NATIONAL CENTRAL UNIVERSITY

GRADUATE INSTITUTE OF APPLIED GEOLOGY

Progress Report

MONITORING LAND SUBSIDENCE IN CHOUSHUI RIVER FLUVIAL PLAIN BY UTILIZING THE SBAS-PS-INSAR TECHNIQUE

2022/04/01

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Student: Truong, Nguyen

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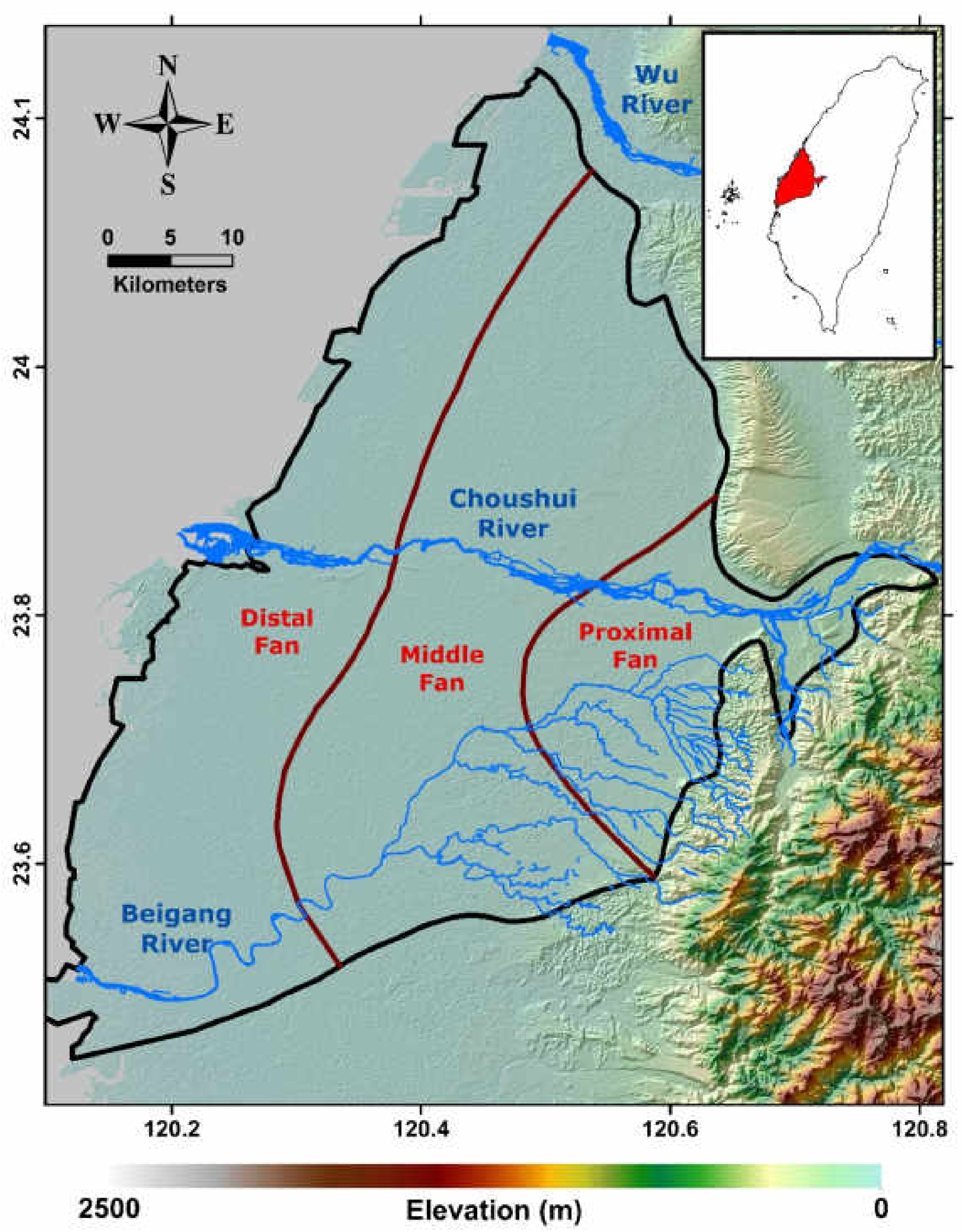
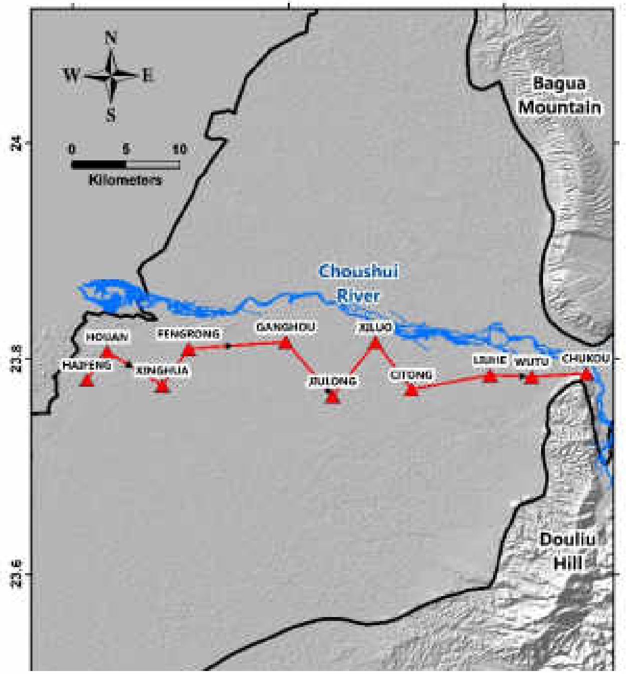


Study Area

- Western coastal region of central Taiwan
- Large agricultural areas
- Elevation is gentle, 0 m in the coastal areas to 100 – 150 m in areas near the hill
- Hydrogeological structures: Proximal-fan, mid-fan, and distal-fan areas.

Study Area

- Proximal fan + Middle fan: gravel & coarse sand
- Distal fan: fine-grain materials - fine sand, clay, and silt



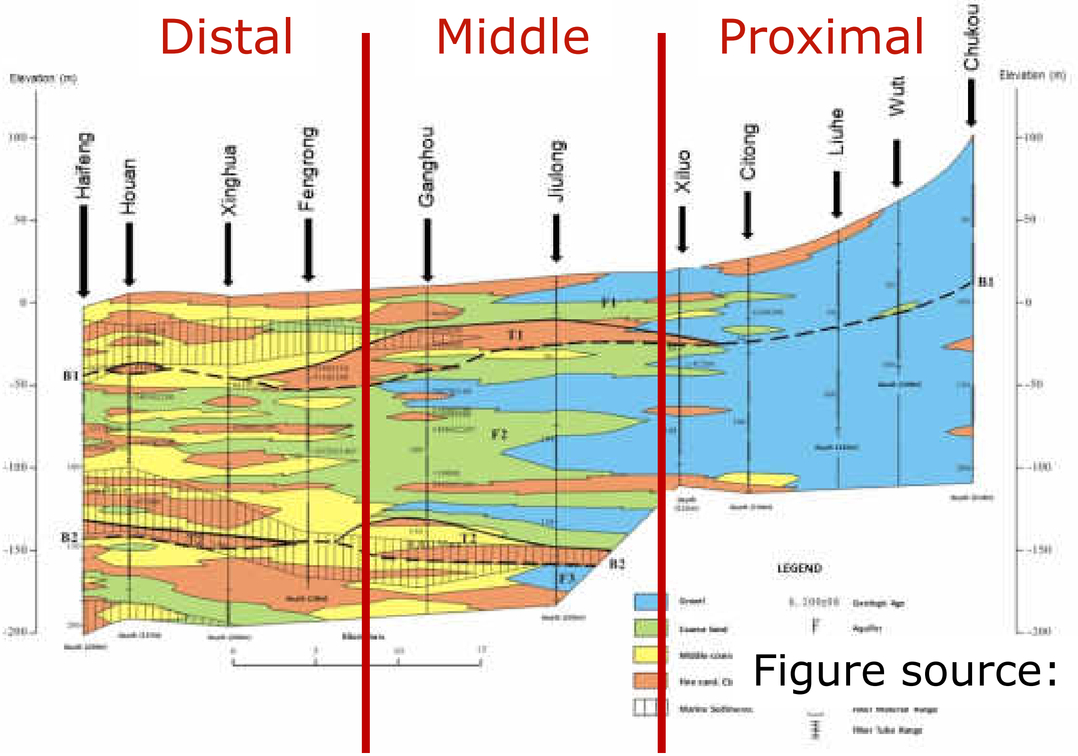
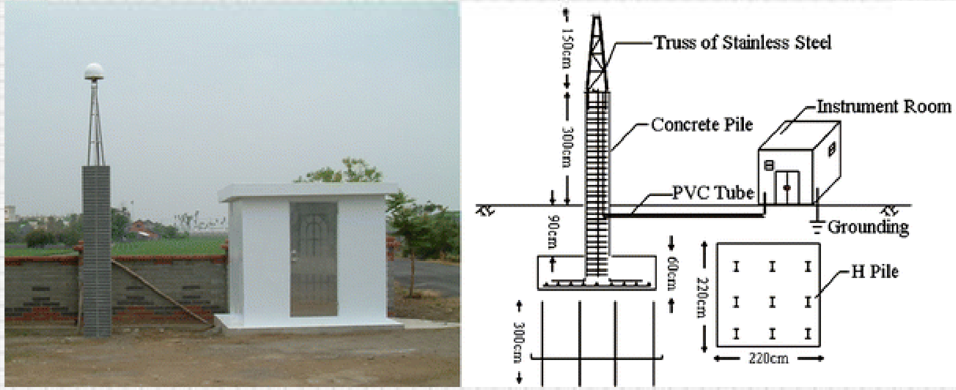
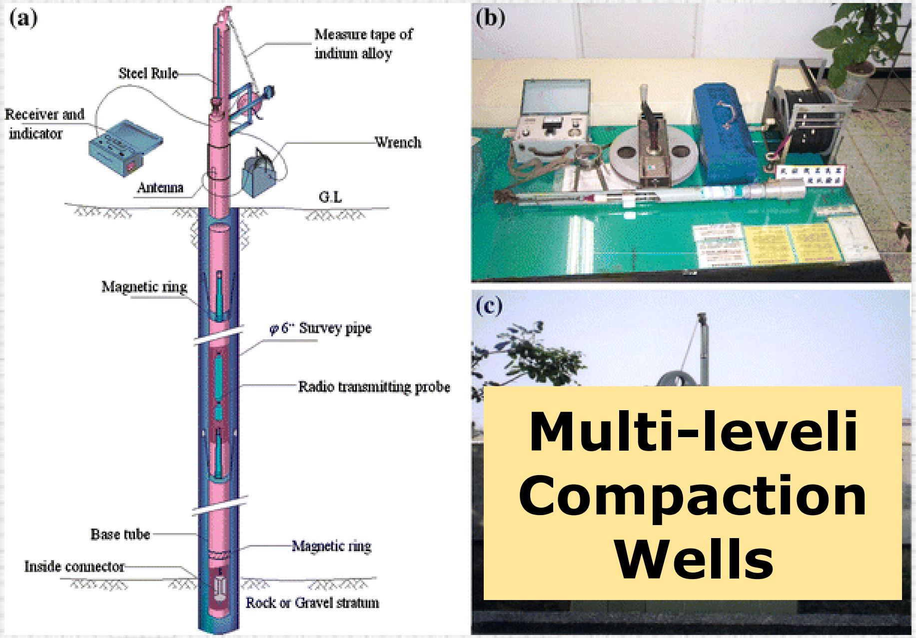


Figure source: Central Geological Survey, Taiwan

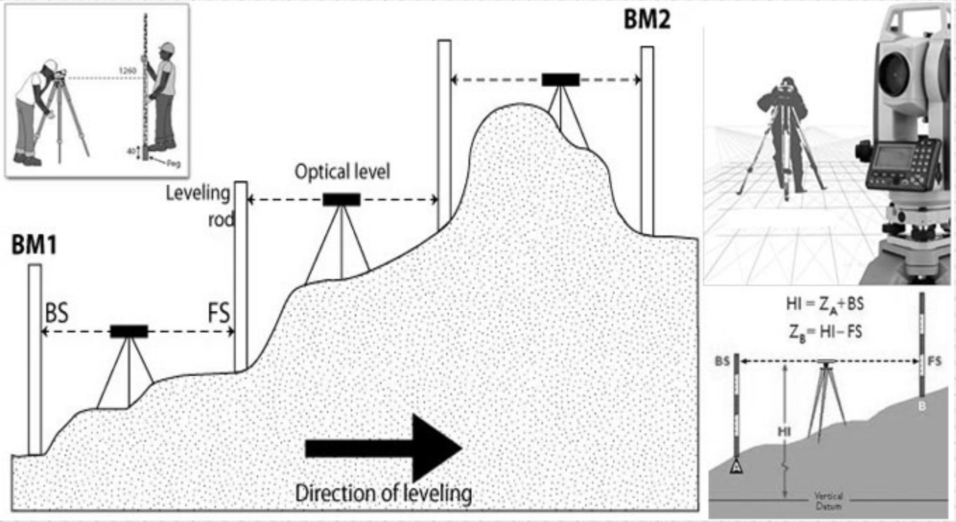
Monitoring Networks



Global Positioning System

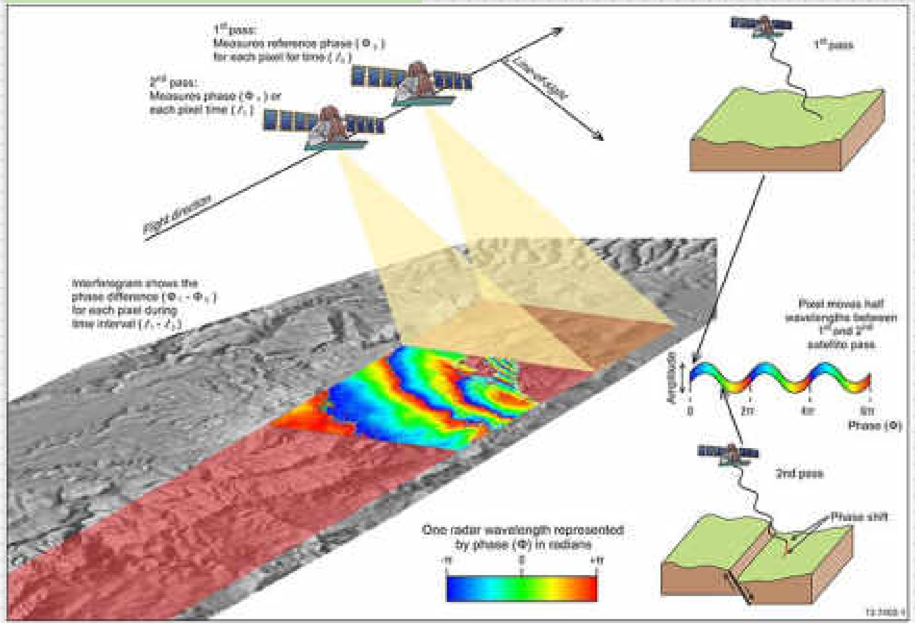


Multi-leveli Compaction Wells



Leveling Survey

InSAR

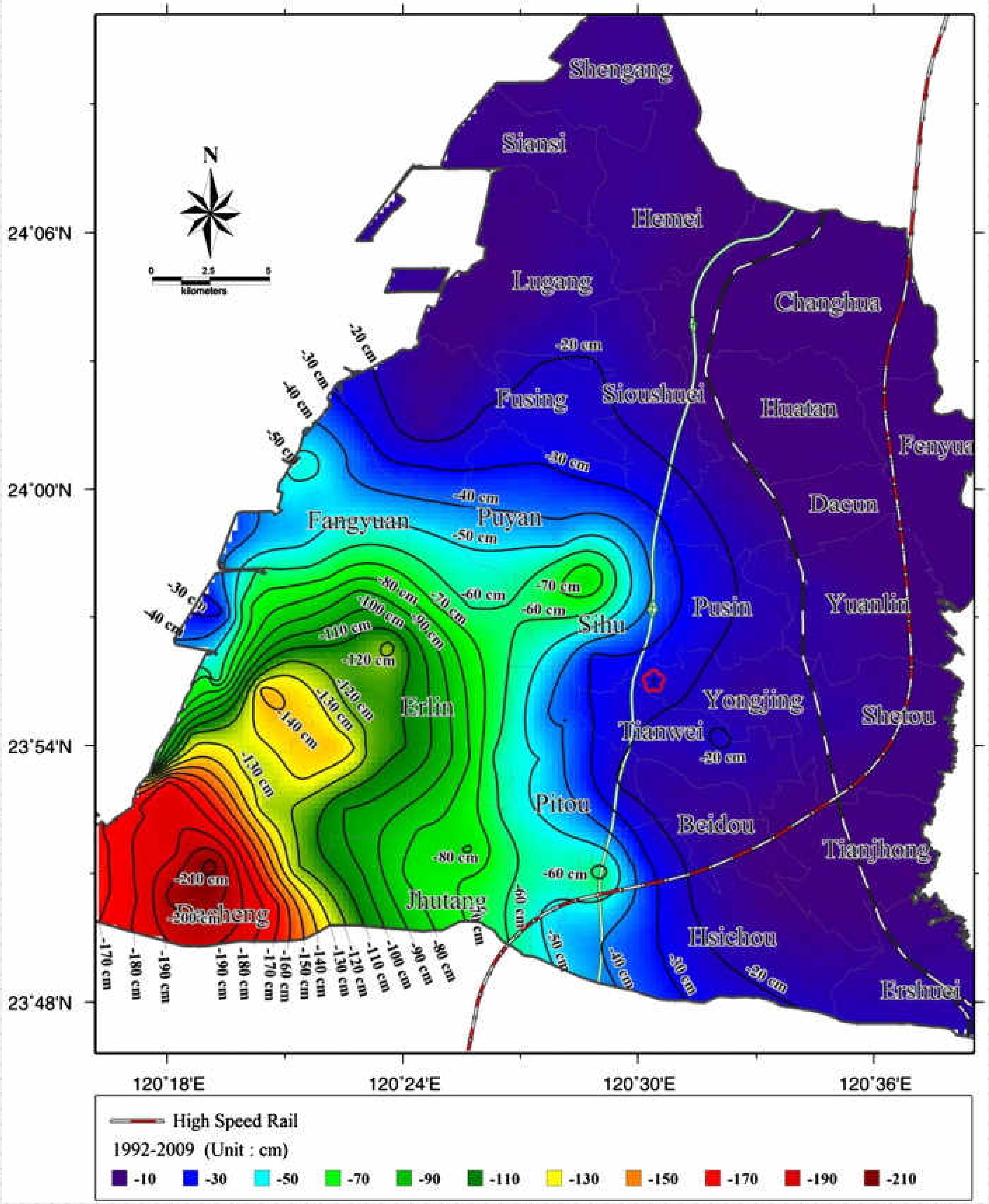


Monitoring Networks

Table: Summarized properties of the monitoring system		
	Leveling	GPS
Spatial Resolution	1.5 km	10 – 15 km
Monitoring Frequency	1 year	1 day
Measurement (vertical) accuracy	0.5 – 1 cm	0.5 – 1 cm

