NORSAR

NORSAR Scientific Report No. 2-2006

Semiannual Technical Summary

1 January - 30 June 2006

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Kjeller, August 2006

6.3 Improvements to SPITS regional S-phase detection; coherent beamforming of rotated horizontal components

Sponsored by US Army Space and Missile Defence Command, Contract No. W9113M-05-C-0224

6.3.1 Introduction

During the refurbishment of the SPITS array in 2004, the number of three-component sites was increased from one to six, as proposed by Schweitzer & Kværna (2002). This new array configuration opened for the possibility to redefine and tune the automatic data processing processing recipes of the SPITS array, including redefinition of the detection beam deployment, procedures for fk-analysis and the rules for fully automatic single array event location. This contribution describes the details of the new beam deployment, and presents some examples of the improvements achieved.

6.3.2 The new beam set

The refurbishment of the SPITS array included installation of new broadband sensors with a transfer function which is flat versus acceleration and having a sampling rate of 80 Hz (Fyen, 2004; Fyen 2005). Because of the relatively small aperture of the array (see Figure 6.3.1), array processing tools are effective only for higher frequencies. Therefore, the lower frequencies are removed, and as a first step of the new detection processing all data are prefiltered with a wide 6th order Butterworth bandpass filter between 0.4 and 30 Hz.

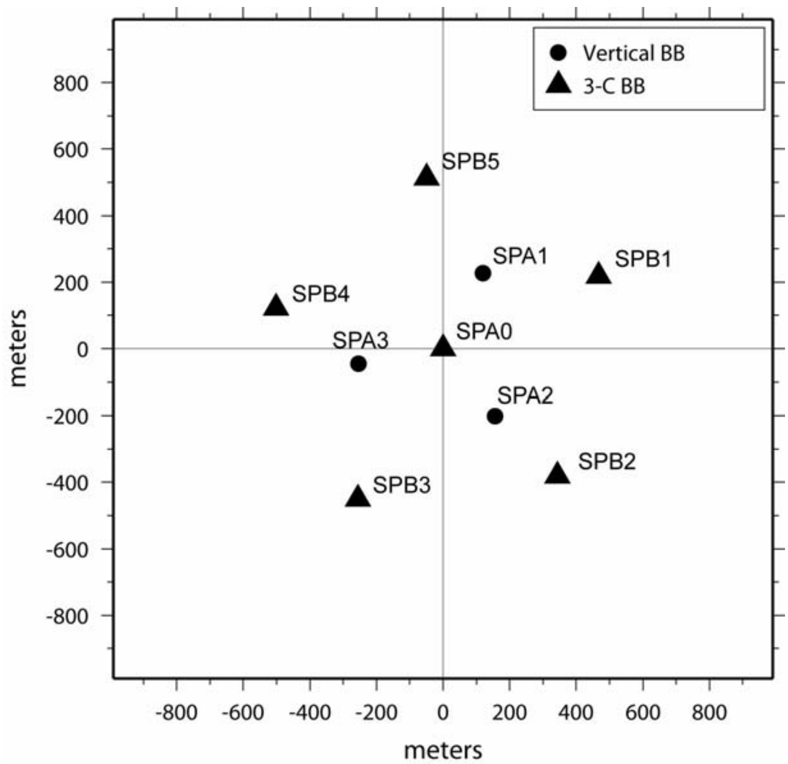

Fig. 6.3.1. Sensor configuration of the upgraded SPITS array. The three sensors of the A-ring are vertical component only, whereas the center instrument SPA0 and the five B-ring sensors are three-component.

Together with the higher sensitivity of the new sensors for higher frequencies, the most important change in the SPITS instrumentation was the installation of five additional 3C sensors. With this change, the array now consists of six sites with horizontal components (SPA0, SPB1, SPB2, SPB3, SPB4, and SPB5), which allows us to run array processing tools also on these components. Based on the observation that regional S-phases at the SPITS array usually have the highest SNR on the horizontal components, the design study for the refurbishment of the SPITS array of Schweitzer and Kværna (2002) proposed the installation of additional 3C sensors. The benefit from having additional 3C sensors are further confirmed by Ringdal and Gibbons (2006) who demonstrated large Sn-phase SNR improvements when using transverse beams for detection of three recent events near Novaya Zemlya.

When using the horizontal components for S-phase detection, it is preferable to decompose the energy into SH and SV components. This is because explosion-type sources are expected to radiate S energy mostly of SV type, whereas many earthquakes (however, depending on the radiation pattern) may dominantly radiate SH energy. Therefore, all horizontal beams are coherently stacked for radial and transverse components after rotating the original north-south and east-west components with respect to the actual backazimuth (BAZ) of the beam. Details about the new beam set are given in Table 6.3.2. A total of 999 beams are defined, out of which 221 are radial component, and 222 are transverse component coherent horizontal beams. The higher sampling rate of the upgraded SPITS array also made it possible to include a high frequency 12-24 Hz filter in the detection processing.

