SEC

1992-1993 SouthEast Caribbean South America Broadband Seismic Experiment

Submitted By

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PASSCAL Data Report 98-001

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abundant local events. Due to limitations in the dynamic range of the 16bit digitizers, the stations were run in a dual gain mode: three channels (vertical, north and east) at a high gain of 32 plus the same three channels of data recorded at a lower gain of 1. The data from the low-gain channels were only saved when large signals were detected (i.e. those signals that would saturate the high-gain data channels). Configured in such a way, the 16bit instrument is able to achieve approximately 21 bits of resolution. The station on Trinidad, which utilized the only set of CMG-3 sensors of the experiment, was not configured in this dual gain mode because of the higher output of the CMG-3 as well as documented distortions in the output signal of these sensors when subjected to large ground motions, especially those enriched in high frequencies. Such a situation is one in which a single gain turns out to have enough dynamic range to handle the useful range of the sensor, so an intermediate gain of 8 was used at this site. The data at each station were recorded onto a disk drive which would later be copied onto DAT tapes when the stations were visited each 4-6 weeks. All stations used the OMEGA navigation signal to maintain synchronization of their internal clocks with Universal Time.

1.2. Station Installations

The stations were installed in one of two ways. The first type of site construction was shared by each of the six stations installed in Venezuela. At these stations, a site was chosen in which a hole could be excavated which would encounter bedrock at approximately one meter in depth, when possible. The only site where bedrock was truly not to be found was ECPV which was located in the large sedimentary Llanos Basin. At all sites, concrete walls were erected to prevent collapse of the surrounding earth and at the bottom of the hole, a thin 10cm concrete pad was poured upon which the STS-2 was laid. This pad was not in direct physical contact with the walls, so soft tar was poured into this gap to discourage water and life forms from making their ways up into the hole. A styrofoam insulating jacket was placed over, but not in contact with, the sensor and a styrofoam cover 10 cm thick was wedged at the top of the concrete walls for additional thermal insulation. Just above this thermal layer, the vault was closed at the top with a heavy metal plate and as much dirt as possible (at least 30 cm) was piled above as a final thermal stability measure. A second hole was dug several meters away which was walled and floored in concrete and covered by a heavy metal plate. This vault was divided into two sections, one for the datalogger and the second for the batteries. Approximately 10 meters from this hole, a five meter high sturdy metal "T" was erected upon which two solar panels and the OMEGA antenna/preamplifier were mounted. The main function of this pole was to deter vandalism and was positioned as far away from the sensor hole as cable lengths would permit (about 15m). The type of installation on Trinidad differed in that it was installed in an existing vault in a building used by the Seismic Research Unit at the University of the West Indies. Each of the sensors was covered with individual styrofoam covers to help maintain thermal stability of each. This station was powered by a battery and battery charger connected to mains power.

Excluding two sites which were vandalized, only one site (MNVV) was found to be too unstable to be left unattended for several weeks. The problem at this site was tilting of the concrete seismometer pad during wet periods which apparently was related to the type of material upon which it was poured. The amount of tilting proved too much to maintain on-scale recordings so after two months, it was moved about 15km to a new site called HSPV. In spite of these problems and others due to bugs in the rapidly evolving software of the dataloggers, valuable data were collected from every station that was constructed and occupied. Table 1 lists some station specific information for the SECaSA92 array.

Data Report
for
The 1992-93 SouthEast Caribbean South America Broadband Seismic Experiment (SECaSA92)

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***** PASSCAL DATA REPORT #98-??? *****

ABSTRACT

This report describes the data collected from the SouthEast Caribbean South America broadband seismic array (SECaSA92) which operated from May 1992 through December 1993 in northeastern Venezuela and Trinidad. The equipment used in this six element array of broadband, three-component stations was REFTEK 72-A PASSCAL 16bit dataloggers paired with Streckeisen STS-2 or Guralp CMG-3 force balance seismometers. Data were recorded continuously at ten samples/second and were also triggered at 50 samples/second to target abundant local events. A total of 1789 teleseismic, regional and local events have been extracted from the continuous data based upon magnitude/distance relationships which were designed to include only those events with promising signal to noise ratios. The data format and organization, calibration, and auxiliary information of these data are discussed.

