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CURRENT AND FUTURE USE OF TOPSAR DIGITAL TOPOGRAPHIC DATA FOR VOLCANOLOGICAL RESEARCH

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Introduction

In several investigations of volcanoes, high quality digital elevation models (DEMs) are required to study either the geometry of the volcano or to investigate temporal changes in relief due to eruptions. Examples include the analysis of volume changes of a volcanic dome (Fink et al., 1990), the prediction of flow paths for pyroclastic flows (Malin and Sheridan, 1982), and the quantitative investigation of the geometry of valleys carved by volcanic mudflows (Rodolfo and Arguden, 1991). Additionally, to provide input data for models of lava flow emplacement, accurate measurements are needed of the thickness of lava flows as a function of distance from the vent and local slope (Fink and Zimbelman, 1986). Visualization of volcano morphology is also aided by the ability to view a DEM from oblique perspectives (Duffield et al., 1993).

Until recently, the generation of these DEMs has required either high resolution stereo air photographs or extensive field surveying using the Global Positioning System (GPS) and other field techniques. Through the use of data collected by the NASA/JPL TOPSAR system, it is now possible to remotely measure the topography of volcanoes using airborne radar interferometry (Zebker et al., 1992). TOPSAR data can be collected day or night under any weather conditions, thereby avoiding the problems associated with the derivation of DEMs from air photographs that may often contain clouds. Here we describe some of our initial work on volcanoes using TOPSAR data for Mt. Hekla (Iceland) and Vesuvius (Italy). We also outline various TOPSAR topographic studies of volcanoes in the Galapagos and Hawaii that will be conducted in the near future, describe how TOPSAR complements the volcanology investigations to be conducted with orbital radars (SIR-C/X-SAR, JERS-1 and ERS-1), and place these studies into the broader context of NASA's Global Change Program.

TOPSAR

The TOPSAR instrument is a C-band (5.6 cm wavelength) radar flown on board a NASA DC-8 aircraft (Zebker et al., 1992; Evans et al., 1992). Topographic data collected by TOPSAR have a spatial resolution of 5 to 10 m, with a vertical accuracy of 1 to 5 m depending upon the relief of the target — smoother surfaces (i.e., at the pixel-scale, those surfaces that have a uniform relief) will have lower height errors than mountainous areas because of the greater uncertainty in characterizing an inhomogeneous pixel with a single height value. TOPSAR swaths are 30 km x 6.4 km in size. These topographic data are acquired concurrently with radar backscatter images at C-band, L-band (24 cm) and P-band (68 cm), which enable surface textures and structure to be investigated in a manner comparable to conventional radar analyses of volcanoes (e.g., Gaddis et al., 1989, 1990; Campbell et al., 1989).

TOPSAR measurements differ significantly from DEMs derived from the interpolation of digitized contour maps. In TOPSAR data sets, a height measurement is made at each pixel and therefore the TOPSAR DEM provides a truer representation of the surface relief. We note, however, that in its current configuration TOPSAR does not have any absolute geodetic control, so that each TOPSAR scene must be referenced to a geodetic grid before absolute elevations and regional slopes (i.e., those slopes measured along or across the entire swath) can be resolved.

Mt. Hekla and Vesuvius

We illustrate the use of TOPSAR data for volcanological research with examples derived from data collected over Mt. Hekla (Iceland) and Vesuvius (Italy) in the summer of 1991.

For Hekla volcano, the thickness of lava flows can be measured from TOPSAR data (Fig. 1), and these thickness measurements can be used with existing numerical models of lava rheology to infer yield strengths of 5000 to 30,000 Pa. (Rowland et al., 1992), comparable to lavas of similar composition (basaltic andesite) elsewhere. In all cases, the calculated yield strength of a flow increases with distance from the vent (reflecting the greater amount of cooling of the furthest-traveled lava), although average flow thickness remains fairly constant. TOPSAR data also permit the geometry of a moberg ridge (which is a volcanic feature formed by a sub-glacial eruption) to be determined (Fig. 2). Although only a few examples of moberg ridges around Hekla were imaged by TOPSAR, it would be possible to use TOPSAR to measure the volume of many ridges, thereby enabling the amount of lava erupted from different vents to be determined (Evans et al., 1992).

