Geolocation Accuracy Evaluation of Radarsat-2 Spotlight and UltraFine Imaging Mode Products

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Outline

- Objective
- Product Descriptions and Specifications
- Methodology
- Evaluation Results

Objectives

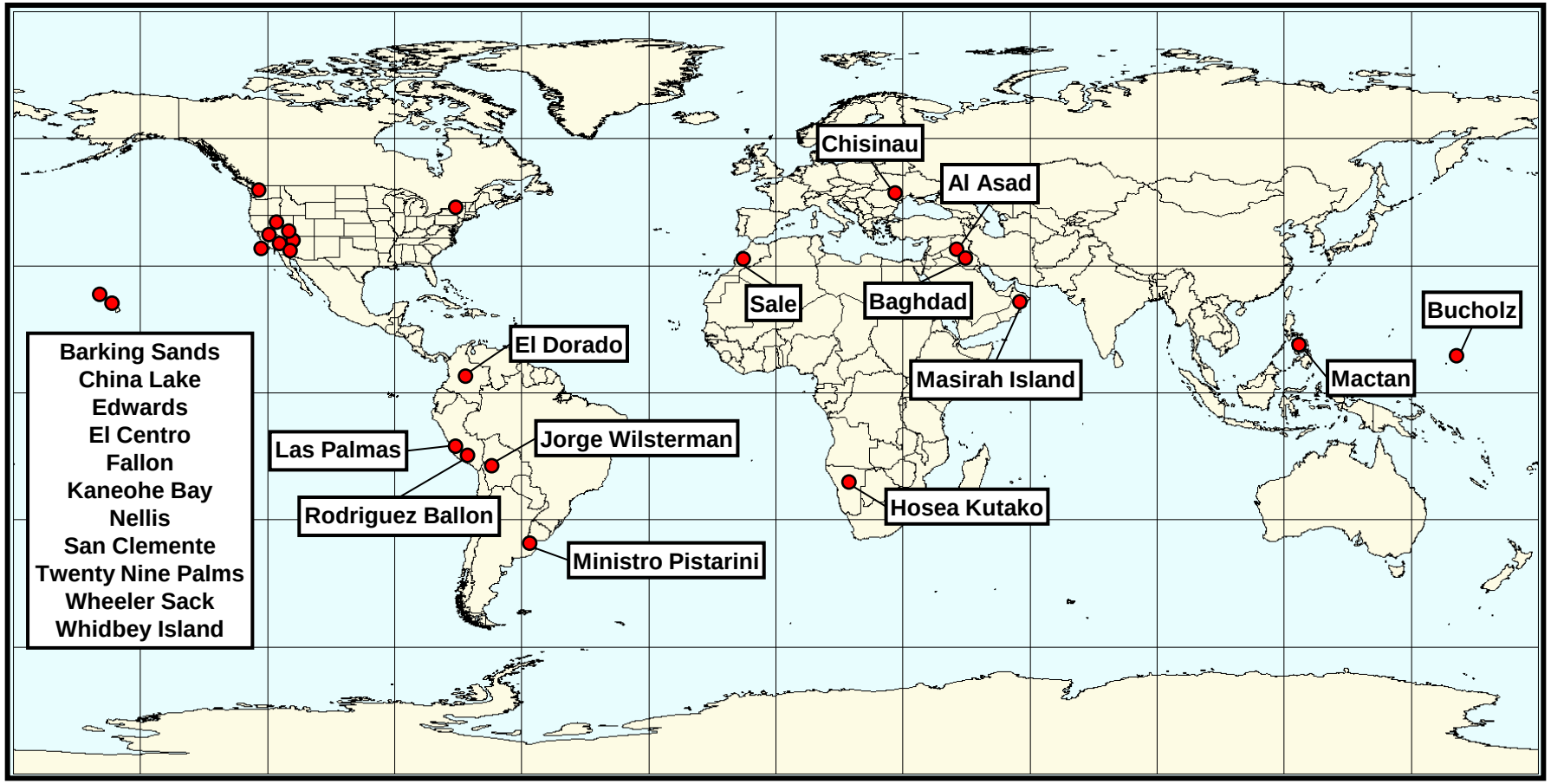
- To estimate the absolute horizontal geolocation accuracy of a sample set of:
  - 27 Spotlight imaging mode products
  - 23 UltraFine (stripmap) imaging mode products

- Both physical sensor model and Rational Polynomial Coefficient (RPC) geometry model support data assessed
  - Essentially same results, so only physical model number reported in this presentation

Radarsat-2

27 Spotlight Images over 24 Test Sites

From Terminal Aeronautical Global Navigation Satellite System (GNSS) Geodetic Survey (TAGGS) Program

