Fast 3D Seismic Wave Simulations of 24 August 2016 M_w 6.0 Central Italy Earthquake for Visual Communication

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Abstract

We present here the first application of the fast reacting framework for 3D simulations of seismic wave propagation generated by earthquakes in the Italian region with magnitude $M_w \geq 5$. The driven motivation is to offer a visualization of the natural phenomenon to the general public but also to provide preliminary modeling to expert and civil protection operators. We report here a description of this framework during the emergency of 24 August 2016 M_w 6.0 central Italy Earthquake, a discussion on the accuracy of the simulation for this seismic event and a preliminary critical analysis of the visualization structure and of the reaction of the public.

I. Introduction

Shakemovies are a visualization of seismic wave propagation resulting by numerical simulations. Originally developed for Southern California (`http://www.shakemovie.caltech.edu`), the concept has been extended by [Tromp et al., 2010] with the creation of Global Shakemovie Portal (`http://global.shakemovie.princeton.edu` that, additionally, provides seismologists with near realtime 1D and 3D synthetic seismograms for recent earthquakes. For the 2009 M_w 6.1 L'Aquila event, the 2012 Pianura Padana sequence and the 2013 M_w 5.1 Lunigiana earthquake we have released shakemovie animations that have been received by the public with surprising high view rate. The 24 August 2016 M_w 6.0 central Italy earthquake has been the first application of a near automatic framework that we have implemented for earthquakes occurring in Italy with magnitude $M_w \geq 5$. Differently from the experiences cited above, we have distributed our shakemovie animations through the INGVterremoti Youtube Channel, as a replacement of a dedicated portal.

II. Methods

In the framework of the PRIN 2012 project SHAKEnetworks, we have developed a fast reacting system for 3D simulations of seismic wave propagation generated by earthquakes in the Italian region with magnitude $M_w \geq 5$. The framework is designed around the numerical code SPECFEM3D_Cartesian ([Peter et al., 2011, Magnoni et al., 2014]) that can accurately simulate seismic wave propaga-

tion taking into account complexities such as topography, 3D lateral wavespeed variations, anisotropy, attenuation. The code has been used for simulations on local and regional scale. Even if the numerical method guarantees parallel computational efficiency, 3D simulations of high resolution seismic wave propagation at regional scale are possible only if high-performance computing (HPC) resources are available. For this reason, immediately after the detection of a $M_w \geq 5$ seismic event by the Italian National Seismic Network (INSN), the system reserves resources at the INGV HPC computational geophysics lab.
The second step of the workflow is the creation of an unstructured hexaedral mesh of the region impacted by the earthquake. The numerical accuracy of this grid is defined by the 3D wavespeed model adopted. We have available some high resolution local tomographies (i.e. Abruzzo Region, [Magnoni et al., 2014]) as well as regional wavespeed models that cover the entire Italian region (i.e., travel time tomography released by [Di Stefano & Ciaccio, 2014]; full wave adjoint IMAGINE_IT tomography, [Magnoni et al., 2015]). As soon as the first moment tensor solution is reviewed by INGV seismologists, the simulation is ready to be submitted both on cores available in the VERCE platform (`https://portal.verce.eu/home`; [Atkinson et al., 2015]) and on INGV HPC clusters.
Exploitation of INGV HPC geophysics lab resources guarantees a fast priority access to computational power during emergencies and the possibility of directly channeling the simulation results into visualization softwares for the generation of volumetric images and animations of wave propagation. Nevertheless, the simulation is submitted first on the VERCE e-infrastructure that provides the possibility of automatic and quicker setup of the experiment, easier handling of the computing code, simplified exploitation of the computational resources, direct access to raw products and automatic visualizations of the results. In addition, a prototype workflow is implemented in this infrastructure for downloading observational data from EIDA FSDN web service (`http://www.orfeus-eu.org/data/eida`), for processing the seismograms and for generating reports of the misfit between data and synthetics. It qualifies as a really useful tool for a fast quantification of the accuracy of the simulation results.
The whole process aims to create a reliable visualization of seismic wave propagation, therefore the focus is both on the promptness of the results and on the match between data and synthetics. Even if the process is not fully automated and the human intervention is still required, especially for the setup of the animation parameters and the quantification of the accuracy of the simulation, in the case of the 24 August, 2016, M_w 6.0 central Italy earthquake the system has been able to create visualizations and reports 3h after the revision of the moment tensor solution.

