Earthquake Forecasting Sensor Possibility

Randall D. Peters

Department of Physics

Mercer University

Macon, Georgia USA

(Copyright October 2012)

Abstract

Based on instrument records, evidence is provided for the possibility of lifesaving warnings that could be issued several hours before an earthquake. Conclusions derive from both experiment and theory as follows: Not only did the record of an M7.7 earthquake on 2012-10-28 show a significant precursor, so also did an earthquake in Aug 2012 (http://physics.mercer.edu/hpage/accelerometer/accelerometer.html). Analyses of these records show features consistent with the physics presented in a recent theoretical paper titled ``Prediction of Catastrophes-an experimental model".

Background

About five years ago the author created a novel pendulum seismograph called the VolksMeter, which is a state-of-the-art instrument having ultra-low-frequency sensitivity to tilt and acceleration [1]. The instrument uses a (patented) displacement sensor of fully differential capacitive type [2]. Numerous experiments that have been performed, involving similar instruments and conducted over more than two decades, demonstrate the abiding importance of `pendulum' type instruments for scientific research.

Although it lost favor with seismologists for decades, there has been a recent resurgence of interest in the `simple' *gravitational* pendulum [3]. It is well suited to operation with capacitive sensors to measure *displacement*, rather than *`velocity'*, as has been customary in the world of professional seismology. To the present, the standard mode of operation of conventional seismographs has been one of generating a signal corresponding to the time derivative of displacement of the inertial mass of the instrument. This mode derives from the earliest means for monitoring motion of the mass. It is one in which the voltage that develops across the ends of a coil is proportional to the time rate of change of flux through the coil, provided by an associated magnet. In one range of frequencies (and this one range only), this Faraday-law detector gives an output that is proportional to the velocity of the inertial mass. This happens when the harmonic acceleration that `drives' the instrument has a frequency that is above the characteristic frequency of mechanical oscillation. For drive below that frequency, if the electronics that amplifies the coil voltage is ``flat" (everywhere independent of frequency); the output is proportional to the time derivative of acceleration. As will be seen from a figure that follows, such a detector is not suitable for use in an earthquake early warning system.

Present Tiltmeter

The instrument responsible for the data of this article is shown in Fig. 1.

