Opinion Article

Electric Phenomena as a Possible Driver of Polar Snow-Air Interactions: Does this Factor Act Synergistically with Photoinduced Effects?

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ABSTRACT

Processes that occur inside polar snow cover significantly affect polar atmosphere but they are still poorly understood. Most studies consider photochemistry as the dominant mechanism of chemical transformations but recent field data cannot be interpreted only by such photochemical model. A concept is proposed to consider electric phenomena that are well known to physics but their role was never analyzed by snow chemistry specialists. But there is a question on how to differentiate influences of photo effects and electric phenomena. It can be supposed that these factors are not independent. On the contrary, they reinforce each other and act synergistically.

Keywords: snow, polar, ozone depletion, bromine, wind, triboelectricity, frost flowers

Snow cover is like a cloud but
under our feet.
Varzatskii O.A

In classic chemistry, the experimenter puts certain ingredients into a flask under certain predetermined conditions and observes what happens as a result of his controlled reaction. In Nature's vast laboratory, where polar snow cover acts as the reactor, snow chemistry specialists can only wonder at the experiments Nature is conducting. We see the results of these reactions, and - like detectives reconstructing events from fingerprints and other clues at the scene of a crime - we attempt to determine what kind of reactions have taken place, what the driving forces were, and what mechanisms and conditions were crucial for their occurrence.

The processes that happen inside this reactor, and significantly affect the polar atmosphere, are still poorly understood. Most studies consider photochemistry to be the dominant mechanism of chemical transformations in the snow. However, some recent field data [1-4] cannot be interpreted in terms of the photochemical model alone. So, what other factors might play a role in snow-air interactions? There is no doubt that one of them is the wind!

The wind is known to change the ionic composition of snow [2], and to increase hydroxyl radicals [3] and ozone levels [4]. Conversely, wind events in the coastal zone sometimes stimulate the destruction of tropospheric ozone (ozone depletion events – ODE) by triggering a bromine emission, the so-called "bromine explosion" [5].

How can wind influence snow chemistry? Polar explorer G. Silin, who described his 1957 wintering at Pionerskaya station [6] on the slope of the Antarctic Plateau in the zone of katabatic wind action, wrote in his memoirs: “When the wind increased, snowflakes carried static electricity, and all the objects at the station were so electrified that if somebody brought a neon bulb to them, it started to glow, and sparks flew between the insulators. All this was amusing, but it damaged the accuracy of our instruments. And from time to time there were unique records in our logbook: ‘Strong electrification, observations cannot be done.’”

Snow can be electrified by friction like any loose material—sand in the desert, flour in an elevator, dust above a volcano. According to [7,8], electric field strength during blizzards can increase significantly reaching values of 30 kV/m exceeding fair-weather field values by two orders of magnitude. If the field strength exceeds the threshold value, that is more possible at the tips of grounded object, corona (point) discharge occurs as channels of energy dissipation. Under the influence of a corona discharge, molecules become excited, and degradation of the excited states leads to the formation of reactive species such as radicals, atomic oxygen, ozone, etc. They actively interact with each other and with neutral molecules. Thus, an increase in levels of ozone, nitric oxide, and hydroxyl radical can be expected as a result of corona occurring during a blizzard. Researches in the field of ice physics have shown that triboelectrification of snow/ice is stimulated by low temperature, dryness, and high-velocity friction (wind speed) [9]. Because Antarctica’s harsh climate makes it the driest, windiest, coldest place on earth, the triboelectric factor can have a substantial effect there [10].

However, the strength of the electric field can reach the threshold value in other conditions; for example, corona can appear at the very sharp tip of a grounded conductor located in an open area. This is how a lightning rod works. The bloom antenna ionizes the air with its sharp edges and can receive radio waves better.

