INFRASOUND SIGNALS FROM GROUND MOTION SOURCES

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ABSTRACT

We present progress on an ongoing research project looking at near-field infrasound signals as a basis for discriminants between underground nuclear tests (UGT) and earthquakes (EQ). We have completed a series of finer zoned time-domain, finite-difference calculations for the set of 30 underground tests included in earlier reports. An update on the modeling approach for earthquake ground motion will be presented. For the earthquakes discussed in our 2005 paper (Mutschlecner and Whitaker, 2005), we have begun looking at source mechanisms that may correlate with the infrasound observations. A new development was pursued during the last year that provided infrasound data, on the duration and amplitude for underground tests and earthquakes, to the Event Classification Matrix (ECM) framework. The analysis followed the standard ECM approach for deriving p-values and forming a bi-variate discriminate that showed very good separation of the two data sets. Three UGTs, Houston, Misty Echo and Texarkana, are closest to the EQ group and will be studied to find what contributes to this behavior. Nevertheless, the inclusion of infrasound in the ECM framework is an exciting development.

OBJECTIVES

The objective of this research is to find differences in the near-field infrasound signals of UGTs and earthquakes that can be the basis for establishing discriminants between the two sources. Such differences in the near-field signal would likely survive to longer range. Here we will present results relating earthquake source mechanisms to infrasound signal as well as new, un-planned, results that add infrasound to the ECM.

RESEARCH ACCOMPLISHED

Background

We will discuss recent analysis on earthquake infrasound signals and new work on UGT and EQ amplitude and duration discriminants. Before presenting those topics, we will review some results on infrasound signals from earthquakes for the benefit of the reader.

Mutschlecner and Whitaker (2005) presented data on infrasound signals from earthquakes with magnitudes from 4.0 to 7.0. Their work concentrated on stratospheric returns and provided data from 31 earthquakes. (See Whitaker and Mutschlecner (2008) for some discussion of thermospheric returns.) LePichon et al. (2006) discussed infrasound signals from a set of generally larger magnitude earthquakes. Figure 1 below is based on LePichon et al (2006) and shows two sets of infrasound data for log(wind corrected amplitude) vs magnitude, (A), and log(signal duration) vs magnitude, (B). For these plots the magnitude M_S was used. The black dots are from the analysis of infrasound signals for the set of earthquakes in Mutschlecner and Whitaker (2005), while the red points are from the LePichon paper.

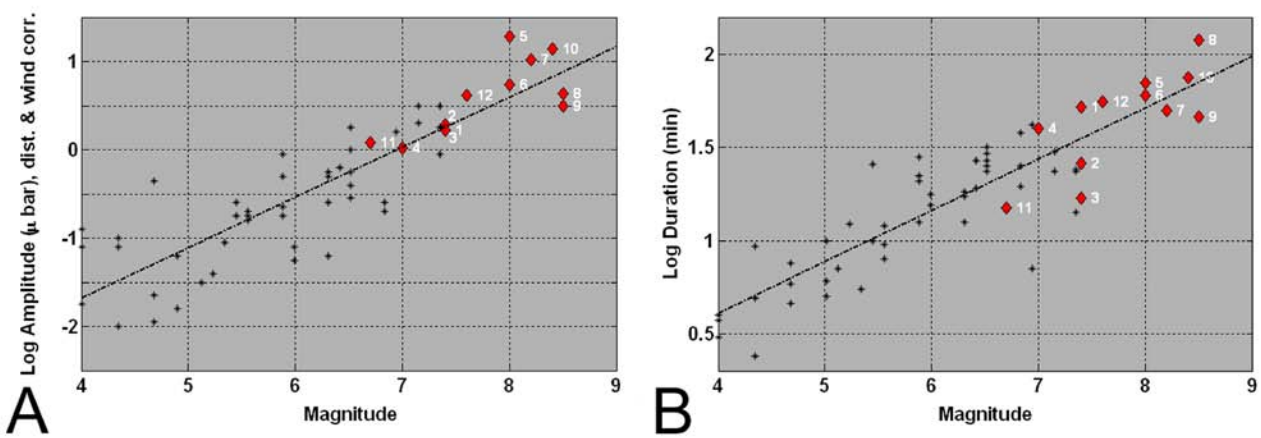


Figure 1. The two sets of EQ events as reported in Mutschlecner and Whitaker (2005) and LePichon et al. (2006). This version of the figure was provided directly by Dr. LePichon.

