

# Ground deformation analysis at Campi Flegrei (Southern Italy) by CGPS and tide-gauge network

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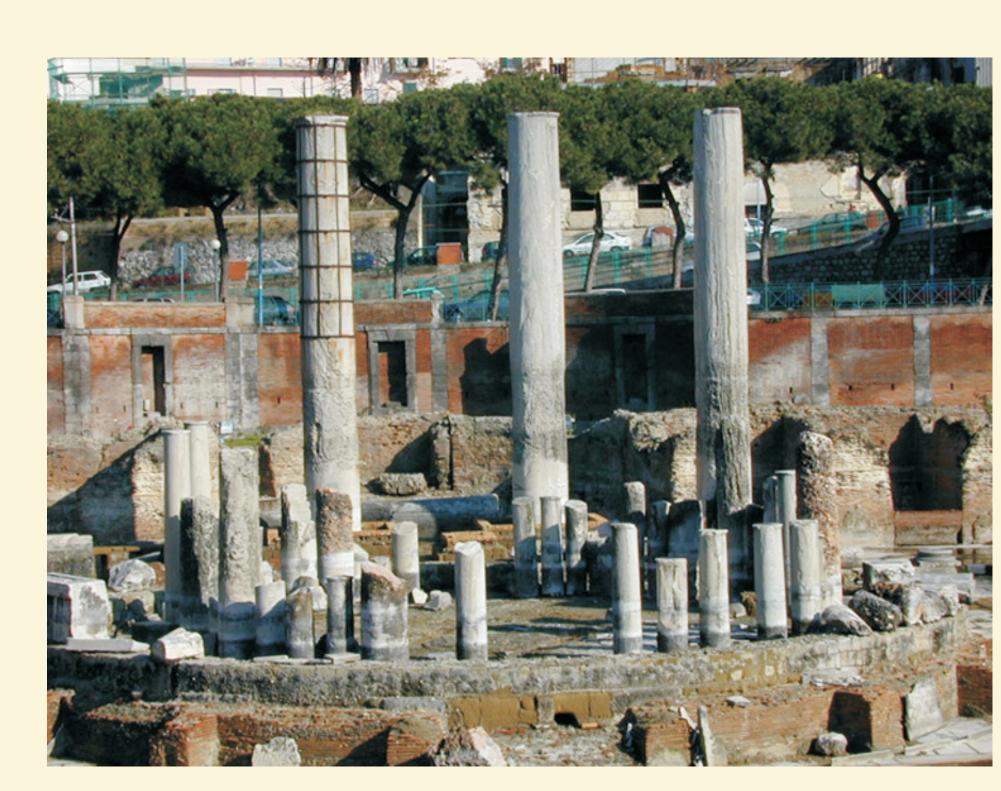
#### **ABSTRACT**

Campi Flegrei caldera is located 15 km west of the city of Naples, within the central-southern sector of a large graben called Campanian Plain. It is an active volcanic area marked by a quasi-circular caldera depression, formed by a huge ignimbritic eruption occurred about 37000 years ago. This caldera was generated by several collapses produced by strong explosive eruptions (the last eruption, occurred in 1538, built an about 130 m spatter cone called Mt. Nuovo). Campi Flegrei area periodically experiences significant deformation episodes, with uplift phenomena up to more than 3.5 m in 15 years (from 1970 to 1984), which caused during 1983-84 the temporary evacuation of about 40000 people from the ancient part of Pozzuoli town.

The deformation field obtainable by CGPS and tidegauge stations plays an important role for the modelling and interpretation of volcanic phenomena, as well as for forecasting purposes.

