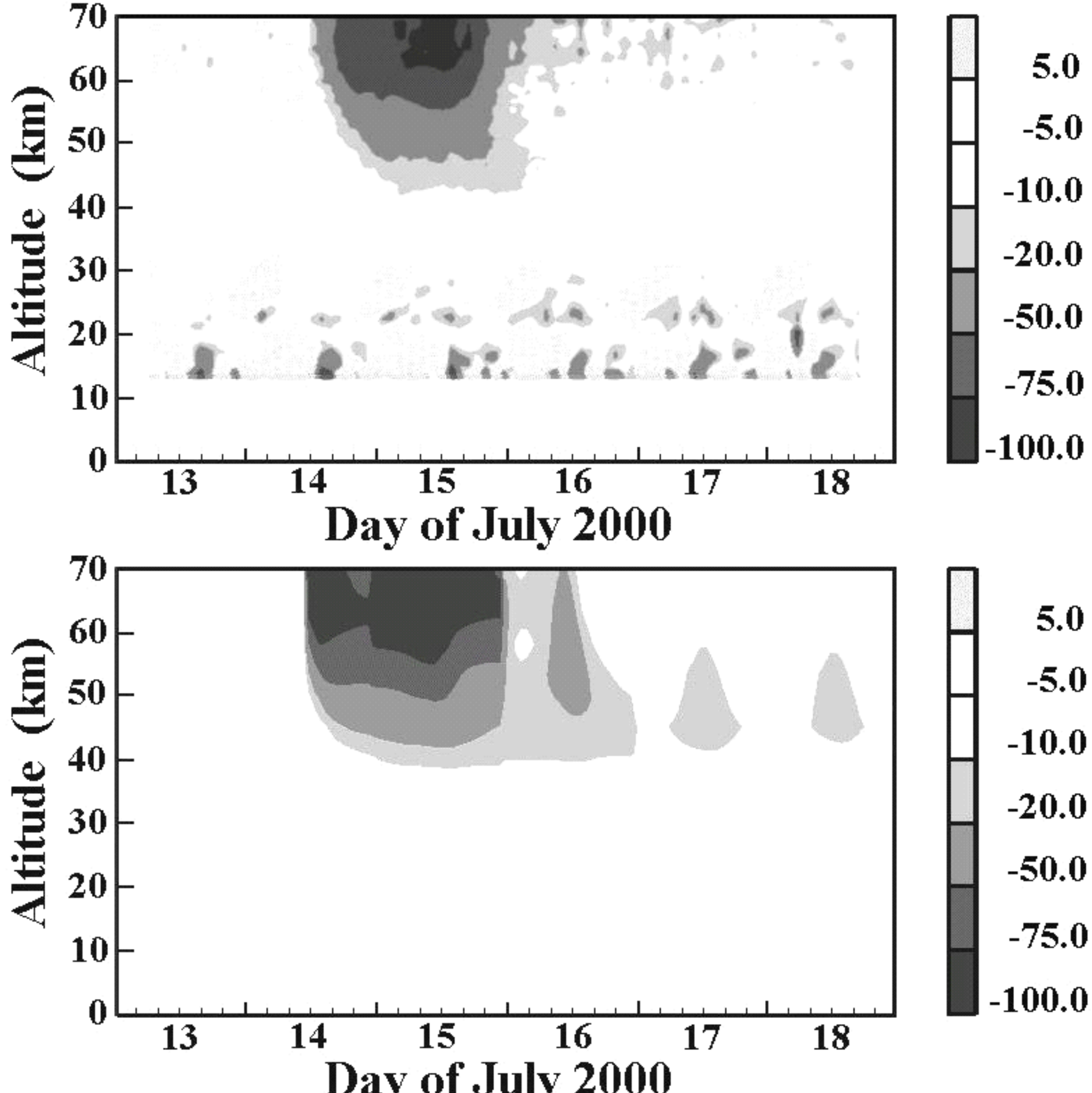


Percentage decrease of the O3 partial pressure versus air pressure derived from the average of the 7 days before 4 August 1972 and 7 day periods centered on 8 and 19 days after the GLE (solid lines). According to Heath et al. (1977).

