EOS IDS Volcanology Team
Data Product Document
Product # 3266

Lava Flow Area Change

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Preface

This document version 0.1 describes plans for an algorithm to monitor and document area changes in active lava flows from interferometric synthetic aperture radar data. Version 0.2 is an evolutionary draft, and much of this information is subject to change.

1. Introduction

1.1 Algorithm and Product Identification

The EOS product number is 3266, and the label is "Lava flow area change." It consists of an algorithm to determine the surface area of active lava flows, and three closely-related products created from the results of that algorithm: lava flow map data files, a tabular of change in surface area from previous observations, and a descriptive file. This product belongs to the EOS IDS Interdisciplinary Science Volcanology Team, led by Peter Mouginis-Mark.

1.2 Algorithm Review

The active flow area algorithm consists of an interferometric radar correlation image detection scheme that identifies what regions in the imaged area decorrelate completely between successive observations, and what the area of the decorrelated region is as a function of time. This algorithm will be applied to data acquired over volcanoes whose activity has been flagged by other algorithms or are known from ground observations to be active. Once a volcano has been identified as active by thermal or SO2 detection algorithms from MODIS or by other means, one of the suite of international synthetic aperture radar (SAR) satellites will target the site, and the data delivered to the IDS team. The time lag for data collection could be several weeks depending on the latitude of the volcano and the satellite used. There will be a further lag in receipt of the data at the processing site which could be several days. The data would then be processed in concert with the previous data collected over the site and correlation maps generated. From here an operator would identify the flows as distinct from other areas of possible decorrelation, and initiate a calculation of flow area. The results from this are stored in tabular form by location. The resulting correlation maps and time history data are then sent to the EDC DAAC EROS Data Center Distributed Active Archive Center. One set of output products will be generated for each of approximately 0-10 eruptions per year.

The above assumes that for each instance of an active volcano alert, we have previously stored a "before" radar image. The IDS team intends to archive a catalog of "interesting" volcanos and potential eruptive sites which will serve this purpose. For new and unexpected eruptions, the time series acquisition will begin with the activity alert. There will an additional delay in generating lava flow data products as the time history is built up from successive observations-- this delay could be days to weeks depending on the radar sensor used.

While the code to generate the products may be made available to the general community, the computational resources and operator understanding of its optimal application will likely preclude voluminous useful product generation at sites other than the planned processing centers.

1.3 Document Scope

This document describes the physical basis for the algorithm, implementation plan, required input, and output products.

1.4 Applicable Documents and Publications

Other applicable documents:
Crisp, J. 1995, manuscript in prep., "Detection of volcanic SO_2 using the satellite infrared imaging radiometers HIRS2 and MODIS. "
EOS IDS Volcanology Data Product Document for product 3290:
"Volcano Eruption Spike," by Luke Flynn.

2. Overview and Background Information

2.1 Experimental Objective

The purpose of this algorithm is to allow the EOS IDS Volcanology Team and other volcanologists to monitor the extent and areal rate increase of active lava flows from eruptions which may be either too dangerous or too remote for field survey techniques. This may result in scheduling of more detailed field observations or a hazard assessment from a central analysis site, with the data capable of being downlinked to on-site emergency or scientific crews. The results of the algorithm will also be useful for retrospective studies of lava flow volumes and other geophysical parameters needed for volcano study.

2.2 Historical Perspective

Remote sensing of volcanic eruptions is attractive for several reasons: i) it may be dangerous for field personnel to collect in situ flow area data, ii) data are immediately available in digital form so they may be readily incorporated in analyses of the eruption event, and iii) data may be acquired in remote areas that may be expensive to reach by conventional means. In this latter case a large number of sites may be studied and responses coordinated from a central location, reducing demands on the local infrastructure in times of pending hazard. Radar remote sensing has the particular advantage of insensitivity to solar illumination (it works as well at night as during the day) and also is less sensitive to atmospheric conditions than optical sensors. Thus, cloud cover or thick eruption plumes do not obscure the targets. Preliminary correlation analyses of volcanic data have been implemented using the NASA SIR-C space shuttle radar and also with the European ERS-1 satellite, and indicate the viability of the technique. Several other free-flying radar satellites are planned for the EOS time period, including ERS-2 and the ENVISAT SAR from Europe, the Canadian Radarsat 1 and 2 satellites, and JERS-1 and 2 from Japan. All of these can be expected to generate useful correlation data for these purposes.

