Assessment of SRTM DTED-2 Accuracy in the Coastal Zone

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Adaptive Signal Processing Laboratory

Outline

- Introduction
  - SRTM data (“Finished” SRTM)
  - ALSM data (University of Florida LIDAR)
  - Multiscale data fusion framework
- Data assessment of SRTM with ALSM LIDAR data
- Error performance analysis
  - Using Autocorrelation function of elevation differences
  - Using estimate results from MKS algorithm
- Multiscale fusion results
  - Multiscale topography and bathymetry over Miami Beach

Introduction to SRTM

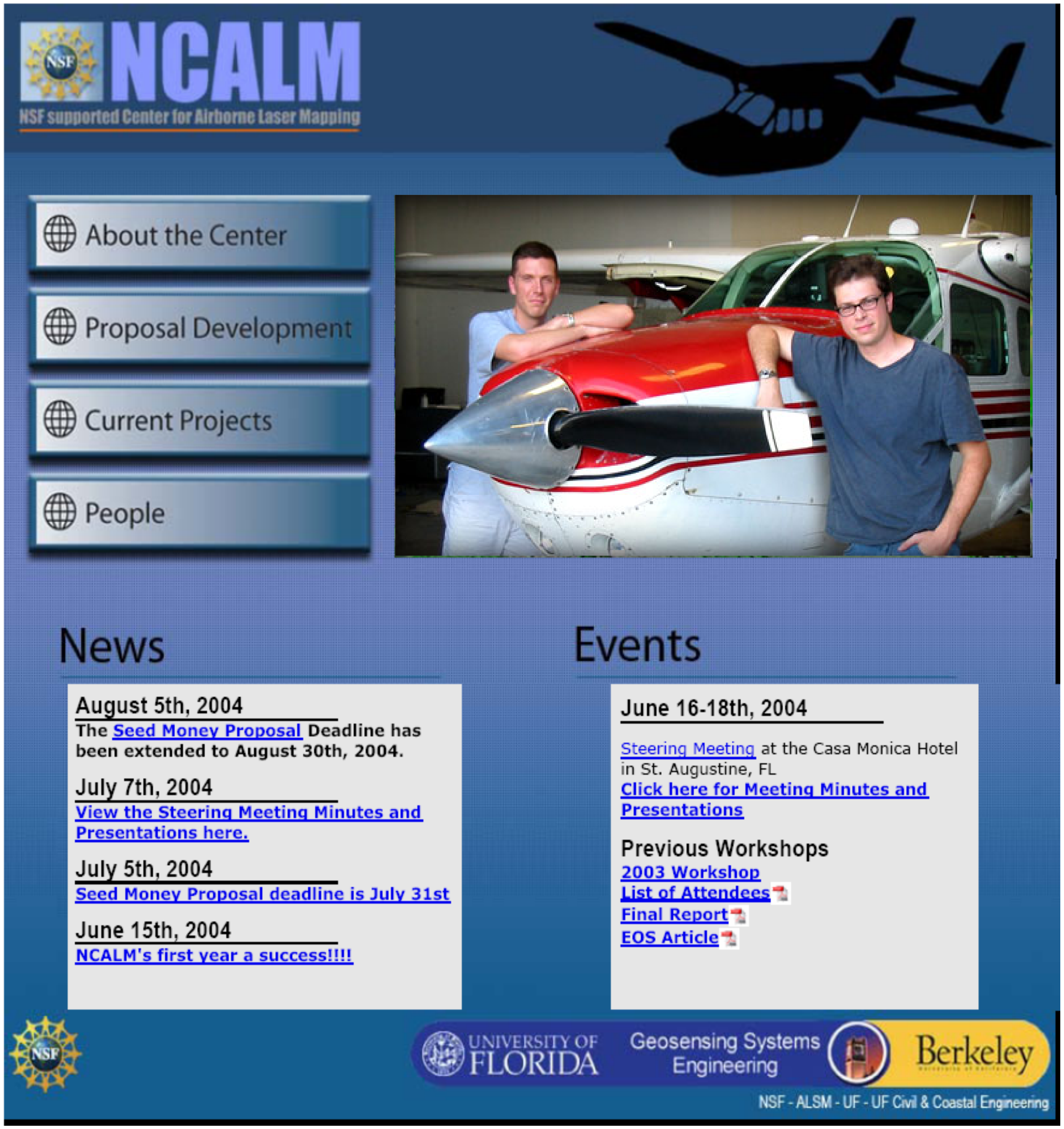
- The SRTM data were acquired in February 2000 by a radar system on-board the Space Shuttle Endeavour
  - Cooperative project of National Geospatial-Intelligence Agency (NGA) , the National Aeronautics and Space Administration (NASA) and the German and Italian space agencies

- Sensor types, coverage, resolutions and accuracy of SRTM
  - Dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer.
  - Data collected over 80% of the Earth's surface (area between 60 degree North and 56 degree South latitude)
  - 1arcsec (~30m) horizontal resolution for the United States
  - 3arcsec (~90m) for the rest of the world
  - Vertical precision of 10m

- Project for "Finished" SRTM data
  - The NGA provides "finished" topographic data from the Shuttle Radar Topography Mission (SRTM).
  - NGA performed quality control checks on the "unfinished" data, filled in small voids and edited the terrain data to correctly portray water bodies and shorelines.
  - The finished product is a uniform grid of elevation values indexed to specific points on the ground in a standardized Digital Terrain Elevation Data (DTED®) format.

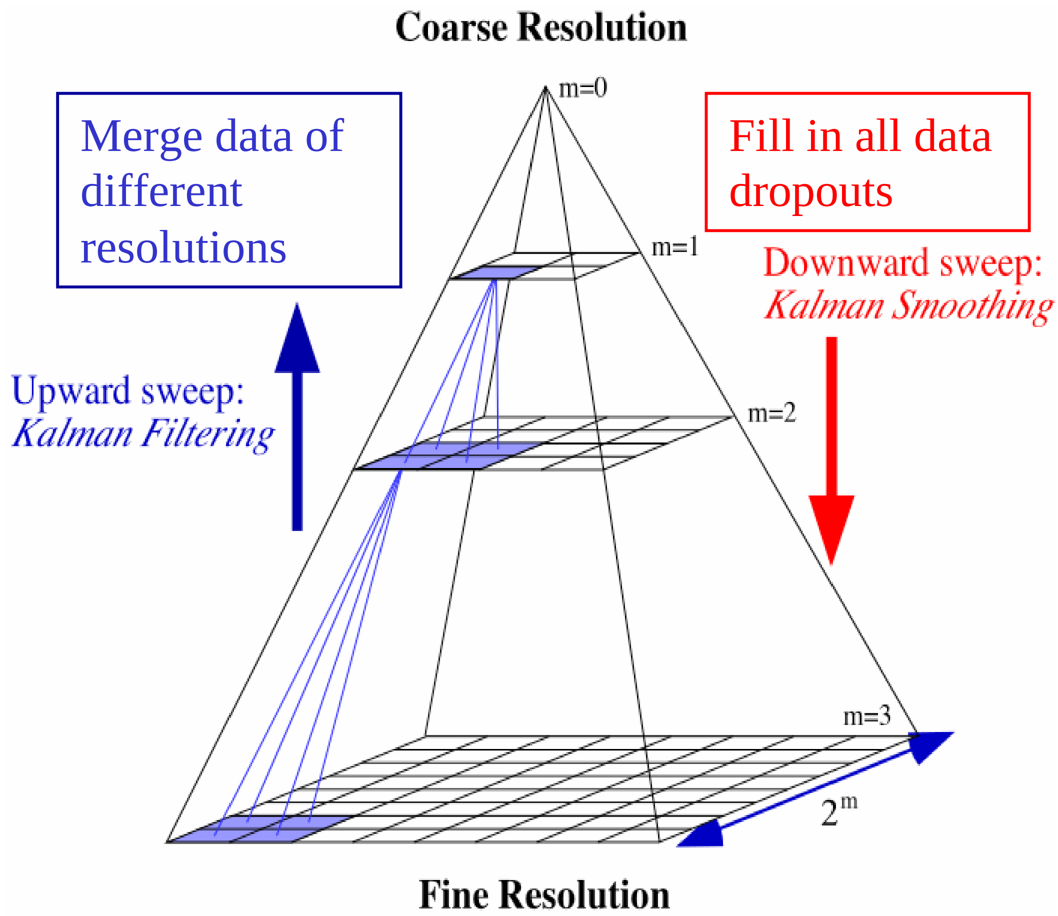
ASPL and the GEM Center

- ASPL is closely affiliated with the Geosensing Engineering and Mapping (GEM) Center
  - The GEM Center currently hosts the National Center for Airborne Laser Mapping (NCALM)
  - an NSF Center under the Geosciences Directorate
  - Established in 2003
  - Collaborate with NSF PIs to acquire, process, and analyze ALSM data
  - http://www.aspl.ece.ufl.edu/
  - http://www.ncalm.ufl.edu/



Multiscale Data Fusion

- Motivation (why bother?)
  - Capture multiscale character of natural processes or signals
  - Combine measurements having different resolutions without inefficiently resampling data to a common scale
- Various methods
  - Fine-to-coarse transformations of spatial models
  - Direct modeling on multiscale data structures, e.g. quadtree
    - Leads to multiscale Kalman smoother (MKS)



MKS algorithm implemented on a quadtree [Chou, *et al*., 1994], [Fieguth, *et al*., 1995]

MKS Algorithm

- MKS is the globally optimal linear mean squared error (MMSE) estimator for fusing image data
  - [Slatton, Crawford, Evans, 2001]
  - Not necessarily the optimal local estimator

- Advantages
  - More efficient than batch weighted least squares due to recursion on a Markov tree data structure
  - Unlike sequential least squares, handles measurement and process noise

- Disadvantage
  - When quadtree is sparsely populated with data, standard implementation of MKS is inefficient. Critical problem when data span large range of scales.
  - Can be ameliorated with data-driven pruning of quadtree nodes on which full MKS recursion occurs [Slatton, *et al*., 2005].

Multiscale Kalman Filter

- Linear process model on the quadtree (scalar form)
  - Evolves in scale [Chou, *et al*. (1994)]

$$
\begin{aligned}
x(s) &= \Phi(s)x(Bs) + \Gamma(s)w(s) && \forall\, s \in S,\ s \neq s_0 \\
y(s) &= H(s)x(s) + v(s) && \forall\, s \in T \subseteq S
\end{aligned}
$$

$x(s) =$ state variable

$y(s) =$ observation (INSAR or LIDAR)

