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Broadband Teleseismic Array Recording in the Adirondack Mountains, New York State

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Directorate of Geophysics
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This technical report has been reviewed and is approved for publication.

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Summary

This is a data report on the Adirondack Teleseismic Array (ATA) experiment, conducted during June to November, 1992. In this experiment five portable seismic stations were run in the Adirondack Mountains of upstate New York in order to record teleseismic body waveforms in a tight array configuration. Seventy-eight regional and teleseismic earthquakes were detected by the array during its operation. The purpose of this experiment is to acquire a data set where array processing techniques can be used to enhance the signals used in a teleseismic receiver structure analysis.

Broadband Teleseismic Array Recording in the Adirondack Mountains, New York State

1.0 Introduction

Between the months of June and November 1992 we installed and operated a five element broadband seismograph array in the Adirondack Mountains of New York State. Our objectives are to characterize the deep crust and upper mantle structure using beamformed teleseismic body waves. Coincident seismic refraction and reflection surveys offer an excellent opportunity to compare broadband model estimates to these higher frequency results. Technical support from the IRIS instrumentation center, Guralp Systems Ltd., and Refraction Technology, Inc. played a significant role in the successful deployment in the Adirondack Mountains. This report documents the experiment and data recorded with a portable small aperture broadband array.

2.0 Geologic Overview

The Adirondack Mountains of New York State consist primarily of lower Paleozoic sedimentary, meta-sedimentary and meta-igneous ~1.1 b.y. Grenville age rocks that form a roughly circular 'breached dome' exposure defined by the dip of the surrounding and overlying Paleozoic strata, located just west of the Appalachian mountain belt (Wiener et al., 1984). Topography across the Adirondack mountains is moderate, with approximately 2 km relief with respect to the surrounding terrain. The exposed Adirondack granulite is believed to represent a small window of the much larger Grenville Province in Ontario (Wiener et al., 1984). High pressure and temperature studies suggest that the Adirondack mountains may represent lowermost crust exposed at the surface (Christensen and Fountain, 1975).

The Adirondack Mountains have been the location of three recent geophysical surveys to estimate underlying crustal structure. The 1988 O-NYNEX seismic survey recorded extensive vertical-component *refraction data across* Ontario, New York, and New England (Leutgert et al., 1990), as well as three-component refraction data in New York and Vermont (Mangino and Cipar, 1990). Hughes and Leutgert (1992) present a detailed interpretation of the O-NYNEX modeling results in the Adirondacks. Owens (1987) determined the Adirondack crustal structure from receiver functions obtained from broadband data recorded at seismic station RSNY, near Malone, NY. The 1983 COCORP Adirondack profiles (Lines 7 and 11), discussed in Klemperer et al. (1985) and Brown et al. (1983), revealed a prominent layered mid-crustal reflection sequence known as the Tahawus complex at 18-24 km depth, and several possible interpretations for this anomalous zone are currently in debate. Electrical conductivity measurements of the Adirondacks have also been carried out, as discussed in Connery and Kuckes (1980). Collectively, these modeling results indicate a 42-44 km thick crust with an average P-wave velocity of 6.5-6.7 km/s. There is a zone of prominent mid-crustal reflections between 18-24 km depth, and a gradational Moho is inferred at the base of the crust with upper mantle P_n velocity 8.05-8.1 km/s (Hughes and Leutgert, 1992; Owens, 1987; Klemperer et al., 1985; Brown et al., 1983).

We installed a 5 element broadband seismograph array located near the center of the Adirondack Massif with an aperture of 15 km by 20 km to investigate the anomalous crust and upper mantle using teleseismic body-wave data. Shown in Figure 1 is a map of the study area indicating array station locations as well as the previous refraction and reflection profiles.

3.0 Deployment and Instrumentation

Adirondack back-country roads are accessible only from late May to November of each year after the effects of heavy snowfall and permafrost are no longer an issue. Site selection, land access permits and vault construction was completed during the month of June, 1992. Seismographs were installed during the first week of July and were deployed until 5 November 1992. All stations were located on Adirondack National Park lands administered by the NY State Department of Environmental Conservation, the Huntington Wildlife Refuge, or by private owners.

Each station consisted of one Refraction Technology model 72A-02 data acquisition system (DAS) equipped with Omega timing, a 175 Mb external hard disk and a Guralp CMG-3T (0.01-50Hz) triaxial seismometer. The seismometer's feet were placed on glass plates in vaults composed of a heavy plastic bin embedded within a 4-5 cu ft concrete base. A second cover was placed over the seismometer and grouted to the cement, and the remaining airspace was layered with insulation. This simple design proved

