Response of the polar middle atmosphere to electron precipitation events

Irina A. Mironova

i.a.mironova@spbu.ru

Saint Petersburg State University

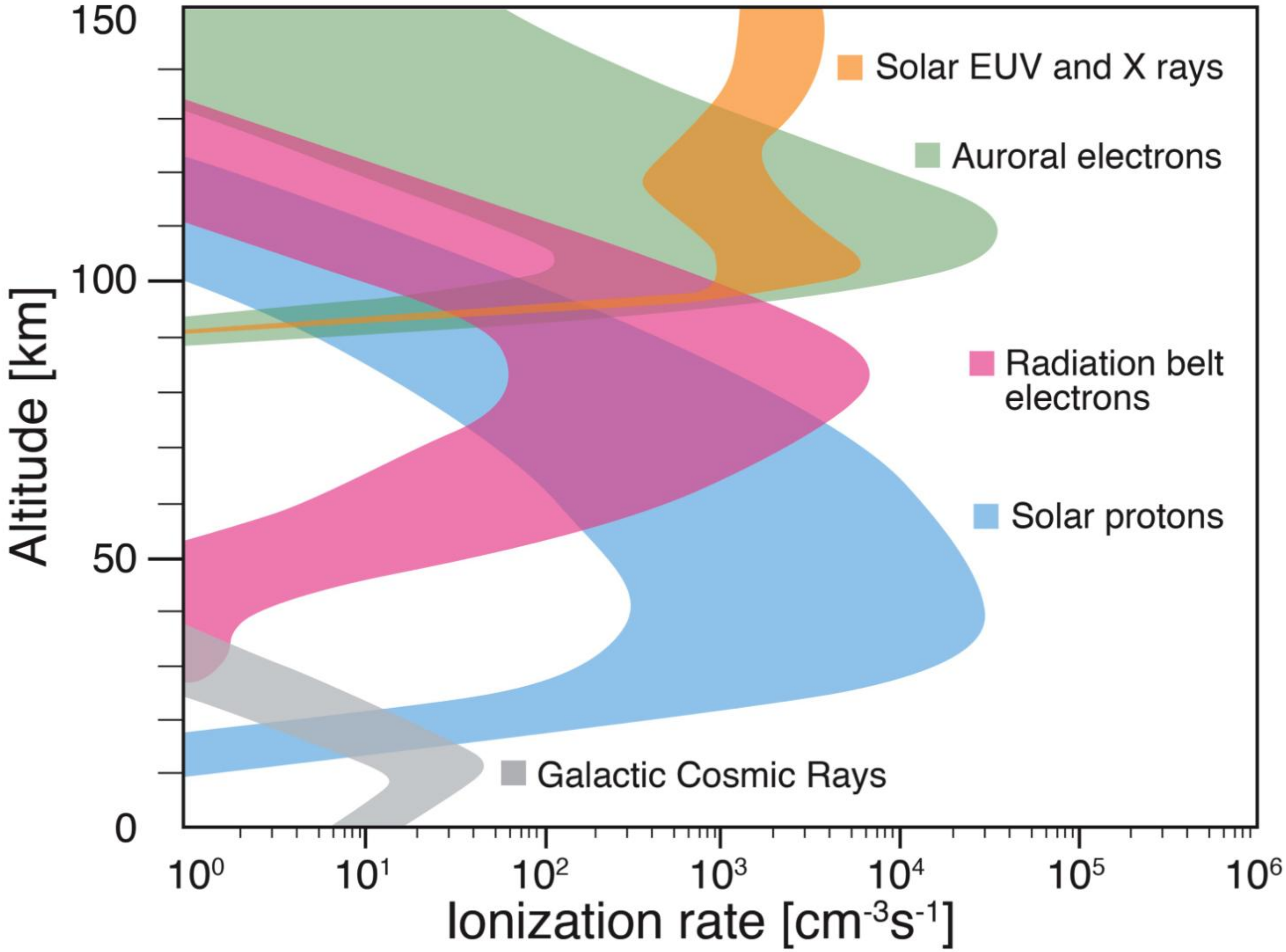
First VarSITI General Symposium
Albena, Bulgaria
08.06.2016

