Høgskulen på Vestlandet

CI2

Collaborative Intelligent Infrastructure Lab

Space Level AI for Monitoring Infrastructure Networks

How AI and Computer Vision come together to decode satellite images

Prof. Reza Arghandeh

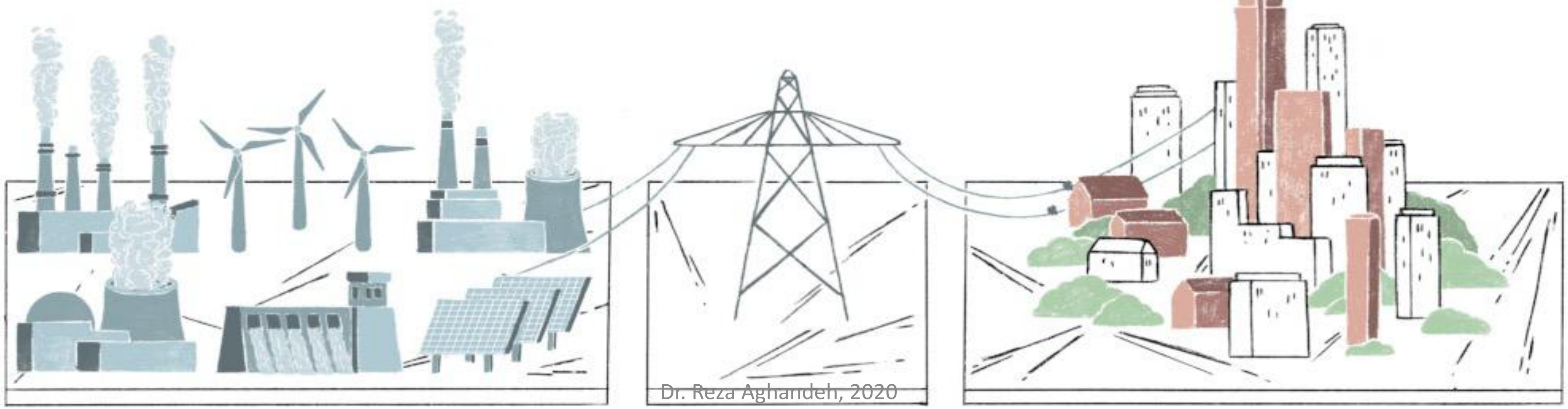
BEL– 20 Sep, 2022

About Me

Energy Networks | Data Sci for Smart Grid | Data Sci for Smart Grid & City

2005 — 2008 — 2013 — 2015 — 2018

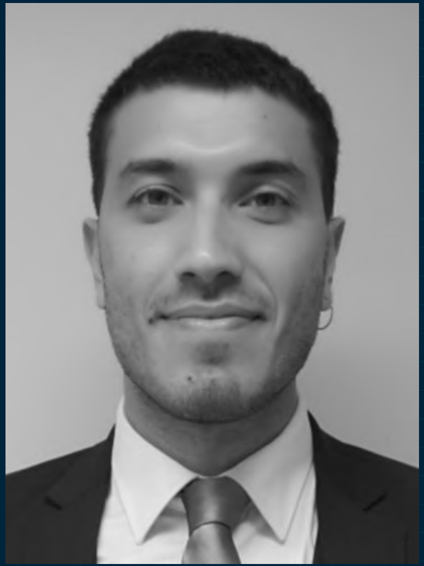
- BS, EE
- MS, ME (The University of Manchester)
- MS, IE; PhD, EE (Virginia Tech)
- Postdoc, EECS (Berkeley, University of California)
- Assistant Prof, ECE (Florida State University)
- Full Prof, EECS



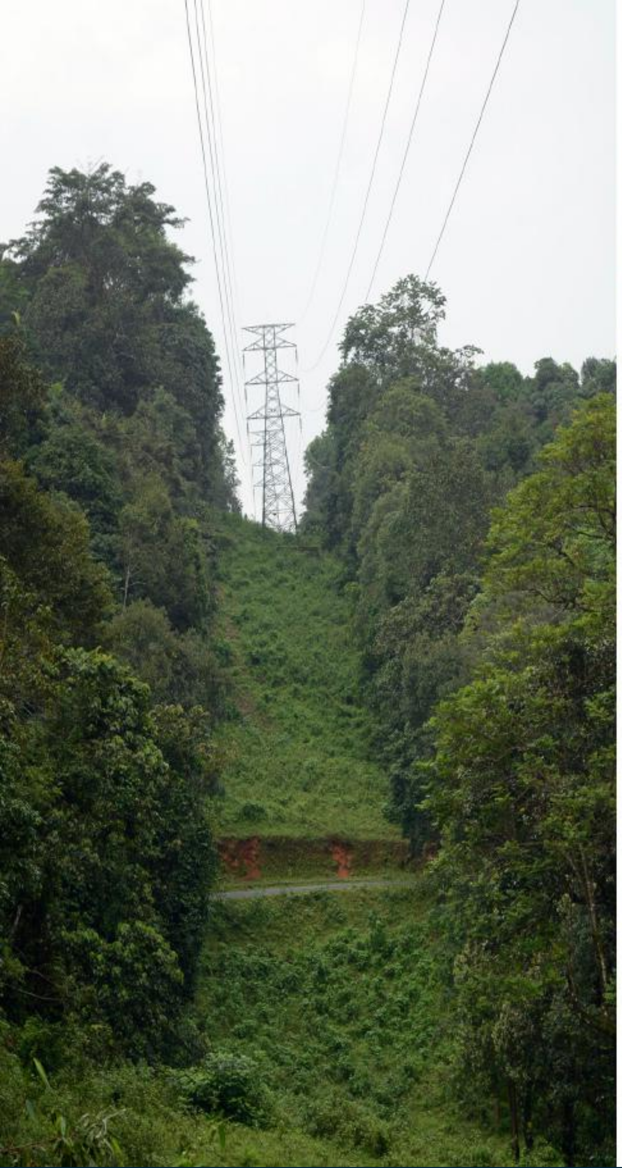
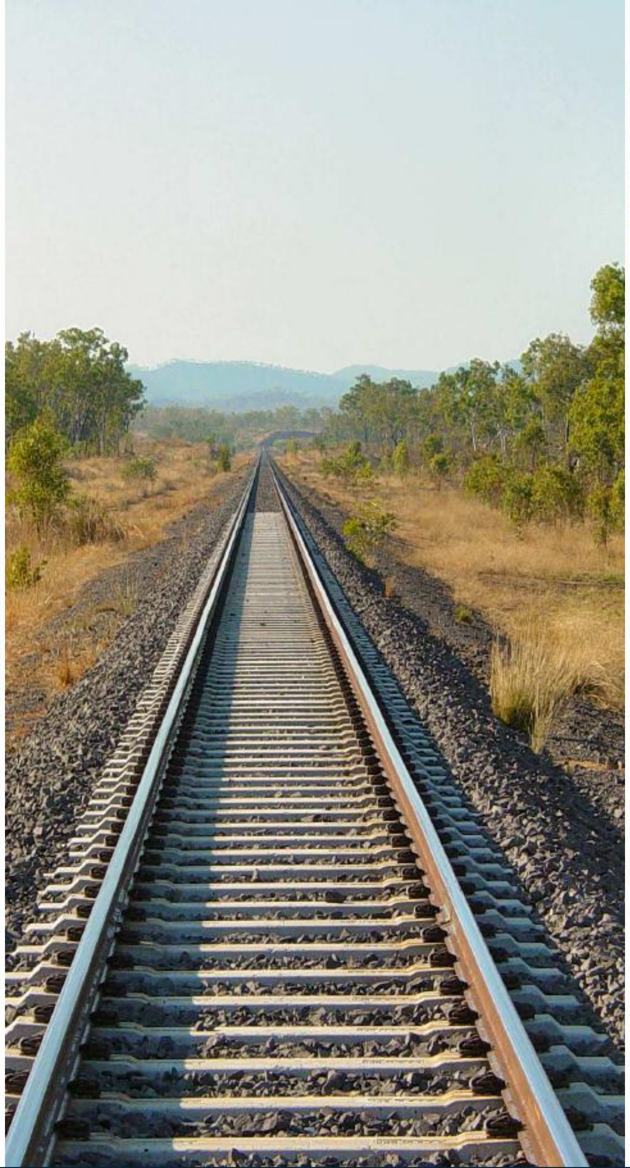
Acknowledgments

Michele Gazzea
PhD Candidate @Ci2Lab
Western Norway University

Eren E Ozguven
Associate Prof. @CEE
Florida State University



Alican Karaker
PhD Candidate @CEE
Florida State University

Infrastructures are exposed to climate and environment…

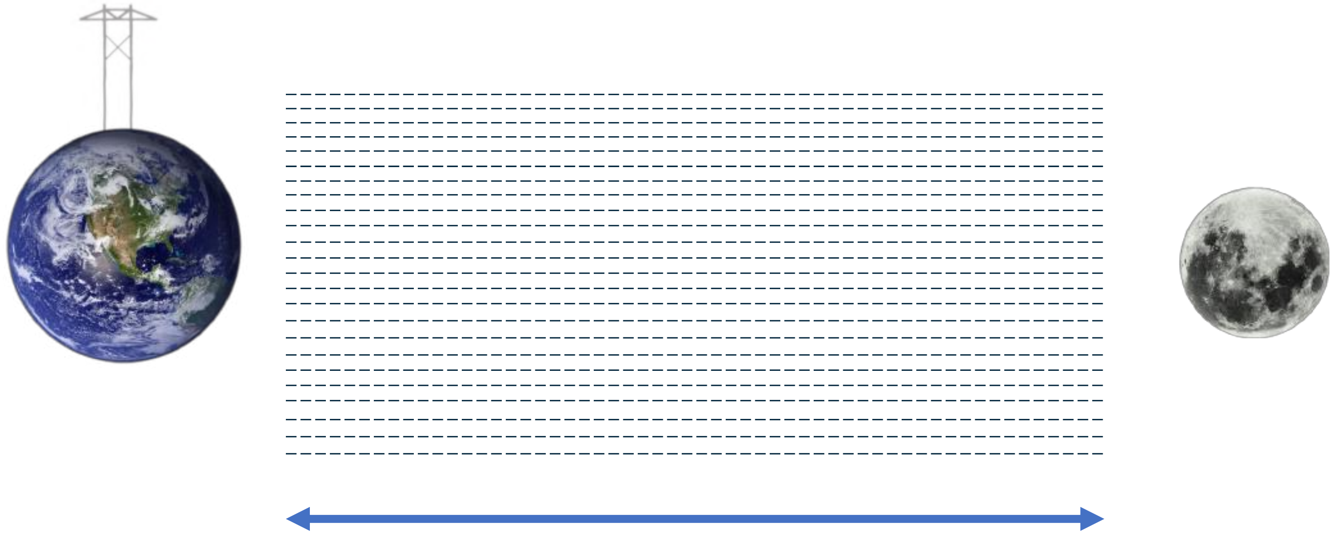
But Climate Change is brutal to them…

e.g., hurricane damages in the only USA is $1.75 Trillion 1980-2019.

Landslide, Alta, Norway 2020

Bad Neuenahr-Ahrweiler, Germany 2020

Hurricane Michael, Tallahassee, USA, 2018



384 400 km

Total length of roads : 64,285,009 km* Wikipedia

Its hard to keep eyes on infrastructures!

- EU Power Lines 25 x to the moon!
- Roadways go around the globe 1604 times!

