# International Conference on Earthquake Engineering

## *CISMID: 40 Years of Science, Innovation and Infrastructure Assessment for Resilient Cities*

# Ground Subsidence Monitoring in Lima, Peru Using Time-Series InSAR

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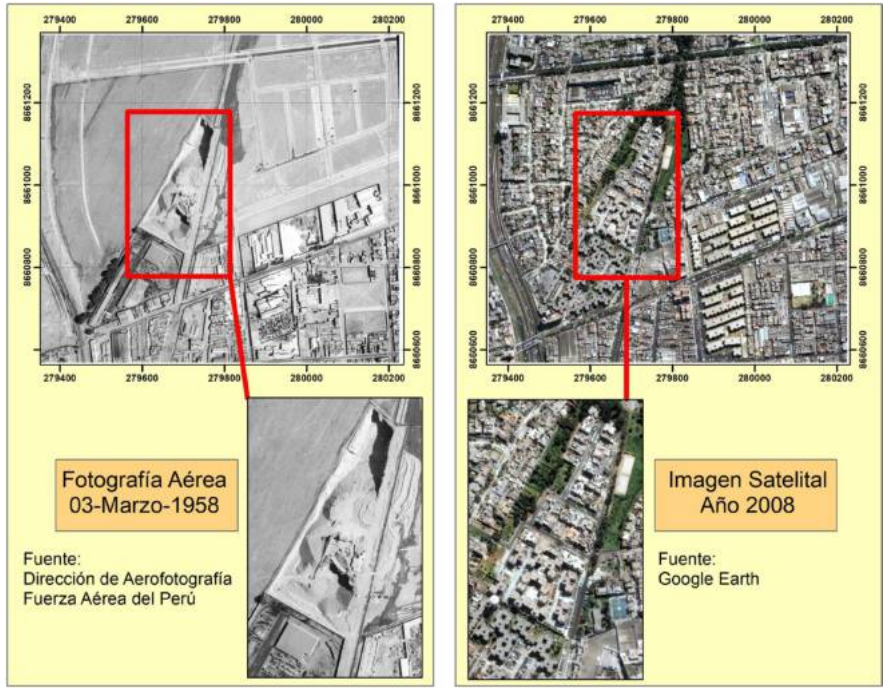
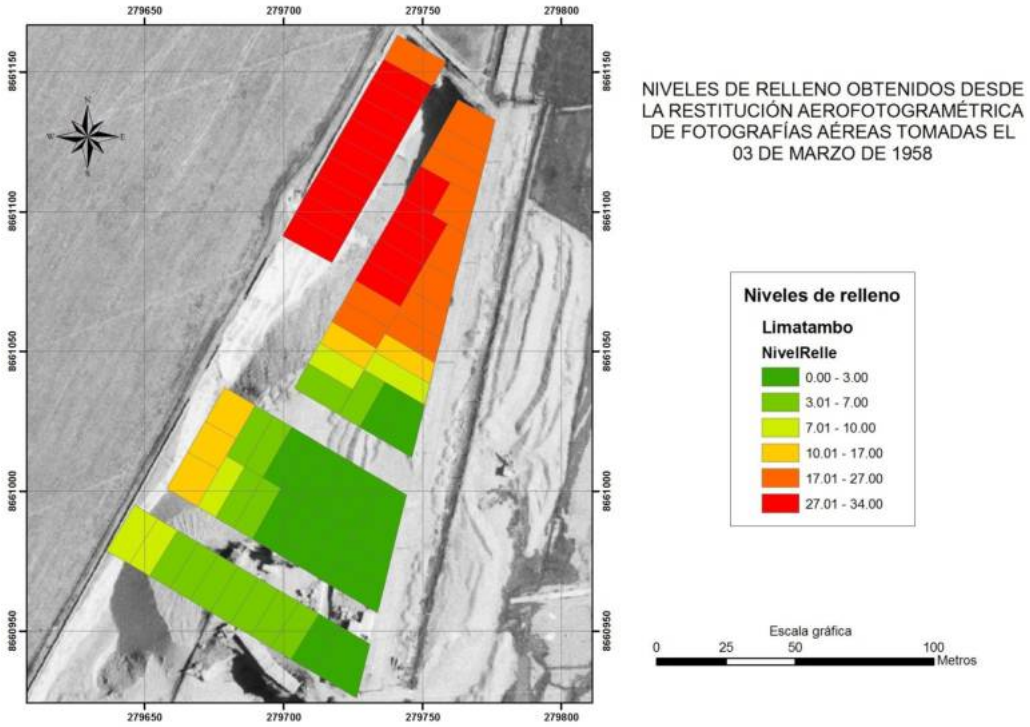
# Background

- The area (Limatambo, Surquillo District, Lima, Peru) was originally a quarry.
- The site was reclaimed using heterogeneous fill with a thickness of up to 34 m.
- Long-term differential settlement has been reported since around 2006.
- The mechanism and current deformation rate remain unclear.




1958 Aerial Photograph

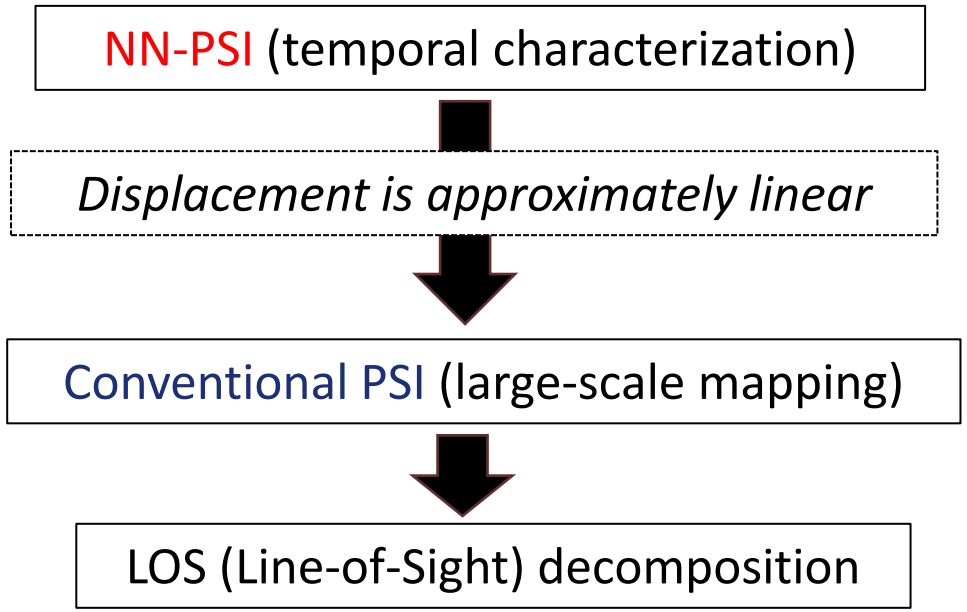
Quarry
↓
Land reclamation
↓
Residential area




stimated Fill Thickness

# Objectives

- Detect and quantify ongoing ground subsidence in the Limatambo area using satellite SAR observations.
- Investigate the temporal characteristics of the observed ground deformation.
- Develop an efficient strategy for large-scale ground subsidence monitoring.



