Recent observations of increased seismic background noise using gPhone gravity meters

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Abstract

There appears to be an increase in the average background seismic noise observed with gPhone gravity meters in Colorado, Minnesota, and Sidney, BC (near Vancouver, BC) for about one month from November 16, 2008 through December 16, 2008. The background noise envelopes are almost identical for the gPhones located in Minnesota (SN#51) and Colorado (SN#69). The noise envelope for the gPhone located in Vancouver (#55), is also highly correlated but there are some notable differences. While it is normal to see increased seismic noise during this time, it appears that this period may be anomalous in sustained noise amplitude. We also present results from different gPhones under test in Colorado from September 2006 through January 2009 that clearly show seasonal variations in the background noise level.

Background

The gPhone gravity meter was introduced in 2006 specifically for low frequency seismic noise and tidal monitoring applications. The instrument is based upon the popular LaCoste & Romberg G meter and utilizes the patented zero-length spring technology (US Patent No. 2,293,437). The gPhone has been shown to be very effective in measuring earthquake signals from earthquakes in Japan and China.

Niebauer et al.[i] have shown that they could detect five round trips around the globe for magnitude 8 disturbances in Japan. They also have shown that the instruments have nearly identical responses during earthquakes and also during periods with no earthquakes when compared with an STS-2 long period seismometer and a superconducting gravity meter located at the same site. While all three instruments are very effective, there are some advantages of the gPhone. The gPhone has a lower frequency response than the STS-2 so it is capable of registering slower signals than a typical seismometer. The superconducting gravity meter employs a seismic filter that reduces its sensitivity to signals in the seismic band compared to the gPhone.

In November of 2008, we noticed a substantial increase in seismic noise background levels with the new gPhones still under preliminary testing at the Micro-g LaCoste test facility. This noise increase was not taken too seriously because the instruments under test are new and do not have a known history. Also they are

disturbed very often by having their levels adjusted, temperature adjusted, and their zeros positions moved. Many of the instruments have electronic and mechanical malfunctions during these tests. The drift of the meters is typically very high when they are first made. It is also quite normal to have the instruments opened and bumped during these tests. A "bump" test is one of the normal tests for these instruments.

In short, the data stored for the instruments under test are evaluated for specific tests and are not normally analyzed for the presence of real seismic signals. In particular, the seismic noise background is not usually evaluated during the testing period. Due to a high backlog, there are no working instruments with a long period history at MGL.

Fortunately, however, most of the adjustments during the test phase of the gPhones do not directly affect the seismic band (0.1-0.5 Hz) performance. During these tests, the gPhones are optimized for temperature, pressure and spring drift. These issues mostly affect frequencies below the seismic band. Therefore, with some effort the test data can be used to glean seismic information even though the instruments are not yet of high enough quality to be shipped to customers.

The observed background noise for gPhone #69 from November 16-December 16 taken at the MGL test facility in Colorado is shown in Figure 1.

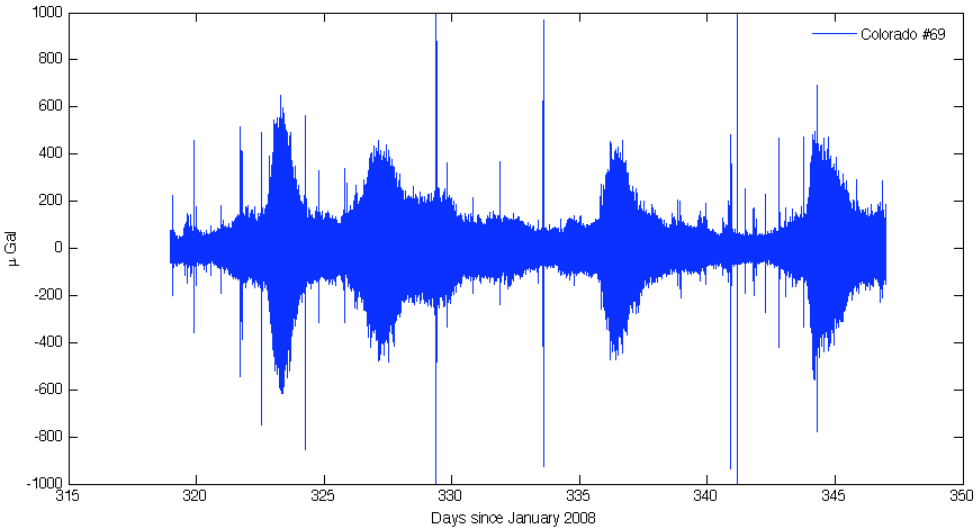

Figure 1: Background Noise in Colorado

The data is plotted at 1-second intervals so that the background noise envelope is easily seen over the month even though one cannot discern the seismic band on this time scale. The 1-second seismic noise envelope fluctuates from a peak-peak amplitude of about 100 μGal during quiet periods to as large as 1000 μGal during noisy periods during this one month span. It is important to note that the noisy periods lasting several days are not explained by traditional earthquakes that have a much shorter duration of a few hours. The high amplitude, short duration spikes in the record are typical of earthquake signatures.

A spectrogram of the data, Figure 2, shows that most of the observed signal is contained in the frequency band 0.12 to 0.35 Hz (3-8s).

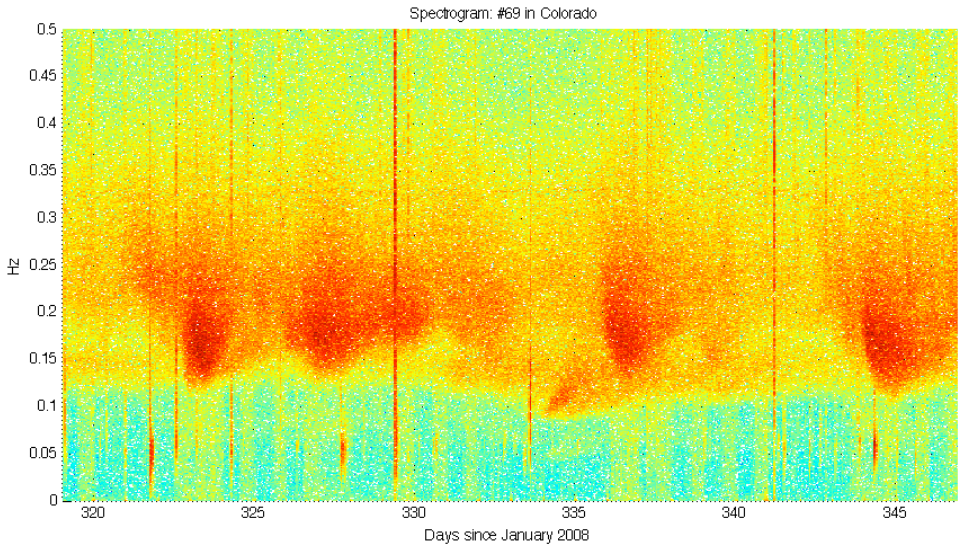

Figure 2 Spectrogram of gPhone data in Colorado

The first three days of data before the first large burst of seismic noise (days 319-322) and also between the third and fourth noise burst (days 340-345) show interesting periods where the seismic noise seems to separate into two clear bands. The spectrogram for gPhone #69 in Colorado from day 319-322, 2008 is shown in Figure 3. There appears to be a band of seismic noise at close to 0.15 Hz and another at about 0.25Hz. We also can see lower frequency noise at .05Hz that starts with the onset of an earthquake at day 321.8 and lasts a few hours.

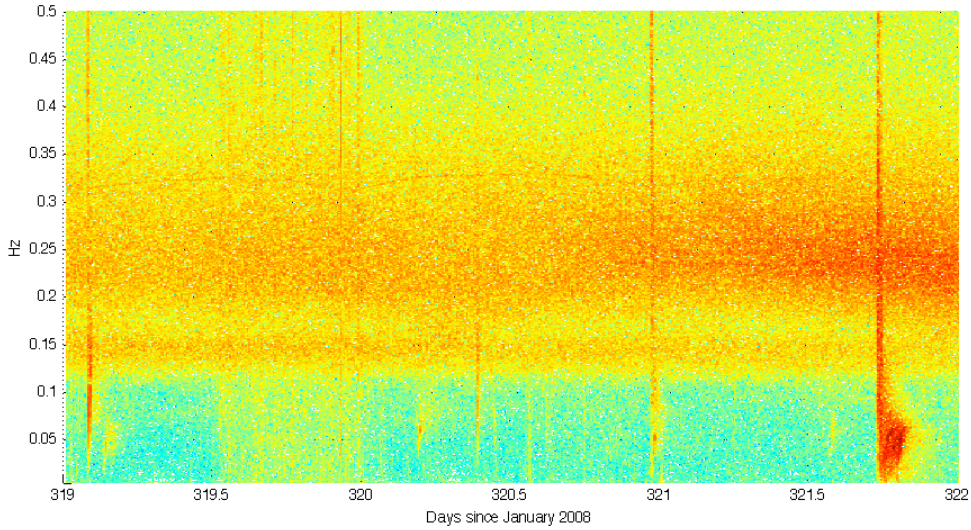

Figure 3: Spectrogram of gPhone data in Colorado (day 319-322, 2008)

We believed that the seismic noise background was higher than normal in November 2008, but in fact a "normal" threshold was not well known. This was due to the combination of factors such the newness of gPhone as an instrument, the newness of the test facility, and the belief that the data from meters under test were

too noisy for analysis of background noise. To make matters even less clear, there was a new building construction across the street from the test facility.

In January, we finally compared data from gPhone #69 under test in Colorado with data from another gPhone (#51) operating in Minnesota. To our surprise, the noise background envelope was extremely well correlated. A plot of the data from Minnesota and Colorado is shown in Figure 4.