Situational Awareness

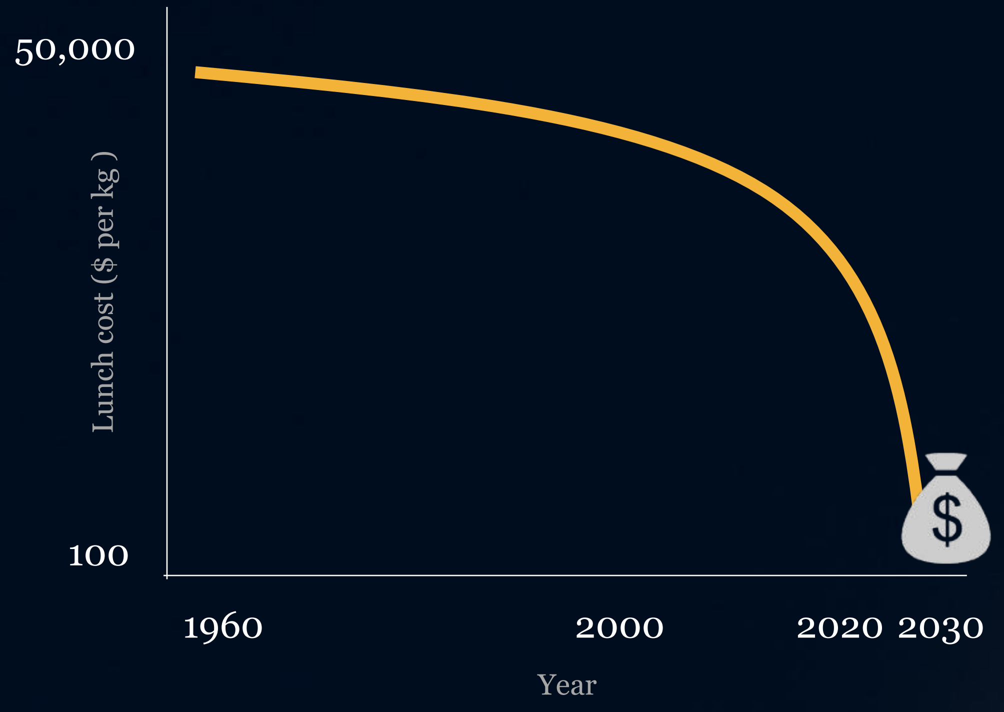
Conventional

using people on the ground , helicopters, or drones.
- Costly
- Time consuming
- highly prone to weather and ground conditions

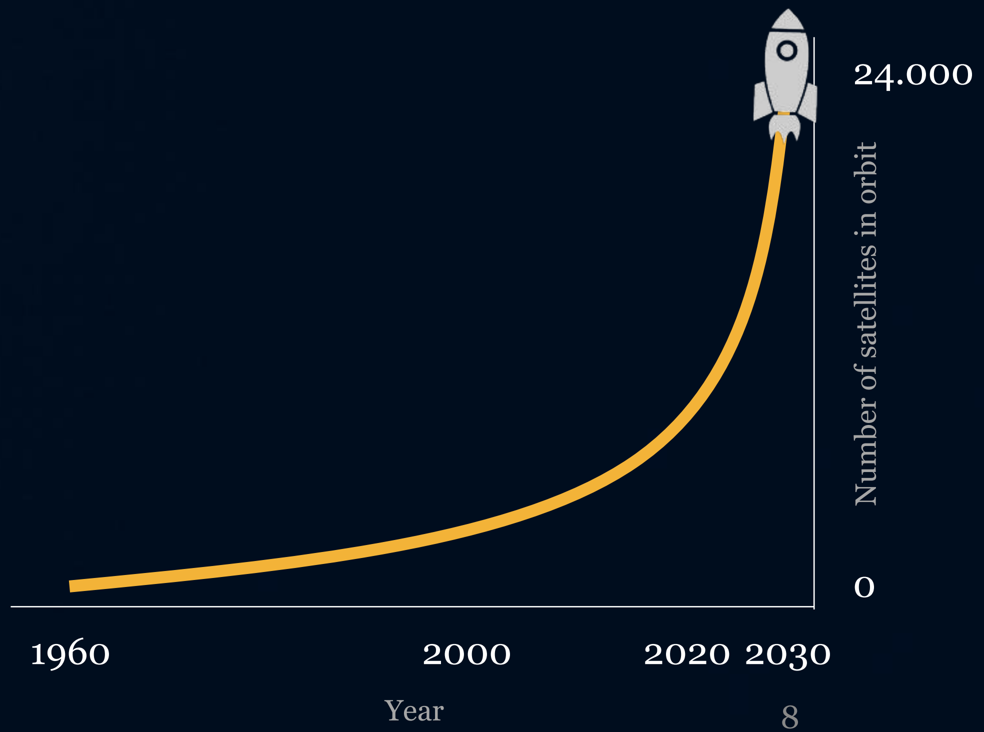
Satellites

using satellite images and machine learning methods can:

- lower the cost
- reduce inspection time
- less prone to weather and ground condition
- high frequency observations

