Estimating the Building Height from Sentinel Data at 10 m Resolution

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LA 558 Final Project

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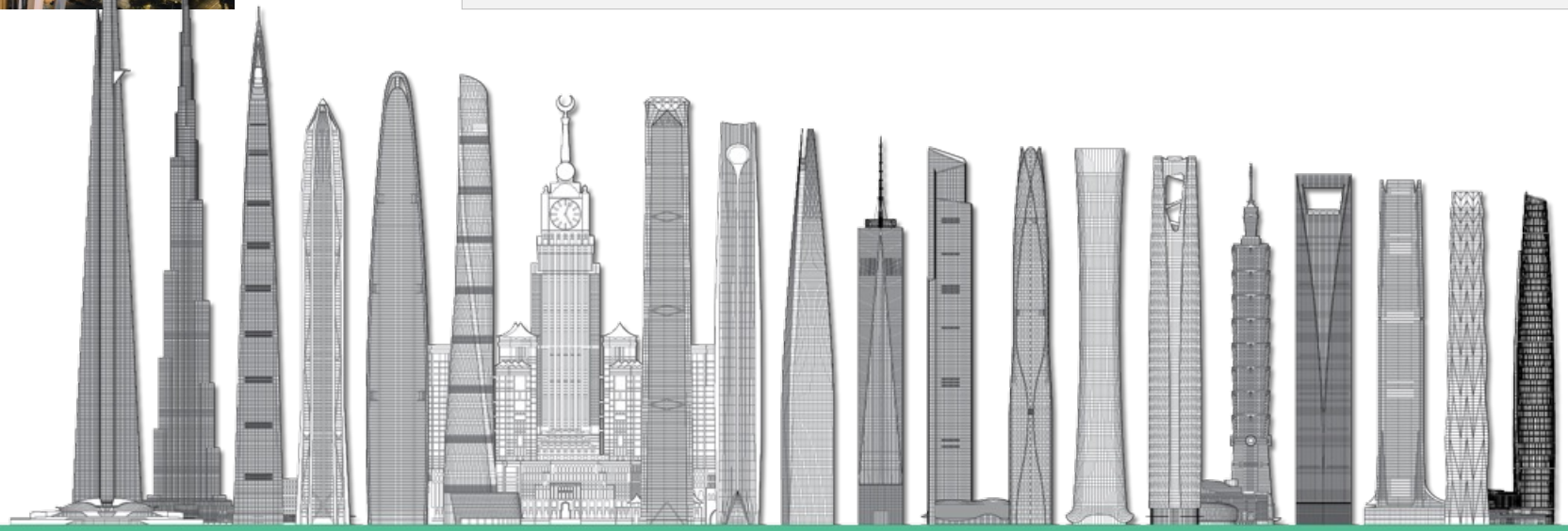
Background

Why we need to know the building height?

Building height --- an important indicator for

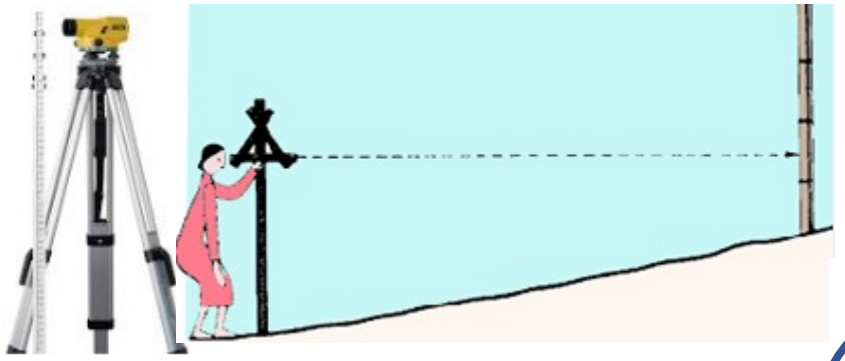
- Estimating energy consumption
- Material stock allocation
- Greenhouse gas emissions
- Urban heat island effects
- Distribution of population
- Urban development plan



