# InSAR Coherence Analysis: A proxy for Change Detection of Pavements

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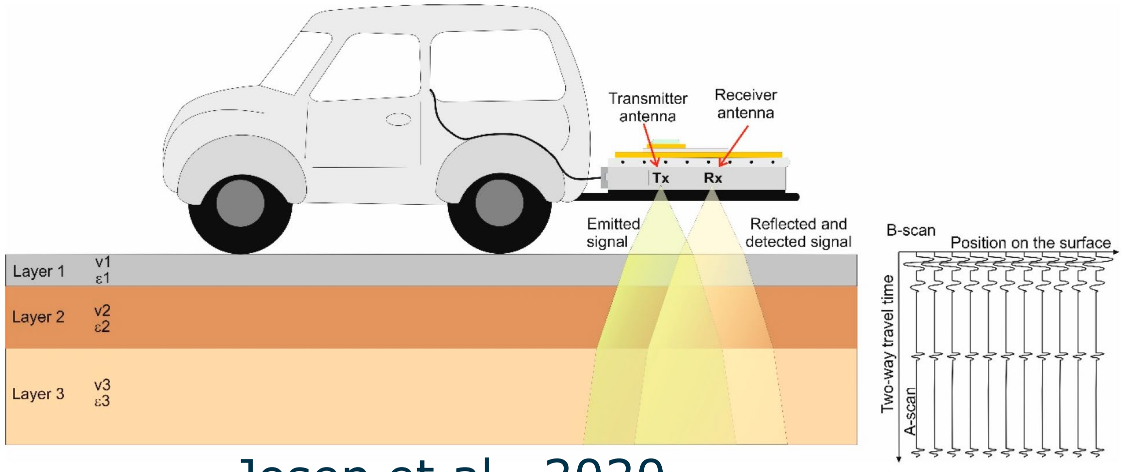
# Motivation

- **Visual assessment** and **non-destructive testing (NDT)** have **limitations** in terms of coverage and timely monitoring
- **Large-scale/ Network level** assessment of road pavement conditions, allowing for early damage detection would be a solution
- Network level assessment could be done using **satellite remote sensing**
- **Integration** with ground-based methods, and informed planning for maintenance and rehabilitation projects

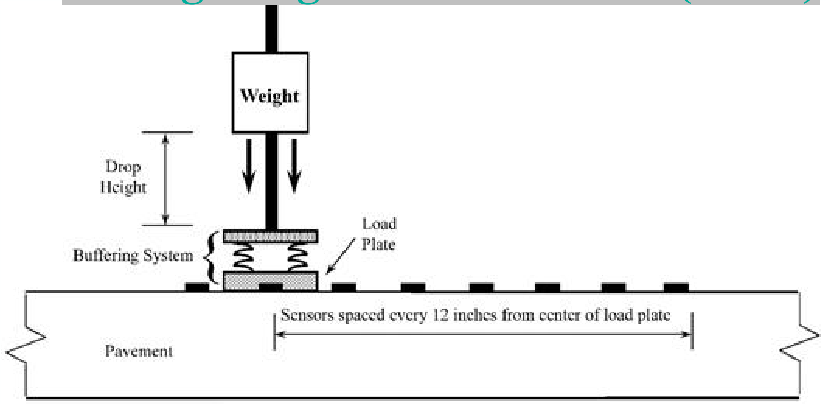
Maintenance and road safety!

