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THREE DIMENSIONAL DETECTION OF VOLCANIC DEPOSIT ON MOUNT MAYON USING SAR INTERFEROMETRY

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ABSTRACT

Volcanic hazard is one of the predominant disasters that constantly threat life and property. There are about seven active volcanoes in Philippines. Historical events and very recent eruptions suggest that Mayon volcano is very active. Proper understanding of the geographical distribution of lava deposits in Mayon area and its changes with time could facilitate in the development of mitigation plan for future disasters. Advancement of satellite remote sensing has offered greater potential for detection of lava deposit at larger scales. The development of weather-independent microwave remote sensing has made the remote detection over large area at any time. However, detection of deposits using only SAR image is sometimes hindered by ambiguities and noise. For instance, ambiguity occurs in deposit area covered by young vegetation, which will give high or low backscatter depending on their orientation and the viewing geometry of SAR. This difficulty can be overcome by using the coherence as additional information to identify these areas. Furthermore, changes in lava deposits before and after an eruption can be identified from height difference information, which was derived using D-INSAR technique with around 5 to 10 meters accuracy. Integration of SAR image, coherent image, height difference and other spatial information is highly suitable for comprehensive analysis of volcanic deposits detection.

1. INTRODUCTION

The volcanic hazard created a concern to develop mitigation plans for diminution of damages. The satellite remote sensing has been used enormously since the launch of the first Earth Resource Technology Satellite in 1972 to monitor and comprehend the peril. But the experiences show that the use of high-resolution visible and infrared satellite sensors is limited by some factors related to atmospheric conditions, cloud covers and revisit capability.

Synthetic Aperture Radar (SAR) sensors on board these space satellites are capable of obtaining desired information, independent of weather conditions and external illumination source (Elachi., 1988). The increment of SAR system made the SAR data more readily available for continues monitoring of volcanic activities. On the other hand, detail extraction of information from grayscale SAR intensity image is practically difficult.

SAR Interferometry has become an attractive technique to acquire the amplitude of the signal and its phase from SAR images. In which two SAR images of the same region, acquired with slightly different sensor position are used to compute the phase difference of these two data sets. The general review of this technique is presented in Gens and Van Genderen, 1996. Further, By disregarding the other influences like atmospheric effect and ground surface cover changes, one can estimate very precise terrain height of each specific location from the different geometry of the interferometric pair images (Armour, B., et al., 1999). But practicality these affects cannot be eliminated very easily. The extension of this basic technique, differential SAR interferometry allows the detection of very small-scale changes of land surface features (Armour, B., et al., 1999). At present, using this technique some of the applications are under investigation. The objective of this study is investigating the applicability of SAR Interferometry technique to measure the amount of volcanic deposits due to 1993 eruption on mount Mayon.

2. STUDY AREA

The symmetrical Mayon volcano is the most active volcano located in Alabay province, Philippines. It is considered as one of the world’s most perfect cones and is visible for miles around in the flat landscape of the region. This Mountain’s summit is about 2460 meters above the sea level and covers an area of about 250 sq. km. Its slope has very steep gradient, from the summit down to 500 meter above sea level. In this zone rainy season begins in June and gradually rainfalls increases from October to January. Dry season is from March to May. The recorded annual rainfall is approximately 3390mm.

The greater part of mountain gradient is bare, consist of lava flows and other loose air fall deposits. Sparse and shrub terrain can be seen in the middle slopes, and this followed by grasslands. Coconut dominates in the gentle slopes and most of them bordering to the upper slope of the Mountain grasslands. Human colonies are found within the coconut plantation and along the flood plain where rice is cultivated. This vicinity is highly susceptible for lahar and mudflow. The recorded eruption was in the 17th century. Since then it has erupted more than 47 times. A eruption in February 1993 was one of the major historical eruptions lasted for 30 minutes. This killed at least 68 people and prompted the evacuation of over 60,000 others. Eruption occurred from the central conduit and vented lava flows that travel far down the flanks. Pyroclastic flows and mudflows have commonly swept down many of the ravines that radiate from the summit and have often devastated populated lowland areas of southeast part of Mayon.

