European Cooperation in the field of Scientific and Technical Research - COST -

Brussels, 15 May 2014

COST 029/14

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action ES1401: Time Dependent Seismology (TIDES)

Delegations will find attached the Memorandum of Understanding for COST Action ES1401 as approved by the COST Committee of Senior Officials (CSO) at its 190th meeting on 14 May 2014.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action ES1401
TIME DEPENDENT SEISMOLOGY (TIDES)

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4114/13 “COST Action Management” and document COST 4112/13 “Rules for Participation in and Implementation of COST Activities” , or in any new document amending or replacing them, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to (1) merge expertise in academia and industry on seismic data processing and modeling for inverse problems; (2) develop the emerging field of time-dependent seismology to monitor complex Earth systems.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 56 million in 2014 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of section *2. Changes to a COST Action* in the document COST 4114/13.

A. ABSTRACT AND KEYWORDS

Seismology is undergoing a revolution, as it is starting to use the full-length records of seismic events and background ambient noise to go beyond still-life snapshots of the interior of the Earth, and look into time-dependent changes of its properties. Data availability has grown dramatically with the expansion of seismographic networks and data centers, so as to enable much more detailed and accurate analyses. COST Action TIDES (TIme DEpendent Seismology) aims at structuring the EU seismological community to enable development of data-intensive, time-dependent techniques for monitoring Earth active processes (e.g., earthquakes, volcanic eruptions, landslides, glacial earthquakes) as well as oil/gas reservoirs. TIDES will network European laboratories in Academia and Industry with complementary skills and will organize a series of workshops and advanced schools to train the next generation of scientists. TIDES will facilitate the exploitation of massive data sets collected by European observational infrastructures - coordinated through the ESFRI EPOS - through the use of high-performance computing facilities. TIDES will strengthen Europe's role in a critical field for natural hazards and natural resource management.
Keywords: Seismology, seismic tomography, data mining, high-performance computing, natural hazards, natural resource management, atmosphere-ocean-lithosphere interaction, ambient noise, cryosphere-lithosphere interaction, glacial earthquakes, volcanic unrest

B. BACKGROUND

B.1 General background

Seismology is undergoing a true revolution: seismologists can now exploit much more information contained in seismic data — seismograms recorded in real time at the Earth's surface — thus leaping forward in their ability to model and understand the complexity of natural phenomena such as earthquakes, volcanic eruptions, landslides, glacial earthquakes, mountain building, lithospheric subduction. Seismologists today are using an unprecedented wealth of data, that used to be discarded in the past. Seismograms from relevant earthquakes used to be pre-processed to yield just a few summary parameters, such as wave arrival times, to be then used in the mathematical modeling of the seismic source or the deep structure of the Earth. Today, two specific developments allow us to use orders of magnitude more data. On one side, powerful numerical techniques allow modeling the whole seismogram produced by an earthquake, and, on the other side, scattering theory and correlation techniques allow us to extract detailed information about the geological

structure in the absence of earthquakes — by modeling continuous background “noise”. This is a true breakthrough, holding promise to unravel unprecedented details about deep Earth processes and the coupling between solid and fluid Earth. Now it is time to look into properties of the Earth that vary with time, i.e. to explore 4-D, time-dependent seismology — time is a wholly new dimension that had to be neglected in seismic waveform modeling. Uncovering time variations is fundamental in understanding the earthquake preparation process, the evolution of volcano unrest and eruption, the state of a deep reservoir, or the generation of the magnetic field in the Earth's core.
Why COST?
COST constitutes a unique opportunity, among European funding programs, to organize coordinated open workshops and training schools on a 4-year basis, and to connect research laboratories in a transnational network, such as needed to coordinate and inspire the blossoming developments taking place in the emerging domain of 4-D seismology. The proposed COST Action TIDES (TIme-DEpendent Seismology) is an open network of institutions and high-profile scientists, aimed at maximizing the role of Europe in the current innovational big data-driven stage of seismology.

