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ASSESSING CURRENT SEISMIC HAZARD IN IRPINIA FORTY YEARS AFTER THE 1980 EARTHQUAKE MERGING HISTORICAL SEISMICITY AND SATELLITE DATA ABOUT RECENT GROUND MOVEMENTS

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ABSTRACT

The Apennine sector formed by Sannio and Irpinia is one of the most important seismic districts in Italy, representing a good case of study due to the plenty of recorded earthquakes that have therein occurred from Roman times up to nowadays. We have merged the historical record and the new satellite techniques that allow a precise determination of ground movements, and then derived physical dimensions like strain rate. In this way, we have verified that in Irpinia the hazard of new strong shocks forty years after one of the strongest known seismic events in the district is still high. This aspect must be considered very important from many points of view, particularly for Civil Protection plans, as well as civil engineering and urban planning development.

1. TECTONICS AND GROUND MOTION IN SOUTHERN APENNINES

The study is based on the analysis of a fine-scale ground velocity map of Italy determined by the fusion of Global Navigation Satellite Systems (GNSS) with the synthetic aperture radar interferometry (InSAR) derived from satellite [1]. The datasets cover a period of observation of twenty years, between 1991 and 2011. The InSAR dataset is part of the “Piano Straordinario di Telerilevamento” (Special program for Remote Sensing, promoted by the Italian Ministry of Environment).

The fusion of GNSS with InSAR is a method based on the calibration of InSAR with GNSS measures derived from permanent stations and survey campaigns [2,3]. The results are a coherent fine-scale ground velocity map with a spatial resolution that is unreachable with the previous velocity field maps determined only with the GNSS technique. Farolfi, Piombino and Catani [1] provided new information about the complex geodynamics of the Italian peninsula and thanks to the high spatial resolution of the ground movements map, identify interesting patterns of small areas respect to the surrounding ones. Moreover, that work confirmed the division of peninsular Italy in two sectors with opposed E-W component of the movement in the Stable Europe Frame (fig.1) depicted by older works based only on GNSS stations movements [4, and references therein]: the western block (Tyrrhenian) is moving westward, while the eastern one (Adriatic) shows an eastward movement. The relative motion of these blocks implies their divergence, whose effect is represented by the numerous currently active normal fault systems along central and southern Apennines, which are close to the border between these two sectors, and the associated seismicity; this regime allows also the emplacement of melt intrusions along lithospheric faults in the crust [5] - the last occurrence of this kind probably triggered the 2013 / 2014 Matese seismic swarm [6] - and widespread emissions of deep – originated CO_2 [7].

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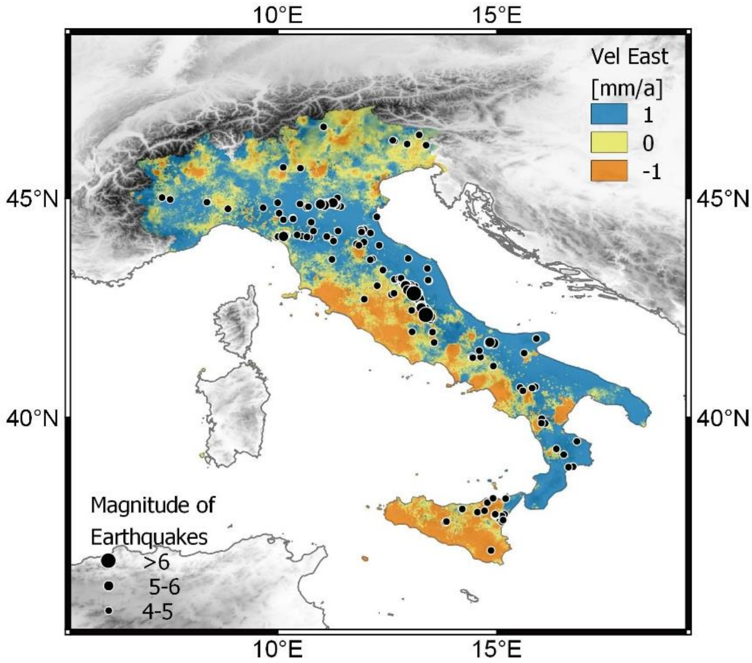

Figure 1. Map of the East component of the ground velocity field of Italian Peninsula derived from GNSS and InSAR during more than two decades of observation (1990-2017). The area of Central Apennines presents the major earthquake from 1990 to the present. The geographical link between the border of the two blocks with different EW component and the main seismic sources is an evidence.

