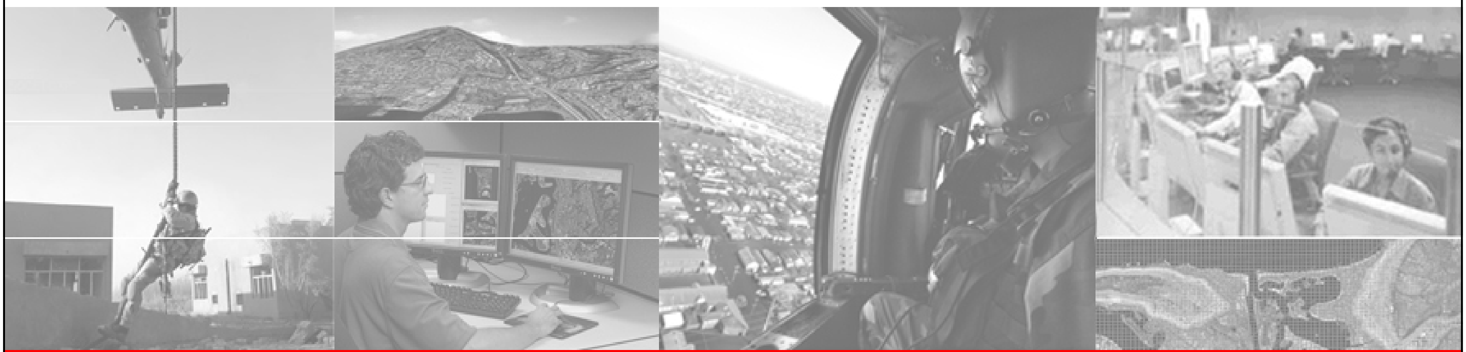
New Approaches to Generating and Processing High Resolution Elevation Data with Imagery

Kurt DeVenecia, Denver, USA
Stewart Walker, Bingcai Zhang, San Diego, USA

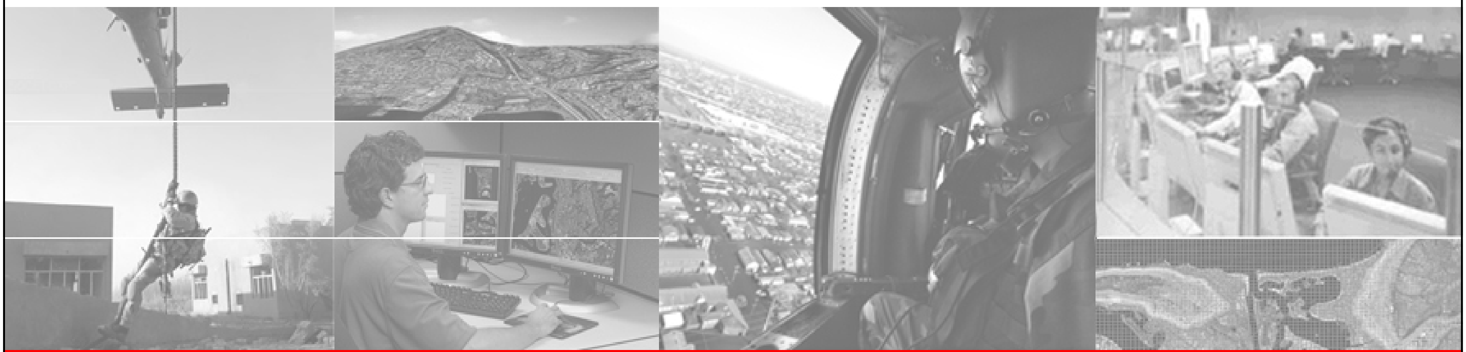


Outline

- Elevation generation in SOCET SET®
- Automatic Terrain Extraction (ATE)
  - Review
  - Recent developments
  - Examples
- Next-Generation Automatic Terrain Extraction (NGATE)
  - Principles
  - Case studies
  - Future developments
- Conclusions

Automatic Terrain Extraction (ATE)

Review, Recent Developments, and Examples

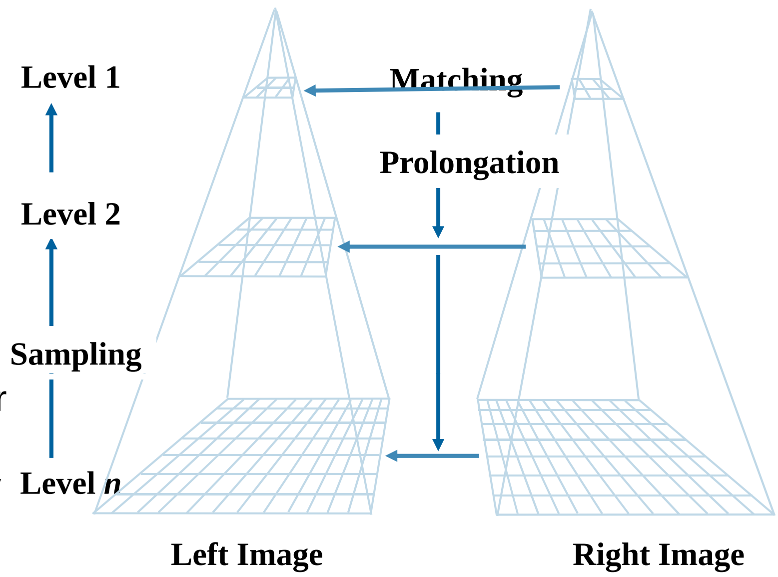


Elevation generation in SOCET SET

- Origins in DMA workstations in 1980s
- Improvements over 20 years, resulting in SOCET SET ATE module
  - Strategies
  - Adaptive ATE
  - Back-matching
  - Multi-image matching
  - Distributed computing
- Introduction of NGATE

ATE - mid to late 1980s

- ATE utilizing Hierarchical Relaxation Correlation (HRC)
  - Object based area matching with on-the-fly rectification
  - Normalized cross correlation
  - Strategy-based (terrain type)
    - 1D or 2D correlation
    - R-Sets
    - X-Parallax “pull-in”
    - Correlation cutoff
    - Signal power cutoff
    - Difference in signal power
    - Correlation function (curvature and secondary peaks)
    - Over-collect
    - Etc.



ATE - early to mid 1990s

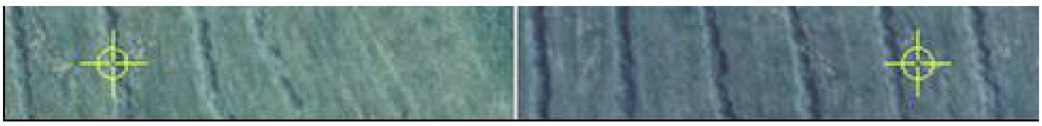
- Improvements
  - TIN or Grid output
  - Additional strategy items for per-pass and post-processing
    - Spikes and wells
    - Thinning
    - Obstruction identification
    - Smoothing
  - Incorporate manual edits and feature data
- Additional research including
  - Iterative Orthophoto Refinement (IOR)
  - Global Least Squares Matching (GLSM)

ATE - late 1990s to early 2000s

- Adaptive ATE (AATE)
  - Elimination of strategy selection
  - User interface allowing for determination of:
    - Smoothing level
    - Precision
    - Thinning
    - Break lines
  - Seed terrain

ATE – recent improvements

- ATE back-matching for blunder elimination in terrain — useful in flat areas with low contrast and bare-earth for trees



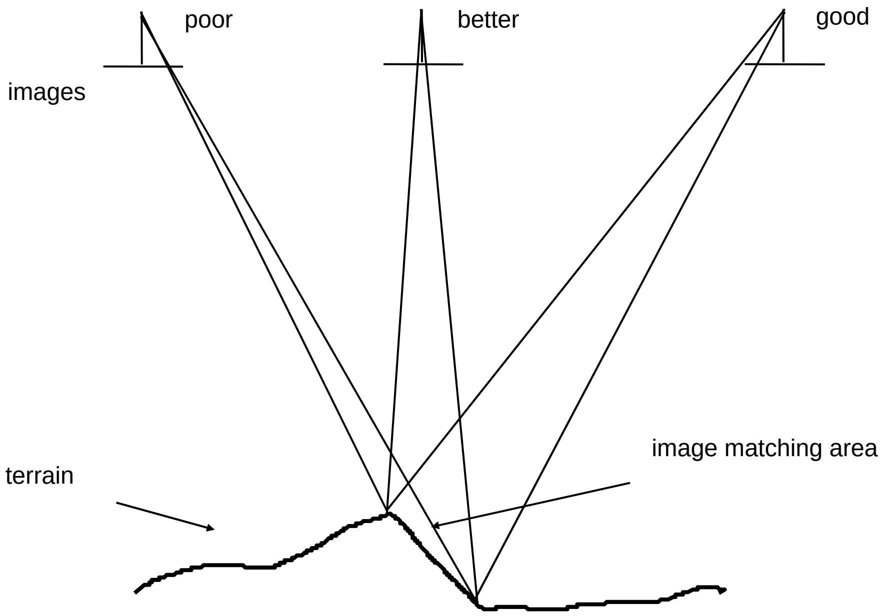
Left Image Window/Search

Right Image Search/Window

  - Correlation success depends on 100% forward and backward matching success, otherwise the point is rejected and subsequently interpolated from surrounding good elevations

