An Agent-based Tsunami Alert System

Giuseppe Barbaro, Maria Donatella Gangemi, Giandomenico Foti
DICEAM, University Mediterranea
89122 Reggio Calabria, Italy
Email: {barbaro,mdonatella.gangemi, foti}@unirc.it

***Abstract*—Natural tsunami catastrophes occurred over the years have developed the interest in studying the associated physical phenomena in order to refine existing modeling tools and enhance alert mechanisms. To this purpose, it is essential to carry out an adequate risk analysis for the most exposed areas and therefore to study any historical event that may provide useful indications on the dynamics of the area. To this aim, recently, a fully nonlinear and dispersive long wave model FUNWAVE-TVD and a 3D (sigma-coordinate) non-hydrostatic model NHWAVE were respectively proposed to simulate the tsunami propagation and its slide generation. However, these models require to analyze a great amount of data coming both *i*) by wavemeters, which measures the sea anomalies in real time, and *ii*) by historical data. Given the complexity of these tasks, in this paper we propose to adopt the agent technology to verify the wavemeters reliability and to analyze the results of the models cited above in order to realize a reliable tsunami alert system.**

***Index Terms*—Alert System, Multi-Agent System, Trust System, Tsunami Hazard.**

I. INTRODUCTION

Many severe seismic disasters, followed by catastrophic tsunami, occurred in various areas of the world over the years, some of which are quite recent. On December 26, 2004, one of the largest earthquakes ever recorded struck off the coast of Indonesia, triggering a tsunami that overwhelmed entire communities around the Indian Ocean, and again on March 11, 2011 a powerful earthquake off the northeastern coast of the Japans main island, initiated a series of large tsunami waves that devastated many coastal areas of the country instigating a major nuclear accident at a power station.

Such events have given new impulse to researches on tsunami by developing considerable interest towards prevention. However, the question of how to protect a given segment of coastline, industrial plant, or buildings from tsunami attack, within a given period of time (or return period) in the future, is much debated. Many advanced tsunami warning systems were developed in the wake of the massive devastation caused by the tsunami, although in absence of a reliable tsunami model to predict possible earthquakes effects, in terms of the resulting tsunami magnitude and time arrival, such approaches do not guarantee the necessary level of security.

In the aforementioned context, either the sea state monitoring or the knowledge of potential risks assume a crucial relevance. As for the monitoring, the key parameter is the real-time observation of the hydrometric sea level provided by measuring stations distributed in the area of interest.

At the same time, the only reasonable action that can be taken for the risk assessment is that of considering the largest events known to have hit the area of interest in the past history, to best (*i*) reconstruct these events from their historical source, (*ii*) simulate the events through numerical modeling, (*iii*) compute tsunami wave action on coastal environments and on structures that have to be protected and, finally, (*iv*) estimate the tsunami time arrival on the coast.

To realize a reliable tsunami alert system, a possible advantageous solution is that of exploiting the software agent technology [1] to manage the complex interdisciplinary aspects involved in modeling natural or human phenomenas and the several heterogeneous component interactions existing in the considered context, aspects where the agent systems are widely used in a profitable way [8]–[12].

More in detail, our idea is that of realizing a distributed agent system where each wavemeter is associated with a software agent that both (*i*) monitors the wavemeter data and (*ii*) collaborates with its neighbor agents in order to manage a trust system devoted to detect possible wavemeter malfunctioning in order to allow the only use of *certified* wavemeters data. To this aim, the Trust Reputation Reliability (TRR) model [13]–[15] has been adopted because this trust system is able to take into account of the existing interdependencies among the trust measures in order to obtain more reliable trust values. A central agency provides to gather both (*i*) the wavemeters data coming via their associated software agents and (*ii*) their trust evaluations. By combining such data with local historical data then the agency evaluates the tsunami risk.

The combined use of a multi-agent system, the monitoring activity and the historical information, is illustrated in the present research by applying the methodology to the Messina Straits, an area whose level of tsunami risk is high since it was affected by three important historical events, the latest on December 28, 1908. With regard to the wave measuring, it was taken in consideration the Italian national sea-tide network operation.

