GPS accuracy: Hand-held versus RTK

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ABSTRACT

Source and receiver points for seismic lines recorded during the geophysics field school near Spring Coulee Alberta were surveyed with a Sokkia real time kinematic (RTK) GPS survey. The points were also surveyed with two hand-held Garmin GPS receivers. In order to determine what sort of station spacing could be adequately surveyed with the hand-held units, geophones were repeatedly surveyed with all three systems. The RTK system had a maximum error of 10 cm in *x*, *y* and *z*. Repeated hand-held measurements cannot resolve stations less than two meters apart in *x* and three meters apart in *y*.

INTRODUCTION

A variety of GPS measurements were collected by students attending the geophysics 549 field school in August/September of 2008 at Spring Coulee, Alberta. The primary purpose was to survey source and receiver locations for two seismic reflection lines with 10 m station spacing (chained) that were acquired in the course of the field school. The equipment used for this primary survey was a Sokkia GSR2700 ISX RTK system in RTCA GNSS mode (Table 1). The approximate centre of Vibrator pad marks, and the west side of individual geophones (~5 cm offset from centre of the geophone) were surveyed. In addition, geophone locations were surveyed using two different models of hand-held GPS units, a Garmin eTrex and a Garmin GPSMAP (Table 1). While the Sokkia system is clearly more accurate than the Garmins based on the specifications, we only have one of these (expensive) Sokkia systems. So the question becomes: If the Sokkia is not available and we are forced to survey source/receiver locations with a hand-held, will the results be accurate enough for our purposes?

DESCRIPTION OF SURVEY

A Sokkia base station was setup over an unknown point represented by a nail hammered into the ground. The base station was set up over the nail from scratch every morning for two weeks. The location of the unknown point was initially determined by averaging 200 autonomous GPS measurements the first time the base station was set up. This location was saved in a file, and re-used each time the base station was set up. Two Alberta Survey Control Monuments (ASCMs) exist near a road within range (~6-7 km) of our unknown point. Both ASCMs were surveyed once with the Sokkia roving unit. Horizontal position errors in *x* and *y* were obtained that are well within the published specifications for autonomous mode (Table 2). The vertical error (Δz) is roughly double that of the maximum horizontal error (Δx).

Geophone locations were surveyed with the Garmin handhelds by storing latitude, longitude and altitude information as waypoints. The lat/longs were converted to UTM eastings/northings for this study using *Geotrans2* (National geospatial-intelligence agency), which has a 1 meter accuracy on the conversions. In spite of warnings, we forced it to output results to the nearest decimeter.

The Garmin GPS units record altitude from barometric altimeters. The altimeters were calibrated to the Sokkia base station GPS ellipsoid height at the beginning of each day. However, there were problems with the calibration procedure. For example, the next waypoint recorded had the calibrated elevation, even if the GPS had been moved well away from the base station in the meantime. As a result, the hand-held altitudes are less consistent from day to day than we had hoped. Following calibration, geophone locations were surveyed by storing waypoints with the hand-held GPS units held at approximately waist height (varied from student to student) above a geophone.

RESULTS

While the Sokkia real time kinematic (RTK) accuracy should be on the order of 1 cm (rover antenna relative to base station antenna; Table 1), repeated measurements yield a maximum (Δx, Δy, Δz) error of (0.1, 0.l, 0.1 m; Table 3, blue diamonds in Figure 1). This decimeter scale inconsistency could be due to 1) different students placing the range pole in a slightly different position relative to the geophone, 2) subtle differences in base station setup from day to day, or 3) the range pole not being exactly vertical for the measurement. The top of a 2.5 m range pole is displaced 0.1 m horizontally from the base if the pole is just 2.3 degrees from vertical.

