LAUR-92-4409

December 1992

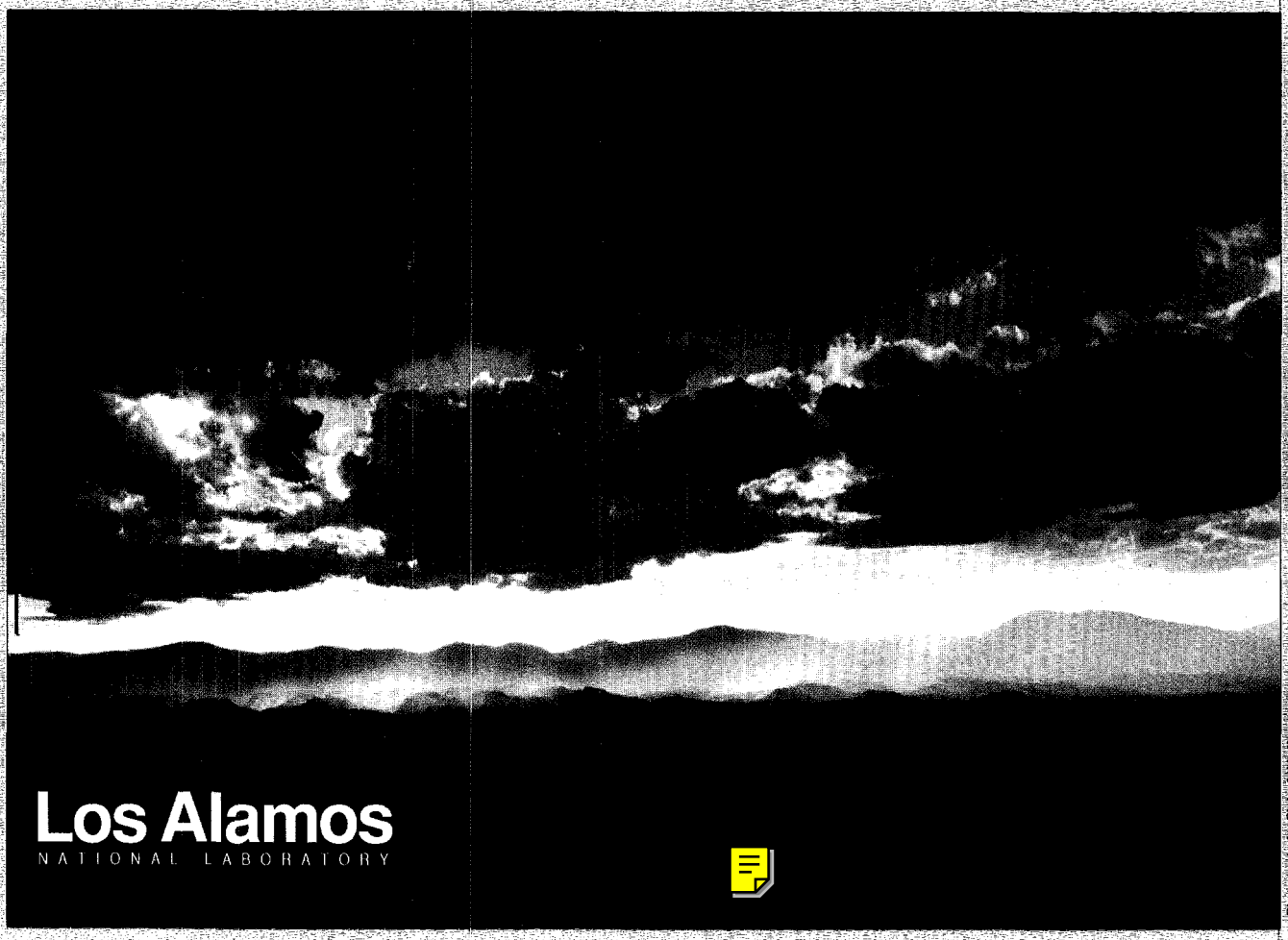
INTEGRATED VERIFICATION EXPERIMENT DATA COLLECTED AS PART OF THE LOS ALAMOS NATIONAL LABORATORY'S SOURCE REGION PROGRAM

APPENDIX C:

INFRASONIC MEASUREMENTS OF IVE EVENTS

Rodney W. Whitaker and Susan D. Noel

LOS ALAMOS SOURCE REGION PROGRAM



Los Alamos
NATIONAL LABORATORY

Photograph by Chris J. Lindberg

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APPENDIX C:

INFRASONIC MEASUREMENTS OF IVE EVENTS

RODNEY W. WHITAKER
SUSAN D. NOEL

Geoanalysis Group EES-5
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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APPENDIX C

Infrasonic Measurements of IVE Events

Rodney Whitaker and Sue Noel
EES-5 Los Alamos National Laboratory

The summary report by Tom Weaver gives the overall background for the series of IVE experiments including information on the full set of measurements made. In this appendix we will present details of the infrasound data for the IVEs and discuss certain aspects of a few special experiments. Prior to FY90, the emphasis of the Infrasound program was on underground nuclear test (UGT) detection and yield estimation. During this time the Infrasound Program was a separate program at Los Alamos, and we suggested to DOE/OAC that a regional infrasound network be established around NTS. The IVE experiments took place in a time frame that allowed us to simultaneously test possible network sites and examine propagation in different directions. Whenever possible, we combined infrasound stations with seismic stations so that a large number could be efficiently fielded; this co-location strategy made good use of personnel. Ultimately, the regional infrasound network was not pursued by DOE, as world events began to change the direction of verification toward non-proliferation. Starting in FY90 the infrasound activity became part of the Source Region Program which has a goal of understanding how energy is transported from the UGT to a variety of measurement locations, e.g. free field siesmic, ground surface, and atmosphere.

Three permanent four-microphone arrays were involved in the IVE work. These arrays were at St. George, UT, about 250 km from NTS; at Los Alamos, NM, about 900 km from NTS; and at the southern end of NTS. The one exception was that for Mineral Quarry on July 25, 1990, NTS was not operational. Numerous other measurement stations were used in the IVEs, generally east, west or north of NTS. Because of microphone limitations some stations had only single microphones, while a few had full arrays. For stations with three or four microphones, the

microphones were deployed in an array. Analysis of any array data is done with standard beamforming techniques and provides the usual outputs: correlation coefficient, power spectrum, bearing estimate, trace velocity, average propagation velocity, etc. The single microphone stations can be used for signal identification if other signal characteristics are derived from full array stations.

Because the upper atmospheric winds exert a significant influence on acoustic signals, two of the IVEs were dedicated to examining the distribution of energy in the first bounce footprint. Fig. 1 shows acoustic rays propagating east and west from a source at the center. A typical winter wind, blowing from west to east, was used, and the results demonstrate the wind effect. Notice that to the east the rays bounce in a small region for the first two bounces, while to the west the rays spread out rapidly. This difference in propagation affects the measured amplitudes as would be inferred from the ray diagram. We have derived a normalization procedure for this effect and refer to normalized pressure amplitudes as wind corrected amplitude, WCA. The upper atmospheric winds, up to 60 km altitude, blow to the east in winter and to the west in summer; this seasonal behavior is well known. The wind speed at 50 km is used in the normalization, and wind speeds at these altitudes come from meteorological rocket launches, rocketsondes. There are two components of these winds: Zonal for east/west , and meridional for north/south. In the middle of winter and summer, the zonal is the larger of the two. Propagation to the north or south will often be more like the west direction in Fig. 1. Stations east or west of a source can take advantage of the large zonal component in wind conditions.

The average travel velocity is useful in determining the propagation conditions. Average travel velocity is the great circle distance, source to receiver, divided by the travel time. For "with wind" propagation the average velocity is 0.29 km/sec. While for "against wind" propagation, it may be as low as 0.22 km/sec. Velocities lower than 0.29 km/sec indicate refractions at altitudes greater than 50 km, while faster velocities indicate lower altitude refractions.

In Table I we give the full list of stations for all IVEs. In this table, each IVE entry has a header with shot name, execution data, zero time, and total number of stations. This is followed by the individual station name, the raw peak-to-peak

pressure amplitude for the main signal, the number of microphones at the station, and the distance of the station from the event. After the distance, the upper case letters indicate the direction of the station from the event. The station at NTS is too close to the events to receive signals from the atmospheric paths described above. However, energy may reach this site if local conditions are such that low level ducting occurs. Such low ducts could be caused by temperature inversions or certain wind conditions. The NTS site is used more for analysis of other signals, such as earthquakes.

A few comments about the raw data in Table I may be helpful in considering these results. In many of the cases where single microphone stations show no signal, wind conditions degraded the signal-to-noise ratio making simple visual identification impossible. Array techniques may well have detected signals in these elevated noise levels. The emplacement geology at the Tulia hole was such that a deeper burial was required for containment purposes. This over burial reduced the ground motion and no signals were identified at St. George or Los Alamos. For Amarillo, the Murphy, ID, station had high local winds and no signal was found in the poor conditions. The California stations on Hornitos, were in an "against wind" propagation condition, for NTS events, and showed significant energy from microbaroms in the Pacific. Microbaroms are acoustic signals from ocean areas under low pressure systems and can be identified by their narrow band frequency content. The microbaroms dominated the California data. For the events between June and early September and for stations east of NTS, the raw pressure amplitudes are for signals from the higher refraction heights, as expected for counter wind conditions. At the time of Bullion, the NTS wind data showed a low, high-speed zonal jet of 40 m/sec at 12 km altitude. This creates a very low altitude sound channel with an average velocity of about 0.34 km/sec. Thus for Bullion in the raw pressure column, the number in parenthesis is the amplitude for the very low duct, while the other is the amplitude for the higher, counter-wind duct.

In Table II, IVE results for the St. George array are collected together for ease of comparison, because much of our analysis of acoustic signals from UGTs is based on the St. George data. The columns are as follows:

DAY/YR	the day of the year and year of the test
AR	the area at NTS for the test

WCA	the wind corrected pressure amplitude of the infrasound signal, in microbars
RPA	the raw pressure amplitude in microbars
TV	the derived trace velocity of the signal across the array, m/sec
FR	the frequency of maximum power in the highest correlation part of the signal, Hertz
DOB	the depth of burial, m, of the event
SWL	the static water level at the emplacement hole for the event, in meters
WD	number of days from event for which rocketsonde wind data are available
STA	the location of the rocketsonde launch where CC- Cape Canaveral, FL PM- Point Mugu, CA WI- Wallops Island, VA WS- White Sands, NM CAL- interpolated from data collected during the year
SPD	the zonal wind speed at 50 km altitude in m/sec

For the propagation paths discussed above, we have found trace velocities in the range of 350 m/sec to 420 m/sec. From the surface ground motion records, characteristic time scales are seen to be around one second, which implies a characteristic frequency of around one Hertz. The frequencies in Table II are nicely in agreement with that estimate. The sign convention for the SPD column of Table II is that winds from the west to east are positive. For Mineral Quarry, a summer event, we have listed the result from Bishop, CA, which was in the favorable propagation direction.

In Figures 2 through 18 selected array processing results are shown. In each figure, three parameters are shown as a function of time, and each parameter is derived from the time-delay and sum beamformer. Azimuth is given in the top panel, trace velocity in the middle, and the correlation coefficient at the bottom. Data are processed continuously in 20 second windows, and the result for each window is a point on the plot. The station name is given in the header at the top of the plot along with the frequency band and sampling rate. An arrow on the time axis shows the peak correlation time of the NTS event at the station and is the time of the raw pressure given in Table I.

Texarkana collapsed to the surface about 20 minutes after the event, and in Fig. 3 the collapse signal is the high correlation event between 20:38 and 20:39 UT. Ingot collapsed to the surface about 44 minutes after the event and was seen at ST. George and Los Alamos. There was electrical noise on the St. George channels at

the collapse arrival, and it is not seen in Fig. 5; though it was evident on a strip chart. For Los Alamos, the collapse signal is the high correlation event between 15:33 and 15:34 UT in Fig. 6. Fig. 10 shows a short signal at Reedly, CA, for Amarillo. This should have been a "with wind" propagation condition, and a longer signal would have been expected. Reedly was almost 290 km from the event, and this station may not have been in the strong part of the first bounce. Metropolis collapsed to the surface about 80 minutes after the event, and in Fig 13 for St. George this is the high correlation data between 17:38 and 17:39 UT. As discussed above, a strong 12 km altitude wind channel existed at the time of Bullion, and the signal from this structure can be seen in the St. George and Little Creek data in Figs. 14 and 15. In Fig 14 this signal is between 16:12 and 16:13 UT, and in Fig: 15, between 16:14 and 16:15 UT. In Fig. 17 the signal from Bexar is unambiguous until 19:15:30 UT; after this time, signals from small explosions at Nellis AFB are detected which continue until 19:30:00 UT.

For Texarkana and Ingot we deployed a series of stations spread in an E-W line around the St. George Array to measure the pressure distribution in the first bounce. On the Texarkana event day, we have upper atmospheric wind data from Point Mugu, as well as low level wind data from NTS. As will be discussed, the wind data were essential to the proper understanding of the Texarkana results. The station at Delamar, NV, should have been in a zone of relative silence, halfway from the source to the first bounce. In Figs. 19 to 22 raw channel data for several of the Texarkana stations are presented to illustrate raw signal character. The name of the station appears above the channel plot along with the time at the beginning of the plot. All plots are for 60 seconds. In the station name an "M" denotes the main signal from the 50 km altitude channel, while a "P" denotes the early signal from a low wind-formed duct. Figs. 19 and 20 are for the Texarkana event, and Figs. 21 and 22 are for the collapse signal. The bold triangle denotes the expected signal arrival based on a nominal average travel velocity of 0.29 km/sec. The station at Delamar had a strong signal which saturated the recorder. This was due to the low zonal jet at 12 km altitude and seen in the NTS wind data. In Fig. 23 we show the raw peak-to-peak pressure amplitudes for the Texarkana and Ingot events. Both the event signal and the collapse signal are plotted, and both are for the usual 50 km altitude path. Ray tracing results, using the measured winds, are in agreement with the measured pressures.

These measurements have shown the greater dependability of the zonal ducts, as expected from our knowledge of upper atmospheric winds. Efforts are now directed toward calculating near field pressures from the measured ground motions for the IVEs. These results can then serve as inputs to our wave propagation code to predict peak-to-peak pressures for the first bounce distance.

We would like to thank the many people from Groups EES-3 and EES-5 who participated in the field deployments for the IVEs. Their dedicated efforts contributed to the success of this work, which was supported by the Department of Energy, Office of Arms Control.