Note that, concerning the analysis of historical event, this matter was already dealt in [16] and developed in [17], where numerical simulations with a state-of-the-art of tsunami generation and propagation models were performed. In particular, the best possible bathymetric and topographic data, to re-evaluate the hypothesis of a dual source tsunami, co-seismic and submarine mass failure, were used. Typical outcomes of such numerical modeling studies are maps of maximum

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[1] The interested reader might refer to an overwhelming number of surveys on the matter among which [1]–[7].

wave heights, currents, impact forces, and maximum wave penetration distances (flow depth/inundation and runup). Furthermore, tsunami time arrival can be easily deduced in any given localities.

Therefore, given the premises above, in this paper we present the state-of-art of our studies to implement a multi-agent system to realize the most effective tsunami hazard planning and prevention as possible.

The paper is organized as follows. In Section II the monitoring activity of the wavemeters, realized by the software agents, is described. In Sections II-A and III the adopted TRR and Tsunami risk assessment are presented. Section IV provides a brief overview on the current state of this project, while in Section V some conclusions are drawn.

II. THE WAVEMETER MONITORING AGENT ACTIVITY

In our model, the monitoring activity of the wavemeters is realized by exploiting the capabilities of the software agents. In particular, each wavemeter is associated with a software agent which monitors the data flow and verifies the reliability of such data by collaborating with the agents monitoring the wavemeters in its neighboring on the basis of a trust model.

In the context of our experimentation, we will simulate our model by exploiting the Italian national sea-tide network. It consists of 36 stations uniformly distributed across the national territory and predominantly located inside the port.

Each one of this level sensor is referred to a tidal clamp whose dimension is determined by reference of the Military Geographic Institute altimeter network and accurately connected to the nearest IGM benchmark. The stations are also equipped with an anemometric sensor (speed and wind direction at 10 meters from the ground), a barometric sensor, an air temperature sensor, a water temperature sensor as well as a sensor for the relative humidity. In addition, 10 stations have been equipped with a multi-parameter probe for water quality assessment. The measured parameters are the following: water temperature, pH, conductivity and redox.

Moreover, all these stations are equipped with a local data management and storage system (UMTS), and a real-time transmission system at the central system. A second satellite data transmission system with IRIDIUM technology is available in 9 strategic stations for the measurement of particular phenomena (abnormal waves), which also ensures connection even in the presence of UMTS black-out situations.

Note that data collected by these wavemeters, and validated by the agents in our case, are without usefulness to the aim of a tsunami alert. Indeed, given the particular installation of these wavemeters, for the most part inside the port, the tsunami will be detected when it is already on the coast. For a real use, the wavemeters should be located in open sea and, in this case, it should be difficult to verify their correctness by remote without the help of suitable technologies (e.g., the agent technology in our case).

A. The Trust Reputation Reliability Model

An important feature of our model should be that of assuring the reliability of the data collected by each wavemeter. This activity has to be realized by remote and in an automatic way. To this aim, in our proposal the agent associated with a wavemeter exploits a trust system.

The use of trust and reputation systems is a convenient and easy way to monitor grid of sensors. In particular, in the following we will refer to a standard implementation of the Trust Reputation Reliability (TRR) model [13], [15], given the involved dimension of the wavemeter sensor grid. The TRR model was already used, in a distributed version, in [14] to monitor a grid of acoustic sensors in an urban traffic context.

The TRR model, extension of the mathematical model described in [18], is characterized by an high accuracy. Briefly, in TRR each agent has its individual perception of the trust (τ) of each other agent (in its community) providing a service, for instance data on the basis if its reliability (ρ) and reputation (π) measures.

In the following the TRR model will be described in the detail.

1) Reliability in the TRR model: In TRR each agent a could have its own reliability model independently from the other agents (but this is not our case). The reliability of the agent b (i.e., $\rho_{ab} \in [0,1] \in \mathbb{R}$) for the agent a is given by $\rho_{ab} = f_a(e_{ab})$, where e_{ab} is the number of events that a and b performed together. In other words, the level of knowledge a has of b (i.e., e_{ab}) due to their past events is considered. In our case, an event is represented by a wave detected by both a and b over time.