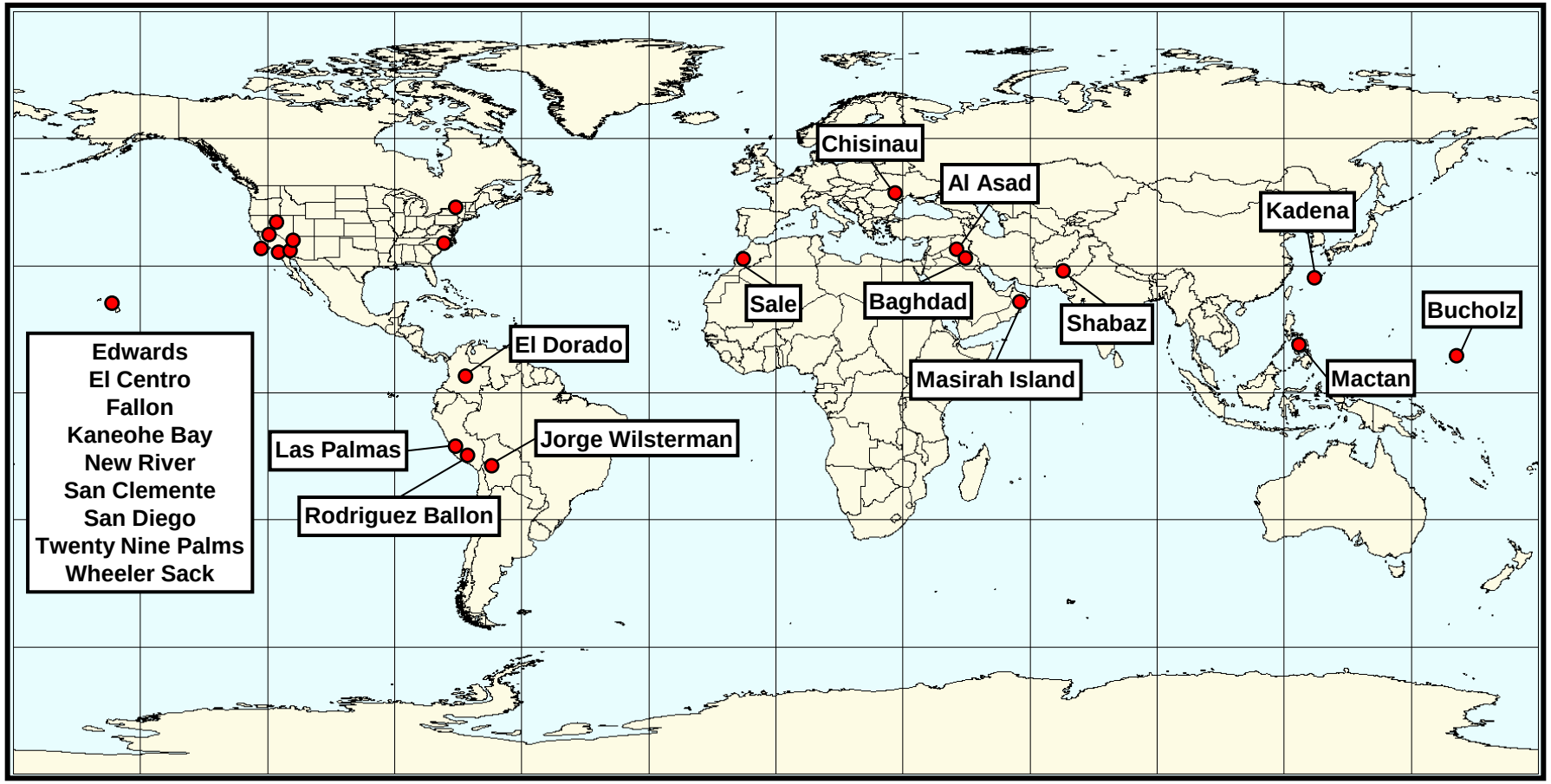


Images collected between July 2008 and February 2009 and processed between February and April 2010.

Radarsat-2

23 UltraFine Images over 22 Test Sites

From TAGGS Program, except San Diego which is a corner reflector site



Images collected between July 2008 and May 2009 and processed between February and April 2010.

Definitions of Sample Statistics

- Circular Error 90% (CE90)
  - In horizontal plane
  - Radial error distance centered at zero within which 90% of the data points fall

Radarsat-2 Product Processing

Imaging Mode	Geometric Processing	Product Pixel Sampling (m)		Ground Resolution (m)	
		Range	Azimuth	Range	Azimuth
Spotlight	Flight-Path / Ground Range-Oriented Path Image Plus (SGX)	1.0	0.33	2.1 – 4.6	0.8
UltraFine (Stripmap)		1.0	1.0	2.1 – 4.6	2.8

Based on MDA Corporation presentation, expected accuracy of ~10 m CE90.

