TURTLE SENSE

CAPE HATTERAS NATIONAL SEASHORE
SEA TURTLE MONITORING PROJECT
2014 REPORT

NerdsWithoutBorders.net

Sponsoring Non-Profit Corporation:

Hatteras Island Ocean Center

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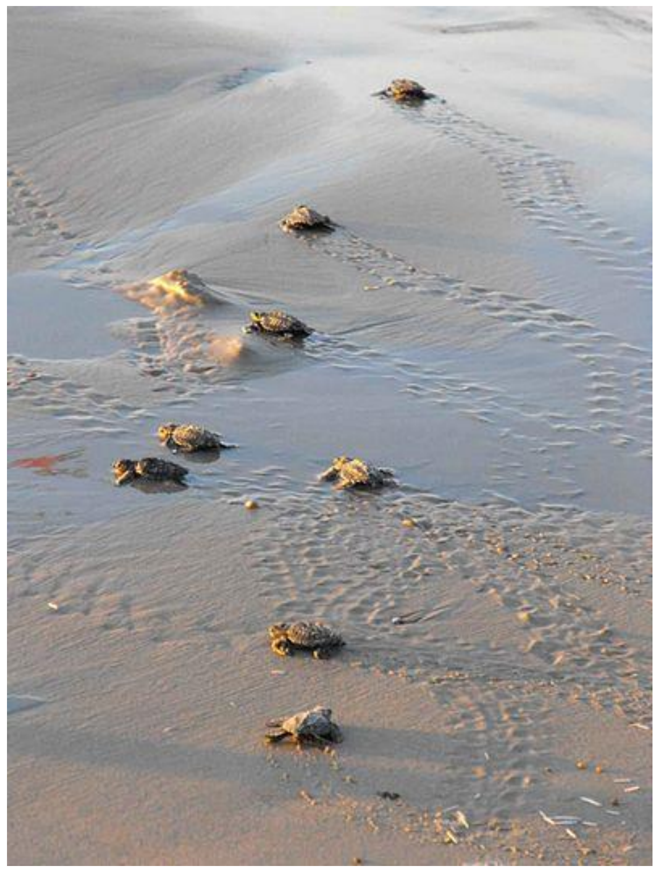
I. Project overview

The sea turtles found in the waters of Cape Hatteras National Seashore are protected by the U.S. Endangered Species Act. While the National Park Service (NPS) must protect the Seashore's nesting sea turtles, the NPS is also obligated to uphold its mission to make the Seashore available to people for "enjoyment, education, and inspiration." As the popularity of the Seashore has grown, it has become increasingly difficult for the NPS to meet its obligations to both people and sea turtles. The goal of Turtle Sense is to help people and sea turtles share the beaches of the Seashore in a way that benefits both humans and sea turtles.



When a sea turtle nest is found on a Seashore beach, a small enclosure is built around the nest to keep pedestrians and vehicles away. About 50 to 55 days later, the nest closure is expanded, often closing the beach to vehicular and foot traffic. Hatching occurs on some unpredictable date over a six-week span. This uncertain time period creates lengthy protection methods that conflict with other uses of the beach area. Because there is no reliable way to predict when the tiny turtles will emerge from their nests near the dune-line and parade to the surf, closures can sometimes last for more than a month.

Turtle Sense is a very low powered, inexpensive system designed to address this problem by monitoring the motion and temperature within sea turtle nests. Designed to withstand a harsh ocean beach environment, an ultra-low powered motion sensor and microprocessor is encased in a small plastic egg. This "Smart Sensor" buried in the sand on top of a nest can measure, record, and evaluate motion and temperature for an entire turtle nesting season. The Smart Sensor is attached by cable to an above-ground tower. The tower houses a cell phone board that uploads frequent reports on the activity in the nest to a server on the Internet. The data in the reports is used to predict hatching dates from the motion of the hatchlings as they cut through the leathery egg and move around. Because this motion occurs several days before hatchlings emerge, Turtle Sense makes it possible to narrow the protection window to just a few days. This can help free up the beaches and encourage eco-tourism while helping protect the baby turtles.

II. History of the project

a. Origin

The Turtle Sense project began with an idea from Eric Kaplan, founder of a company that develops Bluetooth wireless technology test equipment. Kaplan sold his company to his employees and later founded the Hatteras Island Ocean Center (www.hioceancenter.org), a nonprofit, 501(c)(3) ecology education center on Hatteras Island in North Carolina. The Hatteras Island Ocean Center is the sponsoring non-profit institution that administers the receipt and disbursement of funds for materials and other expenses.

Kaplan saw the need for using technology to help monitor sea turtle nests and approached his childhood friend Tom Zimmerman, a Research Scientist at IBM Research–Almaden (San Jose, CA). Zimmerman designed the Phase One sensor package in 2013 as a public service commitment from IBM. Tom recruited his college buddy, Samuel Wantman, a retired software designer in San Francisco, CA. They worked on developing the first phase of the design with support from IBM and from the National Park Service. Britta Muiznieks, a biologist with the NPS has been coordinating the Park's involvement.

b. Phase One history

The first phase of the project was a very quick and inexpensive hack of cell phones with a simple custom circuit board to test the viability of the concept. The devices were tried in a few nests in 2013, but unfortunately it was too late in the season to get data from viable nests. Even so, there was enough learned to make everyone involved in the project believe that there was the potential to make the technology work.

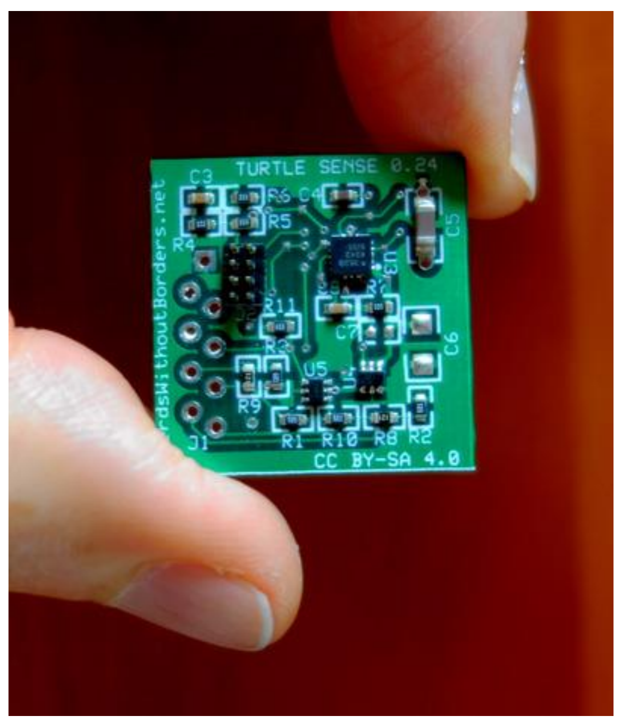
For Phase One, a motion-and-temperature sensor (Analog Devices ADXL362, 3-Axis, digital output MEMS accelerometer), soldered to a Sparkfun “breakout board,” was soldered to a CAT5 cable. The board was sealed in a Ping-Pong ball by filling it with “aquarium safe” silicone caulk. The Ping-Pong ball, about the size and shape of the sea turtle eggs, was placed in the sea turtle nest by National Park Service rangers. The other end of the cable attached to the "egg" assembly was electrically connected to a hacked cell phone that was programmed with a very small, low-powered TI MSP430 microprocessor. The phone sent out brief text messages with a summary of the motion and temperature data every two hours. The cell phone was protected from the elements by a communications tower made from 4" PVC pipe and pipe fittings. Though the first device had its problems, field tests done at Hatteras in October 2013 were positive. The signal from a single surviving hatchling was eight times larger than the background signal, giving hope for the extensive tests planned for Phase Two in 2014.

c. Phase Two history

Wantman took over management of the project in 2014, as Zimmerman had to return to other commitments at IBM. Additional volunteers were recruited, including David Hermeyer, a retired electrical engineer, and Charles Wade, a retired IBM Research manager. Phase Two of the project involved developing a more robust custom sensor embedded in a plastic sphere (the same size and shape as a turtle egg) with industry-standard technology for transmitting data over cell phone networks.

The project inspired Wantman to start NerdsWithoutBorders.net to help organize the project, recruit volunteers, and inspire other projects. All of the Turtle Sense project members (with the exception of the NPS employees) donate their time. The NerdsWithoutBorders team is designing Open Hardware and Open Source Software and encouraging the participation of scientists, engineers, programmers, writers, artists, web designers, and others to help in envisioning the design, engineering the equipment, writing code, creating a website, and interpreting the data.

Planning for Phase Two began during the implementation of Phase One. Wantman and Hermeyer began working on the engineering for a more robust design in the Fall of 2013 in San Francisco. Phase Two Units were built in the first half of 2014. Field testing by the NPS starting in June of 2014. Several problems were identified during Phase One that were addressed in Phase Two:



The circuit board in the Smart Sensor

The Phase One sensors had reliability problems communicating with the cell phones because of the long distance between the sensor and the microprocessor in the Communications Unit. This was addressed in two ways. The sensor was mounted on a very small (1 inch by 1 inch) circuit board inside the "egg" that goes in the nest. The circuit board in the “egg” also contains a microprocessor and a RS485 transceiver that allows reliable communication over very long cable lengths.

The cell phone used in Phase One, having been designed with a human interface, was often unpredictable. Occasionally, messages would pop up prompting a human reply (like a notification that the phone was charging). This made programming the device difficult because of all of the possible messages and the timing of their appearance are not predictable. At one point, the Phase One devices stopped working because the cellular service provider required all its users to upload new operating software. An appropriate user response was not possible in field-installed pre-programmed units. Because of this problem, the Phase Two design uses industry standard M2M (Machine to Machine) methods of sending data over a cellular network.

The Phase Two communications assembly contains the circuit board, power supply, a microprocessor, an M2M cell phone board and RS485 transceiver. Inset is a quarter for size reference.

Text messages and disposable cell phones were not a cost-effective way to send large amounts of data. Phase Two uses FTP protocols with devices and data plans that have much less expensive data charges.

Hacked cell phones would be difficult to mass produce, so the Phase Two design uses off-the-shelf, plug-in cell phone boards and custom circuitry that can be mass produced.

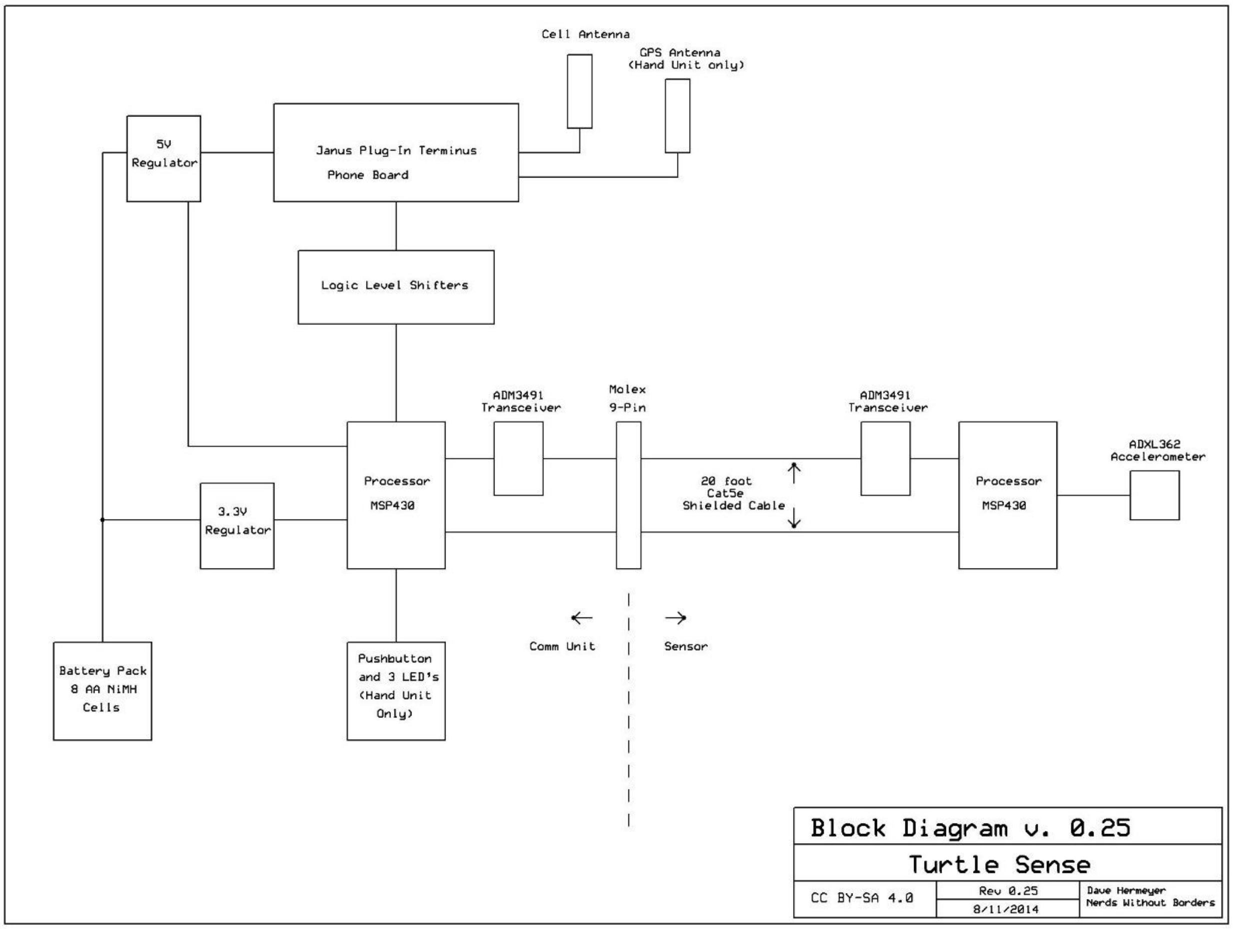
Phase One used single-use D cell alkaline batteries. Phase Two uses rechargeable NiMH AA batteries. Even though the batteries are much smaller, the units achieve a longer battery life, as the package is carefully designed for low energy needs.

Most of the turtle-specific calculations are now done in the microprocessor embedded with the sensor in the "egg." The communication system is designed so that it can be modified for other sensors.

The silicone filling the Ping-Pong balls that housed the sensors in Phase One never cured. For Phase Two, mold of a Ping-Pong ball (which is the same size and shape as a turtle egg), was used to cast solid polyurethane "eggs" around the sensor circuit boards. The polyurethane is fully set in less than a day, does not out-gas, and is extremely hard and durable.

III. Description of the technology

a. Turtle Sense hardware design



The Smart Sensor (the right half of the diagram above) uses an accelerometer to record changes in acceleration up to 400 times per second. The readings are analyzed by the microprocessor to produce a profile summary of the forces acting on the sensor. Because it is not possible to wirelessly transmit data from underneath wet salty sand, a set of summaries is uploaded to a separate Communications Unit (the left half of the diagram) that is mounted atop a PVC pipe embedded in a bucket of cement. The Comm Unit and the Smart Sensor are connect by Cat5e shielded cable. Communications over the cable is facilitated by RS485 transceivers in both the Smart Sensor and the Comm Unit. The cables are typically about 20 feet (6 meters) long, but because of the transceivers at each end, they can be much, much longer if needed. The Comm Unit is controlled by another microprocessor that controls the communication with the Smart Sensor and also controls a plug-in cellular communications board. Several interchangeable versions of this board are available that work with different telecom networks, so the devices can work all over the world. Cellular communication uses the bulk of the power needed by the system, so its power supply is powered down when communication is not needed. It is typically only powered up for a few minutes each day. The entire device is powered by a battery pack of eight rechargeable AA NiMH cells. This is enough power to run the system for many, many months.

In order to keep track of multiple nesting sites, we also created a hand-held communications device that is used to test the sensors, check for good cell phone reception, and register the date and GPS location of the nesting sites. Since this device is small and portable, it can be carried along with Smart Sensors on the daily beach patrols of park personnel. When a nest is found, it is excavated and a Smart Sensor is placed on top of the nest. The Smart Sensor is connected to the hand-held device to register the nest. The sensor is tested to make sure it is functioning correctly and communicating with the hand-held device. The Cell reception is tested and reported by the unit, and the GPS location and date are recorded on the sensor so that the sensor knows where it is and when the nest was registered. A short report is sent out that confirms that the registration was successful. Testing and registering the sensor just takes a few minutes. Then the cable is buried, with its 9-pin Molex connector sealed in a plastic pill bottle. The location of the end of the cable is marked with a stake.

After a few days or weeks, a larger Comm Unit is brought to the nest site and connected to the sensor. This Comm Unit is housed in sealed PVC pipe in a foundation of concrete. The Comm Unit enters a sleep mode if no sensor is plugged in. It powers up fully when a Smart Sensor is connected, and it starts sending reports.

Detailed reports are regularly uploaded to a server on the Internet. These text file reports are readable by humans and machines. Future upgrades include the possibility of a web-based interface for controlling the parameters of the system and viewing data. Preliminary work on such a system has already been started by NerdsWithoutBorders volunteers. If successful, an automated system will accurately predict hatching events and send alerts of pending hatching to wildlife managers, researchers, and the general public. To make that possible, analysis of the data must be correlated with human observations at several nesting sites to come up with a reliable signature of impending hatching activity. For the 2014 season, since we didn't know what we would see in the data, all analysis was done by human observation and analysis of the data.

SYSTEM SUMMARY

Phase Two Features:

- Smart Sensor custom circuit board 1" x 1" , encapsulated in epoxy, then cast inside 1.5" diameter polyurethane/epoxy ball
- Accelerometer (motion and tilt) and temperature sensor (Analog Devices ADXL362)
- Remotely-programmable data recording and transmission using a TI MSP430FR series microprocessor
- Constantly reads and analyzes motion up to 400 times per second
- 16K FRAM Memory
- Impervious to ocean beach salt water environment
- Stable to temperatures up to at least 60 deg C (140 deg F)
- Data transceiver for connection with communications board
- Communications custom board 1.5" x 3.2"
- Headers for phone board (GPS optional)
- Data transceiver for connection with the Smart Sensor
- a TI MSP430FR series microprocessor controls the phone board and the Smart Sensor
- The communications board is mounted in a weather-proof PVC tower anchored in concrete.
- A modified version of the board is used to make a portable hand-held device that registers the date and GPS location of nests as well as test sensors installed in nests without having to install the larger communications tower. Since there is no motion to monitor for the first few weeks, communication towers can be installed later, a single tower servicing multiple nests during a season

Device features:

- Reports transmitted to the web at variable frequency (hourly, daily, several times a day)
- Variable logarithmic profiles of recorded motion recorded every 15 seconds to 6 minutes
- Very low power (rechargeable NiMH AA cells)
- Batteries last longer than a turtle hatching season
- Reliable performance in ocean beach environment (withstood exposure to Hurricane Arthur!)

b. Turtle Sense software design

The microprocessor in the Smart Sensor has 16K of memory that can be used for code or data. Another identical microprocessor is in the Comm Unit. For Phase Two, we are using about half the space in each microprocessor for programming and the other half to collect data. The software is written in C and compiled using Texas Instruments' Code Composer Studio.

The microprocessor in the Smart Sensor controls the sensor chip, reads data from the sensor, processes it, and stores it. It does this continuously. After a while (a variable number of hours), the Smart Sensor programming decides that it is done collecting data and alerts the microprocessor in the Comm Unit that it is ready to send data. The Comm Unit wakes up, turns on the transceiver chips that send the data over the Cat5e cable, and receives the data from the Smart Sensor. Once the data is sent (it takes a second or two), the transceivers are turned off, and the Smart Sensor goes back to collecting data. With all the old data now in the Comm Unit, the microprocessor in the Comm Unit turns on the power supply for the cell phone board, connects to the Internet, and uploads a file to a Turtle Sense server. The Comm Unit also checks to see if its operating parameters have been altered. It does this by looking for a parameter file in the Turtle Sense directory with a serial number that matches the serial number of the Smart Sensor. If it finds such a file, it reads it in and sends the new parameters to the Smart Sensor. The entire cell phone connection takes about 2 minutes.