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

VarSITI

Instantaneous Ionization Raters of the Earth atmosphere

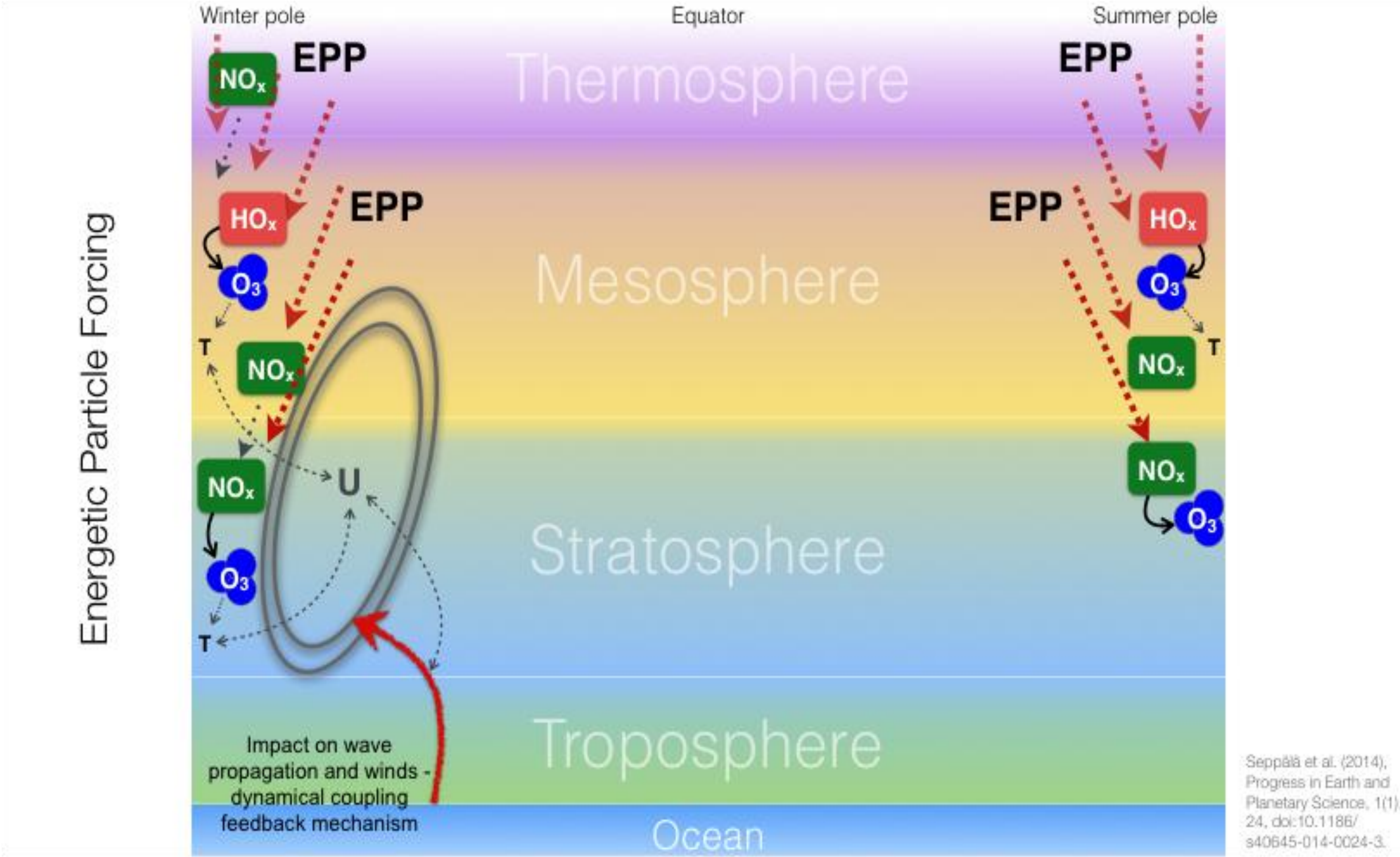
EPP, Solar EUV and X-ray



Mironova et al., Space Science Rev. (2015)

The figure is modified after Baker et al. (2012)

Energetic Particle Precipitation Forcing



Seppälä et al. (2014), Progress in Earth and Planetary Science, 1(1), 24, doi:10.1186/ s40645-014-0024-3.

Solar Forcing for CMIP6

- Solar Spectral Irradiance (SSI) and Total Solar Irradiance (TSI)
- Energetic Particle Precipitation :

Protons –
galactic cosmic rays (GCR), solar energetic protons (SEP)

- Proton forcing – ionization rates => HOx and NOx production

Electrons –
low energy auroral electrons (LEE),

middle and high energy radiation belt electrons (MEE an HEE)

- Electron forcing – Ap and Kp index, Ap-based parametrization of auroral production of NOx (by LEE)

Forcing of MEE an HEE ?

INTERNATIONAL SPACE SCIENCE INSTITUTE

Electron Precipitation Events

Catalogue of electron precipitation events as observed in the long-duration cosmic ray balloon experiment

Lebedev Physical Institute balloon cosmic ray experiment

Balloon experiment

Cosmic Rays balloon experiment: 1957–up to now

Cosmic Ray Measurements with Standard Radiosound by Meteorological Balloon

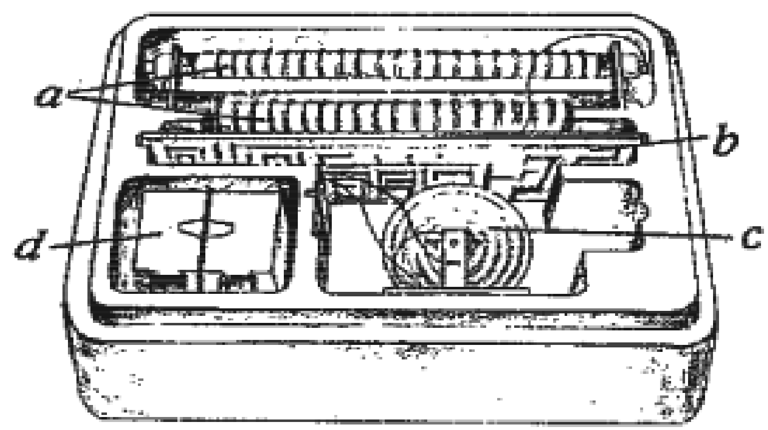
INSTRUMENTS

a)Two geiger counters (Aluminium filter inserted)

