SCIENTIFIC RAPPORT

By the STSM

STSM title: Climate and atmospheric electricity

COST Action: CA15211

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3. STSM PERIOD: 4 September 2017 to 24 September 2017

Purpose of the STSM

The STSM aims at the study of the impact of GEC (Global Electrical Circuit) on climate using chemistry-climate model (CCM) SOCOL (model of the Host institution). The CCM SOCOL (tool for studies of SOlar Climate Ozone Links) has been developed in Switzerland (PMOD/WRC and IAC ETHZ) and used for the study of climate and ozone layer changes driven by different anthropogenic and natural forcing agents.

During this STSM we intended to extend CCM SOCOL by adding:

- The parameterization of the ionospheric potential (IP) developed by Mareev et al. [2014];
- Conductivity calculation module, and
- Dependence of the autoconversion rates in the clouds on the electrical field strength proposed by Harrison et al. [2015].

The extended model version should allow to study possible connections between climate and GEC under the influence of different climate forcing.

The aim of the STSM is directly related to the COST action addressing the connection of the atmospheric electricity and climate. This STSM is a part of the WG3 activity plan discussed during the meeting in Alexandropoulos in March 2017 (http://www.atmospheric-electricity-net.eu). The Host institution are represented by Eugene Rozanov (co-leader of WG3). The STSM plan was designed to solve overall goals of WG3 of the COST Action CA15211. The STSM shopuld enhance our understanding of the physical processes involved in the connection between atmospheric electricity and climate and will enhance the collaboration inside COST Action CA15211 community.

Description of the work carried out during the STSM

During the STSM the parameterization of the ionospheric potential (IP) described by Mareev et al. [2014] was incorporated into chemical-climate model (CCM) SOCOLv2 as an additional. After that we performed several 2-year long model experiments for the 2004-2005 period and analyzed the obtained behavior of the ionospheric potential in comparison with available data.

The next step was to incorporate the dependence of the cloud properties (i.e., autoconversion rate) on the B_y-component of interplanetary magnetic field by proposed by Lam and Tinsley [2015]. This step was aimed on the simulation of the Manusrov effect described by Lam et al. [2014] using our CCM SOCOL. It is first time when this effect is evaluated using climate model. For the analysis of the model output we applied the method identical to the approach proposed by Lam et al. [2014].

Then we carried out a substantial theoretical study to find a proper way to simulate atmospheric conductivity. Finally, we decided to use simple and well known equation (e.g., Lucas, 2010, equation N) describing the conductivity of the cloud and aerosol free atmosphere. This equation was incorporated into the SOCOL model and couple test model runs were carried out to check the results.

Except of the main goals of the work during this STSM I learned of how to modify and run climate models and, of course, I improved my knowledge in programing with FORTRAN, Shell Scripting and Matlab as well as the different data formats and the main methods of the data interpretation. I have learned a lot of new aspects of theory behind the atmospheric electricity and climate interaction.

Description of the main results obtained during the STSM

1. Ionospheric potential in CCM SOCOLv2.

The following parameterization of ionospheric potential Mareev et al. [2014] was incorporated into the chemical-climate model SOCOLv2:

$$\Delta V_{\mathrm{i}} = \frac{j_0 S H_0}{\sigma_0 S_{\mathrm{E}}} \exp\left(-\frac{z_{\mathrm{b}}}{H_0}\right)\left(1 - \exp\left(-\frac{\Delta z}{H_0}\right)\right)$$

Where, ΔV_i is the contribution into the IP (kV) from i-th model grid sell; J_0 is the magnitude of background electric current; S is the area of the layer covered by electrified cloud; H_0 is the characteristic vertical scale of the conductivity profile; σ_0 is the conductivity on the Earth surface; S_E is the area of the model grid sell; Δz is the thickness (in km) of electrified cloud; Z_b is the altitude of the cloud bottom (in km).