The accelerometer chip is able to output data as often as 400 times per second and as little as 12.5 times per second. The accelerometer chip has data rate settings for 12.5, 25, 50, 100, 200, and 400 readings per second. Faster rates makes the sensors more sensitive to high frequencies, and slower rates filter out high frequency disturbances. For Phase Two, we set the accelerometer to make 100 readings per second. The setting for the sampling speed can be changed remotely over the Internet when the sensors are in the field, as can other parameters of the system, by creating a new parameter file in the Turtle Sense directory.

Each reading of the accelerometer is a vector. It is measuring the magnitude and direction of the force acting on the sensor at the time of the reading. The readings are reported as X, Y and Z Cartesian coordinates, and each coordinate can vary from positive 2 g to negative 2 g in magnitude. Each coordinate is reported as a 12 bit signed number, so the lowest bit corresponds roughly to a force of 0.001 g. If the Smart Sensor is static (not moving) the magnitude of the X, Y and Z readings of the accelerometer roughly correspond to 1 g of force, and should have a magnitude of about 1024. These readings can also be used to record the static position of the sensor. This can be useful to see if the orientation of the sensor changes, which may be an indication that a nest has collapsed.

The Smart Sensor constantly analyzes the readings from the accelerometer to create a profile of the energy from the motion in the nest over time. The microprocessor compares successive readings from the accelerometer to calculate the change in acceleration (or "jolt"). The jolt is calculated by computing the magnitude of the difference of the two acceleration vectors. The formula for the calculation is:

$$Jolt_n = \sqrt{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2 + (z_n - z_{n-1})^2}$$

The microprocessor in the Smart Sensor can easily and quickly add and subtract and has a built-in math coprocessor. So except for the square root function, the $Jolt$ can be easily and quickly calculated.

Calculating a square root is quite complicated, but to get around that problem, a calculation for the square of the $Jolt$ is done instead:

$$(Jolt_n)^2 = (x_n - x_{n-1})^2 + (y_n - y_{n-1})^2 + (z_n - z_{n-1})^2$$

So rather than store information about the magnitude of the jolts recorded, we store the information about the square of the $Jolt$. It will become clear that this does not change the veracity of the results.

Each reading of the accelerometer has three coordinates, X, Y and Z, and each is a 12 bit number (11 bits and a sign). The difference between two readings in each coordinate is a maximum of 13 bits. The maximum for the square of 13 bits is 26 bits (unsigned), and the sum of three 26 bit numbers is at most a 28 bit number (unsigned). Therefore, the magnitude of the $Jolt^2$ is, at most, a 28 bit number. The magnitude of each $Jolt^2$ is placed on a logarithmic scale divided into 29 different ranges. Since there are 28 bits, and a result of zero is also possible, there are in theory 29 different ranges. (Actual readings have not yet been observed getting as high as the top few ranges.) The program has counters for each of the 29 different ranges. Each counter can be thought of as a bin. If a magnitude is in range, it is thrown into the bin for that range. This is simply done by scanning the $Jolt^2$ to determine the highest bit that is non-zero. One of the 29 counters is incremented corresponding to the highest bit set in the scan.

If we wanted to, we could combine the bins in pairs, and we would end up with 15 bins, which would correspond to the 14 bits of $Jolt$ instead of the 28 bits of $Jolt^2$. But by leaving the 29 bins, there is twice the resolution in the result. Rather than take the square root of the number, the range of each bin can be adjusted by taking the square root of the range boundaries. The lowest range is still zero, the next is readings up to the square root of 2 divided by 2, the next up to 1, the next from 1 to the square root of 2, the next up to 2, and so on. With 15 bins, the ratio between the bins would be 2:1. However, by leaving the result in 29 bins, the ratio between the lower and higher limit of each range is the square root of 2.

$$15\,bins \;=\; (0, 1, 2, 4, 8, \ldots\;\; 8192)$$

$$29\,bins \;=\; (0, \frac{\sqrt{2}}{2}\,, 1, \sqrt{2}, 2, 2\sqrt{2}, \ldots\;\; 8192)$$

After a short period of time, typically 1 minute or 6 minutes, the bin counts are stored in a record along with a temperature and orientation reading, and a new set of bin counters is started. Each record provides a profile of what happened during that period of time. The length of the time is programmable, and by changing parameters, it can be changed while units are in the field. There is also an option to automatically make the period shorter after a set number of days after the nest is laid. For 2014, the records covered a period of 6 minutes for the first 40 days and then were shortened to just a minute after 40 days. The microprocessors can only store 240 records at any time, so when they are filled up, a cell phone call is initiated to upload a text file report to the Internet containing all the data. For the first 40 days, reports are only sent once a day (240 records times 6 minutes equals one day). After 40 days, the reports are sent every 4 hours (240 records times 1 minute).

By looking at how many readings were in each bin, we can get an idea of what jolts occurred while the bins for that record are being filled. This allows us to compress several thousand readings into approximately 32 bytes of information. One hundred samples per second is 600 bytes of information per second. Multiplying by 60 seconds per minute, times 60 minutes per hour, and 24 hours per day comes to 51.8 million bytes of data per day. The reports uploaded to the Turtle Sense server are only 20,834 bytes. This is a compression ratio of almost 2,500 to one.   We lose precision (including the exact sequence) with all the readings, but those details are not important. The 240 to 1440 records created each day give us a very good idea of what is happening in the nest.

The units are programmed so that if the Comm Units are swapped for any reason, the sensors still know where they are and when they were installed. This means that if, for any reason, a Comm Unit needs to be replaced with another unit, the new Comm Unit will continue to send reports that will be named and labeled as coming from the same nest.

A hand-held Comm Unit was made to test and register the sensors when they are first installed in an excavated nest. The hand-held unit has the same circuit boards and components as the other Comm Units with the addition of three LEDs (red, yellow, and green) that indicate the status of the testing and registration process. All the Comm Units have GPS modules in them, but they are only currently used in the hand-held units, so a GPS antenna is included. There is also a power switch and a button that activates the registration process.

After turning on the device, the testing process is initiated by plugging in a sensor. Commands are sent to the sensor to create a record and send back a very short report to the Comm Unit. Meanwhile, the Comm Unit is making contact with the cell network and the GPS satellites. The coordinates from the GPS are used to record the sensor's location, and the time and date is acquired from the cell network. The strength of the cell reception is indicated by the number of blinks by the yellow LED.   If there is a problem with the sensor, the red LED blinks. If everything passes the testing, the red LED turns off, and the green LED becomes solid. At this point it is safe to press the registration button, which is also green.

Once pressed, the hand-held units send a registration report to the Turtle Sense server with the location, date, time, and serial numbers of the sensor and Comm device. The date, time, and location are also sent to the Smart Sensor so it will know the location and age of the nest when a communications tower is brought in and installed several days or weeks later.

c. Data collection methodology

The data collected by the Smart Sensor is transmitted to the Comm Unit and then sent over the cell phone network to the Turtle Sense server on the Internet. The Comm Unit writes a text file with data that can be read by humans or computers. While the eventual plan is to have the data processed and analyzed by an automated process, for 2014, the data was analyzed by humans using computer software.

Research indicates that before emerging from the nest in a "boil," turtle hatchlings congregate underground near the top of the nest. It is thought that this motion stimulates the hatching of the turtles that haven't yet emerged. Our sensors, situated at the top of the nest, can record very small and very large disturbances when the first turtles emerge. But there was little indication in advance how large the disturbances might be and where on the logarithmic scale they would register. Rather than report the counts from all 29 bins, the report only list the counts for the highest 10 bins at, or just below, the highest non-zero bin. If the highest non-zero bin count is from a bin between bin1 and bin10 (the lowest bin counters), then all ten of the lowest 10 bin counts are sent, even if one or more of the top bins are zero. The reports also send a total count of the number of readings and a number that reports which bin was the highest with a non-zero result. Each record also has one temperature measurement and one static x, y and z reading of the Smart Sensor's position.

Here is a sample of a report:

```
Report: 2014-08-21_AA0026_r-041-02.txt
Sensor ID#: AA0026
Installed: 2014-08-21
Comm ID#: C-AA0014
Days active & report #: 041-02
Nest location: 3516.5384N,07531.0389W
Start date/time: 2014/09/30,11:43:30
Report date/time: 2014/09/30,15:44:57
Secs per rec: 003C
# of recs: 00F0
Battery level: 02B0

Rec#,Temp,   X,   Y,   Z, Cnt, Max,Bins: (Low) to (High)
0000,026E,FD5C,039F,0108,1650,0009,0114,01E9,013F,05CE,07D7,036E,00DC,001D,0008,0000
0001,026E,FD5A,03A1,0107,1648,0009,0117,021A,01AB,05D5,078E,033F,00B3,0016,0001,0000
0002,0268,FD58,03A3,0106,164D,0009,011B,0224,0197,05DF,0769,0351,00C0,0019,0005,0000
0003,026A,FD5B,039F,0110,164B,0009,0127,024A,0190,05EA,0751,034C,009C,0023,0004,0000
0004,026A,FD58,039F,010F,164A,0009,012F,023D,01A4,05F5,0722,0369,00A1,0014,0005,0000
0005,0268,FD58,039F,010E,1648,0009,014D,023A,01BC,05F7,0737,0337,0086,0016,0004,0000
.
.
.
00EC,0266,FD5A,039F,010C,1647,0009,0119,0238,018E,05C6,078F,0343,00B9,0015,0002,0000
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00EF,0264,FD58,039F,010C,1645,0009,011A,026D,01AA,05DA,07A5,02F5,0083,001A,0003,0000

TurtleSense 0.2503 -- CC 4.0 BY-SA NerdsWithoutBorders.Net
--end of report--
```

The report starts out with a heading. The first line of the heading is the file name of the report. The file name starts with the date that the nest was registered, followed by the serial number of the sensor installed in the nest, followed by the number of days the nest has been active, followed by the number of the report on this particular day. This information is extracted from the file name on three of the four following lines of the heading. There is also the serial number of the Comm Unit that sent the report. The next line is the GPS location of the nest, followed by the time and date for the first record in the report and then the time and date that the report was uploaded to the Internet.

All the information in the report after this is in Hexadecimal format. While this is difficult for humans to understand, it is easier for microprocessors to send and process, and it makes the length of data shorter. A four byte hexadecimal number corresponds to a five byte decimal number, so there is a 20% savings in the amount of data that needs to be sent.

Secs per rec is the number of seconds of data that is profiled in each record. In this report, 3C is hexadecimal for 60, so each record is 1 minute of motion data.

# of recs is the number of records that are sent in the report. Typically, there are 240 records in a report which is F0 in hexadecimal. Each line in the section that follows is one record. Only the first six and the last four records are shown in the example above.

```
Rec#,Temp,   X,   Y,   Z, Cnt, Max,Bins: (Low) to (High)
0000,026E,FD5C,039F,0108,1650,0009,0114,01E9,013F,05CE,07D7,036E,00DC,001D,0008,0000
```

The first record is shown above. It is numbered zero (numbering goes from zero to 239 in hexadecimal.) Then there is a temperature reading. The temperature readings, while also in hexadecimal, have been programmed to make them easy to convert to an approximate decimal number. The readings are in Celsius but multiplied by 25.6. That means that a reading of 10 degrees C will be 256, which in hexadecimal is 0100. A human looking at this number can think of it as 10.0 degrees. Twenty degrees C will be 0200, 30 degrees is 0300. While this makes reading numbers very easy for numbers that are multiples of 10 degrees, it is more difficult to convert the readings that are not multiples of 10. Fifteen degrees C is reported as 0180.

Next, there is a single static *X, Y,* and *Z* reading of the accelerometer. These numbers can show the relative position of the sensor as well as when its orientation changes. It normally changes very little (if at all), which the example above shows. If it does change dramatically, that may be an indication that the nest has been disturbed or that a depression has formed in the nest. By finding an average of all the static readings, a value of 1g can be calculated to calibrate the readings from the sensor. Without this calibration, the readings from the sensor might be off by as much as 20 percent. However this calibration has not yet been found to be necessary or helpful when predicting nest hatching.

Cnt is the total number of readings made during the record. It is followed by *Max*, the number of the highest bin with a non-zero reading. After *Max* is the highest ten bins that have readings, starting with the lowest on the left. In this case, *Max* is nine, so the bottom ten bins are shown. The number on the far right is zero, which was the count in bin10. Bin9, the one next to it, was the maximum bin with a count, which in this example is eight. In this case, if you add up all the numbers in the ten bins reported, it will equal the number in *Cnt*. If *Max* is greater than ten, this will not likely be true. But, you can determine how many readings are missing if you subtract the total of the ten reported bins from *Cnt*. If *Max* is 11, the missing readings are exactly the number of readings in bin1. Figuring out how many readings are missing can also be used to estimate the total energy for each record. Since there is a logarithmic scale, the missing readings will be much lower in magnitude than the readings that are reported. For example, if *Max* is 16, then the missing readings will be in bin6 and below. Bin 16 is 32 times the magnitude of bin6. For energy calculations, bin16 is 1024 times the magnitude of bin6, so even if half of the low readings are missing, it will only have a very tiny effect on the energy calculations.

As mentioned previously, there are several parameters that can be changed while the units are functioning. If new operating parameters are desired, they are uploaded to the Turtle Sense server as a very small binary file. Every time a report is sent, the Comm Unit looks for a parameter file with its name on it (its serial number). If the file is found, the parameters are downloaded from the server and will take effect after the next report. Most of these parameters will rarely, if ever, change, but thought was put into making the system as flexible as possible so that the behavior of the Smart Sensor could be tailored to different environments and field applications. The ADXL accelerometer has parameters that affect the behavior of the sensor, and all of these are included in the parameter file. In addition, there are parameters related to the timing and frequency of how the microprocessor reads the accelerometer, the quantity and timing of when the data records are uploaded to the server, and calibration data for the temperature sensor. In addition, there is extra room for parameters that might need to be added in the future.

IV. Goals for the 2014 season

It was decided to monitor about 20 nests at the Cape Hatteras National Seashore over the course of the 2014 season. This number seemed large enough to allow for a variety of nesting situations over the course of the season while being small enough to manage.

The testing during the season had several simultaneous goals:

- Testing the reliability of the hardware and software in a harsh ocean environment;
- Adapting the hardware and software to the actual conditions and needs of the NPS;
- Helping the NPS staff use and understand the equipment;
- Collecting data from nests at different times during the season and under different environmental conditions;
- Seeing if hatchling emergence could be predicted in advance, and generating methods to analyze the data to do so;
- Acquiring a better understanding about what happens in the nest before the hatchlings emerge; and,
- Generating ideas about improvements to the equipment and procedures that could be implemented in the future.

Comm Unit

All of these goals were part of the overall goal, which was to test the viability of the project and to decide if there was merit to the approach of using equipment like this to predict hatching events.

Smart Sensor (right) next to turtle egg

V. 2014 Implementation

Starting in mid-June, Smart Sensors were installed in nests as soon as a clutch was found. But only a few of the sensors were connected to communications devices early on. For the first month after a clutch of eggs is laid, there is little or no activity in the nest. The fetuses are just beginning to develop, and there was no reason to believe that we would record any significant motion. But there were good reasons to report data early on from a few nests. Since this was the first field testing of the devices, data needed to be collected about the background noise levels that might have an effect on the data. Would vehicles driving by register? What effect would the surf have? Early deployment also gave the team a chance to work out any software or hardware bugs while giving the NPS staff a chance to work with the devices and understand them better. Britta Muiznieks and Samuel Wantman were able to collaborate on creating a workable protocol for how the devices should be installed during the first deployments.

The first communicators were installed around the end of June, just in time to be tested by some very extreme conditions during Hurricane Arthur. Hurricane conditions were a welcome test of the physical attributes of the system. Would the cement anchors on the PVC pipes that house the communicators be secure enough? Would water find a way into the hermetically-sealed enclosures? Would the nests get washed away? The parameters on the units were temporarily altered so that reports were generated more frequently during the storm--every two hours instead of once a day. If the units were to fail, there would be data right up until at least two hours before they failed. As the storm developed, forecasts predicted that the storm would track directly over where our first reporting devices were installed. The units made it through the Category 2 hurricane without any problems.

Nest	Clutch date	Sensor	Sensor Depth (cm.)	Comm Unit	First Emergence Date	Emergence Day Number	Notes
NH005-reloc	Jun 15	AA0005	15	C-AA0006	Aug 10	57	
NH006	Jun 15	AA0006	37.5	C-AA0007	Aug 10	57	
NH007-reloc	Jun 17	AA0003	23	C-AA0002	Aug 17	62	
NH022-reloc	Jun 27	AA0007	24	C-AA0003	Aug 28	63	
NH034	Jul 08	AA0004	10				Sensor failed
NH036	Jul 13	AA0009	24	C-AA0002	Sep 14	64	
NH037	Jul 13	AA0008	26	C-AA0014	Sep 25	75	
NH039	Jul 16	AA0010	29	C-AA0006	Sep 15	62	
NH043-reloc	Jul 20	AA0011	39	C-AA0015	Sep 19	62	
NH045	Jul 23	AA0012	20	C-AA0007	Sep 21	61	
NH047	Jul 25	AA0013	38	C-AA0016	Sep 29	67	
NH048-reloc	Jul 28	AA0014	15	C-AA0003	Oct 02	67	
NH052	Jul 29	AA0016	34				Nest washed out
NH054	Jul 31	AA0024	44	C-AA0012			Unsuccessful nest
NH056	Aug 06	AA0017	37	C-AA0015	Oct 16	72	
NH058	Aug 10	AA0025	18.5	C-AA0007	Oct 06	58	
NH059-reloc	Aug 12	AA0028	26	C-AA0002	Oct 19	69	
NH061	Aug 21	AA0026	26	C-AA0014			Infertile nest
NH062-reloc	Aug 27	AA0024	45	C-AA0012			Non-viable, late season

After withstanding the onslaught of Hurricane Arthur, more Comm Units were shipped (using the United States Postal Service) from San Francisco to Cape Hatteras for installation in the field. The units are housed in schedule 40 PVC pipe, which is extremely strong and durable, so there was no expectation of any problem using this shipping method. This turned out to be an incorrect assumption. Because of the abuse that the units received in transit, none of them was functioning when they arrived in North Carolina.

Most everything in the device is soldered together, but there are a few connections that are not. The cell phone board is plugged into headers. There are several boards available from the manufacturer that work with different telecoms. The boards could be soldered in, but sockets make it possible to swap in a different board for different cell carriers if need be. With 49 pins holding it in, it takes quite a bit of effort and wiggling to remove it, which seemed very secure. Similarly, the eight AA batteries are secured in a battery pack, and the pack can be unplugged with a standard 9 volt battery clip. These clips take quite a bit of force to put on and take off, but the trip cross country in the mail was enough pull it loose.

The repair for these problems was very simple. To secure the board and the battery clip, a cable tie was tightened around them. Now, there is no way to get them loose without cutting the ties off.

There were about twice as many Smart Sensors ordered and delivered than Comm Units. The Comm Units were more expensive, and there was no reason to believe that nests needed to be monitored for the first 40 days. The first couple of nests were monitored during the early stages to confirm this assumption and to get data for the early stages of development to see if there was anything of interest. Once the nests from the beginning of the season hatched, the Comm Units were moved to nests from later in the season. The Smart Sensors, on the other hand, had to be installed when the nest was first discovered and opened up. This was the only time that a sensor could be placed on a nest. Comm Units were typically in a nest for about 30 days, but Smart Sensors were often in a nest for more than 60 days.

