NATIONAL CENTRAL UNIVERSITY

GRADUATE INSTITUTE OF APPLIED GEOLOGY

Progress Report

Monitoring land subsidence in the Choushui River Fluvial Plain by utilizing the SBAS-PSInSAR method

2022/11/25

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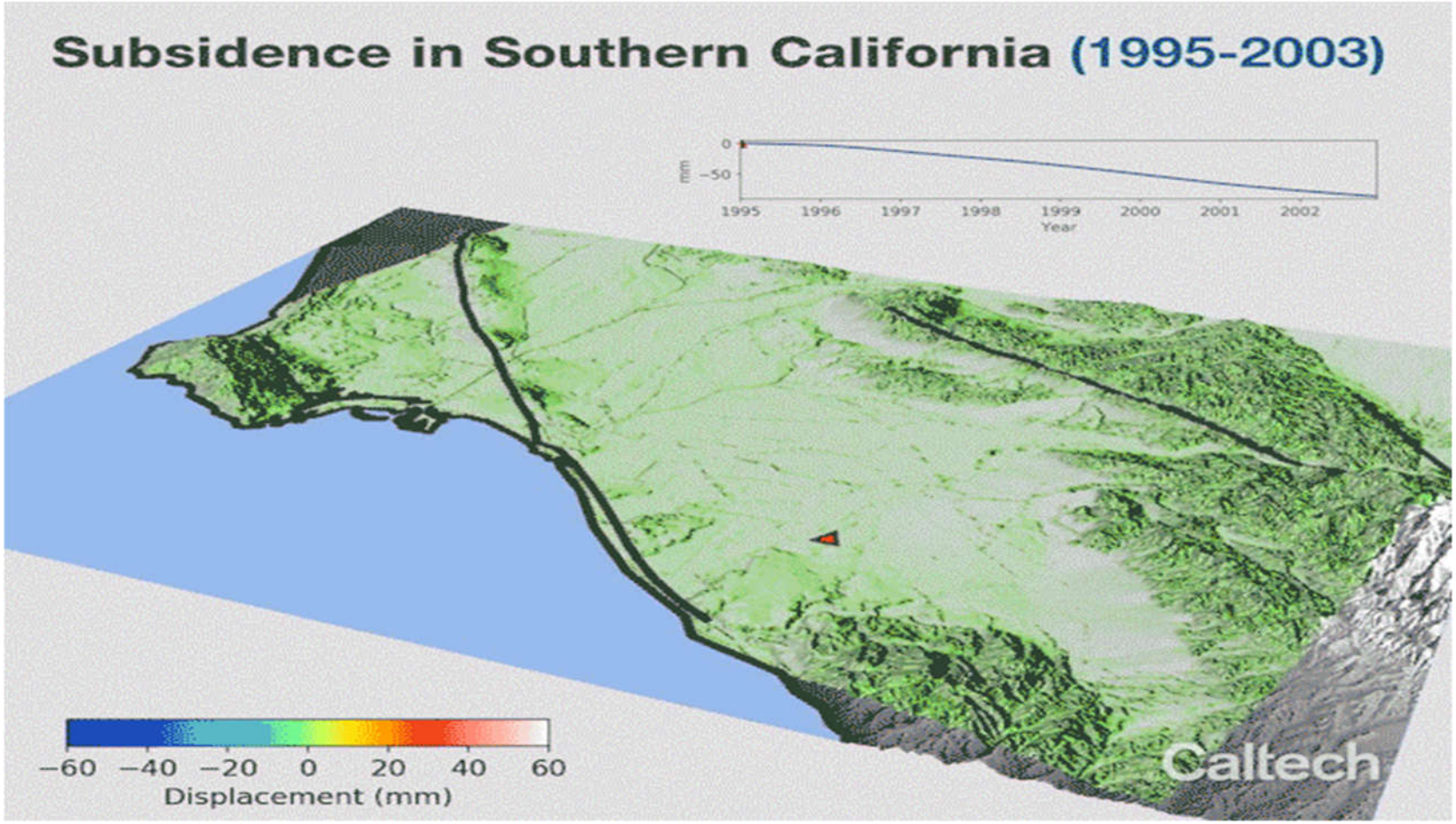
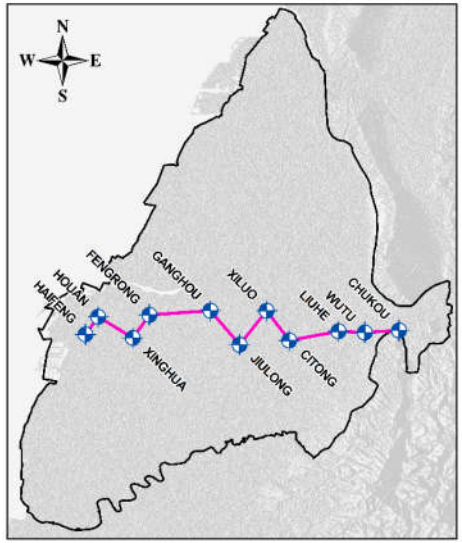
What is land subsidence?

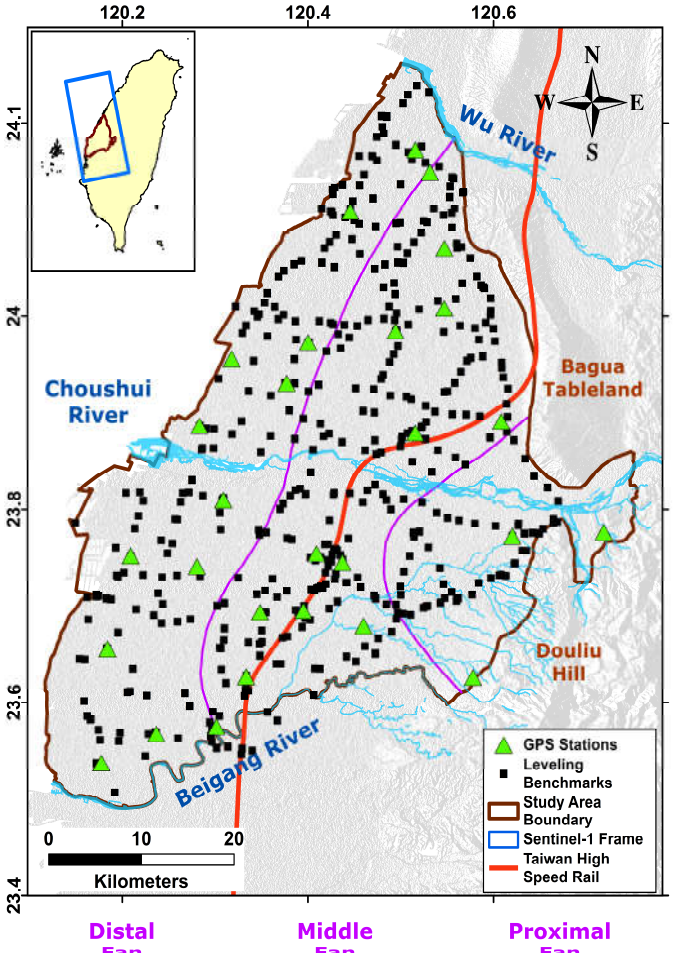
- Land surface sinking/settlement
- Vertical downward movement
- Not include *landslides*

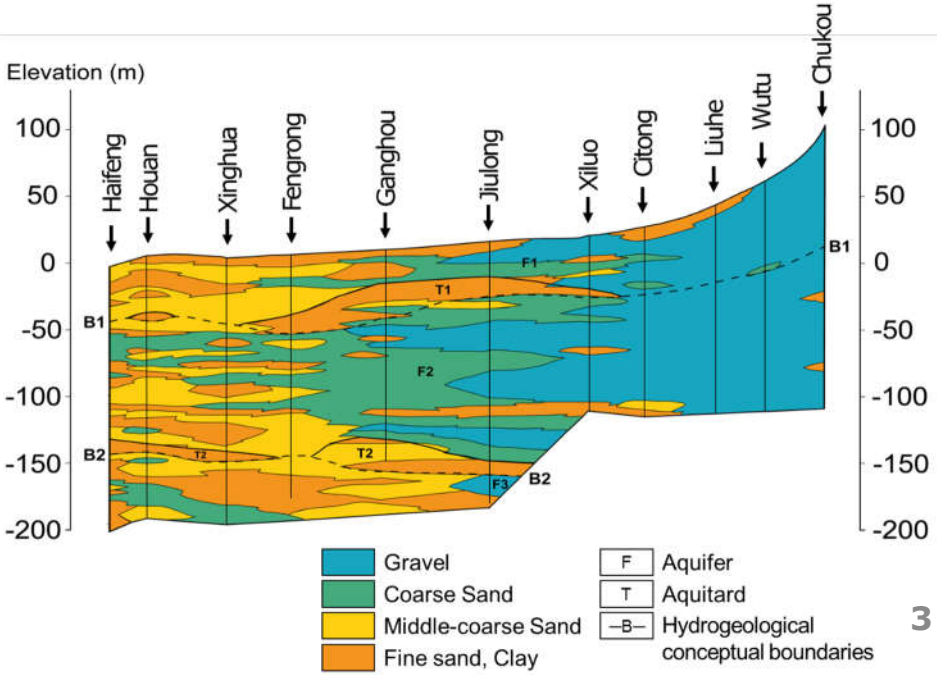


Study Area

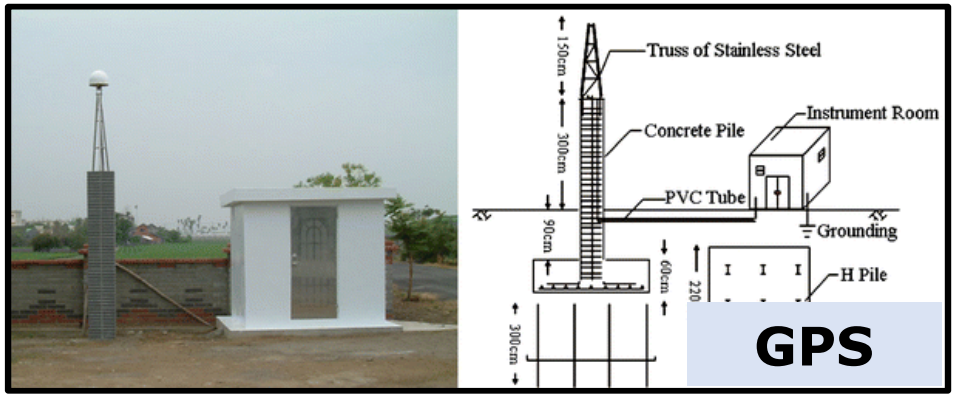
- Choushui River Fluvial Plain (in central region of Taiwan)
- Important agricultural area
- Groundwater for irrigation → Overextraction
- Land subsidence → Affect human lives and infrastructures



