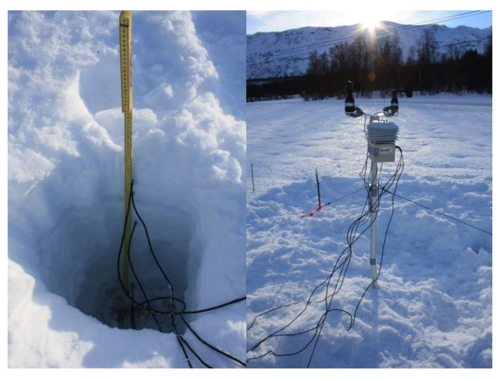
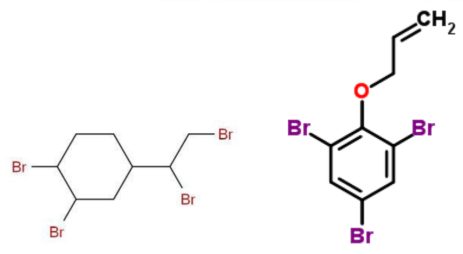
A long way from home: current-use flame retardants in Norwegian snow

Olivier R. A. Bertrand,[1] Crispin Halsall,[1]* Axel Möller,[2] Tore Nordstad,[3] Zhiyong Xie[2] and Ralf Ebinghaus[2]

[1]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK
[2]Helmholtz-Zentrum Geesthacht (HZG), Geesthacht, Germany
[3]Norwegian Polar Institute, Fram Centre, 9096 Tromsø, Norway

* c.halsall@lancaster.ac.uk





In Arctic/sub-Arctic regions:

- Snowfall is efficient at scavenging semi-volatile chemicals from air e.g. washout ratios for persistent organic pollutants have been observed to be 10^4-10^5.[1] Furthermore, the snowpack serves as a contaminant store and may accumulate chemicals until spring melt. Re-emission of more volatile, hydrophobic POPs does occur during snow ageing, however, depending on the chemical properties of flame retardants, this is either unknown or unlikely to occur.
- The role of the snowpack in providing flame retardants to aquatic systems is likely to be important but has not been quantified. Furthermore, post-deposition processing within the snowpack may affect the timing and quantity of chemical available for melt water runoff.

As part of the EU FP7 project 'ArcRisk', a field campaign was conducted in Northern Norway (two sites selected: Frihetsli and Holt within Dividalen National Park, ~140 km south of Tromsø, **within the Arctic circle**) to study flame retardants and other contaminants in snow. In Norway, flame retardants were measured in the winter snowpack, with fresh snowfall and deeper aged layers targeted to determine flame retardant deposition fluxes and migration within the pack. Outline results are presented below.

