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Timing and prediction of CO2 eruptions from Crystal Geyser, UT

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Frank Gouveia and S. Julio Friedmann

Abstract

Special instruments were deployed at Crystal Geyser, Utah, in August 2005 creating a contiguous 76-day record of eruptions from this cold geyser. Sensors measured temperature and fluid movement at the base of the geyser. Analysis of the time series that contains the start time and duration of 140 eruptions reveals a striking bimodal distribution in eruption duration. About two thirds of the eruptions were short (7-32 min), and about one third were long (98-113 min). No eruption lasted between 32 and 98 min. There is a strong correlation between the duration of an eruption and the subsequent time until the next eruption. A linear least-squares fit of these data can be used to predict the time of the next eruption. The predictions were within one hour of actual eruption time for 90% of the very short eruptions (7-19 min), and about 45% of the long eruptions. Combined with emission estimates from a previous study, we estimate the annual CO_2 emission from Crystal Geyser to be about 11 gigagrams (11,000 tonnes).

Introduction

As carbon capture and sequestration (CCS) emerges as a key technology for reducing greenhouse gases (GHG) emissions, there is increasing need to focus on questions of risk, particularly the health, safety and environmental (HSE) risks associated with CO_2 leakage out of the storage reservoir into groundwater or to the surface through cap rock seal failures, faults, fractures or wells. Understanding these risks and developing methodologies for their assessment are critical to site assessment, planning of monitoring and mitigation strategies, and to attaining public acceptance and confidence in CCS deployment.

Although there has been substantial discussion of potential failure modes, the likely pathways for CO_2 to reach the surface (e.g., wells), and of the potential effects and impacts (Gale, 2004), there has been much less attention to the issues of assessing leakage rates and evaluating their associated HSE risks. Detecting and understanding the risks associated with unmapped abandoned wells remains a major carbon sequestration challenge. There are estimates that on the order of 100,000 abandoned wells exist in U.S. oil and gas fields that have potential to be CO_2 sequestration sites.

Natural analogs provide a potential way to obtain such information for some leakage scenarios. This study focuses on Crystal Geyser near Green River, UT as an analog for one important potential mode of CO_2 leakage from wells (Bogen et al., 2006; Wilson and Friedmann, 2006).

Background

CO_2-charged cold geysers are extremely rare, and Crystal Geyser in southeastern Utah (N 38.9383º, W 110.1342º) is the largest cold geyser in the world. This geyser was unintentionally created in the 1930s after a prospective oil well was drilled about 800 m deep into a fault zone above a natural CO_2 reservoir (Baer and Rigby, 1978). Shortly after drilling, this well was abandoned and not properly capped. Now, Crystal Geyser erupts periodically in a dramatic fashion, although the nature of the periodicity has never been studied.

It was proposed (Shipton et al., 2005) that CO_2 from fossil-fuel power plants be injected into deep geological formations as a way to sequester this greenhouse gas. Crystal Geyser can be considered the maximum example of a surface emission from a deep CO_2 reservoir; although the actual storage methods will inject gas at depths greater than 800 m (Allis et al., 2001). Successful injection will retain billions of tons of CO_2 for geologic time periods. Injection activities must be accompanied by monitoring to ensure safety and effectiveness. Abandoned wells, poorly sealed injection sites, and natural faults and fractures have been identified as possible causes for CO_2 leakage (Gale, 2004). Crystal Geyser and the surrounding area provide a unique opportunity to study surface emissions of CO_2. The Little Grand Wash Fault features ancient travertine structures, indicating a long history of gas-driven groundwater leakage.

A previous field study (Gouveia et al., 2005) produced estimates of the emission mass from Crystal Geyser in October 2004. We evaluated airborne concentrations of CO_2 50-m downwind from the erupting geyser. The best-fit Gaussian curve was applied to the concentrations to algebraically yield the emission mass. Although this was a limited study, evaluating only three eruptions, we found that Crystal Geyser emits between 150 and 360 kg/min during an eruption.

Before the October 2004 study, the periodic eruptions from Crystal Geyser had never been objectively monitored. Previous studies relied on anecdotal evidence and personal communications to reconstruct the timing of this geyser. Other more-famous geysers have been extensively studied and monitored. One example is the Old Faithful Geyser in Yellowstone National Park (Azzalini and Bowman, 1990; Rojstaczer et al., 2003). They found an unusual bimodal pattern to the eruption timing data of this geothermal feature. Further, they demonstrated that the time until the next eruption is proportional to the eruption duration.

Five eruptions of Crystal Geyser were observed during the October 2004 study. Although four of the eruptions were between 7 and 25 min, one eruption lasted more than 2 hours. The timing information revealed a correlation between the eruption duration and interim time, as seen in a few geothermal geysers. With such a limited record of eruption timing, there was great uncertainty in the distribution of the eruption durations (Gouveia et al., 2004). Characterization of the uncertainty is central to determine if Crystal Geyser would be an appropriate site for CO_2 plume monitoring, modeling, and detection scenarios and if so, what are its magnitude and rate of CO_2 venting. This information could then constrain the risk posed by CO_2 leaks of similar character.

Measurements

For this study, we monitored the eruptions of Crystal Geyser over a 76-day period, creating a list of start time and duration for 140 contiguous eruptions. Two types of sensors were used to detect the eruptions of Crystal Geyser: thermistors and differential-pressure sensors. Additionally, ambient air temperature was measured near the data logger, about 25 meters from the geyser. All sensors were sampled once a second, and one-minute averages were saved. A Campbell Scientific CR10X data logger (Figure 1) controlled the acquisition and compilation of the raw data. This logger was powered by battery and solar panel. Figure 2 is a photograph of the base of the geyser showing the positions of the three thermistors and two of the differential-pressure sensors.

Thermistors

Geyser eruptions are typically measured with thermocouples or thermistors (Nishi et al., 2000, for example). These rugged sensors are well suited for application in hot geothermal geysers. For this study we deployed three thermistors (Yellow Springs Instrument model 44006) at different points at the base of Crystal Geyser. Each thermistor bead was protected with a thin sleeve of shrink-fit tubing. The thermistors were placed at slightly different heights with the hope that the level of the water could be resolved.

Figure 1. Photo of the data logger box with Crystal Geyser in the background.