## Ground Penetrating Radar (GPR)




Josep et al., 2020

## Falling Weight Deflectometer (FWD)



# Type of Pavement Deterioration

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POTHOLES

FATIGUE CRACKS

RUTTING

UPHEAVAL

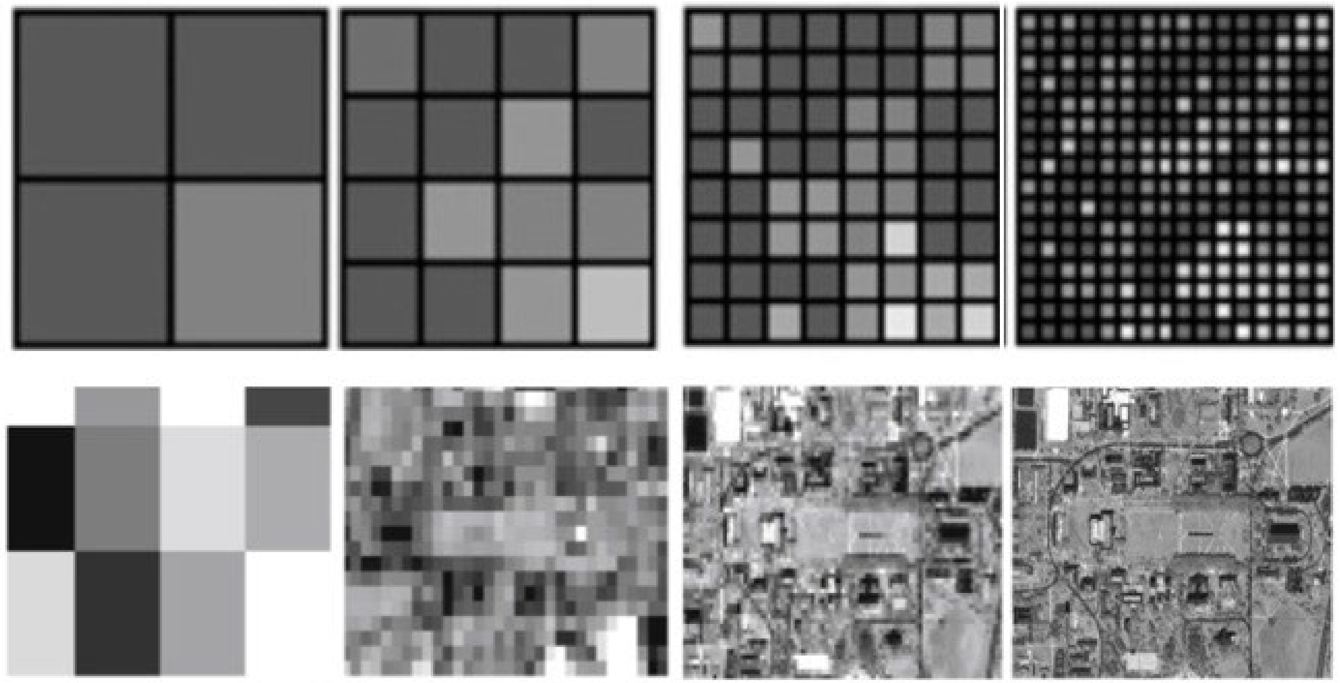
SINKHOLE

RECENT SINKHOLE IN NORWICH

ROOT CRACKS

https://www.truegridpaver.com/types-of-pavement-deterioration

# Spatial Resolution Limitations: Radar Satellites

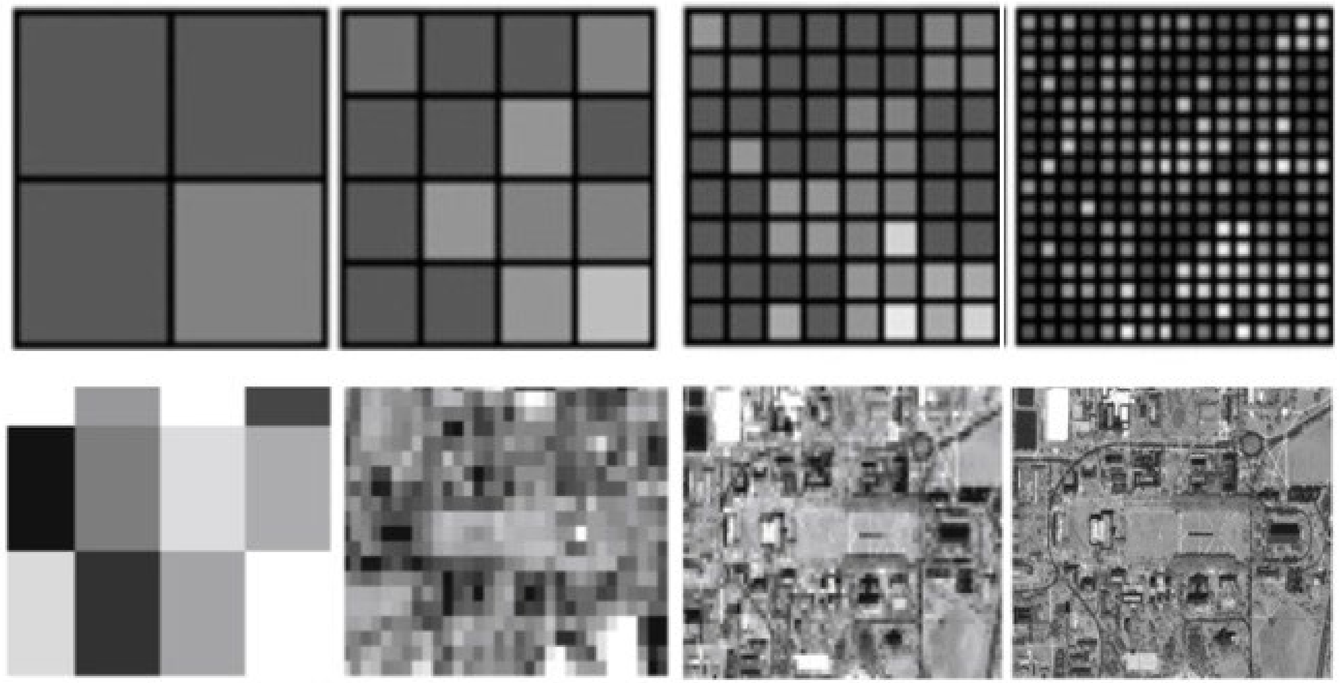


Increases in resolution

Cost of an image

| Satellite (operator) | Imaging mode (spatial resolution) | Maximum area covered | Time of operation |
|---|---|---|---|
| TerraSAR-X (DLR) | Staring Spotlight (0.6m) | 4 x 3.7km | 2013 – today |
| COSMO SkyMed (ASI) | Spotlight-2 (0.8m) | 10 x 10km | 2007 – today |
| HRWS (DLR) | StripMap (1m) | 70 x 70km | expected 2019 |
| TerraSAR-X (DLR) | Spotlight (1m) | 10 x 10km | 2007 – today |
| Radarsat-2 (CSA) | Spotlight (1m) | 8 x 18km | 2007 - today |
| Radarsat-2 (CSA) | UltraFine (3m) | 20 x 20km | 2007 – today |
| ALOS PALSAR-2 (JAXA) | Spotlight (3m) | 25 x 25km | 2014 – today |
| RISAT-1 (ISRO) | FR Stripmap (3m) | 25 x 25km | 2012 – today |
| Sentinel-1 | StripMap (5m) | 80 x 80km | 2014 – today |