After the introduction of the IP module it is necessary to verify that the model cloud fields and calculated IP is correct. Figure 1 demonstrates the 2-year mean geographical distribution of cloud parameters (cloud top boundary, cloud bottom boundary and cloud amount) used for the ionospheric potential calculations and resulting dV_i.

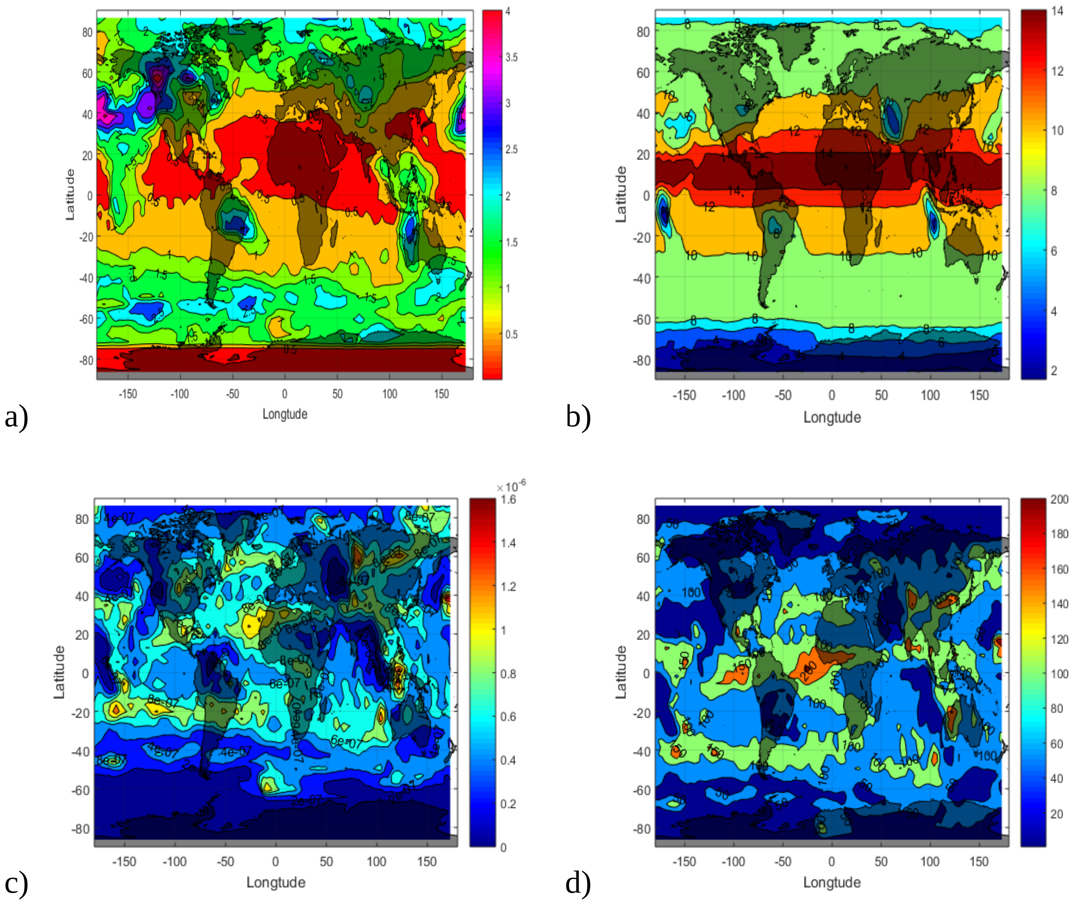
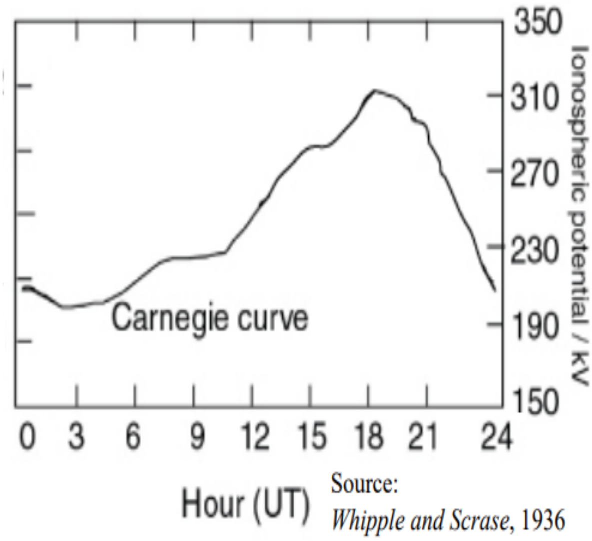


