LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

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Computational Conflict Research

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28.02.2025

Conflict Research – Why?

- Armed (political) conflict responsible for 1000s of fatalities across the globe every month
  - Both intra- & intercountry conflicts

- Armed conflict…
  - …leads to migration within countries and across borders
  - …has disastrous economic consequences
  - …undermines functioning of political systems
  - …prevents countries from escaping poverty
  - …hinders humanitarian assistance (where most needed)

- Research topics:
  - Understanding the determinants & mechanisms of conflict
  - Developing early-warning systems
  - → Would potentially allow for prevention & mitigation
  - What are the consequences of armed conflict?

Overview over joint research projects

- Use of remote sensing data to improve forecasting of conflict
- Analysis of tweets in Ukraine
  - Switch from Russian to Ukrainian
- Designed a statistical model to capture the diffusion of conflict across space & time
- Nowcasting conflict events
  - Ongoing
- Detection of building destruction via publically available satellite images
  - Just finished, topic today ☺

Detection of Building Destruction in Armed Conflict from Publicly Available Satellite Imagery

Daniel Racek, Qi Zhang, Paul W. Thurner, Xiao Xiang Zhu, Göran Kauermann, 2025

Background & Motivation

- Quality & resolution of satellite images has substantially improved in past decade

- Multitude of uses for conflict research:
  - Landcover classification & changes over time
  - Economic activity
  - Detection of destruction & damage

- However: High-resolution satellite images typically not freely available
  - And very expensive ☹

- How far can we get with freely available satellite images?

https://www.bizjournals.com/denver/news/2020/03/25/maxar-satellite-images-denver-coronavirus.html

Research Question

- European Space Agency (ESA) launched multiple earth observation satellites in past decade
  - Images acquired are completely free of use (for public, scientific, or commercial purposes)
- Can we detect destruction during conflict/war using these images?
- Missions of interest:
  - Sentinel-2: Optical images
    - Multi-spectral data with 13 bands
    - Visible, near infrared & short wave infrared light frequencies
    - 10 m to 60 m resolution

    → „Low“ resolution of images makes buildings very pixelated

    → Issues with cloud coverage (sometimes entire image covered by clouds)

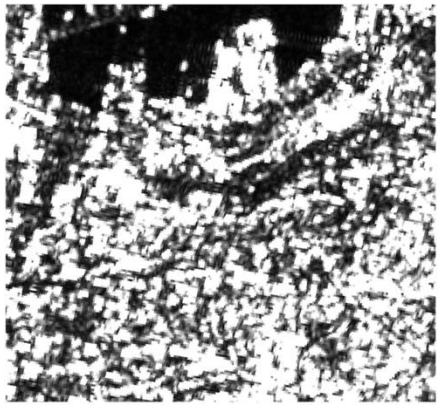
    → Basically impossible

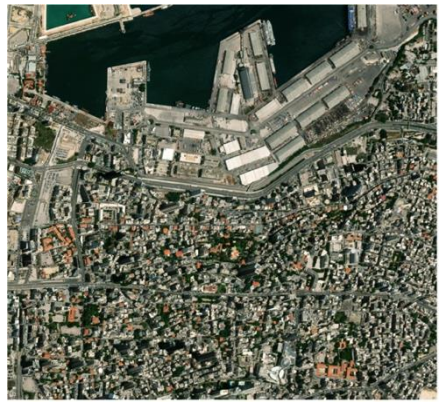
  - Sentinel-1: Synthetic aperture radar (SAR) images
    - Form of radar
    - Allows for three-dimensional reconstructions of objects
    - (Matrix of complex numbers)
    - 20m resolution

    → Not affected by clouds

    → Use of 3D reconstruction helps even when images are of lower resolution

    → More promising ☺





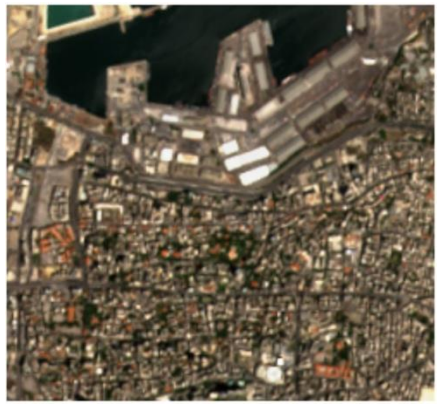
Research Study

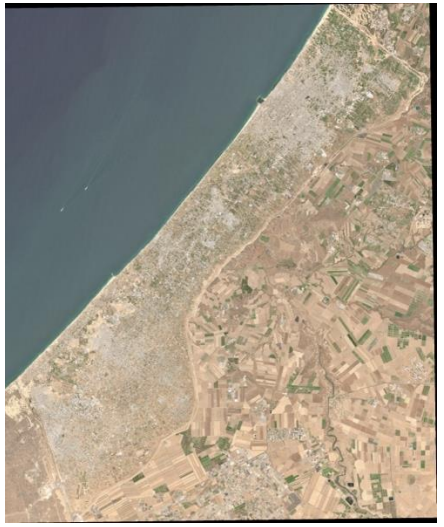
- Evaluation across three case studies

- Beirut:
  - Harbor explosion
  - 4th August 2020
  - Single-day event
  - Ground truth available