# Spatial Resolution Limitations: Radar Satellites



Increases in resolution

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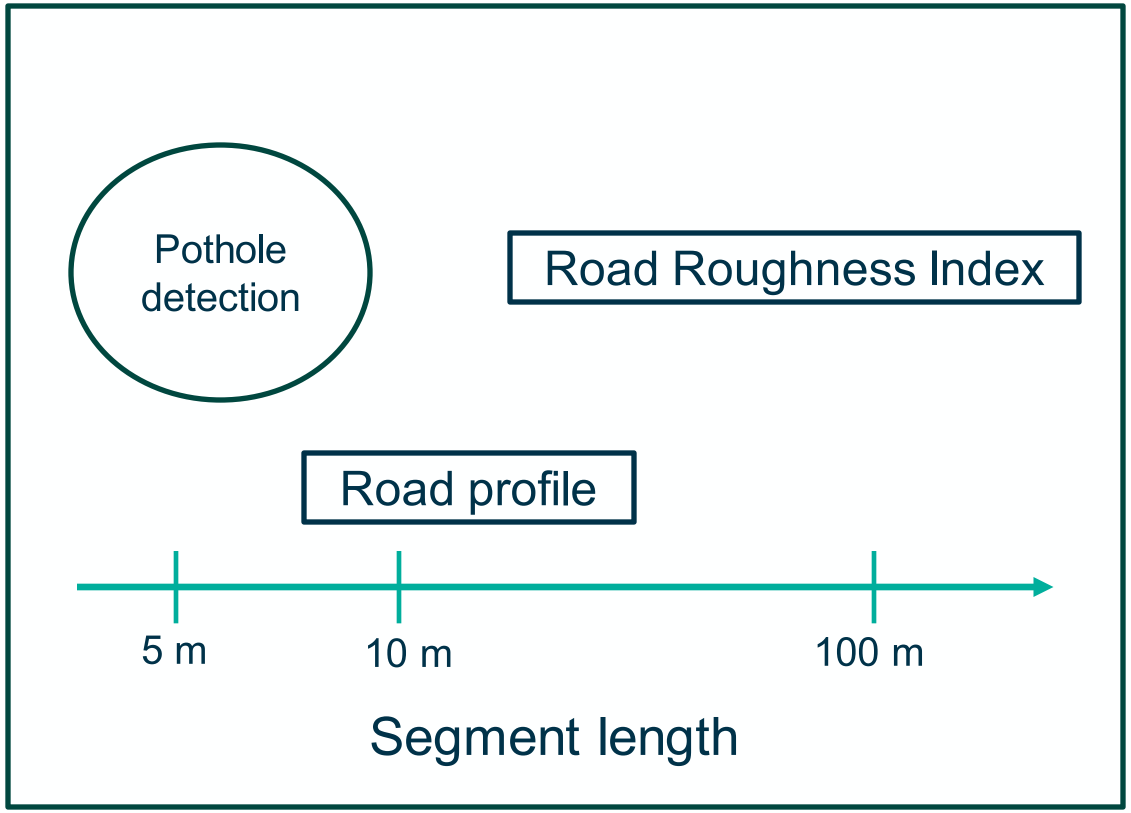


# Traditional NDT Vs Satellite Potentials

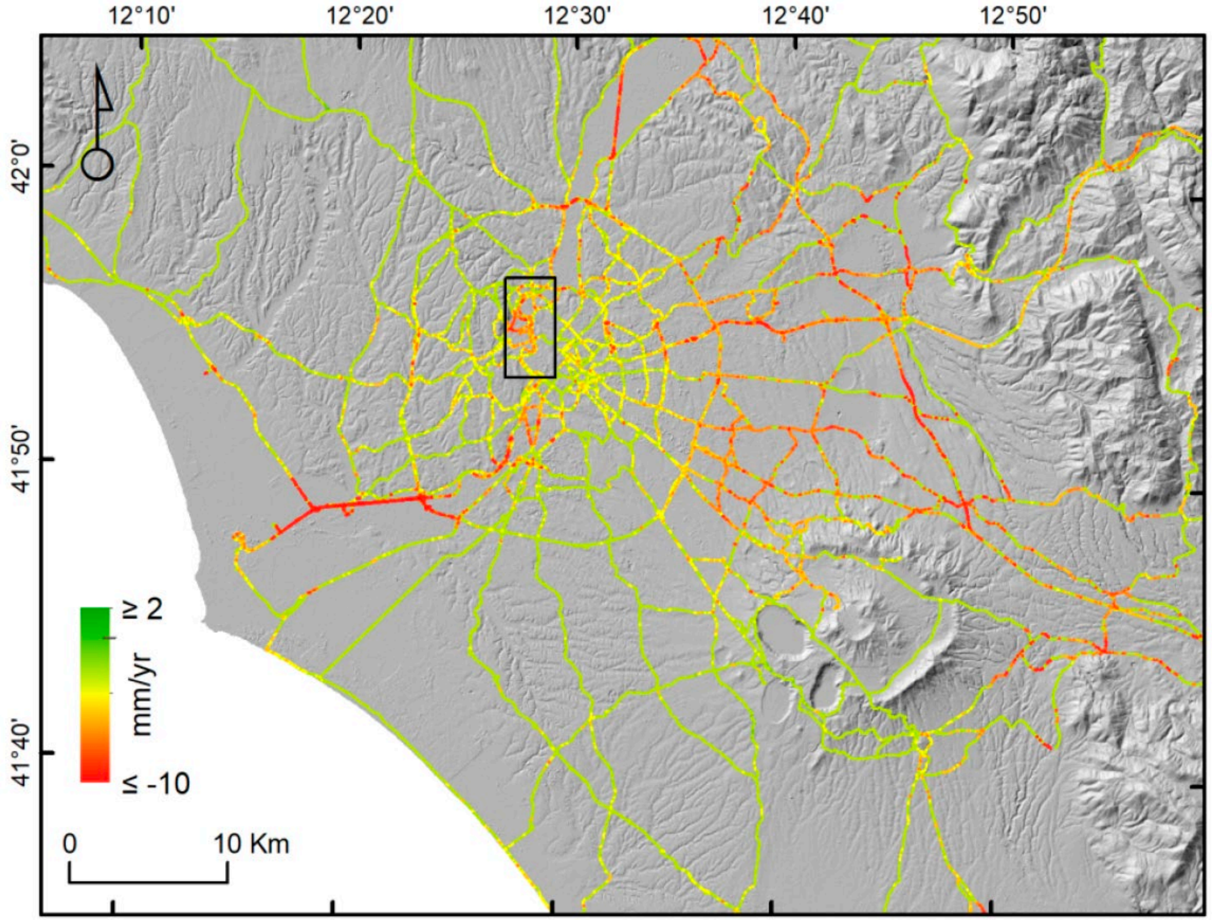
Automatic Road Analyzer (ARAN)


