CONSORTIUM TO STUDY TRENDS IN SEISMICITY

Quarterly report:
July 1–October 1, 2017

by

Rick Miller
Shelby Peterie
Rex Buchanan

Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047-3726

ph (785) 864-3965 / fax (785) 812-0208

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INTRODUCTION

The Kansas Geological Survey's Consortium to Study Trends in Seismicity (CSTS) is a public-private project aimed at studying trends in seismicity in Kansas. The past five years have seen a significant increase in seismicity in Kansas and throughout the midcontinent, leading to a need to better define and understand seismicity, particularly as it relates to subsurface fluid disposal. The CSTS oversees the operation of a seismic network that records and allows accurate location and magnitude estimates of seismicity for both felt earthquakes and especially microseismic events that are hundreds of times smaller than routinely possible with current regional seismic networks.

The CSTS is operated by the Kansas Geological Survey (KGS), a research and service division of the University of Kansas with a long history of studying the state's subsurface and seismic issues. Current members of the CSTS are from the state's Class 1 disposal well community—wells that are used for disposal of municipal and industrial waste and regulated by the Kansas Department of Health and Environment. Membership in the CSTS is voluntary, with a common goal of understanding seismicity in proximity to member facilities. The CSTS works to establish the baseline or background seismicity near those facilities and provide a scientific basis for differentiating natural from induced seismicity.

The following report describes the first three months of CSTS activities, including a discussion of member status; network station installation and operation; earthquakes recorded and identified, and earthquake alerts provided to members; web page development; and plans for the next three months and the coming year. In addition to the quarterly reports that will follow this report, an annual report will be provided to members and an annual meeting will be held shortly after July 1, 2018.

STATUS OF MEMBERS

The CSTS was established with a two-tier membership system. For Tier 1 members, the CSTS provides equipment, installation, and monitoring of a seismograph station; maintaining a catalog of seismic events, updated weekly, with e-mail alerts within 24 hours or less of any earthquakes greater than magnitude 2 within 30 miles of a facility; quarterly reports of monitoring findings; and an annual meeting at which results are discussed and plans formulated for the coming year.

Tier 2 members have access to information related to the general information about the seismicity being studied by the CSTS and can attend the annual meeting, but do not have the right to vote at that meeting.

The CSTS currently has twelve Tier 1 members and one Tier 2 member.

STATUS OF NETWORK

The CSTS seismic network currently consists of 12 stations in Kearny, Ellsworth, Rice, McPherson, Reno, Kiowa, Sedgwick, Butler, and Johnson counties, Kansas (Figure 1). Waveforms for these stations are available for Tier 1 members on the seismic network page of the CSTS website. For each of those locations, ambient noise tests were completed, aimed at identifying noise from nearby highways, trains, pump jacks, and other facilities that might interfere with earthquake analysis. In several cases, stations were re-located from an original installation to a new location in an attempt to minimize the interference of that noise. Many of the existing sites are in cemeteries, on government property, or in other locations where noise levels are likely to be low. In all cases, written agreements with landowners have been obtained.

Each station consists of a seismic sensor that includes a shallowly buried seismometer embedded in a concrete platform atop a gravel layer, and a digitizer. Ground motion detected by the seismometer is transmitted back to KGS offices in Lawrence real-time via a cellular modem. That communication system is powered by a solar panel that charges two deep-cycle marine batteries. The footprint for each station is approximately 10 feet by 10 feet. The stations have operated with a better than 98% continuous data stream and within designated operational sensitivity and signal-to-noise ratio.

EARTHQUAKE ALERTS, EARTHQUAKE CATALOG

Earthquakes with magnitudes of 2 or larger are below felt levels but represent a threshold above which energy levels provide highly confident automatic analysis with a network as dense as the Consortium network in conjunction with the KGS regional and subregional network. It is therefore reasonable to provide accurate epicenter locations using automated picking routines with results available within minutes of the fault rupture responsible for the event. It will be the practice of the KGS to provide members within 30 miles of a M2 or larger earthquake an email notification of time, date, magnitude, proximity to their well, and cluster name. Within the third quarter of the calendar year the following alerts were sent to affected members:

Hutchinson area—

- 7/29/17 3.0 and 2.2 in south Hutchinson swarm
- 8/23/17 2.1 and 2.2 in south Hutchinson swarm

Wichita area—

- M2.2, 10:00 PM, 7/29/17, ~20 miles from facility
- M2.9, 11:00 AM, 8/05/17, ~7 miles from facility, Belle Plaine cluster
- M2.5, 10:52 PM, 8/04/17, ~29 miles from facility, Caldwell cluster
- M3.0, 10:14 PM, 8/04/17, ~29 miles from facility, Caldwell cluster
- M2.8, 12:39 AM, 8/05/17, ~29 miles from facility, Caldwell cluster
- M2.5, 10:52 AM, 8/5/17, ~26 miles from facility and near Milan
- M3.4, 3:13 PM, 8/5/17, ~26 miles from facility and near Milan
- M2.2, 5:14 PM, 8/5/17, ~28 miles from facility and near Milan
- M3.0, 9:38 PM, 8/5/17, ~30 miles from facility and near Milan
- M2.0, 9:43 PM, 8/5/17, ~30 miles from facility and near Milan
- M2.0, 1:48 AM, 8/6/17, ~10 miles from facility and near Pec

- M2.2, 5:30 PM, 8/14/17, ~10 miles from facility, Clear Water cluster
- M2.4, 7:30 AM, 8/15/17, ~25 miles from facility, Milan cluster
- M2.1, 12:09 PM 8/15/17, ~23 miles from facility, Milan cluster
- M2.0, 5:55 PM, 8/18/17, ~13 miles from facility, Belle Plaine cluster
- M2.0, 12:46 AM, 8/19/17, ~13 miles from facility, Belle Plaine cluster
- M2.6, 6:07 PM, 8/20/17, ~27 miles from facility, Milan cluster
- M2.5, 2:57 AM, 8/21/17, ~28 miles from facility, Milan cluster
- M2.5, 6:55 AM, 8/21/17, ~28 miles from facility, Milan cluster
- M2.1, 2:16 AM, 8/22/17, ~25 miles from facility, Milan cluster
- M2.3, 4:57 PM, 8/23/17, ~28 miles from facility, Milan cluster
- M2.2, 12:46 AM, 8/26/17, ~28 miles from facility, Milan cluster
- M3.2, 10:01 AM, 8/27/17, ~20 miles from facility, Milan cluster
- M2.1, 1:58 AM, 8/31/17, ~15 miles from facility, Cheney cluster
- M2.1, 2:07 AM, 8/31/17, ~10 miles from facility, Belle Plaine cluster
- M3.7, 2:21 AM, 8/31/17, ~15 miles from facility, Cheney cluster
- M2.0, 7:47 AM, 8/31/17, ~15 miles from facility, Cheney cluster
- M2.5, 12:12 AM, 9/2/17,18 miles from facility, Cheney cluster
- M2.0, 1:57 AM, 9/2/17, 18 miles from facility, Cheney cluster
- M2.3, 2:45 PM, 9/2/17, 18 miles from facility, Cheney cluster
- M2.4, 2:17 PM, 9/3/17, 18 miles from facility, Cheney cluster
- M2.1, 4:14 PM, 9/3/17, 18 miles from facility, Cheney cluster
- M2.0, 7:07 PM, 9/3/17, 18 miles from facility, Cheney cluster
- M2.3, 1:10 AM, 9/4/17, 18 miles from facility, Cheney cluster
- M2.7, 8:32 PM, 9/4/17, 18 miles from facility, Cheney cluster
- M2.4, 4:59 AM, 9/8/17, 26 miles from facility, Argonia cluster
- M2.5, 10:19 AM, 9/10/17, 26 miles from facility, Argonia cluster
- M2.1, 10:49 PM, 9/11/17, 21 miles from facility, Milan cluster
- M2.0, 3:15 AM, 9/14/17, 18 miles from facility, Milan cluster
- M2.1, 11:39 AM, 9/26/17,19 miles from facility, South of Cheney
- M2.0, 2:45 AM, 9/27/17, 26 miles from facility, Argonia cluster
- M2.8, 8:38 AM, 10/3/17, 11 miles from facility, Belle Plaine cluster

Tables 1 and 2 show earthquakes recorded by the network.

