An improved velocity model for regional epicentre determination in Brazil

Marcelo Assumpção (IAG-USP), Júlio Ardito (IAG-USP; now at Alta Resolução) & José Roberto Barbosa (IAG-USP)

Abstract

Determination of epicentres in Brazil requires a crustal and upper mantle velocity model which takes into account the predominance of old, cratonic lithosphere in most of the country. A set of 15 events well recorded at regional distances (magnitudes ≥4) was compiled using two main criteria: events well located with a local network, and events with an aftershock sequence studied with a local network. The travel times were all corrected for the hypocentral depth and normalized to a crustal thickness of 40 km. The travel times were tentatively fitted with a new upper mantle velocity model. Tests of epicentral location indicates a slightly better performance than the previous BR model used in the Brazilian Seismic Bulletin.

Introduction

An upper mantle velocity model appropriate for the cratonic characteristics of the Brazilian lithosphere was developed by Kwitko & Assumpção (1990), herein called BR90 model. BR90 has been used since then by IAG-USP to locate regional earthquakes in Brazil using a flat-earth approximation and the HYPO71 code. Since many more events with known epicentres are now available an improvement in the early BR90 model is possible. Also, the HYPO71 program is not suitable for large distances because of the use of flat layers. More appropriate programs, such as HYPOCENTER, should now be employed.

Figure 1 and Table 1 show the 15 selected events used for the new compilation of observed travel times.

Two main kinds of events were used:

1) Events well recorded by a local network with uncertainties less than 2 km. Two examples are the João Câmara (RN) event of 1986/12/09 with magnitude 4.6, and the Caraíbas (MG) earthquake of 2009/12/09 with 4.9 mb.
2) Events with an aftershock sequence well studied with a local network. The epicentre of the main event is assumed to be in the middle of the aftershock zone. The origin time of the main event was calculated using nearby regional stations, or even teleseismic stations (ISC sources), with some station time corrections. Examples are the events of Palhano (CE) 1989/10/19, and Sobral (CE) 2008/05/21, both with magnitude ~4.2 m_R.

In addition, some events constrained mainly by macrosseismic information were also included. Although not as accurate as the previous categories, they cover Brazilian regions poorly sampled and are important to make the new velocity model more representative of the Brazilian territory as a whole. One example is the Codajás (AM) earthquake of 1983/08/05. The 1980 Pacajus (CE) event and the 1986 João Câmara mainshock (RN) are also important because they were recorded all over Brazil.

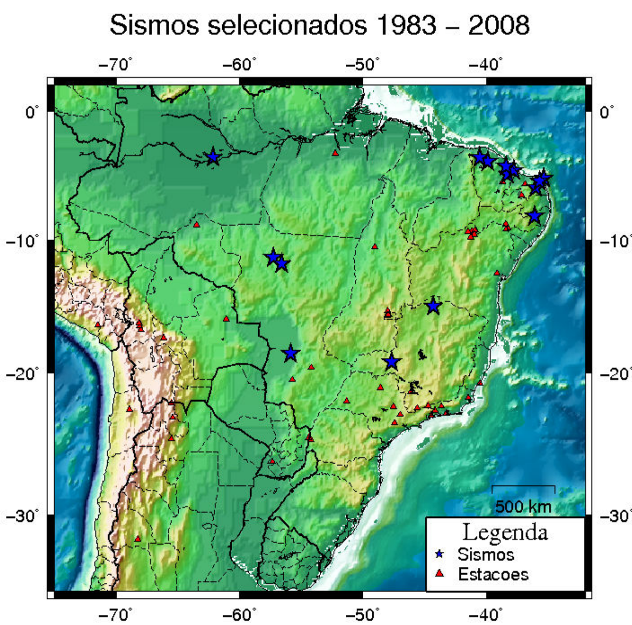

***Fig. 1**. Selected events (stars) and some of the recording statiosn (triangles) used in the new Brazilian velocity model.*

Travel time data set

Ardito (2009) shows all the data compiled for each of the 15 events with their epicentral errors and origin time uncertainties. Table 1 summarizes the present event information.

