Research Centre of Cosmic Rays and Radiation Events in Atmosphere

crreat.eu

1st CRREAT Workshop & SAC meeting

Prague, 19th - 20th December 2017

Czech Academy of Sciences, Národní 3, 117 20 Staré Město, Prague, Czech Republic

Topics

- **Session 1: Dosimetry of ionizing radiation in the atmosphere**
  - Radiation measurements onboard spacecraft, aircraft and balloon flights
  - Radiation measurements at high-mountain observatories
  - Calibration of instruments at the on-ground facilities
  - TGF and other thunderstorm radiation phenomena / TGE and lightning initiation
- **Session 2: Physics of storm clouds and upper-atmosphere phenomena**
  - Modeling of cloud electrification
  - Upper-atmosphere phenomena
- **Session 3: Characteristics of the electromagnetic field in the atmosphere**
  - Influence of natural phenomena and atmosphere on navigation and communication systems
  - Methods for localization of lightning

Organizing committee:

Guenther Reitz, Ondřej Ploc, Kateřina Mocková, Magdalena Hlaváčová

Contact: mockova@ujf.cas.cz

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Programme at glance

Time	Tuesday December 19th	Wednesday December 20th
8:45 - 9:15	Registration	
9:15 - 9:30	Welcome, introduction to CRREAT (P. Lukáš, G. Reitz) @ Conference room 206	
9:30 - 10:30	Progress report O. Ploc, I. Kolmašová, P. Kovář @ Conference room 206	Session 2 (contributions 17 - 20) Chair G. Reitz, Z. Sokol @ Conference room 206
10:30 - 11:00	**Coffee break**	
11:00 - 11:30	Session 1 (contributions 2 - 5) Chair G. Reitz, O. Ploc @ Conference room 206	**Coffee break**
11:30 - 12:30		Session 2 (contributions 21 - 22) Chair G. Reitz, I. Kolmašová @ Conference room 206
12:30 - 14:00	**Lunch** @ Restaurace Klub Techniků, Novotného Lávka 200/5, Prague 1	**End of workshop** **Lunch** @ Restaurace Klub Techniků, Novotného Lávka 200/5, Prague 1
14:00 - 15:30	Session 1 (contributions 6 - 11) Chair G. Reitz, O. Ploc @ Conference room 206	SAC meeting @ Conference room 205
15:30 - 16:00	**Coffee break**	**Coffee break**
16:00 - 17:30	Session 3 (contributions 12 - 16) Chair G. Reitz, I. Kovář @ Conference room 206	Presentation of the SAC results @ Conference room 205
18:15 - 22:00	**Workshop dinner** @ MEET BEER Restaurant	**Dinner with SAC members** @ Castle Residence Hotel

Thursday December 21st

9:00 - 13:45 Excursion and discussions on common topics @ Institute of Atmospheric Physics, Boční II 1401/1A, 141 00 Prague 4 - Záběhlice (http://www.ufa.cas.cz)

14:00 Lunch @ Lokai- Koliba, Gregorova 2298/8, 148 00 Praha 11-Chodov

18:30 Dinner @ Castle Residence

Friday December 22nd

9:00 - 12:00 Proposal for H2020 meeting @ DRD NPI (Chilingarian, Nikolova, Reitz, Kudela, Benton, Ploc, Kákona)

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Scientific program

Day 1: 19.12.2017

	Time	Title	Authors	Session
1	9:30	Progress report of CRREAT	O. Ploc, I. Kolmašová, P. Kovář	1,2,3
2	11:00	ICCHIBAN and importance of ground-based experiments	Y. Uchihori, H. Kitamura, S. Kodaira and ICCHIBAN WG	1
3	11:30	Fragmentation from heavy ion beams in HIMAC BIO room calculated with PHITS and measured with Liulin	O. Ploc, L. Sihver, J. Šlegl, M. Kákona, T. Dachev, H. Kitamura, Y. Uchihori	1
4	11:50	AIRDOS - an open source dosimeter for measurement on board of aircraft	M. Kákona, P. Krist, V. Štěpán, D. Peksová, I. Ambrožová, J. Šlegl, J. Záhora, M. Lužová, M. Sommer, J. Kákona, J. Chroust, O. Ploc	1
5	12:10	Comparison of LET spectra measured with Timepix and TEPC Hawk in mixed radiation fields	M. Sommer, C. Granja, D. Peksová, M. Kákona, O. Ploc	1
6	14:00	Measurement of secondary cosmic ray neutrons at the high-mountain stations	V. Mares, T. Brall, R. Bütikofer, G. Donth, W. Rühm	1
7	14:25	Correlations between secondary cosmic ray rates and strong electric fields at Lomnický Štít (poster)	K. Kudela, J. Chum, M.Kollarik, I. Strharsky, R. Langer, J. Base	1
8	14:30	European Dosimetry Network aboard Aircraft (EDNA)	D. Peksová, I. Ambrožová, M. Kákona, K. Kudela, M. Peksa, V. Štěpán, O. Ploc	1
9	14:45	Experience with measurement of cosmic rays onboard stratospheric balloon flights	Collective of the Nuclear Physics Institute of the CAS (presenting Jakub Šlegl), collective of the Faculty of Electrical Engineering of CTU in Prague, collective of the Faculty of Nuclear Sciences and Physical Engineering of CTU in Prague, Universal Scientific Technologies s. r. o., Soběslav	1
10	15:00	Contribution of different particles onboard spacecraft estimated by means of plastic nuclear track detectors	I. Ambrožová, R. V. Tolochek, O. A. Ivanova,V. A. Shurshakov	1
11	15:15	Position- and Directional-Sensitive Detection of Secondary Cosmic Rays: Evaluation and Calibration of Pixel Detectors at the Microtron and Cyclotron Accelerators	C. Granja, M. Sommer, M. Luzova, P. Krist, D. Chvatil, V. Olsansky, T. Matloha, V. Zach, J. Stursa, S. Polansky, J. Jakubek	1
12	16:00	High Energy Physics in Atmosphere (HEPA) and lightning initiation	A. Chilingarian	1
13	16:20	Spectrograph for investigation of the solar activity in navigation bands and its application for investigation of the impact on GNSS measurement	P. Kovář	3
14	16:40	Online lightning current monitoring in downconductors	J. Mikeš, O. Hanuš, J. Kákona	3
15	17:00	Radio localization and mapping of lightning with high spatial and time resolution	J. Kákona, J. Mikeš, P. Kovář	3
16	17:15	Telemetry system for stratospheric balloon	P. Puričer	3