TABLE I

Shot Name	Fire Date	UT	# Stations
Misty Echo	12/10/88	2030:00	3

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	3.4	4	231 E
Los Alamos, NM	NS	4	894 E
NTS, NV	NA	4	59 S

Shot Name	Fire Date	UT	# Stations
Texarkana	2/10/89	2006:00	11

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	13.9	4	212 E
Los Alamos, NM	1.2	4	881 E
NTS, NV	NS	4	43 S
Delamar Valley, NV	Sig (Pinned)	1	112 E
Guy Wash, UT	31.1	1	173 E
West Coherence, UT	18.0	1	188 E
Racetrack, UT	16.6	1	221 E
Little Creek, UT	6.4	1	256 E
Hildale, UT	2.7	1	268 E
Pipe Springs, AZ	10.0	1	334 E
Kaibab, AZ	12.5	1	291 E

Shot Name	Fire Date	UT	# Stations
Ingot	3/9/89	1405:00	12

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	4.0	4	218 E
Los Alamos, NM	0.8	4	874 E
NTS, NV	NS	4	41 S
Guy Wash, UT	10.5	1	179 E
Racetrack, UT	5.4	1	227 E
Hurricane South, UT	5.2	1	245 E
Little Creek, UT	2.2	1	262 E
Hildale, UT	2.1	1	274 E
Bullfrog Crossing, UT	1.0	4	476 E
Brighton, CO	NS	4	1049 NE
Crowley Lake, CA	NS	4	327 NW
Badger, WI	NS	4	2332 NE

Table I continued

Shot Name	Fire Date	UT	# Stations
Tulia	5/26/89	1807:00	3

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	NS	4	217 E
Los Alamos , NM	NS	4	879 E
NTS, NV	NS	4	43 S

Shot Name	Fire Date	UT	# Stations
Contact	6/22/89	2115:00	6

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	2.3	4	250 E
Los Alamos, NM	NS	4	913 E
NTS, NV	NA	4	75 S
Crescent Valley, NV	NS	1	348 N
Reedly, CA	9.3	4	278 SW
Murphy, ID	Very weak	4	660 N

Shot Name	Fire Date	UT	# Stations
Amarillo	6/27/89	1530:00	6

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	2.4	4	244 E
Los Alamos, NM	NS	4	908 E
NTS, NV	NA	4	72 S
Crescent Valley, NV	NS	1	349 N
Reedly, CA	2.4	4	283 SW
Murphy, ID	NS	4	660 N

Table I continued

Shot Name	Fire Date	UT	# Stations
Hornitos	10/31/89	1530:00	15

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	12.8	4	256 E
Los Alamos, NM	2.4	4	922 E
NTS, NV	1.5 or 4.8	4	78 S
Bean Flat, NV	5.9	1	252 N
Denay Valley, NV	5.3	1	298 N
Crescent Valley, NV	2.6	3	349 N
Boulder Valley, NV	NS	1	387 N
Lime Mountain, NV	42.9	1	208 E
West Coherence, UT	30.0	1	232 E
Hurricane South, UT	14.0	1	284 E
Hildale, UT	5.3	1	313 E
Rancheria, CA	NS	1	274 W
San Joaquin, CA	NS	4	290 W
Eastman Lake, CA	NS	1	309 W
Craven Ranch, CA	NS	1	328 W

Shot Name	Fire Date	UT	# Stations
Metropolis	3/10/90	1600:00	9

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	6.2	4	217 E
Los Alamos, NM	Dead	4	880 E
NTS, NV	NS	4	46 S
Horse Creek, NV	?	1	339 N
Bean Flat, NV	?	1	270 N
Martin Ridge, NV	NS	4	231 N
Coils Creek, NV	Very weak	4	295 N
Denay Valley, NV	?	1	316 N
Hodges Canyon, NV	?	1	251 N

Table I continued

Shot Name	Fire Date	UT	# Stations
Bullion	6/13/90	1600:00	9

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	13.7 (11.2)	4	250 E
Los Alamos, NV	NS	4	914 E
NTS, NV	(1.9)	4	74 S
Lime Mountain, NV	Bad Tape	1	208 E
Little Creek, UT	5.9 (10.7)	4	293 E
West Coherence, UT	7.7 (11.5)	1	226 E
Hildale, UT	pinned (7.6)	1	306 E
Hurricane South, UT	13.8 (12.1)	1	277 E
Fredonia, AZ	Bad Tape	1	357 E

Shot Name	Fire Date	UT	# Stations
Mineral Quarry	7/25/90	1500:00	4

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	NS	4	231 E
Los Alamos, NM	NS	4	895 E
Bishop, CA	3.4	4	222 NW
Fredonia, AZ	Bad Tape	1	331 E

Shot Name	Fire Date	UT	# Stations
Bexar	4/4/91	1900:00	3

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	17.4	4	241 E
Los Alamos, NM	3.0	4	905 E
NTS, NV	2.4	4	73 S

Table I continued

Shot Name	Fire Date	UT	# Stations
Junction	3/26/92	1630:00	3

Station Name	Raw Pres. Amp	# Microphones	Distance (km)
St. George, UT	NA	4	245 E
Los Alamos, NV	NA	4	908 E
NTS, NV	NA	4	72 S

NS = No Signal Detected
NA = Not Analyzed

Table II
IVE St. George (Bishop for 206/90) data (except Junction)

Shotname	DAY/YR	AR	WCA	RPA	TV	FR	DOB	SWL	WD	STA	SPD
Misty Echo	345/88	12	.38	3.4	354	0.79	400		-5	PM	52
Texarkana	41/89	7	1.2	13.9	354	1.13	503	519	0	PM	55
Ingot	68/89	2	0.62	4.0	310	1.62	500	565	-1	WI	49
Contact	173/89	20	1.53	2.3	354	0.57	544	636	0	PM	-37
Amarillo	178/89	20	2.5	2.4	354	1.05	640	629	-2	CC	-48
Hornitos	304/89	20	1.4	12.8	343	0.56	563	569		CAL	53
Metropolis	69/90	2	0.65	6.2	310	0.43	469	479		CAL	54
Bullion	164/90	20	16.3	13.7	354	0.64	674	621	+1	WS	-31
Mineral Quarry	206/90	12	0.91	3.4	328	1.33	389	575	-11	WS	-31
Bexar	94/91	19	8.60	17.4	354	0.94	629	705	-1	PM	16

FIGURE CAPTIONS

Fig. 1: Acoustic ray diagram for winter winds showing bounce patterns east and west of a source at center of diagram.

Fig. 2-18: Examples of summary array data for several of the IVEs. Station name and other data appear at top of each figure, as discussed in text.

- Fig. 2: for Misty Echo.
- Fig. 3: for Texarkana.
- Fig. 4: for Texarkana.
- Fig. 5: for Ingot.
- Fig. 6: for Ingot.
- Fig. 7: for Contact.
- Fig. 8: for Contact.
- Fig. 9: for Amarillo.
- Fig. 10: for Amarillo.
- Fig. 11: for Hornitos.
- Fig. 12: for Hornitos.
- Fig. 13: for Metropolis.
- Fig. 14: for Bullion.
- Fig. 15: for Bullion.
- Fig. 16: for Mineral Quarry.
- Fig. 17: for Bexar.
- Fig. 18: for Bexar.

Fig. 19-22: Raw channel data for Texarkana stations as discussed in text.

- Fig. 19a,b: Normally ducted signal from event.
- Fig. 20a,b: Early signal due to low zonal jet, from event.
- Fig. 21a,b: Normally ducted signal from collapse.
- Fig. 22a,b: Early signal due to low zonal jet, from collapse.

Fig. 23: Raw pressure amplitude as function of range from Texarkana and Ingot for the event and collapse signal.

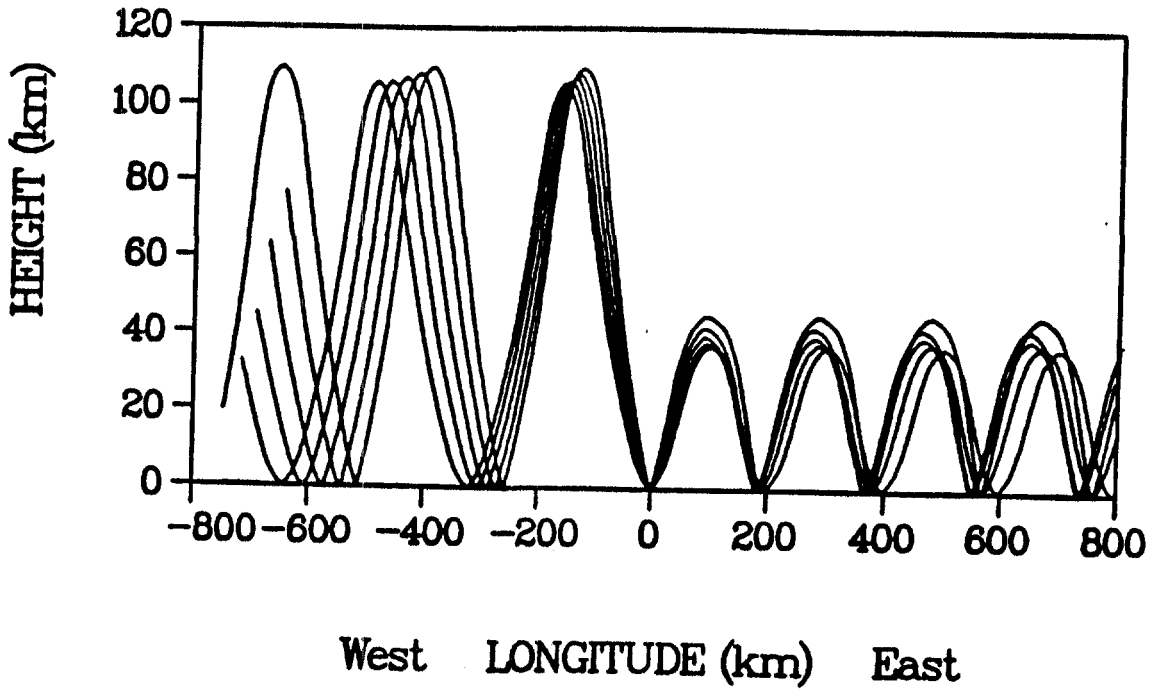
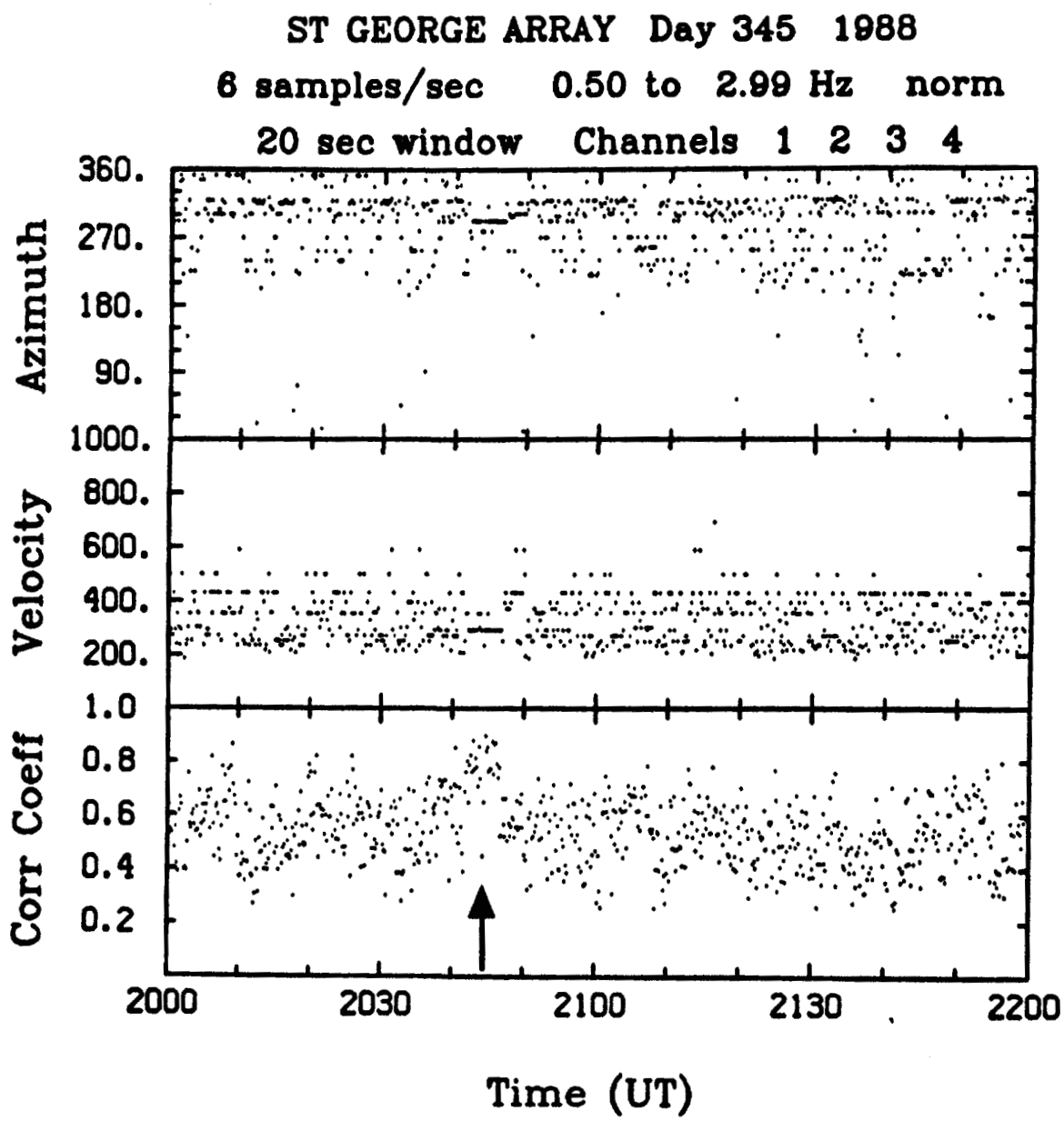

120
100
80
60
40
20
0
HEIGHT (km)
-800
-600
-400
-200
0
200
400
600
800
West
LONGITUDE (km)
East

Figure 1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20 sec window Channels 1 2 3 4
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360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
2000
2030
2100
2130
2200
Time (UT)

Figure 2

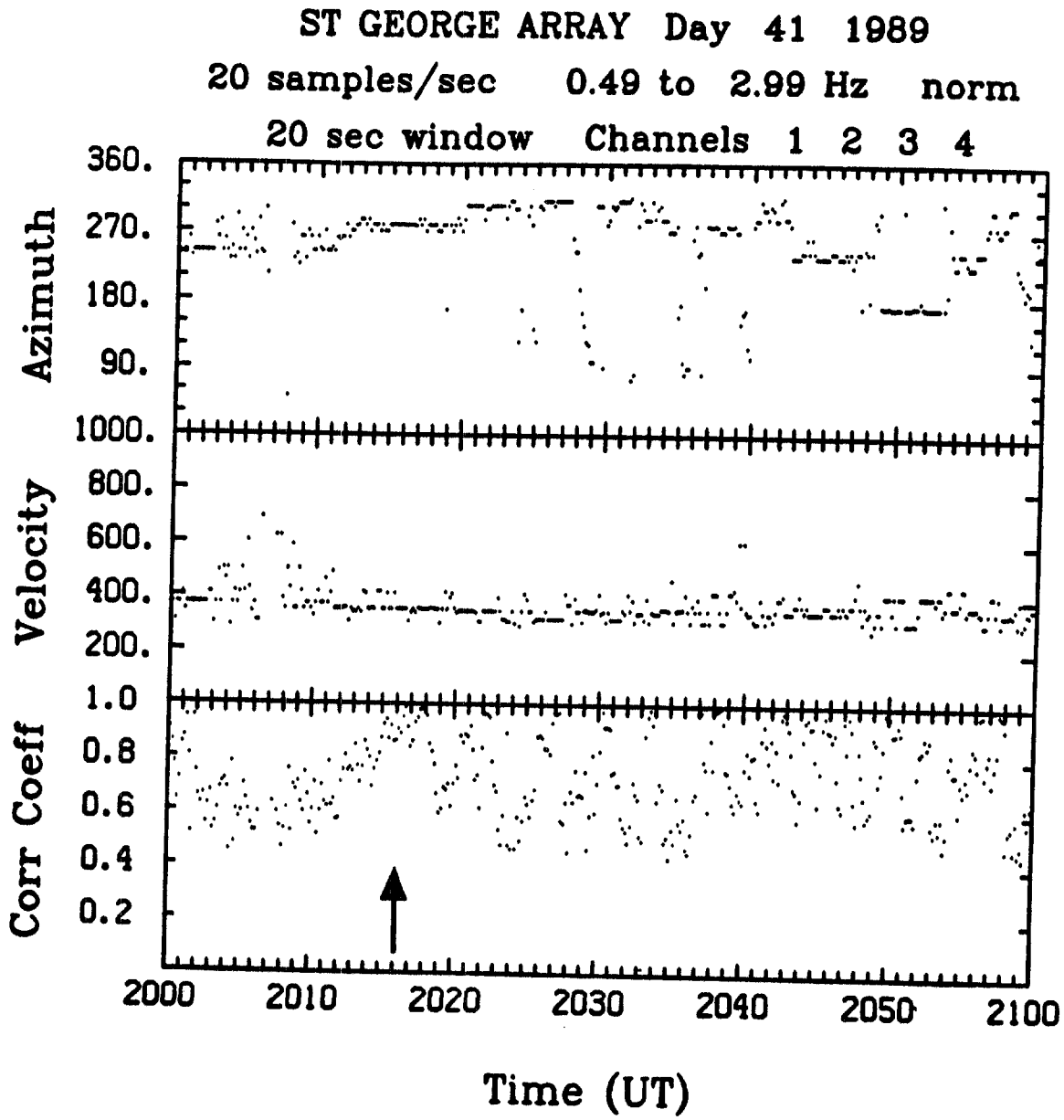

ST GEORGE ARRAY Day 41 1989
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
2000
2010
2020
2030
2040
2050
2100
Time (UT)