b) Electronic plate with high-frequency transmitter

c) Altitude sensor

d) Power supply

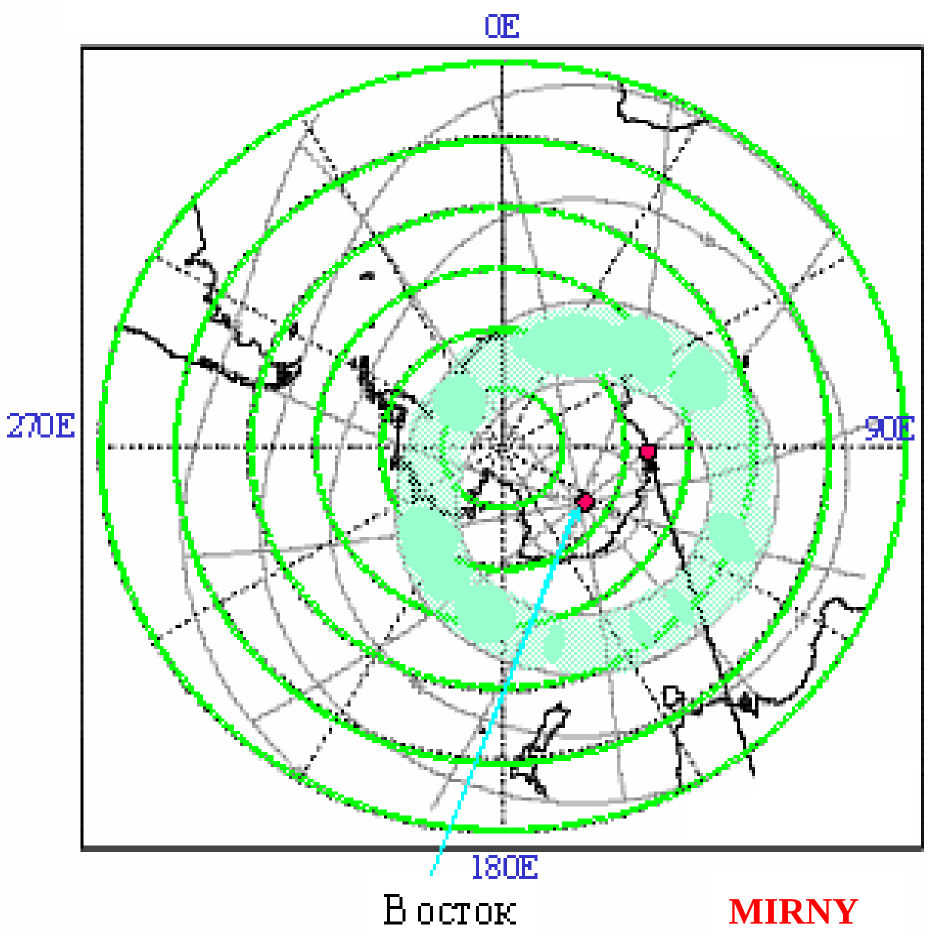


CHARACTERISTIC FEATURES

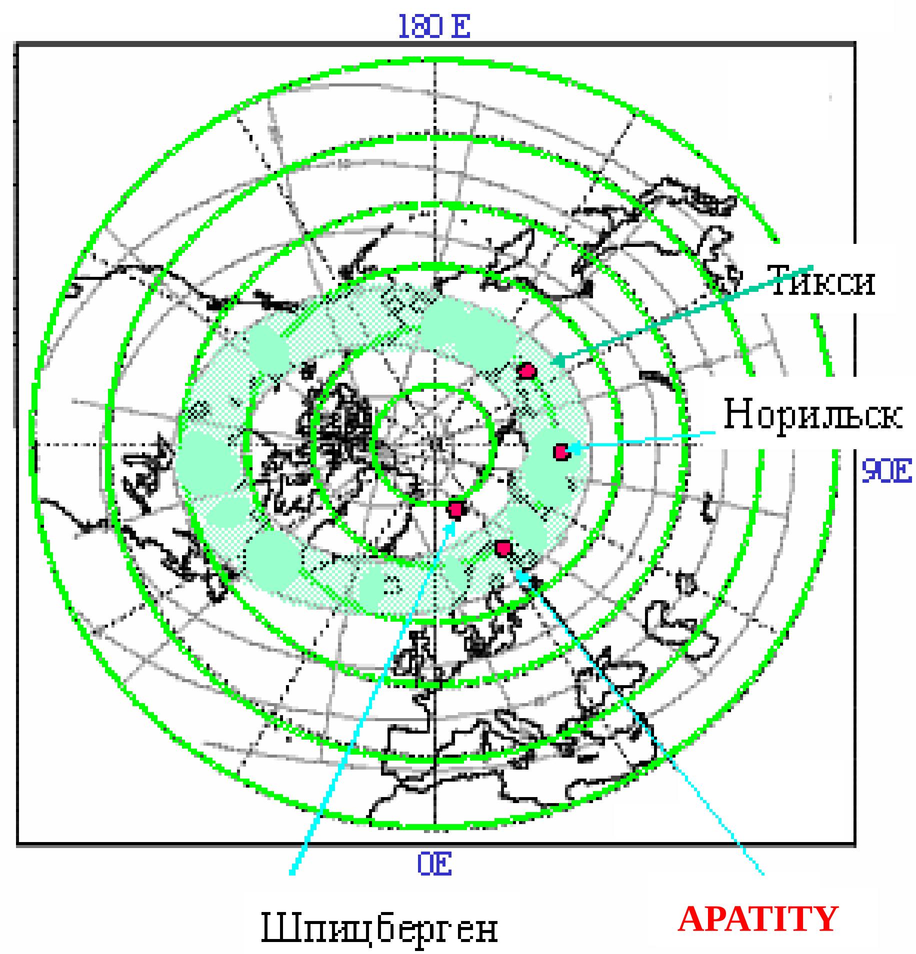
- Maximum altitude about 35 km
- Electron records for E > 0.2 MeV
- Proton records for E > 5 MeV
- Bremsstrahlung photons for E > 20 keV

