Civil & Commercial Applications Project (CCAP): Evaluation of QuickBird Level 1B Data Geopositional Accuracy

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CCAP Mission

- CCAP is the NIMA process to assess the utility of emerging civil and commercial remote sensing systems
- DoD Directive 5105.60 states that NIMA shall:
  - Assess the applicability of evolving commercial capabilities to meet imagery and geospatial information needs of the Department of Defense and the Intelligence Community
- CCAP partners include USGS and NASA-Stennis:
  - JACIE (Joint Agency Commercial Imagery Evaluation) Team
  - Space Act Agreement
- Elements of the evaluations:
  - Image interpretation for intelligence, military, and civil applications
  - Feature extraction for mapping
  - Geopositional accuracy
  - Radiometric fidelity

Study Objectives

- The objective of this study was to determine whether a sample of QuickBird 1B products met the vendor stated geopositional accuracy specifications.
  - Characterize the absolute and relative geolocation accuracy of QuickBird panchromatic imagery
  - CE_{90} should be 23 meters or less at nadir, excluding terrain effects

Vendor Data Specifications

- Basic 1B Product
  - Corrected for radiometric distortions and adjustments for internal sensor geometry, optical and sensor distortions
  - Product used as a photogrammetric source
- Commercial Data Provider (CDP) guarantees a CE_{90} of 23 meters or less
  - Requires 90% of the scene have a geo-location circular error less than 23 meters
- QuickBird data processed by CDP using the Attitude Determination Processor (ADP)
  - Version 2.1 installed February 12, 2003
  - An earlier version, 2.0, was also of interest since there are NIMA customers that still use it.

Attitude Determination Processor

- The Attitude Determination Processor (ADP)
  - a set of filters and processes that operate on the data
  - receives the telemetry from the spacecraft
  - uses that data to estimate the attitude of the spacecraft at the specified time
- Output of the ADP is the time-tagged attitude of the spacecraft in Earth-Centered-Fixed coordinates
  - requires a non-trivial conversion from the Earth-Centered-Inertial Coordinates of the sensor data
  - continuous attitude is individually calculated for each strip of images acquired by QuickBird
  - attitude data is placed into the Production System; where it is combined with ephemeris data, timing data, camera parameters, and Earth elevation data to geolocate the image on the Earth

Approach

- The evaluation of geopositional accuracy of QuickBird Basic 1B is based on a comparison to known Ground Control Points of higher accuracy
- Evaluation support provided by NIMA's:
  - Precision Engagement Staff (PTNT)
  - Front End Processing Environment (FPE)
  - Image Quality & Utility (AEAI)
  - Innovison (IDR)
- Primarily Socet Set was used to measure the coordinates in the imagery products

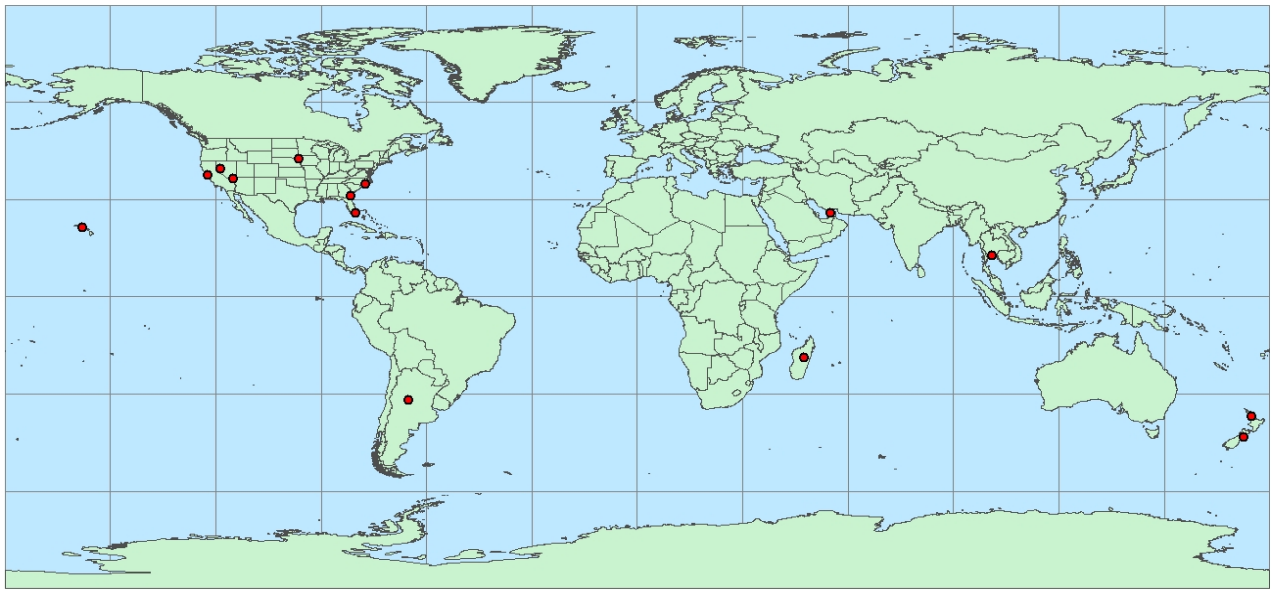
Approach (cont.)

- 13 scenes
  - Various locations having features with known ground truth geo-coordinates
  - Scenes vary by terrain elevation characteristics
- 25 drop points geo-located per scene
  - Ground truth geo-coordinate data derived from controlled base
  - Only latitude and longitude determined – no stereo
- Drop point locations obtained using version ADP 2.0 and 2.1 data
  - ADP 2.1 is of higher interest, and will be used to verify QuickBird's guaranteed accuracy

Level 1B Products

Scene	Collection Date	Order No	Product Type	Attitude Determination Processor (ADP)
Abu Musa, TC	6/21/02	24917	Basic 1B	2.0, 2.1
Auckland, NZ	12/01/02		Basic 1B	2.0
Anatanarivo, MA	09/14-09/27/02	24501	Basic 1B	2.0, 2.1
Camp Lejeune			Basic 1B	2.0, 2.1
Christchurch, NZ	09/30-10/18/02	24544	Basic 1B	2.0, 2.1
Fallon, NV	8/23/02	25004	Basic 1B	2.0, 2.1
Hickam, HI	10/25/02	31046	Basic 1B	2.0, 2.1
Miami, FL	10/18-10/23/02	24557	Basic 1B	2.0, 2.1
Nellis, NV	9/13/02	24559	Basic 1B	2.0, 2.1
Sioux City, IA	10/03-10/13/02	24564	Basic 1B	2.0, 2.1
St. Simon's Island, GA	11/15-12/03/02	24567	Basic 1B	2.0, 2.1
Sunnyvale	4/21/02	24929	Basic 1B	2.0, 2.1
Utapao, TH	10/28/02-01/08/03	24641	Basic 1B	2.0, 2.1
Villa Delores, AR	9/20/02	35075	Basic 1B	2.1

Geopositional Sites



Methodology

- Basic 1B Products
  - Imported into SOCET Set
  - For each GCP
    - Measurement cursor elevation set to GCP elevation
    - Operator selects image pixel representing GCP
    - Horizontal coordinates computed using image Rapid Positioning Capability (RPC) data, GCP elevation, and image line/sample
  - Statistics compiled for all GCPs measured

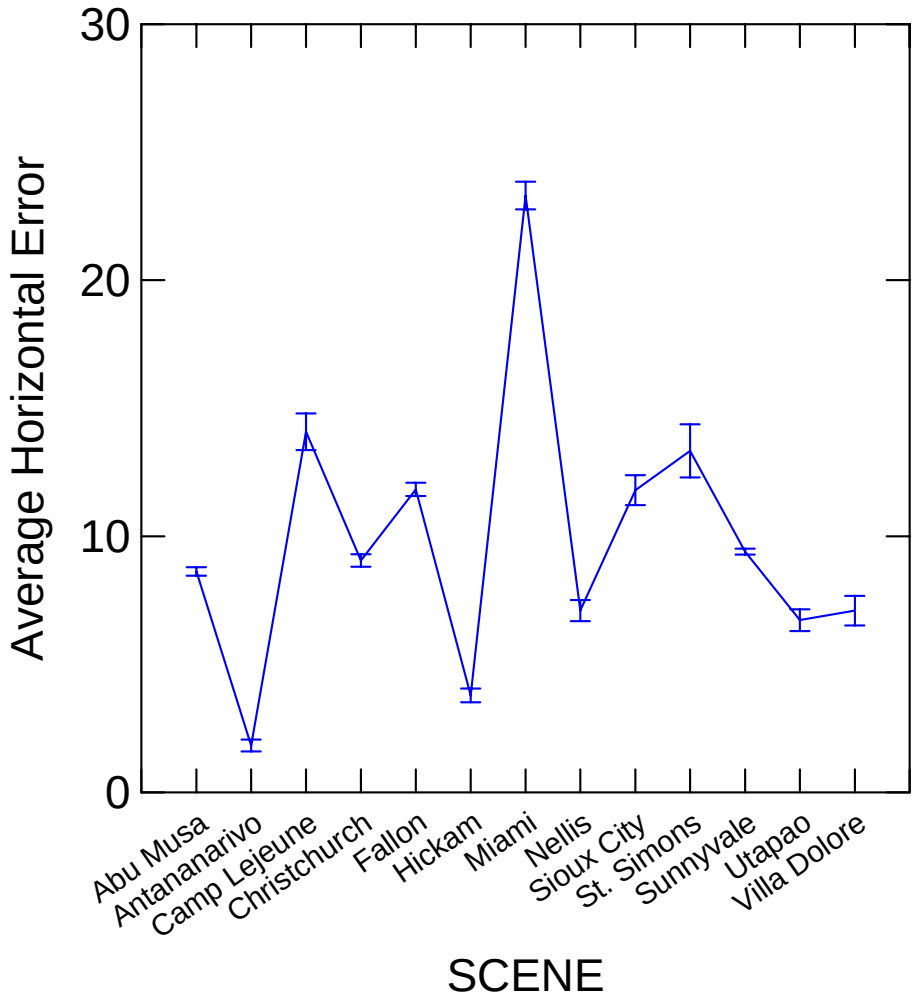
ADP Version 2.1 Analysis

Scene Statistics

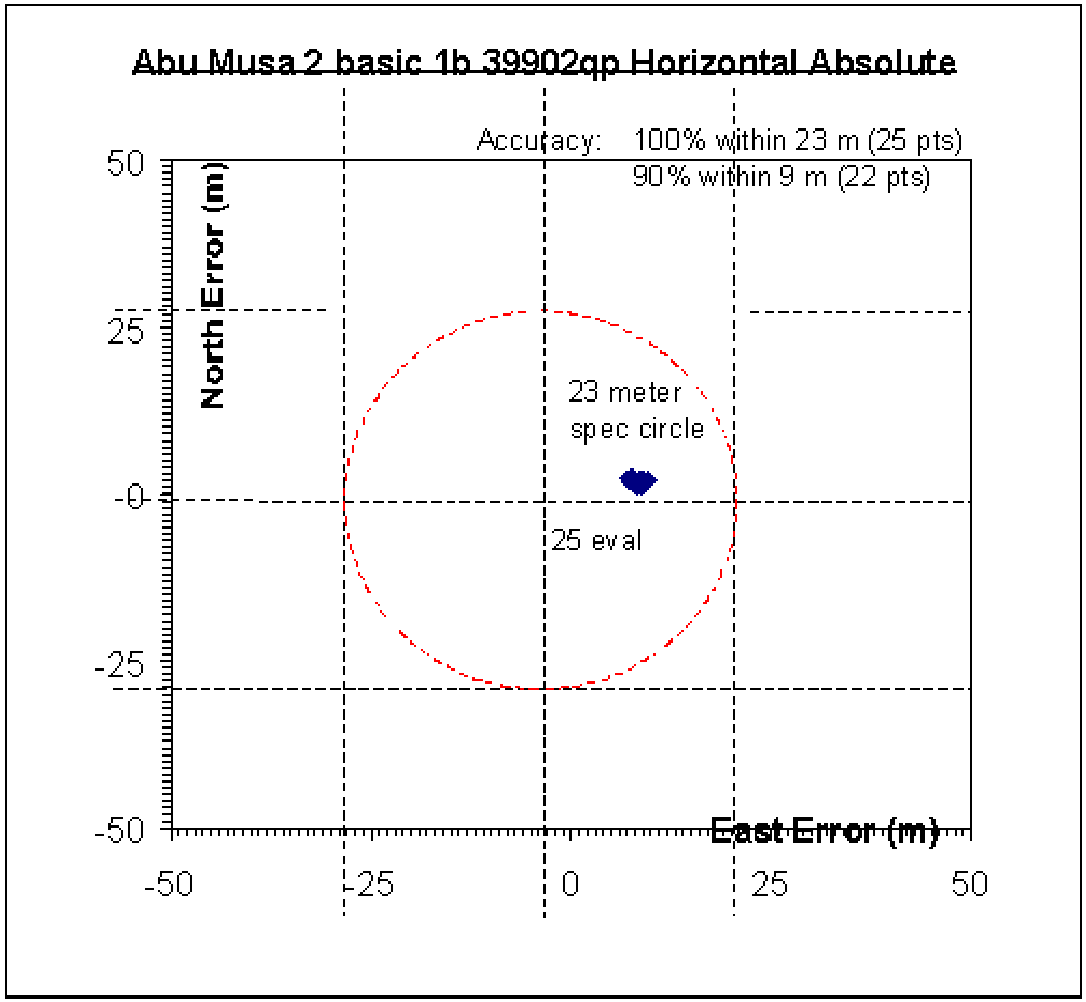
Version 2.1

	Average Error (m)					Standard Deviation (m)		
	Latitude	Longitude	Horizontal	CE90	N	Latitude	Longitude	Horizontal
Abu Musa	1.97	8.39	8.63	9	25	0.41	0.69	0.65
Antananarivo	1.50	0.32	1.83	3	25	0.97	0.96	0.90
Camp Lejeune	2.81	-13.72	14.08	17	25	1.18	2.95	2.81
Christchurch	7.70	0.83	9.06	10	25	1.10	4.77	0.96
Fallon	0.37	11.82	11.83	13	25	0.53	1.03	1.03
Hickam	-2.76	-2.51	3.79	5	25	0.65	1.09	1.06
Miami	-4.09	-22.93	23.31	25	25	0.65	2.23	2.13
Nellis	-6.00	-3.74	7.10	9	25	1.27	1.24	1.63
Sioux City	-5.85	10.12	11.80	15	25	0.60	2.76	2.30
St. Simons	0.42	-13.30	13.34	17	25	0.92	4.10	4.11
Sunnyvale	9.26	-1.03	9.40	10	25	0.47	1.30	0.47
Utapao	4.53	-4.85	6.73	8	25	1.15	1.66	1.68
Villa Dolore	6.83	1.59	7.10	9	25	2.28	1.13	2.28
Average	**1.28**	**-2.23**	**9.85**	**11.54**		**0.94**	**1.99**	**1.69**