Differential Pressure

A unique type of sensor was deployed at 4 locations on the geyser. One-meter lengths of surgical tubing were folded and stretched horizontally across a chord of the geyser vent. The tubing was sealed, forming a water-tight bladder that would distort when in the stream of an active geyser. The bladder was connected to ¼” diameter drip irrigation tubing, which terminated at a differential-pressure transducer (Setra model 265) inside the logger box. These transducers proportionally converted the difference in pressure between the tube and the interior of the enclosure to an analogue voltage, which was digitized and saved by the data logger.

Succinctly, eruptions cause deformation of the motion-sensing bladder resulting in small pressure changes that are transferred via the long tube to the pressure transducer. A small incision in the tube near the transducer allows air to escape slowly, avoiding a buildup of pressure in the tubing. The pressure changes caused by an erupting geyser are very quick, and easily distinguished from the quiescent, near-zero signals from an inactive geyser. The data logger computes the average (ΔP) and standard deviation ($\sigma_{\Delta P}$) of the pressure signal.

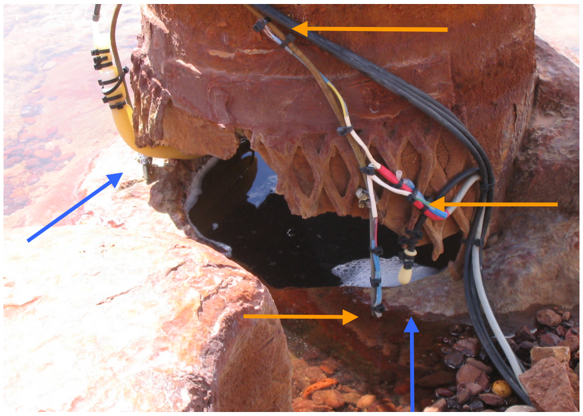

Figure 2. Photo of the base of Crystal Geyser, showing the placement of the thermistors (orange arrows) and differential pressure sensors (blue arrows).

Previous studies have used pressure sensors to monitor the water depth in geysers. Nishi et al. (2000) monitored static pressure at a fixed point below the lowest water level. These methods would be impractical in the energetic Crystal Geyser, although we did deploy thermistors to monitor the water effluent in fashion similar to Nishi and others.

Other measurements

Ambient air temperature was measured near the data logger with a Campbell Scientific 107-L sensor mounted in a 6-plate Gill radiation shield. These measurements were compared against the temperature measurements taken at the base of the geyser.

Results

Eruption Timing

The primary mission of this study was to monitor the eruptions of Crystal Geyser over a two-month period. The monitoring system was erected on 25 August, 2005, and disassembled on 9 November. The first active eruption, witnessed by Mr. Gouveia, started at 19:39:30 MDT on August 25th and ended 20 minutes later (Figure 3).

Every eruption follows a consistent sequence of activity. Hours before the eruption the pool fills with water. Then there is a series of minor bubbling events lasting about ten minutes and separated by quiet times of about 20 min. These non-erupting events increase in energy and expel a significant amount of water. Eventually a bubbling event transitions into an active eruption. The active eruption can last from 7 to 137 min, but the record shows no eruptions lasting between 32 and 98 min. The eruption ends abruptly with a draining of the water in the pool back into the geyser well. It can take several hours for the water level to come back up to the bottom of the geyser.

Close examination of the time series of the temperature and $\sigma_{\Delta P}$ reveals obvious changes that indicate the three states of the geyser: quiescence, bubbling event, active eruption.

Examples of the time series for temperature (Figure 4) and $\sigma_{\Delta P}$ (Figure 5) are typical of the record of all eruptions. From the start of the time series until the start of the eruption at 15:39 both graphs record a series of bubbling events. During one of these events, the 17ºC water flows out of the well and envelopes the thermistors. The pressure sensors are also in this bubbling stream and record the vibrations. Between the minor eruptions, the thermistors are uncovered and act as wet-bulb thermometers sensing temperatures many degrees cooler than the ambient dry temperature measured near the data logger. One pressure sensor (SD2) was high enough not to be affected by the minor bubbling events, where SD1 was in a position to record every event.

At the beginning of the active eruption, the temperature of the water and gas mixture is stable at 17.25ºC. The activity detected by the pressure sensors is much greater than the activity during a minor bubbling event. As the eruption progresses into its second hour, the effluent temperature decreases slightly to about 16.5ºC, perhaps indicating the water is from a deeper source. The pressure sensors also show a possible change in the activity of the eruption over the course of the 2-hour event. It is not known if this corresponds to a change in the CO_2 emission during the eruption, although the October 2004 study did not observe a significant change in emission through the course of the 2-hour eruption.

After the end of the eruption the pool empties into the empty well. The thermistors act as wet-bulb thermometers until they dry and parallel the ambient air temperature.

Figure 3. Photo of the first eruption monitored for this study. The height of the water is approximately 3 meters, although the highest burst can reach 15 meters.

One surprising phenomenon is easily noticed in the $\sigma_{\Delta P}$ record. After a 2-hour eruption there are several sudden bursts of gas forcefully expelled from the vent. Figure 5 shows at least three spikes during these events, the first occurring at 18:00.

The start and end time of every eruption can be ascertained from the graphic and digital time series of temperature, $\sigma_{\Delta P}$, and average ΔP. Table 1 in the Appendix is a complete list of the timing of the 145 eruptions detected during this and the October 2004 studies.

Bimodal Distributions

There is a distinct bimodal character in the distributions of the eruption durations (Figure 6). Of the 145 eruptions, 91 were in the shorter mode and 54 in the longer mode. The average time of the shorter eruptions is 19 min, and the longer eruptions averages 114 min. As stated before, there were no eruptions between 32 and 98 min. The longest eruption (137 min) was also the last one in the record. The time between eruption starts also show the same bimodal shape, although we do not show the histogram. The average time after a short eruption is 7.6 hours, and 22.2 hours after a long eruption.

Although the phenomenology of bimodal eruption duration and episodicity is well defined, it is not clear what mechanisms produce these distributions. Observations of the large eruption data provide some clues. For example, the eruption temperature record in Figure 4 shows a sigmoidal record defined by a two temperature plateaus with an higher initial and lower final temperature. The time duration between these plateaus covers the gap between the two eruption modes. This pattern occurred during many long eruptions, with the short eruptions having the higher temperature of the initial plateau.

There pattern has many possible explanations. Since CO_2 is buoyant, the duration of the long eruptions must be limited by the depth to the reservoir. It may be that short eruptions only evacuate a portion of the well due to insufficient CO_2 charge. Also, CO_2 decompression should cool the water in the well casing, with the deeper water experiencing more rapid decompression. These hypotheses may be tested through simulation or more comprehensive monitoring of Crystal Geyser eruptions.

