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Problems in Interferometric Synthetic Aperture Radar and 3D Radar imaging

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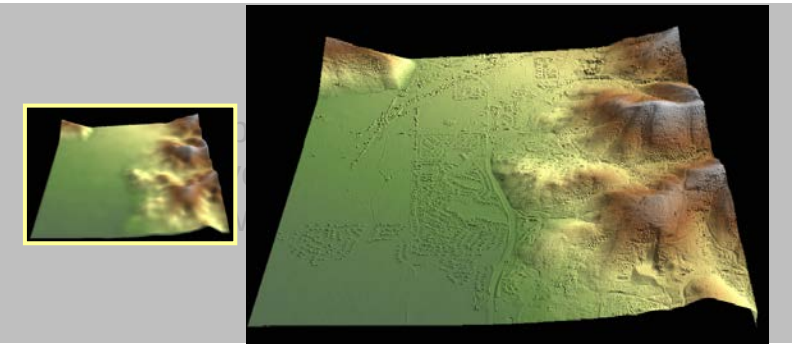

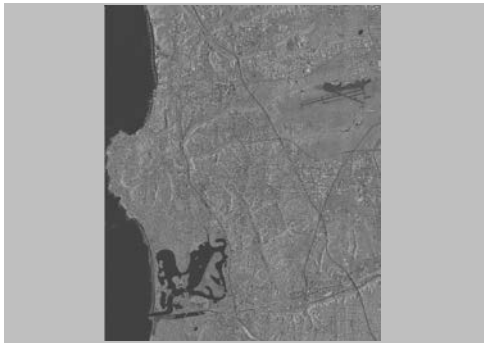

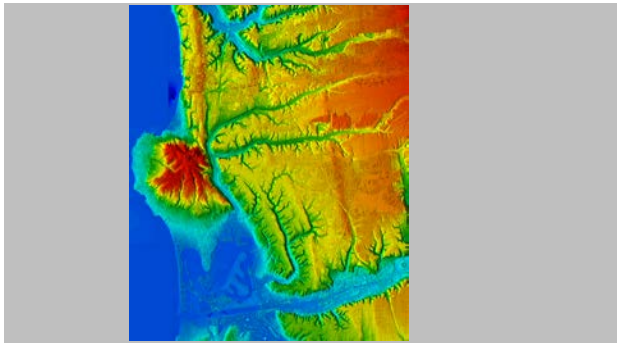

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Outline

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- Outline
- 3D radar imaging and relationship to SAR and InSAR
- Differential interferometric SAR
- Problems in InSAR
- Problems in 3D SAR
- Problems in DInSAR
- 4D InSAR
- SAR (stereo)
- Conclusion