A much larger variation in Garmin versus Sokkia position is seen than in Sokkia versus Sokkia position (Table 3, Figure 1). The maximum eTrex to Sokkia difference (6.3, 12.5, 6.7 m; Table 3) is larger in *y* than our 10 m station spacing, and larger than a half-station spacing in *x*. The error in *y* may be due to note-keeping error, as the mean is (1.5, 2.6, 2.5 m; Table 3). If the recorded station number was off by one, the maximum Δy for this particular geophone location would actually be 2.5 m. Interestingly, a series of eTrex geophone locations at the north end of line 1 are consistently about 10 m apart, but have a greater than station spacing offset from the Sokkia position. The remainder of the eTrex measurements are much closer to the mean and median values presented in Table 3. Finally, the GPSMAP *x* and *y* measurements track the Sokkia positions more closely than the eTrex measurements, even though the accuracy reported in the owner's manual is worse (Table 1). This may be partly due to the fact that fewer GPSMAP measurements were made (about 100 fewer), over a shorter time-span.

When we look at repeated Garmin measurements, an interesting granularity appears (Figures 2 and 3). It seems that both the eTrex and the GPSMAP have resolution limits of ~2 m in *x* and ~3 m in *y* (Figure 3). This means that even if accuracy permitted, we would be unable to resolve a < 3 meter station spacing on a north-south line. Further, when a geophone position was re-surveyed the next day (Figure 3), there was a bulk shift to the northwest (for this location and time; Figure 3). Garmin versus Sokkia measurements have errors less than 2 m, likely because the actual geophone location lies between the points resolvable by the Garmin's.

In order to produce Figures 4 and 5 (and the elevation differences reported in Table 3), the following assumptions were made: 1) Line 1 eTrex and Sokkia station 300 elevations were equal (-6 m correction), 2) Line 1 eTrex station 463 (September 3) elevation was equal to eTrex station 464 elevation (September 4; -14 m correction), 3) Line 1 GPSMAP and eTrex elevations at station 369 were equal (-12 m correction), and 4) Line 2 eTrex elevations are correct, but GPSMAP and Sokkia station 101 elevations were the same (-17 m correction). These corrections have been made because of issues we had with calibrating the Garmin altimeters, and to emphasize similarities in the overall elevation profiles. Note that the overall trend of the Garmin altitude curves follows the Sokkia GPS elevations closely. Furthermore, the change in altitude from station to station is independent of the bulk shifts, and also tracks the Sokkia elevation closely (~ +/-1 m relative to the Sokkia; Figures 6 and 7). The divergence seen between the altimeter data and the Sokkia elevations can be explained by changes in atmospheric pressure over the course of the day (weather). Differences between eTrex and GPSMAP altitudes are less easy to explain, especially for Line 2, where both units recorded waypoints for a given geophone within 5 minutes of each other. In contrast, stations on Line 1 were surveyed over a period of several days.

Table 1. Equipment comparison. Images from bench-mark.ca and garmin.com. Other information from the owner's manuals.

	Sokkia GSR2700 ISX  **RTK**	**Garmin eTrex summit HC** 	**Garmin GPSMAP 60CS** 
Dimensions	22.5 x10.5 cm (single antenna/receiver only)	10.7 x5.6 x3.0 cm	15.5 x6.1 x3.3 cm
Weight	1.8 kg (single antenna/receiver only)	159 g	213 g
Autonomous accuracy	1.5 m	<10 m	<15 m
Altimeter accuracy	-	+/- 3m, 30 cm resolution	+/- 3m, 30 cm resolution
RTK accuracy	1 cm	-	-
Cost	~$40,000	~$300	~$400

Table 2. Sokkia measured positions vs. published values for Alberta Survey Control Monuments (ASCMs; Alberta Land Titles Spatial Information System). The Base station was set up over an unknown point; 200 autonomous measurements were averaged to determine position. Two nearby ASCMs were then surveyed with the roving unit (Average of four fixed measurements, rounded to the nearest centimeter).

Sokkia RTK/ ASCM	Δx (m)	Δy (m)	Δz (m)
ASCM 226415	1.44	0.57	-3.09
ASCM 710467	1.44	0.55	-3.14
mean	1.44	0.56	-3.12

Table 3. Summary of statistics for position errors for GPS measurements. **B** is assumed to be the correct geophone location (ie. **A** is a repeated measurement for the same geophone).