The main faults in Irpinia as well (fig.2), related to the 1962 and 1980 earthquakes, belongs to this geodynamical background, while the 1930 earthquake can be more likely related to a EW trending blind fault belonging to an array of many oblique dextral slip on EW-trending planes crossing the whole Southern Apennines and dissecting the orogen in various contiguous sectors [8].
The E-W component of InSAR movements [1] has also confirmed the frame depicted by [9], in which the Ortona – Roccamonfina is not a single lineament, but a 30 km wide deformation channel: this channel shows prevalent west-directed velocities in the Stable Europe frame, nested in the Adriatic eastward moving block.

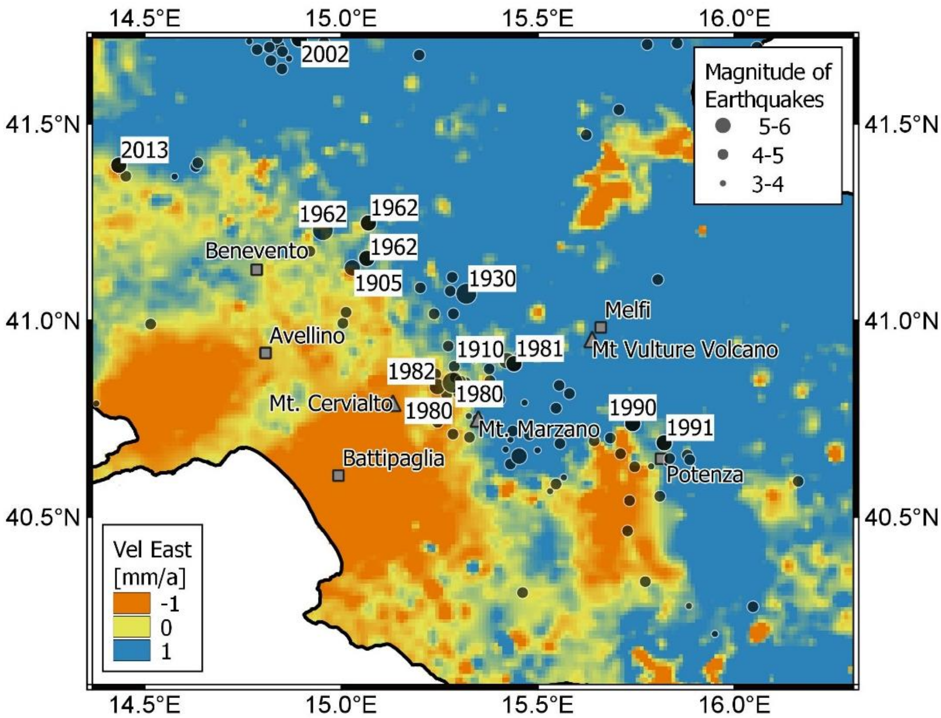

Figure 2. The East component of the ground velocity field of the Irpinia–Sannio area with the main earthquakes occurred since 1900.

The vertical component of InSAR data highlights that the most of Central and Southern Italy are interested by a general uplift, even lower than in the Central Apennines (where it is higher especially in the "Abruzzo Dome" [1]), confirming a wealth of Geological literature; instead, few areas show subsidence, mainly because of Human groundwater exploitation. In this frame the highest uplift values of the whole Southern Apennines – exceeding 1.8 mm/a– are reached in the chain segment between Benevento and Potenza. This area of higher-than-surroundings uplift roughly corresponds to the Irpinia sector, in a belt just west of the Campania – Puglia border. Thus, it is possible to call this area as "Irpinian Dome". Intriguingly, in the middle of the Irpinian Dome, the 1980 earthquake epicentral area is placed in a narrow corridor of low (< 1 mm/a) uplift (fig. 3). The geographical axis of the Irpinian dome approximately corresponds to the isoline of 1 mm/a eastward in the E-W component of the motion. Any useful information of the N-S component of the ground movement can be detect by InSAR satellites because their quasi-polar orbits make possible only the detection of vertical and E-W velocity components.

