Earth Science Applications of Space Based Geodesy

DES-7355

Tu-Th   9:40-11:05

Seminar Room in 3892 Central Ave. (Long building)

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Office: 3892 Central Ave, Room 103
678-4929
Office Hours – Wed 14:00-16:00 or if I'm in my office.

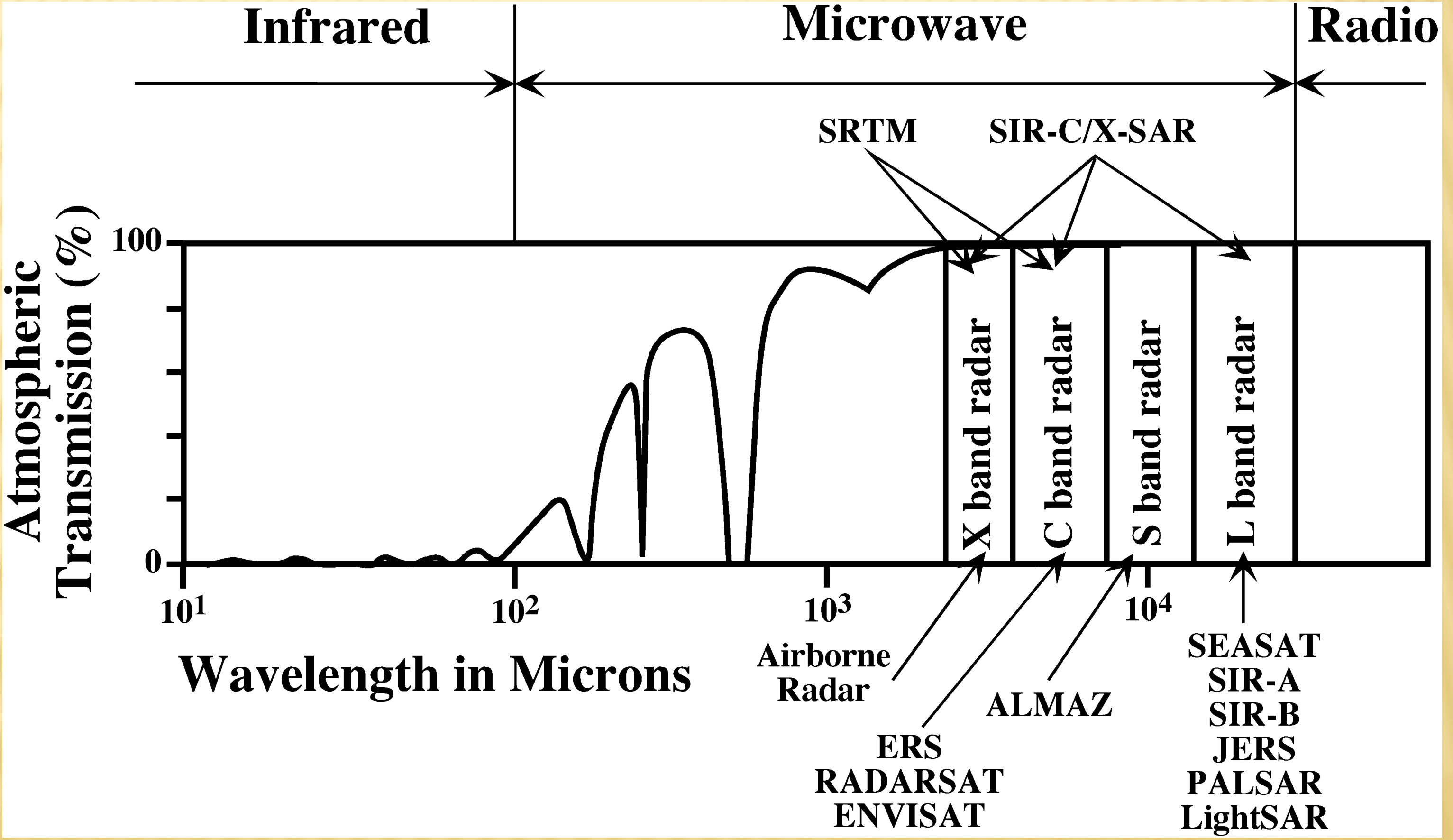
http://www.ceri.memphis.edu/people/smalley/ESCI7355/ESCI_7355_Applications_of_Space_Based_Geodesy.html

Class 22

Imaging Radar – General

- RADAR = RAdio Detection and Ranging
- Uses the microwave region of the electromagnetic spectrum.
- Wavelengths used in imaging radar range between 1 mm and 1 m
- Longer wavelengths are used for communication and navigation.

MICROWAVE REGION



Radar Bands

Wavelength Range and Descriptions

• Ka, K, and Ku Bands

very short wavelengths used in early airborne radar systems but uncommon today

• X-band

used extensively on airborne systems for military reconnaissance and terrain mapping.

• C-band

on many airborne research systems (CCRS Convair-580 and NASA AirSAR) and spaceborne systems (including ERS-1 and 2 and RADARSAT).

• S-band

used on board the Russian ALMAZ satellite.

• L-band

used onboard American SEASAT and J• apanese JERS-1 satellites and NASA airborne system.

P-band

longest radar wavelengths, used on NASA experimental airborne research system

Radar Bands

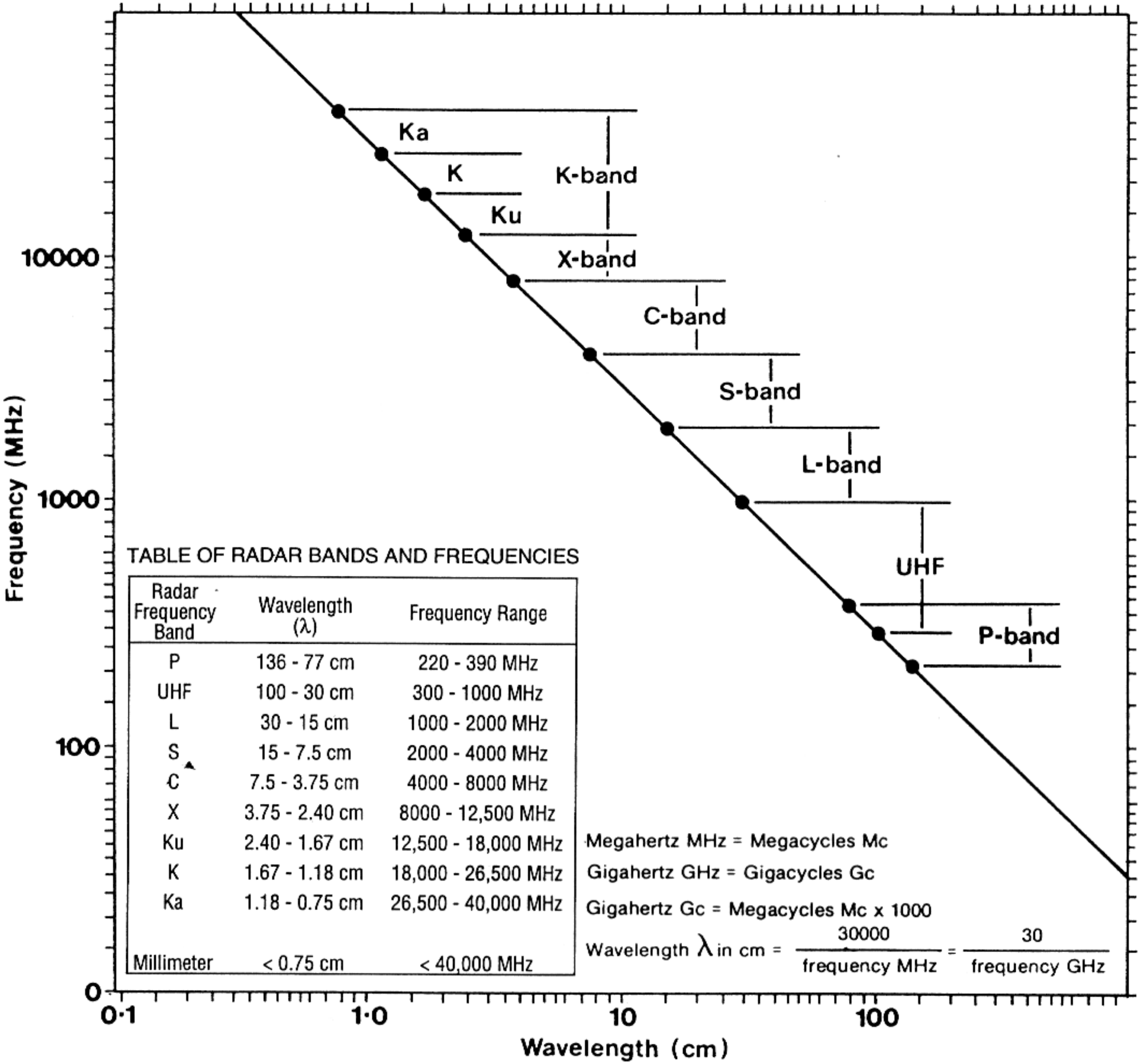


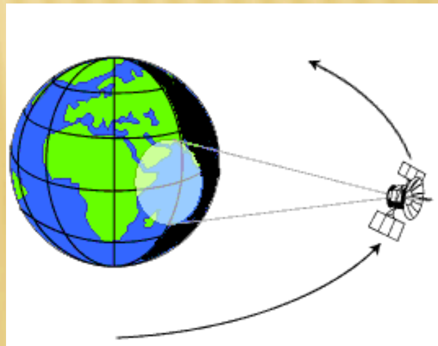
TABLE OF RADAR BANDS AND FREQUENCIES

Radar Frequency Band	Wavelength (λ)	Frequency Range
P	136 - 77 cm	220 - 390 MHz
UHF	100 - 30 cm	300 - 1000 MHz
L	30 - 15 cm	1000 - 2000 MHz
S	15 - 7.5 cm	2000 - 4000 MHz
C	7.5 - 3.75 cm	4000 - 8000 MHz
X	3.75 - 2.40 cm	8000 - 12,500 MHz
Ku	2.40 - 1.67 cm	12,500 - 18,000 MHz
K	1.67 - 1.18 cm	18,000 - 26,500 MHz
Ka	1.18 - 0.75 cm	26,500 - 40,000 MHz
Millimeter	< 0.75 cm	< 40,000 MHz

Murchison

IMAGING RADAR - ADVANTAGES

- Active system (works day or night).
  - There is also passive microwave imaging (radiometer) mode. This senses surface radio-emission, which can be converted to radiant temperatures.
- Not affected by cloud cover or haze if $\lambda > 2$ cm. It operates independent of weather conditions. Water clouds have a significant effect on radar with wavelength $\lambda < 2$ cm.
- Unaffected by rain $\lambda > 4$ cm.
- Can penetrate well-sorted dry sand in hyper-arid regions to a depth of about 2 m.



TERMINOLOGY

- RAR: Real Aperture Radar
- SAR: Synthetic Aperture Radar
- SLAR: Side-looking airborne radar (could be RAR or SAR).
- SIR: Shuttle imaging radar (a SAR)
  - 3 missions: SIR-A (1981), SIR-B (1984) and SIR-C (1994)
- INSAR: Interfereometric SAR. Can be satellite or airborne.
- SRTM: Shuttle Radar Topography Mission (an INSAR mapping mission)
- PSSAR: Permanent Scatterer Synthetic Aperture Radar

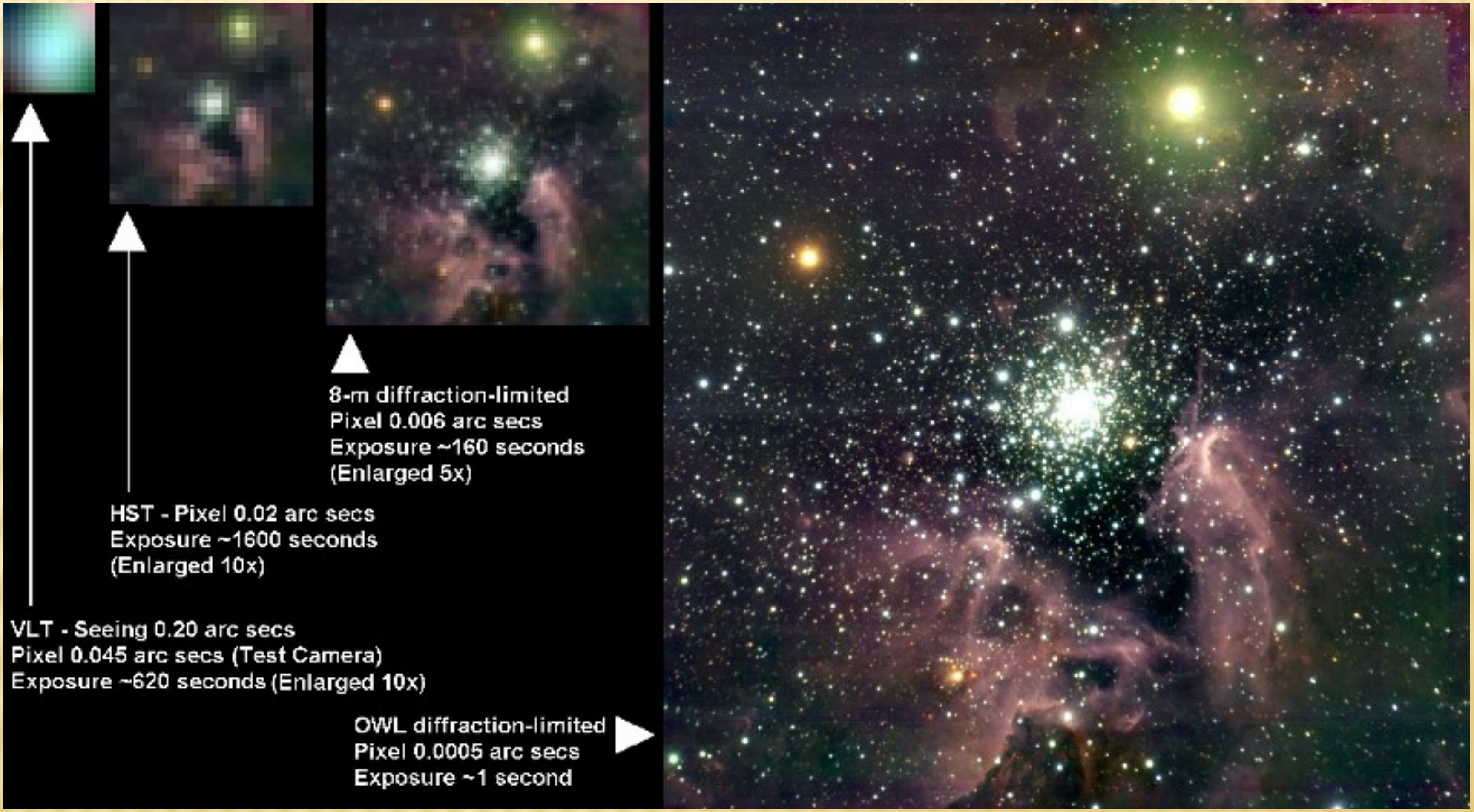
Synthetic Aperture Radar – Systems and Signal Processing

APERTURE

Optics : Diameter of the lens or mirror. The larger the aperture, the more light a telescope collects. Greater detail and image clarity will be apparent as aperture increases.

2.4m Hubble Space Telescope
10m Keck, Hawaii
16.4m VLT (Very Large Telescope), Chile
50m Euro50
100m OWL (OverWhelmingly Large T.)

OVERWHELMINGLY LARGE TELESCOPE



What is InSAR?

- Method using an orbiting satellite that emits and receives radio energy in the form of waves
- Carries two types of information.
    - Information about surface from which radio waves reflected carried in strength, intensity, and phase chages of signal
    - Changes in roundtrip distance seen through phase changes of the radio waves.

Synthetic Aperture Radar – Systems and Signal Processing

REAL APERTURE VS. SYNTHETIC APERTURE

- Real Aperture : resolution ~ Rλ/L

- Synthetic Aperture: resolution ~ L/2

Irrespective of R
Smaller, better?!
- Carl Wiley (1951)

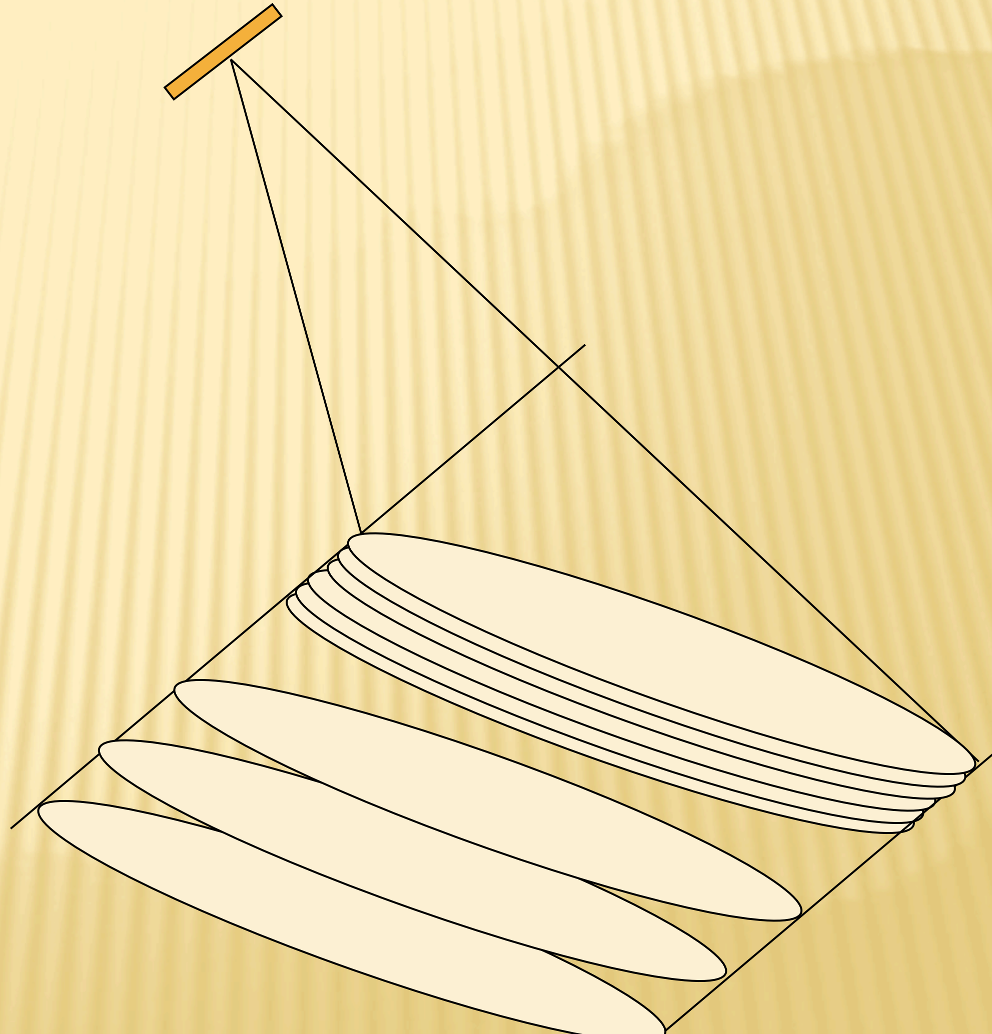
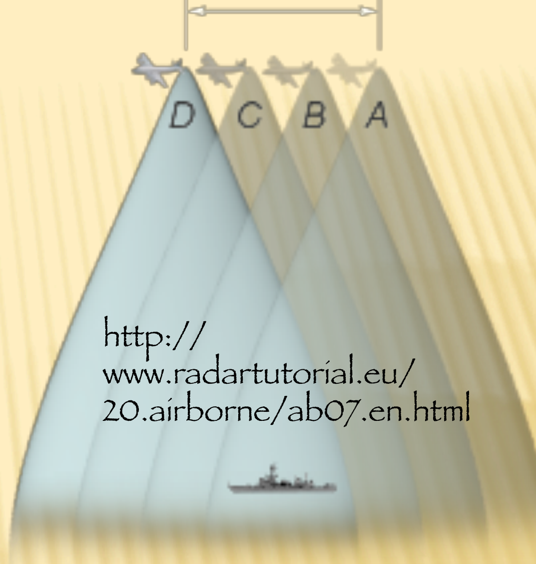


IMAGE ACQUISITION



http://www.radartutorial.eu/20.airborne/ab07.en.html

ERS-1/2 SAR

L: 10 m, D: 1 m

Altitude: 785 km, sun-synchronous orbit

Ground Velocity: 6.6 km/s

Look Angle: Right 17°-23° (20.355° mid-swath)

Slant Range: 845 km (mid-swath) Frequency: C- Band (5.3GHz, 5.6 cm)

Footprint : 100 km x 5 km

Incidence Angle: 19 ° – 26 ° (23 ° mid-swath)

Sampling Rate: 18.96 MHz

Pulse duration: 37.1 µs

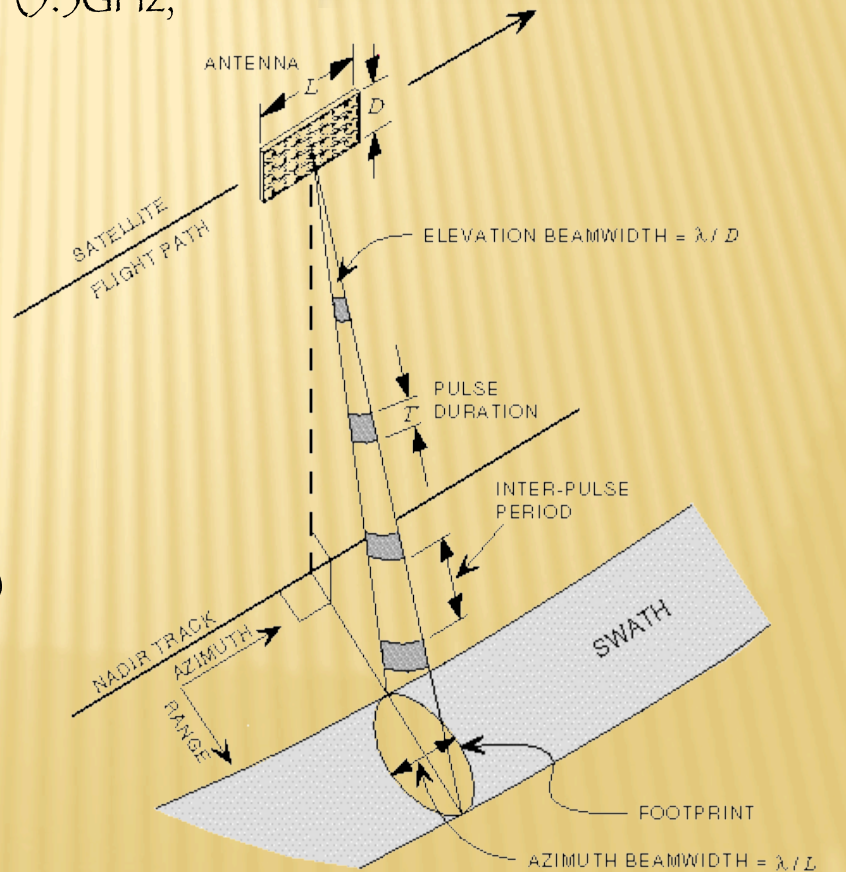
Range gate: ~ 6000 µs

Sampling Duration: ~ 300 µs (5616 samples)

Inter-pulse period: ~ 600 µs (upto 10 pulses)

Pulse Repetition Frequency: 1700 Hz

Data Rate: 105 Mb/s (5 bits/sample)



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SAR SYSTEMS

Spaceborne SAR

SEASAT-A (USA, 1978), SIR-A (USA, 1981), SIR-B (USA, 1984), SIR-C/X-SAR (USA, Germany, Italy, 1994), ALMAZ-1 (Russia, 1991-1993), ERS-1(EU, 1991-2000), ERS-2 (EU, 1995-), JERS-1 (Japan, 1992-1998), Radarsat-1 (Canada, 1995-), SRTM (USA/Germany, 2000), ENVISAT (EU, 2002),

RADARSAT-2 (Canada, 2005), PALSAR (Japan, 2004), LightSAR (US)*, TerraSAR (Germany)*, MicroSAR(EU)*

Airborne SAR

TOPSAR (JPL, USA), IFSARE(ERIM/Intermap, USA), DO-SAR(Donier,Germany), E-SAR (DLR, Germany), AeS-1(Aerosensing, Germany), AER-II (FGAN, Germany), C/X-SAR (CCRS, Canada), EMISAR (Denmark), Ramses (ONERA, France), ESR (DERA, UK)

Planetary SAR

Magellan (US, 1990-1994), Titan Radar Mapper (US, 2004), Arecibo Antenna, Goldstone antenna

* Under development

SAR SYSTEM MODES

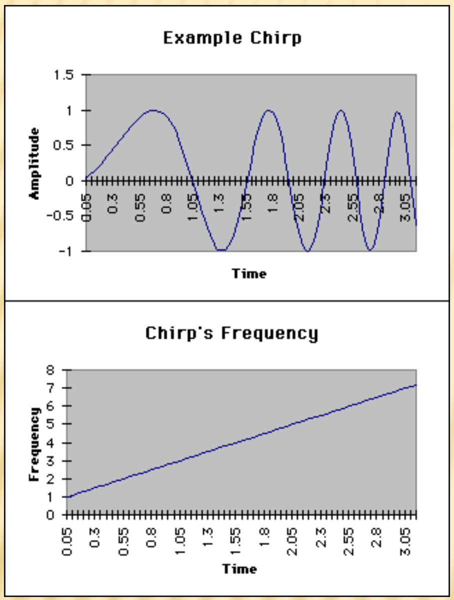
- Target – the Earth or planets
- Vehicle – stationary, airborne, satellite, or spaceship
- Mode – monostatic and/or bistatic
- Carrier frequency – X, C, S, L, and/or P bands
- Polarisation – HH, VV, VH, HV (single-pol, dual-pol, full-pol)
- Imaging geometry – strip, scan, spot

- <examples>
  - SIR-C/X-SAR: space shuttle, mono, L/C/X, full-pol.
  - ERS-1/2, Envisat: Earth satellite, mono, C, VV.
  - SRTM: space shuttle, mono/bistatic, C/X, HH/VV.
  - Arecibo Antenna: planetary, stationary, mono/bi, multi-bands, multi-pol.
  - Magellan, Cassini SAR: Venus and Titan, mono, S, HH.
  - AIRSAR/TOPSAR: airborne, mono/bi, L/C/P, full-pol

RANGE COMPRESSION

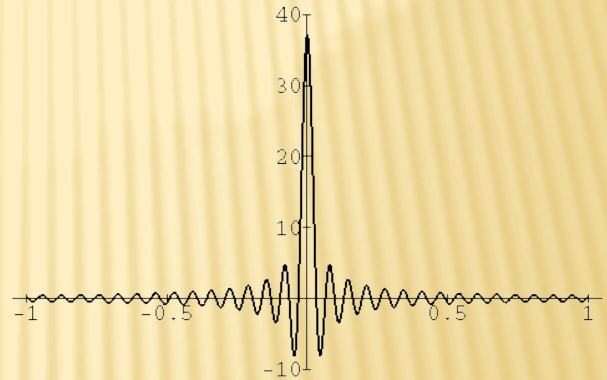
Linear Chirp Signal

The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.