ATE – recent improvements ... 2

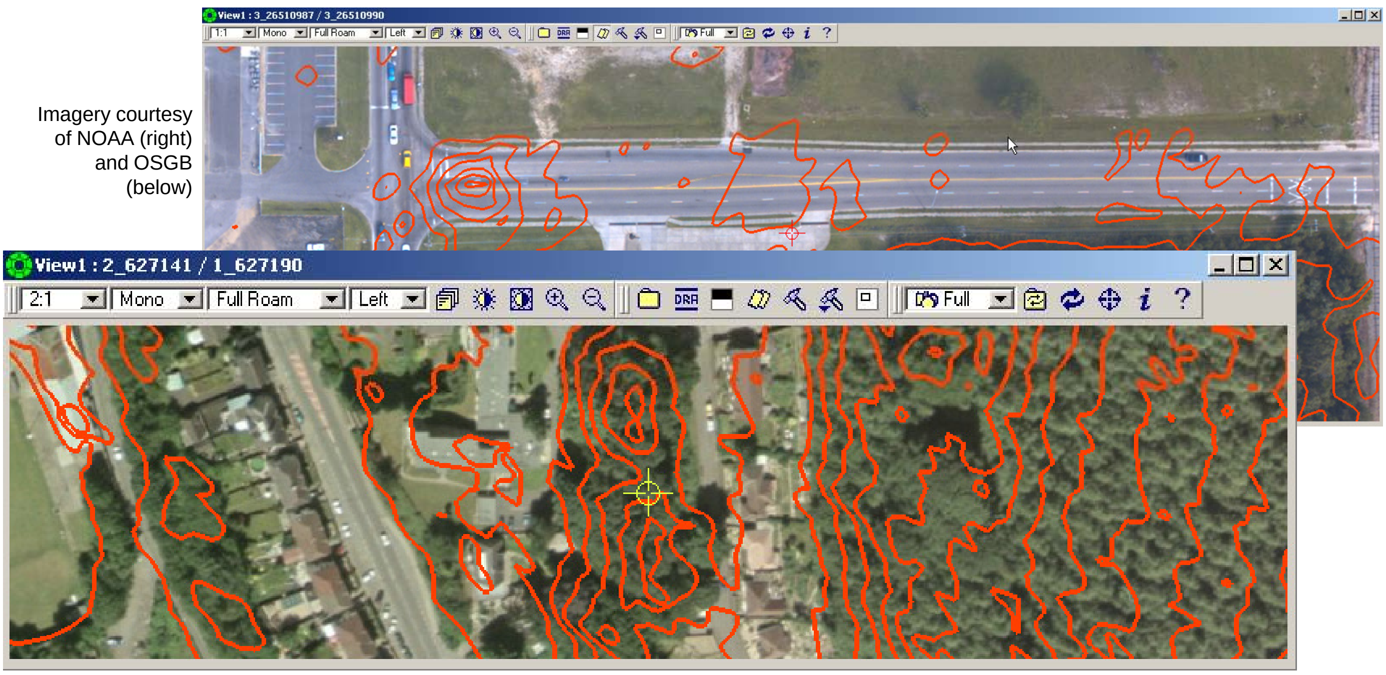
- ATE multi-pair matching option for measuring terrain in occluded areas



ATE – examples of recent improvements... 1

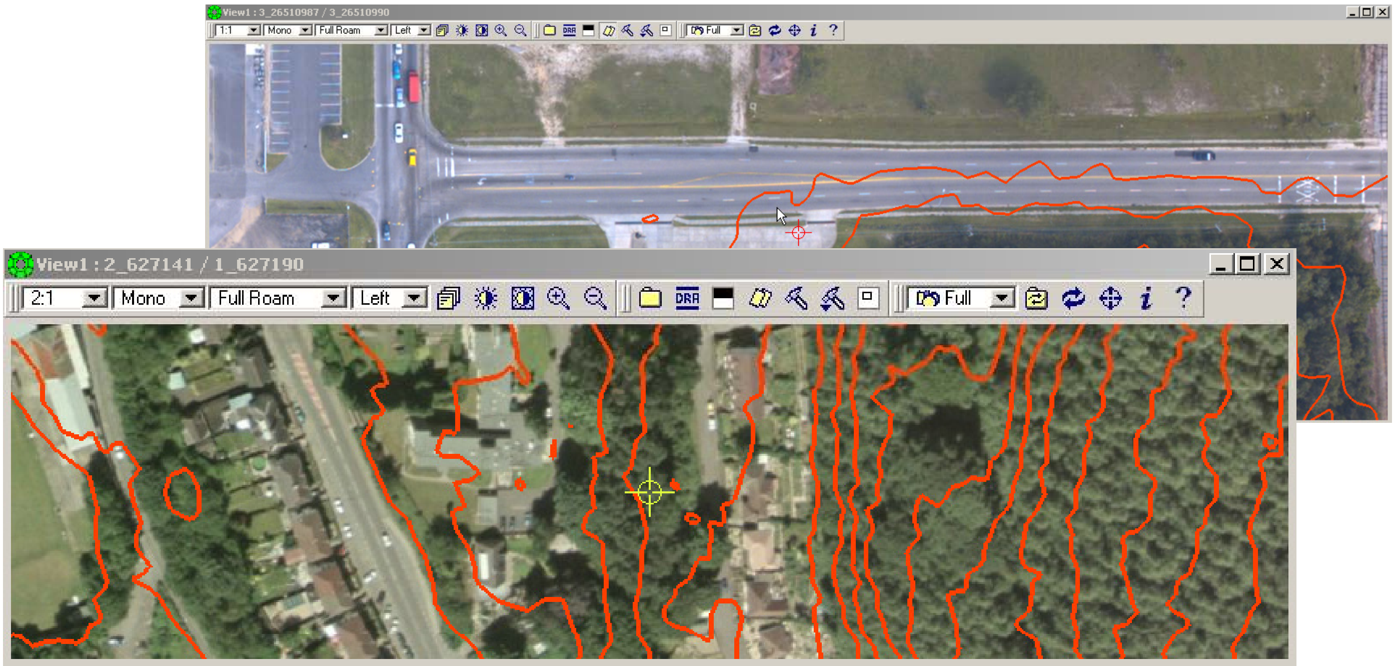
- Raw Adaptive ATE results

Imagery courtesy of NOAA (right) and OSGB (below)



