Safety in Mines Research Advisory Committee

Final Project Report

Pre-feasibility investigation to provide an early warning of roof falls prior to support installation

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Executive Summary

The objective of this research project is the investigation of the association of electromagnetic emissions with rock failure. The possible presence of electromagnetic emissions as a result of material or rock failure have tremendous potential for the development of techniques to provide early warnings of rock failure. In the mining industry, falls-of-ground do occur frequently because of roof failure in underground excavations, causing safety and production problems.

Laboratory experiments to measure electromagnetic emissions from rock failure are difficult to conduct because of difficulties in eliminating external electromagnetic emissions from interfering in the experiment. This research project thus focussed on the measurement of electromagnetic emissions in a typical underground coal mining environment.

Measurements were conducted in a underground coal mine where seismic activity as well as electromagnetic emissions were monitored for a period in a seismically active area. The trial was conducted using an ISS International multiseismometer with a Rohde & Schwarz professional shortwave receiver. Electromagnetic frequencies between 190 kHz and 30 MHz were monitored.

Results showed that some electromagnetic emissions were measured in the same time window in which seismic events were also measured. The results do suggest that the observed electromagnetic anomalies may be electromagnetic emissions which are emitted during roof failure. Measurement of background electromagnetic radiation also suggest that the electromagnetic anomalies are not considered to be artificial or background electromagnetic emissions.

However, the results do not prove without any ambiguity that the observed electromagnetic anomalies can in fact be associated with roof failures. In order to make definite quantitative conclusions, sufficient data need to be collected on which a quantitative statistical analysis needs to be performed.

It is proposed that further measurements be conducted using a seismic monitoring system to quantify seismic events and electromagnetic emissions in terms of location, amplitude, and other characteristics which can be used to quantify the potential for using electromagnetic emissions from seismic events in the mining industry.

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Glossary

Abbreviations

Fall-of-Ground	FOG
Electromagnetic	EM
Rohde & Schwarz receiver	RS
Multiseismometer	MS

Terminology

Seismo-electrical / pre-seismic / geo-electrical
A term which describes electromagnetic radiation which is emitted during rock or material failure. A seismo-electrical signal is thus associated with both a seismic and electromagnetic signal.

Goafing
A total extraction mining method used in underground coal mining.

VAN
A term used to describe a method used by a group under the leadership of Panayiotis Varotsos in Greece. This group claims to predict earthquakes using seismo-electrical emissions.

Seismic event
A confirmed seismic event as a result of roof failure.

Background seismic noise (Non-seismic event)
A seismic signal which is caused by mining personnel/machines and external noise and which did not originate from rock/roof failure.

Background electromagnetic noise
Electromagnetic emission measured during zero seismic activity which thus refers to electromagnetic noise induced by underground personnel/machinery.

Electromagnetic anomaly
Refers to an electromagnetic signal which can be distinguished from the background electromagnetic signal.

1. Introduction

The possible presence of electromagnetic emissions as a result of material failure, or rock failure, has tremendous potential for the development of techniques to provide early warnings of rock failure. In the mining industry, falls-of-ground do occur frequently because of roof failure in underground excavations, causing safety and production problems.

The potential of the measurement of pre-seismic electromagnetic emissions has large potential in areas such as earthquake prediction but also in the underground mining industry which is characterised by seismic events as results of stress in rock surrounding open excavations. In the seismic monitoring industry, the measurement of pre-seismic electromagnetic emissions will provide very accurate information about the origin time of a seismic event due to the fact that electromagnetic radiation does travel much faster than seismic waves. In addition, pre-seismic electromagnetic measurements may be used to measure seismic activity in roofs of excavations which can be implemented to provide an early warning of fall-of-ground (FOG) system.

The aim of this research project is a pre-feasibility investigation to establish the potential to use electromagnetic radiation associated with rock failure in an underground environment to assist mining personnel in identifying roof areas of risk. The output of this project will be the identification of further research (if necessary) and specifications for development of equipment (if appropriate).

The first step in developing a methodology utilizing pre-seismic electromagnetic emissions is to establish whether these emissions can in fact be measured and how it can be measured. Laboratory experiments of seismo-electrical emission are problematic, as it is difficult to separate electromagnetic emissions from testing machines to those originating from the failing rock.

It was thus proposed that actual measurements in an underground coal mine will achieve more than more laboratory experiments as it will inevitably provide critical information on the actual implementation of such a technique. Underground measurements will yield information about non-seismic electromagnetic noise, or artificial sources.

As recommended by SIMRAC, a representative site was chosen to conduct the experimental work. A representative site was defined as a typical working area where machinery and underground personnel are present and where typical routine mining production tasks are performed. A site with known seismic activity in the roof was also critical - if no seismic activity no associated electromagnetic emissions could and will be measured.

After site visits to longwall mining environments it was decided to perform the experimental work in a goafing environment. A longwall environment is problematic as the mining advance rate is large and it is difficult to select an area with known seismic activity. In a stooping environment seismic activity is quite high and is also clearly audible. Brandspruit 2 shaft (SASOL) - Section 32 was finally selected as a suitable test site for conducting the experiment.

Underground measurements were performed with a high quality Rohde and Schwarz short wave radio and the ISS International Seismic System. An active rod antenna was utilized. A small pocket short wave radio was also utilized. A range of electromagnetic frequencies between 9 kHz and 30 MHz was monitored.

The rest of the report entails the results of the literature survey which served as background information to the project as well as to guide the efforts in this research project. The results obtained are discussed in detail and recommendations and conclusions are drawn.

2. Literature Survey

Various papers have been published by researchers in which the measurements of pre-seismic electromagnetic emissions from rock failure have been claimed to be measured. In particular, one group of researchers in Greece, commonly referred to as VAN (Panayiotis Varotsos and co-workers) claim that they can successfully predict earthquakes in Greece by measuring electromagnetic emissions prior to earthquakes. These electromagnetic emissions are also commonly referred to as geoelectrial precursors. Uyeda (*Uyeda: 1997*) supports the VAN method.

Various other researchers in Greece *(Stravakakis:1998)* have criticized VAN regarding the scientific method and credibility of their claims in predicting earthquakes. Geller *(Geller: 1997)* has published various articles in which he criticized the VAN method. The main arguments presented against the VAN method are:

1. VAN claims that electromagnetic precursors are measured before an actual earthquake which are then used to provide and earthquake warning. However, no electromagnetic emissions have been measured at the time of the actual earthquake. In the same manner no seismological precursors are measured at the time when the electromagnetic precursors are claimed to be measured.

2. Many measurements of EM precursors have been made at a single observatory and have not been measured at other VAN observatories in Greece.

3. There appear to be evidence that many of the electromagnetic emissions measured by VAN are in fact generated by artificial sources such as digital radio-telecommunications transmitters and other industrial sources. These sources have been measured and identified by independent observations.

Nesbitt (*Nesbitt: 1994*) conducted two experiments to monitor EM radiation at seismically active sites, approximately 2000 m's underground in a South Africa deep gold mine. One receiver was used to measure EM radiation at 40 kHz, while a second receiver monitored discreet frequencies between 100 kHz and 1.1 MHz. Although some indications of seismic events being accompanied by EM radiation have been observed, no definite conclusions were, and could have been made.

The literature review does provide some evidence that electromagnetic emissions do accompany the fracturing of materials (specifically quartzite which is a piezoelectric material). Some laboratory experiments have been performed in which the measurement of electromagnetic radiation associated with material failure is claimed.

Some very important conclusions can be drawn from the past experimental and theoretical work:

1. In order to measure pre-seismic electromagnetic emissions, all other non-seismic (artificial) electromagnetic noise need to be identified and isolated.

2. Measurements need to be of such a nature that a proper statistical analysis can be performed on the data. In other words, data of sufficient volume need to be collected to prove statistically that pre-seismic electromagnetic emissions are measured. Criticism regarding VAN in this regard is that VAN's predictions have not been proved

successful beyond random chance.

3. It has been documented that electromagnetic emissions have a fairly broad bandwidth although no accurate information is available on typical frequencies one could expect to measure.

4. The piezoelectric effect has been proposed as the key mechanism by which EM is produced together with rock failure. The piezoelectric effect is a mechanism by permanently-polarized material such as quartz (SiO_2) produces an electric field when the material changes dimensions as a result of an imposed mechanical force. These materials are piezoelectric, and this phenomenon is known as the piezoelectric effect. This is also the principle of operation of quartz clocks.

3. Research Methodology

3.1 Introduction

The scope of this particular project called for a detailed literature survey as well as laboratory experiments to establish whether electromagnetic emissions emitted during rock failure can be measured. The problem with laboratory experiments is the difficulty in eliminating electromagnetic interference from associated electromagnetic emissions. Therefore, an actual underground trial measurement was proposed to monitor electromagnetic emissions during roof failure. A simple methodology was employed in which EM radiation was monitored together with seismic emissions in an area with known seismic activity. Seismic events were monitored and recorded, and EM emissions before, during and after the seismic event were also recorded. Investigation of the occurrence of electromagnetic radiation before a seismic event will indicate whether electromagnetic emissions associated with roof failure can and have in fact been measured.

3.2 Data acquisition

The underground experiment was conducted using an integrated seismic and electromagnetic monitoring system with the following list of components:

– Rohde and Schwarz Radio Receiver
– Active Rod Antenna
– Small commercial short-wave radio (pocket size)
– ISS International Multi-Seismometer
– ISS International Ruggedized Data Logger
– 100 Hz uni-axial geophone

3.2.1 Rohde & Schwarz professional shortwave receiver

A Rohde & Schwarz ESH 3 test receiver covering a frequency band of 9 kHz to 30 MHz was used to measure electromagnetic emissions underground. The test receiver has the following functions:

– Demodulation modes (F3, A3J, A3, A1, A0, AUS OFF) which contain amplitude and frequency demodulation modes.

– Speaker and Audio output (Audio output was used to fed data into the ISSI Multi Seismometer)

– Generator output for twoport and remote frequency measurements.

– Supply and coding for a range of test antennas and probes.

– RF attenuation

– Autoranging and display

- Analog indication of measured data with range limits
- Digital frequency display
- Analog frequency-offset indication
- Measurement time settings
- Display modes
  - average value
  - peak value
  - CISPR
  - pulse spectral density
- Storage of nine complete device settings
- Automatic frequency scanning
- Programming via IEC bus
- Frequency setting
  - with rotary knob
  - in presets steps
  - numeric via keyboard
  - automatic frequency scanning with preset start and stop frequencies

3.2.2 Active rod antenna

A broadband active rod antenna HFH 2-Z1 was used. This antenna is a general purpose receiver antenna and measures the electrical field-strength component. The frequency range specified is 9 kHz to 30 MHz.

3.2.3. Small commercial pocket radio

A small off-the-shelf pocket size radio was also used to recorded data in the short wave band. The available frequency band was from 2 MHz to approximately 30 MHz.

3.2.4 ISSI Multi Seismometer

An ISS International Multi Seismometer configured for geophones was used to record the seismic and EM data.

Acquisition software: ISSI Runtime system

Processing software: ISSI XMTS
ISSI MdiSeis

3.2.5 ISSG Ruggedized Laptop

The RockRadar ruggedized laptop was used to acquire data and to run the ISSI Runtime system. The RockRadar data logger is a fully standalone laptop designed for used in rugged conditions encountered in underground mining conditions.

3.2.6 Sensor - 100 Hz geophone

A 100 Hz uniaxial geophone was used to record seismic waves. The sensor was mounted to the roof using a quickset cement and was positioned vertically.

3.3 System configuration

The MS has three inputs of which one was used to monitor seismic activity via the 100 Hz geophone. The uniaxial geophone was mounted with quickset cement onto the sandstone roof. The rod antenna was placed on the floor between pillars. The small short-wave radio was positioned next to the larger rod antenna.

The output of the RS radio and the small radio was fed into the remaining two channels of the MS. The MS thus recorded the following channels:

1. Seismic ground motion via geophone
2. Pocket radio measured electromagnetic emissions
3. RS radio measured electromagnetic emissions

3.4 Site selection

Sasol Brandspruit 2 shaft Section 32 (Sasol Secunda colliery) was selected as a test site for data acquisition because of the following reasons:

1. Mining method is total extraction with stooping. Goafing provides a seismically active roof with roof fracturing.

2. Site is representative of typical mining site with mining continuing in the area during the duration of data acquisition.

3.5 Acquisition methodology

Electromagnetic emissions were monitored at the following frequencies:

190 kHz
200 kHz
500 kHz
1000 kHz
2.31 MHz
2.50 MHz
4.91 MHz

10.0 MHz
29.9 MHz

The MS was configured to trigger on any of the three channels on an incoming signal a specified amplitude above the noise level. Thus, the system would trigger if an incoming seismic wave (from roof failure or mining induced noise) is observed, and will at the same time record the EM radiation observed by the RS radio and the hand-held radio. A buffer of approximately 60-70 milliseconds allowed the MS to record 60-70 ms before the seismic wave (The EM radiation travels much faster than the seismic wave and will arrive before the seismic wave if both were generated from the same source event). In the same manner the system will also trigger if an incoming EM signal above the noise level is observed.

Both radios were tuned off station - specific attention was given to ensure that no coherent EM signal was being monitored by both radios and the seismic system.

4. Results

4. 1 Analysis of seismic events

During the data acquisition period, seismic events were confirmed by the operator who recorded audible seismic events ('bumps'). The seismic event was correlated using the time of the event.

Amongst seismic events, a large number of non-seismic events were also recorded. These events were mining-induced noise generated from mining machinery and personnel.

The electromagnetic emissions/noise measured by the pocket radio showed very few electromagnetic anomalies while the R&S radio showed clear electromagnetic anomalies. The R&S measurements were thus used in the data analysis.

Every event which has been registered by the seismic system is presented in time domain. Three time series data are presented which are:

Top: Seismic waveform
Middle: Electromagnetic emissions monitored by pocket radio
Bottom: Electromagnetic emissions monitored by RS radio

All data are presented on the same time-scale (measured in seconds) although the amplitude scale does vary. All signals are magnified to fill a window vertically and the maximum amplitude can be observed on the y-axis. The following section describes the seismic events which were measured at pre-defined electromagnetic frequencies.

The following information is presented in the tables:

- Time of seismic event,
- Maximum amplitude of seismic event which provides an indication of the relative amplitude of the seismic event,
- The third column indicates whether an electromagnetic anomaly was also observed in the particular time window,
- Comments in which the approximate delay in time between the electromagnetic anomaly and the seismic event is given. This information can be used to provide an indication of the distance from the source location of the seismic event to the measurement position.

4.1.1 Measurements at 190 kHz

Table 4.1.1			
Time of Event	Maximum amplitude of seismic event	Electromagnetic anomalies observed?	Comments
20:16:08	0.003	No	
20:15:44	4e-4	No	
20:15:26	7e-5	No	
20:15:24	4e-4	No	
20:15:34	9e-4	No	
20:08:49	2e-5	No	
20:08:50	2e-5	No	
20:22:39	0.001	No	
20:08:51	0.003	Yes	Delay of approximately 130 milliseconds
20:48:00	0.001	No	
20:29:31	0.002	No	
20:27:49	9e-4	No	
20:23:14	0.001	No	
20:48:04	3e-4	No	
20:40:30	0.004	Yes	Delay not possible to calculate
20:42:24	0.002	Yes	Delay = 10 ms
20:45:44	0.001	Yes	Delay = 20 ms
20:47:07	0.004	No	
20:50:05	-	No	

A total of nineteen events was recorded at 190 KHz. On four of these events, electromagnetic anomalies were observed as indicated in the above table. This gives a percentage of 21% for EM emissions observed together with seismic emissions.

4.1.2 Measurements at 500 KHz

Table 4.1.2			
Time	Seismic Amplitude	EM?	Comments
10:52:21	1e-4	Yes	Delay = 40 ms
11:05:26	1e-4	Yes	Delay = 16 ms
10:28:47	9e-4	Yes	Delay = 0 ms
10:23:02	4e-4	No	
11:47:35	2e-4	No	

A total of five events was observed of which three showed evidence of EM. This results in a percentage of 60% for EM anomalies observed together with seismic events.

4.1.3 Measurements at 1.0 MHz

Table 4.1.3			
20:00:15	5e-5	No	
20:04:12	0.001	No	

Only two events recorded with no EM observed.

4.1.4 Measurements at 2.31 MHz

Table 4.1.4			
17:26:11	1e-5	No	
17:14:54	4e-4	Yes	Delay = 18 ms
17:04:13	2e-4	No	
17:10:23	2e-4	No	
17:12:31	3e-4	No	
16:52:22	0.004	No	
16:55:07	0.009	No	
17:13:56	3e-4	No	

A total of eight events recorded with 1 EM observed which gives 12.5 % for EM anomalies observed together with seismic events .

4.1.5 Measurements at 2.5 MHz

Table 4.1.5			
21:00:43	0.003	No	
21:07:29	6e-4	Yes	Delay = 36 ms
20:54:41	5e-4	No	
21:07:34	5e-4	Yes	Delay = 40 ms
21:16:28	1e-4	Yes	Delay = 60 ms
21:16:37	4e-5	No	
21:32:14	0.002	No	
21:02:08	-	No	

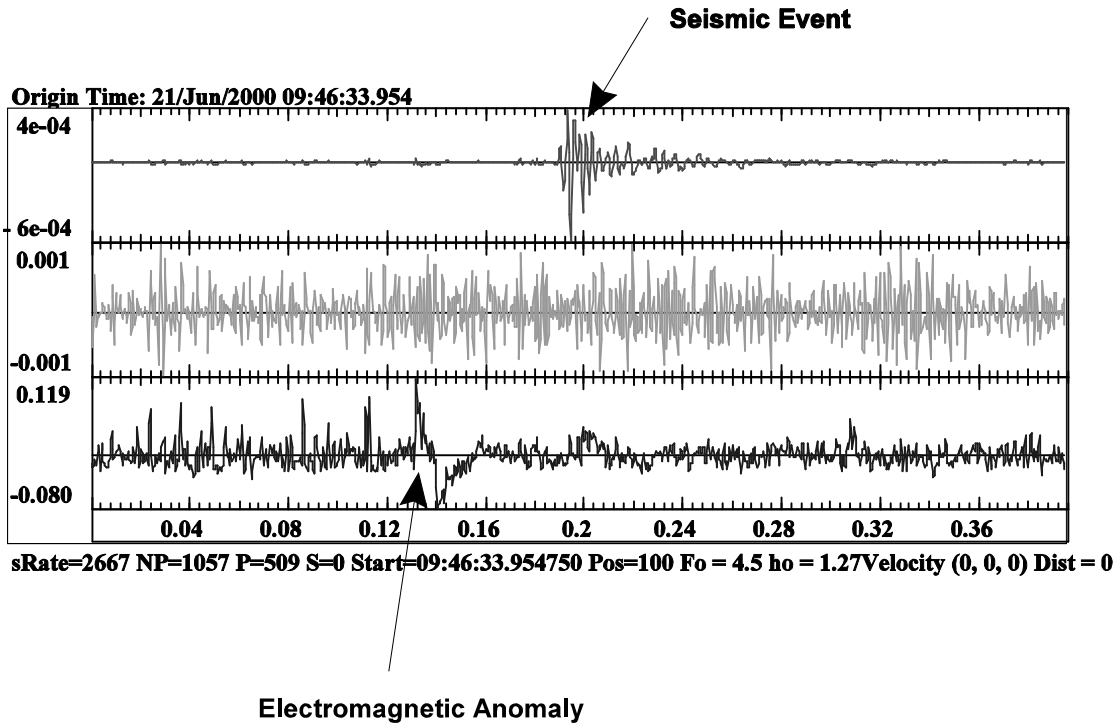
Eight events observed with three possible EM's observed. This calculates a 37.5 % observation for EM anomalies observed together with seismic events

4.1.6 Measurements at 4.92 MHz

Table 4.1.6			
09:49:32	5e-4	Yes	Delay = 44 ms
09:47:23	2e-4	Yes	Delay = 66 ms
09:46:33	5e-4	Yes	Delay = 50 ms
09:44:34	4e-4	Yes	Delay = 52 ms
11:34:30	3e-4	Yes	Delay = 35 ms Delay = 5 ms
11:00:11	-	-	-

A total of six events observed with five possible EM's, producing the highest positive observation of 83.3 %. A typical example is shown in Figure 4.1.6 where the observed electromagnetic anomaly is indicated.

Figure 4.1.6 Electromagnetic anomaly associated with seismic event



4.2 Analysis of background electromagnetic noise

In addition to confirmed seismic events, a large number of background seismic and electromagnetic events were observed. These are caused by underground seismic and electromagnetic noise. Typical sources for these events were:

– Induced vibration by mining machinery;
– Vibration caused by underground personnel;
– Electromagnetic interference by electrically powered equipment.

Although analysis of some of these events may suggest that the events are also seismic events originating from roof failure, these could not be correlated with field notes in which the time and date of a confirmed seismic event were recorded. However, there may be discrepancies when a large number of events were triggered in a short period of time when the system needs to process all the incoming events. In such a case, it is not always possible to correlate an audible seismic event to a specific time. Only the actual confirmed seismic events (correlated with audible confirmation during data acquisition) were used in the data analysis.

The non-confirmed seismic and EM events were used to provide a qualitative assessment of the level and nature of underground mining induced seismic and electromagnetic noise.

Non-seismic events include possible seismic events which could not be confirmed with audible events at the time of the survey as well as other mining-induced seismic and EM events. Non-seismic events are analysed to provide a qualitative assessment of background EM radiation in the underground environment. Background EM is thus defined as mining-induced EM radiation not associated with a seismic event.

Non-seismic events were monitored at the following different frequencies: 190 kHz, 200 kHz, 500 kHz, 1.00 MHz, 2.31 MHz, 4.91 MHz, 10.00 MHz, 29.99 MHz using the R&S radio. **Note that EM is observed on the bottom cross section while the seismic signal is observed on the top cross section.**

4.2.1 Background at 190 kHz

Distinct EM anomalies were observed at 190 kHz by the R&S radio. Refer to event 20:19:47 in which a clear periodic EM signal can be observed although the signal appears to be sporadic - possibly associated with mining-machinery. The approximate frequency observed is eight cycles in a 0.60 seconds time duration which gives a frequency of approximately 13 Hertz (Hz). A spike could also be observed in some of the data (Example Event 20:16:55) of which the origin is unknown.

The background EM anomalies described above were not observed together with seismic events recorded at 190 kHz.

4.2.2 Background at 200 KHz

A very distinct EM anomaly could be observed (refer to Event 19:56:23) which is probably caused by electrically power mining machinery.

4.2.3 Background at 500 KHz

No clear EM anomalies observed although a distinct EM anomaly could be observed on Event 11:51:13.

4.2.4 Background at 1.00 MHz

EM anomalies with a very clear shape can be observed at 1.0 MHz (Event 19:56:32). Duration is approximately 20 milliseconds which also appears to b equal to the period of the anomaly. This results in a frequency of 50 Hz - interpreted as being induced by electrical machinery.

4.2.5 Background at 2.31 MHz

Although no significant EM patterns/anomalies can be observed on the majority of EM observed, a few EM observations do show a clear EM pattern (Refer to Event 17:33:02). This event shows a clear EM pattern observed which is repeated approximately every 60 milliseconds.

4.2.6 Background at 2.5 MHz

No clear EM anomalies/patterns could be observed.

4.2.7 Background at 4.92 MHz

No clear EM anomalies/patterns were observed.

4.2.8 Background at 10.0 MHz

A clear EM anomaly could be observed on Event 09:22:00 which is similar to the EM pattern observed at 1.0 MHz.

4.2.9 Background at 29.99 MHz

No clear patterns or EM anomalies could be observed.

4.3 Discussion

EM anomalies have been observed in the same time window as for seismic events observed. EM anomalies are defined as a clearly visible change in the EM signal which is visible above the background electromagnetic noise level.

The highest presence of EM anomalies in association (in the same time window of less than a second) with seismic events was observed at a frequency of 4.91 MHz. Here five out of the six events was accompanied by EM anomalies. IF one looks at the background EM monitored at this particular frequency (Events 09:00:43, 11:17:10, 09:50:43, 09:39:45, 11:34:28) the amplitude of the background EM varied from as low as 3e-4 up to a maximum of 0.092) Note that these values are relative values but can be used to draw conclusions regarding relative amplitudes of EM anomalies.

The data do suggest that these EM anomalies could be associated with electromagnetic emissions which have been emitted from rock failure because of the following:

– The maximum amplitudes of EM anomalies observed at 4.92 MHz varied between 0.079 to 0.134 which are higher than the maximum amplitudes of background EM observed at this frequency. EM anomalies observed in the same time window as seismic events do have larger amplitudes than background EM noise which does suggest that these EM anomalies are not random background EM noise, but coherent EM events.

– EM anomalies at 4.92 MHz were observed with clear distinct shapes which were not observed in the background EM signals.

– In all of the cases, EM anomalies were observed *before* and *during* the seismic event in time. As electromagnetic waves travel much faster than seismic waves, this supports the postulation that these EM anomalies are associated with seismic events. Typical differences in arrival times between the two different waves were from 35 to 66 milliseconds. If one assumes a typical compressional wave velocity of 2500 m/s and use the arrival time of the EM event as zero time for the seismic event, the distance from the seismic event to the measuring point can be calculated. Typical distances calculated range from 80 to 150 metres which are plausible considering the experimental setup.

5. Conclusions and Recommendations

5.1 Conclusions

In this research project some electromagnetic anomalies have been measured in the same time window for confirmed seismic events. At a centre frequency of 4.92 MHz, electromagnetic anomalies were observed together with seismic events on 80% of the confirmed seismic events.

The results thus do suggest that the observed electromagnetic anomalies may be electromagnetic emissions which are emitted during roof failure. Measurement of background electromagnetic radiation also suggest that the electromagnetic anomalies are not considered to be artificial or background electromagnetic emissions.

However, the results do not prove without any ambiguity that the observed electromagnetic anomalies can in fact be associated with roof failures. In order to make definite quantitative conclusions, sufficient data need to be collected on which a quantitative statistical analysis needs to be performed. Background electromagnetic anomalies have been measured which may be misinterpreted as electro-seismic anomalies, which can only be isolated from the data using statistical methods.

The amplitudes of possible electro-seismic anomalies produced during the monitoring period are also critical in drawing final conclusions. To measure a signal, one needs to measure this signal above the noise level. If the seismo-electrical signal is smaller than the background noise level, it is simply not possible to measure it. In this particular experiment it may have been the case where the seismic-electrical signal, although present, simply was not observed above the background noise level. The distance from the event to the measuring point is also important as electromagnetic waves are attenuated through rock which implies that electromagnetic emissions from faraway roof failures, do not have sufficient amplitude at the measuring point, and is part of the background noise level.

The collection of a large volume of data in a underground coal mine does focus on the need for intrinsically safe equipment. Without intrinsically safe equipment, no permanent (weeks to months) installation of equipment is possible which necessitates the monitoring of EM on a shift by shift base. This necessitates the need for qualified mining personnel to supervise the data collection process. The scope of this particular project did not allow for an extensive data collection period and data was collected without using intrinsically safe equipment.

5.2 Recommendations

To prove the routine ability to measure EM associated with rock failures a large volume of data at various frequencies needs to be collected. Seismic activity needs to be characterised in terms of amplitudes (size of events) in order to correlate amplitudes of EM with seismic amplitudes.

The following measurements need to be conducted:

1. Current measurements were conducted using an off-the-shelf rod-antenna which measures electrical field strength. It is also proposed that measurements be

conducted with a loop type of antenna which measures magnetic field strength. It is also imperative that antennas are optimized for this particular environment and be made sensitive enough to measure low amplitude electromagnetic signals.

2. The following parameters need to be calculated:

   – Location, magnitude, and estimated origin time of seismic events created during roof failure.

     This information will provide information on the amplitude and size of seismic roof failures and it will also provide an estimated position of the seismic event. This will allow for calculation of seismic velocities and the estimated arrival time of possible electromagnetic emissions associated with a particular seismic event. The actual arrival time of electromagnetic emissions can then be correlated with calculated estimated arrival times which will give an improved confirmation of the association of the electromagnetic emission with a seismic event.

   – Magnitude and arrival times of electromagnetic radiation in correlation with seismic events using optimized loop and rod antenna configurations.

   – It is proposed that measurements be conducted by the temporal installation of a seismic monitoring system together with an electromagnetic emission monitoring system and that data be collected for a period of a few months in a stooping environment which is an excellent source of seismic events.

   – Intrinsically safe equipment and installations are required.

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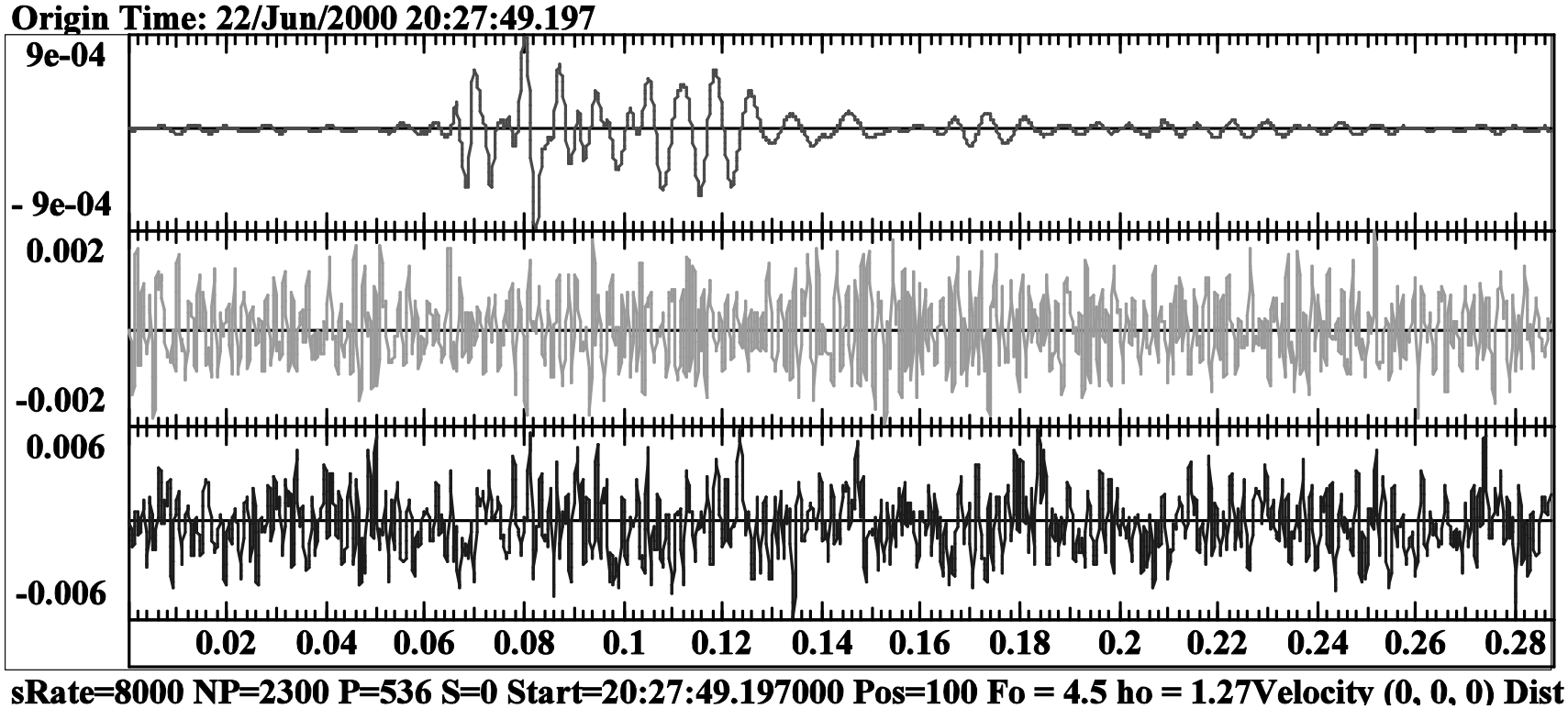
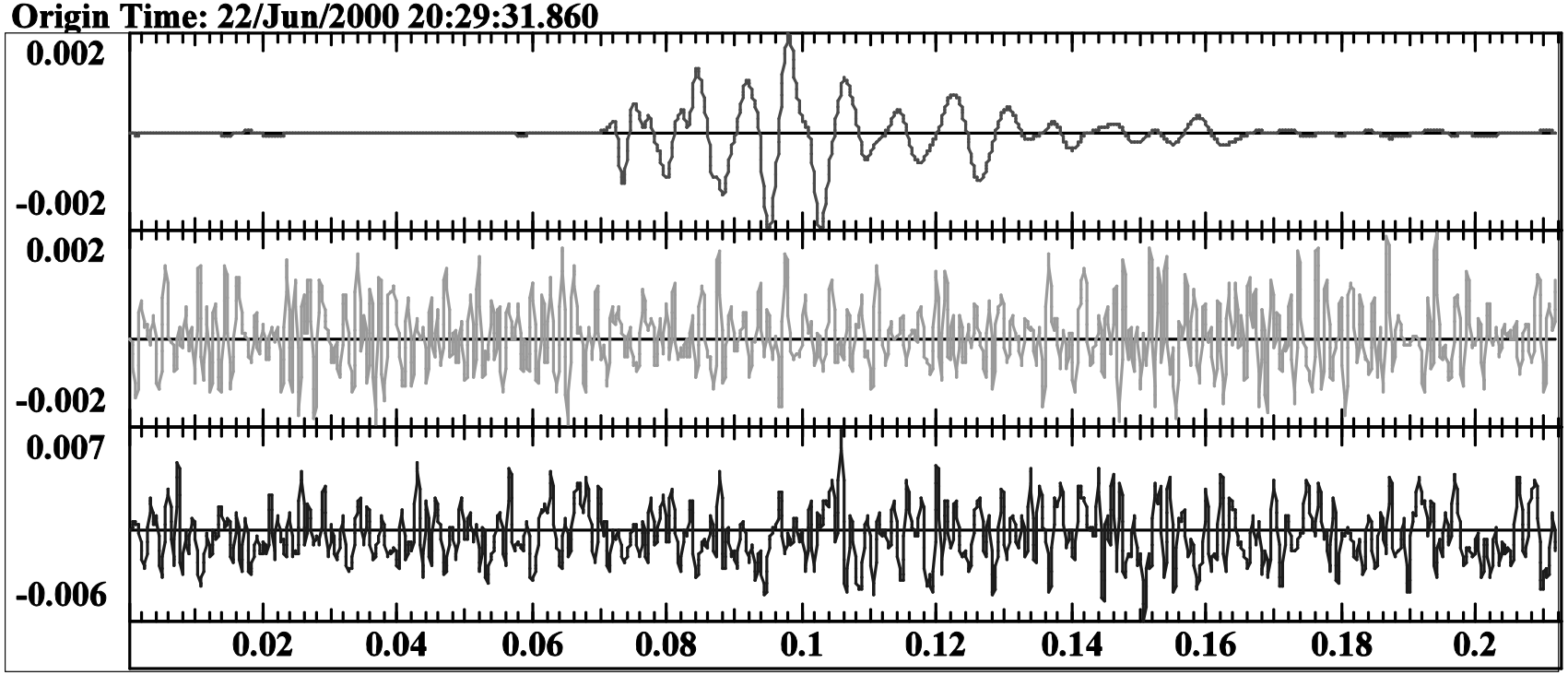
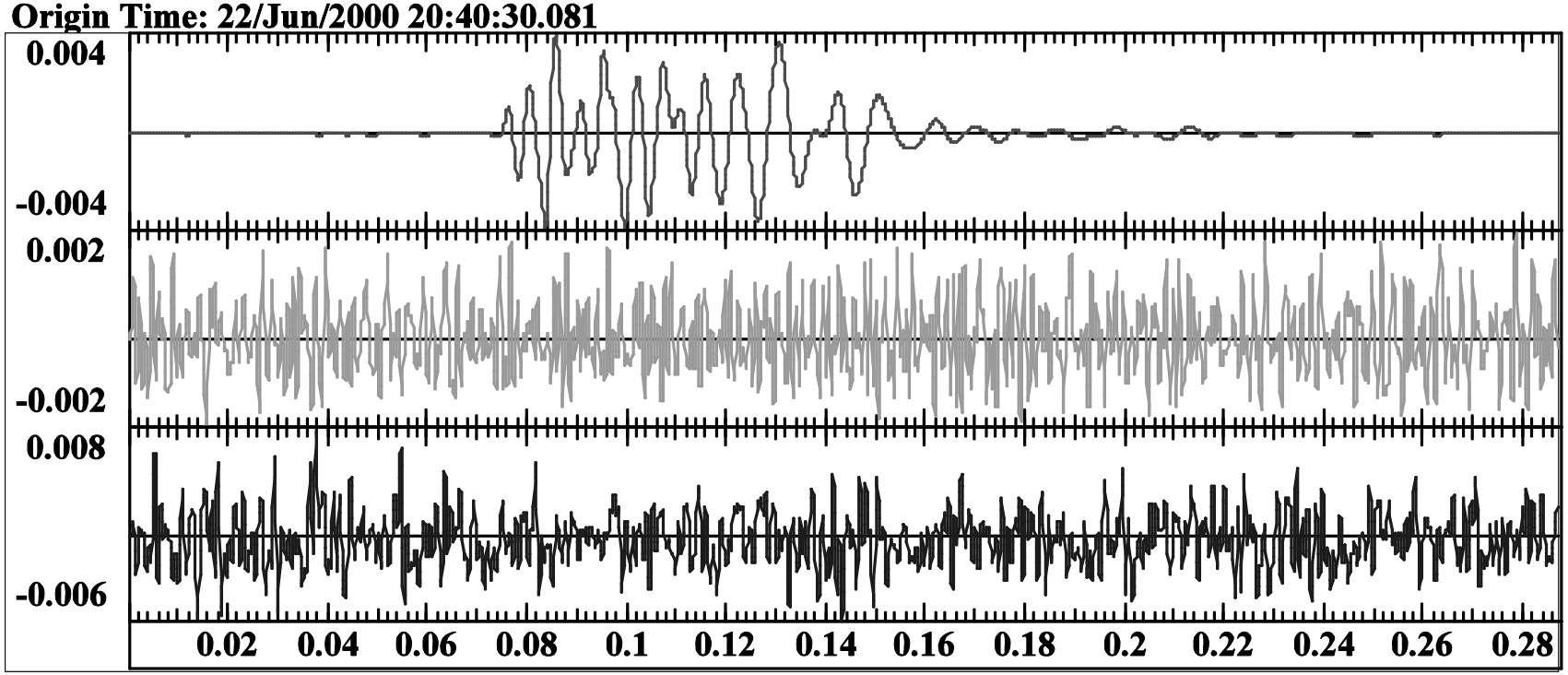
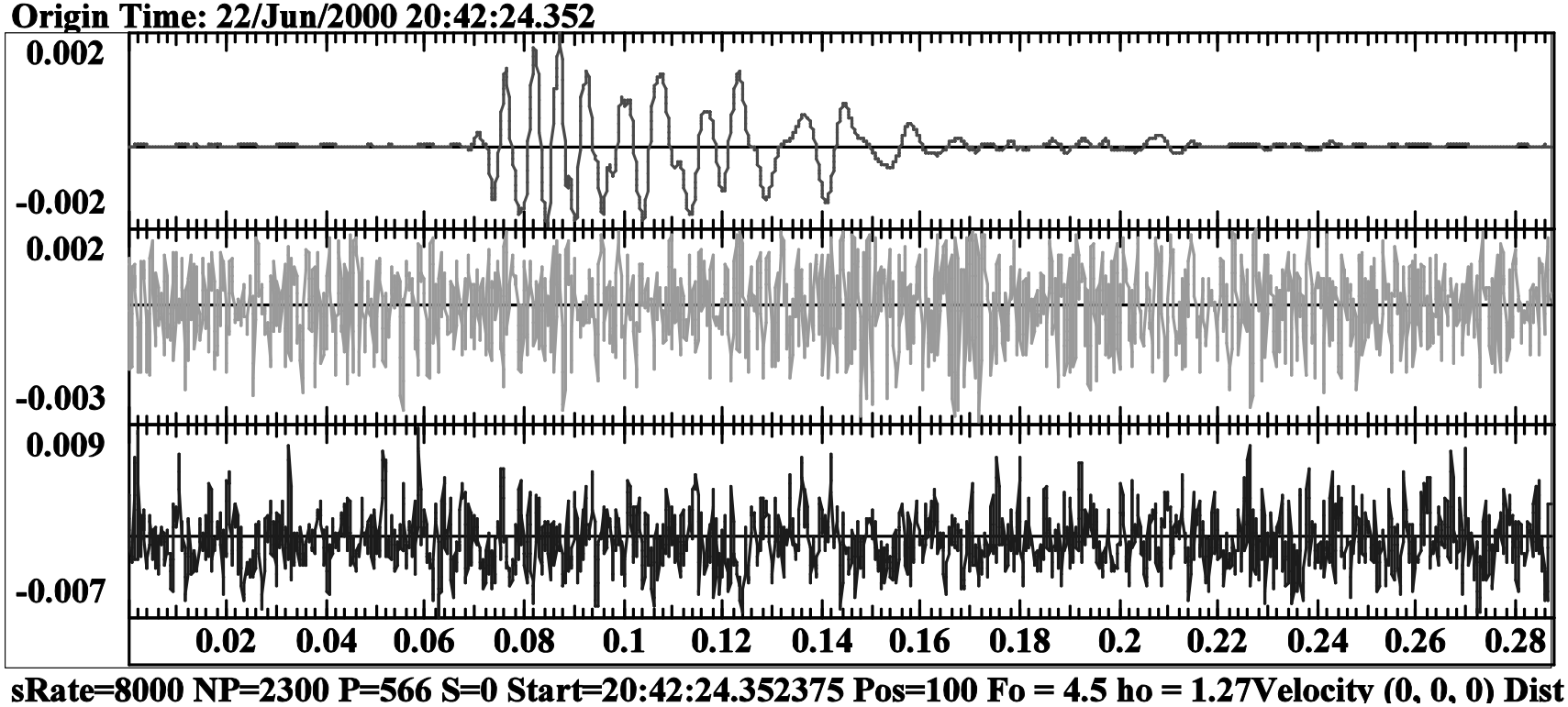
Appendix 1 Seismic events

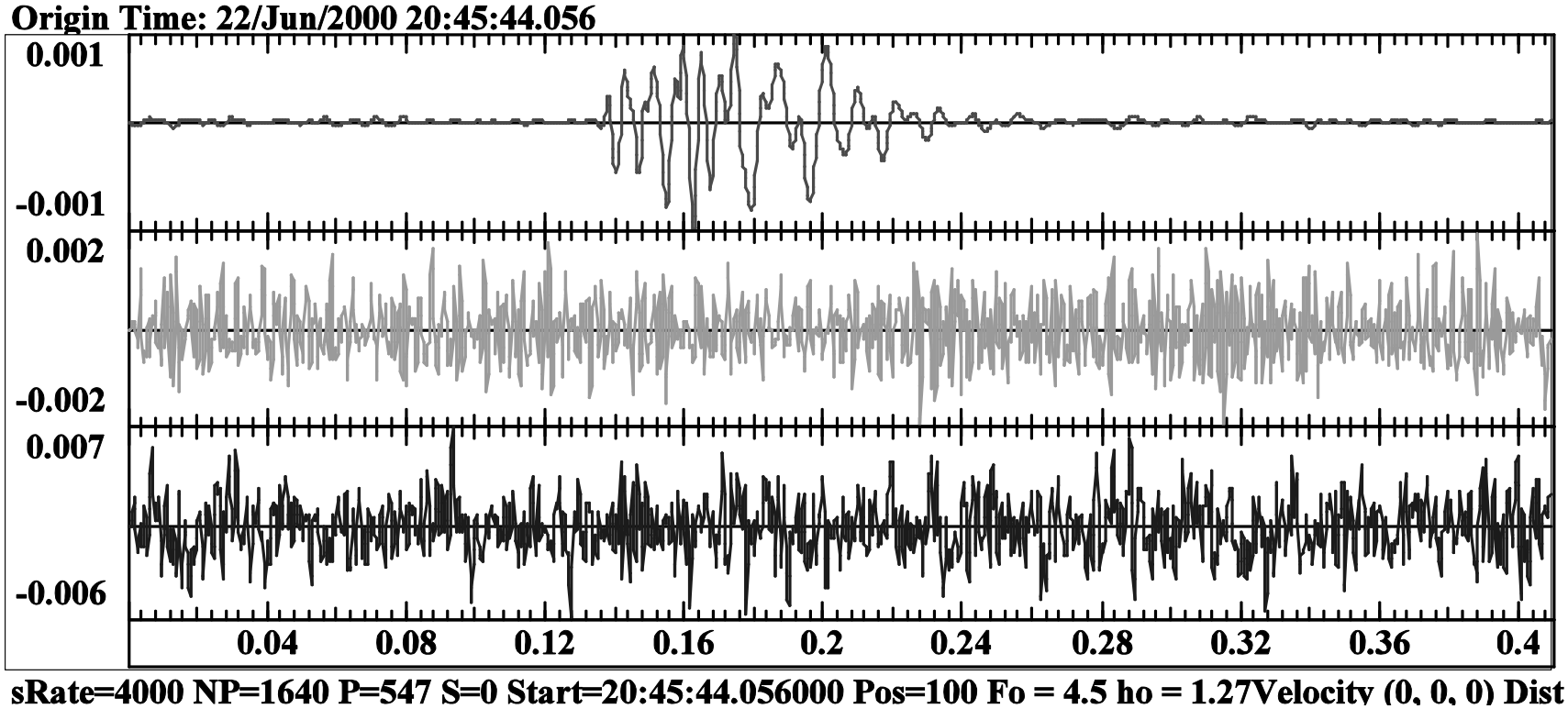
A1.1 Seismic events measured at 190 kHz

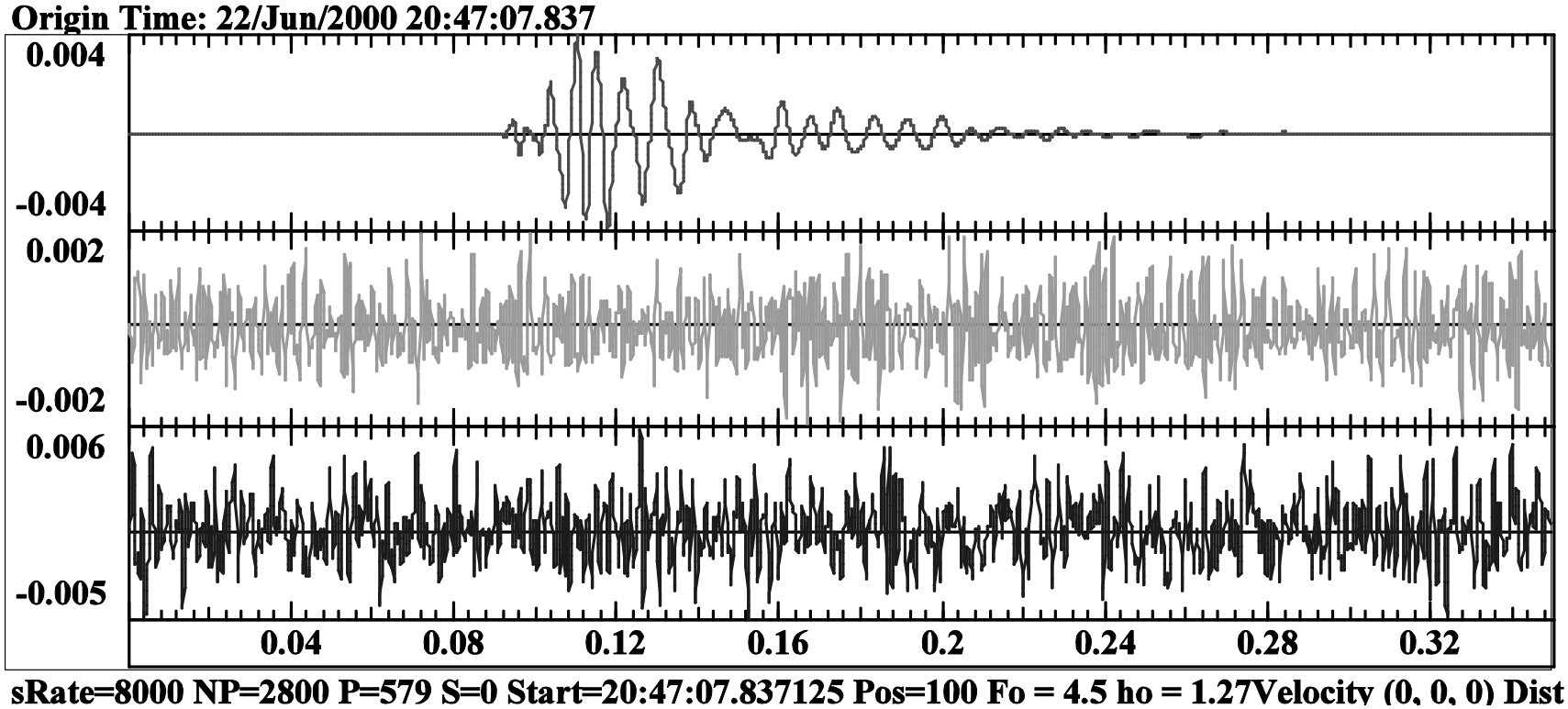

Origin Time: 22/Jun/2000 20:27:49.197
9e-04
- 9e-04
0.002
-0.002
0.006
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
sRate=8000 NP=2300 P=536 S=0 Start=20:27:49.197000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

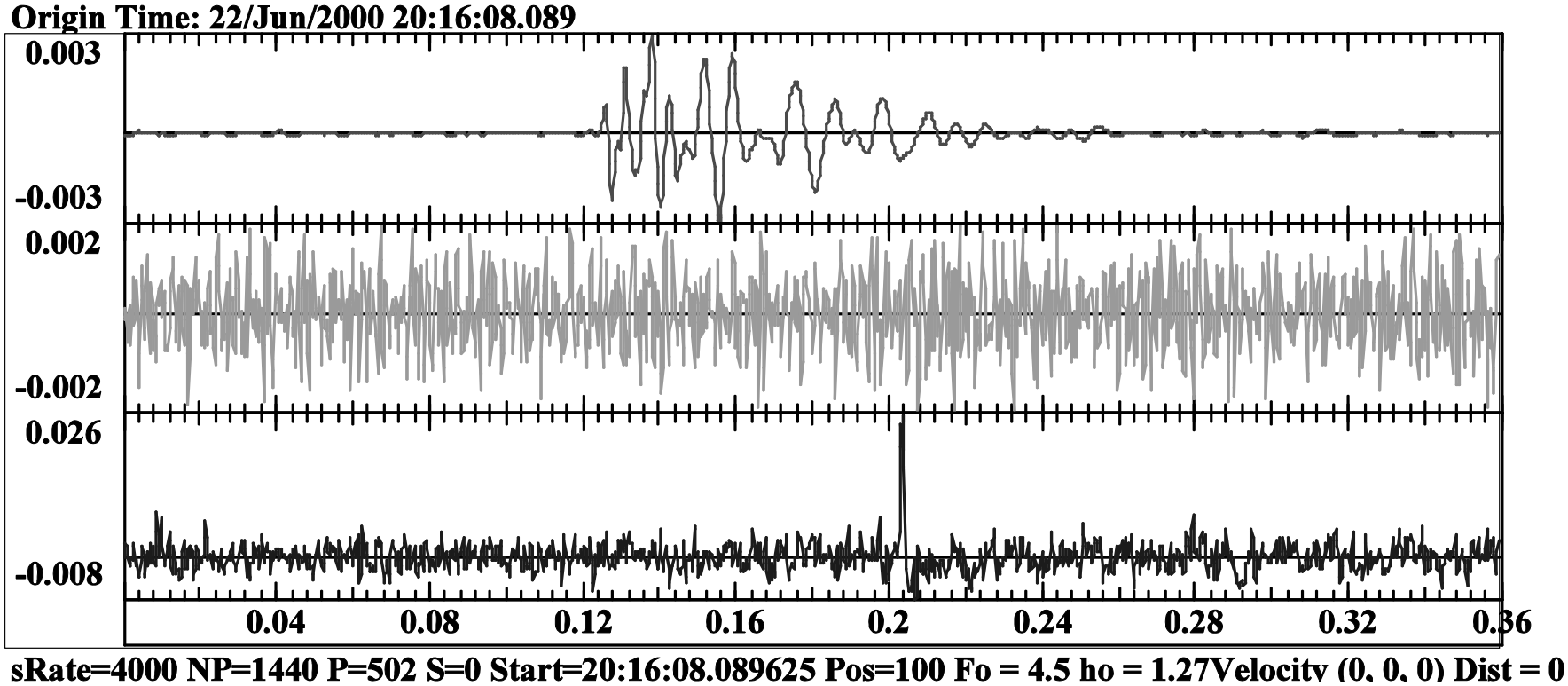

Origin Time: 22/Jun/2000 20:29:31.860
0.002
-0.002
0.002
-0.002
0.007
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1700 P=580 S=0 Start=20:29:31.860000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

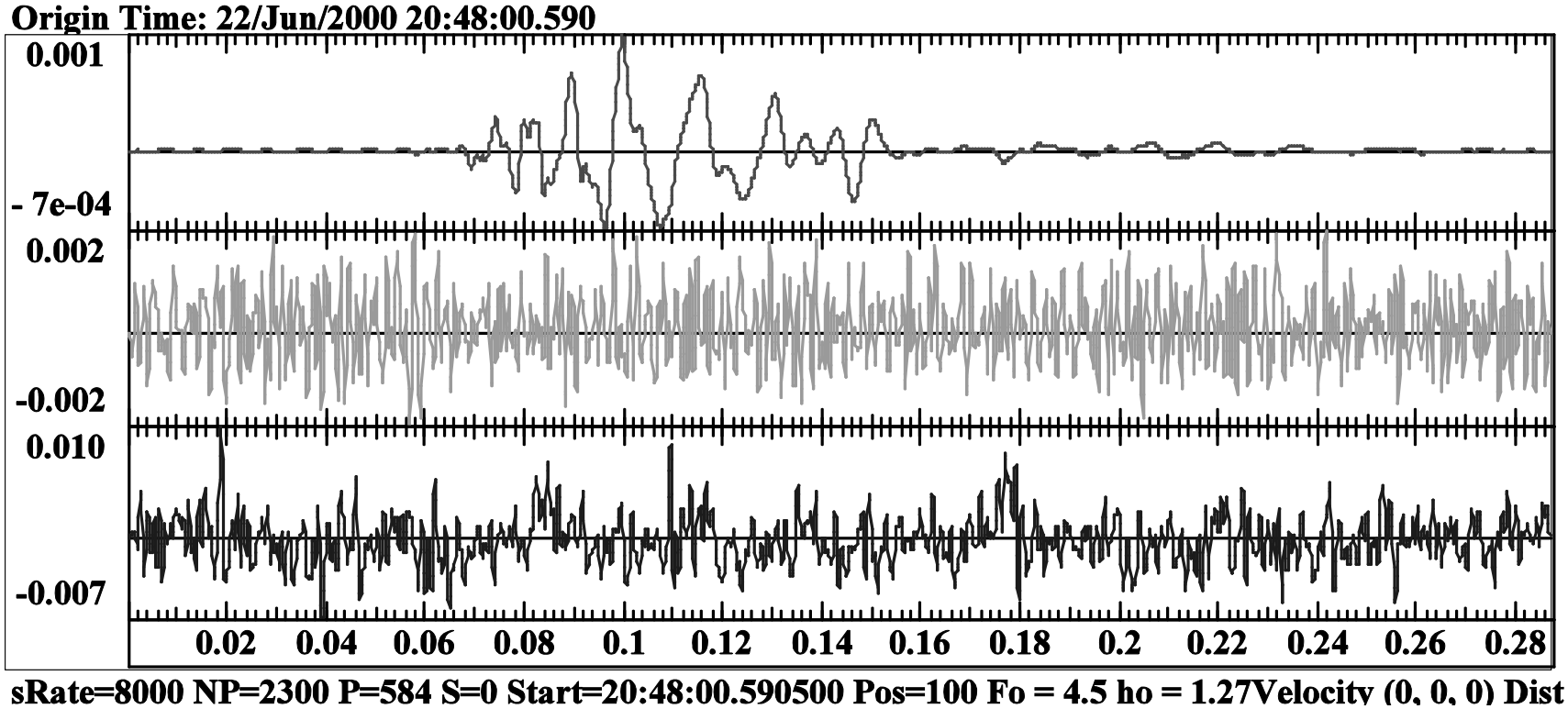

Origin Time: 22/Jun/2000 20:40:30.081
0.004
-0.004
0.002
-0.002
0.008
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
sRate=8000 NP=2300 P=599 S=0 Start=20:40:30.081750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