2) Reputation in the TRR model: The agent a computes the *reputation* of the agent b (i.e., $\pi_{ab} \in [0,1] \in \mathbb{R}$) by asking to each other agent c of its agent community, different from a and b, an opinion about the capability of b in providing a reliable data about an event. In TRR the opinion of c consists of its trust measure (see below) about b (i.e., τ_{cb}) that is weighted by the trust that a has in c (i.e., τ_{ac}). Therefore, in TRR the reputation of an agent is different for each agent depending on both its individual perception and on the opinions of the other agents.

Formally, the reputation π_{ab} is computed as the *weighted mean* of all the opinions (i.e. the trust measures) of each other agent c, different from a and b, weighted by the value of the trust that a has in c as:

$$\pi_{ab} = \frac{\sum_{c \in C-\{a,b\}} \tau_{cb} \cdot \tau_{ac}}{\sum_{c \in C-\{a,b\}} \tau_{ac}} \tag{1}$$

3) Trust: Usually, the trust measure that an agent a assigns to an agent b for its service (i.e., $\tau_{ab} \in [0,1] \in \mathbb{R}$) combines the reliability measure ρ_{ab} with the reputation measure π_{ab}. In this way, the direct knowledge that a has acquired about b and the suggestions coming from the other agents to a about b are considered in the trust measure.

Different trust models require to determine the percentage of relevance given to the reliability with respect to the reputation. In TRR τ_{ab} is computed by exploiting the parameter α_{ab} (i.e., $\alpha_{ab} \in [0,1] \in \mathbb{R}$) which weights the reliability ρ_{ab} and

$(1-\alpha_{ab})$ which weights the reputation π_{ab}. Formally, the trust assigned by a to b is computed as:

$$\tau_{ab} = \frac{\alpha_{ab}}{\chi} \cdot \rho_{ab} + (1 - \frac{\alpha_{ab}}{\chi}) \cdot \pi_{ab} \tag{2}$$

where χ is a positive integer coefficient fixing a threshold to the relevance of the reliability with respect to the reputation.

In this version of TRR, differently from the standard TRR model where the relevance of the reliability with respect to the reputation is assumed to increase with the number of events e_{ab} occurred between the agents a and b (i.e., $\alpha_{ab} = \alpha_{ab}(e_{ab})$), the value of the parameter α is here assumed to be the same for all the agents and it should be fixed in the real domain $[0, 1]$ after a suitable test phase on real data in order to provide a fine tuning of the system.

Moreover, $\chi \geq 1$ is set to 1, but in our case this choice could be unsuitable given the aim of TRR to detect anomalies in the wavemeters data. In particular, χ will be set on the basis of suitable tests in order to optimize the TRR performance into the proposed tsunami alert system.

Consequently, τ_{ab} can be expressed as:

$$\tau_{ab} = \frac{\alpha_{ab}}{\chi} \cdot \rho_{ab} + (1 - \frac{\alpha_{ab}}{\chi}) \cdot \frac{\sum_{c \in C-\{a,b\}} \tau_{cb} \cdot \tau_{ac}}{\sum_{c \in C-\{a,b\}} \tau_{ac}} \tag{3}$$

This equation, written for all the agents, leads to a system of $n \cdot (n-1)$ linear equations containing $n \cdot (n-1)$ variables τ_{ab}, where n is the number of agents. This system is equivalent to that described in [18] and admits only one solution.

III. TSUNAMI RISK ASSESSMENT

The wavemeters data, after their validation performed by their associated agents by using the described TRR model, are collected by the Agency, which recognizes certain parameters, as wave height and period characteristics of a tsunami wave and the related potential coastal impact on the basis of suitable models.

We focused our attention on the catastrophic tsunami that followed the 1908 earthquake in Messina (see Figure 1), destroying large coastal areas in Calabria and Sicily, in southern Italy, to clarify this approach.