This comparison of two independent sets of earthquake infrasound signals shows good agreement and continuity. An obvious area of research would be to extend this analysis to lower magnitude events.

Earthquake Source Parameters

The Mutschlecner and Whitaker (2005) paper presented characteristics of infrasound signals from earthquakes as a starting point for future researchers, but earthquake source mechanisms were not considered in that paper. Here we will begin to look at aspects of source mechanisms. It is easy to see that some component of vertical ground motion would be required in order to couple the ground motion into the atmosphere. In this contribution we are discussing ground motions in and around the epicenter. We will suppose that larger EQs that are not too deep and have predominantly vertical epicenter ground motion are good sources for infrasound generation. Earthquakes may have additional ground motions away from the epicenter due to secondary excitations from surface waves for example. Such examples would have more complicated infrasound signals due to the added regions of excitation. LePichon et al. (2002, 2003, and 2006) discuss examples of the more complicated sources.

As a starting point for examining source mechanisms, we will show central moment tensor solutions for the P axis plunge and the T axis plunge from the Global Central Moment Tensor database, http://www.globalcmt.org for the events in the Table A2.1. We use the P axis plunge and the T axis plunge as these directly indicate the maximum pure compression and tension orientations for the solution. Data were found for 29 of the 39 events. In the simplest case, one might suppose that the source data would show large epicenter vertical ground motions, realizing that such simplicity is hardly ever borne out. We looked at the minimum deviation from vertical for either the P or T axis in this examination such that lower values imply a greater contribution to vertical epicenter motion from the direct ground motion. In the plots, this variable is Minplgdev, and the results are shown in Table A2.2.

In Figure 2 we plot values of Minplgdev as a function of M_{S}. For these data, there is not a clear dependence on magnitude.

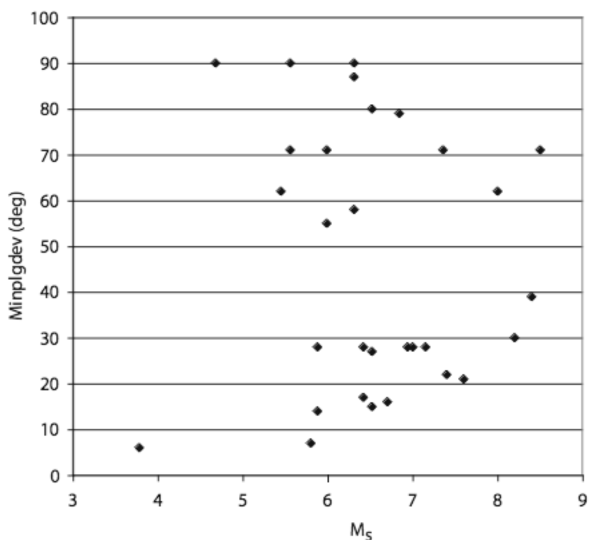


Figure 2. The Minplgdev vs magnitude for the events in Table A2.2.

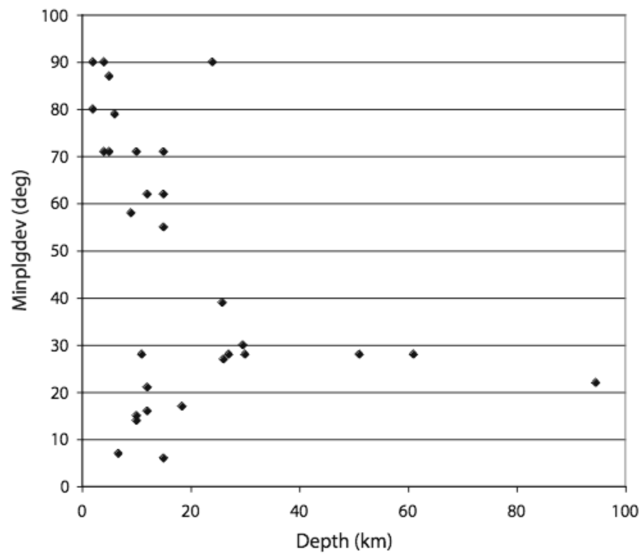
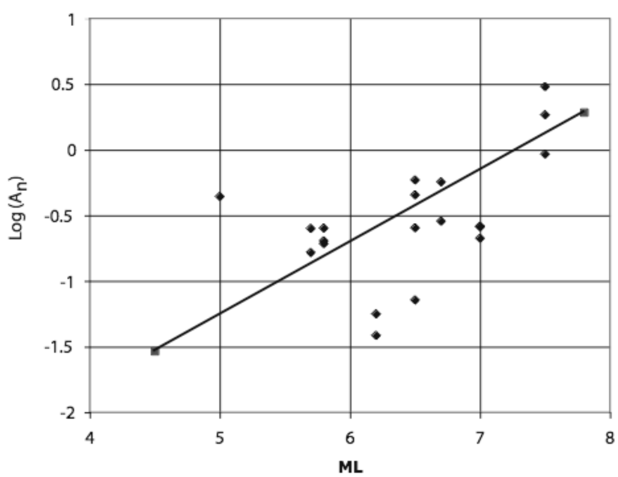