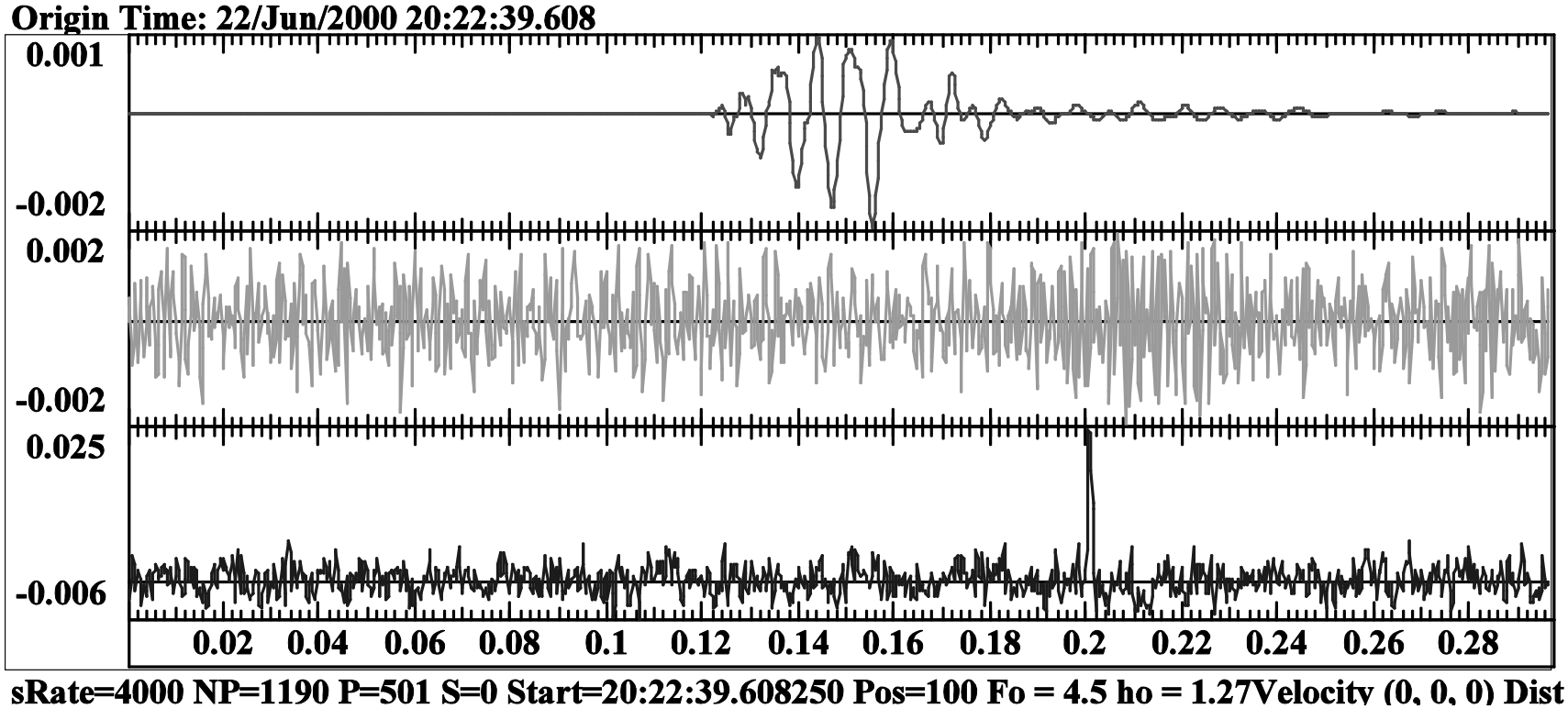

Origin Time: 22/Jun/2000 20:42:24.352
0.002
-0.002
0.002
-0.003
0.009
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
sRate=8000 NP=2300 P=566 S=0 Start=20:42:24.352375 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

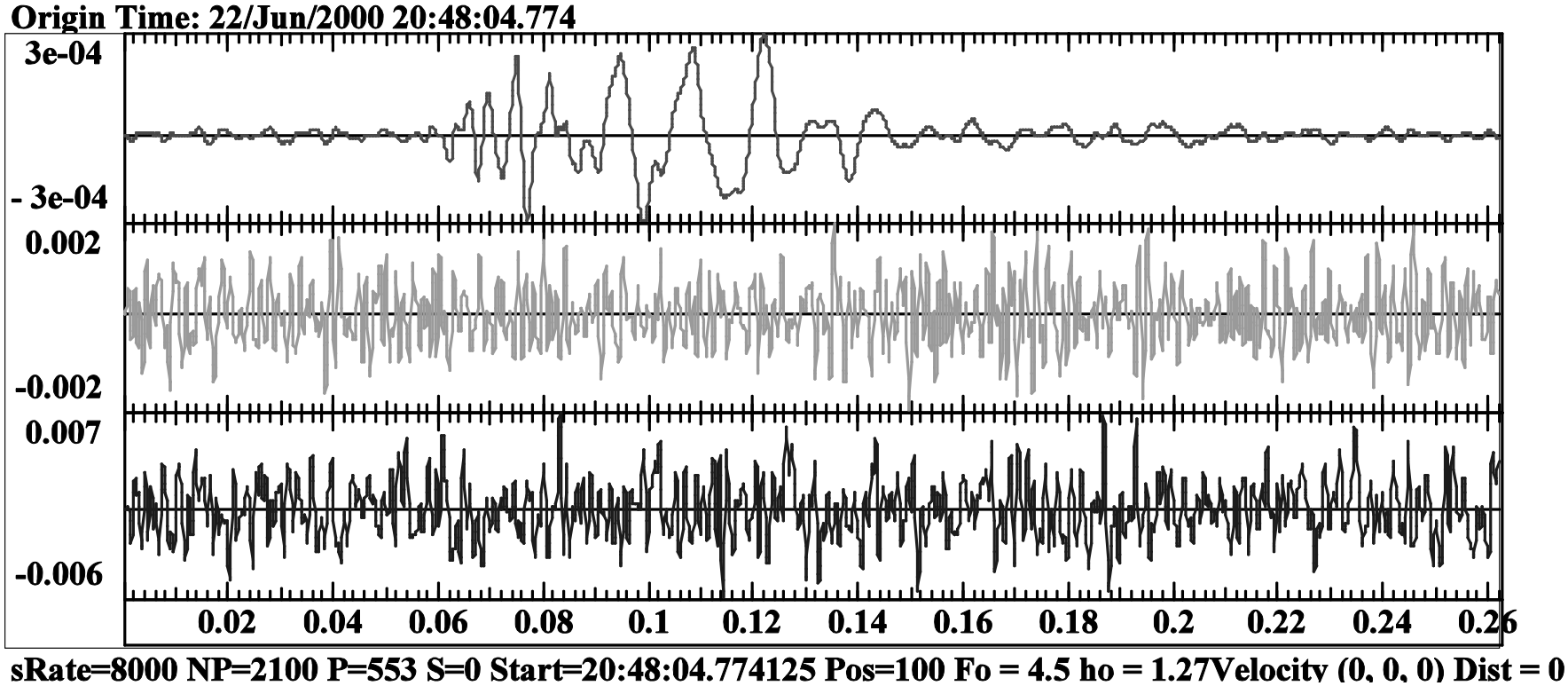

Origin Time: 22/Jun/2000 20:45:44.056
0.001
-0.001
0.002
-0.002
0.007
-0.006
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
sRate=4000 NP=1640 P=547 S=0 Start=20:45:44.056000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

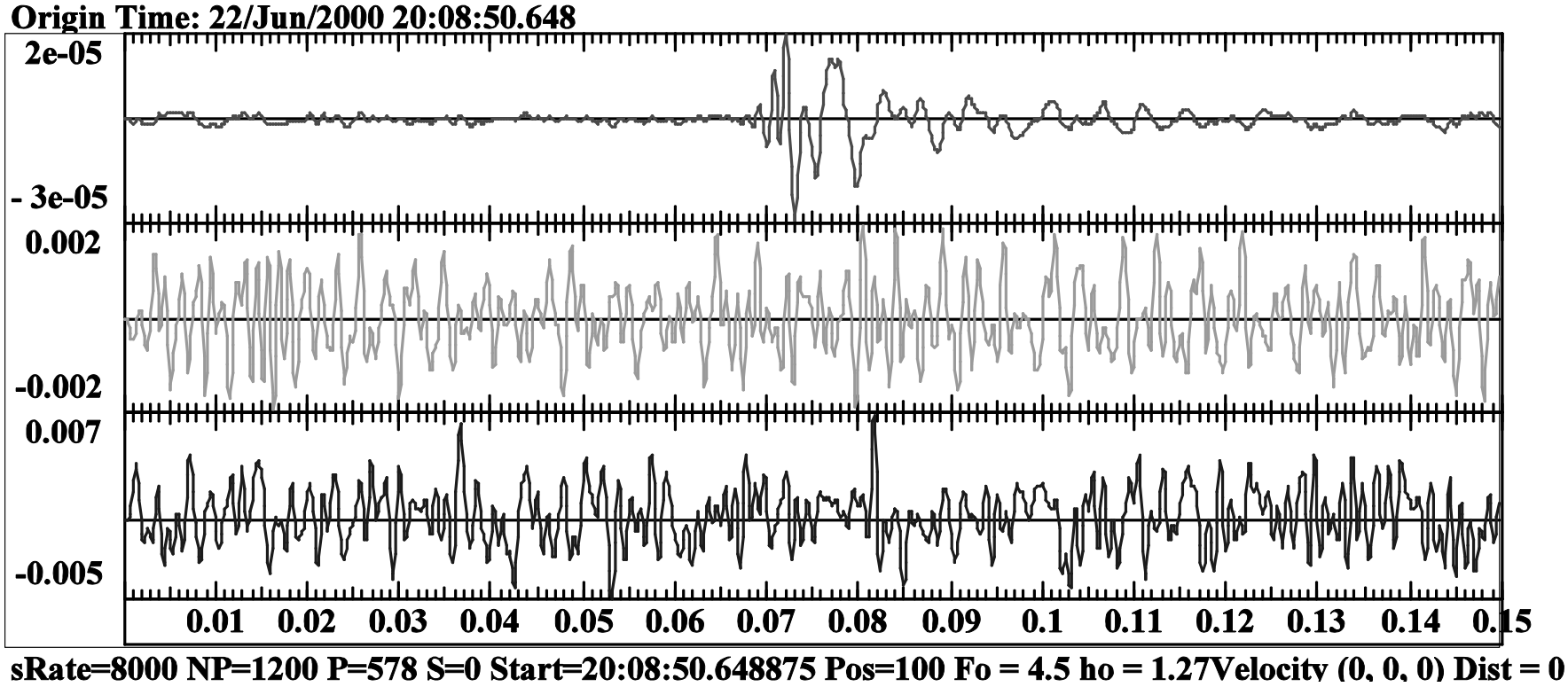

Origin Time: 22/Jun/2000 20:47:07.837
0.004
-0.004
0.002
-0.002
0.006
-0.005
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=8000 NP=2800 P=579 S=0 Start=20:47:07.837125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

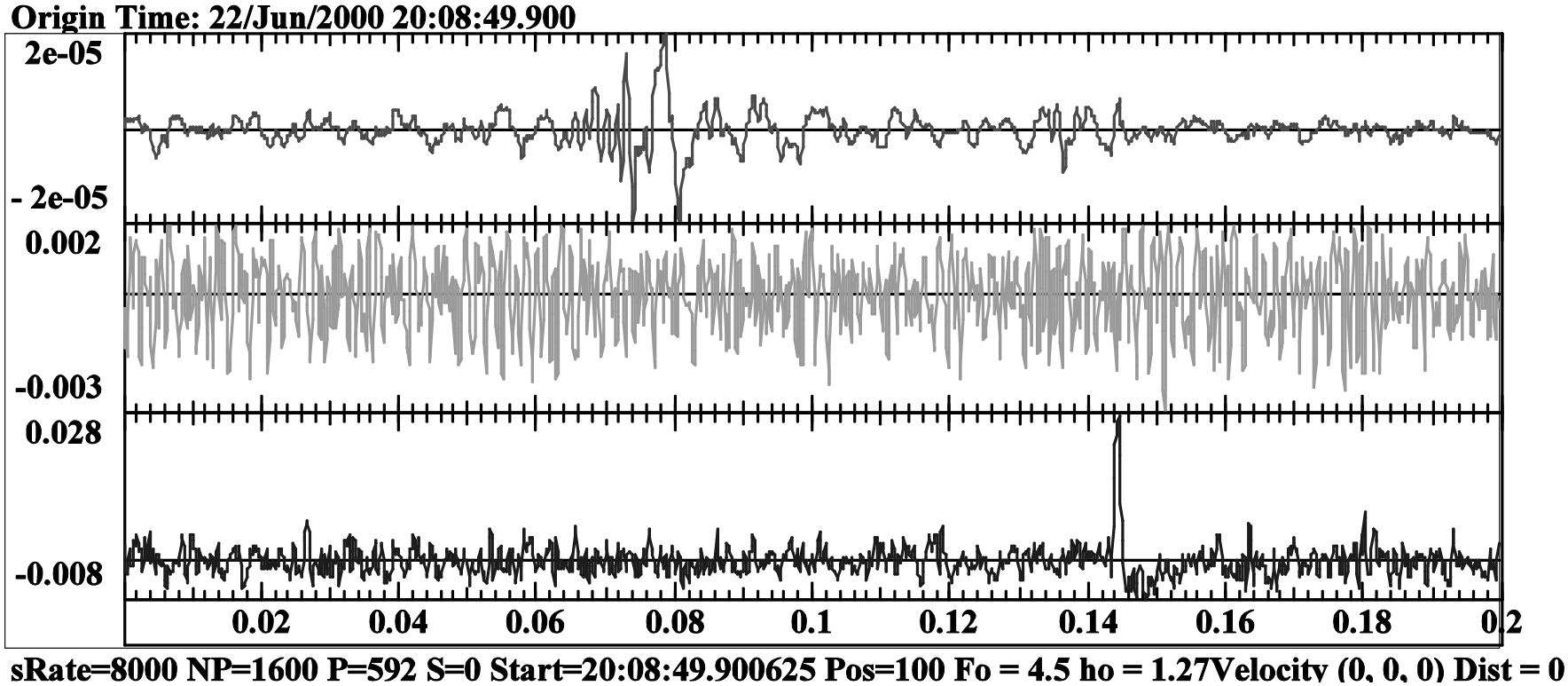

Origin Time: 22/Jun/2000 20:16:08.089
0.003
-0.003
0.002
-0.002
0.026
-0.008
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1440 P=502 S=0 Start=20:16:08.089625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

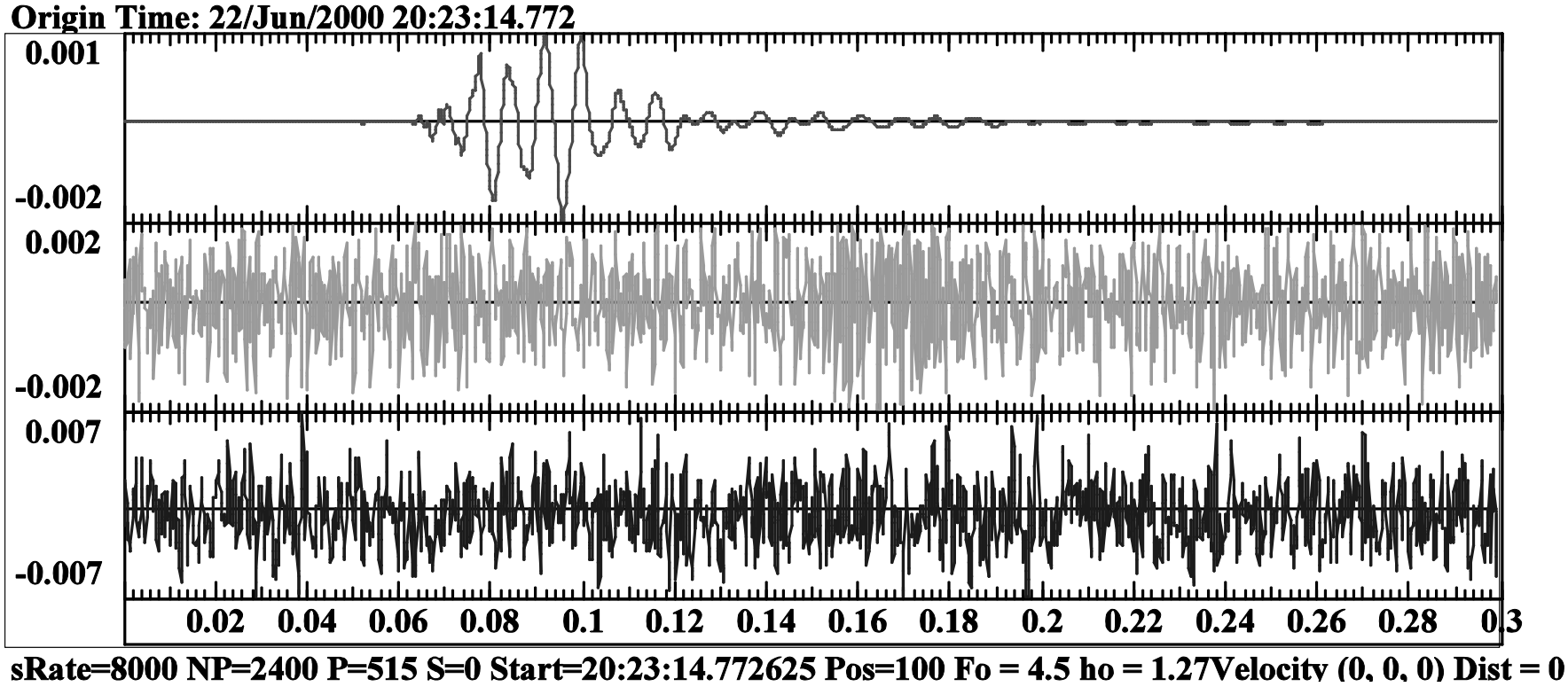

Origin Time: 22/Jun/2000 20:48:00.590
0.001
- 7e-04
0.002
-0.002
0.010
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
sRate=8000 NP=2300 P=584 S=0 Start=20:48:00.590500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

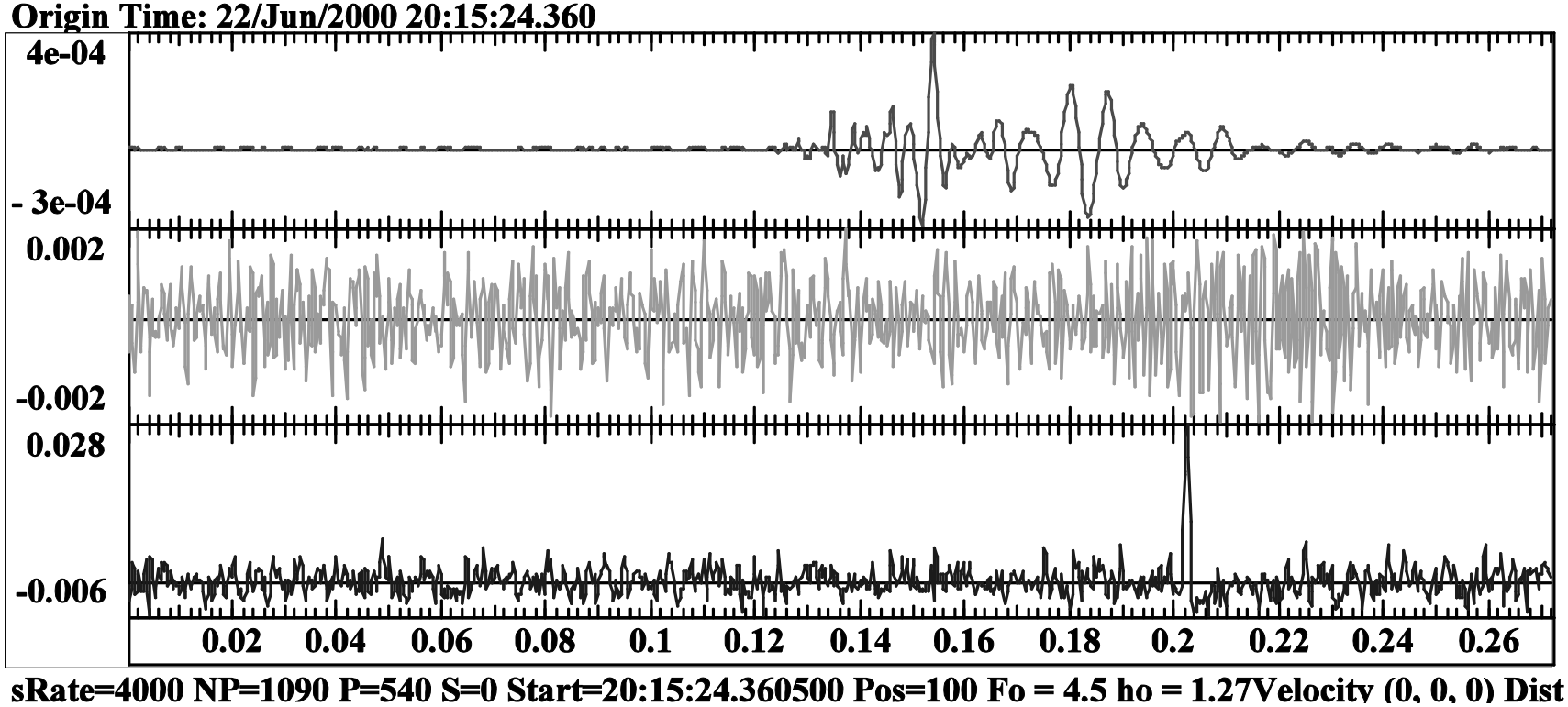

Origin Time: 22/Jun/2000 20:22:39.608
0.001
-0.002
0.002
-0.002
0.025
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
sRate=4000 NP=1190 P=501 S=0 Start=20:22:39.608250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

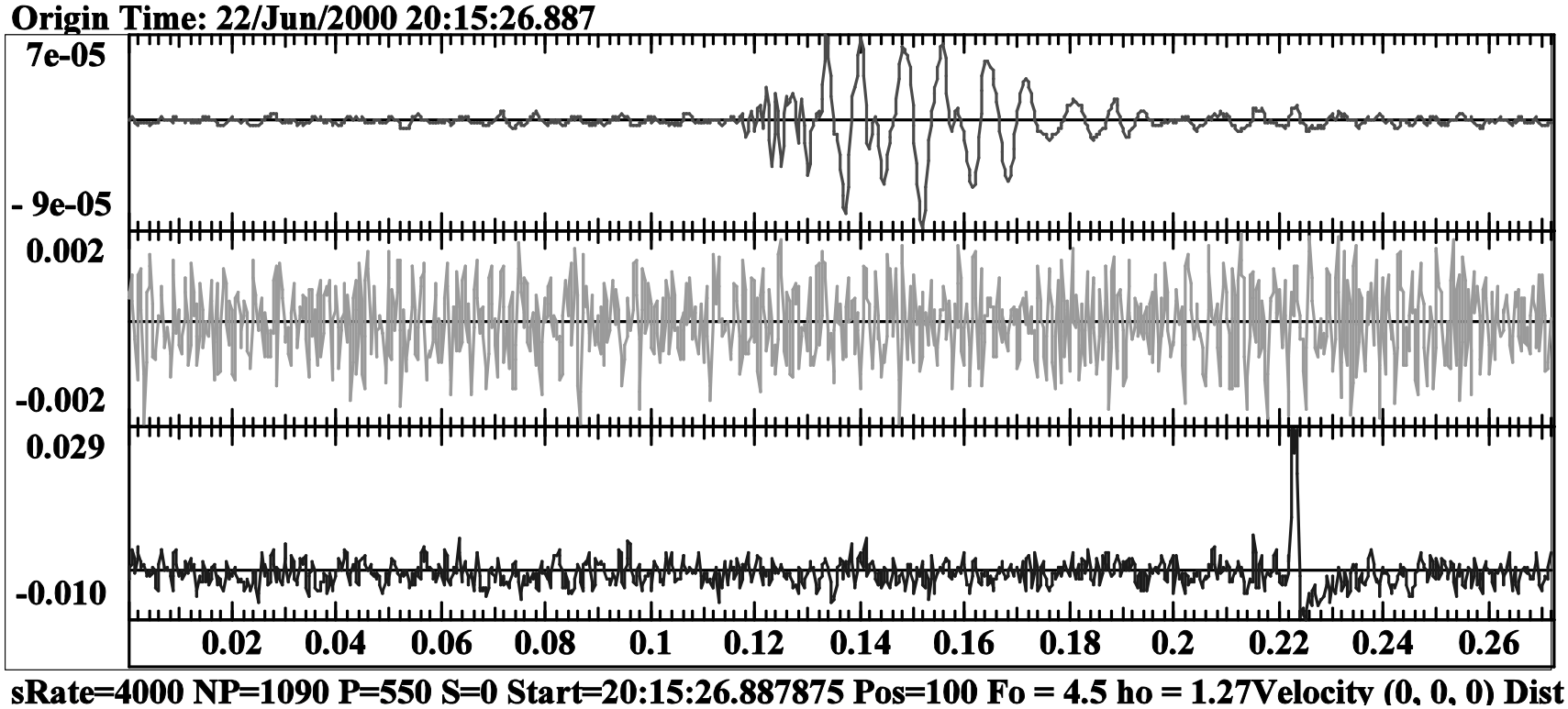

Origin Time: 22/Jun/2000 20:48:04.774
3e-04
- 3e-04
0.002
-0.002
0.007
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2100 P=553 S=0 Start=20:48:04.774125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

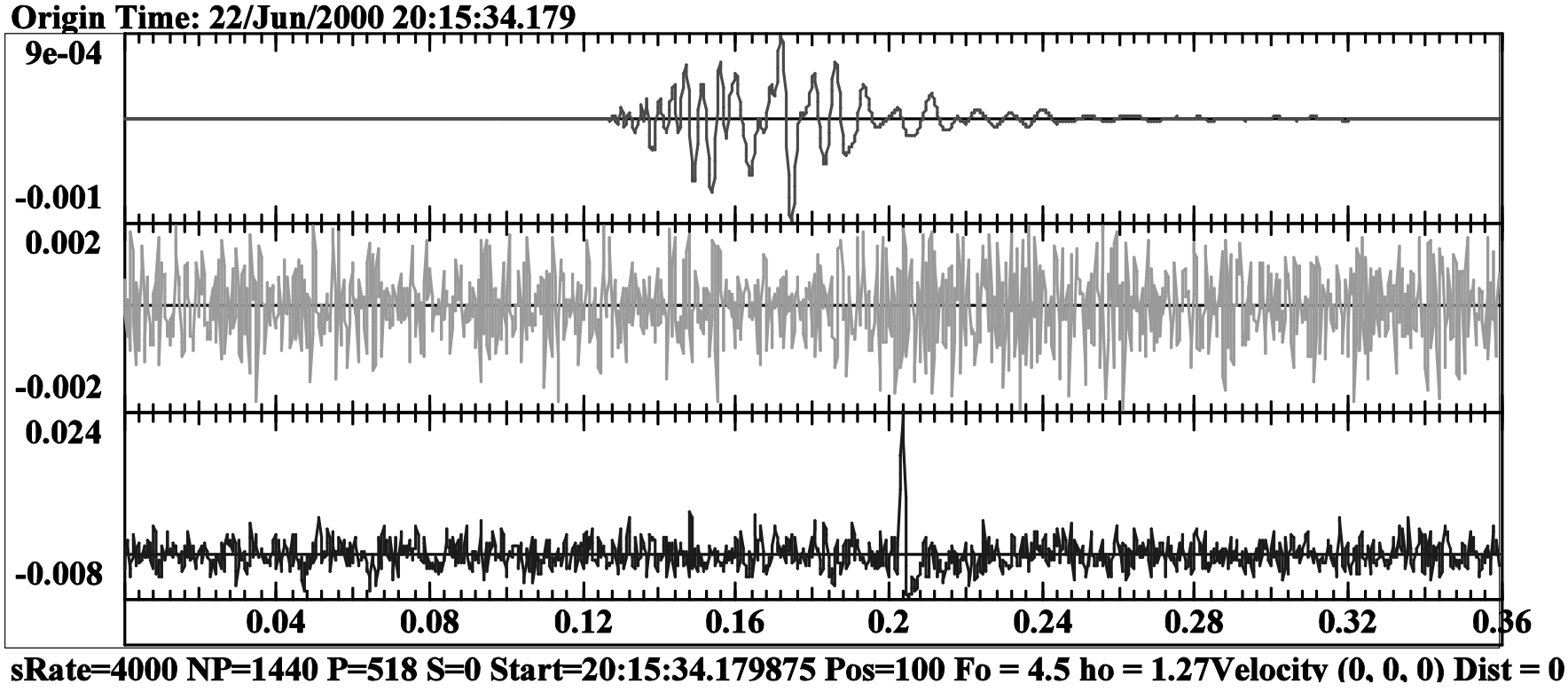

Origin Time: 22/Jun/2000 20:08:50.648
2e-05
- 3e-05
0.002
-0.002
0.007
-0.005
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
sRate=8000 NP=1200 P=578 S=0 Start=20:08:50.648875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 20:08:49.900
2e-05
- 2e-05
0.002
-0.003
0.028
-0.008
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=592 S=0 Start=20:08:49.900625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

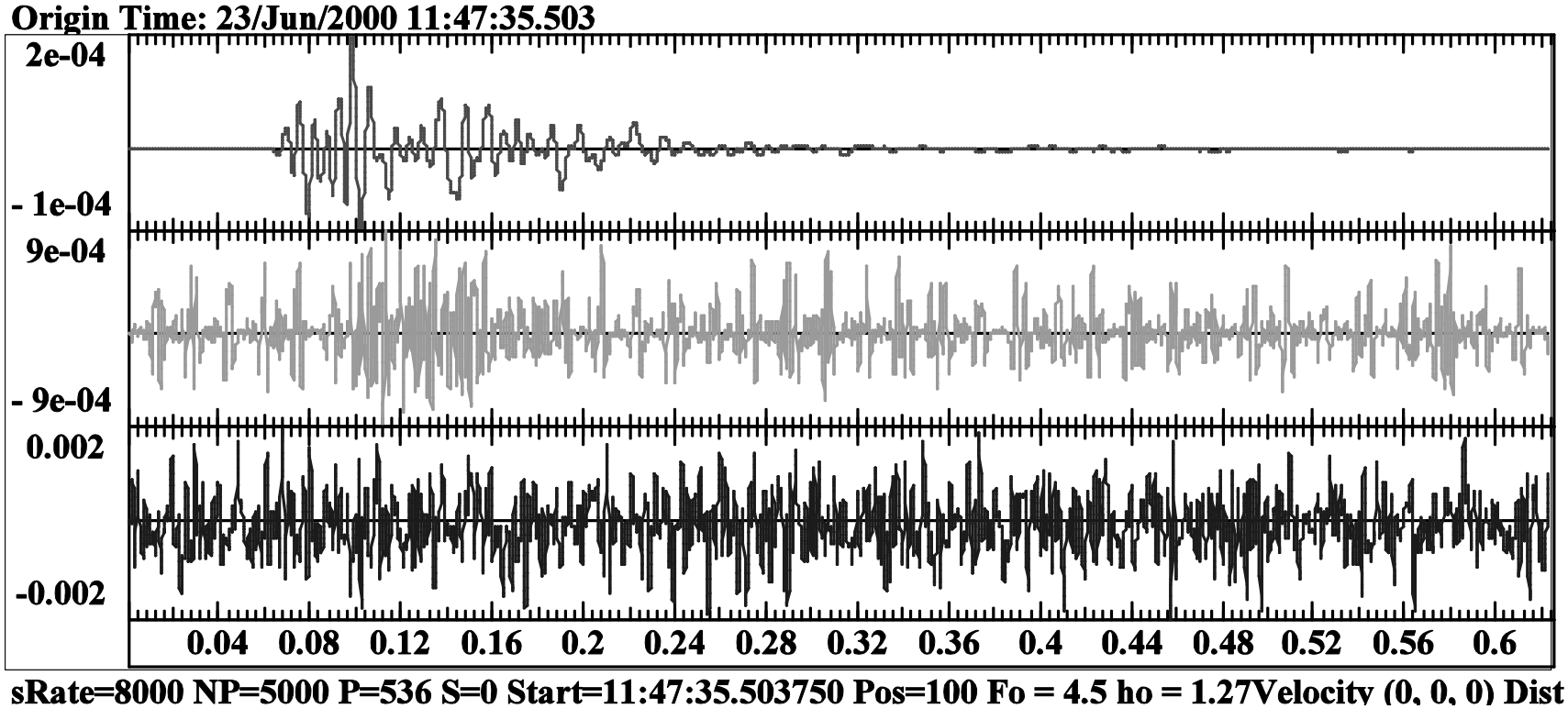

Origin Time: 22/Jun/2000 20:23:14.772
0.001
-0.002
0.002
-0.002
0.007
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
sRate=8000 NP=2400 P=515 S=0 Start=20:23:14.772625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

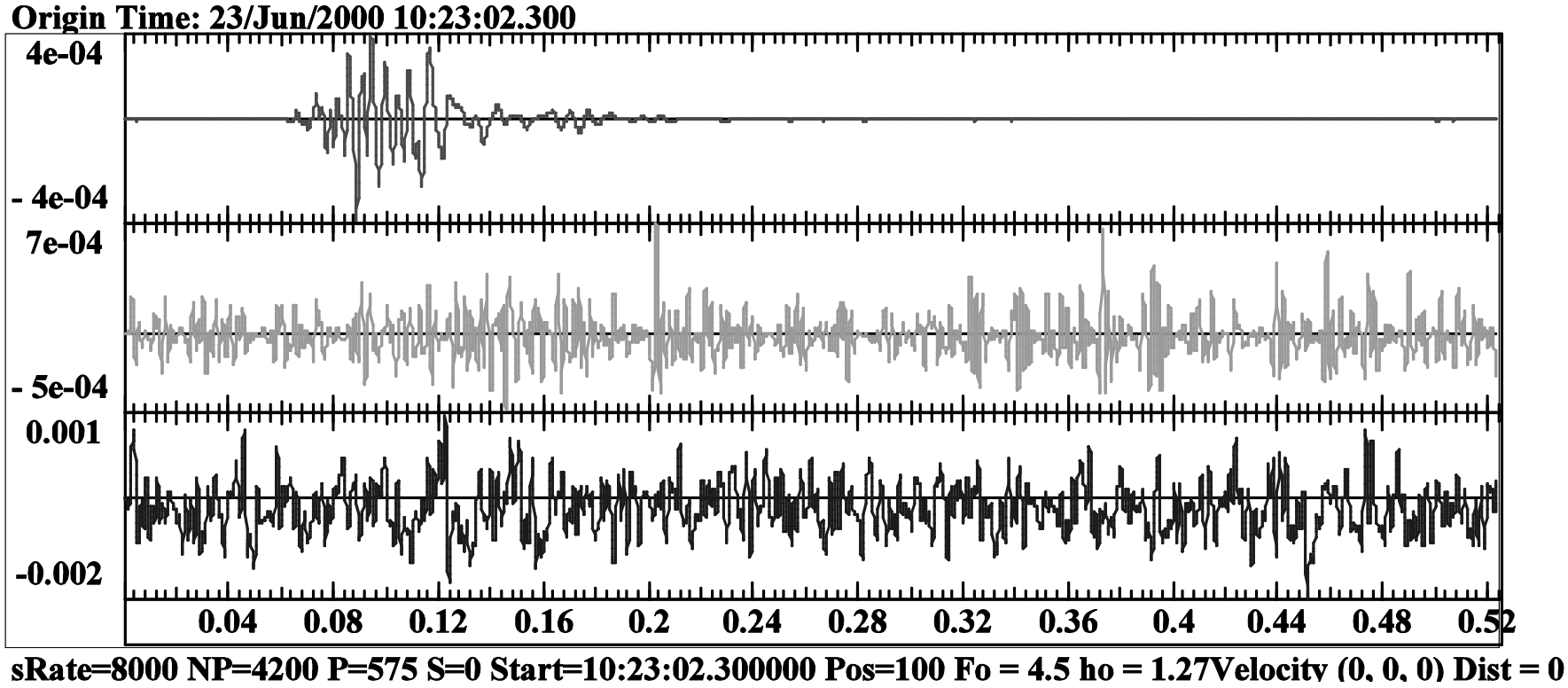

Origin Time: 22/Jun/2000 20:15:24.360
4e-04
- 3e-04
0.002
-0.002
0.028
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=4000 NP=1090 P=540 S=0 Start=20:15:24.360500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

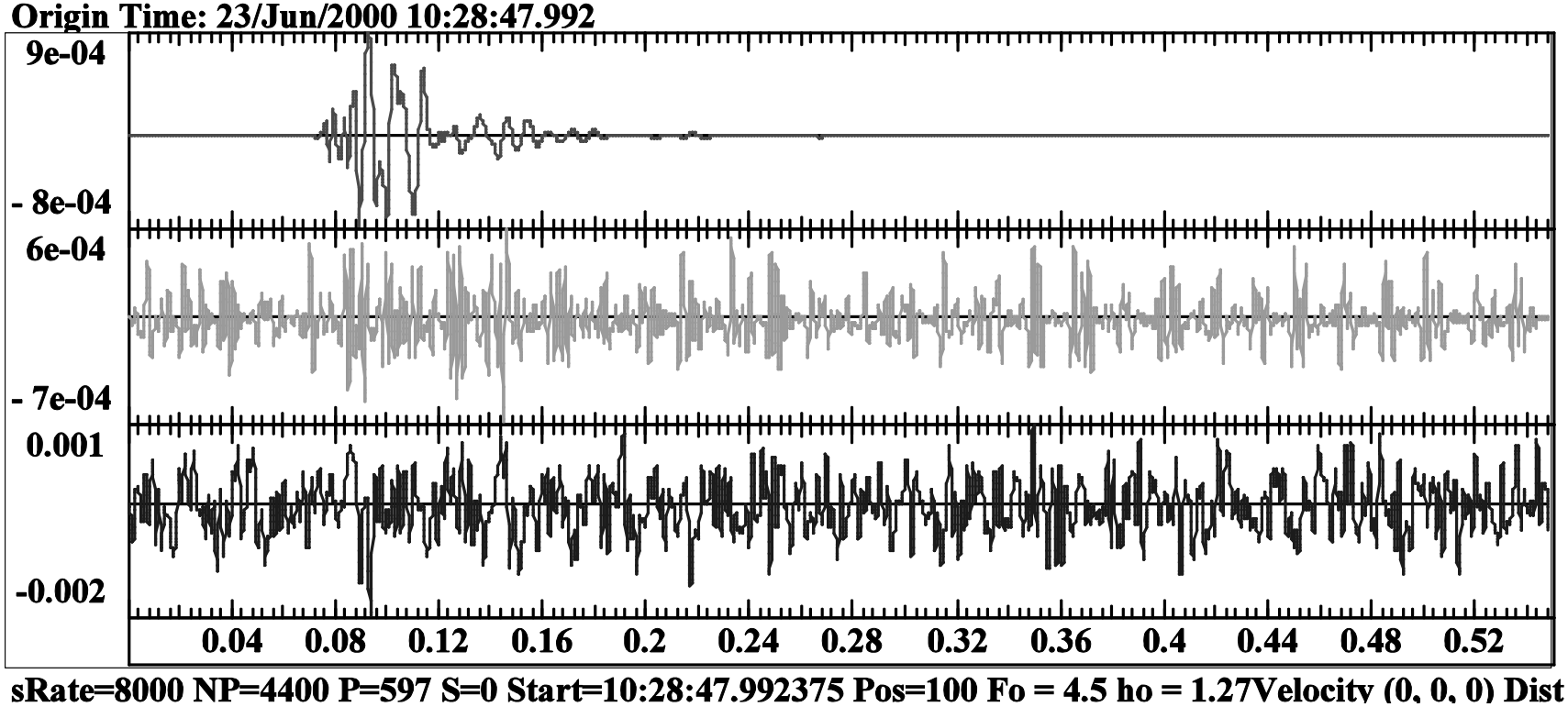

Origin Time: 22/Jun/2000 20:15:26.887
7e-05
- 9e-05
0.002
-0.002
0.029
-0.010
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=4000 NP=1090 P=550 S=0 Start=20:15:26.887875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

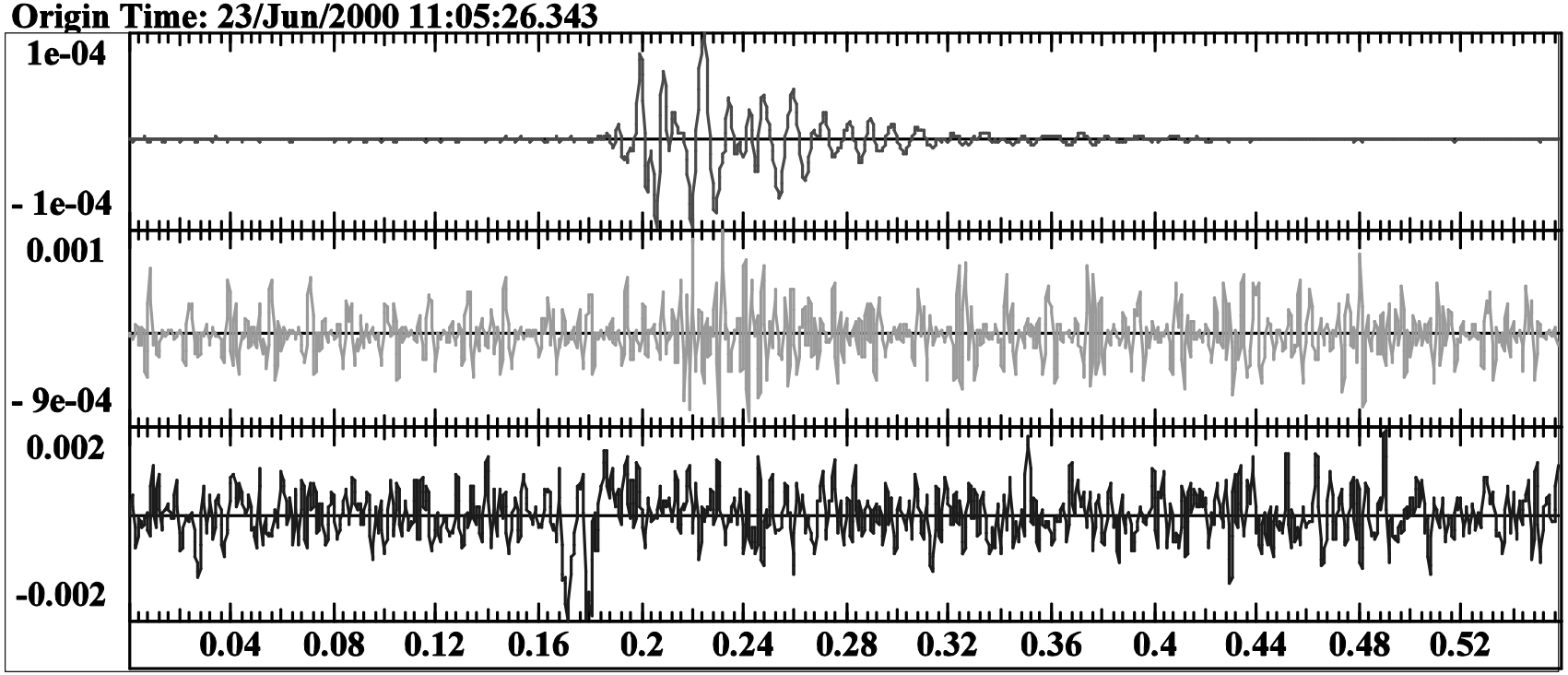

Origin Time: 22/Jun/2000 20:15:34.179
9e-04
-0.001
0.002
-0.002
0.024
-0.008
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1440 P=518 S=0 Start=20:15:34.179875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

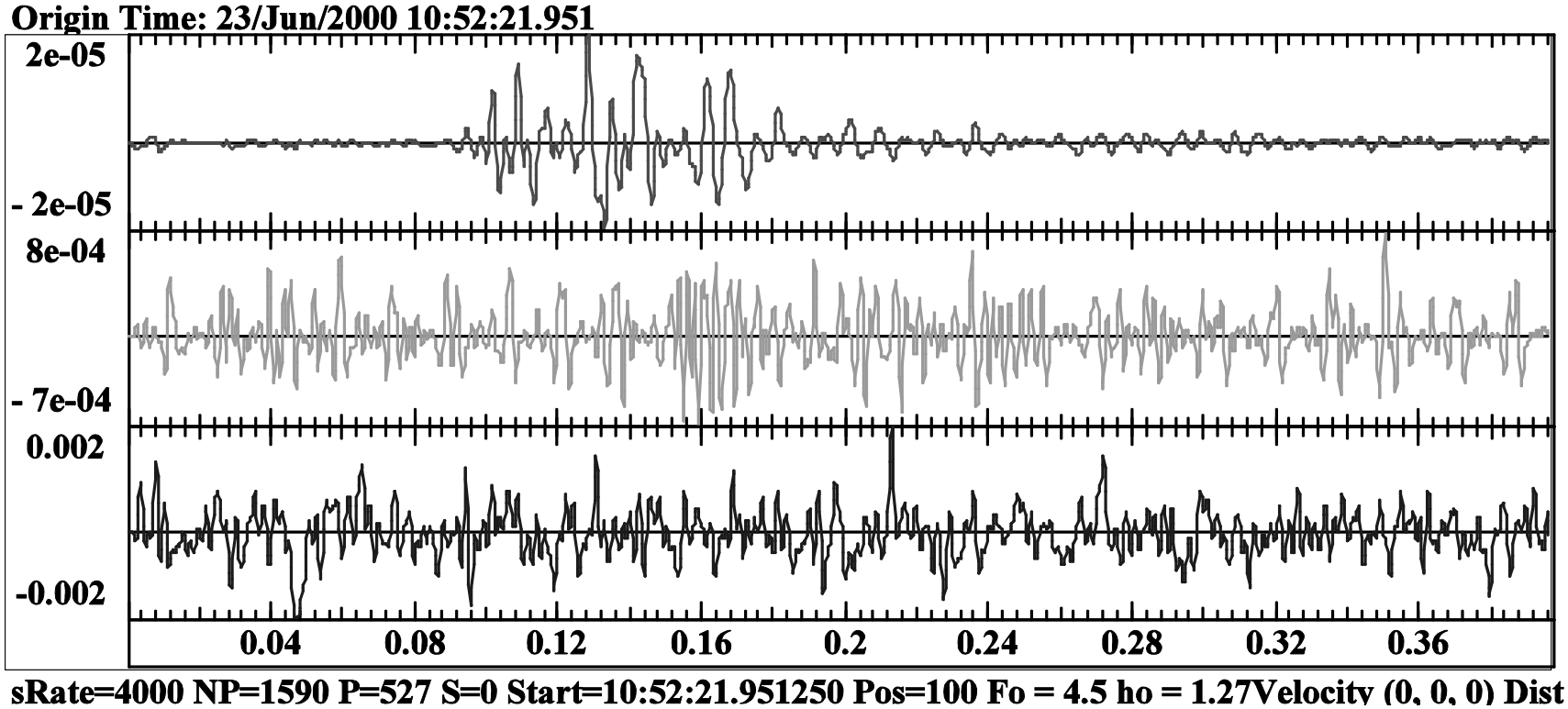
A1.2 Seismic events measured at 500 kHz


Origin Time: 23/Jun/2000 11:47:35.503
2e-04
- 1e-04
9e-04
- 9e-04
0.002
-0.002
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=536 S=0 Start=11:47:35.503750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

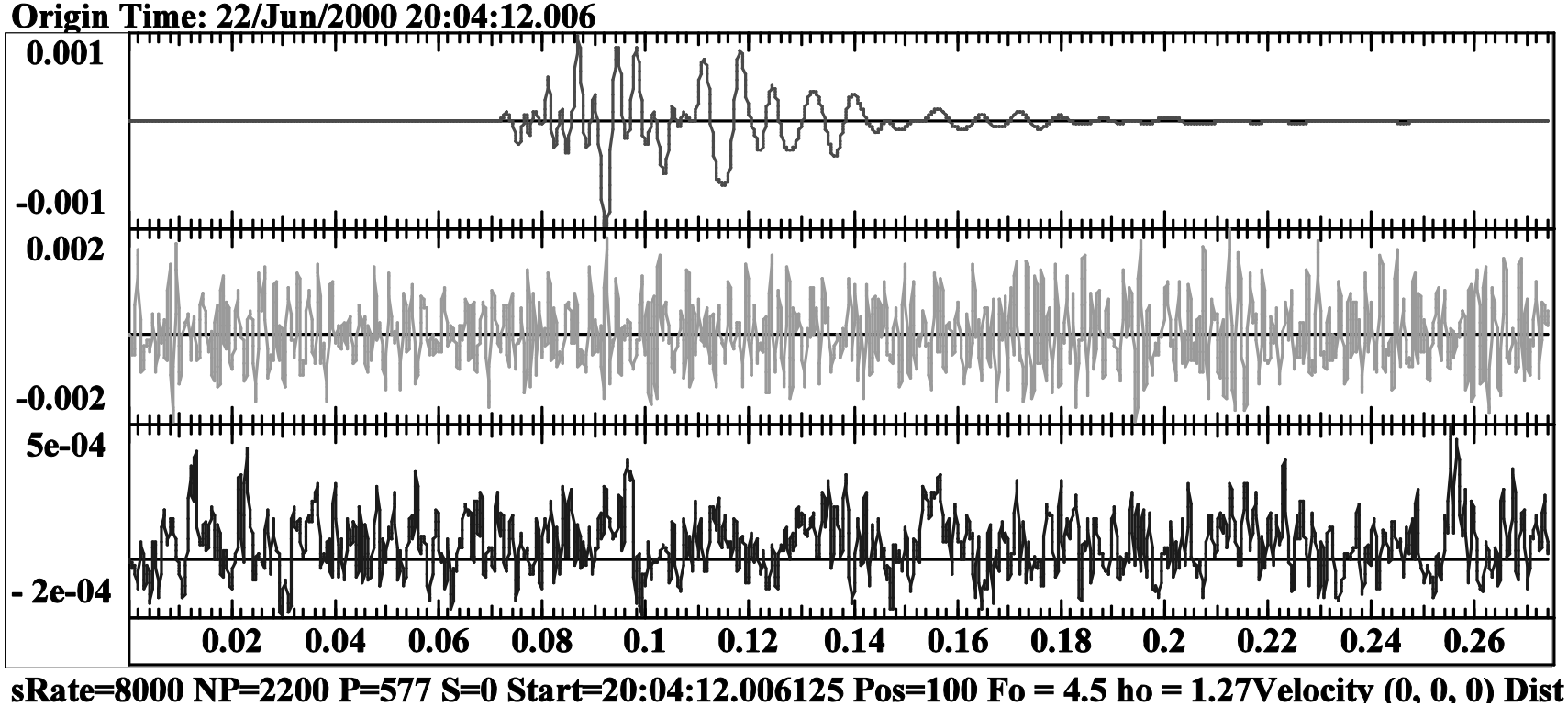

Origin Time: 23/Jun/2000 10:23:02.300
4e-04
- 4e-04
7e-04
- 5e-04
0.001
-0.002
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
sRate=8000 NP=4200 P=575 S=0 Start=10:23:02.300000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

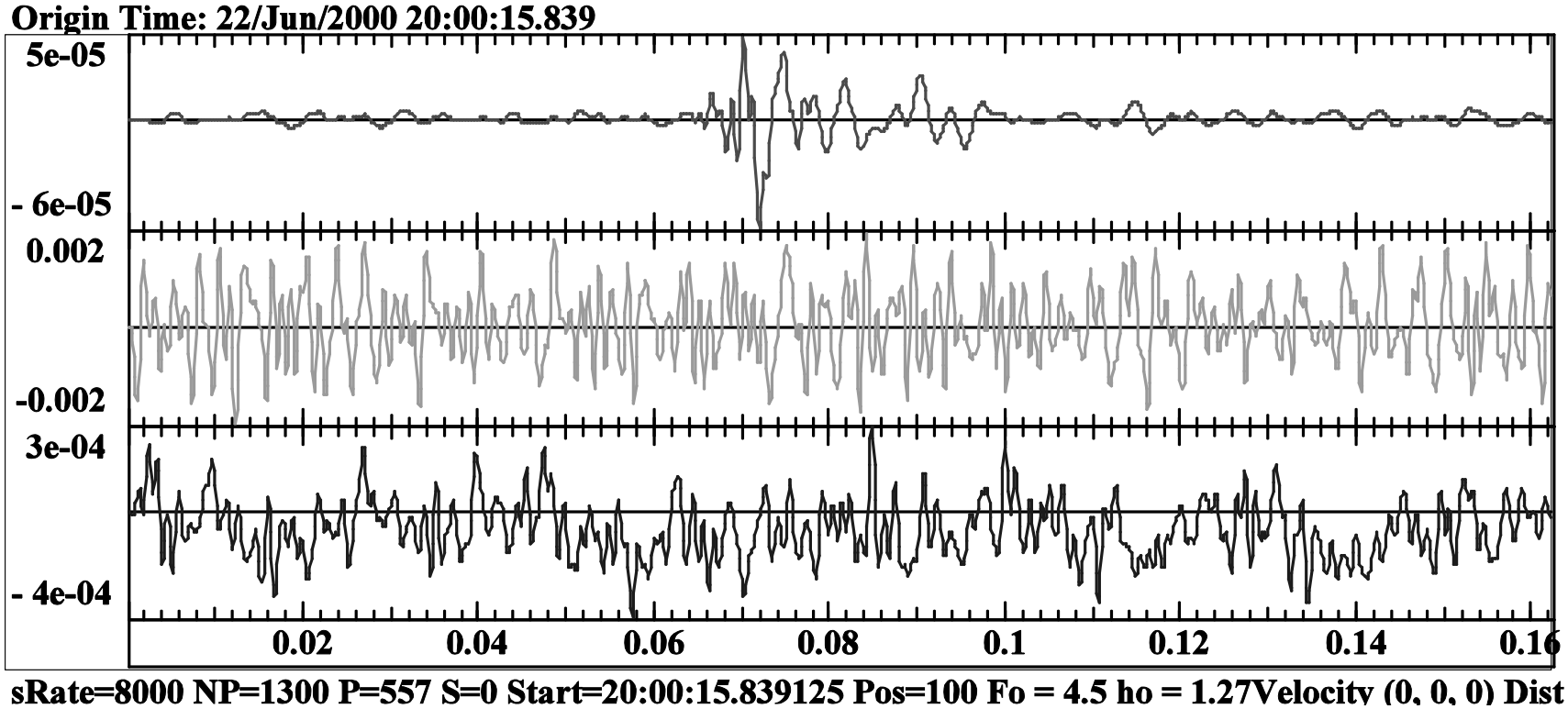

Origin Time: 23/Jun/2000 10:28:47.992
9e-04
- 8e-04
6e-04
- 7e-04
0.001
-0.002
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
sRate=8000 NP=4400 P=597 S=0 Start=10:28:47.992375 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 11:05:26.343
1e-04
- 1e-04
0.001
- 9e-04
0.002
-0.002
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
sRate=2667 NP=1490 P=507 S=0 Start=11:05:26.343250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

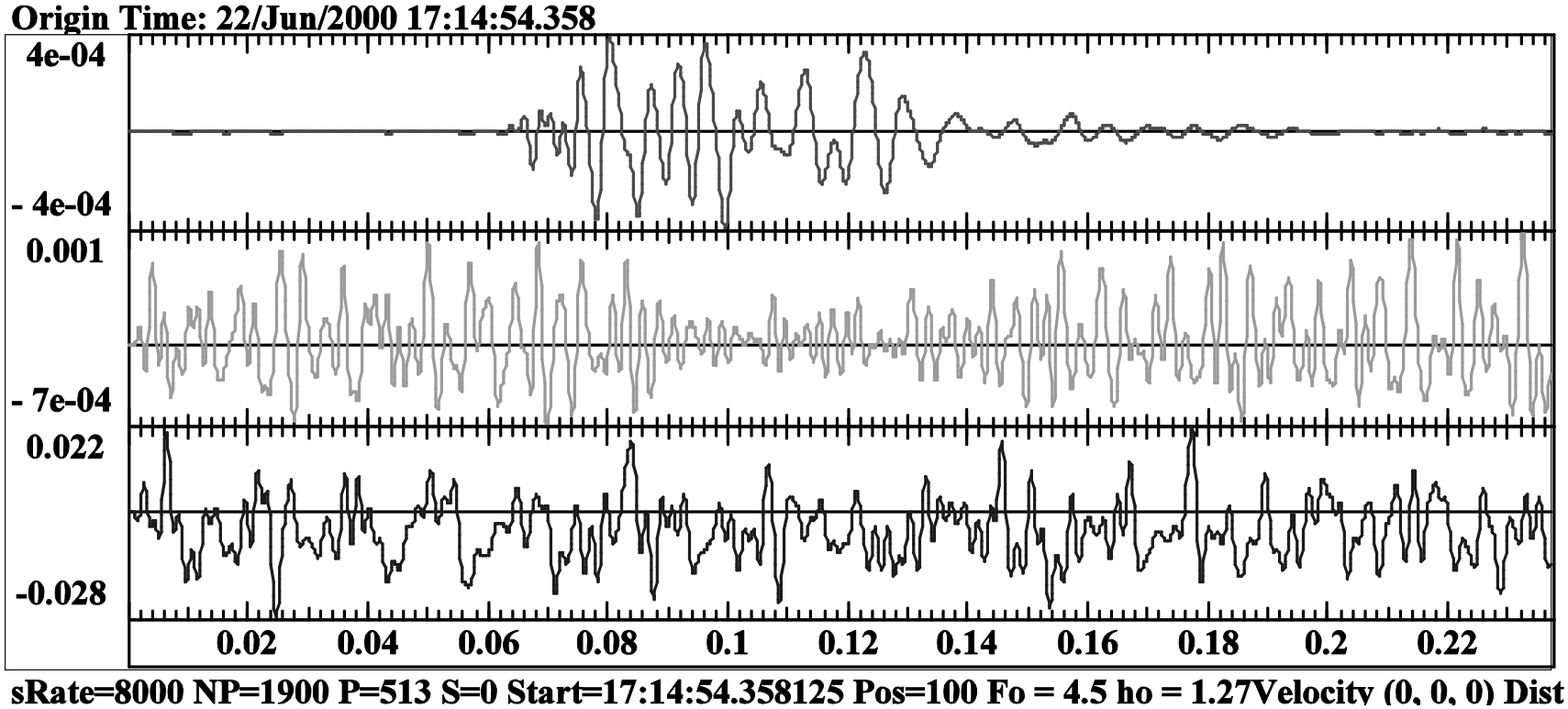

Origin Time: 23/Jun/2000 10:52:21.951
2e-05
- 2e-05
8e-04
- 7e-04
0.002
-0.002
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1590 P=527 S=0 Start=10:52:21.951250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