WEB PAGE CONTENT

The CSTS web page is operated by the KGS. It includes links to information about meetings, publications, network updates, and seismic updates (for Tier 1 members), and information about the seismic network for Tier 2 members. It includes semi-annual newsletters about earthquake activity, along with access to a comprehensive catalog of events, including time, location, magnitude, and the Seismic Action Score (based on evaluation criteria developed by the State's Induced Seismicity Task Force) for each event.

As previously mentioned, installation of and adjustments to stations have been an ongoing project of the KGS Consortium staff throughout the spring and summer of 2017. The web has a series of pictures and accounts of the installation process and gives a feel

for the environment and footprint of each of your consortium stations. Currently there is at least one station within 20 miles of every Tier 1 member's well (Figure 2). A short discussion and set of pictures are posted on the web page documenting the installation process.

PLANS FOR THE NEXT THREE MONTHS

Installation of the earthquake network has required a significant amount of procurement, shop testing and preparations, satellite image analysis, landowner identification and contacts, field work, and sensitivity analysis. Hardware for each station cost upwards of $19,000, with component manufactures located all across the world. Each station location required a landowner access agreement and a noise test. Both of these activities were completed in advance of deploying crews to install the stations. Currently all 12 stations are installed and operating well within acceptable response levels. Over the next three months the KGS consortium team will focus almost exclusively on developing rapid techniques and procedures for accurately locating and characterizing extremely low energy earthquake epicenters.

Events of M2 or larger within 30 miles of any of Tier 1 member wells will continue to be automatically located and alerts provided to members in proximity within 24 hours. There will also be a strong focus on sub-M1 earthquakes and establishing an experience-based understanding of the entire network's sensitivity and potential as well as areas of particular future interest. With that understanding, KGS consortium analysts will be able to search and confidently identify earthquake trends at extremely low energy levels resulting from very short fault ruptures, regardless of the triggering mechanism. The clustering and trends of earthquakes at those very small energy levels will help define areas to avoid or monitor for changes based on injection practices.

Also, improved response time for submitting alerts and a more automated process will also be part of the scope of work for the next three months. Currently those alerts are only brought to the attention of members who have a well within 30 miles. It is our plan to include those alerts in our earthquake blog on the web page that will see an increased frequency of entries over the next three months. Along those same lines, Rex Buchanan (director of the Consortium) will provide thoughts and insights related to seismicity, responses, and governmental trends he is noticing in other states with similar seismicity issues. In addition, planning will begin for the first annual meeting of consortium, which will likely be held in Lawrence in July 2018.

CONCLUSION

The KGS's CSTS has had a successful first quarter. Agreements for 12 Tier 1 and one Tier 2 members have been finalized. Twelve stations have been installed and are operating successfully. Alerts have been issued to members as prescribed by the agreements and additional information has been posted to the website. With instrumentation operation and other basic functions accomplished, the CSTS will develop ways to provide alerts more routinely and post additional information for members on the website. The CSTS will continue conversations to explore the information needs and provide the best possible service to members.