- Mariupol
  - Russia-Ukraine war
  - Start of invasion: 24th February 2022
  - Destruction over multiple weeks
  - Some ground truth available

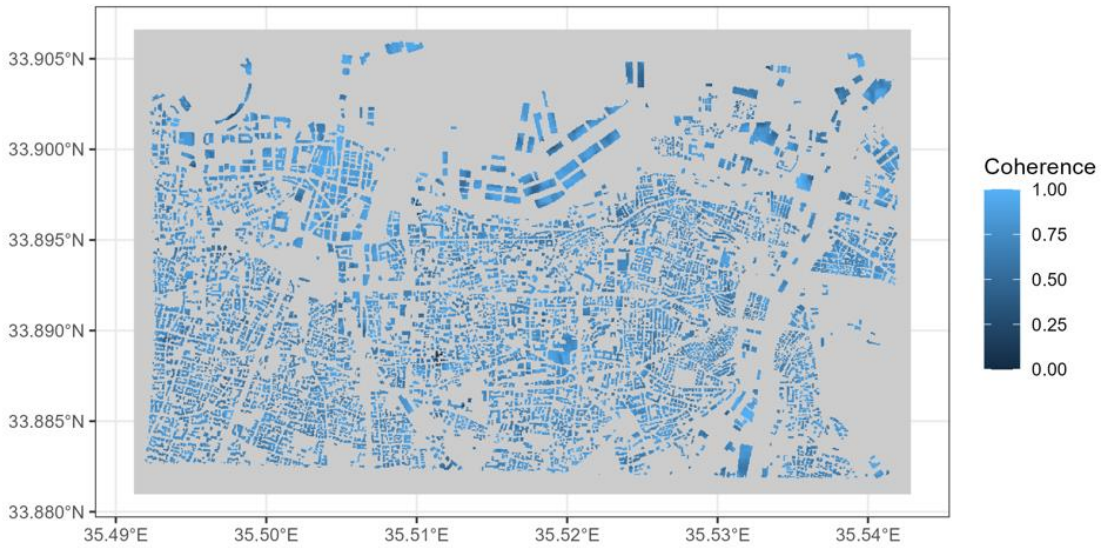
- Gaza:
  - Israel-Hamas war
  - 7th October 2023
  - Destruction over multiple months
  - No reliable ground truth available





Basic Methodology

- Unsupervised detection
  - No „training“ needed
- Images (of same location) are repeatedly taken in 12-day interval
- Construct „coherence“ of pixels between two images
  - How similar are backscattered signals?
    - If highly unsimilar: something must have changed (e.g. destruction of building)
  - Presence of elemental scatteres & geometry of satellite passes introduce noise → techniques to counteract this
  - Via interferometric SAR (InSAR) (Bamler and Hartl, 1998)
  - Final result: time series of coherence scores for each pixel
- Augment results by using known building footprints
  - From OpenStreetMaps

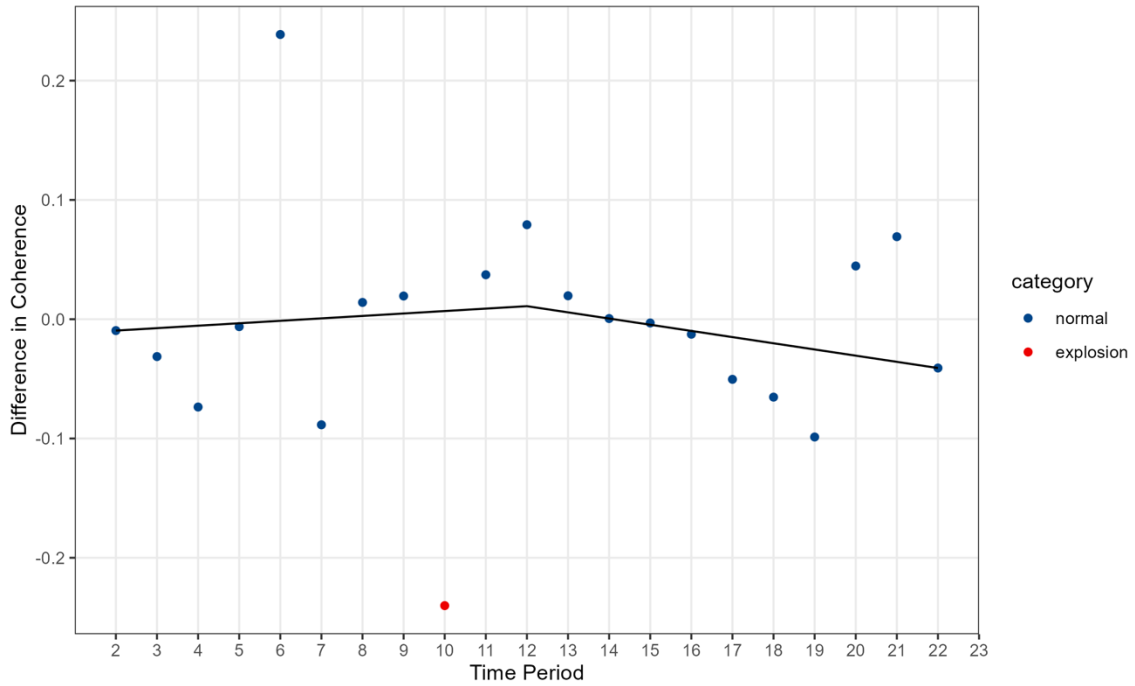


Basic Methodology

- Flexible median regression on each pixel
- Calculate residuals
  - Roughly normally distributed with larger tails
  - Residuals at tails do not follow same distribution
- Estimate SD of residuals with robust-scale estimator (Qn)
  - (Rousseeuw and Croux, 1993)
  - Minimally affected by these outliers
- Under hypothesis of normal distribution with standard deviation $\hat{\sigma}_i$, probability to observe each residual $r_{i,t}$ (or more extreme one)

