BAE SYSTEMS

Commercial Imagery and Terrain Models Used in Computer Vision at BAE Systems

Dr. Byron Smiley

18 Apr 2013

USGS science for a changing world

NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

NASA

USDA

Joint Agency Commercial Imagery Evaluation

JACIE

© BAE Systems 2013. All rights reserved. Approved for Public Release; Distribution Unlimited. Cleared for Open Publication on 18 Apr 2013.

These BAE Systems employees performed this research

- All members the Video Understanding and Exploitation (VUE) directorate
- Dr. Victor Tom, Principal Investigator
  - Brian Berard
  - Dr. Riad I. Hammoud
  - Dr. Rich T. Ivey
  - Scott Kuzdeba
  - Dr. Byron D. Smiley

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Outline

- Description of the research that requires imagery and terrain models
- Imagery and terrain models acquired by BAE Systems, used in the research
- Computer vision matchers that use the imagery and terrain models

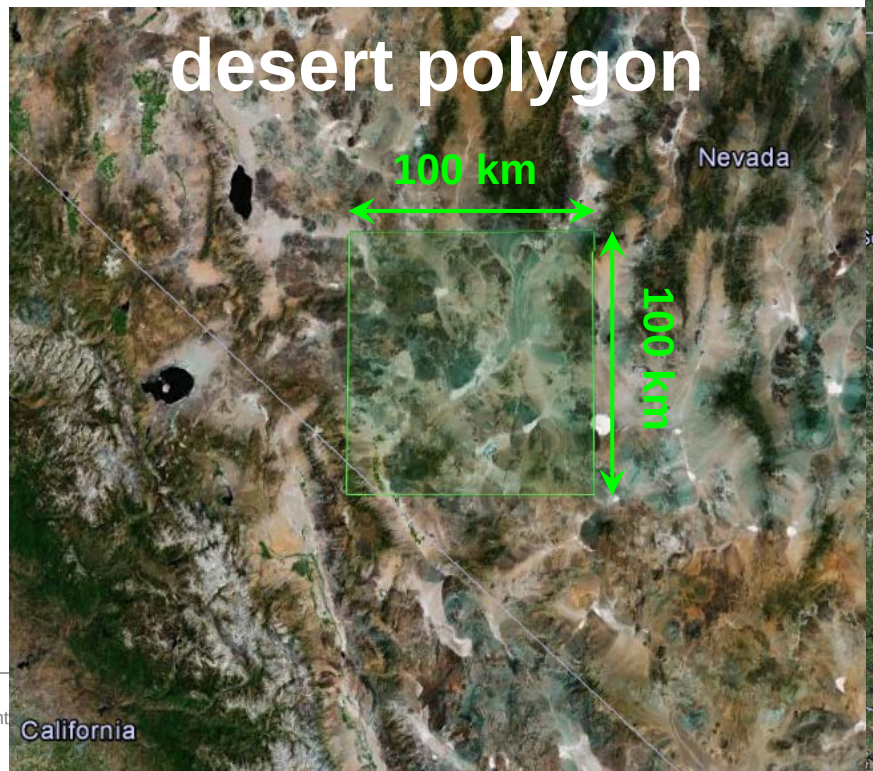
© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

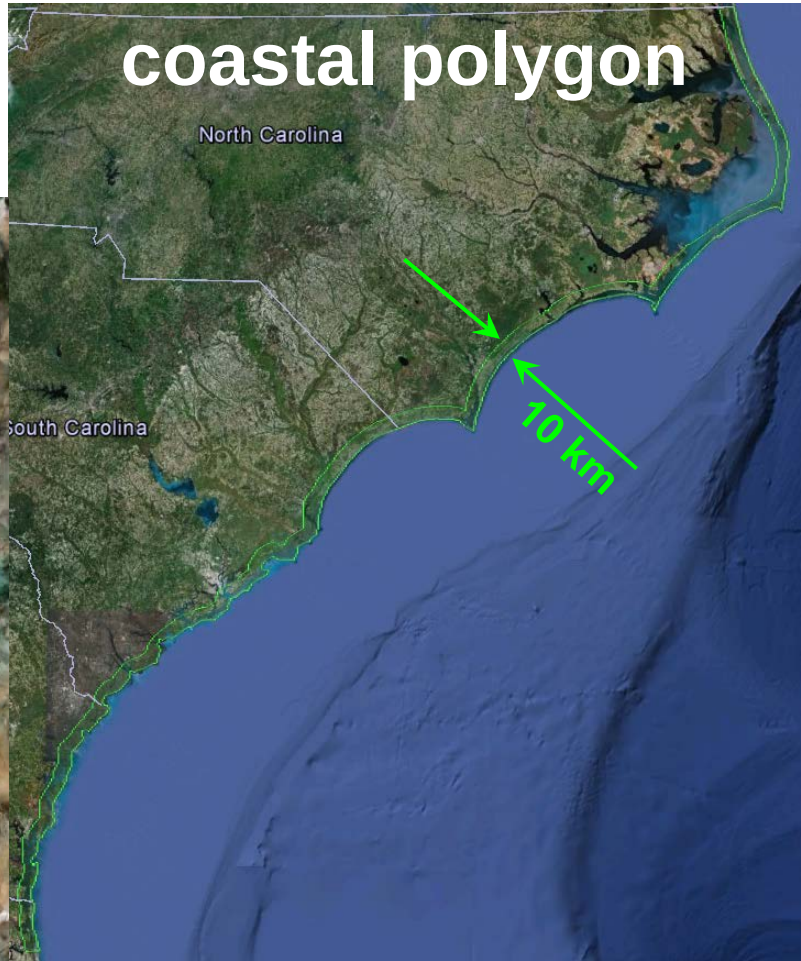
The research

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

BAE Systems is geolocating photos and video sequences

- Given a photo or video, deduce where it was taken
  - The camera location, perspective center, assumed ~2 meters above ground
  - An object's location in the image/video easier sometimes, but this is converted to camera location for the final output
- Currently bounded to two regions in the US, desert and coast





© BAE Systems 2013. All right

Typical photos in the two regions look like this

desert

coast

Must be outdoor photos! (otherwise, remote sensing products aren't helpful!)

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Typical videos in the two regions look like this

desert

coast

Must be outdoor videos! (same reason as before)

Our matchers work with images, so one frame is used that has the most discriminative features.

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

The overhead imagery and terrain models

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

BAE Systems acquired remote sensing products in 2012

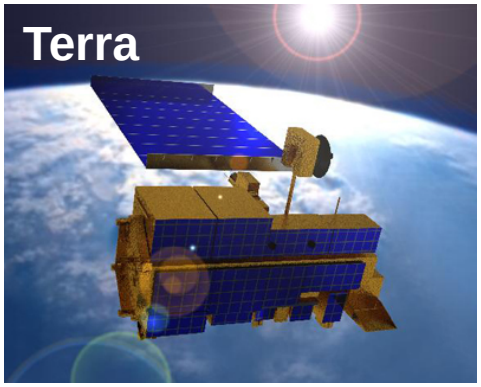
More than this was acquired, but for simplicity, only showing those discussed today.

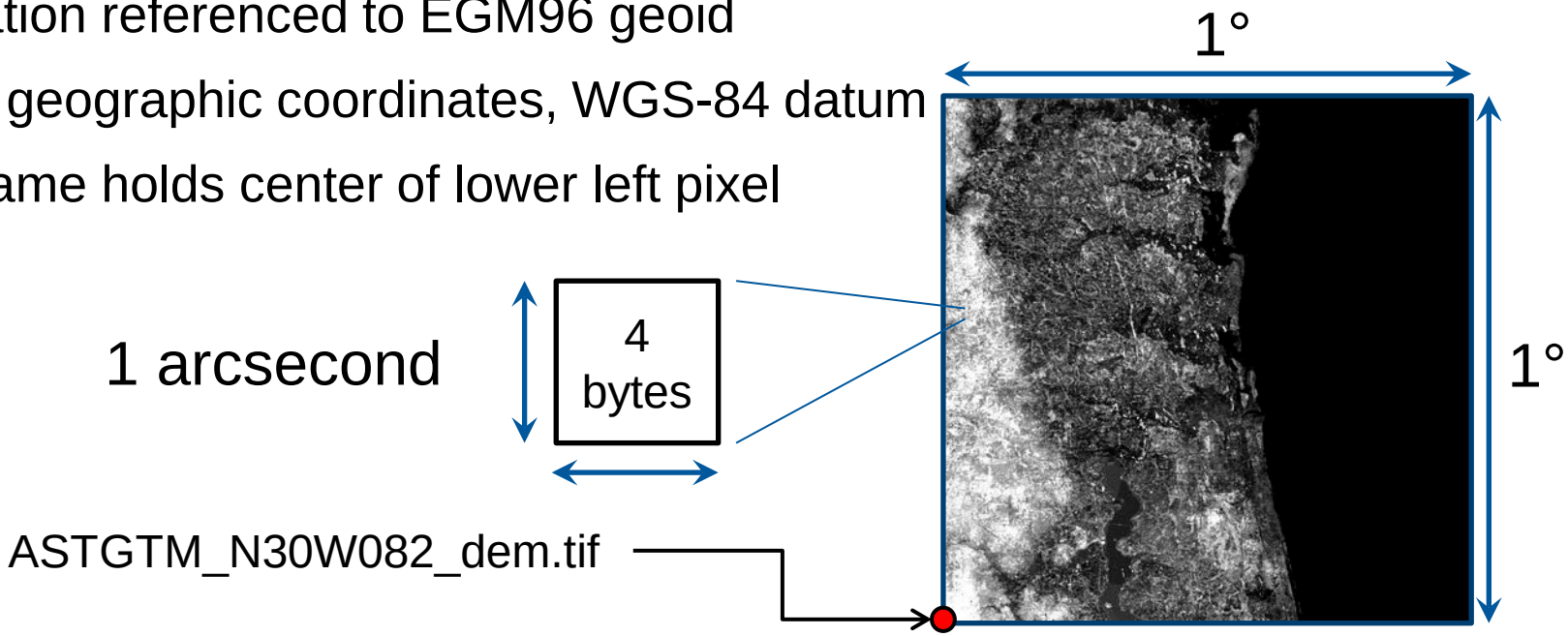
scale	imagery (pixel sizes in meters)	digital elevation models (pixel sizes in meters)
coarse	Landsat 5 and 7, National Land Cover Dataset (30)	ASTER GDEM (~30)
fine	North American Mapping (0.3), High Resolution Orthophotos (0.5), National Agriculture Imagery Program (1)	NOAA free lidar (~2)

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

The ASTER GDEMs were very easy to use as-is

- ASTER GDEMs come from ASTER stereo images
- Each TIF file is a square 1° tile
- Each pixel is 1 arcsecond, 2.7777777777778e-4°
- Each pixel stores elevation as a signed integer
- Elevation referenced to EGM96 geoid
- Uses geographic coordinates, WGS-84 datum
- Filename holds center of lower left pixel