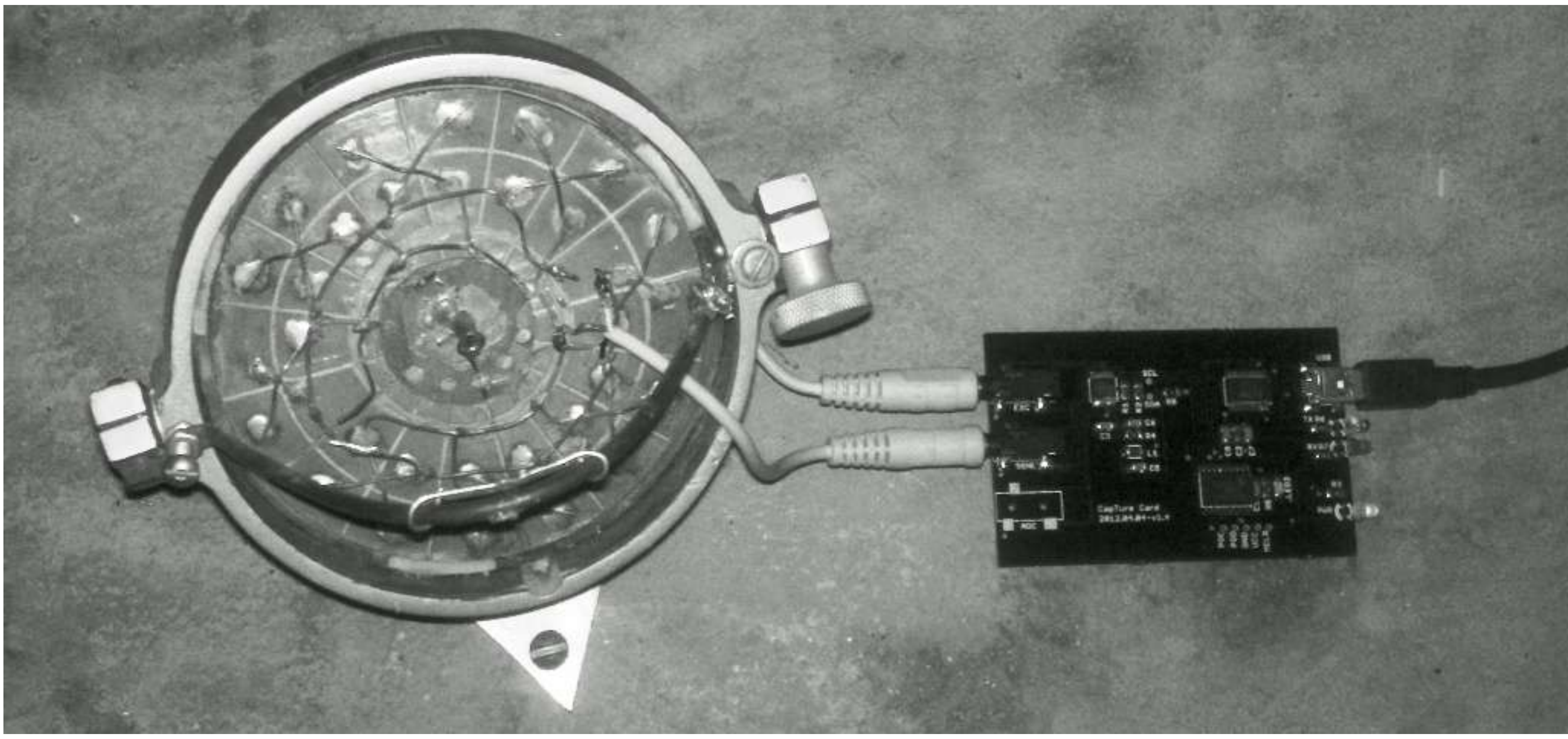

Figure 1. Compact fully digital tiltmeter that operates with a fully differential capacitive sensor array. The electronics support board is also visible, and the (black) USB cable connects at its other end to the computer. Information concerning the electronics is online at http://symcdc.com

The housing for this instrument was once part of an optics assembly. The original front-surface mirror was replaced by the 8-component sensor array that is visible in the photograph. There is an online overview-type description of this torsional balance [4]. A detailed description of its physical properties (though packaged differently) was also published [5].

Low Frequency Advantage

There are a variety of important ultra-low-frequency earth motions that are mostly hidden from view in the output of conventional instruments, such as the tidal tilts that are readily observed with the present instrument, as seen in Fig. 2 (left-side graphics). Seen also in the right side plots is a prominent eigenmode oscillation being driven by remnants of Hurricane Sandy as it came ashore.