B.2 Current state of knowledge

With the explosion during the last ten years of dense seismic networks and antennas, contributing to build massive continuous seismic databases, it is possible to exploit not only earthquake data but also continuous background noise data through correlation techniques. Using correlations of ambient seismic noise instead of deterministic sources became a new paradigm in seismology during the last decade. Noise based surface-wave tomography has allowed for a renewal of lithospheric structure imaging with applications worldwide. At the same time this approach has been applied at various scales ranging from global mantle tomography to shallow structure reconstruction, including high-resolution imaging of reservoir overburdens for hydrocarbon exploration. Most of the applications so far concerned the use of surface waves of scattered waves extracted from noise correlation. It has recently been demonstrated that body waves could be extracted as well from continuous records. Complete global teleseismic sections have been shown to include numerous deep phases. Crustal reflections have also been observed. These new findings open a new wide range of applications of noise based imaging with relevance from shallow exploration to deep Earth structures, including the core.
The other line of development of noise-based techniques is the continuous monitoring of seismic velocities and anisotropies that lead eventually to 4D images of the Earth. By measuring slight

temporal changes in the Earth’s mechanical properties from repetitive noise cross-correlations, it has been demonstrated that one can detect temporal evolutions associated with deformation processes around faults or with the evolution of magmatic systems in volcanoes, co- and post-seismic motion of faults zone, hydraulic loading, injection at depth. Noise-based monitoring allows for an effective large scale continuous monitoring impossible to achieve with active source or earthquake records. Associated with continuous monitoring, recently discovered seismic and tectonic events (slow-slip and low-frequency events, non-volcanic tremors) provide us with new insights into the nature of the seismo-tectonic cycle and the mechanics of faults. A comprehensive, and systematic analysis of continuous seismic (and geodetic) records opens new perspectives for the interpretation of crustal dynamics and natural hazards.

A central challenge in the development of tomographic techniques for time-dependent seismology is to investigate and – when required – to suppress the effect of time-dependent noise sources on the 3D tomographic images of the subsurface. The COST Action TIDES will promote research toward the implementation of seismic tomographic techniques that fully account for the time-variability of noise sources, thereby revealing the subtle changes of subsurface structure induced, for instance, by volcanic activity, fluid injection in geothermal wells, or the extraction of hydrocarbons from reservoirs.

The original idea of time-dependent seismology is to use time-variable inter-station correlations of seismic noise as a proxy of the time-variable subsurface. For linear processes like seismic wave propagation, the correlation of random output time series approximates the system response to an impulsive input, i.e. the Green's function. The first observations of inter-station surface waveforms emerging from microseismic noise correlations, prompted a large number of regional tomographic studies working under the assumption that the inter-station correlation is equal to a scaled version of the Green's function. This concept was extended from microseisms to long period hum used for global surface wave tomography. Body waves are increasingly often identified in noise correlations, indicating that body wave tomography may become feasible as well. The immense popularity of ‘noise tomography’ rests on the possibility to image the Earth without relying on sparsely distributed earthquakes, which can greatly improve coverage and resolution.

While ‘noise tomography’ flourished, it was also established that correlations equal Green's functions only under specific conditions, including wavefield diffusivity and equipartitioning, and the isotropic distribution of both mono- and dipolar uncorrelated noise sources.

However, none of these conditions is satisfied in the Earth. In particular, noise sources are mostly monopolar and anisotropically distributed within small regions with strong atmospheric and ocean wave activity. Furthermore, the absence of sufficiently strong scatterers at microseismic and hum frequencies prevents equipartitioning. The consequences are manifold: amplitudes of noise correlations become difficult to interpret, and this complicates attenuation tomography. The effect of anisotropically distributed noise sources on travel times is small, but sufficiently large to affect the details of tomographic images. Differences between the correlation and Green's functions are introduced in the form of spurious arrivals, and they tend to overwhelm body and higher-mode surface waves that cannot be retrieved reliably.

Furthermore, noise sources are themselves time-dependent, thereby introducing artefacts into the tomographic images. The effect of time-variable noise sources has the potential to overwhelm the weak signal of a time-variable subsurface, and thus has to be accounted for as precisely as possible. While attempts to correct ‘noise tomography’ for the imperfections of noise sources have been made, methods that consistently account for anisotropic noise source distributions and their time-dependence, 3D heterogeneous Earth structure and the full seismic wave propagation physics are yet to be developed. The current absence of such methods prevents, for instance, the accurate incorporation of body and higher-mode surface waves, needed to achieve good tomographic depth resolution. Equating noise correlations with Green's functions is in contrast to traditional seismic tomography which, as a high-precision science, operates on a solid theoretical foundation in the form of the elasto-dynamic equations with deterministic sources. This lack of precision inhibits the inversion of noise correlations with recently developed full waveform inversion techniques that exploit complete waveforms for the benefit of improved resolution and have the potential to reveal changes of Earth structure over time.

