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Mapping a Part of Neuquén Basin in Argentina by Global-phase H/V Spectral Ratio

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SUMMARY

We investigated the applicability of global phases (epicentral distances of $\geq 120^\circ$ and $\geq 150^\circ$) for the H/V spectral ratio to identify the fundamental resonance frequency. We applied the method to delineate a part of Neuquén basin in Argentina without the need for active seismic sources. We obtained fairly identifiable fundamental resonance frequencies in the range 0.15 Hz to 2.5 Hz. Receiver-side resonances were pronounced by stacking the H/V spectral ratio over many earthquake recordings. By doing so, the same fundamental resonances were found by using different window (P and S-phases) as well as different epicentral distances ($\geq 120^\circ$ and $\geq 150^\circ$). Our result, assuming average velocity, shows identical features in comparison with both the Bouguer anomaly and the active seismic profile nearby, indicating that our method is reliable. The method we demonstrate here can be applied in the fields particularly when the seismic array of long-term purposes is available.

Introduction

In oil and gas exploration, maturation and migration processes of hydrocarbons are often related to the characteristics of the basin. In this sense, the estimation of the basin depth (top of basement) is of fundamental importance. For frontier regions, inversion of gravity data gives a first indication of basin depth, if such data is available. A more accurate depth is generally not found until an active seismic survey is conducted. In this study, we propose a passive seismic method that can provide such solid estimation without the need for active seismic sources.

Among passive seismic approaches, it is well known that the resonance frequencies of the subsurface can be retrieved by H/V (horizontal/vertical) spectral ratio (e.g., Nakamura, 1989) using ambient noise. With the law of quarter wavelength, one can interpret the thickness of the sediments above the basin when the velocity model is known (Tsai, 1970).

In the following, we propose to use the H/V spectral ratio using global earthquakes phases (we abbreviate our method as GloPHV) and apply it to data from the Malargüe region, Argentina (Fig.1). In this region, the Malargüe basin is located. The Malargüe basin is a sub-basin of the Neuquén basin that has been producing about 44 % of oil and gas in Argentina over many years and is expected to contribute for unconventional type of play as well. Since global phases have almost vertical incidence with respect to the receivers at the surface, the resonance spectra can be directly interpreted. Moreover, the usage of global phases pushes the lower frequency down sufficiently to capture the fundamental resonance frequency, which can be related to the depth of the top of basement. Furthermore, we compare two results when earthquakes with epicentral distances $\geq 120^\circ$ (about 80 global phases) and $\geq 150^\circ$ (about 35 global phases) are used, respectively.

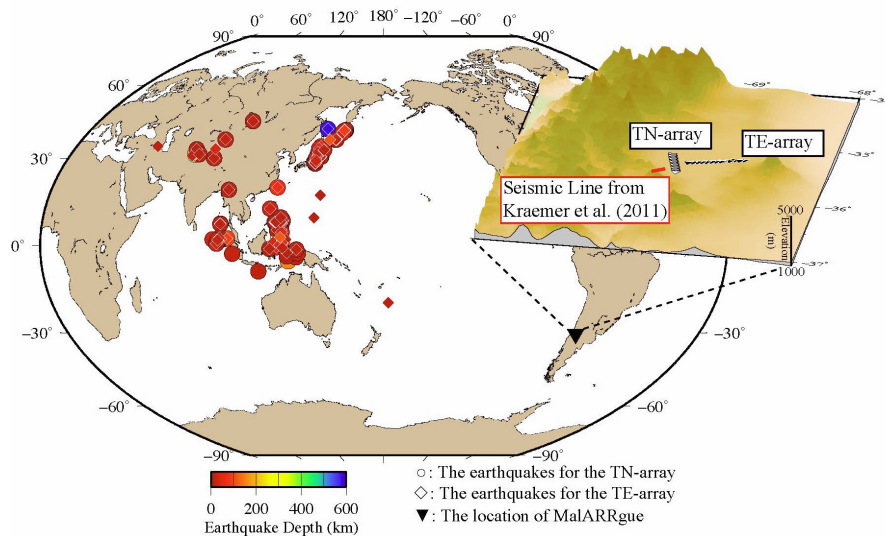


Figure 1 Topography of TN- and TE-array east of Malargüe, Argentina, (Ruigrok et al. 2012) with a location map of global earthquakes we used for GloPHV (epicentral distance $\geq 120^\circ$). The red line denotes the location of an active seismic survey (Kraemer et al. 2010).