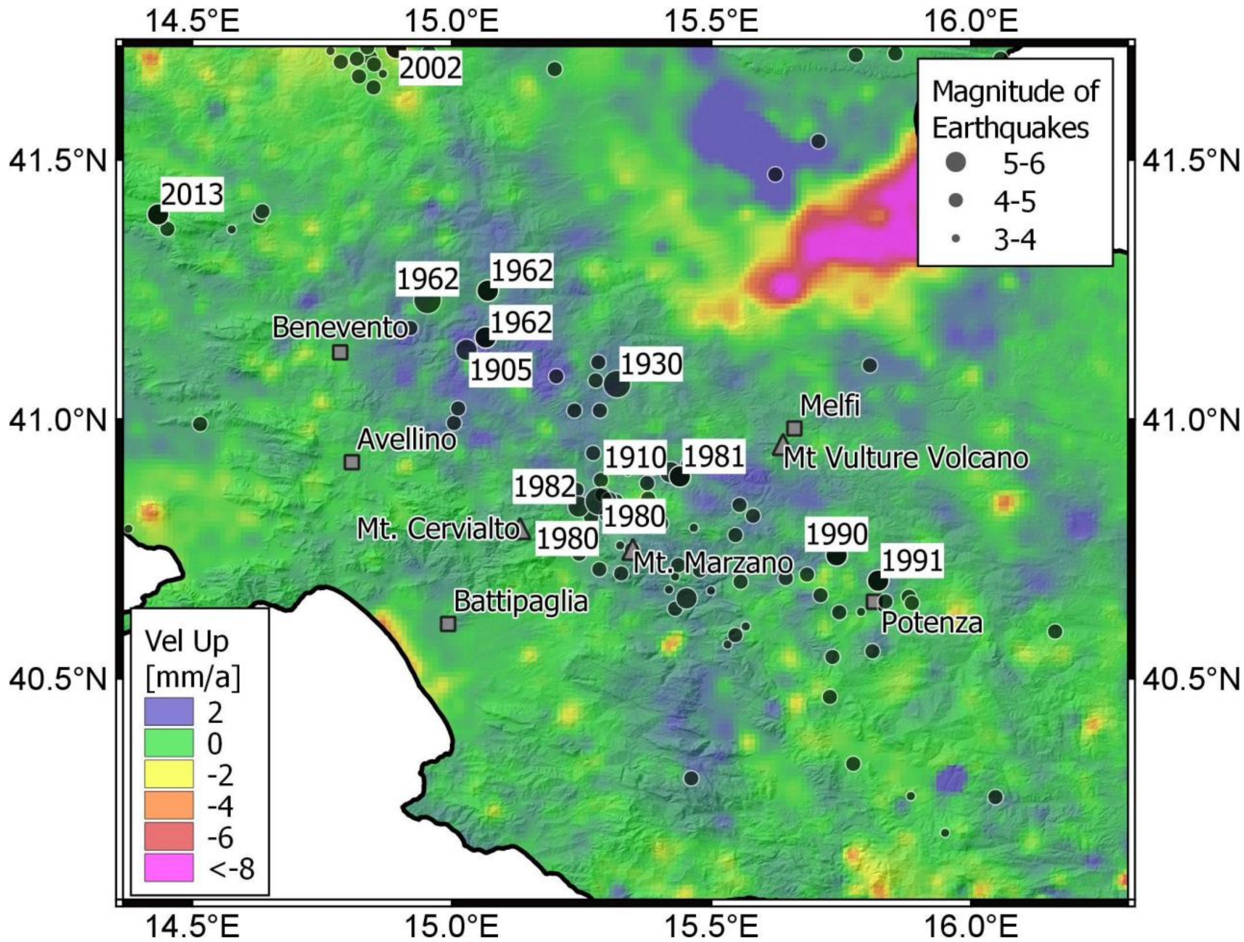

Figure 3. Map of the vertical component of the ground velocity in Irpinia with the main earthquakes occurred since 1900.

2. THE HISTORICAL RECORD OF EARTHQUAKES IN IRPINIA

"Irpinia" is a historical-geographical area of southern Italy located in the Campania region, approximately corresponding to the territory of the current province of Avellino, which in turn largely recalls the historic province of Principato Ultra of the Kingdom of Naples.

The Irpinia area is one of the most seismically active sectors of the entire Italian territory. The seismogenic belt that runs along the Apennine chain in fact crosses the northern and eastern part of the province of Avellino, where strong earthquakes have frequently occurred over centuries.
The most important historical seismic events are placed in the hangingwall of the Monte Marzano fault system [10].
If we take a polygon with vertices at the coordinate points: 41.314° N, 14.971° E; 41.105° N, 14.874° E; 40.739° N, 15.352° E; 41,056° N, 15,574° E, corresponding to the Apennine seismic belt, site of the major historical and instrumental seismicity, the parametric catalog of Italian earthquakes CPTI15 [11] reports about twenty earthquakes with magnitude Mw≥5.0 starting from the year 1000 (see table). Of these, seven have Mw between 6.0 and 6.8. It must be said that the catalog is complete only for the strongest events and only for the last 3 or 4 centuries, that is, approximately from 1600 up to today.
From figure 4, it can be seen that until the end of the XVII century the seismic history of the Irpinia sector is largely incomplete and poorly documented: in fact, only a couple of earthquakes are known (in 1466 and 1517), plus an event prior to the year 1000, which occurred in the year 889 [12], thus outside the reference window of the historical catalog. The earthquake of 5 December 1456 was not deliberately taken into consideration here in the present study because it is a complex event that affected a very large area, causing damage from Puglia to Abruzzo, and whose epicenter is not well located nor defined; probably that earthquake was made up of several shocks that occurred in different sectors of the central-southern Apennines few days apart, and Irpinia was only one of the several areas which were struck [13].
The seismic history of Irpinia is more documented starting from the end of 1600, and as for minor events (4.0 ≤ Mw ≤ 5.0) it can be considered complete only starting from 1900 (Fig. 4).

