Mapping Large-scale 3D Urban Structure Using Open Data

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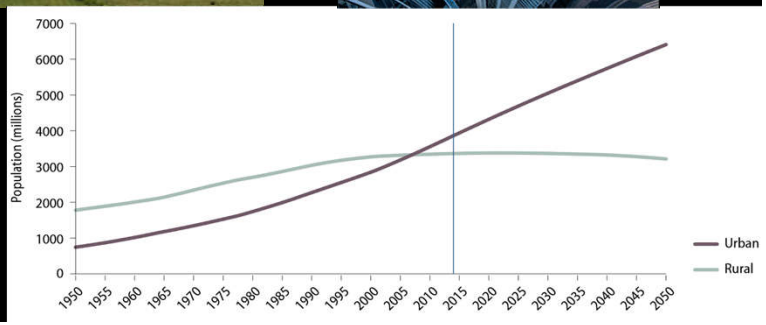
Key Messages

- Urban remote sensing has reached a key milestone and heading towards new directions.
- With open satellite data and machine learning technologies, we can fill in the knowledge gaps in large-scale 3D urban structure.
- Remotely sensed 3D urban structure brings the representation of urban landscape to a new level and enables important applications.

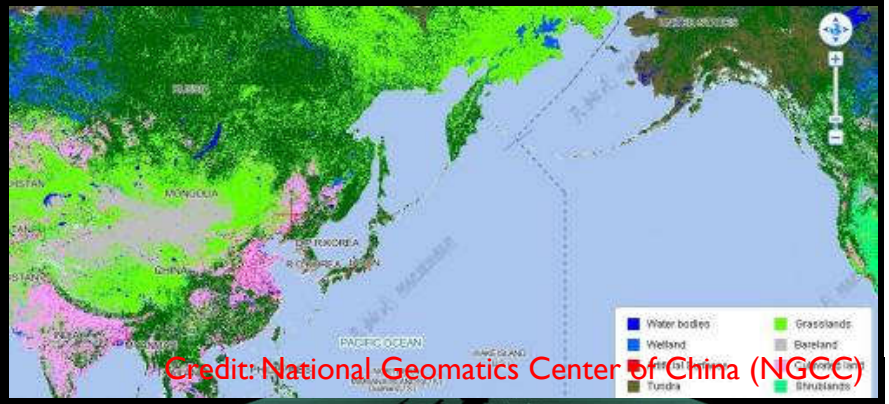
Why Urbanization Matters?

- Broad environmental and societal impacts of urbanization:
  - Local-to-regional climate and hydrology
  - Habitat loss and biodiversity
  - Energy consumption and emissions
  - Loss of agricultural land and food security
  - Societal, economical, and cultural challenges of demographic change
  - Impacts embedded in global trade



Urban Remote Sensing: Global Urban Extent

- Since 2016, several global urban extent maps have been produced.
- GlobeLand30, a global land cover map with an "urban" class, was created by National Geomatics Center of China (NGCC).
- Global Human Settlement Layer (GHSL) was created by the EU Joint Research Centre (JRC) using Landsat data.
- Global Urban Footprint (GUF) was created by the German Aerospace Center (DLR) using TanDEM-X SAR data.