Method

Our assumptions in GloPSI for a P -window (input data with global P -wave phases) are:

- Global phases become almost planar with respect to the receiver array and have no predominant resonance frequency within the frequency band of interest (0.3 to 1.5 Hz), prior to interaction with the crust below the array.
- Illuminating wavefront contains only P -wave phases inside the P -window.

- Horizontal-component recording contains primarily P-to-S converted waves.

If the above assumptions are fulfilled, the observed amplitude spectra for vertical and horizontal components can be written as (e.g., Field and Jacob, 1995)

$$|\hat{O}^V(\mathbf{X}_R)| = |\hat{E}\hat{G}^P(\mathbf{X}_B, \mathbf{x}_S)\hat{L}^P(\mathbf{X}_R, \mathbf{x}_B)\hat{I}(\mathbf{X}_R)| \quad (1)$$

$$|\hat{O}^H(\mathbf{X}_R)| = |\hat{E}\hat{G}^S(\mathbf{X}_B, \mathbf{x}_S)\hat{L}^S(\mathbf{X}_R, \mathbf{x}_B)\hat{I}(\mathbf{X}_R)| \quad (2)$$

where \hat{O} is the observed amplitude spectrum, \hat{E} is the source spectrum of a global earthquake, $\hat{G}(\mathbf{X}_B, \mathbf{x}_S)$ is the Green's function between the source \mathbf{x}_S and the top of the basement \mathbf{X}_B , $\hat{L}(\mathbf{X}_R, \mathbf{x}_B)$ is the local site effect between the top of the basement and the receiver \mathbf{X}_R , $\hat{I}(\mathbf{X}_R)$ is the instrument response, the hats indicate that the quantities are in the frequency domain, superscripts V and H denote the vertical and the horizontal component, respectively, and superscripts P and S denote P- and S-waves, respectively. Then, GloPHV is obtained by the spectral division from equations (1) and (2):

$$GloPHV = |\hat{O}^H(\mathbf{X}_R)| / |\hat{O}^V(\mathbf{X}_R)| \approx |\hat{L}^S(\mathbf{X}_R, \mathbf{x}_B)| / |\hat{L}^P(\mathbf{X}_R, \mathbf{x}_B)|. \quad (3)$$

GloPHV can be applied to an S -window (input data; global P - and S -wave phases) as well assuming:

- The observed amplitude spectra for vertical and horizontal components are dominated by direct P -wave phases (e.g., PPP) and direct S -wave phases (e.g., SKS), respectively.
- Earthquake source spectra for the P - and S -wave phases are the same or related by frequency-independent scaling factor.

The paths effects $G^{P,S}$ for the S -wave phases are different from the P -wave phases. However, resonance frequencies along the paths (e.g., D-double-prime layer) should fall outside (be lower frequency than) the band we use. Hence, we obtain a scaled version of equation (3) from the S -window (Fig.2).

A conceptual diagram of GloPHV for the P -window or the S -window is given in Fig.2.

