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Evolution and strengthening of the Calabrian Regional Seismic Network

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Abstract. The Calabrian Arc is an area of high seismic hazard, in the past often affected by destructive earthquakes. The seismicity of the Calabrian region is monitored by the Italian National Seismic Network integrated by the Calabrian Regional one and, in the last three years, by the Pollino temporary array. We have applied the Seismic Network Evaluation through Simulation to assess the individual contribution of each network in locating earthquakes with epicentres in the Calabrian region and surrounding. We shows that the Calabrian Regional Seismic Network greatly improves the quality of the coverage in almost the Calabria territory except in the Crotone Basin, in the Serre and in the offshore areas. We show that the contribution of the Pollino temporary array is instead restricted to a very small area centred on the Pollino Chain. Due to the presence in the Serre of important seismogenic volumes, which in the past have generated destructive earthquakes, it would be opportune to add at least several seismic stations in this area and surrounding to improve the seismic monitoring.

1 Introduction

Italian seismicity results from the relative motion between the African and Eurasian plates, accommodated by a complex system of faults that developed during the processes of subduction and collision in the Central Mediterranean area. From a geodynamic point of view, Southern Italy is divided into two regions: the southern-most, the so-called Calabrian Arc, where the Ionian lithosphere is still subduting beneath the Tyrrhenian Sea and the northern one, the so-called Southern Apennines, that constitute the accretionary prism of the Adriatic plate subduction.

Due to its geodynamics contest, the southern Italian territory (with the exception of the Salento peninsula and some areas of Sicily) is characterized by an high seismic risk (Crowley et al., 2008) with maximum seismic activity along the Calabrian axis and the eastern part of Sicily. In historical times several destructive earthquakes ($M_S > 7$) occurred in Southern Italian territory, many of which with epicenter in the Calabrian region, like those occurred in 1638, 1783, 1905 and 1908.

The seismicity of the Italian territory is monitored by the Italian National Seismic Network (INSN) managed by Istituto Nazionale di Geofisica e Vulcanologia. After the destructive Irpinia earthquake (1980), the INSN was initiated with about 100 short-period vertical instruments. In recent years the INSN has been technologically renovated and has now reached a configuration of more than 300 seismic stations. However, as showed by D'Alessandro et al. (2011a), the performance of INSN in locating low energy shocks in the Calabria Region is still not fully satisfactory.

In the late 70's the University of Calabria activated the Calabrian Regional Seismic Network (CRSN, Fig. 1a), nowadays constituted by 15 seismic stations. Since 1986 the CRSN located about 40 000 earthquakes with epicenter in the Calabrian region (Fig. 1b) and contributed significantly to integrate the INSN coverage.

Since almost three years the area at the northern boundary of Calabria, marked by the presence of the Pollino mountain chain if affected by a dense series of seismic swarms characterized by an energy release sufficient to be frequently felt by local inhabitants, generating diffuse bother (Totaro et al., 2012). Only in two cases permanent effects accompanied the shocks. In particular, the most important event of the sequence (M_L 5.0) on 25 October 2012 caused a

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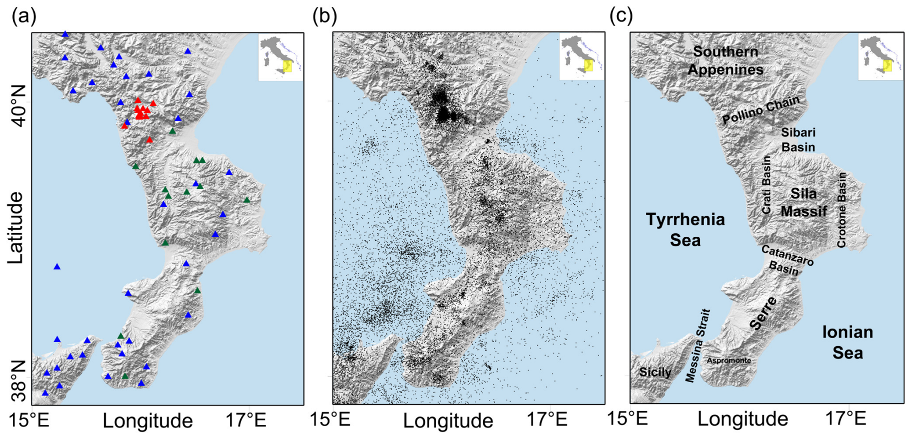

Fig. 1. (a) Distribution of the seismic stations on the Calabrian territory; blue: INSN, green: CRSN, red: Pollino array; **(b)** epicenter distribution of the instrumental seismicity recorded by the CRSN from 1986 (about 40 000 earthquakes); **(c)** main geological-geographic domains of the Calabria region.

maximum intensity evaluated in the degree VI of the MCS Scale (D'Amico and Scarfì, 2012).