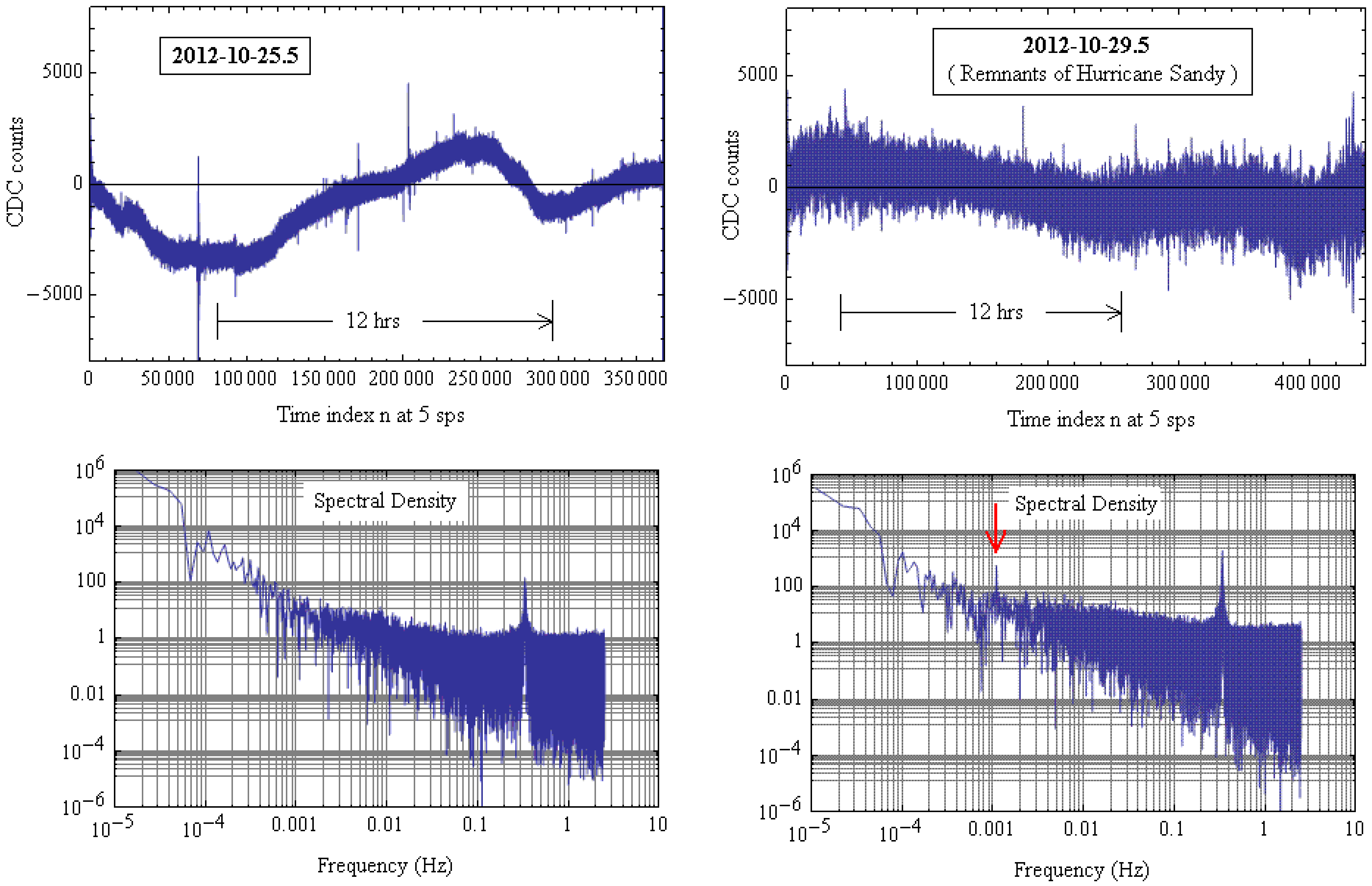

Figure 2. Illustrations of the d.c. lower limit frequency response advantage of the instrument, by showing (i) tilt due to the 12-hr periodic crustal tide (left) and a sharp spectral line (right, red arrow) due to the earth's being driven to oscillate by Hurricane Sandy. For these and all other records of this article, the instrument was sitting on the concrete slab floor of the author's basement, located 140 miles north of Atlanta, Georgia.

It is interesting also to note the dramtically larger background noise level that was present throughout the record involving Hurricane Sandy. Some of this was due to greater wind levels in the vicinity of the instrument. A significant additional component of the noise must have derived from earth disturbances closer to the eye of the storm, which was at a great distance from Georgia. This conclusion was reached on the basis of the eigenmode oscillation whose spectral line is present in the record. Earth oscillations driven by hurricanes are known to exist, as previously documented by the author [6].

Record containing an Earthquake of M 7.7

All data processing for this article was performed with Mathematica 8. The original data collection rate from the instrument was at 50 samples per second (sps). For most of the present figures, the graphs were generated from a sub-sampled data set corresponding to 5 sps.

Shown in Fig. 3 (upper graph) is a plot of the output from the instrument that was recorded on 28 October 2012.