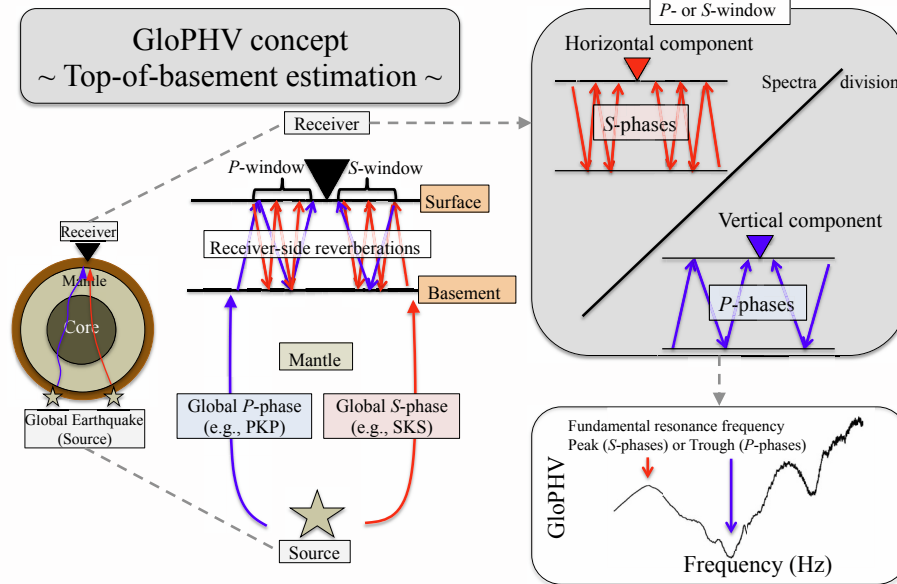


Figure 2 GloPHV concept using a P -window or an S -window. No matter which window (P - or S -window) we use, P - and S -waves are dominant in vertical and horizontal components, respectively, yielding identical fundamental resonance frequencies.

According to Tsai (1971), the fundamental resonance frequency, can be written as

$$f_0^{P,S} = V_{P,S} / 4Z, \quad (4)$$

where $f_0^{P,S}$ is the resonance frequency for a P- or a S-wave, $V_{P,S}$ is the P- or S-wave velocity, and Z is the layer's (sediment) thickness. Fig.3 shows the general data-processing flow we applied.

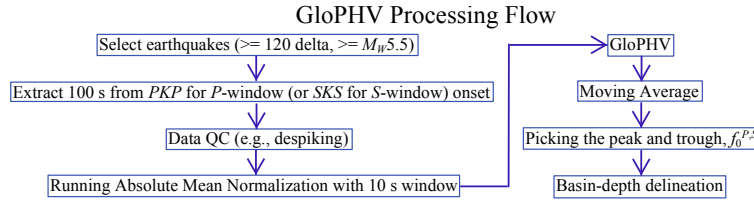


Figure 3 Seismic processing flow we apply in this study.

Results and Discussions

GloPHV results for epicentral distance $\geq 120^\circ$ of TN- and TE-array for P - and S -windows are shown in Fig.4, together with the P -window results for epicentral distance $\geq 150^\circ$. For the case of epicentral distance $\geq 150^\circ$, the number of used phases drops from 69 to 38 and 80 to 32 for TN- and TE-array, respectively, compared to the case with epicentral distance $\geq 120^\circ$. We find that regardless of window (P or S) or epicentral distance ($\geq 120^\circ$ or $\geq 150^\circ$) used, the results show almost identical fundamental resonance frequencies, indicating that the aforementioned assumptions for GloPHV are fairly fulfilled.