Balloon experiment

Stations:
Geomagnetic Locations

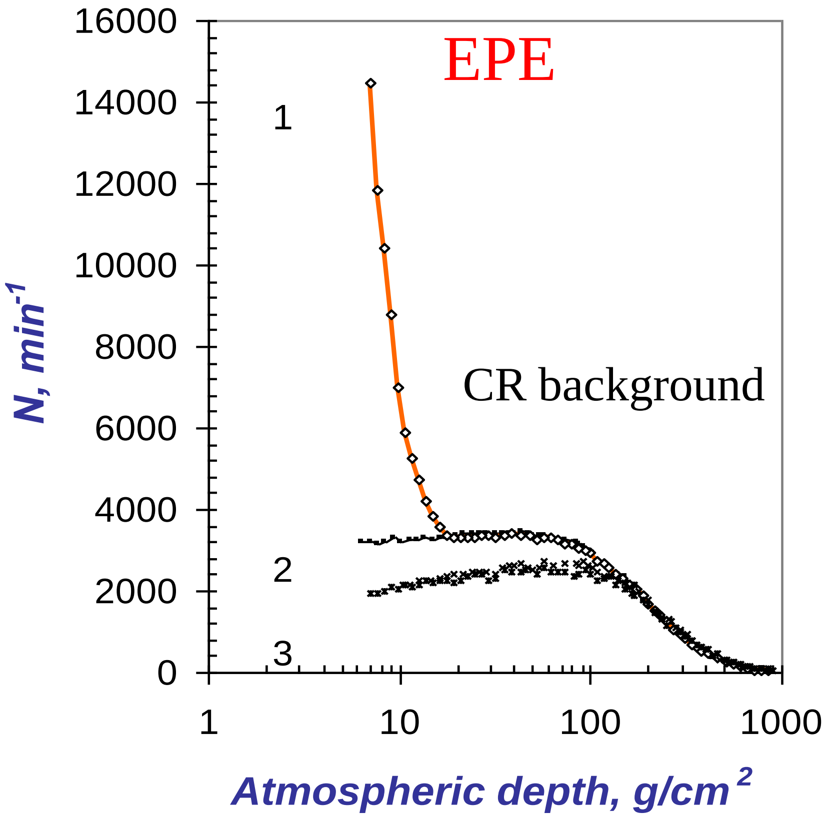


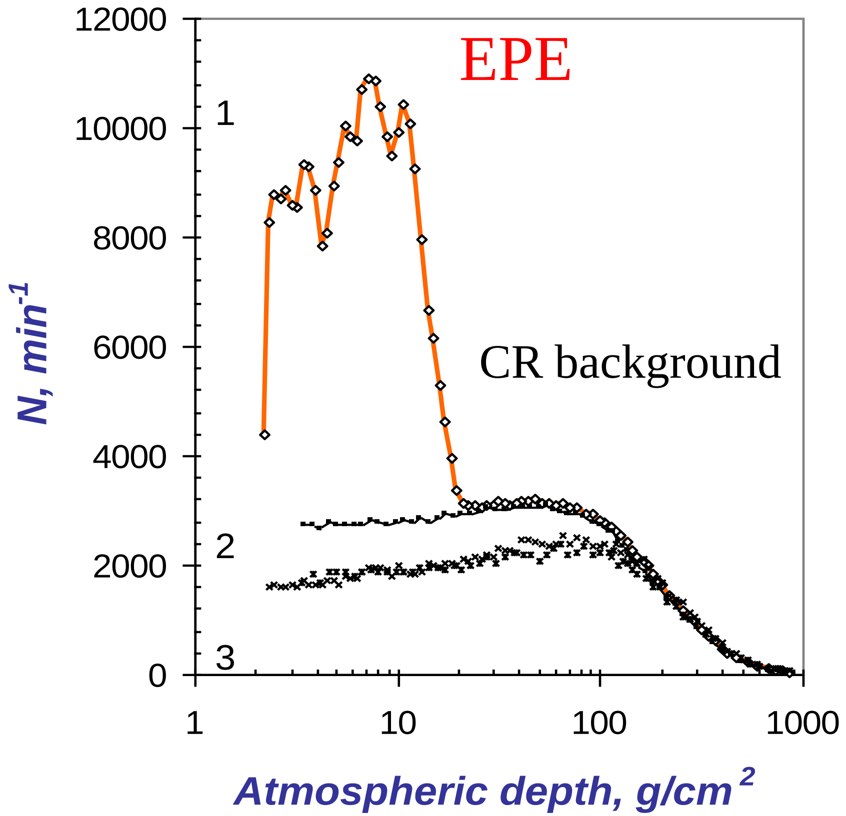
SOUTH



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.

Catalogue of Electron Precipitation Events (1961-2014)

Table 1
List of high-latitude stations of stratospheric cosmic ray monitoring (R_c – geomagnetic cutoff rigidity).

