CSIRO PUBLISHING

Environ. Chem. **2012**, *9*, 119–120
http://dx.doi.org/10.1071/EN11147

Perspective

Comment on 'Possible contribution of triboelectricity to snow–air interactions'

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Received 30 November 2011, accepted 20 February 2012, published online 27 March 2012

Tkachenko and Kozachkov[1] discuss how the unique weather conditions in wind-swept snowy areas, e.g. Antarctica, can favour electrical phenomena in the lowermost atmosphere. They suggest that electrical discharges can trigger and sustain chemical reactions. They further postulate a significant influence of this effect on the chemistry in snow and on the budget of atmospheric trace gases. Here, we take to opportunity to comment on the paper by Tkachenko and Kozachkov by placing it in a wider context.

In their paper, Tkachenko and Kozachkov open with an interesting discussion, namely if there are important reactive processes in snow chemistry under stormy conditions associated with drift snow. Snow hosts a vivid chemistry. There is convincing evidence from field studies, modelling and laboratory investigations underlining the importance of this chemistry and of snow–air exchange on atmospheric chemistry and snow composition.[2] It is now widely accepted that exceptionally high concentrations of trace gases – for example above the Antarctic plateau – result from snow-pack emissions that concentrate in a stable and very shallow boundary layer.[3–5] Field measurements of atmospheric trace gases under stormy conditions, where the boundary layer is neither stable nor shallow, are only rarely reported. To our knowledge Neff et al.[6] were the first to show persistent high levels of nitrogen oxides during high-wind periods and a consequently thick boundary layer. We agree with Tkachenko and Kozachkov that the effect of electrostatic phenomena on chemistry is generally not considered in atmospheric science.[2,7] Nevertheless, the effect of electric phenomena is not completely overlooked. Recently, Asmi et al.[8] characterised coastal Antarctic aerosol and described charged ion formation events at days with high wind speeds, which is an observation in support of Tkachenko and Kozachkov. Also the latter paper is somewhat speculative, the quantity and size of blowing snow events in Antarctica was rather underestimated.[9] In this sense, the hypothesis of Tkachenko and Kozachkov should be investigated further. Before coming back to the issue of triboelectricity, we would like to discuss two other issues that might contribute to snow chemistry under stormy conditions.

Blowing snow as surface for reactions

Jones et al.[10] demonstrated that elevated BrO levels and the chemistry destroying ozone are not restricted to a shallow boundary layers, but prevail during blizzards. They further showed that a combination of turbulent mixing, blowing snow and ventilation favours ozone destruction under stormy conditions. Clearly, this hypothesis might also, in a more traditional way, explain the unique chemistry during windy conditions over snow-covered areas. The effect of blowing snow on chemistry still needs to be tested using photochemical box models. We fell that other suggestions of mechanism explaining these observations, such as the electrostatic phenomena proposed by Tkachenko and Kozachkov, are highly welcome.

Thorsten Bartels-Rausch studied chemistry at the University of Würzburg, Germany, the Norwegian University of Science and Technology in Trondheim, Norway, and the Swiss Federal Institute of Technology in Zürich (ETH), Switzerland. In 2003, he received his Ph.D. from the University of Bern, Switzerland, for which he investigated the uptake of trace gases to ice surfaces. After a postdoctoral stay at the University of Toronto, he returned to Switzerland and joined the Surface Chemistry group of the Laboratory of Radiochemistry and Environmental Chemistry at the Paul Scherrer Institute, Villigen, Switzerland. His current activities include laboratory studies of mechanisms and kinetics of gas–ice partitioning and reactions in snow and ice.

