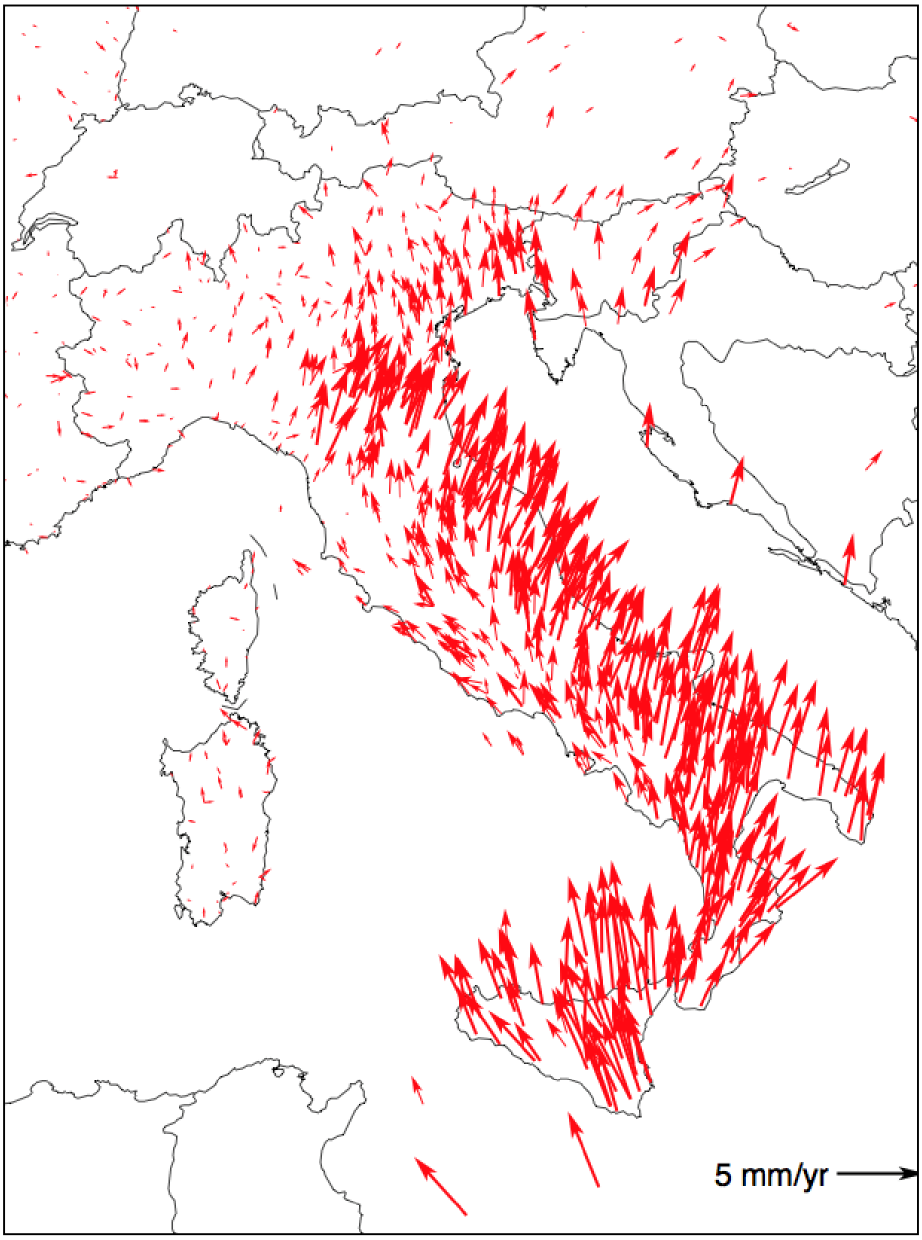
ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

RING strategic plan 2021-2025

Prepared by the geodetic scientific community



Introduction

This strategic plan outlines the future technological developments of the RING in the framework of a scientific view discussed by the INGV geodetic community. The RING is an open research infrastructure whose data and results are useful for many scientific applications and INGV projects. In the past years, we have created the conditions to develop innovative research fields partly moving away from the original scope that drove the birth of the network. These conditions offered a unique occasion of multi-research/multidisciplinary approach to Earth science, including the study of non-tectonic signals, anthropogenic/industrial processes, applications of high rate geodesy, hydrological and space weather applications, Tsunami early warnings and more. Nevertheless, the network has been designed primarily to resolve the kinematics of Italy, in terms of velocity and strain-rate fields, in the framework of the continental tectonics of the Mediterranean region, given the existence of other geodetic networks, managed by private and public entities. In 2017, we published a common work that fixed the main achievements in terms of velocity field (Devoti et al., 2017), which can be considered as the result of a great scientific experiment, involving scientists, technicians, geodetic analysts, information technologists, modellers.

