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TREATY ORGANIZATION

Integration of RSTT SSSCs in OPS

Christos Saragiotis, Ronan Le Bras & Ali Kasmi
CTBTO, IDC/{SA, OD, MDA}

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Outline

History

- Early 2000s: the IDC started using SSSCs to model regional propagation effects for Pn, Pg, Sn and Lg
- 2011: Sandia NL developed RSTT velocity model for N. America (Pn) and Eurasia (Pn, Pg, Sn, Lg)
- 2016: RSTT-based SSSCs delivered to IDC and tested since then
- 2020 Aug: RSTT-based SSSCs have been deployed in OPS

Description of test data

Bulletin: REB events only

Events:

Shallow: depth ≤ 40 km

Large: ndef ≥ 20

Period:

Before: $[d_0 - 1\text{yr}, d_0)$ and

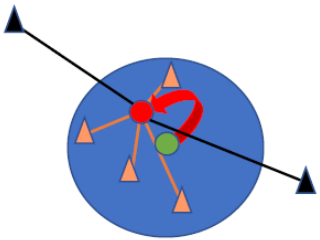
After: $(d_0, d_0 + 1\text{yr}]$[1]

Stats for:

- World
- North America
- Australia (no SSSCs before)
- Africa (no SSSCs before)

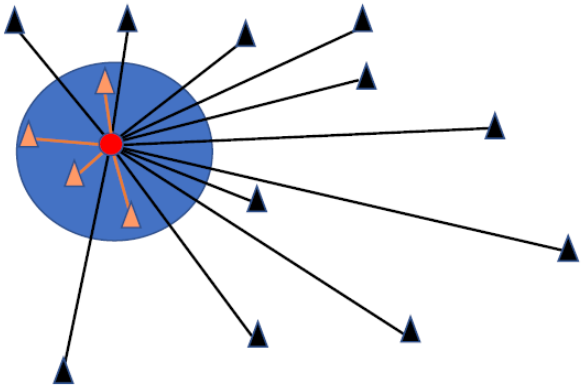
[1] d_0 is August 13th, 2020.

Why large ndef



- Small event, few teleseismic phases
- Location contolled by regional phases
- Even if the RSTT model is not accurate, the time residuals will be small
- High precision but possibly low accuracy

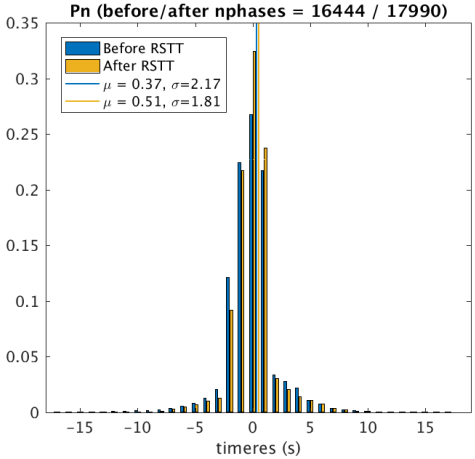
Why large ndef

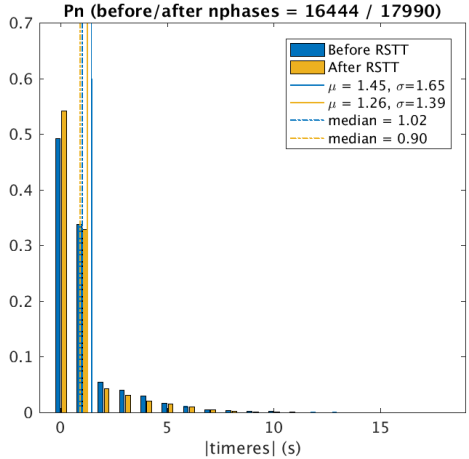


- Large event, many teleseismic phases
- Location controlled by teleseismic phases
- If RSTT model is not accurate, the residuals are expected to be large
- High precision implies and high accuracy