III. Results

For the 24 August, 2016, M_w 6.0 central Italy earthquake, the seismologists' reviewed TDMT solution is reported on `http://cnt.rm.ingv.it/event/7073641`. We have adopted the traveltime tomography produced by [Di Stefano & Ciaccio, 2014] as 3D wavespeed model and constructed a grid of 1200x1200x80 km covering the whole Italy and honoring the topography with a resolution on the surface of 2 km. The simulation is numerically accurate for seismic waves of period down to 5 s. It has been submitted on 256 cores provided by Fraunhofer Institute for Algorithms and Scientific Computing SCAI in the VERCE e-infrastructure and on 512 cores of INGV HPC clusters.
The resolution of the simulation has been chosen with the goal of providing a visualization of the seismic wavefield propagation to the general public showing the wavefront distortions due to topographic effects and to the presence of lateral heterogeneities of material properties. Fig. 1 shows a comparison between data (black seismograms) and 5-100 s lowpass-

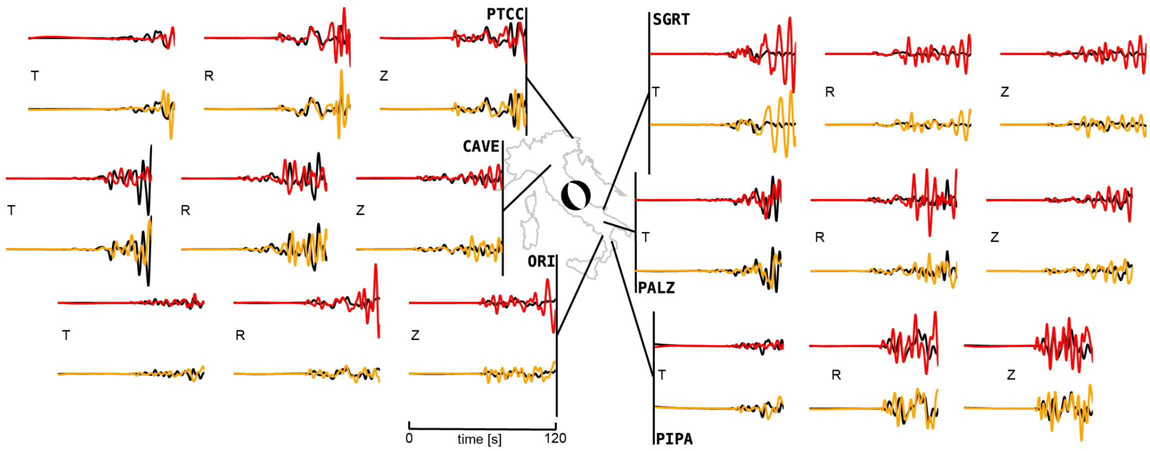

Figure 1: *Comparison of data (black) and synthetics three-component velocity seismograms at selected stations of INSN network (red - velocity model [Di Stefano & Ciaccio, 2014]; green - velocity model IMAGINE_IT). Seismograms are 20-50 s lowpass-highpass filtered, the traces are 180 s long. The TDMT moment tensor solution is reported at* `http://cnt.rm.ingv.it/event/7073641`