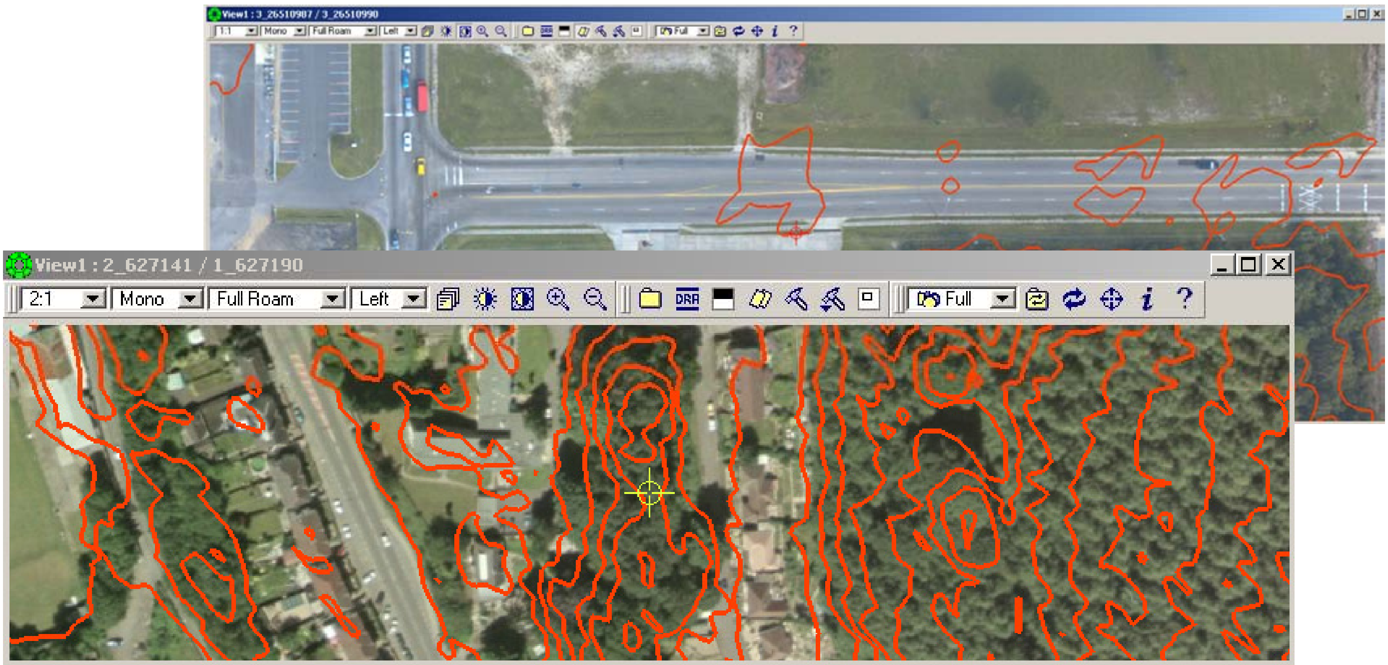
ATE – examples of recent improvements... 2

- Back-matching



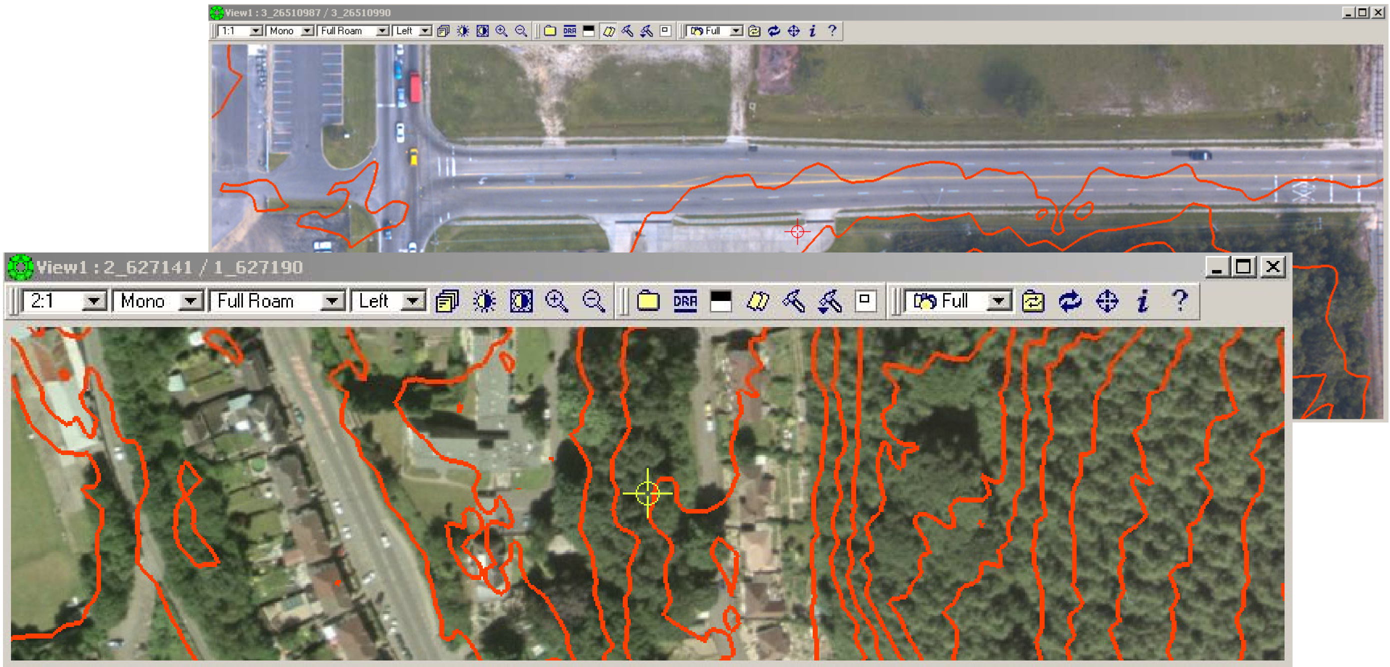
ATE – examples of recent improvements... 3

- Multi-pair matching



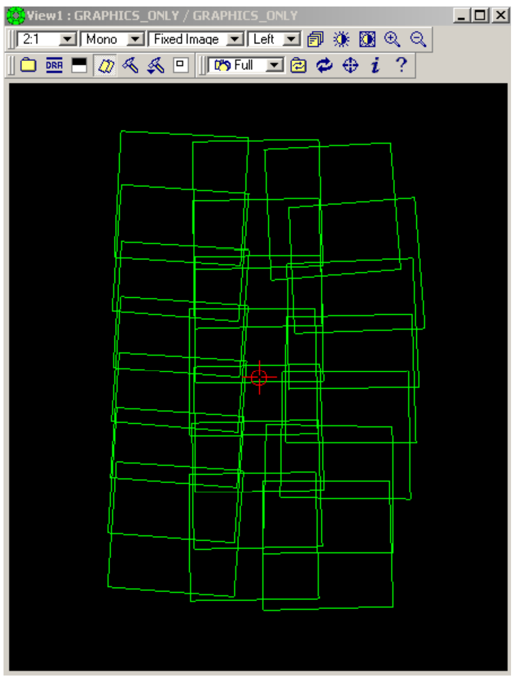
ATE – examples of recent improvements... 4

- Multi-pair matching with back-matching



ATE – examples of recent improvements ... 5

	Adaptive ATE	Back-matching	Multi-pair matching	Multi-pair matching with back-matching
Correlation Success	85%	66%	86%	62%
Percent Requiring Editing	10 – 15% roads running parallel to the flight line	5 – 10% assuming output is a terrain surface – edit buildings	5 – 10% assuming output is a reflected surface model – roads running parallel to the flight line where multiple pairs don't exist	5 – 10% assuming output is a terrain surface – edit buildings
Time	30 minutes	30 minutes	50 minutes	50 minutes

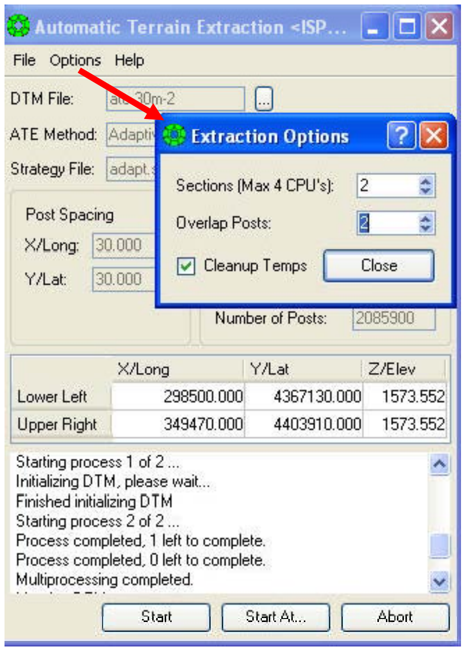


Full block terrain extraction

Imagery courtesy of NOAA

ATE – examples of recent improvements ... 6

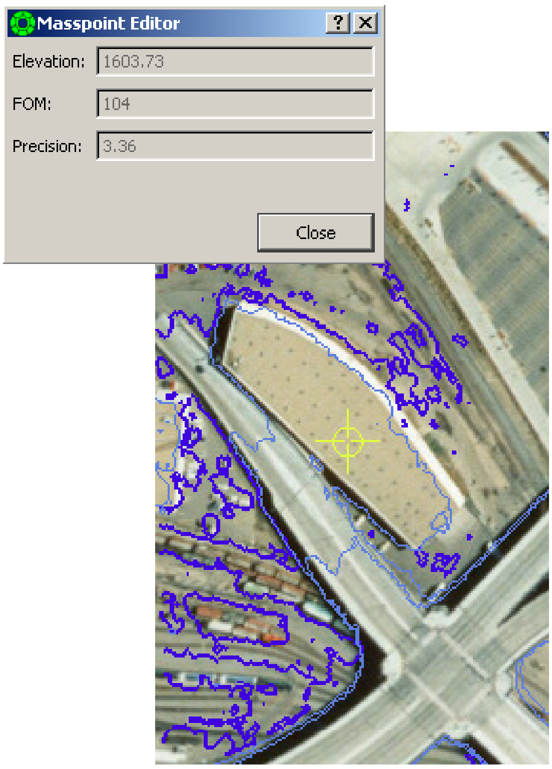
- Parallel processing – the ATE process and licensing allow for parallel processing when multiple processors are detected; the ATE application allows for processing of terrain tiles on multiple processors
  - ➢ Example from two overlapping CartoSat-1 stereo pairs
    - 30 m spacing resulting in 1.4 million points
    - Back-matching enabled