$\Phi(s) =$ state transition operator

$\Gamma(s) =$ stochastic detail scaling function

$H(s) =$ measurement - state relation

$w(s) =$ white process noise $\sim N(0,1)$

$v(s) =$ white measurement noise $\sim N(0, R(s))$

$R(s) =$ measurement variance

$s =$ node index

$s_0 =$ root node

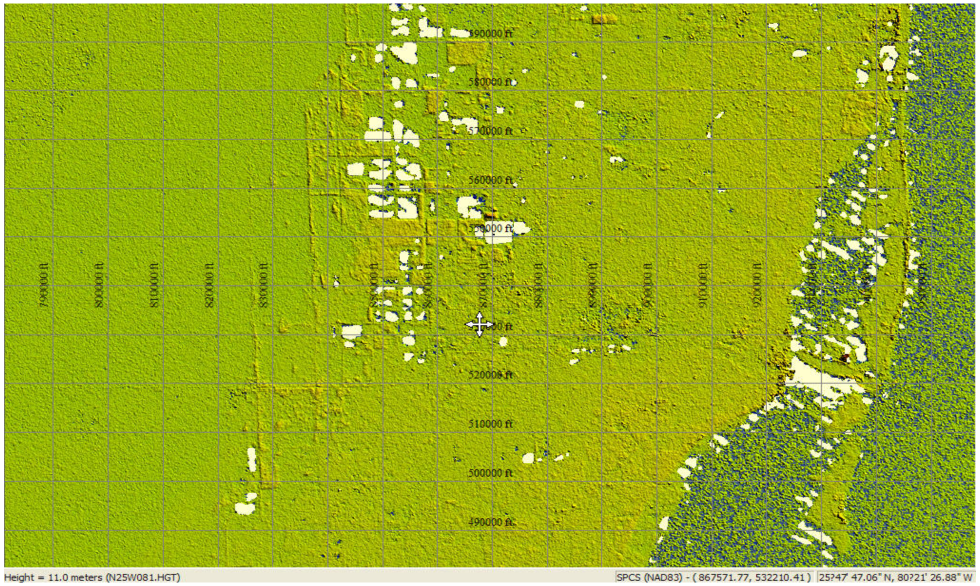
$S =$ set of all nodes on tree

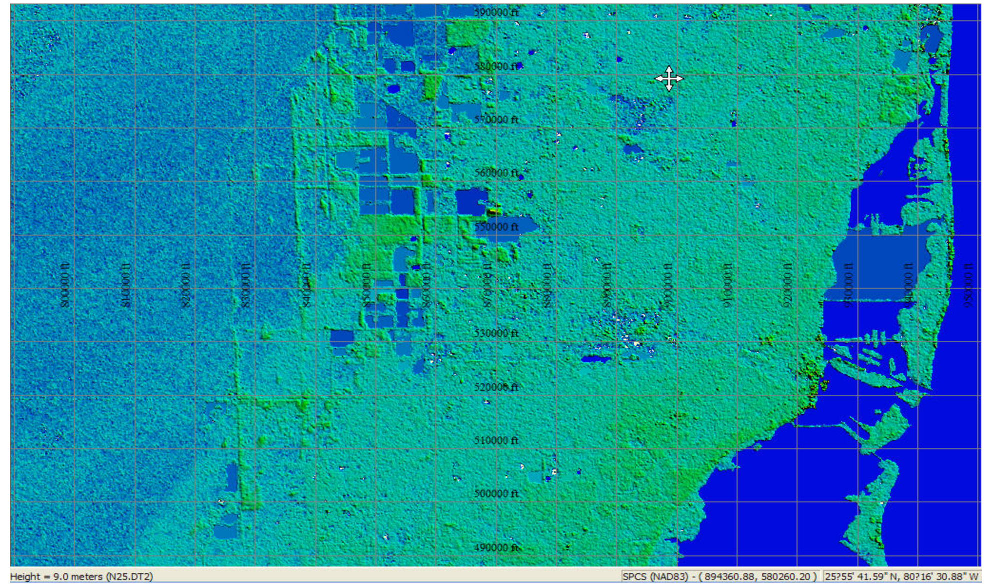
$T =$ set of all nodes where a measurement exists

$B =$ backshift operator

$Q = \Gamma^2 =$ process noise

Unfinished vs. Finished SRTM

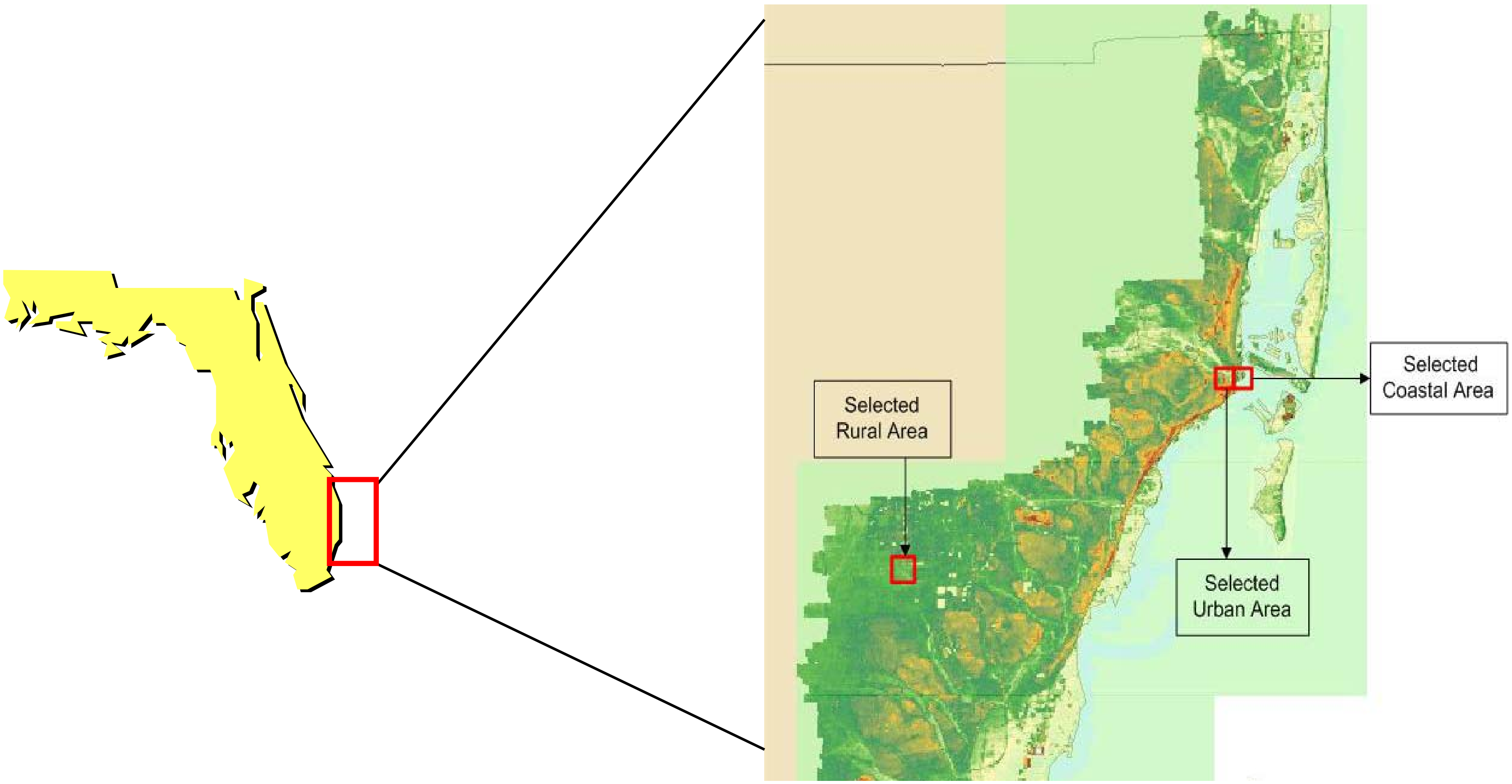




- Unfinished SRTM (left: white mapped areas are voids) and finished SRTM (right)
  - Covered area : Longitude/ Latitude (decimal degree) : 80~81/ 25~26 (Grid shown in state plane coordinate)
  - Resolution: 1 Arc Second (30m)
  - Horizontal / Vertical Datum: WGS84/ EGM96 Geoid
- "Unfinished" SRTM:
  - Contains occasional voids, or gaps, where the terrain lay in the radar beam's shadow or in areas of extremely low radar backscatter
  - Such as sea, lakes and many water covered surfaces that are flat
- "Finished" SRTM : (provided by NGA)
  - Water bodies set to constant value (set to zero).
  - Large river and lakes set to monotonically decreasing values.
  - Small voids are interpolated across. (Filled area remained as low confident elevations)

Descriptions of study sites(1)

- Three studied Sites
  - Selected from Dade County, Florida (Miami metro area)
    - Coastal area: Longitude/Latitude : 80.183 ~80.198 / 25.762~25.776
    - Urban area : Longitude/Latitude : 80.200 ~80.211 / 25.762~25.776
    - Rural area: Longitude/Latitude : 80.472 ~80.487 / 25.612~25.626



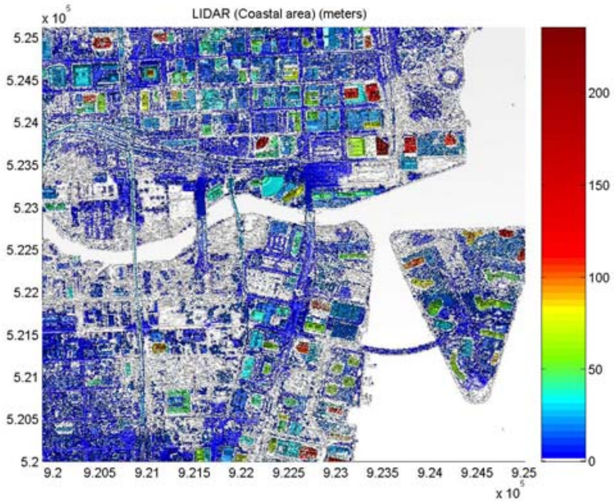
Description of Data Sets

- "Finished" SRTM DTED® Level 2
  - Original resolution : 1 arc second (101 feet or ~30m)
  - Re-sampled grid spacing of DEM: 80 feet × 80 feet (DEM size 64 × 64)
  - Used as coarse resolution data for MKS fusion (at 7th scale)
  - Relative accuracy : 6m (Flat area) ~10m (Non-flat area)

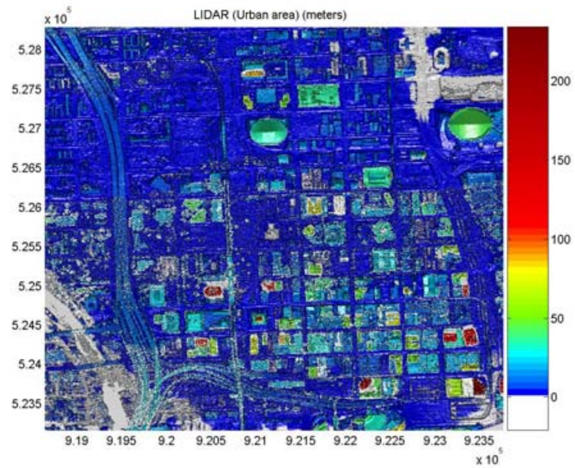
- Topographic LIDAR
  - Acquired by UF Airborne Laser Swath Mapping (ALSM) system
  - Wavelength: 1064 nm (does not penetrate water)
  - Grid spacing of DEM: 5 feet × 5 feet (DEM size 1024 × 1024)
  - Vertical accuracy : ~0.12m
  - Used as high resolution data for MKS fusion (at 11th scale)

Descriptions of study sites(2)

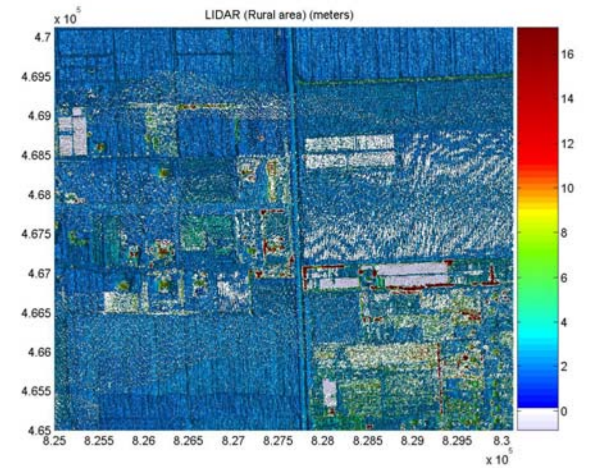
• LIDAR : Grid spacing 5 feet (~1.5m), size: 1024 by 1024