The long term sustainability of RING is a primary goal for the development of good science. The sustainability is intended in terms of personnel and financial resources for maintenance and technological update. The former is at least assured by the recent stabilization of all the temporary positions although some additional IT and technical positions are needed to achieve the goals and guarantee the activities foreseen in the strategic plan. A proposal, in this sense, will be made at the end of the plan. Ordinary financial resources for the maintenance and developments of RING are decided and made available each year. At the moment, there is not a long term planning of the budget assigned to the RING infrastructure, as well as for all the other INGV infrastructures. This limits the capability to sustain the network in the long term and it could create some difficulties for good scientific planning. Following this line, we decided to present this strategic plan for the next five years after a discussion within the INGV geodetic community to assist in assigning the proper financial resources with a medium-term perspective. This plan is deliberately short to be readable, useful and simple. It is composed of a state of the art of the network, the 2019 final balance adopted by the coordination board, and the scientific and technological planning in a 5 years' time window.

RING state of the art

Here, we briefly summarize the present day RING infrastructure. As infrastructure, we intend the network of GNSS stations, the acquisition centers and the processing centers. The network is composed of 215 receivers all over Italy, with a greater density in southern Italy, with a few (6) receivers installed abroad (1 in Malta and 5 in Greece). Most of the receivers are GPS receivers but we are gradually upgrading the greater part to full GNSS. Most of the RING stations have been installed using as monument a custom version of the short brace tripod designed by Unavco (D'ambrosio et al., 2008). Data is transmitted, for most of the stations, in real-time via different systems, including: satellite link, wi-fi connections, internet and UMTS connections. Daily observations, sampled at 30 seconds, and metadata, in the form of IGS log files, are archived both in Grottaminarda centre, Osservatorio Etneo, and mirrored at the INFN ReCas data centre of University of Bari. Data are openly distributed to the whole scientific community. We refer to Avallone et al., 2010 and to the RING web site (http://ring.gm.ingv.it) for a detailed description of the network. Since 2007, we started to integrate 30-s rinex data from other networks belonging to private agencies, Regional administrations, Universities, and other research institutions for a broad region including the Africa-Eurasia plate boundary, extending across the African and European plates. Presently the augmented RING archive, known as GNSSGIVING, contains data from ~4000 GNSS stations operating in the Euro-Mediterranean and African regions. The observations and metadata, which are routinely obtained from rinex headers or station log-files, are analyzed by at least three different analysis centers, using three different scientific software (BERNESE, GAMIT/GLOBK, GIPSY-OASIS), providing displacement time-series and velocities. At this regard, specific HW and SW infrastructures have been developed in the last ten years to achieve an automatic analysis on a daily or weekly basis. The GNSSGIVING archive also contains high-rate GNSS data, with sampling frequency from 1 to 20 Hz, acquired during the earthquake sequences since 2009 from RING or other networks belonging to private agencies, Regional administrations, Universities, and other research institutions. These observations and the relative metadata have been analyzed by using GIPSY-OASIS scientific software, providing dynamic coseismic displacements and early coseismic static displacements for earthquake source studies.

The governance of this valuable scientific asset is currently supported by a board of coordination composed by the ONT Director, by the responsible of the technical and scientific staff, and by other four researchers or technologists. The duty of the board is to prepare the provisional and final balance, discuss the scientific and technical development of the network and to follow the implementation of the relevant developments. Presently, the board is composed only by ONT personnel. The opening to other INGV components, involved in the network management, is highly desirable. The maintenance of the network is ensured by about 20 personnel units, distributed over 4 INGV sections, covering the technical, IT, and administrative aspects.
The RING is fully involved in long term initiatives. The two main ones are the European Plate Observing System (EPOS) and the agreement with the Civil Protection Department (DPC). RING, within EPOS initiative, is part of the Thematic Core Service GNSS data, providing the precise point positioning solution for all the European networks included in EPOS and contributing to the final combination. In the latter long term initiative, within DPC collaboration, RING has the duty to provide a rapid response in case of a large earthquake in Italy.

Financial resources and final balance 2019

The financial resources to sustain the network are allocated both to the ONT and to the Central Administration (AC). The AC covers the personnel salary, rental sites, and part of the transmission costs. Other long term resources derive from the ordinary budget of the Ministry of Scientific Research, DPC Agreement, EPOS initiative, all managed by ONT. Specific project contributions complete the financial balance available for the maintenance and development of the RING. We report the final balance 2019 divided by costs for sustainability (table 1) and development (table 2) of the network. The balance is referred only to the budget allocated to ONT. All the costs covered by AC can be retrieved from the official INGV balance. It is also reported the actual expenditures for 2019 (table 3) made by ONT. It should be noted that the ordinary fundings (FOE) from the Ministry of Research are used only for the sustainability of the network and the development is guaranteed by the two quoted long term initiatives and other external fundings.

