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VII.7 Event locations using small arrays and single-site 3-component records

There are in principle 3 approaches to the problem of accurately locating seismic events, which in turn reflects parameter extraction, namely:

i) P-arrival times from a network of stations

ii) For arrays and 3-component stations - the slowness vector or distances estimates from differential travel times

iii) Waveform parameterization in combination with pattern recognition technique, available seismicity information, etc.

In this section we will address mainly point ii), exemplified by analysis of NORESS data, and discuss point iii) in terms of 3-component and semblance parameterization of the whole event record.

Single-site epicenter location principles

Single-site estimates of epicenter coordinates are tied to the geometry of a triangle (station, North Pole, epicenter) on a sphere. Parameters needed here are azimuth and epicentral distance. The latter can be obtained from an estimate of apparent velocity, which is then converted to epicentral distance via standard tables like the J.B. Very accurate distance estimates can be achieved if more than one phase can be identified in the records - with a corresponding conversion of differential travel time to distance via J.B. Note that for local and regional events two identified phases are normally required since the associated velocity gradients vs distance are zero or at best very small. Another problem for local and regional phases is that specific travel time curves have to be generated, and this is also addressed below.

Event locations using NORESS broadband records

This is the simplest case of single-site event location because low frequency body waves are generally transparent to crustal heterogeneities and in generally prominent secondary phases like PP, PPP, S, etc., are easy to identify.

An example of 3-component analysis of NORESS broadband records is shown in including times, velocity and azimuth for all phases identified. Note that the given apparent velocities were derived using an upper crustal P velocity of 7 km s^{-1} when correcting for the actually measured apparent angle of incidence (P to S interference on the surface). In other words, low frequency waves "see" a relatively large portion of the lithosphere.

In our event location experiment here, 6 earthquakes with good SNR were analyzed as indicated above, and the ensuing event locations are tabulated in Table VII.7.1. The average mislocation error is only 1 deg ($43^o < \Delta < 154^o$), which is rather impressive as no sort of corrections have been introduced.

Teleseismic event locations - short period records

This is the most difficult case when single-site 3-component records are used, the reason being that the distance estimate in most cases can only be derived from the measured apparent velocity. For example, at 60^o an error of 1 deg in the angle of incidence corresponds to 4 deg in distance. Nevertheless, single-site 3-component record analysis can provide a first rough estimate of epicenter locations as illustrated in Table VII.7.2, where the outcome of an experiment in locating a number of Central Asia (Hindu Kush) events is given. Additional constraints on epicenter locations now under consideration are thos of incorporating seimsicity information and/or probabilities from 3-component analysis patterns. For example, in the case of the Aleutian Islands events, incorporating seismicity information implies that distances are "locked" to the epicenter distribution in the said region, while at the same time retaining the original azimuth estimate.

Occasionally an event location may be very wrong, but a properly trained analyst should on the basis of past experience (access to processed 3-component records of previously occurring events in the same general area) be able to handle such cases in a decent manner.

Event locations at local and regional distances

As mentioned, travel time curves for crustal phases have constant gradients, so apparent velocity estimates mainly serve as a diagnostic for phase identification but hardly provide an acceptable distance estimate. Exceptional cases may be repeated quarry blasting, etc., where signal spectral content (spectograms) may suffice for recognition of event location. In this section we treat the more conventional approach to event locations, that is, in principle similar to the approach used in analysis of NORESS broadband event records described above. There is one minor but significant difference here: standard travel time curves like J.B. are not very representative for Fennoscandia, so local travel time curves have to be generated. A reasonable approach here is outlined below:

The standard approach here is to generate travel time curves on the basis of seismic profiling results in terms of layer thicknesses and associated velocity distributions. Besides considerable local variations in these parameters, the extent of velocity gradients in the crust is not well known. Anyway, our approach to this problem is to combine NORESS observed travel times for crustal phases with epicenter solutions as reported by local seismological agencies. Considering such a data set to be equivalent to that from a refraction profiling survey, we have used inversion techniques (e.g., see Braille, 1973; Ruud, 1986) to estimate velocities and crustal thickness. The outcome of such an experiment, on the basis of "3-component" arrival time pickings for Pg, Sg, Pn and Sn for 11 local events, are shown in Table VII.7.3. We take such a model and associated travel time curves to be representative for NORESS per se. We note in passing that the crustal thickness estimate of about 34 km obtained here compares favorably with that of Berteussen (1976) of 33 km on the basis of spectral ratio analysis of NORSAR long periodic records. For localizing travel time curves, we may restrict the observational data to events in a small area. The resolution of the estimated parameters becomes poorer, but the travel time curves would be more accurate.

In the case of estimating epicenter coordinates plus focal depth, the above procedure is reversed, that is, now distance, origin time and depth are taken as unknowns, and the outcome of an experiment of locating 13 local and regional events is presented in Table VII.7.4. For the depth parameter estimation, the Sn is most informative and this phase is occasionally prominent on transverse records.