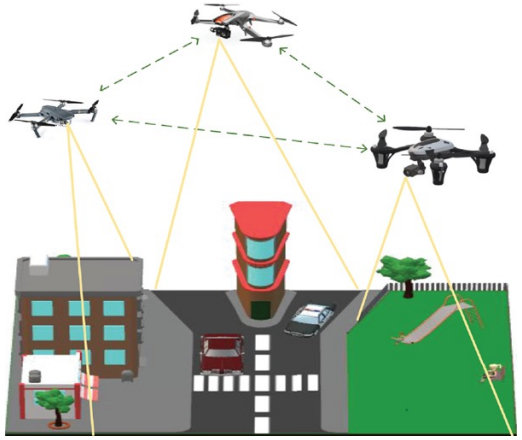
Background

How to measure the height of building? **New technology!**

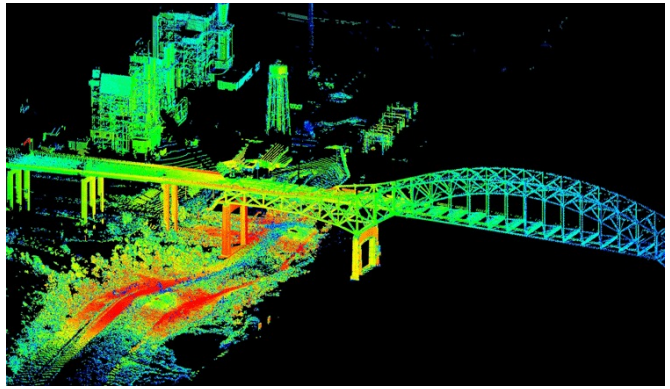
Handy



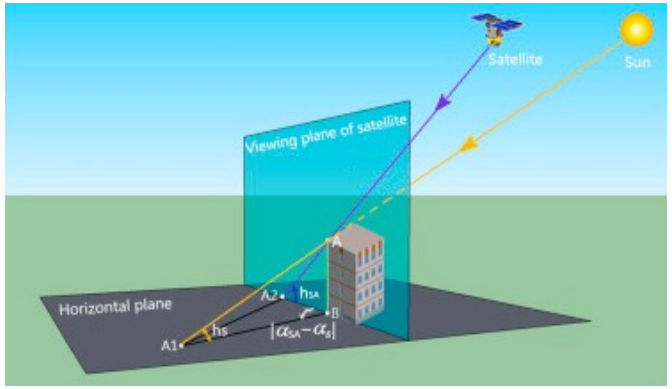
Photogrammetry



Lidar



Satellite



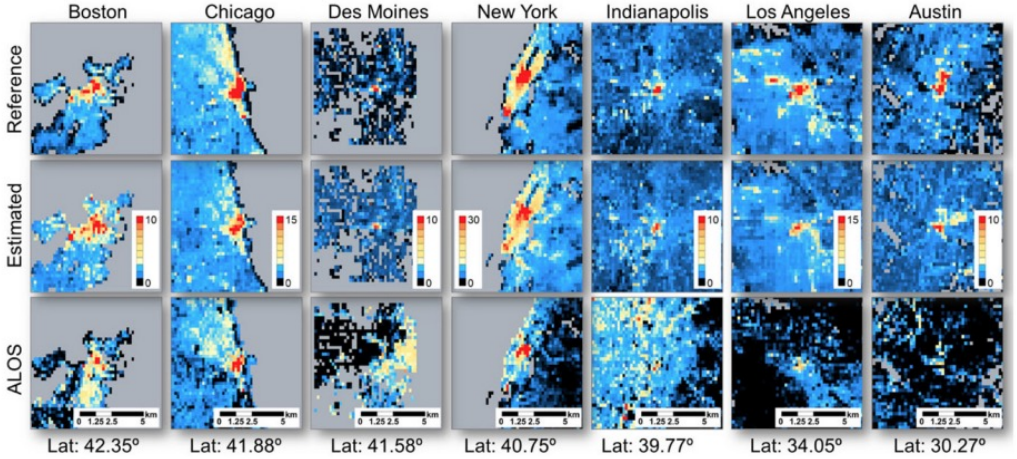
Research Gap

What's the research frontier?