2.3 Instrument Characteristics

Several satellite radar systems are either currently in orbit or will be operational during the EOS time frame beginning in 1998. They operate at various wavelengths, as shown in the table below. In addition, it is likely that NASA will launch a 24-cm system (which we denote TOPSAT for its likely topographic focus) in the same time period that is optimized for interferometric radar data acquisition. As the satellites are in near-polar orbits global coverage is available, thus most volcanic events will be observable. Detailed information on the parameters listed an their importance may be found in the references.

Interferometric radar satellite systems - Nominal parameters

System	RADARSAT	ERS-x	JERS-x
Frequency	5.3 GHz	5.3 GHz	1.275 GHz
Range bandwidth	11-30 MHz	15.55 MHz	15 MHz
Peak transmit power	4000 W	4800 W	1100-1500 W
Pulse repetition rate	1600 nominal	1679 nominal	1505-1606
Antenna dimensions	15 by 1.6 m	11 by 1 m	12 by 2.2 m
Antenna elevation beam width	6.2°	6°	6.2°
Critical baseline length	1100 m	1100 m	4500 m
Altitude decay, appr.	10 m/day	10 m/day	10 m/day
Satellite altitude	800 km	790 km	568 km

Look angles	20-50°	21-26°	35°
Ground range swath	100 km	100 km	85 km

System	ENVISAT
Frequency	5.3 GHz
Range bandwidth	11-30 MHz
Peak transmit power	4000 W
Pulse repetition rate	1600 nominal
Antenna dimensions	15 by 1.6 m
Antenna elevation beam width	6.2°
Critical baseline length	1100 m
Altitude decay, appr.	10 m/day
Satellite altitude	800 km
Look angles	20-50°
Ground range swath	100 km

The expected parameters for the NASA TOPSAT system are not yet determined, but a reasonable guess is given by Zebker et al. (1994b).

3. Algorithm Description

3.1 Theoretical Description

3.1.1 Physics of the Problem

The analysis technique is based on the coherence of radar echoes from surfaces that move on the pixel or subpixel scale between observation times (Zebker and Villasenor, 1992; Goldstein and Zebker, 1987). Since the backscatter from any resolution element is the coherent sum of echoes from all of the wavelength-scale scatterers within a resolution element meters in size, if the surface is viewed from two different angles or if the surface distribution of scatterers changes between observations, the correlation will decrease. The geometrical part of the correlation behavior is called baseline decorrelation, and sets limits on how close the satellite orbits must repeat to achieve coherence. The second effect, that of subpixel motion, is what concerns us here. During an eruption, a surface may be "written over" with an entirely new set of scatterers when a new lava flow inundates older terrain. This immediately destroys the echo coherence with previous observations. Since radar image intensity is dependent on the statistics of the scatterers rather than their exact locations, the new surface is usually indistinguishable from an older surface in terms of its visual and statistical appearance except in certain situations. Thus monitoring of the coherence repeatedly yields areas which have changed since the previous observations. A time series of measurements yields the flow's growth pattern.