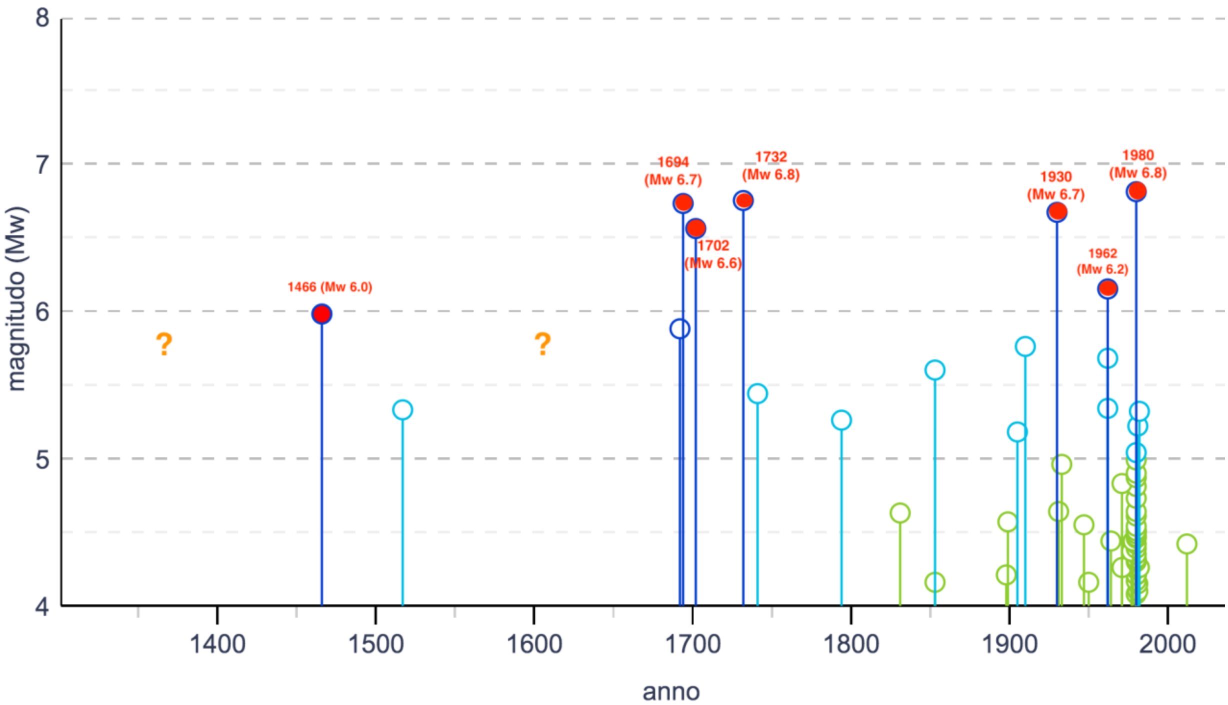

Figure 4. Correggere la legenda Year e Magnitude. Seismic history of the Irpinia area as from the CPTI15 catalog [11]. A polygonal area was considered with vertices in the coordinate points: 41.314°N, 14.971°E; 41.105°N, 14.874°E; 40.739°N, 15.352°E; 41,056°N, 15,574°E. Such a historical record is well documented only from the end of 1600, whereas for the previous centuries it is poorly known, with long spans of time lacking information. The figure also shows some clusters of strong earthquakes, such as the one between 1692 and 1732, as well as the one occurred during the last century.

From its seismic history it can also be seen that in Irpinia the strongest earthquakes (Mw> 5.5) seem to tend to group together over time, spaced from long phases characterized by lower and less frequent seismicity.

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At the turn of the seventeenth and eighteenth centuries, over a period of 40 years Irpinia was affected by four damaging earthquakes, three of which in just 10 years (1692, 1694, 1702 and 1732); the ones occurred in 1694 (considered as a sort of twin of the 1980 earthquake), 1702 and 1732 were large events with Mw>6.5, each of which caused extensive destruction over large areas and many casualties. Another cluster of strong earthquakes is the one that hit the sector in the twentieth century, between 1910 and 1980.
It is unlikely that in the 200 year-span between 1732 and 1930 there were large earthquakes in the Irpinia area, since these are not present in the historical record, while in the same time interval not only "minor" earthquakes are well documented in the very same area (i.e. the 1741 Mw 5.4, 1794 Mw 5.3, and 1853 Mw 5.6 Irpinian events; see table 1, fig.5), but also strong events are well known to have struck other adjacent Apennine areas (the 1805 Mw 6.7 Matese earthquake; those of 1851 Mw 6.5 and 1857 Mw 7.1 in Basilicata [11]. Therefore it can be assumed that the historical seismicity of Irpinia has been characterized by periods of intense activity, with strong earthquakes over a few years or decades, interspersed with long periods of minor-to-moderate activity, with earthquakes of magnitude lower than 6.0.