Correlation and Predictions

There is a strong correlation between the eruption duration and the subsequent time until the start of the next eruption. Figure 7 is drawn with data from this and the October 2004 studies. The linear least-squares fit of the data can be used to predict the start time of the next eruption. The equation for this line is

$$Y = 0.153 \cdot X + 4.71, \qquad (1)$$

where X is the duration of an eruption in minutes, and Y is the time until the next eruption in hours.

Equation 1 was used to predict subsequent eruptions, and the results are presented in Table 1 under the heading “Prediction.” Also in this table is a column for the error of the prediction. It is clear the prediction is more accurate after the short eruptions (Figure 8).

Another view of this data is presented as Figure 9. The 143 eruptions are divided into three nearly equal divisions for very short (7-19 min), short (20-33 min), and long (98-133 min) eruptions. This chart provides useful information when predicting the next eruption with Equation 1. For instance, after a very short eruption about 90% of eruptions were within ±60 min of the prediction. After a long eruption only about 45% of the predictions were within one hour, and 80% of the predictions were within two hours.

Equation 1 will predict the time of the next eruption, but how long will that eruption last? Reviewing Table 1 reveals a pattern in the eruption duration time; a very short eruption is followed by a longer eruption and then a 2-hour eruption. This pattern occurs in the record 32 times. Only once (10/21/05) did the opposite pattern occur where a short eruption (17 min) was followed by a significantly shorter one (13 min).

Another pattern can be found where a single short eruption is between two 2-hour eruptions. This happened 19 times. For this pattern, the shorter eruptions tend to be of moderate length (11-25 min).

Cumulative Eruption Time

We can also create a time series of the cumulative eruption time (Figure 10). The resulting graphic shows a consistent accumulation of eruption time. There were 7733 total minutes of eruption over the 76-day study, averaging just over 100 minutes per day.

Conclusions

The unique sensors used in this study to measure the timing of Crystal Geyser proved to be durable, easy to maintain, and reliable. Eruption start and end times can easily be deduced from the time series of the pressure and temperature measurements. This type of objective measurement has never been done at Crystal Geyser, revealing new information. The distinct bimodal nature of this geyser's eruptions has never been reported. Two thirds of the eruptions last about 20 minutes; the longer eruptions persist for about 2 hours.

In addition, we have presented a relationship between eruption duration and time until the next eruption. This relationship is accompanied by the expected error in the prediction time, with more accurate predictions after the shorter eruptions.

Annual Emissions

Combining the timing information gained by this study and the emission estimates from the October 2004 study we can estimate the total mass of CO_2 emitted from Crystal Geyser over a year. Emission rate ranged from 2.6 to 5.8 kg/s. Using a mid-range value of 5 kg/s (300 kg/min) and the average value of 100 minutes per day of eruption time yields a total annual emission of 11 gigagrams (11,000 tonne) of CO_2.

Source-term Definition and Risk

The instantaneous rate, the daily rate, and the annual emissions can be used as source terms that serve as analogs to potential leakage scenarios (Gouveia et al., 2005). For such scenarios, it appears that in many circumstances the instantaneous leakage rates do not present a substantial risk to human health. It also appears that leakage of this kind, even in such spectacular cases, may not be detected more than 100 m from the vent due to atmospheric mixing. This presents a challenge to monitoring planning and array optimization. It should be said, however, that other scenarios may present a more substantial risk (Bogen et al., 2006; Wilson and Friedmann, 2006).

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Bibliography

Allis, R., S. White, T. Chidsey, W. Gwynn, C. Morgan, M. Adams, J. Moore (2001), "Natural CO_2 reservoirs on the Colorado Plateau and Southern Rocky Mountains: Candidates for CO_2 sequestration," Proceedings of the First National Conference on Carbon Sequestration, Washington DC, May 2001.

Azzalini, A., and A. W. Bowman (1990), "A look at some data on the Old Faithful Geyser," Appl. Statist. **39**, 3.

Bogen, K., E. Burton, S.J. Friedmann, and F. Gouveia (2006), "Source terms for CO_2 risk modeling and GIS/simulation based tools for risk characterization," 8th Greenhouse Gas Technology Conference, Trondjheim, Norway.

Baer, J. L. and J. K. Rigby (1978), "Geology of the Crystal Geyser and environmental implications of its effluent, Grand County, Utah," Utah Geology **5**, 2.

Gale, J. (2004), "Geological storage of CO_2: What do we know, where are the gaps and what more needs to be done?" Energy **29**, 1329-1338.

Gouveia, F., M. R. Johnson, R. N. Leif, and S. J. Friedmann (2004), "Aerometric measurement and modeling of the mass of CO_2 emissions from Crystal Geyser, Utah," Lawrence Livermore National Laboratory, Livermore, CA, UCRL-TR-212870.

Gouveia, F., M. R. Johnson, R. N. Leif, and S. J. Friedmann (2005), "Aerometric measurement and modeling of the mass of CO_2 emissions from Crystal Geyser, Utah," NETL 4th Annual Conference on Carbon Sequestration, Alexandria, VA, ExchangeMonitor Publications.

Nishi, Y., T. Ishido, M. Sugihara, T. Tosha, N. Matsushima, and B.J. Scott (2000), "Monitoring of geyser activity in Whakarewarewa, New Zealand," Proceedings World Geothermal Congress 2000, Kyushu – Tohoku, Japan, May 28 – June 10, 2000.

Rojstaczer, S., D. L. Galloway, S. E. Ingebritsen, D. M. Rubin (2003), "Variability in geyser eruptive timing and its causes: Yellowstone National Park," Geophysical Research Letters **30**, 18.

Shipton, Z. K., J. P. Evans, B. Dockrill, J. E. Heath, A. Williams, D. Kirschner, and P. T. Kolesar (2005), "Natural leaking CO_2-charged systems as analogs for failed geologic sequestration reservoirs," in Carbon Dioxide Capture for Storage in Deep Geologic Formations, Volume 2, D. C. Thomas and S. M. Benson, Eds. (Elseveir Science Publishing, North Holland, Amsterdam), pp. 699-712.

Wilson, E.R., and S.J. Friedmann (2006), "Squaring the Long View: Regulatory and geological considerations for establishing future research agendas for Carbon Capture and Sequestration," NETL 5th Annual Conference on Carbon Sequestration, Alexandria, VA, ExchangeMonitor Publications.