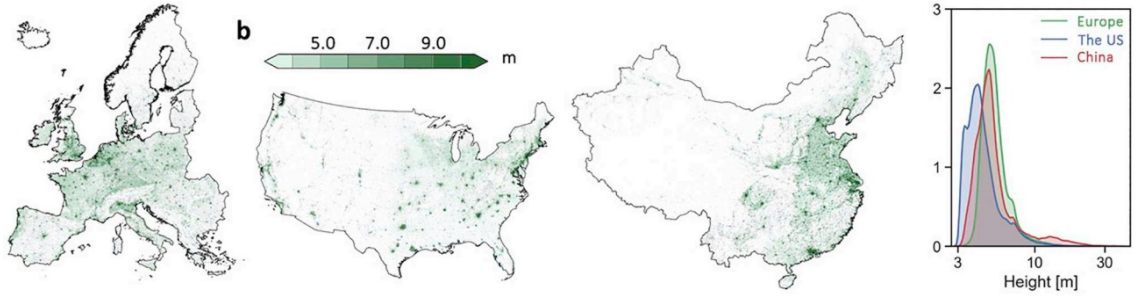
1. Li et al., 2020

$$VVH = VV * \gamma^{VH}$$

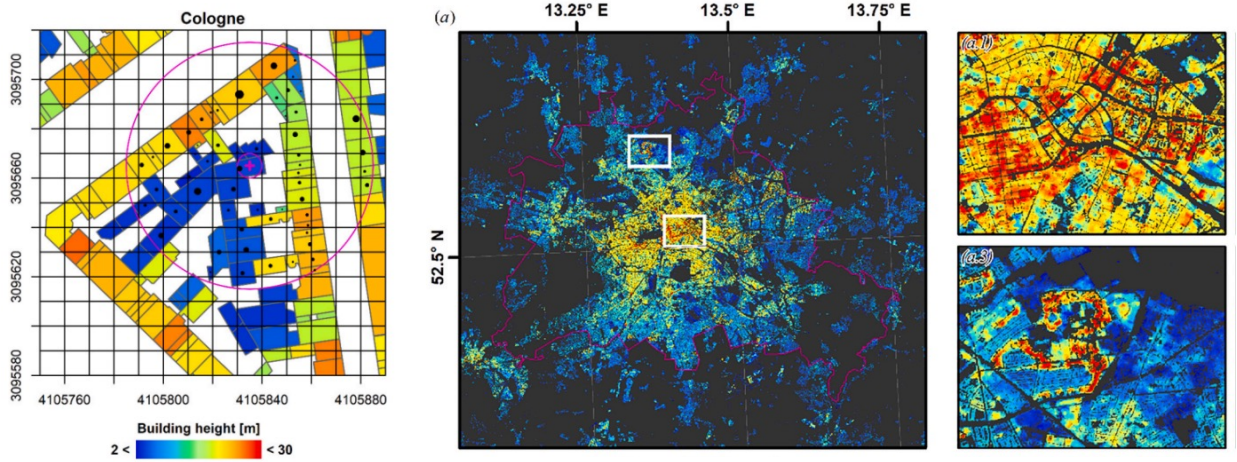
$$\ln H = a * VVH^{b} + c$$



2. Li et al., 2021



3. Frantz et al., 2021



Research goal:

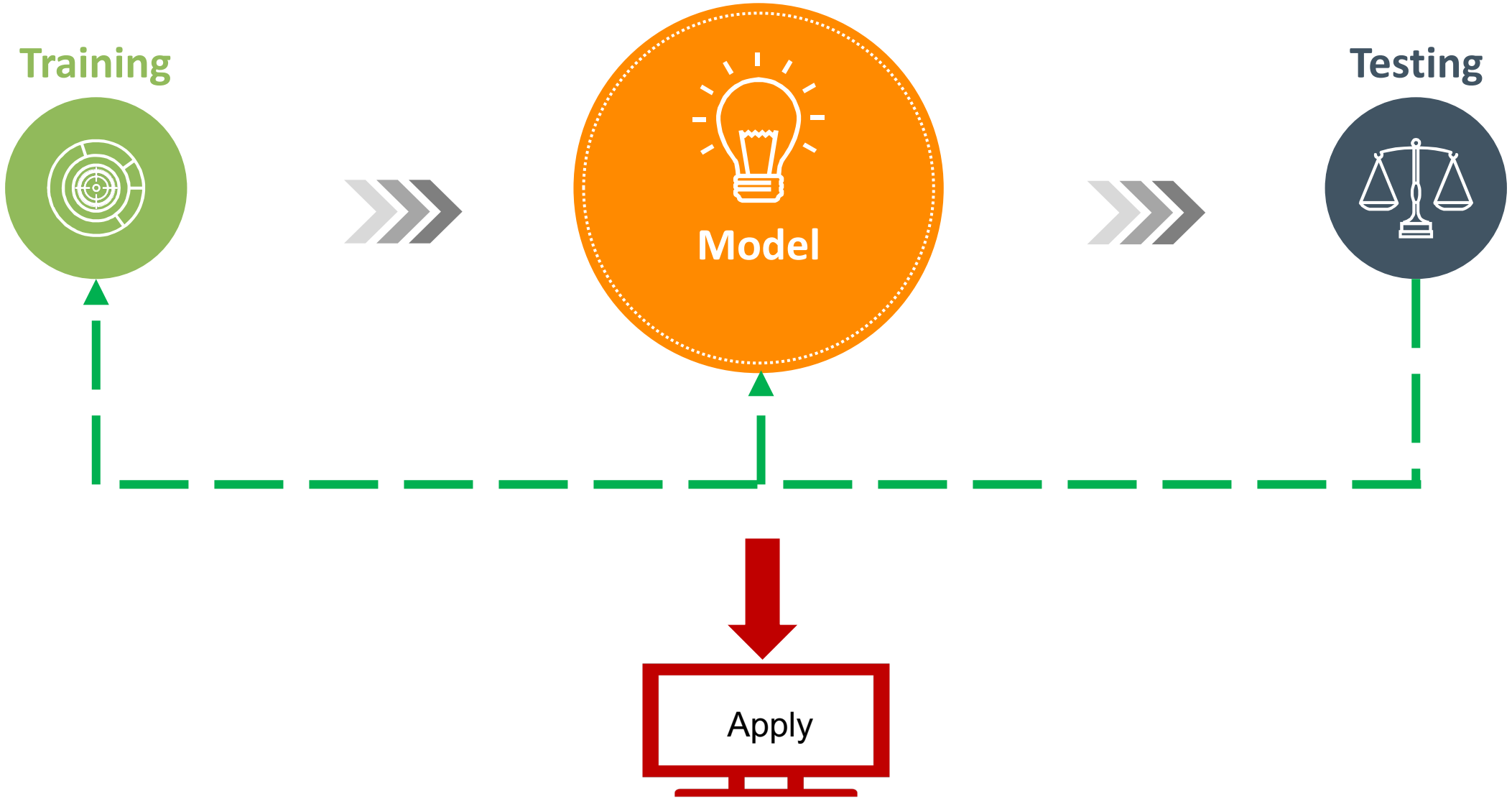
- Develop an effective and accurate model to estimate building height at 10 m resolution.
- Obtain national or global building height data.