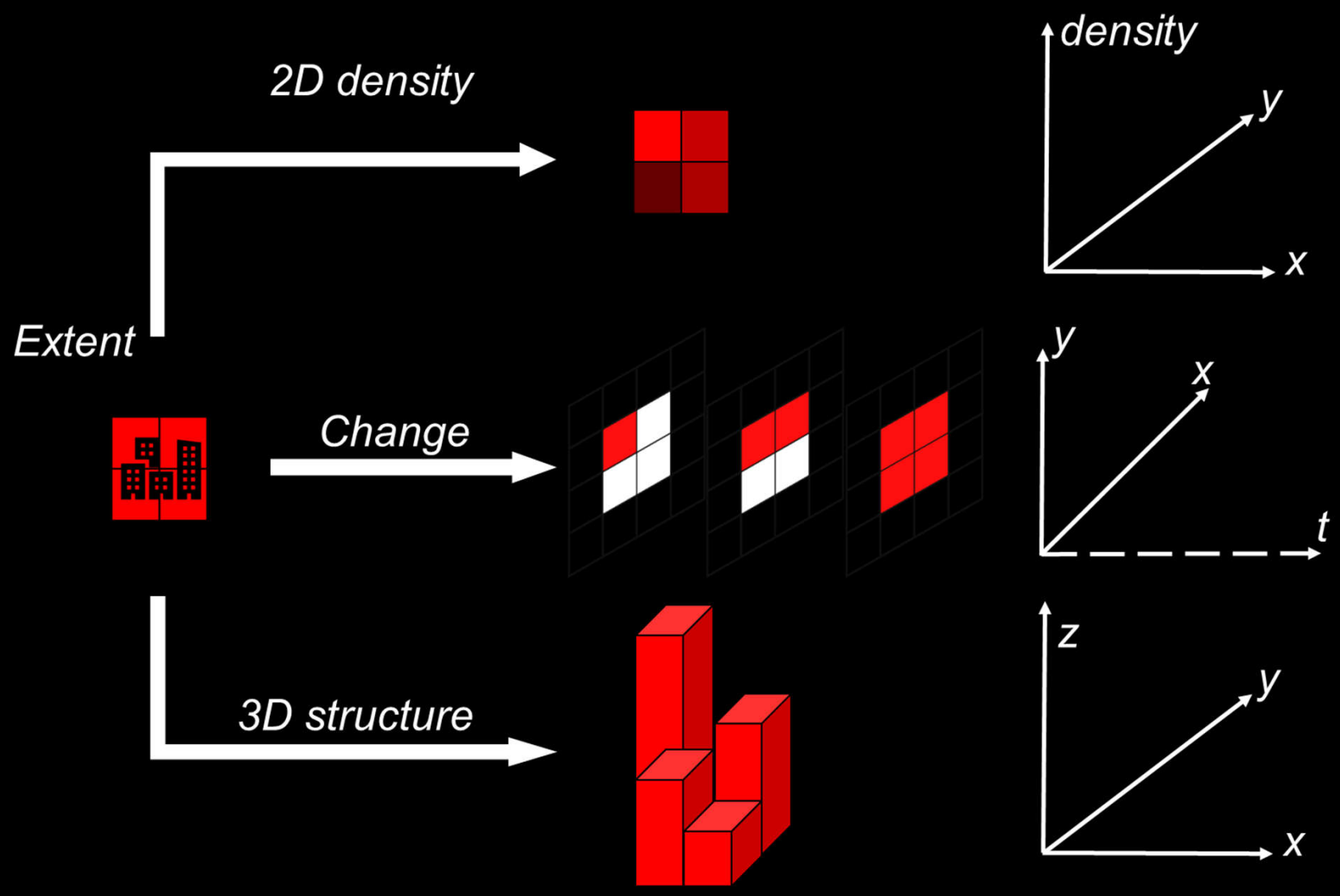


Credit: National Geomatics Center of China (NGCC)


Credit: EU Joint Research Centre (JRC)

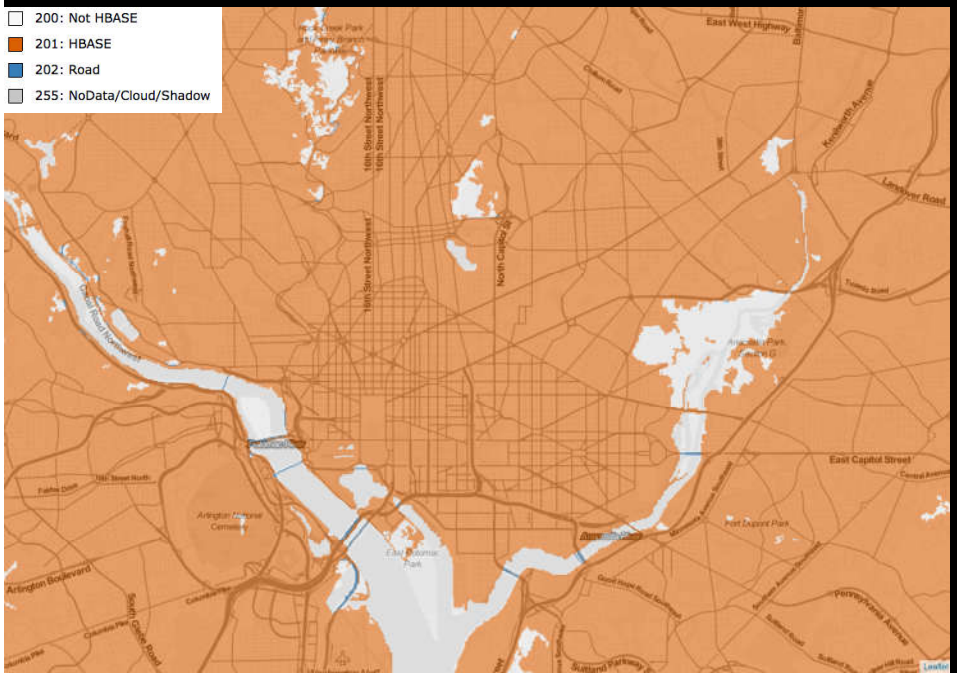

Credit: German Aerospace Center (DLR)