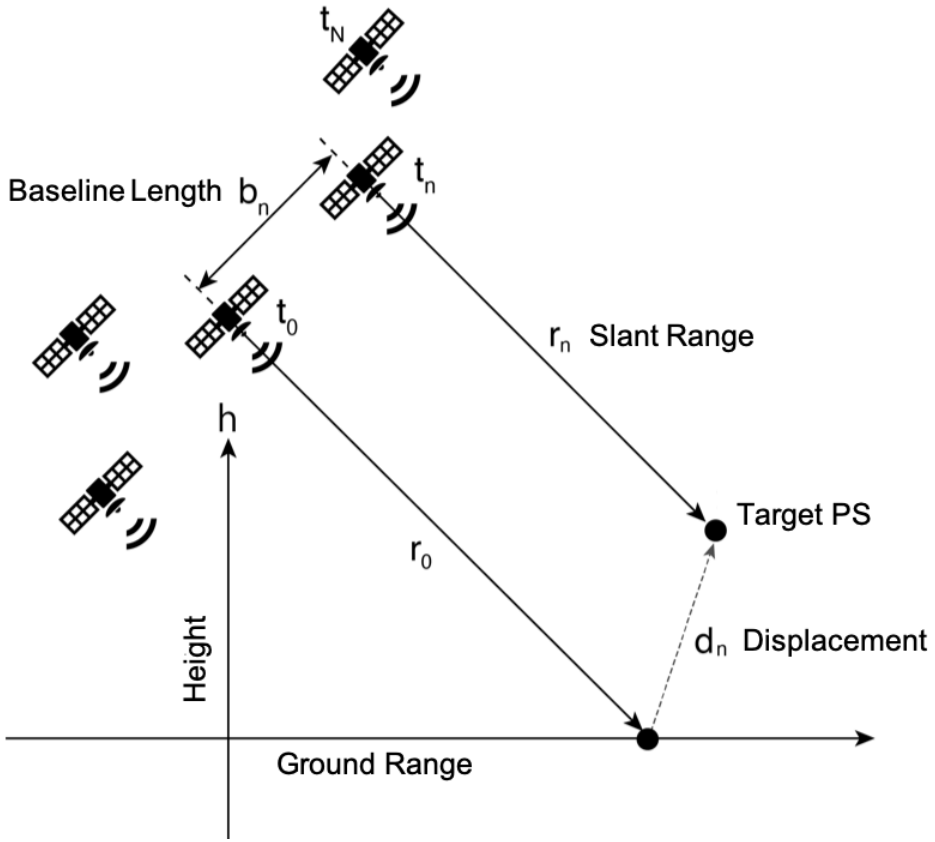

**Time-Series InSAR Analysis Strategy**

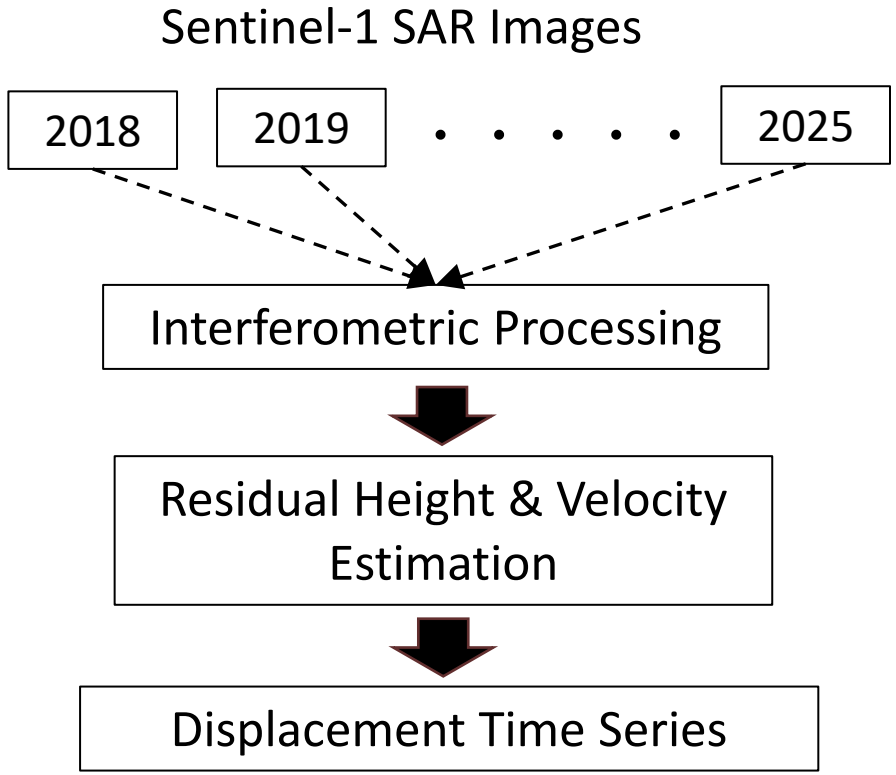
Photo taken on 2026/3

# Time-Series InSAR

## Purpose

- Detect long-term ground deformation from repeated SAR observations.
- Reduce atmospheric and orbital artifacts by exploiting multiple acquisitions.
- Estimate displacement time series at persistent scatterers (PSs).



# Performance of Time-Series InSAR

Ogushi et al. (2021)* proposed NN-PSI (Non-Linear Non-Parametric Persistent Scatter Interferometry) which is based on conventional PSI with improved methods for estimating object height and calculating displacement velocity.

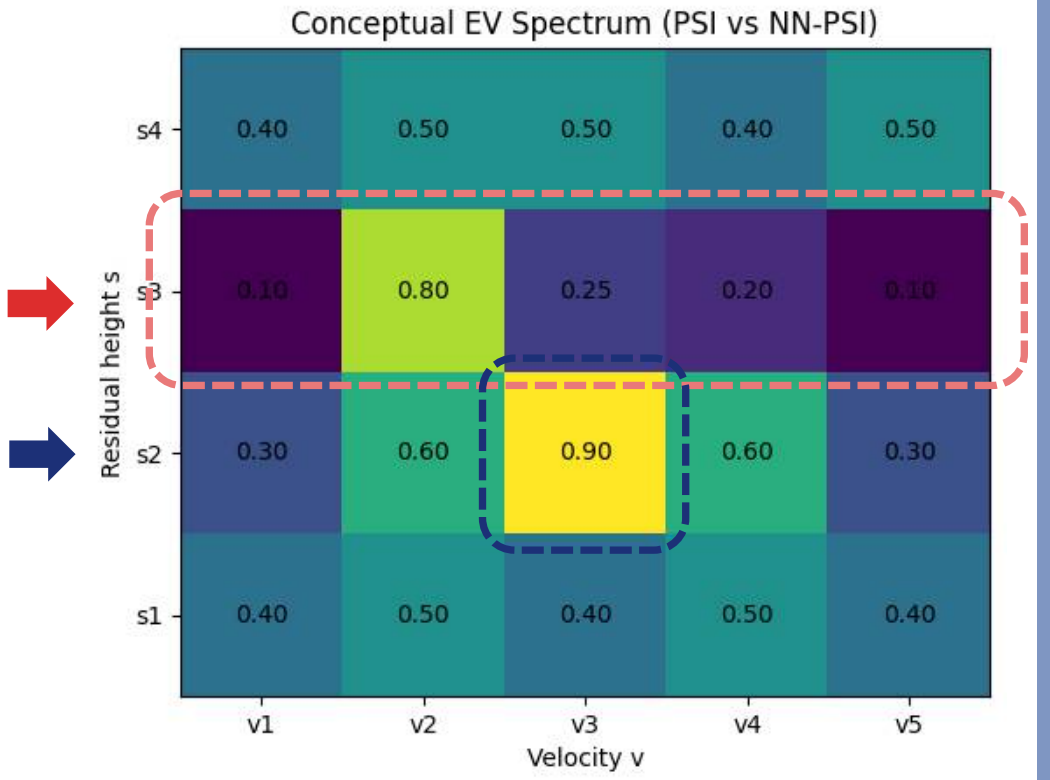
| Method | Urban areas/Buildings Layover | Large displacement (beyond by 2π ambiguity) | Non-linear Estimation | Computational Cost |
|---|---|---|---|---|
| SBAS | × | ○ | ○ | △ |
| Conventional PSI (ConvPSI) | ○ | × | △ | ○ |
| Proposed method (NN-PSI) | ○ | ○ | ○ | × |

* Ogushi, F.; Matsuoka, M.; Defilippi, M.; Pasquali, P. Implementation of Non-Linear Non-Parametric Persistent Scatter Interferometry and Its Robustness for Displacement Monitoring, Sensors, 21, 1004, 2021.

# NN-PSI

- Conventional PSI estimates the residual height by maximizing coherence and models deformation as a constant linear velocity.
- NN-PSI estimates the residual height using the minimum accumulated coherence criterion.

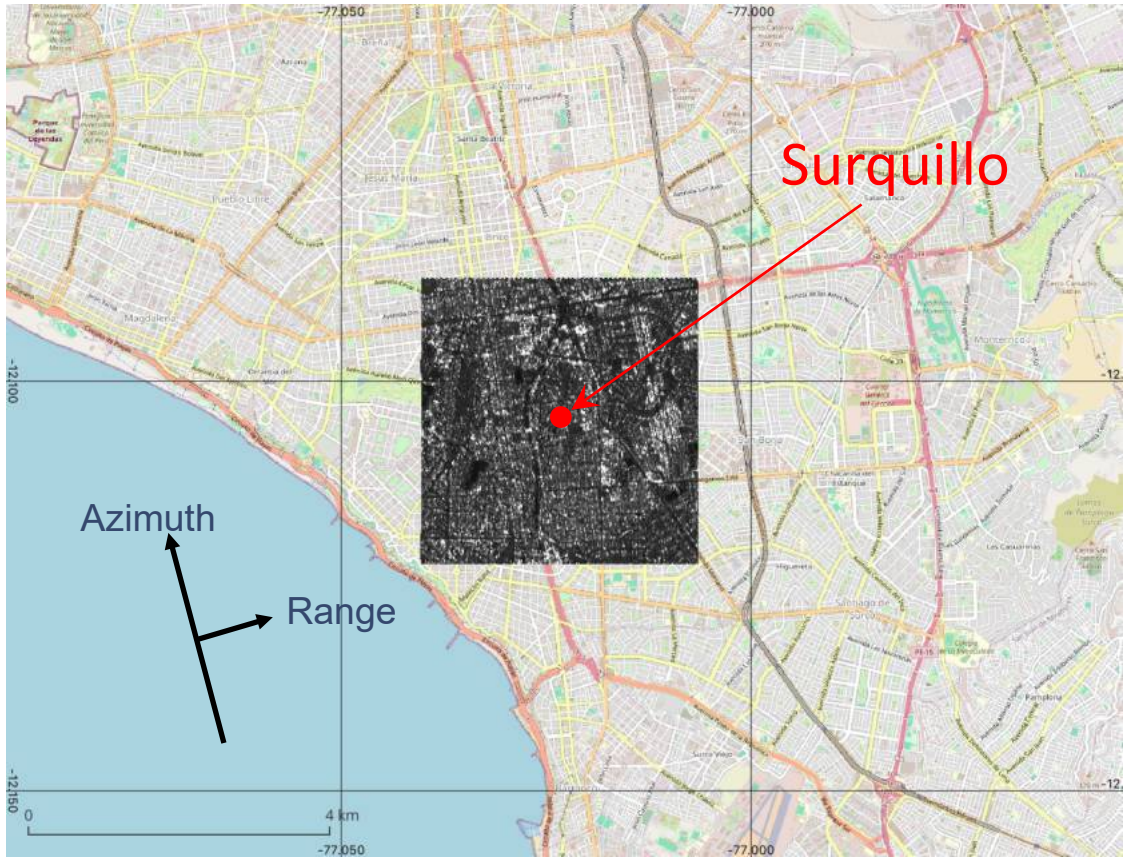
- Displacement at each acquisition is estimated without assuming a constant linear velocity model.
- This enables the detection of localized, large, and non-linear deformation.