Data and Method

Independent variables
Dependent variable
Feature selection
Model ensemble
Model evaluation

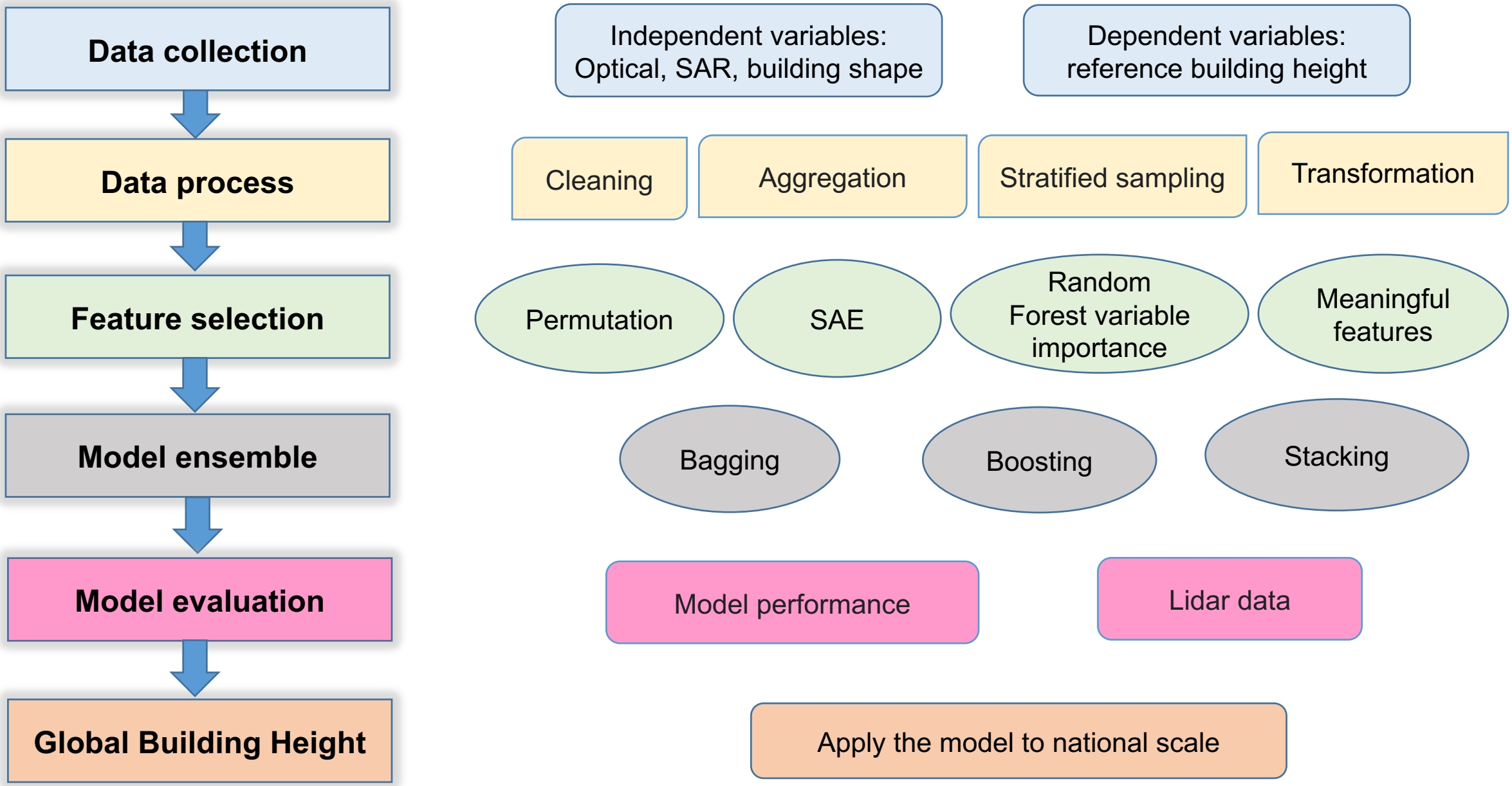
How to build a machine learning model

Basic logic



Flow chart

More detailed flow



Independent variables

Spatial – Spectral - Temporal feature database

Spectral Indexes

Sentinel-2

Band 2,3,4,8 (10m)

