A Standardized Approach to Phase Unwrap Detection/Removal and Void Fill of the Shuttle Radar Topography Mission (SRTM) Data

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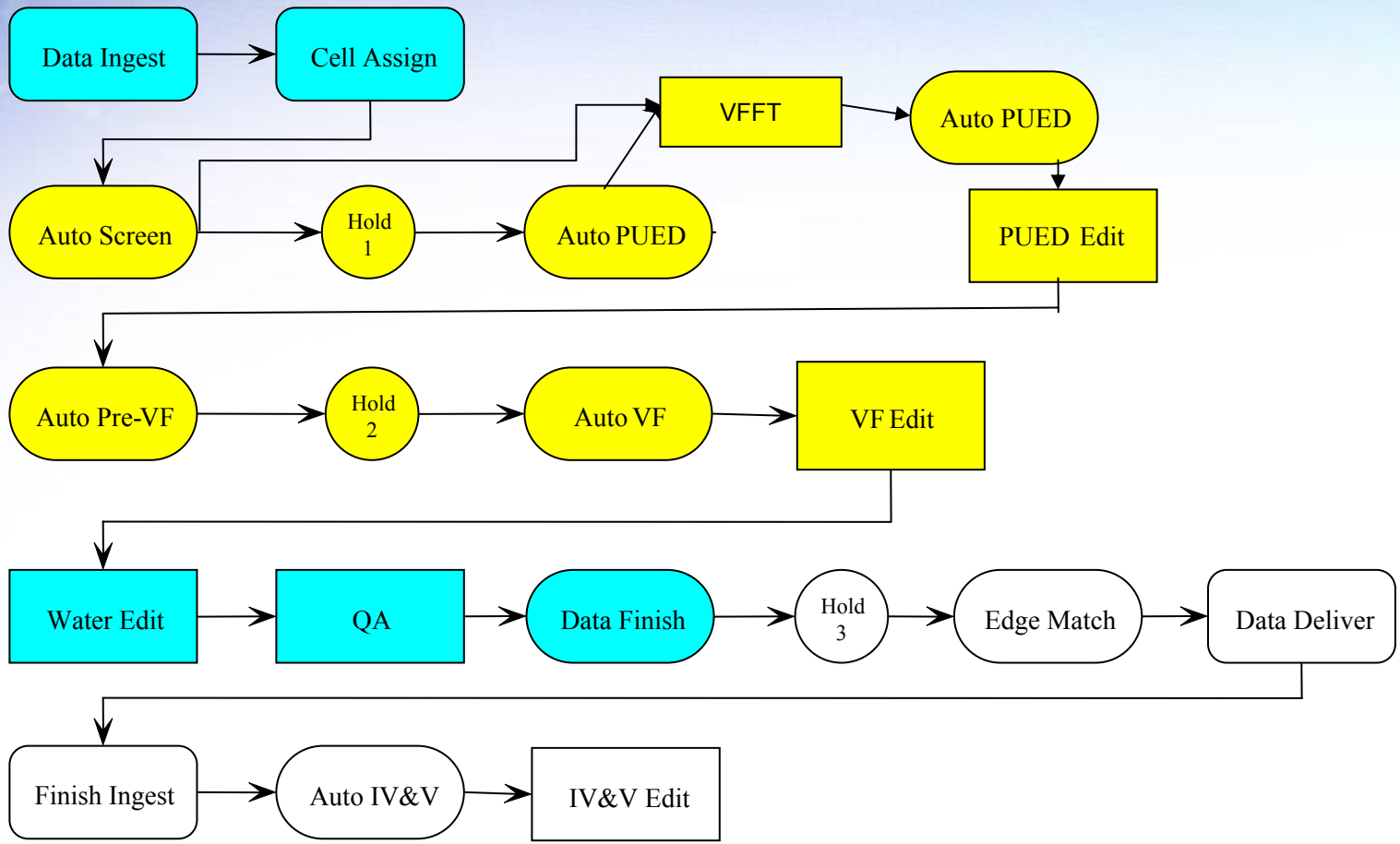
Overview

- Overview of the Void Fill Process
- Phase Unwrap Error Detection/Removal
- Void Fill using the Continuous Surface Merge Algorithm
- Void Fill Production Statistics/Graphics
- Performance Evaluations of our Void Fill method
- Conclusions

Void Fill Process

White - no change from Phase 1 Production
Blue – modified from Phase 1 Production
Yellow - new



GFI Fill Source DEMs

- ✓ Obtained from NGA's worldwide holdings of DTED® Level 2 & DTED® Level 1, and USGS National Elevation Data (NED).
- ✓ The first in priority fill options.
- ✓ They are collectively labeled GFI Fill Source DEMs.

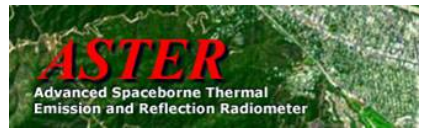
Alternate Source DEMs (ASDEM)

The following DEMs are considered Alternate Source DEMs and are next in line as fill sources in void fill. SPOT5, RADARSAT, and ASTER data were evaluated by Boeing and NGA through a prototype. These sources were chosen for the study because of their global availability.

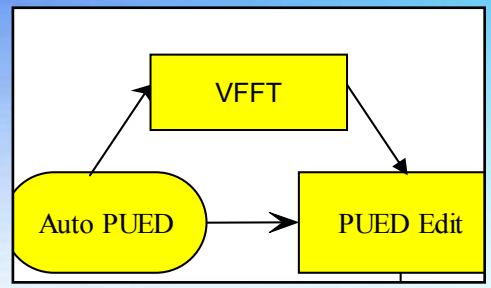
- ✓ SPOT5
- ✓ RADARSAT*
- ✓ ASTER*
- ✓ STAR3i **

*Not approved for use at this time, although our software supports them.

**Currently under contract to convert NGA's STAR3i data holdings into DTED2 format, usable for Void Fill

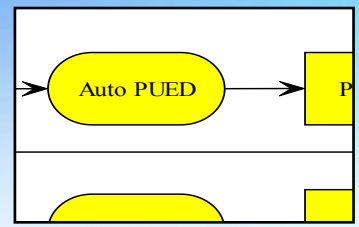


Void Fill Feasibility Tool:



- ✓ Looks at acceptability of GFI DEM and ASDEM data.
- ✓ Provides feedback related to available coverage of GFI and Alternate sources.
- ✓ Produces reports and statistics for void fill production.
- ✓ Updates in real-time as data is ingested and is available to NGA through the web
- ✓ NGA reviews the results and investigates cells with failed source coverage.
- ✓ After further review by NGA, some source DEMs that did not meet the minimum requirements for acceptability can be put into production.

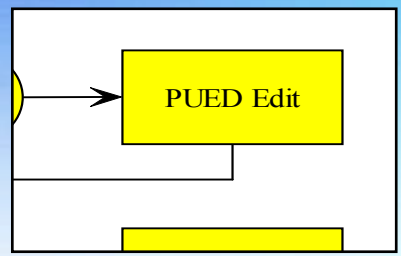
Phase Unwrap Error Detection:



- Phase Unwrap Errors: caused when the radar processor cannot determine where to start unwrapping the phase (the wave's starting point or advancement (fraction) relative to an arbitrary origin) or the wrong phase is assigned.

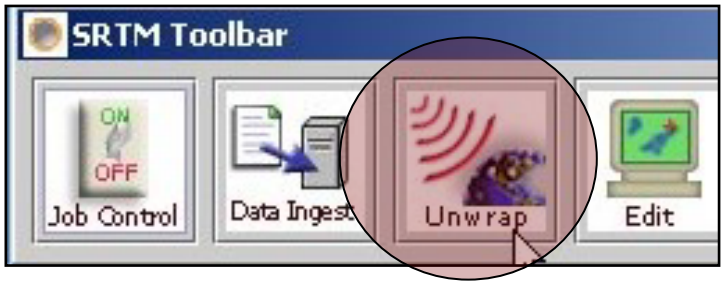
- General Description of the PUED Algorithm:
  - A **PUE post** in Void Fill production is effectively defined as the elevation of any SRTM post that is more than 200 m different than the source DEM it is being compared to.
  - A **PUE region** can then be expanded to any set of posts connected to the "PUE Point" that is more than 100 m different than the source DEM.
  - "**Islands**" (areas of data completely surrounded by void) <=100 posts in size are also automatically identified as Phase Unwrap Error Candidates (PUECs)

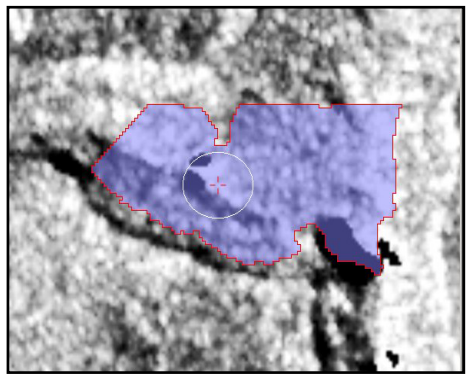
PUED Classification Edit:



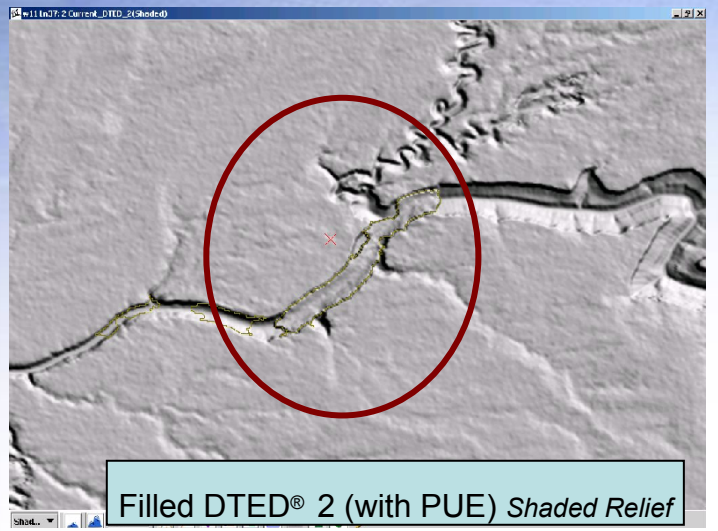
- ✓ Small PUECs (<= 16 pixels) and PUEC void islands 100 posts or less in size will not be queued for manual operator review.

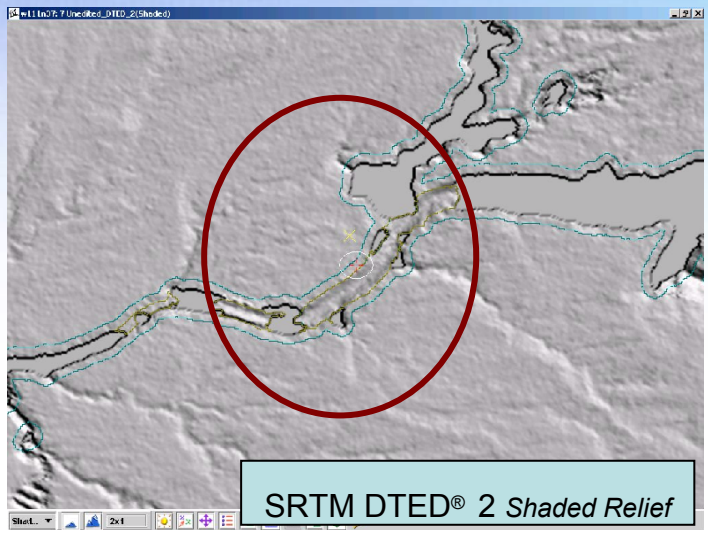
- ✓ The editor will accept or delete each reviewed PUEC based on the PUECs validity as determined by training and experience.