In conclusion, while the methodology of ambient noise analysis is flourishing with the potential to look at the time-dependence of Earth’s internal structure for the first time, we are far from the ability to reliably understand this 4D behavior. This COST action aims at channeling these developments and prepare tools that improve the quality of our imaging with impact on the understanding and forecasting of processes in all spatial scales (e.g., global Earth, fault systems, volcanoes, reservoirs).

B.3 Reasons for the Action

Time is now ripe to capitalize on the wealth of data accumulated in the last thirty years, and on the excellent computing infrastructure and scientific environment, by stimulating fresh approaches to data mining, modelling and imaging time-dependent parameters. With TIDES, Europe will be able to continue to play a leading role in that emerging field.

The main needs, that TIDES will address, are:

- Need for interaction among: academic and industrial seismologists, acousticians, helioseismologists, other geophysicists (rock mechanics, geodynamics, geomagnetism)

- Promote networking inside this emerging community

- Provide a forum between academia and industry on seismic monitoring issues

- Attract and train at the cutting-edge level current research young geoscientists to satisfy the growing European industrial and technological needs. In this way, the COST action TIDES can help answer major social and economic challenges, while hopefully retaining in Europe essential scientists who might be tempted to leave Europe for lack of a continent-wide center of excellence in geosciences. Another aim is to attract young geoscientists from rapidly developing countries that will help these countries move forward and will ensure strong future links with Europe.

B.4 Complementarity with other research programmes

TIDES will complement ongoing European actions. The EU research infrastructures are coordinated by various targeted programmes (NERA, VERCE, SHARE, REAKT, STREST). EPOS is providing a coordination umbrella to organize international and national initiatives, as done by TOPO-EUROPE for geodynamics. Following the GEO Supersite initiative, three projects support monitoring infrastructures in specific geological hazard sites (MARSITE, FUTURVOLC, MED-SUV). The scientific community has also been developed and organized during the last years through training networks such as SPICE and QUEST. Several scientists behind the present initiative hold ERC grants (WAVETOMO, WHISPER, ILAB, iGEO, ROMY, SLIDEQUAKES) in connected topics. In the USA, there are initiatives on computational infrastructures (CIG) and summer schoools and conferences (CIDER and Gordon conferences) but there is no integrated approach on the emerging topic of data-intensive time-dependent seismology. TIDES will substantially benefit from the e-infrastructure project VERCE that develops computational tools for data- and cpu-intensive applications for the seismological community via a scientific gateway. By the time TIDES will start this gateway will be available.

C. OBJECTIVES AND BENEFITS

C.1 Aim

The main objectives of the Action are: (1) to merge uncoordinated expertise in academia and industry on seismic data processing, wave propagation and inverse problem theory, numerical modeling and simulation; (2) to develop the emerging field of time-dependent seismology and applications to monitoring complex Earth systems such as seismogenic and volcanic zones, landslides, glacial earthquakes, oil/gas reservoirs, global Earth.

C.2 Objectives

As seismology is turning to a new paradigm, as a data-driven science, the scientific community must now liaise with infrastructures to maximize the impact and the success. By networking complementary skills in the different scientific institutions, we aim at facilitating such groundbreaking transformation of the wide European community to keep the pace, and even surpass, the developments that are taking place elsewhere in the world.
Objectives:

- integration and validation of innovative data mining techniques and numerical methods
- development of new design for massive field experiments
- evaluation of uncertainties in full-waveform inversion and time-dependent tomography
- development of strategies for real-time data assimilation
- development of reliable techniques for monitoring active processes (earthquakes, volcanic eruptions, landslides, …)
- networking of top-level laboratories, coordination among academia and industry in time-dependent seismology
- organization of effective exchange programs for early-stage researchers
- catalysis of creative initiatives
- stimulation of discussion with other data-driven disciplines – climate and ocean science, acoustics, geology, astrophysics

C.3 How networking within the Action will yield the objectives?

The objectives of TIDES will be addressed through ongoing national and European research programs. All partners have their own research funding but TIDES will enable them to share their expertise and initiatives, to integrate their research findings, to develop strong interaction and to launch new collaborations. TIDES will produce the following deliverables:

- organization of a series of regular workshops and training schools on time-dependent seismology, to create a multidisciplinary discussion platform. Lecturers from both academia and industry will present new findings, bottlenecks and challenges.

- short-term scientific missions at institutions of COST countries, in particular for early-stage researchers

- publications in high-impact scientific journals. The objective is to create an inter-disciplinary library of scientific papers related to the field and to promote joint publications between partners.

- public software library for forward and inverse modelling. Researchers used to develop their own computing codes. In order to avoid the duplication of efforts, codes useful for the community will be made freely accessible on the TIDES website and benchmarked.