TOPSAR data for Vesuvius, Italy, permit the geometry of the volcano flanks to be determined (Mouginis-Mark and Garbeil, 1993). There is a large number of valleys on the flanks of the older portion (Mt. Somma) of Vesuvius. These valleys are primarily water-carved in origin, but they have also been used as pathways for pyroclastic flows. TOPSAR enables a slope map of the flanks to be derived, and valley geometry to be measured. Slope maps can provide valuable input when examining the likelihood that different areas will be affected by volcanic hazards such as pyroclastic flows, lava flows, and lahars. We have found the slopes of the flanks of Mt. Somma to be typically ~13 - 24° at lower elevations, ~25 - 36° closer to the rim, with a maximum value of > 48° on the inner walls of the craters.

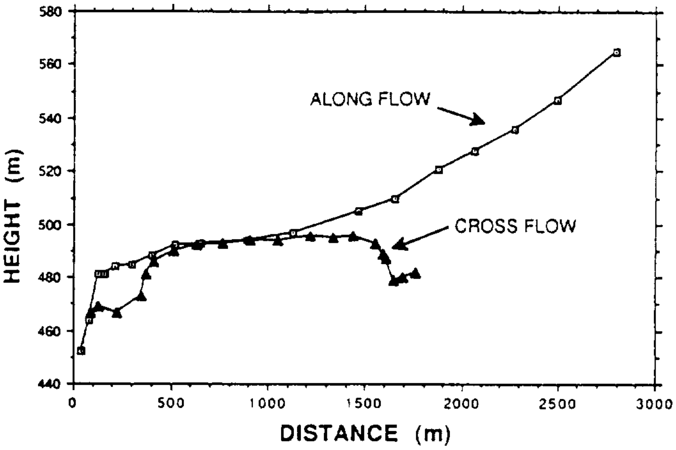

Fig. 1: TOPSAR profiles across and along a single lava flow erupted from Mt. Hekla, Iceland.

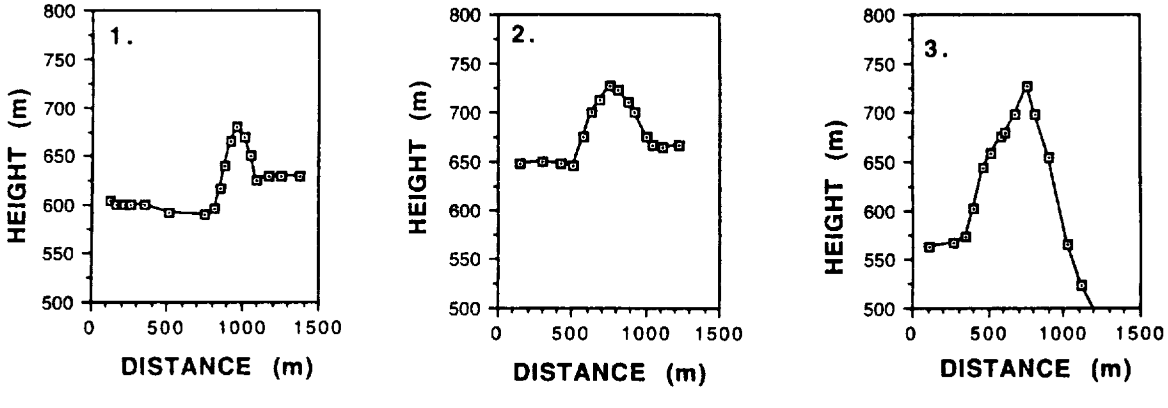

Fig. 2: 3 profiles across a single moberg ridge close to Mt. Hekla, Iceland, derived from TOPSAR data. Length of moberg ridge perpendicular to these profiles is ~3800 m.