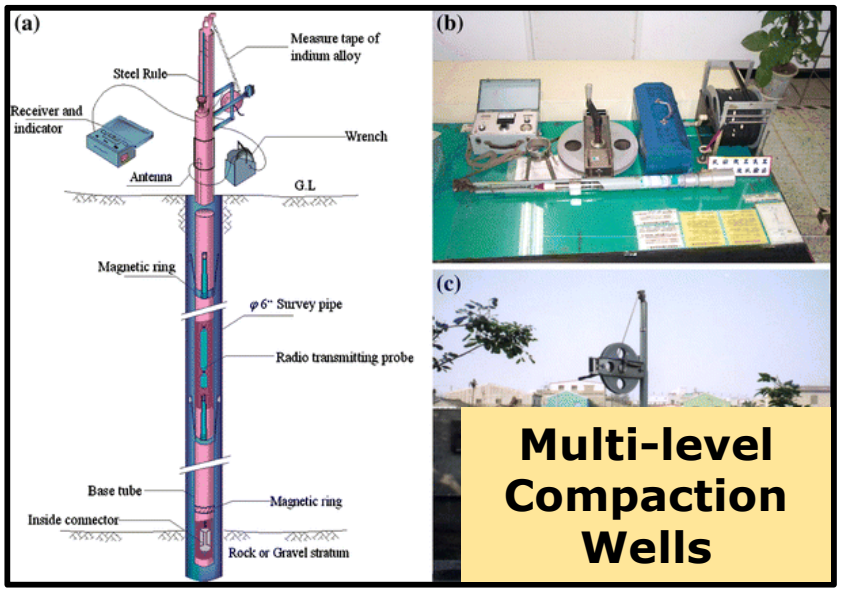




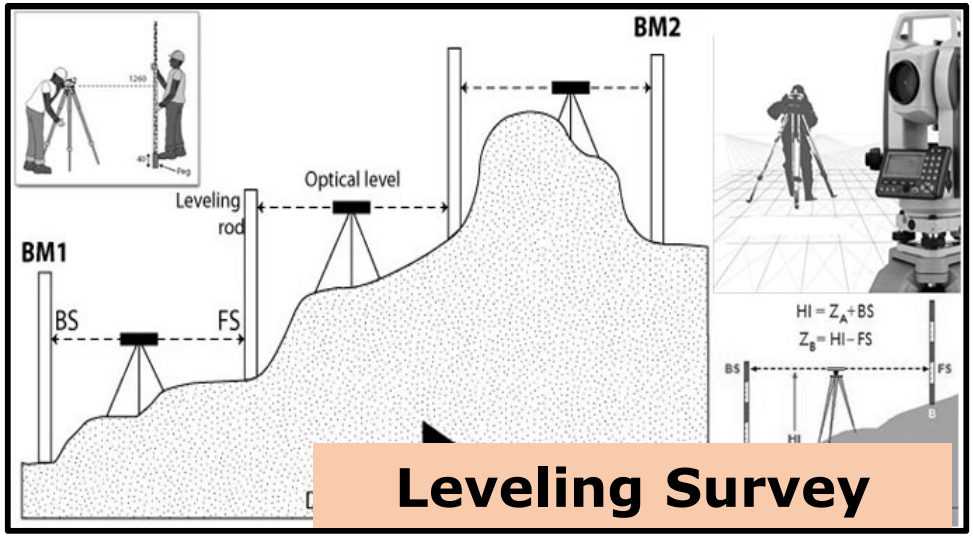
Current Monitoring Networks



GPS

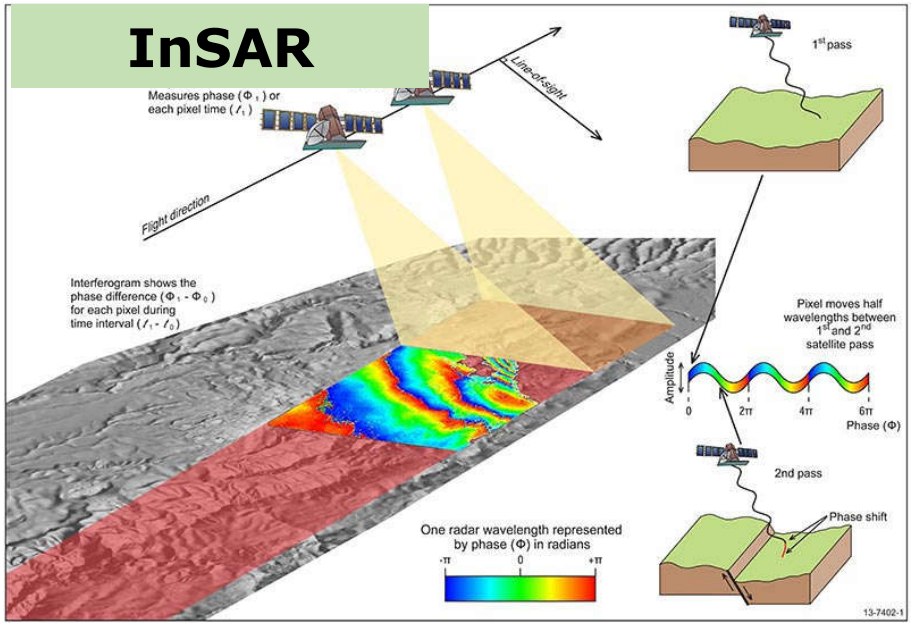


Multi-level Compaction Wells



Leveling Survey

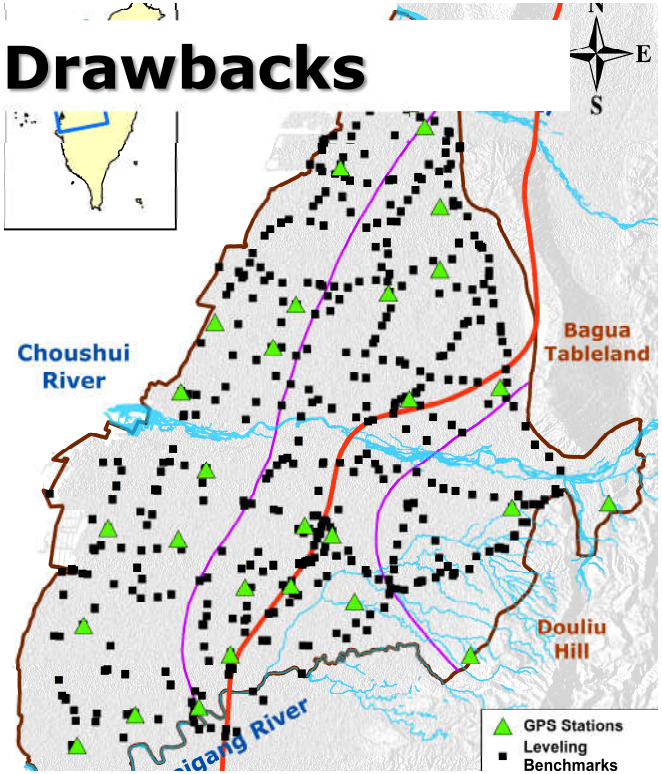
InSAR



Research Motivations

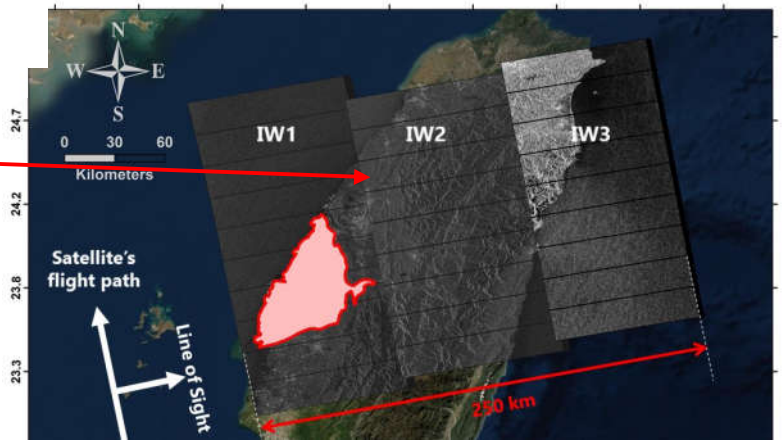
Traditional Monitoring Method Drawbacks

- GPS → Costly installation
- Leveling → Time-consuming
- Point-wise measurements
- Imply errors when interpolating values between points



SAR images and InSAR-based techniques

- Large coverage
- High visiting frequency
- Free data (Sentinel-1)



Research Motivations

Previous study inadequacies

- SBAS-InSAR only → phase unwrapping errors & time consuming
- Ignoring horizontal motions → simplify workflow

$$\delta_{vert} = \frac{\delta_{LOS}}{\cos\theta}$$

$$(\theta: incidence\ angle)$$

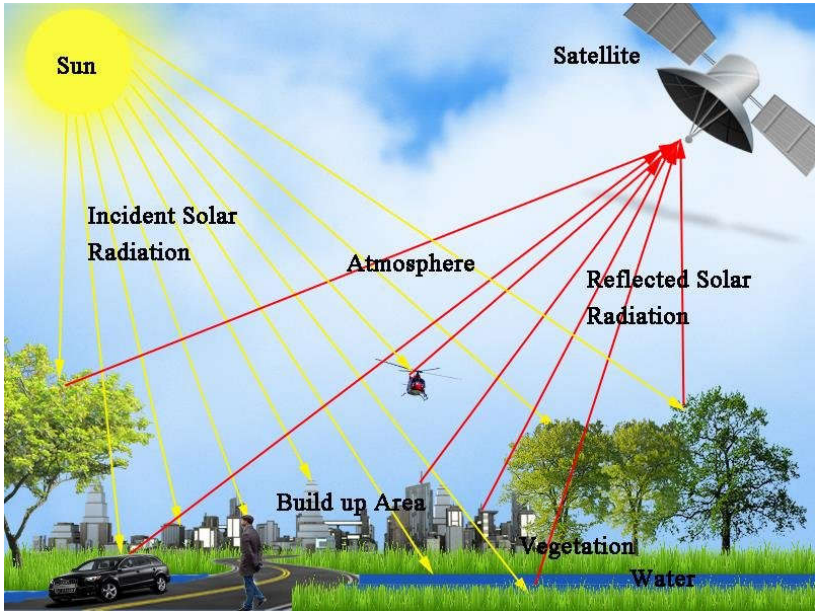
- Not showing deformation time series or subsidence profiles

Objectives

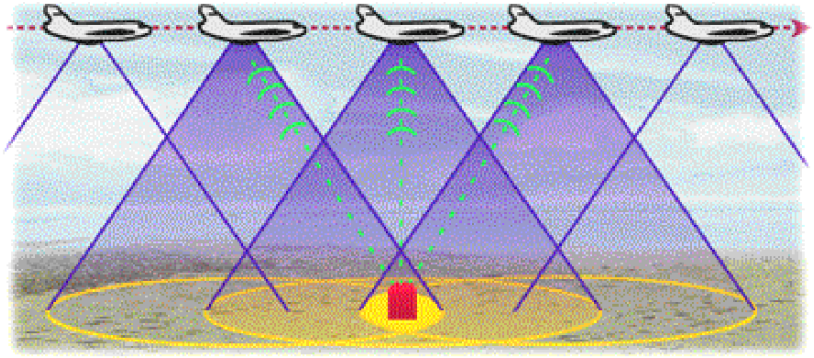
- Recent surface deformation in CRFP, 2016 – 2021
- Consider horizontal movements during calibration process
- Deformation time series in subsiding areas
- Show the subsidence profile along and across THSR

Optical satellite images & SAR images difference?

