Pre and co-eruptive deformation field at Merapi volcano from kinematic GPS surveys in the summit area

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Abstract

Merapi volcano (Java, Indonesia) is in almost continuous activity with growth of an andesitic lava dome inside a horseshoe shaped crater. To monitor the evolution of near field surface displacements and to model the associated magmatic sources parameters, we established starting 1999 a new strategy based on a dense network of about 50 benchmarks measured with a combination of static and kinematic GPS positioning. The measurement of this network takes only few hours (when summit access is possible), and brings a 1.5 cm error on the three component displacement vectors. Data processing has been automated in order to be easily used as one of the monitoring techniques by the observatory.

We present the results of 16 surveys from 1999 to 2007, a period that includes two eruptive episodes in 2001 and 2006. Our results show large pre-eruptive and co-eruptive displacements associated to these eruptions, and evidence for deep fracturing in the vicinity of the main crater rim.

Introduction

Volcanic eruption and rock slope problems forecasting needs:
- Definition and magnitude
- Source type (magmatic / phreatic)
- Precise area localization (volume)

Answers come from monitoring observations combined with an interpretative model. But numerical models need boundary conditions, i.e., internal structures geometry (magma chamber, duct and fractures) and source parameters (pressure and stress state). Because volcano edifices deform due to fluid transport (magma, gas, or water), these parameters can be partially retrieved from the deformation field analysis.

Methodology

Rock slopes monitoring need a dense geodetic network and brief campaign at summit. We developed a simple method using the following characteristics:
- GPS dual-frequency small receivers
- About 50 benchmarks and very short baselines (~500 m)
- Kinematic trajectories and rapid-static baselines with common points
- Joint adjustment of the network positions
- Automatic processing routines for fast interpretation (Matlab)

New network and procedure

The new GPS network has been implanted in December 1999 with about 50 new benchmarks (geodetic 12-cm nails hammered in the lava slope) around the main crater. It has been measured successively in 2000 (March, May, June, July, August and November, 2002 (October), 2003 (August), 2004 (August and December), 2005 (June, July and September, 2006 (March), and 2007 (January)). During January 2001 and April 2006 eruptions, access to summit was prohibited for security reasons. Rapid-static baselines and kinematic trajectories are first processed using commercial software (Sercel receivers), to output simple coordinates files. Then automatic Matlab routines have been developed to extract kinematic positioning data and make the join inversion. This allows producing numerical results and graphics within few hours just after each field campaign, making this procedure usable for monitoring purposes.

Results: Displacements field from Dec. 1999 to Jan. 2007

Conclusions & Perspectives

- Uncertainties after joint adjustment (kinematic + static) ~1.5 cm for the entire network and 3 components East, North, Up. The method needs at least 15 trajectories and 3 rapid-static baselines (1-day campaign).
- Significant displacements (maximum 1.75 m) are detected and associated with magma production. Displacement field is sufficiently dense to reveal major discontinuities inside the edifice and identify stable zones.
- Almost all the benchmarks have disappeared during centennial eruption in 2010, that deeply modified the summit morphology.

References


Summary deformations 1988-1997

Merapi summit deformations have been observed by American, Indonesian and French teams using EDM since 1988 [Young et al., 2000] and GPS measurements since 1993 [Beauducel et al., 2000]. Before the 1992 dome growth episode, horizontal displacements reached 1.2 m/year, associated with strain rate of 11.10^-8 per year. Main discontinuities have been roughly localized and modeled from 1993 to 1997 GPS observations, using 3-D boundary elements method [Coyotl and Cornet, 1997].

Figure 4. Computed horizontal displacements at the summit (red triangles) and in the edifice (red dots) from GPS measurements since 1993 [Beauducel et al., 2000]. During the two eruptive episodes in 1992 and 1994-1995, independent zones separated by fractures show (only in 1994) different behaviour and are observed, presenting a deformation process similar to a “kinematic” pattern. The deformation at Merapi is still detectable after the eruptions. Fractures have been observed and located on surface, and observed with about 10 m of numerical modeling. The northern zone did not exhibit any strainable behaviour, this was interpreted as a new eruptive (after Young et al., 2000).