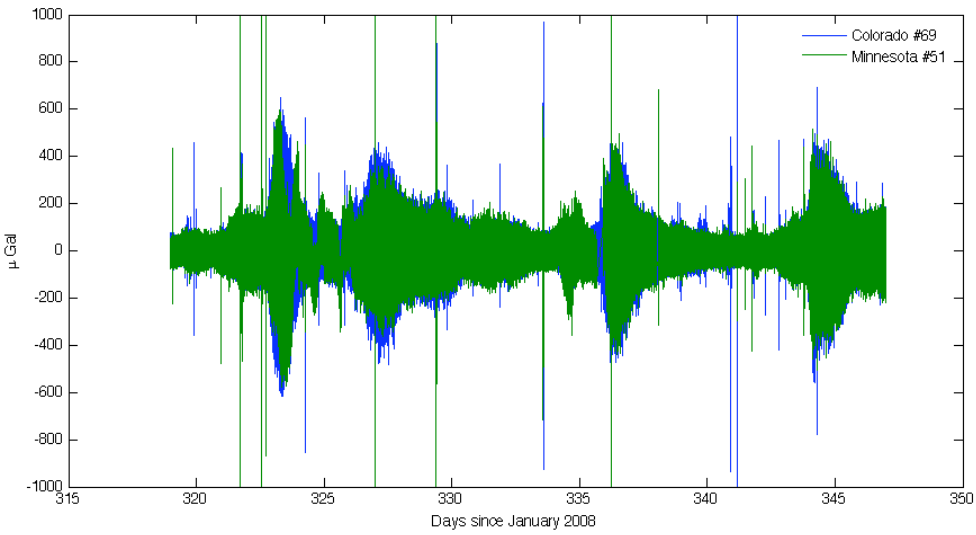

Figure 4. gPhone data in Colorado and Minnesota

The high degree of correlation between these instruments ruled out local disturbances (i.e. from the nearby building construction) as the source for the increased noise. We were quite surprised about how well the noise envelope correlated for two sites separated by 1100km.

We then obtained data for the same period from gPhone #55 located in Vancouver, BC (more precisely in Sidney about 72.5 km south of Vancouver). These data are plotted together with the data from Colorado and Minnesota in Figure 5. There were some gaps in the Vancouver record but the data clearly shows the same general envelope of background seismic noise. The second high noise period at day number 327 (November 23rd) in 2008 shows almost perfect correlation between all three locations. It is important to note that no adjustment was made to the amplitude or time scales for of any of these gravity meters. The amplitude scale of the seismic noise band is the same for all three gravity meters (1μGal= 10^{-6} cm/s^2). This means that all three gravity meters have almost identical noise envelopes for the second large noise event (November 23rd) with apparently little or no attenuation over 2000 km between Minnesota, Colorado, and Vancouver.

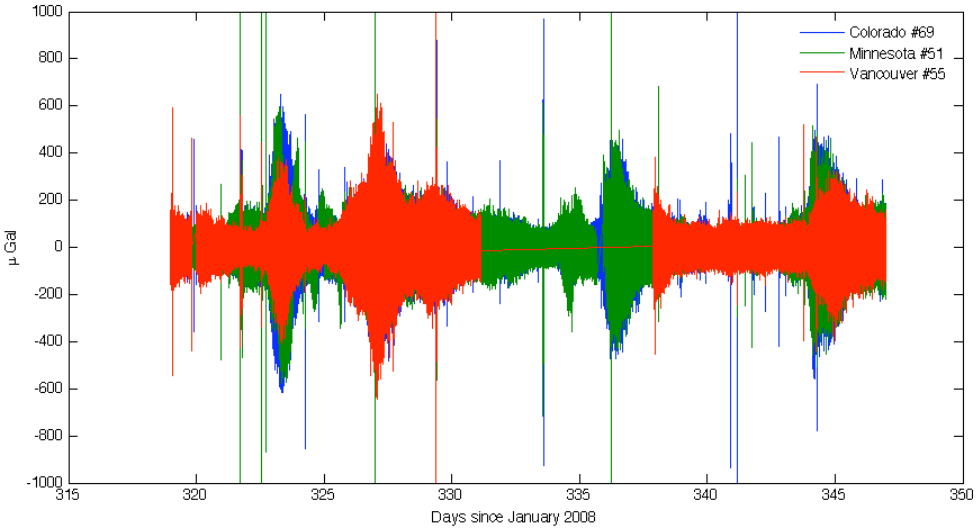

Figure 5: gPhone data from Colorado, Minnesota, and Sidney (Vancouver), BC

We decided to next try to determine a "normal" background noise level for our site to verify our feeling that the noise was anomalously high during this period. This turned out to be a bit more difficult than we first expected due to the very high noise levels of the meters in test. There were large gaps where the meters were turned off or not recording data. There were also periods with very large disturbances from the tests so that even the seismic band was not useable. Sadly once the instruments started performing within specification they were immediately shipped to customers with the result that data from the best working gravimeters was short lived. With much effort, however, it was possible to piece together a more or less continuous record from September 2006 until January 2009. These data are shown in the **Appendix**. The records were pieced together using data from many different instruments under test. The records were de-trended to remove drift and de-spiked to remove frequent disturbances caused by the testing. Many records from the gravity meters under test were unusable, however, whenever good data were available from more than one gravity meter at the same time, the correlation between different instruments was excellent.

It is clear, from these data that data the winter months are noisier than the summer months. For example if we look at the data from June, the quietest month, for 2007 and 2008 (Figure 6 and Figure 7) we see a much lower noise level than observed in November. In fact the background noise level is so low that one can observe that the noise, due to people and local traffic, increases during the day and decreases at night and on the weekends.

The instruments were initially referred to as Portable Earth Tide meters (PET) when they were first introduced into the market. Later they were upgraded so that they functioned well as long period vertical seismometers. The software also includes the ability to integrate the gravity to obtain velocity and position signals for easier comparison with conventional seismometers (velocity) and ground based interferometers (position). The sensor of the instrument was not changed but the instrument was then renamed to the gPhone. The plots of the earlier instruments

(lower serial numbers), have the model designation of PET meters whereas the later instruments are referred to by the gPhone model designation. For the purposes of this report, however, all of the data is calibrated gravity and is of similar quality between the gPhone and PET meters.

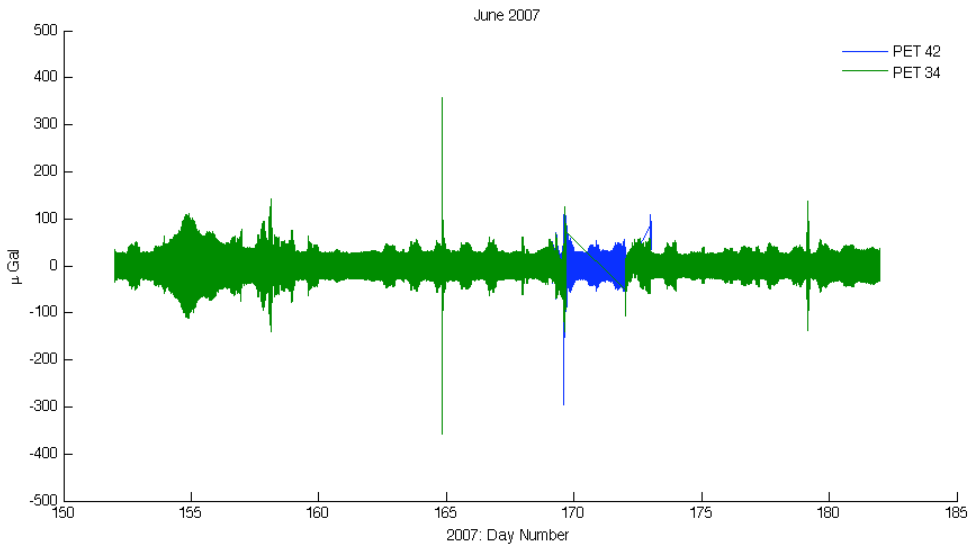

Figure 6: gPhone data during June 2007 in Colorado

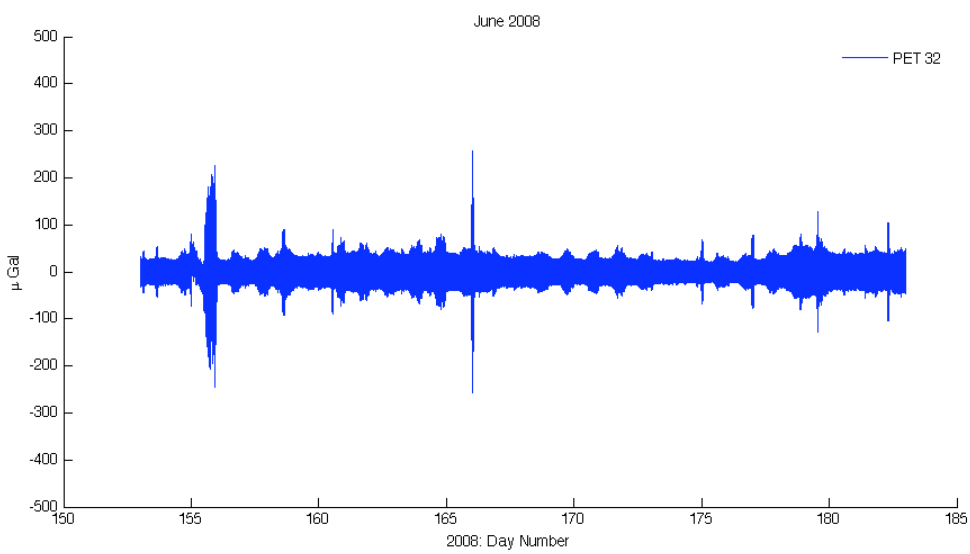

Figure 7: gPhone data during June 2008 in Colorado

Comparing the quiet June records to the high noise records in November (Figure 8, Figure 9, and Figure 10) we see that there is a large seasonal variation of background seismic noise. During quiet months it is unusual to see the background seismic noise level at 1 second above 100 μGal peak-peak and it is likewise unusual to find the background noise level this low during the winter months.