Computer configuration	Processing time (single processor)	Processing time (dual processor)	Improvement
Dual core hyper-threaded Dell 670	38 minutes	20 minutes	47%

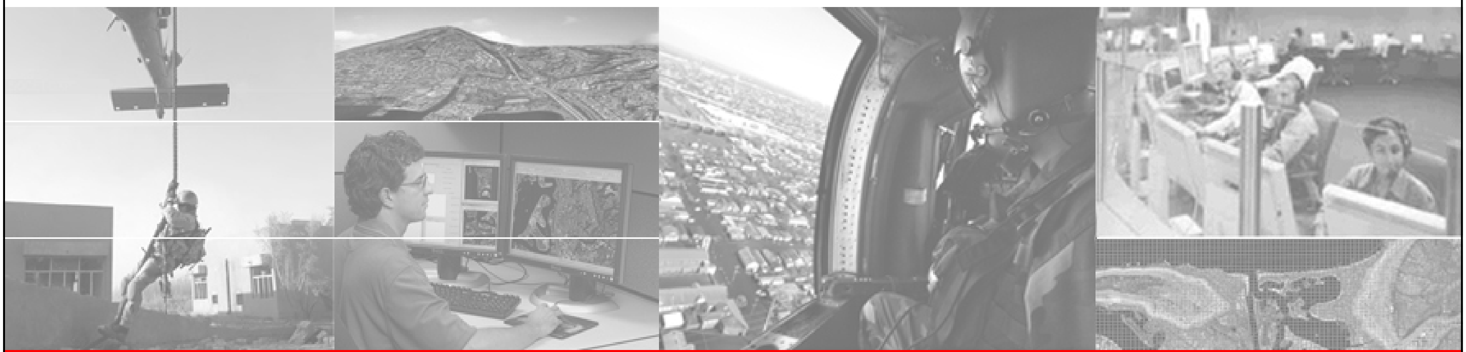
Recent improvements for terrain

- Terrain precision added for all terrain processing (ATE, NGATE, ITE, Merge)
  - Relative precision of terrain data is stored per post
  - Error propagation from source imagery
  - Basis for improved terrain merging algorithms



Next-Generation Automatic Terrain Extraction (NGATE)

Principles, Case Studies, Future Developments, Conclusions



NGATE principles

- Area based image correlation, or area matching, is based on the assumption that elevation or X-parallax within a correlation window and corresponding match is constant
- Because of varying elevation, pixels ‘2’ in left image are not adjacent to pixels ‘1’ in right image
- Area based image correlation matches pixels ‘*’ from right image with pixels ‘2’ from left image

1	1	2
1	1	2
1	1	2

left image

1	1	*	2
1	1	*	2
1	1	*	2

right image

NGATE principles … 2

- Correlation coefficient is related to variation of elevation within the window
- Appropriate window size is related to variation of elevation within the window
- Need to compute elevation for every pixel
    - Time consuming and puts a strain on system resources (>100 million pixels per image)
- NGATE computes elevation for every pixel extremely fast, and efficiently

NGATE principles ... 3

- Edge matching is more robust dealing with buildings
- Elevation discontinuities such as building edges usually generate image edges
- Edge matching “masks” out pixels that are not edge pixels, which are likely to have significant elevation difference
- Pixels ‘0’ (non-edge pixels) are masked out

1	1	0
1	1	0
1	1	0

left image

1	1	*	0
1	1	*	0
1	1	*	0

right image

NGATE principles … 4

- NGATE is based on a hybrid approach
- Results from area matching are used to guide and constrain edge matching
- Results from edge matching are used to guide and constrain area matching
- The final results are a combination of both area matching and edge matching with blunder detection and inconsistency checking

Comparison of NGATE and ATE

NGATE	ATE
Image matching on every pixel	Image matching on each post
Combines results optimally from area matching and edge matching	Uses only area matching
Accuracy and speed are based on which RSET level to stop	Accuracy and speed are based on post spacing and RSET level
Back matching is on by default	User can turn on/off via the GUI
Performs better with large-scale imagery in urban areas	
Less editing time resulting from highly accurate DTMs	

NGATE: user selections

- NGATE and ATE offer similar GUI options
  - Inputs
    - Imagery
    - File containing seed terrain points (if available)
  - Selections
    - Format – TIN or Grid
    - Spacing
    - Extent (boundary)
    - Filters
    - Strategies
    - Maximum images per point
    - Number of sections for multiple processors
    - Accuracy/Speed

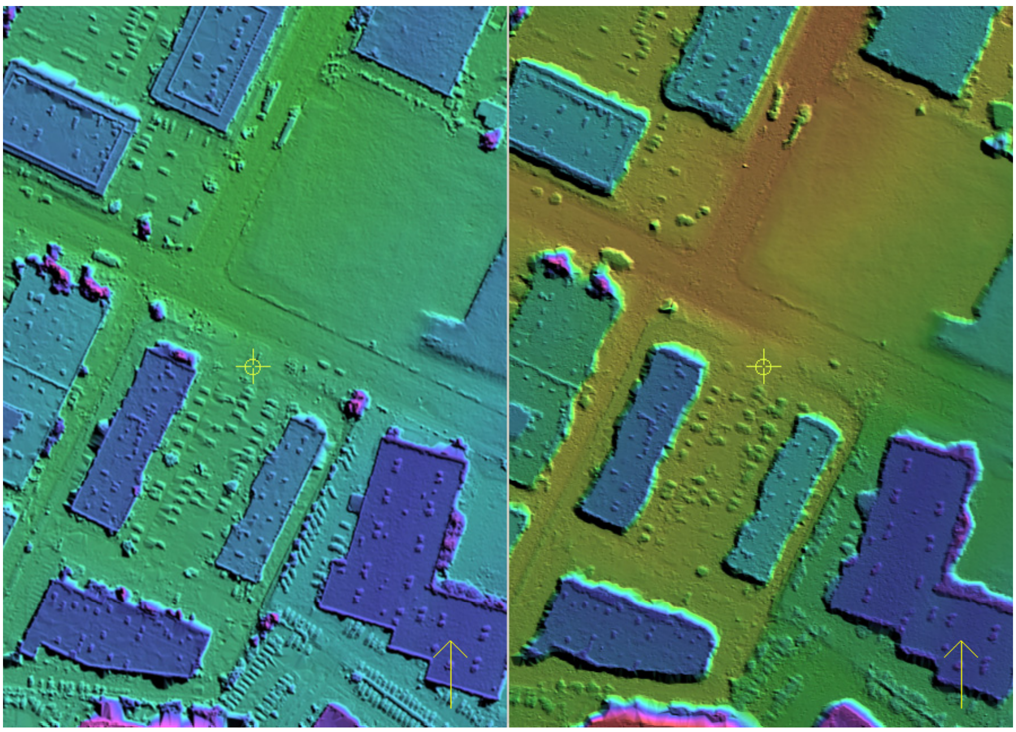
Case Studies

Five examples

Case study 1: scanned film

Location	San Diego, California
Type of terrain	Urban
Coordinate system	UTM
Imagery	Film, scanned at 12.5 µm
Image scale	Large
Spectral characteristics	Color, 3 bands, 8 bits per pixel per band
Number of images	21
GSD (m)	0.05
DTM representation	Grid
DTM spacing (m)	0.25 in both X and Y
Number of points	52,200,024
NGATE strategy	ngate_urban.strategy