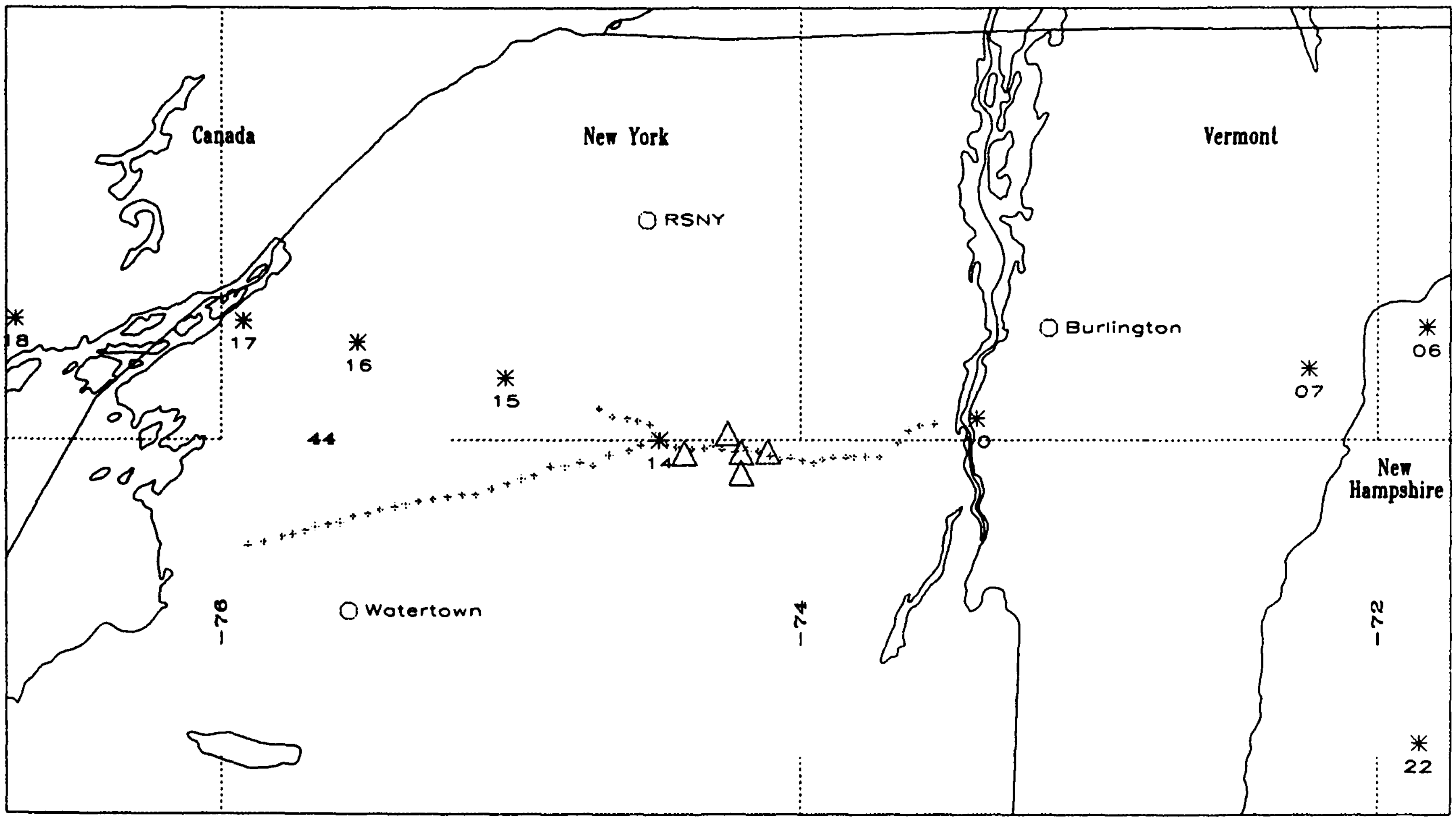

Figure 1. Map of sites of the Adirondack Teleseismic Array Stations (triangles) along with the positions of the O-NYNEX shotpoints (stars) and the O-NYNEX recording profile (plusses).

waterproof and maintained a relatively constant temperature. After the first few visits to each site, the electronically balanced CMG-3T remained stable (±2 volts) throughout the deployment. DC power was supplied by two 75 Amp-hour deep-cycle, lead-acid marine batteries charged by two Siemens M-65 (40 volt) solar panels connected in parallel. Figure 2 shows a typical station configuration for array elements 2 through 5. Station 1, the central element, was installed within a storage facility maintained by the Huntington Wildlife Refuge. At each site we recorded a single data stream consisting of three channels at 16-bit resolution at 10 samples per second. Listed in Table 1 are all station locations, and listed in Table 2 are the wiring connections for the DAS to CMG-3T. Table 3 contains the recording parameters used for one station.

Within the first week of operation, three stations failed due to disk write errors encountered during the DAS auto dump sequence. This instrument malfunction was quickly corrected in the field by installing new DAS software. A hardware modification (forced-perfect terminators) also enabled station data to be transferred from the 175 Mb disks to a larger 660 Mb 'dump' disk. The dump disk was later returned to the laboratory and mounted directly to a workstation. We also downloaded data to Exabyte tape and converted the RefTek ASCII/binary output into SAC format using the standardized routines provided by IRIS.

After upgrading to DAS software version V02.47, a previously unnoticed station location programming error where the station location was input in "decimal:degrees" instead of "degrees:minutes" resulted in erroneous Omega time 'corrections' between the 12 and 24 hours recording formats. Fortunately, as a standard practice in the field during the period with this timing problem, the data transfer in the field was always followed by a system reset and a RAM clear. A format disk command sequence was then issued and GMT was reset manually. This careful instrument reinitialization in the field meant that the GMT time for the first event is known at each station.

Toward mid-October a third problem which was encountered was the gradual loss of power at each station due to lower levels of available sunlight coupled with ice and snowfall accumulations on the solar panels. Each station was powered by batteries charged in parallel by solar panels and required an average of 6 watts continuous power. To maintain sufficient operational voltage, the solar modules must collect enough energy and the batteries must have sufficient storage capacity to be capable