Appendix A - Graphs

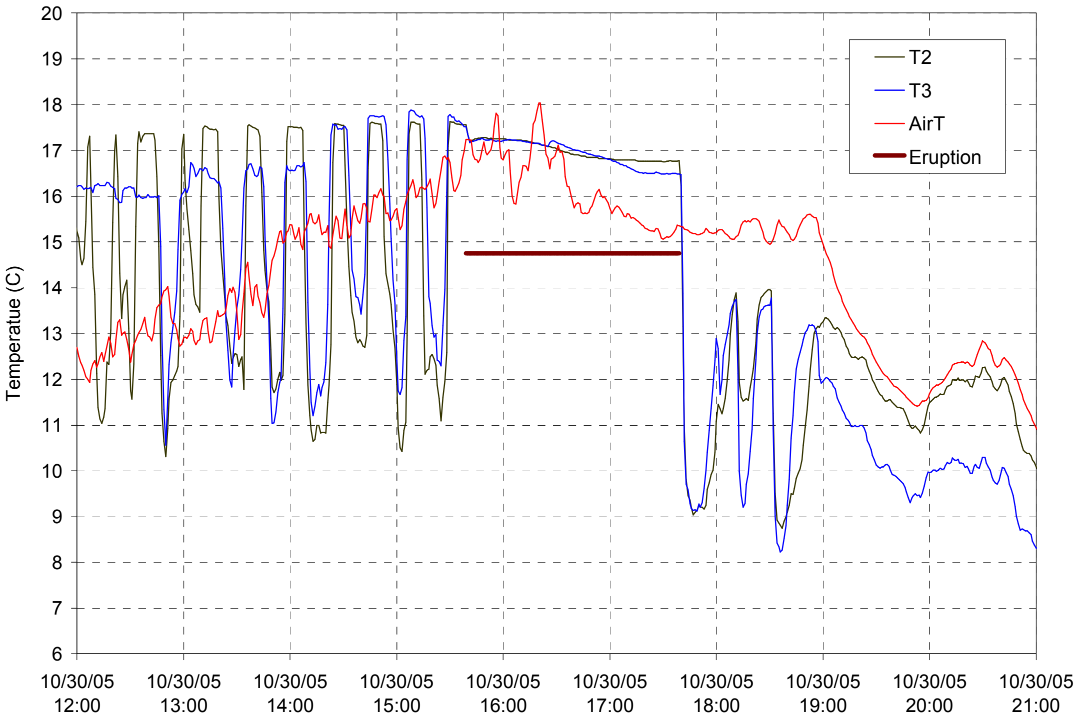

Figure 4. Time series of temperature measured at the base of the geyser (T2 & T3) and in the ambient air (AirT). The horizontal bar indicates the time of the active eruption. Time is based on Mountain Daylight Time.

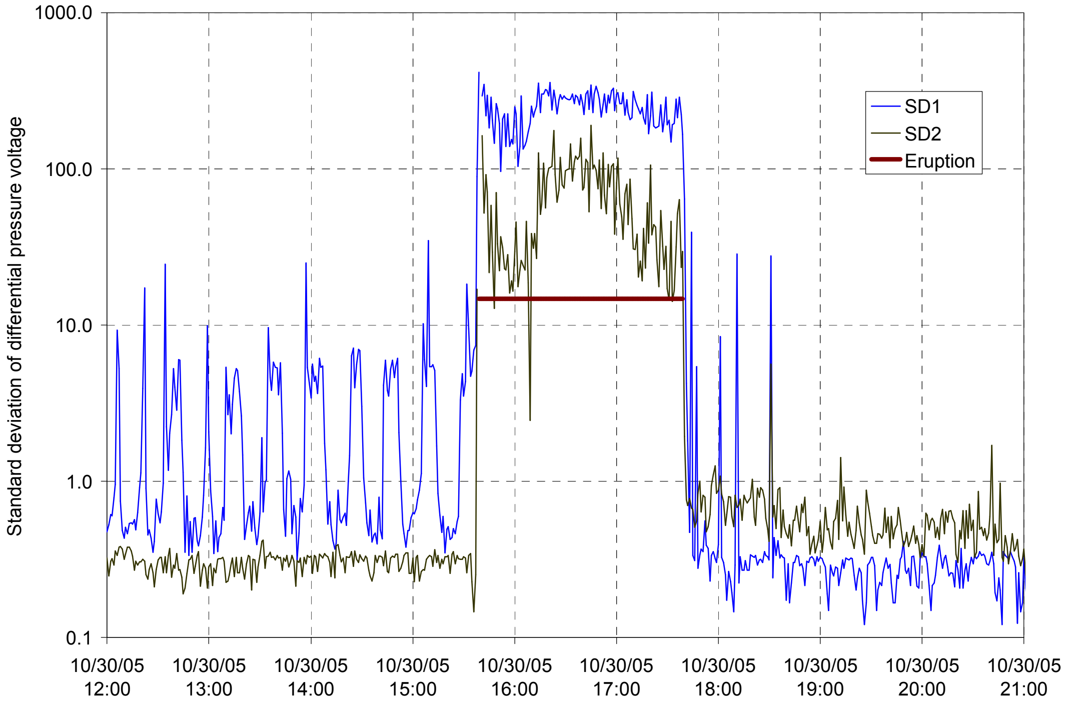

Figure 5. Time series of the standard deviation of the voltage output from the differential pressure sensors. The horizontal bar indicates the time of the active eruption. Time is based on Mountain Daylight Time.