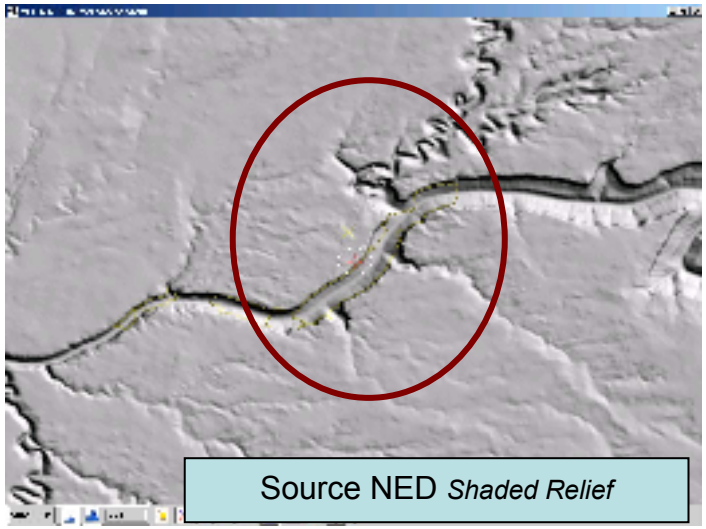


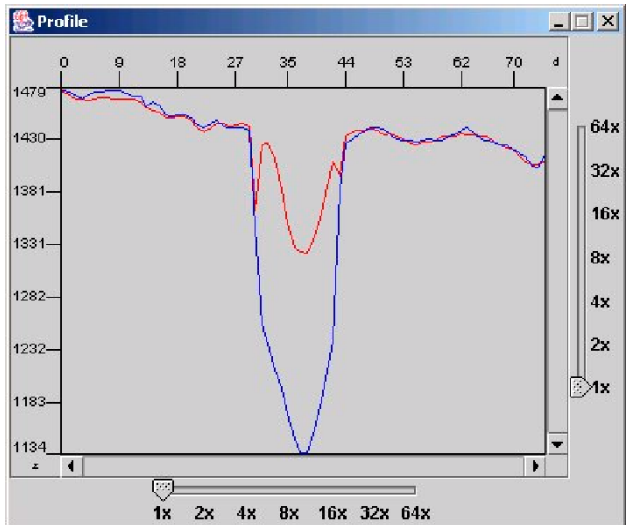


PUED Classification Edit: *Example*



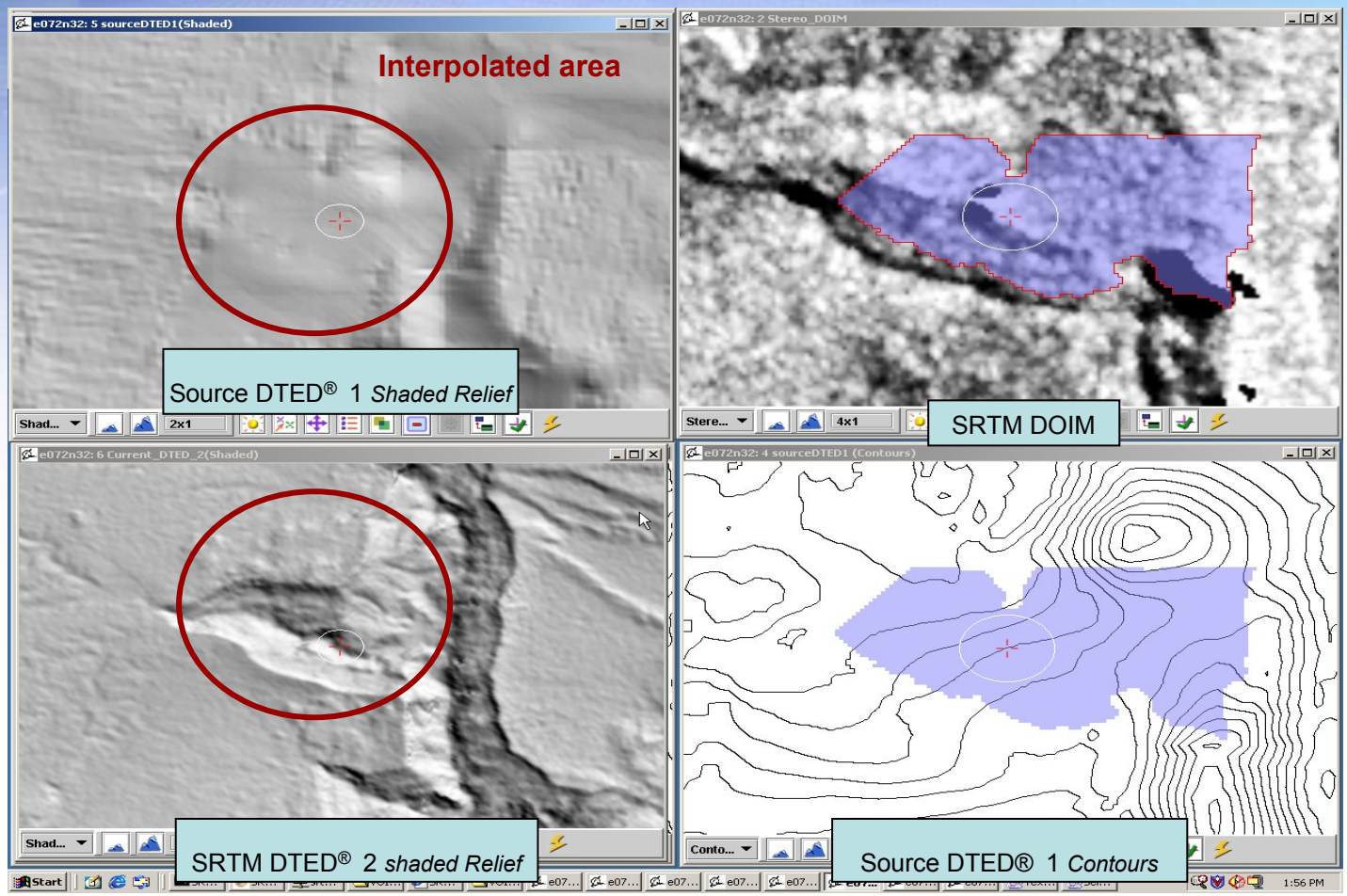






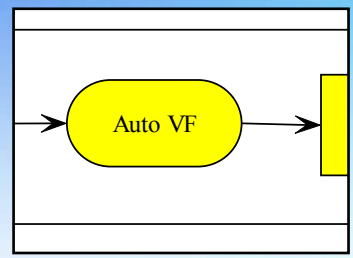
- This is an example of a positive PUEC – notice the resulting poor fill when this anomaly was not removed

PUED Classification Edit: *Example*



- PUEC was removed (candidate was removed from consideration – **not the data**) because the SRTM DTED® look good and there appears to be interpolation in the Source DTED®1.

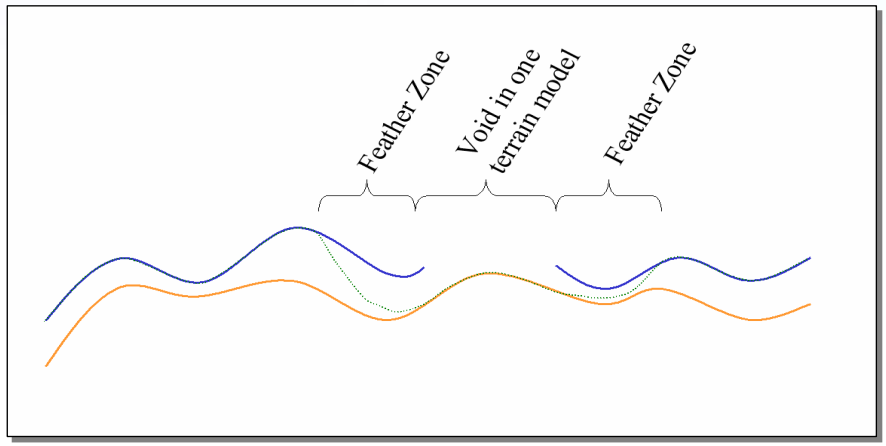
Automated Void Fill:



- ✓ PUECs turned to void
- ✓ Automated Spike/Well removal (60m threshold wrt neighbors)
- ✓ Noise reduction filter run on void edges
- ✓ Voids are filled using Continuous Surface Merge algorithm
- ✓ THED is updated.
  - ✓ Accuracy of the fill source used for each void is reflected in the updated THED
- ✓ Remaining unfilled voids are interpolated (if they meet criteria)
  - ✓ In some instances, NGA directs that all voids in a cell should be interpolated, if no other fill source is available, the voids are of small size, and the terrain is very flat.

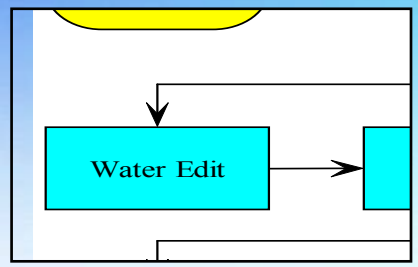
Continuous Surface Merge Algorithm (CSM)

- **Outside a Feather Zone:** the original SRTM terrain model remains unaltered (*locked*).
- **Inside a Void Area**. In these areas, the CSM surface is the arithmetic average of all non-null terrain elevation models.
- **Inside a Feather Zone**. In the "feather zone" the relative weight of a given source elevation model is linearly reduced in such a manner so as to have near-zero weight at the edge of the void and full weight at the *feather distance* from the void. The *feather distance* is defined as a linear ground distance that defines the boundary width for feathering. All posts within the feather distance of a void have some reduction in their relative weight.

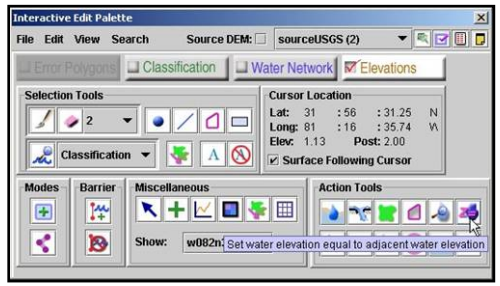


Results of CSM, after *Locking* the Blue Surface

Void Fill and Water Edit:

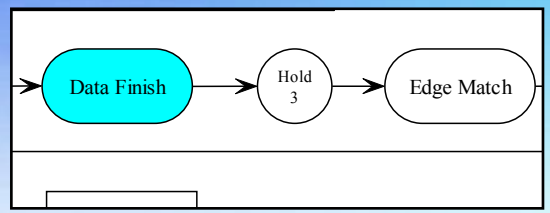


- ✓ Void filled areas are validated by the operator.
- ✓ Many different options to view the filled data are available to the operator to validate and view the filled voids:
  - Overlays of the filled areas and feathered areas.
  - Difference images.
  - Vectors show filled voids adjacent to water.



- ✓ Drive to list of voids adjacent to water is searched.
- ✓ Only water in filled areas can be edited.