Figure 1. *Different cloud parameters used for the calculation of the ionospheric potential (IP). A) Cloud top boundary; b) cloud bottom boundary; c) cloud amount; d) IP.*

The geographical distribution of the cloud parameters determining IP has a maximum in the tropical area where the amount of the electrified clouds is expected to be the highest. Thus, the model generated cloud properties related to the IP calculations are reasonable. To validate the obtained IP values and its daily/season evolution we compare our results with the Carnegie curve (daily variation of fair weather electric field with universal time (UT)) published by Whipple et al. [1936]. Figure 2 shows simulated (on the right panel) and observed (on the left panel) daily cycle variation of the ionospheric potential.

a)



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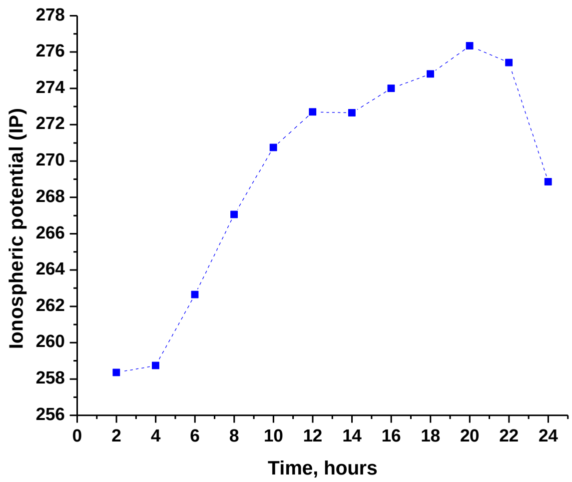

Figure 2. *Daily cycle variation of the ionospheric potential (IP). a) The Carnegie curve* Whipple et al. [1936]*; b) Modeled daily variation of IP averaged over 2004-2005 years.*

The both curves maximize on the 20 hours which suggests that our calculation are correct. The seasonal march of the ionospheric potential is presented in Figure 3.

