Supplementary Materials: Joint Terrestrial and Aerial Measurements to Study Ground Deformation: Application to the *Sciara Del Fuoco* at the Stromboli Volcano (Sicily)

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THEODOROS

All benchmarks in the *Sciara Del Fuoco* (SdF) were installed along a linear profile running on the NE sector of the SdF, in order to monitor the motion of the area that was already affected by the 30 December 2002 landslide and filled by the new lava flows during the 2002–2003 eruption. The monitoring network is made up of four groups of benchmarks (Figure S1a): (i) the reference system; (ii) the atmosphere calibration group; (iii) the control group; and (iv) the monitoring group in the SdF. The first three groups all consist of reference benchmarks installed outside the SdF (*i.e.*, in the stable part of the volcano with respect to SdF); the first allows for the calculation of the "free station" coordinates of the Total Station and the orientation of the reference system, the second for the atmospheric refractivity, and the third to check the stability of the system. The fourth group includes the monitoring points and consists of benchmarks installed inside the SdF to monitor its movements. All benchmarks are equipped with single round quartz crystal prisms for maximum accuracy (Figure S1b).

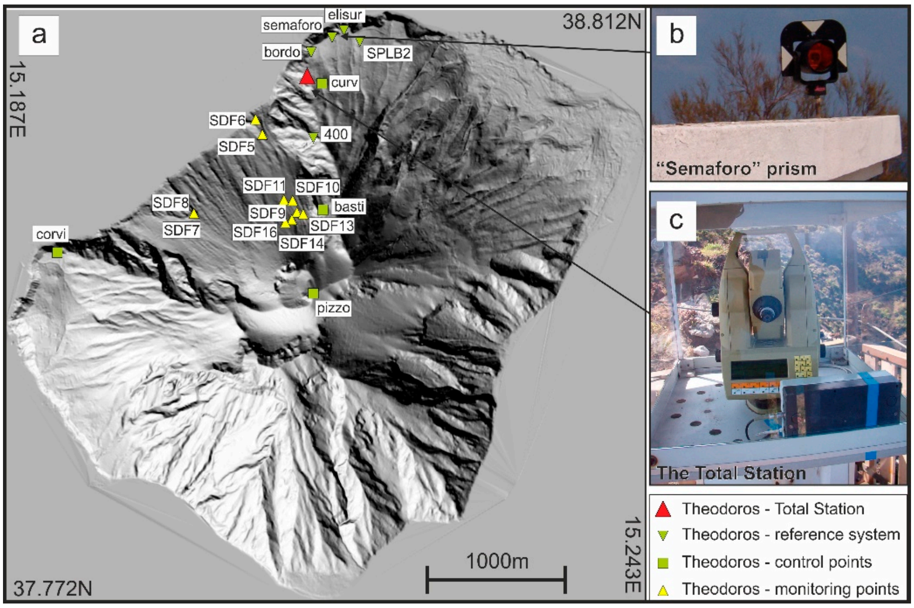

Figure S1. (**a**) Map showing the terrestrial robotized monitoring system of the *Sciara del Fuoco* (SdF) at Stromboli (THEODOROS); pictures on the right (**b**) show a typical reflecting prism and (**c**) the robotized Total Station.

The TCA 2003 (Figure S1c) is able to perform point measurements in 3 s by automatically detecting the prism and centering it with a maximum deviation of 1 mm, rotating at a velocity of 45°/s and a precision of 1 mm + 1 ppm along the distance and an angular precision of 0.5″. In order to reduce errors, each series consists of left/right measurements. The measurement cycles entail an appropriate combination and scheduling of a series of measurements of the different groups: (i) measurements of the reference system, every half hour; (ii) measurements of the atmosphere calibration group, every hour; (iii) measurements of the control points, every 20 min; (iv) measurements every 10 min on the monitoring group. Data are transmitted continuously to the S. Vincenzo Observatory, where the control of THEODOROS system is installed, and from there to INGV in Catania.

Orthoimagery Correlometry

The May 2003 flight (26 May 2003) is a color RGB acquisition with a ground sample distance (GSD) of 0.50 m over the entire Stromboli Island. Images acquired during this flight represent the status before the end of the 2002–2003 eruption. In September 2003, the first data after the end of the 2002–2003 eruption were acquired (4 September 2003). This consists of black-and-white (gray-scale) imagery with a GSD of 0.20 m over the Sciara area. A year later, in September 2004 (4 September 2004) a new flight acquired color RGB images with a GSD of 0.50 m over the whole Stromboli Island. Finally, in May 2005 (20 May 2005), a last flight in black and white (gray-scale) with a GSD of 0.20 m over the Sciara area was repeated.

A robust phase-fitting image correlation method was applied to extract the surface ground deformation [21]. The algorithm starts from already orthorectified images, either using conventional rational polynomial methods [16] or rigorous methods [22]. The approximately co-registered images (to the same reference system) are then correlated using a small sliding window, to which a Tukey window filtering is applied to make the signal circularly symmetric. Then, the discrete Fourier transform of the individual images and their cross product was computed. The phase difference of the cross product is extracted, considering the long period of the ground deformation signal (*i.e.*, applying an ideal low-pass filter with a cut-off of 0.5 of the normalized sampling frequency), and then in- and outliers using the RANSAC algorithm are detected. Finally, the best fitting plane using a re-weighting iterative least squares with bisquare weights is solved (Figure S2). This method has been tested under several relevant performance scenarios to verify its robustness with the addition of white noise, aliasing, and bit quantization [21]. The technique is explained in detail in [21].