1. Flame retardant (FR) scavenging from the air by Arctic snow: enrichment and deposition composition

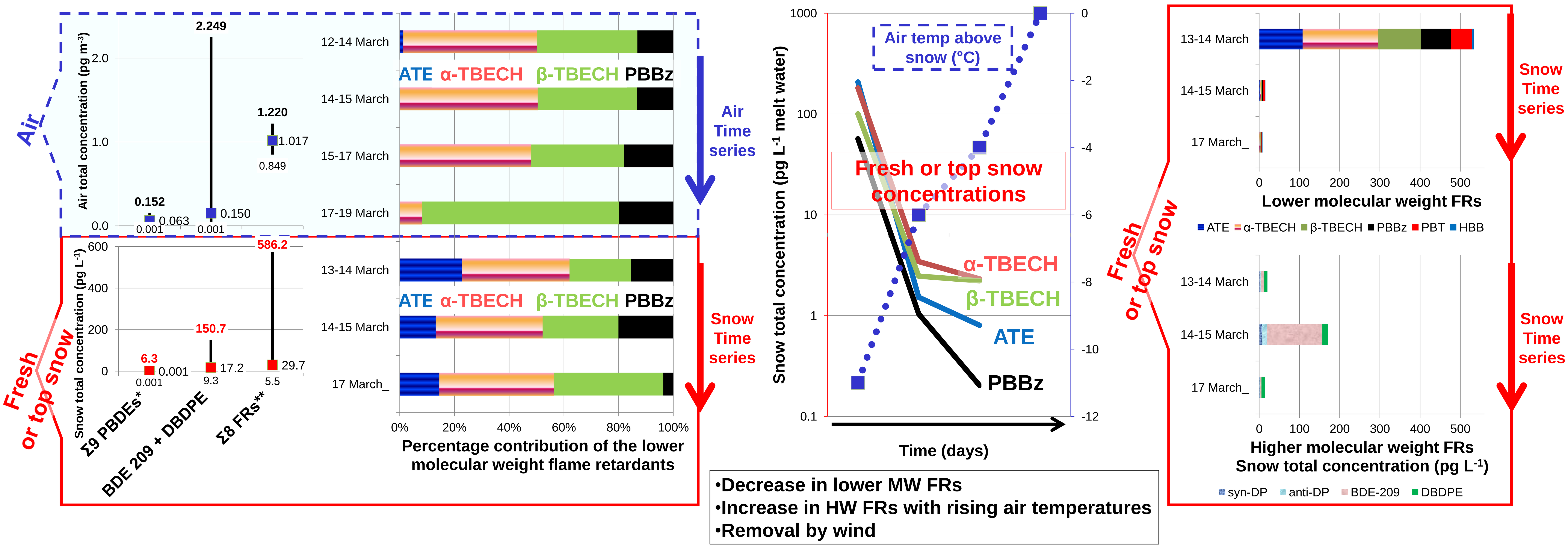


Figure 1. Chemicals measured in snow and air alongside air temperature. Flame retardants (FRs) analysed are displayed in elution order (from lower to higher molecular weight, MW).[2]
*"Legacy" Σ9 PBDEs: BDE-28, -47, -66, -100, -99, -85, -154, -153 and -183. **Σ8 FRs: ATE, α-TBECH, β-TBECH, PBBz, PBT, HBB, *syn*-DP and *anti*-DP.

2. Post-depositional behaviour of flame retardants (FRs) in the snowpack

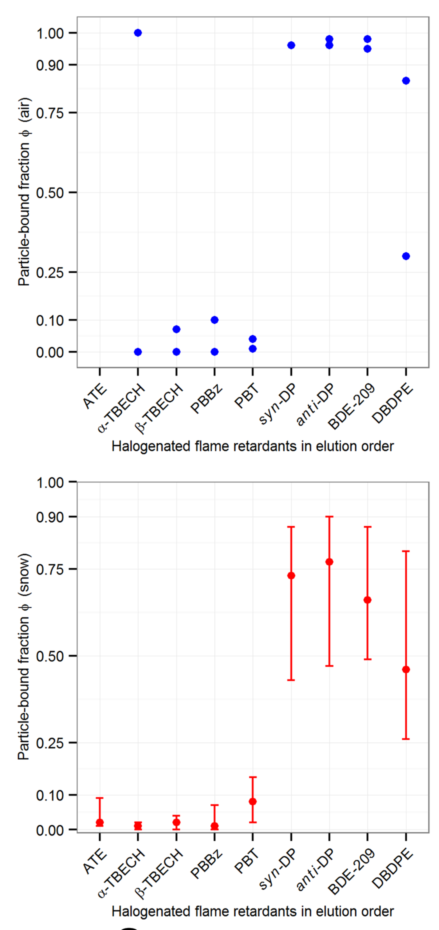


Figure 2. Particle-bound fractions (Φ) of select flame retardants in air (top, blue dots, n = 2) and snow (bottom, medians and quartiles in red, n = 13) increase with molecular weight.