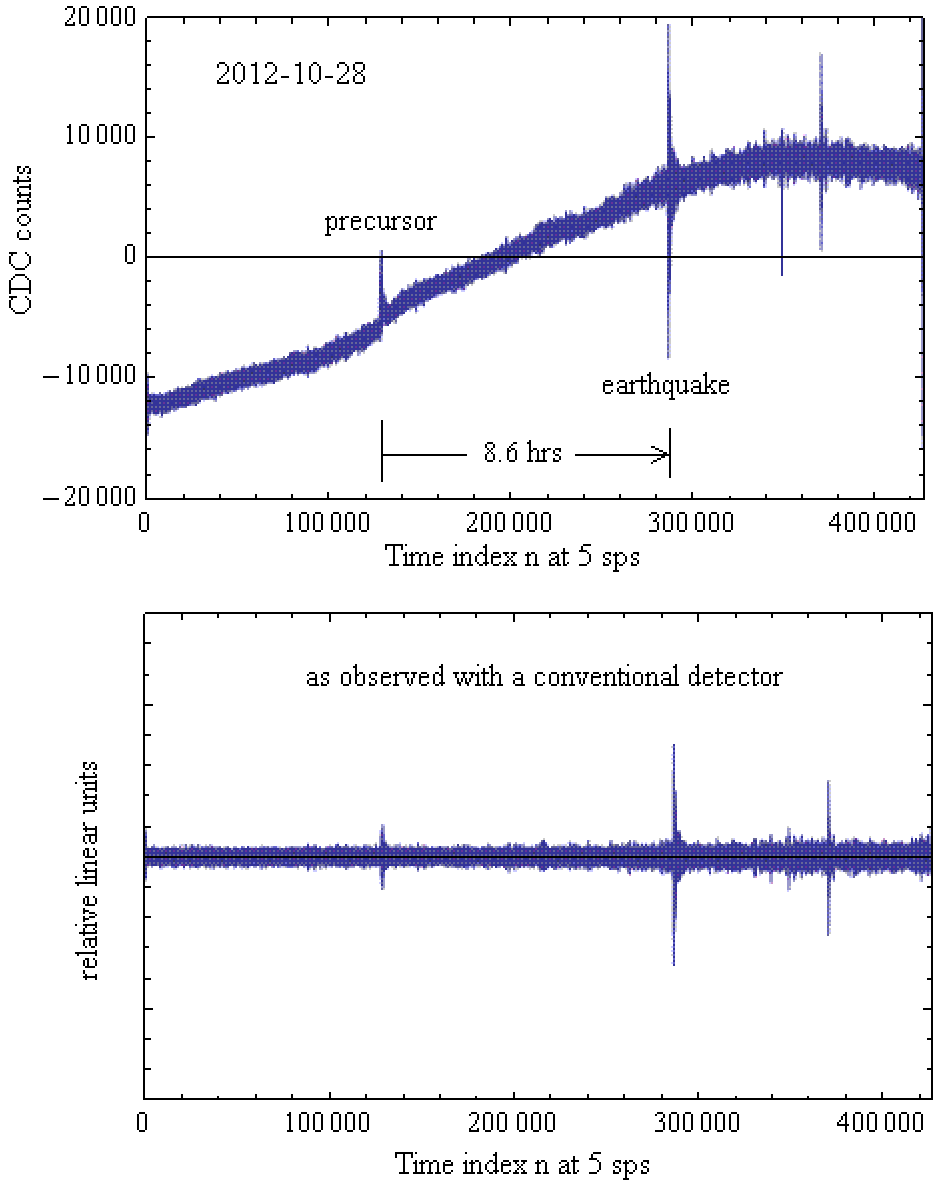

Figure 3. Record containing a large earthquake and the unmistakeable precursor that occurred about 8-1/2 hours earlier (top plot). Also shown (lower plot) is an estimate (numerical simulation) of what the record would have looked like had the sensor been of conventional type; i.e., a signal that is proportional to the derivative of earth acceleration.

The significant difference between displacement sensing and `velocity' sensing should not be under-estimated. The `off-set signature' of the precursor, that is clearly visible in the top plot is altogether missing from the lower plot. Although the precursor is still visible (though significantly distorted) in the lower plot, it is much more likely to be interpreted as a noise spike.

In another important regard, the present tiltmeter is radically different from most every other seismic instrument. No purposeful external damping has been applied to suppress the oscillatory free decay of the `inertial' mass. At larger levels, the inherent damping is mainly due to the air in the space between the moving (rotating) electrodes and the static electrodes of the sensor. The noise threshold was measured to be 140 capacitive to digital converter (CDC) counts, and it is determined by the lower level of power source stability of the electronics (coming from the computer through the USB cable). In decaying downward from levels near the limit imposed by dynamic range, the damping is first influenced significantly by nonlinear air drag. It progresses from there through a place largely influenced by linear (viscous) drag. Finally, at levels near the noise threshold, it is largely influenced by internal friction (hysteretic) damping of the twisting tungsten wire of the instrument [7,8]. Especially because of the granular nature of hysteretic damping, it is (for present purposes) beneficial to take advantage of the inherent `dithering' that occurs through oscillations of the undamped instrument, whose quality factor was measured from a free decay record at $Q = 210$.

Individuals concerned with the extraction from seismic records of information to reveal place, depth, and type of an earthquake will be clearly ill at ease with this feature of the author's instrument. Virtually all conventional seismographs operate near critical damping ($Q = 0.5$), with $Q = 0.707$ being ideal. Such is needed to avoid complications from the transient response of an undamped instrument; which is ever more significant, the larger the value of Q. It is important to understand that the present instrument is being used for a very different purpose. As seen from Fig.2 above and also Figures 4 and 5 that follow, there is nevertheless greatly useful spectral information to be gleaned from the output of the undamped tiltmeter.

