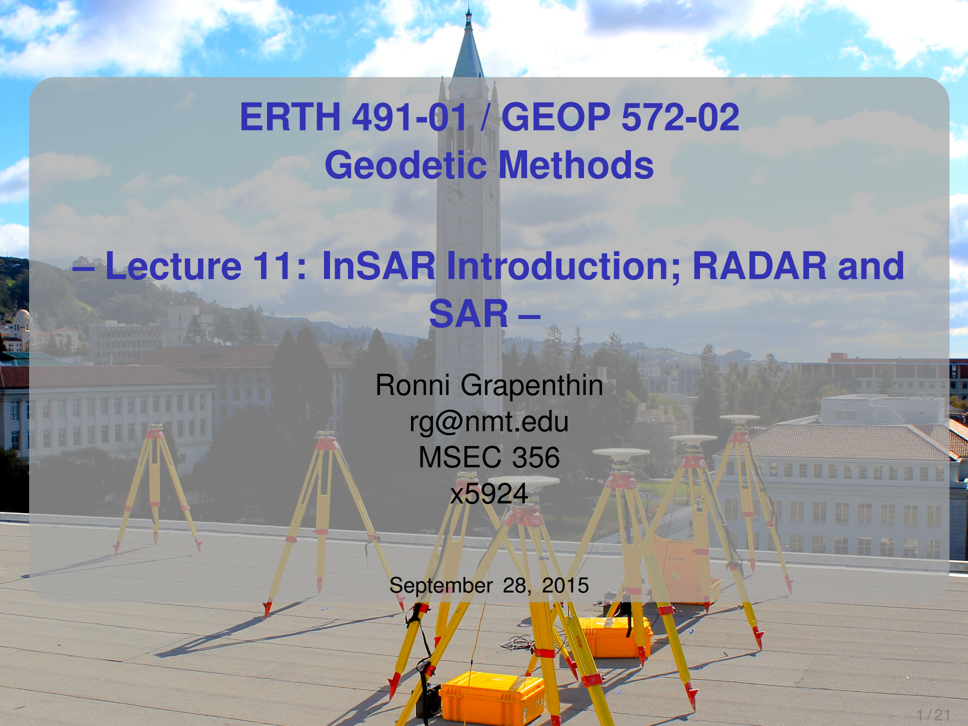

ERTH 491-01 / GEOP 572-02
Geodetic Methods

– Lecture 11: InSAR Introduction; RADAR and SAR –

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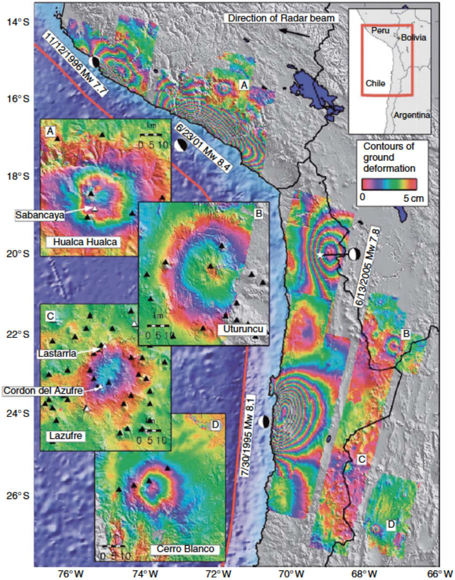
The First InSAR Applications

- 1992 M_w=7.3 Landers Earthquake
- before that (1987 onwards):
- ocean currents, ice motion, soil swelling in Imperial Valley

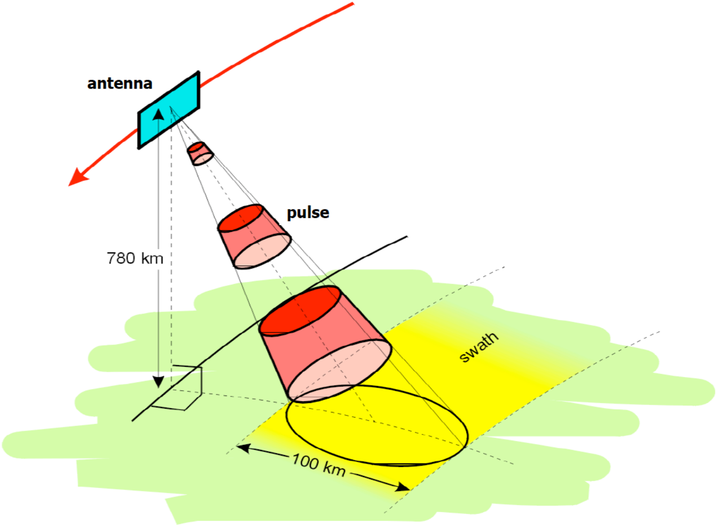
Massonnet et al., 1993

Now: “Fishing Trips”