# Sentinel-1 SAR Dataset

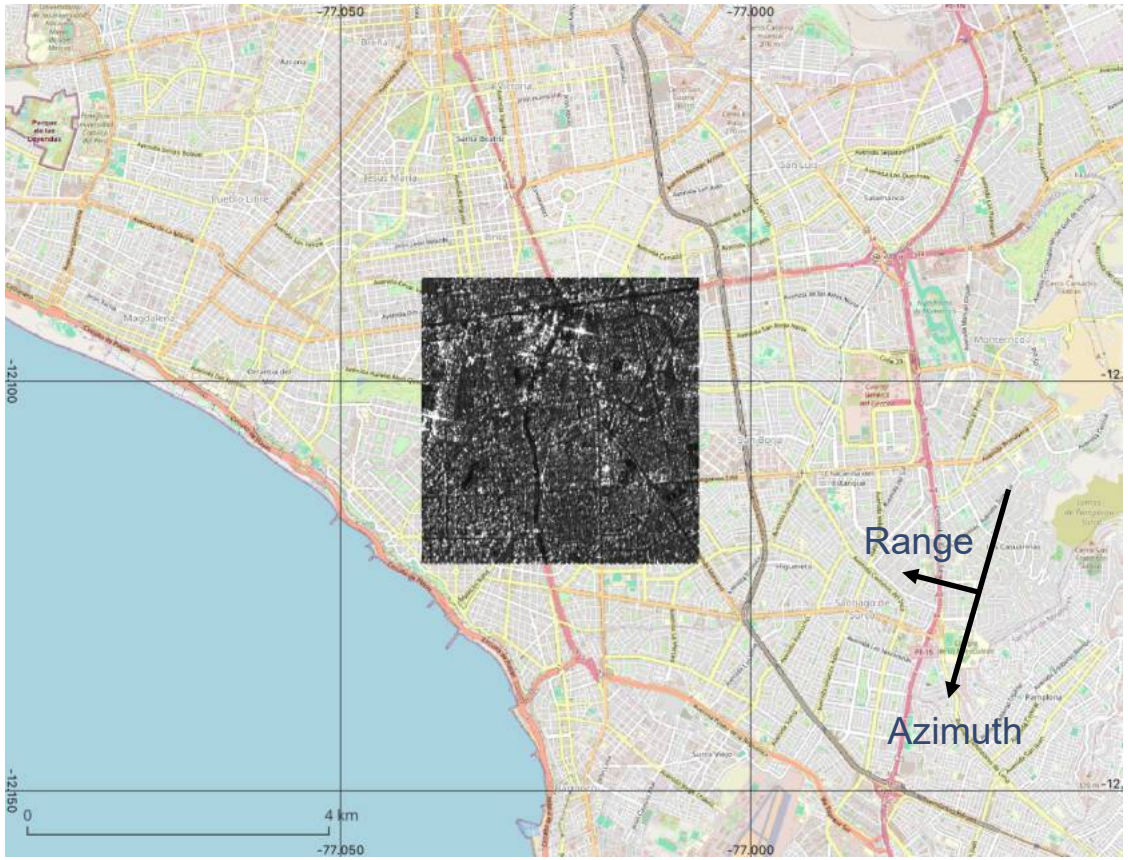
Ascending data:

2017/12/31~2025/8/27 (230 scenes)



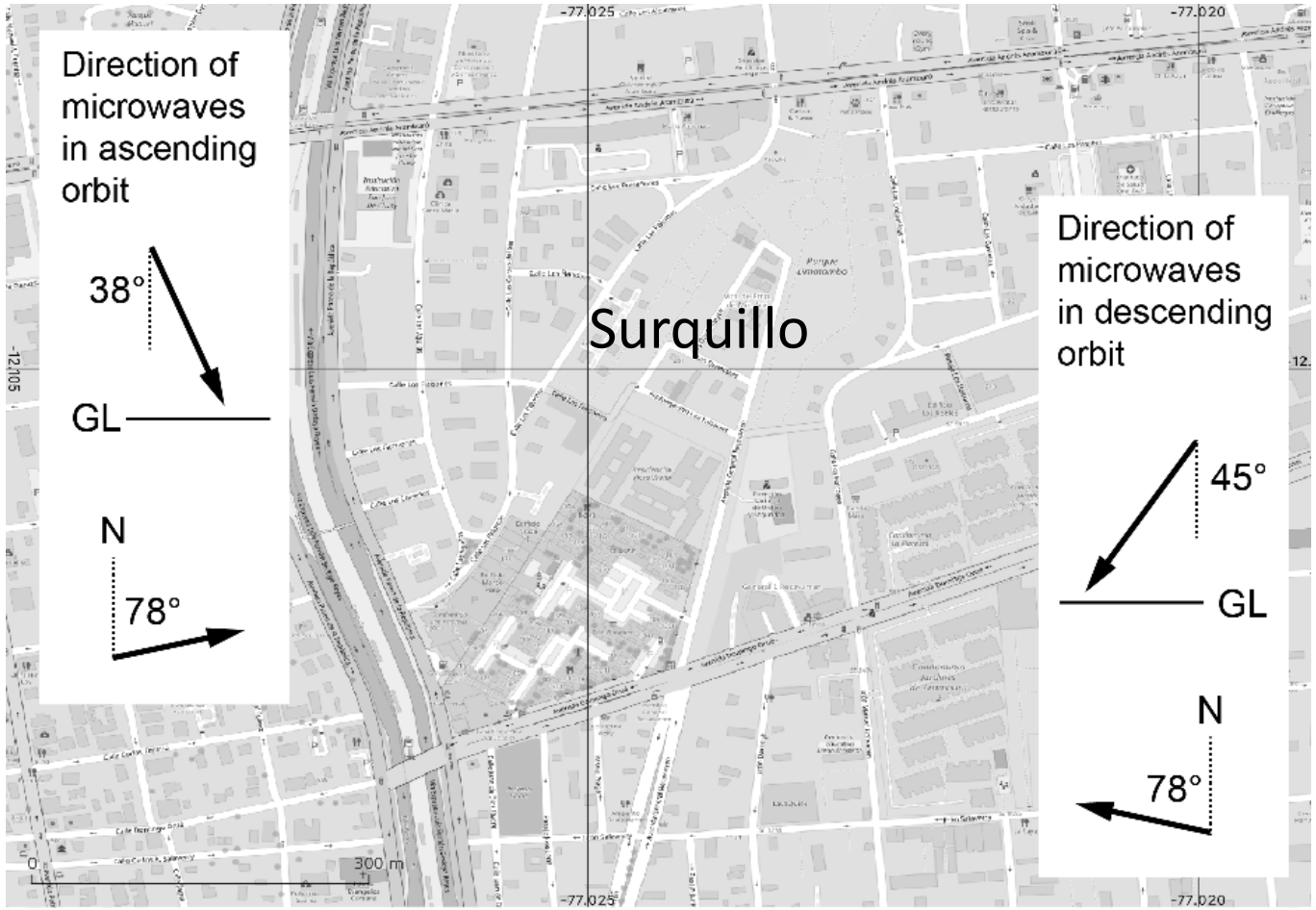

Descending data:

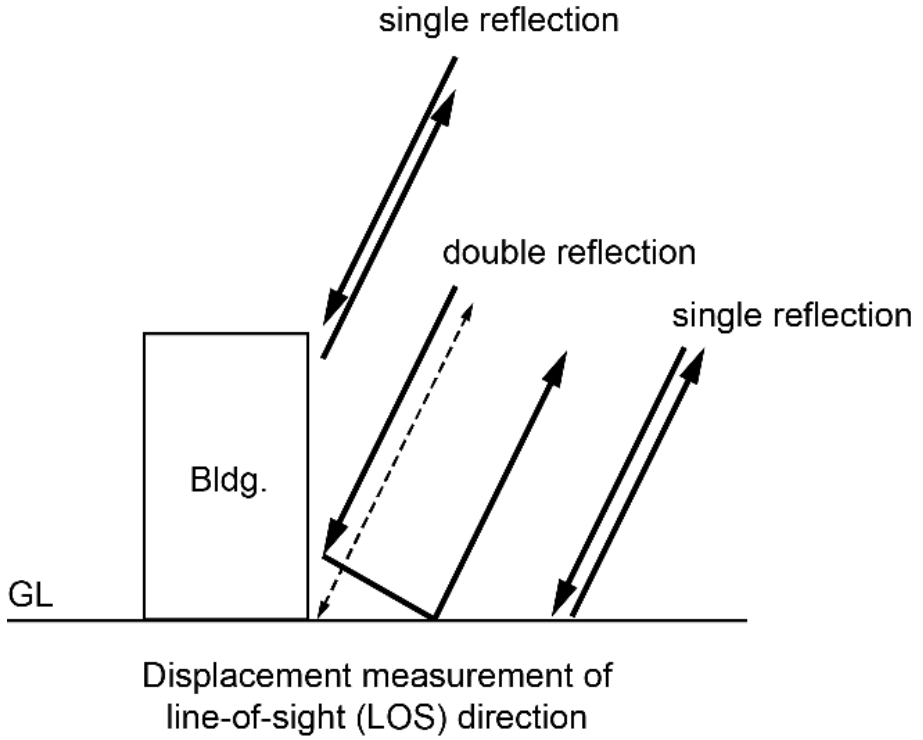
2018/1/11~2025/8/26 (222 scenes)