Profiles down the length of individuals valleys (Fig. 3a) can also be determined. Potentially, it may be possible to use TOPSAR data to recognize different lithologic units (either different in the mechanical properties or absolute age) by this method, since the degree of erosion of materials on a given slope should vary as a function of strength and/or age. In order to explore the physical basis for these relationships, a more rigorous study would be required to identify and evaluate the possible significant variables (e.g., Knighton, 1974). The profiles across a valley at different distances from the rim of Mt. Somma (Fig. 3b) also show that the geometry of the valley varies from one place to another. From our morphologic data, there appears to be a trend towards proportionally deeper valleys with increasing slope. In general, for each valley, on slopes > 30° depth can be twice that on slopes < 10°. This may be interpreted to be an indication of the lower erosive action of the flows (either debris flows or running water) on the lower slopes than on steep slopes, or of deposition on the lower slopes.

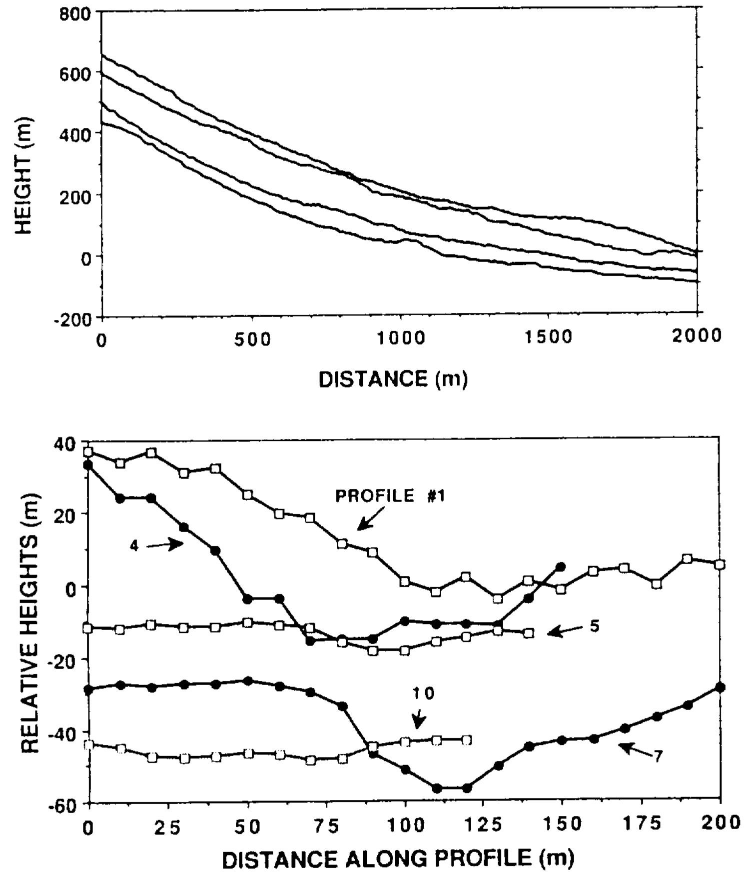

Fig. 3a (Left, at top): Profiles for individual valleys on the flanks of Mt. Somma. Fig. 3b (left, at bottom) Cross-sections through a single valley on flanks of Mt. Somma, as determined from TOPSAR data. Only a few representative cross-sections are shown, but the original data were obtained at every 250 m down the flanks.

Future TOPSAR data sets

To date, only a few TOPSAR data sets have been collected over volcanoes; the most useful are the data for the western Galapagos Islands. These volcanoes constitute one of the Space Shuttle Radar (SIR-C/X-SAR) "Super-Sites", and are also one of the targets for the JERS-1 Verification Program. Use of the TOPSAR DEM, as well as the AIRSAR multi-wavelength backscatter images and the JERS-1 SAR data, will therefore aid in the analysis of these orbital data sets.

Several structural and volcanological investigations of the Galapagos volcanoes have been conducted using air photographs (Chadwick and Howard, 1991) and satellite images (Munro and Mouginis-Mark, 1990; Rowland and Munro, 1992), but the detailed topography of the islands is poorly known. Fernandina and Isabela Islands were imaged in May 1993 by TOPSAR, but at the time of writing the analysis of these data has not been initiated. The use of TOPSAR data to investigate the spatial distribution of rift zones through the generation of slope maps, the measurement of lava flow thickness on different slopes, and the calculation of volumes of cinder cones and summit calderas, should all significantly improve our knowledge of these infrequently visited volcanoes.

