

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

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. Author proposed a concept of how 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. Author supposes that these factors are not independent. On the contrary, they reinforce each other and act synergistically.

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

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.’”

41 Snow can be electrified by friction like any loose material—sand in the desert, flour in
42 an elevator, dust above a volcano. If the field strength exceeds the threshold value, corona
43 (point) discharge occurs as channels of energy dissipation. Under the influence of a corona
44 discharge, molecules become excited, and degradation of the excited states leads to the
45 formation of reactive species such as radicals, atomic oxygen, ozone, etc. They actively
46 interact with each other and with neutral molecules. Thus, an increase in levels of ozone,
47 nitric oxide, and hydroxyl radical can be expected as a result of corona occurring during a
48 blizzard. Researches in the field of ice physics have shown that triboelectrification of
49 snow/ice is stimulated by low temperature, dryness, and high-velocity friction (wind speed)
50 [7]. Because Antarctica's harsh climate makes it the driest, windiest, coldest place on earth,
51 the triboelectric factor can have a substantial effect there [8].

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

56 Amazing ice structures, known poetically as "frost flowers," grow on young polar sea
57 ice if the ambient temperature drops sharply below -20°C and a supersaturated zone
58 appears above the surface of the ice [9]. It seems that these dendritic ice formations can
59 "work" like grounded conductors because they "grow" from the puddles of brine and are
60 covered with a briny coat. They remain "alive" and "growing" only as long as these ideal
61 conditions exist. The tip of the rapidly growing dendrite crystal is quite sharp (with a radius
62 as much as $0.1\ \mu\text{m}$, according to Gonda and Takaki [10]. Negative ions, components of sea
63 salts, migrate like beetles as they crawl along electric field lines up the frost flower stems.
64 Their run speed is determined by their charge, ability to be polarized, steric effects, planarity,
65 and size. This phenomenon would seem to be similar to capillary electrophoresis. If electric
66 field strength at the tip reaches the threshold value, the corona discharge can occur and
67 halogen ion (for example, Br^-) in the field of the corona will be oxidized into HalO^- which
68 interacts with Hal^- to produce Hal_2 , which could be a way for halogen ions to transfer from
69 the condensed phase into the atmosphere.

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

73 The author's hypothesis [11] can also explain other inconsistencies – the poor
74 reproducibility of ODE, the initiation of which can be stimulated by different conditions and
75 various substrates. The author suggested that the "clue" to determining the possibility of the
76 process starting is whether or not the electric field strength at the ice tips exceeds the
77 threshold value. It is the result of the combined effects of various environmental conditions. It
78 is like an equation in which many variables have to be solved, and each of them can be
79 influenced by different factors. Sometimes ice crystal morphology is critically important. If the
80 ice tip radius is less than $1\ \mu\text{m}$, then even small changes in the environmental electric field
81 strength can turn the process on or off – such fluctuations in the electric field by an order of
82 magnitude can occur during geomagnetic storms [12] and in the fog or haze created by
83 leads in the sea ice [13]. And less sharp grounded objects can cross the threshold value
84 during blizzards [5].

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

92 Now another question arises: can we observe the "clear effect" of electric phenomena
93 without any contribution from photochemistry? It was proposed that the influence of electric

94 forces will be measured during the polar night (seminar on June 22, 2018, IGE, Université
95 Grenoble Alps). But it seems that these processes are hard to differentiate. If the snow
96 initially underwent photoirradiation, its electrification during a blizzard should be higher. If the
97 winds are very strong, as described in Sanin's memoirs, winter electrification may also be
98 high, but I believe that the possibility of overcoming the E threshold value under moderate
99 winds is higher in spring and summer due photoinduced processes in the snow. This is
100 consistent with Van Dam et al. observations in Summit [4]. These researchers noted the
101 influence of the wind on ozone levels but only during the sunny period. And ODEs can only
102 be observed in springtime, not in winter.

103 Thus, it looks as if the roles of electric and photo phenomena are not independent. On the
104 contrary, they reinforce each other and act synergistically. Electric phenomena in snow are
105 well known to physicists and meteorologists, but it is unexplored territory for specialists in
106 snow chemistry, and it looks as though it will be a very promising area for research
107

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