1. Introduction

The 1992-1993 SouthEast Caribbean South America (SECaSA92) experiment was a proposal to install and operate a six element temporary broadband array of REFTEK/STS-2 seismic systems in northeastern Venezuela and Trinidad. The goal was to image crustal and upper mantle structures of the eastern Caribbean-South America plate boundary. The array was deployed along two arms: one trending east-west parallel to the northern coasts of Venezuela and Trinidad, and a second trending WSW from the coast of Venezuela to the Llanos basin south of the plate boundary zone (see map). This geometry was chosen because these two lines cross and parallel important and observed structures of the eastern SA-Ca plate boundary zone (R.M. Russo et al., 1996). The station spacing was roughly 100km and the deployment lasted from May 1992 until December 1993. SECaSA92 was a collaborative endeavor among the seismic engineering group at INTEVEP S.A. in Venezuela, scientists at the Seismic Research Unit of the University of the West Indies in Trinidad, and the Carnegie Institution of Washington's Department of Terrestrial Magnetism.

1.1. Instrumentation

The instrumentation for this project consisted of 16bit REFTEK 72A PASSCAL six-channel dataloggers matched with either Streckeisen STS-2 or Guralp CMG-3 sensors. The data were recorded continuously at 10 samples/second as well as in a 50 samples/second triggered mode designed to catch

Table 1 -- Station Information for SECaSA92

Station Code	Station Name	Site	Latitude	Longitude	Elevation (meters)	Sensor Model	Operating Interval
barv	Barcelona	Barcelona, Edo. Sucre, Venezuela	10.65	-63.17	300	STS-2	May 1992-Aug 1993
cecv	Cerro el Cardonal	Tacarigua, Edo. Sucre, Venezuela	10.57	-64.17	200	STS-2	May 1992-Jun 1993
ecpv	El Chaparro	El Chaparro, Edo. Anzoategui, Venezuela	9.18	-65.03	100	STS-2	Jul 1992-Mar 1993
hspv	Hato San Pedro	Urica, Edo. Anzoategui, Venezuela	9.87	-64.17	700	STS-2	Jan 1993-Oct 1993
mnvv	Mundo Nuevo	Mundo Nuevo, Edo. Anzoategui, Venezuela	9.95	-64.03	600	STS-2	Jul 1992-Aug 1992
rslv	Rio Salado	Rio Salado, Edo. Sucre, Venezuela	10.65	-62.25	200	STS-2	Jun 1992-Aug 1993
trnv	Trinidad	SRU Trinidad, St. Augustine, Trinidad and Tobago	10.65	-61.40	024	CMG-3	Jan 1993-Dec 1993

1.3. The Data Sets

The data from SECaSA92 have been divided into three sets. The Event Data Set contains all teleseismic, regional and local events which were extracted or "sliced" from the continuous 10 sample/second data. The events in this list were selected from the complete list published by the National Earthquake Information Service (NEIS) using simple magnitude and distance relationships designed to include only those events with promising signal to noise ratios. In addition to the waveforms in SAC (Seismic Analysis Code) format, this data set also contains the auxiliary information included or discussed in this report. These data have been checked extensively for timing errors, instrument malfunction as well as other quality control concerns and scrubbed whenever possible. This set is about 1.5 Gigabytes in volume and should be considered the primary release for SECaSA92. In truth, the events included in this release are a very liberal collection and hopefully include just about everything of even remote usefulness save those signals needed for finer analyses of the local and regional events.

For more detailed studies of the local and regional earthquakes, the Trigger Data Set may be of help. This is a subset of all of the 50 sample/second triggered high and low gain data, compiled by culling those triggers which were believed to be local or regional earthquakes and grouping them into clusters. A cluster was defined as a local or regional event (epicentral distance less than about 30 deg.) which triggered at least one station. If more than one station was triggered by the same event, it was included in the same cluster. There were 1689 clusters found, the majority of which are not a part of the NEIS or *any* listing, for that matter. (It is the humble opinion of the author that this represents an extremely valuable dataset whose riches have yet to be tapped as of this writing. There are over 500 events recorded at more than one station and about half of those recorded at more than two stations!) These data have been checked for gross timing errors, instrument malfunction as well as other quality control concerns and cleaned whenever possible. This set is about 320 Megabytes in volume and will be included as a separate release.

The Raw Data Set contains all of the continuous and triggered SEGY data collected during this experiment. This includes some low-gain data recorded at 10 samples/second which may be needed for on-scale recordings of the larger events in the Event Data Set. Due to the large volume of this set (8.4 Gigabytes), quality control measures were limited only to those recognized and logged by the field crew or discovered in the processing of the previous two datasets (e.g. OMEGA leap seconds off, seismometers against the stops, buggy software glitches, etc.). For these reasons, the Raw Data Set should be considered just that and not much more of it will be mentioned in this report. However, these data will be available at Carnegie until the tapes that hold them become unreadable.