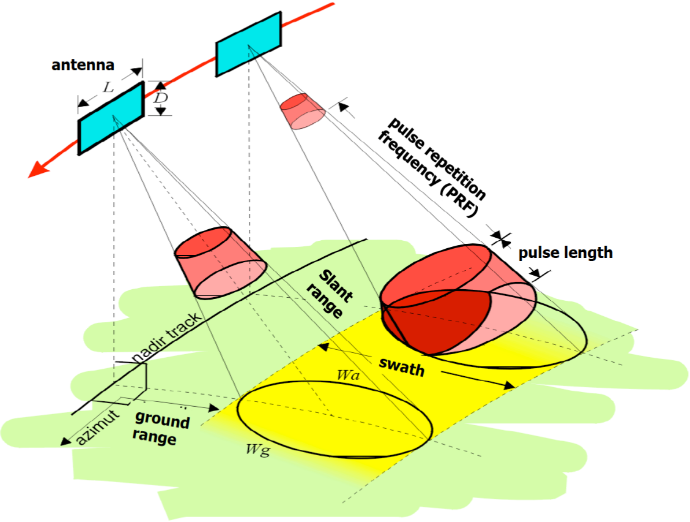
Simons and Rosen, 2007

InSAR - General Concept



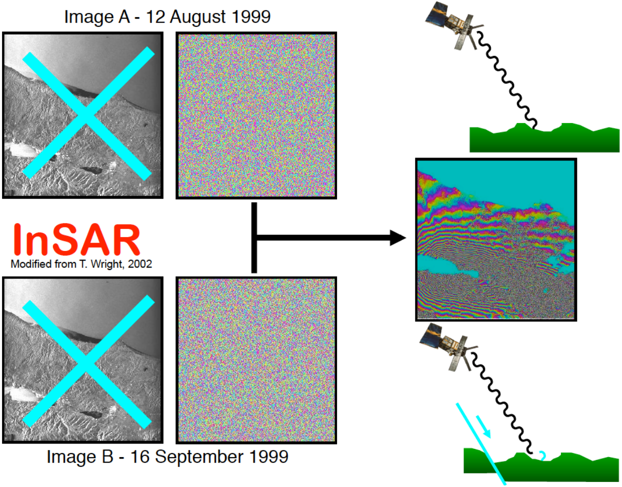
loaned from *J. Freymueller*

InSAR - General Concept



loaned from *J. Freymueller*

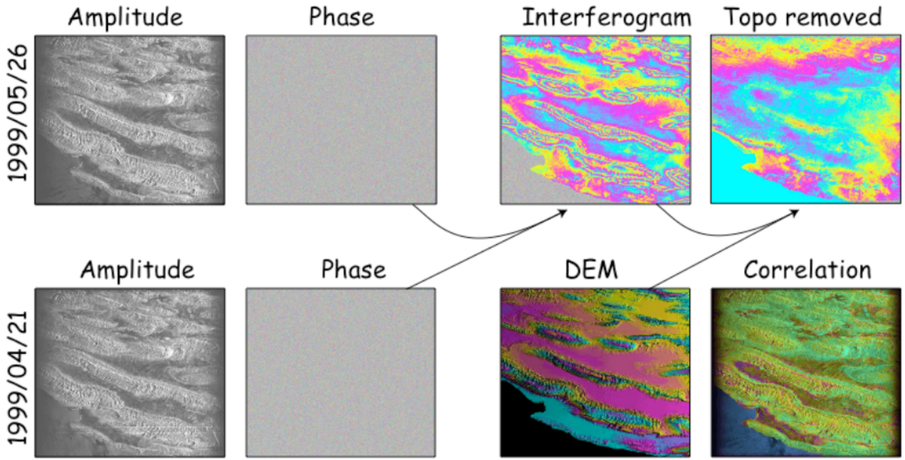
InSAR - General Concept



loaned from *R. Bürgmann*

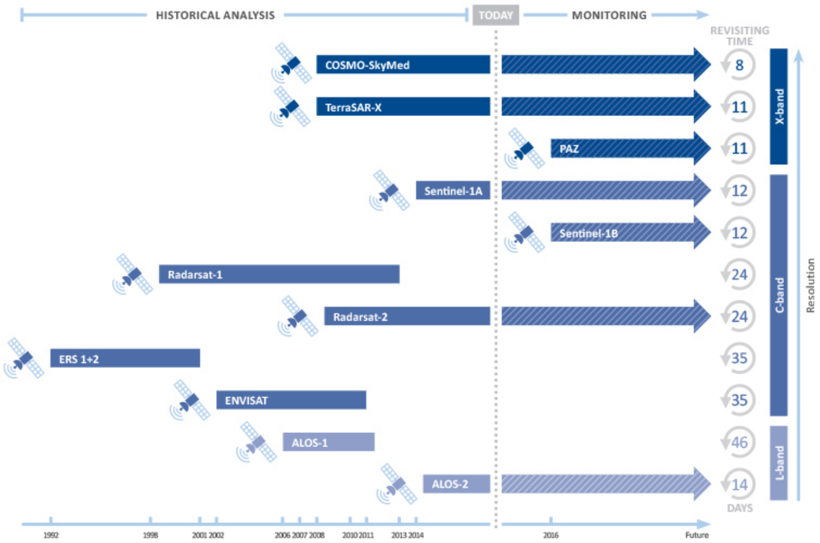
complex values radar signal contains information on amplitude $a = \sqrt{Im^2 + Re^2}$, and phase $\phi = arctan\frac{Im}{Re}$

InSAR - General Concept



loaned from *J. Freymueller*

InSAR - Mission Overview



from *http://treuropa.com/newsletter/15-years-expertise-advanced-insar-technology/*

InSAR - Processing Flow

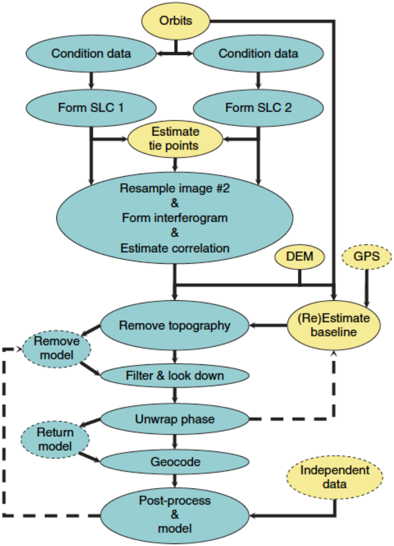


Figure 6 Representative differential InSAR processing flow diagram. Blue bubbles represent image output, yellow ellipses represent nonimage data. Flow is generally down the solid paths, with optional dashed paths indicating potential iteration steps. DEM, digital elevation model; SLC, single look complex image.

Simons and Rosen, 2007

