Agreement DPC-INGV 2012-2021

Seismological Programme
(2012-2013)

Project S3
"Short-term earthquake prediction and preparation"

Project Director: Dario Albarello
Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente
Università degli Studi di Siena

Programme Coordinator: Riccardo Caputo
Università di Ferrara

Programme Responsible: Giuseppe Di Capua
Istituto Nazionale di Geofisica e Vulcanologia

Final Report

DPC-INGV-S3 Project
"SHORT TERM EARTHQUAKE PREDICTION AND PREPARATION"

Prediction is very difficult, especially about the future
(N.Bohr, 1885-1962)

Sommario

Introduction

In the frame of the guidelines defined in the general agreement between the Dept. of Civil Protection and National Institute of Geophysics and Volcanology (DPC and INGV respectively) for the period 2012-2021, three new research projects were planned aiming at exploiting more advanced researches carried on in Italy to improve preparedness to future seismic events and supporting risk reduction programs. One of these projects focuses on “short term earthquake prediction” and represents, from the cultural point of view, a strong discontinuity with respect to the main trend of seismological researches performed in Italy in the last 30 years.
After the strong interest on this topic that has followed the successful Haicheng prediction (1975), researches and field experiments were promoted in all developed countries. After about 15 years of studies, frustration prevailed having the Parkfield failed prediction experiment (1980-1990) as a paradigmatic example of unsuccessful prediction (False Alarm). In Italy, in particular after the devastating Irpinia earthquake in Southern Italy (November, 23 1980), the problem of earthquake forecasting assumed the form of a public harsh debate that invested both the scientific community and public opinion. In 1985 (23th January), a short term (three days) seismic alarm was issued for the Garfagnana zone (Northern Tuscany) but no seismic event occurred. Mainly due to the lack of preparedness of local population and a possibly negligence in communication (the alarm was abruptly issued during the TV prime time, see Pastore, 1987) this “false alarm” involved significant disruption to normal life, with associated costs and stresses and was again the source of a dramatic public debate (involving legal consequences for scientists and Authorities). Since that, partially due to the lack of outstanding results, partially for the negative uncontrolled reactions experienced in 80’ and partially for the global trend involving USA and most of other western countries, no coordinated research project was planned in Italy and no significant funding was provided for this kind of researches. A paradigmatic position denying any possibility of earthquakes forecast became the mainstream (at least as concerns communication outside of the scientific community) and the word “forecasting” itself became at some extent “impolite”. A common misunderstanding is probably at the base of this apodictic position. In fact, it answers to a wrong question: the problem is not if the forecast is possible but instead what kind of forecast we are able to provide. Actually “earthquake forecasts” continued to be provided (seismic hazard maps actually represent a “forecast” for the maximum reasonable ground shaking expected in a future exposure time), but they mainly concerned long-term predictions and scarce “mediatic” attention was devoted to middle and short term prediction studies. Anyway, beyond the lack or scarcity of financial support for researches, this situation also generated a “no-man land” that was occupied by any kind of “enthusiastic volunteers” in many cases out of any systematic scientific control. This generated the dramatic situation arisen during the 2009 L’Aquila seismic crisis with a frontal crash of the scientific community on one side (denying any possibility of earthquake forecasting) and “self-made” answers to the growing demand coming from public opinion. After that event, an “International Commission on Earthquake Forecasting for Civil Protection” was

established to provide an "external" referee about the status of knowledge about earthquake prediction (Jordan et al., 2011). The outcome of this commission was a "state of the art" review (see also Cicerone et al., 2009) but, more straightforwardly, also a number of important recommendations. Among these, it was stated that "*A basic research program focused on the scientific understanding of earthquakes and earthquake predictability should be part of a balanced national program to develop operational forecasting (Recommendation C)"* and *"DPC should continue its directed research program on development of time-independent and time dependent forecasting models, with the objective of improving long-term seismic hazard maps that are operationally oriented (Recommendation D)".* Of course, *"Forecasting methods intended for operational use should be scientifically tested against the available data for reliability and skill, both retrospectively and prospectively. All operational models should be under continuous prospective testing (Recommendation F1)."*

This position (that can be defined as "well-disposed scepticism" in contrast with "wishful data mining" that characterized early researches) also reflects a renewed interest towards this kind of studies (e.g., Kagan, 1997, Kagan and Jackson, 2000, Johnson, 2009) in USA and other countries that, at least partially, is the result of the unsatisfactory status of seismic hazard assessment studies, that at presents are mainly linked to time-independent estimates provided in the frame of 40 years-old Cornell-McGuire Approaches (see, e.g., Stein et al., 2012; Mucciarelli and Albarello, 2012).

As a result of this new climate, Department of Civil Protection and INGV decided to promote new explorative studies on earthquake forecasting (both in the long, middle and short term) to provide National Institutions of new tools for earthquake hazard assessment. This DPC-INGV-S3 project was the result of this initiative.

Beyond the different time scale of concern, both Seismic Hazard Assessment (SHA) and Short-term Earthquake prediction (SEP) share the same target of earthquake forecasting. A major difference between SHA and SEP is the target of forecasting: while SHA focuses on the ground motion scenario, SEP aims at the definition of time and location of future seismic sources activations. There are also significant methodological differences underlying these two kinds of studies. While SEP is carried on by identifying observable phenomena able to characterize the present status of ongoing seismogenic processes potentially responsible for future damaging earthquakes, SHA is mainly characterized by statistical/phenomenological approaches related to the stochastic modelling of the underlying processes.

Beyond these differences, however, being both SHA and SEP provided by considering uncertain and incomplete information, outcomes (predictions) have in both cases a probabilistic form to express the actual degree of belief associated to each "forecast". Thus, no solution of continuity exists between SHA and SEP. Furthermore, SEP tools represent a fundamental integration to refine SHA outcomes as concerns middle and short term forecasting. In particular, they could help in defining priorities for choosing areas where more urgent are risk reduction interventions and improving emergency preparedness.

Conceptual background

The preliminary step for the definition of an effective research project devoted to earthquake forecasting is the identification the classes of observables of potential interest among those that in the last years were the argument of researches and experimental observations (see, for an extensive review, Cicerone et al., 2009). The first class of observables that was the subject of major scientific interest in the last years (Jordan et al., 2011), is that related to seismicity studies carried on by considering stochastic models and tools. The second class concerns monitoring of underground fluids (Radon, piezometry of confined aquifers) and variations of physical/mechanical properties of the crust (electrical conductivity, thermal anomalies, regional scale strain field variations, Vp/Vs ratios, seismic anisotropy, etc.) from surface measurements. The third class concerns large scale remote sensing (ground displacements, variations in the electromagnetic field, thermal radiation studies, etc.) from satellite data. These classes include quite different and complementary phenomena, all potentially related to the seismogenic process. In front of this wide spectrum of possible observations, there is the general lack of a well accepted and experimentally sound physical model linking the active seismogenic process to each of the observables listed above (Mulargia and Geller, 2003).

Recent data (Amoruso and Crescentini, 2012) suggest that nucleation of earthquakes affects a relatively small volume around the potential hypocenter (less than 100 km^3 in the case of the 2009 L'Aquila earthquake) and this makes highly problematic, except than in very peculiar situations, the direct monitoring from the surface of preparation phenomena. This could explain the lack of clear one-to-one correspondences between "anomalies" of any kind and the subsequent earthquake generation (Jordan et al., 2011). On the other hand, several Authors (e.g., Kagan, 1994; Main, 1995, 1996) suggest that the seismogenic process is "critical" in nature (e.g. Kagan, 1992; Turcotte, 1992) being the effect of small scale mechanical interactions of a multitude of elementary seismogenic structures (e.g., Sacks e Rydelek, 1995; Castellaro e Mulargia, 2001). This kind of systems exhibits a strong sensitivity to small variations of the tectonic environment hosting the potential seismogenic structure. In particular, small strain field variations (of the order of 0.1 μstrain), could severely modify the local seismic hazard (e.g., Rydelek and Sacks, 1999). In this view, identification of observables able to provide short term indications about incoming earthquakes seems to require a change in the cultural paradigm that characterizes this kind of studies (Albarello, 2005): instead of a "silver bullet" relative to any forecasting "anomaly", one should search for multiparametric indexes able to capture short term variations of the regional strain field that have the earthquake as a possible effect. In this view, "anomalies" are not expected to be generated by the earthquake nucleation process, but reflecting larger scale (both in time and space) crustal phenomenon (Raydelek e Sacks, 1990, Pollitz et al., 2006; Rayder et al., 2007; Viti et al., 2003; Mantovani et al., 2010; Mantovani et al., 2012). Thus, forecasting of local/punctual phenomena as a seismic event requires the multiparametric analysis involving different events scattered in space and time. This purpose, gathering data for different sources becomes mandatory along with availability of suitable processing techniques also based on Artificial Intelligence Strategies (e.g.,Buscema and Benzi, 2011).

