Rio de Janeiro - Brazil
16-19th of August, 2021

# Shallow Structure of the Pantanal Basin with Receiver Function, Surface Wave Dispersion and H/V Curve

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This paper was prepared for presentation during the 17th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 August 2021.



## Abstract

Receiver functions and surface waves have been used to study crust and lithosphere under the Pantanal Basin. However the upper crust in the region still lacks information. We inverted high frequency receiver functions, as well as dispersion and H/V spectral curves to obtain Vs-profiles, focusing on shallow structure of the crust. We used two procedures to invert the data: case a, we inverted H/V curve alone and used its final model as initial model for joint inversion of receiver function and dispersion; case b, we developed a program to invert the three data sets together. Results for C2SB station (BL network, Chapadão do Sul, MS), which is close to the basin, show a good adjustment to data, with basement at about 3 km and low wave velocities in the first km. We had some discrepancies in the Moho (between 4 and 47.5 km), as low frequency receiver function would be more appropriated for this depth.

## Introduction

Pantanal Basin (PB) has been target of recent studies, since the model of its origin is still under discussion. It is a sedimentary basin of the Andes foreland system, located in South-West Brazil (Fig. 1). Ussami et al. (1999) have proposed that the basin was formed due to the stresses during the passage of the forebulge. Horton & DeCelles (1997), however, ague that the basin is located in the back-bulge. Cedraz et al. (2020) have pointed that the Transbrasiliano Lineament, a great tectonic structure that crosses South America from the Chaco Basin, in Paraguay, to Northeastern Brazil, had an important role in the basin development, which could have resulted from delamination. Although new studies have brought new information of deep crust and lithosphere structure of PB (e.g. Rivadeneyra-Vera et al., 2019), the region still lacks information of its shallow structure. Basement depth is estimated at 500 m from 12 drill holes, seismic and gravity data (Ussami et al., 1999).

Receiver function (RF) is widely used in crustal studies to determine wave propagation velocity profiles (Ammon, 1991; Owens et al., 1984). Due it is a non-unique inversion problem, it is common that RF is jointly inverted with surface waves dispersion curves (DC) (e.g., Julià et al., 2000). Joint inversion of RF and DC can be used to study shallow crustal structure, but it is not always possible to obtain short periods DC, making it difficult to obtain reliable shallow models (e.g., Assumpção et al., 2009). Horizontal / vertical spectral ratio (H/V curve) can be used to constrain sedimentary layers in DC inversion (García-Jerez et al., 2016). It is possible to invert it with RF instead, bringing stability for inversion in shallow layers while long period DC stabilize the inversion in deep layers.

In this work, we use receiver functions, dispersion curves and H/V curves to calculate S-wave velocity profiles beneath Pantanal Basin, providing more data of shallow structure of the crust in region.

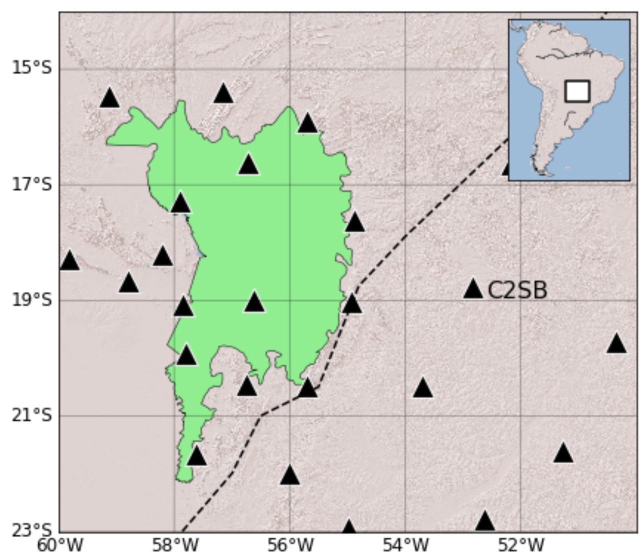


***Fig. 1*** *- Pantanal Basin, in green, with stations in triangles. The dashed line is the Transbrasiliano Lineament, an important tectonic structure in South America.*

## Methods

Deconvolution of radial and vertical components of seismograms removes source and instrument effects and isolates the geological structure near the station site (Ammon et al., 1990). The resulting trace, the receiver function (RF), marks the arrival times of P-to-S conversions and the reverberations under the station (Fig. 2). We selected events of distance < 30º (to avoid attenuation of high frequencies in the asthenosphere) recorded at stations of XC, BR and BL networks of PB region (Fig. 1). We applied time domain deconvolution (Ligorría and Ammon, 1999) with gaussian filters of 1 and 2.5 Hz (gaussian width parameter of 2 and 5, respectively).