$$p(r_{i,t}) = Pr(R_{i,t} \leq r_{i,t})$$

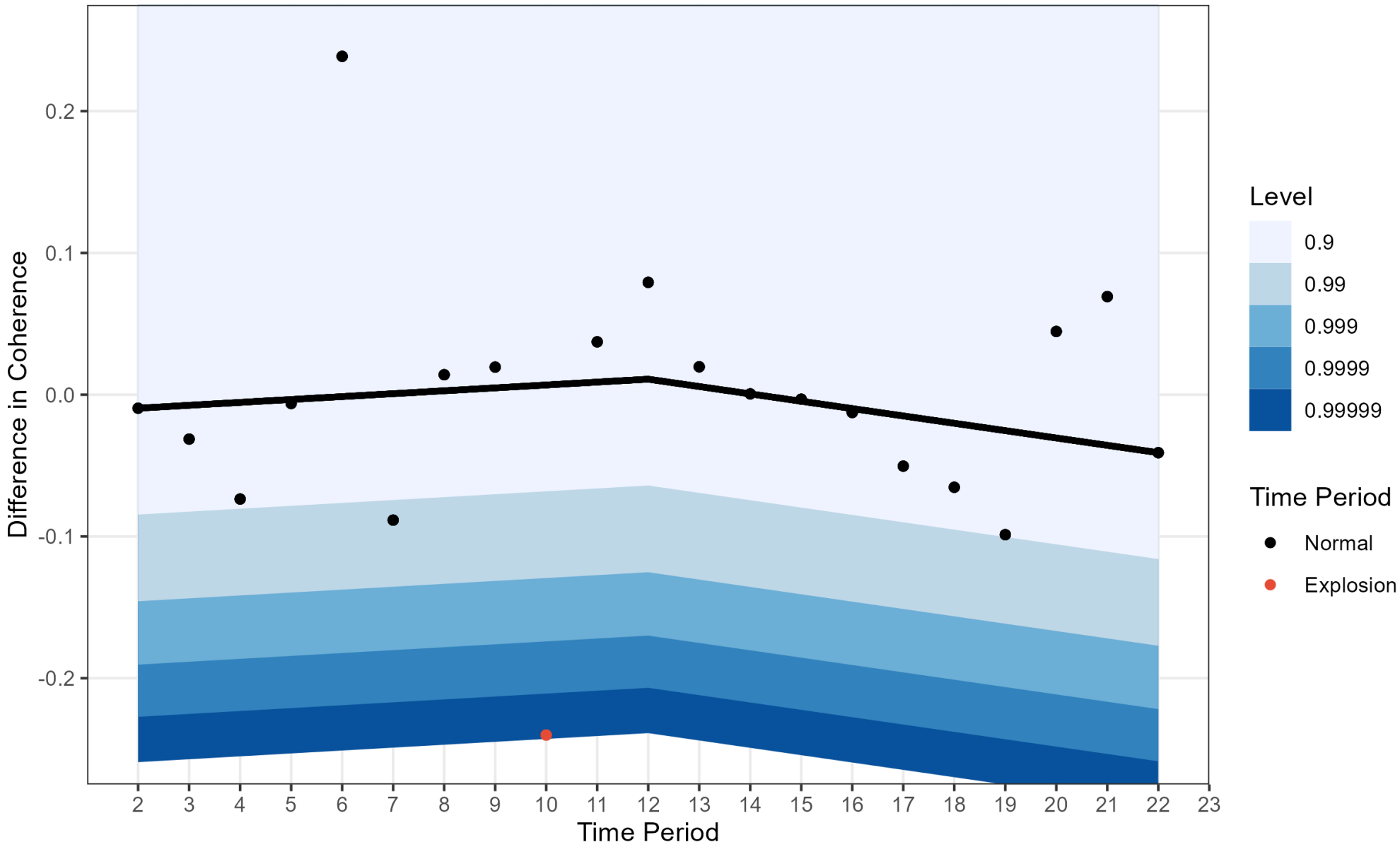
  - With $R_{i,t} \sim \text{Normal}(0, \hat{\sigma}_i^2)$
  - → one-sided p-value