The structural complexity of the Campi Flegrei area, together with the evidence of a strong interaction between magmatic chamber and shallow geothermal system, calls for a detailed characterization of the substructure and of magma-water interaction processes

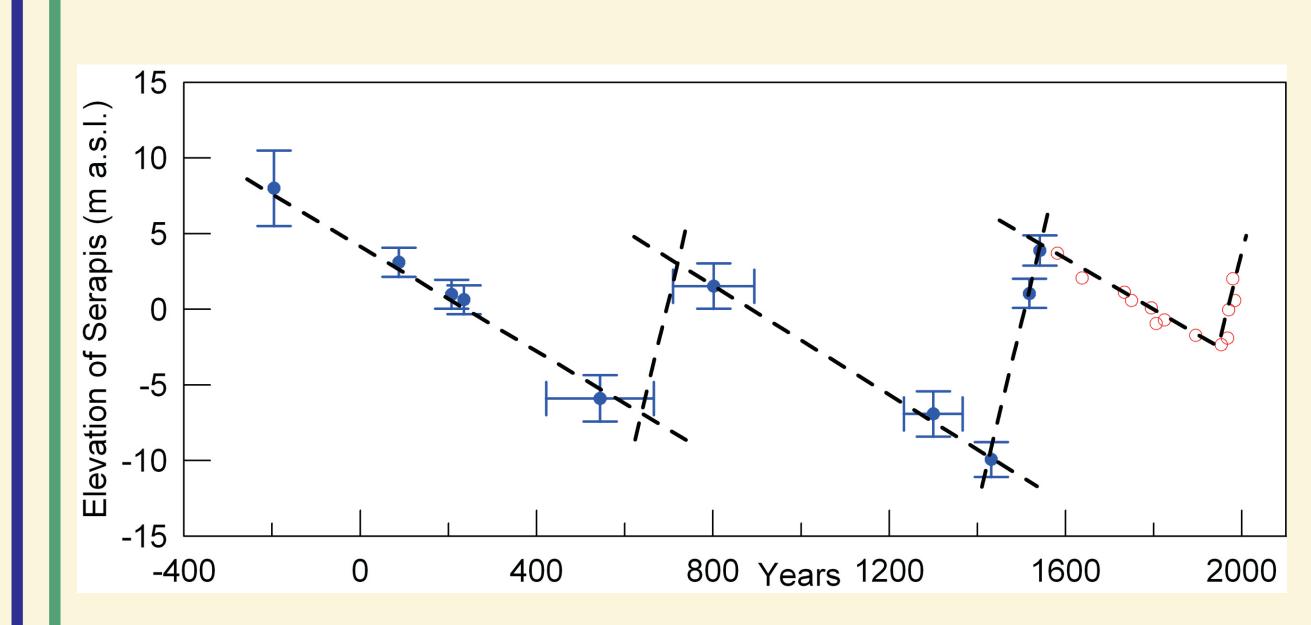
The incoming experiment of deep drilling, down to about 4 km, will give detailed structural and physical constraints able to resolve the intrinsic ambiguities of geophysical data and in particular geodetic ones. In this poster we describe the recent ground deformations at Campi Flegrei area by means of GPS technique and tide gauge stations, discussing the possible interpretations also in light of further constraints likely coming from the next CFDDP (Campi Flegrei Deep Drilling) deep drilling experiment.



