SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: CA15211
STSM title: Assessment of the effect of a potential ’worst-case scenario’ on atmospheric electricity
STSM start and end date: 18/02/2019 to 23/02/2019
Grantee name: Ilya Usoskin

PURPOSE OF THE STSM:

(max.200 words)

The main scientific purpose of the STSM was to assess the upper bound of the effect caused by a major (worst-case scenario) solar energetic particle event on the atmospheric conductivity and atmospheric electricity, being directly within the focus of the COST--15211 action.

Atmospheric electricity is driven, in particular, by air conductivity, which is governed by the level of ionization in the atmosphere and ion mobility. The slowly variable effect galactic cosmic rays (GCR) is well known, but sporadic solar eruptive events may occur on the Sun leading to acceleration of bulk of charged particles (mostly protons) to high energies of up to several GeV. The effect of such events, called solar particle events (SPEs), on atmospheric electricity is not studied in great detail and is based on isolated empirical studies. Here we proposed to study such events in their extreme (worst-case) scenario.

The aim of the proposed STSM was to assess a possible effect of an extreme ‘worst-case’ SPE on atmospheric conductivity and electricity and set up the range of possible solar energetic particle influence.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

(max.500 words)

The following work has been done during the STSM:

1) Parameters (energy spectrum, time profile, solar/heliospheric conditions) of the ‘worst-case’ scenario of SPE were fixed for modelling. Here we considered the background of galactic cosmic rays (GCR) corresponding to a moderate phase of the solar cycle (the modulation potential was set for 600 MV – see Gil et al., 2015). For the extreme SPE we considered a scenario for the strongest know event of the year 774 AD, as reconstructed by Mekhaldi et al. (2015). Moreover, we have considered the upper limit of the event integral strength to perform a conservative estimate. According to this scenario, the energy spectrum of SEPs was hard (similar to that of the strongest directly observed SPE of 23-feb-1956) and scaled up with a factor of 100.

2) Atmospheric ionization profiles were calculated for the selected scenario were calculated in the entire atmosphere (3D+time) using the CRAC-CRII model developed at the University of Oulu (Usoskin et al., 2010), updated for the upper atmospheric layers (0.001 – 1 hPa). The ionization rate due to GCR was calculated using the improved parameterization of the heavier (Z>1) species of cosmic-rays, recently

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developed by the University of Oulu (Koldobsky et al., 2019). Examples of the computed profiles of the atmospheric ionization are shown in Figure 1.

3) Atmospheric conductivity/resistance was computed using the CCM SOCOL (v. 2) model developed at PMOD and coupled to GEC during previous STSM. Ionospheric potential, conductivity, the effect of radon emission, were considered consistently by the model. The results are discussed in the next section of this report.

4) A schematic skeleton of a research paper about the results was prepared. However, additional studies need to be performed to finalize the results. This will be made later this year either remotely between the grantee and the host, or in the framework of another mission.