The first boil occurred on August 10th. The changes in the data were so pronounced that it quickly became apparent that something was happening. The day before the boil, Wantman sent Muiznieks an email:

> *It looks like this nest might be getting a little more active -- my guess is about 20-40% above the background noise level. Perhaps it is motion of the embryos in their shells...*
>
> *I'll try and put together a graph to see what is happening...*

Data from a Phase One nest from the previous year showed motion that was several times the background level. Because this motion was assumed to have been caused by a single hatchling, there was also the assumption that the motion of dozens of hatchlings would be even more dramatic. While the activity that was recorded was enough to be noticed, at the time it was not clear that it was, in fact, the motion of hatchlings about to emerge from the nest.

Early in 2014 when the first test unit was made, it was tested by having it operate for weeks sitting on a counter in San Francisco. It never skipped a beat, missed a report, or had a problem of any kind. The units in the field were initially not as reliable. Some of them worked flawlessly for months, and some of them never powered up. Testing electronics in the wet, salty sea environment tests your design in extreme ways. The devices were built and programmed more than 2500 miles from where they were deployed. They needed to run, unattended, for more than two months, enduring moisture, salt, wind, blowing sand, critters, and who knows what else. When they stop working, there is no simple way to determine exactly what went wrong, and that was a challenge. With two custom devices interconnected and running a third device talking to a server, there are many places where things can go wrong.

It is one thing to get the basic functions of a device up and running. It requires innovation and creative design. But getting everything to work flawlessly in the field requires diligence, attention to detail, and a good deal of trouble shooting. For this project to be successful, units must be extremely reliable.

Over the course of the 2014 season, quite a bit was learned about the ways things can go wrong. Boards can come loose, and connections can break. Moisture and salt can get into places they are not supposed to get into. Cell phone reception can be interrupted by lightning, and that can cause embedded code to hang. Many of the software processes that could fail were anticipated, and the code was programmed to handle the problems as they happened. For everything else, there is a watchdog timer that resets the device when the software stops working for more than about four minutes. But it is difficult to test how things will behave when they fail, if they can't be observed while they are failing. Thunderstorms in San Francisco are quite rare, and in the middle of the city, the cell phone reception is excellent.

Almost all of the problems that were encountered in the first month or two have been resolved. One sensor that totally failed in a nest due to a bad connection was replaced. Many problems were related to how the cable coming from the Smart Sensor is connected to the Comm tower. After the first couple of units were installed, the connection was redesigned to make it stronger and more durable. Later, in the middle of the summer, we discovered that additional Parafilm sealing tape needed to be used by NPS staff during installation to keep moisture out of the connections. After these changes, the units operated virtually trouble free.

Wantman and Hermeyer were able to travel to North Carolina in late September to meet the NPS personnel and see the nest sites. They had the opportunity to see baby sea turtles making their way to the ocean and to talk with wildlife managers and biologists. They went out for several nights to visit a nest where a boil had been predicted using the data from our sensor. The turtles emerged two days later than expected, but that was not surprising considering that the temperature had been cooling down in the prior two weeks, and the previous nests had hatched during warmer periods.

Hatching activity was noticed in the data before hatchings emerged in virtually all of the remaining viable nests that were monitored, with one or two exceptions. Typically the activity was noted three or four days before hatchings emerged.

VI. 2014 Nest data and results

Data from the Turtle Sense devices were compared with observations and data taken from NPS staff, which they recorded on paper field reports titled *Sea Turtle Nest Forms*.

There is an overwhelming quantity of data reported from the Turtle Sense devices. The first monitored nest that hatched had a collection of about 90 uploaded reports with a total of 20,706 records containing about 320,000 pieces of data, which had been condensed from approximately 120 million readings over the period of 15 days. Since it was not immediately obvious what the data would show and when, an easy way to visually scan the data needed to be developed. Methods were considered that combine all the data into a single graph with the goal of showing the activity in the nest, with the assumption that the activity graph would clearly show hatching activity before the emergence of hatchings above ground.

Motion data

Most of the work focused on graphing an integrated number calculated from combining all the accelerometer readings in each record. The integrated number roughly corresponds to the total kinetic energy during the period of each record.

The maximum reading from each record is sent as part of the report, but the calculation of total kinetic energy in the motion recorded in each record is not done in the sensor and needs to be calculated afterwards. The total kinetic energy is computed by simplifying the energy formula:

$$energy = ½\, mass * velocity^2$$

The change in energy from one instant to the next is proportional to the change in velocity squared.

$$energy_0 = ½\, mass * {velocity_0}^2$$

$$energy_1 = ½\, mass * {velocity_1}^2$$

$$\Delta energy = ½\, mass * ({velocity_1}^2 - {velocity_0}^2)$$

Since the ball is essentially staying still, we can think of every impulse as having started at rest, and then finishing with a velocity. On average, the sensor is not in motion. Setting $velocity_0 = 0$ yeilds:

$$\Delta energy = ½\, mass * {velocity_1}^2$$

$velocity_1$ equals the change in acceleration times the change in time:

$$velocity = \Delta acceleration * \Delta time$$

Substituting yields:

$$\Delta energy = ½\, mass * \Delta acceleration^2 * \Delta time^2$$

If the mass is constant and the change in time is held constant, the change in energy is proportional to the square of the change in acceleration:

$$\Delta energy \propto \Delta acceleration^2$$

By integrating the change in acceleration squared for a set, constant period of time, the result will be proportional to the total energy during that period:

$$\int_0^t \Delta energy \propto \int_0^t \Delta acceleration^2$$

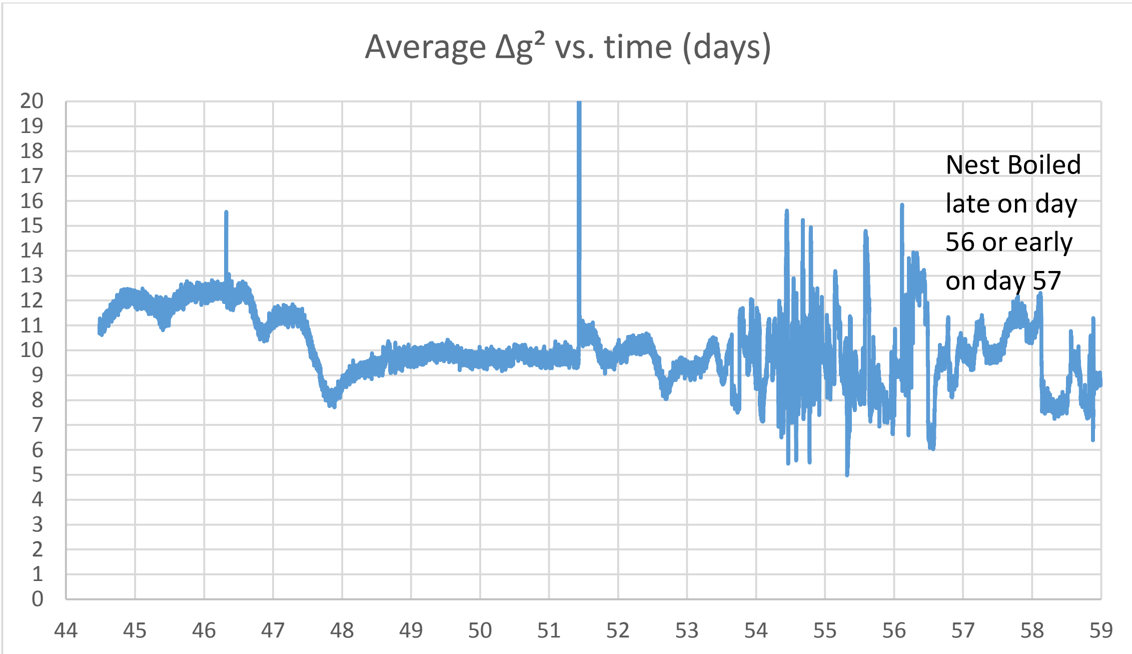
$$total\ energy_t \propto \int_0^t \Delta acceleration^2$$

So to calculate a number roughly proportional to the average energy during each record, simply add up all the $Jolt^2$readings and divide by the number of readings. To do that, we simply multiply each bin count by the $Jolt^2$value of that bin, and add the products from all the bins. Then the total is divided by the total number of readings (*n*) to get the ***average Δg²*** -- the numbers reported are in thousandths of a G, so squaring that number means that a reading of a million corresponds to an average g force of 1.

$$average\ energy = \frac{total\ energy}{n} \propto \frac{\int_0^t \Delta acceleration^2}{n}$$

$$average\ energy \mathrel{\underset{\sim}{\propto}} \frac{\sum_{i=1}^{n} \Delta acceleration_i{}^2}{n}$$

Graphing the single number $average\ energy$ result from each record over time gives a very good picture of the activity in the nest. Several attempts at graphing the initial data were tried, but so far, the approximation of average energy described above yielded the most usable results.



Nest NH005

A graph like this was created right after the boil was reported on day 57. Some features were immediately noticed:

- Most of the time the data does not vary much;
- There are occasional large spikes;
- The data becomes erratic for several days before the boil;
- There are occasionally periodic variations that happen daily; and,
- The long term trend does not seem to follow any pattern.

Also noted is what was not seen:

- There is no obvious indication of when the boil occurred;
- During the erratic period before the boil, the level is both higher and lower than what was recorded previously;
- During the day before the boil, the level was low and stayed low for a few hours; and,
- During the days just before the boil, all the readings remain in the low bins.

Except for two spikes, the data does not vary much in the short term before day 53. The variation that is recorded is at the magnitude of the lowest reading of the accelerometer–one bit–which is also the noise level of the accelerometer. Since we are not averaging the exact readings but using the bin counts to get an average, there is some quantization noise.

We found that all the data has small spikes during the first few minutes of data collection. We suspect that this may be the result of some sort of electrical interaction between the accelerometer and the phone board. The small spikes happen precisely at the times when the phone board is making a connection with the cell network. Because of this, we ignore all the data that was recorded when the phone board is on. The removed data is just 3 minutes in the course of 4 hours, so it has virtually no effect on the results. These spikes are not shown in the graphs in this report.

The spikes that remain are also quite short events, usually just a minute or two. The first spike is only a magnitude of about 15 and corresponds to a period that had a hardware problem of unknown cause. Since it is very similar in duration and magnitude to the filtered spikes, and because there was a hardware problem at the same time as this first spike, it could be a spike that just didn't get filtered out with by our normal filtering process.

The other large spike is more interesting. It goes off the graph, and reaches a magnitude of over 200. Many potential causes of this spike were considered, with the most popular likely cause being intrusion in the nest by a ghost crab. Many more of these spikes were recorded in the nests that followed.

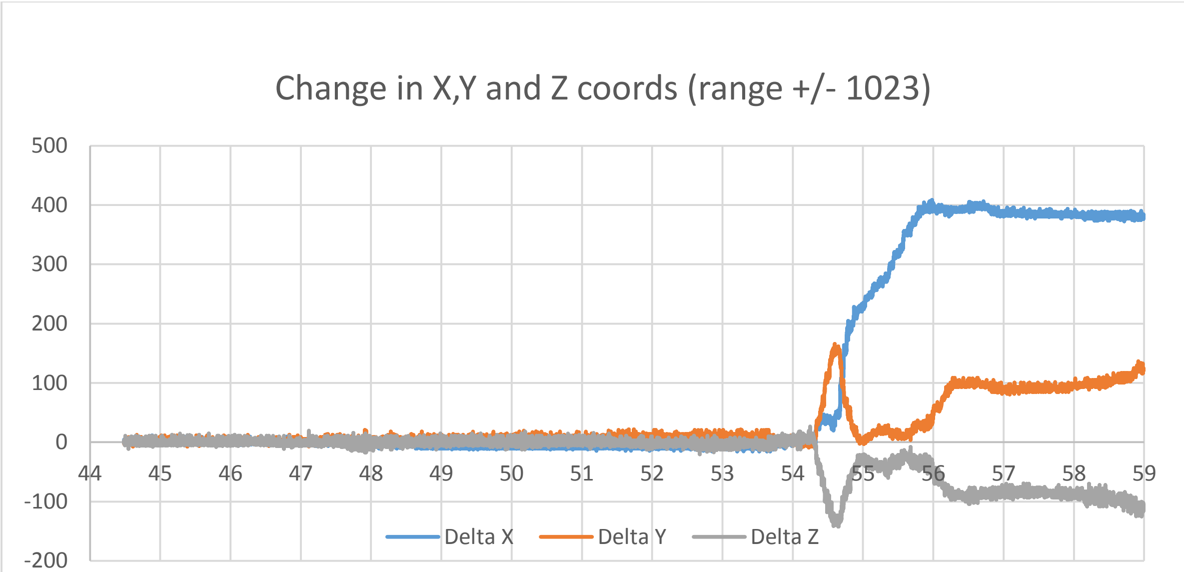
Three distinct periods of activity can be seen in the graphed data:

1. (days 44-53) A quiet period with very little activity and subtle changes, often with daily patterns
2. (day 53 to mid-day on day 56) A noisier period that lasts about three to five days with erratic data--the average values extending both higher and lower than normal
3. (mid-day on day 56) A brief quiet period immediately follows and does not last long. The average value of this brief period is usually lower than the levels in the first period.

Team members began calling this three period pattern, the "popcorn pattern" because it is reminiscent of what happens during the making of popcorn. When the kernels heat up, they start to jiggle a little, and then they all start to pop at once. When you hear the popping quiet down, you know it is time to pour everything out of the pot.

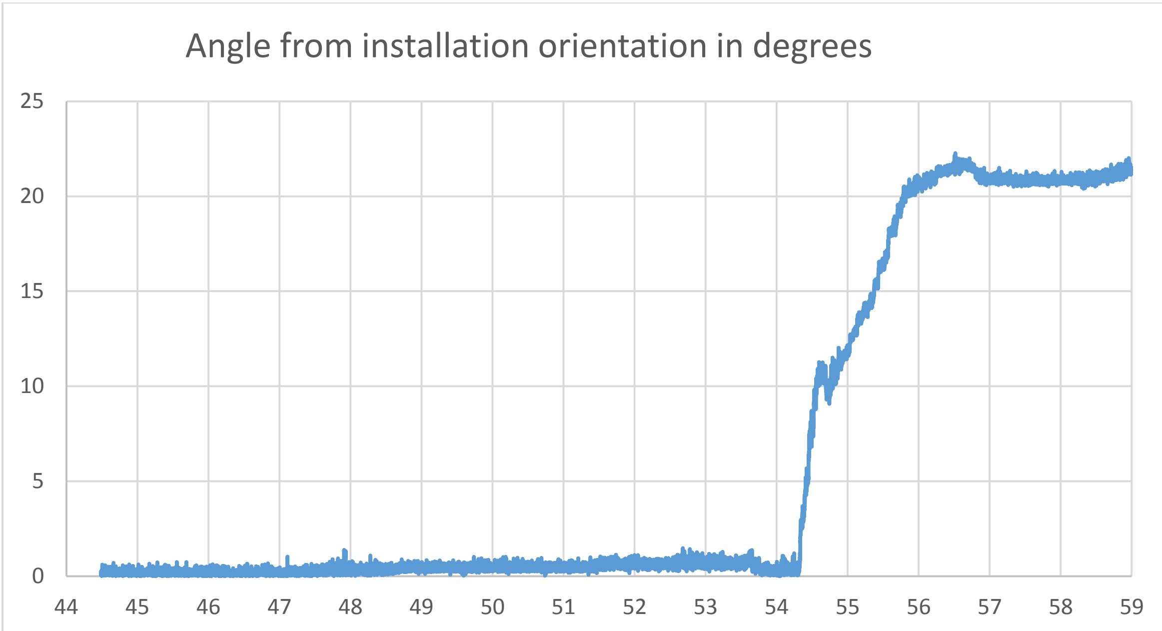
Using the "popcorn pattern," we were able to predict boils. Popping shows up in our data a few (usually three to five) days before the turtles pour (boil) out of the nest.

Every data record also contains a snapshot of the absolute orientation of the Smart Sensor. By looking at the orientation of the sensor, it appears to have rotated for a period of about two days starting on day 54 (August 7th), which appears to be the period when there were the largest jolts. Because this phenomenon was usually observed after the erratic "popping" was first reported, the phenomenon was not focused on as a predictor of hatchlings emerging. The phenomenon was also not seen as frequently as the "popping." There were nests that had little, if any, change in orientation of the sensor. When it was noticed, it was a valuable secondary indicator that hatchlings would soon be emerging.



This graph shows the change in the readings in each of the three coordinates, x, y, and z for nest NH005. Since the readings span a range from -1023 to +1023, the change of 400 in the x coordinate is significant. The other two coordinates moved much less and mirrored each other above and below zero. The combination of these three graphs indicate that the rotation of the Smart Sensor was mostly on a single axis. Because nests are known to form depressions before boils, it is safe to assume that the sensor moved down with the nest formed a depression. The orientation likely changed because the cable needed to flex when it moved.

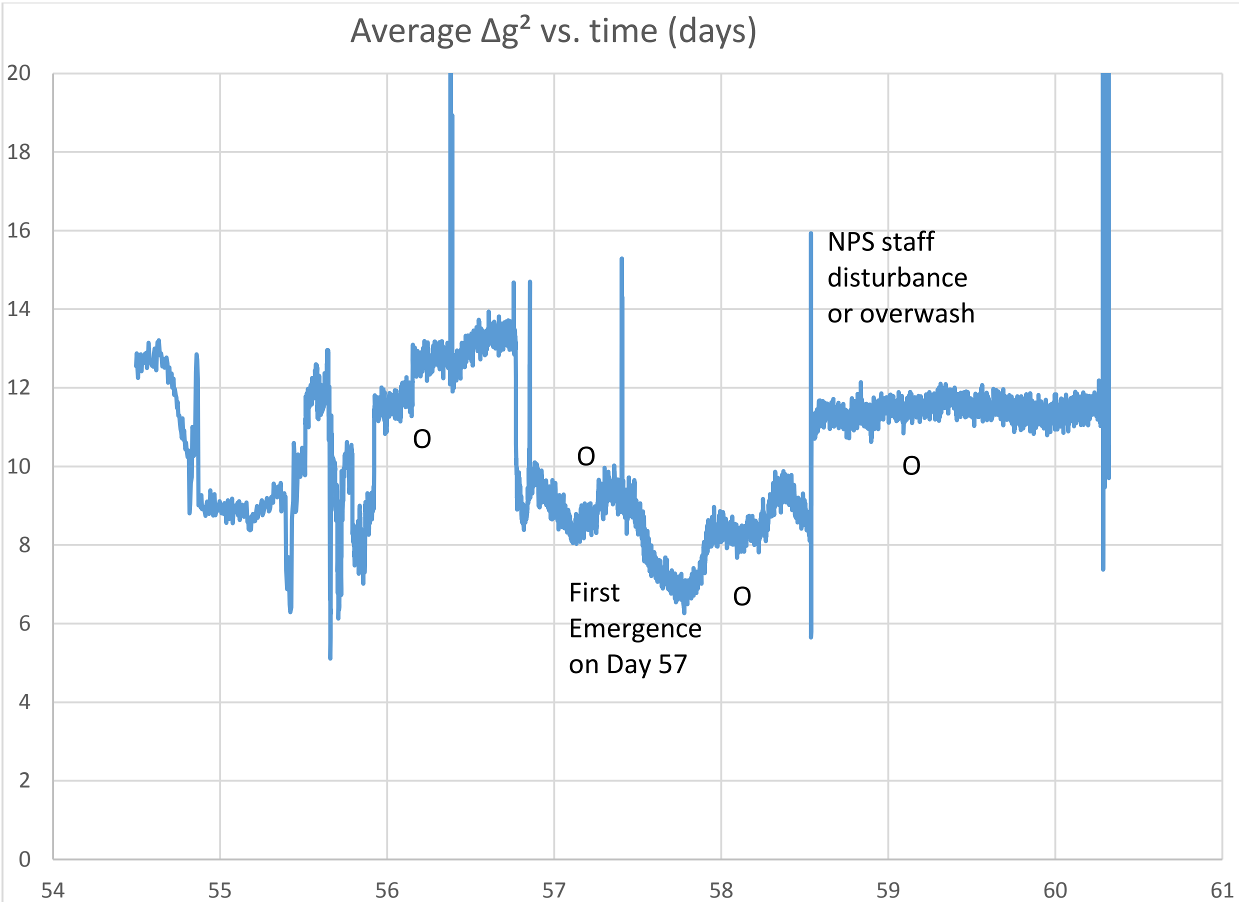
There is no current method to indicate the actual direction in which the sensor rotated. It is only possible to compare the motion to the sensor's orientation shortly after it was installed. The initial readings of the sensor are measuring the force of gravity, so the coordinates of those readings are a vector pointing down toward the center of the earth. The deflection measured later is how much the new vector has rotated away from that initial down vector. All of the sensors were mounted with their cables coming out of the Smart Sensor in a horizontal direction, but inside the Smart Sensor, the orientation of the sensor chip varies quite a bit. No attempts were made to calibrate the orientation during the manufacturing of the Smart Sensor, and it would be difficult to position the sensor accurately during installation in a nest, even if the orientation of the sensor within the egg was accurately known. The rotation of the Smart Sensor that is recorded is because the coil of cable installed around it is being extended into a spiral as the sensor moves down. The cable, which was originally coiled in a horizontal plane, tilts down as the Smart Sensor moves down. Since the coil in the cable may be different in each nest, the magnitude of the rotation cannot be interpreted in any meaningful way. So, considering that there is no reason to believe that the sensors will move in any direction other than down, calibrating the sensors seems pointless. The graph that follows combines the x, y, and z coordinates to arrive at a single value of the angle the sensor changed compared to the average orientation of the sensor at the beginning of the graphing period:



Even though the sensor shows a rotation of over 20 degrees, no depression was noticed by the National Park Service staff before nest NH005 boiled, so aside from the Turtle Sense prediction, there was no other indication that a boil was imminent.