Year Mo Da	Epicentral area	Lat	Lon	Io	Mw
1466 01 15	Irpinia-Basilicata	40.765	15.334	8-9	6.0
1517 03 29	Irpinia	41.011	15.210	7-8	5.3
1692 03 04	Irpinia	40.903	15.196	8	5.9
1694 09 08	Irpinia-Basilicata	40.862	15.406	10	6.7
1702 03 14	Sannio-Irpinia	41.120	14.989	10	6.6
1732 11 29	Irpinia	41.064	15.059	10-11	6.8
1741 08 06	Irpinia	41.049	14.970	7-8	5.4
1794 06 12	Irpinia	41.108	14.924	7	5.3
1853 04 09	Irpinia	40.818	15.215	8	5.6
1905 11 26	Irpinia	41.134	15.028	7-8	5.2
1910 06 07	Irpinia-Basilicata	40.898	15.421	8	5.8
1930 07 23	Irpinia	41.068	15.318	10	6.7
1962 08 21	Irpinia	41.248	15.069		5.7
1962 08 21	Irpinia	41.230	14.953	9	6.2
1962 08 21	Irpinia	41.158	15.065		5.3
1980 11 23	Irpinia-Basilicata	40.842	15.283	10	6.8
1980 11 24	Irpinia-Basilicata	40.811	15.268		5.0
1981 01 16	Irpinia-Basilicata	40.890	15.439		5.2
1982 08 15	Irpinia	40.832	15.244	6	5.3

Table 1. List of the main Irpinia earthquakes (Mw> 5.0) extracted from the CPTI15 catalog [11]. For the description of the various parameters see this catalog at https://emidius.mi.ingv.it/CPTI15-DBMI15/index_en.htm

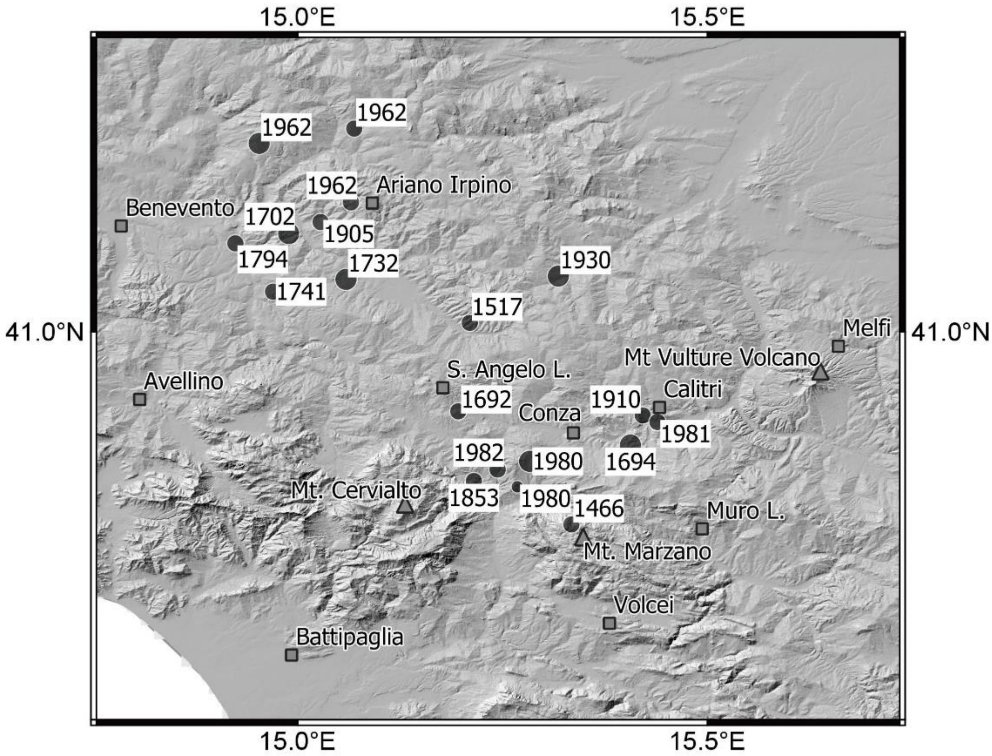

Figure 5. Map of the main historical seismic events from 1466 until 1982 of Irpinia reported in Table 1.