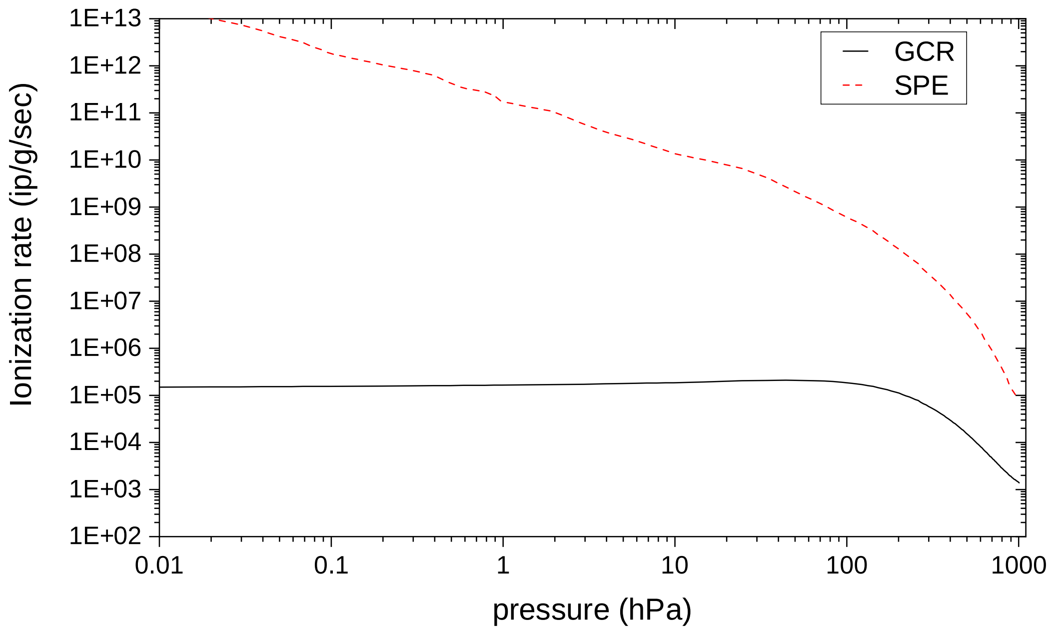

Figure 1. Ionization rate profiles in the polar atmosphere as functions of the barometric pressure, for GCR (solid black curve) and the worst-case SPE (red dashed curve).

DESCRIPTION OF THE MAIN RESULTS OBTAINED

(max.500 words)

During the STSM we have first computed the full 3D profile of the atmospheric ionization for the two scenarios: the quiet one (only GCR) and extreme one (GCR+SEP), using CRAC-CRII model. Next, using SOCOL model we calculated the atmospheric conductivity, considering, in addition to the outer-space radiation also terrestrial factors, affecting the conductivity, such as radon (Rn222) and aerosols. Then, the columnar atmospheric resistance was calculated, as well as the ionospheric potential in realistic conditions, including the actual orography. Finally, the global distribution of the vertical atmospheric current was obtained, as shown in Figures 2 and 3, for the two scenarios, respectively.

As one can see, during the quiet period (Figure 2), the current density is affected by several competing processes of roughly equal importance: the geomagnetic shielding of GCR (visible as the latitude gradient); orography (enhanced spots on the Antarctic Plateau and Himalaya); radon-222 emission (spots in Africa and Australia). The overall spatial variability of the vertical current is within a factor of two between roughly 1.5 and 3 pA/m^2.

On the other hand, the vertical current density during the extremely disturbed period (Figure 3) depicts much higher (up to a factor of 25) values and a different geographical pattern, where the most important is the latitudinal gradient, second is the orography, while near-ground radon-222 plays no important role. The variability over the Globe is up to 1.5-order of magnitude for the extreme scenario (from maximum of 3 to ~90 pA/m^2 in the Antarctic plateau region). The strongest enhancement of the vertical current is expected in Central Antarctica and Greenland, while it is only a few tens of percent in the equatorial region, because of the geomagnetic shielding and a relatively soft SEP energy spectrum.

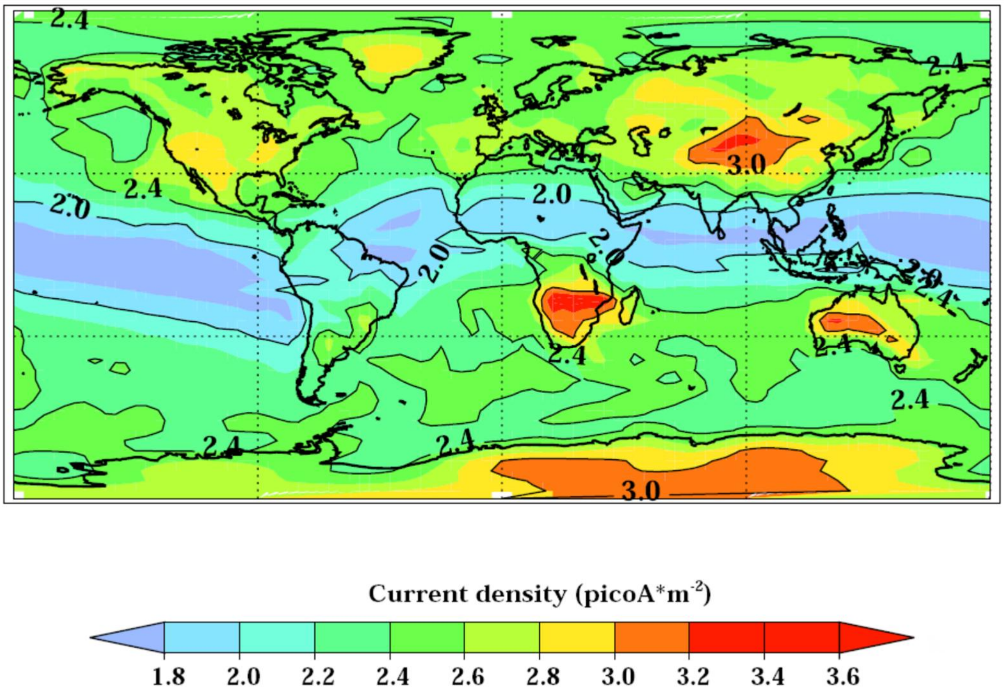

Figure 2. Map of the vertical current density distribution for the quiet scenario (GCR + Rn222 only)