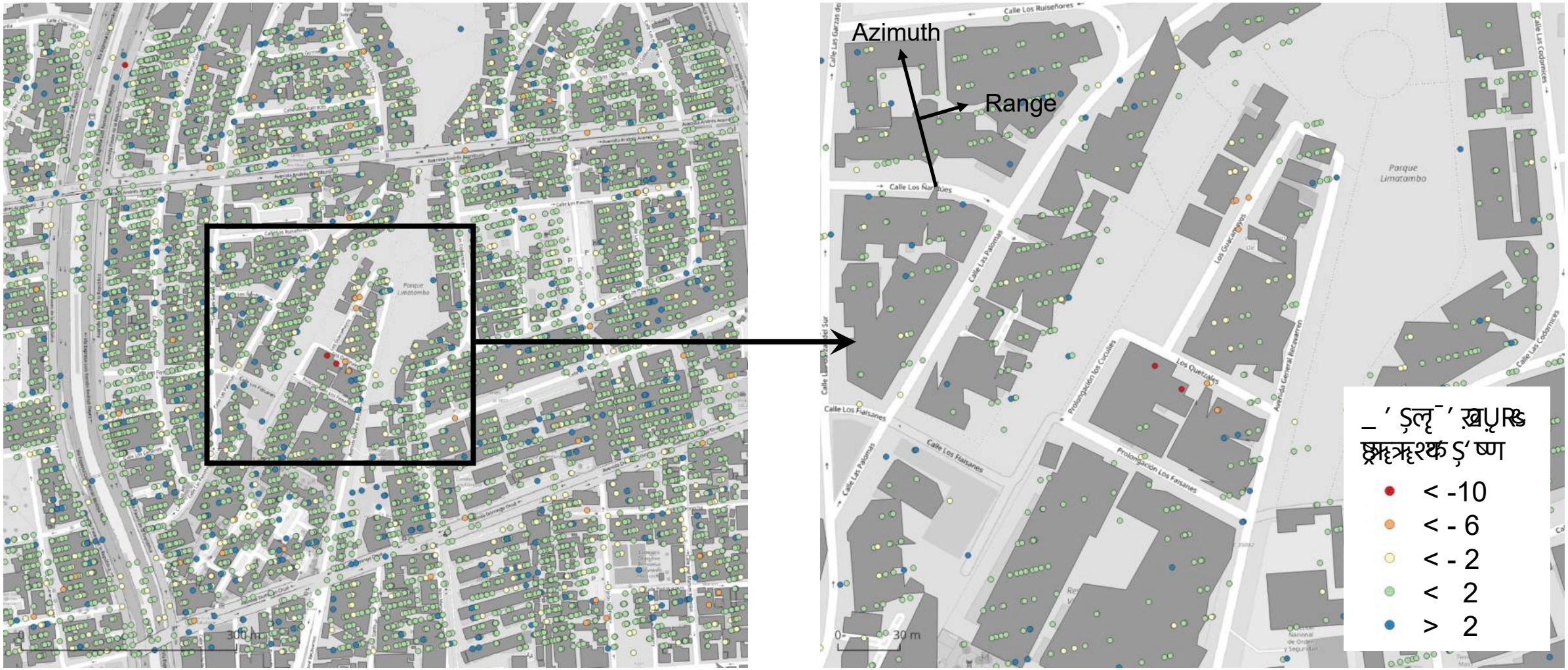
# Observation Condition (relationship between building/ground and microwave direction)

The observation geometry influences the visibility of individual buildings and ground surfaces.
Therefore, NN-PSI results are independently analyzed for the ascending and descending datasets.

