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An Examination of Telemetry Delay in the Central Weather Bureau Seismic Network

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ABSTRACT

Timing is a key factor for an earthquake monitoring system and may affect the determination of earthquake location and related studies. In this work, we examined the telemetry delay within the Central Weather Bureau Seismic Network (CWBSN) from 1991 to 2011 and found that the timing systems, at most of the stations in the CWBSN, could contain an approximate 0.2 sec telemetry delay. Based on our results, the telemetry delay was found to cause a 0.2 sec shift in earthquake origin times during the earthquake location process. However, the delay may not cause a significant difference in earthquake location results.

Key words: Earthquake, Seismic network, Earthquake location, Taiwan

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1. INTRODUCTION

Taiwan, an island located in the western portion of the Pacific Rim seismic belt, is one of the most seismically active regions in the world. Along the Ryukyu trench located in the eastern portion of the island, the Philippine Sea plate subducts northward under the Eurasian plate. Off the southern tip of the island, the Eurasian plate subducts eastward under the Philippine Sea plate (Fig. 1). The CWBSN is the system responsible for earthquake monitoring in Taiwan, and records approximately 18000 events each year in a region of roughly 400 × 550 km (Shin 1992). Serious and damaging events, occurring over the past few decades, have been recorded and carefully studied (Wang and Shin 1998; Chang et al. 2000, 2007; Teng et al. 2001; Wu et al. 2003, 2008; Huang et al. 2008; Lin 2010; Huang et al. 2011). The CWBSN provides a wealth of earthquake records relating to studies surrounding Taiwan.

In earthquake monitoring, system timing is a key factor for determining earthquake location. The CWBSN is a real-time system. Signals from field stations are transferred to central stations via leased telephone lines and earthquake times are stamped by the central station. The data transferring procedure results in a telemetry delay for the timestamps marked in each record. Generally, the telemetry delay is roughly 0.2 sec different than the actual time recorded by the CWB staff. In 2010, the CWBSN began to use the new system and to stamp the time at local stations, providing the opportunity needed to systematically investigate telemetry delays within the currently CWBSN.

2. SYSTEM CONFIGURATION

The CWBSN system has been carrying out real-time digital recordings since 1991. The network currently consists of a central recording system with 71 telemetered stations that are equipped with three-component Teledyne/Geotech S13 seismometers. Including retired stations, a total of 90 different sites exist. Figure 1 displays the distribution

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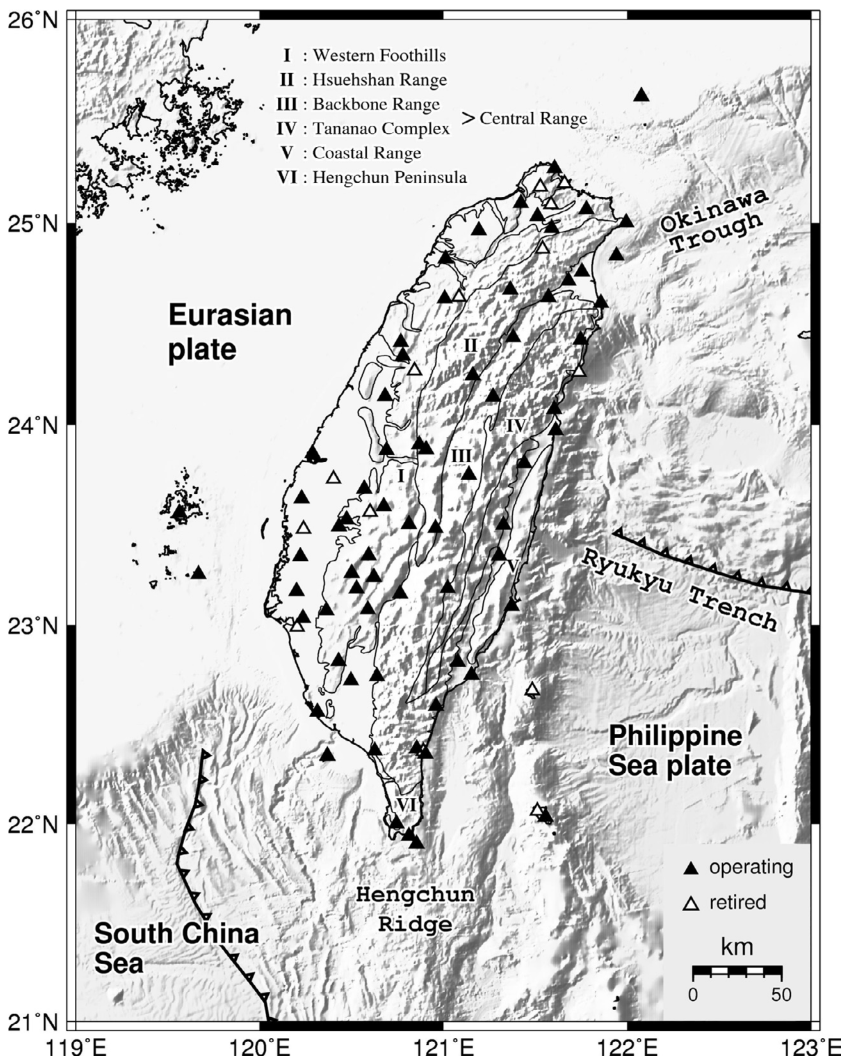