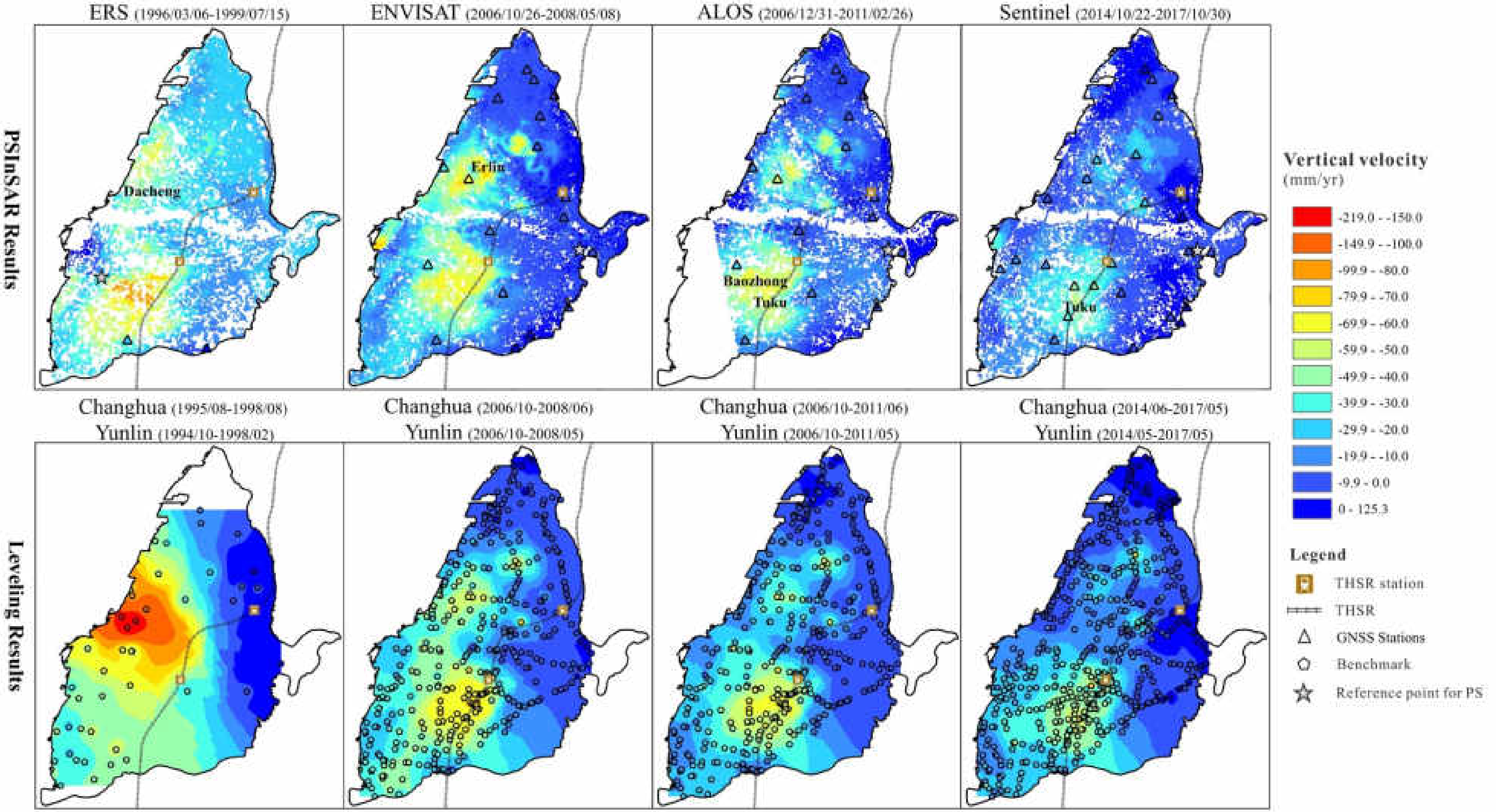
Subsidence progress monitored by previous studies

Subsidence in Changhua county from 1992 to 2010 measured by continuous GPS records



Hung, W. C., Hwang, C. W., Liou, J. C., Lin, Y. S., & Yang, H. L. (2012). Modeling aquifer-system compaction and predicting land subsidence in central Taiwan. *Engineering Geology, 147*, 78-90.

Subsidence progress monitored by previous studies



Subsidence in Changhua and Yunlin (1997 – 2017) obtained from measurements of leveling survey and InSAR

Lu, C.-Y., Hu, J.-C., Chan, Y.-C., Su, Y.-F., & Chang, C.-H. (2020). The Relationship between Surface Displacement and Groundwater Level Change and Its Hydrogeological Implications in an Alluvial Fan: Case Study of the Choshui River, Taiwan. *Remote Sensing, 12*(20), 3315.

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INTRODUCTION

BASIC CONCEPTS

WORKFLOW

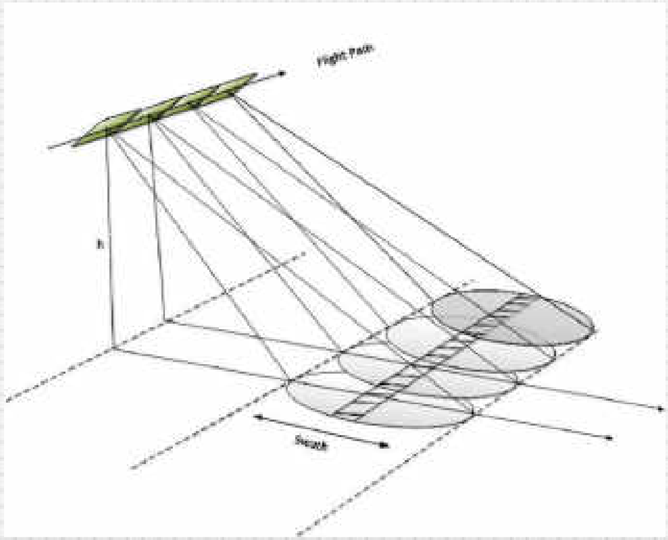
PREMILINARY RESULTS

FUTURE WORK

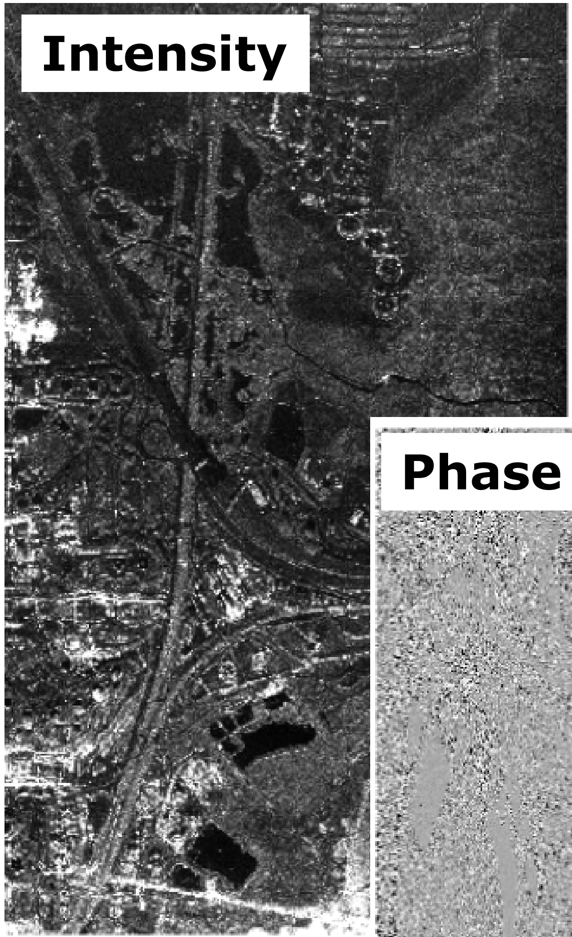
SAR images

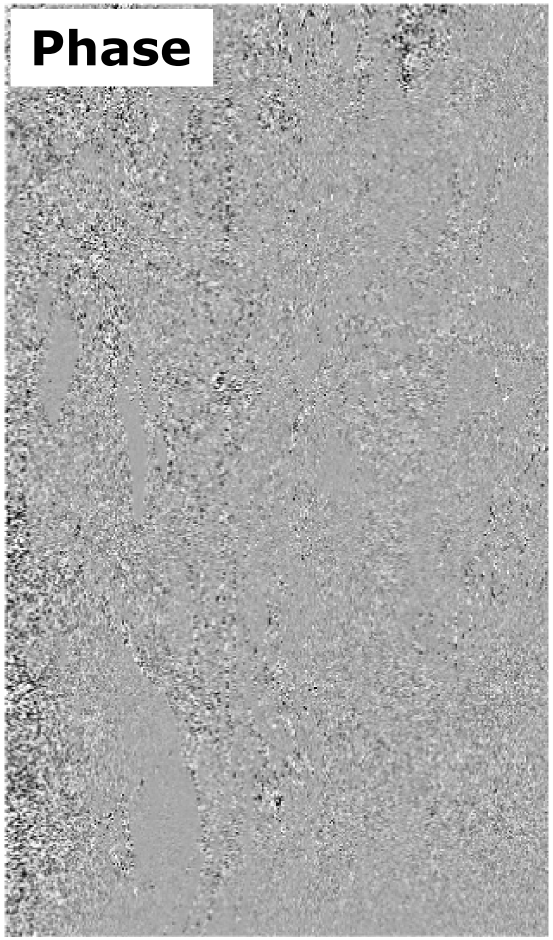
Generate an image using radio waves (3, 5.6, 23 cm or longer)

Small antenna move along azimuthal direction to synthetize the effect of long antenna → Synthetic aperture radar



Ley, A., D'Hondt, O., & Hellwich, O. (2018). Regularization and completion of TomoSAR point clouds in a projected height map domain. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 11*(6), 2104-2114.





SAR images

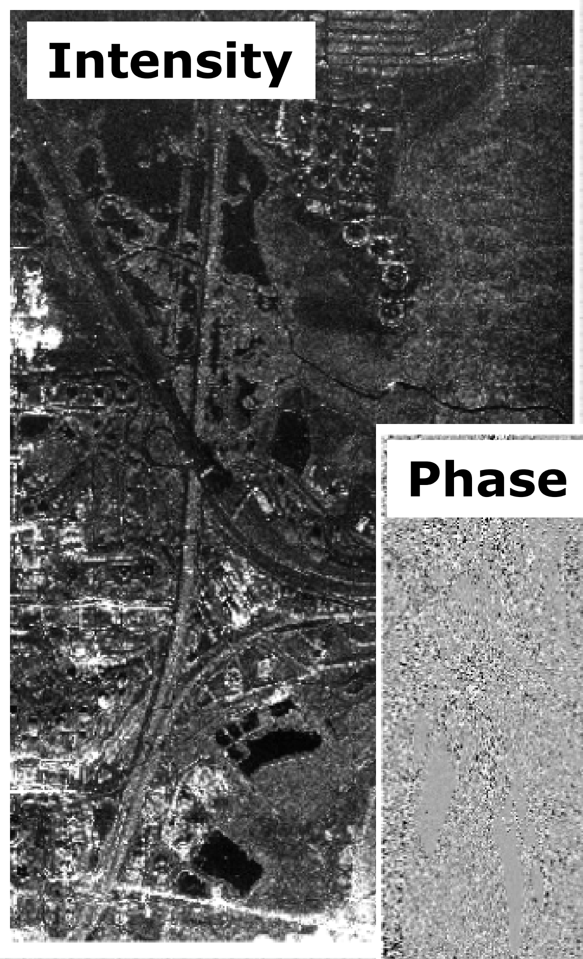
A SAR image contains two components:
Intensity and **Phase**

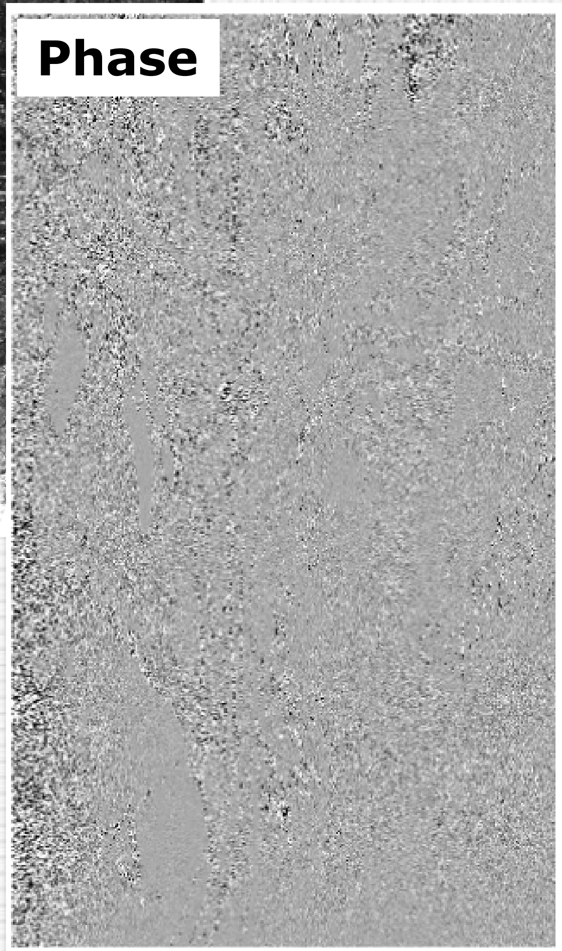
Delivered as Single Look Complex (SLC) data → Intensity and Phase components as complex numbers for each pixel

SLC data is in the (slant) plane projection, not correspond to geo-coordinates

$$C(r,a) = A(r,a)e^{i\varphi(r,a)}$$

C(r,a) : complex value





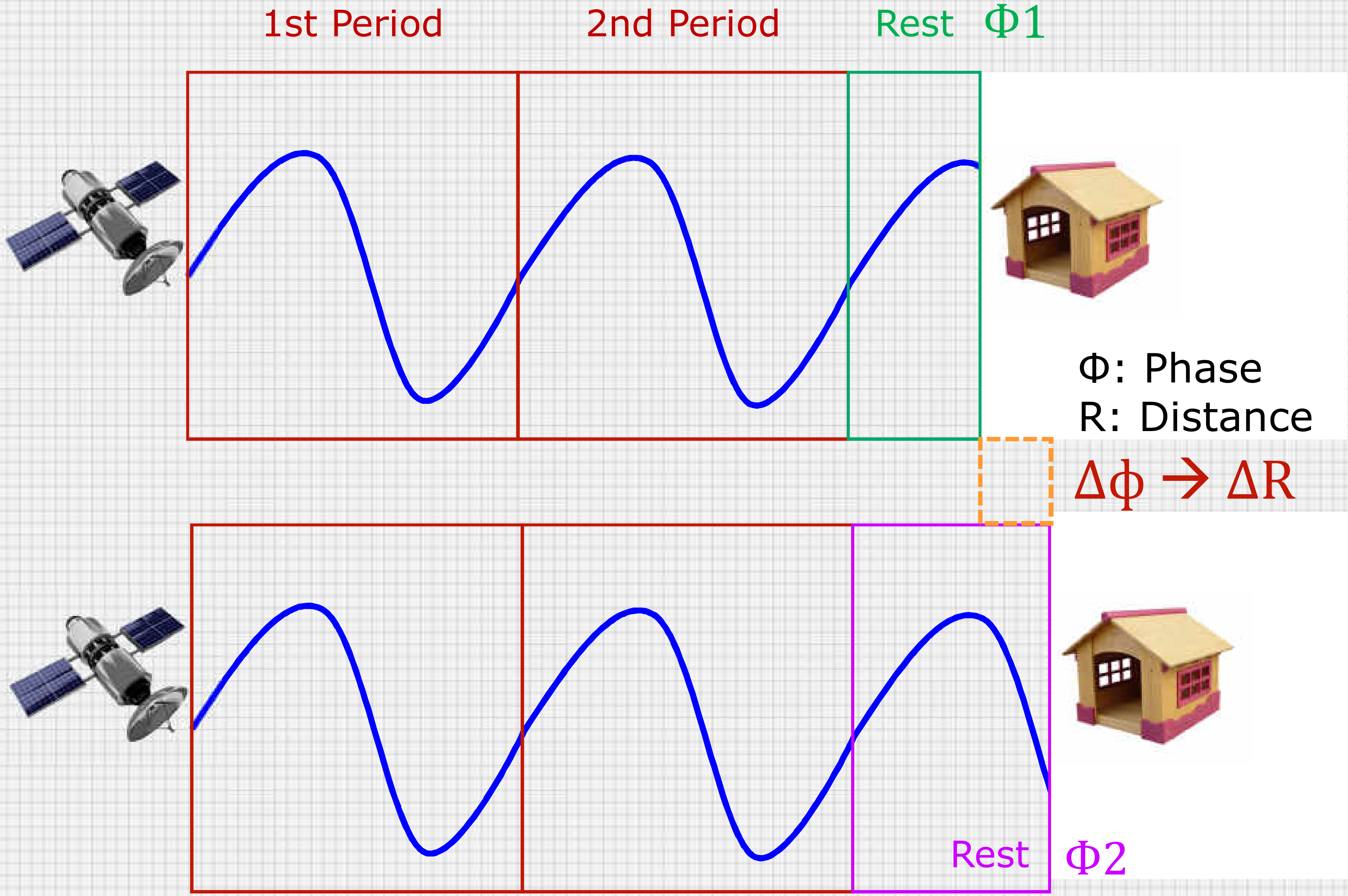
SAR images

The general terms of the single look complex (SLC) image can be written:

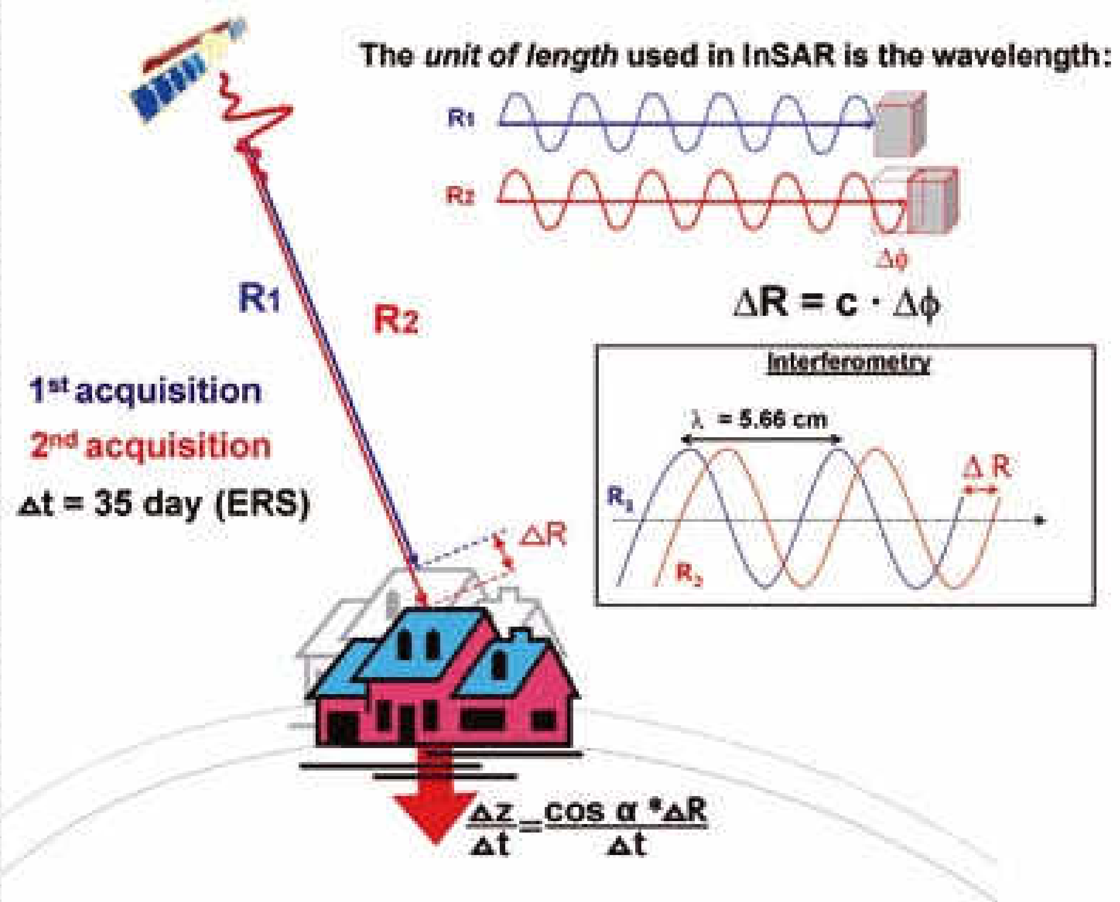
$$C(r,a) = A(r,a)e^{i\varphi(r,a)}$$

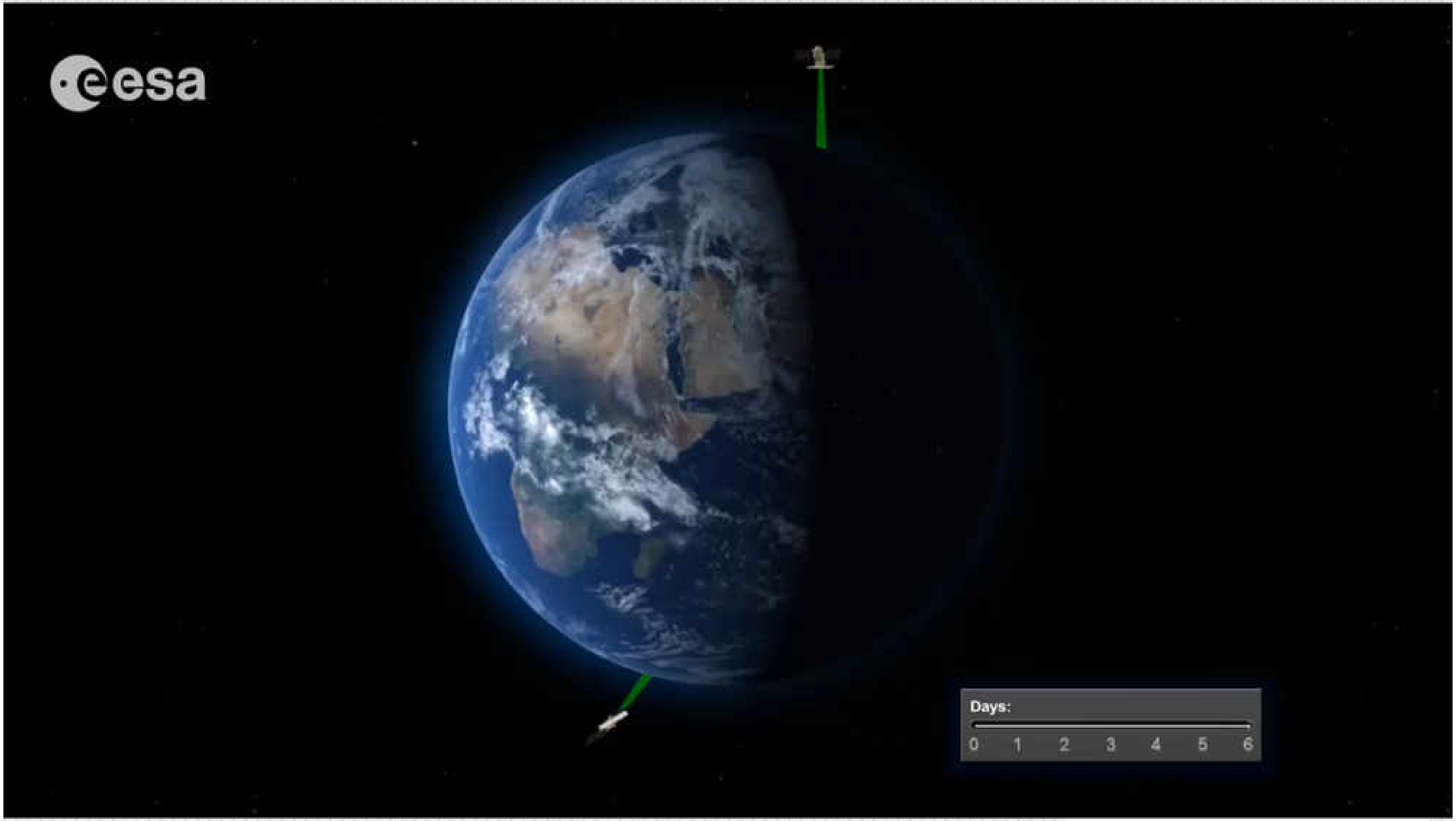
- r: range   a: azimuth
- C(r,a): complex value
- A(r,a): amplitude
- Φ(r,a): phase
- e: Euler's number of exponential function
- i = $\sqrt{-1}$: imaginary number

Phase Difference

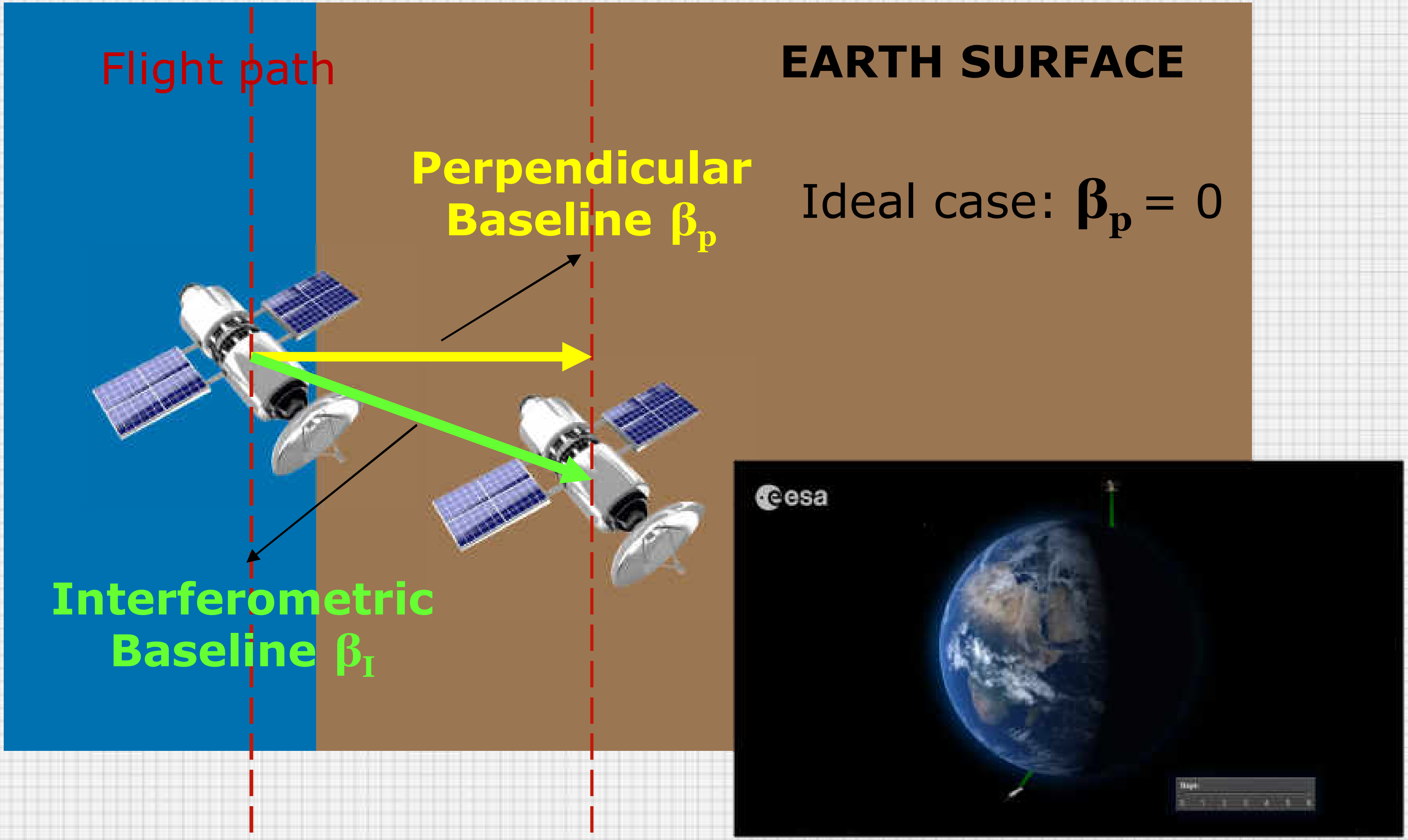


Phase Difference

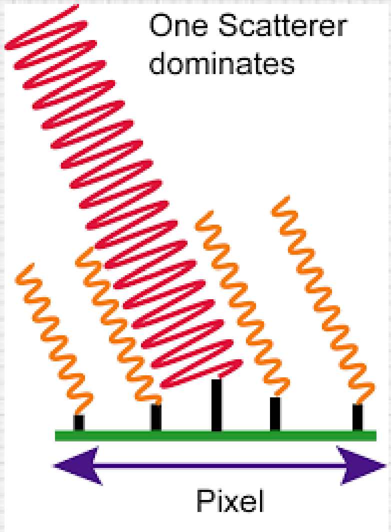


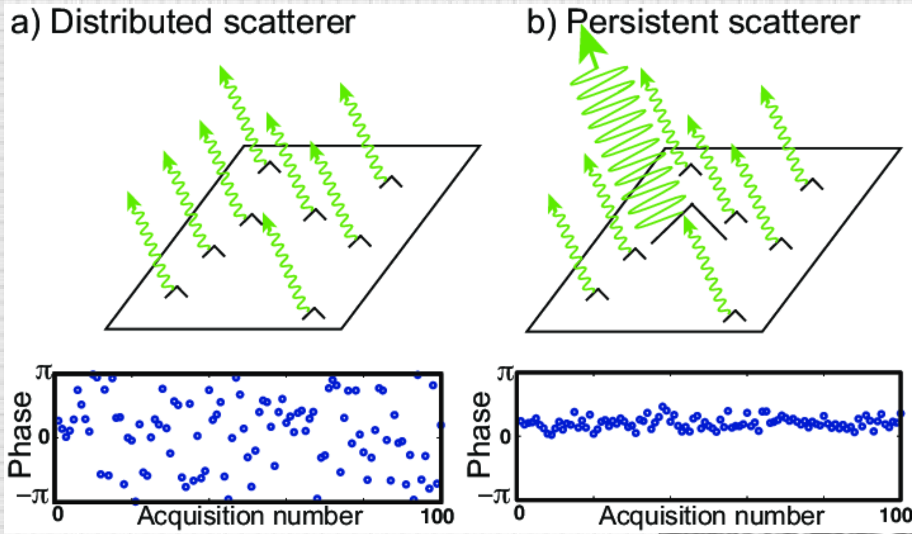

Days:
0
1
2
3
4
5
6

SBAS – Small Baseline Subset

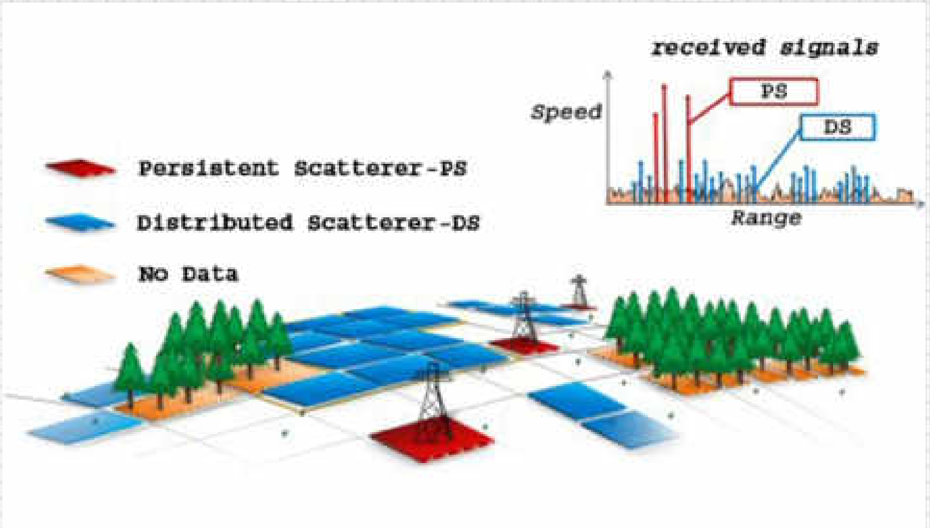


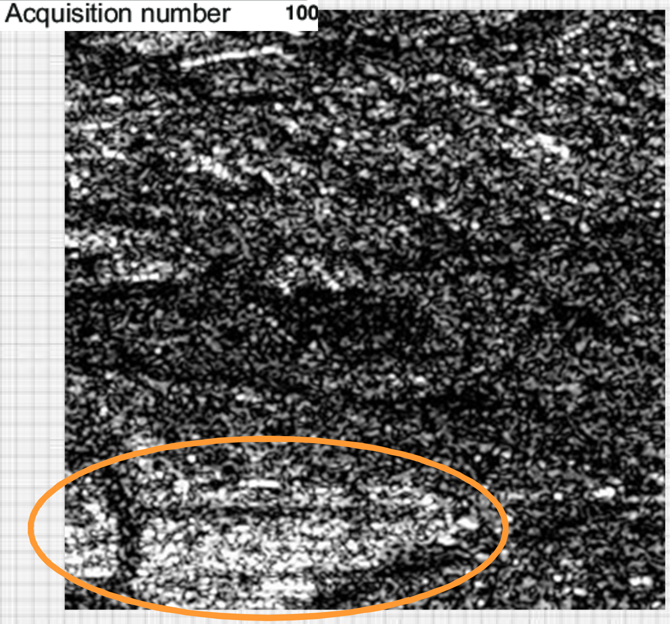
PS – Persistent Scatters





Pixels that are stable (constant over time) in backscattered amplitude and phase





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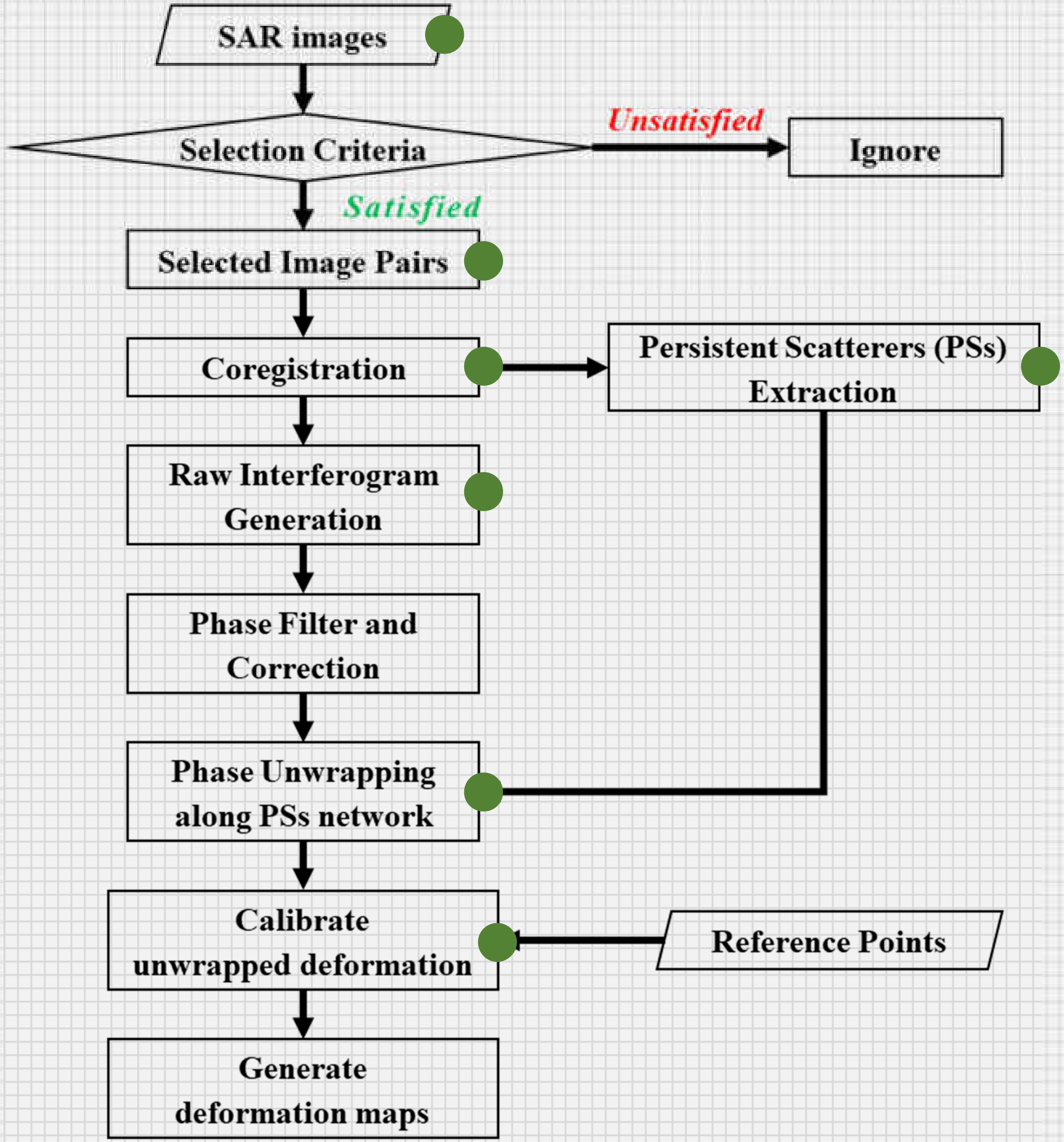
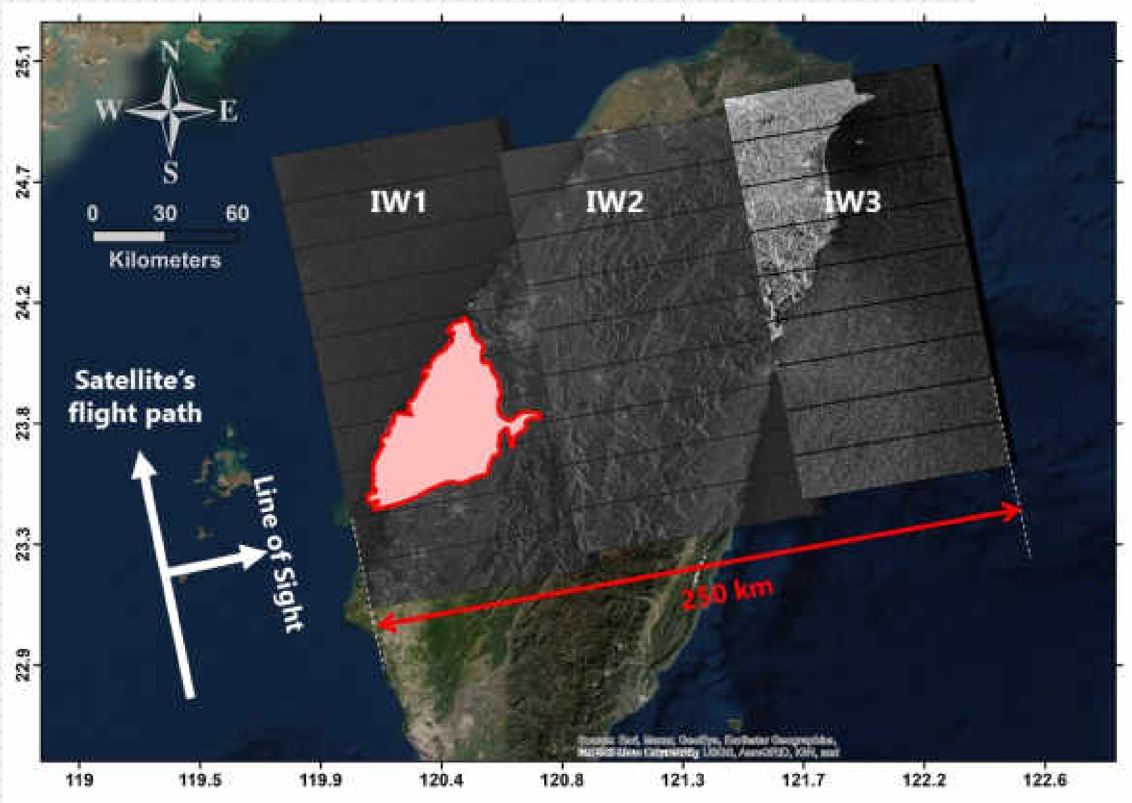
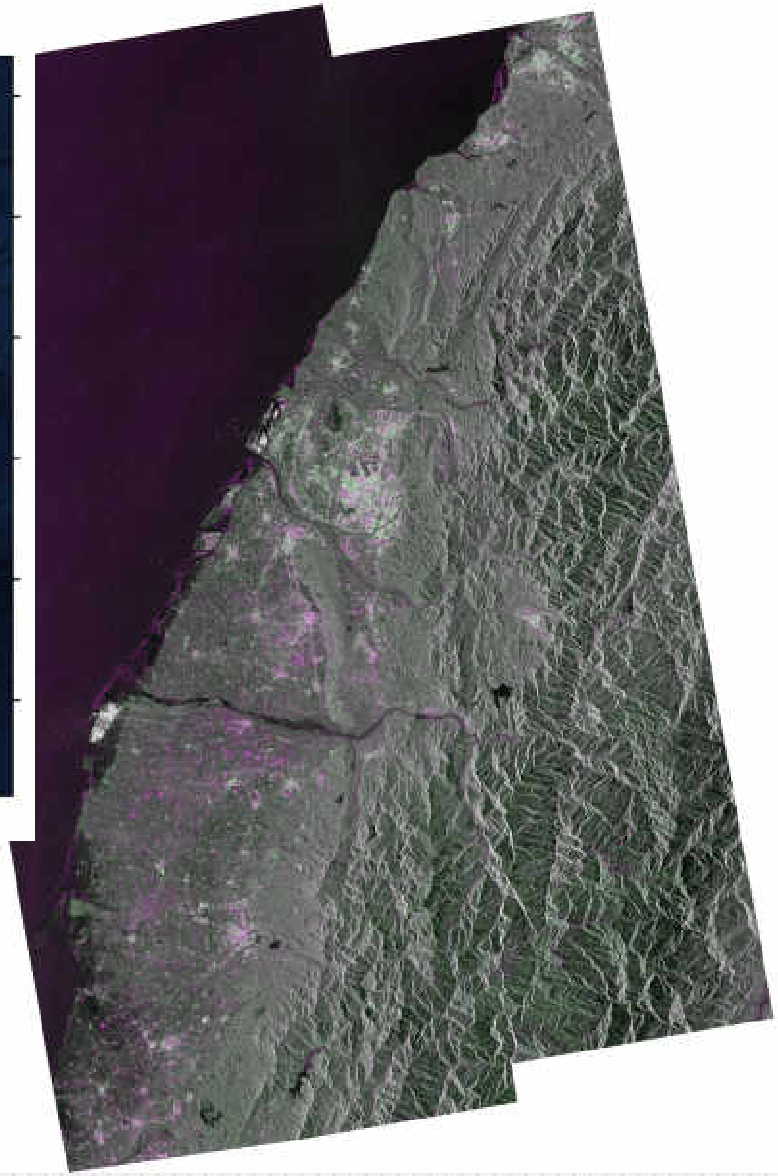

