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Altitude profile of atmospheric radiation in the Arctic region obtained during a scientific balloon flight with MDU-1 Liulin

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Measurements of the natural radiation background, specifically in the upper troposphere and low stratosphere, are important in order to compare and eventually inter-calibrate different experimental set-ups, as well as to provide a reliable basis for improving the existing models related to the environmental radiation in the Earth's atmosphere. Here, we report results from a new zero-pressure stratospheric balloon flight in the frame of the HEMERA-2 mission, obtained by measurements performed with a small portable device, (MDU)-1 Liulin. We derived the altitude profile of the atmospheric radiation in the Arctic region, namely in between Esrange Kiruna, Sweden and Rovaniemi, Finland. The preliminary analysis shows a good agreement between the measurements and Oulu models for atmospheric ionization and exposure to radiation.

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1. Introduction

High-energy particles penetrating the Earth's atmosphere, namely cosmic rays (CRs), determine the complex radiation field, specifically in the stratosphere by induced complicated nuclear-meson-electromagnetic cascades, which are particle showers produced by a series of consecutive interactions of the primary particle with atmospheric constituents, yielding large amounts of secondaries. [1, 2]. The produced secondaries dissipate energy mostly by ionization of the ambient air, therefore the CRs are the main source of ionization in the middle atmosphere [3–5].

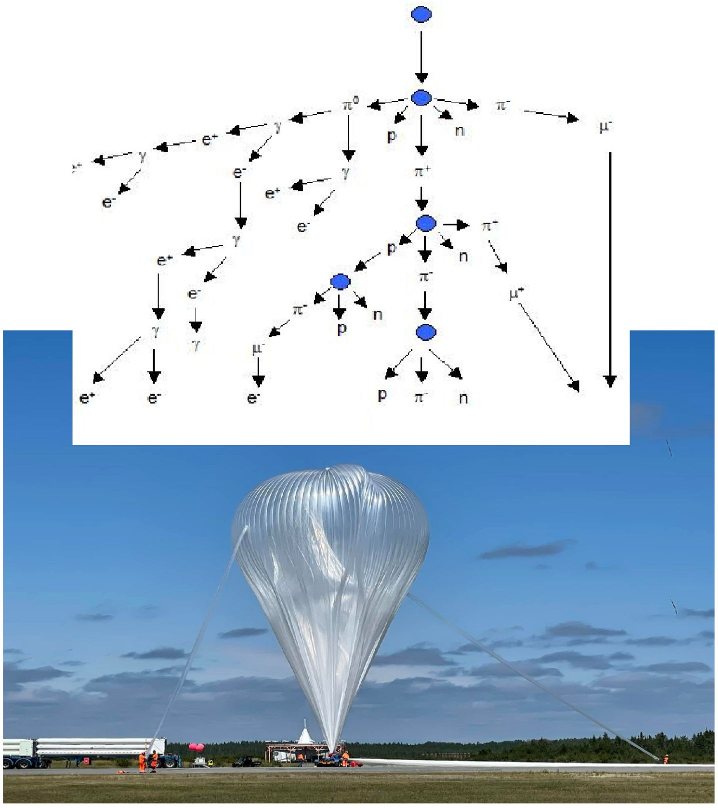

Figure 1: Sketch of measurements of EAS caused complex radiation field measured by a scientific balloon.

Precipitating high-energy charged particles play an important role in the processes related to the physics and chemistry of the atmosphere [6] and space weather effects, particularly the radiation field at flight altitudes [7]. Therefore, methodological measurements of the natural radiation at various conditions, altitudes and with different devices, specifically in the stratosphere allow, in one hand to inter-calibrate different experiments, and on the other hand, to provide the necessary background to validate and improve the corresponding models related to the effects of precipitating particles [8, 9].

Here, we present recent measurements with mobile dosimetric unit MDU-1 Liulin of the altitude profile of atmospheric radiation field performed during the B-TRUE experiment flown on a HEMERA-2 scientific balloon flight on 11 September 2021.

