EARTHSCOPE ISCE+ INSAR TRAINING

Lecturer:
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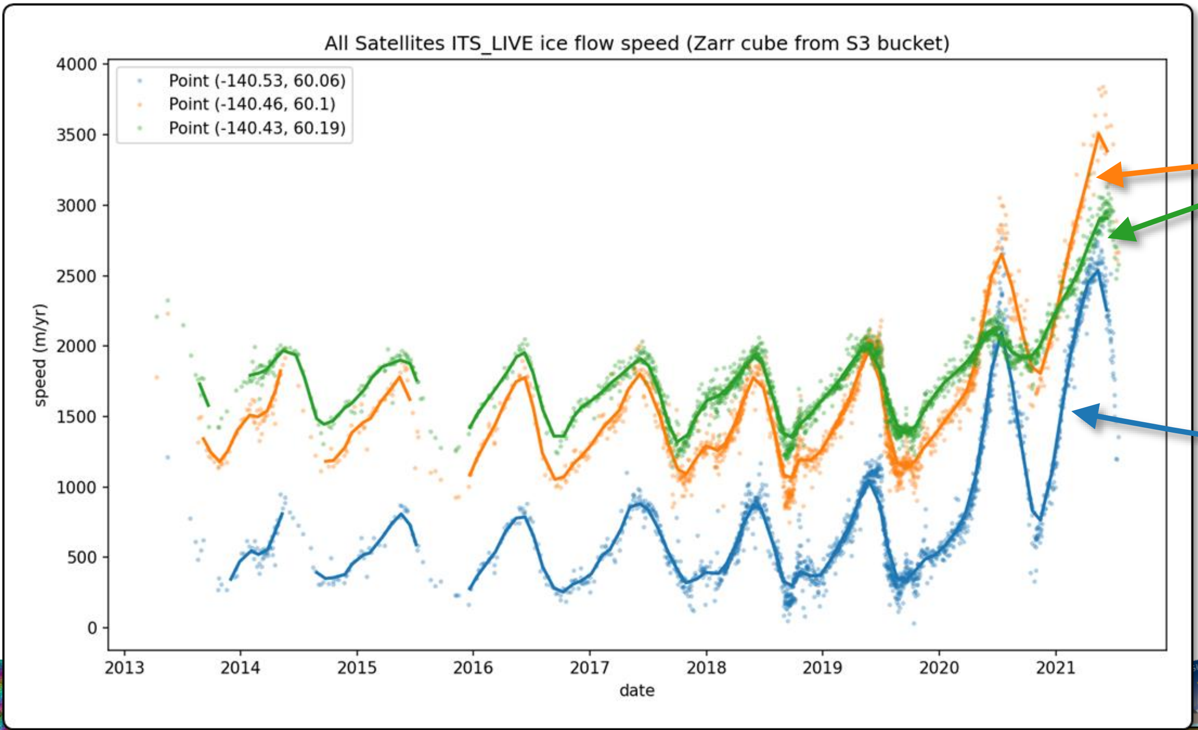
Motion Mapping using Template Matching and Feature Tracking

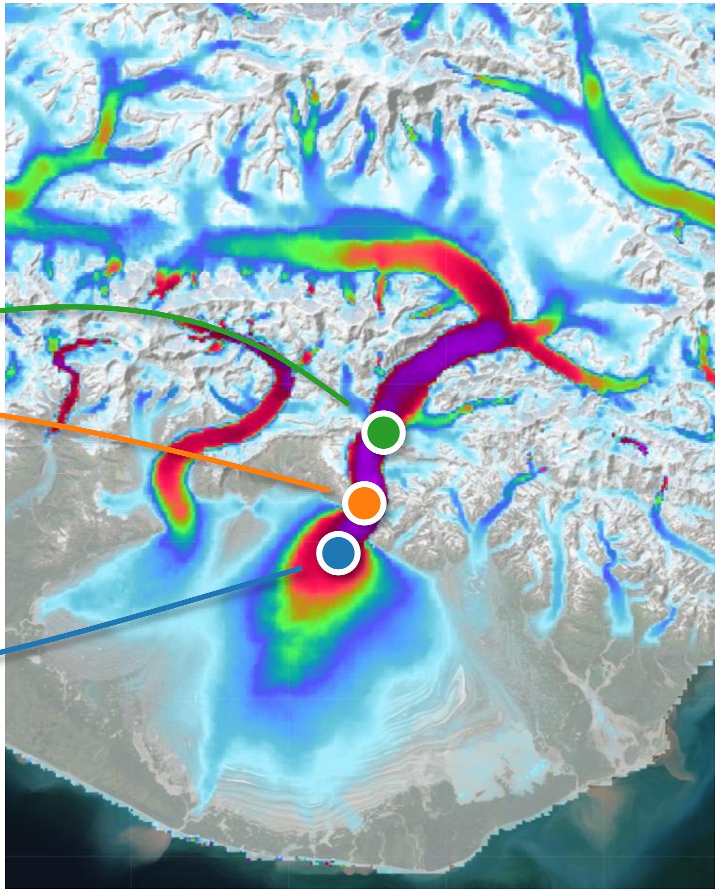
Why a Second Concept to Motion Mapping?

Why Do We Need A Second Concept for Measuring Motion?

Limitation of InSAR

- **InSAR-based motion tracking requires that the two images of an InSAR pair are aligned at a sub-pixel level ($\approx {}^{1}/_{100}$ of a pixel)**
- **Assume pixel size of $80m$ (Sentinel-1 image after 20×4 multi-looking)**
  - Maximum allowed movement between images: $\Delta x_{max} = {}^{80}/_{100}\ [m] = 0.8\ [m]$
  - For images 12 days apart → maximum measurable velocity: $v_{max} = 24\ [m/yr]$
- **Example: Glacier velocity Malaspina Glacier**