Different energy sources



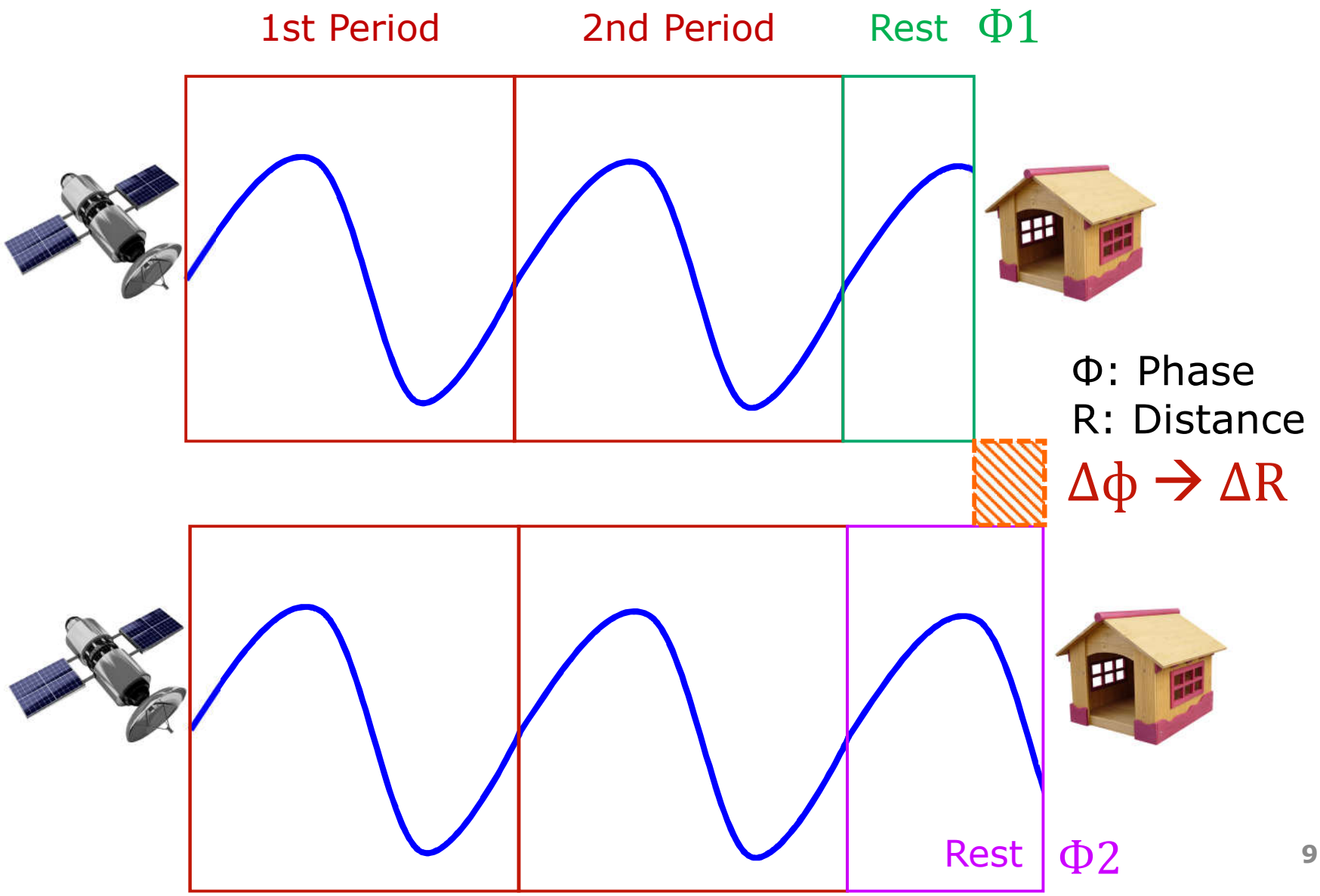
Optical images



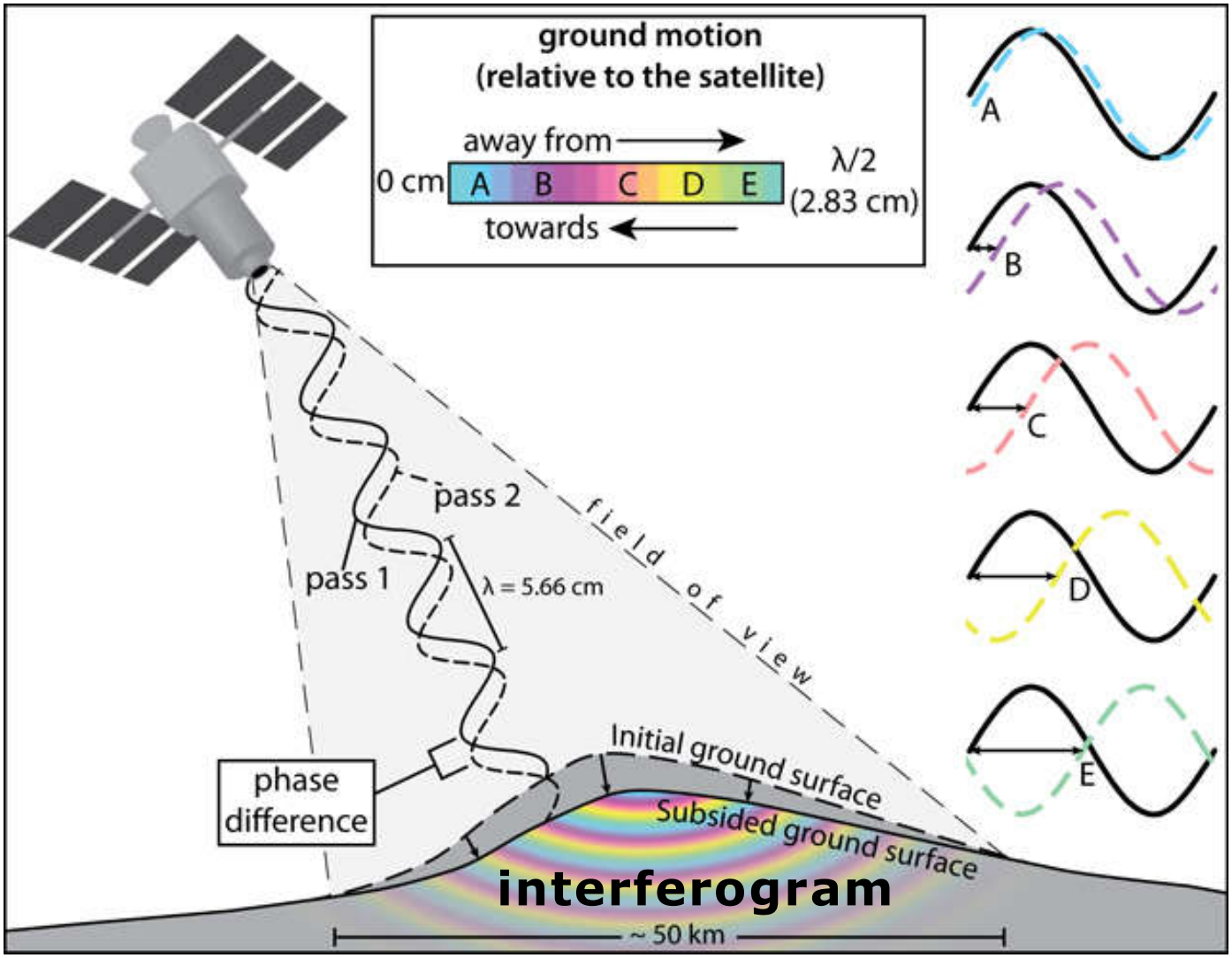
SAR* images

SAR : Synthetic Aperture Radar

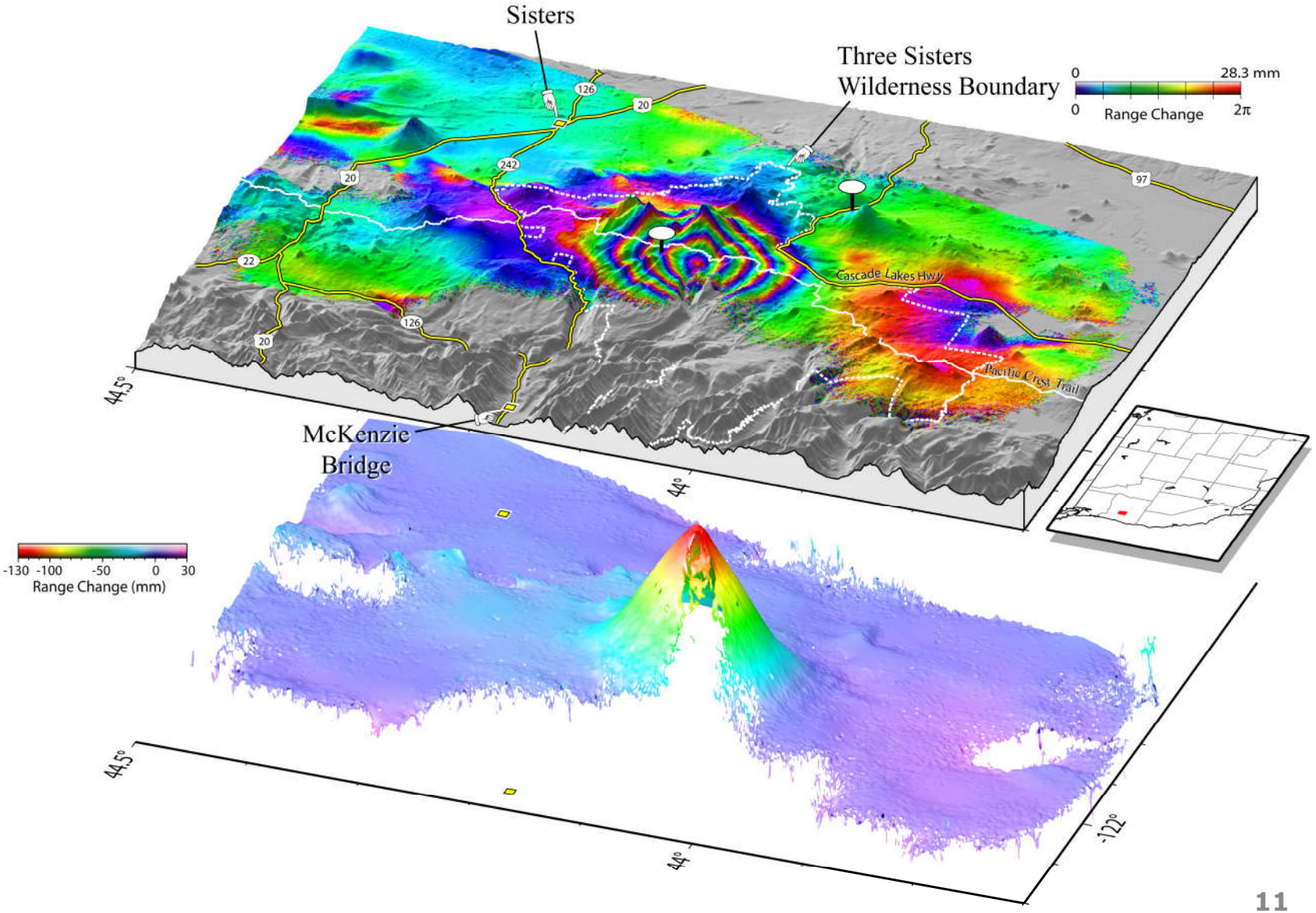
Phase Difference



Phase Difference

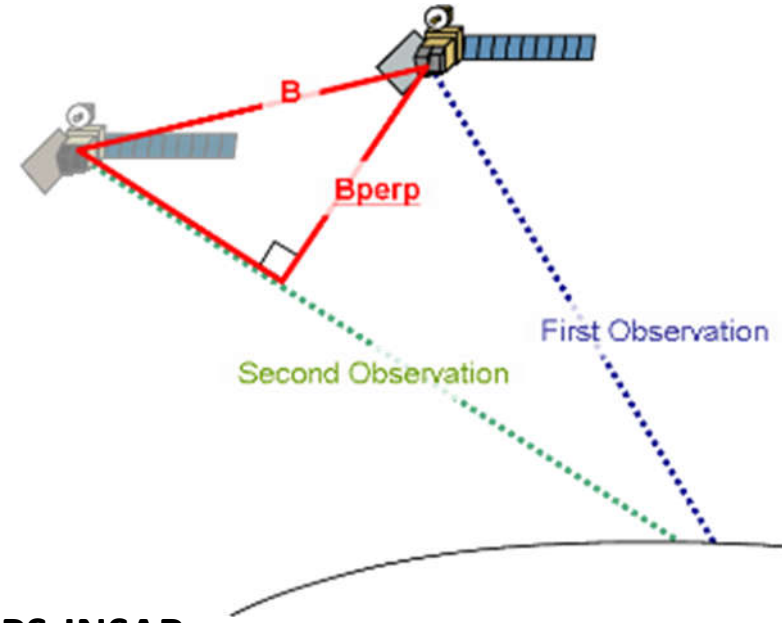


Phase Difference

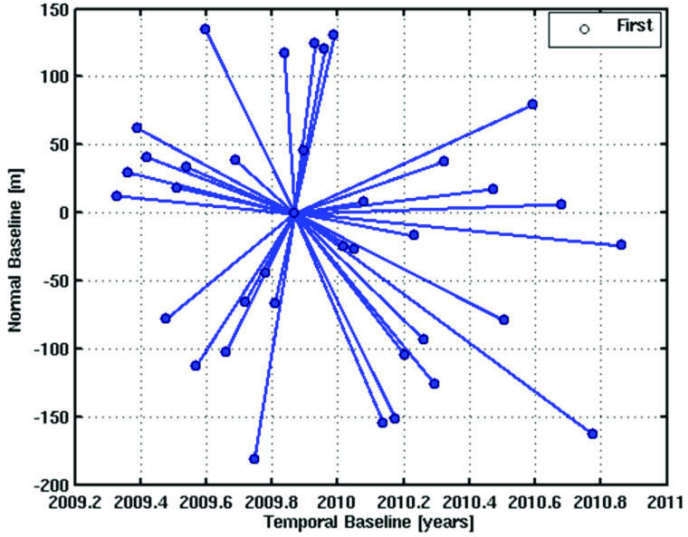


SBAS – Small Baseline Subset

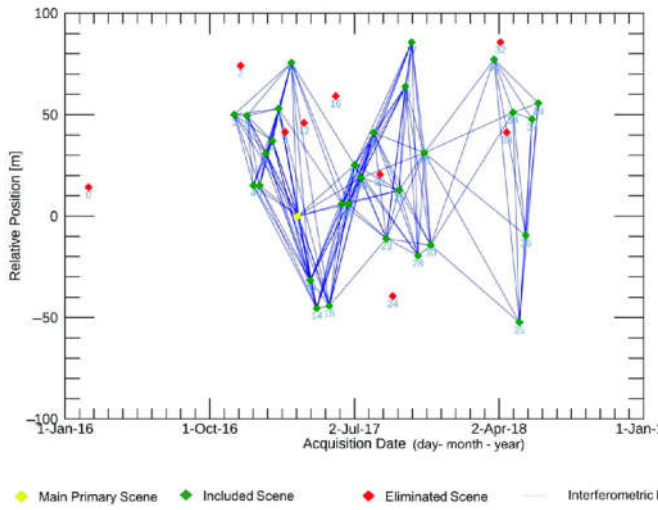
Ideal case: $\beta_{perp} = 0$



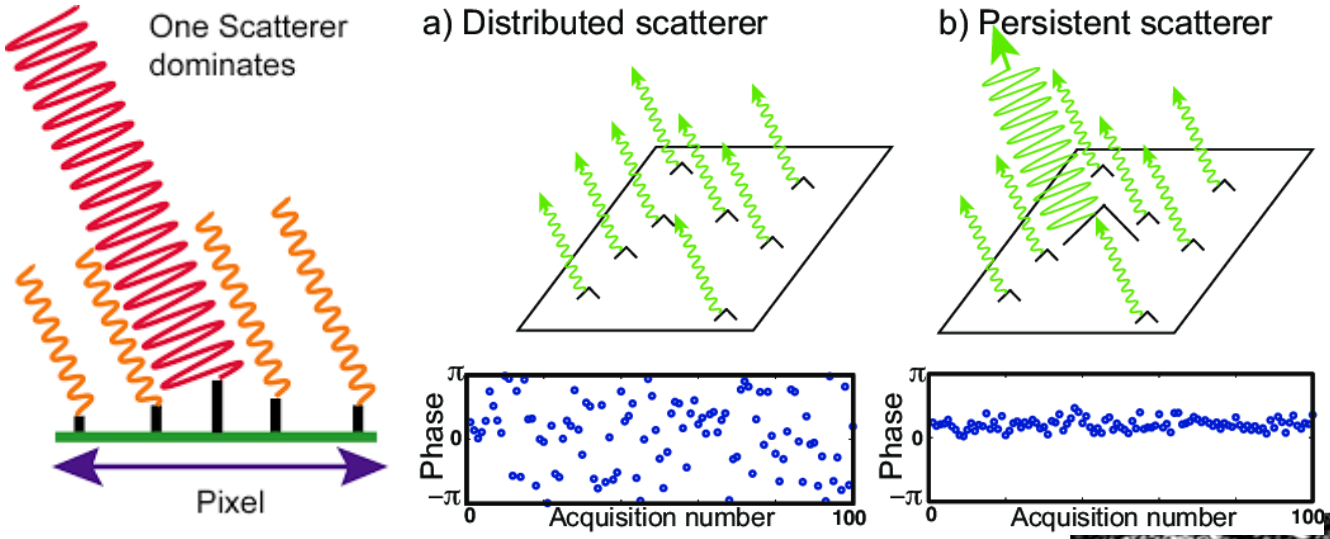
PS-INSAR



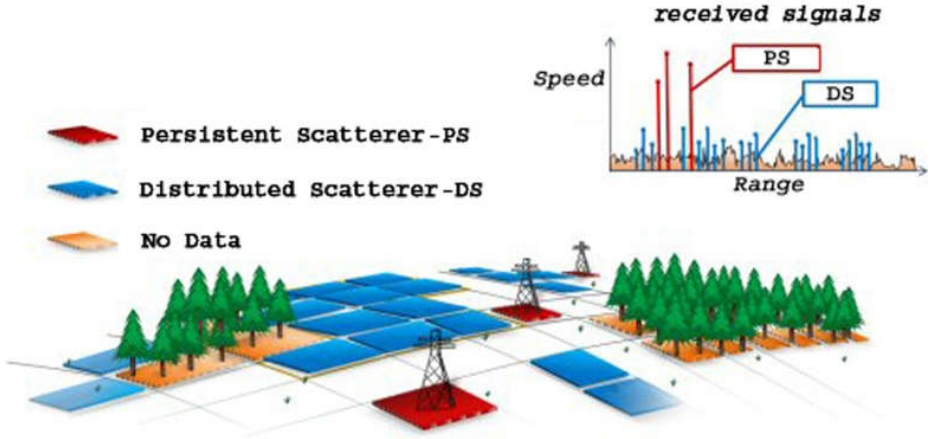
SBAS-INSAR



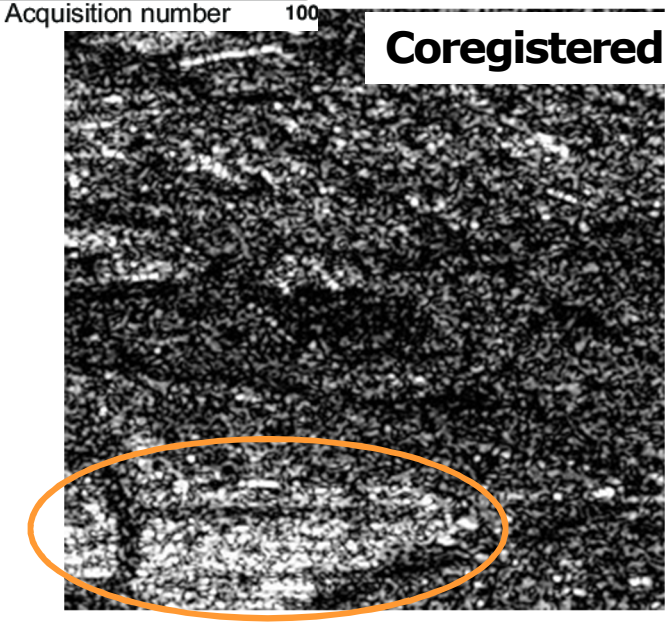
PS – Persistent Scatterers



Pixels that are highly correlated in backscattered amplitude and phase



Coregistered images



Data set

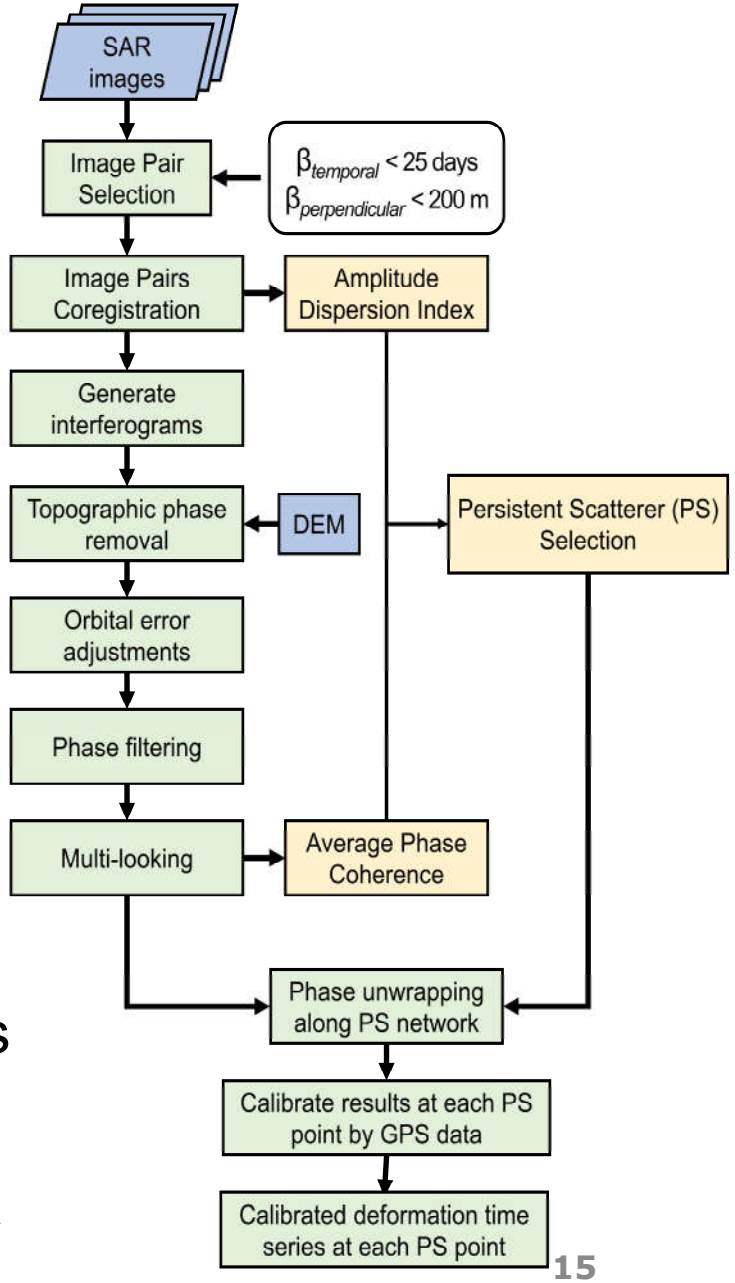
Table 1: Sentinel-1 data information		
	Sentinel-1A	Sentinel-1B
Orbit direction	Ascending	
Product Type	Single Look Complex (SLC), Interferometric Wide swath (IW) mode	