Fig. 1. The station distribution of the Central Weather Bureau Seismic Network (CWBSN) and the tectonic structures of the Taiwan region. Solid and open triangles show the locations of operating and retired stations, respectively.

of CWBSN stations (solid squares). From 1991 to 2011 (hereafter referred to as the old CWBSN), seismic signals were digitized at 12 bits, and 100 samples per second from each station were transmitted, via dedicated telephone lines, to the data center in Taipei where timestamps were assigned (Fig. 2). Therefore, telemetry delays were inevitable in records generated using the old system.

In 2010, the Central Weather Bureau (CWB) began upgrading the CWBSN system to a 24-bit system (hereafter defined as the new CWBSN). Figure 2 displays the new configuration. Currently at field stations, Teledyne/Geotech Smart24 seismometers are used to log data and to obtain times from the Global Position System (GPS). Real-time seismic signals, digitized at 24 bits, based on 100 samples per second from each station, are packaged and transmitted to headquarters via various IP-based networks, such as Frame-Relay, ADSL, GPRS, or satellite telemetry. Various telemetered networks can be arranged within a secure environment for seismic data transmission. For data acquisition and processing, a cluster of computers running the Earthworm system developed by United States Geological Survey (USGS) was installed at the central station in Taipei. Obviously, the new CWBSN system attenuates the telemetry delay problem.

3. TELEMETRY DELAY TEST

The new data recorder used in the CWBSN system, Smart24, has calibration functions, can be controlled remotely, and can send calibration signals to S13 sensors. The calibration signal can be transmitted simultaneously through the new and old CWBSN systems. In this work, we compared the arrival times between the records of the two systems and estimated the telemetry delay of the old CWBSN system in 2011. Figure 3 displays the calibration signals recorded by the new and old systems. Table 1 indicates the telemetry delay of the old CWBSN stations. We performed five tests for each station for data recorded on different days and times. In total, 67 of the 71 stations were tested. Since there were no internet connections, the remaining four stations could not be tested.

Telemetry delays may result from two modems and a leased telephone line (Fig. 2). Based on our test results, the telemetry delays for the majority of stations were approximately 0.2 sec. The stations had similar delays in values (most of the standard deviations were between 0.01 and 0.02 sec). Figure 4 displays the distribution of tested stations. The size of the solid circles represents the length of the telemetry delay. We found that telemetry delays were independent of the transmission distance and that they could be separated into two groups. Most of the delays were around 0.2 sec, others were close to 0.1 sec. Based on our laboratory tests, transmitting a signal to a modem (handshaking protocol type) may cause about 0.05 sec delay. Since two modems were used in the old CWBSN, there was a 0.1 sec delay. Due to the fact that a few of the stations directly use T1 line transmissions rather than modems, telemetry delays at these stations are close to 0.1 sec. For the majority of stations, the delays are approximately 0.2 sec. One-half of all of the delays were caused by the two modems and the other half was caused by transmissions.

