How Earth's internal structure is characterized by seismic and muon tomographies

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Talk Abstract

In the study of Earth physics, mathematical theories are employed to quantify and model the physical properties of the inner Earth. In this work, two different methodologies, widely used in geophysics, are presented: seismic and muon tomography. The seismic tomography determines the velocity of seismic wave propagation, while the muography – as a new geophysical tool – measures the transmission of muons, which are consequently converted into densities. These two techniques complement each other and provide information about different rock properties (densities and velocities), related by empirical formulas. In seismic tomography, we use earthquakes or vibrations emitted by humans to record the seismic waves' arrival times at the seismometers implemented around the area of interest. We talk respectively about passive and active seismic tomography. In the first case, two inverse problems need to be resolved: 1- the earthquake localization, determining the position and origin time of the earthquake, and 2- the computation of the velocity of seismic wave propagation. On the other hand, active seismic tomography consists of installing geophones and creating vibrations in different ways to create a distribution of seismic rays in an area intended to be explored. In that case, one unique problem needs to be resolved: predicting the velocity distribution in two or three dimensions. Both problems have the objective of understanding the structure of the Earth's interior, having a resolution of some kilometers, for passive inversion, and a few meters, for active seismic tomography, using the same inverse theory with different degrees of control on the model resolution. The second approach, the muography, uses the natural emission of muons coming from the interactions between cosmic rays and the atmosphere to study the structure of mines, volcanoes, and archeological sites. The muographs describe the distribution of the average density deduced from the attenuation of the muon flux, measured using a muon telescope while crossing a media. The recording of the accumulated muon detections forms a muon direction map reflecting the muon flux's attenuation while crossing a specific material. This attenuation is proportional to the density of the crossed material and/or the amount of detected muons. Therefore, areas traversed by a large number of muons will be related to low densities, while those with high density will detect a poorer quantity of muons. To obtain high-resolution muographs (i.e. "muon r-ray" images), the detection maps are normalized using the open sky muon flux. Merging this information and the distance that the muon will travel through a media, muon counts can be translated to average rock densities calculated within the column of matter being crossed in each direction. Both models are obtained by employing the inverse theory, which is non-linear for seismic inversion and linear for muography, using different mathematical approaches. The inverse problem is generally applied to predict a model based on a specific dataset. In this approach, various models can be obtained from the same set of data leading to the non-uniqueness of the solution. This means that, due to the errors present in the data, some model details cannot be resolved. This barrier in the resolution of the inverse problem is accepted, and mathematical and physical theories as well as prior information about the model, should be used to constrain the solutions and give more realistic inverted models. As an outcome, these two geophysical approaches are joined together to converge to a complete and reliable interpretation of the Earth's structure and lower its uncertainty.

Keywords: inverse problem, active seismic tomography, passive seismic tomography, muon tomography.

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