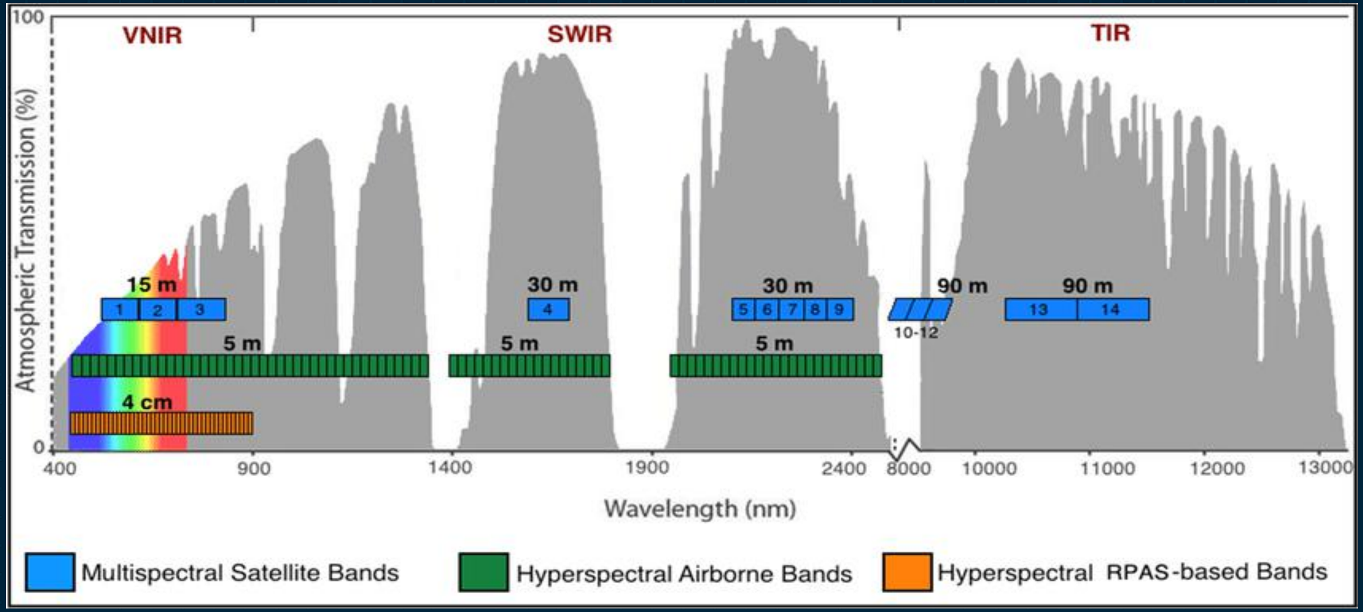


The space revolution is taking off

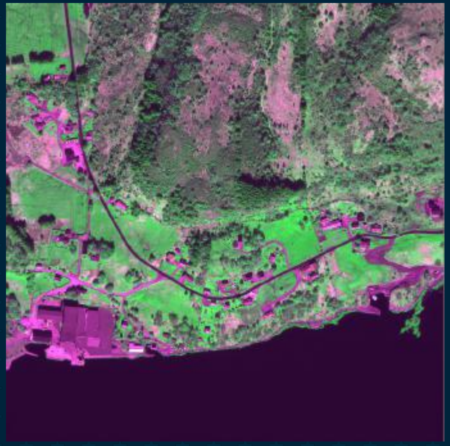


Source: Center for Strategic and International Studies

Multispectral Satellites Perception

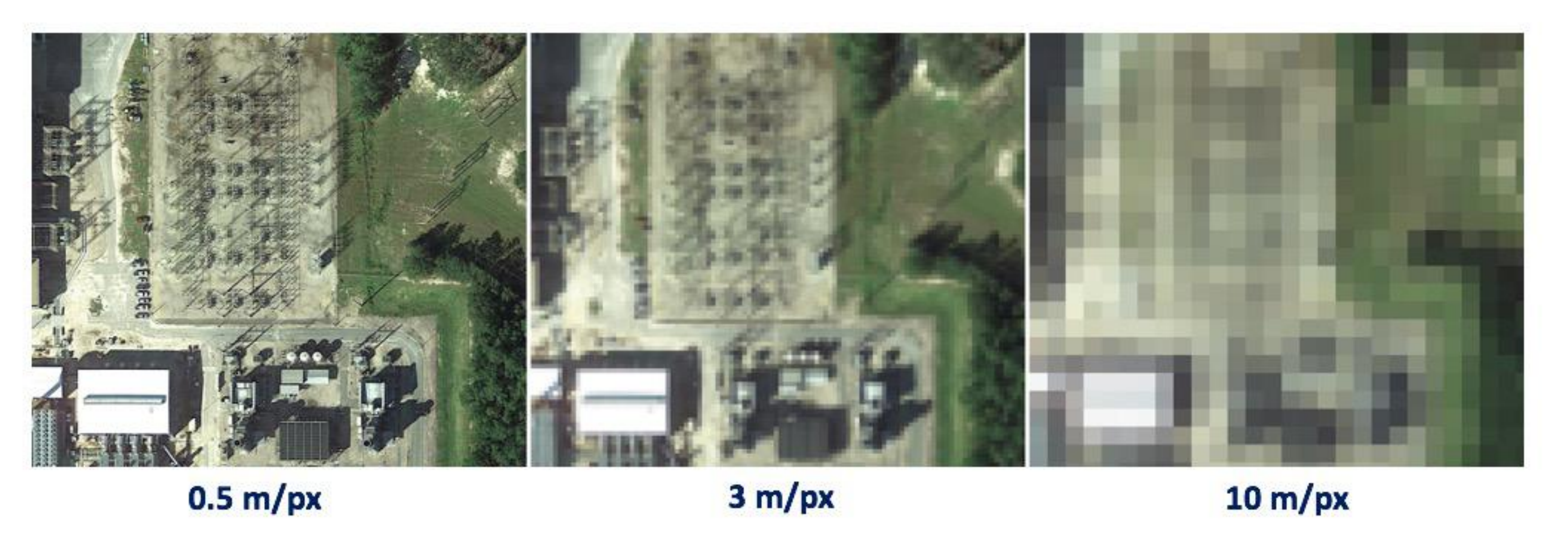


Compared to a human, AI can see more in each image

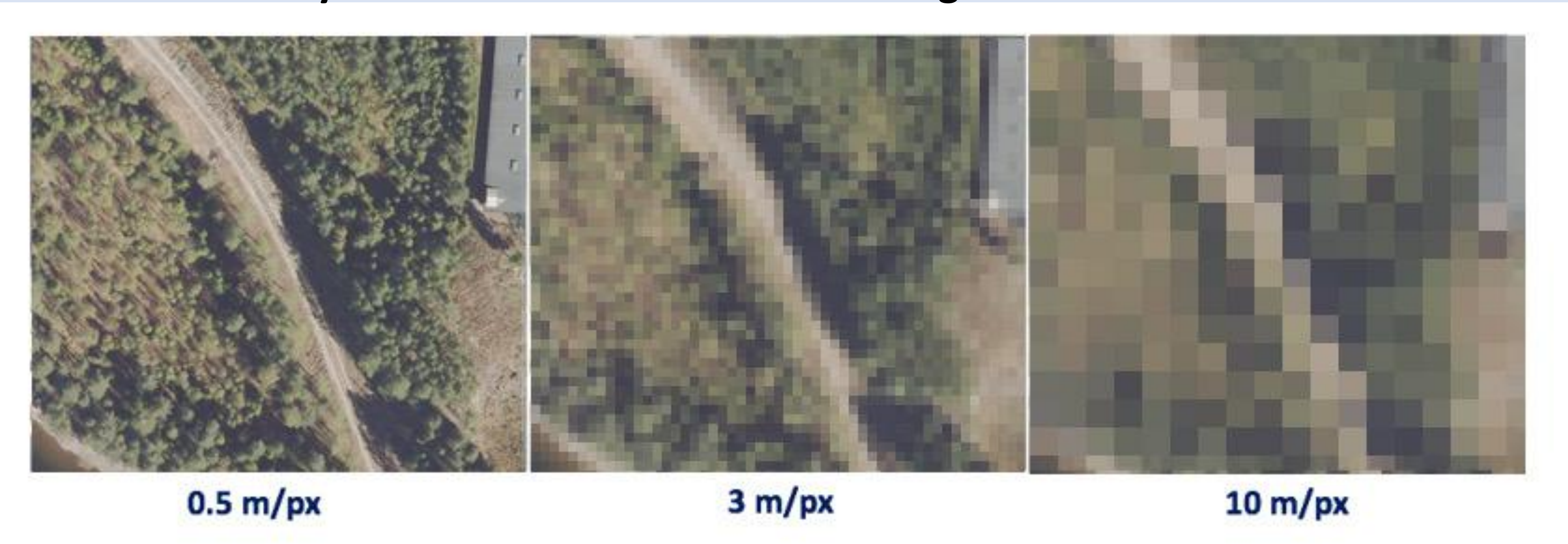


What higher resolution at lower cost means

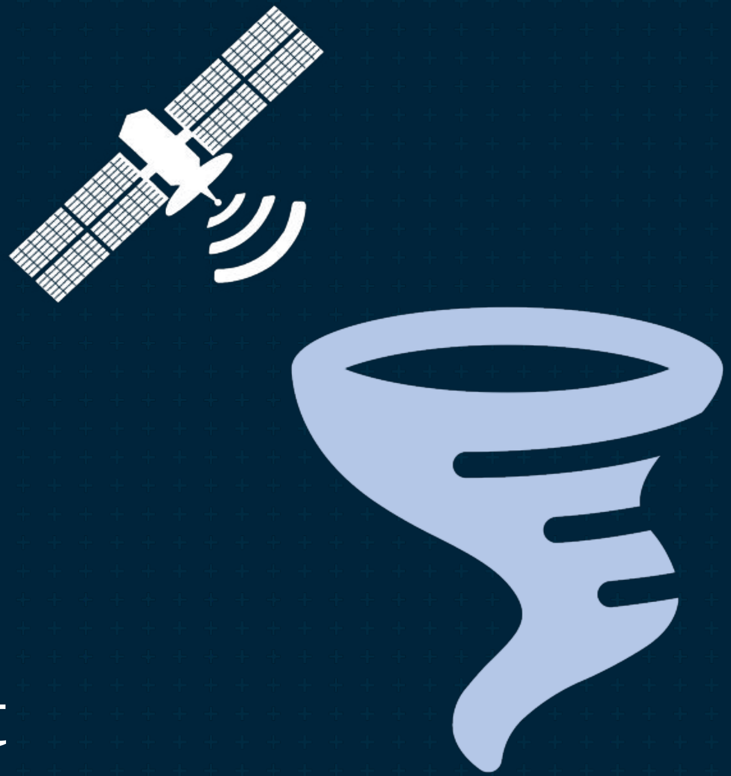
A substation as seen in different satellite image resolution



A section of railway as seen in different satellite image resolution



Høgskulen på Vestlandet
CI2 Collaborative Intelligent Infrastructure Lab



Pre-Storm Assessment

- Vulnerability analysis
- Prevention and resilience

Post-Storm Assessment

- Damage assessment
- Recovery optimization

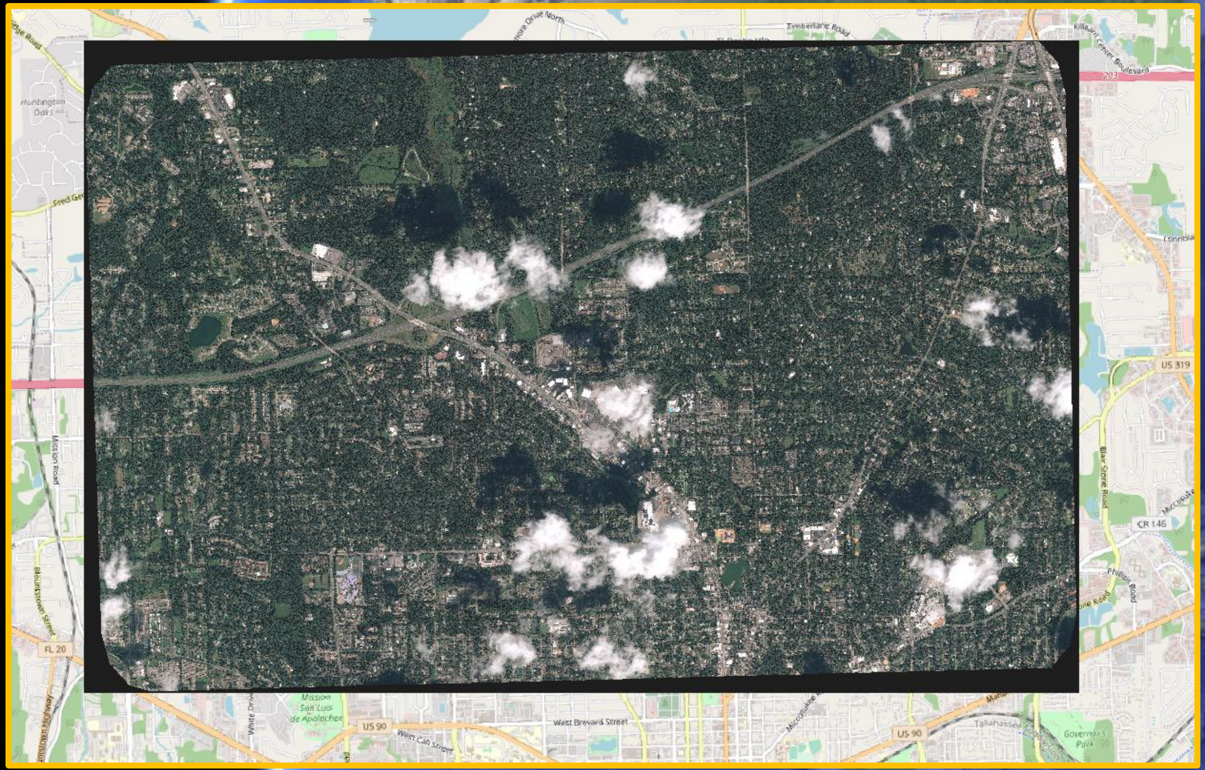
time

Post-Storm Assessment (Recovery)