Fig. 2 shows all raw travel time data compared with the Jeffreys-Bullen (1940), Herrin (1968) and the IASP91 (Kennet & Engdahl, 1991) curves.

The travel times for each event were then corrected for the event depth, normalizing the travel times to 0 depth. In addition, a systematic bias (shorter travel times) was found for events in Northeastern Brazil, compared with events in other areas (Fig. 2). This was caused by the thinner crust (~30km) in NE Brazil compared with generally thicker crust (~40km) in other areas far from the continental margin. For this reason, another correction was applied to normalize all travel time data to a standard 40km thick crust. This correction was applied to both the epicentre and the recording station.

The final travel time data set is shown in Fig. 3 compared with the Herrin (1968) travel-time curve. The Herrin (1968) tables are more representative of the average continental structure. Even so, it is clear that the Brazilian territory has higher lithospheric velocities (shorter travel times) than the average Herrin model.

Resulting velocity model

The data set in Fig. 3 was tentatively fitted by trial-and-error forward modeling. A standard 2-layer crustal structure with 40 km thickness was adopted. P-wave velocities in the upper mantle were adjusted to best fit the travel time data. The resulting new model (called newBR) is presented in Fig. 4.

A set of 18 events (Ardito, 2009), not necessarily with well constrained epicentres, was used to estimate the average Vp/Vs for the Brazilian lithosphere using a Wadati diagram. The result (Fig. 5) shows that the average Vp/Vs in Brazil is 1.738 ± 0.003.

Table 2 shows the P-wave velocity profile of the new BR model ina format to be used in the “hypocenter” code.

Epicentres determined with the new velocity model were compared with previous models. In general (e.g., Fig. 6) a slight improvement was obtained with respect to the previous BR model.

Discussion and Conclusions

A slight improvement in epicenter location was obtained with an updated velocity model. The model presented here is still preliminary and further improvements could be obtained by:
a) adding a few other well located events (magnitudes ~4) to the set of Table 1.
b) improving the origin times of the main events with only aftershock sequence recorded. We used teleseismic (ISC) P-arrivals to get the origin time of these events using the IASP91 times assuming they are a good approximation for teleseismic distances. More systematic station corrections could be used to improve these origin times.

Acknowledgements

We thank all colleagues from UnB, UFRN, IPT and UNESP for providing phase data for the Brazilian Seismic Bulletin.

References

Ardito, J.C., 2009. Determinação de Epicentros Regionais. *Trabalho de Graduação*, IAG-USP, 2009.

Assumpção, M., Ferreira, J.M., Carvalho, J.M., Blum, M.L., Menezes, E.A., Fontele, D., Aires, A. 1989. Seismic activity in Palhano, CE, October, 1988, preliminary results. *Rev. Bras. Geofísica*, 7, 11-17.

Barros, L.V., M. Assumpção, R. Quinteros & D. Caixeta, 2009. The intraplate Porto dos Gaúchos seismic zone in the Amazon craton — Brazil. *Tectonophysics,* 469, 37-47. doi: 10.1016/j.tecto.2009.01.006

Chimpliganond, C.N., 2002. Caracterização da sismicidade induzida no reservatório de Nova Ponte, MG, Brasil. *Dissertação de Mestrado,* UnB, 132pp.

Chimpliganond, C.N., M. Assumpção, M. von Huelsen & G.S. França, 2010. The intracratonic Caraíbas-Itacarambi earthquake of December 09, 2007 (4.9 mb), Minas Gerais State, Brazil. *Tectonophysics*, 480, 48-56.

Ferreira, J.M., Oliveira R.T., Takeya, M.K., Assumpção, M., 1998. Superposition of local and regional stresses in northeast Brazil: Evidence from focal mechanisms around the Potiguar marginal basin. *Geophys. J. Int*., 134, 341-355.