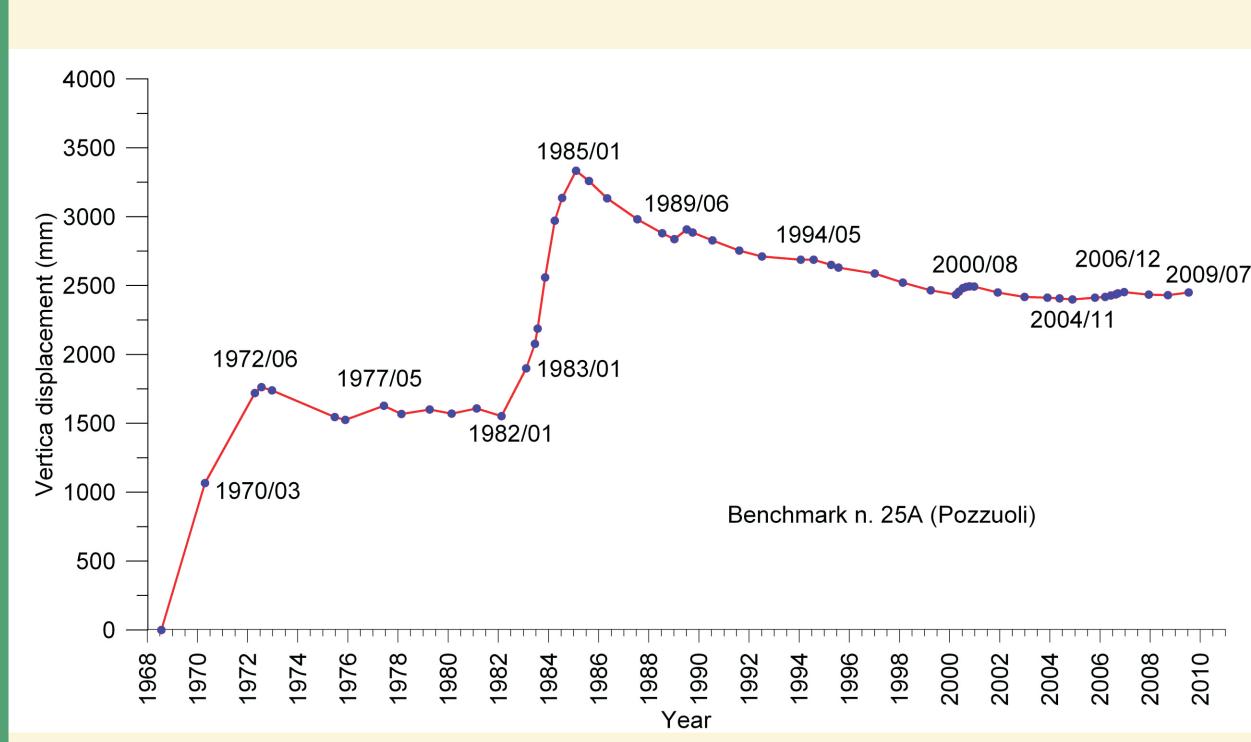
Macellum of Pozzuoli, also known as Serapis

# GROUND DEFORMATION HISTORY

Campi Flegrei, a caldera characterized by high volcanic risk due to the explosivity of the eruptions and to the intense urbanization of the surrounding area, has been the site of significant unrest for the past 2000 years (Dvorak and Mastrolorenzo, 1991). More recently, the caldera floor was raised to about 1.7 meters between 1968 and 1972; then a subsidence phase of about 0.2 m occurred between 1972 and 1975 followed by a stable period until 1981. Between 1982 and 1985 an uplift occurred and the caldera rose about 1.8 m, without any eruptive phenomenon. Then a subsidence phase began, with small and fast mini-uplifts superimposed (1989, 1994 and 2000), after which the previous phase of subsidence began again. This behaviour was observed until the end of 2004 when the subsidence stopped and a new uplift phase started, different from previous ones for duration and amplitude, which with a non monotonic trend lasted until the end of 2009...



