Obtaining Accurate Vertical and Horizontal Coordinates using Kiwi OSD

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Summary

STATUS

GPS-based timing systems can also provide positional information.
Accuracy usually achieved:

Latitude and longitude: satisfactory if (SA is off)
Elevation: believed to be unsatisfactory

PRESENT PURPOSE

Test positional accuracy by visiting accurately surveyed monuments

THE STUDY

Equipment Kiwi OSD with Garmin GPS 18
Scope Eight test series at four locations

RESULTS

Horizontal accuracy is much better than needed
Vertical accuracy can be adequate if three simple criteria are met

[minimum signal quality; average after convergence; correct geoid height]

Applicability

Worldwide to any system using Garmin GPS 18 --
but confirmation is desired

(WAAS-enabled systems should be more accurate,
but it is available only within the U.S.)

The experimental approach described here can be used to evaluate any system using any GPS.

Acknowledgments

Geoff Hitchcox, of Christchurch, New Zealand, is the creator of Kiwi OSD, the device used to obtain all of the data presented in this report. Geoff was also very helpful in developing my understanding of the terminology of geodesy, in working out the different relationships involved in measuring elevations, and in interpreting the results.

Ed Morana, of Livermore, California generously contributed his time and equipment so that data could be obtained to allow comparison between two Kiwi OSD systems.

Outline: Here's what's coming

I - Accuracy requirements

II - NGS accuracy experience

III - Equipment

IV - Test locations

V - About WGS84

VI - Where are we? (geographically)

VII - Experimental data

VIII - Summary and recommendations

I - Accuracy requirements

From:

≡*Chasing the Shadow*: The IOTA Occultation Observer's Manual

7 Site Position Determination

7.1 Accuracy Requirements

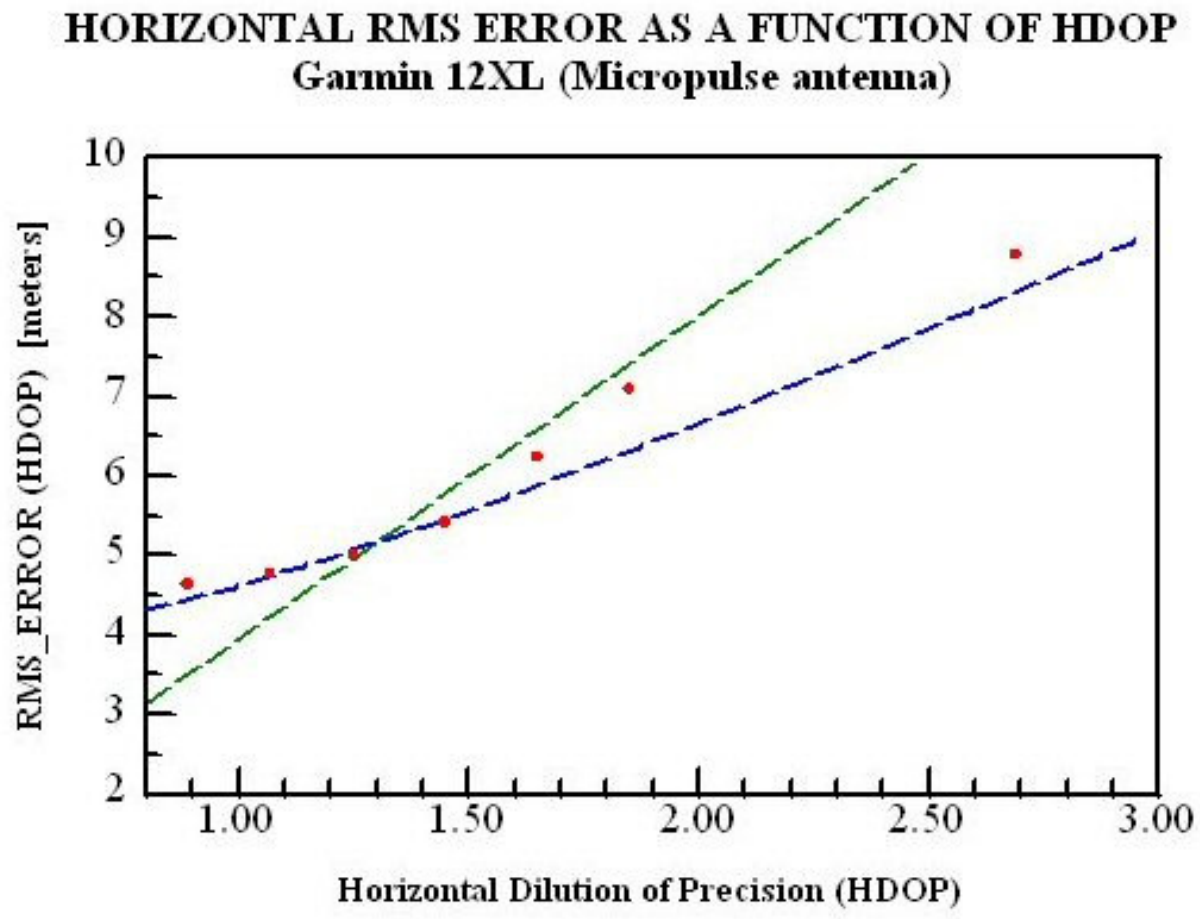
The precision needed for ground positions for occultation work is:

Total Occultations	± 0.5" (±15 meters)
Grazing Occultations	± 0.3" (±10 meters)
Asteroid Occultations	± 3" (±100 meters)
Solar Eclipses	± 0.5" (±15 meters)
Elevations	± 15 meters

Lat/long accuracy translation

+/- 10 metres in Latitude	=	+/- 0.**005**4 arcminutes
+/- 10 metres in Longitude:		
at the equator	=	+/- 0.**005**4 arcminutes
at latitude 30 degrees	=	+/- 0.**006**2 arcminutes
at latitude 40 degrees	=	+/- 0.**007**0 arcminutes
at latitude 50 degrees	=	+/- 0.**008**4 arcminutes
at latitude 60 degrees	=	+/- 0.**010**8 arcminutes

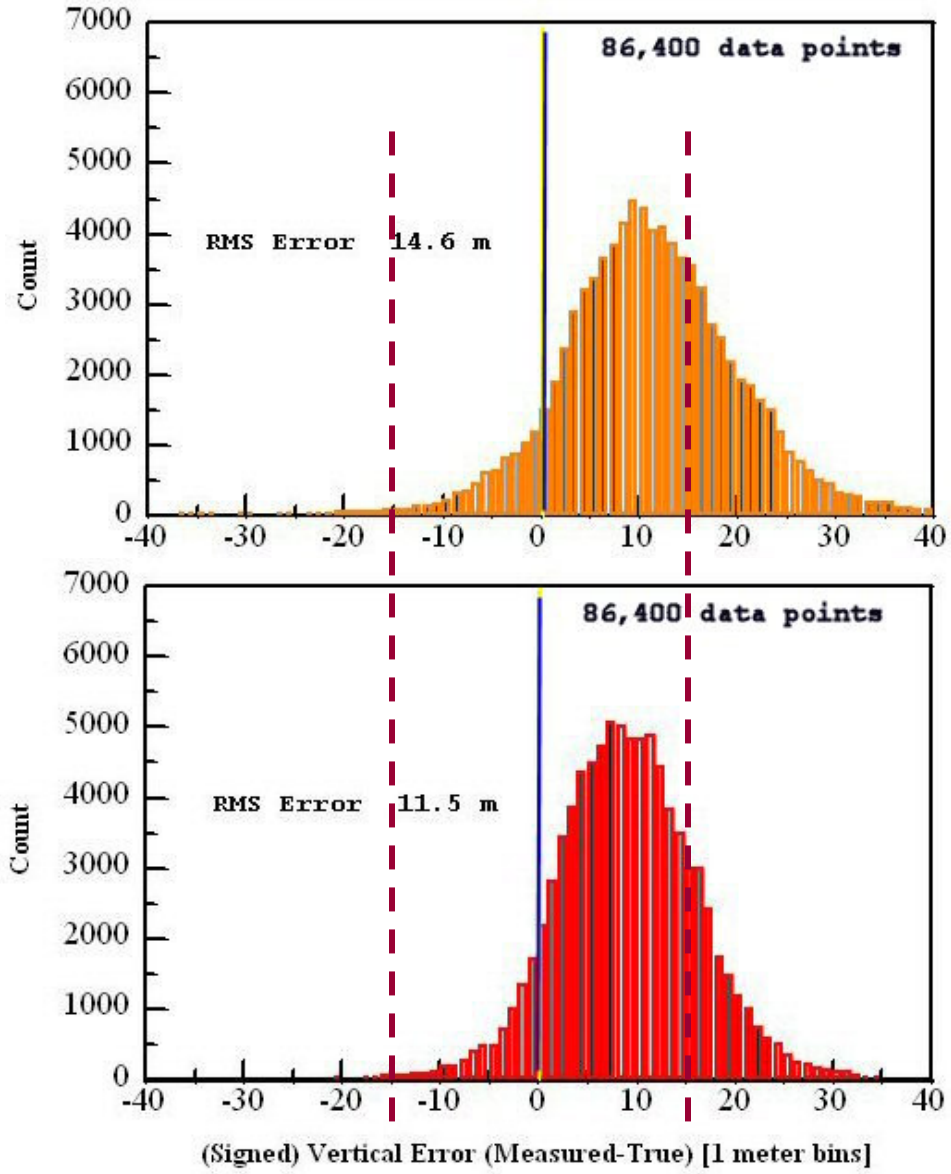
II - NGS accuracy experience



Green line:
A theoretical relationship.

