A Landsat analysis of supraglacial pond variability for Langtang Valley’s debris-covered glaciers, Nepal
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1. Motivation and Objectives
Debris-covered glaciers have received renewed interest in recent years in an attempt to improve understanding of climate-glacier interactions in High Mountain Asia. Conceptual understanding of key processes occurring in supraglacial ponds has advanced to include conduit-collapse subformation, subaqueous and waterline melting, calving, and englacial filling and drainage. The behaviour of systems of ponds has received little attention, with most process observations 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 analyze 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) and use 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;
2) Evaluate surface gradient and glacier velocity as controls on pond occurrence;
3) Document the seasonal cycle of pond occurrence and disappearance;
4) Determine if surface ponding has increased over time for the study glaciers.

2. Landsat Data Processing
Images are converted to surface reflectance using the LandCor implementation (Zelazowski 2011) of the 65 radiative transfer code (Kotchenova 2006):
1. Sun-scene sensor geometry accounted for across scene.
2. Elevation-based parameterizations of AOD, TSWV, and ozone
3. Adapted for ASTER, TM, ETM+ data (OLI soon!)

1. Landsat TM/ETM+ Processing (Zelazowski 2011)
• Cloud mask
• Cloud shadow
• Snow mask (MODIS)
• Geometric correction
• Band-ratio processing
1. Cloud mask
2. Cloud shadow
3. Snow mask (MODIS)
4. Geometric correction

Supraglacial Ponds (3)

Spectral and geographic operations are used to mask confounding factors. Thanks to strong radiometric agreement after LandCor processing, uniform thresholds are applied:
• Snowcover is mapped using NDSI
• Clouds are mapped using Fmask 3.2.1 routines (Zhu 2015)
• Deep shadows are assessed using Fmask, B1, B5, and slope

Last, locations of ponded water are determined:
1) High likelihood ‘water seeds’ are determined using band ratios (bands 2, 4, bands 4 & 5) and the NDWI
2) These are adjusted using image morphological techniques to define a segmentation of naturally-associated objects
3) Each object’s mean spectral properties are reevaluated with band ratios and brightness temperature as thawed ponds

3. Results: Spatial Variability

3.1. Individual pond locations are highly recurrent over 15 years: 40.5% of pond locations occur in 2+ years, many locations span 15 years
3.2. Analysis has a high success in identifying other glacial lakes in the study area
3.3. Ponds are most common and largest in zones of low surface gradient and velocity
3.4. Surface gradient controls pond density
3.5. Velocity appears to control pond size.

4. Results: Temporal Variability

4.1. Pond seasonality has strong implications for surface energy balance, as ponds inject atmospheric energy directly to the glacier interior, bypassing the thick debris mantle:
• Whole-glacier estimates of pond-associated ablation need to account for variable pond coverage in space and time.
• Pond density is highest early in the ablation season, when surface energy from the presheltered debris area is in late May or early June, slightly preceding the monsoon
• Pond cover declines during the monsoon
• A sharp decline occurs in the postmonsoon
• Thawed ponds are only occasionally observed in winter

4.2. Changes over the study period
Langtang Glacier is the largest of the study glaciers, with the most ponds. Reduced seasonality in 2-month periods
• Weak increases (R^2=0.5, p<0.1) in ponded area
• Apparent postmonsoon decline after 2009
• High interannual and seasonal variability
• No strong relationship: T, P, PDD

5. Conclusions and Outlook

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5.3. Select Literature

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