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AN INTUITIVE 3D INTERFACE FOR DEFINING SEISMIC PROFILES BY PLINIUS

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Abstract

Costa Rica is a country with a huge tectonic riches to the seismologists, but also is a hight risk zone. Defining those zones is important to warn the population. Until now, most of the data analysis is carried out using two-dimensional systems. For these reasons, we developed Plinius, with this tool we reduce the cognitive burden involved in this type of visualization, helping visualize earthquake hypocenters for earthquakes occurred during 1984-2016, thereby, a total of 1012,413 earthquakes. One of the most important problems to resolve is: how it be defined seismic profiles to determine hight risk areas? In this paper, we present the interface that is proposed in Plinius like an answer to the seismic profile problem. The objective of the seismic profiles is to display a cross-section cut showing tectonic plate subduction trends. This paper presents an overview of an intuitive human interface that allows users to access multiples seismic profiles within a few seconds. This interface is part of Plinius, a 3D tool that visualizes all earthquakes occurred in Costa Rica since 1984. Plinius was developed explicitly for this purpose. Through Plinius, the location of 112,413 earthquakes occurring from 1984-2016 can now be observed in three dimensions. Additionally, the user can save images and data in several formats for comparison and analysis at a later time.

Keywords

3D visualization; hypocenter; seismic profiles; subduction zone; earthquake visualization; seismic attributes; seismic interpretation,

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1. Introduction

Traditionally, seismic profiles are used to analyze the structure and distribution of subduction zones. Seismic profiles can be used to calculate how one crust goes under another and which deformation and slope are associated with the elastic response.

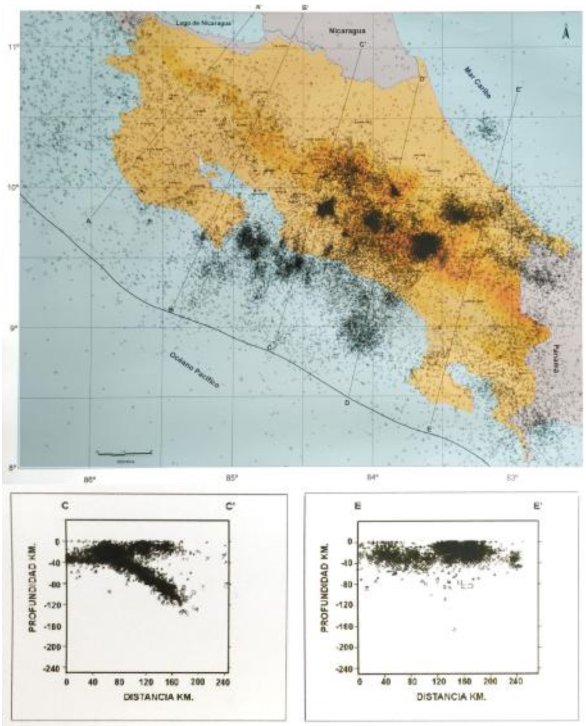

Fig.1 Presents a traditional analysis (cross-section cuts based on depth) and depicts subduction of the Cocos Plate underneath the Caribbean Plate (OVSICORI). Figure 1: Seismicity and seismic profiles in Costa Rica (OVSICORI)

Symbology, such as crosses and squares, are used on the map to define depths, and a similar symbology is used in the cross sections to show the magnitude of the earthquakes (hypocenters). The cognitive burden of the image presented in Figure 1 is extremely high and becomes even more complex when attempting to monitor activity over different time periods.

To minimize the cognitive load and reduce the errors associated with traditional analysis approaches we propose the use of an interface that is designed to define the seismic profiles inside a 3D visualization.

Plinius is a visualization tool that has been specifically developed for this purpose (http://skizata.com/ireal-3.0.html). Through Plinius, the location of more than 112,000 archived earthquakes occurring from 1984-2016 (collected by Volcanological and Seismological

Observatory of Costa Rica, OVSICORI, http://www.ovsicori.una.ac.cr) can be observed in three dimensions within the context of Costa Rica's geographic features.

2. Related Work

As previously described, traditionally, seismic profiles are used to assess the behavior of crusts in great subduction zones (Nakamura et al. 1996; Hashida et al. 1984; Patel et al., 2008).

A 2D approach (like that presented in Figure 1) has been commonly used (Schepers et al. 2017).

Some exceptions work tridimensionally, like that employed by Yiping et al. (2010). However, the user needs a lot of time to obtain the profile (Ercoli et al. 2012; o Su et al. 2014), or the tools emphasize the geologic characteristics of the soil (Cerfontaine 2016).

There are also approaches that employ two-dimensional slices in three-dimensional spaces, as in Hayes (2012) and Maesano (2016). However, the three-dimensional nature of data deserves to be treated as such to increase the efficiency of the analysis.

Plinius is completely three-dimensional, and all profiles and analysis are developed in this space.