A	vs. B	Statistic	Samples	|Δx| (m)	|Δy| (m)	|Δz| (m)
Sokkia	Sokkia	**Min**	118	0.0	0.0	0.0
eTrex	Sokkia		474	0.0	0.0	0.0
GPSMap	Sokkia		368	0.0	0.0	0.0
GPSMap	eTrex		364	0.0	0.0	0.0
eTrex	eTrex		68	0.0	0.0	0.2
Sokkia	Sokkia	**Max**	118	0.1	0.1	0.1
eTrex	Sokkia		474	6.3	12.5	6.7
GPSMap	Sokkia		368	3.7	7.5	8.5
GPSMap	eTrex		364	6.1	9.4	7.6
eTrex	eTrex		68	4.0	6.3	7.7
Sokkia	Sokkia	**Mean**	118	0.0	0.0	0.1
eTrex	Sokkia		474	1.5	2.6	2.5
GPSMap	Sokkia		368	0.9	1.4	3.9
GPSMap	eTrex		364	1.5	2.2	3.5
eTrex	eTrex		68	1.7	2.1	4.1
Sokkia	Sokkia	**Median**	118	0.0	0.0	0.1
eTrex	Sokkia		474	1.4	2.0	2.4
GPSMap	Sokkia		368	0.9	1.2	4.4
GPSMap	eTrex		364	2.0	3.0	3.5
eTrex	eTrex		68	2.0	3.0	3.6
Sokkia	Sokkia	**Stddev**	118	0.0	0.0	0.0
eTrex	Sokkia		474	1.0	2.1	1.3
GPSMap	Sokkia		368	0.6	1.2	2.5
GPSMap	eTrex		364	1.3	2.1	1.8
eTrex	eTrex		68	1.3	2.0	2.3

