UNVEILING THE ENIGMA OF THE 1955, m_b 6.6, SERRA DE TOMBADOR, MATO GROSSO, BRAZIL, EARTHQUAKE OF JANUARY 31, 1955, THE LARGEST KNOWN BRAZILIAN EVENT

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Organization of the Presentation

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1. Preamble, Motivation, and the Paper Goal

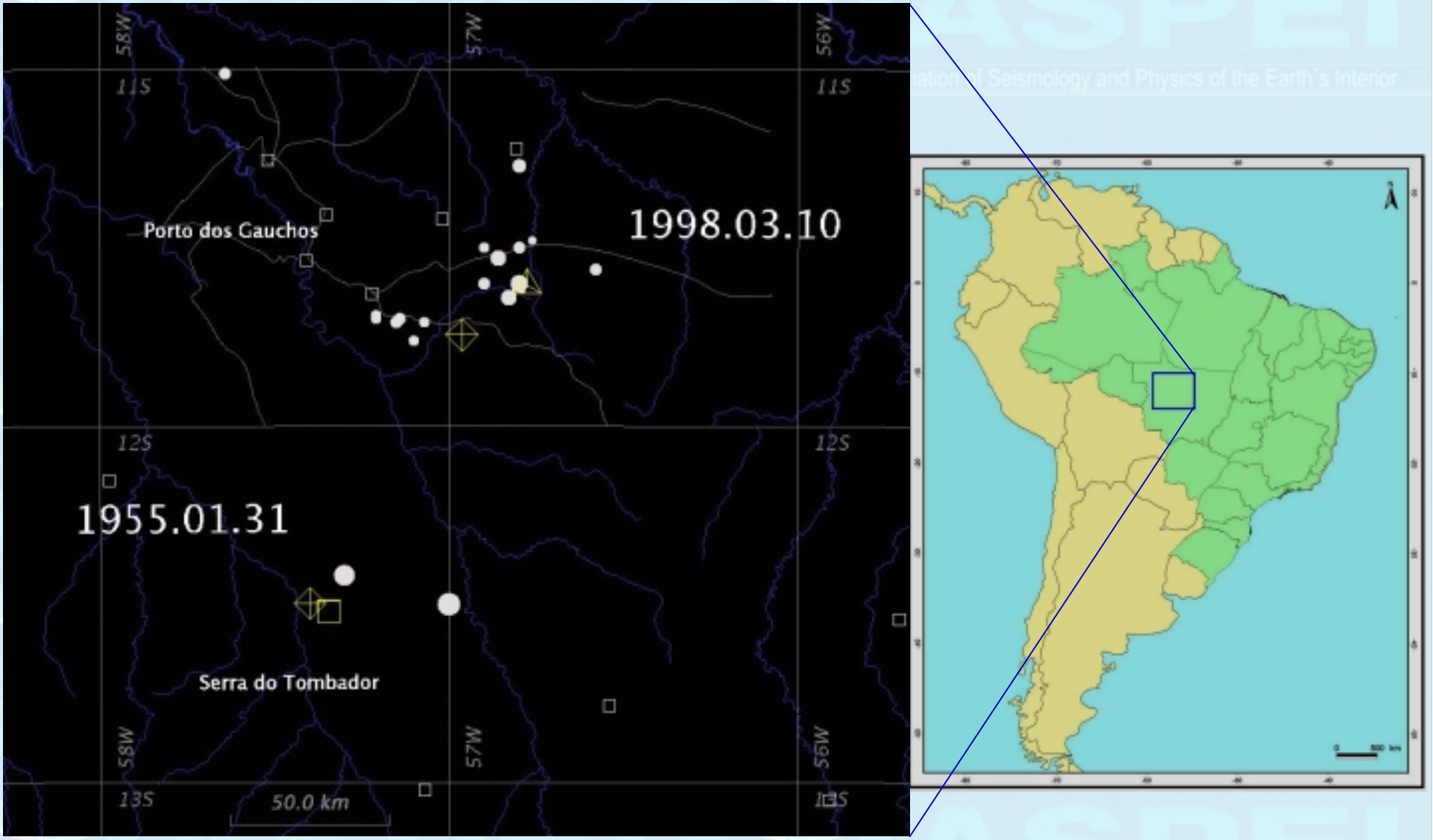


Fig. 1 - Overall map of seismicity in Porto dos Gauchos seismogenic area. Diamond - ICC locations; Yellow Square - Engdahl (2002); White circles - epicentres; White squares - towns.

Table 1. Hypocentre parameters for northern Mato Grosso, Brazil, 1955 JAN 31 event according to various sources/authors

Source	Date	O.T. (GMT)	Lat. (º S)	Lon. (º W)	Depth (km)	Horiz. Error (km)	m_b
ISS (1962)	1955 JAN 31	05:03:02	12.5	57.4	n	N.A.	N.A.
CGS/USGS	1955 JAN 31	05:03:03	12.5	57.0	n	N.A.	6.8*)
Berrocal *et al.* (1984)	1955 JAN 31	05:03:07	12.42	57.30	15 (fixed)	N.A.	6.6
Engdahl (2002)	1955 Jan 31	05:03:05.6	12.52	57.35	15 (fixed)	7.3 (S.E.)	N.A.

Note: n = normal depth (i.e., 33 km);
N.A. = not available;
S.E. = location standard error
*) m_B or M_S scale (?)

2. Seismotectonic setting of the area

Fig. 2. Epicentral map of Brazil´s seismicity (period: 1981-2004; magnitude cut-off: 3.0; number of events 804) [*Source:* SISBRA]

A modern instrumental (1981-2004 period) seismicity map of Brazil is presented in Fig. 2. The most western part of the Brazilian territory (west of roughly 72° W) at the Brazil–Peru border region is an Active Continental Region, the result of interaction between Nazca and South American plates. But the major part of the Brazilian territory is characterized by an intraplate seismicity of Stable Continental Region (SCR) type (*e.g.*, Johnston 1989, Schulte & Mooney 2005, etc). The blue box marks the study area.