Summary

The examples given above demonstrate clearly that using 3-component event records, good to very good event locations are feasible at any distance. Further refinements in analysis like using seismicity information and/or wavefield decomposition patterns should make further improvements realistic. It would be most interesting to check the event location performance for a combination of two 3-component stations being a few hundred kilometers away from each other.

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References

Berteussen, K.-A. (1977): Moho depth determinations based on spectral ratio analysis of NORSAR long period P-waves. Phys. Earth Planet. Inter., 15, 13-27.

Braille, L.W. (1973): Inversion of crustal seismic refraction and reflection data, J. Geophy. Res., 78, 7738-7744.

Ruud, B.O. (1986): Inversion methods in seismic prospecting. Semesteroppgave, Inst. for Geology, Univ. of Oslo.

Event	Origin Time h m s	Lat. (deg)	Long. (deg)	H (km)	m_b/err. (deg)	Dist. (deg)	Azi (deg)	Vel. (km/s)	Region
6/6-85	02.40.12.8	0.95N	28.43W	10	6.3	67.10	224.21	17.4	Central Mid-
(1)	(02.40.05)	(0.20N)	(28.70W)	(33)	(0.80)	(67.90)	(224.20)	(19.65)	Atlantic Ridge
29/7-85	07.54.44.3	36.19N	70.89E	101	6.7	42.10	93.30	13.60	Hindu Kush Region
(2)	(07.54.42)	(37.54N)	(71.54E)	(33)	(1.45)	(43.50)	(94.0)	(13.55)	
23/8-85	12.41.59.7	39.42N	75.27E	33	6.4	43.9	89.0	13.80	Southern Xinjang,
(3)	(12.42.02)	(39.31N)	(75.39E)	(33)	(0.14)	(44.0)	(89.0)	(13.44)	China
21/9-85	01.37.13.8	17.82N	101.67W	33	6.3	85.21	298.59	22.4	Near coast of
(4)	(01.37.15)	(16.94N)	(102.61W)	(33)	(1.26)	(86.40)	(299.0)	(22.55)	Guerrero, Mexico
5/10-85	15.24.02.2	62.26N	124.31W	10	6.5	52.49	335.88	15.0	Northwest Territories,
(5)	(15.23.57)	(61.29N)	(124.94W)	(33)	(1.01)	(53.50)	(335.10)	(15.10)	Canada
7/11-85	19.12.29.8	35.20S	179.36W	33	6.2	153.5	20.3	32.0	East of North Island,
(6)	(19.12.08)	(35.18S)	(178.16W)	(33)	(0.98)	(153.7)	(18.1)	(55.1))	New Zealand

Table VII.7.1 Focal parameters, taken from the PDE listings of USGS, for the events used in analysis. Parameters in parentheses are those estimated from the single-site 3-component broadband recordings (NORESS). The distance differences between the two sets of event location estimates are listed in the m_b-column.

Event	Origin Time h m s	Lat. (deg)	Long. (deg)	H (km)	m_b/err. (deg)	Dist. (deg)	Azi (deg)	Vel. (km/s)	Region
18/7-85	17.40.12.9	30.36N	94.84E	33	4.9	60.70	79.50	16.3	Hindu Kush
(1)	(17.38.45)	(11.10N)	(90.70E)		(19.6)	(75.0)	(94.0)	(19.0)	
29/7-85	07.54.44.3	36.19N	70.89E	101	6.7	42.10	93.30	13.60	Hindu Kush (BB)
(2)	(07.54.42)	(37.5N)	(71.5E)		(1.5)	(43.5)	(94.0)	(13.60)	
7/8-85	15.43.22.7	27.88N	53.05E	15	5.4	43.0	120.8	13.70	Hindu Kush
(3)	(15.46.41)	(46.60N)	(38.40E)		(22.0)	(21.0)	(120.0)	(10.1)	
13/8-85	03.42.40.8	36.30N	71.12E	75	5.1	44.30	95.50	13.90	Hindu Kush
(4)	(03.41.45)	(28.90N)	(72.50E)		(7.5)	(51.00)	(100.0)	(14.80)	
23/8-85	08.32.56.9	39.36N	75.37E	66	5.0	43.90	89.0	13.80	Hindu Kush
(5)	(08.32.49)	(37.70N)	(74.80E)		(1.7)	(45.00)	(91.0)	(13.90)	
23/8-85	12.41.59.7	39.42N	75.27E	33	6.4	43.90	89.0	13.80	Hindu Kush
(6)	(12.49.09)	(38.40N)	(71.80E)		(2.9)	(43.0)	(93.0)	(13.7)	
23/8-85	14.11.41.8	39.56N	75.22E	33	4.9	43.90	89.0	13.80	Hindu Kush
(7)	(14.10.44)	(31.10N)	(76.20E)		(8.5)	(51.0)	(95.0)	(14.80)	
23/8-85	16.25.32.2	39.45N	74.83E	33	4.9	43.90	89.0	13.80	Hindu Kush
(8)	(16.25.32)	(41.50N)	(78.90E)		(3.7)	(44.0)	(84.0)	(13.8)	
23/8-85	20.33.48.2	39.27N	73.01E	33	4.8	42.90	91.90	13.60	Hindu Kush
(9)	(20.34.29)	(42.20N)	(67.60E)		(5.0)	(38.0)	(93.0)	(13.1)	
4/9-85	08.32.25.8	36.23N	71.02E	66	4.9	44.30	95.60	13.90	Hindu Kush
(10)	(08.31.45)	(32.9N)	(75.2E)		(3.7)	(49.0)	(94.5)	(14.50)	
11/9-85	01.57.20.9	40.36N	63.10E	33	4.7	37.20	99.0	13.10	Hindu Kush
(11)	(01.56.24)	(33.10N)	(65.10E)		(7.4)	(44.0)	(104.0)	(13.8)	

