GeoTerrace Conference

EAGE

GeoTerrace-2020-010

GPS/GIS system for updating capable faults in the Calabrian territory through the use of soft computing techniques

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SUMMARY

Calabria is crossed by a system of active faults which represents a high seismic risk for the whole territory. In order to provide a contribution to territorial monitoring and control also for the purpose of "forecasting catastrophic events" and territorial prevention, the Geomatics Lab of the Mediterranean University of Reggio Calabria is working on updating the database of faults capable of the Calabria Region through the creation of territorial topographic networks for the monitoring and control of potentially active faults, to be managed through a GIS. In this regard (thanks to the large amount of displacement data acquired over time by the GPS networks implemented), we are also working on the experimentation of a neural network for the prediction of the probability of occurrence of an earthquake of a given magnitude following others occurring in the surrounding area, relating the data provided by the National Institute of Geophysics and Volcanology, with those obtained from the experimental GPS surveying networks, used to monitor active faults (to date the Castrovillari fault, the fault in the area between Fuscaldo - Falerna, and the Reggio Calabria fault).

Introduction

Calabria is, as is well known, a territory with a high seismic risk, in terms of victims, damage to buildings and direct and indirect costs expected following a strong earthquake. This territory has a very high seismic hazard (due to the frequency and intensity of repeated phenomena over the years), a very high vulnerability (due to the fragility of the building, infrastructural, industrial, productive and services heritage) and a very high exposure (due to population density and presence of a historical, artistic and monumental heritage in areas affected by active faults). Calabria is exposed to "geological" risks as it is located exactly along the contact zone between the European plate in the north and the African plate in the south, which are approaching at a speed of 7 millimeters / year. Due to these movements of the earth's crust linked to continental drift, the rock layers are compressed until they break. Along the rupture surfaces (faults), displacements are produced and, consequently, friction that cause the instantaneous release of the elastic energy accumulated before the rupture, in the form of "seismic" energy, that is, seismic waves (earthquake). Calabria is crossed by a fully active fault system (red lines, Figure 1), which develops from the Crati Valley, passes through the Strait of Messina and ends in eastern Sicily. These faults represent sectors with a high seismic risk and have originated almost all of the catastrophic earthquakes that hit Calabria in historical times: the Crati Valley earthquake of 1183, the Reggio and Messina earthquake of 1908, the seismic crisis of southern Calabria of 1783, earthquakes of central Calabria of 1638 and 1905, the earthquakes of Cosenza of 1835, 1854 and 1870. In order to provide a contribution to territorial monitoring and control also for the purpose of "forecasting catastrophic events" and territorial prevention, the Geomatics Lab of the Mediterranean University of Reggio Calabria, is working on updating the database of capable faults of the Calabria Region through the creation of territorial topographic networks for the monitoring and control of potentially active faults, to be managed through a GIS (Barrile et al. 2016; Barrile et al. 2019a; Barrile et al. 2019b). In this regard (thanks to the large amount of displacement data acquired over time by the GPS networks implemented), we are also working on the experimentation of a machine learning classifier for the prediction of the probability of occurrence of an earthquake of a given magnitude following others occurring in the surrounding area, by relating the data provided by the National Institute of Geophysics and Volcanology, with those obtained from the experimental GPS surveying networks, used to monitor active faults (today the Castrovillari fault, the fault in the area between Fuscaldo - Falerna, and the Reggio Calabria fault) (Barrile et al. 2009; Barrile et al. 2014).

Case study

The Castrovillari fault, (the most northerly Calabrian foult) is located on the southwest side of the Pollino Range and is made up of three main trend-setting, southwest-facing NNW escarpments extending for 10-13 km. The scarp tracks have a complex geometry: they are parallel to each other through a 1-2 km wide area and form a stepped pattern. In general, the slopes produce abrupt changes in the local topography which, in the central part of the structure, reach 25 m (Figure 2).

Figure 1*. Calabria's active faults (red) and Earthquake (yellow).*

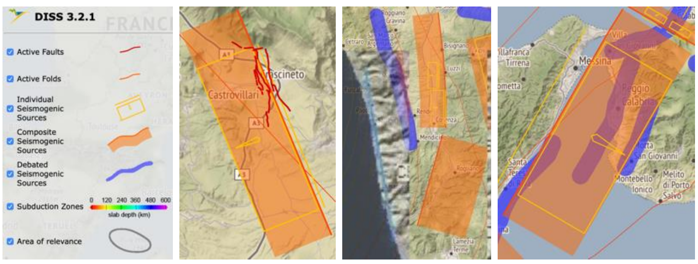

Figure 2 *Monitored faults, Castrovillari fault, Fuscaldo-Falerna fault (overlay of 2 images), Reggio Calabria fault, database of Italian seismological sources (DISS), INGV.*

The Fuscaldo - Falerna system (Figure 2) is formed by the faults bordering the Calabrian block towards the west, degrading in the marine area towards the Paola Basin, which constitutes one of the major Quaternary depocentres of the South Tyrrhenian area; the rejection is overall of the order of 4000 m and in the emerged area the fault surfaces visibly affect the Tyrrhenian and pre-Tyrrhenian terraces. Historically no earthquakes associated with these structures are remembered, and even the instrumental activity of the last decades has remained at modest levels.