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Day 2: 20.12.2017

	Time	Title	Authors	Session
17	9:30	TARANIS - a satellite for the study of TLEs and TGFs	J - L. Pincon	2
18	10:00	Daytime Tweek Atmospherics Originating from European North Atlantic Winter Thunderstorms	O. Santolík, I.Kolmašová	2
19	10:20	Multi-instrument observations of transient luminous events associated with a small-scale winter thunderstorm occurring in the southwest of Czechia	I. Kolmašová, O. Santolík, P. Spurny, J. Borovička, J. Mlynarczyk, M. Popek, R. Lan, L. Uhlíř, G. Diendorfer, R. Slosiar	2
20	10:40	The LSBB URL, a low background noise underground facility for interdisciplinary science and technology	S. Gaffet	2
21	11:30	Model of cloud electrification for the COSMO numerical weather prediction model	Z. Sokol	2
22	11:50	Application of the Model of Cloud Electrification (MCE)	J. Minářová	2
	12:10	Closing ceremony	G. Reitz, O. Ploc	

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ICCHIBAN and importance of ground-based experiments

Yukio UCHIHORI[1], Hisashi KITAMURA[1], Satoshi KODAIRA[1] and ICCHIBAN WG

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Radiation measurements of cosmic rays are required for radiation control of astronauts/cosmonauts and air-crews. Dosimeters and detectors of radiation measurements have been developed in institutes and universities in world and these dosimeters and detectors have been calibrated by themselves. These calibrations are very important to confirm the capabilities of dosimeters and detectors. Especially, in space environment and high altitude, there are high LET particles which are absent in ground-based environment and the calibration should be executed in a special facility.

After discussions in WRMISS (Workshop for Radiation Measurements in the International Space Station), campaigns of inter-comparison and inter-calibration of these instruments using particle beams like heavy ion accelerators and proton accelerators were needed. Some of the campaigns was performed as the ICCHIBAN project (Inter-Comparison for Cosmic-rays with Heavy Ion Beams At NIRS) from 2002. More than 10 campaigns were performed in HIMAC (Heavy Ion Medical Accelerator in Chiba), NSRL (NASA Space Radiation Laboratory), Loma Linda University Medical Center and CERN (European Organization for Nuclear Research). 23 institutes and universities in 13 countries attended the ICCHIBAN project. Methodologies and some results of the ICCHIBAN project will be presented.

In addition, the HIMAC accelerator facility, which more than 10,000 patients were treated in, and its utilization will be shown.

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Fragmentation from heavy ion beams in HIMAC BIO room calculated with PHITS and measured with Liulin

O. Ploc[1], L. Sihver[2,3], J. Šlegl[1], M. Kákona[1], T. Dachev[4], H. Kitamura[5], Y. Uchihori[5]

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[4] Space Research and Technology Institute of the BAS, Sofia, Bulgaria
[5] National Institutes for Quantum and Radiological Science and Technology, Chiba, Japan

The Heavy Ion Medical Accelerator in Chiba (HIMAC) is not only an excellent cancer-treatment facility but also a facility to perform experiments related to radiation therapy, space radiation protection and basic nuclear physics. HIMAC BIO is an irradiation room used for experiments related to both radiobiology and physics, e.g. calibration of active and passive detectors used for cosmic ray dosimetry onboard aircraft and spacecraft. When performing such experiments, it is essential to know the experimental setup, as well as the beam characteristics, in details. The advantage of HIMAC BIO is that both narrow and broad parallel heavy ion beams (up to 10 cm), with flat circular profile at the isocenter, can be used for experiments. However, the exact beam composition including the fluence and energies of the secondary fragments and neutrons are usually unknown. The purpose of this paper is to provide detailed information about the components in the beam line at the HIMAC BIO room to facilitate accurate particle and heavy ion transport simulations of the beam characteristics. The main sources of secondary particles have been investigated, and the beam composition was calculated with the 3-dimensional general purpose Monte Carlo Particle and Heavy Ion Transport code System (PHITS) and compared with measurements using a silicon detector (Liulin) exposed to various monoenergetic and SOBP heavy ion beams. Good agreement between measurements and simulations was observed. These results are of importance when evaluating experiments at HIMAC performed by NASA, JAXA, ESA, etc.

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AIRDOS - an open source dosimeter for measurement on board of aircraft

M. Kákona[1,2], P. Krist1, V. Štěpán[1], D. Peksová[1,2], I. Ambrožová[1], J. Šlegl[1,2], J. Záhora[2], M. Lužová[2], M. Sommer[1,2], J. Kákona[2,3], J. Chroust[3], O. Ploc[1]

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We introduce the new dosimeter AIRDOS developed for measurement on board of aircraft. This dosimeter is based on CANDY project [Kákona et al., WRMISS 2015, WRMISS 2016] and represents our effort for an open source platform for measurement in low intensity mixed field of ionising radiation. The AIRDOS houses as main parts a silicon PIN diode as radiation detector, electronics for conversion of the signal to the pulse-height spectra, an GPS module and, a memory chip (card) and batteries for one-month continues monitoring. We'll present a calibration method for evaluation of dosimetric quantities with AIRDOS, results from several experiments (e.g. from exposures in reference fields at CERF and, HIMAC, on an stratospheric balloon, and in aircraft), and compare it with data from Liulin measurements exposed into the same radiation fields. Calibration data are used to assess dosimetric quantities necessary to determine radiation risks of civil air crews.

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Comparison of LET spectra measured with Timepix and TEPC Hawk in mixed radiation fields

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The linear energy transfer (LET) is an important quantity from which the quality factor (Q), used as the indicator of radiation quality, can be calculated. Quality factor Q was chosen to describe the radiobiological efficiency per unit dose of a radiation type in humans and is defined as a function of LET. The product of absorbed dose and Q is called dose equivalent, which is often used in radiation protection as a conservative approximation of effective dose which is directly related to radiation risk.

The LET is dependent on the energy of charged ionizing particle, type of the particle and on the material in which it was measured. The linear energy transfer in tissue might be measured directly with tissue equivalent proportional counter or with silicon chip based detectors. If the silicon chips are used, the conversion factor for energy deposit from silicon to water has to be applied. When the LET in water is recalculated from silicon detectors, the challenge is to precisely determine the type and the energy of incoming particles.

We have conducted series of experiments on various beams including mixed radiation field at CERF and measurement on board aircraft. The LET spectra were measured with three different types of detectors – Liulin, Timepix and TEPC Hawk. Our goal was to study the possible application of Timepix for aircraft dosimetry and its accuracy compared to the other dosimeters used for on board dosimetry.

