



Accuracy Evaluation

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ERDAS, Inc.
2801 Buford Highway, NE, Suite 300
Atlanta, Georgia 30329-2137 USA

Phone: 404/248-9000
Fax: 404/248-9400
www.erdas.com
User Support: 404/248-9777

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Introduction

This document details testing and accuracy evaluation performed using the IMAGINE StereoSAR DEM module. You may find the conclusions helpful in processing your own work.

The accuracy and precision of the IMAGINE StereoSAR DEM software was determined using RADARSAT imagery from three areas, all in California. These were Death Valley, Orange County (South of Los Angeles), and Camp Roberts (Coalinga area). Truth DEMs were prepared by creating mosaics from USGS 30 m DEMs.

Overall Accuracy

Overall Accuracy	Mean	StdDev	LE90 ¹	LE80	Rel. LE90
Death Valley	+16	70	82	54	81
Orange County	-20	31	55	38	45
Camp Roberts	-23	40	74	57	61

1 See "DEM Evaluation Metrics" on page 10 for an explanation of LE90, LE80 and Rel. LE90.

- Results are highly reproducible to within +/- 3 m.
- The parallax filters appear to be doing the correct amount of filtering, and the output DEMs do not require noise reduction.
- The automatic correlation software and .ssc library are extremely robust. This allows use of image pairs with large intersection angles which increases accuracy. While selection of correlation parameters (.ssc files) does affect the accuracy of the final DEM, the effect is reasonable.



The .ssc files provided with the IMAGINE StereoSAR DEM module are located in the <IMAGINE_HOME>/etc/correlators directory, where <IMAGINE_HOME> is the location of ERDAS IMAGINE on your system.

Truth DEMs

For each test area, 30 to 50 USGS 7.5 minute digital elevation model (DEM) files (purchased from USGS Denver) were mosaicked into the truth DEMs. As received, these DEMs were variable in format. While most were in UTM WGS 72 projection, some were in UTM Clark 1866. Most DEMs were in meters, but a few were in feet and required conversion.

In addition, six quads were selected with easily located features. The 30 m DEM quads were compared with the paper quad sheets to verify that elevations were correct and consistent. The USGS quad sheets have a horizontal datum of NAD27 with a vertical datum of NGVD-29. Comparison of elevations on USGS quad sheets with the USGS DEM elevations found them to be in good agreement.

Each DEM created by IMAGINE StereoSAR DEM was compared separately to both the entire USGS DEM mosaic and to each of the six selected and verified DEM quads. The results from comparison to the six digital quads were averaged and compared to the full scene statistics.



IMAGINE StereoSAR DEM

Beam Mode Selection

Final accuracy and precision of the DEM produced by the IMAGINE StereoSAR DEM module is predicated on two separate calculation sequences. These are automatic image correlation and the sensor position/triangulation calculations. These two calculation sequences are joined in the final step: Height. The two initial calculation sequences have disparate beam mode demands.

Automatic correlation works best with images acquired with as little angular divergence (intersection angle) as possible. This is because different imaging angles produce different-looking images, and the automatic correlator is looking for image similarity. For the same reason, images taken at different times can be hard to correlate. For example, images taken of agricultural areas during different seasons can be extremely different and, therefore, difficult or impossible for the automatic correlator to process successfully.

Conversely, the triangulation calculation is most accurate when there is a large intersection angle between the two images. To quantify the effect of intersection angle and automatic correlation on the resultant DEM, the StereoSAR Stereo Solutions Tool was used. For a number of image pairs, the effect of one pixel of mismatch (in either X or Y) on the resultant height calculation was determined.



For more information on the StereoSAR Stereo Solutions Tool, see "CHAPTER 4: IMAGINE StereoSAR DEM™ Tour Guide" of the IMAGINE Radar Mapping Suite Tour Guide.