Case study 1: ATE and NGATE



NGATE (left), ATE (right) terrain shaded relief

0.25 m grid

Case study 1: quality statistics of ATE and NGATE

NGATE

Points	Rmse (m)	% removed
204	0.18	0.0
201	0.13	1.5
195	0.11	4.6
192	0.10	6.3

ATE

Points	Rmse (m)	% removed
204	0.76	0.0
197	0.33	3.6
191	0.19	6.8
188	0.16	8.5

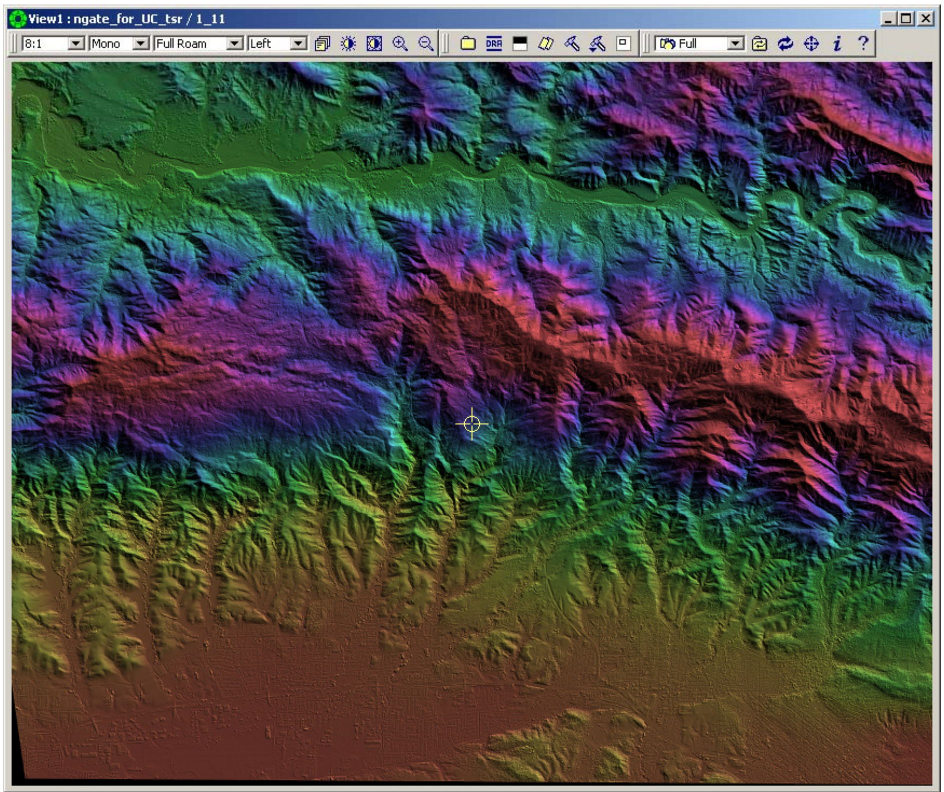
Case study 1: summary

- With 6.8% of the points removed, the ATE results compare with the raw data from NGATE. That's 3.4 million points of total 52.4 million points.

Case study 2: scanned film

Location	Santa Barbara, California
Type of terrain	Urban, rural, lakes, airport, mountains
Coordinate system	Geographic
Imagery	Film, scanned at 14 μm
Image scale	Medium
Spectral characteristics	Color, 3 bands, 8 bits per pixel per band
Number of images	90
GSD (m)	0.35
DTM representation	Grid
DTM spacing (m)	3 in both X and Y
Number of points	56,981,100
NGATE strategy	ngate_urban.strategy

Case study 2: NGATE TSR



NGATE terrain shaded relief

3 m grid

Case study 2: quality statistics of ATE and NGATE

NGATE

Points	Rmse (m)	% removed
347	1.12	0.0
344	1.06	0.9

ATE

Points	Rmse (m)	% removed
347	1.83	0.0
340	1.40	2.1
336	1.32	3.3
331	1.24	4.8

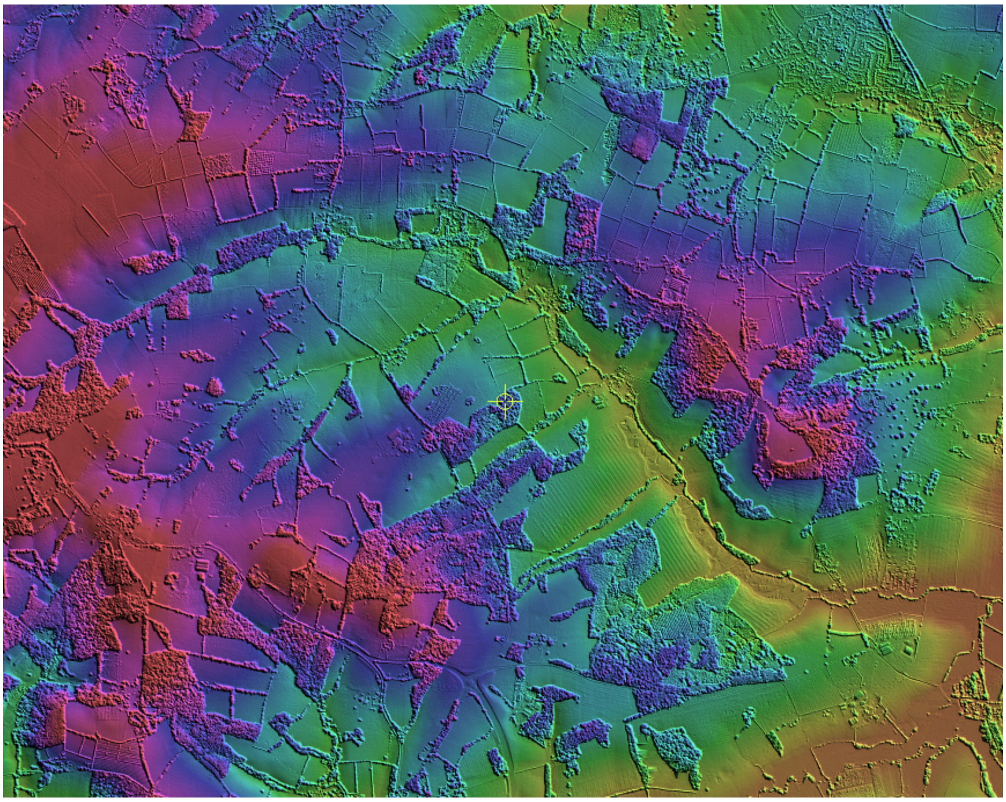
Case study 2: summary

- With 4.8% of the points removed, the ATE results compare with the raw data from NGATE. That's 2.7 million points of total 57 million points.
- A small subset was sampled over an airport consisting of 96 manual measurements. The RMS of this sub-area was 0.31 m compared with the overall 1.12 m RMS of the chaparral covered, mountainous terrain

Case study 3: digital frame

Location	Sussex, UK
Type of terrain	Suburban and rural
Coordinate system	LSR
Imagery	Digital: Intergraph DMC
Image scale	Medium
Spectral characteristics	Color, 3 bands, 8 bits per pixel per band
Number of images	320
GSD (m)	0.25
DTM representation	Grid
DTM spacing (m)	1.5 in both X and Y
Number of points	55,823,460
NGATE strategy	ngate.strategy