The RF inversion in a non-unique inversion problem, since each peak in the signal can be interpreted as a Ps conversion in an interface or as a reverberated multiple. The joint inversion of dispersion curves (DC) is a way to bring stability to the inversion (Julià et al., 2000). We used DC of phase velocity of Rayleigh waves from Shirzad et al. (2020) in the PB region, with periods ranging from 6 to 80 s.

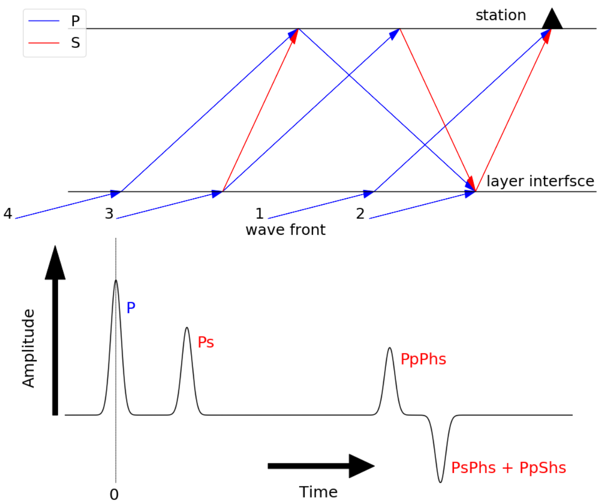


***Fig 2** - Example of P-to-S conversions from a single layer (top) and a receiver function (bottom), with P phase (1), Ps conversion (2) and multiples: PpSs + PsPs (3) and PpPs (4).*

The periods of DC, however, are not short enough to stabilize the inversion in sedimentary layers (Assumpção et al., 2009). So, we added a third data set, the horizontal / vertical spectral ratio (H/V curve), that gives a measure of ellipticity of Rayleigh waves caused by large contrast discontinuities of acoustic impedance in geological structure (Ullah, 2017). We used ambiental noise of 1-day recording, following Albarello et al. (2011) quality criteria, to calculate H/V curves ranging from 0.2 to 15 Hz.

We inverted data in two different ways:

case a) we followed two steps: first, we used García-Jerez et al. (2016) program to invert H/V curves; second, we combined the final model of this inversion with Cedraz et al. (2020) results to use as initial model for joint inversion of RF and DC with Julià et al. (2000) joint inversion, using influence factor of 0.25 and smooth factor of 0.4.

case b) we developed a program to jointly invert the three data sets using Herrmann (2013), Lomax & Snieder (1995) and García-Jerez et al. (2016) routines to calculate predicted data from a given model. We took S-wave velocity $v_s$ as inversion parameters, calculating P-wave velocity from a fixed value of Vp/Vs ratio and density as an empirical function of Vp (e.g. Berteussen, 1977). The objective function $F$ is given as:

$$F = i\,|r_{RF}|^2 + j\,|r_{DC}|^2 + k\,|r_{HV}|^2 + \\ + \mu^2\,|Hv_s p|^2 + \lambda\,|v_s - v_{s0}|^2 \qquad (1)$$

where $r_{RF}$, $r_{DC}$ and $r_{HV}$ are the residuals for RF, DC and H/V curve, respectively, calculated as observed data minus predicted data. $i, j$ and $k$ are influence factors, controlling how much each data set contributes to the inversion. Note that the values are not normalized, so residual of different data types have different magnitudes, what implies that giving the same value for all does not mean that all data sets will have the same contribution. We used 1, 10 and 0.5, respectively. The term $\mu^2|H v_s p|$ is the smoothness term, where $\mu^2$ is the regularization factor (we used 1.0). $H$ is the regularization operator, which is a continuity measure given by:

$$H = \begin{pmatrix} 1 & -1 & 0 & \dots & 0 & 0 \\ 0 & 1 & -1 & \dots & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \dots & 1 & -1 \end{pmatrix} \qquad (2)$$

