An Evaluation of the TOPSAR Topographic SAR Interferometer Performance

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TOPSAR EVALUATION EXPERIMENTS 1991

- Across-track interferometric SAR data were acquired over Ft. Irwin, California, and Walnut Gulch near Tombstone, Arizona.
- Radar derived rectified height maps were generated using an integrated processor including SAR processing, interferometric processing, and geometric rectification
- Ft. Irwin data were evaluated by comparison to a USGS DEM with 30 m horizontal pixel spacing and 7 m vertical accuracy. The resulting difference map had a 5.5 m standard deviation
- Walnut Gulch data were evaluated by comparison to a DEM provided by the U.S. Agricultural Department. This DEM had a 40 m horizontal pixel spacing and a photogrammetric accuracy of 0.5 m. Some errors in the reference were apparent. The resulting difference map had a 3.6 m standard deviation

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THE FT. IRWIN NATIONAL TRAINING CENTER EXPERIMENT 1992

- Sponsored by DARPA JPL collected data over the Army National Training Center (NTC), Ft. Irwin, California on July 8th, 1992
- 3 TOPSAR data sets were acquired. Two east-west opposite side mapping tracks, and one north to south track
- 10 corner reflectors deployed by JPL. Corner reflectors surveyed by the Defense Mapping Agency (DMA) to centimeter accuracy using differential GPS
- Very accurate DEM developed by the Topographic Engineering Center (TEC) using digital correlation methods on 1:20,000 scale digitized photographs

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ANALYSIS APPROACH

- Evaluation based on standard TOPSAR product (run 1 & run 3) with 10 m pixel spacing (5 m product is also available).

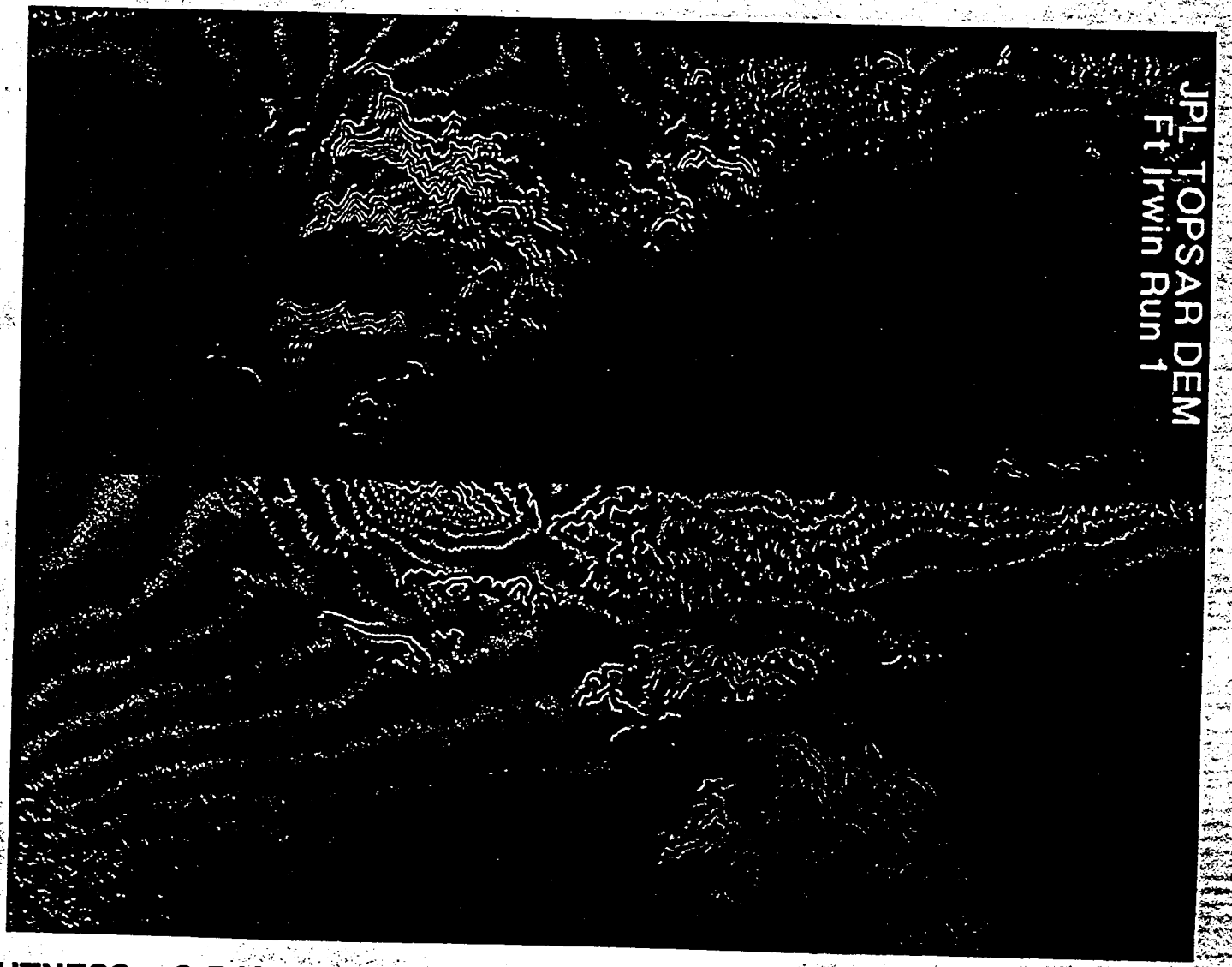
- Radar DEMs were co-registered to TEC DEM horizontally using corner reflectors. Azimuth, range scaling errors were determined and skew estimated.