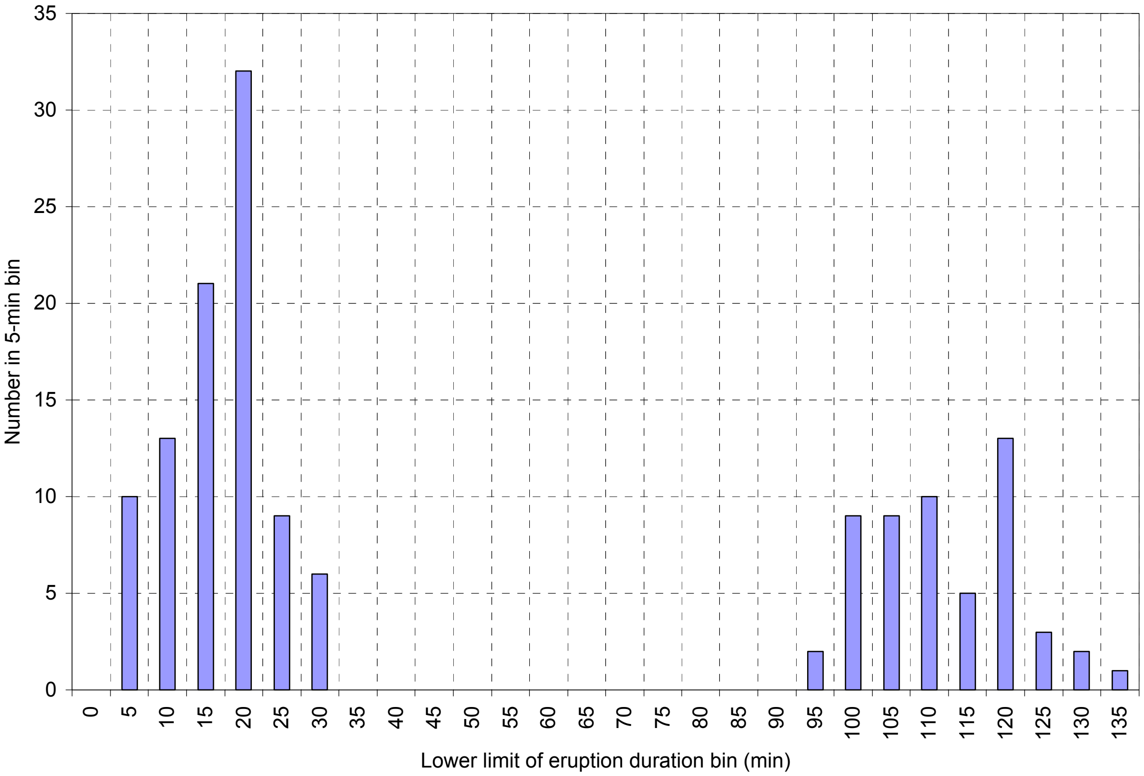

Figure 6. Histogram of eruption duration for all 145 eruptions.

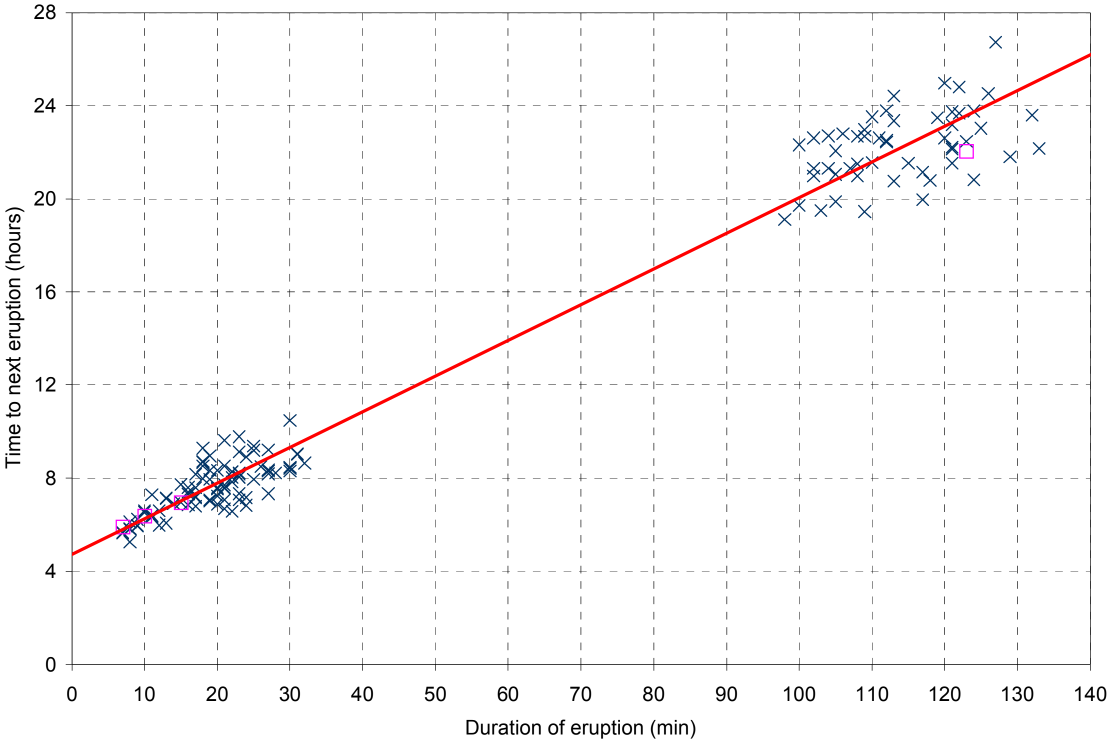

Figure 7. Graph of eruption duration versus time until start of the next eruption. Red line is the linear least-squares fit of all 143 data points. The four box data points are from the October 2004 study

Figure 8. Error in the prediction (Equation 1) plotted by the eruption duration.