Red points:
Observed relationship (blue line is fit)

NGS Elevation Error Data



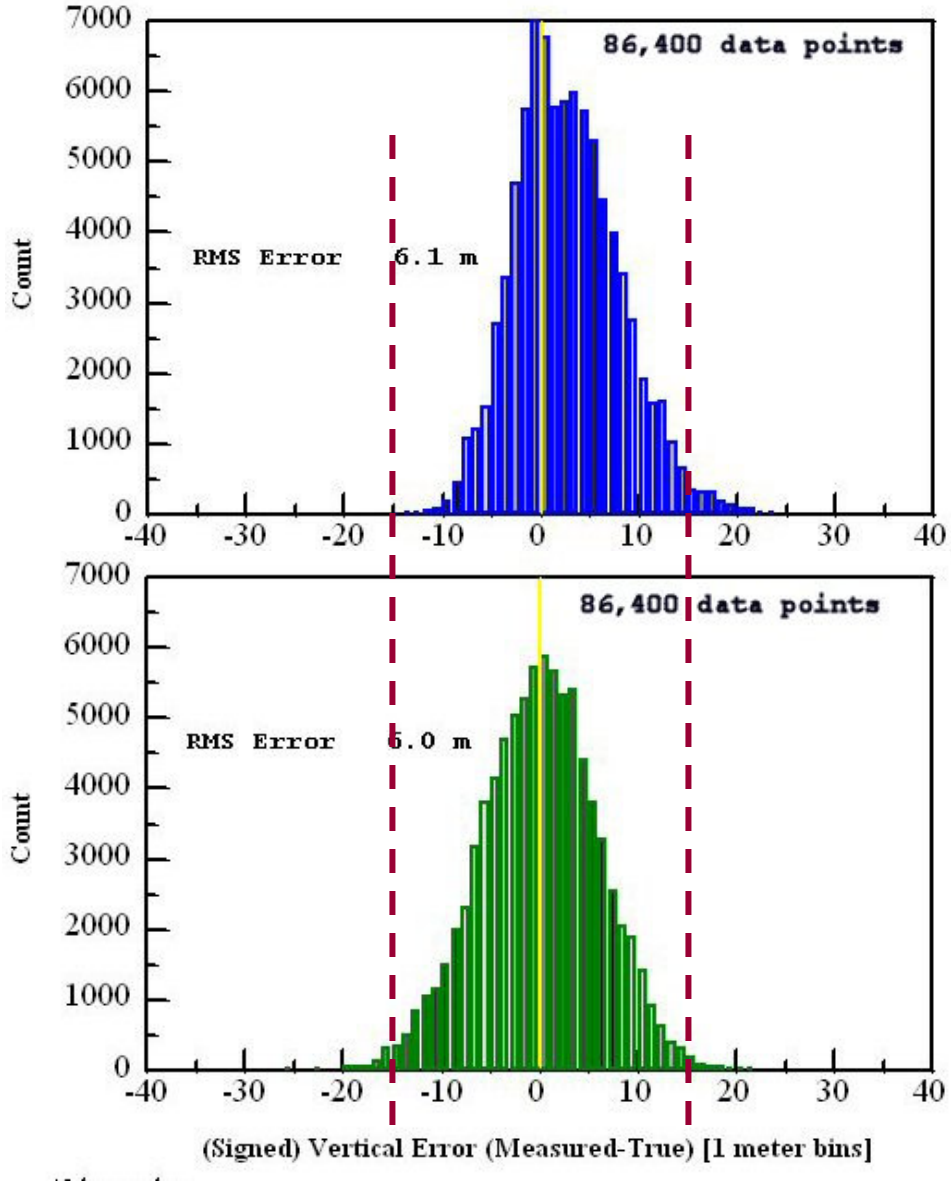
Distribution of vertical error:
48-hour data collection

<< Garmin 12XL

<< Garmin III Plus

Both data sets appear to be offset about 10 m

NGS Elevation Error Data



Distribution of vertical error:
48-hour data collection

<< Eagle Explorer

RMS error = 6.1 m

<< Garmin eMap

RMS error = 6.0 m

III - Equipment

A representative time display

hh : mm : ss msec1 msec2 ff

hh = hours UT
mm = minutes UT
ss = seconds UT
msec1 = milliseconds after ss (start/end)
msec2 = milliseconds after ss (end/start)
ff = field count since last reset

Interpretation:

One frame is displayed, consisting of two fields.
First field start: msec1 = 298; end: msec2 = 315.
Second field start: msec2 = 315; end: msec1 = 331.
Field counts are 1458 and 1459.

A display of horizontal coordinates

North Latitude **West Longitude**

Horizontal coordinates are displayed for five seconds during each reset cycle.

The resolution of 0.0001 arcminutes is Equivalent to approximately 0.1 to 0.2 metres.

A display of vertical coordinates

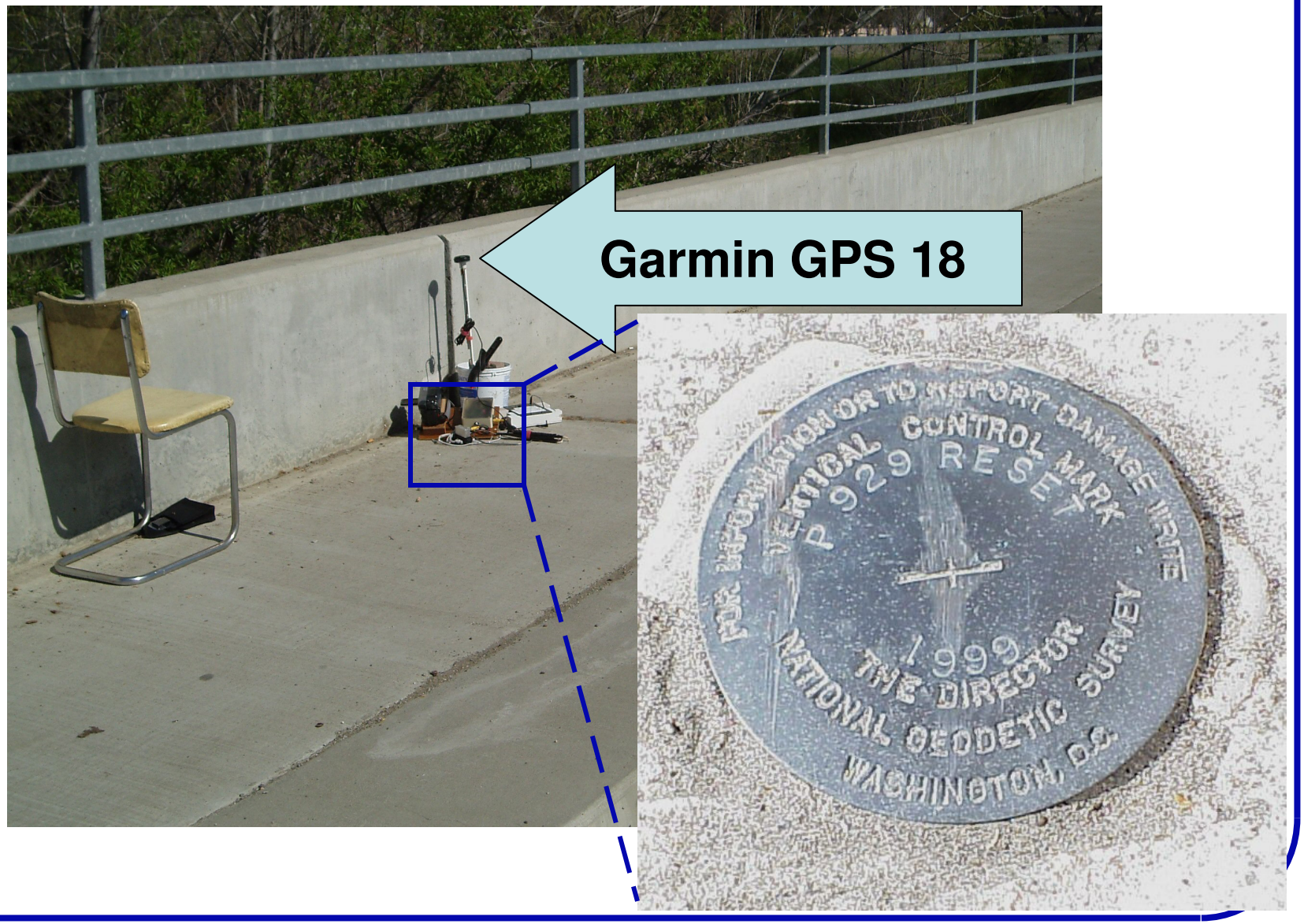
V nn HDOP mmm.m U gg.g

V = integrity check indicator
nn = number of GPS satellites acquired
HDOP = Horizontal Dilution of Precision
(an accuracy index)
mmm.m = elevation
U = units (metres in this case)
gg.g = Geoid height (aka N)

Vertical coordinates are displayed for seven seconds during each reset cycle.

IV – Test Locations

Test Location A: First Street



Location B: Finley Road

Location D: Park

Location D: Park

Location C: Airport

Location C: Airport

Google Earth view of Livermore airport

Google Earth targeting ‘Tom L’

Google Earth targeting ‘Tom L’

V - About WGS84

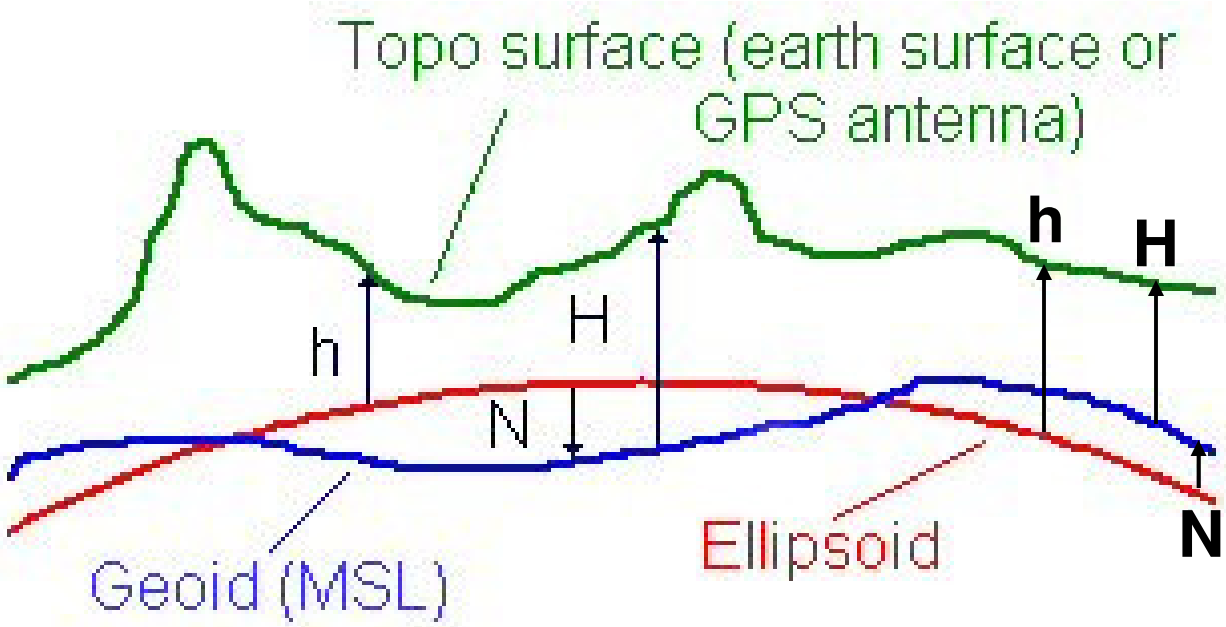
Origination ~1980

ACTION / DATE	NAME
First implementation Jan 23, 1987:	WGS84(orig.)
Effective June 28, 1994:	WGS84(g730)
Effective January 29, 1997:	WGS84(g873)
Effective January 20, 2002:	WGS84(g1150)