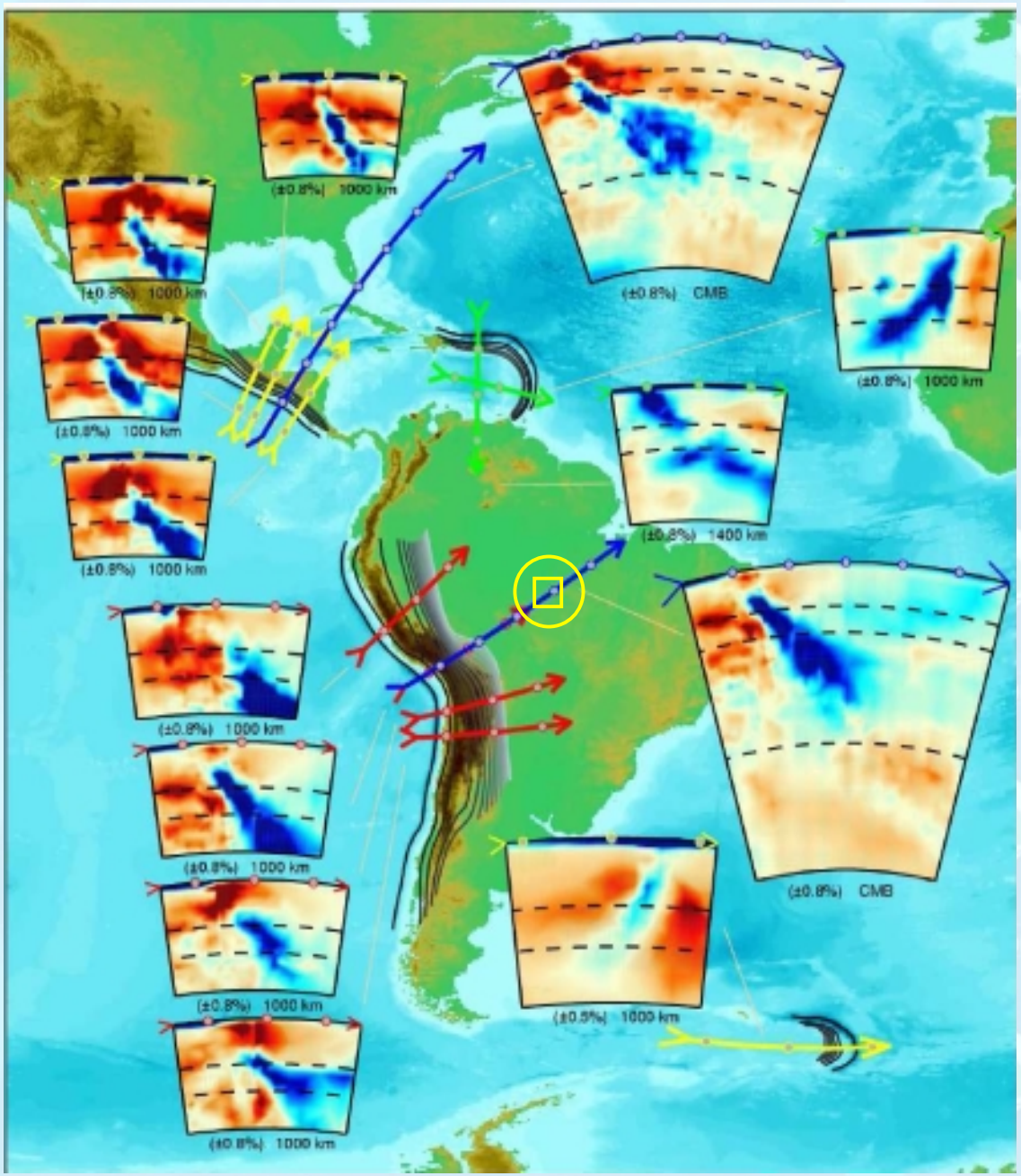


Figure 3 - P wave model showing the complexity of slab structures for South American plate and environs [Courtesy of Van der Hilst, in preparation].

The yellow box shows the study area, note on this raypath the strong wavespeed positive anomaly (blue color).

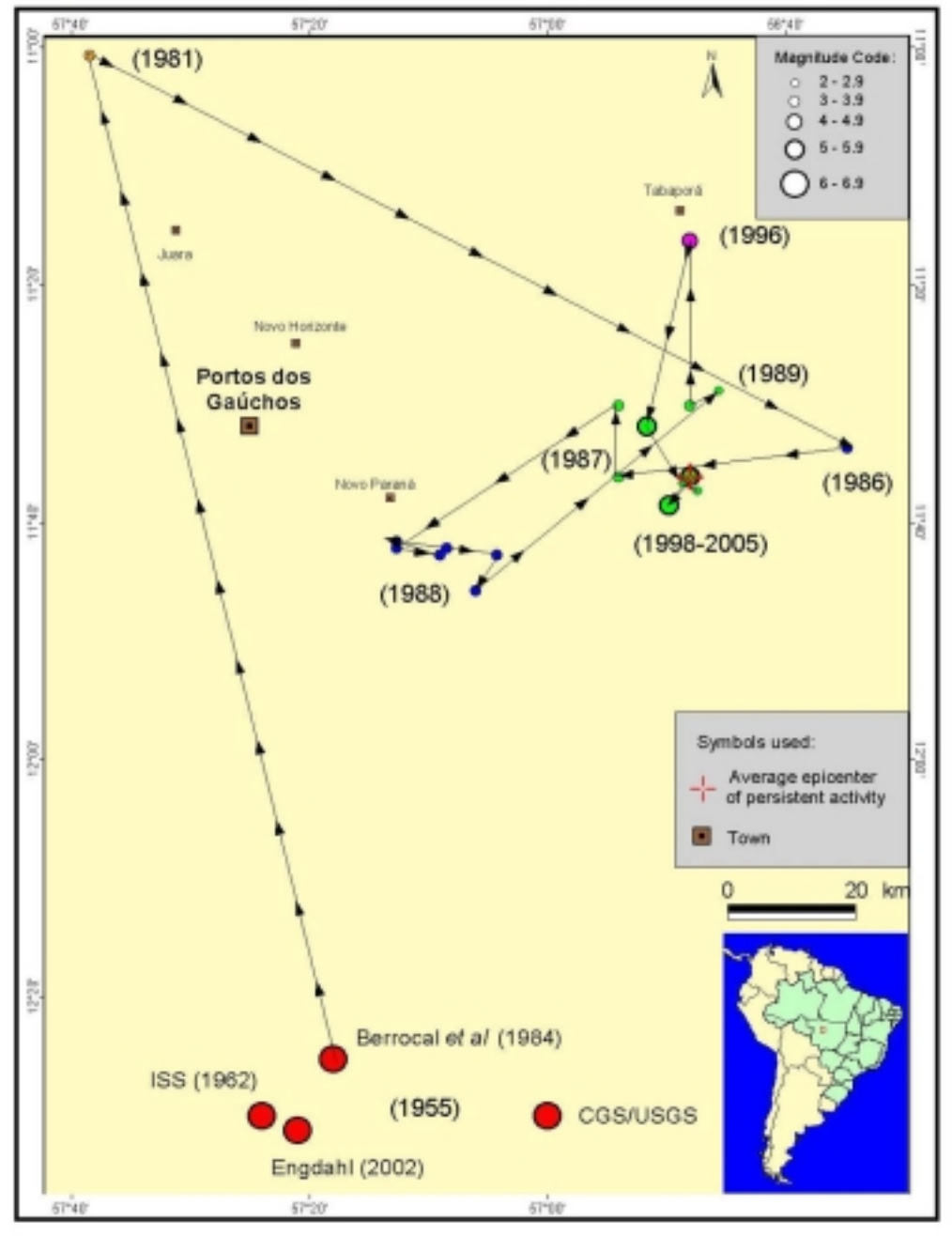


Fig. 4. Map showing the epicentral distribution and time evolution of epicenter locations for events in Porto dos Gauchos, MT, area (see Table 3 for hypocentral parameters). Colors (transition from red to green) are meant to qualitatively indicate the gradual (temporal) improvement in location (years in brackets show approximately the time for each stage)

The seismogenic area of Porto dos Gauchos is the most active area in the SCR of Brazil (see Table 4) and has been a focus of interest and research on Brazilian seismicity.