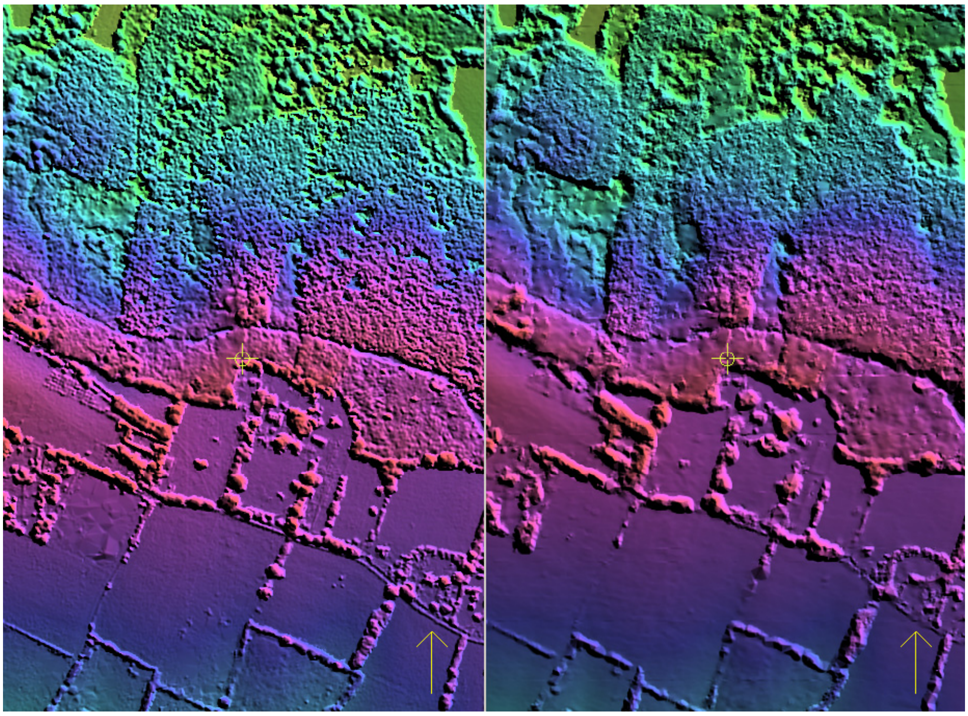
Case study 3: NGATE TSR



NGATE terrain shaded relief

1.5 m Grid

Case study 3: ATE and NGATE



NGATE (left), ATE (right) terrain shaded relief

Case study 3: quality statistics of ATE and NGATE

NGATE

Points	Rmse (m)	% removed
522	0.56	0.0
513	0.42	1.8
504	0.35	4.2

ATE

Points	Rmse (m)	% removed
522	1.76	0.0
508	0.89	2.8
492	0.61	6.1
479	0. 50	9.0

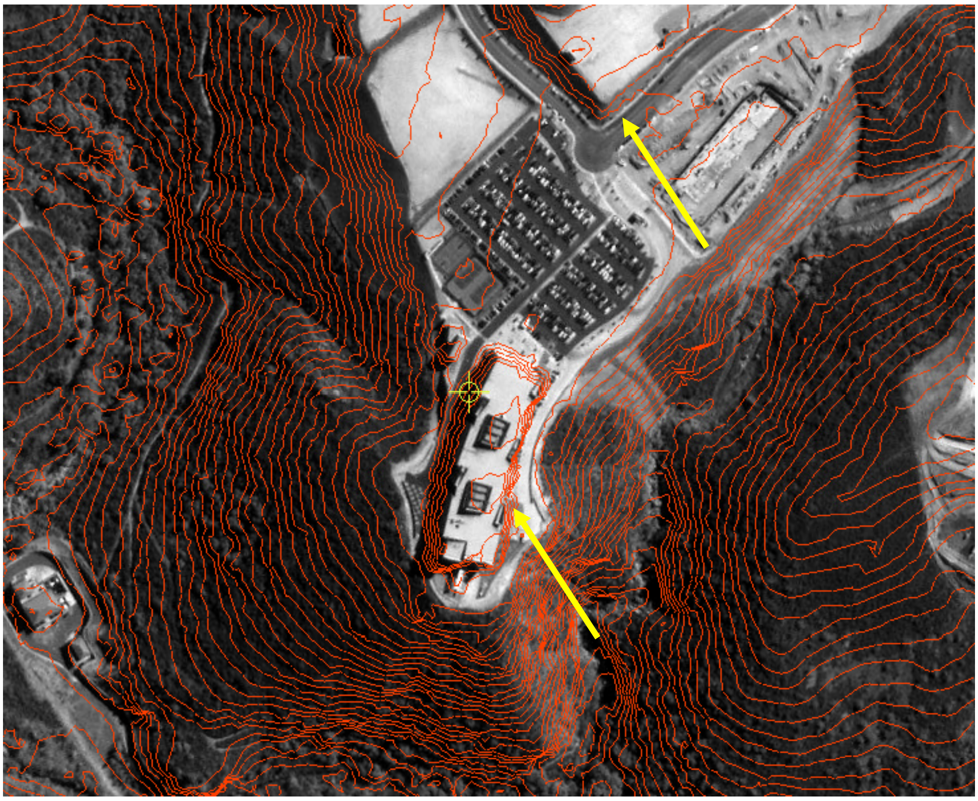
Case study 3: summary

- With 6.1% of the points removed, the ATE results compare with the raw data from NGATE. That’s 3.4 million points of total 56 million points.

Case study 4: characteristics

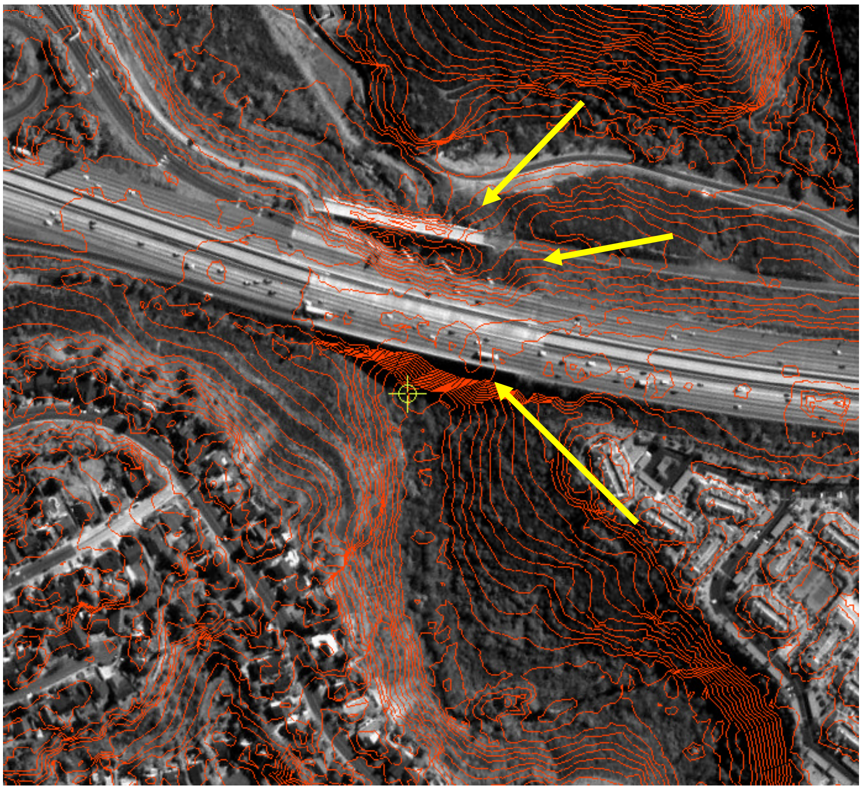
Location	San Diego, California
Type of terrain	Urban, rural, highways, water bodies, construction sites, forest
Coordinate system	UTM
Imagery	GeoEye™ IKONOS®
Image scale	Very high resolution satellite
Spectral characteristics	Panchromatic
Number of images	2
GSD (m)	1.0
DTM representation	Grid
DTM spacing (m)	5
Number of points	8,206,380
NGATE strategy	ngate.strategy

Case study 4: NGATE on buildings



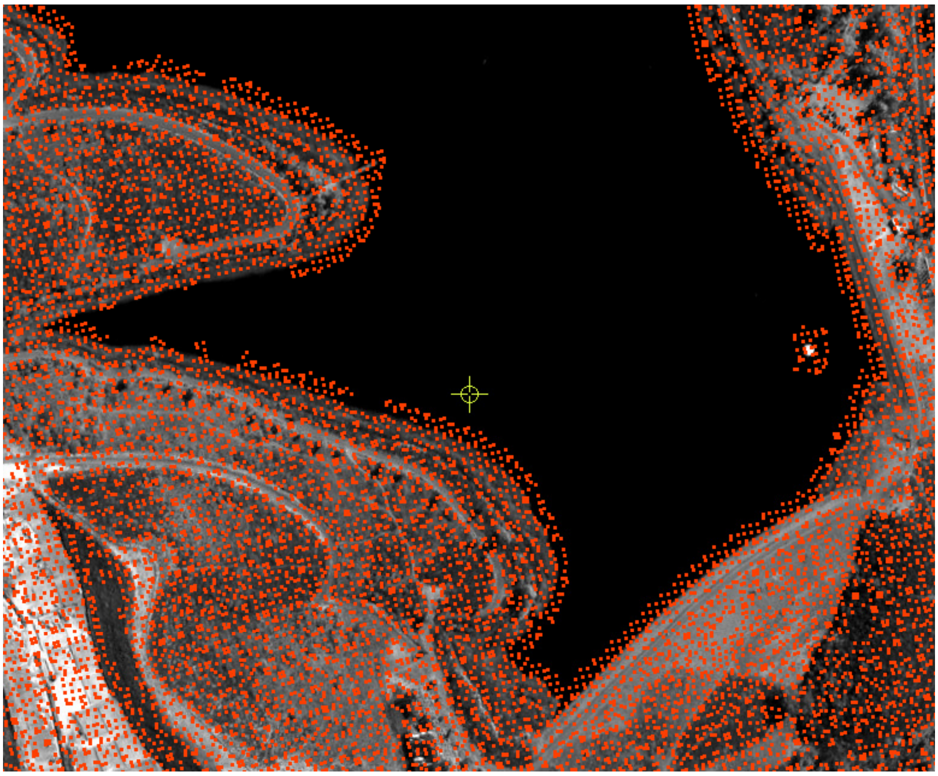
- Buildings are modeled well
- 3 m contours