The beam deployment of the old SPITS array (Schweitzer, 1998) included 257 beams, and after the 2004 refurbishment, an initial attempt was made to improve the S-phase detection by introduction of so-called incoherent beams. Each of the incoherent beams were calculated from all 12 horizontal N-S and E-W channels, which first were bandpass filtered, rectified through short-term-average (STA) calculations, and finally the STA traces were stacked without time shifts (incoherent beamforming). Incoherent horizontal beams were introduced in four different frequency bands, i.e., 1.5-3.5 Hz, 3.0-5.0 Hz, 5.0-10.0 Hz and 6.0-12.0 Hz.

6.3.3 Initial assessment of the new SPITS detection processing

Following the implementation of horizontal coherent beams in the new detection process, corresponding modifications had to be included for the subsequent automatic f-k analysis. We have now run the new SPITS processing setup for 58 consecutive days for the time period 19 February 2006 (day-of-year (DOY) 050) to 17 April 2006 (DOY 107). This resulted in an average of 2945 detections per day, which is about twice as many as the number of detections found when using the old processing recipe (average of 1655 per day).

For this same time period we have run automatic multi-array phase association and event location using the Generalized Beamforming (GBF) approach (Ringdal and Kværna, 1989; Kværna et al., 1999). Focusing on the Barents Sea area, north of 70^o latitude, we have searched for events where the SPITS and the ARCES arrays both have defining P- and S-phase detections. The criterion that both P- and S-phases are automatically found at two arrays is quite strong, in the sense that such events are quite unlikely to be caused by false phase associations and that the corresponding event locations are usually quite good. Figure 6.3.2 shows the location of the 36 events of this type found during the actual time period. For reference, we show in Figure 6.3.3 the location of similar type events found from processing using the old SPITS detection recipe for the same time period (17 events). A striking improvement is attributed to the three recent events near Novaya Zemlya (Ringdal and Gibbons, 2006), where S-phase signals at SPITS are now detected on the horizontal coherent beams and associated with the P- and S-phases at ARCES and the P-phase at SPITS.

Table 6.3.1 shows details about the three Novaya Zemlya events as defined by the GBF process. We find that the seismic phases of the two first events are correctly associated as Pn and Sn at SPITS and ARCES. However, for the third event, in the attempt to maximize the number of associated phases, the GBF process incorrectly attribute an Sn-coda detection at ARCES to Lg. This again results in erroneous association of ARCES Sn and SPITS Pn, and a location error of almost 190 km relative to the analyst location result presented by Ringdal and Gibbons (2006). The ARCES Lg is typically absent, or very weak, for regional events located in the Barents Sea. In order to avoid future phase association errors of the type demonstrated above, we plan to fully implement regionalized criteria for the propagation of different phases at different stations in the GBF processing setup (e.g., no Lg at ARCES for regional events in the Barents Sea).

It is also apparent from Figs. 6.3.2 and 6.3.3 that more S-phases from the events in the western Barents Sea and along the mid-Atlantic Ridge are now detected at the SPITS array. Examples of the benefit from using coherent beamforming of rotated horizontal components for S-phase detection are shown in Figs. 6.3.4 and 6.3.5, in terms of SPITS Sn beams for two events located at regional distances from SPITS.

Following this initial assessment of the new SPITS detection processing, we will continue to analyze the processing results. Of particular interest will be to evaluate the SNR improvements and the stability of the S-phase f-k estimates (apparent velocity and back-azimuth) when using the horizontal components. Other factors like the density in slowness space of the coherent Sn beams, detection threshold setting and false alarm rate also need to be investigated. We are now in the process of running both the old and new processing setup in parallel, and, provided that no major problems are found, we plan to put the new setup into regular operations in the near future.