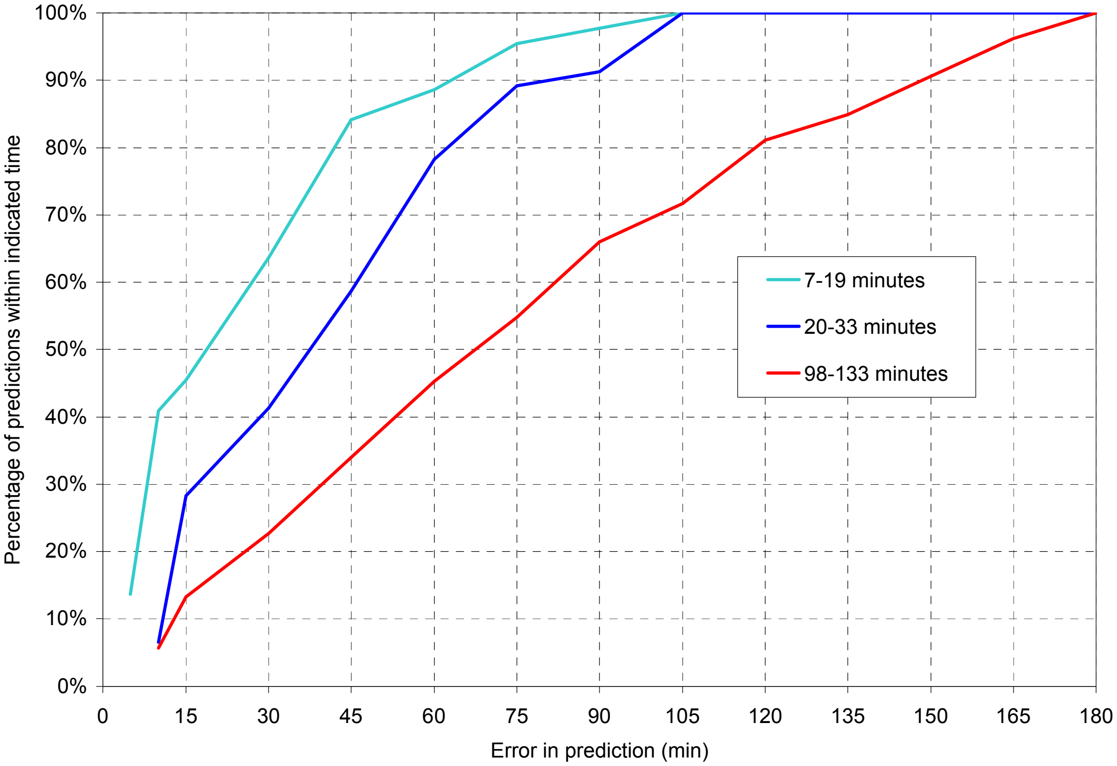

Figure 9. Accuracy of the prediction based on Equation 1. The 143 eruptions are divided into three equally sized groups based on eruption duration

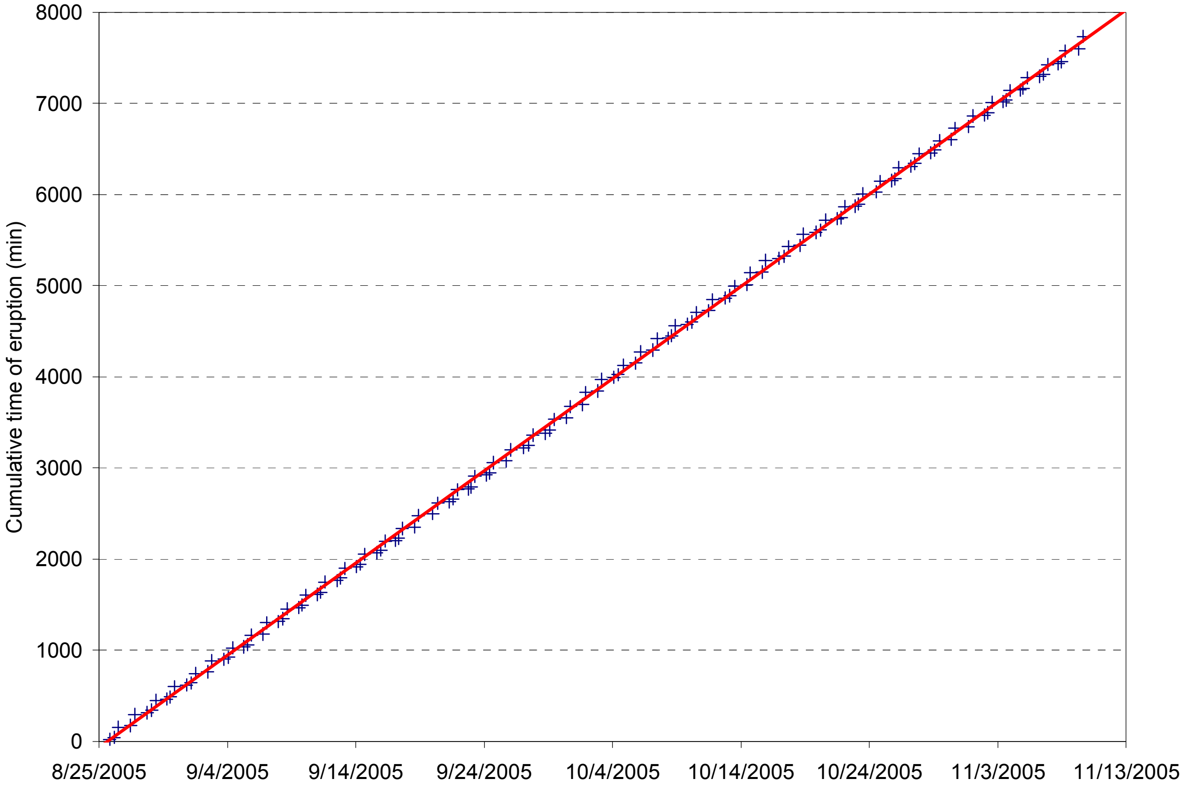

Figure 10. Cumulative eruption time over the course of this study. The slope of the line is 101 minutes per day.

Appendix B – Table of Eruptions

Table 1. Start and end times (MDT) of eruptions of Crystal Geyser observed during this and the previous study (Gouveia et al., 2005). The eruption duration and the error in prediction have units of minutes. The time between eruptions has units of hours. The first five eruptions in this list were part of the October 2004 study.