Coastal area

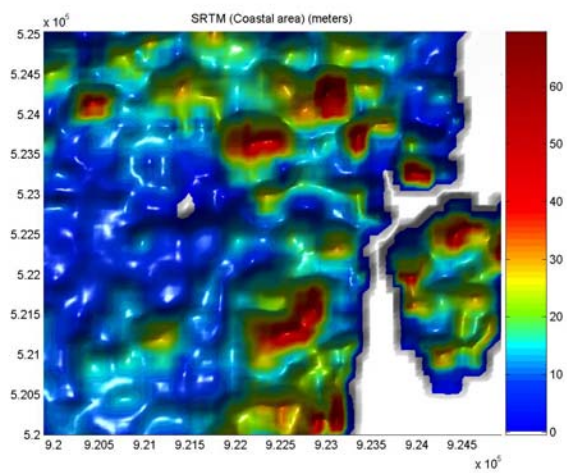


Urban area

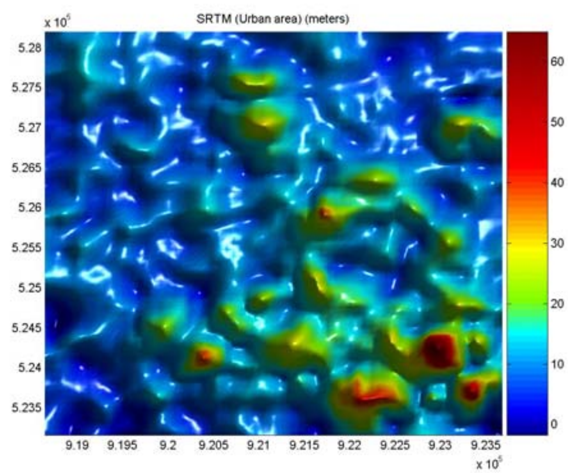


Rural area

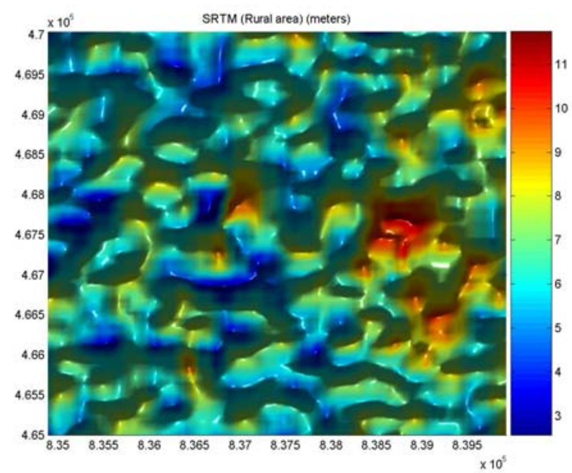
• Finished SRTM : Grid spacing 80 feet (~24m), size: 64 by 64



Coastal area



Urban area



Rural area

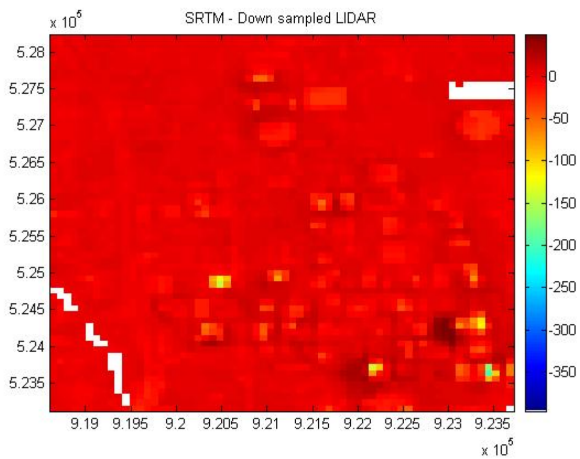
How to determine the sensor noise of SRTM

- Deterministic Approach
  - Up sampled SRTM – LIDAR
  - SRTM – Down sampled LIDAR

- Stochastic Approach
  - Using innovation term in MKS
  - Innovation = SRTM – Prior estimate

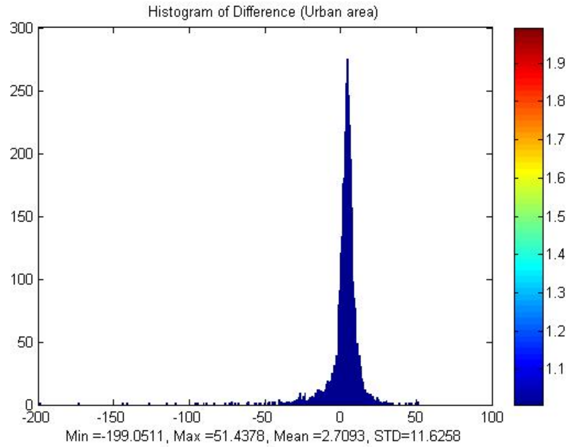
ACF comparisons between lidar and SRTM (1)

- Area #1: Urban Area



(1)

Figure.
(1) Error = SRTM- Down sampled LIDAR
(2) Histogram of Error
(3) Horizontal transect of Error ACF
(4) Vertical transect of Error ACF
(5) Histogram of Normalized Error
(6) Horizontal transect of normalized Error ACF
(7) Vertical transect of normalized Error ACF



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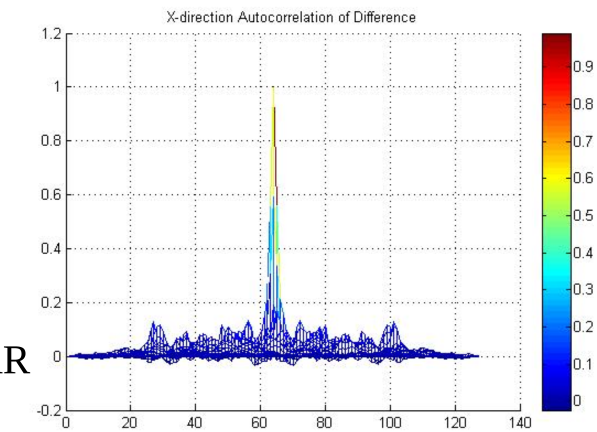

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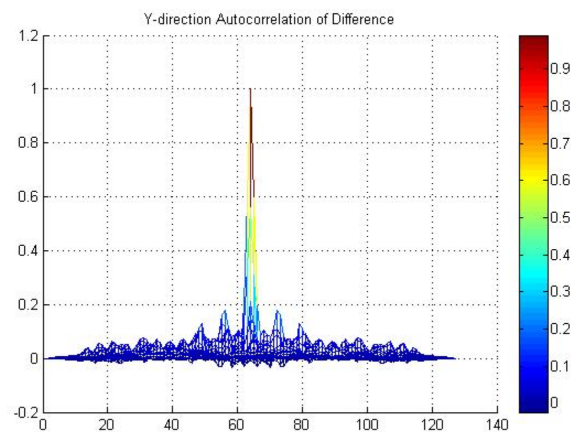

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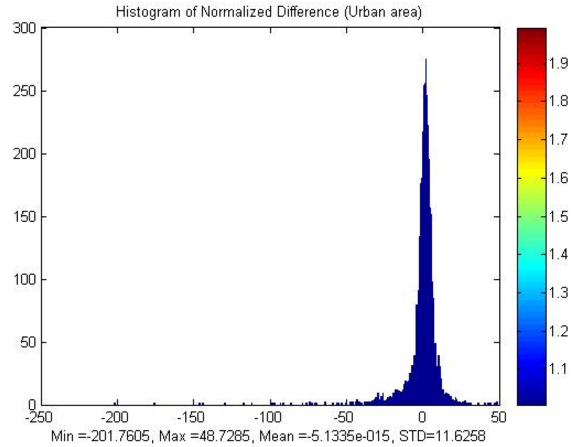

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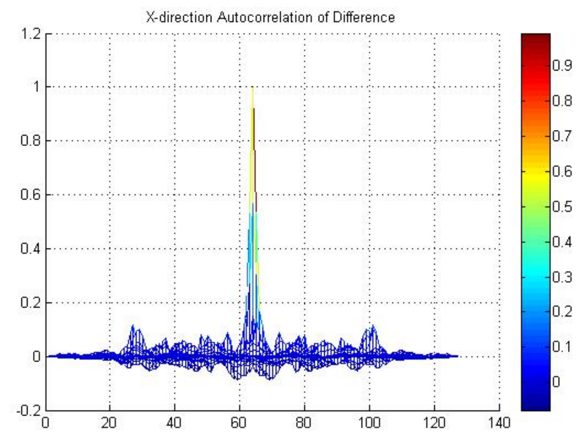

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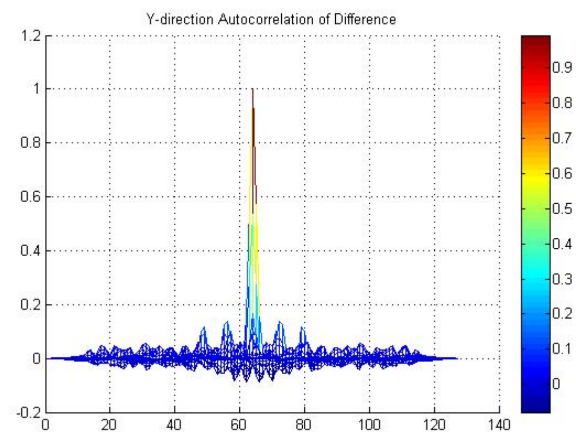

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ACF comparisons between lidar and SRTM (2)

- Area #2: Rural Area

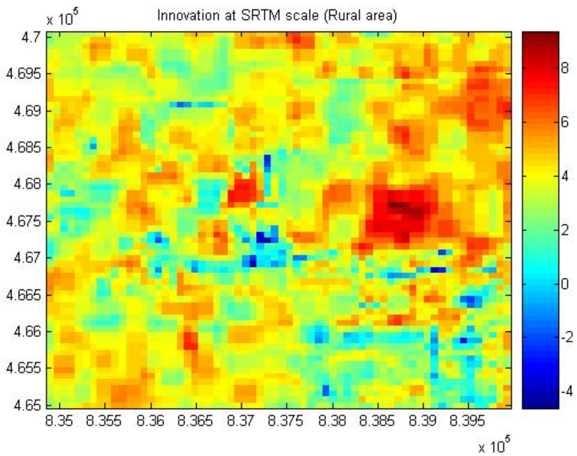

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Figure.

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(6) Horizontal transect of normalized Error ACF

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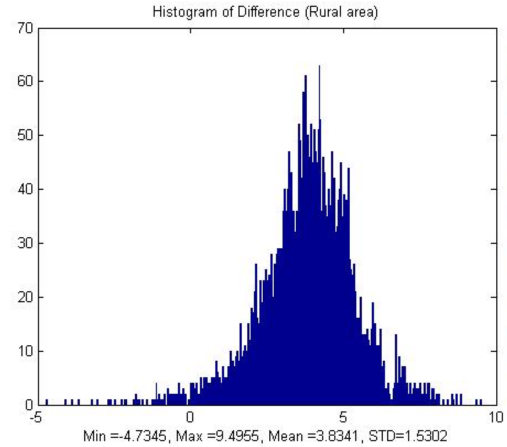

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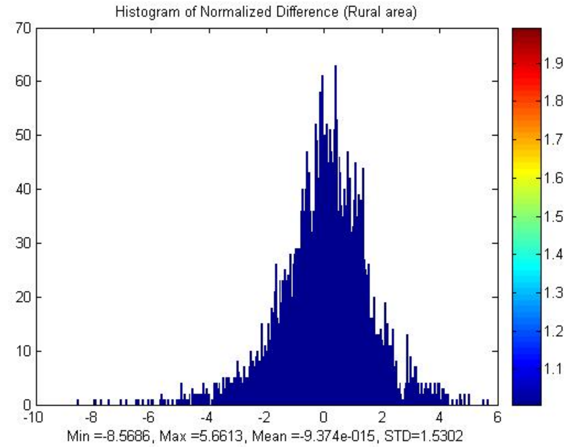

