Frost flowers on sea ice - a multi-disciplinary research effort for the upcoming International Polar Year (IPY)

L. Kaleschke[1], A. Richter[1], J. Burrows[1], G. Heygster[1], J. Notholt[1], J. Hollwedel[2], R. von Glasow[2], T. Wagner[2], H. W. Jacobi[3], A. Herber[3], R. Weller[3], R. Sander[4], H.K. Roscoe[3], E. W. Wolff[3], M. Hutterli[3], A. Jones[3], X. Yang[4], L. Carpenter[7], S. Kaspari[8]

(1) Institute of Environmental Physics, University of Bremen, Germany, (2) Institute of Environmental Physics, University of Heidelberg, Germany (3) Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany,(4) Max-Planck Institute of Chemistry, Mainz, Germany
(5) British Antarctic Survey, Natural Environment Research Council, Cambridge, UK, (6) Centre for Atmospheric Science, University of Cambridge, UK, (7)University of York, Dept of Chemistry, UK, (8) University of Maine, Climate Change Institute, USA

1 Introduction

Figure 1: Frost flowers on young sea ice in the Barents Sea. Photograph by Hans-Werner Jacobi, 2003.

Frost Flowers (FF), sometimes also referred to as salt flowers, are a common sea-ice feature in the Arctic and Antarctic. These ice crystals grow on a liquid layer of concentrated brine. The liquid brine gets onto the crystals by capillary suction resulting in an ion concentration triple of that of sea water[8]. The delicate crystals are easily blown away by the wind and thus can produce salty aerosol[9,12]. The hypothesized role of frost flowers for atmospheric chemistry will be investigated in several projects during IPY.

2 Remote Sensing of Frost Flowers

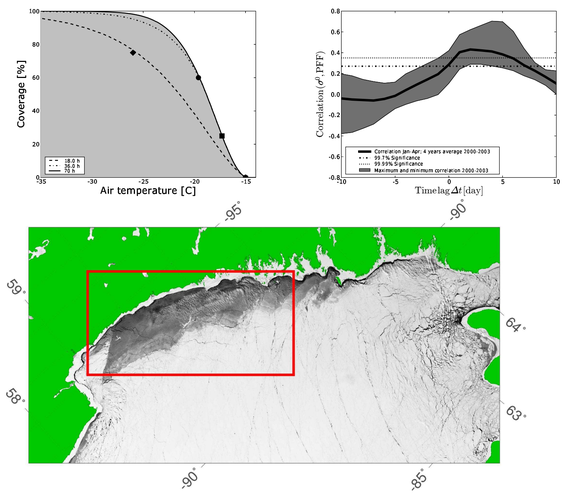

Figure 2a): Potential Frost Flower (PFF) coverage. The PFF value is the upper limit of coverage for a given air temperature. Laboratory experiments of Martin *et al.* (1996) show that the coverage reaches an asymptotic level as a function of air temperature [3]. The PFF model shown here is parameterized to fit these laboratory observations.
Figure 2b): Time-lagged correlation between the averaged Ku-band backscatter coefficient and the averaged PFF coverage. Daily values of the average PFF coverage were analysed for the north-western Hudson Bay polynya (Fig. 2c). The thick line is the average correlation for the first 120 days of the years 2000 to 2003. The envelope indicates the corresponding minimum and maximum correlation. A significant (99.99%) correlation occurs for the time-lag Δt between one to five days which is interpreted as the typical lifetime of FFs.
Figure 2c): MODIS image of the area of investigation (red box) in the Hudson Bay, 5 March 2003. Offshore winds frequently cause the opening of the ice near the coastline.

FFs strongly enhance the surface roughness and thus the radar backscatter coefficient σ^0, enabling to detect FF blooms by their bright signature in radar images[4]. SeaWinds scatterometer data were used by Rankin *et al.* (2002) to detect FF blooms near the Antarctic station Halley[8]. The PFF method (Fig. 2a) is an indirect way to estimate the FF coverage. The method is based on the assumption that FF will grow on recently frozen areas as a function of air temperature. The PFF value derived from SSM/I ice concentration[5] and NCEP surface air temperature is time-lagged correlated to the backscatter coefficient (Fig. 2b).

3 Bromine Explosion

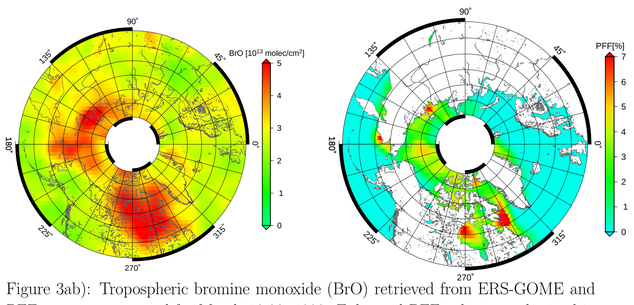

Figure 3ab): Tropospheric bromine monoxide (BrO) retrieved from ERS-GOME and PFF coverage, averaged for March 16-22, 1998. Enhanced PFF values are obtained in the Hudson Bay, and the Davis Strait, coastal zone polynyas in the Siberian Sea and the Bering Sea. The high PFF values are in agreement with the greatly enhanced BrO concentration over these areas[1, 3].