Nest NH005 boiled the evening of day 56 to 57. The NPS records the date of evening hatches as happening the following day. Approximately 55 hatchling tracks were counted on the morning of August 10th (day 57). An infrared camera was placed on this nest after the first boil was detected, but no additional emerging hatchlings were observed.

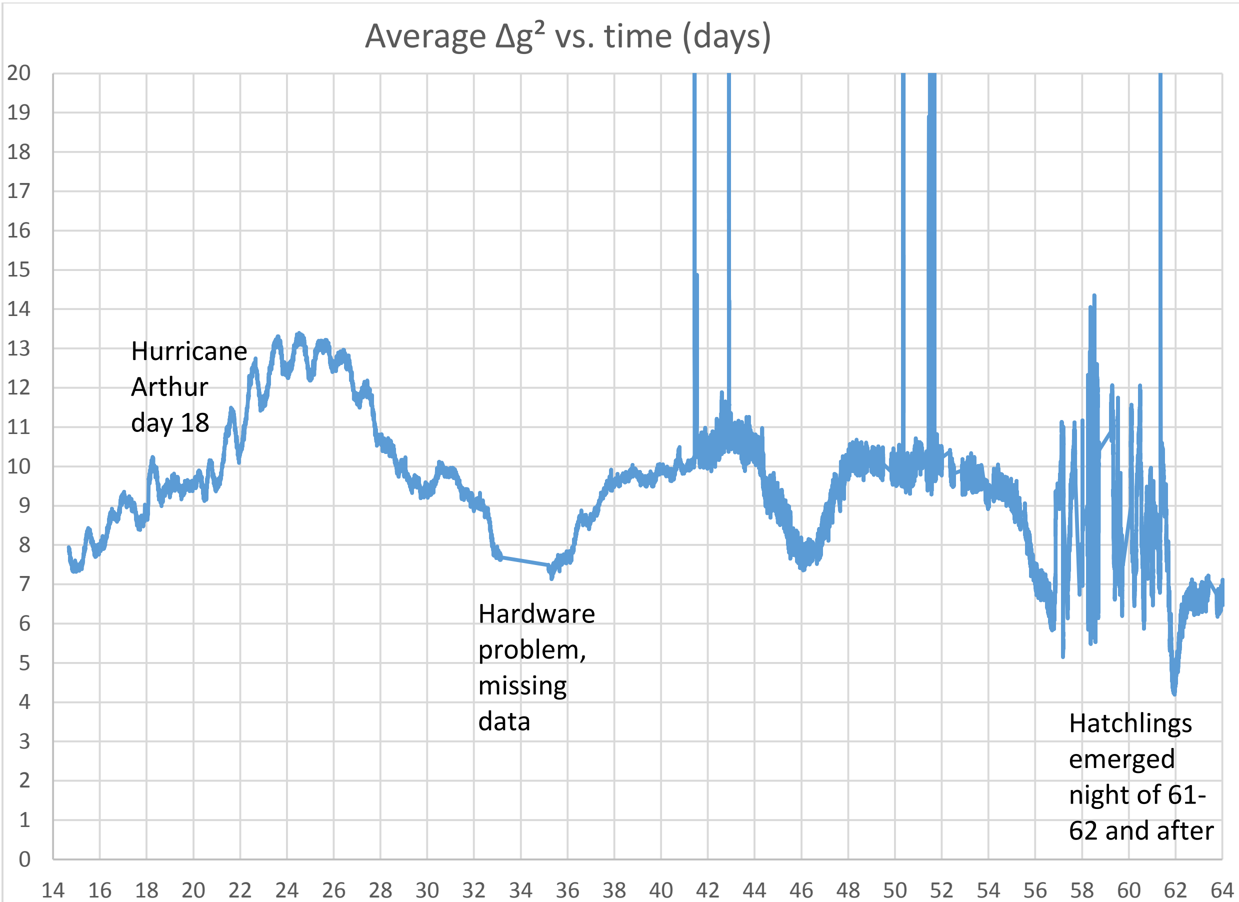
NH005 was excavated the morning of August 13th (day 60). The nest still had a 28 live hatchlings in it when it was excavated. The majority of the hatchlings were over the top of the sensor. Muiznieks reported that the hatchlings found in the nest probably would have emerged that evening if the nest had not been excavated. This might explain why there was still erratic motion recorded after the boil.



Nest NH006

Monitoring of Nest NH006 began fairly late. The actual time of the boil is not known precisely but is suspected to be on day 57. Over-washes were noted by the beach patrols on days 56 through 59. The actual time of the over-washes is not known. The approximate time that they were probably noticed is indicated with an "O" on the graphs. The over-wash may have occurred at any time in the previous 24 hours. What is notable in this nest is that there is only one day of erratic activity noted and that there are several dramatic sudden changes in the ΔG^2 values in the data, which seem to correspond to being in the 24 hours previous to recorded over-washes. This pattern is found in the data of many more nests. Also notable is that these dramatic changes sometimes are sudden increases, but on day 56 there is a sudden drop. There is also a sudden downard spike in the data along with an upward spike and upward level change on day 58. This means that within a short period of time, more activity than normal was recorded, less activity was recorded, and the typical reading also dramatically changed to a higher level. The NPS visited the nest on day 58 at 12:50 PM, which is the time the spikes appear in the data.

Because there is so little data for this nest, it is not clear if and how the three periods mentioned in NH005 apply to this nest.



NH007-reloc

This nest was one of the first to be monitored (along with NH022), and both went through Hurricane Arthur on July 4th (Day 18). The units made it through the Category 2 hurricane without any problems. The extent of background noise had been a concern before our tests. Audio recordings made by Lou Browning indicated that there might be a fair amount of background noise from the surf and blowing sand. In addition, there was concern that nearby vehicles might distort our readings, making it hard to tell the difference between those disturbances and hatching eggs. The data recorded from sensors two feet below the beach during the hurricane shows very little disturbance. The noise level from crashing waves, blowing sand, and torrential rain are barely noticeable in the data.

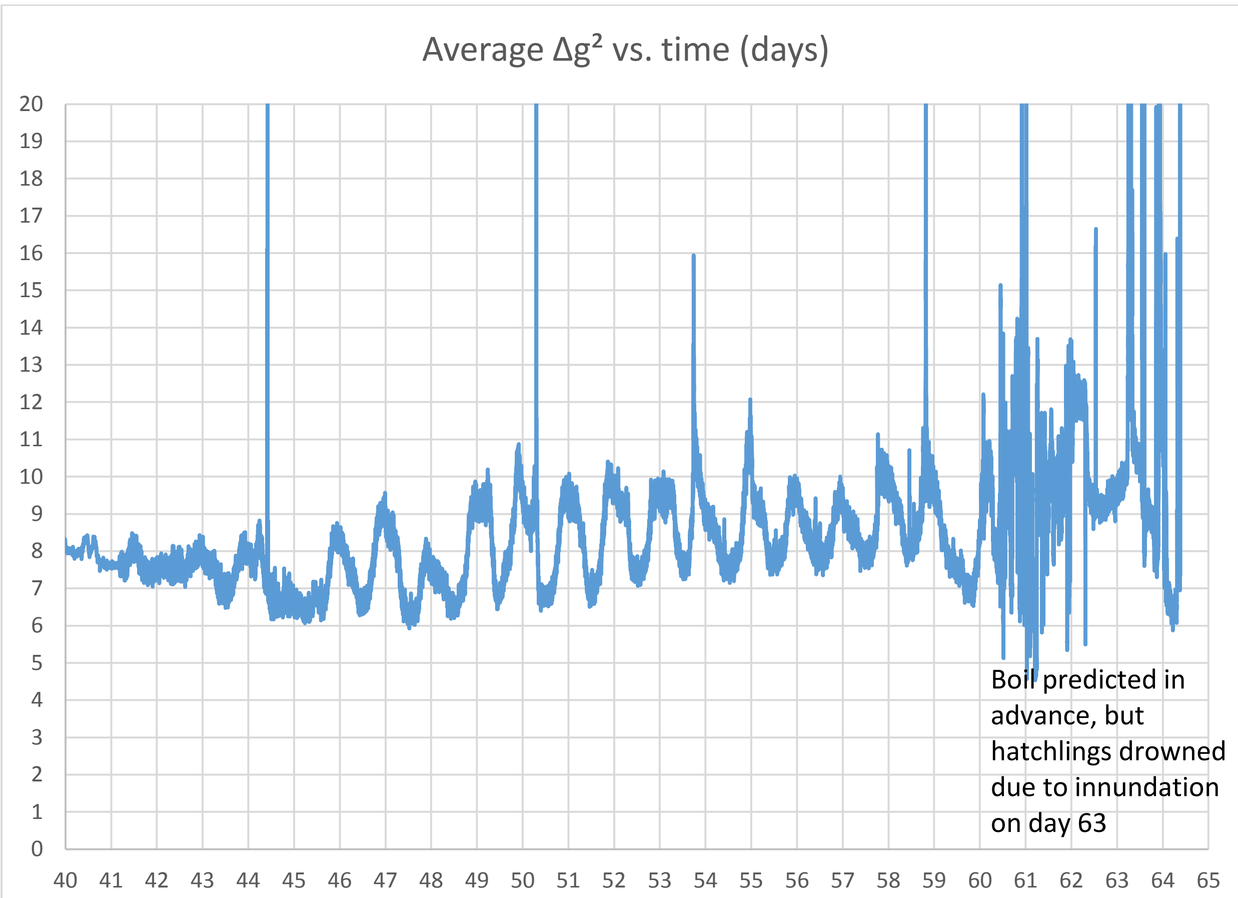
The units are programmed to create new records every 6 minutes for the first 40 days, and then to switch to records every minute. This helps lower data costs by having only one report sent over the cell network for the first 40 days. After 40 days, when hatching is possible, the more frequent reports--every 4 hours--mean that activity can be noticed within a 4 hour period instead of 24 hours. The 6 minute data appears to filter out some of the minute-to-minute variation of the data.

This nest also has some large spikes before hatching. After excavation, it was noted that 13 eggs were lost by ghost crab predation.

Three periods can be seen in this nest. Period One is up until day 56. Period Two is from day 56 to day 62. And Period Three is a significant downward dip at the very beginning of day 62. This is the lowest value recorded during the entire 50-day period graphed, and it corresponds to the time when the hatchlings started to emerge.

While the activity in Period Two is erratic, it only barely and very briefly extends to values any higher than the maximum values recorded during the first 30 days. The values recorded in Period Two are often lower than any of the values from Period One.

After the nest was excavated, there was a mishap with the Comm Unit. Because it was not properly secured in the back of the NPS truck, it got knocked about and broke apart. The damage was easily repaired, but it required shipment back to San Francisco.



NH022-reloc

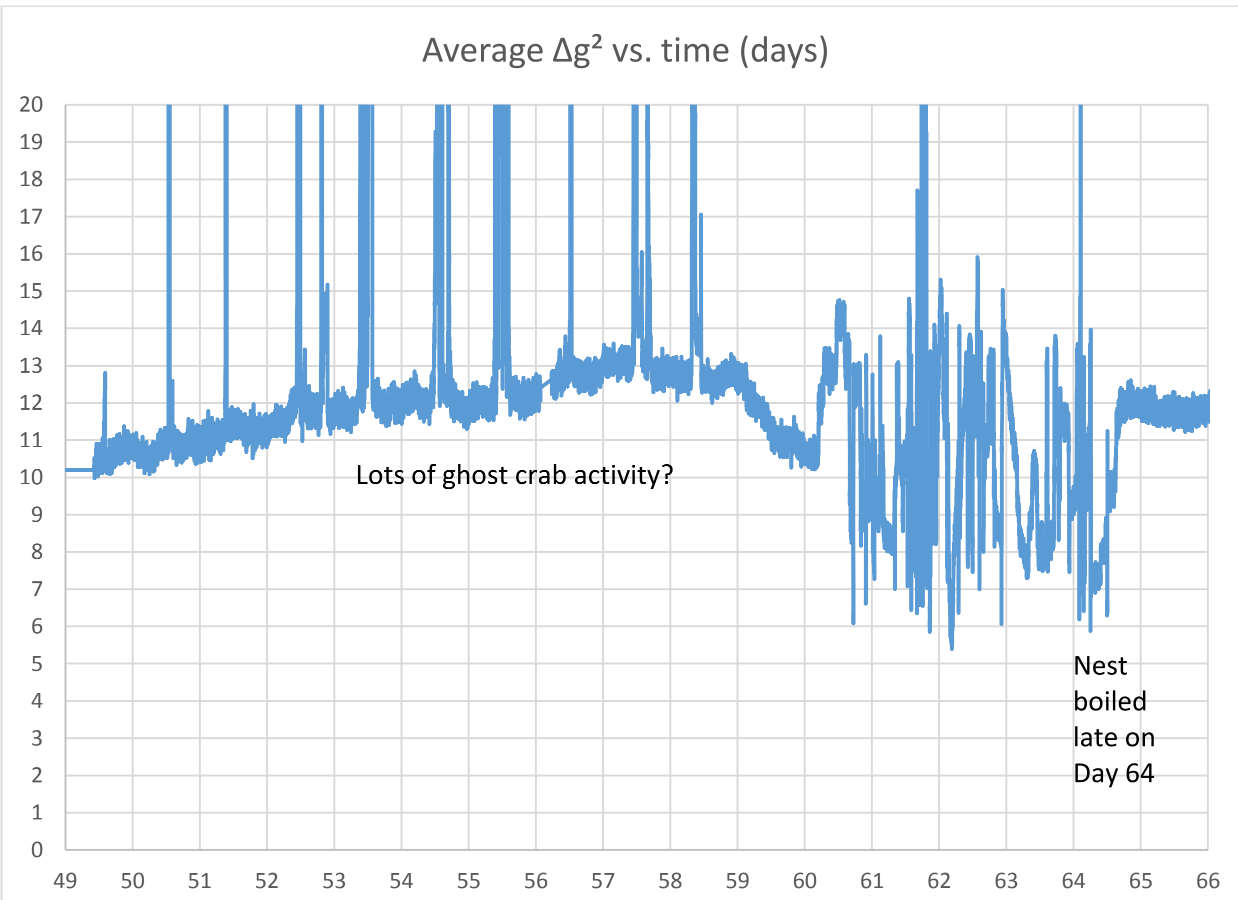
This nest also went through Hurricane Arthur unscathed. Monitoring began on day four, but only the data after day 40 is graphed here. The three periods can be observed in this nest, and after previously observing three nests, a prediction was made that hatchings would emerge.

Unfortunately the nest was lost before the hatchlings emerged. From the data, it looks like a boil would have happened just after the inundation. A video camera recorded what happened. A Nor'easter offshore caused extremely high tides. The surf crested the berm the first time at 10:33 PM on August 26th (day 62). The water drained away pretty quickly. The turtle patrol passed the nest early the next morning (day 64). At the time it looked fine, but then shortly thereafter the high tide came in, crested the berm, and the water did not recede (07:26 AM). Sometime around 1:00 PM, the nest was checked for the slim possibility of any surviving live hatchlings, but instead only dead hatchlings were found. The Comm tower and sensor were still in the nest, and the nest was excavated the following day. There were 52 dead hatchlings—48 above the sensor and four below.

No over-washes were noted for this nest before the tragic last two days, so spikes in the data are from some other cause, most likely ghost crabs.

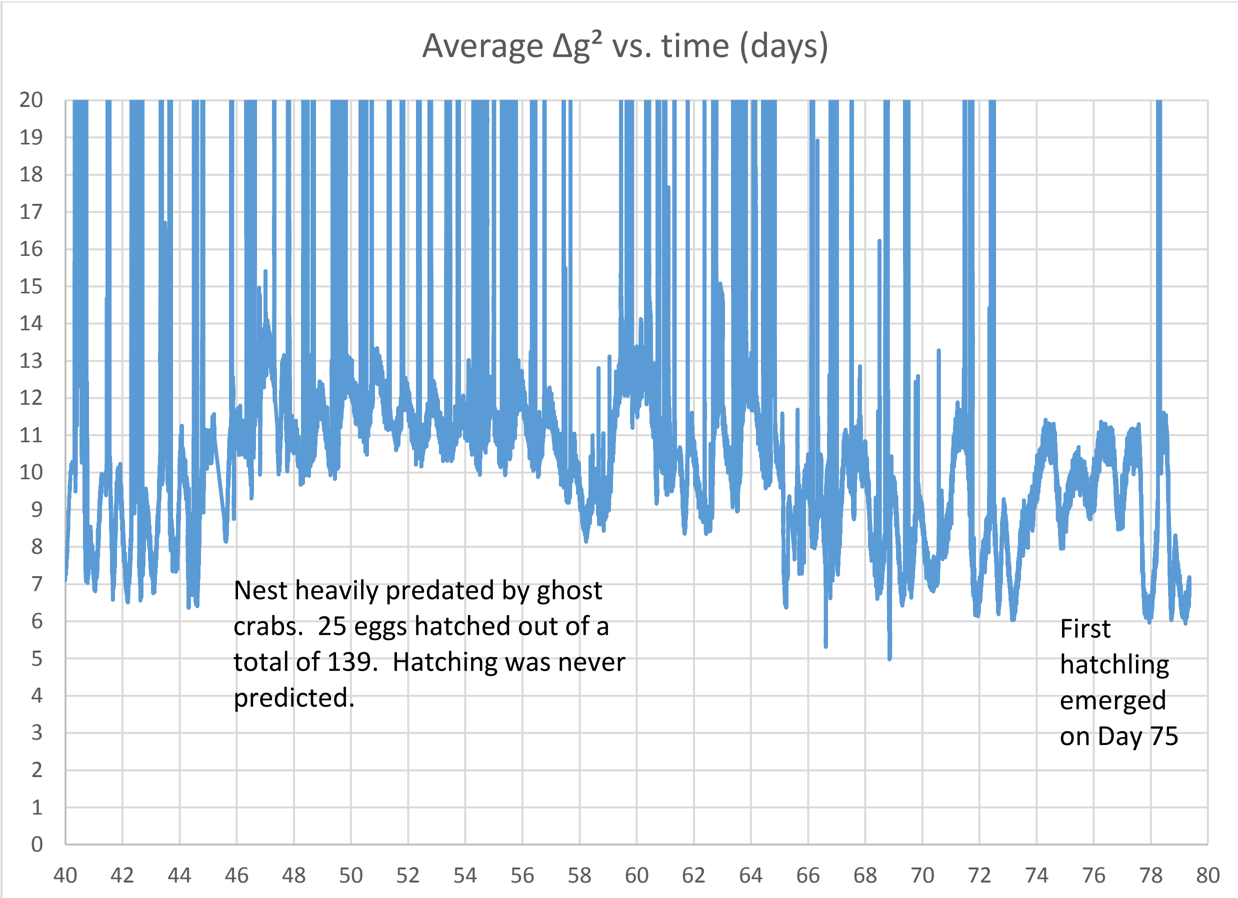
The same area had five relocated nests in it. All of them were lost. One of them was Nest NH052. A sensor had been installed in this nest, but a Comm tower had not yet been connected because the nest was fairly young, so there is no data from this nest.