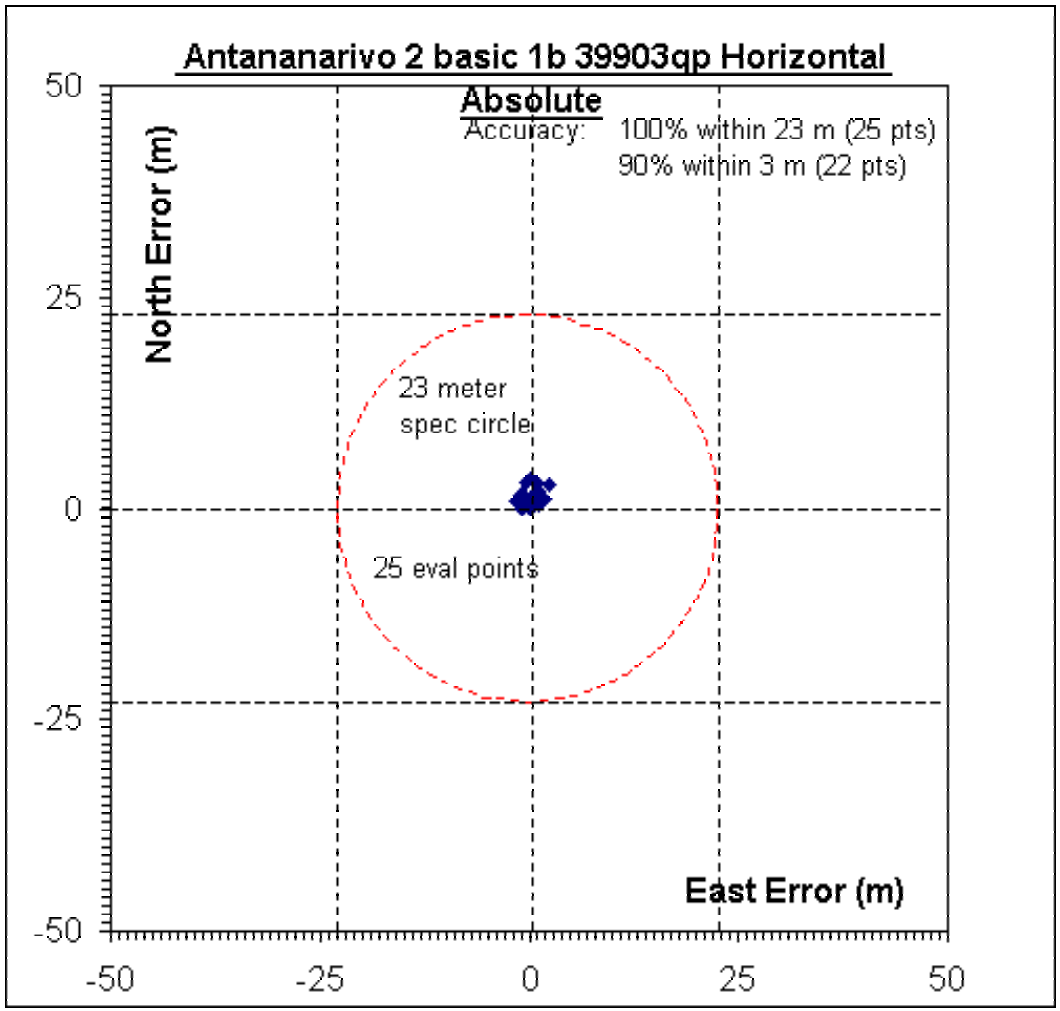
Plot of Average Horizontal Error



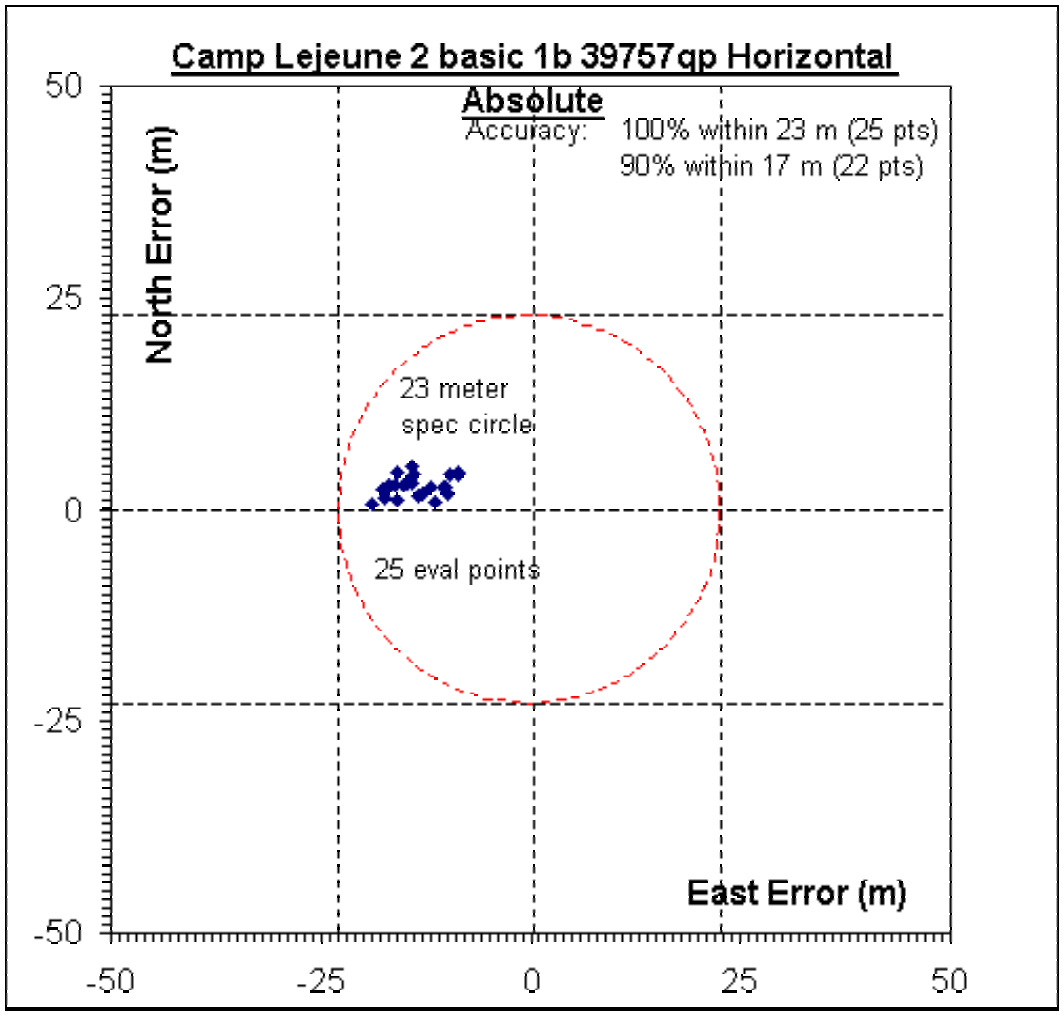
Abu Musa


Abu Musa 2 basic 1b 39902qp Horizontal Absolute
Accuracy: 100% within 23 m (25 pts)
90% within 9 m (22 pts)
North Error (m)
East Error (m)
23 meter
spec circle
25 eval
50
25
-0
-25
-50
-50
-25
0
25
50