Methodology

- General Approach:
  - Mono CE90: Mono intersection of range/Doppler arcs to checkpoint (CP) heights
- Images *not* allowed to adjust during evaluation
- Goal of evaluation is to estimate CE90 error statistics for population of images, not individual images

Methodology

1) **Load image onto workstation with SOCET Set® photogrammetric software**

2) **Import geometry model support data accompanying imagery**
   - Physical sensor metadata
     - Including sensor information and ephemeris points
   - RPC replacement geometry model metadata

Methodology

3) Compute ground coordinates of checkpoints from test imagery geometry model support data

- Use ground-surveyed control points as checkpoints
- Measure pixel positions (line, sample) of checkpoints
- Hold test imagery fixed (by holding geometry model support data fixed) and allow checkpoint horizontal ground coordinates to adjust to pixel measurements using triangulation tool

Methodology

4) **For each checkpoint, subtract ground-surveyed coordinates from test-imagery-derived ground coordinates**
   - Results in a list of "Δ Easting" and "Δ Northing" values

Methodology

5) Compute 2 types of data points for each image

a) Error Centroid

- Compute mean "Δ Easting" and "Δ Northing" values and convert into horizontal "Δ Radial" value

b) Root Mean Square Error (RMSE)

$$RMSE_E = \sqrt{\frac{\sum_{i=1}^{n}(\Delta E_i)^2}{n}} \qquad RMSE_N = \sqrt{\frac{\sum_{i=1}^{n}(\Delta N_i)^2}{n}}$$

$$RMSE_r^{Horizontal} = \sqrt{RMSE_E^2 + RMSE_N^2}$$

n is number of ICPs

- Each image represented by one or the other of these single data points for Mono CE90 estimation
- Additional statistics:
  - Number of checkpoints
  - Maximums & minimums of Δ Easting and Δ Northing values
  - Standard deviations of Δ Easting and Δ Northing values

Methodology

Why single data point for each image?

- …test sites have varying number of checkpoints
- …goal of evaluation is to estimate CE90 error statistic for population of images, not individual images

Why choice of “error centroid” versus RMSE data points?

Methodology

Error Centroid Approach

- Shows “central tendency” which can indicate product absolute accuracy
- Tends to “average out” pixel measurement and CP identification error introduced by tester
  - Can be desirable to eliminate tester-introduced random error
    - TAGGS CPs surveyed for use with electro-optical imagery rather than SAR, so CP identification and measurement error can be significant contributor to assessed error
    - Tester-introduced random error more significant as sensor absolute accuracy increases
  - Risk that it could also “average out” actual random errors in image

Methodology

RMSE Approach

- Incorporates all errors, including tester-introduced random error
  - Thus, difficult to separate tester-induced influence versus actual imagery errors

Estimating CE90 using both approaches is good technique

- Look at standard deviations of error centroid data points
- Look at closeness of error centroid and RMSE data points
- Consider how identifiable CPs are
- Consider expected product accuracy versus measurement error

Using corner reflectors for SAR imagery reduces CP identification and measurement errors

Methodology

6) Estimate CE90

- CCAP uses non-parametric estimator (“Percentile Method”)
- Sort error centroid or RMSE data points in ascending order
- Cut-off at 90th percentile
  - For n data points, 0.9*n + 0.5 defines position in ordered list
  - Linearly interpolate from ordered list as required

- Additional statistics:
  - Number of images
  - Maximums and minimums of data points
  - Standard deviations of data points

90th Percentile Estimator for Ordered Statistics

Given n ordered data points $x_{(1)}, x_{(2)}, \ldots, x_{(n)}$,

where $x_{(i)} = \Delta r_{(i)}$ or $x_{(i)} = \mathrm{RMSE}_{r_{(i)}}$.

Then,

$$CE90 = (1 - f) * x_{(i)} + f * x_{(i+1)}$$

where

i = integer part of $0.9 * n + 0.5$, and

f = fractional part of $0.9 * n + 0.5$.

Radarsat-2 Spotlight Imaging Mode Evaluation Results
(Physical Sensor Model Data)