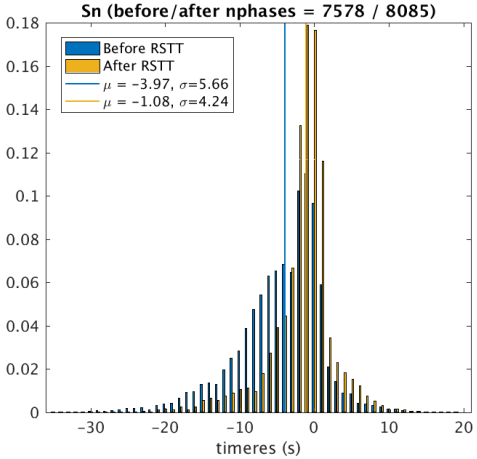
Outline

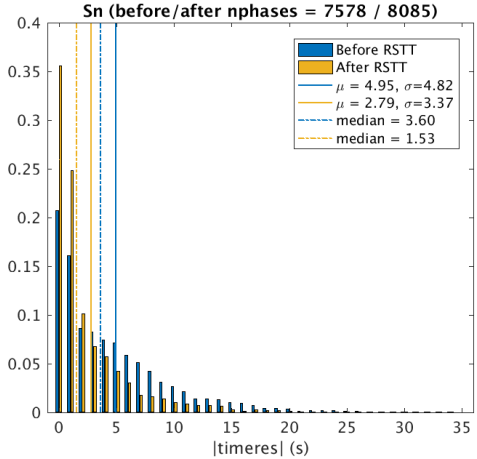
Worldwide — Pn time residuals



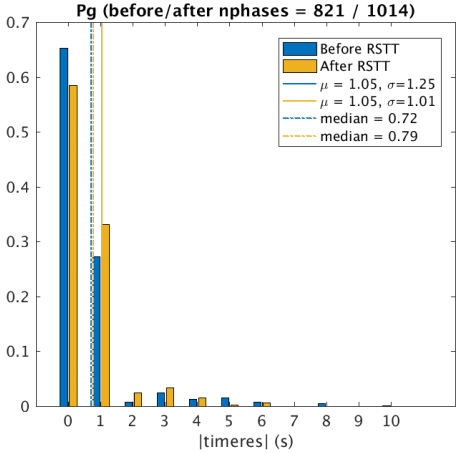


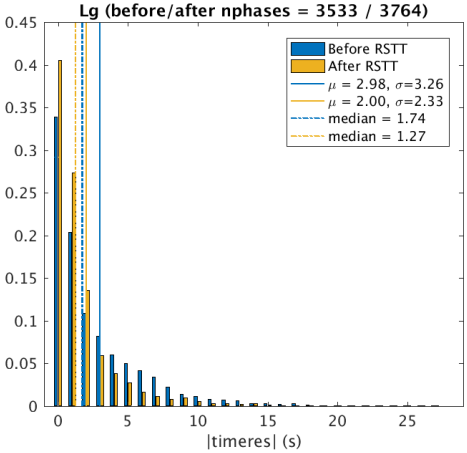
Worldwide — Sn time residuals



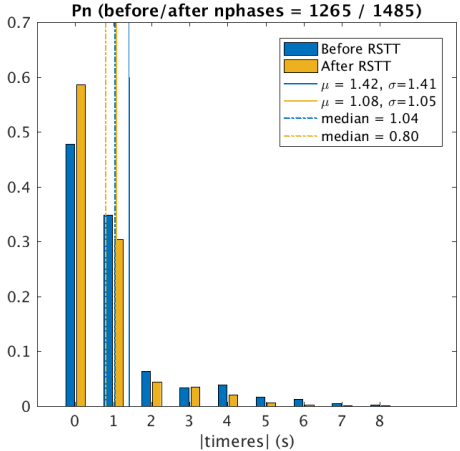


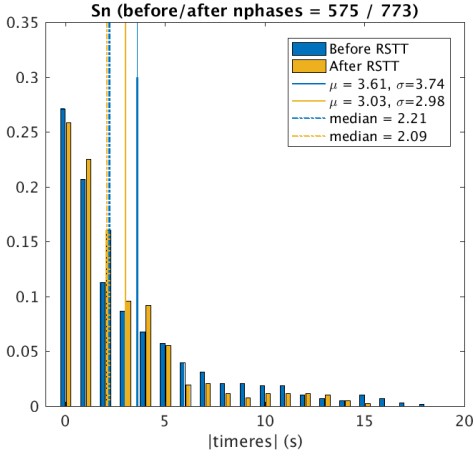
Worldwide — Pg, Lg time residuals



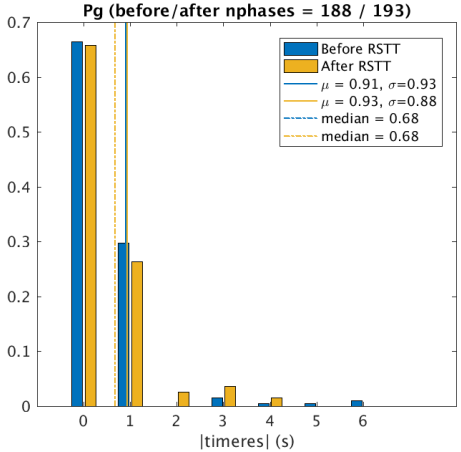


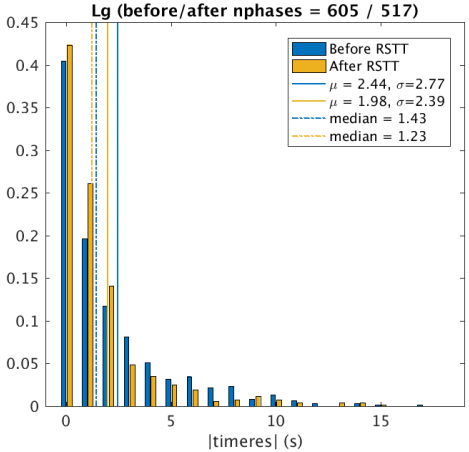
North America — Pn, Sn time residuals



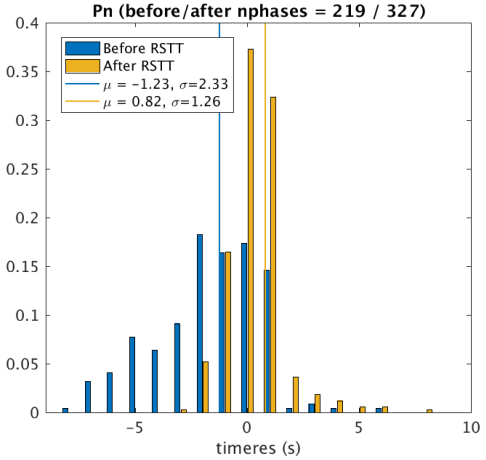


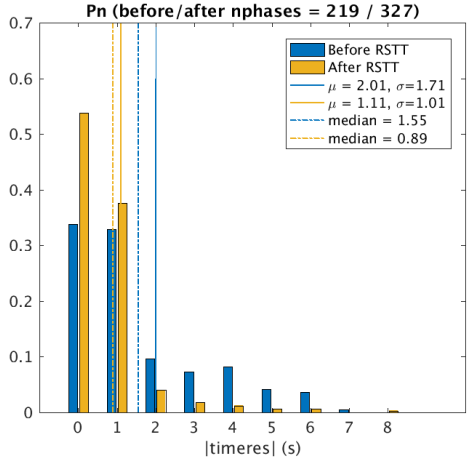
North America — Pg, Lg time residuals



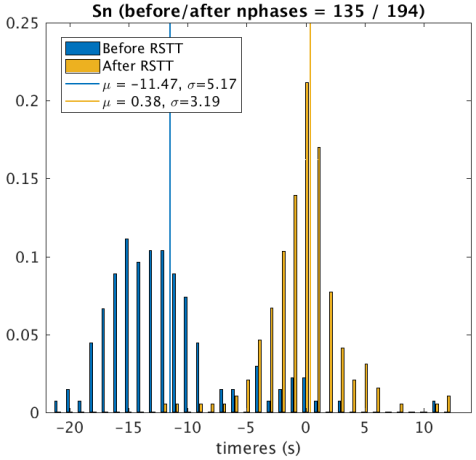


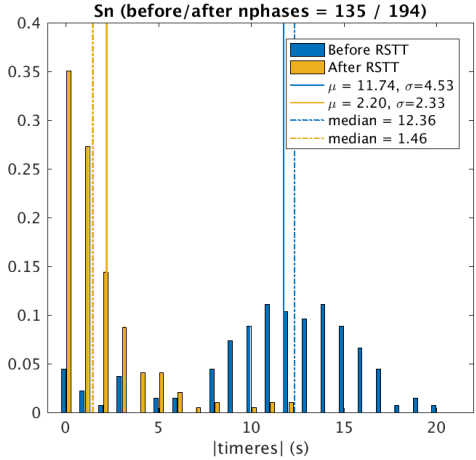
Australia — Pn time residuals





Australia — Sn time residuals





Example events in Timor region, Indonesia

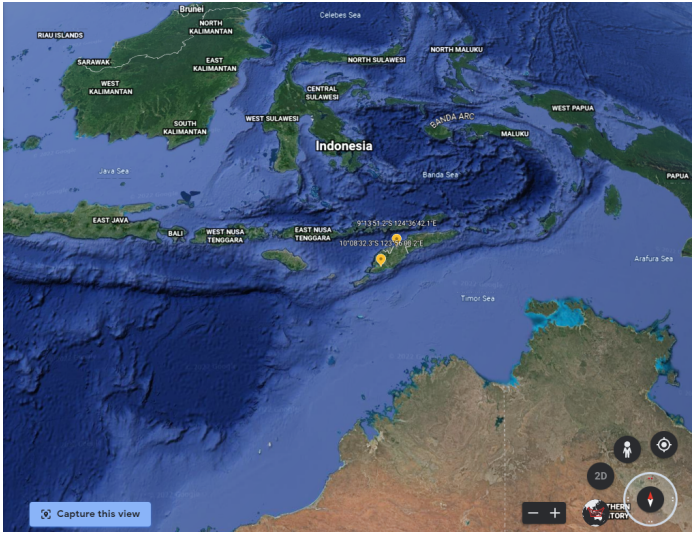
Comparison of two REB events in about the same location:

Location: $(-9.2°, 124.6°)$ vs $(-10.1°, 123.9°)$

Dates: 2019 (before) vs 2021 (after)

m_b: 4.8 vs 4.7

Depth: 0 km (fixed)



Example events in Timor region, Indonesia

EVENT 17186515 TIMOR REGION, INDONESIA

