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A Landsat analysis of variability of supraglacial ponds for the debris-covered glaciers of the Langtang Valley

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Debris-covered glaciers have received renewed interest in recent years in an attempt to improve understanding of climate-glacier interactions in High Mountain Asia. Understanding of key processes occurring in supraglacial ponds has advanced conceptually to include conduit-collapse formation, subaqueous and waterline melting, calving, and englacial filling and drainage. The behaviour of systems of ponds, however, has received little attention, as most process observations have been made on individual features. Several studies have used satellite data to determine pond distributions at a single point in time or their variability across several years or decades. However, no attempt has been made to document the seasonal and inter-annual variability of ponds, even though individual ponds have been observed to fill and drain periodically.

We analyse 172 Landsat TM/ETM+ scenes for the period 1999-2013 to identify thawed supraglacial ponds for the debris-covered tongues of five glaciers in the Langtang Valley of Nepal. We apply an advanced atmospheric correction routine (LandCor/6S) and improve upon previous band-ratio and image morphological techniques to identify ponds, then apply this database of identified ponds to: 1) measure the density of supraglacial ponding for five glaciers with differing characteristics, and evaluate the dependency of pond density to those glaciers' characteristics; 2) evaluate the controls that surface gradient and glacier velocity in particular exert on pond occurrence; 3) document the seasonal cycle of pond thawing and formation followed by freezing and draining; 4) document pond persistence, recurrence, and evolution over the 15-year period; and 5) determine if surface ponding has increased over time for the study glaciers.

We find high variability between glaciers (0.08-1.69% of debris-covered area during ablation season), related primarily to glacier size, velocity, and surface gradient. At the glacier scale, pond cover is also correlated with the standard deviation of surface velocity, but shows no relationship with cumulative historical downwasting. Spatially, ponds are most commonly observed in zones of low surface gradient and velocity, with surface gradient exhibiting control on pond density and velocity controlling pond size. The ponds show a pronounced seasonality, appearing rapidly in the premonsoon as snow melts, peaking in cover in the monsoon at 2% of debris-covered area, then declining in the post-monsoon as ponds drain or freeze. Pond seasonality has strong implications for the glacier's energy budget, as pond inject atmospheric energy to the glacier interior, bypassing the thick debris mantle. Ponds at the study site are highly recurrent and persistent, with 40.5% of pond locations apparent in multiple years, while many locations appear to persist or recur for the entire analysis. Individual pond locations show simple expansion and disappearance as well as complex patterns of coalescence and division. Accounting for biases of seasonality and observable glacier area, the glaciers show strong interannual variability rather than a steady increase in total cover.