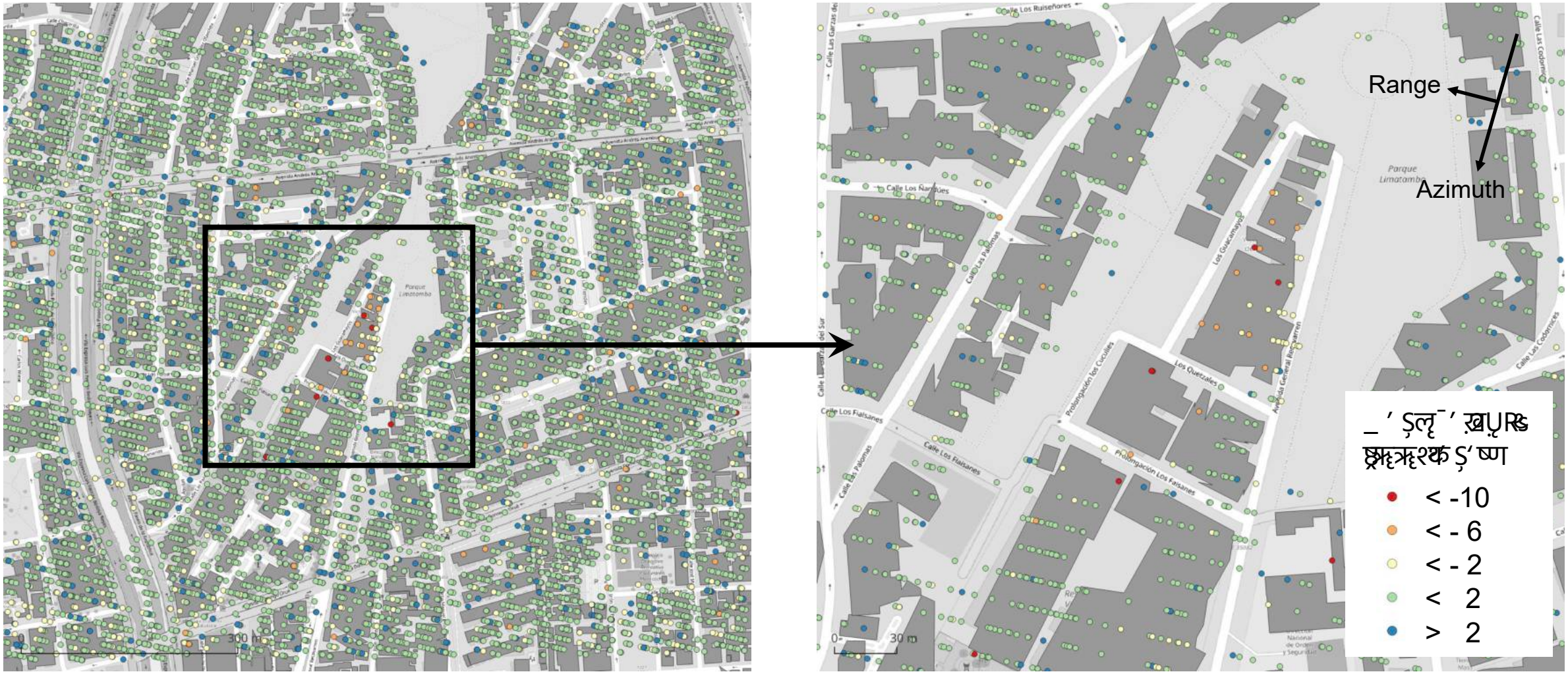


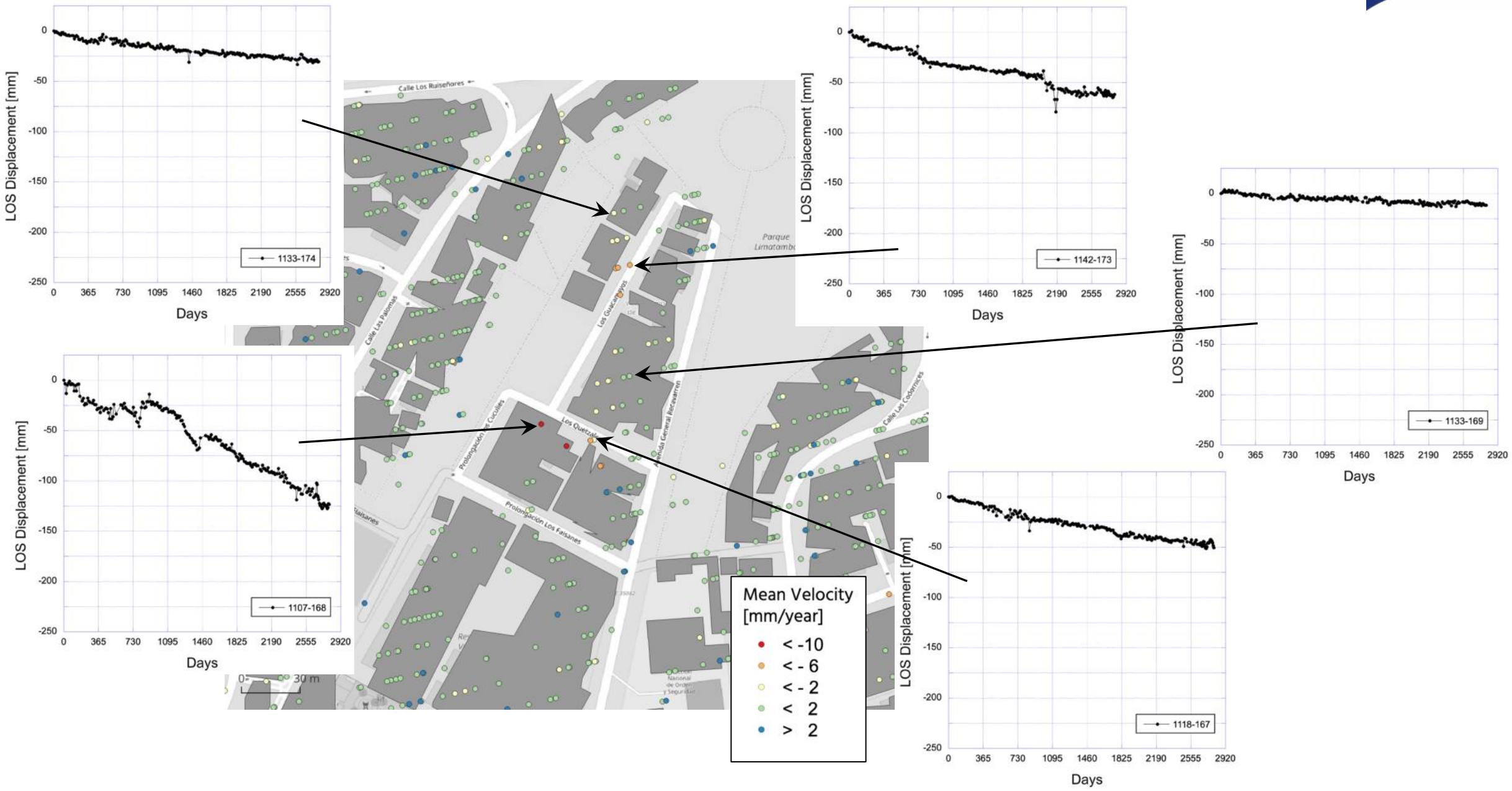
# NN-PSI Results (Ascending Data)



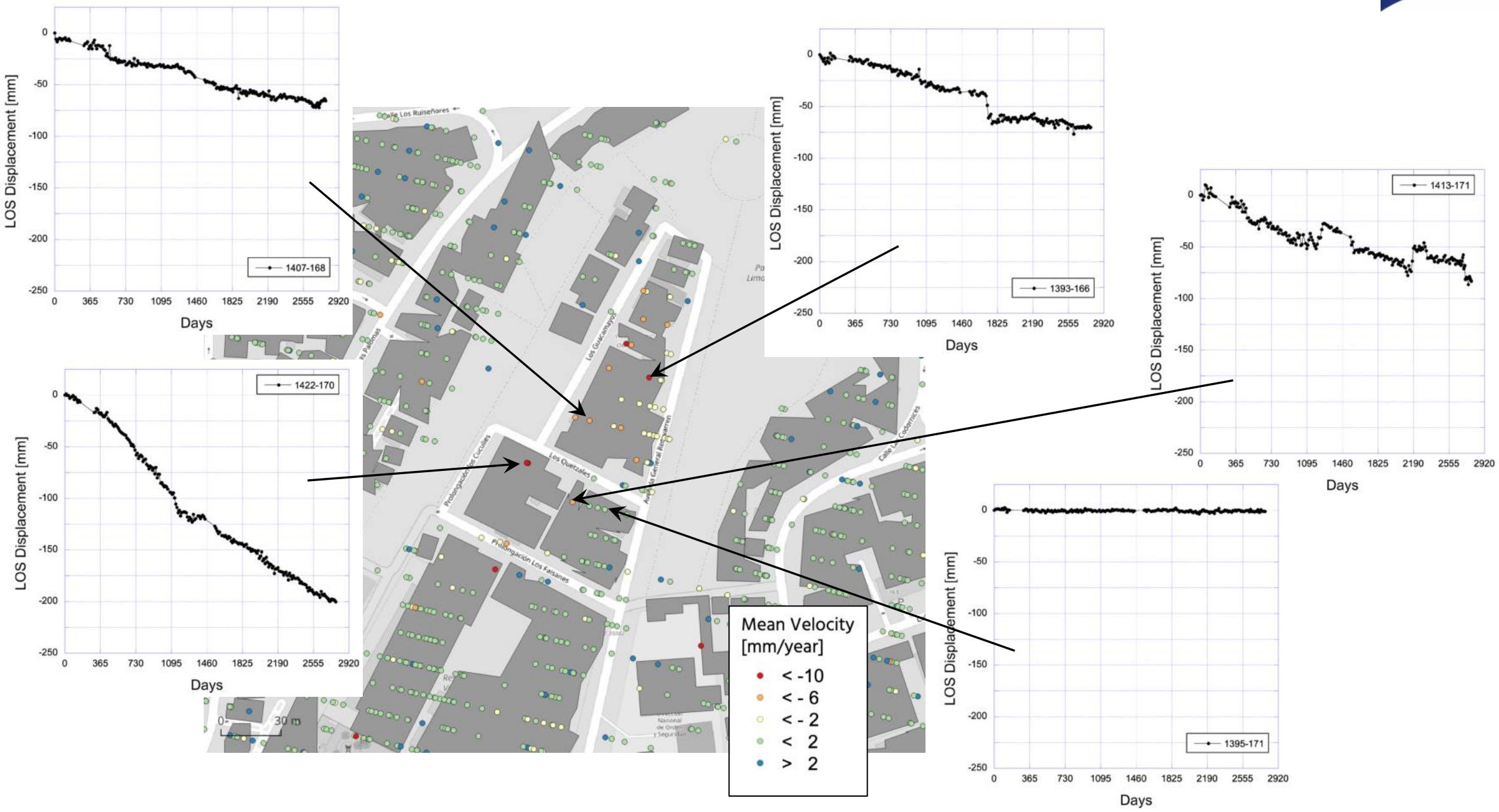
# NN-PSI Results (Descending Data)