Bilancio Consuntivo RING 2019				
	Mantenimento			**TOTALI**
	EPOS	**DPC**	**FOE**	
Pubblicazioni				
Carta, cancelleria e stampati				
Materiale informatico		4.747,00€		4.747,00€
Strumenti tecnico-specialistici non sanitari				
Indennità di missione e di trasferta		15.000,00€		15.000,00€
Licenze d'uso per software				
Allestimento e manutenzione di osservatori e siti delle reti	20.000,00€	30.100,00€	17.632,00€	69.182,00€
Manutenzione ordinaria e riparazioni di impianti e macchinari	5.785,00€	8.984,50€		14.769,50€
Incarichi libero professionali di studi, ricerca e consulenza				
Stampa e rilegatura				
Servizi Integrati				
Hardware n.a.c.		7.000,00€		7.000,00€
Acquisti di impianti, attrezzature e macchinari				
	€25.785,00	€65.831,50	17.632,00€	**€110.698,50**

Table 1: final balance for 2019 referred to maintenance

Bilancio Consuntivo RING 2019				
	Sviluppo			TOTALI
	EPOS	DPC	Altri Progetti	
Pubblicazioni				
Carta, cancelleria e stampati				
Materiale informatico				
Strumenti tecnico-specialistici non sanitari				
Indennità di missione e di trasferta				
Licenze d'uso per software		35.172,00€		35.172,00€
Allestimento e manutenzione di osservatori e siti delle reti	12.000,00€			12.000,00€
Manutenzione ordinaria e riparazioni di impianti e macchinari				
Incarichi libero professionali di studi, ricerca e consulenza		934,00€		934,00€
Stampa e rilegatura				
Servizi Integrati				
Hardware n.a.c.				
Acquisti di impianti, attrezzature e macchinari	80.000,00€		133.985,00€	213.985,00€
	92.000,00€	36.106,00€	133.985,00€	**262.091,00€**

Table 2: final balance for 2019 referred to development

Descrizione	UF di riferimento	RUP	EPOS	DPC	FOE	Altri Progetti	Totale X RING
Canoni stazioni RSN e RING	Roma/AC	Mondiali			45.272,00 €		10.000,00 €
Acquisto N 20 GNSS	Grottaminarda/Roma	Selvaggi	80.000,00 €			95.990,00 €	175.990,00 €
Riparazione 4 GNSS	Grottaminarda/Roma	Cecere	5.785,00 €				5.785,00 €
Acquisto server GNSS	Grottaminarda	Mondiali/D'Ambrosio		7.000,00 €			7.000,00 €
Pulizia siti area Puglia	Grottaminarda	Mondiali/memmolo			1.800,00 €		900,00 €
Stazioni Belice	Grottaminarda	Mattia/Avallone	12.000,00 €				12.000,00 €
Pulizia Siti rete Basilicata	Grottaminarda	Mondiali/memmolo			1.500,00 €		750,00 €
Puizia Siti rete Molise	Grottaminarda	Mondiali/memmolo			1.500,00 €		750,00 €
Manutenzione MELA	Grottaminarda	Mondiali/memmolo			1.500,00 €		750,00 €
Pulizia siti rete Campania	Grottaminarda	Mondiali/memmolo			4.900,00 €		2.450,00 €
Materiale Informatico	Grottaminarda	Abruzzese/Vicari		5.165,00 €			2.582,50 €
Pulizia Siti rete Calabria	Grottaminarda	Mondilai/Memmolo			2.600,00 €		1.300,00 €
Moduli GPS Libra	Grottaminarda	Abruzzese/Vicari		6.013,00 €			3.006,50 €
Acquisto GNSS(Quinto di gara)	Grottaminarda/Roma	Selvaggi				34.762,00 €	34.762,00 €
Acquisto Switch CED	Grottaminarda	Abruzzese/Falco		4.330,00 €			2.165,00 €
Impatto Ambientale Pianosa	Grottaminarda	Abruzzese/Zarrilli		934,00 €			934,00 €
Acquisto BOX Rittal	Grottaminarda	Vicari/abruzzese		58.135,00 €			20.000,00 €
Recupero materiale da discarica sui siti	Grottaminarda	Mondiali/Memmolo			1.464,00 €		732,00 €
GNSS Emlid	Grottaminarda	Cecere/Famiglietti				3.233,00 €	3.233,00 €
Riparazione Ricevitori	Roma	Sepe		5.978,00 €			5.978,00 €
Lotto 1 - Fotovoltaico	Grottaminarda	Vicari/abruzzese		25.000,00 €			5.000,00 €
Lotto 2 - Batterie	Grottaminarda	Vicari/abruzzese		45.500,00 €			15.500,00 €
Lotto 3 - Materiale Elettrico	Grottaminarda	Vicari/abruzzese		10.000,00 €			5.000,00 €
Lotto 4 - Ferramenta	Grottaminarda	Vicari/abruzzese		9.300,00 €			4.650,00 €
Aggiornamento FTP PUSH GNSS	Grottaminarda	Abruzzese/Vicari		35.172,00 €			35.172,00 €
Totale							356.390,00 €