Matched Filtering

Chirp autocorrelation Function



For ERS-1/2,

Pulse duration (T): 37.1 μs

Bandwidth : 15.5 MHz

Half power width of autocorrelation function: 0.065 μs

Pulse Compression Ratio: 575 (ERS-1/2)

Ground Range Resolution: 12.5 m

Input → Range FFT → Range Matched Filtering → Range iFFT →

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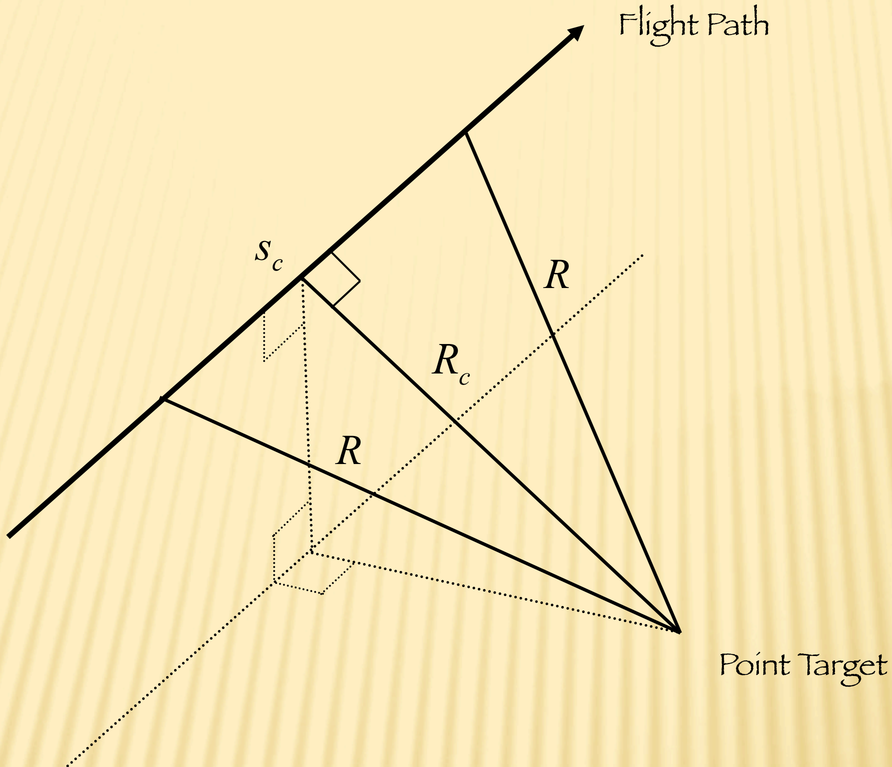
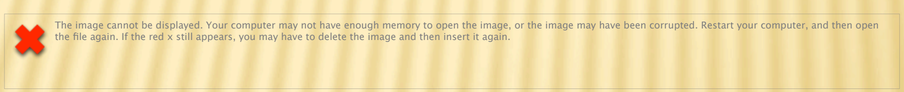
RANGE MIGRATION



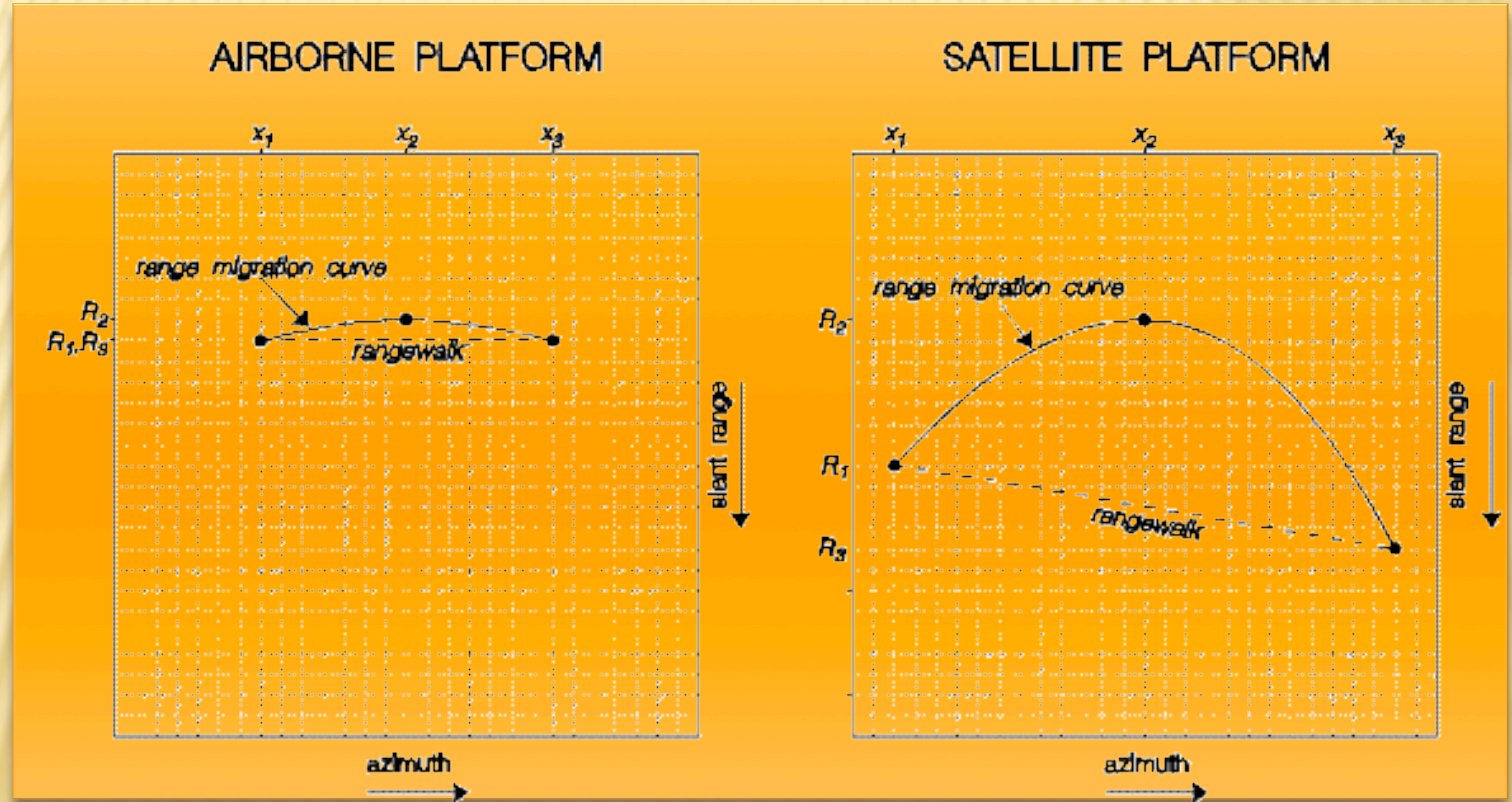


Linear
(Range Walk)

Quadratic
(Range Curvature)

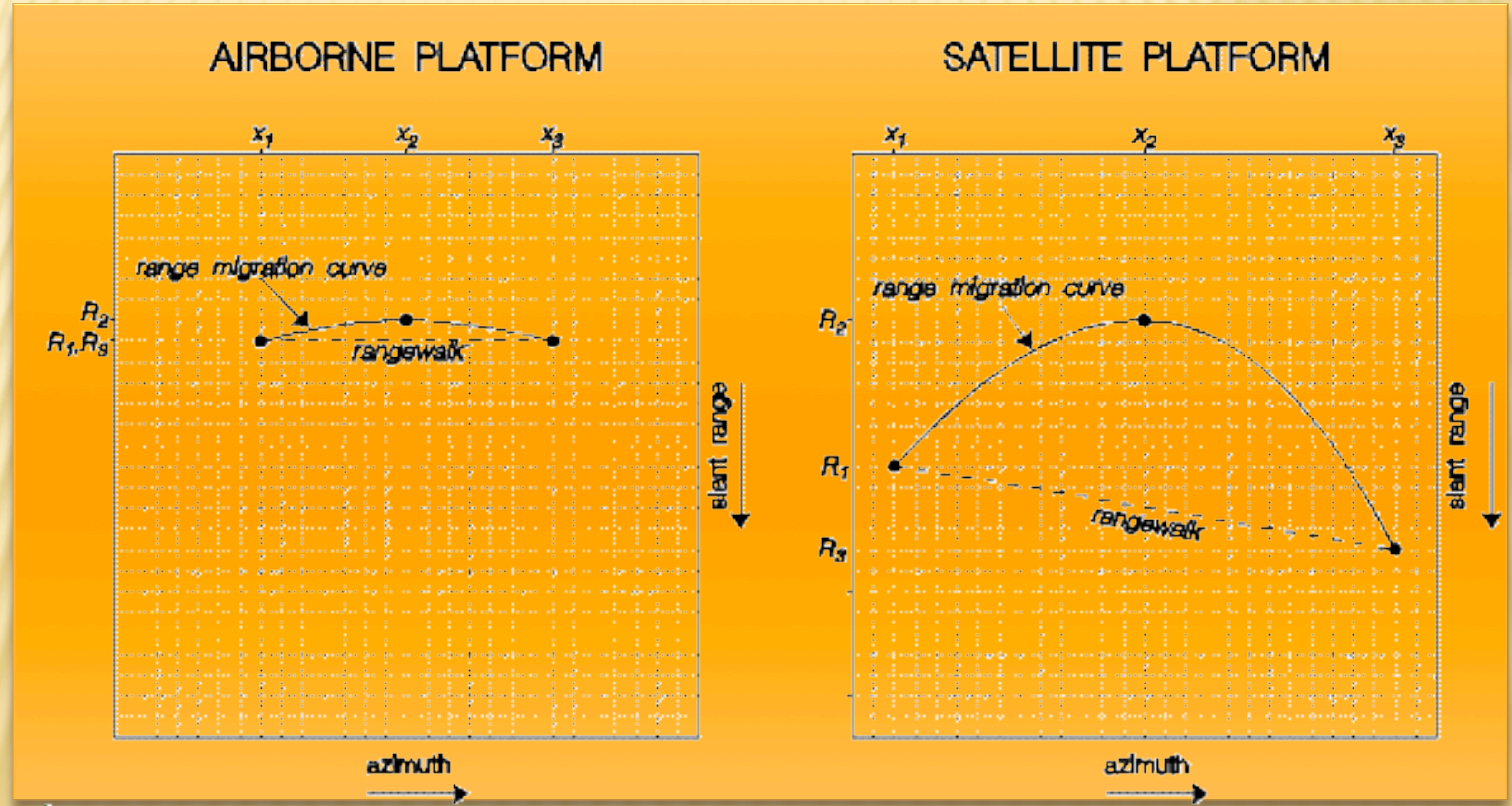
Azimuth FFT

Left side: range mitigation curve and rangewalk for airborne SAR – consider earth flat and stationary , range mitigation curve relatively flat.



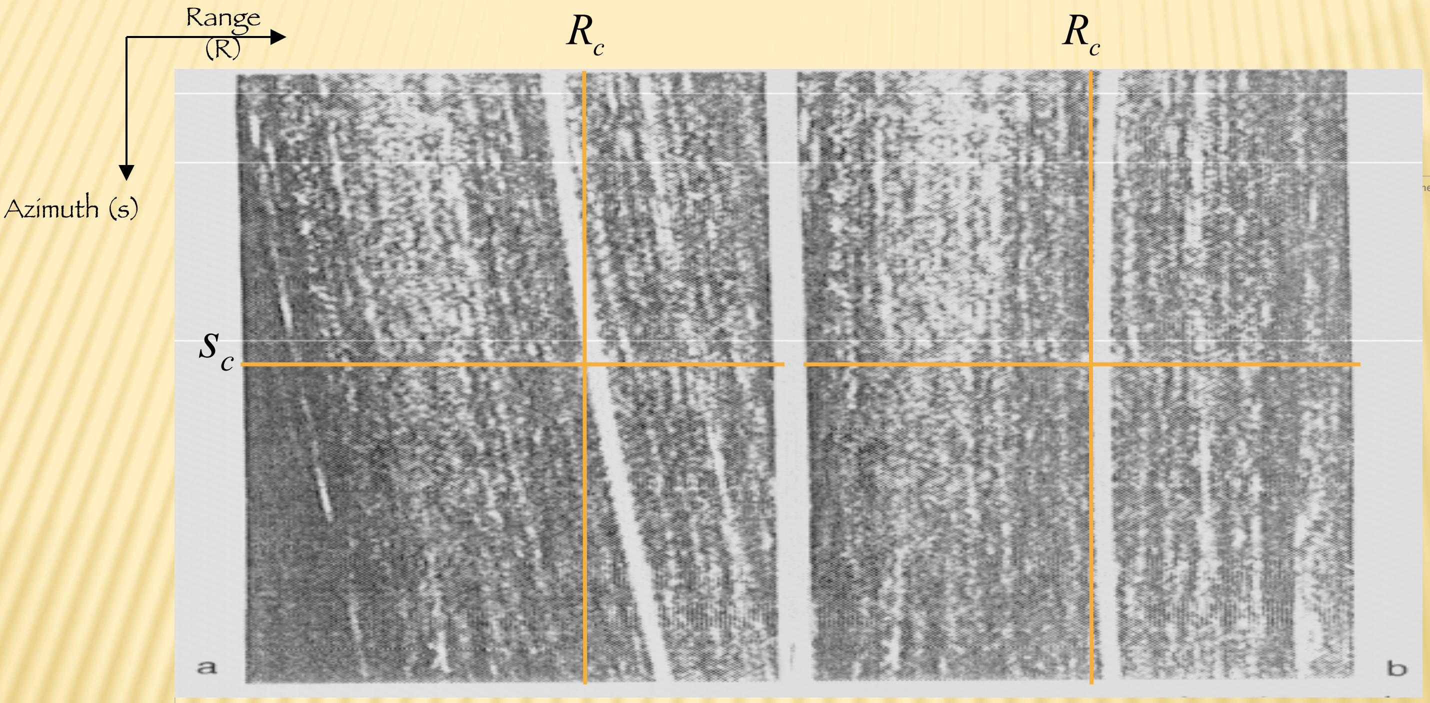
http://www.geo.uzh.ch/~fpaul/sar_theory.html

Right side: range mitigation curve and rangewalk for spaceborne SAR – have to take into account that earth is sphere and "moving" (from rotation of earth).



http://www.geo.uzh.ch/~fpaul/sar_theory.html

RANGE MIGRATION COMPENSATION



After Range Walk Compensation

Range Migration

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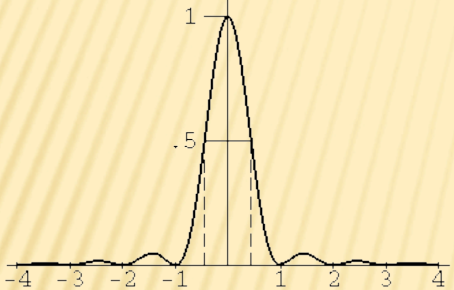
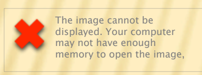
AZIMUTH COMPRESSION

Real Aperture





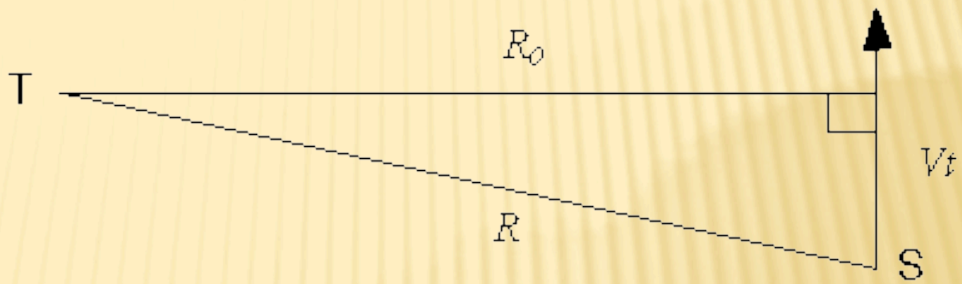
λ: wavelength

L: Antenna length

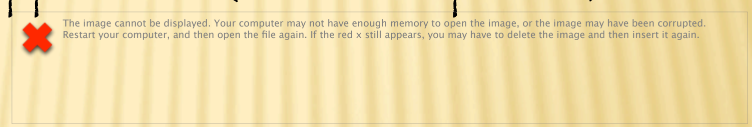
Azimuth footprint width:

5 km (ERS-1/2)

Synthetic Aperture



Doppler Shift (Linear Chirp Pulse)



Matched Filtering

For ERS-1/2,

Coherent Integration Time (S): 600 ms (5 km footprint)

Bandwidth: 1260 Hz

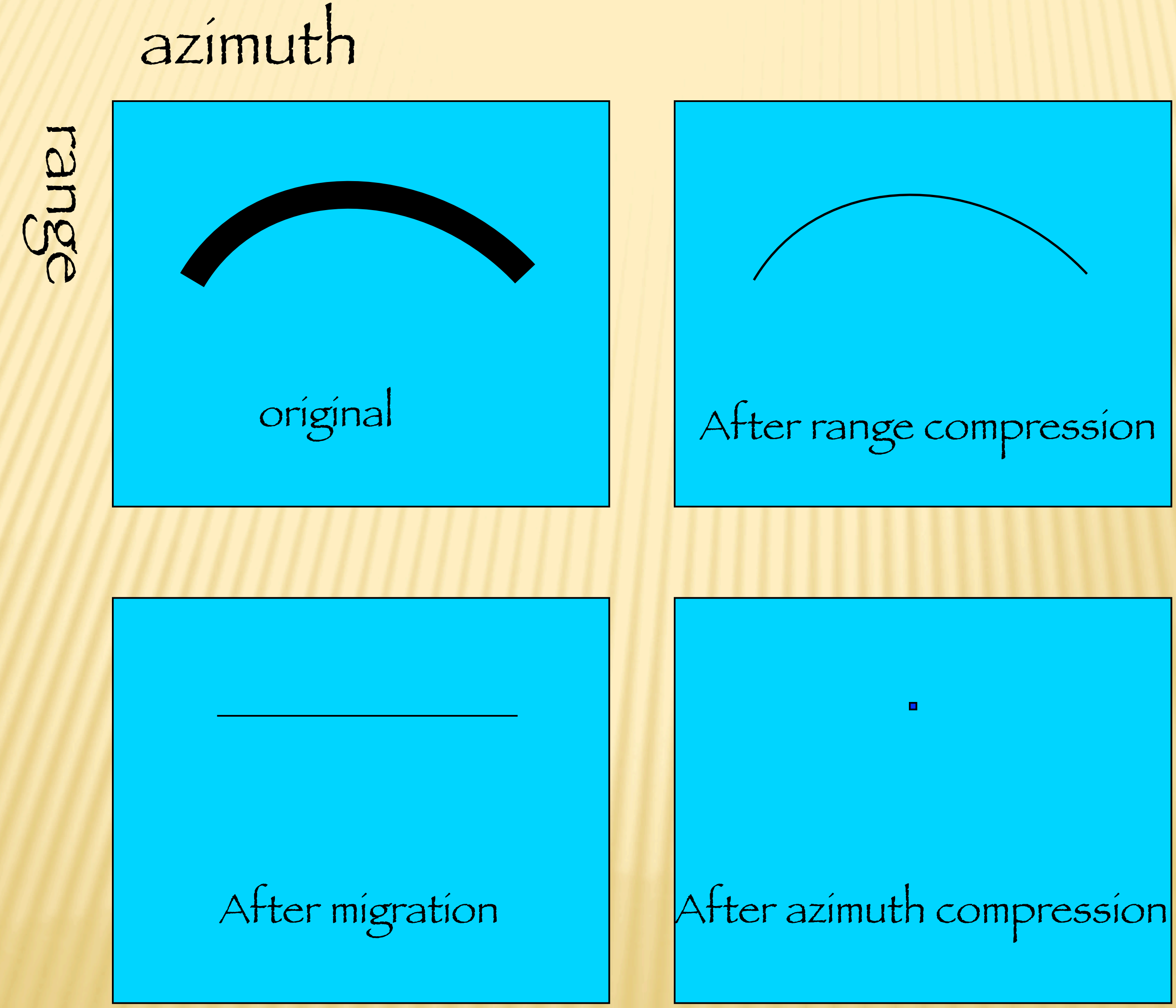
Half power width of autocorrelation function: 0.8 ms

Pulse Compression Ratio: 756 (ERS-1/2)