Two TOPSAR deployments over Kilauea Volcano, Hawaii, are planned for September and October 1993. These flights will enable the derivation of a "topographic difference map", which should permit the quantitative measurement of the volume of new lava erupted during the intervening month. This will allow an average effusion rate for the volcano to be determined, as well as facilitate the study of the growth of a compound lava flow field. Finally, as part of the Decades Volcano program (Bennett et al., 1992), planning is under way for a TOPSAR deployment to Santa Maria Volcano, Guatemala, as well as the collection of ERS-1 orbital SAR data from the temporary ground receiving station in Atlanta, USA. Some time in the future we hope to use TOPSAR to aid the analysis of the Santiaguito lava dome, and help with the production of new hazard maps through the construction of detailed topographic maps.

Acknowledgments

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References

Bennett EHS, Rose WI, Conway FM (1992) Santa Maria, Guatemala: A Decade Volcano. Eos 73: 521 - 522

Campbell BA, Zisk SH, Mouginis-Mark PJ (1989) A quad-pol radar scattering model for use in remote sensing of lava flow morphology. Remote Sens Environ 30: 227 - 237

Chadwick WW, Howard KA (1991) The pattern of circumferential and radial eruptive fissures on the volcanoes of Fernandina and Isabela islands, Galapagos. Bull Volcanol 53: 257 - 275

Duffield W, Heiken G, Foley D, McEwen A (1993) Oblique synoptic images, produced from digital data, display strong evidence of a "new" caldera in SW Guatemala. J Volcanol Geotherm Res 55: 217 - 224.

Evans DL, Farr TG, Zebker HA, van Zyl JJ, Mouginis-Mark PJ (1992) Radar interferometric studies of the Earth's topography. Eos 73: 553 and 557 - 558

Fink JH, Malin MC, Anderson SW (1990) Intrusive and extrusive growth of the Mt. St. Helens lava dome. Nature 348: 435 - 437

Fink JH, Zimbelman JR (1986) Rheology of the 1983 Royal Gardens basalt flows, Kilauea Volcano, Hawaii. Bull Volcanol 48: 87 - 96

Gaddis L, Mouginis-Mark P, Singer R, Kaupp V (1989) Geologic analyses of Shuttle Imaging Radar (SIR-B) data of Kilauea Volcano, Hawaii. Geol Soc Amer Bull 101: 317 - 332

Gaddis LR, Mouginis-Mark PJ, Hayashi JN (1990) Lava flow surface textures: SIR-B radar image texture, field observations, and terrain measurements. Photogram Eng Remote Sensing 56: 211 - 224

Knighton AD (1974) Variation in width-discharge relation and some implications for hydraulic geometry Geol Soc Amer Bull 85: 1069 - 1076

Malin MC, Sheridan MF (1982) Computer-assisted mapping of pyroclastic flows. Science 217: 637 - 640

Mouginis-Mark, PJ and Garbeil, H. (1993) Digital topography of volcanoes from radar interferometry: An example from Mt. Vesuvius, Italy. Submitted to Bulletin Volcanology.

Munro DC, Mouginis-Mark PJ (1990) Eruptive patterns and structure of Isla Fernandina, Galapagos Islands from SPOT-1 HRV and Large Format Camera images. Int J Remote Sensing 11: 15011 - 1174

Rodolfo KS, Arguden AT (1991) Rain-lahar generation and sediment-delivery systems at Mayon Volcano, Philippines. In: Sedimentation in Volcanic Settings, SEPM Sp. Pub. No. 45: 71 - 87

Rowland SK, Munro DC (1992) The caldera of Volcan Fernandina: a remote sensing study of its structure and recent activity. Bull Volcanol 55: 97 - 109

Rowland, SK, Garbeil, H. and Mouginis-Mark, PJ (1992). Yield strengths of recent Hekla lavas. Fall 1992 AGU Abstracts, p. 648.

Zebker HA, Madsen SN, Martin J, Wheeler KB, Miller T, Lou Y, Alberti G, Vetrella S, Cucci A (1992) The TOPSAR interferometric radar topographic mapping instrument. IEEE Trans Geosci Rem Sen 30: 933 - 940.