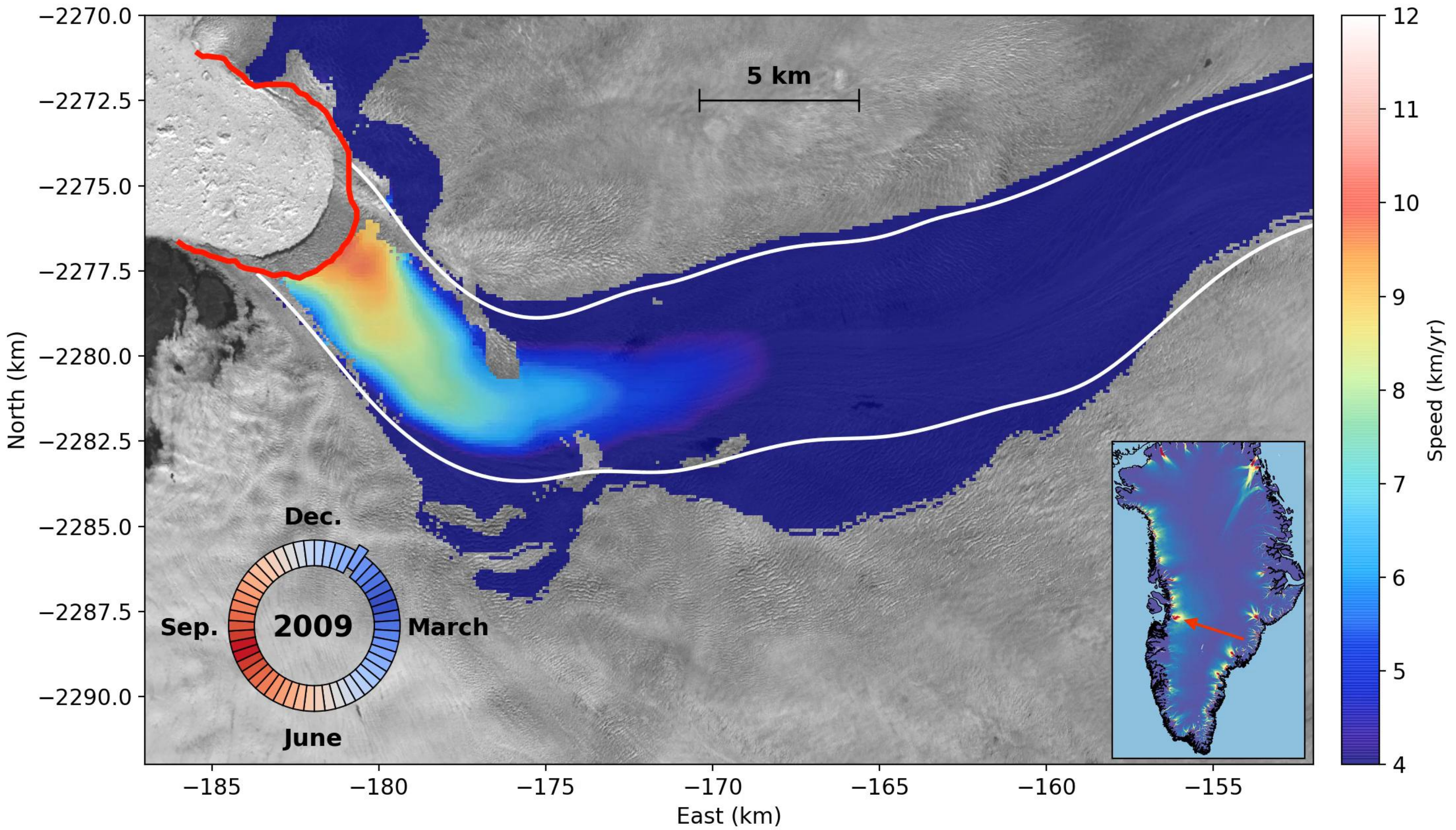


Topic 3: Surface Displacement from Images

Fast(er) Motion Monitoring [m/y to km/y] Using Feature Tracking and Optical Flow

- **Lot's of surface motions can be too fast for InSAR to work (see lectures later on):**
  - **Glacier motion (and variations thereof)**
  - Sea Ice motion
  - Large earthquake motion

- **We will use feature tracking and optical flow techniques to estimate motion velocities and directions**



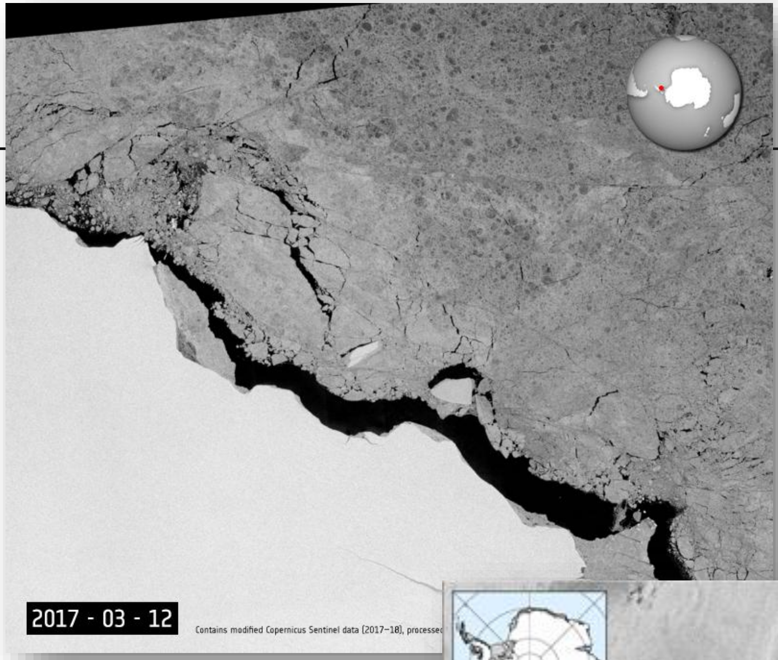
Bryan Riel. 2020. [Animation of time-dependent velocity magnitudes for Sermeq Kujalleq (Jakobshavn Isbræ) from 2009 - 2019.](doi:10.18739/A2W66990B) Arctic Data Center. doi:10.18739/A2W66990B.

TEMPLATE AND FEATURE MATCHING PRINCIPLES

Image Matching Use Cases

Matching entities

- **Images from** **different viewpoints**
  (e.g. stereo parallax matching; tie points)
- **Images from** **different times**
  (e.g. change detection; terrain displacements)
- **Images from** **different sensors/sensor channels**
  (multi-modal; e.g. co-registration; co-registration of channels or sub-systems; fusion)
- **Images of** **different** **ground, illumination and atmospheric conditions**
- **Images and** **templates / models** **(reference pattern, image chips)**
  (e.g. fiducial marks, ground control point data base, objects)
- **DEMs** **or other spatial datasets**



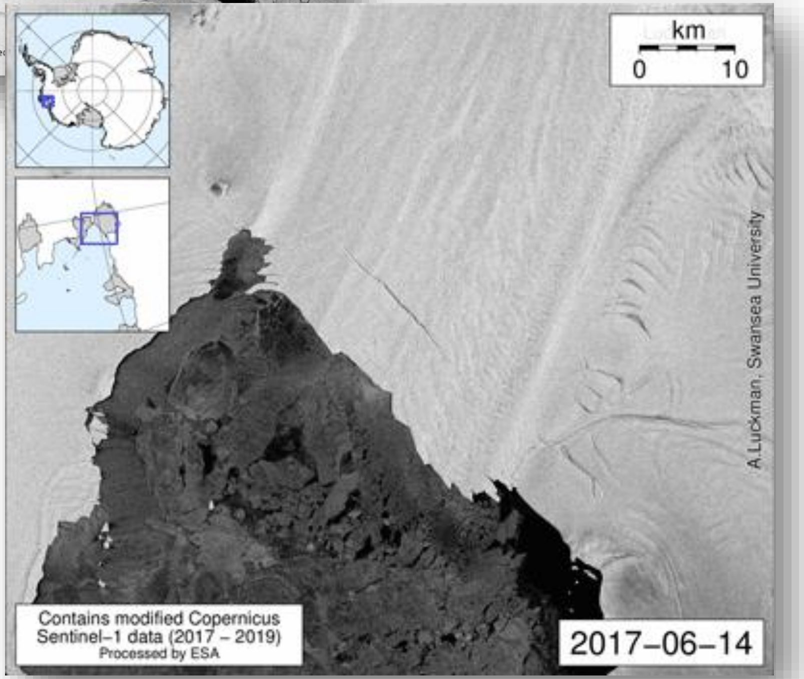


Image Matching Approaches

Image matching
- original image
- image derivatives (e.g. edges, gradients)