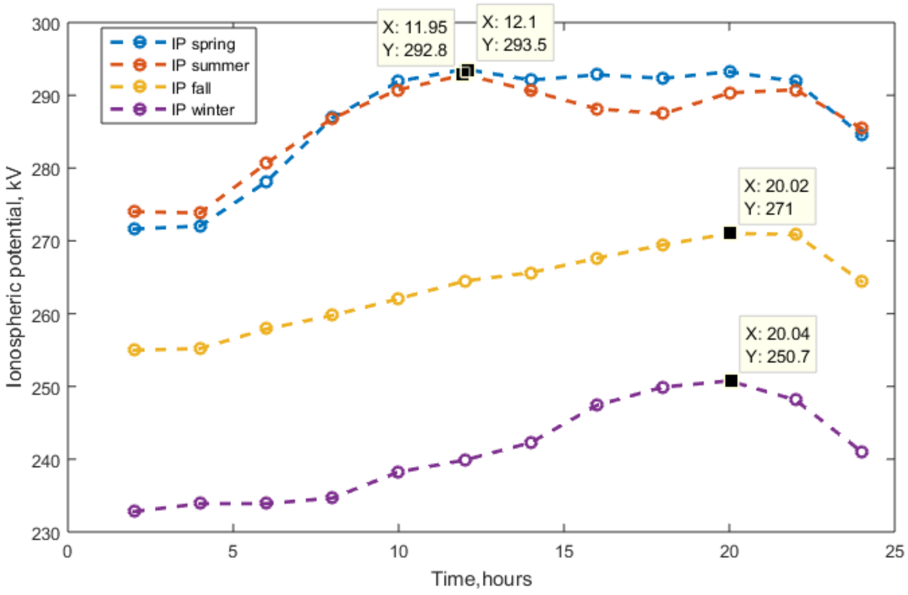

Figure 3. *Seasonal variation of ionospheric potential, average for 2 years.*

The obtained results demonstrate that the daily IP cycle depends on the season. During fall and winter IP reaches its maximum on the 20 UT, while during boreal spring and summer the IP variability is rather flat from 12 to 20 UT. The shift of the maximum can be explained by the dependence of the lightning activity areas on the season. During boreal summer and spring stronger lightning activity located in Africa and Europe area, but during boreal fall and winter the lightning activity is shifted to American continent.

Figure 4 illustrates the 2-year mean IP for every day of the year. The maximum of ionospheric potential (IP) in 2-year means is close to boreal spring/summer time. In spite of some underestimations of IP values during boreal winter the yearly variation of IP resembles the theory.

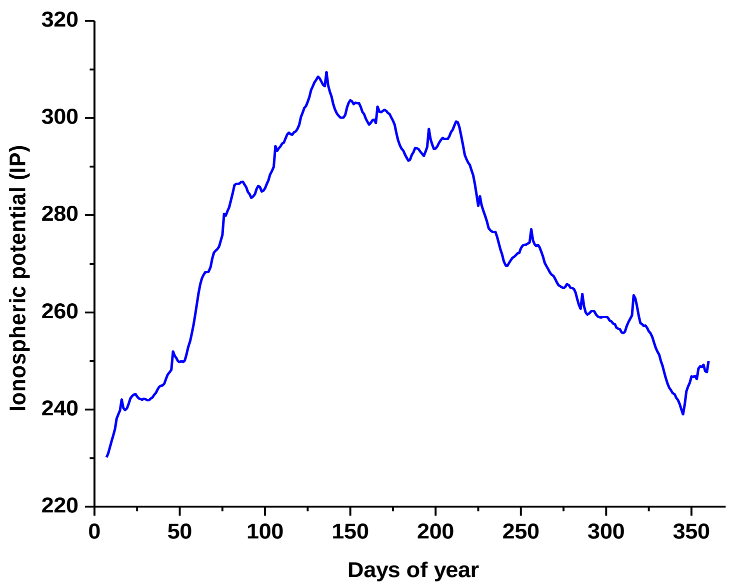

Figure 4. *2-year averaged ionospheric potential (IP) for 2004-2005 years.*

2. Conductivity in the CCM SOCOLv2.

The conductivity module is based on the following expression Lucas [2010]:

$$\sigma = \frac{P_0 T}{T_0 P} \mu_0 \ * e * N;$$

Where n is the ion concentration, e is the elementary charge, μ_0 is the ion mobility (value μ_0 used in this work is 3,3 $cm^2\ V^{-1}\ s^{-1}$), N ion production, P and T is a pressure (hPa) and temperature (K) at the certain atmospheric level, P_0 and T_0 are at 1013 hPa and 273K respectively.

$$N = f(IR, \alpha);$$

$$N = \sqrt{\frac{IR}{\alpha}};$$

N is a function of ionization rates and α is ion-ion losses. Coefficient α depends on the altitude:

$$0 \leq z < 10km;\ \alpha = 6 \times 10^{-8} \frac{\sqrt{300}}{T} + 1{,}702 \times 10^{-6} (\frac{300}{T})^{-1{,}984} * [M]^{-0{,}451}$$
$$10 \leq z < 20km;\ \alpha = 6 \times 10^{-8} \frac{\sqrt{300}}{T} + 1{,}035 \times 10^{-6} (\frac{300}{T})^{4{,}374} * [M]^{0{,}769}$$
$$20km < z;\ \alpha = 6 \times 10^{-8} \frac{\sqrt{300}}{T} + 6{,}471 \times 10^{-6} (\frac{300}{T})^{-0.191} * [M]^{0.901}$$

[M] is the concentration of air molecules in units of $2{,}69*10^{19}\ cm^3$ and T is the absolute temperature in K.