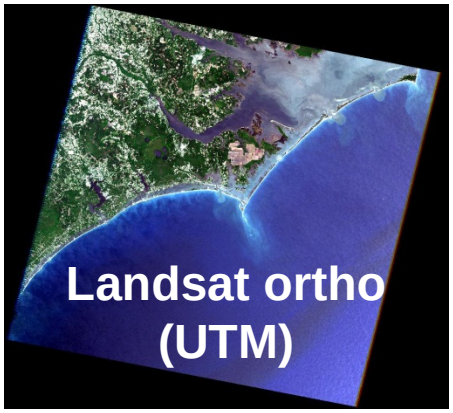


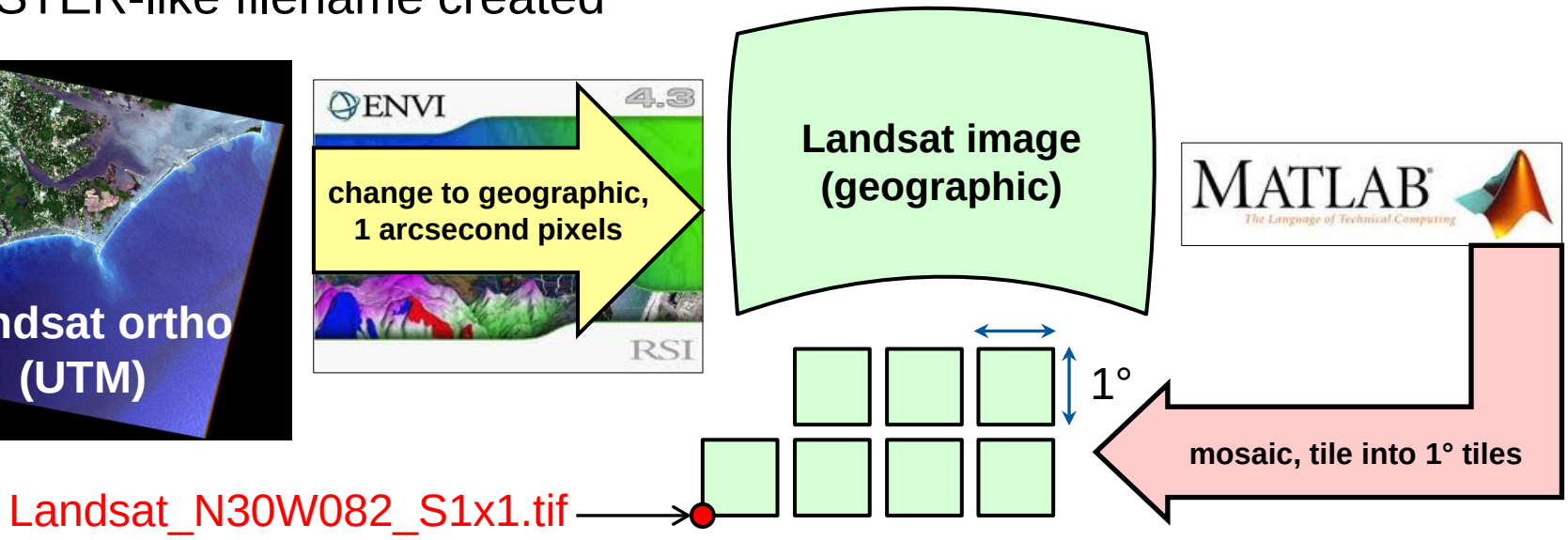


© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Landsat images were reprojected for easier use

- Landsat 5,7 (bands: 1, 2, 3, 4, 5, 7) [2003-2006] L1T products were UTM, 30 meter pixels, ~1 arcsecond
- Used IDL to unproject back into geographic coordinates, also resample to pixel size of 1 arcsecond exactly
- Used MATLAB to mosaic all data, then chop into 1° tiles
- ASTER-like filename created





© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

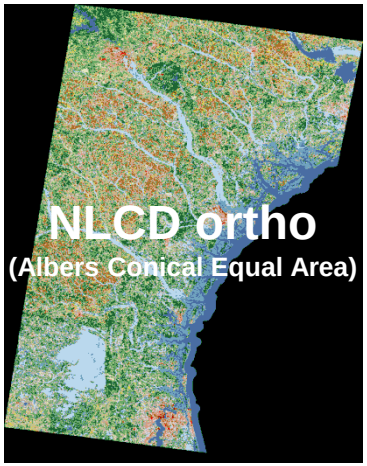
National Land Cover Dataset tiles were also reprojected

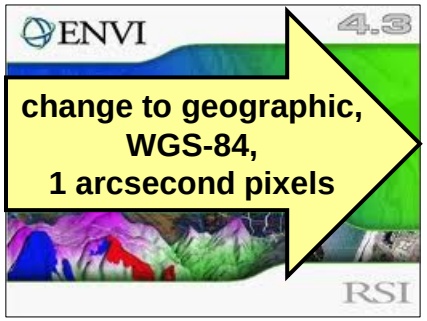
- NLCD (2006 data, released in 2011) used Albers Conical Equal Area projection, NAD-83, 30 meter pixels
- Used IDL to unproject back into geographic coordinates using WGS-84 datum, resampled to 1 arcsecond
- Used MATLAB to mosaic all data, then chop into 1° tiles
- ASTER-like filename created

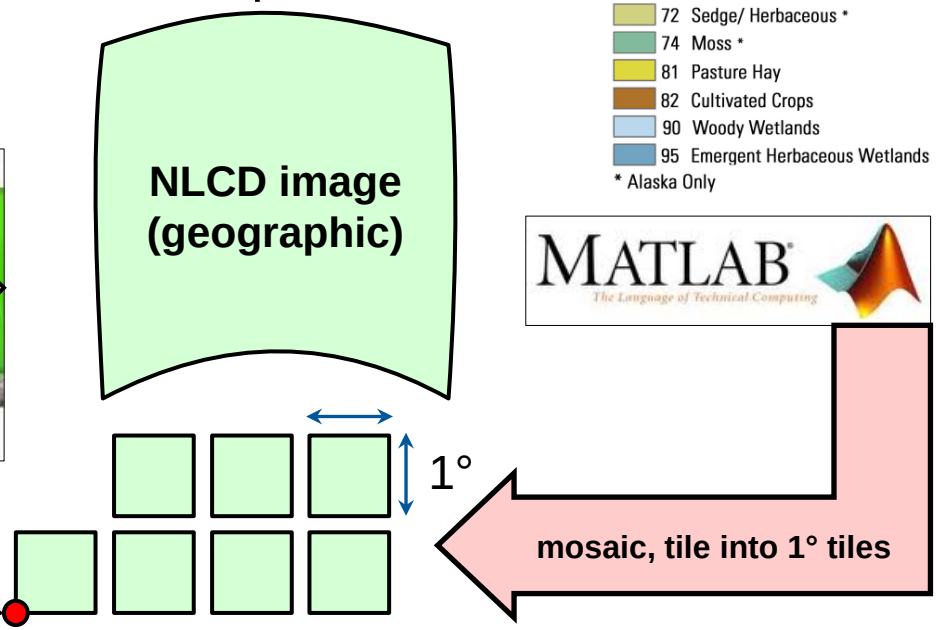
NLCD Land Cover Classification Legend

- 11 Open Water
- 12 Perennial Ice/Snow
- 21 Developed, Open Space
- 22 Developed, Low Intensity
- 23 Developed, Medium Intensity
- 24 Developed, High Intensity
- 31 Barren Land
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest
- 51 Dwarf Scrub*
- 52 Shrub/ Scrub
- 71 Grassland/ Herbaceous
- 72 Sedge/ Herbaceous *
- 74 Moss *
- 81 Pasture Hay
- 82 Cultivated Crops
- 90 Woody Wetlands
- 95 Emergent Herbaceous Wetlands

* Alaska Only







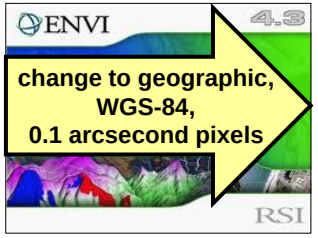
NLCD_N30W082_S1x1.tif

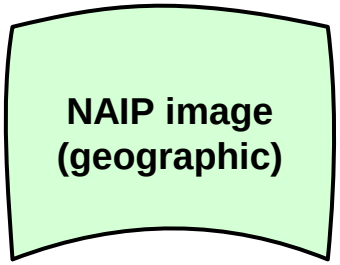
© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

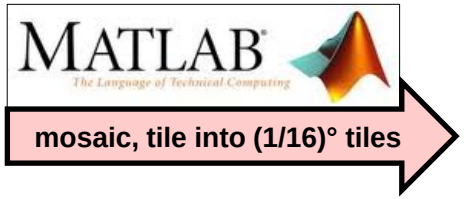
All aerial imagery was reprojected, and also resampled

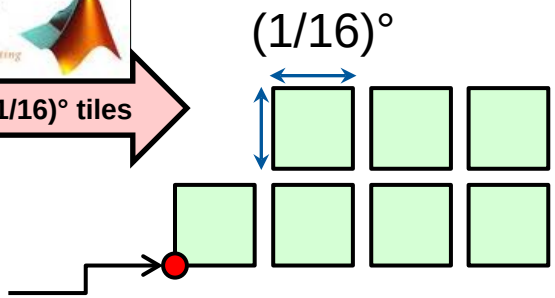
- Aerial imagery all used UTM projection, NAD 83 datum
- Pixel size differed, though:
  - North American Mapping (NAM), 0.3 meters
  - High Resolution Orthophotos (HRO), 0.5 meters
  - National Agriculture Imagery Program (NAIP), 1.0 meters

- Used IDL to unproject back into geographic coordinates, using WGS-84 datum, resampled to 0.1 arcsecond (~3 meters)
- Used MATLAB to mosaic all data, then chop into (1/16)° tiles
- ASTER-like filename created







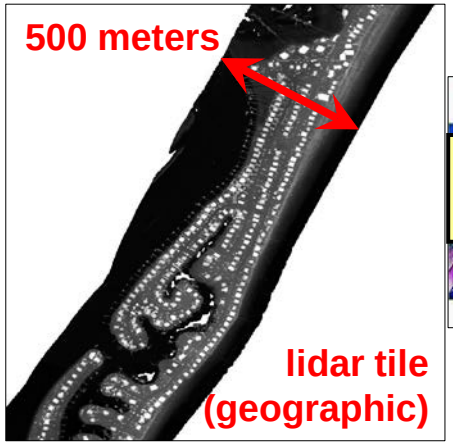


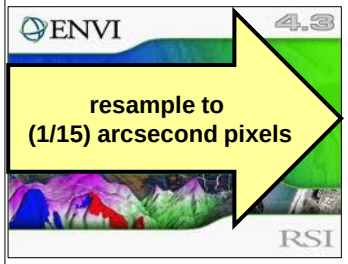
NAIP_N30.3125W081.4375_S0.0625x0.0625.tif

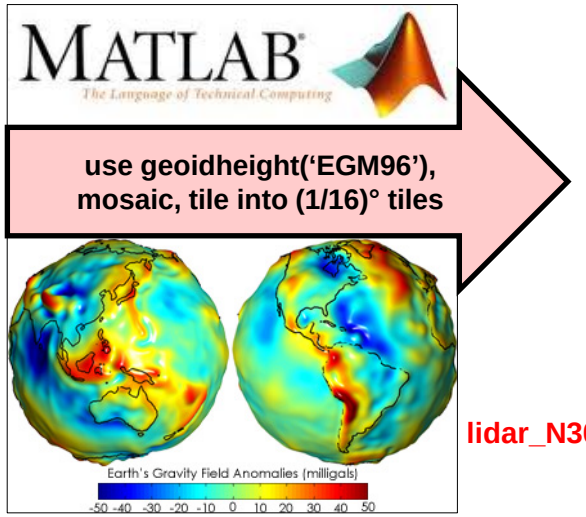
© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

