Correspondence

The effect of measurement geometry on recording solar radiation attenuation in snowpack (e-folding depth) using fibre-optic probes

The accurate measurement of solar irradiance in snowpack is critical for determining the optical properties of snowpack (e.g. Lee-Taylor and Madronich, 2002). Optical properties of snow are used to calculate photochemical reaction rates occurring in snowpack (e.g. Domine and Shepson, 2002; France and others, 2007) and to determine the isotopic depletion found in nitrate anions in snow, owing to photolysis of nitrate in snowpack (Frey and others, 2009). Snowpack photochemistry is implicated in the release of gaseous NO_x to the atmosphere above the snow (e.g. Domine and Shepson, 2002), halogen activation (e.g. Abbatt and others, 2010) and the transformation of bioaccumulative substances (Klán and Holoubek, 2002). The metric of light attenuation in snowpack is the e-folding depth, described by the Bouger–Beer–Lambert law (Barkstrom, 1972):

$$I_z = I_{z'}^{\frac{(z'-z)}{\varepsilon(\lambda)}} \quad (1)$$

where I_z is the light intensity at depth z within the snowpack, z' ($<z$) is the initial depth into the snowpack, and $\varepsilon(\lambda)$ is the wavelength- (λ-)dependent asymptotic e-folding depth for a homogeneous medium (the depth at which incident diffuse irradiance has been reduced to 1/e (~37%) of its initial value). Values of e-folding depths are frequently reported in the characterization of snow optical properties with typical values of 10–20 cm in the ultraviolet/visible wavelength range for Antarctic plateau near-surface snow (France and others, 2011a). It has been inferred by Warren and others (2006) that the measurement of e-folding depth may depend upon the geometry of the measurement. This correspondence provides evidence that careful measurement of the e-folding depth in several different measurement geometries does not affect the measured value of the e-folding depth.

During previous campaigns in Arctic, mid-latitude and Antarctic snowpack regions (e.g. King and Simpson, 2001; Fisher and others, 2005; Beine and others, 2006), a snow pit was dug and fibre-optic probe(s) were placed horizontally into the fresh snowpack face at different depths. More recently, studies have used vertically placed probe(s) in the laboratory (France and others, 2010) and in the field (Warren and others, 2006). It has been suggested by Warren and others (2006) that the vertical insertion of probes without a snow pit is preferable because the open pit required for horizontal placement of probes into the snowpack may significantly alter the radiation field being sampled.

Figure 1 demonstrates the measured e-folding depth as a function of solar wavelength measured in a drifted snowpack at Dome C, Antarctica, by fibre-optic probes placed (1) vertically, (2) at 45° to the horizontal (both with no snow pit dug) and (3) horizontally (with a snow pit). The method is described in the Appendix. The agreement between the three geometries of the measurements is convincing, suggesting that the geometry of the fibre placement does not matter. Note that when recording the irradiance in snowpack using horizontally placed fibres from a snow pit, the fibres are typically one to three e-folding depths below the surface and four to six e-folding depths from the snow-pit wall, so the perturbation of the radiation field through the snow pit is minimal. It was found with the vertical and angled fibre-optic placement that it was difficult to place the fibres without damaging the snow surface near the fibre placement, an issue for measuring e-folding depths close to the surface. With angled fibre-optic placement, it is also difficult to judge the depth of each fibre in the snowpack.

The data in Figure 1 are the result of a single experiment and are within the 20% repeatability uncertainty previously recorded for the repeated measurement of e-folding depth using an inferior instrument (France and others, 2011b). Thus we can conclude that the geometry of measuring e-folding depth may not be important and provides limited experimental evidence to disagree with the inference of Warren and others (2006). Using angled probes is the least preferred method due to the problems retaining a consistent angle and the decrease in the range of the depths that can be measured. Owing to the variability of snowpack stratigraphy, it is recommended that the vertical method is only used when it is not possible to probe horizontally using a pre-dug snow pit. The pre-dug snow pit also allows workers and sensitive equipment shelter from the cold winds.