Data Finishing & Edge Match:

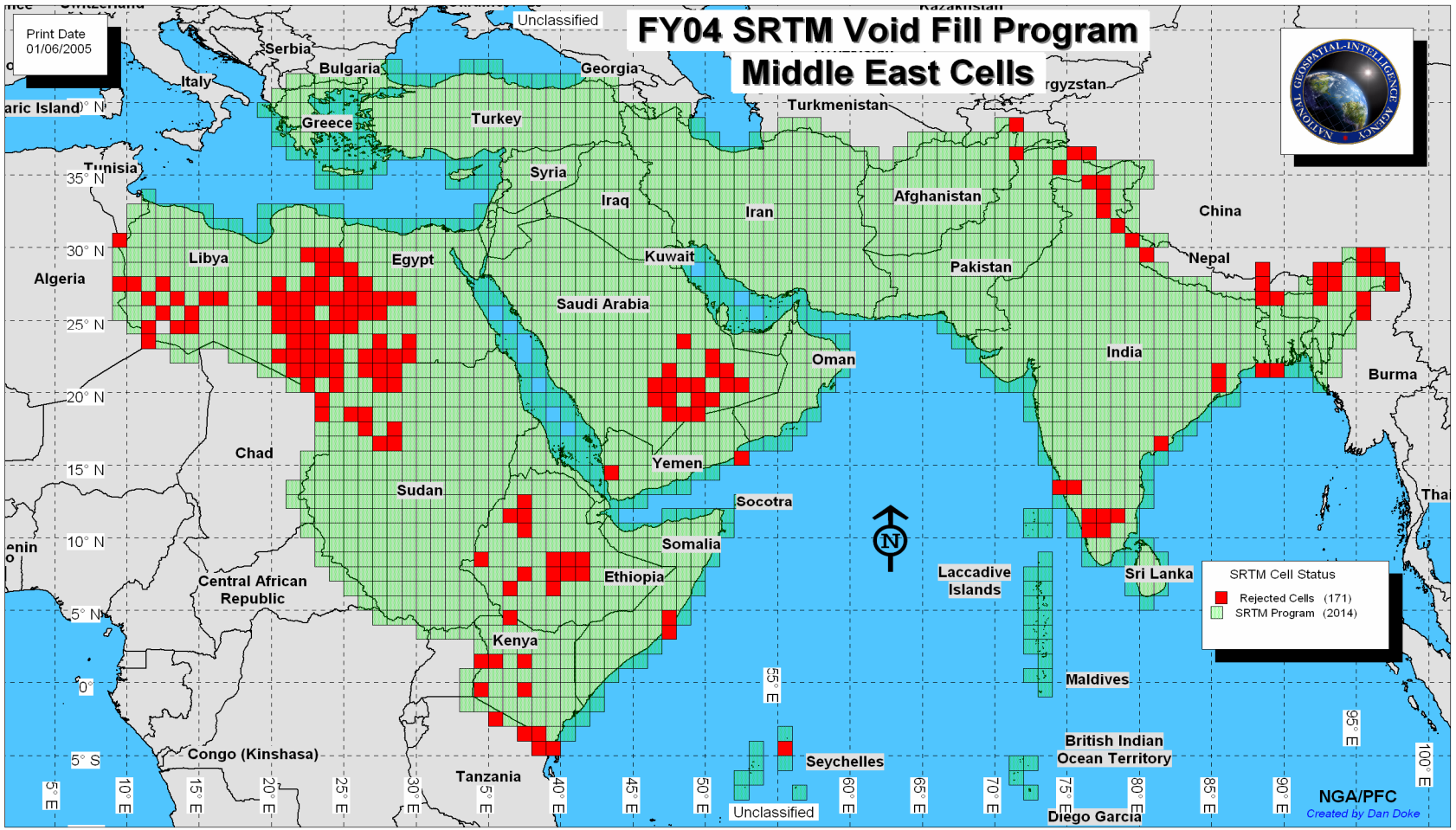


- ✓ Automated process to update SRTM data products:
  - ✓ SHCM, DTED®-1, SWBD
  - ✓ DTED®-2 and THED were updated as cell was edited
  - ✓ DTED® Header indicates what fill source was used
- ✓ Cell edges are checked.
- ✓ Final Void Fill data statistics are generated.
- ✓ Data is validated for compliance to specification and rejected if failed.

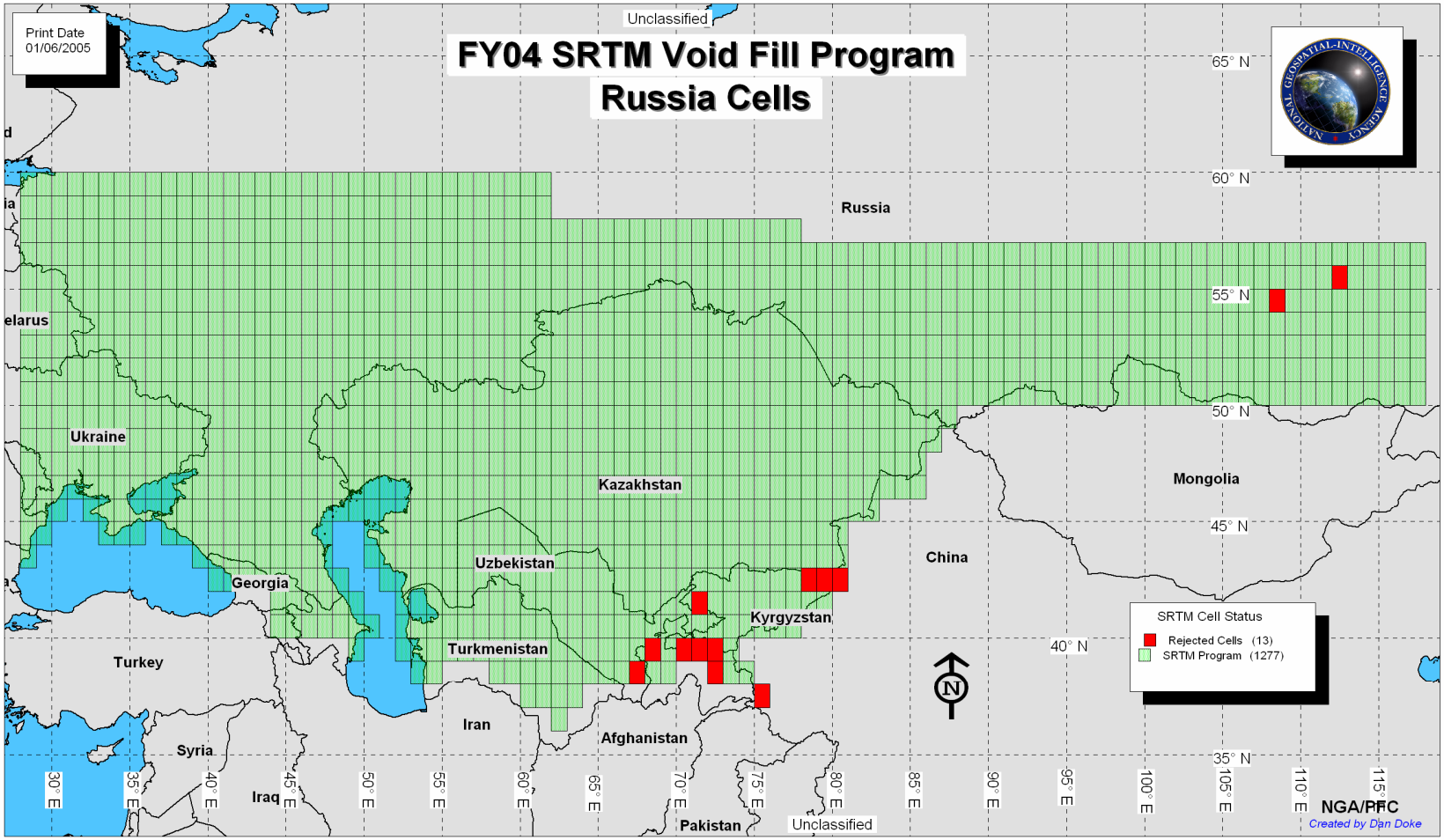
Production Statistics

- Currently the Boeing-Intermap team is enhancing 350 cells per month using this process.
- This high-volume production rate is possible due to the highly automated production software and robust production management system we developed.
- Approximately 7,000 cells will have been void filled by the end of 2005.

