Change Detection for Remote Monitoring of Underground Nuclear Testing: Comparison with Seismic and Associated Explosion Source Phenomenological Data

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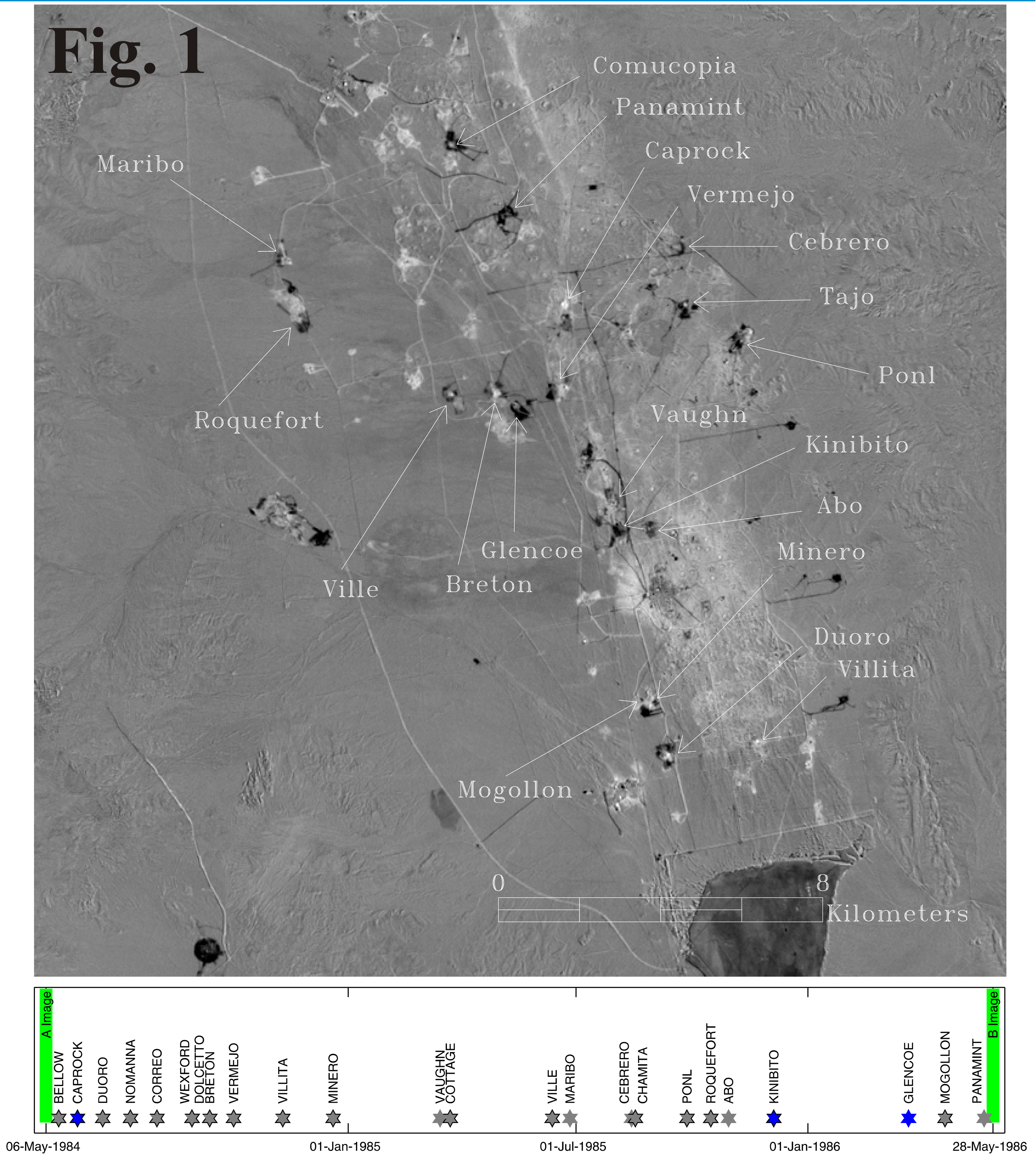
Introduction

In this study we focus on the use of conventional multispectral satellite imagery with a moderate ground resolution of 30 m (Landsat TM, ASTER) to detect changes over wide areas important for monitoring nuclear test activities. We chose the Nevada Test Site (NTS), USA, for a case study because of the large amount of available ground truth information. The analysis is based on the multivariate alteration detection (MAD) algorithm proposed by Nielsen et. al. (1998). The technique is applied to images of historical underground nuclear explosions detonated at the NTS between 1984 and 1992. The detected change signals are compared with existing seismic data which include explosion times, locations, yields and depth of burial as well as available data about surface collapse (subsidence) phenomena like e. g. crater depth and diameter. An attempt is made to derive the detection threshold of change signals for the MAD technique in terms of visible explosion effects and explosion size.