2. Description of the Event Data Set

The SECaSA92 Event Data Set is divided into two subdirectories: *secasa92/events* and *secasa92/info*. The *events* directory contains the events which were extracted from the entire set of SECaSA92 continuous 10 sample/second high-gain data. The *info* directory contains this document and accompanying map as well as the station and event information of Tables 1 and 4 in an ASCII format more easily accessible by user programs. It also includes various SAC macros which were used to set the headers and correct the timing of these data. These are included to aid those users who may wish to modify these headers later. The structure and format of these two subdirectories are discussed below.

2.1. Extracted Events

The list of events which were extracted from the continuous data is shown in Table 4 and was last updated by the National Earthquake Information Center in March 1994. As mentioned, this is a subset of the complete NEIS listing, created through the use of simple-minded magnitude/distance criteria. These "magic" criteria can be qualitatively summarized as follows: the farther away the earthquake was, the larger its magnitude must be for it to be extracted. Table 2 summarizes the magnitude/distance relationships which were used to exclude events from the complete NEIS listing. The events which remained after applying this algorithm were placed in a list known as the "magic" list. (For example, if an event was greater than 10 degrees away and its mb and Ms were both less than 4.0, it would not be extracted from the continuous data.)

Table 2 -- The "Magic" Criteria Used to Cull Events from the NEIS Listing

The following events will NOT be extracted from the data:

if both mb and Ms are less than:	AND the distance (deg.) is greater than:
0.1	5.0
4.0	10.0
4.5	20.0
4.9	35.0
5.1	45.0
5.4	100.0

For each event in the resulting "magic" list, a 35 minute time window was sliced from the continuous data which commenced three minutes before the first arriving P wave as predicted by the IASPEI91 travel time tables.

In addition to the 35 minute window extracted for events in the magic list, there were longer time windows used for two special subsets of this list. The first of these was a 90 minute window to catch larger events whose surface waves would have been missed by the 35 minute time window. These 172 possible events are known as the "surf" list. The second of these subsets was a 240 minute time window which was used for a handful of huge events whose signals may be expected to ring on for several hours. These 13 possible events are known as the "huge" list. These three lists of events are in files called *magic_events.loc, surf_events.loc* and *huge_events.loc,* and can be found in the *secasa92/info/qed* subdirectory. Also included in this directory is a file called *secasa_stn.loc* which contains the station locations shown in Table 1.

As mentioned above, the waveforms themselves have been put into the *secasa92/events* subdirectory. Each event is in SAC binary format and has been named according to the following format:

yyddd/hh.mm.ss.stnm.c.sac

where *yyddd/hh.mm.ss* is the origin time of the event from Table 4, *stnm* is the four-letter station code from Table 1, and *c* is the channel number. It is important to note that the time given in the filename does not refer to the start time of the file as is the case in most data distributions. The orientations of the channel numbers are as follows: *1,4* up positive; *2,5* north positive; *3,6* east positive. The horizontal components have been aligned to true north and east. Channels 1-3 were recorded at high gain and channels 4-6 (if they exist) at low gain. All data are given in volts.

The *secasa92/info/macros* directory contains SAC macros named *stnm.sachdr.macro.* These macros contain all of the commands needed to change the following information in the SAC header: event location, station name, station location and seismometer orientation. All of these macros have been run on the data, but should this information change in the future or be unsuitable for your applications, they may be handy as repair routines. The *secasa92/info/calb* directory contains calibration information which will be discussed in the next section.

The *secasa92/info/timing* directory contains files which attempt to characterize the timing of these data. Appendix A discusses the meaning of these files and summarizes all timing corrections which were made to these data. Therefore, if absolute timing or relative timing among the stations is crucial to your studies, then this appendix should not be ignored. If your results do not depend upon these factors, then I encourage you to avoid it at all cost.

2.2. Calibration

As with any scientific data, precise calibration of the recording instrument is essential. Fortunately for this experiment, both the STS-2 and CMG-3 seismometers are force-feedback sensors which intrinsically gives them well defined responses. The feedback electronics in these instruments not only gives them stable response characteristics, it also allows them to be designed to have responses which behave like those of conventional electromagnetic seismometers with effective damping coefficients of 0.7 critical. In the case of the STS-2, the effective free period is 120 seconds and for the CMG-3, it is 30 seconds. The basic response of these sensors also includes low-pass filters at 50 and 30 Hz for the STS-2 and CMG-3 respectively, but since the maximum Nyquist frequency of the data collected in this experiment is only 25 Hz for the trigger data, we will ignore them.

