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Summer energy balance and ablation of high elevation glaciers in the central Chilean Andes

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Glaciers of the semi-arid central Chilean Andes are an important freshwater source for the populous Central Valley region of Chile, but have been shrinking in recent decades. The surface energy balance of these glaciers is of high scientific interest as summer ablation occurs through both sublimation and melt. During the 2012-13 Austral Summer a glacio-meteorological monitoring programme was established on Olivares Alfa (3.9 km2, 4130-4800 m elevation) and Beta (8.3 km2, 3620-4850 m elevation) Glaciers and their forelands in the Upper Olivares Valley, 33°00'-33°11' S, 70°05'-70°15' W, approximately 50 km north-east of Santiago. This included complete automatic weather stations (AWSs) with sonic rangers to record surface ablation on the ablation zones of the two glaciers, and one AWS in the proglacial area of Olivares Alfa Glacier including precipitation gauge. To complement these point data, daily images of the glaciers were captured with fixed cameras in order to calculate snow cover and albedo distributions. To calculate the surface energy balance and rates of melt and sublimation, a model was developed which uses direct AWS measurements of the radiative fluxes and calculates the turbulent fluxes of sensible and latent heat using the bulk aerodynamic approach. The model also calculates the subsurface heat flux and includes a simple scheme to estimate refreezing of melt water within surface snow or ice. Meteorological data and model results for the December to May period will be presented in this paper. Model calculations match closely the cumulative ablation curve of the sonic ranger at Olivares Alfa, with a slight overestimation, and overestimate cumulative ablation recorded by the sonic ranger at Olivares Beta, possibly due, at least in part, to uncertain snow density values. Modelled cumulative ablation in the December-April period is 2.2 m water equivalent (w.e.) at Olivares Alfa (0.10 m sublimation, 2.10 m melt) and 2.34 m w.e. at Olivares Beta (0.18 m sublimation, 2.16 m melt). The surface energy balance is dominated by shortwave radiation, which is the only net energy input, apart from a minor contribution from sensible heat, while the main outputs of energy are net longwave radiation, melt and sublimation. Ablation is dominated by melt during the warmer midsummer months at the two AWS sites, with mean rates exceeding 30 mm w.e. per day. However, due to the high latent heat of sublimation, it is only in January and February that the melt energy flux clearly exceeds the sublimation energy flux. Sublimation rates are typically $\sim$1 mm w.e. per day and are 50 to 100 % higher at Olivares Beta as a result of higher wind speed and surface temperature, despite similar air temperatures at the two sites. Melt rates are around twice as high in summer months with mean air temperature > -2° C, compared with cooler months. This implies that future atmospheric warming will accelerate shrinkage of these glaciers as the ablation regime switches increasingly from sublimation to a more efficient melt regime.