Figure 3. Minplgdev vs EQ depth

In Figure 3, we show Minplgdev vs depth. Here we see a group of shallow EQs with larger values of Minplgdev (motion not along the vertical). These are numbers 1, 2, 4, 7, 9, 11, 12, 15, 21, 22, 25, 29, 34, and 36. An obvious question is how do these events plot in the amplitude vs magnitude relation? In Figure 4, we show the ones from the Mutschlecner and Whitaker (2005) paper.



In Figure 4 some of the events were observed by more than one infrasound station, giving more than 12 points from the list above. The line represents the regression fit from Mutschlecner and Whitaker (2005).

Figure 4. The normalized amplitude vs magnitude events for low vertical ground motion events in the Mutschlecner and Whitaker (2005) dataset.

For comparison Figure 5 shows all of the events in the Mutschlecner and Whitaker paper.

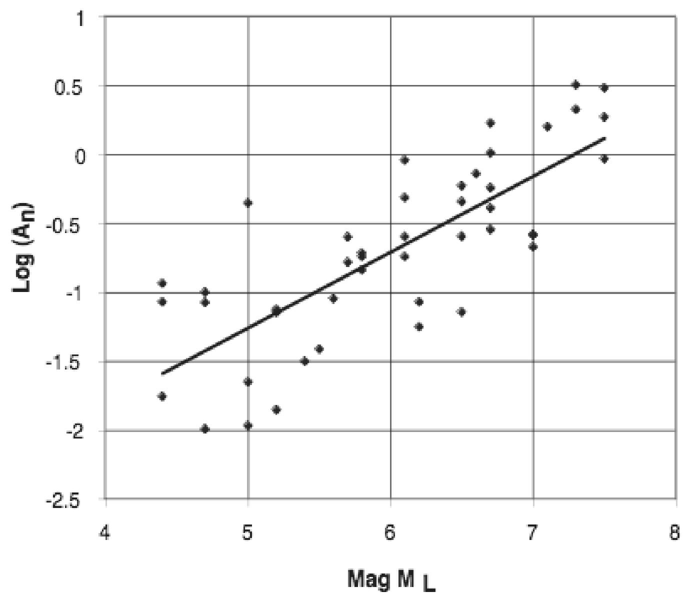


Figure 5. The full set of normalized amplitude vs magnitude.

One can see that not all the data in Figure 4 fall below the fit relation. And there are some points in Figure 5 (between magnitudes 4.5 and 5.5) that fall below the regression line and have larger potential for better vertical ground motion, at least as we examine in this contribution. Our simple approach, which represents a first look at infrasound EQ signals and EQ source parameters, is clearly not capturing all the generation processes. This points to the need for more data on infrasound signals from earthquakes as well as the associated earthquake source parameters for understanding the important ground motion drivers as well as to extend the relation shown in Figure 1 to smaller magnitude events.

Adding an Infrasound Discriminant to the ECM

During the year an opportunity arose that was not part of the original plan of work but was considered relevant to the project. This was to try to quantify the preliminary discriminants between UGTs and EQs that had been found during the earlier infrasound program (1982 – 1992) at Los Alamos National Laboratory (See Appendix 1). This program was a Department of Energy funded project to measure the atmospheric infrasound signal generated by the vertical ground motion from UGTs. At least two arrays were operated continuously in the 1982 – 1992 period (St. George, UT, and Los Alamos, NM). Because of continuous operation, in addition to the UGT sources, other sources could be measured as well, such as EQs. The two measures were wind corrected amplitude (WCA) and signal duration, from stratospheric returns, with UGTs showing larger WCA and EQs showing longer durations. Actually the amplitudes are normalized for winds and distance as given in Mutschlecner and Whitaker (2005). The wind effects are those from stratospheric heights that are seasonally dependent and have a large effect on observed amplitudes. Distance normalization is needed because of the span of ranges of the earthquakes from the infrasound stations.