highpass filtered synthetic seismograms (red seismograms). Synthetic traces show a good agreement with data, especially for the first arrivals. Horizontal components show reverberation in later arrivals (see SGRT station) suggesting that the traveltime tomography is not able to capture the surface waves. We have initially adopted this velocity model proposed by [Di Stefano & Ciaccio, 2014] since it is ready to be used in the workflow and freely available on the VERCE platform at the time of the seismic event. Nevertheless, in order to understand the impact of the adopted wavespeed model, during the weeks after the earthquake we have performed some simulations (orange seismograms) using the new lithospheric full wave tomography resulting from adjoint inversion inside the PRACE project IMAGINE_IT ([Magnoni et al., 2015]). These simulations confirm that a better result for surface waves is obtained if full wave tomography is adopted ([Zhu et al., 2012]), so we plan to substitute the traveltime tomography with the IMAGINE_IT model. Anyway, the results of the previous analysis confirm that the simulation with [Di Stefano & Ciaccio, 2014]'s tomography provides a good agreement of data and synthetic seismograms from the point of view of visualization purpose. In particular, we have decided to visualize the vertical component of the velocity wavefield that doesn't suffer of late reverberations. Shakemovie snapshots at different time steps along the topographic surface are represented in Figure 2. Red colors denote positive values (up) and blue negative values (down). The view is from South-West. Wavefront distortions are due to topographic effects and to the presence of lateral heterogeneities of material properties. In addition to the visual perception of the earthquake, the animation provides a first idea that seismic waves propagated with North-North East and South-West preferential direction. We highlight that at this stage we didn't incorporate any kinematic behavior of the fault, so the cause of such directional amplification is related to the orientation of moment tensor axes and to the material heterogeneity described in the adopted tomography (see seismograms in Fig. 1). The animation supports the results on the fast macroseismic field elaborated by haisentitoilterremoto (`http://mappe.haisentitoilterremoto.it/7073641`) through realtime online surveys, that report higher intensity in the municipalities located NNE to the epicenter. In particular, the animation clearly explains why the felt intensities are lower in Tuscany and in North-Tyrrhenian regions. This result is confirmed by the empirical shakemap (`http://shakemap.rm.ingv.it/shake/7073641/intensity.html`, Fig. 3). The animation has been constructed using Paraview (`www.paraview.org`). Human intervention is needed for the choice of a prospective point of view that maximizes the viewer perception of main geographical features, in particular valleys and mountains that affect the seismic wavefield. After the analysis of the accuracy of data and synthetics, significantly sped up by the VERCE e-infrastructure, we have released a video to the public through the Youtube Channel INGVterremoti approximately 6h after the mainshock. The mesh, the velocity model and the input files are openly available on the VERCE e-infrastructure (`https://portal.verce.eu/home`) for the researchers who want to reproduce the simulation results.

IV. Discussion

The main reason to release a fast but accurate simulation of the seismic wave propagation is not only to satisfy a request of reliable scientific information in the realtime world of the media system. The driven motivation is to provide a visualization of the natural phenomenon to the general public. The animation is composed by two layers. The first one consists of a background image: the topographic representation of the region affected by the earthquake. Its recognition is based on what has been defined a distal adjustment ([Dondero and Fontanille, 2014]): the viewer looks from an unusual point of view, however, this cognitive effort is pretty reduced by the familiarity that even the general public has with satellite pictures. This layer offers the viewer a referential anchorage. The lack of colors introduces a minimum degree of abstraction that helps recognizing the video as a scientific schematization. The second layer consists of the graphic animation and it conveys scientific information through conventional representation: a "semi-symbolic system" ([Greimas, 1984]) that, in this case, requires some form of instruction to be decoded and a certain amount of cognitive effort. How does the public of this video understand the seismic phenomenon? The first way (more correct but more difficult too) is to interpret the animated infographic decoding the conventional representations of physic dimensions. The second way is to interpret it on the basis of the knowledge of other phenomena that present some structural or visual analogies with the animation (i.e. one comment says: "a stone thrown in the center of Italy that produces waves"). Together with the visual features we have already described, this creates what in art history or media studies has been called a "transparency" ([Marin, 1993]) or "immediacy" ([Bolter and Grusin, 1998]) effect: the viewer illusion of being seeing the actual world (for instance: a painting is conceived as the view we have looking through a window).

We have already observed during the 2013 seismic sequence in Lunigiana (Italy) (`https://youtu.be/LCXKuixgTyU`) that such animations attract attention of a surprising large audience. Our hypothesis is that the request of shakemovie's visual content derived from the need of "seeing" the earthquake. If we compare it to a volcanic eruption, it is evident the lack of "visual perception" and we can expect that the people, affected by the shaking or simply observing the damages on news programs, try to fill up this visual gap.