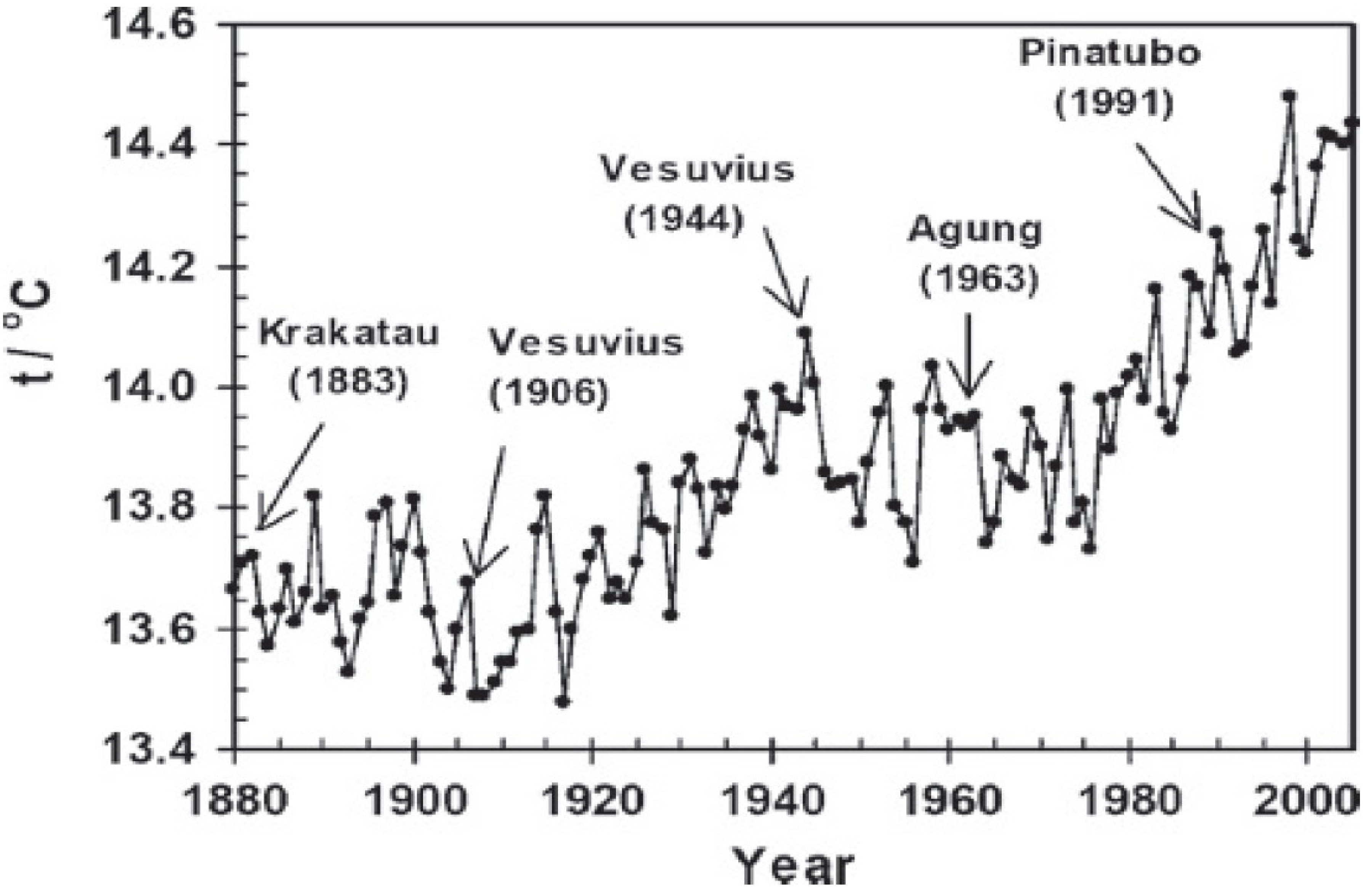


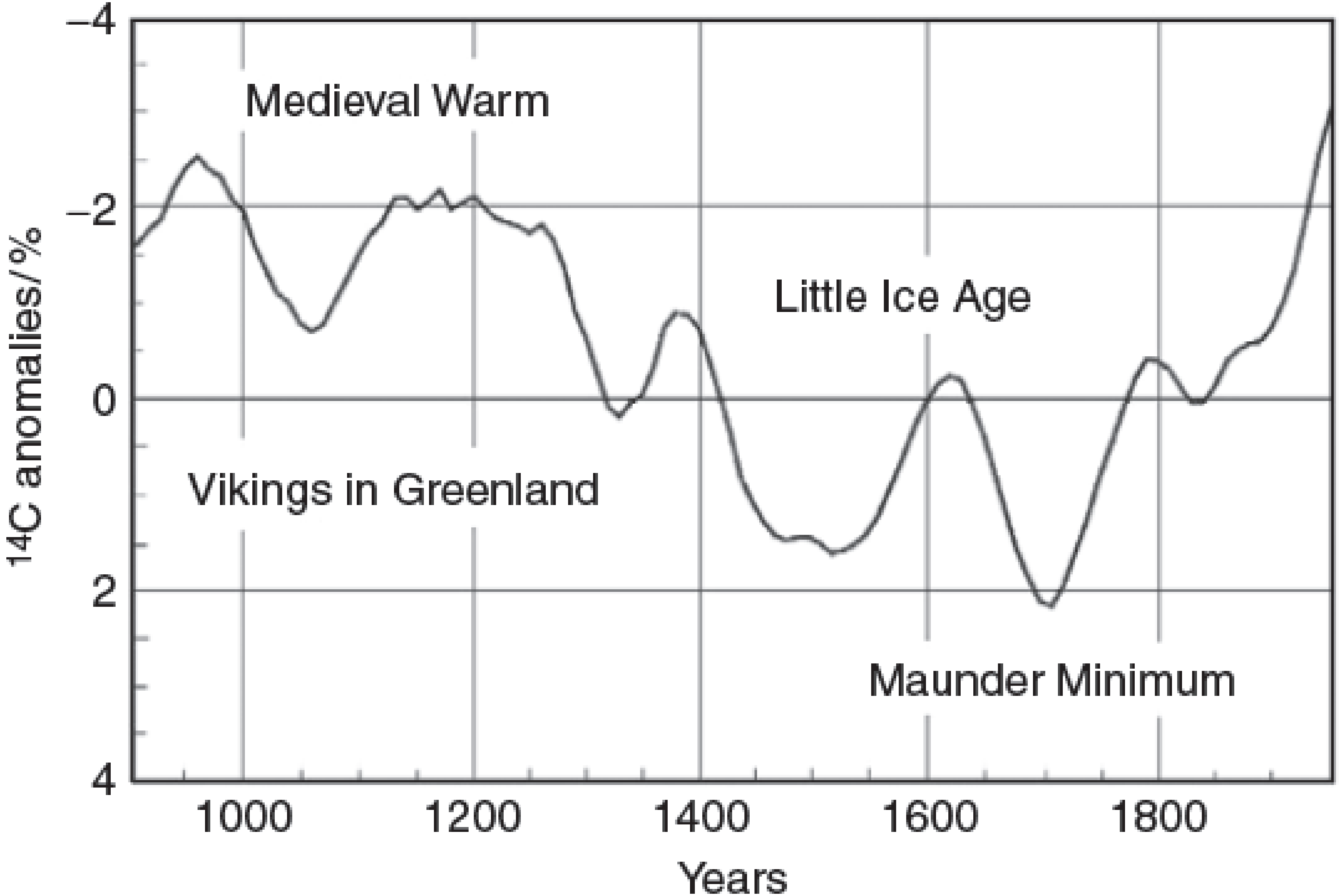
Variations compared to background level in O3 in % (down panel modeled and upper panel observed) during the event in July 2000.

According to Quack et al (2001).