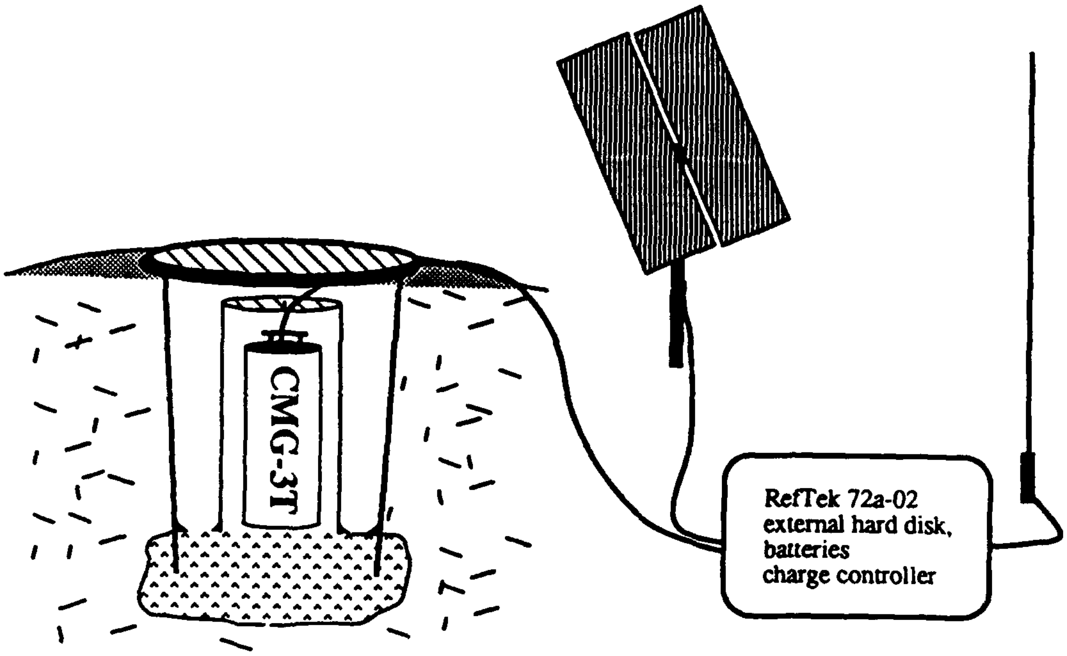

Figure 2. Illustration of the physical layout of the sensors and recording system used for the Adirondack Teleseismic Array.

Table 1

Station Locations

Station	Name	Latitude	Longitude
1	SAW1	43.970	74.209
2	MOW2	43.915	74.211
3	EDC3	43.970	74.113
4	MIL4	44.024	74.254
5	ROM5	43.970	74.403

Table 2

CMG-3T to DAS72a-02 Sensor Cable Wiring

Guralp		DAS	Channel	Signal
A	brown	A	ch1 +	Z
B	red	B	ch1 -	
C	orange	C	ch2 +	N-S
D	yellow	D	ch2 -	
E	green	E	ch3 +	E-W
F	blue	F	ch3 -	
H	white	L	cal +	
J+L	black	K	common	

Table 3

```
CPU SOFTWARE V02.47
Station Channel Definition  92:220:18:41:28:411   ST: 0454
Experiment Number = 2
Experiment Name = ADIRONDACK  TELESEISMIC
  Comments - ATA
  Station Number = 01
  Station Name = SAW1
    Station Comments - NEWCOMB, NY
    Time Clock Type = OMGA
    Clock Serial Number = NONE
Channel Number = 1
Name - Z
Azimuth - 0
Inclination - 0
Preamplifier Gain = 1
Sensor Model - CMG-3T
Sensor Serial Number - 362
Volts per Bit = 114.4 uV
Channel Number = 2
Name - N-S
Azimuth - 0
Inclination - 90
Preamplifier Gain = 1
Sensor Model - CMG-3T
Sensor Serial Number - 362
Volts per Bit = 114.4 uV
Comments - ALIGNED TO  MAGNETIC N
Channel Number = 3
Name - E-W
Azimuth - 90
Inclination - 90
Preamplifier Gain = 1
Sensor Model - CMG-3T
Sensor Serial Number - 362
Volts per Bit = 114.4 uV
Comments - ALIGNED TO  MAGNETIC N
Wake-up Sequence Definition
Power State : CP
Recording Mode : SC
Data Stream Definition
Data Stream  1    DATA ONE
Channels 123
Sample rate   10 samples per second
Data Format 16
Trigger Type CON
Record Length (seconds) 3600
```

of powering the station through several consecutive days of cloudy weather. Cloud cover and early snow coupled with lower available peak sunlight during October led to low voltage conditions resulting in an automatic station shutdown. Doubling the number of solar panels and batteries would effectively double the charge and storage capacity, and therefore, extend the recording life under similar conditions in future experiments.

4.0 Array Resolution and Coverage

Advances in signal enhancement and identification have been achieved in seismology in recent years through coherence processing of data from stragetically-placed seismic arrays. The signal characteristics of interest for our small aperture array include the amplitude and frequency content of the teleseismic P-waveform and the consistency of identifiable depth phases for both large and small magnitude events relative to the ambient noise field. Beamforming a given event across the array reduces the scattered signal energy for estimating the P wave spectrum and allows us to obtain a more robust estimate of the receiver waveforms. In particular, reflections and conversions at the crust-mantle boundary and within the upper mantle in the first 30-60 seconds of data can be enhanced by these data processing methods.

Vertical resolution of the thickness of a layer in the teleseismic modeling method is dependent upon velocity and dominant frequency, while lateral resolution is dependent on these parameters as well the layer depth. Shown in Figure 3 are the Fresnel zones for a vertically incident 1-Hz S-wave beneath each array element for a reflective Moho at 40 km depth. Beamforming the coherent energy reflected from the Moho in Figure 3 averages the Moho structure over the total Fresnel zone covered by the entire array (the shaded Fresnel zone in Figure 3). Because of the geometry of the reflected ray paths, this Fresnel zone at the Moho is elongated along the azimuth of approach of the seismic energy.