3D radar imaging and relationship to SAR and InSAR

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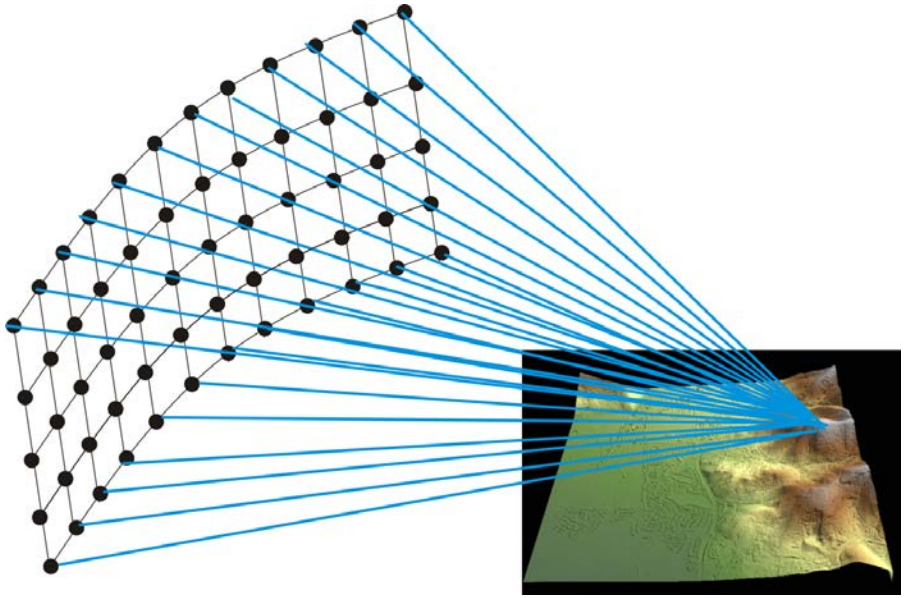
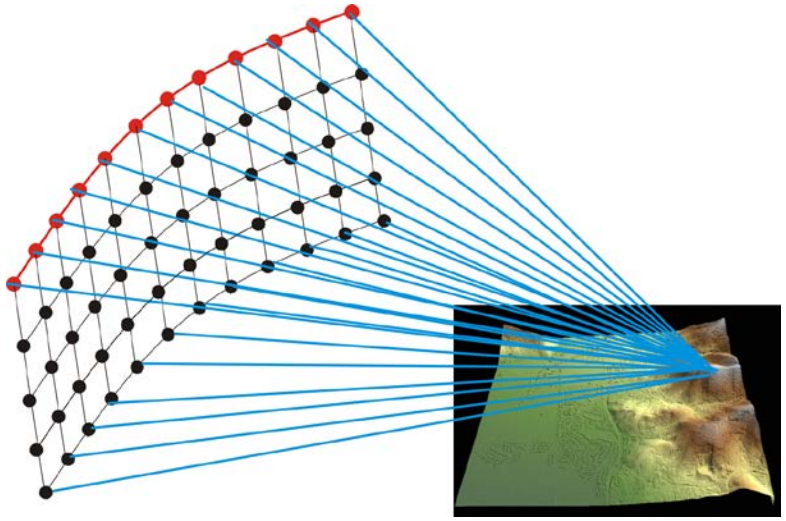
- 3D perspective:
  - A 2D aperture can be used to generate a 3D image via beamforming
  - A 1D aperture leads to synthetic aperture radar (SAR)
  - Image formation can be thought of as removing the RF phase and summing (backprojection)





3D radar imaging and relationship to SAR and InSAR

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- From a signal processing perspective, SAR is all about range
- To a reasonable order, we can think of the position part of SAR/InSAR as a multilateration problem
- The far-field phase of an RF signal contains range information (as well as the time-of-arrival)
- The far-field phase is scaled by frequency which can be quite high for higher frequency radar systems
- This scaling greatly increases the range sensitivity
  - Blessing – we are sensitive to very tiny changes in range
  - Curse – we are sensitive to very small errors in range
- Phase information is ambiguous in terms of 2π radians (i.e., modulo 2π)