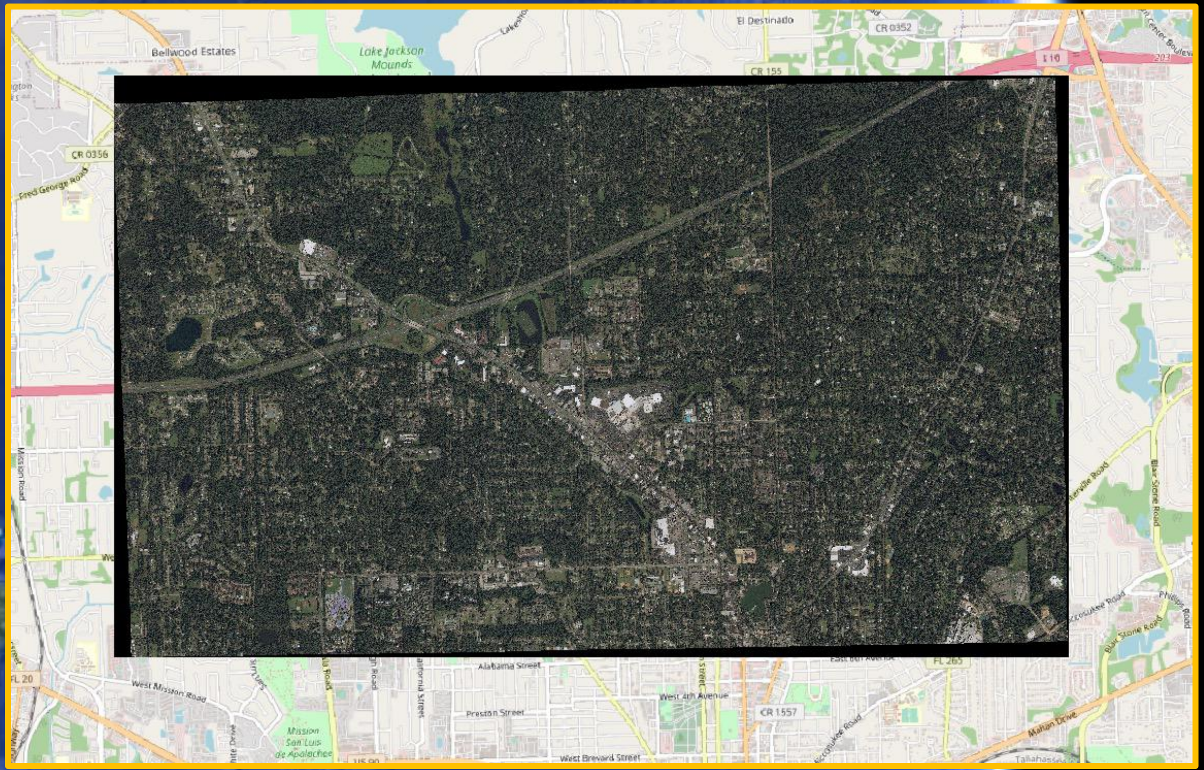
Hurricane Michael, Tallahassee, FL, Oct

Use Case

Hurricane Michael, Tallahassee, FL, Oct 2018



September 2018



October 2018

Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Image IBCAO

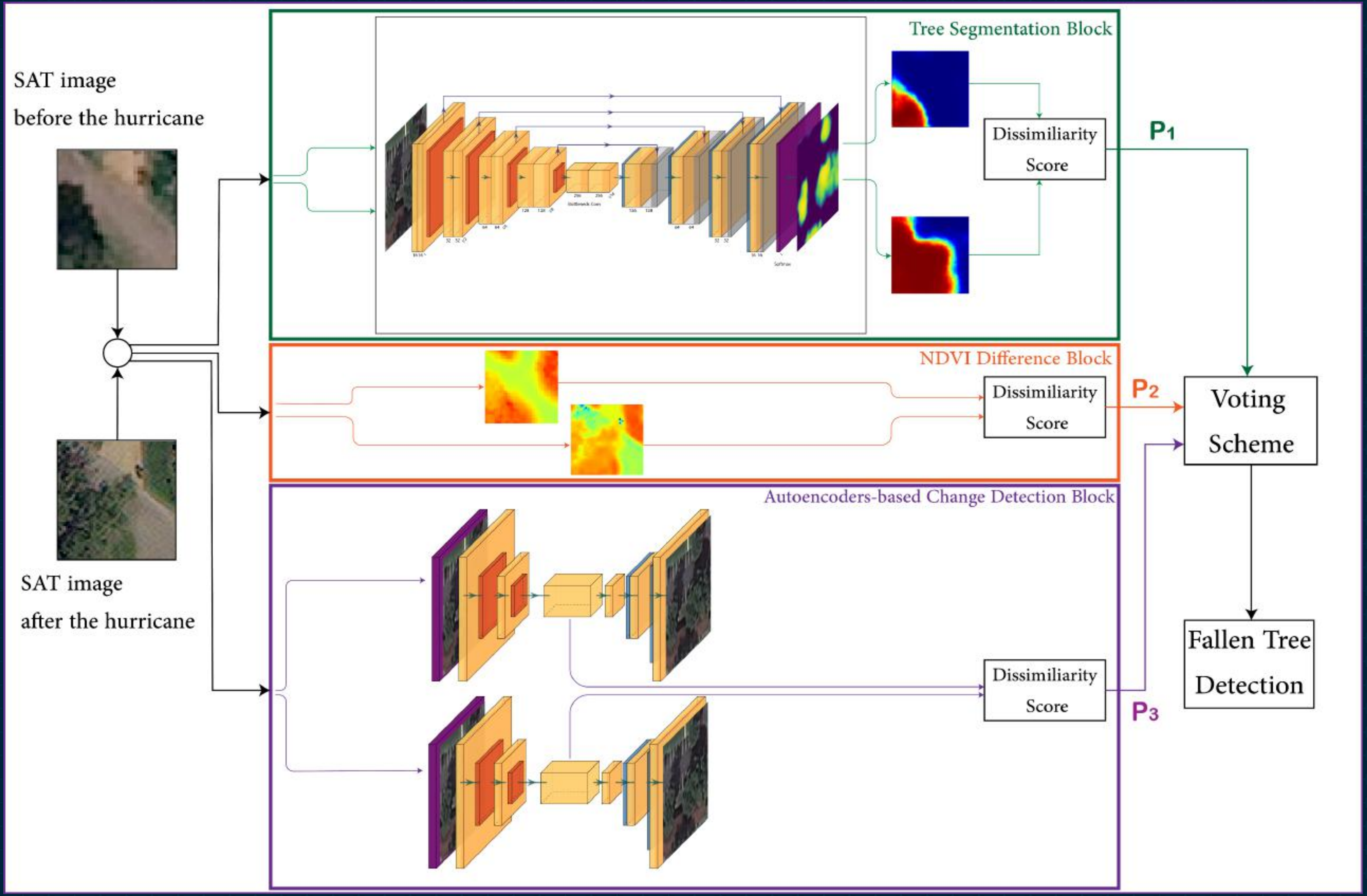
Google Earth

Høgskulen på Vestlandet

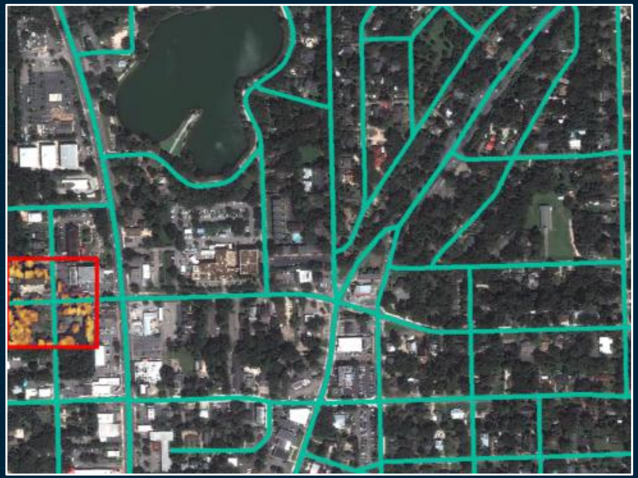
CI2 Collaborative Intelligent Infrastructure Lab

Our Method

An **unsupervised anomaly detection** approach without labeled data for fallen trees.



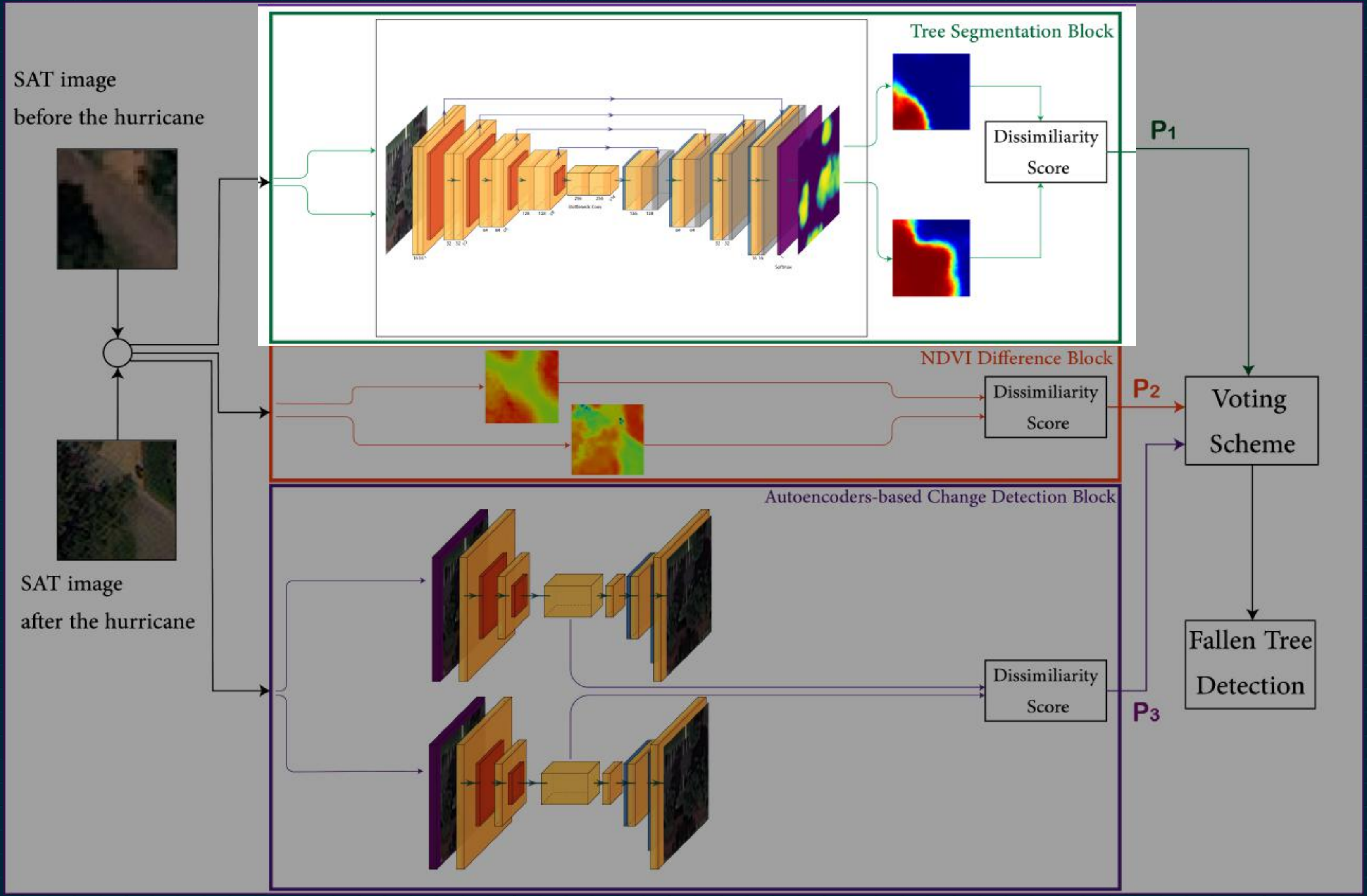
Tree Segmentation Block



The model is based on the *Unet* architecture trained to recognize trees in images.

The dissimilarity score D_{tree}:

$$D_{tree} = \iint_{Patch} \left(M_{aft}^{tree} - M_{bfr}^{tree}\right) \times K$$



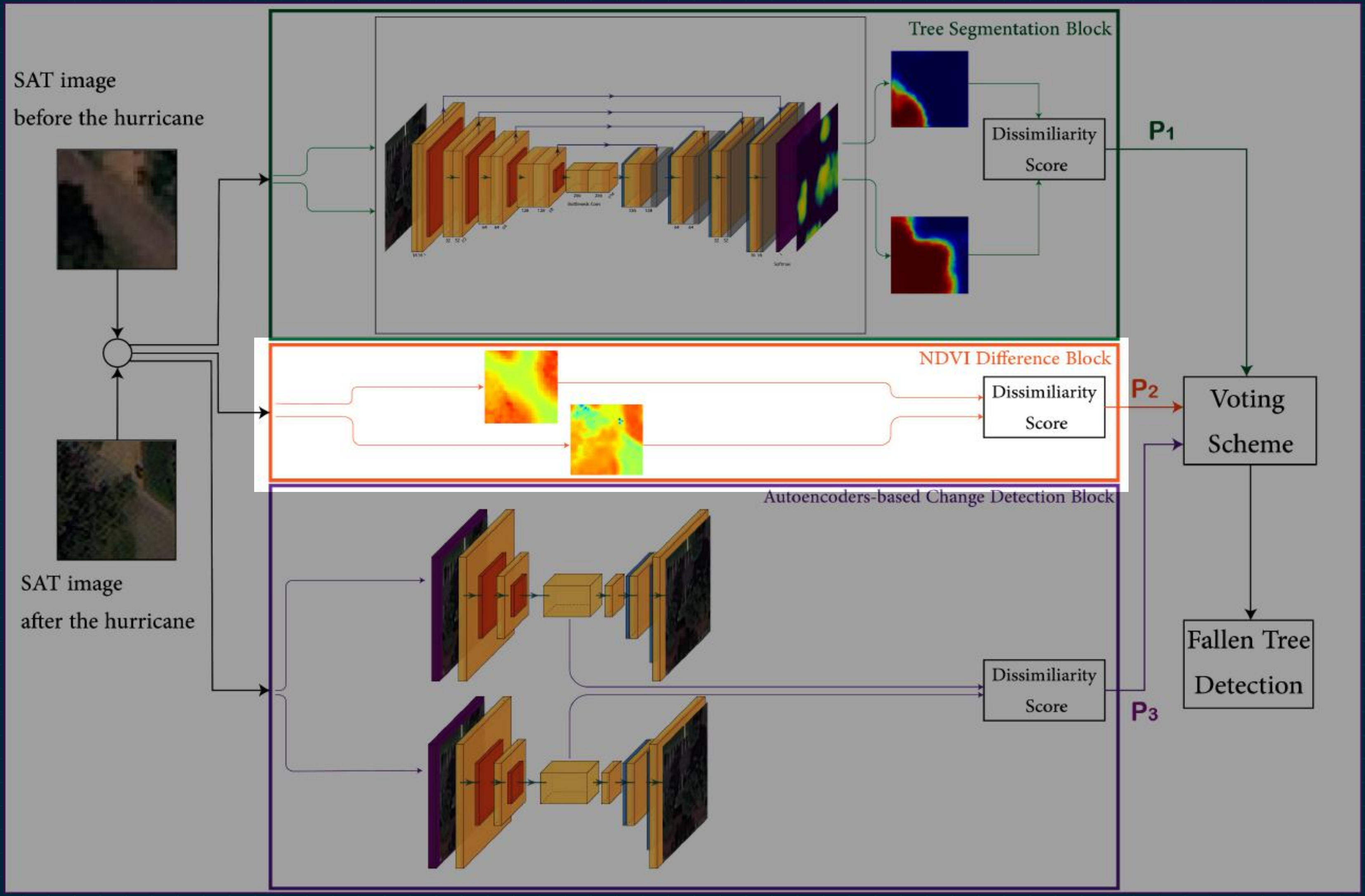
Normalized Difference Vegetation Index (NDVI) Block

NDVI is computed as:

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

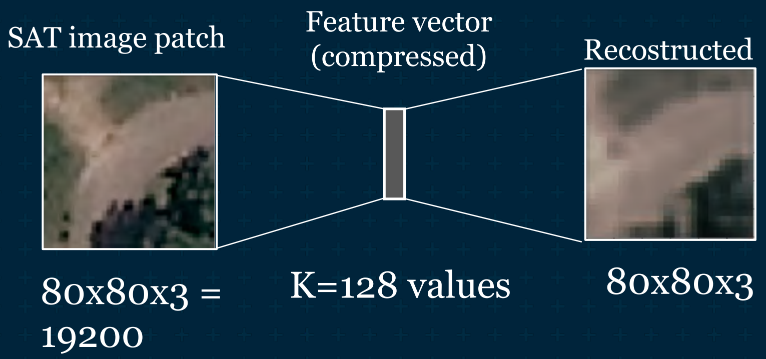
The dissimilarity score D_{NDVI}:

$$D_{NDVI} = \iint_{Patch} (NDVI_{aft} - NDVI_{bfr}) \times K$$



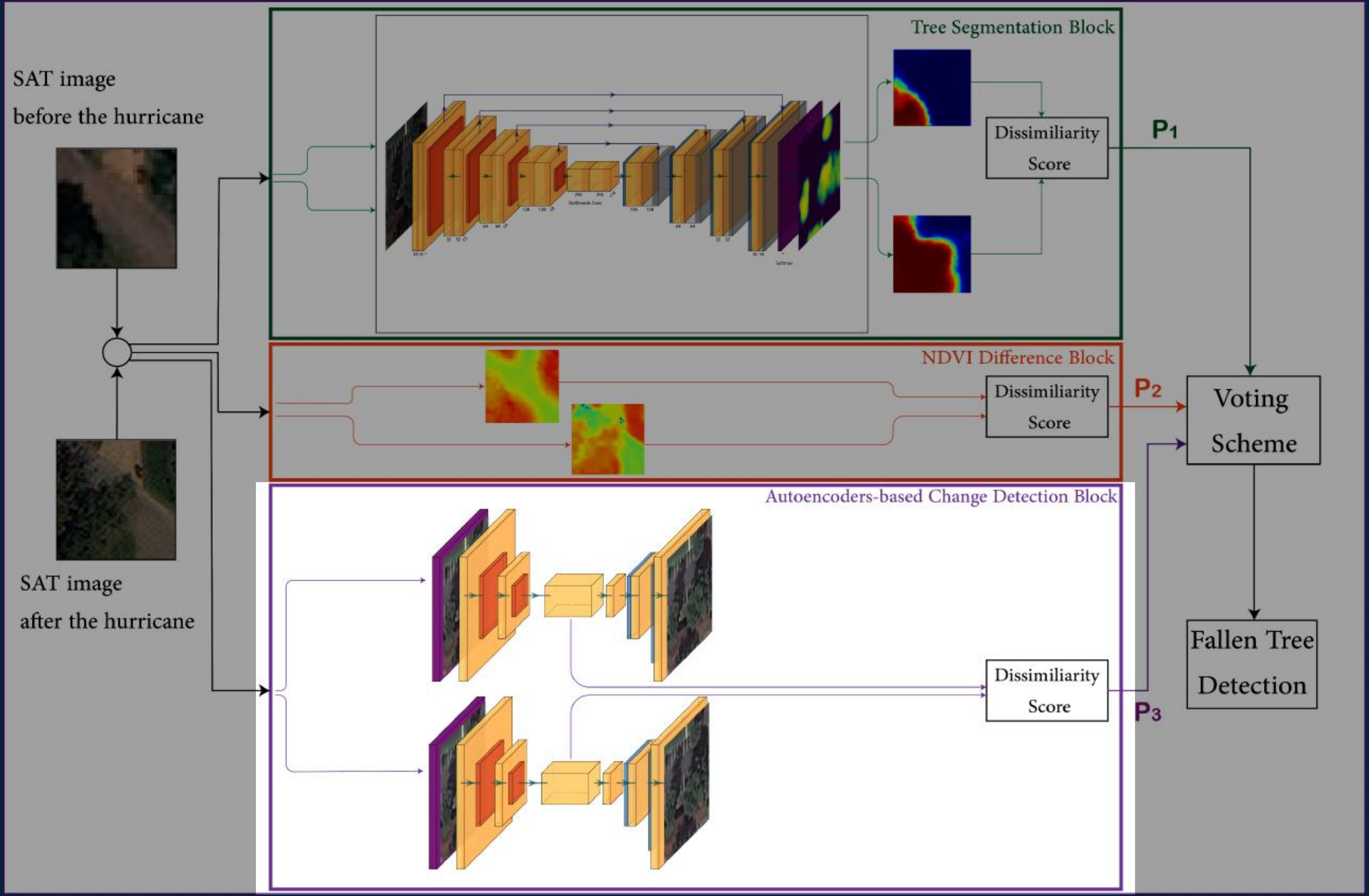
Variational Auto-Encoder Block

$$Loss = \underbrace{MSE(x, \tilde{x})}_{\text{Reconstruction loss term}} + \underbrace{KL\left(p_\theta(x|z)\,||\,p(z)\right)}_{\text{Regularization term}}$$



The dissimilarity score D_{VAE}:

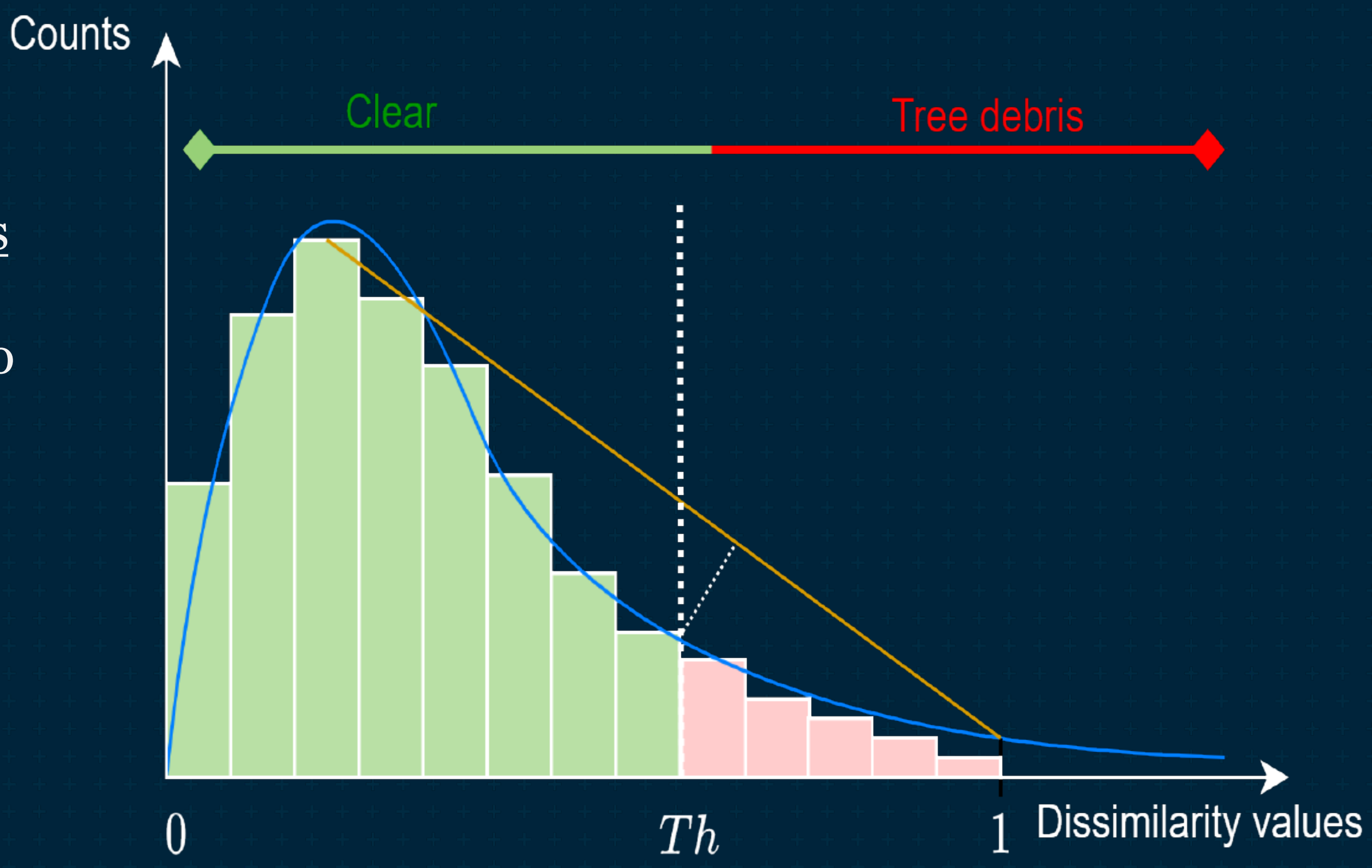
$$D_{VAE} = \left|F_{aft} - F_{bfr}\right|_2$$



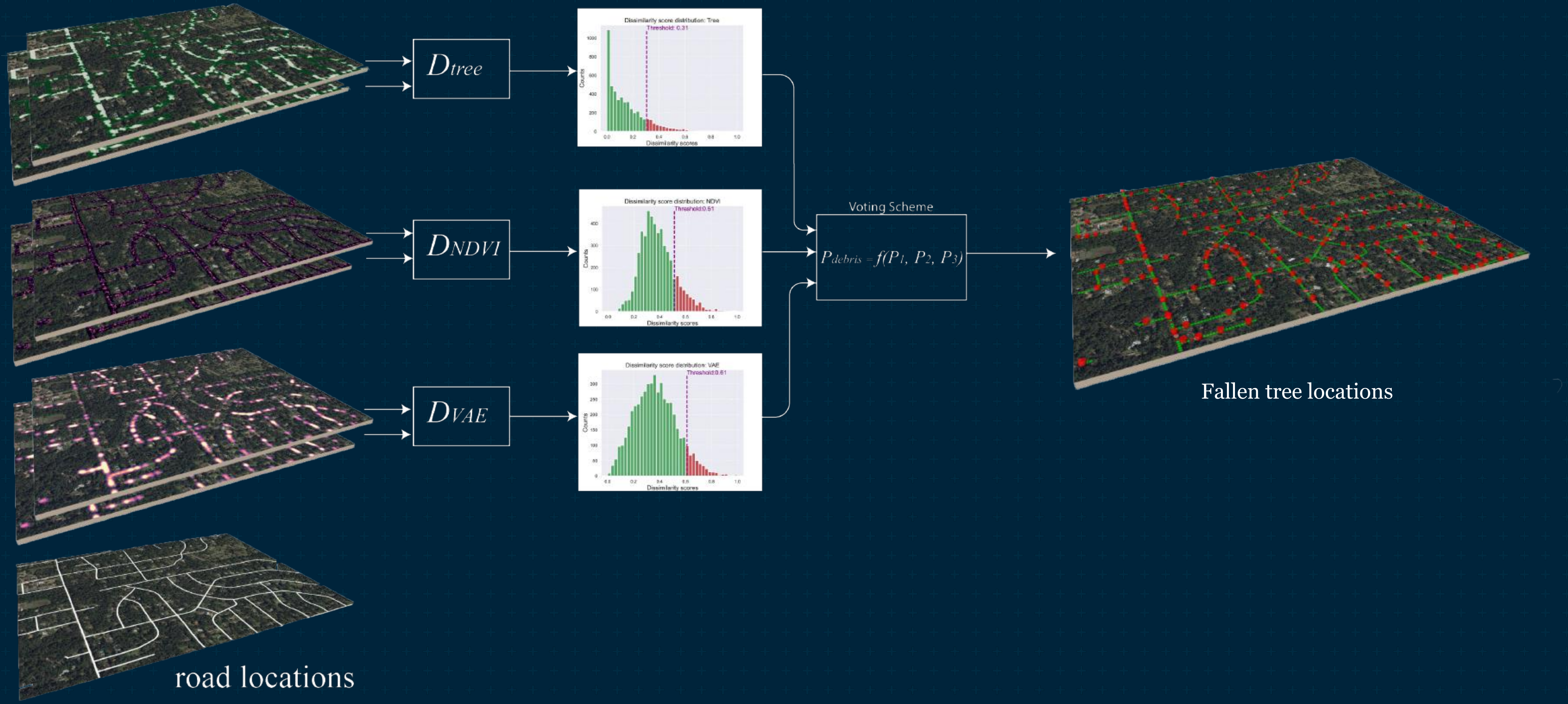
Fallen Tree Detection Block

- Dissimilarity score histograms (D_{tree}, D_{NDVI}, D_{VAE}) are unimodal distributions where one group (no-fallen tree) dominates the histogram with respect to the secondary group (fallen tree).