Figure 3

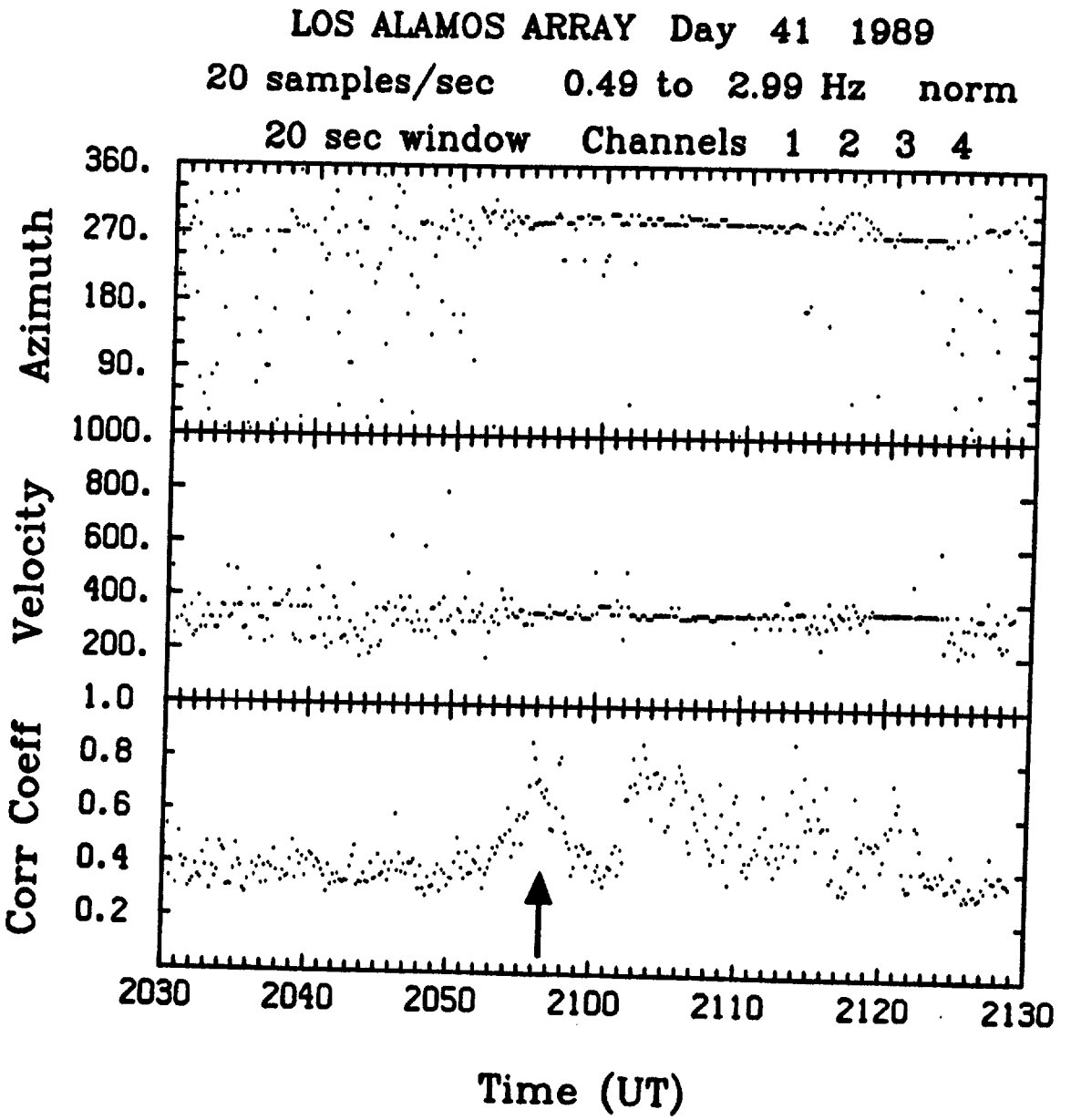

LOS ALAMOS ARRAY Day 41 1989
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
2030
2040
2050
2100
2110
2120
2130
Time (UT)

Figure 4

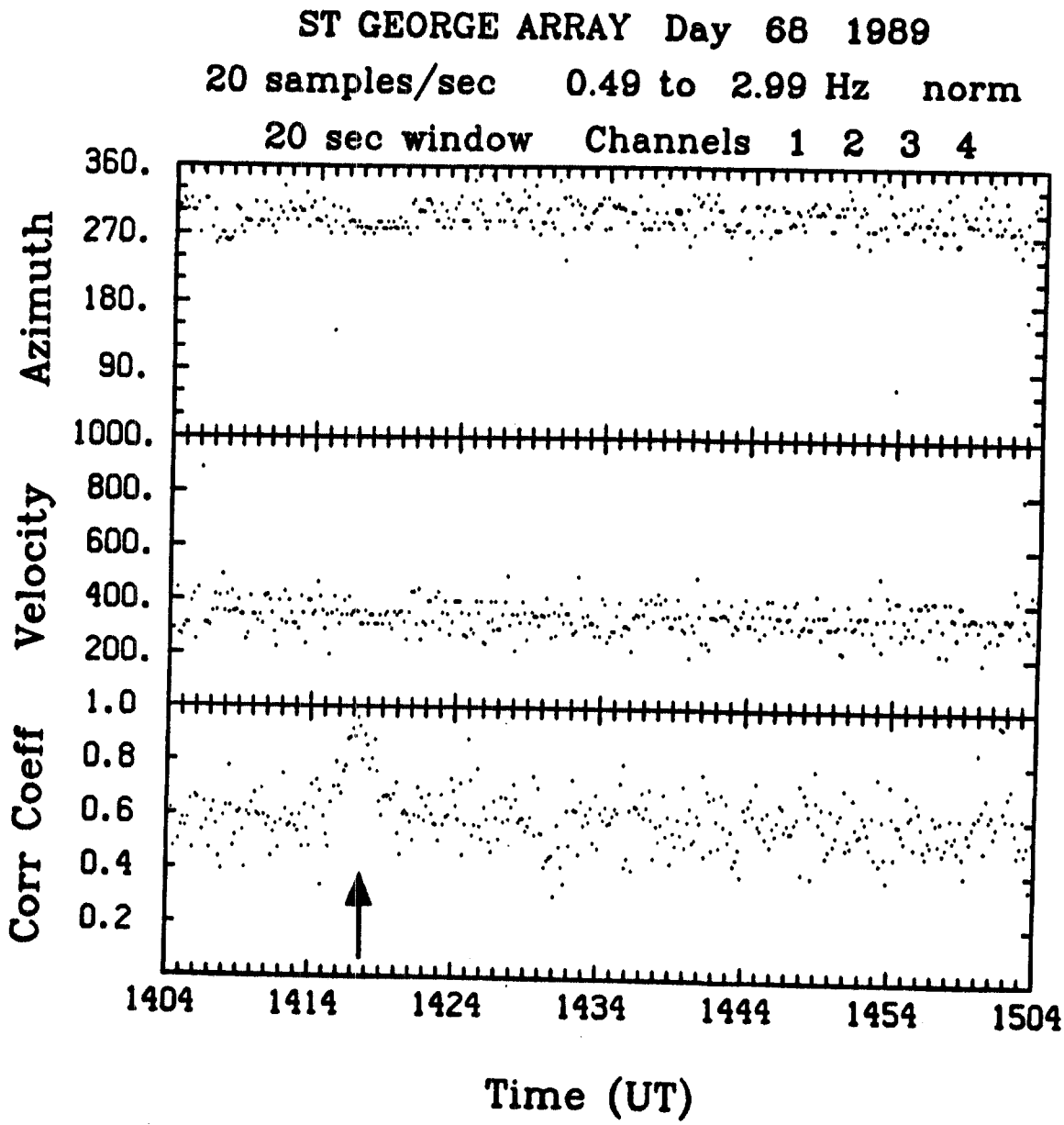
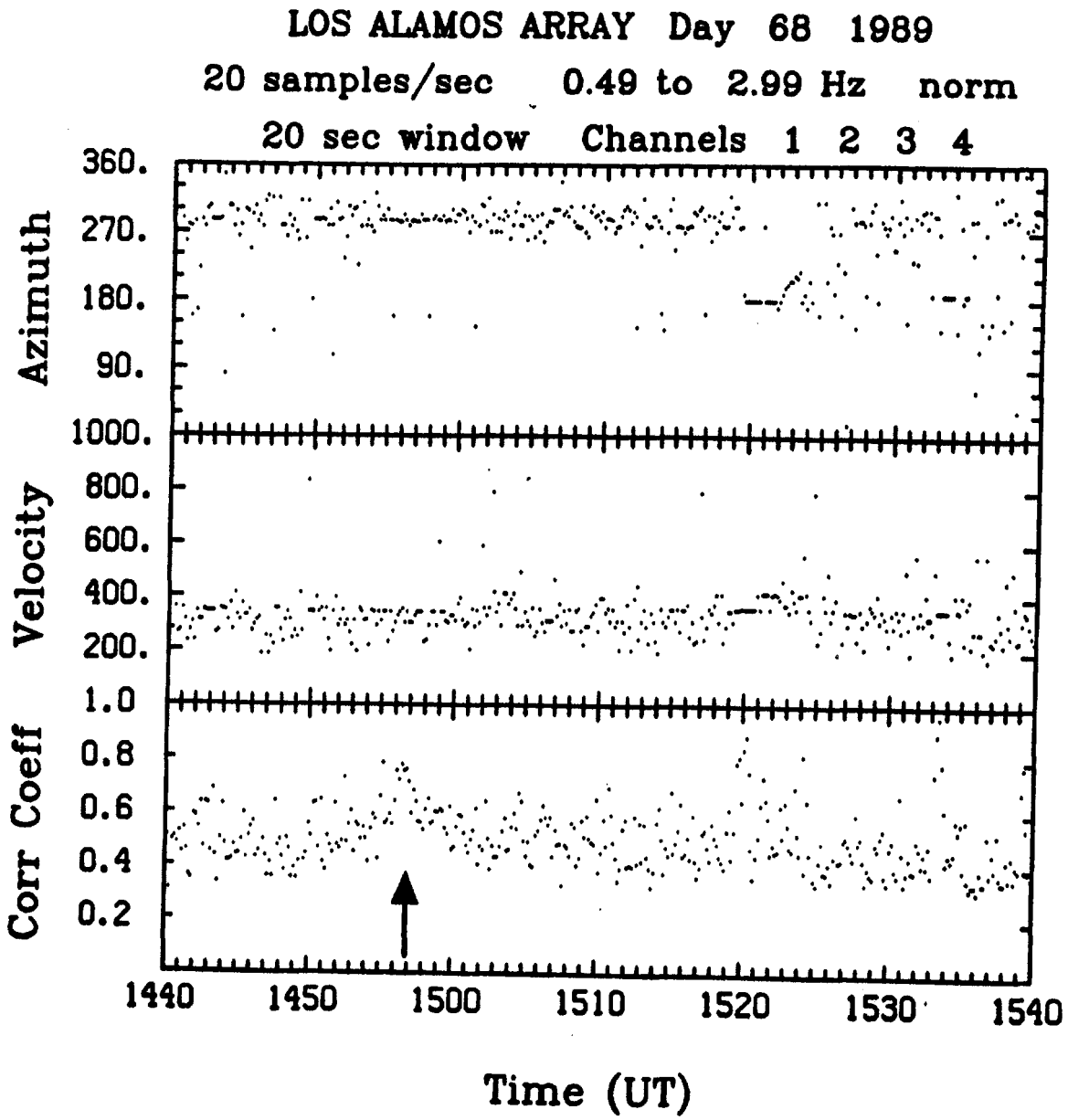

ST GEORGE ARRAY Day 68 1989
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1404
1414
1424
1434
1444
1454
1504
Time (UT)

Figure 5


LOS ALAMOS ARRAY Day 68 1989
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
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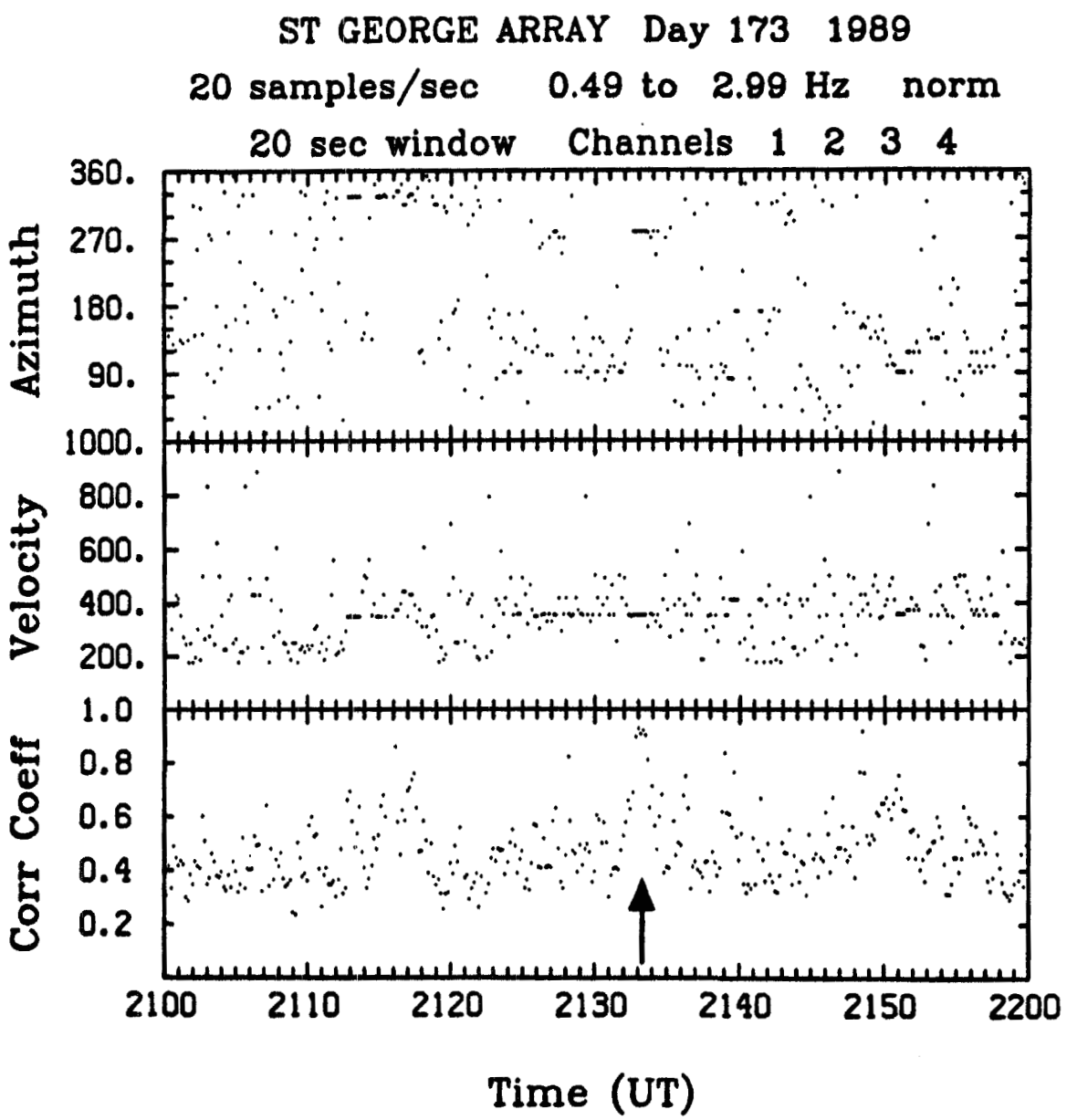
0.2
1440
1450
1500
1510
1520
1530
1540
Time (UT)

Figure 6


ST GEORGE ARRAY Day 173 1989
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
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90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
2100
2110
2120
2130
2140
2150
2200
Time (UT)