Herrin, E., 1968. Seismological Tables for P phases. *Bull. Seism. Soc. Am*., 58: 1193-1241.

Jeffreys, H. & Bullen, K. E., 1940. Seismological Tables. British Association, Gray Milne Trust.

Kwitko, R., & Assumpção, M. 1990. Modelo de velocidades para o manto superior no Brasil e determinação de epicentros regionais. *Proceedings, 36º Congr. Bras. Geol.,* Natal, RN, 5, 2464-2469.

Kennett, B.N.L. & Engdahl, E.R., 1991. Travel times for global earthquake location and phase identification. *Geophys. Int*, 106, 429-465.

Neto, H. C., Ferreira, J. M., Nascimento, A. F., & Bezerra, F. H. R., 2009. Estudo da atividade sísmica em São Caetano-PE em 2007. *11th Int’l Congr. of the Brazilian Geophysical Soc.*, Salvador, Brazil, Aug 24-28, 2009.

Takeya, M.K., Ferreira, J.M., Pearce, Assumpção, M., Costa, J.M., & Sophia, C., 1989. The 1986-1988 intraplate earthquake sequence near João Câmara, northeast Brazil - evolution of seismicity. *Tectonophysics*, 167, 117-131.

Sismos utilizados no modelo de velocidades											
N°	ANO	Mês	Dia	LOCAL	MAG	LAT	LONG	erro (km)	PROF (km)	obs.	FONTE
1	1980	Nov	20	Pacajus – CE	5.1	-4,3000	-38,4000	5	5	macross.	Kwitko & Assumpção 1990
2	1983	Ago	5	Codajas – AM	5.5	-3,5800	-62,1400	15	23	macross.	RGBf, 1984
3	1986	nov	30	Joao Camara - RN	5.1	-5,5410	-35,7580	3	5	macross.	Takeya et al. 1989
4	1986	Dez	9	Joao Camara - RN	4,6	-5,5260	-35,7380	1	5	rede local	Kwitko & Assumpção 1990
5	1988	mar	31	Sobral - CE	4.1	-3,9480	-40,3360	2	8	rede local	Kwitko & Assumpção 1990
6	1988	oct	19	Palhano - CE	4.2	-4,8070	-37,9800	3	4	réplicas	Assumpção et al. 1989
7	1989	mar	10	Joao Camara - RN	5.0	-5,4600	-35,6900	3	8	p. rede local?	Kwitko & Assumpção 1990
8	1989	mar	26	Palhano - CE	4.5	-4,8100	-37,9700	3	4	réplicas	Assumpção et al. 1989
9	1991	abr	19	Taperuaba - CE	4.9	-3,9300	-39,8700	5	10	réplicas	Ferreira et al. 1998
11	1998	mar	10	P. Gauchos - MT	5.2	-11,6000	-56,7420	4	5	réplicas	Barros et al. 2009 pg 5
10	1998	Mai	22	N. Ponte - MG	4.0	-19,1700	-47,6800	2	3	rede local	Chimpliganond, 2002
12	2005	mar	23	P. Gauchos - MT	5.0	-11,6000	-56,7580	4	3	réplicas	Barros et al. 2009 pg 5
13	2006	Mai	20	São Caetano – PE	4.0	-8,2600	-36,1600	5	6	rede local	Neto et al. 2009
14	2007	dez	9	Caraibas - MG	4.9	-15,0326	-44,2953	0,5	0,65	rede local	Chimpliganond et al. 2009
15	2008	mai	21	Sobral - CE	4.2	-3,6200	-40,5000	5	5	réplicas	UFRN