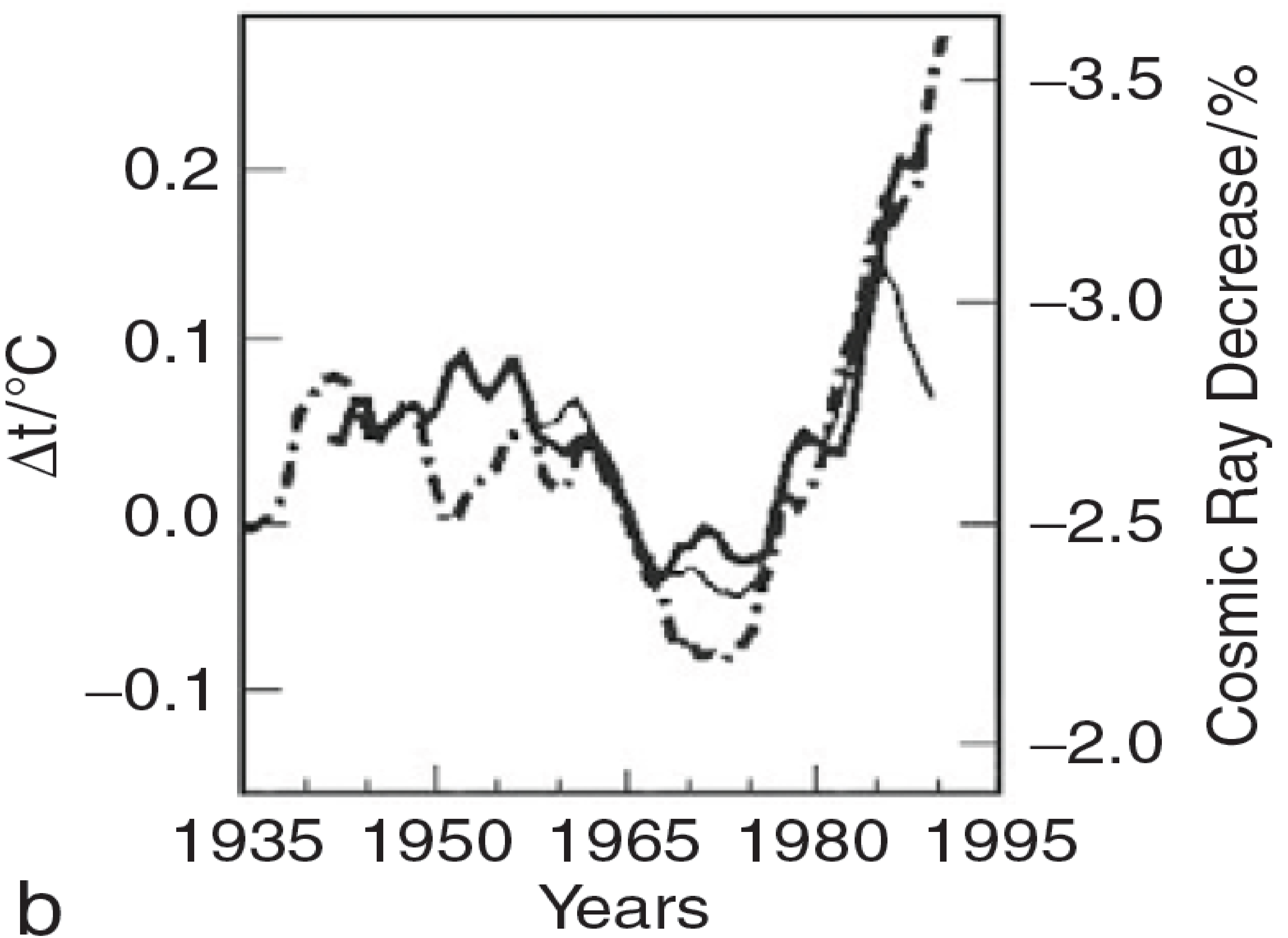


4. Cosmic Ray Influence on Planetary Cloud-Covering and Long-Term Climate Change

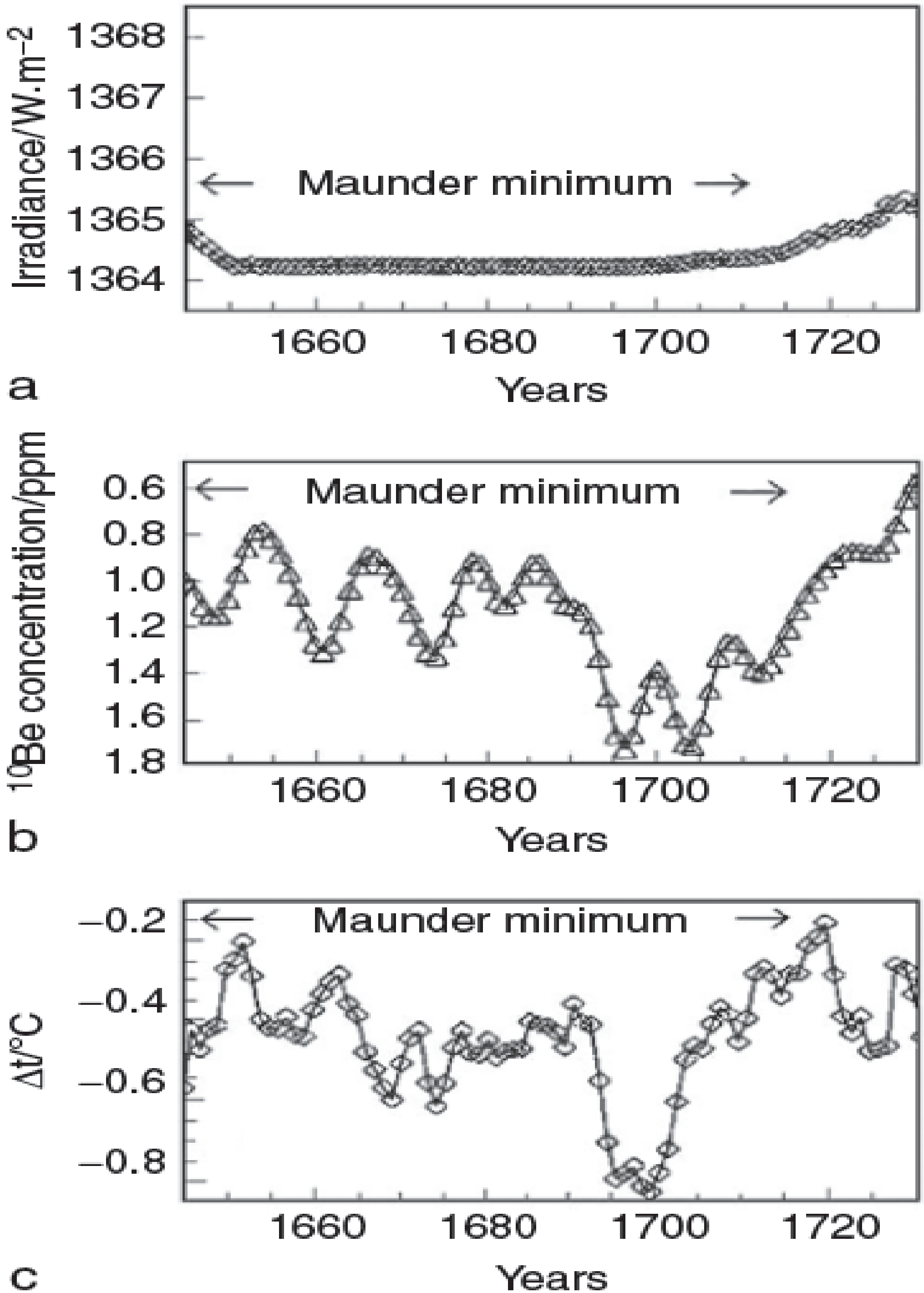




−4
−2
0
2
4
Medieval Warm
Vikings in Greenland
Little Ice Age
Maunder Minimum
14C anomalies/%
1000
1200
1400
1600
1800
Years



0.2
0.1
0.0
−0.1
Δt/°C
−3.5
−3.0
−2.5
−2.0
Cosmic Ray Decrease/%
1935
1950
1965
1980
1995
Years
b


Irradiance/W.m^{-2}
1368
1367
1366
1365
1364
Maunder minimum
1660
1680
1700
1720
Years
a
^{10}Be concentration/ppm
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Maunder minimum
1660
1680
1700
1720
Years
b
Δt/°C
−0.2
−0.4
−0.6
−0.8
Maunder minimum
1660
1680
1700
1720
Years
c

