Examining Urban Built-up Volume using High Spatial Resolution SAR and Lidar Data: A Case Study in Detroit, Michigan, USA

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Introduction

Accurate mapping of urban infrastructures, specifically buildings, and extent is a high priority in addressing environmental and socioeconomic problems [1,2]. Importantly, such mapping must account for the three-dimensionality (3D) of the urban environment that has traditionally been lacking (e.g., land cover and land use change—LCLUC—analyses often utilize two-dimensional satellite imagery). Undoubtedly, considerable development and change in urban areas takes place in the vertical dimension [3,4].

__Objective:__ ***Examine how Synthetic Aperture Radar (SAR) data can monitor 3D urban built-up volume by comparison with lidar data at high spatial resolution.***

Data and Methods

Analysis conducted for the Detroit metropolitan area [Fig. 1] comparing SAR and lidar data.

Synthetic Aperture Radar (SAR) data

- Sentinel-1 C-band SAR backscatter data
  - Increase in spatial resolution (40 m) accomplished by aggregating an entire year of data (2015).
  - HH (horizontal transmit and horizontal receive) and HV (horizontal transmit and vertical receive) analyzed.

Light detection and ranging (lidar) data

- Lidar-derived last-return digital height model (LR-DHM) rasters of 1 m spatial resolution
- Building volume, extracted using building footprints, aggregated to match radar pixels
- Analysis extent dictated by available lidar (leaf-on 2015)
  - ~1,200 sq. km. [Fig. 1]

1

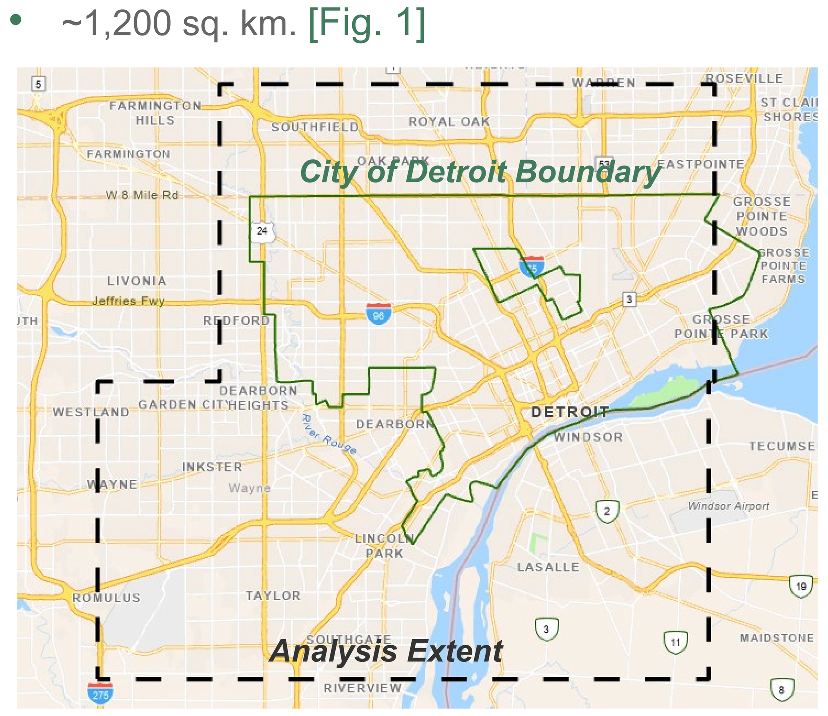

Figure 1. Data analysis extent in the Detroit metropolitan area.

Analyses

- Direct comparisons of SAR vs. lidar
  - Can be problematic because of differing spatial resolutions, discrete vs. continuous nature [3]
  - However, direct comparisons are useful to assess actual agreement between datasets
    - Conducted at multiple aggregated spatial resolutions: 40m, 80m, 120m, 160m, 1km
- Correlation and regression analyses (r^2, r, ρ, and τ)
  - Raw SAR vs. lidar at varying resolutions [Table A]

Results

Statistical comparisons

Correlations indicate moderate, positive agreement between SAR and lidar while linear regression results show weak, positive relationships [Table A]. Results correspond with work at coarser spatial scales [3]. Use of HH and HV resulted in slightly different outcomes with higher correlation coefficients for HH in most cases. Regarding spatial resolution, relationships depend on aggregation scale with 120m and 160m (better for HV) showing the highest linear agreement.

Table A. Correlations between raw SAR (mean) and raw lidar (sum) data.

A

		r^2	r	ρ	τ
40m	HH	0.14	0.38	-	-
	HV	0.13	0.37	-	-
80m	HH	0.19	0.44	0.58	0.43
	HV	0.22	0.43	0.48	0.36
120m	HH	0.22	0.47	0.61	0.46
	HV	0.20	0.45	0.50	0.37
160m	HH	0.23	0.48	0.62	0.46
	HV	0.22	0.67	0.50	0.37
1km	HH	0.24	0.49	0.52	0.39
	HV	0.13	0.35	0.35	0.25

r^2: coefficient of determination in linear model; r: Pearson correlation coefficient; ρ: Spearman rank correlation coefficient; τ: Kendall rank correlation coefficient. All correlations significant with p-values < 0.01 unless otherwise noted (< 0.05*).

