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Earthquake relocations and InSAR analysis following the June 12th 2011 eruption of Nabro volcano, Afar

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Nabro volcano sits on the southern part of Danakil block to the east of the Afar depression, on the Arabian plate. On the 12th June 2011, Nabro volcano suddenly erupted after being inactive for 10,000 years. The eruption caused a 17-km-long lava flow, a 15-km-high ash cloud, and ranks as one of the largest emissions of SO_2 since the Mt. Pinatubo (1991) event. This eruption creates an important opportunity to use seismicity and surface deformation measurements to understand the subsurface magmatic system and deformation of a hazardous, off axis caldera during continental rupture. We installed a network of 8 seismometers around Nabro caldera which began recording on the 31st August and tasked SAR acquisitions from TerraSAR-X (TSX) and Cosmo-SkyMed (CSK) satellites. The SAR images used for this study post date the eruption. We used TSX stripmap mode images from ascending and descending orbits. Using a small baseline approach, we used 25 images acquired between the 1st July 2011 to the 5th October 2012 on descending orbit 046, to create 34 interferograms. We complemented these with 19 images from ascending orbit 130 spanning the 6th July 2011 to the 10th October 2012 from ascending orbit 130, which we used to create 21 interferograms. We produced a velocity ratemap and timeseries using π-RATE showing subsidence of up to 25cm/yr centred on Nabro. We used a Monte-Carlo hybrid downhill simplex technique to invert the dataset and found the best fitting solution as a mogi source at 6.9 $\pm$1.1 km depth, and located at a 13.35 (lat) and 41.69 (long). The time dependence observed is consistent with a viscoelastic relaxation around the magma chamber, following depletion. Concurrent with the TSX acquisitions, CSK imaged the volcano on a descending track between 26th June 2011 and 18th July 2012 within the ASI project SAR4Volcanoes, and 64 images were used to produce 171 interferograms which were inverted to form a timeseries using a SBAS approach. This dataset has an overall subsidence signal, but the time series shows a shorter wavelength fluctuation of ground deformation, which is not apparent in the TSX data. We processed the seismic signals detected by the temporary local network and by a seismic station within a permanent regional array, to provide hypocentre locations for the period September-October, 2011. We used Hypoinverse-2000 to provide preliminary locations for events, which were then relocated using HypoDD. Absolute error after Hypoinverse-2000 processing was approximately $\pm$2 and $\pm$4 km in the horizontal and the vertical directions, respectively. Using HypoDD, relative errors were reduced to $\pm$20 and $\pm$30 m in the horizontal and vertical directions, respectively. The hypocentres show clusters of activity as well as aseismic regions. The majority of the earthquakes are located at the active vent, with fewer events located on the flanks. There is a smaller cluster of events to the south-west of Nabro beneath neighbouring Mallahle volcanic caldera, despite no eruption occurring here nor any post-eruptive deformation. This may imply some stress triggering mechanism or some pressure connection between the magma system of the two calderas. We present both the seismic and InSAR datasets as a joint approach to understand this eruption, as well as further implications for other 'quiet calderas'.