IMPACT OF DEBRIS COVER ON GLACIERS

RESEARCH PRIORITIES AND RELATION TO GLACIER-CLIMATE INTERACTIONS ON CLEAN-ICE GLACIERS

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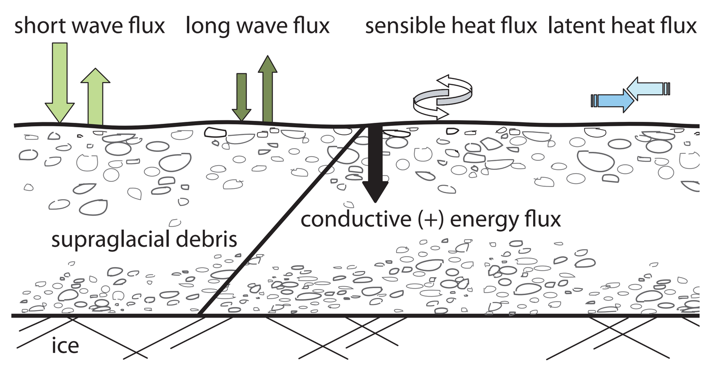
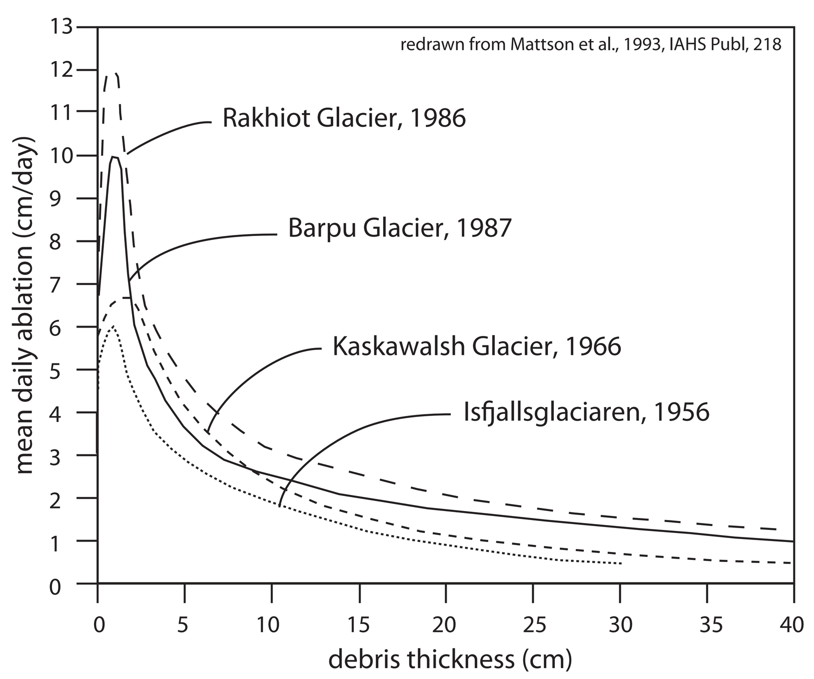
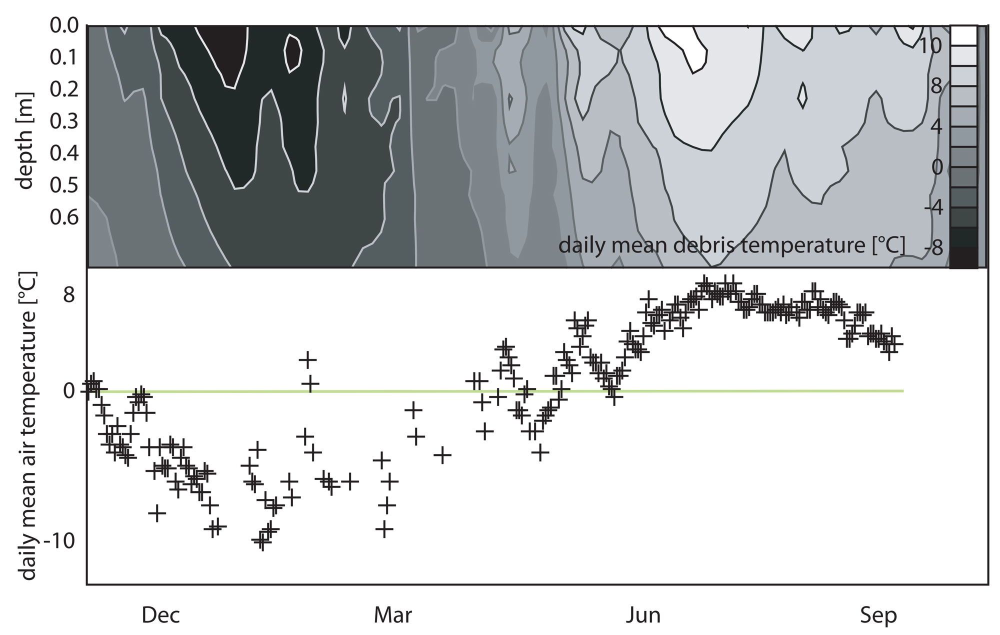
INTRODUCTION Debris-covered glaciers are a common feature in many high mountain regions, and the proportion of surviving ice that is debris-covered is increasing. Four key ways in which debris-covered glaciers differ from clean ice glaciers are presented here and research priorities are identified.