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MEASUREMENT OF SECONDARY COSMIC RAY NEUTRONS AT THE HIGH-MOUNTAIN STATIONS

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In this paper, the influence of the parameters that might affect the energy spectrum of the neutrons of the secondary cosmic rays (CRs) measured at selected high-mountain stations is discussed.

An extended range Bonner sphere spectrometer (ERBSS) with 16 measuring channels has been installed in 2004 at the Environmental Research Station "UFS Schneefernerhaus" (2,650 m a.s.l.) close to the summit of the Zugspitze Mountain, Germany, to measure continuously the energy spectrum of the neutrons of the secondary CRs in the Earth's atmosphere. With the time series of the deduced neutron spectra, it is possible to investigate the parameters that might affect the neutron energy spectra, as the solar activity cycle, the atmospheric pressure and the snow in the environment.

In addition, the energy spectra of the neutrons from the secondary CRs were measured for the first time with an ERBSS at two locations (3,466 m a.s.l. and 3,571 m a.s.l.) on Jungfraujoch, Switzerland in June 2016. There were observed significant differences in the measured neutron energy spectra at Jungfraujoch when comparing with the results obtained at the UFS. These differences due to different altitudes, topography and snow cover at both locations are also discussed.

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Correlations between secondary cosmic ray rates and strong electric fields at Lomnický Štít

K. Kudela[1,2,*], J. Chum[3], M. Kollarik[2], I. Strharsky[2], R. Langer[1,2], J. Base[3]

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Since March 2014, there is a continuous measurement of secondary cosmic rays by the detector system SEVAN (Space Environmental Viewing and Analysis Network) at Lomnický štít, altitude 2,634 m above sea level. Starting from June 2016, the count rates (1 s resolution) obtained from the three SEVAN detectors and from their coincidences are available, along with selected meteorological characteristics. Since 30 May 2016 the electric field measurements have been installed at the same site. Several events with clear increase of the count rate in the upper detector of SEVAN were observed during the thunderstorms until 17 September 2016. Examples of these measurements are presented and discussed. Barometric pressure correction and elimination of low-frequency variability from the signal allow to extract 2 min averaged increases from the data. It is shown that the 2 min averaged increases of count rates measured by SEVAN correspond with periods of high electric field (with higher probability during negative polarity) rather than with the individual discharges (lightning).

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INSTITUTE OF ATMOSPHERIC PHYSICS CAS

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

European Dosimetry Network aboard Aircraft (EDNA)

D. Peksová[1,2], I. Ambrožová[1], M. Kákona[1,2], K. Kudela[1], M. Peksa[3,4], V. Štěpán[1], O. Ploc[1]

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The Department of Radiation Dosimetry has been involved in the long-term monitoring of cosmic rays on board aircraft since 2001. With the Liulin semiconductor detector, more than 40 long-term measurements have been carried out to verify computer programs for routine dosimetry of aircraft crews and to look for radiation phenomena such as ground level enhancement (GLE) and Forbush decrease.
All those dosimetric data became part of European Dosimetry Network aboard Aircraft (EDNA), which was created with the support of ESA within the SOCIS project. EDNA allows collection, processing, and visualization of time-dependent data from physical measurements on board aircraft. The database is implemented as a server-side application with web client. Currently, the access to EDNA is via web address http://edna.ujf.cas.cz/.
The database was created to enable collaboration of multiple scientific groups measuring cosmic rays on board aircraft and aiming to elucidate radiation phenomena. The CRREAT project should help to clarify the relationship between cosmic radiation and high-energy atmospheric physics, especially the terrestrial gamma-ray flashes (TGF), the radiation phenomena associated with lightning. Thus, its results will aid in determination of radiation risk of aircraft crews caused by lightning.

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Experience with measuring cosmic rays onboard stratospheric balloon flights

J. Šlegl and Collective of the Nuclear Physics Institute of the CAS, collective of the Faculty of Electrical Engineering of CTU in Prague, collective of the Faculty of Nuclear Sciences and Physical Engineering of CTU in Prague, Universal Scientific Technologies s. r. o., Soběslav

On board of three stratospheric balloon flights launched in 2015 and 2017 PIN diode detectors CANDY were placed which are developed for measurements onboard aircraft. The second flight called LetFik2 was organized as a student project with a goal to measure cosmic radiation in high altitudes with a detector in development and compare it with CARI programme. We will present developed electronics, program for calculation of balloon height and prediction of its impact Fíkus using atmospheric data from WRF provided by Institute of Computer Science of the CAS. From the third flight, held in Toruń, Poland, under the Visegrad funded conference NearSpace 2017, we will present measured data and position of *pfotzer-regener* maximum.

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Contribution of Different Particles Onboard Spacecraft Estimated by Means of Plastic Nuclear Track Detectors

I. Ambrožová1, R.V. Tolochek[2], O.A. Ivanova[2], V.A. Shurshakov[2]

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[2] Institute of Biomedical Problems, Russian Academy of Sciences, Moscow, Russia

Cosmic radiation is composed of primary high-energy galactic and solar particles, particles trapped in Earth's radiation belts, and also of secondary particles created in nuclear interactions of primary radiation when passing through spacecraft walls or material load. The contribution of the secondary particles to total radiation exposure can be comparable with that of the primary field. To separate different components of the radiation onboard spacecraft, plastic nuclear track detectors (PNTD) can be used. We will present a method to discriminate high-energy primary ions and secondary particles according to their range in the detector's material. Tracks corresponding to primary high-energy heavy ions are supposed to have a long range, so they can penetrate deep into the detector. On the other hand, tracks corresponding to the secondary component and low-energy particles are visible over a limited thickness only. The exposed detectors are etched several times and the same area of the detector is carefully analyzed after each etching and paired tracks are compared. Tracks of short-range particles become over-etched after long etching. The method is demonstrated using detectors exposed onboard ISS and biological satellite BION-M1.