$p$ is an array that allows us to control how much each layer affect the regularization, which helps to determine the depth of discontinuities. Finally, the term $\lambda\,|v_s - v_{s0}|^2$ allows us to use *a priori* information to constrain inversion. $\lambda$ is a weight array for each layer, set by user before inversion. The inversion is linearized and the objective function is minimized using modified Powell (1964) algorithm, which is a conjugate direction method.

In all inversions, we considered a Vp/Vs ratio of 1.8 for the soil and soft sediments and 1.73 for the crystalline crust.

## Results

Here we present the results for one station just outside PB, C2SB of BL network (Chapadão do Sul, MS). It is localized on quaternary sedimentation of the Paraná Basin. The results show some similarities and differences between inversions of cases (a) and (b) (Figs. 3 to 6).

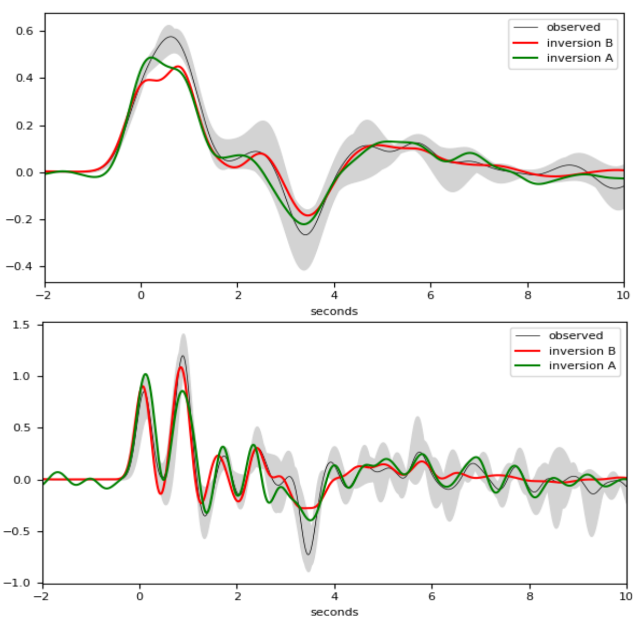


***Fig. 3** - Inversion of receiver functions of frequencies 1 (top) and 2.5 Hz (bottom). We used more than one RF for each frequency (represented by gray region, black line is its average). Green and red lines are results of inversions in cases A and B, respectively.*

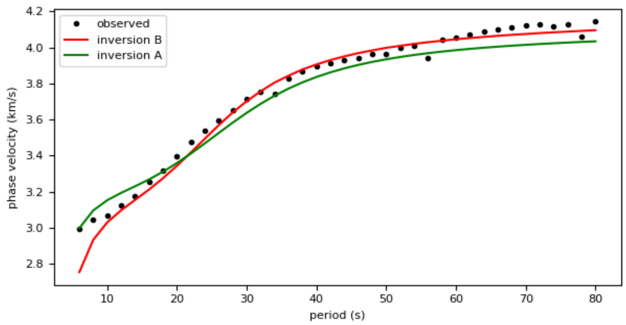


***Fig. 4*** *- Inversion of phase velocity dispersion curve for Rayleigh waves. Black points are observed data. Green and red lines are results of inversions in cases A and B, respectively.*