Intersection Angle and Automatic Correlation Effects

		Change in Calculated Elevation per Parallax Pixel	
Beam Pair	Intersection Angle	Range Pixel	Azimuth Pixel
F2/F4	4.0 Deg.	50.0 m	3.0 m
S3/S5	5.5 Deg.	48.5 m	0.1 m
S5/S7	8.0 Deg.	31.0-36.0 m	1.5 m
S3/S6	10.0 Deg.	40.0-54.0 m	3.0 m
S1/S3	10.0 Deg.	15.0 m	0 m
S4/S7(SLC)	10.0 Deg.	49.0 m	
S3/S7	13.5 Deg.	17.0-22.0 m	.25 m
S1/S6	20.0 Deg.	10.5 m	.30 m

In practice, an intersection angle of 10 to 20 degrees is an acceptable compromise. A stereopair consisting of a RADARSAT S3 or S4 image and an S6 or S7 image meets these criteria.

Death Valley

This data set consists of an S1/S6 stereopair. As noted in the table above, this results in a very favorable geometry, but since the images are quite different, it is harder for the automatic correlator to match them. The correlator file STD_HP_LF_2.ssc was designed around this data pair.





The *STD_HP_LF_2.ssc* correlator is located in the *<IMAGINE_HOME>/etc/correlators* directory, where *<IMAGINE_HOME>* is the location of ERDAS IMAGINE on your system.

This is a difficult test area because the terrain has very high local relief, which causes significant layover-induced differences in the images to be matched. In addition, there are very few cultural or natural features, thus the automatic correlator has scant detail to lock on to, particularly with small correlation windows. For these reasons, the Death Valley data set was considered the primary data set for testing and refinement of the automatic correlation software.

GCPs for this data set were collected using the data and images on the Harris DEM Fly-Off CD¹. Four (4) points were found on the available images which could also be identified on the CD. The GPS-derived control tabulated on the CD was then used. These WGS 84 elevations differ from the USGS NAD27/29 elevations in being 28 +/-1 m lower. This is consistent with published conversion tables.

Analytical Summary

							Absolute		Rel.
Data set	Platform	Min	Max	Mean	Med	StdDev	LE90	LE80	LE90
DV S1/S6	SUN	-820	782	15.1	17	71.5	82	53	81
6 Quad Ave	SUN	-159	149	19.7	18	28.7	60	44	42

DEM Comparison Between Platforms

	Min	Max	Mean	Med	StdDev
NT minus W95	-136	253	-0.5	0	9.4
NT - NT (total rerun)	-488	212	2.4	9	58.0
DEC minus DEC	-239	97	2.9	2	10.0
SUN minus DEC	-248	124	0.7	1	10.1
SUN minus DEC (rerun)	-146	127	-1.9	-2	10.6

Death Valley Conclusions

- Overall accuracy mean equals +15 m +/- 72 m, LE90 equals 82 m LE80 equals 53 m, Rel. LE90 equals 81 m.
- Results are highly reproducible to within +/- 3 m.

1. The Harris CD was obtained in conjunction with the *DOD Utility of RADARSAT Data Elevation Extraction Study*, compiled by Lockheed Martin and the National Imagery and Mapping Agency, et al. March 1997.

IMAGINE StereoSAR DEM

- The high full scene LE90 (82 m) is due to some areas of poor results (i.e., Grotto Cyn), while the basal accuracy (6 quad averages of 60 m) is similar to scenes such as Orange County that have no major relief. Upon inspection, temporal differences are noted in the two Death Valley scenes that preclude good correlation. Also, areas of extreme relief can look very different due to foreshortening effects. This is a penalty of the S1/S6 stereopair.
- Results for the 90 m DEM are identical to the 30 m DEM results. Since the USGS 90 m DEMs are allegedly degraded versions of the 30 m DEMs, this is reasonable. The fact that the standard deviation is identical suggests that the parallax filters are doing their job, and the increased degrade to the 90 m DEM is not required to suppress noise.

Orange County, Los Angeles

This data set consists of a complete S1-S7 image series. For the accuracy analysis, the S3/S7 and S3/S5 pairs were selected. These scenes were very easy to automatically correlate, and several of the .ssc correlator files produced good results.

GCPs were taken from 1:24,000 USGS quad sheets. A geoid correction of -33 m was applied to convert the ground control elevations to WGS84.