This paradigm displaces the attention from the search of single “anomalies” of any considered observable, to the collection of data sets aimed at reconstructing regional scale processes responsible for the expected earthquake. In this way it may become possible retrieving a more coherent and straightforward perspective that will allow overcoming difficulties and conflicts that endlessly dominated the seismological debate in the last years.

The S3 project

A major difference of Research projects devoted to SEP with respect to those relative to SHA is the lack of previous experiences (at least in Italy) of coordinated researches devoted to this topic. It results in fact evident that the main limitation of researches so far carried on in the field of short term earthquake forecasting relies on the lack of observational data having sufficiently extended coverage both in time and space (Albarello e Meletti, 2012). In the recent years, no systematic, well supported and coordinated effort was devoted to monitoring observables of potential interest. In order to select the most interesting ones four basic issues have to be considered:

- Multiparametric observations over wide areas should be preferred since these are potentially able to provide an integrated image of ongoing geodynamic processes responsible for the incoming earthquake
- Economic suitability of monitoring procedures is of major concern (low operating costs) to allow long term monitoring (well beyond the project duration)
- Availability of physical models (whether incomplete) accounting for the possible association of the observable and ongoing seismogenic processes
- Possibility to falsify hypotheses concerning the above association on the basis of empirical tests.

A further constraint came from the strong temporal (one year possibly extended to further two years) and financial constraints (less than 300 K€). This made mandatory a preliminary selection of possible activities to be developed in the frame of the project. Three main research lines were identified:

1. *Review of the state of the art and reappraisal of data collected in the last years about observable and phenomena possibly related with ongoing seismogenic process. These data will be merged to provide a comprehensive multi-parametric database for retrospective validations and fixing observational protocols and standards*
2. *Retrospective empirical validation of patterns proposed as representative of ongoing seismogenic processes*
3. *Location of future monitoring networks relative to validated observables for an effective "forward" validation test*

In each research line, specific tasks were identified and funds allocation was provided (Table 1).

After a public call, 28 research proposals were submitted. Few words about the selection criteria adopted the proposals to be included in the project:

- due to the financial limitations, no acquisition of new instrumental tools is allowed; the short time span of concern does not allow new monitoring campaigns in support of the proposed technique; thus, the bulk of the project is the reappraisal of data collected in the last years to provide a comprehensive multiparametric database for retrospective validations and fixing observational protocols and standards

- exploration of new promising research lines, internationally considered as feasible and so far less considered in Italy for monitoring seismogenic processes are favoured;
- following indications provided by the Dept. of Civil Protection, two specific geographical areas (Po Plain and Southern Apennines) are focused on: this implied that research project relative to possible observations only carried on outside the areas of interest were not considered for funding
- observables relative to wide areas (e.g., those provided by observation networks or remote sensing) and characterized by good temporal continuity will be of special interest
- application of statistical testing procedure to validate effectiveness of proposed observations for monitoring seismogenic process will be of paramount importance
- of major importance is defining areas most prone to next future earthquakes and where institution of specific observational networks will allow, in the next years, more effective testing of proposed protocols

Table 1*: Scientific organization of the S3 Project*

Research line	Task	Topic	Funds (KEuro)
Line 1	Task 1	Deep seated underground fluids	44
	Task 2	Variations in the mechanical properties of the crust from seismic measurements	40
	Task 3	Seismicity patterns	20
	Task 4	Variations in the crustal displacements and strain field from satellite measurements	45
	Task 5	Variations in the electromagnetic field from ground based measurements	43
	Task 6	Variations of ground thermal emissions by satellite measurements	30
Line 2	Task 7	Application of validation protocols to available observations	18
Line 3	Task 8	Medium/short term forecasting of areas most prone to future seismic activations in the Po plain and Southern Apennines	30

By taking these criteria into account, 10 Research Units (RU) were established including public companies (ARPA-Emilia-Romagna) research institutions (INGV, OGS and CNR-IMAAA) and university (Bologna, Basilicata, Bari, Siena and Trieste): more than 70 researchers were involved. Table 2 summarizes the involved research units and the relative financial support.

Expected outcomes of the project were planned in the form of deliverables. In essence three main kinds of deliverables are planned, corresponding to three main work packages (WP). The first kind of deliverable (WP 1) aims at providing DPC of an effective overview of most recent experiences in Italy and elsewhere to evaluate what has been done and what could be done. A result will also be the definition of best practice to monitor the relevant observables. This is a basic aspect in a research field where well grounded scientific research is mixed to enthusiastic and fanciful experiences. Results of this WP will have the form of 5 deliverables (D1.1, D2.1, D4.1, D5.1 and

D6.1) respectively devoted to hydrogeochemical, seismological, geodetic, electromagnetic and thermal emission data. These deliverables will have the form of a scientific paper and will be submitted for publication on a scientific journal for a peer-review screening after the end of the project.

***Table 2**. Structure of the S3 project. Colours refer to the three main Research lines in Table 1*

	Description	UR Leaders	RU	Funding (Euro)	Personnel	Other
Task 1	Hydrogeochemical data	Martinelli (ARPA ER)	RU1	24000	18000	26000
	Multiparametric Observations	Riggio (OGS)		20000		
	Seismic data (Ambient Vibrations)	Zaccarelli (INGV)		*18000*		
Task 2	Seismic data (Vp/Vs etc.)	Piccinini (INGV)	RU2	*32000*	5000	45000
Task 3	Seismicity data	Buscema (SEMEION)	RU3	*20000*	20000	0
Task 4	Ground displacement (SAR)	Tolomei (INGV)	RU4	*25000*	15500	9500
	Ground displacement (GPS)	Mantovani (UNISI)	RU5	20000	25000	13000
	Electromagnetic data (VLF/UF)	Biagi (UNIBA)	RU6	22000	15000	7000
Task 5	Electromagnetic data (MT)	Telesca (CNR-IMAA)	RU7	21000	10000	11000
Task 6	Satellite thermal data	Tramutoli	RU8	30000	23000	7000
Task 7	Validation	Mulargia (UNIBO)	RU9	15000	0	15000
	Validation	Albarello (UNISI)	RU5	3000		
	Forecasting (Pattern Recogn.)	Peresan	RU10	15000	12500	2500
Task 8	Forecasting (Geodynamic Mod.)	Mantovani	RU5	15000		
					Personnel	Other
			Total	**280000**	144000	136000

The second kind of deliverable is a database collecting observations actually available in the Italian area relative to each kind of observable. A preliminary analysis of possible interrelation of any "anomalous pattern" and earthquakes is explored by considering each observable separately.

The third kind of deliverable is a report relative to possible the analysis of available evidence to evaluate heuristic potential to considered observations and indications about areas most probably expected as earthquake prone in the next years and that could be of major interest for future monitoring activities. The organization of expected outcomes is planned in the form of the deliverable listed in Table 3.

Table 3. *Organization of expected outcomes (deliverables) from the S3 project. Colours refer to the three main Research lines in Table 1*