Hora de Origem dos Sismos utilizados no modelo de velocidades						
N°	***LOCAL***	***H.O. Anterior***		***H.O. (ISC[1])***	**N° est. teles. na correção**	***H.O. (corrigida)***
1	Pacajus – CE 1980	03:29:45.50	Kwitko & Assumpção, 1990	03:29:41.77	43	03:29:45,32
2	Codajas – AM 1983	06:21:42.90	Kwitko & Assumpção, 1990	06:21:42.85	94	06:21:45,13
3	Joao Camara – RN 1986	05:19:50	boletim sismico brasileiro	05:19:48.20 (NEIC[2])	21	05:19:50,56
4	Joao Camara – RN 1986	06:48:44	boletim sismico brasileiro	-	-	06:48:44,00*
5	Sobral – CE 1988	0:36:34.2	Kwitko & Assumpção, 1990	-	-	00:36:34.2*
6	Palhano – CE 1988	02:15:50	boletim sismico brasileiro	02:16:12.86	3**	02:15:51,28
7	Joao Camara – RN 1989	04:11:22.4	boletim sismico brasileiro	04:11:22.53	61	04:11:25,36
8	Palhano – CE 1989	13:25:30	boletim sismico brasileiro	13:25:36.23	11	13:25:39,31
9	Taperuaba – CE 1991	10:12:47.20	Ferreira et al. 1998	10:12:47.05	31	10:12:49,22
11	P. Gauchos – MT 1998	23:32:44	Barros et al. 2009	23:32:43.55	125	23:32:45,31
10	N. Ponte – MG 1998	17:35:43,40	Chimpliganond 2002	17:33:05,88	2	17:33:03,41
12	P. Gauchos – MT 2005	21:12:13	Barros et al. 2009	21:11:59.55	55	21:12:00,17
13	São Caetano – PE 2006	04:25:00	boletim sismico brasileiro	04:26:01.42 (IDC)	1	04:26:06,55
14	Caraibas – MG 2007	02:03:28.36	Chimpliganond et al. 2009	02:03:29.44 (NEIC)	87	02:03:28,69
15	Sobral – CE 2008	19:29:41	boletim sismico brasileiro	19:23:57.32 (NEIC)	5	19:23:59,35

Table 1. Epicentres and Origin Times of the 15 earthquakes used in deriving the travel times (Ardito, 2009)