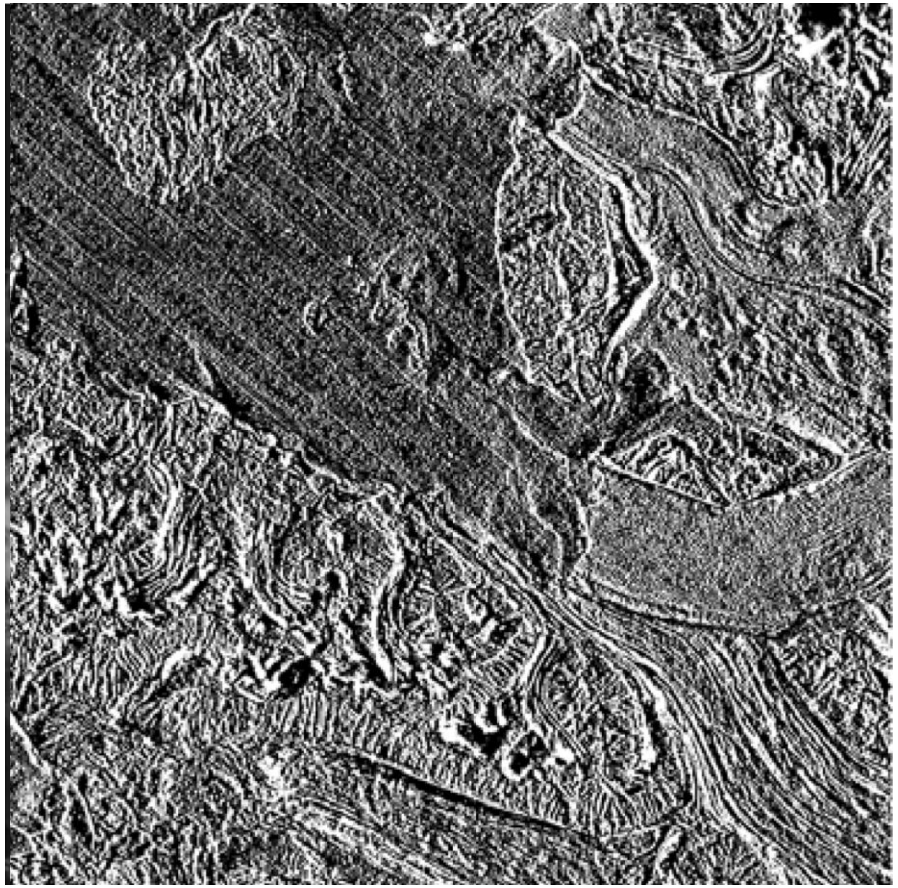
Area-based (intensity) methods

others

Spatial domain
- Cross-correlation
- Least-squares matching (LSM)
- …

Frequency domain
- Fourier
- Wavelet

Feature-based methods
- Geometric features (points, lines, regions)
- Spectral features
- Statistical features
- Higher-level features



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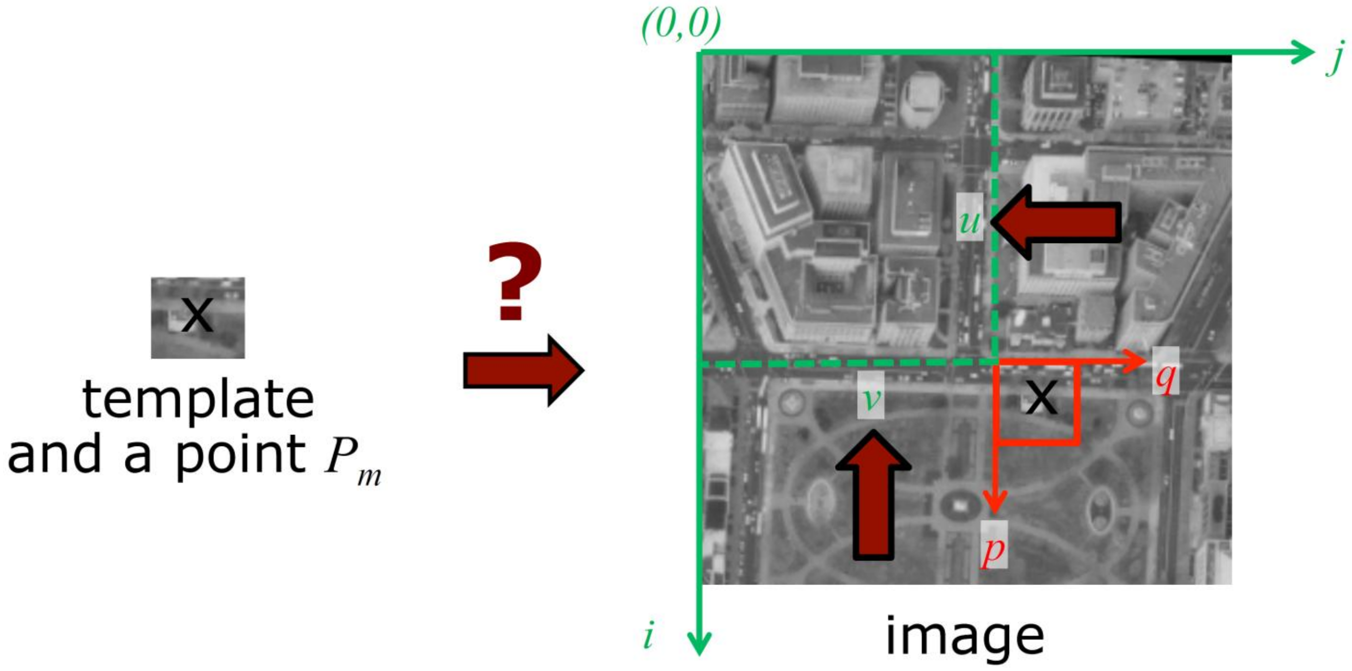
Cross Correlation-Based Image Matching

Cross Correlation:

- **Cross correlation is a powerful tool to:**
  - Find certain image content in an image
  - Determine its location in the image
- **Key assumption: Images differ only by**
  - Translation
  - Brightness
  - Contrast
- **Cross correlation is a template matching approach**
  - Find the location of a small template image within a (larger) image
  - Usually: size of template << size of image



Cross Correlation Principle

Cross Correlation:

- Given image $g_1(i,j)$ and template $g_2(p,q)$, find offset $[\hat{u},\hat{v}]$ between g_1 and g_2

Assumptions:

- Geometric Transformation

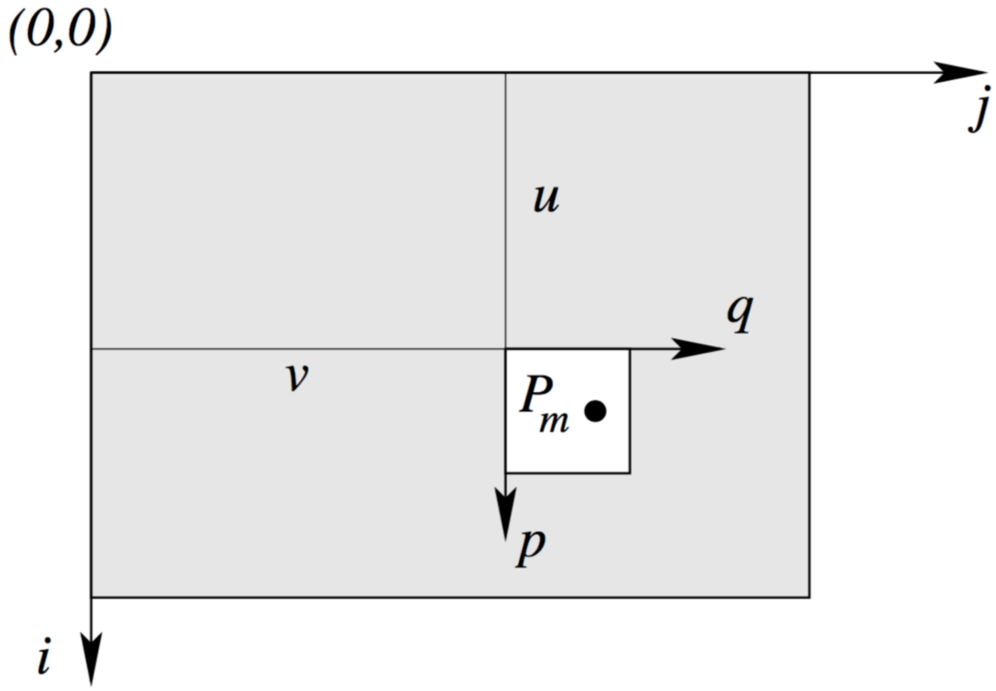
$$T_G: \begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} i \\ j \end{bmatrix} - \begin{bmatrix} u \\ v \end{bmatrix}$$