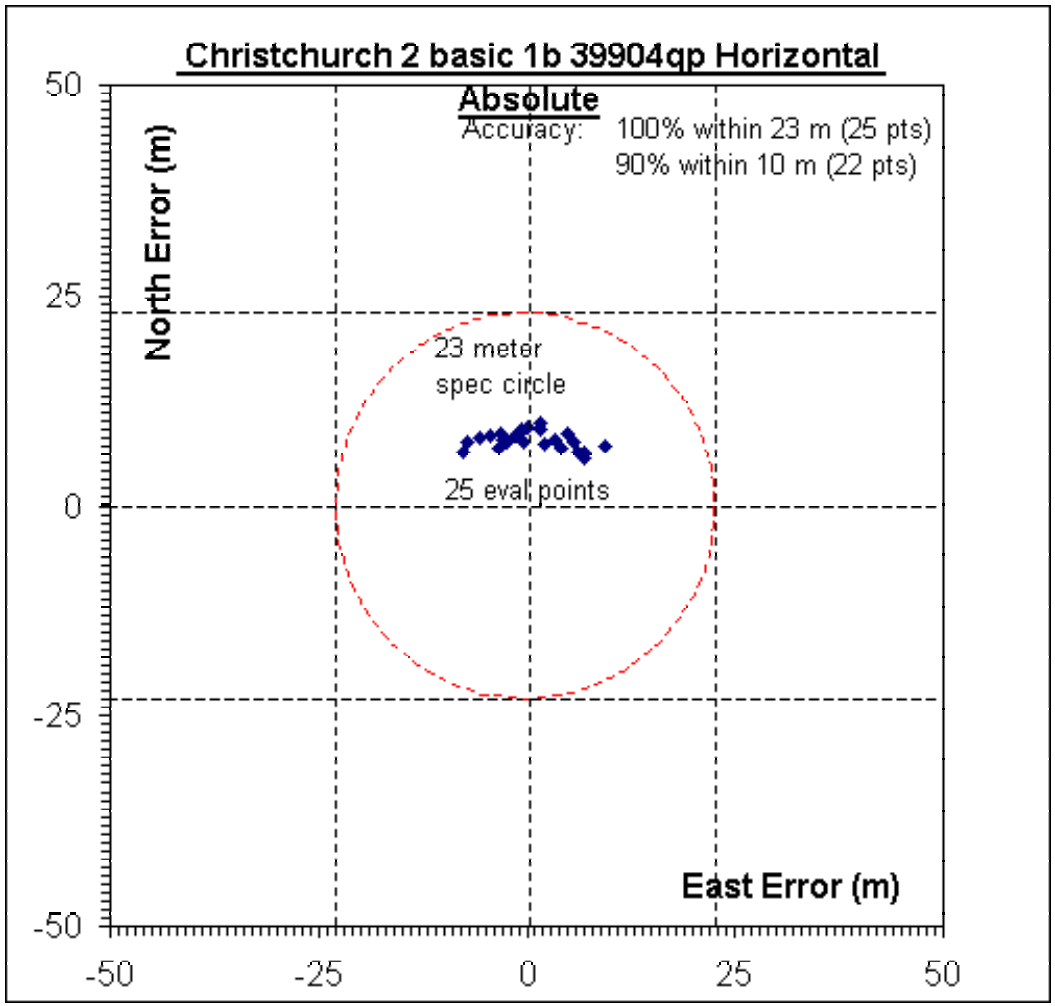
Antananarivo



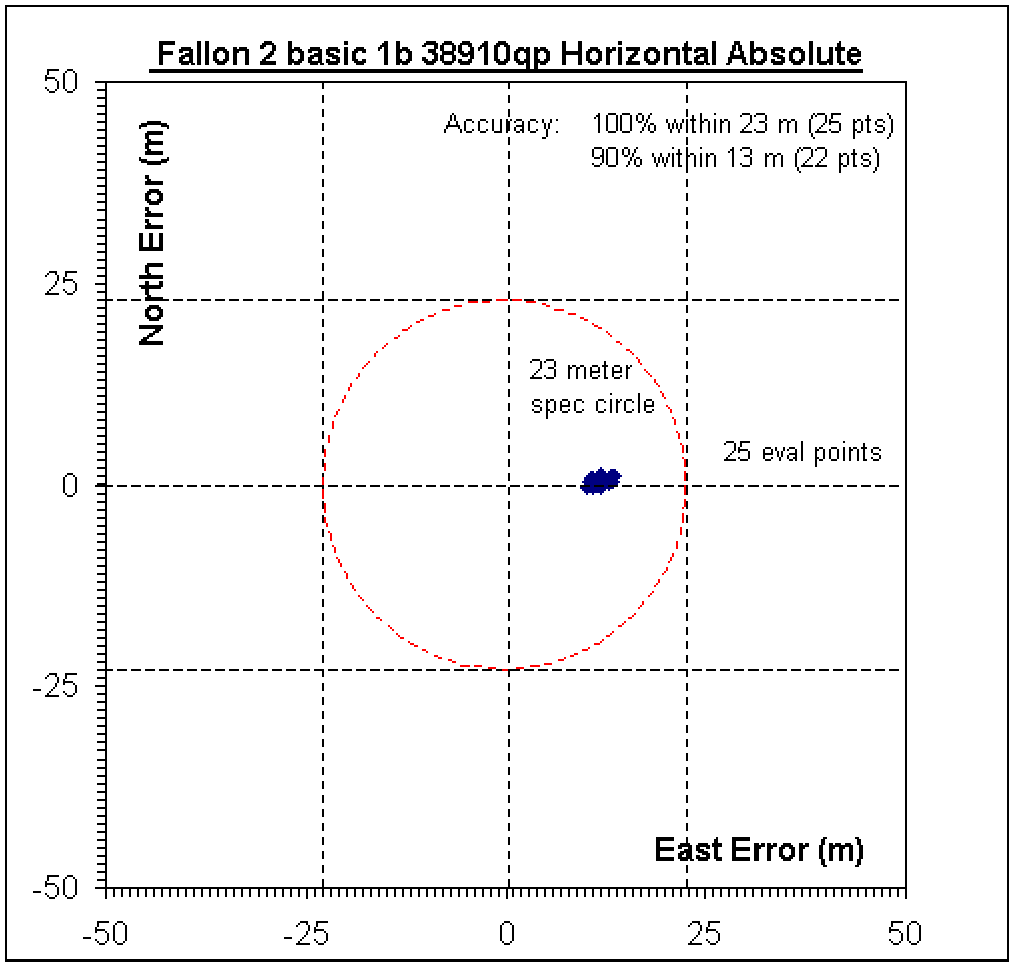
Camp Lejeune



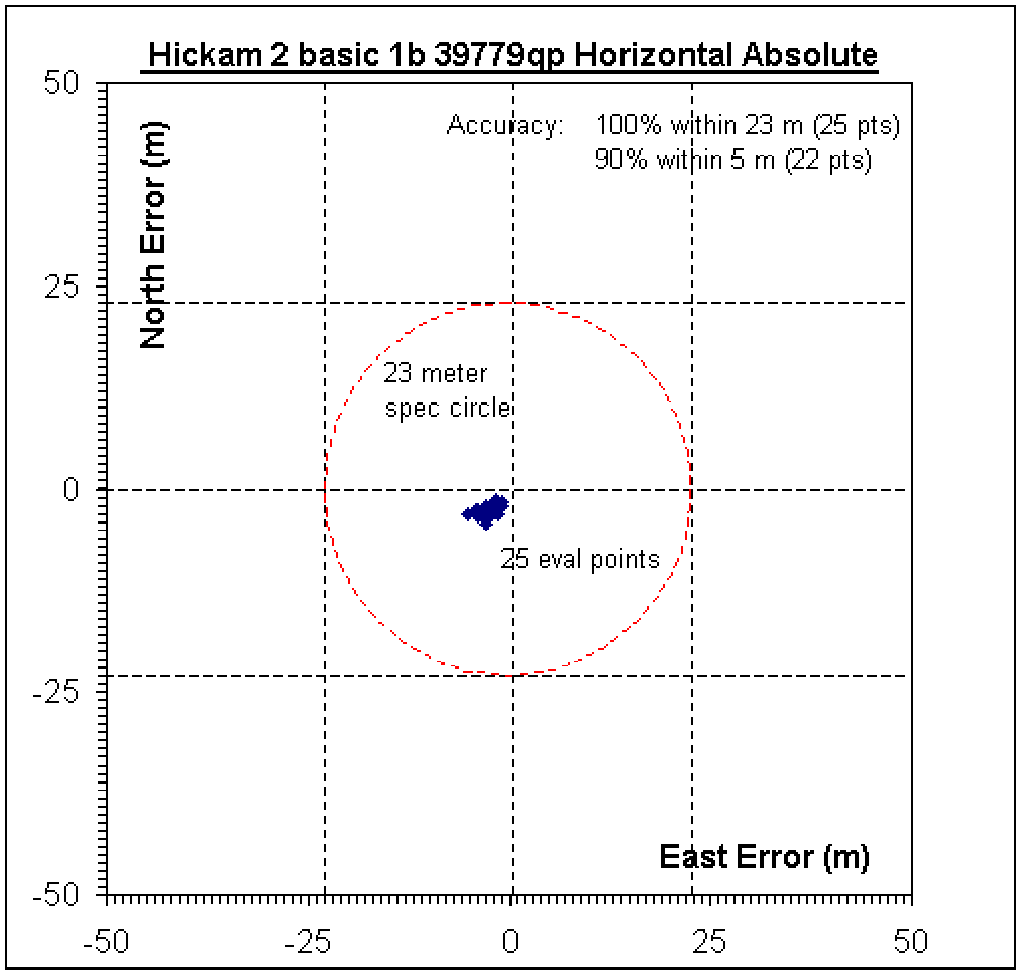
Christchurch



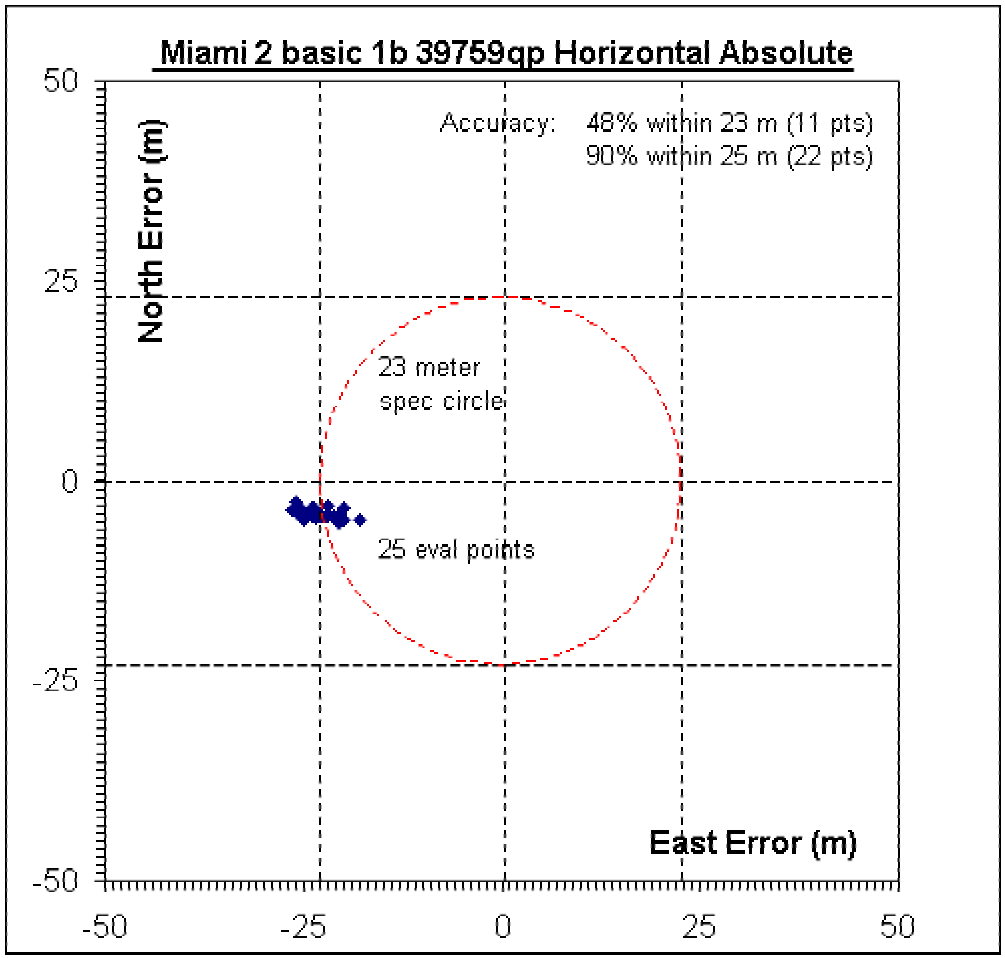
Fallon


Fallon 2 basic 1b 38910qp Horizontal Absolute
Accuracy: 100% within 23 m (25 pts)
90% within 13 m (22 pts)
23 meter
spec circle
25 eval points
North Error (m)
East Error (m)
50
25
0
-25
-50
-50
-25
0
25
50

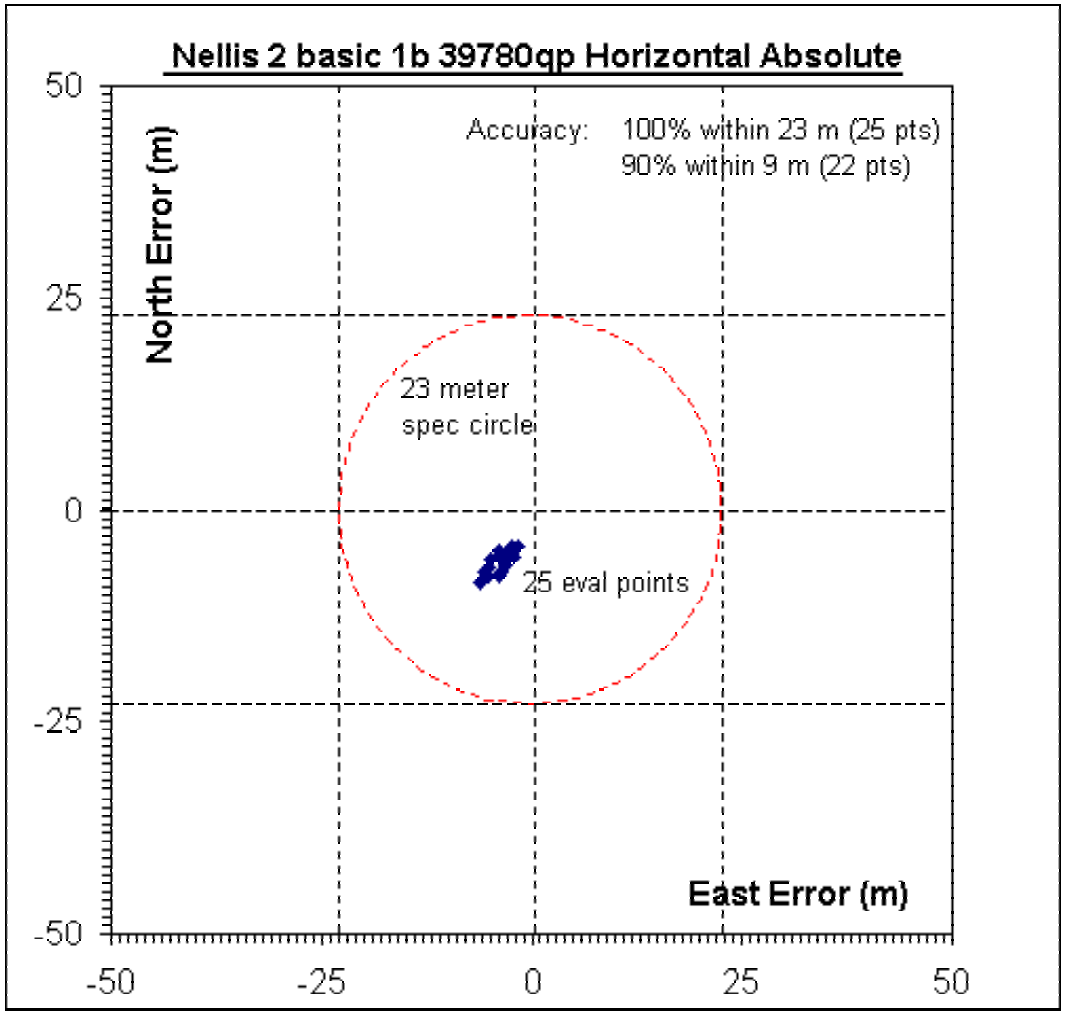
Hickam


Hickam 2 basic 1b 39779qp Horizontal Absolute
Accuracy: 100% within 23 m (25 pts)
90% within 5 m (22 pts)
North Error (m)
East Error (m)
23 meter
spec circle
25 eval points
50
25
0
-25
-50
-50
-25
0
25
50