Path	69	69
Frame	74	73
Incidence Angle (degree)	31º – 46º	
Heading Angle (degree)	347.6 º	
Azimuth resolution (m)	20	
Range resolution (m)	5	
Polarization	VV+VH	
Number of images	151	88
Acquisition Period	14th April 2016 – 31st May 2021	

Workflow Summary

1. **Image Pair Selection:**
   - Maximum num. of image pairs
   - Avoid temporal and spatial decorrelation
2. **Noise phase removal**
3. **Select stable scattering pixels** by:
   - High average phase coherence
   - Low amplitude dispersion index

$$D_A = \frac{\sigma_{amp.}}{\mu_{amp..}}$$

4. **Phase unwrapping** to get displacements at stable pixels
5. **Calibrate** raw displacements by GPS data

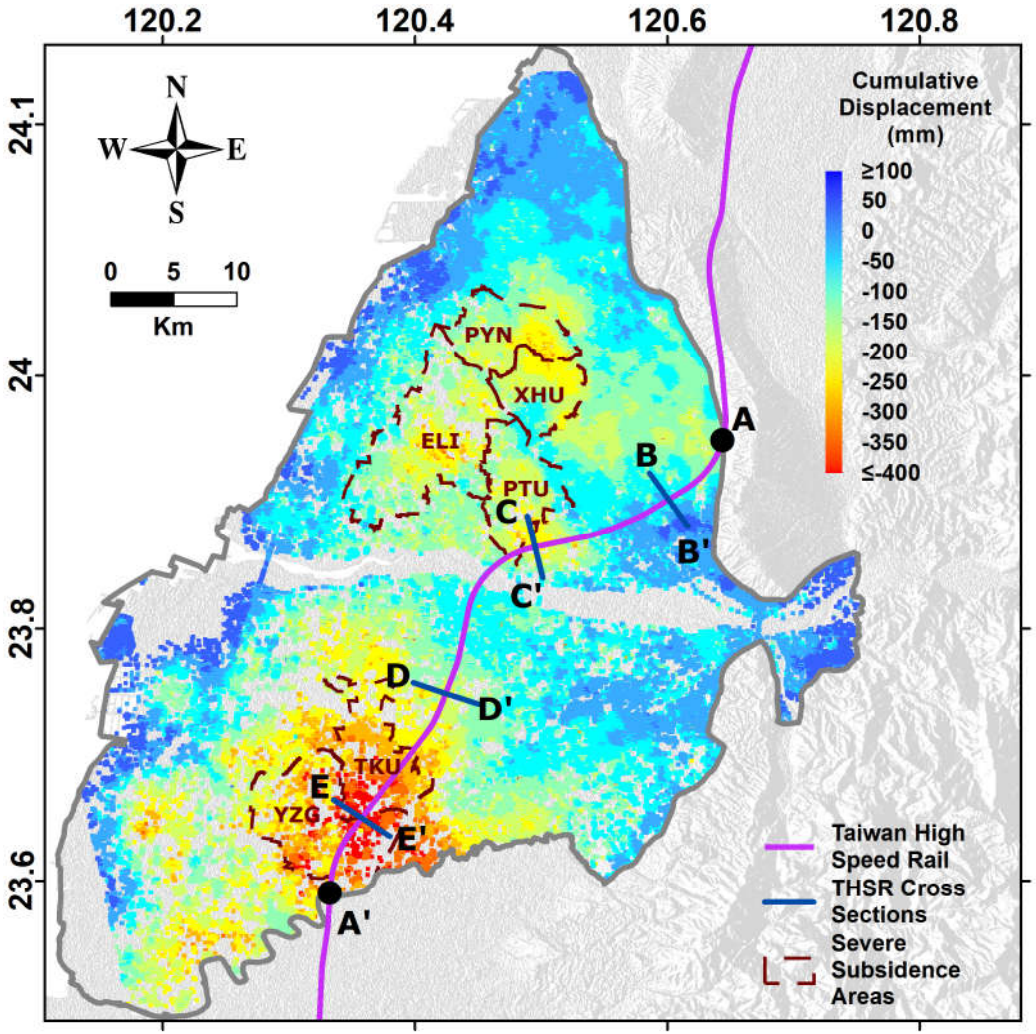


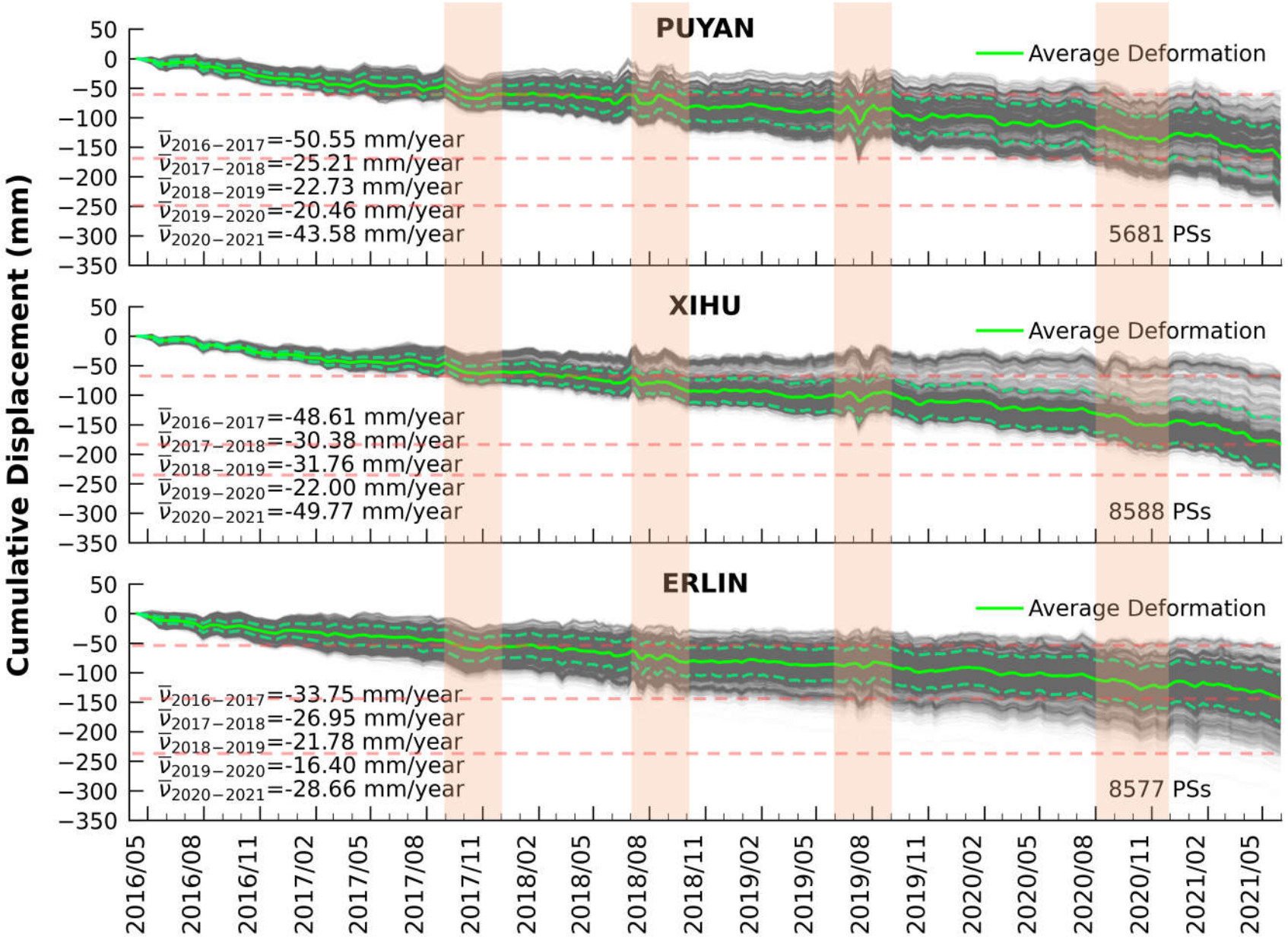
Cumulative deformation map

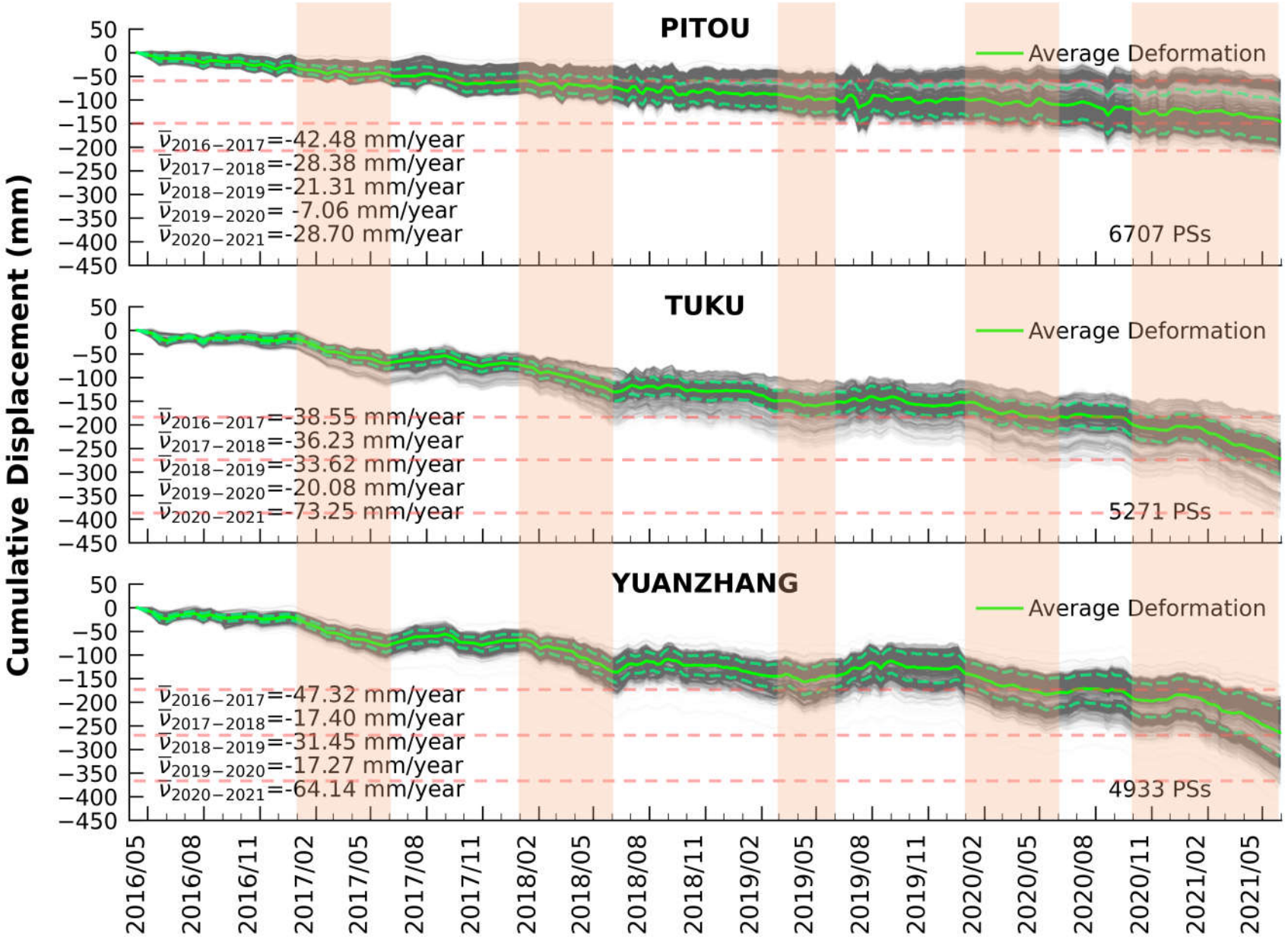
- Period 4/2016 – 5/2021
- Temporally relative to the first acquisition (2016/4/14)