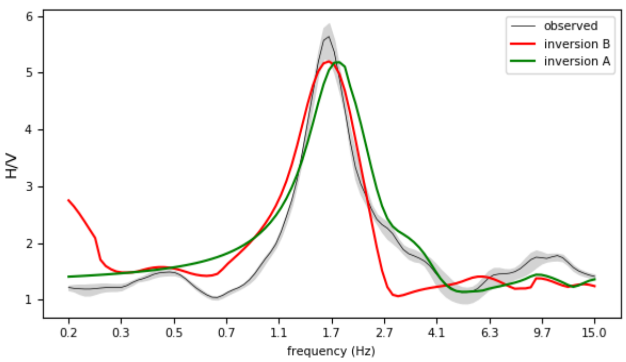


***Fig. 5*** *- Inversion of H/V curve. We used H/V curves (gray region) calculated from ambient noise registered in 5 random days between 2014 and 2019. Black line is its average. Green and red lines are results of inversions in cases A and B, respectively.*

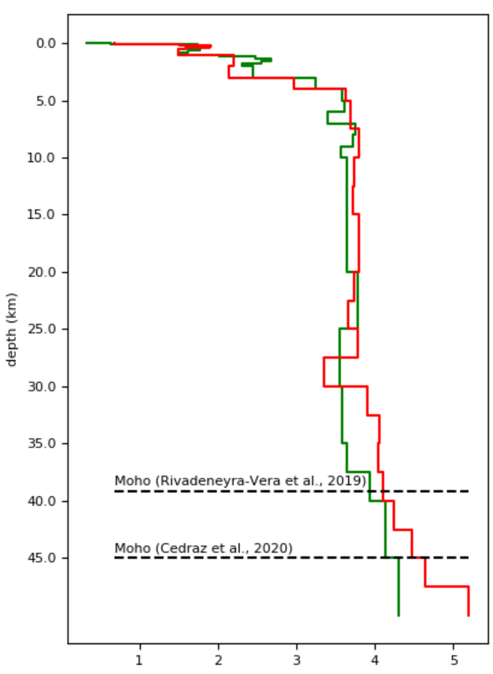


***Fig. 6*** *- Final models of inversions of cases A (green line) and B (red line). The dashed lines show Rivadeneyra-Vera et al. (2019) and Cedraz et al. (2020) calculations for Moho.*

The shallower layers show lower velocities (about 0.35 km/s in case A and 0.7 km/s in case B), which may correspond to non-consolidated sediments. Velocity increases to 2.4 km/s until 3 km, where sediments perhaps have some consolidation degree. An important discontinuity appears at about 3 km depth in both cases, which we interpret as the basement. This result is quite consistent with the 3.5 km basement depth seen in the Paulipetro stratigraphic well RA-MS, located about 40 km from the station C2SB.

In case A we interpret Moho at 40 km, in agreement with previous calculation of 39.2 km by Rivadeneyra-Vera (2019). But in the case B we interpret it at 47.5 km, closer to Cedraz et al. (2020) results. Here is where we found the most discrepancy between the models, which may be explained by high frequency RF not being so good to obtain models at such depth. Another feature we can point is a low-velocity zone about 30 km, which causes the negative peak in the RF at about 3.5 s.

Besides, it is important to remember that the DC does not have much influence in inversion of sedimentary layers because the periods are too long (periods from 2 to 4 s would be better), but certainly helps restricting the inversion in deeper layers. The H/V curve is a good substitute, stabilizing inversion of RF in shallow layers.

Neither case A nor case B inversions fit well short periods of DC, which is due, perhaps, a greater uncertainty in short periods of data. For RF and H/V, both procedures had good results, but the inversion of case B had slight better adjustment.

## Conclusions

We presented results of inversion of high frequency receiver functions for shallow structure of crust near the Pantanal Basin. As it is not always possible to obtain short period dispersion curves due to technical difficulties, high frequency receiver function working together with H/V spectral ratio may be an important tool to provide information on the shallow crustal structure beneath sedimentary basins. We presented two procedures for that:

a) inversion of sedimentary layers with H/V curves, generating a Vs profile that can be used as initial model for joint inversion of receiver functions and long period dispersion curve;

b) joint inversion of receiver functions, dispersion and H/V curves.

Inverting H/V curves of ambient noise with RF is a good alternative to study crustal structure of sedimentary basins, specially in the upper crust, where procedure B seems to be slight better than A. For deeper layers, low frequency RF with long period DC is more appropriate.

## Acknowledgments

Scholarship from CNPq - Brazil (131309/2020-0).

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