The sensor installed in nest NH034 proved to be defective and was returned to San Francisco for repair.



NH036

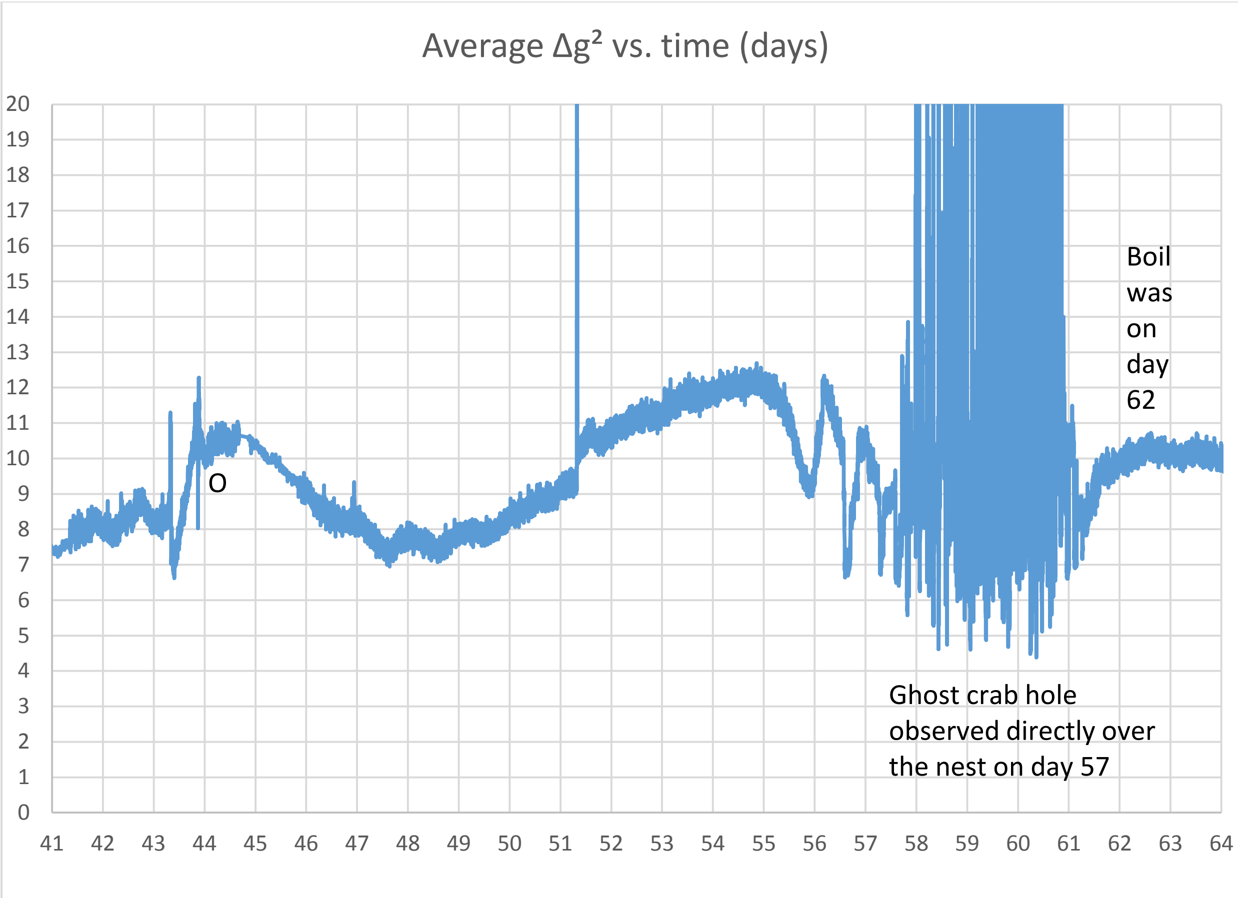
Nest NH036 is notable for the number of large spikes that occurred daily before the nest became active. Even with the spikes, the three distinct periods can be seen in the data. Another subtle pattern that can be seen in several of the nests is very noticeable in this one. Just before the data gets erratic (the second period), there is a dip to a level that is often lower than anything that came before for many days. Early on day 60, the level dips down to 10, which is lower than it had been since day 50.



NH037

NH037 was the most problematic nest of the season. The nest was heavily predated by ghost crabs, and only 25 eggs hatched out of a total of 139. The hatchlings did not boil out together, and they emerged fairly late compared to the other nests at this time of year. While it may be possible to analyze the data and find some sort of pattern, it is not obvious at first. The three periods noticed in previous nests are not seen here. There is so much predation activity that it is likely masking the erratic motion caused by the few hatchlings that emerged from their eggs intact. The only thing that seems notable is that the spikes stopped about two days before the first hatchlings emerged. This may just be a coincidence.

The quantity of spikes and the observations of ghost crab predation enforce the correlation between the two, which had already been noticed.

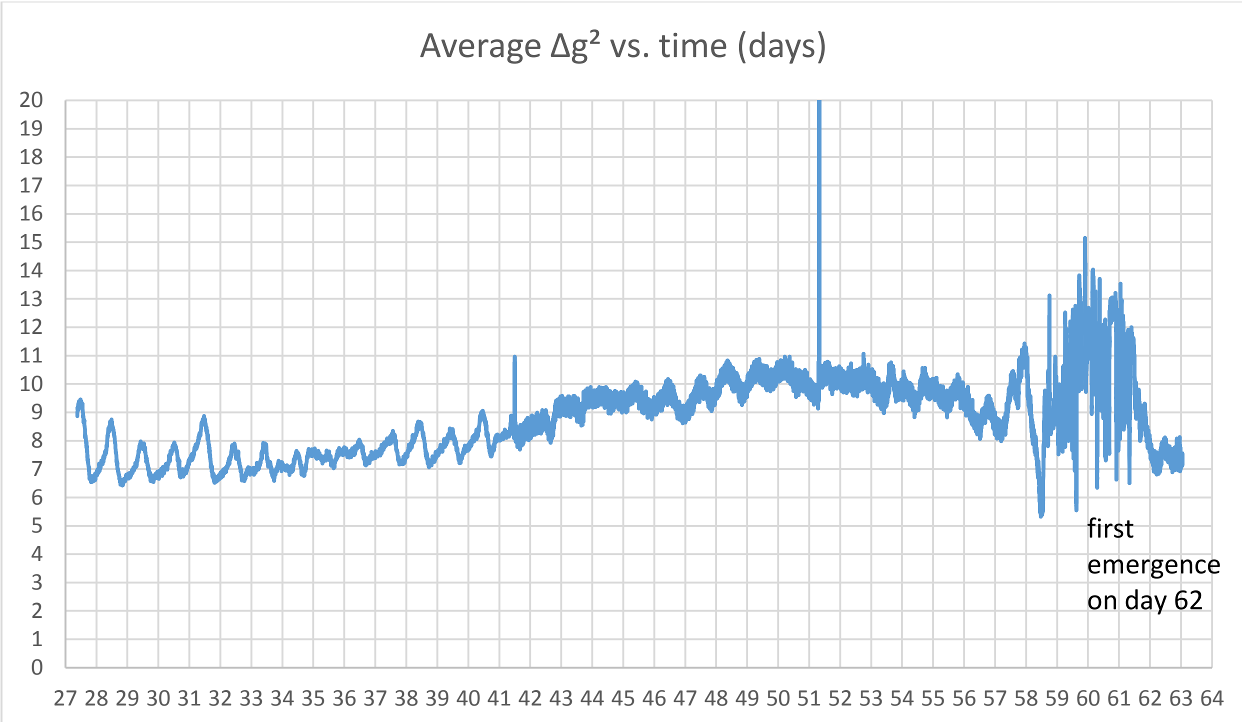


NH039

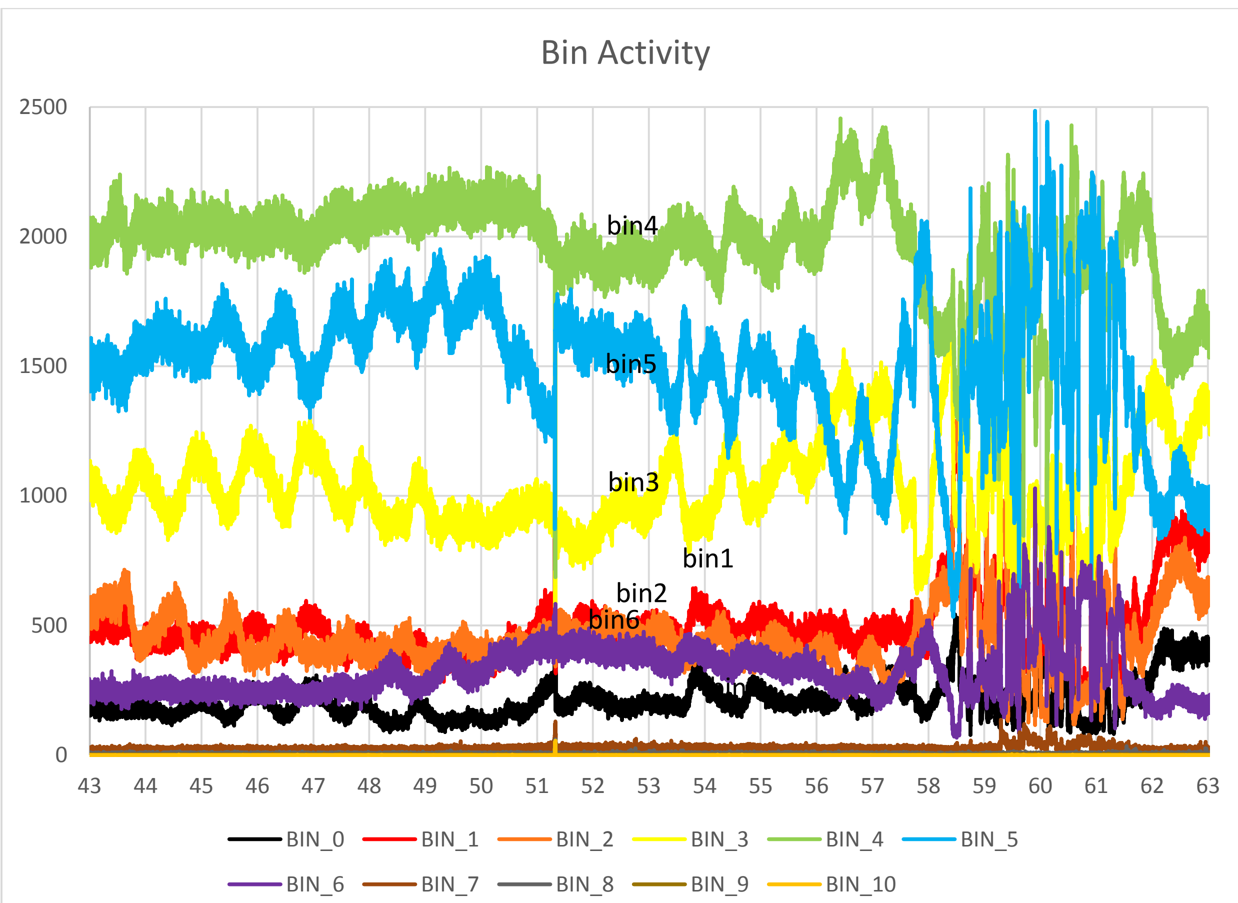
This nest shows the three periods and the newly noticed dip at the end of the first period. The dip is interesting here because it seems to have happened several times before the activity became erratic. Again the dip reached a level on day 56 that was lower than anything in the previous two weeks, and the levels recorded during the erratic period are even lower. The very high spikes during the erratic period might be from the ghost crabs that were observed directly over the nest. The final quiet period before the boil was quite short in duration, again just a few hours.

An over-wash was noticed by the turtle patrol the morning of day 44; this corresponds with the erratic data recorded on day 43.

Unfortunately the data was not looked at for several days before day 61 when a prediction was made that a boil was imminent. The boil occurred that night. In retrospect, it seems clear that a prediction could have been made on day 58, four days before the boil.


Average Δg² vs. time (days)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64
first emergence on day 62

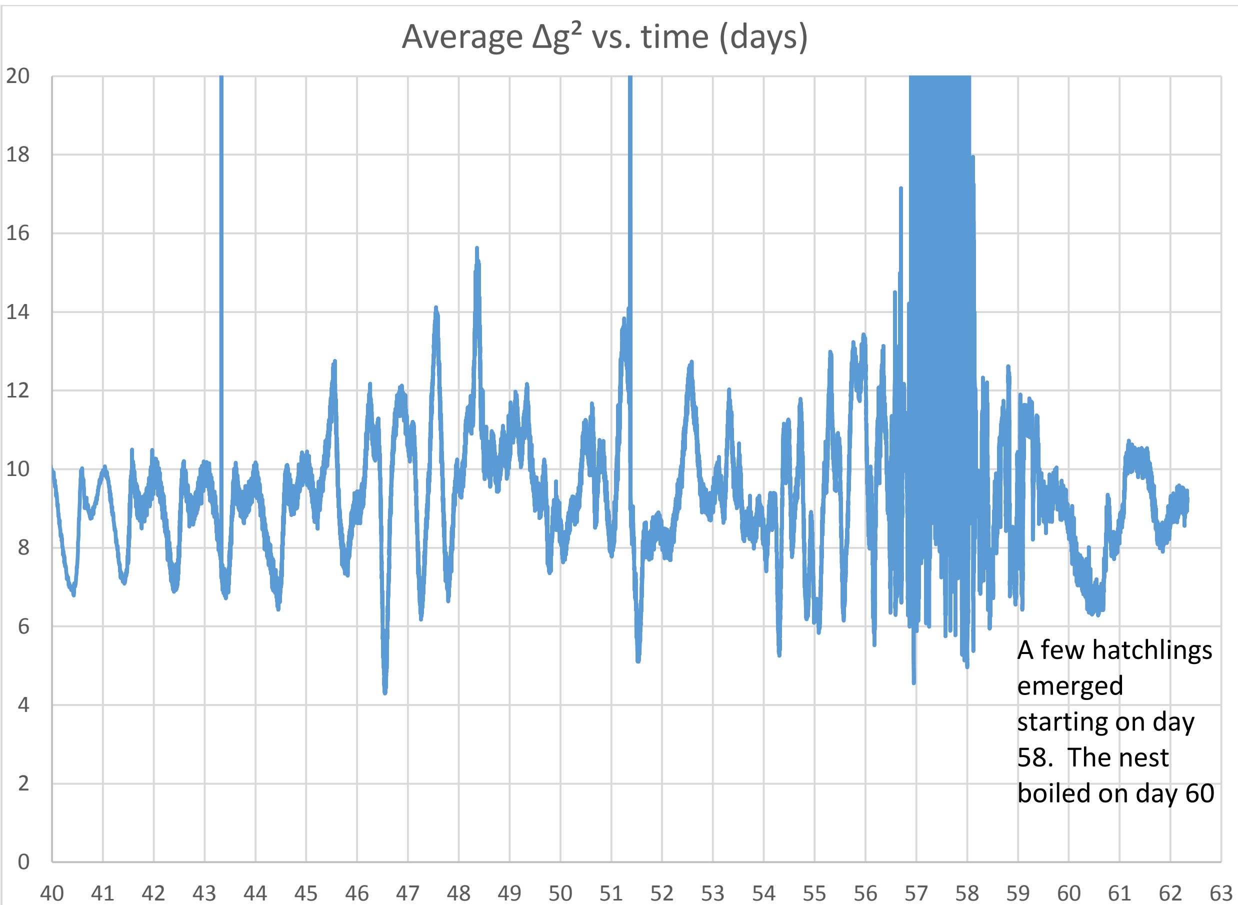
NH043-reloc


Bin Activity
2500
2000
1500
1000
500
0
43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63
bin4
bin5
bin3
bin1
bin2
bin6
BIN_0
BIN_1
BIN_2
BIN_3
BIN_4
BIN_5
BIN_6
BIN_7
BIN_8
BIN_9
BIN_10

Data from nest NH043 shows a very pronounced low dip before the erratic period begins. The level–just over five–is lower than anything recorded previously in this nest. The erratic period is shorter and less pronounced than in some of the previous nests. The hatchlings in this nest did not all boil out together at the same time.

This nest is notable in that there is a diurnal fluctuation in the data that stays fairly constant during the entire first period. This had been noticed in nests previously, but it is very pronounced in this nest.

The second graph shows the activity recorded in each data bin. Each bin corresponds to readings at a different range, so looking at the plots of bin counts separately makes it possible to see what happens at different energy levels. The diurnal signal and the erratic period can be seen in virtually all of the bins.



NH045

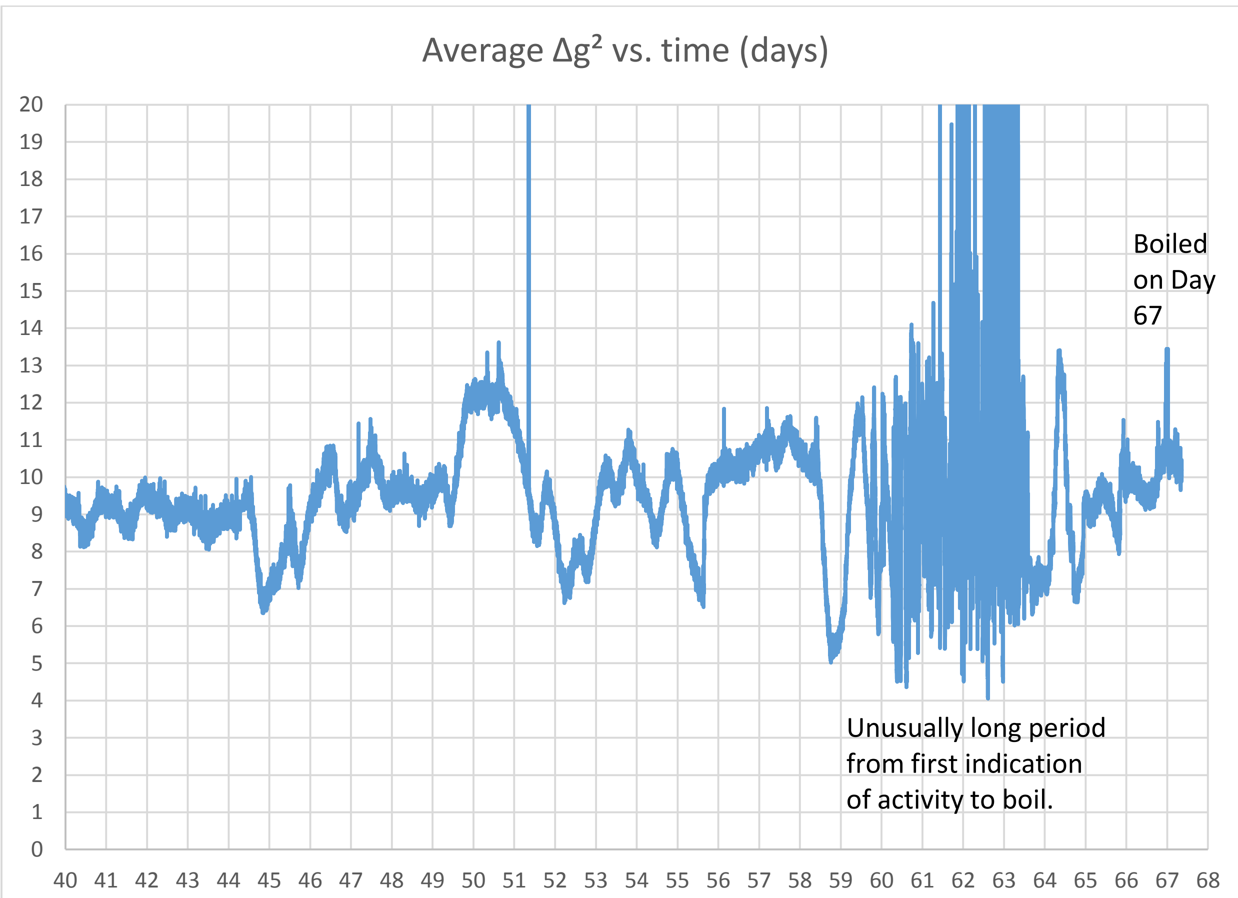
The data in NH045 is more dynamic than the data from previous nests. The diurnal cycles noticed in the previous nest are more pronounced here and less consistent, especially as it got closer to hatching time.