Fig. 1: Reference area of the 1908 tsunami

Many potential sources, co-seismic, underwater landslides, or a combination of those, have been proposed and simulated in numerical models to explain the tsunami above. However, there are still significant discrepancies between the proposed mechanisms of tsunami generation and the observations of coastal impact made in the weeks and months following the event, and hence no real consensus yet on the actual sources for the tsunami. Therefore, in order to realize a more effective tsunami alert mechanism a new model has been designed to this aim.

More in detail, the hypothesis that the 1908 tsunami was generated by a dual source, which included a submarine landslide (SMF) triggered by the earthquake, is here considered. For this purpose, we refer to [16], [17], where simulations of a source proposed in literature were performed in order to validate the earlier parameters of the landslide (including location).

Because the generated wave trains are comprised of both longer and shorter waves, the latter associated with landslides, the fully nonlinear and dispersive long wave model FUNWAVE-TVD [19]–[23] was used to simulate tsunami propagation, in a series of nested grids of increasingly fine resolution, by one-way coupling. TVD refers to the Total Variation Diminishing shock-capturing algorithm that is used to more accurately simulate breaking waves and the associated dissipation and coastal inundation.

For landslide tsunami generation, the three-dimensional (sigma-coordinate) non-hydrostatic model NHWAVE [24]–[26], which solves the incompressible Navier-Stokes equations in conservative form was used. For rigid slides or slumps, the geometry together with semi-empirical laws of motions are specified as bottom boundary conditions in NHWAVE.

Both models are parallelized using a domain decomposition technique, the Message Passing Interface (MPI) protocol with non-blocking communication for data communication between processors, that allows for the modelling of large grids in a reasonable time.

Numerical modelling can provide important and useful information for coastal hazard assessment, on the interaction of the tsunami waves with the local coastal morphology of a given area, and the numerous man-made developments existing today.

At the same time, recognizing a landslide-tsunami when the mass failure is entirely submarine is very challenging, even though it is indispensable to mitigate potential risks associated with future events, considering that the arrival time of these tsunamis on the coast is very short while the associated run-up can be very extensive [27]–[29].

The starting point for identifying areas predisposed to such tsunamis, are marine surveys and the analysis of historical tsunamis where these events are adequately documented. The application of this methodology should lead to the calculation of thematic maps related to hazard, vulnerability, and risk, such as inundation maps and therefore to the acquisition of all available information on the state of vulnerability in the area. So far no such maps exist for the Italian coast, which means that filling this gap should be a priority task over the next few years. As for the analysis of historical events, it is important to point out here that changes in coastal morphology because of erosive phenomena must be taken into account. These are due both to natural (such as the inequality between longshore and river sediment transport) and anthropic causes (such as the presence of coastal structures), as widely treated in [30]–[33].

Afterword, this activity should address the assessment of the level of risk in different areas, and tsunami modeling can provide very interesting and useful information on wave interaction with local coastal morphology and the various existing infrastructures. Clearly, the identification and monitoring of areas threatened by tsunamis and the definition of potentially tsunami sources are essential to mitigate this danger especially in populated areas, and the use of reliable and detailed physical models, such as those presented above, become indispensable to the activity.

The basic idea is that, once the possible scenarios are defined as above illustrated and then note the consequent possible actions, to think of appropriate countermeasures, so this type of analysis of large historical events, that might repeat in the future, should be the basis for any action aimed at the development of tsunami risk assessment for the Messina Straits area and then to correctly plan an alert system, based on the use of wavemeters that continuously acquire wavelength measurements, mid and peak times and propagation direction. These parameters are useful to recognize a possible tsunami wave and to identify the coastal tracts that might be affected, on the basis of previous modeling.