Radarsat-2 Spotlight Images

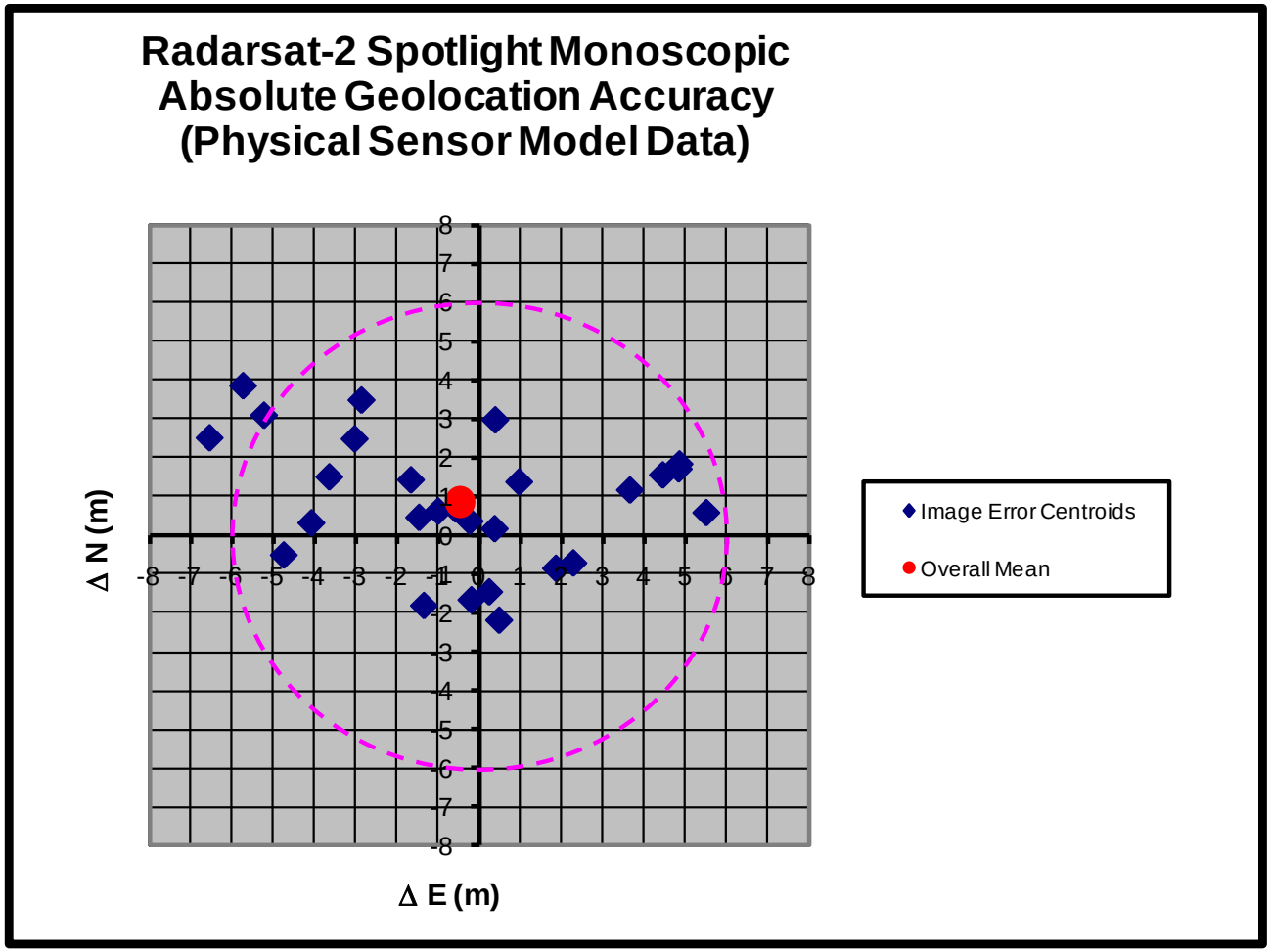
Horizontal Errors (n=27)