Station	Geograph. Coordinates	R_c (GV)	Start time of balloon launch (UT)	Period of measurements	Number of balloon launches	Number of EPEs recorded till 2014
Olenya, Murmansk region	68°57′N 33°03′E	0.6	5–8	07/1957–2002	~ 40,000	524
Apatity, Murmansk region	67°33′N 33°20′E	0.6	12–15	2002–present time		
Mirny, Antarctica	66°34′S 92°55′E	0.03	6–9	03/1963–present time	16,700	10
Norilsk	69°00′N 88°00′E	0.6	5–8	11/1974–06/1982	760	10
Tixie Bay	71°36′N 128°54′E	0.5	5–8	02/1978–10/1987	1190	17

Table A.1
Catalogue of Electron Precipitation Events recorded in the long-term cosmic ray experiment in the stratosphere at the polar stations Murmansk region (Olenya, Apatity), Norilsk, Mirny and Tixie Bay. The 3-min averages of data were used. For each event the following information is given: event number date (day, month, year) time interval of the EPE observation (T_0–T_e, Start and End Time of observation, hour, minutes). A_e – parameter of the flux of incident electrons in cm^{-2} s^{-1} keV^{-1}. E_0 – characteristic energy of electron spectra in keV $J(E>20$ keV) – integral flux of incident >20 keV electrons in cm^{-2} s^{-1}.

N	Date			T_o-T_e (UT)				A_e	E_o, keV	J(E>20 keV)
1	9	5	1961	8	15	8	27	6.52E+06	6	1.978E+06
2	9	5	1961	11	21	11	32	2.21E+04	14	8.334E+04
3	12	9	1961	8	12	8	29	1.78E+04	17	1.030E+05
4	26	4	1962	8	19	8	25	4.87E+08	4	1.254E+07
5	20	7	1962	8	24	8	38	5.57E+02	40	1.387E+04
6	31	8	1962	8	40	8	53	8.60E+03	30	1.347E+05
7	8	7	1963	8	17	8	25	3.49E+07	7	2.086E+07

Makhmutov et al., JASTP (2015)