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Snow metamorphism during storms

We fully agree with Tkachenko and Kozachkov in that the current understanding of snow chemistry is insufficient to fully capture observations in simulations. As they mention, one reason might be the incomplete parameterisation of snow metamorphism and its role on the release of trace gases to the atmosphere. The role of the surface area of snow on the partitioning of trace gases between the air and snow phase is well established; and it is also clear that snow and its surface area are not static but change with time.[11] Progress in parameterising snow metamorphism under natural conditions has recently been described. In their study, Pinzer and Schneebeli[12] discuss surprisingly high recrystallisation rates when the snow was exposed to temperature gradients typical for a polar environment and suggest that the high recrystallisation rates influence chemical snow–air interactions. The role of wind on snow metamorphism, and on the transport of trace gases through the snowpack, is controversially discussed.[13,14] It is thus not surprising that chemical models do not capture observed trace gas concentrations under windy conditions. Chemistry models do currently not parameterise snow metamorphism at all. Typically, the snow is described by densely packed, static ice spheres.[15]

Ultimately, it remains unclear if triboelectricity is needed to explain observations. However, it could still contribute as one chemical factor, taken that blizzards are frequent in Antarctica. Tkachenko and Kozachkov suggest – based on electric field measurements – that corona discharges can take place up to 0.5 m above the surface. This alone would represent quite a large dynamic volume for triboelectricity to take place. The high wind speed and amount of snow transported in Antarctica[16,17] make a scenario where triboelectricity plays an important role in snow chemistry not unlikely.

An open key question remains, however: what is the yield of the overall chemistry? We suggest testing this hypothesis by deriving efficiency, rates and products of the plasma chemistry. This would allow an estimate of the relevance of the proposed chemical pathway. Additionally, more field data on atmospheric composition during storms are urgently needed to deepen our understanding of polar chemistry.

References

[1] E. Y. Tkachenko, S. G. Kozachkov, Possible contribution of triboelectricity to snow–air interactions. *Environmental Chemistry* [Published online early 13 September 2011]. doi:10.1071/EN10074

[2] A. M. Grannas, A. E. Jones, J. E. Dibb, M. Ammann, C. Anastasio, H. Beine, M. H. Bergin, J. Bottenheim, C. S. Boxe, G. Carver, G. Chen, J. H. Crawford, F. Domine, M. M. Frey, M. I. Guzman, D. Heard, D. Helmig, M. R. Hoffmann, R. Honrath, L. G. Huey, M. Hutterli, H.-W. Jacobi, P. Klan, B. Lefer, J. McConnell, J. Plane, R. Sander, J. Savarino, P. B. Shepson, W. Simpson, J. R. Sodeau, R. von Glasow, R. Weller, E. W. Wolff, T. Zhu, An overview of snow photochemistry: evidence, mechanisms and impacts. *Atmos. Chem. Phys.* **2007**, *7*, 4329. doi:10.5194/ACP-7-4329-2007

[3] D. D. Davis, J. Seelig, G. Huey, J. Crawford, G. Chen, Y. Wang, M. Buhr, D. Helmig, W. Neff, D. Blake, R. Arimoto, F. Eisele, A reassessment of Antarctic plateau reactive nitrogen based on ANTCI 2003 airborne and ground based measurements. *Atmos. Environ.* **2008**, *42*, 2831. doi:10.1016/J.ATMOSENV.2007.07.039

[4] D. Helmig, B. Johnson, S. J. Oltmans, W. Neff, F. Eisele, D. D. Davis, Elevated ozone in the boundary layer at South Pole. *Atmos. Environ.* **2008**, *42*, 2788. doi:10.1016/J.ATMOSENV.2006.12.032

[5] D. Helmig, B. J. Johnson, M. Warshawsky, T. Morse, W. D. Neff, F. Eisele, D. D. Davis, Nitric oxide in the boundary-layer at South Pole during the Antarctic Tropospheric Chemistry Investigation (ANTCI). *Atmos. Environ.* **2008**, *42*, 2817. doi:10.1016/J.ATMOSENV.2007.03.061

[6] W. Neff, D. Helmig, A. Grachev, D. Davis, A study of boundary layer behavior associated with high NO concentrations at the South Pole using a minisodar, tethered balloon, and sonic anemometer. *Atmos. Environ.* **2008**, *42*, 2762. doi:10.1016/J.ATMOSENV.2007.01.033

[7] T. Bartels-Rausch, V. Bergeron, J. H. E. Cartwright, R. Escribano, P. J. Gutierrez, J. Haapala, W. F. Kuhs, J. B. C. Pettersson, S. D. Price, C. I. Sainz-Diaz, D. Stokes, G. Strazzulla, E. S. Thomson, H. Trinks, N. Uras-Aytemiz, Ice structures, patterns and processes: a review across the ice fields. *Rev. Mod. Phys.*, in press.

