

EOS IDS Volcanology Team
Data Product Document
Product # 3272

Volcano Deformation and Change

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Preface

This document version 0.2 describes plans for an algorithm to determine topography deformation of volcanoes from interferometric synthetic aperture radar data and for data products to document the results. Version 0.2 is the second draft, and much of this information is subject to change.

1. Introduction

1.1 Algorithm and Product Identification

The EOS product number is 3272, and the label is "Volcano Deformation and Change." It consists of an algorithm to determine topographic deformation of a world-wide set of volcanoes, and three closely-related products created from the results of that algorithm: topographic deformation model data files, the corresponding radar backscatter and correlation images, and descriptive data files that describe the products. This product belongs to the EOS IDS Interdisciplinary Science Volcanology Team, led by Peter Mouginiis-Mark.

1.2 Algorithm Review

The volcano deformation and change algorithm consists of an interferometric radar technique to obtain a digital representation of volcano surface deformation at the cm level from repeat passes of orbiting synthetic aperture radar systems. This algorithm will be applied to data acquired over a set of volcanoes scattered around the world. Once obtained, these deformation models will serve as fundamental data for various modeling volcanic activities and geophysical processes. During the EOS time frame, as active volcanoes are identified, one of the suite of international synthetic aperture radar (SAR) satellites will be targeted to the site, and these data will be delivered to the IDS team. The time lag for receipt of the data at the processing site could be as much as several days after acquisition, which in turn could be a few weeks after the initial data request. The data would then be processed to form the deformation maps. The resulting height and ancillary correlation maps are then sent to the EDC DAAC EROS Data Center Distributed Active Archive Center. Several sets of output products will be generated for each of approximately 0-10 volcanoes per year; data throughput after that will depend on the number of active volcanoes identified. We note that a reference baseline topographic data set, such as that produced by EOS product number 3269, is required to assess deformation.

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:

EOS IDS Volcanology Data Product Document for product 3266: Lava flow area change

EOS IDS Volcanology Data Product Document for product 3269: Volcano topography

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 obtain topographic deformation information from a wide range of volcanic areas. 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. We note, however, that this near real time capability would depend on the satellite data acquisition delays to be minimal. The results of the algorithm will also be useful for retrospective studies of volcano morphology and evolution and other geophysical parameters needed for volcano study.

2.2 Historical Perspective

Determination of the deformation of a volcano due to an eruptive event aids in many modeling studies and in the understanding of the geophysical processes associated with volcano evolution. Increased interest in little-known volcanoes follows from identification of newly active regions or regions otherwise thought to be in a quiescent state. These can easily be located in remote regions of the world such that remote sensing is the only viable means to study them. Remote sensing of volcanic eruptions is attractive for several reasons: i) it is dangerous for field personnel to collect in situ 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 in particular, has the 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 interferometric analyses of volcanic data have been implemented using the NASA SIR-C space shuttle radar and also with the European ERS-1 satellite, and they have demonstrated the viability of the technique to obtain both topographic and deformation data. Several other free-flying radar satellites are planned for the EOS time period, including the ENVISAT ASAR 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 and their importance may be found in the references.

Interferometric radar satellite systems - Nominal parameters

System	RADARSAT	ERS-x	JERS-x
Frequency	5.3GHz	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

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

3. Algorithm Description

3.1 Theoretical Description

3.1.1 Physics of the Problem

The algorithm is based on the interferometric reduction of radar echoes from surfaces observed from slightly different aspect angles (Gabriel et al, 1989). In summary, the 3 dimensional location of a point is determined to meter scale accuracy from a single pair of radar images. However, the presence of even slight (cm level) deformation of the surface between these baseline observations and a third radar pass yields a phase shift in the observed signal that is well within the limits of detectability. Such measurements have been demonstrated in data acquired over earthquakes-- cm level motions are quite accurately mapped (Massonot et al, 1993; Zebker et al, 1994.) The time interval (usually days or weeks) for the acquisition of the pair or triplet used must include the eruptive event.

Various geometrical factors related to illumination geometry determine the accuracy of measurements derived from radar interferometry (Rodriguez and Martin, 1992; Zebker and Villasenor, 1992.) Chief among these is the interferometer baseline, or the distance between the antennas on the satellite repeat passes viewing the same region on the surface. 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. Thus, 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. Another important effect, that of subpixel motion, also 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, making it difficult to obtain reliable topographic data from that interferometric pass pair. Thus, it is important to obtain baseline topography before significant eruptions occur if complete coverage of the volcano is desired.