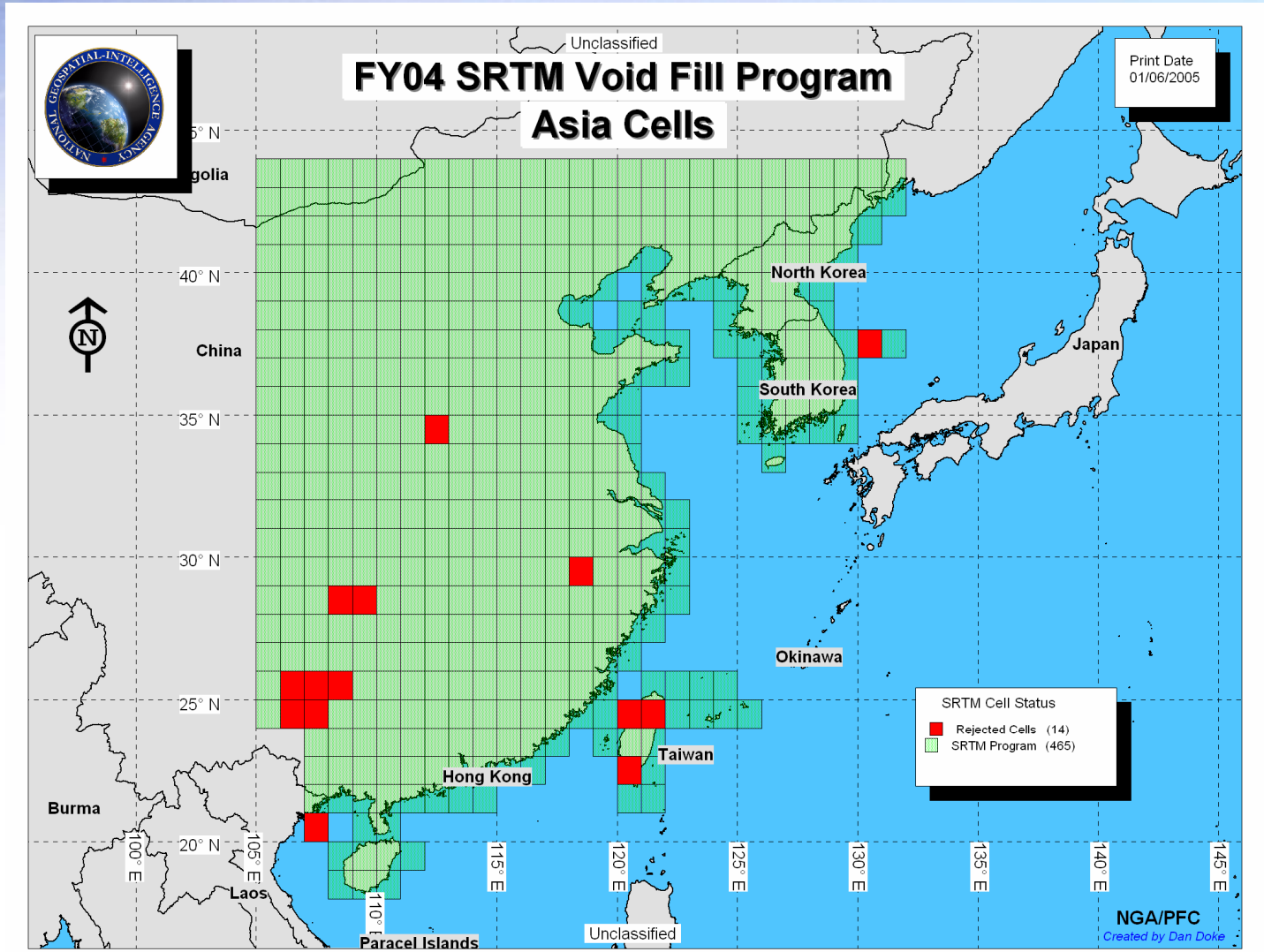
FY04 SRTM Void Fill Program Graphic



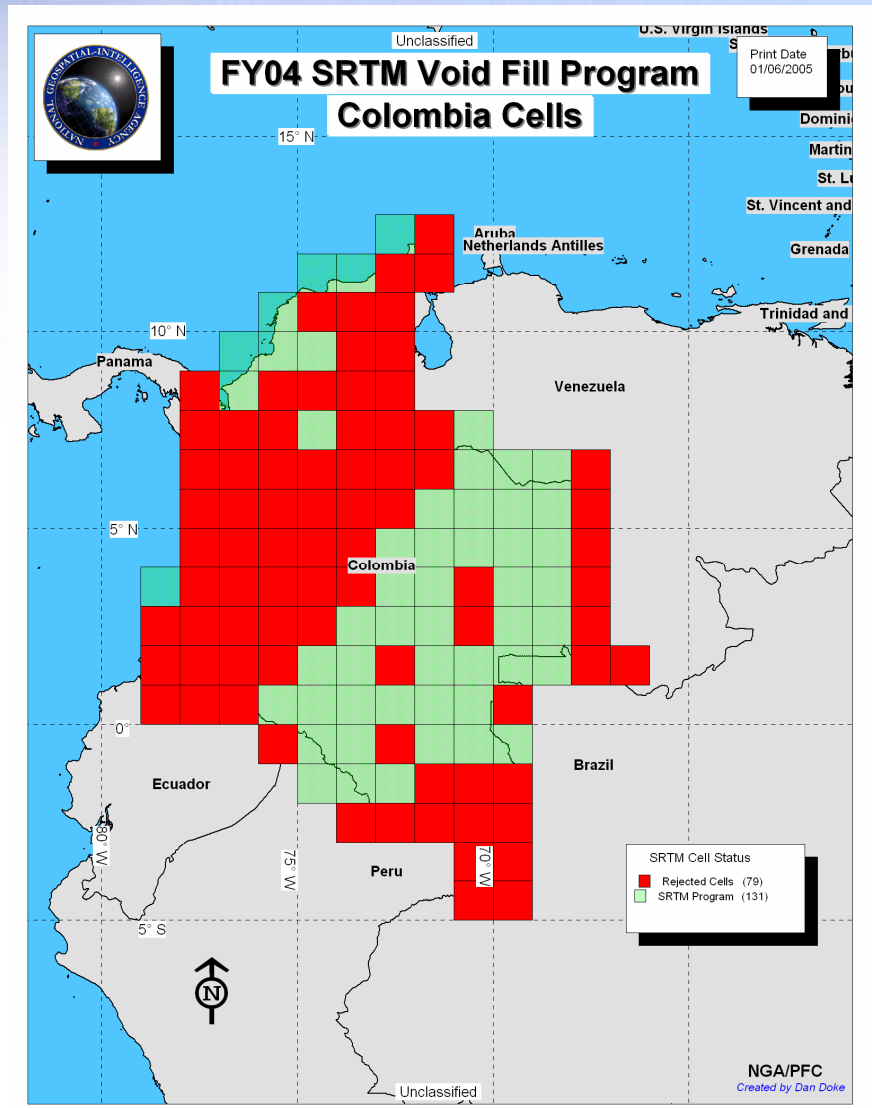
FY04 SRTM Void Fill Program Graphic



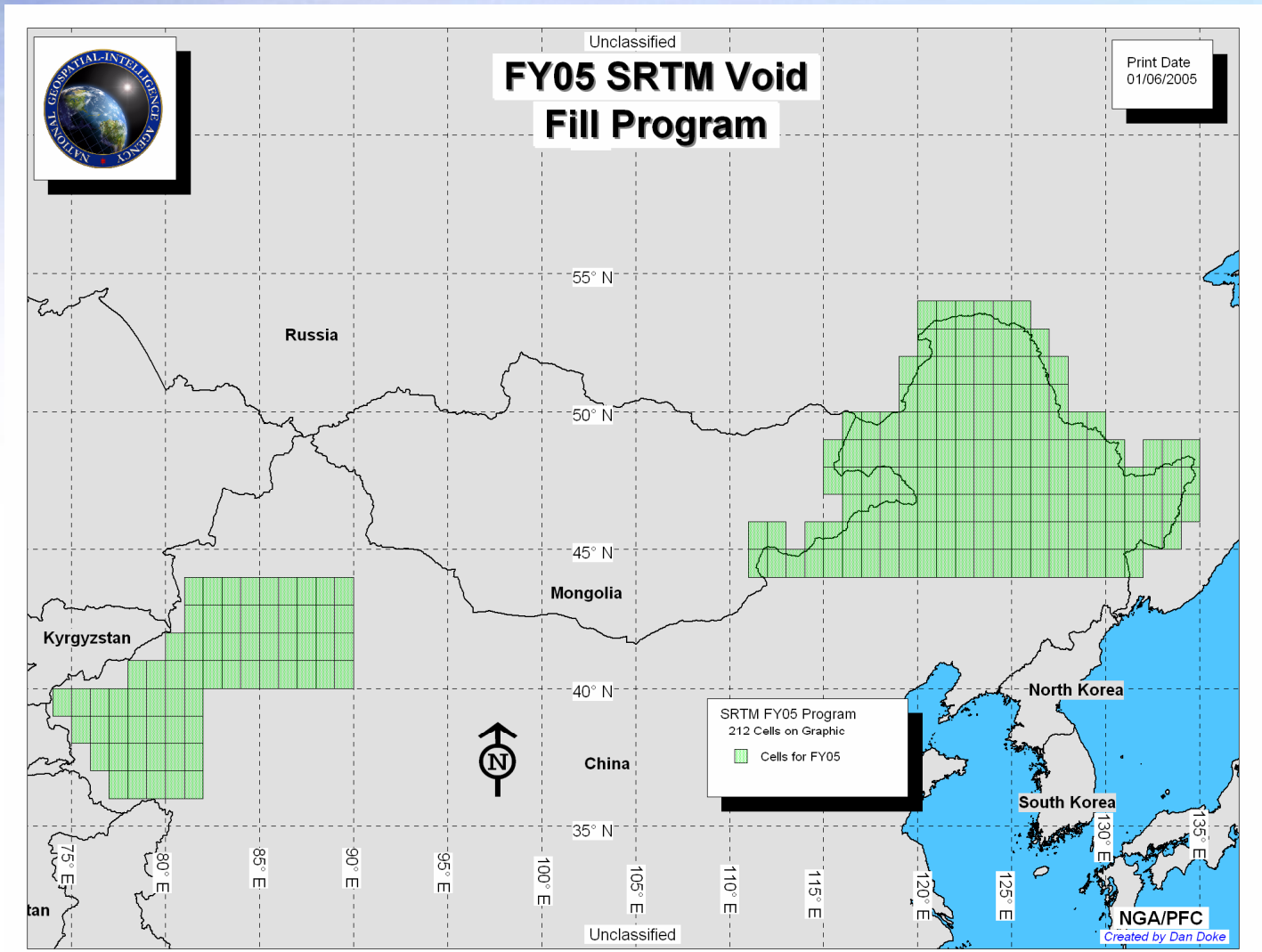
FY04 SRTM Void Fill Program Graphic



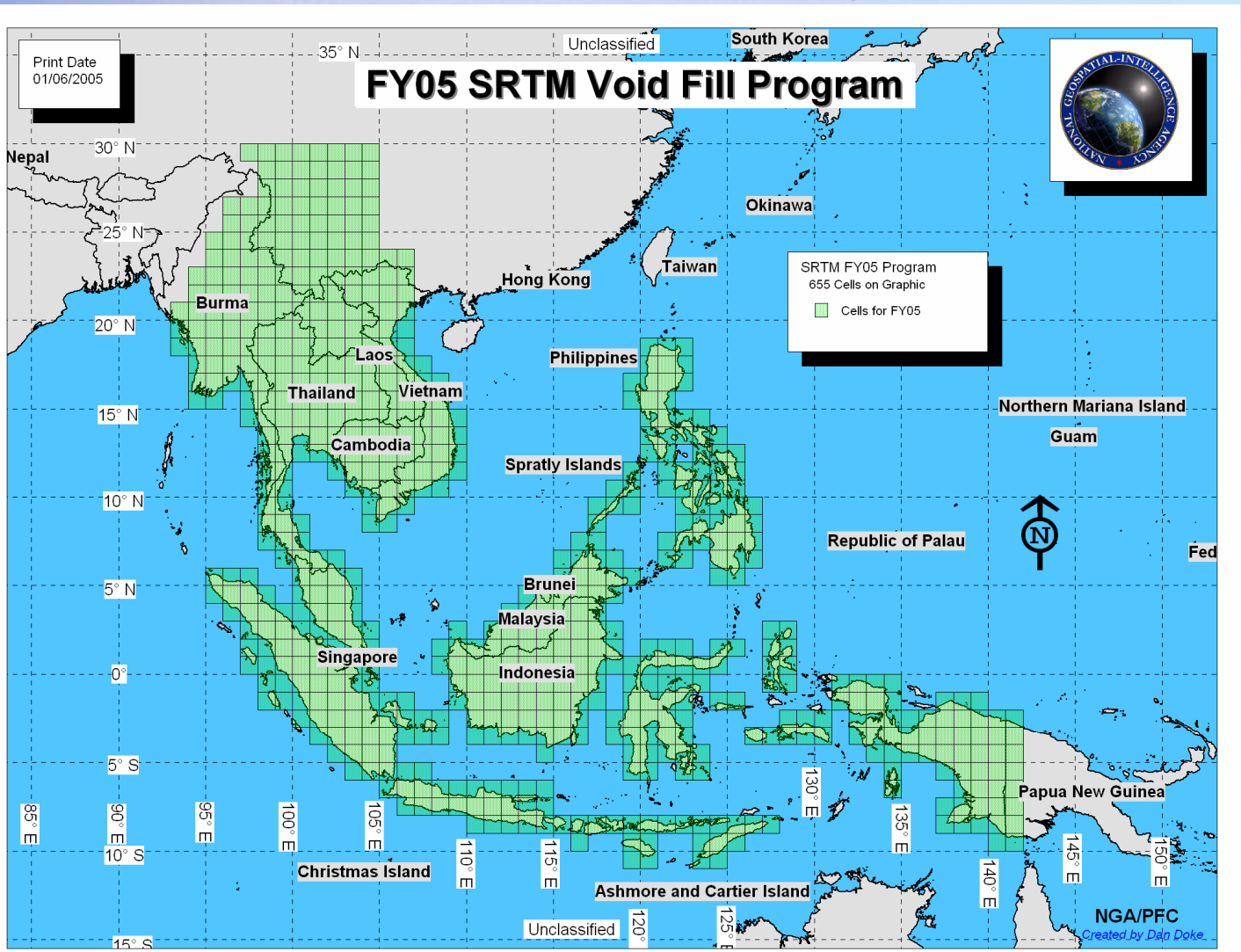
FY04 SRTM Void Fill Program Graphic



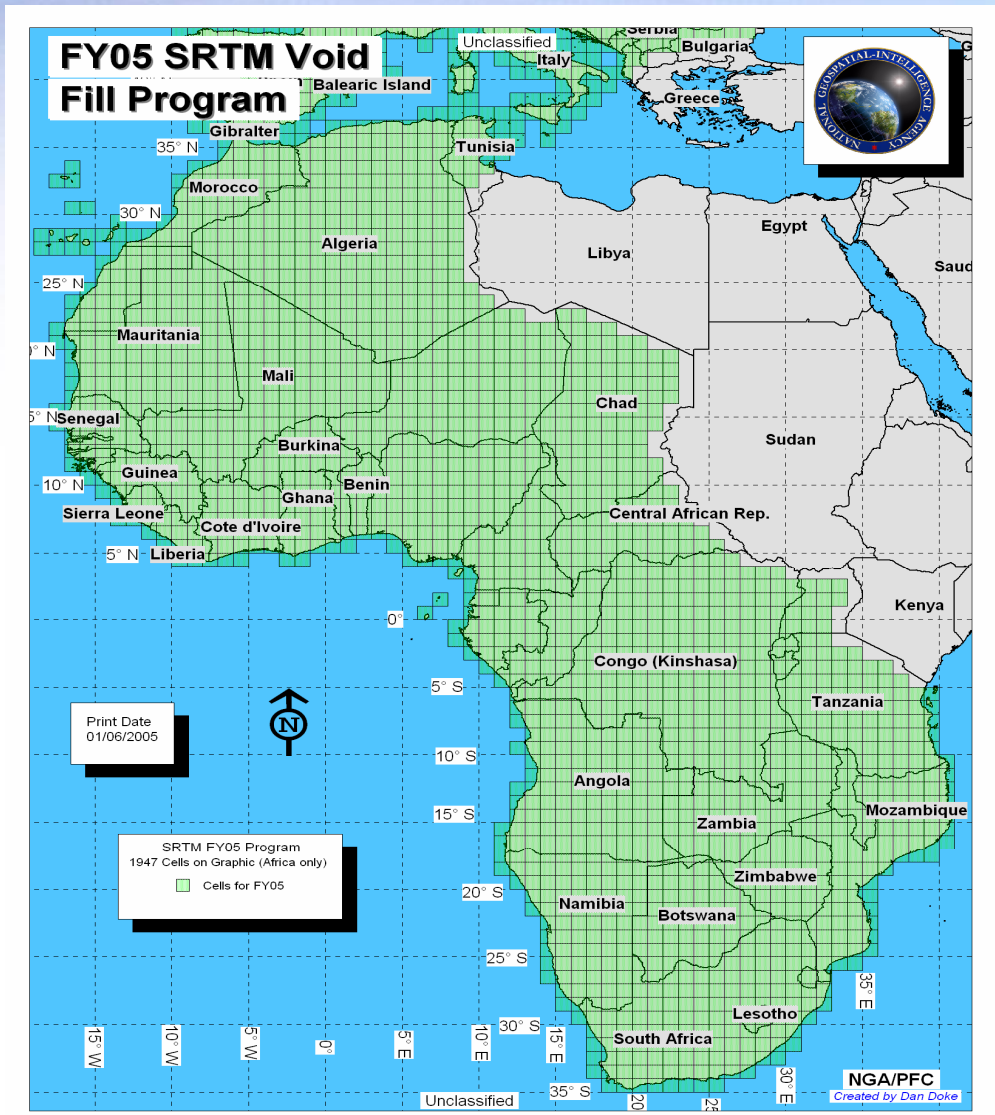
FY05 SRTM Void Fill Program Graphic



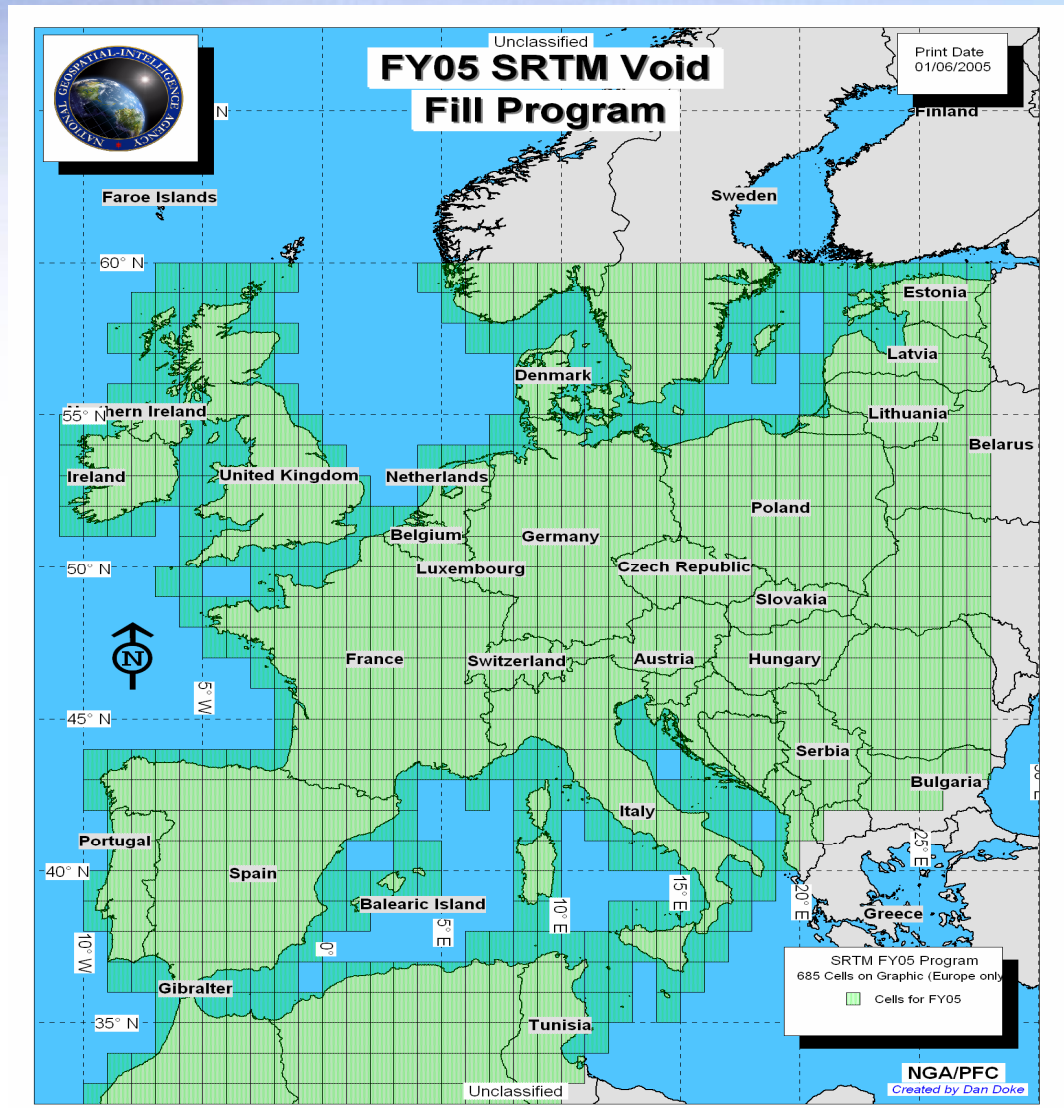
FY05 SRTM Void Fill Program Graphic



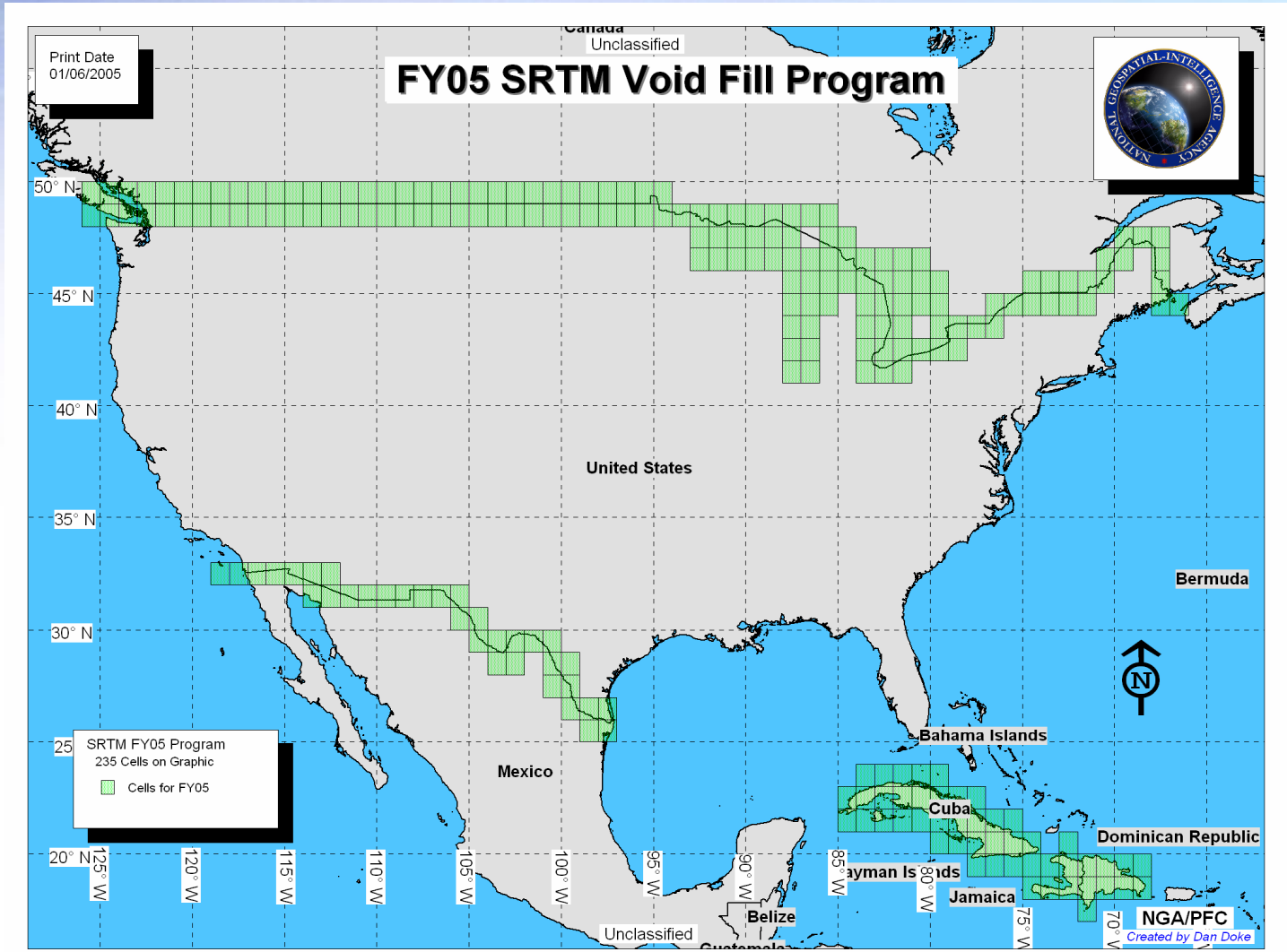
FY05 SRTM Void Fill Program Graphic



FY05 SRTM Void Fill Program Graphic



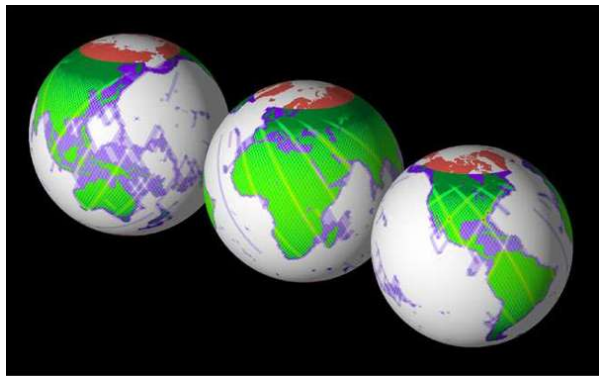
FY05 SRTM Void Fill Program Graphic



VOID FILL OF SRTM ELEVATION DATA: PERFORMANCE EVALUATIONS

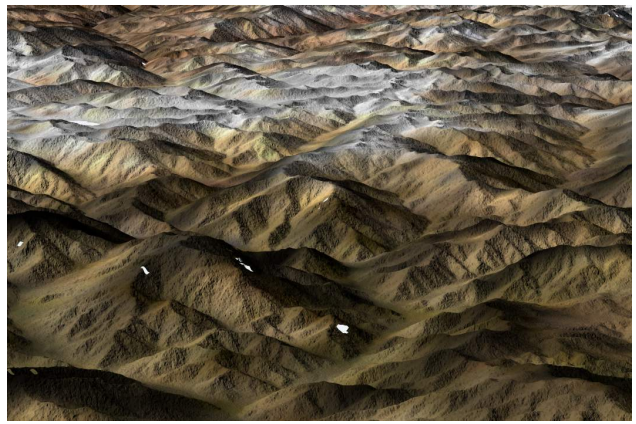
OBJECTIVES

- To conduct a more in-depth vertical accuracy assessment of the Boeing-Intermap SRTM VF process.
- To compare the results from the Boeing-Intermap SRTM VF process to those from some freeware VF programs.



Evaluation Process

- Cell Selection
- Reference Datasets
- Statistical and Visual Analysis
