



Localization of mountain glacier termini in Landsat multi-spectral images

Nezamoddin N. Kachouie^{a,b,*}, Peter Huybers^c, Armin Schwartzman^{a,b}

^a Department of Biostatistics, Harvard School of Public Health, United States

^b Department of Biostatistics and Computational Biology, Dana Farber Cancer Institute, United States

^c Department of Earth and Planetary Sciences, Harvard University, United States

ARTICLE INFO

Article history:

Available online 26 July 2012

Keywords:

Glacier terminus location
Satellite imagery
Landsat multispectral images
Inflection point
Polynomial regression
Correlated noise

ABSTRACT

This paper addresses the quantification of glacier retreat through remote sensing. Specifically, we use multi-spectral Landsat satellite images for the estimation of glacier termini locations. Different frequency bands—including visual, infrared, thermal, and processed bands—are examined with respect to their utility in identifying the location of glacier termini and the associated standard error across several scenes. The methodology is to extract an intensity profile along the glacier path from the spatially registered Landsat imagery such that the complexity of the problem is reduced from 2D (image intensity) to 1D (glacier profile intensity). Local polynomial regression is then used to smooth the 1D glacier intensity profile, where the underlying function is assumed to be corrupted with correlated noise. The glacier terminus is then detected by locating an inflection point in the smoothed glacier profile, where a constrained bandwidth selection method is introduced to ensure a single inflection point along the glacier path. Using our method with thermal band B62 and a standard processed band called normalized difference snow index (NDSI) often permits for separating ice from soil but does not lead to a consistent identification of termini location, relative to ground based observations. We therefore introduce a new processed band that combines B62 and NDSI, termed normalized difference thermal snow index (NDTSI). Applying our method along with NDTSI to multiple frames from the Franz Josef, Gorner, Rhone, and Nigardsbreen glaciers indicates an ability to accurately and robustly identify the position of glacier termini, though confirmation of skill awaits application to a larger population of observations.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

There exists a need to better catalog changes in mountain glacier systems, both to more fully assess relationships with climate change (Oerlemans, 2005) and to better monitor and predict changes in water supply (Cullen et al., 2006; Moussavi et al., 2008; Thayyen et al., 2005; Collins, 2008). While the retreat of mountain glaciers has been studied via ground measurements (Moussavi et al., 2008), there is a need to develop automated methods to quantify glacier retreat with a wider scope. A promising means for monitoring glacial changes globally is to make use of available remote sensing information. Among the remote sensing information that is available, the Landsat program provides multi-spectral satellite images for the earth over the past 40 years (Landsat; Landsat.Nasa), constituting a unique multi-decadal resource by which to study temporal variations in the size and shape of glaciations (Landsat.Org; Wulder et al., 2008). Numerous studies have focused on using remote sensing to study single glaciers of interest (Kodde et al., 2007; Höfle et al., 2007; Sidjak and Wheate, 1999),

but in order to catalog the temporal changes in even a small percentage of the vast number of glaciers worldwide, a robust and semi-automated methodology would be beneficial, though such an approach is complicated by cloudiness, shadows, seasonal snowfall that can be difficult to distinguish from ice, debris atop glaciers, and other sources of uncertainty.

Here we explore the degree to which Landsat multispectral images can be used to estimate glacier retreat by applying an automated method, where performance is judged against ground measurements (National Snow and Ice Data Center (NSIDC)). In the proposed approach, we first extract an intensity profile along the glacier path for different spectral bands of spatially registered Landsat images. In this way, for each band, we solve a 1D problem by locating the glacier terminus, instead of solving a more complex 2D problem by segmenting the image and classifying the glacier. The glacier path was sketched once for each glacier in this paper and similar results were obtained where different users sketched the glacier path. However, future research will be conducted to detect the glacier path using image processing and pattern recognition methods. The main goal of this paper is to use and compare different Landsat spectral bands in their ability to extract the glacier terminus as the feature of interest. We show that estimation of the glacier terminus through remote sensing is feasible and

* Corresponding author at: Department of Biostatistics, Harvard School of Public Health, United States.

E-mail address: nezam.nk@gmail.com (N.N. Kachouie).

promising for purposes of significantly augmenting the limited number of presently available ground based measurements of terminus retreat.

Several image processing steps are needed prior to application of the primary statistical methods presented here. Briefly, the dataset for each glacier is prepared as follows: (1) search the glacier of interest in Landsat multispectral data bank; (2) download the large scenes of interest for each glacier separately; (3) register the multispectral images; The images are automatically registered based on geographical coordinates; (4) crop the glacier area from the large scenes; (5) clean up the dataset by removing the unusable images including those covered by clouds or corrupted by black stripes due to malfunctioning of the Landsat satellite sensors; and (6) sketch the glacier path once for each glacier on spatially registered Landsat images. Note that determining the glacier path, whether it is through manual sketch of the glacier path or through image processing, is presently of secondary interest.