Table 4. The largest known earthquakes in Brazil

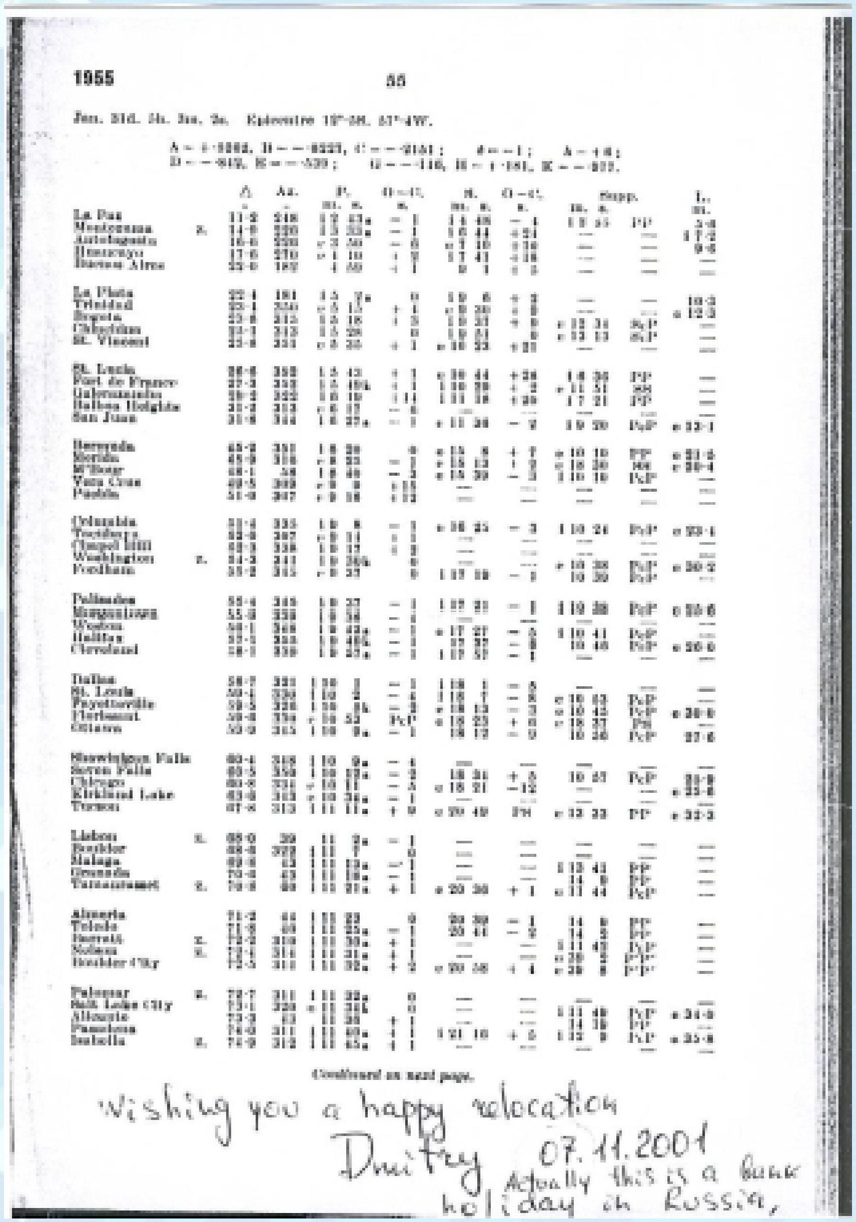
#	Date	Location			Depth (km)	m_R (≈ m_b)			Remarks
		Lat. (°S)	Lon.(°W)	Location/State		*)	**)	Other	
1	31 JAN 1955	(12.4)	(57.3)	P. dos Gaúchos/S. do Tombador/MT	Shallow	6.6	6.2	-	I.E.I. = IX (MM)
2	01 MAR 1955	19.8	36.8	Continental Platform,Vitória, ES	Shallow	6.3	6.1	-	-
3	28 JUN 1939	29.0	48.0	Plataforma Continental Tubarão, SC	Normal	5.5	5.5	-	-
4	05 AGO 1983	3.6	62.2	Codajás, AM	23	-	5.5	-	E.I. = VII (MM)
5	12 FEV 1990	31.19	48.92	Continental Platform, Pto Alegre, RS	13	-	-	5.5 (1)	-
6	13 FEV 1964	18.1	56.7	NW of Mato Grosso do Sul state, MS	5	5.4	5.4	-	-
7	30 MAR 1998	11.7	57.0	Porto dos Gaúchos, MT	V. Shallow	-	-	5.3 (4)	E.I. ≈ VI-VII
8	20 NOV 1980	4.3	38.4	Pacajús, CE	Shallow	-	5.2	5.2 (2)	E.I. = VII (MM)
9	27 JAN 1922	22.2	47.0	Mogi Guaçu/Pinhal, SP	20	5.1			E.I. = VI (MM)
10	30 NOV 1986	5.5	35.8	João Câmara, RN	Shallow	-	-	5.1 (3).	E.I. = VII (MM)
11	05 FEB 1959	(11.6)	(56.8)	Porto dos Gaúchos, MT	V. Shallow	-	-	5.1 (5)	E.I. = VI½ (MM)
12	14 DEC 1963	2.3	61.0	Manaus, AM	45	-	-	5.1 (6)	
13	17 SEP 1949	3.8	51.8	Oiapoque , AP	?	5.0			
14	07 nov 1969	37.0	43.8	South Atlantic Ocean	?			5.0 (4)	
15	03 MAR 1989	5.81	35.56	João Câmara, RN	Shallow			5.0 (7)	E.I. = VI (MM)
16	23 MAR 2005	11.59	56.77	Porto dos Gaúchos, MT	V. Shallow	-	-	5.0 (7)	E.I. = VI (MM)

Notes: Main Sources: *) Berrocal *et al.* (1984) *Sismicidade do Brasil (Seismicity of Brazil)*, IAG/USP & CNEN, São Paulo, 320 pp
) Assumpção M. (1998) *Física de la Tierra*, **N. 10, p.149-166.

Other Sources:
(1) Berrocal *et al.* (1996) *Geofísica Int.* **35**: 257-272.
(2) Berrocal *et al.* (1983) *Earthq. Predict. Res.* **2**: 191-2-8.
(3) Brazilian Seismic Bull. N° 16 (1996) *Rev. Bras. Geofísica* **14**: 77-82.
(4) *I.S.C. Regional Catalogue*, International Seismological Centre, UK.
(5) Marza *et al.* (1999) Special Report No. 2, Seismological Obs., Univ. of Brasilia.
(6) Assumpção, M. & Suarez, G. (1988) *Geophys. J.* **92**: 253-267.
(7) *NEIC/USGS Bulletin*, National Earthquake Information Center, U.S. Geological Survey, Boulder, CO.

Acronyms:
E.I. = epicentral (maximum) intensity; I.E.I. = inferred E.I.;
MM = Modified Mercalli Intensity;
mR = regional magnitude scale for Brazil; mb = teleseismic body wave magnitude scale.

3. Data set


1955 55

Jan. 31d. 5h. 3m. 2s. Epicentre

Continued on next page.

Wishing you a happy relocation
Dmitry 07.11.2001
Actually this is a bank holiday in Russia