- Testing of Freeware VF packages



Cell Selection

Based on:

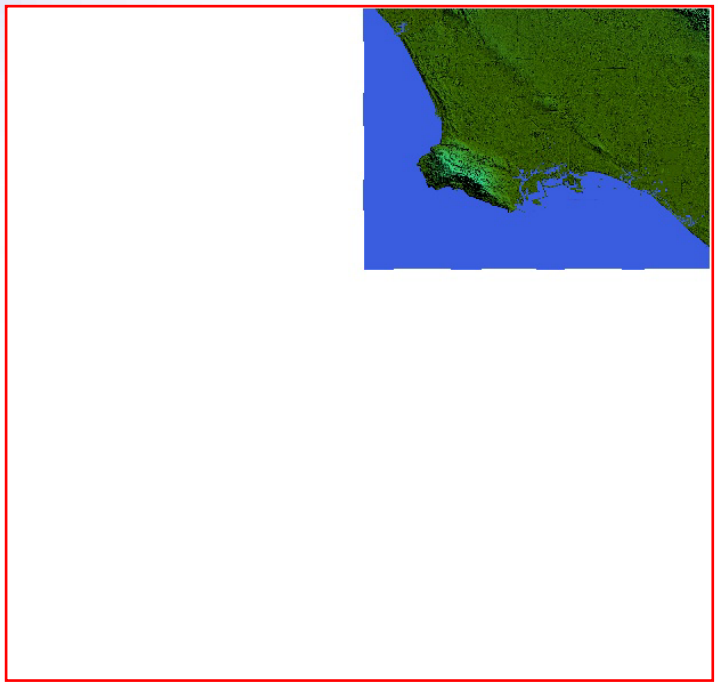
- Terrain types
- Distribution and size of voids
- Availability of accurate reference data

Characteristics of Evaluation Cells

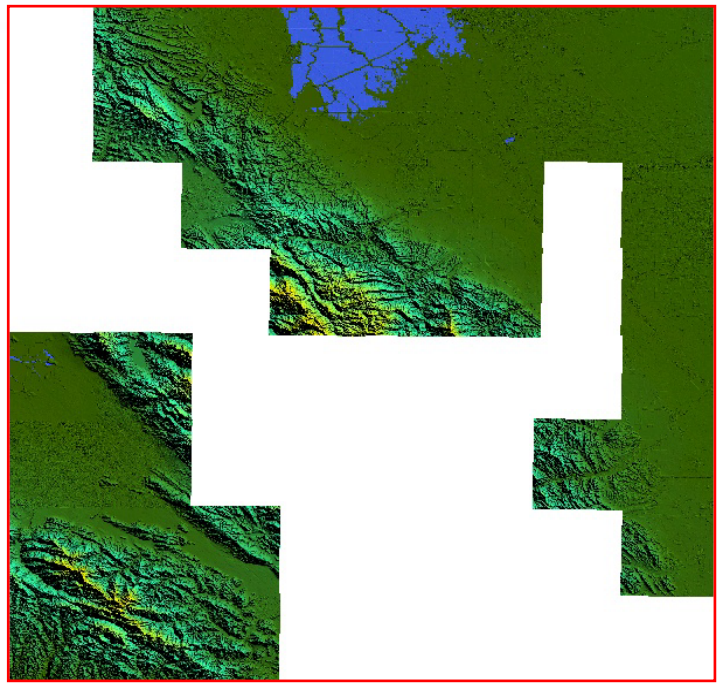
	Relief (m)	Description	Void Area (km^2)
Cell 1	781~1202	Rolling/flat terrain	5.3
Cell 2	931~1351	Very flat terrain/rolling hills	1.1
Cell 3	-26~640	Mostly ocean with flat terrain/ mountainous areas	7
Cell 4	-62~1317	Mostly mountainous/flat terrain to the north east.	56
Cell 5	-39~685	Mostly flat terrain/mountains (NE)/water bodies.	8

Reference Datasets

- STAR-3*i* - Intermap's airborne IFSAR DEM
- Re-sampled from 5m to 1 arc-second resolution.



STAR-3*i* Coverage for Cell 3

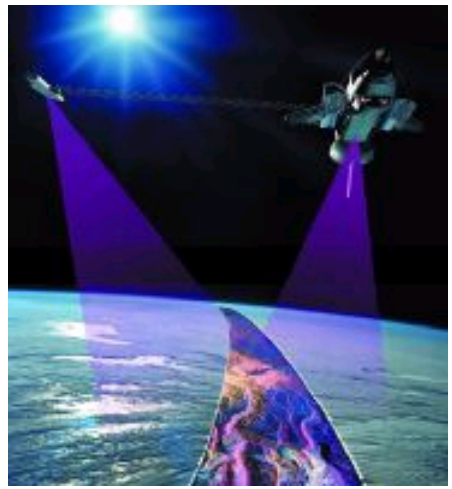


STAR-3i Coverage for Cell 4

Statistical Evaluations

- NGS GCPs were used to evaluate the vertical accuracy (mean elevation difference and RMSE) of:
  - STAR-3*i* reference
  - Source DEM
  - Unfilled SRTM DTED®
  - Filled SRTM DTED®

- Difference images were also calculated between the filled SRTM and reference DEM.