2. MDU-1 Liulin and HEMERA-2 mission

Precise measurements of the altitude profile of the complex radiation field in the stratosphere and troposphere, specifically at aviation altitudes is a rather complicated task [10]. Scientific balloon flight gives such a possibility with a convenient device Fig. 1. Zero-pressure balloons for heavy payloads can be flown at altitudes up to about 40 km, with a typical ascending speed of about several m/s. Therefore, they are suitable for the registration of precipitating energetic particles and can serve for the assessment of the altitude profile of the complex radiation field in the troposphere and stratosphere. The HEMERA mission represents a research infrastructure, encompassing different teams in the field of astrophysics, atmospheric physics and chemistry, climate research, biology, space research and technology [11].

The HEMERA-2 zero-pressure stratospheric balloon was flown on 11 of September 2021 from the Esrange base of the Swedish Space Corporation, near Kiruna, with MDU-1 Liulin, in the frame of the B-TRUE experiment, aiming to obtain measurements of precipitating relativistic electrons in the high Arctic atmosphere [12, 13] and eventually validate recent models [14, 15] Fig.2.

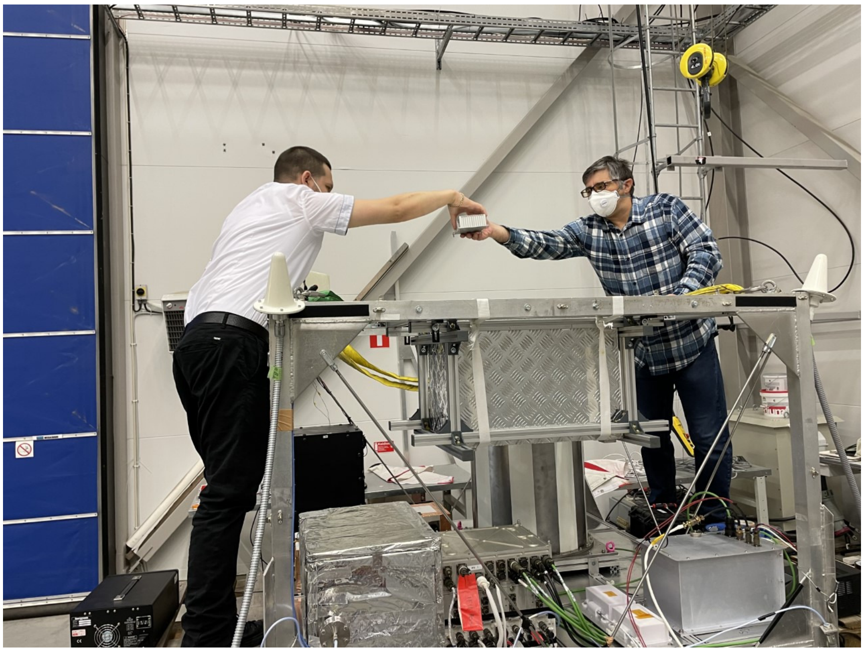

Figure 2: Mounting of the MDU-1 Liulin in the gondola of HEMERA-2 scientific balloon mission by A. Binios (left) and A. Mishev (right). Photo by E. Turunen.

Mobile dosimetric unit MDU-1 Liulin is based on a silicon semiconductor detector, measuring the deposited energy and the amount of interacting particles, that is dose rate in silicon and particle flux. MDU Liulin is widely used for measurements of the exposure to radiation (absorbed dose) in space missions, and aviation [16]. Liulin-type detectors were successfully used and compared with other devices at aviation altitudes [17]. Besides, the team possesses experience with the operation of the device [18, 19]. In order to provide optimal temperature conditions for proper operation of the MDU-1 Liulin, a thermally insulated aluminium box was constructed, using a standard manufactured box with added 20 cm styrofoam insulation (see Fig. 3).

Figure 3: MDU-1 Liulin in the insulated box, near to the facility of SGO. Photo by A. Mishev.

3. Results

The HEMERA-2 was launched at 11 September 2021. Here we present, the altitude profile of absorbed dose as the 10 min. running mean (Fig. 4), the full details are given in [20].

