Ultraviolet protection on a snowball Earth

Conference or Workshop Item

ULTRAVIOLET PROTECTION ON A SNOWBALL EARTH

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Introduction: On a Neoproterozoic (700-600 Myr ago) snowball Earth, the exposure of organisms to ultraviolet radiation would be determined by the characteristics of ice and snow-covered micro-habitats. A diversity of habitats in the Antarctic, studied using miniature dosimeters, potentially provide an insight into the ultraviolet environments experienced by organisms on snowball Earth. Thick ice and snow covers (of ~1 meter and greater) would reduce DNA-weighted irradiances to negligible values whilst still allowing photosynthesis, similarly to present-day perennially ice-covered Antarctic lakes. However, even modest ice covers of just a few millimeters thickness, such as those at the leading edge of snow-pack or on the surface of glacial meltwater bodies, could have improved UV protection, particularly if their structure is heterogeneous as is usually the case in real environments. For those organisms that could survive in the postulated temperature conditions of a global freeze-over, the snowball period probably respresented a 'golden age' of physical UV protection compared to the requirements placed on many exposed organisms today, particularly in the photic zone of the oceans.

Methods: Three types of small-scale dosimetry were used to assess the protective role of snow and ice covers. **1**. A hand-held UVB meter with a maximum wavelength response at 320nm. The dosimeter possesses a small sensor that can be placed into habitats or under ice surfaces to measure UV irradiance. In the case of lake ice covers, the sensor was covered in a whirlpak bag which reduced transmission by 7%. **2.** A small 4 x 6cm electronic dosimeter was used to investigate the biologically weighted irradiances received in habitats over time. The dosimeter (Giga-Hertz Optiks, Germany) has a broadband sensor designed to provide a measure of biologically weighted irradiances. The dosimeter can be used to log weighted irradiances at 1 second intervals or longer. **3.** Monolayers of spores of Bacillus subtilis prepared as biofilms (DLR-Biofilm) were used to assess the biological effect of UV irradiation in microenvironments. The films, of size 1 x 2cm, measure the effects of UV irradiation on a biological endpoint, i.e., spore inactivation.

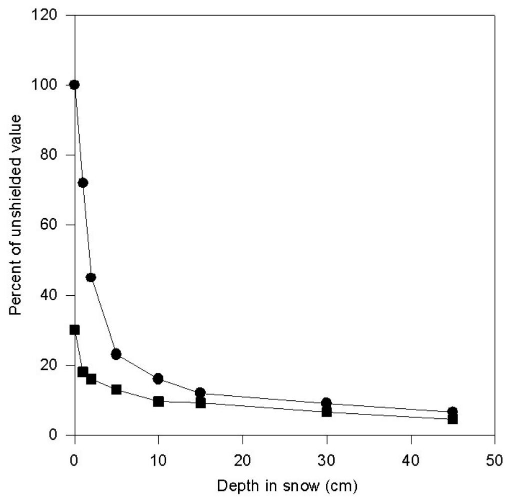
Results and Discussion: Several micro-habitats were studied. They include; snow and ice lake covers, the leading edge of snow pack, and ice covers over small glacial streams. Table 1. shows the different habitats examined.

Table 1. UV protection on snow-ball Earth. Typical micro-habitats under snow and ice, protected from UV radiation, are shown. Reductions of DNA-weighted irradiances, as measured in Antarctica, are estimated. (Measurements taken at Rothera (UK) base, 67°S. Zenith angles were ~40-55°in all cases).

Type of micro-habitat	*Reduction in DNA-weighted irradiance compared to full sky value*
Lake ice covers (1cm and greater) – includes oceanic ice	40% for 1 to 2cm of ice up to complete protection for thick ice covers
Snow-pack (2cm and greater)	30% under 2cm of snow. Reduction at depth in snow according to exponential function
Leading edge of snow pack (10cm and thinner)	40% reduction at edge (1mm of snow-covered ice) up to ~80-90% reduction at base of snow-pack overhang (~5-10cm depth)
Thin ice covers over supra-glacial streams (Often 1cm and thinner)	20% and greater depending on ice thickness and heterogeneity
Thin snow covers on ground (a few millimetres and less)	Up to 15% reduction

Snow covers. The attenuation of UV radiation into snow-pack, like ice, is determined by an exponential function as shown in Figure 1. Reflection from the snow surface itself can be 15% of the incident DNA-weighted irradiance at zenith angles of ~50°. However, at 1cm depth in thick snow-pack, organisms also recieve upwelling irradiance such that the scalar irradiance seen by the whole organism approximates to the value received by an organism on uncovered ground. However, at 2cm depth the reduction in downwelling and upwelling irradiance is such that organisms receive ~70% of the unshielded value on the surface of the ground. At greater depths protection is more effective. As expected, the reductions become proportionally greater, partly because the absorbance is an exponential function with depth and partly because the diffuse attenuation coefficients at shorter wavelengths are greater than longer ones in the UV region. Even thin snow coverings (<1cm) on bare ground could provide a reduction of DNA-weighted irradiances of ~15-20%.