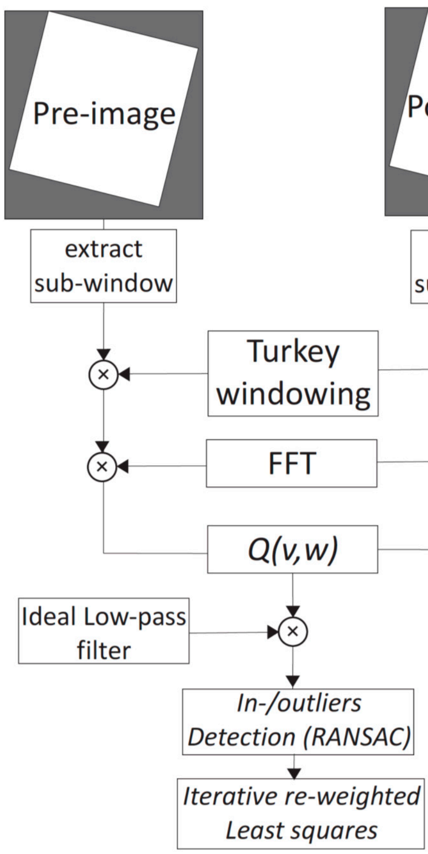

Figure S2. Algorithm workflow diagram of the applied robust phase fitting image cross-correlation method.

Data Comparison

Figure S3 panels show the correlation for the EW (pink) and NS (cyan) displacements for the periods 2003–2004 (upper row) and 2004–2005 (lower row) determined using the correlation method, manual 3D tracking, and the THEODOROS system. It can be observed that the associated errors of the THEODOROS system results are lower than those obtained with the correlation methods.

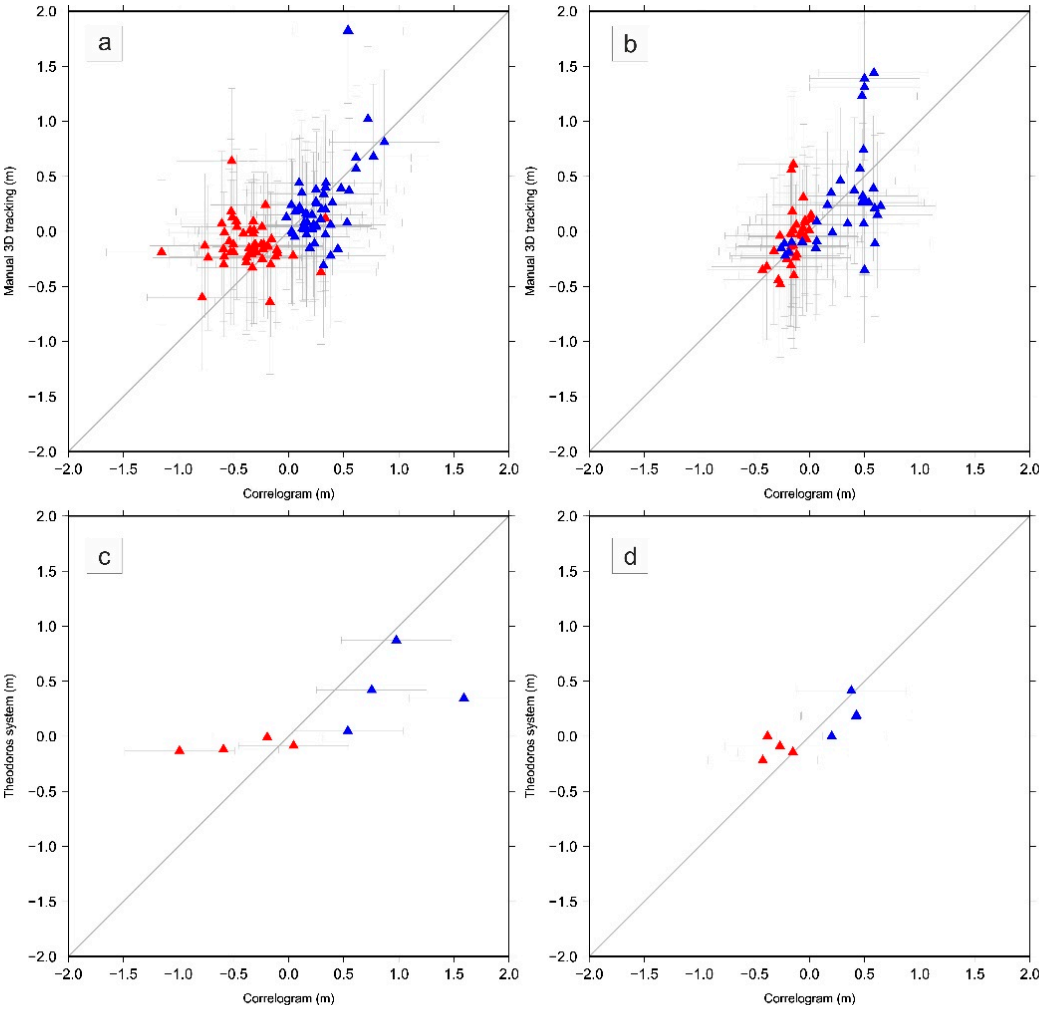

Figure S3. Pair-wise correlation for the EW (red) and NS (blue) displacements between the correlograms and the other two different techniques; (**a**) manual 3D tracking for 2003–2004; (**b**) manual 3D tracking for 2004–2005; and (**c**) THEODOROS system for 2003–2004 and (**d**) THEODOROS system for 2004–2005.