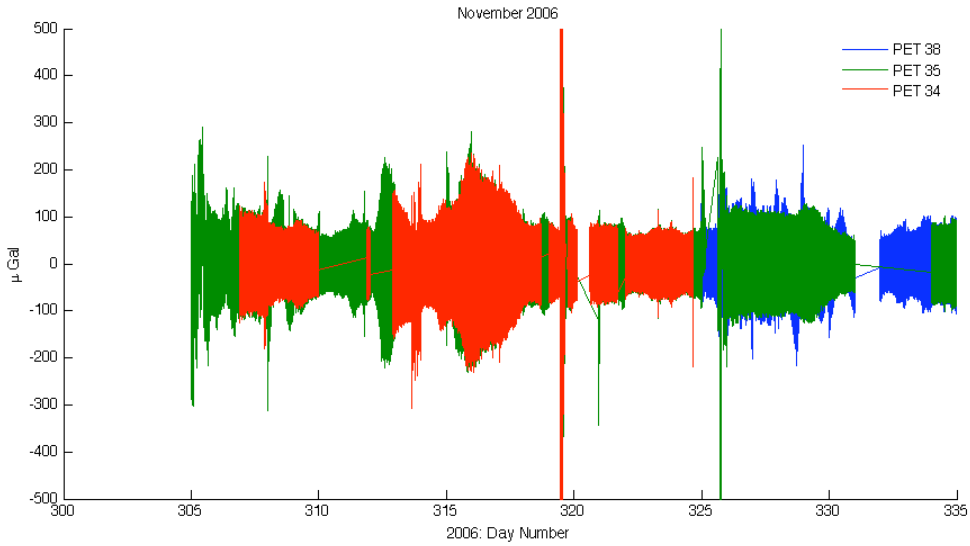

Figure 8: gPhone data during November 2006 in Colorado

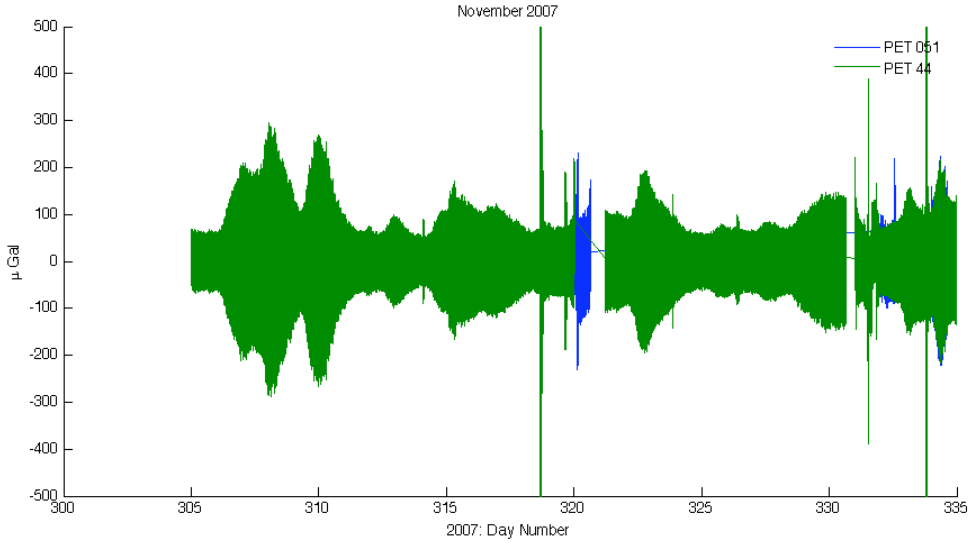

Figure 9: gPhone data during November 2007 in Colorado

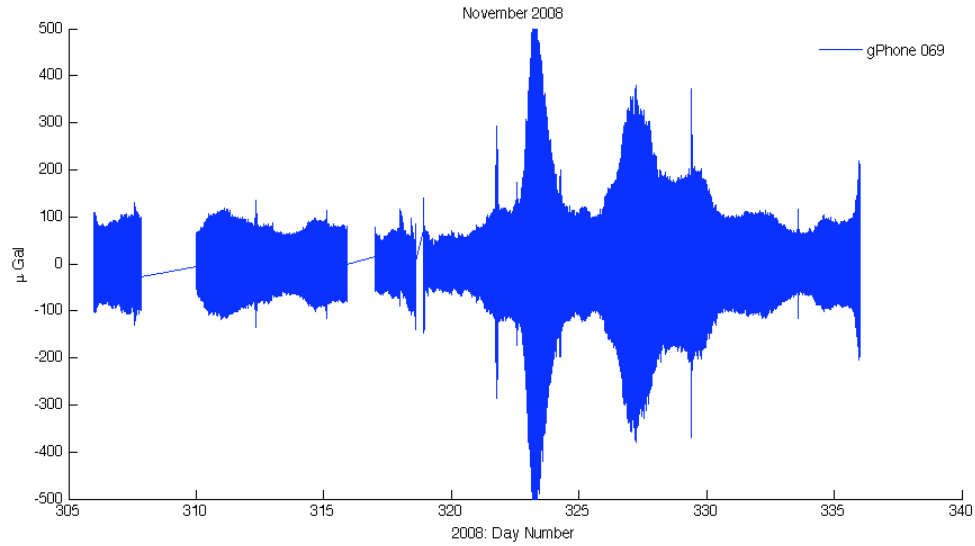

Figure 10: gPhone data during November 2008 in Colorado

Conventional wisdom is that the seismic background level is due to ocean storms in the open sea (pelagic zone storms). However, it is interesting to note that the largest ocean storm near the US in 2008 was called hurricane Ike and was active from September 4th through September 15th (day 248 -259). The September gPhone record is shown in Figure 11. Hurricane Ike hit landfall in Texas only 1000 miles from Colorado and was unable to produce seismic noise anywhere near the level of the events in November.

We found it a bit surprising that the anomalously high background seismic noise observed from November 16 through December 16, 2008 seems to be very ubiquitous having a very similar amplitude and shape over a wide area on the continental USA.

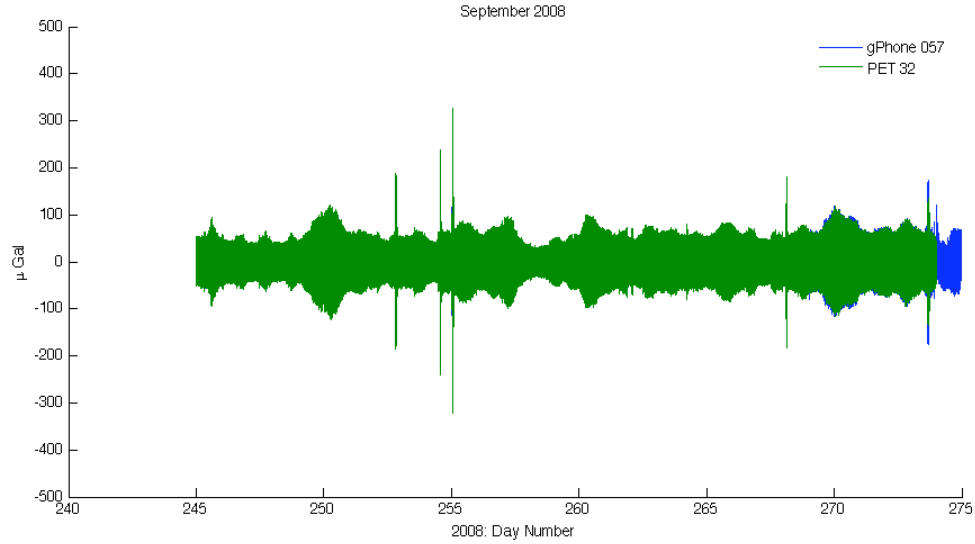

Figure 11: gPhone record in Colorado, September 2008

It is interesting to speculate on the precise origin of the background seismic noise. Haubrich et al[ii] for example, open their article with the following description of the seismic noise background and the large interest it has generated over the years as well as the intractability of its investigation:

> The low-level background unrest of the earth, called microseisms or earth noise, has puzzled seismologists and other scientists for nearly a century. The problem of its nature and causes has proved particularly unyielding, not, however, for lack of investigation. A bibliography covering work up to 1955 [Gutenberg and Andrews, 1956][iii] lists over 600 articles on the subject; one covering the years from 1955 to 1964 [Hjortenberg, 1967][iv] lists 566. Unfortunately, much of this work has advanced the subject but slightly.

In their concluding remarks they state

> No evidence in our results indicates pelagic sources near storms; this contrasts with the situation for higher-frequency body waves that come from the wake of storms. Seven-sec microseisms are usually poor storm trackers, explaining some of the difficulties in attempts to use them for this purpose [Gilmore, 1946][v].

Despite the fact that they could not specifically link their observations to ocean storms that they conclude that coastal reflection of ocean waves is responsible for most of the seismic generation in the seismic band that we are observing. More recently, Bromirski[vi], has published very similar spectrograms from seismic stations across North America during the famous October 1991 "Perfect Storm". It seems clear that the generation of microseismic noise is a topic of considerable interest.

Conclusions

We recently compiled the entire gPhone data set of instruments that were under test at the Micro-g LaCoste test facility in Lafayette, CO. These data clearly show that the seismic noise background has a strong seasonal component. The lowest noise background month generally occurs in June and the highest noise month is November. The background noise fluctuates from about 100 μGal/sec peak to peak in the seismic band between 0.12 to 0.35 Hz (3-8s) during quiet periods and can be as large as 1000μGal peak-peak during noisy periods. The observed background noise fluctuations are not associated with quick slip earthquakes and vary slowly over the time scales of several days.

We recently observed what appears to be an anomalously high background seismic noise period lasting one month from November 16th – December 16th, 2008. The seismic noise envelope correlates extremely well a gPhone operating in Minnesota at the same time. These records also agree well (although with measureable differences) with a gPhone in Vancouver, BC. The noise is often ten times the normal background seismic noise and lasts for many days. There are many

possible explanations for the high background seismic noise observed in November 2008. While we have not ruled out ocean storms, it seems that this might be an interesting month to investigate for other possible sources for this background noise.

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[i] T.M. Niebauer, Jeff MacQueen, Daniel Aliod, and Olivier Francis, 2007, Earthquake monitoring with gravity meters, unpublished but available at www.microglacoste.com/pdf/gphonepap.pdf

[ii] Richard A. Haubrich and Keith McCamy, Microseisms: Costal and Pelagic Sources, Reviews of Geophysics, 7, pg 539-571 (1969).

[iii] Gutenberg, B., and F. Andrews, Bibliography of Microseisms, 2nd ed., 134 pp., Seismological Laboratory, California Institute of Technology, Pasadena, 1956.