Table 3 - Actual expenditures referred to 2019. Note that some costs are shared with the National Seismic Network group.

MAIN SCIENTIFIC GOALS AND TECHNOLOGICAL DEVELOPMENTS

Here we outline the main scientific goals in which the geodetic community is involved including some new research fields that we think will be addressed in the coming years. Most of the topics are under investigation and funded mainly by specific projects. This very short description of the scientific research is the premise to the technical development also outlined here.

1) Geodetic Strain Build-up in Italy

The RING network was realized with the goal of mapping geodetic deformation rates at national scale. Its development relied on the existence of other GNSS networks, operated by international and regional administrations and private companies. The initial goal has been accomplished, as well testified by the high level scientific products (publications, reports, projects, international collaborations, etc) from the INGV personnel involved.
The next step is to map surface velocity gradients with a higher spatial resolution and better characterize the temporal evolution of strain at fault scales, with the goal of improving our knowledge on active tectonic deformation and related hazards.
In order to accomplish these goals, we require a significant increase in the number of RING stations, decreasing substantially the stations distance in large part of the national territory, pointing also towards the realization of a more uniformly distributed national backbone, not strictly relying on existing non-geophysical GNSS stations that do not guarantee medium/long-term continuity required by spatially and temporally dense monitoring of tectonic deformation. This plan must be accompanied by important upgrades and developments in administrative, logistical/technical and computational facilities at INGV. An improved, and denser, national backbone can facilitate network densifications, including those required as earthquake response, development of fault-scale observatories, by allowing, for example, sharing of communication infrastructures and local facilities.
Technological development and requirements: To achieve this goal, there is the need to empower administrative, technical and technological facilities, in order to realize a timely improvement of the RING network and regional densifications, facilitating all the processes that go from site selections, to site authorizations to the

final site realization, and a significant improvement of computation facilities for the dissemination of state-of-the-art observations and products, also in real-time.
Budget: A provisional budget takes into account 100 new receivers including transmission costs, installation costs, travel, administrative bureaucracy and upgrade of storage and computational capabilities for the new data. We estimate, based on the experience of three European tender to contain the costs within 12.000,00 euro per station. The budget for one hundred stations (**1.2 M€**) can be covered by the contribution to INGV to the development of scientific infrastructures obtained in 2017.

2) Earthquake cycle

A backbone network as described in the previous section will allow a more detailed strain map at the national level. With the addition of dedicated temporary stations in the proximity of regions affected by destructive earthquakes, this stable framework will be essential to allow a timely intervention in specific regions in case of emergency. Nonetheless, it is well known that tectonic strain accumulates on faults, and thus a higher densification in the proximity of selected active sites is desirable. Despite not knowing where the next large earthquake will strike, to properly understand how friction behaves at a natural scale it is fundamental to collect data as close as possible to the displacement source throughout the whole seismic cycle, and not only after the mainshock has already occurred. Having in mind the examples set by the Near Fault Observatories (NFOs, https://www.epos-ip.org/data-services/community-services-tcs/near-fault-observatories), we plan to densify the network in the surrounding of selected known active faults. Many known faults are at a different stage of their seismic cycle and they share similar characteristics as strain rates, geometry and seismogenic layer. The close monitoring of different active faults will reveal similarities and differences in the way strain is accumulating at the local scale in different stages of the seismic cycle. The selection of the regions to be studied will need an in depth analysis and discussion involving the geodetic and seismological communities. The synergy with the seismological community is crucial if we want to be able to quantitatively derive important quantities like the percentage of moment released aseismically vs seismically during all stages of the seismic cycle. Furthermore, the detection of transient signals (either pre- or post-mainshock) may allow a quantitative estimation of faults' frictional parameters. Also a non-detection while seismic activity is recorded will bring scientifically valuable results, since a densified local network will allow to eventually lower the upper bound of the aseismic component associated with the nucleation phase of an earthquake.

The *Technological development and requirements* and *the Budget* are already covered by what indicated the previous point. There is no extra budget required here.

