

# Volatile organic compounds in Arctic snow: Concentrations and implications for atmospheric processes

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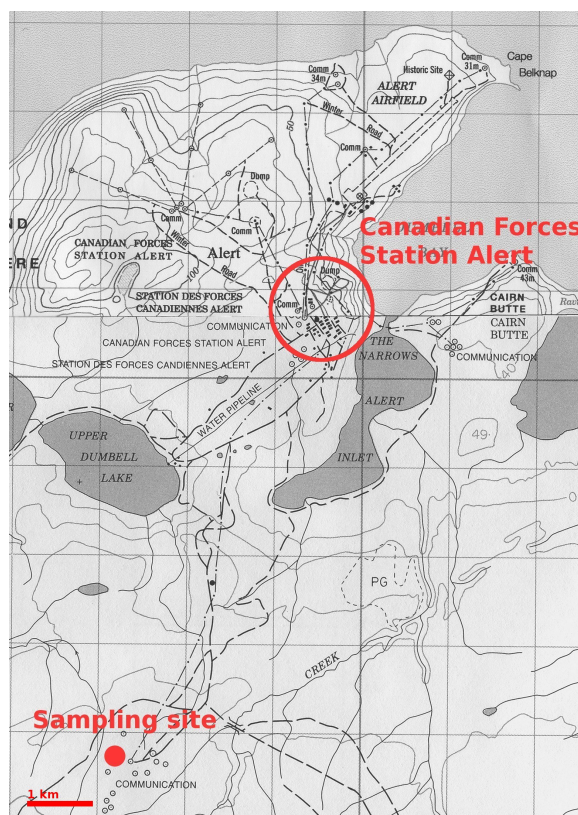
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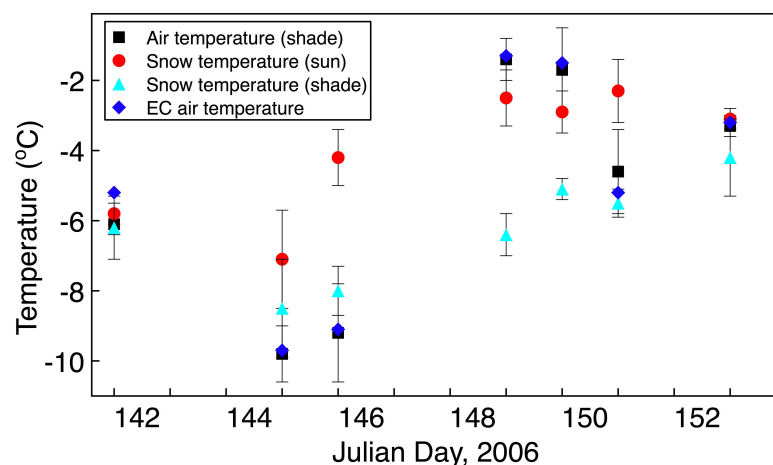
## A Electronic Supplementary Information: Complementary Information and Numerical Data

The following figures and tables provide complementary information and numerical data used in the figures with uncertainties.

