TITLE:
Arctic snow black carbon concentrations, and absorption by other light-absorbing aerosol.

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DATA SET OVERVIEW, INSTRUMENT DESCRIPTION & DATA COLLECTION AND PROCESSING:

The data presented are from samples of snow or melting sea ice gathered by ourselves or by volunteers, mostly from 2006 to 2009 but with some data from earlier years. Almost all samples were collected in the spring season (March to early May) when the combination of snow cover and exposure to sunlight is maximized, and before the snow had started to melt. In many locations (Canadian Arctic, Russia, Greenland, Tromsø and Ny Ålesund) samples were gathered at intervals throughout the snowpack depth, giving information on the seasonal evolution of BC concentrations as the snow accumulated (and/or sublimated) throughout the winter.

Three sub-sets of the data include samples of snow which was actively melting or which had previously melted:
1. Samples were gathered in the summer from melting Arctic snow/sea ice. Some of these samples were collected by volunteers, who in some cases identified the samples as "snow" or "melting snow". However, the surface of melting sea ice looks very much like melting snow, and samples gathered in July or August are much more likely to be melting sea ice than melting snow. Due to this ambiguity, we have labeled these samples as "unknown".
2. Samples were gathered in the summer from Greenland, which is perennially snow-covered, of both cold and melting snow. In particular, in 2008, three snow pits were dug near the Dye-2 station (66.474°N, 313.720°E), which is in the percolation zone: each summer the surface snow melts and percolates into the snowpack until it reaches a depth where temperatures are again below freezing, and it refreezes. Three adjacent pits were sampled, and for all three there was a layer of newly fallen snow on top of a melt layer; below that is snow that had not recently melted but which may have been affected by the percolation of melt water into the snow. For these

profiles, only the samples of snow which had experienced melt are labeled as "melting snow"; the snow below this is just labeled as "unknown".
3. Samples were gathered in the late spring 2008 from Tromsø, Norway over a series of days when the snowpack first started to melt, which occurred on 23 May. We have labeled all samples from throughout the snowpack depth as "melting snow" from 23 May onward. While it was only the surface snow that was actively melting, we do not know how deep the melt layer was nor how the sub-melt-layer snow was affected by the percolation of meltwater through the snowpack.

In all cases we attempted to gather samples away from local sources of pollution. In many cases test samples were gathered along transects moving away from, e.g., roads, snowmobile tracks, or local research stations in order to confirm that the samples included here were regionally representative. In most cases we believe the data included here are free of the influence of local sources. However, we would like to highlight one sub-set of the data where this was not the case: entries 604-609 from ~67.718°N, 64.379°E were taken ~30km from the Russian city of Vorkuta. The BC concentrations here were dramatically higher (>>100ng/g) than anywhere else in the Arctic and we believe therefore that they are not more broadly representative of northwest Russia, though they do highlight the fact that a sufficiently large source of BC can influence a relatively large region.

We have labeled all samples as either "newly fallen snow", "snow", "melting snow", "sea ice" or "uncertain". As noted above, "uncertain" applies to, e.g., samples from the surface of Arctic sea ice which could be either melting snow or melting sea ice. The labels "newly fallen snow" and "melting snow" are only used when there is no ambiguity that this is the case. The more generic label "snow" – which encompasses most of our samples – covers a broad category of variously aged snow, windblown snow, sastrugi, and possibly surface frost (new or aged). We have tried to be careful in assigning these labels but with the range of people involved in snow sampling it is impossible to be completely confident all samples are appropriately labeled. Where such information is available, we also indicate what fraction of the total snowpack depth the sample was taken from.

All snow and sea ice samples were melted, filtered and then optically analyzed for spectrally-resolved (300-750nm) light absorption. Light absorption was converted to a mass loading on the filter ($\mu g/cm^2$) using the measured absorption in the 650-700nm wavelength band and a set of calibration standards. This loading, together with the filter exposed area and the volume of water poured through the filter, give a BC mass concentration (units: 10^{-9} grams BC per gram of snow, or ng/g, or ppb). The calibration standards are filters loaded with known amounts of synthetic soot with a mass absorption efficiency of $6m^2/g$ at 550nm. The spectral-dependence of light absorption of this synthetic soot, as with uncoated atmospheric BC, follows a λ^{-1} relationship. Our derived concentrations of BC therefore reflect the true concentration of BC if the BC in our samples has the same optical properties as these calibration standards. If the mass absorption efficiency of BC from our snow/ice samples is in fact, e.g., higher (such as $7.5m^2/g$ as suggested by Bond and Bergstrom, 2006), we will have over-estimated the BC concentrations by ~25%.