Next version probable about 2009

Surfaces described

$$h = H + N$$



h=ellipsoid height
H=orthometric height
N=geoid height

Example: correcting reported elevation

Kiwi-displayed MSL elevation:	112.8 m	(H')
Kiwi-displayed Geoid height:	-27.6 m	(N')
Ellipsoid height (h = H' + N')	**85.2 m**	

85.2 m is the quantity actually measured, the elevation relative to the WGS84 ellipsoid.

The approximation problem

A coarse table of geoid heights is in GPS memory.
Interpolation produced -27.6 m for geoid height.
The accurate geoid height at this location is

$$N = -32.2 \text{ m}$$

(from <http://www.ngs.noaa.gov/cgi-bin/GEOID_STUFF/geoid03_prompt1.prl>)

Since $H = h - N$

$$H = 85.2 - (-32.2) = 117.4 \text{ m}$$

This is the **Kiwi-derived** MSL elevation.
The **Kiwi-displayed** MSL elevation was 112.8 m
The difference is 4.6 m.

The arithmetic

$$H = h - N$$

Real-time		Afterward	
(h)	85.2	(h)	85.2
(N')	-27.6	(N)	-32.2
(H')	112.6	(H)	117.2
(displayed)		(derived)	

VI - Where are we? (geographically)

The NGS Data Sheet

```
**********************************************************************
 PACS          -  This is a Primary Airport Control Station.
 DESIGNATION   -  TOM L
 PID           -  AC6328
 STATE/COUNTY  -  CA/ALAMEDA
 USGS QUAD     -  LIVERMORE (1980)

                        *CURRENT SURVEY CONTROL

* NAD 83(1998)-  37 41 45.66198(N)     121 49 08.94549(W)
* NAVD 88     -       117.98   (meters)      387.1    (feet)

 EPOCH DATE   -         1998.50
 X            - -2,664,247.892 (meters)
 Y            - -4,293,786.627 (meters)
 Z            -  3,878,853.808 (meters)
 LAPLACE CORR-              2.69  (seconds)
 ELLIP HEIGHT-             85.72  (meters)          (04/24/01)
 GEOID HEIGHT-            -32.21  (meters)
```

Transforming coordinates

```
**************************************
HTDP (version 2.9) OUTPUT

TRANSFORMING POSITIONS
      FROM NAD_83(CORS96)    (EPOCH = 07-03-1998)
        TO WGS_84(G1150)     (EPOCH = 04-08-2007)

             INPUT COORDINATES    OUTPUT COORDINATES
LATITUDE      37 41 45.66198 N      37 41 45.67824 N
LONGITUDE   121 49  8.94549 W     121 49  9.00272 W
ELLIP. HT.              85.720               85.177 m
```

(http://www.ngs.noaa.gov/cgi-bin/HTDP/htdp.prl?f1=4&f2=1)

Impact of transform process

Latitude: coordinates are ~ 0.5 metres North

Longitude: coordinates are ~1.3 metres West

Elevation: lower by ~ 0.5 metres

These are non-trivial, but minor compared to the error that can be introduced if displayed elevation is reported as MSL

VII - Experimental Data

Convergence

Question

After its first fix, how soon will valid data be reported?

An extreme experiment

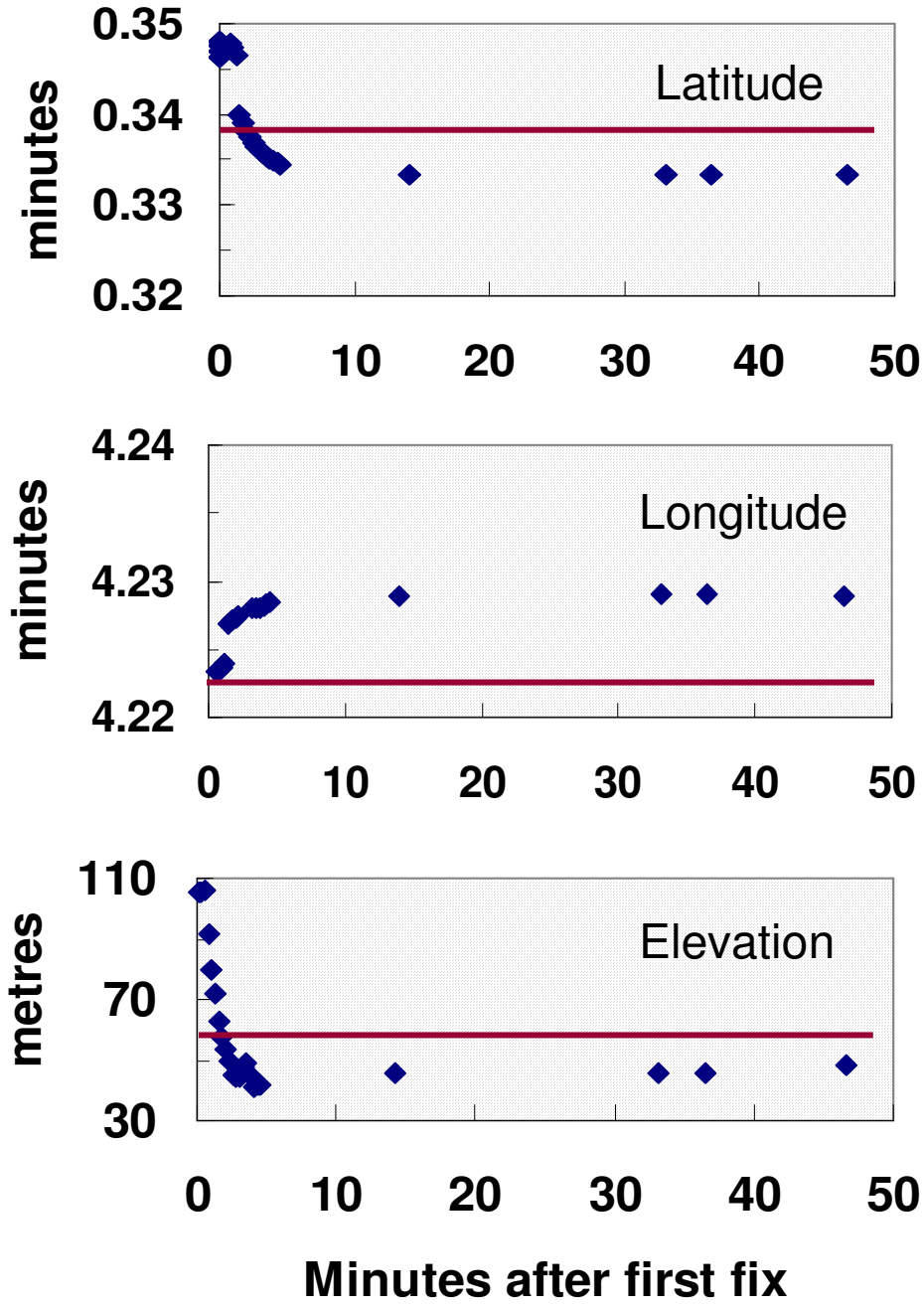
Observations immediately after a 146 km move.