Test Site	Collection Date	CPs	Product ID	Δ E (m)				Δ N (m)				Δ r (m)	RMS (m)		
				Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max		Δ E	Δ N	Δ r
Argentina, Ministro Pistarini	20-Jan-2009	3	PK126344	-0.2	1.0	-0.8	0.9	-1.7	0.8	-2.4	-0.8	1.7	0.8	1.8	2.0
Bolivia, Jorge Wilsterman	18-Jan-2009	10	PK126341	-1.7	1.2	-2.6	1.2	1.4	1.1	-0.6	2.5	2.2	2.0	1.8	2.7
Colombia, El Dorado	18-Aug-2008	3	PK126339	2.3	1.2	0.9	3.0	-0.7	0.6	-1.3	-0.3	2.4	2.5	0.8	2.6
Iraq, Al Asad	26-Jan-2009	15	PK126337	1.0	0.9	-0.9	2.6	1.4	0.7	0.3	2.4	1.7	1.3	1.6	2.0
Iraq, Baghdad	18-Aug-2008	4	PK126334	4.8	0.3	4.6	5.2	1.7	0.6	1.3	2.6	5.1	4.8	1.8	5.2
Marshall Islands, Bucholz	24-Jan-2009	8	PK126333	-5.2	0.9	-7.2	-4.4	3.1	0.8	2.1	4.0	6.1	5.3	3.2	6.2
Moldova, Chisinau	22-Jan-2009	15	PK126331	-4.7	0.8	-5.8	-3.4	-0.5	0.9	-3.0	0.6	4.8	4.8	1.0	4.9
Morocco, Sale	21-Jan-2009	6	PK126329	-6.5	0.9	-7.8	-5.3	2.5	0.9	1.7	4.0	7.0	6.6	2.6	7.1
Namibia, Hosea Kutako	24-Jan-2009	4	PK126327	4.5	0.7	3.7	5.3	1.6	0.4	1.1	2.2	4.7	4.5	1.6	4.8
Oman, Masirah Island	21-Jan-2009	14	PK126325	3.7	1.0	2.2	4.9	1.2	1.0	-0.3	2.6	3.8	3.8	1.5	4.1
Peru, Las Palmas	16-Jan-2009	4	PK126277	-3.0	0.4	-3.6	-2.7	2.5	0.9	1.7	3.7	3.9	3.0	2.6	4.0
Peru, Rodriguez Ballon	26-Jan-2009	8	PK126280	-1.3	1.0	-2.4	0.1	-1.8	0.8	-2.7	-0.1	2.2	1.6	1.9	2.5
Philippines, Mactan	19-Jan-2009	11	PK126276	5.5	1.1	3.7	6.7	0.6	1.0	-0.9	1.8	5.5	5.6	1.2	5.7
United States, Barking Sands	30-Jul-2008	3	PK51598	-4.1	1.5	-5.2	-2.4	0.3	1.0	-0.8	1.2	4.1	4.2	0.9	4.3
United States, China Lake	21-Sep-2008	12	PK126273	0.4	2.3	-3.6	4.6	3.0	1.2	1.5	5.1	3.0	2.3	3.2	3.9
United States, Edwards	28-Jul-2008	13	PK51596	-1.0	1.2	-2.3	1.8	0.6	1.0	-0.6	2.3	1.2	1.5	1.1	1.9
United States, El Centro	26-Jan-2009	15	PK113519	0.5	0.9	-1.9	1.5	-2.2	0.6	-3.2	-1.3	2.2	1.0	2.2	2.5
United States, El Centro	23-Feb-2009	17	PK113529	-2.9	1.2	-4.7	-1.3	3.5	1.2	1.4	6.0	4.5	3.1	3.7	4.8
United States, Fallon	16-Jan-2009	4	PK113509	4.9	1.3	3.7	6.1	1.8	1.0	0.9	3.3	5.2	5.0	2.0	5.4
United States, Kaneohe Bay	28-Jan-2009	9	PK113520	-5.7	0.9	-6.8	-4.3	3.9	1.2	2.6	5.9	6.9	5.8	4.0	7.1
United States, Nellis	29-Jul-2008	5	PK51597	-3.6	1.4	-5.0	-1.7	1.5	1.7	-0.7	2.9	3.9	3.8	2.1	4.4
United States, San Clemente	29-Jan-2009	8	PK113521	-0.2	1.7	-2.8	1.8	0.4	1.5	-1.7	2.1	0.4	1.6	1.4	2.1
United States, Twentynine Palms	20-Jan-2009	9	PK113515	-1.5	0.6	-2.4	-0.6	0.5	0.6	-0.5	1.3	1.5	1.6	0.7	1.7
United States, Wheeler Sack	10-Feb-2009	6	PK113527	0.2	1.4	-1.6	2.3	-1.4	0.5	-1.9	-0.6	1.5	1.3	1.5	2.0
United States, Wheeler Sack	20-Feb-2009	8	PK113528	-0.6	1.4	-2.5	1.1	0.7	1.3	-0.7	3.1	0.9	1.4	1.4	2.0
United States, Whidbey Island	22-Jan-2009	25	PK113517	0.4	1.7	-2.9	3.2	0.2	1.5	-3.6	2.9	0.4	1.7	1.5	2.3
United States, Whidbey Island	1-Feb-2009	23	PK113525	1.9	1.6	-2.0	5.6	-0.8	1.7	-3.1	3.4	2.0	2.4	1.9	3.0

Mean (m)	-0.5	1.1	-2.1	1.2	0.9	1.0	-0.5	2.3	3.3	3.1	1.9	3.8
Std Dev (m)	3.4	0.4	3.4	3.5	1.6	0.3	1.8	1.9	1.9	1.7	0.9	1.7
Maximum (m)	5.5	2.3	4.6	6.7	3.9	1.7	2.6	6.0	7.0	6.6	4.0	7.1
Minimum (m)	-6.5	0.3	-7.8	-5.3	-2.2	0.4	-3.6	-1.3	0.4	0.8	0.7	1.7

Radarsat-2 Spotlight Images

Horizontal Errors (n=27)



Radarsat-2 Spotlight Images

Horizontal Accuracy (n=27)

Test Site	Date	Sorted Δ r (m)
United States, Whidbey Island	22-Jan-2009	0.4
United States, San Clemente	29-Jan-2009	0.4
United States, Wheeler Sack	20-Feb-2009	0.9
United States, Edwards	28-Jul-2008	1.2
United States, Wheeler Sack	10-Feb-2009	1.5
United States, Twentynine Palms	20-Jan-2009	1.5
Argentina, Ministro Pistarini	20-Jan-2009	1.7
Iraq, Al Asad	26-Jan-2009	1.7
United States, Whidbey Island	1-Feb-2009	2.0
Bolivia, Jorge Wilsterman	18-Jan-2009	2.2
United States, El Centro	26-Jan-2009	2.2
Peru, Rodriguez Ballon	26-Jan-2009	2.2
Colombia, El Dorado	18-Aug-2008	2.4
United States, China Lake	21-Sep-2008	3.0
Oman, Masirah Island	21-Jan-2009	3.8
Peru, Las Palmas	16-Jan-2009	3.9
United States, Nellis	29-Jul-2008	3.9
United States, Barking Sands	30-Jul-2008	4.1
United States, El Centro	23-Feb-2009	4.5
Namibia, Hosea Kutako	24-Jan-2009	4.7
Moldova, Chisinau	22-Jan-2009	4.8
Iraq, Baghdad	18-Aug-2008	5.1
United States, Fallon	16-Jan-2009	5.2
Philippines, Mactan	19-Jan-2009	5.5
Marshall Islands, Bucholz	24-Jan-2009	6.1
United States, Kaneohe Bay	28-Jan-2009	6.9
Morocco, Sale	21-Jan-2009	7.0