Amazing ice structures, known poetically as “frost flowers,” grow on young polar sea ice if the ambient temperature drops sharply below -20°C and a supersaturated zone appears above the surface of the ice [11] (Fig.1). It seems that these dendritic ice formations can “work” like grounded conductors because they “grow” from the puddles of brine and are covered with a briny coat. They remain “alive” and “growing” only as long as these ideal conditions exist. The tip of the rapidly growing dendrite crystal is quite sharp (with a radius as much as 0.1 μm, according to Gonda and Takaki [12]. Negative ions, components of sea salts, migrate like beetles as they crawl along electric field lines up the frost flower stems. Their run speed is determined by their charge, ability to be polarized, steric effects, planarity, and size. This phenomenon would seem to be similar to capillary electrophoresis. If electric field strength at the tip reaches the threshold value, the corona discharge can occur and halogen ion (for example, Br^-) in the field of the corona will be oxidized into $HalO^-$ which interacts with Hal^- to produce Hal_2, which could be a way for halogen ions to transfer from the condensed phase into the atmosphere.

The mechanism described above may be the answer to the question snow chemists have been asking themselves for many years: how can halogen pass from a condensed phase to a gaseous one to trigger the process of troposphere ozone destruction?

The author’s hypothesis [13] can also explain other inconsistencies – the poor reproducibility of ODE, the initiation of which can be stimulated by different conditions and various substrates. The author suggested that the “clue” to determining the possibility of the process starting is whether or not the electric field strength at the ice tips exceeds the threshold value. It is the result of the combined effects of various environmental conditions. It is like an equation in which many variables have to be solved, and each of them can be influenced by different factors. Sometimes ice crystal morphology is critically important. If the ice tip radius is less than 1 μm (Fig.1), then even small changes in the environmental electric field strength can turn the process on or off – such fluctuations in the electric field by an order of magnitude can occur during geomagnetic storms [14] especially in auroral zone in spring. Less sharp grounded objects can cross the threshold value during blizzards [5].

Thus, it can be supposed that variations of ambient electric field value and diurnal, seasonal and latitudinal variation of bromine concentrations can be linked. And one more example: it is known that ozone destruction is more intensive in places that are influenced by sea ice leads [15] and this fact can also be interpreted if one recall that electric field inside sea fog is 3–30 times higher than in clear air [16].

The appearance of the corona can lead to the formation of ozone, but after halogen (bromine) has transferred from the condensed phase to the gas phase as per the mechanism described above, all present ozone is destroyed. This type of ion transport mechanism may also explain changes in the ionic composition of snow during a blizzard [2]. Thus, if the corona is a "suspect" in our detective story, in one case it is "guilty" of increased ozone production during blizzards in polar regions far from the sea zone, and is also “guilty” of bromine emissions in the coastal zone and the resulting ozone destruction.

Now another question arises: can we observe the “clear effect” of electric phenomena without any contribution from photochemistry? It was proposed [17] that the influence of electric forces will be measured during the polar night. But it seems that these processes are hard to differentiate. If the snow initially underwent photoirradiation, its electrification during a blizzard should be higher. If the winds are very strong, as described in Sanin’s memoirs, winter electrification may also be high, but I believe that the possibility of overcoming the E threshold value under moderate winds is higher in spring and summer due photoinduced processes in the snow. This is consistent with Van Dam et al. observations in Summit [4]. These researchers noted the influence of the wind on ozone levels but only during the sunny period. And ODEs can only be observed in springtime, not in winter.

It looks as if the roles of electric and photo phenomena in polar snow-air interactions are not independent. On the contrary, they reinforce each other and act synergistically.

CONCLUSIONS

Electric phenomena in clouds are well known. Drivers and mechanisms of cloud electrification are well developed, although there are many theories and no agreement what factors are most important: triboelectricity, thermoelectricity, photoelectricity, etc. [18]. Most likely, all these mechanisms of electrification act together. Snow cover at earth is also like a cloud, especially during snowstorms. Electric phenomena in snow cover is unexplored territory for specialists in snow chemistry, and it looks as though it will be a very promising area for research.

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Fig. 1. Frost flower as grounded conductor.
Electric field strength at the tip **E** linearly depends on ambient electric field value $\mathbf{E_o}$ and on conductor's length **h** and it is inversely related to tip's radius. Radius depends from growth conditions. $\mathbf{E_o}$ depends from meteorology, location, seasonal and diurnal variations, cosmic influences, presence of open water, etc