- We used the maximum deviation method to compute a threshold and divide the histogram in two parts.

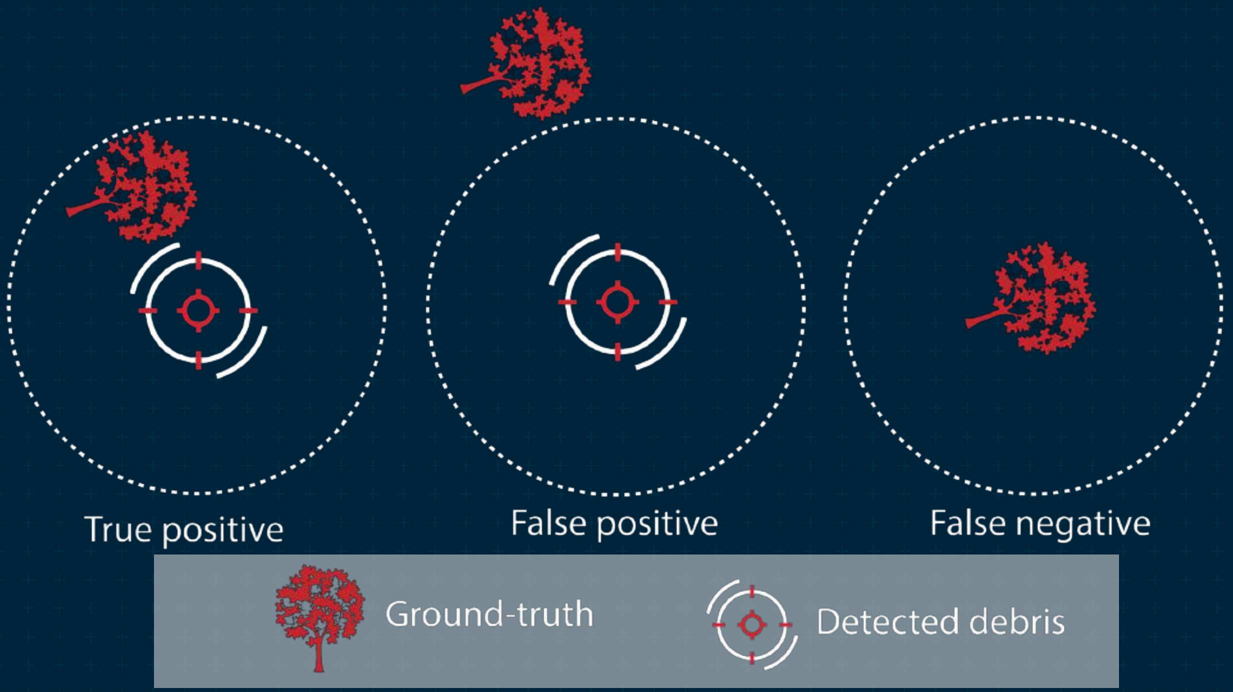


Results



D_{tree}
D_{NDVI}
D_{VAE}
Dissimilarity score distribution: Tree
Threshold: 0.31
Counts
Dissimilarity scores
Dissimilarity score distribution: NDVI
Threshold:0.51
Counts
Dissimilarity scores
Dissimilarity score distribution: VAE
Threshold:0.61
Counts
Dissimilarity scores
Voting Scheme
$P_{debris} = f(P_1, P_2, P_3)$
Fallen tree locations
road locations

Results



Algorithm	F1-score
Our approach	**0.859**
Sparse AEs [1]	0.642
Joint AEs [2]	0.744
CNN [3]	0.821
GLCM+SVM [4]	0.748
LBP+SVM [5]	0.757

$$F1score = \frac{2(Recall + Precision)}{(Recall \cdot Precision)}$$

M. Gazzea et al., "Automated Satellite-Based Assessment of Hurricane Impacts on Roadways," in IEEE Transactions on Industrial Informatics, 2022.

Pre-Storm Assessment (Preparedness)

Vulnerability Formulation

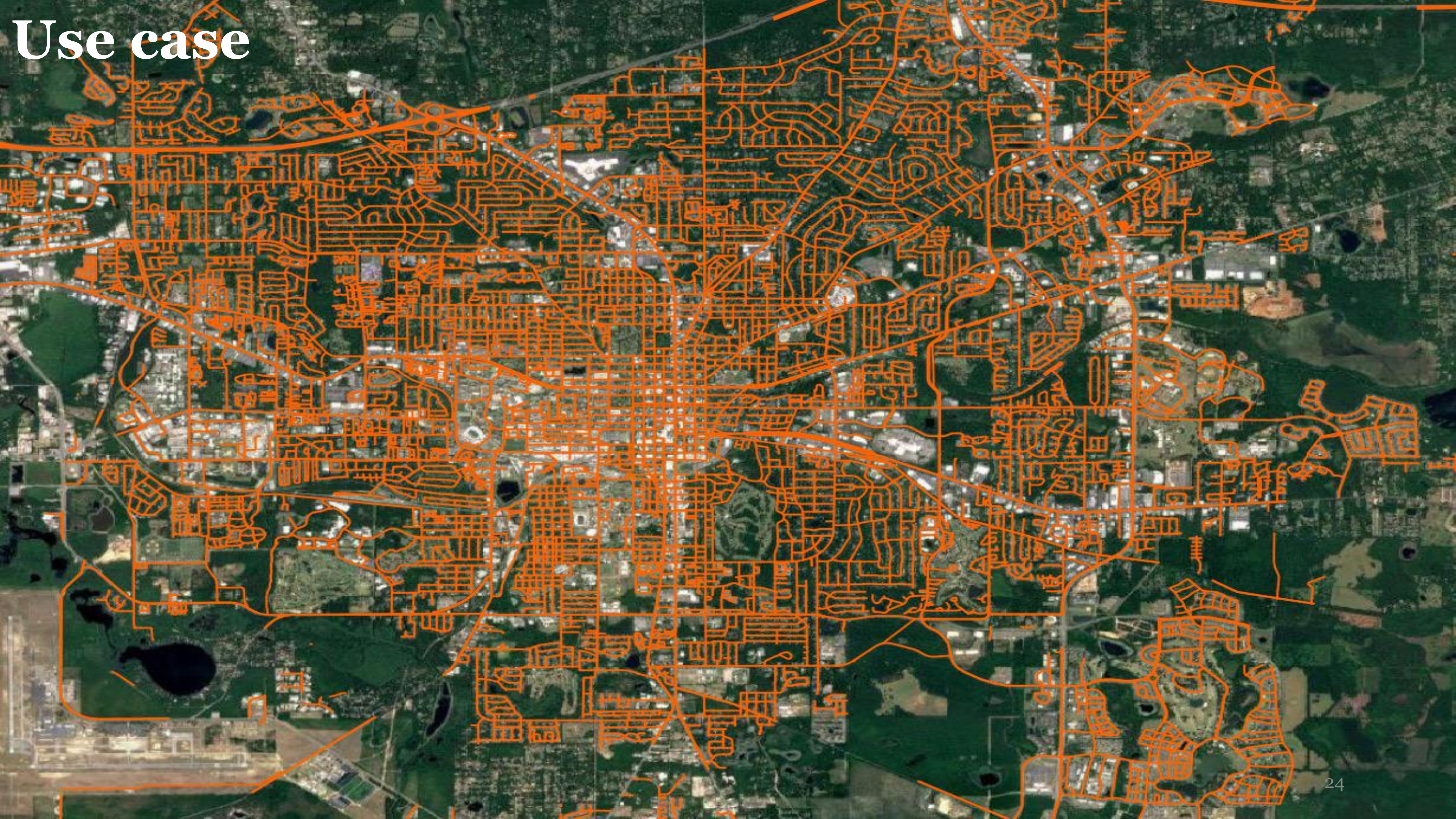
The infrastructure vulnerability is calculated as a combination of vegetation exposure to roadway E and the impact (I) of a roadway closure

$$Vulnerability(V) = Impact(I) \times Vegetation\ Exposure\ (E)$$

In our study we are interested in estimating the roadway vulnerabilities against storms

- E ∝ tree density, tree height, tree health, …
- I ∝ network topology, traffic amount, number of citizens affected,…