Case study 4: NGATE on bridges and highways



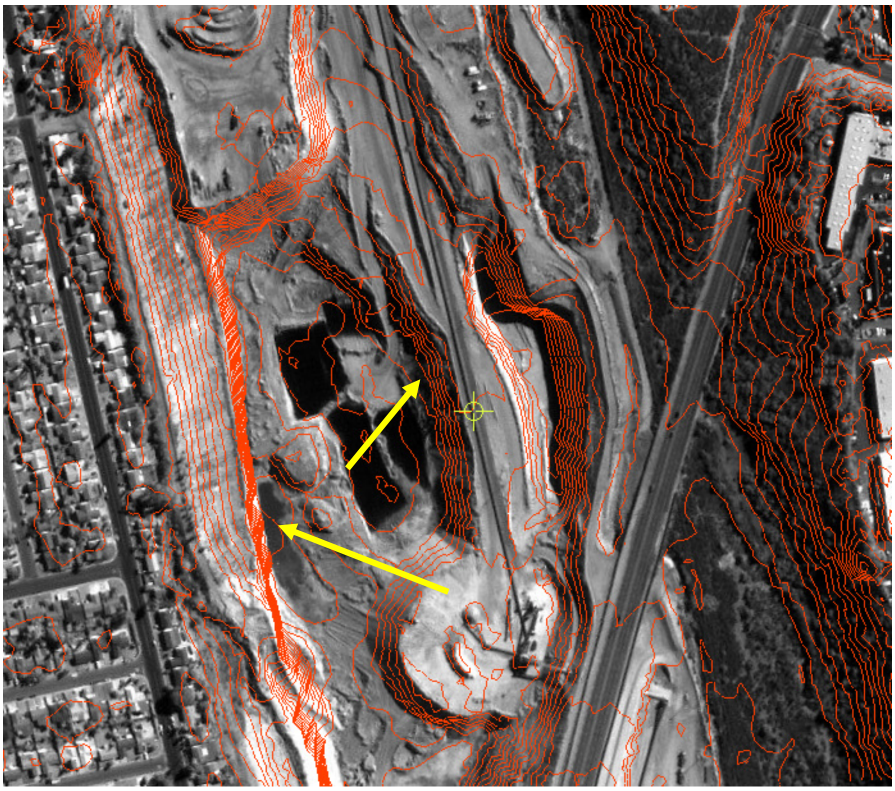
- Two adjacent bridges
- River bed between two bridges
- Highway with moving/different vehicles

Case study 4: NGATE on water



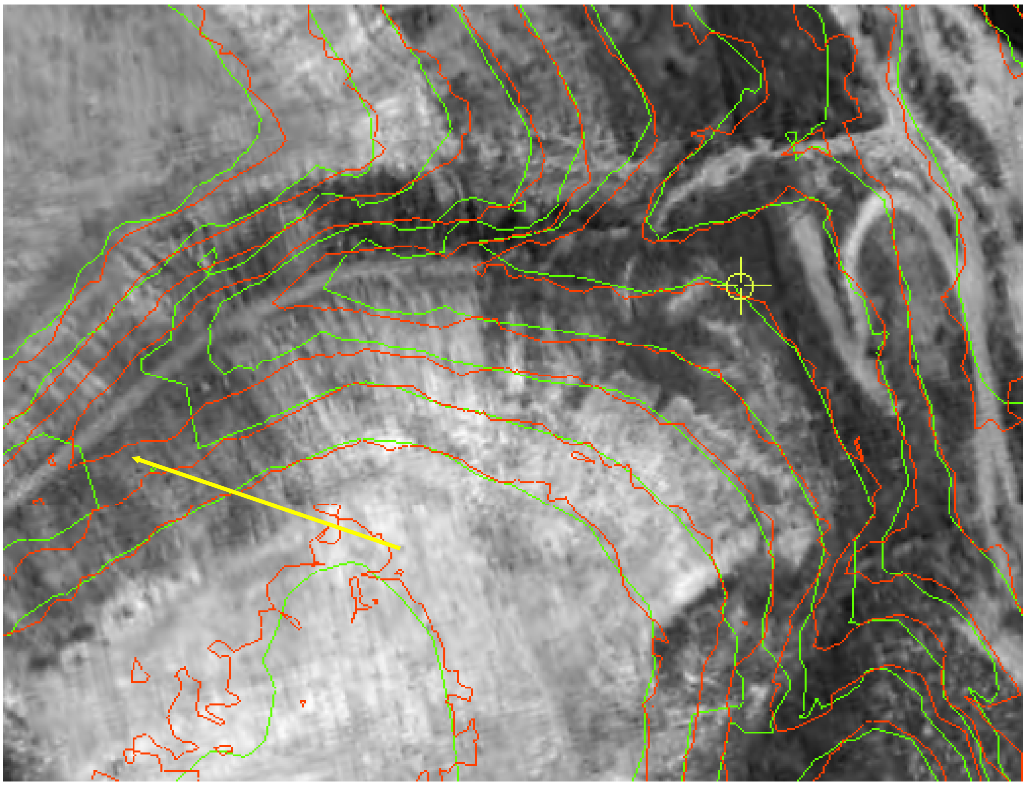
- Water body
- Red dots are TIN elevation points
- Object on water surface

Case study 4: NGATE on steep slopes



- Construction site
- Very steep slope is modeled precisely

Case study 4: NGATE on open terrain



- NGATE models the ditch more precisely
- Contour interval: 5 m
- Red: from NGATE
- Green: from ATE with back matching
- No editing is needed for NGATE

Case study 4: timing results

- Dell 690 - Dual Xeon 3.2 GHz processors, 2 GB RAM, 230 GB SCSI drive

ATE and NGATE performance and RMS

Spacing	ATE	NGATE high/slow	NGATE med	NGATE low/fast
3m	565 min 2.5 m	198 min 1.9 m	64 min 2.2 m	10 min 3.2 m
10m	47 min 2.6 m	190 min 1.9 m	33 min 2.3 m	10 min 3.2 m
30m	11 min 3.5 m	189 min 2.4m	33 min 2.4 m	10 min 3.1 m

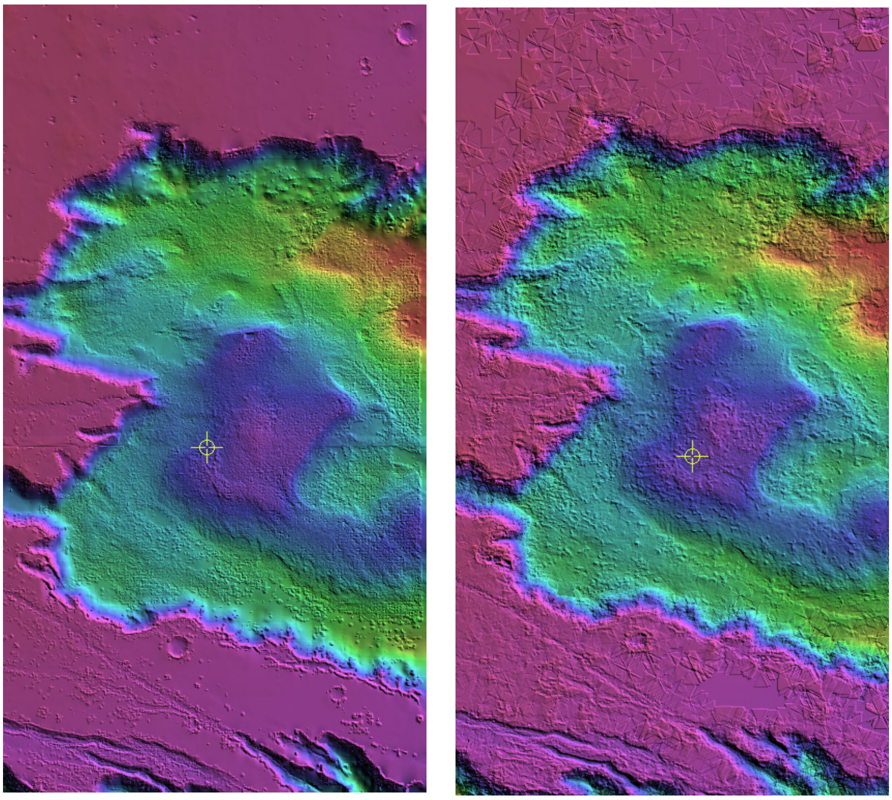
Case study 4: performance summary

- Computation of image matching
  - NGATE per pixel
    - Default - optimized for dense terrain spacing of 1 to 5 times the image GSD
    - Options to stop algorithmic processing at a reduced image resolution for increased performance
    - Option to change strategy to perform area matching without edge matching for increased performance
  - ATE per post
    - Optimized for terrain spacing of 15 times or more of the image GSD