Displacement details

Latitude - 145 km north

Longitude - 18 km west

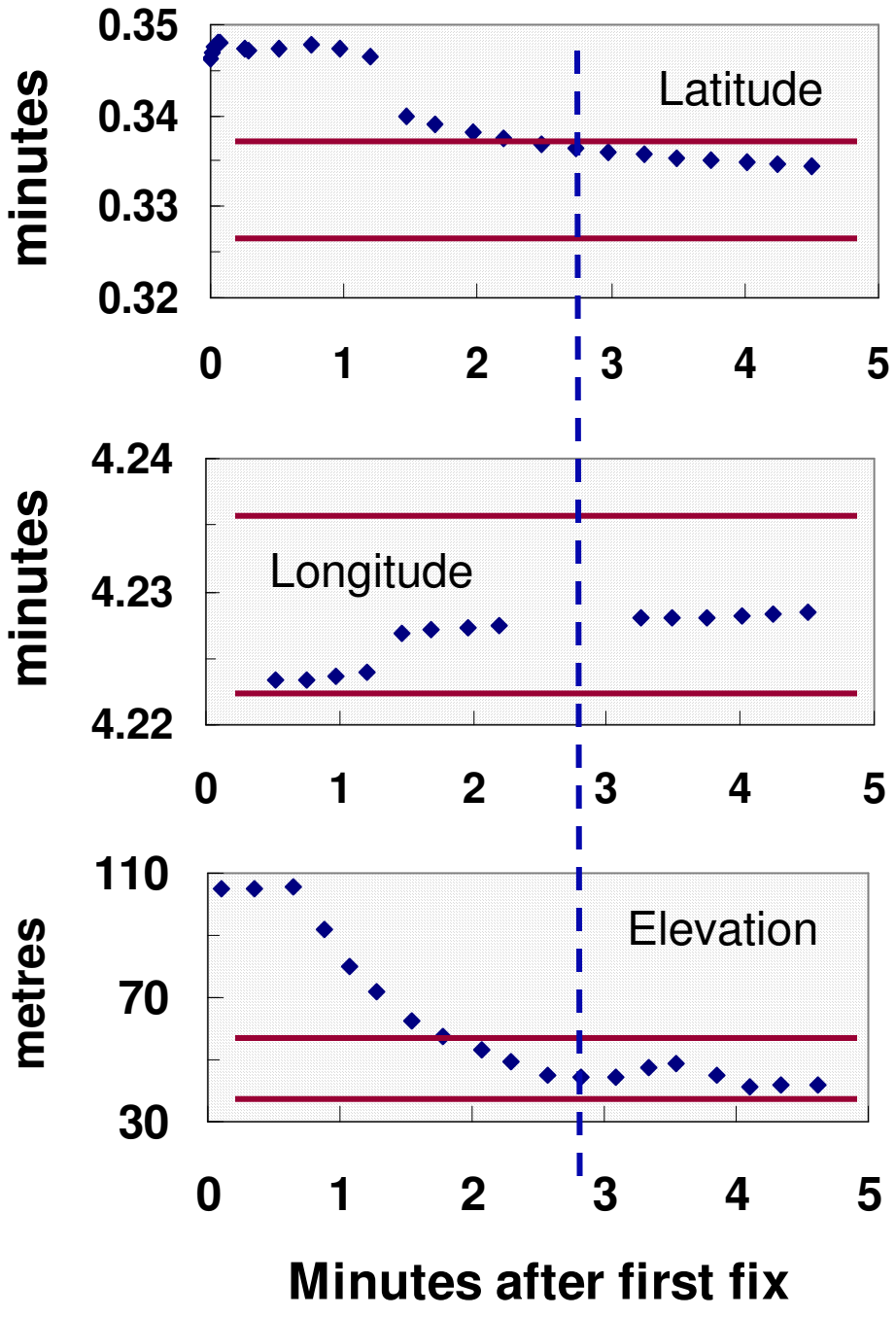
Elevation - 60 metres lower



Convergence data

after 146 km displacement

Red lines are displaced 10 metres from the final values



Convergence trends immediately after first fix

Red lines are +/-10 metres from final values

All coordinates have converged to within 10 metres in less than three minutes.

Data from four locations

Plotted data

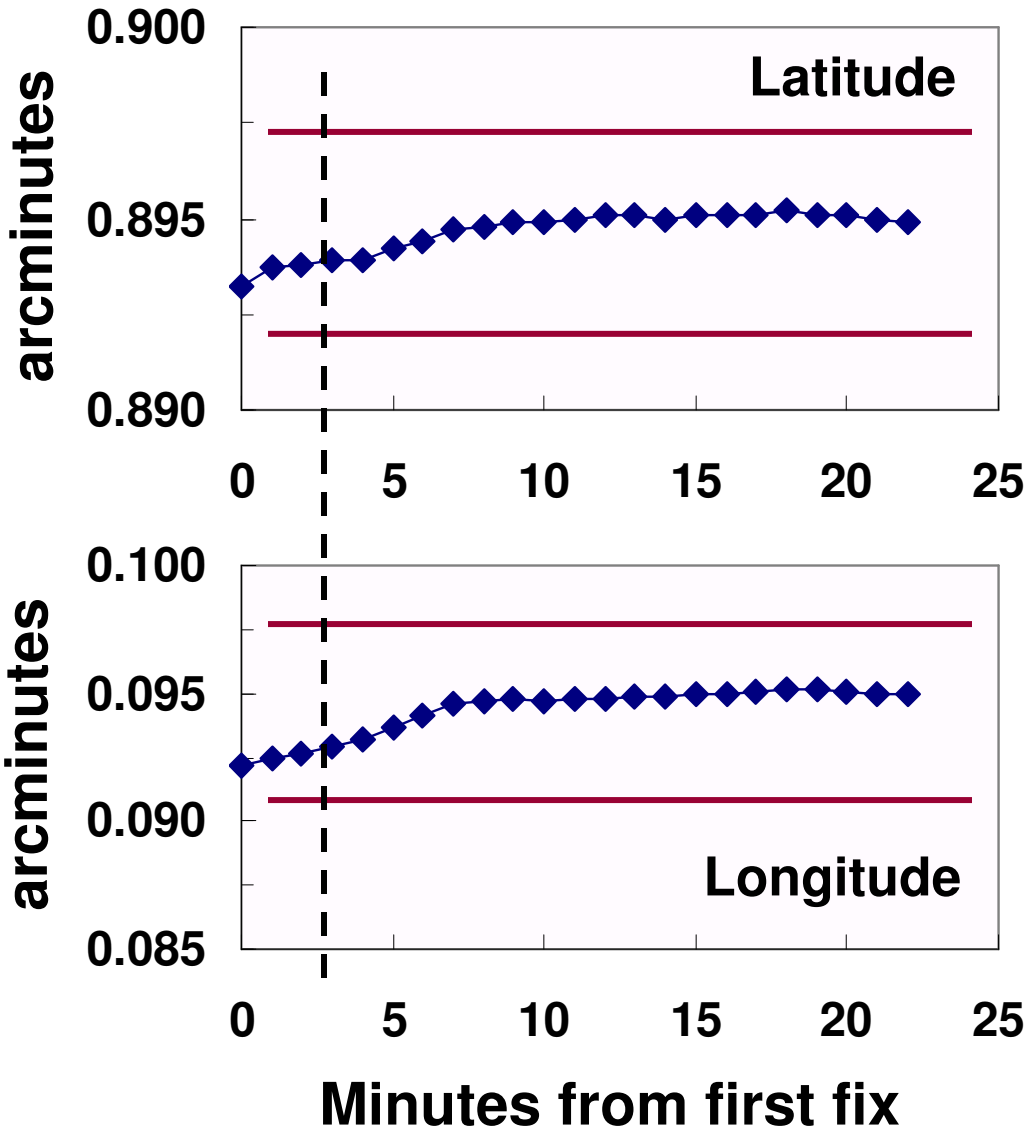
A. First Street - (March 17)

B. Finley Road - (March 22 & 25)

C. Airport - (April 13 & 16)

D. Park - (April 13 & 16)

First Street – horizontal coordinates



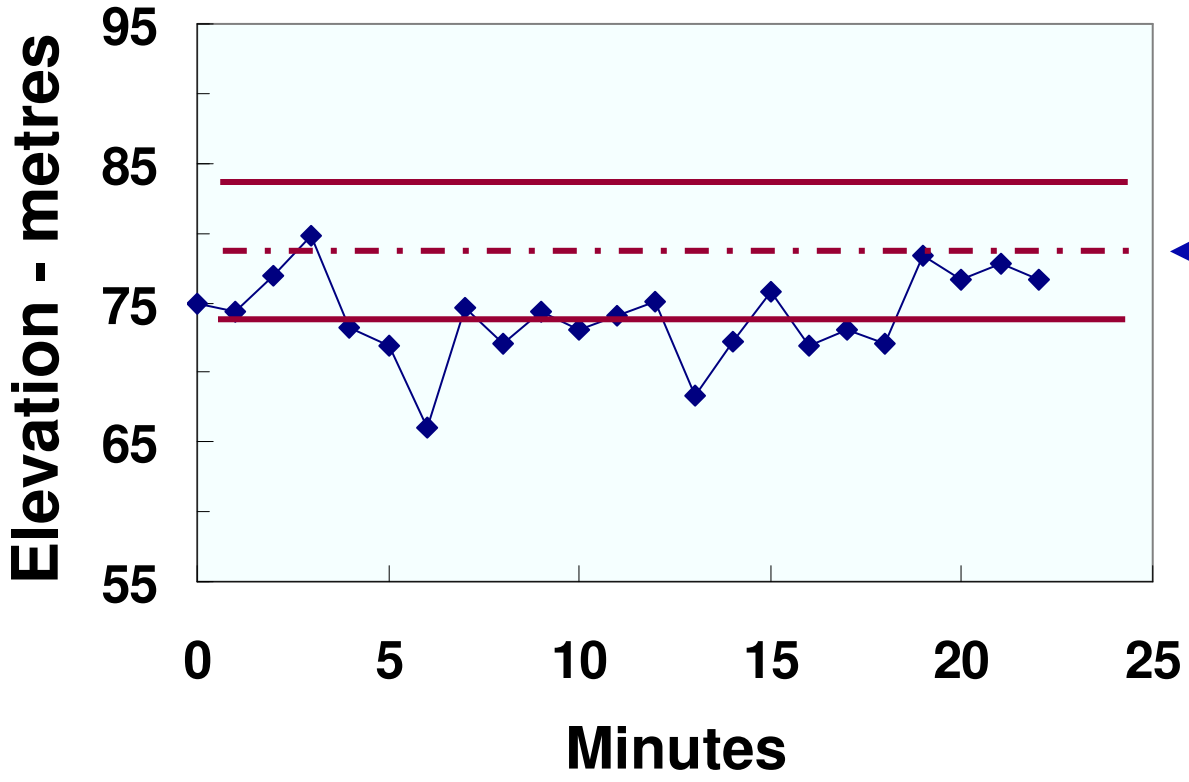
Accurate horizontal coordinates are not available at this location.

For reference, parallel red lines separated by 10 metres have been added to the plots.