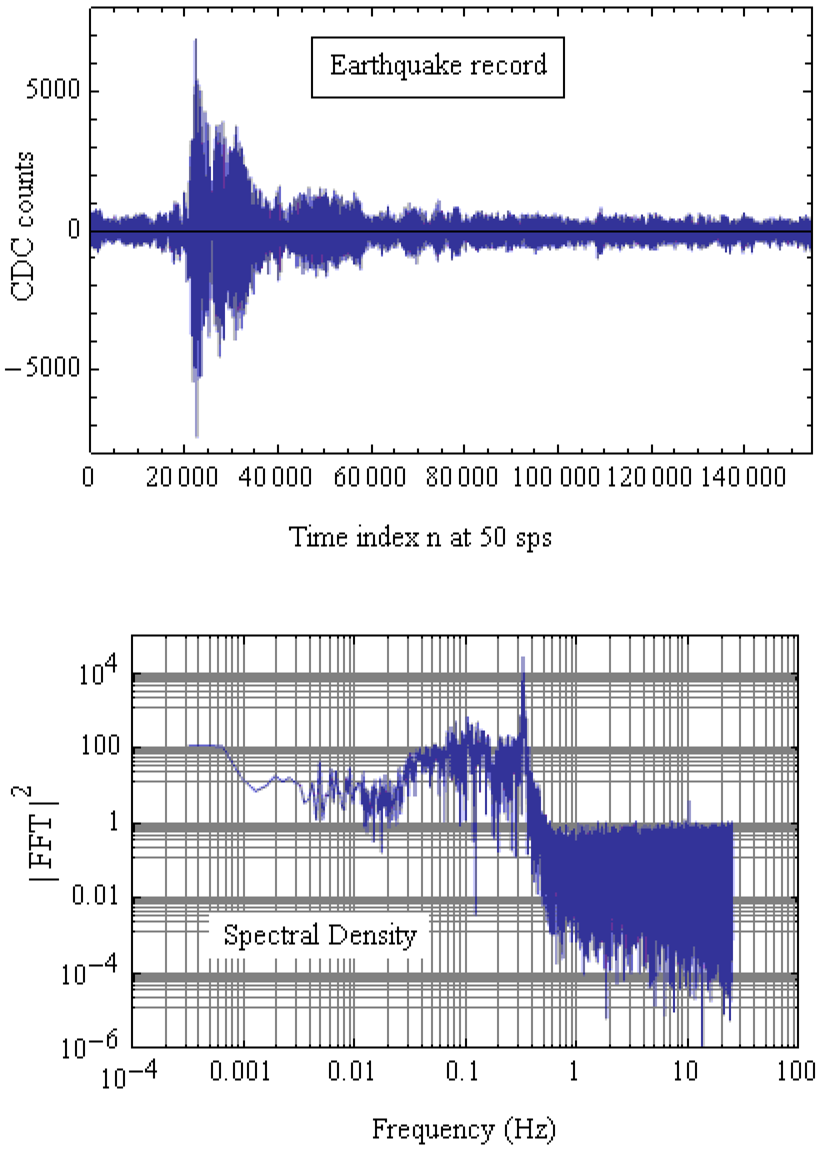

Figure 4. Short time segment bracketing the earthquake that was observed in the record of Fig. 3. (The full sample rate of 50 sps was used in the generation of this figure, after the offset and trend were removed.).