Figure 7

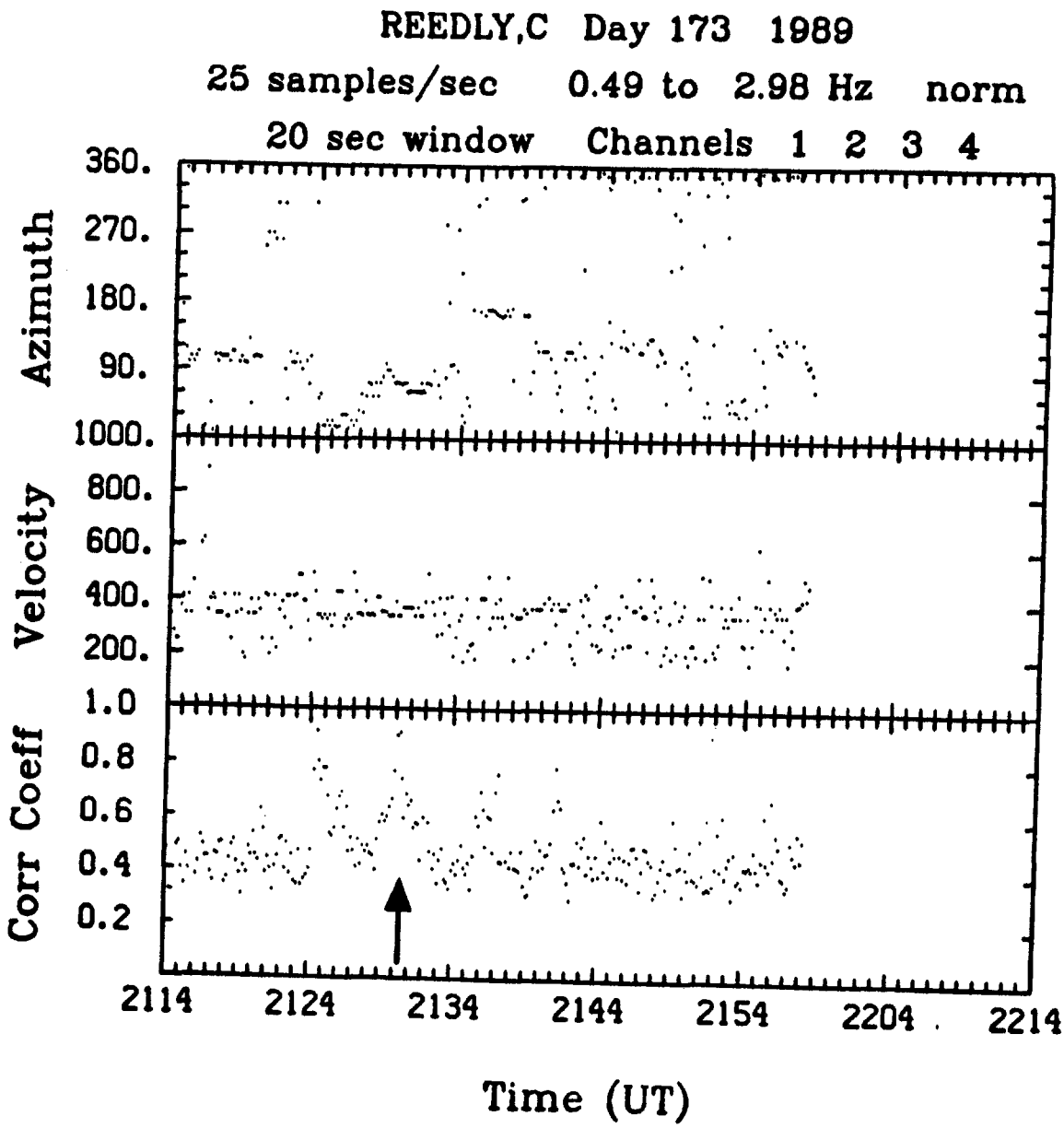
REEDLY,C Day 173 1989
25 samples/sec 0.49 to 2.98 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
2114
2124
2134
2144
2154
2204
2214
Time (UT)

Figure 8

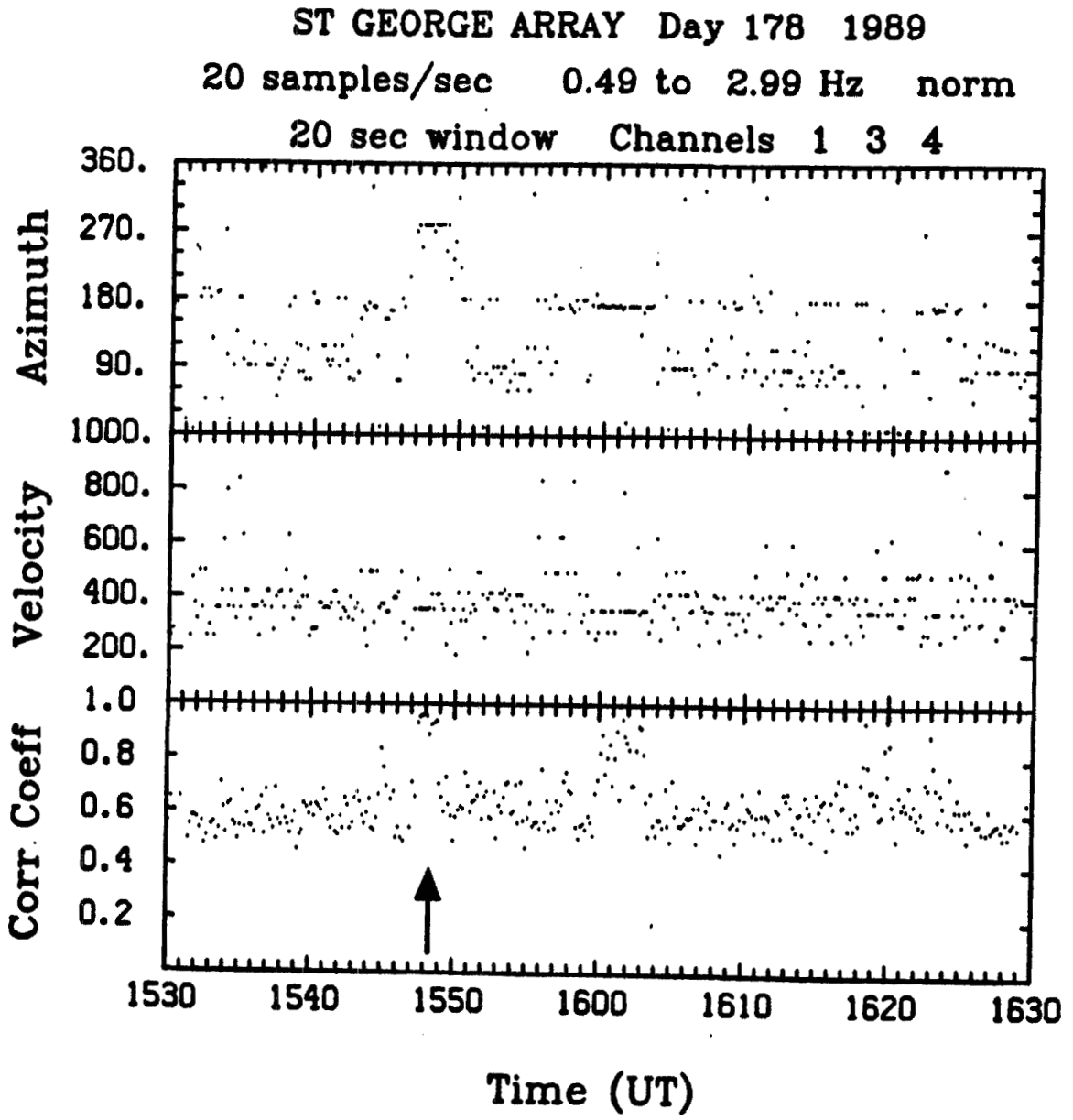
ST GEORGE ARRAY Day 178 1989
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr. Coeff
1.0
0.8
0.6
0.4
0.2
1530
1540
1550
1600
1610
1620
1630
Time (UT)

Figure 9

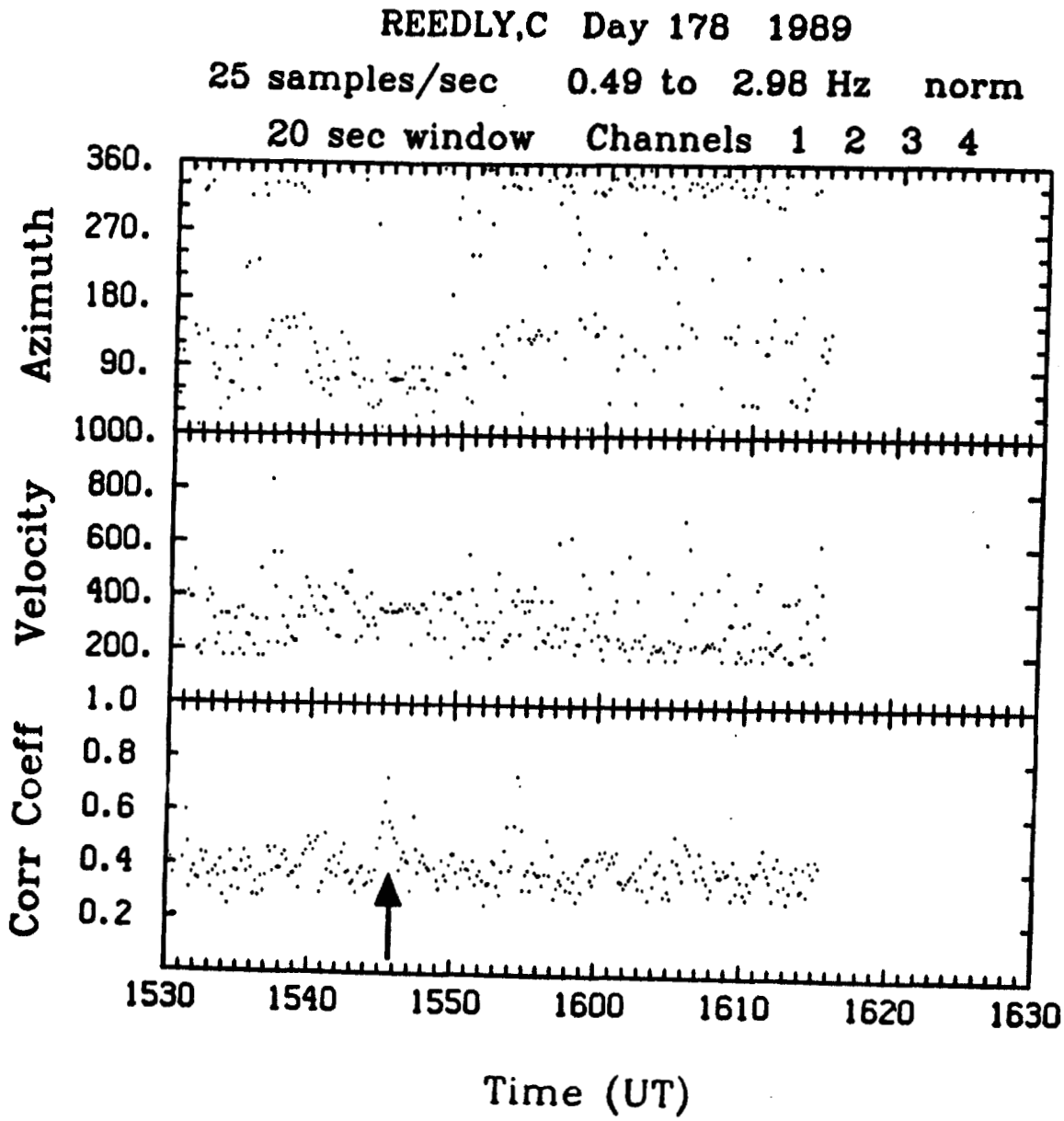
REEDLY,C Day 178 1989
25 samples/sec 0.49 to 2.98 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1530
1540
1550
1600
1610
1620
1630
Time (UT)

Figure 10

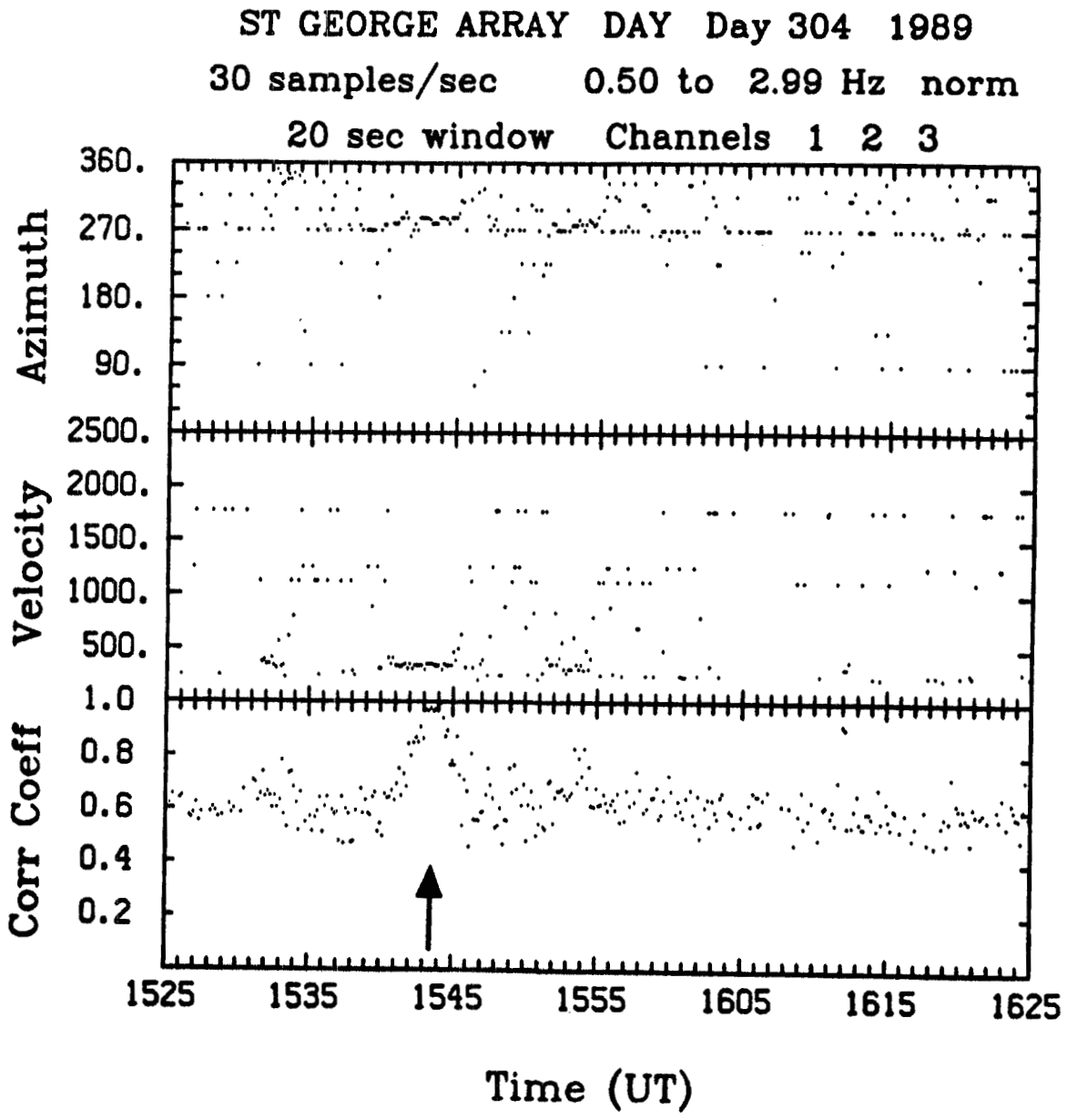
ST GEORGE ARRAY DAY Day 304 1989
30 samples/sec 0.50 to 2.99 Hz norm
20 sec window Channels 1 2 3
Azimuth
360.
270.
180.
90.
Velocity
2500.
2000.
1500.
1000.
500.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1525
1535
1545
1555
1605
1615
1625
Time (UT)