3. Seismic Profiles in Plinius

We have developed a simple interaction process to define each possible profile that the user could need in the three-dimensional space. Taking advantage of the fact that Plinius always works in 3D, the user can see all possible profiles in real time.

Traditionally, a seismic profile is achieved by defining two parallel lines. In Plinius, we need only three points: The first two points to set the first line and the third to determine the parallel line (see Figure 2).

We have a point cloud with all the 112.413 hypocenters and filter them with the planes defined by the user. To achieve that, first of all, in accordance with the user's indication, Plinius will automatically navigate to an exact orthogonal point of view, a place at which the aspect ratio between the perspective and the screen coordinates are know. At this particular point of view, we collect the three points, $P_1 = (x_1, y_1)$, $P_2 = (x_2, y_2)$, and $P_3 = (x_3, y_3)$, from the user.

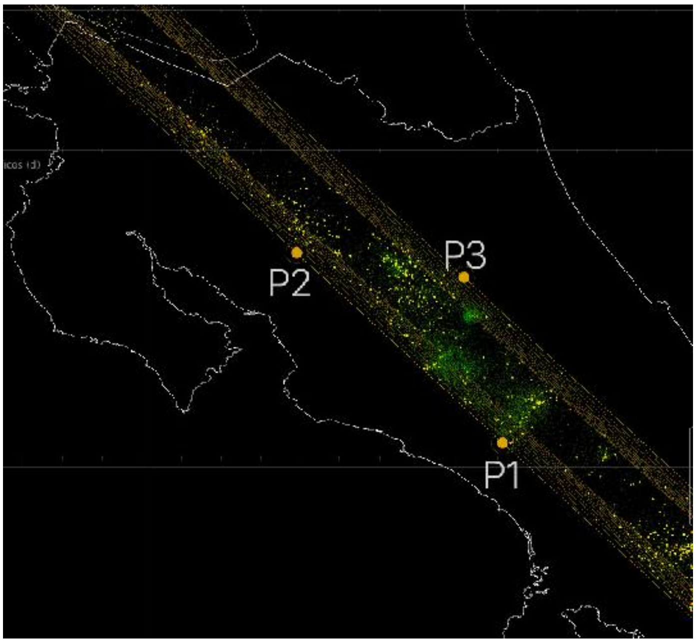

Fig.2 The three points needed to define a seismic profile in Plinius

The detection of hypocenters inside the planes is achieved by calculating the equations for both generated curves, in this case, corresponding to two lines. The equations employed are as follows:

(1) Typic equation of the flat cylinder (first line) $\pi: f(x) = y = m \quad + b_1$, where

(2) $m = \frac{y_2 - y_1}{x_2 - x_1}$;

(3) $b_1 = y_2 - m \quad x_2$;

(4) Second line (equation of the flat cylinder) $\phi: g(x) = y = m \quad + b_2$ because of $\pi \parallel \phi$ with

$b_2 = y_3 - m \quad x_3$;

Using these, we can define which hypocenters are in between the planes. In order to achieve that we used the epicenters instead of hypocenters. First, given a epicenter $E(x_e, y_e)$, we calculate the y-values for x_e in both lines by:

(4) $f(x_e)$

(5) $g(x_e)$

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Now, we take the original y_e and compare its position with $f(x_e)$ and $g(x_e)$. If $f(x_e) < y_e < g(x_e)$ then, the epicenter is between the lines (see Figure 3), and hypocenter is between the planes.

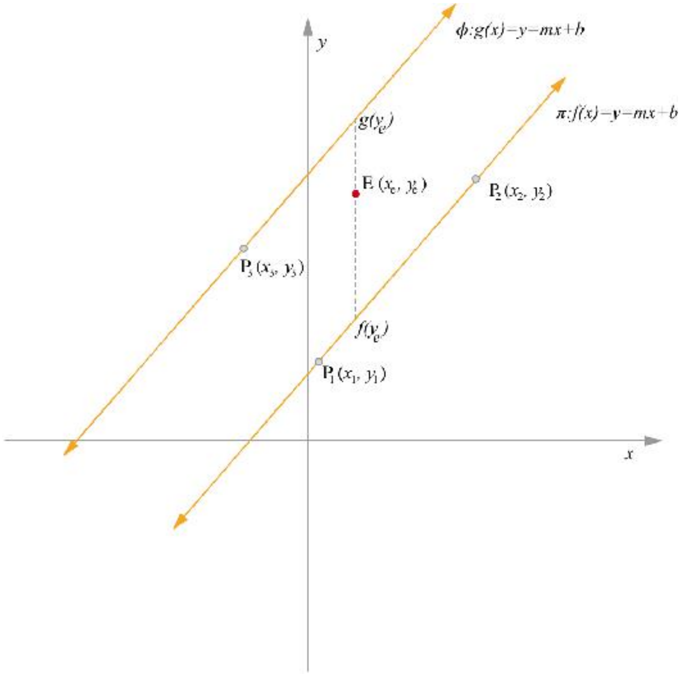

Fig.3 An example of an epicenter $E(x_e, y_e)$ between the lines π and ϕ

The z_e value of the hypocenter is ignored because the planes are orthogonal to the Earth's surface; ergo, If $f(x_e) < y_e < g(x_e)$ then, the hypocenter is inside the selected profile.