ID	Deliverables	Task
D1.1	Review of the main results and state-of-the-art optimal methodologies and experimental procedures concerning the use of hydrogeochemical data for the study of ongoing seismogenic processes. Responsible:	1
D1.2	Database of time series relative to hydrogeochemical observations in the Po Plain and Southern Apennines. This database will also include location of observation sites (map , coordinates, stations reports) and ancillary data (relevant meteoclimatic time series, etc.). Responsible: **Giovanni Martinelli and Anna Riggio (UR1)**	1
D2.1	Review of the main results, state-of-the-art optimal methodologies and experimental procedures (in English) for the retrieval of information about short-medium term variations in the *mechanical properties of the crust deduced from seismic measurements* . Responsible: **Piccinini and Zaccarelli (UR2)**	2
D2.2	Database of time series relative to seismic observations relative to Vs , Vp and seismic anisotropy short-medium term variations in the Po Plain and Southern Apennines. This database will also include location of observation sites (map, coordinates, stations reports). Responsible: **Piccinini and Zaccarelli (UR2)**	2
D3.1	Monthly reports relative to forecasts provided by the ANN alogorithms in the Po Plain and in the Southern Apennines. Responsible: **Buscema (UR3)**	3
D4.1	Review of the main results, state-of-the-art optimal methodologies and experimental procedures (in English) for the study of short-medium term variations in the ground deformation deduced from InSaAR and GPS procedures. Responsible: **Salvi (UR4), Mantovani (UR5)**	4
D4.2	Database of subsequent images relative to medium-short term variations in the ground deformation field from InSAR studies. Responsible: **Tolomei (UR4)**	4
D4.3	Database of GPS time series and subsequent strain field estimates in the Po Plain and Southern Apennines from GPS data measured at permanent stations. The database will include ancillary data (station reports). Responsible: **Mantovani (UR5)**	4
D5.1	Review of the main results and state-of-the-art optimal experimental methodologies (in English) for the study of electromagnetic field variations associated to seismogenic processes. Responsible: **Lepenna, Telesca (UR7)**	5
D5.2	Database of electromagnetic measurements at permanent stations The database will include ancillary data (meteoclimatic data, station reports): **Biagi (UR6)**	5
D6.1	Review of the main results and state-of-the-art optimal experimental methodologies (in English) for the study of thermal emission and their time variations from satellite observations. Responsible: **Tramutoli (UR8)**	6
D6.2	Database of subsequent thermal anomaly maps (one per day) relative to medium-short term variations in the thermal Earth's emission from satellite data in the Po Plain and Southern Apennines. **Tramutoli (UR8)**	6
D7.1	Review of the main results, state-of-the-art optimal statistical methodologies (in English) of multiparametric time-series analysis and validation of patterns possibly associated to seismogenic processes. Responsible: **Mulargia (UR9)**	7
D7.2	Results of time-series analyses and empirical validation procedures for observations provided by tasks 1-5 in the Po Plain and Southern Apennines with particular regard to the seismic sequences in Emilia and Pollino areas. Responsible: **Mulargia (UR9), Albarello (UR5) and Lapenna (UR7)**	7
D8.1	Short-medium term forecasting (1-2 years) of sites in the Po Plain and Southern Apennines most prone to possible future earthquake from pattern recognition analysis. Responsible: **Peresan (UR10)**	8
D8.2	Short-medium term forecasting (1-2 years) of sites in the Po Plain and Southern Apennines most prone to possible future earthquake from seismotectonic modelling. Responsible. Responsible: **Mantovani (UR5)**	8

Project development

Coordination activity

The kick-off meeting (Bologna, 12 July, 2012) represented the first opportunity for involved researcher to meet and define a common view of the project. Almost all RUs were present and a preliminary schedule of planned activity was drawn. In this phase, coherently with the general lines of the S3 project, four work packages were identified:

- *Dissemination*
- *Definition of the state-of-the-art about heuristic potential, monitoring and processing techniques for the parameters of interest*
- *Population of an extensive database of the parameters of interest*
- *Data processing to identify possible precursory patterns and empirical testing of their feasibility as seismic precursors*
- *Identification of areas most prone to significant earthquake in the next future by considering empirical and deterministic approaches*

After this first meeting, a new opportunity to evaluate progresses was offered by the 32° GNGTS meeting that was held in Potenza (20-22 November 2012). In that occasion, most RU presented to the scientific community ongoing work, to collect suggestions and criticism. The last general meeting was held in Bologna (16 January 2013), to evaluate situation of activities, manage critical situations and orientate the work in the last part of the project activity. All RU attended this middle term meeting. Project Committee was constantly informed of ongoing activity (minutes were published on the website) and the coordinator attended some of the S3 meetings.
In the following, development of activity and results obtained relative to the work packages described above will be summarized.

Dissemination

The first activity planned was the development of a web site where activities of the RUs involved in the project are communicated to other units and to the whole scientific community. Documents of common interest (papers, deliverables). The web site was finally established (September 2012) and was populated by basic information concerning the project (rationale, outcomes, etc.).
The front page of the S3 website (https://sites.google.com/site/ingvdpc2012progettos3/home) is shown in Fig.1. The GNGTS mailing list was used to inform the Italian Seismological community that the website was active.

Fig.1 *Front page of the S3 project website*

Beyond this, dissemination of S3 was continuously performed in international and national meetings by the involved RUs, that also published results obtained in peer-review papers. In the Annex, a list of meetings and publications relative to S3 activity is presented.

State-of-the-art

All RUs involved in monitoring and gathering existing data about considered observables (Hydrogeocehmical data including Rn measurements, elastic properties of the crust, geodetic data concerning transient crustal deformations, electromagnetic parameters and thermal satellite observations) were asked to provide an extensive review of the relevant observations. The basic aim of this task is providing Civil Protection of a critical review of monitoring activity carried on in other countries by identifying best practices for data collection and processing. These reviews were provided in the form of specific deliverables that were completed in the range January-March 2013. As a whole, 8 Deliverables were released (D1.1a, D1.1b, D2.1, D4.1a, D4.1b, D5.1a, D5.1b and D6.1). Then, the final version of Deliverables was transmitted to the Program Committee that examined the content and allowed their publication on the Web Site (Fig.2). The deliverable specifically devoted to describe best practice in empirical testing of proposed precursory patterns was not provided. In fact it became clear that complete overviews on this topic have been recently published (e.g., Schorlemmer and Gerstenberger, 2007; Schorlemmer et al., 2007) and, above all, material published in the CSEP web site (http://www.cseptesting.org/) and continuously renewed, makes a document devoted to this topic clearly redundant.

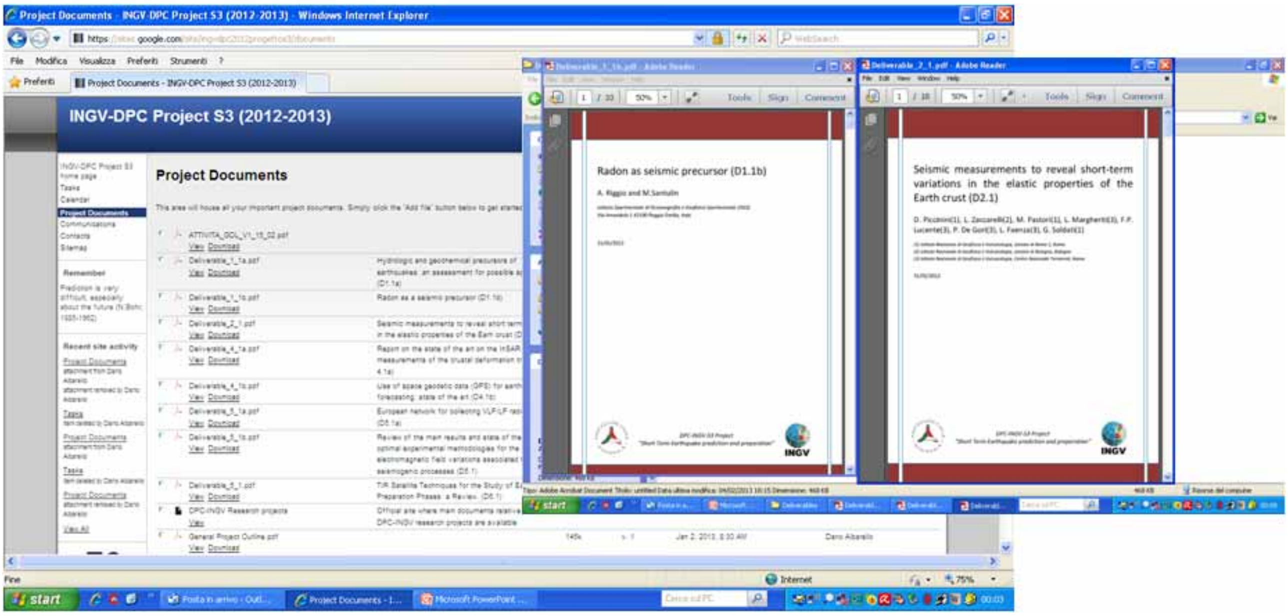

***Fig.2** . Publication of the first 8 deliverables produced in the frame of the S3 project*

Population of an extensive database of parameters of interest

This work package represents the core of the whole project. Actually, no validation procedure can be performed in the lack of a reliable database of information collected on sufficiently wide areas and long times. In particular, key aspects of the expected database were:

1. *Clear and exhaustive characterization of the site and of sampling procedures*
2. *Maximum possible time coverage, irrespective to the occurrence of earthquakes (spot sampling just after the earthquakes has not been considered*
3. *Maximum spatial coverage, well beyond the two areas of potential interest*
4. *Construction of a comprehensive georeferenced database*

A basic difficulty met by some RUs for gathering data, was that data are widely dispersed over the territory and managed by a number of public and private companies that are not interested in sharing data and provide uniform formats. This is particularly true as concerns hydrogeochemical and Rn observations.