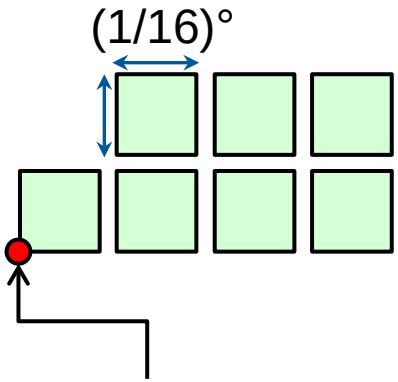
NOAA lidar data was re-referenced to the EGM96 geoid

- 2009-11 coastal surveys, free at http://www.csc.noaa.gov/dataviewer/#
- Already in geographic coordinates, WGS-84 datum, ~2 meter pixels
- Used IDL to resample to (1/15) arcsecond pixel size
- Used MATLAB to mosaic all data, then chop into (1/16)° tiles
- Also used MATLAB to convert elevations from height above ellipsoid (HAE) to orthometric (MSL) using EGM96 geoid, to match the ASTER GDEMs
- ASTER-like filename created







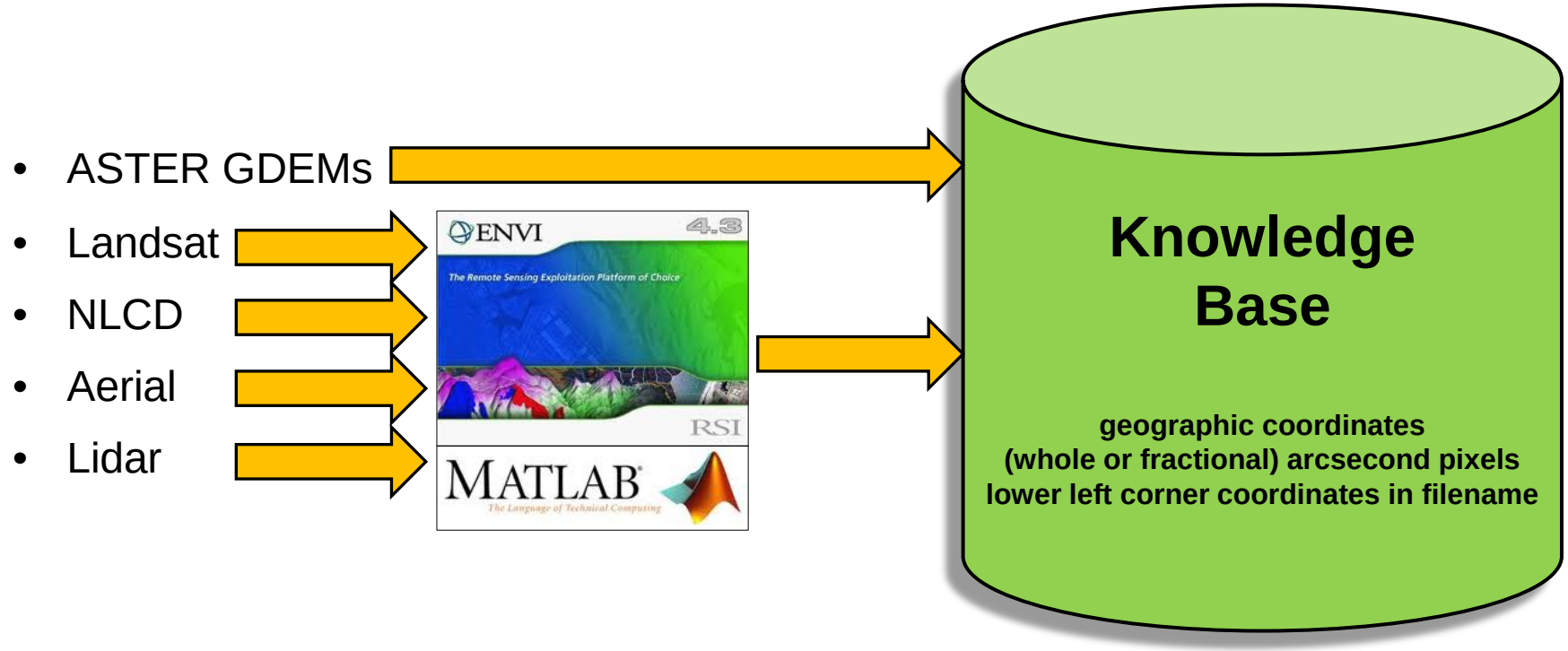


lidar_N30.3125W081.4375_S0.0625x0.0625.tif

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

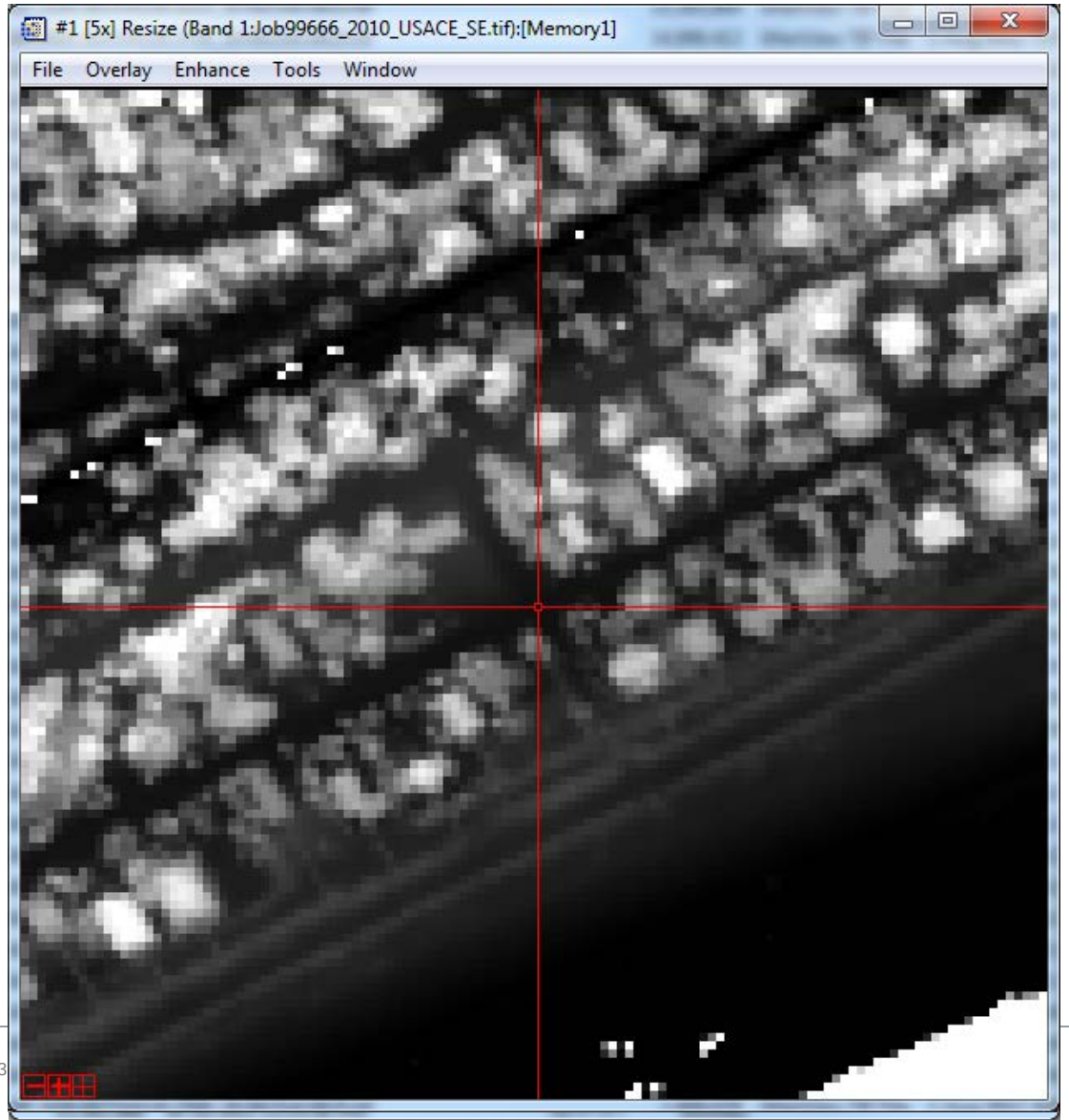
ASTER GDEMs inspired the format of the Knowledge Base

- All overhead imagery and terrain models now have a common format
- All data now equally easy to use
- All matchers can now draw from a common “Knowledge Base”



© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

The lidar to NAIP registration was excellent, within 1 pixel



Folly Beach, SC

registered to one (3 meter) pixel

© BAE Systems 2013

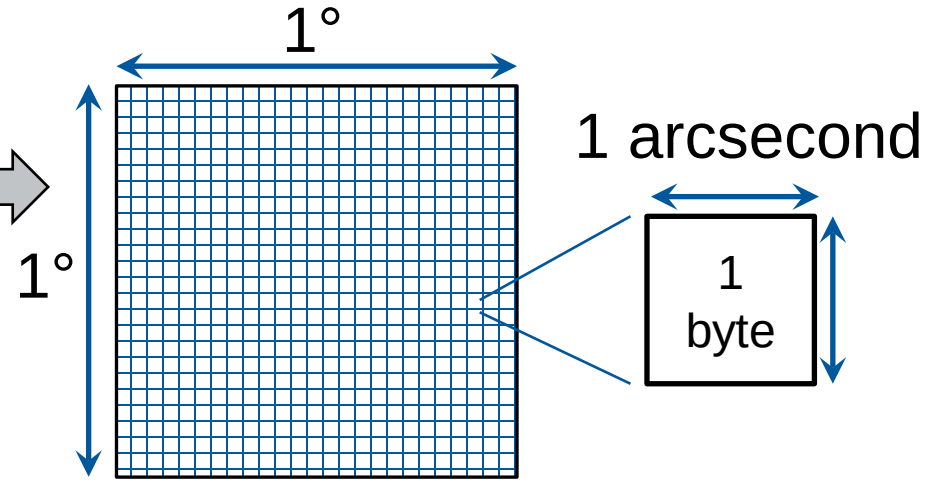
The matchers

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

BAE Systems' matchers have an ASTER-like output format

- All the computer vision matchers:
  - Take an image as the input, either a still photo or video frame
  - Return an ASTER-like output array, square 1° cell with (8-bit) arcsecond pixels