Analytical Summary

Data set	Min	Max	Mean	Med	StdDev	Absolute		Rel.
						LE90	LE80	LE90
6 Quad Ave S3/S7	-182	113	-26.1	-21	28.3	57	41	38
Full Scene S3/S7	-349	234	-19.2	-16	30.9	55	38	45
Full Scene S3/S5	-490	240	-83.1	-85	86.9	197	161	136

DEMs are generated using two .ssc correlators. These DEMs are then differenced with the following results.

Effect of Different Correlators

	Min	Max	Mean	StdDev
STD_HPHF-STD_LPHF (NT)	-125	235	13.7	24.6
STD_HPLF-STD_LPLF (SGI)	-87	199	11.0	20.4

DEM Comparison Between Platforms

Platforms	Min	Max	Mean	Med	StdDev
SUN minus NT	-10	15	-.05	0	0.4
SUN minus SGI	-7	6	-.05	0	0.4
SGI minus NT	-10	15	.01	0	0.3

DEM Comparison Between Platforms

Platforms	Min	Max	Mean	Med	StdDev
SUN minus DEC	-9	15	-.05	0	0.3
SUN minus W95	-92	233	.90	1	6.8
SUN minus W98	-17	23	-.06	0	0.4

**Orange County
Conclusions**

- Overall accuracy mean equals -19 m +/-31 m, LE90 equals 55 m, LE80 equals 38 m, Rel. LE90 equals 45 m.
- Use of different correlators does result in a small (10-15 m) variance in the resultant DEM. This error is a significant percentage of the total error, but corresponds to less than 1 pixel of change in calculated elevation per parallax pixel.
- The quad averages and the full scene have nearly identical results, which suggests that the entire image was uniformly correlated.
- The LE90 results of the S3/S5 stereopair versus the S3/S7 stereopair supports the suggestion of an incidence angle greater than 10 degrees.

Camp Roberts, Coalinga, California

This data set consists of an S4/S7 SLC stereopair. This is exactly the data set used in the Harris report. Ground control is taken directly from the Harris CD.

Effect of Different Correlators

Correlators	Min	Max	Mean	Med	StdDev
HPLF STD-Fine (NT)	-300	515	-7.4	-5	27.5
HPLF STD-Fine (SUN)	-357	1101	-6.8	-3	27.2
Fine (SUN) - STD (SGI)	-188	271	6.9		20.1
Degrade3-Deg2 (SUN)	-116	89	-0.1	0	7.2

Analytical Summary

Data set	Min	Max	Mean	Med	StdDev	Absolute		Rel.
						LE90	LE80	LE90
Full Scene SUN WGS72	-288	571	-19.1	-19	41.7	74		
SUN WGS72	-293	167	-27.5	-27	39.1	76	59	62
Degrade2 SUN WGS72	-304	184	-27.4	-27	40.6	78	61	
Fine_HPLF SUN WGS72	-284	216	-21.0	-21	38.1	70	54	60
Fine_HPLF SUN WGS84	-282	218	-19.0	-19	38.1	69	52	61
Average of Above			-22.8		39.5	73	57	61
6 Quad Ave SUN	-205	158	-19.3	-19	39.7	76		
6 Quad Ave SUN	-194	113	-29.4	-27	36.2	79	62	59
Fine_HPLF SUN	-183	129	-22.4	-21	36.2	72	57	57

Camp Roberts Conclusions

- Overall accuracy mean equals -23 +/- 40 m, LE90 equals 73 m, LE80 equals 57 m, Rel.LE90 equals 61 m.
- Harris AOI accuracy mean equals -19 +/- 33 m, LE90 equals 61 m, LE80 equals 48 m, Rel. LE90 equals 52 m.
- The six quad averages and the full scene have nearly identical results, which suggests that the entire image was uniformly correlated.
- Using a degrade factor of 2 prior to the final DEM calculation is slightly less accurate than a factor of 3 due to the larger standard deviation. This suggests that the parallax filters are adequate and this final degrade is appropriate.
- Using the Fine correlator yields slightly better results. This is reasonable as this SLC data set has smaller pixels than a Standard data set.