Laser Profilometer


- Are advanced methods and well-established
- Effective in assessing the pavements
- Have limitation in large scale coverage

Digital Image Scanning

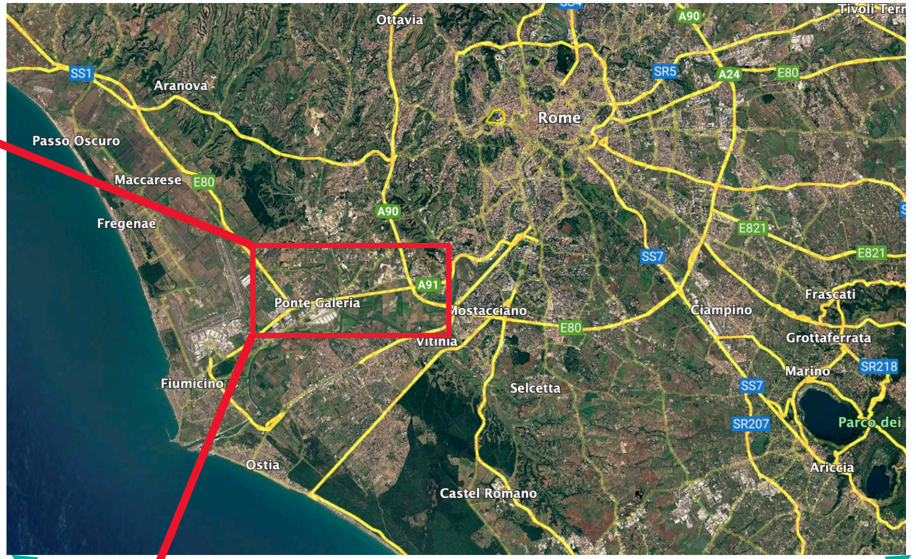
InSAR: Network Level Analysis



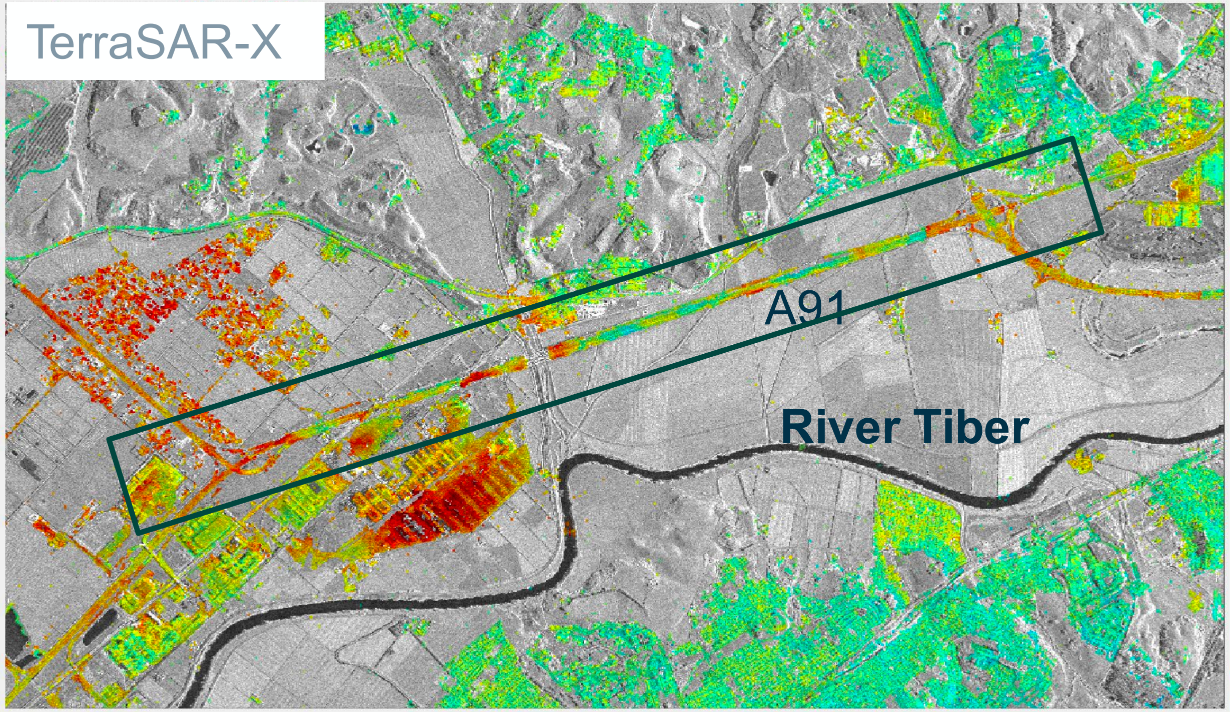

Delgado et al., 2019