# Representative Time Series (Ascending Data)



# Representative Time Series (Descending Data)



# LOS Displacement (Descending Data)

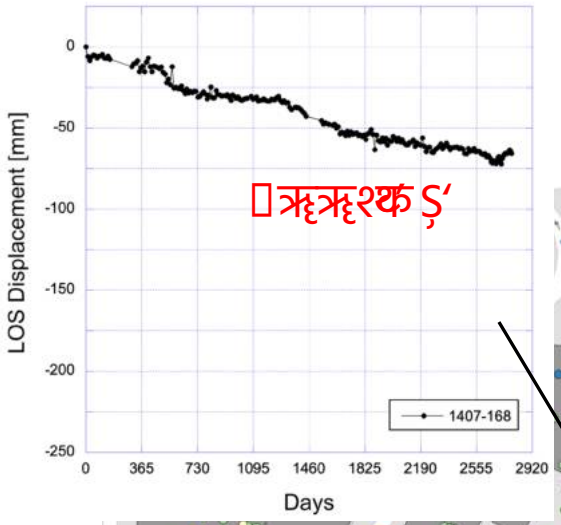






Photo taken on 2026/3

# LOS Displacement (Descending Data)

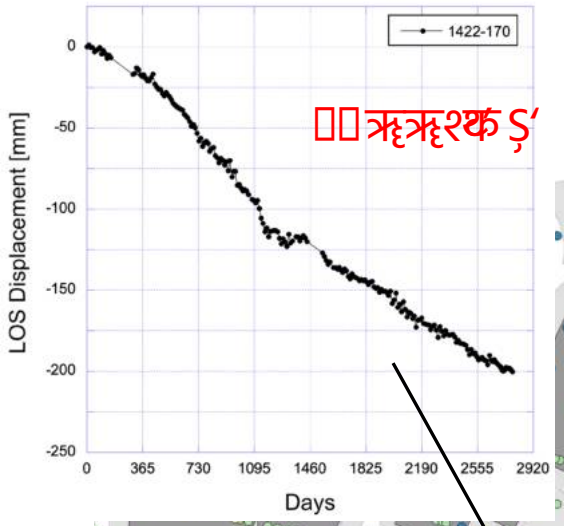


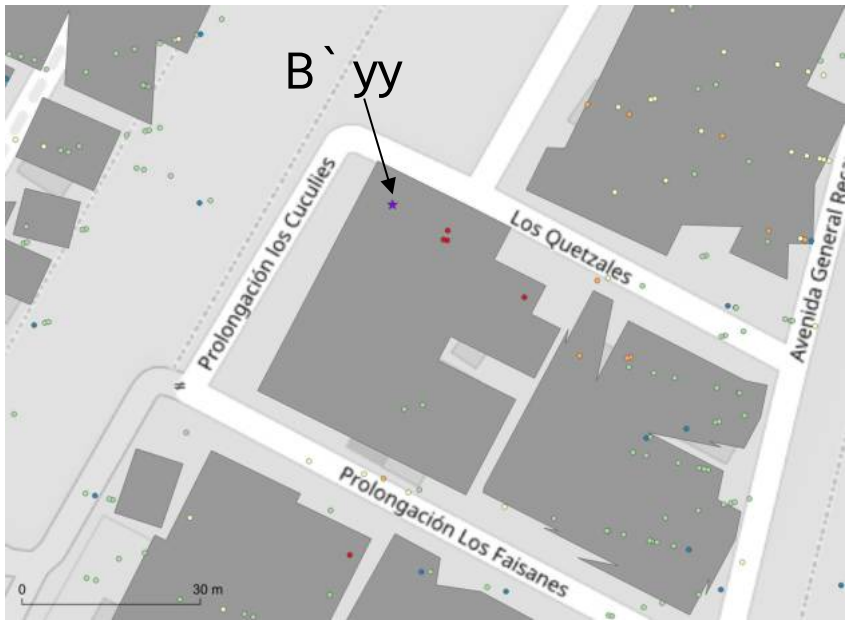


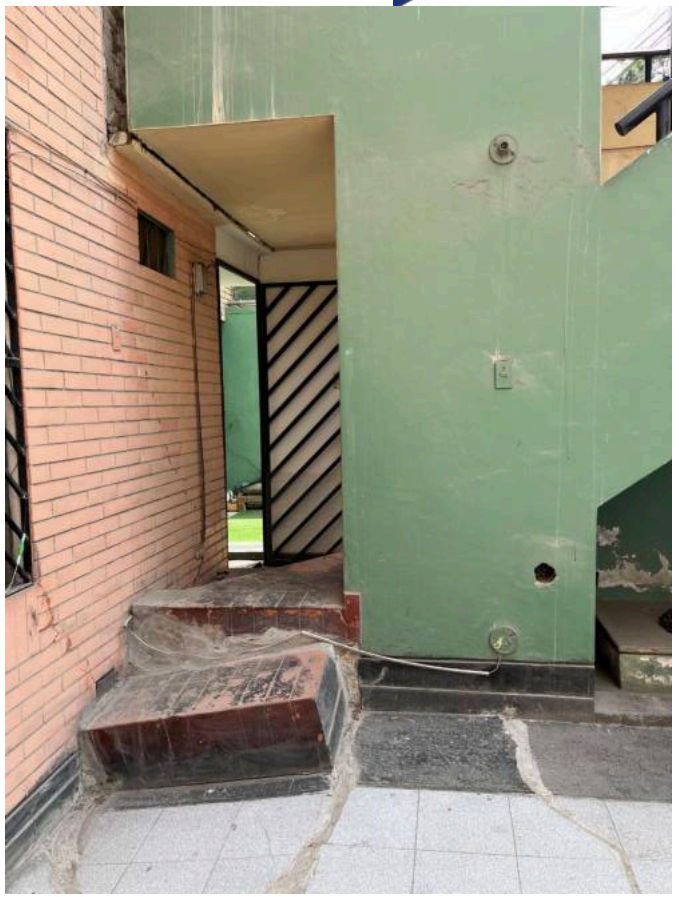


Photo taken on 2026/3

We observed significant damage

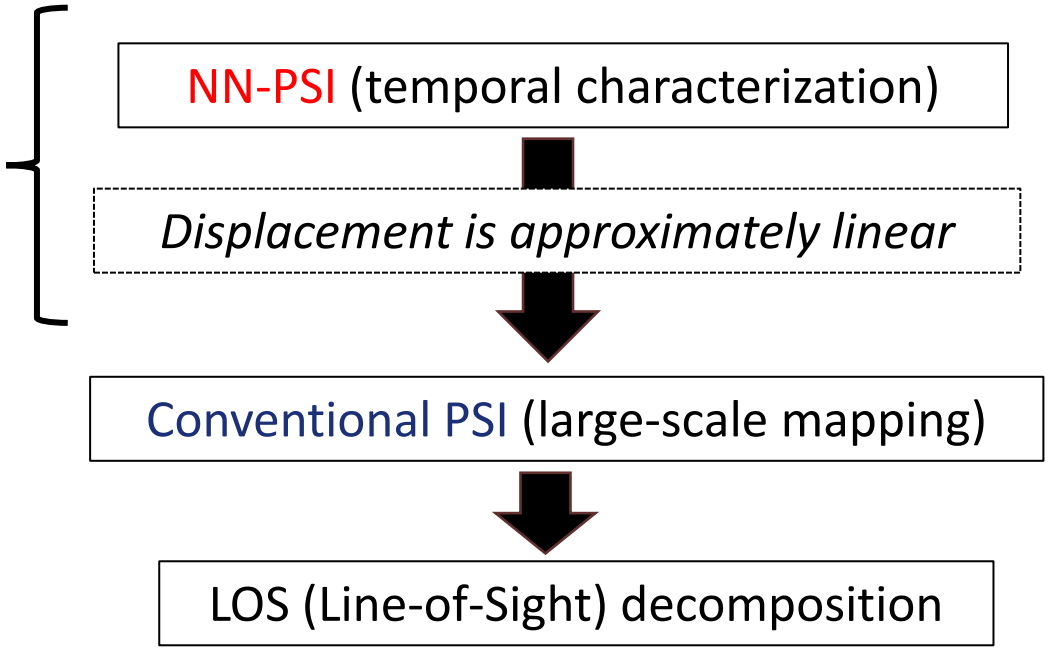
# Buildings where GNSS installation is planned



# Key Findings from NN-PSI

- Ground subsidence is concentrated within the reclaimed area, while the surrounding area remains relatively stable.
- The displacement time series show an approximately linear trend, with no significant phase jumps or abrupt changes.
- Larger subsidence tends to occur where the reclaimed fill is thicker, suggesting that ongoing consolidation is the dominant mechanism.
- The nearly linear displacement behavior justifies the application of conventional PSI for efficient large-scale displacement mapping.