Estimated Mono CE90 = 6.0 m

Test Site	Date	Sorted RMS (m)
United States, Twentynine Palms	20-Jan-2009	1.7
United States, Edwards	28-Jul-2008	1.9
Argentina, Ministro Pistarini	20-Jan-2009	2.0
United States, Wheeler Sack	20-Feb-2009	2.0
United States, Wheeler Sack	10-Feb-2009	2.0
Iraq, Al Asad	26-Jan-2009	2.0
United States, San Clemente	29-Jan-2009	2.1
United States, Whidbey Island	22-Jan-2009	2.3
United States, El Centro	26-Jan-2009	2.5
Peru, Rodriguez Ballon	26-Jan-2009	2.5
Colombia, El Dorado	18-Aug-2008	2.6
Bolivia, Jorge Wilsterman	18-Jan-2009	2.7
United States, Whidbey Island	1-Feb-2009	3.0
United States, China Lake	21-Sep-2008	3.9
Peru, Las Palmas	16-Jan-2009	4.0
Oman, Masirah Island	21-Jan-2009	4.1
United States, Barking Sands	30-Jul-2008	4.3
United States, Nellis	29-Jul-2008	4.4
Namibia, Hosea Kutako	24-Jan-2009	4.8
United States, El Centro	23-Feb-2009	4.8
Moldova, Chisinau	22-Jan-2009	4.9
Iraq, Baghdad	18-Aug-2008	5.2
United States, Fallon	16-Jan-2009	5.4
Philippines, Mactan	19-Jan-2009	5.7
Marshall Islands, Bucholz	24-Jan-2009	6.2
United States, Kaneohe Bay	28-Jan-2009	7.1
Morocco, Sale	21-Jan-2009	7.1

Estimated Mono CE90 = 6.1 m

Radarsat-2 UltraFine Imaging Mode Evaluation Results
(Physical Sensor Model Data)

Radarsat-2 UltraFine Images

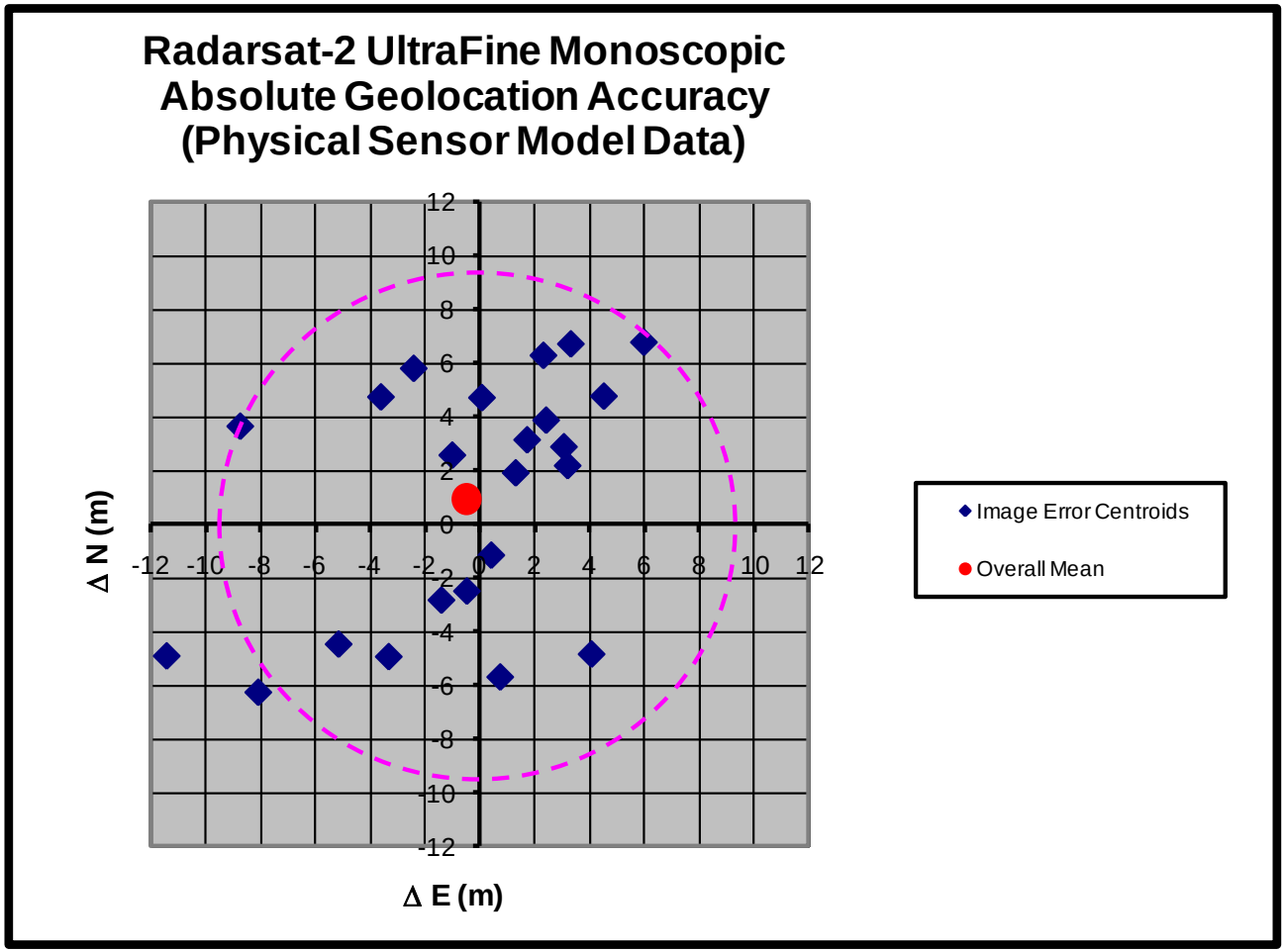
Horizontal Errors (n=23)