Use case



Høgskulen på Vestlandet

CI2 Collaborative Intelligent Infrastructure Lab

Vulnerability Model for Each Road *r*

Vulnerability function

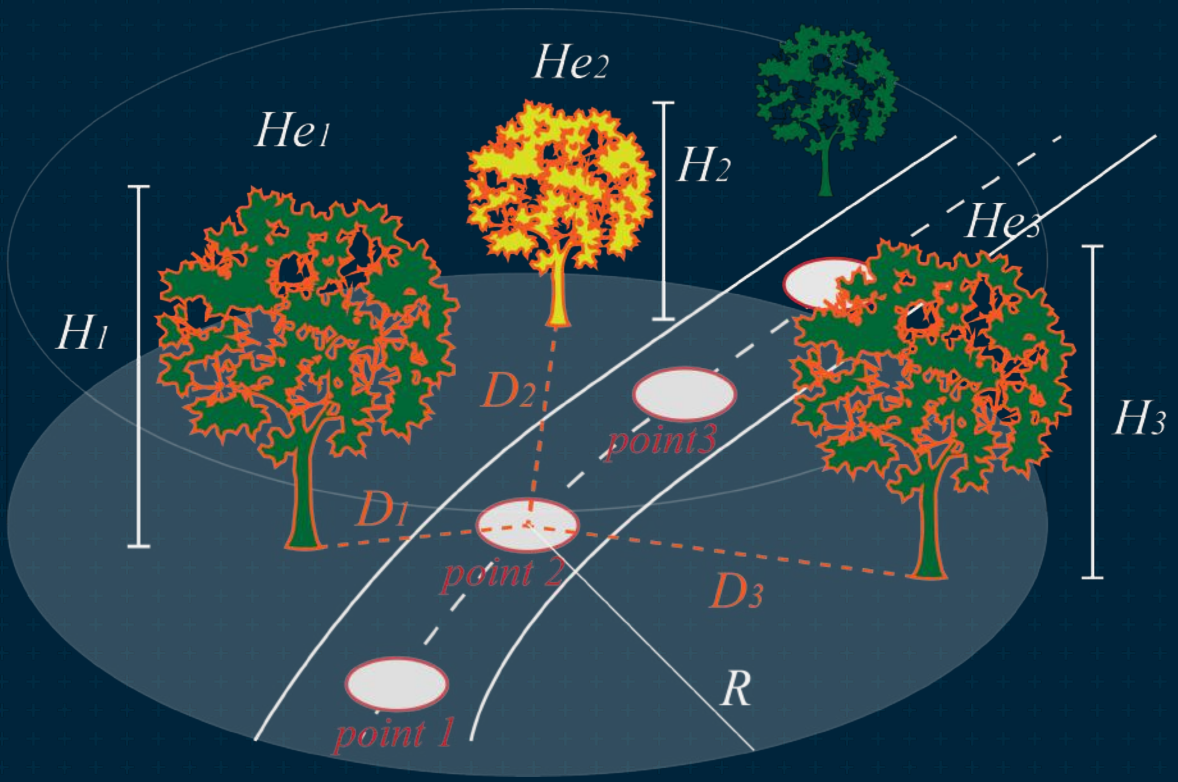
$$V_r = f(VE_r; B_r; \iota_r)$$

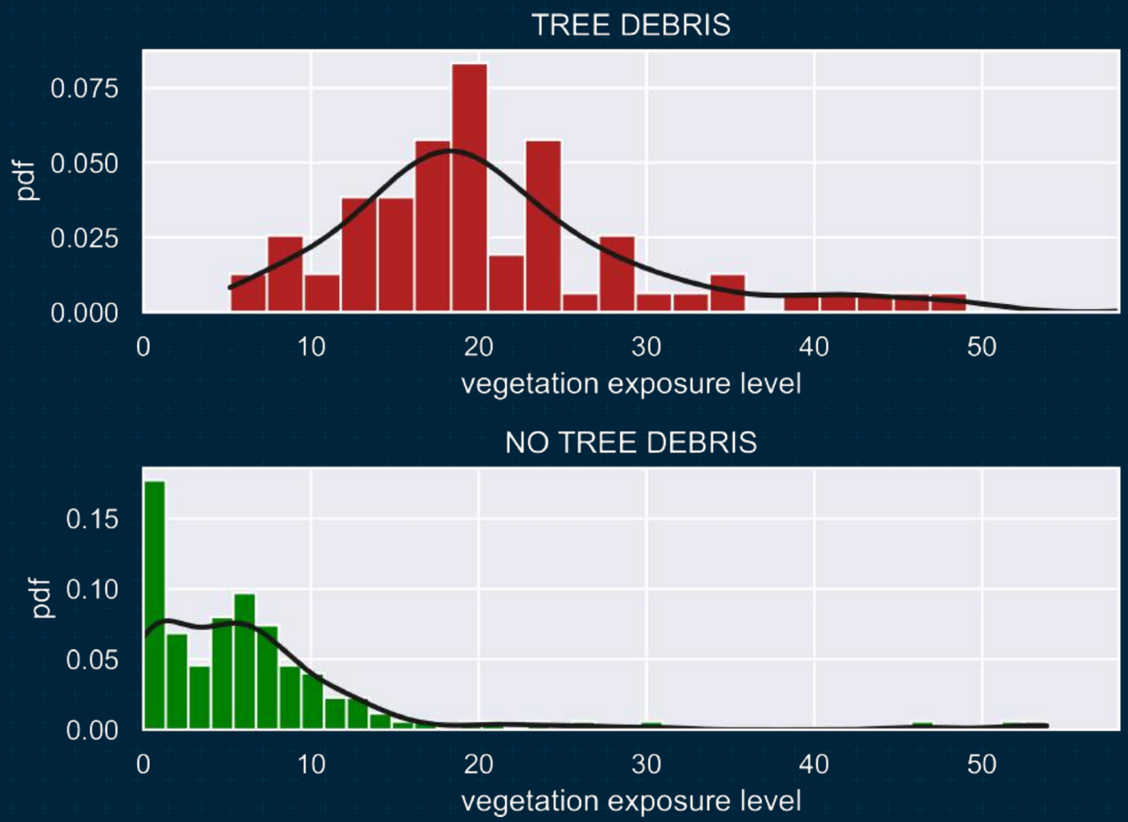
Vegetation exposure

Building density

Road importance

Vegetation Exposure

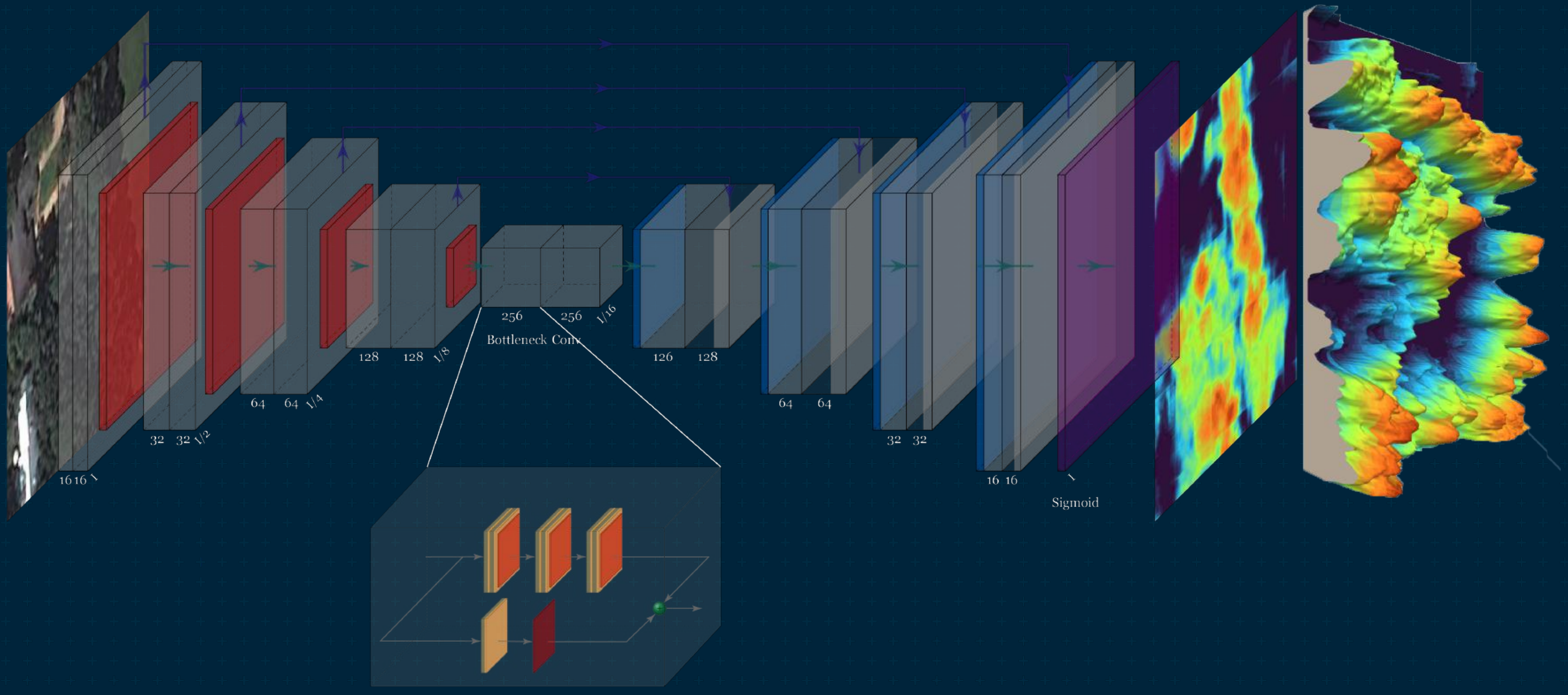




$$VE_{road} = \max(VE_{point}) \quad \forall point \in road$$

$$VE_{point} = f(tree\_param)$$

Vegetation Height Estimation

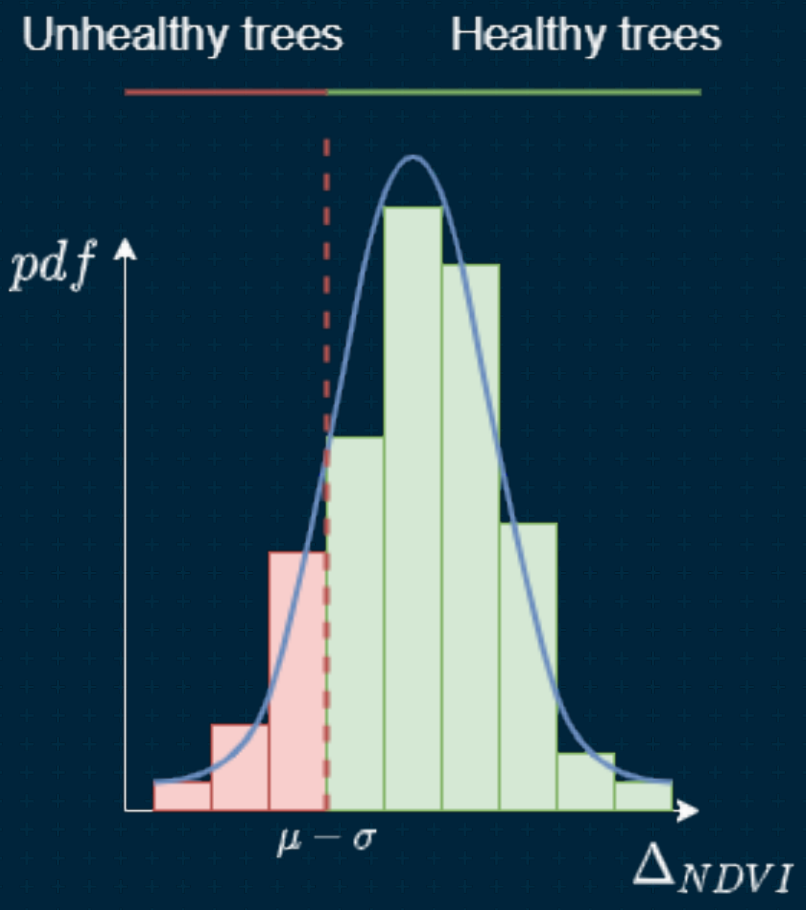


Vegetation Health Estimation

Normalized Difference Vegetation Index (NDVI) is computed as:

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

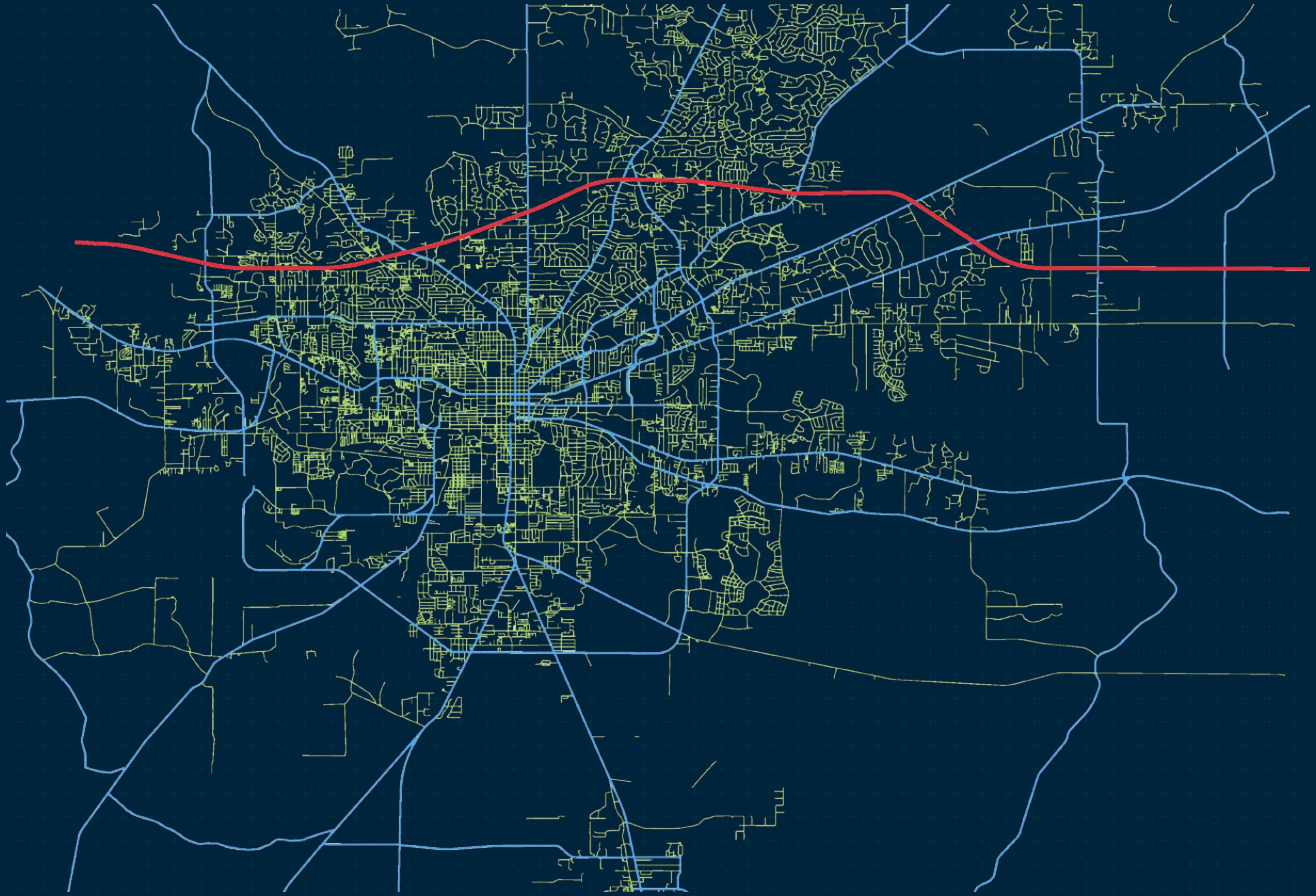
1. Compute NDVI from multi-temporal images
2. Compute the mean value of NDVI over the year
3. Compute $\Delta NDVI$ between years