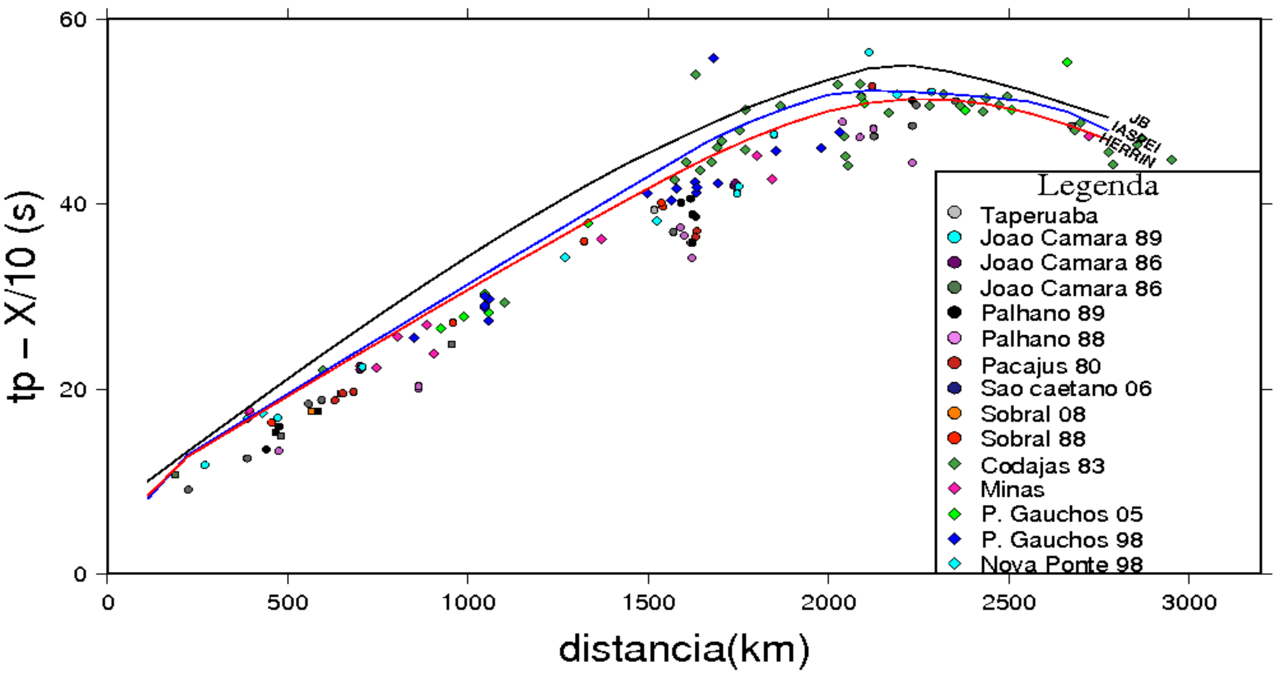

Figure 2. Reduced travel time data with no corrections. Solid lines are Jeffreys-Bullen (black), IASP91 (blue) and Herrin-1968 (red) curves. Circles are data for earthquakes in NE Brazil.

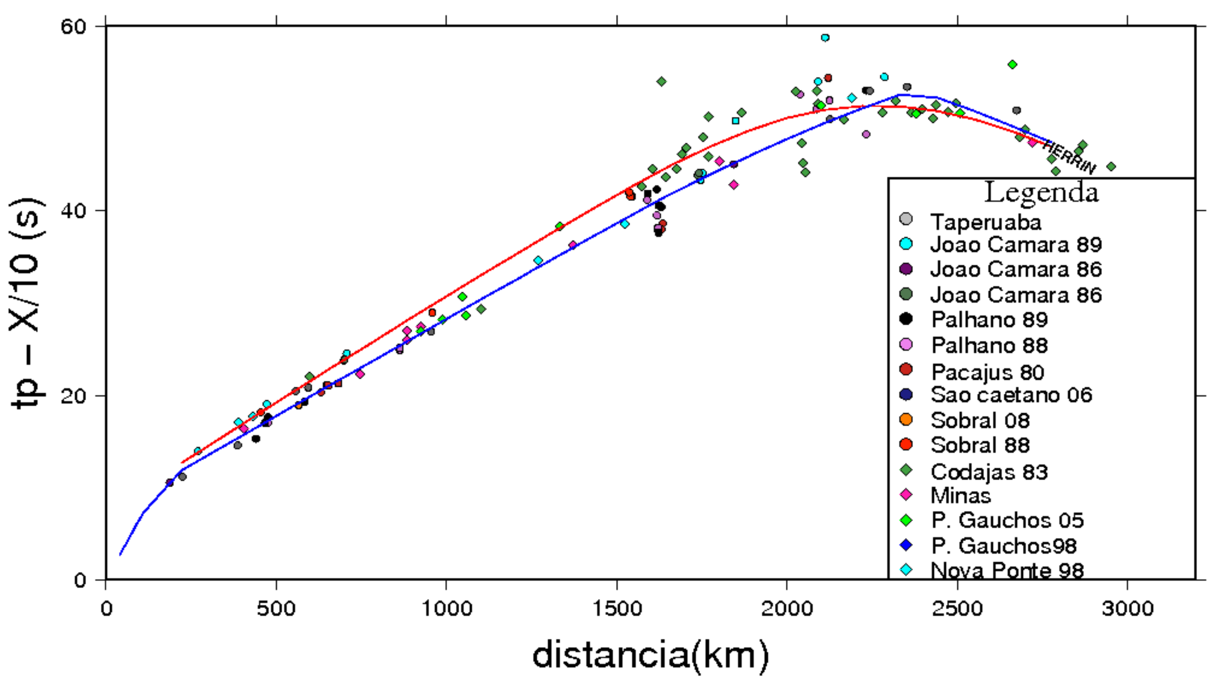

Figure 3. Reduced travel time data corrected for 0 depth and normalized to a 40km thick crust. Red solid line is the Herrin (1968) curve; the **blue line** is the fit obtained with the **New BR model** shown below.