3D radar imaging and relationship to SAR and InSAR

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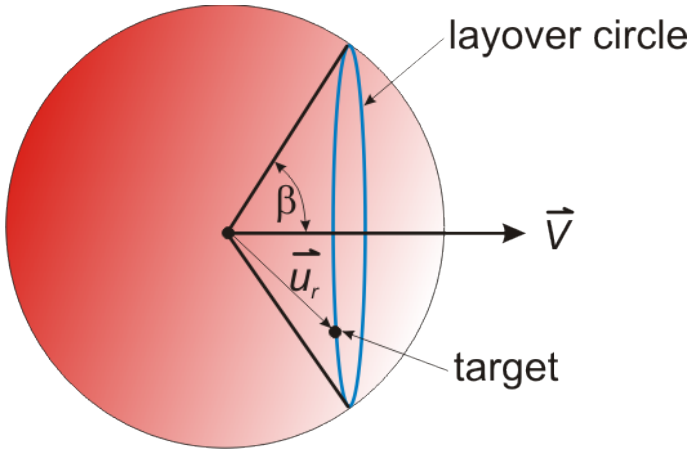
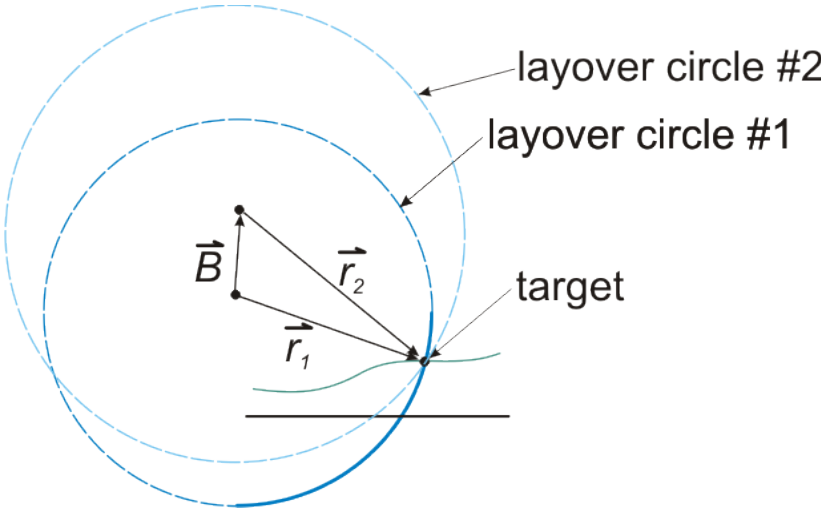
- The “synthetic” part of synthetic aperture radar means that we synthesize the 2D aperture by building up the spatial samples in time.
  - For 1D synthetic aperture this means flying a (typically horizontal straight-line path) and sampling as we go
  - For 2D synthetic apertures, this means combining several 1D synthetic apertures at different elevations
- Foreshadowing:
  - Generating the synthetic apertures takes time – for some applications this is good, for others, not so much
  - How much time do we have?
  - How well can we place our spatial samples?
  - Thermal noise always makes the estimation a random process

3D radar imaging and relationship to SAR and InSAR

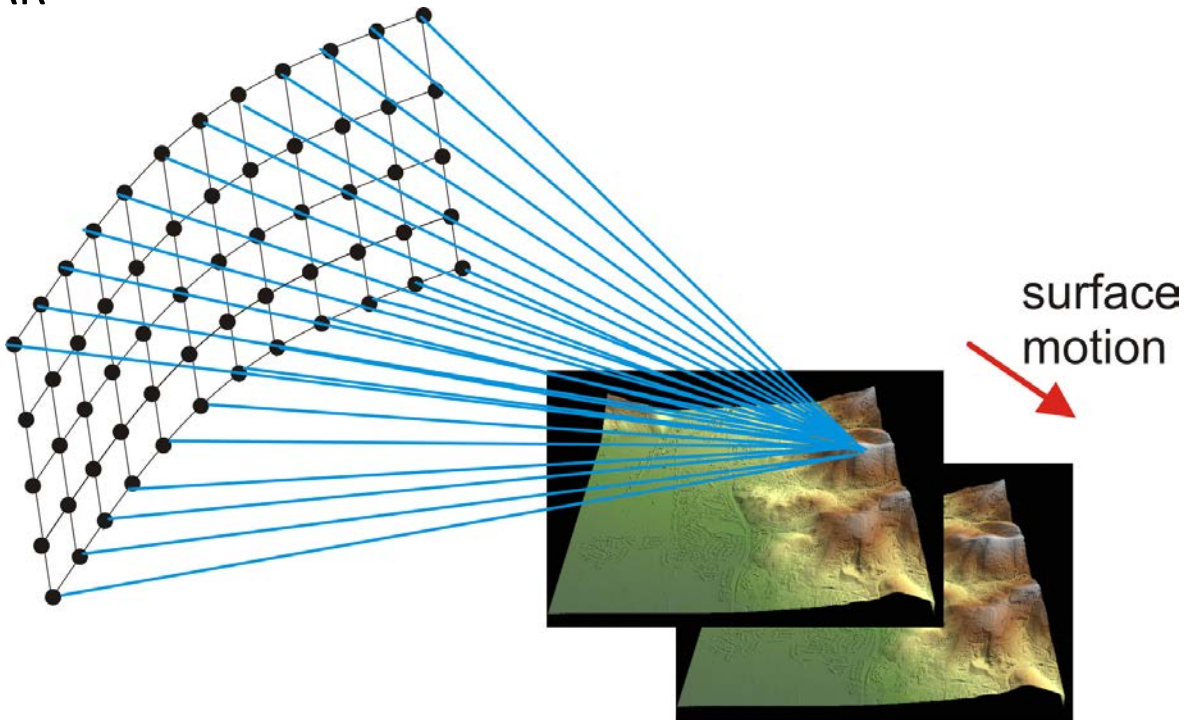
- Why InSAR or 3D SAR, etc?
  - Almost always, 1D SAR is ambiguous in height
  - For example, a (perfect) straightline flight yields a cylindrical symmetry which is insensitive to elevation angle (in 1D SAR, this is referred to as the "layover" problem)
- Therefore, the more we fill in the 2D aperture, the more information we have about the 3D nature of the target