- Three subsidence bowls in Changhua
- C.Disp. up to -25 cm (max.)
- Average velocity -2 to -4 cm/year

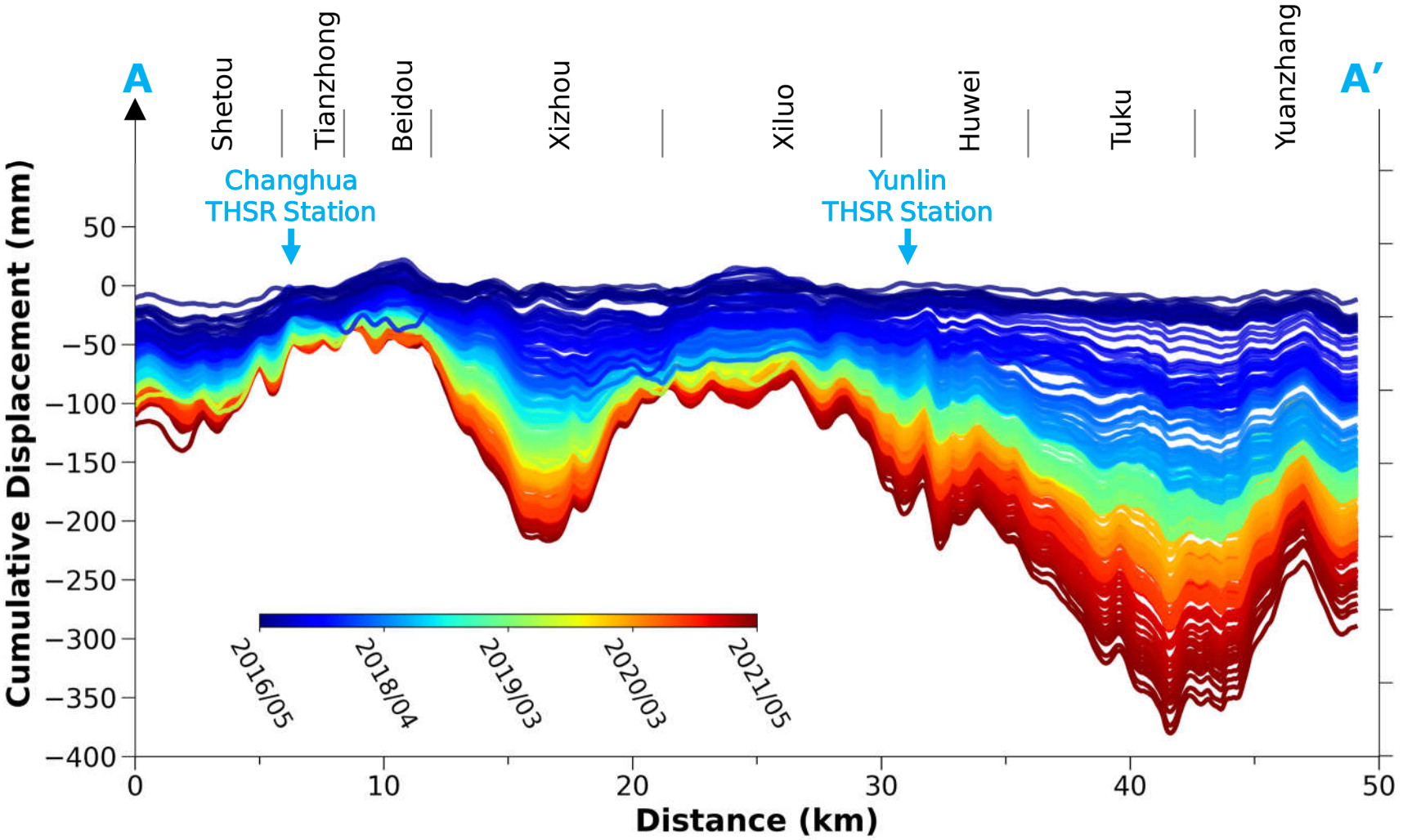
- A large subsiding spot centered at border Tuku – Yuanzhang
- Max. C.Disp. reach nearly -40 cm
- Avg. Velocity -3 to >-6 cm/year



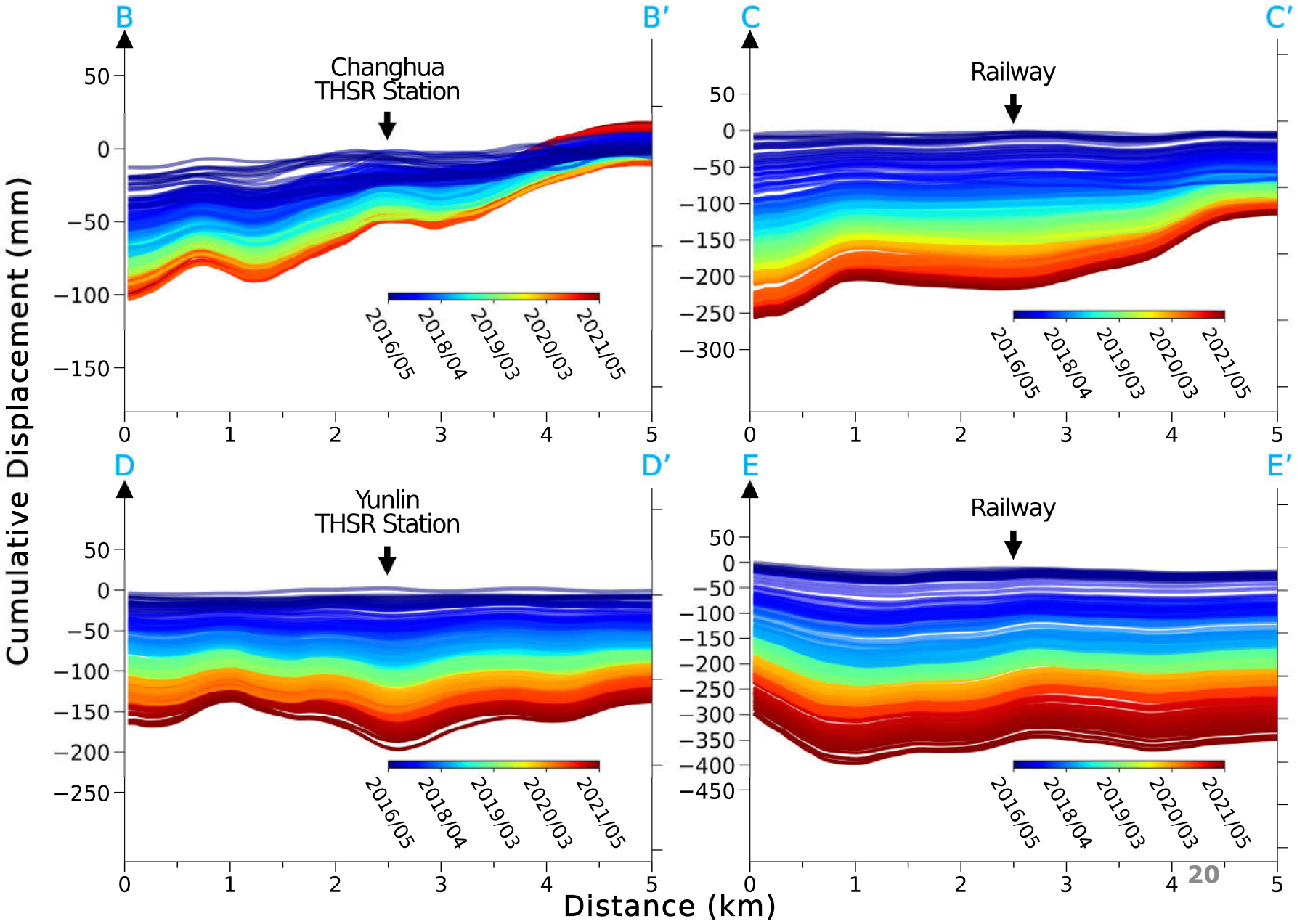

PUYAN
Average Deformation
$\bar{v}_{2016-2017}$=-50.55 mm/year
$\bar{v}_{2017-2018}$=-25.21 mm/year
$\bar{v}_{2018-2019}$=-22.73 mm/year
$\bar{v}_{2019-2020}$=-20.46 mm/year
$\bar{v}_{2020-2021}$=-43.58 mm/year
5681 PSs
XIHU
Average Deformation
$\bar{v}_{2016-2017}$=-48.61 mm/year
$\bar{v}_{2017-2018}$=-30.38 mm/year
$\bar{v}_{2018-2019}$=-31.76 mm/year
$\bar{v}_{2019-2020}$=-22.00 mm/year
$\bar{v}_{2020-2021}$=-49.77 mm/year
8588 PSs
ERLIN
Average Deformation
$\bar{v}_{2016-2017}$=-33.75 mm/year
$\bar{v}_{2017-2018}$=-26.95 mm/year
$\bar{v}_{2018-2019}$=-21.78 mm/year
$\bar{v}_{2019-2020}$=-16.40 mm/year
$\bar{v}_{2020-2021}$=-28.66 mm/year
8577 PSs
Cumulative Displacement (mm)
50
0
−50
−100
−150
−200
−250
−300
−350
2016/05
2016/08
2016/11
2017/02
2017/05
2017/08
2017/11
2018/02
2018/05
2018/08
2018/11
2019/02
2019/05
2019/08
2019/11
2020/02
2020/05
2020/08
2020/11
2021/02
2021/05


PITOU
Average Deformation
$\bar{v}_{2016-2017}$=-42.48 mm/year
$\bar{v}_{2017-2018}$=-28.38 mm/year
$\bar{v}_{2018-2019}$=-21.31 mm/year
$\bar{v}_{2019-2020}$= -7.06 mm/year
$\bar{v}_{2020-2021}$=-28.70 mm/year
6707 PSs
TUKU
Average Deformation
$\bar{v}_{2016-2017}$=-38.55 mm/year
$\bar{v}_{2017-2018}$=-36.23 mm/year
$\bar{v}_{2018-2019}$=-33.62 mm/year
$\bar{v}_{2019-2020}$=-20.08 mm/year
$\bar{v}_{2020-2021}$=-73.25 mm/year
5271 PSs
YUANZHANG
Average Deformation
$\bar{v}_{2016-2017}$=-47.32 mm/year
$\bar{v}_{2017-2018}$=-17.40 mm/year
$\bar{v}_{2018-2019}$=-31.45 mm/year
$\bar{v}_{2019-2020}$=-17.27 mm/year
$\bar{v}_{2020-2021}$=-64.14 mm/year
4933 PSs
Cumulative Displacement (mm)
50
0
−50
−100
−150
−200
−250
−300
−350
−400
−450
2016/05
2016/08
2016/11
2017/02
2017/05
2017/08
2017/11
2018/02
2018/05
2018/08
2018/11
2019/02
2019/05
2019/08
2019/11
2020/02
2020/05
2020/08
2020/11
2021/02
2021/05

Cumulative subsidence along THSR



Cumulative subsidence across THSR



- Apply SBAS-PSInSAR method to analyze 239 Sentinel-1's SAR images
- Monitoring land subsidence development in CRFP (2016 – 2021)
- Results calibrated by GPS and validated by leveling survey

- Three subsidence bowls in **Changhua**, c.disp. up to -25 cm; average velocity -2 → -4 cm/year
- A huge subsidence bowl in **Yunlin**, c.disp. Reach -40 cm; average velocity -3 → -6 cm/year
- Deformation time-series show stronger variations in Yunlin
- Subsidence THSR profiles indicate 3 serious subsidence locations, average velocity -3 → -6 cm/year
- Subsidence velocity accelerate in 2020 – 2021


THANK YOU
FOR YOUR
ATTENTION

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**,

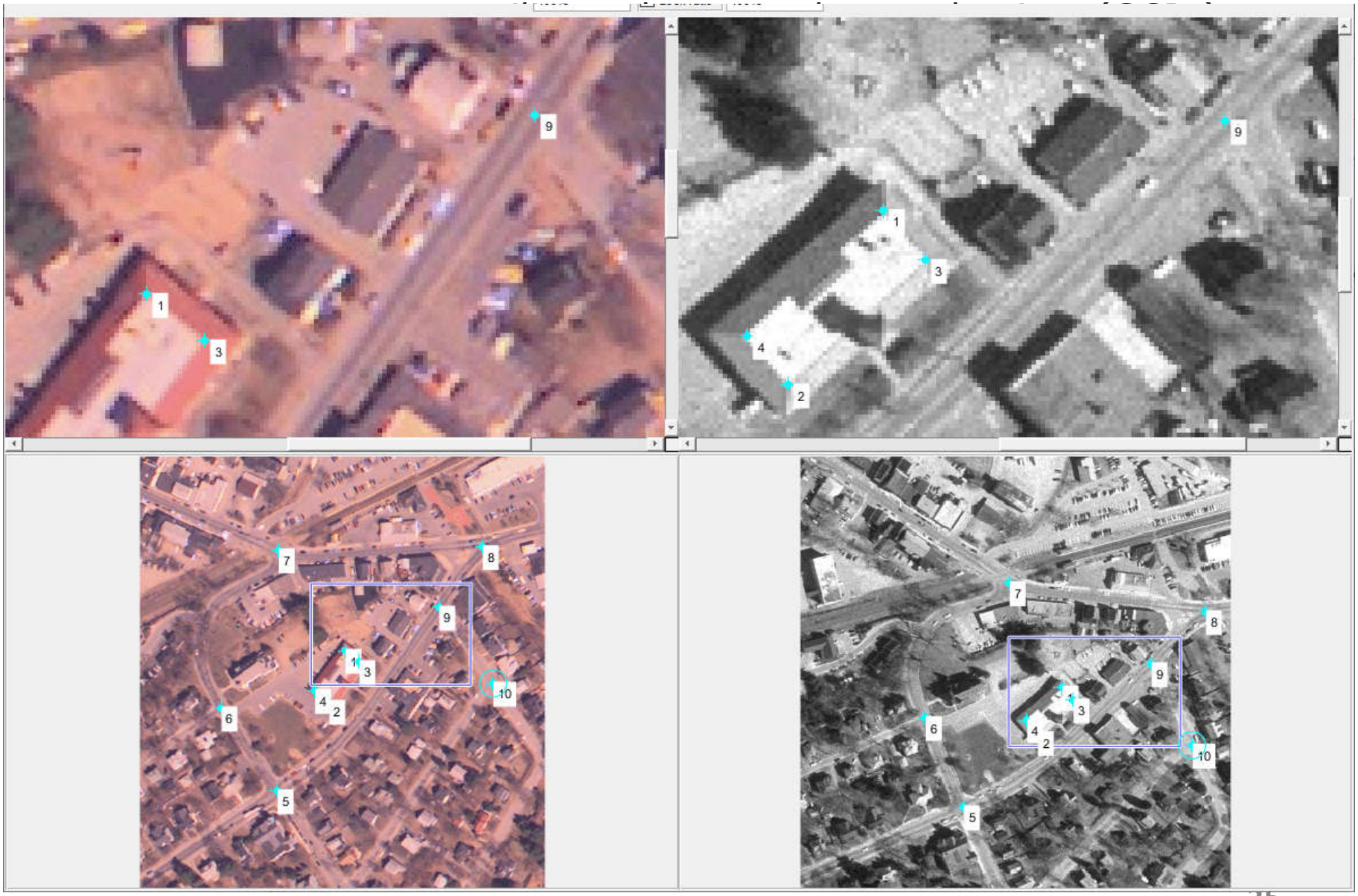


Image 1 spatially aligned with **Image 2**, utilizing the ground control points (GCPs)