SAR images
Selection Criteria
Unsatisfied
Ignore
Satisfied
Selected Image Pairs
Coregistration
Persistent Scatterers (PSs) Extraction
Raw Interferogram Generation
Phase Filter and Correction
Phase Unwrapping along PSs network
Calibrate unwrapped deformation
Reference Points
Generate deformation maps





63 Sentinel-**1A** & **1B**

SAR images

(4/2017 – 4/2019)

~32 GPS Stations

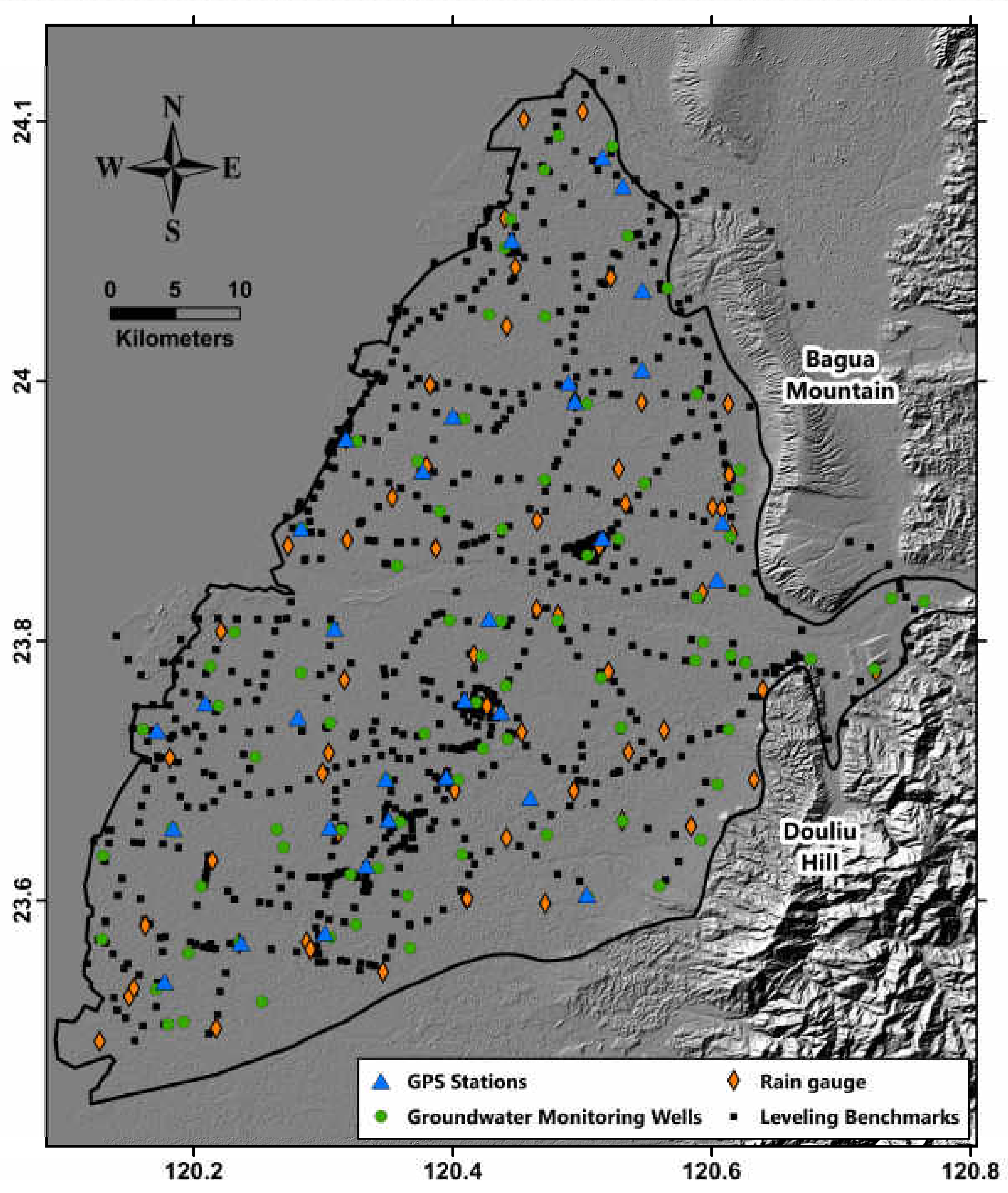
(blue triangles)

Calibrate and

assess the results

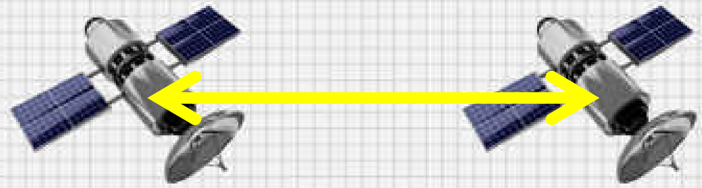
from the

InSAR process

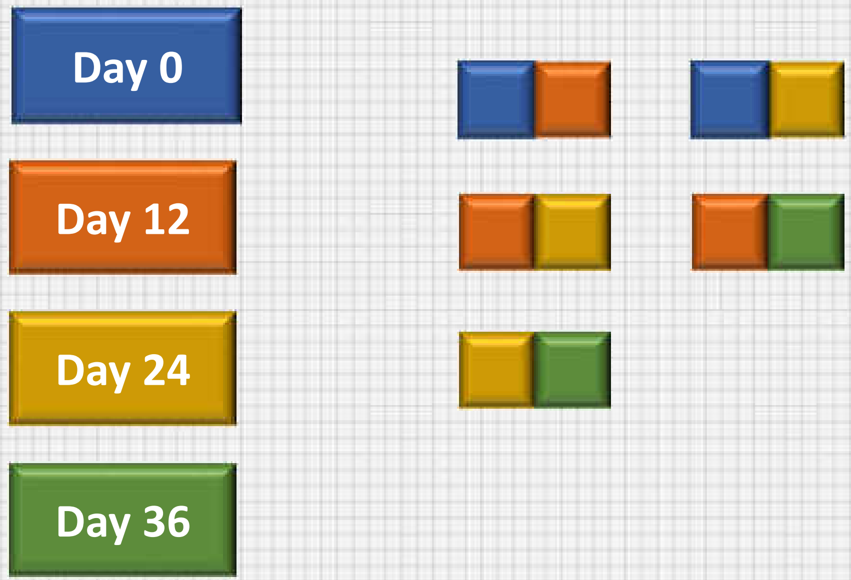


1. Image Pairs Selection
2. Coregistration
3. Create Raw Interferogram
4. Noise and Phase Correction
5. PS Candidate Selection
6. Phase Unwrapping
7. Deformation Calibration
8. Stacked Deformation Map

Example of Pairing Criteria



1. Perpendicular Baseline < 200m
2. Acquisition Date between two images < 25 days



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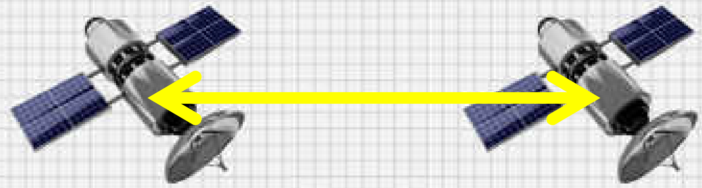

1. Perpendicular Baseline < 200m
2. Acquisition Date between two images < 31 days

Results?

→ 360 interferograms

1. Image Pairs Selection
2. **Coregistration**

Image 1 spatially aligned with **Image 2**, utilizing the ground control points (GCPs)

So that any feature in **Image 1** overlaps as well as possible its footprint in **Image 2**

Image courtesy of Massachusetts Executive Office of Environmental Affairs

Orthophoto image (Master image)

Image courtesy of mPower3/Emerge

Aerial photo image (Slave image)

Image 1 spatially aligned with **Image 2**,

Image 1 spatially aligned with **Image 2**, utilizing the ground control points (GCPs)
So that any feature in **Image 1** overlaps as well as possible its footprint in **Image 2**

Master image

$$C_1(r,a) = A_1(r,a)e^{i\varphi_1(r,a)}$$

Slave image

$$C_2(r,a) = A_2(r,a)e^{i\varphi_2(r,a)}$$

A complex interferogram

$$C_2 C_1^* = A_1 A_2 e^{i(\varphi_2 - \varphi_1)}$$

***** is the complex conjugation

Lu, C.-H., Ni, C.-F., Chang, C.-P., Yen, J.-Y., & Chuang, R. Y. (2018). Coherence difference analysis of sentinel-1 SAR interferogram to identify earthquake-induced disasters in urban areas. *Remote Sensing, 10*(8), 1318.

1. Image Pairs Sele
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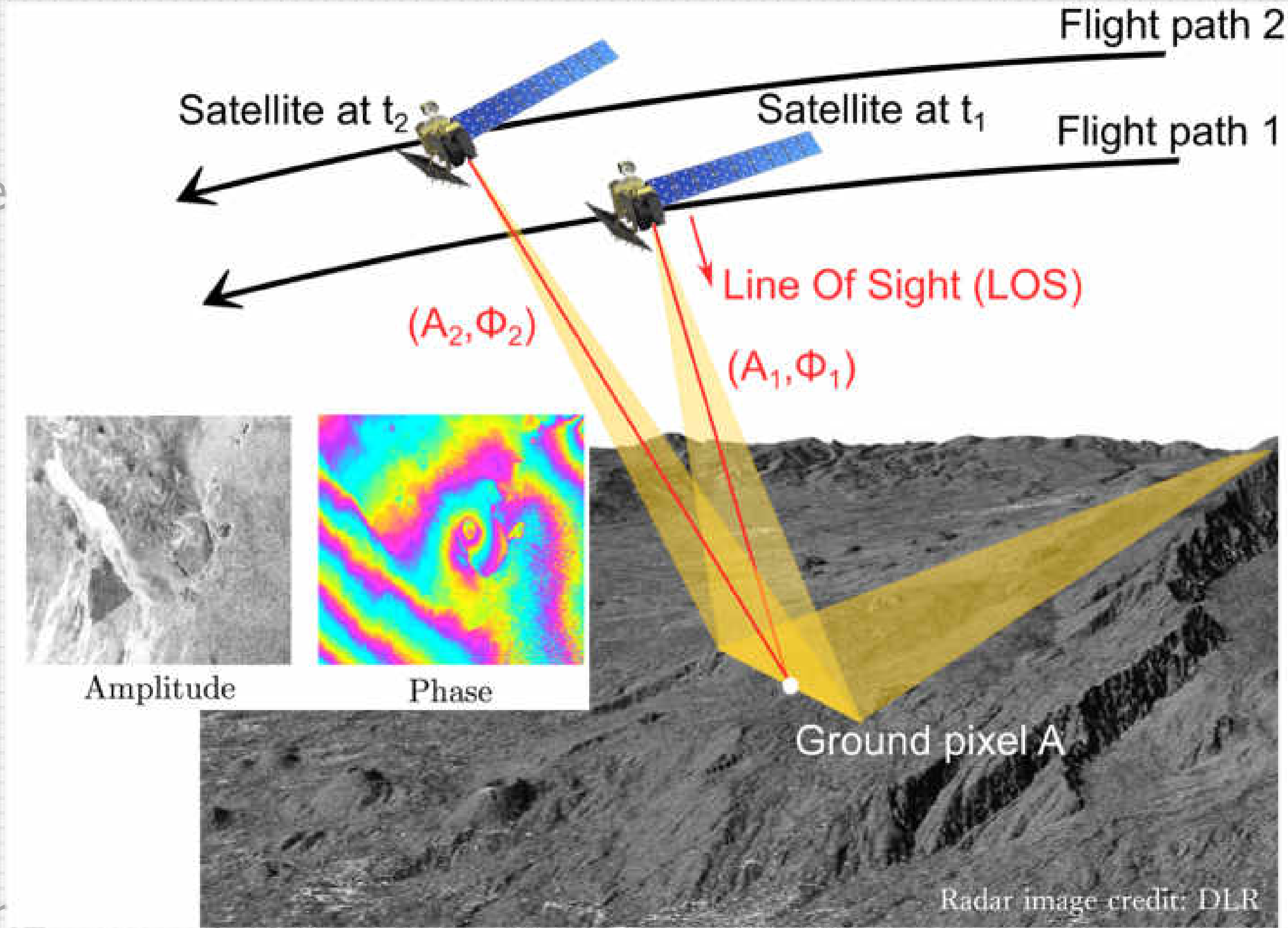
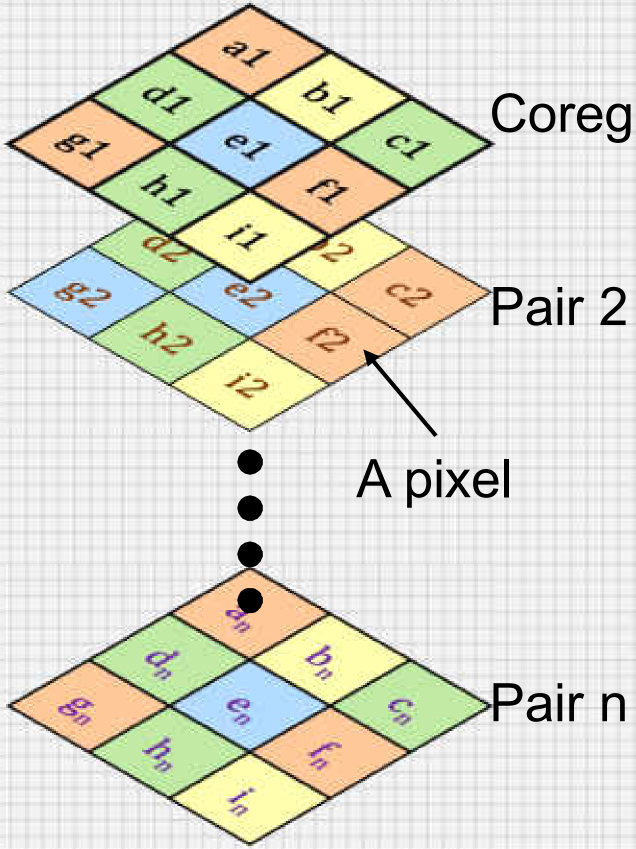


- Even the GCPs are all matched, some pixels have difference in phase due to spatial and temporal changes
- Those pixels will provide surface deformation