3. METHODOLOGY

Local eruptional and erosional activities decelerate the topography sufficiently to prohibit the use of differential radar interferometry, which is useful to identify topographic changes. On the other hand if the changes are very large it can be observable by simple differencing of before and after DEM. Herein on account of unavailability of SAR data, topographic map of 1982 was used and modeled by ARC/INFO TIN to derive base DEM. So as to generate interferometric DEM from the 1996 interferometric pair the GAMMA software was used. By means of subtraction the DEM difference was identified. Followed by possible error correction models were developed to improve the accuracy level. Next to select the sample points for error model changed and unchanged areas were identified from the coherence image. Finally the result was validated by DEM from 1999 topographic map and field data, which was acquired in 1998. The overall methodology is shown in Figure 1.

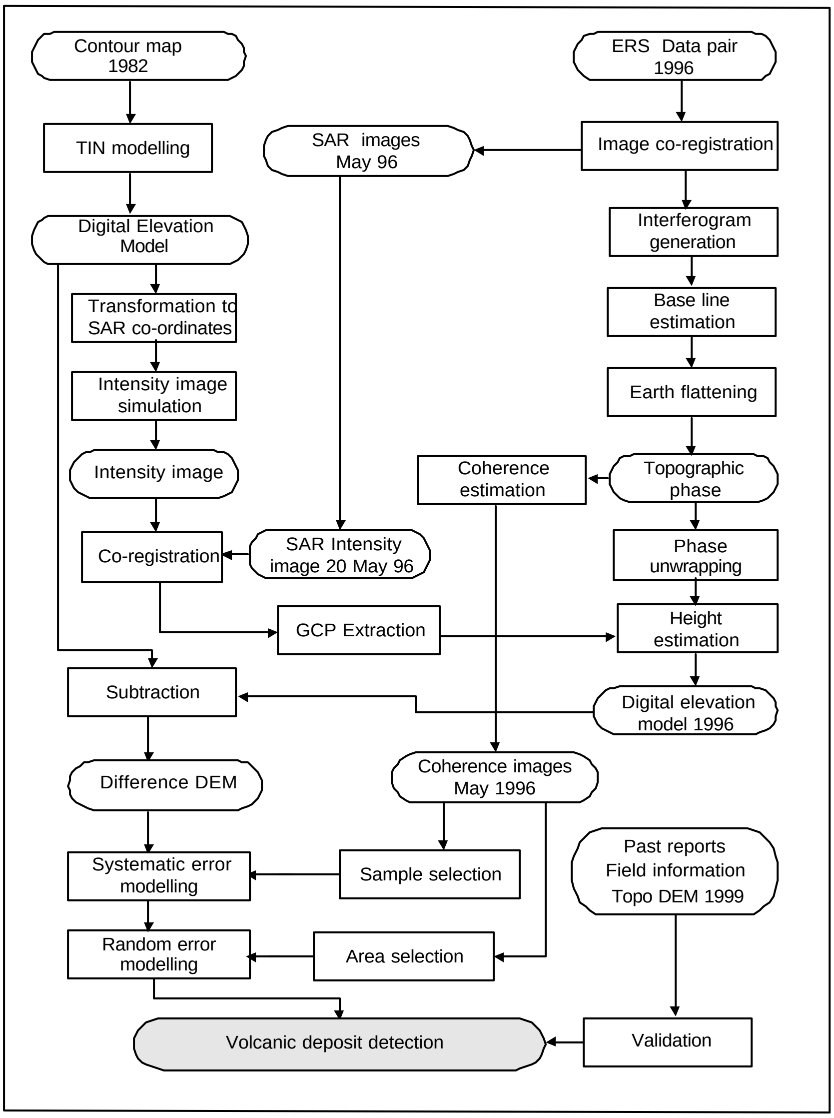

Figure 1: Overall methodology

4. RESULTS AND DISCUSSION

4.1 Interferometric Process

Pair of SAR images acquired in May 1996 was processed using GAMMA software. The process requires co-registration of the two images at sub-pixel accuracy. Therefore to apply co-registration, cross correlation method and fringe visibility method were applied to determine offset polynomial coefficients. Once the offset functions were known, the two SLC images were co-registered and interferogram was calculated. At the same time SAR intensity images were generated. To make use of additional information, from the interferogram and two intensity images, the degree of coherence was estimated. An adaptive filter was applied to the flatten interferogram to reduce the phase noise and residues. Finally the phase unwrapping was implemented successfully. The precise baseline, that needs to convert unwrapped phase to elevation, can be optioned by ground control points (Zebker et al., 1994). Based on ground control points selected from topographic DEM, precise baseline was estimated. Using this precise baseline (94.069 m) interferometric DEM in slant range was generated from unwrapped image. Then it was ortho-rectified to ground range system. Because of layover effect, western part and peak of the mountain was not mapped.

4.2 Height Difference Between Before And After Eruption