Sentinel-1

VV, VH, VVH

Indexes

NDWI, NDVI, LSWI, NDBI, mNDWI

B2	496.6nm (A) / 492.1nm (B)	Blue
B3	560nm (A) / 559nm (B)	Green
B4	664.5nm (A) / 665nm (B)	Red
B8	835.1nm (A) / 833nm (B)	NIR

$$VVH = VV * 5^{VH}$$

$$NDWI = \frac{\rho_{Green} - \rho_{NIR}}{\rho_{Green} + \rho_{NIR}}$$

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

$$LSWI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}$$

$$NDBI = \frac{\rho_{SWIR} - \rho_{NIR}}{\rho_{NIR} + \rho_{SWIR}}$$

$$MNDWI = \frac{\rho_{Green} - \rho_{SWIR}}{\rho_{Green} + \rho_{SWIR}}$$

A total of 160 features

Temporal Indexes

Average, standard deviation, 0/10/25/50/75/90/100% quantiles, range, interquartile range, skewness, and kurtosis

156

+

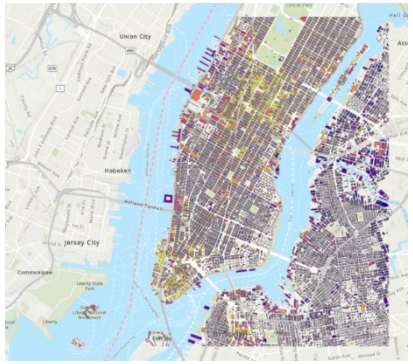
Spatial index

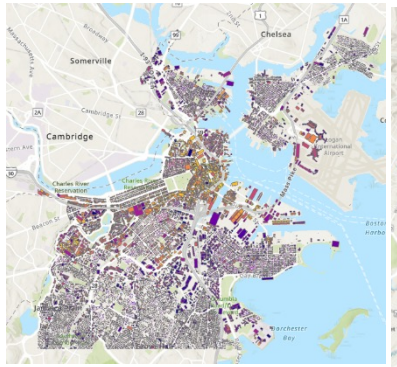
Length
Width
Near distance
Orientation

4

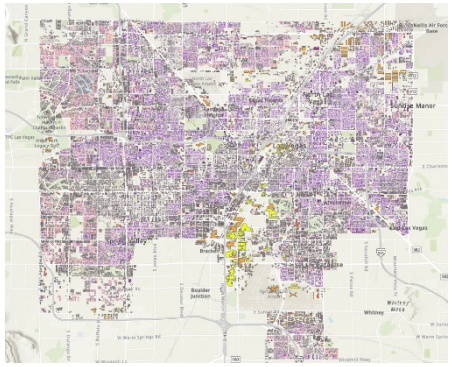
Dependent variable: building height

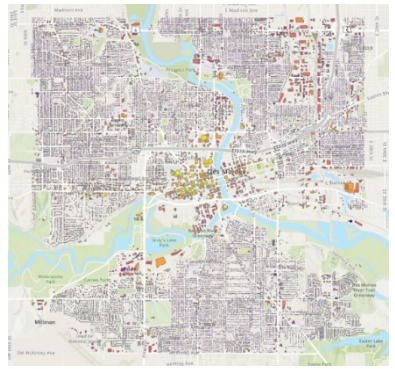
Reference building height data from twelve cities