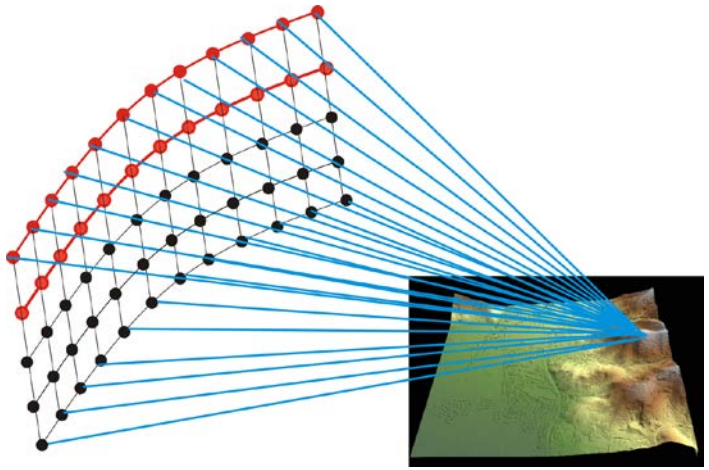
Differential Interferometric SAR (DInSAR)

- What if the surface is not stationary but moves in some very small but smooth/measurable manner between some set of passes?
  - Then you can have DInSAR
- Sensitive to:
  - Seismic movement
  - Thermal expansion of structures
  - Settling of the earth



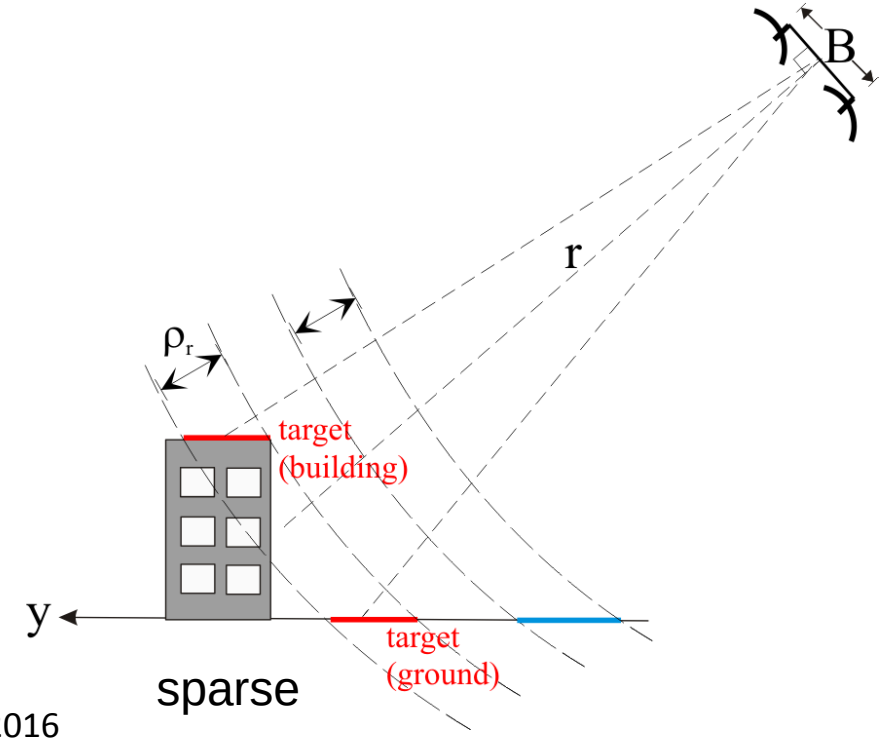
Problems in InSAR (sometime called IFSAR)