- standards for data and 4D model sharing: seismic data are now archived and exchanged through a standard format (SEED format). The same effort of standardization must be undertaken for the exchange of output models, including uncertainties and quality control.

- guidelines for end-users on monitoring systems: there is often a gap between scientists developing their basic research, and innovative techniques, and scientists in charge of networks and monitoring systems of seismic, volcanic activity (or any other active processes) . TIDES will provide a forum of exchange for facilitating the transfer of knowledge between basic science and operational systems.

- preparatory measures for large-scale EU science programs/initiatives : the regular meetings of partners will enable to discuss and launch new programs at the European and international levels, to find the best strategy and the appropriate tools to ensure the success of these initiatives.

C.4 Potential impact of the Action

The Action involves a large variety of fields in Geoscience and the potential applications in basic science and in industry are very diverse. By the coordination and organization of the current research efforts, TIDES should strengthen the role of Europe in this emerging field and maximize its impact at the international level.

The expected scientific impact of TIDES COST Action are:

- development of the new area of time-dependent seismology
- training of a new generation of scientists who will be ready to carry on the future developments
- improvement of collaboration between academia and industry
- new proposals to fund fresh initiatives – at the national, multi-national and European levels
- innovative developments in European infrastructures, in connection with EPOS
- improvement of monitoring systems with impact on seismic and volcanic hazards in particular for European hotspots (e.g., seismic active regions in Italy, Greece, Turkey, Switzerland, etc.; volcanic monitoring in Italy, Greece, Iceland)
- transfer of the knowledge gain to early-warning systems

C.5 Target groups/end users

This Action targets three groups of potential users: academic and research institutes; industry; and civil authorities. For the first two groups the aim is to foster the transfer of innovative technologies for imaging and monitoring time-dependent processes and reservoirs. This has high potential interest for monitoring Earth hazards, such as earthquake and landslides preparation, or volcanic eruptions. The coordination of the research activities in this area will drastically improve the quality control of results in this area through the development of data and processing standards, best-practices, and community controlled tools.

The eventual benefit goes to the agencies that carry out monitoring activities for natural hazards such as earthquakes and volcanoes. It is already foreseeable that the methodologies proposed in these projects – once they become reliable - will have a tremendous impact on the understanding of the build-up of our dynamic Earth systems towards failure.

The general public will also be targeted with specific outreach activities. Many of the involved scientists routinely deal with the public media in connection with the provision of information in the presence of current natural catastrophes (earthquakes, volcanic eruptions).

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

A main challenge for TIDES is to investigate temporal changes in physical properties in different geological contexts. Adding the time dimension to 3D tomographic images, will open new perspectives in Earth dynamics and natural hazards.
The current system of seismic networks at global, regional, or local scales looking into the Earth consists of ~5000 stations, producing about 300 Gb of publicly accessible data per day. It constitutes some kind of planetary antenna available to study various issues, from the surface down to the center of the Earth. The innovation, for seismology, is the fact that all these data are nowadays important to a scientist, who used to extract only a very small fraction of them. This is a great challenge. Now, the entire waveforms produced by earthquakes, and the whole continuous background noise records contain information that can be exploited. New kinds of seismic events (glacial earthquakes, slow-slip and low-frequency events, non-volcanic tremors, landslides) are still not well understood, and must be investigated.
Also, high-definition 3D numerical simulations compute the full wavefields, needed to image the deep structure of the Earth with the so-called adjoint technique, and each such computation for a single earthquake may amount to O(1 Tb). New datasets are now available and not yet integrated in seismic investigations, such as rotational seismological data, tiltmeters, infrasound, continuous GPS, ionospheric data. In short, forefront seismological research is turning to a real data-intensive endeavour and a 'deluge' of data (recorded in the field, result of simulations) needs to be processed. This methodological leap is allowing us to look at the Earth in a fresh way, where the properties of the sub-surface structure are not anymore 'frozen', but we can address temporal changes — like for instance in the neighborhood of an active fault zone to study fluid migration that may influence aftershock occurrence, or in a volcano environment, or even to map time variations in the Earth's core. Many networks have been in operation for the past 30 years, opening the opportunity to investigate active processes for the past decades. Time-dependent seismology will determine time variations of physical parameters such as seismic velocity, anisotropy, anelasticity which can ultimately be translated into stress and strain field changes relevant for seismic and volcanic hazards. Similar techniques can be applied to monitor reservoirs. Reservoirs in the crust include

aquifers, magma chambers and oil/gas fields, all of them have economic and societal importance. Better imaging, monitoring and management of these reservoirs are crucial to our long-term supply of water, geothermal energy, oil and gas. Furthermore, when depleted, such reservoirs can also serve as repositories for CO_2 and radioactive waste. Understanding spatial and temporal variations in such sites requires an integrated multidisciplinary approach and a strong involvement of industrial partners.

