EOS IDS Volcanology Team
Data Product Document
Product # 3269

Volcano Topography

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Preface

This document version 0.1 describes plans for an algorithm to determine the topography of volcanoes from interferometric synthetic aperture radar data and for data products to document the results. Version 0.1 is the first draft, and much of this information is subject to change.

1. Introduction

1.1 Algorithm and Product Identification

The EOS product number is 3269, and the label is "Volcano Topography." It consists of an algorithm to determine topography of a world-wide set of volcanoes, and three closely-related products created from the results of that algorithm: digital elevation model data files, the corresponding radar backscatter images, and descriptive data files that describe the products. This product belongs to the EOS IDS Interdisciplinary Science Volcanology Team, led by Peter Mouginis-Mark.

1.2 Algorithm Review

The volcano topography algorithm consists of an interferometric radar technique to obtain a digital elevation model of volcanoes from repeat passes of orbiting synthetic aperture radar systems. This algorithm will be applied to data acquired over a baseline set of volcanoes scattered around the world. Once obtained, these DEMs (digital elevation models) will serve as fundamental data for several volcano modeling activities. In addition, during the EOS time frame, as additional volcanoes whose activity has been flagged by other algorithms are identified, one of the suite of international synthetic aperture radar (SAR) satellites will be targeted to the site, and these data also wil be delivered to the IDS team. We note that the algorithm requires multiple passes over a given volcano by the same radar, thus the set of volcanos imaged by one radar sensor may be different than that imaged by a second radar system. The time lag for acquisition of these data could be as long as several weeks, and subsequent receipt of the data at the processing site could be several days later. The data would then be processed to form the height maps. The resulting height and ancillary correlation maps are then sent to the EROS Data Center Distributed Active Archive Center. One set of output products will be generated for each of approximately 50 volcanoes over three years; data throughput after that will depend on the number of previously unstudied active volcanoes.

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 3272: "Volcano deformation and change"
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 provide the EOS IDS Volcanology Team and other volcanologists with baseline topographic information for numerous volcanic target 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 provided in an online format to on-site emergency or scientific crews. The results of the algorithm will also be useful for retrospective studies of volcano morphology and other geophysical parameters needed for volcano study. Although not part of the IDS Team's focus or responsibilities, this algorithm would also meet many of the EOS requirements at launch (1998) for high resolution topographic data for regional sites.

2.2 Historical Perspective

Determination of the topographic state of a volcano aids in many modeling studies and in the understanding of the geophysical processes assocoated 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. Remote sensing of volcanic eruptions is attractive for several reasons: i) it is 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, in particular, has advantages 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 indicate 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 ERS-2 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 which 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	5.3GHz	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	10-30 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. (1994b). Another possibility is that NASA will fly a mission utilizing the Space Shuttle radar to measure much of the Earth at a height accuracy of 20 m and a spatial resolution of 80 m-- this data set would cover volcanos between ±55° latitude or so.

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 (Zebker and Goldstein, 1986). Various geometrical factors related to illumination geometry determine the accuracy of DEMs 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 a baseline set of topography before significant eruptions occur.

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 form complex (amplitude and phase) images, the phase differences are generated, forming the interferogram, and from the interferogram and imaging geometry data, the height map z(x) is formed using the following equations:

$$\delta = \phi\lambda/2\pi$$

$$\sin(\theta-\alpha) = ((\rho+\delta)**2 - \rho**2 - \mathrm{B}**2)/(2*\rho*\mathrm{B})$$

$$z(x) = h - \rho\cos(\theta)$$

where ϕ is the measured phase shift, ρ is the range from the radar to the point on the ground, λ is the radar wavelength, θ is the look angle, α is the orientation of the baseline with respect to horizontal, and B is the baseline length. These values are determined for the entire radar scene to form the digital elevation 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, surface roughness, and required resolution of the measurements. The algorithm generating the heights also produces an error estimate for each point in the output scene. The algorithm for estimating the uncertainties is described by Rodriguez and Martin (1992), and experimental validation of the theory may be found in Madsen et al. (1995).

3.2 Practical Considerations

It is sometimes difficult to predict in advance the error in the height images in advance as 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.

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.

3.2.2 Programming / Procedural Considerations

3.2.2.a Radar processing step

The radar data will be processed to form complex images sharing the set of software used by two other EOS IDS algorithms, products 3266 "Lava flow area change" and 3272 "Volcano deformation and change". The interferograms generated by this algorithm will be required by each of these other 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 dem products within a specified time interval due to the necessary operator interaction and scheduling of radar observations. However, if thermal and SO2 alarms occur and satellite radar acquisition systems can be targeted promptly, the output products might 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 aircraft data from sensors such as the NASA/JPL TOPSAR, the DTED-1 data base produced by the US government and available to EOS through special arrangements, stereoscopic ASTER observations, existing USGS data bases, 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 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. In addition, certain subareas on otherwise complete DEMs may not yield high quality height reconstructions, such as regions where snow cover has changed between observations. Such gaps will be noted in the descriptive file 3.2.7.c. The descriptive file will also note whether a volcano 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 are raw radar signal samples from a pair or longer time series of radar passes over a volcano. Multiple passes, especially from different viewing geometries, will help compensate for data droputs due to imaging artifacts such as layover and shadowing. In addition, platform orbit location data are required.

3.2.7 Output Products

Three types of products will be generated, listed below as items a through c. All five 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 Digital elevation data files

A binary file will contain the height and backscatter image data, usually in less than one week after the data is received at JPL/Hawaii from the satellite receiving station for that sensor. 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 10 Mbytes of storage per dem, and will be generated at approximately 15 sites per year for the life of the project, unless discontinued by the EOS IDS Team.

3.2.7.b Correlation ancillary data and error estimate

Each dem will be accompanied by a height error map to present the accuracy of the product as calculated from radar parameters.

3.2.7.c Descriptive files

An ASCII text file record length < 10000 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 origin volcano name and location, and any reported characteristics particular to that volcano. The file size will be less than 10Mb per year, and typically less than 1 Mb. The descriptive file in some cases may contain the results of the radar derived correlation values with an ASTER decorrelation stretch image--this may yield clues to unusual surface lithologies.

Expected Total Storage Required per Year Mb at the EDC DAAC
a Digital elevation data files

15 digital elevation model and backscatter images, 10 Mbyte each DEM/backscatter HDF file

b Correlation ancillary data and error estimate

15 products, 2.5 Mbyte each, one quarter the size of the corresponding DEM/backscatter file

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 will in addition attempt to combine data from multiple disparate geometries, so that the artifacts due to a peculiar combination of surface slope and imaging geometry will be greatly lessened.

5. References

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