- We achieved better accuracy by outputting the DEM as WGS84 and converting the USGS DEM to WGS84 than by outputting the DEM as WGS72 and using the USGS DEM as is.
- Use of different correlators results in an extremely small (<7 m) variance in the resultant DEM. This speaks very highly for the automatic correlation algorithm and correlator parameter library (.ssc files).

Final Conclusions

- Results are highly reproducible to within +/- 3 m.
- The parallax filters appear to be doing the correct amount of filtering, and the output DEMs require no noise reduction.
- The automatic correlation software and .ssc library are extremely robust. This allows use of image pairs with large angular separation which increases accuracy. While selection of correlation parameters (.ssc file) does affect the accuracy of the final DEM, the effect is not unacceptably large.
- An incidence angle of at least 10 degrees is required for accurate results.

Tips for Accurate Work

- Select images with minimal temporal variation.
- Select image pairs with large intersection angles.
- The final accuracy of the output DEM is greatly affected by the sensor position modeling. While input data ephemeris can be sufficiently accurate, there is no *a priori* way of determining this. If an accurate GCP is available, use it.
- The IMAGINE StereoSAR DEM sensor model is based on a WGS84 Ellipsoid. All GCPs used to refine the sensor orbit must be relative to this datum for maximum accuracy. Similarly, the output DEM is relative to the WGS84 Ellipsoid Datum and must be converted to the desired vertical datum.
- Despeckle both images with a small (3 × 3) moving window.
- Accurately register the images using numerous tie points well-distributed around the images. Be sure to emphasize the highest and lowest elevations as these determine the minimum and maximum parallax which are used to define the correlation parameters.
- Using the Minimum and Maximum for the X and Y Shift (from the **Register** step), modify one of the correlator parameter files (.ssc) such that the lowest Level in the hierarchy (usually 6 or 8) covers a slightly larger search range. Modify the search range in the higher levels to effect a smooth transfer of parallax values between levels. Save this as the correlator parameter file for this data set.



Do not modify the ERDAS IMAGINE .ssc library. (This is important on PCs that may allow altering of ERDAS IMAGINE data files.)

- It may prove worthwhile to try several of the ERDAS IMAGINE Quick Test (-QT.ssc) correlator parameter files first to aid in selecting the most appropriate correlator for a specific data set.



IMAGINE StereoSAR DEM

- Visual inspection of the intermediate parallax layers indicates at which level holes or imperfections first appear in the parallax image. This allows intelligent modification of the .ssc file to eliminate the holes. Note that once they appear at a certain parallax level, they are not usually removed at subsequent levels. They can only be removed by modifying the correlator parameter file.
- Use a degrade value that averages the DEM to slightly larger than your intended posting. A degrade factor of 3 has been found optimal with RADARSAT Standard Beam imagery producing a 30 m output pixel DEM.



See "CHAPTER 3: IMAGINE StereoSAR DEM™ Application" in the *Radar Mapping Suite Tour Guide* for more information.

DEM Evaluation Metrics

LE90 or LE80

The designations LE90 (linear error 90%) and LE80 (linear error 80%) are used to quantify the elevation error in a DEM versus the real world or truth DEM. At every point within the DEM in question, there is an elevation error: maybe 1 m, maybe 7 m, maybe -32 m. LE90 is the error range which would include 90% of the pixels within the DEM. Thus, an LE90 of 50 indicates that 90% of the pixels within the DEM vary from the truth by 50 m or less. LE80 gives the error range of 80% of the pixels.

Absolute LE90 is defined as the LE90 calculation for the DEM with no corrections applied. The error includes the effects of position and elevation inaccuracies. As discussed above, this is the value most applicable to real-world scenarios where horizontal or vertical correction values and truth DEMs are not available.

Relative LE90 is a measure of the error in the surface shape of the DEM. It is calculated by correcting the output DEM for its mean error prior to LE90 calculation.

CE90

The designation CE90 (circular error 90%) is a measure of the combined errors in latitude and longitude of the test DEM. CE90 is a circular radius in meters, which would include 90% of the positional errors of the test DEM versus the truth DEM. Visualize a target at which you fired 100 shots at the bull's-eye. How large of a circle would you have to draw on the target to enclose the closest 90 shots? The radius of that circle is your CE90 as a marksman.