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

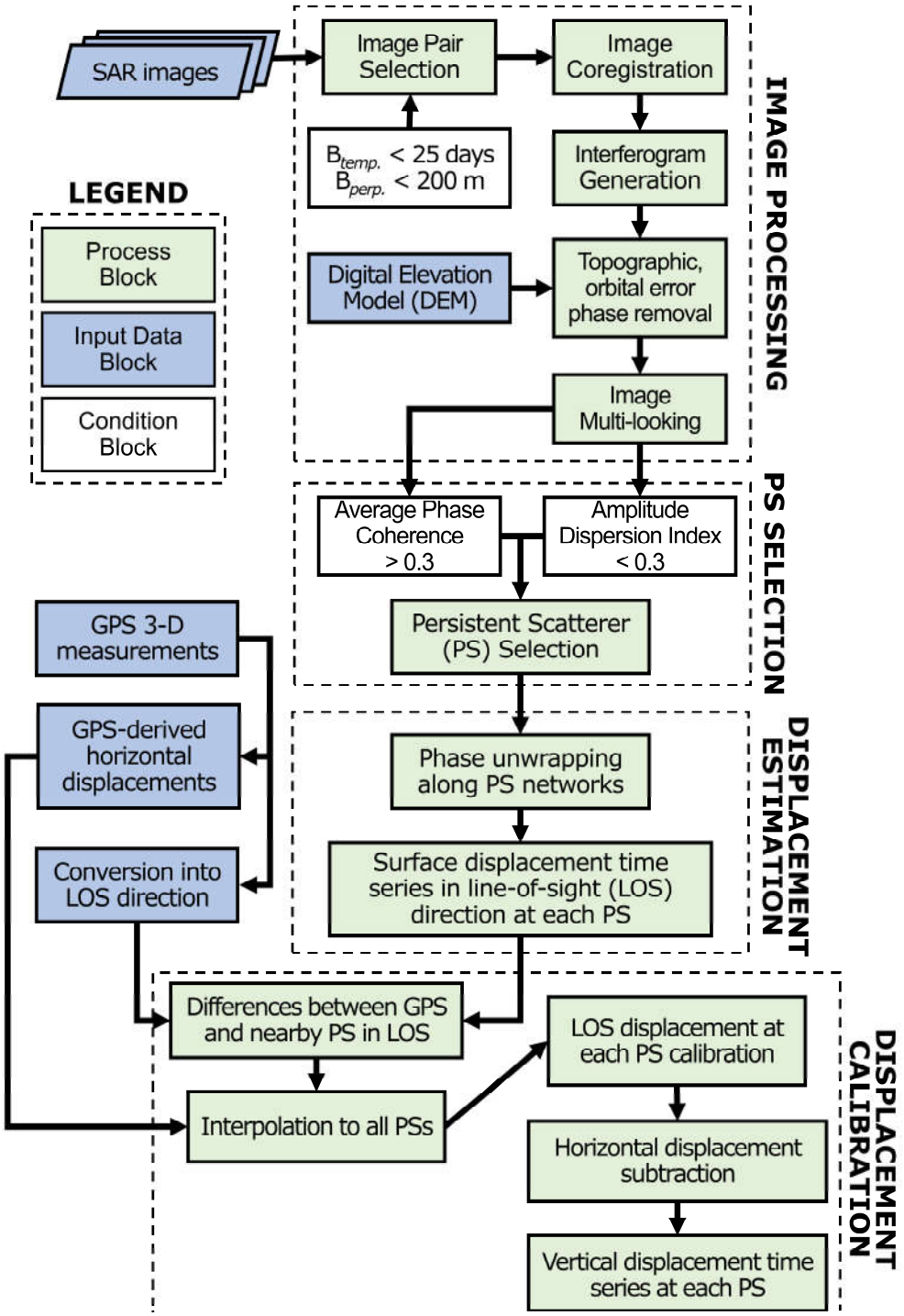
$$C_2(r,a) = A_2(r,a)e^{i\varphi_2(r,a)}$$

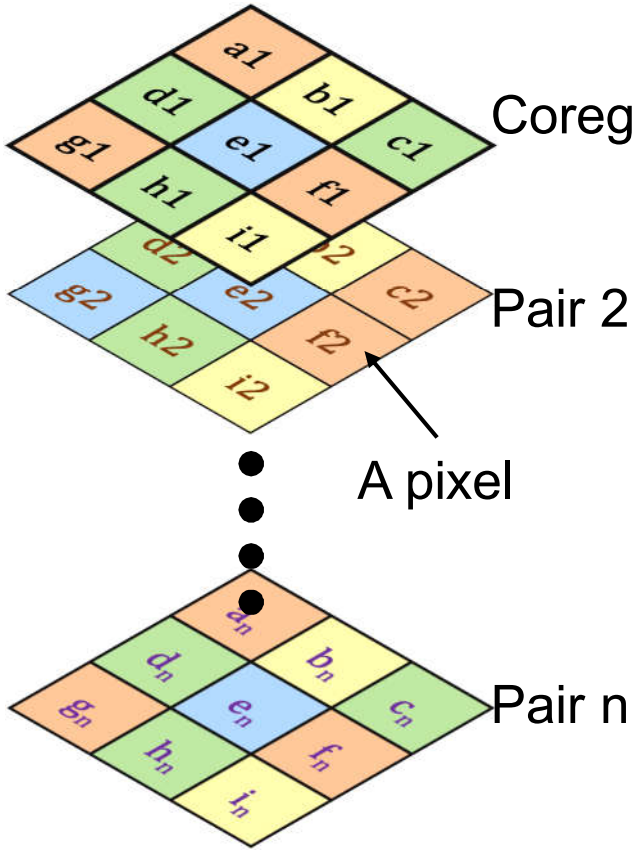
A complex interferogram

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

* 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.


SAR images
Image Pair Selection
Image Coregistration
$B_{temp.}$ < 25 days
$B_{perp.}$ < 200 m
Interferogram Generation
Digital Elevation Model (DEM)
Topographic, orbital error phase removal
Image Multi-looking
IMAGE PROCESSING
LEGEND
Process Block
Input Data Block
Condition Block
Average Phase Coherence > 0.3
Amplitude Dispersion Index < 0.3
Persistent Scatterer (PS) Selection
PS SELECTION
GPS 3-D measurements
GPS-derived horizontal displacements
Conversion into LOS direction
Phase unwrapping along PS networks
Surface displacement time series in line-of-sight (LOS) direction at each PS
DISPLACEMENT ESTIMATION
Differences between GPS and nearby PS in LOS
Interpolation to all PSs
LOS displacement at each PS calibration
Horizontal displacement subtraction
Vertical displacement time series at each PS
DISPLACEMENT CALIBRATION



PERSISTENT SCATTERER EXTRACTION

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

D_A : Amplitude Dispersion Index

σ_A: St.Dev of amplitude values

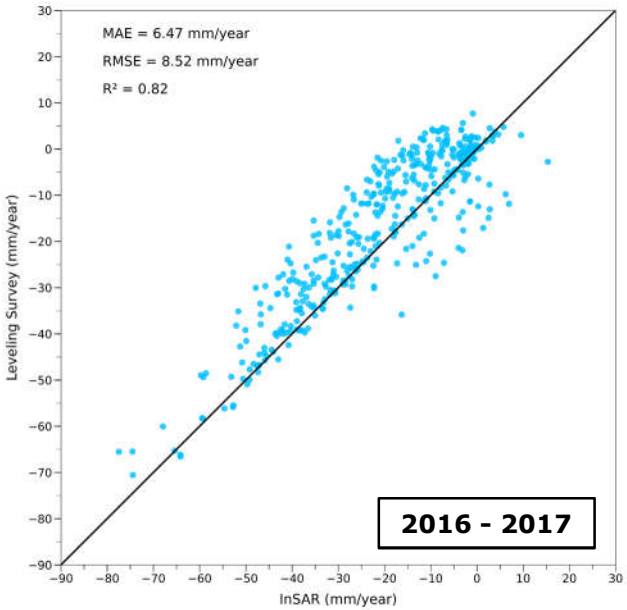
m_A: Mean of amplitude values

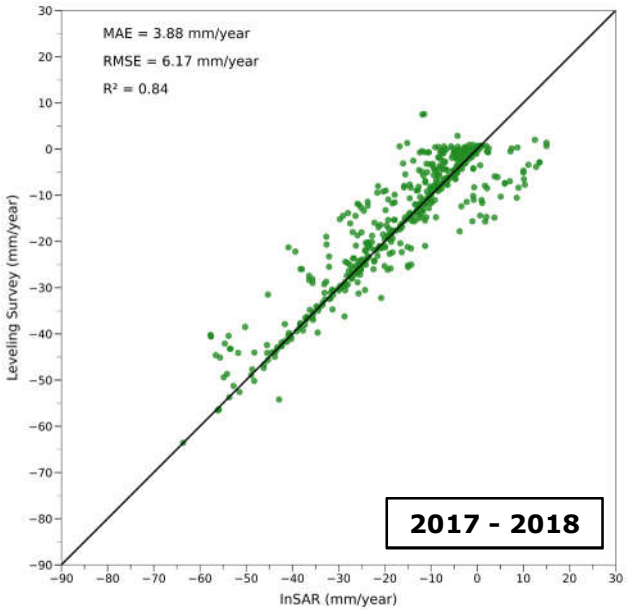
$$\boldsymbol{D_A \leq 0.3}$$

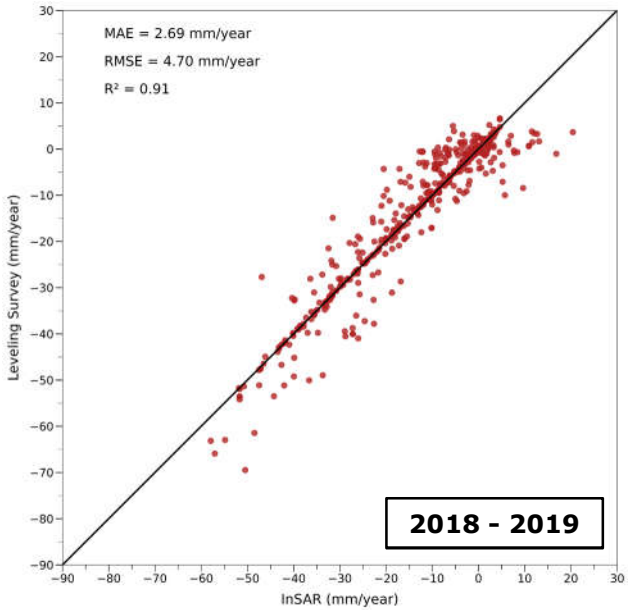
$$m_a = \frac{1}{k}\sum_{k=1}^{n} a_k$$

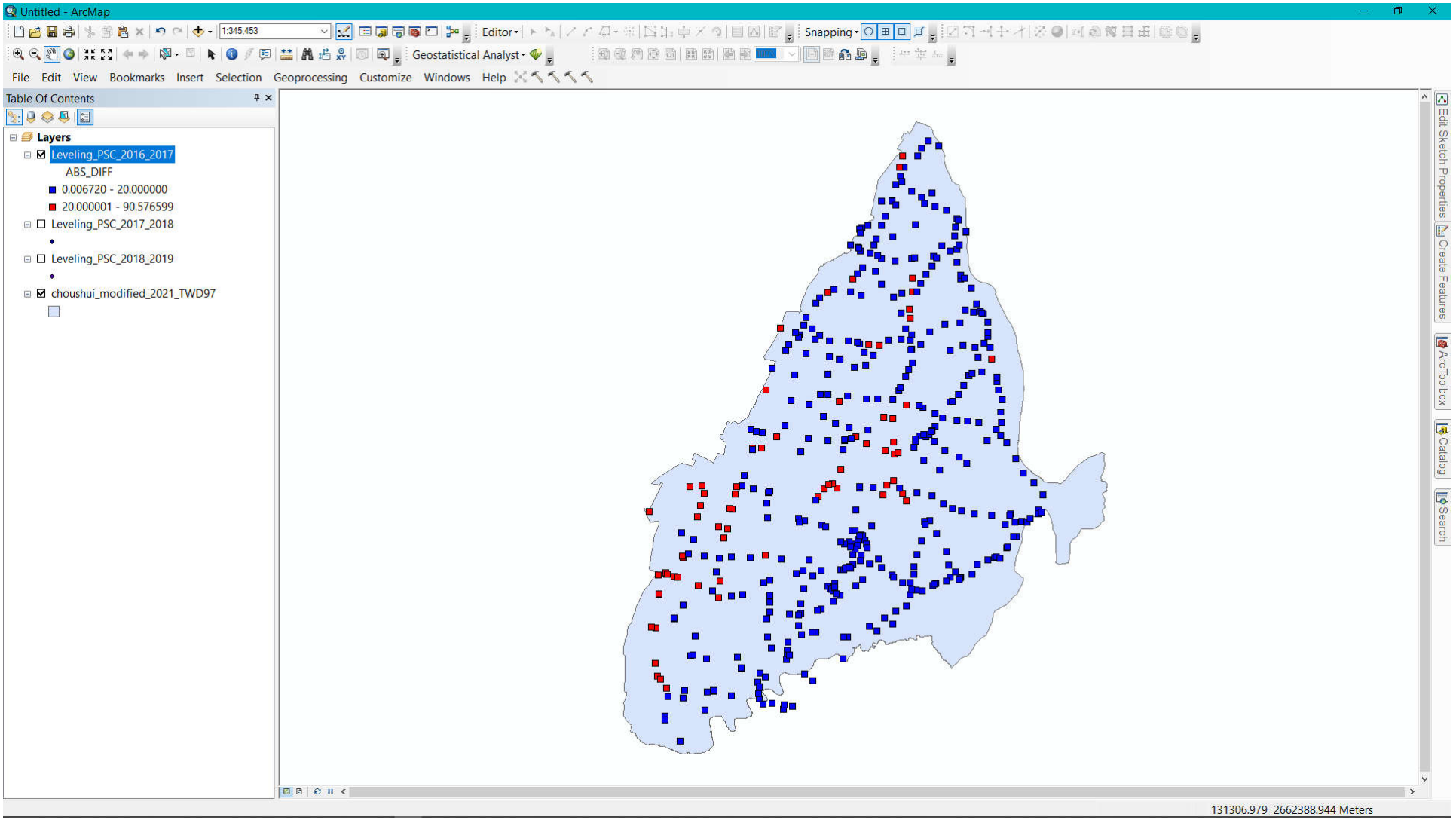
$$\sigma_a = \sqrt{\frac{1}{k}\sum_{k=1}^{n}(a_k - m_a)}$$