matcher



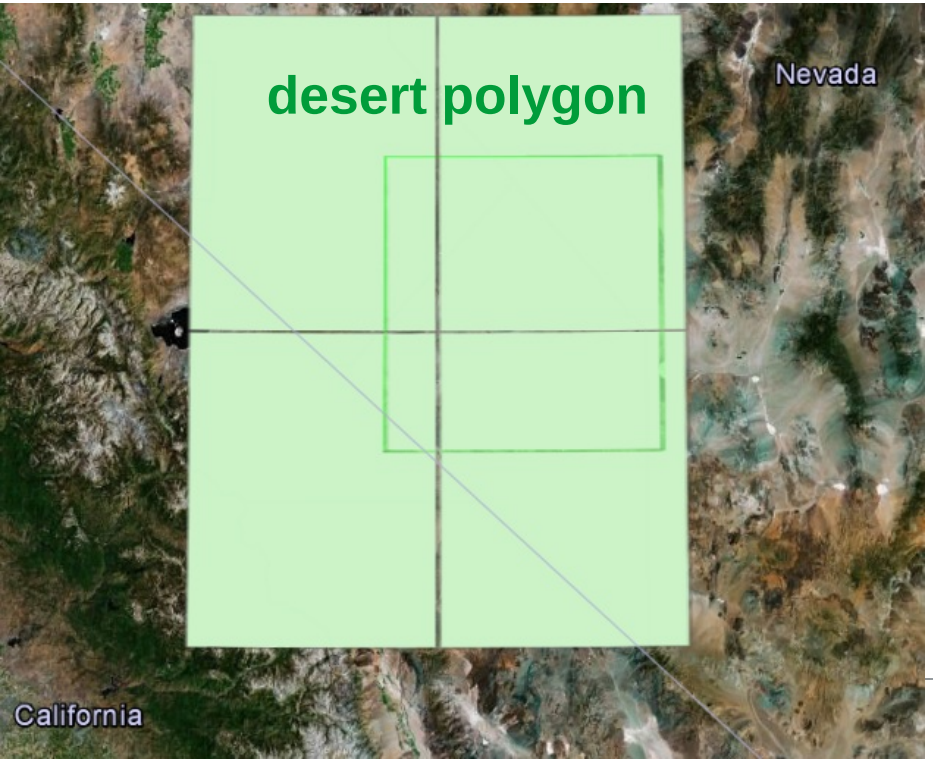
8-bit value represents higher or lower probability of photo coming from that lat/lon

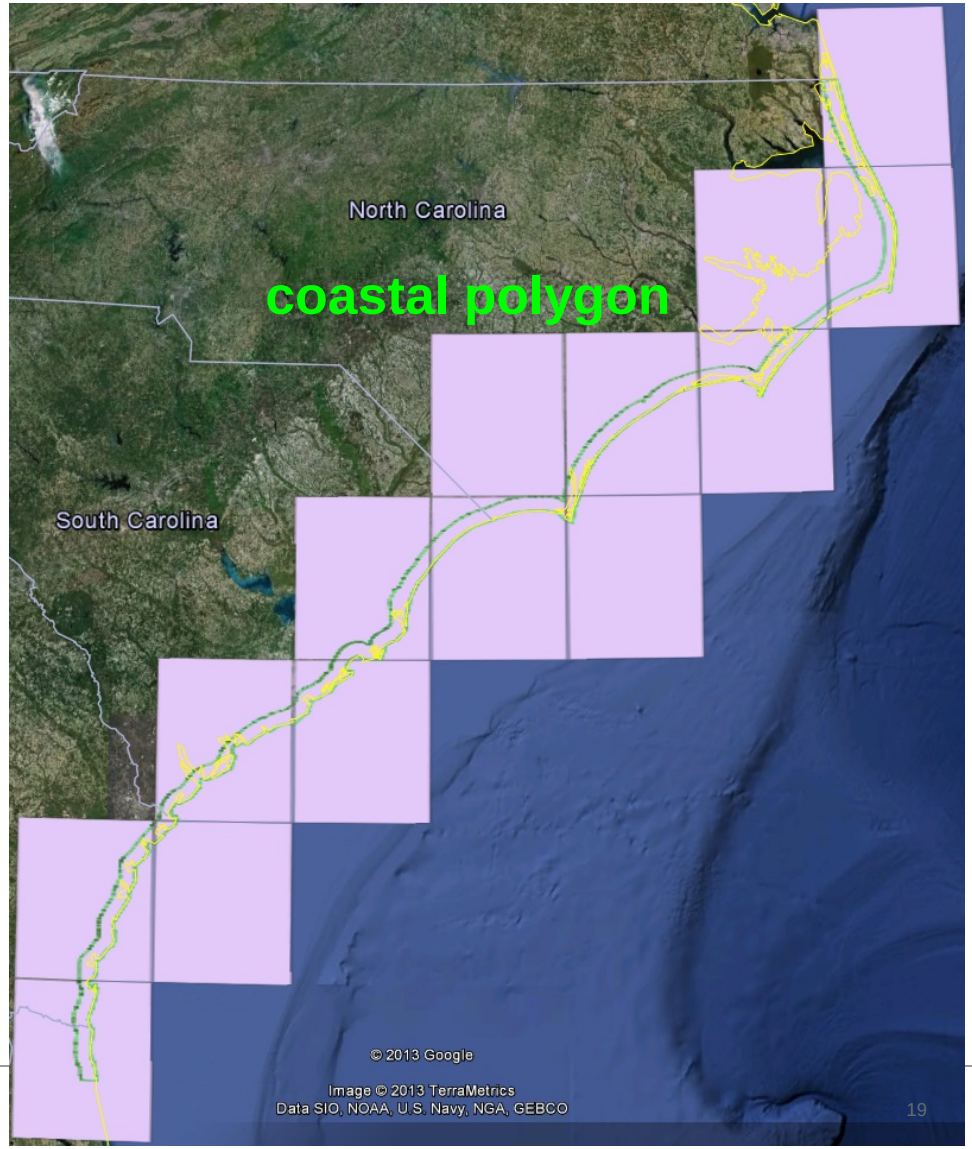
- 255 – certainly taken there
- 127 – same prob as random chance
- 1 – certainly not taken there
- 0 – no data, not evaluated

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Eighteen 1° cells are needed to cover both regions

- 1° cell coverage:
  - 14 over the coast polygon
  - 4 over the desert polygon
- Matchers loop over all 1° cells





The Land Use Aggregate Scene Matcher uses the NLCD

- Written by Brian Berard
- Takes user specified land classes for camera location
- Can also add classes within view

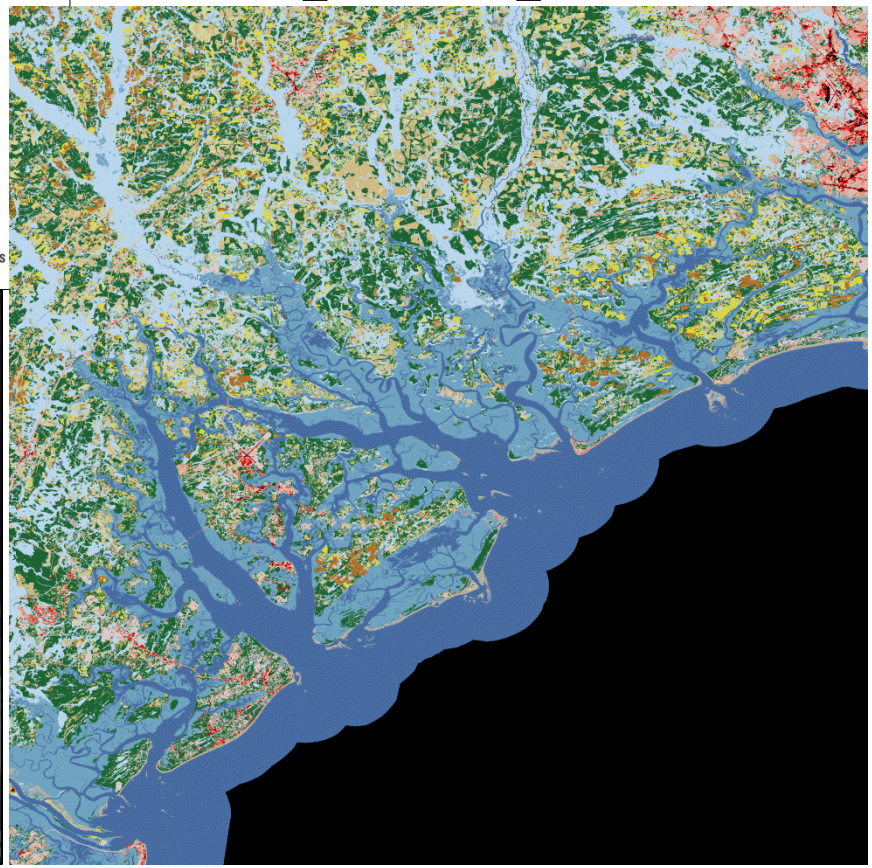
NLCD Land Cover Classification Legend

- 11 Open Water
- 12 Perennial Ice/Snow
- 21 Developed, Open Space
- 22 Developed, Low Intensity
- 23 Developed, Medium Intensity
- 24 Developed, High Intensity
- 31 Barren Land
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest
- 51 Dwarf Scrub*
- 52 Shrub/ Scrub
- 71 Grassland/ Herbaceous
- 72 Sedge/ Herbaceous *
- 74 Moss *
- 81 Pasture Hay
- 82 Cultivated Crops
- 90 Woody Wetlands
- 95 Emergent Herbaceous Wetlands

