



Ice sails of the Karakoram

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Ice sails are clean ice features that protrude from the surface of debris covered glaciers, and can grow to more than 25 m in elevation. Observations of these features date back to the first exploration of the glaciers and mountains in the Karakoram (in 1864), where they seem to occur preferentially. Even though melt rates beneath supraglacial debris and of clean ice should be rather different, ice sails can exist in equilibrium for decades. However, no detailed scientific analysis of ice sails has been carried out until now. The apparent restriction of ice sail existence to high elevation, dry atmosphere and long and flat debris covered glaciers, suggests that they require low debris thickness and a high evaporative heat flux for survival.

We postulate that ice sails can develop from one of two mechanisms, both of which require clean ice to be surrounded by debris covered ice, where the debris layer is shallow enough for the ice beneath it to melt faster than the clean ice, i.e. typical debris thicknesses of less than 5-10 cm. Our image analysis confirms that ice sails can persist for decades. Debris layer thickening eventually causes a reversal in the relative melt rates and the ice sails submerge back into the glacier. During their stable phase, the slope of the ice sail faces constantly adjusts to the available melt energy, so that a steady state with the surrounding ice melt can be reached. This can be demonstrated by application of an energy balance model and use of the well-known Östrem-curve for sub-debris ice melt.