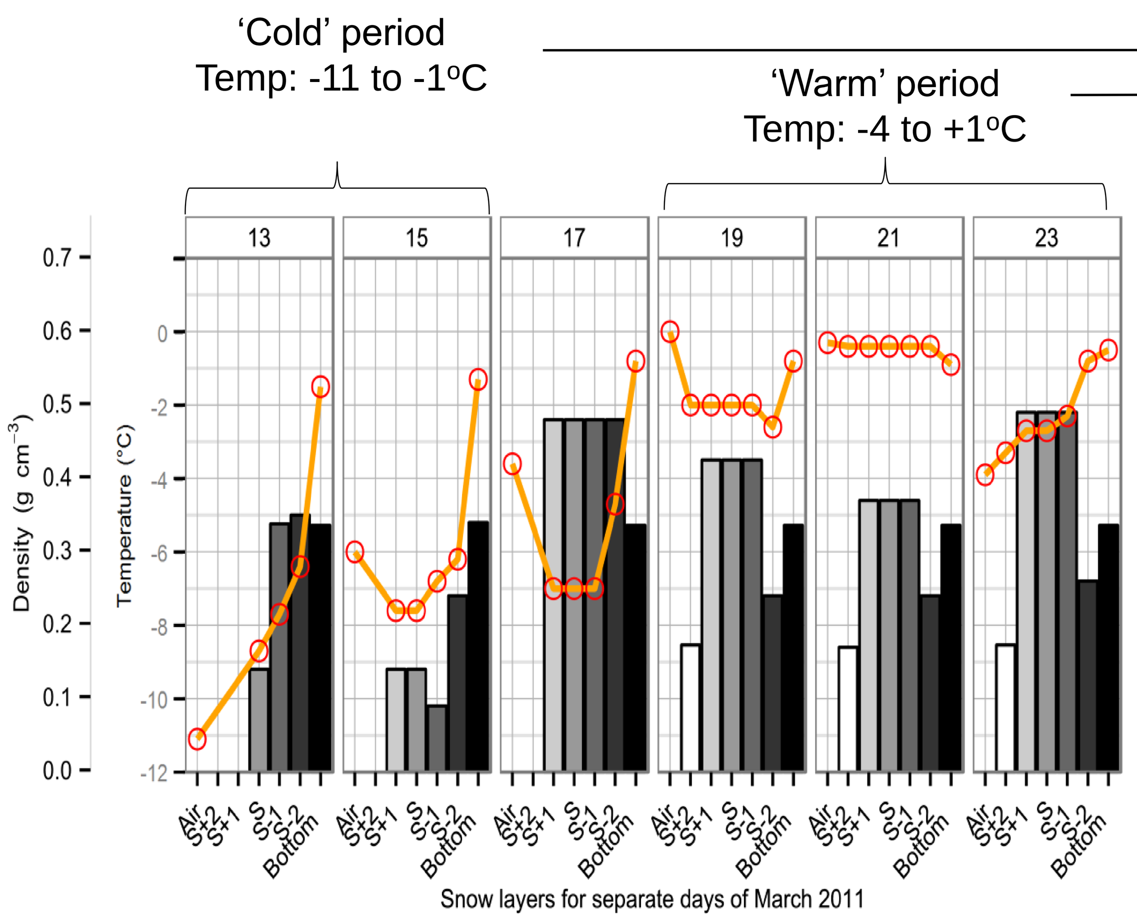


Figure 3. Snow layer densities (bars) and temperatures (orange) over 13-23 March. The snowpack was ~0.85 m deep with a surface layer (S) sampled on the 13 March. Subsequent snowfall events are S+1 (14/15th) and S+2 layers (18th) ('upper snow', also including S-1) and S-2 and bottom represent deeper snow (see Figure 4).