Date	Time	Err	RMS	Latitude	Longitude	Smaj	Smin	Az	Depth	Err	Ndef	Nsta	Gap	mdist	Mdist	Qual	Author
2019/04/07	02:18:13.42	0.35	0.97	-9.2309	124.6117	15.9	10.1	69	0.0f		63	53	44	8.87	154.23	m i uk	IDC_LEB

Magnitude	Err	Nsta	Author	OrigID
ML 5.2	0.2	3	IDC_LEB	17223194
mb 4.8	0.1	28	IDC_LEB	17223194
mbtmp 4.8	0.1	31	IDC_LEB	17223194
Ms 3.7	0.1	27	IDC_LEB	17223194

Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual	Magnitude	ArrID
KAPI	6.39	310.7	Pn	02:19:58.819	10.0	141.0	9.7	9.3	-4.4	___	38.6	6.8	0.33	a__		140709158
FITZ	8.87	173.6	Pn	02:20:21.300	-1.7	2.9	9.5	10.7	-3.0	T__	402.3	33.5	0.33	a__	ML 5.4	140709188
												66.9	0.37		mbtmp 5.4	
FITZ	8.87	173.6	Sn	02:21:51.700	-13.3	235.7	-118	22.8	-1.8	___	13.3	111.2	0.33	a__		140709192
WRA	14.21	139.6	Pn	02:21:31.575	-4.5	317.1	4.3	13.2	-0.6	___	515.3	37.8	0.33	a__		140708361
WRA	14.21	139.6	Sn	02:23:54.975	-20.8	313.2	-4.0	19.5	-4.9	___	13.5	42.7	0.33	a__		140708363
ASAR	16.88	149.3	Pn	02:22:07.200	-4.1	325.1	-1.6	12.7	0.1	___	478.5	17.9	0.33	a__		140708227
ASAR	16.88	149.3	Sn	02:25:01.875	-19.0	319.4	-7.3	20.6	-3.7	___	13.9	11.3	0.33	a__		140708232