This work has been carried out in part within the framework of the Global Monitoring for Security and Stability **(GMOSS) Network of Excellence** initiated by the European Commission.

Change detection: Yucca Flat (NTS)



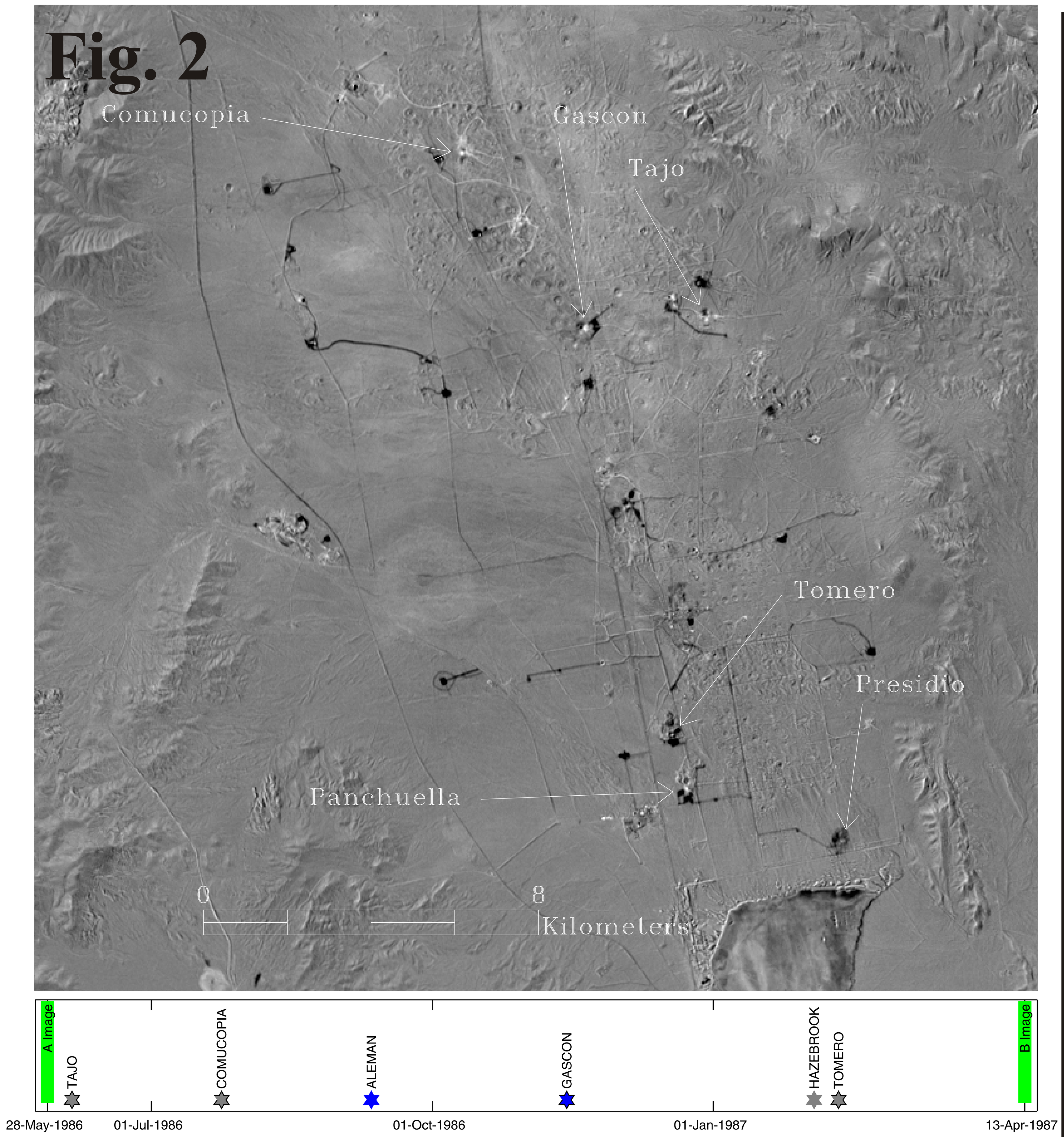


Fig. 2: Landsat TM change image of the Yucca Flat test area (NTS, USA) between May 28, 1986 and April 13, 1987. Arrows point to the locations of known tests, labelled with code names. Middle gray pixels indicate no change, light or dark pixels indicate changes. Time bar at the bottom as in Fig. 1.