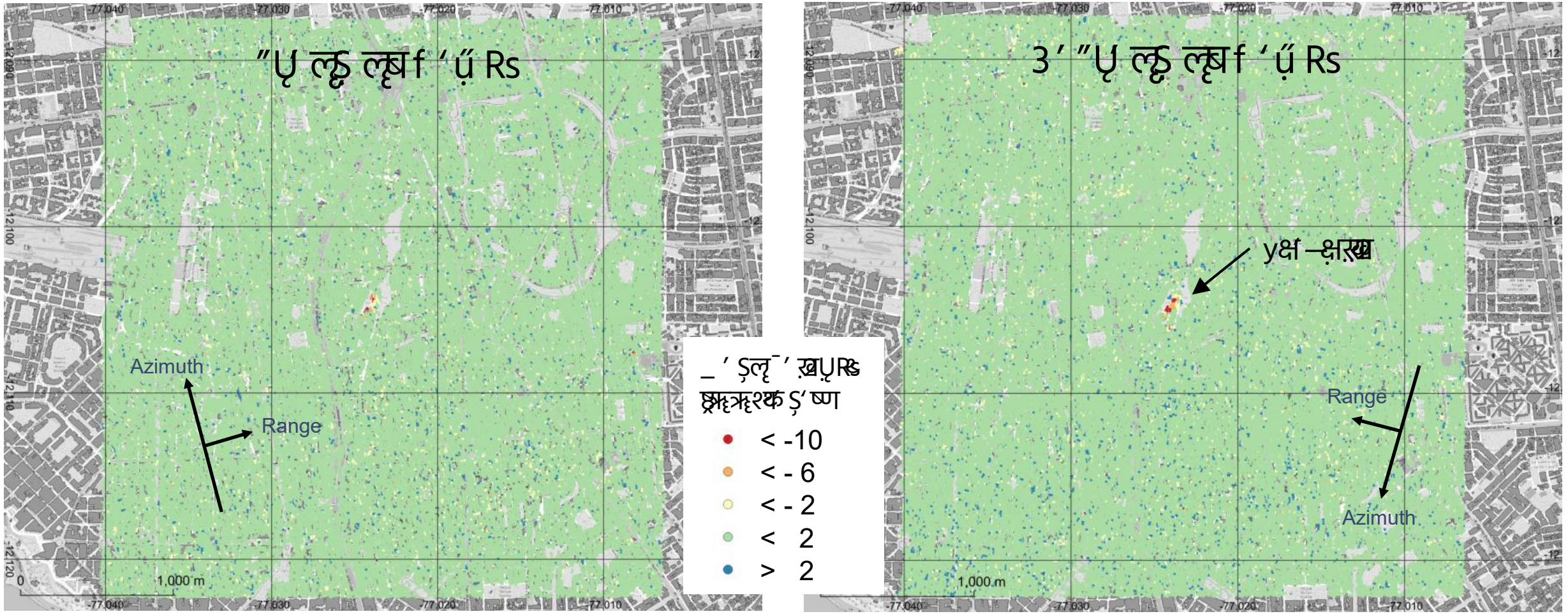



**Time-Series InSAR Analysis Strategy**

# Large-Scale Monitoring by Conventional PSI

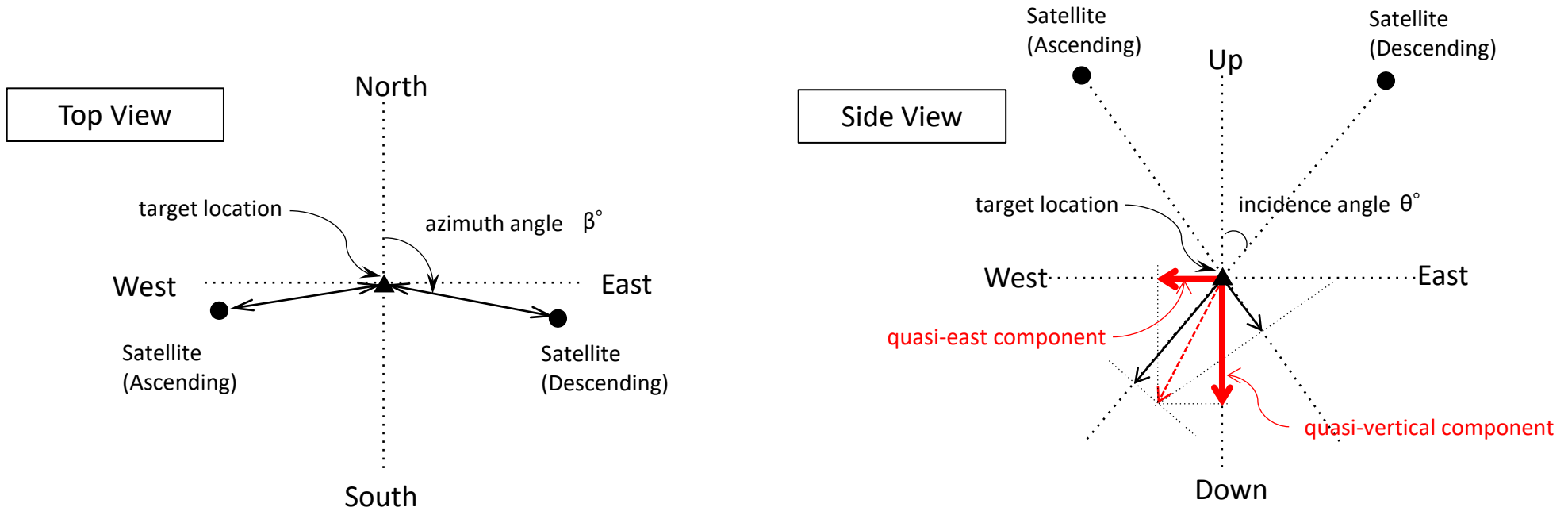
Institute of SCIENCE TOKYO

Conventional PSI enables efficient monitoring over a much wider area.
The results confirm that significant ground subsidence is restricted to the Surquillo district, while no notable deformation is detected elsewhere.



# Decomposition into Quasi-east and Quasi-vertical Components

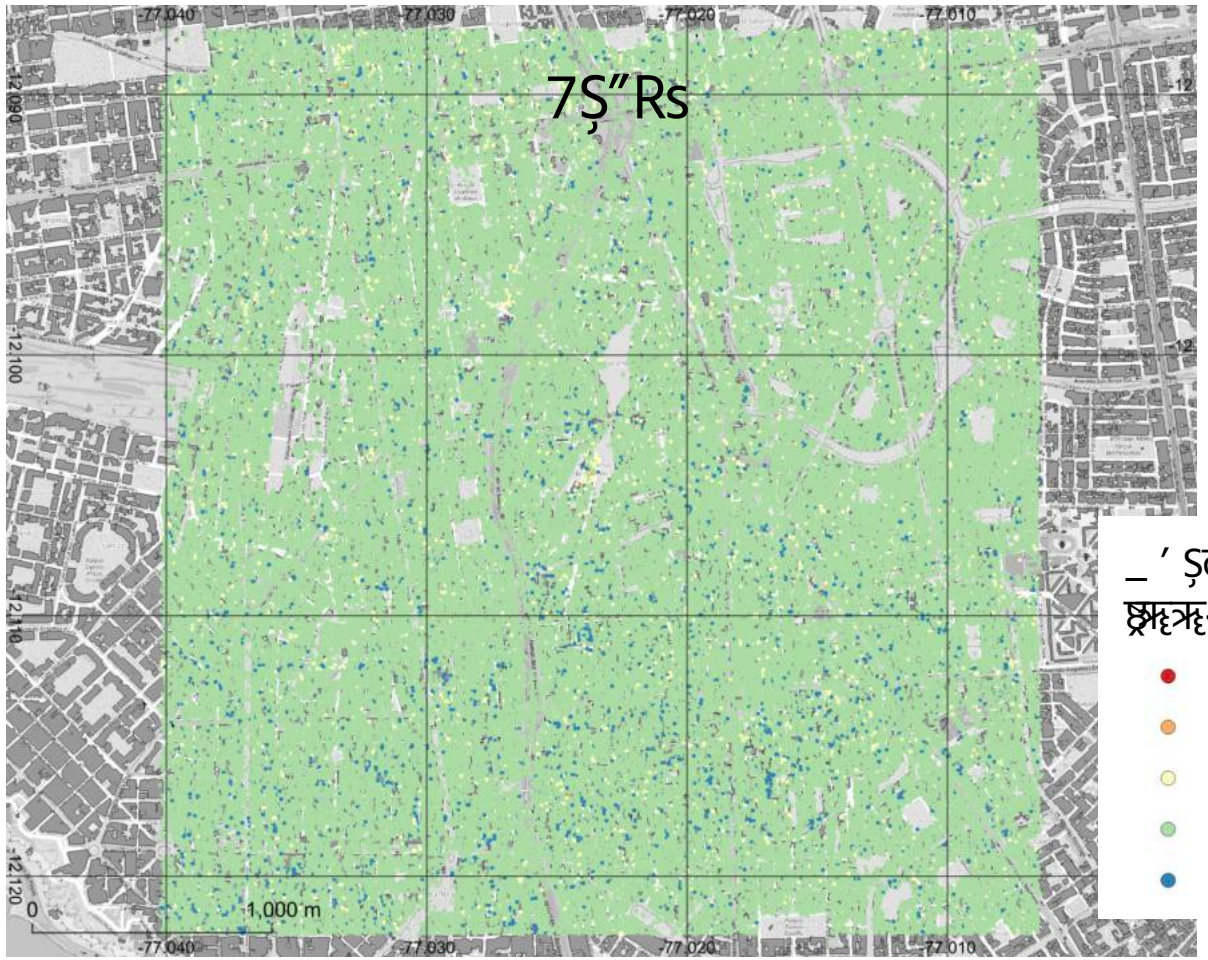
To better understand the deformation pattern, the LOS displacements from the ascending and descending observations are decomposed into quasi-vertical and quasi-east components.

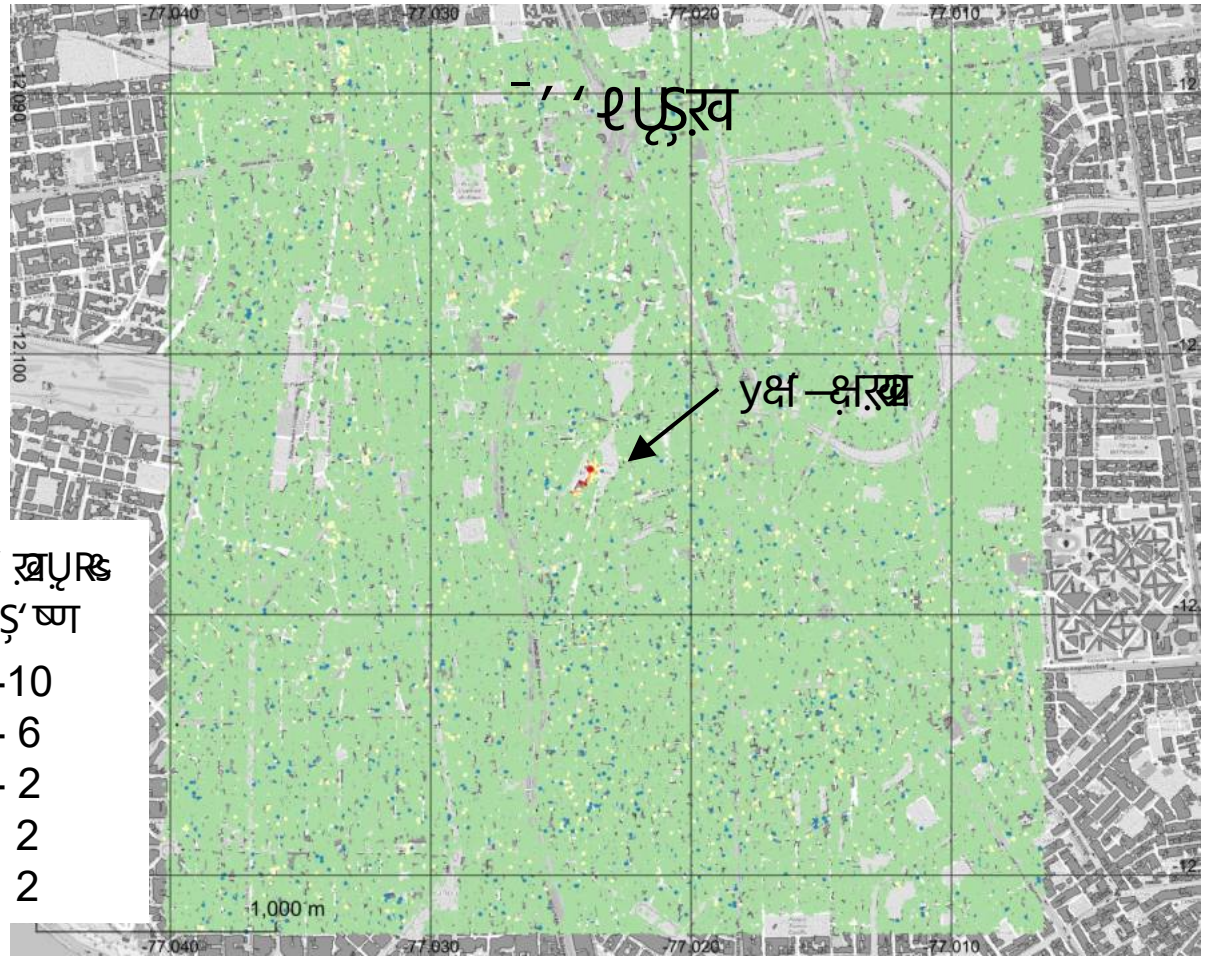



*The displacement (red dotted line) in the plane created by the lines of sight (LOS) from two directions (approximately east and west) is obtained from the two LOS displacements and further separated into a quasi-vertical component and a quasi-east component (red solid line). The expression "quasi-" is used because the above planes do not show a perfect east orientation and are not vertical due to the different irradiation and incidence angles of the two observations and the different points in the image.*