  - Two unknown parameters: $p_g = [u,v]^T$

- Radiometric transformation

$$T_I: g_2(p,q) = a + b g_1(i,j)$$

  - Intensities of each pixel in g_2 are linearly dependent on those of g_1
  - Two additional unknown parameters: $p_R = [a,b]^T$



Task: Find the offset $[\hat{u},\hat{v}]$ that maximizes the similarities of the corresponding intensity value

Cross Correlation quantifies image template similarity

Examples of Template-Based Similarity Measures

f	Standard	Normalised
Absolute	$\sum \lvert A-B \rvert$	$\dfrac{\sum \lvert A-B \rvert}{\sqrt{\left(\sum \lvert A \rvert\right)\left(\sum \lvert B \rvert\right)}}$
Square	$\sum (A-B)^2$	$\dfrac{\sum (A-B)^2}{\sqrt{\left(\sum A^2\right)\left(\sum B^2\right)}}$
Power	$\sum \lvert A-B \rvert^p$	$\dfrac{\sum \lvert A-B \rvert^p}{\sqrt{\left(\sum \lvert A \rvert^p\right)\left(\sum \lvert B \rvert^p\right)}}$
Correlation	$\sum AB - \dfrac{\left(\sum A\right)\left(\sum B\right)}{N}$	$\boxed{\dfrac{\sum AB - \dfrac{\left(\sum A\right)\left(\sum B\right)}{N}}{\sqrt{\left(\sum A^2 - \dfrac{\left(\sum A\right)^2}{N}\right)\left(\sum B^2 - \dfrac{\left(\sum B\right)^2}{N}\right)}}}$

Cross Correlation: Search Strategy

How to Find the Offset that Maximizes Similarity?

Exhaustive Search

- For all offsets $[u, v]$ compute Cross Correlation $\rho(u, v)$
- Select offset $[u, v]$ for which $\rho(u, v)$ is maximized

More Efficient Approach: Use Image Pyramid

- Iteratively use resized images from small to large
- Start on top of the pyramid → match gives initialization for next level

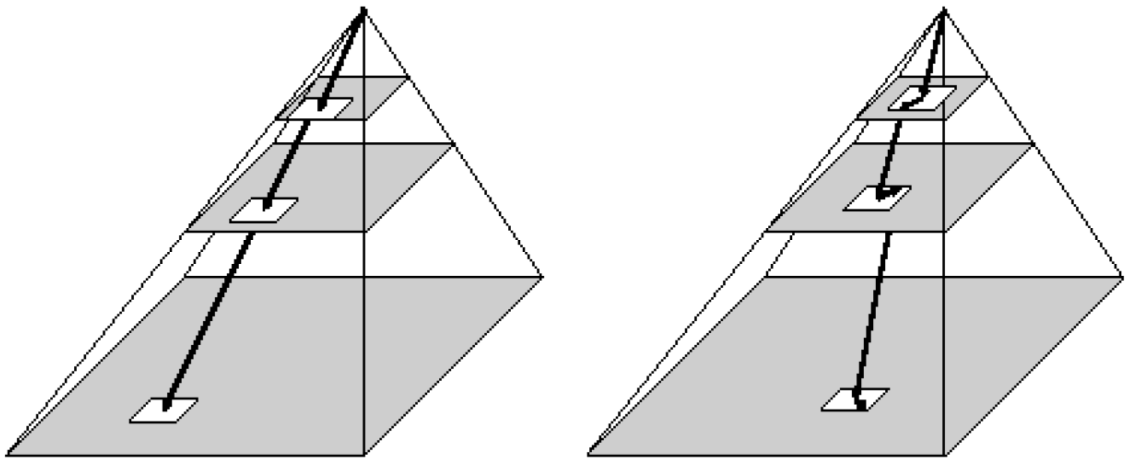
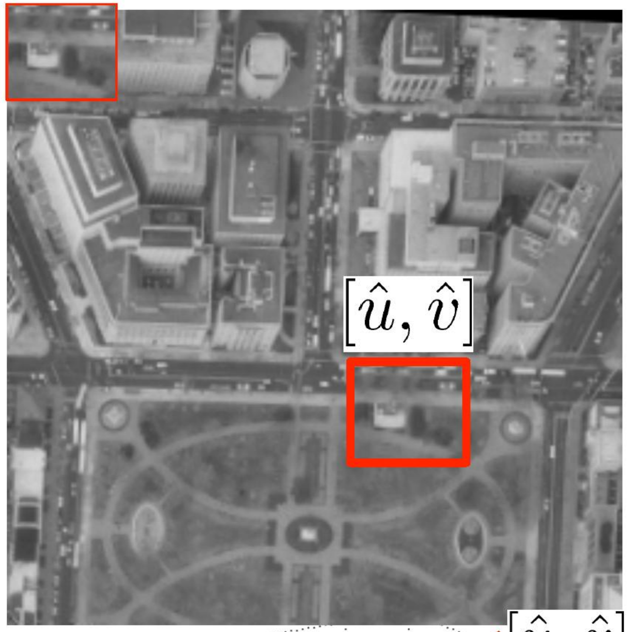
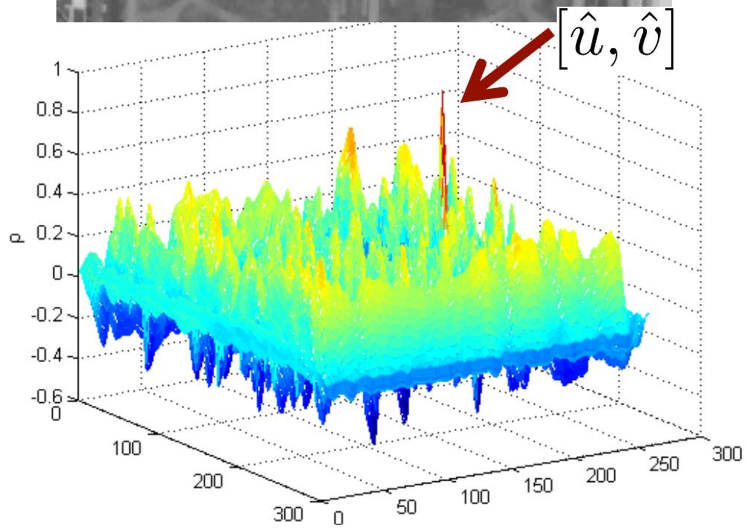