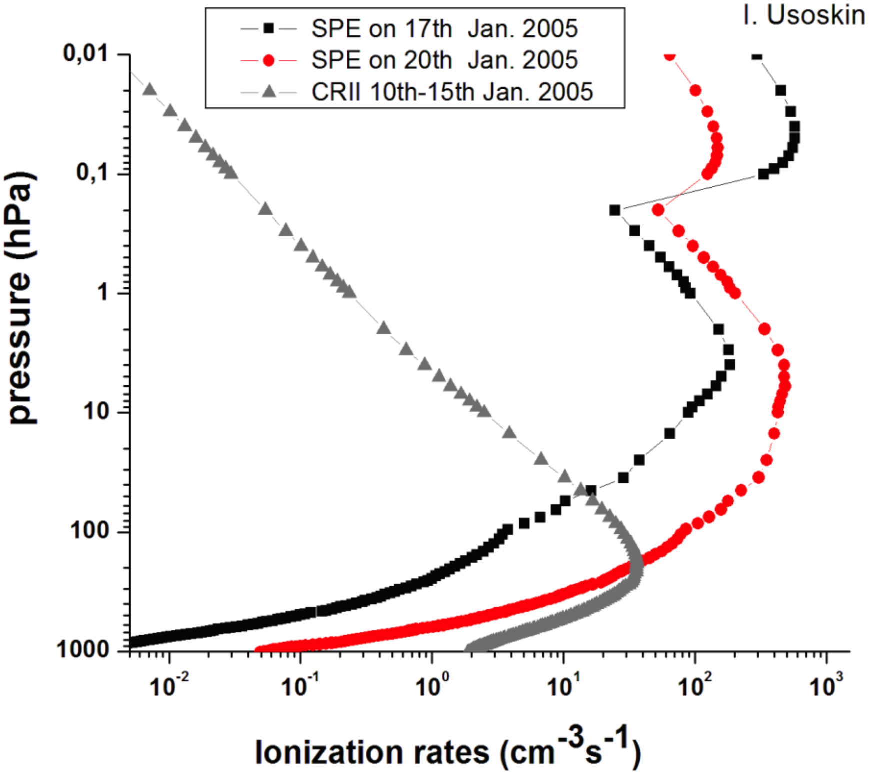
INTERNATIONAL SPACE SCIENCE INSTITUTE

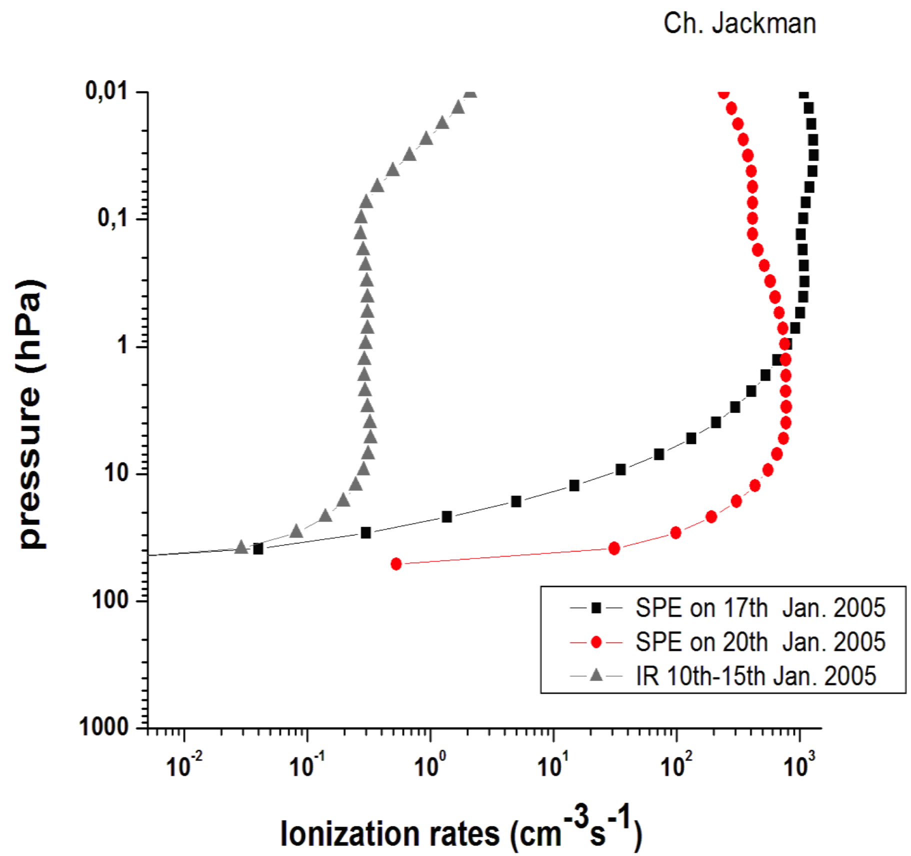
Proton Precipitation Events

during events 17^{th} and 20^{th} Jan.2005 :

SEP, GLE and Forbush decreases of GCR

Ionization of atmosphere during Jan.2005 (model results)



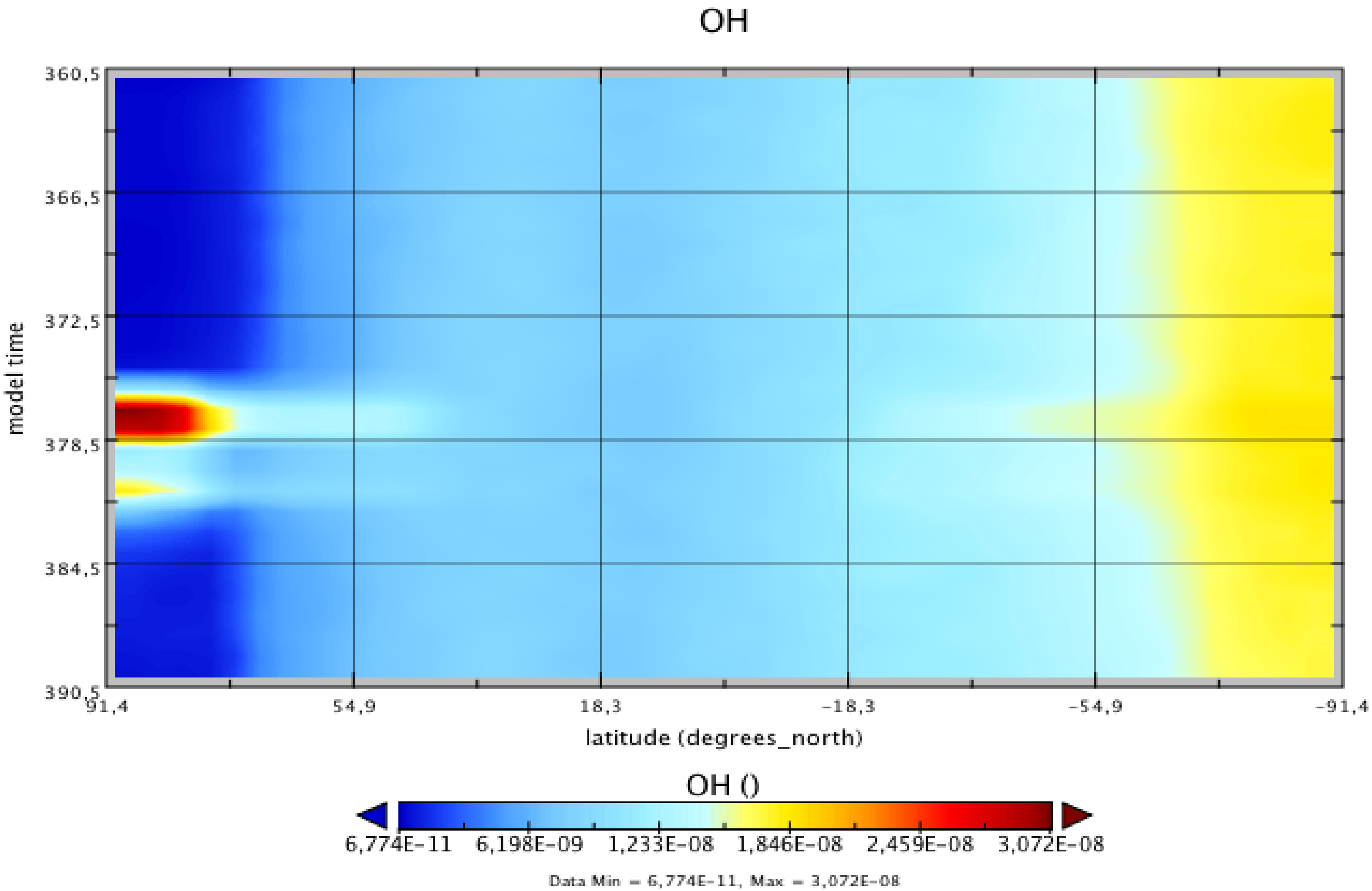


IR by using model
of Usoskin et al.