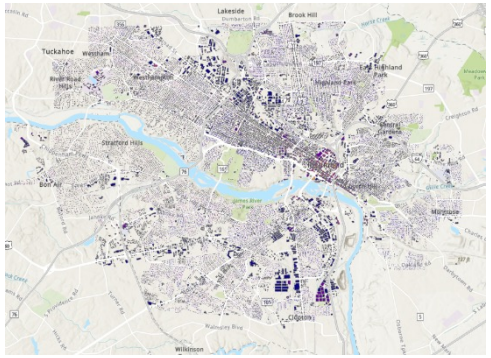

New York

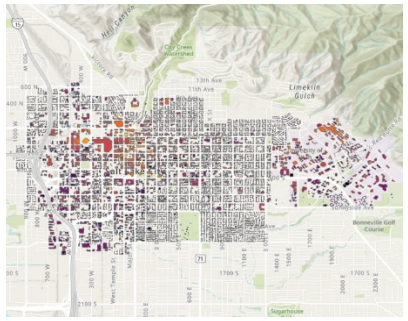

Boston

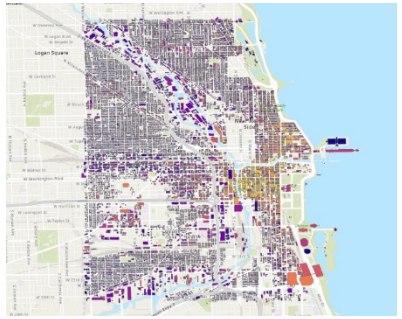

Austin

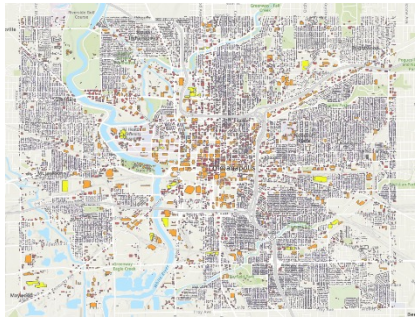

Las Vegas

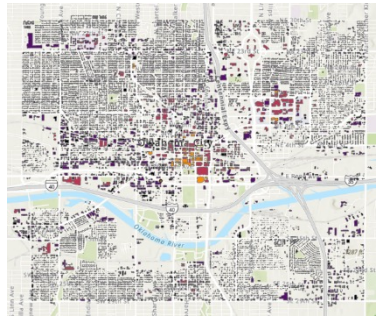

Des Moines

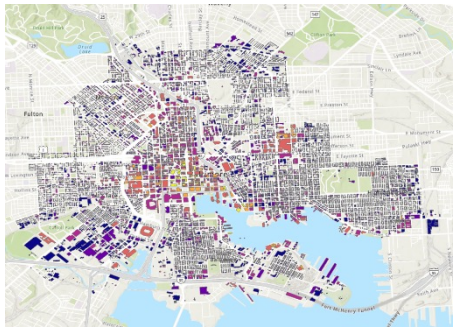

Richmond

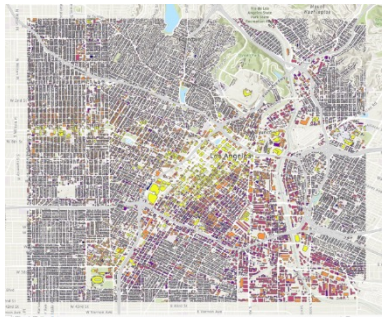

Salt Lake City


Chicago


Indianapolis


Oklahoma


Baltimore


Los Angeles

Building footprint source: https://github.com/microsoft/USBuildingFootprints

Feature selection

Get the stable features

❖ Shapley Additive Explanations

This value is the average marginal contribution of a feature value across all the possible combinations of features.

❖ Permutation feature importance

This approach directly measures feature importance by observing how random re-shuffling (thus preserving the distribution of the variable) of each predictor influences model performance.

❖ Random Forest variable importance

The default method to compute variable importance is the mean decrease in impurity mechanism: At each split in each tree, the improvement in the split-criterion is the importance measure attributed to the splitting variable, and is accumulated over all the trees in the forest separately for each variable.

❖ Meaningful features

Besides above statistic indicators, we can also select the meaningful features manually.

Independent variables: MBG_Length, MBG_Width, LSWI_kurtosis, LSWI_skew, NDVI_skew, NDWI_skew, B3_p10, B4_p10, NDVI_interquatile_range, VV_mean, VH_mean, VVH_mean, VVH_stdDev

Model ensemble

RF VS. SVM VS. Glmnet VS. gamboost

- **Random Forest regression**
- **Support Vector regression**
- **Glmnet**
- **Generalized Additive Models**