The advantage of modeling with broadband array data are higher signal to noise levels and a diminution of the effects of laterally varying structure. This latter effect occurs when the array data are stacked at an apparent velocity equal to that for a particular phase, such as the direct P or the P-to-S conversion at the Moho. Shown in Figure 4a are the vertical component array records for a m_b 5.4 teleseism

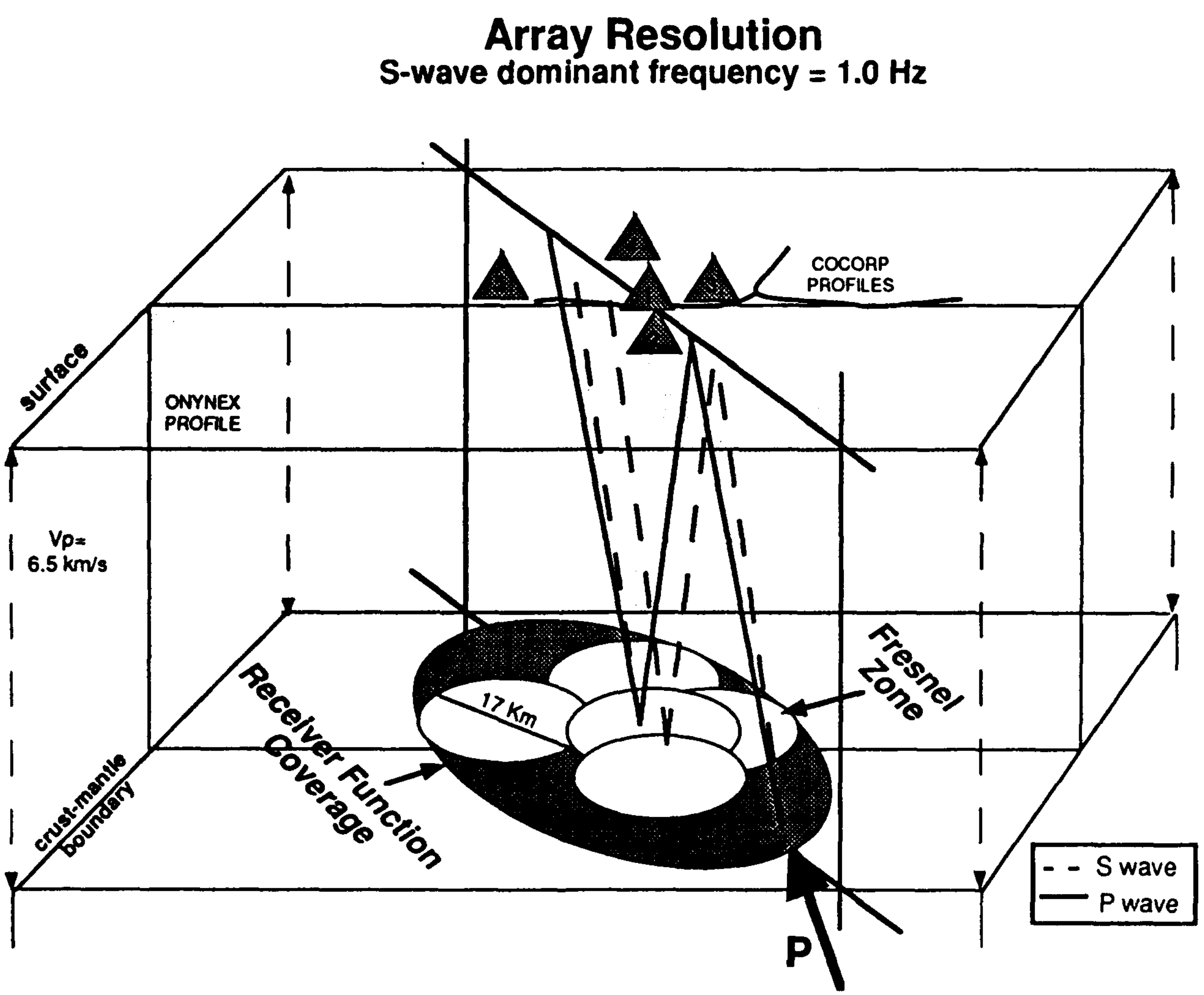

Figure 3. Illustration of the relative locations of the Fresnel Zones at the Moho for the individual stations (triangles) of the Adirondack Teleseismic Array for an incident P wave. The ray paths of the Moho-reflected P and Moho-reflected S (converted from the direct P at the Moho) are also shown.