Figure 11

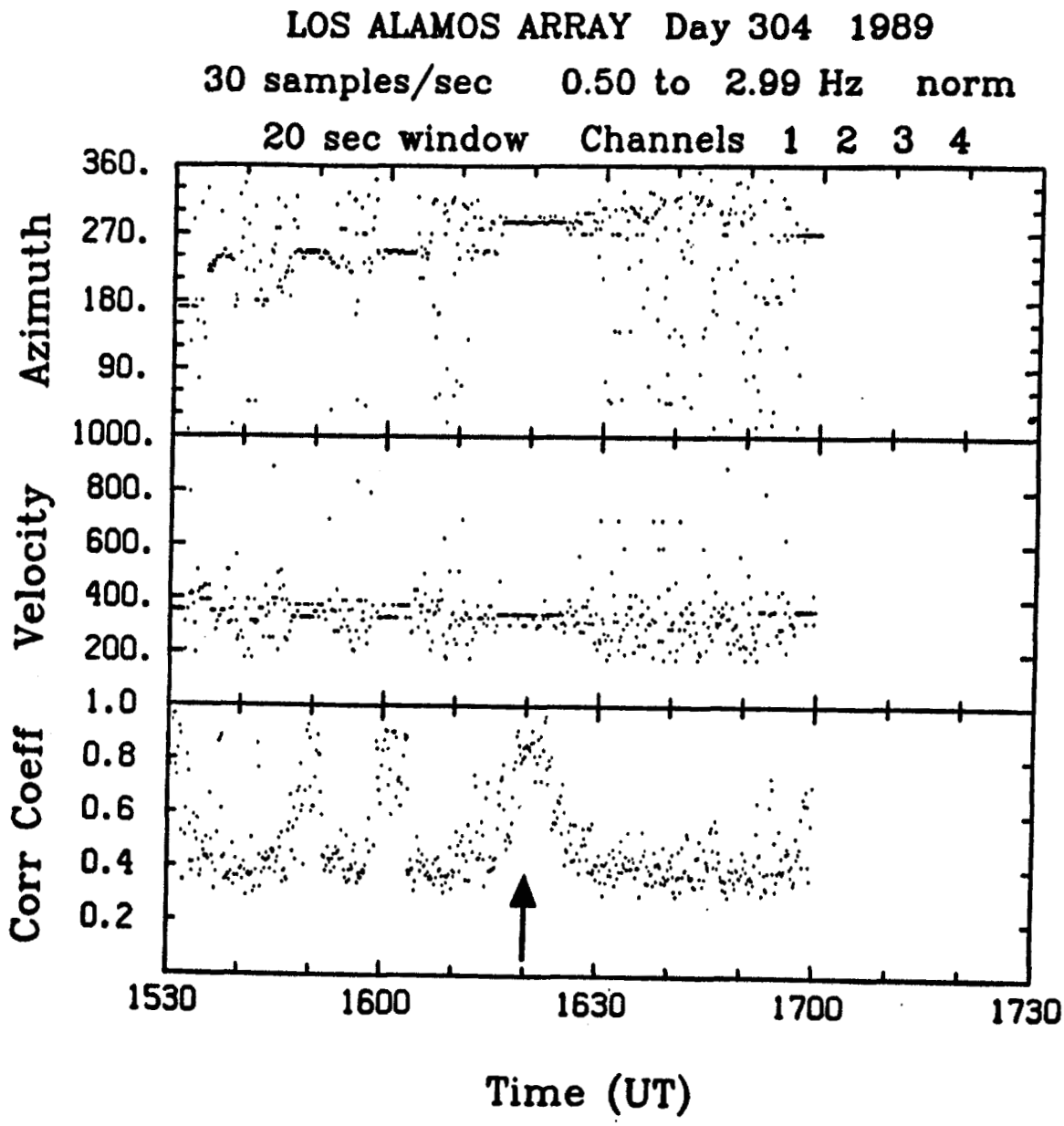
LOS ALAMOS ARRAY Day 304 1989
30 samples/sec 0.50 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1530
1600
1630
1700
1730
Time (UT)

Figure 12

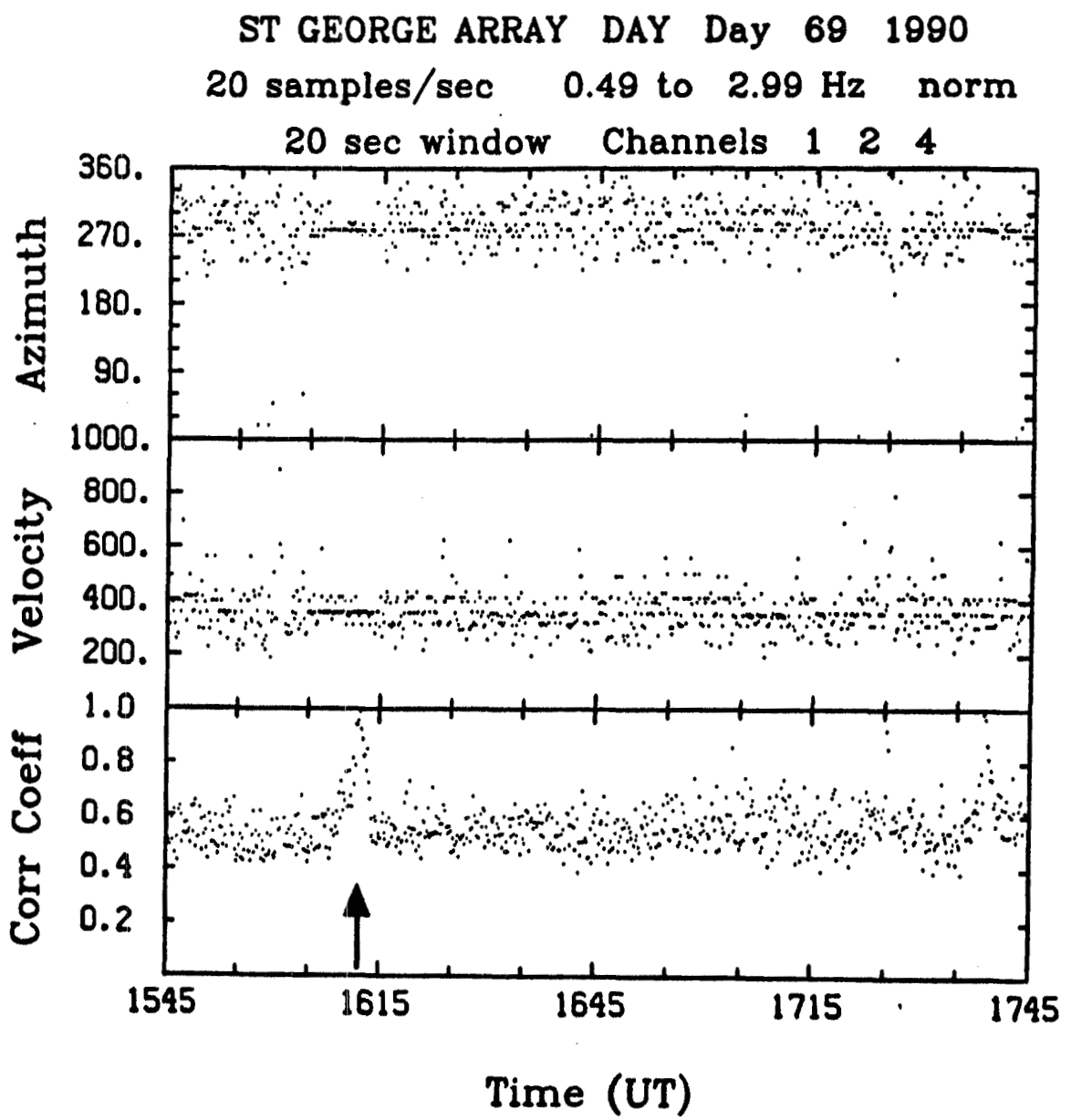
ST GEORGE ARRAY DAY Day 69 1990
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1545
1615
1645
1715
1745
Time (UT)

Figure 13

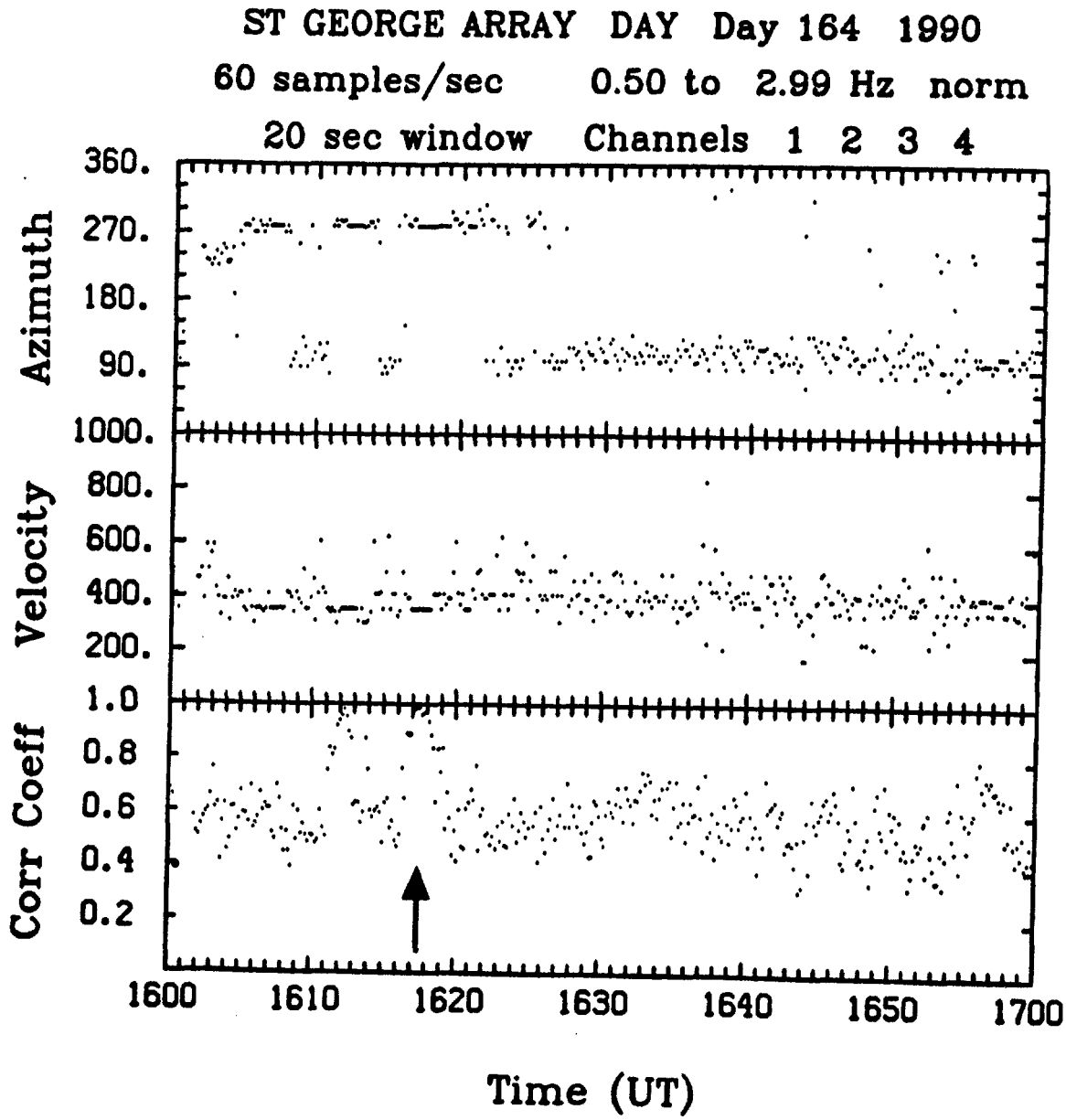
ST GEORGE ARRAY DAY Day 164 1990
60 samples/sec 0.50 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1600
1610
1620
1630
1640
1650
1700
Time (UT)

Figure 14

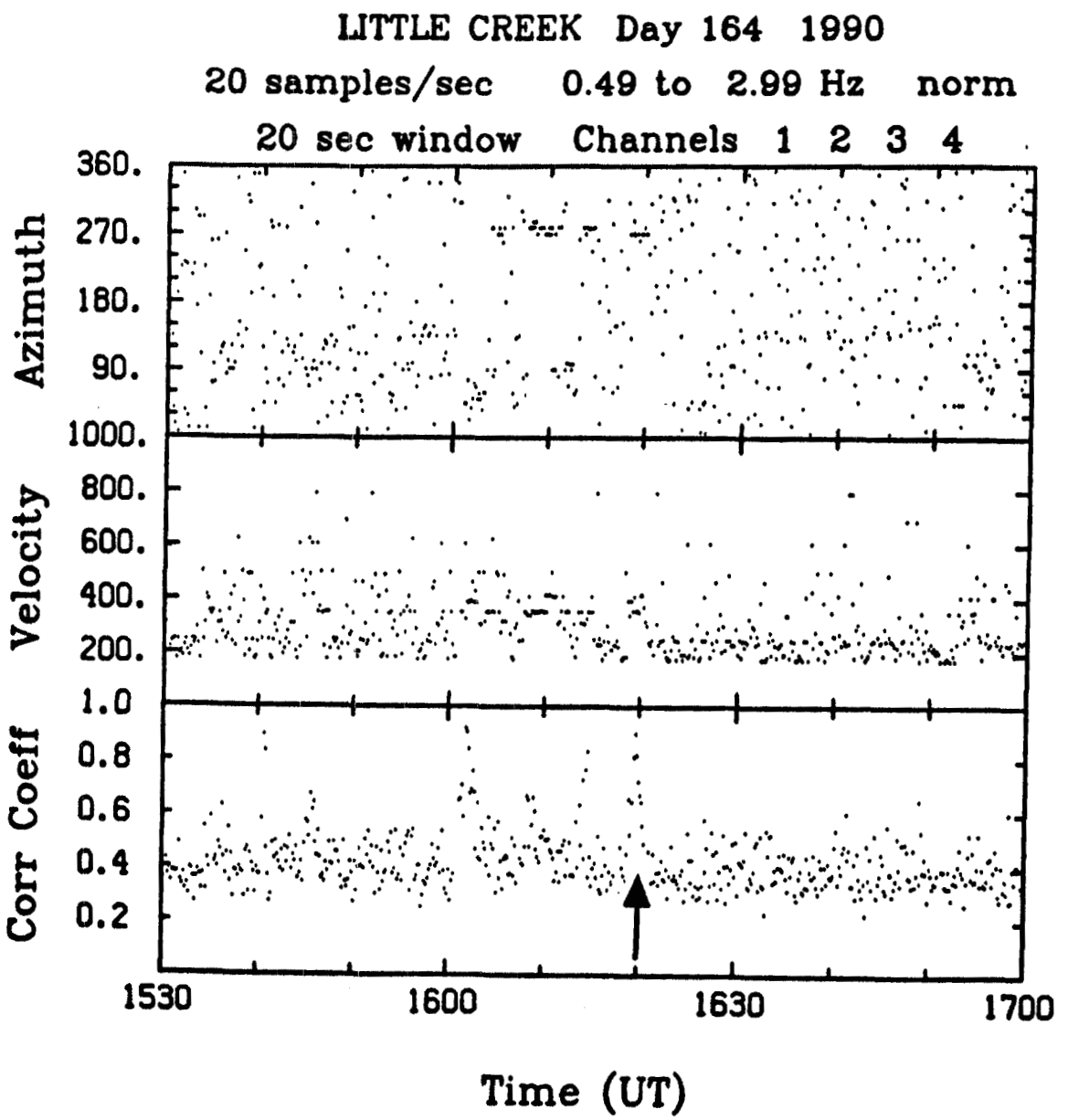
LITTLE CREEK Day 164 1990
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1530
1600
1630
1700
Time (UT)

Figure 15

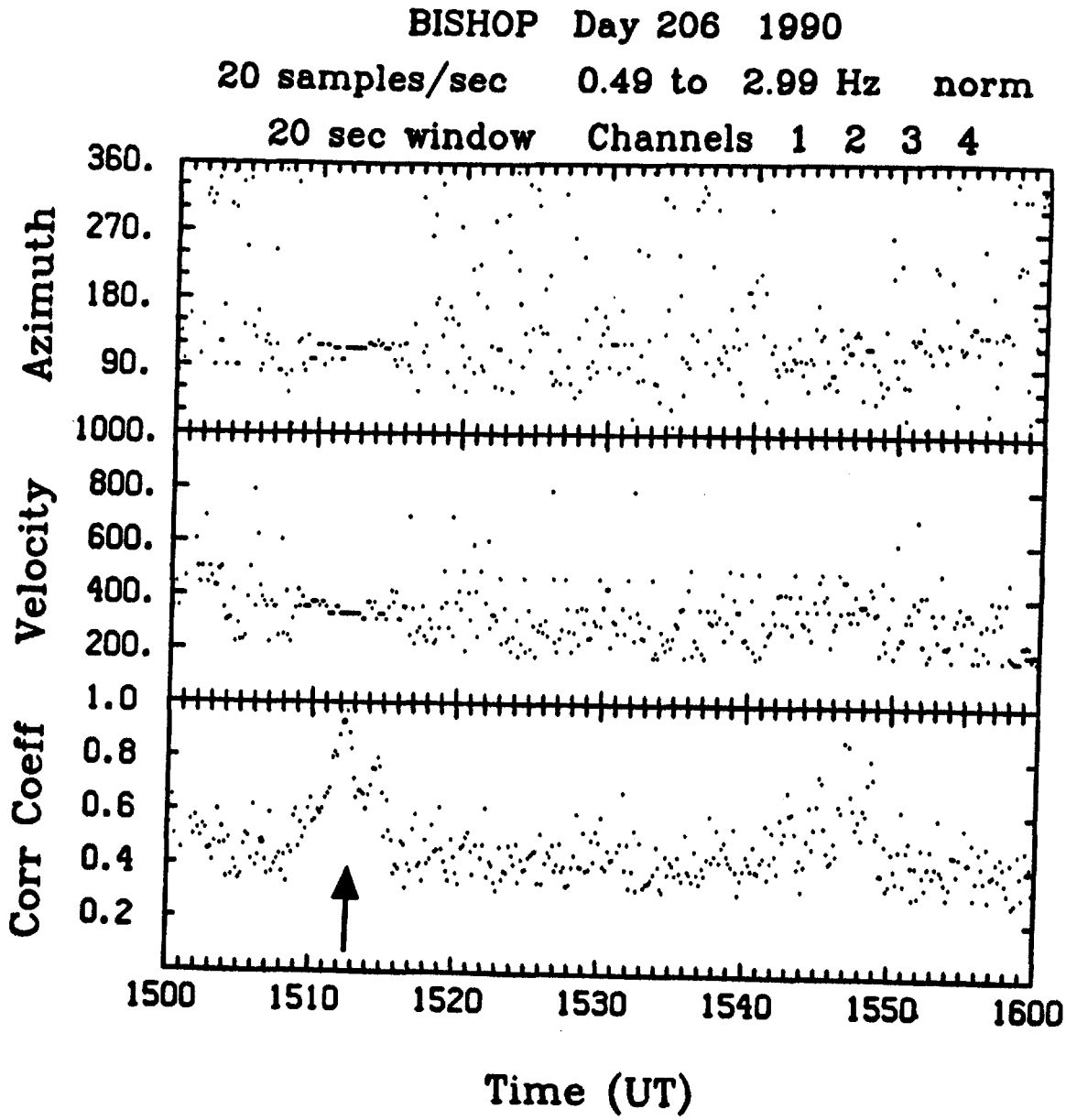
BISHOP Day 206 1990
20 samples/sec 0.49 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1500
1510
1520
1530
1540
1550
1600
Time (UT)