$$m_a = \frac{1}{k}\sum_{k=1}^{n} a_k$$

$$\sigma_a = \sqrt{\frac{1}{k}\sum_{k=1}^{n}(a_k - m_a)}$$

PERSISTENT SCATTERER EXTRACTION

$$D_A = \frac{\sigma_A}{m_A}$$

D_A : Amplitude Dispersion Index

σ_A: St.Dev of amplitude values

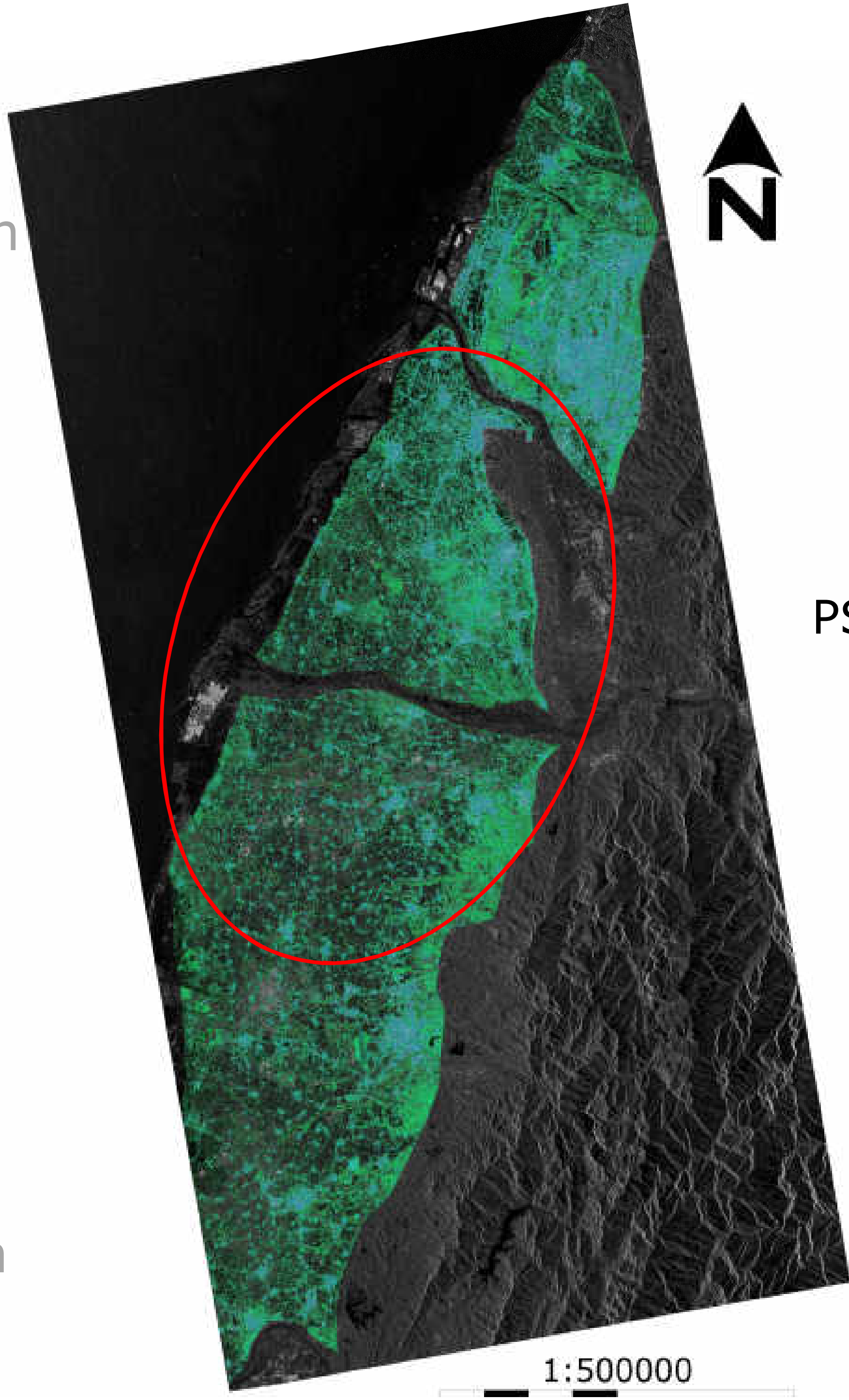
m_A: Mean of amplitude values

$$\boldsymbol{D_A \leq 0.3}$$

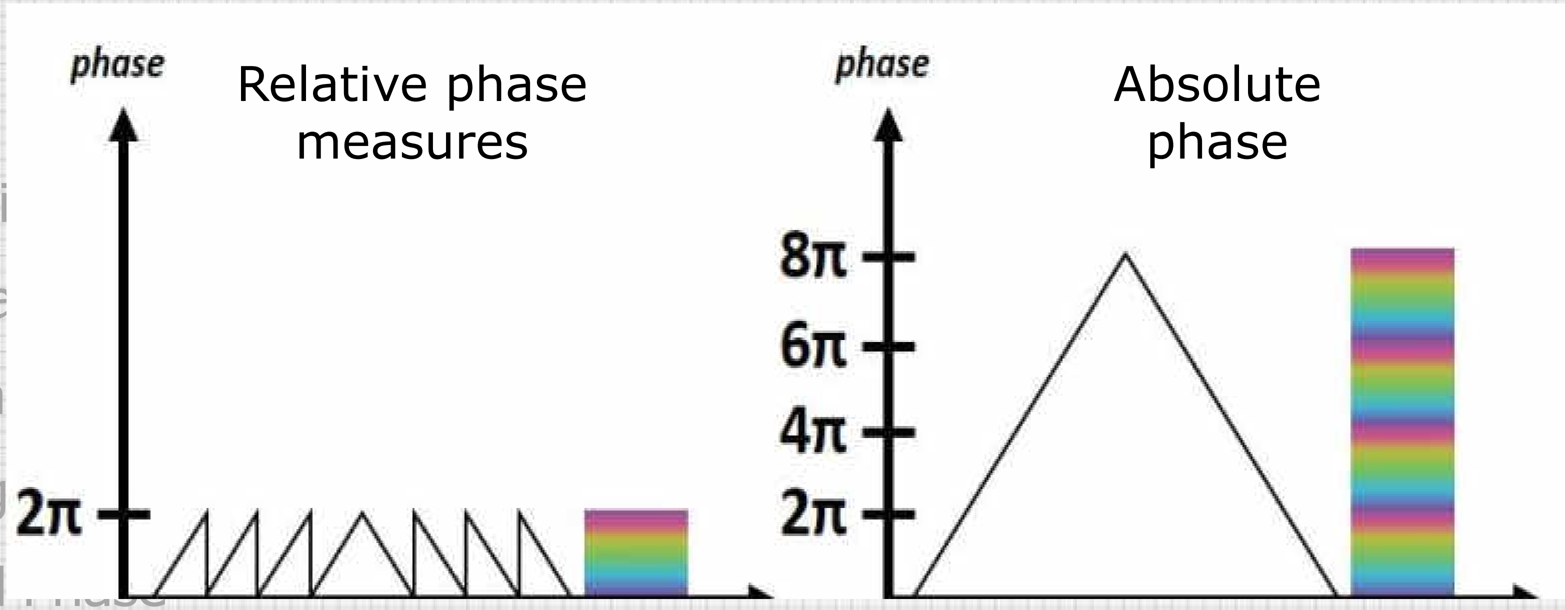
Found **835 369** PS candidates

Density 383 PSCs / km²

1. Image Pairs Selection
2. Coregistration
3. Create Raw Interferogram
4. Noise and Phase Correction
5. **PS Candidate Selection**
6. Phase Unwrapping
7. Deformation Calibration
8. Stacked Deformation Map



835 369
PS candidates



1. Image Pai
2. Coregistra
3. Create Ra Interferog
4. Noise and Correction
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8. Stacked Deformation Map

- Interferometric phase is relative (ambiguous)
- Known within 2π (or within 360º), being wrapped
- Adding integer numbers of 2π to recover absolute phase difference (called phase unwrapping)
- To achieve raw displacement values

Why need calibration?

Error sources include:

- Ignore horizontal displacements
- Atmospheric effects
- Phase unwrapping errors

How much error due to ignoring horizontal velocity component?

Maximum error due to projection of LOS into the vertical velocity induced by the horizontal velocity component:

$$\Delta V_e = \tan\theta(V_E \cos\alpha - V_N \sin\alpha)$$

Fuhrmann, T., & Garthwaite, M. C. (2019). Resolving three-dimensional surface motion with InSAR: Constraints from multi-geometry data fusion. *Remote Sensing, 11*(3), 241.

Average error due to neglecting the horizontal velocity components at the GPS stations in CRFP = -2.4 mm/year

Yang, Y.-J., Hwang, C., Hung, W.-C., Fuhrmann, T., Chen, Y.-A., & Wei, S.-H. (2019). Surface deformation from Sentinel-1A InSAR: relation to seasonal groundwater extraction and rainfall in Central Taiwan. *Remote Sensing, 11*(23), 2817.

Converted the InSAR LOS-velocities to vertical velocities as:

$$V_h = \frac{V_{LOS}}{\cos\theta}$$

θ : Sentinel-1A incidence angle

1. Image Pairs Selection
2. Coregistration
3. Create Raw Interferogram
4. Noise and Phase Correction
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Calibration Processes