* Alaska Only

query image

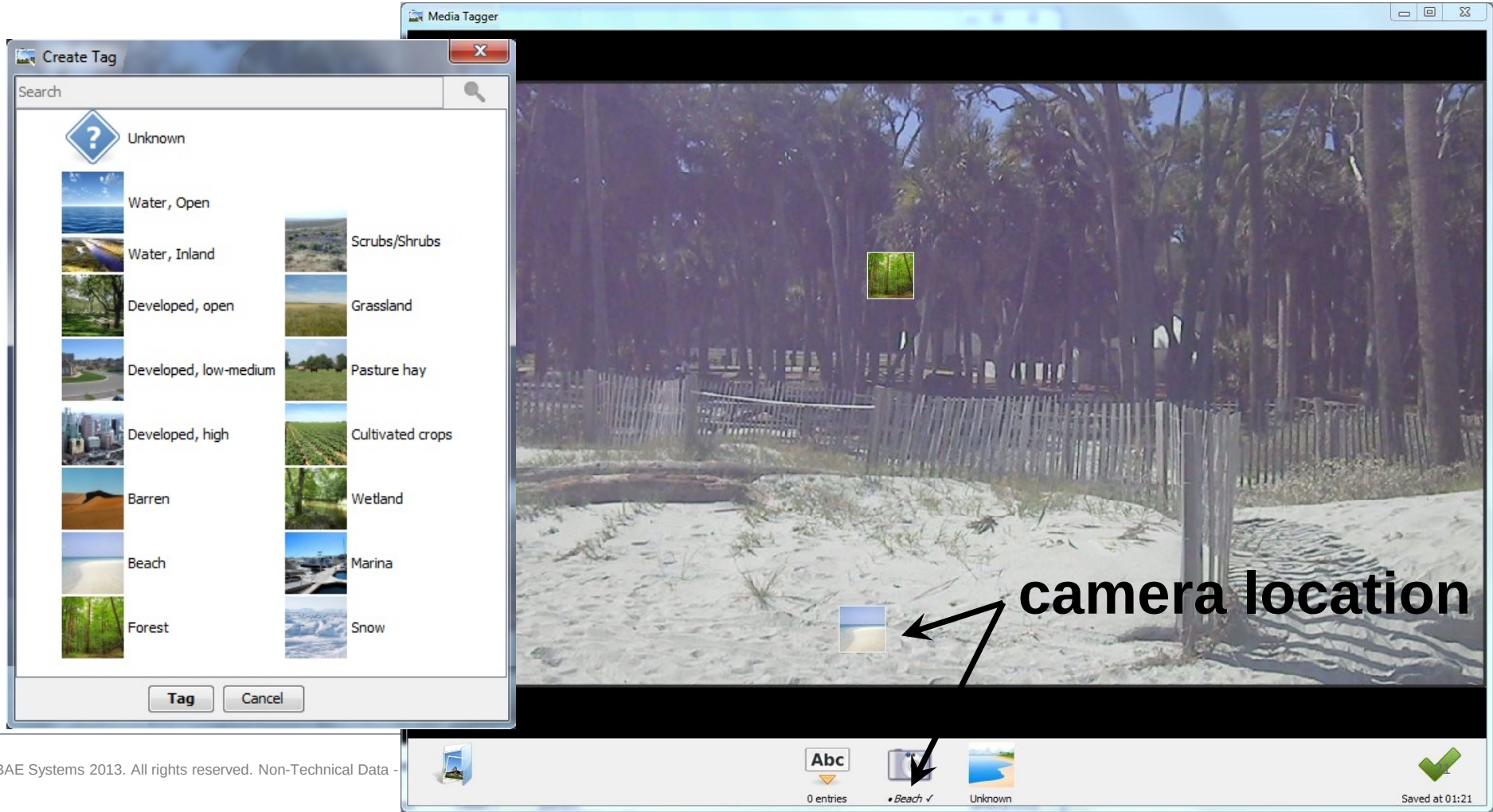
NLCD_N32W081_S1x1.tif



© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

The user tags visible land classes in the query image

- Java based Media Tagger allows user to specify which land classes are seen for the Land Use Aggregate Scene Matcher

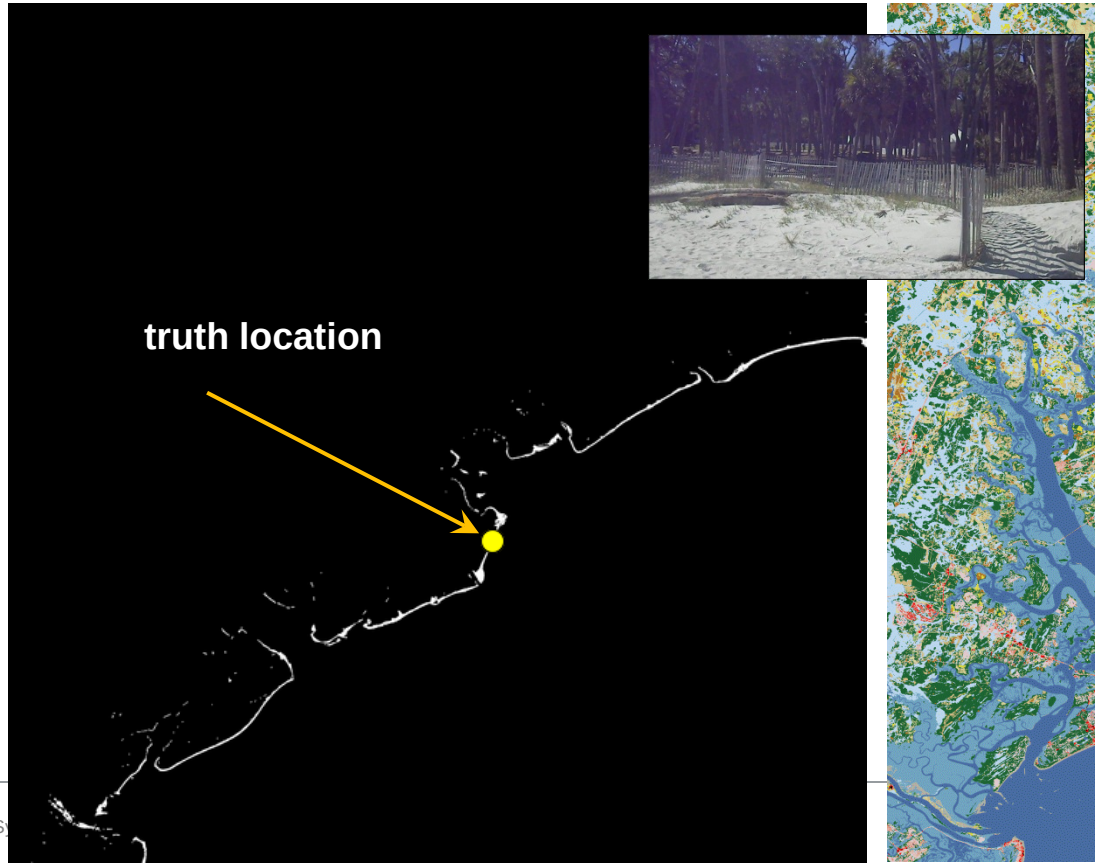


© BAE Systems 2013. All rights reserved. Non-Technical Data -

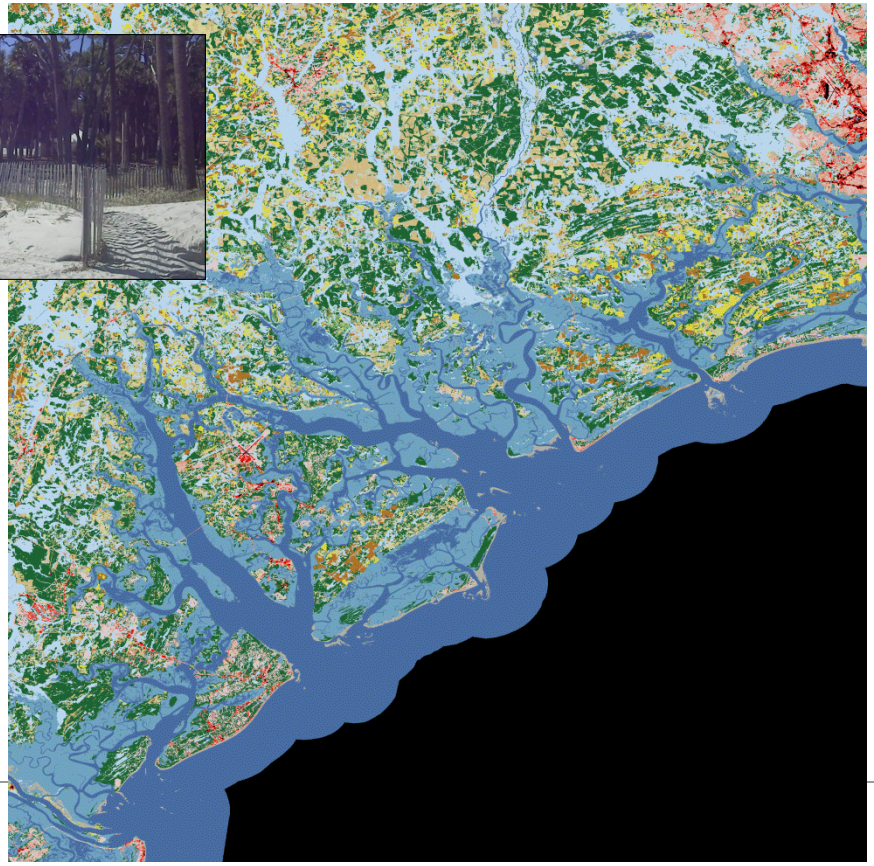
The NLCD can eliminate many possible camera locations

- Land Use Aggregate Scene Matcher returns “barren” class in output array, since camera location was on the beach
- This simple observation eliminates much of the 1° cell!