Preliminary accuracy comparison of different models

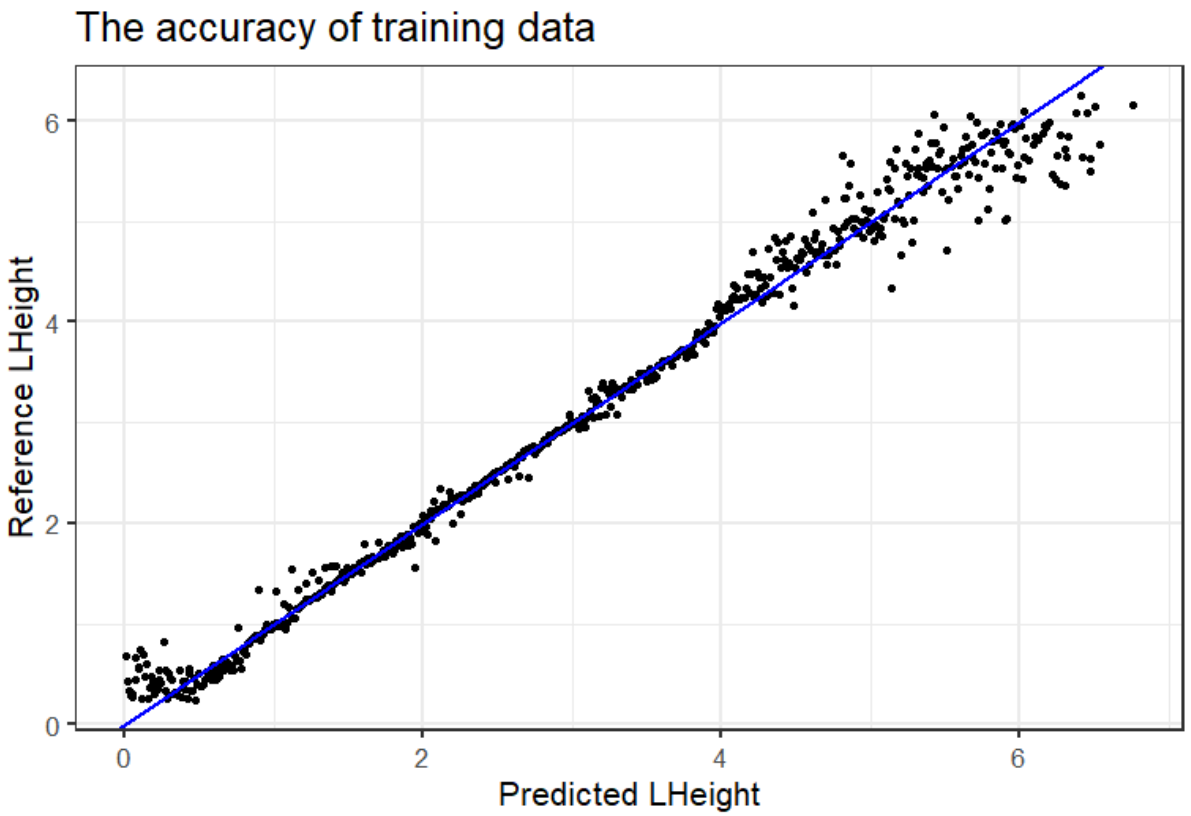
Rsquared

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
rpart	0.4178080306	0.4478954	0.5066016	0.4968194	0.5297325	0.5954782	0
glm	0.0001710916	0.6088913	0.6225619	0.5265694	0.6360930	0.6831387	0
glmnet	0.5973529469	0.6186869	0.6352957	0.6351207	0.6477667	0.6902985	0
lm	0.0001710916	0.6088913	0.6225619	0.5265694	0.6360930	0.6831387	0
rf	0.6804925350	0.7203345	0.7385717	0.7352511	0.7560331	0.7973643	0
knn	0.4489230663	0.4971347	0.5325895	0.5298389	0.5486733	0.6448886	0
svmRadial	0.6760886457	0.7073117	0.7270151	0.7264737	0.7484454	0.7805409	0
gausssprLinear	0.5980602391	0.6171075	0.6351901	0.6348789	0.6474015	0.6919441	0
gamboost	0.6492994480	0.6632784	0.6823294	0.6807147	0.6943563	0.7222680	0