Europe has been at the leading edge of many of these innovations in seismology, from the introduction of spectral-element numerical methods to the discovery of usable information in background noise records. COST Action TIDES will help not only maintaining leadership in introducing and discovering new methods, but also in applying them and diversifying the range of applications in an integrated and efficient way.

D.2 Scientific work plan methods and means

Work will be organized in seven thematic Working Groups (WGs), with strong interaction and integration among them. All Working Groups will be open, but will include specialists who will identify the most relevant open issues and animate discussion at the meetings — but also between meetings — to identify possible new approaches, and catalyze new research directions.

WG1: Workflow integration of data and computing resources.

Imaging requires high-quality data observed in dense seismic arrays and/or local/global seismic networks. It is important to note that with large-scale projects like NERIES (structuring European seismic networks), USArray, VEBSN and many others, massive quantities of seismic waveform data are becoming available. This implies that data mining becomes an issue for high-performance computing systems. The last decade has seen a paradigm shift from seismic event-based observations to permanent observations of ground motions including oceanic- and atmospherically-driven background noise (micro-seismicity and seismic hum). The analysis of noise has led to a new methodology to image the Earth's interior without the need for earthquake sources. Event-based and virtual source data – if processed properly – may change our view of the Earth. The seismic networks are becoming so dense that – at least in principle – high-resolution imaging of the Earth's interior and of seismic sources is becoming possible at all scales. In TIDES research topics, computational simulations will play a leading role in hypothesis testing and data modelling. In addition to the existing links between the TIDES participants and their local supercomputing centres, TIDES will be associated with the European supercomputer grid infrastructure through

VERCE and EPOS.

WG2: Seismic interferometry and ambient noise.
“Noise correlation” theorems relating correlation functions and Green's functions can be proved for fully random source distributions or equipartitioned scattered wave fields. Indeed, actual seismic noise does not satisfy these conditions perfectly. The conditions of emergence of the different types of waves need to be further studied. The fact that the existence of scattering improves the Green's function reconstruction has been verified for short period waves. The influence of scattering at longer periods for long time series has to be studied carefully. The issue of the role of scattering is of first importance for time dependent imaging since multiple scattered waves are essentially weakly dependent on the noise source fluctuations. Also, the origin and location of noise sources are not yet completely understood and must be investigated. Quantifying the effects of scattering requires studies from different perspectives. Beyond the analysis of seismological data, laboratory experiments in controlled complex media have to be performed to understand the physics of multiply scattered random fields and their correlation properties. As far as possible, numerical simulations in models based on the background properties of the Earth (average speeds, layering) are also required. Noise based imaging and monitoring would benefit from a better quantitative description of scattering properties such as mean free paths, even in regions and frequency bands for which scattering is not a problem for direct wave imaging.

Different strategies of signal processing can be adopted for the computation of the long-term averages of the correlations that are identified eventually as the Green's function or components of it. In the light of the mathematical results on which the noise-based imaging and monitoring are based, the processing aims at forcing the stationarity of the initial records by various normalization techniques. The correlations are computed for limited time windows and then stacked to obtain a satisfactory level of convergence towards the Green's function. Pre-stack adaptive filtering schemes have been applied based on different approaches. These processing steps have to be evaluated for different contexts and frequency ranges and their performances compared for imaging and monitoring. New challenges for the processing are to consider simultaneously the multicomponent records of dense arrays and to apply array processing advanced tools.

First applications of noise-based monitoring actually rely on spatial averaged properties of the speed of seismic waves. New methods emerged to provide 4D models of the changes, that is, including a step of spatial imaging of the changes. It was recently shown that other parameters such as the local cross-section of the materials could be monitored as well with coda waves. This measurement is performed from the temporal variation of the coherence of noise cross correlations. These imaging approaches are based on sensitivity kernels of coda waves computed with diffusion or radiative transfer theories. So far strong hypothesis were made for the computation of the kernels (scalar waves, homogeneous background,..). The development of more realistic kernels is required to improve the time dependent imaging.