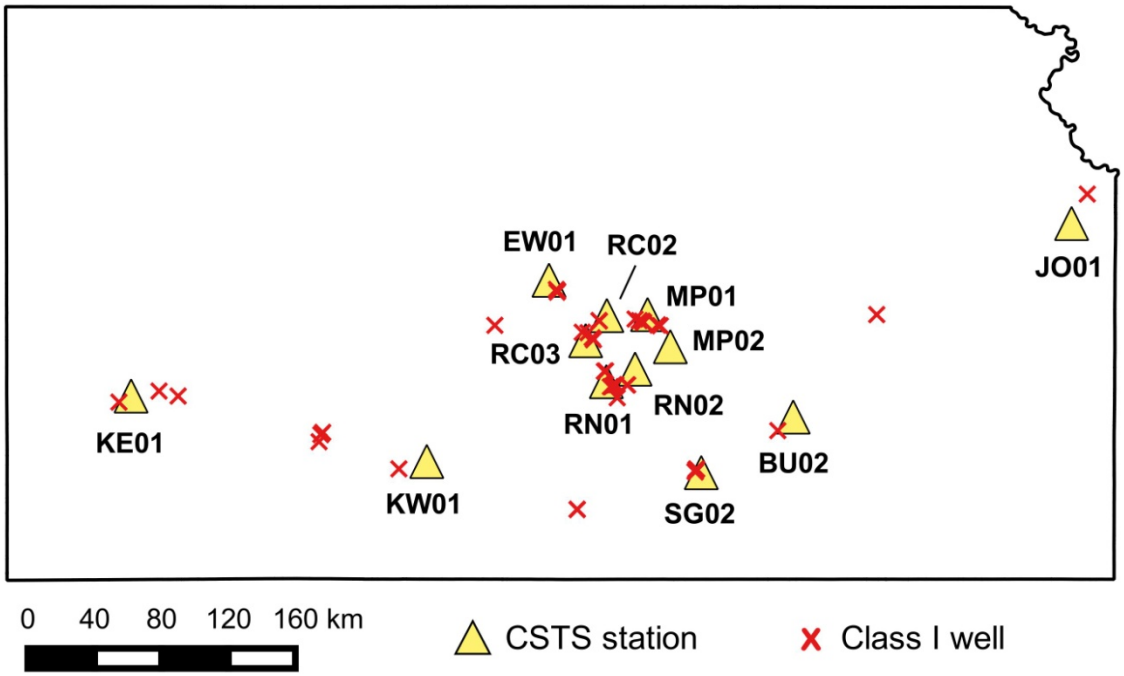

Figure 1. The 12 stations in the current CSTS seismic network.

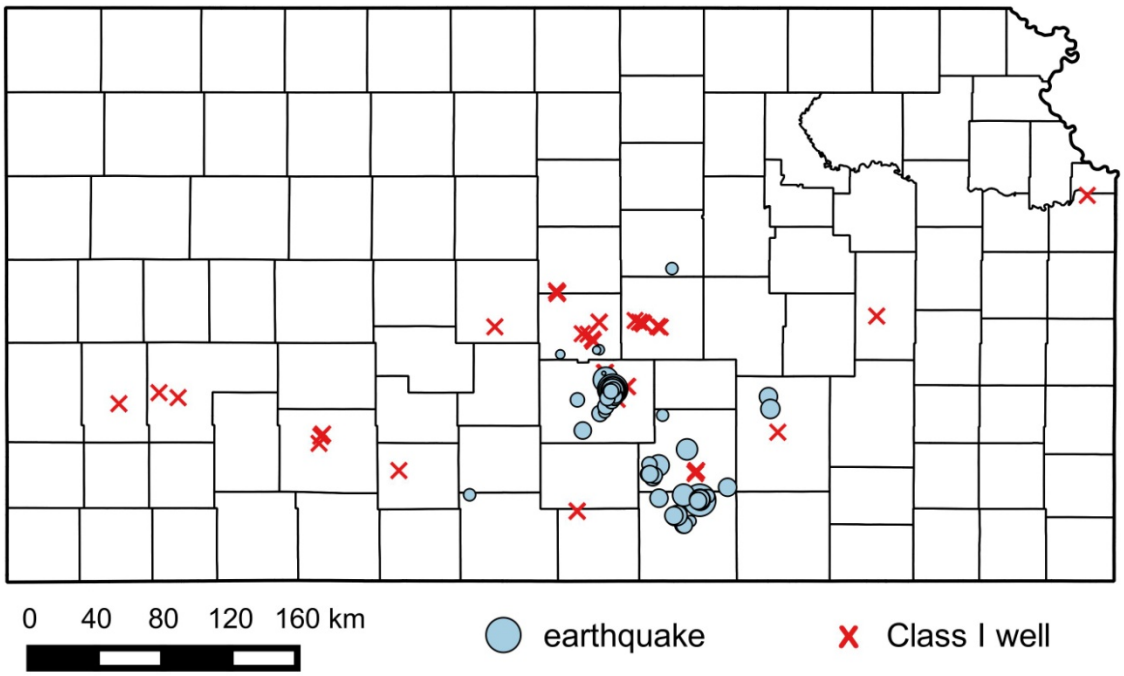

Figure 2. Earthquakes located within 20 miles of member wells.