SURFACE ENERGY BALANCE Debris cover primarily affects surface ablation, altering the surface energy balance compared to that of a clean ice glacier, and forming a secondary barrier between the glacier ice and the atmosphere through which energy must be transmitted to the underlying ice.







The impact of debris on ablation rate is a complex result of climate, debris properties, debris thickness, and clean ice melt rate.

Overlying snow, and phase changes in the debris layer, affect heat flux to the ice on longer timescales.

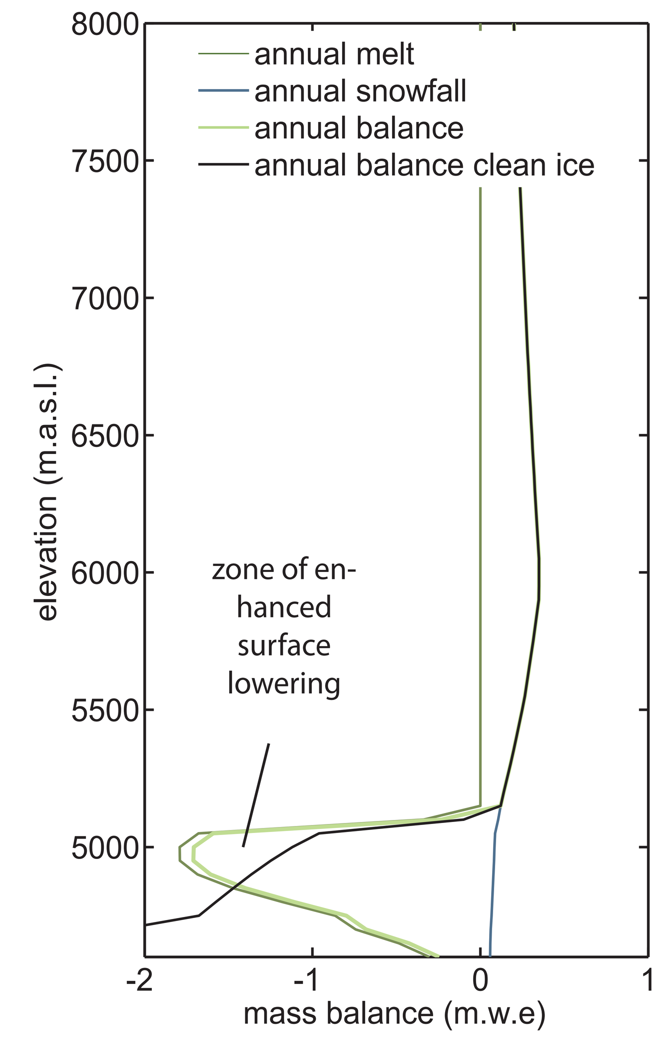
PRIORITY: detailed modelling studies to untangle the sensitivity relationships of sub-debris ablation and integrate this in glacier-scale mass balance models.

MORAINE DEPOSITION Many debris-covered glaciers are bounded by very large terminal and lateral moraines (see right), with the current glacier surface lying below the moraine crests. Their formation is related to inefficient evacuation of debris from the glacier system, but the processes remain relatively poorly understood and climatic interpretation of these features remains elusive.