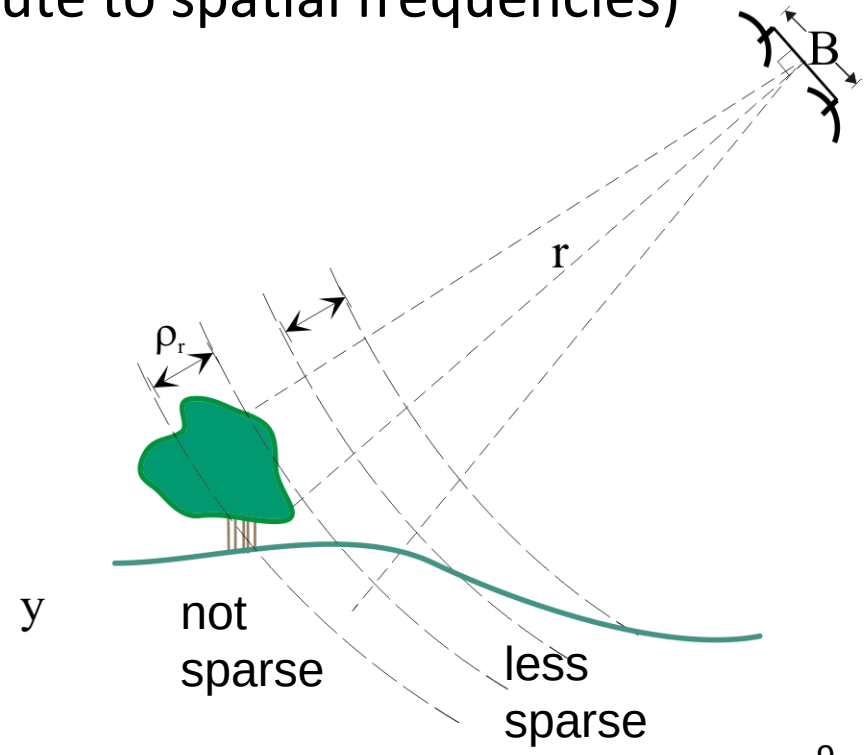
- InSAR is refers to processing of 2 SAR images
  - Either from 2 flight passes, or by 1 flight pass with two different antennas separated in elevation
- InSAR issues:
  - Elevation aperture is sampling sparse
  - Elevation resolution is limited (in a traditional sense)
  - Modulo 2π (or phase unwrapping) is a problem



Problems in InSAR (sometime called IFSAR)

- An advantage we have is that the terrain can also be assumed to be sparse (lends itself to sparse aperture techniques)
- The less sparse it is in elevation the more spatial samples in elevation we need (they contribute to spatial frequencies)





Problems in InSAR

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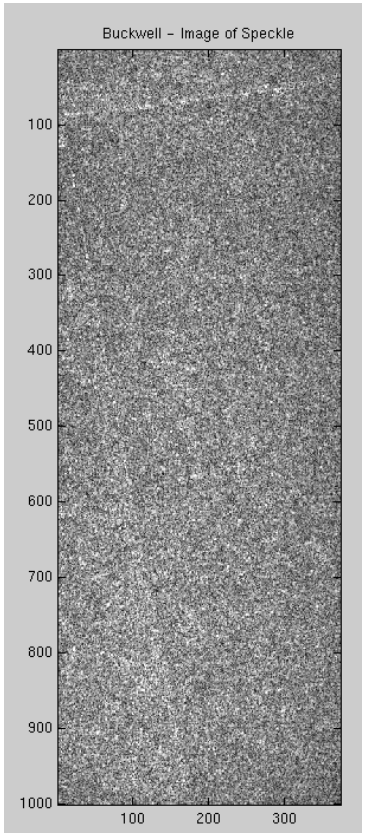
- Complex targets
  - Ideal case is a simple omnidirectional Dirac delta function response ("point target")
  - In practice this does not occur except in limited geometries
  - Natural targets (e.g., grass, trees, rocks, dirt, etc.) are taken to be superposition of a large number of targets that approach spatially “white”, i.e., independent complex circularly white Gaussian (so called "speckle")
  - This means that their correlation is introduced by the spatial filtering processes in the SAR image formation
  - Wind/weather limit the coherence time between passes leads to random changes for natural terrain - decorrelation
- Noise is assumed to have a similar behavior except that it is temporally "white" rather than spatially "white"