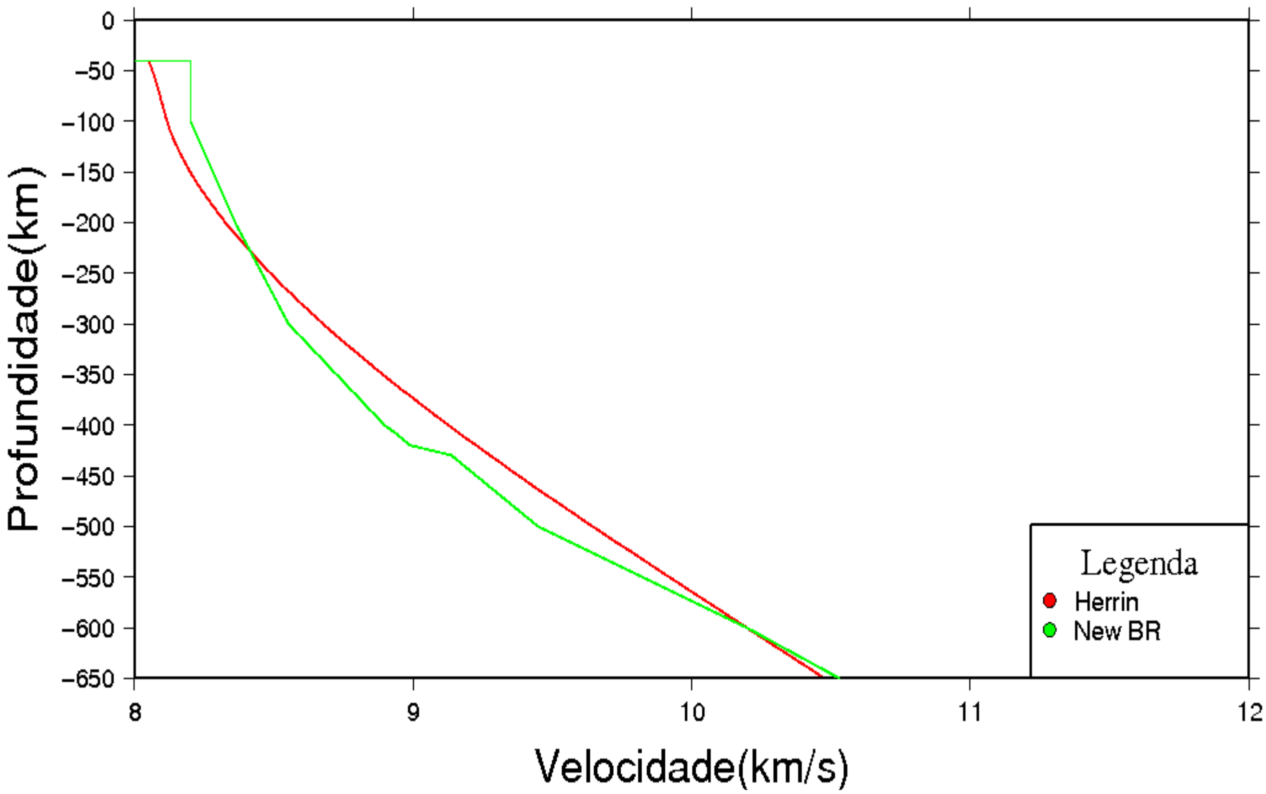

Figure 4. P-wave velocity profiles . Red line is the Herrin (1968) model; the **green line** is the **New BR model** shown below.