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Position- and Directional-Sensitive Detection of Secondary Cosmic Rays: Evaluation and Calibration of Pixel Detectors at the Microtron and Cyclotron Accelerators

Carlos Granja[1], Marek Sommer[1], Martina Lužová[1], Pavek Krist[1], David Chvátil[1], Václav Olšanský[1], Tomáš Matlocha[1], Václav Zach[1], Jan Štursa[1], Štěpán Polanský[2], Jan Jakubek[2]

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[2] Advacam, Prague, Czech Republic

Pixel Detectors of the Timepix/Medipix type are being increasingly used for detection and characterization of mixed radiation fields such as secondary cosmic ray detection in the atmosphere. Tests and calibration of pixel detectors in various architecture and readout configurations were performed at defined radiation fields using mono-energetic charged particle beams at the electron Microtron accelerator and at the proton Cyclotron in Rez. In addition to single-chip devices, such as the highly miniaturized miniPIX detector, we tested arrays of Timepix detectors in double-stack or also a highly-integrated and wide field-of-view four-layer Timepix WidePIX 3D particle telescope. We evaluate the resolving power in terms of particle types, deposited energy resolution and directional sensitivity for energetic charged particles. Results and comparison with data from cosmic ray detection will be presented.

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High Energy Physics in Atmosphere (HEPA) and lightning initiation

Ashot Chilingarian[1]

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The newly emerging field of high- energy physics in the atmosphere involves measuring as many environmental parameters as possible, such as particle fluxes, electric-field disturbances, radio emissions from the thunderclouds, and meteorological environments. The bulk of information on particle fluxes correlated with thunderstorms can be used to better understand the electrical structure of thunderclouds. Only very specific electric configuration of the lower part of the cloud can support the sustainable acceleration of the electrons. The monitoring of particle fluxes, electric fields and meteorological condition during thunderstorms on Aragats Mountain in Armenia, allows establishing relationship of the particle fluxes to the electrical structure of thunderclouds and to the enigmatic lightning initiation. Measuring the intensity and energy spectra of the particle beams from the thunderclouds (the so-called Thunderstorm Ground Enhancements – TGEs) we can estimate the electric field within lower dipole in the thundercloud. Recent observations of hundreds of the TGEs provide an extensive source for the development of models of particle acceleration in the thunderclouds, as well as- thundercloud electrification. The well-known effect of the TGE dynamics is the abrupt termination of the particle flux by the lightning flash. With new precise electronics, we can see that particle flux decline occurred simultaneously with the rearranging of the charge centers in the cloud. The analysis of the TGE energy spectra before and after the lightning demonstrates that intense high-energy part of the TGE energy spectra disappeared just after lightning stroke. Thus, particle fluxes can provide enough ionization to play a significant role in the unleashing of the lightning flash.

One from numerous randomly emerging TGEs in the thundercloud open path to the lightning leader!

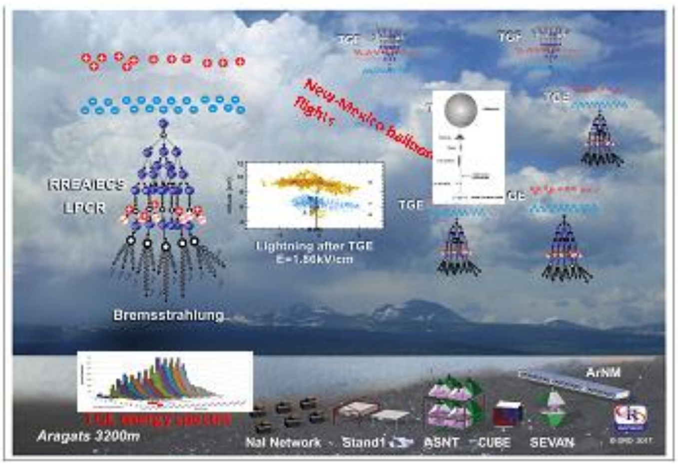

Figure 1. Electrification of the Thundercloud. The emerging electromagnetic avalanches opened path to the lightning leaders

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Spectrograph for investigation of the solar activity in navigation bands and its application for investigation of the impact on GNSS measurement

Pavel Kovář[1]

[1] Faculty of Electrical Engineering, Czech Technical University in Prague, Czechia

The current radio navigation and radio navigation systems are designed to be able to reliably operate in the presence of standard noise background. The quiet Sun radiation is one of the main sources of the radio noise. The problems can be caused by Sun radio bursts that increase the radio emission of up to 40 or 50 dB for several minutes or tens of minutes. Their occurrence is very sparse and random. The contribution will describe Sun spectrometer developed in the frame of CRREAT project for Sun radio emission monitoring as well as a planned experiments. The SDR is based on the direct conversion receiver of bandwidth 250 MHz. The signal processing is configured to the FPGA that calculates energy spectra of the signal in real time parallel for all frequency bins. The imperfections of the direct conversion receiver are compensated by the feedback loops, that compensates DC offsets of both I and Q branches, and amplitude and phase unbalance. The Sun spectrometer will use Solar telescope antenna of Astronomical Institute of CAS. The measurement will be correlated with GNSS scintillation and TEC monitoring station installed in Milešovka as well as with the radiation detectors of the CRREAT partners.

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Online lightning current monitoring in downconductors

Jan Mikeš[1], Ondřej Hanuš[1], Jakub Kákona[1]

[1] Faculty of Electrical Engineering, Czech Technical University in Prague, Czechia

Most commercially available lightning detection counters do not provide real-time information about situations when the object is struck by lightning. These are often only passive systems that require direct service of their operator. If they allow data transfer, then they are connected to internal wiring. We presents ways to carry out wireless monitoring of lightning strikes on buildings and to deal with their impact on lightning conductors. The purpose of the newly designed wireless lightning detection counter is to provide information on lightning strokes both at private and commercial objects in real time.

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Radio localization and mapping of lightning with high spatial and time resolution

Jakub Kákona[1], Jan Mikeš[1], Pavel Kovář[1]

[1] Faculty of Electrical Engineering, Czech Technical University in Prague, Czechia

The lightning mapping radio systems currently have significant capabilities to reconstruct lightning as a cloud of points. Unfortunately, the systems have reduced resolution for intra-cloud movement of charges at the very beginning of lightning formation. Our idea is to replace the maximum power per time window radio mapping method. By a more sophisticated detection and mapping algorithm which allows describing a lightning with vectors of charges movement instead of cloud of points.

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Telemetry system for stratospheric balloon

Pavel Puričer[1]

[1] Faculty of Electrical Engineering, Czech Technical University in Prague, Czechia

The contribution presents long-range telemetry system for tracking of the stratospheric balloons developed for supporting the CRREAT team. The system is based on the Internet of Things IoT radio transceivers that were reprogrammed to the extremely long-range communication that was reached by the optimization of the noise bandwidth of the receiver. The communication system uses industrial, scientific and medical (ISM) radio band 846 MHz. The transmitted power does not exceed 0,5 W.

The system was tested during FIK2 balloon experiment in March 2017.