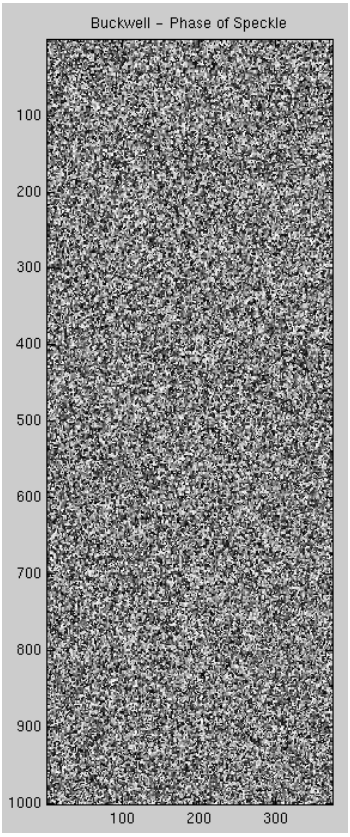
Problems in InSAR

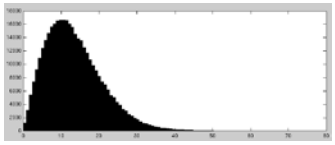
- Speckle

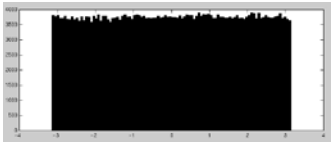
SAR Image Amplitude



SAR Image Phase