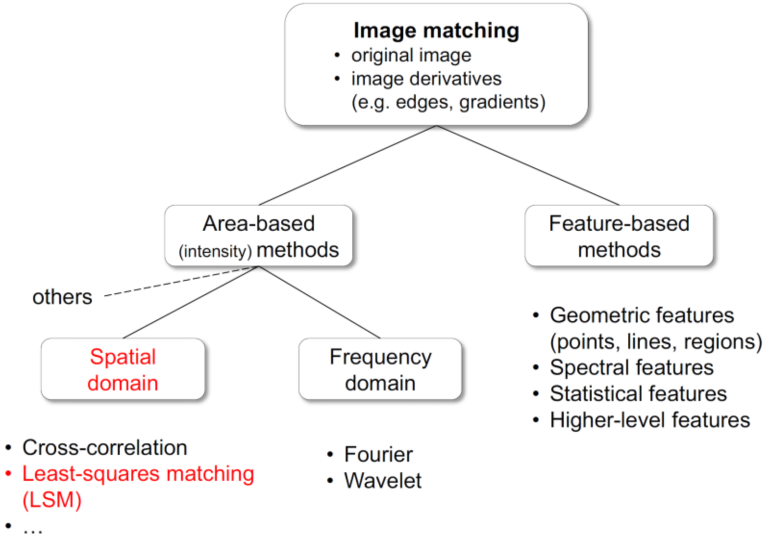
Image courtesy: Förstner





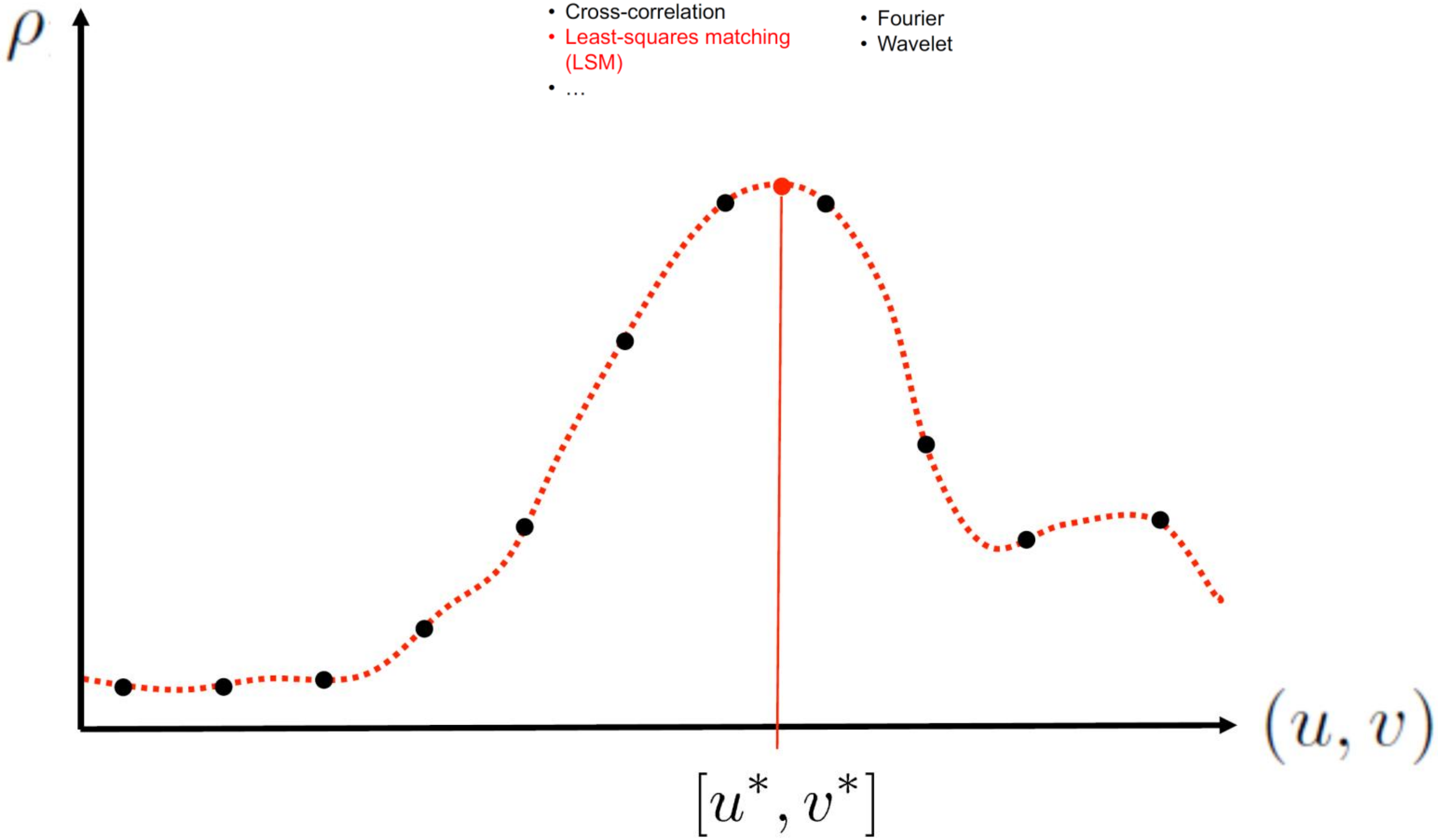
Cross Correlation: Sub-Pixel Estimation of Offsets

- Result of template matching by cross correlation provides initially only integer-valued offsets
- More precise estimate can be obtained through subpixel estimation

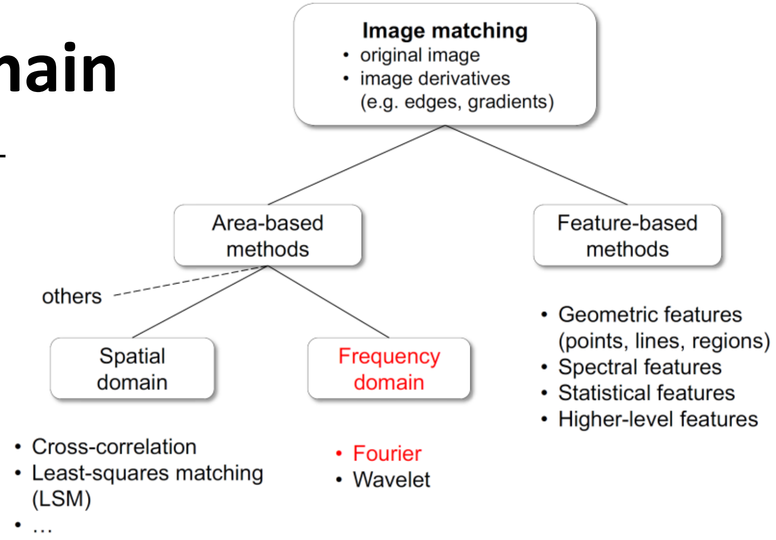


Procedure:

- Fit a locally smooth surface through $\rho(u, v)$ around the initial position $[\hat{u}, \hat{v}]$
- Estimate it's local maximum using least-squares matching to arrive at subpixel estimate of offsets $[u^*, v^*]$