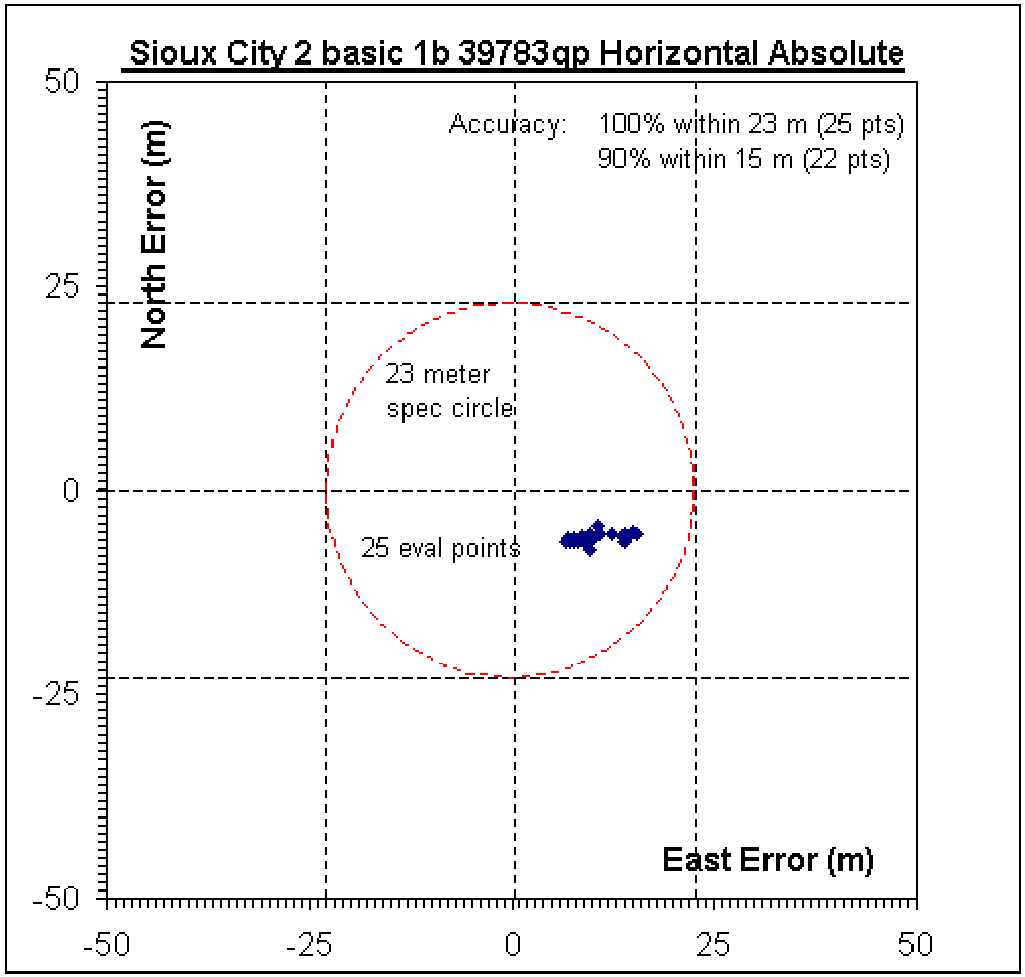
Miami


Miami 2 basic 1b 39759qp Horizontal Absolute
Accuracy: 48% within 23 m (11 pts)
90% within 25 m (22 pts)
North Error (m)
East Error (m)
23 meter
spec circle
25 eval points
50
25
0
-25
-50
-50
-25
0
25
50

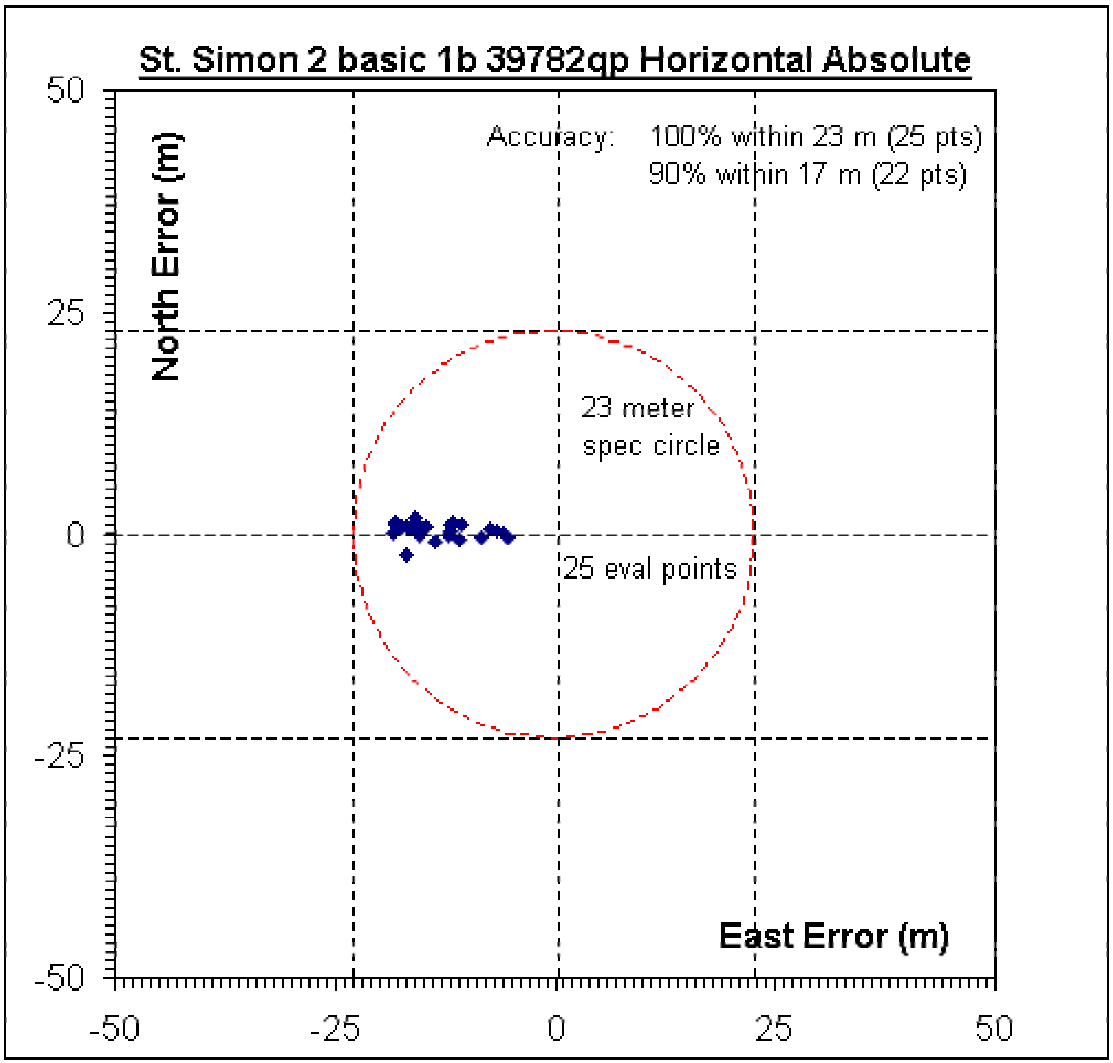
Nellis


Nellis 2 basic 1b 39780qp Horizontal Absolute
Accuracy: 100% within 23 m (25 pts)
90% within 9 m (22 pts)
North Error (m)
23 meter
spec circle
25 eval points
East Error (m)
50
25
0
-25
-50
-50
-25
0
25
50

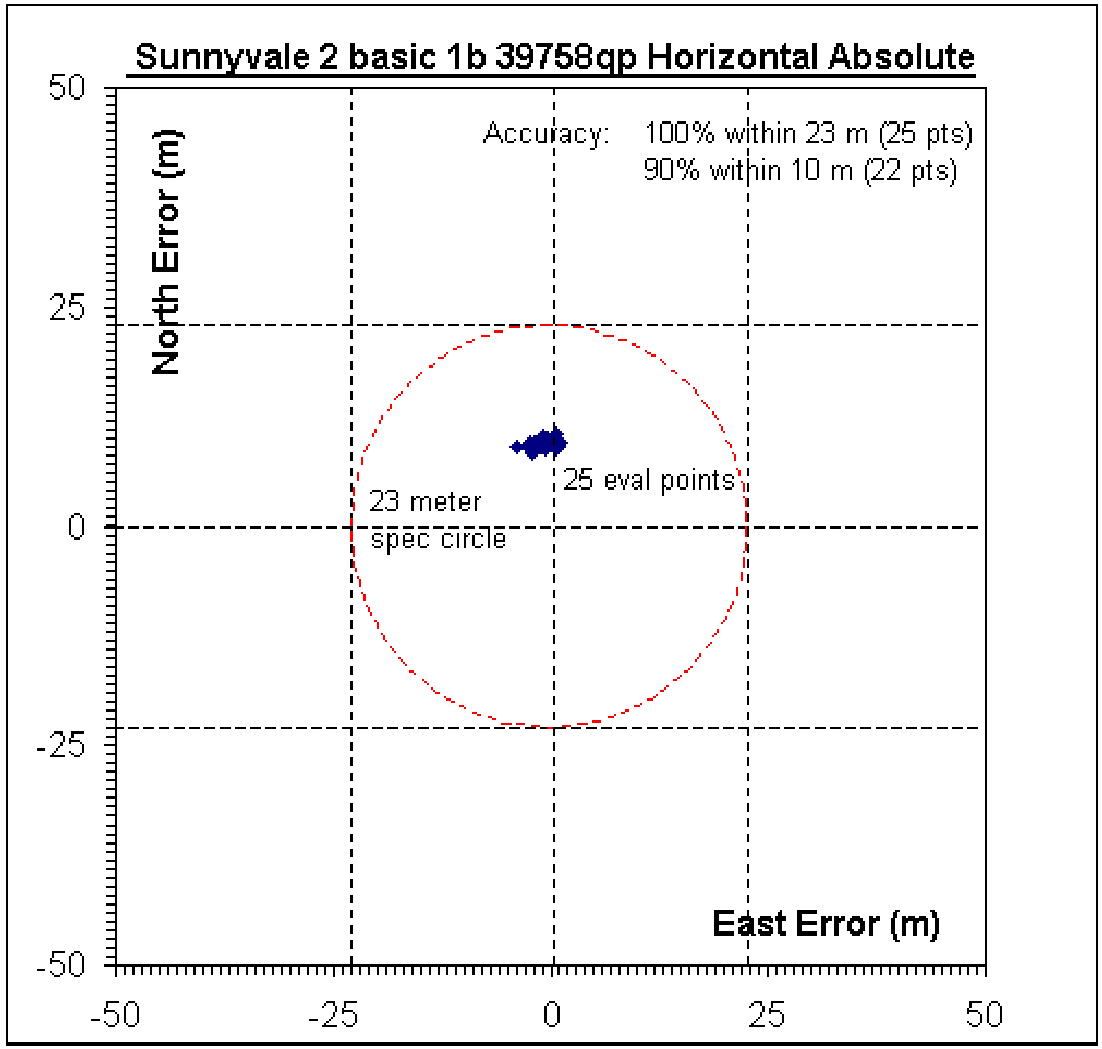
Sioux City


Sioux City 2 basic 1b 39783qp Horizontal Absolute
Accuracy: 100% within 23 m (25 pts)
90% within 15 m (22 pts)
23 meter
spec circle
25 eval points
North Error (m)
East Error (m)
50
25
0
-25
-50
-50
-25
0
25
50