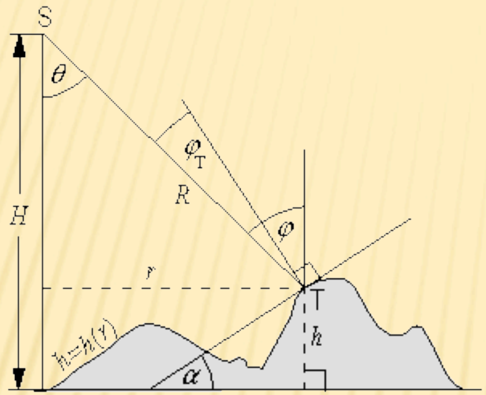
Azimuth Resolution: 5 m

→ Azimuth Matched Filtering → Output

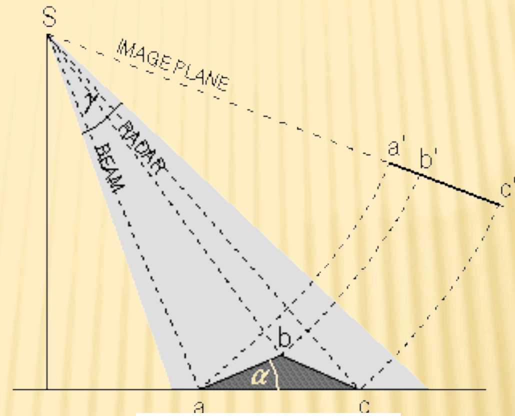
SAR FOCUSING – POINT TARGET



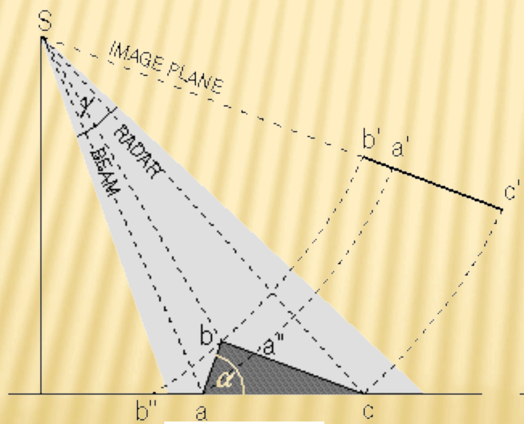
GEOMETRIC DISTORTION



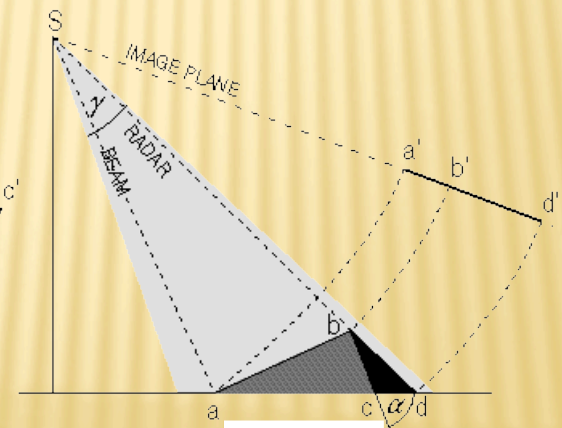
Terrain Imaging Geometry



Foreshortening



Layover



Shadow

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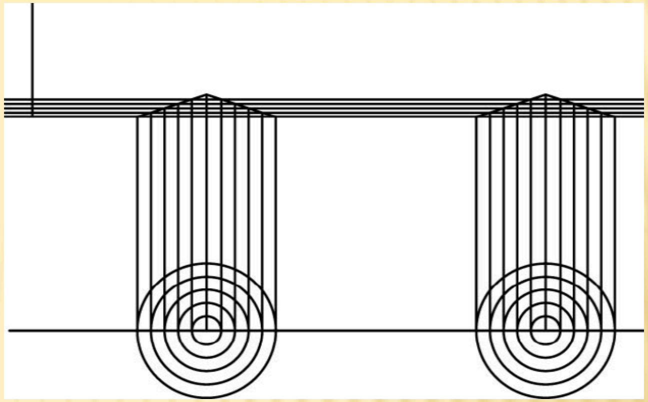
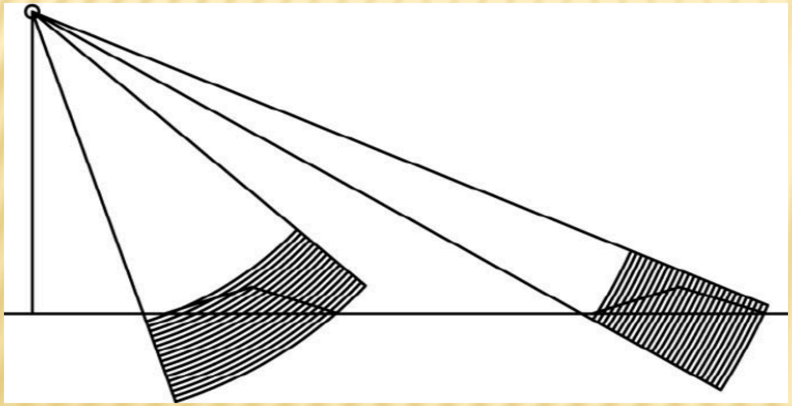
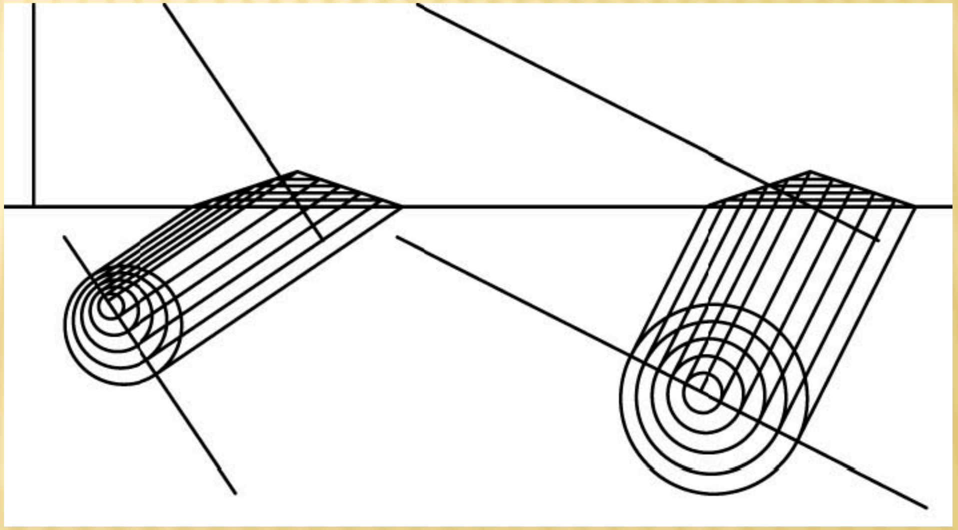
SAR Relief Displacement, Foreshortening, and Layover







https://engineering.purdue.edu/~bethel/sar_relief.pdf

SAR Relief Displacement, Foreshortening, and Layover

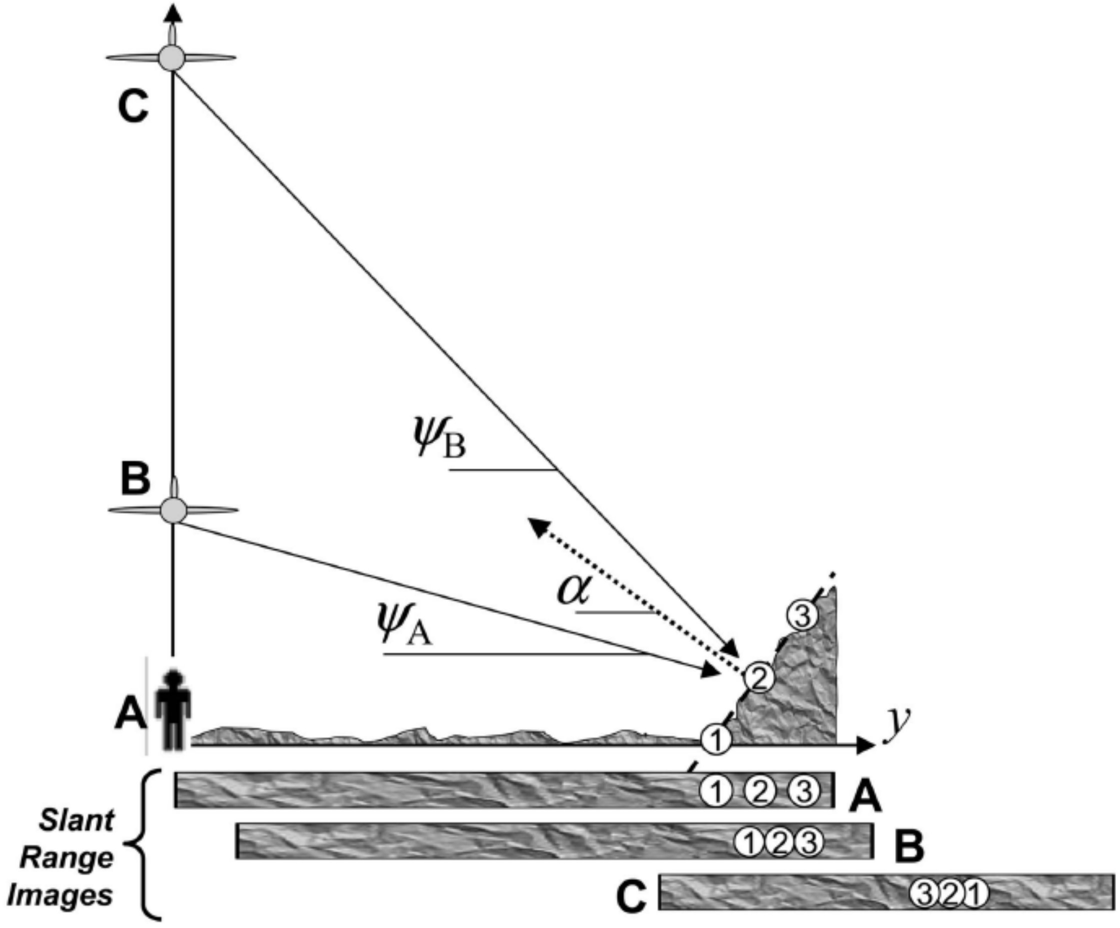
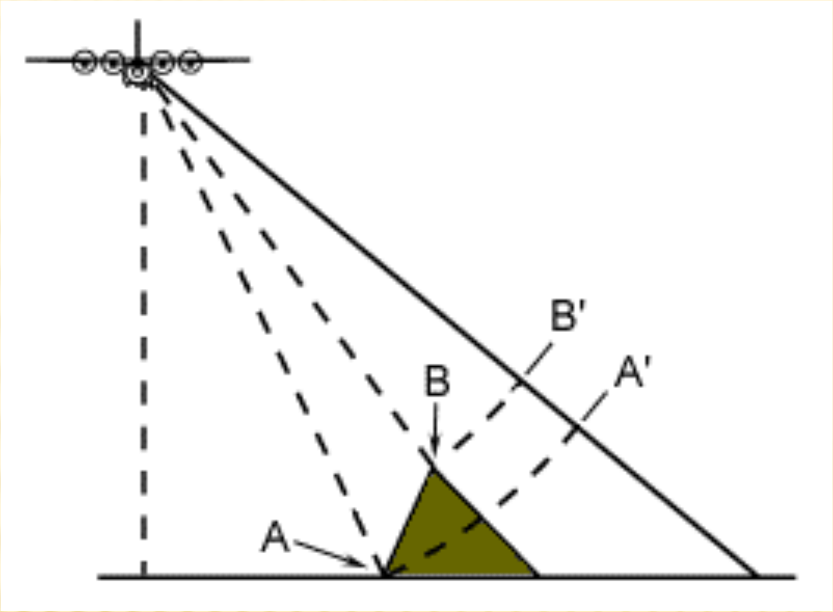


Fig. 6. Layover and foreshortening. Scene viewed from aircraft B is subject to foreshortening. Scene viewed from aircraft C is subject to layover.

users.ece.gatech.edu/mrichard/AESS%20IFSAR%20Tutorial.pdf

RADAR IMAGE GEOMETRY – LAYOVER

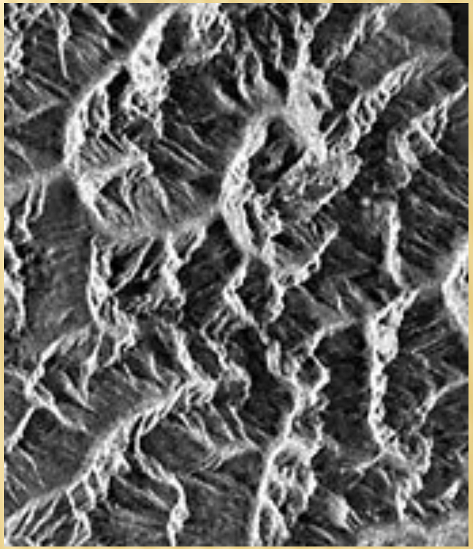


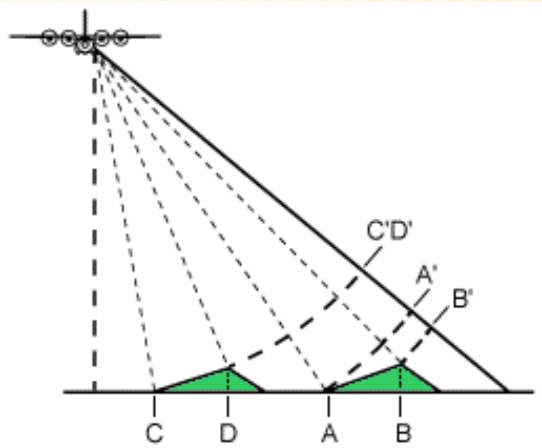
Layover occurs when the radar beam reaches the top of a tall feature before it reaches the base. The top of the feature is displaced towards the radar sensor and is displaced from its true ground position – it 'lays over' the base.

Images also on http://hosting.soonet.ca/eliris/remotesensing/bl130lec13.html

FORESHORTENING

Even if there is no layover, radar returns from facing steep slopes will make the terrain look steeper than it is. This is known as 'foreshortening'. Features which show layover in the near range will show foreshortening in the far range.



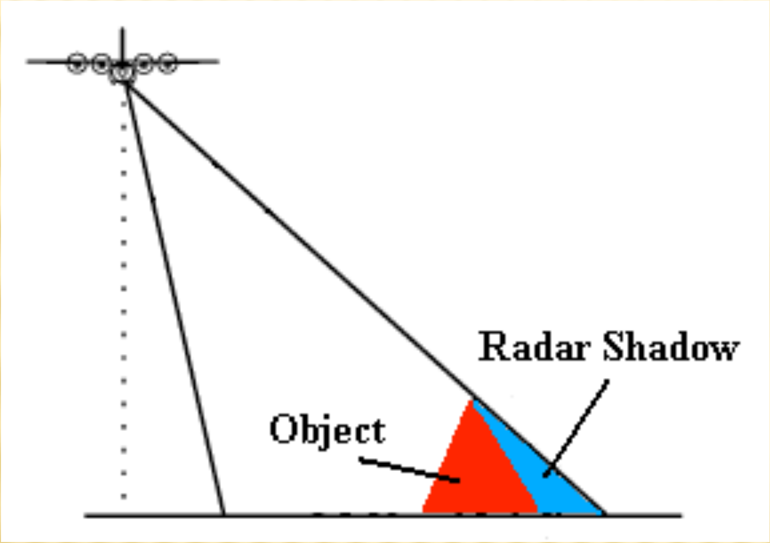


Foreshortening occurs because radar measure distance in the slant-range direction such that the slope A-B appears as compressed in the image (A'B') and slope C-D is severely compressed (C'D')

Murchison

Radar Shadow occurs when the radar beam is not able to illuminate the ground surface.

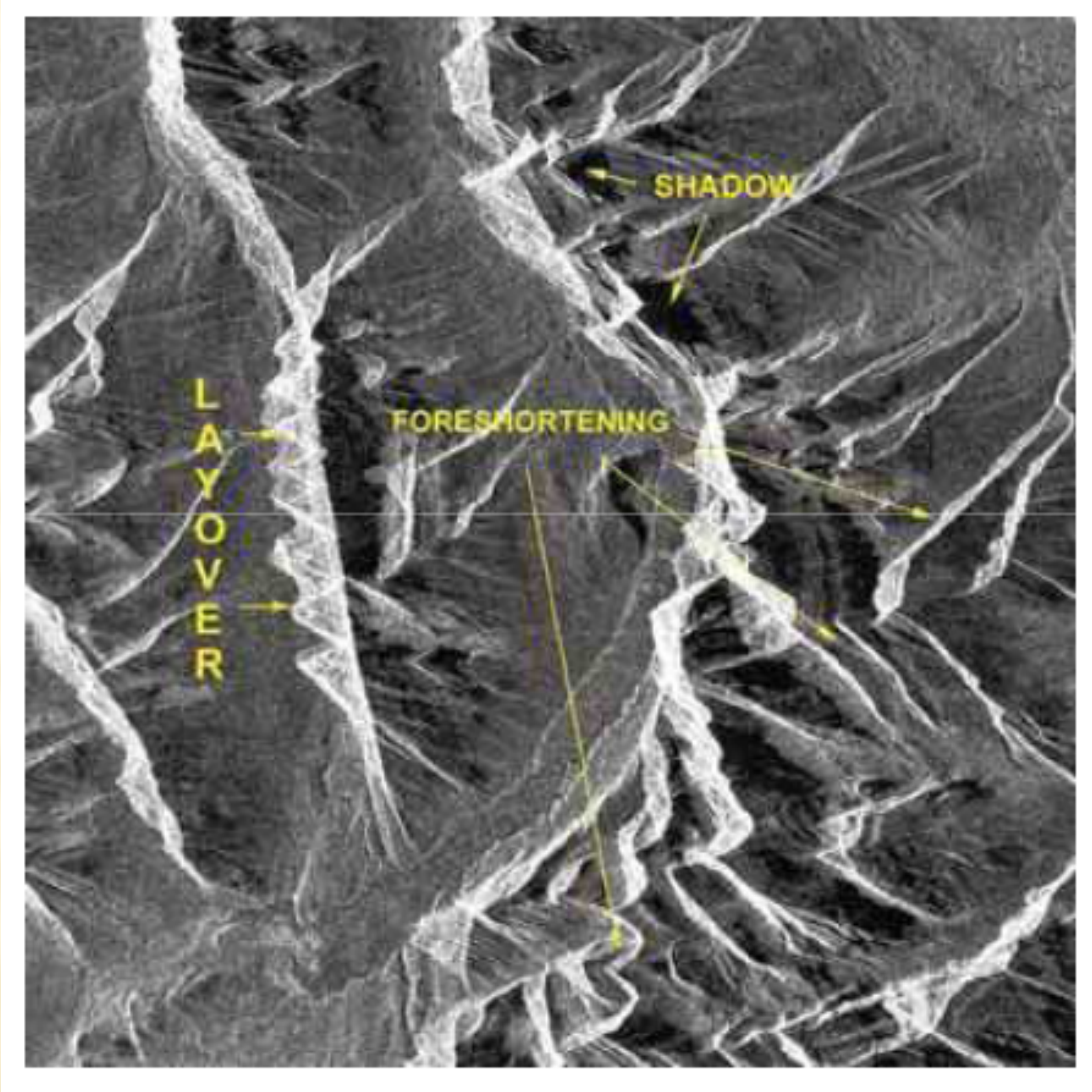
Radar Shadow



Hilly Terrain

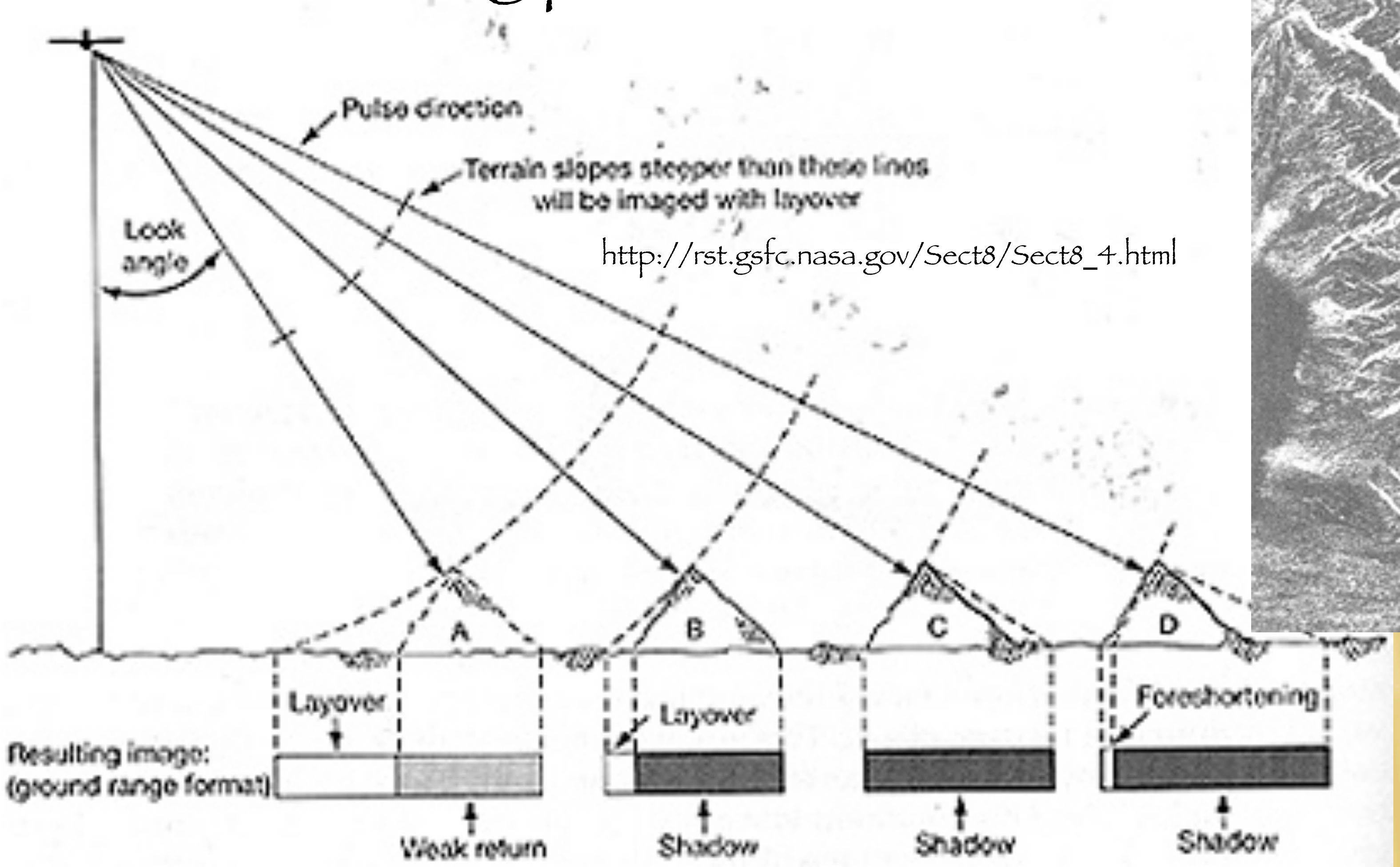
http://hosting.soonet.ca/eliris/remotesensing/bl130lec13.html

All Together



www.geo.mtu.edu/rs4hazards/links/Bruning_SAR_pdf.pdf

Topo irregularies can have a significant effect on the image. Slopes facing the radar are subject to a distorted appearance. The terms layover and foreshortening apply to this appearance. In most instances, layover and foreshortening produce the same end result visually.