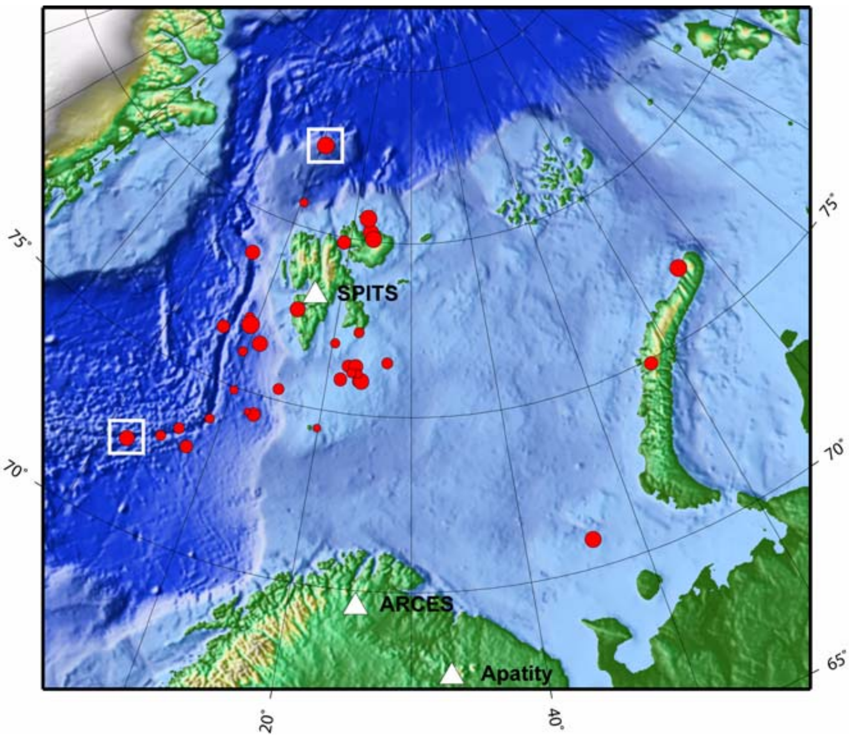

Fig. 6.3.2. GBF locations for events north of 70^{o} latitude for the time period 19 February to 17 April 2006. Shown are events with defining P- and S-phases both at SPITS and ARCES. The new SPITS processing results have been used as input to the phase association process. SPITS beams for the two events marked by white squares are shown in Figs 6.3.4 and 6.3.5.

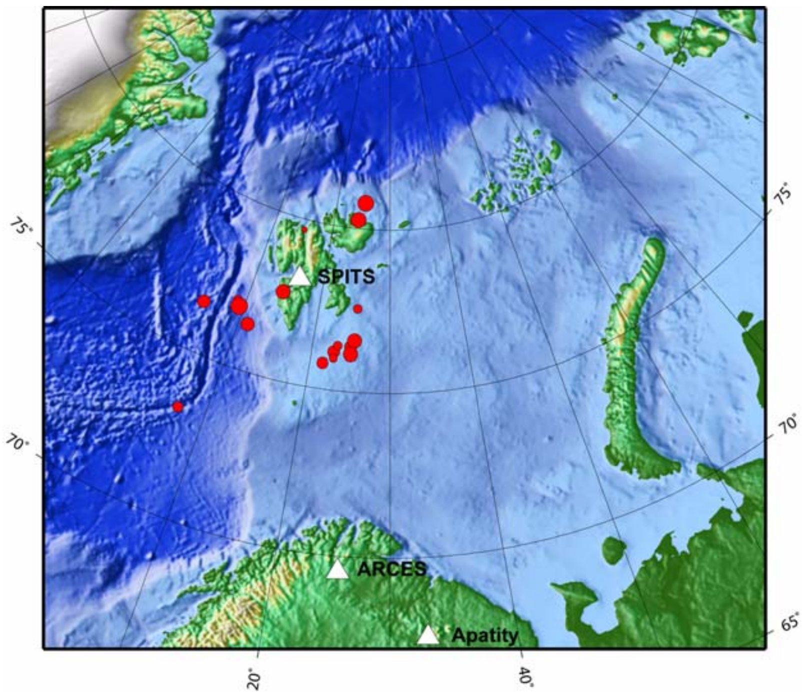

Fig. 6.3.3. GBF locations for events north of 70^{o} latitude for the time period 19 February to 17 April 2006. Shown are events with defining P- and S-phases both at SPITS and ARCES. The old SPITS processing results, created without coherent horizontal beams, have been used as input to the phase association process.

Table 6.3.1. Automatic on-line GBF results for the three Novaya Zemlya events using the new SPITS detection recipe

NOVAYA ZEMLYA, RUSSIA

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase	Ntot	Nsta	Netmag
2006-064:23.17.34.0	76.80	66.04	6.46	0.97	2.58	4	11	2	2.63

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Arid	Mag
SPI	1176.3	72.5	Pn	23.20.03.6	-1.3	76.1	3.6	8.2	130.2	1590.9	7.25	2	225715	
SPI	1176.3	72.5	p	23.20.11.7		79.9	7.4	6.5	10.5	1130.4	7.09	2	225735	
SPI	1176.3	72.5	p	23.20.15.8		81.4	8.9	7.8	5.0	340.8	5.00	1	225740	
SPI	1176.3	72.5	p	23.20.18.0		84.7	12.2	8.2	5.7	452.0	5.52	1	225745	
SPI	1176.3	72.5	Sn	23.21.56.5	1.2	76.7	4.2	4.7	23.0	731.1	5.60	3	225760	2.73
SPI	1176.3	72.5	s	23.22.02.7		83.0	10.5	4.6	3.4	1551.0	9.11	3	225770	
SPI	1176.3	72.5	s	23.22.04.8		72.3	-0.2	4.3	5.7	379.0	5.42	3	225775	
ARC	1497.3	39.9	Pn	23.20.43.4	-0.5	57.5	17.6	9.6	4.8	38.0	6.25	2	482275	
ARC	1497.3	39.9	p	23.20.47.5		47.0	7.1	10.4	6.5	44.4	7.00	1	482276	
ARC	1497.3	39.9	Sn	23.23.03.8	0.9	39.4	-0.5	3.5	9.0	44.9	3.46	3	482289	2.42
ARC	1497.3	39.9	s	23.23.09.3		59.0	19.1	5.0	7.2	62.0	3.72	3	482292	2.53