Wantman sent the following e-mail to the NPS after analyzing the data up to and including September 17th (day 57):

NH045 (AA0012) Hatching began on the night of 9/15-9/16. This nest has the most intense hatching motions recorded in any nest so far or there is a very big predator mucking about! Could this be a different species … Since I haven't seen any other signs of predation, I predict a boil in the next 48 hours. If the intensity of the motion means that they are all hatching at the same time, then I'd predict an earlier boil rather than later in the next 48 hours.

The first hatchlings emerged the following day, and the boil was about 48 hours later.

The reason why this nest has a much greater dynamic range is unknown. One likely suspect is the variability of the readings from the sensors. The low dip before the erratic period is not seen clearly in this nest, and the lows seen during the erratic period are not lower than the values recorded previously. Even so, the three distinct periods seen in almost all the other nests can also be seen in this one.



NH047-reloc

Nest NH047 was probably the nest most closely watched during the entire season. There was a near complete set of data starting on day 22. A National Public Radio (NPR) reporter was planning to be there around the time this nest was expected to boil, so the hope was that the timing of the boil would cooperate and become a star of the radio segment. Samuel Wantman and David Hermeyer planned a trip from San Francisco to North Carolina to meet other team members and NPS staff and to be there at the same time as the reporter, and hopefully to experience a boil.

After looking at the data on September 20th (day 58) Wantman reported:

> *No signs of hatching, no crabs. There was a sudden quick drop in recorded motion today. I've seen this phenomena before. I wonder what causes these? …*

Two days later (Day 60) Wantman reported:

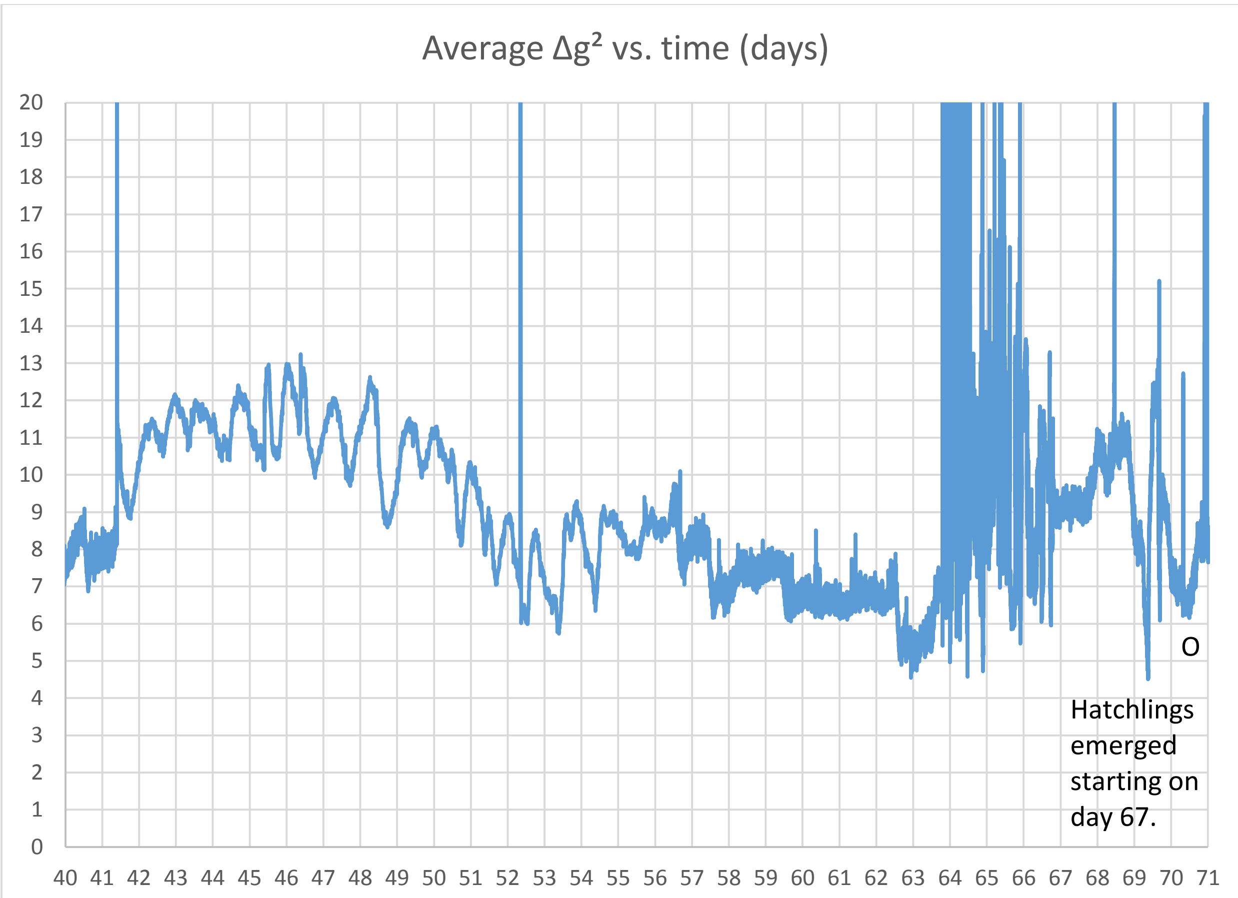
> *… I'm going to stick my neck out and predict that NH047 will be boiling on Thursday evening/night [Day 63] … This is the first time I've tried predicting the timing 3 days away from the event, and since I mentioned the possibility of this nest becoming active yesterday, it might really be an update on a four day prediction. After looking at all the nests that have hatched and boiled so far, I noticed that there is a signature slowing of activity the day before hatching begins. It doesn't appear in every nest, but it was in this one, and I spotted it before things got active. Once things get active, it seems that boils usually happen about 4-5 days later. There is some variation to this, but since we are now 1 day into the hatching activity, a three day prediction seems reasonable. When the nests haven't fit this pattern, it seems as though they take longer to boil, and not less. So I'll be surprised if the boil is on Wednesday evening/night, but not surprised at all if it is on Friday. Nest NH045 took a day longer than I expected, so perhaps it is more likely that this one will be a day late as well. Perhaps the wet weather and decline in temperature recently is the cause of this delay. The more nests we look at and the more detailed our analysis gets, the better we should be at making predictions. I'm really pleased and surprised by the success we have had in seeing all these events clearly.*

After another two days after reviewing the data for Wednesday August 24th (day 62), Wantman reported:

> *…. I wish I could tell you exactly when it will boil, but with a data set of only about 8 boils to go by so far, this is more of a guess than science. The nest was still in the active phase of hatching on Wednesday. Usually things quiet down for a day before the boil. But sometimes that quiet phase is short, and sometimes it is long. Since the quiet phase has not appeared yet, it makes it harder to predict. But if I compare it to our other nests that we have data, it looks very much like NH043 which just boiled a few days ago and also had a very short quiet phase. Matthew Godfrey says that this end stage is very unpredictable, and the timing is not well understood. Matthew thinks the quiet stage might be because the turtles are working their way upwards, and are above the sensor. But if they don't all leave at the same time, then it can remain active at the sensor for longer. That was what happened with NH043, and not all the turtles were in the first boil. So there's little scientific knowledge to help me make this prediction. However, if this nest continues to follow NH043's example, it will boil tonight. I'm going to be there tonight to watch...*

Before everyone made their way to the nest site on the evening of day 63, the data was checked again. The erratic period had stopped, and the readings were getting low indicating that the emergence of hatchlings was imminent. But for some unknown reason, this nest did not follow the pattern of the nests before (or after). As if sensing the presence of the audience waiting above ground, the stagefrightened hatchlings did not make an appearance for three more nights. And, as it turned out, the boil was a couple of hours after we all gave up for the night and went home.

Even though we observed numerous ghost crabs around this nest and even found a ghost crab tunnel directly over the nest, there was only one hatchling lost to predation. Perhaps it was the crabs that scared the hatchlings.

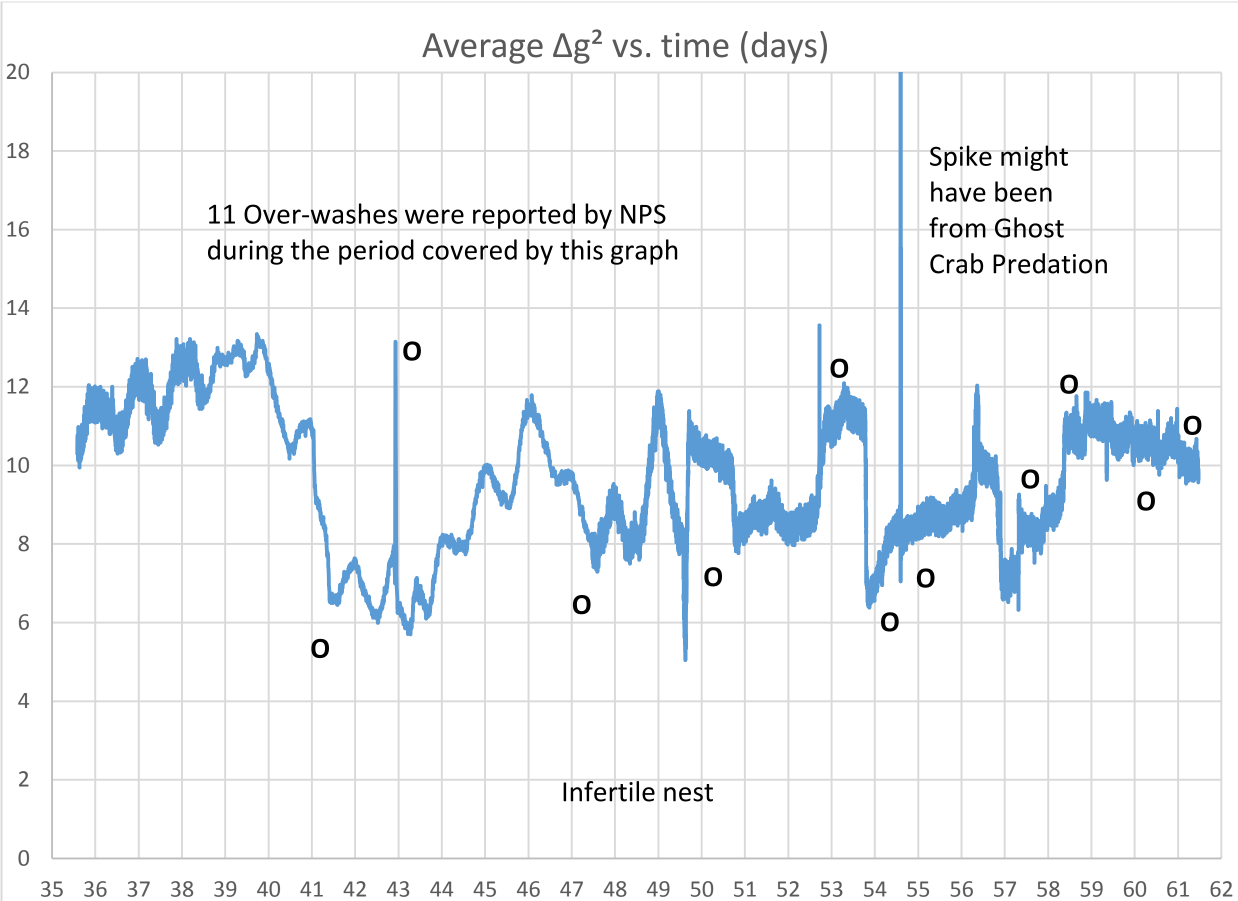


NH048-reloc

This nest was quite typical, showing diurnal activity, a new low at the end of the first period, and a four-day erratic period. The final quiet period is not clear in the data. Unlike NH047, once the nest quieted down, the hatchlings emerged on schedule.

NH052

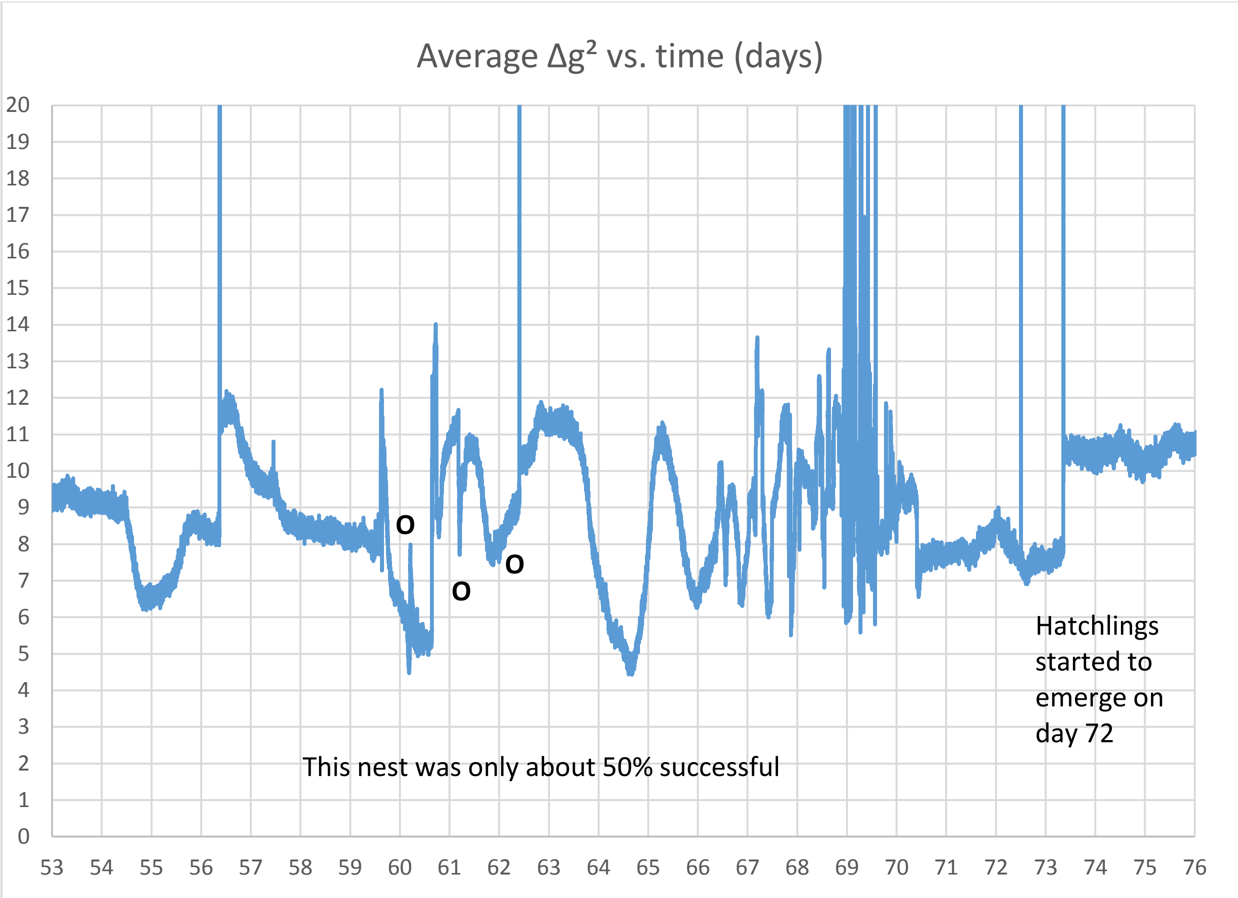
As mentioned previously, NH052 was lost before being monitored.



NHO54

This was the first nest to be monitored that did not produce any hatchlings. At first glance, it looks very different from the others. There is a steep decline from day 39 to day 41. Small upward and downward spikes correspond to times when over-washes were recorded.

The fact that this nest was infertile shows that the diurnal motion that was recorded was not related to the movement of embryos in the eggs. So this nest is significant.



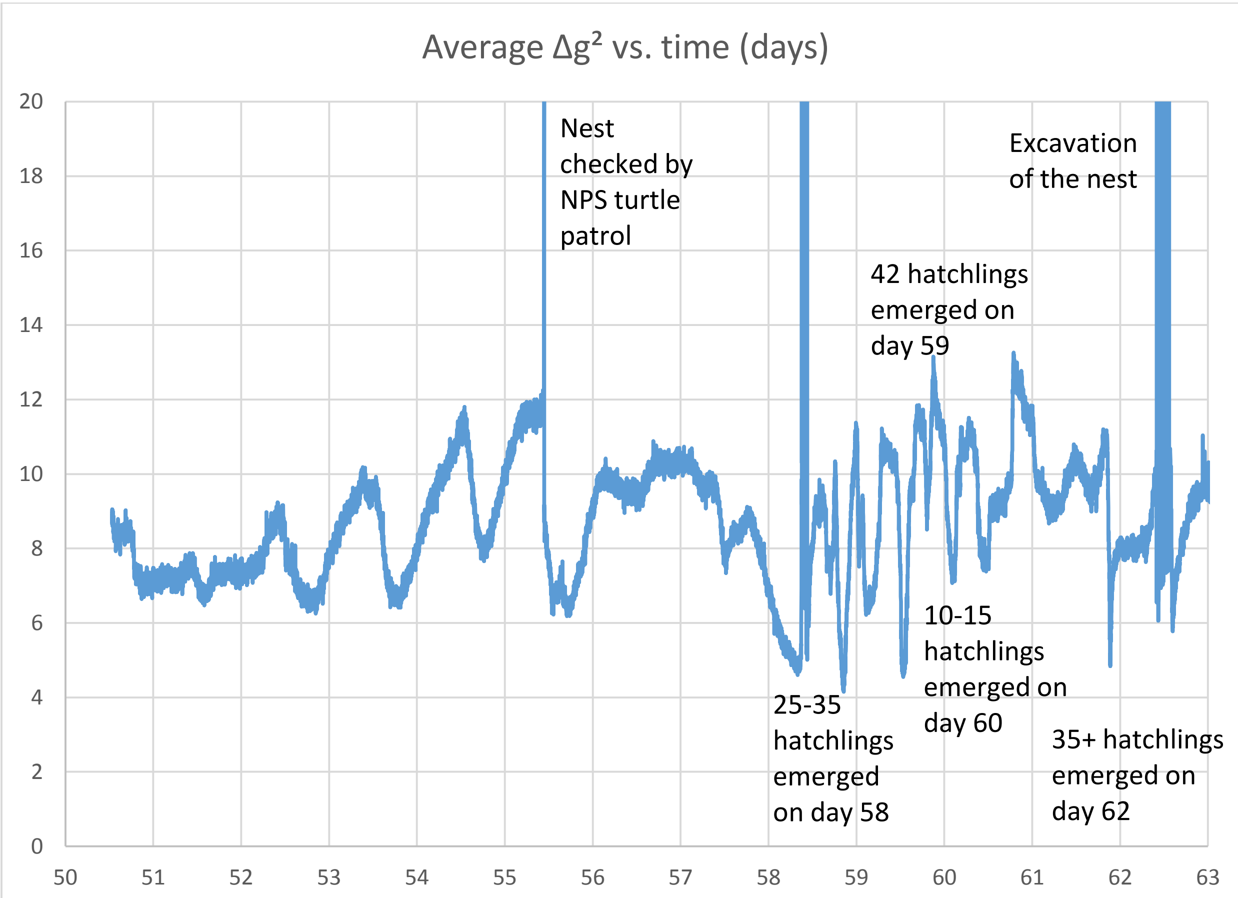
NH056

This nest also showed some of the same erratic behavior as NH054. The over-washes that were noted in the nest reports correlate to data patterns similar to those in previous nests–small spikes and abrupt level changes. The dip on day 64 reached a new low and is more pronounced if you discount the lows recorded near the time of over-washes between days 59 to 62. The quiet period before emergence is longer than normal, extending for more than two days. By day 72, it was October 16th and the weather was getting cooler, which may account for all of these changes.