http://rst.gsfc.nasa.gov/Sect8/Sect8_4.html

SAR perceptual confusion

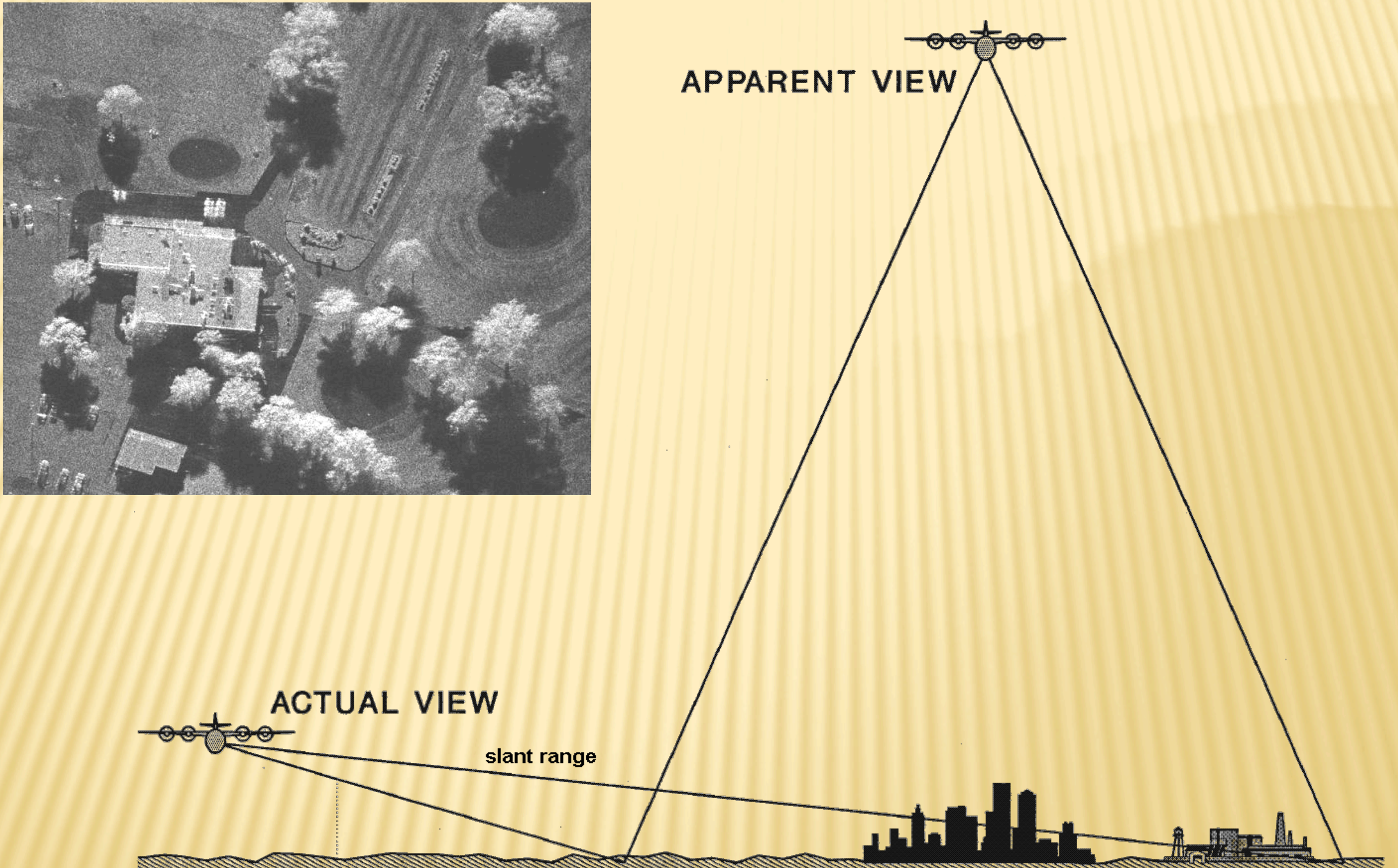
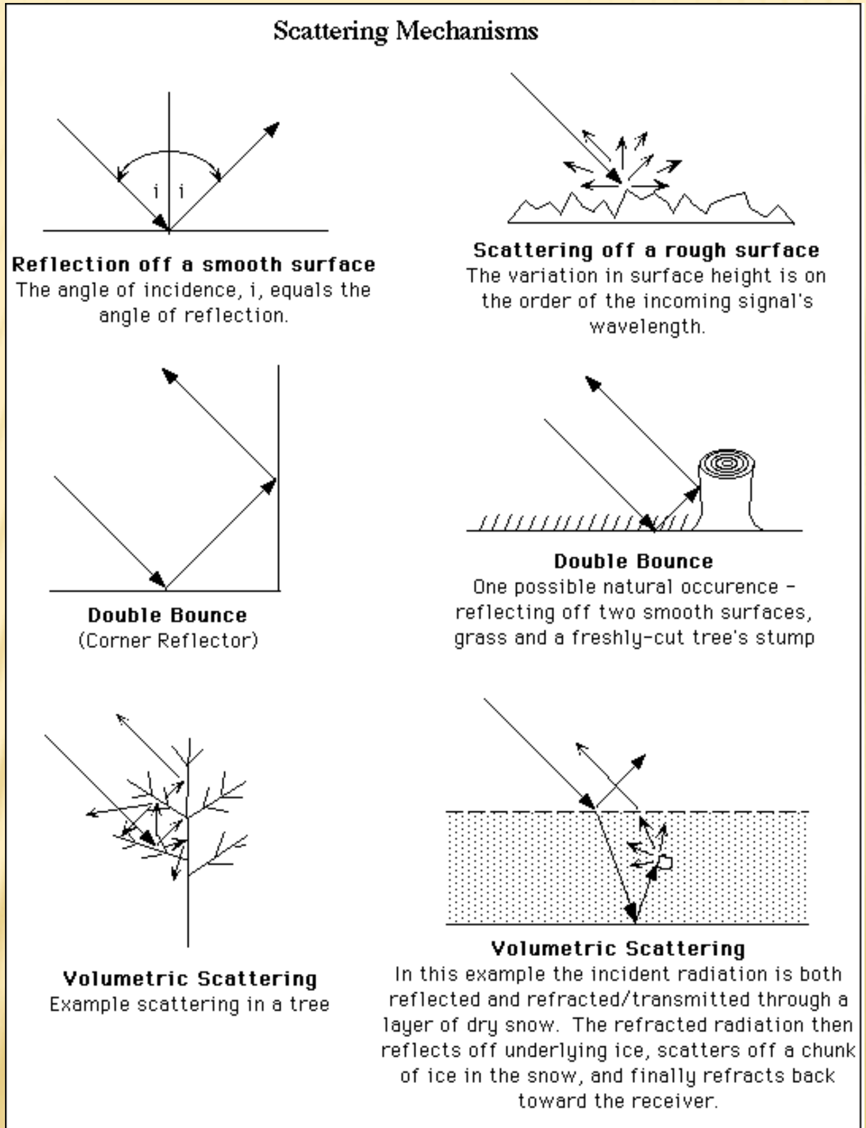


Figure 5-10. Perceptual confusion in synthetic aperture radar (SAR) images – images obtained from the side appear like images obtained from overhead.

people.eecs.ku.edu/~callen/826/826_InSAR_basics-S09.ppt

SCATTERING MECHANISMS



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RULE OF THUMB IN SAR IMAGES

•Backscattering Coefficient

•Smooth – Black
•Rough surface – white

•Calm water surface – black
•Water in windy day – white

•Hills and other large-scale surface variations tend to appear bright on one side and dim on the other.

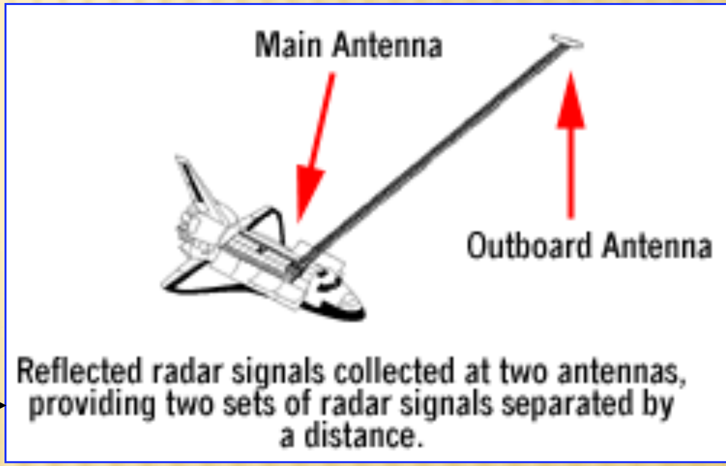
•Human-made objects - bright spots (corner reflector)
•Strong corner reflector- Bright spotty cross (strong sidelobes)

1. INTERFEROMETRIC SYNTHETIC APERTURE RADAR (INSAR OR IFSAR)

- Is a process whereby radar images of the same location on the ground are recorded by
  - Two antennas of one platform separated by a few meters (single pass), or
  - The same radar system at different times (multi-pass or repeat-pass)
- Applications on
  - Elevation (DEM) derivation (single or multi pass)
    - Can be as accurate as DEM from traditional optical photogrammetric techniques. However, InSAR operate through clouds, day or night.
    - The first worldwide DEM (99.97%) was acquired in 2000 by SRTM, not by the photogrammetry
  - Surface displacement study (multi-pass only)

EXAMPLES

- One SAR with 2 antennas (single-pass)
  - AIRSAR/TOPSAR
    - Along track interferometric mode (ATI) (L and C)
      - Ocean current and waves
    - Cross track interferometric mode (TXI) (L or C)
      - DEM (3-5 m or 1 m)
  - Shutter Radar Topographic Mission (SRTM)
    - C band and X band antennas separated by 60 m

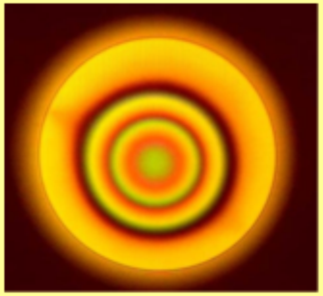


Reflected radar signals collected at two antennas, providing two sets of radar signals separated by a distance.

- One SAR in different times (multi-pass)
  - SIR-C
  - ERS 1,2

Interferometry

- Study of interference patterns from two sets of electromagnetic waves reflecting from surface
  - E.g., thin film of oil on water
- When we measure the radar pulse, we consider not just the amplitude but the phase too



$$\text{Phase (cycles)} = \frac{\text{distance}}{\text{wavelength}}$$

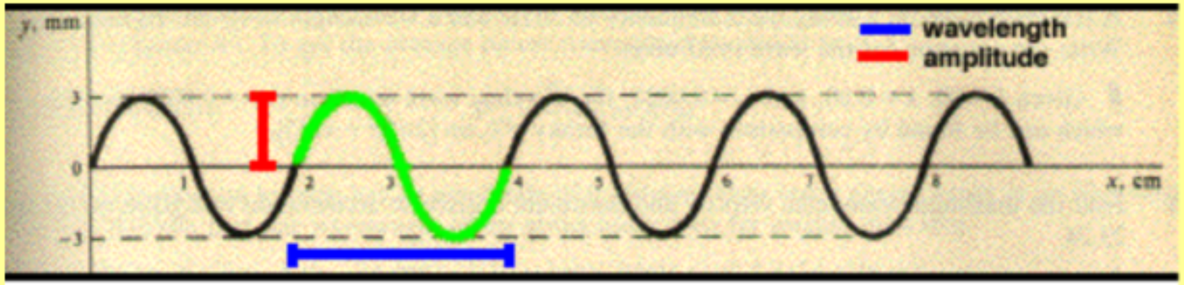


Figure 1: Wave Graph

Phase is total number of cycles at any given distance (or target) from transmitter, including fractional part. One cycle of phase is equal to 360 degrees (or 2π).

Can make use of this information with 2 receiving antennas

Figure 2: One Receiver

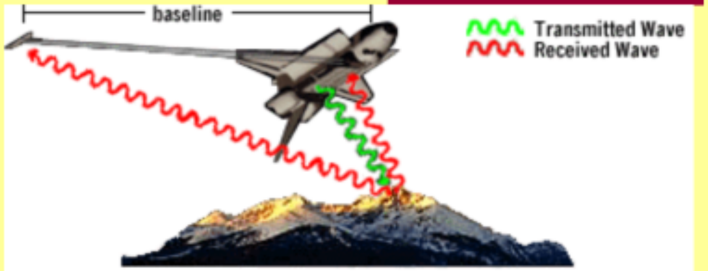
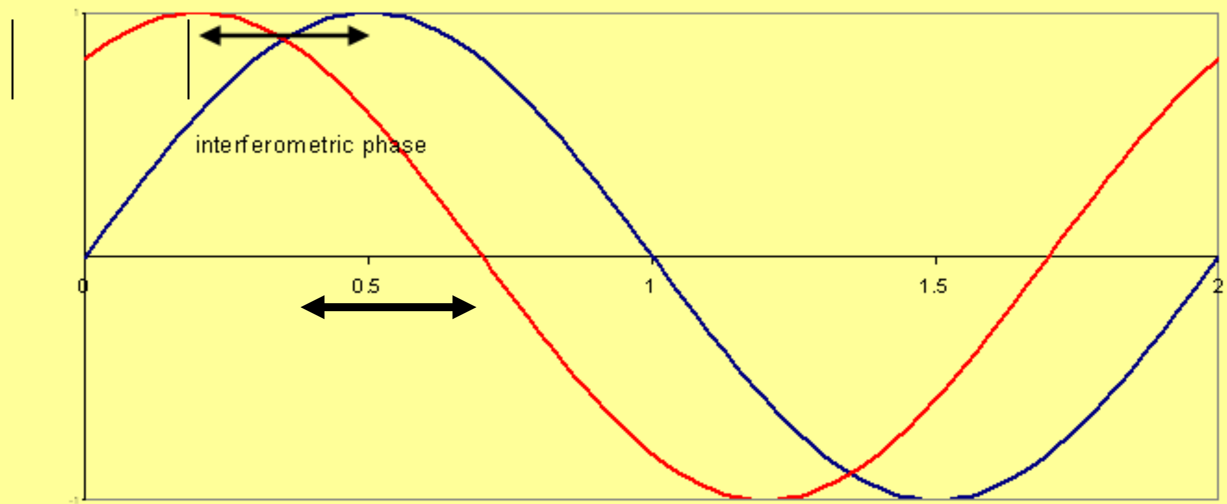
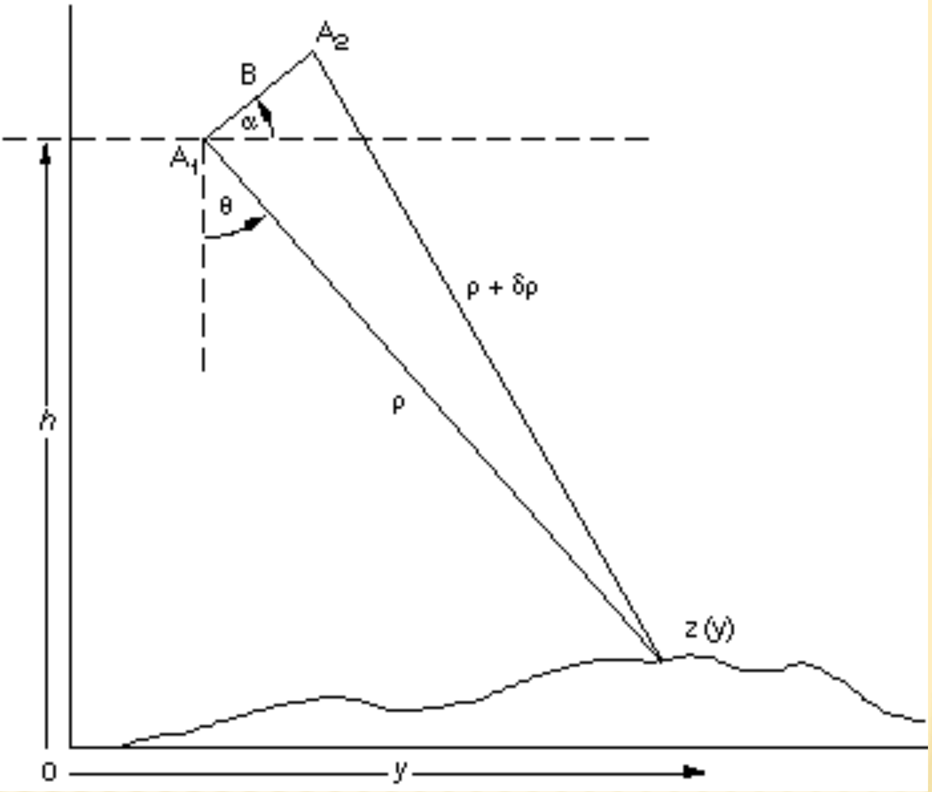


Figure 3: Two Receivers



6

phase difference called "interferometric phase" - determined by subtracting measured phase at each end of baseline, is actually the distance difference from each receiver to same target.



CALCULATE ALTITUDE

$$z(y) = h - \rho \bullet \cos\theta \qquad (1)$$

$$(\rho + \delta\rho)^2 = \rho^2 + B^2 - 2\rho B\cos(90 - \theta + \alpha) = \rho^2 + B^2 + 2\rho B\sin(\alpha - \theta) \qquad (2)$$

$$\delta\rho = \frac{\varphi}{2\pi} \times \lambda \qquad (3)$$

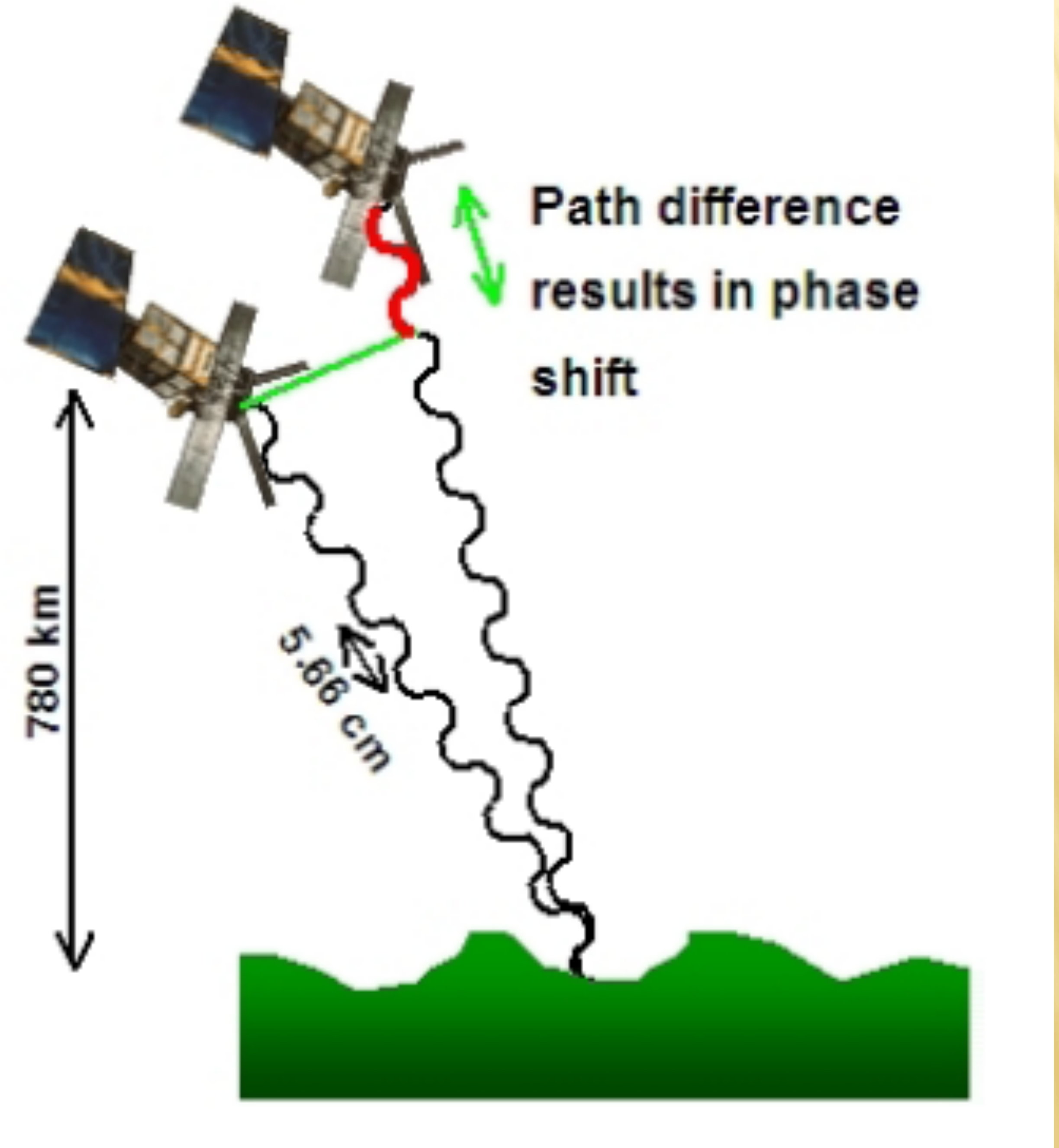
(Phase difference)

$$z(y) = h - \frac{B^2 - (\frac{\lambda\varphi}{2\pi})^2}{\frac{\lambda\varphi}{\pi} - 2B\sin(\alpha - \theta)} \bullet \cos\theta \qquad (4)$$

φ is the fractional phase (value 0-2π radians), λ is wavelength

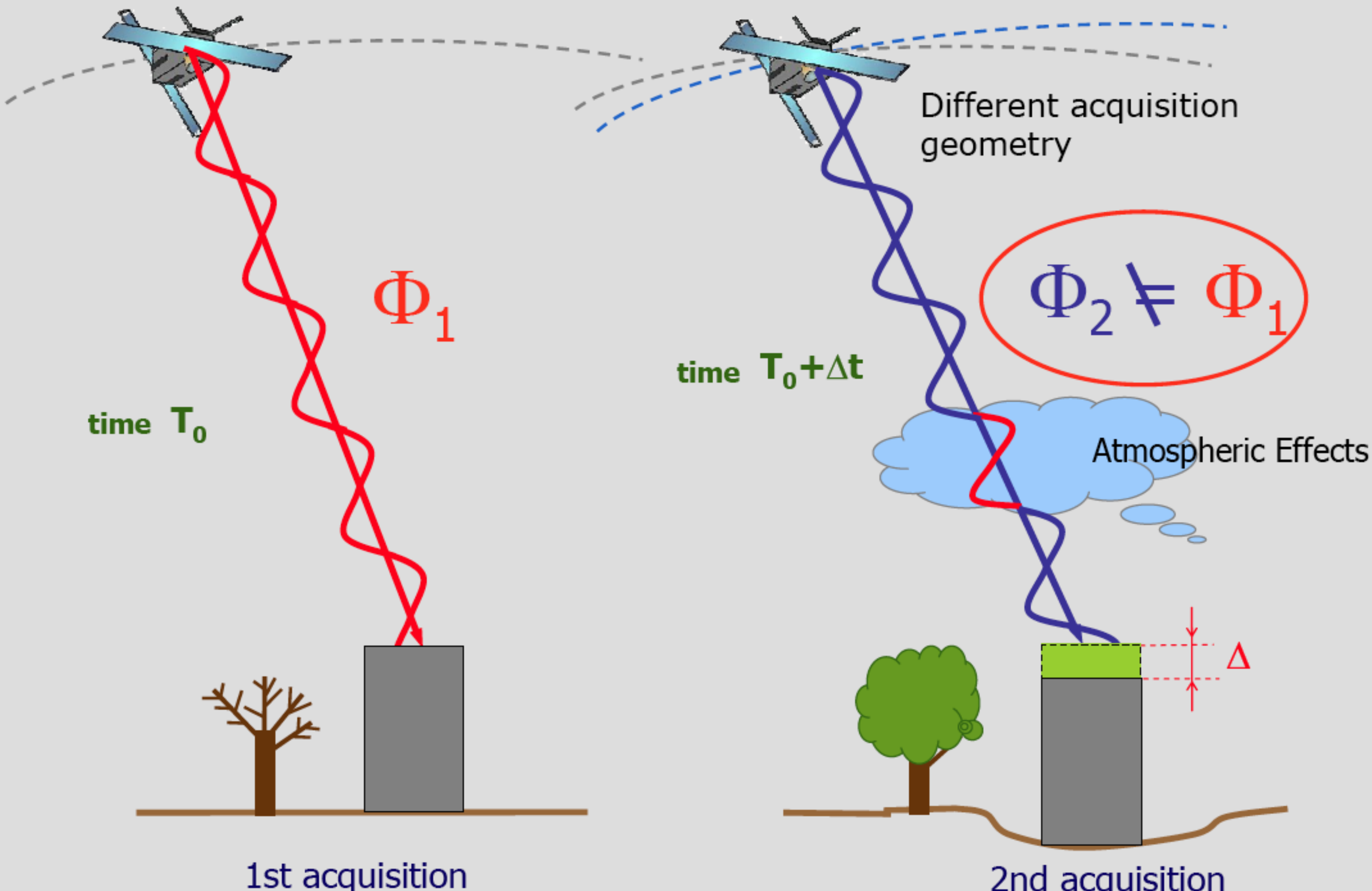
Repeat-pass interferometry

- If we don't have a single vehicle with 2 antennas, we can use repeat-pass interferometry
  - Same vehicle, different days, *slightly* different position
  - This also allows us to detect subtle *changes* in surface elevation between the passes



Hongjie

How Does InSAR Work?



How Does InSAR Work?

Signal Phase contribution of a single SAR acquisition can be expressed as:

$$\phi = \psi + \frac{4\pi r}{\lambda} + \alpha + \text{noise}$$

ψ = reflectivity of the target

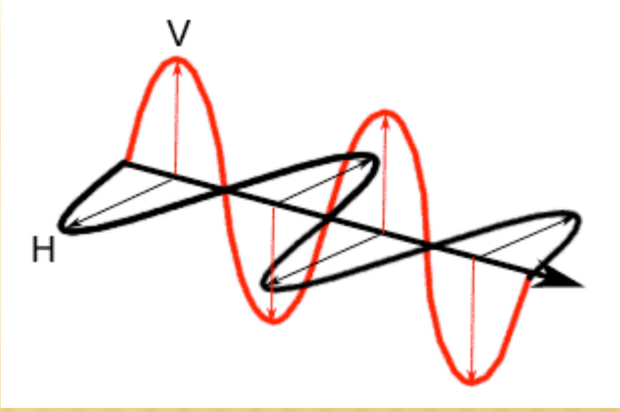
$\frac{4\pi r}{\lambda}$ = distance between sensor and target

α = atmospheric phase contribution

Radar Signal Polarization

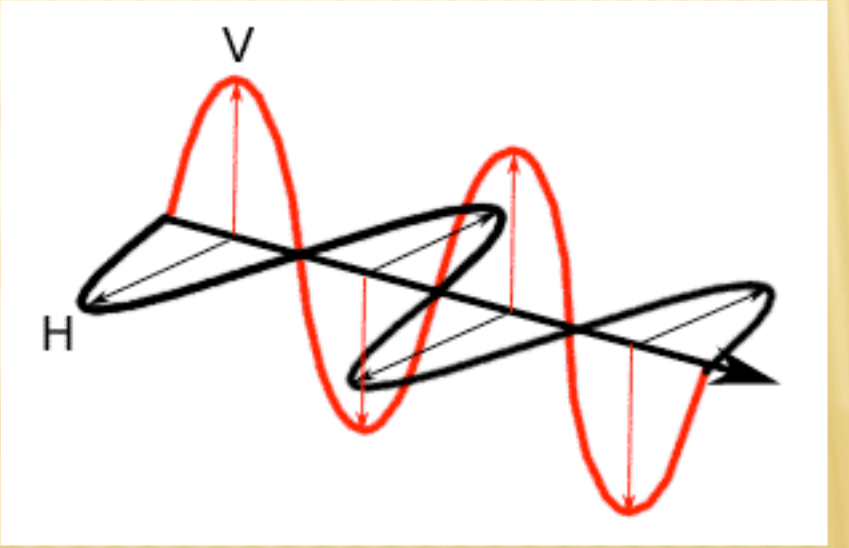
Polarization of the radar signal is the orientation of the the electromagnetic field and is a factor in the way in which the radar signal interacts with ground objects and the resulting energy reflected back.

