


**GEOS 657 – MICROWAVE REMOTE SENSING**  
**GRADUATE-LEVEL COURSE AT THE UNIVERSITY OF ALASKA FAIRBANKS**

**Lecturer:**  
 Franz J Meyer, Geophysical Institute, University of Alaska Fairbanks, Fairbanks; [fimeyer@alaska.edu](mailto:fimeyer@alaska.edu)

**Lecture 15: InSAR Time Series Analysis Basics & PS-InSAR: Time Series Analysis using Point Targets**



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**BEFORE WE START ...**



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**Think – Pair – Share:**

Remember the Complete d-InSAR Phase Equation:

$$\Delta\phi = W \left\{ \frac{4\pi}{\lambda} \frac{B_{\perp}}{R \cdot \sin(\theta)} h_{\text{top}} + \frac{4\pi}{\lambda} v \cdot \Delta t + \phi_{\text{atmo}} + \phi_{\text{orbite}} + \phi_{\text{noise}} \right\}$$

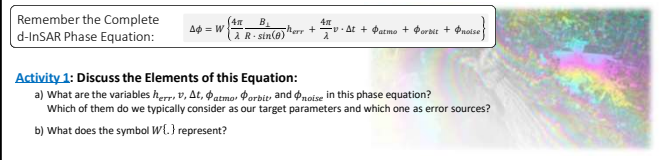

**Activity 1: Discuss the Elements of this Equation:**

- What are the variables  $h_{\text{top}}$ ,  $v$ ,  $\Delta t$ ,  $\phi_{\text{atmo}}$ ,  $\phi_{\text{orbite}}$ , and  $\phi_{\text{noise}}$  in this phase equation? Which of them do we typically consider as our target parameters and which one as error sources?
- What does the symbol  $W(\cdot)$  represent?

**Activity 2: Interferometric Coherence  $\gamma$ :**

The amount of phase noise  $\phi_{\text{noise}}$  is quantified by the coherence  $\gamma(\Delta t)$ , which is typically a function of the temporal baseline  $\Delta t$ .

- Discuss coherence properties of the following 2 surface types in a C-band SAR interferogram:
  - Deciduous forest:** Describe qualitatively how coherence  $\gamma(\Delta t)$  behaves with  $\Delta t$ . How long may the InSAR phase stay coherent over this area?
  - Urban environment:** Describe the dependence of  $\gamma(\Delta t)$  on  $\Delta t$  for this area. How is it different from  $\gamma(\Delta t)$  for deciduous forests and why?
- Both areas are subsiding with  $v = 1 \text{ cm/year}$ . Can a traditional single-pair InSAR approach measure this deformation in both areas?

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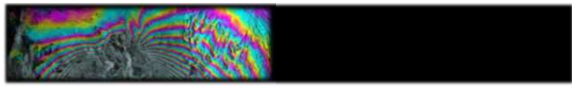
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**THE BASIC CONCEPTS OF INSAR TIME SERIES ANALYSIS**

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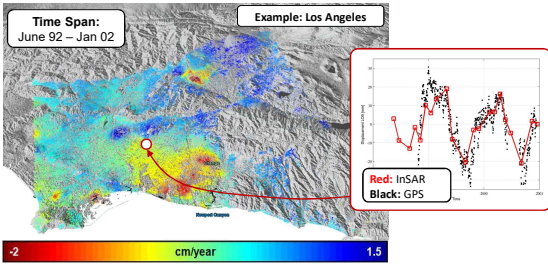
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**Study Deformation Across Time Scales**

Time Span: June 92 – Jan 02   Example: Los Angeles



-2   cm/year   1.5

Red: InSAR   Black: GPS

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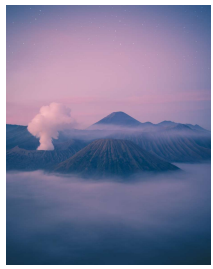
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**Why Use Time Series Analysis?**