4. DISCUSSION AND CONCLUSIONS

Telemetry delays directly affect earthquake location. Based on our test results, the delay is almost constant at each station. Therefore, we further examined earthquake location results calculated with and without telemetry delay

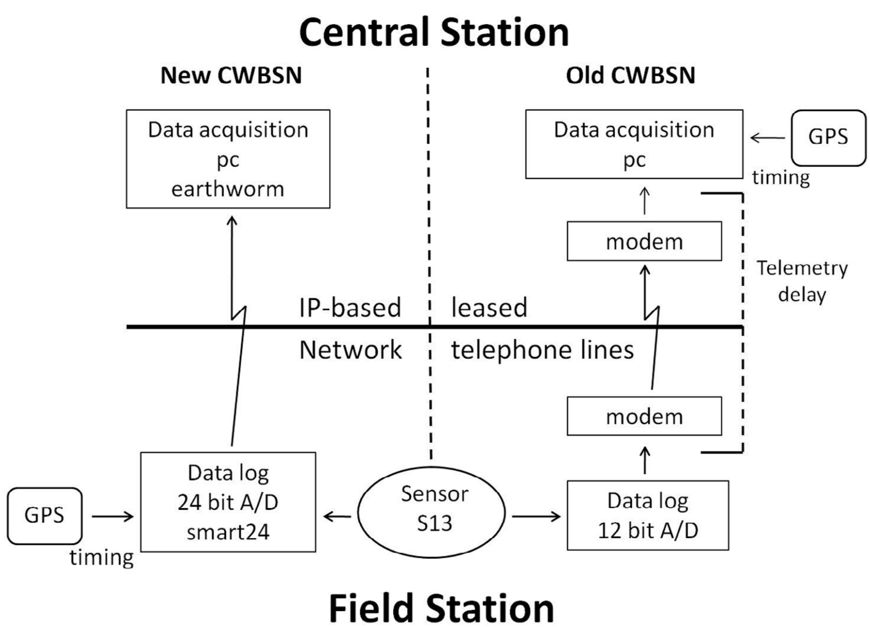

Fig. 2. The system configuration of the CWBSN.

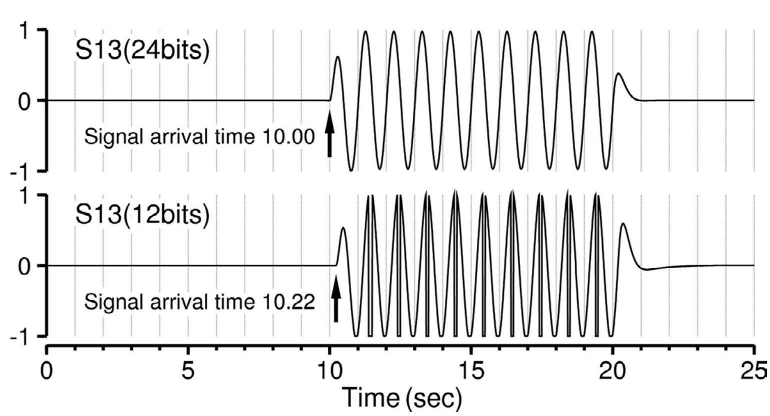

Fig. 3. The calibration signals recorded by the new (upper) and old (bottom) CWBSN systems.

Table 1. Results obtained from the telemetry delay tests (unit in seconds).