Fig. 3: Same as Fig. 1 but for a shorter time difference between image taking (May 28 and June 13, 1986). The enlarged scene shows the change detection signal of the TAJO test.

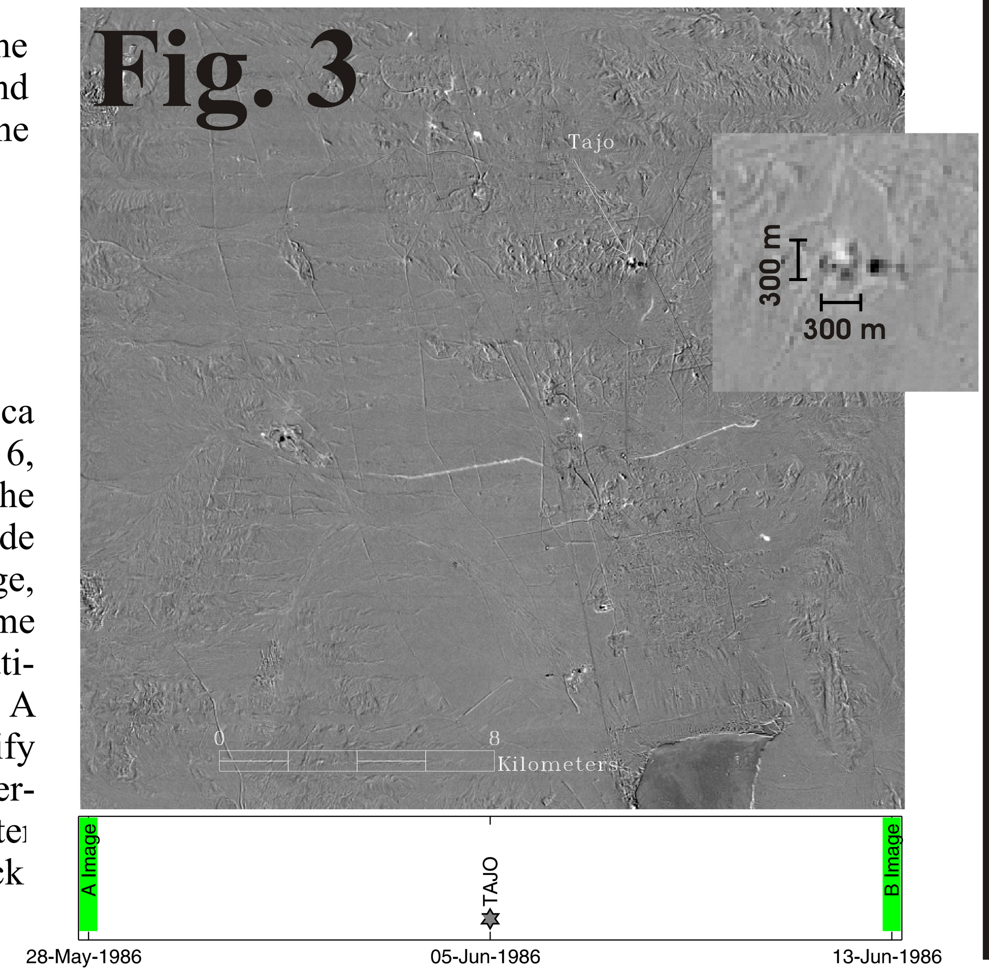
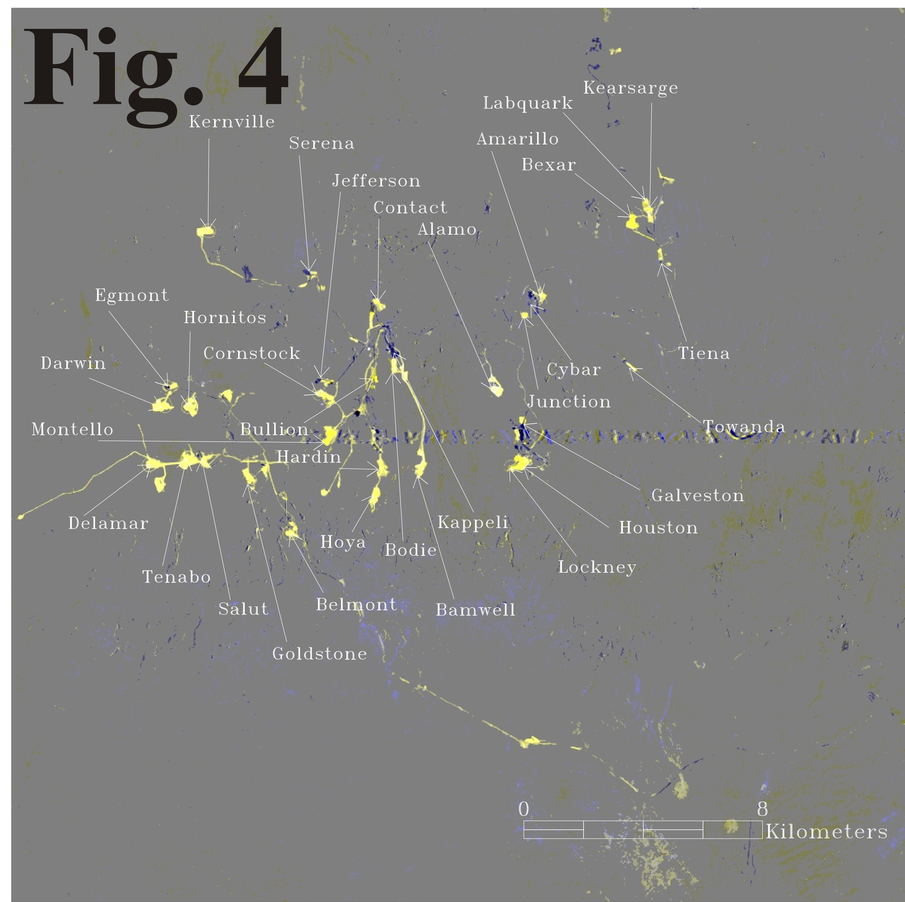