Test Site	Collection Date	CPs	Product ID	Δ E (m)				Δ N (m)				Δ r (m)	RMS (m)		
				Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max		Δ E	Δ N	Δ r
Bolivia, Jorge Wilsterman	18-Jan-2009	4	PK126342	1.3	1.1	-0.1	2.3	1.9	0.7	1.0	2.5	2.3	1.6	2.0	2.6
Colombia, El Dorado	16-Jan-2009	2	PK126340	4.6	0.1	4.5	4.6	4.7	1.0	4.0	5.5	6.6	4.6	4.8	6.6
Iraq, Al Asad	19-Jan-2009	7	PK126335	1.8	0.9	0.1	3.0	3.1	0.7	2.5	4.4	3.6	2.0	3.2	3.7
Iraq, Baghdad	21-Jan-2009	3	PK126336	-3.3	0.3	-3.6	-3.1	-5.0	0.5	-5.4	-4.5	6.0	3.3	5.0	6.0
Japan, Kadena	27-Jul-2008	7	PK127087	-5.1	0.7	-6.1	-4.4	-4.5	0.8	-5.9	-3.7	6.8	5.2	4.6	6.9
Marshall Islands, Bucholz	17-Jan-2009	5	PK126332	-8.0	0.7	-8.9	-7.2	-6.3	0.8	-7.6	-5.5	10.2	8.1	6.3	10.3
Moldova, Chisinau	21-Jan-2009	13	PK126330	2.5	1.1	0.6	4.0	3.8	0.9	1.3	5.5	4.6	2.7	3.9	4.8
Morocco, Sale	16-Jan-2009	3	PK126328	6.0	0.7	5.2	6.6	6.7	0.9	5.8	7.6	9.0	6.0	6.8	9.1
Oman, Masirah Island	14-Jan-2009	9	PK126324	3.2	0.9	2.2	4.7	2.1	1.0	0.6	3.8	3.9	3.3	2.3	4.1
Pakistan, Shabaz	14-Jan-2009	5	PK126281	-8.7	1.0	-10.0	-7.4	3.6	0.9	2.9	5.1	9.4	8.7	3.7	9.5
Peru, Las Palmas	23-Jan-2009	3	PK126279	-11.4	0.4	-11.9	-11.0	-4.9	1.0	-5.9	-3.9	12.4	11.4	5.0	12.4
Peru, Rodriguez Ballon	19-Jan-2009	4	PK126278	0.1	0.9	-0.9	1.3	4.7	1.0	4.0	6.2	4.7	0.8	4.8	4.8
Philippines, Mactan	18-Jan-2009	4	PK126275	0.8	0.7	0.2	1.7	-5.7	0.8	-6.6	-4.8	5.8	1.0	5.8	5.9
United States, Edwards	19-Jan-2009	12	PK113512	3.4	1.3	0.8	5.6	6.7	1.1	4.7	8.2	7.5	3.6	6.8	7.7
United States, El Centro	30-Jan-2009	10	PK113524	-0.4	0.8	-1.4	0.9	-2.5	0.9	-3.9	-1.3	2.6	0.9	2.7	2.8
United States, Fallon	19-Jan-2009	3	PK113513	4.1	0.9	3.4	5.2	-4.9	0.9	-5.8	-4.1	6.4	4.2	4.9	6.5
United States, Kaneohe Bay	30-Jan-2009	5	PK113522	-3.6	1.0	-4.8	-2.5	4.7	1.1	3.5	6.4	5.9	3.7	4.8	6.1
United States, New River	18-Jan-2009	9	PK113511	3.1	1.5	0.3	5.8	2.8	1.5	1.0	4.6	4.2	3.4	3.2	4.7
United States, San Clemente	16-Jan-2009	7	PK113510	0.5	1.4	-1.4	2.2	-1.2	1.2	-2.2	1.3	1.3	1.4	1.7	2.1
United States, San Diego	5-May-2009	3	PK126274	-1.0	0.2	-1.2	-0.8	2.5	0.1	2.4	2.6	2.7	1.0	2.5	2.7
United States, Twentynine Palms	30-Jan-2009	10	PK113523	-1.4	0.8	-2.6	-0.4	-2.9	1.0	-3.9	-1.0	3.2	1.6	3.0	3.4
United States, Wheeler Sack	3-Feb-2009	9	PK113526	-2.4	1.3	-4.5	-0.1	5.8	1.4	4.3	7.7	6.2	2.7	5.9	6.5
United States, Wheeler Sack	27-Feb-2009	8	PK113530	2.4	1.2	0.3	3.7	6.3	1.4	4.5	8.0	6.7	2.6	6.4	6.9