As concerns hydrogeochemical observations (Task 1, RU 1), an extensive survey was carried on and public companies (Regional administrations, CNR, ARPA, INGV) charged for extensive and long lasting deep fluid monitoring and owners of the relevant databases were contacted in the two areas of concern. In general, data from some Regional administrations only concern very shallow aquifers and this made relevant data useless for the project. Furthermore, data from Basilicata were not available since no well network is presently operating in the territory. A general agreement was found with remaining local administrations and research institutions to contribute to the general databases. As a whole, more than 5400 sites were identified where monitoring of underground fluids is monitored. These sites are distributed all over the Italian territory and of a huge amount multi-parametric observations (of the order of 10^6) were collected. More problematic was situation as concerns RADON data whose continuous monitoring is performed in few areas only (Piedmont, Friuli, Abruzzo and Volcanic districts). Anyway, a comprehensive collection of these data was performed and included about 4000 monitored sites providing a number of observations of the order of 10^6 data points. An aspect that was also considered is the collection of ancillary data sets (mainly meto-climatic observations) relative to the considered sites that can be used to filter spurious signals. All the above data set was collected and used to populate a geo-referenced database (see Deliverable D1.2 for details).

A different kind of problem arose in collecting data relative to seismic observations (RU2) to be used to monitor elastic properties of the crust (Task 2). In particular, as concerns seismic records, data were collected from the stations of the National Seismic Network that were operating in the two areas of interest (Southern Apennines and Po Plain) during the period 2010-2012. However, due to the huge amount of data to be considered, severe technical problems were encountered by the RU2 involved in this task due to some malfunctioning in the hosting computer (in Rome at INGV). These problems were finally solved but partially hampered the project progresses. Furthermore, quite time consuming resulted the pre-processing phase mainly as concerns seismic noise analysis. Collected data, time and space coverage are discussed in the relevant deliverable (D2.2).

As concerns seismicity data to be collected by RU3 to provide short term forecasts on the basis of a ANN (Artificial Neural Network) phenomenological approach (see Deliverable D3.1 for details), epicentral information provided by ISIDe (Italian Seismic Instrumental and parametric database, managed by INGV) and other public sources were considered for processing.

Database for the Task 4 (Monitoring Earth's motion displacements via satellite and ground based measurements) have been completed in time, despite a number of difficulties. As concerns satellite monitoring of ground motion displacements by the analysis of COSMO-SkyMed and ENVISAT images, data collection was completed. Main difficulties concern the small length of the COSMO-SkyMed archive that doesn't yet have sufficient long time series of images to analyze a mainshock preliminary phase occurring before the last seismic sequences in Emilia-Romagna and Northern Calabria. Anyway, by an agreement with the Italian Space Agency (ASI), a continuous monitoring immediately after the beginning of a sequence was planned to provide important information to the triggering processes and stress diffusion studies (see Deliverable D.4.2).

Situation concerning GPS geodetic data is different as concerns the two study areas considered in the project (details are in the report by RU5). In particular, a good database relative to 347 permanent stations in Central-Northern Italy are organized in a data bank by an international standard protocol. The observation periods of these sites end at July, 2013 and start at various times since January 1, 2001. For the Southern Italy sites, the organization of data bank was also completed by collecting data from 101 sites. A number of these sites (43) is managed by scientific institutions, while the other 58 sites relate to commercial networks (see Deliverable D4.3 for details) .

Database of electromagnetic observations (Task 5) took advantage by the cooperation with pre-existing research projects based on existing monitoring networks. In particular, LF/VLF data were collected by the monitoring network managed since 2009 by researchers involved in the project (RU6). Time series were made available in the Web (http://beta.fisica.uniba.it/infrep/Home.aspx)

Magneto-Telluric ULF data in the Southern Apennines were collected and stored by RU 7. (details are reported in Deliverable 5.2).

Synergy with PRE-Earthquakes European research project (http://www.pre-earthquakes.org) managed by RU8 researchers, made available many observations relative to thermal satellite data (Task 6) for the Italian region in the last years. These observations have the form of images typically obtained day-by-day and relative of observed anomalous patterns.

Data processing to identify possible precursory patterns and empirical testing

After that data collection was completed, the RUs were asked to provide a first processing of data to search for possible "anomalous" patterns representative of impending earthquakes. In particular, the request focused on the two areas of maximum interest for DPC (central Po Plain in Northern Italy and Pollino in Southern Italy) where two damaging seismic events took place just before starting of the project (May 2012 and October 2012 respectively) with magnitudes lower than 6. This made possible a retrospective analysis aiming at detecting possible precursory patterns. Beyond this main task, RUs were also solicited to analyze series eventually available for other sites to detect eventual anonymous patterns to be tested against observed seismicity.

The aim of this analysis was evaluating the capability of single observables to capture eventual pre-seismic signals. This analysis has been planned to perform in two distinct phases. In the first phase, any RU try to identify anomalous patterns as much as possible without considering the occurrence of eventual earthquakes. This identification had to be performed after the removal of eventual spurious effects (e.g. meteoclimatic conditions) by each RU. The anomalous pattern eventually identified for any observable had to be used to attempt "predictions" relative to any area and time interval. These pieces of information had to be passed to RU9 that had to test these predictions against a seismic catalogue developed on purpose (see Deliverable D7.2 for details). This clear separation between the data-mining phase (identification of anomalous patterns) and testing against earthquake occurrence is necessary to avoid possible biases that are characteristic of this kind of analyses (anomalies are defined as a function of earthquake occurrences).

However, due to the fact that data gathering resulted to be very time-consuming, relatively few time was left for an accurate data processing. Partially due to this, to the short duration of the time series available or other problems, not all RUs were able to identify "anomalies" in the monitored parameters and participate in the testing process.

Such an outcome was tentatively provided by RU1 (see Deliverable D1.2 for details) relative hydrogeochemical data obtained at a small number (7) of test sites distributed all over the Italian area, including one of the areas of maximum interest. As concerns Rn, one single test site was considered that is located far away from the two zones of major interest (Friuli). No significant pre-seismic pattern was identified by RU2 as concerns elastic properties of the crust (see Deliverable D2.2 for details) and from InSAR data (see Deliverable D4.2) as concerns the Po Plain and Pollino. A small number of weak uneven possible anomalies were detected by GPS time series relative to 26 sites in the two areas of maximum interest (see Deliverable D4.3). However, appearance of these possible anomalies only occurred at single stations (despite of the fact that other stations exists at the same distance from the source. This lack of correlation significantly weakens any hypothesis relative to any physical link with ongoing seismogenic processes in the study areas. Due to the lack of time, no systematic search for possible precursory pattern was attempted on VLF/LF electromagnetic signals, while Magneto-Telluric data did not show any clear pre-seismic signal in the Pollino area (see Deliverable D5.2). Satellite thermal ground emission provided instead a number of potential anomalies (See Deliverable 6.2). In summary just a small set of anomalies was available for testing (hydrogeochemical, Rn and observations relative to satellite thermal data).

A large number of “forecasts” was provided by RU3 on the basis of the analysis of seismicity patterns by the use of Artificial Intelligence techniques (Artificial Neural Networks). These forecasts mainly concern low magnitude events occurring all over the Italian area (see Deliverable D3.1 for details).

These last forecasts, along with hydrogeochemical and Rn observations were considered for testing by RU9. The results obtained, illustrated in the Deliverable D7.2, indicate that co considered the data presented for both hydrogeochemical and Rn anomalies failed to show a significant association with earthquakes.. As concerns seismicity patterns, instead, the statistical analysis indicates that the performance of this possible precursor is good at low magnitude M<3, but becomes progressively worse at higher magnitudes. This makes the method ineffective just where it would be more important. This is possibly due to intrinsic properties of the ANN technique that is based on a training procedures that, to be effective, needs extended series of seismic events having features similar to the events to be predicted. In the case of analysis carried out in S3, time series considered for learning were not extended in time and furthermore, lacking of the strong seismic. Having the possibility to make training with the neural networks based on long time series dataset consisting of multiparametric variables, the results of ANN approaches is expected to improve.

Satellite thermal due to their features were considered by RU9 insufficient for statistical testing. On the other hand, by adopting a different view, researchers of RU8 claim for encouraging results with false positive rate of 25% (even less in selected area) and a missing rate of 33% (see deliverable D6.2). It is worth to note, however, that these rates include both precursory anomalies and anomalies following the event. Furthermore they clearly indicate a basic limitation of the procedure, that is the limiting presence of cloud coverage that prevents monitoring continuity.