3.1.2 Mathematical Aspects of the Algorithm

The complete algorithm follows from several data processing steps, many of which are well documented in the literature (see Curlander 1991 for a review of SAR processing, and Zebker et al. 1994a,b for interferometric processing steps.) In summary, radar data pass pairs are processed together to complex (amplitude and phase) images, the phase differences are generated, forming the interferogram. From the interferogram and individual channel intensity data, the correlation coefficient is formed using the following equation:

$$c = \frac{E\left(s_1 s_2^*\right)}{\sqrt{E\left(s_1 s_1^*\right) E\left(s_2 s_2^*\right)}}$$

where c is the correlation, E() denotes expectation determined by spatial averaging, and the s values represent complex single look radar measurements. These values are determined for the entire radar scene and an operator evaluates the area of individual flows as areas of low correlation. Time series histories for each flow are then generated from a sequence of radar images.

3.1.3 Variance / Uncertainty Estimate

The variance of the observed correlation measurements depends on many parameters, such as radar signal-to-noise ratio, surface roughness, and required resolution of the measurements. Current research is focused at quantifying these effects and the results will be applied to the analysis algorithms as available.

3.2 Practical Considerations

As discussed in section 1.2 above, we assume that there exists an archive of "before" images for contrast with radar images of active volcanos. Since each sensor is characterized by its own look angle, wavelength, and orbit, base images from each potential sensor must be stored. Thus, on-line disk storage limitations will constrain the number of volcanos that may be catalogued at any time.

It is difficult to predict the contrast in the correlation images in advance as non-eruptive factors influence radar correlation values. For example, vegetated areas will not correlate well after long periods of time, particularly at the shorter (<10 cm) wavelengths. Thus, it is necessary to have a human operator in the analysis cycle at present to identify lava flow decorrelation from knowledge of geologic context. Due the the infrequency of active eruptions, however, that should not pose a major burden on the process.

Another possibility is to utilize vegetation maps from other EOS sensors such as MODIS to eliminate volcanos for which the likelihood of the algorithm's success is limited. This will be investigated and if such masking is useful, it will be applied to reduce the required set of online radar image data.

The algorithm is expected to be operational at the start of the EOS mission, in 1998.

3.2.1 Numerical Computation Considerations

The radar data processing code will be written in Fortran, however, since it is quite computationally intensive, high-speed fast Fourier transform libraries are reqired and probably platform dependent. Our intention is to implement the code on dedicated workstations, the prototype of which is a Hewlett Packard 755 workstation with Convex math libraries. The flow isolation and area calculation routines which operate on the correlation images will also likely be written in Fortran, with windows interaction software in C. These will allow operators to interactively select individual flows and determine their area and spatial location.

3.2.2 Programming / Procedural Considerations

3.2.2.a Radar processing step

The radar data will be processed to complex images sharing the set of software used by two other EOS IDS algorithms, products 3269 "Volcano Topography" and 3272 "Volcano Deformation and Change". The interferograms generated from the data will be required by each of these algorithms although separate radar post-processing procedures are needed to generate the various output products. The radar interferograms will be produced within 2 days after receipt of the data at the processing center, located either at JPL or U. Hawaii.

3.2.2.b Data product generation at JPL or Hawaii SCF

No guarantee will be made by the EOS IDS Volcanology Team to create the lava flow area products within a specified time interval, due to the necessary operator interaction and scheduling of radar observations. However, if the alarms or other means of quick identification occur, satellite radar acquisition systems targeted promptly and data acquired, the output products should be produced within several days of an event.

There will also be required an algorithm to determine whether or not a given eruption merits lava flow analysis. Thsi will depend on various factors, including hazard potential, geologic significance, and operational considerations. This algorithm is TBD.

3.2.3 Calibration and Validation

Results for the algorithm will be compared to other sources of information, such as Smithsonian Global Volcanism Network reports, weather satellite images (for thermal activity) , ASTER observations (for thermal activity and changes in surface area), and field survey maps, to confirm that the algorithm is working properly. The results of these comparisons will be included in the data descriptive file .

3.2.4 Quality Control and Diagnostics

When and if the operator intervention is eliminated from the procedure, thresholds for decorrelation will be set and checked by human interpretation. Automated products will be then included in the output data files, and the change will be documented in the descriptive file 3.2.7.c. There will be no attempt to reprocess older data if an algorithm is updated.