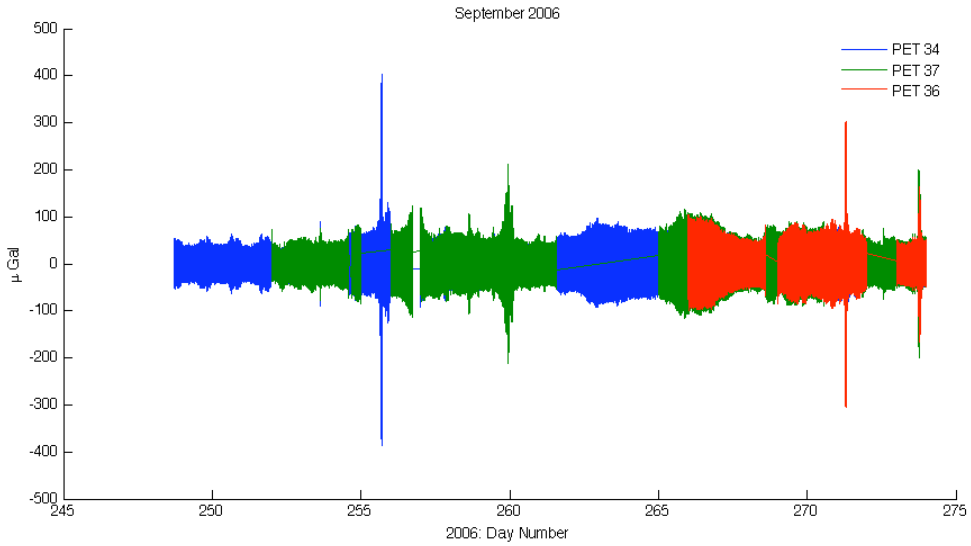
[iv] Hjortenberg, E., Bibliography of Microseisms, 1955-1964. Geodaetisk Instituts Skrifter 3, Raekke Bind 38, Blanco Lunos Bogtrykkeri A/S, Copenhagen, 1967.

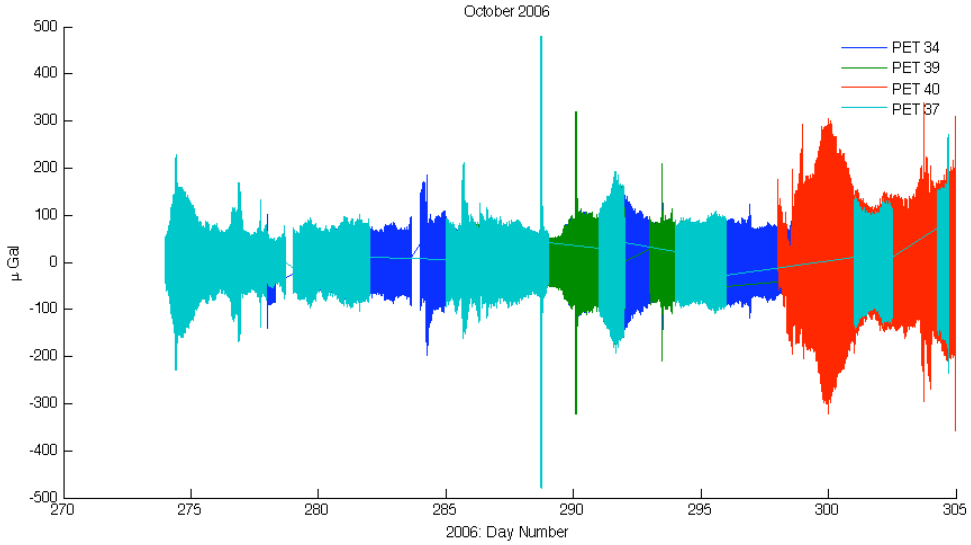
[v] Gilmore, M. H., Microseisms and ocean storms, Bull. Seismol. Soc. Am., 36, 89-119, 1946.

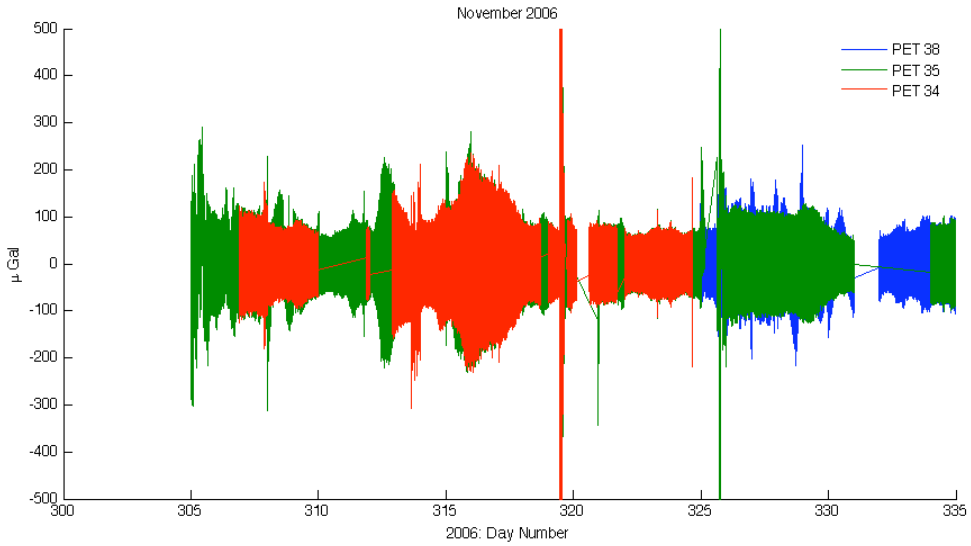
[vi] Peter D. Bromirski, Vibrations from the "Perfect Storm", Geochem. Geophys. Geosys., 2(7), doi:10.1029/2000GC000119 (2001)

Appendix: Background Gravity Noise at Micro-g LaCoste test Facility from September, 2006 through January 2009.

The following records were pieced together from many different instruments under test. The records have been de-trended to remove drift and de-spiked to remove disturbances caused by the testing. Many records from the gravity meters under test were discarded. However, whenever data from more than one gravity meter was not disturbed the correlation between different instruments was excellent.