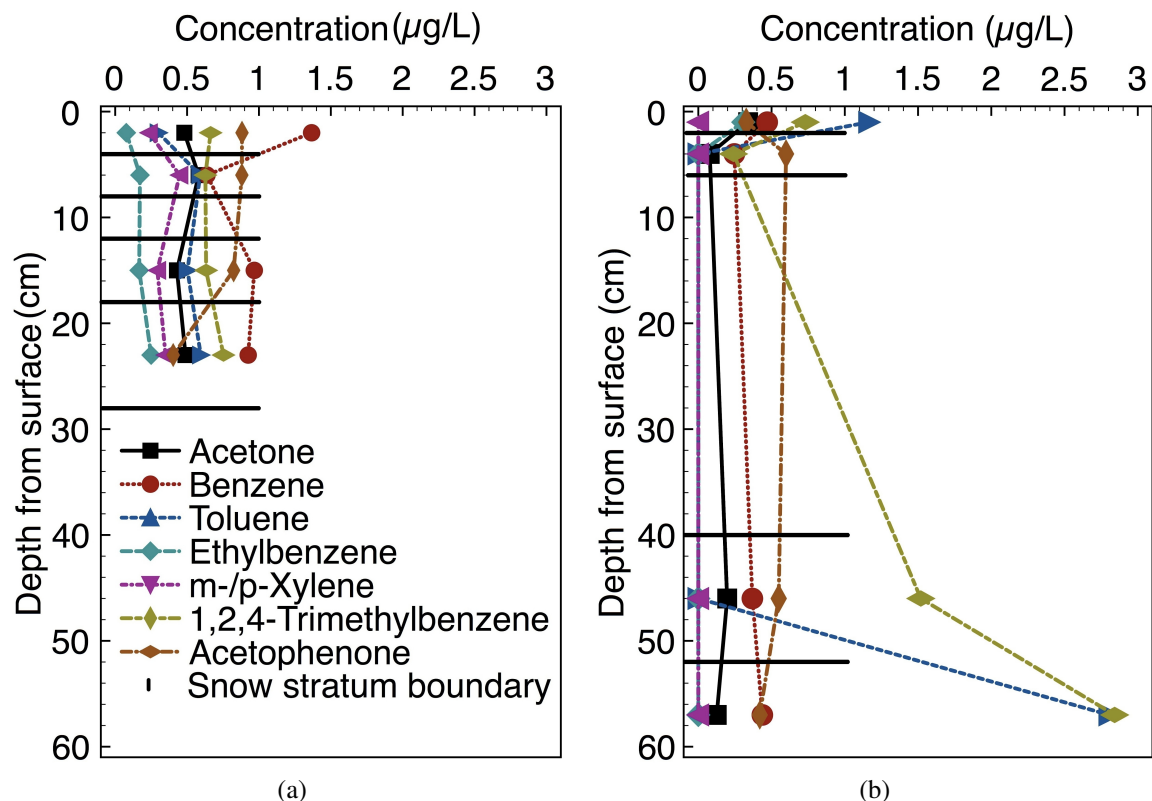
1. Snow and air sampling locations in Alert, Nunavut: Figure A.1.
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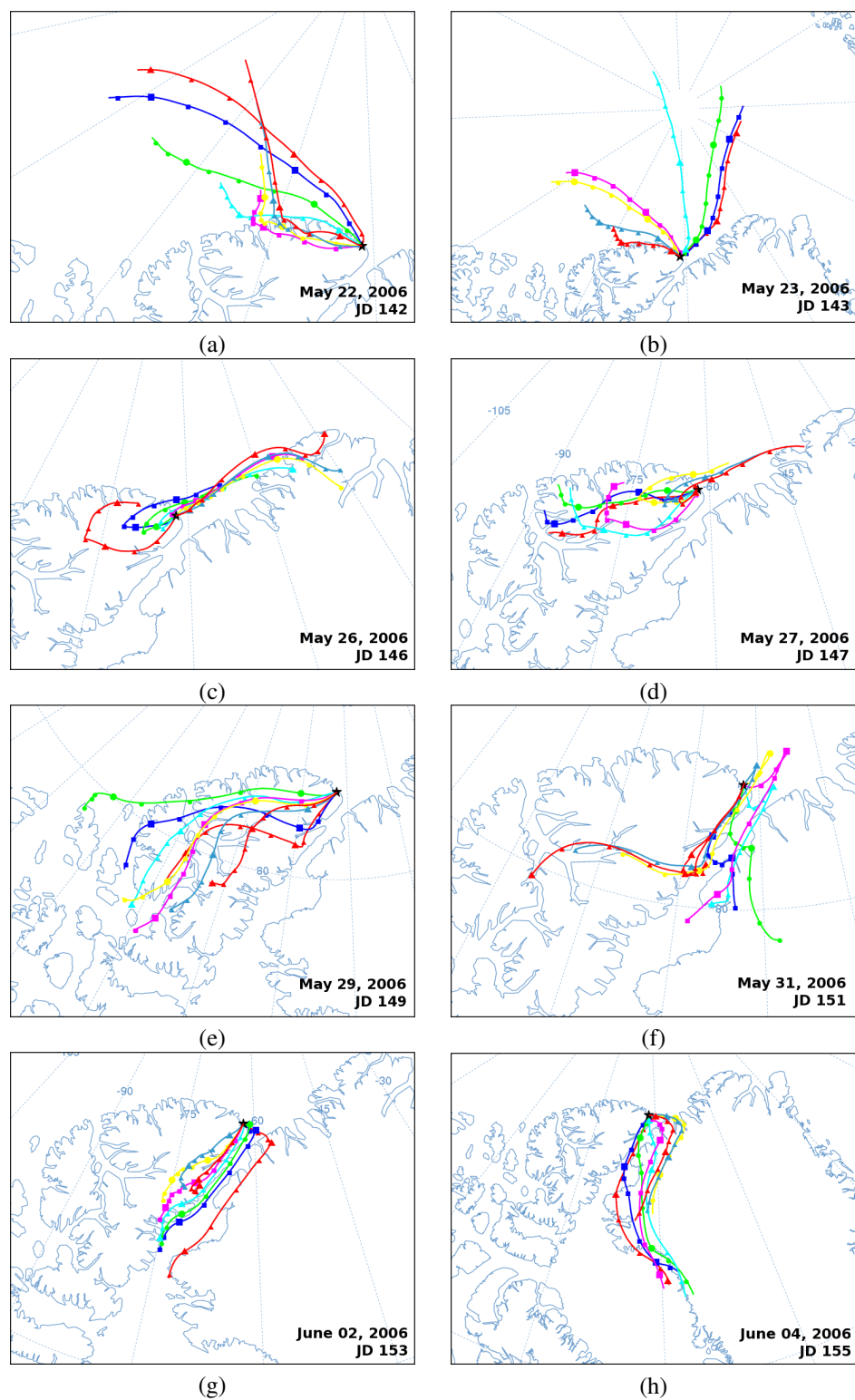
**Fig. A.1** Snow and air sampling locations in Alert, Nunavut (82° 29' 58" N, 62° 20' 5" W). Sampling site located over soil upwind of the military base (red circle) and airfield. Predominant wind direction was from the South-West. © Topographic map reproduced under licence from Her Majesty the Queen in Right of Canada, with permission of Natural Resources Canada. Scale: 1:50,000.