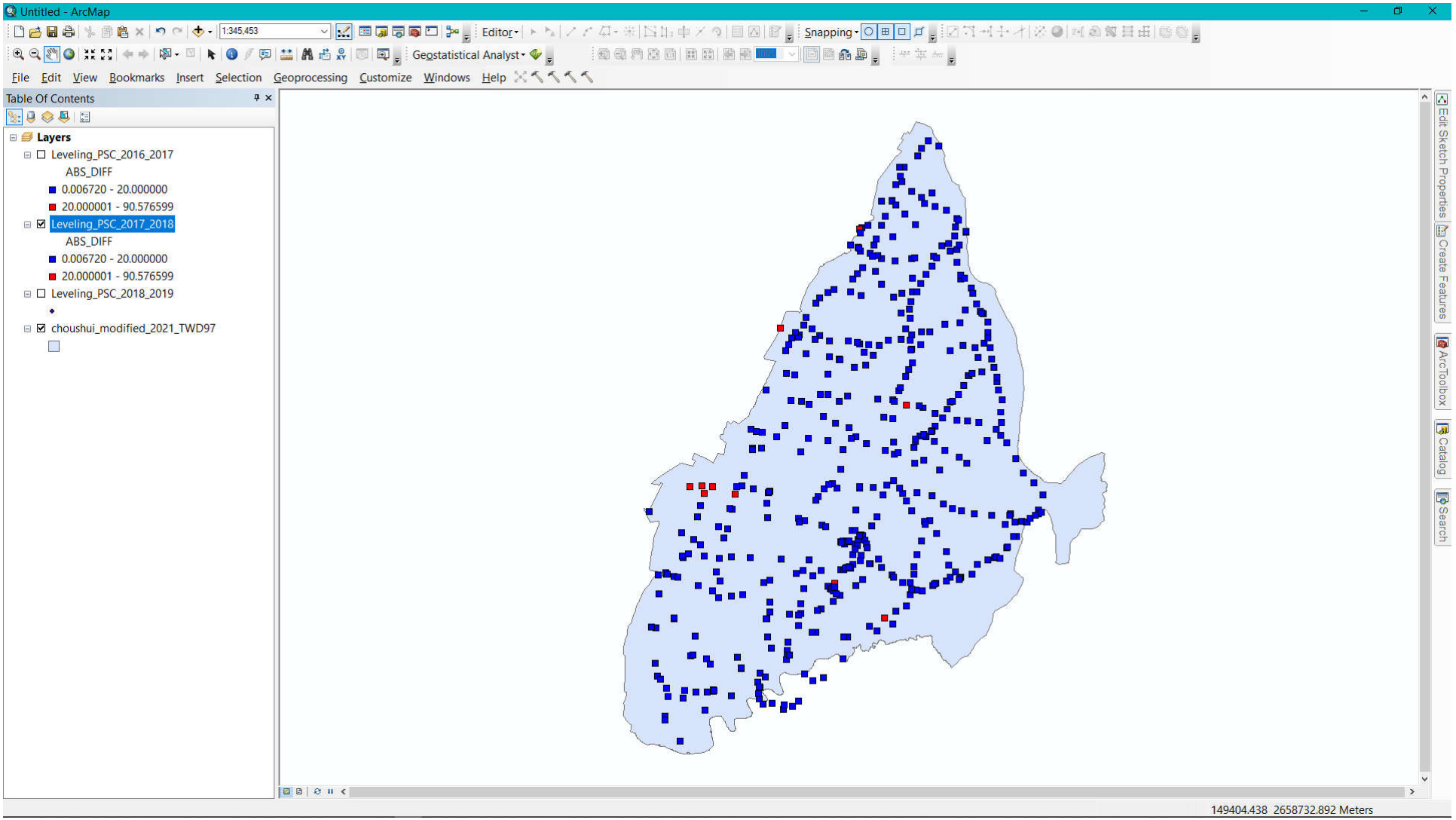
Validation by Leveling








Untitled - ArcMap
1:345,453
Editor
Snapping
Geostatistical Analyst
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
Table Of Contents
Layers
Leveling_PSC_2016_2017
ABS_DIFF
0.006720 - 20.000000
20.000001 - 90.576599
Leveling_PSC_2017_2018
Leveling_PSC_2018_2019
choushui_modified_2021_TWD97
Edit Sketch Properties
Create Features
ArcToolbox
Catalog
Search
131306.979 2662388.944 Meters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20.000001 - 90.576599
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20.000001 - 90.576599
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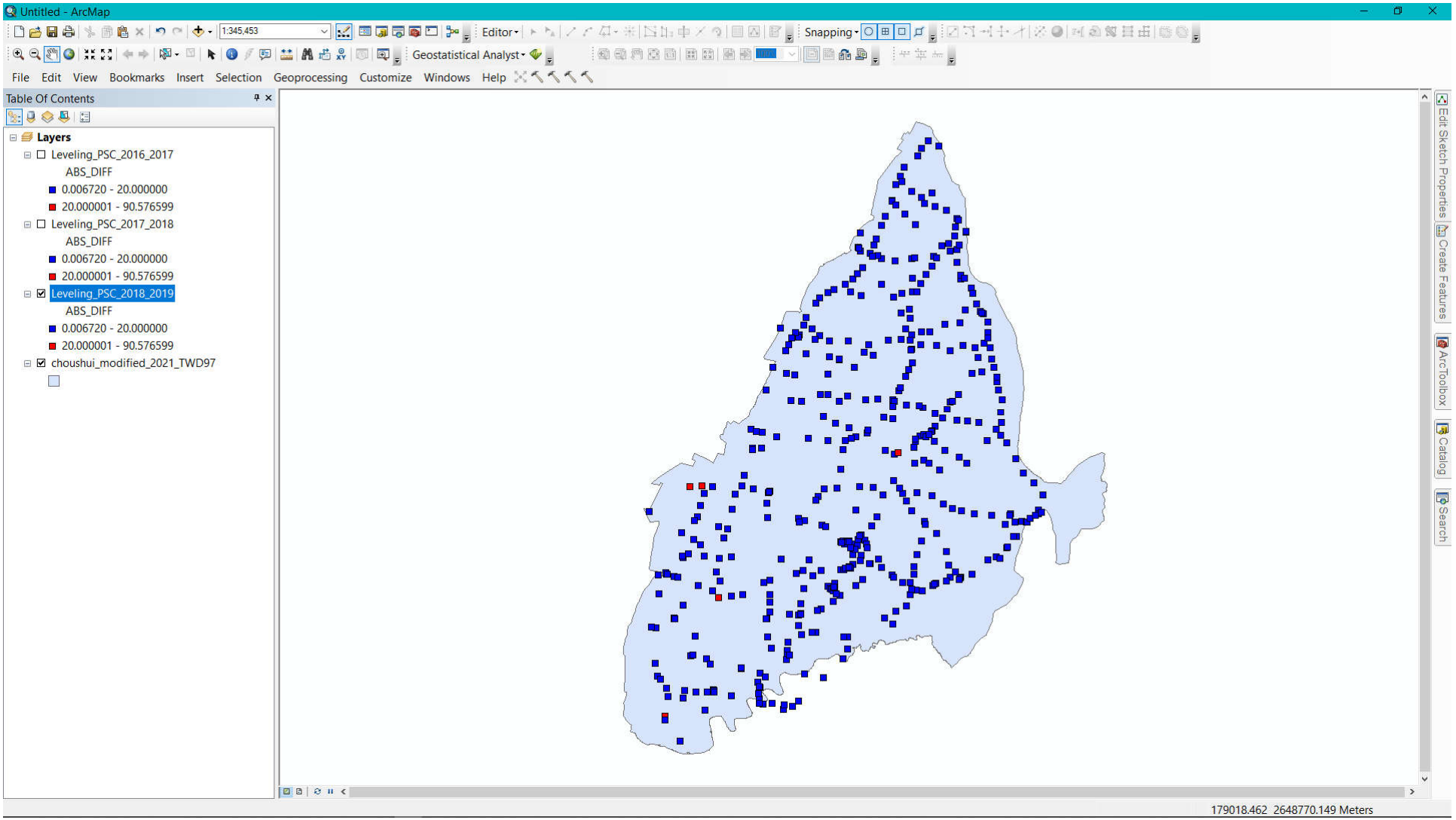
ArcToolbox
Catalog
Search
149404.438 2658732.892 Meters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Geostatistical Analyst
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
Table Of Contents
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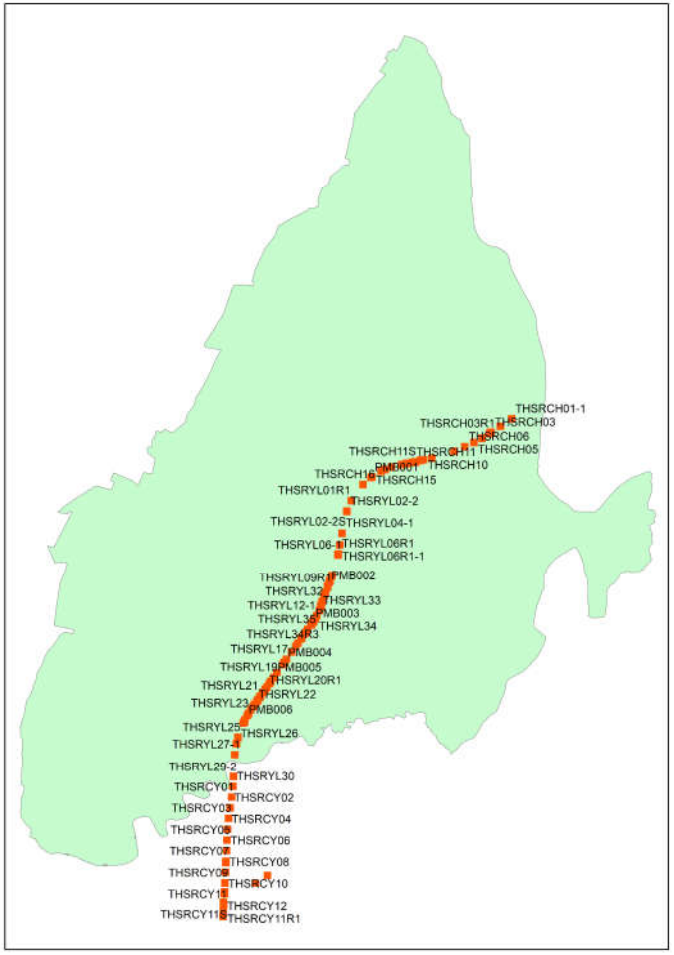
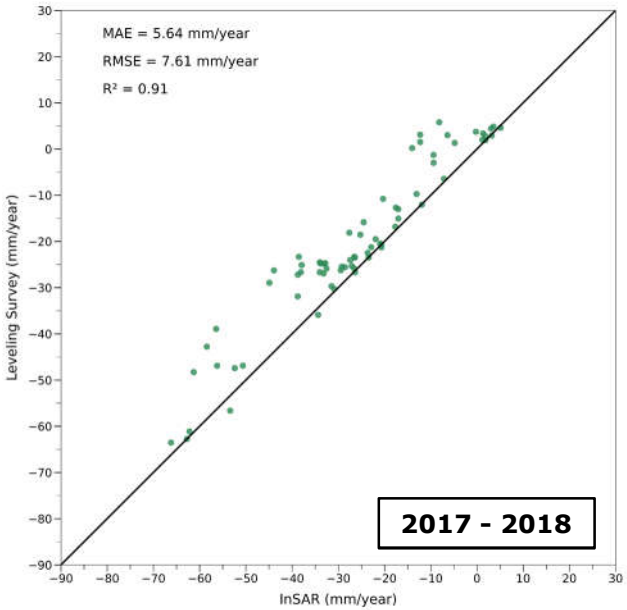
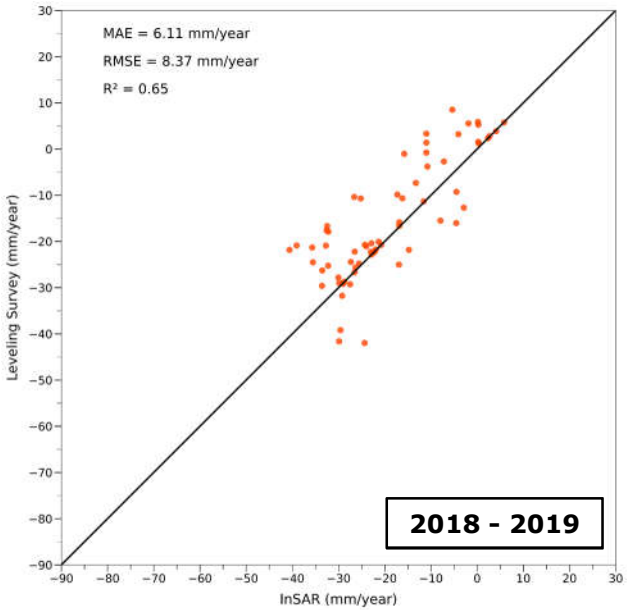
ABS_DIFF
0.006720 - 20.000000
20.000001 - 90.576599
Leveling_PSC_2017_2018
ABS_DIFF
0.006720 - 20.000000
20.000001 - 90.576599
Leveling_PSC_2018_2019
ABS_DIFF
0.006720 - 20.000000
20.000001 - 90.576599
choushui_modified_2021_TWD97
Edit Sketch Properties
Create Features
ArcToolbox
Catalog
Search
179018.462 2648770.149 Meters