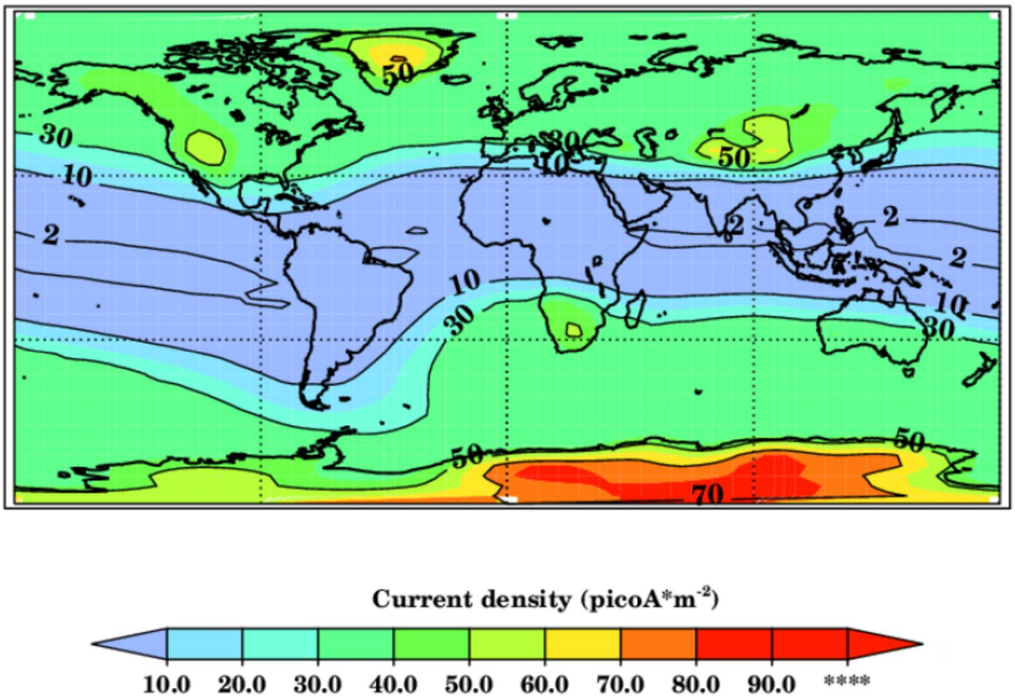

Figure 3. Map of the vertical current density distribution for the extreme scenario (GCR + Rn222 and the extreme SPE).

Therefore, the simulation implies that the atmospheric vertical current can be dramatically enhanced during an extreme solar event, particularly in high-elevated polar regions (Greenland and Antarctica). We note that only the effect of the increased ionization rate due to solar energetic particles is considered here, while other effects, such as the influence of a geomagnetic storm on the ionospheric potential, were neglected. Studies of the atmospheric and climatic impacts of this enhanced current lie beyond the scope of this STSM and will be performed later.

CONCLUSIONS AND SUMMARY

During this STSM all the proposed objectives were attained as planned:

- a scenario, based on a moderate solar-activity level and the strongest historically know SEP event of 774 AD, was set to evaluate the effect of an extreme (worst-case) SEP event on the global electric circuit;
- atmospheric ionization profiles for the selected scenarios were computed for the entire Earth's atmosphere using the CRAC-CRII model developed at the University of Oulu;
- atmospheric conductivity, columnar resistance and subsequently, the vertical electric current were subsequently calculated based on the ionization results;
- a map of the vertical atmospheric current global distribution was calculated;

As a result, the first quantitative assessment of the effect of an extreme SEP even on the atmospheric current has been made.

It is concluded that an extreme solar event (the worst-case SEP scenario) may lead to a dramatic (a factor of up to 30) increase of the vertical atmospheric current density, reaching ~90 pA/m^2 in high-elevated polar regions (Central Antarctica and Greenland), with only little enhancement in equatorial regions. This effect may impact other atmospheric and climatic properties, but a study of those impacts lies beyond the framework of this STSM and will be performed later.
A joint publication with be prepared by the teams, with an acknowledgement to the COST CA15211 action.

FUTURE COLLABORATIONS (if applicable)

The result of this STSM provide ground for further studies of possible effects of extreme solar events on the atmospheric and climatic patterns. This work will be done by the teams as a part of further collaboration, leading to several peer-review research publications and conference presentations, with acknowledgements to the COST CA15211 action.

REFERENCES

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