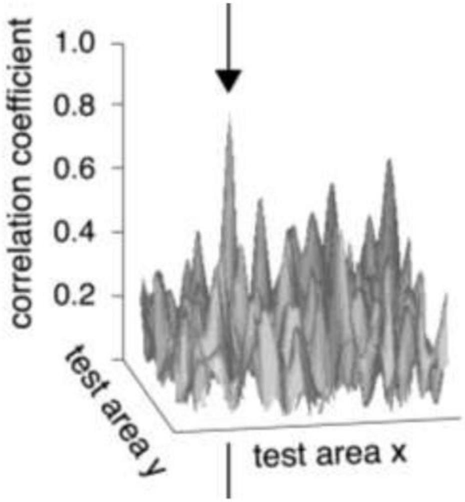
Side Note: Image Matching In the Frequency Domain

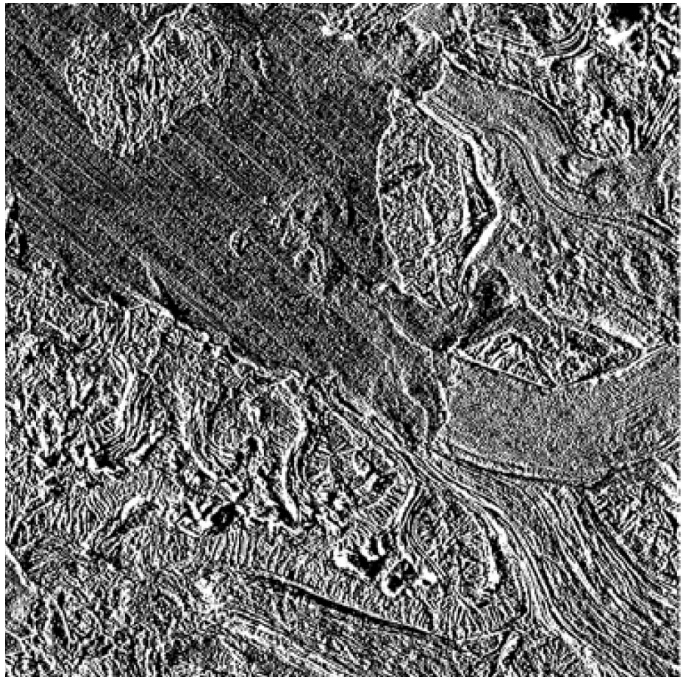


- **Correlation is a time demanding process** when done in the spatial domain, **but in the frequency domain this process can be done much more efficiently** with a single multiplication (convolution theorem):

$$CC(i,j) = IFFT\big(F(u,v)G^*(u,v)\big)$$

- **Image normalization** cannot be done easily in frequency domain
- **Approaches of normalization:**
  - Phase correlation
  - Orientation images





Feature-Based Image Matching

- Feature-based approaches use easily identifiable image features such as corners, edges, street corners …
- Identification and matching of features was addressed in Lecture 5 and include techniques such as **SIFT** = **S**cale **I**nvariant **F**eature **T**ransform

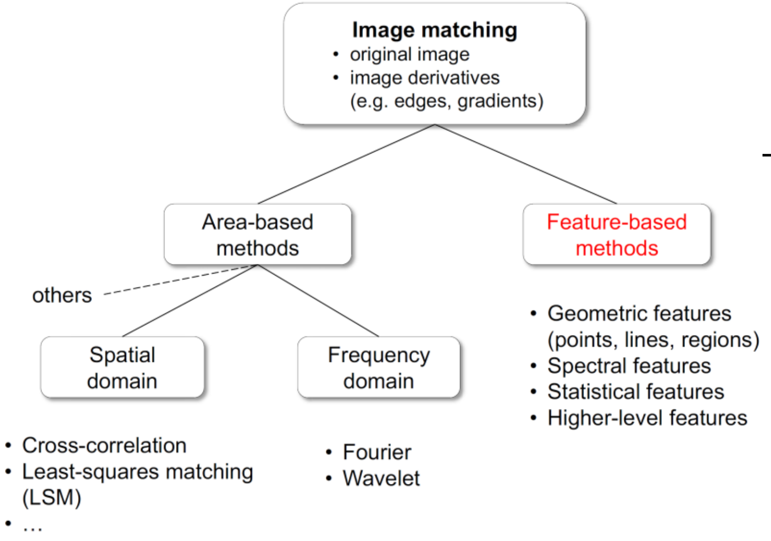
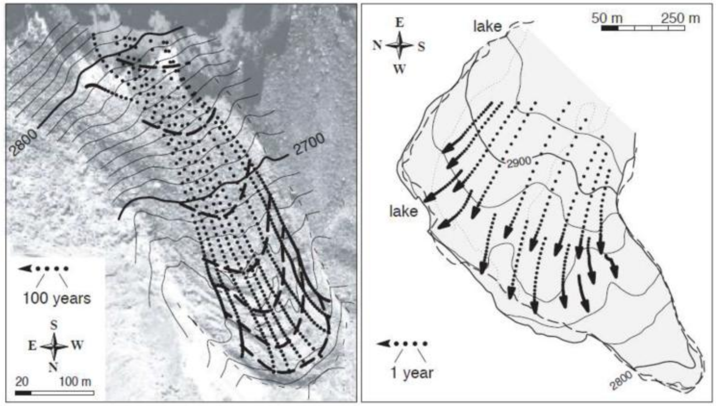


Image Pre- and Post-Processing Error Sources

Image Pre-Processing and Product Post-Processing

Pre-Processing:

- Image enhancements / transforms such as gradient calculation and noise filtering
- Image pyramid calculation to speed up processing
- Image allignment
- Interest point extraction for feature-based methods

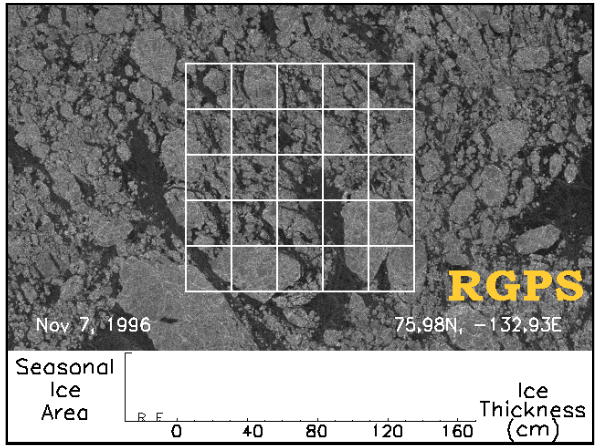


Flow-line extraction

Post-Processing:

- Outlier-detection and removal (e.g., using geometric constraints; neighborhoods; quality metrics)
- Filtering
- Derivatives
- Extraction of streamlines and trajectories

Outlier Removal through gridding



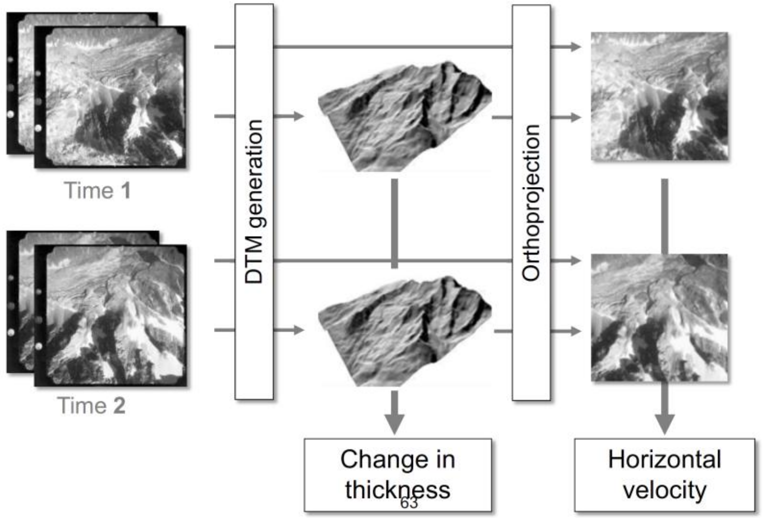
Error Sources and Problematic Areas for Image Matching