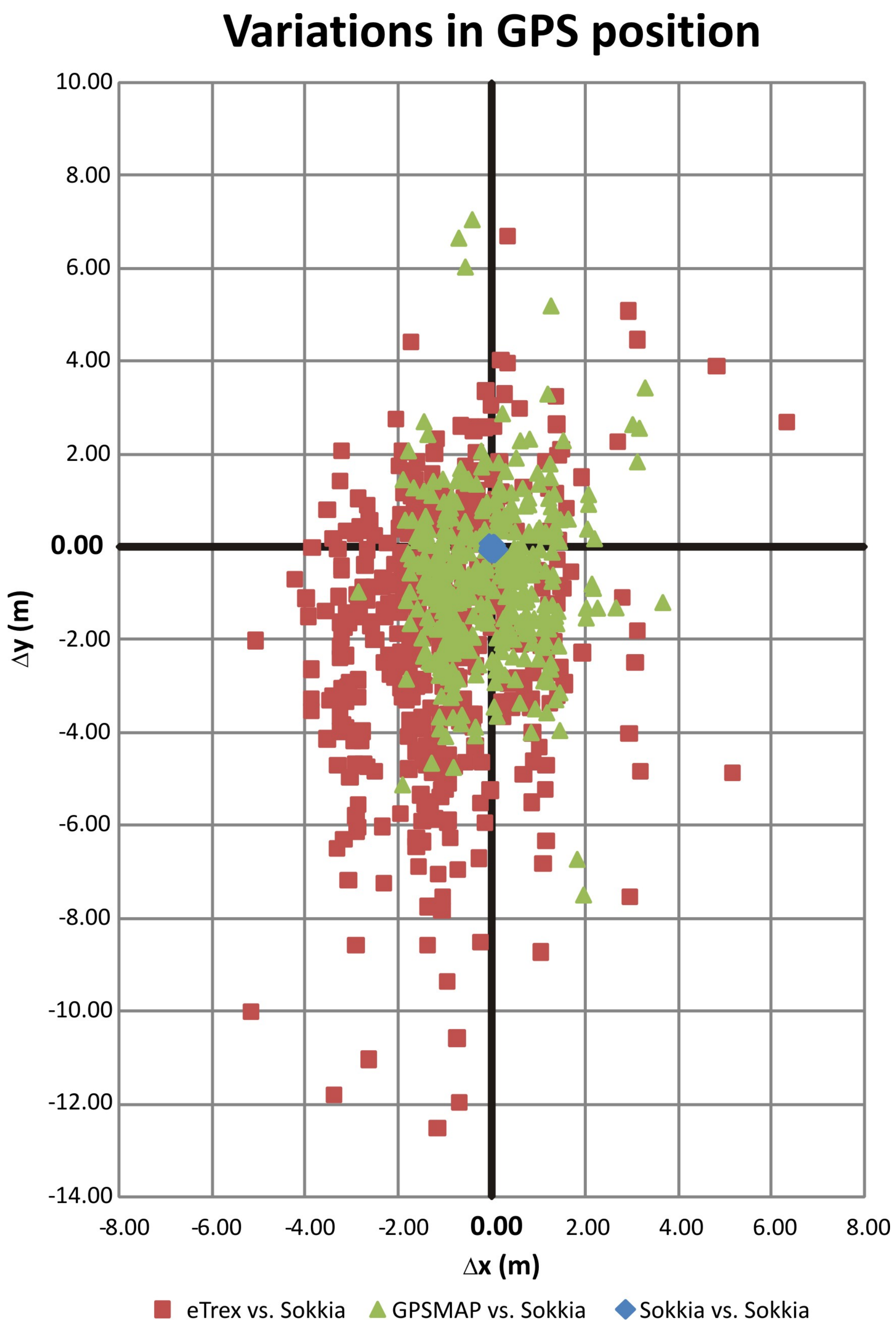

FIG. 1. Plot of Δ*x* vs. Δ*y* for repeated measurements of geophone location. In all cases, the first Sokkia measurement is assumed to be the correct geophone location, i.e. if there is no error, the data points would all plot on (0,0). Red squares are eTrex vs. Sokkia (474 measurements), green triangles are GPSMAP vs Sokkia (368 measurements), and blue diamonds are Sokkia vs. Sokkia (118 measurements).

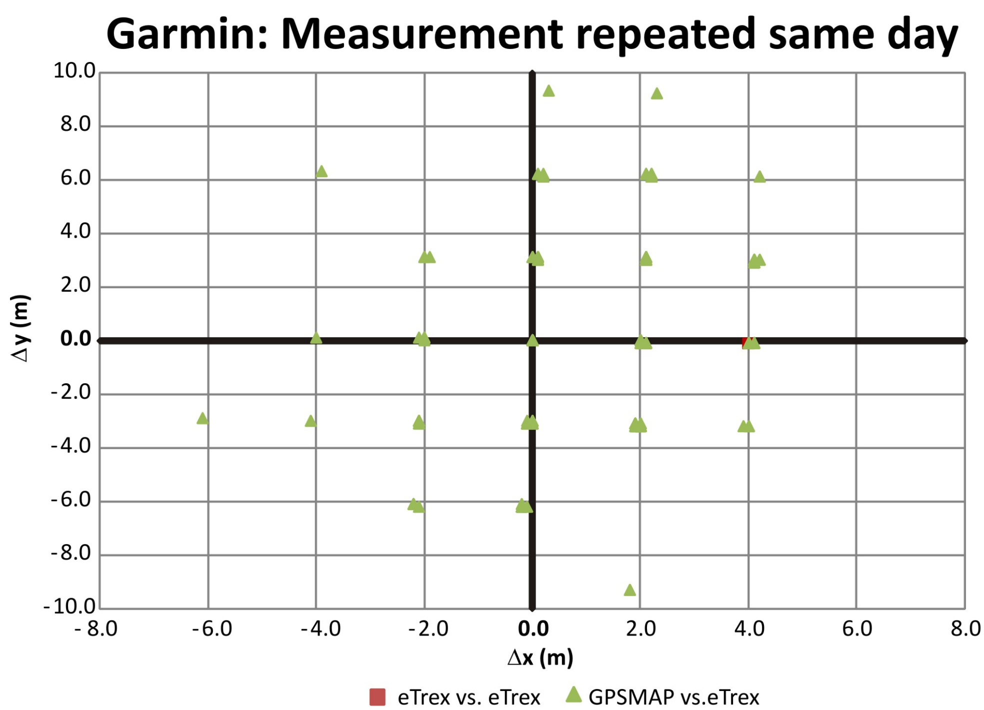

FIG. 2. Plot of Δ*x* vs. Δ*y* for repeated measurements of geophone location on the same day (typically within 5-30 minutes). In all cases, the first eTrex measurement is assumed to be the correct geophone location. Red square is eTrex vs. eTrex (1 measurement), green triangles are GPSMAP vs eTrex (297 measurements).