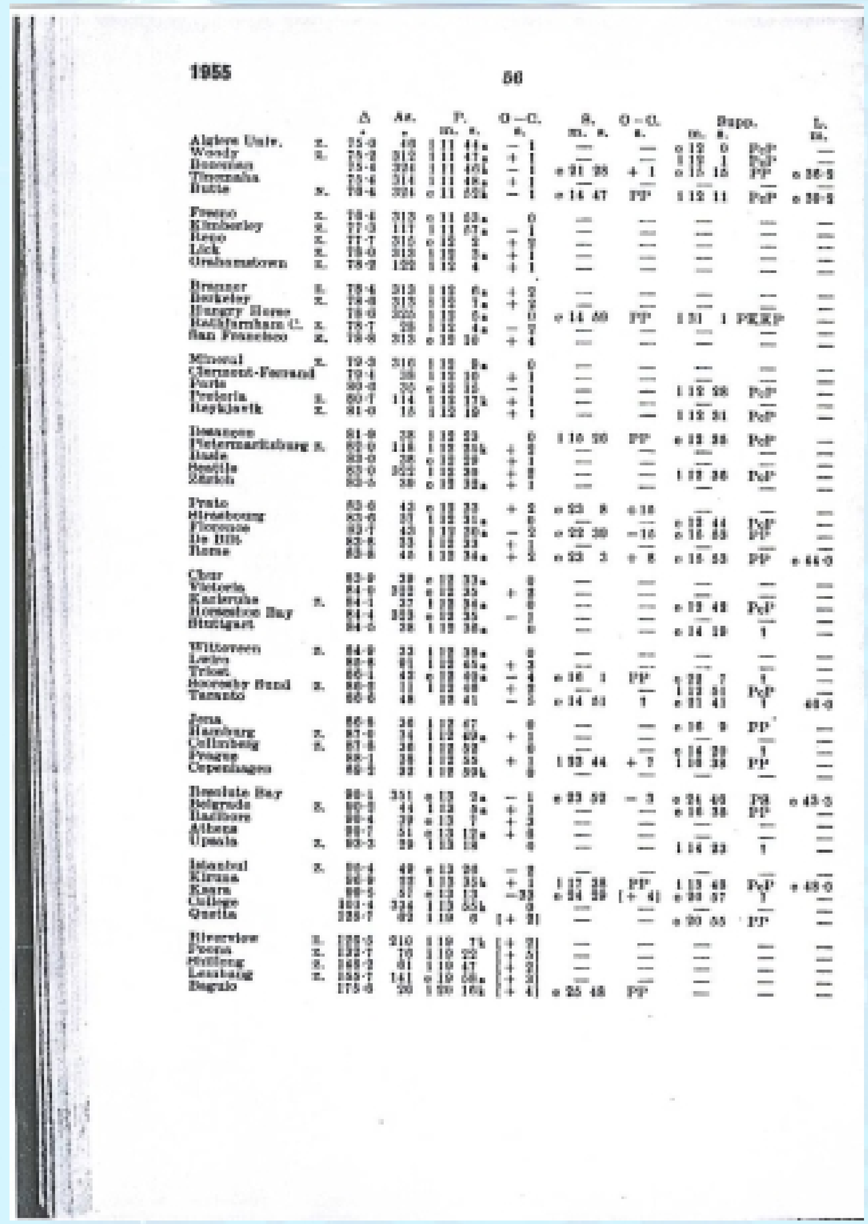

1955 56

Fig. 5. Except of the output of ISS Bulletin for 1955 JAN 31 Brazil earthquake

4. Location Technique

In this work we perform the relocation trials with the NonLinLoc package (Lomax *et al.*, 2000, 2001; Lomax, 2005; www.alomax.net/nlloc; NLL hereafter).

4.1. Likelihood Functions

NLL makes available two different likelihood functions to build the PDFs. One likelihood function incorporates the familiar least-squares L2 norm (LSL2, hereafter). The other likelihood function is based on the equal differential-time (EDT, hereafter). The EDT-likehood function is much more robust than LSL2-likehood function in the presence of outliers in the data. With LSL2 norm many of the locations do not converge to reasonable solutions due to strong outlier data.

4.2. Velocity Model and Travel-Time Calculation

The travel times used for location are calculated for a spherical Earth using the TauP Toolkit (Crotwell *et al.*, 1999; www.seis.sc.edu/software/TauP), using the 1D, ak135 model (Kennett *et al.* 1995).

Table 2. Hypocentre parameters for Porto dos Gauchos, MT, Brazil, 1998 MAR 10 mainshock according to various sources

Source	O.T. (UTC)	RMS (s)	Lat. (º S)	Lon. (º W)	Depth (km)	Smaj; Smin (km)	Mag.	Δr (km)
IDC	23:32:43.3		11.588	56.855	0 (f)	17.1; 14.5	5.1L	
NEIC	23:32:43.7	0.9	11.672	57.002	10 (f)		5.2b	
ISC	23:32:43.5	0.9	11.745	56.963	10 (f)	6.0; 5.5	5.3b	
OBSIS/UnB	23:32:39.9	1.7	11.65	56.83	2 (f)		5.2R	

NOTE: **Δr** = shift from average epicenter;
Mag. = magnitude (L stands for M_L; b stands for m_b; and R stands for m_R scales)

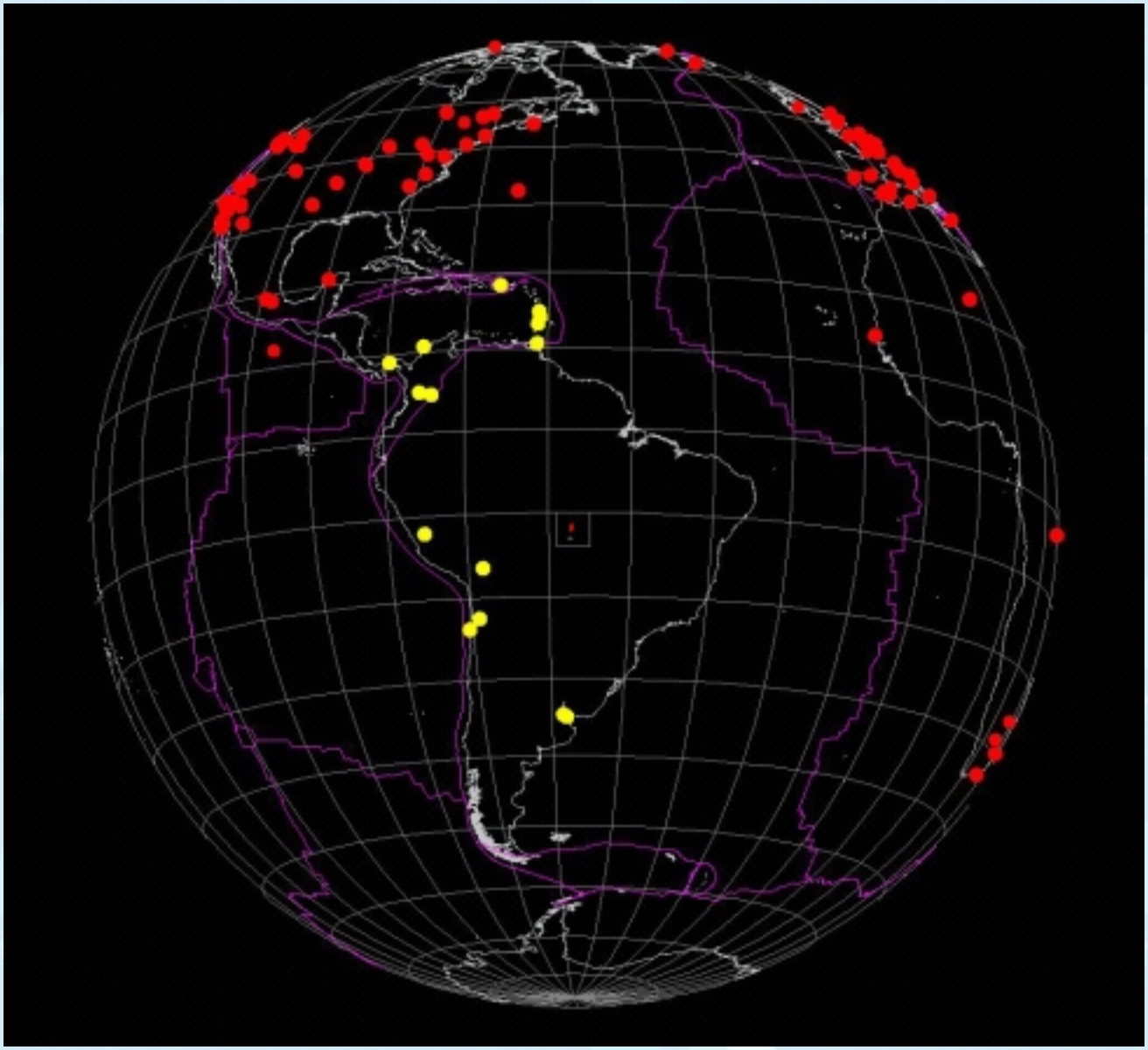
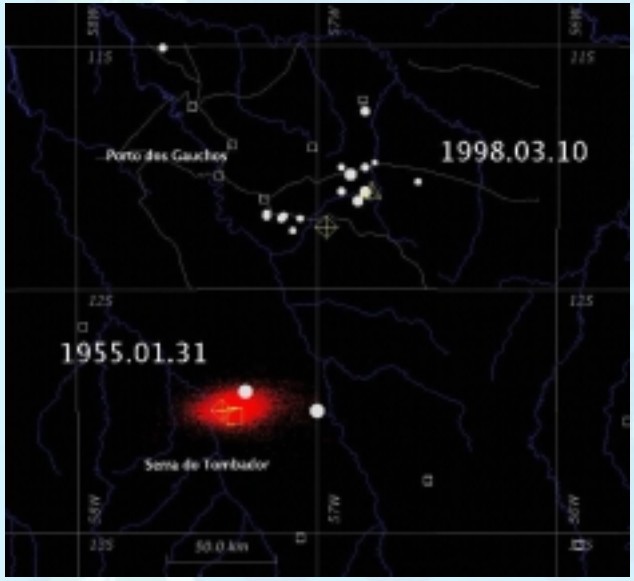