WG3: Forward problems, High-performance computing applications

A central tool of seismology is the calculation of synthetic seismograms that can be compared with observations. The only way to generate 'realistic' synthetic seismograms for complex three-dimensional models is by means of numerical methods, implemented on supercomputer hardware. TIDES participants have been leading this field in Europe and beyond for several years and numerous algorithms that solve the wave propagation problem on reservoirs, regional and global scales, are available and implemented on supercomputers. One of the most important points and the central motivation for TIDES is the fact that only now computational power has reached a point where many such "forward calculations" (i.e., simulations of wave propagation) can be done making it feasible to perform the imaging by trying to fit complete waveforms (rather than travel times).

WG4: Seismic tomography, full waveform inversion, uncertainties

When all random processes are described by Gaussian random variables, fast analytic expression for the final or posterior model can be employed. This is most likely not the case for the data nor forward theory approximations. The only way forward is then to employ sampling techniques. Sampling techniques are well studied in the mathematical literature, but need a fast solution of the forward problem to overcome the curse of dimensionality due to the high number of parameters that need to be determined. The strongest approximations are therefore required to make the forward problem computationally tractable. It is essential that we include a realistic description of the uncertainty in ray theoretical approximations, otherwise the posterior probability density could be seriously biased. A lot of progress has been made on the sampling side in high dimensions with the multi-nest Markov Chain Monte Carlo algorithms. A fundamental question is if fast approximate forward algorithms with appropriate uncertainty give satisfactory solutions with enough structural detail. Do we need to include better forward theories, which in a Monte Carlo application are computationally exorbitant? For example, a solution to this problem might lie in surrogate modelling. The idea is to replace the expensive forward theory with a computationally cheap surrogate based on neural networks or support vector machines. The surrogate, although not exact, maps almost all complexities of the expensive forward problem and is much better than ray theoretical approximations. The uncertainty can also be modelled without any additional cost. While this is quite common in complex engineering problem the concept of surrogates needs to be fully investigated for the imaging and source modelling problems.

WG5: 4-D structure in seismically active regions and volcanoes
The recent catastrophic events in Japan (2011), Chile (2010), Haiti (2010) and Italy (2009) are reminders of the need to better understand the predisposition to earthquakes (and possible associated tsunamis and landslides). The recent Japan (2011) and Sumatra (2004) mega-thrust events are forcing a revision of the decades-old paradigm for tsunamigenic earthquakes and a reassessment of the corresponding risk worldwide. Large explosive volcanic eruptions can have even larger impacts on society: the one which occurred in Iceland in 2010 highly affected the flight scheduling in North and Central Europe and completely paralyzed a few airports; while an unquantified risk is posed by the possible reactivation of the Vesuvius – Phlegrean Fields system in a highly inhabited area. The interpretation of changes of elastic properties in term of physical process is difficult and ambiguous. Simultaneously with the accumulation of actual observations of the temporal changes, the different possible mechanisms have to be studied quantitatively in a pluri-disciplinary effort. Different physical processes were proposed including non-linear mesoscopic elasticity, poroelasticity, and damage. It is required to gather specialists of seismology and tectonics with experts of rock mechanics and material physics to develop an interpretative framework for the time variable response of elastic speed which has to be adapted to various forcings such as earthquake, transient slow slip, hydraulic loading, magma ascent.

WG6: Industrial applications: 4D reservoirs
The other main domain of application of seismic monitoring of time variations is in the industrial field, related to monitoring of oil/gas reservoirs. Better imaging, monitoring and management of the reservoirs such as aquifers, magma chambers or oil/gas fields are crucial to our long-term supply of water, geothermal energy, oil and gas. Understanding spatial and temporal variations in such sites requires an integrated multidisciplinary approach. For example, the geomechanical response to production or injection is linked to observable seismic, geophysical and geochemical signals, which may be used as monitoring tools. Modeling deformation and seismic waveform propagation in such structures requires sophisticated mathematical and computer modelling, which can be linked to in situ observations. Laboratory simulations of fluid-rock interactions in such settings can be done

both numerically and experimentally. PhD projects in this theme will be inherently multidisciplinary, exploiting different strengths at several Institutions and industrial partners in TIDES. This working group will also address the needs of industry in terms of what specific training may be requested to academia, to form excellent European candidates for high-level jobs.

WG7: Dissemination and outreach

This working group will specifically target actions to disseminate information on the TIDES activities to the scientific community and the general public. These actions will include 1) Press release at the project onset; 2) Setup of a project www site with openly accessible mail lists of various levels (expert, non-expert); 3) Electronic newsletters that can be subscribed; 4) Organization of special sessions with TIDES reference at the international Geoconferences (EGU, AGU); 5) Special outreach activities linked to hazard/risk relevant national and international activities in the latter half of the project; 6) scientific publications in top international journals; 7) Dissemination of project information through commission channels; 8) Access to TIDES developed software through own library or links to related software libraries (e.g., WHISPER, ObsPy).