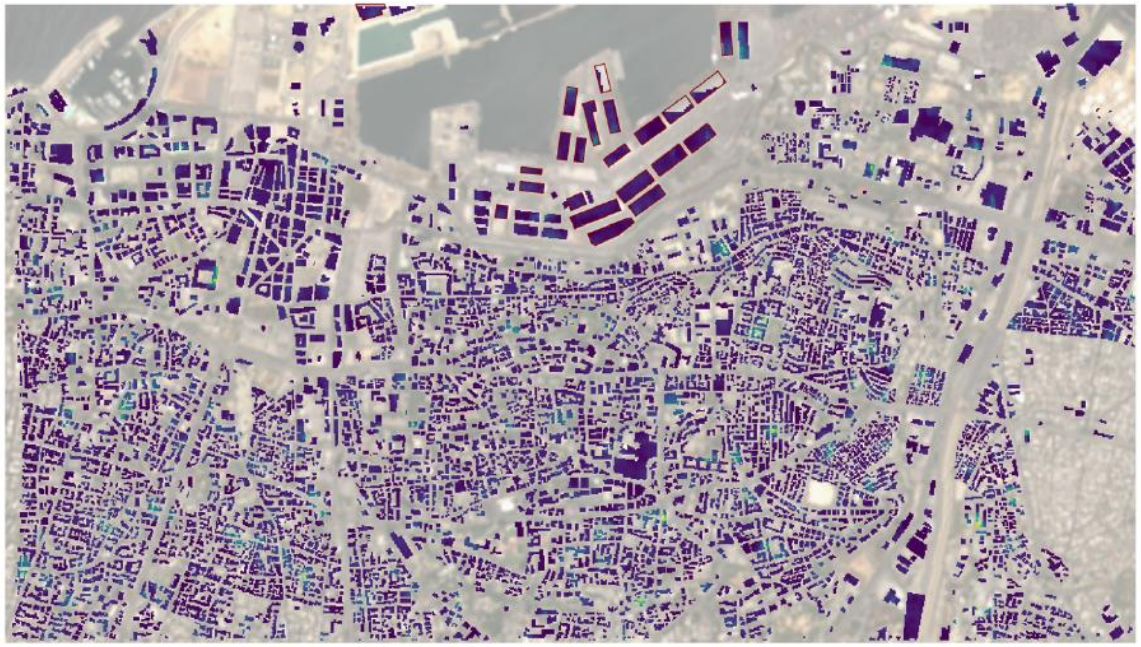
→ Evidence coherence score not just observed by chance, but instead due to structural changes of building

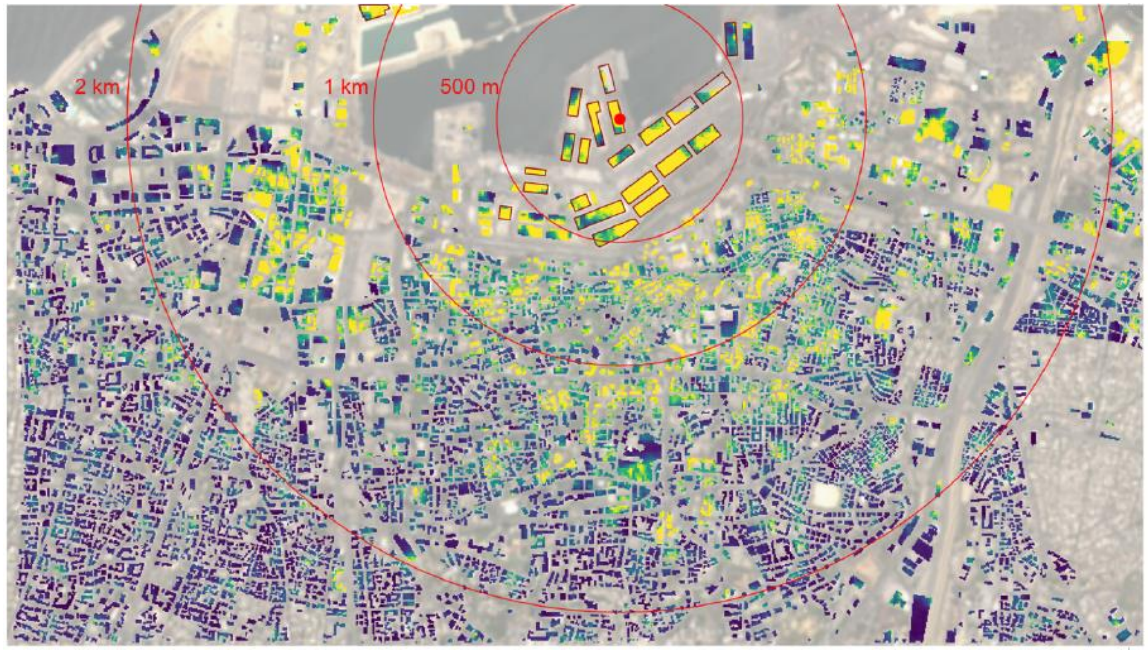
→ Straightforward methodology to combine p-values for buildings consisting of multiple pixels (harmonic mean)