To compare DEM created using topographic data of 1982 and DEM from INSAR processing, first they were co-registered precisely. To do this intensity image was simulated from topographic DEM. Then SAR intensity image and simulated intensity image were co-registered with sub pixel accuracy. In order to obtain height difference, topographic DEM (1982) was subtracted from interferometric DEM (1996). As the change was happened in southeastern part of the mount, that area was extracted from whole image. From the difference image volcanic deposit can be identified. Though, the accuracy of the height difference is not high because of a systematic error due to the topography. The error can be caused by inaccurate orbital parameters or inaccurate reference DEM (Zhou et al., 2000). This systematic error that is in the form of ring pattern along the elevation, can be clearly observed in the height difference image.

4.3 Systematic Error Model

A relationship between elevation and error was modeled using the random sample points. While selecting the points, possible changed areas were avoided with the use of coherence image. In order to get a best fit, the sixth order polynomial function be applied (Figure 2).

$$y = -8E\text{-}16x^6 + 4E\text{-}12x^5 - 8E\text{-}09x^4 + 7E\text{-}06x^3 - 0.0025x^2 + 0.2861x$$

The above function was used to make a spatial model, and to remove the systematic error, spatial model was subtracted from the height difference image. Slight improvement is found in the result. Because of atmospheric effects over the certain areas random error was encountered in the systematic error corrected image. Atmospheric effects are independent of the terrain topography or the coherence and could not be quantified easily (Crosetto and Crippa, 2000).

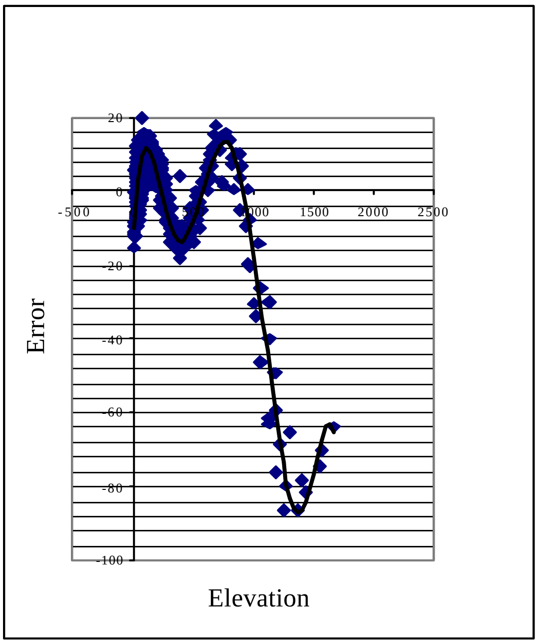

Figure 2: Trend line between elevation and error

4.4 Random Error Model

To correct random error, the error in the unchanged areas was used to predict the error in changed area. To select the unchanged area, the area that has greater than 0.4 coherent values, was masked out. In order to eliminate some small islands in the changed area majority filter was applied. Then the ARC/INFO kriging interpolation method was applied to build a surface model. To remove the random error, a spatial error model was subtracted from the systematic error corrected image.