IR by using model
of Ch. Jackman

Global mesospheric effect of SEP, GLE during Jan.2005 over 90^0 NH

Model: Chemistry- Climate Modle (CCM) SOCOL (SOlar Climate Ozone Links)



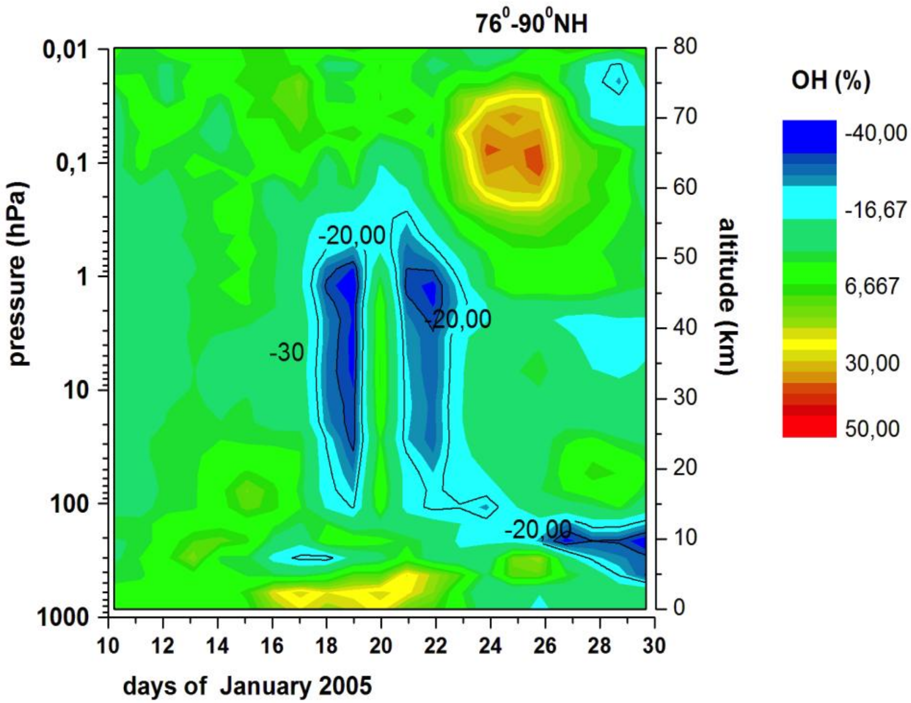
Model Experiment Setups

Chemistry- Climate Modle (CCM) SOCOL (SOlar Climate Ozone Links)

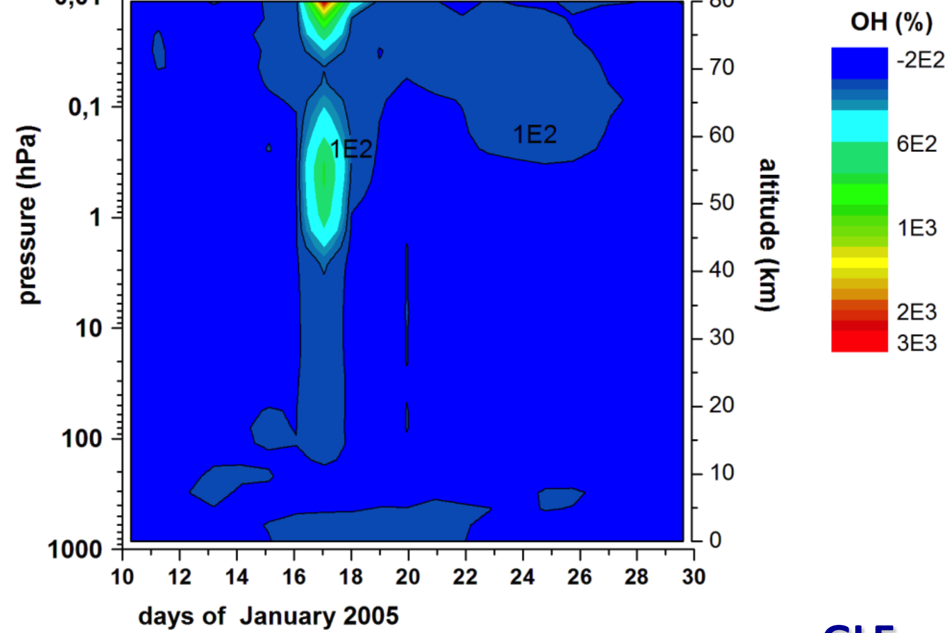
Experiments	Number of assemblers	Explanations
1. Reference	10	Phi=651 SPE = 0 Ionization: constant
2. GCR	10	SPE=0, Phi=f(DOY) Ionization: with Forbush effect
3. SEP	10	Phi=f(DOY)+SEP1 Ionization: with SEP (17 Jan. 2005)
4. GLE	10	Phi=f(DOY)+SEP1+SEP2 Ionization: with SEP (17 Jan. 2005) and SEP/GLE (20 Jan. 2005)