Results and Observations:

Statistical Analysis Using GCPs

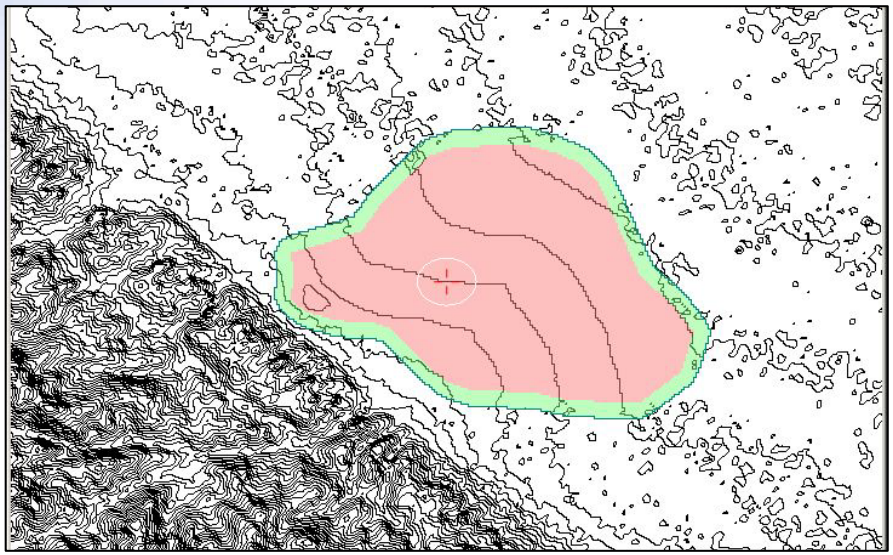
	Cell 1 and 2			Cell 3			Cell 4			Cell 5		
	Mean (m)	RMSE (m)	# of GCP	Mean (m)	RMSE (m)	# of GCP	Mean (m)	RMSE (m)	# of GCP	Mean (m)	RMSE (m)	# of GCP
Source DEM	-1	2	15	-1.6	3.6	87	-1.2	3.8	200	-2.3	4.1	277
Reference DEM	0.1	0.5	12	-0.5	1.5	65	1.1	2.5	144	-0.4	1.4	205
Filled SRTM	3	4.3	15	-0.1	4.5	88	-2.6	4.8	202	-3.3	4.5	277

Statistical Analysis of Difference Images

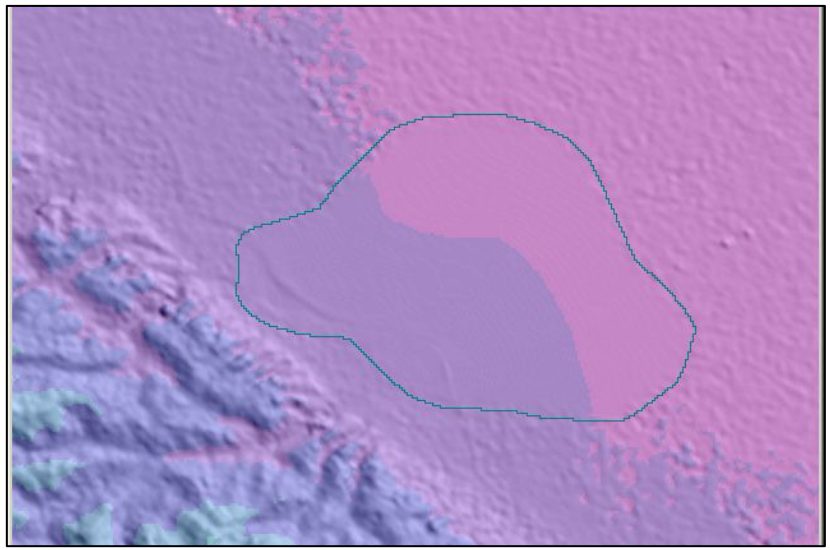
	Cell 1/2			Cell 3			Cell 4			Cell 5		
	~Area km ^{2}	LE90 (m)	Mean (m)	~ Area km²	LE90 (m)	Mean (m)	~Area km ^{2}	LE90 (m)	Mean (m)	~Area km ^{2}	LE 90 (m)	Mean (m)
Unfilled SRTM – STAR-3*i*	4378	7.7	4	Non-Void Area	5.3	1.7	Non-Void Area	10	-2.1	Non-Void Area	4.1	-1.3
Fill Source DEM (void areas) – STAR-3*i*	0.1	22.8	-13.3	4	2.2	0.2	47	9.1	-0.4	7	2.5	0.1
Filled SRTM (void areas) – STAR-3*i*	0.1	5.9	3.4	4	4	1.6	47	7.9	-1.8	7	2.7	-0.3

Visual Analysis (1/3)

Performed to evaluate the internal consistency of the filled voids, using *profiles*, *contours* and *shaded relief*.