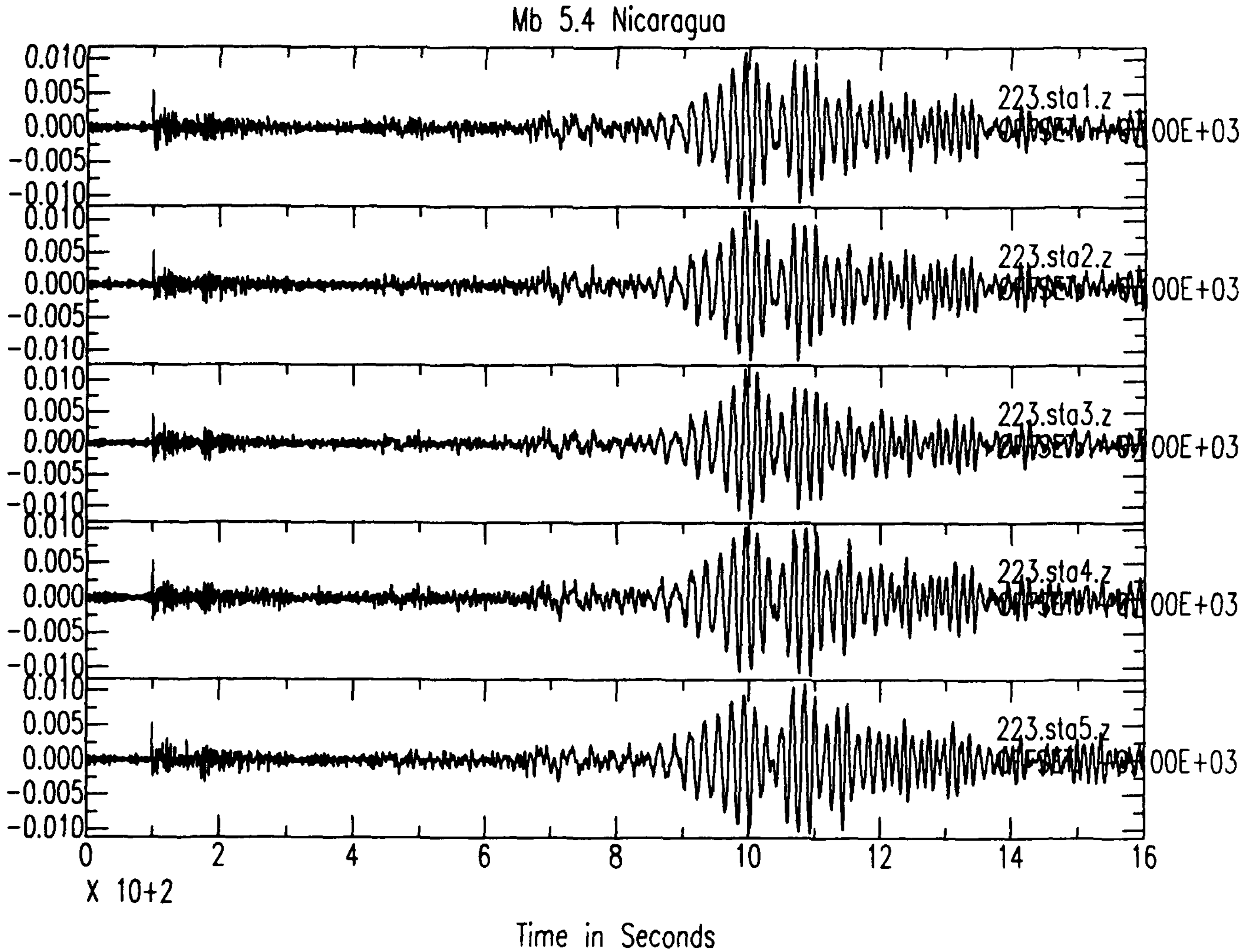

Figure 4a. Signals recorded by the Adirondack Teleseismic Array for the mb=5.4 teleseism from Nicaragua on August 10, 1992.