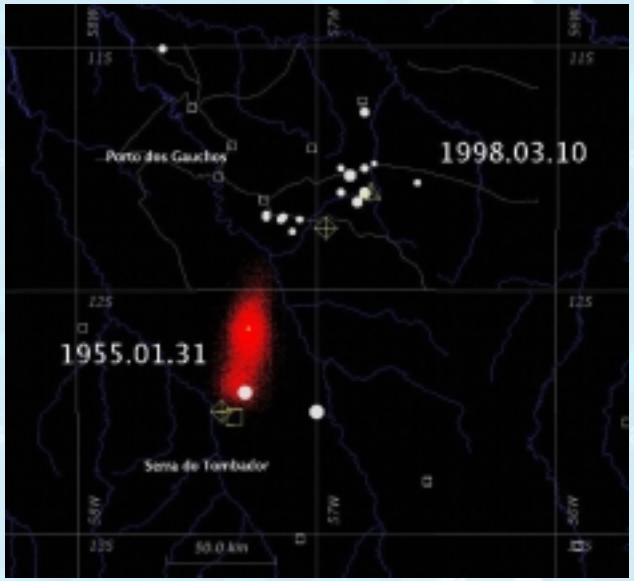
Figure 6 - Station distribution for 1955 events.
Yellow dots are "close 40" stations, whereas red dots are "far 40" stations

5. Methodology and the Results

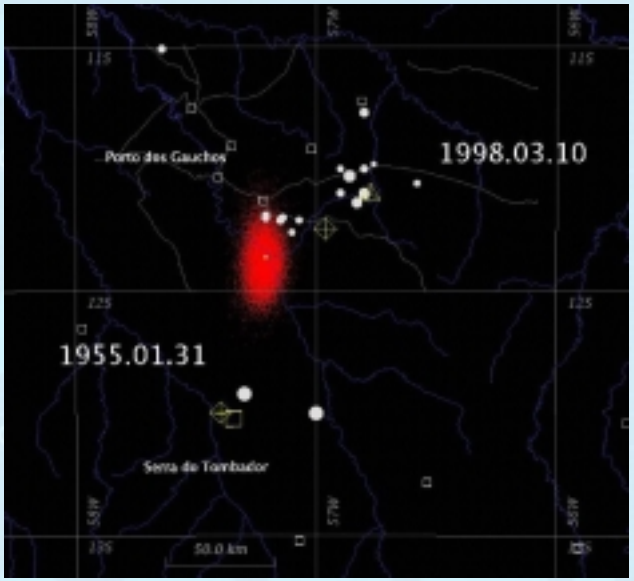
5.1. Relocations of the 1955 Earthquake



Close 40 data set



All data set



Far 40 data set

Compound plot of locations for 1955 event

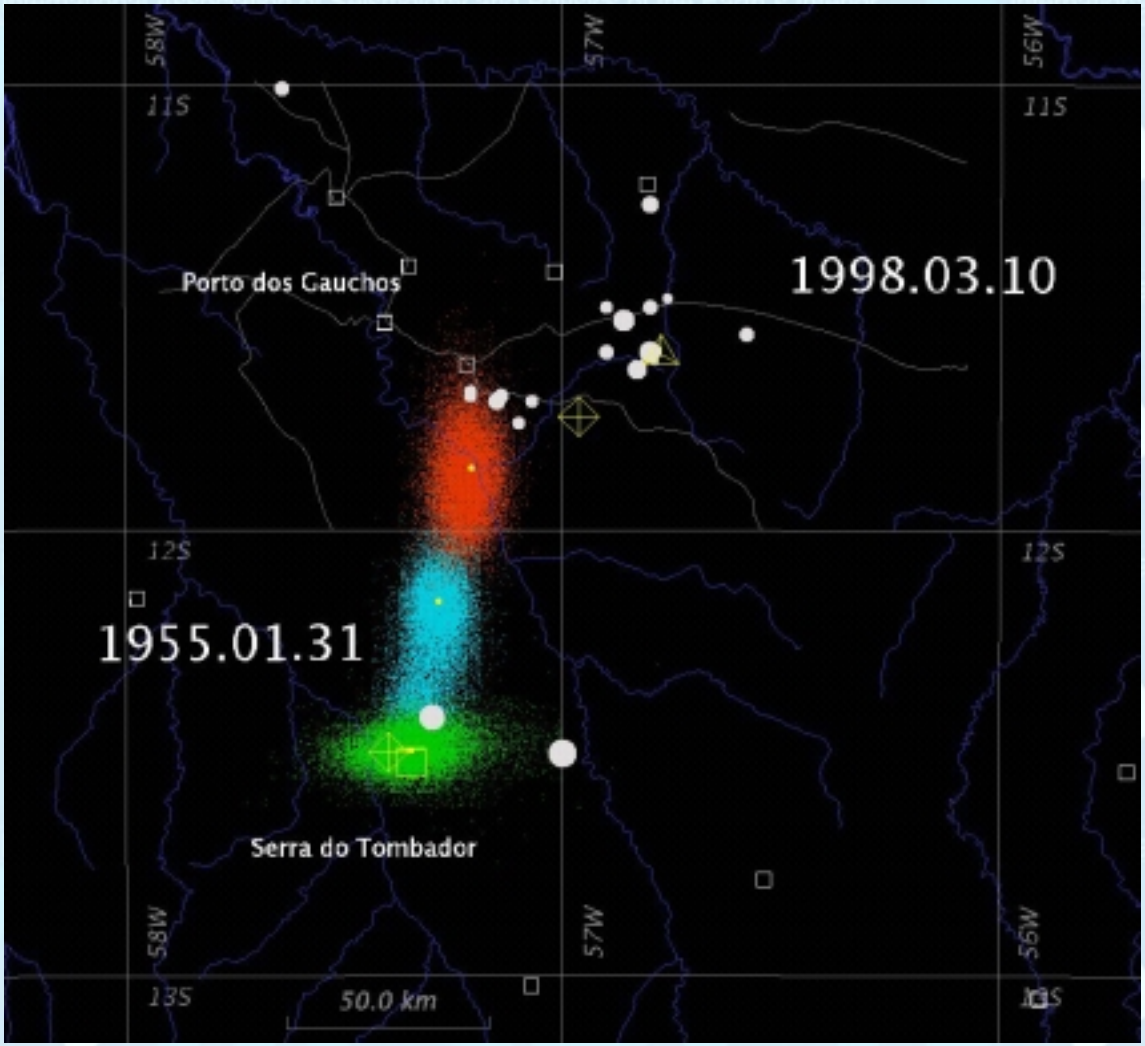


Fig. 7. Compound plot of the NLL relocation of the 1955 mainshock. Red PDF cloud represents 'far 40' data set, blue PDF cloud represents 'all' data set, and green PDF cloud represents 'close40' data set. Diamond symbol marks the epicentres of ISS/ISC, cube marks Engdahl (2002) 1955 epicentre, and tetrahedron marks the "persistent epicentre".