Sequence	Start time	End time	Duration	Time between	Prediction	Error in prediction
1	10/14/04 17:26	10/14/04 17:33	7		10/14/04 23:13	-7
2	10/14/04 23:20	10/14/04 23:35	15	5.9	10/15/04 6:20	4
3	10/15/04 6:17	10/15/04 8:20	123	7.0	10/16/04 5:51	92
4	10/16/04 4:19	10/16/04 4:29	10	22.0	10/16/04 10:33	-7
5	10/16/04 10:41	10/16/04 11:06	25	6.4	10/16/04 19:13	---
6	8/25/05 19:39	8/25/05 20:00	21		8/26/05 3:35	-35
7	8/26/05 4:10	8/26/05 4:32	22	8.5	8/26/05 12:15	3
8	8/26/05 12:12	8/26/05 14:01	109	8.0	8/27/05 9:37	-75
9	8/27/05 10:53	8/27/05 11:14	21	22.7	8/27/05 18:49	13
10	8/27/05 18:36	8/27/05 20:37	121	7.7	8/28/05 17:52	5
11	8/28/05 17:47	8/28/05 18:06	19	23.2	8/29/05 1:24	-42
12	8/29/05 2:07	8/29/05 2:33	26	8.3	8/29/05 10:49	12
13	8/29/05 10:37	8/29/05 12:26	109	8.5	8/30/05 8:02	119
14	8/30/05 6:04	8/30/05 6:16	12	19.5	8/30/05 12:37	-3
15	8/30/05 12:40	8/30/05 13:07	27	6.6	8/30/05 21:31	40
16	8/30/05 20:51	8/30/05 22:42	111	8.2	8/31/05 18:35	-53
17	8/31/05 19:28	8/31/05 19:48	20	22.6	9/1/05 3:14	-33
18	9/1/05 3:48	9/1/05 4:11	23	8.3	9/1/05 12:02	0
19	9/1/05 12:02	9/1/05 13:44	102	8.2	9/2/05 8:23	-136
20	9/2/05 10:39	9/2/05 10:58	19	22.6	9/2/05 18:16	37
21	9/2/05 17:40	9/2/05 19:41	121	7.0	9/3/05 16:56	-28
22	9/3/05 17:24	9/3/05 17:41	17	23.7	9/4/05 0:43	-51
23	9/4/05 1:34	9/4/05 1:57	23	8.2	9/4/05 9:48	3
24	9/4/05 9:45	9/4/05 11:27	102	8.2	9/5/05 6:06	-38
25	9/5/05 6:44	9/5/05 6:54	10	21.0	9/5/05 12:58	-21
26	9/5/05 13:20	9/5/05 13:44	24	6.6	9/5/05 21:43	74
27	9/5/05 20:30	9/5/05 22:14	104	7.2	9/6/05 17:09	-39
28	9/6/05 17:49	9/6/05 18:02	13	21.3	9/7/05 0:31	-27
29	9/7/05 0:58	9/7/05 3:01	123	7.2	9/8/05 0:32	66
30	9/7/05 23:26	9/7/05 23:41	15	22.5	9/8/05 6:26	-43
31	9/8/05 7:10	9/8/05 7:40	30	7.7	9/8/05 16:28	54
32	9/8/05 15:35	9/8/05 17:25	110	8.4	9/9/05 13:09	2
33	9/9/05 13:08	9/9/05 13:20	12	21.6	9/9/05 19:41	34
34	9/9/05 19:07	9/9/05 19:34	27	6.0	9/10/05 3:58	91
35	9/10/05 2:27	9/10/05 4:15	108	7.3	9/10/05 23:43	17
36	9/10/05 23:26	9/10/05 23:36	10	21.0	9/11/05 5:40	-17
37	9/11/05 5:58	9/11/05 6:21	23	6.5	9/11/05 14:12	11
38	9/11/05 14:01	9/11/05 15:53	112	8.1	9/12/05 11:54	-37
39	9/12/05 12:31	9/12/05 12:48	17	22.5	9/12/05 19:50	31
40	9/12/05 19:19	9/12/05 19:46	27	6.8	9/13/05 4:10	33
41	9/13/05 3:37	9/13/05 5:22	105	8.3	9/14/05 0:25	-14
42	9/14/05 0:40	9/14/05 0:59	19	21.0	9/14/05 8:17	34
43	9/14/05 7:44	9/14/05 8:12	28	7.1	9/14/05 16:44	47

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Sequence	Start time	End time	Duration	Time between	Prediction	Error in prediction
44	9/14/05 15:57	9/14/05 17:46	109	8.2	9/15/05 13:22	-92
45	9/15/05 14:55	9/15/05 15:11	16	23.0	9/15/05 22:05	-14
46	9/15/05 22:19	9/15/05 22:49	30	7.4	9/16/05 7:37	51
47	9/16/05 6:47	9/16/05 8:25	98	8.5	9/17/05 2:31	37
48	9/17/05 1:54	9/17/05 2:01	7	19.1	9/17/05 7:41	7
49	9/17/05 7:34	9/17/05 7:57	23	5.7	9/17/05 15:48	70
50	9/17/05 14:38	9/17/05 16:26	108	7.1	9/18/05 11:54	-85
51	9/18/05 13:19	9/18/05 13:36	17	22.7	9/18/05 20:38	6
52	9/18/05 20:32	9/18/05 22:39	127	7.2	9/19/05 20:43	-152
53	9/19/05 23:15	9/19/05 23:36	21	26.7	9/20/05 7:11	-102
54	9/20/05 8:53	9/20/05 10:48	115	9.6	9/21/05 7:13	49
55	9/21/05 6:25	9/21/05 6:39	14	21.5	9/21/05 13:16	-2
56	9/21/05 13:19	9/21/05 13:51	32	6.9	9/21/05 22:56	58
57	9/21/05 21:58	9/21/05 23:38	100	8.7	9/22/05 18:00	20
58	9/22/05 17:41	9/22/05 17:49	8	19.7	9/22/05 23:37	40
59	9/22/05 22:57	9/22/05 23:18	21	5.3	9/23/05 6:53	52
60	9/23/05 6:01	9/23/05 8:02	121	7.1	9/24/05 5:17	104
61	9/24/05 3:33	9/24/05 3:44	11	21.5	9/24/05 9:57	0
62	9/24/05 9:57	9/24/05 10:21	24	6.4	9/24/05 18:20	94
63	9/24/05 16:47	9/24/05 18:39	112	6.8	9/25/05 14:40	-114
64	9/25/05 16:34	9/25/05 16:53	19	23.8	9/26/05 0:11	-79
65	9/26/05 1:31	9/26/05 3:33	122	9.0	9/27/05 0:56	-15
66	9/27/05 1:11	9/27/05 1:34	23	23.7	9/27/05 9:25	-54
67	9/27/05 10:19	9/27/05 10:46	27	9.1	9/27/05 19:10	29
68	9/27/05 18:41	9/27/05 20:31	110	8.4	9/28/05 16:15	-116
69	9/28/05 18:12	9/28/05 18:34	22	23.5	9/29/05 2:17	15
70	9/29/05 2:02	9/29/05 2:33	31	7.8	9/29/05 11:30	27
71	9/29/05 11:03	9/29/05 13:04	121	9.0	9/30/05 10:19	63
72	9/30/05 9:16	9/30/05 9:36	20	22.2	9/30/05 17:02	11
73	9/30/05 16:52	9/30/05 18:53	121	7.6	10/1/05 16:08	68
74	10/1/05 15:00	10/1/05 15:21	21	22.1	10/1/05 22:56	75
75	10/1/05 21:41	10/1/05 23:54	133	6.7	10/2/05 22:47	176
76	10/2/05 19:51	10/2/05 20:06	15	22.2	10/3/05 2:51	3
77	10/3/05 2:49	10/3/05 5:01	132	7.0	10/4/05 3:46	81
78	10/4/05 2:25	10/4/05 2:45	20	23.6	10/4/05 10:11	15
79	10/4/05 9:57	10/4/05 10:27	30	7.5	10/4/05 19:15	-69
80	10/4/05 20:25	10/4/05 22:05	100	10.5	10/5/05 16:27	-136
81	10/5/05 18:44	10/5/05 19:09	25	22.3	10/6/05 3:16	-50
82	10/6/05 4:07	10/6/05 6:12	125	9.4	10/7/05 3:59	51
83	10/7/05 3:09	10/7/05 3:27	18	23.0	10/7/05 10:37	-31
84	10/7/05 11:08	10/7/05 13:12	124	8.0	10/8/05 10:51	175
85	10/8/05 7:57	10/8/05 8:06	9	20.8	10/8/05 14:02	9
86	10/8/05 13:54	10/8/05 14:16	22	6.0	10/8/05 21:59	90
87	10/8/05 20:29	10/8/05 22:21	112	6.6	10/9/05 18:22	-33
88	10/9/05 18:55	10/9/05 19:13	18	22.4	10/10/05 2:23	-75
89	10/10/05 3:38	10/10/05 4:02	24	8.7	10/10/05 12:01	-31
90	10/10/05 12:33	10/10/05 14:17	104	8.9	10/11/05 9:12	-122
91	10/11/05 11:15	10/11/05 11:36	21	22.7	10/11/05 19:11	22
92	10/11/05 18:49	10/11/05 20:48	119	7.6	10/12/05 17:46	-31
93	10/12/05 18:18	10/12/05 18:36	18	23.5	10/13/05 1:46	-64