→ Classification threshold possible

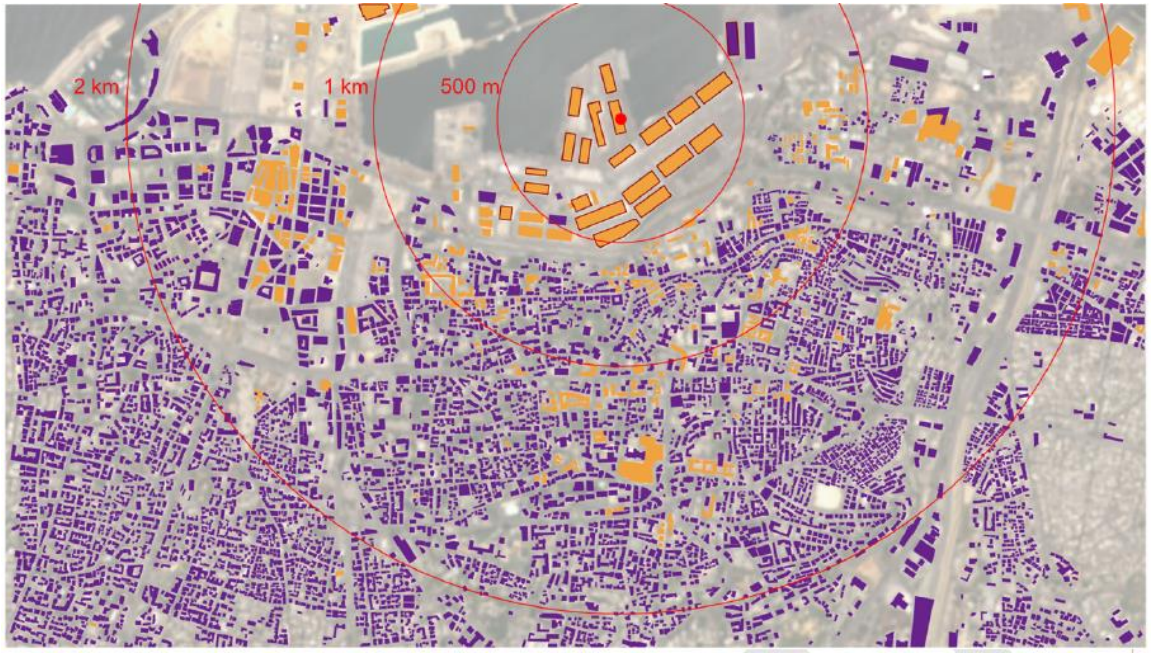

Difference in Coherence
0.2
0.1
0.0
-0.1
-0.2
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Time Period
Level
0.9
0.99
0.999
0.9999
0.99999
Time Period
Normal
Explosion