Since 2010 several 3-D stand-alone seismic stations were installed by the University of Calabria in the Pollino area (Fig. 1a). In only three years the Pollino temporary array (POLL), nowadays constituted by 16 stand-alone seismic stations, have recorded several thousand local seismic events.

In this paper we examine into details the evolution and the strengthening of the CRSN. We analyzing the location performance of the CRSN and of the Pollino array, integrating the INSN, to show their support in local earthquakes detection and location. The performance analysis and the contribution of each seismic network on earthquakes location was performed using the SNES (Seismic Network Evaluation through Simulation) method proposed by D'Alessandro et al. (2011a).

2 Evaluation of the networks performance

Seismic networks are essential tools to monitoring seismicity, characterizing seismogenic volumes and assessing seismic hazard. To detect and locate small magnitude earthquakes a seismic network must constituted by a dense and well distributed low-noise stations. It is important to assess existing network capabilities, to identify seismogenic areas that are not adequately covered and to quantify measures that will allow network improvement. With this aim D'Alessandro et al. (2011a) proposed the SNES method. In the last years the SNES method was widely used to analyze the network performance of many national seismic networks (D'Alessandro et al., 2011a, b, 2012a, b, 2013; D'Alessandro and Ruppert, 2012; D'Alessandro and Stickney, 2012).

The SNES method allows to determine, as a function of magnitude, hypocentral depth and confidence level, the spatial distribution of the following parameters: magnitude detection threshold, number of stations active in the location procedure, azimuthal gap and confidence levels of hypocentral parameters. Details on the SNES method and on the computation algorithms can be found in D'Alessandro et al. (2011a).

To evaluate the contribution of the CRSN and of the Pollino temporary array to locate local and regional seismicity we applied the SNES method at different networks configuration: INSN, INSN+CSN and INSN+CSN+POLL. We discretized the study area using a square mesh having 1 km sides. For $M_L \geq 2$ the Italian territory is already well covered by the INSN (D'Alessandro et al., 2011a). Therefore, our analysis is limited to the small magnitude earthquakes and the SNES maps were calculated for M_L 1.5, with 95 % confidence intervals. Almost all the instrumental seismicity in the Calabria onshore is confined to the upper 15 km, so in the present simulation we set the hypocentral depth to 10 km. To mitigate the random noise a 2-D moving average with square windows having 5-point sides was applied to the maps, followed by application of a cubic 2-D spline interpolation to improve the graphics.

Figures 2, 3 and 5 show the SNES maps estimated for M_L 1.5 for the INSN, INSN+CRSN and INSN+CRSN+POLL, respectively. Black areas in the error maps are where the error on the space coordinates results to be $\geq$ 10 km. Each SNES map is divided into six submaps that report the number of active stations in the location procedure, the azimuthal gaps and the amplitude of the confidence interval of latitude, longitude, hypocentral depth and RES parameter (Radius of the Equivalent Sphere, see D'Alessandro et al., 2011a). Figures 4 and 6 show the individual contribution of the CRSN and of the POLL. These maps were calculated subtracting from the SNES maps determined for the INSN+CRSN that of INSN and subtracting from that determined for the INSN+CRSN+POLL that of INSN+CRSN, respectively.