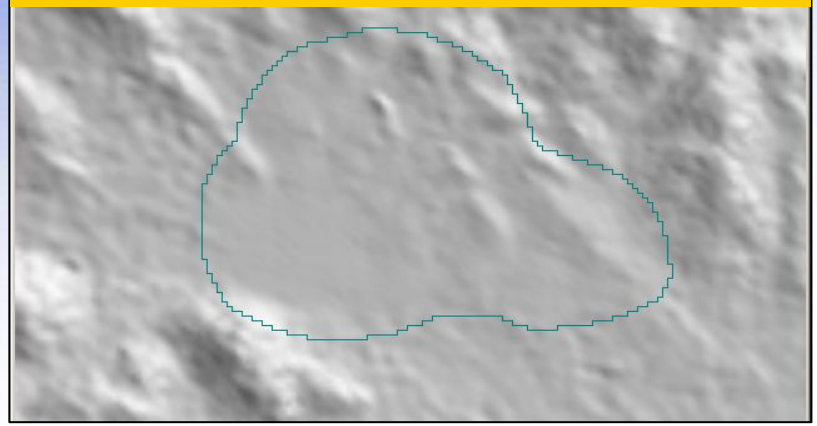
Contour Image for Filled Void #1



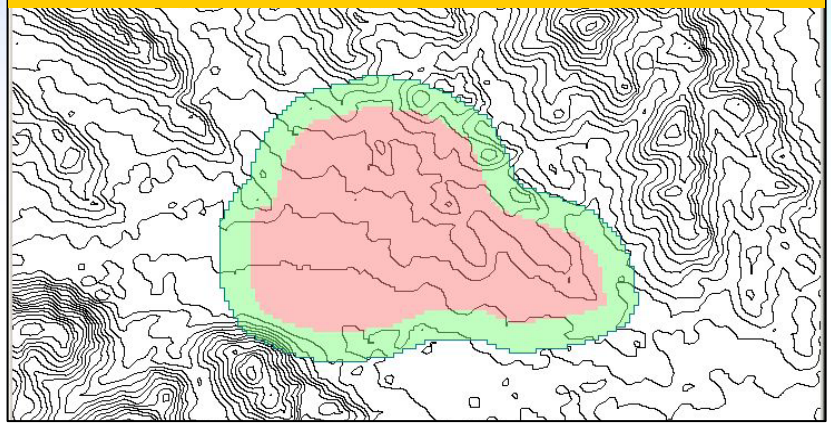
Color-coded Shaded Relief for Filled Void #1

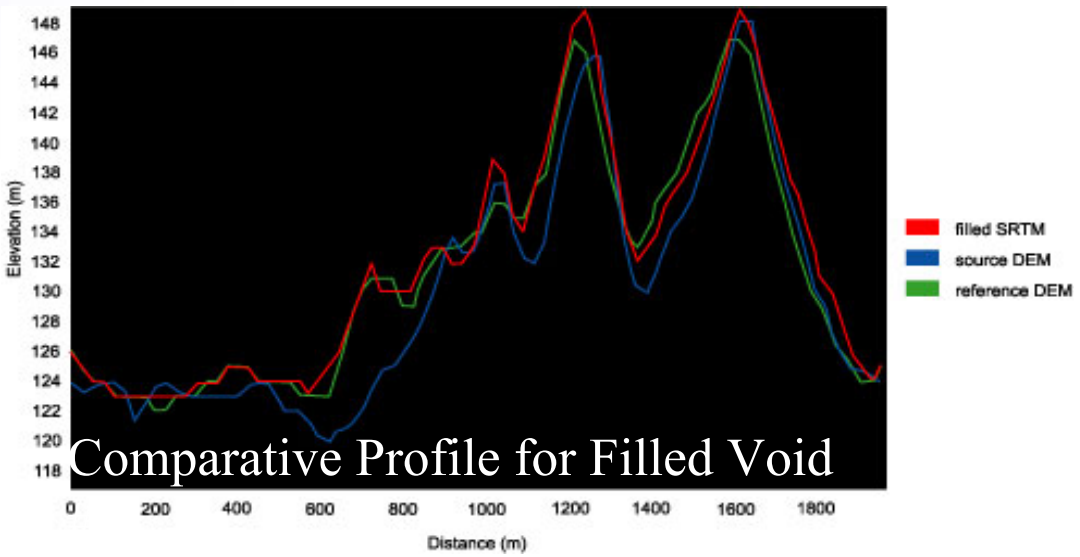
Visual Analysis (2/3)

Shaded Relief for Filled Void #2



Contour Image for Filled Void #2



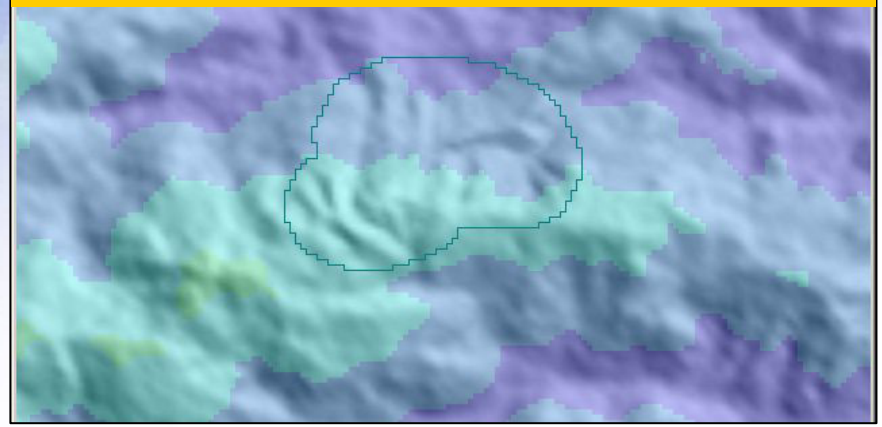


Comparative Profile for Filled Void

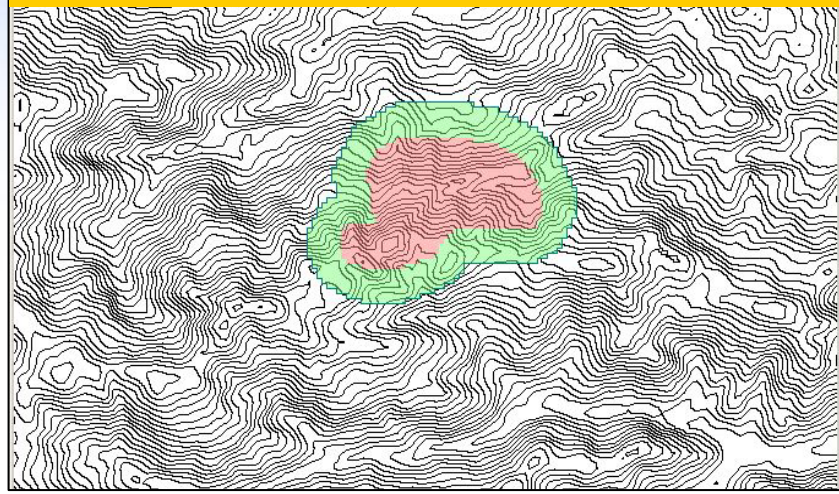
Visually, all voids generally appeared to fill very well.

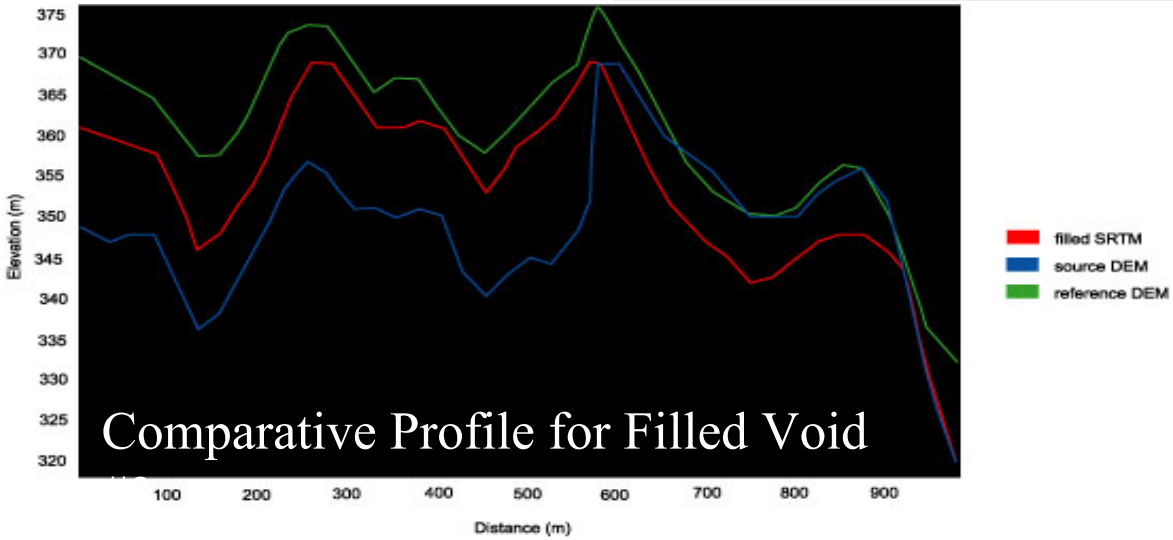
Visual Analysis (3/3)