Another important factor in the calibration of seismic data is called the sensitivity. This factor is needed to convert the voltages that the datalogger has recorded into physical units of ground motion. Since the STS-2 is a triaxial sensor, the electrically derived responses to ground motion in the up-down, north-south and east-west directions can be matched quite well. For this reason, we will assume that they take on their nominal values. The CMG-3 differs in that it employs separate vertical and horizontal seismometers and therefore, will have separate sensitivities for each component. Fortunately, we were able to record data from the STS-2 and the CMG-3 simultaneously before this experiment began which gives us the opportunity to determine the sensitivities which are able to effectively calibrate the data of the entire experiment. Table 3 shows those calibration parameters which can be used to normalize all data from the SECaSA92 experiment.

Table 3 -- Calibration Parameters for SECaSA92

Seismometer		Free Period (sec)	Fraction Critical Damping	Sensitivity (volts/meter/sec)
Streckeisen STS-2	vert	120.	0.7	1500.0
	north	120.	0.7	1500.0
	east	120.	0.7	1500.0
Guralp CMG-3	vert	30.	0.7	4187.6
	north	30.	0.7	5055.1
	east	30.	0.7	3998.4

While the above parameters were proven to normalize the data quite well, the sensors were calibrated with a voltage step function for approximately 20 minutes each time the site was visited. The resulting calibration pulses were spot checked for gross anomalies, but we did not attempt to invert them to obtain objective measurements of the parameters. These calibration pulses have not been included in this release, but may be obtained if requested.

The *secasa92/info/calb* directory contains several files which can be used by SAC routines to remove the instrument responses from these data. The three files called *cmg3.pole0.[z,n,e]* contain the poles and zeros for each component of the CMG-3 sensors and the file called *sts2.pole0* contains the poles and zeros for the STS-2. The format of these four files is compatible with the SAC routine "transfer". In addition to the responses of the seismometers, there are two files which describe the anti-alias filters used by the datalogger: *secasa92.fir.10sps.sac* and *secasa92.fir.50sps.sac*. These files contain the FIR filter coefficients applied to the data at 10 samples/sec (10sps) and 50 samples/sec (50sps) and are both in SAC binary format. If the frequencies of interest in your studies are less than four Hz for the 10 sample/sec data (20 Hz for the 50 sps trigger data), then these filters can be ignored.

2.3. Data Report Format

Included in the *secasa/info/docs* directory is this document in UNIX troff format and the map in PostScript format. On a PostScript printer, the text in this document and the map can be printed using

```
tbl secasa92_doc.ms | troff -ms | dpost | lpr    (8 pages)
tbl magic_events.ms | troff -ms | dpost | lpr    (27 pages)
lpr secasa92_map.ps
```

3. Data Distribution

The data referenced herein may be obtained through:

IRIS Data Management Center
http://www.iris.washington.edu/assembled/assembled.htm

Also, if there are any concerns which this document does not address, feel free to contact me at:

kuehnel@dtm.ciw.edu

4. Acknowledgements

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5. References

Russo, R.M., P.G. Silver, M. Franke, W.B. Ambeh, D.E. James (1996). Shear-wave splitting in northeast Venezuela, Trinidad, and the eastern Caribbean. *Phys. Earth Planet. Inter.*, **95** , 251-275.

6. Appendix A - SECaSA92 Timing Analysis

There were three well understood factors which resulted in incorrect timing of the original data recorded by the SECaSA92 array: leap seconds, one second time jumps and unlocked OMEGA clocks. Timing errors resulting from either of the first two are easily found in the data and can be corrected with confidence. On the other hand, an OMEGA receiver which unlocks periodically can often spawn complicated time keeping behavior in the datalogger. Fortunately, one can begin to understand such behavior when some assumptions are applied. If there is internal consistency in the apparent behavior of the data after applying these assumptions, a time correction can very often be proposed. These assumptions and the timing corrections which were applied to the Event Data Set will be explored below.

6.1. Leap Seconds

An important feature of the now defunct OMEGA time keeping system is that it only supplied a synchronizing pulse for the datalogger and did not itself contain any "time of day" information. Since the OMEGA signal repeated every 10 seconds, the "time of day" information had to be set by the user to be within +/- 5 seconds, or the time would have been off by at least 10 seconds once the signal had been received and the internal clock of the datalogger had "locked" to it. Thanks to the careful work of everyone who did the servicing, none of the SECaSA92 stations were ever left running in such a way which resulted in the time being locked to the "wrong" 10 second interval.