**Two compelling reasons**

- 1. Study temporally extended phenomena**
  - Volcanic inflation
  - Landslides
  - Inter-seismic slip
  - Groundwater-related subsidence
- 2. Improved estimation of deformation signal** by exploiting time series to remove
  - Atmosphere
  - Topography (DEM errors)
  - and other noise sources

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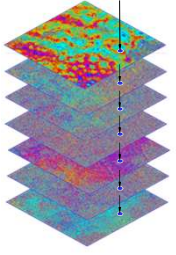
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### Treatment of Error Sources and Limitations Through InSAR Time Series Analysis



**Concepts included in Time Series InSAR**

- Use many ( $N \gg 2$ ) interferograms (ifgrms) spanning long time span**
  - $N \gg 2$  observations and only two unknowns (topography  $h$ ; deformation  $v$ )
  - Suppression of noise (atmosphere; orbit errors; noise) [response to Limitation 4 in Lecture 13]
  - Improve precision of deformation estimates [response to Limitation 2 in Lecture 13]
- Find patches that are coherent in all ifgrms**
  - Sophisticated algorithm required to identify pixels that are coherent over long time frames [response to Limitation 2 in Lecture 13]
- Analyze phase of coherent pixels over time & across space**

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### Separate Phase Components With Time Series Analysis

$$\phi = \underbrace{\phi_{defo}}_{\text{Main interest}} + \underbrace{\phi_{topo} + \phi_{atmo} + \phi_{noise}}_{\text{Nuisance}}$$

smooth in time (usually)

↑

proportional to spatial baseline

↑

random in time – smooth in space  
orbit error similar

↑

random in time and space

↑

Separate components based on their temporal, spatial and baseline characteristics

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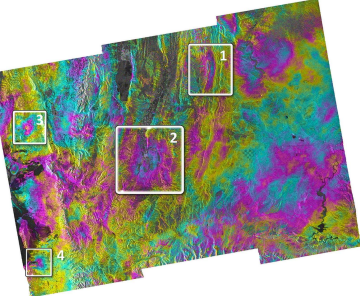
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### Think – Pair – Share: Take 3

#### Spot the Deformation Signal

The interferogram shown here contains a deformation signal related to a M5.7 earthquake. Despite its magnitude, the surface expression of this earthquake is rather small, making it very difficult to spot the location of the event against the noise background in the interferogram.



• **Activity:** Look at the four suggested locations above. Which of the four do you think shows the earthquake?

- Area 1
- Area 2
- Area 3
- Area 4

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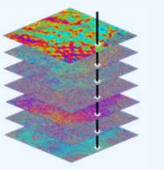
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### Rationale of InSAR Time Series Analysis

**Input**  
Time series of SAR images



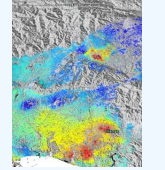
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**Processing**

Key steps

- Interferogram formation
- Unwrapping
- Isolate deformation

**Output**  
Deformation



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### Multiple Approaches to Time Series Analysis

A key distinction is the type of target that is analyzed

**Point-like scatterers**

One scatterer dominates the signal from a SAR resolution cell




**Point Target InSAR**

- + high quality for selected points
- + retains full resolution
- **only few coherent points**
- does not work well for short stacks

Persistent Scatterer Interferometry (PSI)

**Distributed targets**

Many scatterers contribute to signal  
Extended targets



**Distributed Target InSAR**

- + **higher point density**
- + flexible, easily applicable to large areas
- usually higher noise level
- averaging reduces resolution

Small Baseline Subset (SBAS)

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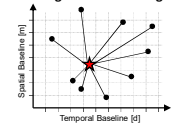
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### Two Philosophies on How to Form Interferograms from Multiple Images

• **PSI uses single reference image**

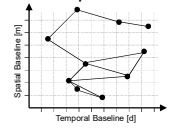


– Ifgrms formed relative to one unique reference image

Used in **Persistent Scatterer InSAR (PSI)**  
[Lecture 15]