E. ORGANISATION

E.1 Coordination and organisation

Following the COST implementation rules and procedures, the Management Committee (MC) will supervise all relevant activities within TIDES, and provide reports to the COST Office as required. During the first meeting, the different Working Groups will be formed. The composition of WG's will however be flexible, and any partner may decide to join at any time. A total number of 7 Working Groups will be formed, but they will be free to organize their own work and split or merge if they need to.

The main thread will be the organization of yearly workshops, and biannual Working Group meetings. WG will report about their work at each yearly workshop.

Short-term Scientific Missions will for the most part be reserved to young scientists (PhD students and post-docs), from TIDES Parties, to visit other TIDES laboratories to work on specific scientific issues as approved by the MC.

Each WG will have a chairperson, elected by participants, who will regularly report to the MC. An early-stage researcher (ESR) will co-chair each WG. All WG will closely coordinate with other relevant ongoing projects.

Achievements of the WG will be closely monitored and evaluated by the MC. This will be done with continuous free interaction, but mainly it will occur within the biannual meetings of the WG and MC that will take place at the TIDES-organized conferences, and at other selected venues at open scientific congresses. The meetings at the congresses —where TIDES participants will convene scientific sessions — will be an excellent occasion of confrontation with the general scientific audience, and hence offer a very good measure for the MC to gauge the impact of TIDES COST Action activities.
The coordinating institution will designate an administrator who will 1) organize the communication with the commission; 2) oversee the financial actions of the COST action; 3) administer the project www page content; 4) co-organize the TIDES workshops and schools; 5) distribute information to the partners and associates; 6) help in preparing the reports; 7) serve as contact person for the COST action. Because of the involvement of several TIDES scientists in large scale EU-funded initiatives we have access to a large pool of administrative staff highly qualified for these tasks.

E.2 Working Groups

Work in TIDES will be organized in 7 Working Groups (WG), coordinated by the Management Committee (MC) including a member from each participating institution. The MC will supervise the progress of project activities, and will organize workshops and training schools. Workshops will represent the forums where creative ideas and results will be presented and discussed, and will provide structural opportunities to catalyze innovative initiatives, such as proposals to fund new activities. TIDES will invite scientists from other data-driven fields – climate and ocean science, astrophysics, acoustics -- to compare their experience with ours. The MC will organize dissemination activities (interactive web site, publications).
Industrial partners will be encouraged to be active part in all WGs.
The Working Groups will be devoted to:
- WG1: workflow integration of data and computing resources
- WG2: seismic interferometry and ambient noise
- WG3: forward problems, improvement of efficiency
- WG4: tomographic techniques and inversion of full waveforms
- WG5: time-dependent parameters and hazard in active zones (seismogenic, volcanic)
- WG6: industry: monitoring of oil/gas reservoirs
- WG7: dissemination and outreach

Their main objectives have been detailed in the Scientific work plan (D.2).

E.3 Liaison and interaction with other research programmes

TIDES will interact with other ongoing European actions. The EU research infrastructures are coordinated by various targeted programs (NERA, VERCE, SHARE, REAKT, STREST). EPOS is providing a coordination umbrella to organize international and national initiatives, as done by TOPO-EUROPE for geodynamics and EMSO for marine geosciences. Following the GEO Supersite initiative, three projects support monitoring infrastructures in specific geological hazard sites (MARSITE, FUTURVOLC, MED-SUV). Several scientists behind the present initiative hold ERC grants (WAVETOMO, WHISPER, ILAB, iGEO, ROMY, SLIDEQUAKE) in connected topics. We plan to have a liaison person with these projects and programs.
Time dependent seismology is a very timely hot topic benefiting from all these European projects by using their data and resources. COST Action TIDES will be an excellent forum to discuss cutting-edge research advances linked to these various European projects, gathering together the various communities, and enabling new collaborations and joint efforts about the topic of geological time dependent phenomena and monitoring.

E.4 Gender balance and involvement of early-stage researchers

This COST Action will respect an appropriate gender balance in all its activities and the Management Committee will place this as a standard item on all its MC agendas. The Action will also be committed to considerably involve early-stage researchers. This item will also be placed as a standard item on all MC agendas.