The first results of the model simulation of conductivity are presented in Figure 5. As expected for the cloud and aerosol free atmosphere the conductivity distribution is strongly depends on the ionization rates by galactic cosmic rays. The highest values of the conductivity are confined to the poles where the cut-off rigidity and ionization rates are at maximum.

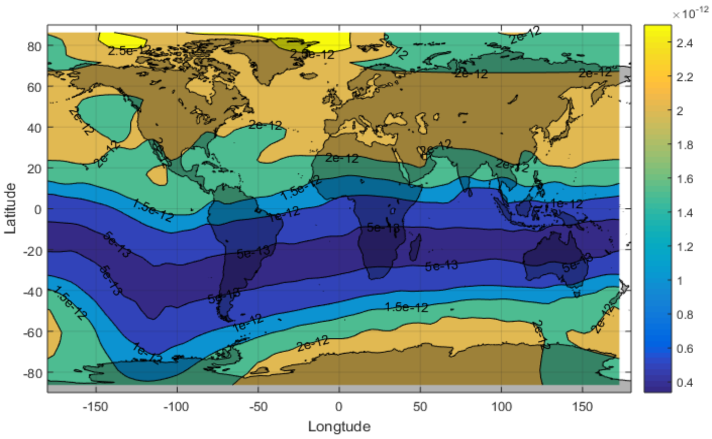

Figure 5. *Global distribution of the conductivity on 1 January 2004 near the ground.*

3. Results of Dependence of the autoconversion rates in the clouds on the electrical field strength with added of By-component of IMF.

Lam and Tinsley [2015] demonstrated that the variations of B_y-component of interplanetary magnetic field (IMF) correlate with the changes in surface pressure (Mansurov effect). They suggested that this effect is caused by the influence of IMF on the polar-cup ionospheric potential and microphysical processes within the cloud. In this part of work we tried to simulate this chain of processes with the CCM SOCOL. We use the observed daily By-component variations for the 2004-2005 years. This time series is presented in Figure 6.

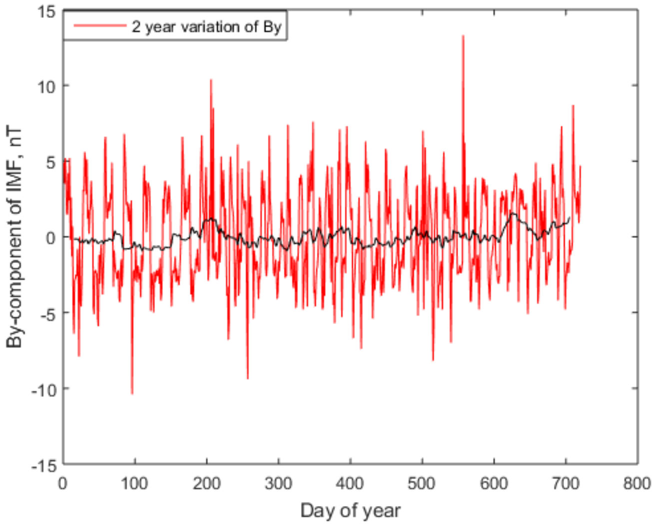

Figure 6. *Variation of By-component of IMF for the 2004-2005 year. (Black line it is the 30-day smooth for well visibility)*

We describe the above mentioned mechanism introducing linear dependence of the autoconversion rate in the cloud on the IMF B_y-component. This simple approach is based on the hypothesis of Harrison et al. [2015] about the intensification of the rain drops formation in the charged cloud environment. The 2-year long model run with this process switched on was carried out to see possible response in the surface pressure filed.