The fault that crosses Reggio Calabria (Figure 2), one of the best known and most studied, is perhaps one of the most dangerous in Europe and can generate earthquakes up to magnitude 7.

Method and Theory

The GPS data. As part of a monitoring project of active faults, starting from the network established in collaboration with the Politecnico di Milano (which installed the first GPS network in Castrovillari), the Geomatics laboratory of the University of the Mediterranean has set up on the fault Castrovillari, on the Fuscaldo - Falerna fault and on the Reggio Calabria fault, a GPS network whose points are constantly detected for several years (on a weekly/monthly basis). Each of the three networks (one for each of the three faults mentioned above) counts some points straddling the three faults (to date still six vertices for each fault) and others (to date still only three vertices) in the external area, located in a stable area, (generally two on the east side and one on the west side). Due to the lack of funds, instrumentation (only 3 GPS receivers could be used) and availability of staff for such a long period of time, the measurement campaigns carried out by the Geomatics Laboratory (for several years to date on a monthly and/or weekly basis), have used from time to time the triangulation method on three points of the network (Postrorino et al. 2006). The statistics and parameters obtained from the processing and adjustment of the data acquired in the years from the institution to date are shown in tab. 1. Having therefore available parameters (and statistics) of displacement on GPS networks repeated over time, it is possible to carry out the analysis of the significance of these displacements (on the vertices of the networks established over the faults) using statistical techniques. The aforementioned activities have been implemented within a GIS (Figure 3), which, thanks to its potential (appropriately implemented), allows to obtain and consequently display:

- A free adjustment of the single networks;
- The Geodetic Datum's choice (set of the network points statistically stable) through statistical test;
- The estimate of the new coordinates of the network points on identified Datum (transformation);
- A constrained networks adjustment, singularly in the identified Datum;
- Calculation displacements of the network points.

Table 1 *Global parameters of adjustment of Castrovillari fault, Fuscaldo-Falerna fault, Reggio Calabria fault.*

	Castrovillari fault					Fuscaldo – Falerna fault					Reggio Calabria fault				
	δ_0	X^2_{sp}	$X^2_{95\%}$	S_{max} (m)	S_{med}(m)	δ_0	X^2_{sp}	$X^2_{95\%}$	S_{max} (m)	S_{med}(m)	δ_0	X^2_{sp}	$X^2_{95\%}$	S_{max} (m)	S_{med}(m)
2007	1.09	71.3	76.2	0.065	0.026										
2008	1.11	80.6	82.1	0.061	0.022										
2009	1.11	100.3	100.6	0.058	0.025										
2010	1.10	68.5	69.4	0.055	0.021						1.15	70.4	71.4	0.060	0.026
2011	1.13	75.2	75.8	0.054	0.018						1.18	80.1	80.8	0.059	0.023
2012	1.10	81.4	82.3	0.051	0.015						1.15	86.3	87.3	0.056	0.020
2013	1.12	72.5	82.7	0.056	0.024	1.10	69.3	80.5	0.054	0.022	1.17	77.4	87.7	0.061	0.029
2014	1.12	73.1	82.9	0.058	0.021	1.10	69.1	80.7	0.056	0.019	1.17	78.1	87.9	0.063	0.026
2015	1.11	80.4	78.5	0.060	0.023	1.08	78.2	76.5	0.058	0.021	1.16	85.3	81.5	0.065	0.028
2016	1.11	80.2	78.9	0.061	0.022	1.09	78.0	76.7	0.059	0.020	1.16	85.2	82.9	0.066	0.027
2017	1.12	78.0	81.2	0.061	0.022	1.10	76.0	79.1	0.059	0.020	1.17	81.1	86.2	0.066	0.027
2018	1.11	79.9	80.2	0.059	0.019	1.09	78.7	78.3	0.056	0.017	1.16	82.8	85.2	0.064	0.024
2019	1.11	80.1	82.5	0.062	0.019	1.09	78.2	80.3	0.060	0.017	1.16	85.1	87.5	0.067	0.024
δ_0	Estimation of the standard deviation of unit weight														
X^2_{sp} $X^2_{95\%}$	Experimental value of the static for the overall model and the upper limit to the level of significance of 5%														
S_{max} S_{med}	Maximum and average values of the semi axes of the ellipsoid standard error														

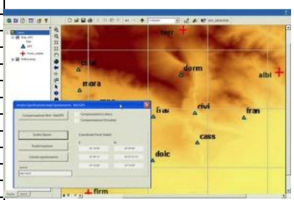

Figure 3 *Example of processing and viewing on implemented GIS.*

Seismic data. The seismic data used in our work are provided by the National Institute of Geophysics and Volcanology (seismic surveys performed 24 hours a day, 7 days a week), relating to:
- events occurred around (50 km radius) from the investigated areas;

- a time window from 2007 (for the Castrovillari fault), from 2013 (for the Fuscaldo - Falerna fault), from 2010 (for the Reggio Calabria fault) to date;
- seismic events of magnitude greater than 3;
- seismic events with magnitude less than 3.