# Quasi-East and Quasi-Vertical Displacements

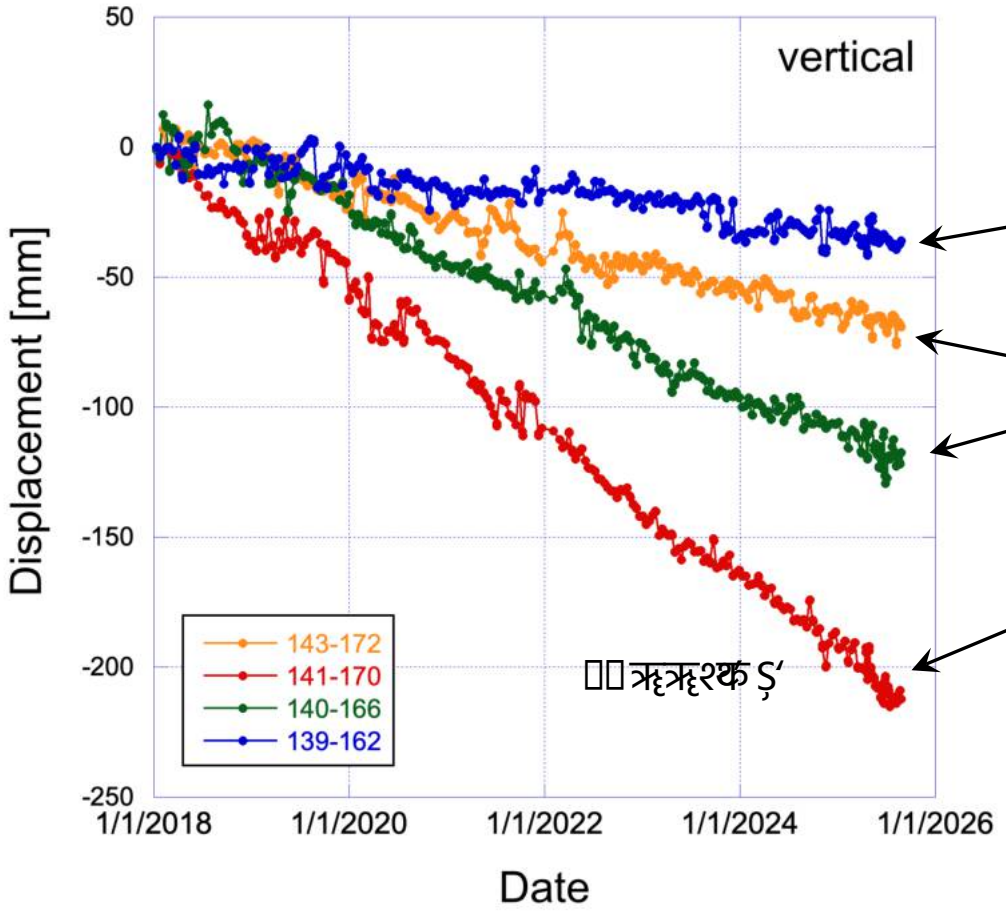
The decomposition results indicate that most of the observed LOS displacement originates from vertical ground subsidence.
In contrast, the quasi-east component is generally small throughout the study area.

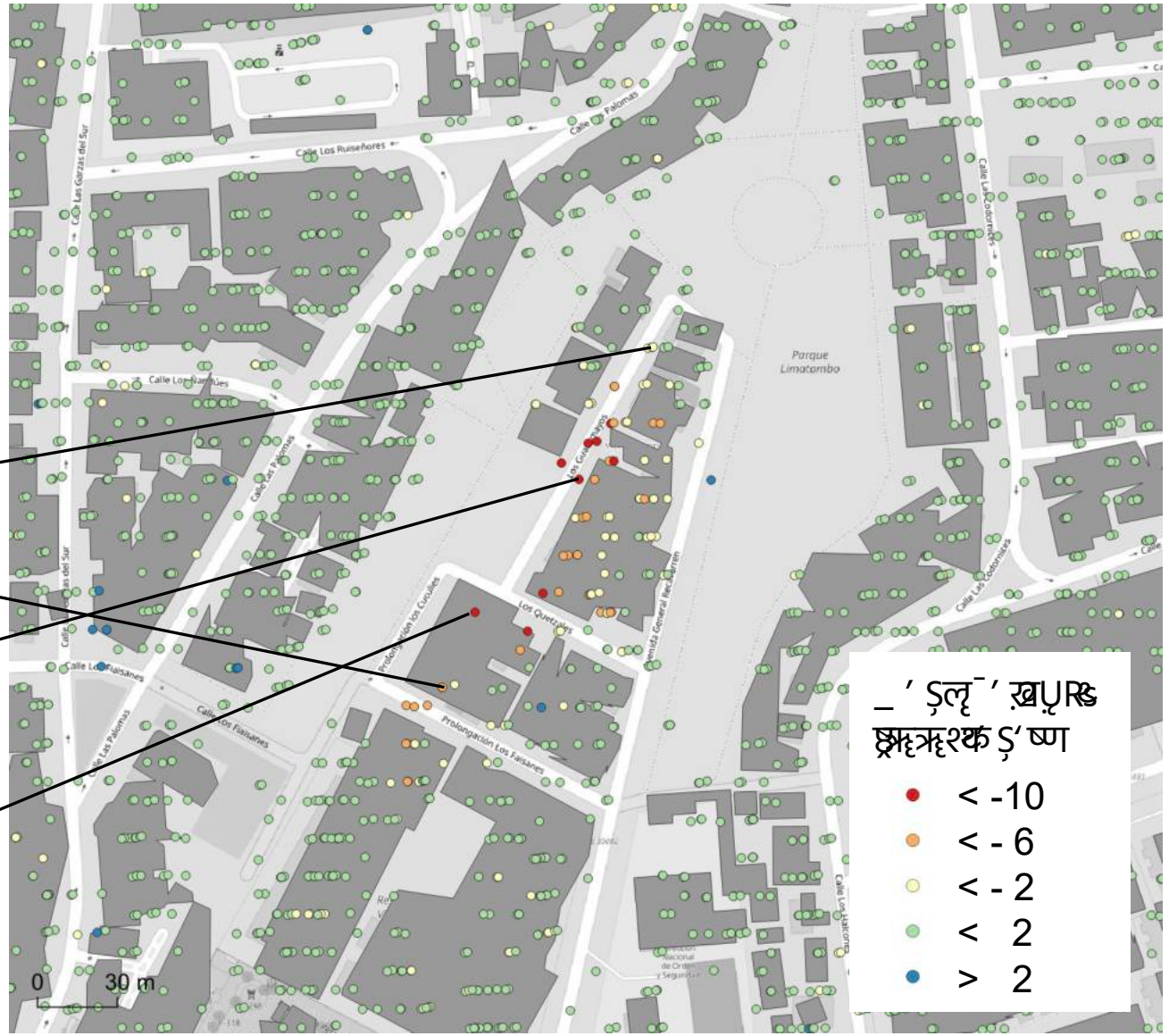


# Quasi-Vertical Displacement

- The maximum quasi-vertical subsidence reaches approximately 28 mm/year.
- This suggests that long-term consolidation of the reclaimed ground is still ongoing.



# Conclusions

- NN-PSI successfully characterized the temporal behavior of ground subsidence in the Limatambo area.
- The displacement was found to be approximately linear, allowing efficient large-scale monitoring using conventional PSI.
- The deformation is dominated by vertical ground subsidence, reaching approximately 28 mm/year, and is likely associated with the long-term consolidation of reclaimed ground.

*Future work: Validation using field observations (GNSS, leveling, and corner reflector observations) and continued long-term monitoring.*

# Corner Reflector (CR)


A corner reflector has been installed at CISMID as a test site.
Similar reflectors are planned to be installed in the subsiding area for future validation of the InSAR results.

It is a tetrahedral reflector with a side length of **80 cm.**

Coordinates:
-12.013455°
-77.050782°