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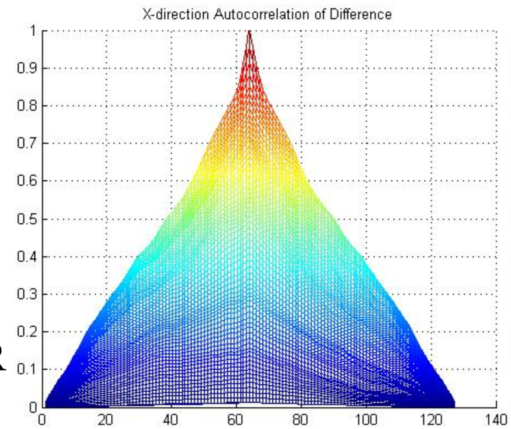

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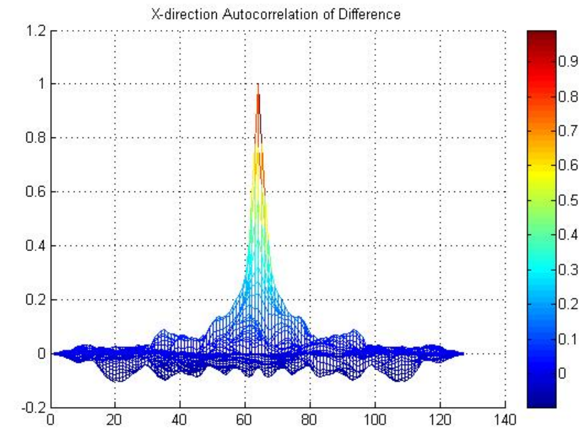

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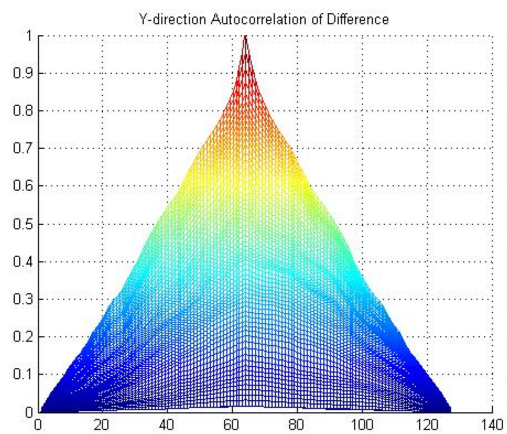

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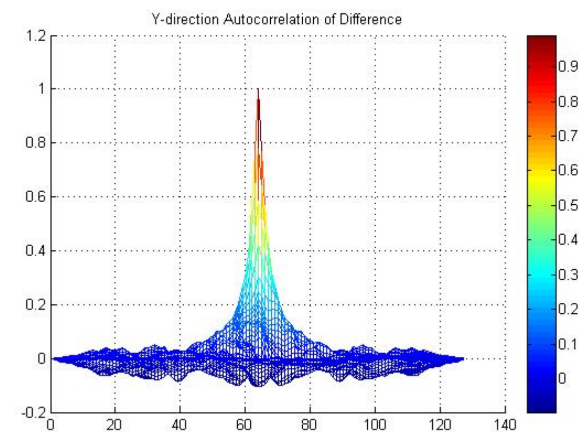

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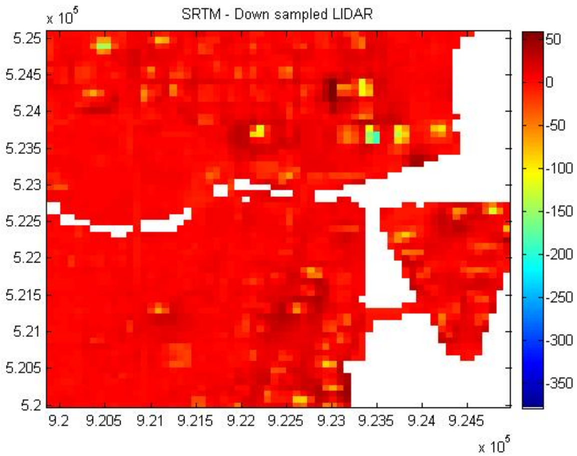
ACF comparisons between lidar and SRTM (3)

- Area #3: Coastal Area



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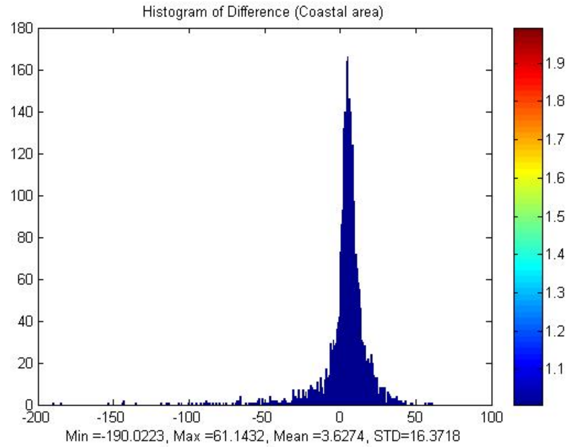

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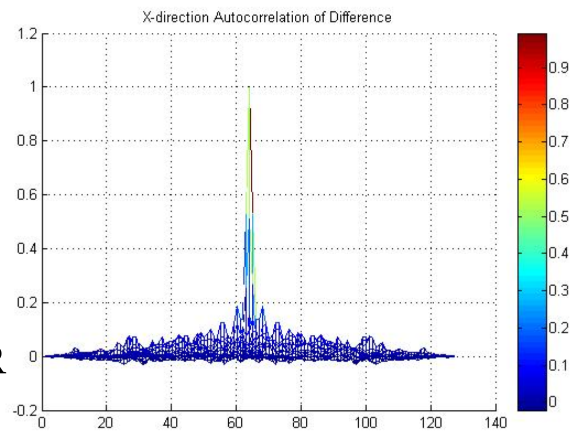

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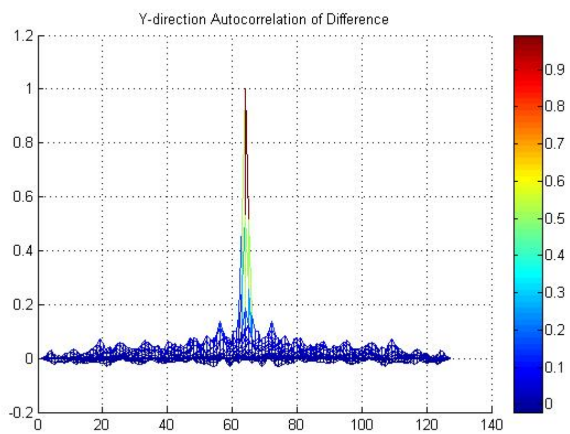

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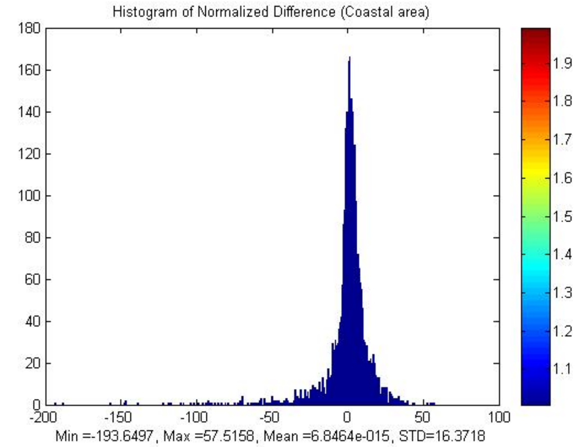

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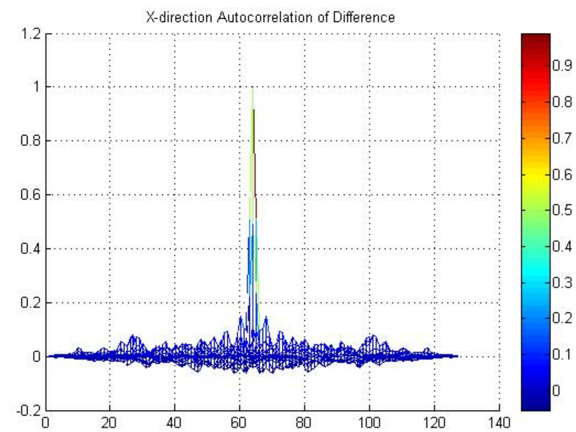

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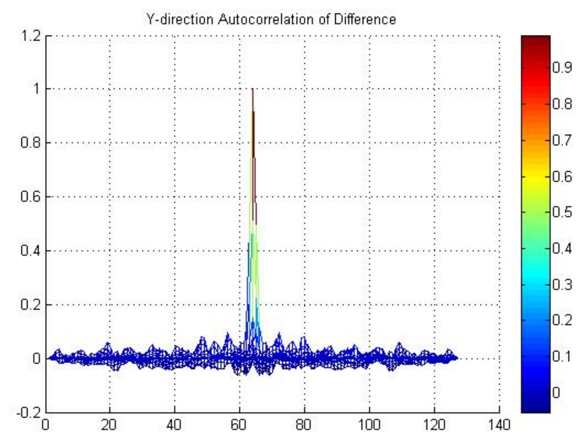

(7)

Figure.

(1) Error = SRTM- Down sampled LIDAR

(2) Histogram of Error

(3) Horizontal transect of Error ACF

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(5) Histogram of Normalized Error

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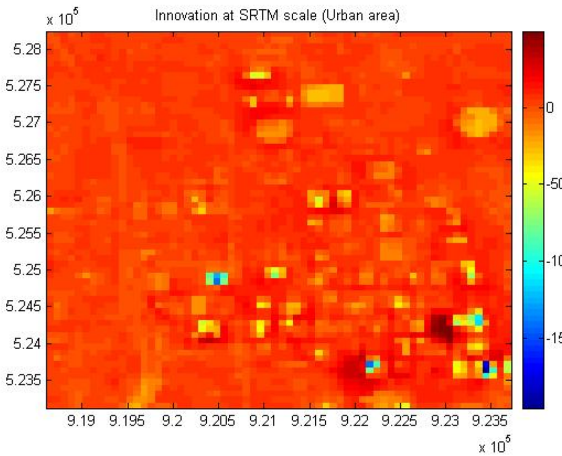
Innovation analysis at SRTM Scale (1)

- Area #1: Urban Area



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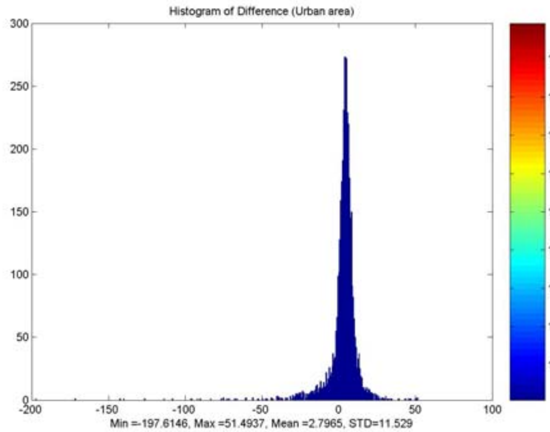

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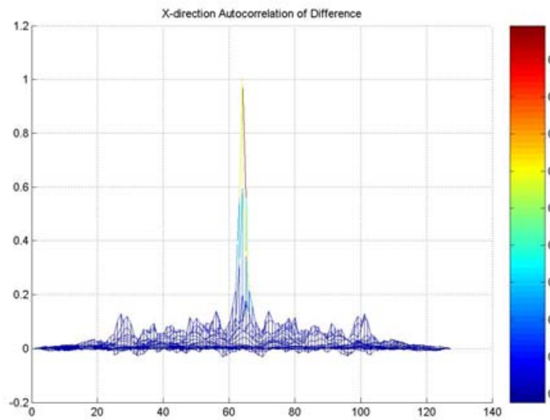