Response of polar atmosphere to SEP, GLE and GCR

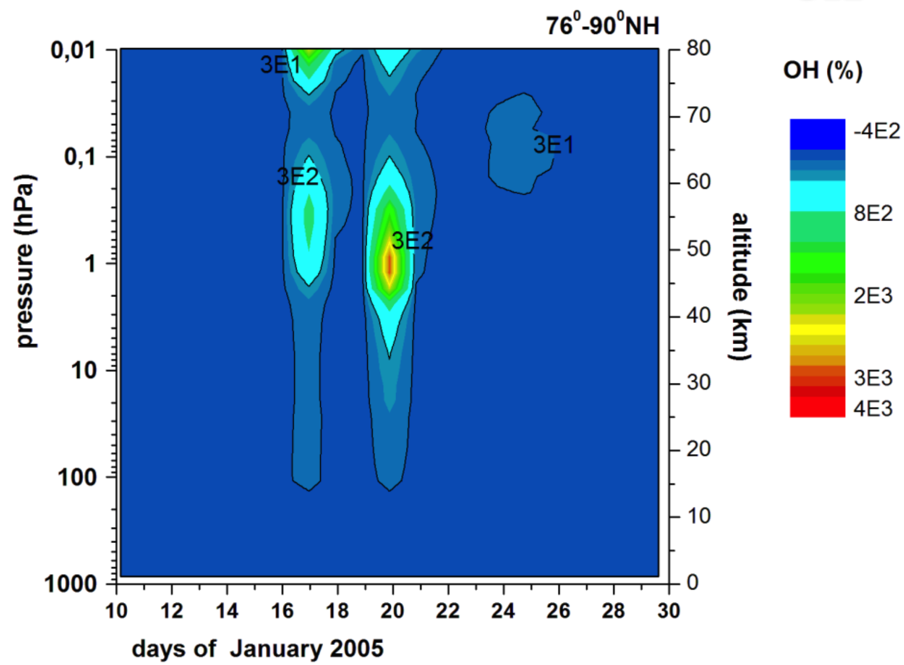
GCR



SEP



GLE



Summary

What we know/ What we can do:

- IR by protons – EPP: cosmic rays (CR), galactic (GCR) and solar origin (SEP);
- Scheme of impact of EPP on chemistry of atmosphere and Earth's temperature

Farther steps:

- New model that include IR by electrons - (EEP) – radiation belt electrons
- Comparison of model results and observations: chemical components, winds, temperature etc. => climate

ISSI Team project
http://www.issibern.ch/teams/ionizationsources/

Specification of Ionization Sources Affecting Atmospheric Processes

INTERNATIONAL SPACE SCIENCE INSTITUTE

Welcome Meetings Private Publications

Specification of Ionization Sources affecting Atmospheric Processes

Welcome to our ISSI website

Team members:

- **Karen L. Aplin** (GB)
- **Galina A. Bazilevskaya** (RU)
- **Bernd Funke** (ES)
- **Giles R. Harrison** (GB)
- **Alexei Krivolutsky** (RU)
- **Vladimir Makhmutov**(RU)
- **Irina A. Mironova** (RU)
- **Keri Nicoll** (GB)
- **Eugene V. Rozanov** (CH)
- **Miriam Sinnhuber** (DE)
- **Ilya G. Usoskin** (FI)
- **Jan Maik Wissing** (DE)

Young Scientists:

- **Olesya Yakovchouk** (RU)
- **Anton Artamonov** (FI)

Invited expert:

- **Frank Arnold** (DE)

As the main result of the Project, we aim at increasing and synthesizing understanding of the ionization sources in the Earth atmosphere, in particular the parameterization of the ionization rates by energetic particles of different rages of energies. Accordingly, we expect that the effect can be implicitly included into modern state-of-the-art climate models leading to a breakthrough in the level of modeling of natural variability of climate.

Output results

ISSI Teams 2010-2012 and 2013-2015 :

Invited Review Manuscript in **Space Science Review Journal** 194, 1-96, 2015, doi:10.1007/s11214-015-0185-4

Energetic particle influence on the Earth's atmosphere

Irina A. Mironova · Karen L. Aplin · Frank Arnold · Galina A. Bazilevskaya · R. Giles Harrison · Alexei A. Krivolutsky · Keri A. Nicoll Eugene V. Rozanov · Esa Turunen · Ilya G. Usoskin

Energetic particle influence on the Earth's atmosphere

Space Sci Rev (2015) 194:1–96
DOI 10.1007/s11214-015-0185-4

CrossMark

Energetic Particle Influence on the Earth's Atmosphere

Irina A. Mironova[1] · Karen L. Aplin[2] · Frank Arnold[3] · Galina A. Bazilevskaya[4] · R. Giles Harrison[5] · Alexei A. Krivolutsky[6] · Keri A. Nicoll[5] · Eugene V. Rozanov[7] · Esa Turunen[8] · Ilya G. Usoskin[9]

Table 3 Assessment of stratosphere atmospheric responses to energetic particles and cosmic rays with possible climate relevance

Topic	Aspect	Assessment	Comment	Importance for climate
Stratosphere				
Polar vortex (*see Sect. 3.2*)	Ozone depletion leads to cooling of polar vortex interior and acceleration of polar night jet	Probable	Predicted by results of some models	Potential effect on polar surface temperature
	Acceleration of the polar vortex leads to positive shift of the Arctic Oscillation (AO) phase	Probable	Predicted by results of some models; mechanism unclear	
Stratospheric aerosol (*see Sect. 3.4.2*)	Freezing of stratospheric aerosols (nitric acid trihydrate (NAT) particles)	Suggested	Observed in laboratory for some systems	Influence on polar stratospheric clouds
	Effect through polar aerosol and temperature decreasing	Observed	Observed under effect of major SEP/GLE events	
Chemical effect of galactic cosmic rays (*see Sect. 3.2.3*)	NO_x and HO_x are produced by GCR in the lower stratosphere/upper troposphere	Possible	Predicted by model results	Influence on polar stratospheric clouds
Nitric acid production (*see Sect. 3.1.2*)	Production of nitric acid from GCR	Well established	Source of stratospheric nitric acid, which are precursors of polar stratospheric clouds	

Thanks to **VarSITI** for providing travel support for attendance of the **First VarSITI General Symposium** in Albena.

Thank you for your attention