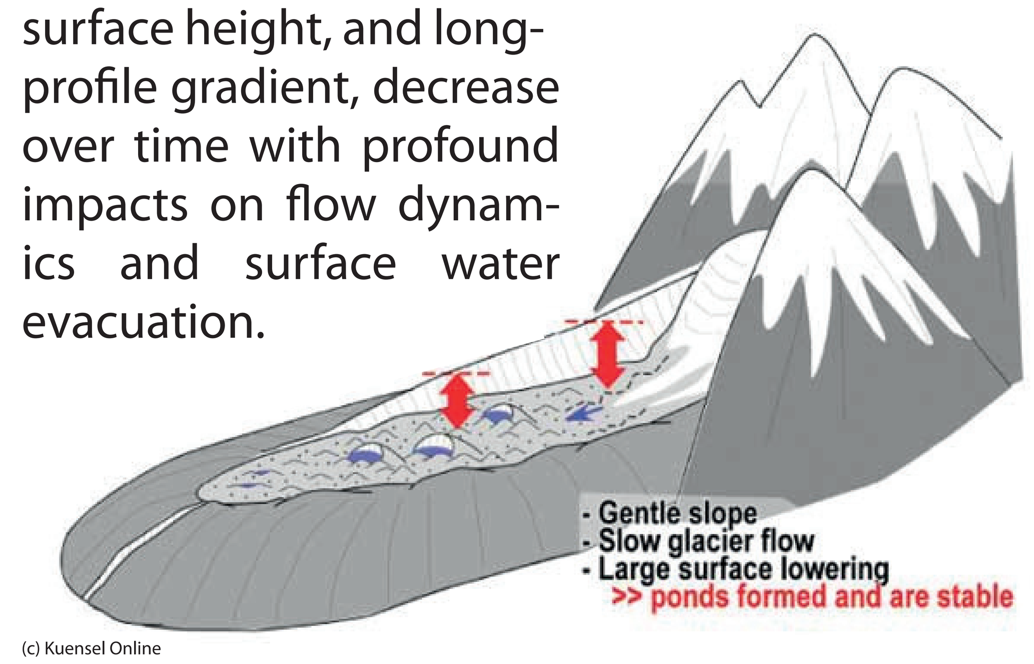
The moraines are often ice cored, which has a fundamental impact on (a) their capacity to dam up glacial meltwaters into large and potentially dangerous lakes and (b) their long term stability if the ice cores begin to decay.

PRIORITY: determining a way to interpret these moraines as a record of former large scale glacier change, and determining what, if anything, they can tell us about former climatic conditions.

MASS BALANCE GRADIENTS Debris thickness increases towards the terminus, which results in inversion of the mass balance gradient, so that the most negative mass balance occurs upstream of the terminus.

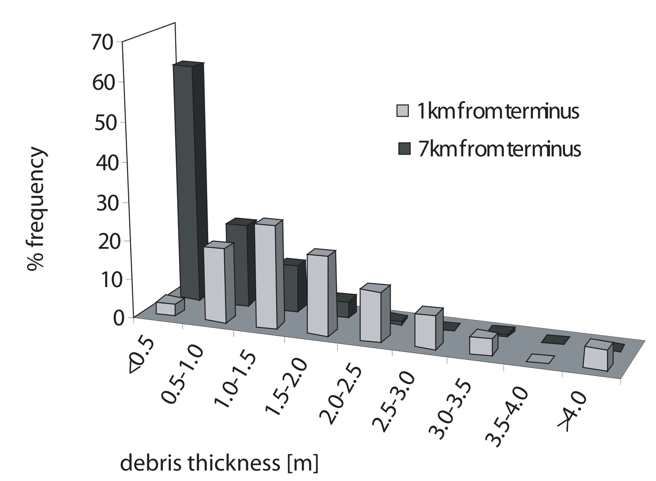


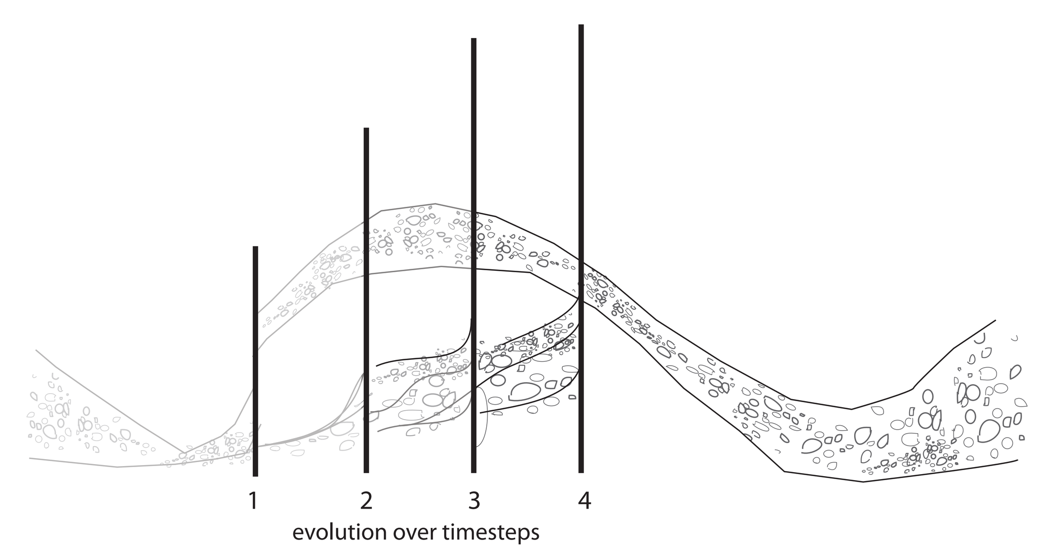
Within the debris-covered zone, the glacier surface height, and long-profile gradient, decrease over time with profound impacts on flow dynamics and surface water evacuation.