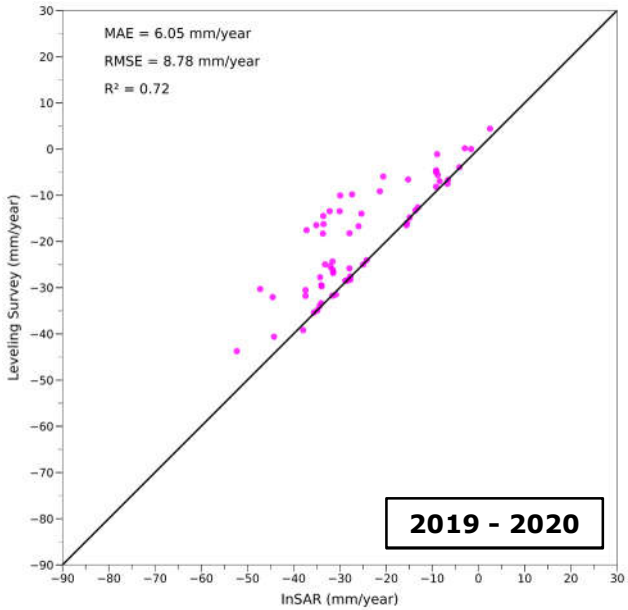
Validation by Leveling (near THSR railway)

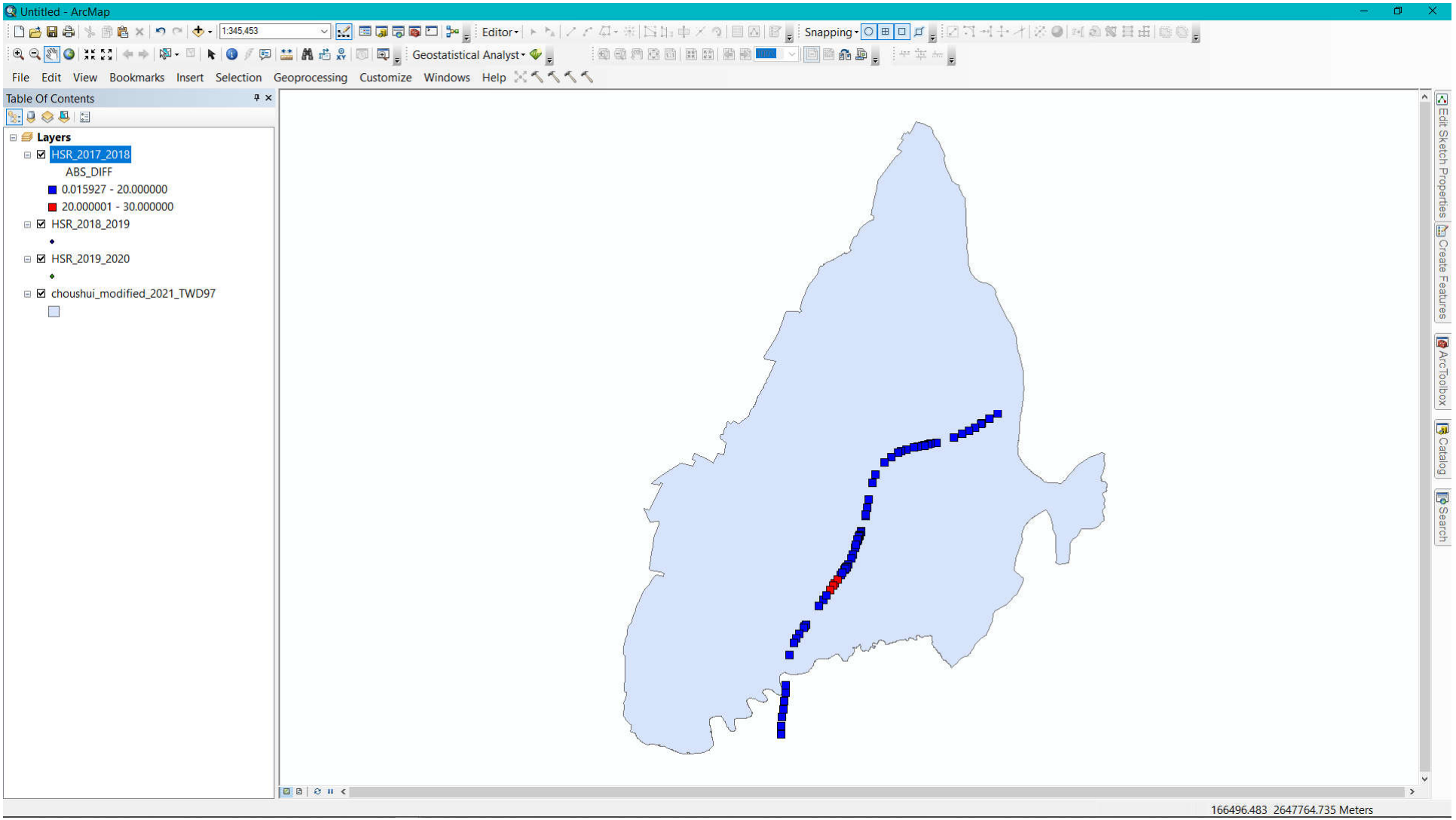


Validation by Leveling (near THSR railway)





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Snapping
Geostatistical Analyst
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
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HSR_2017_2018
ABS_DIFF
0.015927 - 20.000000
20.000001 - 30.000000
HSR_2018_2019
HSR_2019_2020
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Edit Sketch Properties
Create Features
ArcToolbox
Catalog
Search
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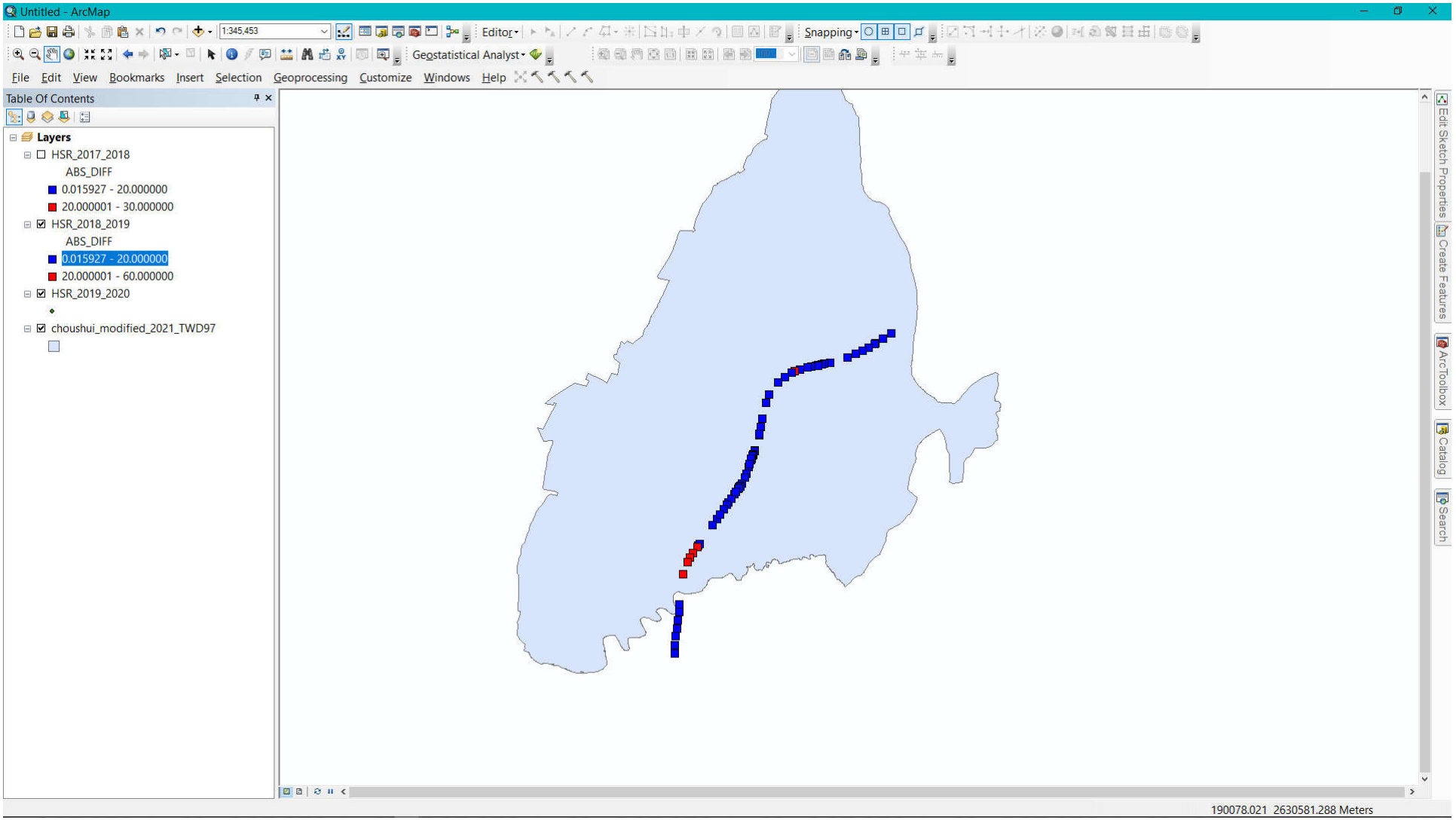
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Snapping
Geostatistical Analyst
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Catalog
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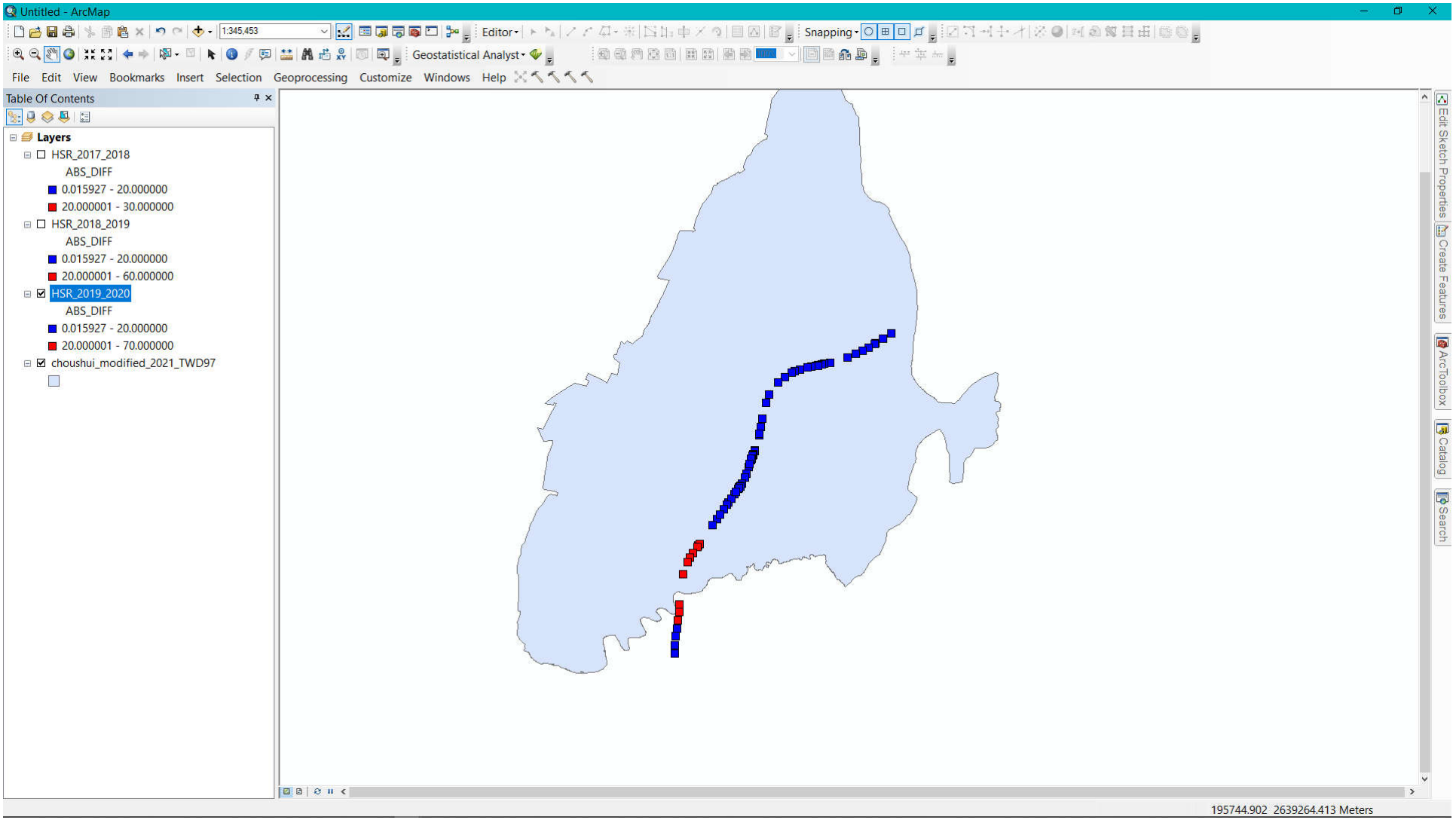
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