1. Reference points

To define the stable areas

→ To have InSAR-derived results similar patterns to GPS measurements

→ Reduce differences

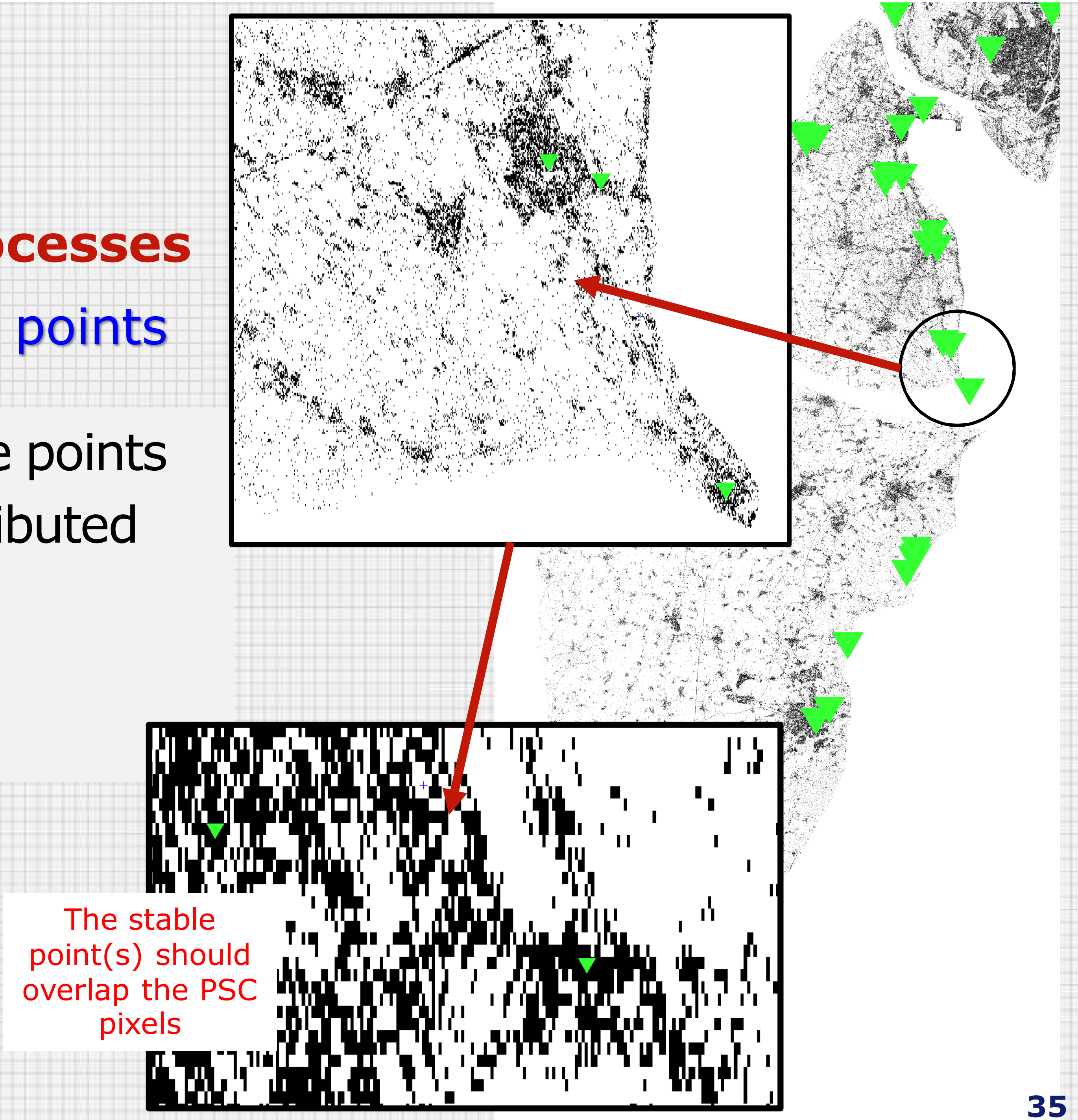
2. GPS data

Calibration Processes

1. By reference points

Provide reference points ▼, properly distributed

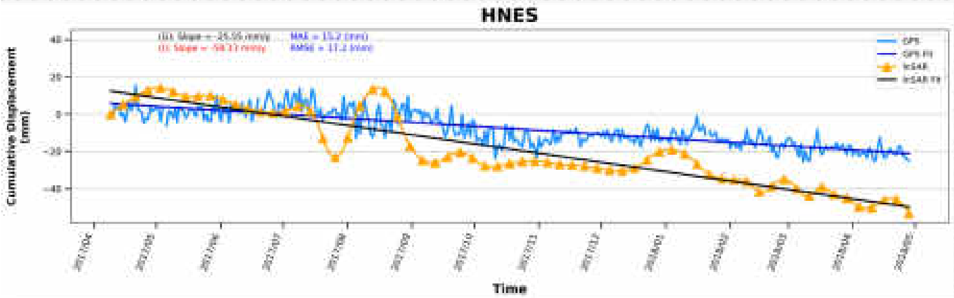
Reference points
→ Stable areas

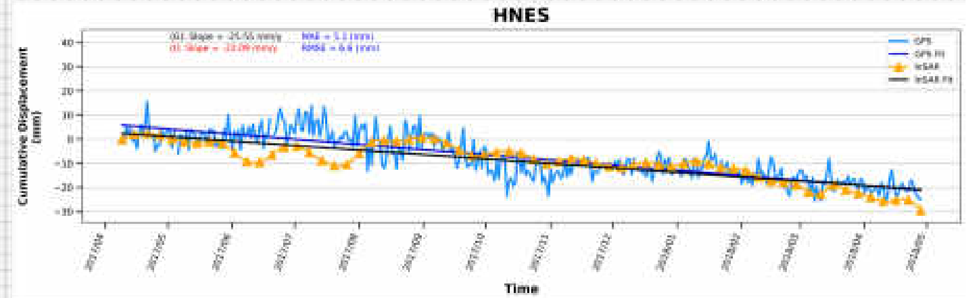


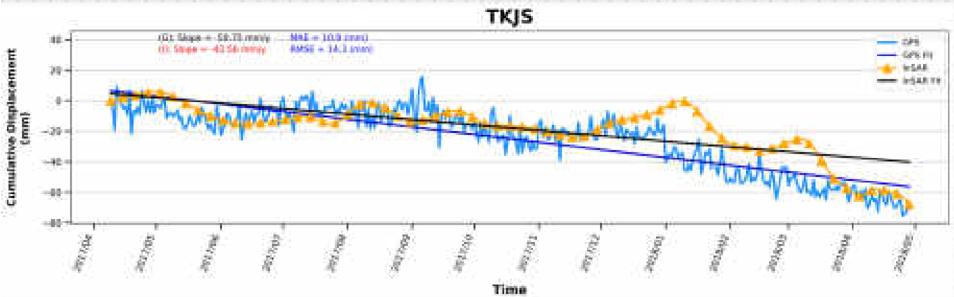
Calibration Processes

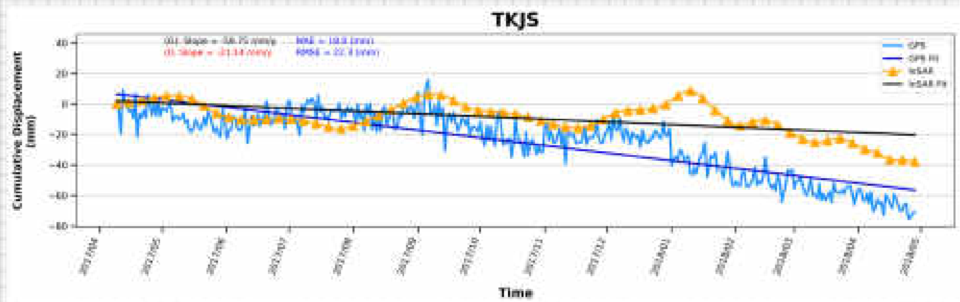
1. By reference points

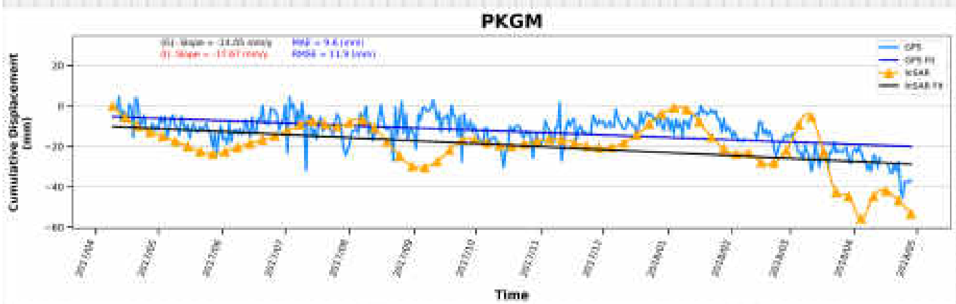
BEFORE | **AFTER**

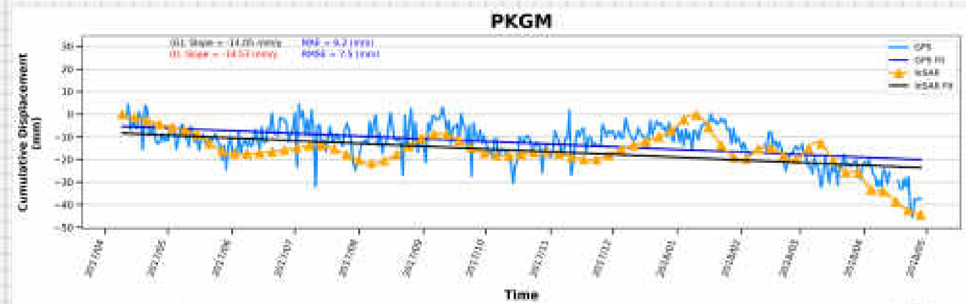




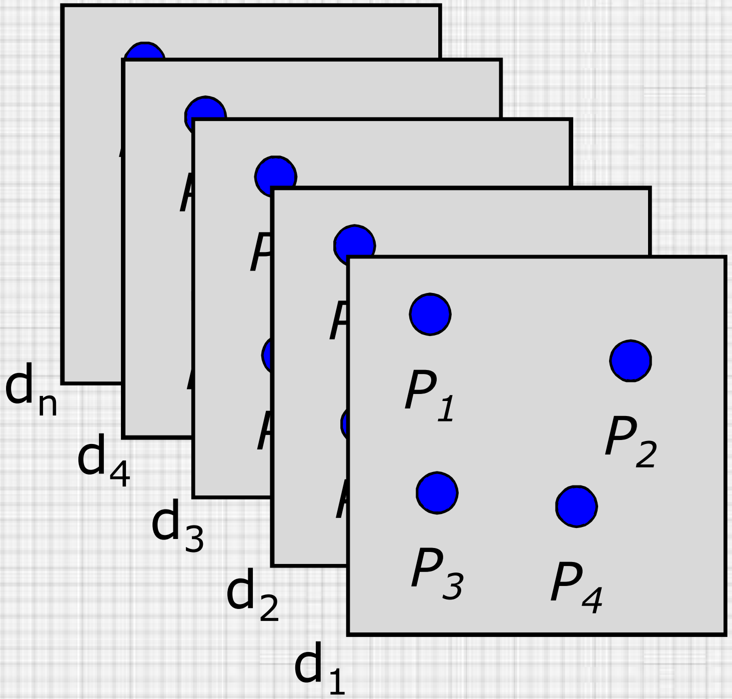


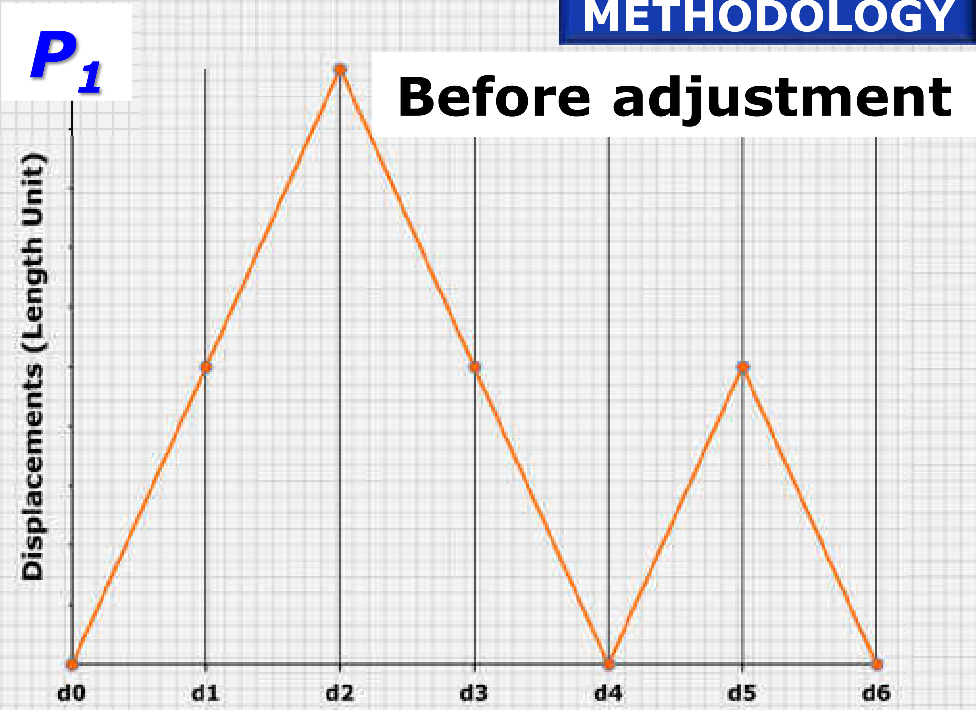


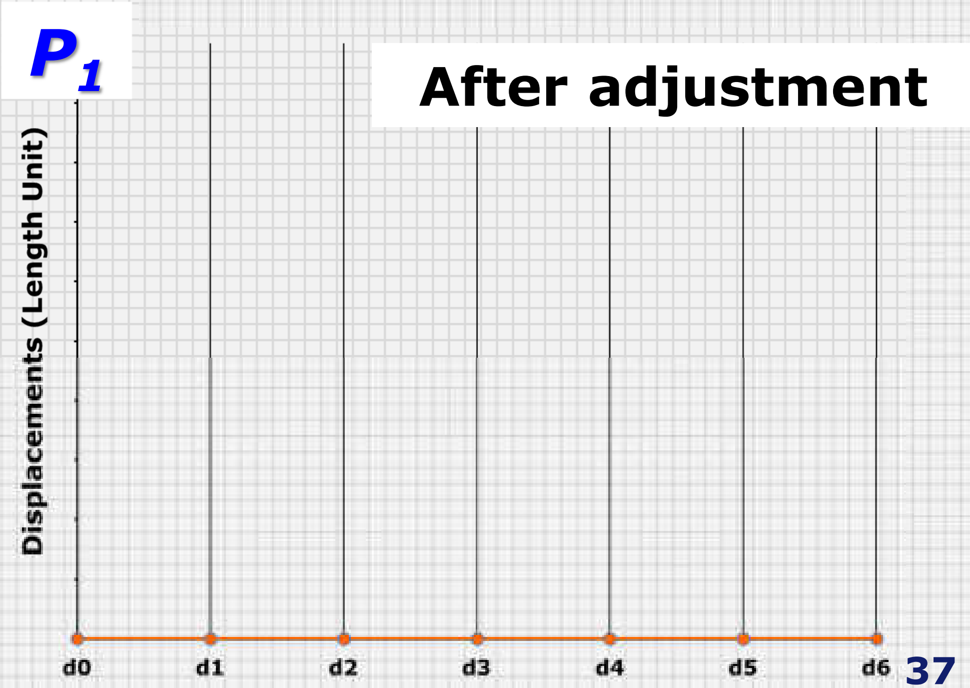




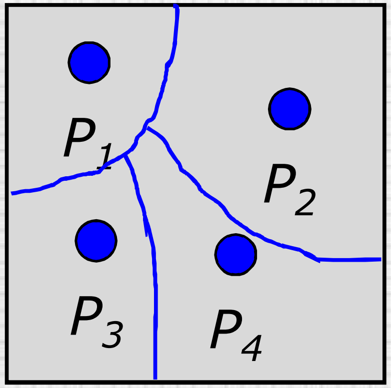
Calibrated Subsidence Map



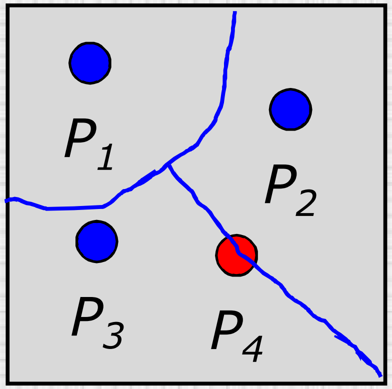




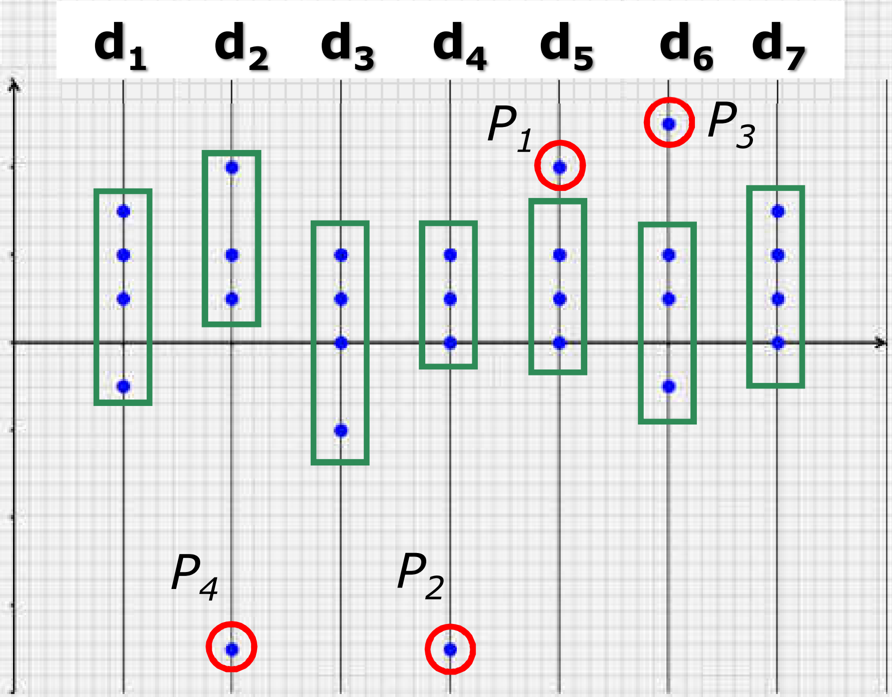
Calibrated Subsidence Map



d_1



d_2

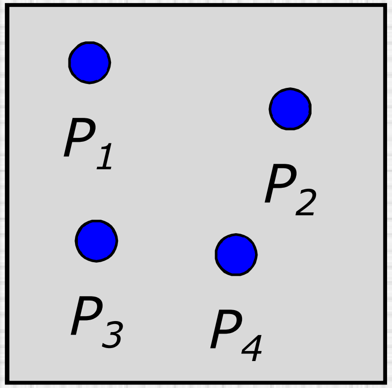


Selection criteria:
UNDERSIGMA2.0

Take the point whose adjustment value is **smaller than 2*σ** to implement the interpolation

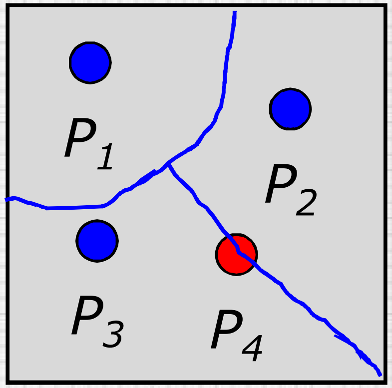
σ: stdev of all adjustment values

Calibrated Subsidence Map



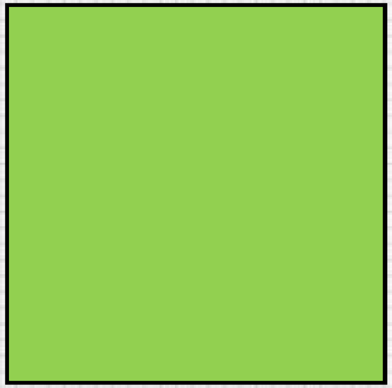
Orginal map
d_n

−

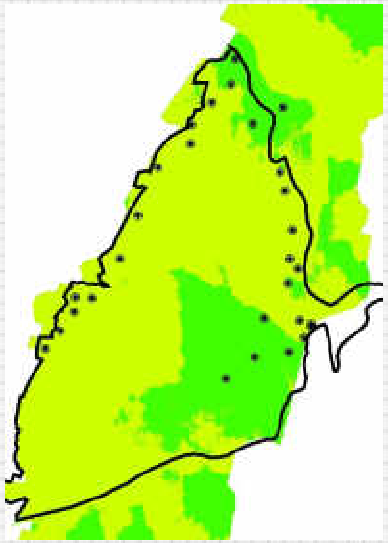


Interpolation of adjusted displacement values for map
d_n

=



Adjusted displacement map
d_n



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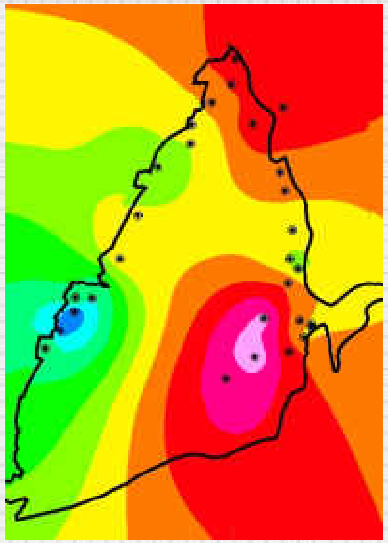

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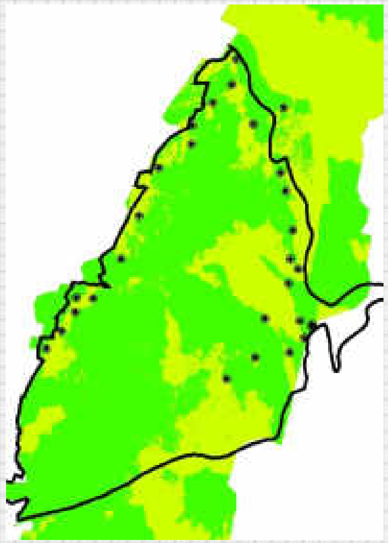


Calibration Processes

2. By GPS data

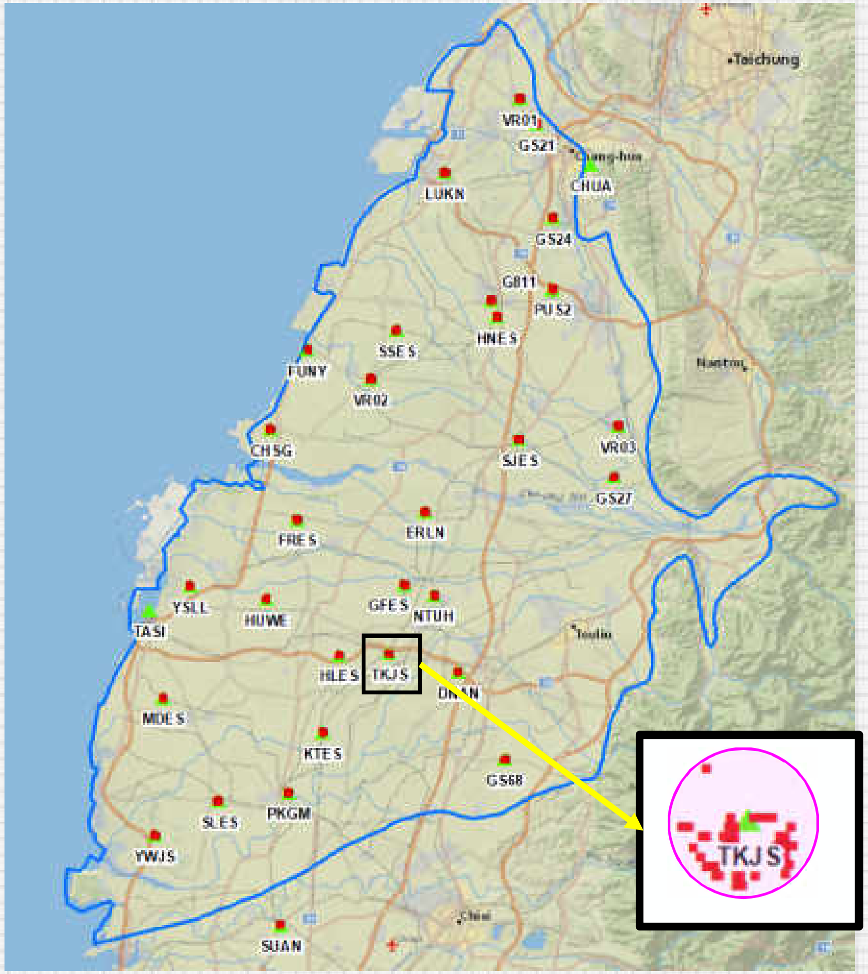
Concept:

- Surface deformation = a natural phenomenon
- Measured by GPS and InSAR
- Assuming: Both methods produce same results
- GPS : point-wise measurements, a part of InSAR measurements

→ Calibrate InSAR results by GPS data

Calibration Processes

2. By GPS data



1. Collect the PSCs within radius of 200m surrounding the GPS stations
2. Calculate the average displacement of PSCs (at a particular time step)
3. Take difference between displacement measures of GPS and InSAR → a table

STATION	Day 12	Day 18	Day 24
STAT_1	X1	Y1	Z1
STAT_2	X2	Y2	Z2
…	…	…	…
STAT_N	Xn	Yn	Zn

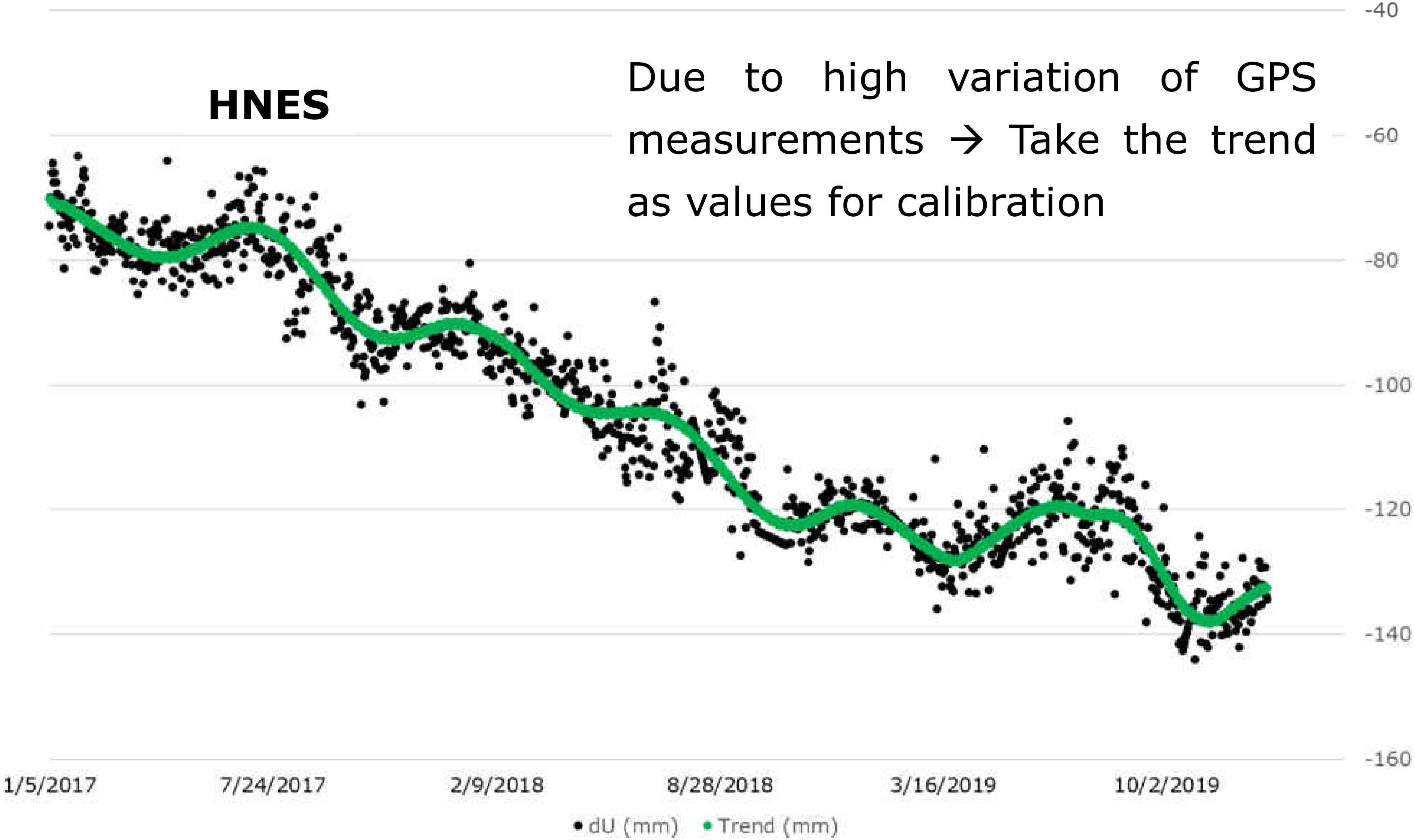
Calibration Processes

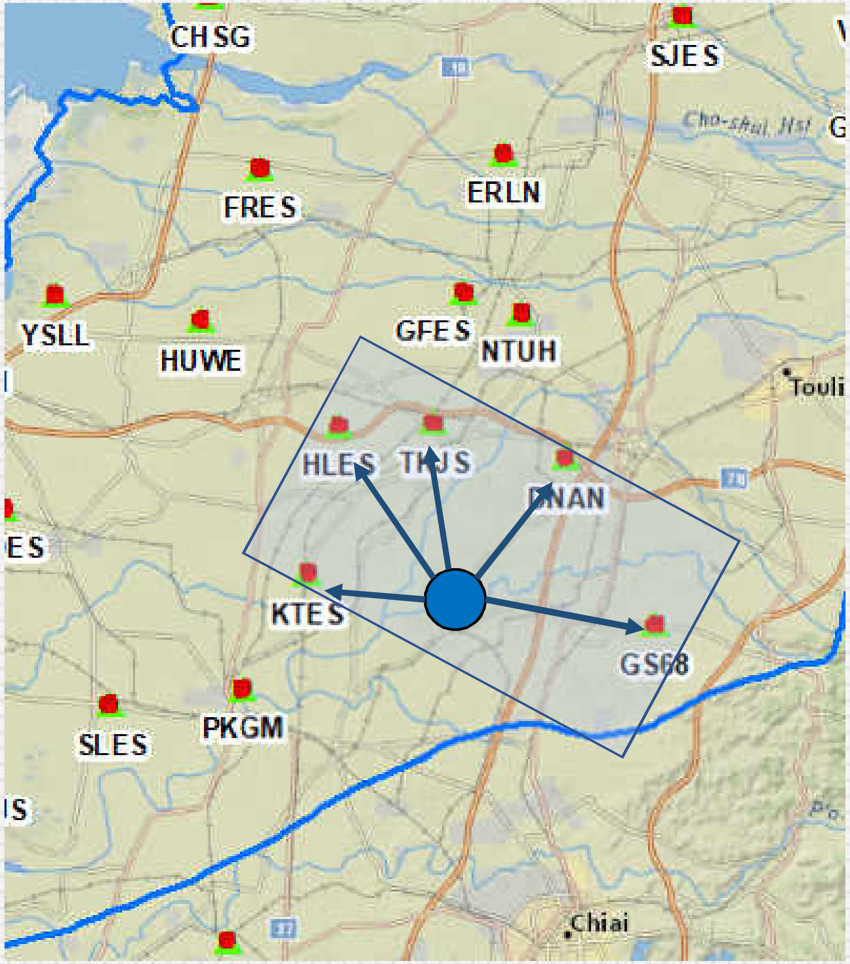
2. By GPS data

1. Collect the PSCs within radius of 200m surrounding the GPS stations
2. Calculate the average displacement of PSCs (at a particular time)
3. Take difference between displacement measures of GPS and InSAR → a table

Calibration Processes

Due to high variation of GPS measurements → Take the trend as values for calibration