NOVAYA ZEMLYA, RUSSIA

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase	Ntot	Nsta	Netmag
2006-073:20.56.49.0	74.87	57.40	7.99	0.78	2.78	4	10	2	2.19

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Arid	Mag
SPI	1104.0	88.3	Pn	20.59.10.5	-0.7	94.7	6.4	8.4	21.1	329.5	10.68	3	346615	
SPI	1104.0	88.3	p	20.59.15.4		95.2	6.9	8.2	11.0	453.1	9.75	3	346620	
SPI	1104.0	88.3	p	20.59.17.9		101.4	13.1	8.4	9.1	508.1	11.12	3	346625	
SPI	1104.0	88.3	p	20.59.20.3		90.4	2.1	7.7	6.9	377.8	6.24	1	346630	
SPI	1104.0	88.3	p	20.59.22.5		84.8	-3.5	8.6	4.2	267.0	6.58	1	346640	
SPI	1104.0	88.3	Sn	21.00.56.5	1.3	92.4	4.1	4.7	6.4	388.6	10.20	3	346650	1.73
SPI	1104.0	88.3	s	21.01.03.2		81.1	-7.2	5.0	3.9	142.5	3.86	3	346660	2.14
ARC	1220.8	46.8	Pn	20.59.24.4	-1.0	57.5	10.7	10.6	5.4	47.1	5.65	2	519914	
ARC	1220.8	46.8	Sn	21.01.20.0	0.2	57.5	10.7	4.7	4.4	57.2	6.19	3	519921	2.07
ARC	1220.8	46.8	s	21.01.22.3		55.8	9.0	5.4	5.5	58.5	4.36	2	519923	2.23

BARENTS SEA

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase	Ntot	Nsta	Netmag
2006-089:10.46.26.0	70.80	45.91	11.21	4.38	7.18	5	16	2	2.56

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Arid	Mag
ARC	782.8	70.1	Pn	10.48.11.0	1.8	75.7	5.6	8.6	18.3	70.1	5.08	1	35736	
ARC	782.8	70.1	p	10.48.16.5		72.2	2.1	9.1	5.7	64.5	6.63	2	35737	
ARC	782.8	70.1	p	10.48.21.7		72.9	2.8	8.8	5.3	71.8	3.35	1	35738	
ARC	782.8	70.1	p	10.48.27.0		76.0	5.9	8.4	3.8	51.5	4.73	1	35742	
ARC	782.8	70.1	Sn	10.49.17.0	-7.7	47.4	-22.7	4.7	3.8	375.4	1.00	1	35752	1.95
ARC	782.8	70.1	s	10.49.50.2		73.8	3.7	5.3	12.4	305.6	3.91	1	35753	
ARC	782.8	70.1	s	10.49.53.6		83.3	13.2	3.2	10.8	407.1	3.07	1	35754	2.63
ARC	782.8	70.1	s	10.49.57.1		78.3	8.2	3.1	4.8	163.6	3.71	3	35755	
ARC	782.8	70.1	Lg	10.50.06.0	-3.5	75.9	5.8	3.9	4.0	249.0	2.50	1	35756	2.31
SPI	1183.8	118.1	p	10.48.48.5		111.9	-6.2	7.8	31.9	225.9	4.16	1	571905	
SPI	1183.8	118.1	Pn	10.48.56.4	-1.4	100.9	-17.2	8.2	7.5	187.5	6.08	2	571920	
SPI	1183.8	118.1	p	10.49.02.0		104.0	-14.1	9.1	5.4	289.2	10.14	2	571930	
SPI	1183.8	118.1	Sn	10.50.56.4	7.4	113.3	-4.8	4.4	12.8	256.4	5.22	3	571940	2.34
SPI	1183.8	118.1	s	10.50.58.5		112.8	-5.3	4.7	15.5	506.5	6.18	3	571955	2.49
SPI	1183.8	118.1	s	10.51.02.6		103.6	-14.5	4.4	8.8	212.1	4.32	3	571960	
SPI	1183.8	118.1	s	10.51.05.3		103.8	-14.3	4.7	3.6	189.3	5.17	3	571965	