No.	Station Code	Test					Average
		1	2	3	4	5	
1	ALS	0.25	0.22	0.23	0.24	0.26	0.24 ± 0.02
2	CHK	0.20	0.21	0.21	0.20	0.22	0.21 ± 0.01
3	CHN1	0.21	0.21	0.23	0.20	0.21	0.21 ± 0.01
4	CHN2	0.18	0.13	0.16	0.16	0.13	0.15 ± 0.02
5	CHN3	0.22	0.23	0.22	0.21	0.22	0.22 ± 0.01
6	CHN4	0.21	0.20	0.22	0.23	0.21	0.21 ± 0.01
7	CHN5	0.21	0.21	0.22	0.22	0.21	0.21 ± 0.01
8	CHN8	0.17	0.17	0.16	0.17	0.14	0.16 ± 0.01
9	CHY	0.21	0.21	0.21	0.21	0.23	0.21 ± 0.01
10	EAS	0.20	0.21	0.21	0.18	0.19	0.20 ± 0.01
11	ECL	0.20	0.21	0.20	0.22	0.19	0.20 ± 0.01
12	EGS	0.24	0.19	0.19	0.21	0.23	0.21 ± 0.02
13	EHY	0.20	0.21	0.22	0.23	0.24	0.22 ± 0.02
14	ELD	0.22	0.20	0.17	0.20	0.20	0.20 ± 0.02
15	ENA	0.20	0.21	0.22	0.20	0.22	0.21 ± 0.01
16	ENT	0.22	0.21	0.21	0.21	0.20	0.21 ± 0.01
17	ESL	0.21	0.20	0.22	0.21	0.23	0.21 ± 0.01
18	HEN	0.22	0.23	0.23	0.22	0.20	0.22 ± 0.01
19	HSN	0.24	0.21	0.22	0.22	0.21	0.22 ± 0.01
20	HWA	0.09	0.11	0.10	0.09	0.09	0.10 ± 0.01
21	ILA	0.21	0.19	0.20	0.20	0.21	0.20 ± 0.01
22	KAU	0.19	0.22	0.21	0.21	0.21	0.21 ± 0.01
23	KNM	0.20	0.19	0.22	0.19	0.21	0.20 ± 0.01
24	LAY	0.17	0.18	0.20	0.22	0.20	0.19 ± 0.02
25	NCU	0.21	0.20	0.20	0.20	0.24	0.21 ± 0.02
26	NNS	0.20	0.21	0.20	0.22	0.20	0.21 ± 0.01
27	NSK	0.19	0.21	0.21	0.22	0.21	0.21 ± 0.01
28	NST	0.20	0.21	0.20	0.21	0.21	0.21 ± 0.01
29	NSY	0.23	0.19	0.21	0.21	0.22	0.21 ± 0.01
30	NWF	0.20	0.19	0.22	0.22	0.23	0.21 ± 0.02
31	PNG	0.20	0.20	0.21	0.20	0.19	0.20 ± 0.01
32	SCL	0.23	0.23	0.23	0.21	0.24	0.23 ± 0.01
33	SCZ	0.22	0.21	0.22	0.22	0.24	0.22 ± 0.01
34	SEB	0.20	0.19	0.16	0.20	0.20	0.19 ± 0.02
35	SGL	0.22	0.18	0.23	0.24	0.22	0.22 ± 0.02
36	SGS	0.22	0.20	0.22	0.23	0.23	0.22 ± 0.01
37	SML	0.22	0.21	0.21	0.19	0.23	0.21 ± 0.01
38	SSD	0.23	0.24	0.20	0.19	0.23	0.22 ± 0.02
39	STY	0.23	0.22	0.22	0.24	0.22	0.23 ± 0.01
40	TAI1	0.23	0.21	0.21	0.22	0.21	0.22 ± 0.01
41	TAP	0.10	0.06	0.08	0.09	0.06	0.08 ± 0.02
42	TAP1	0.06	0.08	0.04	0.07	0.07	0.06 ± 0.02
43	TAW	0.20	0.20	0.20	0.19	0.22	0.20 ± 0.01
44	TCU	0.19	0.22	0.22	0.19	0.21	0.21 ± 0.02
45	TTN	0.08	0.09	0.08	0.09	0.10	0.09 ± 0.01
46	TWA	0.21	0.27	0.22	0.24	0.25	0.24 ± 0.02

Table 1. (Continued)

