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Analysis of aerosol-cloud-solar radiation-photosynthesis interactions in boreal forests based on field observations

Ekaterina Ezhova (1), Ilona Ylivinkka (1), Alisa Krasnova (2), Steffen Noe (2), Kaupo Komsaare (3), Marko Vana (3), Mikhail Arshinov (4), Boris Belan (4), Joel Kuusk (5), Veli-Matti Kerminen (1), and Markku Kulmala (1)

(1) INAR – Institute for atmospheric and Earth system research / Physics, University of Helsinki, Finland (ekaterina.ezhova@helsinki.fi), (2) Estonian Environmental Research Center, Tartu, Estonia, (3) Laboratory of Environmental Physics, Institute of Physics, University of Tartu, Estonia, (4) V. E. Zuev Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Science, Tomsk, Russia, (5) Tartu Observatory, Faculty of Science and Technology , University of Tartu, Toravere, Estonia

The mechanisms behind climate-related feedback loops are crucial to our understanding on the effects of the climate change. The focus of the present work is quantification of the solar radiation-related steps of the carbon-induced atmosphere-biosphere terrestrial feedback loop proposed by Kulmala et al. (2013).

The main idea under the feedback loop can be formulated as follows. The increase in the carbon dioxide concentration stimulates photosynthesis, and consequently, leads to the increase in gross primary production (GPP). More active plants produce more biogenic volatile organic compounds, a source/precursors of low-volatile vapours responsible for the formation and growth of atmospheric aerosol particles. Subsequently, there are more secondary organic aerosols able to scatter solar irradiance and thus, increase the diffuse irradiance. The latter, in its turn, enhances the light use efficiency (LUE is defined as GPP per unit photosynthetically active irradiance). Under appropriate conditions, when global irradiance is still high but its diffuse fraction is already significant, the GPP is further increased and enhances the carbon dioxide uptake, resulting in a negative feedback.

We quantify the two steps of the carbon-induced feedback loop based on several data sets from the research stations in Finland, Estonia and Russia. We confirm the growing trend in the dependence of the diffuse fraction of the global irradiance on the condensation sink (standing roughly for aerosol surface). The next step of the loop, announcing the increase in GPP with this ratio due to aerosol, has also been confirmed. The nonlinear GPP dependence on the diffuse fraction of the global irradiance is revealed and the effects of aerosol and clouds on the photosynthesis are separated based on the simplified clear-sky radiative transfer model. We show that the maximum of the photosynthetic activity for all ecosystems considered is attributed to clouds and emphasize the importance of LUE growth rate with the diffuse fraction of global irradiance for the maximum GPP that can be reached by the ecosystem.

[1] Kulmala, M., T. Nieminen, R. Chellapermal, R. Makkonen, J. Bäck and V.-M. Kerminen (2013). Climate feedbacks linking the increasing atmospheric CO_2 concentration, BVOC emissions, aerosols and clouds in forest ecosystems, in: Niinemets Ü. & Monson R.K. (eds.), Biology, controls and model tree volatile organic compound emissions, (Springer, Dordrecht), 489.