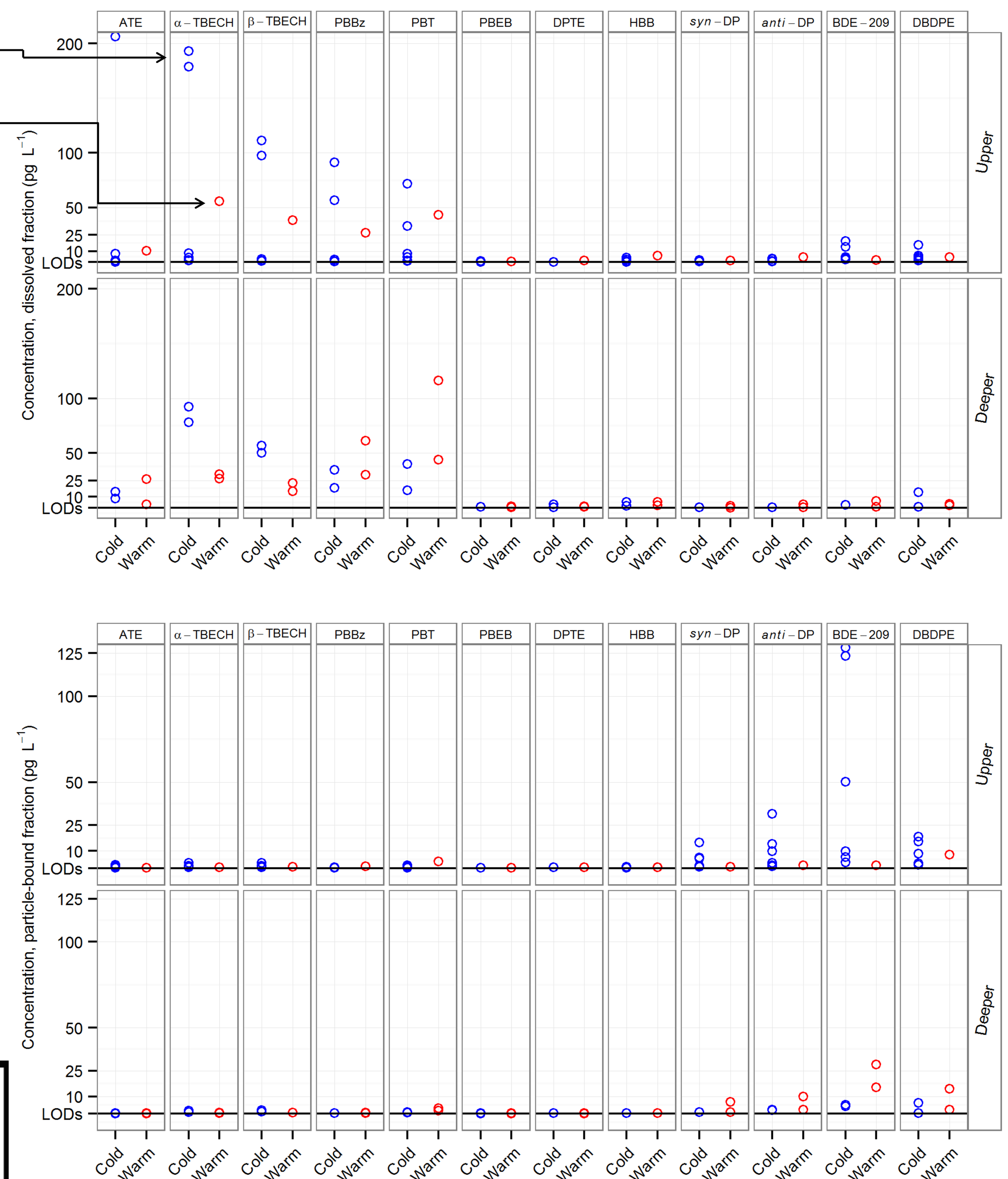


Figure 4. Flame retardant concentrations in upper and deeper snow layers for dissolved and particle-bound fractions. Hollow points represent the 'cold' period (blue) and the 'warm' period (red). Note the elevated concentrations in fresh snow and the transfer to deeper snow layers during the warm period.

