Geophysical Research Abstracts,
Vol. 10, EGU2008-A-02192, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-02192
EGU General Assembly 2008

The ability of joint seismological-gravity studies to detect states of unrest at active volcanoes

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Over the last few decades, methods and techniques aimed at monitoring active volcanoes and studying the dynamics of their plumbing systems have improved significantly. Among the other signals, volcanic tremor is routinely employed at most volcanoes. Conversely, continuous observations of the gravity field are relatively infrequently used due to the high cost of spring gravimeters, which limits the number of instruments available at a single site, and due to the high instrumental sensitivity, required to assess the expected changes (within a few tens of microGal), but implying a high response to environmental perturbations (temperature, pressure, etc.). In spite of the above intrinsic difficulties, a mini-array of three continuously running gravimeters was installed at Mt. Etna during the nineties and has worked intermittently since then. A good practice to recognize gravity anomalies with a good chance to be volcano-related, consists in cross-analyze the gravity signal with other geophysical time series. In particular, cross analysis performed between tremor and gravity sequences acquired simultaneously at Mt. Etna allowed to discover common anomalies on two occasions: during the 2002-03 eruption and during the December 2005-January 2006 period of quiescence. During the course of the 2002-03 eruption, marked increases of the tremor amplitude (up to a factor of 4) occurred simultaneously with gravity decreases (10-30 microGal) observed at the only station working during that period. The concurrent gravity/tremor anomalies last 6 to 12 hours and terminate with rapid (up to 2 hours) changes, after which the signals return back to their original levels. Based on volcanological observations encompassing the simultaneous anomalies, we infer that the accumulation of a gas cloud at some level in the conduit plexus feeding the active

eruptive vent could have acted as a joint source. During the December 2005-January 2006 non-eruptive period, the tremor amplitude at Etna markedly increased and negatively correlated with the gravity signal from one of the two summit stations, over 2- to 3-hour fluctuations. No correlation was found with the signal from the other gravity station. In this case, relying on the relative position of the two gravity stations, we can define the volume within which the gravity source must lie. During the period of marked anti-correlation, the tremor source, located by inverting the spatial distribution of seismic amplitudes, intersects this volume in a region located 1000 m S-SE of the summit craters and about 2000 m beneath the surface. This finding suggest that the anti-correlation marks the activation of a joint source process, possibly related to the arrival of fresh, gas-rich magma and the consequent gas separation. Both the 2002-03 and the 2005-06 anti-correlated tremor/gravity anomalies are indicative of a quasi-closed system, becoming progressively enriched in volatiles. This occurrence may evolve to local accumulations of gas pockets, which in turn may climax with energetic, potentially dangerous paroxysms. Therefore, the ability to detect such accumulation processes is critical to any early identification of energetic eruptive episodes. In particular, during the 2005-06 period, sustained gas segregation did not lead to volcanic activity and thus it could be detected only on the grounds of the analysis of the available geophysical data. The above observations imply that joint seismological-gravity studies also have the ability to detect “hidden” states of unrest at active volcanoes and thus are of considerable potential value for volcano monitoring.