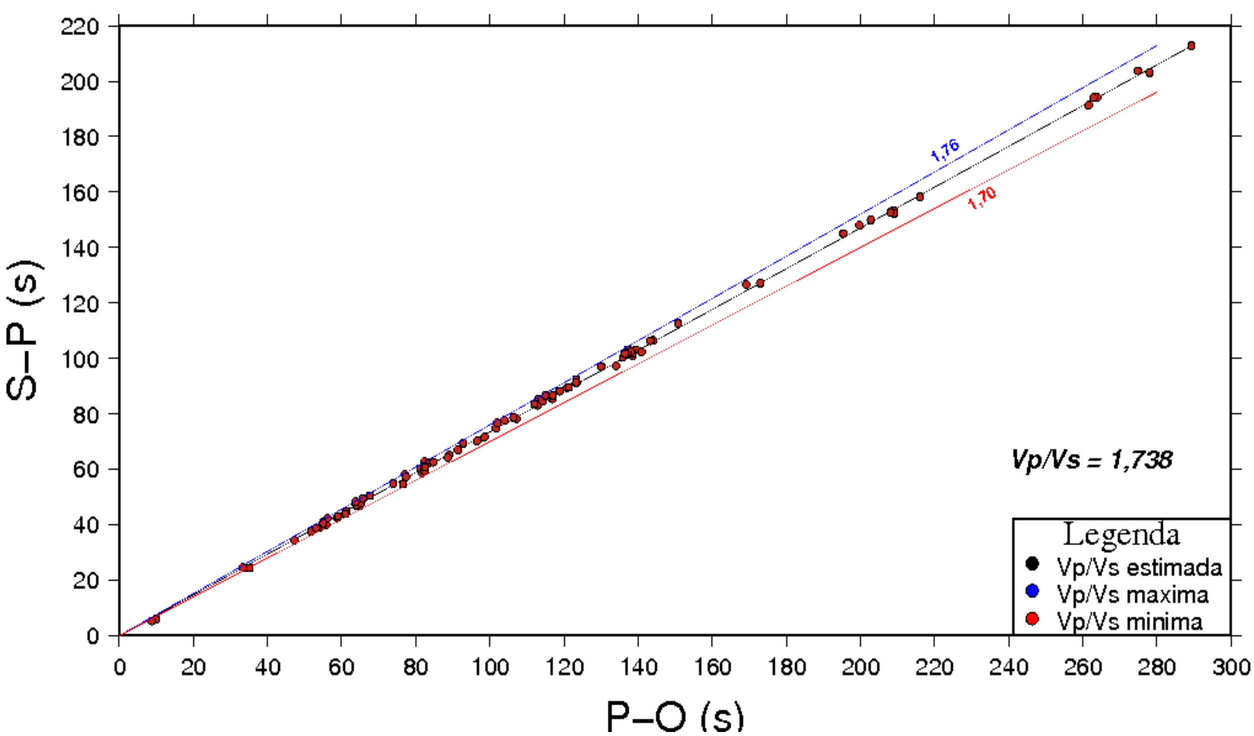

Figure 5. Wadati diagram to estimate the average Vp/Vs ratio for the Brazilian lithosphere. Vp/Vs=1.738 ± 0.003