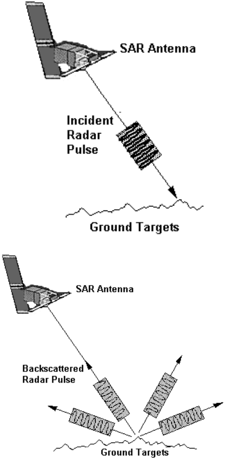
Interferometric **S**ynthetic **A**perture **R**adar

Need to talk about:

- Radar (today)
- Synthetic Aperture (today)
- Interferometry (Wednesday)
- phase unwrapping, noise sources (next Monday)
- timeseries, stacking, permanent scatterers (next Wednesday)

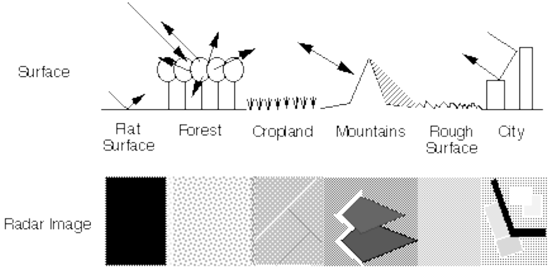
Radar

- Radio Detection and Ranging
- active system uses EM waves
- reflection, refraction, polarization, interference with one another
- principle:
  - send pulse of oscillating EM energy
  - frequency f, duration τ
  - scatter - some energy returns to radar
  - $\lambda = c/f$
  - $R = ct/2$



from: `http://southport.jpl.nasa.gov/desc/imagingradarv3.html`

Radar Scattering



from: `http://southport.jpl.nasa.gov/desc/imagingradarv3.html`

Rules of Thumb for Surfaces in Radar Images:

- Smooth (calm water surface) - black
- Rough (water in windy day) - white
- hills, other large scale surface variations - bright on one side, dim on the other
- human made objects - bright spots (corner reflectors)

Radar Resolution

It's an issue - it's low!