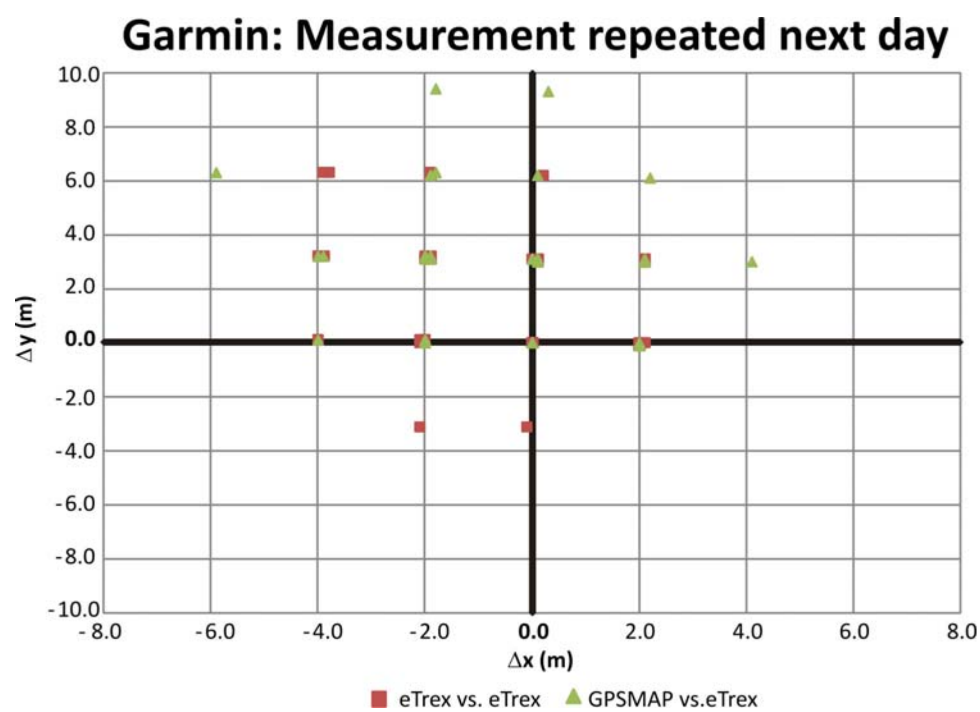

FIG. 3. Plot of Δ*x* vs. Δ*y* for repeated measurements of geophone location on the next day. In all cases, the first eTrex measurement is assumed to be the correct geophone location. Red squares are eTrex vs. eTrex (66 measurements), green triangles are GPSMAP vs eTrex (66 measurements).