No.	Station Code	Test 1	2	3	4	5	Average
47	TWB1	0.21	0.18	0.22	0.18	0.22	0.20 ± 0.02
48	TWC	0.20	0.20	0.20	0.22	0.20	0.20 ± 0.01
49	TWD	0.22	0.22	0.22	0.22	0.20	0.22 ± 0.01
50	TWE	0.22	0.22	0.21	0.23	0.19	0.21 ± 0.02
51	TWF1	0.17	0.20	0.22	0.20	0.22	0.20 ± 0.02
52	TWG	0.22	0.21	0.19	0.19	0.21	0.20 ± 0.01
53	TWK1	0.22	0.22	0.21	0.24	0.26	0.22 ± 0.01
54	TWL	0.23	0.21	0.22	0.20	0.22	0.22 ± 0.01
55	TWM1	0.21	0.19	0.22	0.20	0.21	0.21 ± 0.01
56	TWS1	0.21	0.22	0.21	0.16	0.13	0.21 ± 0.01
57	TWT	0.20	0.21	0.22	0.21	0.22	0.22 ± 0.01
58	TWY	0.14	0.12	0.12	0.23	0.21	0.12 ± 0.01
59	TYC	0.21	0.22	0.21	0.22	0.21	0.22 ± 0.01
60	WDG	0.14	0.13	0.11	0.17	0.14	0.13 ± 0.02
61	WGK	0.23	0.19	0.20	0.21	0.23	0.21 ± 0.02
62	WHF	0.22	0.21	0.21	0.18	0.19	0.22 ± 0.01
63	WLC	0.24	0.21	0.21	0.22	0.19	0.22 ± 0.01
64	WNT	0.22	0.20	0.20	0.21	0.23	0.22 ± 0.02
65	WSF	0.23	0.20	0.21	0.23	0.24	0.22 ± 0.01
66	WTC	0.24	0.20	0.22	0.20	0.20	0.23 ± 0.02
67	WTP	0.23	0.22	0.22	0.20	0.22	0.22 ± 0.01

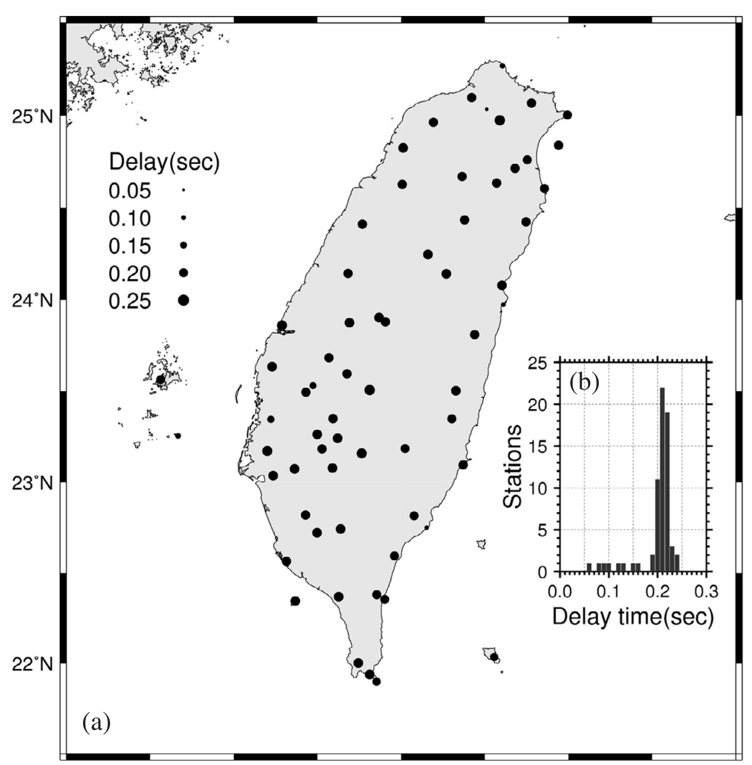

Fig. 4. The distribution of the tested stations. The size of the solid circle represents the value of the telemetry delay. Most of the delays are distributed around 0.2 sec.