Error Sources

- Image alignment
- Matching error (mismatch; e.g. similar features, lack of contrast)
- Matching accuracy
- Self similar objects

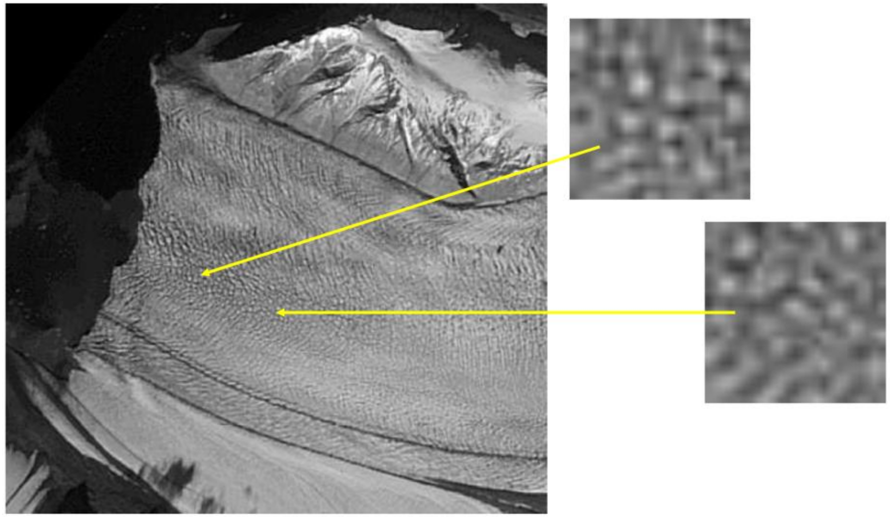
Problem Areas:

- Areas with low contrast (accumulation areas)
- Areas with much surface transformation
- Cloudy areas



Accurate alignment is essential
Geocoding approaches can be used for this task

Self-similar objects can be an issue in image matching

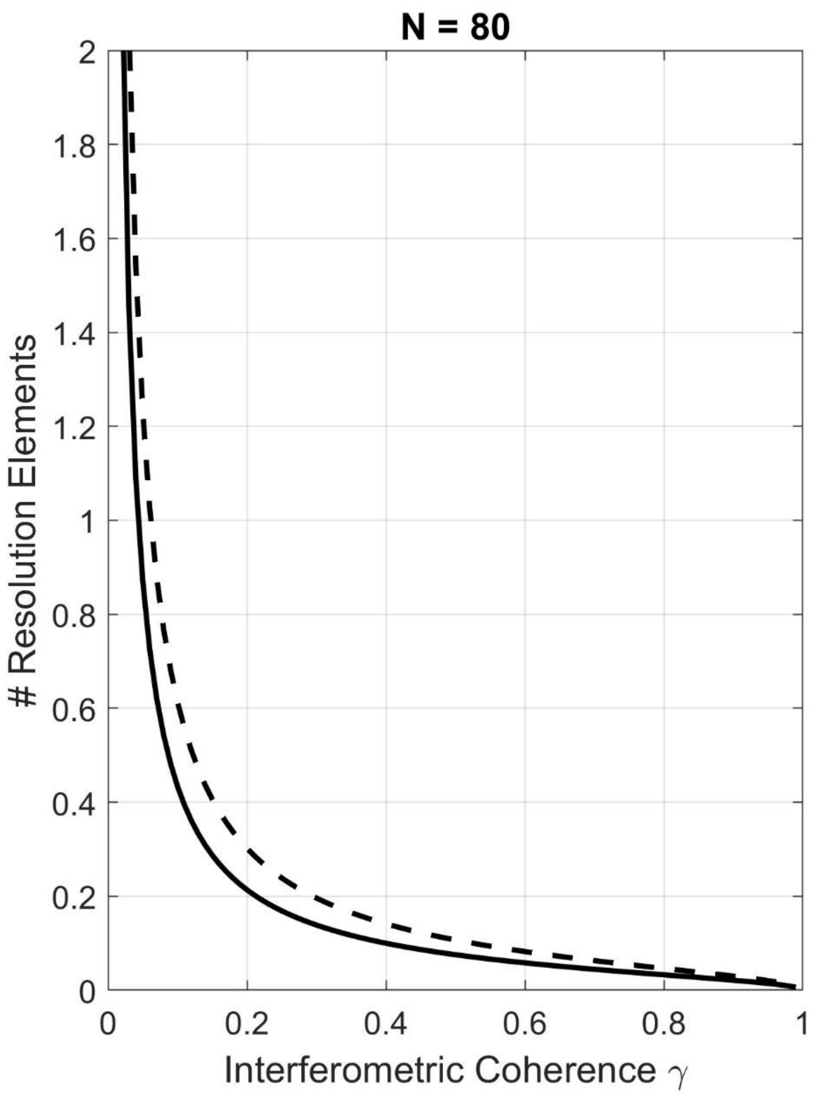


Accuracy of Cross-Correlation Estimates in SAR Images

Speckle Tracking

- **SAR images lend themselves well for template-based offset tracking because**
  - SAR images have speckle noise → images are very noisy
  - Noise can be tracked with high accuracy if noise remains coherent
- **Speckle tracking can be implemented either through**
  - Complex Cross-Correlation, OR
  - Amplitude-only Cross-Correlation (see previous discussion)
- **Speckle tracking accuracy can be calculated for coherent (σ_{CR}) & amplitude (σ_C) CC as function of interferometric coherence γ & the window size N used in CC calculation**
  - **Coherent** CC accuracy: $\sigma_C = \sqrt{\frac{3}{2N}} \cdot \frac{\sqrt{1-\gamma^2}}{\pi\gamma}$
  - **Amplitude** CC accuracy: $\sigma_A = \sqrt{\frac{3}{2N}} \cdot \frac{\sqrt{1-\gamma^2}}{\pi\gamma} \cdot \sqrt{2}$