F. TIMETABLE

After the kick-off, as foreseen by COST Action rules, and the initial creation of the Management Committee, Working Groups will be set up and will start informal contacts and preparatory actions until the first open workshop, where their work program will be discussed.
The activities will be paced by the 4 workshops that will take place once a year.

Task/Milestone/ Deliverable	**Year 1**				**Year 2**				**Year 3**				**Year 4**			
Meetings:																
Kick-off meeting	**X**															
MC meeting	**X**		**X**		**X**		**X**			**X**		**X**		**X**		**X**
WG meetings	**X**		**X**		**X**		**X**			**X**		**X**		**X**		**X**
TIDES Conferences			**X**				**X**			**X**				**X**		
Working group activity:																
WG 1-7 work	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Website and software library:																
Preparation	**X**	**X**	**X**	**X**												
Online - update			**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		
Legacy web site														**X**	**X**	**X**
Reporting:																
Annual reports				**X**				**X**				**X**				
Final report																**X**

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: CH, CZ, DE, ES, FR, IE, IS, IT, NL, NO, PT, SK, TR, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 56 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The general geoscience scientific community; the geophysical and environmental monitoring industry; policy-makers and public authorities; and the general public are the main target groups of TIDES dissemination activities.

Innovations in new imaging techniques — involving sharper image resolution, better uncertainty analyses, exploitation of background seismic signal, and finally mapping of time variations — will constitute the main objective of the TIDES COST Action. The relevant scientific community will quite naturally be interested in learning and contributing to such innovations. Similar monitoring techniques are being developed also in the industry monitoring natural gas/oil reservoirs, so that we predict significant interest from economic actors.

Population growth and the general move to large urban complexes lead to ever increasing issues on prevention of a number of natural risks, including earthquakes and tsunamis, volcanic eruptions, and landslides; as well as on access to energy supply, water, waste disposal. The geosciences are often the main provider of solutions to these problems. Better imaging of the inner structure of the Earth, and accurate mapping of its time variations, is inherently connected to all such natural hazard and resource issues. This is why policy-makers and the general public are further, obvious, targets for the dissemination and outreach activities that will be an integral part of TIDES.

H.2 What?

Many and various instruments will be used to reach different communities.
Publications on peer-reviewed scientific literature and presentations at conferences (such as European Geosciences Union - EGU, American Geophysical Union - AGU, International Association of Seismology and Physics of the Earth's Interior - IASPEI, International Association of Volcanology and Chemistry of the Earth's Interior - IAVCEI) will be the main means to reach the wide scientific community. We may also consider to edit special thematic volumes of scientific journals and review papers, that may allow to better represent the interdisciplinarity of the field. TIDES Cost Action participants will organize coordinated special thematic symposia at conferences, that provide good opportunities to publicize new directions in science.
The yearly workshops that TIDES will organize will themselves constitute great opportunities to reach beyond the simple scientific community. They will be organized in areas where TIDES research has special relevance (e.g., volcanoes, high-seismic hazard regions, reservoirs) so as to build occasions to reach stakeholders in the civil society (general public, civil authorities).
The TIDES web site will be a main hub for collecting, organizing, and diffusing information, results, relevant news, reports, personal and institutional contacts, job postings. It will be structured with different levels, so as to reach different target groups, from the specialist to the general public.
Other publications are also envisaged, such as short reports and a newsletter, that will be distributed

solely in electronic form.

H.3 How?

Working Group 7 will be put on charge of dissemination and outreach activities, in strong interaction with the Management Committee. Its main task will consist of collecting and organizing all contributions from the other WG’s, as well as stimulating actions and initiatives. It will also act as an editorial committee of the TIDES web site, under the supervision of the MC.
TIDES will act proactively with the dissemination of results. Reports and the newsletter will be regularly sent to interested stakeholders, to publicize innovations and new results. Particularly relevant results will be the subject of press releases.
All Working Groups will be involved in all dissemination activities, although the first 4 WG's are more specialist and technical (but can, and will, provide outreach products to scientifically-interested general public) while the last 2 WG's are more specifically oriented to applications with direct impact on the society. All WG's will also be involved in the preparation of training material (from class material to software) to be made freely available on the web site.
The main component of the TIDES COST Action consists of workshop and schools, that will constitute at the same time occasions for specialist interaction, catalysis of new ideas and directions, framework for discussion, training for younger scientists, job opportunity forum, but also circumstances for reaching the general public and the society. The locations of the workshops will be chosen to make this exchange between scientists and the stakeholders in the civil society possible.