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. 1994 for interferometric processing steps.) In summary, radar data pass pairs are processed together to complex (amplitude and phase) images and the phase differences are generated, forming an interferogram for each of two pairs possible from three radar passes. From the interferogram pair and imaging geometry data, the deformation is inferred using the following phase measurement relations:

$$\phi = 4\pi\mathbf{B}\sin(\theta - \alpha)/\lambda$$

$$\phi' = 4\pi\mathbf{B}'\sin(\theta - \alpha')/\lambda$$

where ϕ and ϕ' are the measured phase shifts from two interferometric pairs with two different baseline angles α and α' , λ is the radar wavelength, \mathbf{B} and \mathbf{B}' are the interferometer baseline lengths, and θ is the look angle, assuming no motion has occurred between observations. If there is motion associated with the primed observation, then the phase has an extra term as given by

$$\phi' = 4\pi\mathbf{B}'\sin(\theta - \alpha')/\lambda + \Delta\rho 4\pi/\lambda$$

where the motion in the radar line of sight $\Delta\rho$ gives rise to the additional phase. Measurement of the extra phase in the image pair yields the deformation map. These values are determined for the entire radar scene to form the digital deformation model, which is combined with the radar brightness at each point to aid in visualization of the result.

3.1.3 Variance / Uncertainty Estimate

The variance of the observed correlation measurements depends on many parameters, such as radar signal-to-noise ratio, interferometer baseline geometries, and required resolution of the measurements. The algorithm generating the heights also produces an error estimate for each point in the output scene.

3.2 Practical Considerations

It is sometimes difficult to predict in advance the error in the height images, because temporal 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. Since all of the anticipated radar platforms except TOPSAT are capable only of repeat pass interferometry, they will be subject to this limitation. If TOPSAT data are available during EOS, we will use them, otherwise we will utilize the other systems.

It has also been observed from the exact repeat phase of the SRL-2 mission that local meteorological effects can produce phase changes on the order of the topographic deformation signal, thus detailed examination of the deformation measurements taking into account these effects will be required, at least at first. If multiple observations are available, though, the degradation should be minimal.

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 required and probably platform dependent. Our intention is to implement the code on dedicated

workstations at JPL and the University of Hawaii, the prototype of which is a Hewlett Packard 755 workstation with Convex math libraries.

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 3266 "Lava flow area change" and 3269 "Volcano topography". 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 usually be produced within 7-14 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 deformation products within a specified time interval due to the necessary operator interaction and scheduling of radar observations. However, if a new eruption is detected by EOS or by ground observations and satellite radar acquisition systems can be targeted promptly, the output products should be produced within several days of an event.

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 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 other ground truth data are available, the results will be checked. Also, if repeated observations of the same volcano from different or the same geometries are available, multiple DEMs and deformation maps can be generated and intercompared. The level of effort applied to this redundant analysis will be dependent on other commitments by the IDS team, but will remain a priority for critical areas. 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 a volcano 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 a volcano. In addition, platform orbit location data are required. At least one of the passes must occur before the deformation to be measured, and at least one after. Of necessity, only a few (20-50) of the world's volcanoes will be routinely studied in this manner.

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 Topographic deformation data files

A binary file will contain the deformation data, usually in less than 100 hours after the data are received at JPL/Hawaii from the satellite receiving station for the sensor used in acquisition. These data will be in line of sight displacements in meters, as well as radar backscatter images coregistered to provide identification of features. If multiple azimuth aspect angle data are required, such as from different satellites in different orbits, then three dimensional deformations will be produced. 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 deformation image will require 10 Mbyte of storage per interferogram pair, and will be generated at a rate of approximately 15 images per year for the life of the project, unless discontinued by the EOS IDS Team.

3.2.7.b Backscatter and correlation ancillary data

Each deformation map will be accompanied by backscatter and correlation data sets to aid in the interpretation of the deformation images. The backscatter images allow for identification of features and regions in the scene, while the correlation maps provide additional information on subpixel motion within the image. These will be at a scale such that the pixel spacing in several times greater than the product in 3.2.7.a, to permit for quicker browsing of the products.

3.2.7.c Descriptive files

An ASCII text file 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 origin volcano name and location, and any reported characteristics particular to that volcano. The file size will be less than 10 Mb per year, and typically less than 1 Mb. Observations of the local weather, as could affect the measurements through atmospheric effects, will be annotated in the ascii file as well.

Expected Total Storage Required per Year Mb at the EDC DAAC ≈ 197.5 Mbyte / yr

a Topographic deformation data files

15 Topographic deformation maps , 10 Mbyte each

b. Backscatter and correlation ancillary data

15 products, 2.5 Mbyte each

c Descriptive File

Up to 10 Mbyte/year

4. Constraints, Limitations, and Assumptions

The major constraint is in uncertainty of the correlation from non-active-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.

We also assume that weather related phenomena are minimal in effect on the measurements, that the timing of the data acquisitions is appropriate for the before and after images, and that in many cases two dimensional line of sight motion is acceptable.

5. References

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