As a whole, the analysis performed in the frame of the project suggests that proposed precursors when considered separately are unable to provide useful results. In fact, no conclusive data supporting a significant empirical association with earthquakes were presented. Two different attitudes resulted from this outcome. The first one states that this result is in line with basic conceptual premises of the S3 project (no "silver-bullet" exists for earthquake forecasting) but this does not exclude the possibility that multiparametric precursory patterns (not considered in the present study due to lack of time) can provide more reliable results. The second position is much less "optimistic", stating that the lack of statistical evidence supporting effectiveness of the proposed precursors discourages further studies in this direction except as concerns earthquake clustering. In fact, despite of the fact that no conclusive indication was provided during the project in support of this phenomenon as a reliable precursor, it can be considered the only physical phenomenon for which a significant association with impending mechanical failure has been demonstrated (see, for a discussion, Geller et al., 2007; Malargia and Geller , 2003). The composition of these two alternative views into a single shared position was not possible in the frame of the S3 project .

Identification of areas most prone to significant earthquake in the next future by considering empirical and deterministic approaches

In the frame of the S3 project a "window" was also tentatively opened on the possibility that middle term forecasting can be provided. E.g., some observations relative to piezometric and patters (see Deliverable D1.2) could suggest the possibility that long term fluctuations of in the strain field could exist and could be revealed by suitable analyses not performed here (e.g. Albarello and Martinelli, 1994). Anyway no such analysis was carried on in S3. However, some attempt in this direction was provided by following two different approaches.

The first one is based on pattern recognition analysis of geomorphological features (zero-approximation termless prediction) and seismicity time-space distribution. The termless zero-approximation, restrains the alerted areas (defined by CN or M8) to the more precise potential location of large events (Peresan et al., 2011, 2012). Intermediate-term middle-range predictions are routinely updated every 2 Months (CN) and 6 Months (M8S). During the project, a specific application of the zero-approximation termless prediction was developed to select sites most prone to earthquakes, with M≥5, in the Po plain. Furthermore several stability analyses were performed to evaluate sensitivity of the Intermediate-term middle-range prediction methodology to seismic catalogues used as input for processing. Some forecasts were also provided but not included in the relevant deliverable (D8.1): these will be provided on request. This methodology was not the object of validation analysis by RU9, who recalls in fact that the method was already extensively evaluated worldwide, demonstrating better performances than random Poissonian predictions. UR9 however indicates the need for a more specific validation analysis and states, that it ".. was not possible in the present project, and must be framed in a specialized ad hoc study" (see Deliverable D7.2).

An alternative, deterministic, approach has been considered by RU5, that aims at constraining possible paths of next major earthquakes in the Italian peninsula by considering the ongoing geodynamic context and the significant seismicity regularity patterns so far identified in the central Mediterranean region (see Deliverable D8.2). In particular, the recognition of a number of systematic interactions of periAdriatic seismic sources (whose significance in the last centuries is evaluated by statistical tests) may delineate a possible tool for recognizing when the probability of major shocks is highest in some Italian zones. The evidence and arguments described in this study suggestthat in the next future the probability of major earthquakes is highest in the Northern Apennines and Northern Dinarides and lowest in Calabria and Southern Apennines, while an intermediate probability is suggested for the Eastern Alps and Central Apennines At present, no indications are proposed for Sicily, for which the connection between tectonics and seismicity is still under study. The results of this study manly aim at providing priority criteria for the choice of the Italian zones where next observations and/or eventual action for seismic risk mitigation might be most fruitfully carried out.

Main Results

After many years, during which earthquake forecasting was considered as “impossible”, a national research project specifically devoted to this controversial topic has been established in Italy and directly supported by National Institutions (DPC) interested in defining operational forecasting tools. Despite of the limitations imposed by the relatively small funding and the short-term horizon (1 year possibly extended to further two years), this project represented a great “cultural” novelty in the seismological research in Italy. A new scientific paradigm supports this project that aims at overcoming methodological difficulties that undermined previous attempts in this direction. The common work allowed involved researchers to share awareness that significant progresses can be attained only by defining well defined experimental protocols and validation procedures, focused on the multiparametric observation of ongoing seismic phenomena: no single precursor is expected to be able to provide useful information. Collecting data and defining “anomalous” patterns independently from the actual occurrence of earthquakes has been accepted as a basic element for effective testing of claimed “forecasts”.

A basic contribution of S3, that could be of major help for Civil Protection purposes is the availability of a comprehensive geo-referenced database concerning observations relative to a number parameters potentially related to the seismogenic process (*observables*). This database includes both most traditional observations (deep seated fluids, Rn emissions, electromagnetic and satellite thermal data, seismicity) and more recent proposals (seismic noise analysis, transients detection by GPS data, pre-seismic deformations by InSAR observations). All the considered data are characterized by a good time-space coverage (provided by the full exploitation of databases existing in the Italian area) and by an optimal cost-benefit ratio that makes them useful for monitoring large areas for long time. Best-practices relative to data collection and processing were also defined and provided to DPC in the form of specific deliverables.
A key aspect of this collection is that monitoring has been performed (as much as possible) independently from earthquake occurrences: pre- peri- and post-seismic observations were collected. Furthermore, data are well distributed all over the Italian territory and which will allow their exploitation for a number of possible purposes (environmental studies, etc.).
Basic features of this data base are:

1. *Well defined experimental procedures, that is necessary to evaluate actual reliability of collected information*
2. *Maximum time-space coverage*
3. *Accessibility warranted by the implementation of the database into a Geographical Information System*

The database includes a huge amount of observations (of the order of 10^7 as whole) and its compilation required a big effort by involved RUs to gather and merge data provided by a number

of different institutions. This collection probably represents the most extensive data base relative to earthquake related phenomena actually available for research applications in western countries. These efforts also revealed the lack systematic observations in many parts of the Italian area and the absence of standardized protocols. Many of these protocols representative of the state-of-the-art have been defined in the frame of the project and could be of help in planning future observation campaigns.
As concerns Civil Protection purposes, this database could be of primary importance for at least three reasons:

1. *It makes accessible to the scientific community a huge amount of data that are sparsely stored in a number of different databases,*
2. *allows multivariate and multiparametric analyses to identify transient phenomena representative of ongoing seismogenic processes,*
3. *allows the definitions of suitable validation protocols for proposed precursory patterns.*

A second major outcome that results from data processing and analyses carried out during the project is the shared acknowledgment that, to be optimistic, single observables and relevant "anomalies" (defined in some ways) can only represent a very weak short term precursor of future events. In fact, none significant and empirically robust "anomalous" pattern was revealed among the considered parameters before the important seismic sequences that struck the Po plain and Northern Calabria (Pollino). This is true both concerning more "traditional" parameters and the ones here considered for the first time. At least partially, this lack of evidence could be due to incompleteness of collected information (e.g., no Rn measurements were available for sites in the two zones), insufficient data analysis (no systematic data-mining activity was attempted to exploit with advanced data processing the huge amount of data collected during the project), or to the fact that considered earthquakes have been considered not "large" enough to generate anomalous patterns in some of the proposed observables. On the other hand, since the one here presented constitutes the major effort never produced in Italy to identify precursory patterns in a large set of parameters and by taking as well into account that the "unpredicted" events can produce significant damages (and thus they cannot be considered as "minor"), the lack of significant results casts a shadow over the possibility that single parameter can provide effective forecasts.
From this outcome, some of the participants in the project infer that the lack of empirical evidence supporting any physical link of the selected observables with earthquakes also prevents the possibility that these, when jointly analyzed, may be more effective. Other participants, instead, claim that this result is in line with the idea underlying the whole S3 project that no direct one-to-one link exists between a single observable and the earthquake occurrence. Furthermore, they suggest that all "single parameter" approaches do not allow to fully appreciate the informative contribute that the same parameter could offer, instead, in a multi-parametric real-time monitoring scheme. In fact, when this kind of approach is considered for testing, avoiding false positives is much more important than catching all events. For this reason the identification of

“anomalous transients” in the time-series of a single observable is performed by applying the highest level of significance (e.g. 3-sigma and more) which, in an integrated multi-parametric scheme could be instead avoided. From this point of view, the absence of anomalous transients in the analysis of single time-series, can be positively considered in terms of robustness against false alarm proliferation without exclude possible improvement achievable by using the same parameter within an integrated multi-parametric scheme suitable for incorporating (without increasing false positives rate) also anomalous transients at lower level of significance. The hypothesis to explore is to consider multiparameter indices to identify "patterns of precursors" of different origins. Artificial Neural Networks are models that can be of help to verify this hypothesis. Actually, limitations imposed by a one-year research activity mainly devoted to data gathering, did not allow to explore actual feasibility of combined parameters to better constrain probability of future seismic occurrences.