3. CURRENT STRAIN RATE IN IRPINIA

The study benefits of a new fine-scale strain rate field of the whole continental Italy and Sicily (fig.6) [14] determined from the surface ground movements map [1]. The strain rate provides a measure of the superficial deformation, and for this reason is an useful information to study and analyze the geodynamics, and a robust theoretical relation linking the strain rate with the magnitude of seismic events is exposed in [14] by the analysis of the events occurred since 1991. This new theory based on observables identifies high hazard seismic areas with high strain rate areas. It gives a new view for the interpretation of the recent earthquakes occurred and this theory also predicts the events occurred after the observation period of the study: in the outer side of the Alps the strongest earthquakes recorded in the last decades occurred in just two of the 4 areas of this sector showing high strain rate value: the M 5.3 20 December 1991 Graubunden [15] and the M 5.3 22 March 2020 Zagabria earthquake [16] – the others selected areas being around the cities of Marseille and Innsbruck); after 1991 in Italy all earthquakes with M > 5.1 and a hypocenter less than 15 km deep occurred only in areas showing high strain rate: the 1997, 2009 and 2016 Central Apennines seismic sequences, the 2012 Emilia earthquakes, but also the 2013 Lunigiana earthquake (on the surface of the Po Plain SR is lower than in the buried and seismic Apenninic units because of its attenuation in the plastic neogene sedimentary cover).

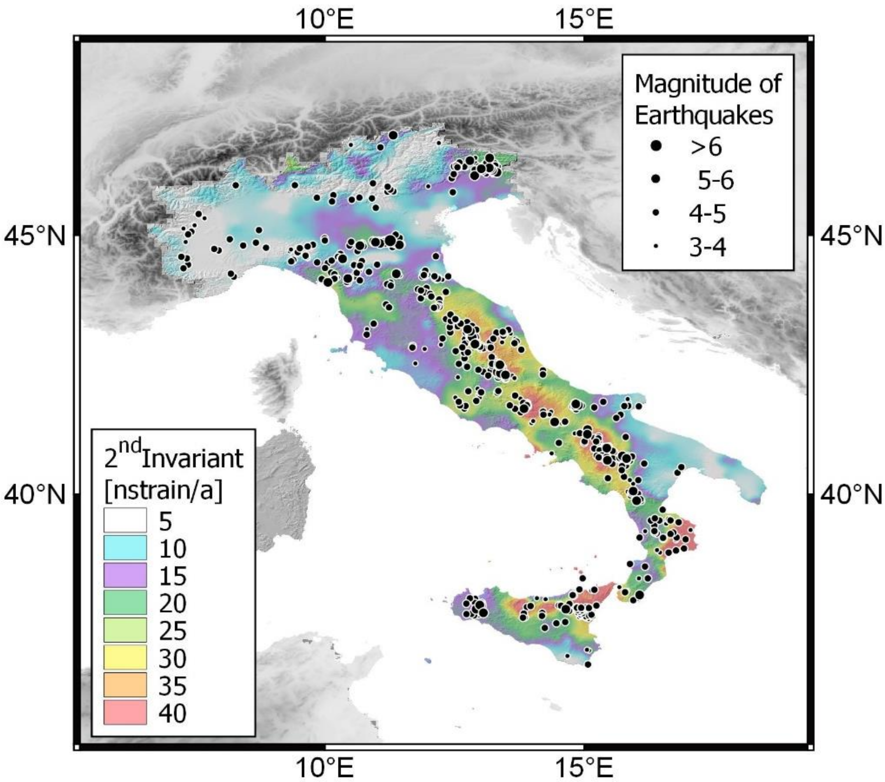

Figure 6. Map of the horizontal strain rate field of Italian peninsula determined by infinitesimal approach from the horizontal velocity field derived from GNSS and InSAR during more than two decades of observation (1990-2017). Main earthquakes occurred from 1900 to 2017 are represented on the map.