Land Use Aggregate Scene Matcher output array

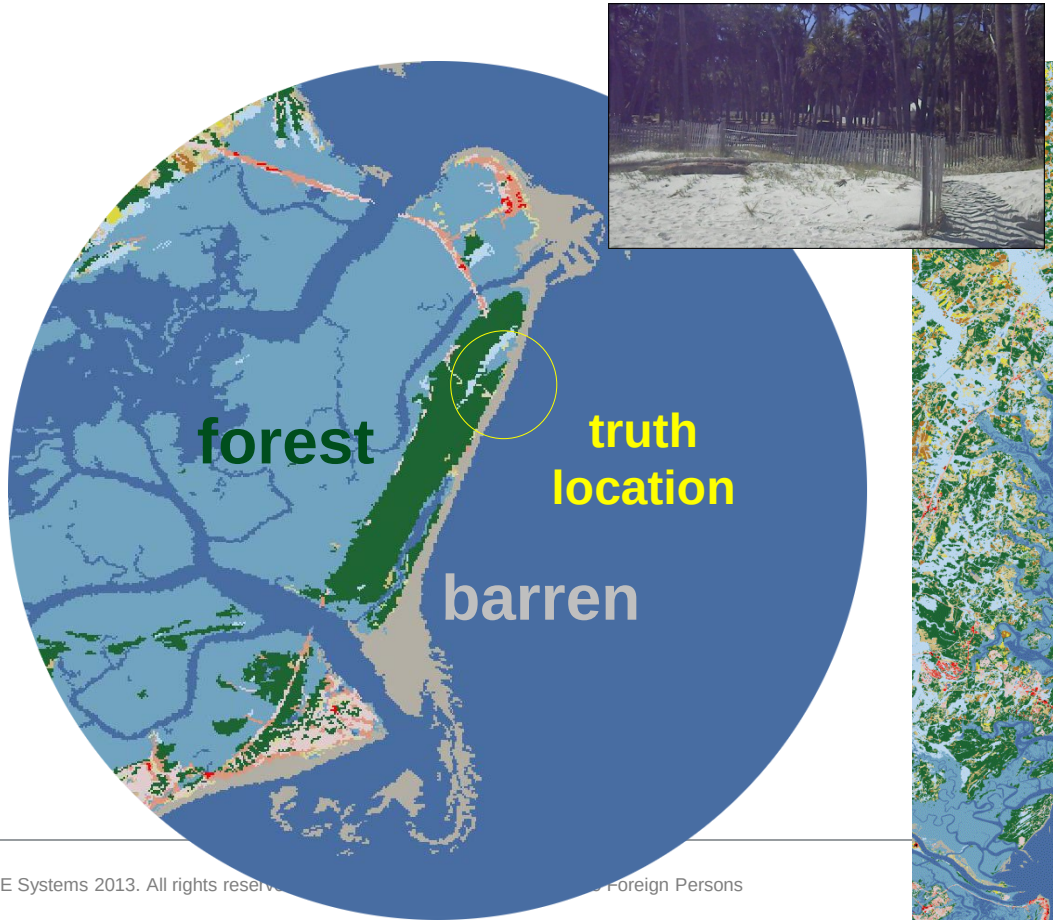


National Land Cover Database tile

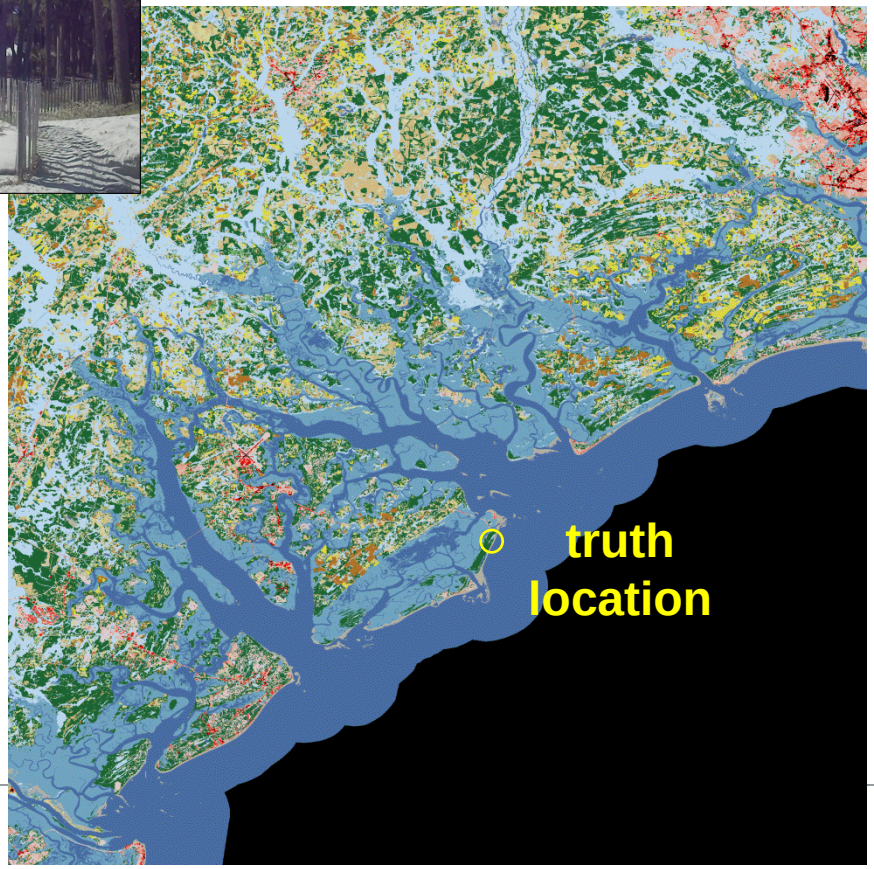


Identifying multiple land classes in view helps even more

- Note how truth location was on beach in front of forest (also taggable)
- Future versions of Land Use Aggregate Scene Matcher will handle adjacency between land classes, in addition to unions



National Land Cover Database tile

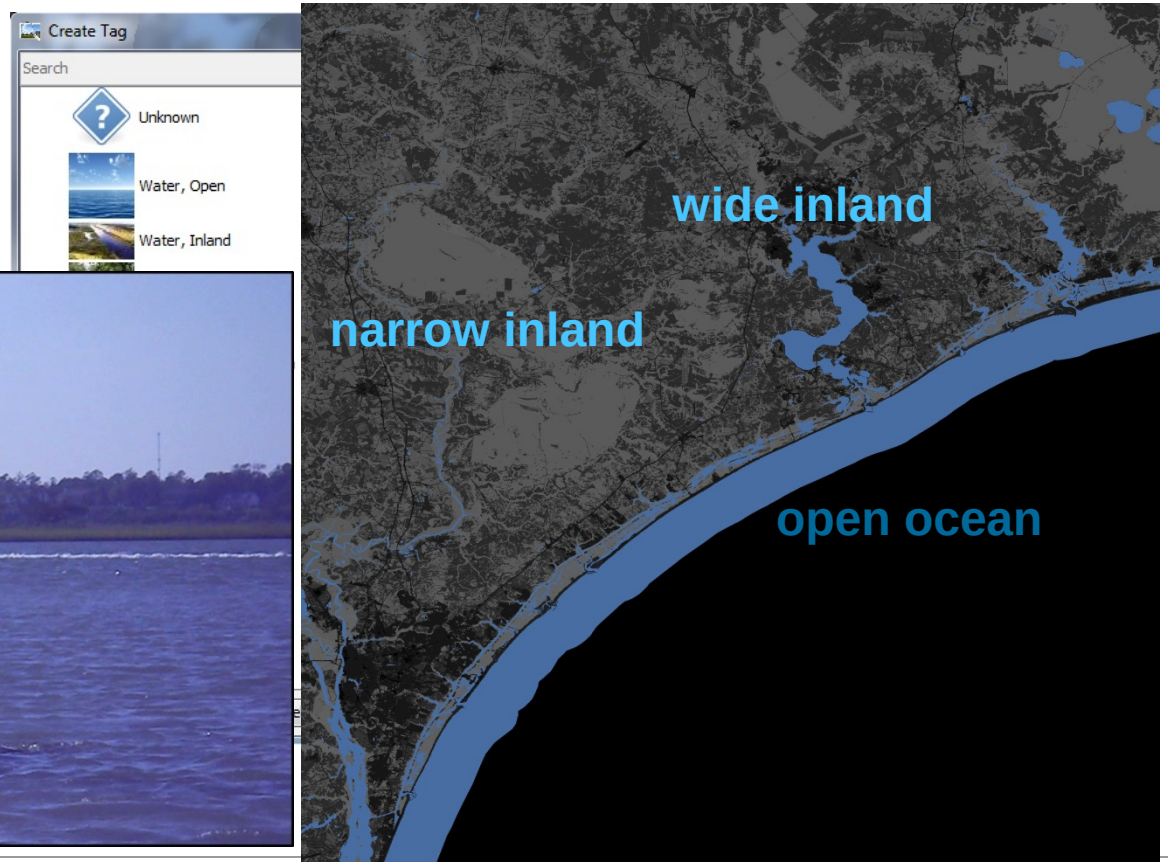


© BAE Systems 2013. All rights reserv
Foreign Persons

NLCD is also used by the Context Matcher - Water

- Written by Scott Kuzdeba
- Algorithmically reclassifies NLCD water class into three subclasses:
  - Open ocean
  - Wide inland water
  - Narrow inland water

NLCD_N34W078_S1x1.tif



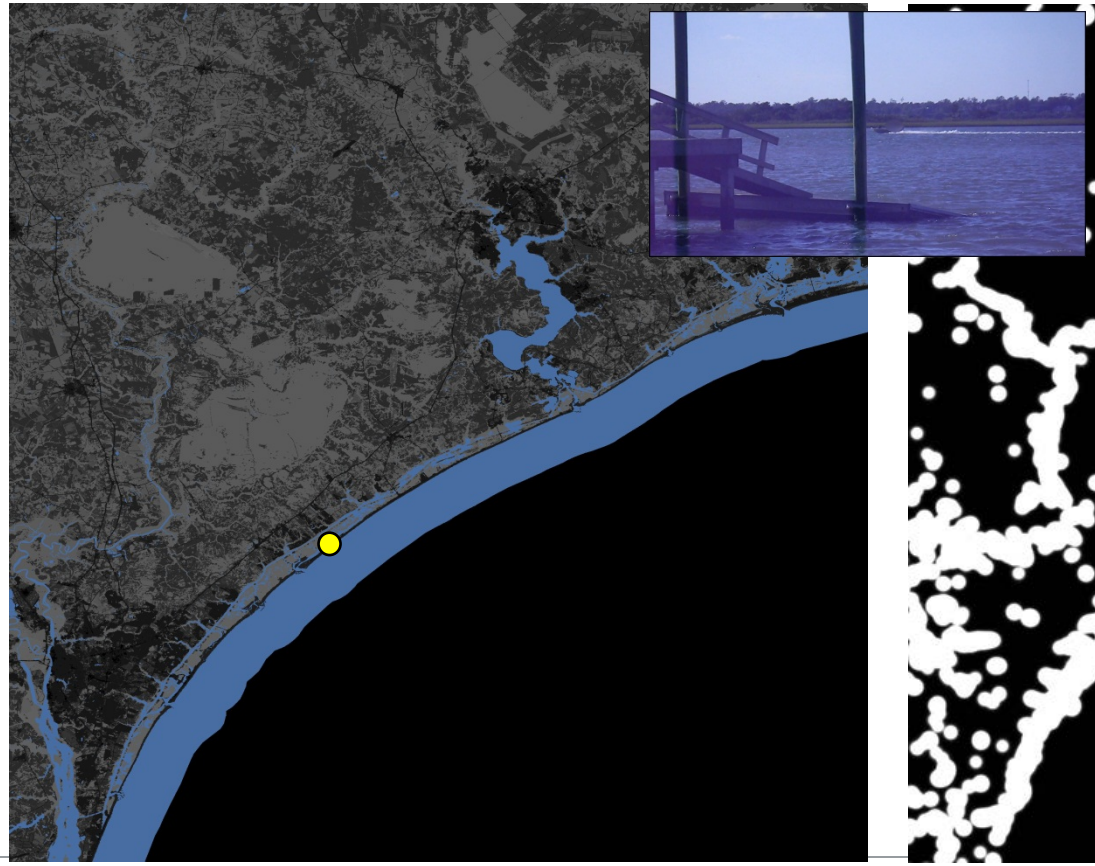
query image

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

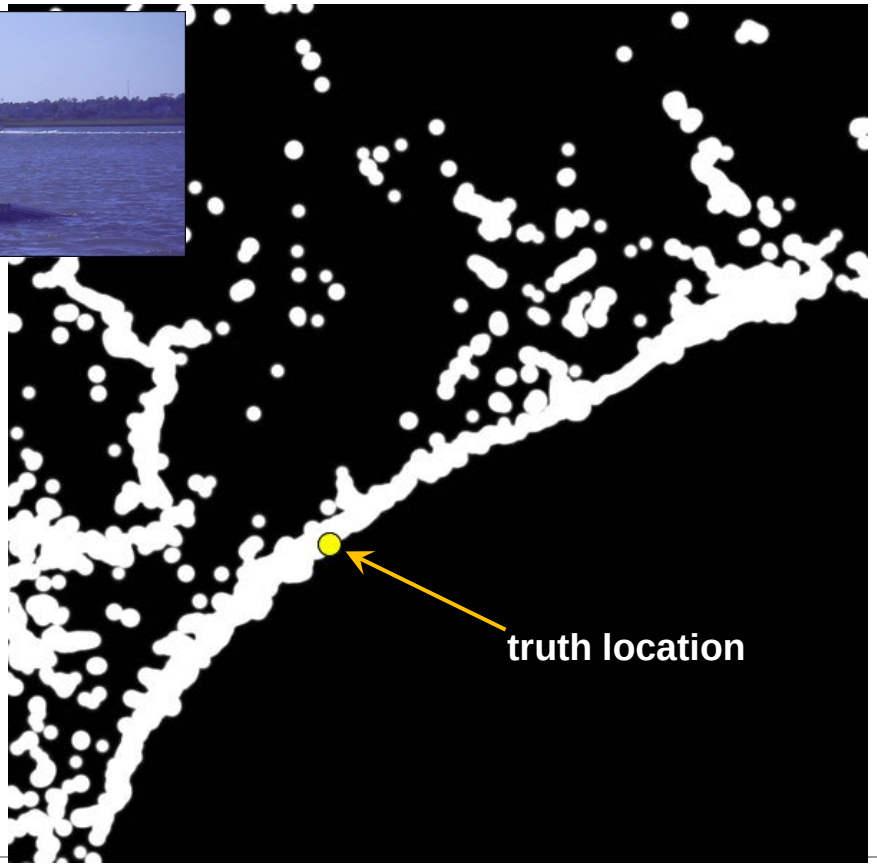
Water clues reduce possible camera locations