Roadway Importance

A) Roadway types:

- National road
- County road
- Normal road



Roadway Importance

B) Betweenness Centrality over edge, weighted by travel time :

$$c_B(e) = \sum_{s,t \in V} \frac{\sigma(s,t|e)}{\sigma(s,t)}$$

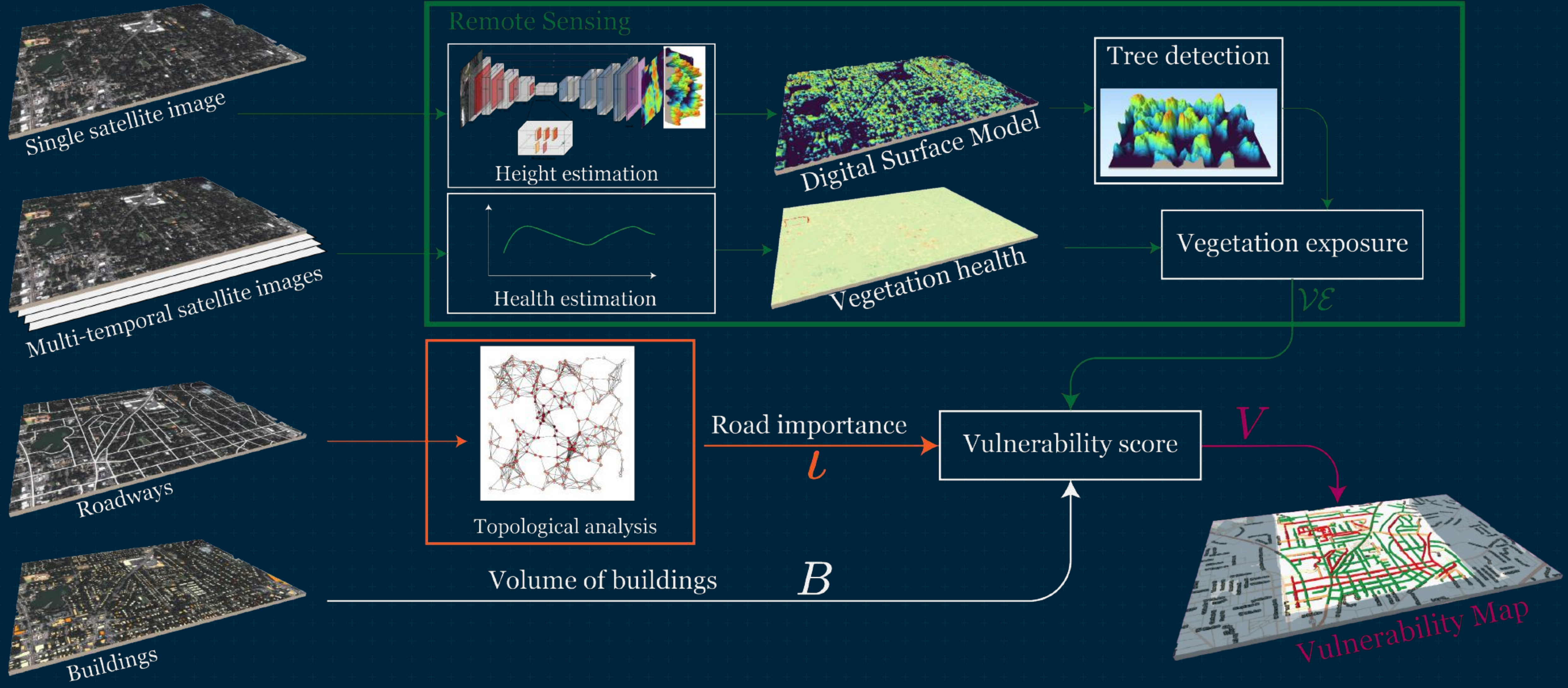
V is the set of nodes,
$\sigma(s,t|e)$ is the number of paths minimizing the traffic time between the two nodes, and
$\sigma(s,t)$ is the number of paths between the two nodes

Buildings

- Buildings foorprints from OSM data + height from Lidar
- Critical infrastructures (hospitals, emergency shelters, fire-fighter stations)

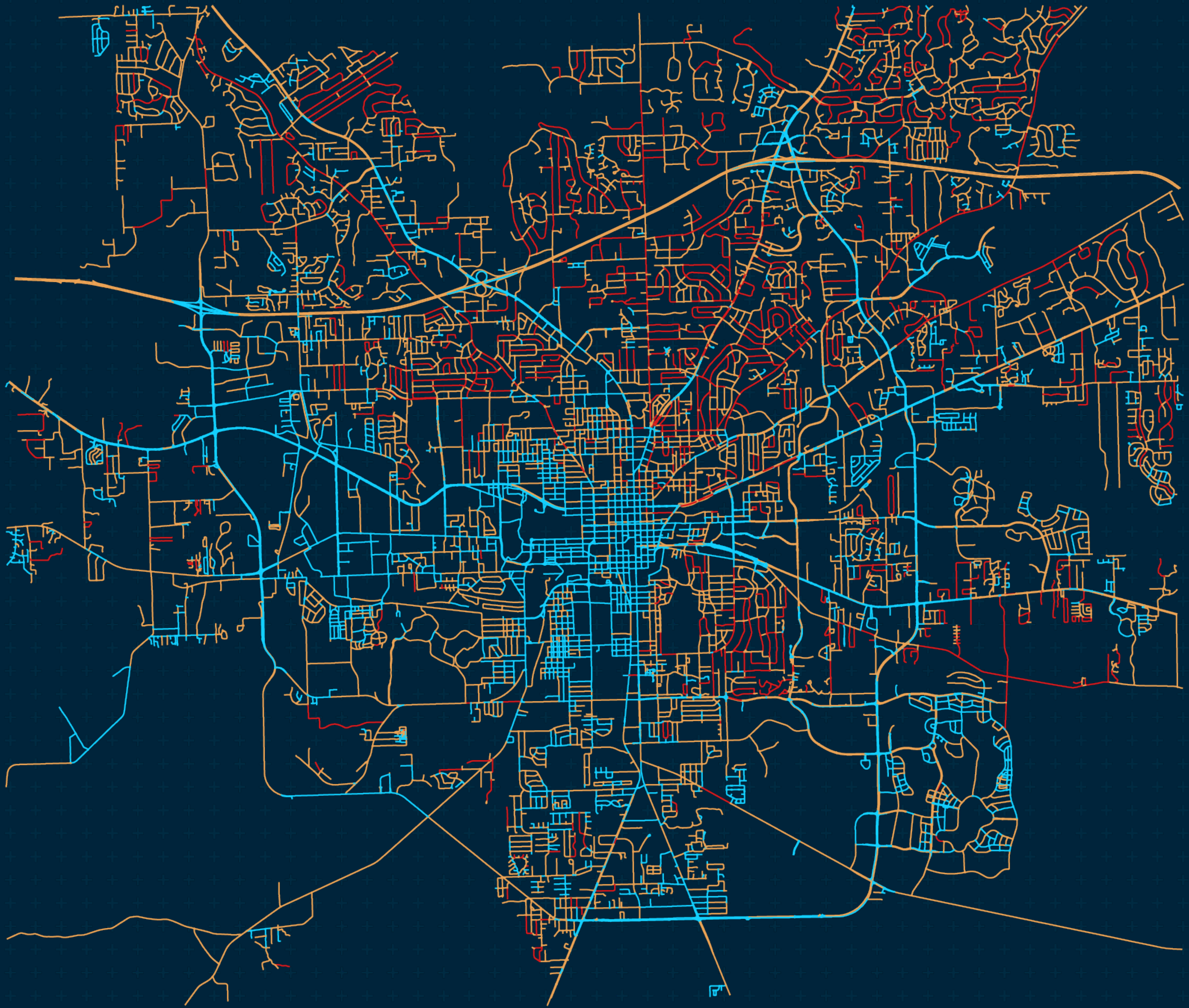
Buildings footprints can also be retrieved directly from satellite images

Our Method



Single satellite image
Multi-temporal satellite images
Roadways
Buildings
Remote Sensing
Height estimation
Health estimation
Digital Surface Model
Vegetation health
Tree detection
Vegetation exposure
VE
Topological analysis
Road importance
ι
Vulnerability score
V
Volume of buildings
B
Vulnerability Map

Vulnerability Map



Publications

1. M. Gazzea et al., "Automated Satellite-Based Assessment of Hurricane Impacts on Roadways," in IEEE Transactions on Industrial Informatics, vol. 18, no. 3, pp. 2110-2119, 2022.

2. M. Gazzea et al., "Automated Power Lines Vegetation Monitoring using High-Resolution Satellite Imagery," in IEEE Transactions on Power Delivery, vol. 37, no. 1, pp. 308-316,, 2022.

3. A. Karaer et al., "Remote sensing-based comparative damage assessment of historical storms and hurricanes in Northwestern Florida," in International Journal of Disaster Risk Reduction, vol. 72, pp. 102857, 2022.

4. M. Gazzea et al. Satellite-based Hurricane Risk Assessment for Roadways via Vegetation 3D Modeling and Building Detection. In Transportation Research Board 101th Annual Meeting 2022.

5. A. Karaer et al., "Post-Hurricane Vegetative Debris Assessment Using Spectral Indices Derived from Satellite Imagery," in Transportation Research Record, vol. 2675, pp. 504-523, SAGE, 2021.

6. M. Gazzea et al. Post-hurricanes roadway closure detection using satellite imagery and semi-supervised ensemble learning. In Transportation Research Board 100th Annual Meeting 2021.

7. M. Gazzea et al, "Automated 3D Vegetation Detection Along Power Lines using Monocular Satellite Imagery and Deep Learning," 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 2021, pp. 3721-3724.

Thank You

Visit us at www.ci2lab.com

Prof. Reza Arghandeh
Leader Data Science Group, HVL
reza.arghandeh@hvl.no