3) Non Tectonics signals and hydrological loading

Recently, it has been shown that displacement time series contain deformation signals associated with hydrological processes occurring at different temporal and spatial scales. In some cases, these signals can be of magnitude comparable to, or greater than, tectonic signals. Their detection and their proper spatial/temporal characterization and interpretation can provide new clues on changes in groundwater storage at meso- and regional-scales, elastic properties of the Earth, mechanical properties of faults and hydrologically active fractures.

Importantly, accounting for non-tectonic, non-seasonal, transient deformation is mandatory to achieve the highest accuracies and precisions in the estimate of tectonic velocities, while improving our ability to detect small tectonic transient signals associated with the earthquake cycle. Such hydrological deformation signals have been detected and studied, thanks to GNSS networks, in the Alps and in the Apennines and a relationship between hydrology and earthquakes has been found in both tectonically active areas. These studies are at an early stage but are a promising direction of GPS/GNSS network design.

Technological development and requirements: The capability to keep the full efficiency of each GNSS station is not only related to personnel resources but also to the efficiency and robustness of the architecture of the transmission, acquisition, archiving and software dedicated to quality control. A necessary condition for these studies is the continuity and homogeneity of each time series of a station.

For homogeneity conditions we mean to have the least number of component changes, or environmental changes, that can influence the time series trend, as antenna change, firmware updates, site conditions, ecc. During the life of RING, we have done a lot on this side but still there is to do in terms of strengthening each ring of the system.

The main technological development is linked to software analyses for quality check and control. We have and we will invest in new software.

Budget: The budget is dedicated to the ordinary maintenance of the GNSS remote sites to avoid data interruptions or lower signal to noise ratios in the GNSS signal. This budget is estimated to be of the order of 30 k€/year.

4) Vertical land movements and sea level rise

Sea level is rising at a rate of about 30 cm per century, thus representing a factor of hazard for many coastal populations. Sea level projections estimate a rise up to about 1.1 m by 2100 (www.ipcc.ch) and even more from independent studies, thus representing among the most serious impacts of climate change to face by 2100 and beyond even in the Mediterranean. Besides sea surface height measurements based on radar altimeters from space, tide gauge measurements are widely used to estimate sea level heights from minutes to decades. These instruments are installed along the coasts of mainland and islands, in sheltered zones like harbors and bays and measure the sea level relative to nearby geodetic benchmarks. Sometimes these data span across the last three centuries. Because tide gauges are connected to land, they also provide measures of the Vertical Land Motion (VLM) in consequence of local and regional effects (i.e. post-glacial rebound, tectonic uplift or subsidence, including for anthropogenic causes). Therefore, while analyzing time series of relative sea level data collected at these stations, VLM must be considered and removed to establish changes in eustatic sea level over decades. To this goal, the GNSS networks can provide precise measurements of VLM along the coastal zone, especially when co-located with tide gauges. In addition, GPS technique is providing measurements of tides and water levels by interferometric technique, even using low-cost GNSS receivers.

Technological development and requirements: GNSS data collected along the coasts can provide valuable data both on the current rates of vertical land movements and sea level trends. It will be necessary to set up a set of new GNSS stations along the coast of Italy and possibly in the surrounding regions to monitor the sea level rise induced by climate change (primarily caused by the melting of continental ice and thermal expansion due to global warming) and the vertical land movements induced by natural (tectonics, volcanism, soil compaction, etc.) and anthropogenic (fluid extraction, etc.) causes. Data will support climatic and tectonic research and monitoring.

Budget: The budget is already covered by what indicated at point 1). There is no extra budget required here.

5) Space weather: Ionospheric Total electron content and scintillations

GNSS is nowadays one of the most useful instruments for the investigation of the morphology and dynamics of the Earth ionosphere/plasmasphere system. In fact, the wide coverage of the GNSS receivers allows a detailed mapping of the Total Electron Content (TEC) in the ionosphere with the aim of studying the physical processes driving the regular variability of the ionosphere as well as the formation of the so-called ionospheric irregularities, especially during solar and geomagnetic storms. RING network is a valuable network for mapping and monitoring of the ionosphere in the Mediterranean region that allowed the development of a tool named IONORING (IONOspheric RING) that produces TEC maps over Italy with a very high spatial and temporal resolution (0.1°x0.1°x10 minutes). IONORING maps are available in real-time on the INGV ionospheric portal eSWua (http://eswua.ingv.it/index.php/gnss-tec/italy). Moreover, RING network measurements contribute to the modelling of the ionospheric maximum critical frequency (f0F2) over Europe through the assimilation of TEC measurements in ionospheric models. The products based on RING measurements are included in several international initiatives such the Space Weather service for aviation requested by ICAO (International Civil Aviation Organization) and provided by the PECASUS consortium (http://pecasus.eu/).