corrections. In all, 3265 events were examined in this study. In order to relocate these events, we used 1D velocity structures (Chen and Shin 1998). Events from 01 July 2010 to 30 June 2011 with focal depths less than 80 km, bounded latitudes and longitudes from 21.4°N to 25.4°N and 119.4°E to 122.6°E, respectively, and magnitude ranges from 2.5 to 6.0, were selected. Figure 5 displays epicenter distributions between earthquake locations, calculated using data with and without telemetry delay corrections. The dots represent the locations obtained using data with telemetry delay corrections. The other side of the connected line shows related locations obtained using data without a correction. In general, inside the network, the locations were approximately the same. Only regions with large station coverage gaps had a small location difference. We also compared the earthquake location differences with and without a correction for earthquake origin time was -0.21 ± 0.05 sec (Fig. 6). And for hypocenter differences for longitude, latitude, and depth were -0.05 ± 0.40 km, 0.01 ± 0.23 km, and 0.01 ± 0.39 km, respectively (Fig. 6). Based on these results, the telemetry delay within the old CWBSN caused a 0.2 sec shift in the earthquake's original time. Location differences between hypocenters were determined using data with and without a telemetry delay correction were generally less than 1 km.

We interpreted the results based on three statistical error measurements, as follows: 1) the root-mean-square (RMS) of the travel time residuals, 2) the error in depth (ERZ), and 3) the error in the epicenter (ERH; Flinn 1965), for events of earthquake location with a telemetry delay correction. For the majority of events, the RMS, ERH, and ERZ were distributed in ranges of 0.2 to 0.5 sec, 1 to 3 km, and 1 to 3 km, respectively (Fig. 7). In general, the statistical error