Another aspect only marginally explored during the S3 project, was the possibility of middle-term forecasting (months to years) on the basis of the analysis of medium long term series of measurements (tens of years) relative to specific observables (e.g, piezometric data relative to deep seated fluids or geodetic observations) or by considering phenomenological and deterministic approaches to delineate future scenarios. Some results were obtained in the S3 project by considering a pattern recognition approach and seismotectonic modeling accounting for systematic interactions of periAdriatic seismic sources and spatio-temporal regularity patterns of strong earthquakes. Both these approaches were supported by empirical evidence but no attempt was actually performed in the frame of the project to validate them systematically in a prospective way.

Riassunto e Conclusioni

Dopo molti anni, durante i quali previsione dei terremoti è stata considerata "impossibile ", un progetto di ricerca nazionale specificamente dedicato a questo controverso argomento è stato promosso in Italia e supportato direttamente da istituzioni nazionali (DPC) interessate a definire strumenti di previsione operativi. Nonostante le limitazioni imposte dai vincoli finanziari a il ridotto orizzonte temporale (1 anno eventualmente esteso a ulteriori due anni), questo progetto ha rappresentato una grande novità "culturale" nella ricerca sismologica in Italia.

Un nuovo paradigma scientifico è stato messo alla base di progetto con l'ambizione di superare le difficoltà metodologiche che avevano ostacolato i precedenti tentativi in questa direzione . Il lavoro comune ha consentito costruire nei ricercatori coinvolti in questo progetto la consapevolezza condivisa che significativi progressi possono essere raggiunti solo attraverso la definizione di protocolli sperimentali ben definiti corredati da procedure di monitoraggio incentrate sull'osservazione multiparametrica dei fenomeni sismici: nessun singolo precursore sembra in grado da solo di fornire informazioni utili sulla futura occorrenza di terremoti. Raccogliere dati e definire modelli di "anomalia" indipendentemente dall'effettivo verificarsi di eventi sismici è stata accettata come un elemento di base per un controllo efficace di pretesi fenomeni precursori dei terremoti.

Un contributo fondamentale di S3, che potrà essere di grande aiuto a fini di Protezione Civile, è la disponibilità di una banca dati georeferenziata relativa osservazioni relative ad un numero parametri potenzialmente rappresentatovi del processo sismogenetico (osservabili). Questa banca dati include sia le osservazioni relative a parametri oggetto di studio già da molti anni (fluidi profondi, emissioni Rn , dati elettromagnetici e dati termici satellitari, sismicità) sia parametri finora meno studiati e (analisi sismica rumore, rilevazione fenomeni transitori con dati GPS, deformazioni pre- sismiche da osservazioni InSAR) . Tutti i dati presi in esame sono caratterizzati da una buona copertura tempo-spazio (legata al pieno sfruttamento delle banche dati esistenti nell'area italiana), e da un rapporto costo -benefici ottimale che li rende utili per il monitoraggio di grandi aree per tempi prolungati.

Un aspetto chiave di questa collezione è che il monitoraggio dei diversi parametri è stato eseguito (per quanto possibile) in modo indipendente dall'occorrenza di eventi sismici: sono state raccolte osservazioni riguardanti le fasi pre - peri- e o post- sismiche. Inoltre, i dati sono ben distribuiti su tutto il territorio italiano e questo permetterà il loro impiego sfruttamento anche per scopi differenti (controllo ambientale, ecc.)

Caratteristiche di base di questa banca dati sono:

1. *una chiara definizione delle condizioni sperimentali e delle procedure di campionamento adottate, caratteristiche essenziali per valutare l'affidabilità delle informazioni raccolte*
2. *Massima copertura spazio-tempo*
3. *Accessibilità garantita dalla realizzazione di database in un sistema di informazione geografica*

La banca dati comprende una grande quantità di osservazioni (dell'ordine di 10^6 misure) e la sua compilazione ha richiesto un grande sforzo da parte delle UR impegnate in questo tipo di ricerca per raccogliere e uniformare i dati forniti da diverse istituzioni. Questa raccolta rappresenta probabilmente la più vasta base di dati di questo genere fra quelle effettivamente disponibili per applicazioni di ricerca nei paesi occidentali. Questi sforzi hanno rivelato anche la mancanza di osservazioni sistematiche in molte parti del territorio italiano e l'assenza di protocolli standardizzati. Protocolli rappresentativi dello stato dell'arte sono stati definiti nel quadro del progetto e potrebbero essere di aiuto nella pianificazione di campagne di osservazione future.

Per quanto riguarda le finalità della protezione civile , la banca dati potrebbe essere di primaria importanza per almeno tre motivi :

1. Rendere accessibile alla comunità scientifica una quantità enorme di dati che vengono scarsamente memorizzata in un certo numero di diversi database
2. Consentire analisi multivariate e multiparametrica per identificare fenomeni transitori rappresentante dei processi sismogenici in corso
3. Permettere la definizione di protocolli di validazione adatte per i modelli di precursori proposte

Bisogna comunque notare che, all’atto della stesura di questa relazione, le modalità di utilizzo delle osservazioni presenti in questa banca dati sia dagli appartenenti al progetto che da altri utenti esterni devono essere ancora stabilite dall’Ente proponente in ottemperanza anche alle attuali leggi che regolano la proprietà e la divulgazione di dati appartenenti ad enti pubblici e privati.

Un altro risultato importante ottenuto nell’ambito dal progetto è il riconoscimento condiviso che, ad essere ottimisti, singoli osservabili e relative "anomalie " (definite in qualche modo) possono rappresentare soltanto una indicazione molto debole della possibile occorrenza di futuri terremoti. In effetti, le analisi effettuate prima delle importanti sequenze sismiche che hanno colpito la pianura padana e nord Calabria (Pollino) non hanno permesso di identificare, nel breve termine, nessuna “anomalia” significativa tra i parametri considerati.

Almeno parzialmente, questa mancanza di conferme potrebbe essere dovuta alla incompletezza delle informazioni raccolte o al fatto che i terremoti considerati non possono essere considerati "di grandi dimensioni" (la magnitudo massima non ha superato 6). Comunque, dal momento che quello qui presentato costituisce il maggiore sforzo mai prodotto in Italia per identificare fenomeni precursori considerando un numero significativo di parametri ed anche tenendo conto che gli eventi " imprevisti " sono comunque in grado di produrre danni significativi (e quindi non possono essere considerati come " minori"), la mancanza di risultati significativi getta un'ombra sulla possibilità che ciascun singolo parametro sia effettivamente in grado di fornire previsioni efficaci.

Da questo risltato condiviso, alcuni dei partecipanti al progetto trae la conclusione che l’assenza di evidenze empiriche riguardo a possibili legami di tipo fisico fra gli osservabili considerati e l’occorrenza dei terremoto preclude la possibilità che, anche qualora questi fossero analizzati congiuntamente invece che uno alla volta, possano fornire indicazioni utili alle previsione di eventi sismici futuri. Altri sottolineano invece che questo risultato è in linea con l'idea alla base dell'intero progetto S3 che suggerisce l'assenza di una corrispondenza uno-a-uno fra "anomalie" relative a singoli osservabili e i terremoti. L'ipotesi da esplorare consisterebbe quindi nel considerare indici multiparametrici per individuare "pattern di precursori" con origini diverse. Le Reti Neurali Artficiali sono modelli che possono aiutare a verificare questa ipotesi.Le limitazioni imposte da una attività di ricerca di dimensione annuale, peraltro dedicata in larga parte alla raccolta dei dati, non hanno effettivamente permesso di esplorare questa possibilità Comunque, qualora fosse ritenuto utile, i dati raccolti nel quadro del progetto potrebbero consentire una tale tipo analisi nel prossimo futuro.

Un altro aspetto solo marginalmente esplorato durante il progetto S3, è quello legato alle possibilità di previsione a medio termine (mesi o anni) dei terremoti sulla base dell'analisi delle serie temporali estese (decine di anni) e relative a specifici osservabili (ad esempio dati piezometrici relativi ai fluidi profondi o osservazioni geodetiche) oppure considerando gli approcci fenomenologici applicati (CN ed M8S) o quelli deterministici delineati nel corso del progetto. Alcuni risultati sono stati ottenuti in questa direzione nell'ambito del progetto sia considerando approcci basati sul riconoscimento di diversi patterns precursori riscontrabili nella sismicità sia utilizzando la modellazione sismotettonica per l'interpretazione di sistematiche interazioni fra l'attività di zone sismo geniche dell'area peri-Adriatica e l'emergenza di andamenti regolari nell'andamento spazio-temporale della sismicità intensa. Entrambe gli approcci sono supportati da evidenze empiriche e sono stati applicati nell'ambito del progetto anche se non è stato fatto nessuno specifico tentativo di analisi prospettiva dei risultati prodotti per valutarne l'effettivo potenziale informativo.