3.2.5 Exception Handling

If data are missing, it will simply not show up in the output products. Such gaps will be noted in the descriptive file 3.2.7.c. The descriptive file will also note whether an eruption was missed due to a temporal gap in interferometric radar data.

3.2.6 Data Dependencies Input Data

The input data needed for the algorithm is raw radar signal samples from a series of radar passes over an active volcano. In addition, platform orbit location data are required.

The sensor suite utilized for the radar data consists of ERS-1/2, JERS 1/2, RADARSAT, ENVISAT, and any NASA spaceborne system which will be in operation during the EOS time frame. Data from several DAACs will be required; the exact list is TBD and depends on the sensors used.

Auxiliary algorithms, such as those designed to eliminate low priority or low probability of success sites, will require data from instruments such as MODIS to generate vegetation maps or other ground cover factors. The algorithms and sensors required are TBD.

3.2.7 Output Products

Three types of products will be generated, listed below as items a through c. All three will be archived in the EDC DAAC. No computer code will be run at the DAAC; the DAAC will only be required to archive the data products which will be sent from an EOS IDS SCF at JPL or Hawaii. The current plan is to use cylindrical equidistant projections for the maps, and to store the maps as raster files in EOS-HDF format.

3.2.7.a Correlation data files

A binary file (HDF format) consisting of radar backscatter measurements and interferogram correlation values will contain the correlation image data, usually in less than two working days after the data is received at JPL/Hawaii from the satellite receiving station for that sensor. The radar backscatter values will be relative to TBD, and the correlation values will be floating point numbers ranging from 0 for no correlation to 1 for perfect correlation. At first, these files will be created manually, but if the algorithm is found to be working in a reasonable fashion, then later this process will be automated. Each correlation image will require 1 Mbyte of storage per interferometric pair, and pairs will be generated at several day to several week intervals, depending on the sensor, for the life of the eruptive event, unless discontinued by the EOS IDS Team.

A header record included in the HDF format will contain additional information such as geocoded positional information, orbit geometry, and time tags.

3.2.7.b Approximate Daily Areal Time Series

The areal calculation for each flow will be tabulated and saved in text files where, for each interferometric pair, the areal and flow identification, in terms of position, are appended to the previous data.

3.2.7.c Descriptive files

An ASCII text file record length < 1000 characters will discuss the results of the algorithm and will document algorithm changes. The file will be updated and appended to, in as timely a fashion as possible. At the end of each calendar year, a new data file will be started. The file will include a description of the data file format and the algorithm versions. When possible, it will identify the original volcano name and location of the lava flows detected, and any reported characteristics of the flows. Large eruptions that were not imaged by the radar will also be noted. The file size will be less than 10Mb per year, and typically less than 1 Mb.

The descriptive file will also contain a summary of the volcanos currently in the archive of "before" images, identifying the potential eruptive sites which could be studied easily. It would also permit feedback from the science community about sites which have not been identified by the IDS team.

Expected Total Storage Required at the EDC DAAC = 35 Mb per Year

a Correlation Data Files

25 Correlation images, 1 Mbyte each

b Approximate Daily Areal Time Sreies

5 time series, each less than 10Kbytes in size

c Descriptive File

Up to 10 Mbyte/year

4. Constraints, Limitations, and Assumptions

The major constraint is in the uncertainty of the correlation from inactive flow areas on the volcanoes. Severe environmental conditions can cause decorrelation that could be misinterpreted as flow activity. For this reason we have left human operators in the analysis at present. If our continued accumulation of experience permits generation of automated approaches, these will be incorporated into the algorithms and the progress will be documented in the descriptive files.

The variance of the correlation estimates depends greatly on the sensor resolutions and signal to noise performance. A detailed tradeoff of resolution vs. uncertainty remains to be done, and will require some experience with data to complete. We project that the approximate values will be known TBD.

5. References

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ERS-1 system description,

JERS system description,

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