Technological development and requirements: In addition to what already mentioned in terms of efficiency and reliability of the whole architecture (from acquisition to data transmission and storage), ionospheric monitoring and modelling would benefit from the installation of new GNSS stations (e.g. Sardegna, Isole Pelagie, Morocco) for a better coverage of the area at the edge of the Italian peninsula. Moreover, it would be useful to install a few GNSS receivers capable of monitoring ionospheric scintillation parameters (e.g. Septentrio PolaRx5S) in the southernmost region of the network coverage.

Budget: The provisioning and installation of 3 scintillation monitoring stations can be estimated in 80 k€.

6) GPS reflection studies

GNSS interferometric reflectometry (also known as GNSS-IR, or GPS-IR for GPS signals) is a technique that uses data from geodetic-quality GNSS instruments for sensing the near-field environment. In contrast to positioning, atmospheric, and timing applications of GNSS, GNSS-IR uses the signal-to-noise ratio (SNR) data. GNSS-IR has been demonstrated and validated for measuring surface soil moisture, snow depth, permafrost melt, tides, ice-up, firn density and vegetation water. A systematic use of this technique, where field and environmental conditions will allow, will be important for: a) monitoring the local characteristics (i.e. growing

vegetation) at the RING remote sites before they could affect the acquired signals at the antennas; b) providing independent measurements of sea level rise on the coasts; c) provide valuable constraints for hydrologic, climatic, and ecologic models.
Technological development and requirements: The technological development will consist of a dedicated virtual machine in a cloud or external resources. The available GNSS-IR software is free and open-source, but the development will be focused in adapting the application of such a software also in real-time or quasi-real-time conditions.
Budget: The budget for the exploitation of this virtual machine or external resources is around 5 k€/year.

PARTICIPATING IN MAJOR PROJECT

The RING infrastructure participates in major scientific projects, usually through Research Agreements or Memorandum of Understanding with Universities, Research Institutes or third public bodies. Here we outline the most important initiatives that give prestige to the RING.

1) Einstein Telescope observatory of gravitational waves

Within the framework of a collaboration with the INFN and the University “Sapienza Università di Roma”, RING is going to contribute to characterize the stability of the site that has been nominated to host a 3rd generation Einstein Telescope observatory of gravitational waves. The RING contribution will focus on the long-term stability and foresees the installation of a RING GNSS station and set up possible local measurement campaigns. The budget is 20 K€ including the GNSS instrumentation, the geodetic monumentation and travel costs. Power supply and data transmission costs will be shared with the technological development related to the installation of a co-located seismic station.

2) Ring Laser Gyroscope

In the framework of the MoU (INGV-INFN), INGV is participating in the GINGERINO program, a research proposal led by INFN to construct a Ring Laser Gyroscope sensing "absolute" rotation rates with very high sensitivity. Laser gyroscopes are sensitive to Earth’s rotation variations (Earth Rotation Parameters) and earthquake-induced rotational ground motions. The research program foresees the contribution to the proposal of a laser ring array hosted at the Laboratori Nazionali del Gran Sasso and the analysis and interpretation of the GINGERINO observables.

3) Italian Altimetric Reference System

A cooperative research project supported by INGV involving national partnerships like the Istituto Nazionale di Ricerca Metrologica (INRiM), the Italian Space Agency (ASI), Politecnico di Milano and University (Sapienza Università di Roma). The project will be developed through the acquisition of absolute gravimetric measurements associated with measurements of the vertical gradient and topographic and GNSS surveys at each measurement site. The geo-referencing of the gravimetric stations will build up the reference frame for the definition of the Italian Altimetric Reference System. An absolute Quantum Gravimeter based on laser-cooled free fall atoms will be acquired for testing and pre-operational activities. The cooperation foresees a repeated measuring campaign in different national sites and no further costs are foreseen for this activity.

4) Tsunami Early Warning

INGV signed a Memorandum of Understanding with the National Observatory of Athens with the aim of monitoring and studying earthquakes and tsunamis in the Mediterranea region. Within the framework of this MoU, RING installed five GNSS stations, with real-time data transmission, in the West Hellenic Arc (Greece) From Zakynthos island to Antikythera island. A real-time data exchange is also in progress to acquire data from other GNSS stations that can contribute to a future integration of GNSS in the Tsunami Early Warning.

5) Unavco member

INGV is an Associate Member of the UNAVCO, a US-University-governed consortium that operates and supports geodetic networks, software tools for data access and processing, and technological developments.