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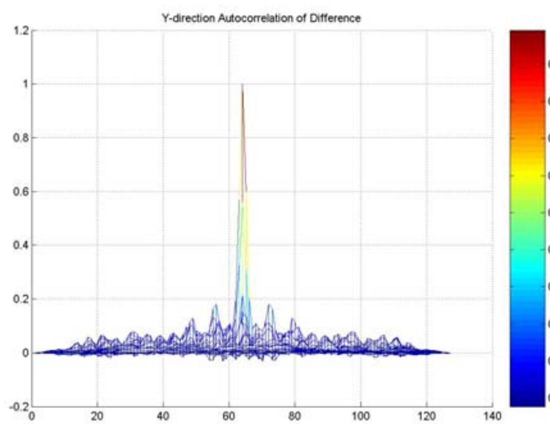

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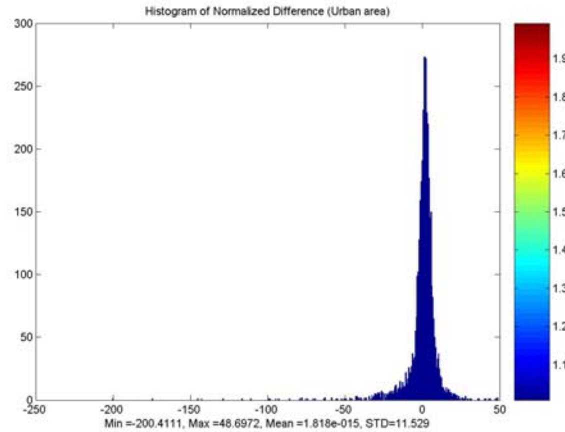

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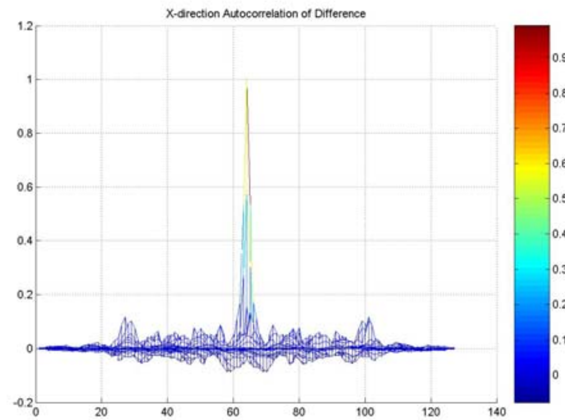

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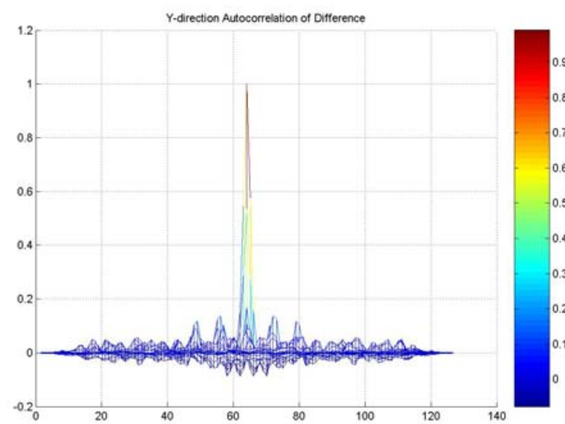

(7)

Figure.
(1) Innovation = SRTM – prior estimate
(2) Histogram of Innovation
(3) Horizontal transect of Innovation ACF
(4) Vertical transect of Innovation ACF
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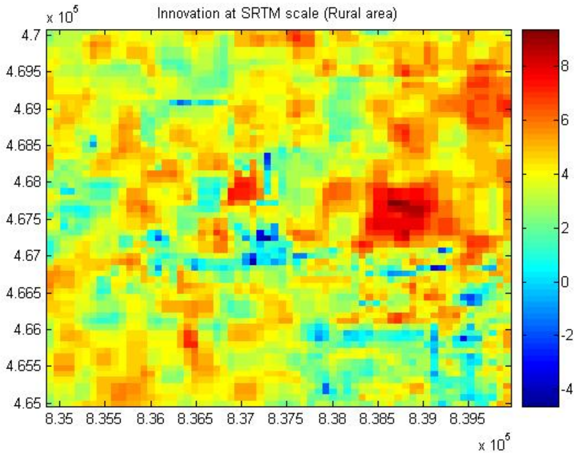
Innovation analysis at SRTM Scale (2)

- Area #2: Rural Area



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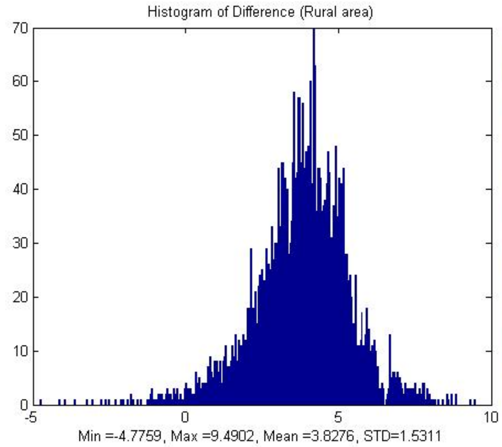

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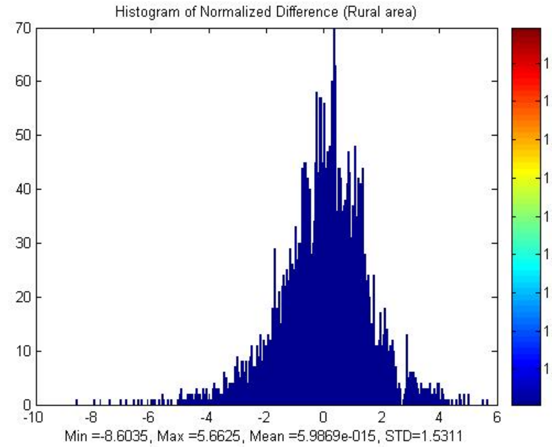

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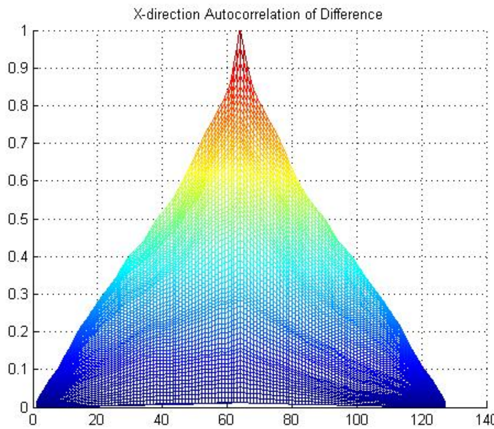

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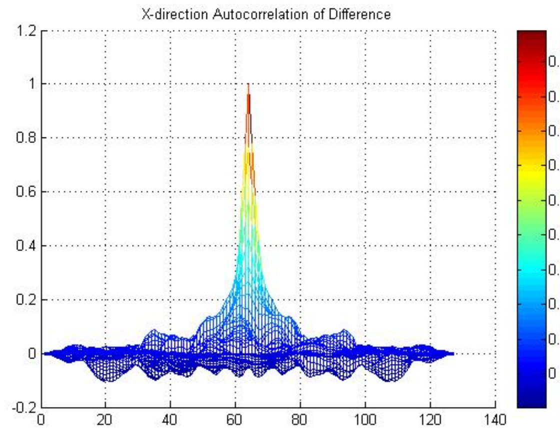

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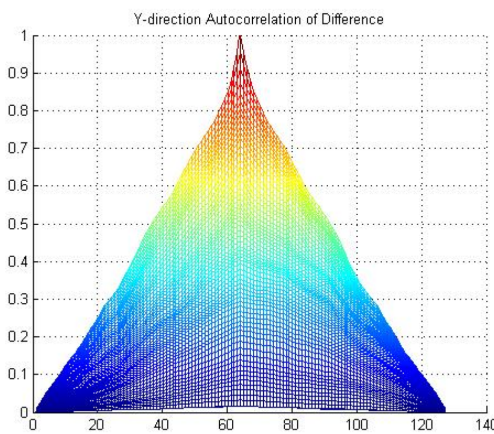

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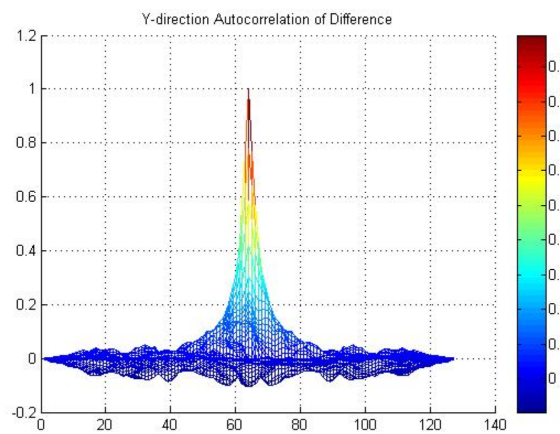

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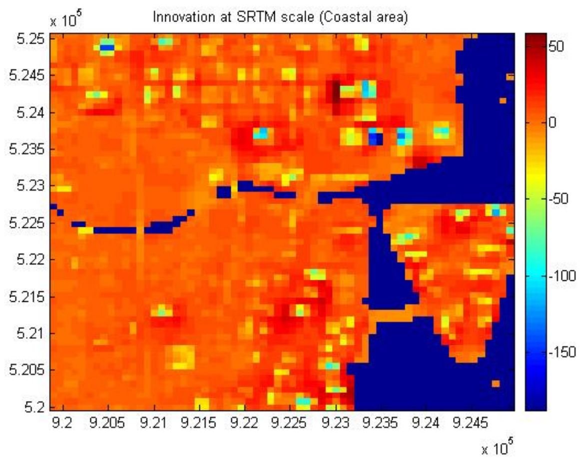
Innovation analysis at SRTM Scale (3)

- Area #3: Coastal Area



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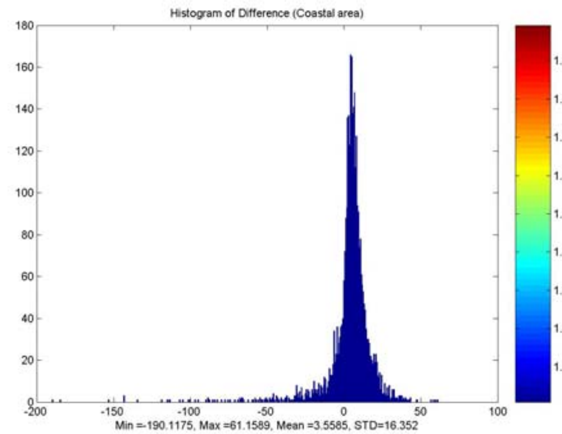

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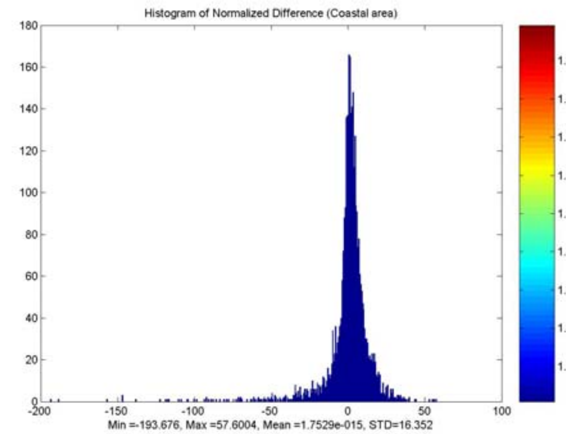