We have taken the first step toward incorporating infrasound data, on the amplitude and duration of UGT and EQ signals, into the ECM framework, Anderson et al. (2007). This is the first non-seismic technology to be incorporated into the ECM. With this work, we can really determine whether the early indication of a discriminant between UGTs and EQs could be quantified including sources of error.

First, from the analysis of covariance, we show the results for the individual p values for normalized amplitude and duration in Figure 6, where p-values were based on log (amplitude) and log (duration).

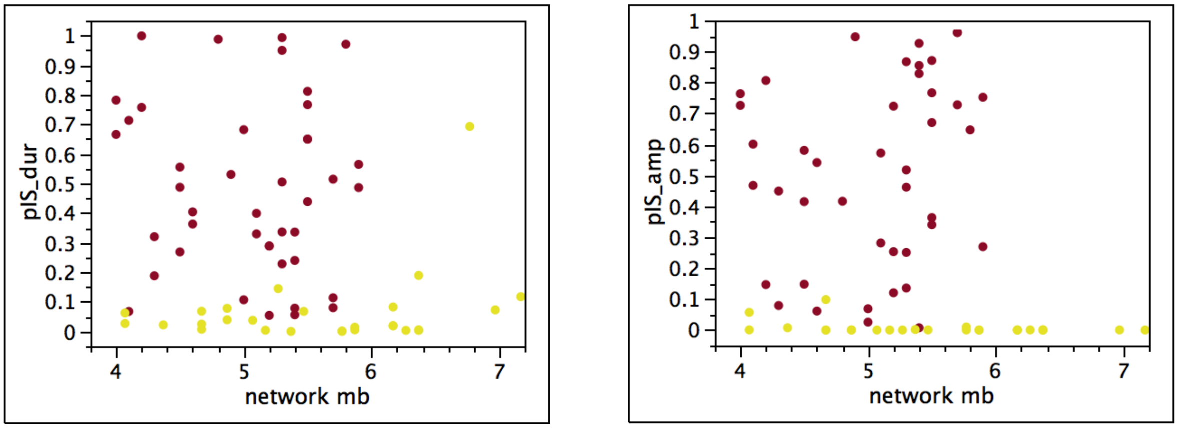


Figure 6. Individual p-values vs network mb for duration, left, and normalized amplitude, right. Here UGT events are red and EQ events are yellow.

These can be combined into a bi-variate discriminate as shown in Figure 7, with the same color-coding as in Figure 6.

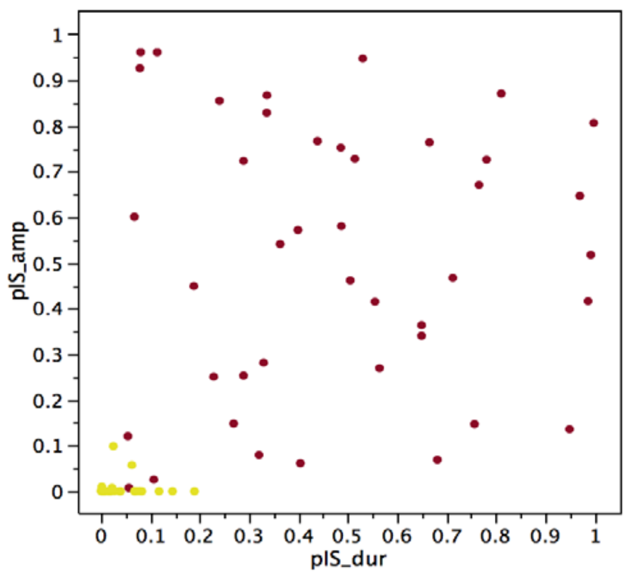


Figure 7. The combined result for amplitude and duration for the UGT and EQ data.