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PET 34
μ Gal
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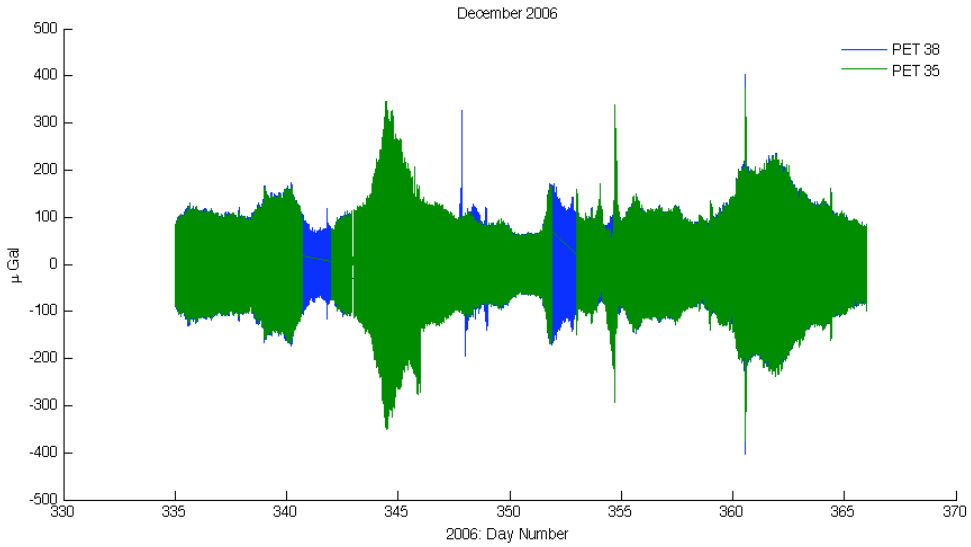
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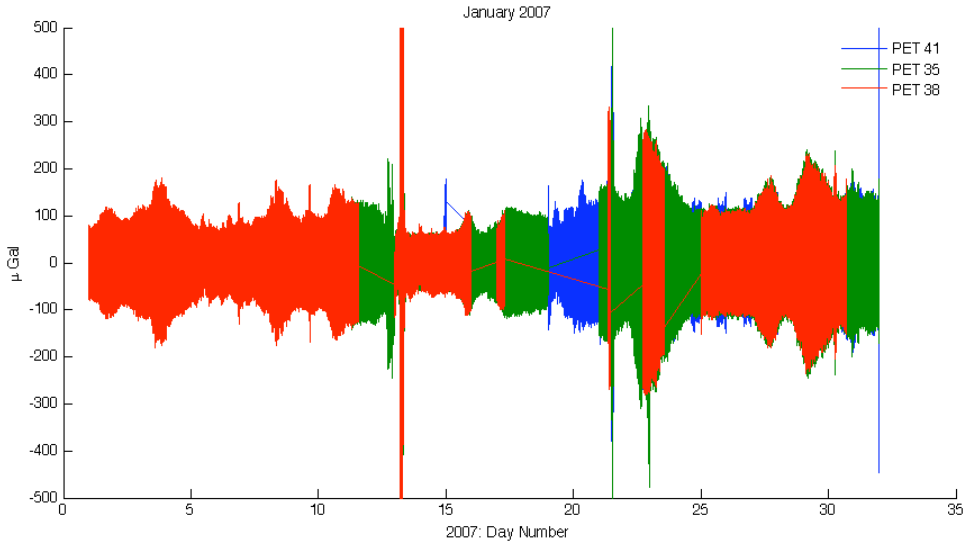
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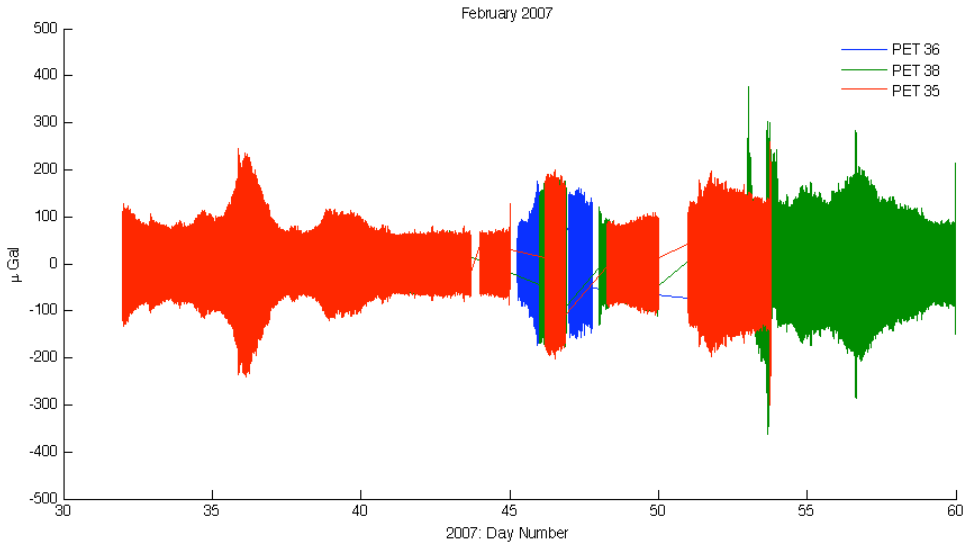
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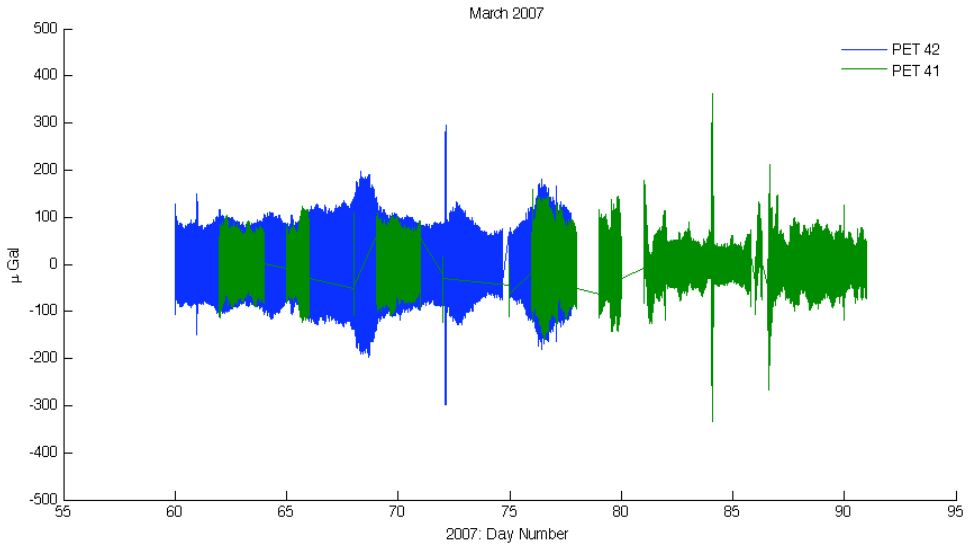
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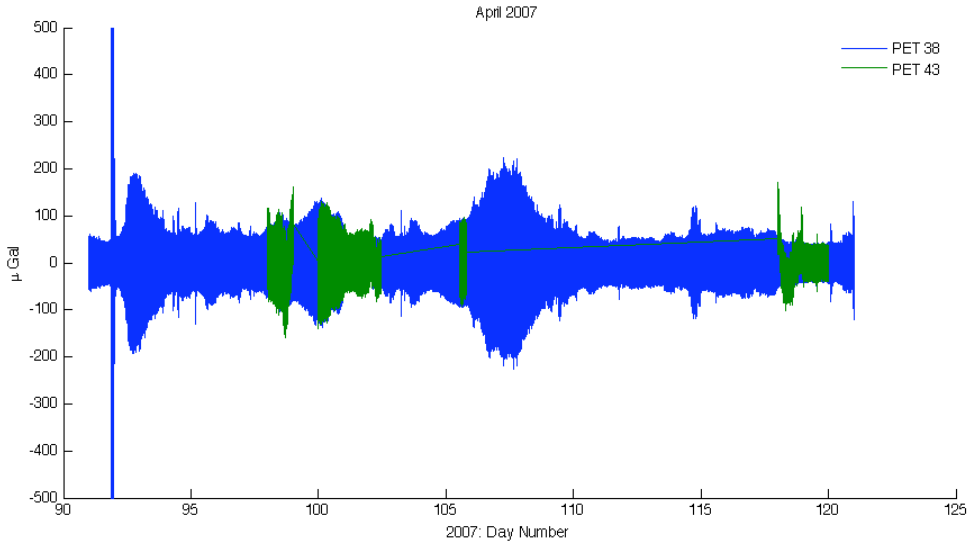
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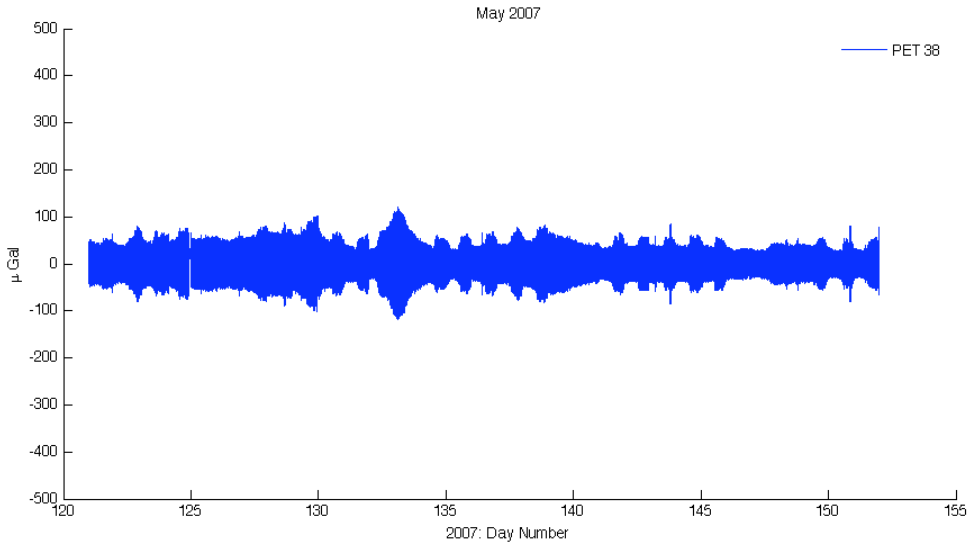
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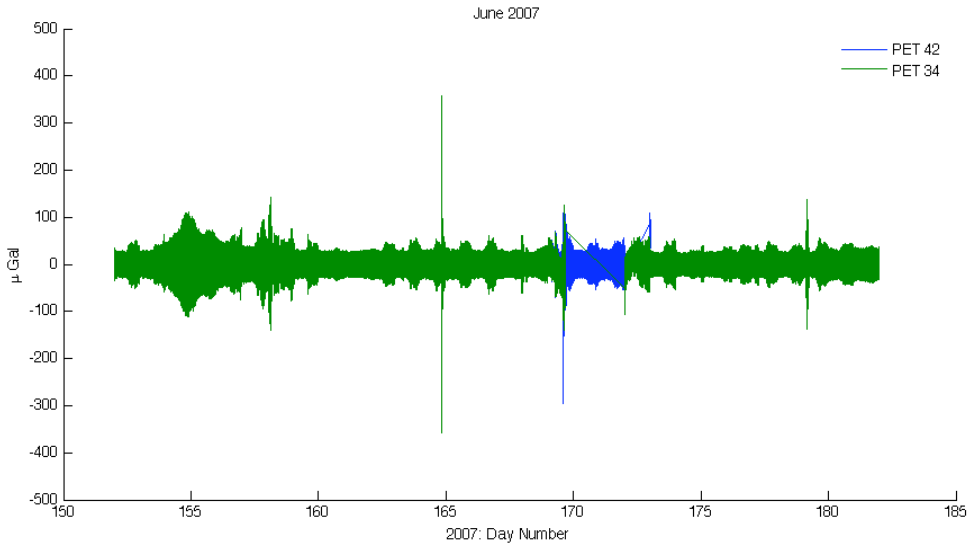