Table 1. Earthquakes located within 20 miles of member wells.

Origin (UTC)	Latitude	Longi-tude	Magni-tude
2017-07-06 06:33:27	38.068	-98.027	2.5
2017-07-06 07:02:43	37.979	-96.936	1.8
2017-07-09 19:10:58	37.552	-97.712	1.7
2017-07-14 10:32:48	37.459	-98.940	1.2
2017-07-16 05:05:55	37.319	-97.458	1.1
2017-07-16 05:11:08	37.307	-97.481	0.8
2017-07-18 02:14:58	37.499	-97.210	1.8
2017-07-24 01:28:10	37.427	-97.373	1.7
2017-07-24 02:28:04	37.455	-97.373	1.7
2017-07-24 04:16:31	37.889	-98.064	1.3
2017-07-24 07:33:38	37.962	-98.217	1.4
2017-07-26 15:21:44	37.890	-98.066	1.6
2017-07-27 02:19:48	37.985	-97.994	1.5
2017-07-27 02:54:00	37.899	-98.034	1.2
2017-07-30 00:13:46	38.018	-97.981	3.0
2017-07-30 00:16:15	38.014	-97.981	2.7
2017-07-30 02:36:43	38.014	-97.990	1.4
2017-07-30 10:37:53	38.028	-97.976	1.5
2017-08-02 07:09:51	37.428	-97.467	1.6
2017-08-02 11:17:00	37.994	-97.963	1.7
2017-08-05 05:15:50	37.430	-97.397	3.2
2017-08-05 05:30:43	37.454	-97.360	1.2
2017-08-05 07:20:30	37.452	-97.340	1.3
2017-08-05 08:25:13	37.914	-96.923	1.9
2017-08-06 06:48:56	37.435	-97.394	2.0
2017-08-06 07:18:06	37.881	-97.646	1.2
2017-08-06 13:22:08	37.999	-97.975	1.2
2017-08-07 08:01:45	38.018	-97.982	1.5
2017-08-09 07:07:14	37.434	-97.398	1.6
2017-08-10 00:13:08	37.441	-97.670	1.8
2017-08-11 06:32:38	38.021	-97.988	1.4
2017-08-12 22:46:31	37.457	-97.505	2.2
2017-08-15 06:18:54	37.928	-98.027	1.6
2017-08-15 15:15:43	38.013	-97.979	2.4
2017-08-19 05:46:44	37.434	-97.398	2.0
2017-08-19 08:33:44	37.435	-97.394	1.9
2017-08-21 17:29:51	37.427	-97.408	1.7
2017-08-21 20:32:28	37.615	-97.672	2.1
2017-08-23 07:34:15	38.027	-97.979	2.1
2017-08-23 22:49:25	38.019	-97.992	1.8
2017-08-26 21:01:43	38.014	-97.981	2.2
2017-08-26 21:10:09	38.012	-97.998	1.4
2017-08-26 23:24:04	37.955	-97.987	1.5
2017-08-27 07:09:47	37.978	-97.967	1.7
2017-08-29 05:27:12	37.579	-97.724	1.5
2017-08-29 08:47:57	38.011	-97.993	1.5
2017-08-30 10:35:02	38.652	-97.583	1.2
2017-08-30 12:00:00	37.620	-97.734	1.5
2017-08-31 05:17:55	37.981	-97.963	1.4
2017-08-31 07:07:34	37.700	-97.482	2.1
2017-08-31 18:11:38	38.226	-98.070	1.0
2017-09-01 12:14:57	37.562	-97.701	1.6
2017-09-03 13:04:34	37.569	-97.740	1.6
2017-09-03 14:41:39	37.565	-97.738	1.4
2017-09-06 19:30:46	37.300	-97.507	1.7
2017-09-07 01:36:18	38.102	-98.040	0.4
2017-09-07 02:19:44	38.202	-98.332	0.9
2017-09-07 02:20:12	38.224	-98.088	0.8
2017-09-10 04:01:25	37.346	-97.564	1.9
2017-09-12 22:58:47	37.297	-97.500	1.6
2017-09-14 08:15:28	37.349	-97.548	2.0
2017-09-15 05:37:22	38.017	-97.977	1.5
2017-09-24 03:29:24	37.348	-97.570	1.8
2017-09-25 15:28:11	37.800	-98.181	1.7
2017-09-25 18:03:46	37.971	-98.016	1.5
2017-09-28 17:47:46	38.007	-97.992	1.5
2017-09-29 14:43:49	37.569	-97.731	1.7