Precursor

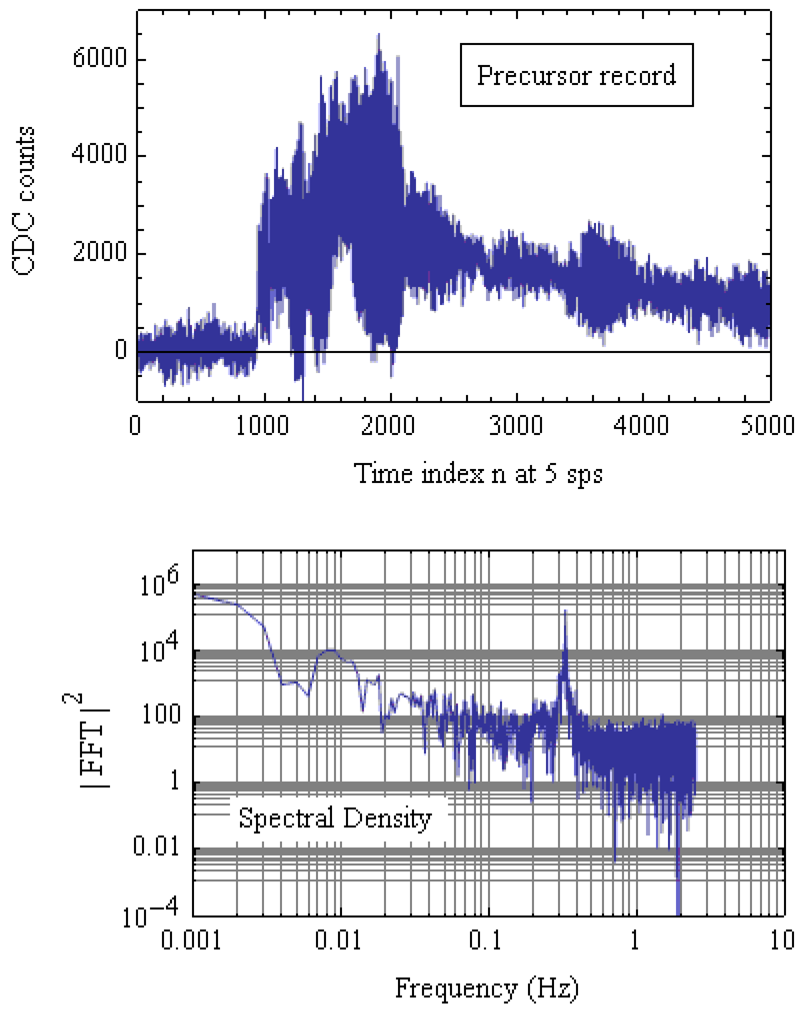

Figure 5. Short time segment bracketing the precursor that was observed in the record of Fig. 3. (The offset of Fig. 3 was removed.)

***Signature* of Impending Catastrophe**

Described in the article ``Prediction of catastrophes: an experimental model" are changes of spectral type that might be expected to occur generally in a system before it experiences a catastrophe [9]. Spectra calculated from measured lengths of a ductile metal (solder) wire were found for that case to show such variation. Experiment was found to agree well with predictions based on a saddle node theory. Although there was no experimental evidence to support the claim provided in that paper, we suggested that the same type of spectral`signature' might occur before an earthquake. It is one that is characterized by a `critical slowing down in the noise' (CSDN). The cumulative spectral power (CSP) tool [10] that was recently developed by the author is especially well suited to observations of the CSDN signature.

Present Earthquake Case

In Fig. 6 the CSDN signature is seen in the four plots of the lower right graph. To generate the four curves shown, the record of the upper left graph (consisting of 65536 values) was first segmented into four equal length (16384) parts. The fast Fourier Transform (FFT) was calculated for each, and then an integral was performed on each density spectrum to yield its corresponding cumulative spectrum. To distinguish the ordering of these four (overlaid) cumulative spectra, colors were chosen for the plots of blue (first), red, purple, and black (last) in time respectively.

