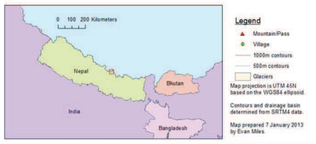
Remote sensing approaches to construct hydrologic calibration and validation datasets for a data-sparse debris-covered basin, Langtang Khola, Nepal

Evan Miles[1*], Ian Willis[1], Neil Arnold[1], and Francesca Pellicciotti[2]

*Contact: esm40@cam.ac.uk, [1]Scott Polar Research Institute, University of Cambridge, [2]Institute of Environmental Engineering, Swiss Federal Institute of Technology

Introduction

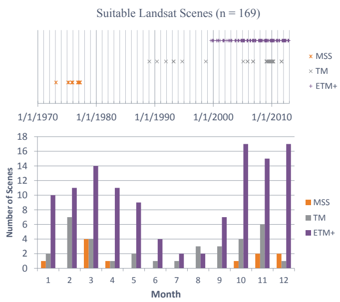
Glacier retreat in response to climate warming causes changes to the pattern and timing of meltwater production, routing and storage, resulting in substantial modifications to the hydrographs of glaciated basins (Bajracharya and Mool 2010, Bolch et al 2012). Glacio-hydrological modeling has been successfully applied to assess these changes (Immerzeel et al 2011, Ragettli and Pellicciotti 2012), particularly for study sites with good records of high-quality input data including climate, hydrologic, and glacier extent. However, the communities most vulnerable to changes in glacier discharge are often situated downstream of glaciers with unreliable or broken environmental records. This is evident in High Mountain Asia, which supplies water to over one quarter of the globe's population but combines several glaciological challenges: high climate variability, lack of historic data, uncertainties in climate change and glacier response, and numerous debris-covered glaciers. For these basins, the satellite record can be a powerful model calibration tool, because snowcover is a critical data gap from a basin-wide hydrologic perspective. This research seeks to develop historic snowcover and surface water distribution datasets for use in a glacio-hydrologic model.



Goals

1. Process Landsat and ASTER data to a near-uniform radiometric scale
2. Develop an 'objective' snow classification routine to be uniformly applied to ASTER and all Landsat sensors.
3. Determine historic snowcover for the Langtang basin and consider MODIS data fusion to form a 'complete' dataset.

Data Processing



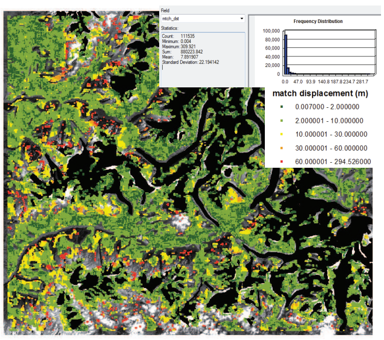
Scene Selection

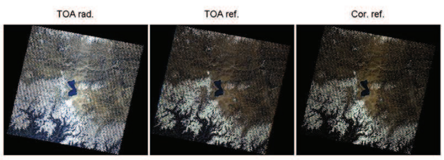
A total of 169 Landsat scenes with no cloud cover are available over the study site (not whole scene). The 16- and 18-day return intervals and May-August monsoon are major limitations. This study focuses on the period 2000-present, coinciding with other hydrologic measurements and ASTER and MODIS availability.

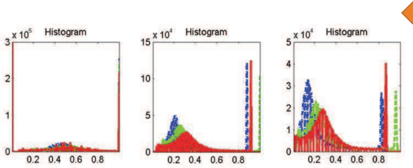
Co-registration

Scene co-registration evaluated using cross-correlation:

- Glaciers masked using RGI 2.0.
- IMCORR used (VisiCorr implementation: Dowdeswell and Benham 2003) to assess displacement in terrain, disregarding outliers.
- Reregistration and resampling occurs if a general displacement of >½ pixel is evident.







Atmospheric Correction

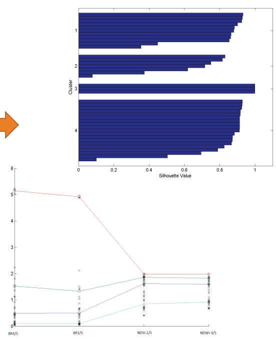
Images are converted to surface reflectance using the LandCor implementation (Zelazowski et al 2011) of the 6S radiative transfer code (Kotchenova et al 2006):

- Sun-scene-sensor geometry accounted for across scene.
- Adapted for MSS, TM, ETM+, and ASTER data.
- Daily ozone values are bilinearly interpolated from 1-degree TOMS data (produced by Masek et al 2012).
- Aerosol and water vapor values determined by monthly elevation-dependent parameterizations based on MODIS atmosphere products.
- Assumes a Lambertian surface to generalize across all terrain in the scene.