- + solving of equation system "simple"
- + very low noise level of selected points
- **Only few coherent points**
- Long time lag to reach critical number of images in stack

• **SBAS uses multiple reference images**



– Ifgrms formed between all image pairs that fulfill user defined baseline requirements (min – max allowed baselines)

Used in **Short Baseline Subset InSAR**  
[Lecture 16]

- + **higher density of coherent point**
- + quicker stack buildup
- equation system underdetermined
- higher phase noise → lower absolute accuracy or filtering required

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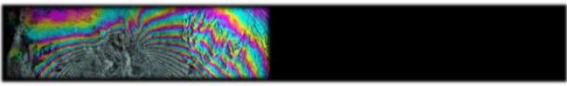
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**POINT TARGET-BASED INSAR TIME SERIES ANALYSIS**

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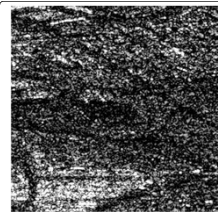
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**Persistent Scatterer Interferometry (PSI)**

- Developed by A. Ferretti, F. Rocca, and, C. Prati, Politecnica di Milano, Italy
- Idea:** Every interferogram *always* contains *a few coherent pixels* whose phase can be exploited for deformation analysis



Incoherent average of 70 ERS SAR images



Individual images (9 years)

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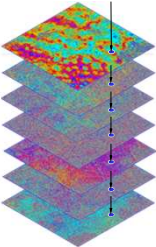
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**Persistent Scatterer Interferometry (PSI)**



- Many interferograms all referenced to *single reference image*
- Identification of isolated stable points
- Analyze *phase difference* between pixels both in time and space
- Phase difference analysis is a powerful means for noise suppression
- Detectable velocities from cm/day to mm/year

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### General Scatterer Types in SAR Images

- Distributed targets:**
  - Many scatterers contributing to the signal from a resolution cell with about equal importance
  - Examples include:** vegetated surfaces; bare soil; general natural terrain
- Point-like scatterers:**
  - One scatterer dominates the signal from a SAR resolution cell
  - Examples include:** Corner reflectors; man-made features such as buildings



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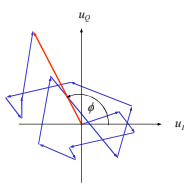
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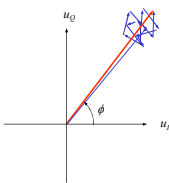
### Characteristics of Distributed and Point Targets

Goal: Understand Nature of Persistent Scatterers

**Distributed Targets**



**Point Targets**



Point Targets are likely to show consistent phase and amplitude over time → **most persistent scatterers are point-like targets (rocks, manmade structures, ...)**

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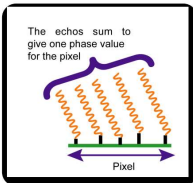
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### Characteristics of Distributed and Point Targets

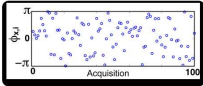
Distributed Targets Decorrelate Quickly

The echos sum to give one phase value for the pixel



Distributed scatterer pixel

If scatterers move with respect to each other, the phase sum changes



(similar effect if incidence angle changes)

Source: A. Hooper, University of Leeds; UNAVCO InSAR Training

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### Characteristics of Distributed and Point Targets

Point-Like Targets Keep Coherent For Long Times

Source: A. Hooper, University of Leeds; UNAVCO InSAR Training

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### Persistent Scatterer Interferometry (PSI)

Phase of an interferogram:

$$\phi = W\{\phi_{topo} + \phi_{defo} + \phi_{atmo} + \phi_{orbit} + \phi_{noise}\}$$

$$= W\left\{\frac{4\pi}{\lambda} \frac{B_{\perp}}{R \cdot \sin(\theta)} h + \frac{4\pi}{\lambda} v \cdot \Delta t + \phi_{atmo} + \phi_{orbit} + \phi_{noise}\right\}$$