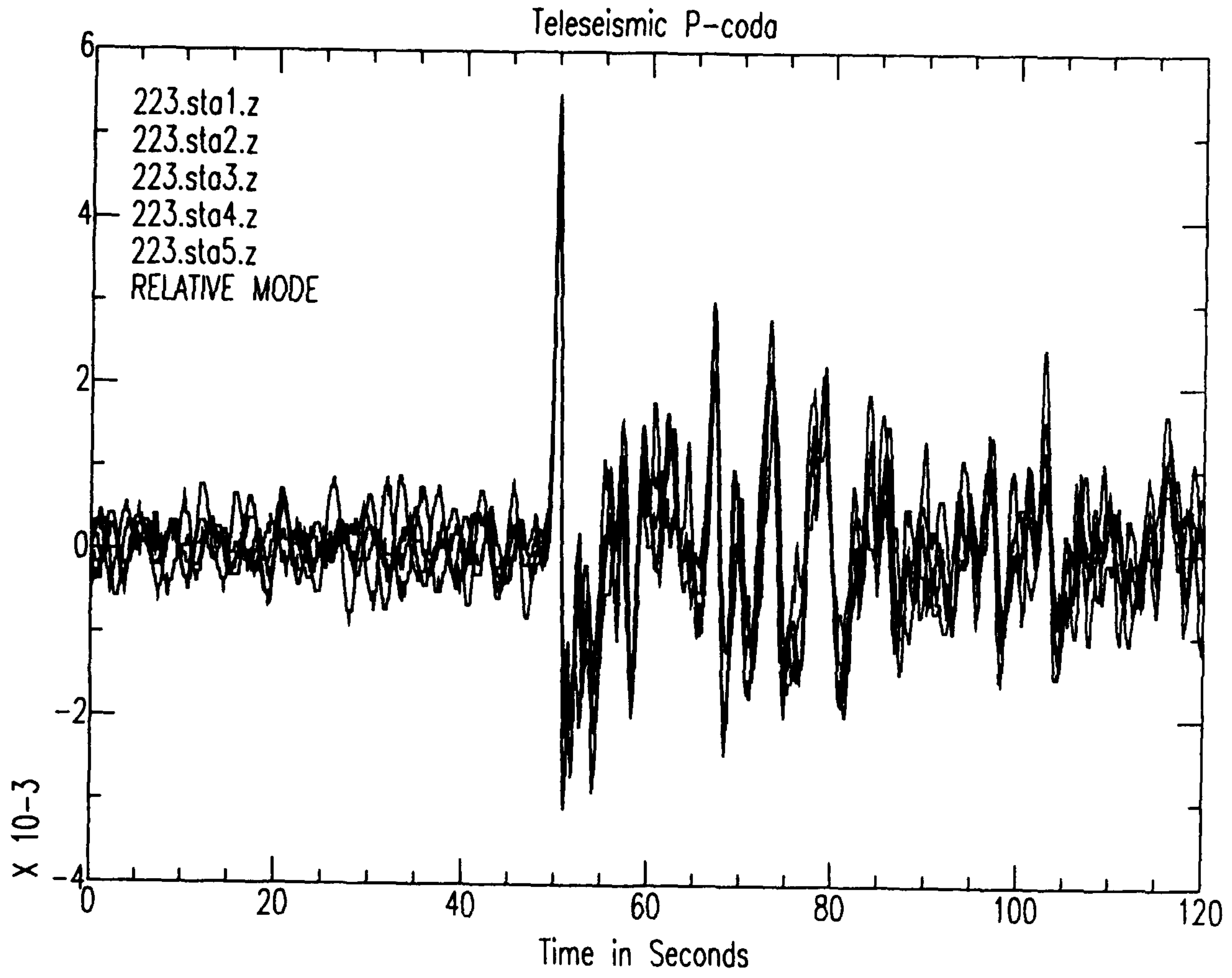

Figure 4b. Plot of the first minute or so of the P wave and P-wave coda for the Nicaragua teleseism. All of the traces here have been normalized to the same peak amplitude.

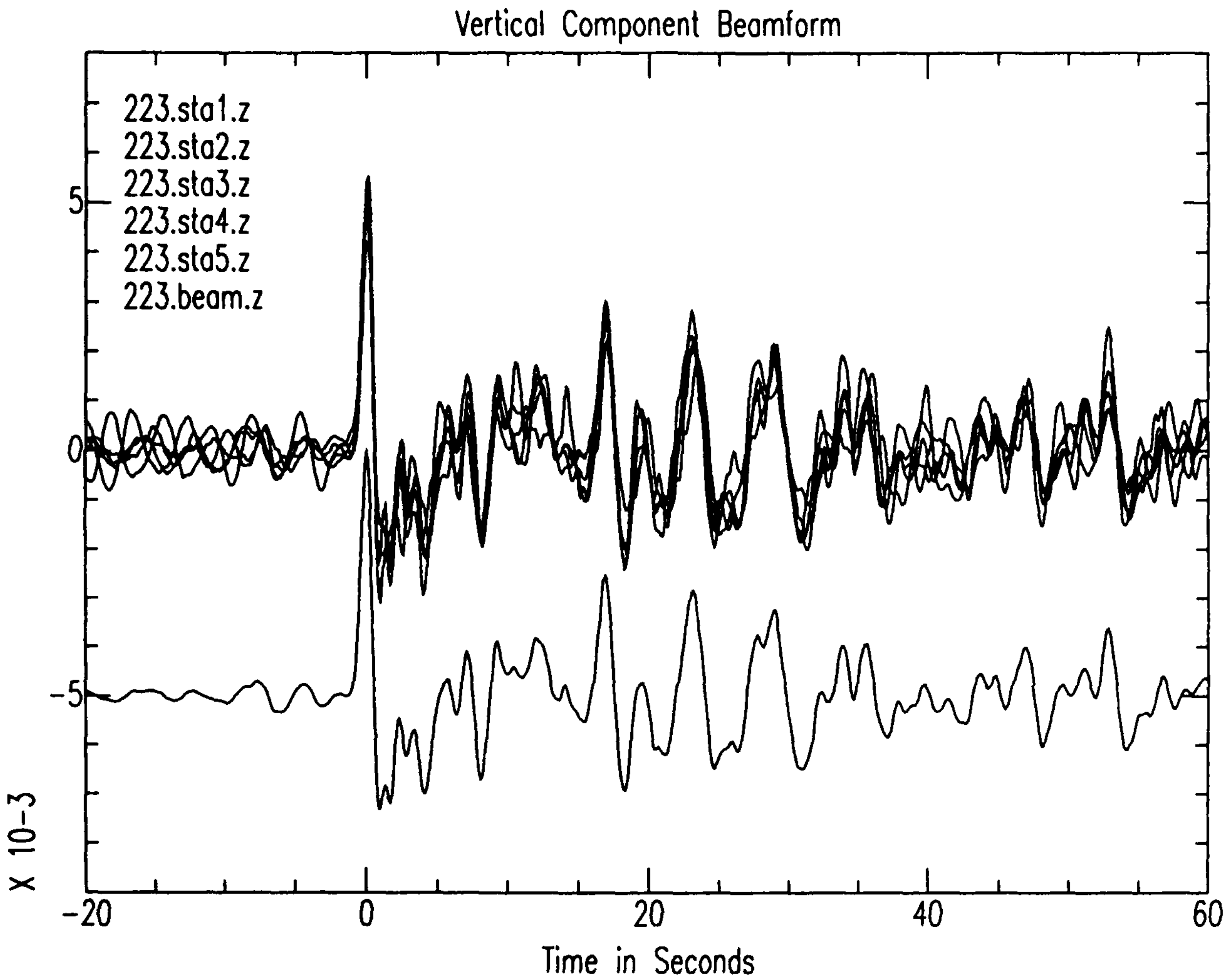

Figure 4c. Plot of the individual station traces and of the raw array beamform for the mb=5.4 Nicaragua teleseism.

from Nicaragua, ~34 degrees epicentral distance. Figure 4b shows a superposition of the P-codas, and Figure 4c shows the raw array beamform for the direct P wave. Figure 4c represents the P wave expected from a laterally averaged seismic structure from under the array. The amplitude spectrum of the this stacked signal in Figure 4c is compared to the spectrum of a stack of the noise at each station (Figure 5). The signal level is above the noise level over the entire frequency band where the seismometers have their maximum sensitivity.