Most radar imaging sensors are designed to transmit microwave radiation either horizontally polarized (H) or vertically polarized (V), and receive either the horizontally or vertically polarized backscattered energy.



Polarizing Radar has four possible combinations of both transmit and receive polarizations as follows:

HH - for horizontal transmit and horizontal receive,
VV - for vertical transmit and vertical receive,
HV - for horizontal transmit and vertical receive, (cross-polarized)
VH - for vertical transmit and horizontal receive (cross-polarized).

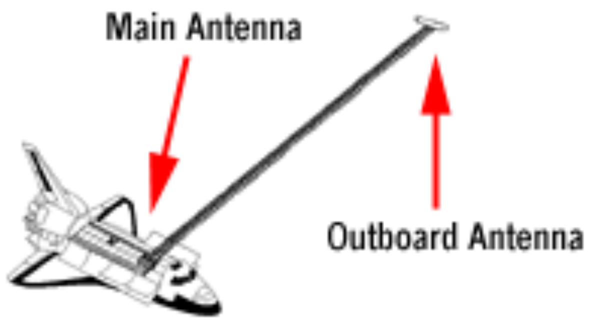


NASA's Shuttle Radar Topography Mission

- SIR-C/X-SAR flew two 10-day missions
  - April and October 1994
  - L-band, C-band, and X-band
- Instrument was then converted to an interferometer
  - C- and X-band only
  - 2nd receiving antenna added
- SRTM flew a 10-day mission in February 2000
  - Collected data on most of the land surface between 60°N–54°S

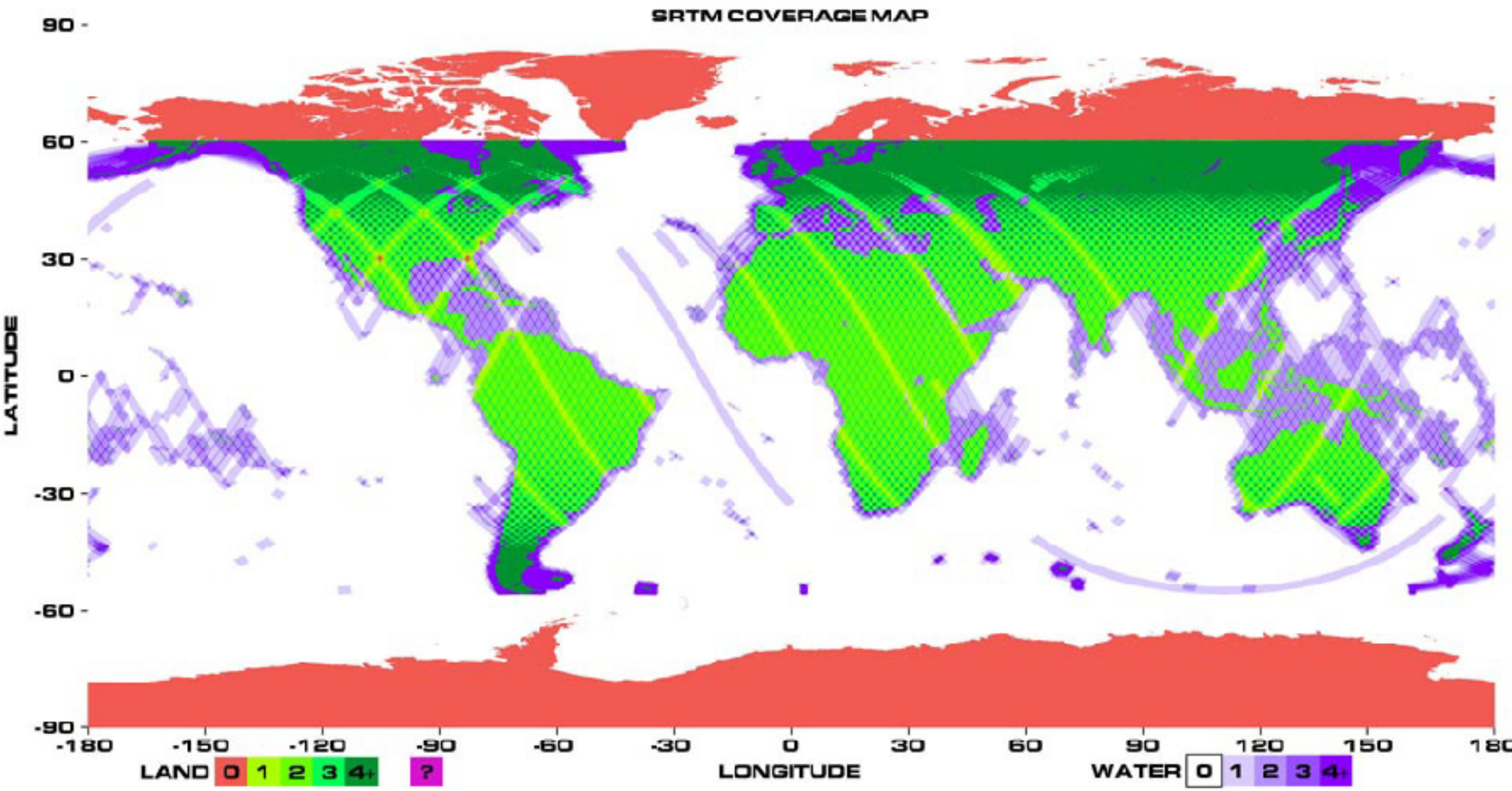
Both C (5.6 cm) and X (3 cm) bands in the Main Antenna transmit and receive radar signals, but in the Outboard Antenna only receive signals.

Hongjie

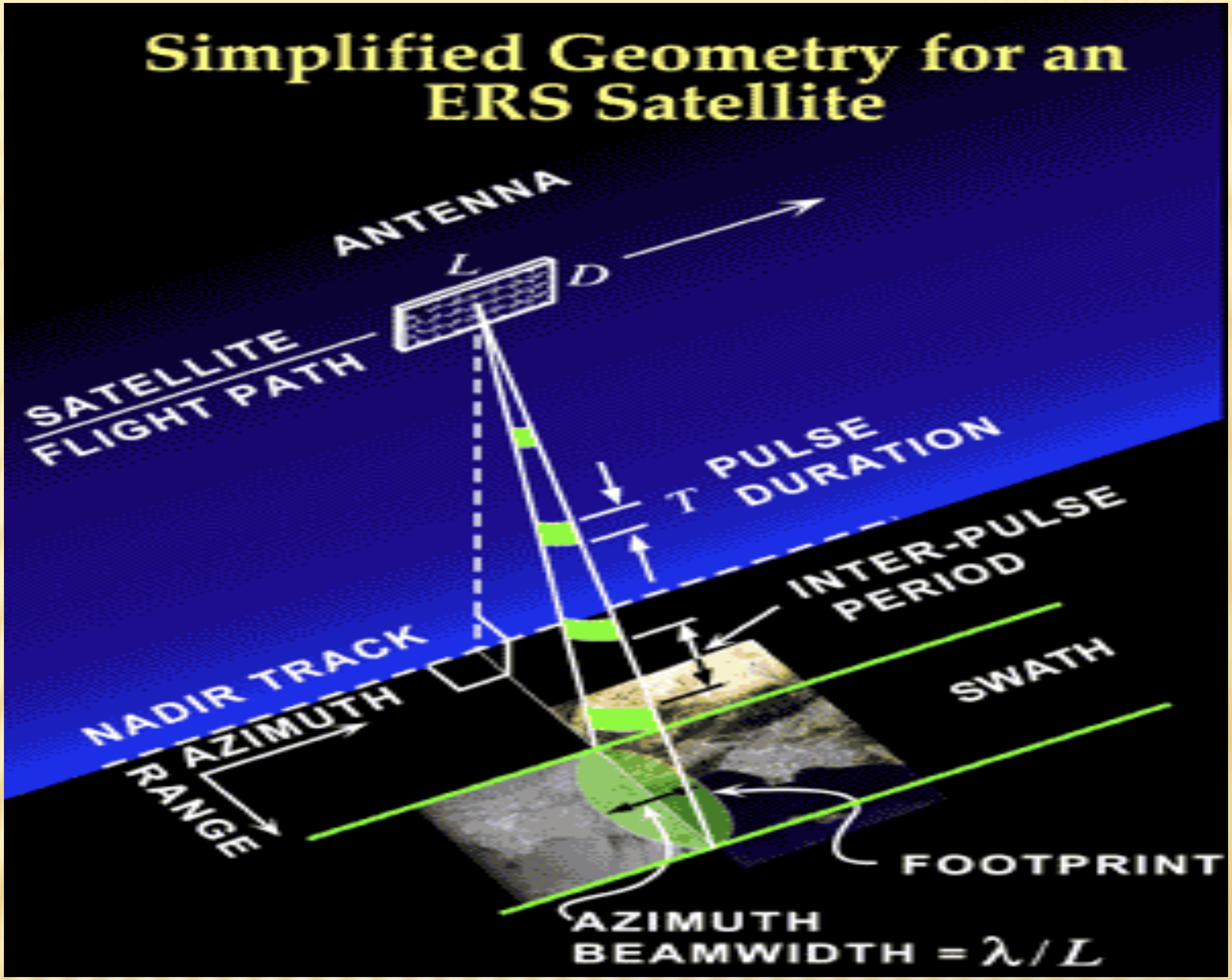


Reflected radar signals collected at two antennas, providing two sets of radar signals separated by a distance.

SRTM COVERAGE MAP

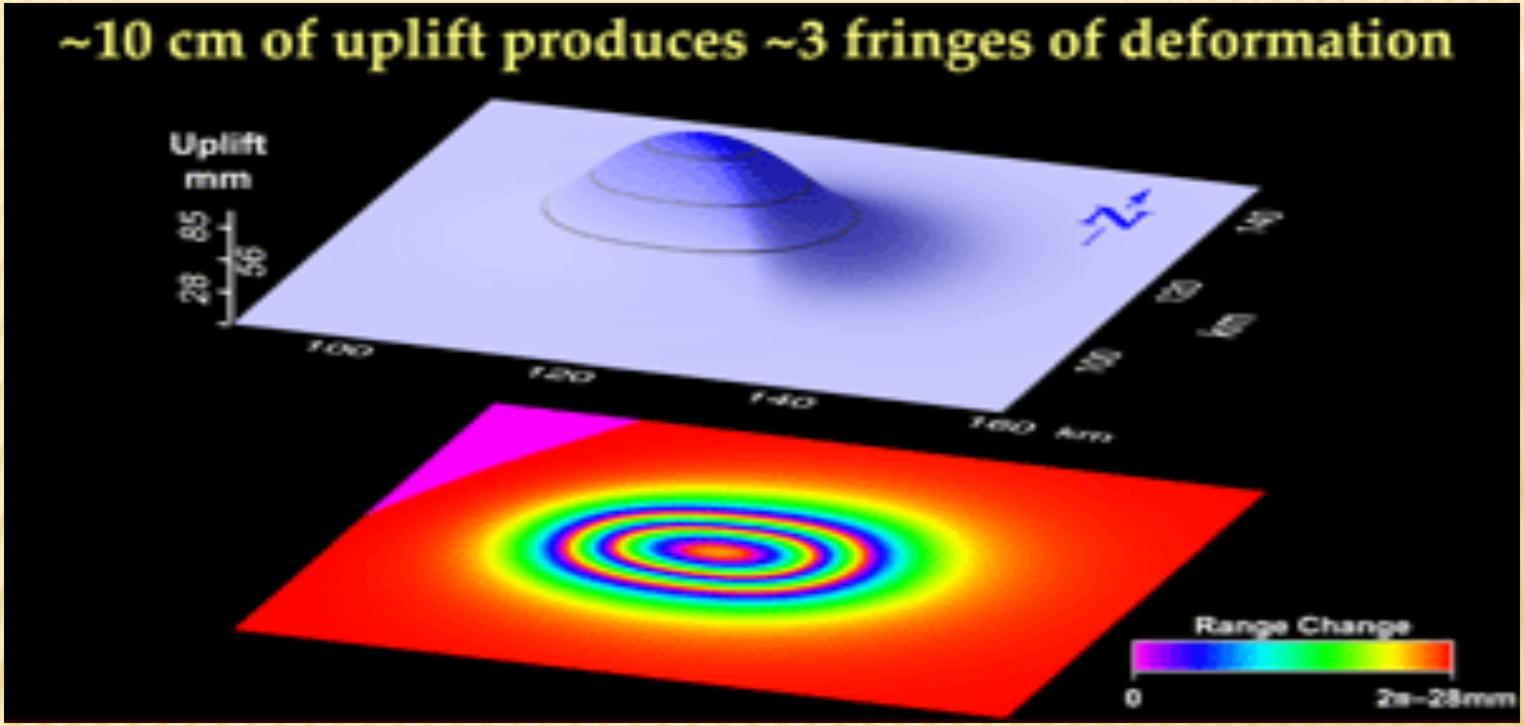


To download from here http://seamless.usgs.gov/



3-Dimensional view of InSAR geometry.

Graphics from unknown source



Colors on an interferogram map into elevation changes.

Fringes – each one signifies change of 1 wavelength.

Graphics from unknown source

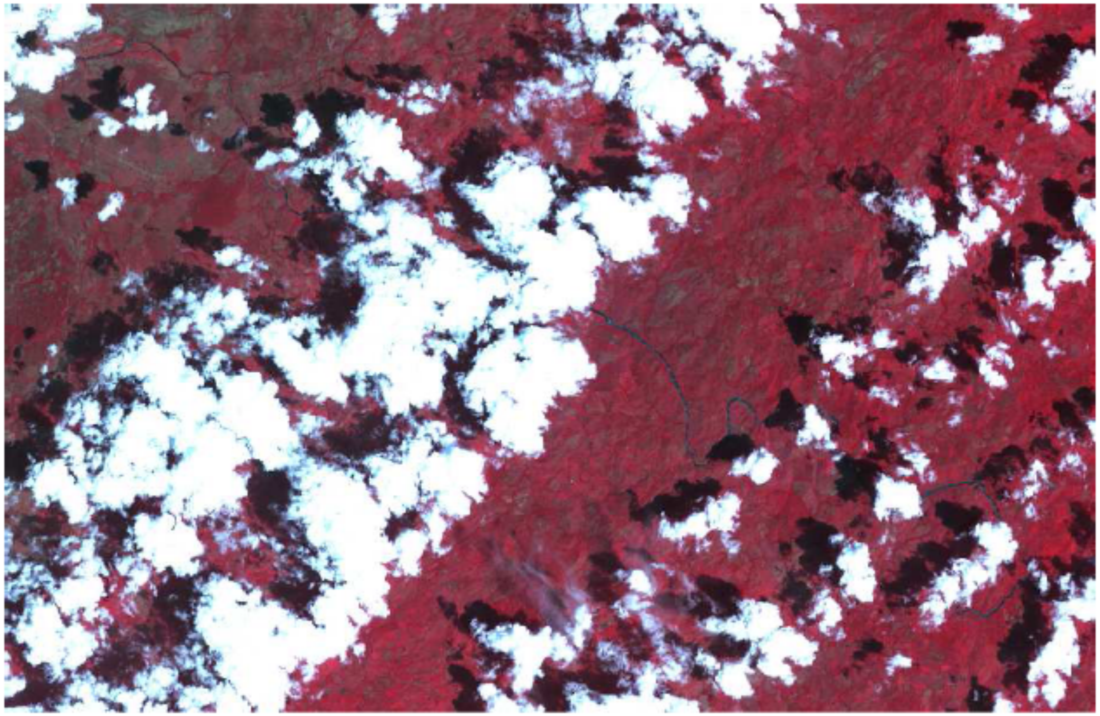
SAR satellites

	repeat cycle (days)	wave-length (cm)
European ERS-1/ERS-2 1992-2001(+)	35	6
Canadian Radarsat-1 1995-present	24	6
European Envisat 2003-present	35	6
Japanese ALOS launched Jan. 2006	48	24
German TerraSAR-X launched July 2007	11	3
Italian COSMO/SkyMed 2 launched 2007	16/2	3
Canadian Radarsat-2 launched Dec. 2007	24	6

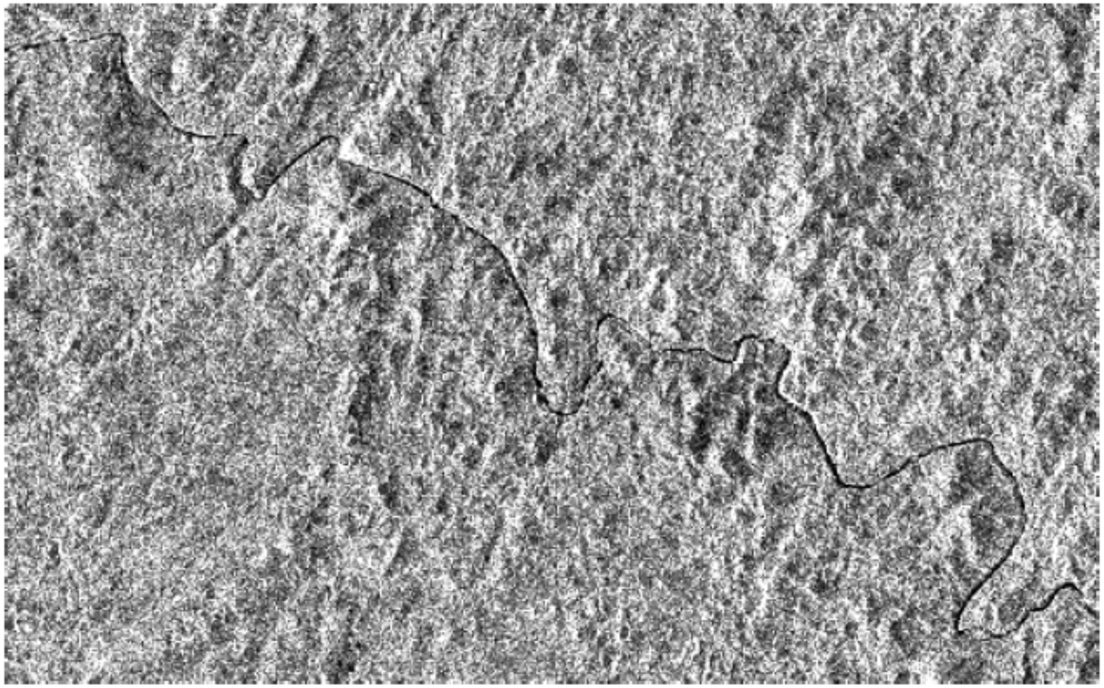
SIDE INFO: ASTER GLOBAL DEM

- This is not from INSAR tech, but It has an along-track stereoscopic capability using its near infrared spectral band and its nadir-viewing and backward-viewing telescopes to acquire stereo image data with a base-to-height ratio of 0.6.
- 30 m in pixel size
- 30 m accuracy in horizontal and 20 m accuracy in vertical
- Free downloaded from
  - http://www.gdem.aster.ersdac.or.jp/
  - https://wist.echo.nasa.gov/~wist/api/imswelcome/

ASTER

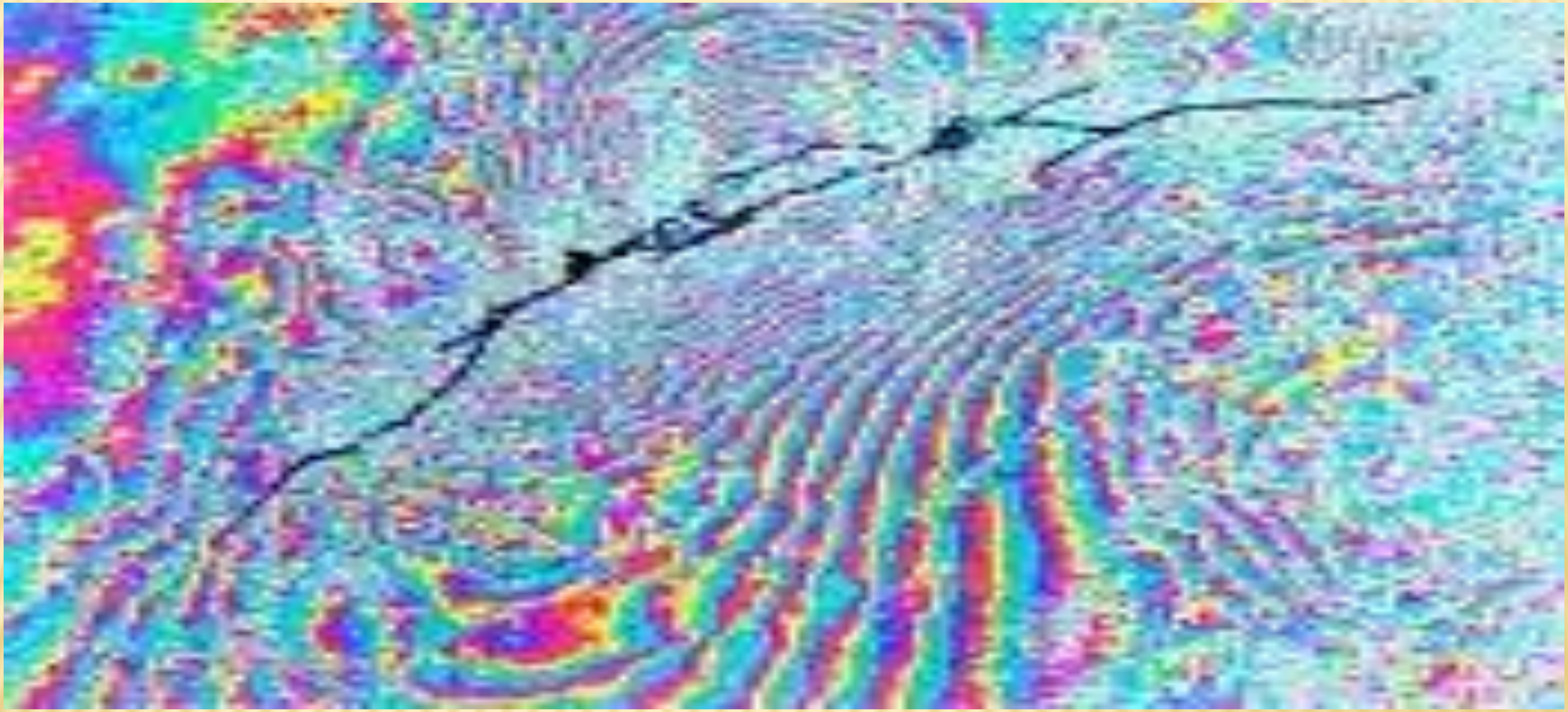


RADARSAT



Interferogram

The data obtained from the satellite is mainly used to create an interferogram like the one showed in figure 1. An interferogram is actually a combination of 2 images of the exact same area with a time elapse in between. When these images are overlaid the change in phase shift can be color coded and will then show the deformation of a given area.