(W: wrapping operator → ϕ: [−π, π])

- Form several interferograms referenced to a unique "reference" image
  - i-th image = reference
  - j-th image = secondary

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### PSI Processing Chain

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### PSI Processing Chain

Steps (1) – (3): InSAR and D-InSAR Processing

1. Interferogram generation:

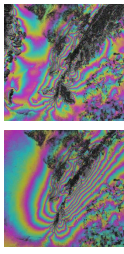
$$\phi_k^k = W \left\{ \frac{4\pi}{\lambda} \frac{B_k}{R \cdot \sin(\theta)} h_x + \frac{4\pi}{\lambda} v_x \Delta t^k + \phi_{x,atmo}^k + \phi_{x,orbit}^k + \phi_{x,noise}^k \right\}$$

$h = h_{DEM} + h_{ERR}$

2. Remove DEM via D-InSAR processing:

$$\Delta \phi_k^k = W \left\{ \frac{4\pi}{\lambda} \frac{B_k}{R \cdot \sin(\theta)} h_{x,err} + \frac{4\pi}{\lambda} v_x \Delta t^k + \phi_{x,atmo}^k + \phi_{x,orbit}^k + \phi_{x,noise}^k \right\}$$

- $h_{x,err}$  remains due to
  - Imperfect interferometric baseline
  - Imperfect DEM



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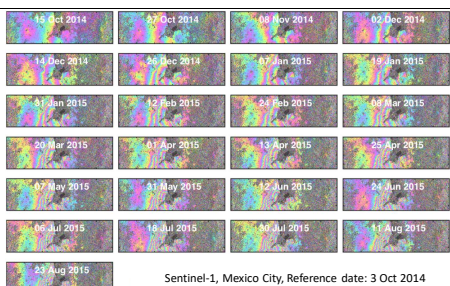
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### Example of Single-Reference d-InSAR Stack



Sentinel-1, Mexico City, Reference date: 3 Oct 2014

Source: A. Hooper, University of Leeds; UNAVCO InSAR Training

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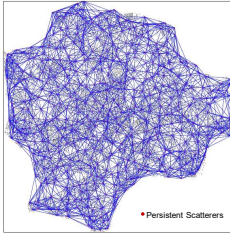
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### PSI Processing Chain

Steps (4) & (5): Selection of Persistent Scatterer (PS) Candidates

- Various ways for detecting PS:
  - Amplitude dispersion index:  $D_A = \frac{\sigma_A}{\mu_A} \rightarrow$  points with stable amplitude  $A$  over time
  - Points with high signal-to-clutter ratio
  - ...
- Features of Persistent Scatterers:
  - No temporal decorrelation
  - Very low phase noise
- Goal: Dense spatial distribution of high quality PS
  - Favorable description of spatial deformation signal
  - Easier phase unwrapping



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**PSI Processing Chain**  
**A Few Words on the Amplitude Dispersion Index**

• Amplitude Dispersion Index initially published in (Ferretti et al., 2001)

$$\sigma_\phi = \frac{\sigma_A}{A} = \frac{\sigma_A}{\mu_A} = D_A$$

• **Approach:** Calculate  $D_A$  per pixel and use points with  $D_A < \text{threshold}$

• Data analysis has shown that  $D_A$  is a good approximation for  $\sigma_\phi$  for low values of  $D_A$

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**PSI Processing Chain**  
**Step (6a): Spatio-Temporal Modeling**

• **Linear deformation model:** phase  $\phi_{x,defo}^k$  of pixel  $x$  of ifgrm  $k$

$$\phi_{x,defo}^k = \frac{4\pi}{\lambda} v_x \Delta t^k$$

• **Linear dependence of DEM error on interferometric baseline  $\rightarrow$**

$$\phi_{x,topo}^k = \frac{4\pi}{\lambda} \frac{B_{\perp}^k}{R \cdot \sin(\theta)} h_{x,err}$$