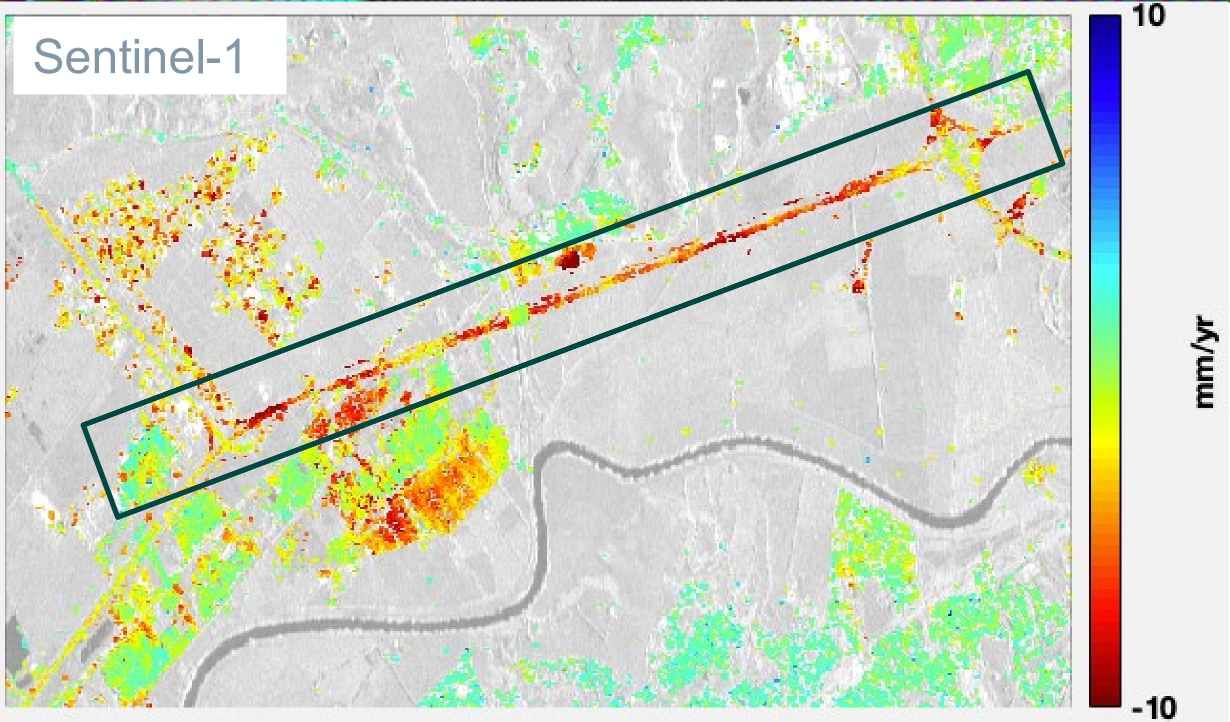
# Study Area

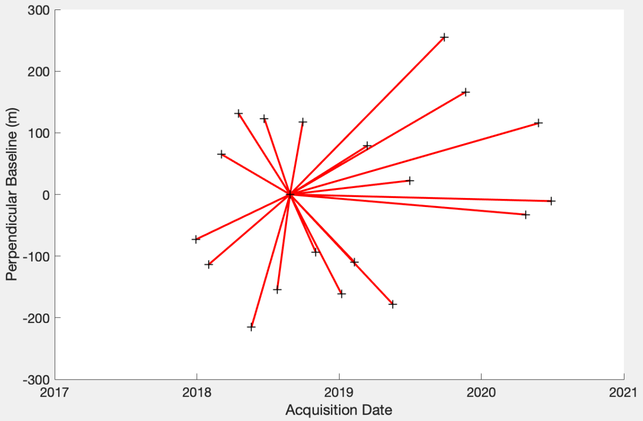
Italy, Rome, Fiumicino


# PS-InSAR

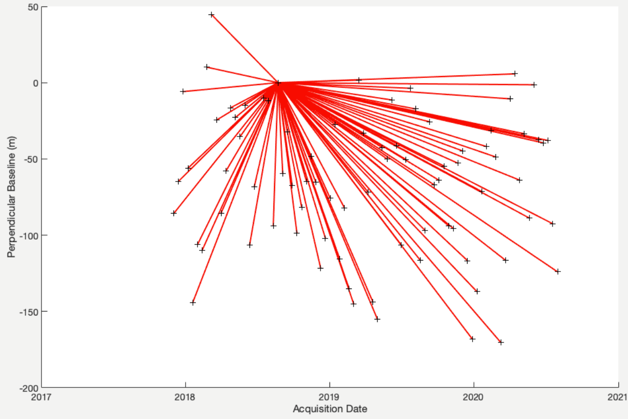


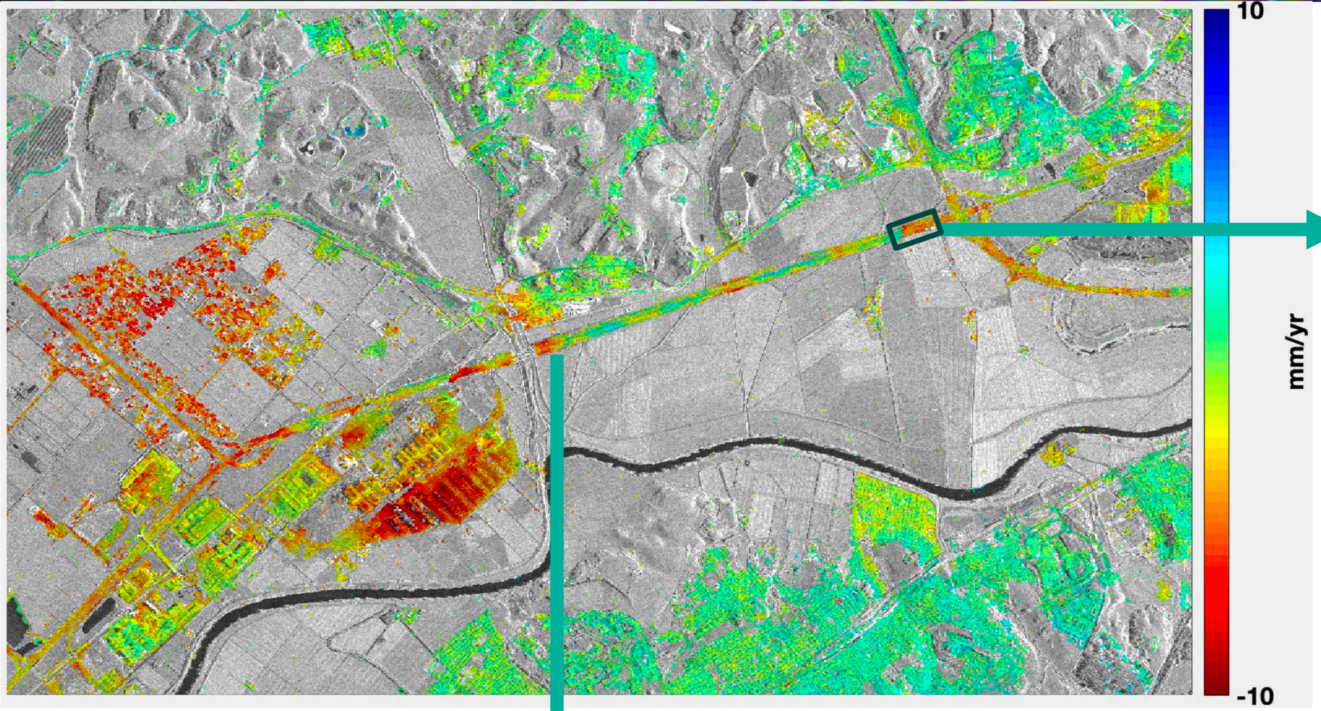

TerraSAR-X
Dec-2017 to July-2020
34 days repeat pass
20 images
3 x 3 m resolution