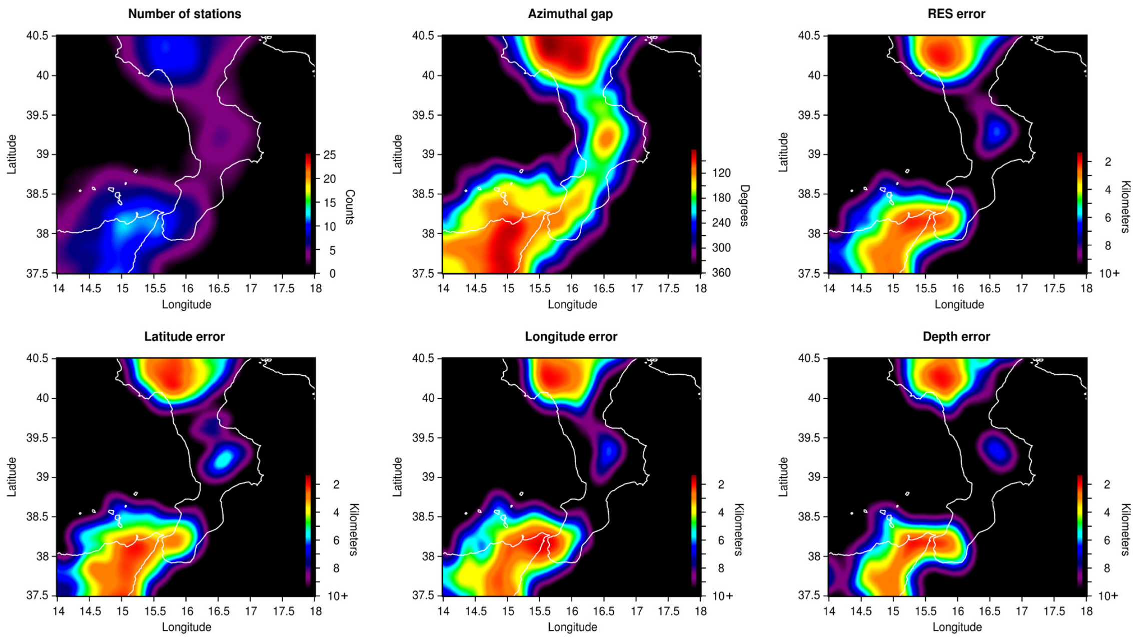

Fig. 2. SNES maps for the INSN at M_L 1.5, hypocentral depth of 10 km and confidence level of 95 %.

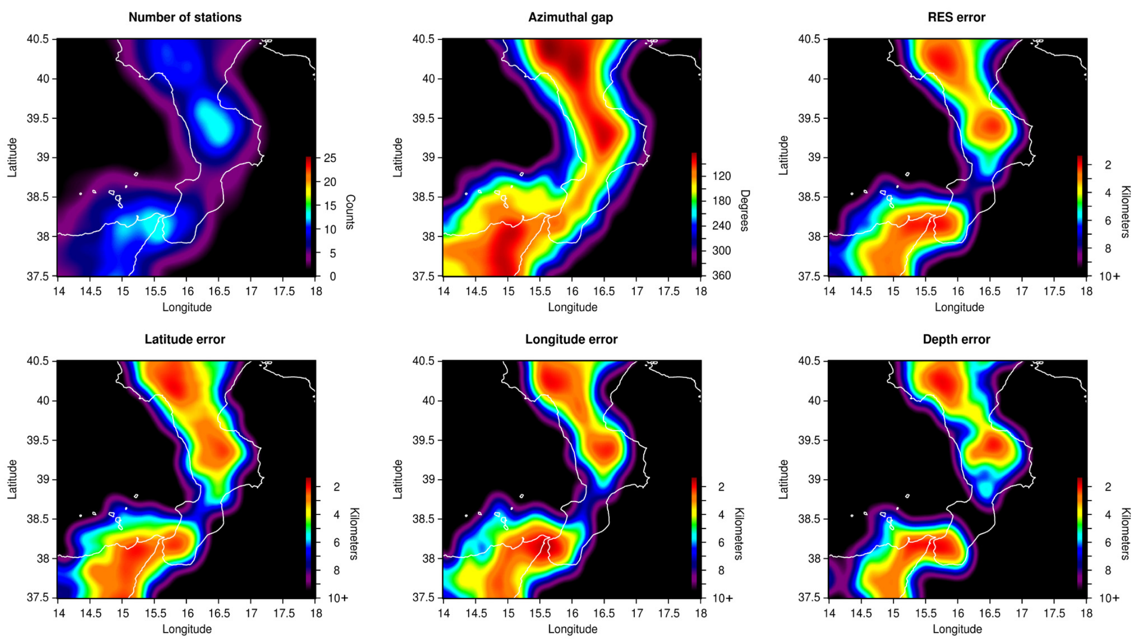

Fig. 3. SNES maps for the INSN+CRSN at M_L 1.5, hypocentral depth of 10 km and confidence level of 95 %.