**Fig. A.2** Temperatures at the sampling site during sampling events from May 22 to June 2 (JD 142-153). Data were collected in a 1 m circle around the snow sampling area; error bars represent 3s with n=5. Environment Canada (EC) data were measured at the EC meteorological station at the time point closest to the sampling time.



**Fig. A.3** Depth profile data of snow pit samples for (a) May 26 and (b) June 2 for aromatic and oxygenated compounds. Black vertical bars represent snow layers sampled. Error bars were omitted for clarity; all relative standard deviations for duplicate measurements were < 15%.



**Fig. A.4** Additional HYSPLIT back trajectory data for days and times of snow sampling.

**Table A.1** Ancillary data collected during snow and air sampling. Environment Canada (EC) data were measured at the Alert meteorological station and obtained from the EC Canada National Climate Data Archive for the hour of sampling. All other - i.e., sampling site specific data, were collected in a 1 m circle around the snow sampling area. Times rounded to 15 min for field measurements and to the nearest hour for EC data. Wind direction rounded to 45 degrees for measured data. Snow terminology from <sup>9</sup>.

| Date (2006)               | May 22      | May 23     | May 25  | May 26  | May 27 | May 29       | May 30  | May 31  | June 02           | June 04           |
|---------------------------|-------------|------------|---------|---------|--------|--------------|---------|---------|-------------------|-------------------|
| Sampling time (EST)       | 17:00       | 16:15      | 14:00   | 12:30   | 14:00  | 12:00        | 13:00   | 13:00   | 12:00             | 16:00             |
| EC Rel. humidity (%)      | 88          | 81         | 89      | 87      | 87     | 92           | 89      | 98      | 93                | 74                |
| EC column ozone (d.u.)    | 384.1       | 390.9      | 395.7   | 385.1   | 386.1  | 380.8        | 396.1   | 415.0   | 401.2             | 363.5             |
| EC Wind speed (km/h)      | 9           | 4          | 15      | 7       | 0      | 13           | 9       | 7       | 4                 | 19                |
| EC Station Pressure (kPa) | 102.51      | 102.06     | 100.64  | 100.71  | 101.26 | 101.56       | 100.92  | 100.08  | 100.34            | 100.33            |
| EC Wind direction (deg)   | 340         | 360        | 120     | 90      | 90     | 350          | 120     | 320     | 100               | 210               |
| Wind direction (deg)      | 315         | 225        | 135     | 45      | 90     | 135          | 180     | 180     | 225               | 225               |
| Snow depth (cm)           | 103         | 48.0       | 106     | 85.0    | 19.0   | 21.0         | 27.0    | 43.0    | 61.0              | 29.0              |
| Cloud cover               | full        | full       | partial | partial | thin   | thin         | thin    | thin    | thin              | partial           |
| Precipitation             | light snow  | light snow | none    | snow    | none   | blowing snow | none    | none    | none              | none              |
| Snow flake properties     | needle-like | broken     | small   | large   | large  | rounded      | rounded | rounded | clustered rounded | clustered rounded |
| Snow clusters             | none        | light      | light   | light   | light  | medium       | medium  | strong  | strong            | strong            |

**Table A.2** VOC determined in Alert using GC/FID methodology in alphabetical order. 'Ret. time snow/LOQ snow' – retention time/limit of quantitation of compound in snow sample; 'Ret. time air/LOQ air' – retention time/LOQ of compound in air sample; LOQ calculated as 10 times the standard deviation of the blank. Data in this table refer to the standard solution. 'ND' – not determined

| Compound                | CAS No.                   | Ret. time snow<br>(min) | Ret. time air<br>(min) | LOQ snow<br>( $\mu\text{g/L}$ ) | LOQ air<br>( $\text{ng/L}$ ) |
|-------------------------|---------------------------|-------------------------|------------------------|---------------------------------|------------------------------|
| Acetone                 | [67-64-1]                 | 1.510                   | 1.910                  | 0.085                           | 0.0002                       |
| Acetophenone            | [98-86-2]                 | 12.39                   | 11.76                  | 0.037                           | 0.0003                       |
| 1,2-Dichlorobenzene     | [95-50-1]                 | 12.12                   | 11.41                  | 0.064                           | 0.0019                       |
| 1-Chloro-2-bromopropane | [3017-95-6]               | 7.363                   | 8.042                  | 0.011                           | 0.049                        |
| Bromoform               | [75-25-2]                 | 9.623                   | 9.342                  | 0.12                            | 0.022                        |
| Chlorobenzene           | [108-90-7]                | 8.871                   | 9.168                  | 0.067                           | 0.015                        |
| Chloroform              | [67-66-3]                 | 2.853                   | 9.057                  | 0.053                           | 0.0011                       |
| Dibromochloromethane    | [124-48-1]                | 7.712                   | 7.716                  | 0.13                            | 0.011                        |
| Dibromomethane          | [74-95-3]                 | 5.018                   | 5.671                  | 0.17                            | 0.026                        |
| Trichloroethene         | [79-01-6]                 | 4.946                   | 5.338                  | 0.039                           | 0.0053                       |
| 1,3,5-Trimethylbenzene  | [108-67-8]                | 11.06                   | 10.51                  | 0.027                           | 0.025                        |
| 1,2,4-Trimethylbenzene  | [95-63-6]                 | 11.41                   | 10.20                  | 0.039                           | 0.031                        |
| Benzene                 | [71-43-2]                 | 3.811                   | 4.295                  | 0.016                           | 0.0039                       |
| Ethylbenzene            | [100-41-4]                | 9.163                   | ND                     | 0.0063                          | ND                           |
| Styrene                 | [100-42-5]                | 9.726                   | 9.406                  | 0.038                           | 0.0001                       |
| Toluene                 | [108-88-3]                | 7.026                   | 7.137                  | 0.030                           | 0.0007                       |
| m-/p-Xylene             | [108-38-3]/<br>[106-42-3] | 9.822                   | 9.084                  | 0.032                           | 0.0010                       |
| o-Xylene                | [95-47-6]                 | 9.733                   | 9.473                  | 0.028                           | 0.0058                       |