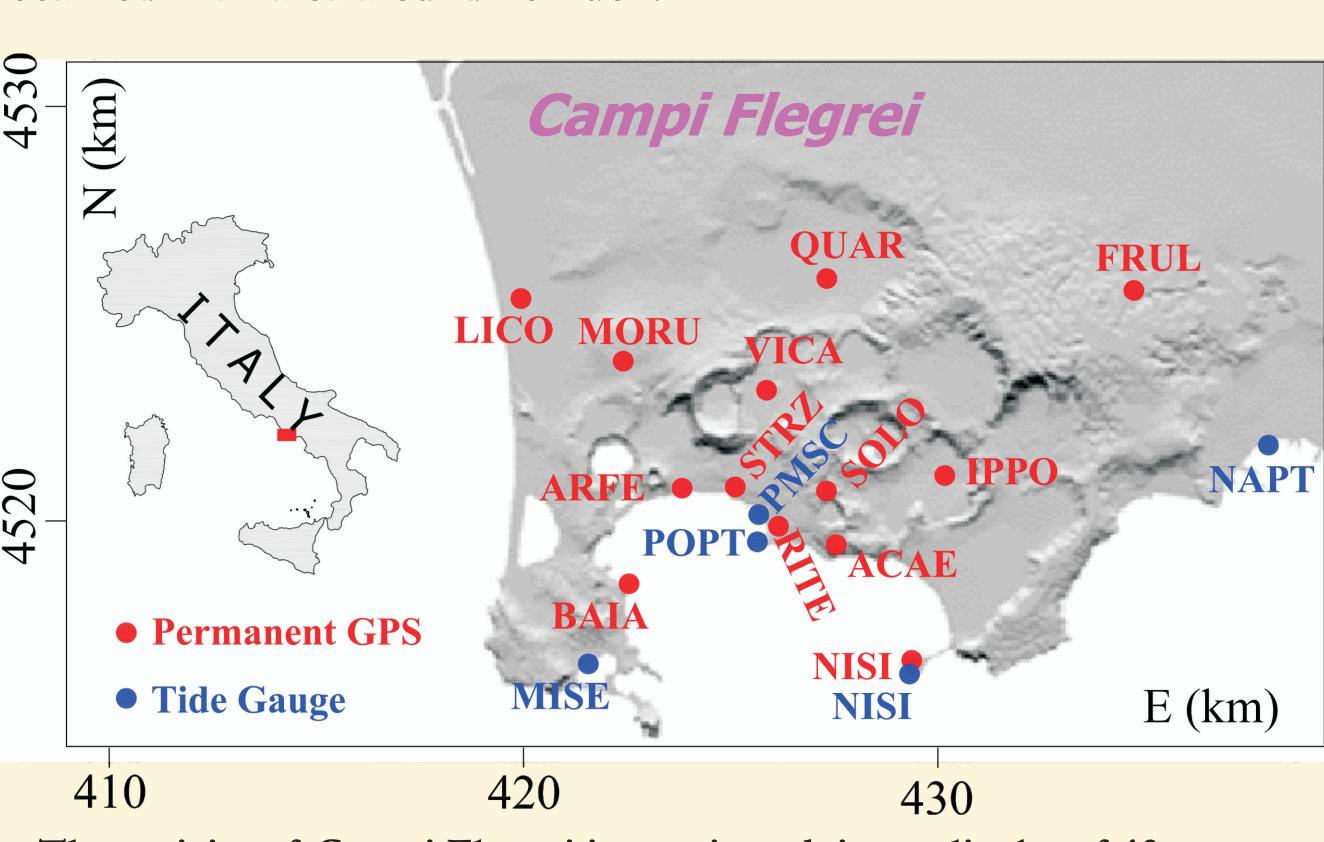
Schematic vertical movements history at Macellum in Pozzuoli, known as Serapis Temple (Bellucci et al., 2006). Blue circles represent the constraints found from radiocarbon and archaeological measurements by Morhange et al. (2006); red circles (post-1538) represent inference from Dvorak and Mastrolorenzo (1991).



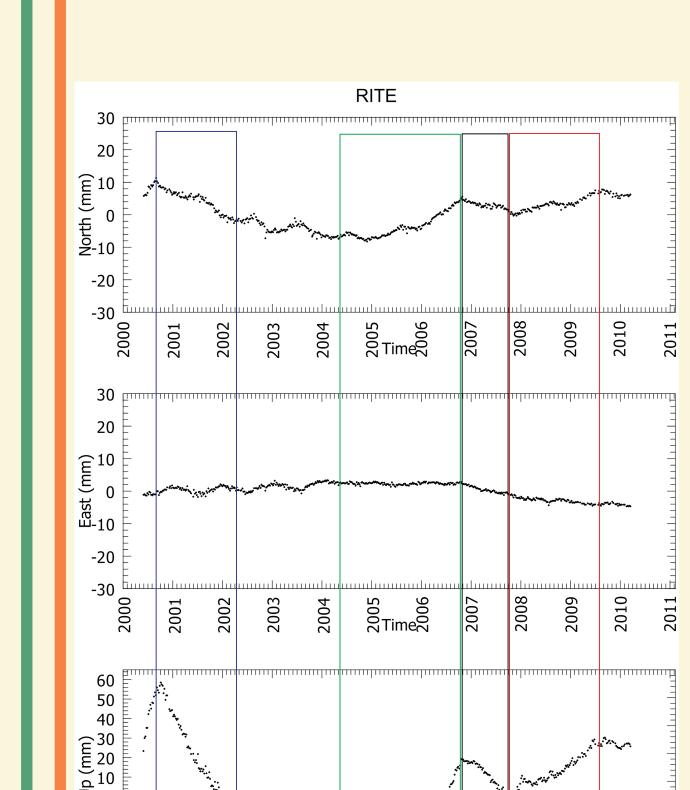
Vertical ground displacements as recorded at Pozzuoli Harbour (benchmark 25A) by levelling data in the period 1969–2009 (Del Gaudio et al., 2009).