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TARANIS - a satellite for the study of TLEs and TGFs

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TARANIS is a French satellite dedicated to the study of Transient Luminous Events (TLEs) and Terrestrial Gamma-ray Flashes (TGFs). By mid 2019, TARANIS will be operating in space and will provide: combined Nadir observations of TLEs and TGFs, high resolution measurements of energetic electron beams, and high resolution wave field measurements from DC up to 35 MHz. The measured data will be distributed to the atmospheric electricity community through the TARANIS Scientific Mission Center (CMS-T). The TARANIS payload, the strategy adopted to maximize the scientific return of the mission, and the present status of the mission will be presented and discussed.

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Daytime Tweek Atmospherics Originating from European North Atlantic Winter Thunderstorms

O. Santolik[1,2] and I. Kolmasova[1,2]

[1] Institute of Atmospheric Physics of the CAS, Prague, Czechia
[2] Faculty of Mathematics and Physics, Charles University, Prague, Czechia

We present first results of propagation analysis of unusual daytime tweek atmospherics originating from strong thunderstorms which occurred during winter months 2015 in the North Atlantic region. Using newly developed analysis techniques for 3-component electromagnetic measurements we are able to determine the source azimuth and to attribute these rare atmospherics to both positive and negative lightning strokes in northern Europe. We consistently find unusually large heights of the reflective ionospheric layer which are probably linked to low fluxes of solar X rays and which make the dayside sub-ionospheric propagation possible. Although the atmospherics are linearly polarized, their dispersed parts exhibit left handed polarization, consistent with the anticipated continuous escape of the right-hand polarized power to the outer space in the form of whistlers.

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Multi-instrument observations of transient luminous events associated with a small-scale winter thunderstorm occurring in the southwest of Czechia

I. Kolmasova[1,2], O. Santolik[1,2], P. Spurny[3], J. Borovicka[3], J. Mlynarczyk[4], M. Popek[1], R. Lan[1], L. Uhlir[1], G. Diendorfer[5], and R. Slosiar[6]

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[3] Astronomical Institute CAS, Ondrejov, Czechia
[4] Department of Electronics, AGH University of Science and Technology, Krakow, Poland
[5] OVE Service GmbH, Dept. ALDIS, Vienna, Austria
[6] SOSA (Slovak Organization for Space Activities), Slovakia

We present observations of transient luminous events (TLEs) produced by a small-scale winter thunderstorm which occurred on 2 April 2017 in the southwest of Czechia. Elves, sprites and associated positive lightning strokes have been simultaneously recorded by different observational techniques. Optical data include video recordings of TLEs from Nydek (Czechia) and data recorded by high time-resolution photometers at Primda and Kocelovice stations (Czechia) which measured the all-sky brightness originating from lightning return strokes. Electromagnetic data sets include 3-component VLF measurements conducted in Rustrel (France), 2-component ELF measurements recorded at the Hylaty station (Poland) and intensity variations of a VLF transmitter (DHO 38, Rhauderfehn, Germany) recorded in Bojnice (Slovakia). Optical and electromagnetic data are completed by positions and peak currents of all strokes recorded during the observed thunderstorm by the EUCLID lightning detection network. We focus our analysis on positive lightning discharges with high peak currents and we compare properties of those which produce TLE with properties of discharges for which TLE was not detected.

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The LSBB URL, a low background noise underground facility for interdisciplinary science and technology

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The LSBB, low-noise underground laboratory of Rustrel - Country of Apt Luberon (France) derives from the decommissioning of the underground lauching-control post of the strategic missile group of the French nuclear dissuasive force located on the plateau of Albion until 1996. The conversion led to the creation of a worldwide unique laboratory for sustainable development of interdisciplinary knowledges.

The LSBB results on the synergy of a hardened fully equipped infrastructure within an area with very low anthropogenic perturbations, and a clean geological, geophysical, electromagnetic and hydrogeological environment. This association allows multi-disciplinary research and development and multi-disciplinary observatory considering - Subterranean water around the Mediterranean - Contemporary and Cold War history - The characterization of seismic, acoustic and electromagnetic wave fields propagating in the Earth system - The exploration of the physical, mechanical, geological properties of rocks - The interactions of the cosmic radiation with the Earth - The measurement and exploration of gravitational waves - The metrology and high sensitivity instrumentation - The life and biology in rocks - The high electroencephalography in the field of neurodegenerative diseases.

The integration of the infrastructure and its development potential in the context of this geological, hydrogeological and anthropogenic environment makes the LSBB a multi-scale, low noise laboratory unique in the world, a unifying space by the CNRS, the University of Paris. Avignon and the Pays de Vaucluse, Aix-Marseille University and University Nice - Sophia-Antipolis.The LSBB is open to interdisciplinary high-sensitivity experiments, observations and characterizations and to the development or creation of multidisciplinary technological platforms.

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Model of cloud electrification for the COSMO numerical weather prediction model

Zbyněk Sokol[1]

[1] Institute of Atmospheric Physics of the CAS, Prague, Czechia

The contribution will present the current state of the task to develop a Model of Cloud Electrification (MCE) including lightning parameterization and its inclusion into the COSMO numerical weather prediction model. The COSMO model is a non-hydrostatic high resolution model, which we use with two moment cloud microphysics. The MCE differs from similar models by its close relation to the COSMO microphysics and dynamics. The development of hydrometeor charges is an integral part of the driving COSMO model. In the presentation, I will describe the MCE in details.

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Application of the Model of Cloud Electrification (MCE)

Jana Minářová[1]

[1] Institute of Atmospheric Physics of the CAS, Prague, Czechia

A 3D Model of Cloud Electrification (MCE) with 2-moment microphysics has been developed and implemented into the COSMO numerical weather prediction model. In case of idealized thundercloud, the model reproduces the electrification and the structure of the charge in the cloud. In the presentation, I will show the application of MCE on the idealized thundercloud and likely on real data from 2016.