Since there are other areas of high strain rate that have not be rattled by moderate-to-strong earthquakes in recent times, this work tracks the lines for understanding where the probability of new strong earthquakes is higher in Italy and Alps: in this map many areas showing high strain rate that have not been affected by strong earthquakes from 1990 to today are recognized, mainly in Central and Southern Italy, and so it's not unlike that they will be rattled by significant seismic events in the next decades. Year 1990 is taken as a milestone because, beginning the survey in 1991, the former earthquakes do not influence the data. Also Irpinia shows high strain rate (fig.7 right and left): currently north of it, in the Sannio sector, strain rate is at low level with a value of 20 nstrain/a 10 km north of Benevento; but from this city to SE the value increases to 35 nstrain/a in less than 30 km at Grottaminarda, reaching the highest levels (48 nstrain/a) 15 km south of the epicenter of the 23 November 1980 earthquake. Therefore, Irpinia is still currently one of the areas with higher strain rate in Italy, with values always > 32 nstrain/yr, and particularly showing the maxima in the hanging wall of the Monte Marzano fault system. Southward strain rate dramatically drops to 35 nstrain/a near Polla, but while north of Irpinia along the chain axis the value drops rapidly under 30 nstrain/a, southward the values remains above this value well longer, up to the Pollino line, the border between Central Apennines and Calabria – Peloritani arc. In the picture of the EW-trending litospheric faults dissecting the Apenninic orogen these sudden strain rate drops north and south of the Irpinia can be related to different strain rate conditions occurring in the adjacent sectors.

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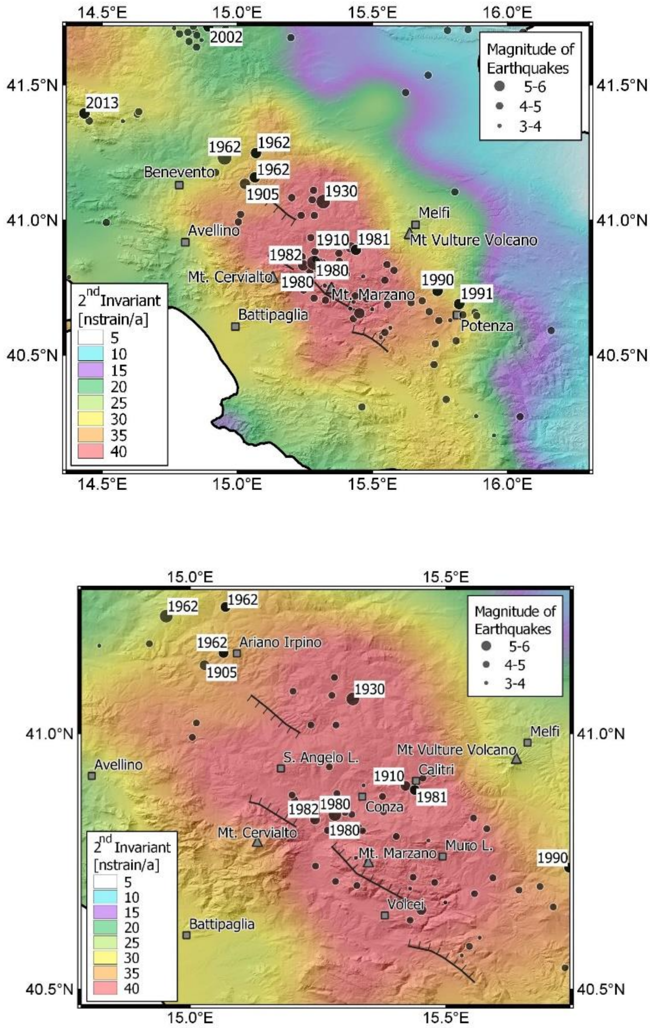

Figure 7. Top -Map of the horizontal strain rate field of Irpinia derived from GNSS and InSAR during more than two decades of observation (1990-2017). Main earthquakes occurred from 1900 to 2017 are represented on the map. **Bottom –** Focus of the area with high-strain rate with toponyms.

4. CONCLUSIONS

in the last twenty years the main shallow earthquakes in Italy and Alps have occurred only in some of the horizontal strain rate zone depicted by [14], while strain rate is now low in other areas interested by recent earthquakes occurred before the 1991 – 2011 survey, like Belice (1968) and Friuli (1976), as also where the higher seismic events have occurred from 1915 to us: the area of the 1915 Marsica earthquake as well, shows lower-than-surroundings strain rate values, as in Central and Eastern sections of the Northern Apennines (in the Western sector a higher seismicity barely correspond to a higher strain rate).

Instead in Irpinia, as seen, high strain rate has been detected, implying from a theoretical point of view a high possibility of new strong earthquakes in the area. This can be somehow counterintuitive, since this area hosted the most of the strongest earthquakes in southern Italy after 1908, in 1930, 1962 and 1980: only the Mw 6.4 1968 Belice and the Mw 6.0 1978 Patti gulf events (both in Sicily) reached a similar magnitude [11], and only in the NE Sicily rattled by the 1978 earthquake strain rate is still very high as in Irpinia.
Therefore, we can argue from this point of view that also in Irpinia the probability of a new strong event is still very high.

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The historical seismicity as well can allow this – somehow unexpected – statement, given the time intervals between Irpinian earthquakes, as seen before.