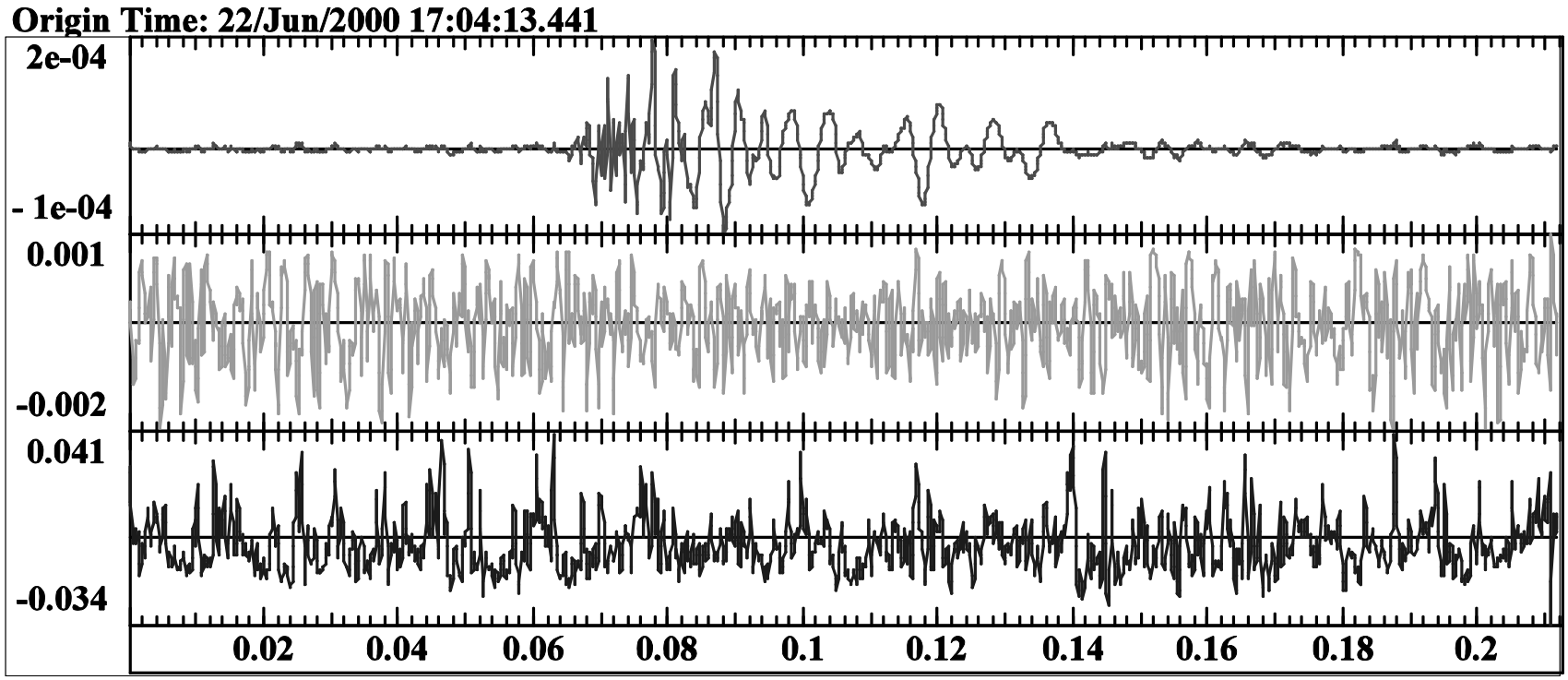
A1.3 Seismic events measured at 1.0 MHz

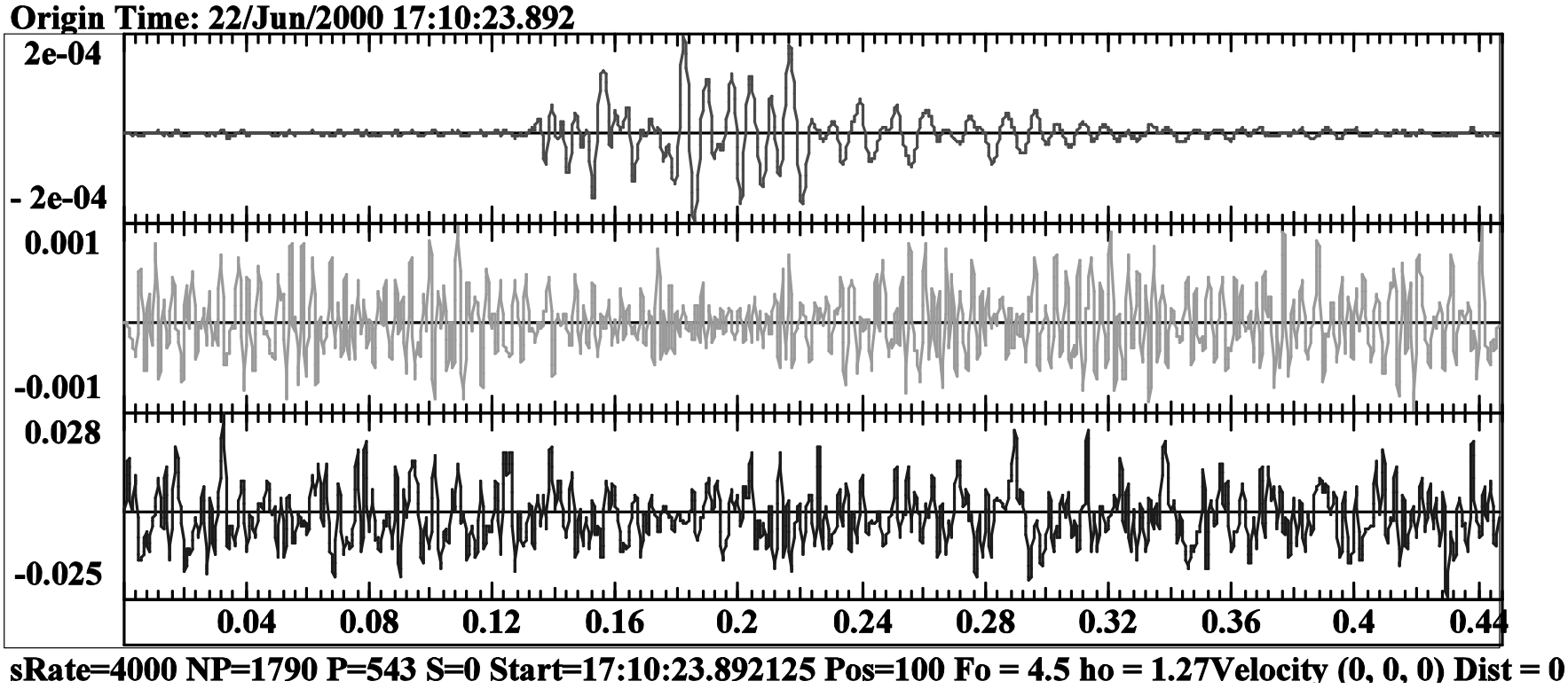

Origin Time: 22/Jun/2000 20:04:12.006
0.001
-0.001
0.002
-0.002
5e-04
- 2e-04
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2200 P=577 S=0 Start=20:04:12.006125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

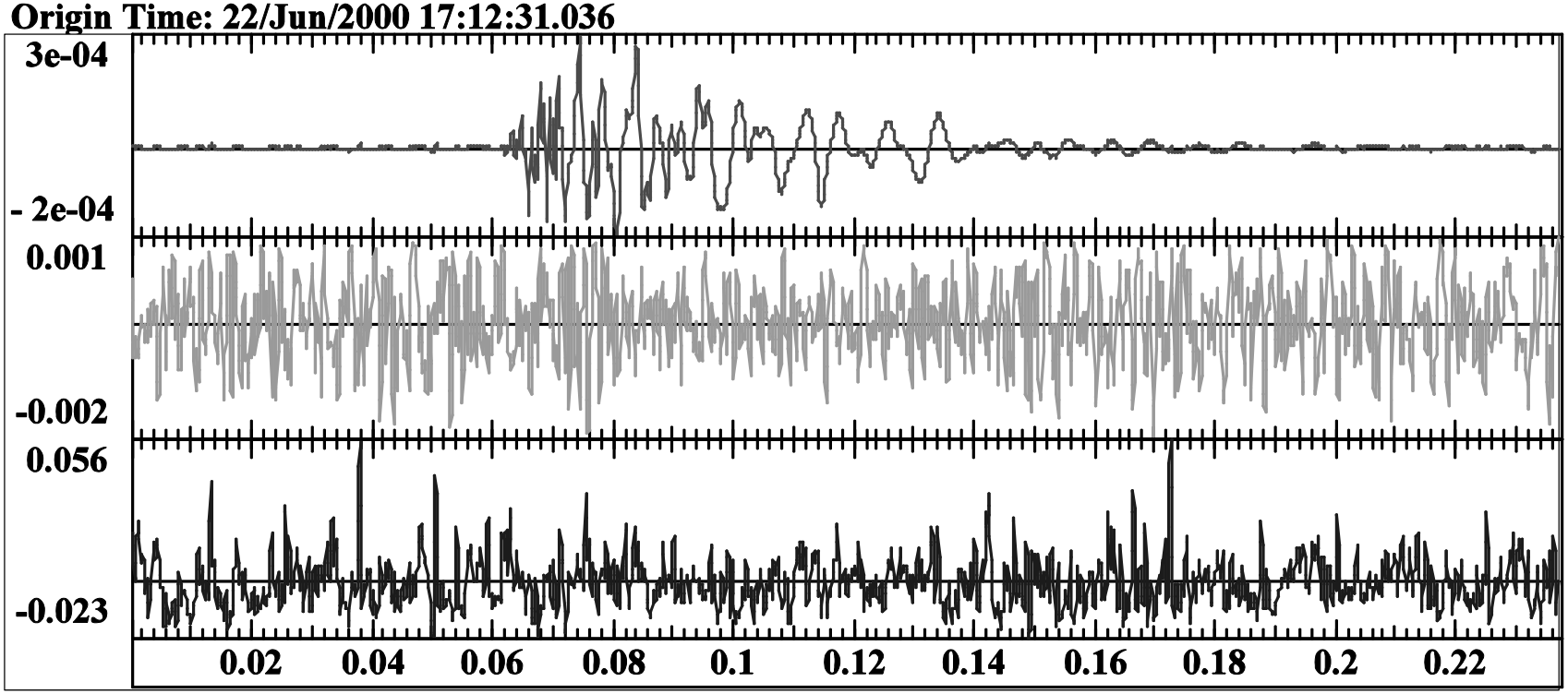

Origin Time: 22/Jun/2000 20:00:15.839
5e-05
- 6e-05
0.002
-0.002
3e-04
- 4e-04
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
sRate=8000 NP=1300 P=557 S=0 Start=20:00:15.839125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

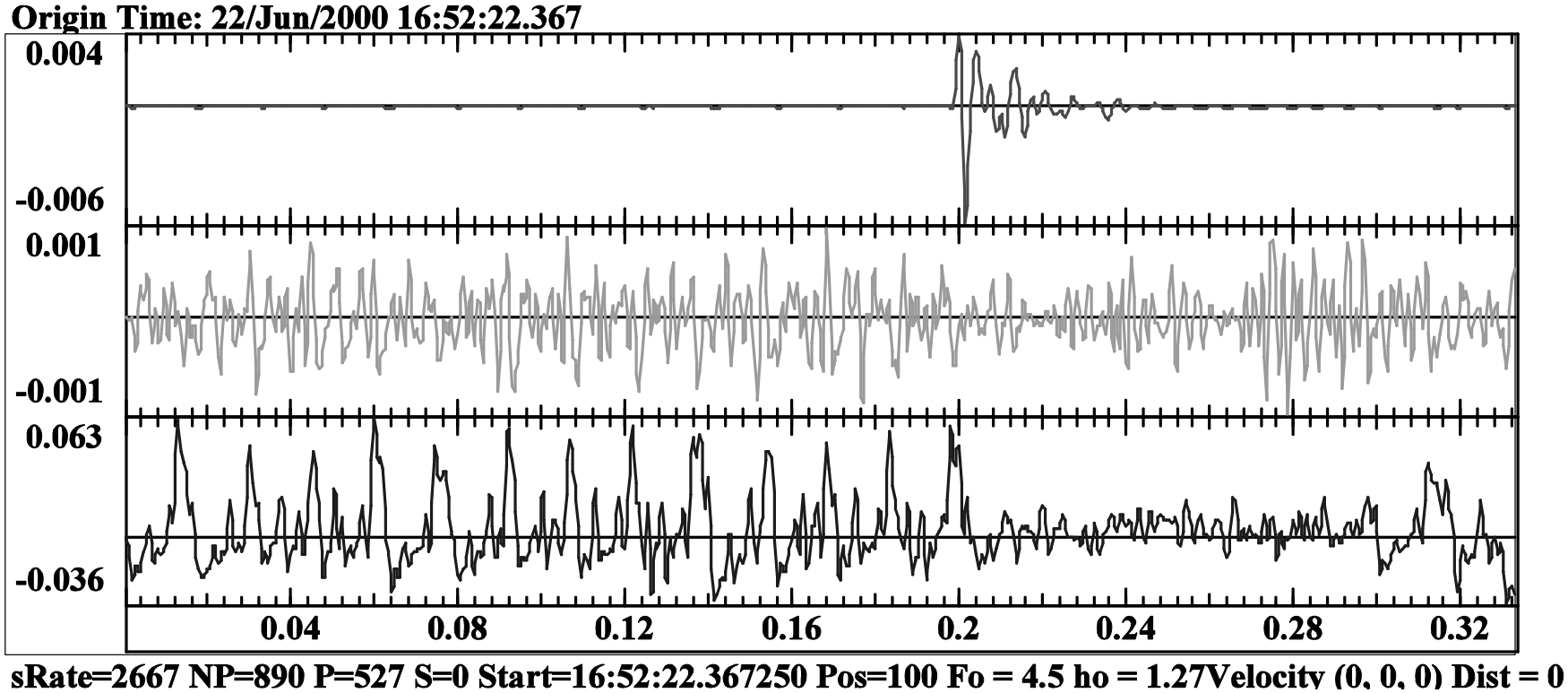
A1.4 Seismic events measured at 2.31 MHz

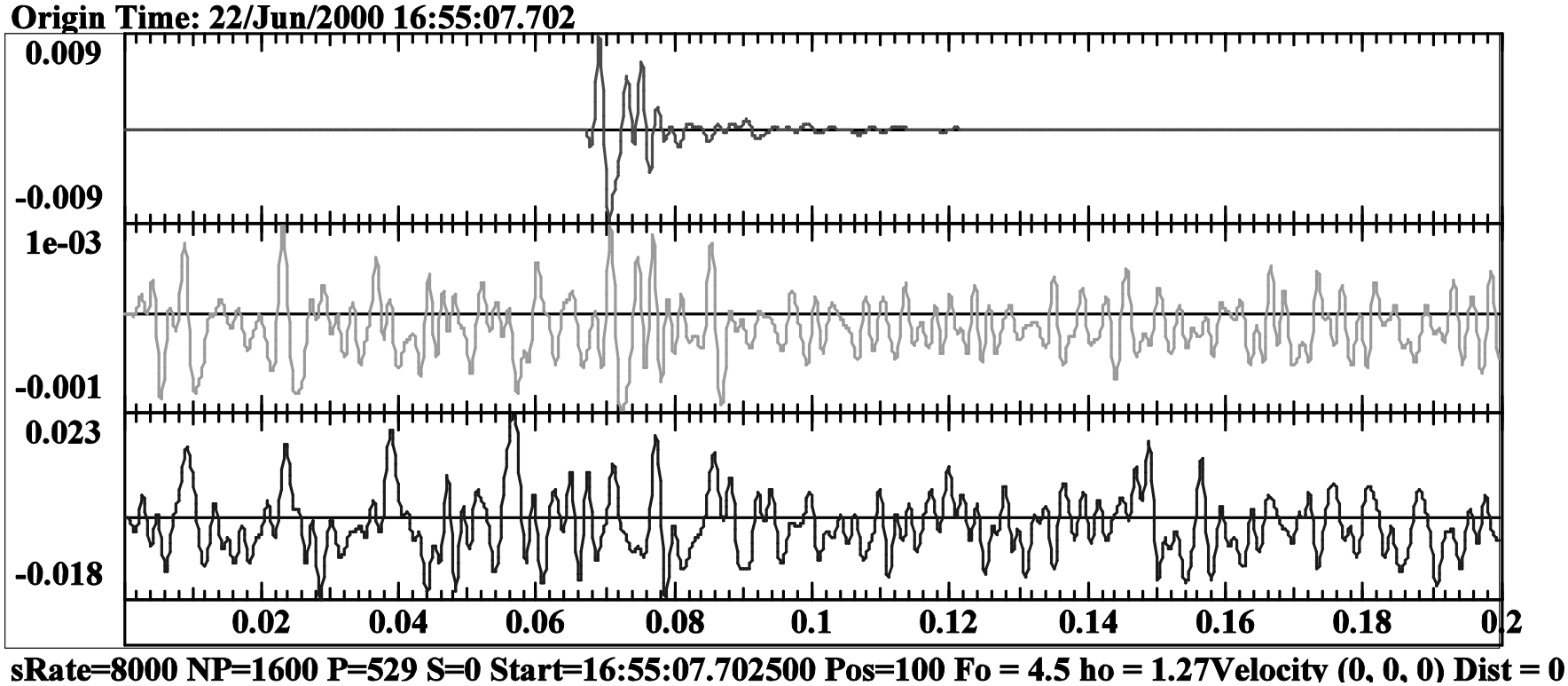

Origin Time: 22/Jun/2000 17:14:54.358
4e-04
- 4e-04
0.001
- 7e-04
0.022
-0.028
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
sRate=8000 NP=1900 P=513 S=0 Start=17:14:54.358125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

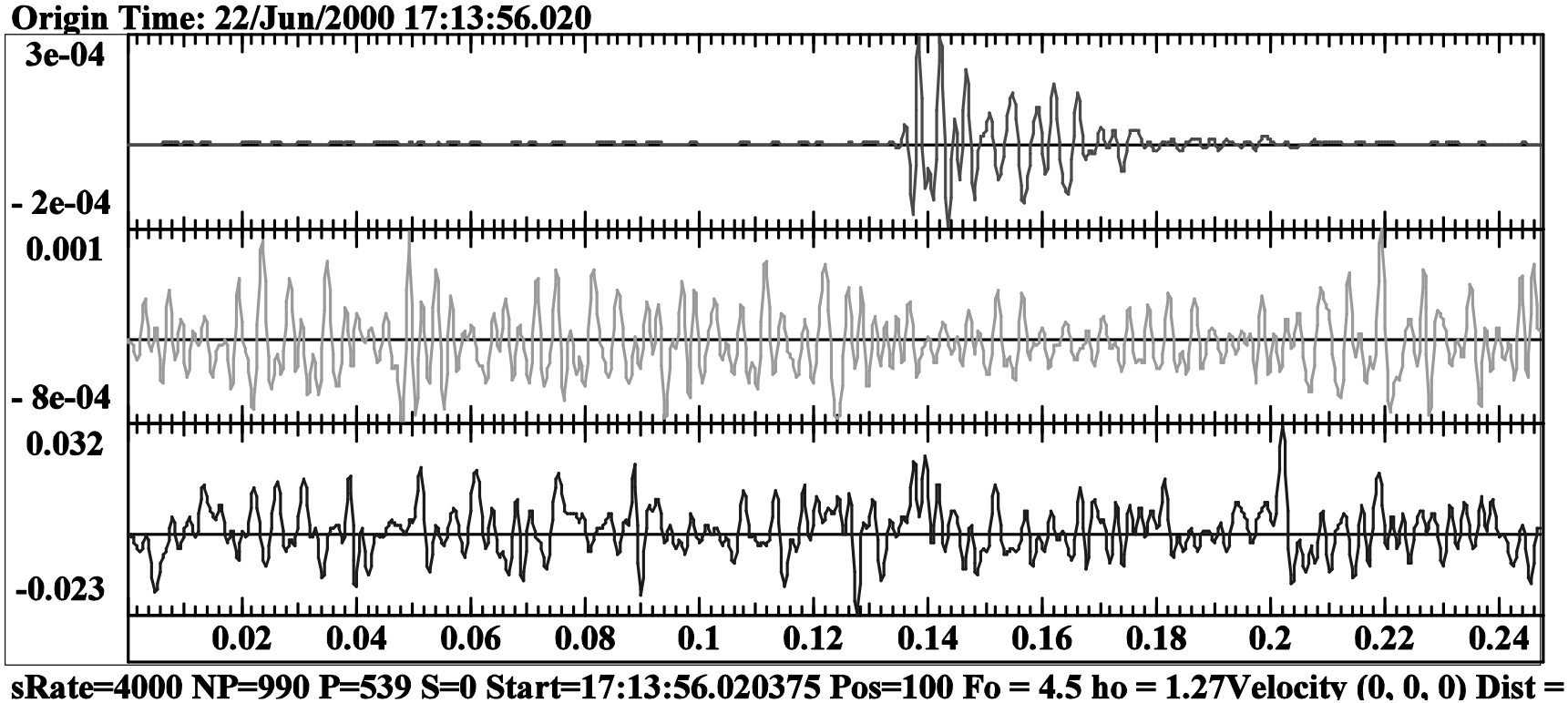

Origin Time: 22/Jun/2000 17:04:13.441
2e-04
- 1e-04
0.001
-0.002
0.041
-0.034
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1700 P=554 S=0 Start=17:04:13.441625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

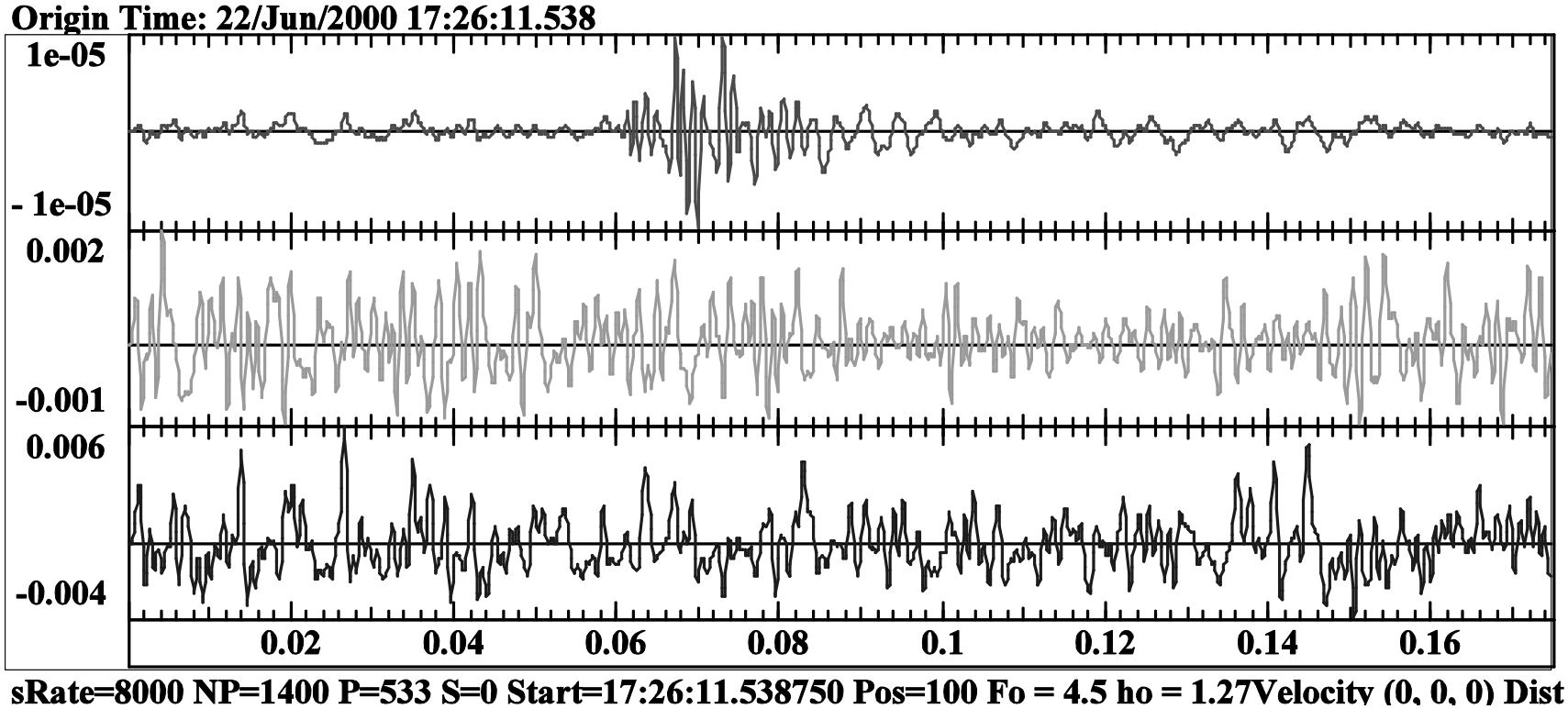

Origin Time: 22/Jun/2000 17:10:23.892
2e-04
- 2e-04
0.001
-0.001
0.028
-0.025
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
sRate=4000 NP=1790 P=543 S=0 Start=17:10:23.892125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 17:12:31.036
3e-04
- 2e-04
0.001
-0.002
0.056
-0.023
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
sRate=8000 NP=1900 P=521 S=0 Start=17:12:31.036000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist =

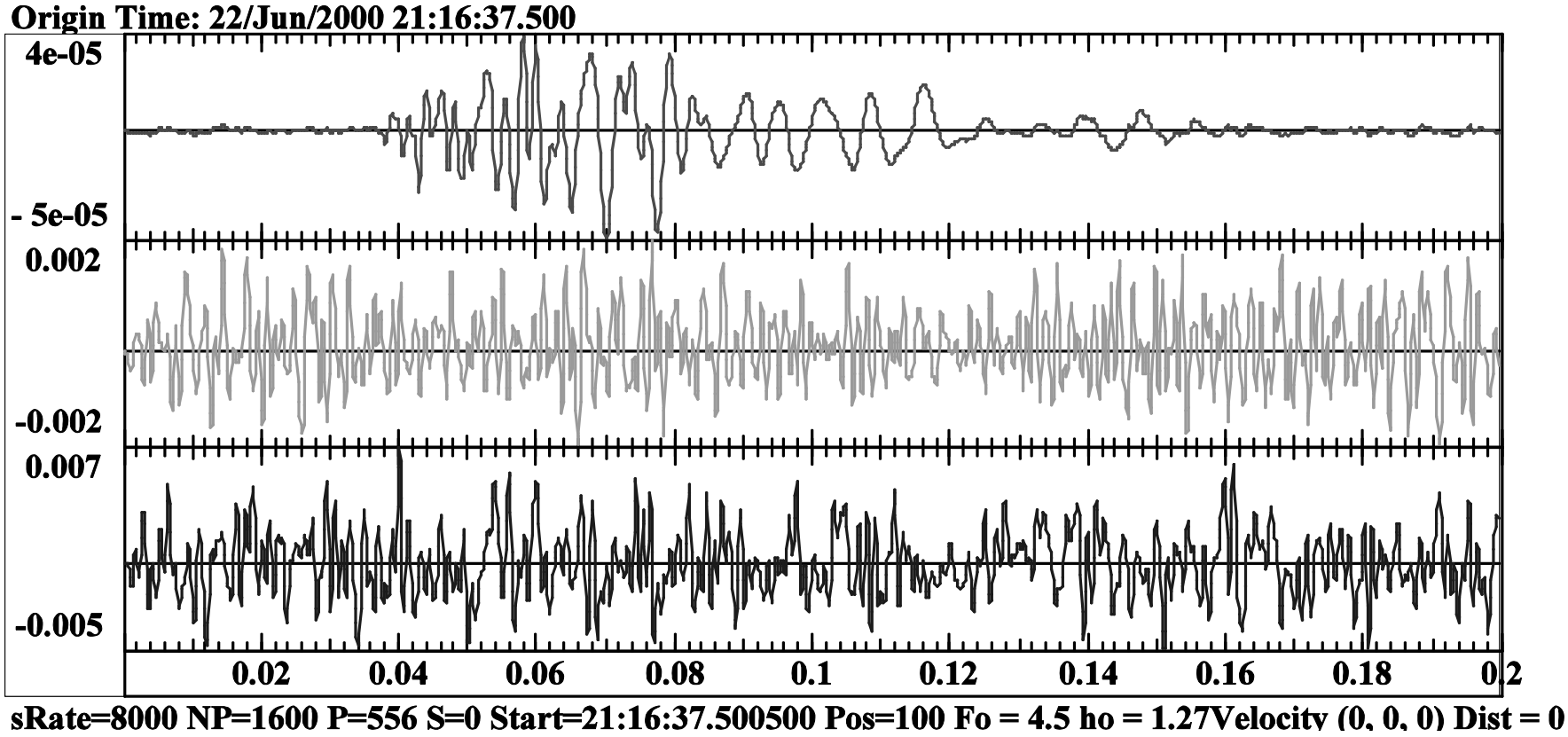

Origin Time: 22/Jun/2000 16:52:22.367
0.004
-0.006
0.001
-0.001
0.063
-0.036
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=2667 NP=890 P=527 S=0 Start=16:52:22.367250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

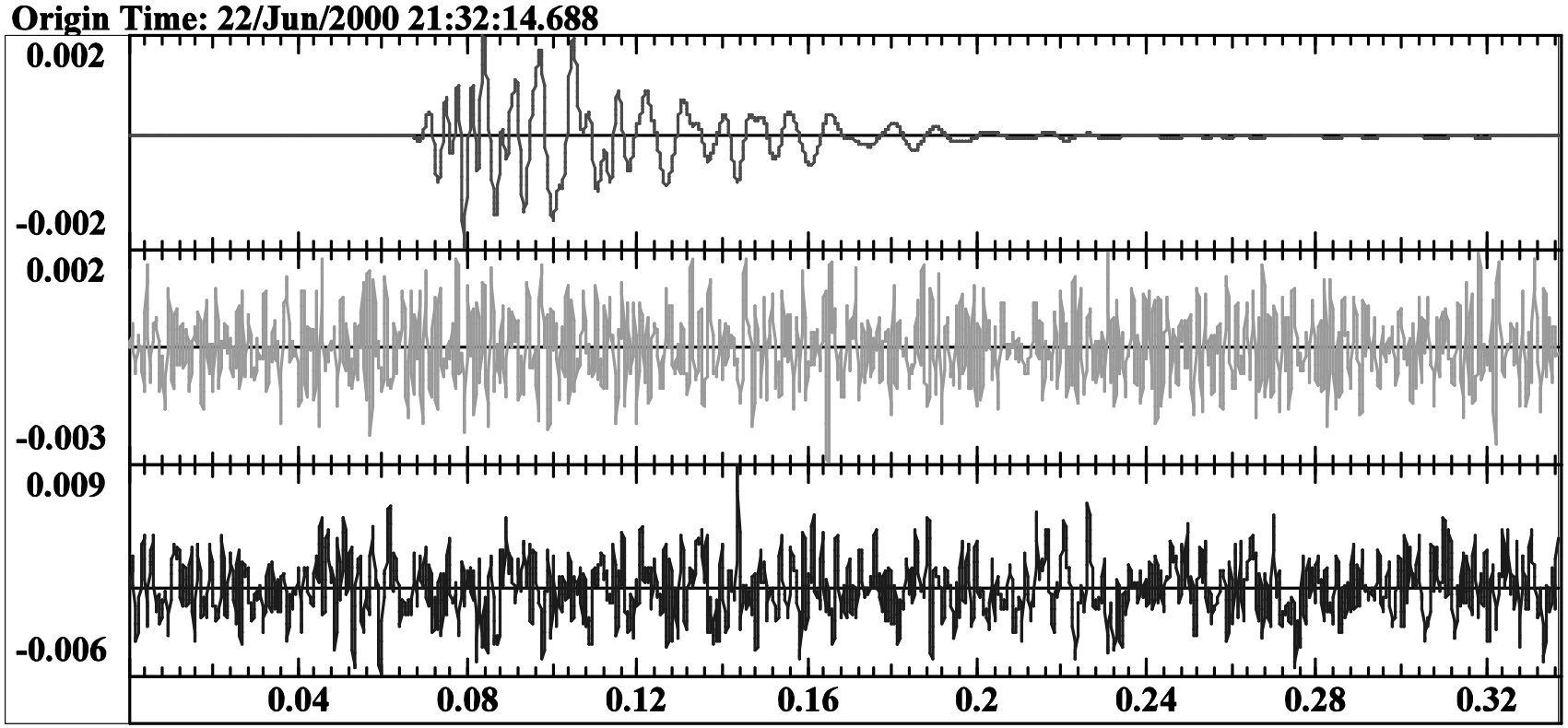

Origin Time: 22/Jun/2000 16:55:07.702
0.009
-0.009
1e-03
-0.001
0.023
-0.018
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=529 S=0 Start=16:55:07.702500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

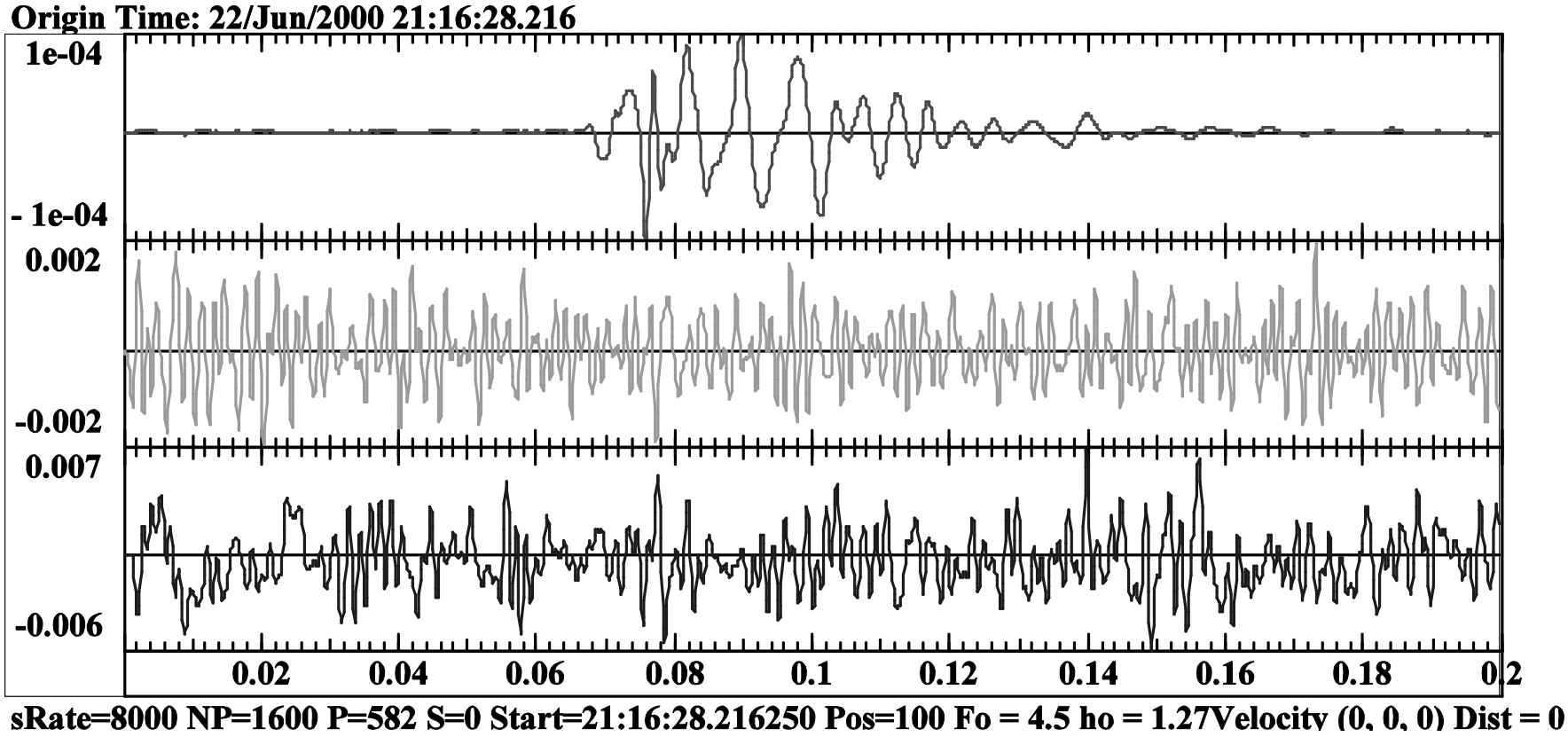

Origin Time: 22/Jun/2000 17:13:56.020
3e-04
- 2e-04
0.001
- 8e-04
0.032
-0.023
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
sRate=4000 NP=990 P=539 S=0 Start=17:13:56.020375 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

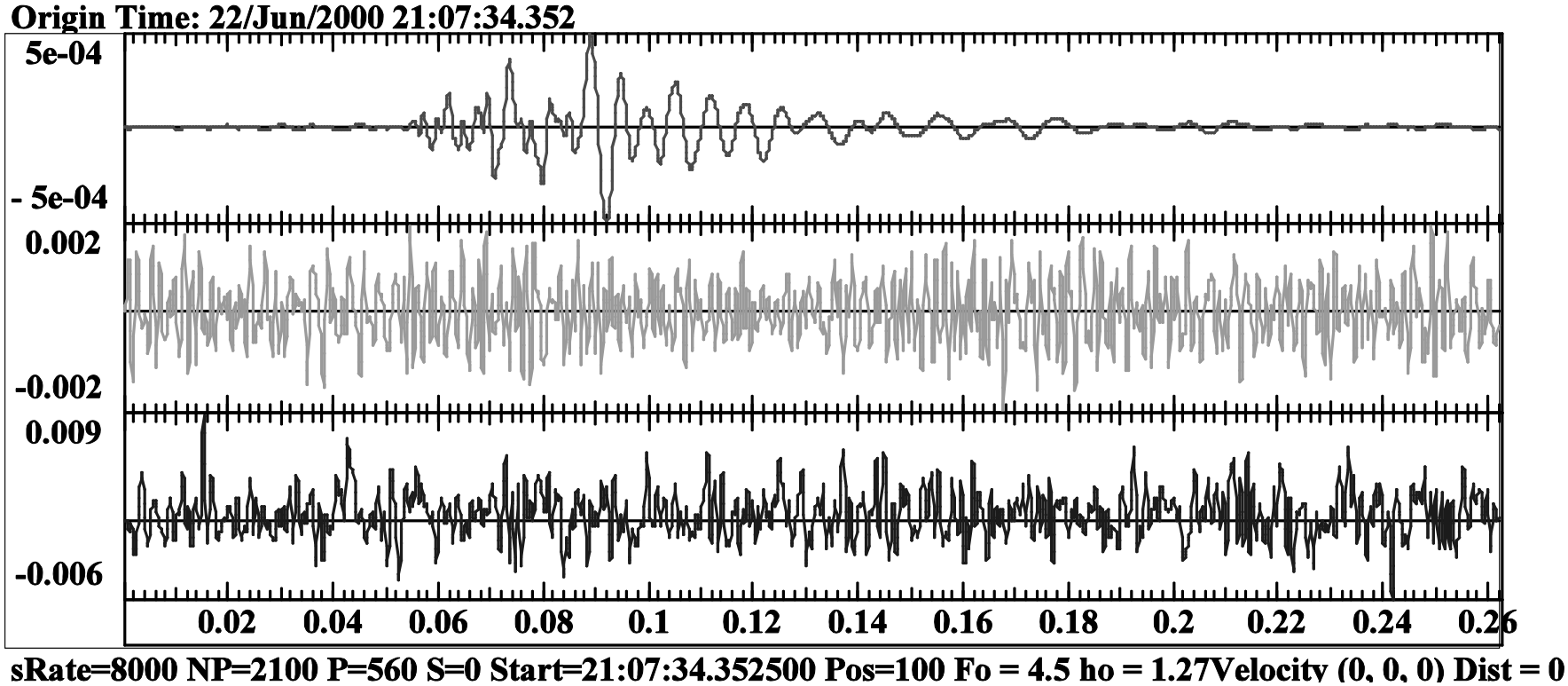

Origin Time: 22/Jun/2000 17:26:11.538
1e-05
- 1e-05
0.002
-0.001
0.006
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
sRate=8000 NP=1400 P=533 S=0 Start=17:26:11.538750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

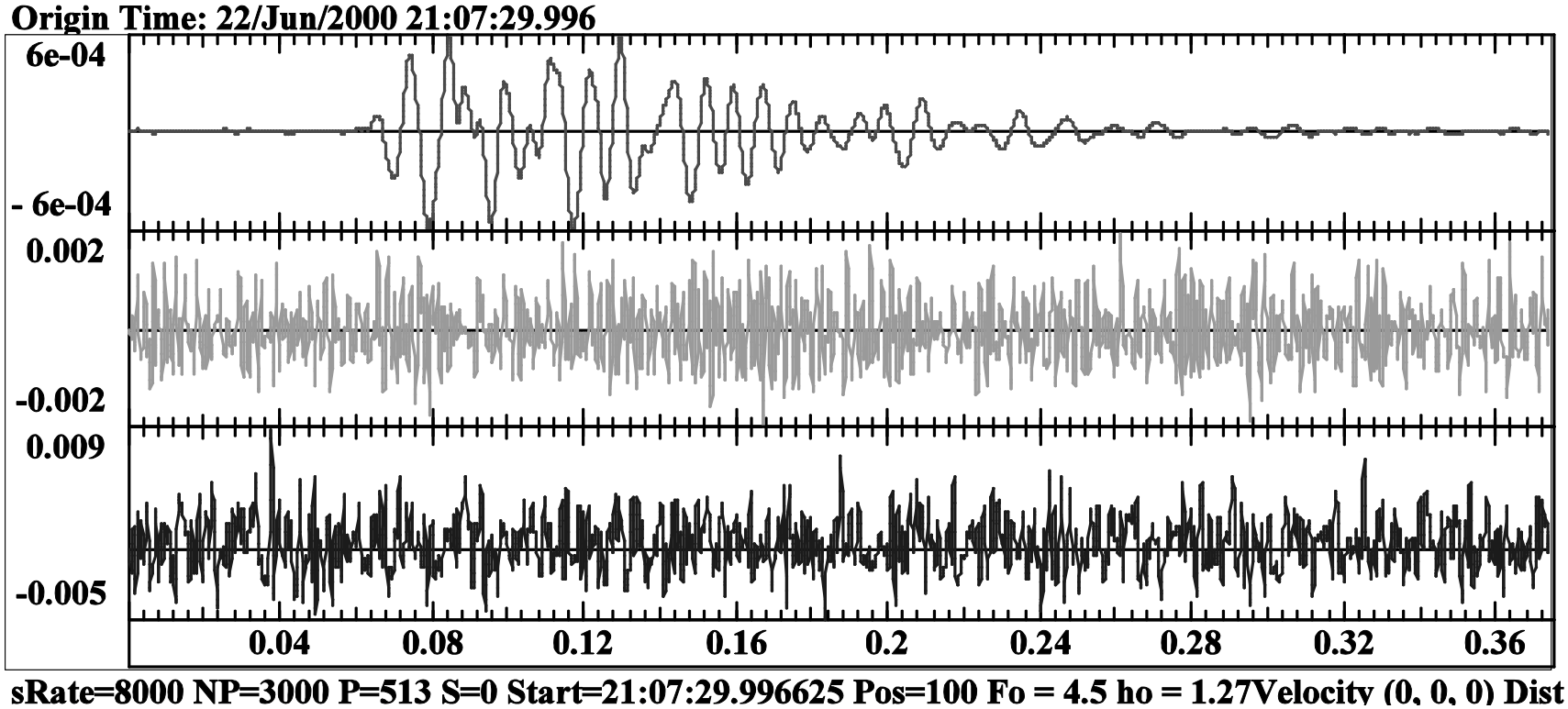
A1.5 Seismic events measured at 2.5 MHz

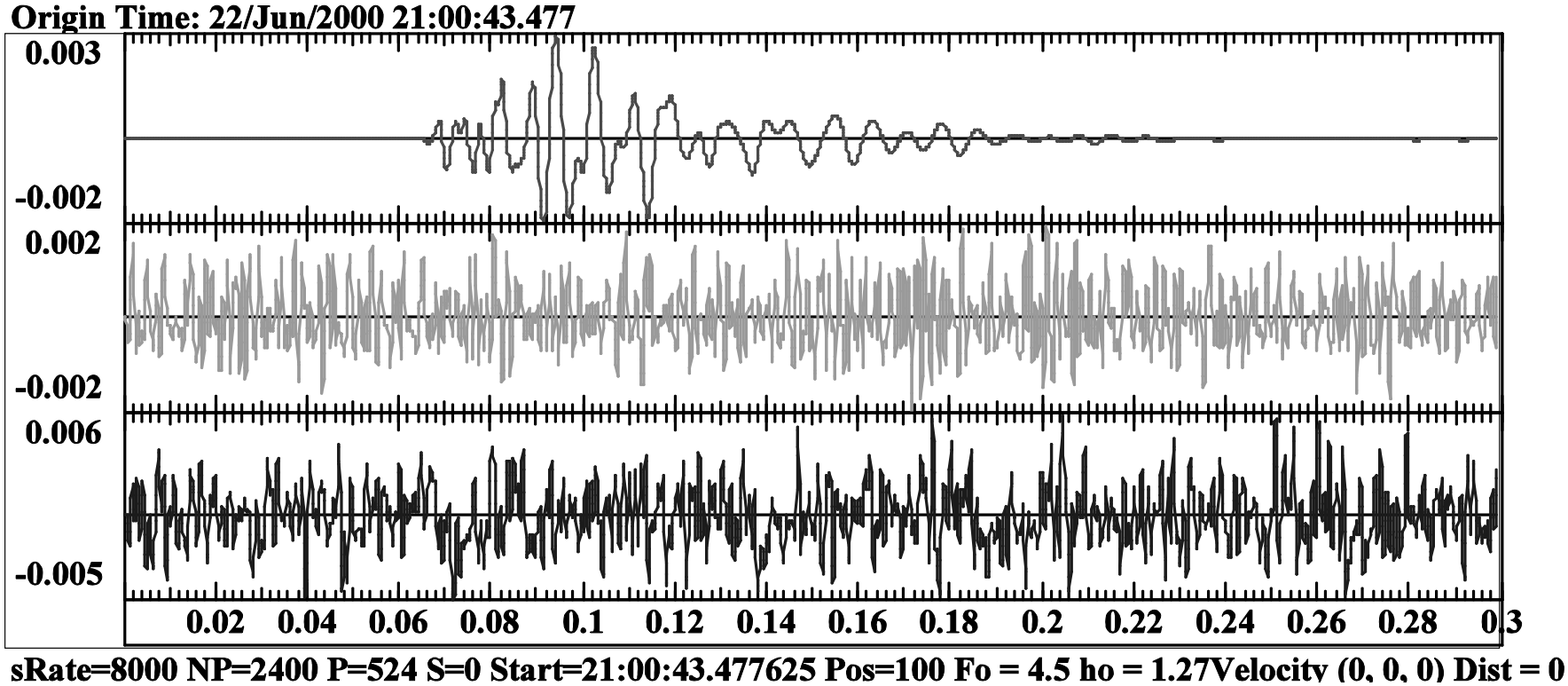

Origin Time: 22/Jun/2000 21:16:37.500
4e-05
- 5e-05
0.002
-0.002
0.007
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=556 S=0 Start=21:16:37.500500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

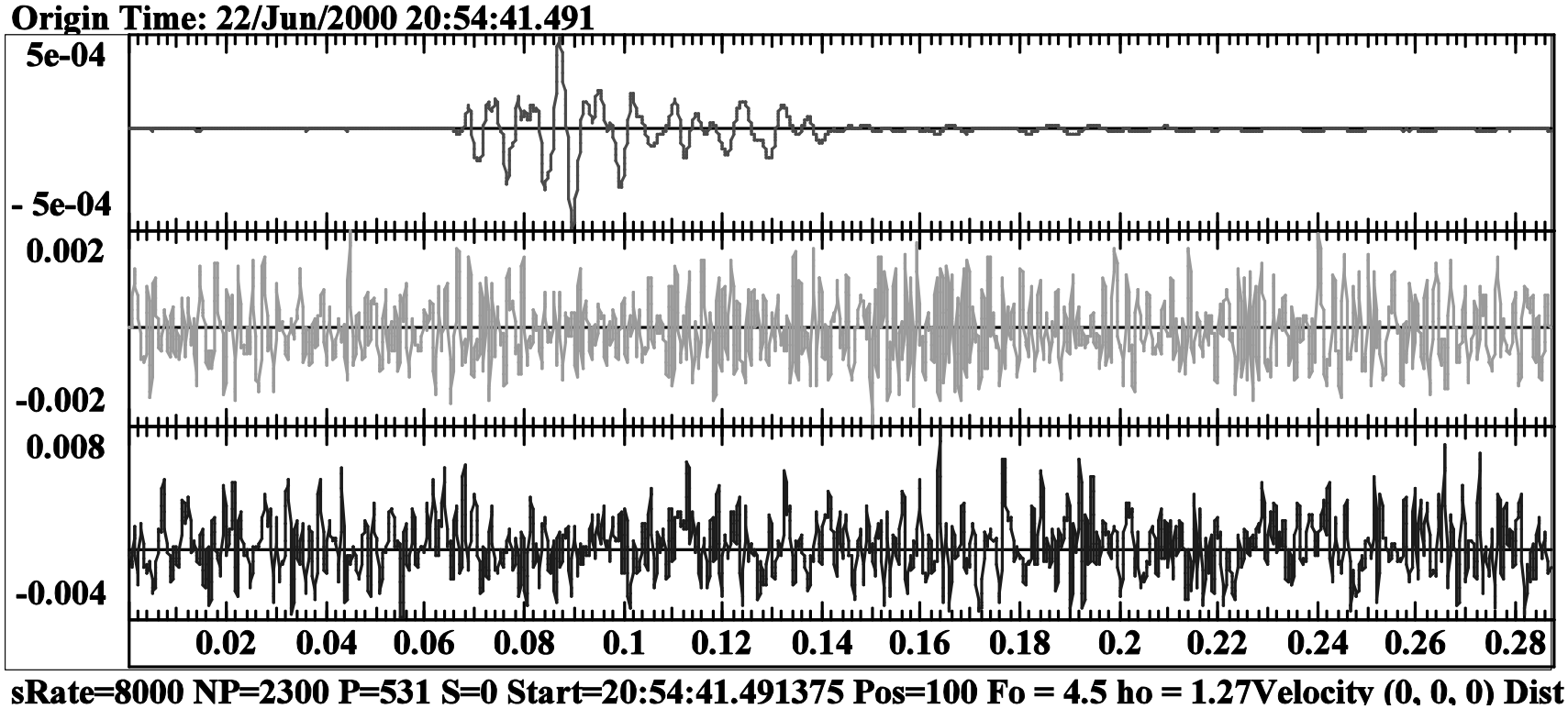

Origin Time: 22/Jun/2000 21:32:14.688
0.002
-0.002
0.002
-0.003
0.009
-0.006
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=8000 NP=2700 P=546 S=0 Start=21:32:14.688125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 21:16:28.216
1e-04
- 1e-04
0.002
-0.002
0.007
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=582 S=0 Start=21:16:28.216250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

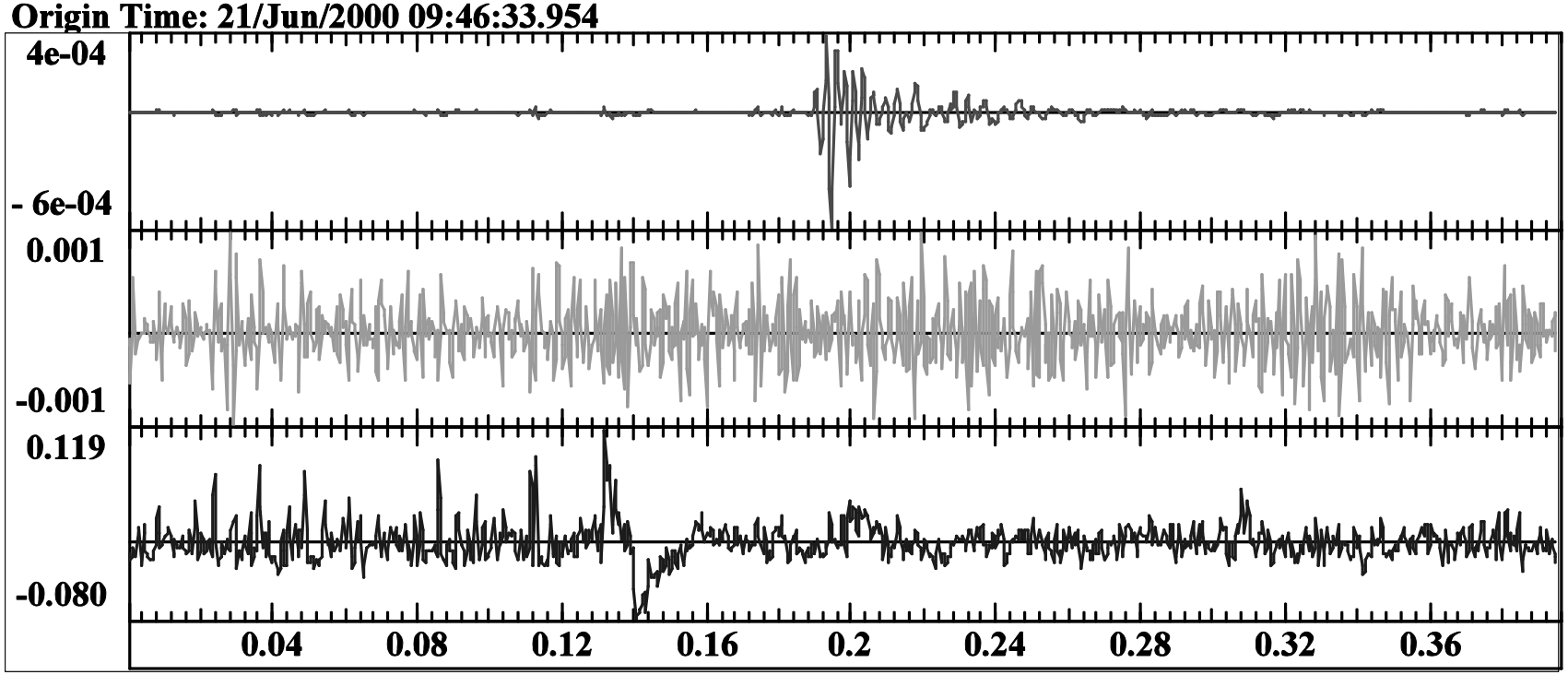

Origin Time: 22/Jun/2000 21:07:34.352
5e-04
- 5e-04
0.002
-0.002
0.009
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2100 P=560 S=0 Start=21:07:34.352500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