Until the NPS reported that there had been over-washes, there was the possibility that that the data from days 59 through 62 were the dip at the end of the first period and the beginning of the second period. Once the over-washes were confirmed, the possibility was no longer considered. The first prediction about this nest was made after analyzing the data through October 11th (Day 67):

> *There's activity in NH056 (A17). I think that pipping may have started as long ago as October 7th [Day 63], perhaps in two batches with the second batch on 10/9 [Day 65]. Hatching activity looks like it started on 10/10 which would mean that a boil should be sometime between 10/14 and 10/17.*

By this point, the working theory was that the dip at the end of the first period was due to hatchlings pipping their heads out of their shells and that the erratic period was related to the hatchlings moving out of their shells. Theories related to the analysis of the data are discussed later in this report. Even if this theory is not correctly recognizing these periods, it had, by this point, become a very effective method of predicting when hatchlings would emerge. Hatchlings began to emerge from this nest on day 72, right in the middle of the range that had been predicted—day 70 to 73.



NH058

The data from this nest was quite unremarkable except for one major difference. The hatchlings emerged quite early. The dip at the end of the first period appears late on day 57, and hatchlings emerged at about the same time. The 58-day gestation period was much shorter than all the other nests we monitored this late in the season. Only the first two nests, monitored during much warmer weather, had shorter gestations, and those were barely shorter at 57 days.

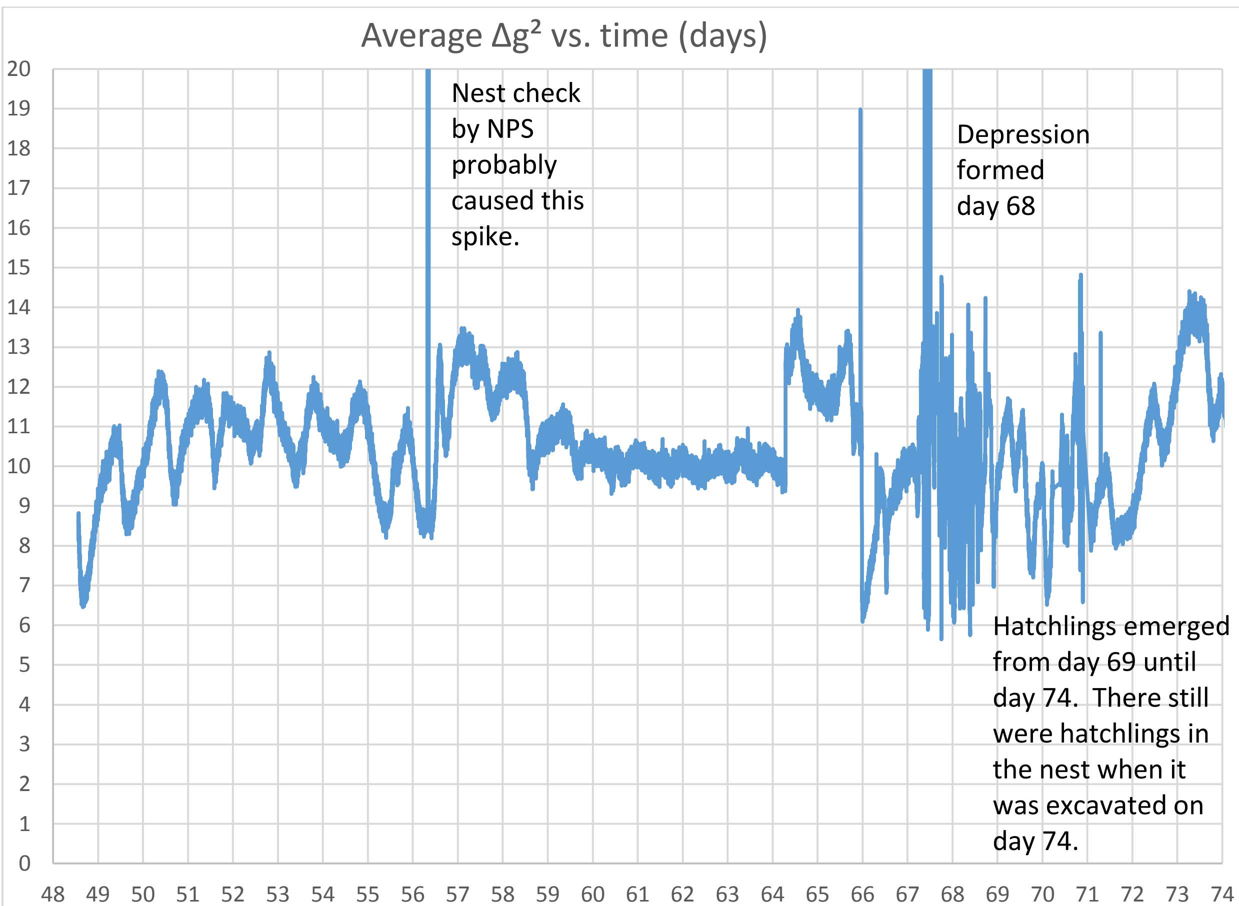
From the look of the data, hatchlings would be expected on day 62, and indeed there were at least 35 of them at that time. So the data is quite normal for the 35+ hatchlings that emerged on day 62 but not for the majority of the hatchlings.

This was a fairly shallow nest—only about 18 centimeters below the surface. The NPS turtle patrol inspected the nest just three days before the first hatchlings emerged. This nest was also the only nest up in the dunes in the sea oats. It is not clear if these things are related to the early emergence of the hatchlings.

Monitoring the nest did show a huge disturbance on day 55. After looking at the data that day, Wantman sent the following e-mail:

> *Something is happening at NH058. There was a huge spike of activity mid-day on the 6th, followed by lots of activity that might be hatching, but the signal doesn't quite look as erratic as hatching in previous nests … The spike of activity looks much bigger than a crab, more like a person poking about. Was anyone inspecting this nest on the 6th? If not, I think a very large crab was trying to eat the sensor!*

The "very large crab" was indeed a member of the NPS Turtle Patrol inspecting the nest.



NH059

Nest NH059 was fairly close to a normal pattern. A new low was reached early on day 66 followed by erratic readings until the first hatchings emerged on day 69. Like NH058, this nest did not have a single distinct boil. The hatchlings that emerged first were ahead of schedule relative to the first indications in the data.

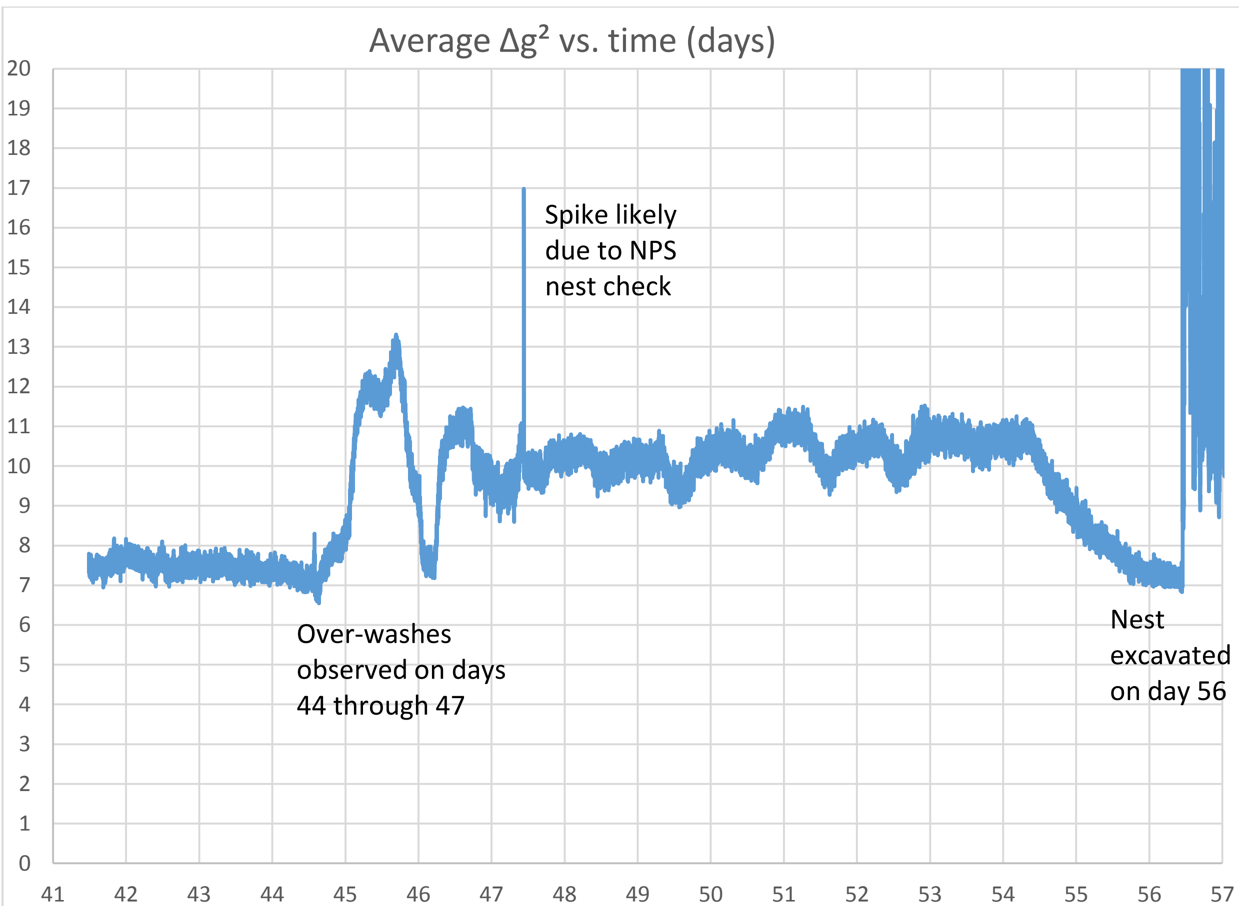
Activity was first noticed on Oct 14th (day 64). Wantman sent this e-mail:

…either there was an over-wash today (Tuesday 10/14) or something is happening. It looks like an over-wash to me. Let me know if that was correct…

By this point in the season, over-washes were suspected as the cause of sudden changes, like the abrupt change from about 10 to 13 that occurred on day 64. Will Thompson reported that he was the cause of the disturbance:

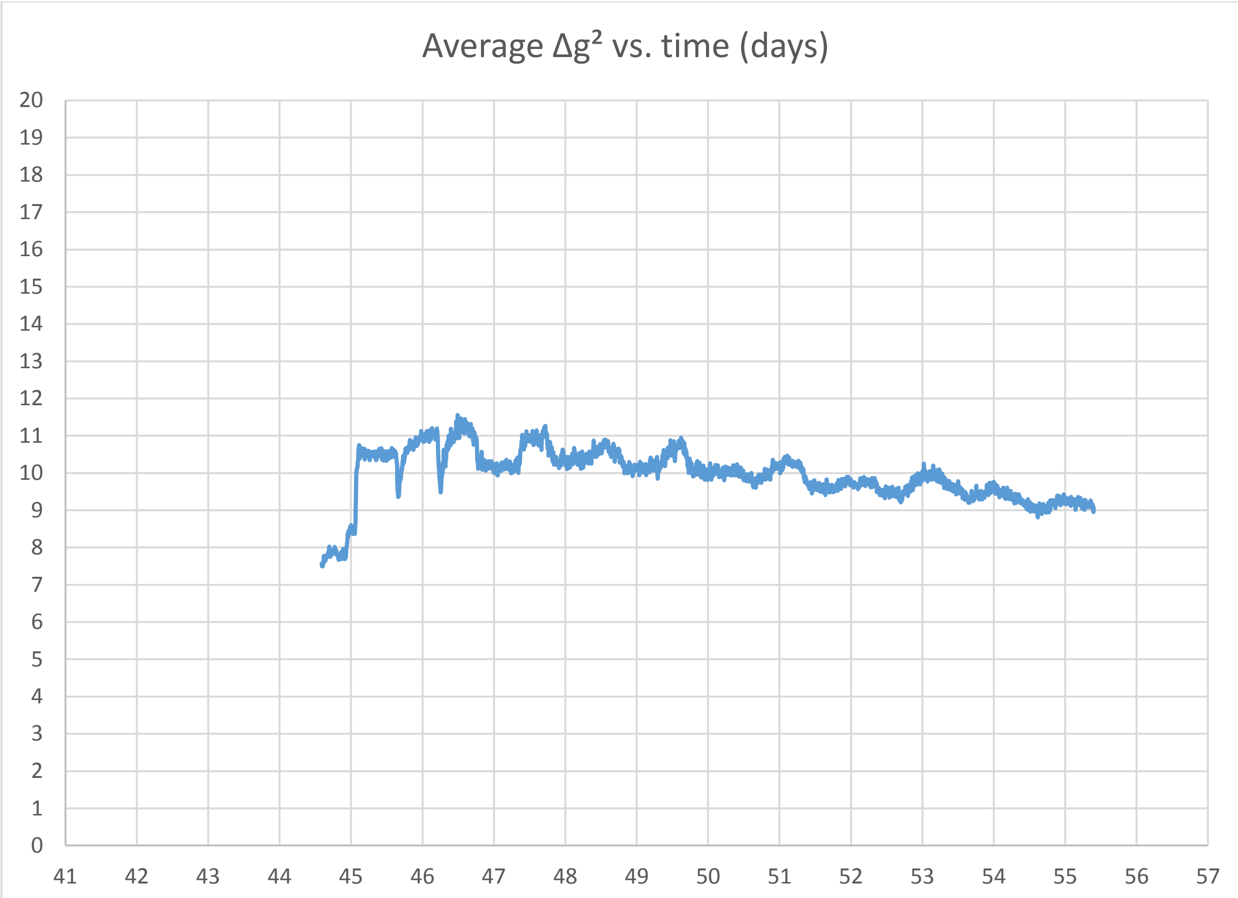
I checked out a ghost crab hole at 0700 on 10/14 on NH059 and got to the eggs, it was probably my nest check that stirred up the sensor readings unless you are still seeing movement.…

The next time the data was looked at, on day 68, it was clear that the emergence of hatchlings was imminent and likely could have been predicted a day or two earlier.



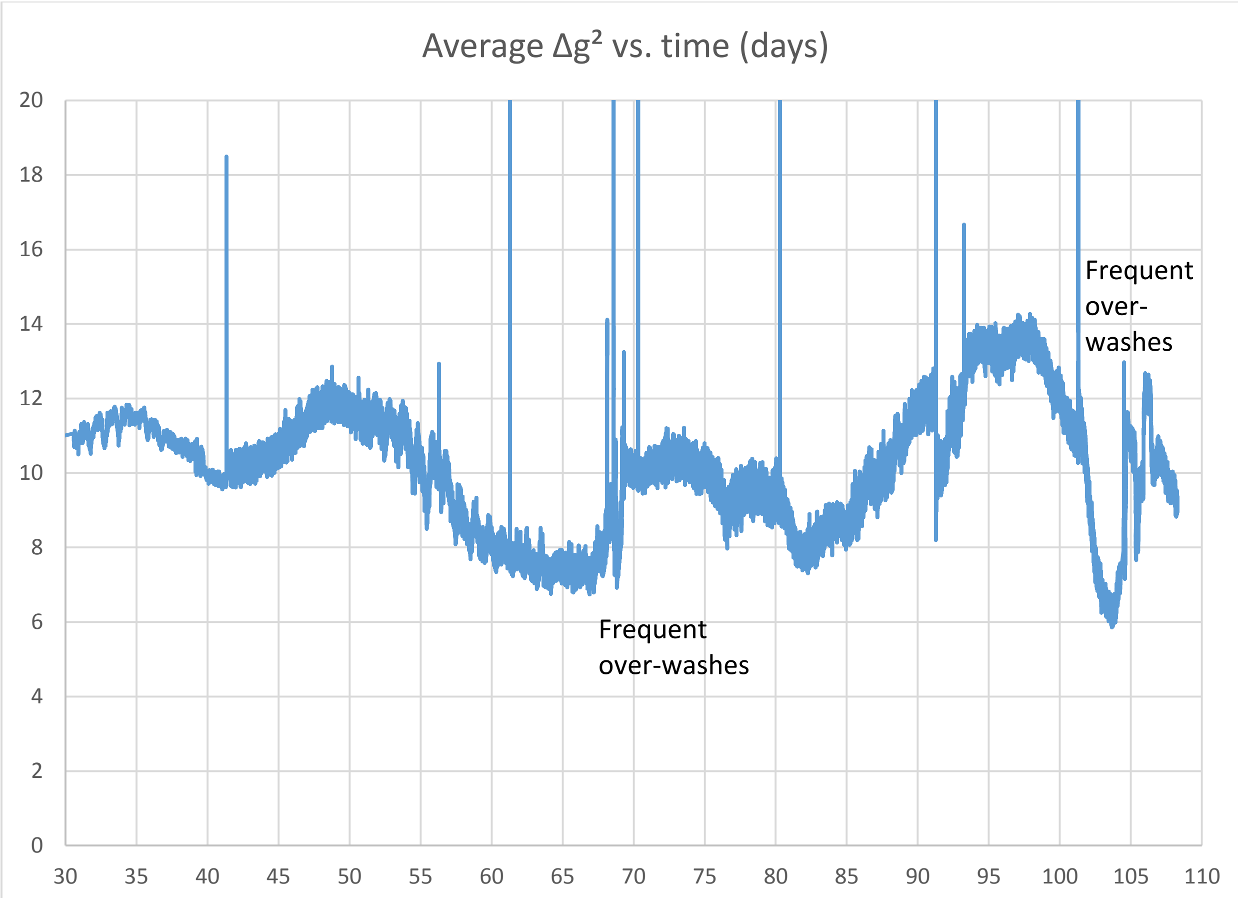
NH061

Nest NH061 was infertile. The data from the nest has very little variation besides the quick level changes recorded during a period with over-washes, a spike recorded when the nest was checked by the turtle patrol, and activity when the nest was excavated. The signal that remains was the result of forces unrelated to the development of sea turtles. There is diurnal activity from days 47 through 54.