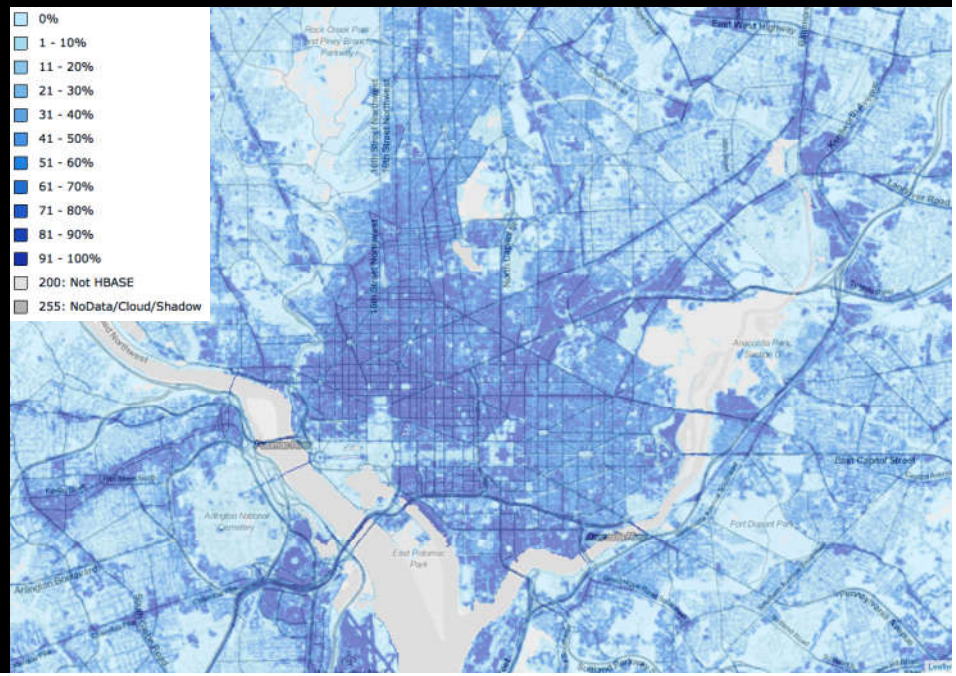
New Directions of Urban Remote Sensing



Urban Remote Sensing: 2D density

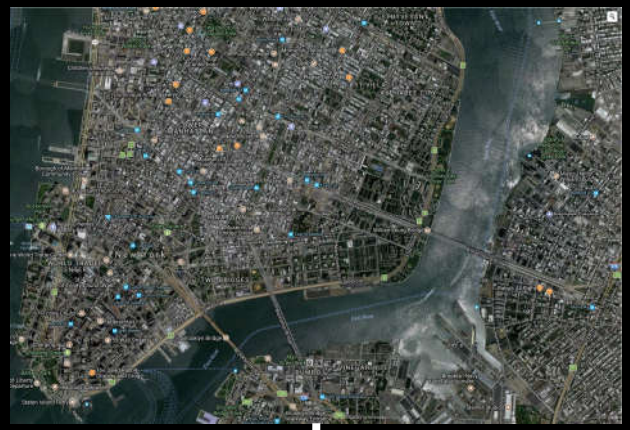
- Global Man-made Impervious Surface (GMIS): a NASA-funded project to produce circa-2010 global 30m impervious surface product using Landsat data.
- A global Human Built-up And Settlement Extent (HBASE) was created by the GMIS project.
- GMIS/HBASE dataset has been released by NASA Socioeconomic Data and Applications Center (SEDAC, hosted by CIESIN, Columbia Univ).





Urban Remote Sensing: 3D Urban Structure

- There is a big knowledge gap in three-dimensional urban structure at large-scale



https://sedac.ciesin.columbia.edu/data/set/ulandsat-gmis-v1

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Remotely Sense of 3D Urban Structure: Methodological Considerations

Challenges:

- Height information only available from global DSMs
- DSM measures absolute top of surface height
- Need effective method to separate ground height
- Quality and spatial coverage of DSM datasets
- Need good quality building height/volume data for cal/val