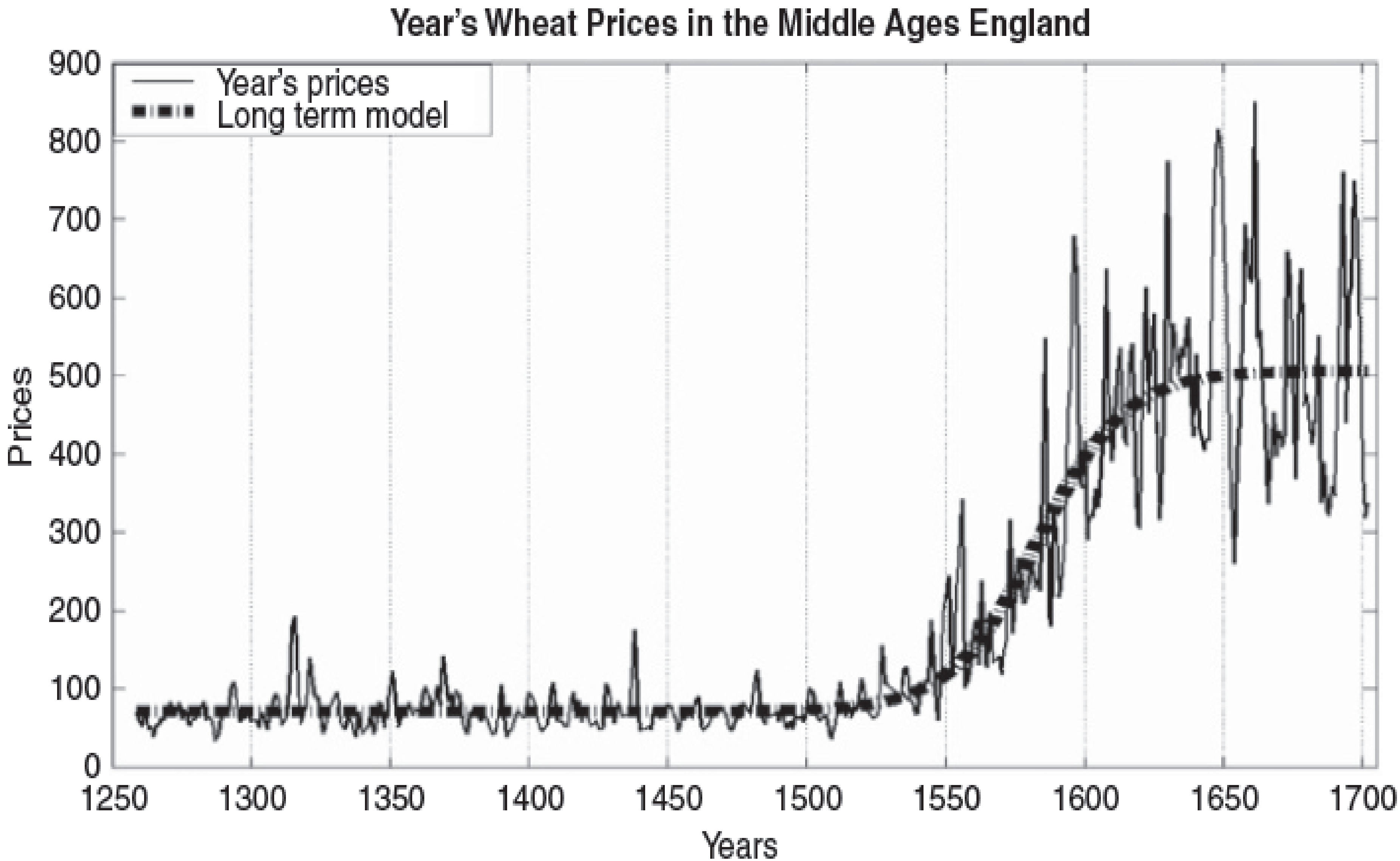


FIGURE 6 Wheat prices in England during 1259–1702 with a price transition at 1530–1630. From Refs. [51,52].