Prediction of large sequences of aftershocks

At this point, using a neural network (appropriately implemented), we tried to connect the displacement data to the seismic data, to verify the possibility of establishing a risk map, which can indicate the probability that a new earthquake will occur and its magnitude (greater or less than 3), in a defined area, upon the occurrence of a seismic event (Parrillo et al. 2015). The occurrence of a large main shock earthquake typically triggers a secondary seismic shock, known as an aftershock. Aftershocks resemble the behavior of a decaying probability model and the magnitude depends significantly on the timing and magnitude of the main shock (Aslani and Miranda (2005)).

Our objective was to test a machine learning classifier capable of producing the correct class (low entity or high entity) of an earthquake, based on the x and y coordinates (displacement of network points and epicenter of the earthquake). We built a 3-layer neural network with one input layer, one hidden layer and one output layer. The number of nodes in the input layer is determined by the dimensionality of our data. Similarly, the number of nodes in the output layer is also determined by the number of classes we have. The input of the network are the x and y coordinates (displacement of the network points and epicenter of the earthquake) and its output will be two probabilities, one for class 0 ("magnitude <3") and one for class 1 ("magnitude >3 "). The learning used to form the network is "reinforcement learning", in which an appropriate algorithm aims to identify a specific modus operandi, starting from a process of observation of the external environment; every action has an impact on the environment and the same environment produces feedback that guides the algorithm itself in the learning process. The more nodes we insert, the higher the computational cost. The activation function chosen is "tanh", a non-linear activation function. Since we require our network to generate probabilities, the function for the output level will be softmax, which is simply a way of converting the raw values into probabilities. Our network makes predictions using forward propagation. To define the error in the training phase, we compare the values obtained from the neural network with the events used as tests. The farther apart the two probability distributions y (the correct labels) and y' (our predictions) are, greater our error is. By finding parameters that minimize the error, we maximize the probability of our training data. Therefore, taking into account the large amount of displacement data of the points of the network deriving from the processing of GPS/GIS data, the tested neural network, in a given region (study area), returns the probability of a seismic event of lower magnitude or greater than 3. The result can be displayed on the GIS using specific functions (Figure 4).

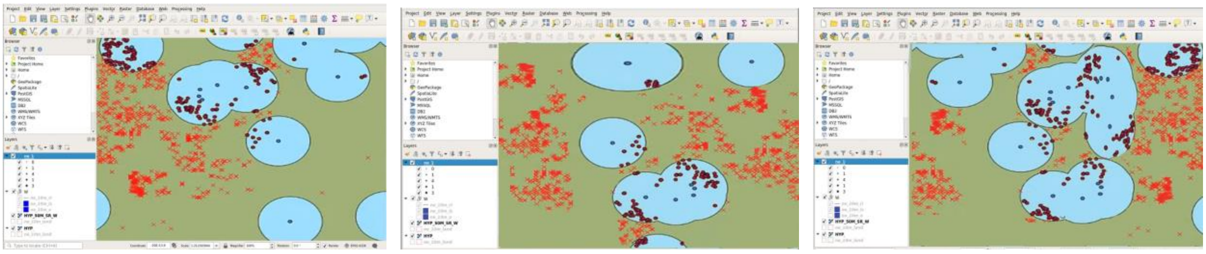

Figure 4 *Map of risk 1) Castrovillari 2) Falerna 3) Reggio Calabria (green area: area with a probability of magnitude<3, Blu area: area with a probability of magnitude>3; red: earthquake magnitude<3; dark blue: earthquake magnitude >3).*

The neural network used and implemented for this work derives from an experimental test that can certainly be improved, and clearly even the results obtained are only in the initial experimental phase. As we know it is not possible to predict earthquakes and taking into consideration only the correlation between surface movements and earthquakes is certainly reductive. However, a link between displacements and earthquakes is undeniable (which requires further investigations to help define the earthquake propagation mechanism).

Conclusions

In order to provide a contribution to territorial monitoring and control also for the purpose of "forecasting catastrophic events" and territorial prevention, our goal is to update the database of capable faults of the Calabria Region (also for further studies by other researchers and scholars belonging to other scientific fields). Territorial topographic networks were therefore created for the monitoring and control of potentially active faults managed through a GIS and we also worked on a first experimentation of a machine learning classifier for the prediction of the probability of occurrence of an earthquake of a given magnitude following another of strong intensity occurred in the surrounding area, linking the data provided by the National Institute of Geophysics and Volcanology, with those obtained from the GPS surveying experimental networks, used to monitor the three active faults (today the Castrovillari fault, the fault in the area between Fuscaldo - Falerna, and the Reggio Calabria fault). This provided a preliminary map of seismic hazard at a detailed scale directly integrated into the GIS environment, to support the various local authorities for the protection and safeguarding of the population.

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