**Table A.3** VOC concentrations in air  $\pm$  3s (n=2); (ng/L) for all sampling events; ' $<LOQ$ ' – below limit of quantitation; 'ND' – not determined.

| Date                     | May 22, 2006        | May 25, 2006        | May 26, 2006        | May 29, 2006        | May 30, 2006        | May 31, 2006        | Jun 02, 2006        |
|--------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Acetone                  | 0.023 $\pm$ 0.006   | 0.004 $\pm$ 0.002   | 0.031 $\pm$ 0.012   | 0.027 $\pm$ 0.012   | 0.070 $\pm$ 0.018   | 0.004 $\pm$ 0.001   | 0.009 $\pm$ 0.002   |
| Chloroform               | 0.005 $\pm$ 0.001   | 0.006 $\pm$ 0.002   | 0.009 $\pm$ 0.002   | 0.015 $\pm$ 0.006   | 0.018 $\pm$ 0.009   | 0.001 $\pm$ 0.001   | 0.003 $\pm$ 0.001   |
| Benzene                  | 0.040 $\pm$ 0.006   | 0.045 $\pm$ 0.015   | 0.024 $\pm$ 0.003   | 0.029 $\pm$ 0.006   | 0.024 $\pm$ 0.003   | 0.045 $\pm$ 0.012   | 0.019 $\pm$ 0.006   |
| Trichloroethene          | 0.094 $\pm$ 0.024   | 0.83 $\pm$ 0.21     | 0.37 $\pm$ 0.12     | 1.0 $\pm$ 0.3       | 0.23 $\pm$ 0.06     | 0.83 $\pm$ 0.18     | 0.520 $\pm$ 0.090   |
| Dibromomethane           | 0.1302 $\pm$ 0.0360 | 0.0797 $\pm$ 0.0240 | 0.0860 $\pm$ 0.0300 | 0.1599 $\pm$ 0.0060 | 0.0314 $\pm$ 0.0030 | 0.0797 $\pm$ 0.0180 | 0.0893 $\pm$ 0.0120 |
| Toluene                  | 0.0039 $\pm$ 0.0006 | 0.0024 $\pm$ 0.0003 | 0.0039 $\pm$ 0.0009 | 0.0052 $\pm$ 0.0018 | $<LOQ$              | 0.0024 $\pm$ 0.0009 | 0.0083 $\pm$ 0.0006 |
| 1-Chloro-2-bromo-propane | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | 0.0397 $\pm$ 0.0060 | $<LOQ$              | $<LOQ$              |
| Dibromochloromethane     | 0.0199 $\pm$ 0.0060 | 0.0735 $\pm$ 0.0150 | 0.0202 $\pm$ 0.0060 | 0.1394 $\pm$ 0.0270 | $<LOQ$              | 0.0735 $\pm$ 0.0090 | 0.0527 $\pm$ 0.0060 |
| Chlorobenzene            | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | 0.0177 $\pm$ 0.0030 | $<LOQ$              | $<LOQ$              |
| Ethylbenzene             | ND                  | ND                  | ND                  | ND                  | ND                  | ND                  | ND                  |
| m-/p-Xylene              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | 0.0081 $\pm$ 0.0021 |
| Bromoform                | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              |
| Styrene                  | $<LOQ$              | 0.0002 $\pm$ 0.0001 | $<LOQ$              | $<LOQ$              | $<LOQ$              | 0.0002 $\pm$ 0.0002 | 0.0004 $\pm$ 0.0001 |
| o-Xylene                 | 0.0075 $\pm$ 0.0015 | 0.0083 $\pm$ 0.0024 | 0.0066 $\pm$ 0.0027 | 0.0144 $\pm$ 0.0015 | 0.0156 $\pm$ 0.0021 | 0.0083 $\pm$ 0.0009 | 0.0230 $\pm$ 0.0090 |
| 1,3,5-Trimethylbenzene   | 0.0347 $\pm$ 0.0060 | 0.0389 $\pm$ 0.0030 | 0.0366 $\pm$ 0.0120 | 0.0471 $\pm$ 0.0060 | 0.0421 $\pm$ 0.0030 | 0.0389 $\pm$ 0.0060 | 0.0291 $\pm$ 0.0120 |
| 1,2,4-Trimethylbenzene   | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              | $<LOQ$              |
| 1,2-Dichlorobenzene      | $<LOQ$              | $<LOQ$              | $<LOQ$              | 0.0017 $\pm$ 0.0003 | 0.0020 $\pm$ 0.0006 | $<LOQ$              | $<LOQ$              |
| Acetophenone             | 0.0005 $\pm$ 0.0001 | 0.0004 $\pm$ 0.0001 | 0.0005 $\pm$ 0.0001 | 0.0010 $\pm$ 0.0003 | 0.0005 $\pm$ 0.0001 | 0.0040 $\pm$ 0.0009 | 0.0011 $\pm$ 0.0003 |