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Closed discussions with SAC on 21st and 22nd December 2017

Date: 21st December, 2017
Location: Institute of Atmospheric Physics of the CAS

1. **EDNA and balloon flights (9:00 -10.45)**
   - Actions:
     - European Dosimetry Network onboard Aircraft - Technical description of the database, routine use
     - AIRDOS, Liulin and installation of other active dosimeters aboard aircraft
     - Installation of TLDs (test of appropriate TLD material, 3D print of TLD boxes)
     - Paper: Review of radiation exposure sources to passenger and crew members
     - Other: Spectrometers for high-mountain observatories, MC Simulations, ...
   - Task leader: Ondřej Ploc
   - Members: Francois Trompier, Eric Benton, Ondřej Štursa, Iva Ambrožová, Dagmar Peksová, Martin Kákona, Marek Sommer, Václav Štěpán

2. **Satellites (9:00-10:45)**
   - Actions:
     - List of Satellite experiment opportunities (AIST, MTR3, TARANIS …)
     - CZENDA - on ground preparation, project for HIMAC
   - Task leader: Guenther Reitz
   - Members: V. Shurshakov, O. Ivanova, E. Benton, I. Ambrožová, C. Granja, M. Kákona, O. Ploc, I. Kolmašová, O. Santolik, J. Minarova

Coffee Break 10:45 to 11:00

3. **SEVAN (11:00-12:45)**
   - Actions:
     - Actual situation of SEVAN at Milesovka
     - Future plan for SEVAN at Milešovka
   - Task leader: Ronald Langer
   - Members: Ashot Chilingarian, Zbyněk Sokol, Petr Pešice, Martin Kákona, Guenther Reitz

4. **Lightning and cloud electrification (11.00-12:45)**
   - Actions:
     - Modeling cloud electrification - next steps
     - Measurement of electromagnetic signals related to lightning initiation
     - Future measurements of lightning initiation combining electromagnetic, SEVAN and cloud profiler data
     - Radio localization of lightning strokes
   - Task leader: I. Kolmasova, Z. Sokol
   - Members: J. Kakona, P. Kovar, J. Mikes, D. Peksová, J. Šlegl, Z. Sokol, O. Ploc, O. Santolík, J. Minarova

Short Reports from the different Groups 12:45-13:45 followed by Lunch @ Koliba

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Date: 22nd December, 2017, 9:00-12.00
Location: Department of Radiation Dosimetry, Nuclear Physics Institute of the CAS v.v.i.

5. New common project for SEVAN network

- Actions:
  - Preparation of the proposal (H2020, JINR, …)
  - Task leader: Ashot Chilingarian
- Members: M. Kákona, O. Ploc, R. Langer, K. Kudela, N. Nikolova; G. Reitz, E. Benton

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CRREAT Objectives

Definition of project research objectives

1. **To deepen knowledge about the relation between the atmospheric phenomena and ionising radiation (IR).**
2. **To clarify phenomena causing variations of the secondary cosmic particles (SCP) in the atmosphere.**

The objectives are complementary. Thus a partial accomplishment of one of the objectives should contribute to the accomplishment of the other.

Objective 1 will be achieved if we will be able to prove a currently not so clearly demonstrated connection between at least one atmospheric phenomenon and ionising radiation. Such a connection may include the detection of ionising radiation generated by an atmospheric discharge or lightning generation triggered by a secondary cosmic particle shower.

Objective 2 will be achieved if we prove an effect of at least one newly identified atmospheric parameter on the detection of SCP or significantly improve the understanding of an effect of a previously identified atmospheric parameter on the detection of SCP.

The acquired knowledge will help to improve the precision of aircraft crew dosimetry, cosmic weather modeling, electromagnetic signal atmospheric propagation modeling, could enable prediction of lightning occurrence and will bring understanding to yet unexplained atmospheric phenomena.

Namely, it will include following findings and phenomena:

1. Finding of relationships between radiation phenomena in the atmosphere and CR particles.
2. Description and understanding of causes of quasi-periodic and irregular phenomena in SCP measured with high time resolution.
3. Understanding of lightning discharge initiation.
4. Understanding the influence of radiation phenomena in the atmosphere on the accuracy of satellite navigation systems and interference in the L, S and C radio-frequency bands used for satellite navigation.

The project outcomes, mainly those investigating (a) the relationship between the storm activity and CR, (b) changes in aircraft radiation doses connected with short-term variations in the atmosphere, mainly lightning, (c) description and understanding of the lightning initiation process by monitoring the vertical hydrometeor profile and electric field modeling are all potentially applicable in other fields: thunderstorms and lightning in particular pose a great danger not only to aviation, but to general population, electricity distribution, fire safety, etc.

Research activities and methods

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Specific research objectives and methods towards their achievement

The following text has structure shown hereunder:

Objective

***Sub-objective** (SO)*

***Research activity** (RA)*

***Key methodical approach** (KMA)*

Objective 1 - To deepen knowledge about the relation between the atmospheric phenomena and ionising radiation (IR).

SO1.1 **Finding suitable methods for detection and dosimetry of ionising radiation generated by atmospheric discharges.**

Both the detection of ionising radiation with a proof of its origin in lightning and its dosimetry pose a problem due to the high energy of the gamma radiation (up to 40 MeV). Computer simulations show a possible very high dose of radiation around 100 mSv [Dwyer et al. 2010] that needs to be confirmed by measurement. Research activities RA1.1.1 till RA1.1.4. will lead to solutions of these problems.

RA1.1.1 Measuring the ionising radiation generated by an atmospheric discharge.
KMA01, KMA02, KMA03, KMA04, KMA05 and *KMA06* will be used to address this RA.

RA1.1.2 Lightning localization.
KMA07, KMA08, KMA09 and *KMA40* will be used to address this RA.

RA1.1.3 Dosimetry of the ionising radiation generated by an atmospheric discharge.
KMA10 and *KMA11* will be used to address this RA.

RA1.1.4 Coincidence measurement of the ionising radiation and lightning.
KMA12 will be used to address this RA.

SO1.2 **To find a relation between the radiation phenomena in the atmosphere and the accuracy and availability of satellite navigation systems.**

Satellite navigation systems such as GNSS are becoming critical infrastructure. Dependence on their services is evident in the fields of human and property security, function of power and telecommunication networks or air, ship and land transportation.

The function, accuracy and availability of the satellite navigation systems is influenced by a number of technical, physical and organisational factors. Atmospheric phenomena represent one of the key factors influencing the signal transmission and causing its interference. In the context of the sub-objective, the impacts of the radiation phenomena in the atmosphere on the GNSS and interferences in the L, S and C bands (which are used by GNSS) will be investigated.

Specifically, we will study the relationship between the dosimetric measurement of the radiation phenomena in the atmosphere and signal errors and the availability of GNSS receivers. Our scientific goal is to better understand what influence radiation has on the operation of satellite navigation systems. We see the scientific contribution in using the most modern dosimetric methods in combination with multi-

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frequency GNSS measurement. The research will help to better understand the errors in GNSS systems, thus improving the security of air and land transportation.