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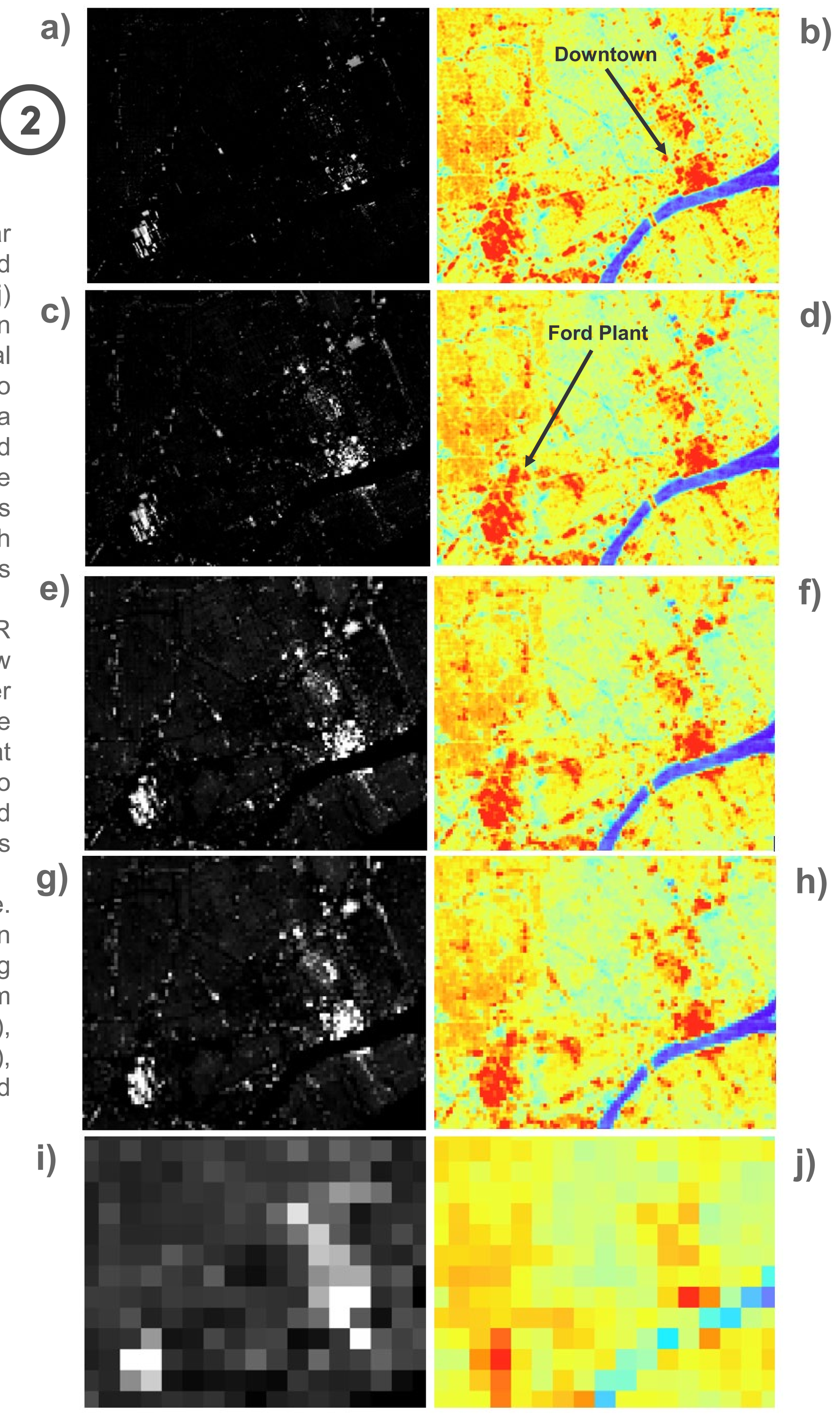

Figure 2. Lidar (a,c,e,g,i) and SAR (b,d,f,h,j) data for a portion of the central Detroit metro area. Lidar data are symbolized with low relative height values as black and high values as increasingly white. SAR images show low backscatter values with blue hue that changes to yellow and eventually red as backscatter values increase. Data are shown with the differing resolutions: 40m (a,b), 80m (c,d), 120m (e,f), 160m (g,h), and 1km (I,j).

Geospatial comparisons

Graphical results for Detroit [Fig. 2] exhibit the same spatial patterns between high SAR backscatter response and high amount of built-up volume—for example, downtown Detroit and the Ford Assembly Plant in Dearborn are similarly represented with high relative values within the datasets. This occurs regardless of spatial resolution [Fig. 2]. More detailed comparisons between the two datasets (1m lidar and 40m transparent SAR) at a finer scale [Fig. 3] show similarities between the datasets with large volume buildings as well some discrepancies along railroad tracks [Fig. 3c] where railroad cars are often parked. The latter example was confirmed in this location because high variation in SAR backscatter response was observed over time.