Example events in Timor region, Indonesia

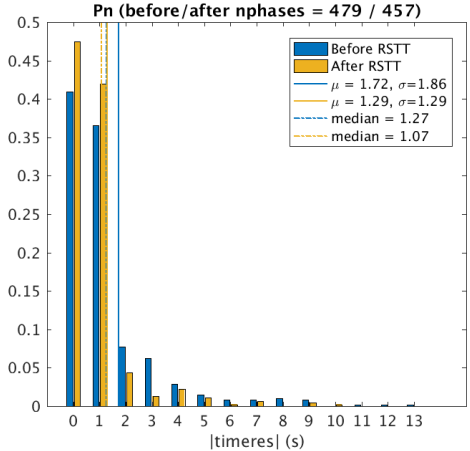
EVENT 19867554 TIMOR REGION, INDONESIA

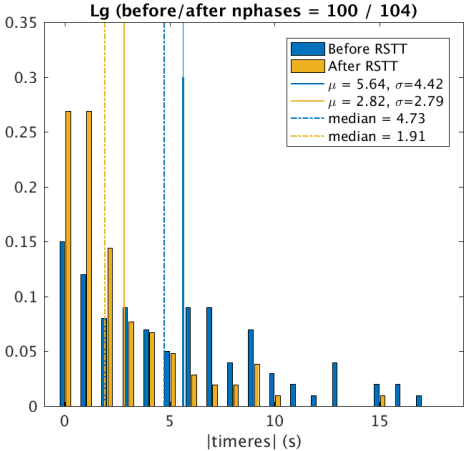
Date	Time	Err	RMS	Latitude	Longitude	Smaj	Smin	Az	Depth	Err	Ndef	Nsta	Gap	mdist	Mdist	Qual	Author
2021/01/05	11:56:18.34	0.48	0.89	-10.1423	123.9334	14.4	9.4	67	0.0f		29	24	90	0.27	123.45	m i uk	IDC_LEB

Magnitude	Err	Nsta	Author	OrigID
ML 4.5	0.1	5	IDC_LEB	19904966
mb 4.7	0.1	15	IDC_LEB	19904966
mbtmp 4.6	0.1	20	IDC_LEB	19904966
Ms 3.8	0.1	21	IDC_LEB	19904966

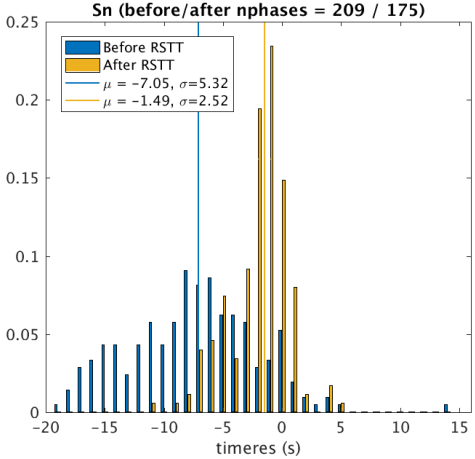
Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual	Magnitude	ArrID
BATI	0.27	256.6	Pg	11:56:25.775	1.0	157.9	81.2	4.7	-14.5	T__	9082	30765.1	0.33	a__		157005352
KAPI	6.57	320.6	Pn	11:58:00.944	1.8	145.2	4.1	10.7	-3.1	T__	14.2	12.1	0.33	a__	ML 4.6	157005346
												37.4	0.47		mbtmp 4.7	
FITZ	8.08	168.4	Pn	11:58:13.675	-0.4	341.8	-6.1	9.1	-4.6	T__	162.0	7.8	0.33	a__	ML 4.7	157005368
												17.3	0.28		mbtmp 4.8	
FITZ	8.08	168.4	Sn	11:59:39.750	0.1	168.7	-179	8.3	-16.4	T__	10.7	22.3	0.33	a__		157005371
SIJI	11.75	38.8	Pn	11:59:10.850	-0.0	173.0	-45.1	6.8	-6.9	T__	10.5	4.0	0.33	a__	ML 4.6	157005327
												8.0	0.62		mbtmp 4.5	
WRA	13.99	135.3	Pn	11:59:32.475	0.7	308.6	-4.0	14.5	0.9	T__	38.3	1.6	0.33	a__	ML 4.3	157004531
												8.7	0.96		mbtmp 4.4	
WRA	13.99	135.3	Sn	12:01:58.339	1.4	308.4	-4.3	23.6	-0.8	T__	12.0	7.4	0.33	a__		157004691
ASAR	16.48	146.0	Pn	12:00:05.750	1.2	316.7	-6.8	11.1	-1.1	T__	160.0	1.7	0.33	a__	ML 4.5	157004465
												6.9	0.65		mbtmp 4.4	
ASAR	16.48	146.0	Sn	12:02:58.553	1.4	310.9	-12.1	20.5	-3.7	T__	8.5	3.2	0.33	a__		157004603

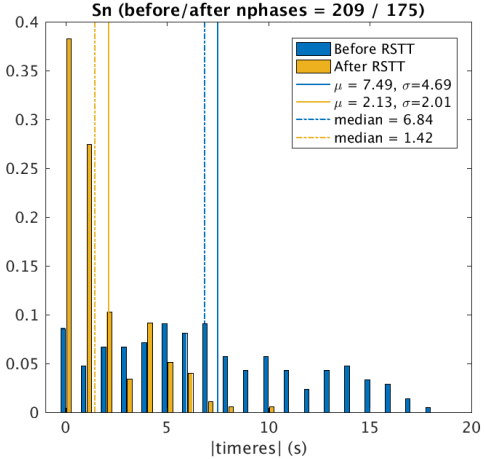
Africa — Pn, Lg time residuals





Africa — Sn time residuals





Example events in Central Africa

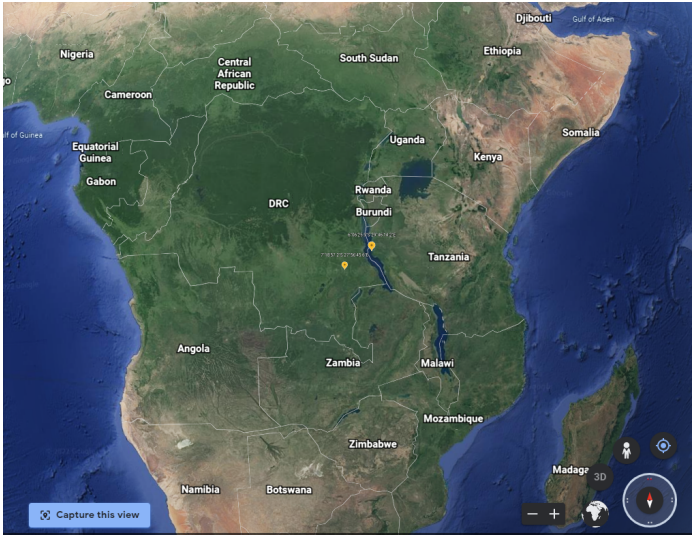
Comparison of two REB events in about the same location:

Location: $(-6.1°, 29.8°)$ vs $(-7.3°, 27.9°)$

Dates: 2017 (before RSTT SSSCs) vs 2022 (after RSTT SSSCs)

m_b: 4.8 vs 4.6

Depth: 0 km (fixed)



Example events in Taganyika/Zaire, C. Africa

EVENT 14353606 LAKE TANGANYIKA REGION

Date	Time	Err	RMS	Latitude	Longitude	Smaj	Smin	Az	Depth	Err	Ndef	Nsta	Gap	mdist	Mdist	Qual	Author
2017/04/29	10:53:20.15	0.41	0.78	-6.1072	29.7706	14.8	10.3	89	0.0f		44	41	56	5.55	130.43	m i uk	IDC_LEB

Magnitude	Err	Nsta	Author	OrigID
ML 5.3	0.4	3	IDC_LEB	14371006
mb 4.8	0.1	31	IDC_LEB	14371006
mbtmp 4.8	0.1	33	IDC_LEB	14371006
Ms 4.6	0.0	35	IDC_LEB	14371006

Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual	Magnitude	ArrID
MBAR	5.55	10.0	Pn	10:54:45.394	1.1	314.4	124.4	3.2	-10.5	T__	108.4	142.1	0.33	a__	ML 5.5	122729822
MBAR	5.55	10.0	Pg	10:55:01.619	0.2	180.0	-10.0	20.2	2.0	T__	9.3	351.5	0.33	___		122839420
MBAR	5.55	10.0	Sn	10:55:46.519	-3.6	100.8	-89.1	21.5	-3.2	___	4.9	786.9	0.33	a__		122729826
MBAR	5.55	10.0	Lg	10:56:09.019	-7.7	245.7	55.7	3.8	-28.0	___	6.7	739.5	0.33	a__		122729829
KMBO	8.96	56.8	Pn	10:55:26.450	-4.7	224.6	-11.7	23.8	10.1	___	41.6	0.2	0.33	a__		122728604
KMBO	8.96	56.8	Sn	10:57:00.000	-14.2	323.4	87.2	23.8	-0.8	___	7.8	0.5	0.33	a__		122728610
KMBO	8.96	56.8	Lg	10:57:51.025	-13.8	331.0	94.7	23.8	-8.0	___	8.8	1.1	0.33	a__		122728616
LSZ	9.24	189.5	Pn	10:55:33.719	-1.2	0.9	-8.9	10.0	-3.7	T__	70.3	22.2	0.33	a__	ML 5.9	122729836
												58.1	0.37		mbtmp 5.3	
LSZ	9.24	189.5	Sn	10:57:11.919	-9.2	343.6	-26.3	13.5	-11.1	___	4.7	36.3	0.33	a__		122729839
LSZ	9.24	189.5	Lg	10:58:07.069	-6.9	109.1	99.3	21.3	-10.4	___	12.6	74.7	0.33	a__		122729847
TSUM	17.61	221.3	P	10:57:23.294	-4.1	31.8	-12.1	12.9	0.5	___	27.5	60.5	0.76	a__		122729858
TSUM	17.61	221.3	S	11:00:26.144	-19.3	294.2	-110	13.1	-11.1	___	6.4	127.0	0.91	a__		122729864
TSUM	17.61	221.3	Lg	11:02:27.194	-12.6	183.4	139.5	9.4	-22.4	___	1.6	4.2	0.33	___		122839409
LBTB	19.22	191.6	P	10:57:44.550	-1.6	10.1	-2.6	13.9	2.9	T__	15.2	2.2	0.33	a__	ML 4.7	122729881
												14.7	0.84		mbtmp 4.6	
LBTB	19.22	191.6	S	11:01:09.475	-14.7	115.1	102.4	12.3	-11.1	___	3.7	69.3	1.02	a__		122729886
LBTB	19.22	191.6	Lg	11:03:18.975	-12.0	271.3	-101	19.8	-12.0	___	1.7	2.7	0.33	___		122839410

Example events in Taganyika/Zaire, C. Africa

EVENT 21692552 ZAIRE

Date	Time	Err	RMS	Latitude	Longitude	Smaj	Smin	Az	Depth	Err	Ndef	Nsta	Gap	mdist	Mdist	Qual	Author
2022/01/26	02:06:07.79	0.40	0.74	-7.3159	27.946	13.2	8.6	113	0.0f		49	40	55	7.23	136.56	m i uk	IDC_LEB

Magnitude	Err	Nsta	Author	OrigID
ML 4.1	0.5	5	IDC_LEB	21724730
mb 4.6	**0.1**	28	IDC_LEB	21724730
mbtmp 4.7	0.1	33	IDC_LEB	21724730
Ms 4.1	0.0	46	IDC_LEB	21724730

Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual	Magnitude	ArrID
MBAR	7.23	22.8	Pn	02:07:52.761	-1.0	183.4	-19.2	9.8	-4.0	T__	16.4	6.6	0.33	a__	ML 4.4	167310975
												15.0	0.25		mbtmp 4.7	
MBAR	7.23	22.8	Lg	02:09:51.119	-2.1	302.4	99.8	22.3	-9.5	T__	13.5	184.3	0.33	a__		167310988
KMBO	11.13	56.9	Pn	02:08:45.700	-0.4	220.7	-15.5	17.5	3.8	T__	24.6	5.9	0.33	a__	ML 4.7	167309645
												7.7	0.30		mbtmp 4.7	
KMBO	11.13	56.9	Sn	02:10:45.575	-1.2	311.4	75.2	24.1	-0.4	T__	3.7	5.9	0.33	___		167437563
KMBO	11.13	56.9	Lg	02:11:51.750	-0.1	152.6	-83.6	21.9	-9.8	T__	19.9	14.5	0.33	a__		167309972
MATP	13.04	177.7	Pn	02:09:11.200	-0.9	0.2	2.6	13.1	-0.5	T__	112.0	25.7	0.33	a__	ML 5.5	167310993
												117.0	0.54		mbtmp 5.7	
MATP	13.04	177.7	Sn	02:11:26.625	-5.9	15.5	17.9	19.5	-4.9	___	3.6	13.2	0.33	a__		167310996
MATP	13.04	177.7	Lg	02:12:54.125	-1.2	44.8	47.2	23.7	-8.1	T__	4.5	23.0	0.33	a__		167311006
TSUM	15.52	219.4	Pn	02:09:43.669	-0.6	32.6	-9.2	11.7	-1.4	T__	32.0	2.0	0.33	a__	ML 2.7	167311011
												8.2	0.41		mbtmp 4.7	
TSUM	15.52	219.4	Sn	02:12:28.169	-1.1	42.6	0.7	23.4	-0.9	T__	5.4	3.8	0.33	a__		167311015
LBTB	17.74	187.0	P	02:10:14.875	-1.7	5.8	-1.9	12.4	0.1	T__	23.4	1.5	0.33	a__	ML 4.5	167311026
												15.2	0.64		mbtmp 4.8	
LBTB	17.74	187.0	S	02:13:24.575	-11.6	324.6	-43.1	3.9	-20.3	___	2.7	33.2	0.82	___		167437562
LBTB	17.74	187.0	Lg	02:15:22.450	-0.8	293.9	-73.8	23.4	-8.4	___	6.7	1.0	0.33	a__		167311035

Example events in South America

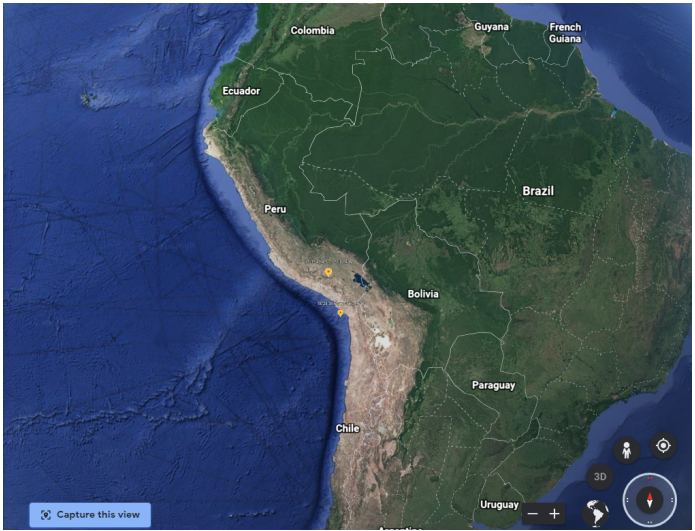
Comparison of two REB events in about the same location:

Location: $(-18.5°, -70.9°)$ vs $(-15.6°, 71.8°)$

Dates: 2019 (before RSTT SSSCs) vs 2021 (after RSTT SSSCs)

m_b: 4.5 vs 4.6

Depth: 0 km (fixed)



Example events close to the Chile/Peru border

EVENT 17799920 NEAR COAST OF NORTHERN CHILE

Date	Time	Err	RMS	Latitude	Longitude	Smaj	Smin	Az	Depth	Err	Ndef	Nsta	Gap	mdist	Mdist	Qual	Author
2019/09/01	21:32:11.69	0.44	0.89	-18.4774	-70.9346	20.3	13.0	69	0.0f		39	36	97	8.61	170.39	m i uk	IDC_LEB

Magnitude	Err	Nsta	Author	OrigID
ML 3.8	0.1	4	IDC_LEB	17819928
mb 4.5	0.1	16	IDC_LEB	17819928
mbtmp 4.4	0.1	20	IDC_LEB	17819928
Ms 4.4	0.1	38	IDC_LEB	17819928

Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual	Magnitude	ArrID
LPAZ	3.45	51.3	Pn	21:33:15.311	8.0	228.7	-1.7	13.1	-0.6	___	129.0	8.5	0.33	a__		144438372
LPAZ	3.45	51.3	Lg	21:34:05.277	3.5	233.6	3.2	12.8	-19.0	___	1.3	18.2	0.33	___		144522229
NNA	8.61	317.7	Pn	21:34:18.733	1.0	147.5	8.3	13.2	-0.5	T__	6.3	3.3	0.33	a__	ML 4.1	144439260
												9.7	0.43		mbtmp 4.4	
NNA	8.61	317.7	Sn	21:35:51.222	-5.7	161.6	22.3	9.6	-15.0	___	1.6	1.3	0.33	___		144522097
SIV	9.74	76.8	Pn	21:34:36.583	3.4	255.9	2.0	15.6	1.9	___	63.9	0.5	0.33	a__		144439273
SIV	9.74	76.8	Sn	21:36:29.890	5.1	204.9	-49.0	17.2	-7.3	___				___		144522092
SIV	9.74	76.8	Lg	21:37:24.580	3.3	210.5	-43.4	19.9	-11.8	___				___		144522214
CFA	13.30	169.9	Pn	21:35:19.750	-2.0	348.7	-0.1	15.5	1.8	T__	6.9	0.5	0.33	a__	ML 3.8	144439280
												1.1	0.31		mbtmp 4.0	
CFA	13.30	169.9	Sn	21:37:33.750	-17.9	226.4	-122	8.1	-16.3	___	1.1	0.2	0.33	___		144553829
ATAH	13.41	326.3	Pn	21:35:24.350	0.5	83.6	-64.3	12.1	-1.6	T__	2.4	0.4	0.33	___	ML 3.7	144553831
												2.5	0.48		mbtmp 4.1	
ATAH	13.41	326.3	Sn	21:37:58.400	3.1	109.4	-38.5	17.9	-6.5	___	1.8	0.1	0.33	___		144522093
CPUP	14.80	124.3	Pn	21:35:41.650	-0.7	244.2	-54.9	0.7	-12.9	T__	4.7	0.1	0.33	a__	ML 3.6	144438244
												0.5	0.61		mbtmp 3.4	