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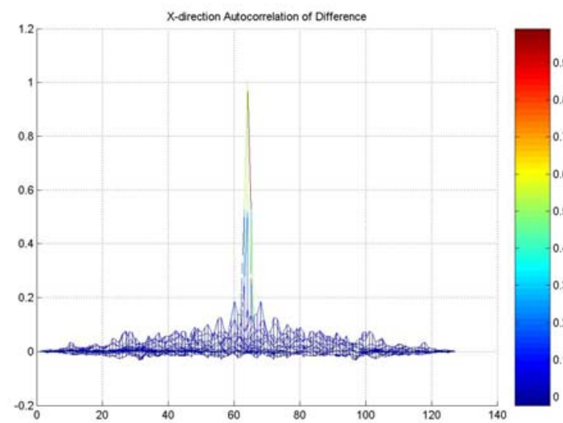

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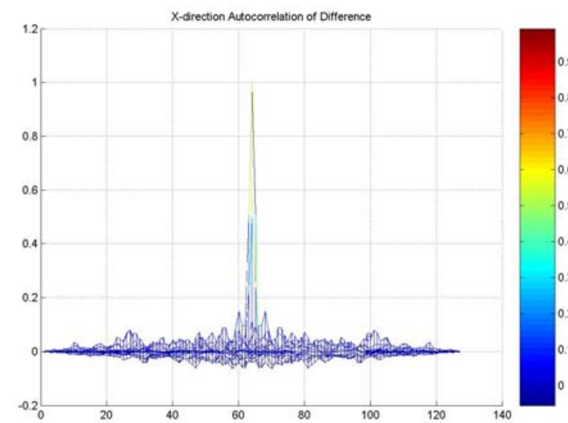
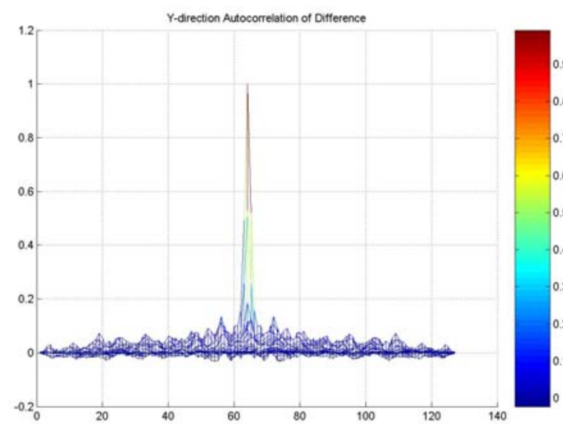
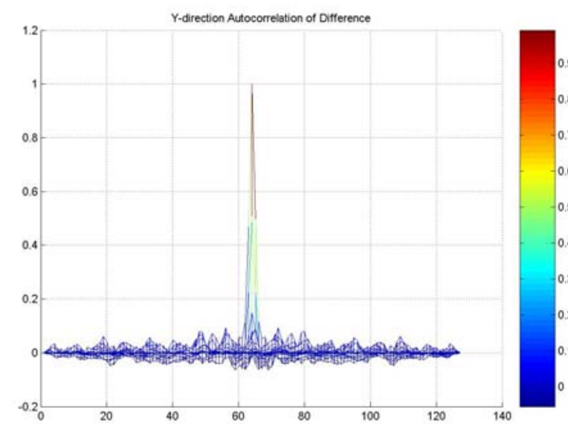


(6)



(4)



(7)

Figure.
(1) Innovation = SRTM – prior estimate
(2) Histogram of Innovation
(3) Horizontal transect of Innovation ACF
(4) Vertical transect of Innovation ACF
(5) Histogram of Normalized Innovation
(6) Horizontal transect of normalized Innovation ACF
(7) Vertical transect of normalized Innovation ACF

Sensor “Noise” for Each Site

- Measurement error varies strongly with terrain type (in increasing order)
  - Rural area
  - Urban area
  - Coastal & Urban area (tall buildings)

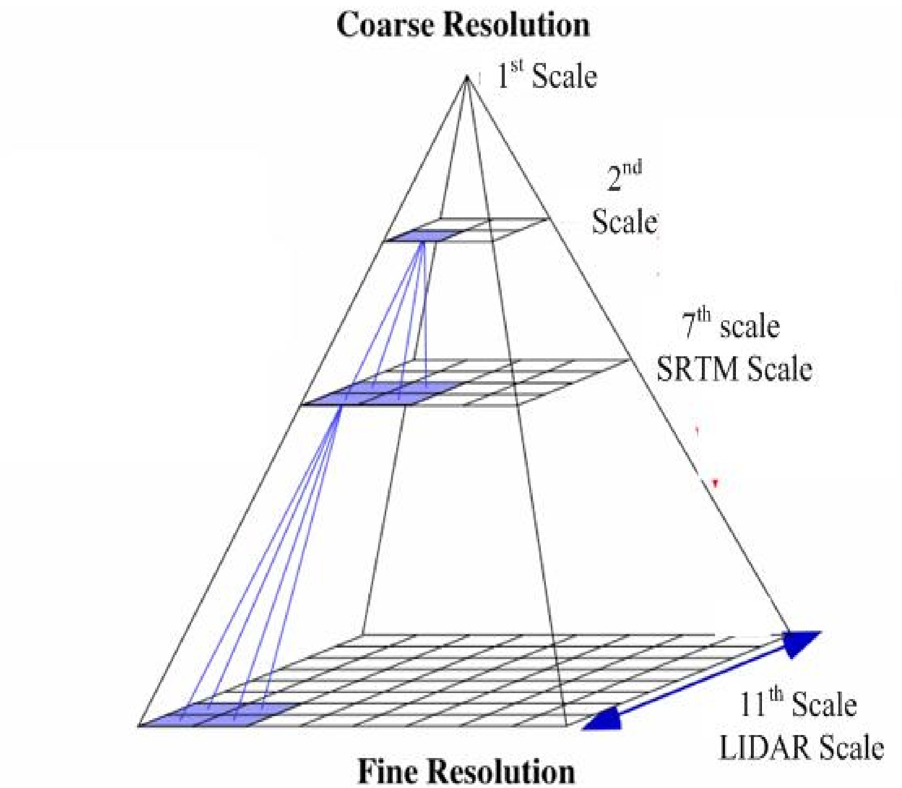
- As expected, noise variance mostly affected by anthropogenic structures such as tall buildings
  - SRTM elevations very good when highly localized features (landcover, development) are minimally present

Table: The difference between down-sampled LIDAR and finished SRTM

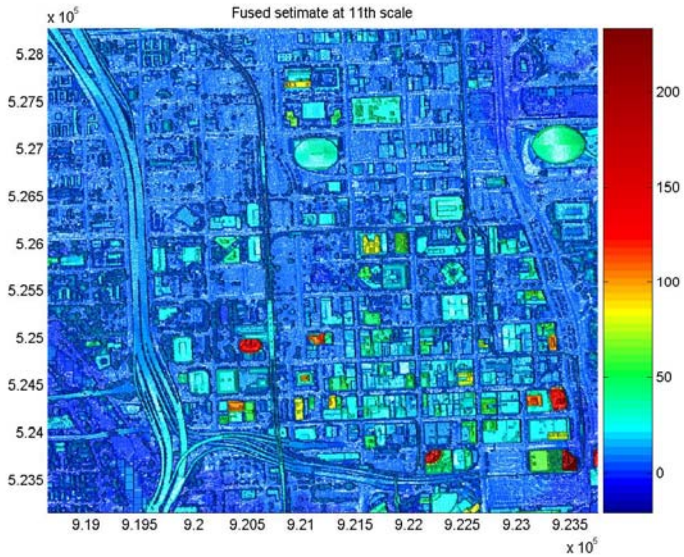
	Rural area	Urban area	Coastal area
Min	-4.7345	-190.0511	-190.0223
Max	9.4955	51.4378	61.1432
Mean	3.8341	2.7093	3.6274
STD	1.5302	11.6258	16.3718

MKS Data fusion

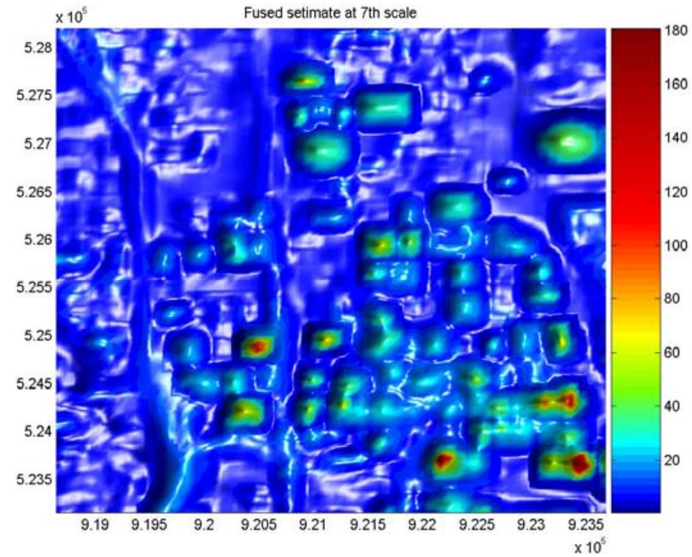
- Two data sets are used on quadtree structure
  - "Finished" SRTM is re-sampled from original resolution (101 feet (~30m)) to 80 feet (~24 m) and located in 7th scale (or SRTM scale).
  - Topography LIDAR is sampled to its original resolution (5 feet (~1.5m)) and located in 11th scale (or LIDAR scale).
- Data sizes
  - "Finished" SRTM : 64 × 64
  - Topography LIDAR : 1024 × 1024



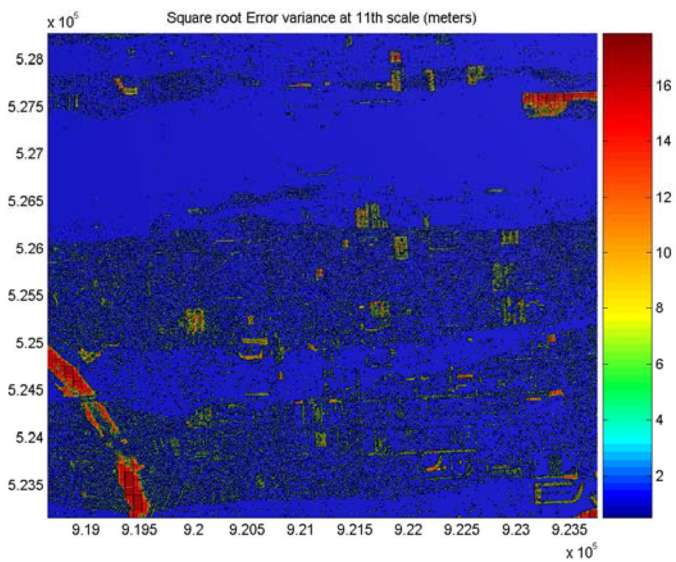
MKS Data fusion (Urban Area)



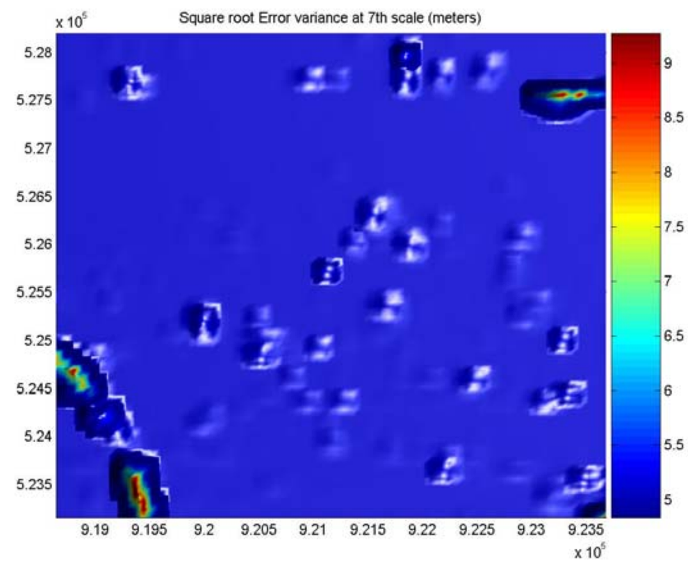
Fused Elevation at 11th scale
(Grid spacing : 5feet by 5feet)