Table 2. Possible sub-network earthquakes (recorded by less than three stations, the minimum required to locate an earthquake) recorded by CSTS stations within 12 miles of member wells (the largest published distance between an induced earthquake swarm and causal well). Epicentral distance is the estimated distance from the earthquake epicenter to the seismic station where it was recorded.

Origin (UTC)	Station	Distance (mi)	Magnitude
2017-07-27 12:29:23	MP01	7.6	0.0
2017-07-30 08:29:42	RN01	4.9	0.6
2017-08-01 05:24:48	MP02	8.9	0.4
2017-08-06 06:37:34	RN01	4.1	0.4
2017-08-06 11:37:30	RN01	4.5	-0.4
2017-08-12 02:30:08	RC02	5.1	-0.6
2017-08-12 07:25:45	RN01	5.5	-0.2
2017-08-12 08:04:09	EW01	4.9	0.3
2017-08-13 17:39:39	RN01	5.2	0.1
2017-08-16 04:21:33	RN02	8.9	-0.2
2017-08-16 09:05:48	RN01	5.8	-0.4
2017-08-19 02:19:16	MP01	4.8	-0.6
2017-08-19 12:49:44	EW01	3.2	-0.6
2017-08-19 13:49:35	RN01	4.9	-0.2
2017-08-21 06:05:01	RN01	5.2	0.3
2017-08-22 08:26:09	RN01	6.8	-0.2
2017-08-24 02:33:32	RN01	5.0	0.0
2017-08-24 22:10:13	RN01	3.8	0.4
2017-08-28 00:17:37	MP01	8.6	-0.4
2017-08-28 11:27:31	RN02	2.7	-0.6
2017-08-29 13:20:06	RN01	4.8	0.0
2017-08-29 16:04:37	RN01	4.7	-0.2
2017-08-30 00:17:22	EW01	2.4	0.1
2017-08-30 03:16:15	RN01	4.7	0.0
2017-08-30 03:43:21	MP01	5.1	0.2
2017-08-30 06:46:24	RC02	6.9	0.0
2017-08-30 12:44:20	RN01	2.3	-0.2
2017-08-31 02:27:19	RC03	9.1	0.5
2017-08-31 02:39:08	RN01	4.7	0.0
2017-08-31 08:55:04	MP02	10.4	0.5
2017-09-01 15:05:11	MP01	1.7	-0.6
2017-09-01 19:14:37	KW01	3.1	-0.6
2017-09-02 15:49:07	RN01	4.9	-0.6
2017-09-03 08:41:51	MP01	4.3	-0.2
2017-09-04 07:47:42	RC03	11.7	0.1
2017-09-05 05:02:56	RN01	3.3	0.4
2017-09-06 02:20:56	RC03	7.7	0.5
2017-09-06 16:36:53	EW01	2.6	-0.9
2017-09-06 21:19:45	RN01	4.9	-0.4
2017-09-07 01:38:09	RN01	7.6	0.4
2017-09-07 01:45:21	RN01	4.5	-0.2
2017-09-07 02:43:09	RC02	1.9	-0.9
2017-09-07 11:04:44	RN01	4.9	0.1
2017-09-07 21:51:18	RN01	5.0	-0.2
2017-09-08 02:09:14	RC03	9.6	0.9
2017-09-10 09:12:36	RN01	5.2	0.2
2017-09-10 09:20:24	RN01	5.9	0.0
2017-09-10 17:49:47	RN01	4.9	-0.2
2017-09-12 16:08:48	BU02	11.3	0.7
2017-09-12 16:19:25	RN01	8.1	0.0
2017-09-13 08:05:10	RN02	2.0	-0.4