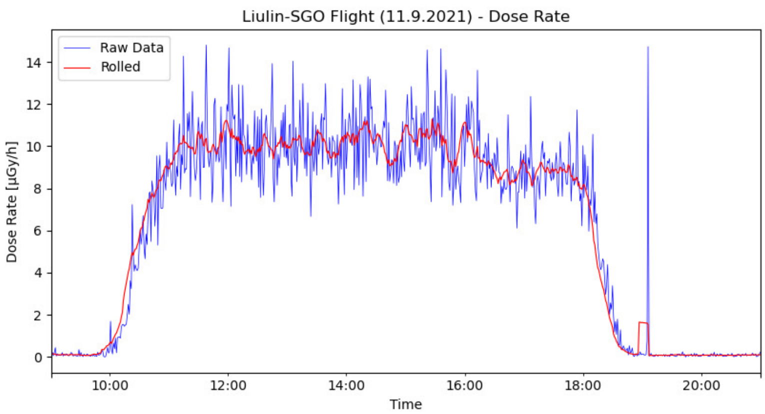

Figure 4: Altitude profile of the exposure to radiation derived with MDU-1 Liulin in the frame of HEMERA-2 mission.

For the analysis we employed a newly developed magnetospheric computation tool OTSO [21] employing a combination of the IGRF geomagnetic model as the internal field model e.g. [22] and the e.g. Tsyganenko 89 model as the external field [23], explicitly considering the measured K_p index during the flight. We emphasize that this combination of models provides very good precision and straightforward computation of the rigidity cut-offs[24, 25].

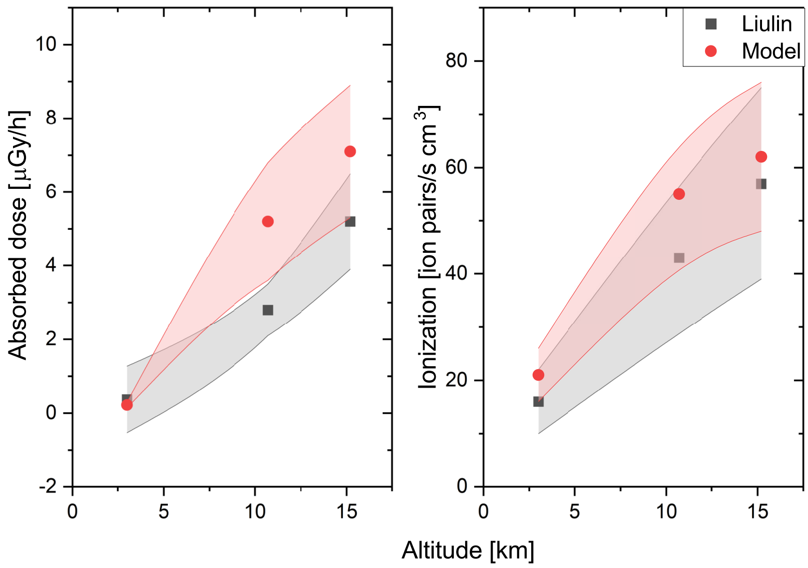

Figure 5: Comparison between MDU-1 Liulin measurements with Oulu exposure and atmospheric ionization models as denoted in the legend. The 95 % confidence limit is given with gray filled area for Liulin and red filled are for the model(s), respectively.

The analysis shows good agreement with Oulu radiation models [26, 27]. We emphasize, that the relatively fast balloon ascent, specifically in the low atmosphere resulted in significant deviation(s), up to altitudes of about 3–5 km above sea level. The difference between the measurements and the model in the low atmosphere are due to contribution of natural radiation background at altitudes up to 5 km above sea level (e.g. Radon and its daughter products), whilst the model [27] accounts for the contribution of CRs solely. Accordingly, at greater altitudes, because of the reduced sensitivity of MDU-1 Liluin to secondary neutrons, the main contributor to the exposure to radiation at flight altitudes [28, 29], the model provides greater values. Note, that the absorbed dose converted straightforwardly to ion pair production has a considerably greater agreement, than the dose. The barely present Regener-Pfotzer maximum [30] of the absorbed dose is most-likely due to the low-rigidity cut-off of the region under study, leading to dominant low-energy contribution of the GCRs.

4. Conclusions

Here, we reported results of measurements of the altitude profile of the natural radiation in the Arctic atmosphere derived with MDU-1 Liulin during a stratospheric zero pressure balloon flight under the HEMERA-2 mission. According to the data analysis, comparison with other models and measurements, one can conclude that MDU-1 Liulin is suitable for measurements of the complex radiation field in the troposphere and stratosphere, yet for more precise results a tissue equivalent equipment shall be used. Flights in the Arctic with such type of devices are specifically important, because there is a lack of systematic studies in this region. The obtained data is useful to deepen our understanding of aviation dosimetry, atmospheric and space physics.

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