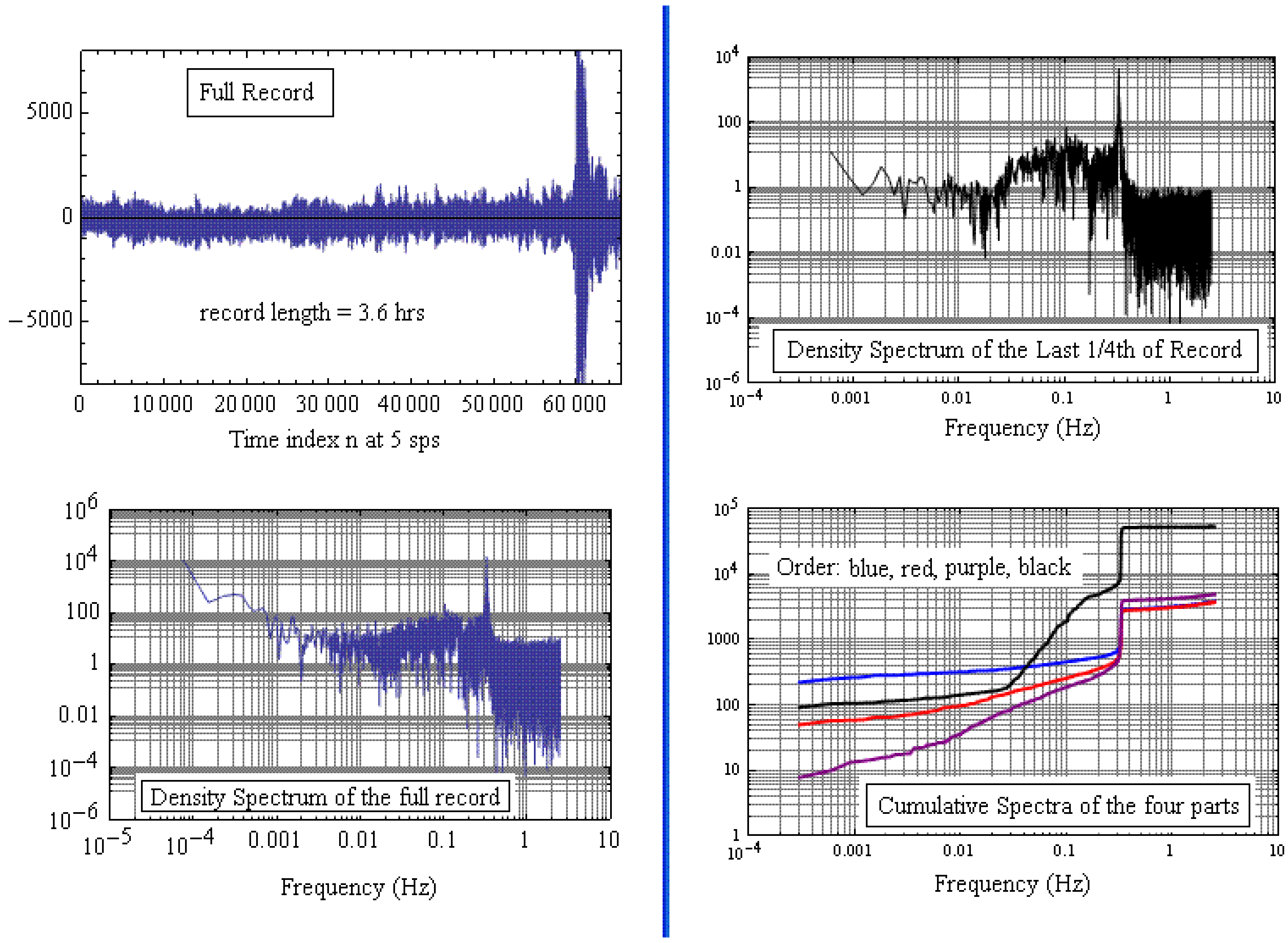

Figure 6. Evidence (lower right graph) for critical slowing down in the noise (CSDN), of instrument output spectra, before the occurrence of the M7.7 earthquake.

The dramatic presence of the CSDN signature is seen here by the manner in which the lowest frequencies of the cumulative spectrum falls in secular manner, in going from blue to red to purple. Then finally the entire cumulative spectrum rises for the record part that includes the earthquake (black curve).

Spectra of the Precursor Event

The CSDN information of type shown in Fig. 6 might of itself be adequate for generating an earthquake warning. In the event that a precursor event should also show up in the recording would provide a special additional benefit. It would serve to alert those responsible for the generation of warnings to pay special attention to spectra that would follow.