References

Albarello D., 2005. Mud volcanoes as natural strainmeters: a working hypothesis. In Martinelli G. and Panahi B. (eds), "Mud Volcanoes, geodynamics and seismicity". NATO Science Series IV, v.51, Kluwer, 239-249

Albarello D. e Martinelli G., 1994 - Piezometric levels as a possible geodynamic indicator: analysis of the data from a regional deep waters monitoring network in Northern Italy. Geophys. Res. Lett., **21**, 1955-1958

Albarello D., Meletti C., 2012. Earthquake forecasting and hazard assessment: a preface. Boll.Geofis.Teor.Appl., Vol. 53, n. 1, pp. 1-5, DOI 10.4430/bgta0058

Amoruso A., Crescentini L., 2012. Pre-seismic phenomena from continuous near-field strain measurements: a brief review and the case of the 2009 L'Aquila, Italy, earthquake. Boll.Geofis.Teor.Appl., Vol. 53, n. 1, pp. 169-190, DOI 10.4430/bgta0039

Buscema P.M., and Benzi R., "Quakes prediction using highly non linear systems and a minimal dataset, in Advanced Networks, Algorithms and Modeling for Earthquake Prediction". Buscema P.M. and Ruggieri M. Eds, River Publishers, Aalborg, Denmark, (2011).

Castellaro S. and Mulargia F., 2001. A simple but effective cellular automation for earthquakes. Geophys.J.Int., 144, 609-624

Cicerone R., Ebel, J.E., J. Britton, 2009. A systematic compilation of earthquake precursors. Tectonophysics, 476, 3–4, 25 371–39.

Johnson B. F., 2009 "Earthquake Prediction – Gone and back again" EARTH

Jordan TH., Chen Y-T., Gasparini P., Madariaga R., Main I., MArzocchi W., Papdopoulos G., Sobolev G., Koshun Yamaoka K. Zschau J., 2011. Operational Earthquake Forecasting: State of Knowledge and Guidelines for Utilization, ANNALS OF GEOPHYSICS, 54, 4, 2011; doi: 10.4401/ag-5350

Kagan Y.Y., 1992. Seismicity: turbulence of solids. Nonlinear Sci. Today, 2 (1), 1-13

Kagan, Y.Y., 1994. Observational evidence for earthquakes as a non linear dynamic process. Physica D, 77, 160-192

Kagan Y.Y., "Are earthquakes predictable?" Special Section-Assessment of schemes for earthquake prediction, Geophysics. J Int. (1997) 131, 505-525.

Kagan Y.Y., and Jackson DD, "Probabilistic forecasting of earthquakes", Geophysics. J Int. (2000) 143, 438-453.

Geller R.J., Jackson, D.D., Kagan, Y.Y., Mulargia, F., 1997, Cannot earthquakes be predicted?, *Science*, 278, 488-490, 1997.

Main i., 1995. Earthquake as critical phenomena: implications for probabilistic seismic hazard analysis. Bull.Seism.Soc.Am., 85, 5, 1299-1308

Main I., 1996. Statistical physics, seismogenesis and seismic hazard. Rev.Geophys., 34, 4, 433-462

Mantovani E., Viti M., Babbucci D., Cenni N., Tamburelli C. and Vannucchi A.; 2012: Middle term prediction of earthquakes in Italy: some remarks on empirical and deterministic approaches. Boll. Geof. Teor. Appl., 53, 89-111, doi: 10.4430/bgta0037

Mantovani E., Viti M., Babbucci D., Albarello D., Cenni N., Vannucchi A.; 2010: Long-term earthquake triggering in the Southern and Northern Apennines. J.Seismol., 14, 53-65

Mucciarelli M., Albarello D., 2012. Comment on "Seismic Hazard Assessment (2003–2009) for the Italian Building Code" by Massimiliano Stucchi, Carlo Meletti, Valentina Montaldo, Helen Crowley, Gian Michele Calvi, and Enzo Boschi. Bull.Seism.Soc.Am. Vol. 102, No. 6, 2789–2792, , doi: 10.1785/0120120040,

Mulargia F., Geller R.J., eds., 2003. Earthquake Science and Seismic Risk Reduction. NATO Science Series, Kluwer Acad Publ., 338 pp.

Pastore M., 1987, Ruolo dei mezzi di comunicazione durante la crisi sismica. In Boschi E. and Dragoni M., (eds.), "Aree sismogenetiche e rischio sismico in Italia", Vol. 1, G.Galilei Ed., Lusanne, 9-16

Peresan A., Zuccolo E., Vaccari F., Gorshkov A. and G.F. Panza, 2011. Neo-deterministic seismic hazard and pattern recognition techniques: time dependent scenarios for North-Eastern Italy. Pure and Applied Geophysics. Vol. 168 (3-4), 583-607. doi 10.1007/s00024-010-0166-1.

Peresan A., Kossobokov V.G. and G.F. Panza, 2012. Operational earthquake forecast/prediction. Rendiconti Lincei. Vol. 23, 131-138. doi 10.1007/s12210-012-0171-7.

Pollitz F.F., Burgmann R. and Banerjee P.; 2006: Post-seismic relaxation following the great 2004 Sumatra-Andaman earthquake on a compressible self-gravitating. Geophys. J. Int., 167, 397-420, doi: 10.1111/j.1365-246X.2006.03018.

Rydelek P.A. and Sacks I.S.; 1990: Asthenospheric viscosity and stress diffusion: a mechanism to explain correlated earthquakes and surface deformation in NE Japan. Geophys. J. Int., 100, 39-58.

Rydelek P.A., and I.S. Sacks, 1999. Large earthquake occurrence affected by small stress changes. Bull.Seism.Soc.Am., 89, 822-828

Ryder I., Parsons B.E., Wright T.J. and Funning G.J.; 2007: Post-seismic motion following the 1997 Manyi (Tibet) earthquake: InSAR observations and modelling. Geophys. J. Int., 169, 1009-1027, doi: 10.1111/j.1365- 246X.2006.03312.x

Sacks I.S., Rydelek P.A., 1995. Earthquake "quanta" as an explanation of observed magnitudes and stress drops. Bull.Seism.Soc.Am., 85, 3, 808-813

Schorlemmer, D., Gerstenberger, M.C., 2007. RELM Testing Center, Seism. Res. Lett., Vol. 78, No. 1, 30-36.

Schorlemmer D., Gerstenberger, M. C., Wiemer, S., Jackson, D.D., Rhoades, D.A., 2007. Earthquake Likelihood Model Testing, *Seism. Res. Lett.,* Vol. 78, No. 1, 17-29.

Stein S. Geller R.J., Liu M., 2012. Why earthquake hazard maps ofte fail and what to do about it. Tectonophys., 562-563, 1-25

Turcotte D.L., 1992. Fractals and Chaos in Geology and Geophysics, Cambridge Univ. Press, 398 pp

Viti M., D'Onza F., Mantovani E., Albarello D. and Cenni N.; 2003: Post-seismic relaxation and earthquake triggering in the southern Adriatic region. Geophys. J. Int., 153, 645-657.

Annex

Dissemination

RU1

Martinelli G., Heinicke J., Cenni N., Dadomo A.- Long term monitoring of a deep borehole in Northern Apennines: evidences of geodynamically induced fluid emission variations. Poster presented in Patras during “ICGG12 - International Conference on Gas Geochemistry 2013”, September 1-7, 2013;

Martinelli G. Cenni N., Dadomo A., Heinicke J. -Multi-year temperature monitoring of thermal waters in the Miano-Corniglio deep well (Northern Apennines). Oral presentation during “WORKSHOP - W 4 Hydrogeochemical precursors of seismic activity”, within the IX edition of the Forum Italiano di Scienze della Terra “Le Geoscienze per la Società”, Pisa, September 12, 2013

Riggio A., M. Santulin; Potential seismic precursors: analysis of the recent earthquakes previous periods and problems related to interpretation. 31° Convegno Nazionale GNGTS, Potenza 2012

Italiano F., Liotta M., Martinelli G., Petrini R., Riggio A., Rizzo A.L., Slejko F., Stenni B. (2012) Geochemical features and effects on deep-seated fluids during the May-June 2012 southern Po Valley seismic sequence. Annals of Geophysics, 55, 815-821

Dadomo A., M. Lemmi,G. Martinelli, M. Menichetti L. Telesca, 2013, Springwater continuous monitoring in the L'Aquila area in concomitance with the April 2009 seismic swarm in central Italy: Constraining factors to possible deep-seated fluid emissions. Chemical Geology, Volume 339, 15 February 2013, Pages 169–176

Riggio A., 2013. Variations in the radon concentration in soil and water, and tectonic stress. Geoitalia 2013 - Workshop -W4 Hydrogeochemical precursors of seismic activity

RU2

Piccinini D., Zaccarelli L., Pastori M., Margheriti L., Lucente F.P., De Gori P., Faenza L., Soldati G. SEISMIC MEASUREMENTS TO REVEAL SHORT-TERM VARIATIONS IN THE ELASTIC PROPERTIES OF THE EARTH CRUST. EGU General Assembly 2013 Geophysical Research Abstracts Vol. 15, EGU2013-10741, European Geosciences Union 2013.