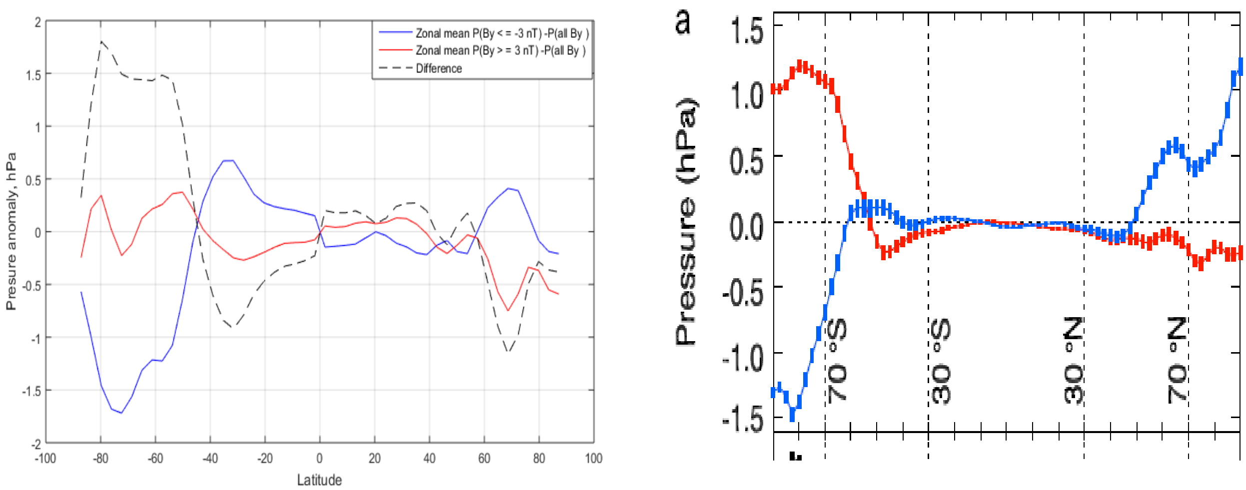

Figure 7. *Zonal and daily mean surface pressure anomaly. Red curve for days with B_y-component of IMF were greater than, or equal to, 3 nT; blue curve when it is less than, or equal to, - 3 nT. Left panel: Simulation with the CCM SOCOL v2. Right panel: The result from* Lam and Tinsley [2015].

The obtained results were processed using the method applied by Lam and Tinsley [2015]. The seasonal cycle was excluded using the reference run of the model performed without B_y-autoconversion rate dependence. Then all surface pressure date were divided according to the B_y values into 2 composites: the days when values of B_y-component of IMF were greater than, or equal to, 3 nT and when it is less than, or equal to, - 3 nT. After this the average of the both of parts (separately) for the 2 years was made. The results of this analysis for the surface pressure are presented in Figure 7 together with the results published by Lam and Tinsley [2015]. The behavior of the simulated surface pressure response is rather similar to the observations over the Polar Regions, but there are some discrepancies in central part where the influence of By-component variability is not visible in the observation data. This issue need further work and probably related to the fact that we introduced B_y-autoconversion rate dependence not only for high-latitude clouds but for all precipitating clouds over the globe.

Future collaboration with host institution

After the mission we plan to perform an ensemble model run on the computer cluster in St. Petersburg University and the results will be carefully analyzed and compared with available observations. We intend to continue collaboration with Physikalisch-Meteorologisches Observatorium Davos improving the new modules incorporated to model during this STSM and developing new module for the calculation of the downward current density J_z.

Foreseen publications to result from the STSM

The results will be used to prepare at least one paper to a refereed journal and presentations for scientific conferences, with acknowledgements to the COST CA15211 action.

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