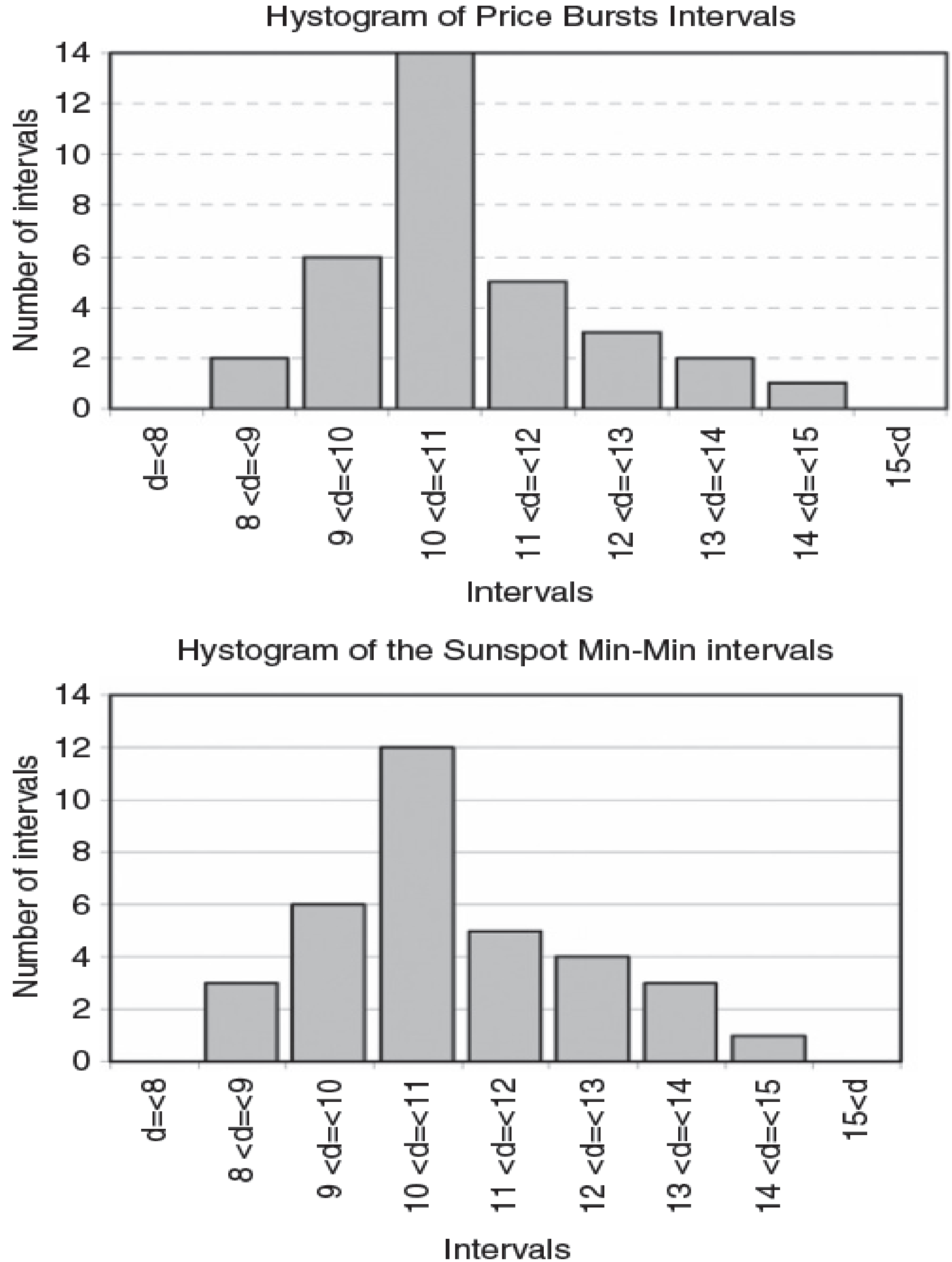
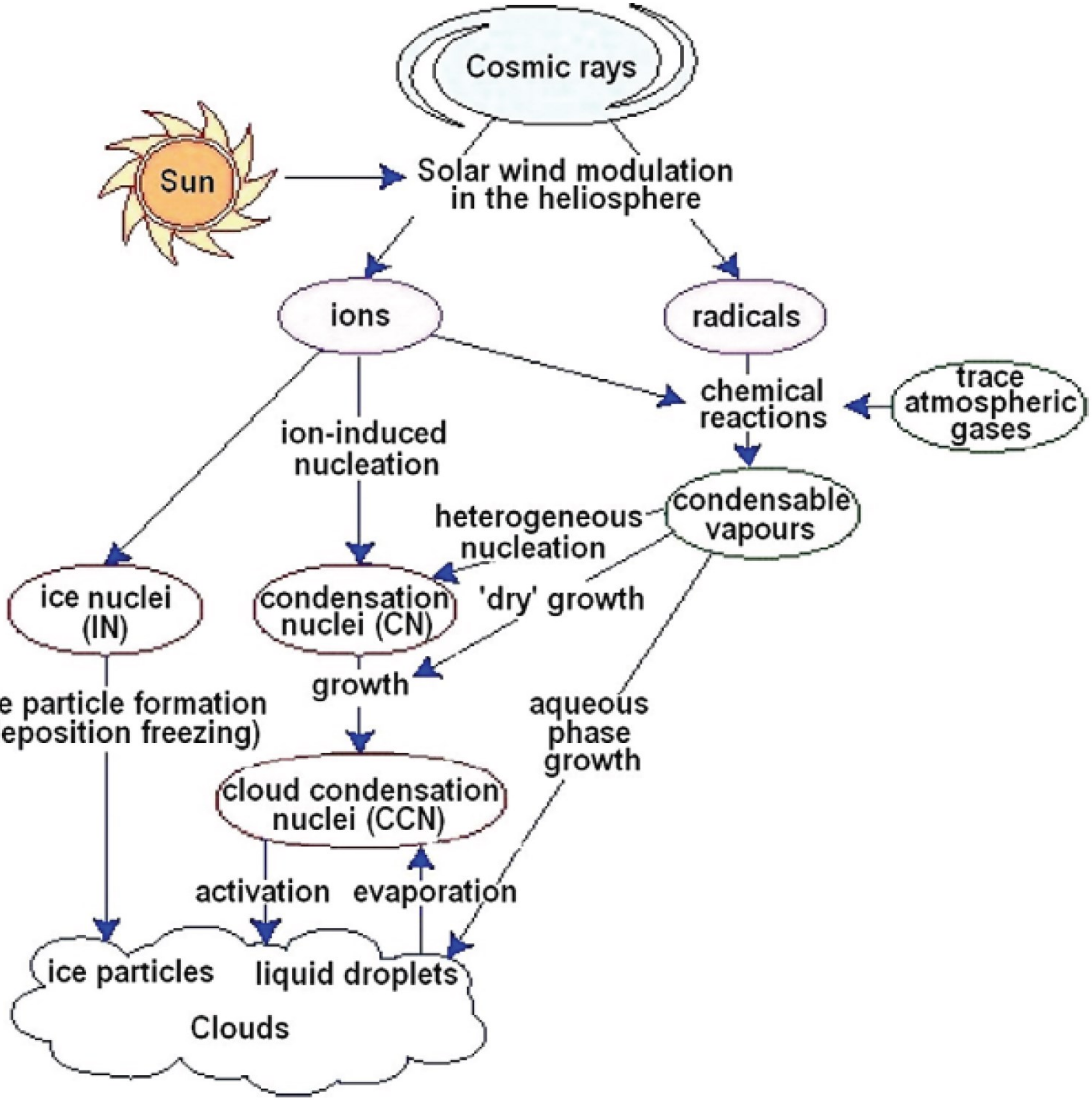
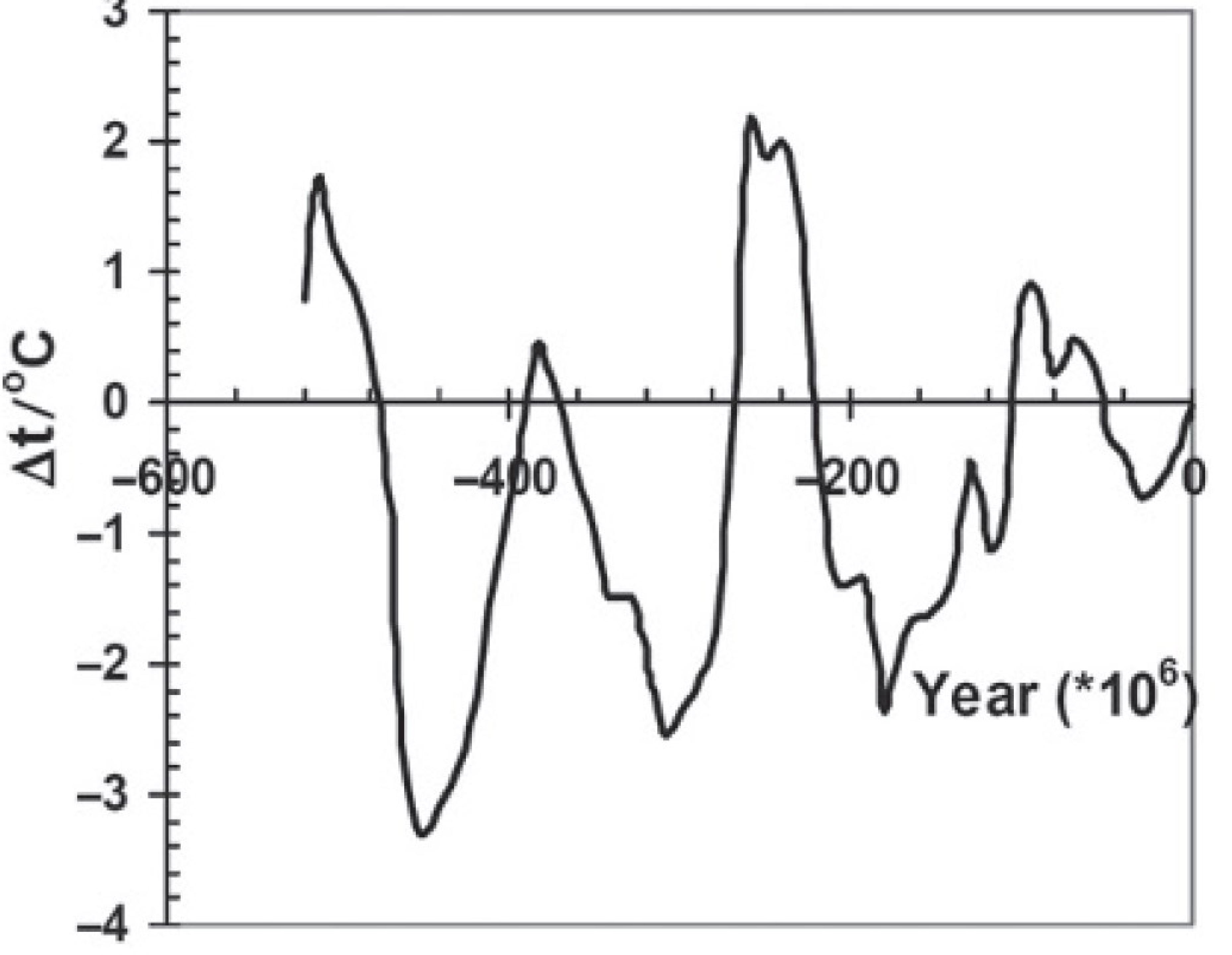