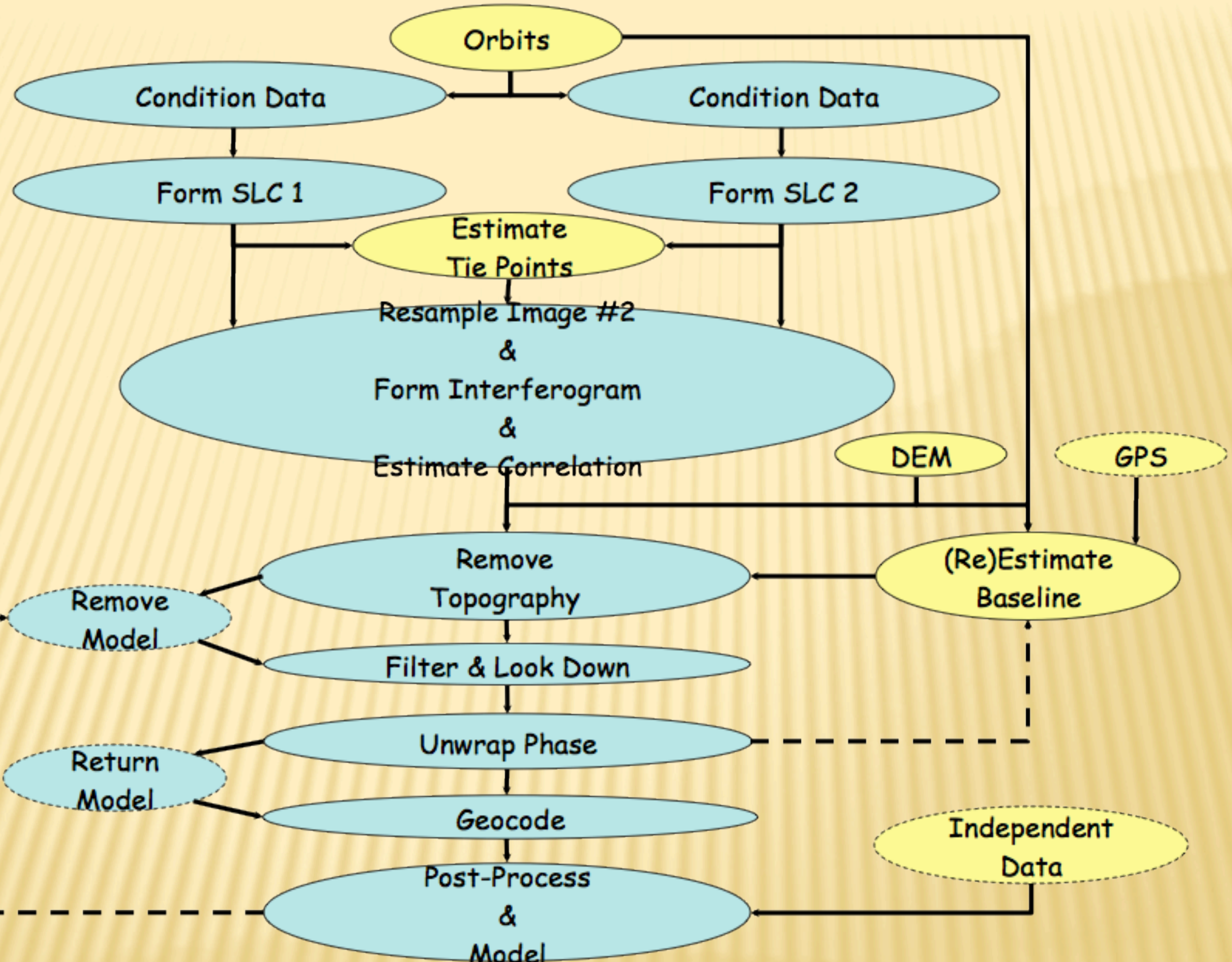


interferogram of the 1992 Lander's Earthquake

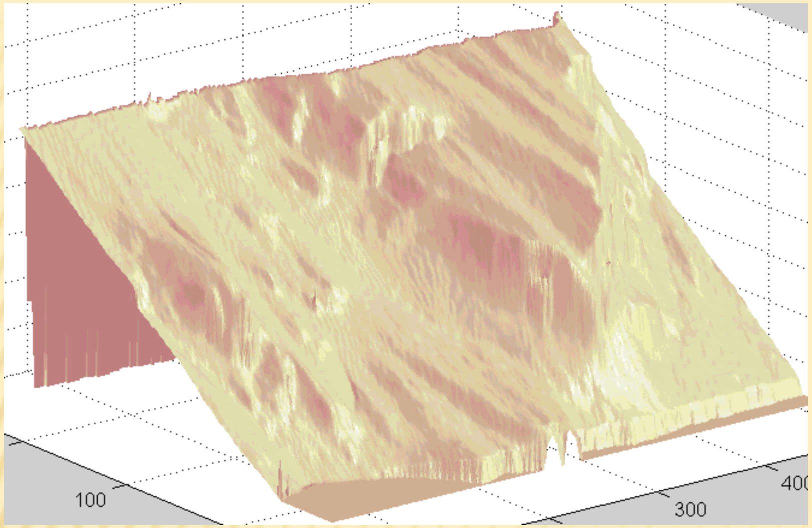
Getting from raw satellite data to an interferogram is not a easy process. Luckily, there is a software program known as ROI_PAC or Repeat Orbit Interferometric Package which helps a lot with this procedure. Using this software package there are just a few simple steps that must be followed.

- Acquire 2 frames of data collected at different times from the same location.
- Acquire orbital data for orbits in question.
- Acquire a digital elevation model for area in question
- Set up environment variables
- Condition the raw data
- Run through ROI_PAC

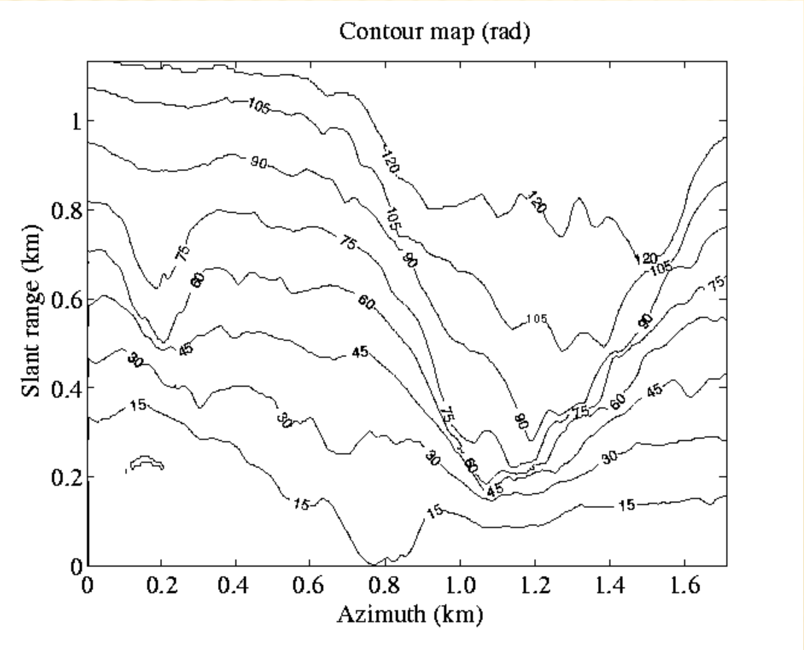
Pablo, Mattioli,Jansma



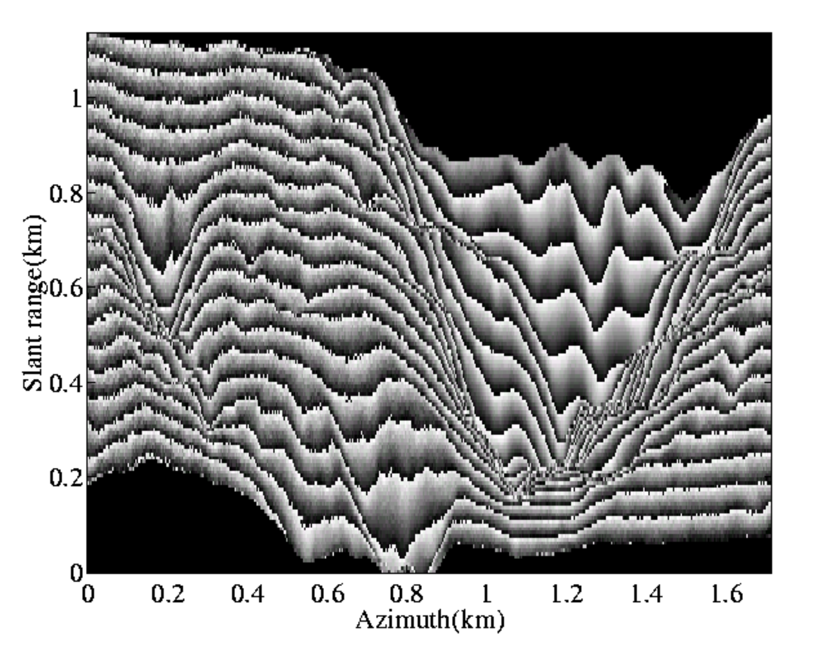
courtesy Mark Simons



Mountainous terrain around Long's Peak, Colorado



Interferogram



José M. Bioucas-Dias

- InSAR can resolve surface displacements with ~cm precision, 10s m spatial resolution, and monthly temporal resolution using remote satellites
- Global coverage; day/night, all-weather imaging capabilities

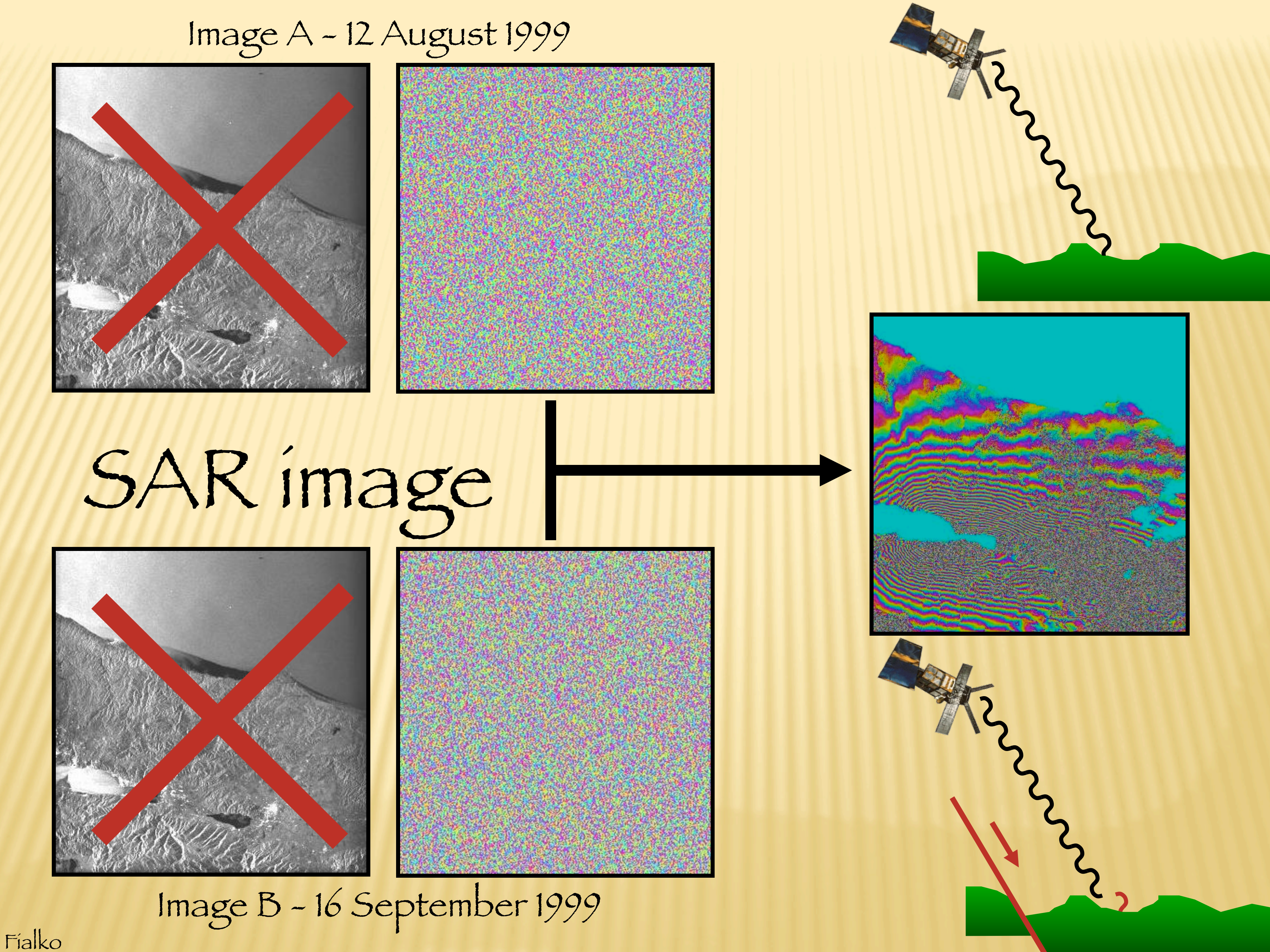
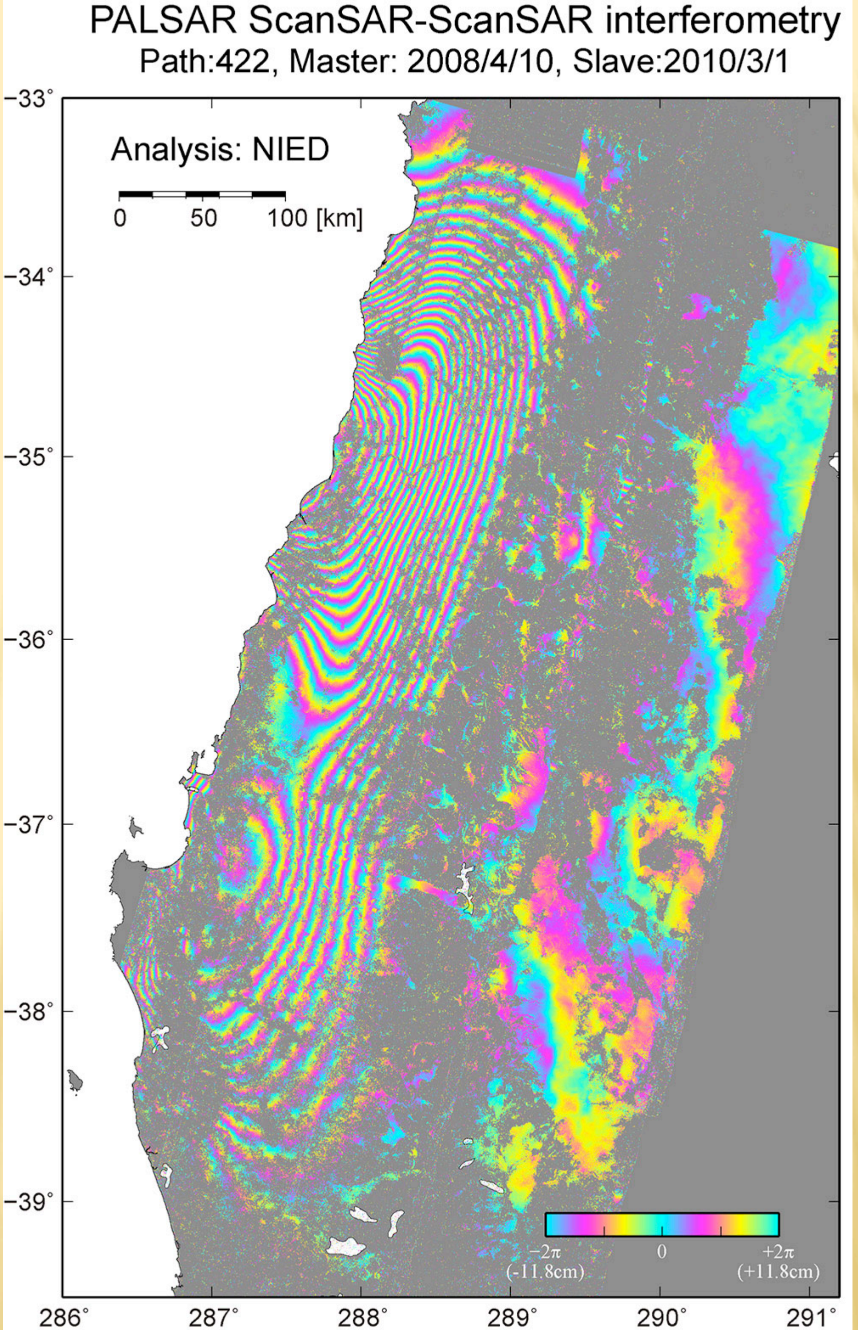


Image A - 12 August 1999
SAR image
Image B - 16 September 1999
Fialko

Coseismic – Maule 2010

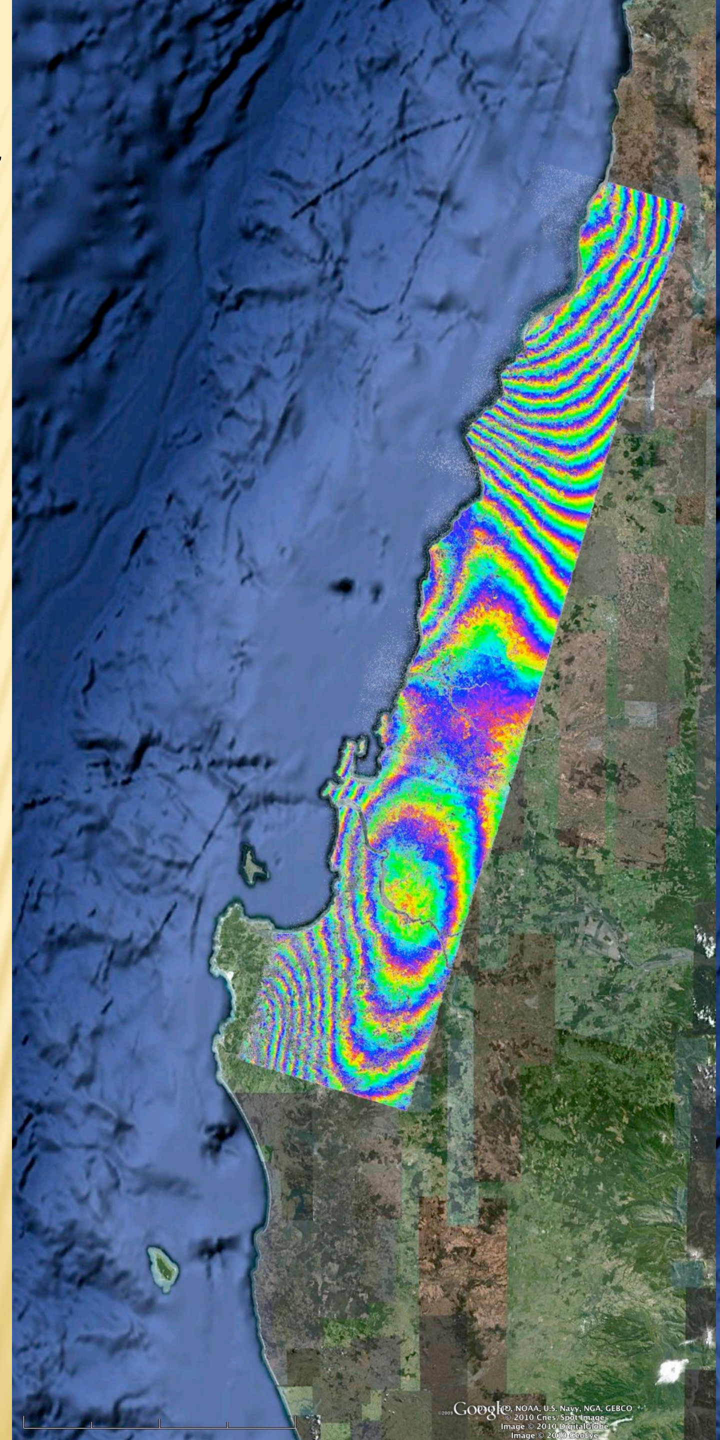


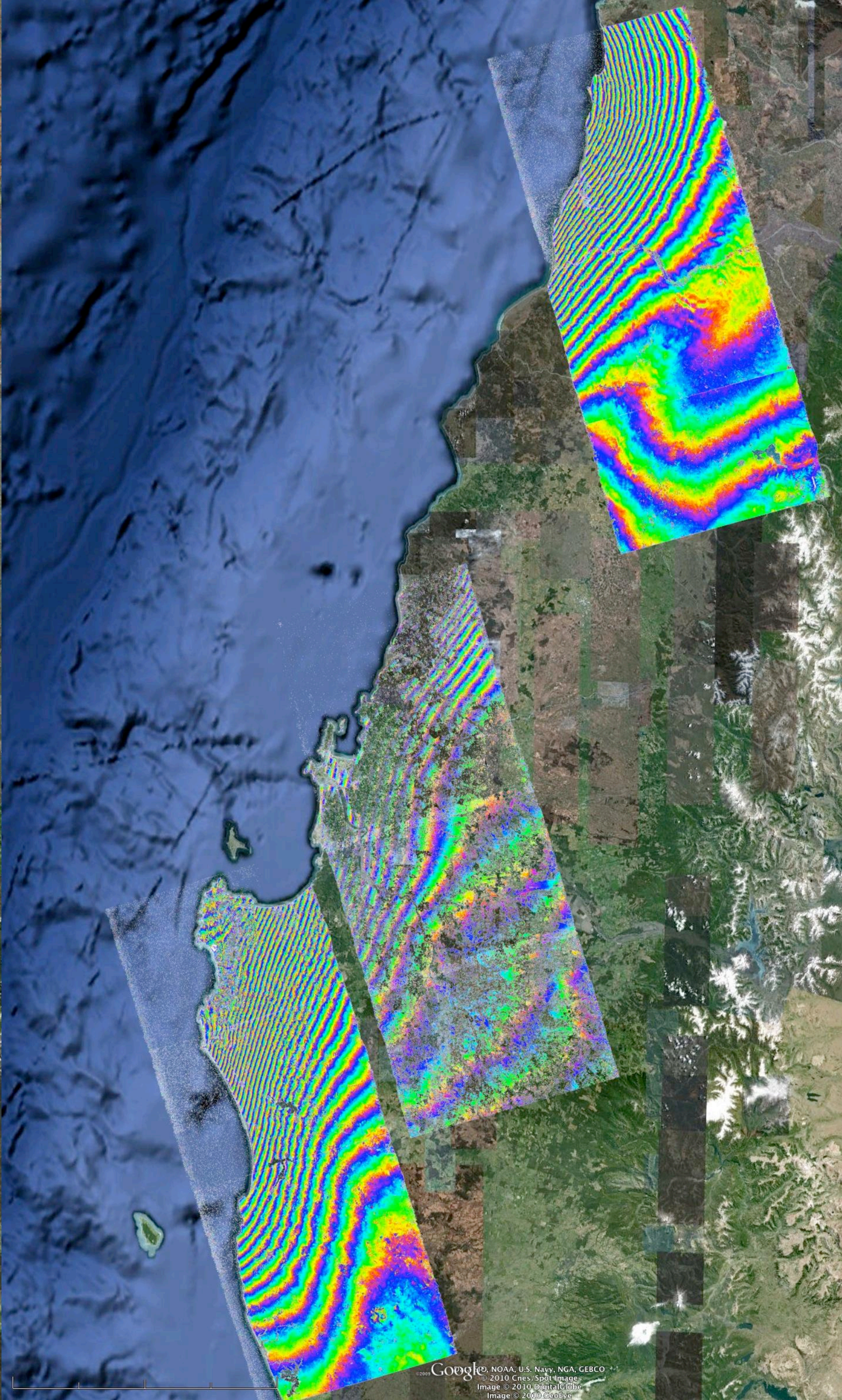
PALSAR level 1.0 data are shared among PIXEL (PALSAR Interferometry Consortium to Study our Evolving Land surface), and provided from JAXA under a cooperative research contract with ERI, Univ, Tokyo The ownership of PALSAR data belongs to METI (Ministry of Economy, Trade and Industry) and JAXA

http://supersites.earthobservations.org/chile.php#SAR

Coseismic – Maule 2010

Interferograms derived from ALOS PALSAR data processed by Xiaopeng Tong and David Sandwell using GMTSAR. kmz-files are available at ftp://topex.ucsd.edu/pub/chile_eq/chile_insar.zip . All raw data are available to WInSAR investigators. Send e-mail to dsandwell@ucsd.edu.





http://supersites.earthobservations.org/chile.php#SAR

Coseismic – Maule 2010

Interferograms derived from ALOS PALSAR data processed by Xiaopeng Tong and David Sandwell using GMTSAR. kmz-files are available at ftp://topex.ucsd.edu/pub/chile_eq/chile_insar.zip . All raw data are available to WInSAR investigators. Send e-mail to dsandwell@ucsd.edu.