The three UGT events in the lower left of Figure 7 are: Houston, U19AZ; Misty Echo, U12N; and Texarkanna, U7CA. Examination of the ground motion records for these three events do not show any unusual features. Because there was a special infrasound experiment for Texarkana, we know that the jet stream was directed along the line from the Nevada Test Site to the infrasound array at St. George, UT. At 12 km altitude there was a zonally directed wind of 40 m/s that ducted energy along rays with elevation angles of 12^0 or less at 12 km altitude. This insonified the region traditionally known as the zone of silence. Because we had a number of stations from 110 km (from the event) to St George, we measured the pressures in this strong tropospheric duct. The station at 110 km had the largest measured amplitude. Because of this, the stratospheric return was probably reduced from what would have been oberserved without the tropospheric duct. Thus of the three events, at least one had significant propagation effects.

This is a first step that shows a promising discriminant. In future work we need to establish how this discriminant would transport to other tests site, how additional stations can be incorporated into a network estimate, and what data quality issues need to be considered in the analysis.

CONCLUSIONS

We have presented an examination, for a limited set of EQ events with measured infrasound, of the relation between indicators of epicentral vertical ground motion. The results are mixed as would be expected for complex ground motion sources such as EQs. There was not a simple "rule of thumb" found for the events of this study. Vertical epicenter ground motion may not be the only source of good infrasound generation. Clearly for secondary regions away from the epicenter, surface waves play an important role. Other mechanisms may play an important role.

ACKNOWLEDGMENTS

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APPENDIX 1

Here we will show the earlier findings comparing UGT and EQ signal amplitudes and signal durations that indicated the discrimination potential. The set of Eqs in these two plots is not quite the same as reported in Mutschlecner and Whitaker (2005). Figure A1 presents the results for signal duration, and Figure A2 presents results for wind corrected amplitude.

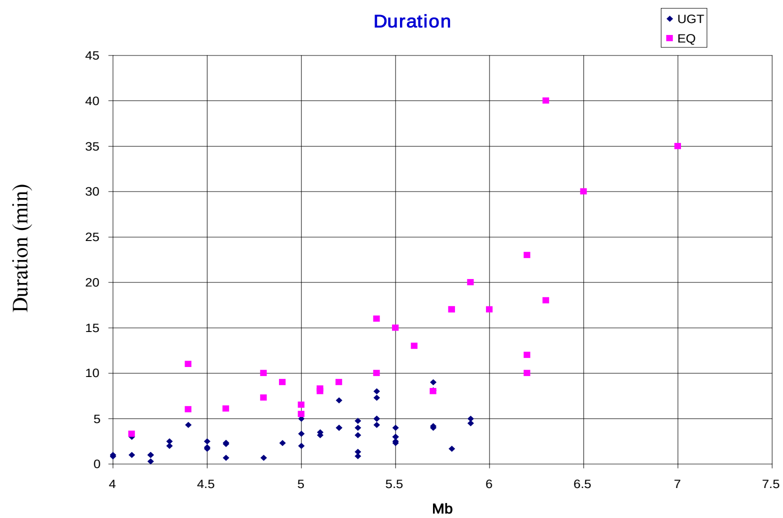

Figure A1. Comparison of infrasound signal durations for UGTs (blue) and EQs (pink) vs seismic magnitude. Durations are in minutes.

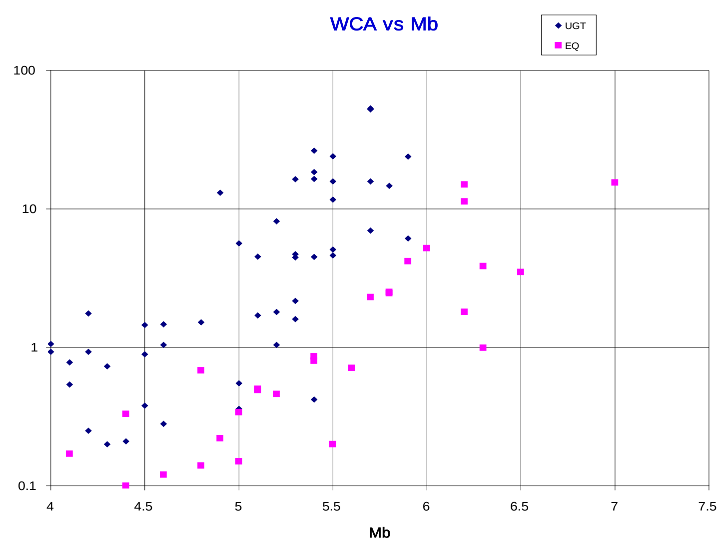

Figure A2. Comparison of infrasound signal amplitudes (microbars) for UGTs (blue) and EQs (pink) vs seismic magnitude.