IV. A BRIEF OVERVIEW ON THE PROJECT STATE

In this section will discuss about the current state of the proposed agent-based alert system. Obviously, it is a challenge requiring significant efforts and time for its realization. Currently, our attention is focused on the implementation of the three main components of the alert system, that we are developing separately for obvious reasons, and namely:

- the TRR code;
- the Tsunami code;
- the Multi-Agent System.

a) The TRR code: Currently, the TRR model [13], [15] introduced in Section II-A is a consolidated component already tested in other contexts of interest with very satisfactory results. Obviously, in the next project steps further tests on real wavemeter data will be necessary to optimze the TRR performance, and in particular the parameters α and χ, in order to detect the wavemeters anomalies at the best.

b) The Tsunami code: The cartesian implementation of the tsunami propagation model required the use of a geographical domain that was built by interpolating bathymetry and topography from the most accurate sources available. In particular the 5 mt resolution Digital Terrain Model provided by the Calabrian Regional Cartographic Center, the 2 mt resolution Digital Terrain Model provided by the National Geoportal and the bathymetry unstructured data provided by the Italian Navy were used. First, it was shown that a seismic source alone cannot justify the event as it occurred. Many different faults form literature were taken in consideration in order to evaluate the most plausible and then to perform the related simulation. Surface elevations were computed for one of them at the locations of forty-four stations where historical measured of run-up and time arrival were collected after the event [34], [35], in order to compare the values. Fig. 2 shows the comparison that suggested the opportunity to investigate an additional source, as the modelled run-up underestimated the survived values.

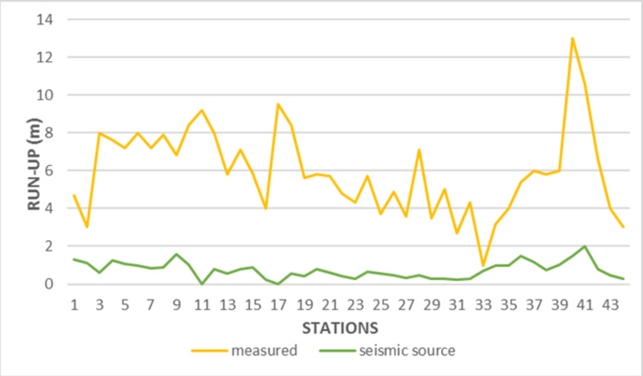

Fig. 2: Comparison between computed run-up in 44 stations for seismic source and historical measures reported in [34], [35].

The dual-source hypothesized in [36], seismic source coupled with a slide, was then simulated. Once the tsunami is fully generated, after the SMF has stopped moving or is too deep to be tsunamigenic, modelling worked by interpolating onto FUNWAVE-TVDs grid for further modelling of wave propagation, both surface elevation and horizontal velocity from previous landslide simulation added to the surface elevation and velocities computed for the seismic source. Fig. 3 shows the modeled maximum surface elevations along the coast, that were interpolated in the same 44 stations above.

Interesting insights, treated with a backward ray tracing method [29], [37] led to identify the underwater landslide triggered by the earthquake itself and located off Etna, confirming what has already been hypothesized in [19], [38]. With the help of the above described models, further studies are currently doing in order to define the characteristic parameters of the landslide responsible of the tsunami.

For the purpose of the present work, it is interesting to compare the simulated instantaneous surface elevation at t=60 sec after the earthquake, in hypothesis of only seismic source (see Fig. 4) or double source (see Fig. 5). It is quite evident that the coastal effects are significantly different either in terms of both wave height and time arrival. It demonstrates how the knowledge of previous events, provides not only elements for the risk assessment as above illustrated, but also to suggest that an appropriate alert systems has to consider times arrival very short and different magnitude depending on the source.

Note as all these computational tasks will be managed by the Agency of a multi-agent system (see below) by exploiting

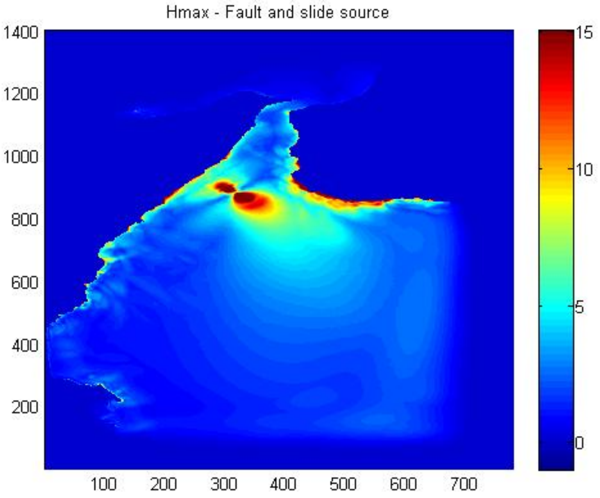

Fig. 3: Maximum surface elevation due to double source modelled with FUNWAVE-TVD [17], [36]