PRIORITY: combined mass balance and flow modelling of longer term glacier geometry adjustments to climatic forcing.and to enable forecast modelling of surface lowering and attendant glacier lake outburst flood hazard potential.

SURFACE TOPOGRAPHY Debris cover is inhomogeneous resulting in differential ablation and consequently uneven topography. This is compounded by collapse of englacial meltwater channels that due to the sluggish ice flow are not efficiently closed by creep.





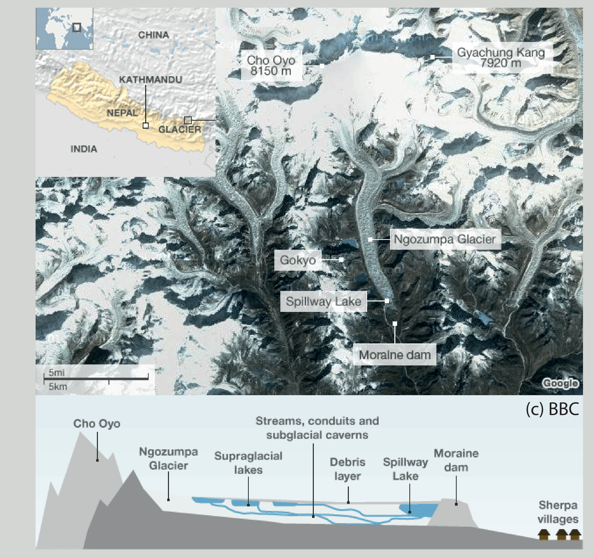
Debris thickness is better described as a distribution with an increasing mean and decreasing degree of skewness downglacier.

Slumping and redistribution of debris gradually means surface relief changes from low-higher-low towards the terminus. Melting of focussed at ice faces exposed by slumping or undercutting by surface water.

PRIORITY: determining the contributions of all the sources of ablation (sub-debris abltion, meltwater erosion, calving and melting in lakes) and determining how to incorporate this spatial variability in glacier-scale mass balance models.

ANATOMY OF A DEBRIS-COVERED GLACIER

Ngozumpa glacier, Nepal. Mature debris-covered glacier with a rapidly expanding lake behind its terminal moraine



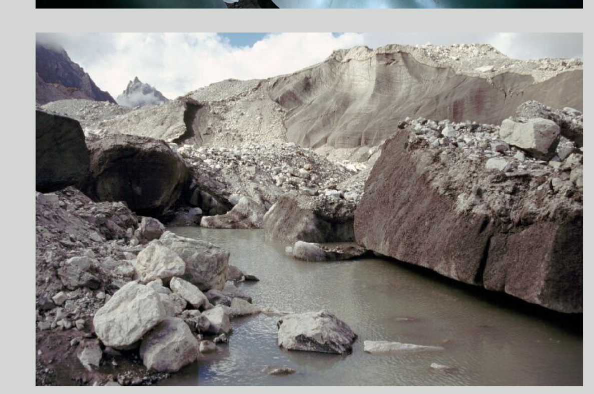
Steep headwalls with frequent avalanches deliver snow and rock debris to high elevation snowfields or to avalanche cones, within which lies the glacier mass equilibrium line

Former tributary glaciers are disconnected in terms of ice dynamics, but may have hydrological connections.

Variable topography studded with supraglacial ponds and flanked by upstanding moraine crests in the middle section of the debris-covered portion of the glacier

Englacial meltwater channels throughout the debris covered portion play a crucial role in both surface and hydrological evolution

Coalescence of lakes near the terminus where supraglacal lakes intersect the englacial water table



Terminal moraine is ice cored and shows stable and geomorphoilogically active areas