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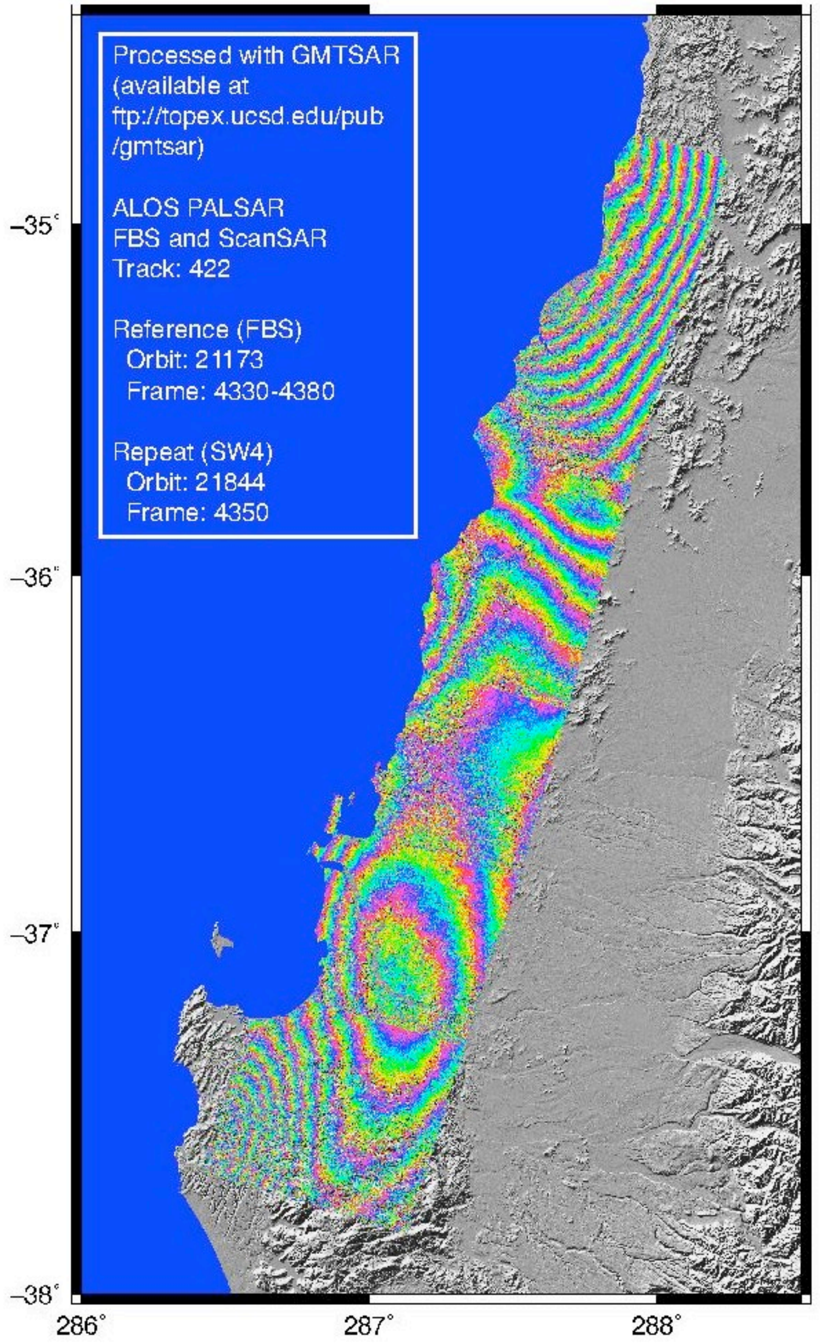
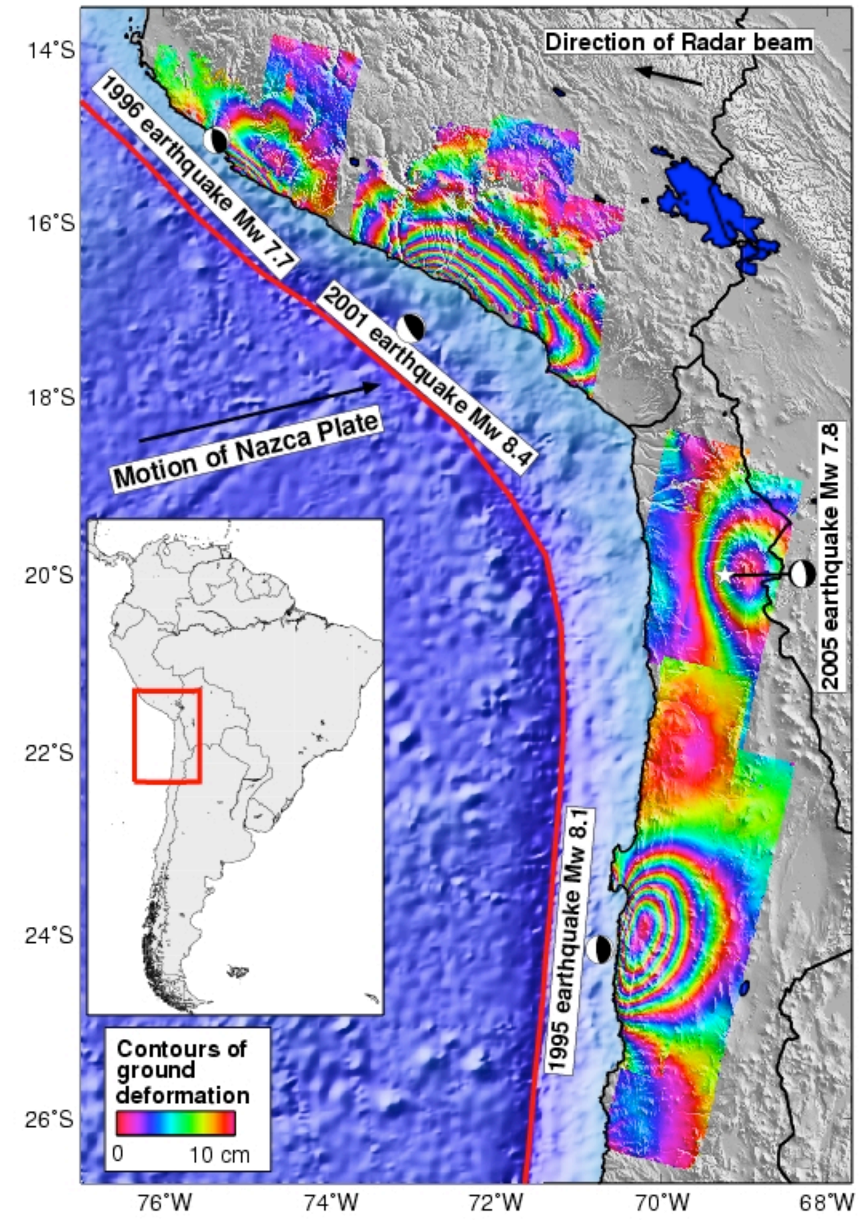
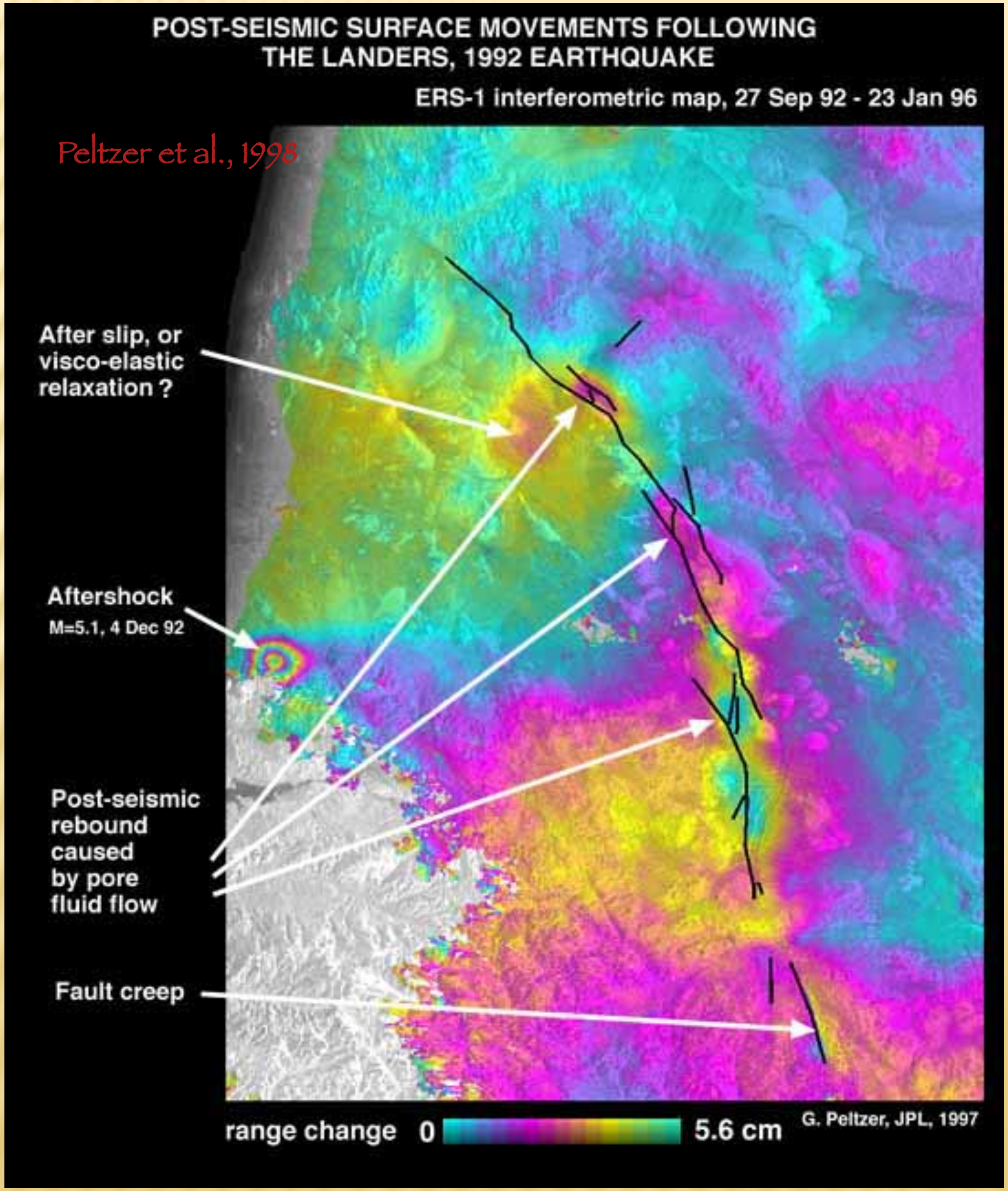
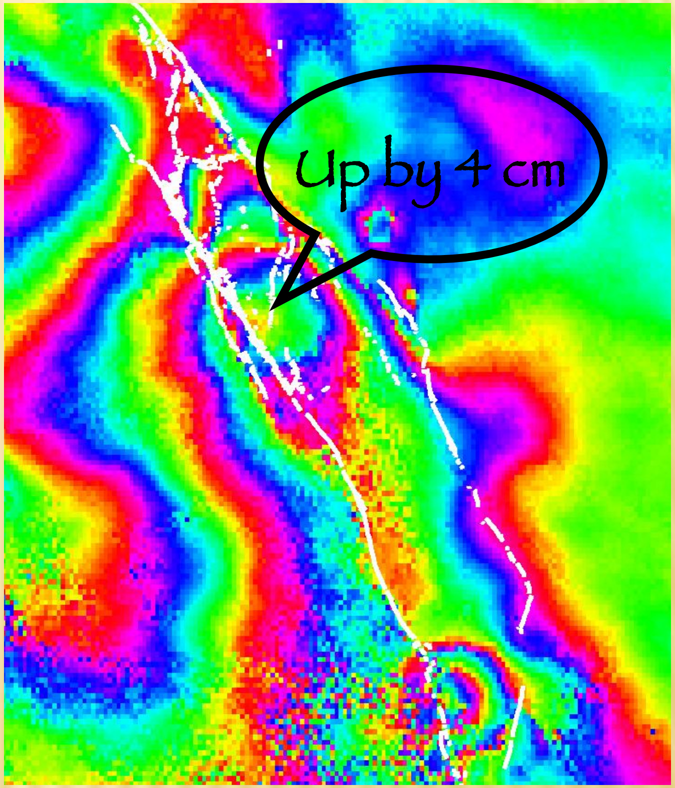




Matt Pritchard

Postseismic – 1992 Landers





Releasing stepovers (pull aparts) rebound, afterslip or v-e relaxation, aftershock, creep.

Massonnet & Feigl, 1998

Postseismic – 1999 Hector Mine

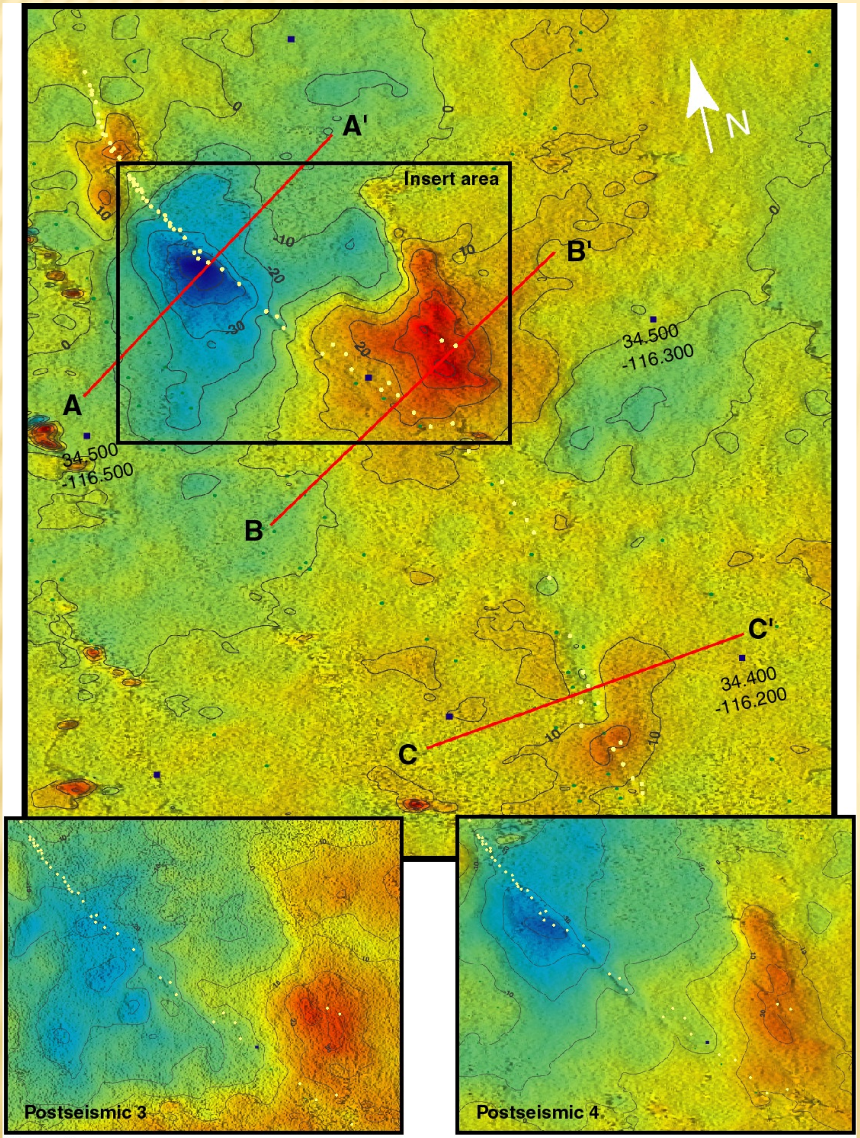
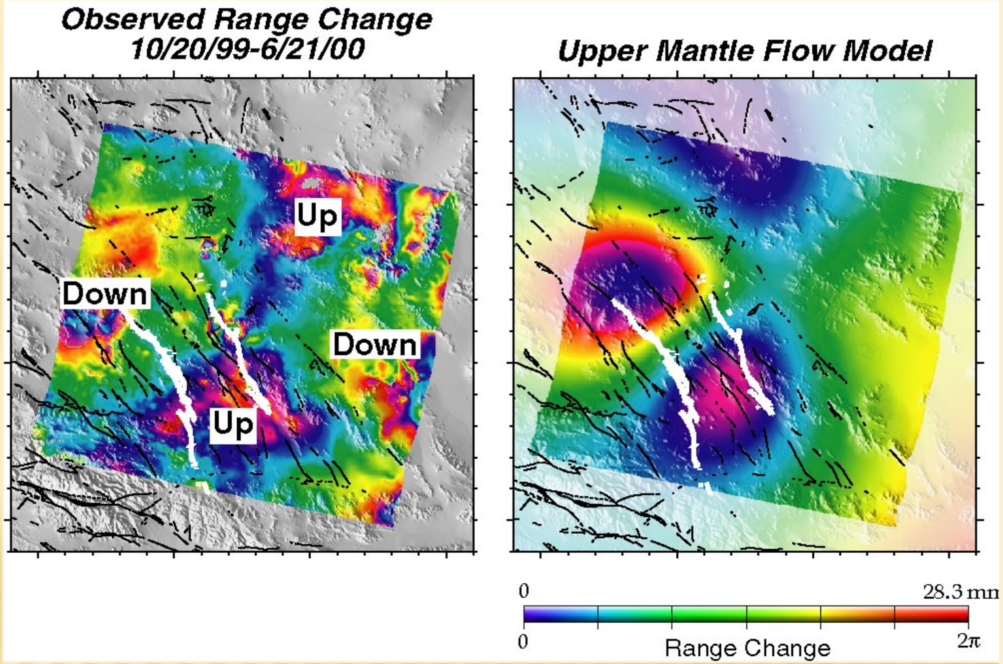


Figure 3

Near field: Shallow afterslip and fault zone collapse?

Jacobs, A., Sandwell, D., Fialko, Y. and L. Sichoix, BSSA, 2002.

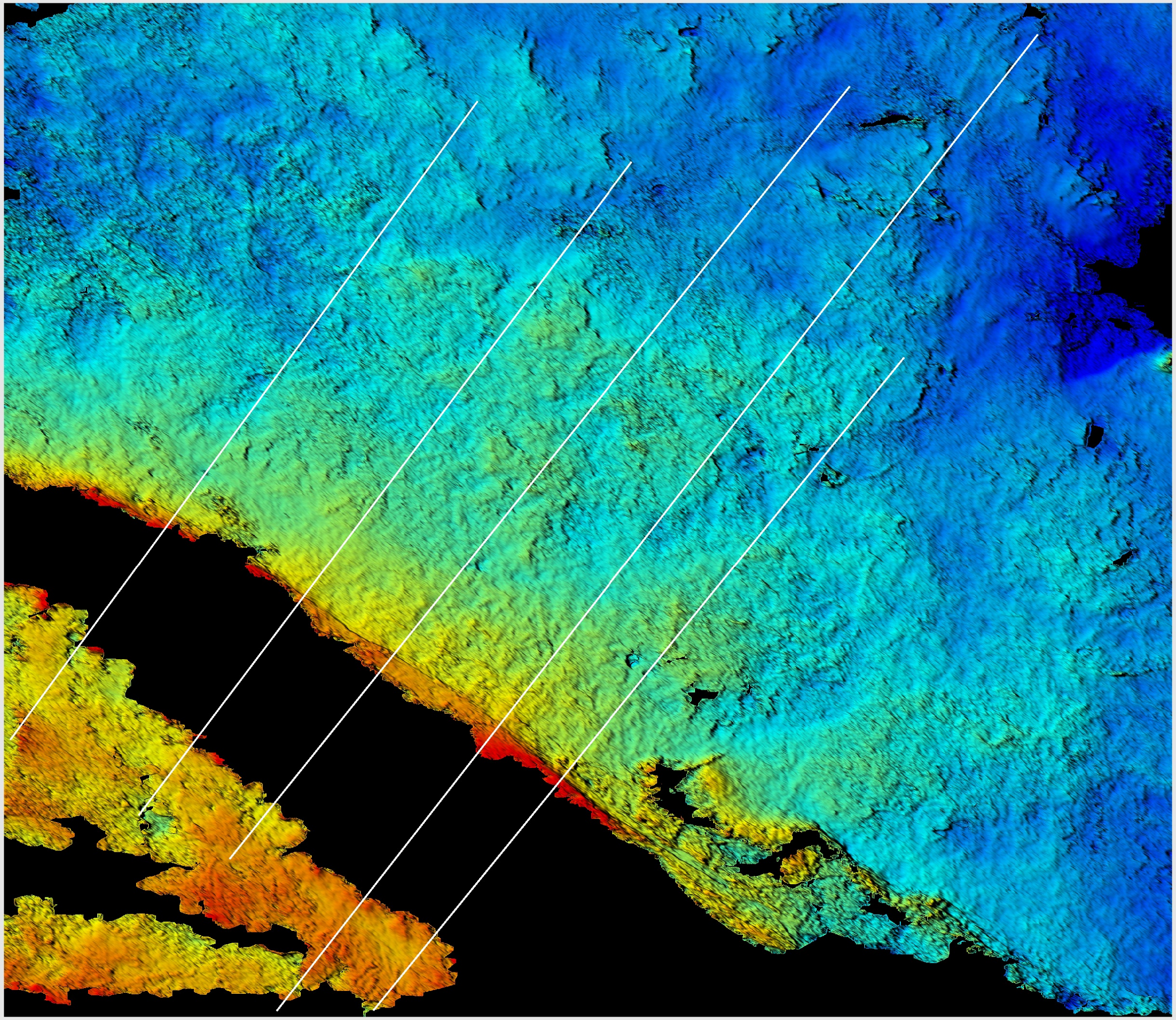


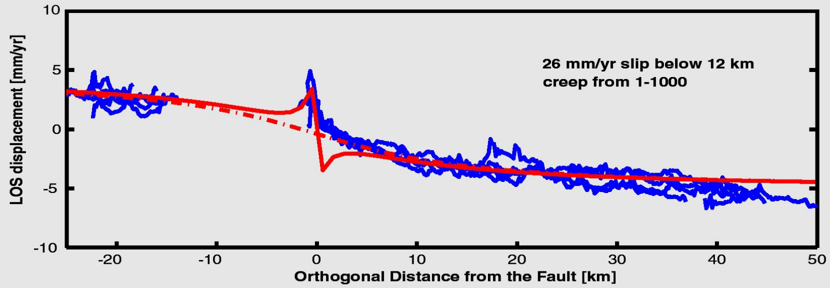
Far field: Upper mantle relaxation?

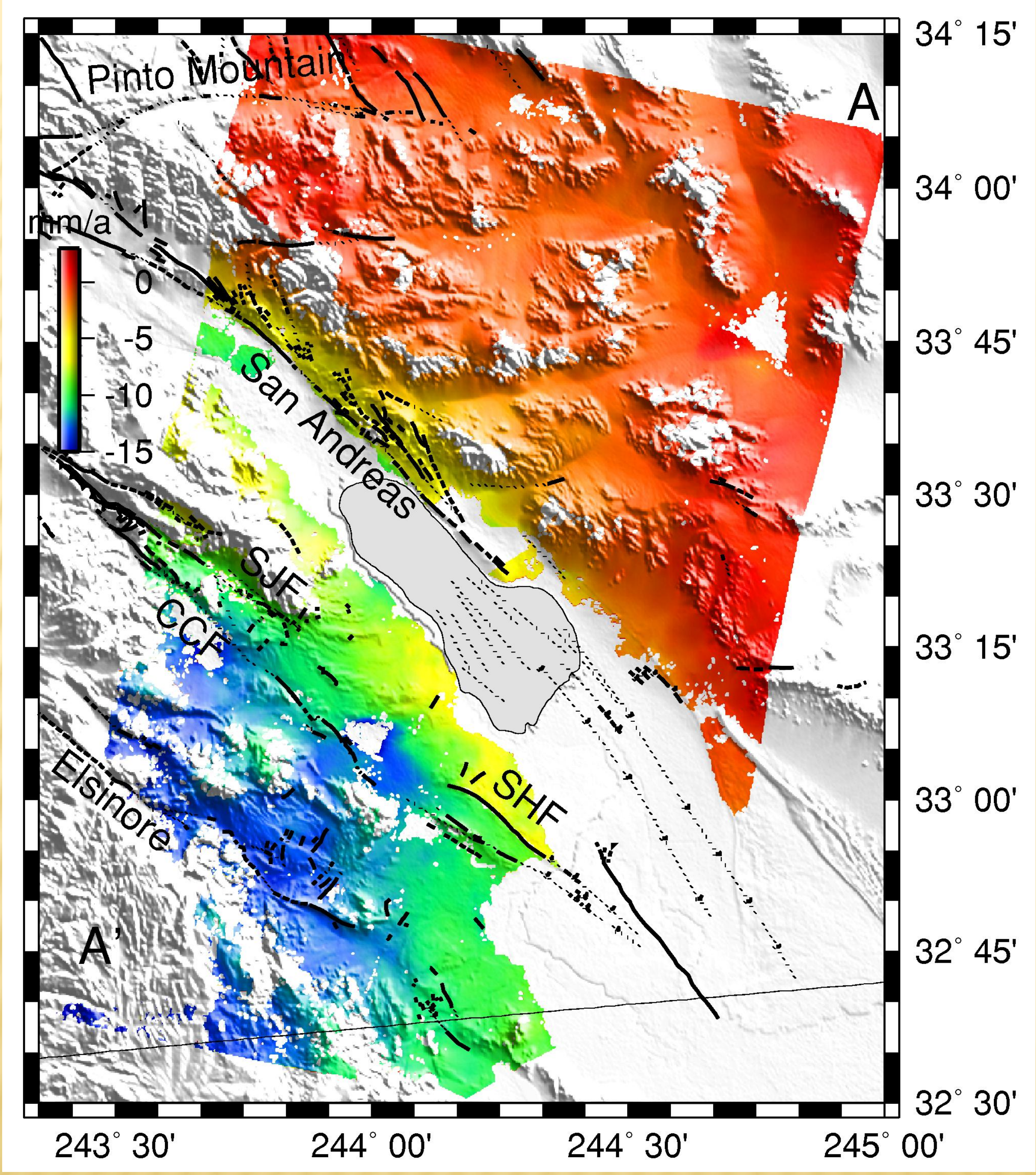
Pollitz et al., Science, 2001

Interseismic – Southern SAF

(Lyons, S. and Sandwell, JGR, 2003)