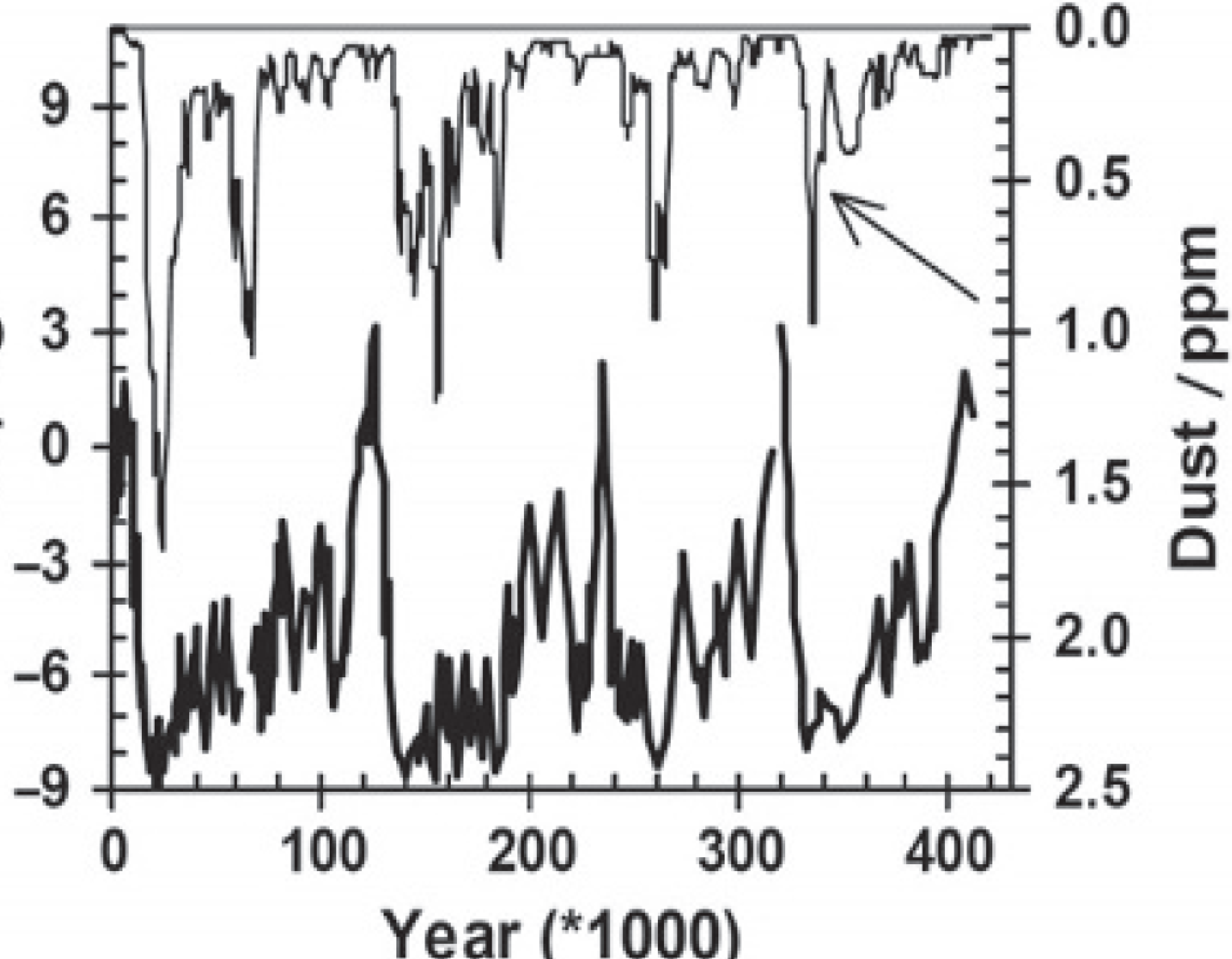
FIGURE 7 Histograms of the interval distribution for price bursts for the period, 1249–1702, and of minimum–minimum intervals of sunspots during 1700–2000. From Refs. [51,52].