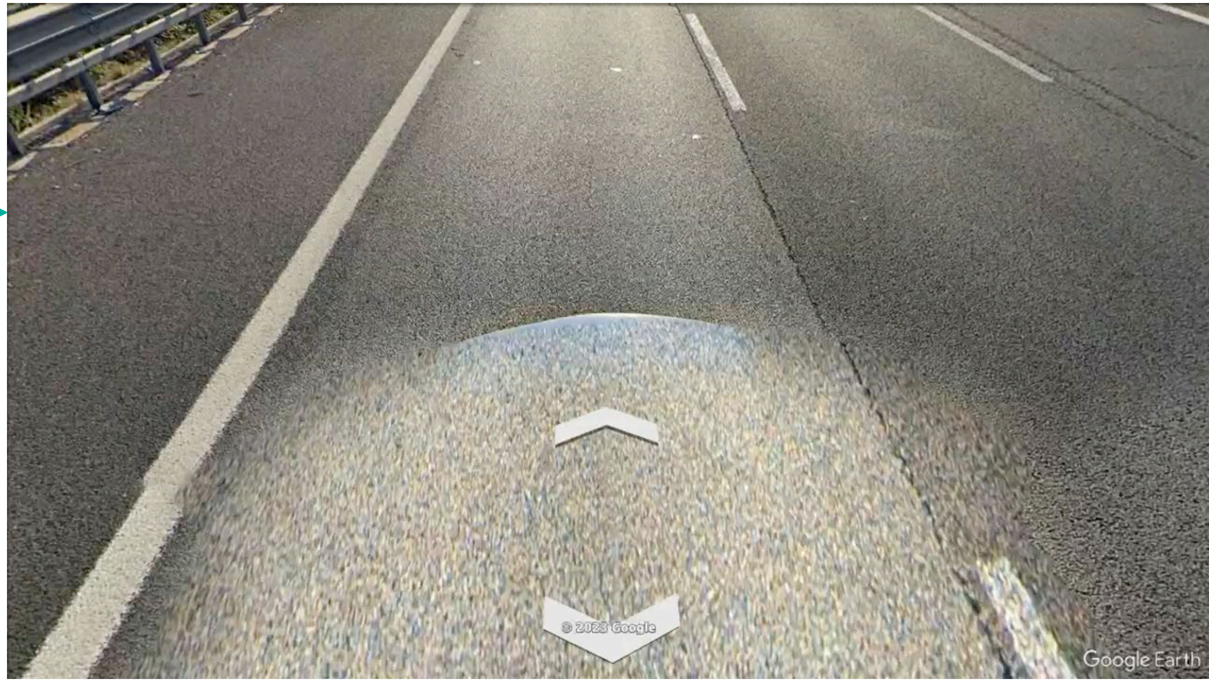
Sentinel-1
Dec-2017 to July-2020
12 days repeat pass
80 images
5 x 20 m resolution

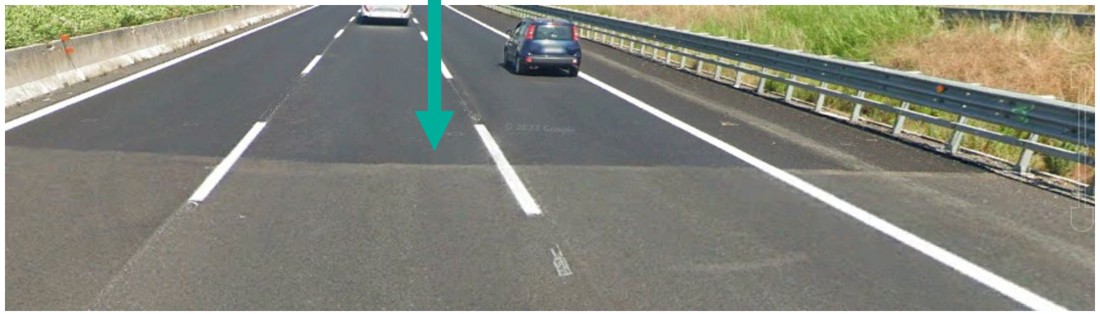



ISCE for interferogram formation
StaMPS for PS analysis

# Pavement Surface Changes



Is it feasible to detect such changes from coherence analysis?

# Methodology: Interferometric Coherence

$$\gamma = \frac{\langle I_1 I_2^* \rangle}{\sqrt{\langle |I_1|^2 \rangle \langle |I_2|^2 \rangle}} = |\gamma| \cdot e^{j\phi}$$