Hence, merging historical seismicity and InSAR Satellite data, we hypothesize that:

- the short time gap between strong events in Irpinia in the periods 1694 – 1732 and 1910– 1980 are linked to periods of continuous high strain rate;
- instead, the long seismic gap (that is the lack of strong seismicity) between 1732 and 1910 could have been originated by a strain rate drop after the 1732 earthquake.

AUTHOR CONTRIBUTIONS:

Conceptualization, A.P, F.B. Historical and geographical investigation F.B., A.P. methodology, software, validation, formal analysis, data analysis, G.F.; investigation, resources, writing—original draft preparation, writing—review and editing, visualization, F.B., A.P. and G.F.; supervision, project administration, A.P..; funding acquisition, F.B.

REFERENCES:

1 Farolfi, G., Piombino, A., Catani, F. Fusion of GNSS and Satellite Radar Interferometry: Determination of 3D Fine-Scale Map of Present-Day Surface Displacements in Italy as Expressions of Geodynamic Processes. Remote Sens. 2019, 11, 394.

2 Farolfi, G., Bianchini, S., Casagli, N. Integration of GNSS and satellite InSAR data: derivation of fine-scale vertical surface motion maps of Po Plain, Northern Apennines and Southern Alps, Italy, IEEE Transactions on Geoscience and Remote Sensing (TGRS) 2018. doi: 10.1109/TGRS.2018.2854371.

3 Farolfi, G., Del Soldato, M., Bianchini, S., Casagli, N. A procedure to use GNSS data to calibrate satellite PSI data for the study of subsidence: An example from the north-western Adriatic coast (Italy). European Journal of Remote Sensing, 52(sup4), 2019, 54-63.

4 Farolfi, G., Del Ventisette C. Contemporary crustal velocity field in Alpine Mediterranean area of Italy from new geodetic data. GPS Solut. 2015, 20, 715–722

5 Italiano, F., Martelli, M., Martinelli, G., Nucci, M. Geochemical evidence of melt intrusions along lithospheric faults of the Southern Apennines, Italy: Geodynamic and seismogenic implications Journal of Geophysical Res. 105, 2000, B6,pages 13,569 - 13,578

6 Di Luccio, F., Chiodini,G., Caliro, S., Cardellini, C., Convertito, V., Pino, N.A., 3 Tolomei, C., Ventura, G. Seismic signature of active intrusions in mountain chains. Sci. Adv. 2018; 4 : e1701825

7 Chiodini, G., Cardellini, C., Di Luccio, F., Selva, J., Frondini, F., Caliro, S., Rosiello, A., G. Beddini, G., Ventura, G. Correlation between tectonic CO2 Earth degassing and seismicity is revealed by a 10-year record in the Apennines, Italy Sci. Adv. 2020; 6 : eabc2938

8 Pino, N.A., Palombo, B., Ventura, G., Perniola, B., Ferrari, G. Waveform modeling of historical seismograms of the 1930 Irpinia earthquake provides insight on ''blind'' faulting in Southern Apennines (Italy) Journal Of Geophysical Research, VOL. 113, B05303, doi:10.1029/2007JB005211, 2008

9 Di Bucci, D.; Corrado, S.; Naso, G. Active faults at the boundary between Central and Southern Apennines (Isernia, Italy). Tectonophysics 2002, 359, 47–63.

10 Galli, P., Peronace, E. New paleoseismic data from the Irpinia Fault. A different seismogenic perspective for southern Apennines (Italy) Earth-Science Reviews 136 (2014) 175–201

11 Rovida A., Locati M., Camassi R., Lolli B., Gasperini P. [eds] . Italian Parametric Earthquake Catalogue (CPTI15), version 2.0, 2019 Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/CPTI/CPTI15.2

12 Rovida A., Locati M., Antonucci A., Camassi R. [eds.] (2017). Italian Archive of Historical Earthquake Data (ASMI). Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/asmi

13 Fracassi, U., Valensise, G. Unveiling the Sources of the Catastrophic 1456 Multiple Earthquake: Hints to an Unexplored Tectonic Mechanism in Southern Italy Bulletin of the Seismological Society of America, Vol. 97, No. 3, pp. 725–748, June 2007, doi: 10.1785/0120050250

14 Farolfi, G., Keir, D., Corti, G., Casagli, N. Spatial forecasting of seismicity provided from Earth observation by space satellite technology. Scientific reports, 2020, 10(1), 1-7.

15 INGV - Italian Seismic Bulletin

16 Markušic, S., Stanko, D., Korbar, T., Belic, N., Penava, D., Kordic, B.´The Zagreb (Croatia) M5.5 Earthquake on 22 March 2020 Geosciences 2020, 10, 252; doi:10.3390/geosciences10070252