Piccinini D., Zaccarelli L., Pastori M., Margheriti L., Lucente F.P., De Gori P., Faenza L., Soldati G. SPATIO-TEMPORAL MONITORING OF SEISMIC WAVE VELOCITIES IN THE UPPER CRUST Atti del XXXI convegno GNGTS - Gruppo Nazionale di Geofisica della Terra Solida, TEMA 2: Caratterizzazione sismica del territorio, Sessione 2.3: Pericolosità, scenari di scuotimento, previsione e rischio sismico), pag. 340-345. Potenza 20-22 Novembre 2012.

Soldati G., L. Zaccarelli, L. Faenza, C. Ladina, S. Marzorati, A. Michelini: *"Resolution limit of velocity variations measured through passive image interferometry"* – AGU fall meeting 2012, San Francisco AGU.

Faenza L., L. Zaccarelli, G. Soldati: "Resolution limit of velocity variations measured through passive image interferometry" – Ambient Noise Imaging and Monitoring Workshop 2013, Cargèse (Francia).

Piccinini D., Pastori M., Margheriti L. ANISOMAT+: AN AUTOMATIC TOOL TO RETRIEVE SEISMIC ANISOTROPY FROM LOCAL EARTHQUAKES. Computers & Geosciences, Volume 56, July 2013, Pages 62-68, ISSN 0098-3004, DOI:10.1016/j.cageo.2013.01.012.

http://www.sciencedirect.com/science/article/pii/S0098300413000265

RU 7

Balasco M., Lapenna V., Romano G., Siniscalchi A., Telesca L., Magnetotelluric monitoring of the Earth's crust in two seismogenic areas of Southern Italy (Val d'Agri and Pollino): preliminary results. 31° Convegno Nazionale del Gruppo Nazionale di Geofisica della Terra Solida, Potenza, Italy , 20-22 Novembre, 2012

Balasco, M., Lapenna, V., Romano, G., Siniscalchi, A., Stabile, T. A., Telesca, L., Electric and magnetic field changes observed during a seismic swarm in Pollino area (Southern Italy), Bull. Seismol. Soc. Am., in revision, 2013

Romano, G., Balasco, M., Lapenna, V., Siniscalchi, A., Telesca, L., Tripaldi, S., On the sensitivity of the magnetotelluric monitoring and source-dependent transfer function variability, Geophys. J. Int., in revision, 2013

RU8

Tramutoli V., Aliano C, Corrado R., Filizzola C., Genzano N., Lisi M., Martinelli G., Pergola N., 2013. On the possible origin of thermal infrared radiation (TIR) anomalies in earthquake-prone areas observed using robust satellite techniques (RST). Chemical Geology, Volume 339, 15 February 2013, Pages 157–168

Since July 2012, the start of S3 project has been just announced in several International Conference in Italy, Germany, Russia, Morocco, Japan and United States. Among the others:

- IEEE Geoscience and Remote Sensing symposium (IGARSS) July 25th, 2012 Munich, Germany;
- 33rd General Assembly of European Seismological Commission, August 19-24, 2012, Moscow
- EMSEV International Workshop on Electromagnetic Phenomena Associated with Earthquakes and Volcanoes, 1-4 October 2012 in Shizuoka, Japan;
- 11th Scientific Workshop: Earthquakes Early Warning from Space, 21-24 October 2012, in Erice, Sicily, Italy;
- 31st National Congress of the National Group of Solid Earth Geophysics (GNGTS), Potenza, 20-22 November 2012;
- The "SAGA-4-EPR Inter-Seminars: From space to seafloor for Earthquake Pattern recognition" August 1st 2012, Roma;

- The AARSE 2012 International Conference "Earth Observation & Geo-information Sciences for Environment and Development in Africa: Global Vision and Local Action Synergy" El Jadida, Morocco, 29 October – 2 November 2012.
- The American Geophysical Union, (AGU) Fall meeting, San Francisco (CA), USA 2-7 December 2012
- IUGG-GEORISK (1st conference) "Extreme Natural Hazards and their Impacts", Orange (CA), USA, 8-11 December 2012.
- The European Geophysical Union Assembly – Vienna, 7-12 April 2013
- European Space Expo, Rome, 29 August – 3 September 2013.

Moreover, during the considered project period, the UR-8 organized, participated to, short meetings and workshops (with the participation of representatives of the UR-1 and other national and international guests) like:

- a Seminar day in Potenza on 20 June 2013 (with Giovanni Martinelli, Katsumi Hattori by Chiba University – JAPAN, Gerardo Romano of CNR-IMAA)
- Geoitalia 2013 – Pisa 12 July 2013

The possibility to capitalize data-products and integration platforms generated by the European FP7 PRE-EARTHQUAKES project (coordinated by V. Tramutoli) already approved by the Steering Committee of PRE-EARTHQUAKES project has been further investigated also in view of a possible continuation of the project.

RU10

Gorshkov A., Peresan A., Soloviev A., Panza G.F. (2013). Morphostructural zonation and pattern recognition of earthquake prone areas in the po plain. Atti del 32° Convegno del Gruppo Nazionale di Geofisica della Terra Solida (Trieste, 19 – 21 Novembre 2013)

Peresan A., G.F. Panza (2012) - Improving earthquake hazard assessment in Italy: an alternative to "Texas sharpshooting". EOS Transaction, American Geophysical Union. Vol. 93, No. 51, 18 December 2012

Peresan A., Magrin A., Vaccari F., Panza G.F. (2012). Prospective testing of time-dependent neo-deterministic seismic hazard scenarios. Atti del 31° Convegno del Gruppo Nazionale di Geofisica della Terra Solida (Potenza, 20 – 22 Novembre 2012). Tema 2: Caratterizzazione sismica del territorio. 429 – 433. Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste. ISBN 978-88-902101-2-9.

Radan, M.Y., Hamzehloo H., Peresan A., Zare M., Zafarani H. (2013). Assessing performances of pattern informatics method: a retrospective analysis for Iran and Italy. Nat Hazards. DOI 10.1007/s11069-013-0660-8

Romashkova, L., Peresan, A. (2013). Analysis of Italian earthquake catalogs in the context of intermediate-term prediction problem, Acta Geophysica, vol. 61 (3), 583-610. DOI: 10.2478/s11600-012-0085-x

Peresan A., Magrin A., Vaccari F., Kronrod T., Panza. G.F. (2012). "Neo-deterministic seismic hazard assessment and earthquakes recurrence" Abstract presented at the ESC2012 – XXXII General Assembly of European Seismological Commission, Moscow, Russia (August 19-25, 2012).

Radan M.Y, Peresan A., Hamzehloo H., Zare M. (2012). "Pattern Informatics analysis in Iran and Italy" Abstract presented at the ESC2012 – XXXII General Assembly of European Seismological Commission, Moscow, Russia (August 19-25, 2012).

Peresan A. (2012). "Metodo neo-deterministico per la valutazione della pericolosità sismica". Oral presentation at the 86° Congresso della Società Geologica Italiana, SGI - Workshop on "La sequenza sismica in pianura Padana e la pericolosità sismica del territorio nazionale" (Cosenza, 18-20 Settembre 2012)

Peresan A. (2012). "Scenari neo-deterministici di pericolosità sismica dipendenti dal tempo". Audizione parlamentare presso la VIII Commissione (Ambiente, territorio e lavori pubblici) della Camera dei Deputati, nell'ambito dell'Indagine conoscitiva sullo stato della sicurezza sismica in Italia (Roma, 26 Settembre 2012).

Peresan A. (2013). "Real-time testing of premonitory seismicity patterns". EGU General Assembly 2013 (Vienna, 7-12 Aprile 2013)

Peresan A, Gorshkov A., Soloviev A., Panza G.F. (2013). "Zonazione morfostrutturale ed identificazione dei nodi sismogenetici nella pianura padana". Congresso AIQUA 2013 (Napoli, 10-21 Giugno 2013)

Gorshkov A., Peresan A., Soloviev A. and Panza G.F., 2013: Morphostructural zonation and pattern recognition of earthquake prone areas in the Po plain. Atti del 32° Convegno del Gruppo Nazionale di Geofisica della Terra Solida (Trieste, 19 – 21 Novembre 2013).