• **Estimation of DEM error and deformation using spatio-temporal model:**  
 - Fitting of a 2-d plane into the phase observations in the spatio-temporal baseline plot (see above)

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**PSI Processing Chain**  
**Step (6b): Persistent Scatterer Estimation I**

• **Goal:**  
 Estimation of  
 - DEM error  
 - Surface deformation  
 at the position of the Persistent Scatterers

• **Problem:**  
 - Noise contributions at the PS positions may mask desired signal  
 - Some phase components are random in time and prevent successful estimation

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### Step (6b): Persistent Scatterer Estimation II

Calculation of Phase Differences between Nearby Points

$$\Delta\phi_{x-y}^k = \frac{4\pi}{\lambda} \frac{B_{\perp}^k}{R \cdot \sin(\theta)} \Delta h_{x-y, err} + \frac{4\pi}{\lambda} \Delta v_{x-y} \Delta t^k + \underbrace{\left( \begin{matrix} \phi_{x-y, atmo}^k + \\ \phi_{x-y, orbit}^k + \\ \phi_{x-y, noise}^k \end{matrix} \right)}_{\text{small}}$$

**PS Pair:**

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### PSI Processing Chain

Step (7c): Integration Step

- We now have estimated  $\Delta h_{x-y, err}$  and  $\Delta v_{x-y}$ , corresponding to the height-error and deformation velocity **differences between pairs of PS points**
- To obtain parameters at the PS locations ( $h_{x, err}$  and  $v_x$ ), we perform a **least-squares integration** with respect to a reference point (X)

**Example:**

- Integration Result for InSAR Stack over Las Vegas

Source: A. Hooper, University of Leeds; UNAVCO InSAR Training

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### Analysis of Residuals to Separate Atmospheric Delay from Noise

**Residuals:**

$$\phi_{x, res}^k = \phi_{x, atmo}^k + \phi_{x, noise}^k + \cancel{\phi_{x, orbit}^k}$$

**Properties:**

- Atmosphere correlated in space and uncorrelated in time
- Noise uncorrelated in both space and time

**→ Separation:**

- Spatial filtering and subsequent interpolation

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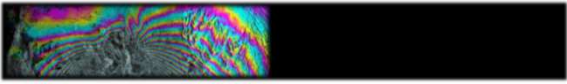
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
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### PS-INSAR (PSI): ACCURACY ASSESSMENT AND EXAMPLES

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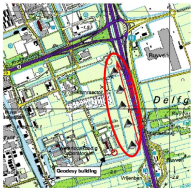
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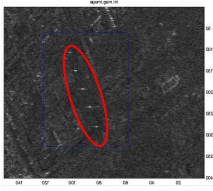
#### Assessment of Accuracy of PS-InSAR




Corner Reflector Experiment Conducted by Delft University, NL

- Experiment Setup:
  - Row of oriented corner reflectors
  - Surveyed using levelling for validation of PSI results







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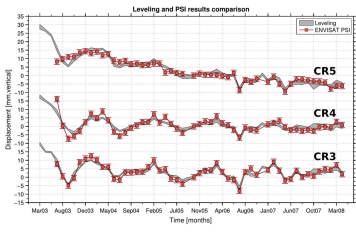
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#### Assessment of Accuracy of PS-InSAR

Corner Reflector Experiment Conducted by Delft University, NL

- Comparison of leveling and PSI deformation measurements
  - Excellent match of measurements