Mean (m)	-0.5	0.9	-1.7	0.6	0.9	0.9	-0.2	2.2	5.7	3.6	4.3	5.9
Std Dev (m)	4.5	0.4	4.4	4.7	4.5	0.3	4.4	4.7	2.7	2.7	1.6	2.6
Maximum (m)	6.0	1.5	5.2	6.6	6.7	1.5	5.8	8.2	12.4	11.4	6.8	12.4
Minimum (m)	-11.4	0.1	-11.9	-11.0	-6.3	0.1	-7.6	-5.5	1.3	0.8	1.7	2.1

Radarsat-2 UltraFine Images

Horizontal Errors (n=23)



Radarsat-2 UltraFine Images

Horizontal Accuracy (n=23)

Test Site	Date	Sorted Δ r (m)
United States, San Clemente	16-Jan-2009	1.3
Bolivia, Jorge Wilsterman	18-Jan-2009	2.3
United States, El Centro	30-Jan-2009	2.6
United States, San Diego	5-May-2009	2.7
United States, Twentynine Palms	30-Jan-2009	3.2
Iraq, Al Asad	19-Jan-2009	3.6
Oman, Masirah Island	14-Jan-2009	3.9
United States, New River	18-Jan-2009	4.2
Moldova, Chisinau	21-Jan-2009	4.6
Peru, Rodriguez Ballon	19-Jan-2009	4.7
Philippines, Mactan	18-Jan-2009	5.8
United States, Kaneohe Bay	30-Jan-2009	5.9
Iraq, Baghdad	21-Jan-2009	6.0
United States, Wheeler Sack	3-Feb-2009	6.2
United States, Fallon	19-Jan-2009	6.4
Colombia, El Dorado	16-Jan-2009	6.6
United States, Wheeler Sack	27-Feb-2009	6.7
Japan, Kadena	27-Jul-2008	6.8
United States, Edwards	19-Jan-2009	7.5
Morocco, Sale	16-Jan-2009	9.0
Pakistan, Shabaz	14-Jan-2009	9.4
Marshall Islands, Bucholz	17-Jan-2009	10.2
Peru, Las Palmas	23-Jan-2009	12.4

Estimated Mono CE90 = 9.6 m

Test Site	Date	Sorted RMS (m)
United States, San Clemente	16-Jan-2009	2.1
Bolivia, Jorge Wilsterman	18-Jan-2009	2.6
United States, San Diego	5-May-2009	2.7
United States, El Centro	30-Jan-2009	2.8
United States, Twentynine Palms	30-Jan-2009	3.4
Iraq, Al Asad	19-Jan-2009	3.7
Oman, Masirah Island	14-Jan-2009	4.1
United States, New River	18-Jan-2009	4.7
Moldova, Chisinau	21-Jan-2009	4.8
Peru, Rodriguez Ballon	19-Jan-2009	4.8
Philippines, Mactan	18-Jan-2009	5.9
Iraq, Baghdad	21-Jan-2009	6.0
United States, Kaneohe Bay	30-Jan-2009	6.1
United States, Fallon	19-Jan-2009	6.5
United States, Wheeler Sack	3-Feb-2009	6.5
Colombia, El Dorado	16-Jan-2009	6.6
Japan, Kadena	27-Jul-2008	6.9
United States, Wheeler Sack	27-Feb-2009	6.9
United States, Edwards	19-Jan-2009	7.7
Morocco, Sale	16-Jan-2009	9.1
Pakistan, Shabaz	14-Jan-2009	9.5
Marshall Islands, Bucholz	17-Jan-2009	10.3
Peru, Las Palmas	23-Jan-2009	12.4

Estimated Mono CE90 = 9.7 m

Questions?

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