The maps of Figs. 4 and 6 are showed to easily quantify the contribution of each seismic network.

Figure 2 shows that for M_L 1.5 the maximum number of active stations of the INSN lay around the Messina Strait. We can observe how only few stations are able to detect small magnitude earthquakes with epicenter in the Sila Massif especially at its border (Catanzaro and Sibari Basin). The Calabria offshore regions, both Tyrrhenian and Ionian Sea, are almost completely uncovered. The azimuthal gap shows its lower values in the Southern Apennines, reaching values of about 100° and in the eastern part of Sicily. The hypocentral parameters errors show acceptable value only in the Southern Apennines, in the Messina Strait and in the eastern part of Sicily, where the mean location error, as 95 % confidence intervals, reaches the values of about 2 km.

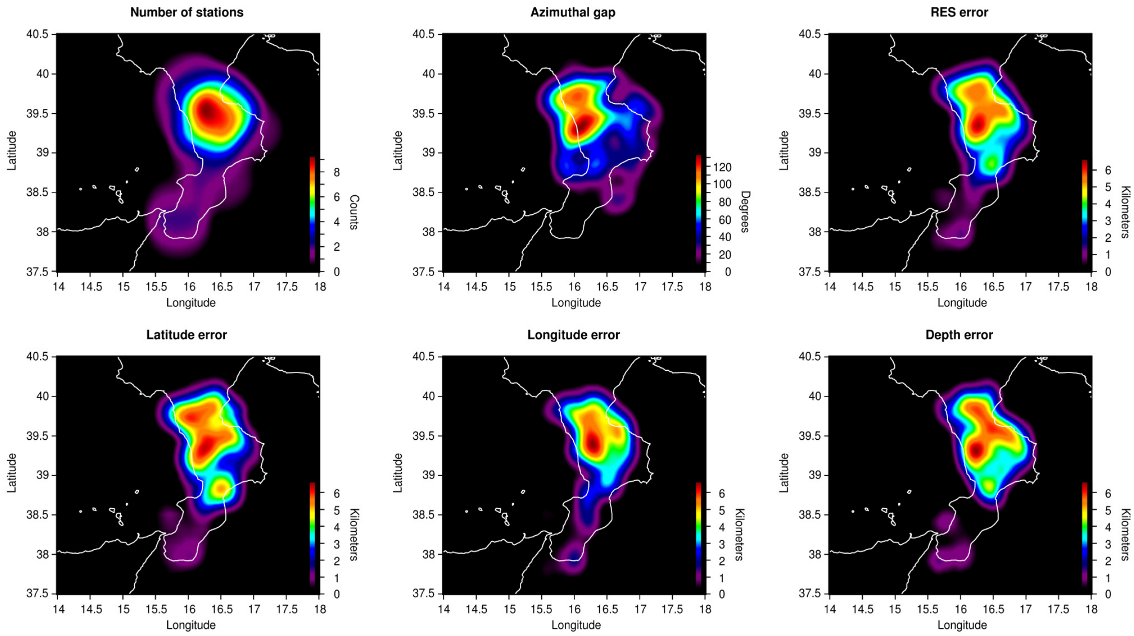

Fig. 4. SNES maps for the CRSN determined as (INSN+CRSN) – INSN at M_L 1.5, hypocentral depth of 10 km and confidence level of 95 %.