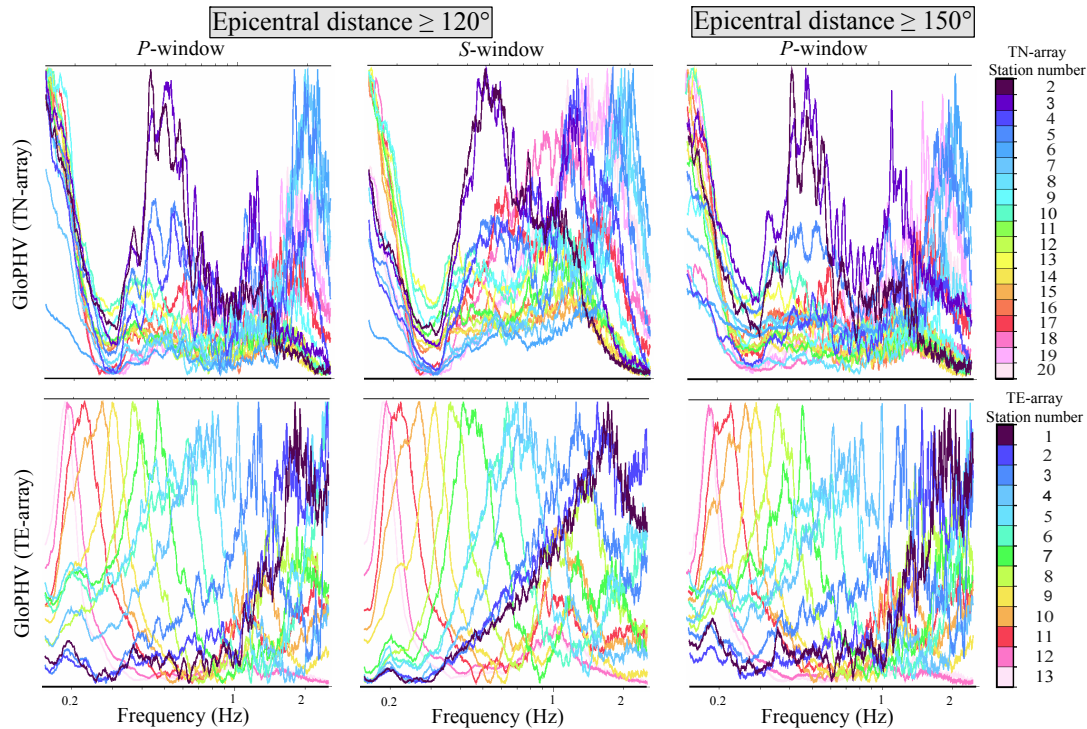


Figure 4 GloPHV results for the TN- (top) and TE-array (bottom) when using P - and S -windows for epicentral distance $\geq 120^\circ$ (left and middle) and P -windows and epicentral distance $\geq 150^\circ$ (right).

For the conversion to depth with equation (4), we use constant P- and S-wave velocity model for the sediments below the TN- and TE-array using Fariás *et al.* (2010) as a guide. We show the GloPHV-estimated depths in Fig. 5. The top-of-basement depth from GloPHV shows a shallowing trend of the basement towards the east. This is in very good agreement with the regional Bouguer anomaly (which is indicative of the basement depth). The active seismic profile by Kraemer *et al.* (2011) (a red line in Fig.1) also shows similar tendency for the top-of-basement depth as our results from GloPHV.

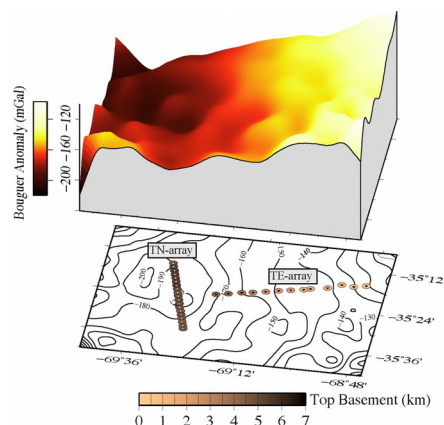


Figure 5 Estimated basin depth by GloPHV (brown-scaled circles) superimposed on a 2D Bouguer anomaly map. The Bouguer anomaly is also shown in 3D (top).

Conclusions

We showed a method that uses global phase for computing the H/V spectral ratio to estimate the depth of top-basement by using different windows (P and S) as well as different epicentral distances ($\geq 120^\circ$ and $\geq 150^\circ$). We used field data recorded in the Malargüe region, Argentina, which is located northeast location of Neuquén basin. Our result shows identical features in comparison with both the Bouguer anomaly and the active seismic profile nearby, indicating that our method is reliable.

Acknowledgements

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References

- Fariás, M., Comte, D., Charrier, R., Martinod, J., David, C., Tassara, A., Tapia, F. and Fock, A. [2010] Crustal-scale structural architecture in central Chile based on seismicity and surface geology: Implications for Andean mountain building. *Tectonics*, **29**, TC3006.
- Field, E.H. and Jacob, K.H. [1995] A comparison and test of various site response estimation techniques, including three that are non reference-site dependent. *Bulletin of the Seismological Society of America*, **85**, 1127-1143.
- Kraemer, P., Silvestro, J., Achilli, F., Brinkworth, W. [2011] Kinematics of a hybrid thick-thin-skinned fold and thrust belt recorded in Neogene syntectonic wedge-top basins, southern central Andes between 35° and 36° S, Malargüe, Argentina. *AAPG Memoir*, **94**, 245-270.
- Nakamura, Y. [1989] A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Quarterly Report of Railway Technical Research Institute*, **30**, 25-30.
- Ruigrok, E., Draganov, D., Gómez, M., Ruzzante, J., Torres, D., López Pumarega, I., Barbero, N., Ramires, A., Castaño Gañan, A.R., van Wijk, K. and Wapenaar, K. [2012] Malargüe seismic array: Design and deployment of the temporary array. *The European Physical Journal Plus*, **127**, 126.
- Tsai, N.C. [1970] A note on the steady-state response of an elastic half-space. *Bulletin of the Seismological Society of America*, **60**, 795-808.