Marinkovic et al, CEOS SAR workshop, 2004

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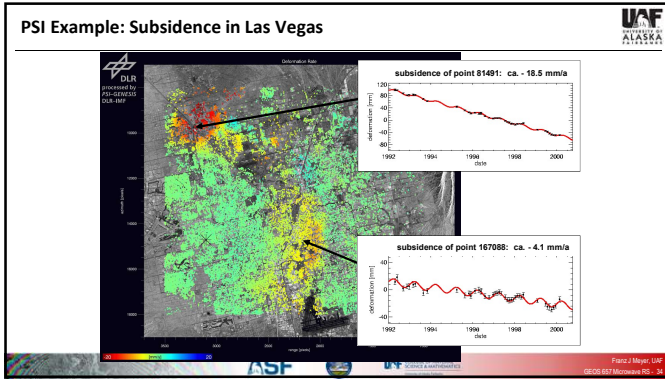
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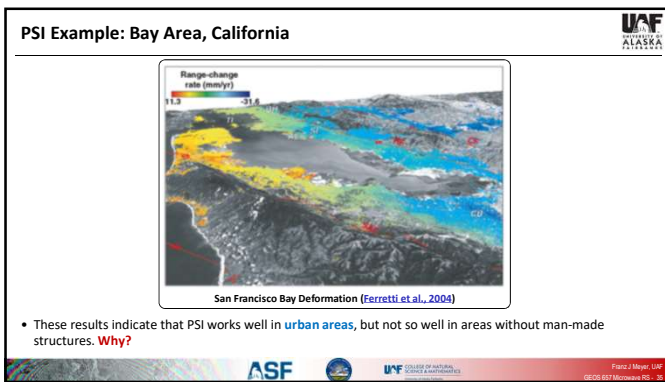
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• These results indicate that PSI works well in **urban areas**, but not so well in areas without man-made structures. **Why?**

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### Think – Pair – Share:

Let's look at some PS-InSAR Data: Explore [the following deformation site](#) on the InSAR Norway PSI Portal

**Activity 1:** Explore and compare ascending and descending deformation data:

- How do the deformation features for ascending and descending compare.
- What do ascending and descending data tell you about the direction of surface motion?

**Activity 2:** Analyze data gaps / point density variations:

- The PSI point density varies throughout this site.
- Look at ascending and descending data. You may notice distinct differences in the point coverage between these geometries.
- Formulate two reasons why point densities may vary between these geometries.