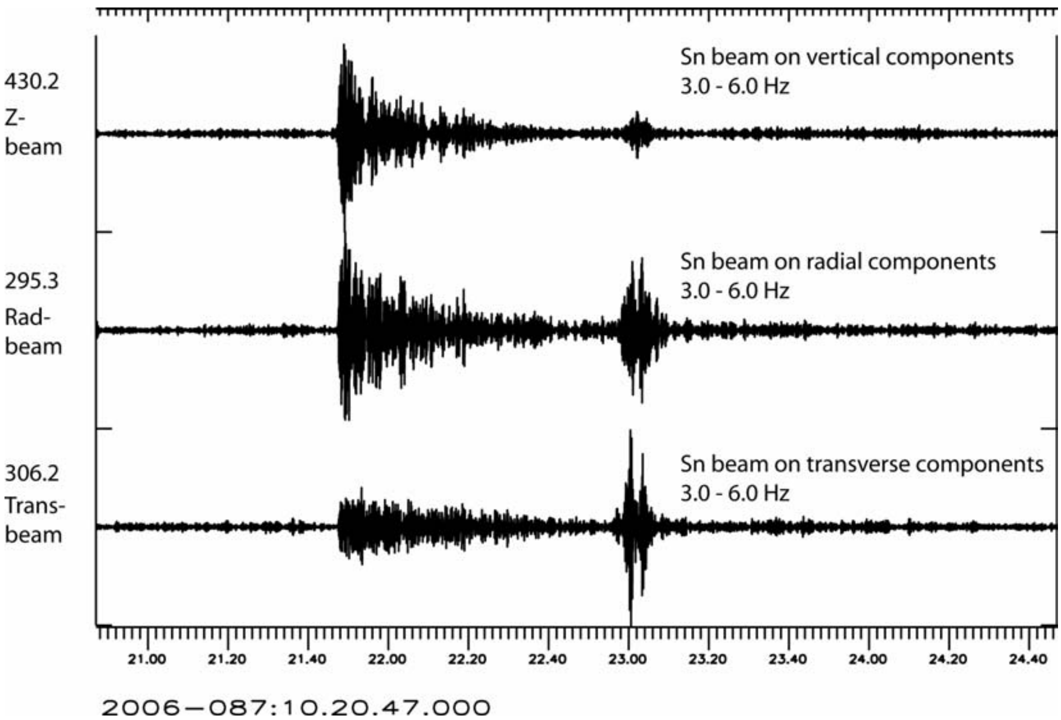

Fig. 6.3.4. SPITS Sn beams for an event on the Mohn's Ridge, located about 750 km south-west of SPITS. The automatic GBF event location is marked by a white square in Figure 6.3.2.

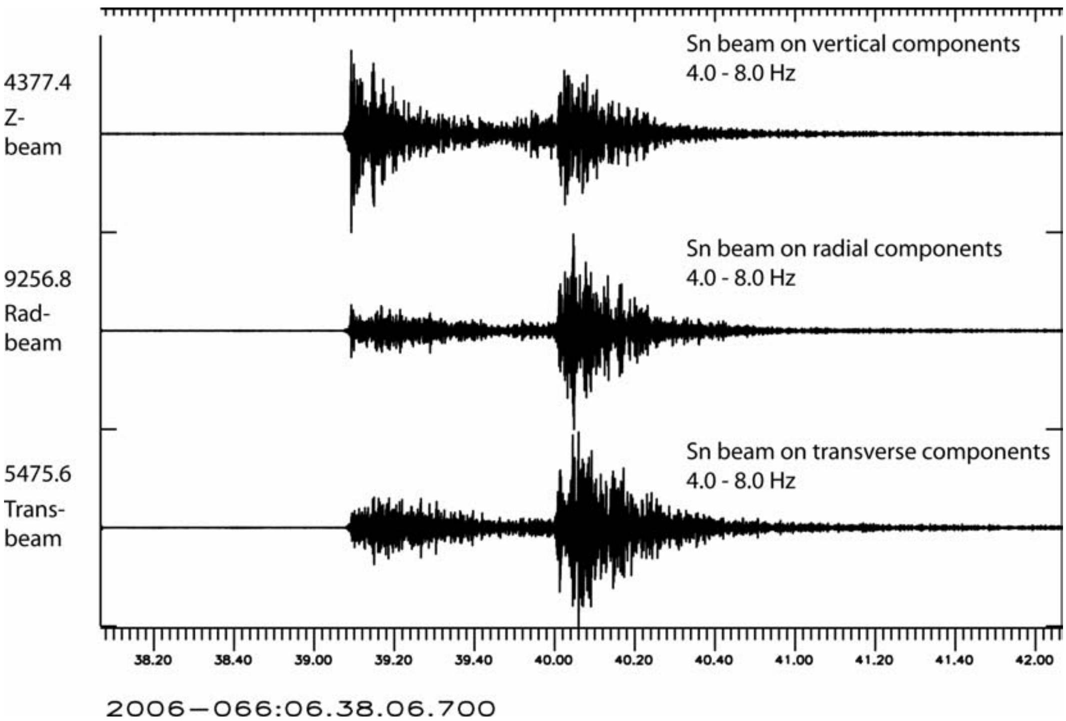

Fig. 6.3.5. SPITS Sn beams for an event north of Svalbard, located about 490 km from SPITS. The automatic GBF event location is marked by a white square in Figure 6.3.2.