- Vertical alignment were established using two different approaches:
  – by removing an azimuth slope, a range slope, and a height off-set based on corner reflector measurements
  – by removing azimuth, range slopes and height off-set that will match the TEC DEM in a least square error sense

- Height errors after re-sampling radar data to reference DEM were analyzed on a pixel to pixel basis. Mean, standard deviation, and standard deviation after rejection of 5 σ values were measured

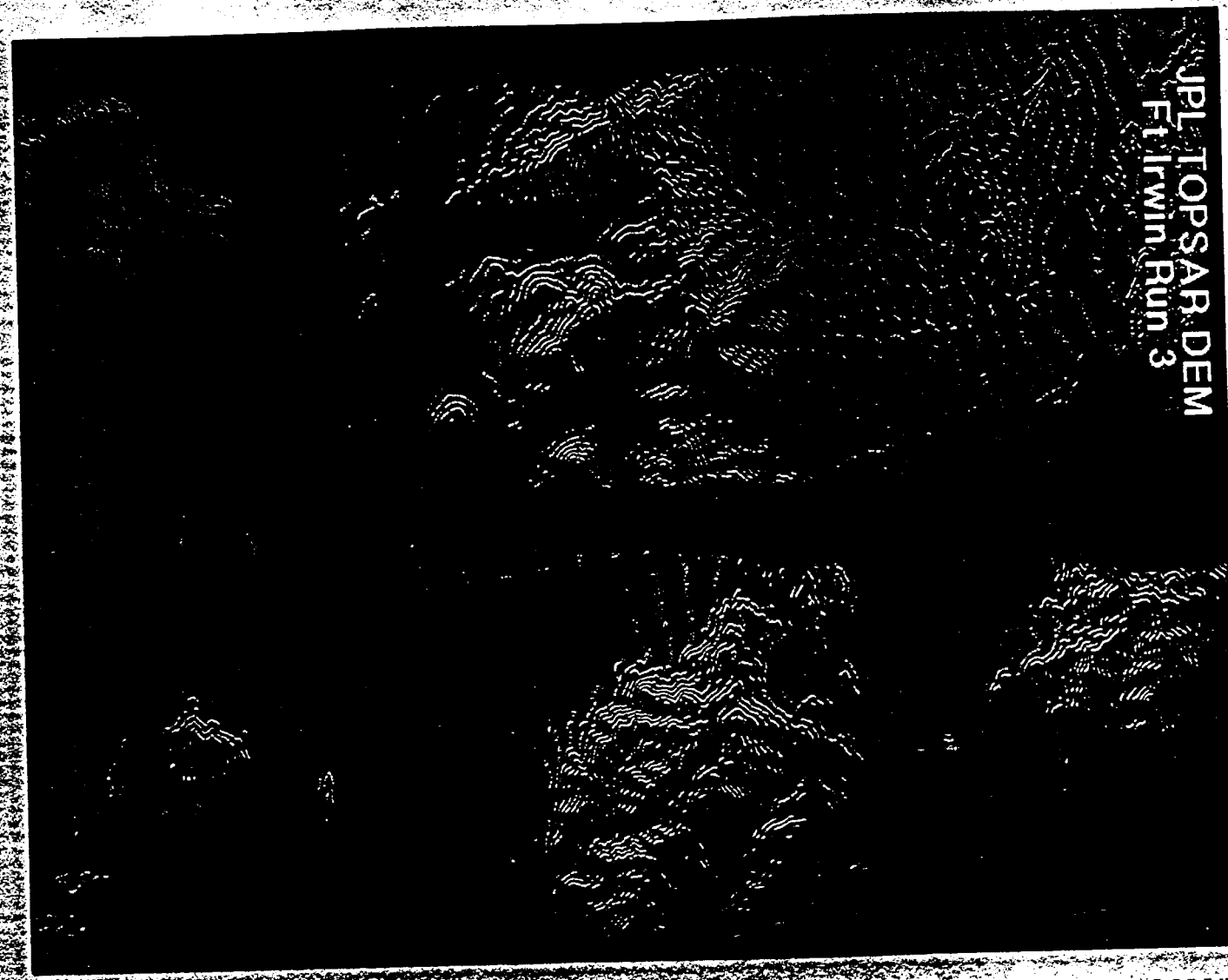
JPL TOPSAR DIGITAL ELEVATION MODEL

FT. IRWIN - NTC RUN 1 (6.5 X 30 KM)



BRIGHTNESS = C-BAND BACKSCATTER COLOR = HEIGHT, 2M/COLOR, 32M/REPEAT

JPL TOPSAR DIGITAL ELEVATION MODEL
FT. IRWIN - NTC RUN 3 (6.5 X 30 KM)



BRIGHTNESS = C-BAND BACKSCATTER COLOR = HEIGHT, 2M/COLOR, 32M/REPEAT

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HORIZONTAL ALIGNMENT TRANSFORMATION

- Transformation applied

$$\begin{pmatrix} x \\ y \end{pmatrix}_{\mathrm{DEM}} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} 1 & 0 \\ \gamma & 1 \end{pmatrix} \begin{pmatrix} \lambda_x & 0 \\ 0 & \lambda_y \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}_{\mathrm{TOPSAR}} + \begin{pmatrix} \delta x \\ \delta y \end{pmatrix}$$

- Transformation parameters

	RUN 1	RUN 3
Azimuth scale factor, λ_x	1.0033	0.9979
R ng scale factor, λ_y	1.0025	1.0036
Skew [radians]	$-2.2 \cdot 10^{-4}$	$(-2.5 \cdot 10^{-4})$
Rotation angle [degrees]	73.3	-16.8

- NTC RUN corner reflectors (4) consistent to 2.4 m in range and 0.8 m in azimuth