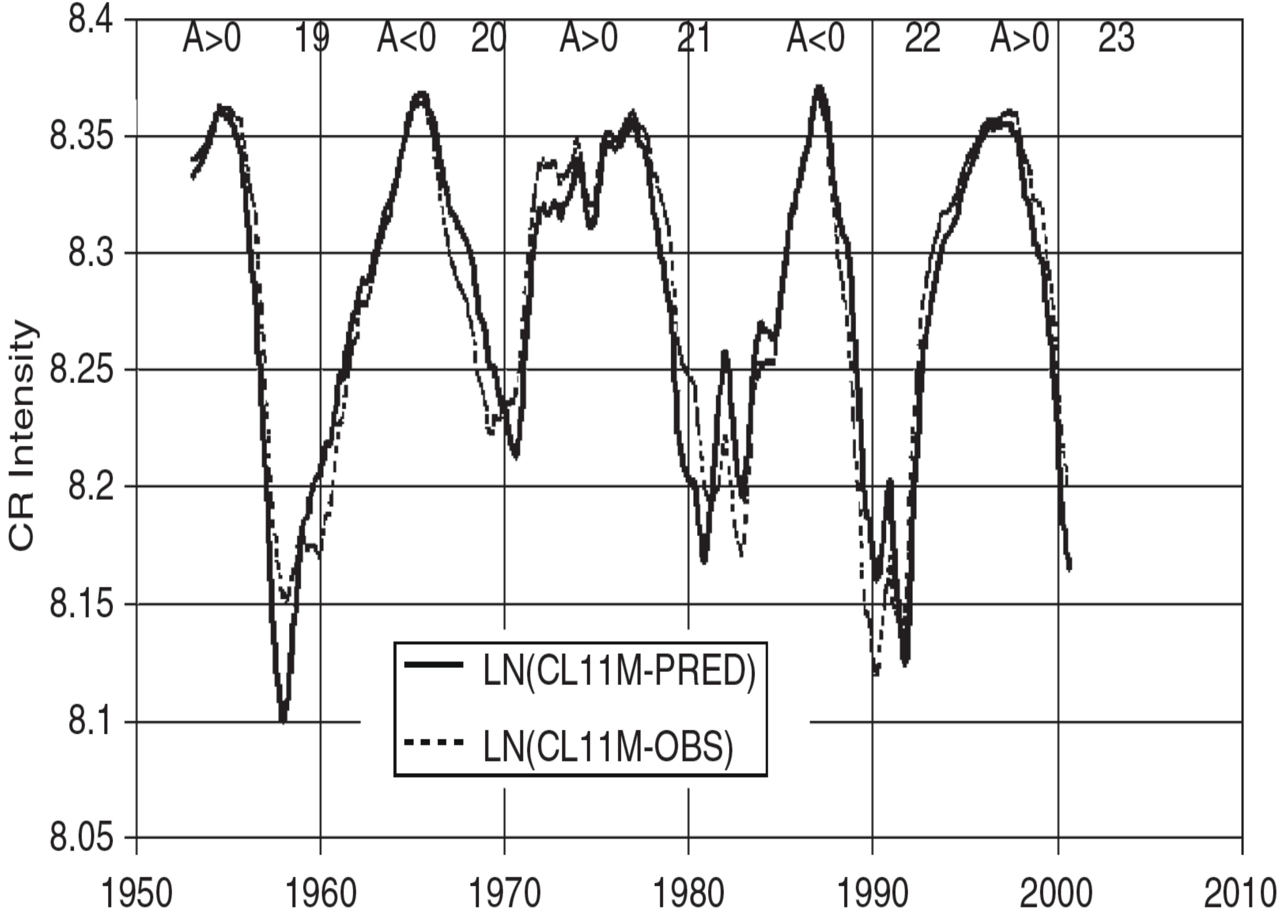
Cosmic rays
Sun
Solar wind modulation in the heliosphere
ions
radicals
chemical reactions
trace atmospheric gases
ion-induced nucleation
condensable vapours
heterogeneous nucleation
ice nuclei (IN)
condensation nuclei (CN)
'dry' growth
growth
ice particle formation (deposition freezing)
aqueous phase growth
cloud condensation nuclei (CCN)
activation
evaporation
ice particles
liquid droplets
Clouds



Δt/°C
3
2
1
0
−1
−2
−3
−4
−600
−400
−200
0
Year (*10^6)



9
6
3
0
−3
−6
−9
Δt / °C
0.0
0.5
1.0
1.5
2.0
2.5
Dust / ppm
0
100
200
300
400
Year (*1000)



A>0
19
A<0
20
A>0
21
A<0
22
A>0
23
8.4
8.35
8.3
8.25
8.2
8.15
8.1
8.05
CR Intensity
1950
1960
1970
1980
1990
2000
2010
LN(CL11M-PRED)
LN(CL11M-OBS)

TABLE 2 Vertical cutoff rigidities (in GV) for various epochs 1600, 1700, 1800, 1900 and 2000, as well as change from 1900 to 2000 owed to changes of geomagnetic field. According to Shea and Smart [73]

Lat.	Long. (E)	Epoch 2000	Epoch 1900	Epoch 1800	Epoch 1700	Epoch 1600	Change 1900–2000	Region
55	30	2.30	2.84	2.31	1.49	1.31	−0.54	Europe
50	0	3.36	2.94	2.01	1.33	1.81	+0.42	Europe
50	15	3.52	3.83	2.85	1.69	1.76	−0.31	Europe
40	15	7.22	7.62	5.86	3.98	3.97	−0.40	Europe
45	285	1.45	1.20	1.52	2.36	4.1	+0.25	North America
40	255	2.55	3.18	4.08	4.88	5.89	−0.63	North America
20	255	8.67	12.02	14.11	15.05	16.85	−3.35	North America
20	300	10.01	7.36	9.24	12.31	15.41	+2.65	North America
50	105	4.25	4.65	5.08	5.79	8.60	−0.40	Asia
40	120	9.25	9.48	10.24	11.28	13.88	−0.23	Asia
35	135	11.79	11.68	12.40	13.13	14.39	+0.11	Japan
−25	150	8.56	9.75	10.41	11.54	11.35	−1.19	Australia
−35	15	4.40	5.93	8.41	11.29	12.19	−1.53	South Africa
−35	300	8.94	12.07	13.09	10.84	8.10	−3.13	South America

Conclusions

- **1. The atmosphere influenced very strong on CR: meteorological effects, cascade processes, generation of new particles, secondary components, albedo radiation.**
- **2. From other hand, CR influenced on the atmosphere and atmospheric processes.**
- **3. This influence is determined by nuclear reactions of primary and secondary CR (mostly, neutrons) with air and aerosol matter accompanied by the formation of many unstable and stable cosmogenic nuclides Be-10, C-14, and many others.**
- **4. It determined by generation in the atmosphere by CR of secondary relativistic electrons and EAS (Extensive Atmospheric Showers) playing a crucial role in atmospheric electric field phenomena.**
- **5. It determined by CR air ionization influences on the low ionosphere and radio wave propagation.**
- **6. It determined by induced chemical reactions, influences on the chemistry of the atmosphere and the ozone layer.**
- **7. It determined by possible influence on long-term global climate change through influence on the formation of clouds (mostly, low clouds).**

- 8. We take into account big variability of CR intensity caused by modulation in the Helio-sphere, generation of solar energetic particles in flare events, and by influence of changing geomagnetic cutoff rigidities.
- 9. Planetary observations on balloons of different components of primary and secondary components of CR as well as air isotopic and chemical contents in dependence of latitude and altitude are crucial for understanding of the nature of CR influence on physical and chemical processes in the Earth’s atmosphere as well as for space weather and global climate change problems.

Main references

1. Dorman L.I., *Cosmic Rays in the Earth's Atmosphere and Underground*, Kluwer Academic Publishers, Dordrecht/London/Boston, pp 862 (2004).