where

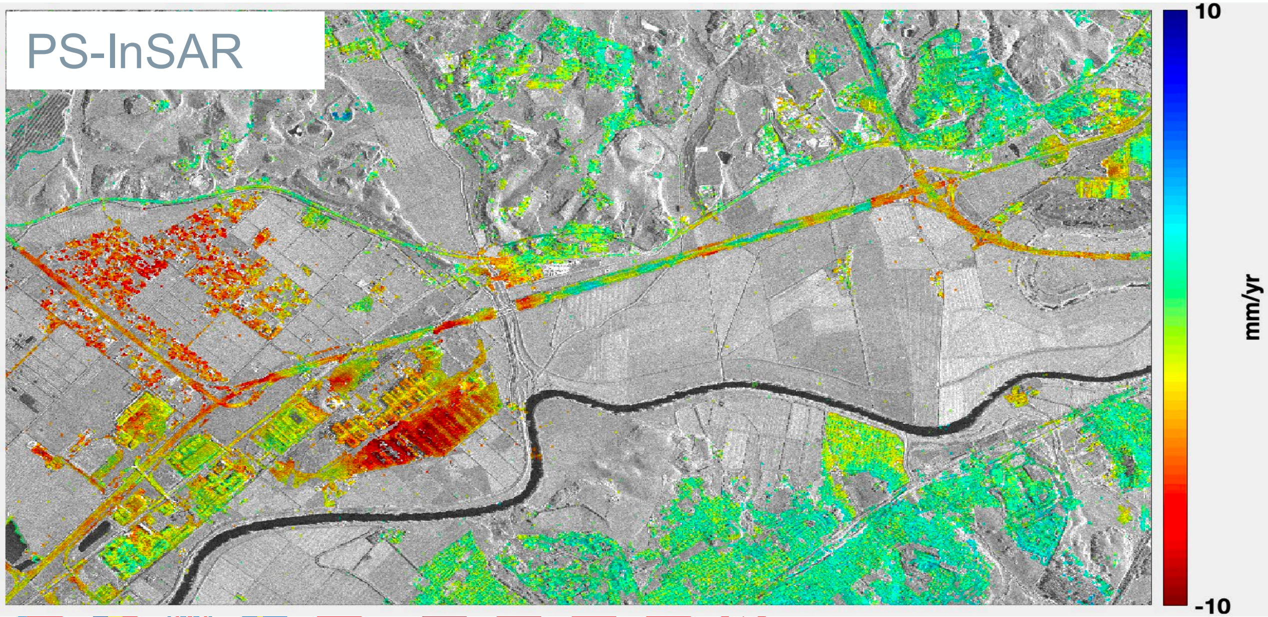
$I_1, I_2$ are complex SAR images,

$|\gamma|$ is the coherence and

$\phi$ is the interferometric phase.

- It is a parameter used to evaluate the quality of the calculated interferometric phase.

- Measures the similarity (correlation) between two SAR Images.

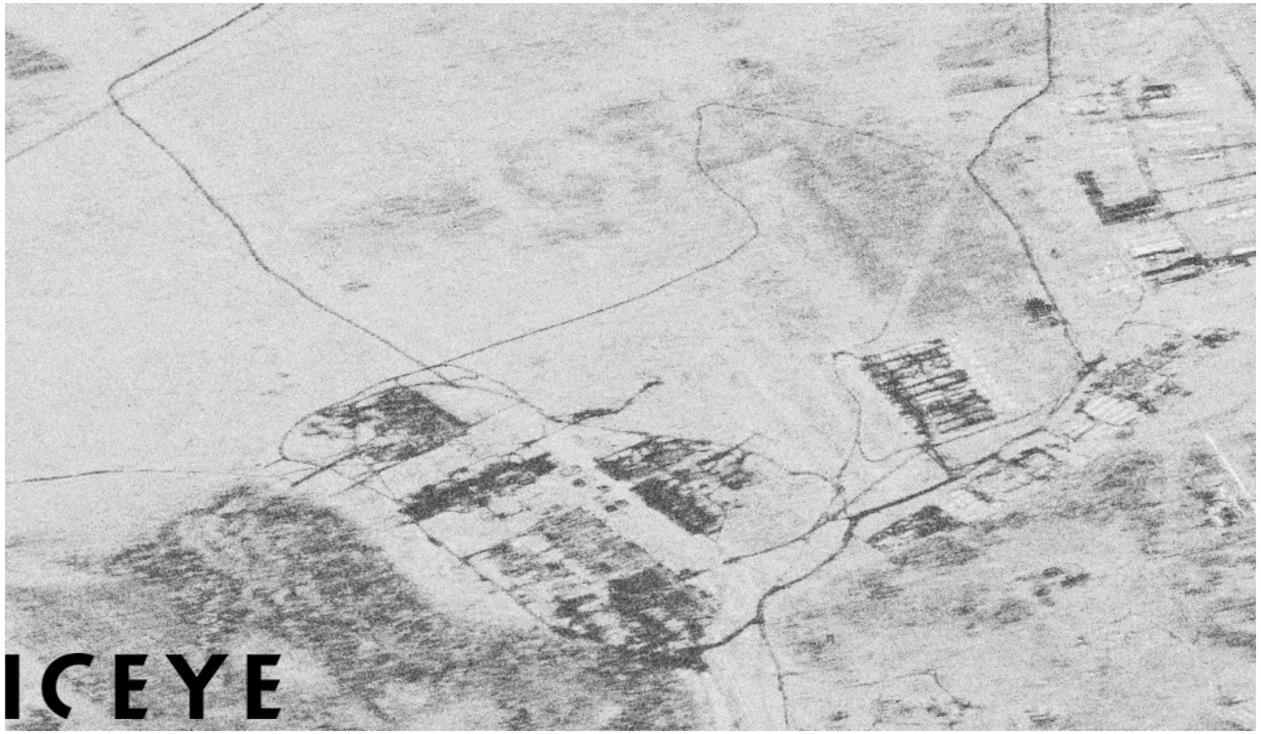



# Methodology: Interferometric coherence

- Coherence has been exploited for the detection of changes
  - Natural disasters
  - Volcanic eruption
  - Emplaced lava flow mapping
  - Snow cover mapping
  - Land cover classification

- Here we use to detect changes in pavements, adopting Trang Le et al, 2019 method used used for volcano monitoring
  - Change Detection Matrix
  - Coherence Image Time Series (ITS) to analyse changes related to pavements.

