**S1**: Summary of molar gas ratios, $\delta^{18}O_{O2}$ (‰) and $\delta^{15}N_{N2}$ (‰) of air entrapped in glacier ice collected from the Agassiz Ice Cap (Ellesmere Island, NU) and the Barnes Ice Cap (Baffin Island, NU).

| Site | $O_2/Ar$ | $N_2/Ar$ | $\delta^{18}O_{O_2}$ | $\delta^{15}N_{N_2}$ |
|---|---|---|---|---|
| *Agassiz Ice Cap* | | | | |
| 145 - 2 | 22.0334 | 82.5811 | 0.23 | -0.02 |
| 145 - 3 | 22.1571 | 86.1663 | | 0.08 |
| 146 - 4 | 23.2384 | 84.7776 | 1.01 | 0.48 |
| 146 - 6 | 22.3223 | 83.2443 | | 0.59 |
| 146 - 7 | 22.2602 | 84.7846 | 0.35 | 0.24 |
| 146 - 8 | 23.0144 | 91.4909 | | 0.91 |
| 147 - 9 | 22.6058 | 88.3066 | 0.66 | 0.83 |
| 147 - 11 | 22.1765 | 89.4300 | | 0.52 |
| 132 - 1 | 23.5879 | 88.1347 | 1.72 | 0.30 |
| 132 - 2 | 22.5692 | 90.9547 | 2.27 | 0.77 |
| 135 - 2 | 22.0974 | 88.8488 | 1.11 | 0.79 |
| 135 - 3.1 | 22.3307 | 87.2859 | 1.70 | 0.97 |
| 135 - 3.2 | 22.6156 | 85.4979 | 3.11 | 0.96 |
| *AVERAGE* | *22.5391* | *87.0387* | *1.35* | *0.57* |
| *SD* | *0.4763* | *2.8080* | *0.94* | *0.34* |
| | | | | |
| *Barnes Ice Cap (Anomalous zone)* | | | | |
| B1.1 | 19.7595 | 77.3237 | -0.25 | -0.46 |
| B1.2 | 19.8799 | 76.6669 | 0.21 | -0.59 |
| B1.3 | 20.3532 | 76.3040 | 0.01 | -0.49 |
| *AVERAGE* | *19.9975* | *76.7649* | *-0.01* | *-0.51* |
| *SD* | *0.3138* | *0.5169* | *0.23* | *0.07* |
| | | | | |
| *Barnes Ice Cap (Pleistocene-age ice)* | | | | |
| W1.1 | 19.6460 | 77.2372 | -0.14 | 0.30 |
| W1.2 | 19.8698 | 77.1636 | 1.41 | -0.13 |
| W1.3 | 19.1271 | 75.8044 | 1.19 | -0.34 |
| W2.1 | 19.8283 | 77.7203 | 1.70 | -0.05 |
| W2.2 | 19.6532 | 76.2106 | 1.28 | 0.21 |
| W2.3 | 17.3531 | 79.3685 | 0.63 | -0.23 |
| W3.2 | 18.8218 | 78.7121 | 0.74 | 0.18 |
| W3.3 | 18.3925 | 81.0981 | 0.28 | -0.12 |
| *AVERAGE* | *19.0865* | *77.9144* | *0.89* | *-0.02* |
| *SD* | *0.8747* | *1.7444* | *0.62* | *0.23* |

**S2**: Summary of molar gas ratios, $\delta^{18}O_{O2}$ (‰) and $\delta^{15}N_{N2}$ (‰) of air entrapped in ice collected from the Firth River aufeis (northern Yukon Territory), late Pleistocene segregated-intrusive ice (Aklavik Plateau, NWT) and Holocene segregated ice (Nunavik, northern Quebec).