### CGPS CAMPI FLEGREI NETWORK CGPS data analysis, during last decade, allowed continuous and accurate

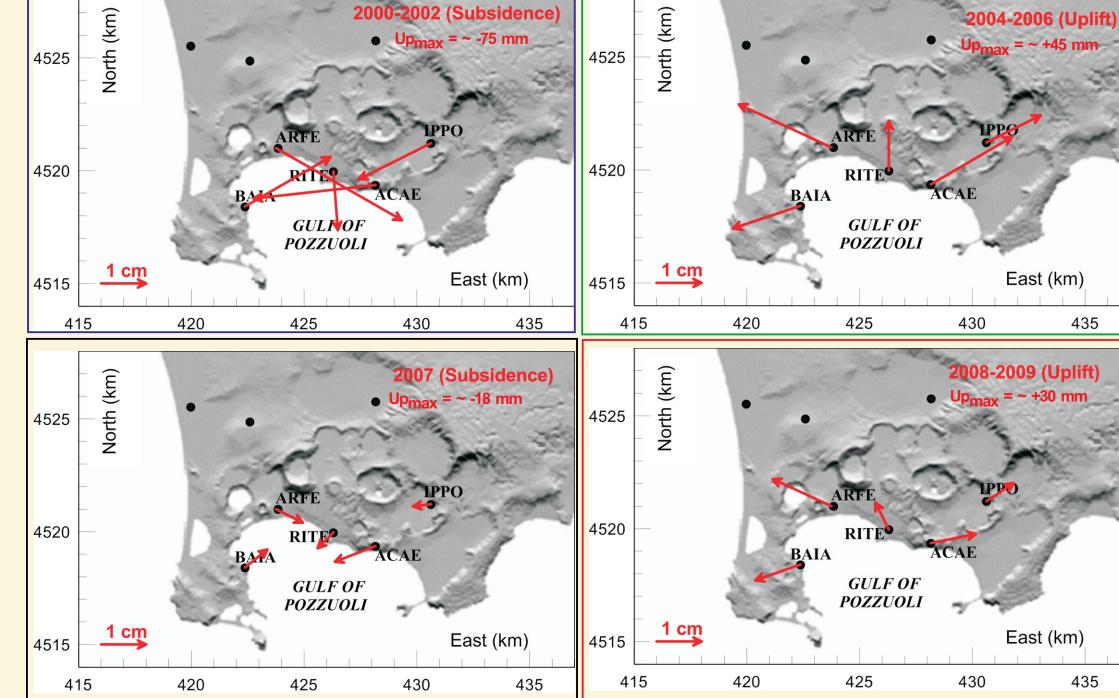
tracking of ground deformation affecting Campi Flegrei area, both for the vertical component (also monitored continuously by tide gauge and periodically by levelling surveys) and for the planimetric components, providing a 3D displacement field, allowing to better constrain the inflation/deflation sources responsible for ground movements. Examples are proved by several authors as Lanari et al., 2004; Pingue et al. 2006; Troise et al., 2007, for 2000 and 2004-2006 uplift and Pingue et al., 2006; De Martino et al., 2007, for the following subsidence. It should be noted that during these episodes the behaviour of planimetric components has been consistent with a source of inflation/deflation localized in an area around Pozzuoli.



The activity of Campi Flegrei is monitored, inter alia, by of 13 permanent GPS and 5 tide gauge. The data are downloaded and analyzed automatically.