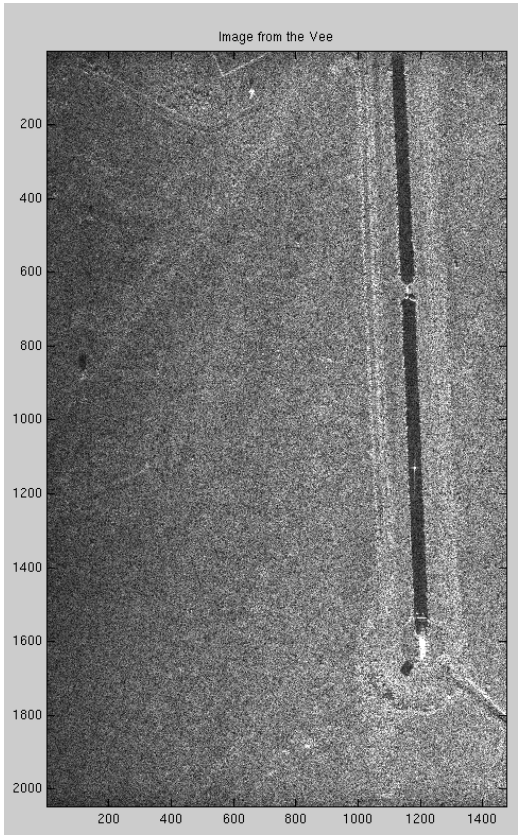




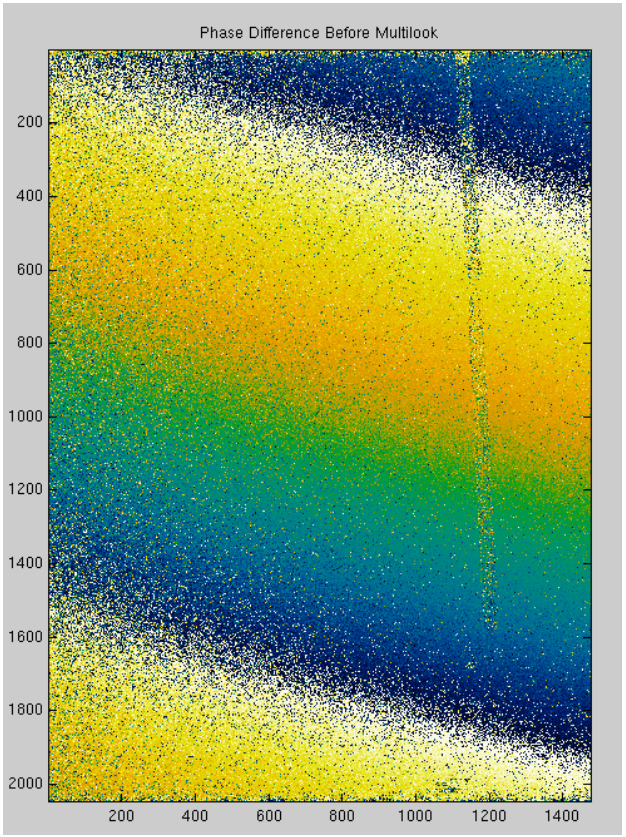


Problems in InSAR

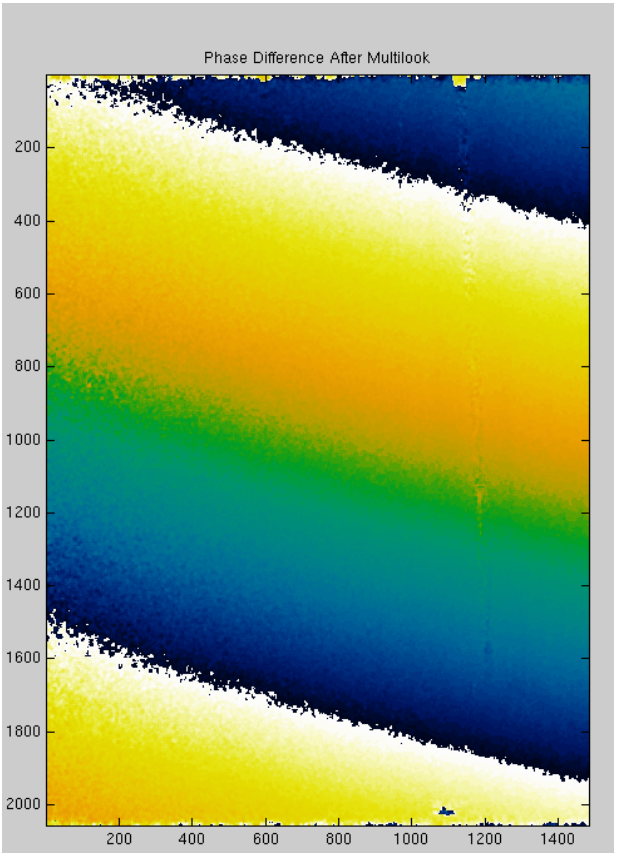
- Interferogram with speckle and noise
- Note phase ambiguities (wraps)