Figure 16

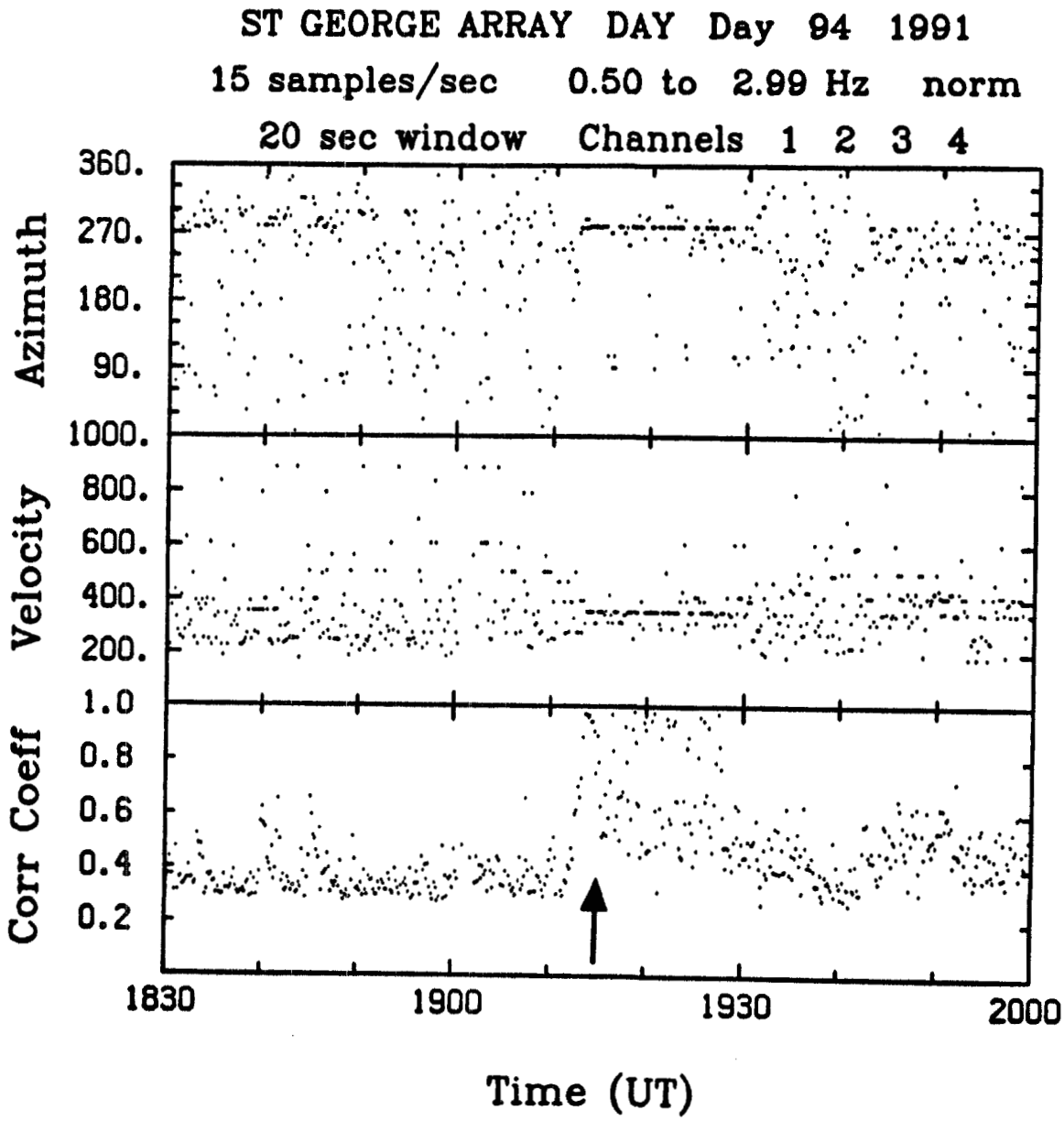
ST GEORGE ARRAY DAY Day 94 1991
15 samples/sec 0.50 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1830
1900
1930
2000
Time (UT)

Figure 17

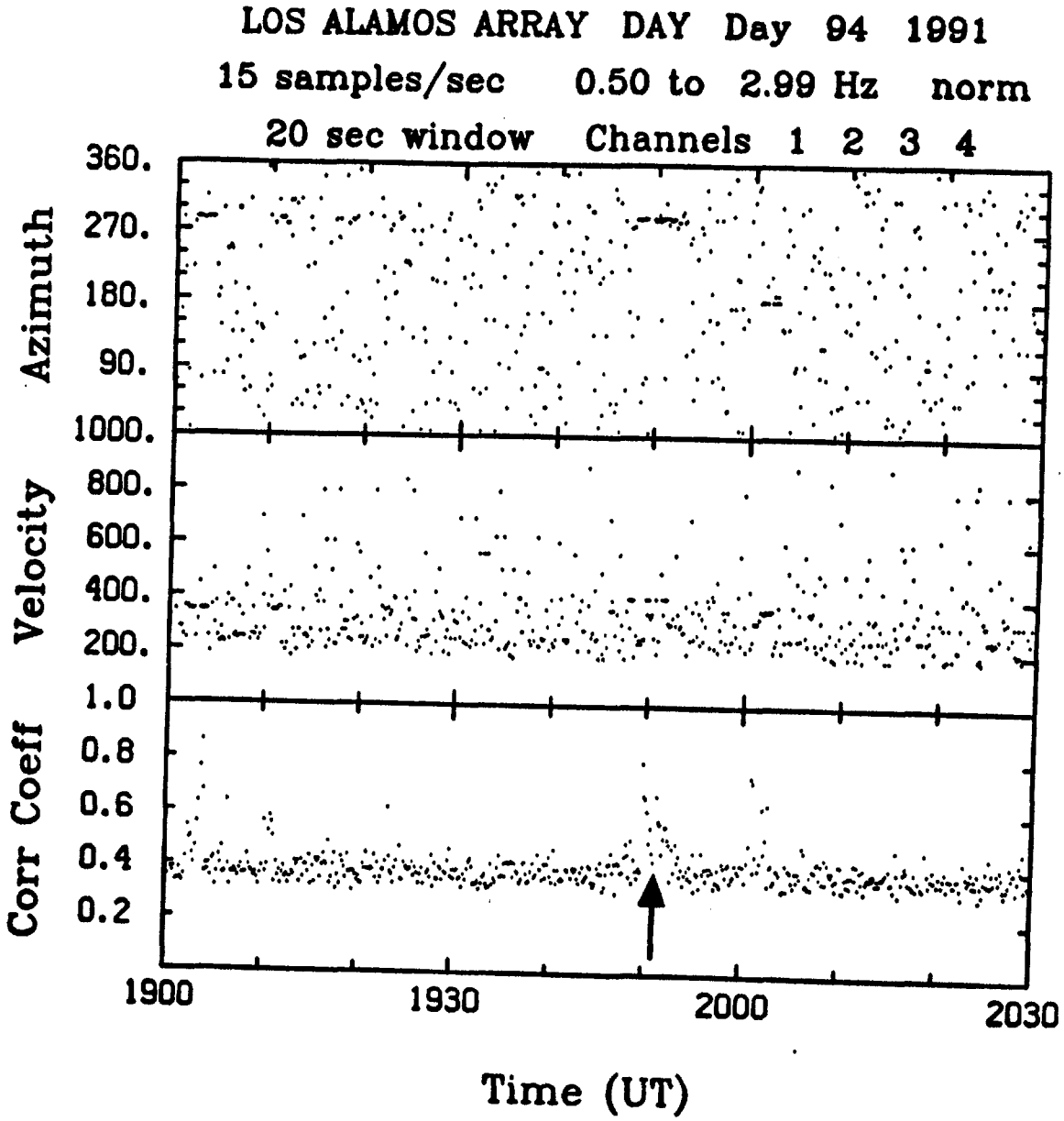
LOS ALAMOS ARRAY DAY Day 94 1991
15 samples/sec 0.50 to 2.99 Hz norm
20 sec window Channels 1 2 3 4
Azimuth
360.
270.
180.
90.
Velocity
1000.
800.
600.
400.
200.
Corr Coeff
1.0
0.8
0.6
0.4
0.2
1900
1930
2000
2030
Time (UT)

Figure 18

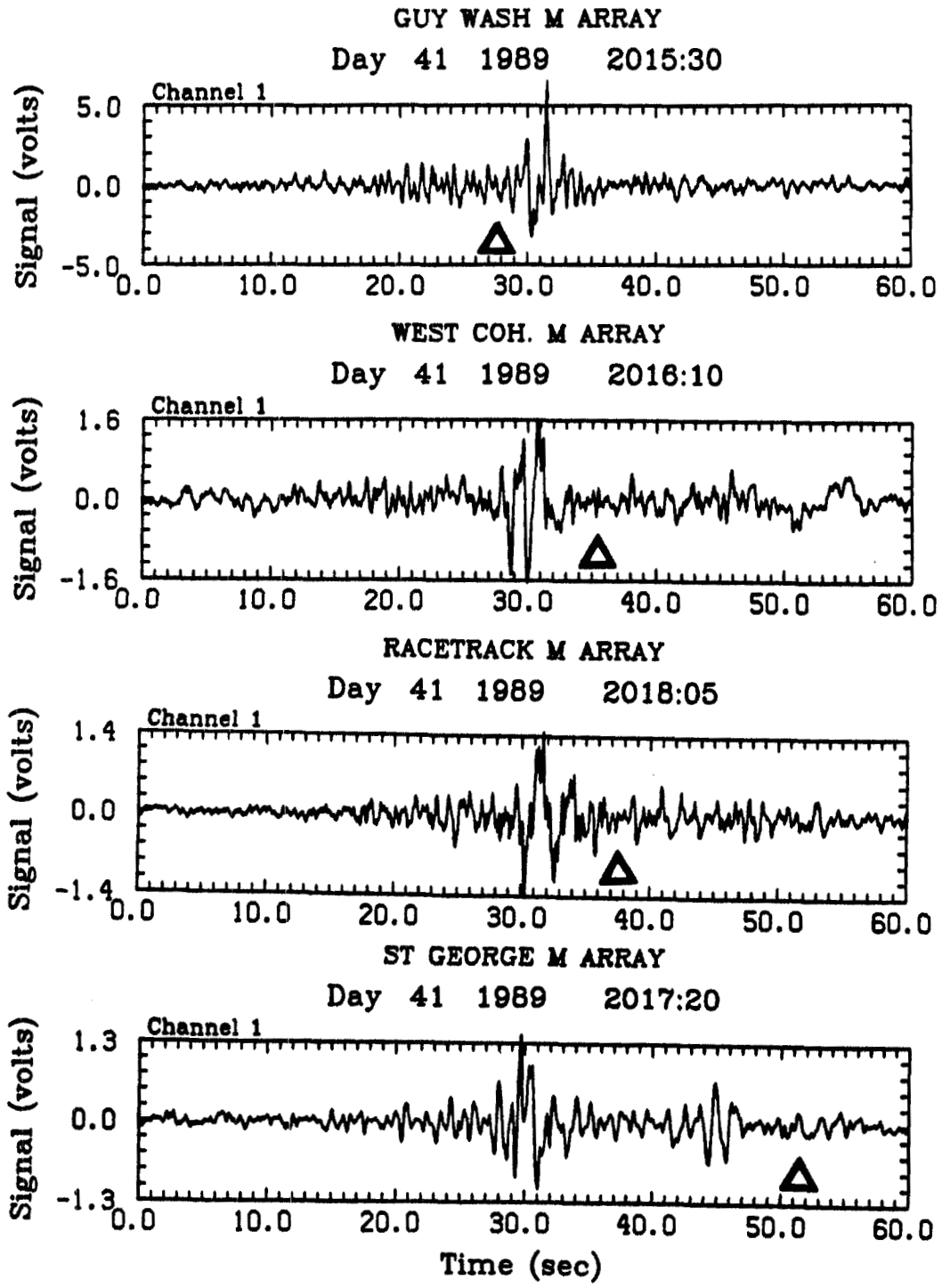
GUY WASH M ARRAY
Day 41 1989 2015:30
Channel 1
Signal (volts)
5.0
0.0
-5.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
WEST COH. M ARRAY
Day 41 1989 2016:10
Channel 1
Signal (volts)
1.6
0.0
-1.6
RACETRACK M ARRAY
Day 41 1989 2018:05
Channel 1
Signal (volts)
1.4
0.0
-1.4
ST GEORGE M ARRAY
Day 41 1989 2017:20
Channel 1
Signal (volts)
1.3
0.0
-1.3
Time (sec)

Figure 19a

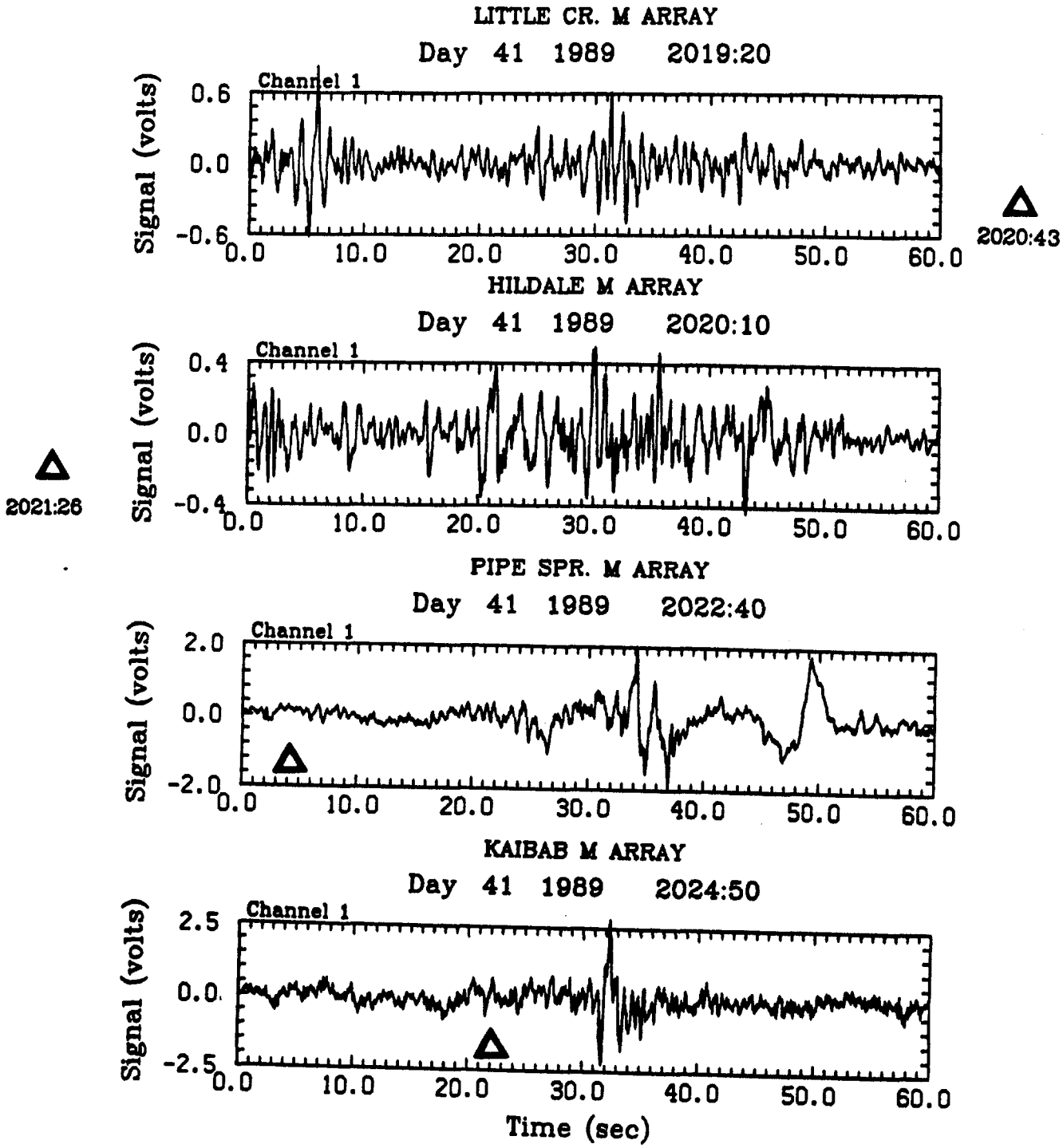
LITTLE CR. M ARRAY
Day 41 1989 2019:20
Channel 1
Signal (volts)
0.6
0.0
-0.6
0.0
10.0
20.0
30.0
40.0
50.0
60.0
2020:43
HILDALE M ARRAY
Day 41 1989 2020:10
Channel 1
Signal (volts)
0.4
0.0
-0.4
2021:26
PIPE SPR. M ARRAY
Day 41 1989 2022:40
Channel 1
Signal (volts)
2.0
0.0
-2.0
KAIBAB M ARRAY
Day 41 1989 2024:50
Channel 1
Signal (volts)
2.5
0.0
-2.5
Time (sec)