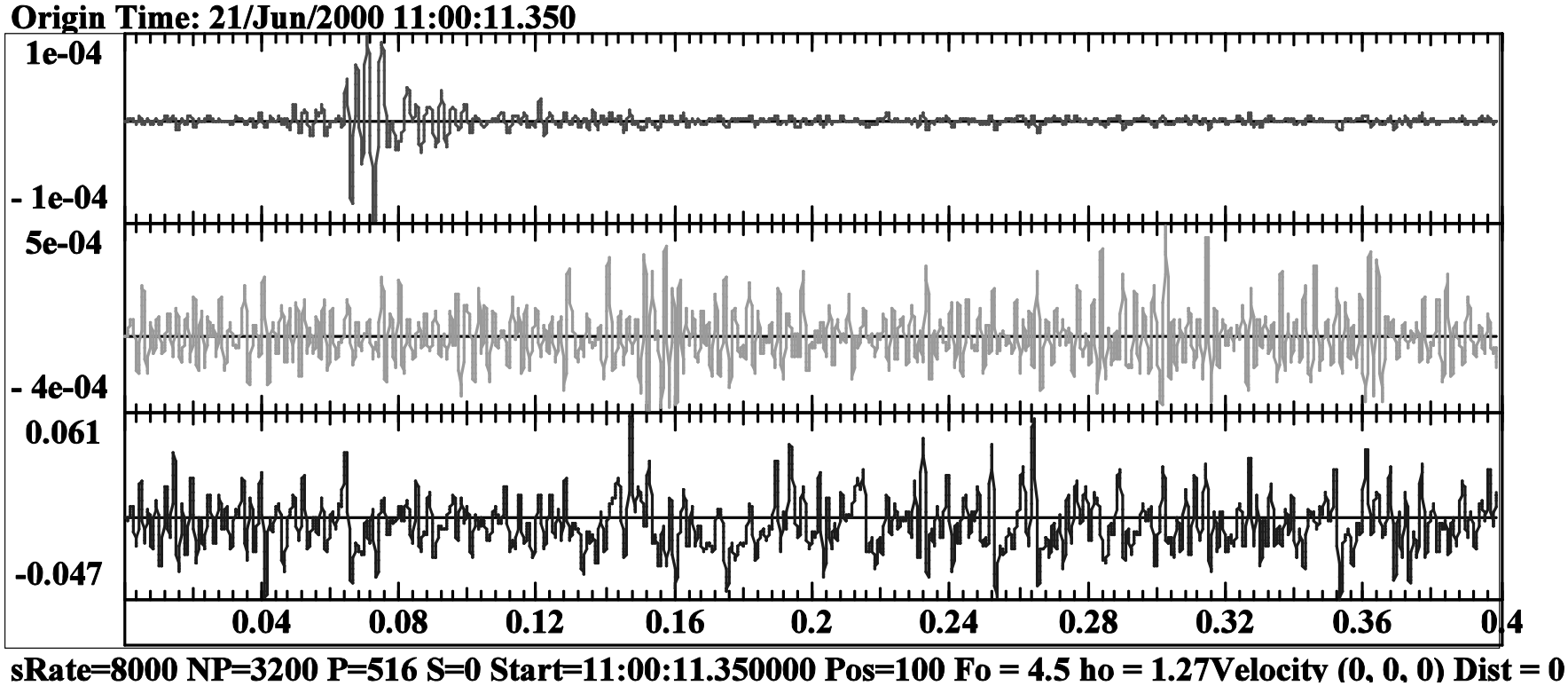

Origin Time: 22/Jun/2000 21:07:29.996
6e-04
- 6e-04
0.002
-0.002
0.009
-0.005
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=8000 NP=3000 P=513 S=0 Start=21:07:29.996625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

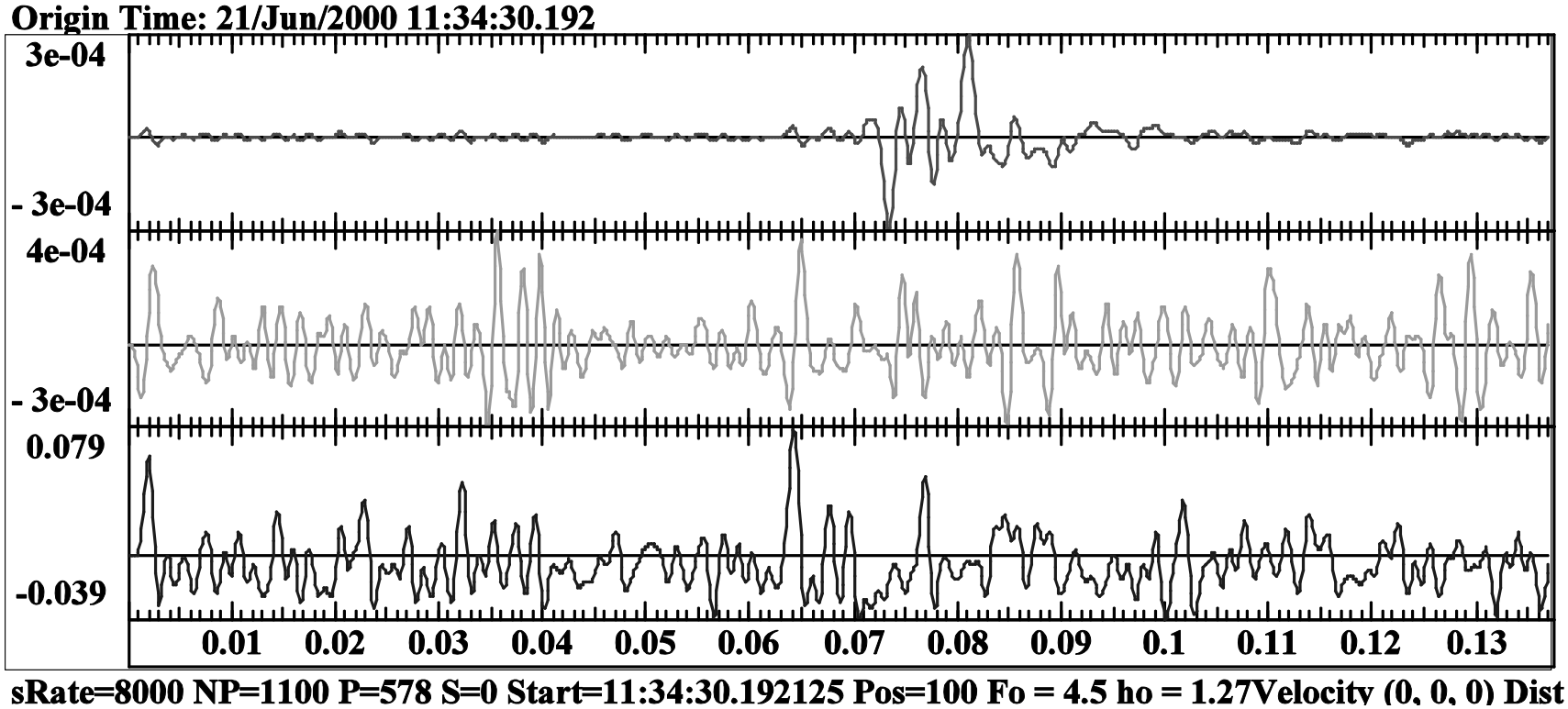

Origin Time: 22/Jun/2000 21:00:43.477
0.003
-0.002
0.002
-0.002
0.006
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
sRate=8000 NP=2400 P=524 S=0 Start=21:00:43.477625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

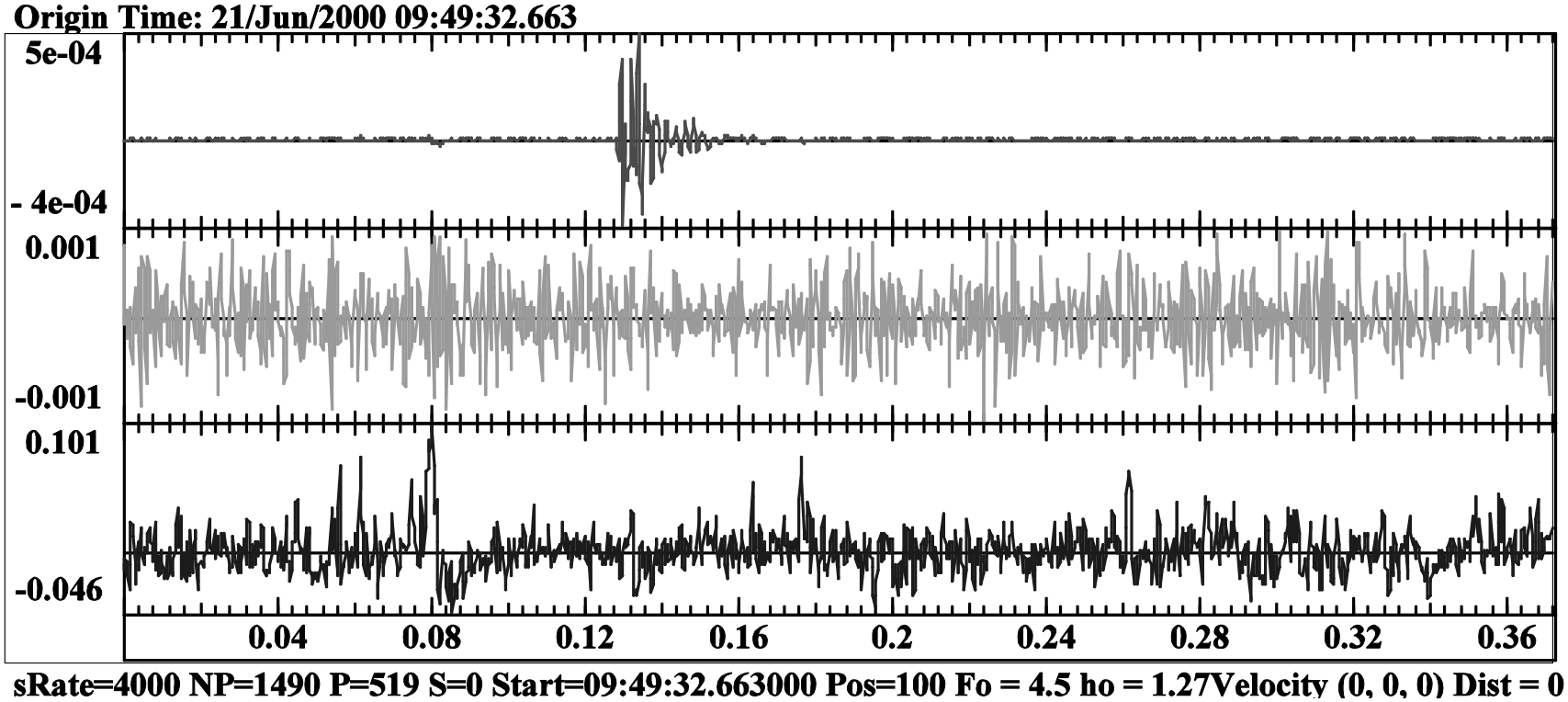

Origin Time: 22/Jun/2000 20:54:41.491
5e-04
- 5e-04
0.002
-0.002
0.008
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
sRate=8000 NP=2300 P=531 S=0 Start=20:54:41.491375 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

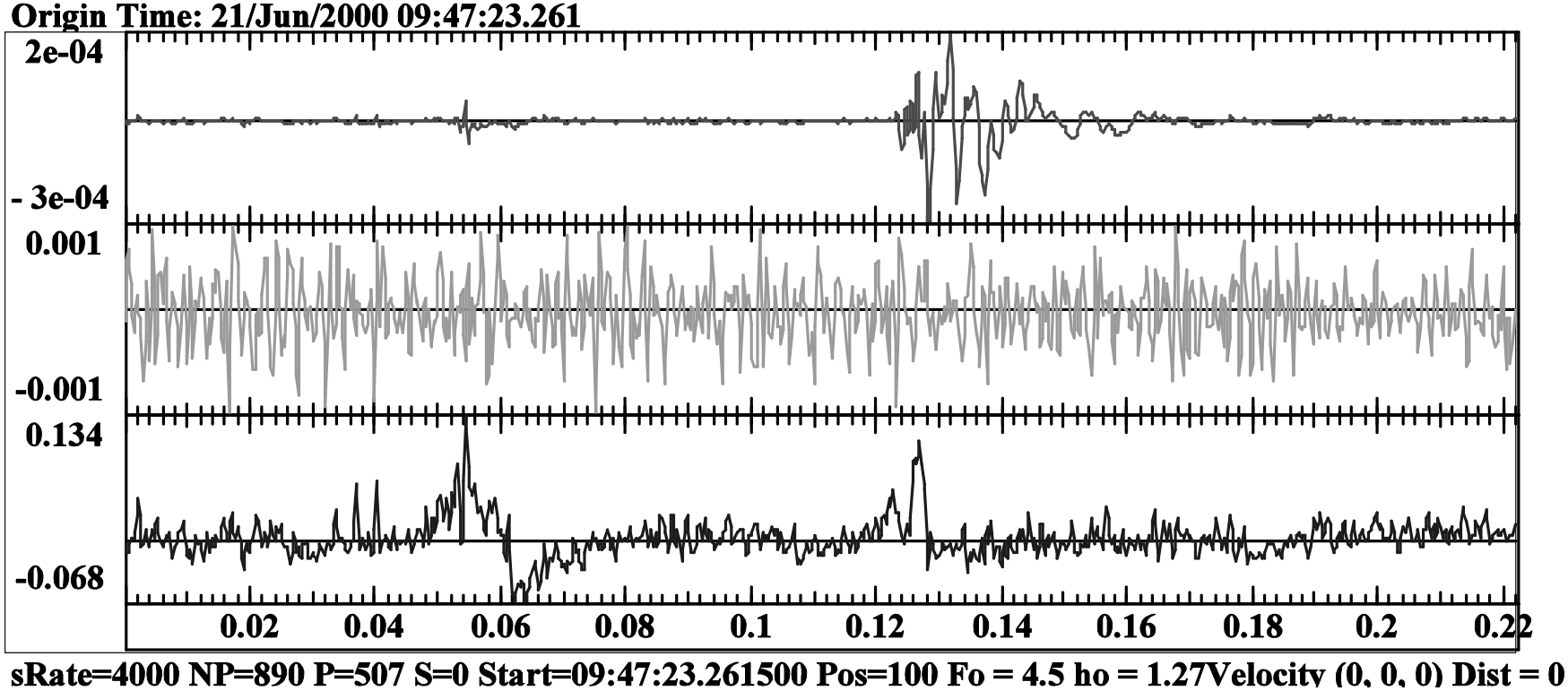
A1.6 Seismic events measured at 4.92 MHz

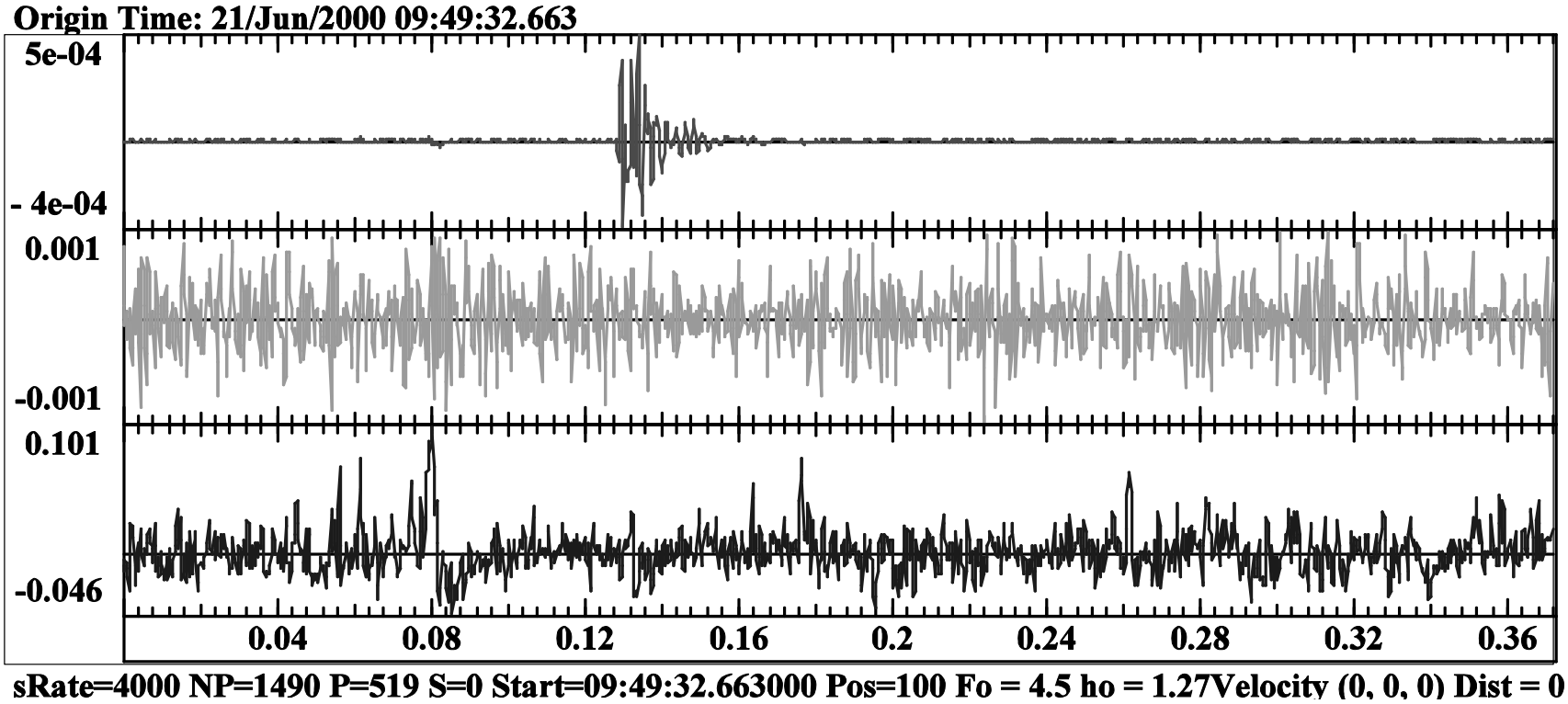

Origin Time: 21/Jun/2000 09:46:33.954
4e-04
- 6e-04
0.001
-0.001
0.119
-0.080
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=2667 NP=1057 P=509 S=0 Start=09:46:33.954750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

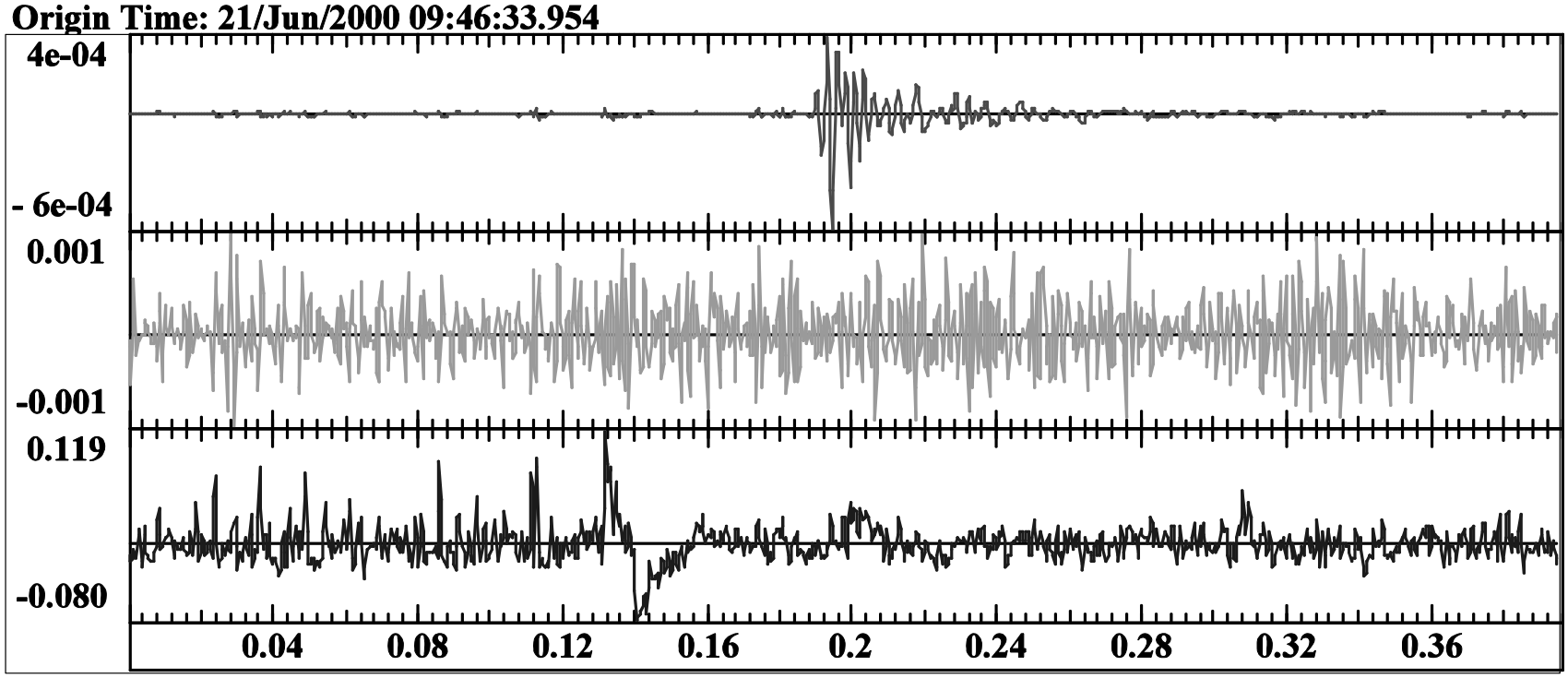

Origin Time: 21/Jun/2000 11:00:11.350
1e-04
- 1e-04
5e-04
- 4e-04
0.061
-0.047
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
sRate=8000 NP=3200 P=516 S=0 Start=11:00:11.350000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

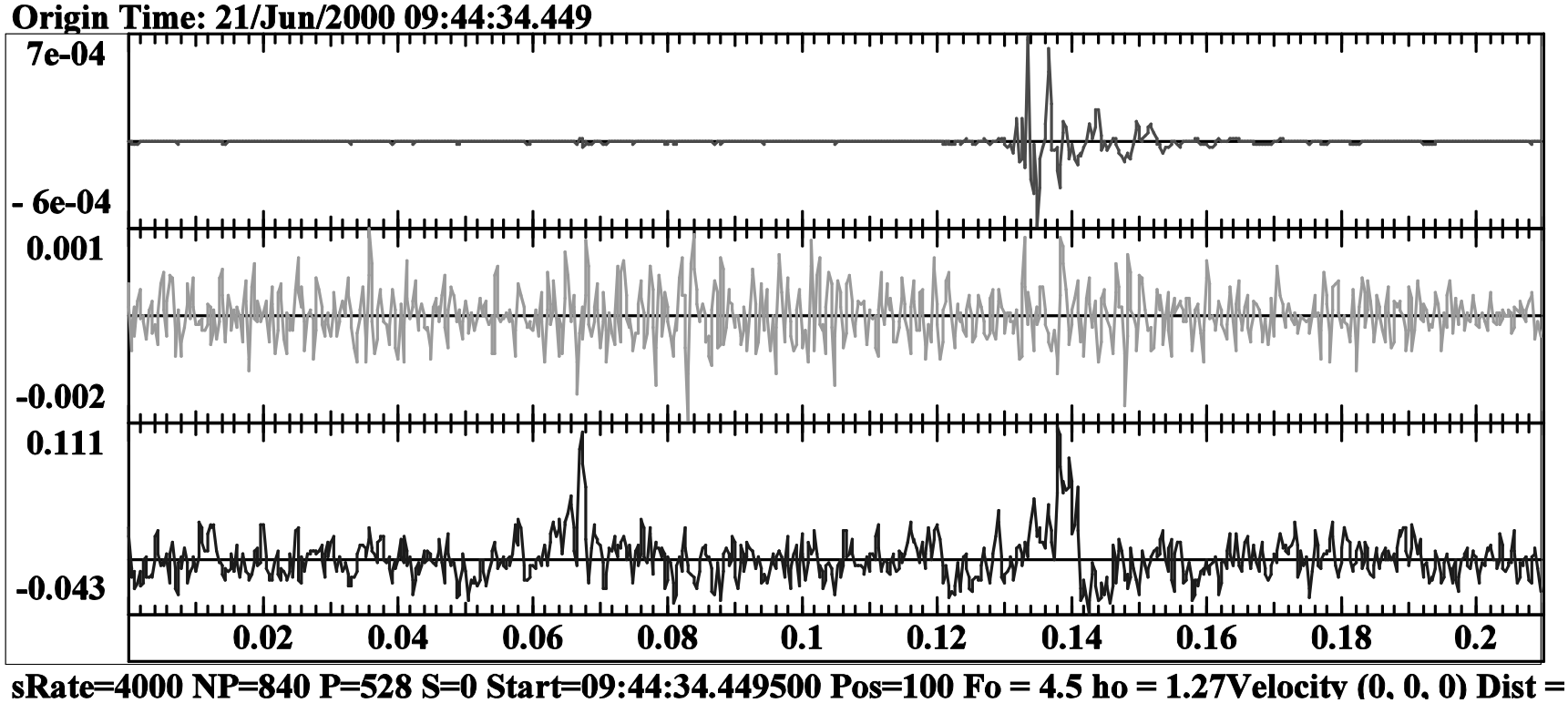

Origin Time: 21/Jun/2000 11:34:30.192
3e-04
- 3e-04
4e-04
- 3e-04
0.079
-0.039
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
sRate=8000 NP=1100 P=578 S=0 Start=11:34:30.192125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 21/Jun/2000 09:49:32.663
5e-04
- 4e-04
0.001
-0.001
0.101
-0.046
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1490 P=519 S=0 Start=09:49:32.663000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 21/Jun/2000 09:47:23.261
2e-04
- 3e-04
0.001
-0.001
0.134
-0.068
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
sRate=4000 NP=890 P=507 S=0 Start=09:47:23.261500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

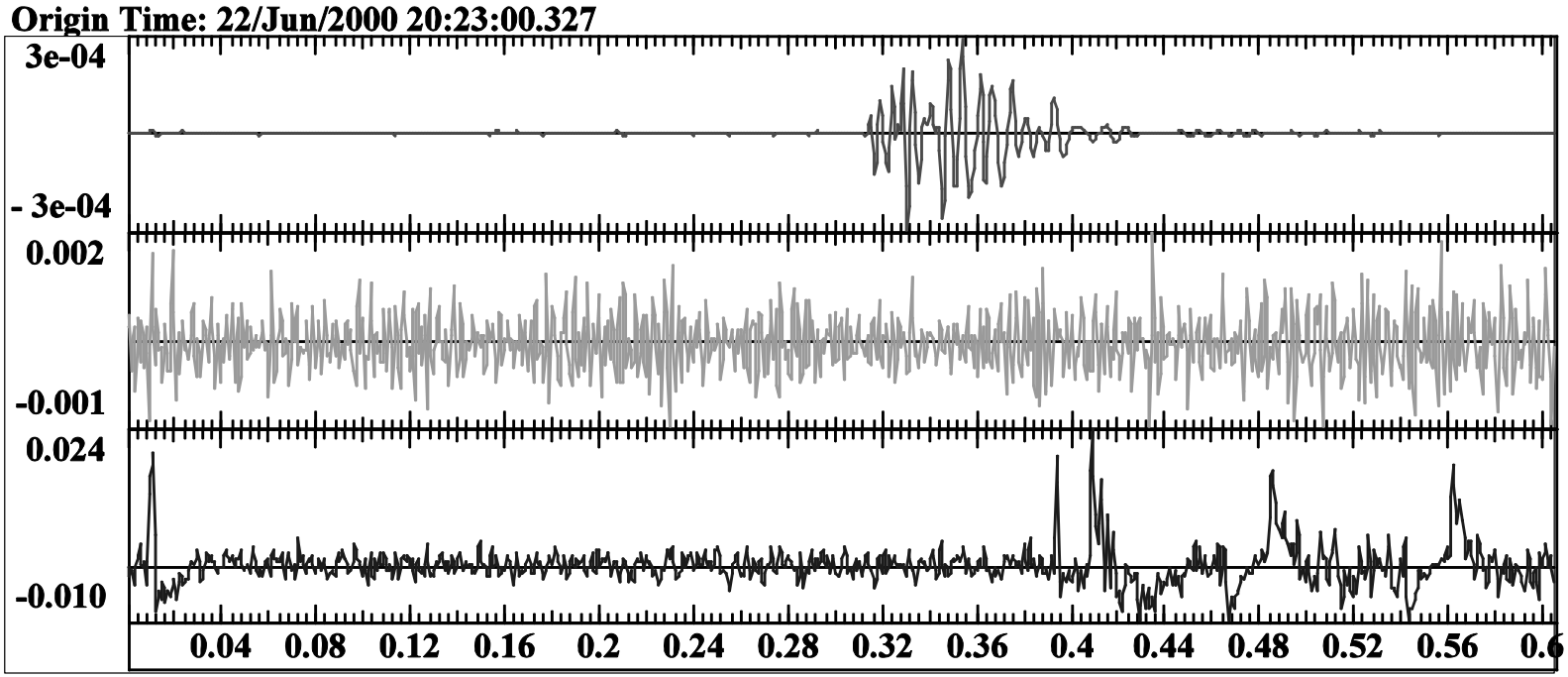

Origin Time: 21/Jun/2000 09:49:32.663
5e-04
- 4e-04
0.001
-0.001
0.101
-0.046
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1490 P=519 S=0 Start=09:49:32.663000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

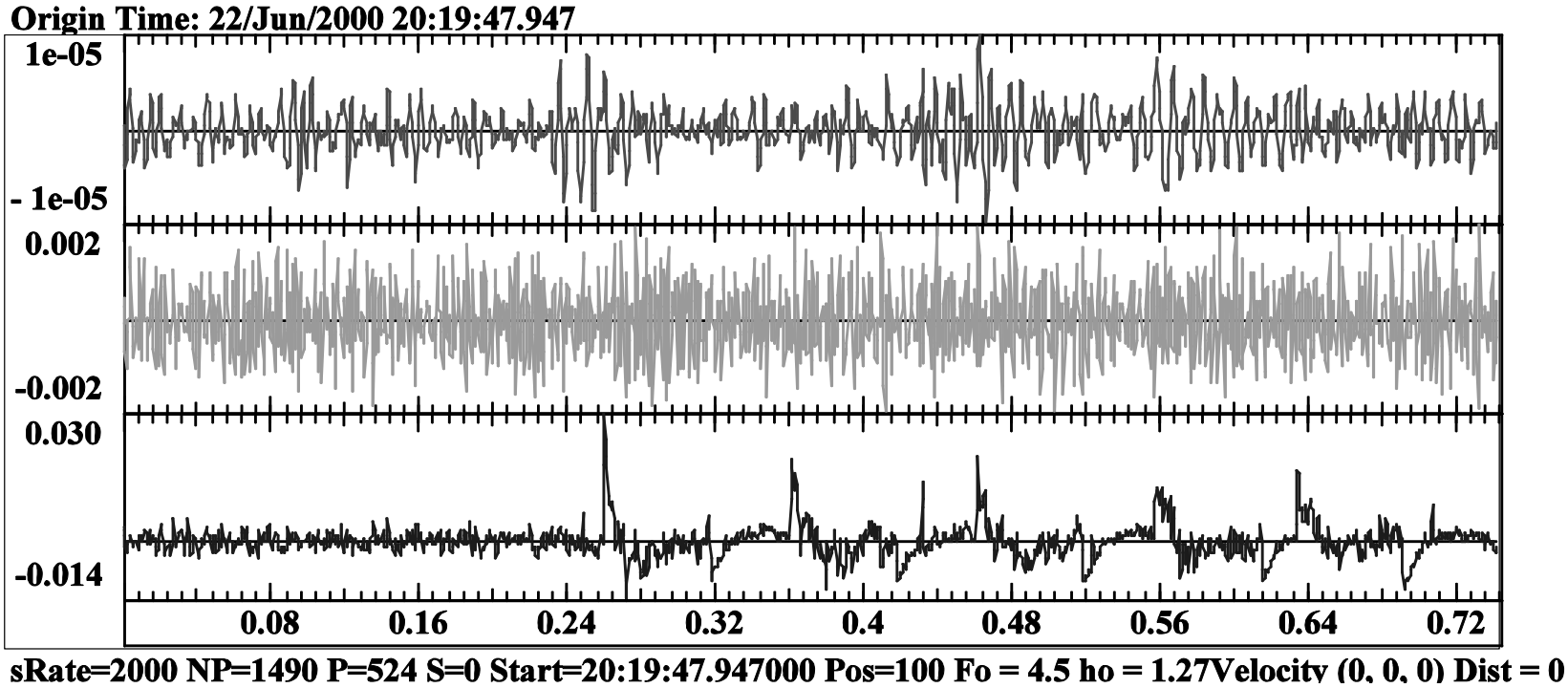

Origin Time: 21/Jun/2000 09:46:33.954
4e-04
- 6e-04
0.001
-0.001
0.119
-0.080
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=2667 NP=1057 P=509 S=0 Start=09:46:33.954750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

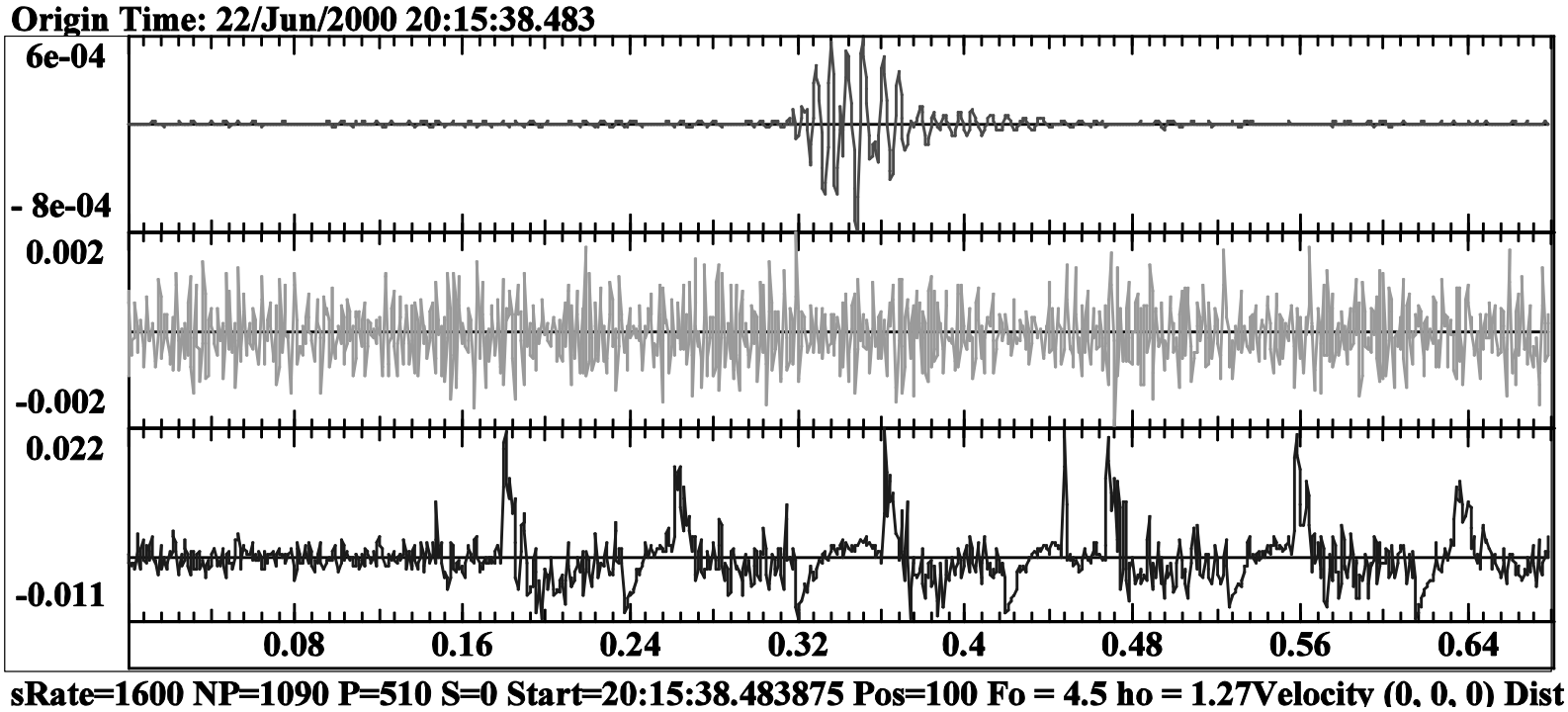

Origin Time: 21/Jun/2000 09:44:34.449
7e-04
- 6e-04
0.001
-0.002
0.111
-0.043
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=4000 NP=840 P=528 S=0 Start=09:44:34.449500 Pos=100 Fo = 4.5 ho = 1.27Velocitv (0, 0, 0) Dist = 0

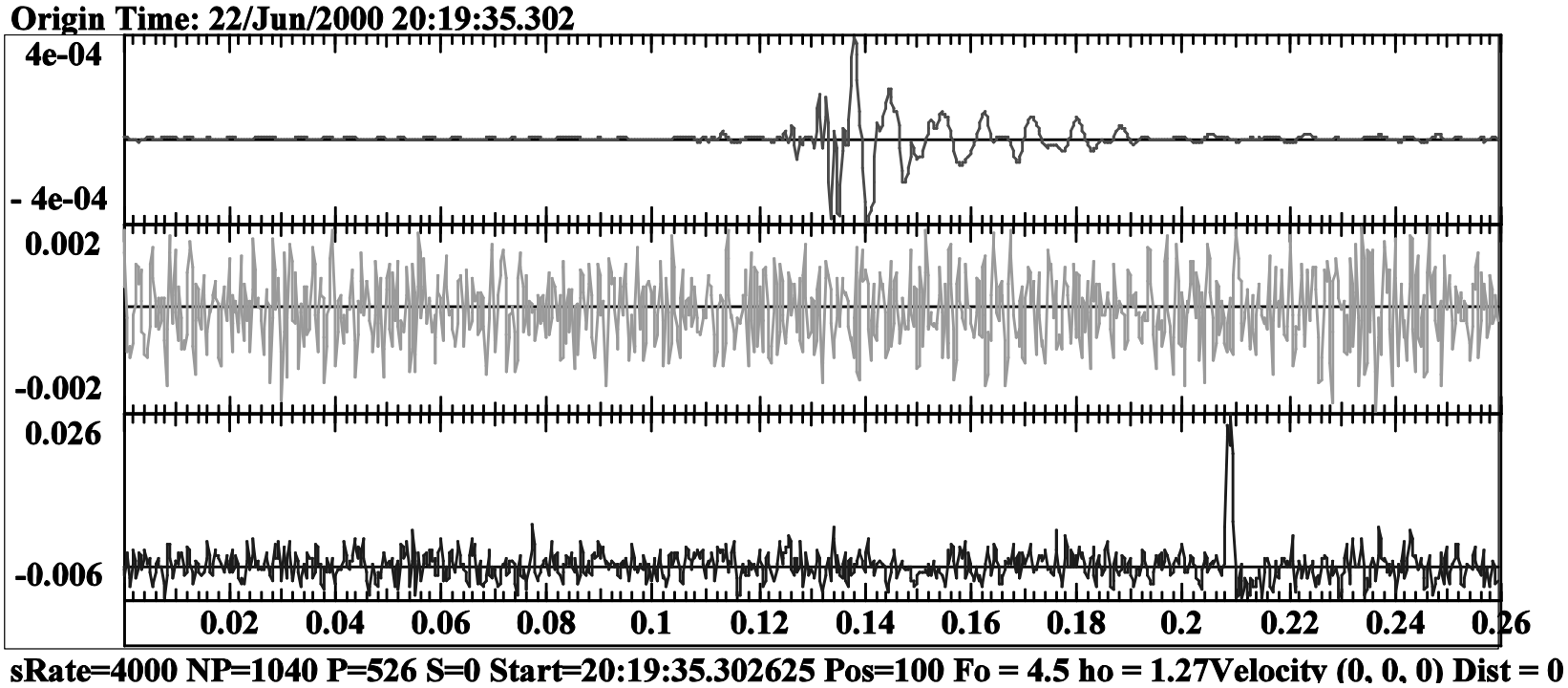
Appendix 2

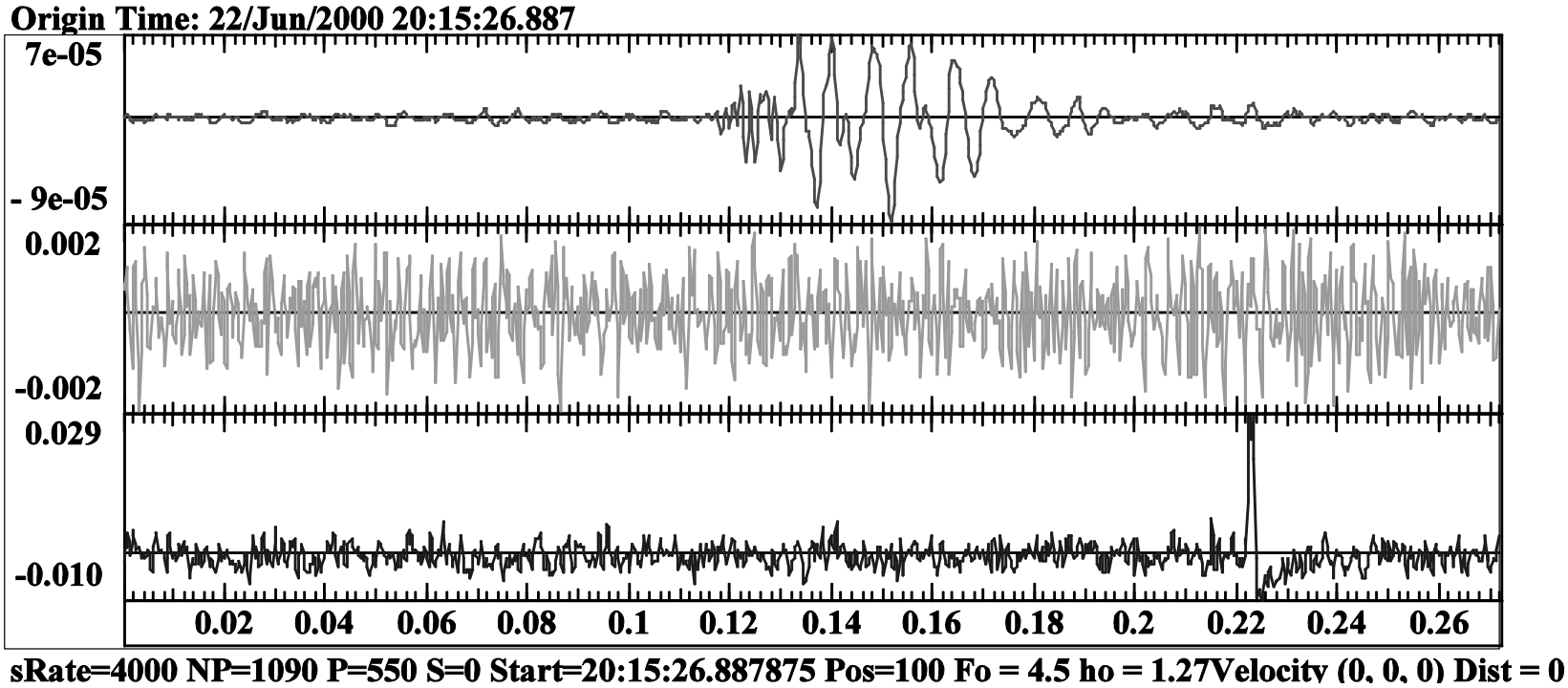
A2.1 Background electromagnetic emission at 190 kHz

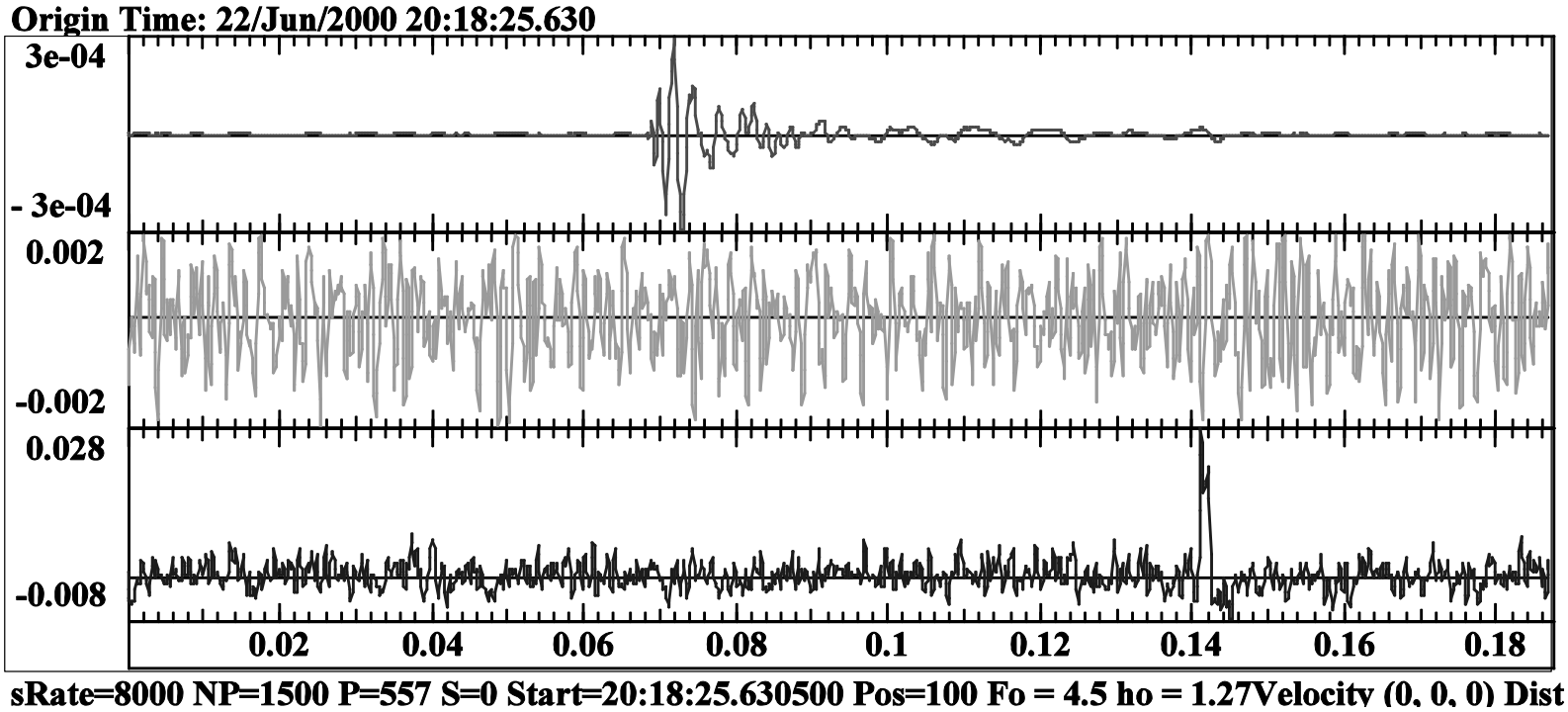

Origin Time: 22/Jun/2000 20:23:00.327
3e-04
- 3e-04
0.002
-0.001
0.024
-0.010
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
sRate=1600 NP=970 P=505 S=0 Start=20:23:00.327000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

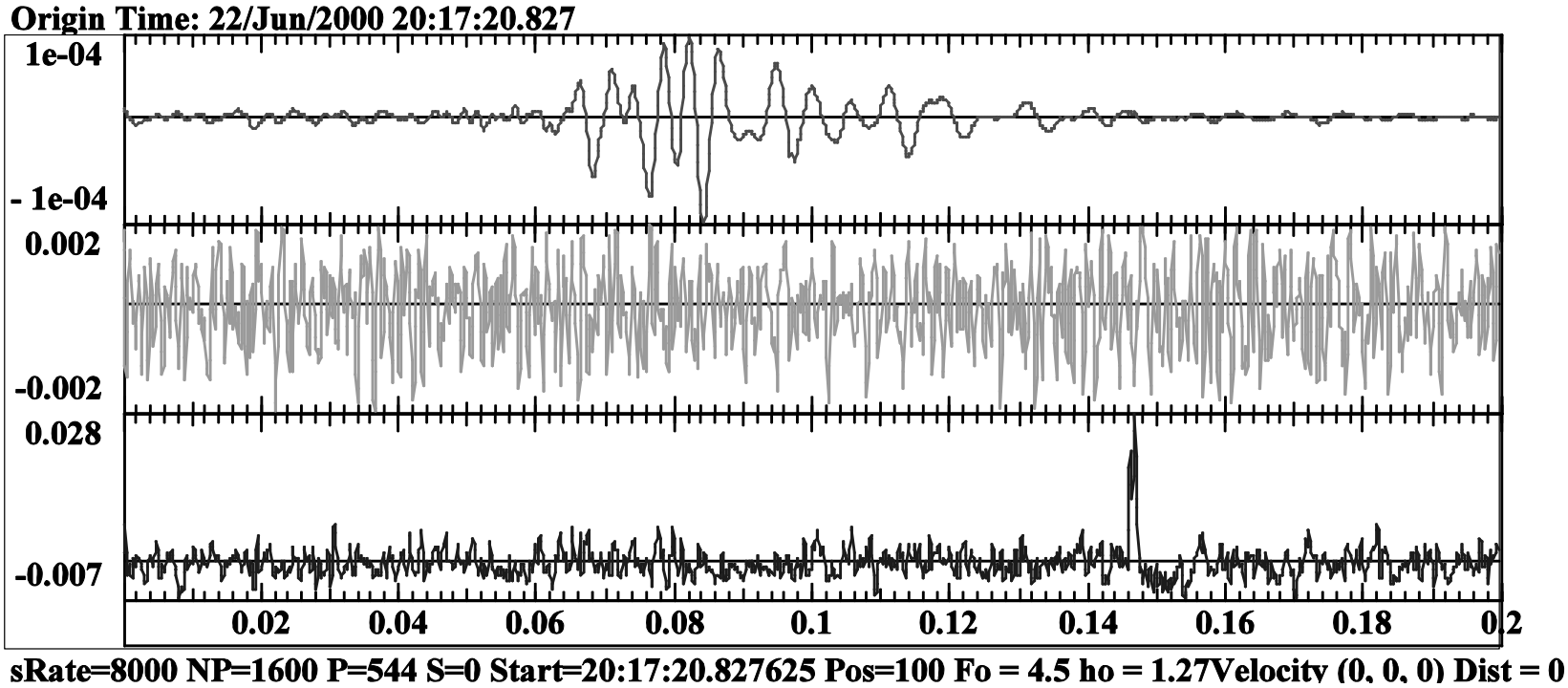

Origin Time: 22/Jun/2000 20:19:47.947
1e-05
- 1e-05
0.002
-0.002
0.030
-0.014
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
sRate=2000 NP=1490 P=524 S=0 Start=20:19:47.947000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

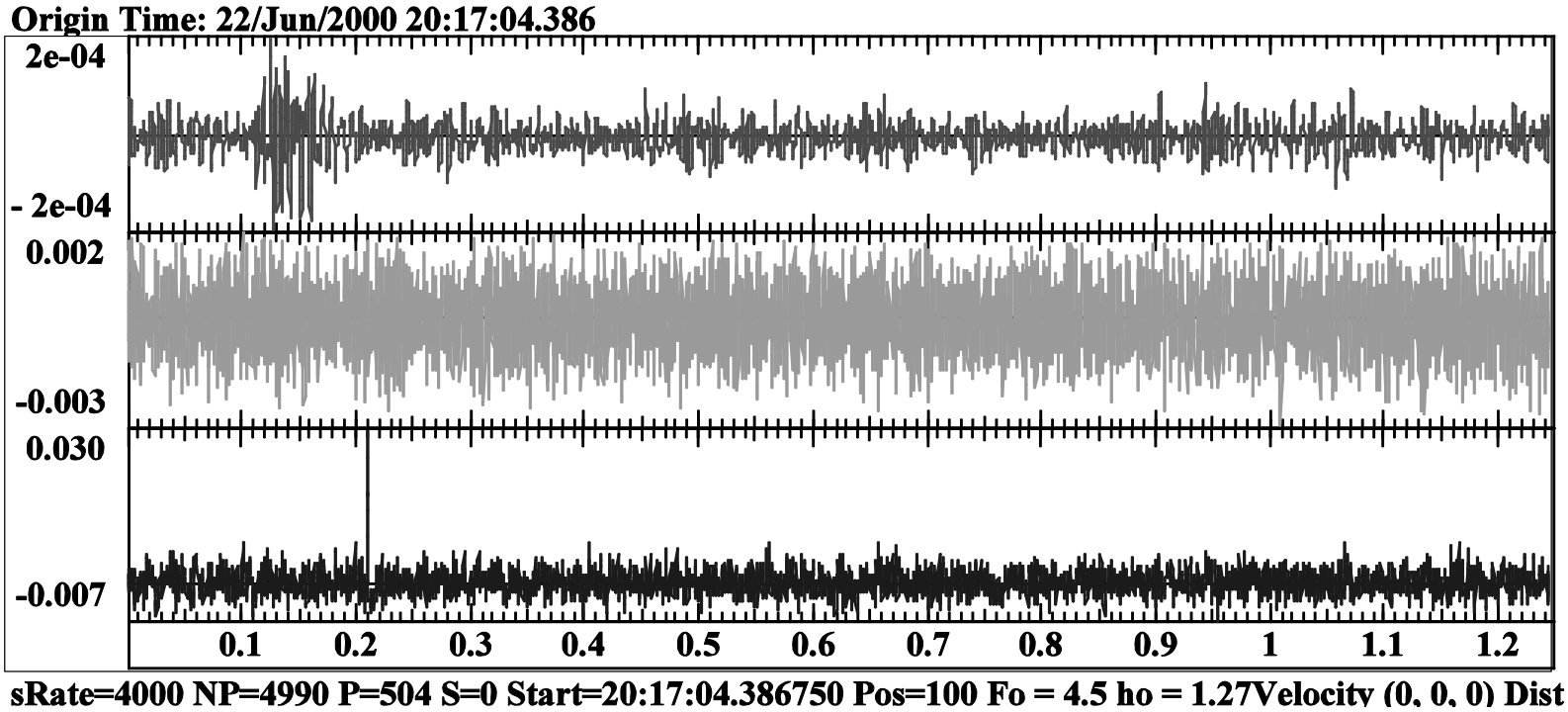

Origin Time: 22/Jun/2000 20:15:38.483
6e-04
- 8e-04
0.002
-0.002
0.022
-0.011
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
sRate=1600 NP=1090 P=510 S=0 Start=20:15:38.483875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

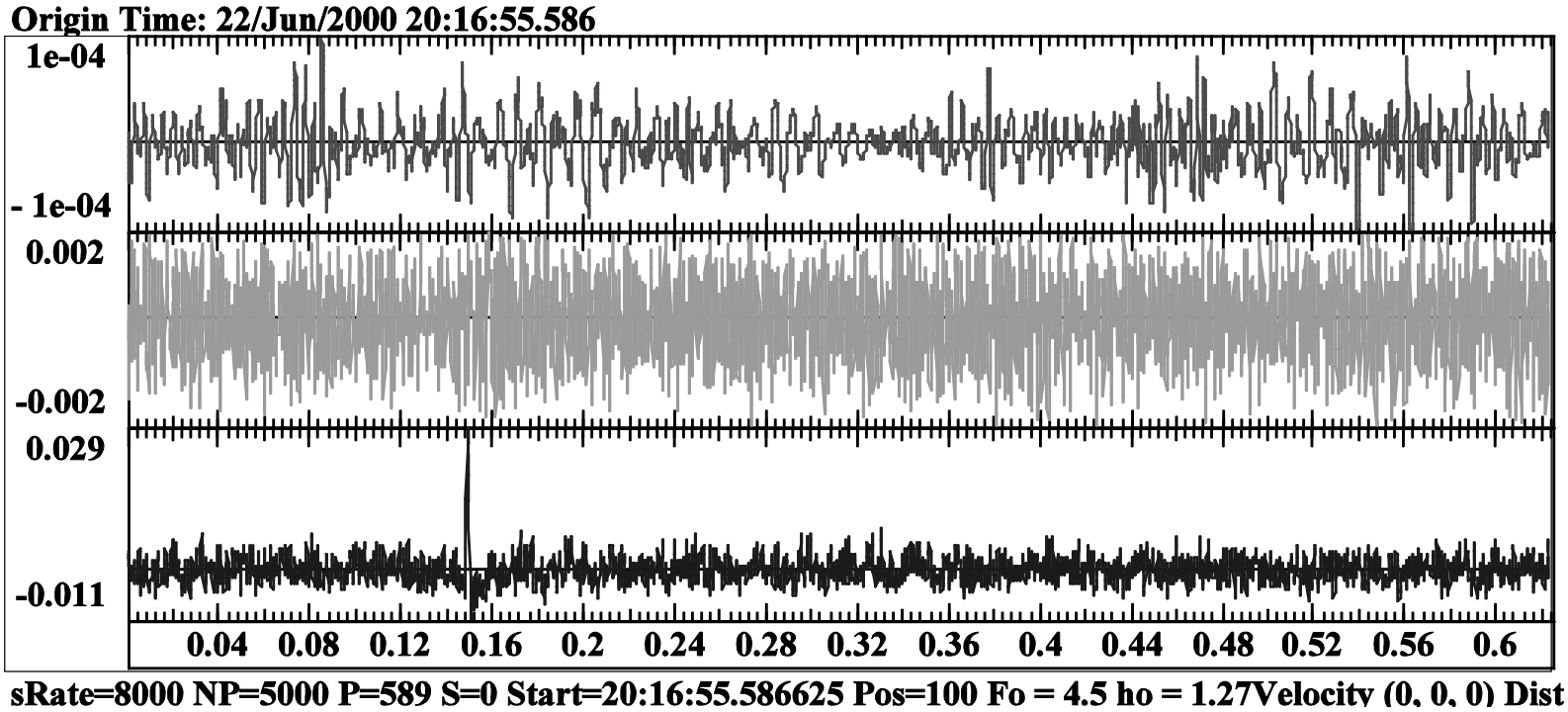

Origin Time: 22/Jun/2000 20:19:35.302
4e-04
- 4e-04
0.002
-0.002
0.026
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=4000 NP=1040 P=526 S=0 Start=20:19:35.302625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