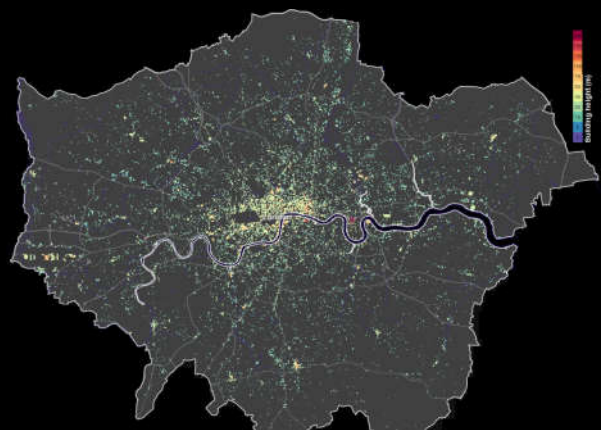


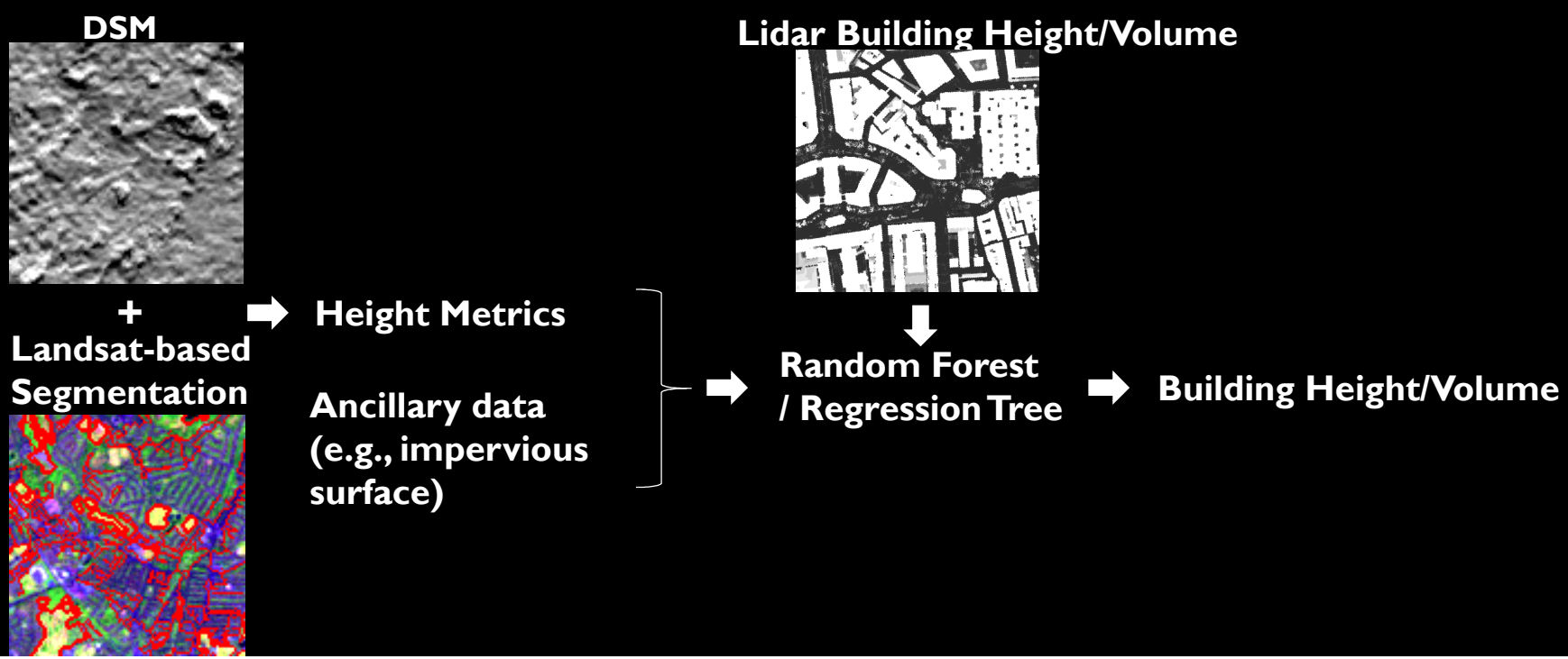
Image credit: Emu Analytics

Solutions:

- Use Landsat-derived objects for spatial units of height information extraction
- Use a suite of object-based height metrics and ancillary information from Landsat for machine learning regression algorithms
- Use multiple DSM datasets
  - performance of global DSMs were found to vary across different areas
- Test algorithm in England, whose Lidar data coverage is over 75%

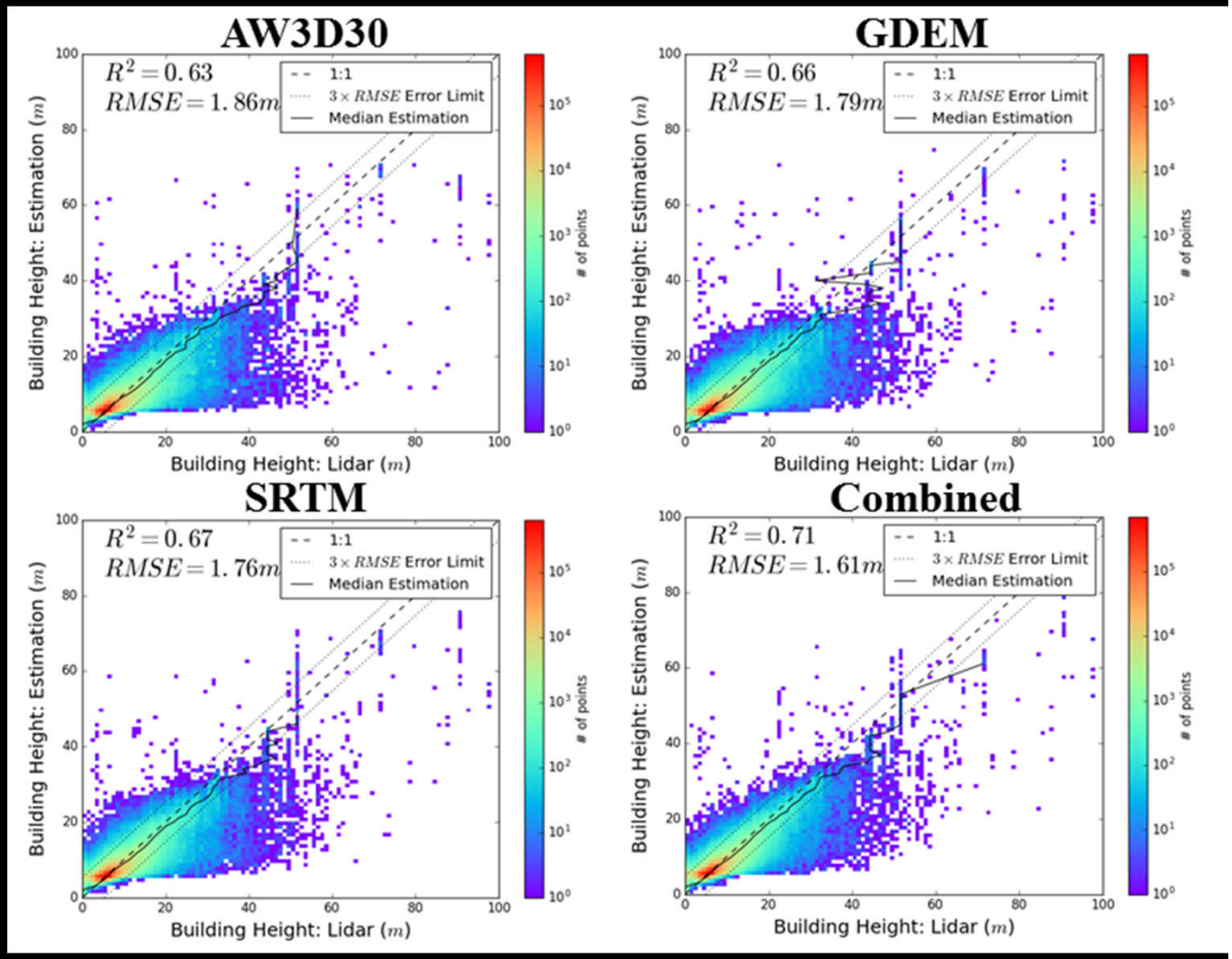
Height/Volume Estimation Using Height Metrics