Time series of weekly coordinates changes from 2000 to present along North, East and Up directions from CGPS stations showing significant displacements. In this time interval three episodes of mini uplifts occurred. The first one occurred from March to October 2000 and was partial recorded by CGPS stations that were installed during May. This event was followed by a subsidence until October 2002 with a maximum value over than 7 cm. After a period of substantial stability a second uplift episode occurred from November 2004 to November 2007 with a maximum uplift of over 4 cm, followed by a subsidence period up to October 2007 with a maximum value of nearly -2 cm. In late 2007, finally, the ground has once again reversed the movement direction with an uplift that, in October 2009, has reached about 3 cm. After that, a new phase of substantial stability seems to be started, even if in presence of an oscillating trend.

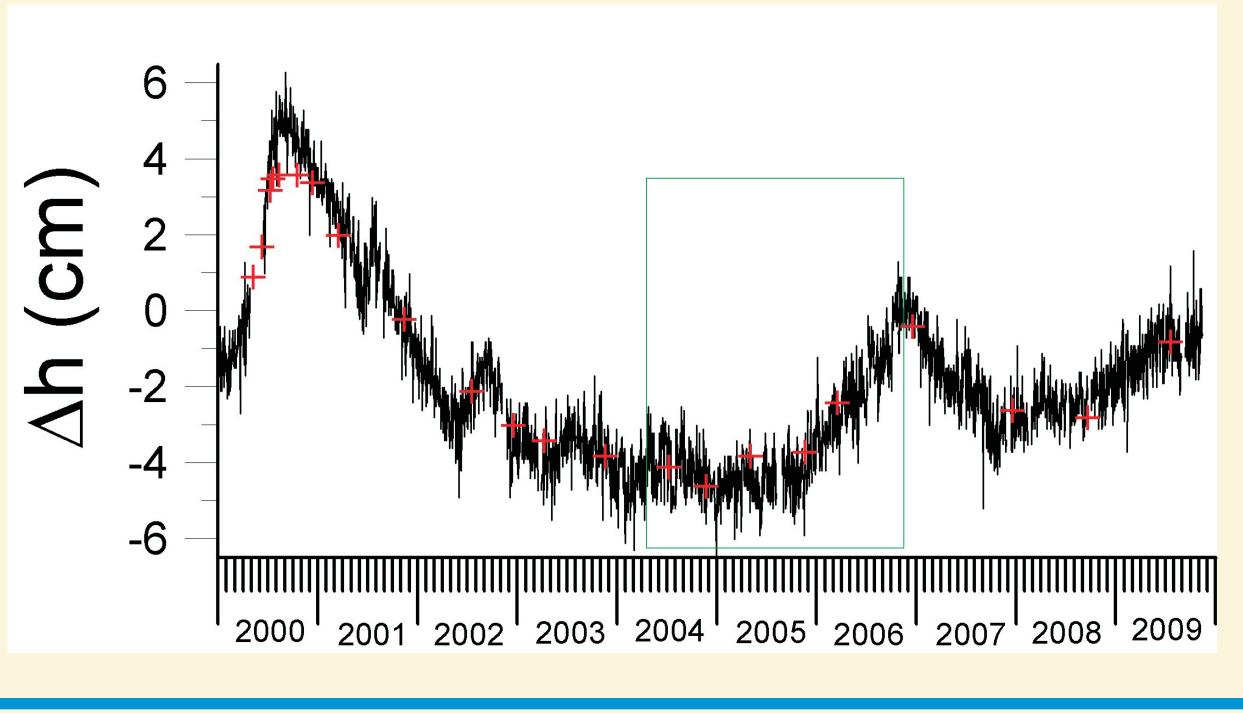


Map of campi Flegrei with CGPS points and inferred planimetric displacements in the different period.

# TIDE GAUGES

The vertical ground displacements at Campi Flegrei are also tracked by the sea level using tide gauges located at the Nisida (NISI), Port of Pozzuoli (POPT), Pozzuoli South- Pier (POPT) and Miseno (MISE), in addition to the reference one (NAPT), located in the Port of Naples. The data allowed to monitor all phases of Campi Flegrei bradyseism since 1970's, providing results consistent with those obtained by geometric levelling, and more recently, by the CGPS network. The data have been analyzed in the frequency domain and the local astronomical components have been defined by harmonic analysis inferring amplitude and phase for the main diurnal and semidiurnal components. The obtained residual respect to the astronomical tide contains information about meteorological component, eustatic variation, ground deformation and noise.