Figure 19b

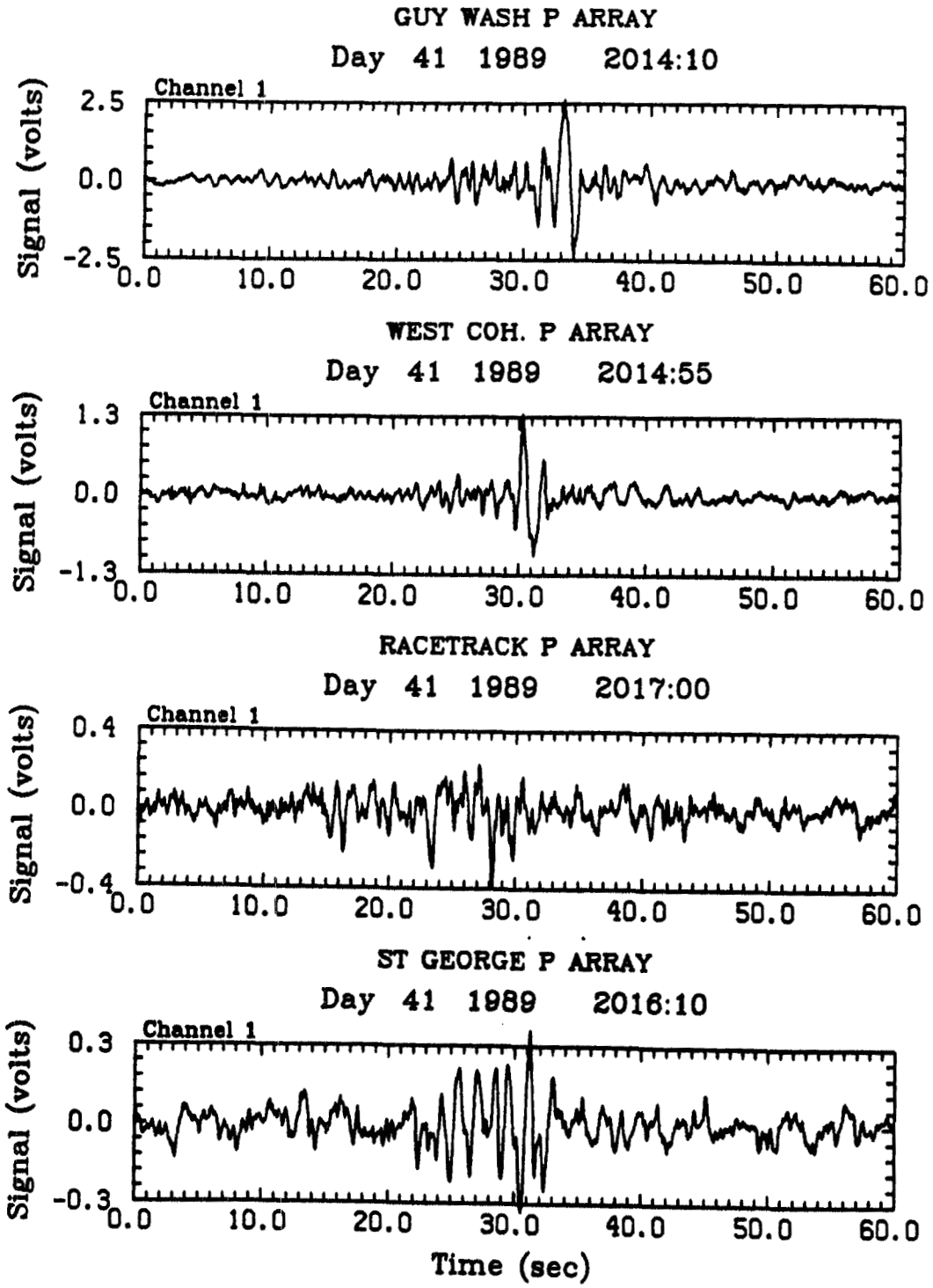
GUY WASH P ARRAY
Day 41 1989 2014:10
Channel 1
Signal (volts)
2.5
0.0
-2.5
0.0
10.0
20.0
30.0
40.0
50.0
60.0
WEST COH. P ARRAY
Day 41 1989 2014:55
Channel 1
Signal (volts)
1.3
0.0
-1.3
0.0
10.0
20.0
30.0
40.0
50.0
60.0
RACETRACK P ARRAY
Day 41 1989 2017:00
Channel 1
Signal (volts)
0.4
0.0
-0.4
0.0
10.0
20.0
30.0
40.0
50.0
60.0
ST GEORGE P ARRAY
Day 41 1989 2016:10
Channel 1
Signal (volts)
0.3
0.0
-0.3
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Time (sec)

Figure 20a

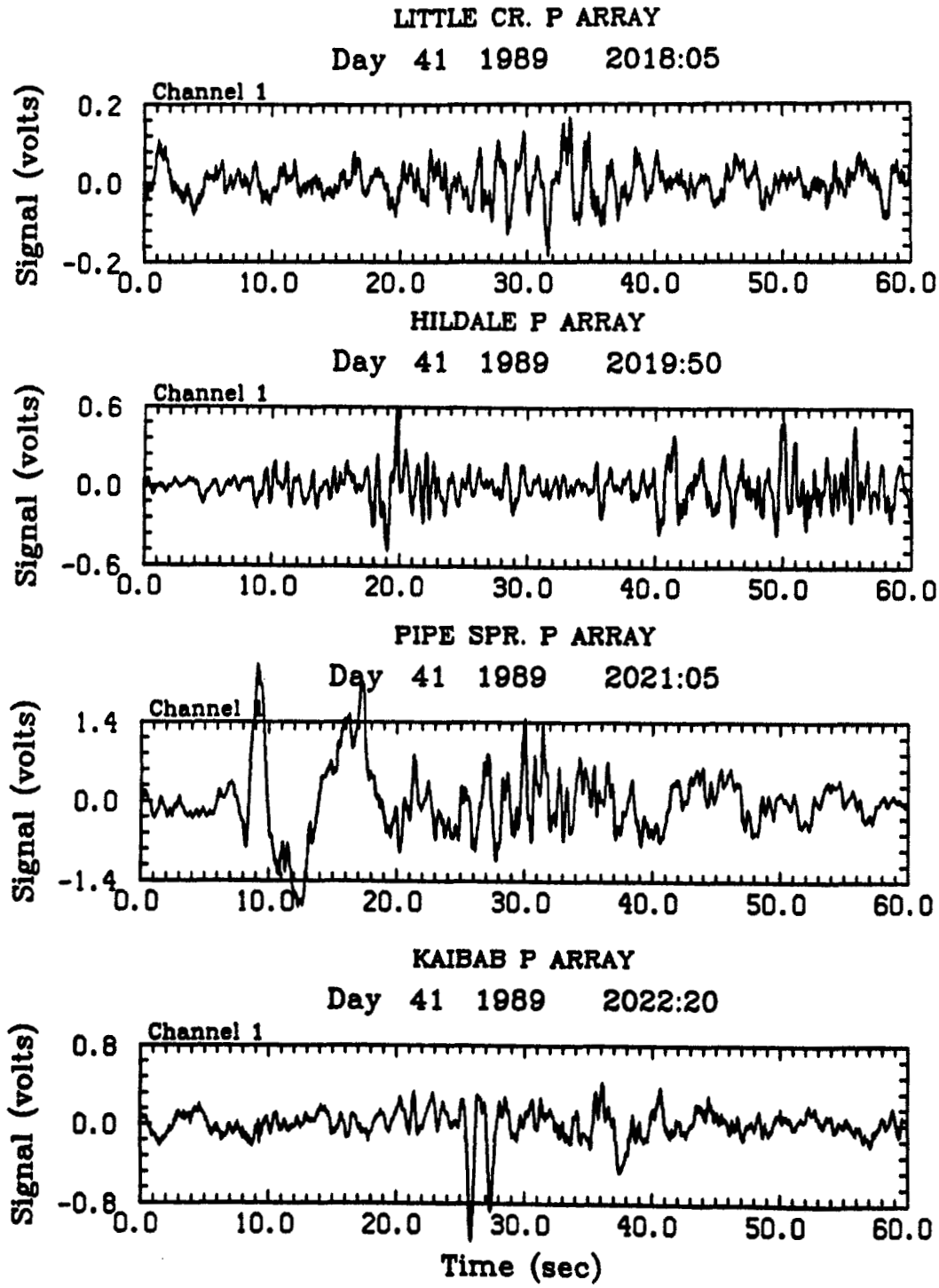
LITTLE CR. P ARRAY
Day 41 1989 2018:05
Channel 1
Signal (volts)
0.2
0.0
-0.2
0.0
10.0
20.0
30.0
40.0
50.0
60.0
HILDALE P ARRAY
Day 41 1989 2019:50
Channel 1
Signal (volts)
0.6
0.0
-0.6
PIPE SPR. P ARRAY
Day 41 1989 2021:05
Channel
Signal (volts)
1.4
0.0
-1.4
KAIBAB P ARRAY
Day 41 1989 2022:20
Channel 1
Signal (volts)
0.8
0.0
-0.8
Time (sec)

Figure 20b

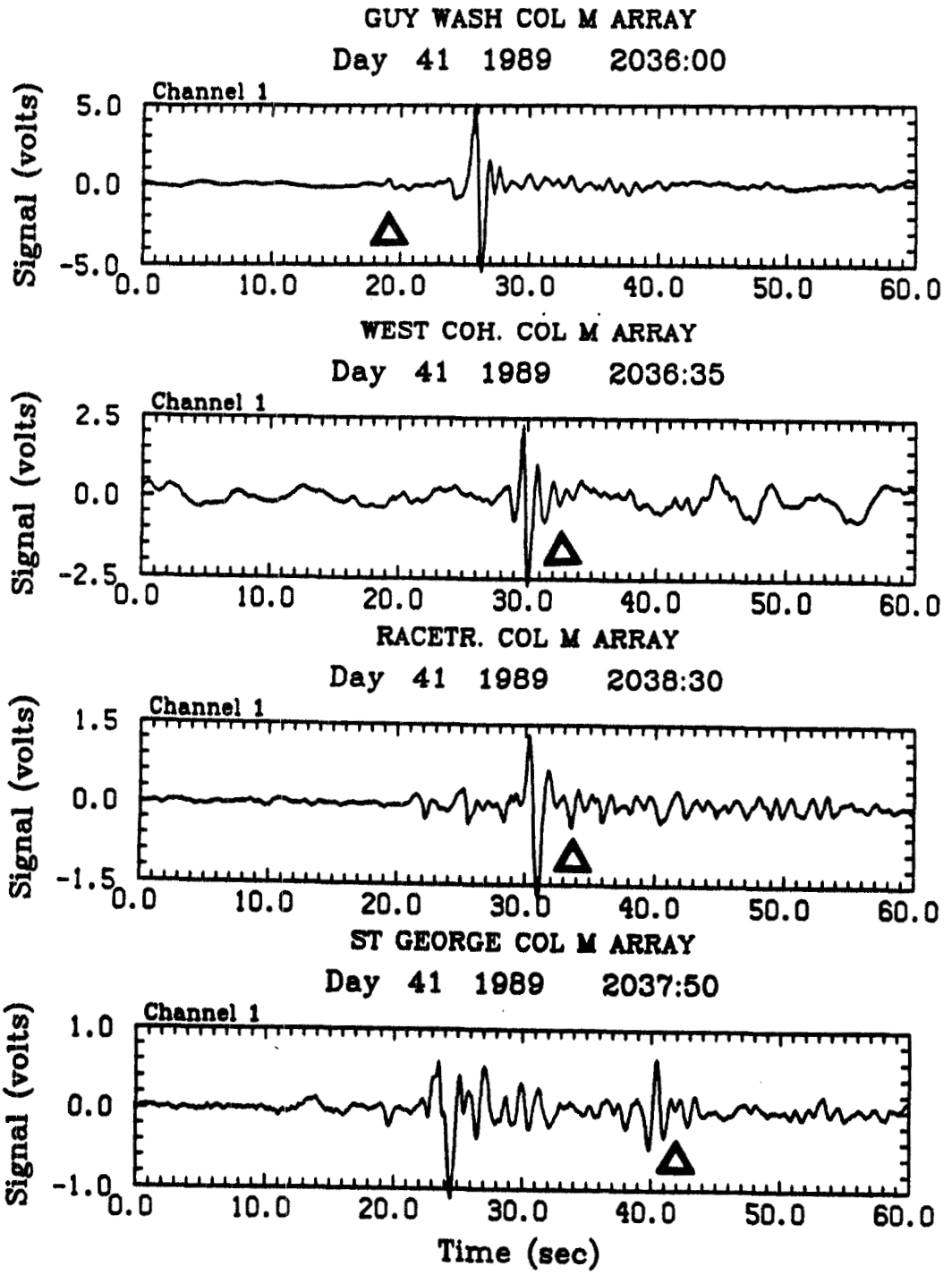
GUY WASH COL M ARRAY
Day 41 1989 2036:00
Channel 1
Signal (volts)
5.0
0.0
-5.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
WEST COH. COL M ARRAY
Day 41 1989 2036:35
Channel 1
Signal (volts)
2.5
0.0
-2.5
RACETR. COL M ARRAY
Day 41 1989 2038:30
Channel 1
Signal (volts)
1.5
0.0
-1.5
ST GEORGE COL M ARRAY
Day 41 1989 2037:50
Channel 1
Signal (volts)
1.0
0.0
-1.0
Time (sec)