Need Synthetic Aperture because angular resolution is governed by ratio of λ to aperture (size of antenna).

Fraunhofer diffraction 1/3

Coherent radiation passes through 1D aperture (follow Sandwell et al., 2011):

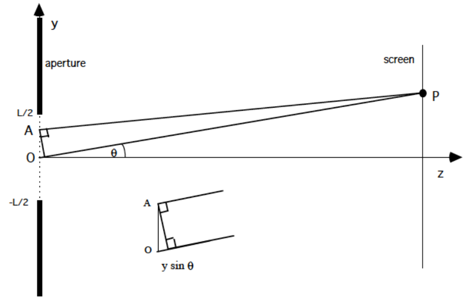


Figure A1 Diagram for the projection of coherent microwaves on a screen that is far from the aperture of length L.

Sandwell et al., 2011, GMTSAR documentation

Fraunhofer diffraction 1/3

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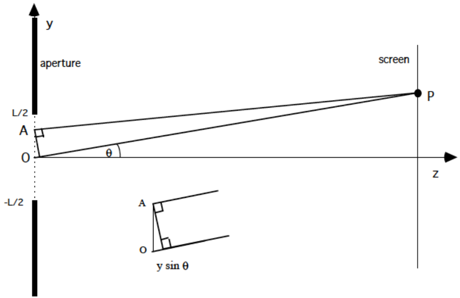

Figure A1 Diagram for the projection of coherent microwaves on a screen that is far from the aperture of length L.

Sandwell et al., 2011, GMTSAR documentation

- point sources of radiation between -L/2, L/2
- screen far away: $AP||OP$; so $AP - ysin(\theta) = OP$
- solve for illumination pattern on screen as function of θ

Fraunhofer diffraction 2/3

Amplitude of illumination at P is integral of all sources along aperture multiplied by their complex phase value:

$$P(\theta) = \int_{-L/2}^{L/2} A(y) e^{-i2\pi yk\sin(\theta)} dy$$

with $k = 1/\lambda$; $P(\theta)$ is *Fraunhofer diffraction integral*

Fraunhofer diffraction 2/3

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with $k = 1/\lambda$; $P(\theta)$ is *Fraunhofer diffraction integral*

Illumination across aperture is uniform, so $A(y) = 1$

Substitute $s = 2\,\pi\,y\,k\,sin(\theta)$ for easy evaluation of integral:

$$\begin{aligned} P(\theta) &= \int_{-L/2}^{L/2} e^{-i\,s\,y} dy = \frac{e^{-i\,s\frac{L}{2}} - e^{i\,s\frac{L}{2}}}{-i\,s} \\ &= \frac{2}{s} sin(s\frac{L}{2}) = L\,sinc(s\frac{L}{2}) \\ &= L\,sinc(\frac{L\,\pi\,sin(\theta)}{\lambda}) \end{aligned}$$

Fraunhofer diffraction 3/3

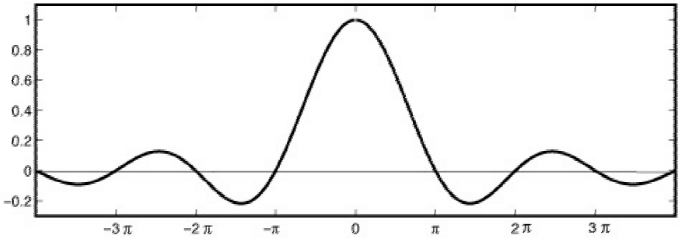

Figure A2. Sinc function illumination pattern for the aperture shown in Figure A1.

Sandwell et al., 2011, GMTSAR documentation

Fraunhofer diffraction 3/3

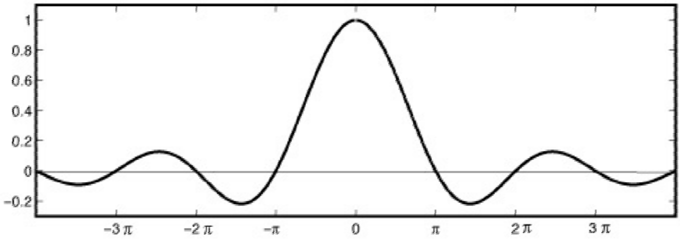

Figure A2. Sinc function illumination pattern for the aperture shown in Figure A1.