We will study, interference the atmospheric radiation phenomena in L, S and C radio bands. The scientific goal is to better understand the mechanisms of interference emergence in the studied bands. The scientific outcomes will be achieved using the combination of dosimetric measurements performed by the most modern methods and broadband measurement of the radio interference. The research will help to understand the mechanisms of interference emanation and will help to develop its statistical models. The outcomes may be practically applied in optimising channel coding methods and in modulation methods in digital radio communication.

RA1.2.1 Analysis and data processing from the radiation sensors and GNSS receivers.
KMA01 and *KMA13* will be used to address this RA.

RA1.2.2 Implementation of atmospheric radiation-induced GNSS errors' model.
RA1.2.1, KMA14 and *KMA15* will be used to address this RA.

RA1.2.3 Search for methods to increase the accuracy and availability of GNSS based on radiation phenomena models.
KMA15 and *RA1.2.4* will be used to address this RA.

RA1.2.4 Influence of the atmospheric radiation phenomena on the radio-frequency interference in L, S and C bands.
KMA16 will be used to address this RA.

RA1.2.5 Methods for radiation sensors and software receiver data processing and analysis.
KMA01 and *KMA16* will be used to address this RA.

RA1.2.6 Implementation of the model of interference caused by the radiation phenomena in the atmosphere.
KMA01 and *KMA16* will be used to address this RA.

RA1.2.7 Search for methods to increase the availability and reliability of radio communication services based on improved interference models.
KMA01 and *KMA16* will be used to address this RA.

SO1.3 **Discharge characterisation based on the analysis of electromagnetic signals generated by lightning**

Lightning discharges generate electromagnetic signals in a wide range of frequencies from a few hertz up to hundreds of megahertz. A detailed analysis of these electromagnetic signals makes it possible to study the characteristics of lightning discharges from a safe distance of tens to hundreds of kilometers.

It also enables the investigation of processes taking place inside the storm cloud. These are very difficult to measure in-situ and optical observations are almost impossible. Two of the least explained phenomena occurring inside the storm cloud are lightning discharge formation and terrestrial gamma ray emergence. So-called runaway electrons, which are products of cosmic ray collisions with the atmosphere, and which are accelerated by a strong magnetic field generated by a storm cloud, probably play a key role in both of the above-mentioned processes. The initial phase of a discharge and its stepwise propagation of in the thundercloud can be monitored by measuring the electromagnetic signals generated by the progressing discharge.

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The frequency of emitted signals in order of MHz corresponds to the distance of current channels inside the cloud, which corresponds to the propagation steps of the in-cloud lightning discharge during its initial phase.

As a part of the project, we will measure the magnetic signals generated by lightning discharges with a wide spectrum magnetic aerials positioned on the observatory or using a mobile version situated in the automobile that will track the movement of the studied storm. The aerial will be in both cases connected to an analyser, which will process the signal. Thanks to our involvement in the satellite project TARANIS (https://taranis.cnes.fr/), after the satellite will be launched in 2018, we will have an opportunity to use data measured by an analyser developed by IAP CAS and placed on the TARANIS satellite together with other instruments. Thus we will be able to observe processes taking place inside the clouds both on the ground and from TARANIS orbit, whose polar orbit will have an altitude of 700 km.

RA1.3.1 Study of signals generated by processes taking place inside clouds during the lightning initiation phase
KMA18, KMA19 and *KMA20* will be used to address this RA.

RA1.3.2 Study of signal emitted by in-cloud discharges potentially generating TGF
KMA20, KMA21 and *KMA22* will be used to address this RA.

RA1.3.3 Effect of lightning of the accuracy and availability of GNSS
KMA07, KMA13 and *KMA15* will be used to address this RA.

***SO1.4* Clarification of the causes of lightning discharge initiation**

There exist theoretical prerequisites for atmospheric discharge initiation by means of cosmic rays. At the same time, there is a shortage of experimental data in this field. Therefore we will carry out measurements of cosmic rays in connection with other atmospheric characteristics like transmission of electromagnetic waves generated by lightning or cloud composition. We assume that these simultaneous measurements will help us to understand so far unexplained short-term phenomena in the atmosphere. We will examine two possible influences on the lightning initiation - the effect of cosmic ray and a physical microstructure of the thundercloud and, possibly, a correlation between them.

RA1.4.1 Research into lighting discharge initiation mediated by hydrometeors
KMA23 and *KMA24* will be used to address this RA.

RA1.4.2 Research into lightning discharge initiation mediated by cosmic rays
KMA25, KMA02, KMA03, KMA07, KMA08, KMA09, KMA26 and *KMA27* will be used to address this RA.

RA1.4.3 Developing a mathematical model describing a formation and a development of an electric field in cloud cower and a lightning formation (electrification model, ME)
KMA28, KMA29, KMA30 and *KMA31* will be used to address this RA.

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Objective 2 - To clarify the phenomena causing variations of secondary cosmic particles (SCP) in the atmosphere.

***SO2.1* Clarification of the influence of atmospheric state on the SCP detection**

Different components of CR have different dependency on the atmospheric conditions, for example on water content in various states. The study of atmospheric influences can help to cleanse the data of such disruptive effects and help to improve the accuracy of CR primary flux measurements. At the same time, understanding the influence of atmosphere will help us refine the other methods for detecting ionising radiation, which will be used in this project.

RA2.1.1 Research into the influence of amount of water in the atmosphere (AWA) on SCP detection
KMA32, KMA33, KMA01, KMA04 and *KMA34* will be used to address this RA.

RA2.1.2 Compensation of atmospheric influence by performing measurements in different altitudes.
*KMA35, KMA01, KMA04, KMA36, KMA41*and *KMA42* will be used to address this RA.

***SO2.2* Understanding of quasi-periodic and erratic phenomena in CR**

Current measurements using neutron monitors (NM) and muon detectors (MD) make it possible to study short-term variations of cosmic ray (CR) secondary components as well. Our project will make use of both presently existing data from selected NM and MD (mainly from the mountain laboratory located on Lomnický peak; 1 min resolution) and data collected during the course of the project (with better resolution) in order to study (a) the relationship with atmospheric conditions in the place of measurement, (b) possible short-term changes during atmospheric discharges detected by NM or MD in the vicinity, and (c) variation of primary CR flux. We assume the use of data from the European lightning measurement network and from the in-situ measurements of the electric field near detectors.

Apart from continuing the analysis of long time series of CR measurements by neutron monitors and muon detectors and analysis of the relationship between the change in CR intensity and external physical parameters (solar, interplanetary, geomagnetic activity), we will investigate a possible connection with atmospheric characteristics in the place of observation. We will study in detail the occurrence of short-term quasi-periodic variations (with period shorter than 1 day) and changes to the flux of secondary CR on the order of minutes to tenths of minutes. Measurements during the storm activities near the CR detector will be precisely analysed. Methods including spectral analysis of time series, wavelet analysis and modeling will be used.