Integer degrees & minutes suppressed:

latitude	37d	39m	N
longitude	121d	52m	W

First Street – vertical coordinate



+5 m

Surveyed elevation

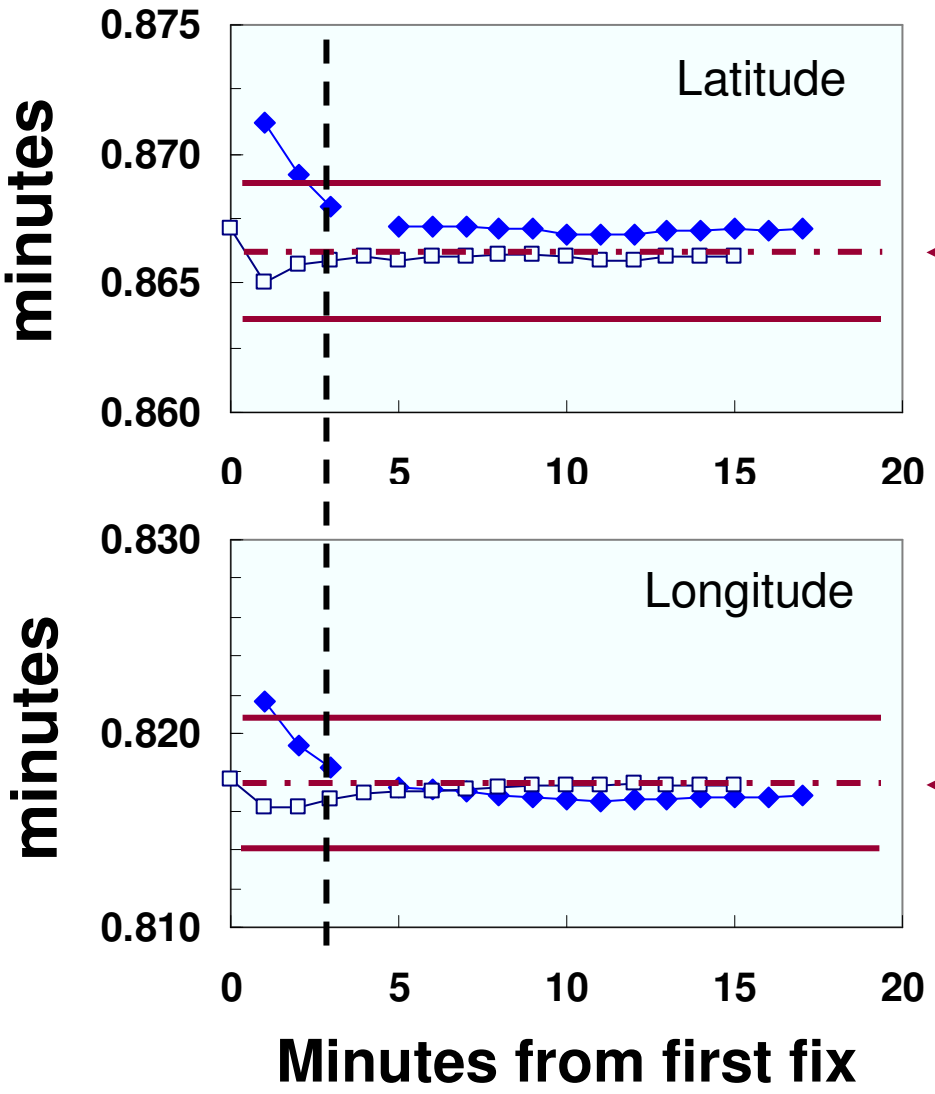
-5 m

Data obtained on March 17

Representative GPS quality:
10 satellites; HDOP = 1.4

Elevation reference:
WGS84(G1150)

Finley Road – horizontal coordinates



+5 m

Surveyed latitude

-5 m

+5 m

Surveyed longitude

-5 m

Integer degrees & minutes suppressed:

latitude	37d	47m	N
longitude	121d	51m	W

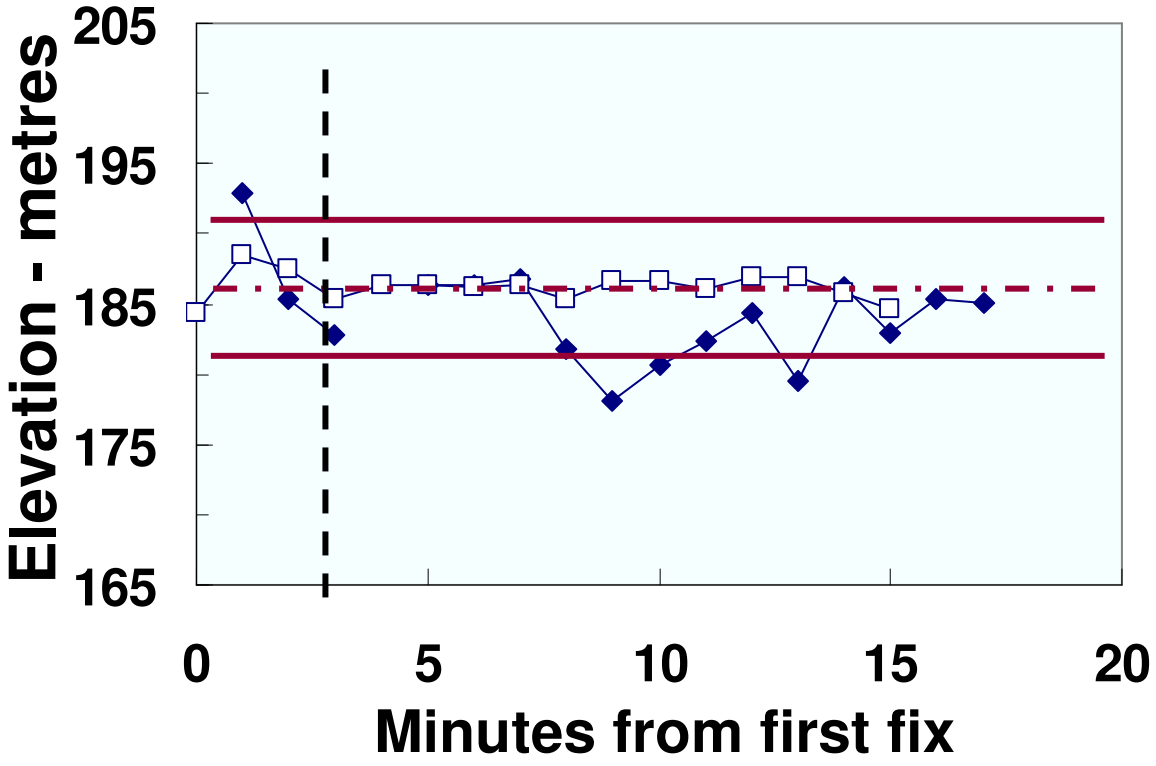
Legend

- Mar. 22
- Mar. 25

Representative GPS quality:

March 22	March 25
8 satellites	10 satellites
HDOP = 1.1	HDOP = 0.9

Finley Road – vertical coordinate



+5 m

Surveyed elevation

-5 m

Legend

March 22

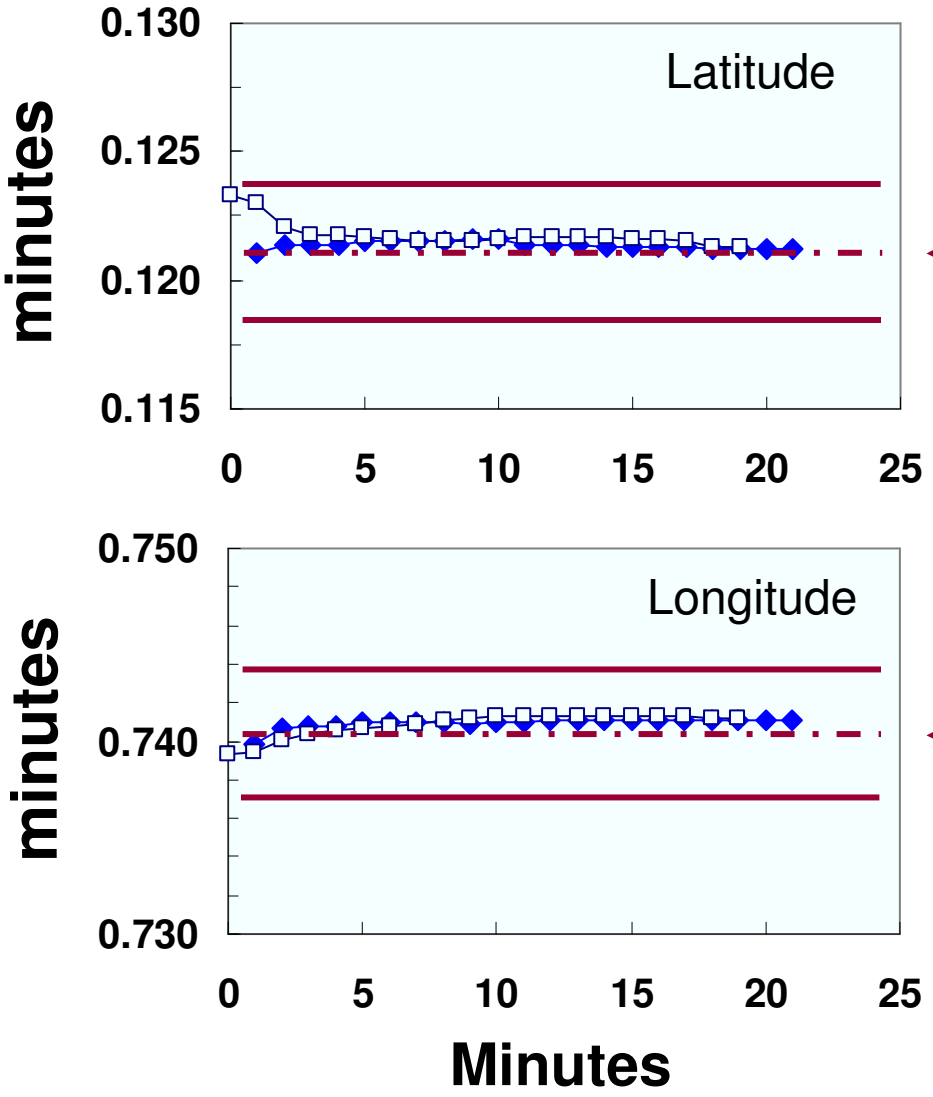
March 25

Representative GPS quality:

March 22	March 25
8 satellites	11 satellites
HDOP = 1.1	HDOP = 0.9

Elevation reference:
WGS84(G1150)