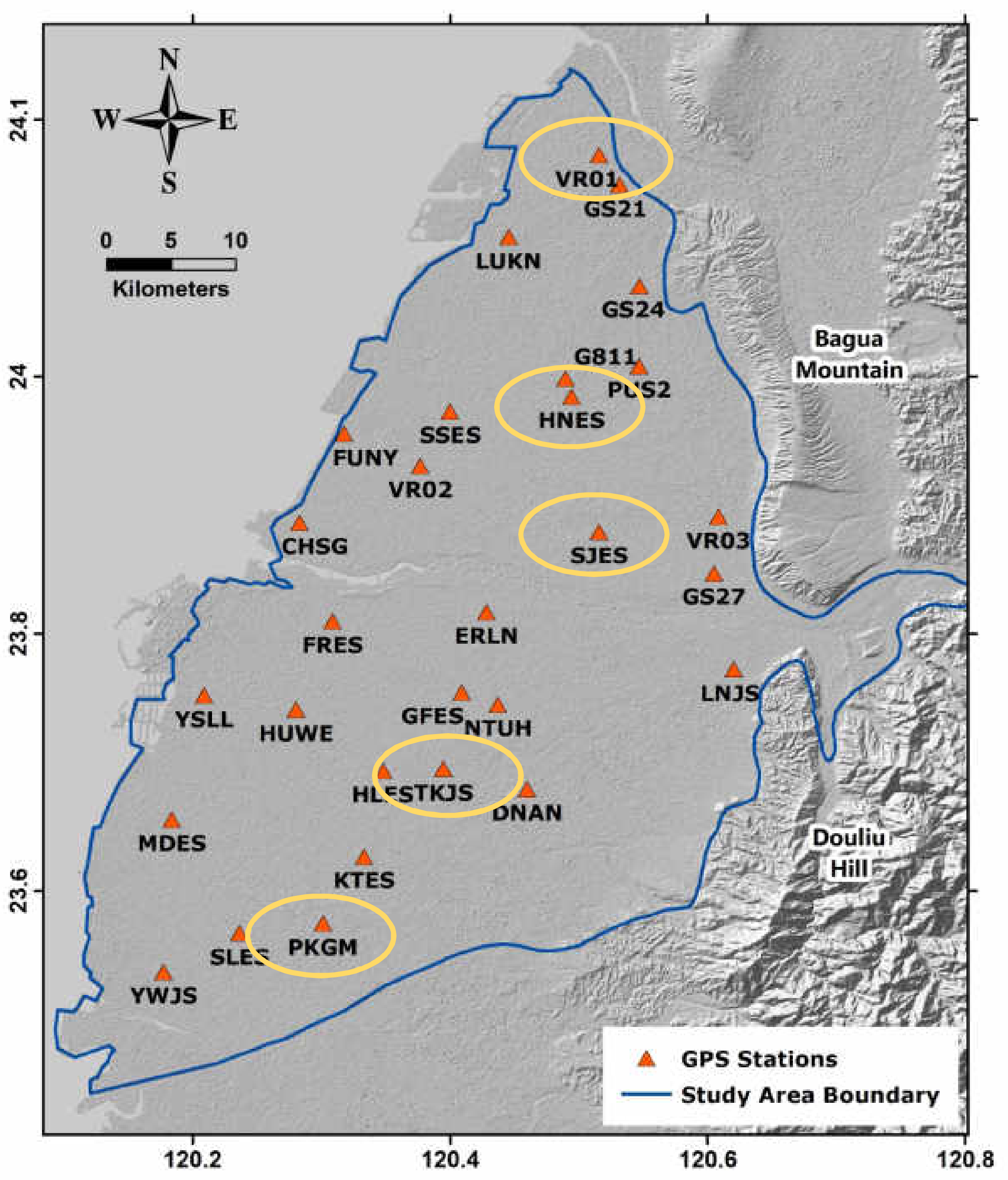


4. For each (other) PSC, choose 5 nearest GPS stations

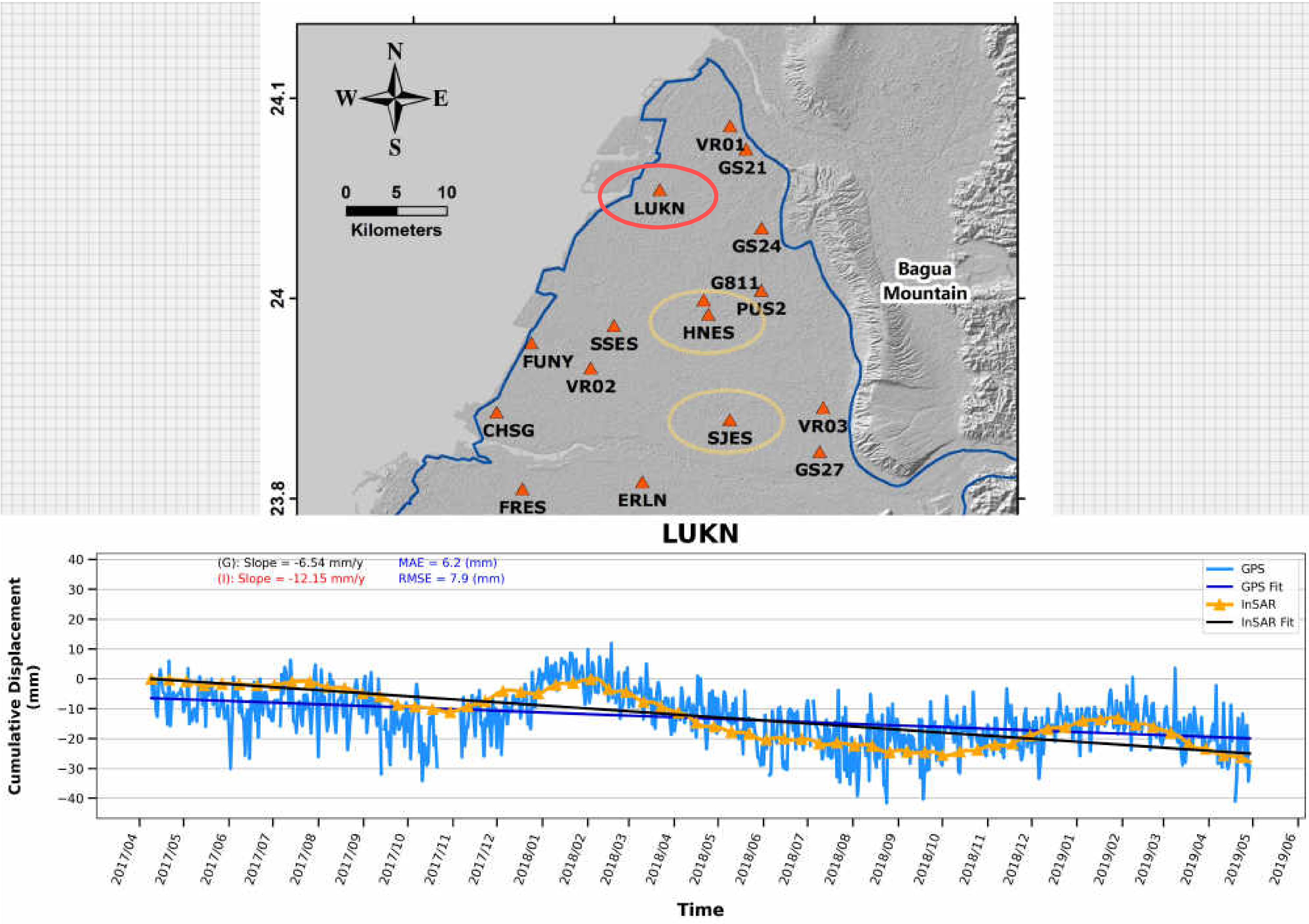
5. Apply thin-plate spline interpolation to interpolate differential values (at a particular time) to the PSC (based on diff. values of nearest stations)

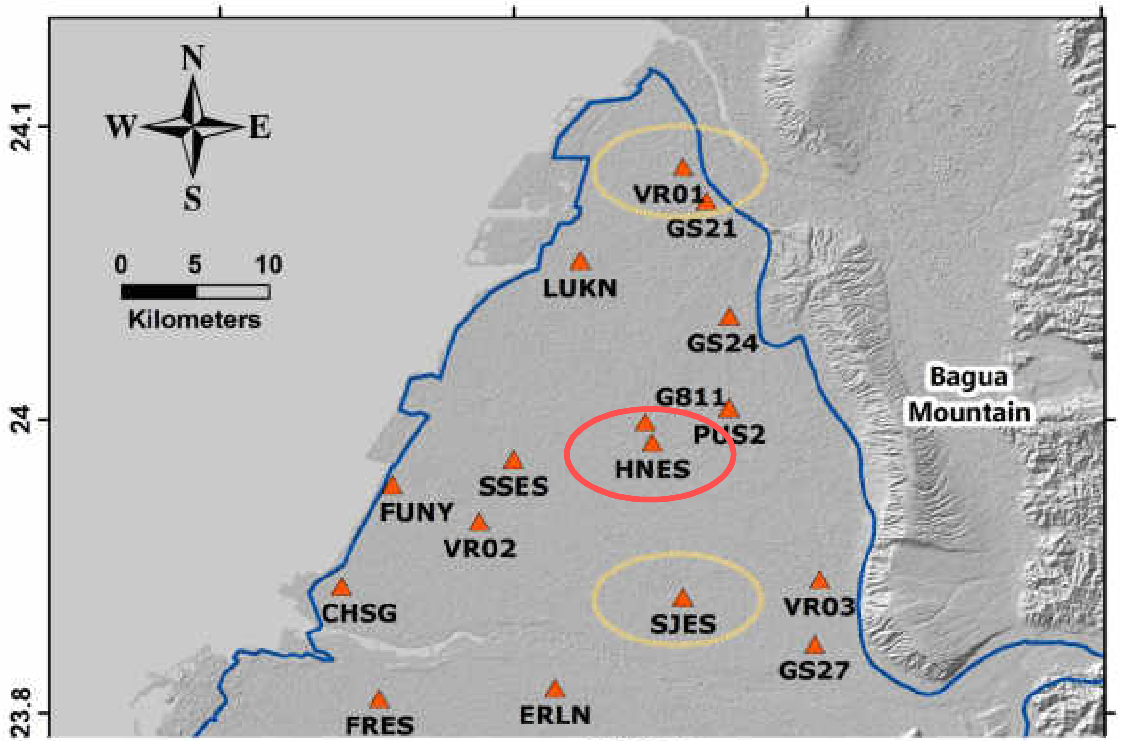
6. Add back the differential values to displacement values of PSCs

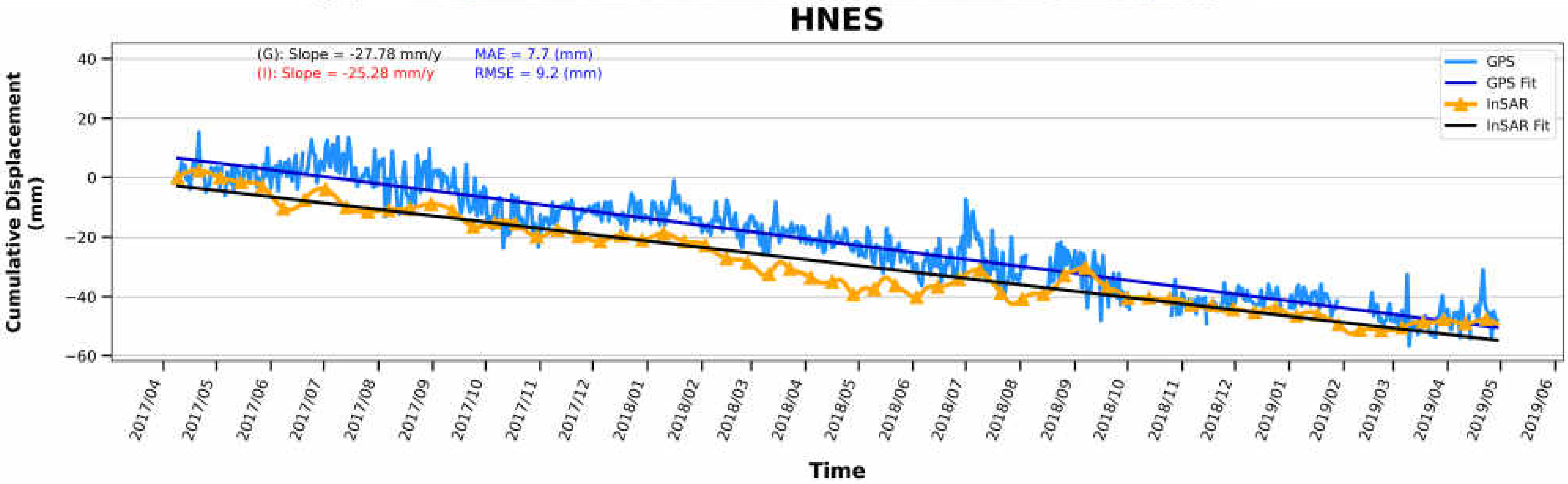
CONTENTS

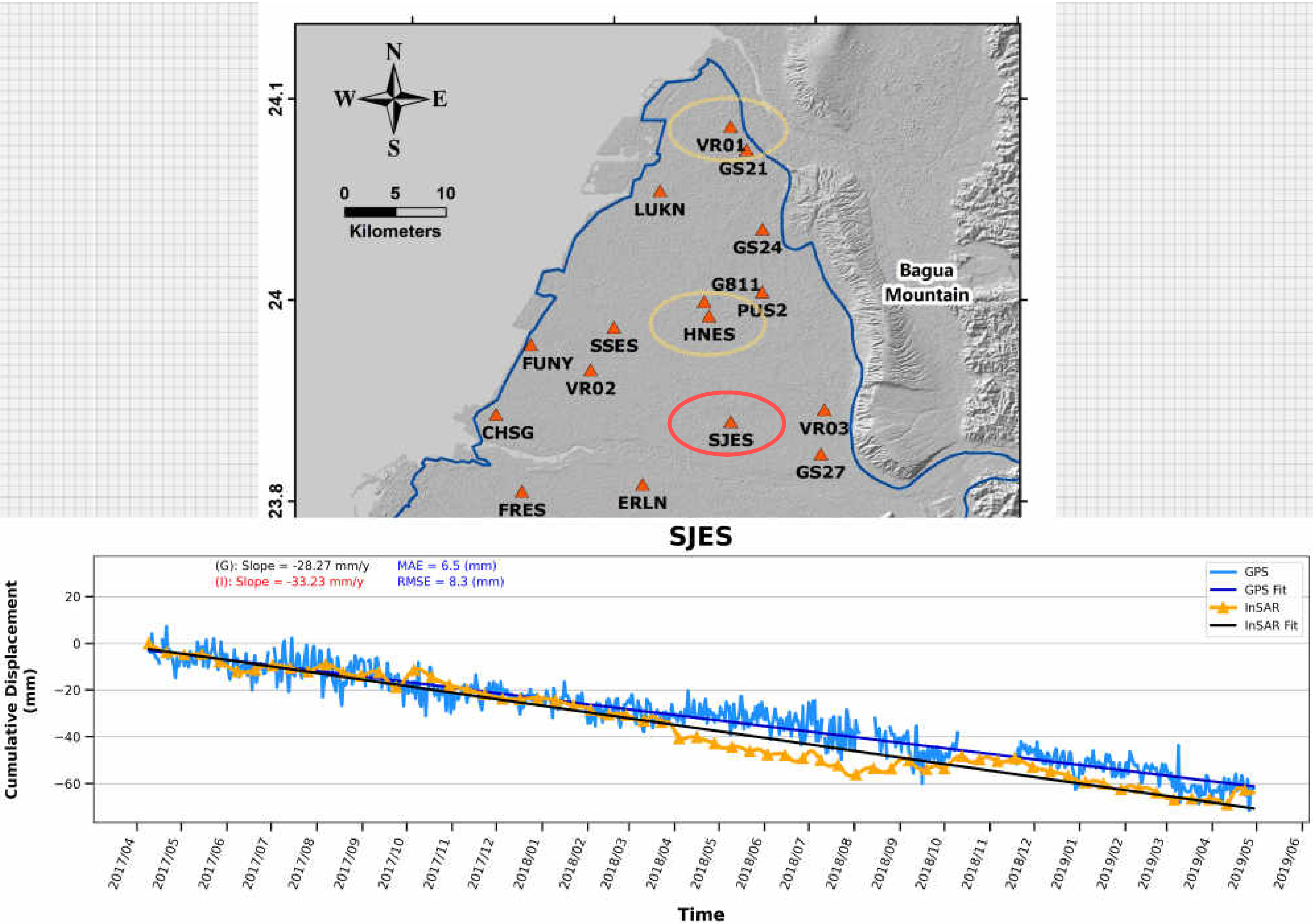


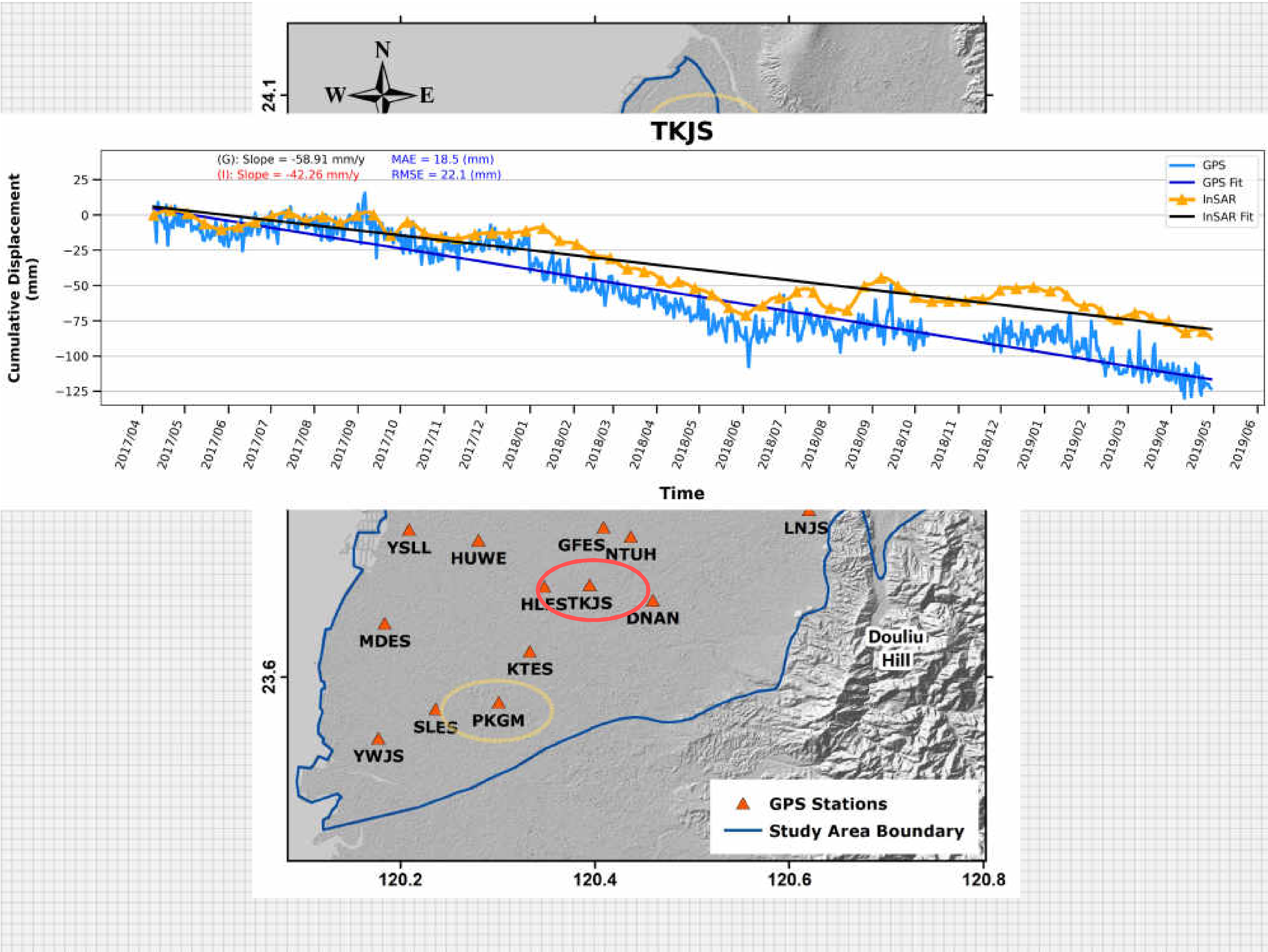
N
W
E
S
0 5 10
Kilometers
VR01
GS21
LUKN
GS24
G811
PUS2
HNES
SSES
FUNY
VR02
CHSG
SJES
VR03
GS27
Bagua
Mountain
FRES
ERLN
LNJS
YSLL
HUWE
GFES
NTUH
TKJS
DNAN
MDES
KTES
Douliu
Hill
PKGM
YWJS
GPS Stations
Study Area Boundary
24.1
24
23.8
23.6
120.2
120.4
120.6
120.8