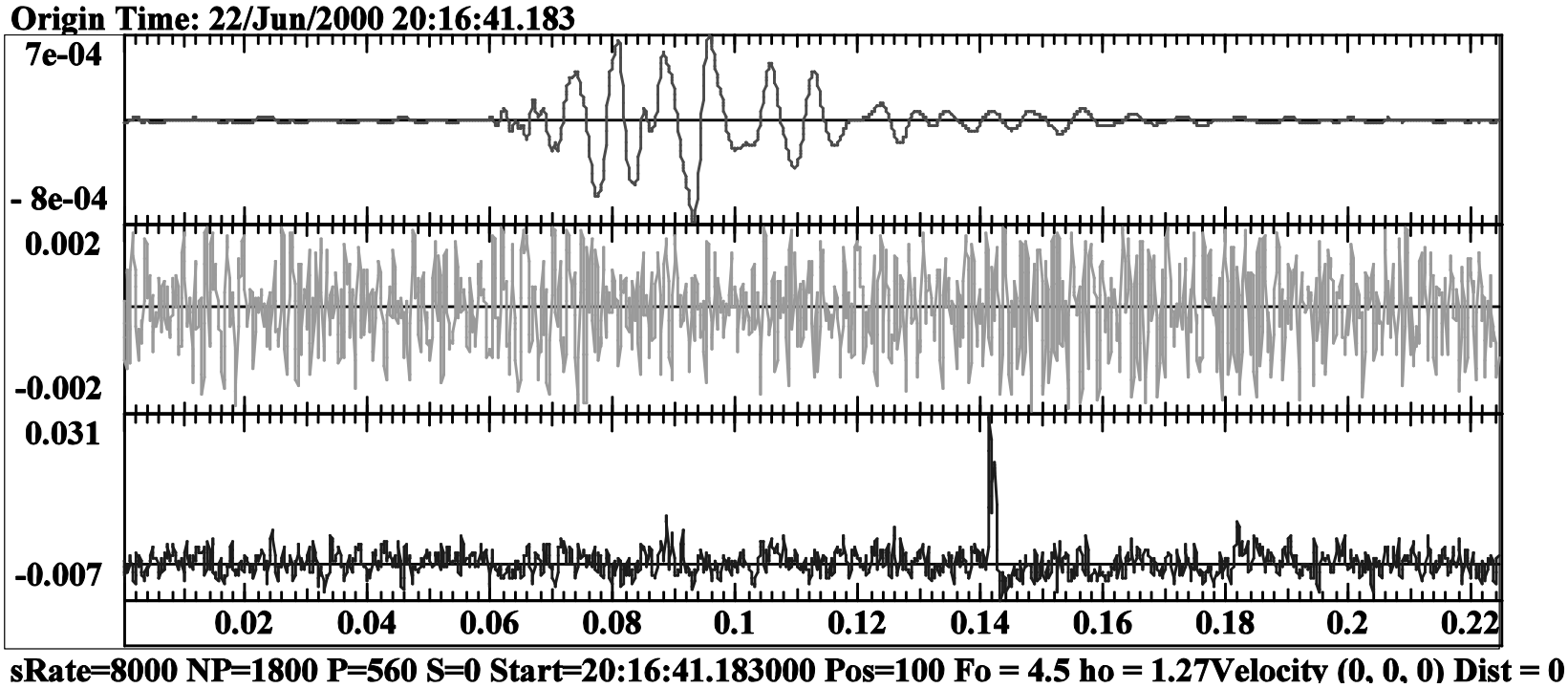

Origin Time: 22/Jun/2000 20:15:26.887
7e-05
- 9e-05
0.002
-0.002
0.029
-0.010
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=4000 NP=1090 P=550 S=0 Start=20:15:26.887875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

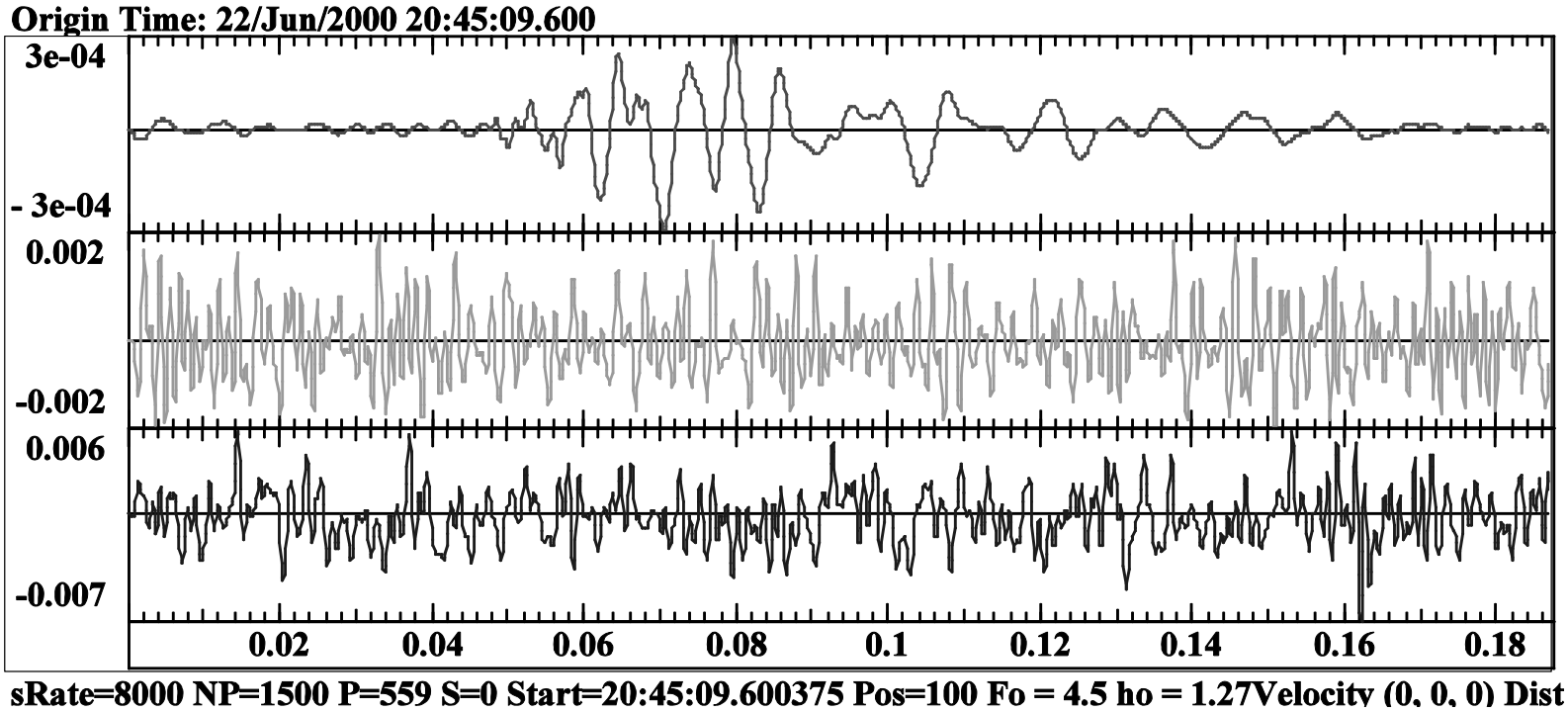

Origin Time: 22/Jun/2000 20:18:25.630
3e-04
- 3e-04
0.002
-0.002
0.028
-0.008
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
sRate=8000 NP=1500 P=557 S=0 Start=20:18:25.630500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

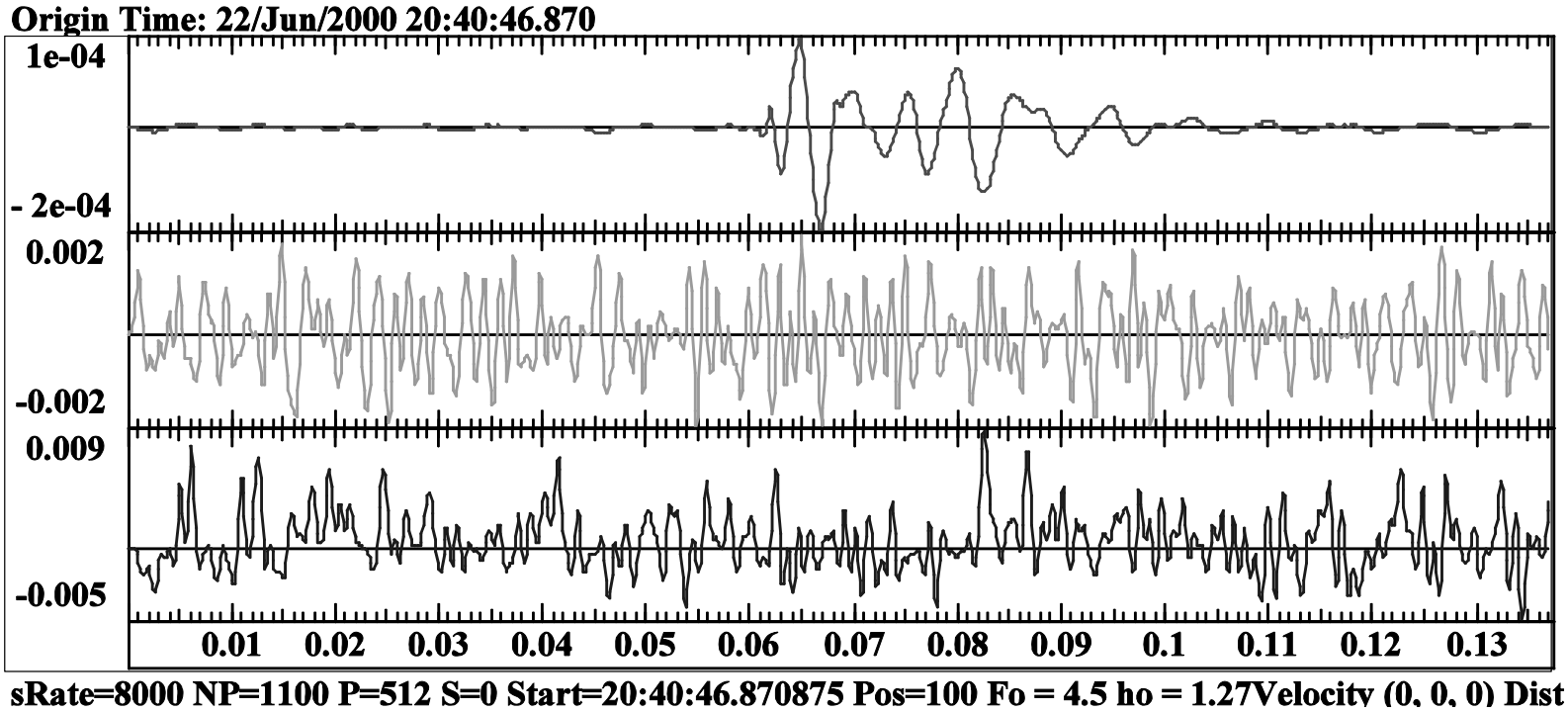

Origin Time: 22/Jun/2000 20:17:20.827
1e-04
- 1e-04
0.002
-0.002
0.028
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=544 S=0 Start=20:17:20.827625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

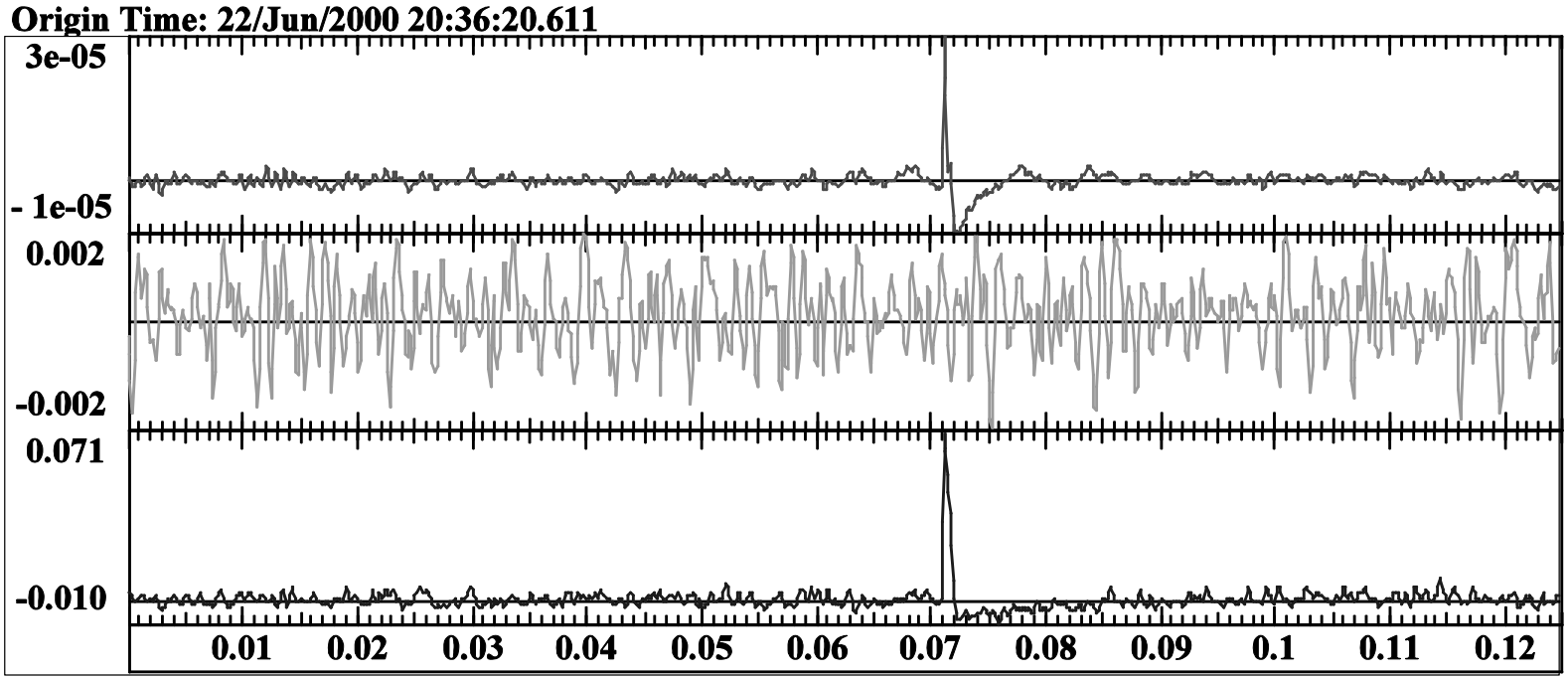

Origin Time: 22/Jun/2000 20:17:04.386
2e-04
- 2e-04
0.002
-0.003
0.030
-0.007
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
sRate=4000 NP=4990 P=504 S=0 Start=20:17:04.386750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

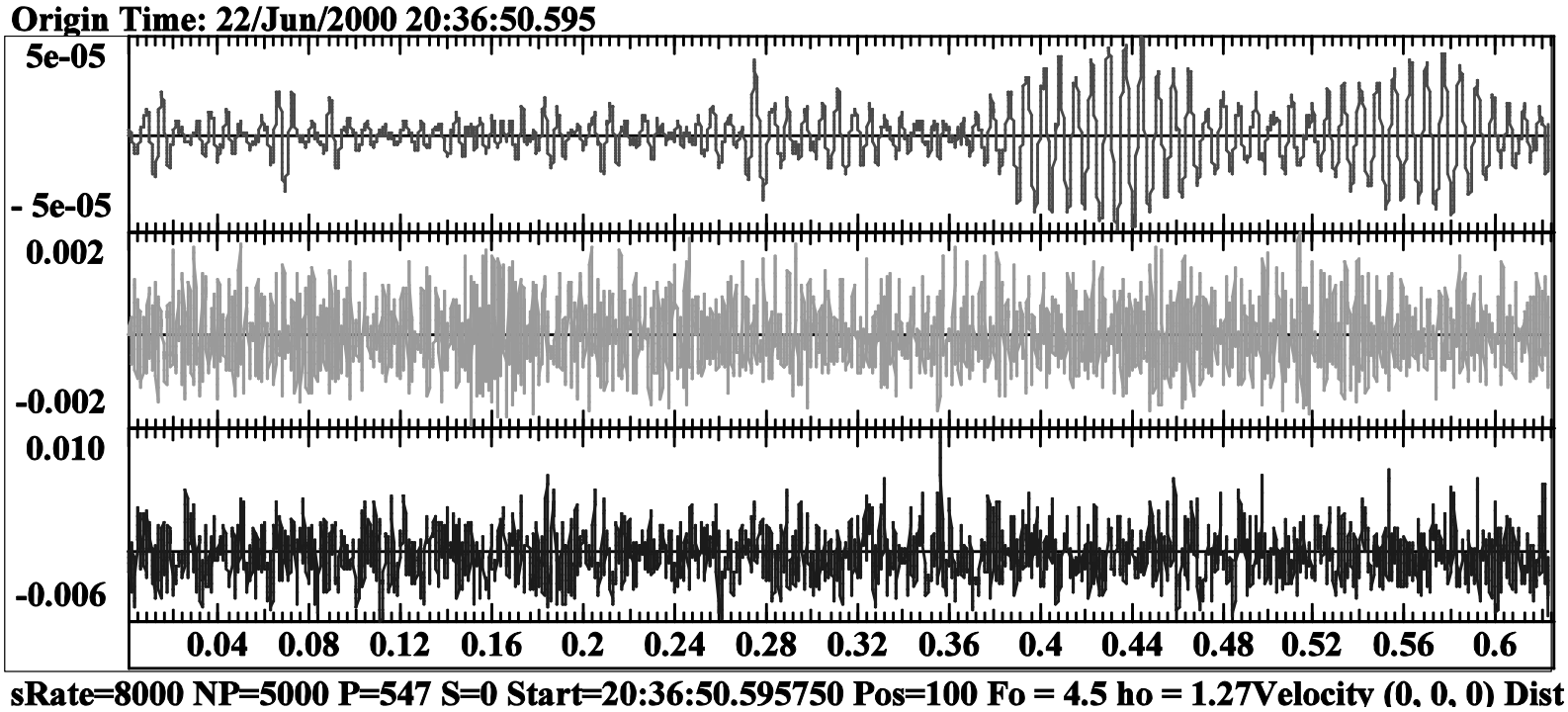

Origin Time: 22/Jun/2000 20:16:55.586
1e-04
- 1e-04
0.002
-0.002
0.029
-0.011
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=589 S=0 Start=20:16:55.586625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

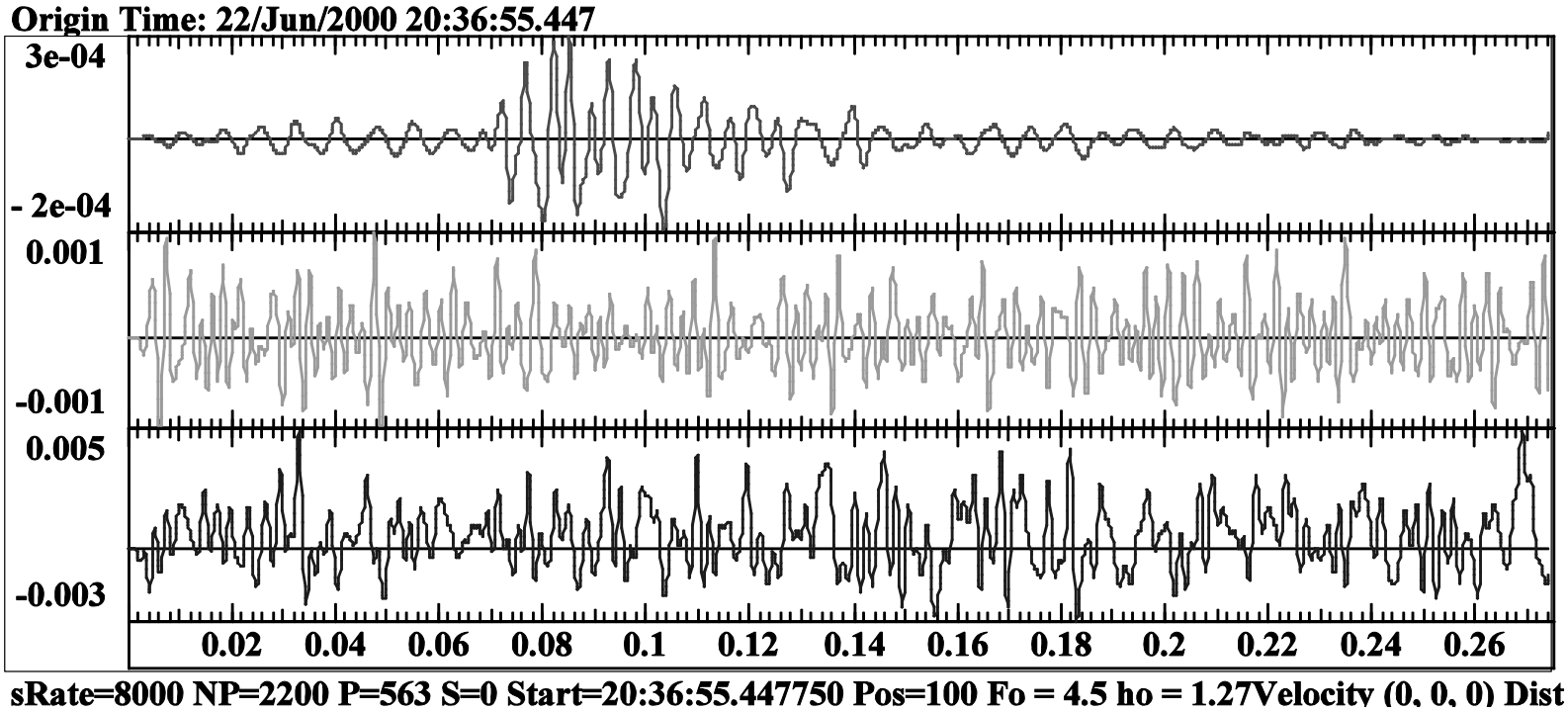

Origin Time: 22/Jun/2000 20:16:41.183
7e-04
- 8e-04
0.002
-0.002
0.031
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
sRate=8000 NP=1800 P=560 S=0 Start=20:16:41.183000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

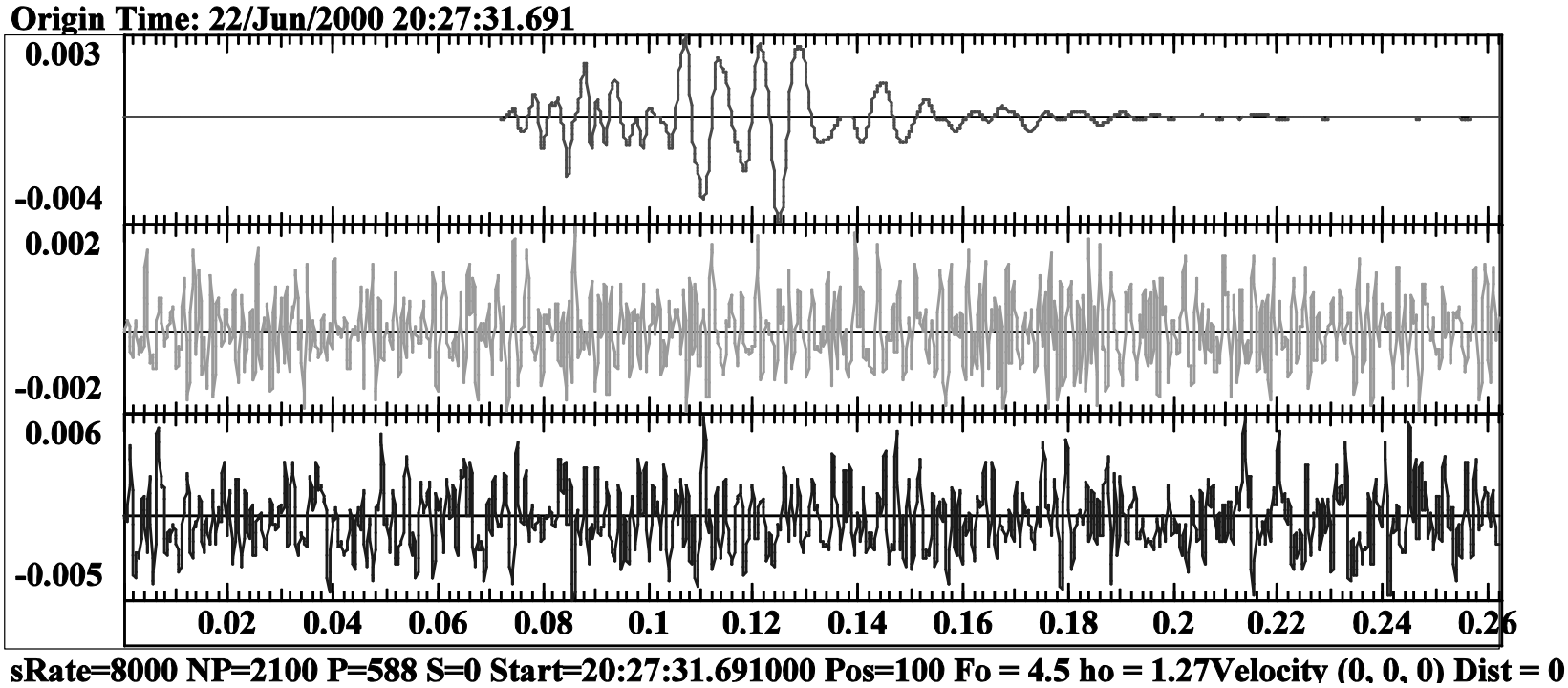

Origin Time: 22/Jun/2000 20:45:09.600
3e-04
- 3e-04
0.002
-0.002
0.006
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
sRate=8000 NP=1500 P=559 S=0 Start=20:45:09.600375 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

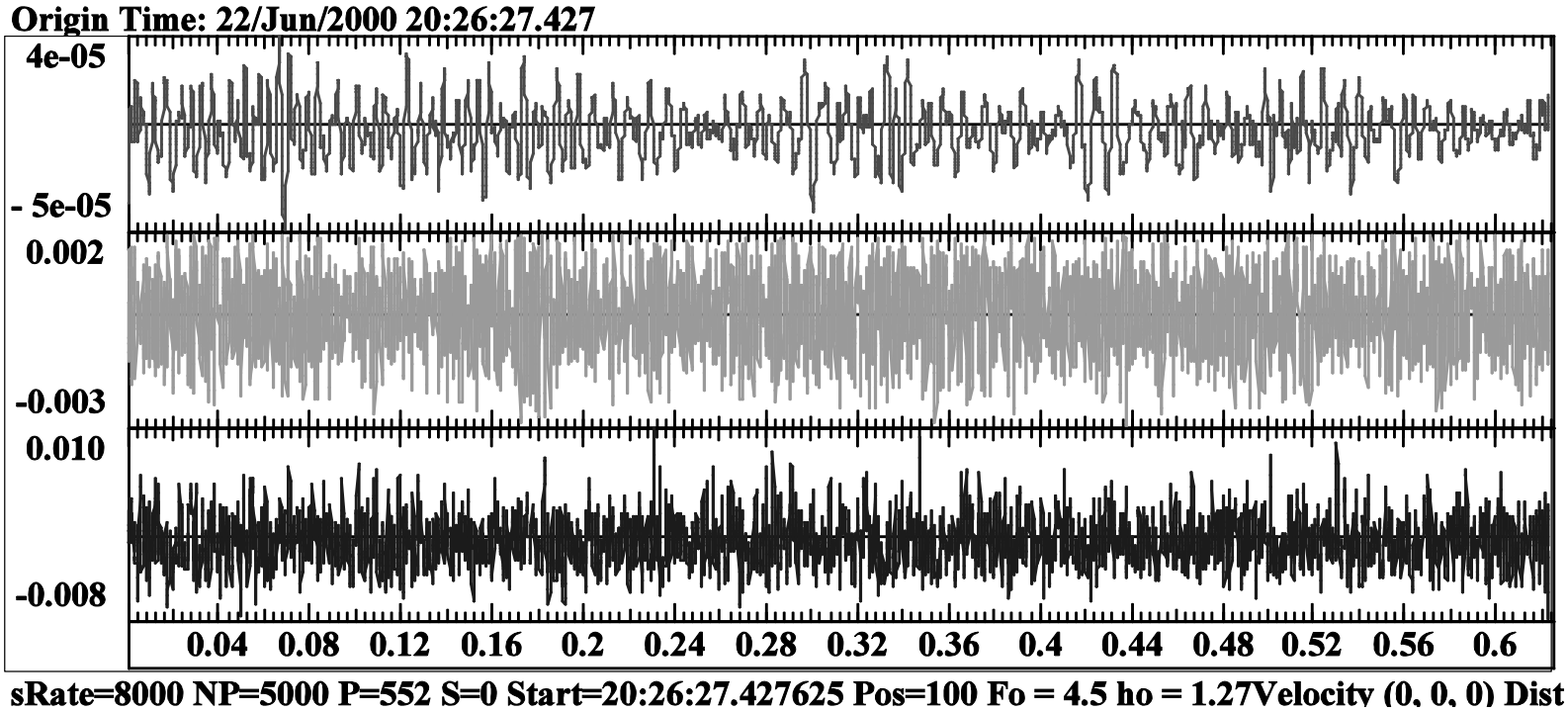

Origin Time: 22/Jun/2000 20:40:46.870
1e-04
- 2e-04
0.002
-0.002
0.009
-0.005
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
sRate=8000 NP=1100 P=512 S=0 Start=20:40:46.870875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

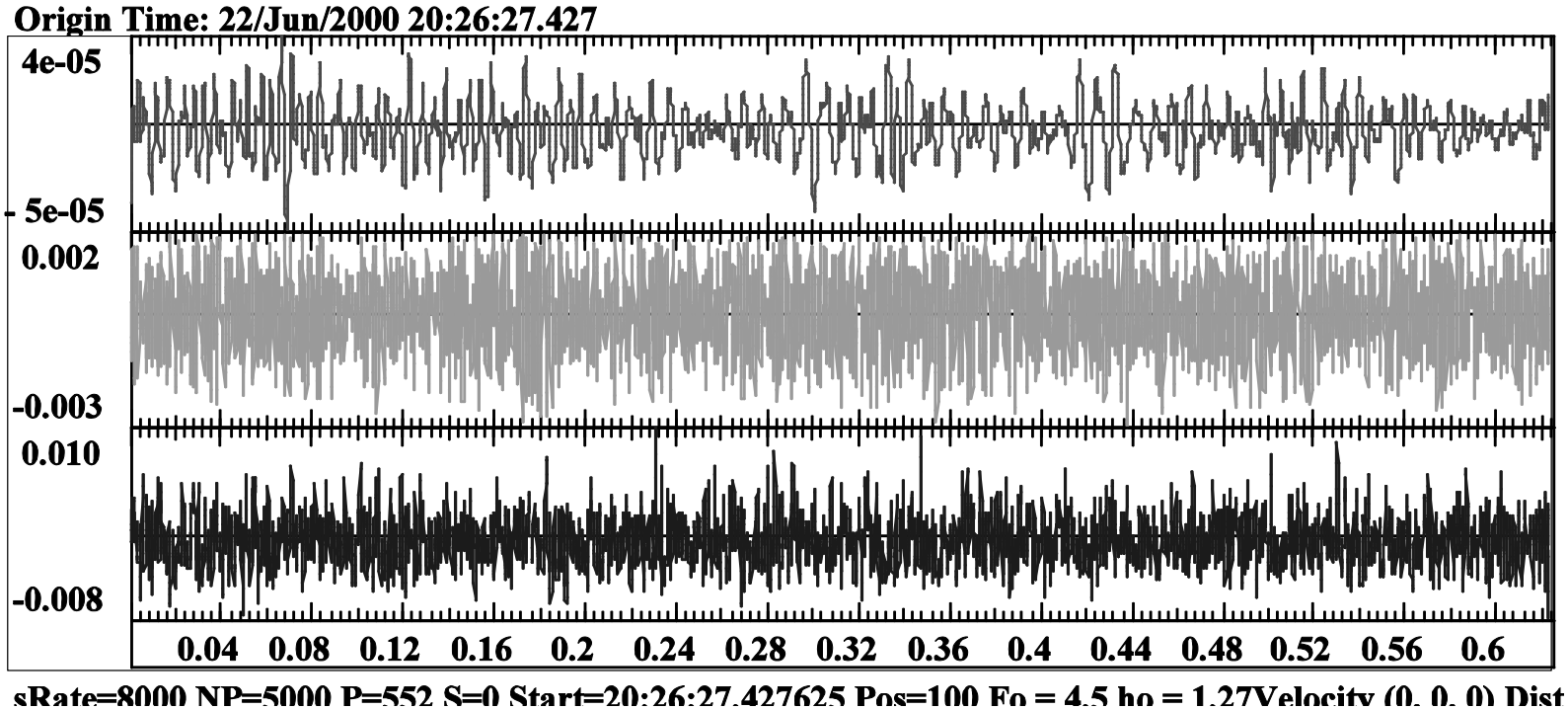

Origin Time: 22/Jun/2000 20:36:20.611
3e-05
- 1e-05
0.002
-0.002
0.071
-0.010
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
sRate=8000 NP=1000 P=573 S=0 Start=20:36:20.611500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

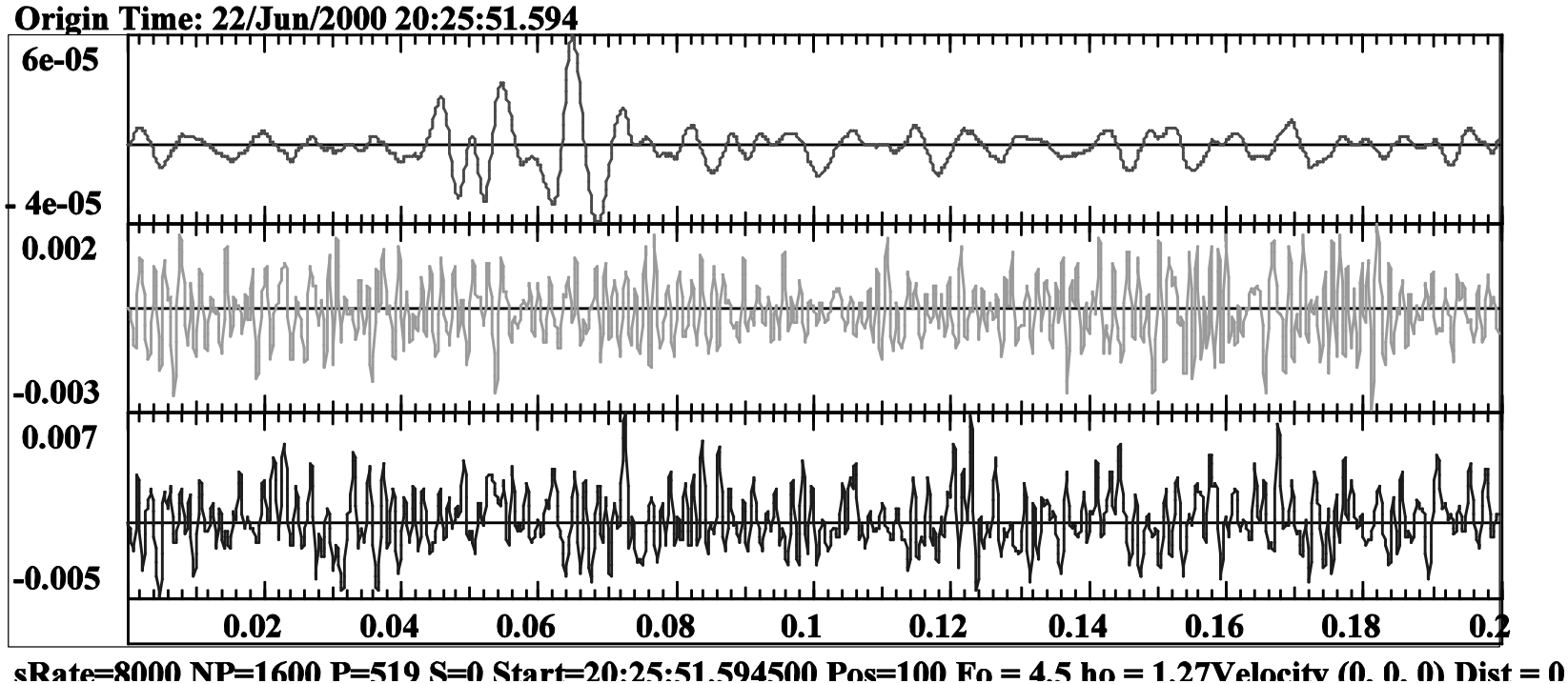

Origin Time: 22/Jun/2000 20:36:50.595
5e-05
- 5e-05
0.002
-0.002
0.010
-0.006
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
sRate=8000 NP=5000 P=547 S=0 Start=20:36:50.595750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

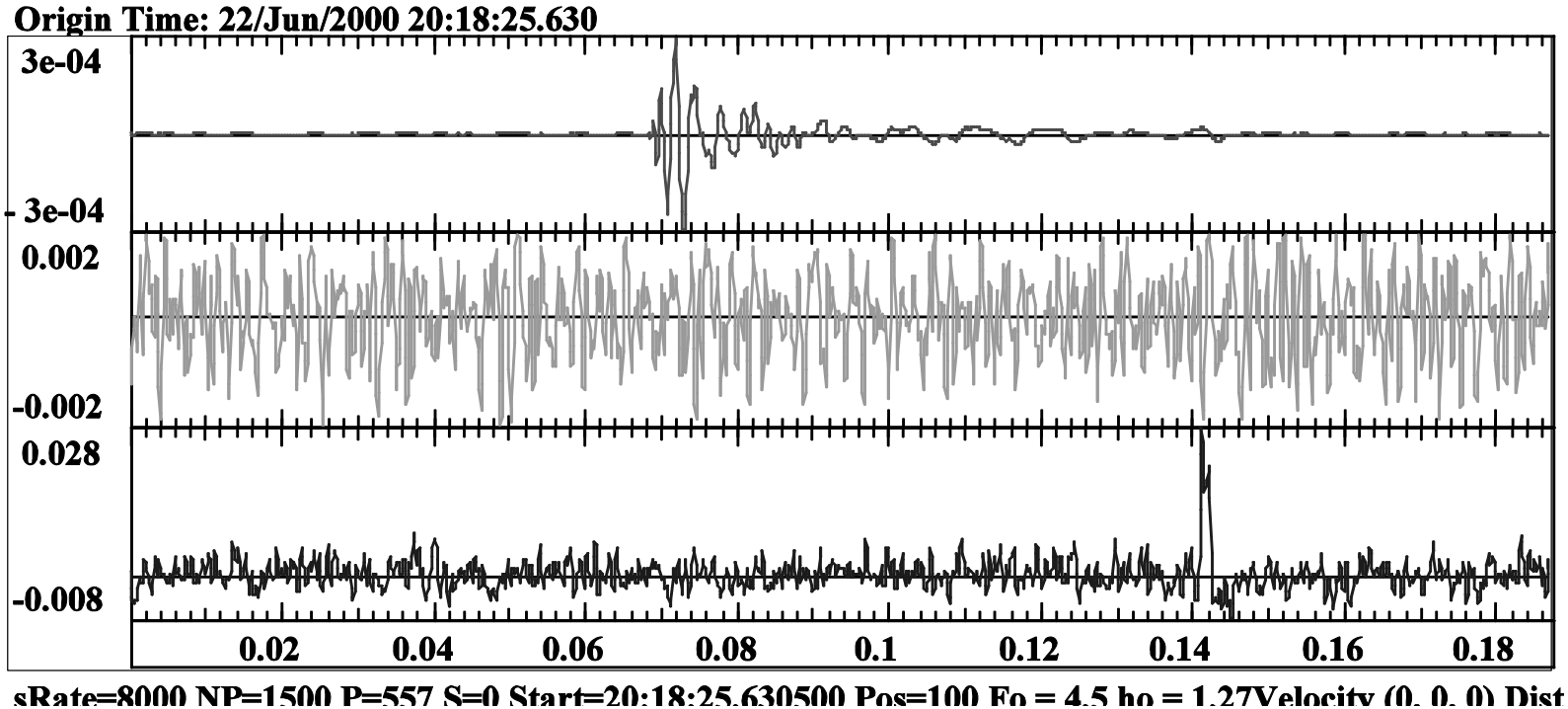

Origin Time: 22/Jun/2000 20:36:55.447
3e-04
- 2e-04
0.001
-0.001
0.005
-0.003
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2200 P=563 S=0 Start=20:36:55.447750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 20:27:31.691
0.003
-0.004
0.002
-0.002
0.006
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2100 P=588 S=0 Start=20:27:31.691000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

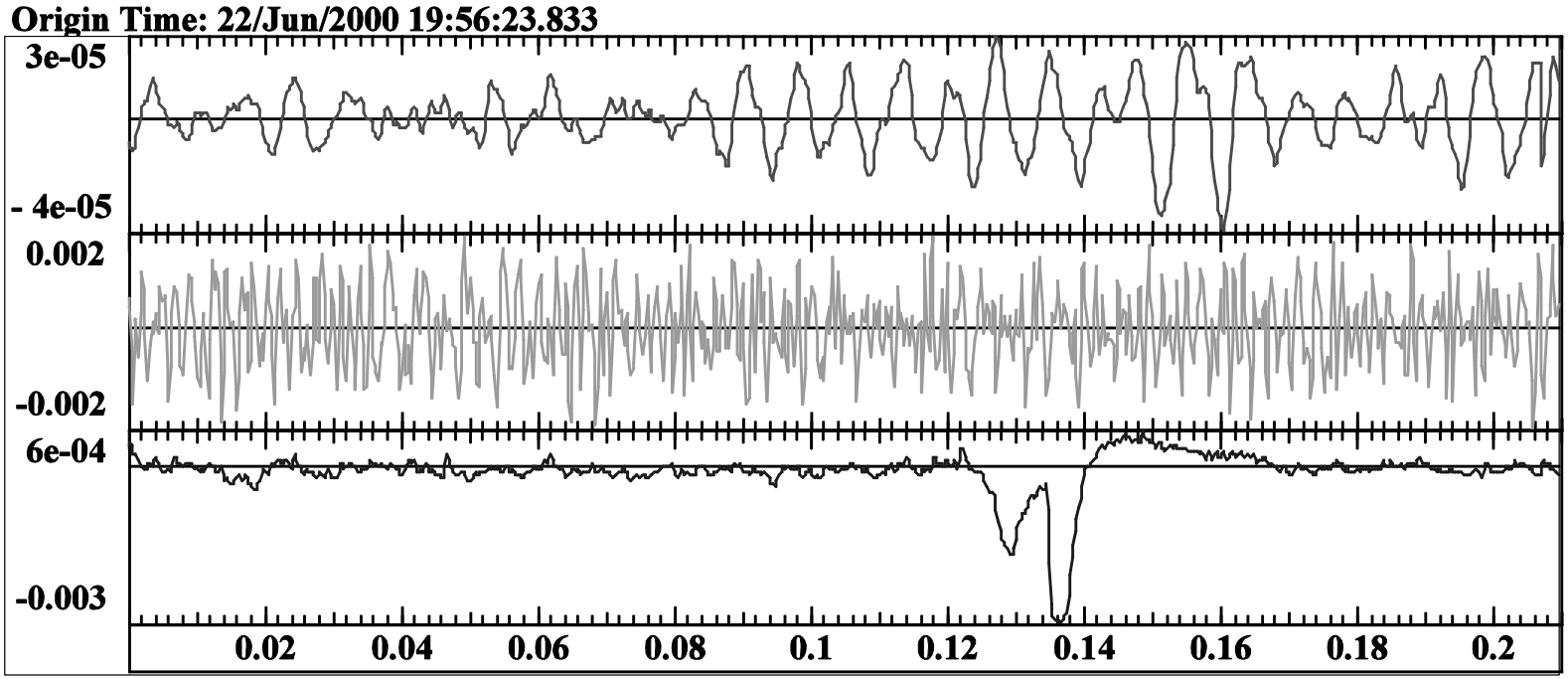

Origin Time: 22/Jun/2000 20:26:27.427
4e-05
- 5e-05
0.002
-0.003
0.010
-0.008
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
sRate=8000 NP=5000 P=552 S=0 Start=20:26:27.427625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 20:26:27.427
4e-05
- 5e-05
0.002
-0.003
0.010
-0.008
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=552 S=0 Start=20:26:27.427625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

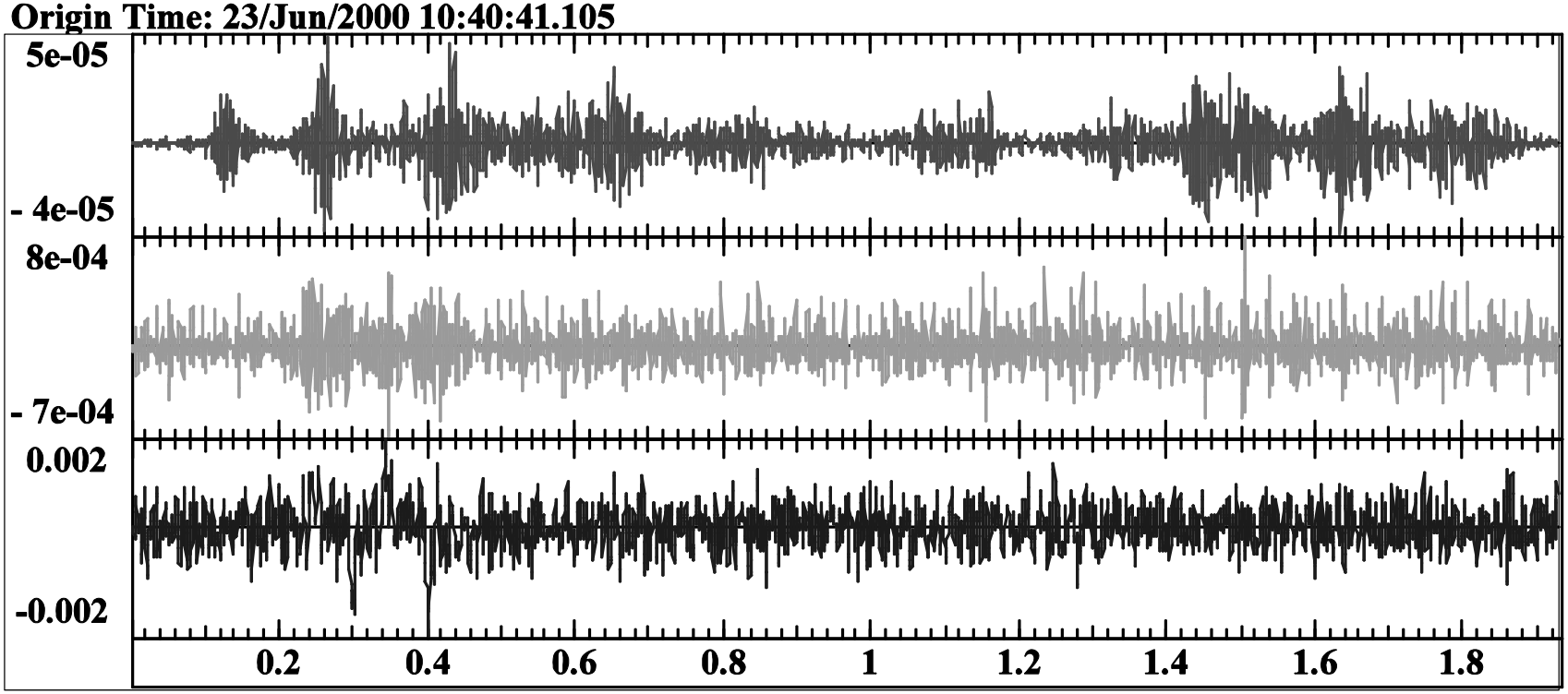

Origin Time: 22/Jun/2000 20:25:51.594
6e-05
- 4e-05
0.002
-0.003
0.007
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=519 S=0 Start=20:25:51.594500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

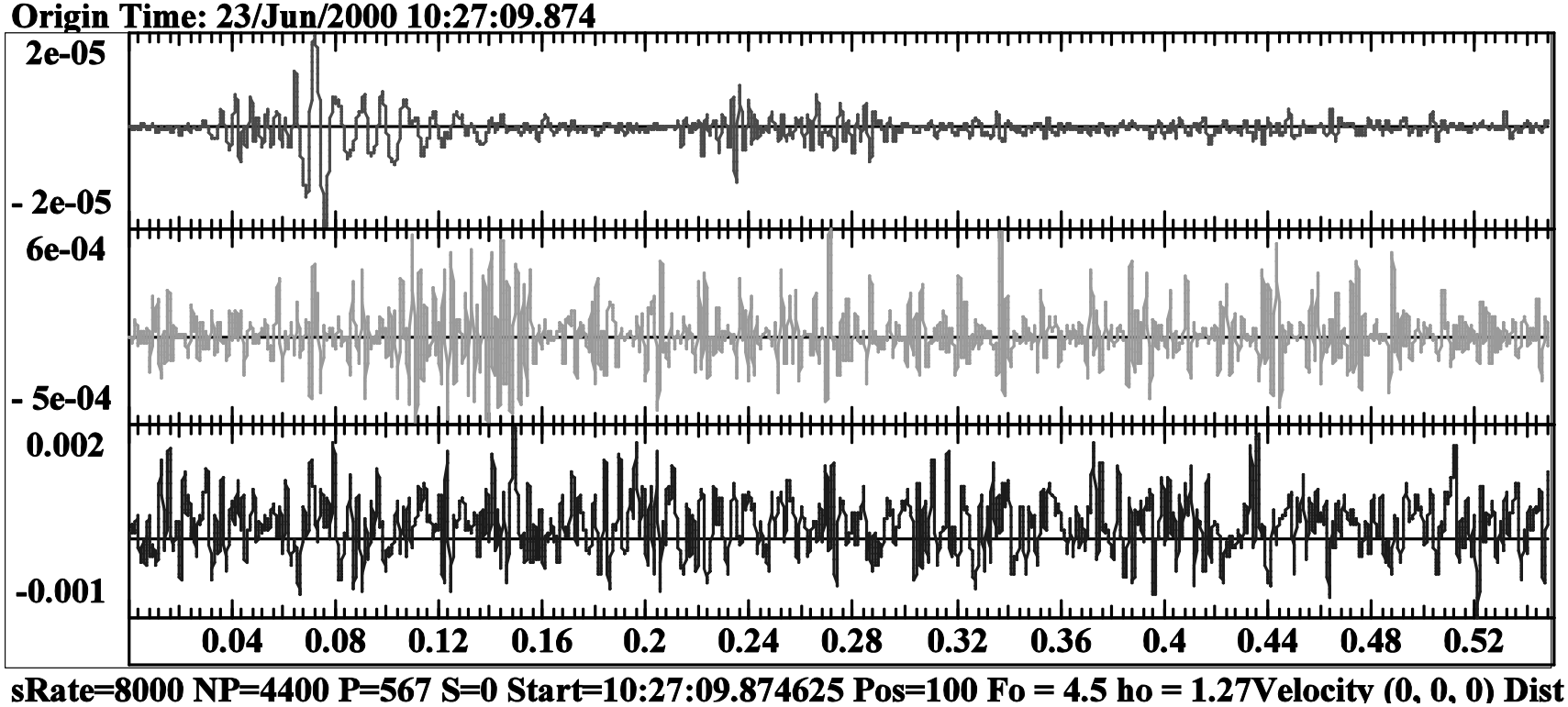

Origin Time: 22/Jun/2000 20:18:25.630
3e-04
- 3e-04
0.002
-0.002
0.028
-0.008
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
sRate=8000 NP=1500 P=557 S=0 Start=20:18:25.630500 Pos=100 Eo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

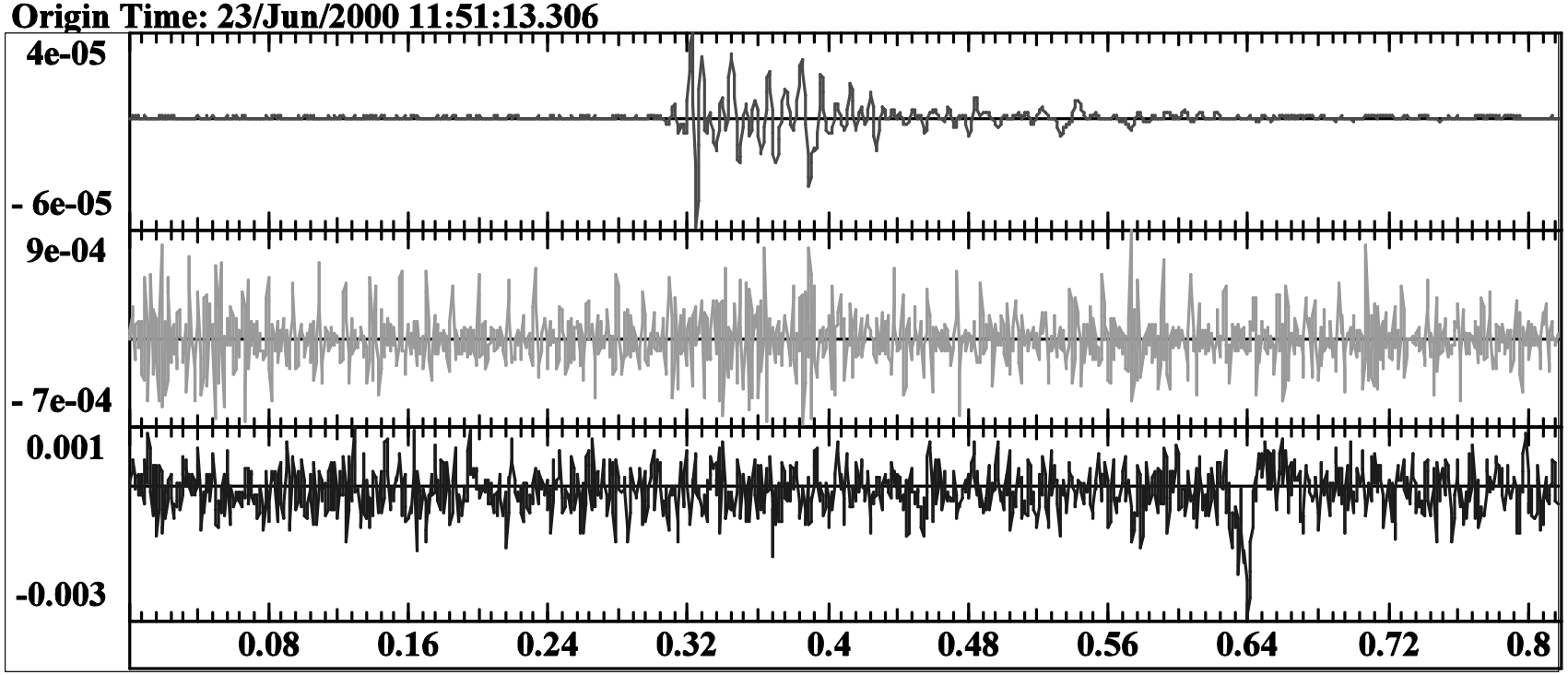
A2.2 Background electromagnetic emissions at 200 kHz

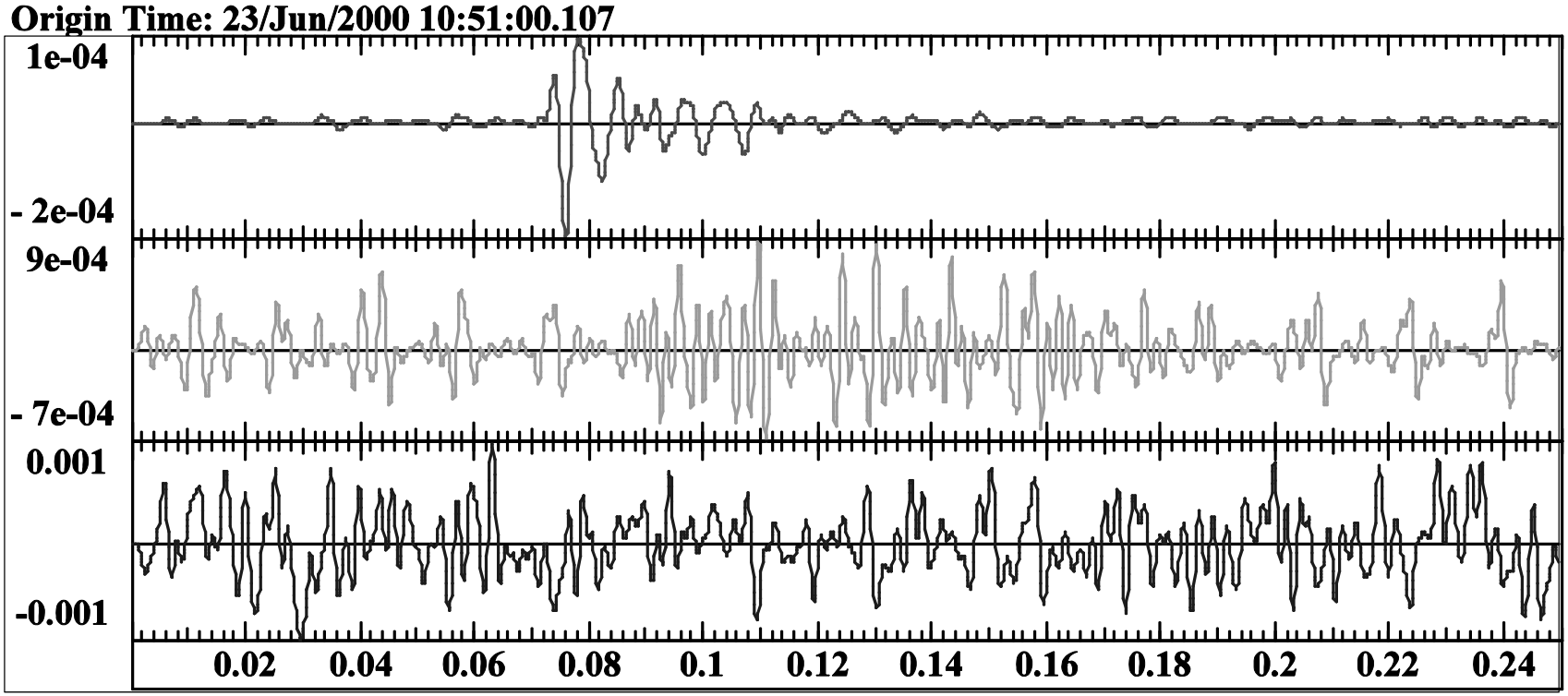

Origin Time: 22/Jun/2000 19:56:23.833
3e-05
- 4e-05
0.002
-0.002
6e-04
-0.003
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=4000 NP=840 P=515 S=0 Start=19:56:23.833875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