one of SAR images in interferogram



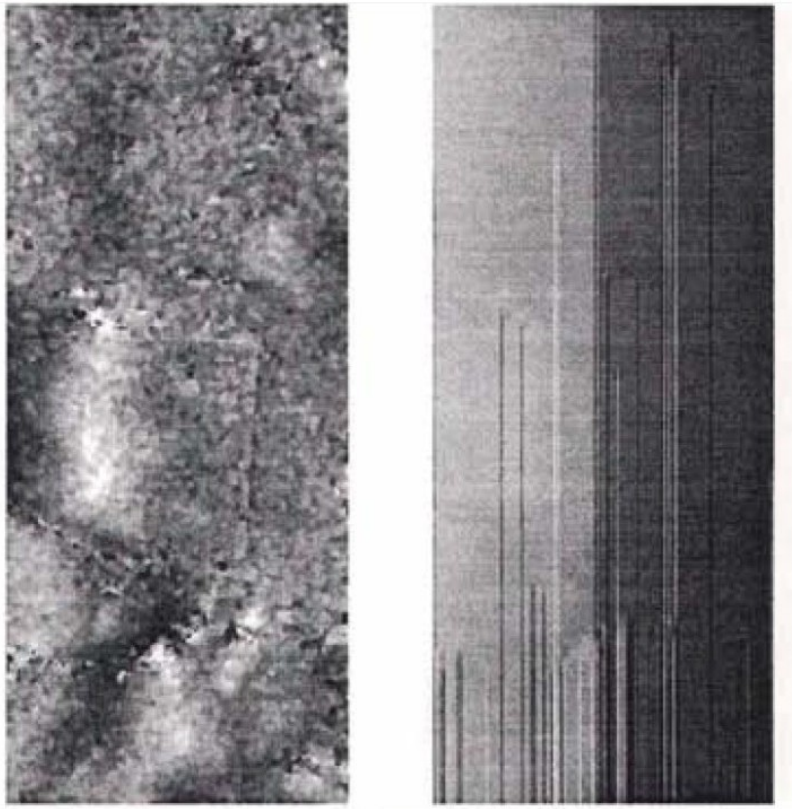
phase of interferogram



Smootheed phase of interferogram

Problems in InSAR

- Speckle and noise complicate various issues in InSAR (and all the other problems we discuss)
- One such example is 2D phase unwrapping
  - Very highly studied problem but solution is elusive
  - Typically done by a path integration, but path dependent
  - Some attempts at least-squares, but it is really a mixed integer problem rather than a float solution



Integration path dependence

Problems in 3D SAR

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- InSAR is not really 3D imaging – SAR with a height estimate for each pixel (but many of same problems prevail)
- 3D SAR is approached by flying multiple lines at different elevation angles
- Some of the problems include:
  - Still have sparsity in the aperture usually
    - don't have unlimited flight geometries or temporal decorrelation
  - Aperture is often not uniformly sampled in any direction
  - Still often do not meet the Rayleigh resolution criteria

Problems in 3D SAR

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- Recent interest in man-made objects since they maintain temporal coherence over longer period of time
  - But they are sparse in the scene
- New temporal concern – thermal expansion
- Another issue for mostly spaceborne systems is that the path length changes between passes due to atmospheric refractivity changes

Problems in DInSAR

- Recall DInSAR is interested in subtle motion change
  - NOT random motion because we lose the information we need due to decorrelation
  - Examples include seismic changes, settling due to pumping water, thermal expansion
- DInSAR has many of the same problems – e.g., atmosphere, etc.
- … but is more sensitive to
  - Temporal decorrelation (random motion of scatterers from wind, etc)
  - Relies heavily on "persistent scatterers" – man-made or other discrete point-like returns
- A new issue:
  - The height information from previous techniques is a nuisance signal
    - This is particulary a problem for airborne systems
  - Ideally wish to fly exact same paths over and over

4D SAR

- 4D SAR is a fairly new field that combines 3D SAR and DInSAR
- Want to estimate the evolution of 3D SAR as a function of time (or a time related quantity)
- E.g., attempt to account for thermal expansion in 3D SAR images of buildings

SAR (stereo)

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- Stereo may be a deviation from terminology used in literature
- Idea is that by flying a circular path, we can obtain a 3D image of objects via multi-lateration using the range time arrival (and not the far-field phase per se)
- Main issue is that the correlation is limited to modest angles for radar returns, particularly natural terrain
- We need very accurate association of the radar returns to estimate the proper range for multi-lateration
- Result is that is difficult to automate

Conclusions

- I find the interferometric SAR area a rich area for new discoveries, new analysis, and new methods to apply against interesting and important problems
- I realize I presented very little math, but hopefully I bridged the gap on terminology and let you know issues that are ripe for new mathematics and methods

- Thank you for your attention

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Questions??

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