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Table 6.3.2. The new beam set for the SPITS array.
THR is the SNR threshold used to define a detection,
ALL means all nine vertical components of the SPITS array (SPA0, SPA1, SPA2, SPB1, SPB2, SPB3, SPB4, and SPB5).
TEL means the vertical components of the center instrument and the B-ring (SPA0, SPB1, SPB2, SPB3, SPB4, and SPB5.
RAD means all radial components of the 3C sites (SPA0, SPB1, SPB2, SPB3, SPB4, and SPB5).
TRA means all transverse components of the 3C sites (SPA0, SPB1, SPB2, SPB3, SPB4, and SPB5).

BEAM NAME	APPARENT VELOCITY [km/s]	BACK-AZIMUTH [°]	Filter		THR	Sensors used
			bandwidth [Hz]	order		
S001	99999.9	0.0	0.8 - 2.0	4	4.5	TEL
S002	99999.9	0.0	0.8 - 2.0	4	4.5	ALL
S003 - S006	20.0	0 90 180 270	0.8 - 2.0	4	4.5	TEL
S007 - S010	15.0	45 135 225 315	0.8 - 2.0	4	4.5	TEL
S011	99999.9	0.0	0.9 - 3.5	3	4.5	TEL
S012	99999.9	0.0	0.9 - 3.5	3	4.5	ALL
S013 - S016	20.0	0 90 180 270	0.9 - 3.5	3	4.5	TEL
S017 - S020	15.0	45 135 225 315	0.9 - 3.5	3	4.5	TEL
S021	99999.9	0.0	1.0 - 3.0	3	4.5	TEL
S022	99999.9	0.0	1.0 - 3.0	3	4.5	ALL
S023 - S026	20.0	0 90 180 270	1.0 - 3.0	3	4.5	TEL
S027 - S030	15.0	45 135 225 315	1.0 - 3.0	3	4.5	TEL
S031	99999.9	0.0	1.0 - 4.0	3	4.5	TEL
S032	99999.9	0.0	1.0 - 4.0	3	4.5	ALL
S033 - S036	20.0	0 90 180 270	1.0 - 4.0	3	4.5	TEL
S037 - S040	15.0	45 135 225 315	1.0 - 4.0	3	4.5	TEL
S041	99999.9	0.0	2.0 - 4.0	3	4.0	TEL
S042	99999.9	0.0	2.0 - 4.0	3	4.0	ALL
S043 - S046	20.0	0 90 180 270	2.0 - 4.0	3	4.0	TEL
S047 - S050	15.0	45 135 225 315	2.0 - 4.0	3	4.0	TEL
S051	99999.9	0.0	2.5 - 4.5	3	4.0	TEL
S052	99999.9	0.0	2.5 - 4.5	3	4.0	ALL
S053 - S056	20.0	0 90 180 270	2.5 - 4.5	3	4.0	TEL
S057 - S060	15.0	45 135 225 315	2.5 - 4.5	3	4.0	TEL
SA01 - SA04	10.0	0 90 180 270	1.0 - 3.0	3	4.5	TEL
SA05 - SA08	9.0	45 135 225 315	1.0 - 3.0	3	4.5	ALL
SA09 - SA12	10.0	0 90 180 270	3.0 - 5.0	3	4.0	TEL
SA13 - SA16	9.0	45 135 225 315	3.0 - 5.0	3	4.0	ALL