Color-coded Shaded Relief for Filled Void #3



Contour Image for Filled Void #3



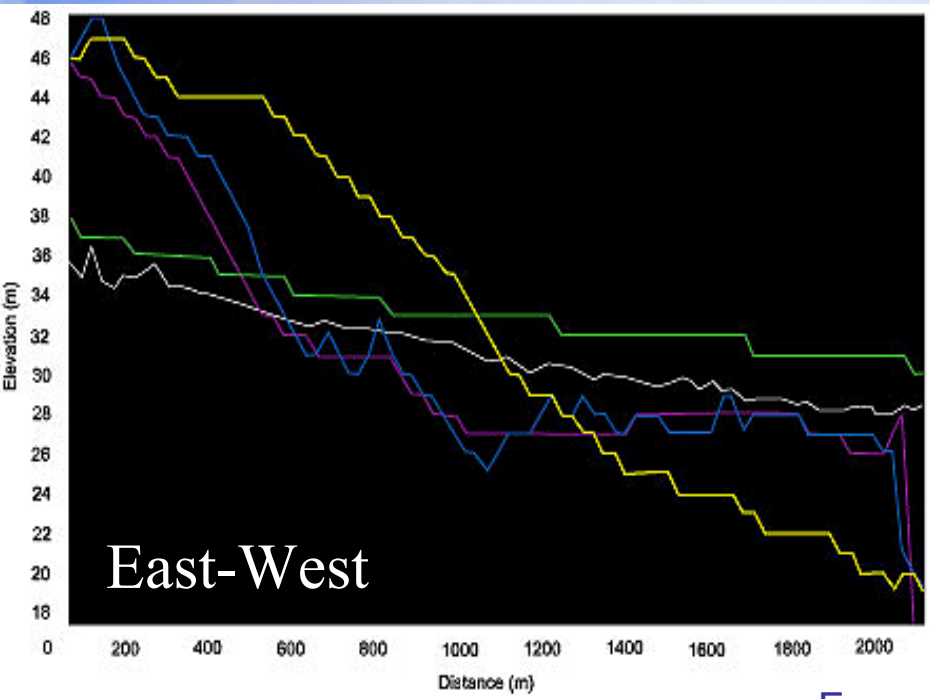


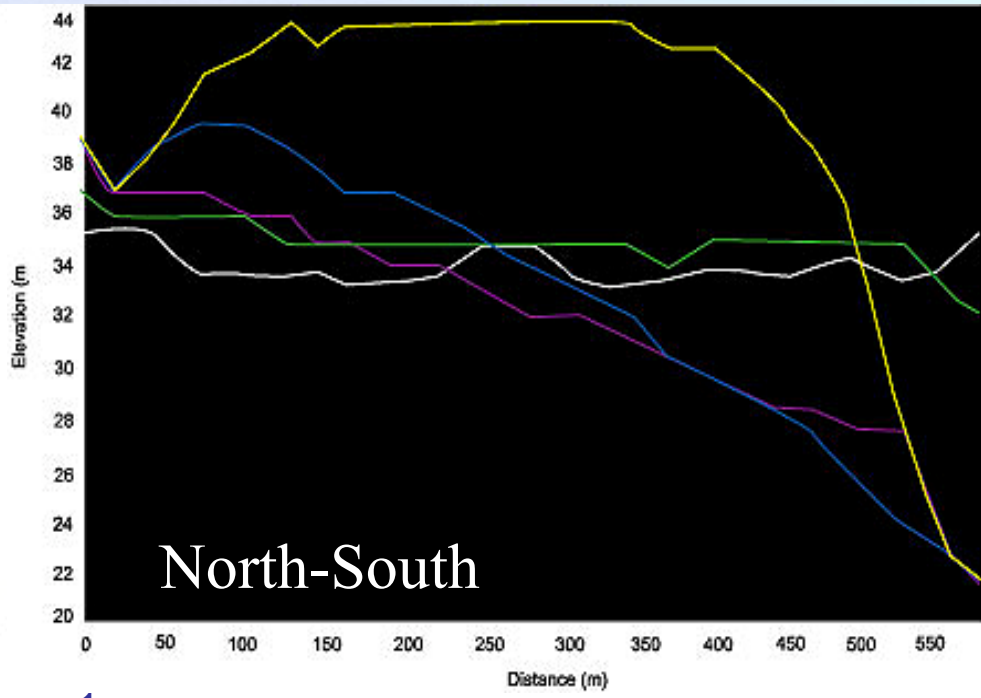
Comparative Profile for Filled Void

Testing of Freeware VF packages

Software	Fill Type / Additional Tools
BLACKART (TerrainMap.com)	- Interpolation algorithm - Does have the ability to use alternate elevation datasets
3DEM (Visualization Software LLC)	- Interpolation algorithm
VTBuilder (Virtual Terrain)	- Interpolation algorithm
Boeing-Intermap SRTM Void Fill Process	- Uses the best source DEM available (from NGA) - Global H/V shifts applied to source DEM - Local vertical shift applied to source DEM for each individual fill region - 3, 5, or 7 pixel feathering to smooth transition from source to SRTM

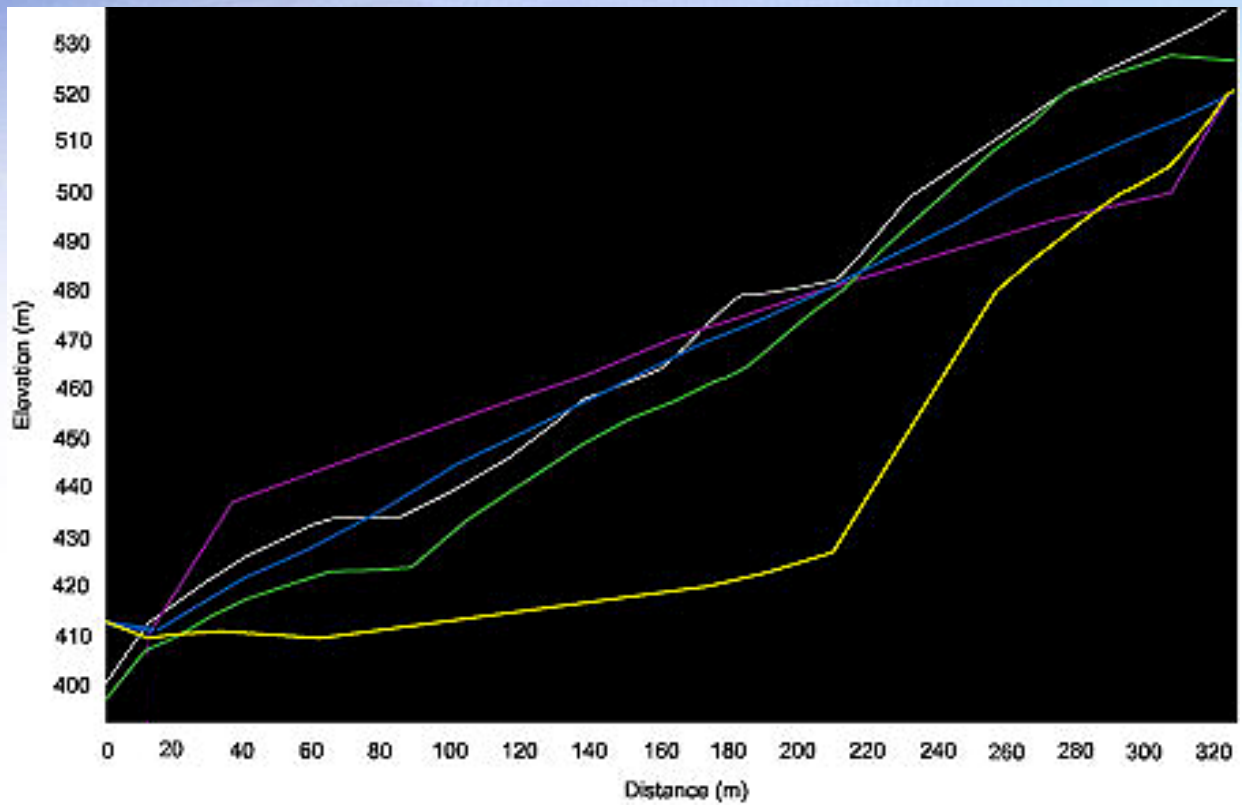
Profiles of Fill Results for Void #1





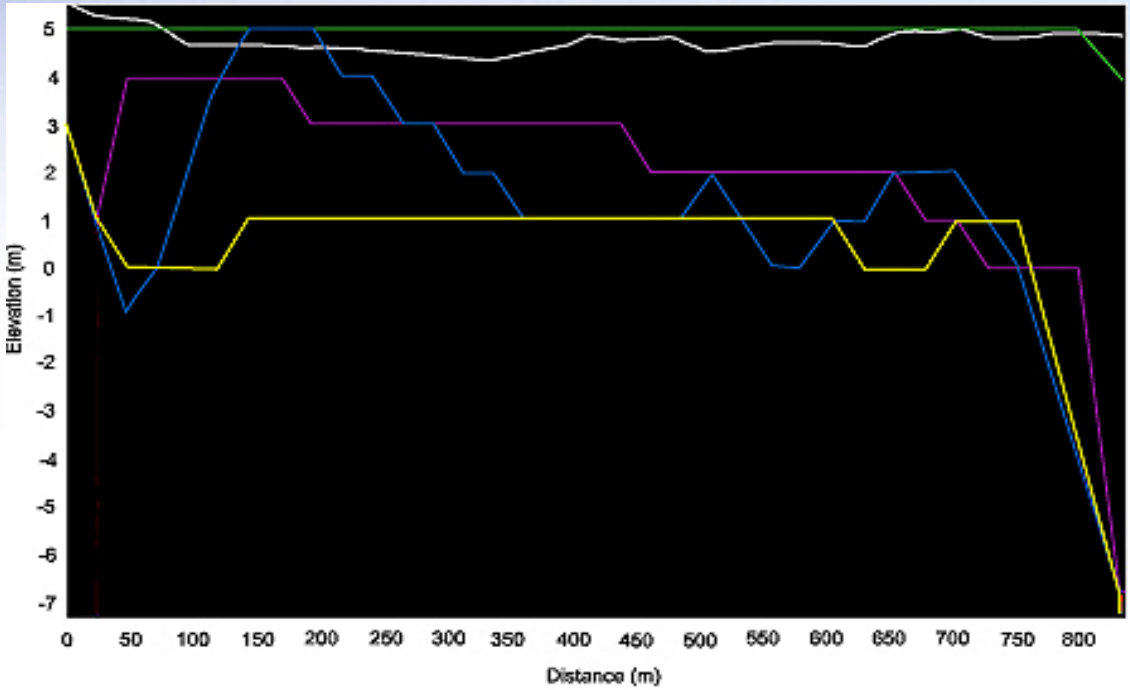
- Freeware 1
- Freeware 2
- Freeware 3
- Boeing-Intermap SRTM VF
- STAR-3*i*

Profiles of Fill Results for Void #2



- Freeware 1
- Freeware 2
- Freeware 3
- Boeing-Intermap SRTM VF
- STAR-3*i*

Profiles of Fill Results for Void #3



- Freeware 1
- Freeware 2
- Freeware 3
- Boeing-Intermap SRTM VF
- STAR-3*i*

Performance Evaluation Summary

- GCP and LiDAR confirmed that STAR-3*i* was an accurate and reliable reference DEM.

- Visual analysis showed the Boeing-Intermap process is effective in providing a natural-looking void-free SRTM product. This is dependent on the quality of the fill source.

- Freeware evaluation - tests performed were not extensive enough to draw broad conclusions of the overall performance.

- However, results do suggest caution when using freeware VF packages to fill SRTM voids

Conclusions

- Consistent method used to evaluate and select fill sources used to fill voids
  - NGA approves the fill sources used to fill each cell
  - Web-based feasibility tool makes it possible for NGA to evaluate large volumes of data in short time-periods
- More than just void filling -- Phase Unwrap Errors are removed from the dataset
- The DTED® header is updated with information on what source was used to fill the voids
- The entire SRTM product suite is updated (THED, SHCM, SWBD, DTED®-2, DTED®-1) – not just the DTED®-2
- We utilize a high-volume production environment so that thousands of cells are enhanced each year.
- This process has been evaluated and proven effective in providing a natural-looking void-free SRTM product.