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Sequence	Start time	End time	Duration	Time between	Prediction	Error in prediction
94	10/13/05 2:50	10/13/05 3:15	25	8.5	10/13/05 11:22	-39
95	10/13/05 12:02	10/13/05 13:48	106	9.2	10/14/05 9:00	-109
96	10/14/05 10:49	10/14/05 11:05	16	22.8	10/14/05 17:59	19
97	10/14/05 17:40	10/14/05 19:49	129	6.8	10/15/05 18:09	162
98	10/15/05 15:28	10/15/05 15:39	11	21.8	10/15/05 21:52	4
99	10/15/05 21:48	10/15/05 23:54	126	6.3	10/16/05 21:50	-29
100	10/16/05 22:19	10/16/05 22:42	23	24.5	10/17/05 6:33	-93
101	10/17/05 8:06	10/17/05 8:28	22	9.8	10/17/05 16:11	-12
102	10/17/05 16:23	10/17/05 18:11	108	8.3	10/18/05 13:39	-14
103	10/18/05 13:53	10/18/05 14:06	13	21.5	10/18/05 20:35	38
104	10/18/05 19:57	10/18/05 22:01	124	6.1	10/19/05 19:40	-2
105	10/19/05 19:43	10/19/05 20:01	18	23.8	10/20/05 3:11	-73
106	10/20/05 4:24	10/20/05 4:51	27	8.7	10/20/05 13:15	-22
107	10/20/05 13:37	10/20/05 15:22	105	9.2	10/21/05 10:25	-75
108	10/21/05 11:41	10/21/05 11:58	17	22.1	10/21/05 19:00	9
109	10/21/05 18:51	10/21/05 19:04	13	7.2	10/22/05 1:33	-26
110	10/22/05 1:59	10/22/05 3:56	117	7.1	10/23/05 0:38	161
111	10/22/05 21:57	10/22/05 22:05	8	20.0	10/23/05 3:53	6
112	10/23/05 3:47	10/23/05 4:10	23	5.8	10/23/05 12:01	11
113	10/23/05 11:50	10/23/05 13:43	113	8.1	10/24/05 9:52	-143
114	10/24/05 12:15	10/24/05 12:34	19	24.4	10/24/05 19:52	-19
115	10/24/05 20:12	10/24/05 22:09	117	8.0	10/25/05 18:51	90
116	10/25/05 17:21	10/25/05 17:30	9	21.1	10/25/05 23:26	8
117	10/25/05 23:19	10/25/05 23:39	20	6.0	10/26/05 7:05	14
118	10/26/05 6:52	10/26/05 8:52	120	7.5	10/27/05 5:58	30
119	10/27/05 5:29	10/27/05 5:45	16	22.6	10/27/05 12:39	-9
120	10/27/05 12:48	10/27/05 13:18	30	7.3	10/27/05 22:06	61
121	10/27/05 21:06	10/27/05 22:53	107	8.3	10/28/05 18:13	-11
122	10/28/05 18:24	10/28/05 18:35	11	21.3	10/29/05 0:48	-53
123	10/29/05 1:41	10/29/05 2:12	31	7.3	10/29/05 11:09	25
124	10/29/05 10:44	10/29/05 12:26	102	9.0	10/30/05 7:05	-58
125	10/30/05 8:03	10/30/05 8:19	16	21.3	10/30/05 15:13	-26
126	10/30/05 15:39	10/30/05 17:39	120	7.6	10/31/05 14:45	-111
127	10/31/05 16:37	10/31/05 16:56	18	25.0	11/1/05 0:05	-109
128	11/1/05 1:54	11/1/05 3:52	118	9.3	11/2/05 0:42	121
129	11/1/05 22:41	11/1/05 22:50	9	20.8	11/2/05 4:46	-8
130	11/2/05 4:55	11/2/05 5:20	25	6.2	11/2/05 13:27	36
131	11/2/05 12:52	11/2/05 14:45	113	7.9	11/3/05 10:54	76
132	11/3/05 9:38	11/3/05 9:46	8	20.8	11/3/05 15:34	8
133	11/3/05 15:26	11/3/05 15:46	20	5.8	11/3/05 23:12	54
134	11/3/05 22:19	11/4/05 0:02	103	6.9	11/4/05 18:49	60
135	11/4/05 17:49	11/4/05 17:56	7	19.5	11/4/05 23:36	9
136	11/4/05 23:27	11/4/05 23:47	20	5.6	11/5/05 7:13	33
137	11/5/05 6:41	11/5/05 8:34	113	7.2	11/6/05 4:43	-79
138	11/6/05 6:02	11/6/05 6:19	17	23.3	11/6/05 13:21	-16
139	11/6/05 13:37	11/6/05 14:00	23	7.6	11/6/05 21:51	54
140	11/6/05 20:57	11/6/05 22:42	105	7.3	11/7/05 17:45	56
141	11/7/05 16:50	11/7/05 16:58	8	19.9	11/7/05 22:46	-11
142	11/7/05 22:57	11/7/05 23:18	21	6.1	11/8/05 6:53	20
143	11/8/05 6:33	11/8/05 8:35	122	7.6	11/9/05 5:58	-83
144	11/9/05 7:21	11/9/05 7:43	22	24.8	11/9/05 15:26	-12
145	11/9/05 15:38	11/9/05 17:55	137	8.3	11/10/05 17:21	---