- Estimated height metrics from object-based DSM profile
  - Maximum, mean, minimum of height, slope
- Incorporated GMIS impervious surface product
- Predicted building height/volume using random forest and regression tree



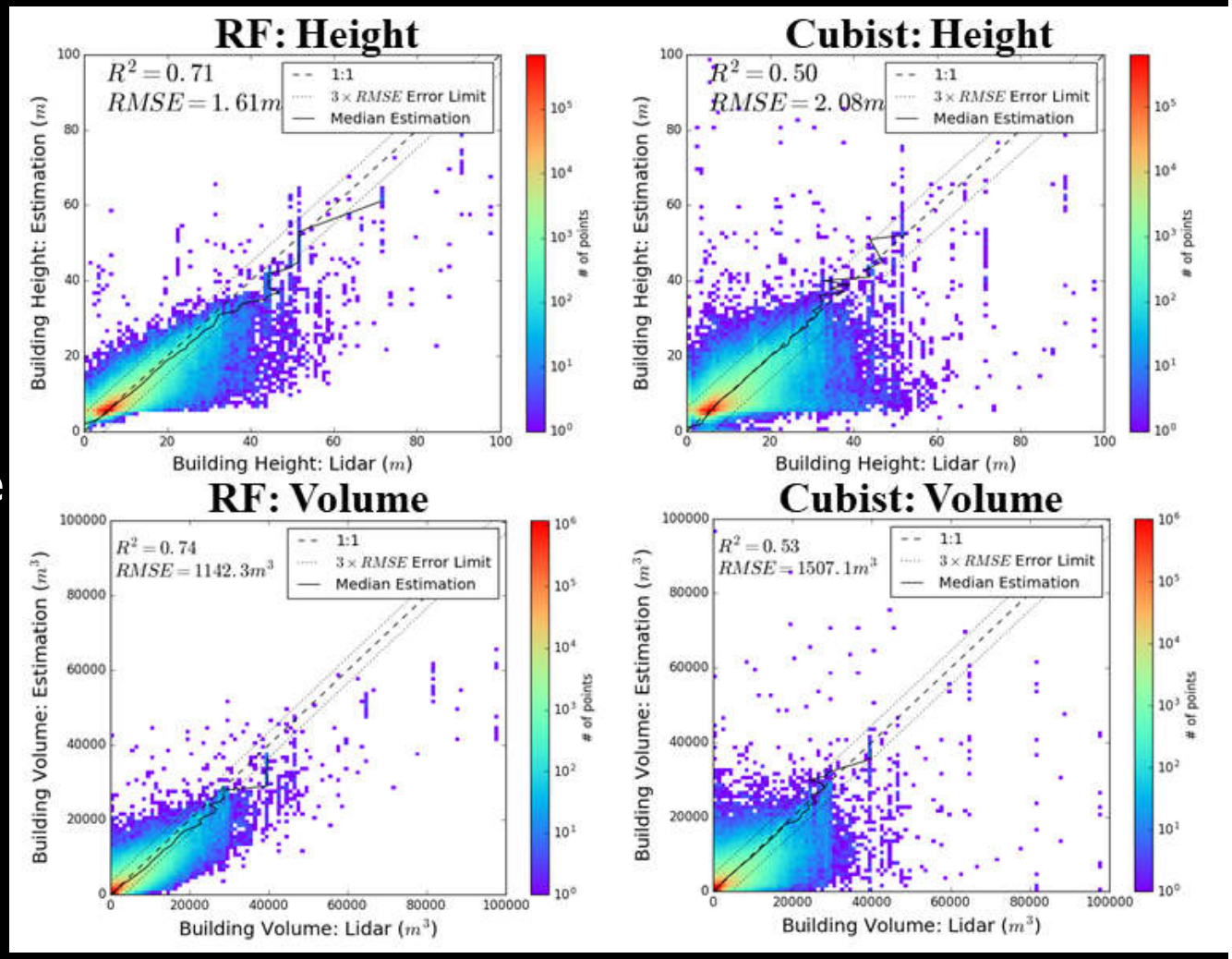
Modeling Result Affected by Input DSM

- Accuracies derived from 10-fold cross validation on Lidar-derived training data
- The best result was obtained by combined use of three DSMs.