The residual sea level variations, for each site, can be represented by two terms: sea level background and local sea level variations due to noise, site effects and ground deformation. Removing, by deconvolution, the differential behavior of the sea-level respect to a reference station, provide an estimation of the ground level variation.



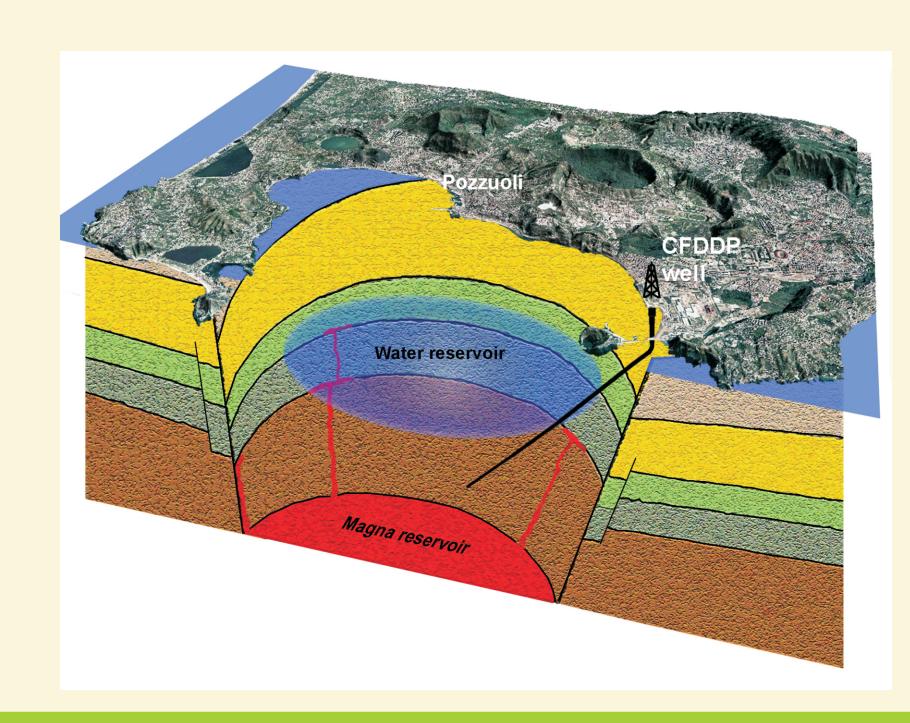
Ground vertical displacement inferred by deconvolution at Pozzuoli Port tide gauge POPT. The box highlights the ground uplift in the period 2004-2006 and it is clear that the vertical displacement is consistent with that inferred from CGPS data. Are also shown the levelling data (red crosses).

# INTERNATIONAL PROJECT 'CAMPI FLEGREI DEEP-DRILLING PROJECT' (CFDDP)

Understanding the volcanic processes and the detailed pre-eruptive behavior of this area is of fundamental importance and it is vital for several hundred thousands of people in one of the most urbanised areas of Europe. A Project of deep drilling at this area, down to about 4 km has been planned to solve the most crucial volcanological questions of leading interest for Civil Defence. It can give fundamental insight into the shallow substructure, the geometry and character of the geothermal systems and their role in the unrest episodes, as well as to explain magma chemistry and the mechanisms of magma-water interaction. Detailed studies of 'in situ' physical properties (e.g. temperature, sonic logs, permeability), at increasing depths will provide information about their evolution. The wells will be hosted by the recently dismissed iron factory ILVA Bagnoli, located at the easternmost border of the city of Naples at the limit of the Pozzuoli town. Detailed geodetic measurements, by GPS and a LEICA total station, will accompain all the drilling phases.

#### Main scientific objectives

- Detailed analysis of the whole aquifer system of Campi Flegrei caldera.
- Understanding the mechanisms of earthquake generation.
- Understanding the mechanisms of magma-water interaction
- in the genesis of unrests and eruptions. Identification of the main metamorphic horizons.
- Identification of depths with water / steam / gas transition.
- Location and analysis of brittle / ductile transition.
- Determination of the magma chamber depth by extrapolation of the purely conductive thermal gradient below the critical temperature layer (3 km).



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