Fig. 1: Landsat TM change image of the Yucca Flat test area (NTS, USA) between May 6, 1984 and May 28, 1986. Arrows point to the locations of known tests, labelled with code names. Middle gray pixels indicate no change, light or dark pixels indicate changes. The time bar at the bottom gives the temporal distribution of test activity between takings of image A and B. Stars labelled with code names identify explosions above (grey) and below the water-table (blue). Explosions with significant crater formation (Springer et al.) are outlined in black

Change detection: Pahute Mesa (NTS)



Conclusion: Detection of changes corresponding to subsidence crater formation was in general possible on the 30 m ground resolution, however this was not always the case (Pahute Mesa; not shown). On the other hand change signals could also be detected for tests without significant crater dimensions (Springer et al.), see Figs. 1, 2 & 4. These changes are very probably associated with test site preparations and were found to be well-correlated with the ground truth data. Temporal correlation is poor due to the sometimes long lead times between preparation and the actual test explosion.

Fig. 4: Same as Fig. 1 but for the Pahute Mesa test area. Time difference between the images on May 6, 1984 and May 26, 1991 is over 7 years. Middle gray pixels indicate no change, light, dark or colored pixels indicate changes. All underground tests which took place after the first acquisition are indicated and are seen to be associated with change signals arising from surface preparation activities.