Sandwell et al., 2011, GMTSAR documentation

- first zero crossing, angular resolution θ_r, at π
- $\frac{L\pi\, sin(\theta)}{\lambda} = \pi$ for $sin(\theta_r) = \frac{\lambda}{L}$
- for small angles $\theta_r \approx \frac{\lambda}{L}$ and $tan(\theta_r) \approx sin(\theta_r)$
- here we have it! angular resolution, θ_r, is governed by ratio of λ to aperture (size of antenna).

Examples

- GEOSAT orbits Earth at 800 km,
- 1 m parabolic dish operates in Ku-band (13.5 GHz, $\lambda = 0.022$ m)
- footprint diameter about 43 km
- ERS: along track footprint = 8.5 km; range-direction footprint about 85 km
- optical system with 1 m aperture, but wavelength $\lambda = 5 \times 10^{-7}$ m has footprint diameter of 0.97 m

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Lesson:

Need major increase in antenna length for microwave system to get high angular resolution!

Synthetic Aperture!

Synthetic Aperture 1/4

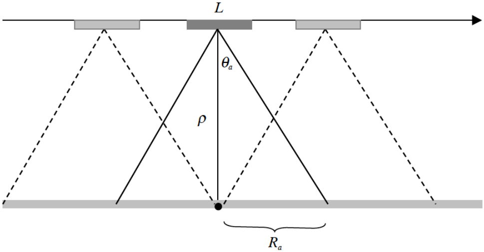

Figure A7. Top view of SAR antenna imaging a point reflector. The reflector remains within the illumination pattern over the real aperture length of $2R_a$.

Sandwell et al., 2011, GMTSAR documentation

- single point reflector on ground illuminated by radar flying by
- length of illumination (twice angular resolution) related to wavelength over antenna length (Fraunhofer diffraction)
- real aperture radar azimuth resolution: $R_a = \rho\, tan(\theta_r) \approx \frac{\rho\lambda}{L} = \frac{\lambda H}{L\, cos(\theta)}$
- where L is antenna length, ρ is slant range

Synthetic Aperture 2/4

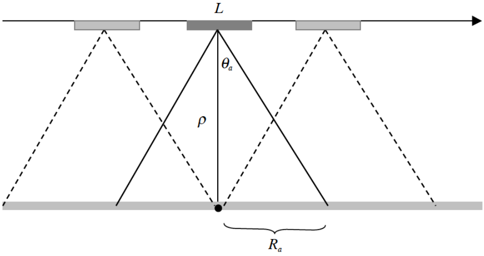

Figure A7. Top view of SAR antenna imaging a point reflector. The reflector remains within the illumination pattern over the real aperture length of $2R_a$.

Sandwell et al., 2011, GMTSAR documentation

- scatterer stationary as radar flys by: can assemble synthetic aperture
- Synthtic Aperture length equal to along track beamwidth $2R_a$
- for ERS: aperture is now 8.5 km.
- new azimuth resolution: $R'_a = \frac{\lambda \rho}{2R_a} = \frac{L}{2}$
- independent of spacecraft height!
- improves as antenna length is reduced!

Synthetic Aperture 3/4

Should we make antenna as short as possible to improve azimuth resolution?

Synthetic Aperture 4/4

- Can't do that!
- radar must be pulsed at along track distance of L/2 or shorter
- avoids aliasing long wavelengths back into shorter (Nyquist)
- pulse rate frequency can't be too large or near-range far-range returns will overlap
- for ERS maximum PRF is 4777 Mhz; actual PRF is 1680 MHz
- real limitation is data ling from spacecraft to ground

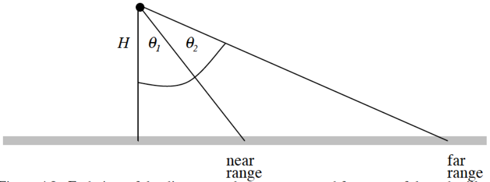

Figure A9. End view of the distance to the near range and far range of the radar illumination pattern.

Sandwell et al., 2011, GMTSAR documentation