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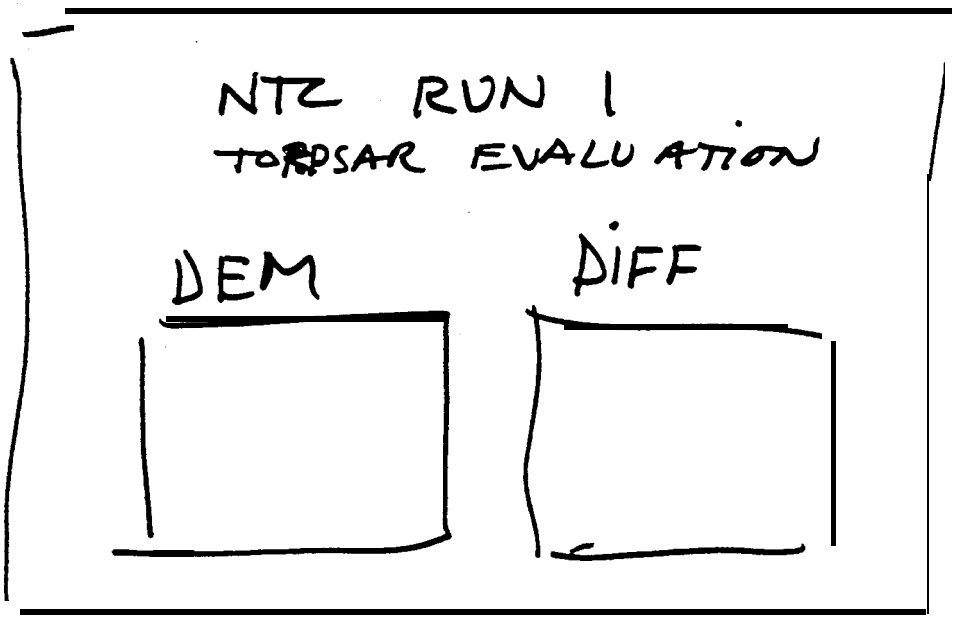
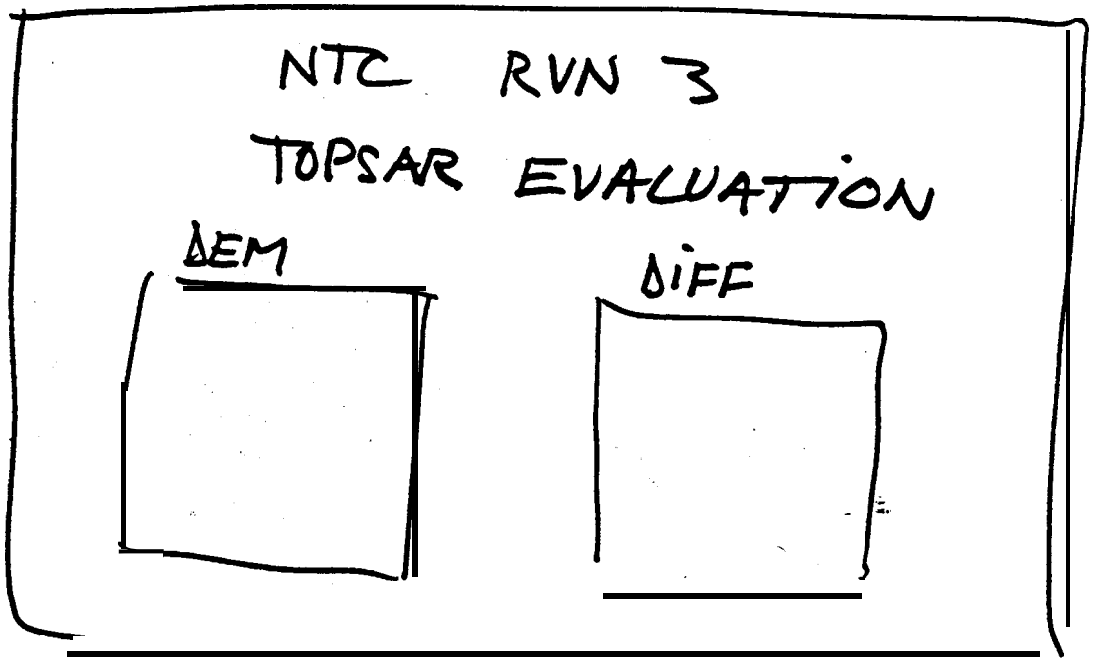
CORNER REFLECTOR BASED VERTICAL ALIGNMENT

	NTC RUN 1		NTC RUN 3	
	En	DEM	En	DEM
Azimuth tilt [mrad = m/km]		0.44		-0.27
Range tilt [mrad = m/km]		8.28		6.78
Horizontal off-set [m]		553.38		571.37
Std. deviation DEM		112.65		112.65
No. of Points		391891		389378
Std. deviation diff. [m]		2.07		3.01
Mean diff. [m]		-0.22		-1.40
5 sigma pts. rejected:				
#pts rejected		279		60
Std. deviation diff. [m]		1.96		2.99

COLOR PLATE 1



COLOR PLATE 3



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TEC DEM Based Vertical Alignment

NTC RUN 1	Entire DEM	Flat area	Mtn. area
Std. deviation DEM [m]	112.65	13.70	74.50
No. of Points	391891	10000	10000
Std. deviation diff. [m]	1.89	1.06	3.31
Mean diff. [m]	0.00	-0.40	1.30
5 sigma pts. rejected:			
#pts rejected	279	0	114
Std. deviation diff. [m]	1.76	1.06	2.25