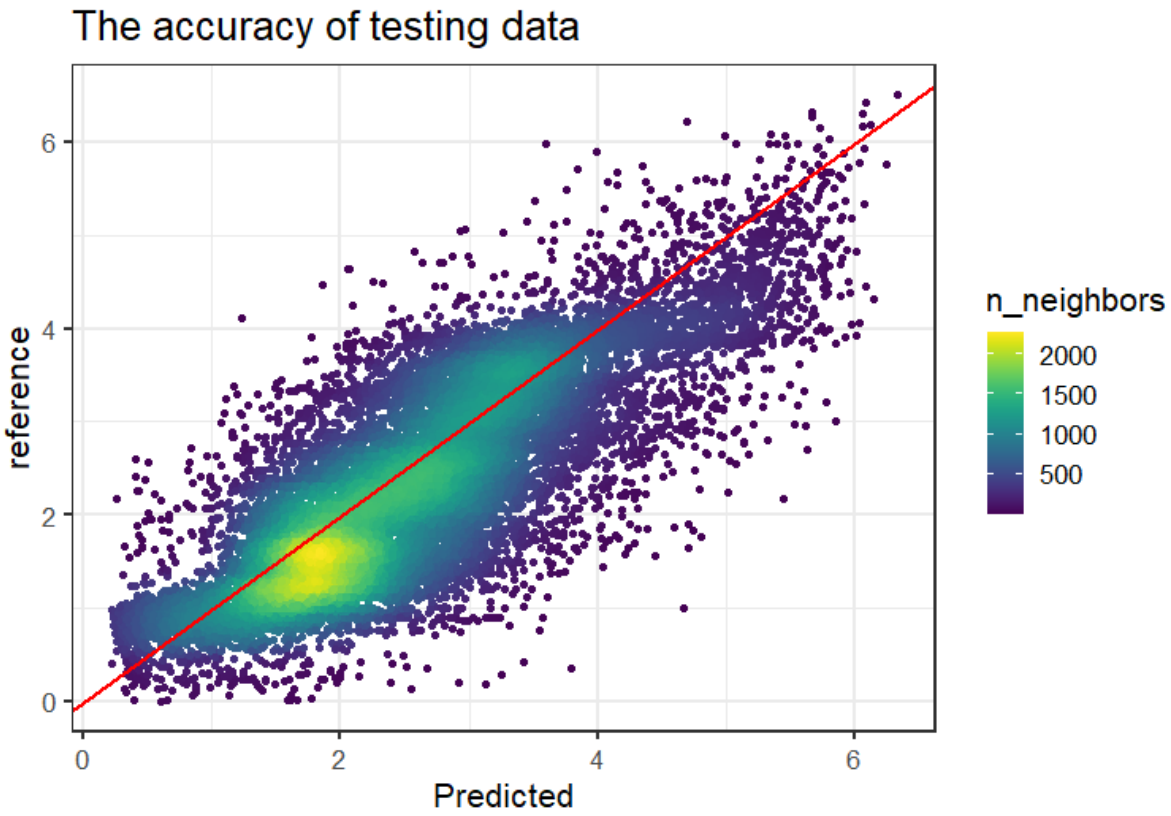
Results

Accuracy
Building height mapping

Test the accuracy



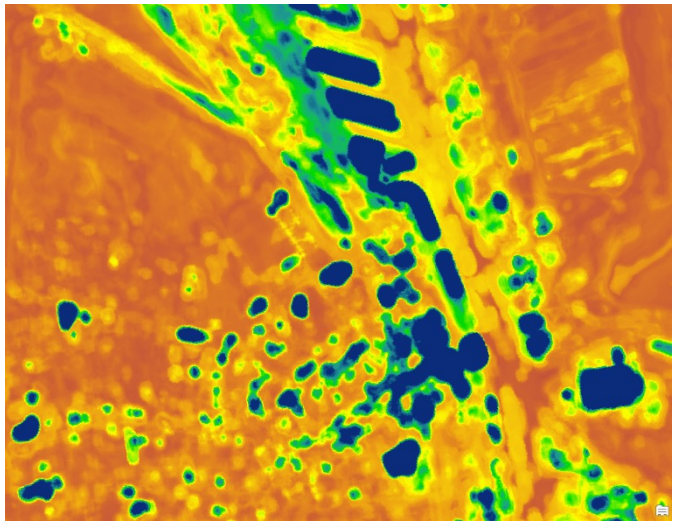
Mean of squared residuals: 0.04895864
% Var explained: 98.72



$R^2 = 0.782$

Building height mapping

Predicted building height in DC, Washington

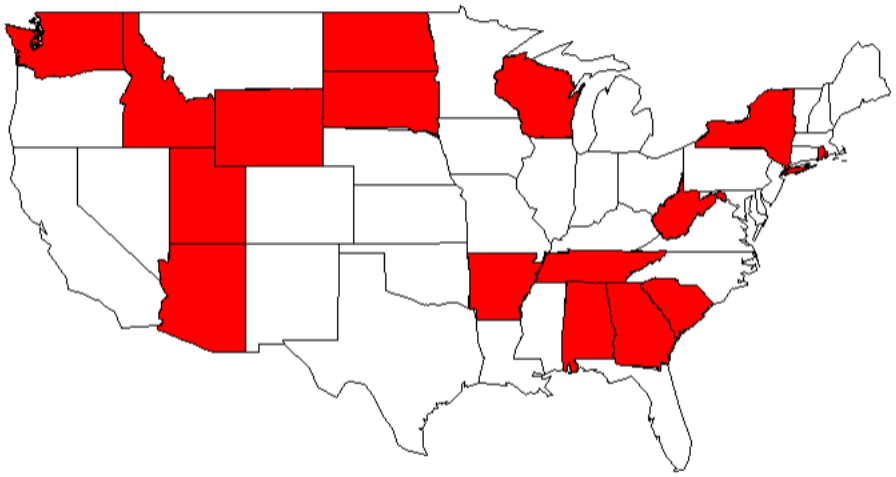


Predicted height in Alabama

Satellite image in Alabama

Building height mapping

Regions where data has been produced



Time consuming……

- Use more and better computer;
- Use server

Discussion and summary

Future works
Summary

Discussion

Deficiency and solutions

- ❑ More systematic accuracy analysis
- ❑ Building height distribution analysis

Summary

TAKEAWAY

Process:

The data are processed in R mostly and displayed in Tableau.

Contributions:

- ❑ Combined optical & SAR imagery, and building shape metrics to propose a set of Spatial – Spectral - Temporal feature database.
- ❑ Build a building height estimation model at 10m resolution.

Applications:

- ➢ Easily estimate and update large-scale (even global) building height.


Thank you
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