BEAM NAME	APPARENT VELOCITY [km/s]	BACK-AZIMUTH [°]	Filter		THR	Sensors used
			bandwidth [Hz]	order		
SA17 - SA20	10.0	0 90 180 270	5.0 - 10.0	3	4.0	TEL
SA21 - SA24	9.0	45 135 225 315	5.0 - 10.0	3	4.0	ALL
SA25 - SA28	10.0	0 90 180 270	8.0 - 15.0	4	4.0	TEL
SA29 - SA32	9.0	45 135 225 315	8.0 - 15.0	4	4.0	ALL
SB01 - SB04	8.0	0 90 180 270	1.5 - 3.5	3	4.0	TEL
SB05 - SB08	7.0	45 135 225 315	1.5 - 3.5	3	4.0	ALL
SB09 - SB12	8.0	0 90 180 270	3.0 - 6.0	3	4.0	TEL
SB13 - SB16	7.0	45 135 225 315	3.0 - 6.0	3	4.0	ALL
SB17 - SB20	8.0	0 90 180 270	4.0 - 8.0	3	4.0	TEL
SB21 - SB24	7.0	45 135 225 315	4.0 - 8.0	3	4.0	ALL
SB25 - SB28	8.0	0 90 180 270	6.0 - 12.0	3	4.0	TEL
SB29 - SB32	7.0	45 135 225 315	6.0 - 12.0	3	4.0	ALL
SB33 - SB36	8.0	0 90 180 270	12.0 - 24.0	3	4.0	TEL
SB36 - SB40	7.0	45 135 225 315	12.0 - 24.0	3	4.0	ALL
SC01 - SC04	6.0	0 90 180 270	2.0 - 4.0	3	4.0	TEL
SC05 - SC08	6.0	45 135 225 315	2.0 - 4.0	3	4.0	ALL
SC09 - SC12	6.0	0 90 180 270	3.0 - 6.0	3	4.0	TEL
SC13 - SC16	6.0	45 135 225 315	3.0 - 6.0	3	4.0	ALL
SC17 - SC20	6.0	0 90 180 270	5.0 - 10.0	3	4.0	TEL
SC21 - SC24	6.0	45 135 225 315	5.0 - 10.0	3	4.0	ALL
SC25 - SC28	6.0	0 90 180 270	8.0 - 15.0	4	4.0	TEL
SC29 - SC32	6.0	45 135 225 315	8.0 - 15.0	4	4.0	ALL
SC36 - SC40	6.0	0 90 180 270	12.0 - 24.0	3	4.0	TEL
SC36 - SC40	6.0	45 135 225 315	12.0 - 24.0	3	4.0	ALL
SD01 - SD12	5.5	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	ALL
SD13 - SD24	5.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 -5.0	3	4.0	ALL
SD25 - SD36	5.5	0 30 60 90 120 150 180 210 240 270 300 330	4.0 -8.0	3	4.0	ALL
SD37 - SD48	5.5	0 30 60 90 120 150 180 210 240 270 300 330	6.0 -12.0	3	4.0	ALL
SD49 - SD60	5.5	0 30 60 90 120 150 180 210 240 270 300 330	12. 0 -24.0	3	4.0	ALL
SE01 - SE12	5.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	ALL
SE13 - SE24	5.0	0 30 60 90 120 150 180 210 240 270 300 330	2.5 - 4.5	3	4.0	ALL
SE25 - SE36	5.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 -8.0	3	4.0	ALL
SE37 - SE48	5.0	0 30 60 90 120 150 180 210 240 270 300 330	6.0 -12.0	3	4.0	ALL
SF01 - SF12	4.5	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	ALL

BEAM NAME	APPARENT VELOCITY [km/s]	BACK-AZIMUTH [°]	Filter		THR	Sensors used
			bandwidth [Hz]	order		
SF13 - SF24	4.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 5.0	3	4.0	ALL
SF25 - SF36	4.5	0 30 60 90 120 150 180 210 240 270 300 330	5.0 -10.0	3	4.0	ALL
SF37 - SF48	4.5	0 30 60 90 120 150 180 210 240 270 300 330	8.0 -15.0	4	4.0	ALL
SG01 - SG12	4.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	ALL
SG13 - SG24	4.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	ALL
SG25 - SG36	4.0	0 30 60 90 120 150 180 210 240 270 300 330	6.0 -12.0	3	4.0	ALL
SH01 - SH12	3.5	0 30 60 90 120 150 180 210 240 270 300 330	1.5 - 3.5	3	4.0	ALL
SH13 - SH24	3.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 6.0	3	4.0	ALL
SH25 - SH36	3.5	0 30 60 90 120 150 180 210 240 270 300 330	5.0 -12.0	3	4.0	ALL
SI01 - SI12	3.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	ALL
SI13 - SI24	3.0	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 5.0	3	4.0	ALL
SI25 - SI36	3.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	ALL
SJ01 - SJ12	2.5	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	ALL
SJ13 - SI24	2.5	0 30 60 90 120 150 180 210 240 270 300 330	2.0 - 4.0	3	4.0	ALL
SJ25 - SJ36	2.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 6.0	3	4.0	ALL
SK01 - SK12	2.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	ALL
SK13 - SK24	2.0	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 4.0	3	4.0	ALL
SK25 - SK36	2.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	ALL
SL01 - SL12	1.7	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	ALL
SL13 - SL24	1.7	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 5.0	3	4.0	ALL
SL25 - SL36	1.7	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	ALL
S101 - S112	5.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	RAD
S113 - S124	5.0	0 30 60 90 120 150 180 210 240 270 300 330	2.5 - 4.5	3	4.0	RAD
S125 - S136	5.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	RAD
S137 - S148	4.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	RAD
S149 - S160	4.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	RAD
S161 - S172	4.0	0 30 60 90 120 150 180 210 240 270 300 330	6.0 - 12.0	3	4.0	RAD
S172 - S184	3.5	0 30 60 90 120 150 180 210 240 270 300 330	1.5 - 3.5	3	4.0	RAD
S185 - S196	3.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 5.0	3	4.0	RAD
S197 - S208	3.5	0 30 60 90 120 150 180 210 240 270 300 330	5.0 - 10.0	3	4.0	RAD
S209 - S220	3.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	RAD
S221 - S232	3.0	0 30 60 90 120 150 180 210 240 270 300 330	2.5 - 4.5	3	4.0	RAD
S233 - S244	3.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	RAD