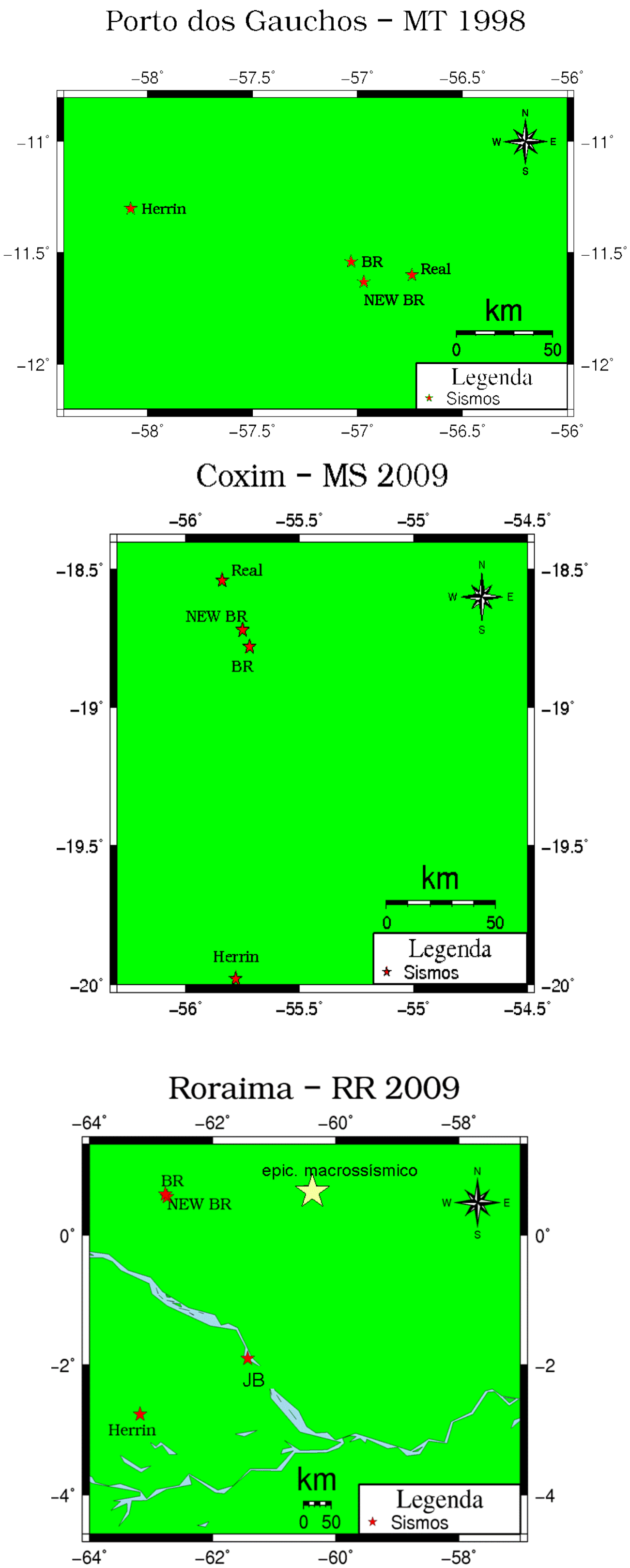

Figure 6. Examples of location improvement with the new BR model. For the Pto.dos Gaúchos event, “real” is the known epicentre based on the aftershocks (Barros et al., 2009). For the 2009 Coxim (MS) event, “real” is the macroseismic epicentre.

Vp(km/s)	Depth(km)
6.000	0.0
6.000	15.0
7.000	15.0
7.000	40.0
7.300	42.0
7.600	44.0
7.900	46.0
8.200	48.0
8.200	65.0
8.200	80.0
8.200	90.0
8.200	100.0
8.230	125.0
8.280	150.0
8.310	175.0
8.361	200.0
8.410	225.0
8.460	250.0
8.510	275.0
8.552	300.0
8.620	325.0
8.700	350.0
8.790	375.0
8.897	400.0
8.900	403.0
8.920	406.0
8.935	408.0
8.947	410.0
8.950	413.0
8.960	416.0
8.970	418.0
8.987	420.0
9.000	422.0
9.400	424.0
9.900	427.0
9.137	430.0
9.200	446.0
9.300	469.0
9.400	490.0
9.447	500.0
9.650	525.0
9.830	550.0
10.000	575.0
10.197	600.0
10.300	612.0
10.400	630.0
10.470	640.0
10.530	650.0
10.540	652.0
10.550	655.0
10.560	658.0

Table 2. Vp profile for the new BR model.