- 2. Dorman L.I., *Cosmic Ray Interactions, Propagation, and Acceleration in Space Plasmas*, Springer, Netherlands, pp 847 (2006).
- 3. Dorman L.I., *Cosmic Rays in Magnetospheres of the Earth and other Planets*, Springer, Netherlands, pp 770 (2009).
- 4. Dorman L.I. "Chapter 3. The Role of Space Weather and Cosmic Ray Effects in Climate Change", in book *Climate Change: Observed Impacts on Planet Earth,* Edited by Trevor M. Letcher, Elsevier, 2009

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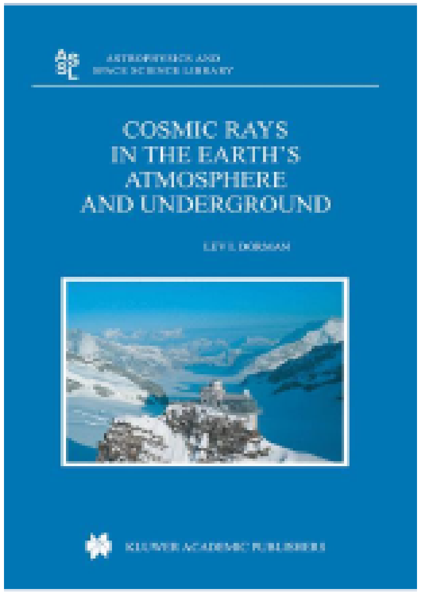

Cosmic Rays in the Earth's Atmosphere and Underground

This book consists of four parts. In the first part (Chapters 1-4) a full overview is given of the theoretical and experimental basis of Cosmic Ray (CR) research in the atmosphere and underground for Geophysics and Space Physics; the development of CR research and a short history of many fundamental discoveries, main properties of primary and secondary CR, methods of transformation of CR observation data in the atmosphere and underground to space, and the experimental basis of CR research underground and on the ground, on balloons and on satellites and space probes.

The second part (Chapters 5-9) is devoted to the influence of atmospheric properties on CR, so called CR meteorological effects; pressure, temperature, humidity, snow, wind, gravitation, and atmospheric electric field effects. The inverse problem - the influence of CR properties on the atmosphere and atmospheric processes is considered in the third part (Chapters 10-14); influence on atmospheric, nuclear and chemical compositions, ionization and radio-wave propagation, formation of thunderstorms and lightning, clouds and climate change.

The fourth part (Chapters 15-18) describes many realized and potential applications of CR research in different branches of Science and Technology; Meteorology and Aerodrome Service, Geology and Geophysical Prospecting, Hydrology and Agricultural Applications, Archaeology and Medicine, Seismology and Big Earthquakes Forecasting, Space Weather and Environment Monitoring/Forecasting.

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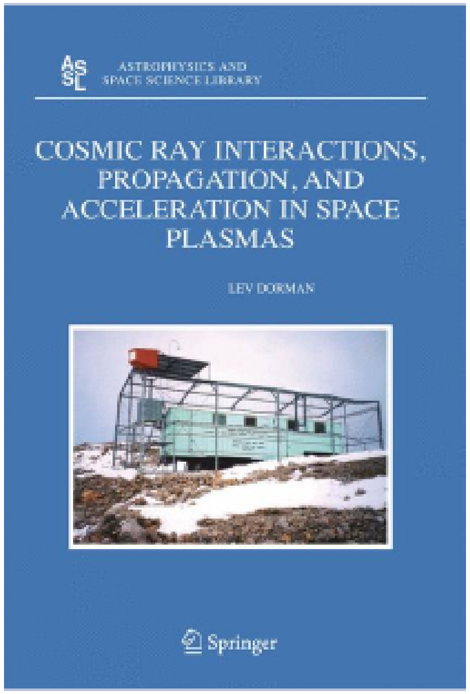

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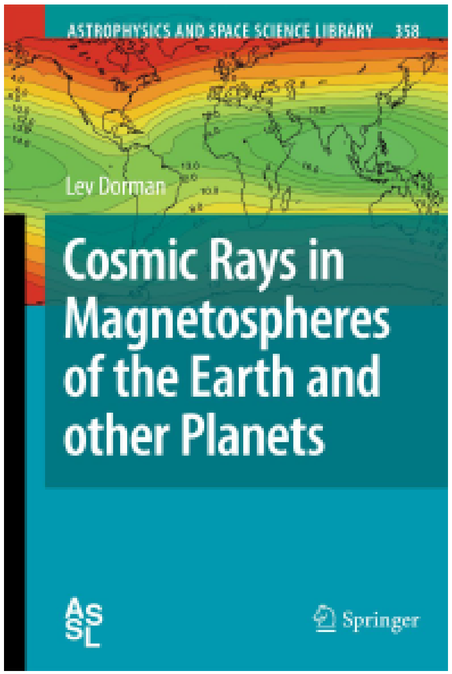

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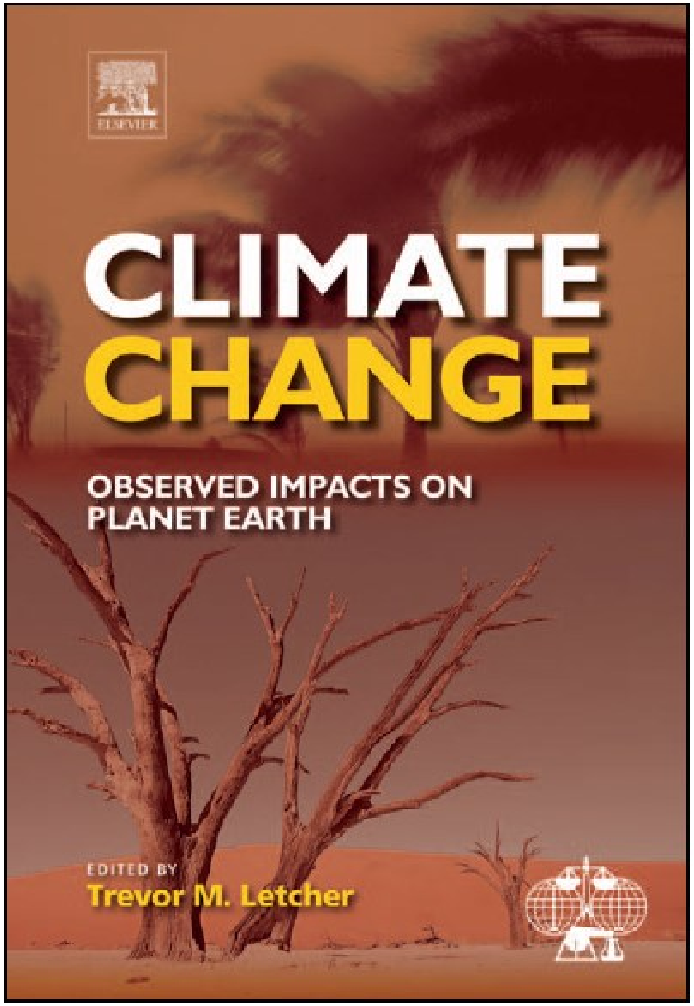

From: Lev I. Dorman, The Role of Space Weather and Cosmic Ray Effects in Climate Change. In Trevor M. Letcher, editor: Climate Change: Observed impacts on Planet Earth, The Netherlands, 2009, pp. 43-76.
ISBN: 978-0-444-53301-2

The Role of Space Weather and Cosmic Ray Effects in Climate Change

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