BEAM NAME	APPARENT VELOCITY [km/s]	BACK-AZIMUTH [°]	Filter		THR	Sensors used
			bandwidth [Hz]	order		
S245 - S256	2.5	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	RAD
S257 - S268	2.5	0 30 60 90 120 150 180 210 240 270 300 330	2.0 - 4.0	3	4.0	RAD
S269 - S280	2.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 6.0	3	4.0	RAD
S281 - S292	2.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	RAD
S293 - S304	2.0	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 6.0	3	4.0	RAD
S305 - S316	2.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	RAD
S501 - S112	5.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	TRA
S513 - S124	5.0	0 30 60 90 120 150 180 210 240 270 300 330	2.5 - 4.5	3	4.0	TRA
S525 - S136	5.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	TRA
S137 - S148	4.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	TRA
S549 - S160	4.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	TRA
S561 - S172	4.0	0 30 60 90 120 150 180 210 240 270 300 330	6.0 - 12.0	3	4.0	TRA
S572 - S184	3.5	0 30 60 90 120 150 180 210 240 270 300 330	1.5 - 3.5	3	4.0	TRA
S585 - S196	3.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 5.0	3	4.0	TRA
S597 - S608	3.5	0 30 60 90 120 150 180 210 240 270 300 330	5.0 - 10.0	3	4.0	TRA
S609 - S620	3.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	TRA
S621 - S632	3.0	0 30 60 90 120 150 180 210 240 270 300 330	2.5 - 4.5	3	4.0	TRA
S633 - S644	3.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	TRA
S645 - S656	2.5	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 3.0	3	4.0	TRA
S657 - S668	2.5	0 30 60 90 120 150 180 210 240 270 300 330	2.0 - 4.0	3	4.0	TRA
S669 - S680	2.5	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 6.0	3	4.0	TRA
S681 - S692	2.0	0 30 60 90 120 150 180 210 240 270 300 330	1.0 - 4.0	3	4.0	TRA
S693 - S704	2.0	0 30 60 90 120 150 180 210 240 270 300 330	3.0 - 6.0	3	4.0	TRA
S705 - S716	2.0	0 30 60 90 120 150 180 210 240 270 300 330	4.0 - 8.0	3	4.0	TRA
SN01	8.4	97.6	1.0 - 4.0	3	3.7	ALL
SN02	8.4	97.6	3.0 - 5.0	3	3.7	ALL
SN03	8.4	97.6	4.0 - 8.0	3	3.7	ALL
SN04	8.4	97.6	6.0 - 12.0	3	3.7	ALL
SN05	8.4	97.6	8.0 - 15.0	4	3.7	ALL
SN06	8.4	97.6	12.0 - 24.0	3	3.7	ALL
SN07	4.7	97.6	1.0 - 4.0	3	3.7	ALL
SN08	4.7	97.6	3.0 - 5.0	3	3.7	ALL

BEAM NAME	APPARENT VELOCITY [km/s]	BACK-AZIMUTH [°]	Filter		THR	Sensors used
			bandwidth [Hz]	order		
SN09	4.7	97.6	4.0 - 8.0	3	3.7	ALL
SN10	4.7	97.6	6.0 - 12.0	3	3.7	ALL
SN11	4.7	97.6	8.0 - 15.0	4	3.7	ALL
SN12	4.7	97.6	12.0 - 24.0	3	3.7	ALL
SN13	4.7	97.6	1.0 - 3.0	3	3.7	TRA
SN14	4.7	97.6	2.5 - 4.5	3	3.7	TRA
SN15	4.7	97.6	4.0 - 8.0	3	3.7	TRA
SN16	4.7	97.6	6.0 - 12.0	3	3.7	TRA
SN17	4.7	97.6	12.0 - 24.0	3	3.7	TRA
SN18	4.7	97.6	1.0 - 3.0	3	3.7	RAD
SN19	4.7	97.6	2.5 - 4.5	3	3.7	RAD
SN20	4.7	97.6	4.0 - 8.0	3	3.7	RAD
SN21	4.7	97.6	6.0 - 12.0	3	3.7	RAD
SN22	4.7	97.6	12.0 - 24.0	4	3.7	RAD