RA2.2.1 Search for quasi-periodic and erratic phenomena in the cosmic ray flux detected with high time resolution
KMA04, KMA36 and *KMA37* will be used to address this RA.

RA2.2.2 Research into mixed radiation fields generated by cosmic rays using new detection and dosimetric methods
*KMA04, KMA38, KMA39, KMA41*and *KMA42* will be used to address this RA.

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Key methodical approaches:

KMA01 Stationary long-term measurement of ionising radiation in Milešovka using SEVAN apparatus.

KMA02 Stationary short-term field measurements using vehicles during storms.

KMA03 Dynamical short-term measurement of ionising radiation using UAV during storms.

KMA04 Dynamical long-term measurement of ionising radiation using airplanes, the use of the European network of dosimetric measurements with EDNA airplanes.

KMA05 Response compensation for various types of used detectors and spatial configuration of measurements using Monte Carlo simulations.

KMA06 Dosimeter testing in laboratory with current and voltage pulse generators.

KMA07 Lightning localisation using an existing lightning database.

KMA08 Building a radio network for lightning detection and localisation, based on TDoA principle.

KMA09 Lightning detector network synchronisation with GNSS using 'common-view' method.

KMA10 Evaluation of detector response to TGF in terms of absorbed dose and ambient dose equivalent.

KMA11 Evaluation of neutron detector response to TNF in terms of absorbed dose and ambient dose equivalent.

KMA12 Alignment of lightning' detections with time recordings of radiation detection.

KMA13 Stationary long-term measurement of GNSS signal in Milešovka using multi-frequency GNSS receiver and a simultaneous measurement of radiation phenomena.

KMA14 Analysis of the influence of cosmic rays on the availability and accuracy of GNSS services, a search for methods to predict GNSS failures based on radiation measurements.

KMA15 modeling of GNSS receiver errors caused by cosmic rays.

KMA16 Stationary long-term measurement of interferences in L, S and C radio-frequency bands in Milešovka using software-defined receiver with a simultaneous measurement of radiation phenomena.

KMA18 Identification of lightning initialisation by searching for characteristic initiation pulse sequences and a study of such sequences.

KMA19 Time assignment of initialisation pulses, vertical size profiles of hydrometeors with time recordings of cosmic rays.

KMA20 Measurement of electromagnetic signals during storm activity using wide-spectrum magnetic aerials and their digitization.

KMA21 Identification of intra-cloud discharges with a potential to generate TGF based on the estimate of peak current.

KMA22 Time assignment of intra-cloud advancing discharge leaps to the TGF time recordings.

KMA23 Measurement of vertical size profile of hydrometeors in storm clouds using cloud profiler.

KMA24 Alignment of the measured vertical size profile of hydrometeors to electromagnetic signals emitted during the lightning discharge initialisation.

KMA25 Stationary long-term measurement of ionising radiation using a system for stationary correlative measurement of extensive showers of cosmic radiation (SCOMES).

KMA26 Time synchronisation of detected lightning with extensive showers of cosmic radiation.

KMA27 Laboratory measurement of artificial lightning discharges.

KMA28 Preparing the concept of ME model based on the literature reviews, constructing the model equation and preparation of computational algorithm.

KMA29 Linking the ME model with a numerical model COSMO and linking it with two-moment cloud microphysics, testing the model on simplified artificial data.

KMA30 Linking the ME with spectral bin cloud microphysics (SBM), testing on real data, eventually carrying out studies in order to tune the model equation including parameter values.

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KMA31 ME verification using the measured data.

KMA32 Using of 'Mrakoměr' cloud sensor to determine the AWA over the detection device.

KMA33 Optical observation and manual entry of cloudiness over the detection device.

KMA34 Time synchronisation of activities described in KMA32, KMA33, KMA01 and KMA04.

KMA35 Measurements carried out by satellites outside the atmosphere (TARANIS, BION-M2).

KMA36 Analysis of long-term SCP data measured by mountain observatories.

KMA37 Comparing the KMA04 and KMA36 and their statistical evaluation.

KMA38 Development of active dosimeters for measurements in mixed radiation fields.

KMA39 Comparative measurement with TEPC and passive LET dosimeters in terrestrial observatories, on board the aircraft and spacecraft.

KMA40 Discharge propagation monitoring using high-speed cameras.

KMA41 Calibration of dosimeters with relevant ionising radiation sources (radionuclide sources, heavy charged particles and reference fields of mixed ionising radiation).

KMA42 Use of computer simulations based on Monte Carlo method for modeling the propagation of ionising radiation through matter

Add *KMA03*, *KMA35*:
As a part of the project we will test both already existing and new detectors for ionising radiation (semiconductor and scintillation detectors mainly) suitable to be incorporated into UAVs and satellites. Different requirements are imposed on these detectors. Sensitivity to particles over a considerable range of energies and types is required. On the other hand, low weight and volume are required as well, in order that UAVs will be able to take them to high altitudes.

Add *RA1.1.3*:
Atmospheric physics at high energies is a newly emerging field. Earth's artificial satellites have measured so-called TGFs. According to simulations (Dwyer et al. 2010), TGFs may be able to produce single doses up to 0.1 Sv onboard aircraft. Simulations predict measurable doses from TGF and TNF at altitudes of several kilometres above the surface of the Earth. However, authors of these simulations warn that it is necessary to obtain relevant experimental data. In order to detect gamma flashes on board the aircraft, new dosimeter development is required due to small cross section of materials that come into consideration for application in aircraft dosimetry.

Add *KMA20*, *KMA23*:
Simultaneous measurements of electromagnetic signals and vertical size profiles of hydrometeors in storm clouds using Cloud profiler device at the moment of lightning initiation has not so far been published anywhere and therefore such findings could considerably help in understanding the formation of lightning discharges. Furthermore, we will develop a cloud electrification module for a numerical model of weather forecasting with explicit cloud microphysics. The module will explicitly: (i) model the development of electric charges produced by different types of hydrometeor, (ii) model the formation and development of positive and negative ions, (iii) calculate the electric field intensity development and (iv) model electric discharges inside a cloud.

Add *RA1.4.2*:
The processes of lightning initiation in the atmosphere are still unclear. There exist hypotheses that assume that the lightning initiation is caused by cosmic rays (Petersen et al. 2008). Such hypotheses are not currently supported by experimental data.

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