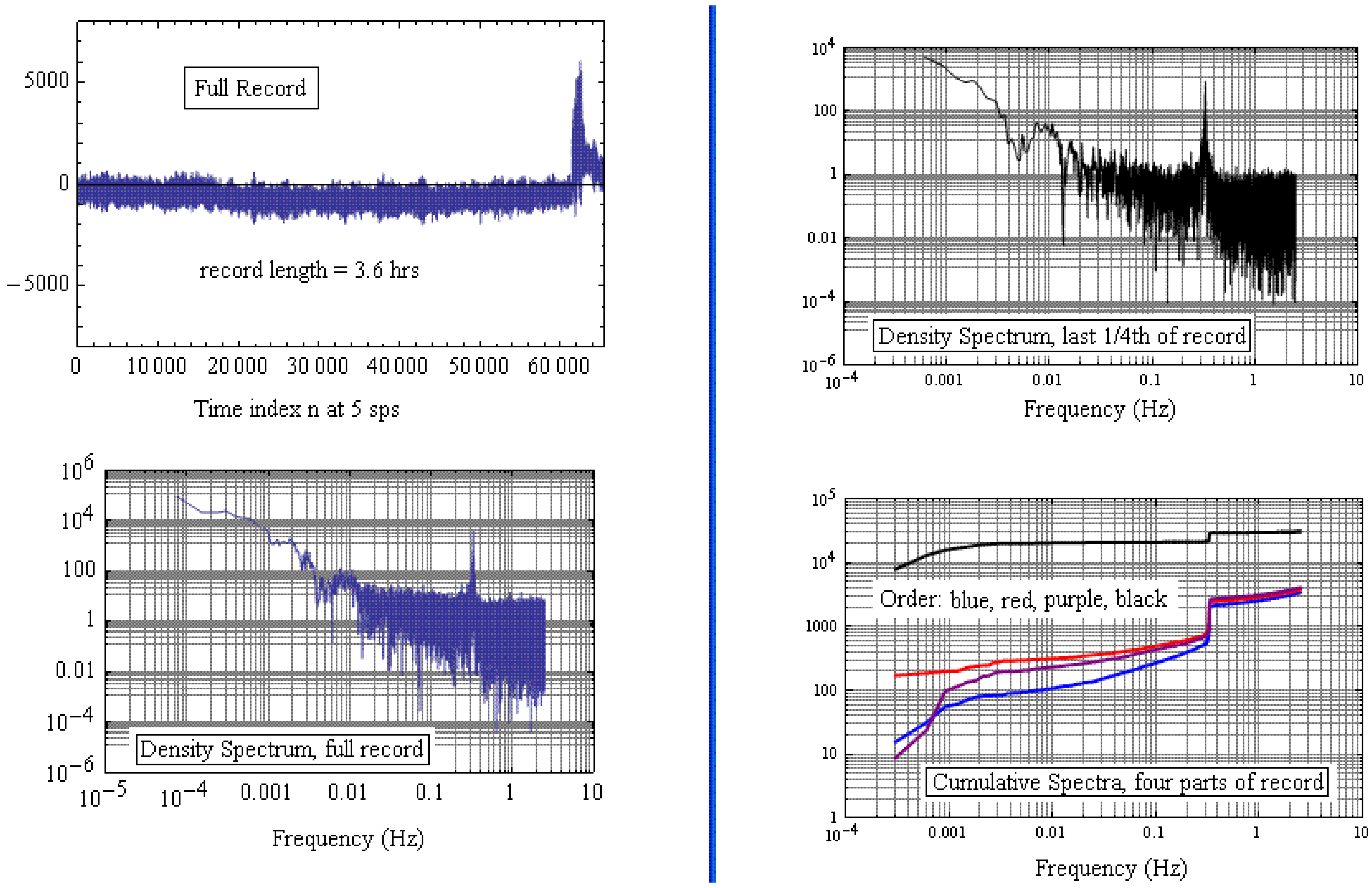

Figure 7. Spectral features of the precursor that was observed 8.6 hours before the M7.7 earthquake.

As seen from the colored graphs of Fig. 7, there is also with the precursor some tell-tale evidence for a CSDN. The change from red to purple (just before the event in black) is dramatic. The initial (blue) curve is `out of place', however (as compared with Fig. 6). The greater intensity of fluctuations roughly 12 hours before the earthquake preclude a clearly visible CSDN. One is led naturally to wonder if the relative amounts of (i) fluctations and (ii) CSDN - could be a factor in determining whether the impending `catastrophe' is of precursor type or of earthquake type.

Conclusions

Compelling evidence is seen to exist for the possibility of creating a meaningful earthquake early warning system. Proof for the viability of such a system would require a pre-deployed network of sensors capable of detecting ultra-low-frequency motions of the earth. It is here shown that a compact and inexpensive novel tiltmeter is a good candidate for such deployment.

References

[1] http://psn.quake.net/volksmeter/State-of-the-art_Digital_Seismograph.pdf

[2] U. S. Patent ``Symmetric differential capacitance transducer ...", described online at www.google.com/patents/US5461319

[3] R. D. Peters, ``Tutorial on Gravitational Pendulum Theory applied to Seismic Sensing of Translation and Rotation", Bulletin of the Seismological Society of America May 2009 v. 99 no. 2B p. 1050-1063. BSSA graciously allows the reader to download this article at http://physics.mercer.edu/hpage/BSSA-tutorial/pend-theory.pdf

[4] Some physical properties are described online at http://www.iris.edu/stations/seisWorkshop04/PDF/NOVELTILTMETER.pdf

[5] R. Peters, ``Mechanically adjustable balance and sensitive tilt meter", Meas. Sci. Technol. 1, 1131 (1990).

[6] R. Peters, ``Earth oscillations induced by Hurricane Katrina", online at http://physics.mercer.edu/hpage/katrina/katrina.html

[7] R. Peters, ``Damping Theory", Ch. 20 of *Vibration and Shock Handbook*, Ed. Clarence de Silva, CRC Press, Taylor and Francis, 2005 (Mech. Engr. Series).

[8] R. Peters, ``Friction at the mesoscale", Contemporary Physics, Volume 45, Number 6, November-December 2004 , pp. 475-490(16)

[9] R. Peters, M. Le Berre, & Y. Pomeau, ``Prediction of catastrophes: an experimental model", Phys. Rev. E86,026207 (2012). A pre-published version of the article is online at http://arxiv.org/abs/1204.1551

[10] R. Peters, ``A new tool for seismology-the cumulative spectral power', online at arxiv.org/pdf/0705.1100

File translated from T_EX by T_TH, version 1.95.
On 31 Oct 2012, 11:40.