Our optical analysis measures light absorption by all insoluble constituents in the snow, not just black carbon. As discussed in Grenfell et al. (2011) and Doherty et al. (2010) the absorption

Ångstrom exponent, *Å*, of pure atmospheric BC is believed to be ~1.0 and is >1.0 for non-BC light-absorbing aerosol. All of our samples have *Å*>1, so it appears there are always light-absorbing constituents other than BC present in the snow/sea ice. We therefore use the measured spectral dependence of absorption and assumptions about the spectral dependence of non-BC constituents to separate absorption by BC and non-BC constituents. This allows us to calculate the following parameters:

- $C_{BC}^{\max}$ (ng/g): *maximum BC* is the mass of black carbon per mass of snow, if all aerosol light absorption at 650-700nm is due to BC.
- C_{BC}^{est} (ng/g): *estimated BC* is the estimated true mass of black carbon per mass of snow, derived by separating the spectrally-resolved total light absorption into BC and non-BC fractions based on the absorption Ångstrom exponent ($Å_{tot}$) of the material on the filter, and by assigning absorption Ångstrom exponents (measured 450-600nm) of 1.0 and 5.0 to BC and non-BC light-absorbing aerosol respectively.
- C_{BC}^{equiv} (ng/g): *equivalent BC* is the amount of black carbon that would need to be present in the snow to account for the wavelength-integrated total light absorption from 300 to 750nm.
- $Å_{tot}$: *absorption Ångstrom exponent*, calculated between 450nm and 600nm, for all light absorbing aerosol deposited on the filter.
- f_{nonBC}^{est}: *fraction of light absorption by non-BC light absorbing aerosol 300-750nm*, weighted by the downwelling solar flux then spectrally integrated.

Uncertainties in these parameters, including the uncertainty associated with the assumptions about *Å* for BC and non-BC constituents required to calculate C_{BC}^{est} and f_{nonBC}^{est} are discussed in detail by Doherty et al. (2010), Section 6.

DATA FORMAT:

Data are provided as both an Excel file (.xlsx) and as comma-separated values (.csv). Values in headers are either self-explanatory (e.g. sample latitude, date) or can be related directly to the five parameters described above.

These data are version 2, dated 2 February 2011. See comments below regarding how they differ from that given in Doherty et al., 2011.

DATA REMARKS:

Two important notes:

1. After publication of Doherty et al., 2010 we found an error in our data analysis which resulted in a low bias in the concentration-dependent parameters ($C_{BC}^{\max}$, C_{BC}^{est} and C_{BC}^{equiv}; see below) of 11%. We have corrected for this error in the data file ArcticSnowBC_Dohertyetal_v1.xls.

2. We will be producing an improved set of calibration standards which will be used to re-analyze all of our samples. This may result in adjustments to our results, though we do not expect these changes to be large (<15%).

We ask that you please notify us if you are going to use these data for published research.

REFERENCES:

→ *Instrument and method description:*

Grenfell, T. C., S. J. Doherty, A. D. Clarke, and S. G. Warren: Spectrophotometric determination of absorptive impurities in snow, *Appl. Opt.*, 50(14), 2037-2048, 2011. Available at: http://www.atmos.washington.edu/~sgw/PAPERS/2010_ISSW_Appl_Opt_submitted.pdf

→ *Summary and discussion of the snow and sea ice data included in "ArcticSnowBC_Warrenetal.xls", including maps of sample locations:*

Doherty, S. J., S. G. Warren, T. C. Grenfell, A. D. Clarke, and R. E. Brandt: Light-absorbing impurities in Arctic snow, *Atmos. Chem. Phys.*, 10, 11647-11680, doi:10.5194/acp-10-11647-2010, 2010. http://www.atmos-chem-phys.net/10/11647/2010/acp-10-11647-2010.html

→ *Analysis of the sources of BC and other light-absorbing aerosol to the snow from a sub-set of the samples presented by Doherty et al. (2010):*

Hegg, D. A., S. G. Warren, T. C. Grenfell, S. J. Doherty, T. V. Larson, and A. D. Clarke: Source attribution of black carbon in arctic snow, *Environ. Sci. Technol.*, 43, 4016–4021, 2009. Available at: http://www.atmos.washington.edu/~sgw/PAPERS/2009_Hegg_EST.pdf

Hegg, D. A., S. G. Warren, T. C. Grenfell, S. J. Doherty and A. D. Clarke: Sources of light-absorbing aerosol in arctic snow and their seasonal variation, *Atmos. Chem. Phys.*, 10, 10923–10938, doi:10.5194/acp-10-10923-2010, 2010. http://www.atmos-chem-phys.net/10/10923/2010/acp-10-10923-2010.pdf