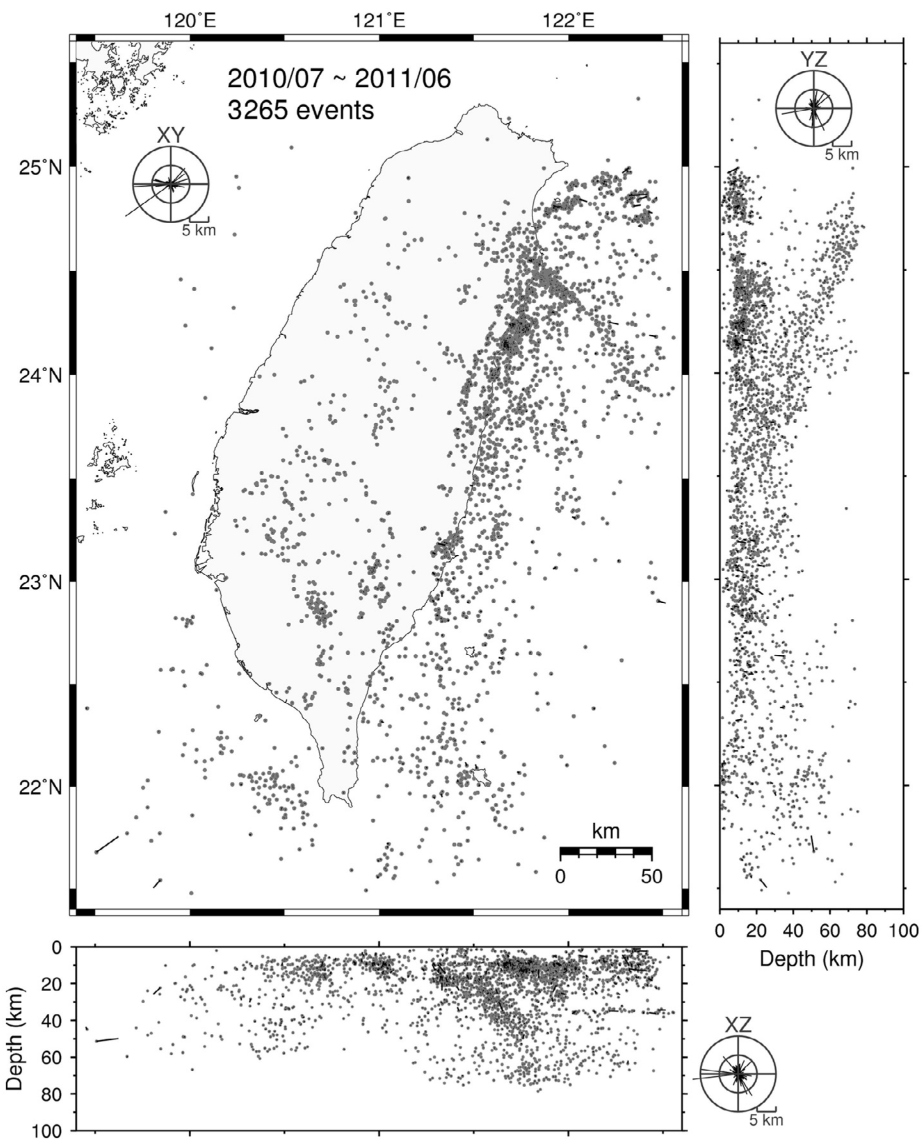

Fig. 5. The epicenter distributions for events with and without telemetry delay corrections in earthquake location. Dots representing the locations obtained using data with a correction; the other side of the connected line shows the related location obtained using data without a correction.

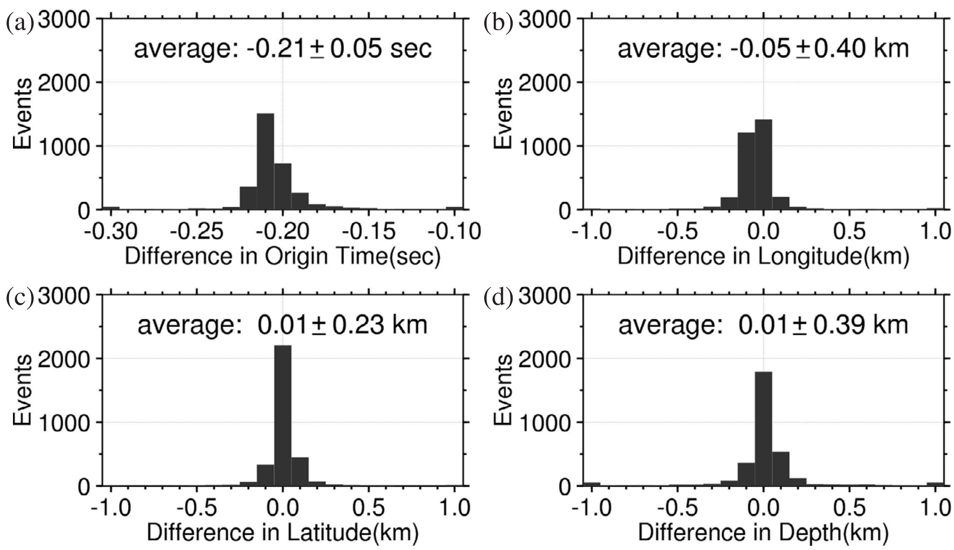

Fig. 6. Earthquake location differences as a result of origin time, longitude, latitude, and focal depth, with and without a telemetry correction.

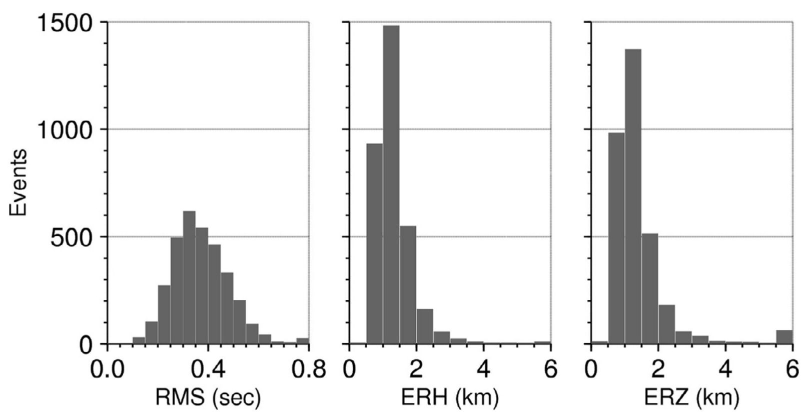

Fig. 7. The root-mean-square (RMS) of the travel time residuals, the error in depth (ERZ), and the error in the epicenter (ERH) for events with a telemetry delay correction in earthquake location.

measurements were larger than the differences caused by telemetry delays. Obviously, the differences between earthquake location with and without a telemetry delay correction were much smaller than the statistical error measurements. In this study, we suggest that the old CWBSN telemetry delay caused an approximate 0.2 sec shift in earthquake origin time. However, the timing shift does not cause a significant difference in earthquake location.

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