Beirut





P-Value
1.000
0.100
0.010
0.001
0.000

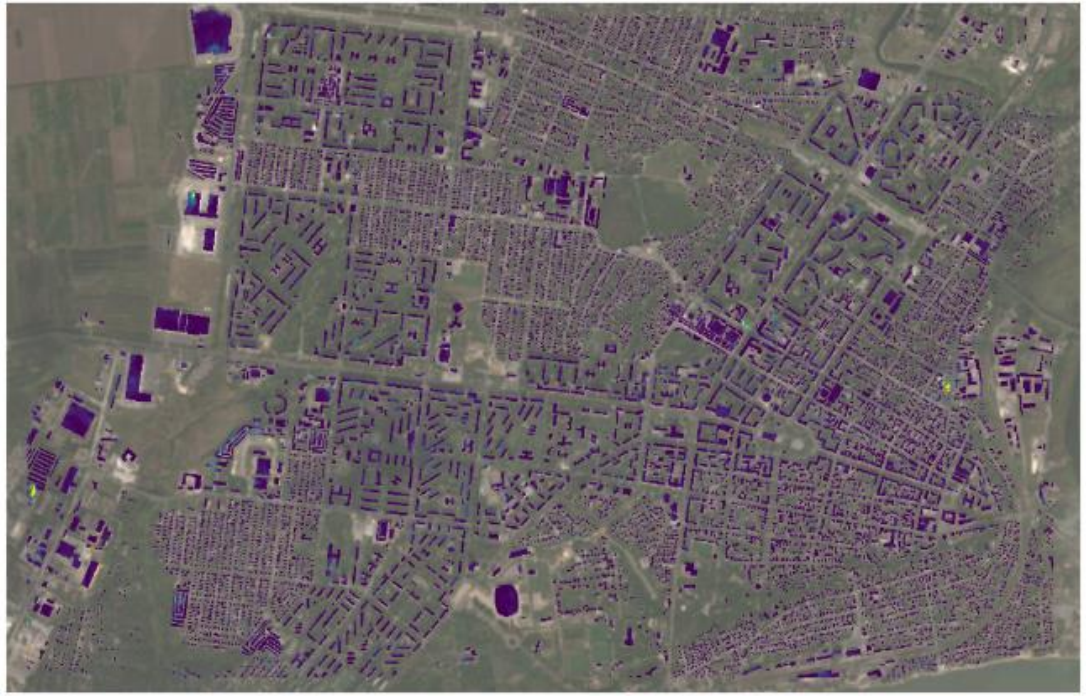


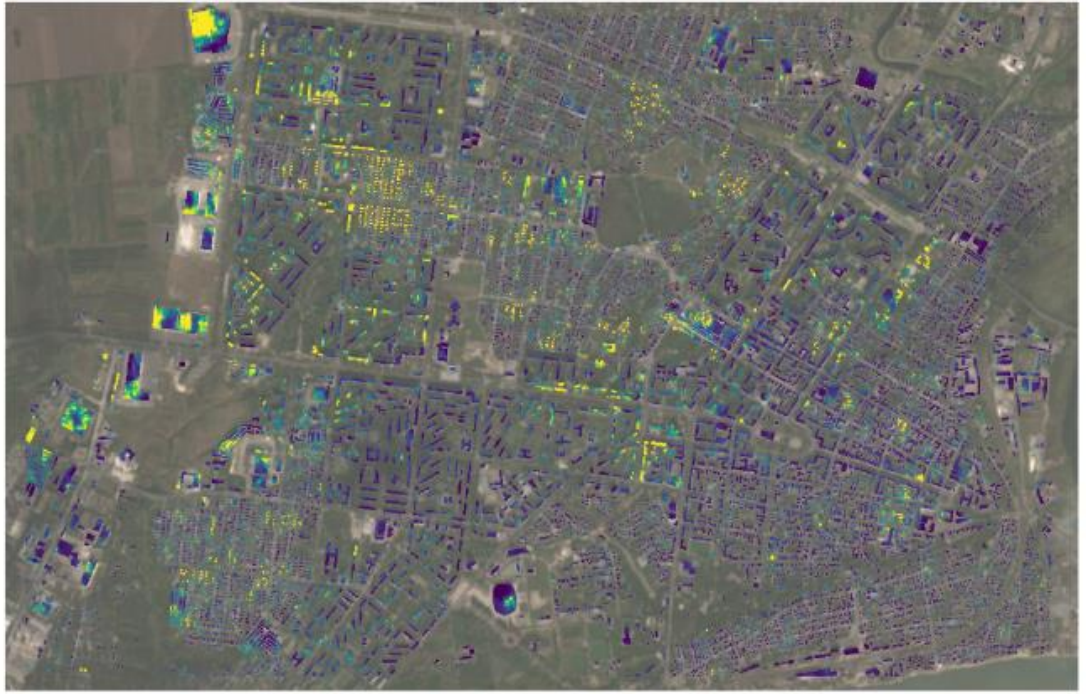
Detection

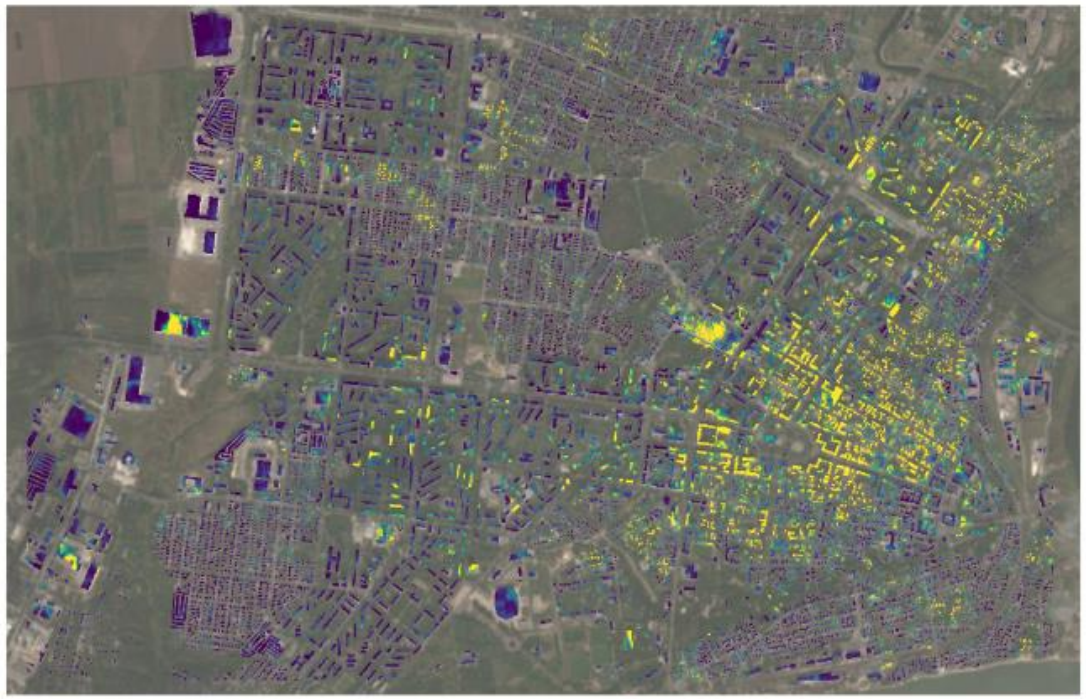
No Destruction

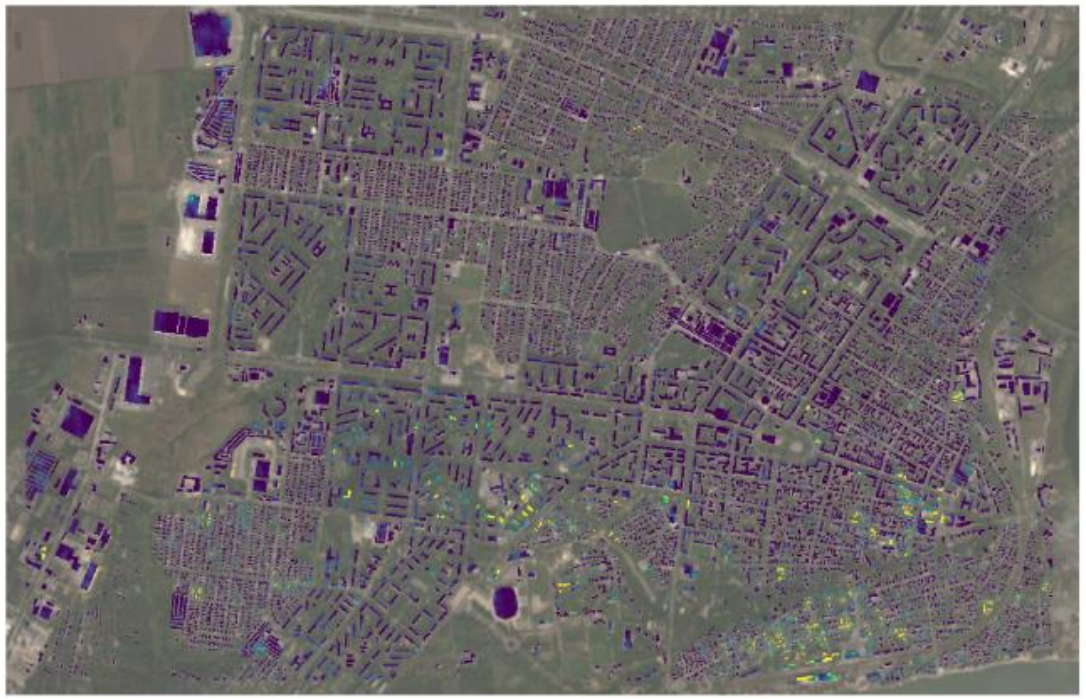
Destruction

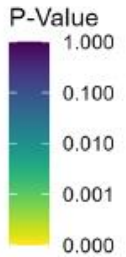
Mariupol

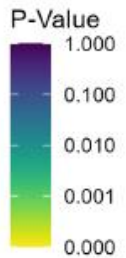









P-Value
1.000
0.100
0.010
0.001
0.000


P-Value