ACKNOWLEDGEMENTS

We thank Institut Paul-Émile Victor (IPEV; French Polar Institute) for logistical support in the field, and staff at Dome C for support and help with this project. J.L.F. and M.D.K. thank the UK Natural Environment Research Council (NERC) for support through grants NE/F0004796/1 and NE/F010788. M.D.K. and J.L.F. thank the NERC Field Spectroscopy Facility for support and expertise through grants 555.0608 and

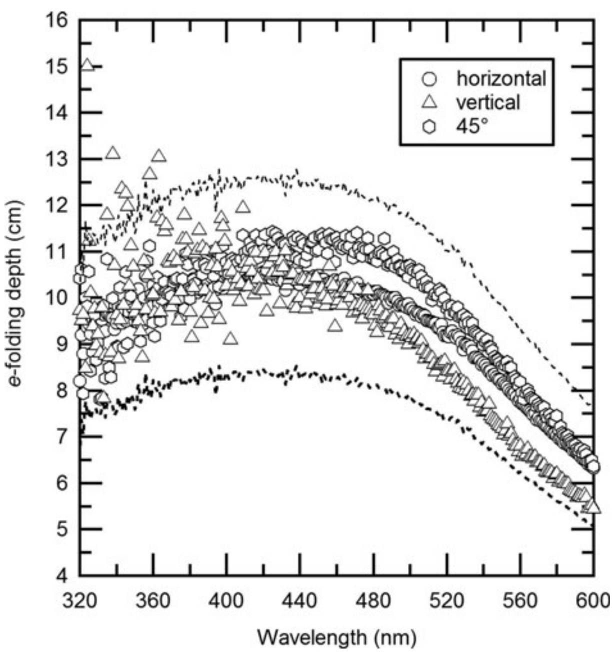

Fig. 1. Measured e-folding depths for a drifted snowpack at Dome C. Fibre optics used to measure in-snow light intensity were placed either horizontally (circles), vertically (triangles) or angled at 45° (hexagons). Dashed lines represent experimental error of 20% on the horizontally placed fibre method.

584.0609 and Royal Holloway Earth Sciences research strategy fund awards.

APPENDIX

A location at Dome C was chosen near to a shelter at 75.0623° S, 123.1945° E where windpacked snow had been artificially built up to generate an unusually homogeneous snowpack. A snow pit ~1.5 m × 1 m × 1 m was dug in this snowpack, and the in-snow irradiance measured using a custom-built six-spectrometer instrument described in detail by France and others (2011a). Each spectrometer was connected to a fibre-optic probe, and each fibre optic has a Lambertian diffusing optic fitted. The six fibre-optic probes were then placed horizontally into the snowpack at varying depths with a vertical spacing of ~5 cm and lateral displacement of ~15 cm between each fibre. The instrument records at different depths simultaneously, so no correction for changing sky conditions is required. Dark spectra were recorded in the field by capping the fibre-optic probes to allow for the removal of background electrical noise. A relative intensity calibration of the spectrometers and fibre optics was performed by simultaneously measuring the intensity of the solar radiation above the snowpack.

At a site 2 m away from the initially dug snow pit (to ensure no light leakage or disturbance from the previous digging or measurement process), but within the same homogeneous snowpack, the fibre-optic probes were inserted vertically downwards into the snowpack to varying depths. No snow pit was dug. To ensure no light leakage through the holes created by the probes, circular PTFE caps of 4 cm diameter were placed around the fibre-optic probe and were designed to sit flush on the snow surface. The horizontal displacements between each fibre-optic probe were ~20 cm and were arranged in a circular formation. A third set of in-snow irradiance measurements was made by means of angled placement of fibre-optic probes using the same method as outlined for the vertical placement, except each fibre-optic probe was inserted into the snowpack at 45° to the snowpack surface. The same calibrations as for the horizontally placed fibre optics were performed for both vertical and 45° angled placements. The sites at which the fibre optics were placed vertically and angled were then excavated to ensure that the snowpack stratigraphy was visually the same as the stratigraphy at the site of the horizontal measurements. The stratigraphy of the drifted snow was a single layer (to at least 40 cm depth) of loosely packed, rounded crystals, with some clustering of grains and typical grain sizes of 0.3–0.5 mm. Snowpack temperature at 15 cm depth varied between –30 and –28°C during measurements. The average density of the snowpack was 0.29 g cm^{-3}. All measurements were taken within ~2 hours of each other to minimize changes in snowpack temperature and changes in conditions due to snow metamorphism. Further details of the technique, analysis and location are provided by France and others (2011a).

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14 January 2012

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