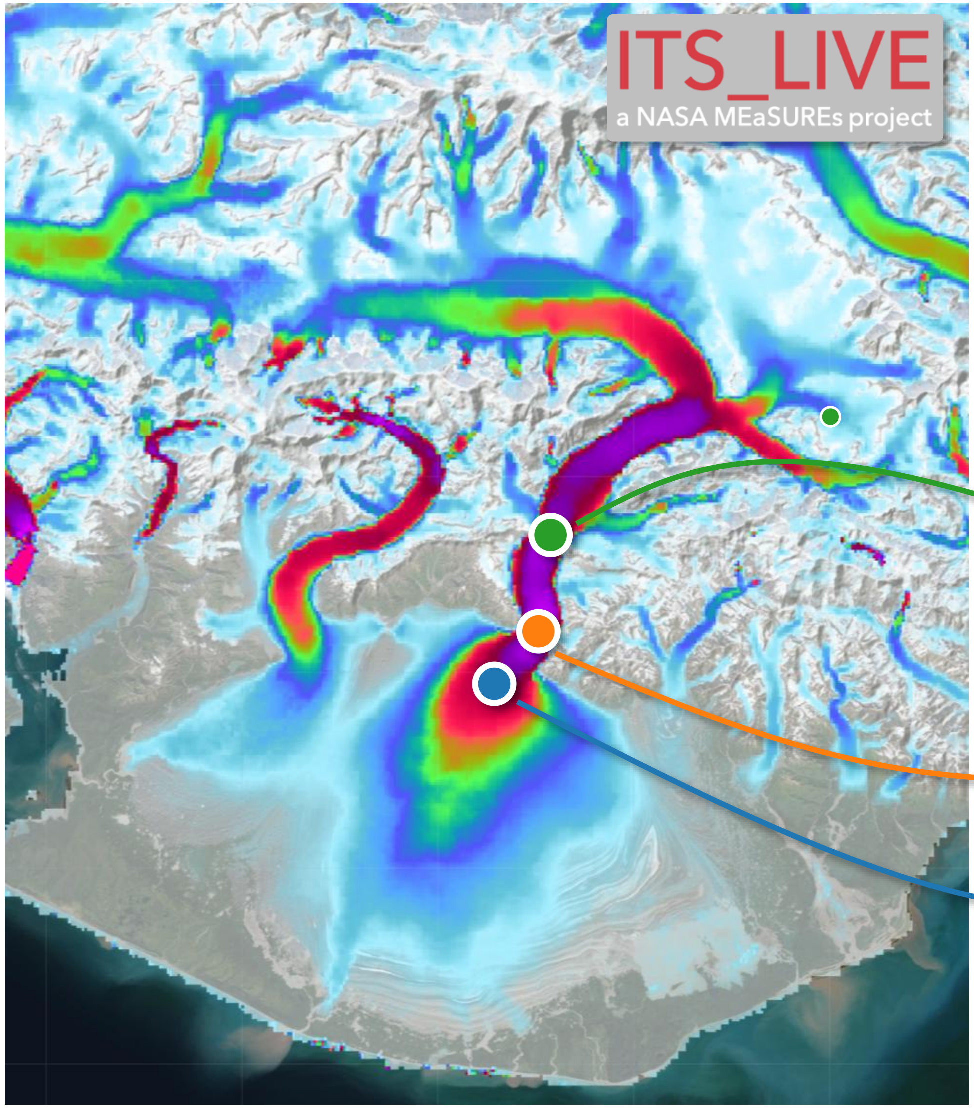
Amplitude CC uses only half of the available information → factor of $\sqrt{2}$ less accurate



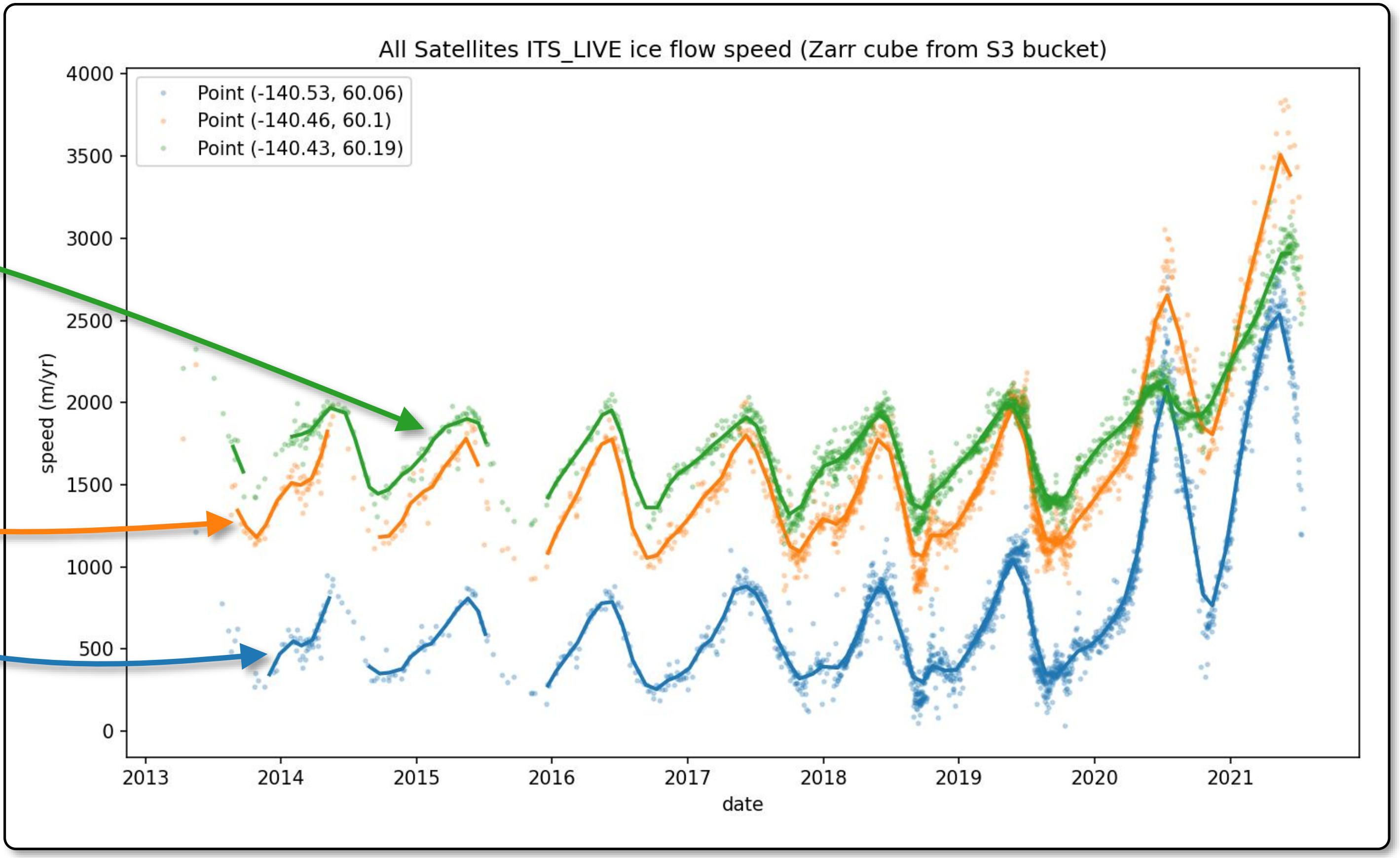
FEATURE MATCHING – AN EXAMPLE [PREPARATION FOR THE LAB]

Why We Measure Displacements

Monitoring Surge of Malaspina Glacier, Alaska using Optical and SAR Data



ITS_LIVE is led by Alex Gardner, JPL and includes partners at UAF. The project uses Feature Tracking from Landsat, Sentinel-2, and Sentinel-1 data to monitor velocities at all glaciers in the world!



Think – Pair – Share:

- **Explore Glacier Velocity Information generated by ITS_LIVE**
  - **Activity #1**: Explore ITS_LIVE archive
    - Go to the project website at https://its-live.jpl.nasa.gov/ and let's explore the data viewer on that page
    - Alternatively, you can access the data through the ITS_LIVE GitHub repository (https://github.com/nasa-jpl/its_live and start the ITS_LIVE Binder Notebook (click on launch binder)
    - Follow the instructions to access the glacier velocity information
    - Pick your favorite glacier
    - Select points and plot velocity time series information
    - Look up some background on your glacier to understand what is happening at the site you picked
  - **Activity #2**: Share your results