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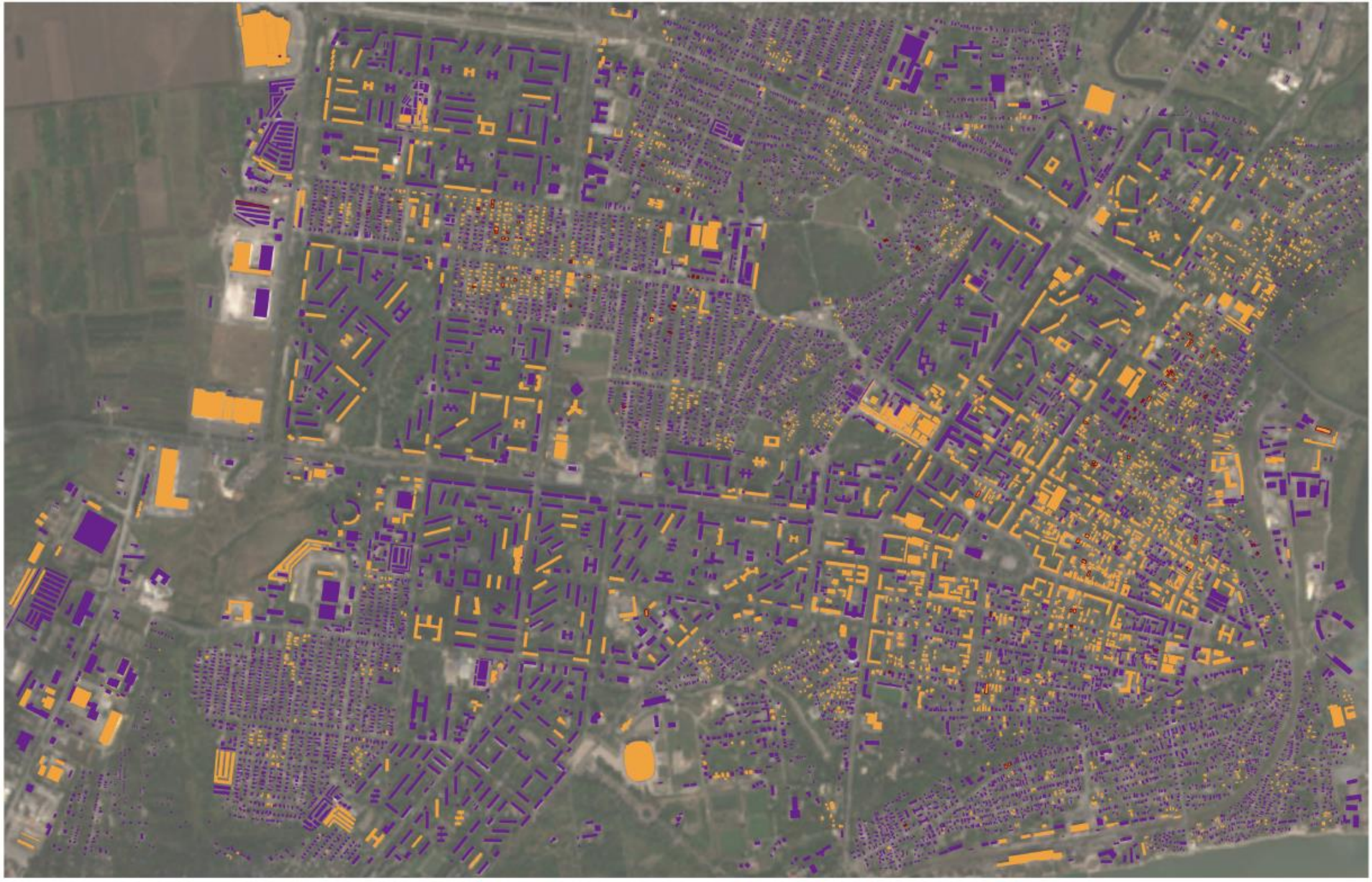
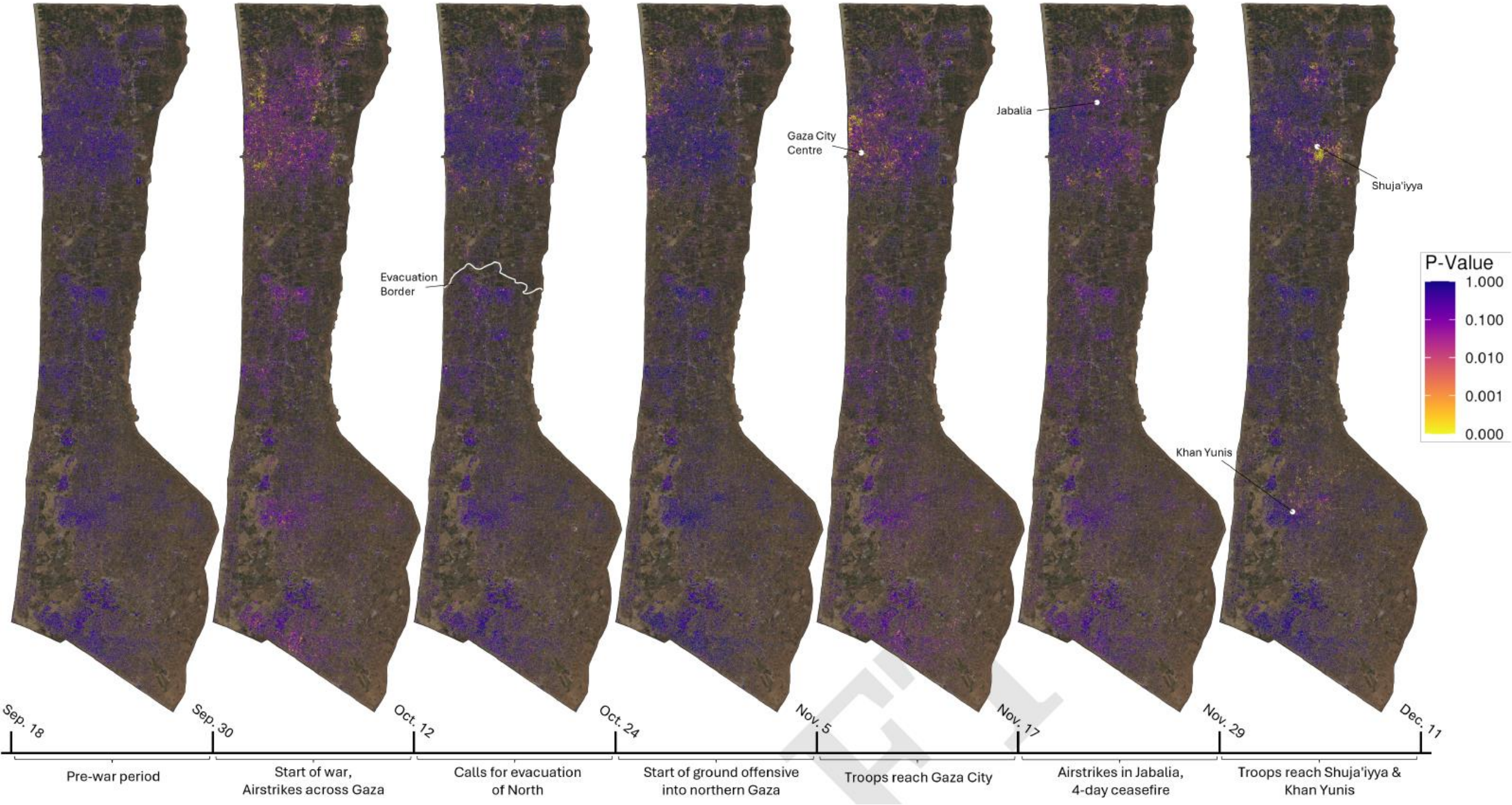
0.100
0.010
0.001
0.000


Detection
No Destruction
Destruction

Gaza


Evacuation Border
Gaza City Centre
Jabalia
Shuja'iyya
Khan Younis
P-Value
1.000
0.100
0.010
0.001
0.000
Sep. 18
Sep. 30
Oct. 12
Oct. 24
Nov. 5
Nov. 17
Nov. 29
Dec. 11
Pre-war period
Start of war, Airstrikes across Gaza
Calls for evacuation of North
Start of ground offensive into northern Gaza
Troops reach Gaza City
Airstrikes in Jabalia, 4-day ceasefire
Troops reach Shuja'iyya & Khan Yunis

References

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- Bamler, Richard, and Philipp Hartl. "Synthetic aperture radar interferometry." Inverse problems 14.4 (1998): R1.
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