For this earthquake as well, the animation reached a broad audience. More specifically, it was broadcast by popular tv shows, such as Porta a Porta, and Public Television news programs; online, it was originally published on INGV YouTube channel (`https://youtu.be/x6tDOjFGTs4`) and on INGV blog (blogpost on August 26 (`https://goo.gl/glqxJ6`), and it was shared (as an "embed", or as an original video) by many news outlets. Literature on social media describes three main different forms of interactions on YouTube: audience, social, and platform interactions. The first can be measured by metrics such as exposures; the second by analyzing comments, shares, etc.; the third can be identified in the related meta-

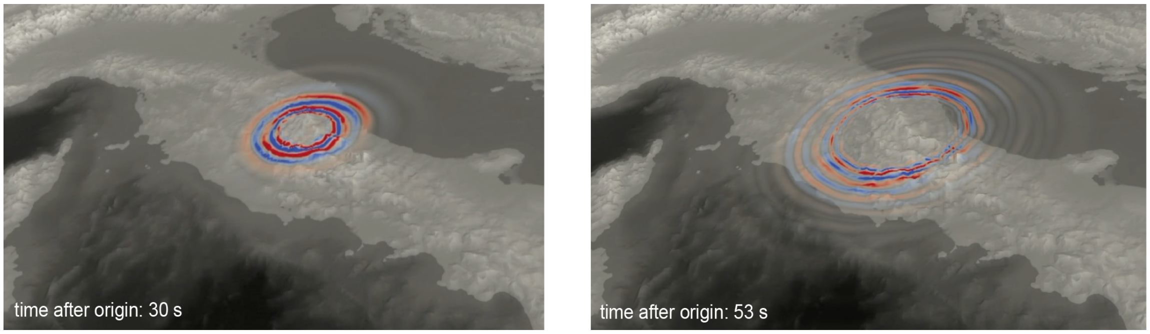

Figure 2: *Snapshots at different time steps of the vertical-component velocity wavefield propagating along the surface. Red denotes positive (up) values and blue negative (down) values. The view is from the South. Wavefront distortions are mainly due to topographic effects and to the presence of 3D heterogeneities, see* `https://youtu.be/x6tDOjFGTs4` *for full animation.*

data ([Giglietto et al., 2012]). With regard to audience metrics, we can underline that the video reached over 260.000 views on YouTube (last update, September 21, 2016). The daily distribution of views rapidly grows on August 24, showing a peak on August 25, and dramatically decreasing in the following days (as usual for earthquake related news).

The YouTube video was mainly viewed through mobile phones (59%), PCs (29%), and tablets (11%). View duration is higher on tablets (0:50; 83% of the whole video), followed by PCs (0:49, 82%), and by mobile phones (0:45, 76%); average view duration is 0:47. Viewers are disproportionately male (75%), and the prevailing age cohorts are 25-34 (27%), 35-44 (23%), and 45-54 (17%). Audiences viewing the video on other online platforms (including the main Italian online newspapers: for instance, Repubblica.it counts more than 150.000 additional views) have to be added to describe the global online impact of the video. When referring to scientific "dissemination videos", audience metrics can be considered "as a good indicator of failure or popularity" ([Thelwall et al., 2012]). While the emotional impact of the central Italy seismic sequence can explain such a great impact, other videos by INGV, related to the same seismic sequence, reached disproportionately lower audiences: for instance, the 3D video showing the fault reached around 53.000 views on YouTube and 8.000 views on Repubblica.it. The statistics are remarkably high considering also similar services, such as California or Global Shakemovie Portal or even comparable with the Shakeout Drill (`https://youtu.be/nvltp9Nf5T4`). Therefore, we can assume that Shakemovie's content or formal aspects triggered audience interest. Nevertheless, even if the analytics support the hypothesis of the visual gap, a survey of the viewers is necessary to demonstrate it. When it comes to social metrics ([Giglietto et al., 2012]), we can observe a medium-high level of audience engagement: the video was shared more than 700 times from YouTube (mainly on Facebook and WhatsApp), and thousands of times from the other platforms. The number of comments is significantly lower than the sharing activity (around 100 on YouTube), and a majority of them is partially off-topic, spreading disinformation about the seismic sequence, or focusing on political issues (criticizing Italian Government and other Institutions). Only a minority of comments focuses on the scientific information proposed, while some users ask for details for understanding the video. In this regard, also considering that some of the comments use foul language or can be classified as hate speech, a constant moderation of INGV's social media channels would contribute to enhance a more constructive online debate, also reducing the circulation of earthquake-related disinformation. The "transparency" effect could