Example events close to the Chile/Peru border

EVENT 21198473 SOUTHERN PERU

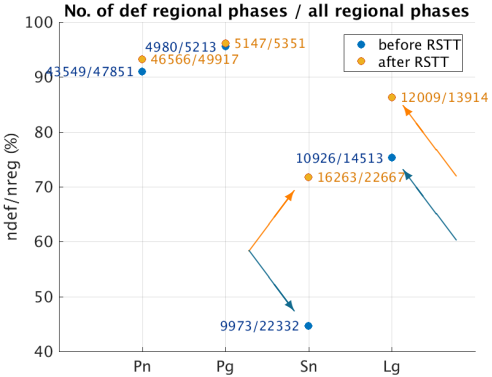
Date	Time	Err	RMS	Latitude	Longitude	Smaj	Smin	Az	Depth	Err	Ndef	Nsta	Gap	mdist	Mdist	Qual	Author
2021/10/09	04:47:45.90	0.42	0.91	-15.5954	-71.8504	16.4	8.9	41	0.0f		37	35	89	3.64	170.75	m i uk	IDC_LEB

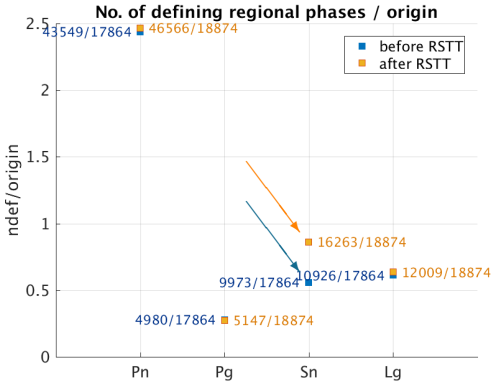
Magnitude	Err	Nsta	Author	OrigID
ML 4.0	0.1	5	IDC_LEB	21223026
mb 4.6	0.1	17	IDC_LEB	21223026
mbtmp 4.5	0.1	22	IDC_LEB	21223026
Ms 5.3	0.0	56	IDC_LEB	21223026

Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual	Magnitude	ArrID
LPAZ	3.64	101.4	Pn	04:48:47.775	0.0	274.5	-5.9	11.3	-2.4	T__	65.1	6.7	0.33	a__	ML 3.9	164541761
												100.7	1.21		mbtmp 4.1	
NNA	6.03	305.9	Pn	04:49:18.369	0.4	134.0	7.0	11.9	-1.8	T__	18.3	11.2	0.33	a__	ML 4.3	164542950
												13.8	0.37		mbtmp 4.3	
NNA	6.03	305.9	Sn	04:50:30.019	1.5	202.6	75.6	13.1	-11.5	T__	3.6	3.8	0.33	a__		164542954
NNA	6.03	305.9	Lg	04:50:54.319	-1.9	52.3	-74.8	23.1	-8.7	T__	2.4	12.0	0.33	___		164598768
SIV	10.38	93.6	Pn	04:50:17.900	1.3	267.6	-3.1	13.0	-0.7	T__	67.3	0.2	0.33	a__	ML 4.3	164542980
												24.3	0.52		mbtmp 4.9	
SIV	10.38	93.6	Sn	04:52:08.760	-3.2	242.1	-28.6	11.5	-13.0	___	1.6	0.0	0.33	___		164645838
ATAH	10.57	322.0	Pn	04:50:21.300	-1.4	170.2	26.9	9.4	-4.3	T__	4.5	0.5	0.33	a__	ML 3.6	164542970
												2.7	0.79		mbtmp 3.8	
CFA	16.27	168.9	Pn	04:51:36.325	0.4	344.8	-2.6	12.2	-0.6	T__	41.9	0.7	0.33	a__	ML 4.1	164542965
												11.2	0.78		mbtmp 4.6	