Park – horizontal coordinates



+5 m

Surveyed latitude

-5 m

+5 m

Surveyed longitude

-5 m

Integer degrees & minutes suppressed:

latitude	37d	49m	N
longitude	121d	47m	W

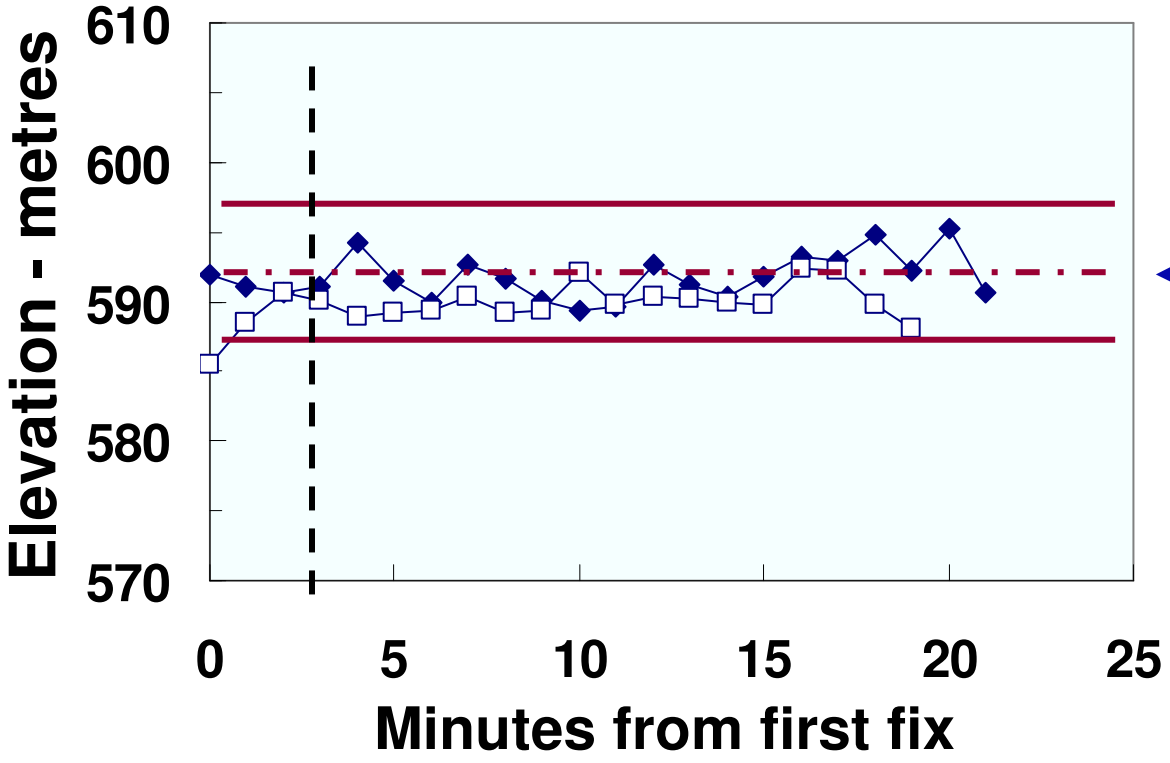
Legend

- April 13
- April 16

Representative GPS quality:

April 13	April 16
9 satellites	10 satellites
HDOP = 1.1	HDOP = 0.9

Park – vertical coordinate



+5 m

Surveyed elevation

-5 m

Legend

April 13

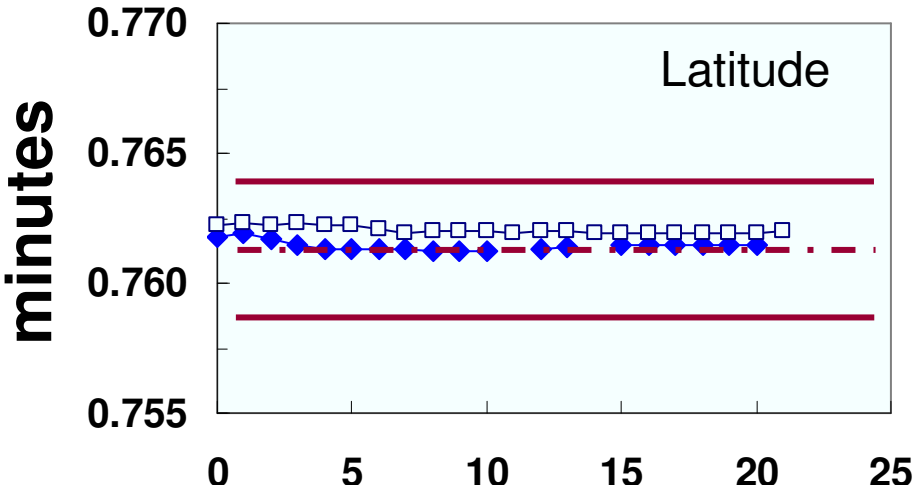
April 16

Representative GPS quality:

April 13	April 16
9 satellites	10 satellites
HDOP = 1.1	HDOP = 0.9

Elevation reference:
WGS84(G1150)

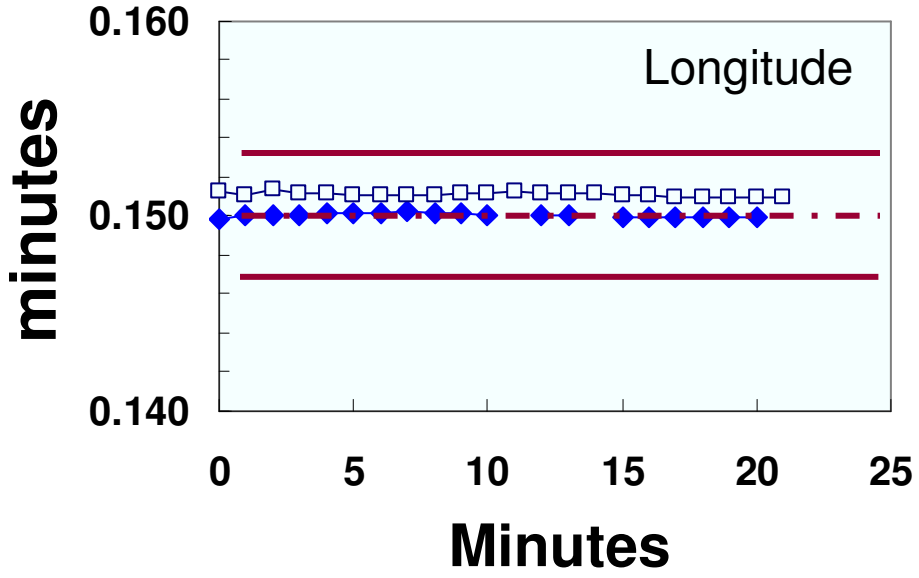
Airport – horizontal coordinates



+5 m

Surveyed latitude

-5 m



+5 m

Surveyed longitude

-5 m

Integer degrees & minutes suppressed:

latitude	37d	41m	N
longitude	121d	49m	W

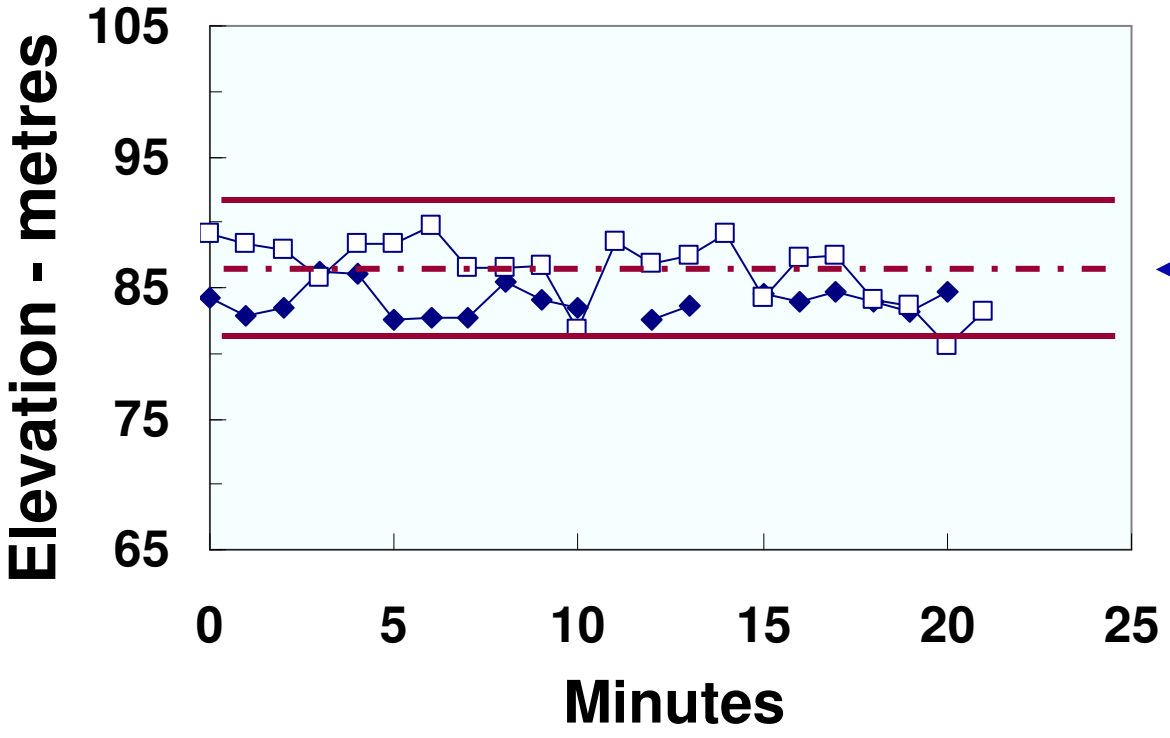
Legend

- April 13
- April 16

Representative GPS quality:

April 13	April 16
11 satellites	10 satellites
HDOP = 0.8	HDOP = 1.0

Airport – vertical coordinate



+5 m

Surveyed elevation

-5 m

Legend

April 13

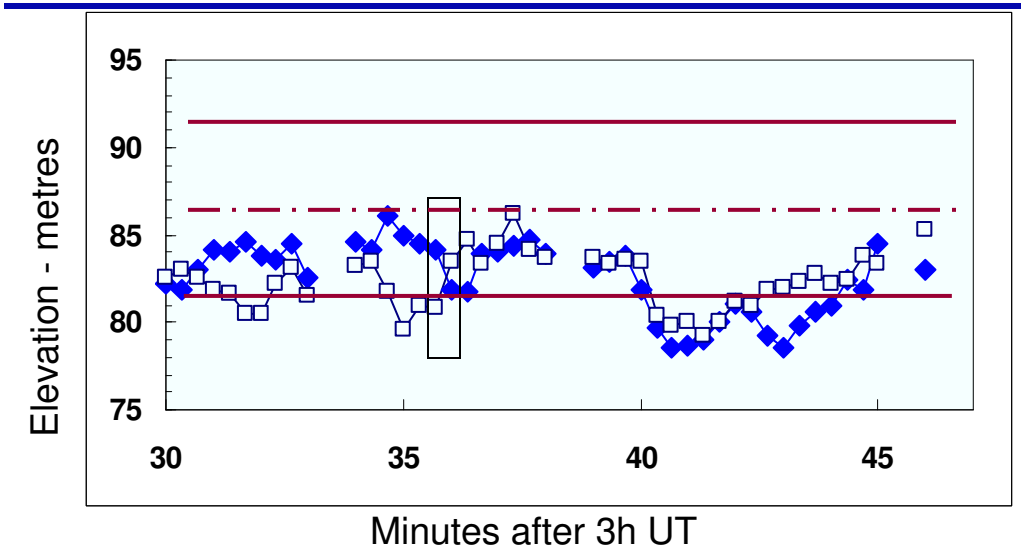
April 16

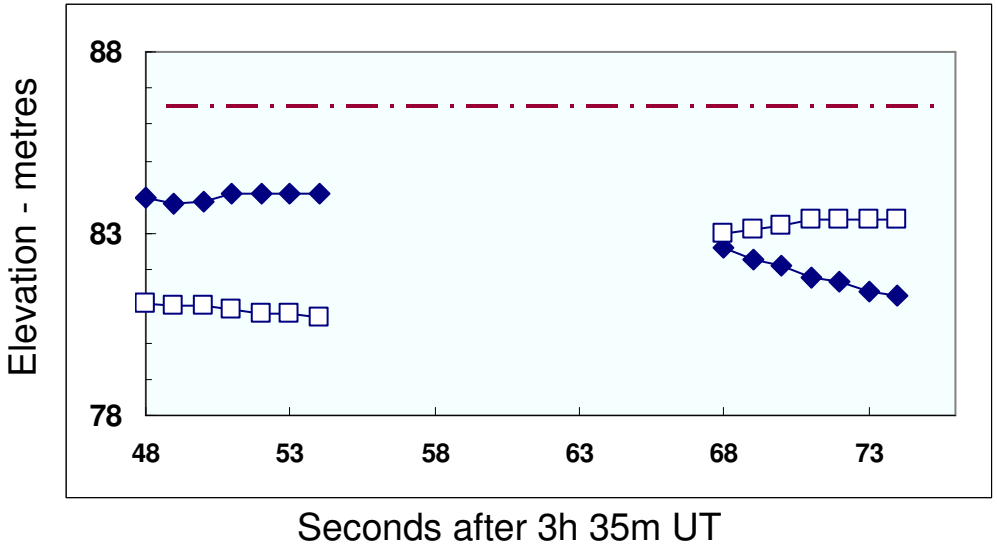
Representative GPS quality:	
April 13	April 16
11 satellites	10 satellites
HDOP = 0.8	HDOP = 1.0

Elevation reference:
WGS84(G1150)

Revisiting Airport, with two Kiwi systems

Revisiting Airport, with two Kiwi systems





Data from June 25

+ 5 m

Surveyed elevation

- 5 m

The four data points enclosed in the small rectangle on the upper plot are enlarged in the lower plot.

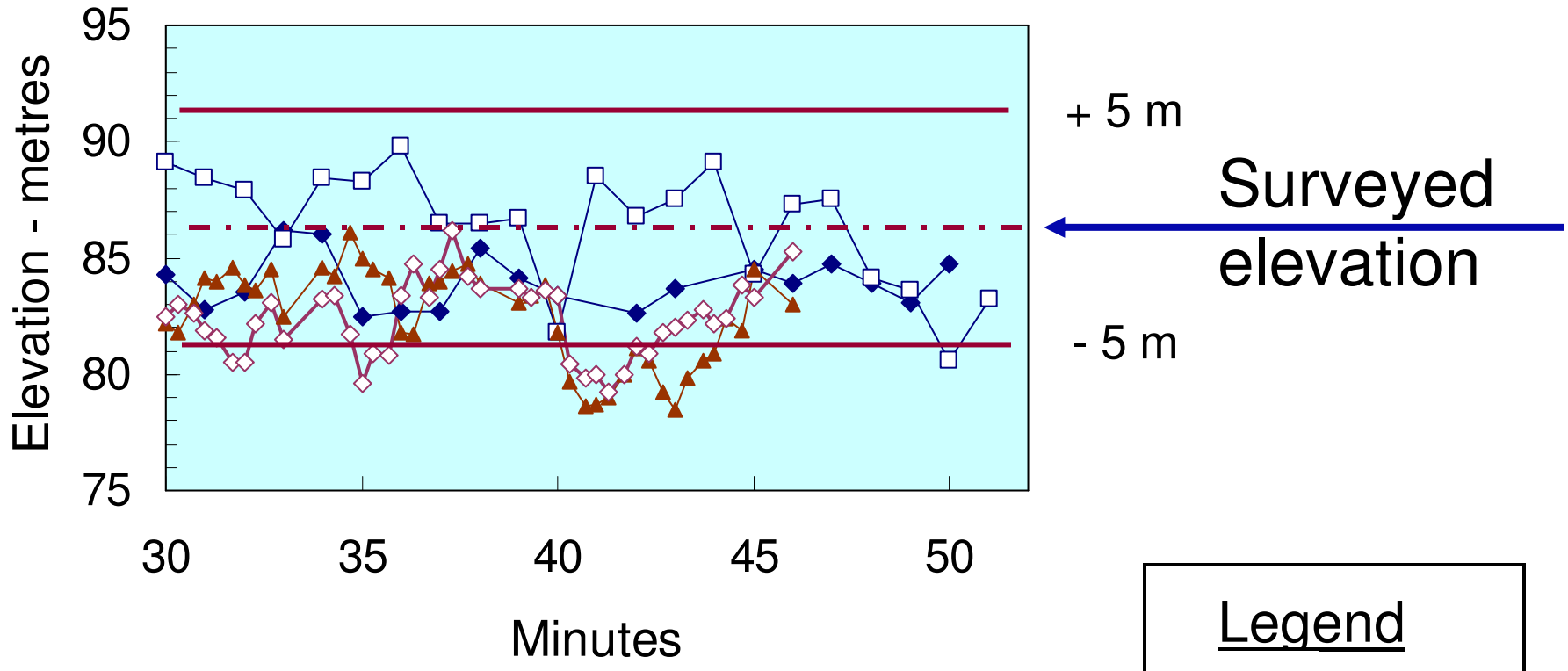
(Each point on the upper plot is actually one from the middle of a set of seven.)

These particular points were chosen to display at higher resolution because both records seemed to be changing.

This demonstrates to me that:
- a different elevation can be reported each second (but not more often);
- "noise" components have periods of at least several seconds.

Prior to 37m UT, 8 satellites were acquired, with HDOP of 1.3. That improved somewhat to 40m, when 10 satellites were acquired, and HDOP was 0.9. From 42:40 on, 9 satellites were acquired, with HDOP 0.9.

Four elevation sets at Airport



Elevation reference:
WGS84(G1150)

Four elevation sets at Airport

Test	No. Pts	Elevation error (m)		(Representative)	
		Mean	RMS	HDOP	No. satellites
April 13	16	-1.87	2.43	0.8	11
April 16	19	-0.56	2.64	1.0	10
June 25 w	43	-4.17	4.64	1.1	9
June 25 e	43	-4.35	4.63	1.1	9

Data obtained simultaneously with two data systems agree much better than data obtained on different dates with a single system.

VIII - Summary & Recommendations

Horizontal coordinate errors

Vertical coordinate errors

Recommendations

Latitude accuracy summary

Test location	Target (arcminutes)	Measured latitude (arcminutes)		Error (metres)
Finley	47.**866**2	Mar22:	47.**867**	1.5 N
		Mar25:	47.**866**	0.4 S
Park	49.**120**9	Apr 13:	49.**121**	0.2 N
		Apr 16:	49.**122**	2.0 N
Airport	41.**761**3	Apr 13:	41.**761**	0.6 S
		Apr 16:	41.**762**	1.3 N
		Jun 25w	41.**761**	0.6 S
		Jun25e	41.**762**	1.3 N