5.0 The Data

Listed in Table 4 are the teleseismic events recorded during this deployment. Event times and locations were obtained from the Preliminary Determination of Epicenter Bulletins. Not all events were recorded at all the Adirondack stations because of the problems mentioned above. Several local and regional events are also included in the listing. The raw field data are archived on Exabyte tape, and the waveforms have also been archived on tar tapes. Events of interest were converted into SAC format for viewing.

6.0 Acknowledgments

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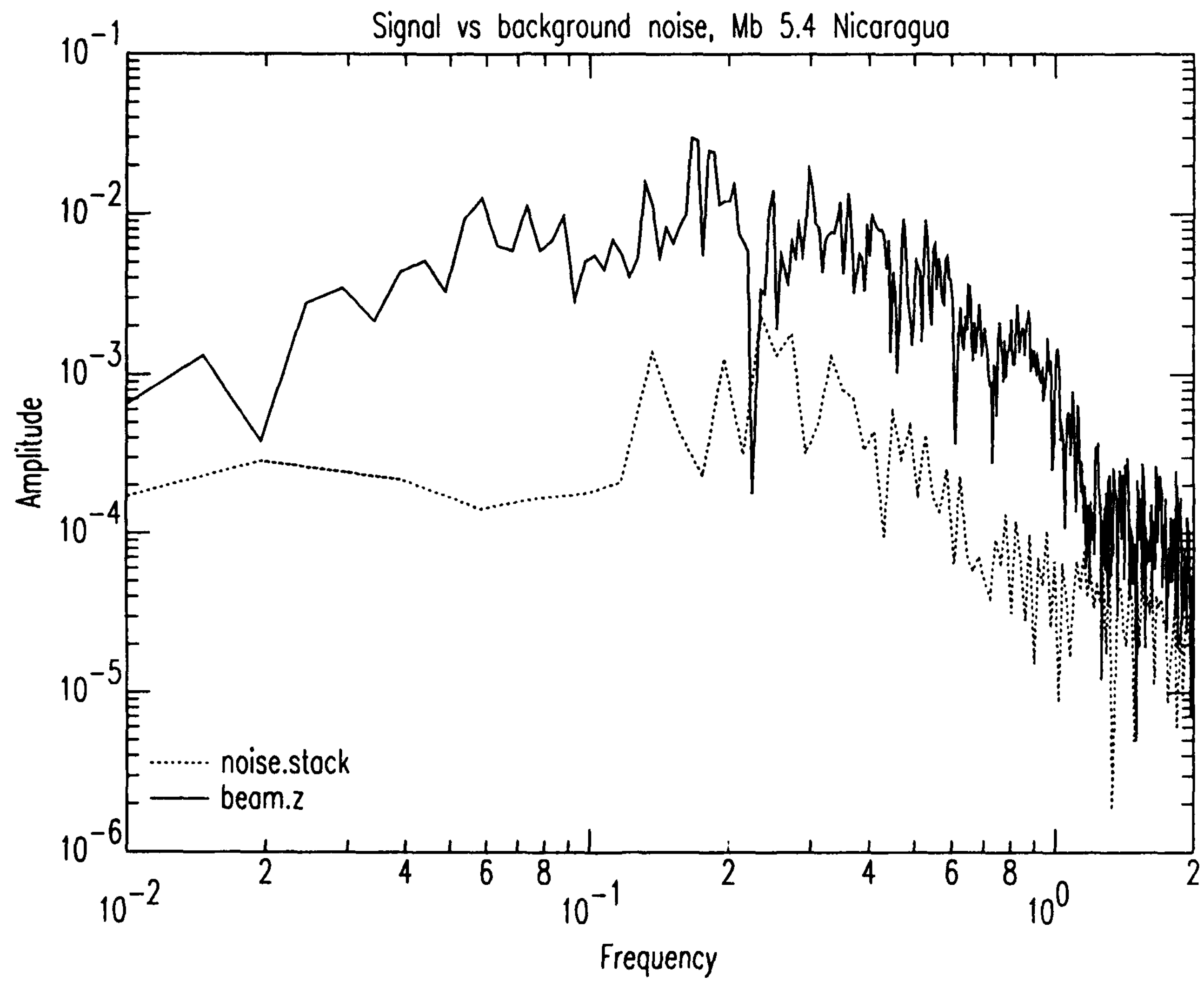

Figure 5. Amplitude spectrum of the stacked beam for the Nicaragua teleseism compared to the amplitude spectrum of the noise at the same station.