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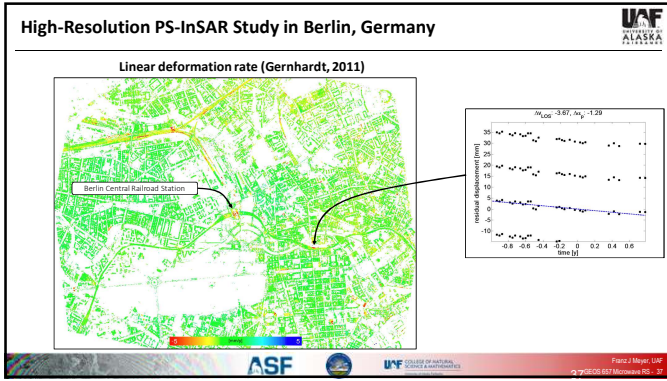
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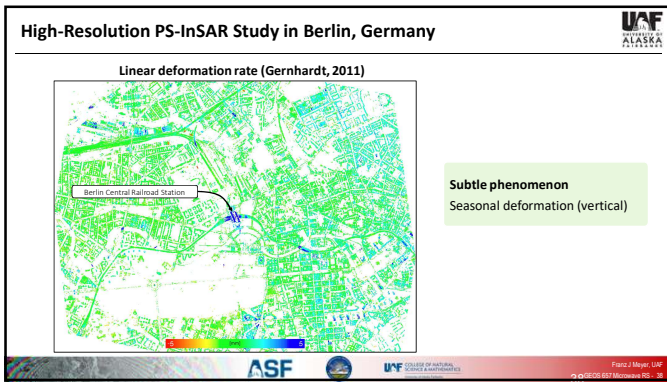
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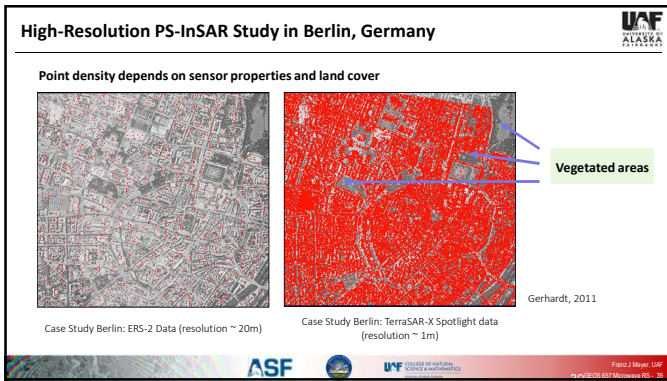
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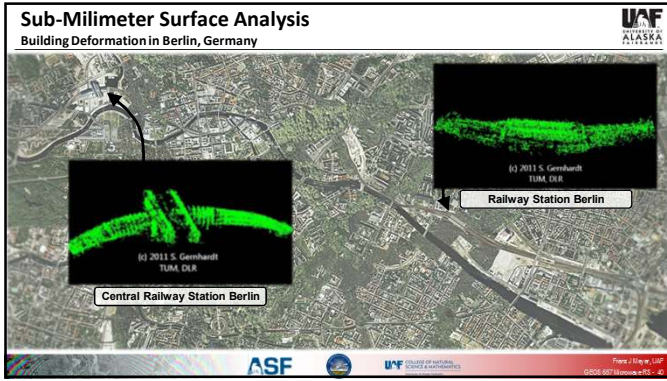
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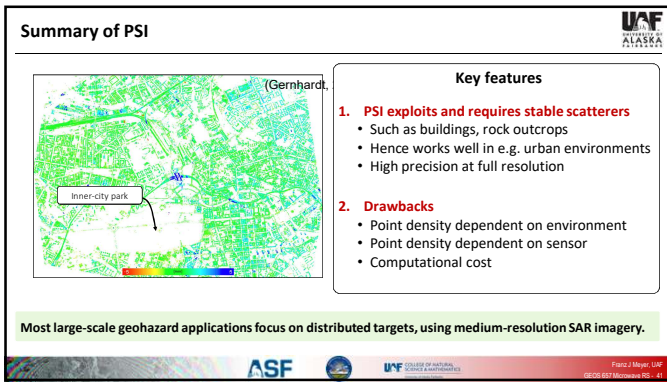
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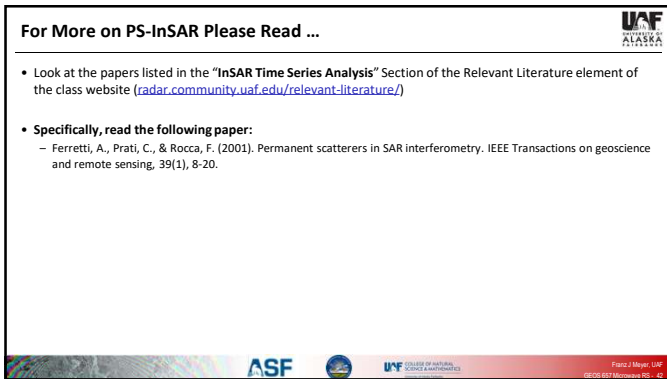
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**What's Next?**

- This is what awaits next:
  - **Thursday** : Lab on Change Detection in SAR Amplitude Time Series Stacks
  - **Next Tuesday**: I will introduce you to an alternative approach to InSAR Time Series Analysis called "Short Baseline Subset (SBAS) InSAR" that is often better suited for natural environments

ASF UAF COLLEGE OF NATURAL SCIENCES & MATHEMATICS Franz J Meyer, UW GEOS 657 (Wednesday, 4/11/2023)

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