Fused Elevation at 7th scale
(Grid spacing : 80feet by 80feet)

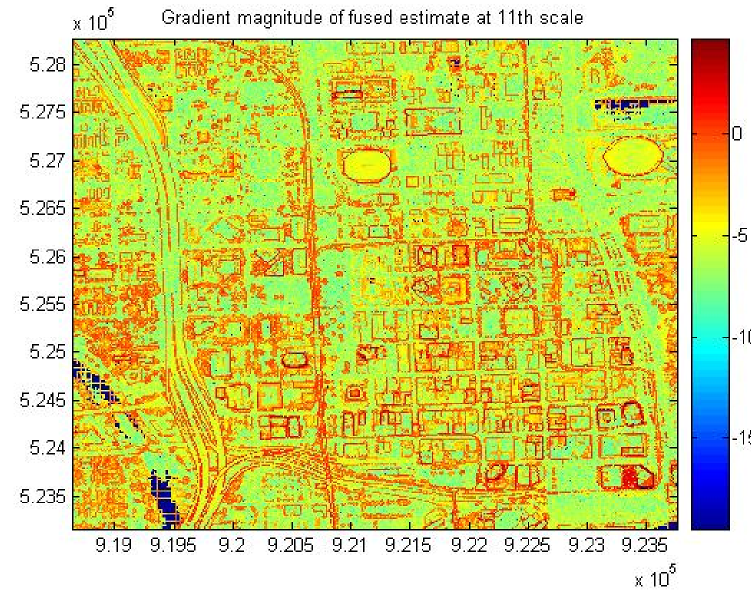


Square root error variance at 11th scale

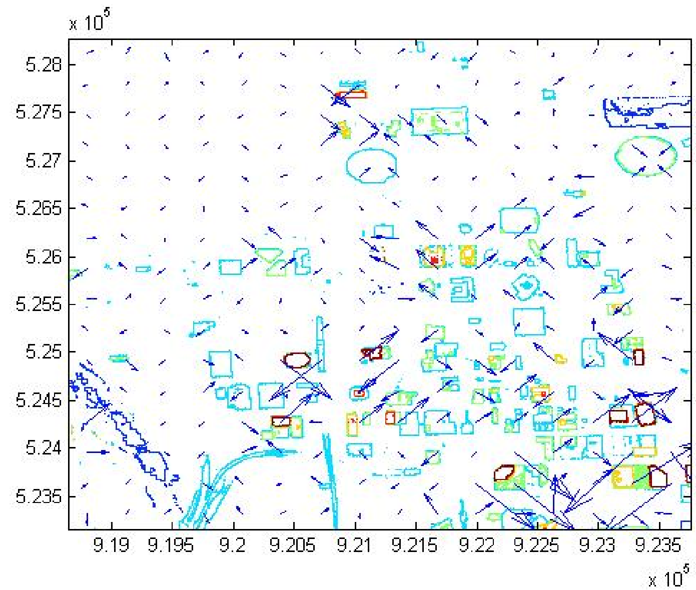


Square root error variance at 7th scale

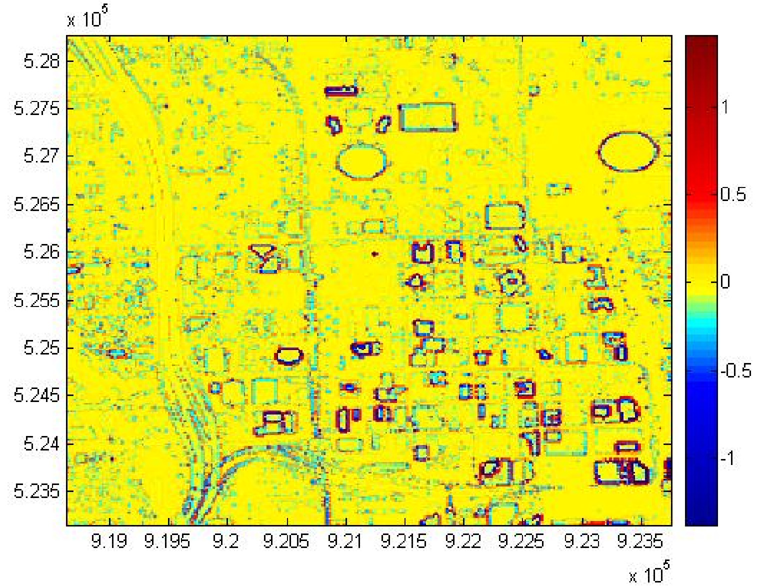
Gradient and Curvature (Urban Area)



Gradient magnitude of fused estimate
at 1.5m (5 feet or 11^{th}) scale (log scaled)

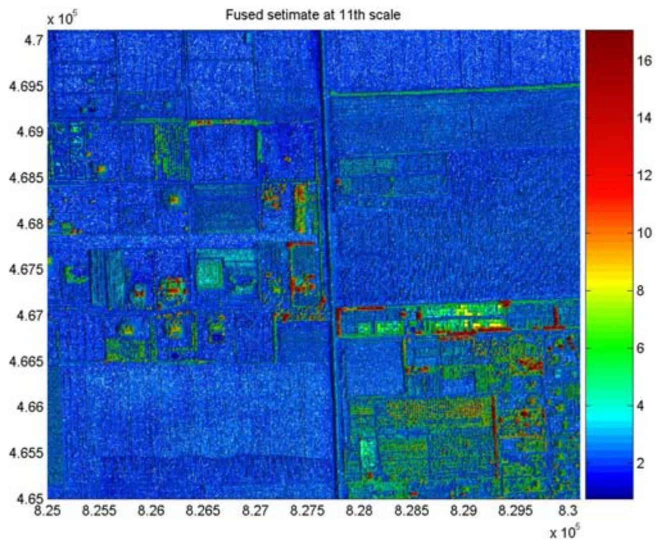


Gradient arrows and contour map of
fused estimate at 1.5m (5 feet or 11^{th}) scale

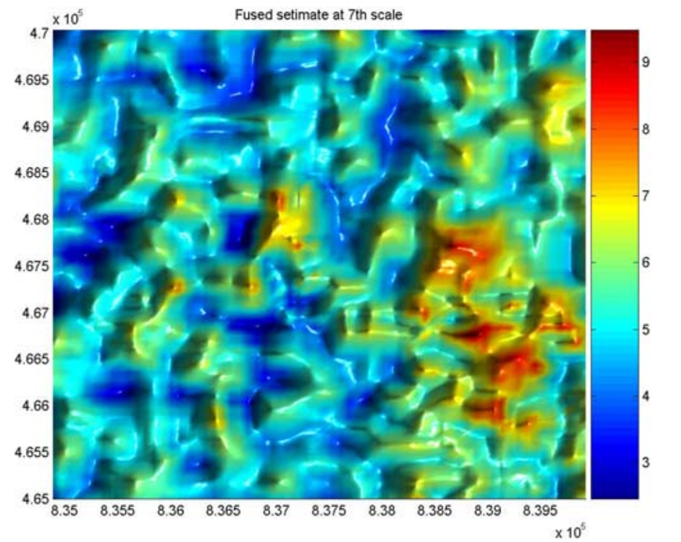


Curvature of fused
estimate at 11^{th}scale

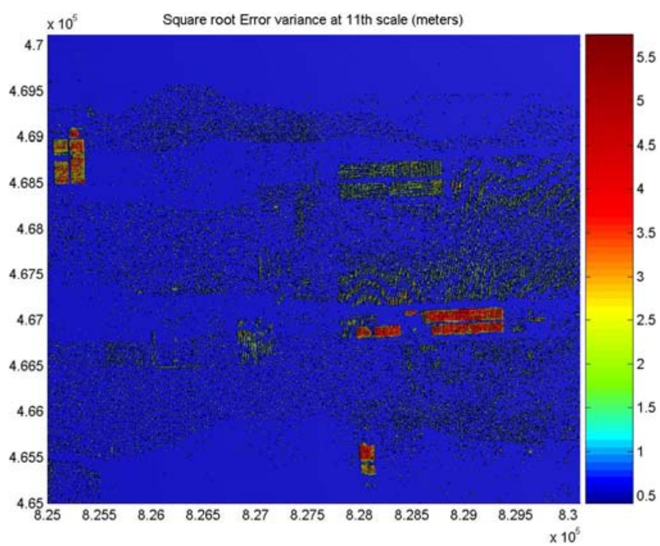
MKS Data fusion (Rural area)



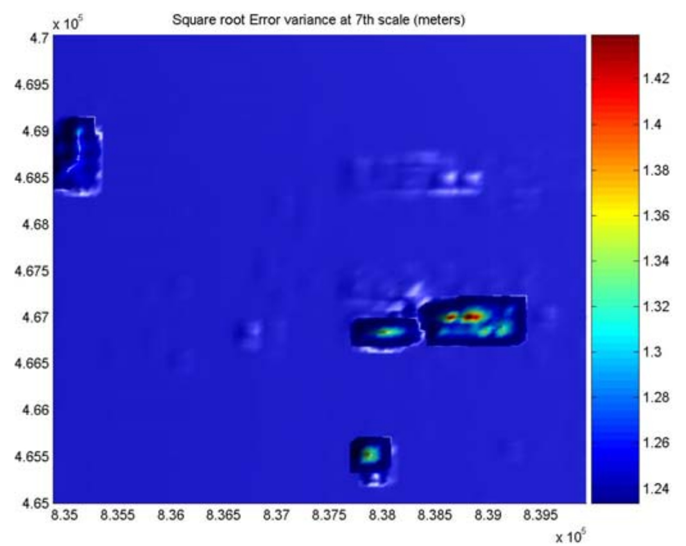
Fused Elevation at 11th scale
(Grid spacing : 5feet by 5feet)



Fused Elevation at 7th scale
(Grid spacing : 80feet by 80feet)



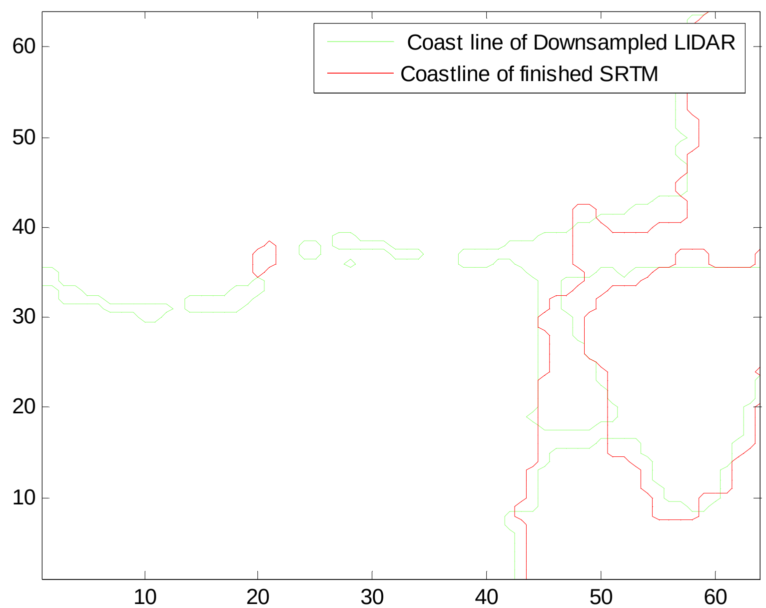
Square root error variance at 11th scale