37 deg north latitude suppressed

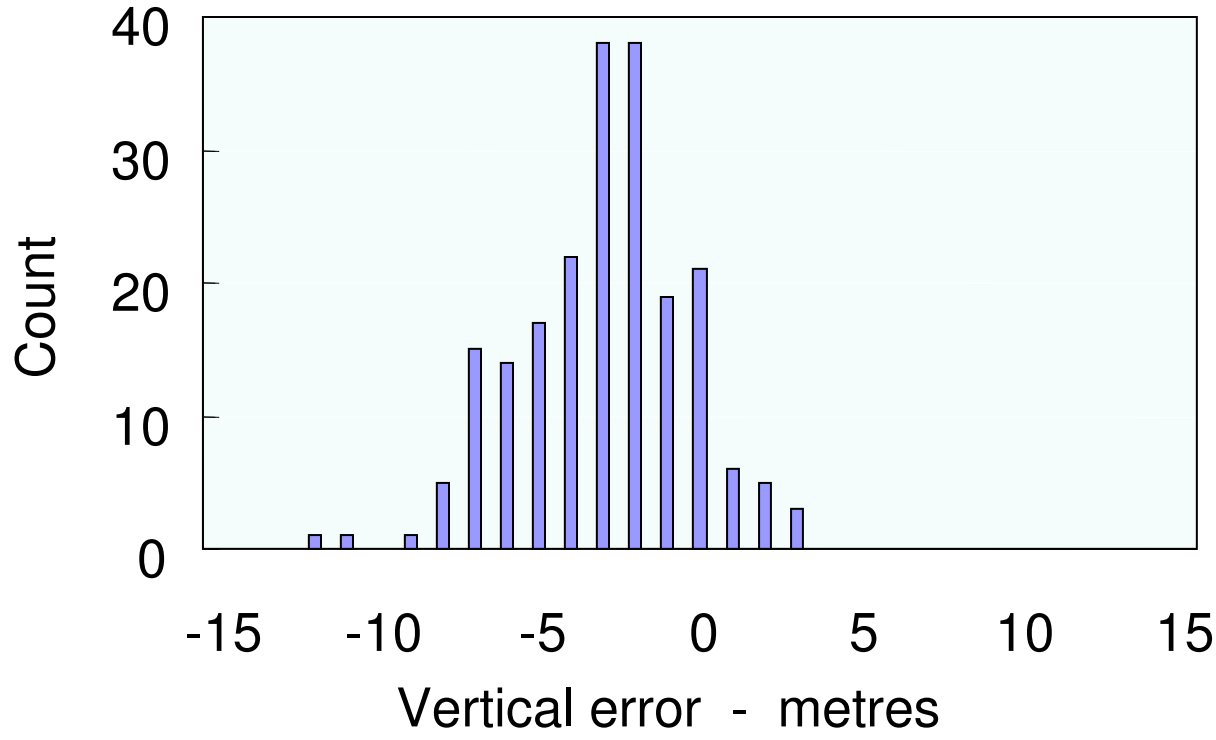
Longitude accuracy summary

Test location	Target (arcminutes)	Measured longitude (arcminutes)		Error (metres)
Finley	51.**817**4	Mar22:	51.**817**	0.6 E
		Mar25:	51.**817**	0.6 E
Park	47.**740**4	Apr 13:	47.**741**	0.9 W
		Apr 16:	47.**741**	0.9 W
Airport	49.**150**0	Apr 13:	49.**150**	0.0
		Apr 16:	49.**151**	1.5 W
		Jun 25w	49.**151**	1.5 W
		Jun25e	49.**151**	1.5 W

121 deg west longitude suppressed

Distribution of vertical errors

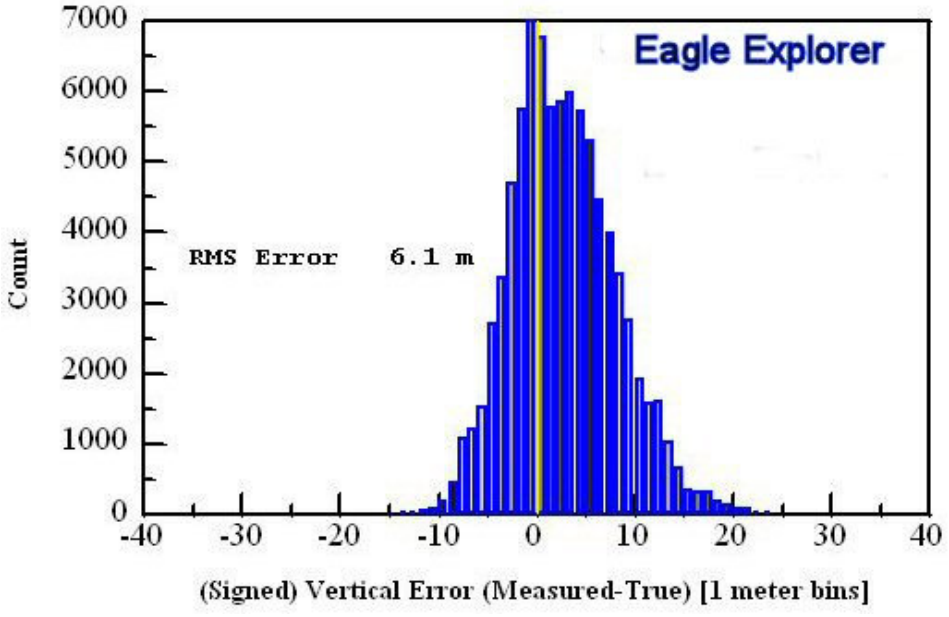
Error distribution for 206 elevation measurements
at four benchmarks

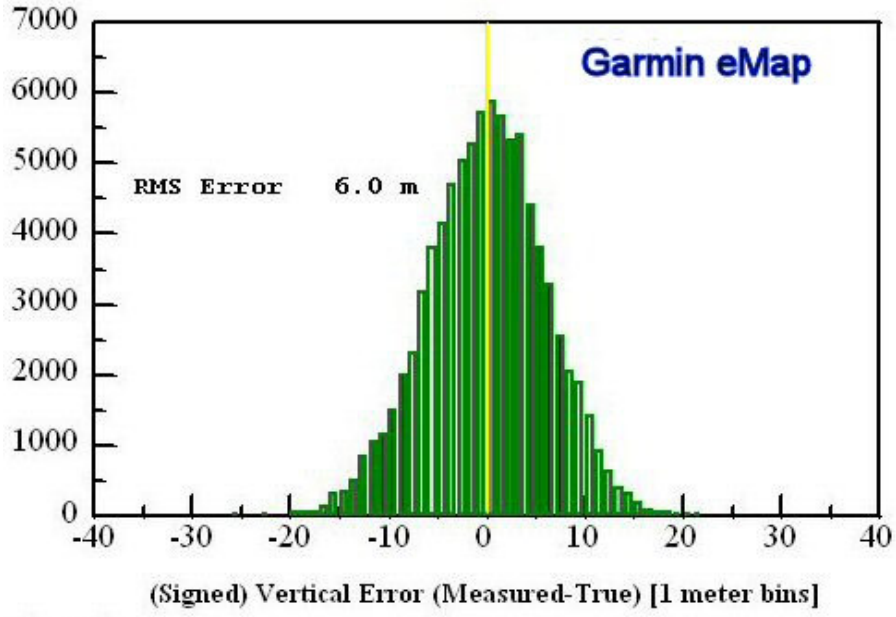


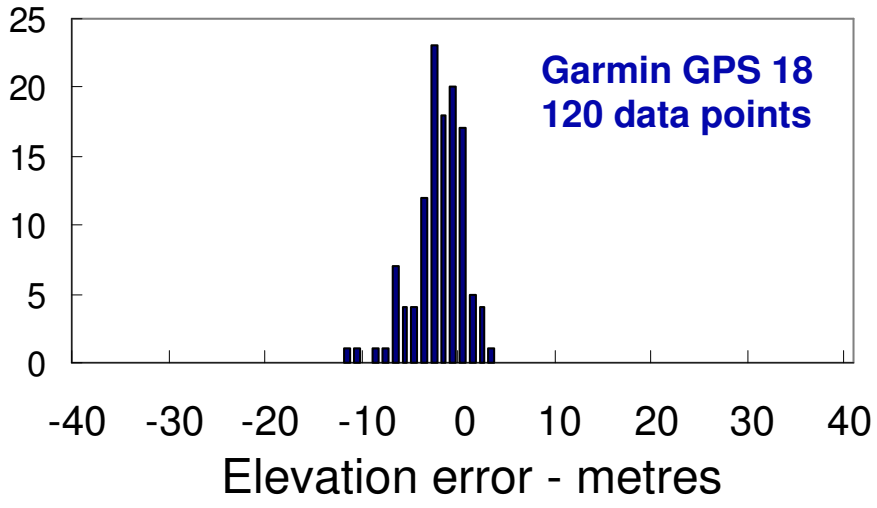
Sample size 206
Bin widths 1 metre

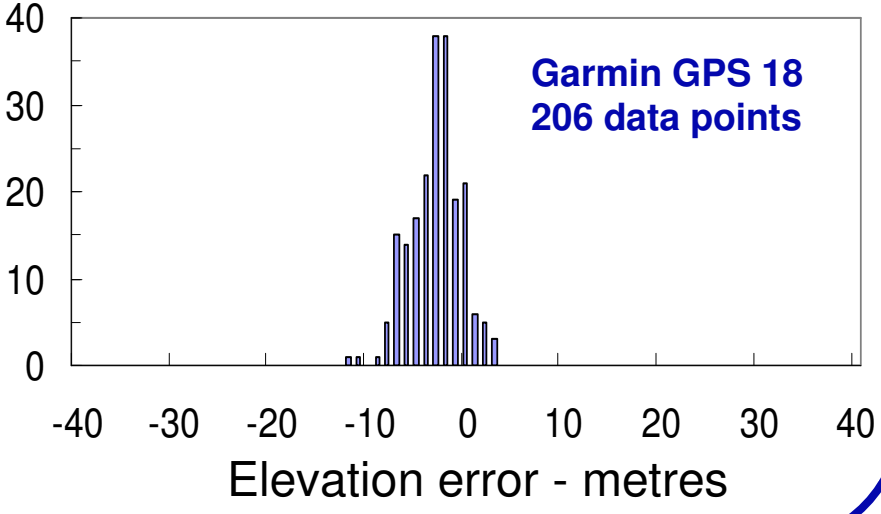
Mean error = -3.0 m
RMS error = 4.0 m

Vertical Error Distribution Comparison









Recommendations

Suggested procedure – to assure sufficient accuracy
for both horizontal and vertical coordinates

Obtain coordinates soon after first fix
(to establish time: expect values to be inaccurate)

Obtain coordinates at least three more times
More than three minutes after first fix
Spanning at least 10 minutes
Separated by at least two minutes

Report averaged values

* Lat/long to 0.001 arcminutes
* Elevation to 1.0 metres – datum WGS84
* Optional: also report MSL elevation, but only if the geoid correction has been made

Qualification: If HDOP is 2.0 or greater, elevation data may be suspect

Final caveat

Because the data presented are mostly from a single Kiwi/GPS system, additional data are needed:

* using different hardware;
* at additional locations.

All GPS-driven systems should be represented, but it may not be possible to extend conclusions to include other than Garmin GPS 18.