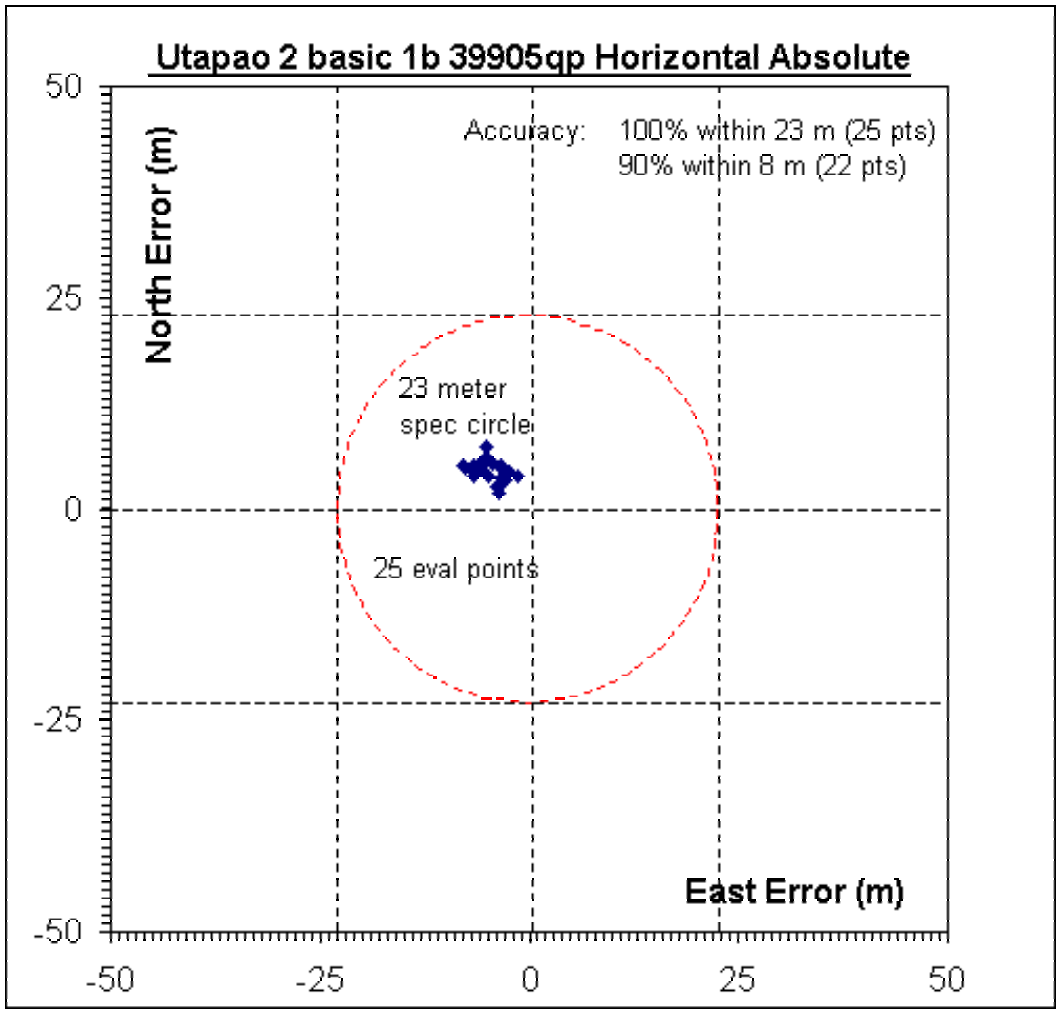
St. Simons Island



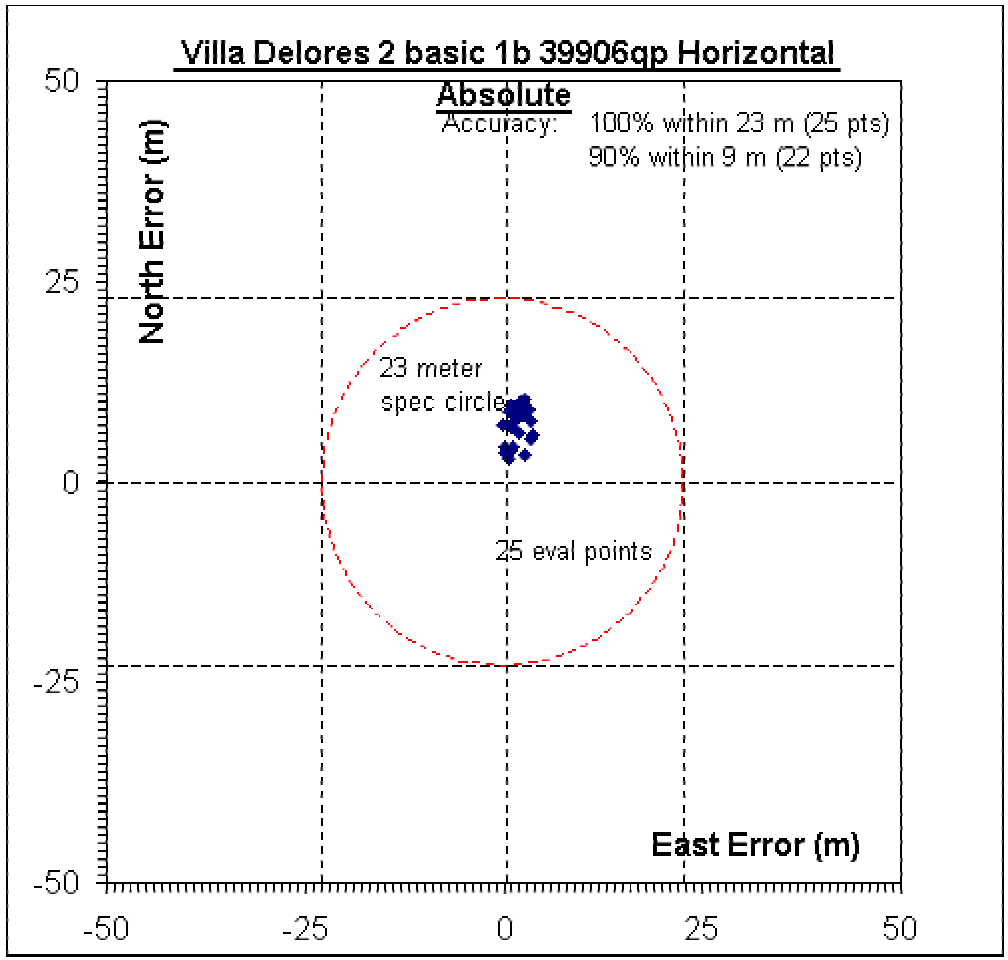
Sunnyvale


Sunnyvale 2 basic 1b 39758gp Horizontal Absolute
Accuracy: 100% within 23 m (25 pts)
90% within 10 m (22 pts)
North Error (m)
East Error (m)
25 eval points
23 meter
spec circle
50
25
0
-25
-50
-50
-25
0
25
50

Utapao


Utapao 2 basic 1b 39905qp Horizontal Absolute
Accuracy: 100% within 23 m (25 pts)
90% within 8 m (22 pts)
23 meter
spec circle
25 eval points
North Error (m)
East Error (m)
50
25
0
-25
-50
-50
-25
0
25
50

Villa Dolores



CE_{90} Analysis for ADP 2.1

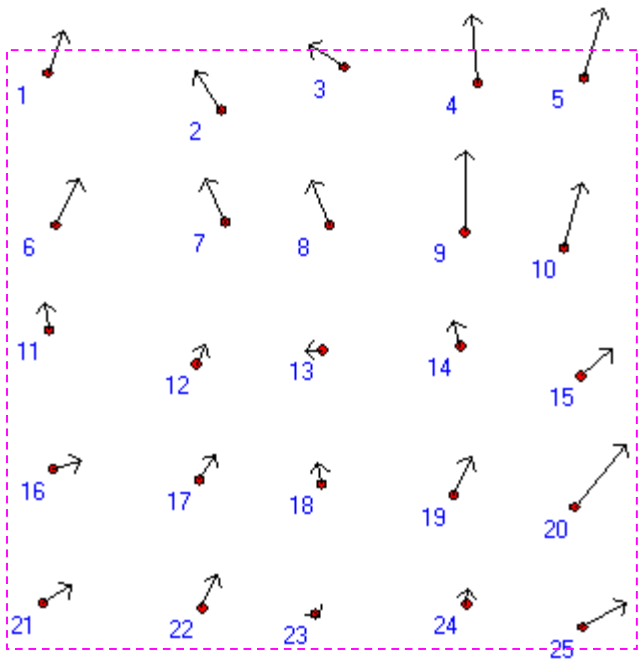
- Analysis 1: Probability that the horizontal error is less than 23 meters
  - 12 of 13 location's have average horizontal error less than 23 meters (92.3%)
  - 311 of 325 drop points have a horizontal error less than 23 meters, for a percentage of 95.7%
  - Both results indicated CE_{90} < 23 meters
- Analysis 2: Estimate of CE_{90} over all scenes
  - Previous charts show the 90th percentile (CE_{90}) for each of 13 locations
  - The 90th percentile over all the locations (combining the data) equal 17.4 meters
  - CE_{90} = 17.4 meters is less than 23 meters as required
- QuickBird meets its guaranteed accuracy using ADP 2.1 processed data

Additional comments

- Note the plots that follow show cases where the within scene ‘random’ error is not really random
  - Rather the direction of the error is correlated with within scene location
  - Possibly due to image warp
- However, this does not invalidate the CE_{90} conclusions
- More analysis will be needed to address this ‘random’ error

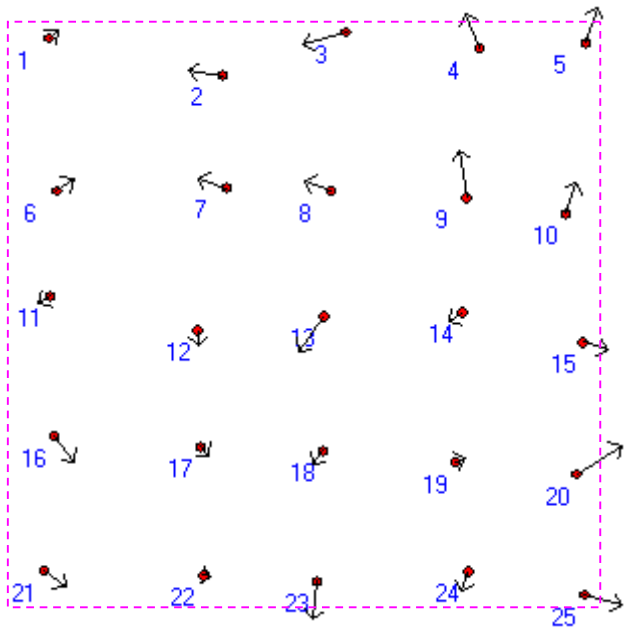
Antananarivo

Antananarivo 2 basic 1b 39903qp
horizontal absolute evaluation



Vector scale: 5 meters

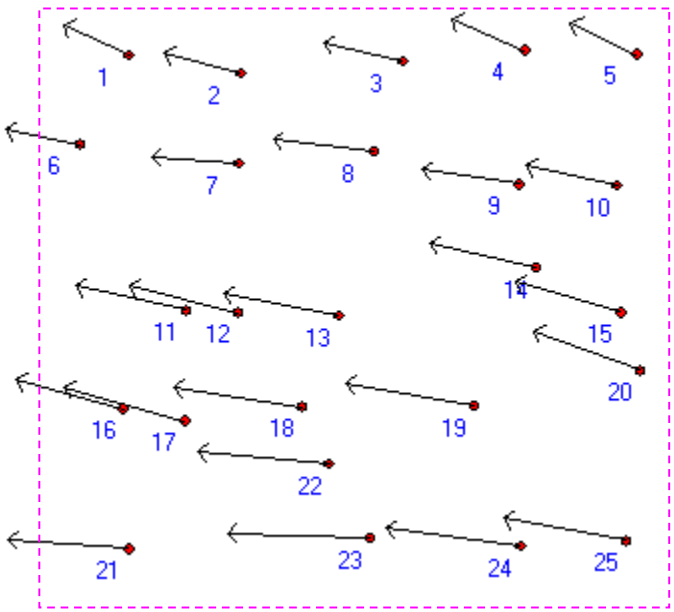
Antananarivo 2 basic 1b 39903qp
horizontal random evaluation



Vector scale: 5 meters

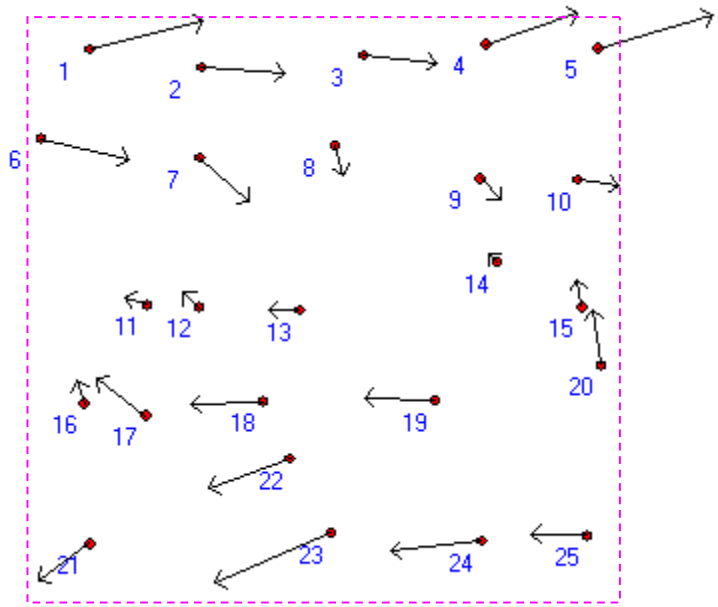
Camp Lejeune

Camp Lejeune 2 basic 1b 39757qp
horizontal absolute evaluation



Vector scale: 15 meters

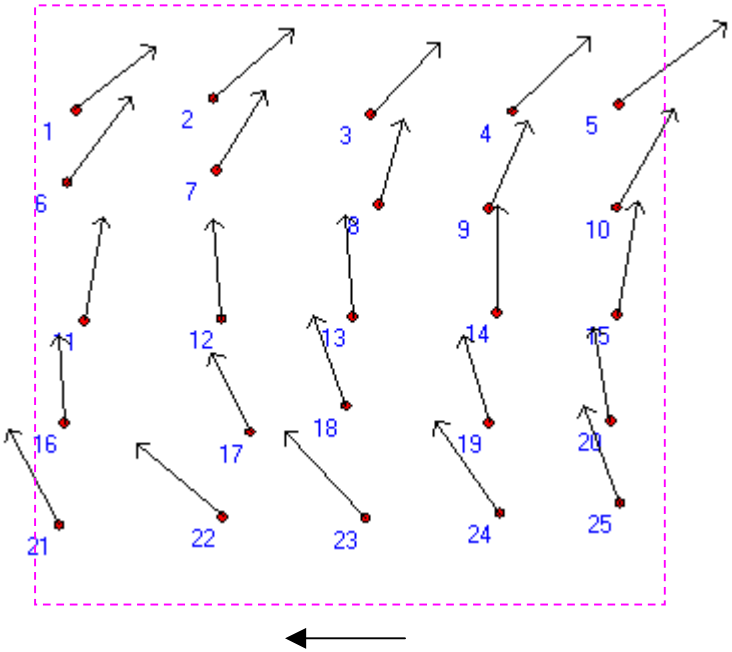
Camp Lejeune 2 basic 1b 39757qp
horizontal random evaluation