Table 5. ML Hypocentres for 1955 January 31 event

Data Set	O.T.	Lat.	Lon.	Depth	rms (sec)	Nphs	Gap (°)	Δr (km)
All	05:00:05.6	-12.1602	-57.2852	21.78	8.3	206	59	82
Close 40	05:00:07.3	-12.4961	-57.3477	37.50	9.8	36	189	116
Far 40	05:00:03.3	-11.8613	-57.2090	0.05	7.7	170	178	53

Note: ML hypocenter highlighted in red is the preferred solution.
Δr = shift from average epicentre

5.1. Relocations of the 1998 Earthquake

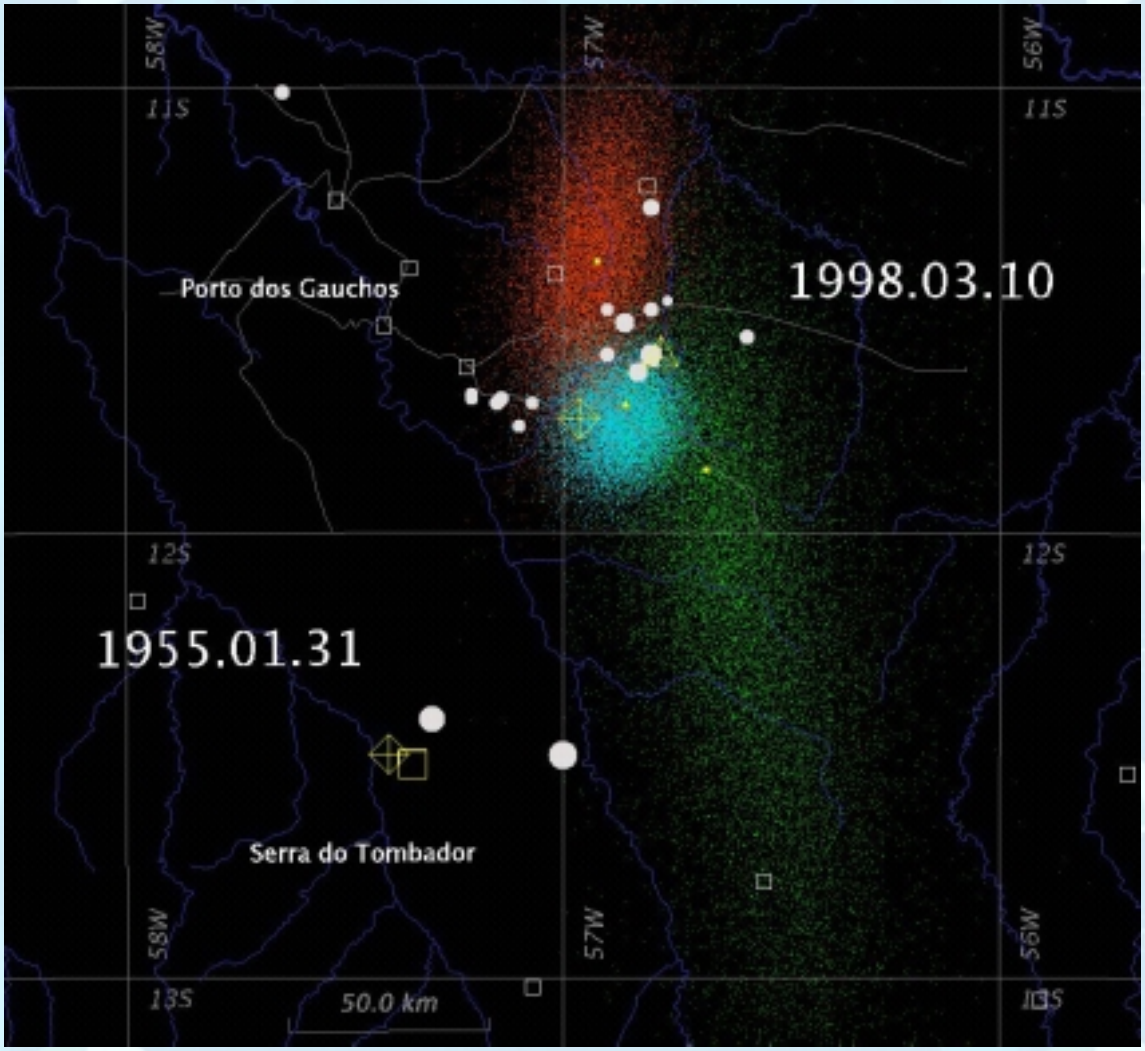
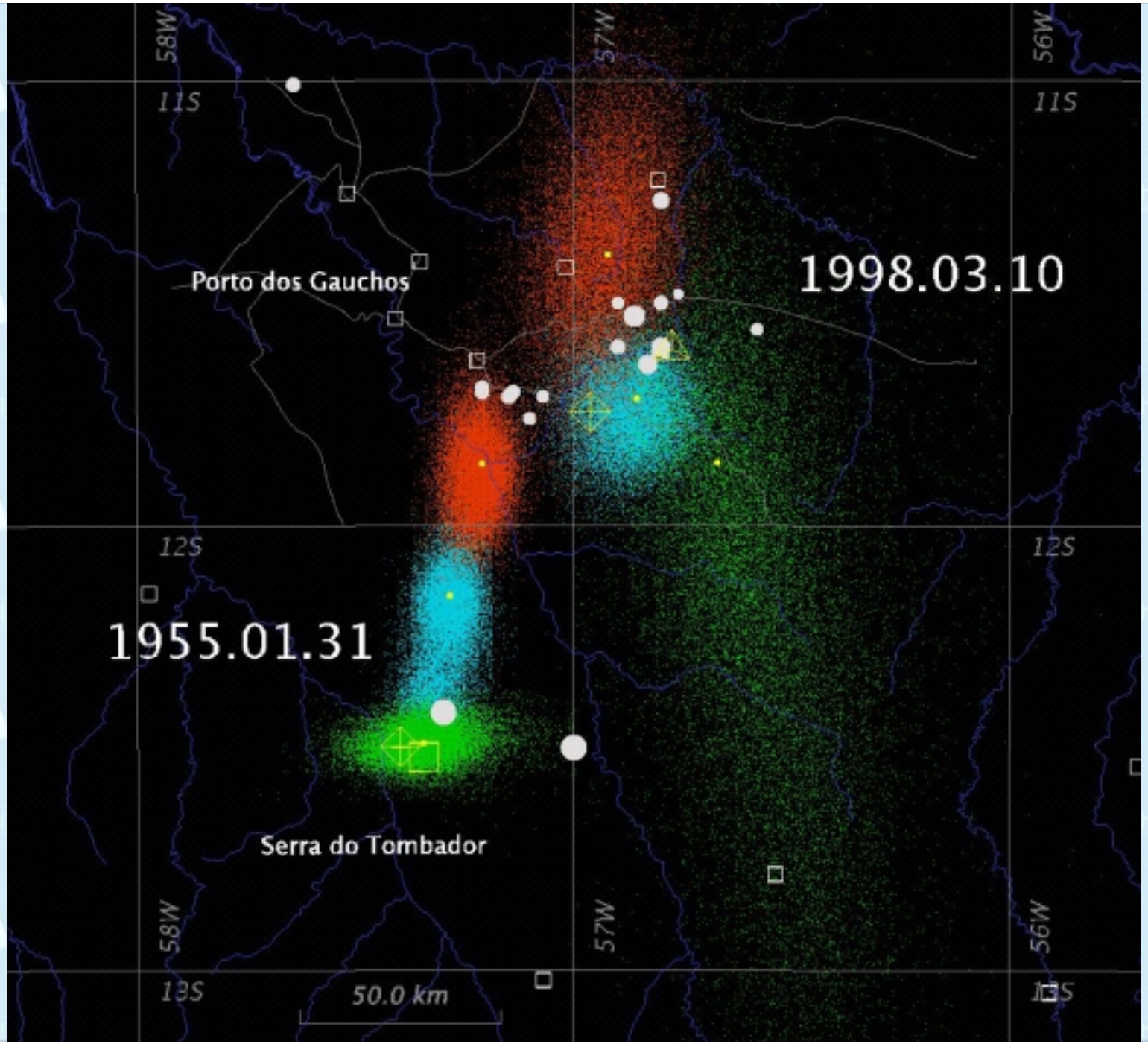
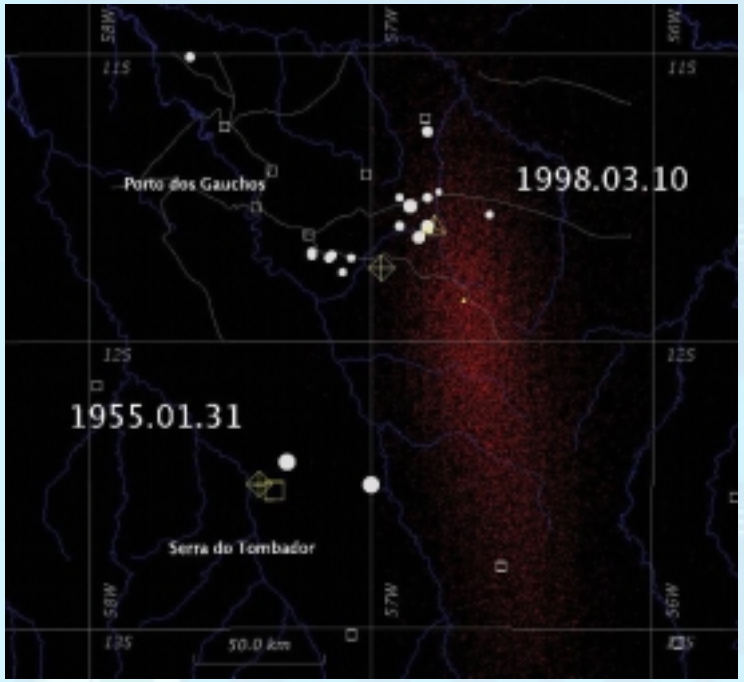


