SLOPE STABILITY ANALYSIS OF THE ILIAMNA VOLCANO, ALASKA, USING ASTER TIR, SRTM DEM, AND AEROMAGNETIC DATA

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Abstract

I use thermal IR and digital elevation models to create a hazard index that characterizes slope stability on active volcanoes using Iliamna, Alaska as a case study. ASTER and SRTM data were processed and scaled, then a script was run to plot the hazard index based on hydrothermal emissions and topographic slope. The plots display areas at risk for slope failure, which correlate well to the geologic field studies. These scripts can be run quickly and easily to improve field safety for geologists, geophysicists, and other field crews.

Introduction

Volcano monitoring in the Aleutians is of great importance due to the heavy amount of airplane traffic in the region in addition to the presence of a large number of active volcanoes for scientific study. In order to classify potential volcano hazard areas the Alaskan Volcano Observatory, a joint venture by the University of Alaska-Fairbanks and the US Geological Survey, sets up and maintains seismic monitoring stations to monitor tremors and eruptions, as well as weather satellite monitoring (Casadevall et. al. 1997). These seismic stations work well but require maintenance; after the 1996 seismic swarm in Iliamna, a team of technicians and geophysicists went to the volcano to fix the old seismic stations and set up new ones (Neal and McGimsey 1997). Also, the AVO has plans to extend their seismic network beyond the twenty monitored volcanoes ultimately to the entire Aleutian Chain (S. Prejean and R. Wessels, personal communication, 2004).

Unfortunately this need for human presence exposes people to unnecessary risk. Many of these volcanoes will be mapped geologically for the first time during the set up of the stations so knowledge of potentially unstable slopes is limited. The problem of slope stability is especially acute on volcanoes where hydrothermal activity and fine-grained deposits create extremely unstable edifices that can slide with or without the presence of an explosive eruption (Miller et. al. 1996). Even on known and well-mapped volcanoes, people are deployed when seismicity occurs (as in the case of Iliamna). This seismicity can rapidly move fluids and degrade slope conditions.

Clearly a system of slope characterization needs to be in place for the safety of crews working near these unmapped volcanoes. In order to provide a quick and relatively simple method that can easily be performed before geologists venture to dangerous areas, I used data scenes from the Advanced Spaceborne Thermal Reflection and Emission Radiometer (ASTER) as well as digital elevation models (DEMs) from the Shuttle Radar Topography Mission (SRTM) both provided by NASA. Also, for geologic comparison, aeromagnetic surveys of the region were considered. The thermal bands of ASTER (Thermal IR, 8 to 12 microns) can show heat plumes, which are a good indication of hydrothermal venting (Abrams et. al. 1999). This is then overlain onto a DEM of the region, and areas of high slope correlated with heavy thermal emissions are considered potential failure zones. In order to illustrate this process, I applied it to the Iliamna Volcano, Alaska, which is well mapped and continuously active.
Iliamna Volcano Geology and Eruptive History

Iliamna sits roughly 225 kilometers southwest of Anchorage, Alaska, on the West side of Cook Inlet across from Homer and Kenai (60 deg 02 min North by 153 deg 05 min West) (Figure 1). It is a heavily glaciated stratovolcano with steep headwalls and numerous avalanche and Holocene lahar deposits (Begét 1996). Iliamna is part of the Aleutian Range, which consists of Jurassic granitic rocks juxtaposed against lava flows and pyroclasts of similar age (Figure 2) by the Bruin Bay fault (Miller et al. 1998). The base is surrounded by juvenile lahar flows older than 250 years (dated by tree ring analysis) (Miller 1996), which illustrates the instability of the region.

There is no well-documented explosive eruption of Iliamna; there is, however, a poorly recorded, unconfirmed report of an eruption in 1867 (Coats 1950). Some geologic evidence exists for an explosive eruption in the Holocene, but probably not as recent as 1867 (Neal and McGimsey 1997). Fumaroles and “unusually large” condensate plumes (up to 1000 m high) continuously rise from the eastern flanks, which are often mistaken for smoke and can be seen from Anchorage on a clear day (Miller et al. 1998).

In the event of catastrophic slope failure, nearby communities are at as great a risk as any field crew on the slopes of Iliamna: the four largest glaciers alone have three times the volume of snow and ice on Mt. Rainier (about fifteen cubic kilometers). Studies by Begét (1996) show lahar deposits that extend all the way to the coast, and a small fraction of this volume could inundate the nearby community of Silver Salmon in less than forty-five minutes. However, a sustained eruption would probably be necessary before such an event occurred (Waythomas and Miller 1999).
Data Acquisition And Basic Processing

The basic procedure involved creating thermal overlays (which presumably are correlated with fumaroles and other venting) onto a three dimensional, georectified topographic model for easy visual reference.

Digital Elevation Models

The DEM data were acquired through the National Map Seamless Data Distribution System by the USGS EROS Data Center. The system allows for an area of arbitrary dimension to be selected, then any available dataset for that area can be downloaded at no cost. The Iliamna dataset I chose to download was 30 m resolution SRTM data.

The DEM data came as a georectified 20 bit geotiff file. To view and edit the data I used 3DEM by Visualization Software, LLC. The SRTM rectified the data using a geodetic projection of latitude and longitude that distorts the data at high latitudes. The dataset was converted to WGS 84 UTM coordinates, which corrected for the distortion. It had small gaps, which are common to SRTM data; these gaps were filled in using a simple linear interpolation. According to Visualization Software’s instructions, for maximum accuracy the interpolation should be performed after conversion to the UTM WGS84 ellipsoid. The dataset was then saved as a processed geotiff (Figure 3), and three-dimensional models of the terrain were made for visual reference (Figure 4). The southwest corner and the northeast corner coordinates were recorded for use in Matlab to plot a georectified model.