Vector scale: 5 meters

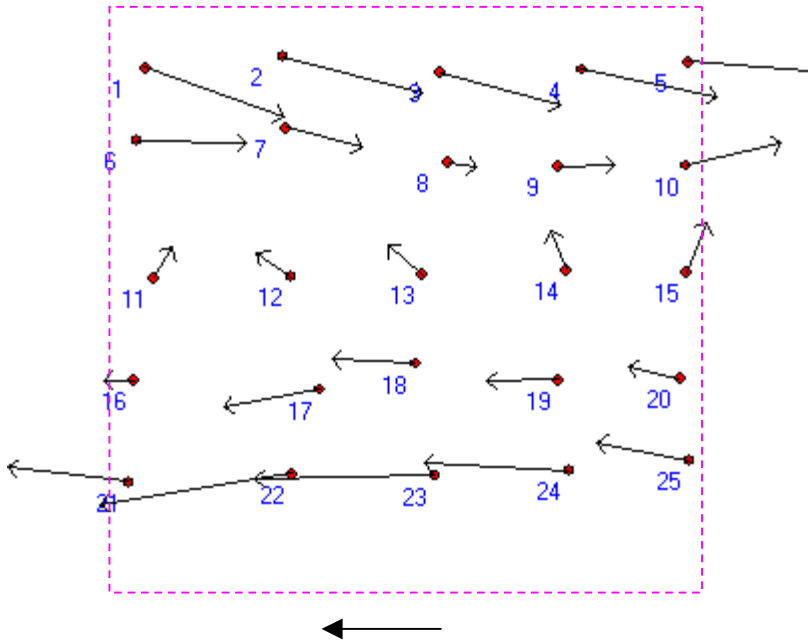
Christchurch

Christchurch 2 basic 1b 39904qp
horizontal absolute evaluation



Vector scale: 10 meters

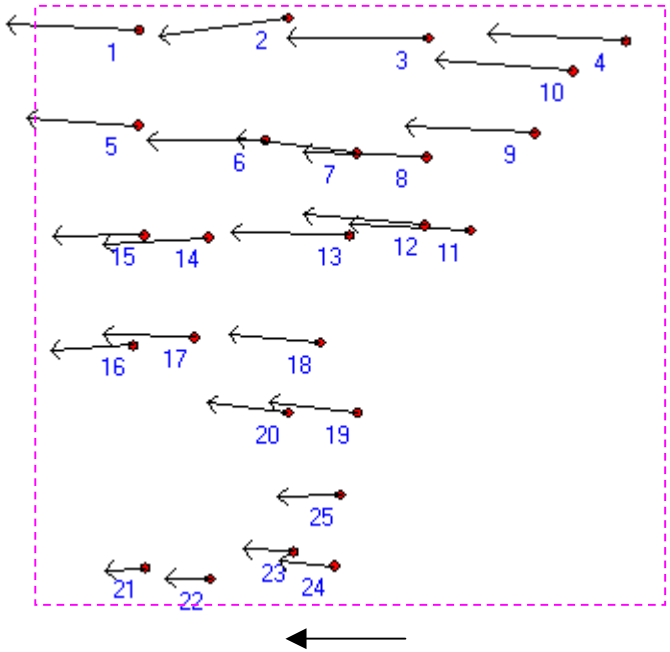
Christchurch 2 basic 1b 39904qp
horizontal random evaluation



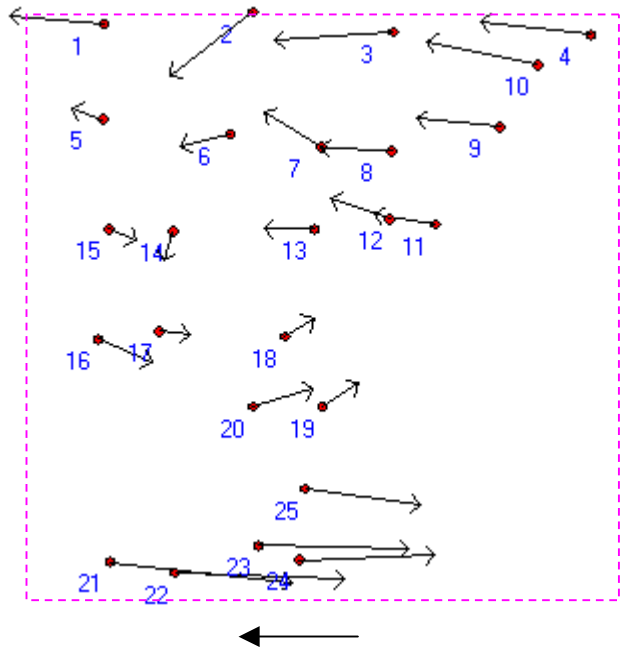
Vector scale: 5 meters

St. Simon's Island

St. Simon 2 basic 1b 39782qp horizontal absolute evaluation



St. Simon 2 basic 1b 39782qp horizontal random evaluation



ADP Version 2.0 Analysis

Background

- 13 scenes
  - but only 12 in common with the ADP Version 2.1 data
  - Auckland replaces Villa Dolores
- 11 scenes have 25 drop points
  - The remaining two scenes have 26 and 39 drop points respectively
- ADP 2.0 data was not used to validate accuracy guarantee – reported here for information only

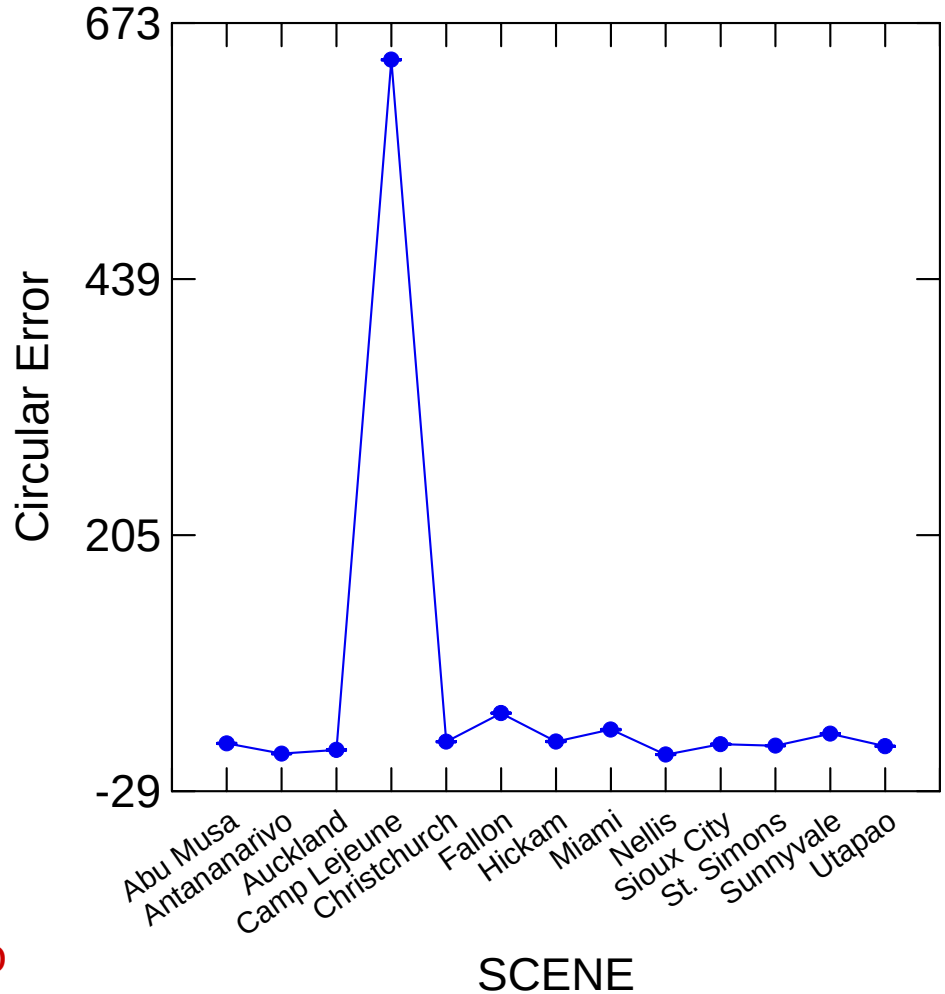
Scene Statistics

Version 2.0

	Average Error (m)					Standard Deviation (m)		
	Latitude	Longitude	Horizontal	CE90	N	Latitude	Longitude	Horizontal
Abu Musa	12.89	7.03	14.70	15	25	0.47	0.81	0.60
Anatanarivo	3.80	3.66	5.33	8	25	1.65	2.05	2.51
Auckland	4.34	-7.40	8.76	10	25	1.27	1.92	1.39
Camp Lejeune	-639.50	-6.65	639.54	642	25	2.13	2.21	2.86
Christchurch	13.21	9.44	16.27	19	25	0.83	4.32	4.35
Fallon	11.20	40.82	42.34	47	25	2.09	2.89	3.25
Hickam	-3.85	-15.87	16.39	20	25	3.25	2.43	3.28
Miami	0.67	-27.35	27.39	31	26	1.22	2.83	2.80
Nellis	0.12	-4.22	4.42	7	39	1.26	2.02	1.97
Sioux City	2.66	13.70	13.97	18	25	1.18	1.85	1.60
St.Simon's	5.30	-11.32	12.58	14	25	0.87	2.85	2.92
Sunnyvale	11.85	-20.32	23.60	27	25	0.89	3.61	3.19
Utapao	7.28	-9.25	12.10	13	25	2.45	1.89	1.16
Average	**-43.85**	**-2.13**	**64.42**	**67.00**		**1.51**	**2.44**	**2.45**

Plot of Average Circular Error

by scene



CE_{90} Analysis for Version 2.0

- Analysis 1: Probability that the horizontal error is less than 23 meters
  - 9 of 13 locations had an average horizontal error less than 23 meters, for a percentage of 69.2%
  - 250 of 340 drop points have a horizontal error less than 23 meters, for a percentage of 73.5%
- Analysis 2: Estimate of CE_{90} over all scenes
  - The 90th percentile over all the locations equal 44.9 meters
  - CE_{90} = 44.9 meters is greater than 23 meters
- Under Version 2.0, QuickBird fails to meet guaranteed accuracy
- The Camp Lejeune data might be considered as outliers. Even if these 25 data points were removed, the CE_{90} would still be 29.9 meters > 23 meters
  - The Camp Lejeune error was generated by a timing error that has been corrected by the CDP

Conclusions

- QuickBird meets its accuracy guarantee under ADP Version 2.1
  - Only near nadir collection geometries verified
  - Estimated CE_{90} = 17.4 meters
  - Pooled random horizontal accuracy is 1.96 meters (std)
- QuickBird does not meet its accuracy guarantee under ADP Version 2.0
  - Estimated CE_{90} = 44.9 meters
  - Pooled random horizontal accuracy is 2.63 meters (std)

Recommendations

- QuickBird Level 1B data processed using ADP 2.1 or better can be used to satisfy NIMA requirements
  - Recommend that NIMA certify the QuickBird Level 1B data
- Recommend that NIMA continue to perform additional analysis with DG to resolve the ‘random’ error questions
  - Coordinate efforts with CCAP and support teams

CCAP Team

- Ken Peterman, Government Lead
  - 301.227.0236
- Jennifer Meisburger, Ph.D., Technical Lead
  - 703.735.3869
- Robert Glittone, Imagery Analyst
  - 703.735.3107
- Paul Beyer, Geospatial Analyst
  - 703.735.3890
- Additional NIMA Support:
  - Paul Basgall, Photogrammetrist
  - Leigh Harrington, Statistician

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  - Paul Basgall
  - Pete Gaska
  - Greg Grohman
  - Mary Glauber
  - Leigh Harrington
  - NIMA FPE
  - NIMA PTNT
  - NIMA AEAI

Back-Up Slides:

ANOVA Results

Additional Vector Plots

Analysis of Variance

Random Error ADP Version 2.1

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SCENE$	8677.9671	12	723.1639	188.5586	5.5E-12
Error	1196.5888	312	3.8352		

The random within scene error, pooled over all locations, has a standard deviation of $3.835^{1/2} = 1.96$ (m)