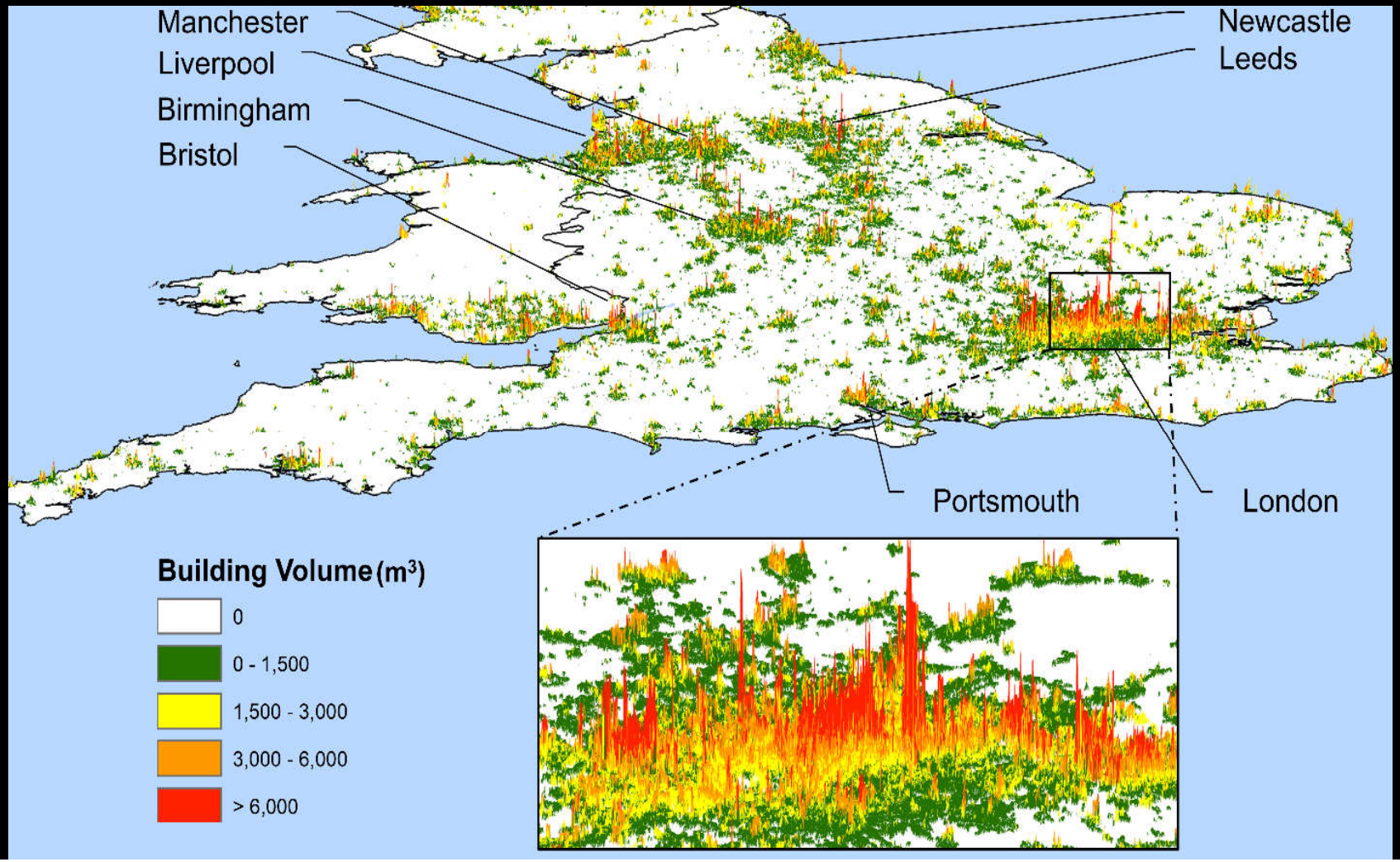
Choice of Algorithm Is Also Important

- Accuracies derived from 10-fold cross validation on Lidar-derived training data
- Better overall performance using random forest than using regression tree
- Random forest handles missing data better and is less likely to over-fit for high-dimensional feature space