Table VII.7.2 Focal parameters, taken from the PDE listings of USGS, for the events used in analysis. Paremeters in parentheses are those estimated from the single-site 3-component recordings (NORESS). The distance differences between the two sets of event locations are listed in the m_b-column.

Layer (km)	P-velocity (km s^{-1})	S-velocity (km s^{-1})
33.5	6.50	3.67
Moho	8.20	4.67

Table VII.7.3 Best-fitting crustal model on the basis of 11 local and regional events recorded by NORESS.

Event	Origin Time h m s	Lat. (deg)	Long. (deg)	H (km)	M_L/err.	Azi. (deg)	Dist. (km)	Agency	Region
29/1-85	11.59.47	59.3N	28.10E	0	-	92.6	931	FIN	Leningrad, USSR
(1)	(11.59.45.5)	(61.08N)	(29.18E)	(15)	(207)	(80.0)	(951)		
2/4-85	19.29.40	66.9N	23.3E	-	-	34.9	893	UPP	Norbotten, Sweden
(2)	(19.29.41.1)	(68.05N)	(18.81E)	(15)	(230)	(20.0)	(883)		
23/4-85	-	58.34N	6.43E	0	-	229.5	392		Titania exp.
(3)	(13.16.27.5)	(58.43N)	(6.34E)	(7)	(11)	(231.0)	(389)		
15/6-85	00.40.21	56.50N	12.10E	-	-	175.8	471	UPP	Offcoast Halland, Sweden
(4)	(00.40.20.9)	(56.48N)	(12.21E)	(13)	(7)	(175.0)	(474)		
27/6-85	-	59.31N	6.95E	0	-	240.1	300	-	Blåsjø
(5)	(08.45.32.4)	(59.51N)	(6.73E)	(4)	(51)	(250.0)	(301)		
28/6-85	-	59.31N	6.95E	0	-	240.1	300	-	Blåsjø
(6)	(15.42.11.8)	(59.51N)	(6.73E)	(1)	(26)	(245.0)	(299)		
30/8-85	07.40.46.9	61.89N	2.19E	15	-	288.5	515	BER	Offcoast W. Norway
(7)	(07.40.47.4)	(61.92N)	(2.29E)	(15)	(7)	(289.0)	(510)		
8/9-85	12.31.57.4	61.24N	3.37E	15	-	280.8	443	BER	Offcoast W. Norway
(8)	(12.31.56.5)	(61.32N)	(3.34E)	(15)	(9)	(282.0)	(446)		
12/9-85	19.17.43.4	61.27N	8.10E	15	-	289.3	195	BER	Tyin/Lærdal
(9)	(19.17.44.9)	(60.95N)	(7.54E)	(13)	(47)	(278.0)	(218)		
31/10-85	02.55.52	62.8N	18.0E	-	-	53.1	410	UPP	Ångermanland, Sweden
(10)	(02.55.52.9)	(63.53N)	(17.01E)	(12)	(95)	(40.0)	(421)		
19/1-86	04.59.24	65.25N	12.50	-	-	5.1	505	UPP	Coast of Central Norway
(11)	(04.59.21.4)	(65.42N)	(12.53)	(5)	(19)	(5.0)	(523)		
25/1-86	23.13.25	61.80N	16.90E	-	-	65.2	310	UPP	Hälsingland, Sweden
(12)	(23.13.25.5)	(61.73N)	(17.04E)	(19)	(11)	(67.0)	(314)		
5/2-86	17.53.35.5	62.74N	4.63E	15	-	304.5	426	BER	Offcoast, NW Norway
(13)	(17.53.35.5)	(62.66N)	(5.08E)	(18)	(24)	(305.0)	(405)		

Table VII.7.4 Single-site 3-component records used for estimating focal parameters for local and regional events. Note the high accuracy in epicenter distance estimates, and also that zero depths are obtained for known explosions.