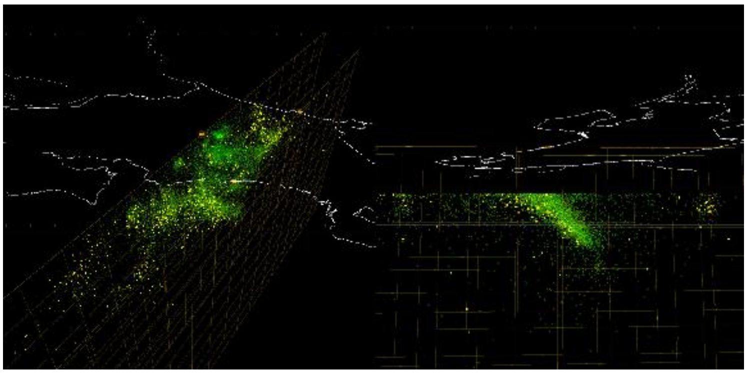

Fig.4: Two perspectives of the same seismic profile defined by users, allowing visualization of plate rupture zone (on the right).

Also, we implemented a new profile that we allow visualizing seismic swarms around a specific point. This filter shows cylindrical cross-section cuts to analyze local failures.

From 2 points, seismologists can define the location and radius of the cylinder. So seismologists can isolate a local area of interest, like a volcano, as in figure 16 (Irazú Volcano).

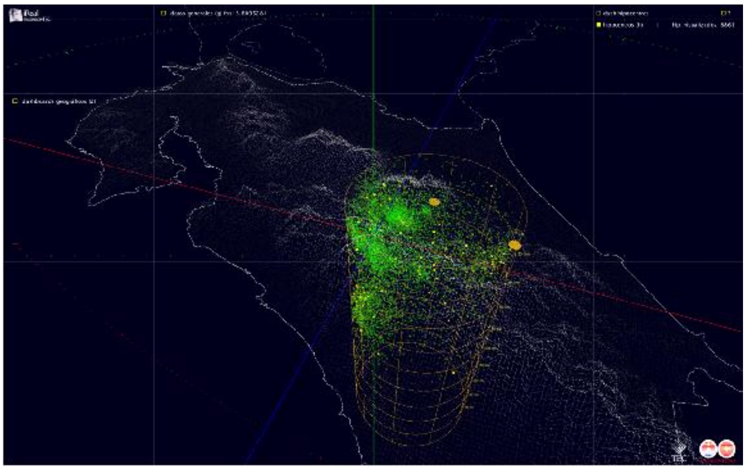

Fig.5 Cylindrical Area of Interest defined by seismologists, allowing visualization of Irazú volcano zone.

4. Evaluation

We conducted a user study through which we compared Plinius with a conventional approach to defining profiles.

Traditionally, scientists have to extract (from a database) the selected hypocenter by calculating the distance between its position and the latitude and longitude of the place of interest. With Plinius, the user sees where he/she wants to locate a profile and the direction and width they want to have it, and asks the system to calculate the results. All these choices are intuitive and located in the desired geographical area.

The subjects were also asked post-use qualitative evaluation questions, including those that sought their insights into how Plinius compared to the conventional approach, which they would prefer to use in the future, and which of two methods they found to be more intuitive. All participants (100%) commented that Plinius was far more intuitive than the conventional approach and stated that they would choose to use Plinius in the future.

These preliminary usability experiments suggest the user interface is quite intuitive for users to utilize with minimal training required.

Scientists additionally mentioned the need for profiles to be saved in different formats. Plinius allows images to be saved in PNG and PDF, and as data files in CSV (comma separated values) format. They want to use these files for further presentations and analyses.

5. Conclusions and Future Work

In this paper, we described an intuitive interface that has been designed to efficiently and effectively define seismic profiles. This 3D interface dramatically reduces the time required to develop and analyze multiple seismic profiles.

While the size of the user study was not broad enough to draw solid conclusions, it provides compelling indications for future work.

We suggested that 3-dimensional data have to be analyzed in 3D ambients. The cognitive burden of analyzing 3D data in 2D interfaces is so high that the time taken to reach conclusions rises exponentially.

A lot of research conducted today, such as searching for oil and gas, and identifying hydrocarbon reservoirs (Patel et al. 2008) and seismogenic and tsunamigenic potential (Gao 2016), employ 3D databases and could benefit from the availability of a 3D approach.

Going forward we (the iReal research group of the Technological Institute of Costa Rica) plan to visualize several 3D databases, including ways to represent, analyze and observe these data, to identify methods of making things easier and more intuitive for the user in the future.

6. Acknowledgements

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