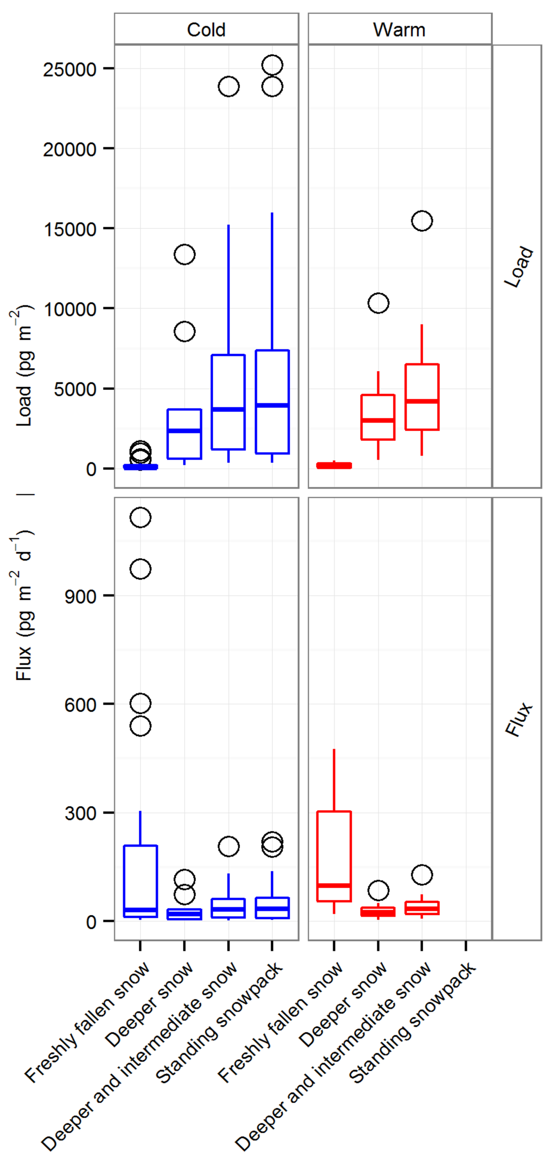


Figure 5. Loads and fluxes of 10 select FRs (ATE, α- and β-TBECH, PBBz, PBT, HBB, *syn*- and *anti*-DP, BDE-209 and DBDPE). Note the importance of fresh snowfall in delivering these chemicals to the snowpack.

3. Interesting observations

* The median flux of 10 select FRs (ATE, α- and β-TBECH, PBBz, PBT, HBB, *syn*- and *anti*-DP, BDE-209 and DBDPE) with fresh snowfall was ~30-100 pg m^2 d^{-1} in Northern Norway, due to variable scavenging influenced by temperature and type of snowfall. The fluxes of BDE-209 and DBDPE were lower than fluxes derived in the Canadian Arctic[3] and in a previous study in Svalbard,[4] which could be due to a pattern of air masses coming mostly from the Atlantic Ocean instead of densely-populated areas at the time of sampling. This suggests the importance of seasonality in the deposition of FRs.

* FR migration from fresh snow occurs relatively rapidly (days) when snowpack temperatures are close to 0°C, with evidence of a corresponding increase in concentrations in deeper, adjacent snow layers, and notably particle-bound higher molecular weight FRs.

* Median snowpack loads of select FRs are relatively stable in the melting pack.

Acknowledgements. We thank Dorte Herzke, Sandra Huber and Eldbjørg S. Heimstad from NILU Tromsø for providing access to their laboratory, Cecilie Sternersen, Andreas Hamre and Svein Sørensen for access to Dividalen II (Frihetsli) station from the Norwegian Meteorological Institute, as well as Norwegian land owners for access to the sites and Philip Smith for the design of a snow density kit for thin snow layers. This work was funded through **ArcRisk** (European Community project: FP7-ENV-2008-1, Grant Agreement Number: 226534).

1. Bergknut M. et al. Modelling the fate of hydrophobic organic contaminants in a boreal forest catchment: A cross disciplinary approach to assessing diffuse pollution to surface waters. *Environmental Pollution* (**2010**) 158: 2964-2969.
2. Bertrand O.R.A. et al. Polybromodiphenyl ethers, alternate flame retardants and dechloranes in the air and the seasonal snowpack of Northern Norway. In preparation.
3. Meyer T. et al. Deposition of brominated flame retardants to the Devon Ice Cap, Nunavut, Canada. *Environmental Science and Technology* (**2012**) 46: 826-833.
4. Hermanson M.H. Deposition history of brominated flame retardant compounds in an ice core from Holtedahlfonna, Svalbard, Norway. *Environmental Science and Technology* (**2010**) 44: 7405-7410.