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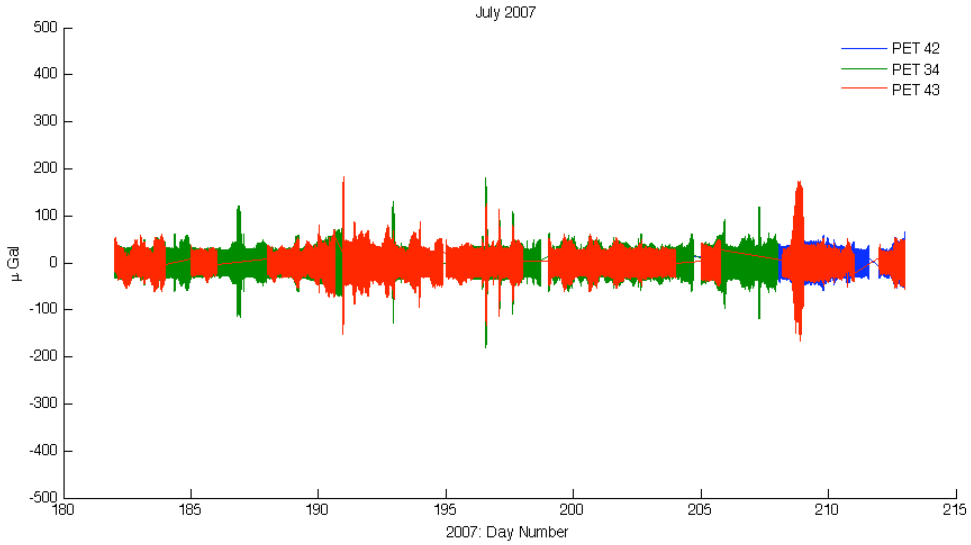
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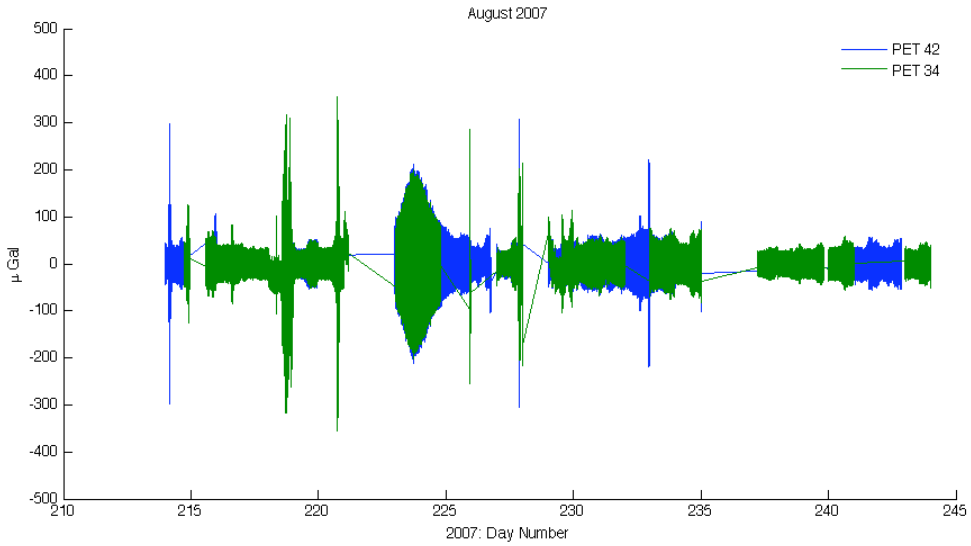
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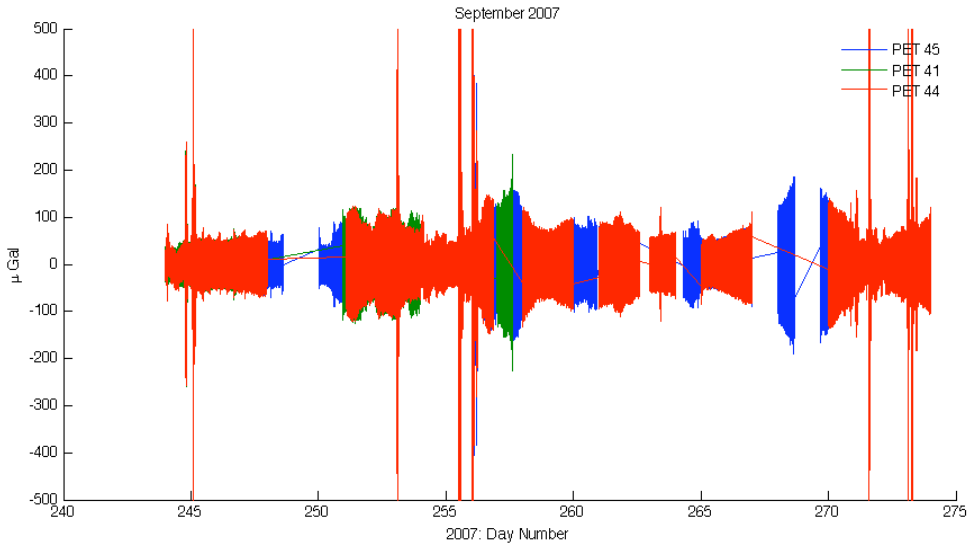
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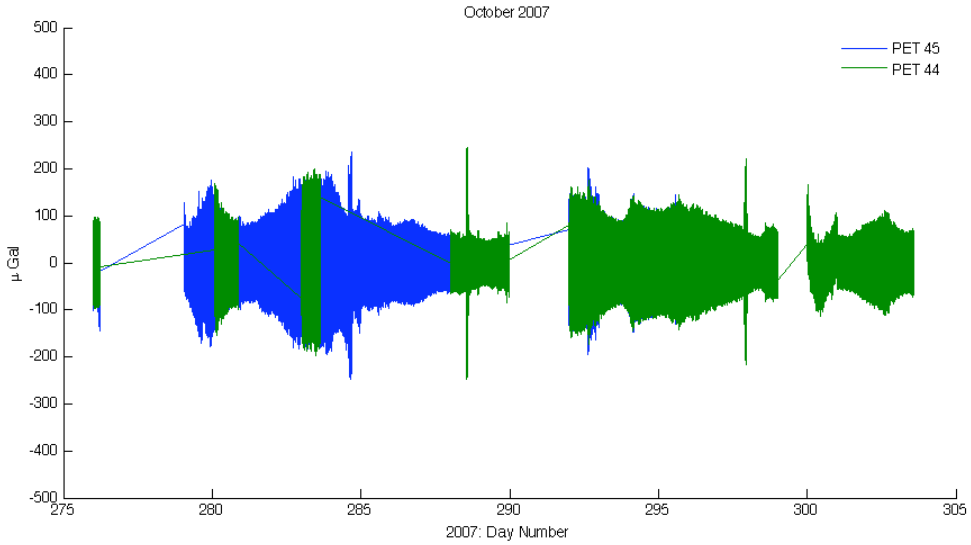
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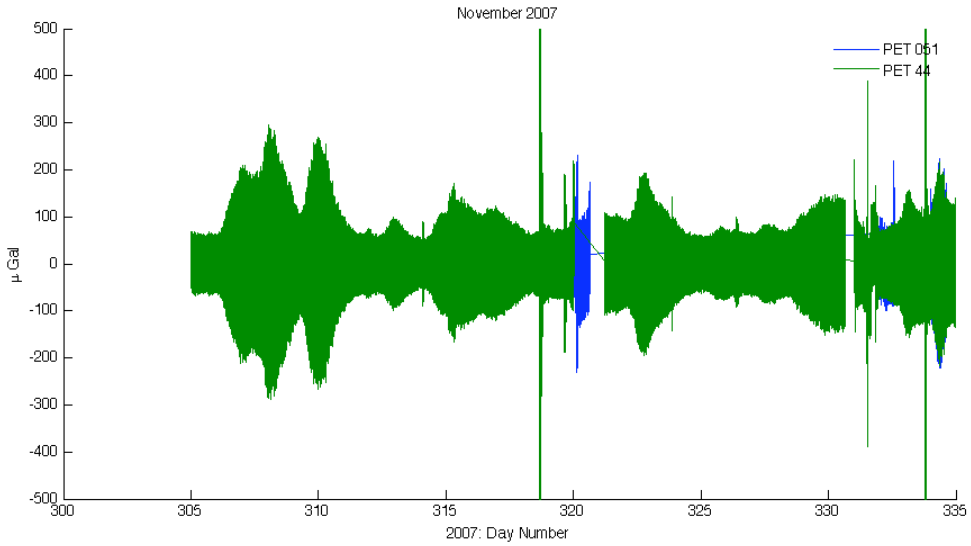
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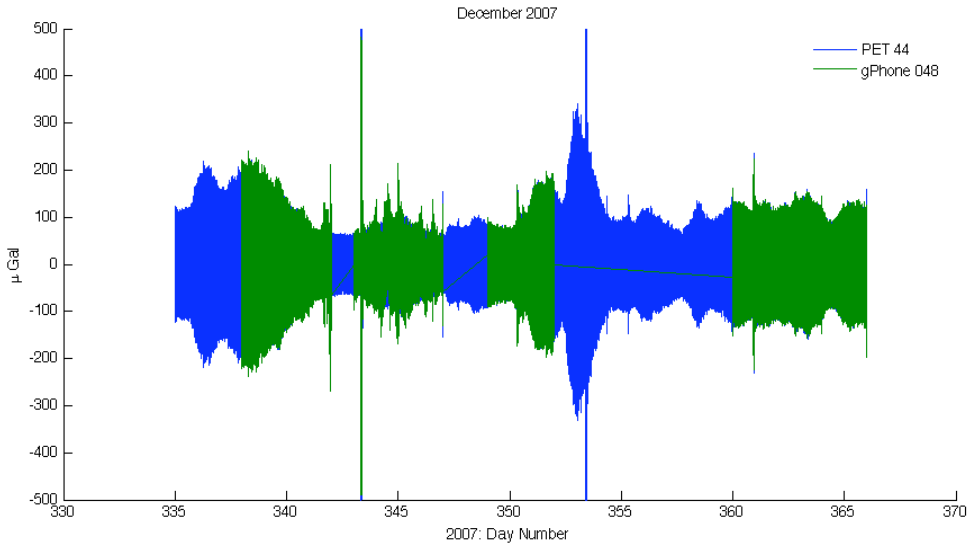
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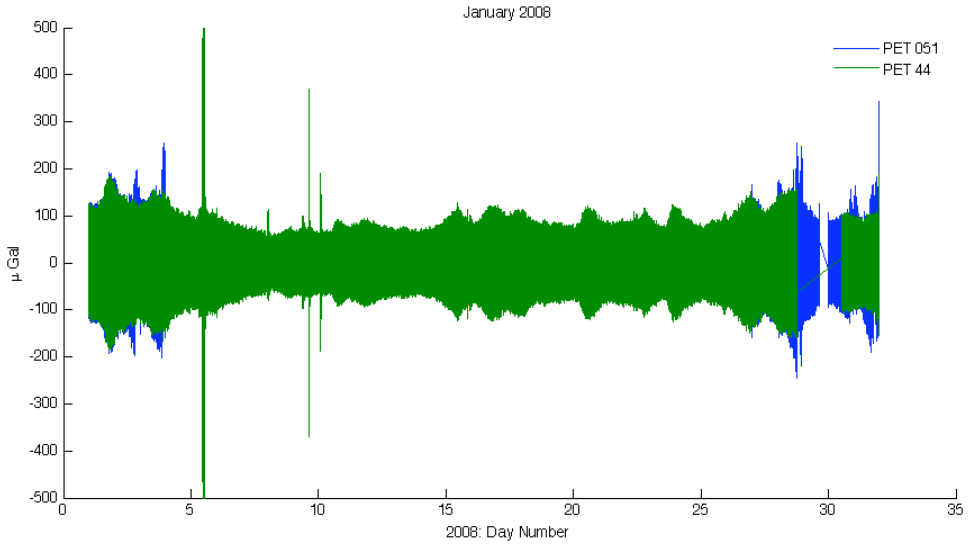
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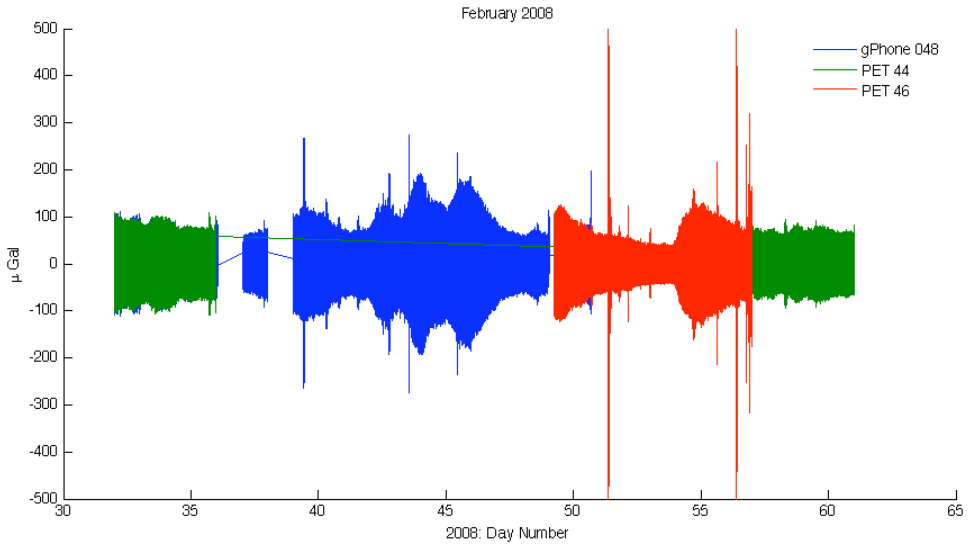