| Site | $O_2/Ar$ | $N_2/Ar$ | $\delta^{18}O_{O_2}$ | $\delta^{15}N_{N_2}$ |
|---|---|---|---|---|
| *Firth River aufeis (northern Yukon Territory)* | | | | |
| FR 0-10 | 20.7288 | 87.0635 | -0.19 | 0.12 |
| FR 9-10 | 18.2851 | 77.9312 | -1.38 | 0.25 |
| FR-20-21 | 17.2214 | 63.0741 | -1.73 | 0.36 |
| FR 23-24 | 17.6451 | 85.6206 | -1.59 | -0.83 |
| FR 28-29a | 17.2319 | 56.8042 | -1.38 | 0.10 |
| FR 28-29b | 16.636 | 56.7593 | -0.97 | 0.13 |
| FR 30-31 | 19.9633 | 60.6799 | -0.52 | 0.14 |
| FR 31-35a | 18.8361 | 70.048 | -0.67 | 0.54 |
| FR 31-35b | 17.8755 | 60.4163 | -0.61 | 0.92 |
| FR 36-37a | 20.3191 | 60.2636 | -1.52 | -0.50 |
| FR 36-37b | 20.5707 | 69.564 | -1.40 | -0.69 |
| FR 42-44 | 20.1197 | 73.2109 | 0.04 | 0.13 |
| *AVERAGE* | *18.7861* | *68.4530* | *-0.99* | *0.05* |
| *SD* | *1.4877* | *10.6633* | *0.59* | *0.50* |
| | | | | |
| *Late Pleistocene segregated-intrusive ice (Aklavik Plateau)* | | | | |
| WR-00-03 | 11.4225 | 75.5299 | -0.07 | -0.93 |
| | | | | |
| *Holocene segregated ice (Nunavik)* | | | | |
| 301 | 1.344 | 62.2114 | 0.54 | 0.27 |
| 254-88 | 2.8754 | 58.3071 | 2.45 | 0.43 |
| 288-1.46 | 3.1187 | 54.7919 | 2.93 | 0.41 |
| *AVERAGE* | *2.4460* | *58.4368* | *1.97* | *0.37* |
| *SD* | *0.9621* | *3.7115* | *1.27* | *0.09* |

**S3**: $\delta^{18}O_{O2}$, $\delta^{15}N_{N2}$ results (‰) of compressed air and compressed air introduced in degassed ice to verify the accuracy and precision of analysis.

| Trial run | $\delta^{18}O_{O_2}$ | | $\delta^{15}N_{N_2}$ | |
|---|---|---|---|---|
| | Comp. air | Comp. air in degassed ice | Comp. air | Comp. air in degassed ice |
| 1 | -11.15 | -6.68 | 0.80 | 0.35 |
| 2 | -11.23 | -6.60 | 0.84 | 0.35 |
| 3 | -10.96 | -6.56 | 0.82 | 0.59 |
| 4 | -10.52 | -6.77 | | 0.58 |
| 5 | -10.59 | | 0.86 | |
| 6 | -10.07 | | 0.42a | |
| *AVERAGE* | *-10.75* | *-6.65* | *0.83* | *0.47* |
| *SD* | *0.44* | *0.08* | *0.02* | *0.13* |

[a]Note that the $\delta^{15}N$ outlier was removed in the compressed air due to a change in flow rate of the standard $N_2$ gas during analysis on mass spectrometer.

**S4**: Molar gas ratios and $\delta^{18}O_{O2}$, $\delta^{15}N_{N2}$ (‰) results of the standard reference gas, which consists of atmospheric air sampled outside the laboratory building.

| Standard | $O_2$/Ar | $N_2$/Ar | $\delta^{18}O_{O_2}$ | $\delta^{15}N_{N_2}$ |
|---|---|---|---|---|
| 1 | 23.2542 | 79.1791 | 0.07 | -0.08 |
| 2 | 23.0937 | 77.0468 | 0.23 | 0.36 |
| 3 | 22.7182 | 72.6509 | 0.51 | -0.00 |
| 4 | 22.0272 | 74.0258 | -0.27 | -0.35 |
| 5 | 21.5612 | 86.1006 | -0.06 | 0.01 |
| 6 | 22.2381 | 88.9197 | -0.15 | 0.23 |
| 7 | 22.1303 | 92.2314 | -0.05 | 0.04 |
| 8 | 21.9121 | 91.3872 | 0.12 | 0.05 |
| 9 | 22.9002 | 90.8738 | -0.48 | -0.33 |
| *AVERAGE* | *22.4261* | *83.6017* | *-0.009* | *-0.0006* |
| *SD* | *0.5848* | *7.8791* | *0.291* | *0.232* |