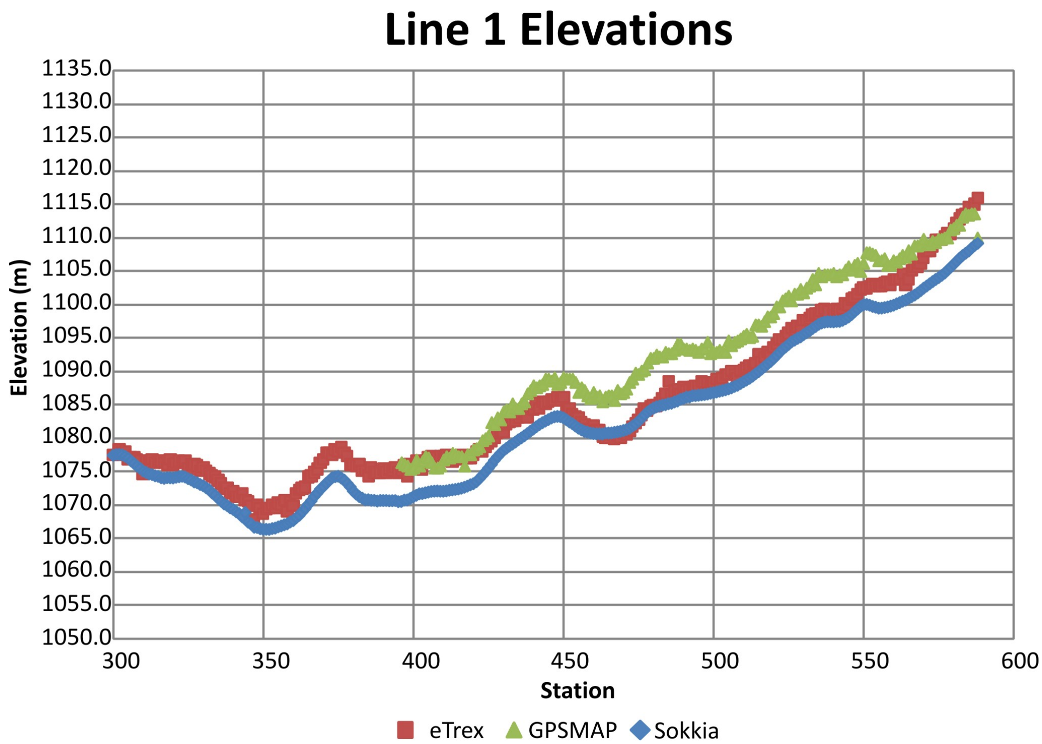

FIG. 4. Elevation profile for south end of Line 1. Red squares are eTrex altitudes, green triangles are GPSMAP altitudes and blue diamonds are Sokkia GPS ellipsoid heights.

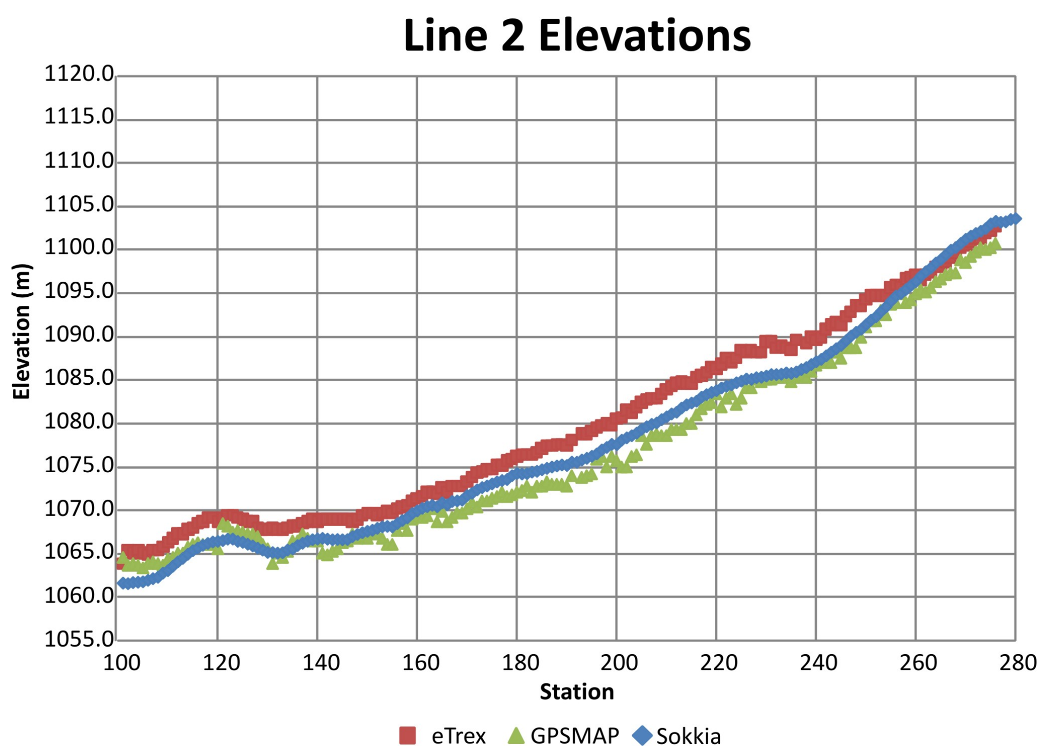

FIG. 5. Elevation profile for Line 2. Red squares are eTrex altitudes, green triangles are GPSMAP altitudes and blue diamonds are Sokkia GPS ellipsoid heights.

