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# Possible connection of electric field variations with the size of ice particles in the polar stratosphere

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**Abstract.** The hypothesis is proposed that ice particles of polar stratospheric clouds (PSCs) are charged and trapped by the Earth's electric field. This hypothesis explains the absence or the lowest vertical transport of chlorine species and allows the assumption of the essential dependence of the sizes of ice particles on the magnitude of the Earth's electric field in the stratosphere. This assumption means that the ozone content in the stratosphere is closely connected to variations in the magnitude of the electric field. This conclusion is justified by experimental observations.

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# Introduction

An analysis of the balance of $Cl_y = HCl + ClONO_2 + ClO_x$ made based on satellite data [*Santee et al.*, 2008] has shown the absence or the lowest vertical transport of chlorine species in the polar stratosphere. We suggest that particles of the polar stratospheric clouds (PSCs) are charged and trapped by the Earth's electric field. This hypothesis is in agreement with the results of [*Belikov and Nikolaishvili*, 2012] based on the same data. In this study, a new mechanism of active chlorine release on ice crystals is developed. This release occurs as a result of dipole interaction and the sticking of molecules of chlorine and other species with a considerable electrical dipole moment to the charged particles of PSCs [*Belikov and Nikolaishvili*, 2012]. Molecules that have a zero or small electrical dipole moment do not stick, or the amount of stuck molecules is small. Such molecules are those of basic components of atmospheric $N_2$ and $O_2$, of large reservoirs such as $CO_2$ and of the tracers $CH_4$ and $N_2O$. Therefore, the decrease of $CH_4$ and $N_2O$ concentrations is possible in experiments of the polar stratosphere as a result of vertical transport, but such a decrease of chlorine species is absent or small.

# Ice Particles and Earth's Electric Field

Let us assume that a spherical ice particle with a mass $m$ and a negative charge $q$ is held by the Earth's electric field. Then,

$$E_z q = mg = \frac{4}{3}\pi r^3 \rho g$$

Here, $E_z$ – the vertical component of the Earth's electric field, $r$ – the radius of an ice particle, $\rho$ – the density of an ice particle, and $g$ – gravitational acceleration. Let us estimate the size of ice particles that can be held by the Earth's electric field at the maximal electrification of these particles. According to [$Reist$, 1984], the size of a solid particle and its maximal charge are connected by the following relationship:

$$q_{\max} = \alpha r^2$$

where for ions $\alpha = 2.22$ coulomb/m$^2$. Substituting the values $q = q_{\max}$ in the first formula, we obtain the value of the radius of a particle at which the holding of the particle in space at the given $E_z$ is possible:

$$r = \frac{(3/4)\alpha E_z}{\pi \rho g}$$

The electric field in the stratosphere was measured repeatedly. The majority of measurements were performed during daytime conditions; however, we also used data of estimations for night and twilight conditions. In the [*Makarova, et al.*, 2004] study based on data analysis of 40 experiments executed in the middle stratosphere at altitudes of $\sim 25-30$ km, the empirical expression for an electric field depending on a daytime position of the magnetopause $R_e$, expressed in units of the Earth's radius is obtained:

$$E = (527.01 - 31.5R_e)10^{-3}\ \mathrm{V\ m}^{-1}$$

Changes to $R_e$ are connected with the dynamics of solar wind. At possible changes of $R_e$ in limits of 6–12, the electric field varies accordingly in limits of 0.15–0.34 V $\mathrm{m}^{-1}$, which corresponds to a change in size of the held particles at 17.7–40.2 microns. At an altitude of $\sim 18-20$ km $E_z$, values of $\sim 1$ V $\mathrm{m}^{-1}$ can be reached according to [*Holzworth*, 1991], which corresponds to a particle size of 118 microns. These estimations of particle size can be considered the upper limit for particles that can be held by the Earth's electric field in the stratosphere.

The images of large ice crystals show that their shape is far from spherical [*de Reus et al.* 2009], as they have a composite shape with the inclusion of “sharp” juts, which means that only “sharp” juts can be highly charged. At the same time, the weight of an ice crystal depends considerably on its “porosity”. Apparently, a peculiar filter of large ice crystals is at work in the stratosphere: only those ice crystals with a shape, weight and charge that satisfy an equilibrium condition remain in the stratosphere.

If $E_z$ increases, then the weight of the held crystals and the area of their surface also increase, resulting in an increase of the ozone depression. In the [*Makarova and Shirochkov*, 2001] study for Antarctic conditions, it was experimentally established that a decrease in total ozone content is closely connected to an increase of the magnitude of the atmospheric electric field and a decrease in distance up to the magnetopause. These observations indicate that the process of trapping charged ice particles by the Earth’s electric field is key process in the formation of ozone depression.

## Conclusion

- The analysis of experimental data shows, that ice crystals of polar stratospheric clouds are charged.

- Interaction of the charged ice crystals with the Earth's electric field results to that in the stratosphere large ice crystals with a negative charge can be trapped. The estimations of the top limit of the size of such ice particles are made.
- Variations of the electric field have result to change of weight and the area of a surface of ice particles on which there are heterogeneous reactions. It results accordingly in variations of the ozone contents in the polar stratosphere. This connection is justified by experimental data.

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