Case study 5: characteristics

Location	Vallis Marineris, Mars
Type of terrain	Mountains, craters, smooth plains
Coordinate system	Mars VM sinusoidal
Imagery	Mars Express HRSC
Image scale	Medium-resolution satellite
Spectral characteristics	Panchromatic, 8 bits
Number of images	2
GSD (m)	26.8
DTM representation	Grid
DTM spacing (m)	75
Number of points	7,560,945
NGATE strategy	ngate_desert.strat
Seed DTM	463 m spacing, 393,216 points

Case study 5: ATE and NGATE

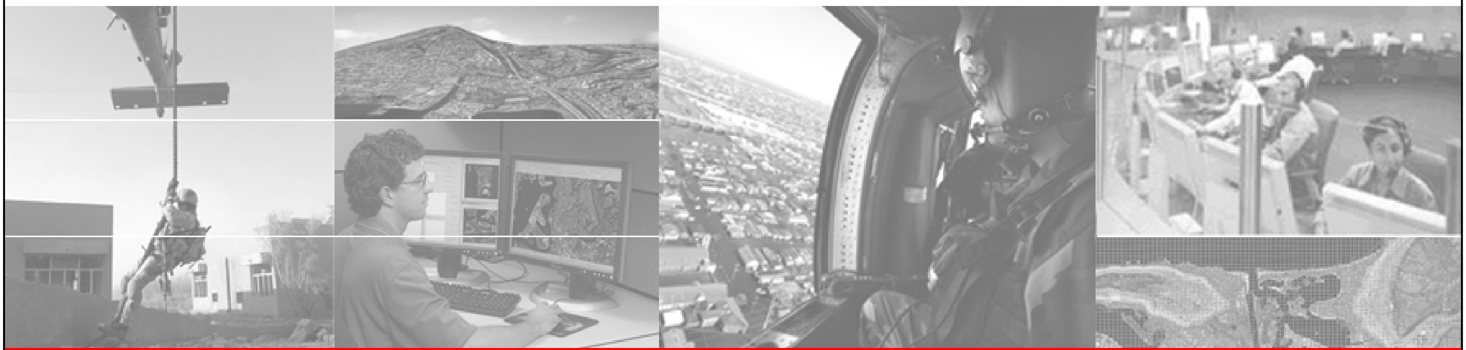


NGATE (left), ATE (right) terrain shaded relief

Case study 5: quality statistics of ATE and NGATE

Algorithm	Points	Rmse (m)
ATE	627	233
NGATE	627	172

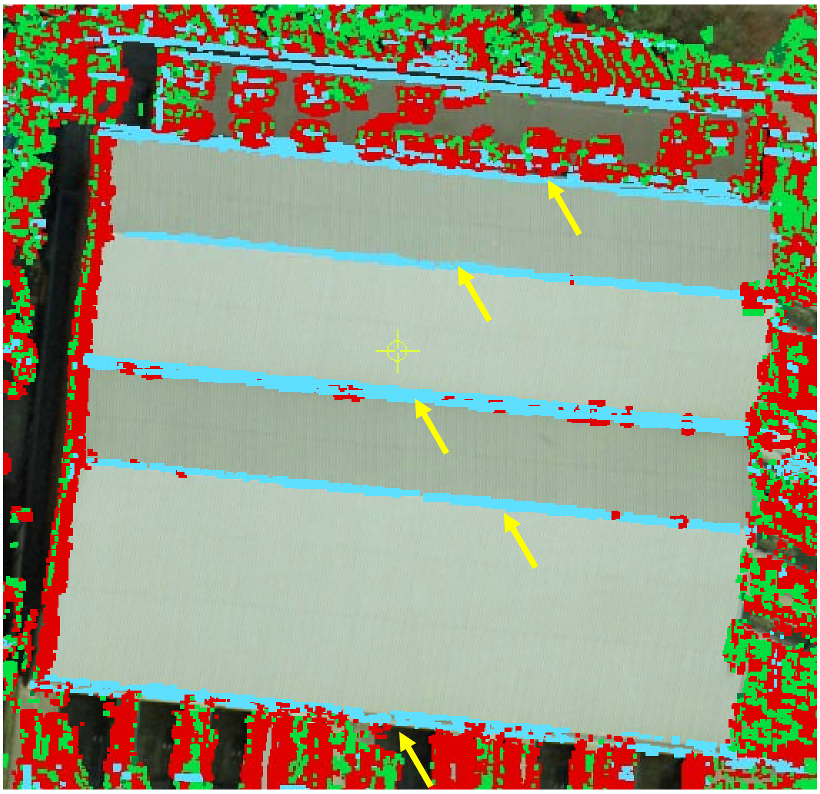
Planned Enhancements



NGATE: planned enhancements

- Hough Transform to match edges that are parallel to epipolar lines and improve edge matching for non-epipolar-parallel edges
- Two DTMs (DSM and bare earth DEM) from NGATE simultaneously
  - Expect much better bare-earth DEM
  - Improve sharpness of DSM at building edges
- Enhancement of bare-earth algorithm, especially for hilly areas, to remove trees.
- Flatten water body for Grid format
- Automatic building extraction from NGATE (longer-term plan)

NGATE: Hough Transform to match epipolar parallel edges

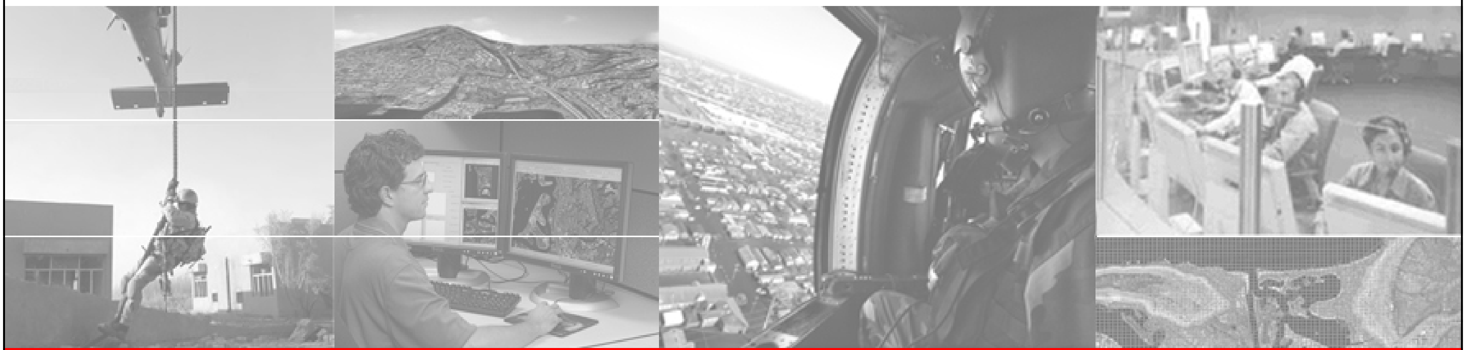


- Edges parallel to epipolar lines are difficult to match
- Hough Transform allows successful matching of epipolar edges as shown in cyan

NGATE: DSM and DEM from NGATE simultaneously

- Bare-earth DEM is often the required product
- Lots of editing from DSM to bare-earth DEM
- Bare-earth algorithm has limited success especially in hilly areas
- New approach is to have two DTMs (DSM and DEM) during NGATE processing
- For bare-earth DEM, elevation points on trees and buildings are NOT used in DEM NGATE processing
- Users have three options for output from NGATE
  - DSM
  - DEM
  - Both DSM and DEM
- SOCET SET v5.4.1 contains many new bare-earth tools rapidly produce terrain surfaces from reflected surfaces

Conclusions



NGATE conclusions

- Main cost of DTM generation is manual editing
  - On small to medium scale imagery, editing is minimal
  - On large scale imagery in natural terrain, editing is minimal
  - On large scale imagery in urban areas, editing is significantly reduced
- Water bodies are flattened: no elevation points on water bodies for TIN format
- Building edges are better modeled
- Streets and featureless areas display many fewer blunders and are more accurately modeled
- Customer experience over the last 8 months has confirmed that editing time is decreased by approximately 30%
- Less Editing … Less Editing … Less Editing ➔ Cost Reduction