2017-09-13 08:39:03	EW01	8.5	0.3
2017-09-13 09:00:01	RC02	7.6	0.1
2017-09-13 11:19:08	SG02	11.0	0.0
2017-09-13 15:31:17	RN01	9.4	0.0
2017-09-14 01:32:52	BU02	2.4	-0.6
2017-09-14 02:22:18	RC03	8.2	0.6
2017-09-14 09:48:02	RN01	5.5	0.1
2017-09-15 03:01:43	RN01	4.4	1.0
2017-09-15 03:29:17	MP01	5.0	0.0
2017-09-15 09:29:50	RN01	5.1	-0.2
2017-09-15 13:36:42	RC03	10.6	0.7
2017-09-16 05:15:32	RN01	4.9	0.2
2017-09-16 16:39:09	BU02	6.2	0.3
2017-09-16 23:24:42	RN01	5.8	0.2
2017-09-18 10:46:52	RN01	3.5	0.7
2017-09-18 12:33:07	MP01	2.5	0.6
2017-09-19 02:53:22	MP01	10.3	0.4
2017-09-19 09:10:06	RN01	5.1	0.2
2017-09-19 11:30:22	RN01	8.3	0.4
2017-09-21 02:22:22	RC03	9.9	0.4
2017-09-22 07:22:18	RN02	3.3	-0.9
2017-09-22 08:09:46	EW01	8.5	0.5
2017-09-22 23:37:10	KW01	7.6	-0.4
2017-09-23 06:11:54	RN01	4.4	-0.4
2017-09-25 12:04:34	EW01	6.3	-0.2
2017-09-25 13:27:48	RC03	4.2	0.4
2017-09-25 13:30:50	RC02	8.8	0.3
2017-09-25 15:11:12	RC03	10.5	0.0
2017-09-25 15:28:22	RN01	2.3	0.4
2017-09-25 17:48:54	MP01	4.6	-0.6
2017-09-25 20:16:53	RC02	3.9	0.1
2017-09-25 23:59:21	MP01	11.2	0.2
2017-09-26 03:54:08	RN01	4.8	0.0
2017-09-26 04:43:52	RN02	9.2	0.9
2017-09-27 01:20:23	RN01	4.5	0.4
2017-09-27 02:23:27	RN01	4.7	0.2
2017-09-27 04:46:30	RN02	9.3	0.0
2017-09-27 04:48:07	RN02	8.8	0.1
2017-09-27 09:44:28	MP01	2.7	-0.4
2017-09-28 05:47:42	RN02	8.3	-0.4
2017-09-28 05:48:29	RN02	10.2	-0.2
2017-09-28 07:21:45	MP01	3.9	0.2
2017-09-28 11:26:07	MP01	4.1	-0.2
2017-09-28 23:08:01	EW01	2.6	-0.6
2017-09-29 00:50:20	EW01	2.6	-0.6
2017-09-29 12:40:41	MP01	4.9	-0.2
2017-09-30 06:40:29	MP01	1.9	-0.9
2017-09-30 06:40:29	MP01	1.9	-1.5
2017-09-30 06:41:04	MP01	2.3	-0.6
2017-09-30 23:29:44	RN02	2.9	-0.4
2017-07-27 12:29:23	MP01	7.6	0.0
2017-07-30 08:29:42	RN01	4.9	0.6
2017-08-01 05:24:48	MP02	8.9	0.4
2017-08-06 06:37:34	RN01	4.1	0.4
2017-08-06 11:37:30	RN01	4.5	-0.4
2017-08-12 02:30:08	RC02	5.1	-0.6
2017-08-12 07:25:45	RN01	5.5	-0.2
2017-08-12 08:04:09	EW01	4.9	0.3
2017-08-13 17:39:39	RN01	5.2	0.1
2017-08-16 04:21:33	RN02	8.9	-0.2
2017-08-16 09:05:48	RN01	5.8	-0.4
2017-08-19 02:19:16	MP01	4.8	-0.6
2017-08-19 12:49:44	EW01	3.2	-0.6
2017-08-19 13:49:35	RN01	4.9	-0.2
2017-08-21 06:05:01	RN01	5.2	0.3