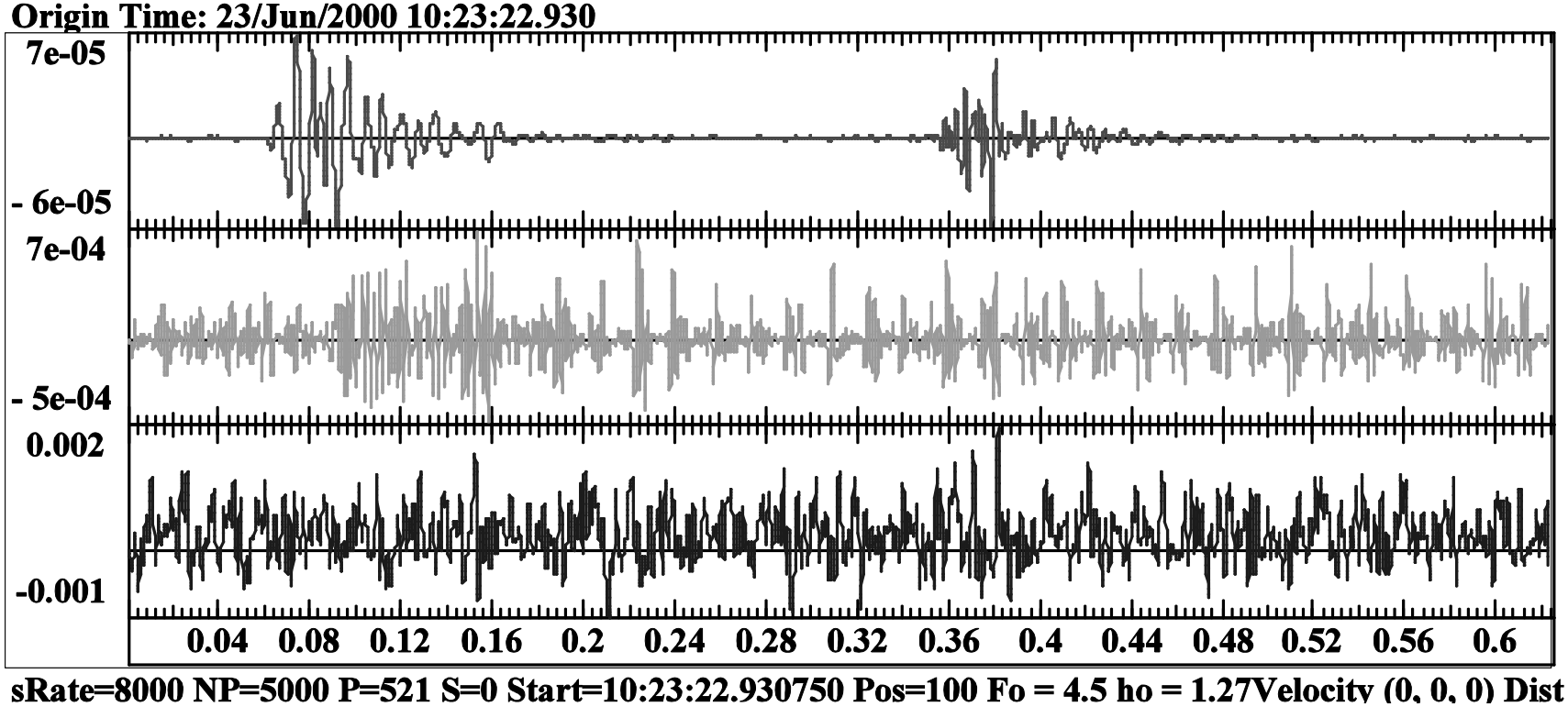
A2.3 Background electromagnetic emissions at 500 kHz

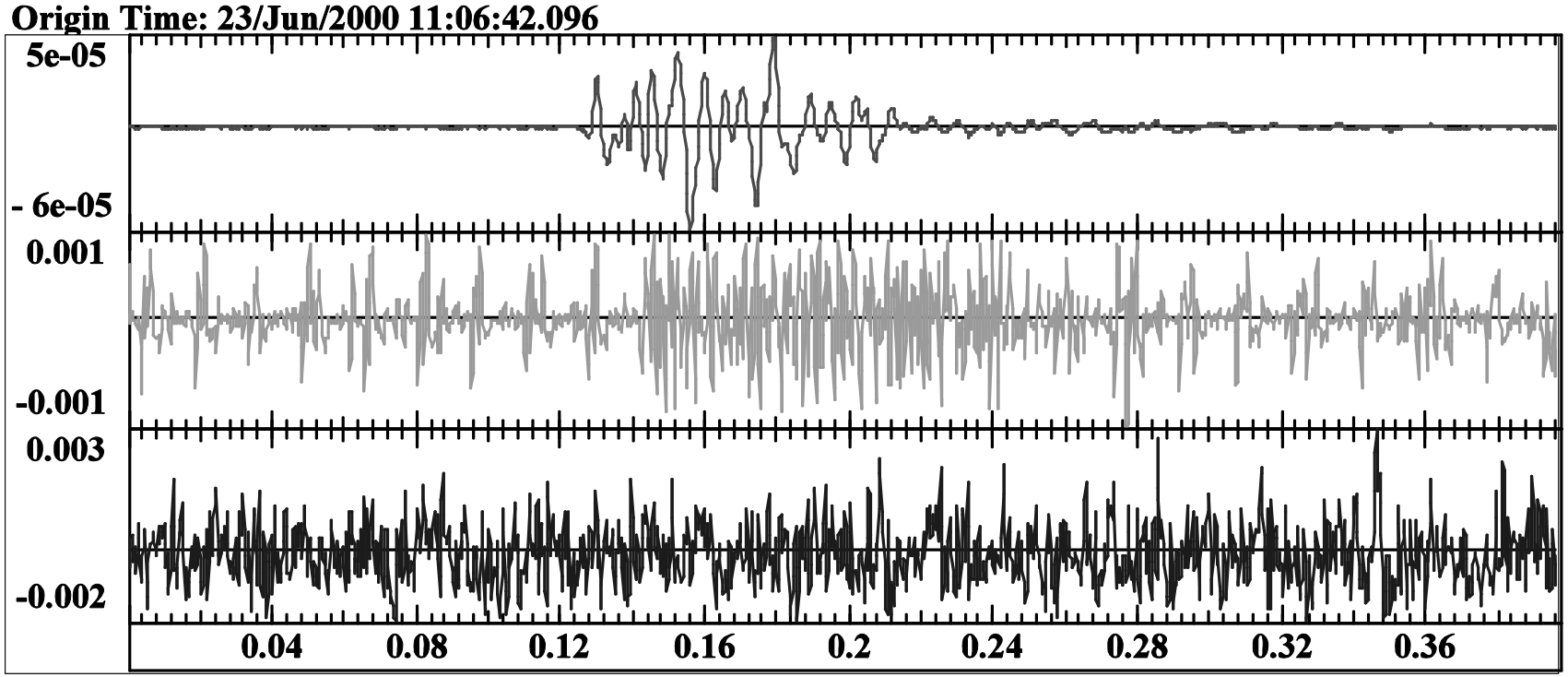

Origin Time: 23/Jun/2000 10:40:41.105
5e-05
- 4e-05
8e-04
- 7e-04
0.002
-0.002
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
sRate=2000 NP=3865 P=510 S=0 Start=10:40:41.105625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist =

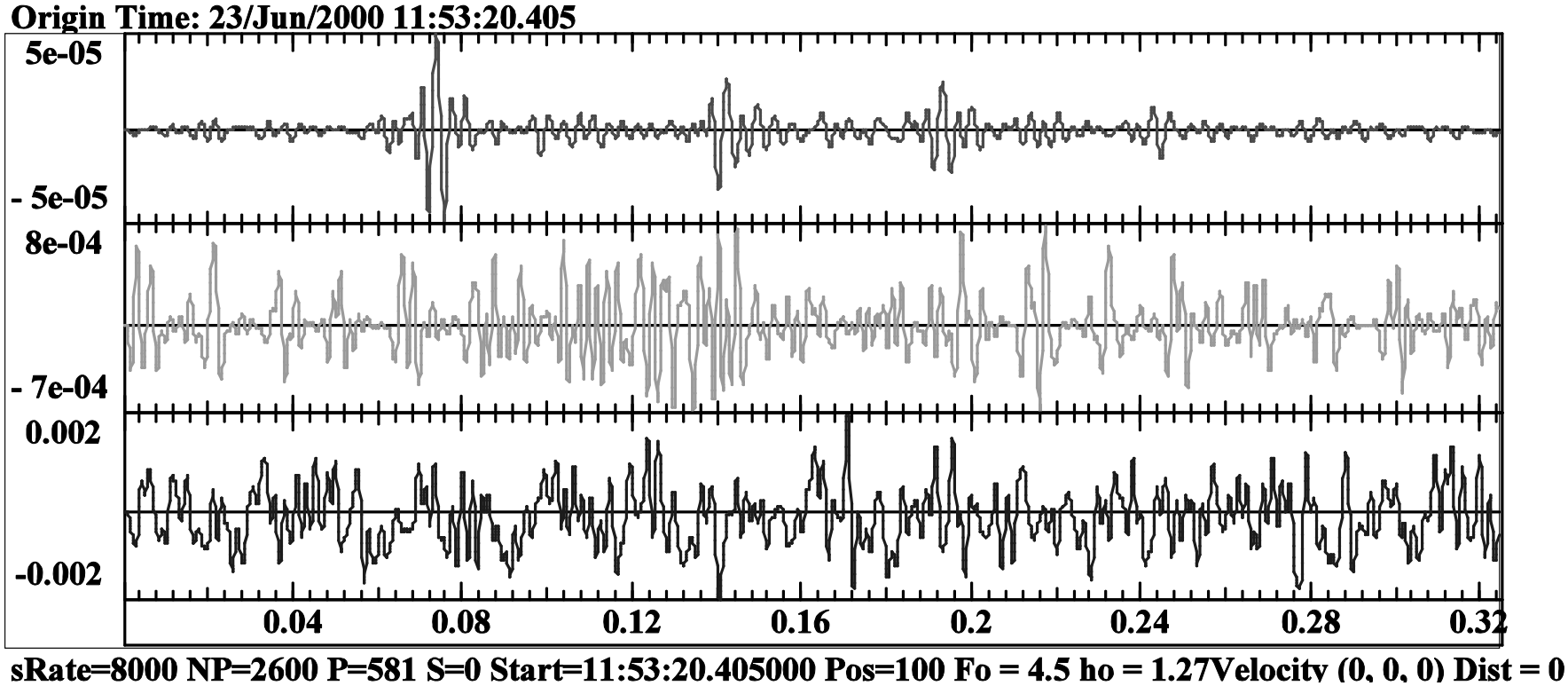

Origin Time: 23/Jun/2000 10:27:09.874
2e-05
- 2e-05
6e-04
- 5e-04
0.002
-0.001
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
sRate=8000 NP=4400 P=567 S=0 Start=10:27:09.874625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 11:51:13.306
4e-05
- 6e-05
9e-04
- 7e-04
0.001
-0.003
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
0.8
sRate=1600 NP=1310 P=510 S=0 Start=11:51:13.306500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

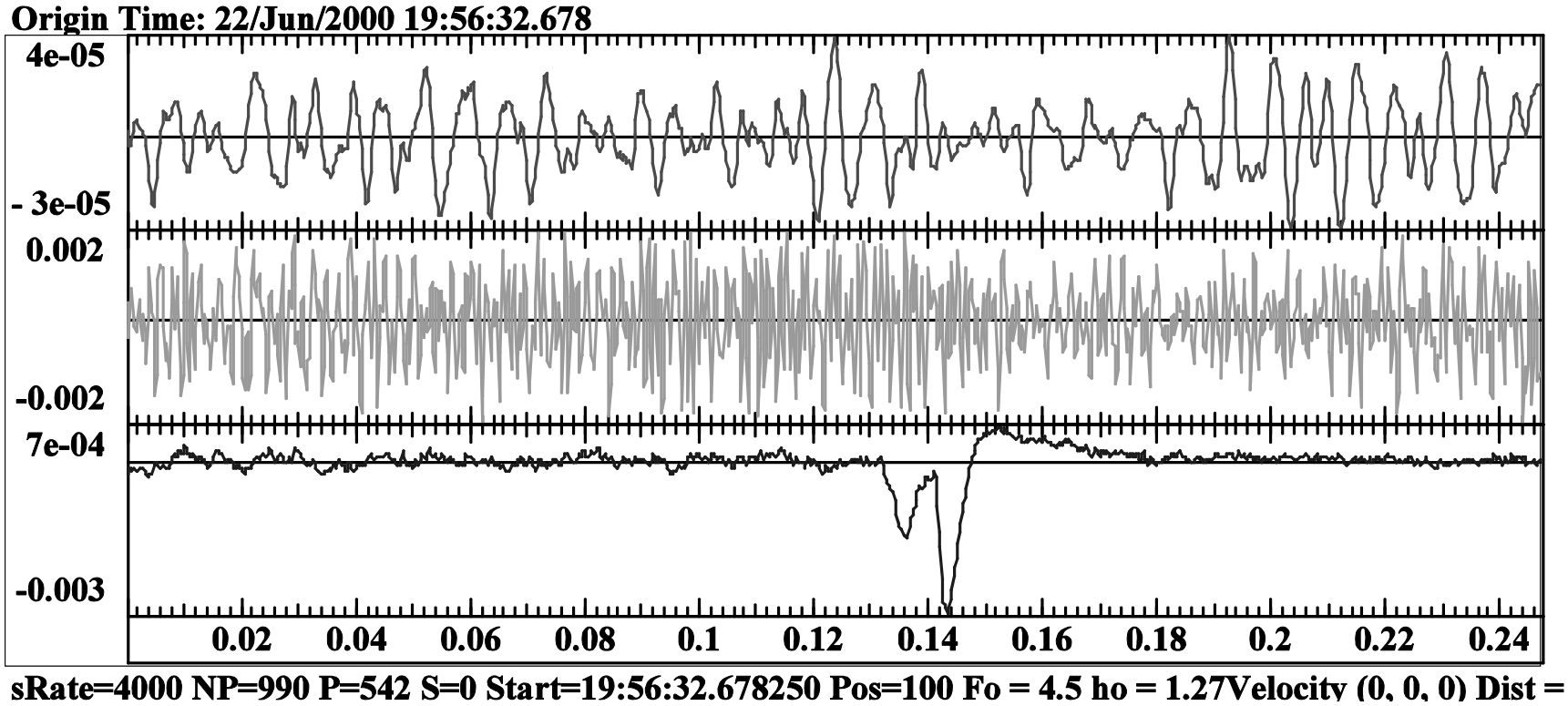

Origin Time: 23/Jun/2000 10:51:00.107
1e-04
- 2e-04
9e-04
- 7e-04
0.001
-0.001
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
sRate=8000 NP=2000 P=597 S=0 Start=10:51:00.107625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist =

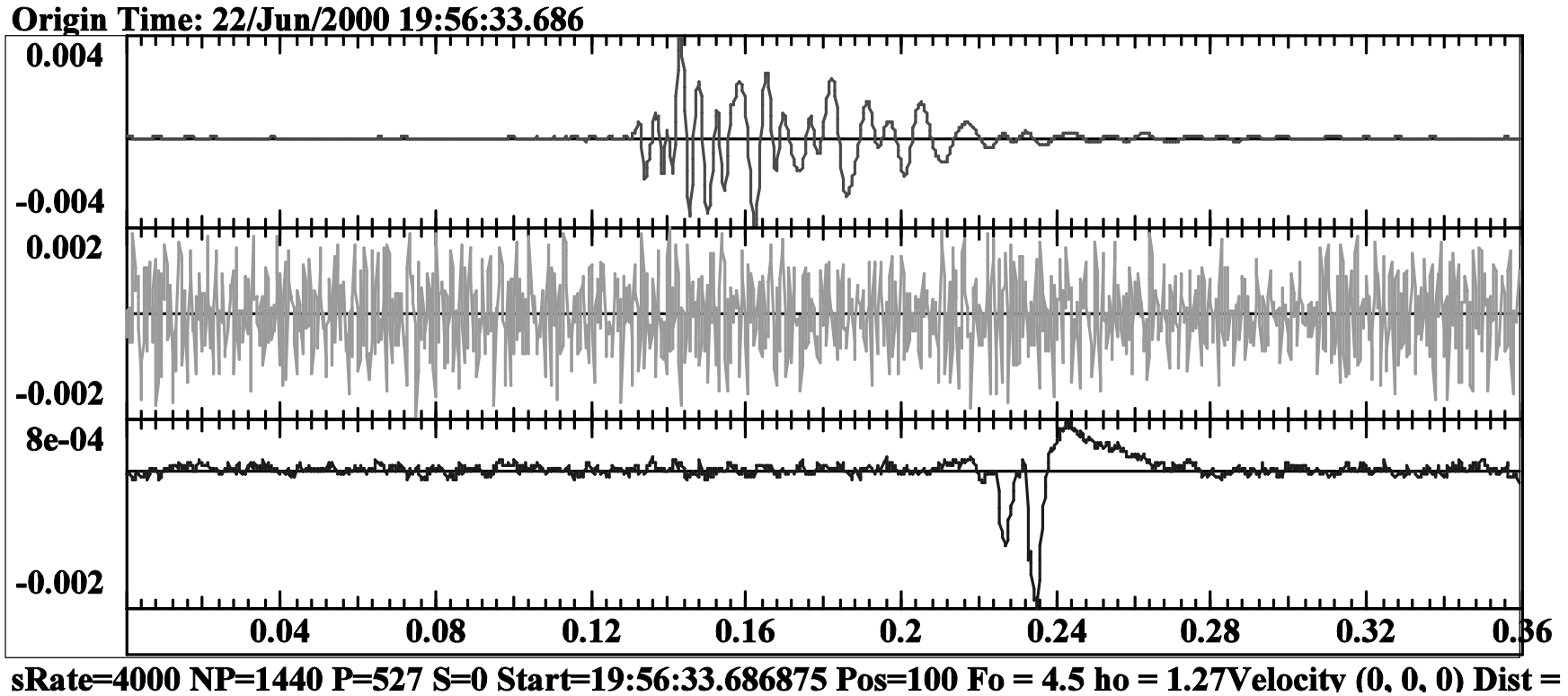

Origin Time: 23/Jun/2000 10:23:22.930
7e-05
- 6e-05
7e-04
- 5e-04
0.002
-0.001
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=521 S=0 Start=10:23:22.930750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 11:06:42.096
5e-05
- 6e-05
0.001
-0.001
0.003
-0.002
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1590 P=522 S=0 Start=11:06:42.096500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

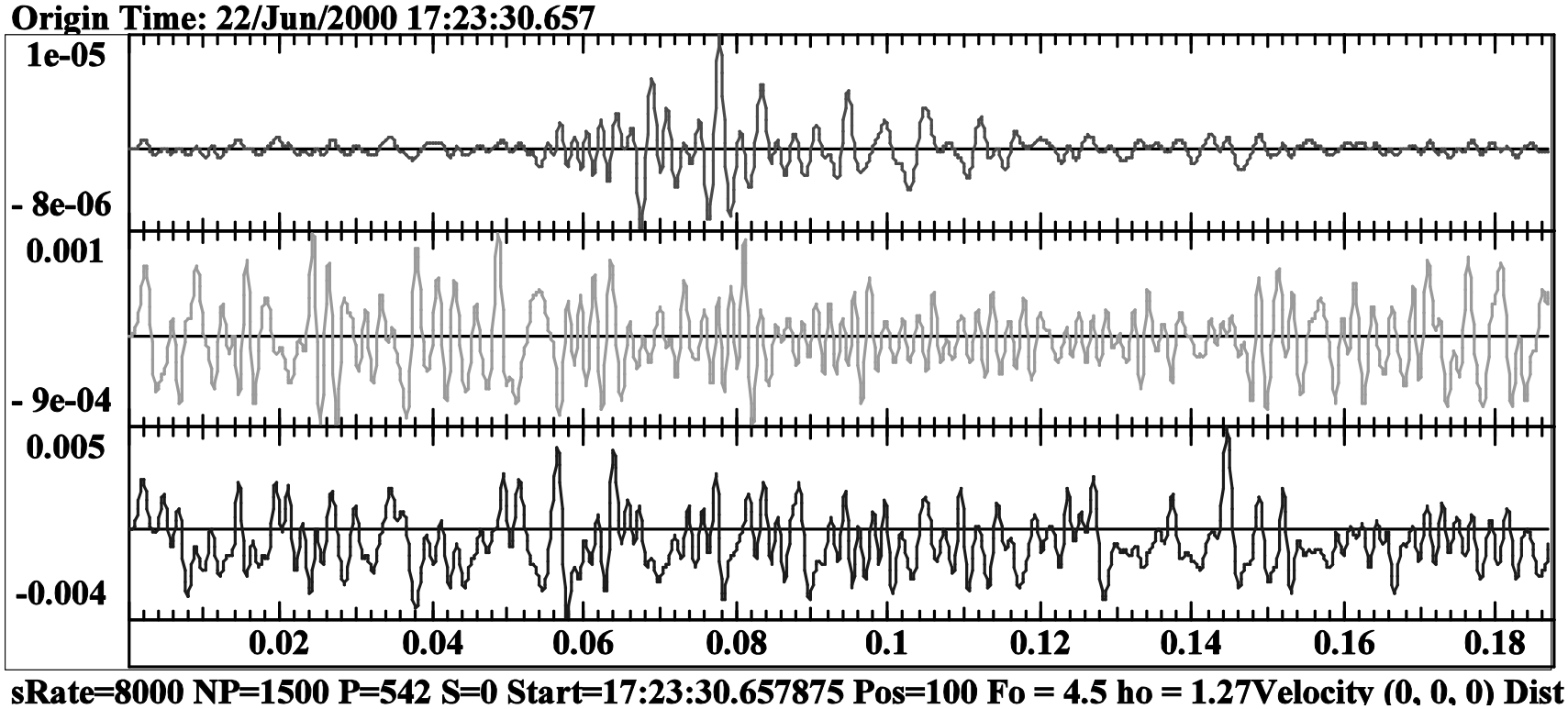

Origin Time: 23/Jun/2000 11:53:20.405
5e-05
- 5e-05
8e-04
- 7e-04
0.002
-0.002
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=8000 NP=2600 P=581 S=0 Start=11:53:20.405000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

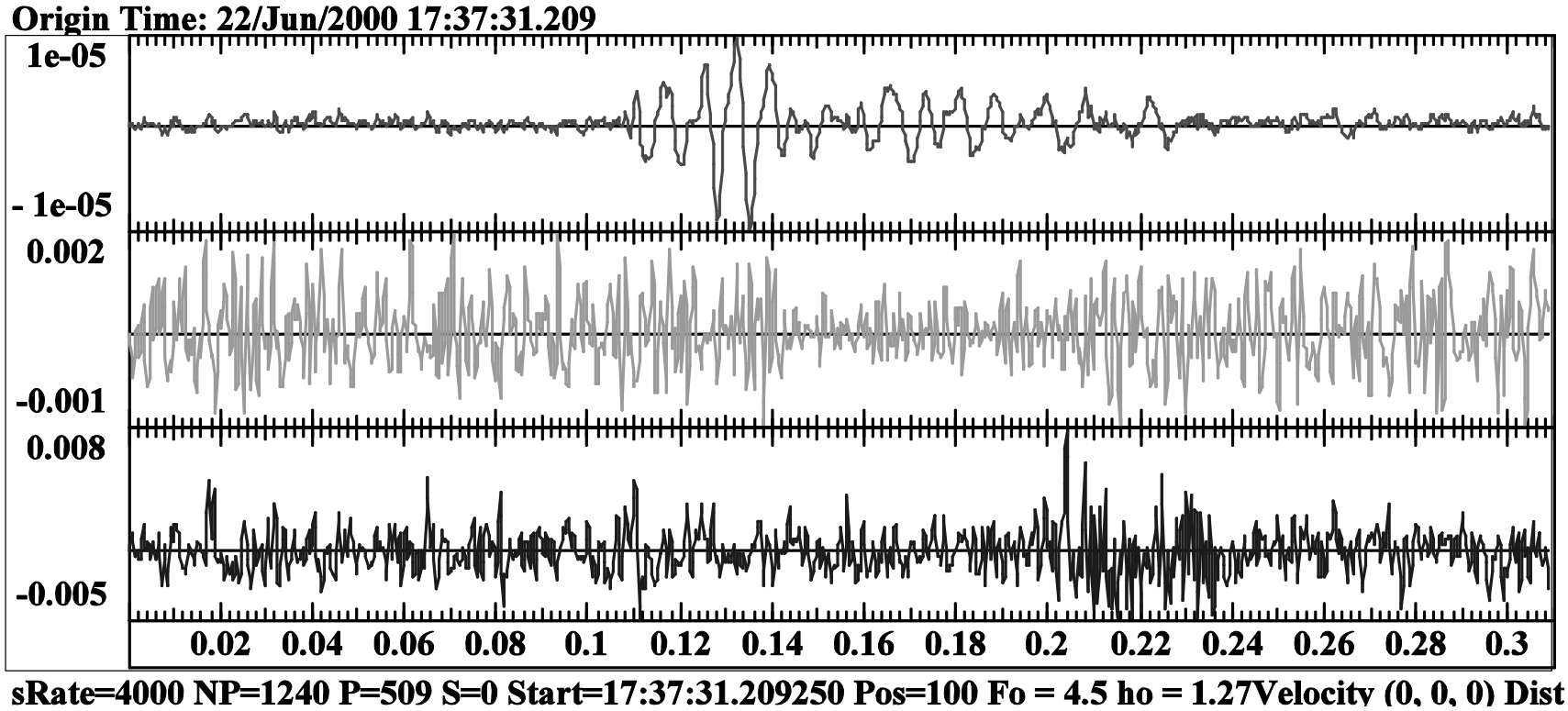
A2.4 Background electromagnetic emissions at 1.0 MHz

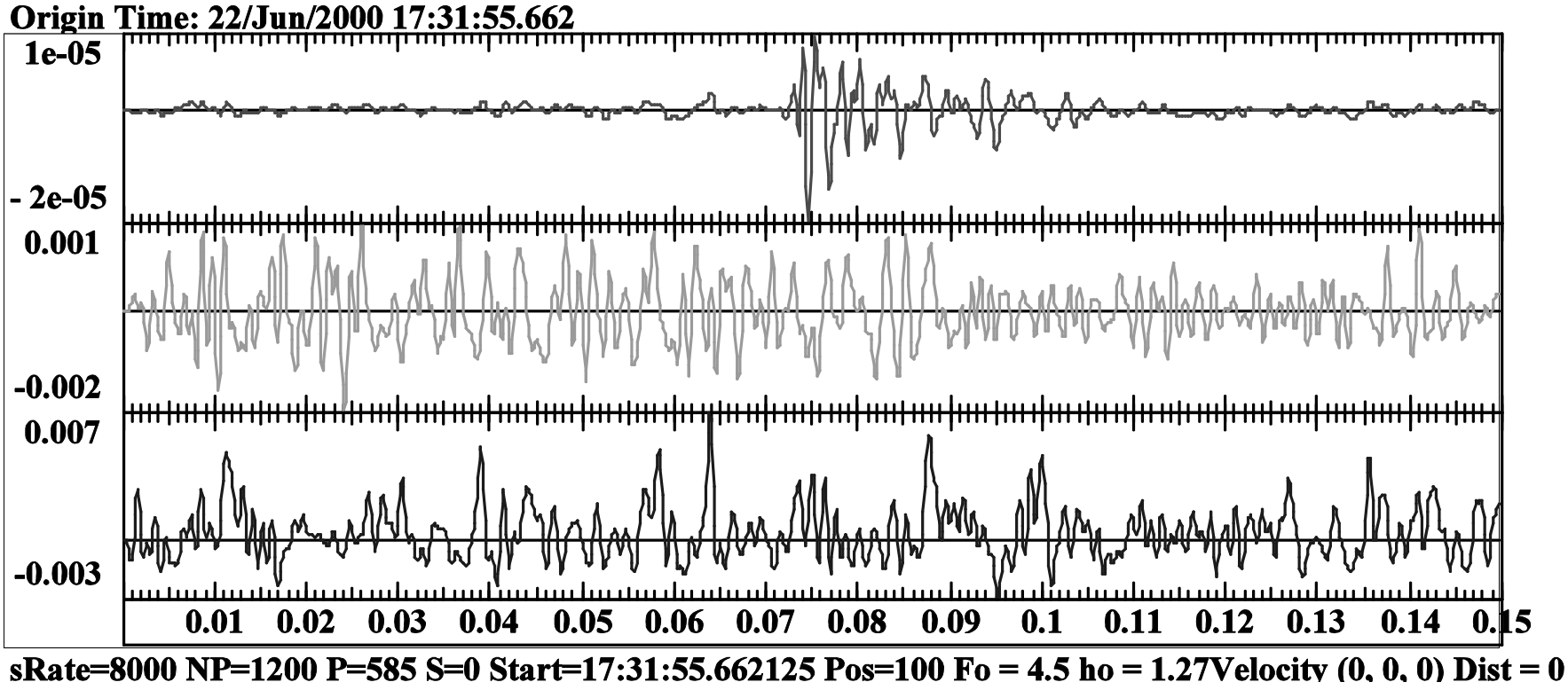

Origin Time: 22/Jun/2000 19:56:32.678
4e-05
- 3e-05
0.002
-0.002
7e-04
-0.003
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
sRate=4000 NP=990 P=542 S=0 Start=19:56:32.678250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

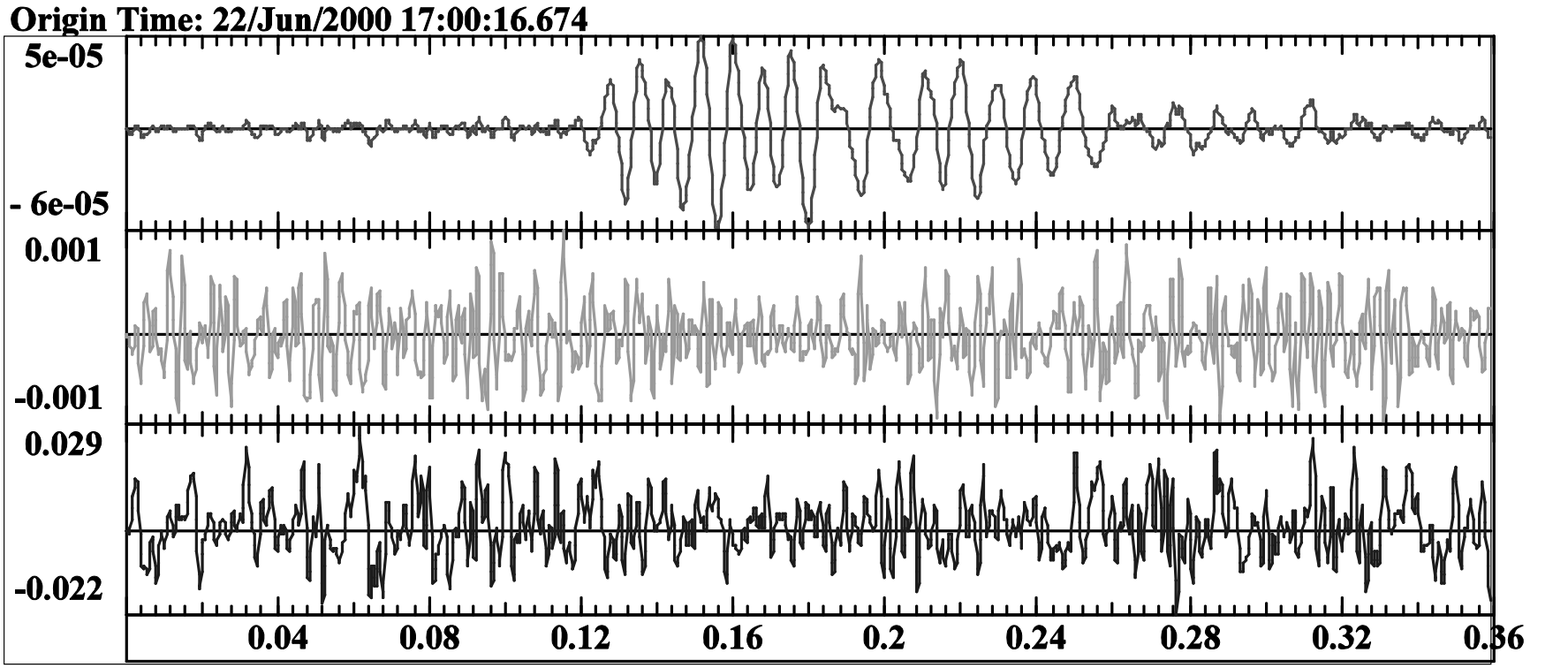

Origin Time: 22/Jun/2000 19:56:33.686
0.004
-0.004
0.002
-0.002
8e-04
-0.002
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1440 P=527 S=0 Start=19:56:33.686875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

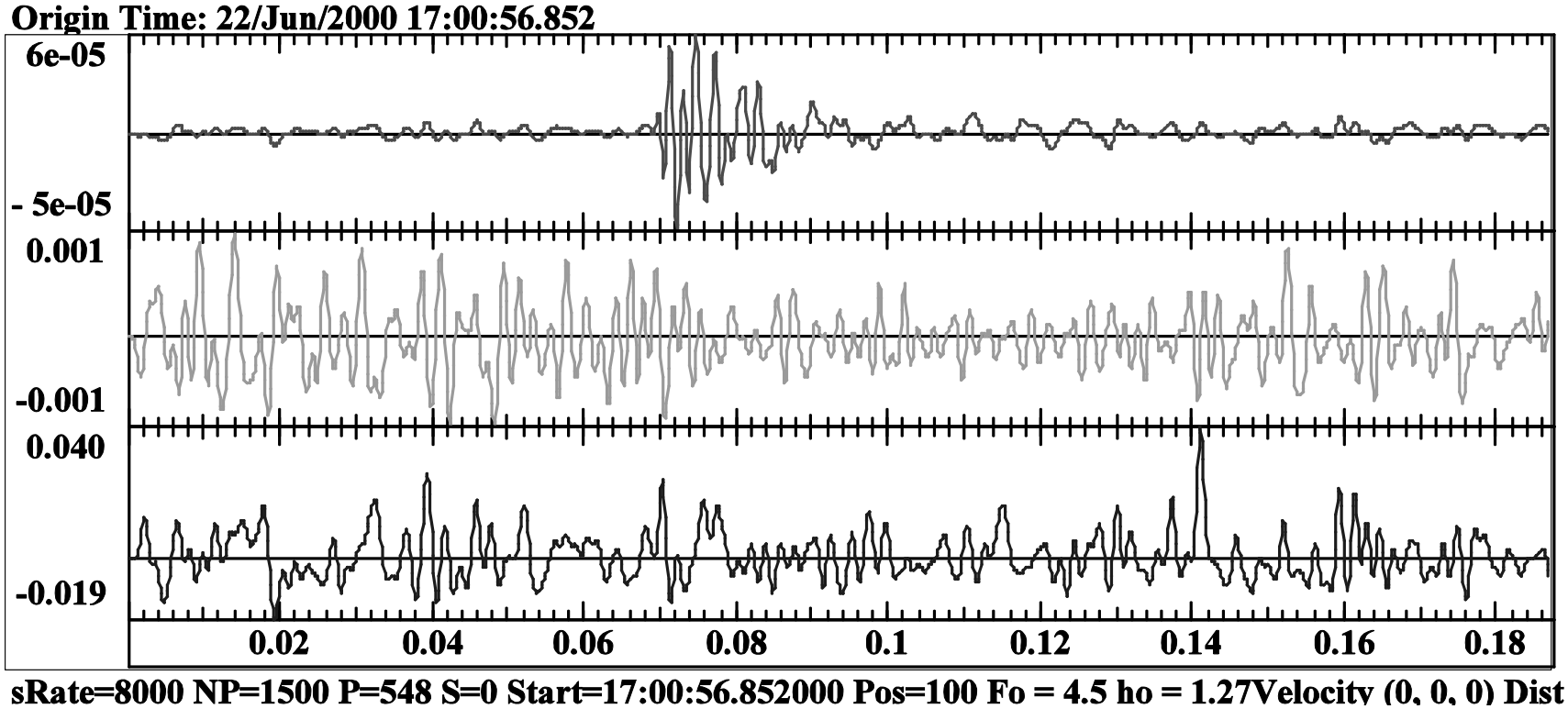
A2.5 Background electromagnetic emissions at 2.31 MHz

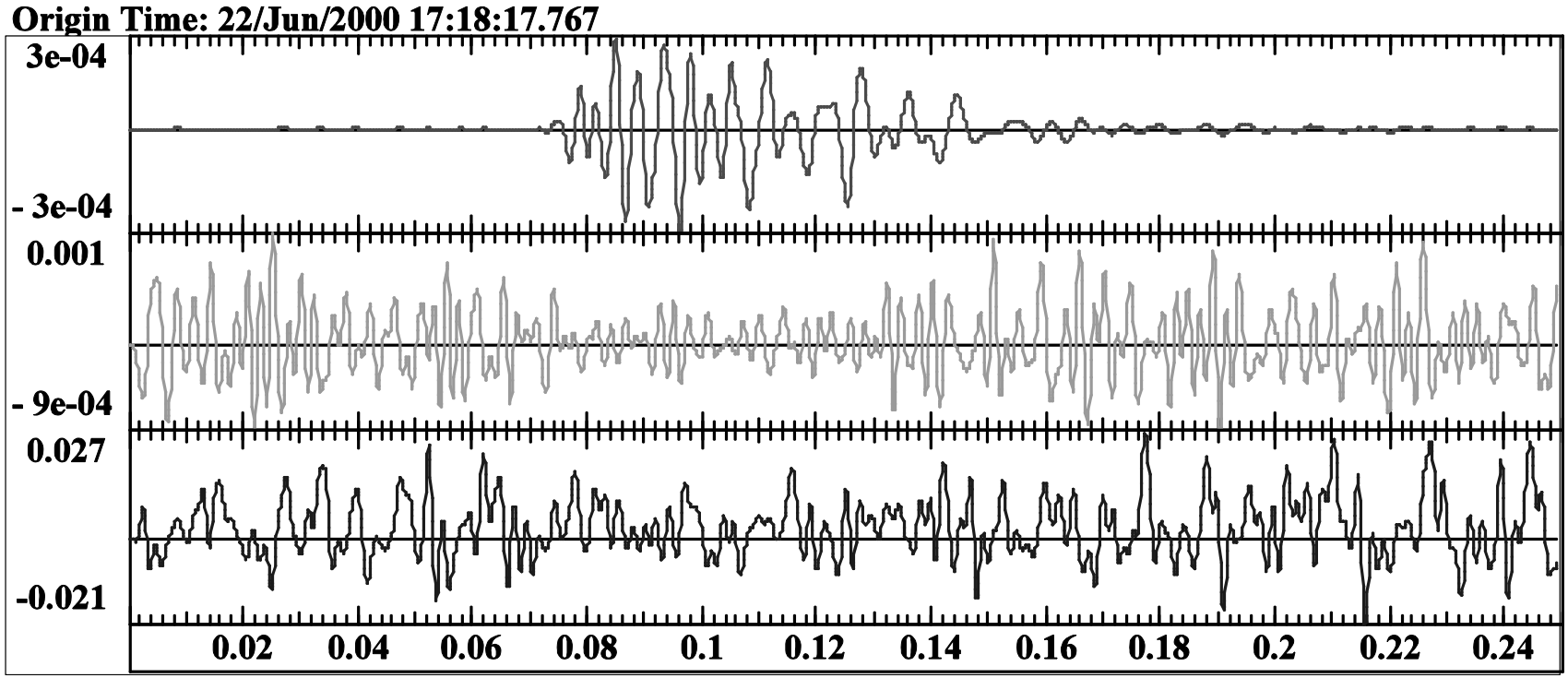

Origin Time: 22/Jun/2000 17:23:30.657
1e-05
- 8e-06
0.001
- 9e-04
0.005
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
sRate=8000 NP=1500 P=542 S=0 Start=17:23:30.657875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

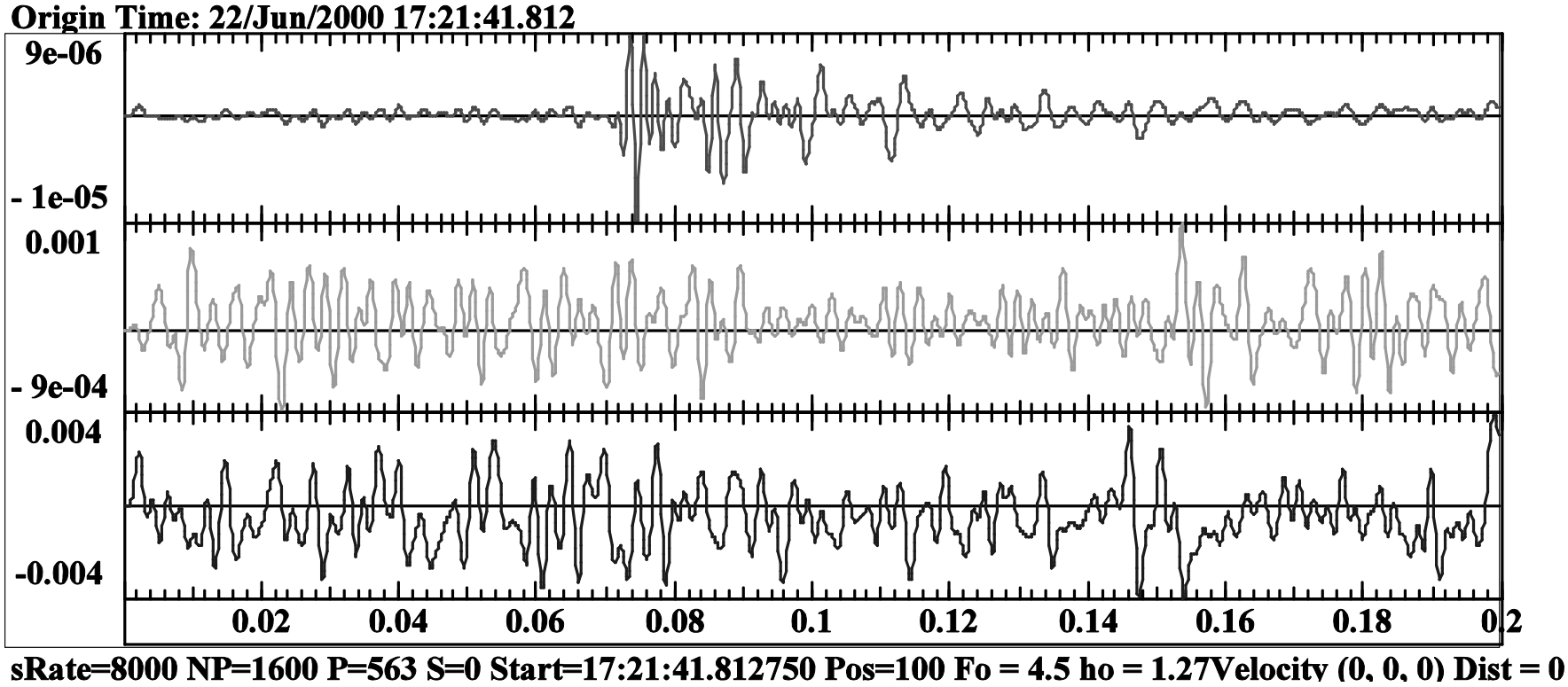

Origin Time: 22/Jun/2000 17:37:31.209
1e-05
- 1e-05
0.002
-0.001
0.008
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
sRate=4000 NP=1240 P=509 S=0 Start=17:37:31.209250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 17:31:55.662
1e-05
- 2e-05
0.001
-0.002
0.007
-0.003
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
sRate=8000 NP=1200 P=585 S=0 Start=17:31:55.662125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

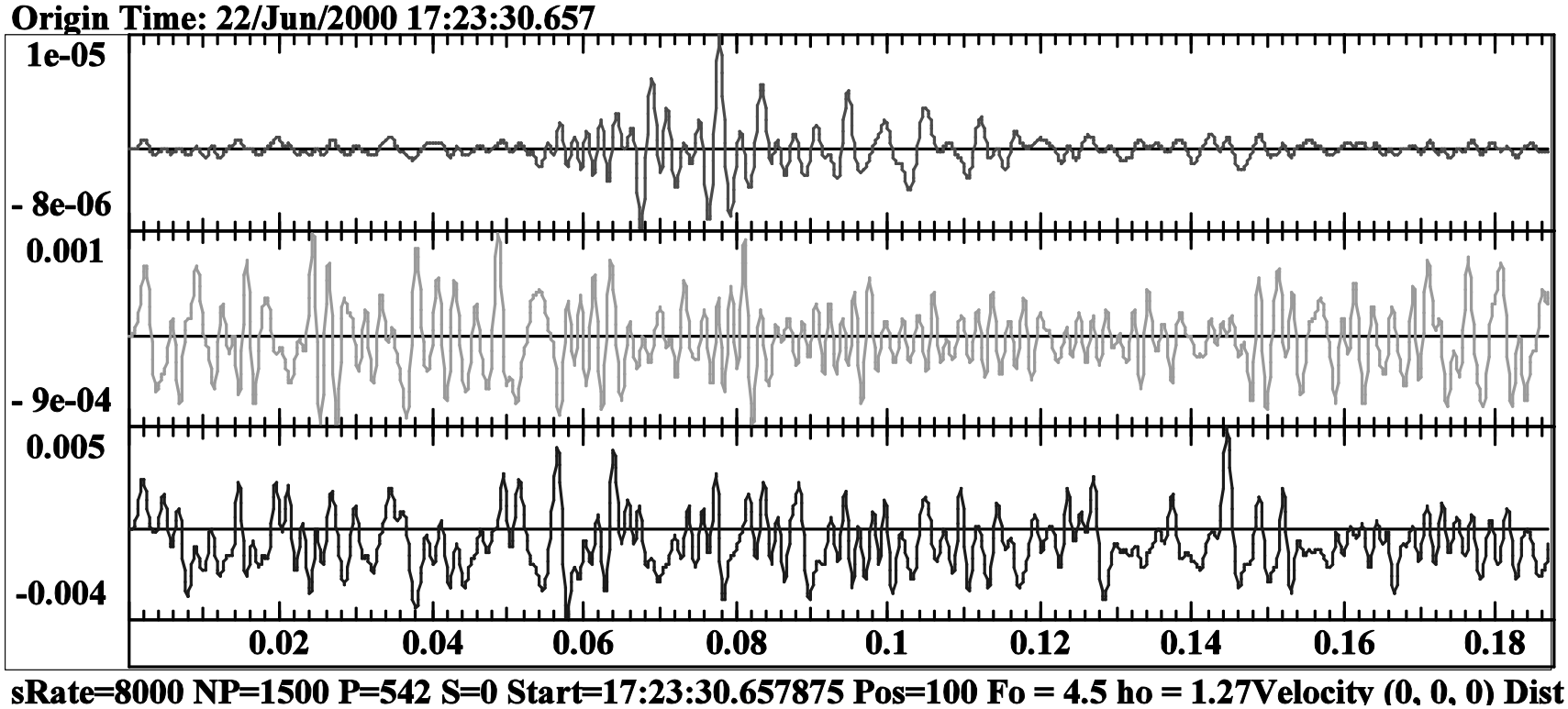

Origin Time: 22/Jun/2000 17:00:16.674
5e-05
- 6e-05
0.001
-0.001
0.029
-0.022
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=4000 NP=1440 P=508 S=0 Start=17:00:16.674250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist =

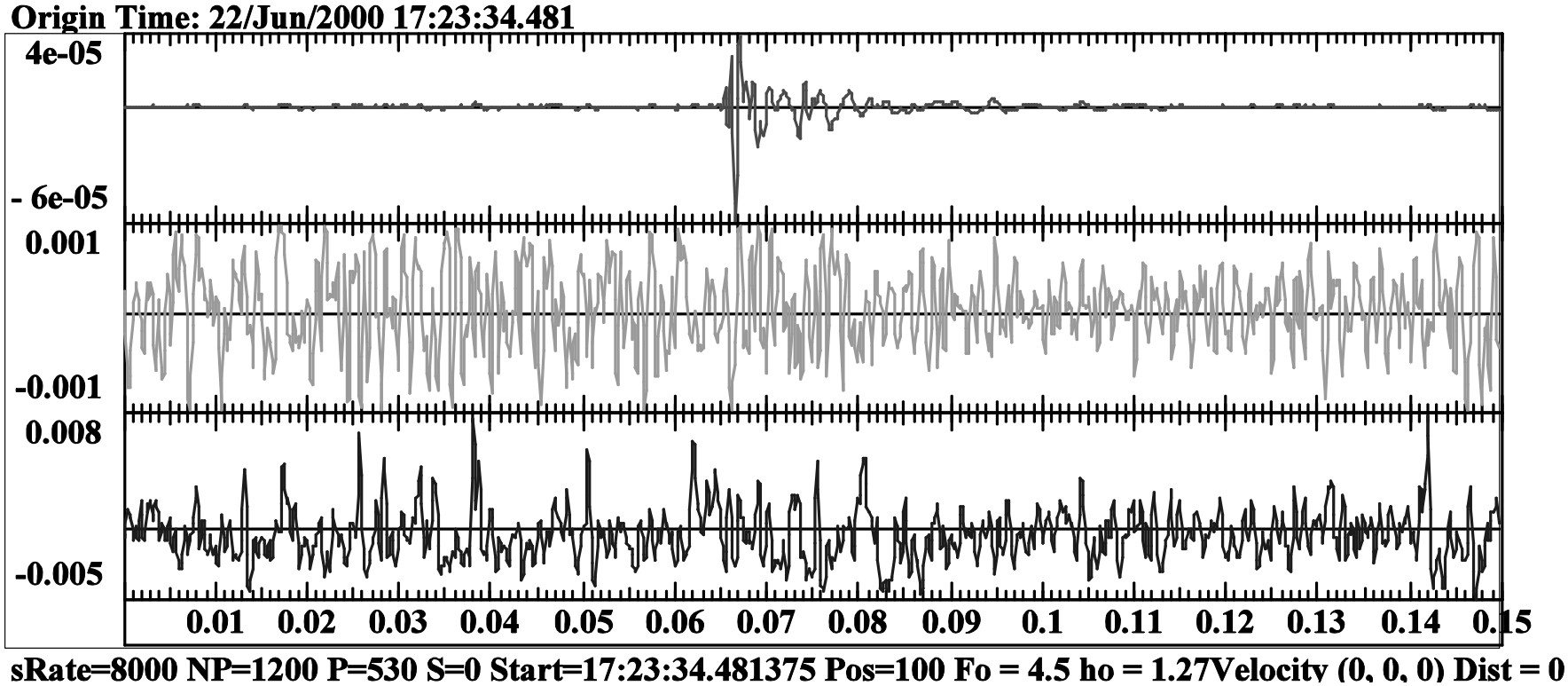

Origin Time: 22/Jun/2000 17:00:56.852
6e-05
- 5e-05
0.001
-0.001
0.040
-0.019
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
sRate=8000 NP=1500 P=548 S=0 Start=17:00:56.852000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

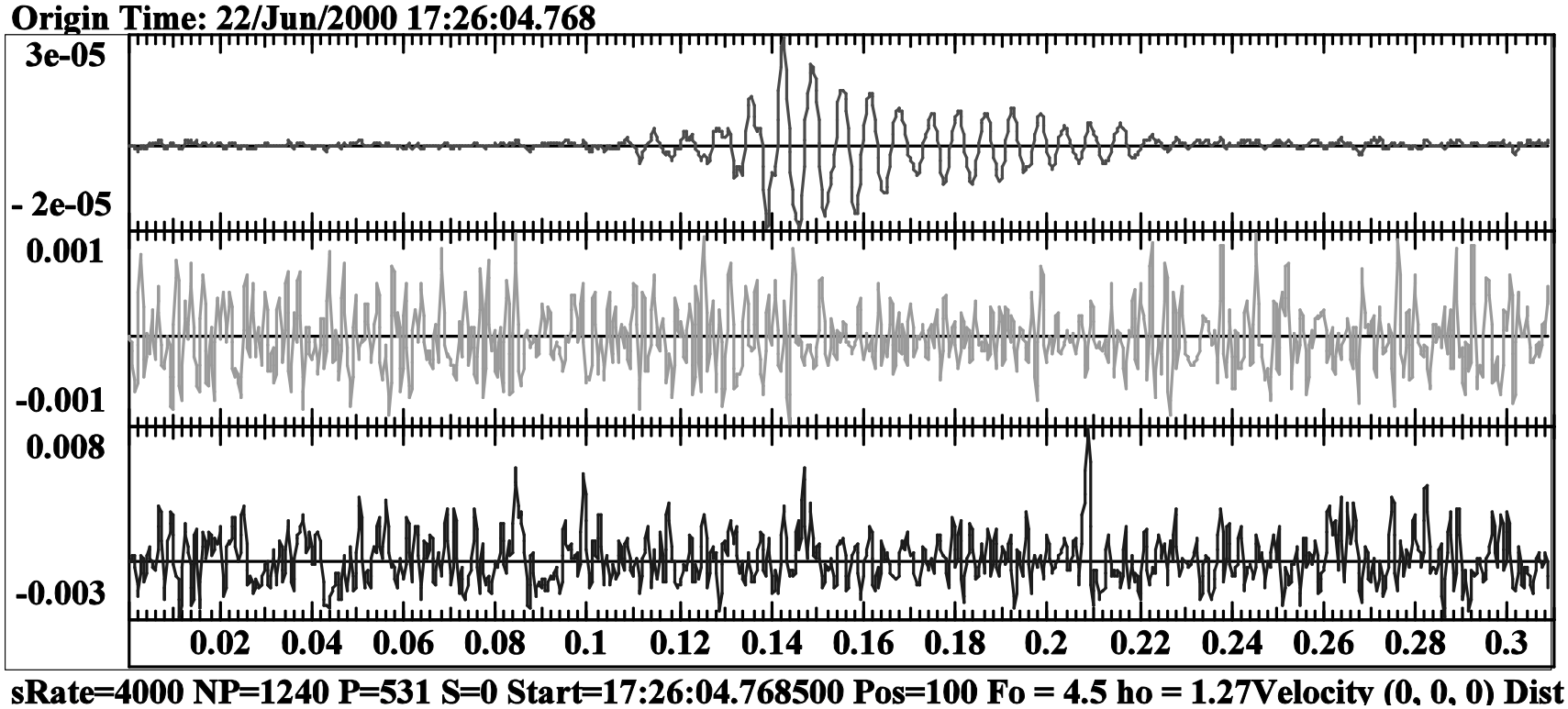

Origin Time: 22/Jun/2000 17:18:17.767
3e-04
- 3e-04
0.001
- 9e-04
0.027
-0.021
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
sRate=8000 NP=2000 P=592 S=0 Start=17:18:17.767125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