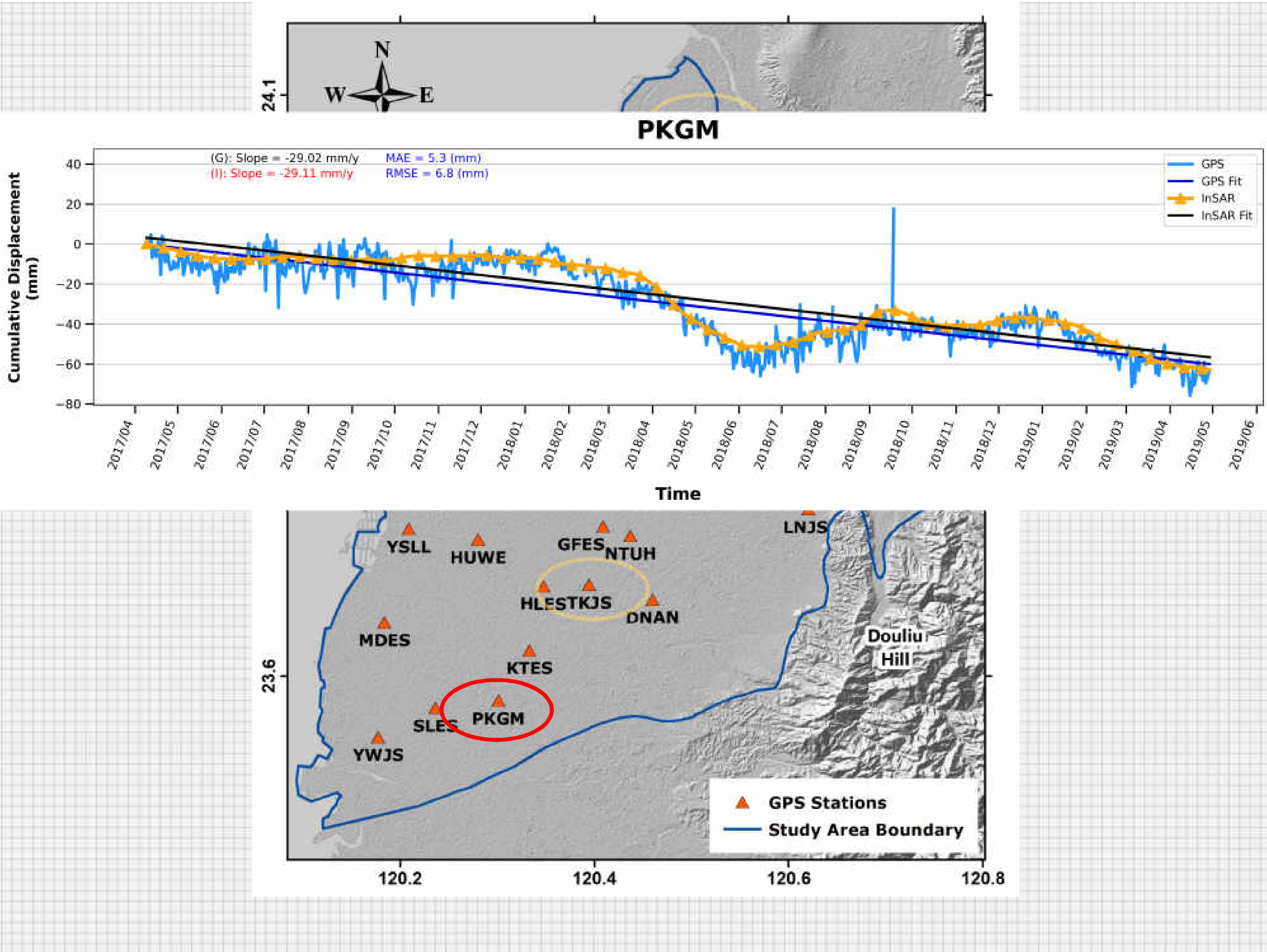

N
W
E
S
0 5 10
Kilometers
24.1
24
23.8
VR01
GS21
LUKN
GS24
G811
PUS2
HNES
SSES
FUNY
VR02
CHSG
SJES
VR03
GS27
FRES
ERLN
Bagua
Mountain
LUKN
(G): Slope = -6.54 mm/y
(I): Slope = -12.15 mm/y
MAE = 6.2 (mm)
RMSE = 7.9 (mm)
GPS
GPS Fit
InSAR
InSAR Fit
Cumulative Displacement (mm)
40
30
20
10
0
-10
-20
-30
-40
2017/04
2017/05
2017/06
2017/07
2017/08
2017/09
2017/10
2017/11
2017/12
2018/01
2018/02
2018/03
2018/04
2018/05
2018/06
2018/07
2018/08
2018/09
2018/10
2018/11
2018/12
2019/01
2019/02
2019/03
2019/04
2019/05
2019/06
Time


N
W
E
S
0 5 10
Kilometers
24.1
24
23.8
VR01
GS21
LUKN
GS24
G811
PUS2
HNES
SSES
FUNY
VR02
CHSG
SJES
VR03
GS27
FRES
ERLN
Bagua
Mountain

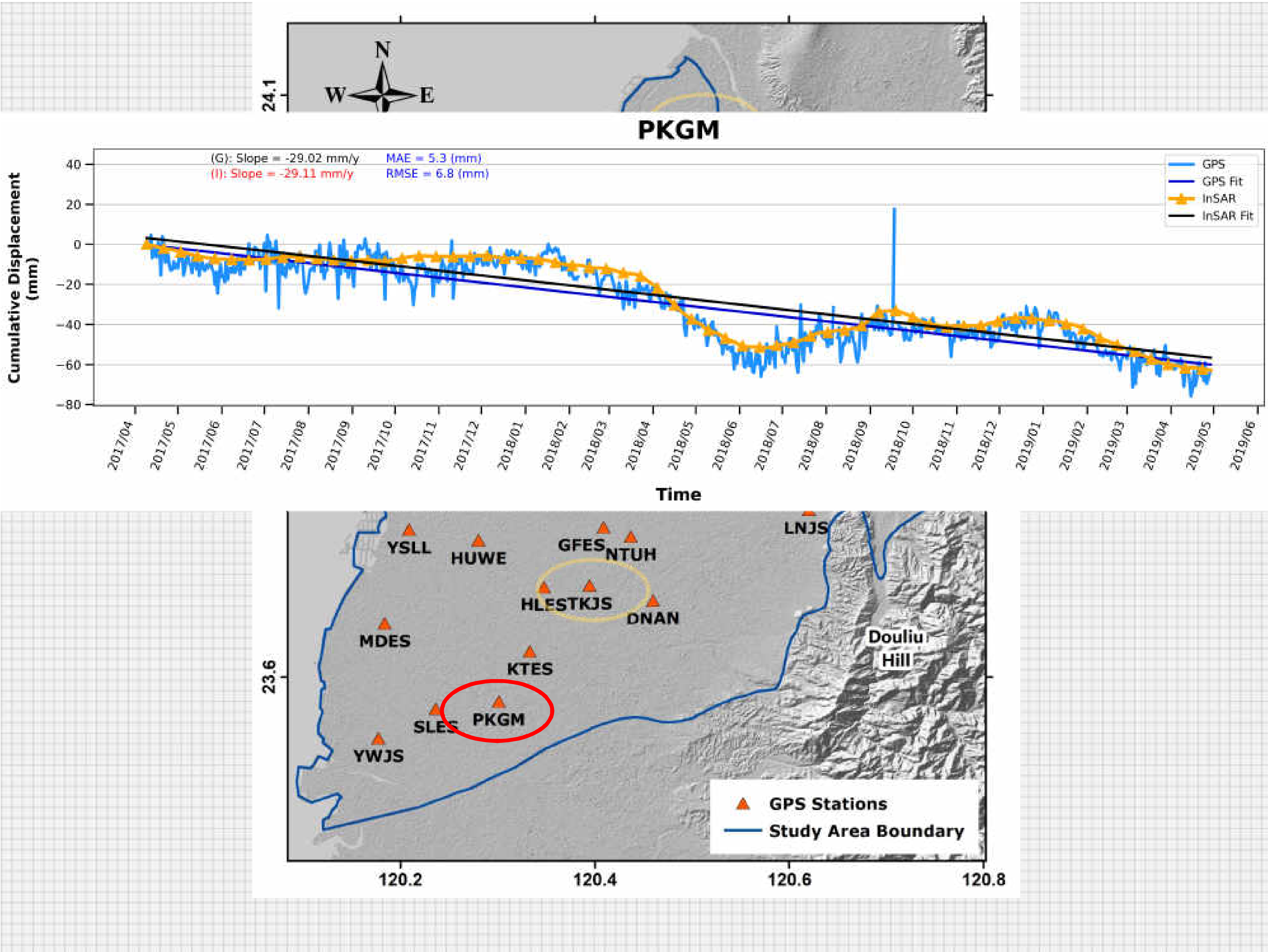

HNES
(G): Slope = -27.78 mm/y
(I): Slope = -25.28 mm/y
MAE = 7.7 (mm)
RMSE = 9.2 (mm)
GPS
GPS Fit
InSAR
InSAR Fit
Cumulative Displacement (mm)
Time


N
W
E
S
0 5 10
Kilometers
24.1
24
23.8
VR01
GS21
LUKN
GS24
G811
PUS2
HNES
SSES
FUNY
VR02
CHSG
SJES
VR03
GS27
FRES
ERLN
Bagua Mountain
SJES
(G): Slope = -28.27 mm/y
(I): Slope = -33.23 mm/y
MAE = 6.5 (mm)
RMSE = 8.3 (mm)
GPS
GPS Fit
InSAR
InSAR Fit
Cumulative Displacement (mm)
20
0
-20
-40
-60
2017/04
2017/05
2017/06
2017/07
2017/08
2017/09
2017/10
2017/11
2017/12
2018/01
2018/02
2018/03
2018/04
2018/05
2018/06
2018/07
2018/08
2018/09
2018/10
2018/11
2018/12
2019/01
2019/02
2019/03
2019/04
2019/05
2019/06
Time

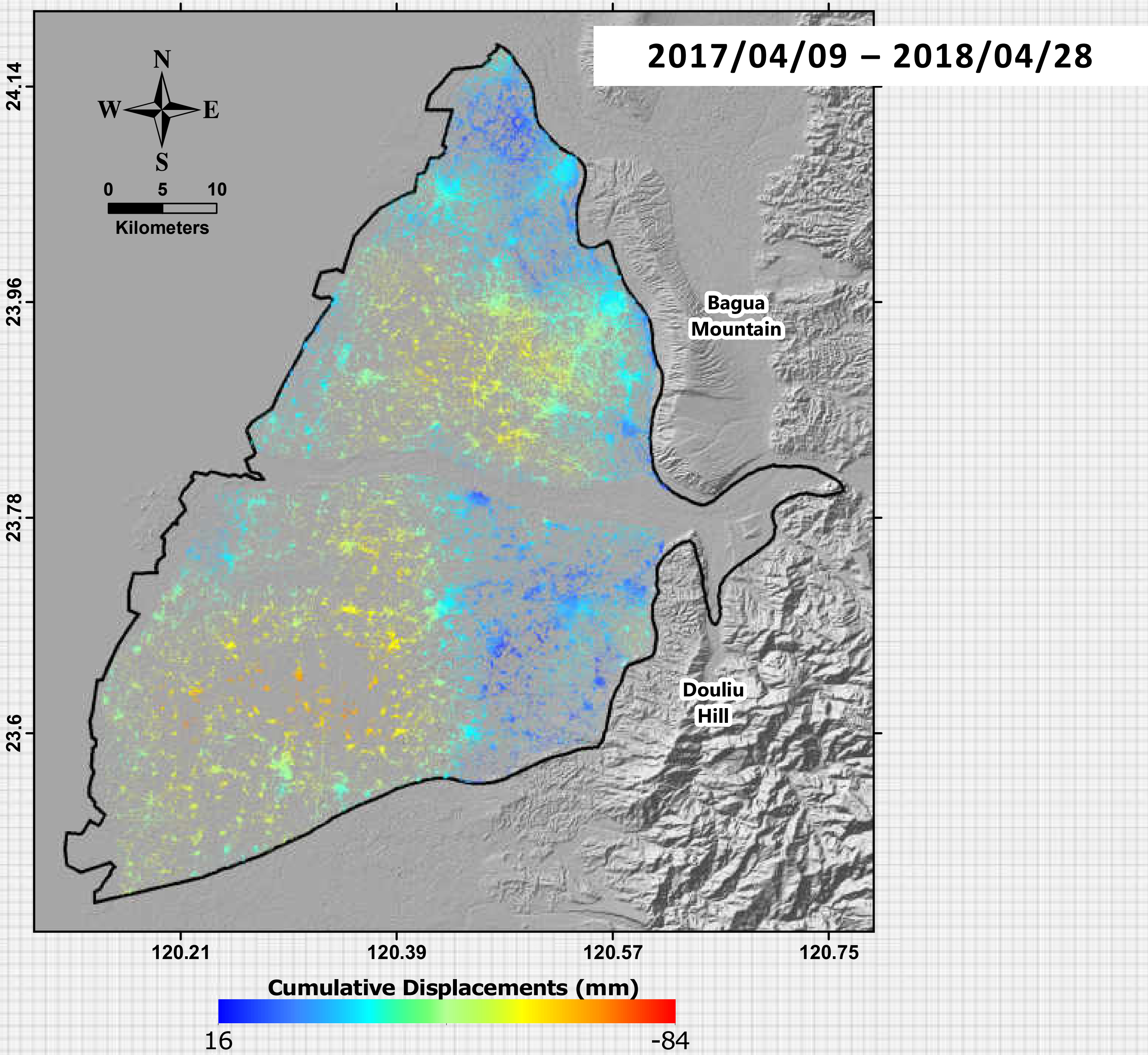

N
W
E
24.1
TKJS
(G): Slope = -58.91 mm/y
(I): Slope = -42.26 mm/y
MAE = 18.5 (mm)
RMSE = 22.1 (mm)
GPS
GPS Fit
InSAR
InSAR Fit
Cumulative Displacement (mm)
25
0
−25
−50
−75
−100
−125
2017/04
2017/05
2017/06
2017/07
2017/08
2017/09
2017/10
2017/11
2017/12
2018/01
2018/02
2018/03
2018/04
2018/05
2018/06
2018/07
2018/08
2018/09
2018/10
2018/11
2018/12
2019/01
2019/02
2019/03
2019/04
2019/05
2019/06
Time
YSLL
HUWE
GFES
NTUH
LNJS
TKJS
DNAN
MDES
KTES
Douliu Hill
23.6
SLES
PKGM
YWJS
GPS Stations
Study Area Boundary
120.2
120.4
120.6
120.8

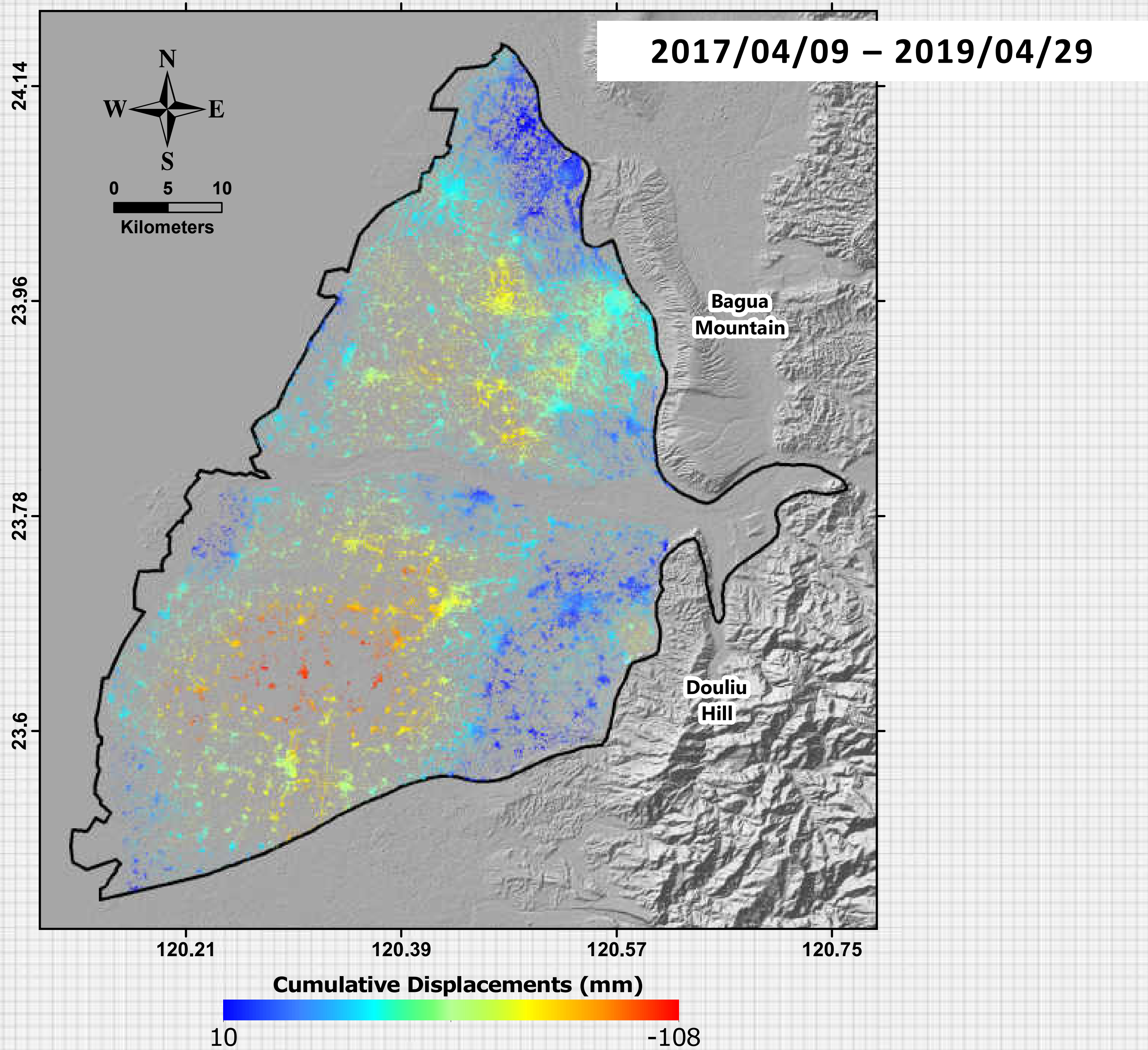


N
W
E
24.1
PKGM
(G): Slope = -29.02 mm/y
(I): Slope = -29.11 mm/y
MAE = 5.3 (mm)
RMSE = 6.8 (mm)
GPS
GPS Fit
InSAR
InSAR Fit
Cumulative Displacement (mm)
Time
YSLL
HUWE
GFES
NTUH
LNJS
HLES
TKJS
DNAN
MDES
KTES
Douliu Hill
SLES
PKGM
YWJS
23.6
GPS Stations
Study Area Boundary
120.2
120.4
120.6
120.8



N
W
E
24.1
PKGM
(G): Slope = -29.02 mm/y
(I): Slope = -29.11 mm/y
MAE = 5.3 (mm)
RMSE = 6.8 (mm)
GPS
GPS Fit
InSAR
InSAR Fit
Cumulative Displacement (mm)
Time
YSLL
HUWE
GFES
NTUH
LNJS
HLES
TKJS
DNAN
MDES
KTES
Douliu Hill
23.6
SLES
PKGM
YWJS
GPS Stations
Study Area Boundary
120.2
120.4
120.6
120.8


2017/04/09 – 2018/04/28
N
W
E
S
0 5 10
Kilometers
Bagua Mountain
Douliu Hill
24.14
23.96
23.78
23.6
120.21
120.39
120.57
120.75
Cumulative Displacements (mm)
16
-84


2017/04/09 – 2019/04/29
N
W
E
S
0
5
10
Kilometers
Bagua Mountain
Douliu Hill
24.14
23.96
23.78
23.6
120.21
120.39
120.57
120.75
Cumulative Displacements (mm)
10
-108

CONTENTS


END OF PRESENTATION
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