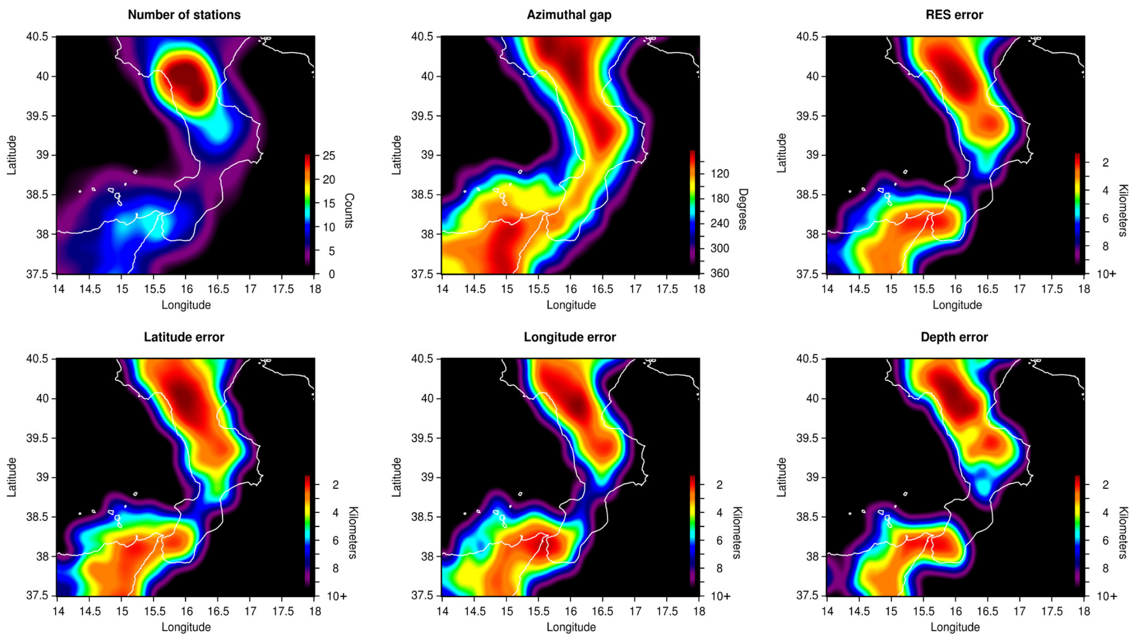

Fig. 5. SNES maps for the INSN+CRSN+POLL at M_L 1.5, hypocentral depth of 10 km and confidence level of 95 %.

Figure 3 shows the clear improvement in coverage as a result of the addition of the CRSN. The mean number of active stations increase considerably in almost the whole Calabrian territory especially in the Sila Massif and in the Sibari Basin. In these areas the azimuthal gap significantly decreases, going down below 100°. With the CRSN contribution the INSN is able to locate with acceptable errors all the small magnitude earthquakes (M_L 1.5) with epicenters inside the Calabria region. We can observe that in the onshore area only the Crotone Basin and the Serre area are not well covered, this last especially for the hypocentral depths. The hypocentral depth is generally the most difficult hypocentral parameter to determine due to the fact that the travel-time derivative with respect to depth changes very slowly as a function of the depth,