![Figure 3: Digital elevation model of the area after processing.](image)

![Figure 4: Perspective digital elevation models from (a) south looking north, (b) north looking south, (c) east looking west, and (d) west looking east.](image)
If the data cross UTM boundaries, however, the conversion from geodetic latitude and longitude to any UTM ellipsoid will not work. In this case, the data must be processed in geodetic coordinates and converted to a particular coordinate system in UTM later.

**ASTER TIR Data**

The ASTER TIR data were also obtained from the Seamless Data Distribution System. All bands that were acquired are included with the download. The area selected for download fully encompassed Iliamna and surrounding glaciers all the way to the Cook Inlet coast. All bands were also available. Unfortunately, mild cloud cover obscured any attempt at spectroscopy on the volcano surface, but fortunately was clear enough to still get definitive heat blossoms over the fumaroles despite the poor resolution (90 m). Also, the volcano is perennially covered in snow, which makes spectroscopy over most of the mountain difficult. In places where snow would not stick due to slope, however, there is little chance for accumulation of clays and other fine grained materials.

Bands ten, twelve, and thirteen were chosen because they sweep a large range of thermal IR. This choice was mostly empirical—trial and error to find the most visible reflection/emission gradient. The bands were displayed and overlapped in grayscale so that the only consideration was intensity.

**Aeromagnetic Survey**

An aeromagnetic survey was flown over the entire region in 1977-78. The contours were compared to any features visible in both the DEM data and the TIR data (Figure 5). The survey was flown with one thousand foot ground clearance, so the high horizontal magnetic gradient could be a feature of acquisition in extremely steep areas as the plane attempted to correct for the sudden ground elevation change. For this reason, magnetics were not heavily considered in this survey, and in general lines flown with constant ground clearance should not be used unless corrections for the features have been made.

![Figure 5](image-url). Aeromagnetic survey of the Iliamna region. The volcano summit is shown by the cross. From USGS Map MF-1114-E.
Final Processing

Once the data were processed adequately, the sets were imported into ENVI (RSI Software, Inc.). Since both ASTER and SRTM data are georectified, ENVI allows a geographic link to be established between the images. ASTER bands ten, twelve, and thirteen were displayed in display one, while the SRTM dataset was displayed in display two. The TIR data in display one were contoured by reflectance/emission intensity and topographic contours were overlain in display 2. The histograms were then equalized so that the intensity limits were roughly equivalent in order to keep topographic features from washing out the thermal features and vice versa after import into Matlab. The area in question was highlighted in both sections, then exported to jpeg files as grayscale. The files were exported at the same scale and size.

From ENVI, the first real correlation between thermal emission and slope can be seen. When an area of high emission is selected, the corresponding area on the topographic image is highlighted. This can show a good qualitative picture of the general stability of regions. However, this procedure is clumsy and prone to ineffective interpretation. Therefore I wrote a Matlab script to apply a more quantitative (if not absolute) result.

Once the data were exported as normal 24 bit jpeg images, a custom designed Kirsch operator was applied to the topographic data which plotted the derivative in eight directions (Appendix A). This plots the local slope based on intensity, which in the case of the DEM data directly translates to elevation. Since the slope is far more critical than elevation, this information is much more useful when determining stability.

The Matlab script imports the processed thermal and the processed slope images into matrices of appropriate size, then adds them. The southwest and northeast coordinates are input, which allows the whole area to be georectified. The results can be printed onto a map or any convenient display for use in the field (Figure 6). The higher the value in any particular index, there exists a higher likelihood of slope instability.

Results And Conclusions

Figure 6 shows three different views of the processed hazard indices from the Iliamna dataset. The volcano summit is approximately in the center of each picture. The area of high index is at the summit and slightly to the south, while another high index runs along the crest of a ridge from the summit to the northeast. The area of extremely high index to the north is an albedo effect as a result of the thermal data being acquired during daylight hours. This area roughly correlates to the southernmost portion of the Tuxedni Glacier.

Using the Iliamna dataset, the method produced excellent results. The area discussed above correlates extremely well to two zones of instability discussed in Waythomas and Miller (1999) from field geologic studies (Figure 7). The results in figure 6 have been scaled from zero to ten due to the fact that the exported intensities are scaled and relative only to themselves.

This procedure is generally applicable only to active volcanoes due to its heavy dependence on thermal emission. It is also heavily restricted by snow and cloud cover, which can be perennial in some places in the Aleutian Chain.

The potential for field safety improvement is large using this method, however the results only indicate potentially unsafe zones that the field crews should be aware of. In addition to field safety, though, this process can also be applied to the prediction of lahar flows and blast directions based on zones of weakness, as well as others. The process is limited only by acquisition conditions.
The procedure described here correlates well, but is incomplete. Future versions of the scripts will include algorithms to process short wave IR and InSAR data in addition to the thermal to identify zones of clay minerals. The correlation between the aeromagnetic data and hydrothermal alteration could also be applied. The abundance of available data at little to no cost as well as the tiny amount of processing power required make this procedure a cheap way to improve field safety.

Appendix A – Kirsch Operator

In order to plot the local derivative of each point on the slope, I used a custom designed Kirsch operator as described in Russ (1995). The Kirsch operator has two distinct advantages over a horizontal derivative operator in that it averages pixels in eight directions rather than just one, as well as avoiding the image shift which will distort the coordinates. I used a 3 x 3 kernel with cyclic convolution with relatively large coefficients so as not to average too many pixels at once while still enhancing the value of the first derivative.
Figure 6.: Hazard Index using the method described plotted as a function of position using WGS-84 datum.
References


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