GNSS FOR THE BENEFIT OF THE SOCIETY

Beside the basic research outlined before, in the last years GNSS networks have pursued goals aimed at the benefit for the society. This include the development of targeted services and applied research to respond to the need of the civil society as the contribution to seismic hazard. Here we recall the main initiatives in which the RING is promoter or involved

1) European Plate Boundary System EPOS

RING represents one of the main INGV infrastructures in the framework of the EPOS Research Program. Its peculiarity is related to different features: a) it has been developed in a region characterized by frequent natural disaster (i. e. earthquakes, volcanic eruptions); b) it the denser, scientific-driven, permanent real-time GNSS network in Europe; c) it is characterized by technologically advanced remote sites, data archive and metadata database, scientific derived products. RING is present in the consortium board of the GNSS Data and Products TCS and contributes in the delivery of data, metadata and products of all the permanent GNSS sites in EPOS for the broad community of the Solid Earth Sciences.
Technological development and requirements: The maintenance and further development of the services developed within the framework of EPOS require dedicated servers for the RING GLASS national node, and the GNSSGIVING archive and database (see paragraph on “RING state of the art”). These servers can be located in clouds or external resources like the agreement between INGV and INFN ReCas at the University of Bari.
Budget: The estimated budget of this activity would correspond to one dedicated IT with permanent position.

2) Rapid estimate of seismic source parameters for earthquake and Tsunami early warning and response with high rate sampling

Since the beginning of its development, the RING remote sites transmit data in real-time to the acquisition data centre located in Grottaminarda. The data are then stored in hourly RINEX files in the RING archives. During the last 11 years, after all the strongest earthquakes occurred in Italy (L'Aquila in 2009, Pollino in 2011, Emilia Romagna in 2012 and Central-Italy in 2016-2017), the RING GNSS data contributed (in addition to those acquired by other permanent GPS networks) to provide robust and accurate estimates of the co-seismic static and dynamic displacements and of the consequent post-seismic deformation. Furthermore, RING is also moving towards a real-time GPS/GNSS data processing in order to provide low latency (a few seconds) displacements, useful for rapid estimates of source parameters for early warnings and responses.

Technological development and requirements: To achieve this goal the technological development consists in the acquisition and maintenance of servers for the real-time data acquisition and for real-time data processing. The technological development will consist of a dedicated virtual machine in a cloud or external resources. For the data processing, different freely available open-source software will be used in this project, one of them within the framework of a specific project (EWRICA), formalized by a software license agreement with GFZ.

Budget: The budget for the exploitation of this virtual machine or external resources is around 10 k€/year.

3) Contribution to seismic hazard

The development of strategies and procedures to work out new seismicity models using geodetic data is currently an important research topic that may have important impacts on seismic risk reduction. For this reason, it is important to be able to estimate the crustal deformation with a high spatial resolution. Starting from the GNSS velocity field, it is possible to compute the spatial distribution of the velocity gradient (strain rate) to be converted into an estimate of the seismic release (activity rates). The basic assumption is that the secular inter-seismic deformation rate measured by GNSS networks, and its spatial distribution, represent a good approximation of the long-term tectonic deformation and the associated seismic release. Over 500 GNSS stations contribute to the definition of the deformation field of the Italian territory and surrounding areas, as published by Devoti et al. (2017), which therefore offers an image with good resolution (average station spacing < 30 km) of the tectonic deformation. This velocity field was included as an input data in the processing of the latest version of the probabilistic hazard map (MPS18) and allowed the construction of a seismicity model based on geodetic deformation. This integration follows the most recent trends of the international scientific community for the preparation of probabilistic hazard maps at both global (GEM, Global

Earthquake Model) and regional (California, UCERF) levels. Increasing the spatial resolution of the GNSS velocity field, especially in critical areas, would increase our knowledge and assessment of seismic hazard in that particular region.
The *Technological development and requirements* and *the Budget* is already covered by what indicated the previous point. There is no extra budget required here.

4) RING real time GNSS (RINGrtG)

The RING has ensured the availability of open access, high-quality GNSS data since 2006. Through the development of activities in real-time, the RING is working to extend its capability to support applications requiring real-time access to RING data and products. After a first stage to test and study the data and products real-time distribution at some of the RING stations, the RINGrtG would allow the use of two layers of data dissemination:

- "Layer 0", consisting in broadcasts raw GPS/GNSS measurements from the stations of the RING Network; the real-time data streaming will be performed using standard formats, like RTCM (or Binex) formats via the Networked Transport of RTCM via Internet Protocol (NTRIP).
- "Layer 1" broadcasts GNSS correction or products; the RINGrtG will study and test the possibility to share also different signal augmentation technologies, like Real-Time Kinematic (RTK) or Network Real-Time Kinematic (NRTK), Precise Point Positioning (PPP) or Precise Point Positioning – Real-Time Kinematic (PPP-RTK)

Once the RINGrtG will be active, it will be available to any users through subscription.