Another artifact of the OMEGA signal is that since the clocks at each OMEGA broadcasting station were not corrected for any leap seconds*, the user was required to input this number as well. When SECaSA92 began, the number of leap seconds was 16, but changed to 17 at midnight on June 30, 1992 and then to 18 on June 30, 1993. Obviously, service visits were not planned around such events, so data which were recorded since the leap second was added until the parameter was changed in the datalogger would appear to be time stamped by a clock which was running one second fast. Since we know when new leap seconds were added and we know what data were recorded with incorrect leap second settings, it was trivial to correct the timing of affected data.

6.2. One Second Time Jumps

Due to the peculiar manner in which the datalogger makes changes to its internal clock, it often occurs that time jumps backward by exactly one second and subsequently jumps forward by one second. The reasons for this are not important for this document, but the consequences of this behavior are. This is because, in practice, the time which elapsed between the one second jump and its subsequent correction might often span minutes, so any data which were time stamped during this interval will be off by exactly one second. Since the continuous data were actually broken into separate files each hour, this would appear as an apparent overlap and subsequent gap in data which should be contiguous. In fact, close inspection of these data showed that indeed they were smoothly continuous, but merely timed incorrectly. Since these time overlaps and time gaps always came in pairs, they were very easy to catch and trivial to correct.

6.3. Unlocking of the OMEGA Clock

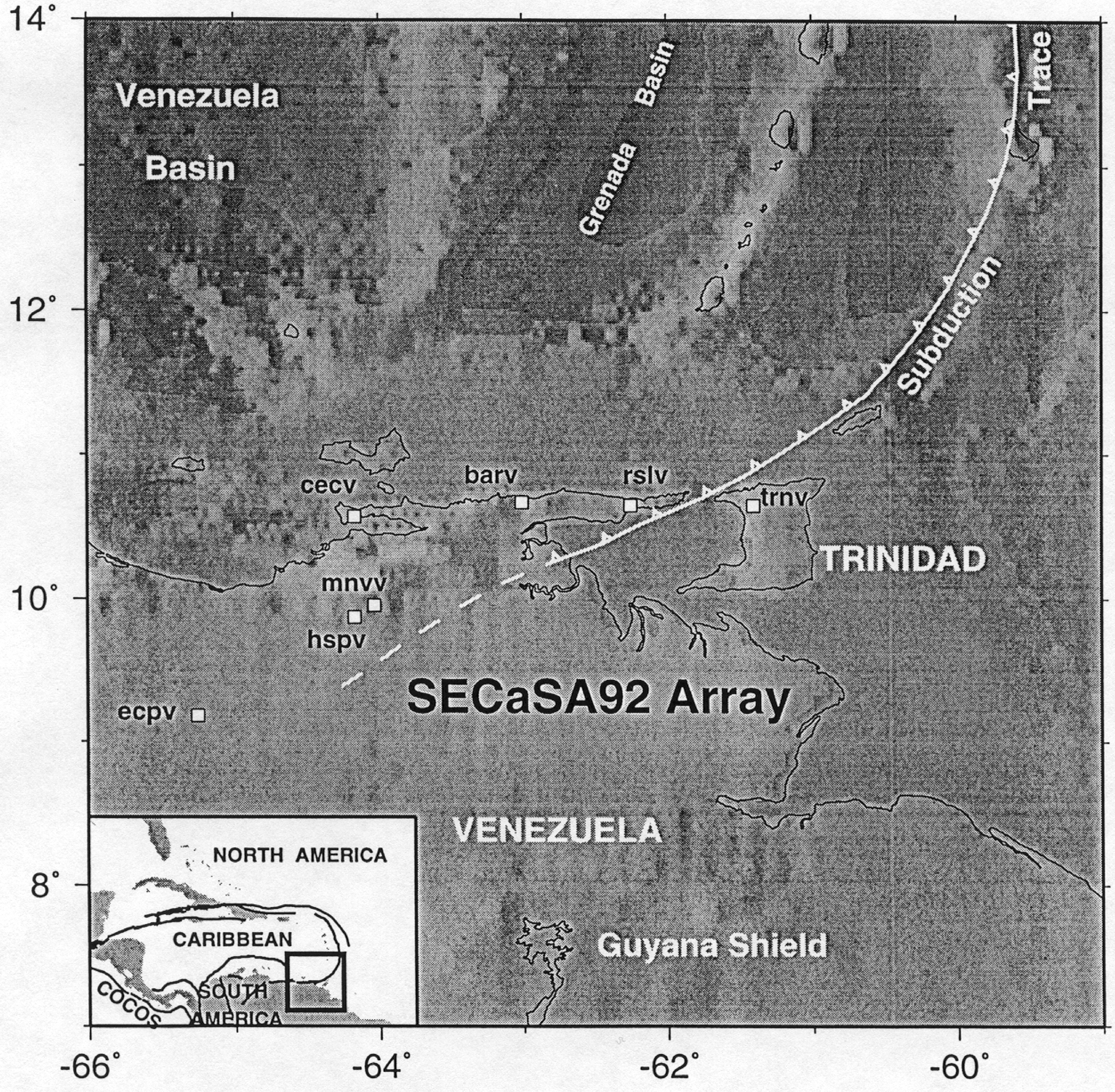
Under perfect conditions, the OMEGA receiver would never lose lock and the internal clock of the datalogger would continuously be kept synchronized with UCT. Since we are not so naive to realize that this is not always going to be the case, we need to understand how the datalogger will behave when the OMEGA clock loses and then regains lock to the OMEGA navigation signal. When the OMEGA clock is unable to receive the broadcast signals of the atomic clocks at any of the OMEGA stations, the datalogger has no choice but to rely upon the time keeping of its own internal clock. Although these clocks were tuned in the laboratory before deployment to tick as precisely as possible, they are not capable of keeping accurate time over many hours and inexorably drift away from UCT in the absence of the regulating OMEGA signal. When reception of the OMEGA signal once again returns with sufficient