A mechanism for halogen release from sea-salt aerosol[10]

$$\begin{aligned}
HOBr + Br^- + H^+ &\leftrightarrow Br_2 + H_2O && (1,\text{-}1)\\
HOBr + Cl^- + H^+ &\leftrightarrow BrCl + H_2O && (2,\text{-}2)\\
BrCl + Br^- &\leftrightarrow Br_2Cl^- && (3,\text{-}3)\\
Br_2Cl^- &\leftrightarrow Br_2 + Cl^- && (4,\text{-}4)\\
Br_2 + h\nu &\rightarrow 2\,Br && (5)\\
2(Br + O_3) &\rightarrow 2(BrO + O_2) && (6)\\
2(BrO + HO_2) &\rightarrow 2(HOBr + O_2) && (7)
\end{aligned}$$

Bromine explosion: Every Br atom entering the liquid phase has the potential to either release two Br atoms to the gas phase (1) or to release just one Br atom and also activate chlorine (2)

The advent of the measurement of tropospheric trace gases from space by the Global Ozone Monitoring Experiment, GOME, led to the discovery of enhanced amounts of BrO close to regions of sea ice in the northern and the southern hemisphere. The release of bromine from salt-laden ice surfaces can be explained by an heterogenous autocatalytic reaction, the so called bromine explosion. There are strong indications that FFs or their aerosols are the long-sought sources of the polar bromine emissions[1,3,9].

4 Impact of Reactive Bromine Chemistry

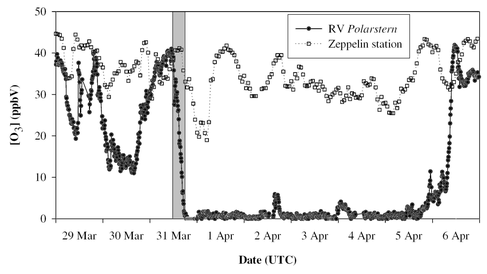

Figure 4: Time series of O3 concentrations measured on board of RV Polarstern and at Ny-Alesund, Spitsbergen. The shaded area indicates the period when O3 decreased from 40 ppbV to below 1 ppbV in less than 7 hours. The analyses of backward trajectories and the synoptical conditions demonstrate that the observed decrease was not caused by the transport of ozone-free air, but that the ozone depletion occurred locally in the vicinity of frost flower fields[1].

In the polar atmospheric boundary layer tropospheric ozone regularly decreases during springtime to negligible concentrations. These events were found to be associated with enhanced amounts of reactive bromine compounds. The impact of the reactive halogen chemistry is manifold[11]. For example, the oxidation of elemental gas-phase mercury is an important mechanism for the pollution of the polar biosphere[2].

5 Chemical Transport and Climate Modelling

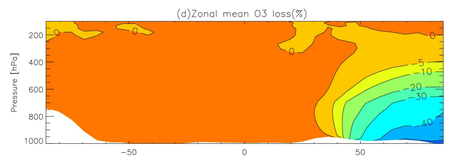

Figure 5: Modeled difference of ozone concentration (zonally averaged) as a consequence of bromine release from FFs. Result from the 3D model p-TOMCAT with a preliminary FF parameterisation[13].

The possible influence of the bromine emissions on the climate system will be assessed by physico-chemical models of different complexity: Are there so far disregarded climate feedback effects? What is the impact of the shrinking Arctic sea ice cover on atmospheric chemistry?

6 New Interpretation of the Glaciochemical Records

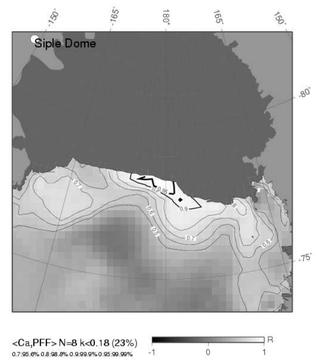

Figure 6: Correlation map of the yearly averaged PFF value and Ca^{2+} ion concentrations from the Siple Dome ice core record[7] for the period 1979-1989. Only the sulfate-depleted samples from FF sources have been considered[6]. The huge Ross Sea polynya shows the maximum correlation for the entire southern hemisphere.

The polar atmospheric sea salt was long-time believed to come from bubble burtsing over open water only. It was difficult to explain the high salt concentration observed during glacial periods and in winter despite the greater sea ice extent. Now it has become evident that the sea ice surface is the dominant source at least for coastal Antarctic sites, making necessary to re-interprete ice core records. The salts of FFs exhibit a depleted sulfate to sodium ratio with respect to bulk seawater. Thus they can be identified in datasets with a high temporal resolution[6]. The question arises if the sea ice production or polynya activities can be derived from glaciochemical records.

7 Related IPY Projects

OASIS The international Ocean-Atmosphere-Sea Ice-Snowpack project
COBRA Impact of combined iodine and bromine release on the Arctic atmosphere
AICI Air-Ice Chemical Interactions
AGAMES Antarctic Trace Gas and Aerosol Airborne Measurement Study
and more...

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