Technological development and requirements: To achieve this objective the technological development consists in the acquisition and maintenance of servers for the real-time data acquisition and for real-time data processing. The technological development will consist of a dedicated virtual machine in a cloud or external resources. For the data processing, different freely available open-source software will be used in this project, one of them within the framework of a specific project (EWRICA), formalized by a software license agreement with GFZ.

Budget: The budget for the exploitation of this virtual machine or external resources is around 5 k€/year.

5) Contribution to the Rete Dinamica Nazionale (IGM)

Currently, the RING infrastructure participates in the definition of the national geodetic network providing GNSS data to the RDN (Rete Dinamica Nazionale) founded in 2012 (DM 10 Nov. 2011). Almost one-third of the overall RDN stations (~90) are RING stations (24), distributed overall Italy.

6) Estimate of atmospheric water vapor or precipitable water for weather forecasting

GPS based remote sensing techniques can now profit from the availability of the more recent satellite navigation systems that enable qualitative improvements of the sounding accuracy, compared to the only GPS system. The high expectations of scientists all over the world were already satisfied by the demonstration of the GPS potential in weather forecasting but further progress is expected in the next years from GNSS to improve weather forecasting, also in near real time, and in atmospheric processes that act over a wide range of temporal and spatial scales, from global climate to micrometeorology. An integration of GNSS stations with weather stations would improve the accuracy of atmospheric delays measurements and would make it possible to use the RING also for weather forecasting. In this context we propose a first test area located in Sicily and Southern Calabria.
Technological developments and requirements: The technological development will deal with the installation of weather stations in a set of selected RING sites in the test area of Sicily and Southern Calabria.

Budget: The cost of a weather station is of the order of 4 k€. An estimated total budget for this activity is 120 k€.

7) Outreach

Since its creation, RING invested a lot in terms of time and funding efforts in the whole infrastructure, but discrete improvements are still required to increase its visibility towards the broad and multidisciplinary scientific community. The RING website represents a good place to retrieve the daily acquired GNSS observations, their metadata and some information about the whole infrastructure. On the other hand, the scientific contents need an update in terms of data and products availability (i.e. high-rate GNSS data, GNSS time series, GNSS velocity fields) and of descriptions of the different GNSS data analysis and activities. Furthermore, the RING will start a dedicated communication strategy, promoting flyers, posters, workshops and training courses on GNSS instrumentation, GNSS data analysis and webinars on the various research topics. This communication activity will include also the use of social networks (i.e. Twitter, Facebook, etc.) to provide information, news and events related to the RING infrastructure.

Technological development and requirements: The technological development will consist of a dedicated virtual machine in a cloud or external resources.

Budget: The budget for the exploitation of this virtual machine or external resources is around 10 k€/year. In addition, we estimate that 2 months/year of an IT with communication expertise are also required.

THE NEED OF A NEW GOVERNANCE

In recent years, the INGV Departments realized a survey of the Research Infrastructures leading to an important update of the INGV assets. This operation was also driven by the EPOS initiative that had the need of a clear picture of the state of the art of INGV infrastructures. However, this effort was not followed by a departmental policy to create forms of governance of the infrastructures themselves. The Departments have then formalised “coordination tables”, not foreseen by INGV Statute or in the Implementing Rules, which are likely to have a poor decision-making capacity, lacking direct dialogue with the operational and research structures that make the life of the infrastructures difficult. This can lead to a separation between technological developments and scientific goals, with the risk of underuse of the data produced by the infrastructures and/or a decrease of their quality.

The “National Earthquake Observatory” (ONT) tried to overcome this limit by defining a “RING coordination board” composed by ONT researchers, ONT technologists, and ONT responsible for operational structures of the infrastructure. Although this organisation is clearly atypical and out of the formality imposed by the Statute or the implementing rules, it helped, at his best, to share decisions pertaining the technological developments of the network among the geodetic community. Presently, we think that the coordination board has come to the critical point of its experience for two reasons. First, in the past two years the Departments played a decisive role in the funding distribution but there has been a poor coordination between the RING board and the Department, mainly due to the RING board nature itself. The operative governance of an infrastructure should be tied up more closely to the Departments. The second reason is the informality of the RING board, which was defined to assist the ONT Director. As said before, the board was born outside Statute and the implementing rules and the absence of a regulatory reference limits its action.

The Statute and the Implementing Rules introduced the organizational form of "Coordination Centres" for the governance of research infrastructures. The Centres are hinged in the Departments but they have never been set up for this purpose as, presently, they have been created only for purpose-built services (CAT, CPS, CMS ecc).

Finally, we stress the importance of an organisation finalised to represent more widely all the INGV scientific sections that make use of the GNSS data. A discussion with the responsible of the INGV strategic decisions is highly desirable and it can be carried on in the near future.