* Since 1972, leap seconds have been inserted (roughly one per year) to keep the atomic UCT time system in agreement with the astronomical time scale (UT1).

strength to justify its use as a synchronizing pulse, the time of the internal clock of the datalogger is adjusted to match that of the OMEGA signal. The amount of time that the internal clock had drifted during the time that the OMEGA clock was not locked was recorded in the datalogger. Assuming a linear drift rate of the internal clock with respect to UCT while the OMEGA clock was unlocked, the "actual" time of any data collected during this time can be reconstructed and corrected if necessary.

Such timing analyses were carried out for all data collected in this experiment. Rather than making wholesale changes to all of the data, we elected to limit the data to which we would impose corrections to only the events which were extracted from the continuous data. Furthermore, we decided that the maximum that we would correct any data through this analysis was 0.025 seconds (or 1/4 the sampling interval). If the clock had drifted less than this at the time that the event was recorded, we accepted that the timing of the data was accurate enough. The results of these analyses can be found in the directory called *secasa92/info/timing*. For each station, the SAC macro which was used to correct the data is called *stnm.clockcor.out.25.m*. These macros contain timing corrections for all of the extracted events, whether or not a timing correction was carried out or was even necessary. The *25* in the filename signifies that only those corrections which were greater than or equal to 25 milliseconds were actually carried out, so any timing corrections less than this have been commented out. Also, it should not go unwritten that while the PASSCAL software to calculate these timing corrections *(refrate* and *clockcor)* was simple and straightforward to use, every timing correction which was made to these data was verified by eye to confirm that it did not violate any of our assumptions about how the datalogger should behave. In cases when suggested corrections were erroneous, they were modified and commented in these macros. (Overall, this software was a great help and I would like to thank the many authors for their work.) These macros are included not only to document work which was done, but for future users who may wish to undo these corrections or to lower the acceptable time "tear" threshold below 25 milliseconds and correct those affected data.

To summarize, the OMEGA clocks at these sites performed extremely well with only two exceptions. Station TRNV was subject to frequent and often lengthy unlock intervals, but fortunately, in all but a handful of events on day 93246, timing corrections could be determined. The other confirmed instance where time could not be corrected was at station ECPV from day 92:194 until day 92:212 due to an OMEGA preamplifier malfunction. Therefore, aside from these two cases and based upon our understanding of the behavior of the datalogger, it would not be rashly optimistic to state that the Event Data Set of the SECaSA92 array should be considered to be reliably timed.



Venezuela
Basin
Grenada Basin
Subduction
Trace
cecv
barv
rslv
trnv
TRINIDAD
mnvv
hspv
ecpv
SECaSA92 Array
VENEZUELA
Guyana Shield
NORTH AMERICA
CARIBBEAN
SOUTH AMERICA
COCOS
14°
12°
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8°
-66°
-64°
-62°
-60°