The result was validated using 1999 topographic data. Initially a difference image of 1999 DEM and 1982 DEM was developed and used as standard data (see Figure 3). Then the comparison was done visually. Figure 4 shows the height difference between topographic DEM 1982 and INSAR DEM 1996 after error correction. Area in red indicates the deposit and area in blue indicates the eroded places. The result is almost fit with the standard data. When statistics of the final accuracy were compared with standard, the accuracy limit of all pixels of deposited area were within –45 to +54, more than 92% pixels were within –10 to +10 and more than 80% pixels were within -5 to +5. Standard deviation of error was 9.

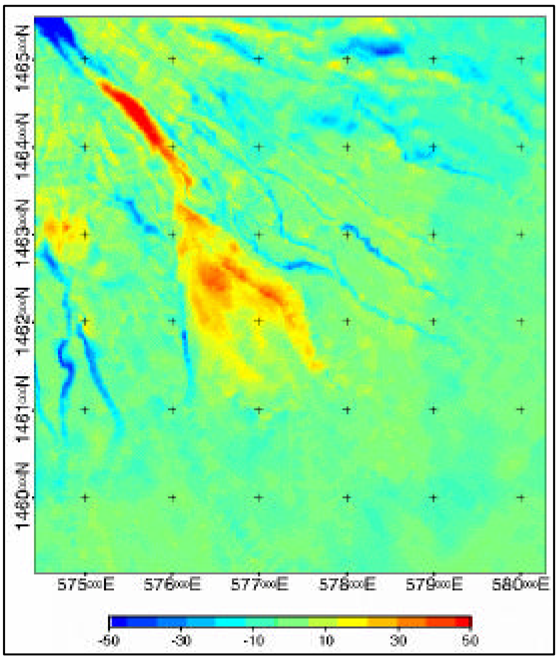

Figure 3: Height different (1999-1982)

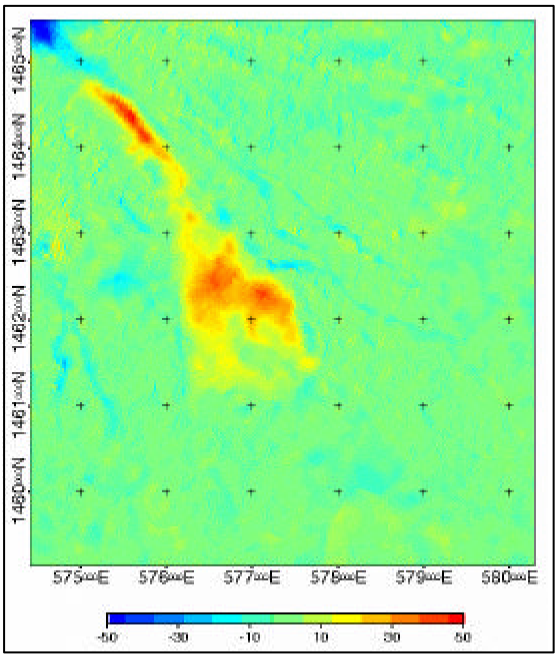

Figure 4: Height different after error correction (1996-1982)

5. CONCLUSION

Using tandem dataset of ERS-1/2 with 94 m base line a good quality interferogram was generated from some parts of the study area. To differentiate volcanic deposits from vegetated areas, the C-band coherence can be used, because the deposit exhibits very high coherence where as vegetated area exhibits relatively low absolute coherence. In the concern of study, the accuracy of difference image derived from interferomtric processing is inadequate to detect lava deposit. Therefore by applying systematic error correction and random error correction model, quality can be improved up to 5 to 10 m. As a result of the unique technique very high accurate lava and lahar deposit detection is feasible using next generation SAR satellite data with appropriate base line. Integration of SAR image, coherent image, height difference and other spatial information could improve the accuracy of volcanic deposits detection. This examination will provide a better solution to understand the eruptional and erosional activities.

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