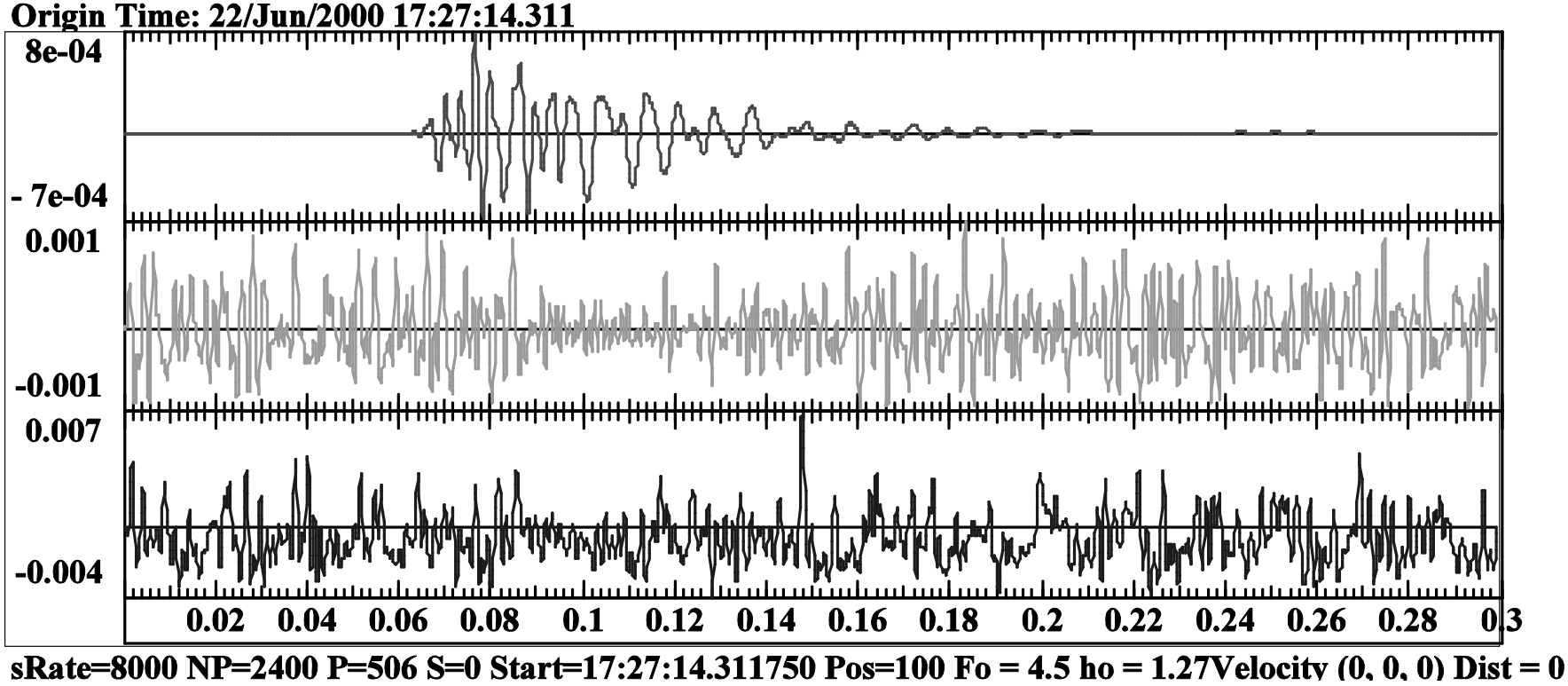

Origin Time: 22/Jun/2000 17:21:41.812
9e-06
- 1e-05
0.001
- 9e-04
0.004
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=563 S=0 Start=17:21:41.812750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

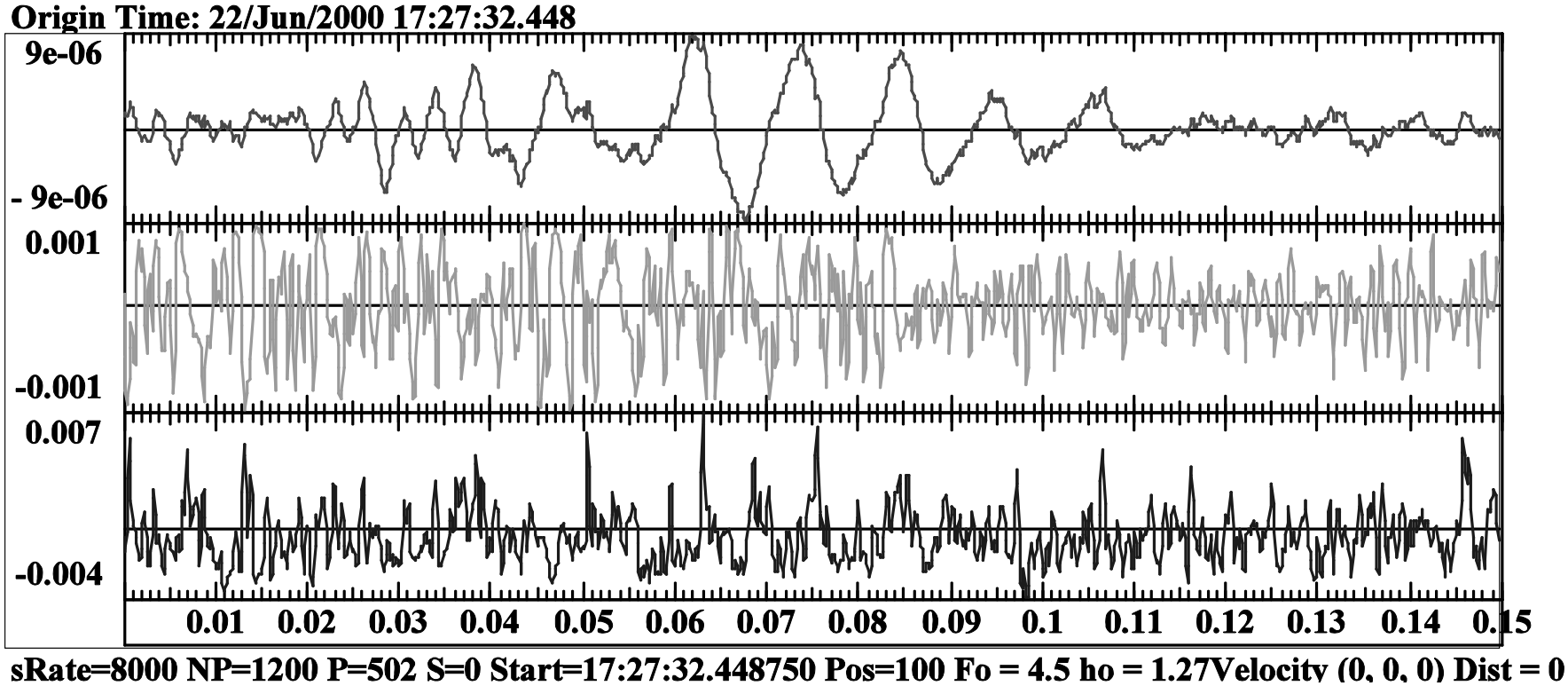
7

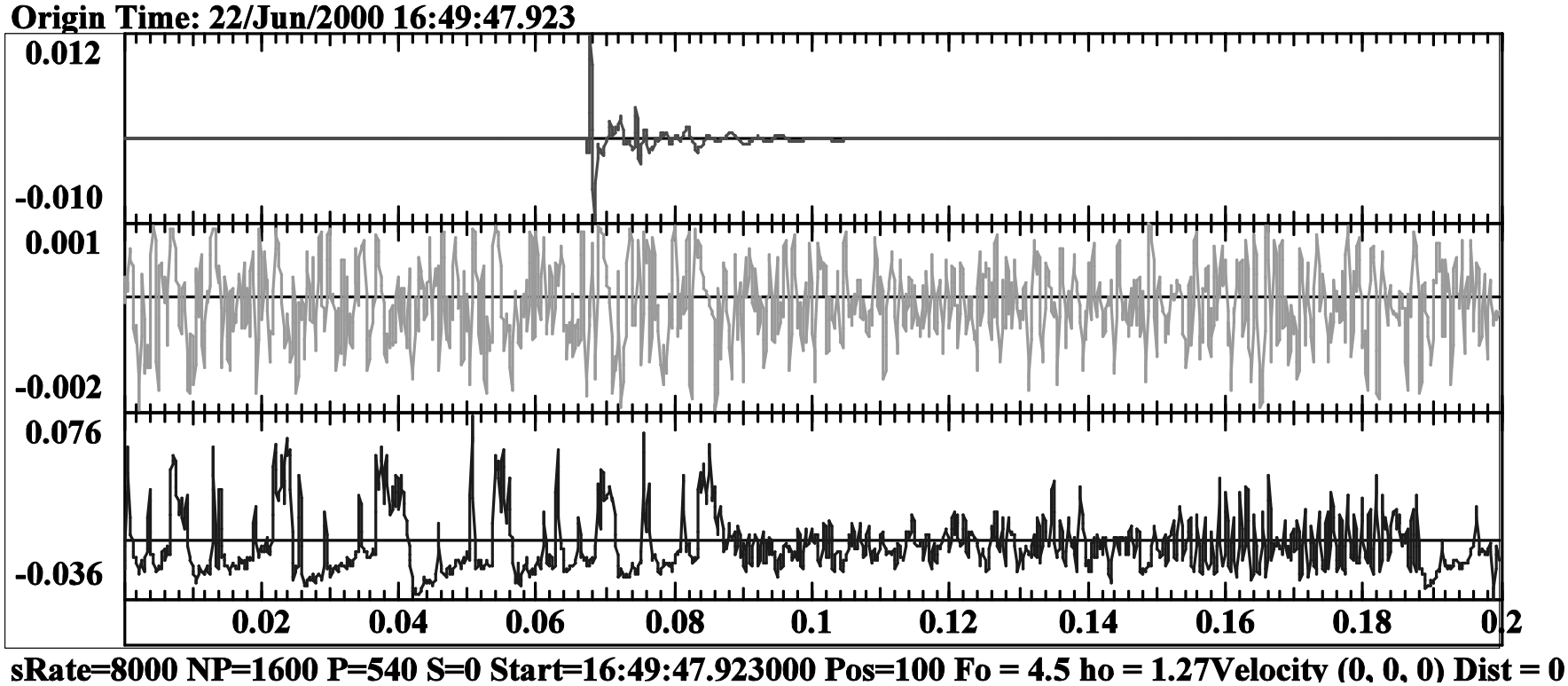

Origin Time: 22/Jun/2000 17:23:30.657
1e-05
- 8e-06
0.001
- 9e-04
0.005
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
sRate=8000 NP=1500 P=542 S=0 Start=17:23:30.657875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

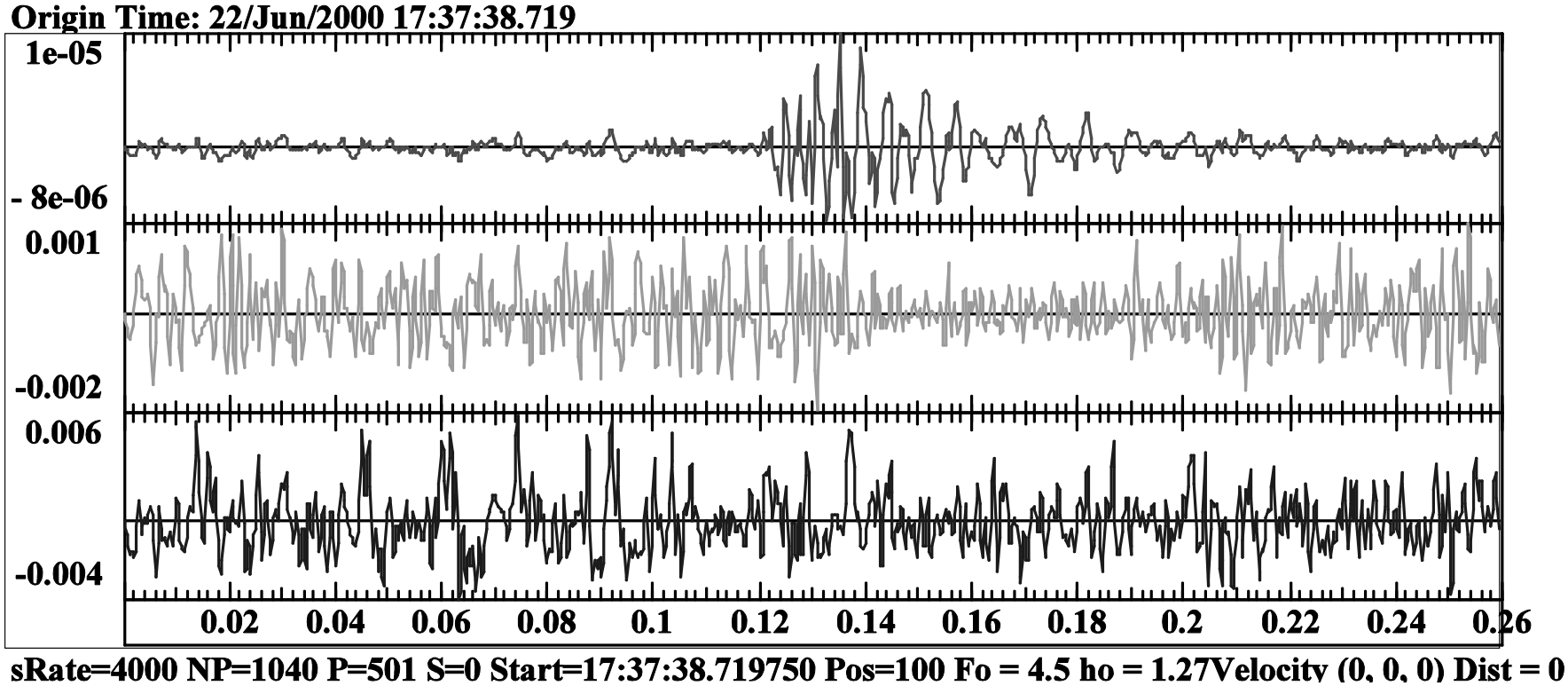

Origin Time: 22/Jun/2000 17:23:34.481
4e-05
- 6e-05
0.001
-0.001
0.008
-0.005
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
sRate=8000 NP=1200 P=530 S=0 Start=17:23:34.481375 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

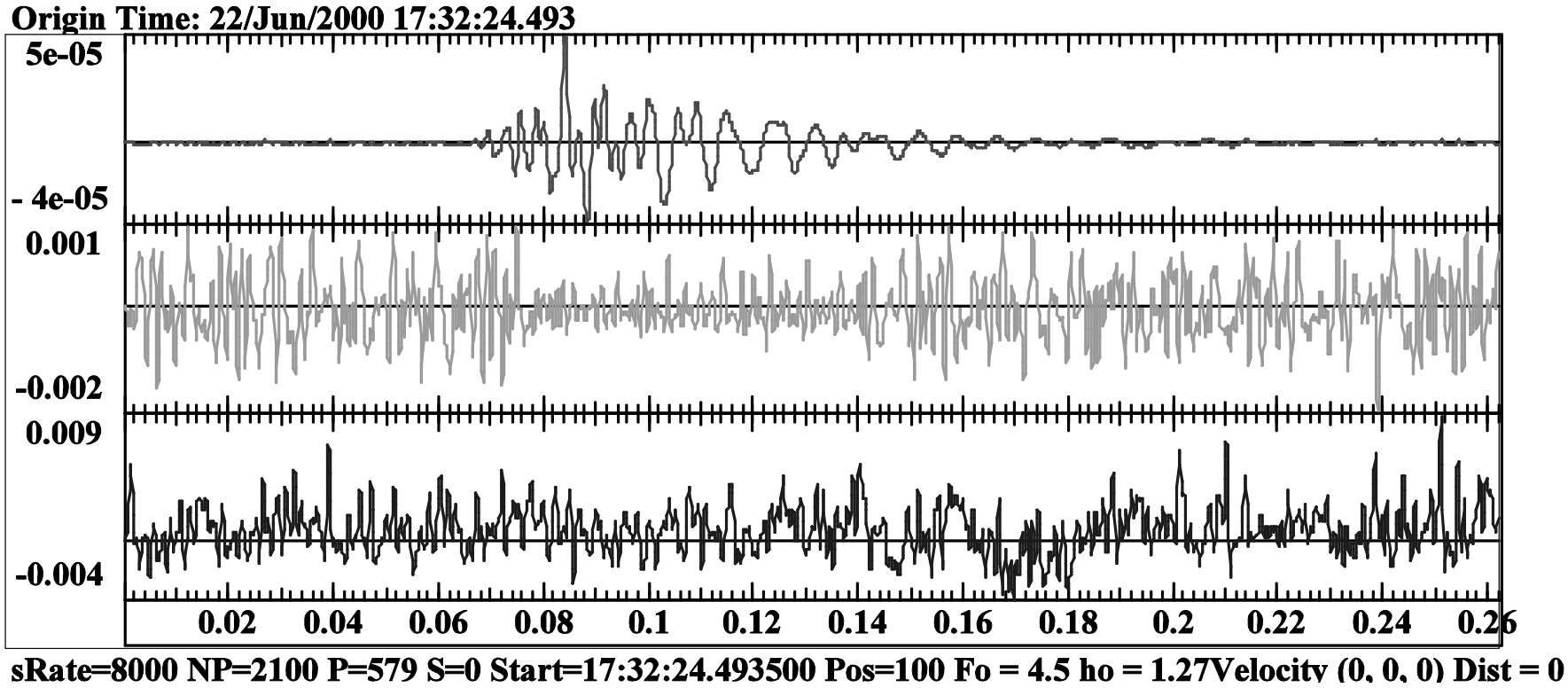

Origin Time: 22/Jun/2000 17:26:04.768
3e-05
- 2e-05
0.001
-0.001
0.008
-0.003
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
sRate=4000 NP=1240 P=531 S=0 Start=17:26:04.768500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

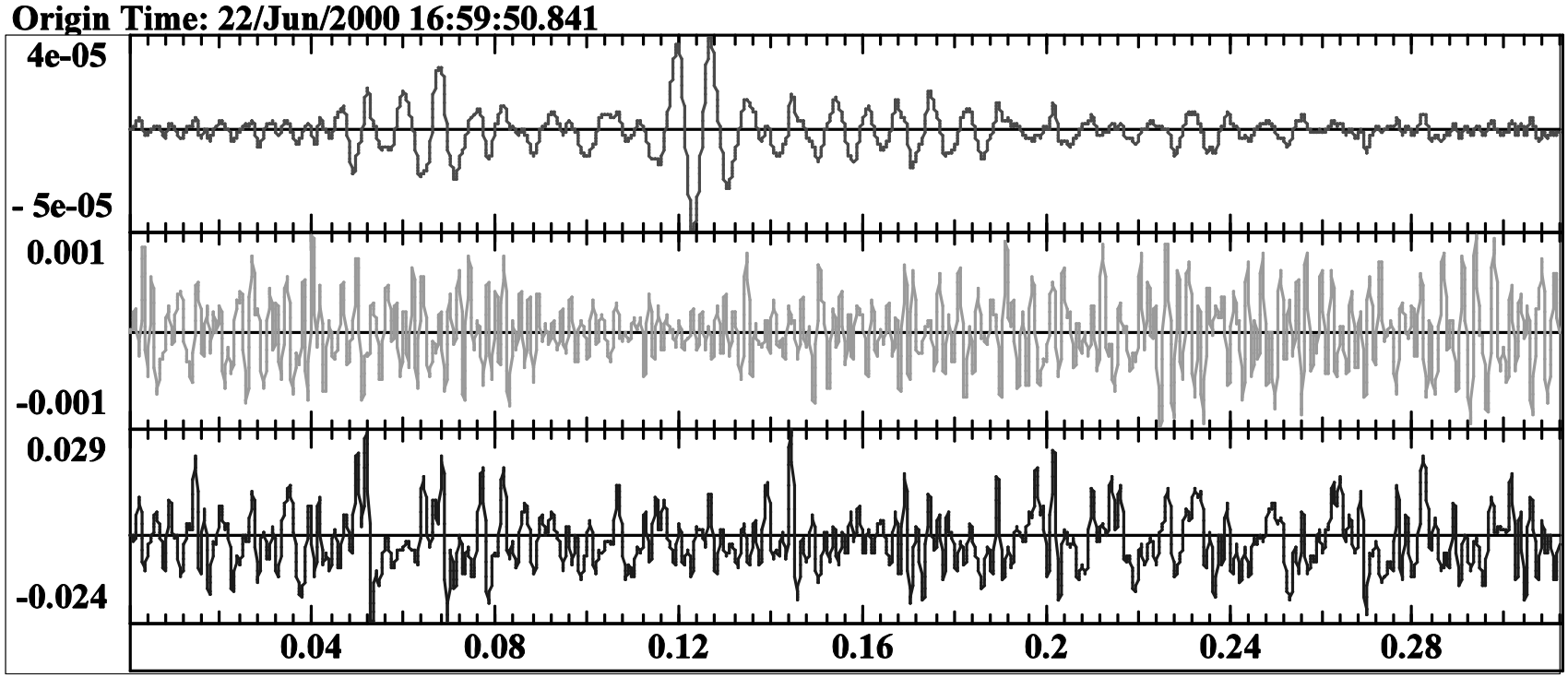

Origin Time: 22/Jun/2000 17:27:14.311
8e-04
- 7e-04
0.001
-0.001
0.007
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
sRate=8000 NP=2400 P=506 S=0 Start=17:27:14.311750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

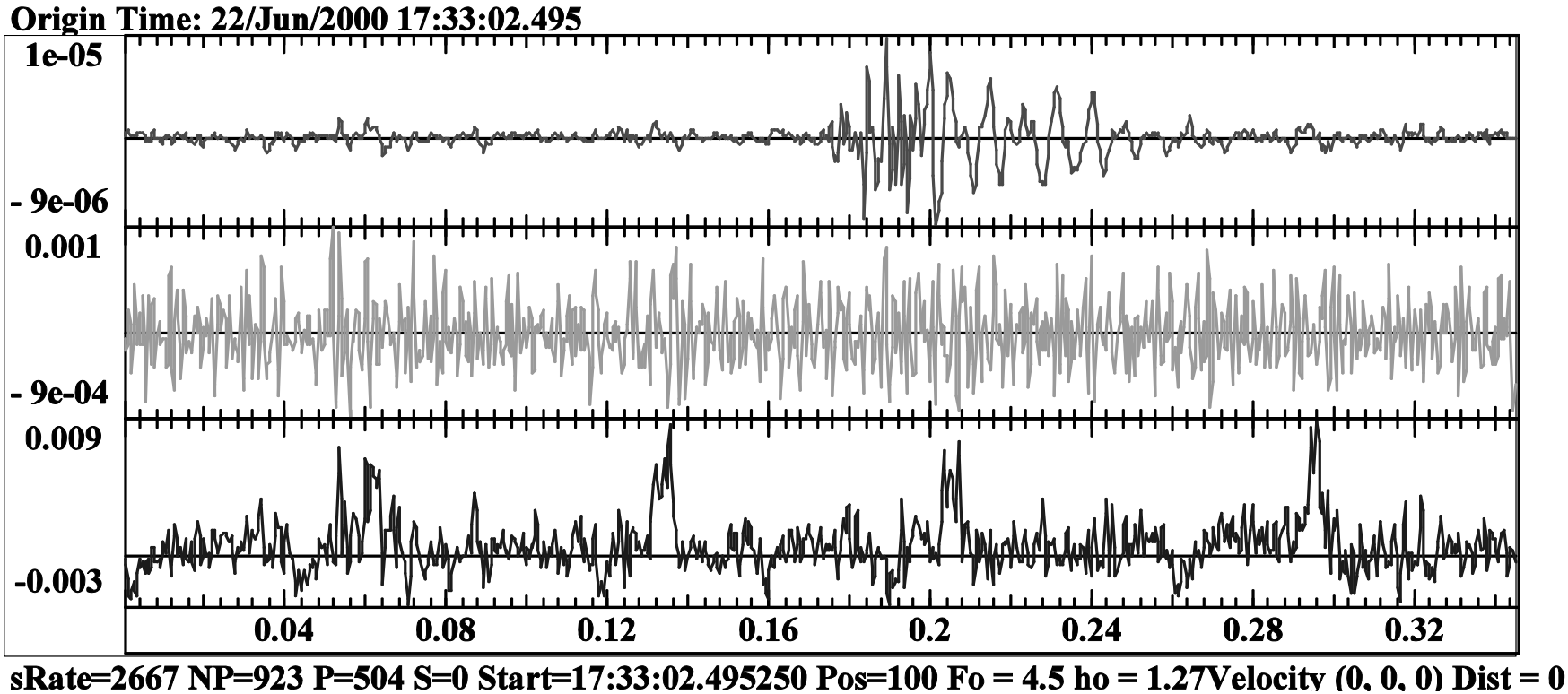

Origin Time: 22/Jun/2000 17:27:32.448
9e-06
- 9e-06
0.001
-0.001
0.007
-0.004
0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.11 0.12 0.13 0.14 0.15
sRate=8000 NP=1200 P=502 S=0 Start=17:27:32.448750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

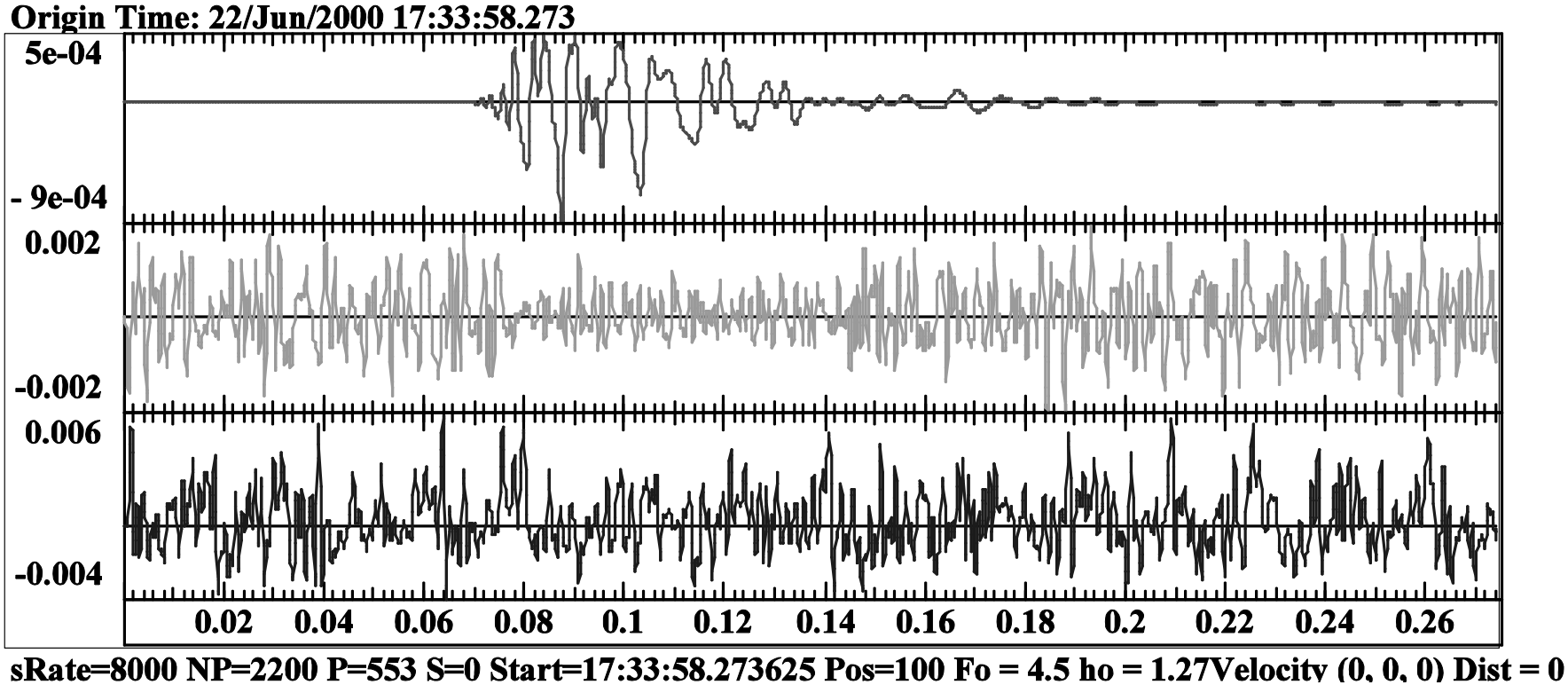

Origin Time: 22/Jun/2000 16:49:47.923
0.012
-0.010
0.001
-0.002
0.076
-0.036
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
sRate=8000 NP=1600 P=540 S=0 Start=16:49:47.923000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 17:37:38.719
1e-05
- 8e-06
0.001
-0.002
0.006
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=4000 NP=1040 P=501 S=0 Start=17:37:38.719750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

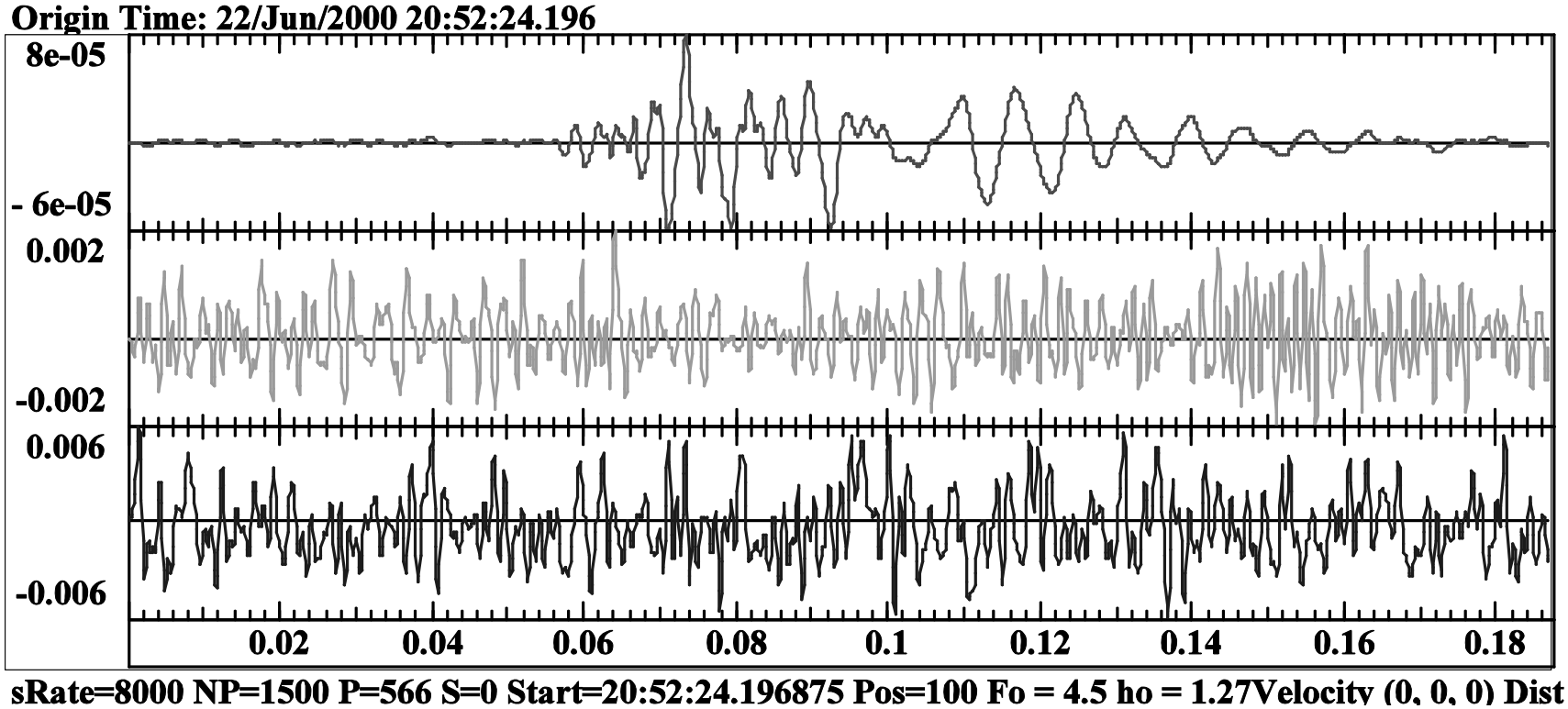

Origin Time: 22/Jun/2000 17:32:24.493
5e-05
- 4e-05
0.001
-0.002
0.009
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2100 P=579 S=0 Start=17:32:24.493500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

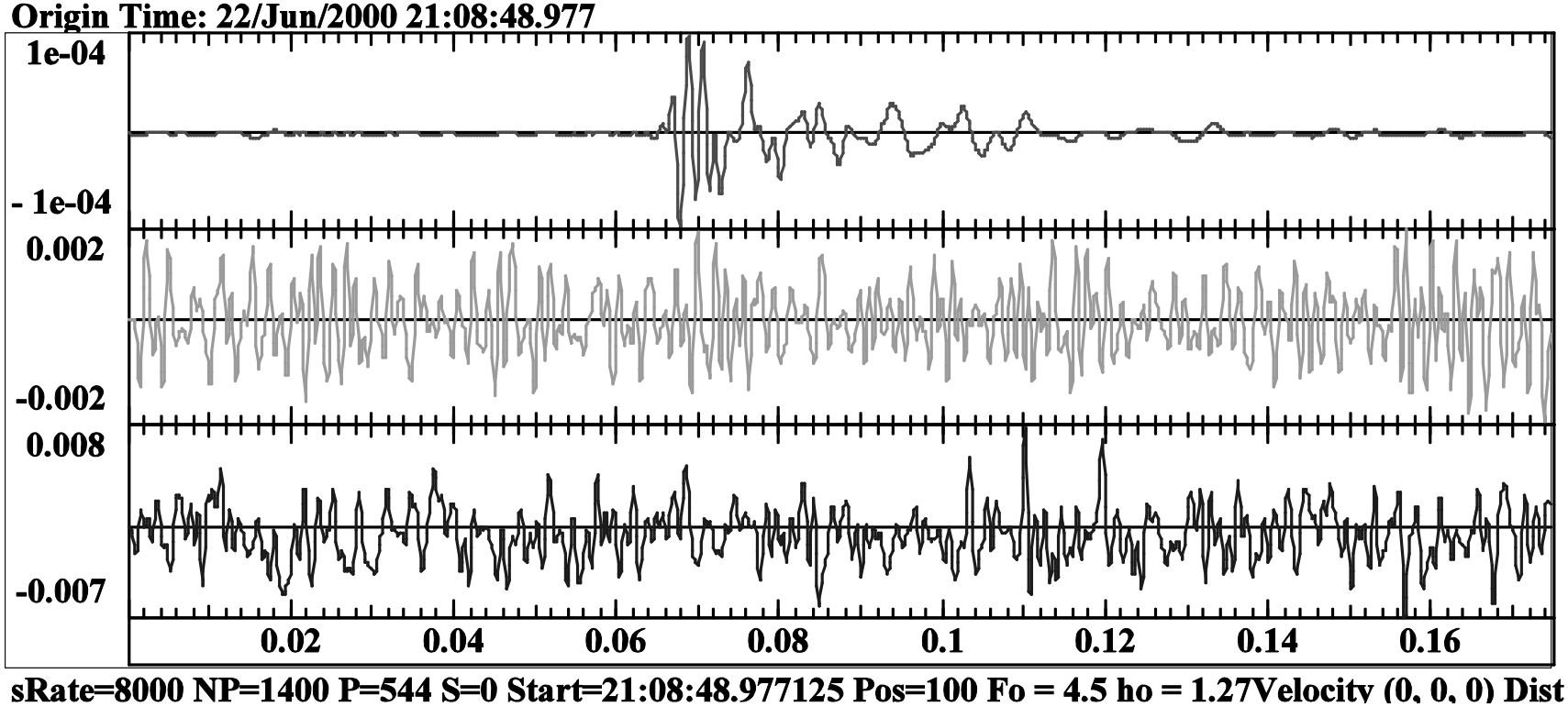

Origin Time: 22/Jun/2000 16:59:50.841
4e-05
- 5e-05
0.001
-0.001
0.029
-0.024
0.04
0.08
0.12
0.16
0.2
0.24
0.28
sRate=8000 NP=2500 P=533 S=0 Start=16:59:50.841625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

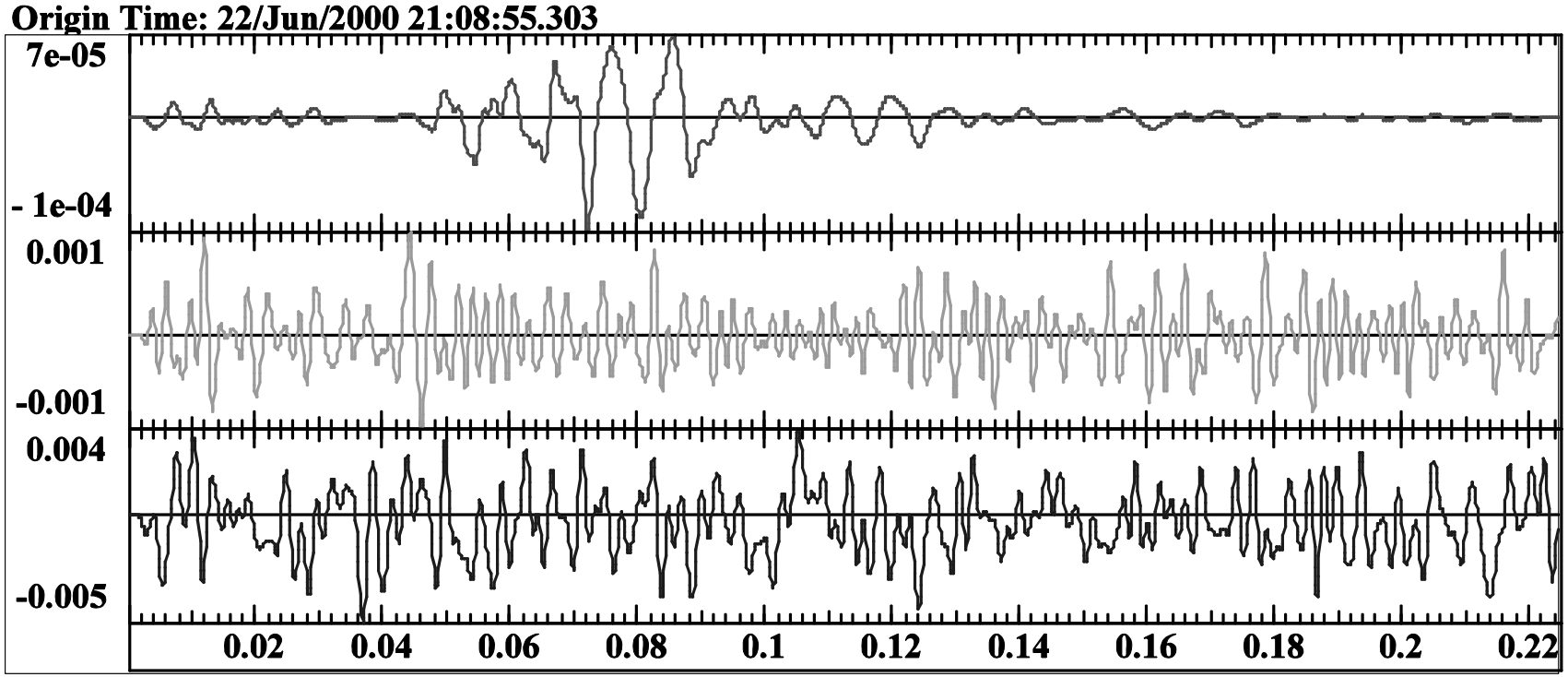

Origin Time: 22/Jun/2000 17:33:02.495
1e-05
- 9e-06
0.001
- 9e-04
0.009
-0.003
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=2667 NP=923 P=504 S=0 Start=17:33:02.495250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

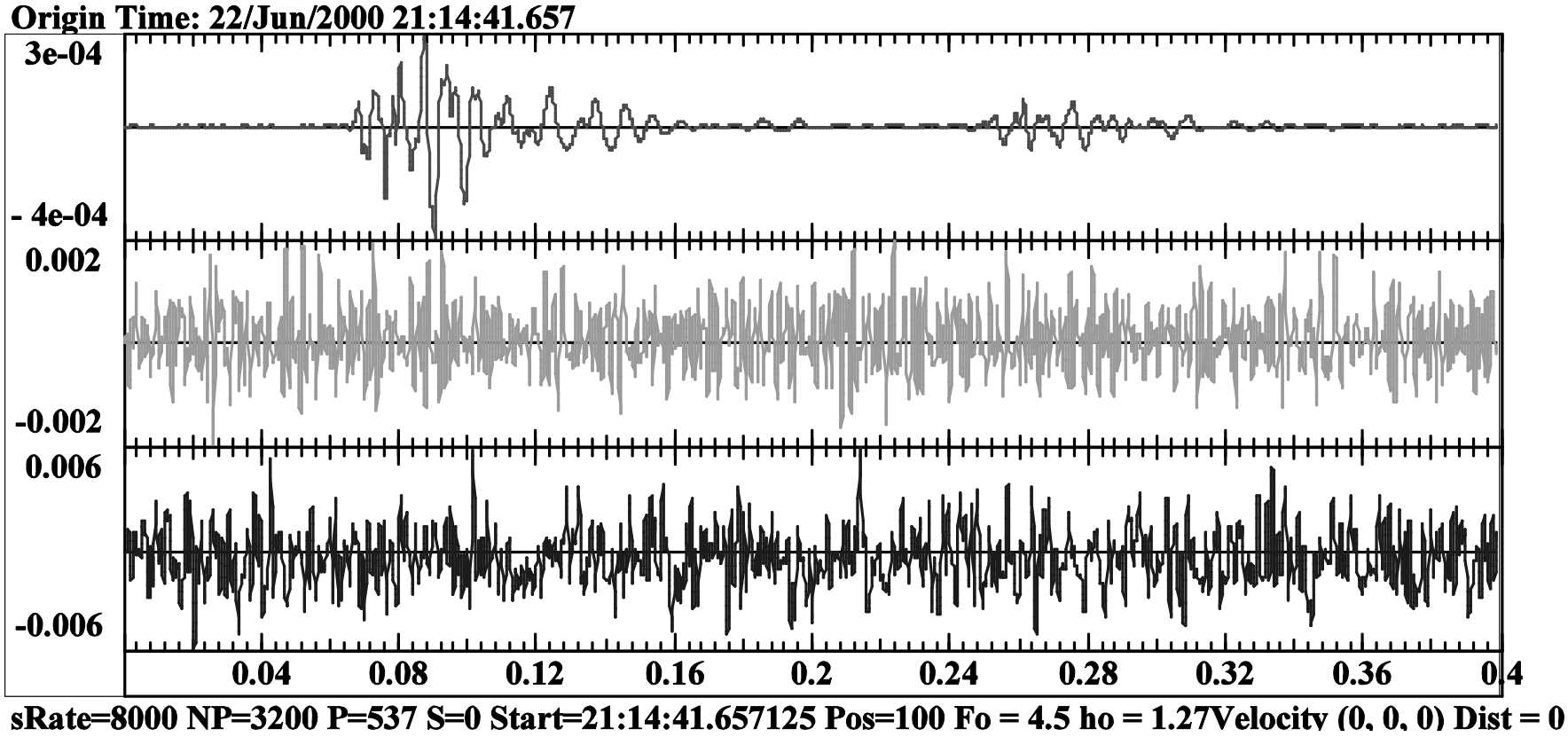

Origin Time: 22/Jun/2000 17:33:58.273
5e-04
- 9e-04
0.002
-0.002
0.006
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2200 P=553 S=0 Start=17:33:58.273625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

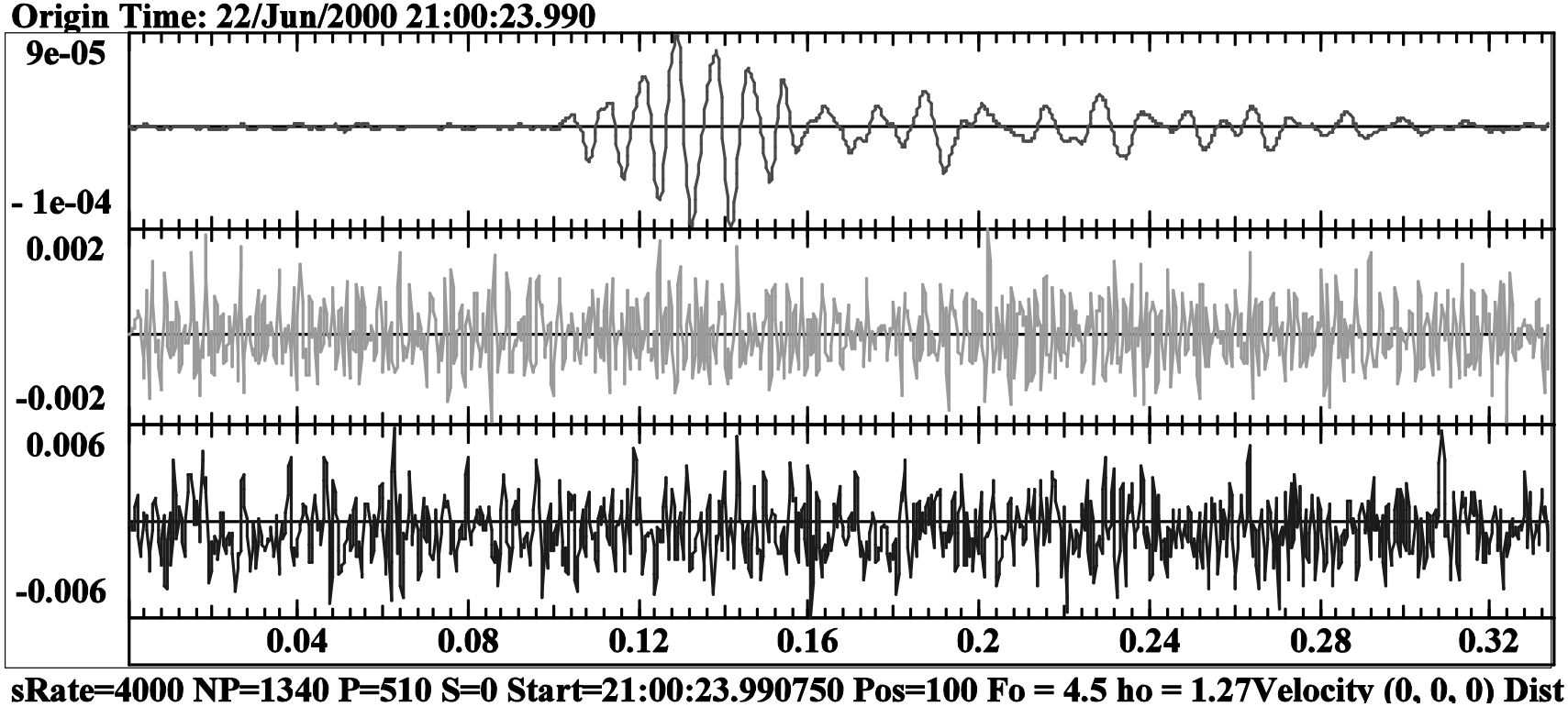
A2.6 Background electromagnetic emissions at 2.5 MHz

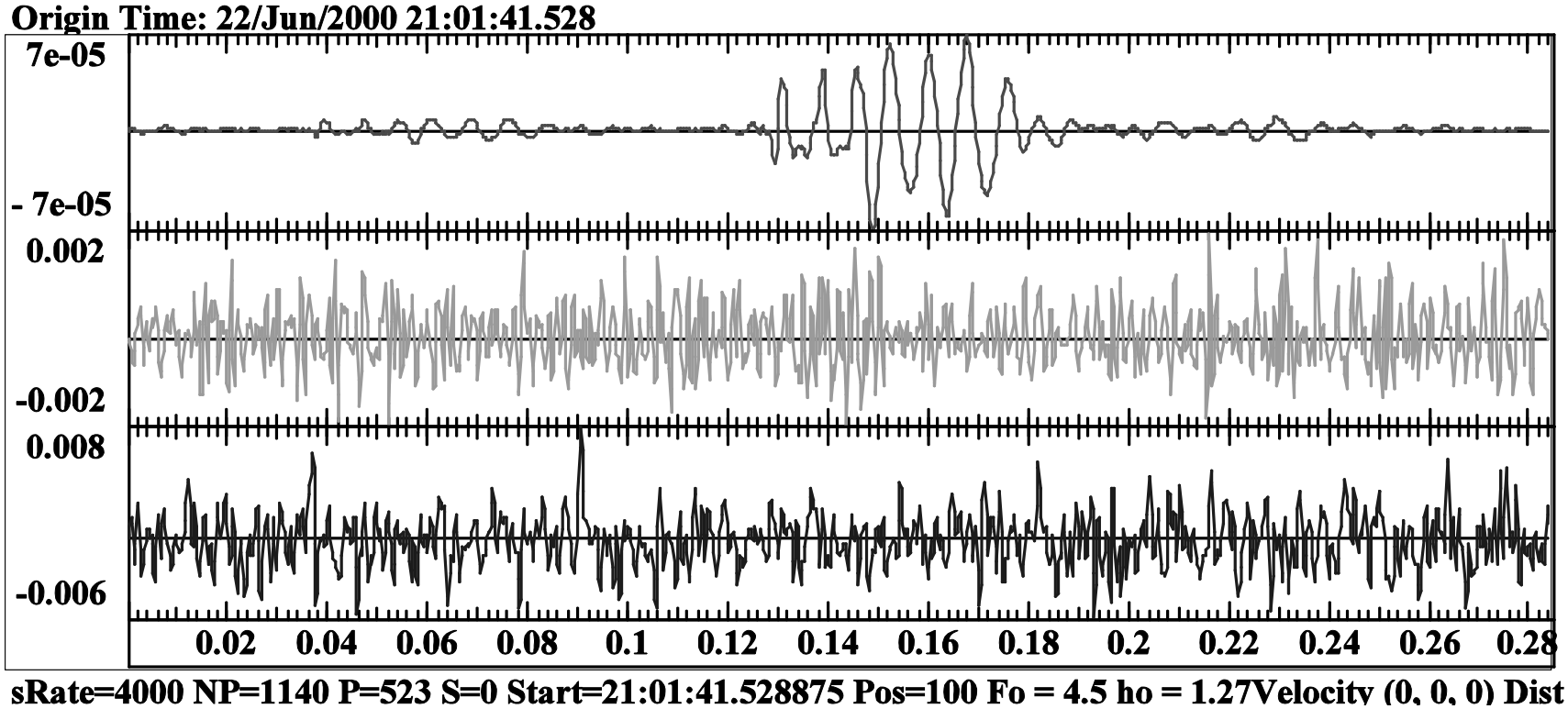

Origin Time: 22/Jun/2000 20:52:24.196
8e-05
- 6e-05
0.002
-0.002
0.006
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
sRate=8000 NP=1500 P=566 S=0 Start=20:52:24.196875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

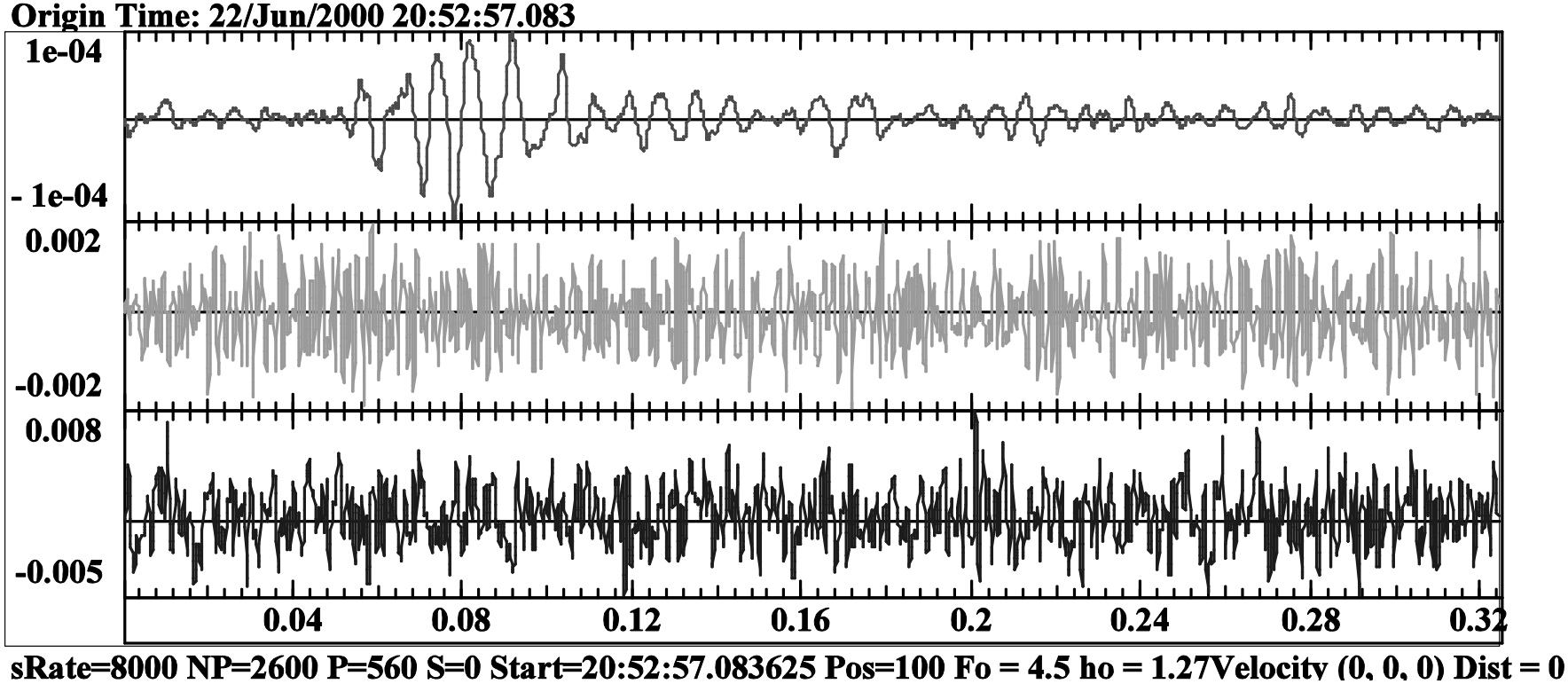

Origin Time: 22/Jun/2000 21:08:48.977
1e-04
- 1e-04
0.002
-0.002
0.008
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
sRate=8000 NP=1400 P=544 S=0 Start=21:08:48.977125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

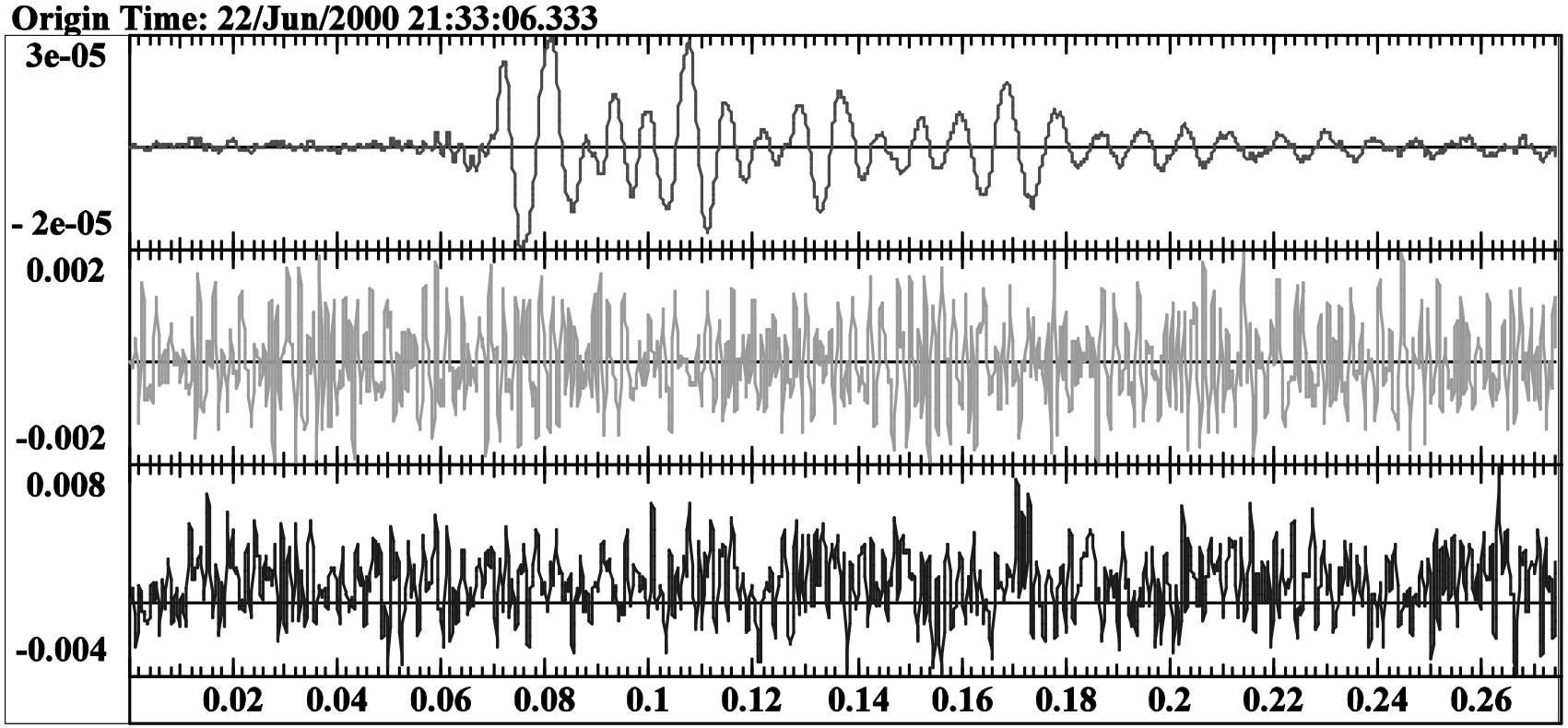

Origin Time: 22/Jun/2000 21:08:55.303
7e-05
- 1e-04
0.001
-0.001
0.004
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
sRate=8000 NP=1800 P=557 S=0 Start=21:08:55.303750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