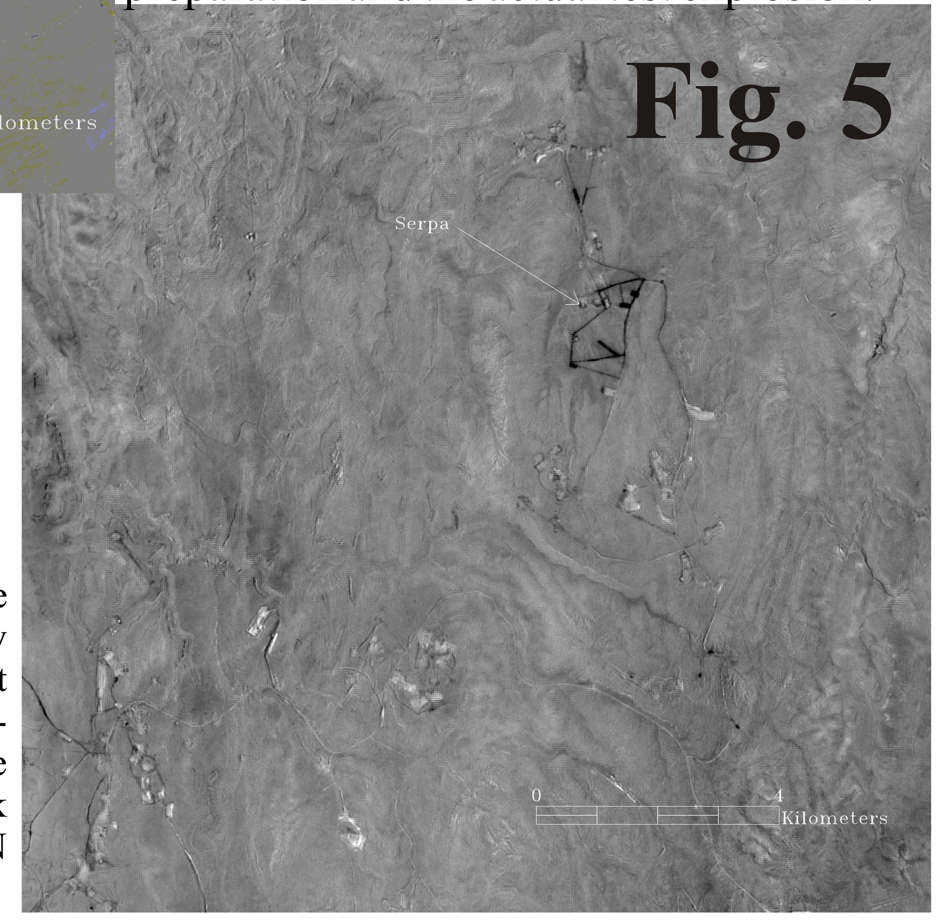
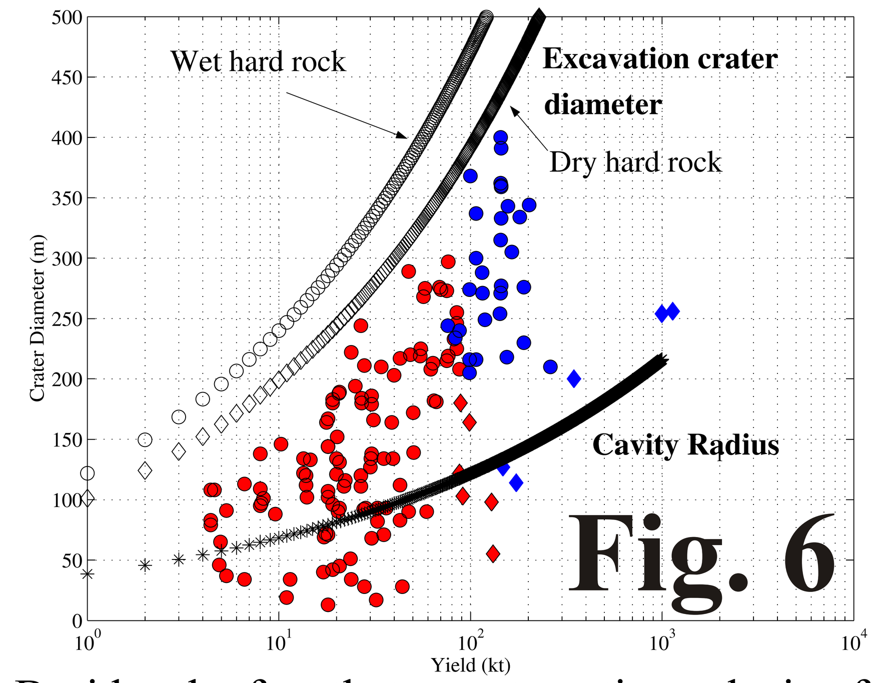


Fig. 5: ASTER VNIR+SWIR change image at the Pahute Mesa test area between June 5, 2001 and July 6, 2003. Middle gray pixels indicate no change, light or dark pixels indicate changes. Considerable construction activity is evident in the northeast near the site of the test code named "SERPA" which took place in December 1980 at coordinates 32.328N 116.314E.

Seismic and associated explosion source phenomenological data

In an attempt to relate explosion signatures detectable in satellite imagery to explosion size, known crater diameters (Springer et al.) are plotted against yield for all underground NTS explosions since 1975 (Fig. 6). Explosions from the sub test sites at Yucca Flat and Pahute Mesa are marked with circles and diamonds, respectively, to indicate above (red) and below (blue) water table explosions. Explosion yield is calculated from scaled depth of burial (SDOB = 122 m/kt$^{1/3}$). The data are compared with empirical relations of Glasstone & Dolan (1977) and Marshall (1999), considered representing estimates of maximum and minimum crater dimension for a given rock type. >>



Besides the fact that a systematic analysis of change signals was not feasible with the current image data, the data variability in Fig. 6 poses a severe problem for the estimation of detection threshold in terms of yield.

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