Fig. 8. Compound plot of the NLL relocation of the 1998 mainshock. Red PDF cloud represents 'far 40' data set, blue PDF cloud represents 'all' data set, and green PDF cloud represents 'close40' data set. Diamond symbol marks the epicentres of ISS/ISC, cube marks Engdahl (2002) 1955 epicentre, and tetrahedron marks the "persistent epicentre".

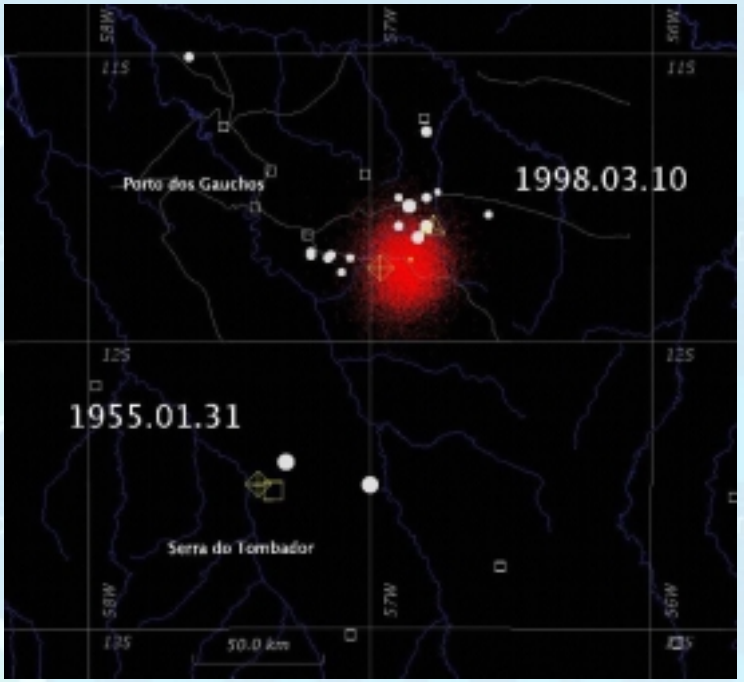
Table 6. ML Hypocentres for1998 March 10 event

Data Set	O.T.	Lat.	Lon.	Depth	rms (sec)	Nphs	Gap (°)	Δ (km)
All	23:32:42.8	-11.7148	-56.8555	0.10	177.9	155	46	14
Close 40	23:32:45.2	-11.8594	-56.6719	11.33	4.0	13	207	32
Far 40	23:32:46.5	-11.3906	-56.9219	15.23	179.8	142	106	27


58W
57W
56W
11S
12S
13S
Porto dos Gauchos
1998.03.10
1955.01.31
Serra do Tombador
50.0 km