Analysis of Variance

Random Error ADP Version 2.0

Analysis of Variance

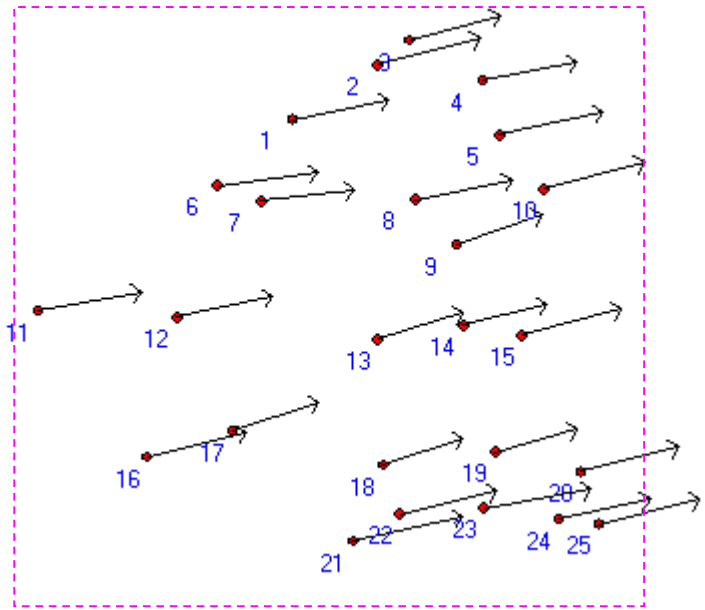
Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SCENE$	9038097.80	12	753174.82	109268.87	2.4E-12
Error	2253.96	327	6.89		

The random within scene error, pooled over all locations, has a standard deviation of $6.89^{1/2}$ = 2.62 meters

This is 34% greater than that calculated for Version 2.1

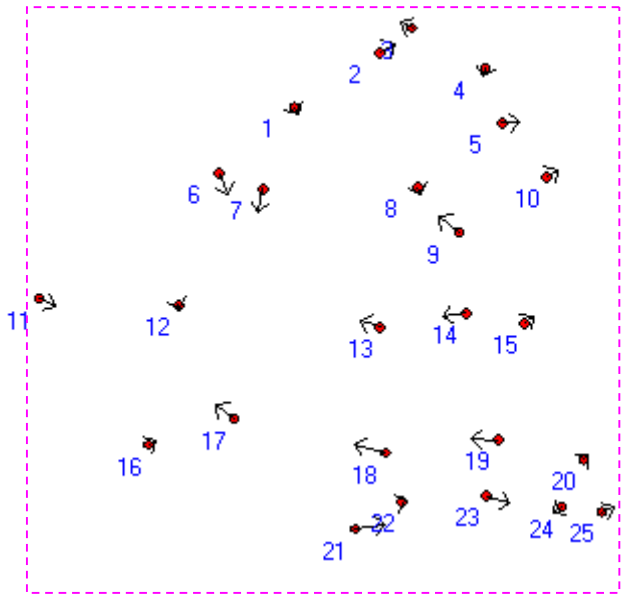
Abu Musa

Abu Musa 2 basic 1b 39902qp
horizontal absolute evaluation



Vector scale: 10 meters

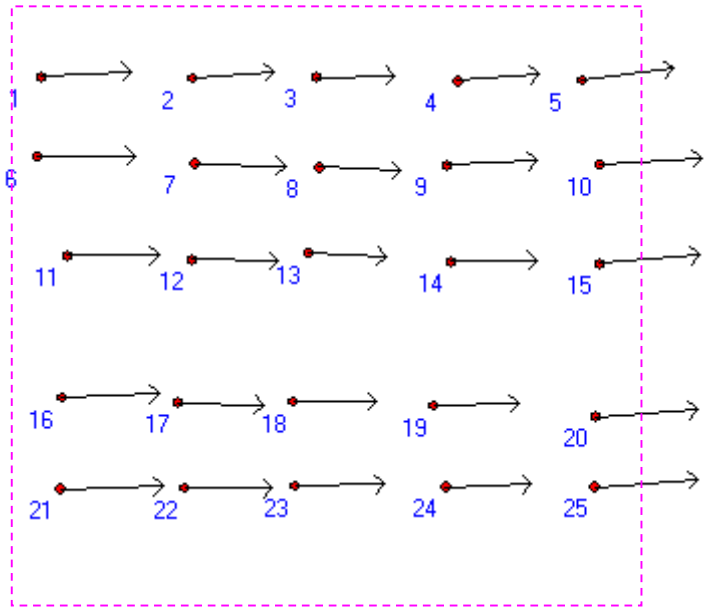
Abu Musa 2 basic 1b 39902qp
horizontal random evaluation



Vector scale: 5 meters

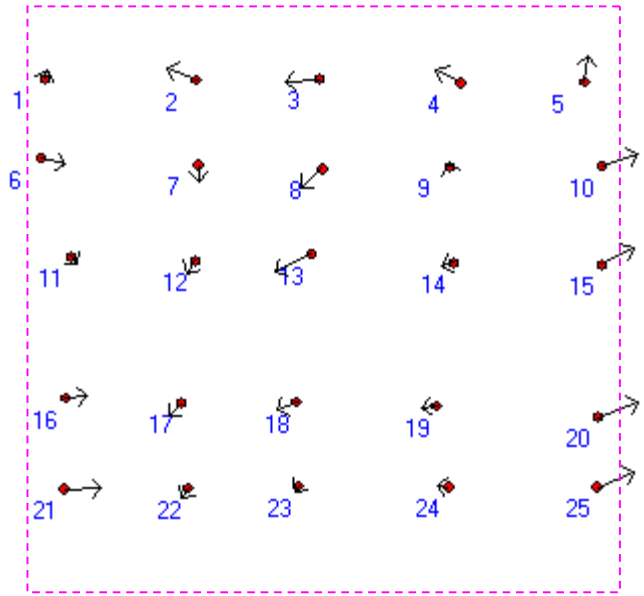
Fallon

Fallon 2 basic 1b 38910qp
horizontal absolute evaluation



Vector scale: 15 meters

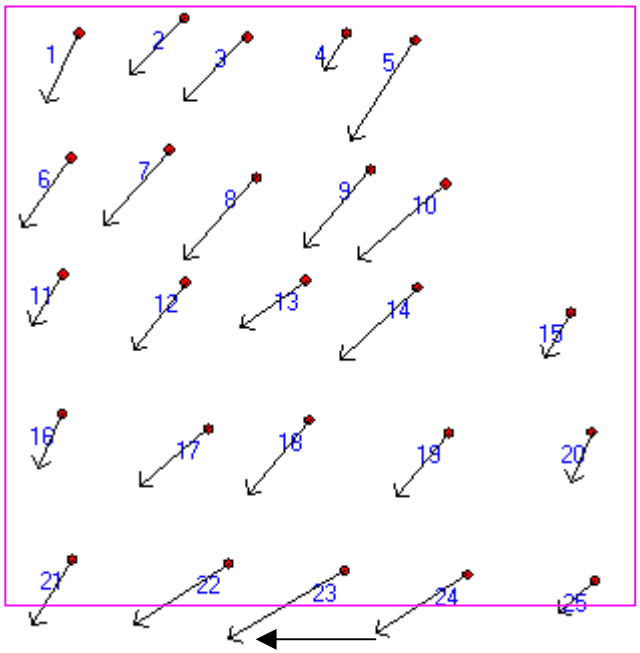
Fallon 2 basic 1b 38910qp
horizontal random evaluation



Vector scale: 5 meters

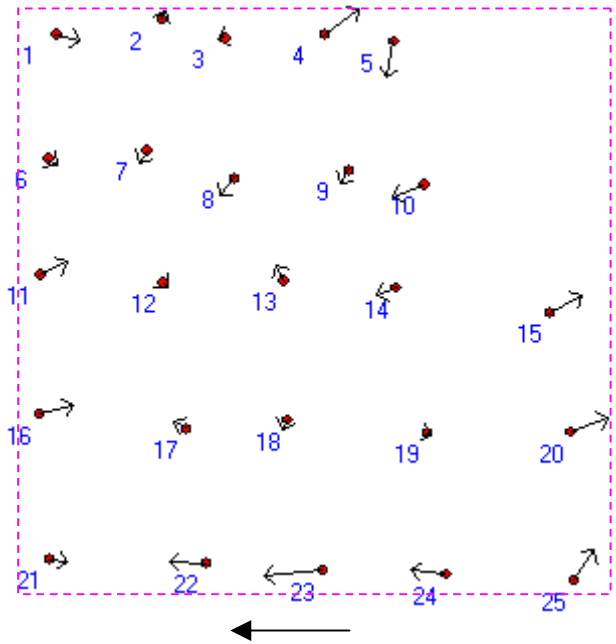
Hickam

Hickam 2 basic 1b 39779qp horizontal absolute evaluation



Vector scale: 5 meters

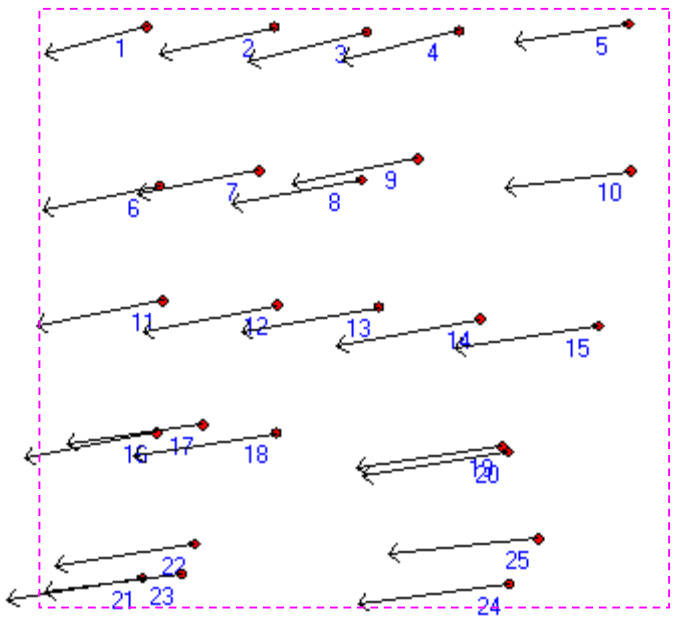
Hickam 2 basic 1b 39779qp horizontal random evaluation



Vector scale: 5 meters

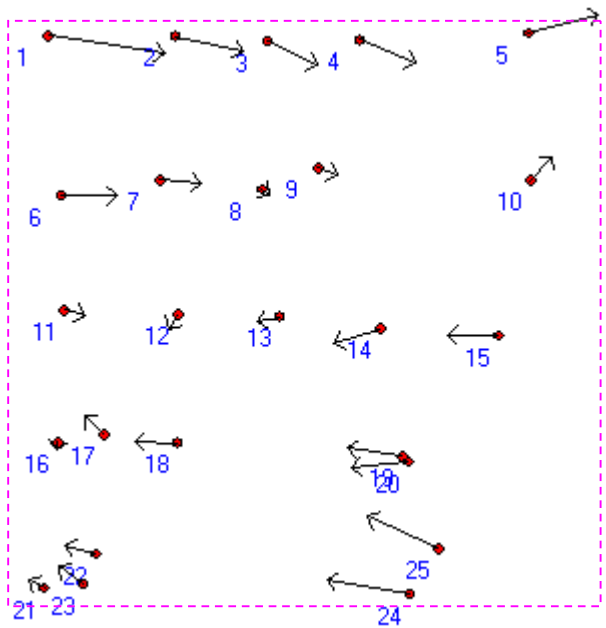
Miami

Miami 2 basic 1b 39759qp horizontal absolute evaluation



Vector scale: 20 meters

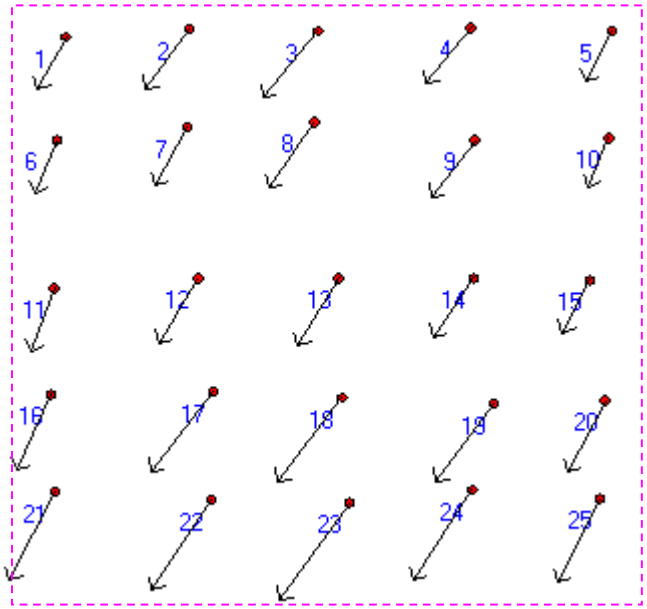
Miami 2 basic 1b 39759qp horizontal random evaluation