- Query photo shows water bounded by land “medium” distance away
- Matcher returns narrow inland water, expanded to capture camera location

NLCD_N34W078_S1x1.tif



Context Matcher – Water output array

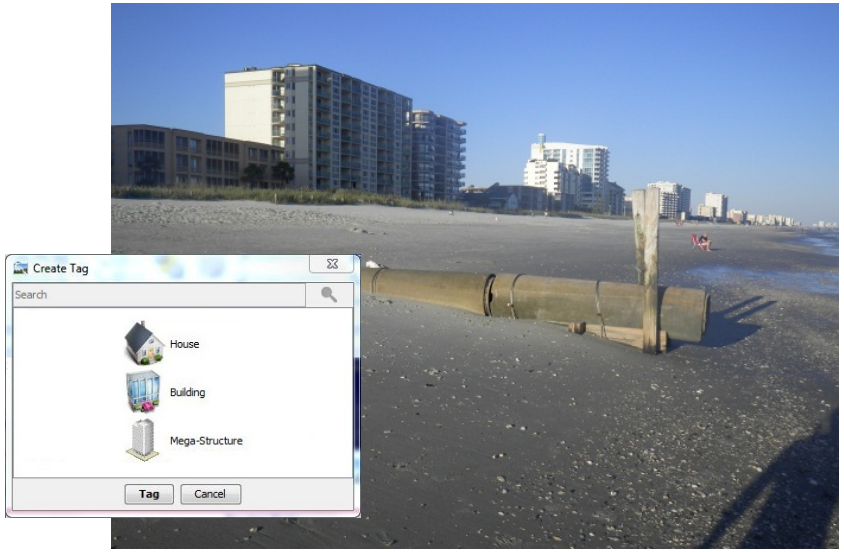


© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Lidar is used by the Context Matcher – Structure Height

- Also written by Scott Kuzdeba
- Uses BAE Systems' URGENT lidar software to obtain building locations
- User can tag three different building classes with Media Tagger:
  - House – 1 to 3 stories
  - Building – 4 to 7 stories
  - Megastructure – large, 8+ stories

query image



BAE SYSTEMS ***URGENT feature extraction***

URGENT Automatically Extracts 3D Urban Features, Geometry and Spatial Relationships for Mission Planning / Rehearsal

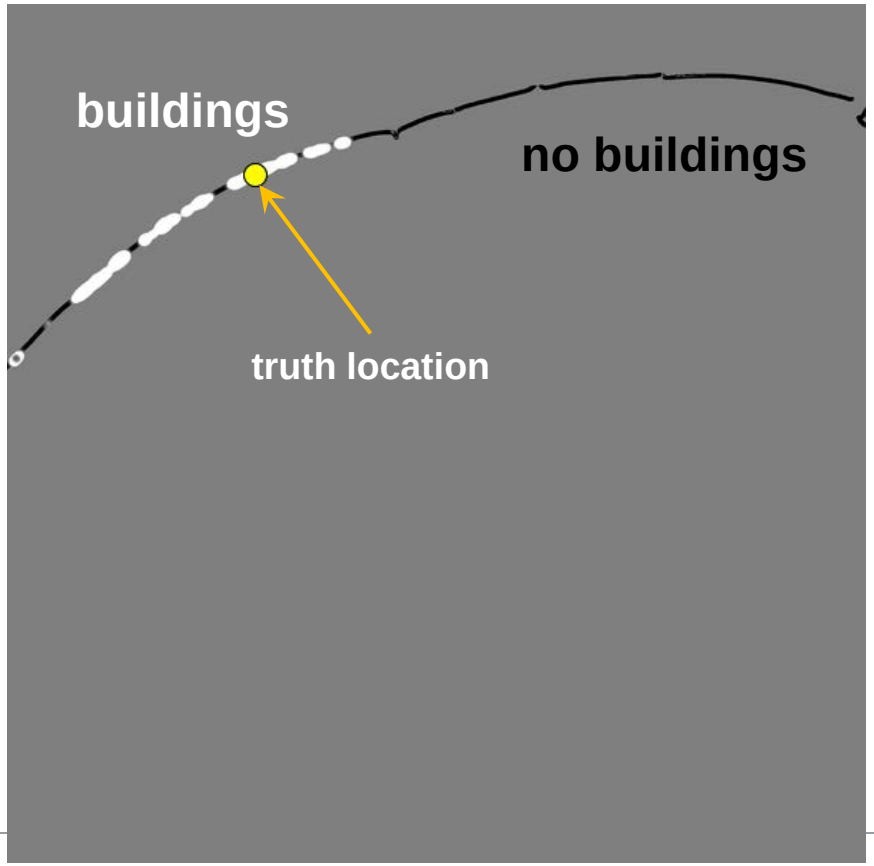
© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Proximity to buildings reduces possible camera locations

- Query image holds buildings and megastructures (commercial hotels)
- User sets distance to buildings, controls donut applied to building centroids
- Matcher also reduces probability in areas with no buildings

query image

Context Matcher – Structure Height output array



© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

The Geometric Primitive Matcher works with skylines

- Written by Dr. Riad I. Hammoud
- Goal is to match visible portions of the skyline against terrain model profiles
- Mountain peaks, ridges, saddle points, valleys, etc create the skyline

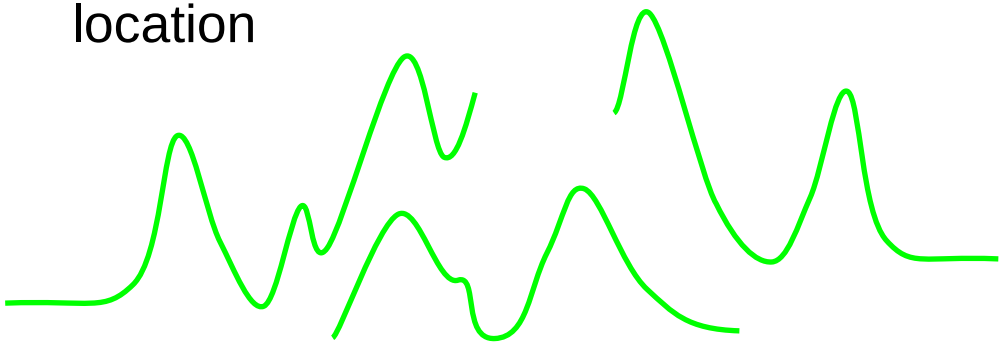
- Bottom edge of sky region is a reliable way to find the skyline
- Either manual or automatic segmentation provides the curve

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

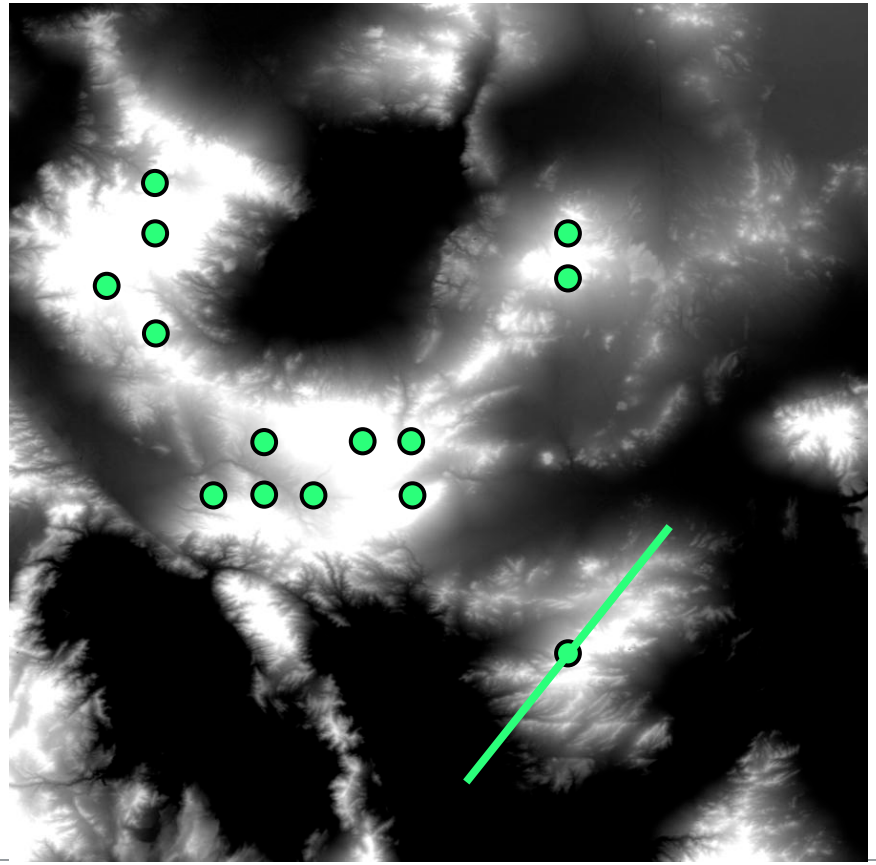
The Geometric Primitive Matcher uses the ASTER GDEMs

- Each 1° ASTER tile is preprocessed before query image is provided
- Segmented into low and high altitude regions
- Points placed in high altitude regions
- For each point
  - Extract a profile
  - Rotate
  - Repeat

  } to account for unknown camera orientation
- Store all profiles for later, indexed by location



ASTERDEM_N37W118_S1x1.tif



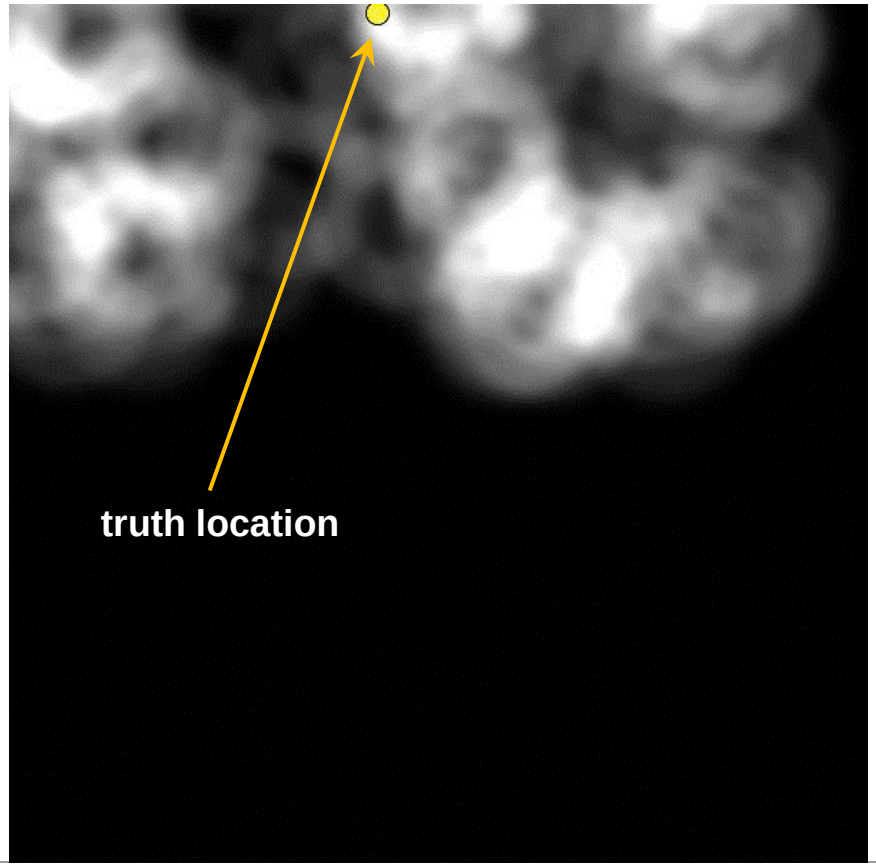
© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