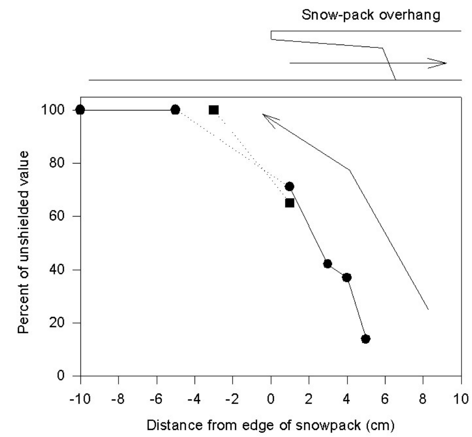
Figure 1. Reduction of DNA-weighted irradiances at depth in one year-old snow. Circles show downwelling irradiance. Squares show upwelling irradiance.



Snow-pack overhang. At the edge of the snow-pack are overhangs created by the thawing of the snow and ice in contact with the high albedo brown soils of many areas in Antarctic (Figure 2). Often, the overhang ice is mottled with snow, contains air bubbles and is therefore every heterogenous. It can act as an effective scatterer. Figure 2 shows the reduction in UV values at the edge of snowpack where the leading edge is ~1mm increasing to 10cm at the base of the pack.

Ice covers. Thick ice covers on lakes can reduce DNA-weighted irrdiances received by organisms to negligible values. We recently demonstrated this in a perennially ice-covered lake in Antarctica [1]. At over 1.5 meters depth, DNA-weighted irradiances in Lake Hoare were almost immeasurable, but enough light penetrated for photosynthesis. This would apply to certain ice-covered regions on a snow-ball Earth, such as equatorial oceans [2]. Even at higher latitudes, where ice thicknesses might block visible light, non-photosynthetic heterotrophs living off advected organics would enjoy complete UV protection. This is in contrast to the situation today. In clear ocean waters, UVB can penetrate to 1% of incidence even at 50m depth. Figure 2 shows that even thin ice covers in other habitats, such as covering glacial meltwater bodies or exposed nunataks, could provide UV protection, particularly if, like the snow-pack overhang, it is quite heterogeneous and scatters light more effectively than pure ice. This is often the case in real environments. Thus, microbial communities inhabiting ponds or lakes on the surface of glaciated regions could obtain some physical UV protection.

Figure 2. Typical profile showing the effect of snow-pack overhang on UV exposure on the ground. Circles show UVB irradiance. Squares are DNA-weighted irradiances. Arrow shows effect of receding overhang on UV exposure. The dotted lines refer to a grey area of UV exposure that depends upon orientation of the snow-pack and the zenith angle of the sun.



Conclusions: Many exposed organisms today require efficient protection and repair processes to cope with the UV fluxes experienced in their habitats. Apart from biological screening, protection from UV radiation can be afforded by physical substrates such as iron, rock, various salts etc. However, protection by these substrates is quite specific to particular habitats. On a Neoproterozoic snowball Earth, physical protection was globally dominated by ice and snow and the manifestations of these substrates in different habitats. In Antarctica various permutations of protection from UV radiation by ice and snow are widely represented, and can be used to develop an inventory of protective environments on snowball Earth as shown in Table 1. Most organisms, even covered in layers of ice just a few millimeters thick, such as microbial mats in glacial meltwater habitats [3], could have been afforded 20% and greater reductions in DNA-weighted irradiances compared to fully exposed values. As the snow and ice cleared to higher latitudes at the end of the snowball period, so greater energy expenditure on biological screening and repair would have been required for many exposed organisms, particularly oceanic organisms in the newly UV-exposed photic zone.

References:

[1] Kepner, R.L. et al. (2000). *Hydrobiol.*, **427**, 155-165, [2] McKay, C.P. (2000). *Geophys. Res. Lett.*, **27**, 2153-2156. [3] Vincent et al., (2000). Naturwissen., 87, 137-141