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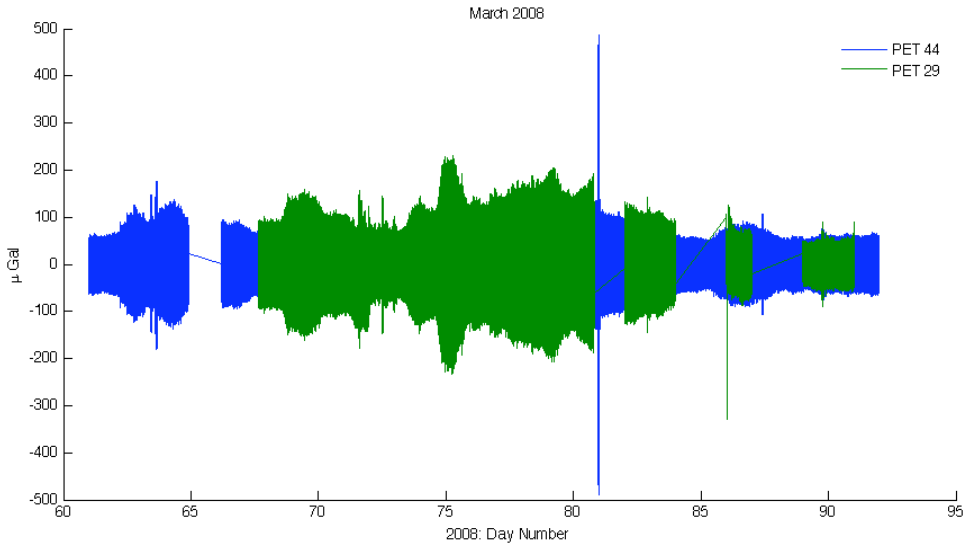
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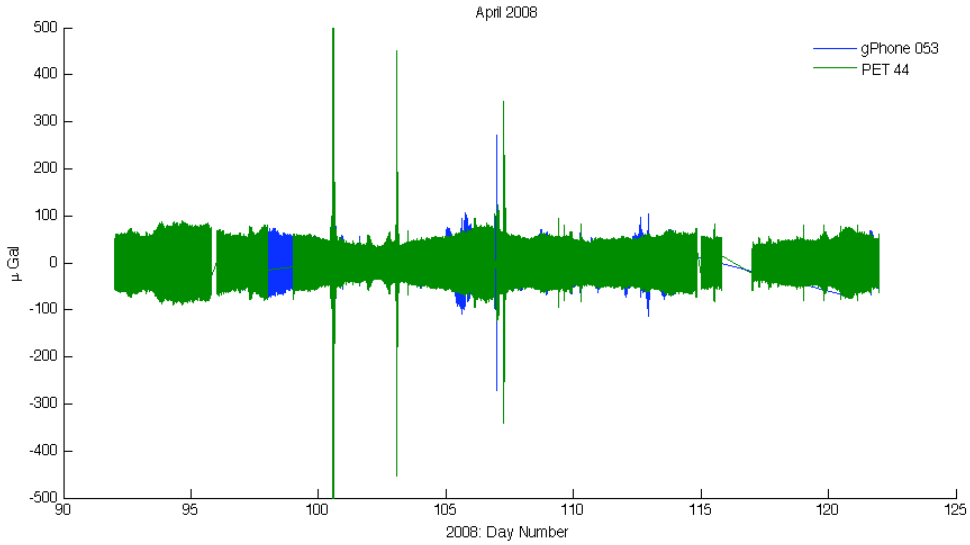
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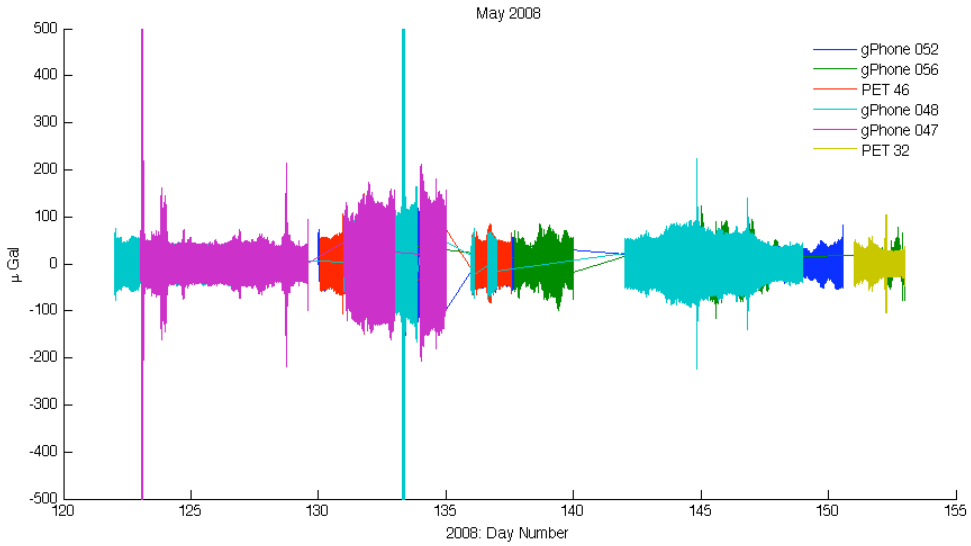
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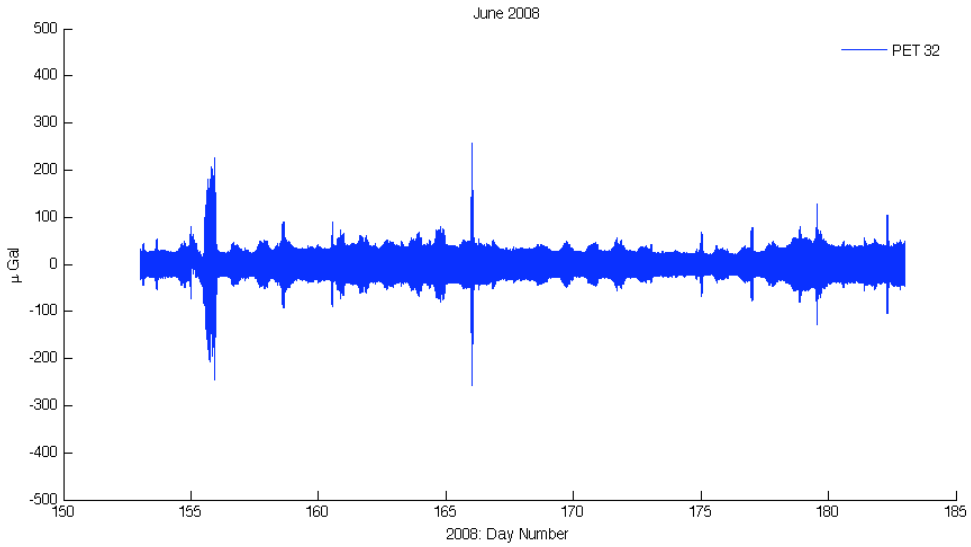
June 2008
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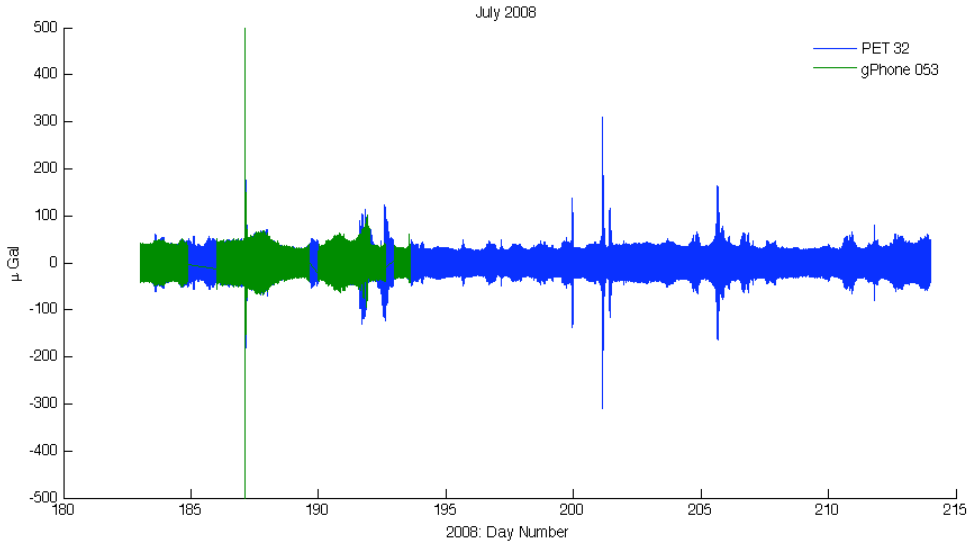
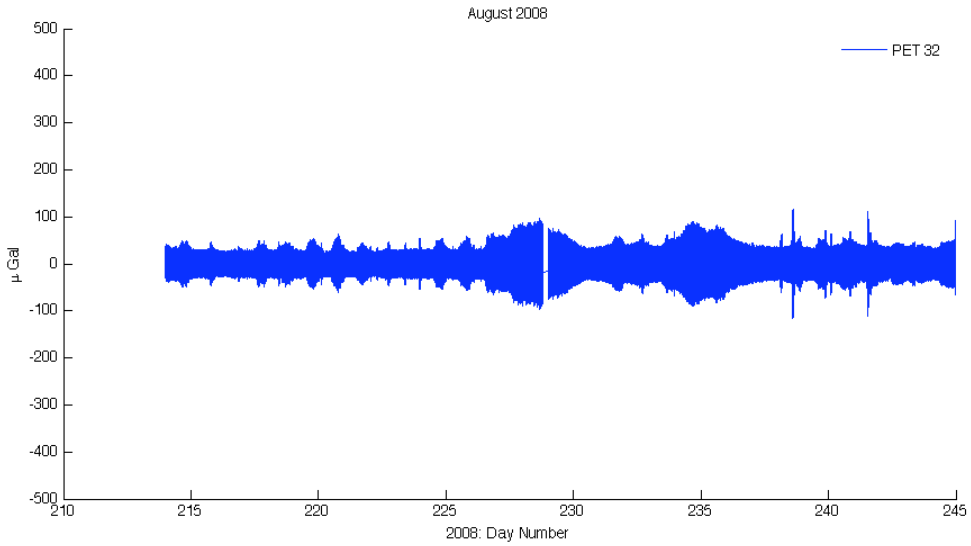
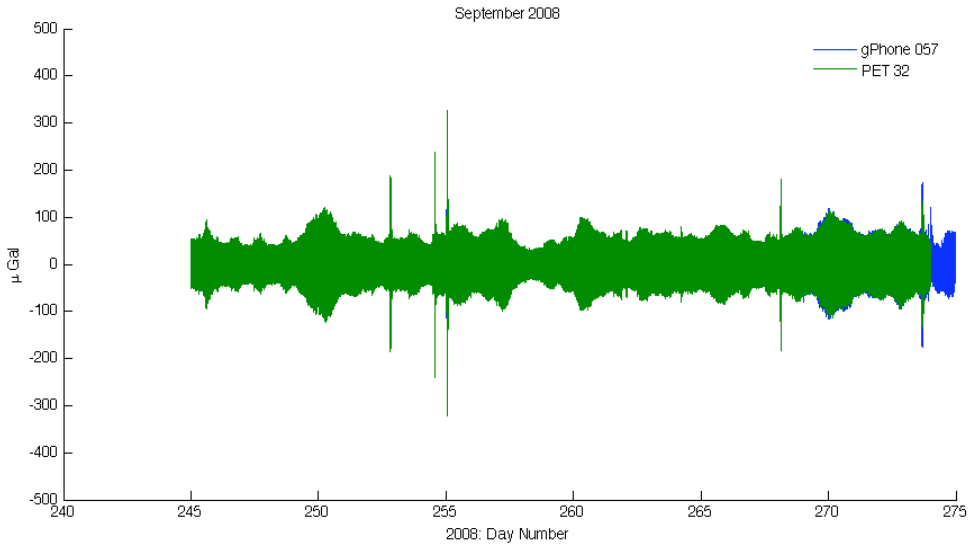
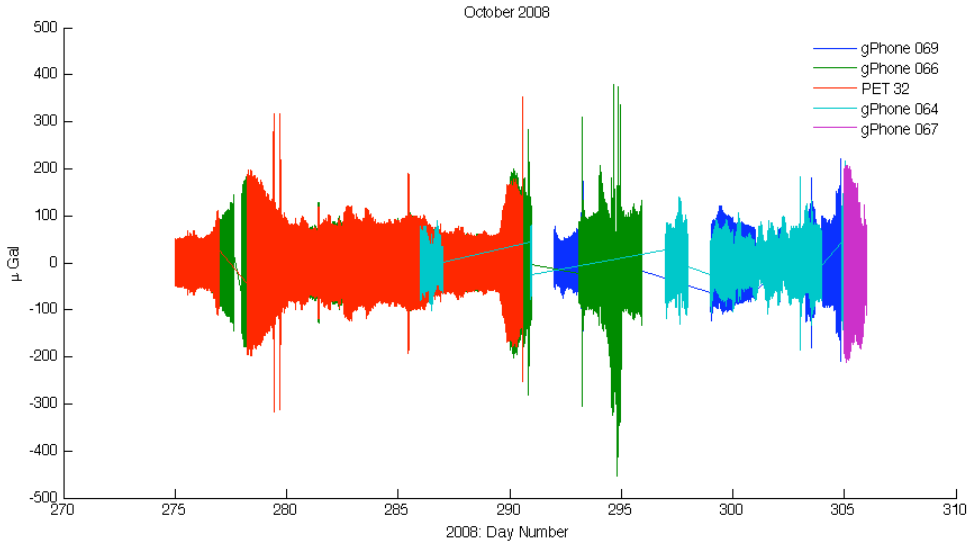
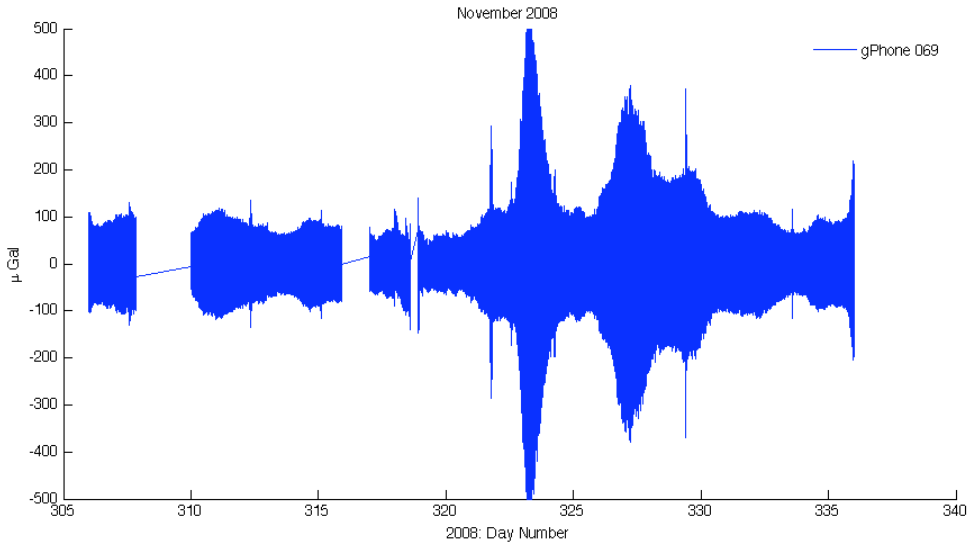
μ Gal
2008: Day Number

