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Primary dispersal of supraglacial debris and debris cover formation on alpine glaciers

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Debris-covered glaciers are receiving increased attention due to the modulation of runoff by supraglacial covers, and to the lake outburst flood hazard at many covered glacier termini. Observed increases in debris cover extents cannot presently be explained in terms of glaciological influences. The supply of englacial debris to the supraglacial zone has previously been understood only in terms of local dispersal due to differential ablation between covered and uncovered ice, for example on medial moraines. Here, we introduce the term primary dispersal to describe the process of migration of the outcrops of angled debris septa across melting, thinning ablation zones. Understanding primary debris dispersal is an essential step to understanding how supraglacial debris cover is controlled by glaciological variables, and hence is sensitive to climatically-induced fluctuation. Three measures of a glacier's ability to evacuate supraglacial debris are outlined: (1) a concentration factor describing the focussing of englacial debris into specific supraglacial mass loads; (2) the rate of migration of a septum outcrop relative to the local ice surface; and (3) a downstream velocity differential between a septum outcrop and the ice surface. (1) and (2) are inversely related, while (3) increases downglacier to explain why slow-moving, thinning ice rapidly becomes debris covered. Data from Glacier d'Estelette (Italian Alps) illustrate primary dispersal processes at a site where debris cover is increasing in common with many other shrinking alpine glaciers. We develop a model of the potential for debris cover formation and growth in different glaciological environments. This explains why glaciers whose termini are obstructed often have steep debris septa feeding debris covers which vary slowly in response to mass balance change. In contrast, at glaciers with gently-dipping debris-bearing foliation, the debris cover extent is sensitive to glaciological change. These findings suggest that the variety of debris-covered glacier types will show a spectrum of response characteristics to negative mass balance.