Square root error variance at 7th scale

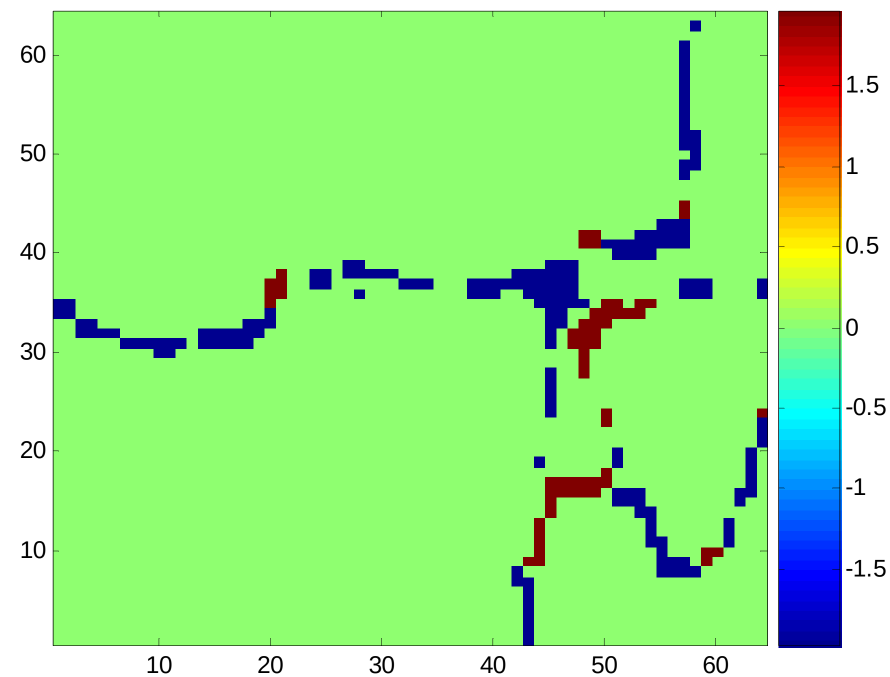
Coastline Pixels

- Coastline exhibits many small-scale variation, particularly near developed areas
  - Marinas, canals, modified shorelines
- Fuse lidar to capture this detail
- Use coastline information from lidar to boost SRTM uncertainty measure prior to fusion

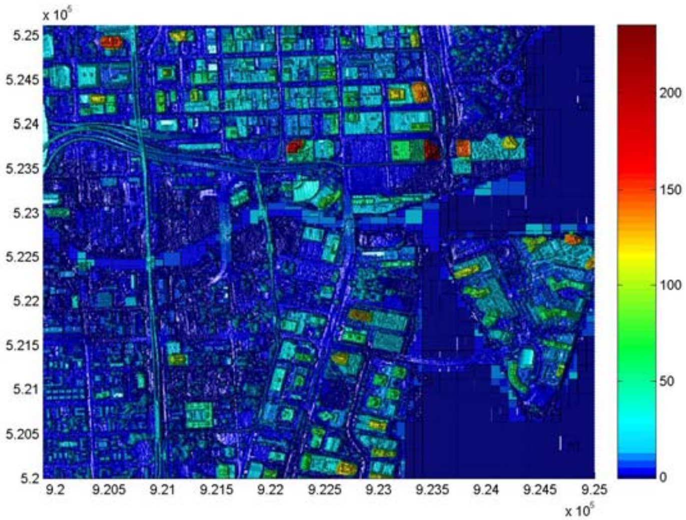


- Difference between classified lidar and classified SRTM
- In blue pixels, we boost *R* for SRTM

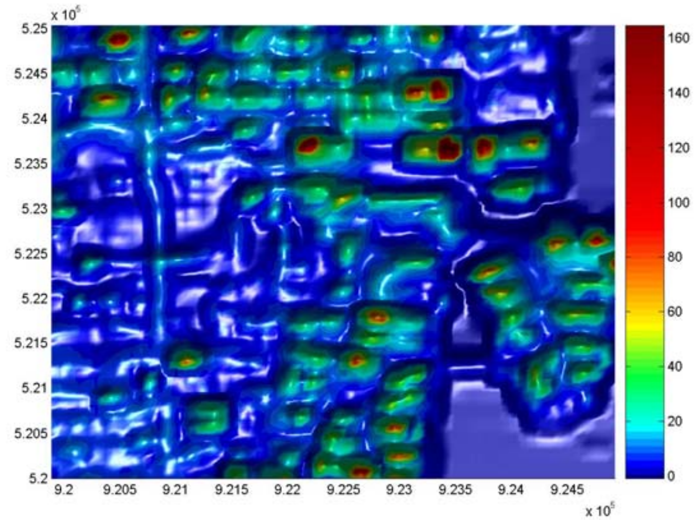
Red: lidar has land / SRTM has no land
Green: lidar has land / SRTM has land or lidar has water land and SRTM has water (assigned water level)
Blue: lidar has no land and SRTM has land



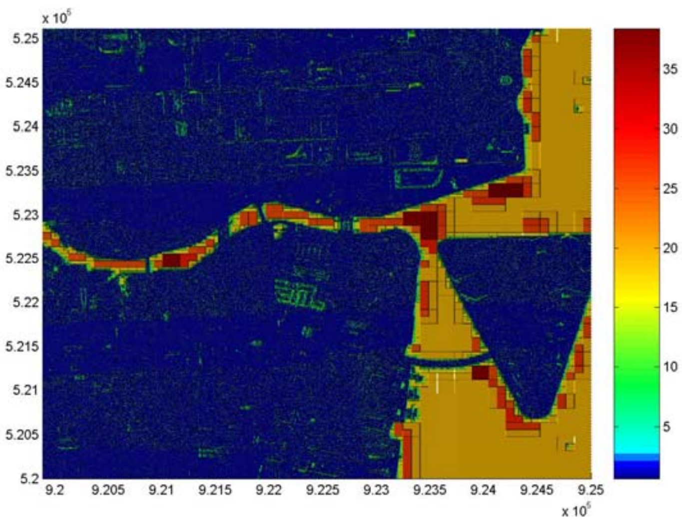
MKS Data fusion (Coastal area)



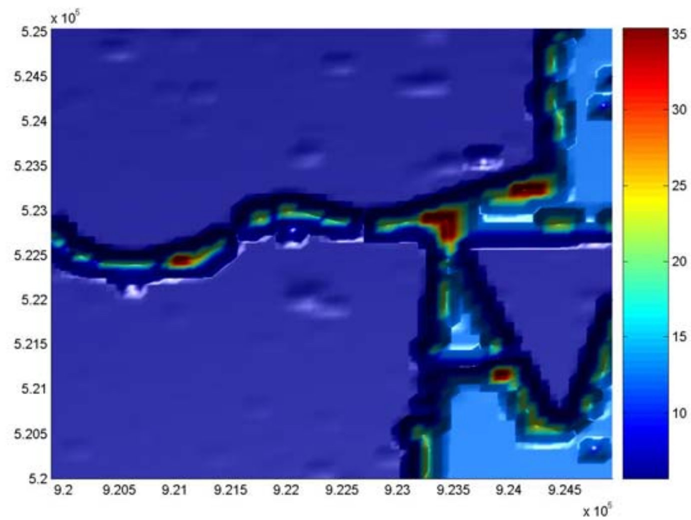
Fused Elevation at 11th scale
(Grid spacing : 5feet by 5feet)



Fused Elevation at 7th scale
(Grid spacing : 80feet by 80feet)

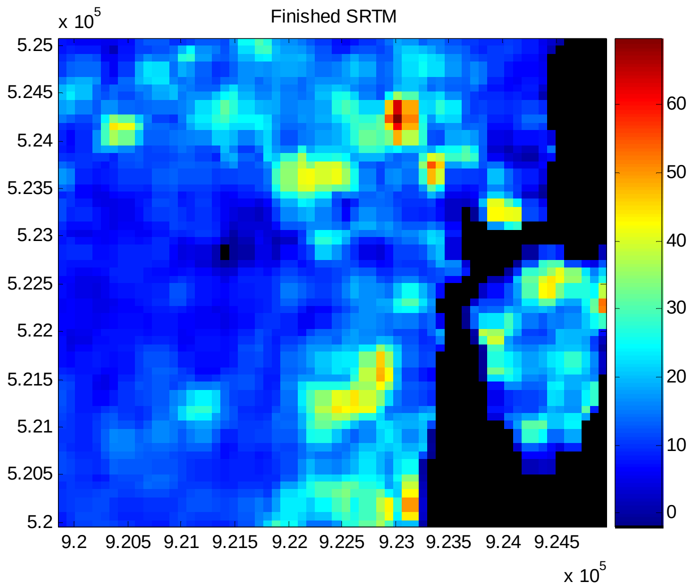


Square root error variance at 11th scale

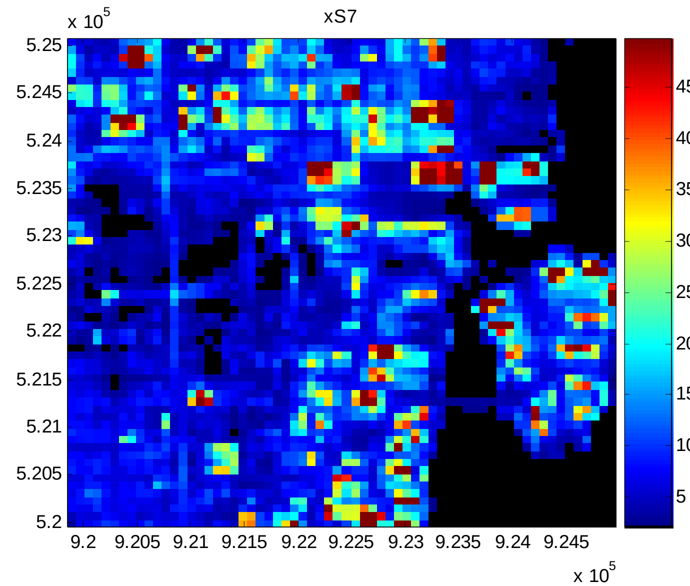


Square root error variance at 7th scale

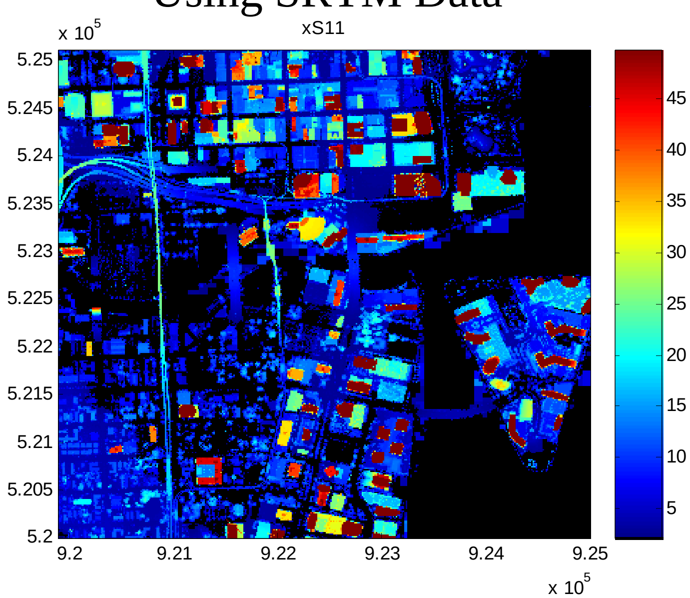
2 meter flood filled image



Using SRTM Data



Using fused estimate at 80 feet scale (SRTM Scale)



Using fused estimate at 5 feet scale (LIDAR Scale)

- Black color mapped sites indicate flooding predicted area (2m water flooding area)

Conclusion

- In this work, data from the Shuttle Radar Topographic Mapping (SRTM) mission are compared to and fused with UF ALSM high resolution topographic LIDAR observations over the shoreline of the South Florida coastline near the city of Miami.
- The evaluation of both vertical and horizontal accuracy of the SRTM DTED-2 near the coast line is made.
- This study is accomplished by statistical characterization of the Kalman innovations.
- We employed the MKS algorithm to assess the potential benefits of including SRTM data in the LIDAR data set.