APPENDIX 2: Table A2.1

Earthquakes for which Global CMT solutions were sought. The table includes the events in Figure 1 with mumbers 1 through 31 are from Mutschlecner and Whitaker (2005) and numbers 32 through 39 from LePichon et al. (2006).

EQ number	date	Time (UT)	Lat (deg)	Long (deg)	Depth (KM)	ms
1	11/3/02	22:12:41	63.52	-147.44	4	7.36
2	2/22/02	19:32:41	32.38	-115.35	10	5.56
3	2/28/01	18:54:32	47.15	-122.73	51	6.42
4	10/16/99	9:46:44	34.59	-116.27	6	6.84
5	1/17/94	12:30:55	34.21	-118.54	18.4	6.42
6	10/2/92	7:19:57	34.6	-116.64	3	4.01
7	6/28/92	15:05:31	34.2	-116.83	5	6.31
8	6/28/91	14:43:55	34.26	-118.01	11	5.88
9	10/24/90	6:15:21	38.05	-119.16	12	5.45
10	4/18/90	13:53:51	36.92	-121.68	5	5.34
11	2/28/90	23:43:36	34.14	-117.7	5	5.99
12	1/16/90	20:08:22	40.23	-124.14	2	5.56
13	1/15/90	5:29:03	37.99	-118.21	5	4.68
14	11/29/89	6:54:38	34.46	-106.89	13	4.35
15	1/30/89	4:06:23	38.82	-111.61	24	4.68
16	1/19/89	6:53:29	33.92	-118.63	12	5.12
17	12/16/88	5:53:05	33.98	-116.68	8	4.9
18	12/3/88	11:38:26	34.15	-118.13	13	4.68
19	1/28/88	2:54:02	32.91	-115.68	6	4.35
20	1/25/88	13:17:51	31.74	-115.84	5	4.9
21	11/24/87	1:54:14	33.08	-115.78	4	6.31
22	11/24/87	13:15:56	33.01	-115.84	2	6.52
23	11/24/87	2:15:26	33.25	-115.62	5	4.01
24	10/1/87	14:42:20	34.08	-118.08	10	5.88
25	7/21/86	14:42:26	37.5	-118.4	9	6.31
26	4/30/86	7:07:18	18.4	-102.47	26	6.52
27	9/21/85	1:37:14	17.8	-101.65	30	6.94
28	9/19/85	13:17:47	18.19	-102.53	27	7.15
29	11/23/84	18:08:25	37.48	-118.65	15	5.99
30	11/23/84	19:12:34	37.44	-118.64	0	5.23
31	5/2/83	23:42:38	36.22	-120.32	10	6.52
32	6/13/05	22:44:40	-20.02	-69.23	94.5	7.4
33	5/26/03	9:24:39	38.94	141.57	61	7
34	11/14/01	9:27:16	35.8	92.91	15	8
35	6/23/01	20:34:23	-17.28	-72.71	29.6	8.2
36	11/3/02	22:13:28	63.23	-144.89	15	8.5
37	4/10/05	10:29:17	-1.68	99.54	12	6.7
38	3/28/05	16:10:31	1.67	97.07	25.8	8.4
39	10/8/05	3:50:51	34.38	73.47	12	7.6

Table A2.2

Events from Table A2.1 for which Global CMT data were found.

EQ Number	PAXPLG deg)	TAXPLG (DEG)	MINPLGDEV (DEG)	DEPTH (km)
1	7	19	71	4
2	19	14	71	10
3	62	28	28	51
4	3	11	79	6
5	6	73	17	18.4
7	0	3	87	5
8	8	62	28	11
9	28	15	62	12
11	5	19	71	5
12	0	0	90	2
15	0	0	90	24
21	0	0	90	4
22	7	10	80	2
24	14	76	14	10
25	32	10	58	9
26	27	63	27	26
27	28	62	28	30
28	28	62	28	27
29	35	22	55	15
31	15	75	15	10
32	68	22	22	94.5
33	27	62	28	61
34	28	13	62	15
35	29	60	30	29.6
36	7	19	71	15
37	16	74	16	12
38	38	51	39	25.8
39	10	69	21	12