NTC RUN 3	Entire DEM	Flat area	Mtn. area
Std. deviation DEM [m]	112.65	17.85	74.50
No. of Points	389378	10000	10000
Std. deviation diff. [m]	2.27	1.99	2.15
Mean diff. [m]	0.00	-0.92	-0.29
5 sigma pts. rejected			
#pts rejected	228	0	16
Std. deviation diff. [m]	2.23	1.99	2.02

JPL's TOPSAR ELEVATION DATA COMPARED TO TEC'S DEM (NTC)

JPL's FILE 1

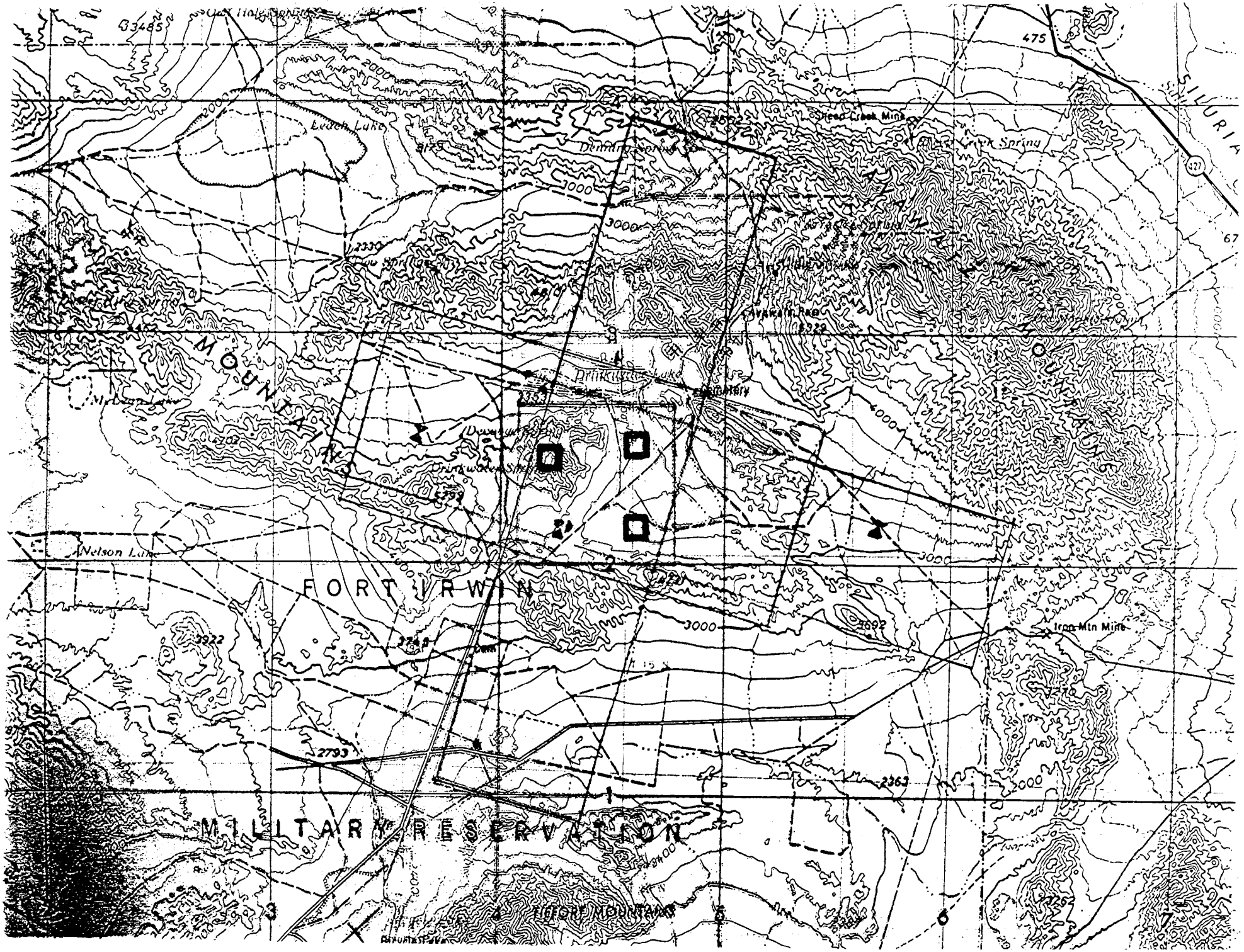
	RAW DATA	ADJUSTED FOR SLOPE ERROR	IGNORE ERRORS > 5 SIGMA	FLAT AREA	MTN AREA
NO PTS	391760	*	(-882)	77700	54400
MEDIAN	2.4m	*	1.7m	1.3m	2.2m
RMSE	3.3m	*	2.3m	1.5m	3.0m
RANGE	-28/+58m	-26/+59m	-12/+12m	-6/+5m	-17/+25m
AVERAGE	-1.3m	0	0	-0.8m	-0.7m
SIGMA	3.0m	2.4m	2.3m	1.3m	2.9m