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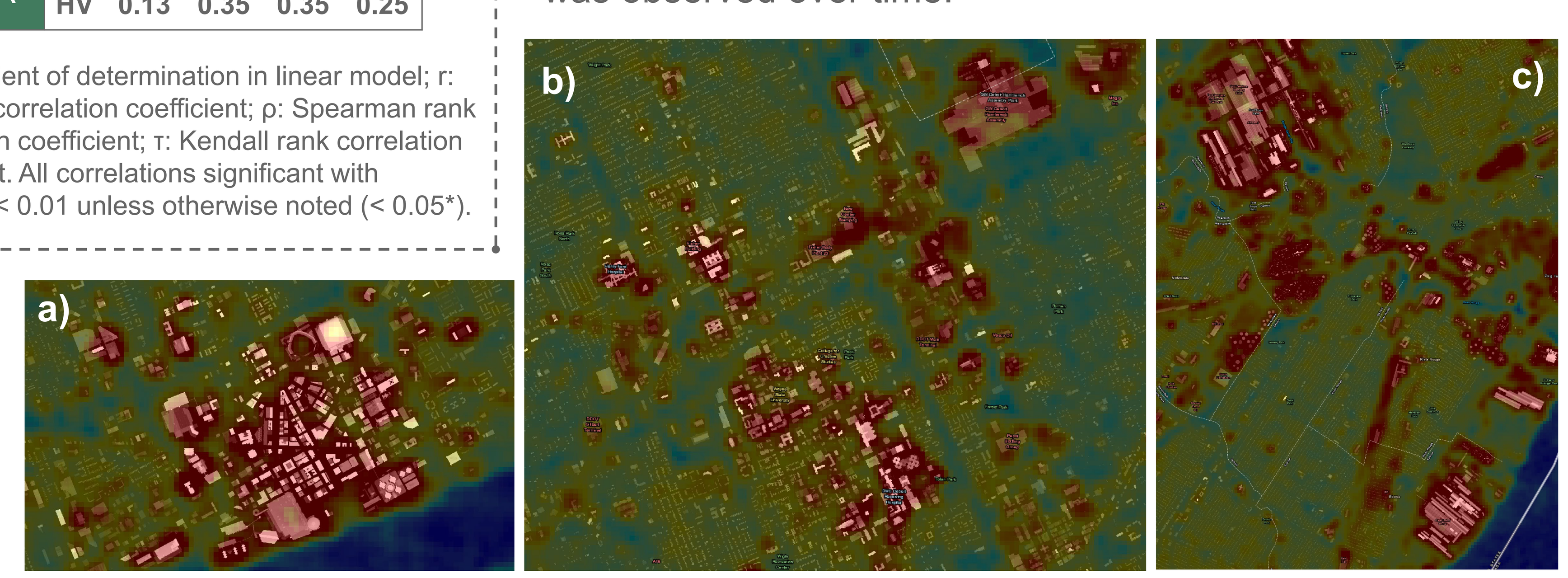

Figure 3. Significant areas of interest in Detroit comparing 1m lidar data translucently overlaid with 40m SAR data (both with same color schemes as Fig. 2). The downtown area (a) shows high backscatter values with red that are spatially collocated with skyscrapers. This area north of downtown (b) contains the General Motors factory/plant to the upper-right (northeast) and Ford hospital to the central-left (west). Both are high built-up volume buildings where high backscatter values can be observed. Industrial area in southwest Detroit metro area (c) containing the Ford Assembly Plant in Dearborn to the top-left (northwest) and other large buildings near the Detroit River in the bottom-right (southeast).

Discussion

Urban analyses must incorporate 3D remote sensing data to conduct comprehensive analyses. This effort confirms that SAR data can be used for this purpose, which is especially pertinent due to the lack of global lidar coverage (although this is changing—e.g., ICESat-2, GEDI). SAR data can detect 3D anomalies at fine scales over time (e.g., new building construction, building demolitions, etc.) further attesting to their utility for comprehensive 3D urban analyses a lower cost and higher repeatability over a much more extensive coverage compared to lidar data.

- **Linear relationship:** Consistency of agreement between areas with low and high built-up volume.
- **Future work:** Consider other approaches that utilize spatial trends to compare radar to lidar [3,4], alter this approach as needed to make realistic comparisons at higher spatial resolutions, and incorporate higher spatial resolution X-band data such as TanDEM-X or COSMO-SkyMed (~3m) for comparison.

Conclusion

Findings confirm, through comparison with aggregated lidar data, the utility of high spatial resolution SAR data for examination of urban built-up volume. Correlation results indicate moderate linear relationships between C-band SAR backscatter and lidar volume.

Acknowledgments

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