The skyline is matched to the ASTER GDEM profiles

- Skyline to GDEM profile matching accomplished with curve-to-curve, curvelet-to-curvelet techniques (very complex!)
- Matched location is the mountain(s) seen in query image
- Convert to camera location with donuts
  - Distance to mountains selected by user
  - Can select near, medium, far distance

query image

Geometric Primitive Matcher output array



© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

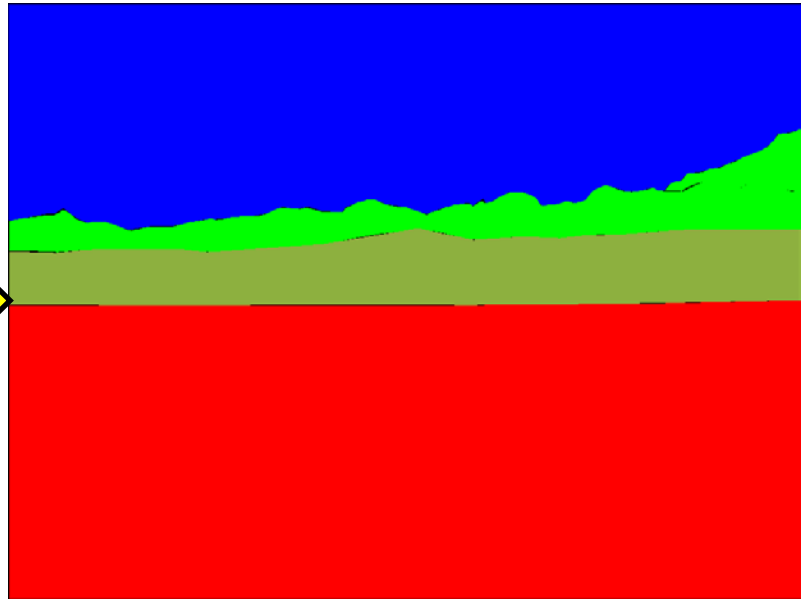
The Scene Configuration Matcher uses rendered scenes

- Written by Dr. Rich T. Ivey
- Goal is to match synthetically generated scenes to the query image itself
- First step segments the query image into **flat**, **transition**, **mountain**, **sky**
- Both manual and automatic segmentation possible, manual shown here

query image

segmentation into classes

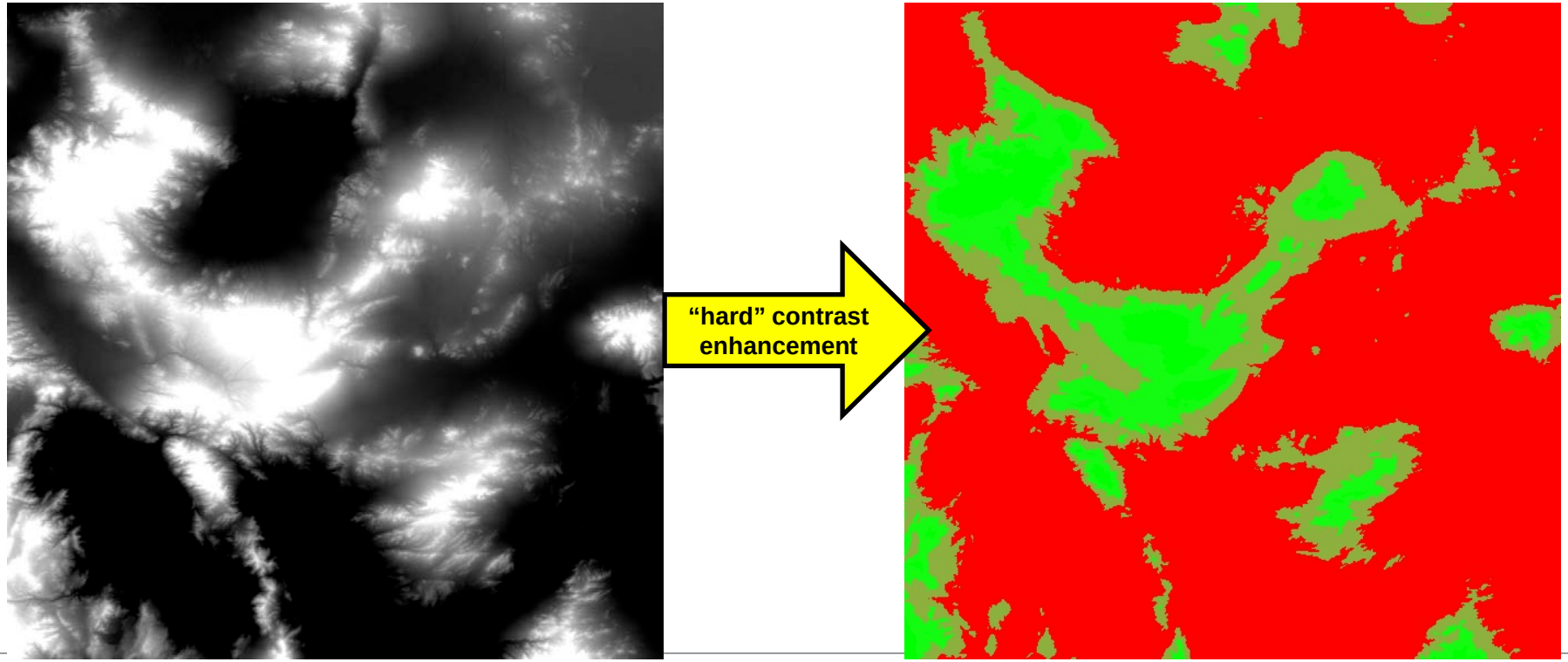
segmented/annotated image



© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

The Scene Configuration Matcher also uses ASTER GDEMS

- ASTER GDEM converted to three land classes, **flat**, **transition**, **mountain**, with colorspace transforms, contrast enhancements
- Possible to use Landsat and aerial pixels to color GDEM, but atmospheric scattering, shadows can interfere with color match



© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

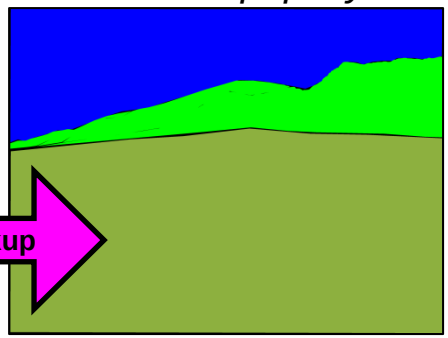
Matched scenes are output as possible camera locations

- Synthetic views rendered with openGL using random location, orientation
- Hue matching determines if synthetic view looks like query image
- "Weighted resampling" ensures near matches get another pass

query image

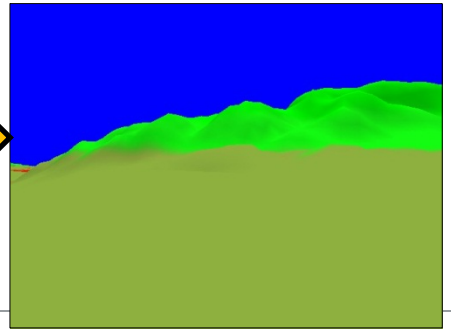
user markup

marked up query

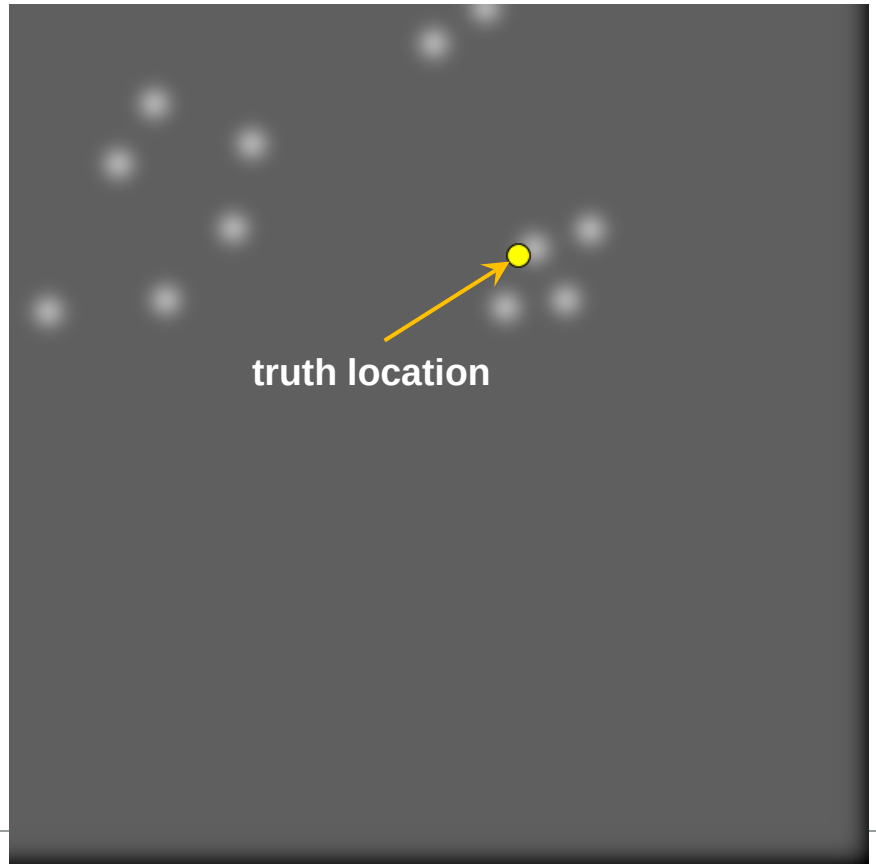


rendered with openGL, camera ~2 meters above ground

synthetic view



Scene Configuration Matcher output array



© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Conclusions

- BAE Systems' VUE directorate has demonstrated mature technology that geolocates photos/videos
- Computer vision matchers reduce the amount of area where photos could have been taken
- BAE Systems is successfully using overhead imagery and terrain models in the matchers

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

BAE Systems welcomes new business, and new people

- New collaboration always welcomed, those with interest in:
  - Matcher technology, for geolocating photos/videos
  - URGENT technology, for working with lidar data
  - Knowledge Base, for doing remote sensing
- Also hiring. Those with background in computer vision, remote sensing encouraged to apply

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons

Acknowledgements

- Supported by the Intelligence Advanced Research Projects Activity (IARPA) VIA Air Force Research Laboratory. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright annotation thereon.
- Disclaimer: the views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of IARPA, Air Force Research Laboratory (AFRL), or the U.S. Government.
- This material is based upon work supported by United States Air Force under Contract FA8650-12-C-7211.
- Any opinions, findings & conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the view of United States Air Force.

© BAE Systems 2013. All rights reserved. Non-Technical Data - Releasable to Foreign Persons