In the proposed method mountain glacier termini locations are detected through identifying inflection points in the smoothed intensity profile along the glacier path. Detection of abrupt changes is a challenging problem in engineering and science. The inflection and change point detection methods can be divided in two groups: (i) on-line methods, to catch a change as soon as it occurs by sequentially inspecting the data with applications in quality control and real time surveillance systems (Desobry et al., 2005; Ke et al., 2007; Mei, 2006); (ii) off-line methods, to detect one or several changes by observing and processing the entire dataset at once with applications in computational biostatistics and off-line computer vision systems (Gustafsson, 1996; James et al., 1987; Takeuchi and Yamanishi, 2006; Yakir et al., 1999; Yao, 1988; Gijbels and Goderniaux, 2004; Joo and Qiu, 2009). In this paper, we introduce a constrained bandwidth selection in local polynomial regression for inflection point detection under independent or correlated noise. We particularly consider B62, a thermal band in the infrared spectrum, and normalized difference snow index (NDSI), a processed band obtained from visual (B20) and infrared (B50) bands (Seidel et al., 2004; Salomonson and Appelb, 2004; Erdenetuya et al., 2006; Irish, 2000). We investigate different bands in the Landsat spectrum and show that terminus location can be better estimated using B62 and NDSI, but none of the Landsat frequency bands can individually separate ice from soil consistently. We therefore introduce a new processed band that combines NDSI and B62 in order to obtain a more robust estimation of the glacier terminus.

The proposed approach is applied to several Landsat 5 and Landsat 7 multispectral images of our glaciers: Franz Josef in New Zealand, Nigardsbreen in Norway, and Gorner and Rhone in Switzerland. As an objective metric, we compare the estimated locations of termini by the proposed approach as function of time against ground measurements of terminus retreat. Results show the feasibility of using the proposed method in conjunction with Landsat multispectral imagery for estimation of terminus location changes over time.

2. Locating the glacier terminus

2.1. The glacier in multi-spectral satellite imagery

Typical multispectral Landsat images are shown in Fig. 1 where false color (RGB = B50, B40, B30) is used to visualize the Franz Josef glacier (blue). Different frequency bands in the multispectral Landsat dataset are investigated to select the best one for our application. The Landsat 7 multispectral datasets contain nine bands including three visual bands (B10, B20, and B30), three infrared bands (B40, B50, and B70), two thermal bands (B61 and B62, see Fig. 1), and one panchromatic band (B80). Bands B10–B50 and

B70 have 30 m resolution, B61 and B62 have 60 m resolution, and B80 has 15 m resolution. Note that Landsat 5 contains only seven bands.

Thermal sensors respond to an object's temperature at wavelengths of 10.4–12.5 μm and, unlike for other bands, are almost unaffected by shadows (Figs. 1 and 2). For instance, when visible bands B20 and B30 are compared with thermal band B62 for typical images of Franz Josef glacier, the visible bands are corrupted and occluded by shadows from the adjacent mountains, where as the B62 image renders that glacier completely visible.

NDSI is a processed band (Figs. 1 and 2) that measures the reflectance differences of the visible band B20 and the short wave infrared (IR) band B50, defined by Seidel et al. (2004) and Salomonson and Appelb (2004)

$$NDSI = \frac{B20 - B50}{B20 + B50}$$

NDSI can usually distinguish ice and soil by combining IR band B50 and visible band B20. The advantage of NDSI for our application is that, in contrast with the other bands, the NDSI glacier images are not as corrupted by shadows as the other bands (Figs. 1 and 2). As depicted in Fig. 1(ii), the glacier is visible in the NDSI image despite the partial loss of contrast due to the shadows.

Therefore, the thermal band B62 and the processed band NDSI were chosen because of their unique characteristics to preserve the visual representation of the glacier in the multispectral Landsat images. While B62 is less affected by shadows, NDSI has higher spatial resolution, and as we will see, one may be better than the other for glacier terminus detection depending on the scene. We should point out that clouds occasionally occlude the glacier terminus in all visual, IR, and processed bands as depicted in Fig. 2 (third column), and that we are unable to make use of such cloudy images.

In order to locate the glacier terminus, a path was manually drawn on the glacier image and applied to all the spatially registered images of the same glacier. Image intensity profiles along the path were extracted from the images across the various bands. The proposed approach for detecting the inflection point along the glacier path intensity profile follows in detail.

2.2. Local polynomial regression for data with independent or correlated noise

The proposed approach applies spatial smoothing of noisy observations while controlling the smoothing bandwidth to ensure a single inflection point under independent or correlated noise. Here, noisy observations of the surface characteristics are made using intensity along the glacier path from multispectral Landsat images. To model the intensity profile along the glacier path, suppose that n pairs of observations

$$(s_i, Y_i), \quad i = 1, 2, \dots, n \quad (1)$$

consist of a response variable Y and a location s on the glacier path and are related by the signal-plus-noise model

$$Y_i = r(s_i) + \varepsilon_i, \quad \varepsilon_i : N(0, \Sigma_\varepsilon), \quad i \in [1, n] \quad (2)$$

where $Y_i, i \in [1, n]$ are observed noisy samples, ε_i is correlated Gaussian noise $N(0, \Sigma_\varepsilon)$, and r is an unknown underlying regression function. The regression function r can be locally approximated at the point s by a polynomial of order P that minimizes the locally weighted mean squared error

$$\begin{aligned} f(A(s)) &= \sum_{i=1}^n K_\gamma(s_i - s) \left(Y_i - \sum_{p=0}^P a^{(p)}(s)(s_i - s)^p / p! \right)^2 \\ &= (Y - X_s A)^T W_s (Y - X_s A) \end{aligned} \quad (3)$$

Download English Version:

<https://daneshyari.com/en/article/534073>

Download Persian Version:

<https://daneshyari.com/article/534073>

[Daneshyari.com](https://daneshyari.com)