**Table A.4** VOC concentrations in snow  $\pm 3s$  ( $n=2$ ); ( $\mu\text{g/L}$ ) for all sampling events; <LOQ for not detected

| Date                     | May 22, 2006      | May 25, 2006      | May 26, 2006       | May 29, 2006      | May 30, 2006      | May 31, 2006      | Jun 02, 2006      |
|--------------------------|-------------------|-------------------|--------------------|-------------------|-------------------|-------------------|-------------------|
| Acetone                  | 0.336 $\pm$ 0.060 | 0.184 $\pm$ 0.060 | 0.580 $\pm$ 0.120  | 0.388 $\pm$ 0.150 | 0.319 $\pm$ 0.012 | 0.277 $\pm$ 0.120 | 0.126 $\pm$ 0.021 |
| Chloroform               | 3.97 $\pm$ 0.96   | 0.291 $\pm$ 0.118 | 0.270 $\pm$ 0.042  | <LOQ              | 2.50 $\pm$ 0.58   | 1.57 $\pm$ 0.31   | <LOQ              |
| Benzene                  | 1.57 $\pm$ 0.42   | 3.76 $\pm$ 0.63   | 0.638 $\pm$ 0.282  | 0.917 $\pm$ 0.243 | <LOQ              | 0.511 $\pm$ 0.036 | 0.437 $\pm$ 0.087 |
| Trichloroethene          | 0.453 $\pm$ 0.068 | 0.393 $\pm$ 0.120 | 0.924 $\pm$ 0.254  | 0.043 $\pm$ 0.003 | <LOQ              | 0.635 $\pm$ 0.109 | 0.573 $\pm$ 0.148 |
| Dibromomethane           | 5.07 $\pm$ 1.67   | <LOQ              | <LOQ               | <LOQ              | <LOQ              | <LOQ              | <LOQ              |
| Toluene                  | 1.27 $\pm$ 0.27   | 0.271 $\pm$ 0.063 | 0.591 $\pm$ 0.090  | 0.408 $\pm$ 0.060 | <LOQ              | 1.00 $\pm$ 0.18   | 2.81 $\pm$ 0.36   |
| 1-Chloro-2-bromo-propane | 0.141 $\pm$ 0.033 | <LOQ              | 0.081 $\pm$ 0.019  | 0.067 $\pm$ 0.009 | <LOQ              | 0.031 $\pm$ 0.003 | 0.086 $\pm$ 0.018 |
| Dibromochloromethane     | 1.43 $\pm$ 0.24   | 0.771 $\pm$ 0.090 | 0.884 $\pm$ 0.210  | 0.514 $\pm$ 0.030 | 0.143 $\pm$ 0.030 | 0.258 $\pm$ 0.033 | 1.48 $\pm$ 0.27   |
| Chlorobenzene            | 0.104 $\pm$ 0.015 | <LOQ              | 1.08 $\pm$ 0.18    | 0.314 $\pm$ 0.090 | <LOQ              | 0.153 $\pm$ 0.027 | 0.376 $\pm$ 0.009 |
| Ethylbenzene             | 0.786 $\pm$ 0.132 | 0.008 $\pm$ 0.001 | 0.172 $\pm$ 0.051  | 0.132 $\pm$ 0.036 | <LOQ              | <LOQ              | <LOQ              |
| m-/p-Xylene              | 1.89 $\pm$ 0.42   | <LOQ              | 0.448 $\pm$ 0.135  | 0.685 $\pm$ 0.147 | <LOQ              | <LOQ              | <LOQ              |
| Bromoform                | 2.02 $\pm$ 0.84   | 0.357 $\pm$ 0.034 | 33.9 $\pm$ 4.7     | 0.623 $\pm$ 0.261 | 19.8 $\pm$ 3.3    | 15.4 $\pm$ 3.0    | 5.14 $\pm$ 1.11   |
| Styrene                  | 39.0 $\pm$ 6.3    | 3.85 $\pm$ 0.45   | 3.46 $\pm$ 0.60    | 10.6 $\pm$ 3.1    | <LOQ              | 11.6 $\pm$ 3.4    | 27.9 $\pm$ 3.4    |
| o-Xylene                 | 1.19 $\pm$ 0.09   | 0.162 $\pm$ 0.033 | 0.587 $\pm$ 0.171  | 0.235 $\pm$ 0.093 | 0.303 $\pm$ 0.066 | 0.219 $\pm$ 0.066 | 0.802 $\pm$ 0.027 |
| 1,3,5-Trimethylbenzene   | 0.537 $\pm$ 0.109 | 1.107 $\pm$ 0.298 | 1.07 $\pm$ 0.26    | 1.16 $\pm$ 0.29   | 0.031 $\pm$ 0.009 | 0.263 $\pm$ 0.058 | 0.577 $\pm$ 0.065 |
| 1,2,4-Trimethylbenzene   | 0.977 $\pm$ 0.284 | 0.424 $\pm$ 0.150 | 0.627 $\pm$ 0.1923 | 0.588 $\pm$ 0.066 | 0.211 $\pm$ 0.102 | 0.289 $\pm$ 0.068 | 0.524 $\pm$ 0.169 |
| 1,2-Dichlorobenzene      | 20.1 $\pm$ 4.5    | 11.6 $\pm$ 3.5    | 7.18 $\pm$ 1.75    | 7.59 $\pm$ 3.01   | 19.7 $\pm$ 3.7    | 18.4 $\pm$ 3.2    | 18.4 $\pm$ 4.2    |
| Acetophenone             | 1.00 $\pm$ 0.25   | 0.365 $\pm$ 0.088 | 0.881 $\pm$ 0.268  | 0.691 $\pm$ 0.034 | 0.149 $\pm$ 0.037 | 0.100 $\pm$ 0.040 | 0.419 $\pm$ 0.117 |