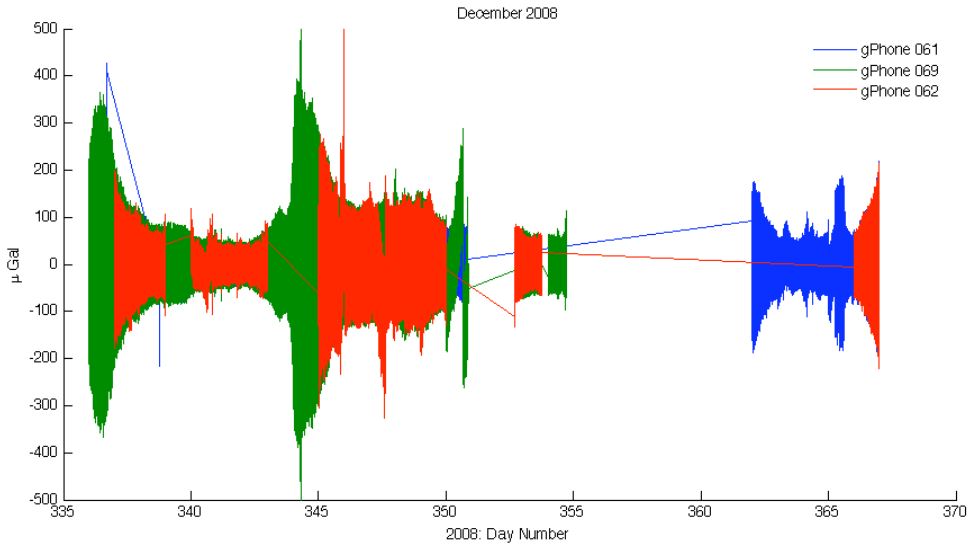

July 2008
PET 32
gPhone 053
μ Gal
2008: Day Number

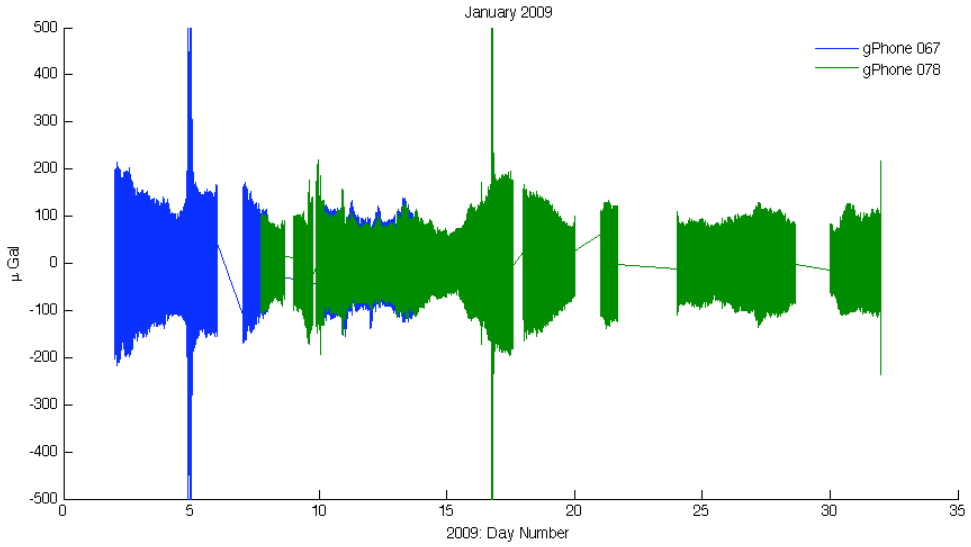

August 2008
PET 32
μ Gal
2008: Day Number


September 2008
gPhone 057
PET 32
μ Gal
2008: Day Number


October 2008
gPhone 069
gPhone 066
PET 32
gPhone 064
gPhone 067
μ Gal
2008: Day Number


November 2008
gPhone 069
μ Gal
2008: Day Number


December 2008
gPhone 061
gPhone 069
gPhone 062
μ Gal
2008: Day Number


January 2009
gPhone 067
gPhone 078
μ Gal
2009: Day Number