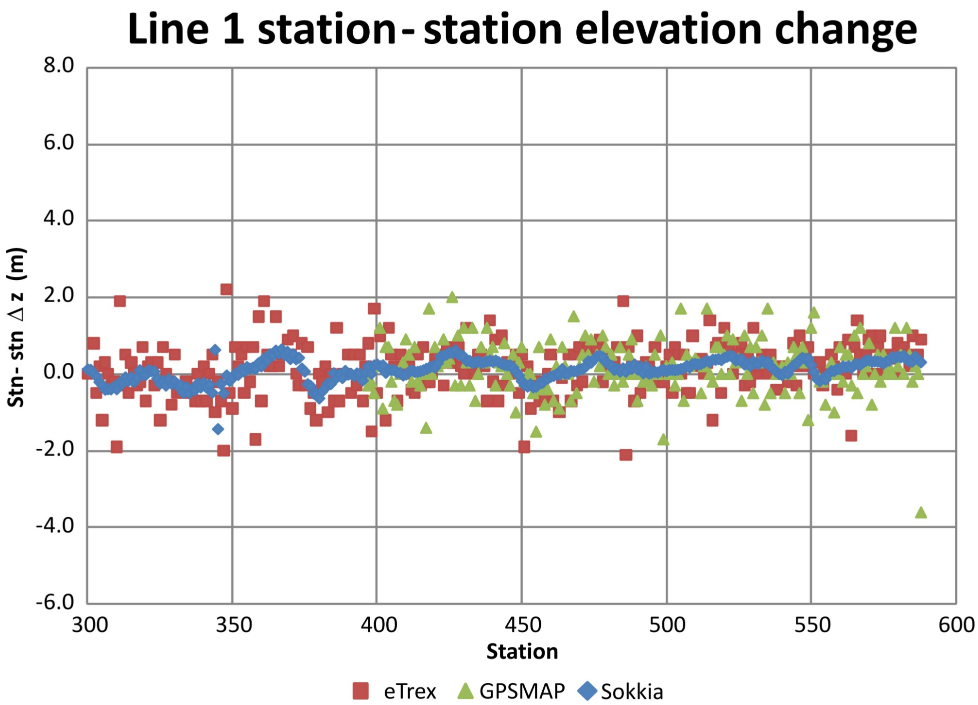

FIG. 6. Station to station altitude/elevation difference for Line 1. Red squares are eTrex Δ*z*, green triangles are GPSMAP Δ*z* and blue diamonds are Sokkia GPS Δ*z*.