JPL's FILE 3

	RAW DATA	ADJUSTED FOR SLOPE ERROR	IGNORE ERRORS > 5 SIGMA	FLAT AREA	MTN AREA
NO PTS	398000	*	(-346)	77700	54400
MEDIAN	9.2m	*	1.9m	1.9m	2.7m
RMSE	10.7m	*	2.5m	2.4m	3.7m
RANGE	-37/+35m	-31/+31m	-13/+13m	-11/+12m	-20/+31m
AVERAGE	-4.2m	0	0	+0.1m	+0.3m
SIGMA	9.8m	2.6m	2.5m	2.4m	3.7m

"RAW DATA".....Original elevations in overlap area rotated to WGS84 UTM system.
"ADJUSTED".....Raw Data transformed (leveled) by dz = ax + by + c.
"5-SIGMA".....Adjusted data without errors exceeding 5 times the sigma error.
"FLAT AREA".....A subset of the adjusted data was extracted from the flat area.
"MTN AREA".....A subset of the adjusted data was extracted from the mountainous area.
* FILE 1 slopes 0.8m per 1000m East, 0.2m per 1000m North.
* File 3 slopes 5.8m per 1000m East, 2.0m per 1000m North

COURTESY F. RAYE NORVELLE, TEC



Leach Lake
Sheep Creek Mine
Sheep Creek Spring
Avawatz Pass
Drinkwater Lake
Cemetery
Nelson Lake
FORT IRWIN
MILITARY RESERVATION
Iron Mtn Mine
TILFORD MOUNTAINS
SILURIA
MOUNTAINS
3000
2000
4000
5000
2330
3922
2793
2363
3692
475
3485

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ERROR SOURCES

Horizontal position errors:	Error Sources:
- Azimuth scale	Velocity bias (nav. system)
- Range scale	Baseline lenght Absolute phase ambiguity Slant range calibration
– Skew	velocity bias, processor
– Rubber sheet distortion	Mocomp = Nav. + Processor
– High frequency across-track	Signal-to-noise-ratio Impulse response (ISLR etc.) Channel co-registration

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ERROR SOURCES (2)

Vertical errors:	Error Sources:
– Azimuth tilt	Vertical velocity bias
– Range tilt	Attitude bias (in particular)
	Baseline orientation
	Absolute phase ambiguity
– Vertical off-set	Nav. system position
– Correlated height error	Mocomp = Nav. + Processor
	Multi-path
	Quantization errors
- High frequency random	Signal-to-noise-ratio
	Impulse response (ISLR etc.)
	Channel co-registration

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DISCUSSION

- Horizontal resolution, and accuracy requirements:
  – Registration errors on the order of 2 to 5 meter have been found to have a significant impact on the measured DEM error
  – In roughed terrain the horizontal positioning accuracy must be approximately equal to the required vertical DEM accuracy. Horizontal resolution is probably less critical by a factor 2–3
  – Processor resampling and regridding algorithms are critical!

- Absolute accuracy requirements:
  – Will additionally require state-of-the-art position, velocity and attitude; motion compensation processing, and atmospheric corrections

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DISCUSSION (2)

- Test/evaluation procedures and experiments:
  – IF-SAR potential for topographic mapping can only be assessed by carefully designed experiments
  – Sensor system effects must be studied separate y from targe interaction effects (volume scattering)
  – Roughed terrain with little or no vegetation is we suited for sensor system evaluation
  – State-of-the-art reference DEMs are required

- Calibration
  – Many parameters to calibrate. Several of them gives correlated errors
  – More work required on designing calibration procedures that wi determine individual parameters