Vector scale: 5 meters

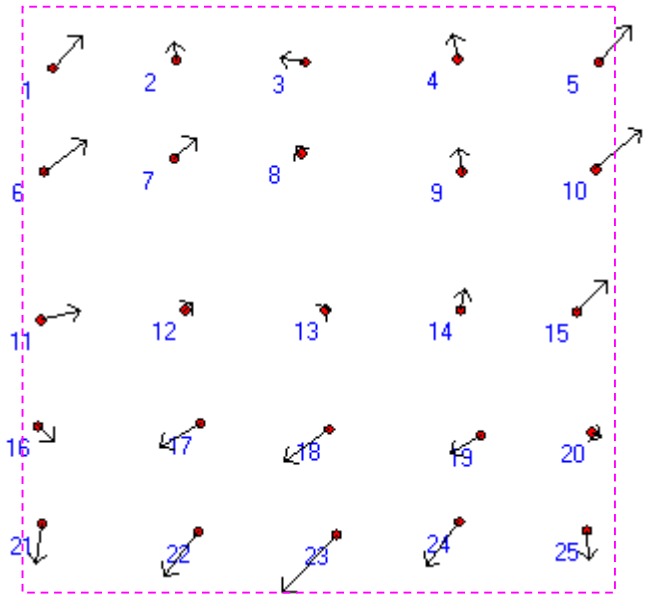
Nellis

Nellis 2 basic 1b 39780qp horizontal absolute evaluation



Vector scale: 10 meters

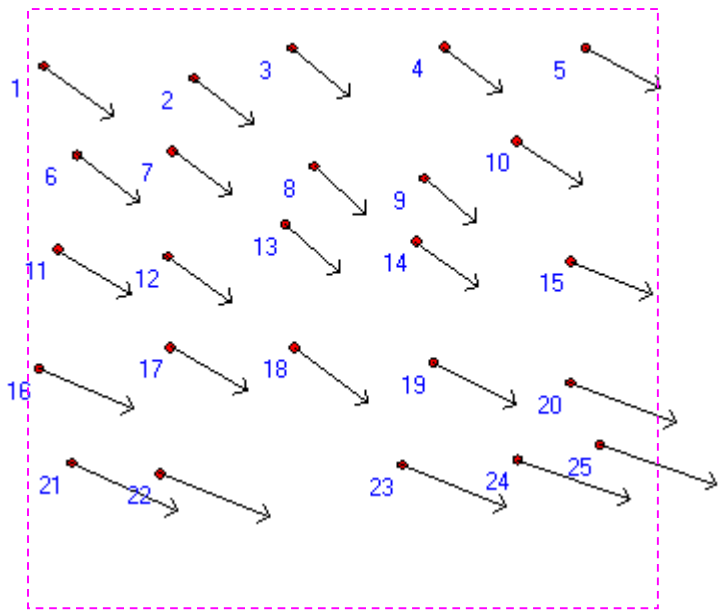
Nellis 2 basic 1b 39780qp horizontal random evaluation



Vector scale: 5 meters

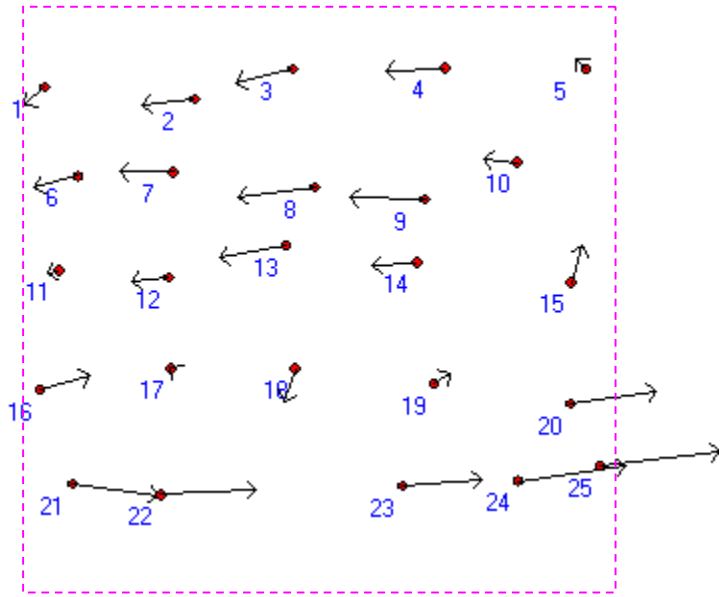
Sioux City

Sioux City 2 basic 1b 39783qp
horizontal absolute evaluation



Vector scale: 15 meters

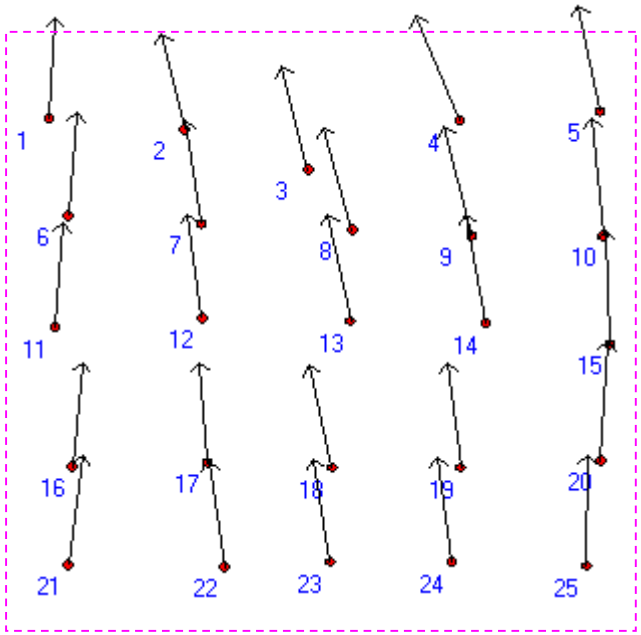
Sioux City 2 basic 1b 39783qp
horizontal random evaluation



Vector scale: 5 meters

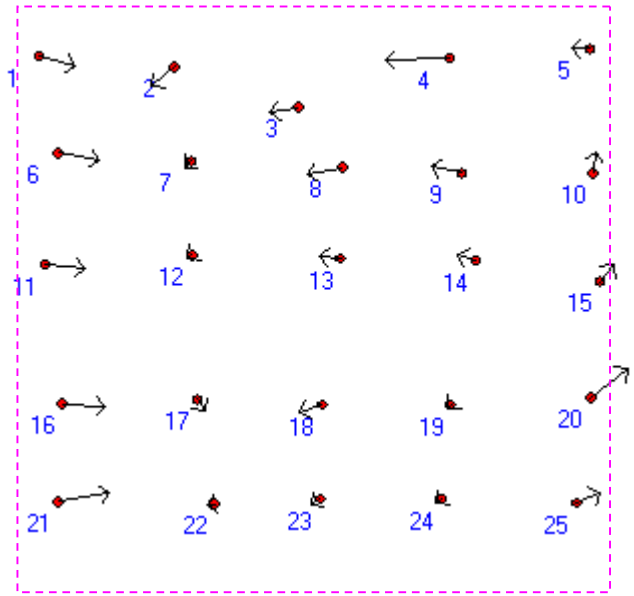
Sunnyvale

Sunnyvale 2 basic 1b 39758qp
horizontal absolute evaluation



Vector scale: 10 meters

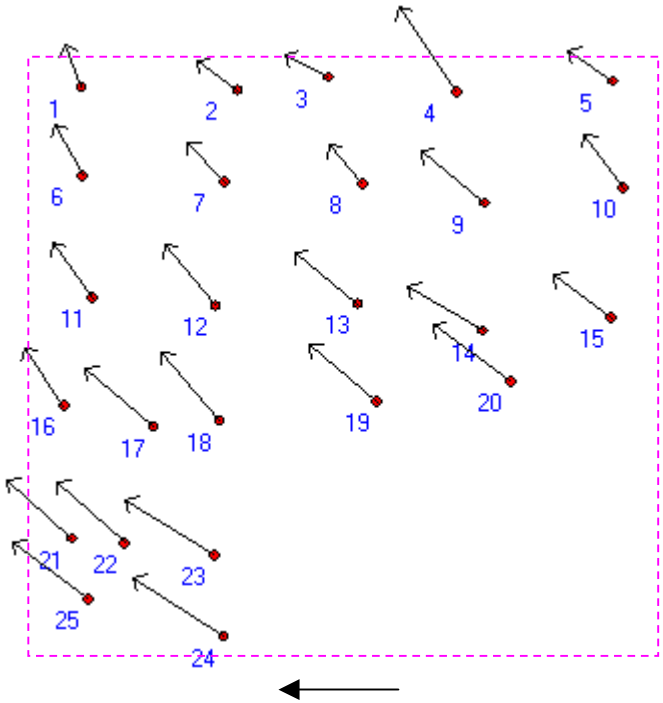
Sunnyvale 2 basic 1b 39758qp
horizontal random evaluation



Vector scale: 5 meters

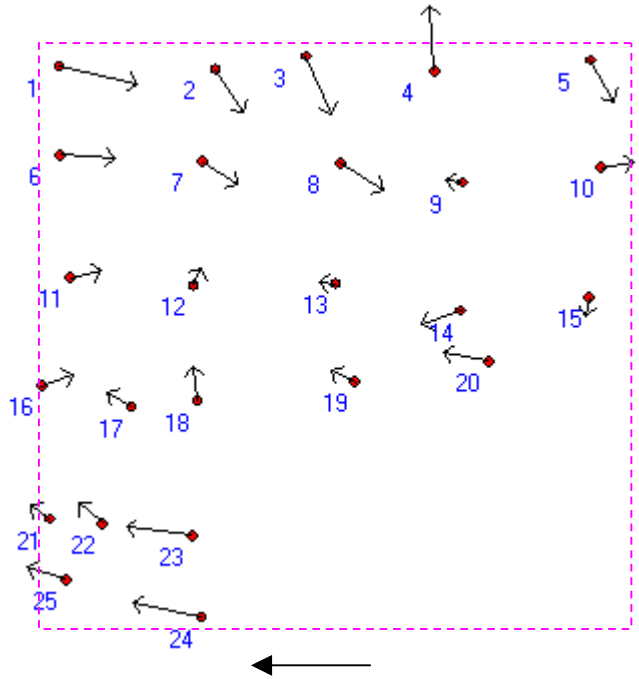
Utapao

Utapao 2 basic 1b 39905qp horizontal
absolute evaluation



Vector scale: 10 meters

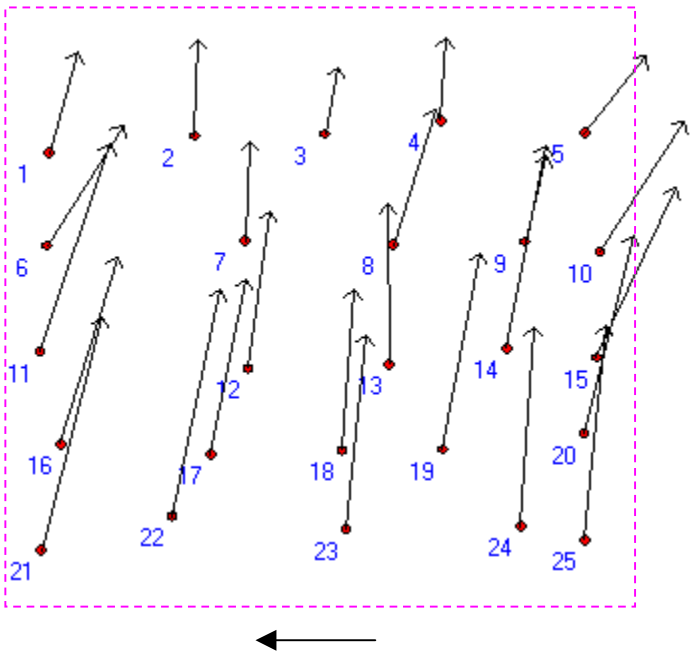
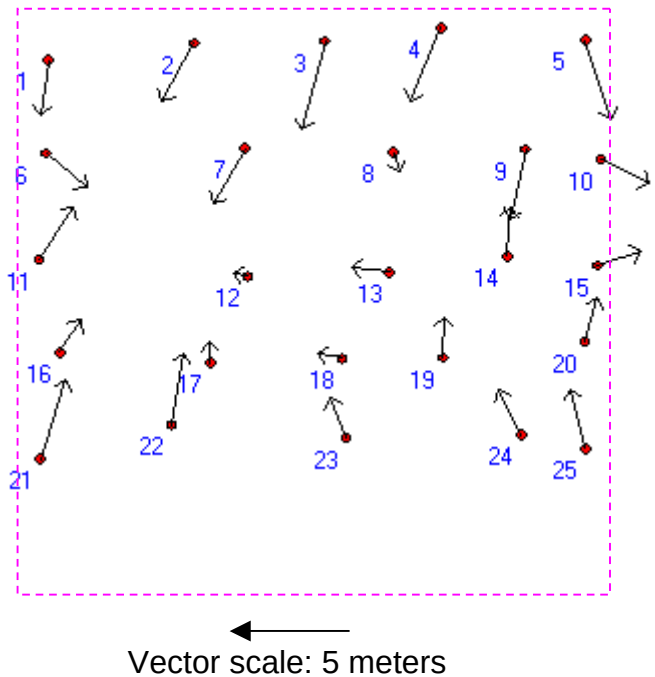
Utapao 2 basic 1b 39905qp horizontal
random evaluation



Vector scale: 5 meters

Villa Dolores

Villa Dolores 2 basic 1b 39906qp
horizontal absolute evaluation



Villa Dolores 2 basic 1b 39906qp
horizontal random evaluation