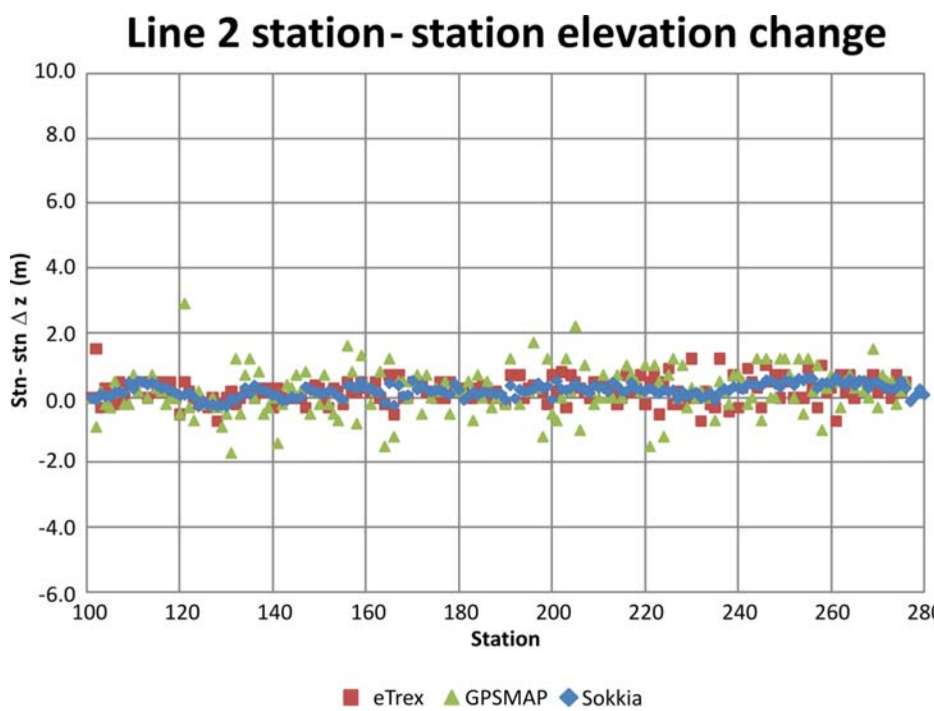

FIG. 7. Station to station altitude/elevation difference for Line 2. Red squares are eTrex Δ*z*, green triangles are GPSMAP Δ*z* and blue diamonds are Sokkia GPS Δ*z*. Note that the *x*-axis has been compressed to approximately the same scale as shown in Figure 6.

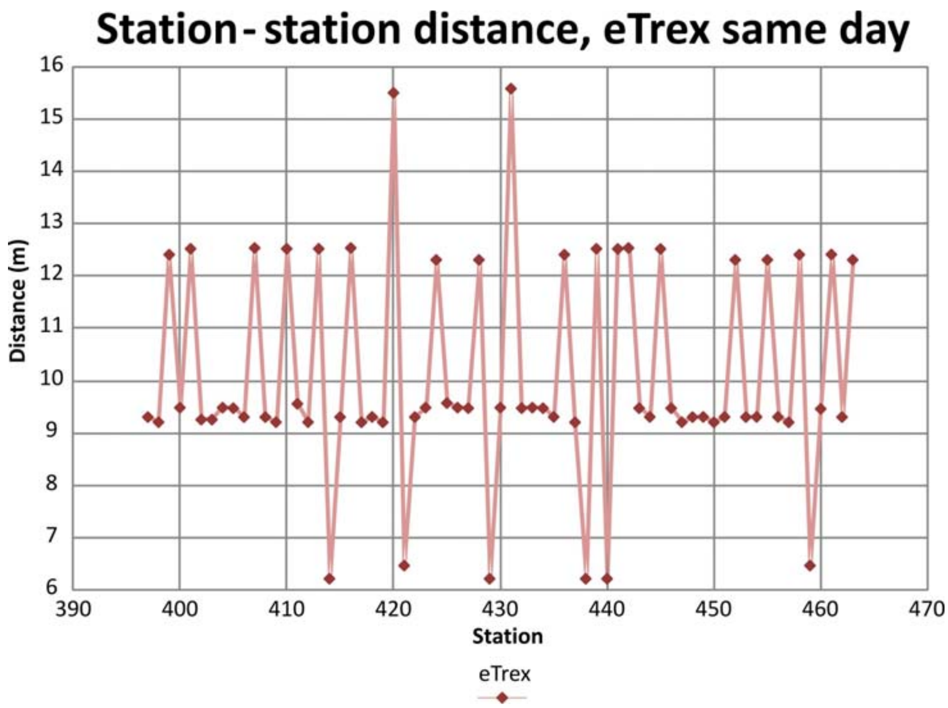

FIG. 8. A three meter resolution in *y* means the Garmin handhelds cannot be used for a 10 m station spacing on a N-S line. Out of 67 measurements 41 (61%) have a station spacing of 9 m, 18 (27%) of 12 m, 6 (9%) of 6 m and 2 (3%) of 15 m.

CONCLUSIONS

Station spacings of less than 3 m in *y* will be not be resolvable with one of the hand-held GPS units described in this report, regardless of accuracy. It will not be possible to survey stations with a 10 m spacing, but with care, we may be able to adequately locate stations with a ~9 or ~12 meter station spacing. Relative altitudes should also be adequate for seismic elevation statics, as long as station-station altitude difference errors on the order of 1-3 m are acceptable. In order to achieve these results, the altimeter in the hand-held should be properly calibrated at a base location (survey control monument if possible) at least daily for a multi-day survey (more often depending on weather).

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