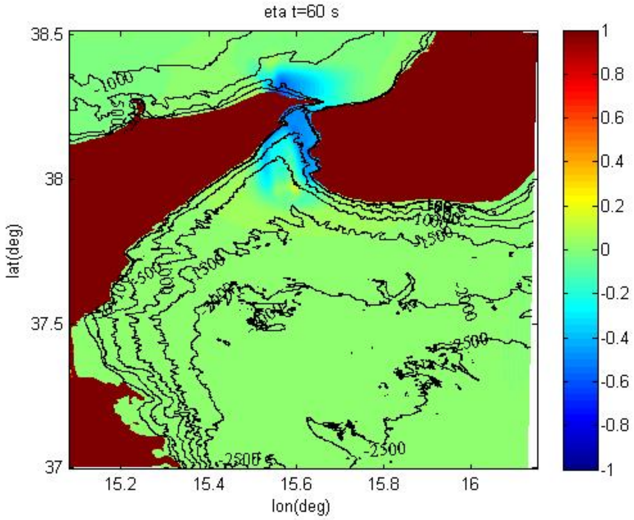

Fig. 4: Instantaneous surface elevations at t=60 sec. for only seismic source, simulated with FUNWAVE-TVD [17], [36]

the wavemeters data validated by the agents managing the wavemeters.

c) The Multi-agent System: The implementation of the multi-agent system managing the different components will be implemented by adopting a JADE [39] platform, which has been chosen among the tools currently available to realize an agent platform that we have considered. In particular, the use of a JADE platform will allow to take advantage from the several components developed for this platform and from the opportunity given by the agents to integrate heterogeneous components, and adding all the future innovations, in an easy way.

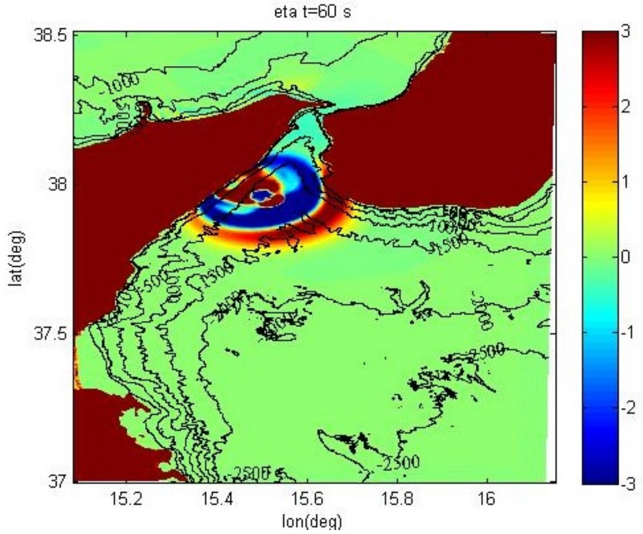

Fig. 5: Instantaneous surface elevation at t=60 sec. for double source simulated with FUNWAVE-TVD [17], [36]

V. CONCLUSIONS

This article describes the project of an agent-based tsunami alert system currently under development. This alert system is based on the combined use of *i*) the TRR trust and reputation system, to verify wavemeter anomalies, *ii*) a fully nonlinear and dispersive long wave model FUNWAVE-TVD, in turn joined with a 3D (sigma-coordinate) non-hydrostatic model NHWAVE to simulate the wave propagation and *iii*) historical events data. To coordinate these components and the required great amount of data in an efficient and effective way, we designed a multi-agent system for taking advantage from the consolidate agent technology.

We hope to realize an operative prototype of the described multi-agent system for the next year.

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