Clustering and Segmentation

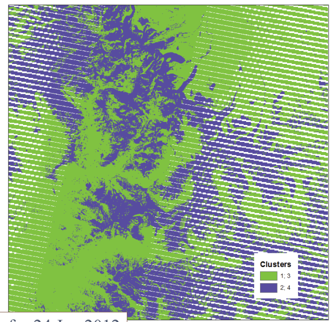
The entire record for each sensor is then classified by a collective migrating-means algorithm:

- NDSI, NDWI, and band ratio 3/5 (TM/ETM+) are computed from the surface reflectance.
- The migrating-means algorithm is iteratively applied to a 100k-pixel sample from each scene with a varying number of clusters (2:6) to determine the optimal clustering.
- Output clusters are then gathered from all scenes, and reclustered to determine the overall optimal segmentation.
- The landcover for each class is identified visually, then this classification is applied to all images.

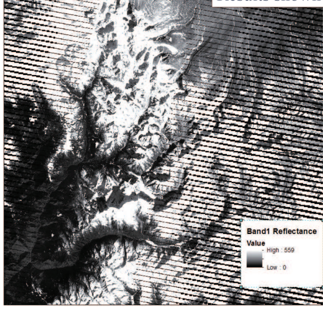


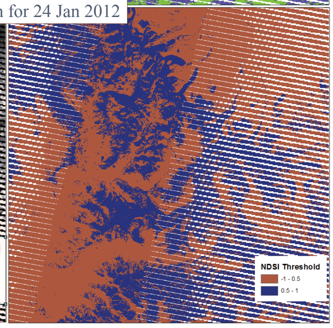
Results

The uniformly-applied migrating-means classification scheme produces snowcover maps nearly identical to manual NDSI thresholding, but is automated and largely objective between scenes and sensors. As with NDSI or band ratios, water bodies are difficult to differentiate from snow/ice, implying the need for a second segmentation scheme. Thus far, only ETM+ and TM data have been processed to snowcover (158 scenes), and additional processing will extend to the MSS and ASTER.



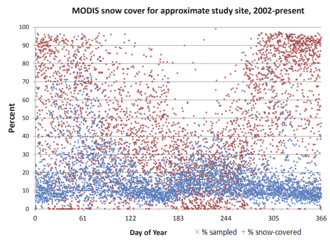
Results shown for 24 Jan 2012



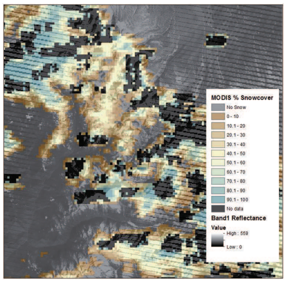


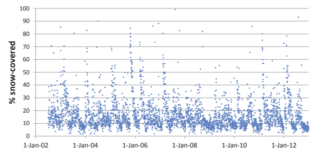
Consideration of MODIS Record

The NSIDC MODIS snow product estimates 500m within-pixel percent snowcover at the daily timestep. The product is sensitive to cloud cover (therefore monsoon) and misses peripheral snow patches. There is some potential for data fusion.



Inconsistent snow extent in Jan-Mar. Poor monsoon data quality could mask much higher percent cover.





Snow cover usually persists for several days after a snowfall.

Next Steps

1. Extend analysis to MSS and ASTER data
   - Will improve temporal resolution 2000-present
   - Will allow 40-year analysis of more permanent features (i.e. lakes)
2. Improve surface water segmentation
   - Current clustering optimizes snow delineation but does not distinguish from surface water.
   - Would allow examination of the spatiotemporal distribution of supraglacial lakes.
3. Determine snowline elevations and consider seasonal snowline variability
   - Comparison with Ueno 1993
   - Simplistic climate forcing for initial runs of model
4. Further evaluate performance relative to MODIS
   - Develop % snowcover maps for 2002-present and compare
5. Consider a MODIS gap-filling strategy and MODIS/Landsat/ASTER data fusion
   - Typical 'scenarios' of snow distribution as determined by self-organizing maps
   - Use 'scenarios' as interpolation method to fill gaps (MODIS) or to downscale to finer spatial resolution

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