Table 4

Date	Julian	Origin Time	Latitude	Longitude	Depth	Mb	Location
7/5	187	21.18.27	34.583N	116.319W	0	5.3	Southern California
7/9	191	01.43.57	34.239N	116.837W	0	5.6	Southern California
7/10	192	09.31.27	44.695N	149.482E	20	6.2	Kurils
7/11	193	10.44.19	22.483S	178.413W	377	6.2	South of Fiji
7/11	193	18.14.16	35.210N	118.066W	11	5.3	Central California
7/12	194	11.08.55	41.457N	142.031E	64	6.0	Hokkaido
7/13	195	15.34.04	51.171N	157.626E	45	5.7	Kamchatka
7/13	195	18.11.34	3.919S	76.602W	97	6.1	Northern Peru
7/14	196	15.17.09	45.361N	151.063E	44	5.7	Kurils
7/17	199	18.46.00	10.380S	78.550W	45	5.5	Peru
7/18	200	08.36.58	39.419S	143.330E	29	6.2	Honshu
7/20	202	07.46.46	78.562N	5.523E	10	5.7	Svalbard Region
7/23	205	13.58.21	32.865S	71.222W	69	5.0	Central Chile
7/25	207	09.12.19	0.461N	25.105W	10	5.2	Cent. Mid-Atlantic
7/28	210	13.27.37	19.837S	69.042W	131	5.2	Chile
7/29	211	04.30.47	39.495S	143.501E	16	5.9	Honshu
7/30	212	13.14.51	50.357S	72.095W	10	5.4	Southern Chile
8/2	215						Local event
8/7	220	18.19.19	57.604N	143.045W	10	6.3	Gulf of Alaska
8/9	222	08.07.06	36.646N	116.312W	10		CA-NV Border
8/10	223	20.03.04	34.982N	97.453W	5		Oklahoma
8/10	223	06.09.14	11.719N	87.327W	28	5.4	Costal Nicaragua
8/11	224	04.03.45	80.293N	0.525W	17	5.1	Svalbard Region
8/12	225						Local event
8/13	226	08.41.14	11.526N	87.430W		4.7	Coastal Nicaragua
8/15	228	19.02.09	5.080N	75.730W	127	5.7	Colombia
8/17	230	00.52.07	4.696S	78.033W	50	5.4	Peru-Ecuador Bdr.
8/17	230	21.09.24	20.262S	68.775W	110	5.2	Chile-Bolivia
8/19	232	00.57.43	50.479N	174.846W	33	6.1	Andreanof Islands
8/19	232	02.04.36	42.084N	73.558E	22	6.8	Kyrgystan
8/21	234	01.02.18	43.927N	128.360W	20	5.5	Coastal Oregon
8/21	234	04.53.03	34.025S	71.233W	70	5.1	Central Chile
8/22	235	12.20.32	39.114N	70.303W	10	4.7	East Coast, USA
8/24	237	06.59.40	41.940N	140.722E	127	6.2	Hokkaido
8/25	238	18.02.45	4.924N	32.643W	10	5.0	Mid-Atlantic Ridge
8/28	241	09.51.29	12.991N	89.725W	24	5.2	Central America
8/29	242	19.19.07	33.157N	138.020E	309	6.0	South of Honshu
9/2	246	00.15.57	11.761N	87.419W	10	5.3	Coastal Nicaragua
9/2	246	10.26.20	37.090N	113.472W	15	5.8	Utah
9/4	248	13.44.17	32.312S	71.409W	78	5.1	Central Chile
9/5	249	21.48.12	11.971N	87.341W	10	5.1	Coastal Nicaragua
9/6	250	13.12.39	11.911N	87.452W	10	5.3	Coastal Nicaragua
9/8	252	05.41.42	4.015N	82.612W	10	5.2	South of Panama
9/9	253	13.08.54	76.205N	7.241E	24	5.7	Svalbard Region
9/10	254	15.03.17	10.239N	86.504W	26	5.3	Costa Rica
9/11	255	03.57.26	6.091S	26.680E	10	6.7	Zaire
9/13	257	10.38.41	11.401N	86.827W	33	5.0	Coast of Nicaragua
9/13	257	10.53.32	11.516N	86.753W	28	5.0	Coast of Nicaragua
9/15	259	08.47.11	34.064N	116.361W	9	4.8	Southern California
9/15	259	18.40.31	11.019N	86.780W	33	5.2	Coast of Nicaragua

9/16	260	23.51.48	12.081N	87.633W	33	4.9	Coast of Nicaragua
9/17	261	22.16.15	60.034N	140.570W	0	5.4	S. Eastern Alaska
9/18	262	10.50.36	3.424N	83.025W	33	5.4	Central America
9/21	265	10.18.49	7.888S	13.529W	10	5.8	Ascention Isl.
9/26	270	05.45.50	64.622N	17.544W	10	5.5	Iceland
9/27	271	17.48.12	53.955N	157.302W	33	5.7	South of Alaska
9/28	272	07.41.28	13.442N	90.706W	72	5.3	Coastal Guatemala
9/30	274	03.28.00	51.416N	178.609W	33	5.9	Aleutian Islands
9/30	274	05.34.00	51.263N	178.066W	33	6.2	Aleutian Islands
10/1	275	05.02.36	51.104N	177.984W	33	6.0	Andreanof Islands
10/3	277	07.42.25	51.089N	178.403E	33	5.0	Rat Island
10/3	277	07.37.25	34.515N	116.541W	0	4.9	Southern California
10/5	279	18.51.01	51.664N	179.079E	68	5.2	Rat Island
10/6	280	15.14.52	51.077N	177.934W	33	5.2	Andreanof Island
10/6	280	17.19.08	51.167N	177.890W	33	5.3	Andreanof Island
10/8	282	16.34.56	51.142N	177.834W	43	5.6	Andreanof Island
10/9	283	09.34.51	0.925S	15.945W	10	5.3	N. of Ascention Isl.
10/10	284	05.52.26	26.029S	70.723W	32	5.2	Northern Chile
10/11	285	23.20.34	50.450N	153.202E	283	5.7	Kuril
10/13	287	18.58.06	68.429N	67.289W	18	4.4	Baffin Island
10/15	289	22.37.07	14.455S	166.628E	33	6.1	Vanuatu
10/17	291	08.32.39	6.866N	76.816W	10	6.2	Northern Colombia
10/18	292	15.11.59	7.123N	76.877W	10	6.6	Northern Colombia
10/19	293	12.03.30	19.370S	169.514E	20	5.7	Vanuatu
10/22	296	09.04.24	29.997S	177.276W	33	60	Kermadec
10/26	300	04.29.19	7.613N	76.437W	10	5.0	Northern Colombia
10/29	303	14.39.17	29.258S	71.096W	46	5.4	Central Chile
10/29	303	22.44.48	7.114N	76.803W	50	5.0	Northern Colombia

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