**Table A.5** Concentrations  $\pm 3s$  (in  $\mu\text{g/L}$ ;  $3s$ :  $3 \times$  standard deviation from duplicate measurements) of toluene, m/p-xylene, acetophenone and bromoform in snow and frost flower samples in Barrow, AK in 2009. All concentrations were determined in surface snow, except for 20 Mar (1), when frost flowers were sampled. ND: Not detected

| Analyte      | 04 Mar (1)      | 04 Mar (2)      | 05 Mar          | 06 Mar          | 07 Mar          | 08 Mar          | 09 Mar          | 20 Mar (1)        | 20 Mar (2)      |
|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------|-----------------|
| Toluene      | $0.33 \pm 0.07$ | $0.28 \pm 0.01$ | $0.28 \pm 0.04$ | $0.34 \pm 0.17$ | $0.29 \pm 0.03$ | $0.28 \pm 0.18$ | $0.29 \pm 0.09$ | $0.022 \pm 0.017$ | ND              |
| m-/p-Xylene  | $0.32 \pm 0.01$ | $0.30 \pm 0.02$ | $0.29 \pm 0.03$ | $0.30 \pm 0.11$ | $0.29 \pm 0.04$ | $0.30 \pm 0.04$ | $1.2 \pm 0.1$   | ND                | ND              |
| Acetophenone | $1.2 \pm 0.1$   | $1.3 \pm 0.02$  | $1.2 \pm 0.07$  | $1.5 \pm 0.1$   | $1.5 \pm 0.1$   | $1.6 \pm 0.3$   | $0.29 \pm 0.02$ | ND                | $0.63 \pm 0.16$ |
| Bromoform    | ND              | ND              | ND              | ND              | ND              | ND              | ND              | $0.19 \pm 0.042$  | ND              |