Ten feet from NH061

To better understand our data, a second sensor was installed ten feet away from nest NH061. Any background disturbances should, in theory, be a component of the signals recorded by both sensors. Here is a graph from that second sensor covering the same period of time as the previous graph from the sensor installed in Nest NH061. Note that the data begins later and ends earlier than the previous one because this sensor was installed later and removed sooner. While there are similarities, there are also differences. The first graph trends upward from days 47 to 54. This one trends downward. Both have similar diurnal motion. The records from this device were made every 6 minutes, while the devices in the nest created records every minute, so there are six times as many data points in the first graph. Creating records less frequently will tend to smooth out the results because infrequent or sporadic jolts and lulls will be averaged in among the greater number of samples.

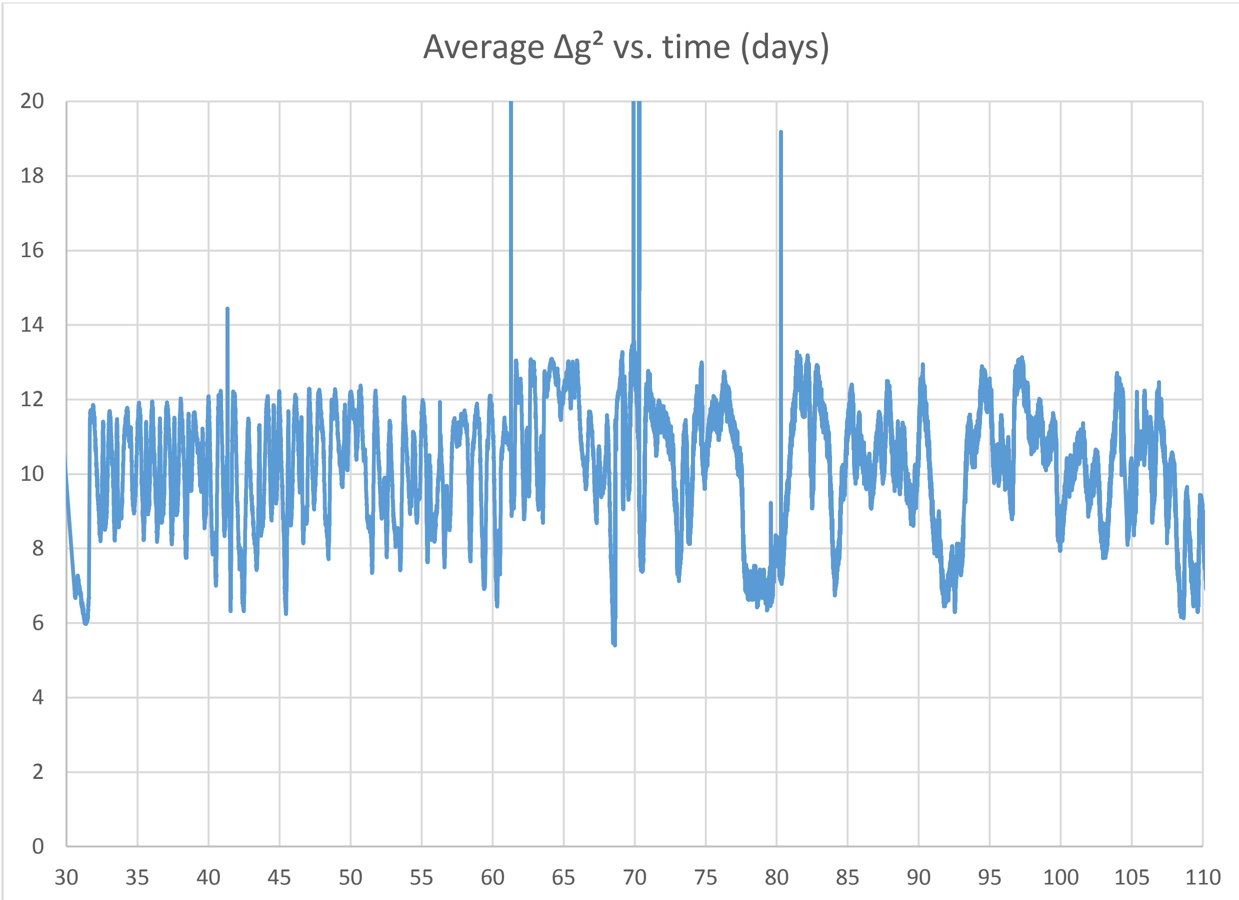


NH062-reloc

Nest NH062 was a nest from late in the season. It was a viable nest until the fetuses succumbed to cold temperatures. Despite the sad fate of this nest, there are a few things of note. There is an almost perfect data set from beginning to end, a period of more than 80 days. Almost all of the spikes and jumps in data can be correlated to nest inspections by NPS turtle patrols and over-washes. The equipment performed as expected, uploading over 400 report files to the server. There were viable eggs found in the nest when it was checked just after day 100. A companion sensor was installed ten feet away from this nest, the same arrangement as the two units at NH061. So in this case, a comparison can be made between viable eggs and background, while NH061 had non-viable eggs.

Toward the end of the period graphed, hatching was suspected because of the low dip around day 103 and the following erratic activity. The NPS turtle patrol reported frequent over-washes, which explained the readings, so no prediction was made. A nest inspection shortly thereafter confirmed that there were no longer any viable eggs.

The long-term variations in the data are very noticeable here. Between days 60 and 65, the readings hover around seven and eight, while between days 93 and 98, they hover around thirteen and fourteen—a level that is almost twice as high. Some of this change seems to be correlated to the intensity of the surf, but a detailed analysis to confirm this has not been made.



Ten feet from NH062-reloc

The graph of the data from ten feet away from Nest NH062 looks dramatically different from the data from the sensor installed in the nest. It also looks much different from the data from the unit installed ten feet away from NH061. However, this is the same sensor that had previously recorded data in NH045. After hatchlings emerged from that nest, the sensor was moved to this site. The data from NH045 shows more dramatic daily variation than many of the other nests, just as the data here shows much more dramatic daily variation from the sensor in the nest. So the cause of the variation may be the result of variation in the hardware in the sensor. Additional testing may shed more light on this.

Temperature data

Temperature data was included in every record from every report. That means that there is a temperature reading every 6 minutes for reports in the first 40 days and every minute for the reports afterward. The temperature in the nest varies very slowly. The temperature readings have a resolution of 0.1 degrees centigrade. The specifications for the sensor do not claim accuracy greater than 1 degree centigrade. The chip manufacturers have a suggested method of calibration, which was implemented in the software design, but the accuracy of those calibrations is not guaranteed. With a little additional effort, the sensors could be recalibrated if more accuracy is needed.

The temperature data recorded from the nests has not been analyzed to help predict the emergence of hatchlings. This is a potential avenue for future research.

VII. Interpretation of the results

a. Background noise

When the first units were installed, there was a concern that environmental noises and disturbances might make it hard to tell the difference between those disturbances and hatching eggs. After installing the first sensors, Muiznieks drove a truck back and forth near a sensor to see if the vibrations from the vehicle's passing would register. That test, along with the data recorded during Hurricane Arthur, showed that it is very quiet two feet below the beach. The noise level from passing vehicles, crashing waves, blowing sand, and torrential rain was barely noticeable in our data.

Two devices were placed ten feet from actively-monitored nests to measure the background noise levels. The observations from these sensors, while not conclusive, seem to indicate that most, if not all of the diurnal signal in the data was the result of diurnal changes in the background noise level. There has been some attempt to correlate these diurnal signals with the tides, surf intensity, and weather, but to analyze this requires finding or acquiring a large volume of data recording the local levels of the tides, surf, and weather. A study analyzing this is beyond the scope of this year's work with Turtle Sense. Such a study is likely not necessary for the purposes of predicting the emergence of hatchlings.

There does seem to be some variation as to how sensors respond to background noise. Some devices were more sensitive to the background noises than others. The cause of this is currently unknown, but may be better understood after further testing and experimentation.

There is some quantization noise that is the result of the method used to count data in bins. The exact level of this noise has not been calculated or measured, but it could possibly be distorting the results to a small degree. The integration of the data as described in this report has shown to be an effective way to condense the huge volume of data into something that can be easily graphed and analyzed. Integration also probably filters out some of the quantization noise. To totally remove quantization noise, future versions of the Smart Sensors can be programmed to do the integration as the data is recorded.

b. Predation and over-washes

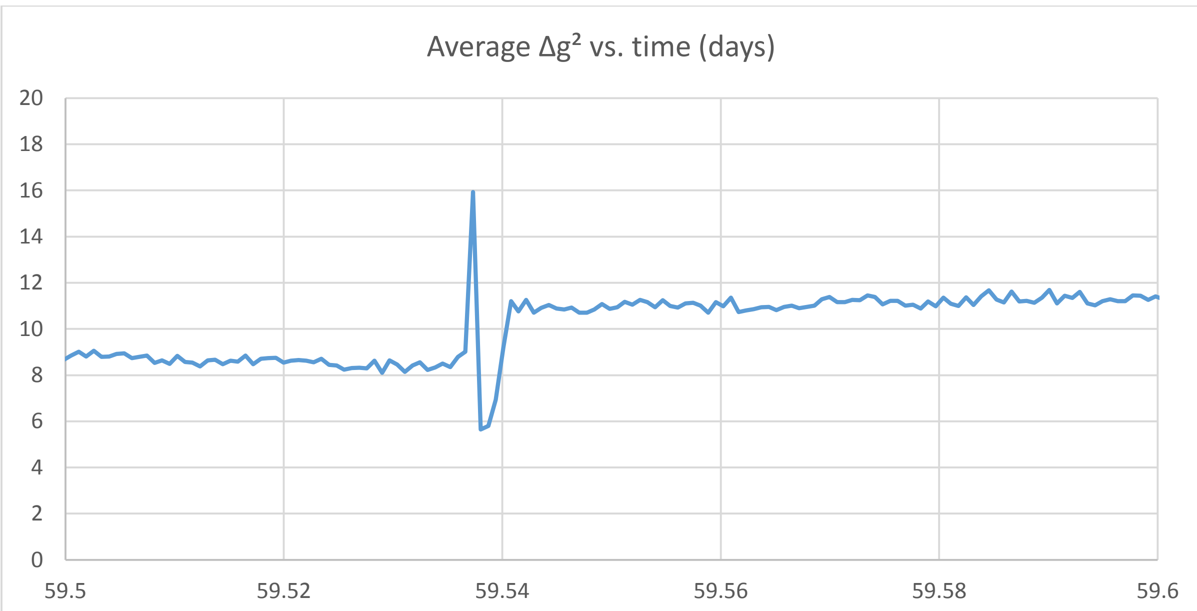
As the season progressed, recognizing predation and over-wash events became more important. Frequent predation events were able to mask the activity of hatchlings in nest NH037. But just as hatching events seem to have a signature (the three periods discussed previously), predation and over-washes also appear to have their own signatures in the data.

Predation events are typically recorded as isolated events of short duration and very large magnitude. The graphs shown so far have chopped the tops off of these predation events. They can reach magnitudes of 10,000 or more, which corresponds to forces of 0.1 g or more. These events might be the result of ghost crabs attacking the Smart Sensor or a nearby egg.

Inspections of the nest by NPS turtle patrols can cause spikes that look just like intense predation events.

Over-washes are typically recorded as events that abruptly change the background noise level in a short time. There is often a short pulse or two in the data, of a small magnitude, and then the noise level changes. Sometimes the pulse is to a higher reading, and sometimes it is to a lower reading. Often it is both. The new noise level is sometimes higher and sometimes lower.

The reasons for these changes in the data are unclear. The pulse might be from the water of the over-wash making physical contact with the sensor. After the over-wash, the sand between the sensor and the surf is now wetter than it had been. The wetter sand may be a better conductor of the surf than dry sand causing the background noise level to rise. Wetter sand may also be more compact and heavier, which might dampen the vibrations. Some of the activity recorded may be from the motion of turtle embryos. If that is the case, surf action might make them more or less active.



Detail of over-wash event

This graph is a detail from nest NH006. This event has the characteristics of an over-wash. Each time line marks 0.02 days, or a little less than half an hour. Each point on the graph is a 1 minute average reading. There is a very quick upward pulse, lasting about a minute, but not nearly as intense as a predation pulse. Then there is a downward pulse that is about 2 minutes long. The background level before the event is between eight and nine. After the event it is about eleven. Ongoing analysis will hopefully determine if this is a typical or unusual over-wash event and perhaps lead to a better understanding of why over-washes cause the data to look like this.

c. Predicting hatching events

Accurate predictions of emerging hatchlings using the “popcorn pattern” were made for almost all of the nests in advance. A couple of nests were missed only because the data was not looked at in time. Monitoring at nest NH006 began too late to get a complete picture of what was going on. Even so, and even though this was one of the first nests, a prediction was made, and it turned out to be correct.

There was only one nest that had no predictions in advance of hatchlings emerging. The data from NH037 was likely obscured by the nearly constant predation by ghost crabs. Because of the heavy predation, only a small percentage of the turtles survived. The small number of hatchlings that did survive may have not been near the sensor. A more thorough analysis of the data from the nest might result in a method that could have been used to make a prediction. It is difficult to reach conclusions when there was only one nest like this.

Hatchlings began emerging from nest NH058 just over 7 days after monitoring began. A prediction was made at just about the same time. With earlier data, the prediction may have been possible earlier. This nest was also the first that was up in the dune grass, and we may need more data and a different approach before we can make predictions about nests similarly located.

d. Turtle nesting biology

Previous studies of the motion of hatchlings in the nest before emerging have theorized that the activity from the turtles moving around in their eggs, and then from hatching, stimulated the other turtles to hatch and that somehow they coordinate the timing of when to emerge in a boil from all this motion.

However, the previous theory does not offer a sufficient explanation of the data obtained by this project. Almost all of the nests monitored showed three distinct “popcorn” periods, the second of which was a period of erratic activity. This data may be the result of turtles hatching and then moving around in the nest, but that does not explain the short quiet third period that follows. The third period precedes the emergence of the hatchlings–often by just a few hours. It also does not explain the downward dip at the end of the first period. Also unexplained are the very low readings recorded at times during the erratic second period. So there are three unexplained periods of relative quiet–the quiet periods just before, during, and just after the erratic period.

The quiet readings are in a range that is usually lower than most, if not all, of the readings that came before. Logically, it is safe to assume that the background noises of the environment nearby do not get quieter when nests are about to hatch. So something new has happened, and this “something new” is a phenomenon that dampens the environmental sound that is usually recorded by the devices.

Matthew Godfrey has suggested that the pipping of the hatchlings through the eggs might be the cause of the first dip in the data. His reasoning is that when the hatchlings pip, fluid in the eggs drains out the bottom of the nest, and the eggs settle opening up a chamber of air in the nest cavity.

If so, the sensor, sitting on top of all the eggs, which had been surrounded by sand, may now be partially or fully surrounded by air. This might attenuate the noise level if air does not conduct sound as well as sand at the frequencies that are being measured. However, the data from nest NH005 shows that the sensor started deflecting about a day *after* the recorded level went down, which seems to indicate that the air cavity in the nest had not yet formed. A possible explanation for both of these phenomena is that the forming of the air chamber below the sensor dampens the environmental noise reaching the sensor, but the sand above the chamber holding the sensor in place remains intact. Many turtle researchers have mentioned hearing "waterfalls" of sand within the nest as the chamber collapses and then a depression forms. The "waterfalls" could very likely be the erratic readings caused by the second period.

Still unanswered by this explanation is why there would be low readings *after* the erratic period has stopped. If a depression has formed, all the sand would have collapsed and the air chamber would be gone. Several nest reports indicate the presence of hatchlings when the nests were excavated. These remaining hatchlings were often noticed at the level of the sensor, often on top of or under the sensors. Other researchers have mentioned that hatchlings congregate at the top of the nest before a boil, and that was the prime reason for choosing the placement of the Smart Sensor in the nest. The expectation was that the motion of these hatchlings would cause dramatically large readings from the sensor. But it appears that the exact *opposite* was the case. There is often a period of very low readings from the sensor, and observations indicating that the hatchlings were near, if not actually touching the sensor.

Hatchlings surrounding the sensor could very well be the reason that environmental noises were attenuated. The bodies of hatchlings, being soft and mostly inelastic, would absorb sounds and impacts from their surroundings. The implication of this, though, is that the turtles surrounding the sensor are not moving.

We were able to use the "popcorn pattern" of the data to predict when turtles emerge from the nest. The "popcorn pattern" also suggests a theory about how sea turtles decide to leave the nest. The turtles' programming may be analogous to listening to popping corn in boiling oil. When the kernels heat up, they start to jiggle a little, and since they are all similar and underwent a roughly similar amount of heating, they all start to pop at about the same time. But there is some variation, so they don't all pop at once. If you are making popcorn, you listen to the popcorn and wait until you no longer hear any popping. After a short time with no pops, it is time to pour everything out of the pot. So, perhaps the turtles are all instinctively listening for things to quiet down after hatching, and that way they know that it is time to leave the nest. The quieting down might be the clue to the turtles that all their siblings have hatched and it is time for a boil. As each turtle hatches, there is no need for it to move anymore and waste its limited energy supply. All it needs to do is wait for everyone else to finish their wiggling. If there is no wiggling, all the eggs have hatched, and it is time to go.

The data was also quite surprising in another respect. The boil itself is hardly noticeable. It is difficult to determine the precise time when boils occurred from looking at the data. Very high readings were expected when the baby turtles moved past the sensor egg. There were, however, very few or no dramatically large motions recorded. It could be that the hatchlings that have already started moving up through the sand are already above the sensor, but observations from the field seem to contradict that theory. The most observed nest of the season, NH047, was inspected a couple of times during the three days before the boil. The data from this nest showed that the erratic period had ended, things had quieted down, and a boil was imminent. The inspections showed that the hatchlings had congregated around the sensor, and all the readings for those last few days are low and undramatic. However, they do increase slightly and reach their highest reading just at the time of the boil. This seems to indicate that the hatchlings were still around the sensor when the boil began.

Most of the nests were accurately predicted by using the “popcorn pattern.” The few outliers often had a history of disturbances to the nest somewhere in the period from a few days before the erratic period to just before emergence. There is not enough data to reach any conclusions about these disturbances. Some of these nests had results that were earlier than expected, and some were later. Determining if disturbances to the nests inhibit or stimulate the emergence of hatchlings is a possible topic for future research

VIII. Publicity and outreach

The project has received a good deal of positive press. Telit, the manufacturer of the cell module used in the device, distributed a press release that was published in the *Wall Street Journal* and picked up in other places. This led to other articles, web posts, and interest by a reporter at IEEE Spectrum, who produced two pieces aired on NPR’s nationally-distributed radio program, “Here & Now.”

The team entered Turtle Sense in the “Hackaday Prize” competition and were one of 50 semifinalists chosen. The attention led to mentions in other places including Engadget.com and PsychologyToday.com. The publicity led to many volunteers coming forward to offer their technical skills and expertise.

Wantman and Hermeyer traveled to North Carolina for two weeks in September, 2014, visiting Cape Hatteras and Bald Head Island. They were able to meet the NPS staff they been working with for the past year.

In October 2014, Kaplan and Muisneiks gave a talk about our project at a gathering about technology and wildlife management.

Charles Wade, a retired IBM scientist, contacted many people working with sea turtles around the country. Wade, along with Wantman and Kaplan, will be attending the South East Regional Sea Turtle Meeting in Jekyll Island, GA in February, 2015 to present the project and the results reported in this document. Most of the groups working with sea turtles in the Eastern US will have representatives in attendance.

Wantman will be giving a talk about the project at the Citizen Science 2015 Conference (CitSci2015) at the San Jose Convention Center also in February, 2015.

More information about this project can be found at TurtleSense.org.

 The author of the document is Samuel Wantman, and contributions of content were also made by Thomas Briley, Matthew Godfrey, David Hermeyer, Eric Kaplan, Harriet Kaplan, Britta Muiznieks, William Thompson, Charles Wade, and Thomas Zimmerman.

The photos on the cover (page 1), the bottom of page 15, page 20, and page 24 were taken by Britta Muiznieks.

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Nerds Without Borders