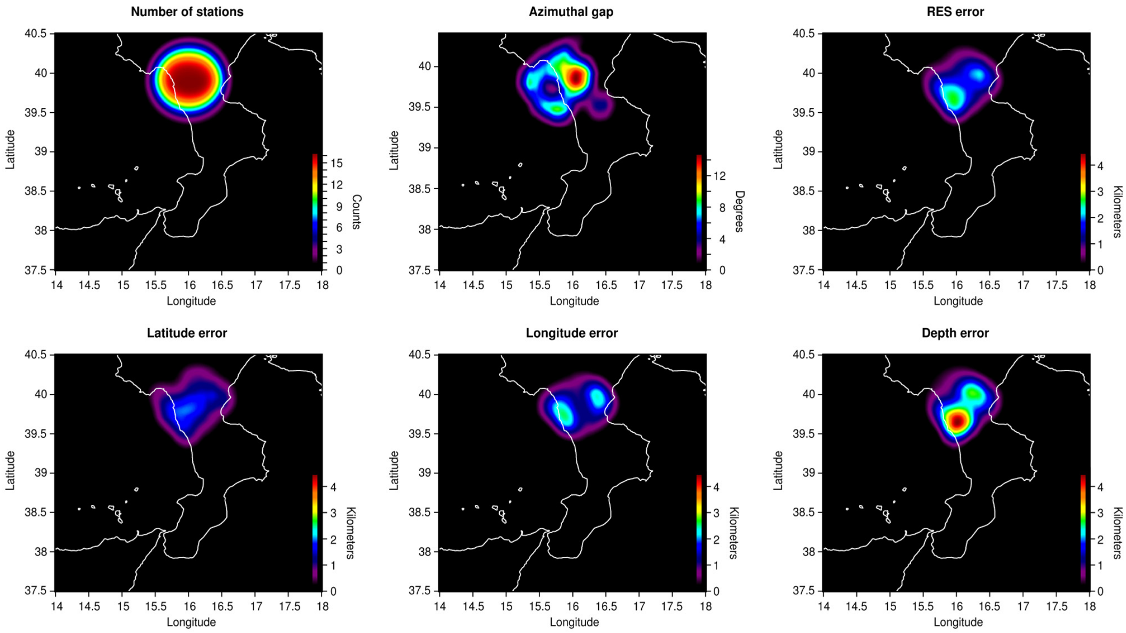

Fig. 6. SNES maps for the Pollino temporary array determined as (INSN+CRSN+POLL) – (INSN+CRSN) at M_L 1.5, hypocentral depth of 10 km and confidence level of 95 %.

unless at least a station is very close to the epicenter. Due to the elongated shape of Calabria and consequently to the distribution of the onshore stations, regrettably the offshore areas are uncovered. For this reason, errors on epicentral longitude result generally greater then on latitude.

Figure 4 permits to quantify the CRSN contribution to earthquakes location. Thanks to the CRSN, local earthquakes are detected by a greater number of stations, which reaches the maximum value of 8 in correspondence of the Sibari Basin. The azimuthal gap is significantly reduced in the whole Sila Massif and neighbouring areas, up to a maximum of about 130°. The maps in Fig. 4 show also how all the hypocenter parameters are better constrained with a reduction in the error localization that in some areas, like the Crati Basin, exceeds 6 km. However it is possible to observe how some areas, like the Southern Apennines and the Aspromonte, are not significantly affected by the presence of the CRSN probably because already well covered by the INSN.

Figure 5 shows the contribute in earthquakes locations of the Pollino temporary array. The Pollino Temporary array was installed between the 2010–2011, in coincidence with the beginning of the Pollino seismic sequence (Totaro et al., 2012) to monitoring the local micro-seismicity presently still in act. Figure 6 allows to easily quantify the contribution in the earthquakes location of the POLL. The contribution of the array is restricted to a very small area centred on the Pollino Chain. It is possible to observe that just for M_L 1.5, all the POLL stations are active in the localization process. The hypocenter parameters errors are significantly reduced only for earthquakes with epicentre inside the array. The hypocenter parameter that most benefit is clearly the hypocentral depth for which the error reduction exceeds 4 km.

3 Discussion, conclusions and remarks

In this paper we have used the SNES method (D'Alessandro et al., 2011a) to evaluate the contribution of the CRSN and of the Pollino temporary array to locate small magnitude earthquakes in the Calabrian region. We analyze three different networks configurations: INSN, INSN+CSN and INSN+CSN+POLL. Our analysis shows that the INSN alone is not able to locate earthquakes of M_L 1.5 in the Calabria offshore area, in the whole Sila Massif region and surroundings. Adding CRSN to INSN permits to improve the quality of the coverage and to reduce the hypocenter parameters errors in almost the Calabria except in the Crotone Basin, in the Serre and in the offshore areas. We show that the contribution of the POLL array is restricted to a very small area centred on the Pollino Chain. However, one must keep in mind that our simulations were carried out using the velocity model adopted by INGV for the whole Italian territory in the location routine. The use of a velocity model optimized for the study area or its sub-areas, would certainly lead to a significant further reduction of the uncertainty on the estimated parameters, in particular in the Pollino area.

Due to the presence in the Serre and surrounding areas of important seismogenic volumes which in the past have generated catastrophic earthquakes it would be opportune to add at least several seismic stations in this area to improve the seismic monitoring and better define the seismogenic structures with the aim of a detailed assessment of seismic hazard. However, due to the elongate shape of the Calabrian territory, it will be very difficult to get optimal coverage without an offshore extension of the seismic networks by deployment of a suitable number of Ocean Bottom Seismometer (OBS, D'Alessandro et al., 2009, 2012b).

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