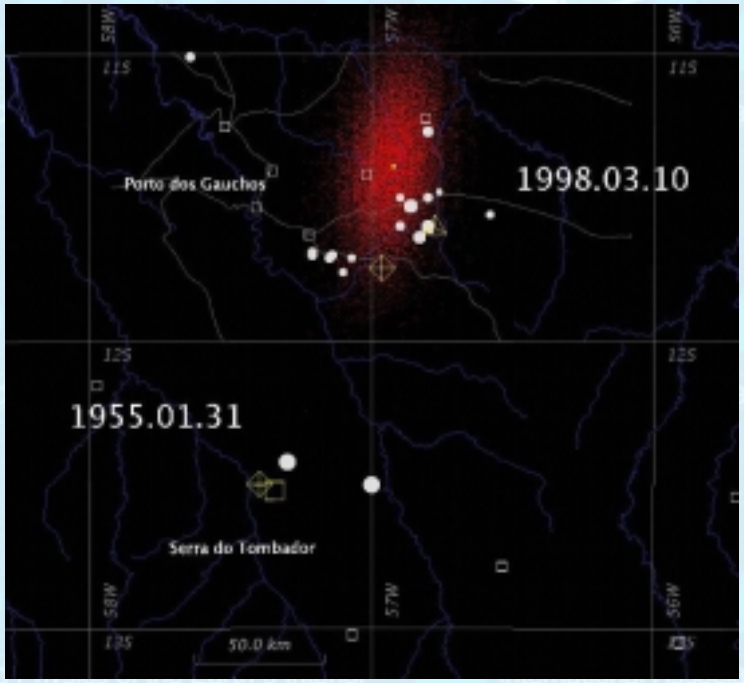


1998 locations



Close 40 data set

All data set

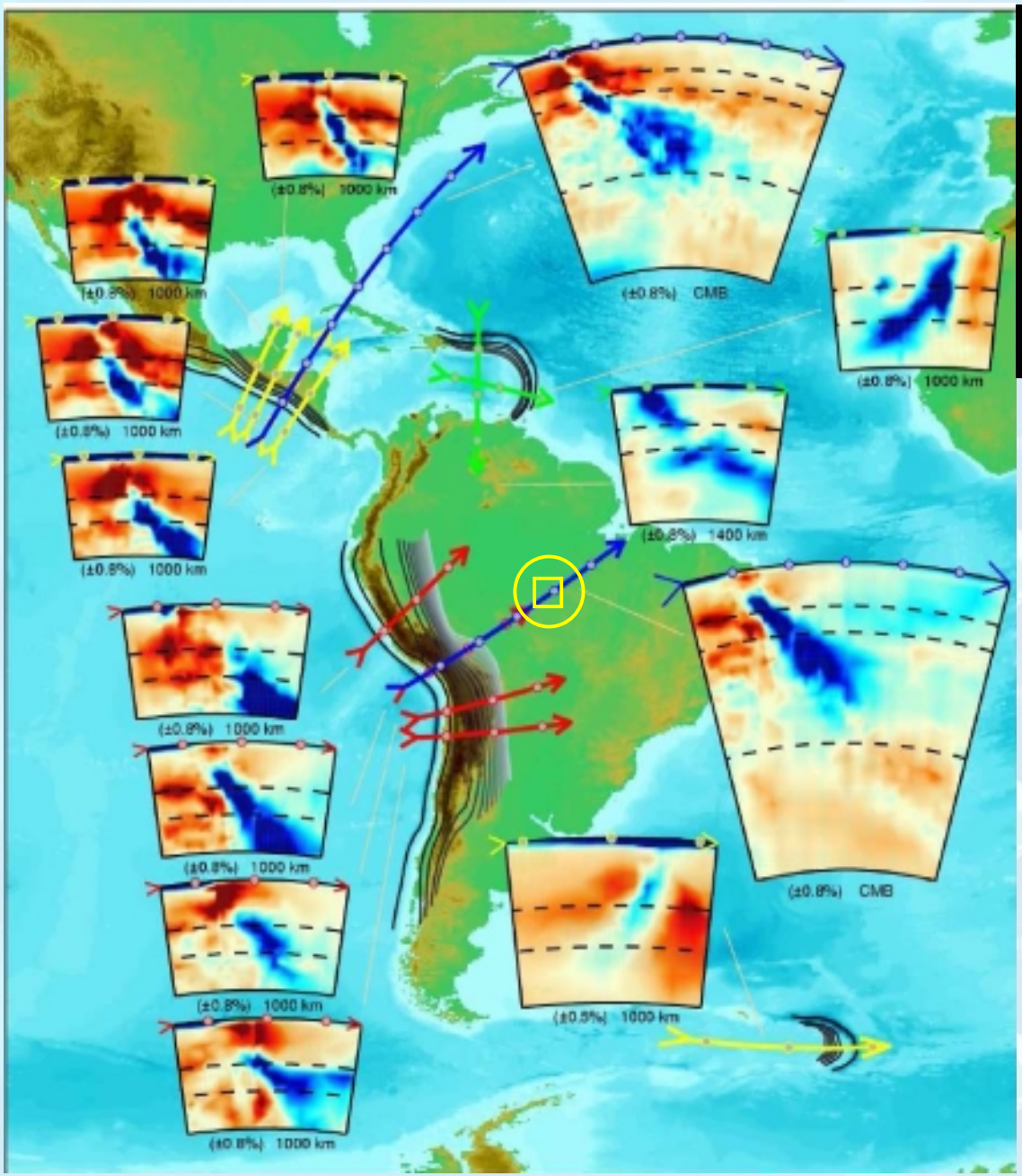


Far 40 data set

6. Discussion

These results show that the previously determined, southern location for the 1955 mainshock may be an artifact of travel time bias due to 3D structure relative to the laterally homogeneous ak135 model for the regional stations at distances up to 40 degrees.

These stations are grouped along the subduction and tectonic zones along the west and north coasts of South America and around the South American craton. Rays towards the Mato Grosso area from the close stations along the western subduction zone and the southern craton and have most of their path lengths in the subducting slab and in the cratonic lithosphere under Brazil (Figure 3).



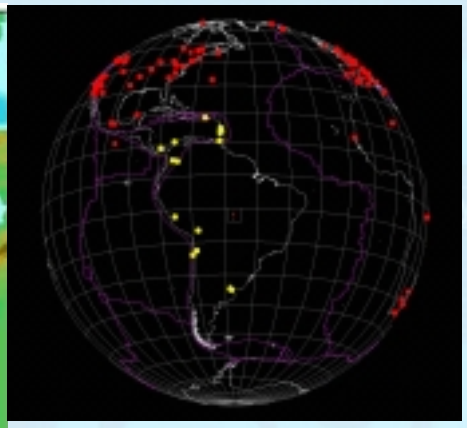


Figure 3 - P wave model showing the complexity of slab structures for South American plate and environs [Courtesy of Van der Hilst, in preparation].

The yellow box shows the study area, note on this raypath the strong wavespeed positive anomaly (blue color).

Upper-right insert shows station distribution used here.

7. Conclusion

Using the robust EDT location technique and different distance subsets of the available phase data we have shown that the epicentre of the 1955 Brazilian earthquake is not in the Serra do Tombador area, but more likely in the Porto dos Gauchos area where all modern seismicity is located.

We find compelling evidence that the Serra do Tombador location for the 1955 epicenter is biased due to the strong 3D structure around Brazil and the inherent limitations of the available data.

8. References

http://alomax.free.fr/pub_list.html

9. Acknowledgments

We thank Antonio Villasenor, Bob Engdahl and Marcelo Assumpçao for collaboration, discussion and criticism.

Dmitry Storchak, of ISC, Thatcham, Berks, UK, kindly provided the copy of ISS Bulletin with the phase data of the 1955 event.

Pedro F. de Andrade helped with editing.

Table 3. Synopsis of hypocentre parameters for located events in seismogenic area of Porto dos Gauchos, MT, Brazil

#	Date	O.T. (UTC)	Lat. (º S)	Lon. (º W)	m_b ($\equiv m_R$)	Δr (km)	Source	Remarks
1	1955 JAN 31	05:03:02	12.5	57.4	N.A.	120	a	Regional & Tele data
1a‡	1955 JAN 31	05:03:03	12.5	57.0	6.8	103	a‡	Regional & Tele data
1a¶	1955 JAN 31	05:03:07	12.42	57.30	6.6	106	a¶	Regional & Tele data
1a#	1955 JAN 31	05:03:06	12.552	57.35	N.A.	119	a#	Regional & Tele data
2	1959 FEB 05	Daytime	(11.6)	(56.8)	5.1	-	b	Macroseismic data
3	1981 MAR 09	17:27:40	11.01	57.64	3.8	113	c	Regional data
4	1986 NOV 17	20:36:06	11.56	56.58	3.6	24	c	Regional data
5	1987 OCT 15	06:01:41	11.6	56.9	3.9	11	c	Regional data
6	1987 DEC 10	18:36:33	11.5	56.9	3.3	16	c	Regional data
7	1988 AUG 11	04:06:13	11.70	57.21	3.7	46	c	Regional data
8	1988 AUG 11	05:06:11	11.71	57.15	3.9	40	c	Regional data
9	1988 AUG 11	07:06:--	11.69	57.21	3.6	46	c	Regional data
10	1988 AUG 11	08:07:--	11.70	57.14	3.8	39	c	Regional data
11	1988 OCT 03	02:02:36	11.71	57.07	3.2	32	c	Regional data
12	1988 OCT 03	05:04:--	11.76	57.10	3.1	37	c	Regional data
13	1989 JUL 31	07:17:--	11.48	56.76	2.5	14	c	Regional data
14	1993 MAY 10	15:17:--	11.5	56.8	3.8	11	c	Regional data
15	1996 NOV 06	04:14:21	11.27	56.80	4.4	37	c	Regional data
16	1998 MAR 10	23:32:44	11.53	56.86	5.3	10	c	Regional data
17	1998 APR 06	08:08:03	11.61	56.81	2.6D	2	c	Local data; AS of #16
18	1998 APR 08	17:56:44	11.61	56.80	2.8D	2	c	Local data; AS of #16
19	1998 APR 09	02:02:43	11.61	56.81	2.2D	2	c	Local data; AS of #16
20	1998 APR 10	11:06:43	11.62	56.79	2.2D	3	c	Local data; AS of #16
21	2005 MAR 23	21:12:00	11.64	56.83	5.0	5	d	Regional & Tele data
22	2005 JUL 20	16:41:25	11.6	56.8	4.3	0	d	Regional & Tele data