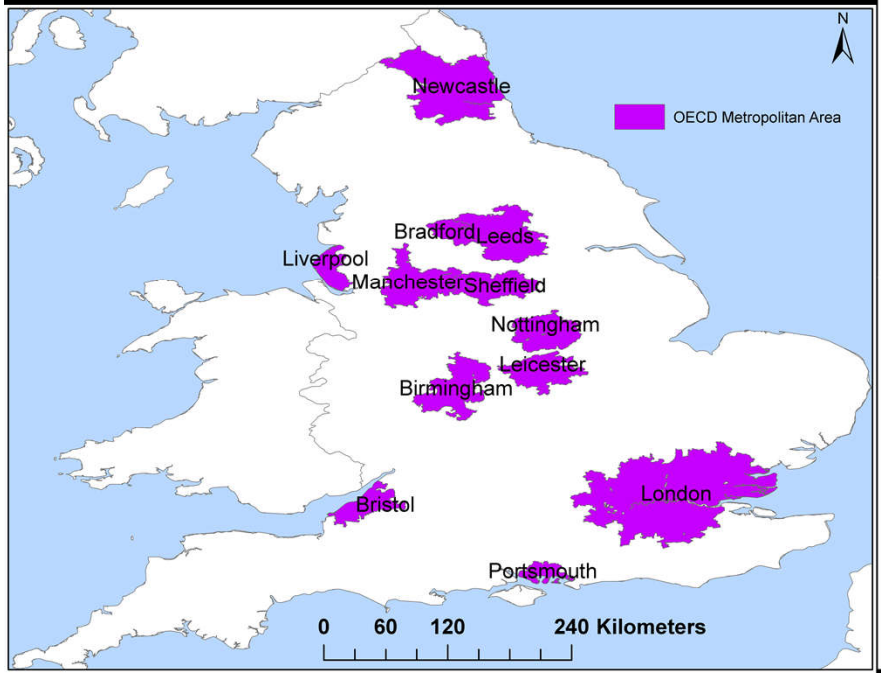
3D Rendition of England Building Volume

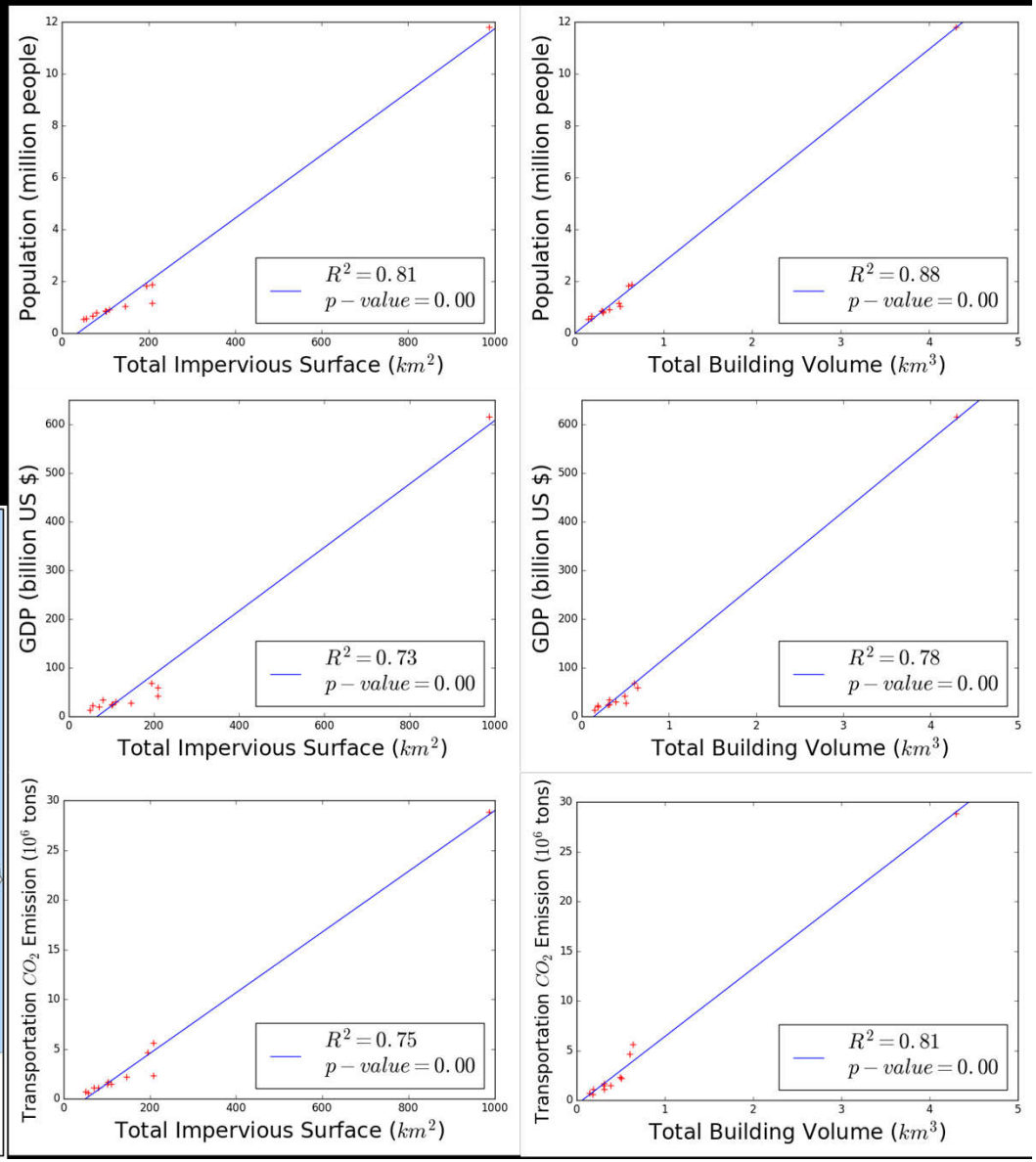
- Country-scale building height and volume mapped for the first time!



Applications: Linking Remote Sensing and Socioeconomic Data

- Analysis done for 12 metropolitan areas in England defined by OECD.
- Strong correlation between building volume and socioeconomic variables.
- Building volume are linked with these variables slightly better than impervious surface.