Figure 21a

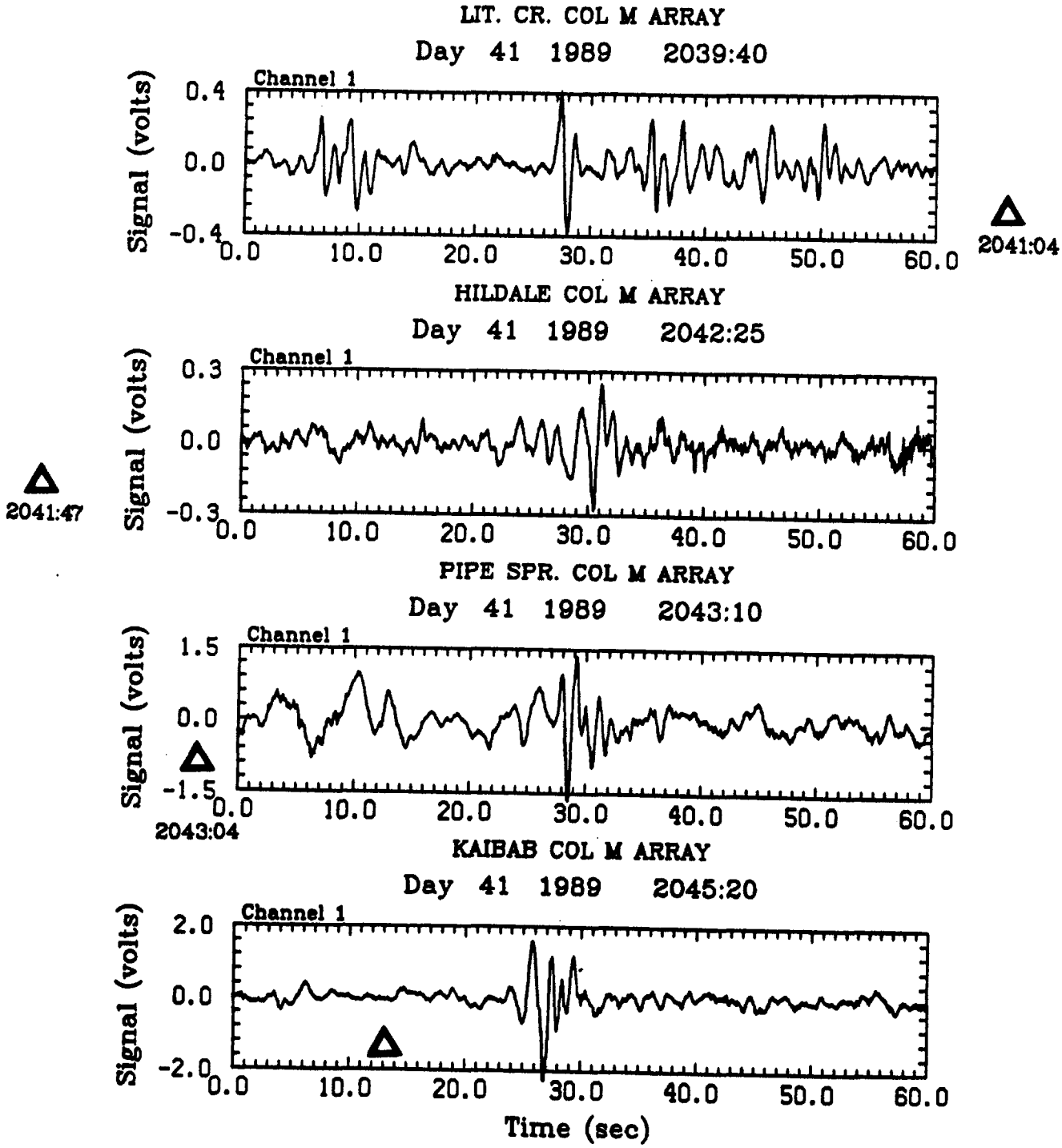
LIT. CR. COL M ARRAY
Day 41 1989 2039:40
Channel 1
Signal (volts)
0.4
0.0
-0.4
0.0
10.0
20.0
30.0
40.0
50.0
60.0
2041:04
HILDALE COL M ARRAY
Day 41 1989 2042:25
Channel 1
Signal (volts)
0.3
0.0
-0.3
2041:47
PIPE SPR. COL M ARRAY
Day 41 1989 2043:10
Channel 1
Signal (volts)
1.5
0.0
-1.5
2043:04
KAIBAB COL M ARRAY
Day 41 1989 2045:20
Channel 1
Signal (volts)
2.0
0.0
-2.0
Time (sec)

Figure 21b

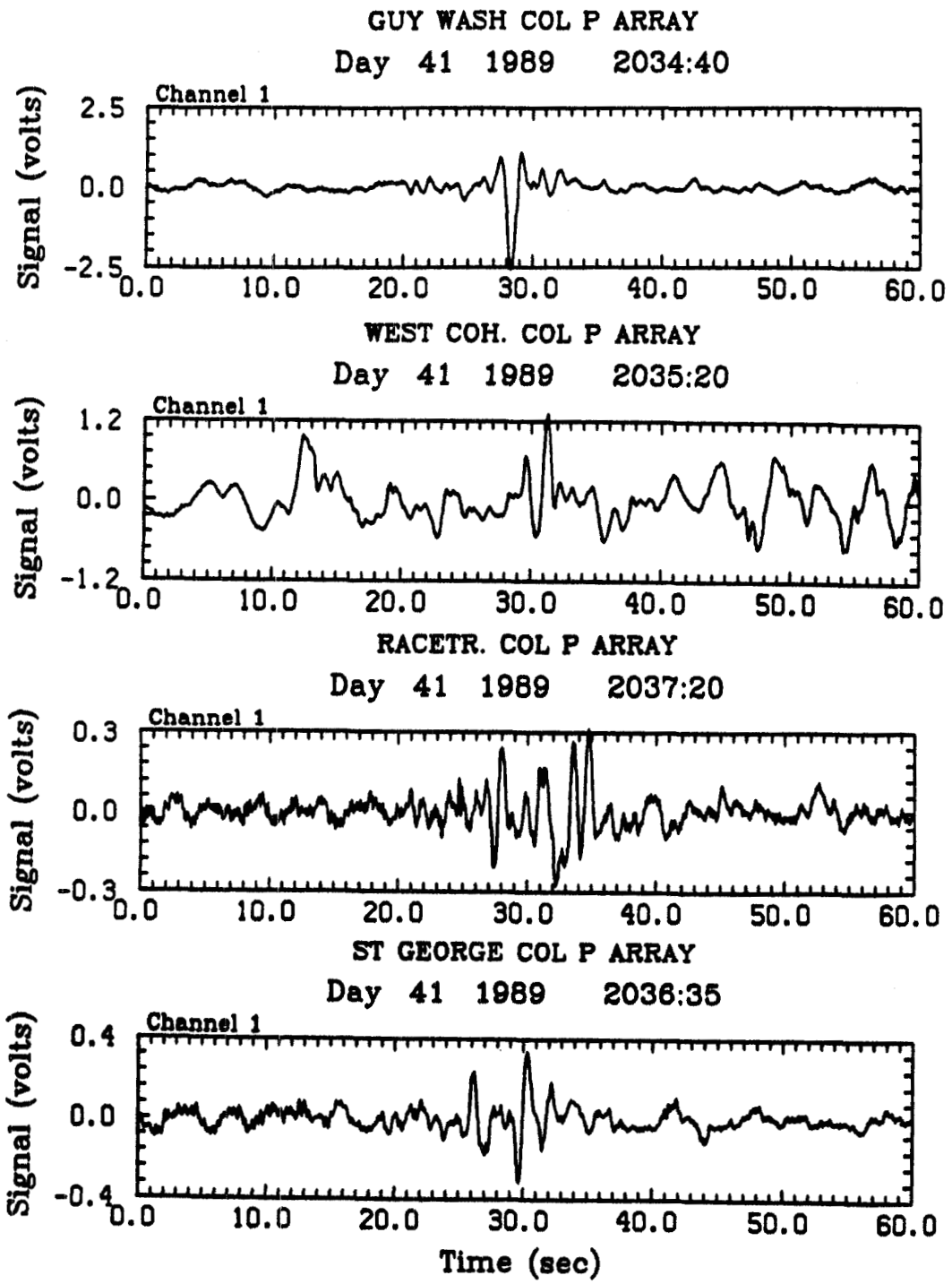
GUY WASH COL P ARRAY
Day 41 1989 2034:40
Channel 1
Signal (volts)
2.5
0.0
-2.5
0.0
10.0
20.0
30.0
40.0
50.0
60.0
WEST COH. COL P ARRAY
Day 41 1989 2035:20
Channel 1
Signal (volts)
1.2
0.0
-1.2
RACETR. COL P ARRAY
Day 41 1989 2037:20
Channel 1
Signal (volts)
0.3
0.0
-0.3
ST GEORGE COL P ARRAY
Day 41 1989 2036:35
Channel 1
Signal (volts)
0.4
0.0
-0.4
Time (sec)

Figure 22a

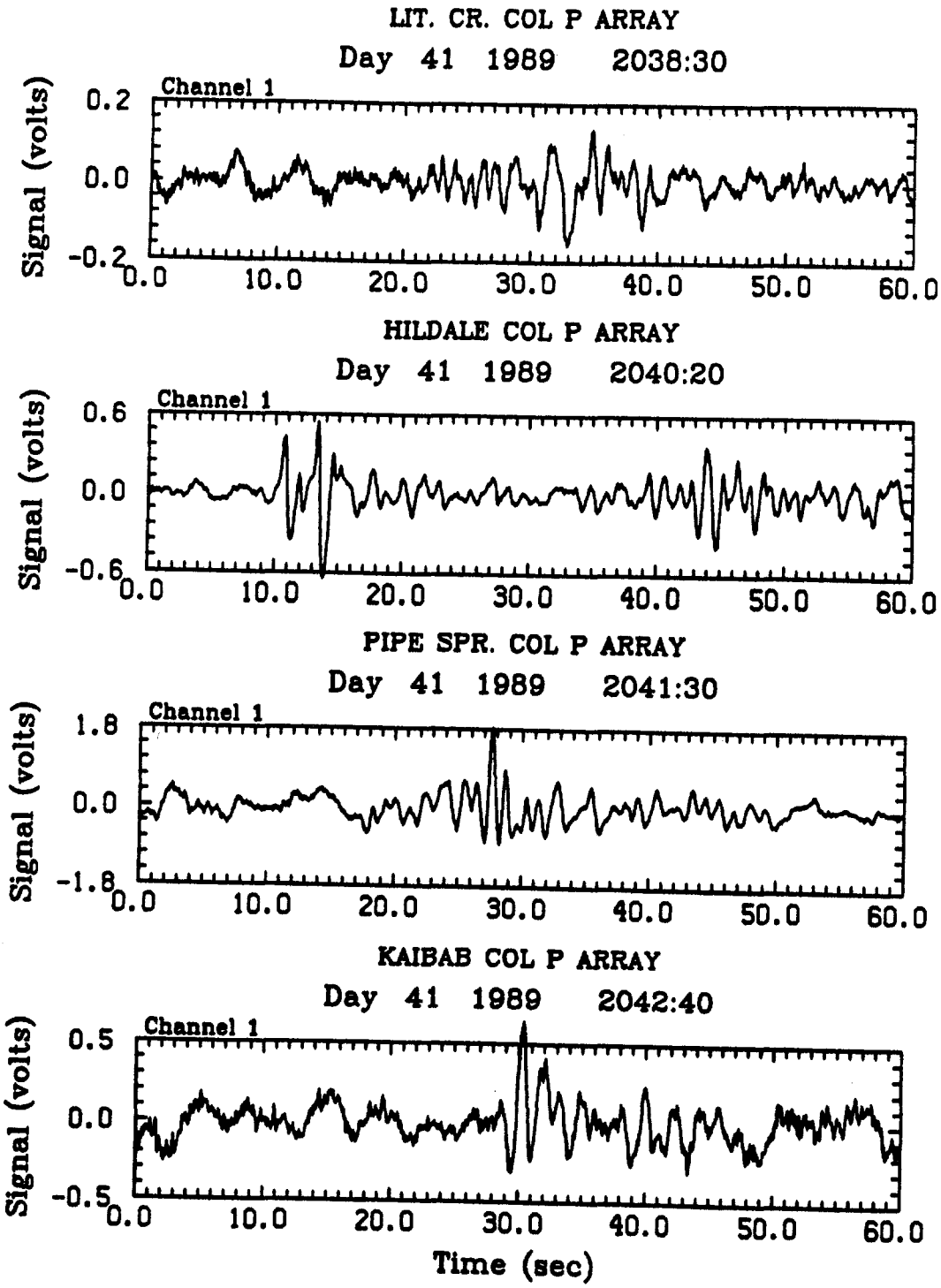
LIT. CR. COL P ARRAY
Day 41 1989 2038:30
Channel 1
Signal (volts)
0.2
0.0
-0.2
0.0
10.0
20.0
30.0
40.0
50.0
60.0
HILDALE COL P ARRAY
Day 41 1989 2040:20
Channel 1
Signal (volts)
0.6
0.0
-0.6
0.0
10.0
20.0
30.0
40.0
50.0
60.0
PIPE SPR. COL P ARRAY
Day 41 1989 2041:30
Channel 1
Signal (volts)
1.8
0.0
-1.8
0.0
10.0
20.0
30.0
40.0
50.0
60.0
KAIBAB COL P ARRAY
Day 41 1989 2042:40
Channel 1
Signal (volts)
0.5
0.0
-0.5
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Time (sec)

Figure 22b

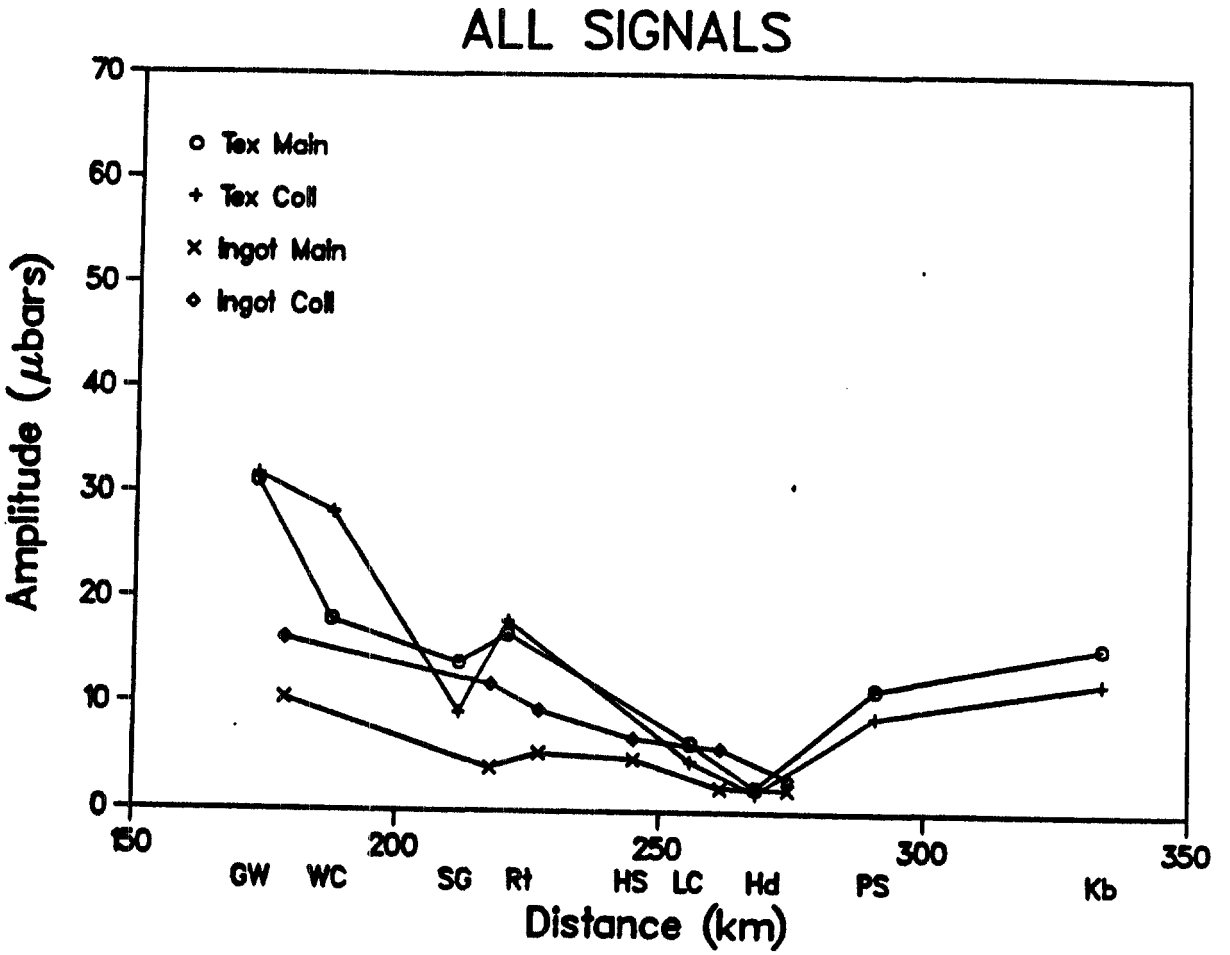
ALL SIGNALS
Tex Main
Tex Coll
Ingot Main
Ingot Coll
Amplitude (μbars)
70
60
50
40
30
20
10
0
150
200
250
300
350
GW
WC
SG
Rt
HS
LC
Hd
PS
Kb
Distance (km)

Figure 23