[8] E. Asmi, A. Frey, A. Virkkula, M. Ehn, H. E. Manninen, H. Timonen, O. Tolonen-Kivimäki, M. Aurela, R. Hillamo, M. Kulmala, Hygroscopicity and chemical composition of Antarctic sub-micrometre aerosol particles and observations of new particle formation. *Atmos. Chem. Phys.* **2010**, *10*, 4253. doi:10.5194/ACP-10-4253-2010

[9] S. P. Palm, Y. Yang, J. D. Spinhirne, A. Marshak, Satellite remote sensing of blowing snow properties over Antarctica. *J. Geophys. Res.* **2011**, *116*, D16123. doi:10.1029/2011JD015828

[10] A. E. Jones, P. Andersson, M. Begoin, N. Brough, M. Hutterli, G. Marshall, A. Richter, H. Roscoe, E. W. Wolff, BrO, blizzards, and drivers of polar tropospheric ozone depletion events. *Atmos. Chem. Phys.* **2009**, *9*, 4639. doi:10.5194/ACP-9-4639-2009

[11] F. Domine, M. Albert, T. Huthwelker, H. W. Jacobi, A. A. Kokhanovsky, M. Lehning, G. Picard, W. R. Simpson, Snow physics as relevant to snow photochemistry. *Atmos. Chem. Phys.* **2008**, *8*, 171. doi:10.5194/ACP-8-171-2008

[12] B. Pinzer, M. Schneebeli, Snow metamorphism under alternating temperature gradients: morphology and recrystallization in surface snow. *Geophys. Res. Lett.* **2009**, *36*, L23503. doi:10.1029/2009GL039618

[13] J. E. Dibb, M. Albert, C. Anastasio, E. Atlas, A. J. Beyersdorf, N. J. Blake, D. R. Blake, F. Bocquet, J. F. Burkhart, G. Chen, L. Cohen, T. J. Conway, Z. Courville, M. M. Frey, D. K. Friel, E. S. Galbavy, S. Hall, M. G. Hastings, D. Helmig, L. Greg Huey, M. A. Hutterli, J. C. Jarvis, B. L. Lefer, S. Meinardi, W. Neff, S. J. Oltmans, F. Sherwood Rowland, S. J. Sjostedt, E. J. Steig, A. L. Swanson, D. J. Tanner, An overview of air–snow exchange at Summit, Greenland: recent experiments and findings. *Atmos. Environ.* **2007**, *41*, 4995. doi:10.1016/J.ATMOSENV.2006.12.006

[14] S. J. Bartlett, M. Lehning, A theoretical assessment of heat transfer by ventilation in homogeneous snowpacks. *Water Resour. Res.* **2011**, *47*, W04503. doi:10.1029/2010WR010008

[15] J. L. Thomas, J. Stutz, B. Lefer, L. G. Huey, K. Toyota, J. E. Dibb, R. von Glasow, Modeling chemistry in and above snow at Summit, Greenland – Part 1. Model description and results. *Atmos. Chem. Phys.* **2011**, *11*, 4899. doi:10.5194/ACP-11-4899-2011

[16] K. C. Leonard, S. S. Jacobs, R. I. Cullather, Mass balance implications of wind-transported snow loss from Antarctic ice shelves. *Eos Trans. AGU* **2008**, *89(53, Fall Meet. Suppl.)*, C31D-0541

[17] C. Scarchilli, M. Frezzotti, P. Grigioni, L. Silvestri, L. Agnoletto, S. Dolci, Extraordinary blowing snow transport events in East Antarctica. *Clim. Dyn.* **2010**, *34*, 1195. [Published online ahead of print 11 June 2009] doi:10.1007/S00382-009-0601-0