Trang Le et al, 2019



Example of coherence change caused by vehicle traffic through fields between January 21/22 and January 22/23, 2022

https://www.iceye.com/blog/beyond-change-detection-measuring-the-changes-that-matter

# Coherence Change Work Flow

InSAR Time-series

↓

Preprocessing

↓

Coherence Image Time-series (ITS)

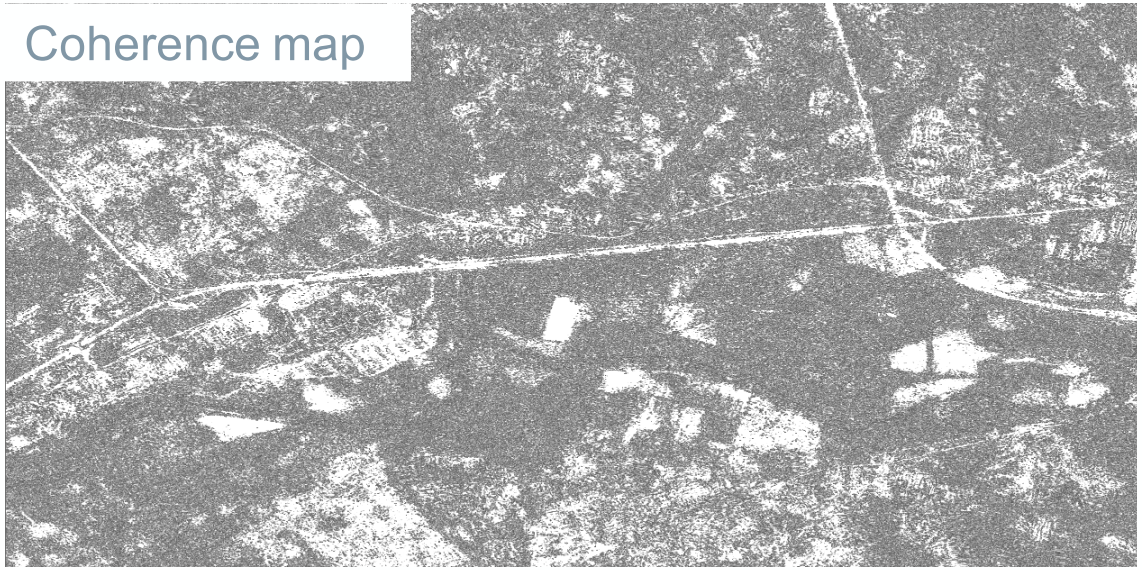
↓

Change Detection Matrix (CDM)
Change Analysis

↓

Coherence change map

Trang Le et al, 2019



# Coherence Change Workflow

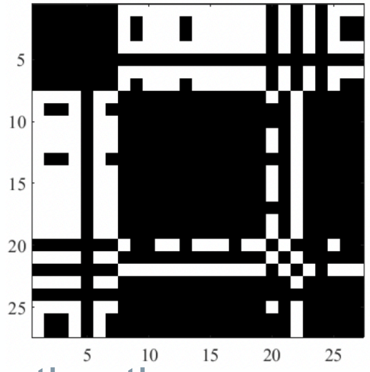
InSAR Time-series
↓
Preprocessing
↓
Coherence Image Time-series (ITS)
↓
Change Detection Matrix (CDM) Change Analysis
↓
Coherence change map

Trang Le et al, 2019

Step-1: CDM construction: for each pixel stack (i; j), a similarity matrix is generated by calculating similarity cross-tests between each two different dates (t; k)

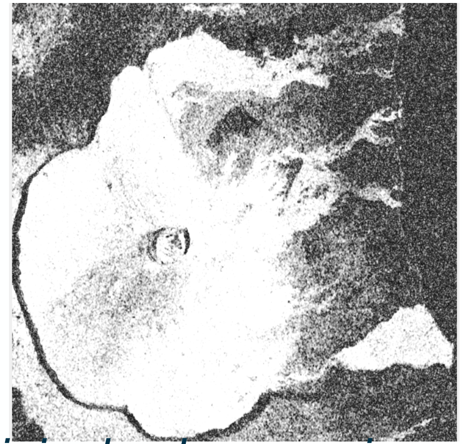
$$S_{(t,k)}^{w(i,j)} = \boxed{\mathfrak{D}}\left(C_t^{w(i,j)}, C^{w(i,j)}\right)_{1\leqslant t,k\leqslant N}$$

Similarity measure

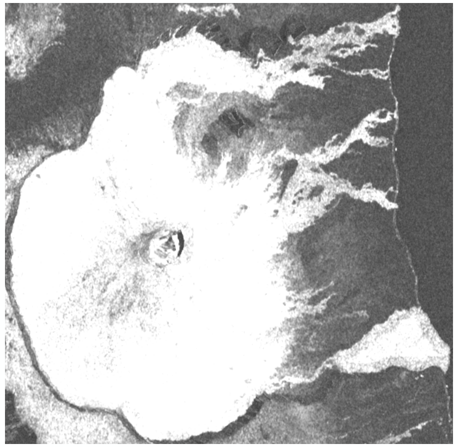



Step-2: Nonlocal temporal interferometric coherence estimation

By aggregating unchanged pixels using the mean statistics, nonlocal temporal mean coherence is estimated



*Original coherence image*



*Nonlocal temporal mean*

# Summary and Future Development

- PS-InSAR technique  revealed the deformation along the pavement.

Work in progress

- Explore the sporadic changes in pavements and identify the changes in coherence over the long range.

- Adopt the method developed for volcano changes (Trang Le et al, 2019) to apply for changes in the surface.

- Integration to other ground based Non-Destructive Testing methods

# Acknowledgments

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European Space Agency

DLR

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Thank you!
Any Question/comments/suggestions

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Delgado Blasco, J.M.; Foumelis, M.; Stewart, C.; Hooper, A. Measuring Urban Subsidence in the Rome Metropolitan Area (Italy) with Sentinel-1 SNAP-StaMPS Persistent Scatterer Interferometry. *Remote Sens.* **2019**, *11*, 129. https://doi.org/10.3390/rs11020129