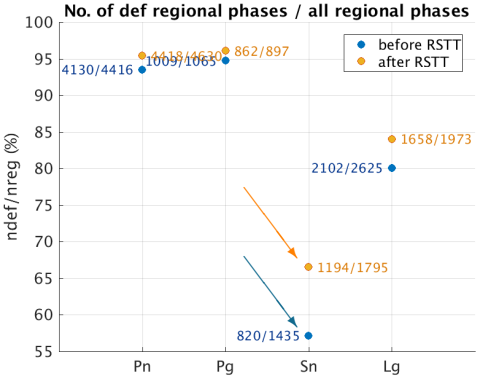
Outline

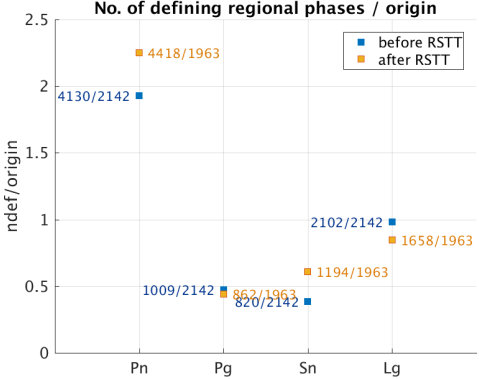
Worldwide — Defining regional phases



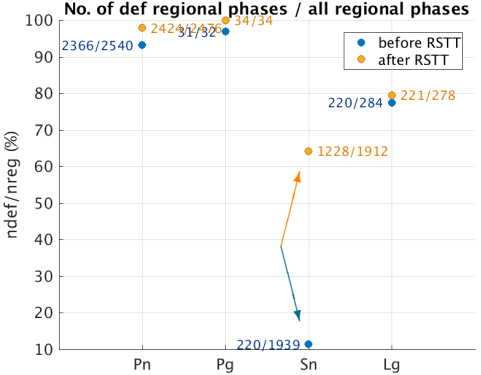


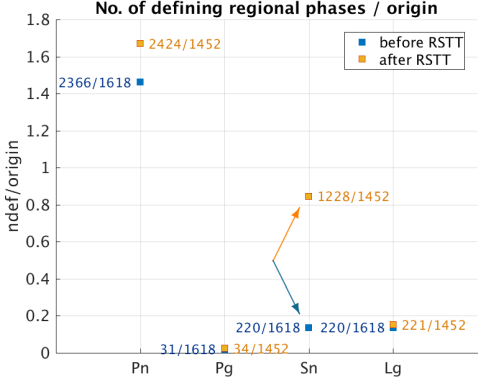
North America — Defining regional phases



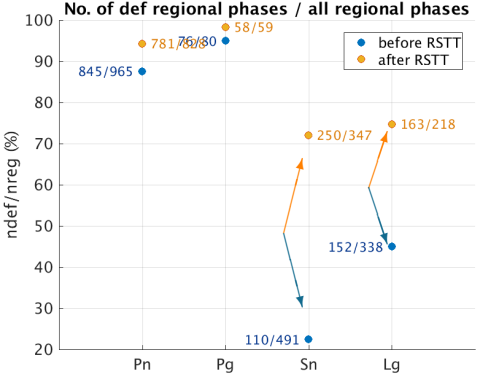


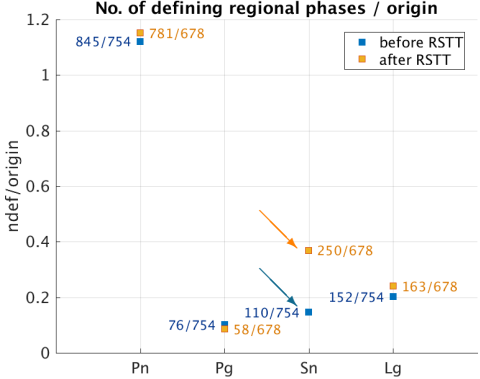
Australia — Defining regional phases





Africa — Defining regional phases





Defining phases — Worldwide

	Before RSTT (17864 orids)			After RSTT (18874 orids)		
Phase	**ndef**	**ndef (%)**	**ndef/origin**	**ndef**	**ndef (%)**	**ndef/origin**
Pn	43549	91.01%	2.44	46566	93.29%	2.31
Pg	4980	95.53%	0.28	5147	96.19%	0.26
Sn	9973	44.66%	0.56	16263	71.75%	0.53
Lg	10926	75.28%	0.61	12009	86.31%	0.58
Total	69428	77.22%	3.89	79985	87.08%	4.24

Defining phases — N. America

	Before RSTT (2142 orids)			After RSTT (1963 orids)		
Phase	**ndef**	**ndef (%)**	**ndef/origin**	**ndef**	**ndef (%)**	**ndef/origin**
Pn	4130	93.52%	1.93	4418	95.42%	2.10
Pg	1009	94.74%	0.47	862	96.10%	0.51
Sn	820	57.14%	0.38	1194	66.52%	0.42
Lg	2102	80.08%	0.98	1658	84.03%	1.07
Total	8061	84.49%	3.76	8132	87.49%	4.14

Defining phases — Australia

	Before RSTT (1618 orids)			After RSTT (1452 orids)		
Phase	**ndef**	**ndef (%)**	**ndef/origin**	**ndef**	**ndef (%)**	**ndef/origin**
Pn	2366	93.15%	1.46	2424	97.90%	1.63
Pg	31	96.88%	0.02	34	100.00%	0.02
Sn	220	11.35%	0.14	1228	64.23%	0.15
Lg	220	77.46%	0.14	221	79.50%	0.15
Total	2837	59.17%	1.75	3907	83.13%	2.69

Defining phases — Africa

	Before RSTT (754 orids)			After RSTT (678 orids)		
Phase	**ndef**	**ndef (%)**	**ndef/origin**	**ndef**	**ndef (%)**	**ndef/origin**
Pn	845	87.56%	1.12	781	94.32%	1.25
Pg	76	95.00%	0.10	58	98.31%	0.11
Sn	110	22.40%	0.15	250	72.05%	0.16
Lg	152	44.97%	0.20	163	74.77%	0.22
Total	1183	63.13%	1.57	1252	86.23%	1.85

Conclusions

- Time residuals overall improve
  - Most significant improvement for Sn phases worldwide
  - Lg time residuals also significantly improved
- No. of defining regional phases generally increases
  - very significant percentage increase for defining Sn phases (45% $\rightarrow$ 70%)
    - overall (45% $\rightarrow$ 70%)
    - in Africa (20% $\rightarrow$ 70%) and
    - in Australia overall (45% $\rightarrow$ 70%)
  - significant increase % of for defining Lg phases
    - overall (75% $\rightarrow$ 85%) and
    - in Africa (45% $\rightarrow$ 75%)
- Overall very significant improvements in Africa and Australia

Further plans

- RSTT-based SSSCs (v3.1.0, rel. 2020) has been deployed in DevLAN
  - has richer ray coverage
  - includes uncertainties
  - includes SSSCs for six more recent stations (ARTI, FURI, HILR, LZDM, QSPA, SHEM)
  - tested in DevLAN (2021/Q4 – 2022/Q2)
  - deployment in testbed (2022/Q1)

CTBTO
PREPARATORY COMMISSION

Vienna International Centre, PO Box 1200
1400 Vienna, Austria
CTBTO.ORG