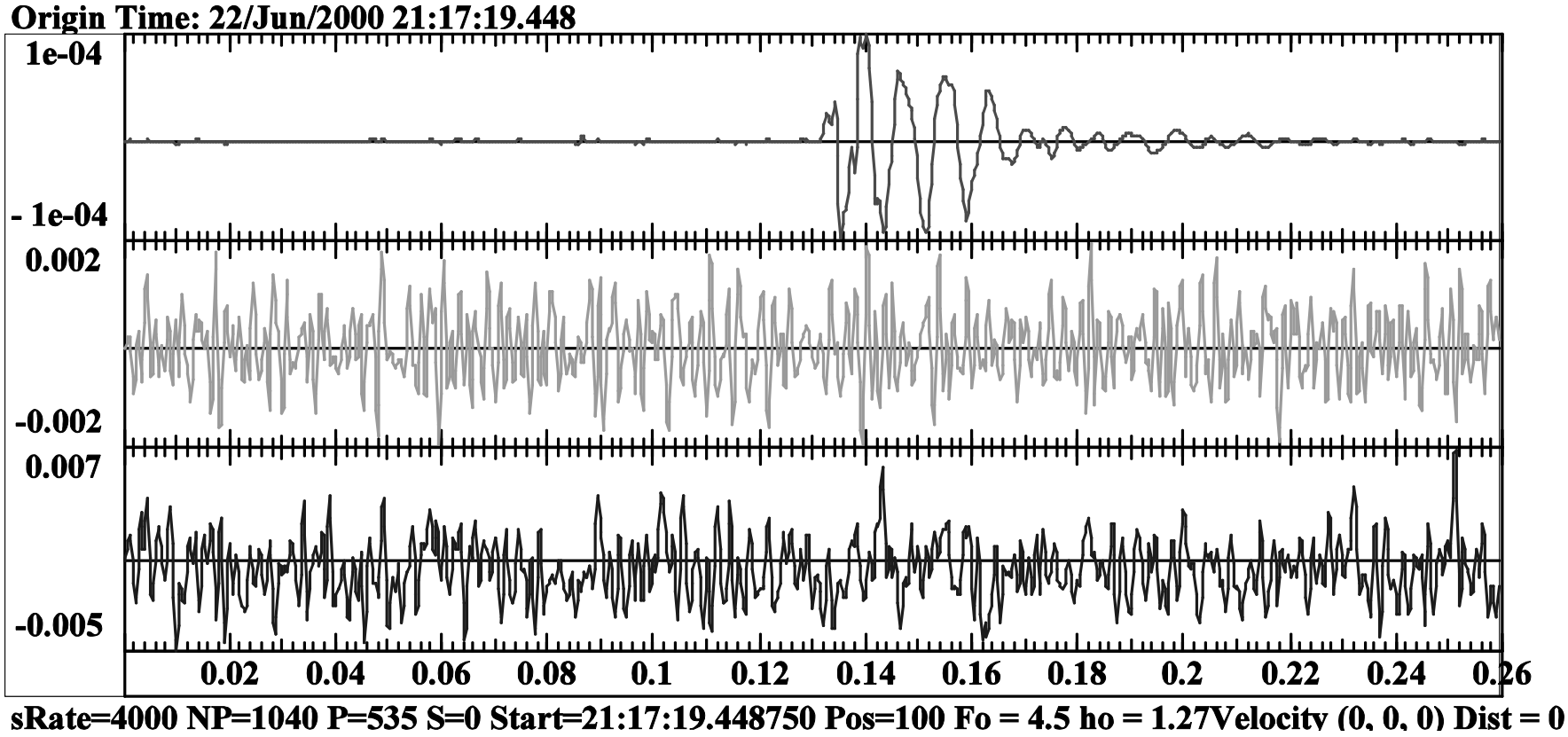

Origin Time: 22/Jun/2000 21:14:41.657
3e-04
- 4e-04
0.002
-0.002
0.006
-0.006
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
sRate=8000 NP=3200 P=537 S=0 Start=21:14:41.657125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

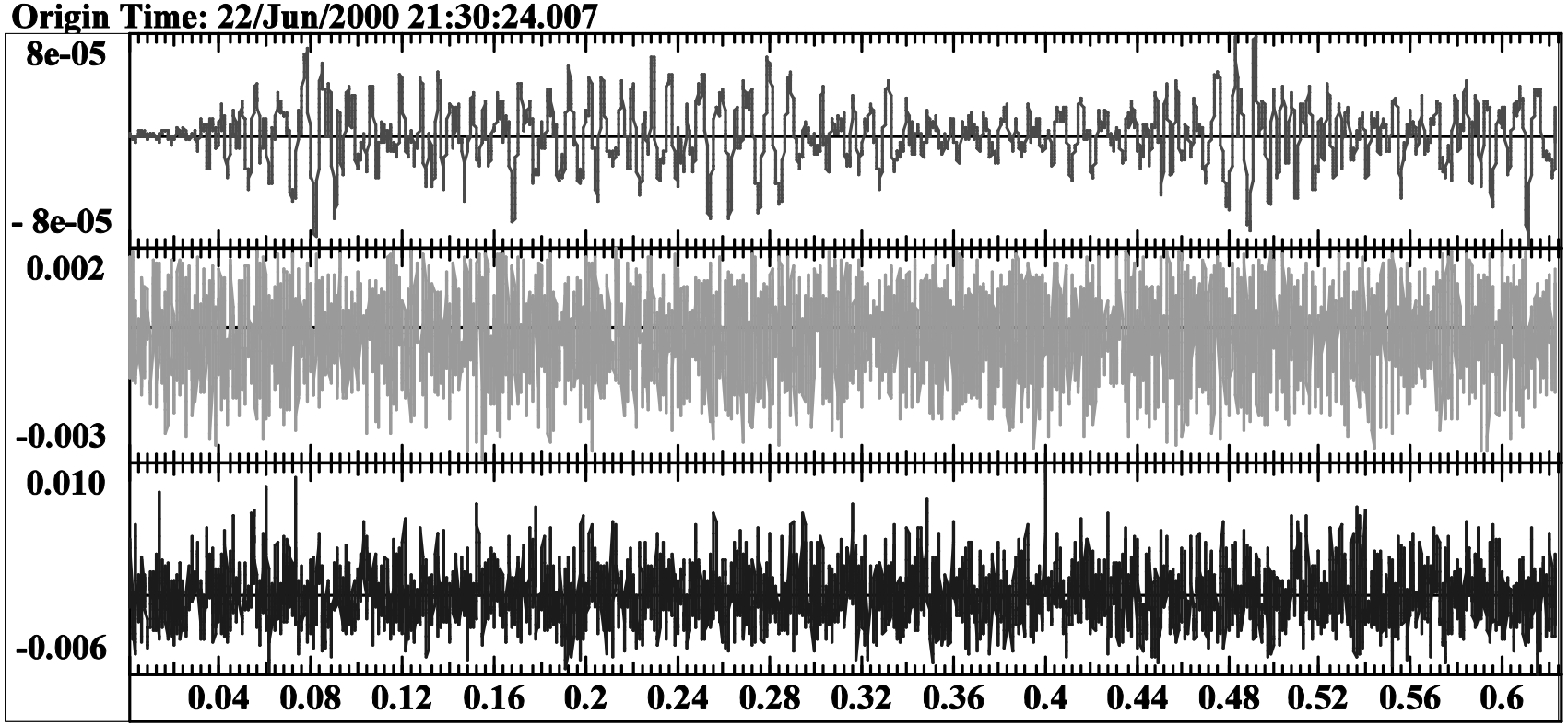

Origin Time: 22/Jun/2000 21:00:23.990
9e-05
- 1e-04
0.002
-0.002
0.006
-0.006
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=4000 NP=1340 P=510 S=0 Start=21:00:23.990750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

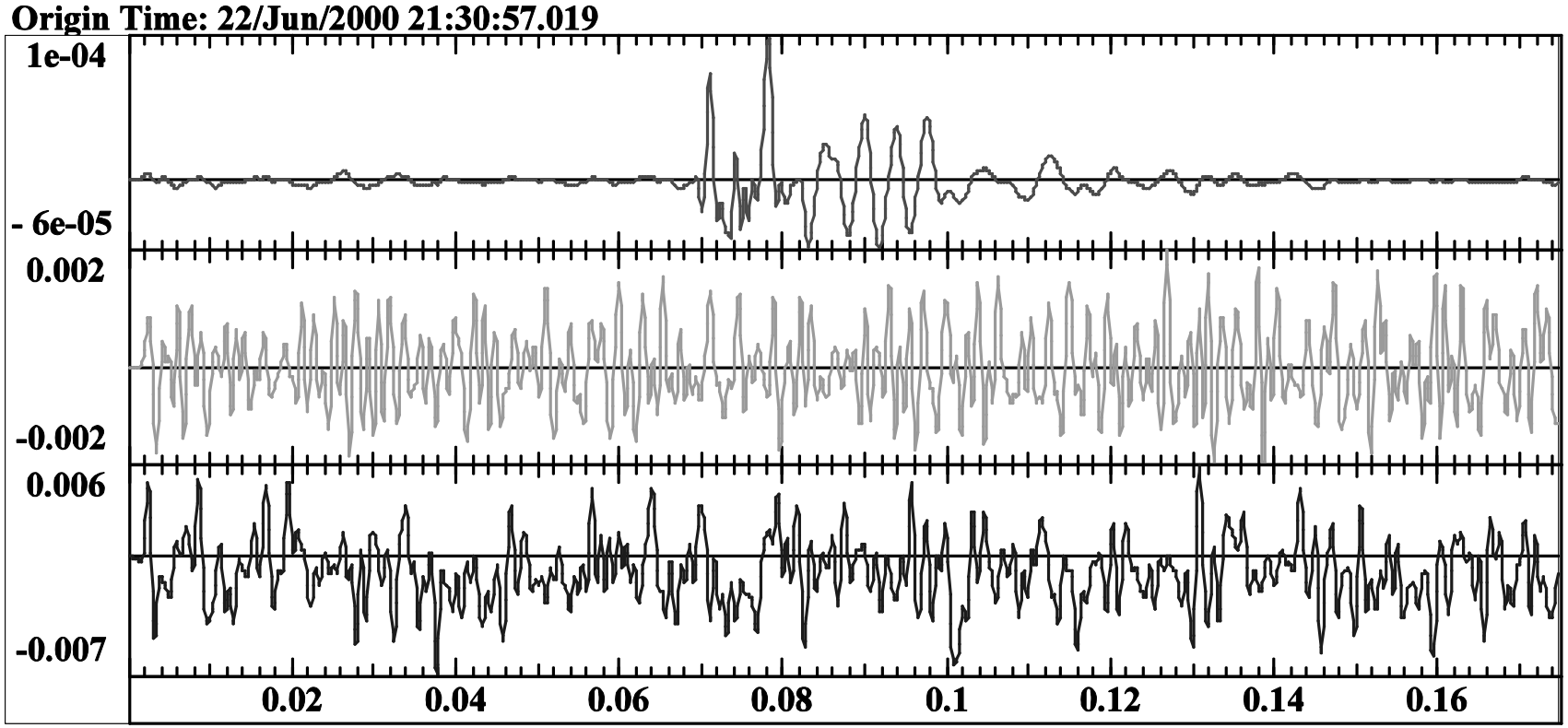

Origin Time: 22/Jun/2000 21:01:41.528
7e-05
- 7e-05
0.002
-0.002
0.008
-0.006
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
sRate=4000 NP=1140 P=523 S=0 Start=21:01:41.528875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

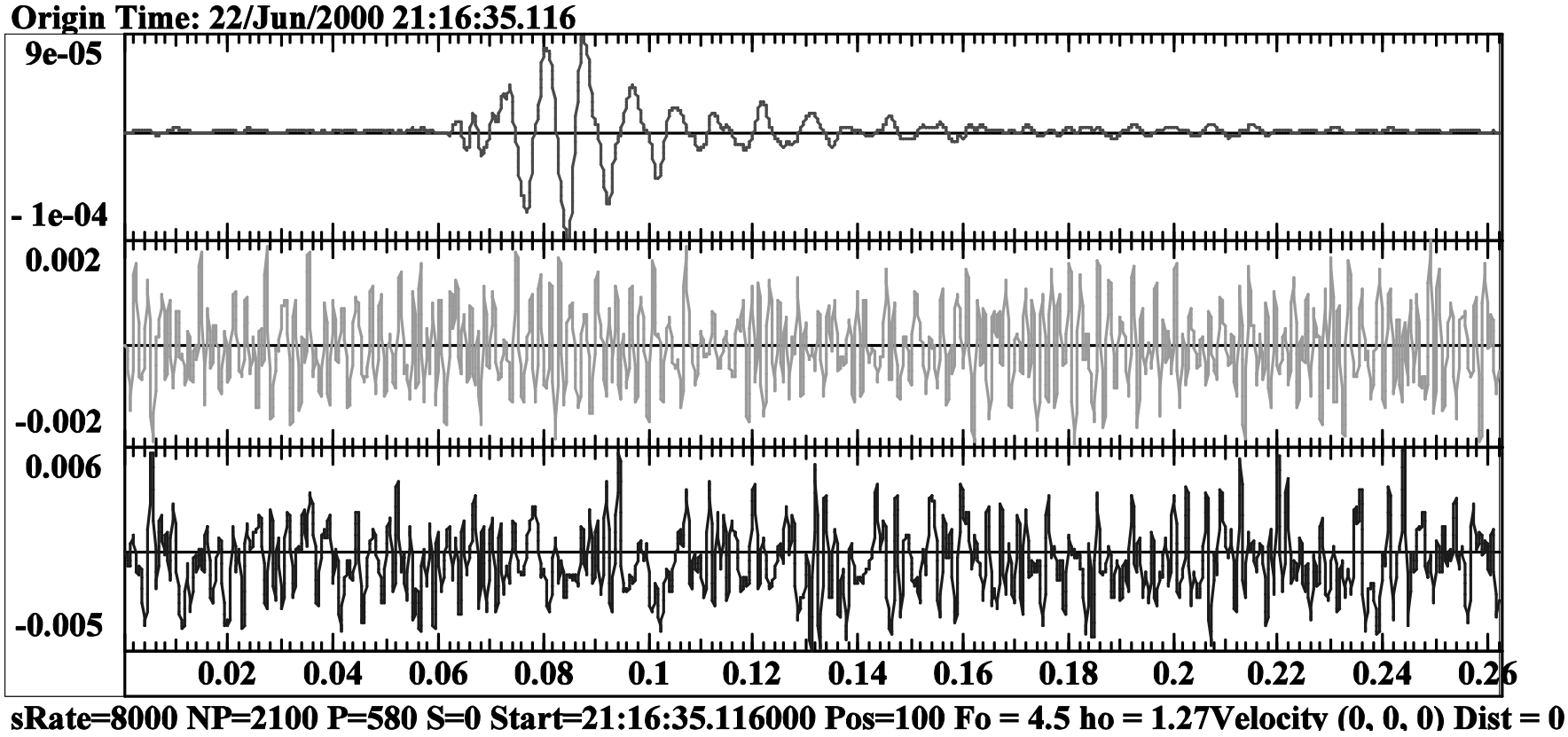

Origin Time: 22/Jun/2000 20:52:57.083
1e-04
- 1e-04
0.002
-0.002
0.008
-0.005
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=8000 NP=2600 P=560 S=0 Start=20:52:57.083625 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 22/Jun/2000 21:33:06.333
3e-05
- 2e-05
0.002
-0.002
0.008
-0.004
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2200 P=597 S=0 Start=21:33:06.333000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

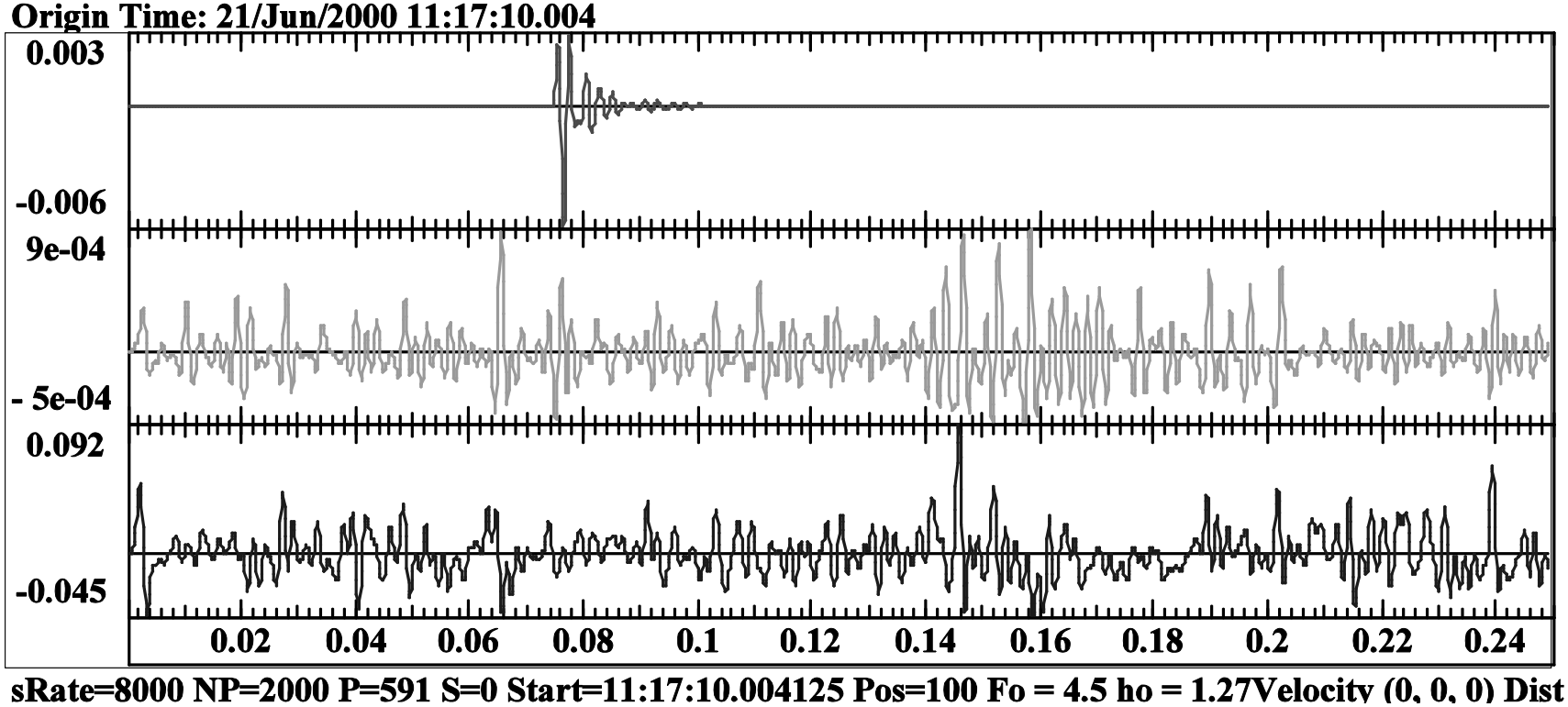

Origin Time: 22/Jun/2000 21:17:19.448
1e-04
- 1e-04
0.002
-0.002
0.007
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=4000 NP=1040 P=535 S=0 Start=21:17:19.448750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

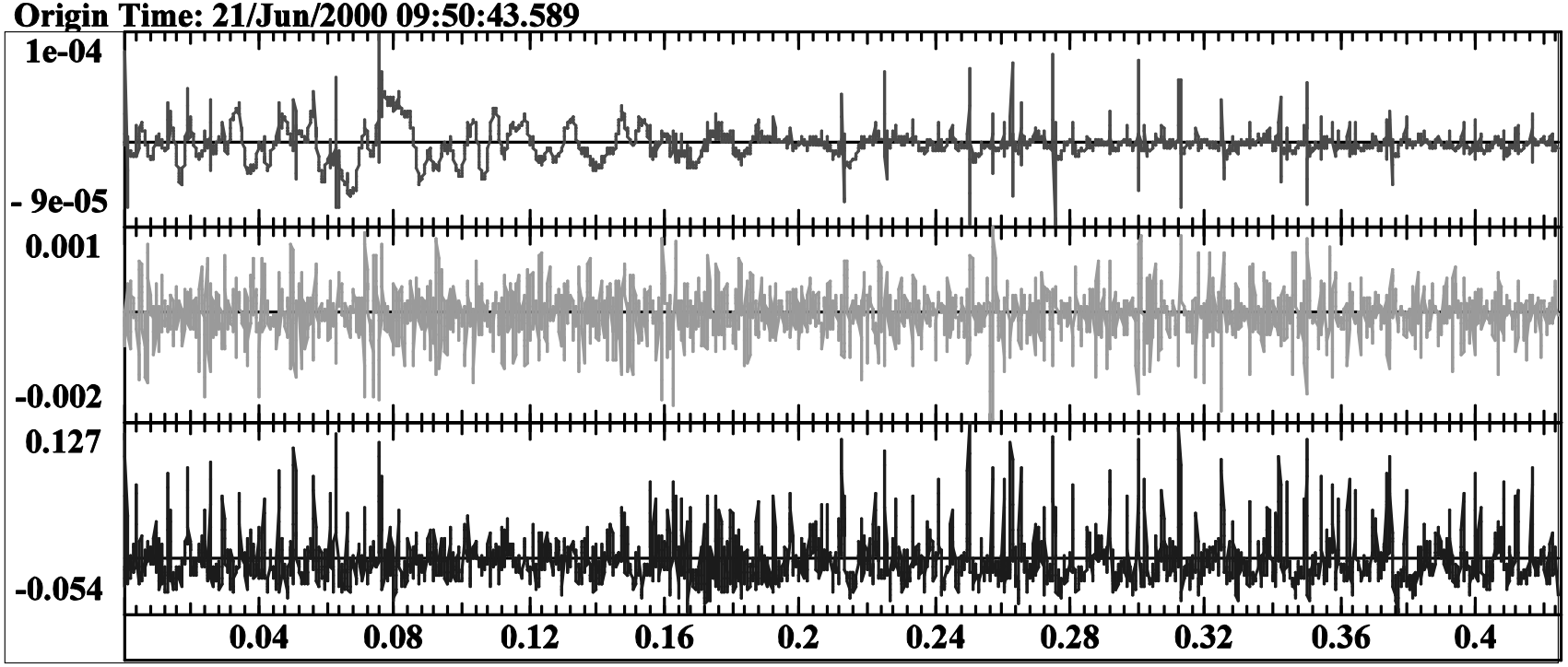

Origin Time: 22/Jun/2000 21:30:24.007
8e-05
- 8e-05
0.002
-0.003
0.010
-0.006
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=584 S=0 Start=21:30:24.007750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

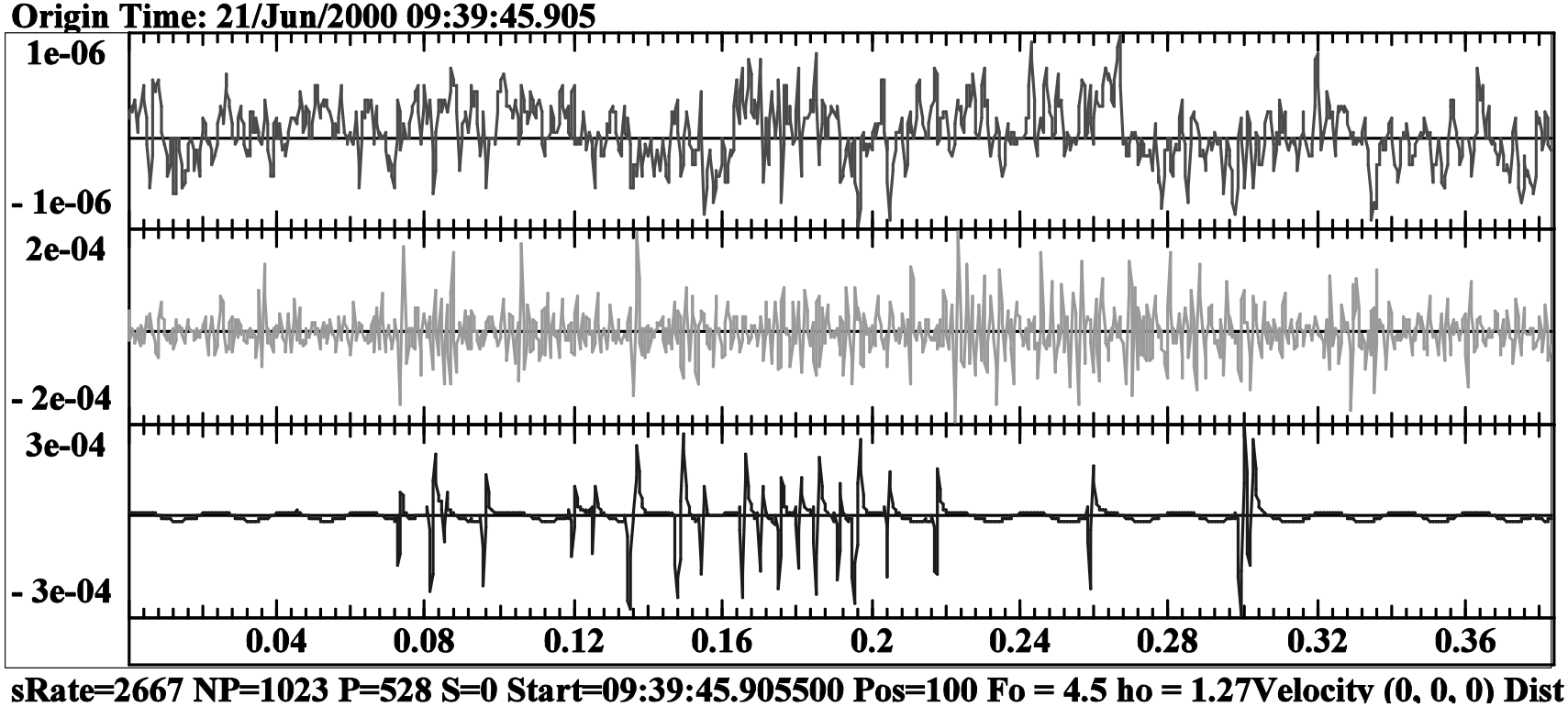

Origin Time: 22/Jun/2000 21:30:57.019
1e-04
- 6e-05
0.002
-0.002
0.006
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
sRate=8000 NP=1400 P=574 S=0 Start=21:30:57.019000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

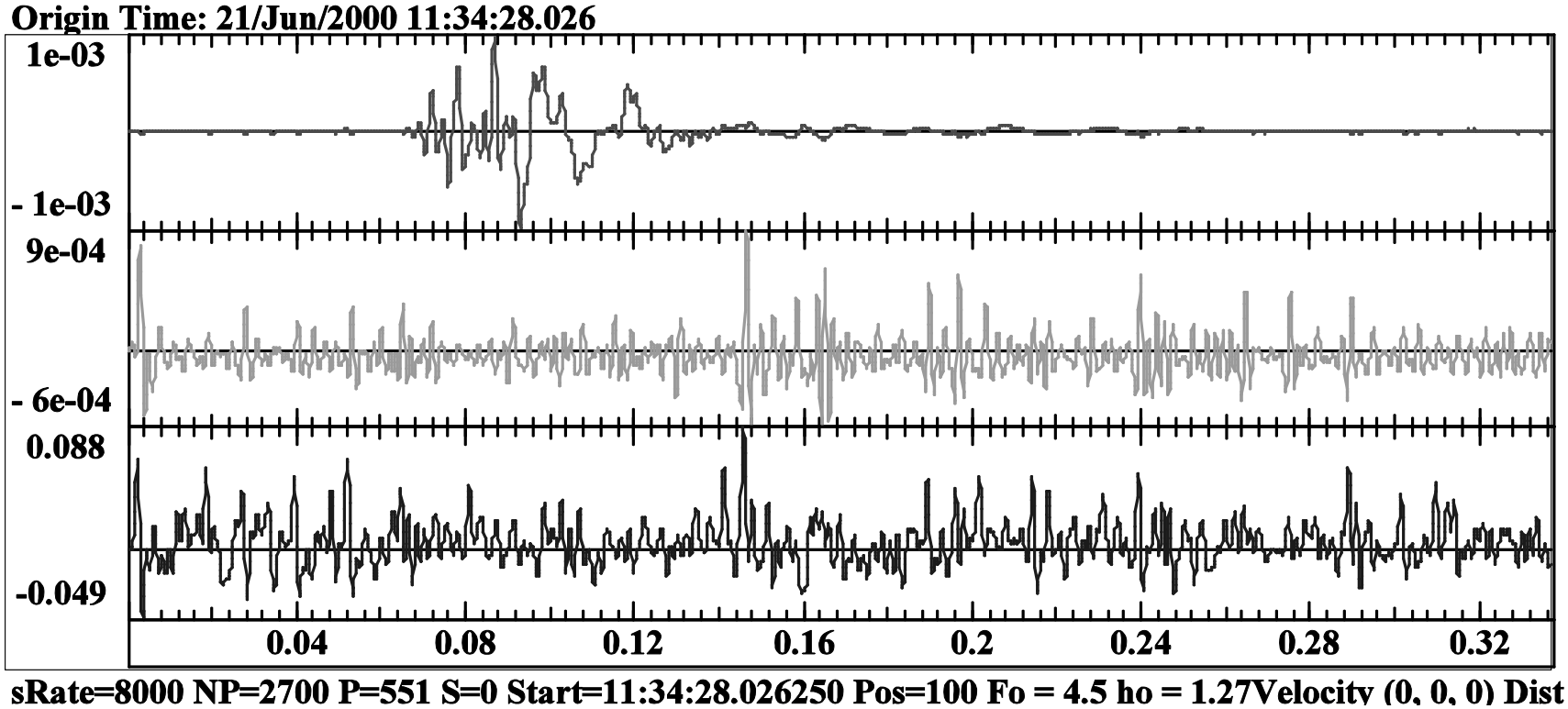

Origin Time: 22/Jun/2000 21:16:35.116
9e-05
- 1e-04
0.002
-0.002
0.006
-0.005
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
sRate=8000 NP=2100 P=580 S=0 Start=21:16:35.116000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

A2.7 Background electromagnetic emissions at 4.92 MHz

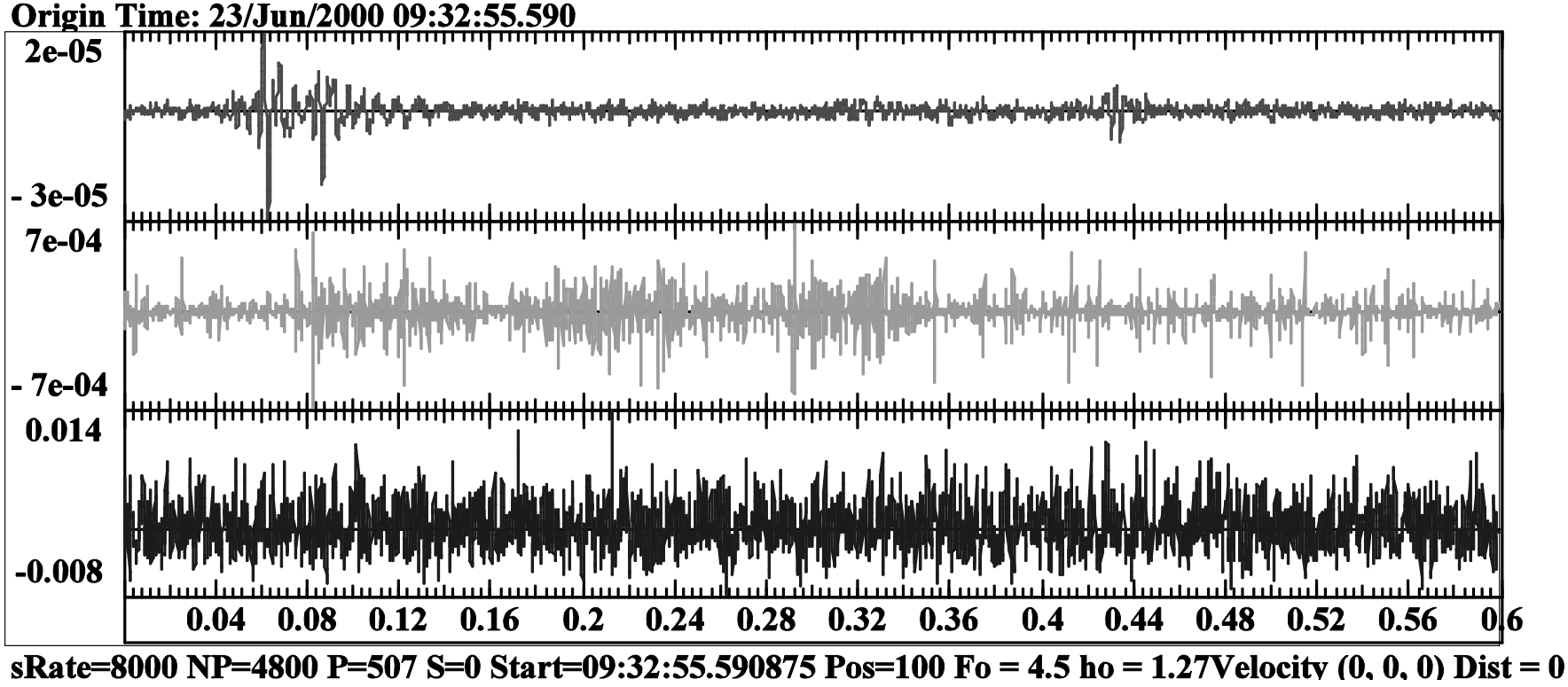

Origin Time: 21/Jun/2000 11:17:10.004
0.003
-0.006
9e-04
- 5e-04
0.092
-0.045
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
sRate=8000 NP=2000 P=591 S=0 Start=11:17:10.004125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

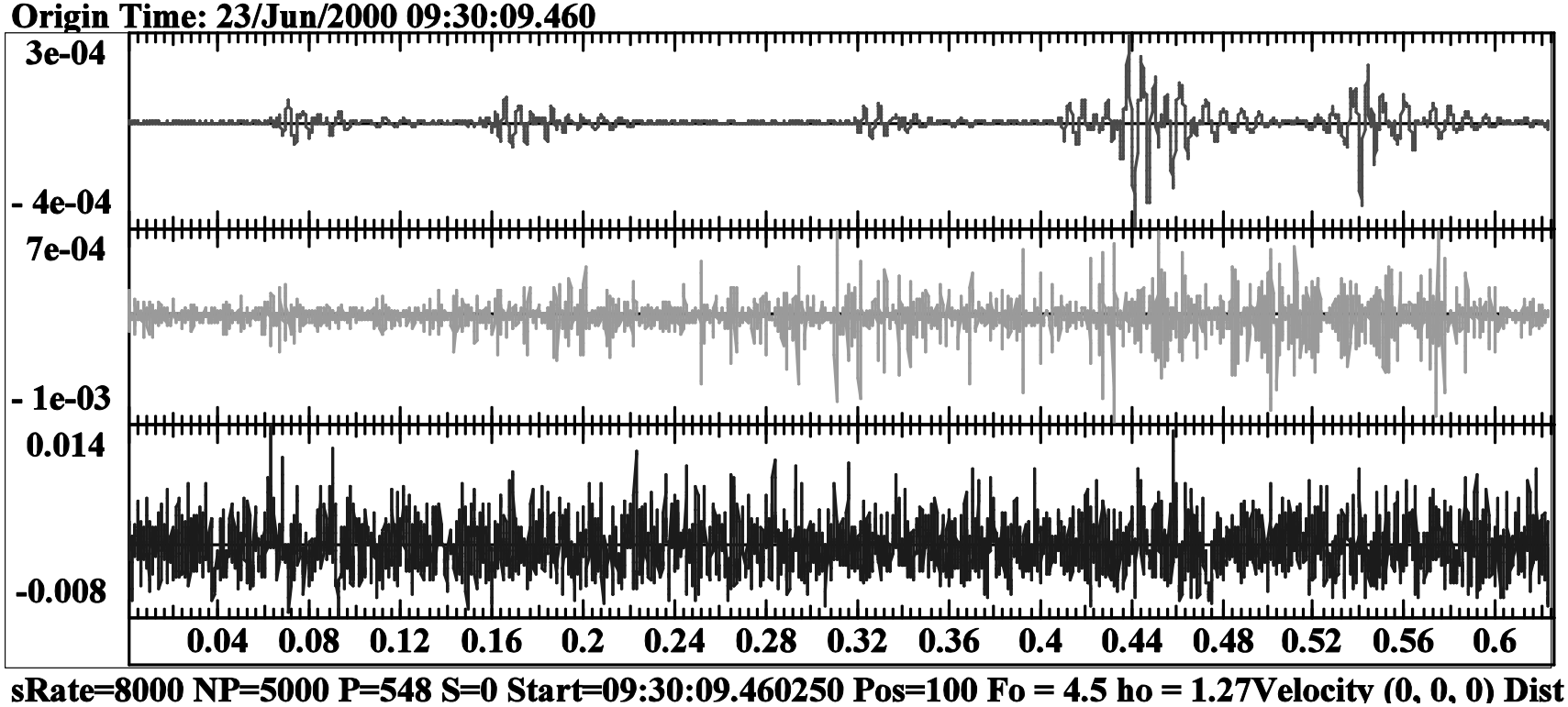

Origin Time: 21/Jun/2000 09:50:43.589
1e-04
- 9e-05
0.001
-0.002
0.127
-0.054
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
sRate=8000 NP=3400 P=545 S=0 Start=09:50:43.589000 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

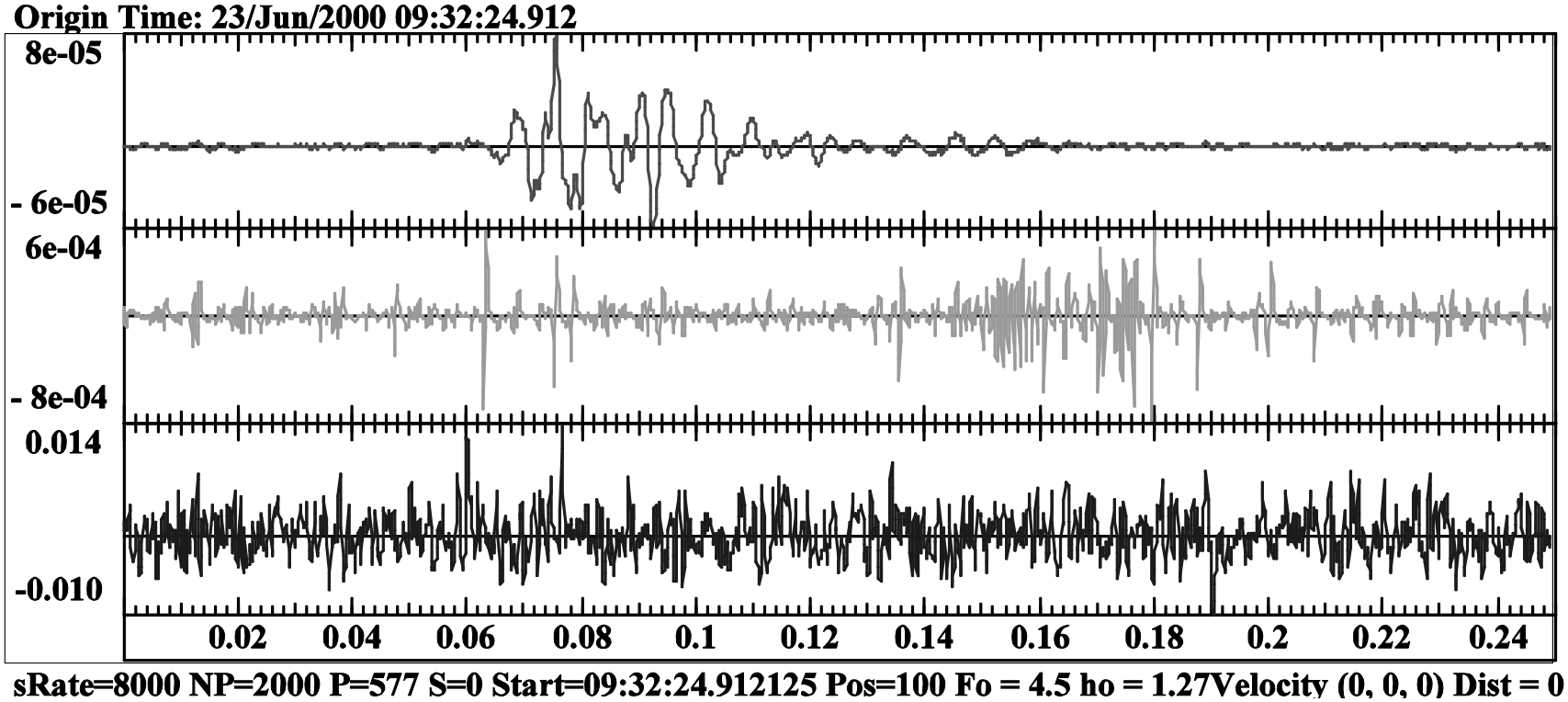

Origin Time: 21/Jun/2000 09:39:45.905
1e-06
- 1e-06
2e-04
- 2e-04
3e-04
- 3e-04
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
sRate=2667 NP=1023 P=528 S=0 Start=09:39:45.905500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

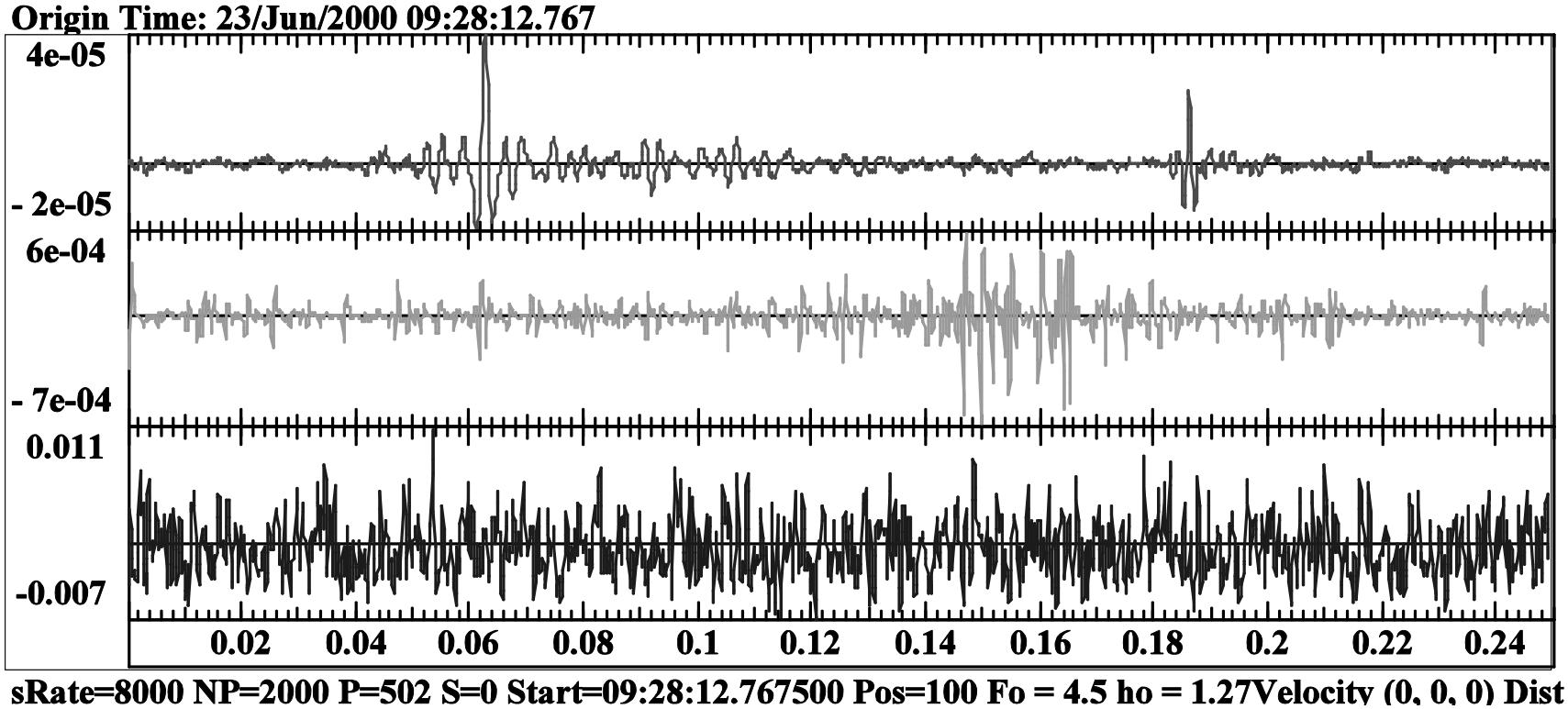

Origin Time: 21/Jun/2000 11:34:28.026
1e-03
- 1e-03
9e-04
- 6e-04
0.088
-0.049
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
sRate=8000 NP=2700 P=551 S=0 Start=11:34:28.026250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

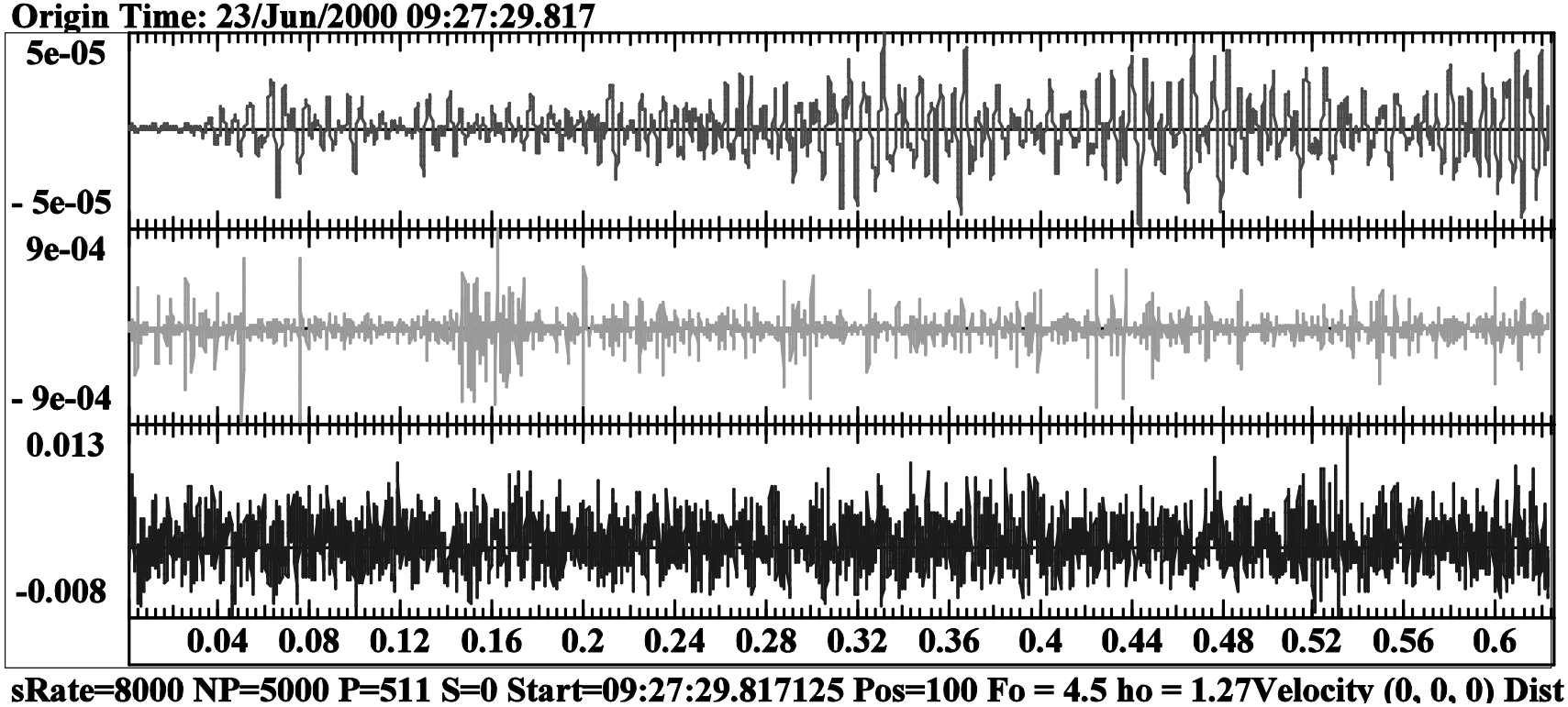
A2.8 Background electromagnetic emissions at 29.9 MHz

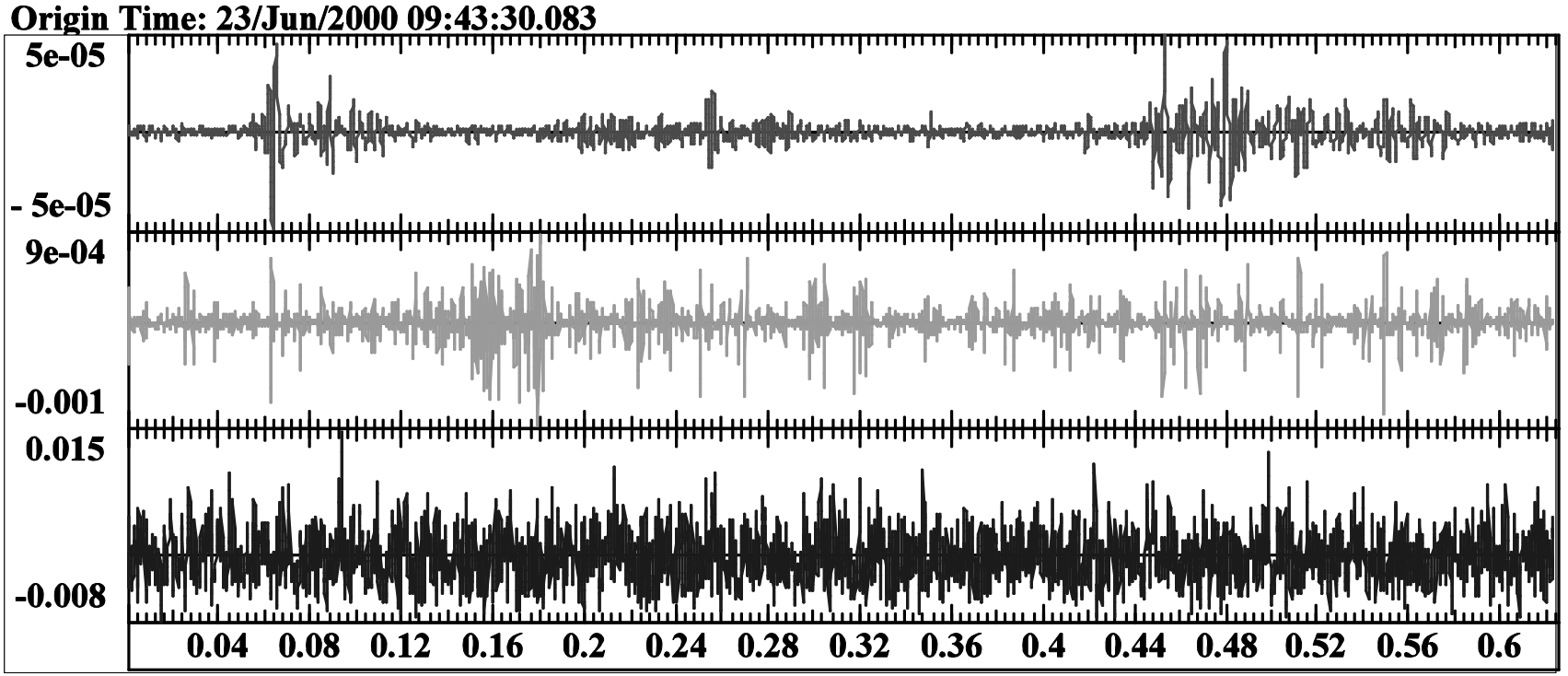

Origin Time: 23/Jun/2000 09:32:55.590
2e-05
- 3e-05
7e-04
- 7e-04
0.014
-0.008
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
0.56
0.6
sRate=8000 NP=4800 P=507 S=0 Start=09:32:55.590875 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 09:30:09.460
3e-04
- 4e-04
7e-04
- 1e-03
0.014
-0.008
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=548 S=0 Start=09:30:09.460250 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 09:32:24.912
8e-05
- 6e-05
6e-04
- 8e-04
0.014
-0.010
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
sRate=8000 NP=2000 P=577 S=0 Start=09:32:24.912125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 09:28:12.767
4e-05
- 2e-05
6e-04
- 7e-04
0.011
-0.007
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
sRate=8000 NP=2000 P=502 S=0 Start=09:28:12.767500 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 09:27:29.817
5e-05
- 5e-05
9e-04
- 9e-04
0.013
-0.008
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=511 S=0 Start=09:27:29.817125 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0


Origin Time: 23/Jun/2000 09:43:30.083
5e-05
- 5e-05
9e-04
-0.001
0.015
-0.008
0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
sRate=8000 NP=5000 P=513 S=0 Start=09:43:30.083750 Pos=100 Fo = 4.5 ho = 1.27Velocity (0, 0, 0) Dist = 0

Appendix 3 Contractual details

COL 703
Project Proposal

Project	Pre-feasibility investigation to provide an early warning of roof falls prior to support installation.
Project Leader	Dr. Hylton White, ISS Geophysics (Pty) Ltd
Primary Output	Rather that utilizing laboratory-scale measurements, it is proposed to install a geophone, microphone and electromagnetic sensing system in the vicinity of a rockmass undergoing failure to establish correlated seismic (rock-borne sound), acoustic (air-borne sound) and electromagnetic emissions from the rockmass. The output of this project will be a report detailing the feasibility of utilizing acoustic and / or electromagnetic emissions to establish the potential for roof falls.
How Used?	To be used by SIMRAC to determine whether acoustic and / or electromagnetic emissions can be used to establish the potential for roof falls, and therefore to initiate development of a mineworthy system.
By Whom?	SIMRAC / SIMCOL
Criteria For Use	Establish whether or not acoustic and / or electromagnetic emissions have merit in establishing the potential for roof falls.
Potential Impact	If acousto-electromagnetic emissions are shown to be potentially useful, then an additional technique will be available for roof integrity determination by the rock engineer.
Other Outputs	In addition (if successful) guidelines, including high-level systems specifications, for the development of suitable equipment will be presented in a report.

Enabling Output	**Enabling Output And Methodology**	**Milestone Dates**
	1 Configure 24-bit, 3 channel Multiseismometer with geophone, microphone and eletromagnetic sensor	04/2000
	1.1 Configure Multiseismometer, geophone, microphone and electromagnetic sensor	
	2 Installation of 24-bit Multiseismometer	04/2000
	2.1 Install Multiseismometer including geophone, microphone and electromagnetic sensor at appropriate site where rock failure is expected.	
	3 Measurement of acoustic, seismic and electromagnetic emissions	05/2000
	3.1 Monitor emissions from rock, and correlate with visual observations.	
	4 Preparation and submission of report	06/2000
	4.1 Submit detailed report, including proposed high-level system specifications if the technique has merit.	

COL 607
Project Proposal

Motivation And Current Position

Since the work of the VAN Group (Varotsos, P., Alexopolous, K. (1984). " Physical properties of the variations of the electric field of the Earth preceding earthquakes", Tectonophysics 110, 73-98, and later work), there has been much speculation in the literature as to whether rock failure is accompanied by electromagnetic emissions. Certainly, it is well known that rock failure, on all scales, is accompanied by acoustic / seismic emissions. The work of the VAN group, especially the laboratory work performed on measuring electromagnetic emissions, has subsequently been largely discredited. Laboratory measurements of seismo-electrical emissions are particularly difficult, as it is difficult to separate electromagnetic emissions from the testing machines from those of the failing rock.

It is thus proposed that further laboratory work will achieve little, and that if there is an interest in laboratory work, then a literature survey of the masses of work already done would yield far more information than a few lab experiments.

Instead, it is proposed to perform these measurements at the coal-face (so-to-speak). This will be done by configuring a 24-bit multi-seismometer (essentially a high-quality sound recorder) together with a geophone installed within the rockmass, a microphone installed a few metres from the rockmass, and an electromagnetic sensor installed a few metres from the rockmass. The site will be selected so that failure of the rockmass will be expected within the duration of the monitoring phase.

Seismic, acoustic and electromagnetic emissions will be monitored for the duration of the experiment an correlated with visual information, in an attempt to determine whether these emissions (electromagnetic and acoustic) exist, are correlated, and provide information of impending failure.

Note: The electromagnetic sensor is essentially a very high-quality short-wave radio, tuned off-station, with sound output fed back to the Multiseismometer.

Professor Matthew Handley (University of Pretoria) will assist in correlating visual information with emissions.

Financial Details

	2000	2001
Project staff costs	88 807	
Operating costs	15 000	
Capital costs	57 000	
Presentations and papers	2 000	
Collaborators	10 000	
Value Added Tax	24 193	
Total Project Cost	197 000	

Collaborators

	Activity	
Matthew Handley, University of Pretoria	Correlate visual failure with emissions	10 000
		10 000