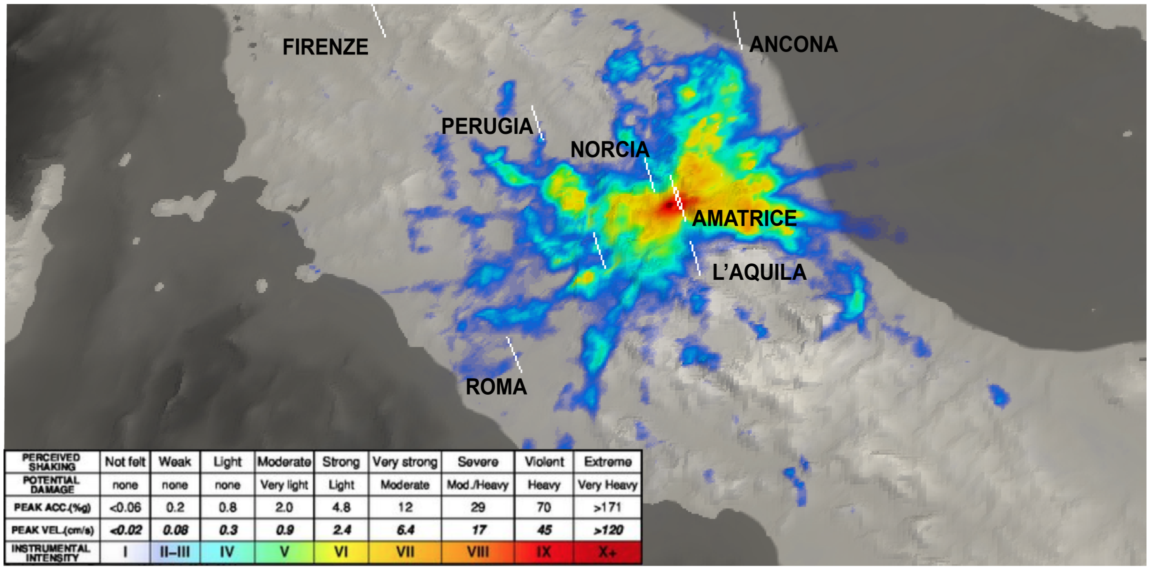

Figure 3: *3D synthetic ground motion shakemap obtained with point source TDMT moment tensor, velocity model of [Di Stefano & Ciaccio, 2014], SRMT30 topography. The comparison with the ground motion data in the epicentral area requires simulation with a finite fault model of the seismic source. Unfortunately, it need additional time to be determined so it is not available for fast simulations with communication purpose.*

contribute to explain why so few comments have focused on scientific aspects: the scientific explanation has been perceived as non-problematic (or transparent, or immediate) and thus attention has been attracted, even more than usual, by other issues (such as politics). It is noteworthy to recognize that the prevalent direction of the wave propagation (and in general the spatial heterogeneous behavior of the seismic wave) is not evident for the majority of the viewers, requiring additional information in the description of the animation. In order to highlight this aspect, a redesign of the animation format could be necessary.
The visibility obtained by the video, in terms of user reach and media outlets shares, can contribute to the perception of INGV not only as a scientific institution, but also as an effective news source, which is able to promptly producing newsworthy material, thus consolidating the relation between INGV and the media system. Unfortunately, the whole process is not fully automated and human intervention is required especially in the creation of the animation and in the evaluation of the accuracy. These parts of the workflow require additional work in order to provide a near realtime visualization of seismic propagation accessible to broad audience.

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