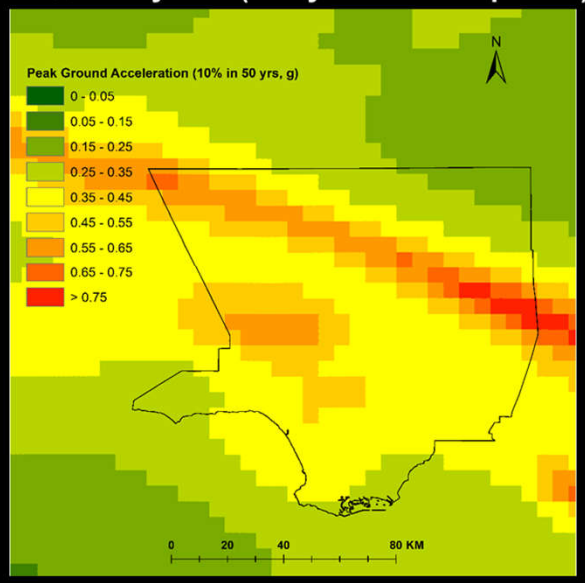




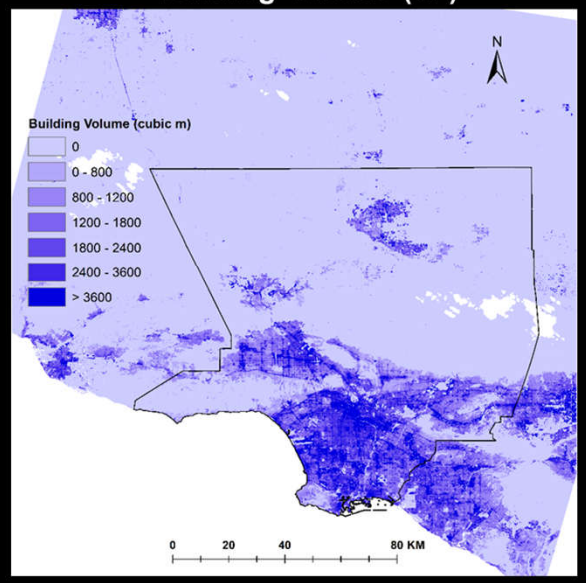
Applications: Assessing Disaster Vulnerabilities

- Resilience to disasters is an important characteristic of sustainable urban development (SDG target 11.B)
- Vulnerabilities to disasters traditionally measured based on population
- Volume based assessment provides valuable additional information

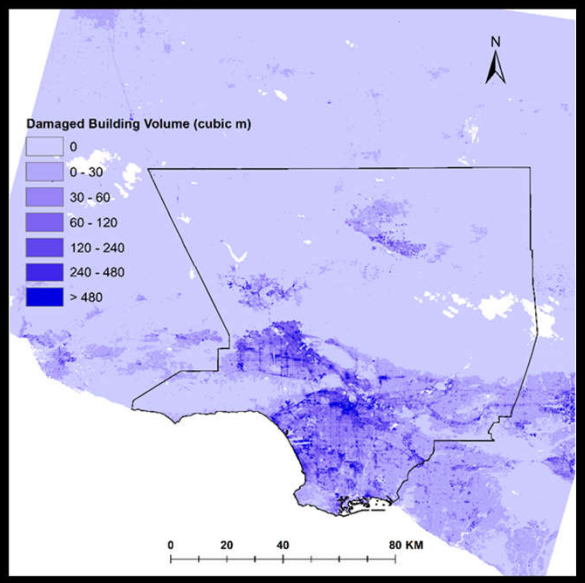
Peak Ground Acceleration (g)
10% in 50years (475 years return period)



Building Volume (m^3)



Damaged Building Volume (m^3)

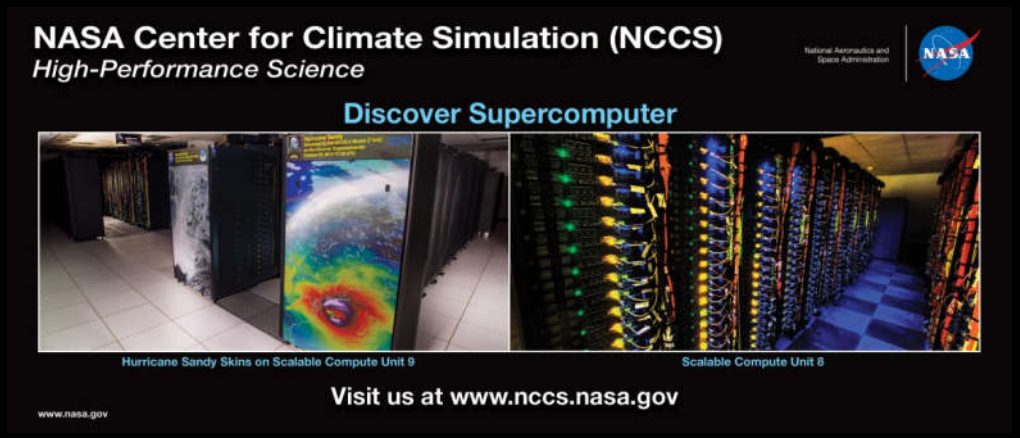


Conclusions

- Machine learning method using object-based height metrics could map building height/volume effectively even with suboptimal elevation data
- But low-quality input elevation data may introduce uncertainty, which could be reduced by using multiple datasets
- There is great potential for country scale to global scale urban structure mapping using the combination of a new generation of optical, InSAR, and Lidar sensors:
  - Landsat-8, Sentinel-2
  - TanDEM-X
  - ICESAT-2, GEDI

Acknowledgements

- Chengquan Huang (Univ of Maryland)
- Eric Brown de Colstoun, James Tilton, Bin Tan (NASA GSFC)



LCLUC

Land-Cover / Land-Use Change Program

Thanks!

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