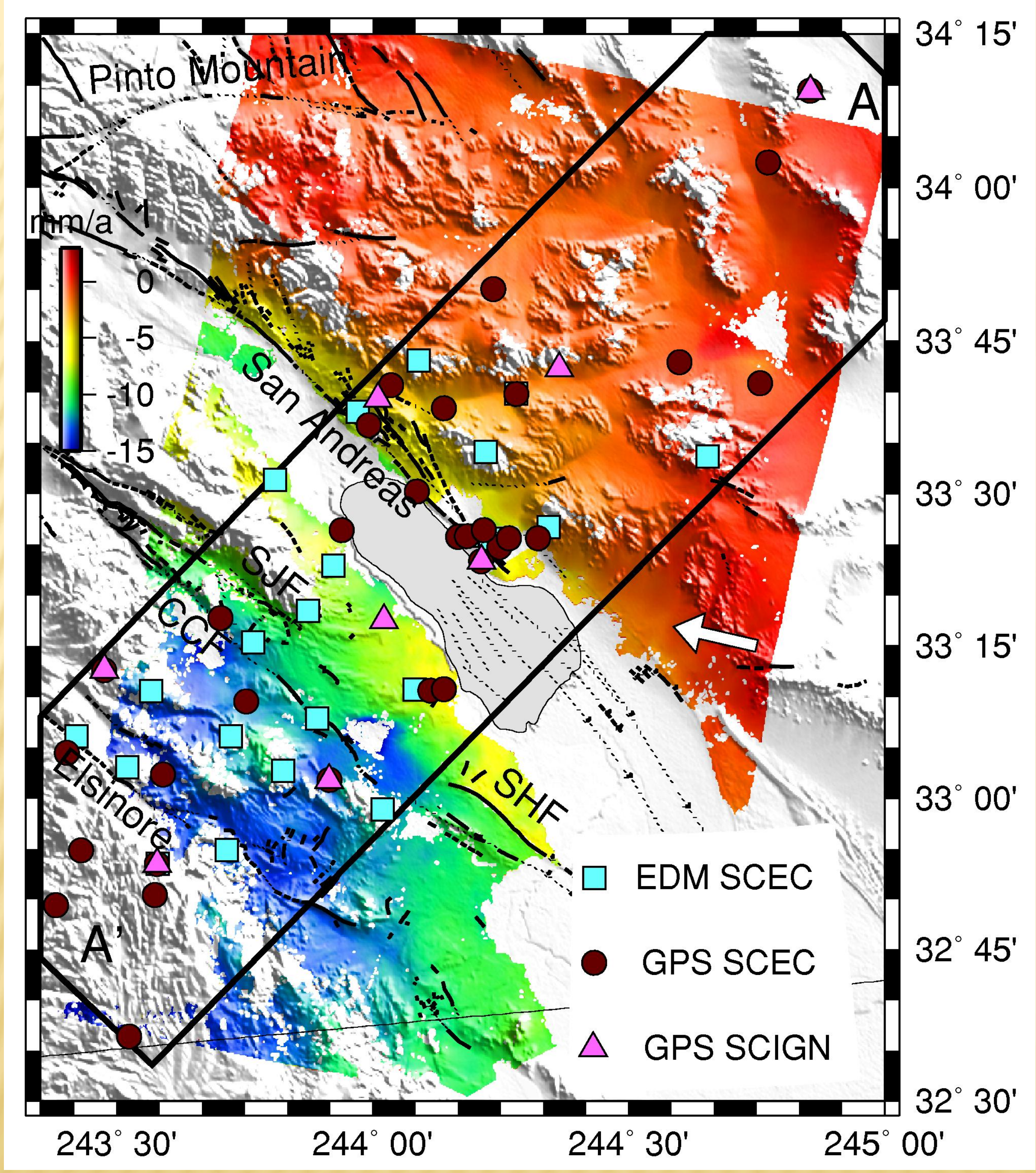


Line of sight velocities from stacked (more on this later) InSAR data

35 interferograms

Epoch: 1992-2000

Fialko, Nature 2006

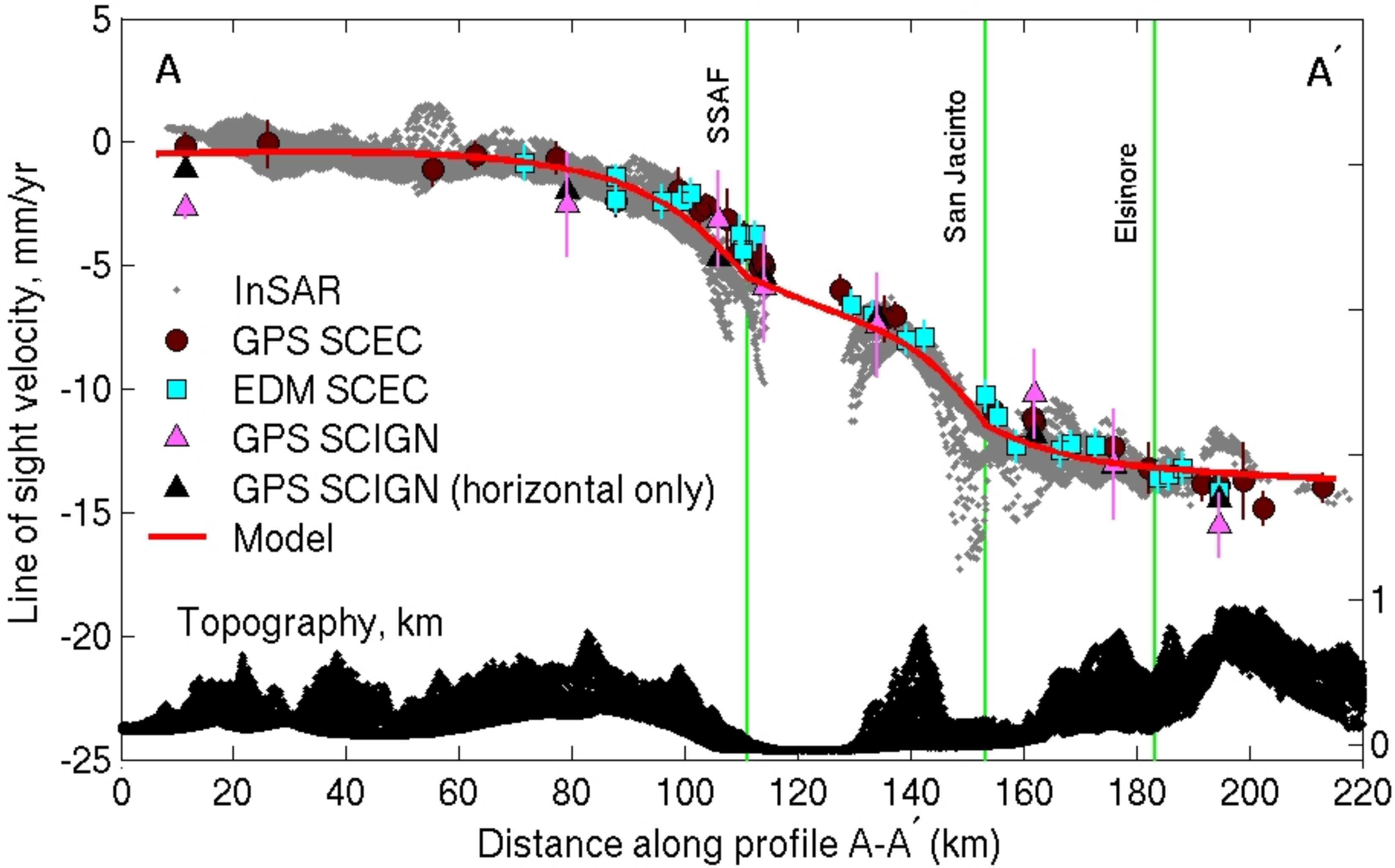


Line of sight velocities from stacked InSAR data

35 interferograms

Epoch: 1992-2000

Fialko, Nature 2006

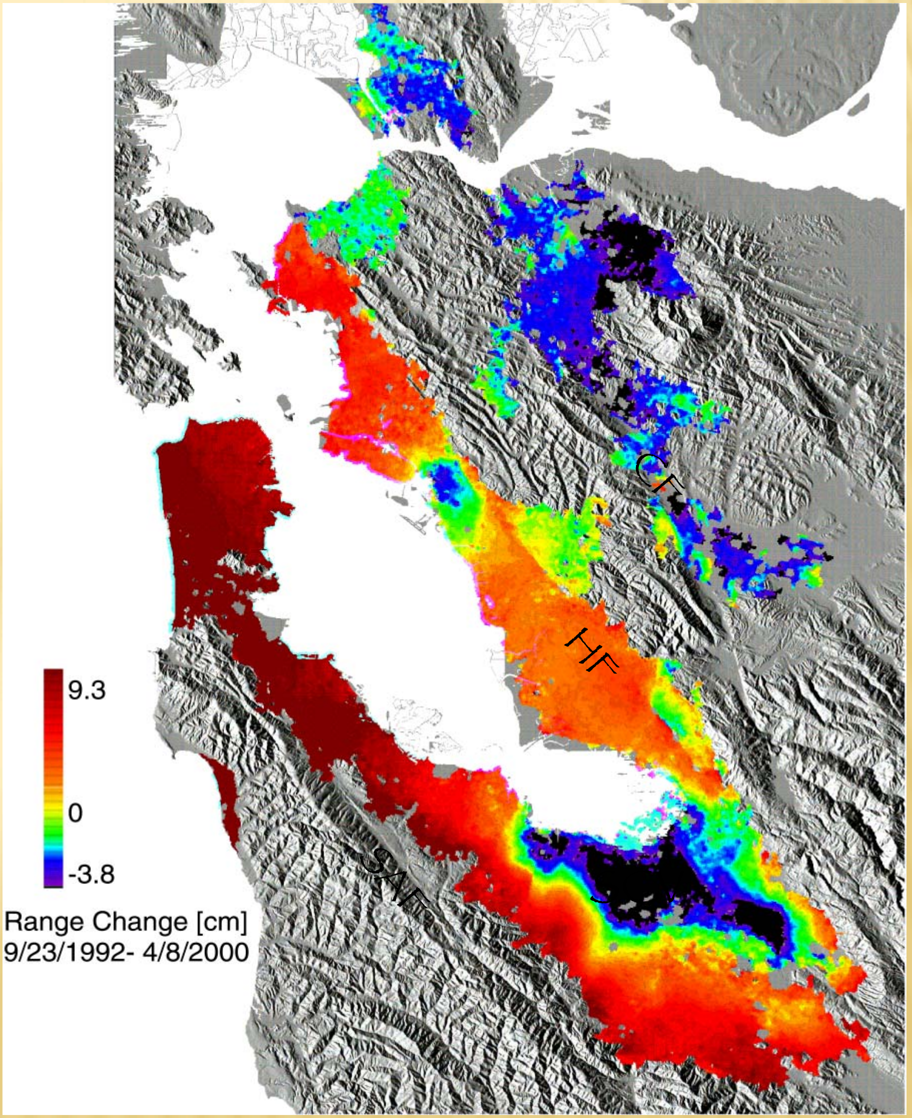


Fialko, Nature 2006

INTERSEISMIC - SAN FRANCISCO BAY AREA

(Burgmann et al., Science, 2000)

- Eight-year interferogram showing:
  - Elastic strain accumulation across San Andreas fault system
  - Creep along Hayward fault
  - Rebound of Santa Clara Valley from aquifer recharge

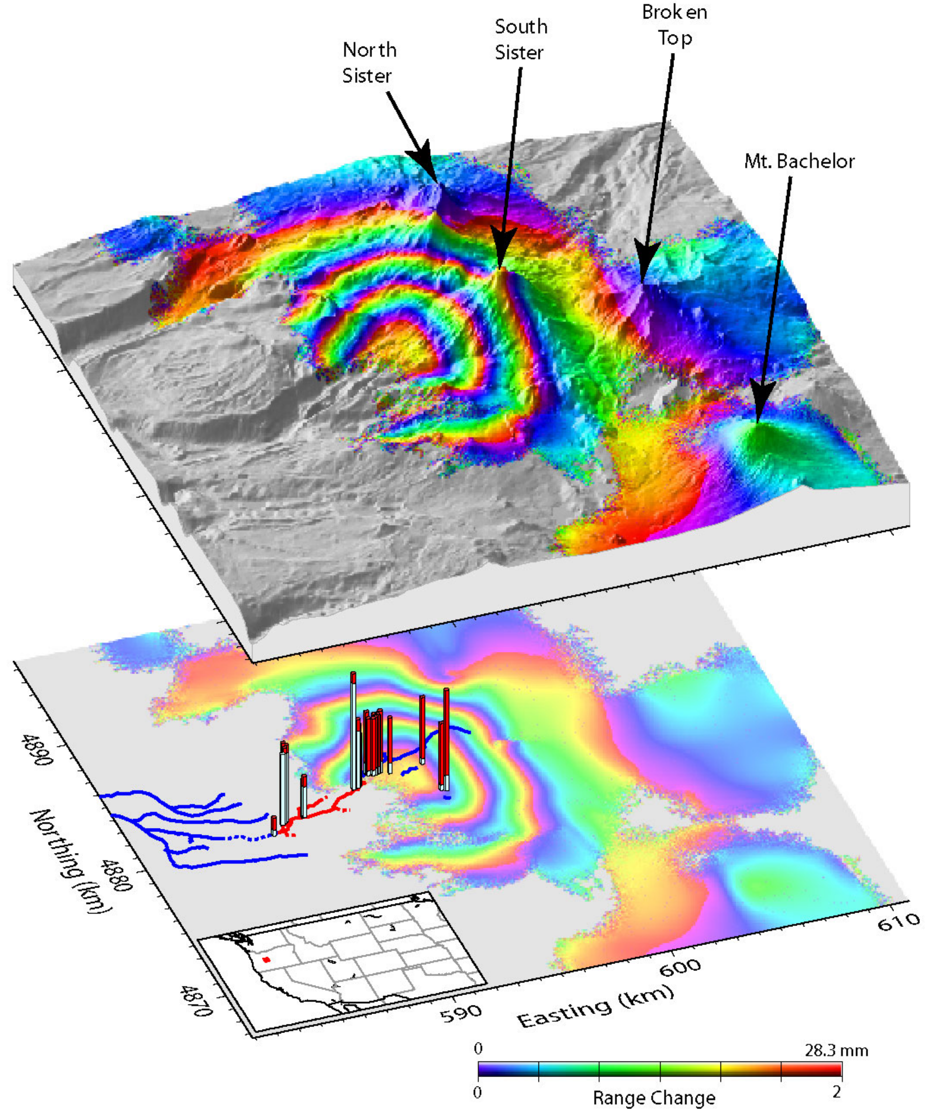


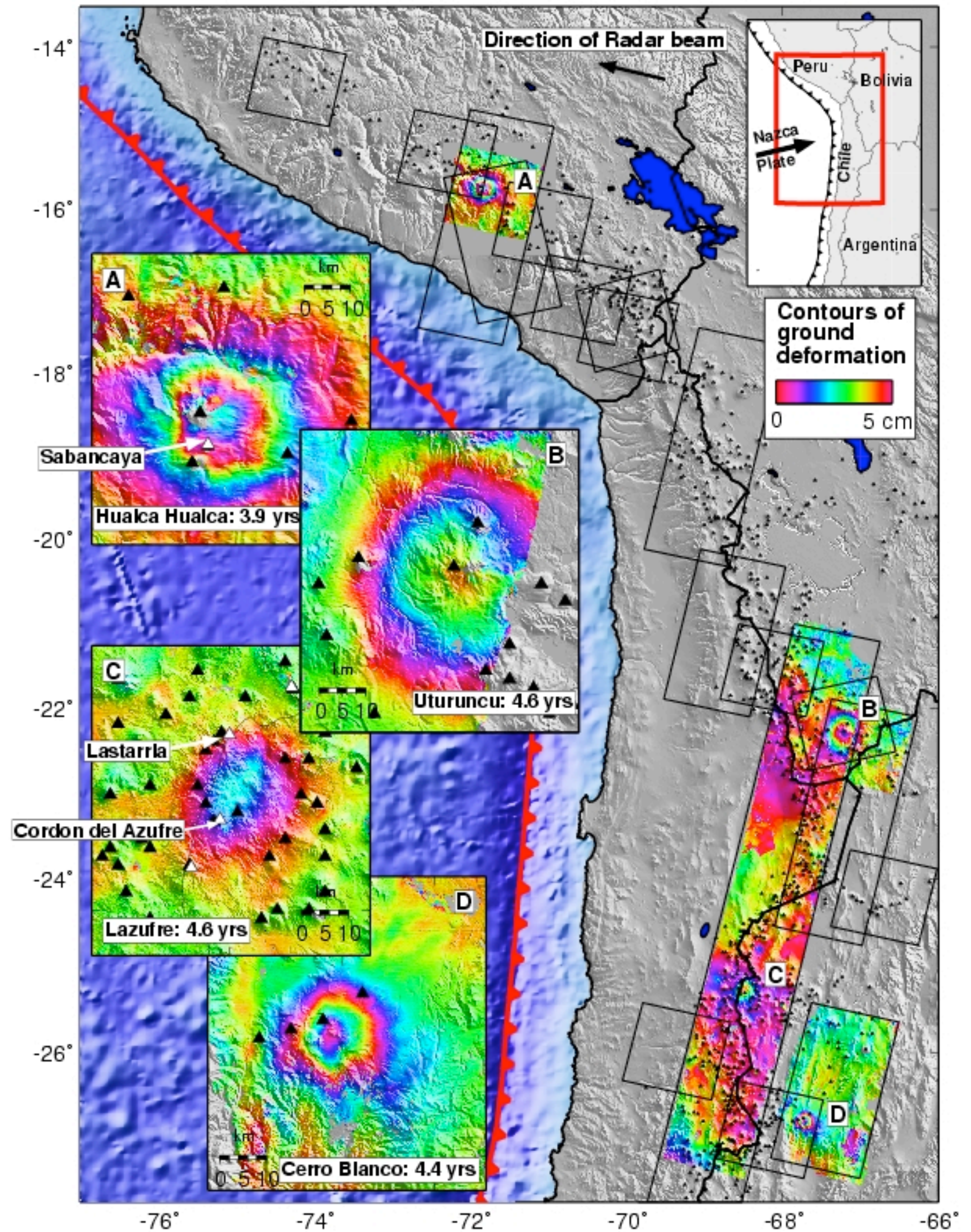
MAGMATIC ACTIVITY: DETECTION AND INTERPRETATION

- Location and geometry of magma reservoirs
- Dynamics of magma supply
- Precursory phenomena
  - Intrusion
  - Eruption

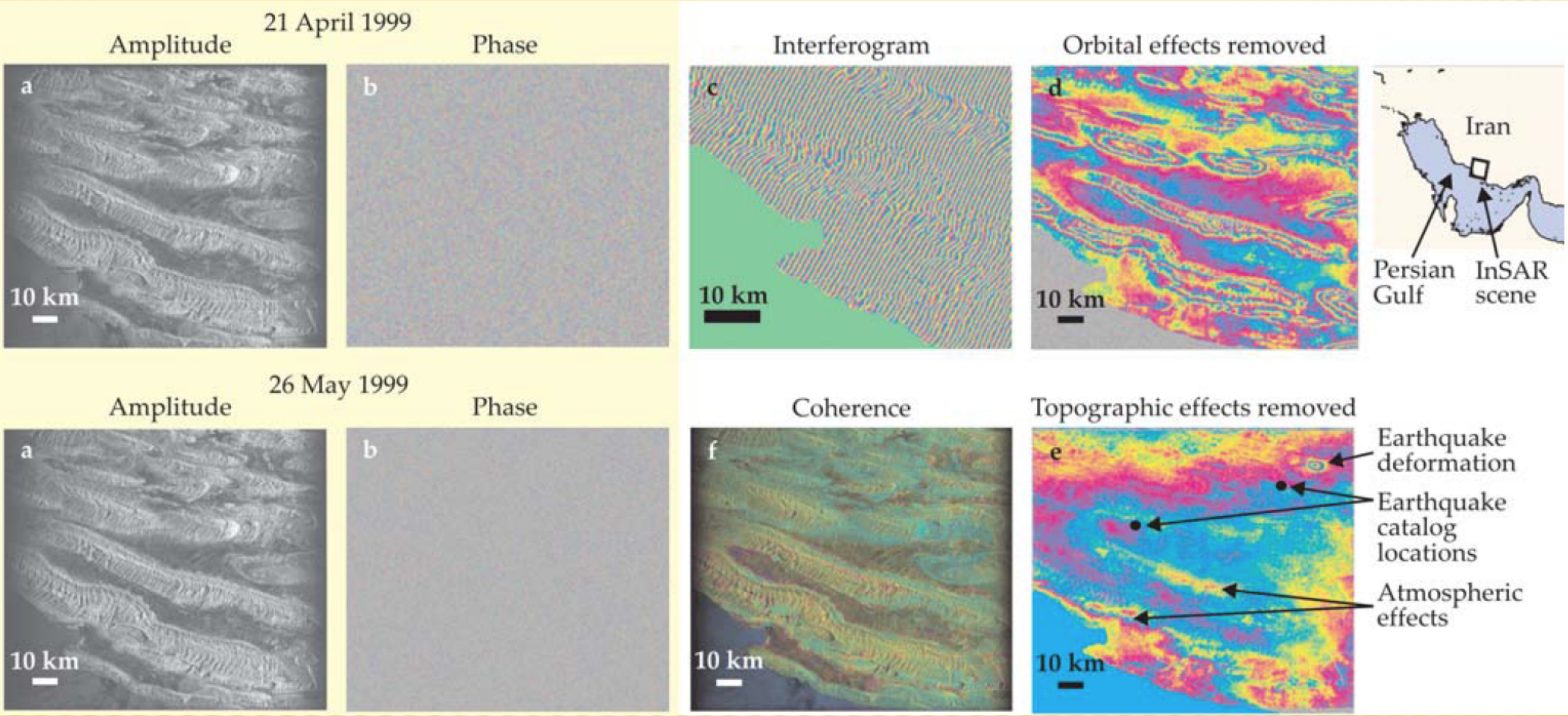
VOLCANIC INFLATION THREE SISTERS, CASCADE RANGE

(Wicks et al., Science, 2002)





Matt Pritchard

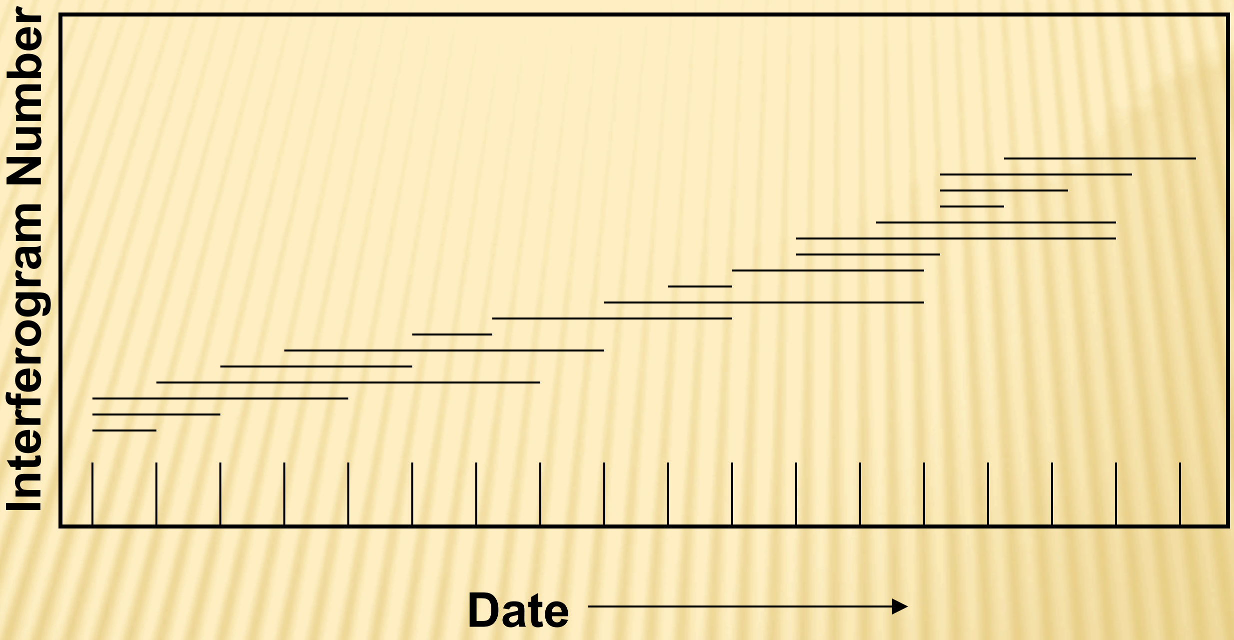


Using InSAR to improve earthquake locations (assuming it causes surface deformation) – can also look for craters associated with underground nuclear tests.

Matt Pritchard, 2006

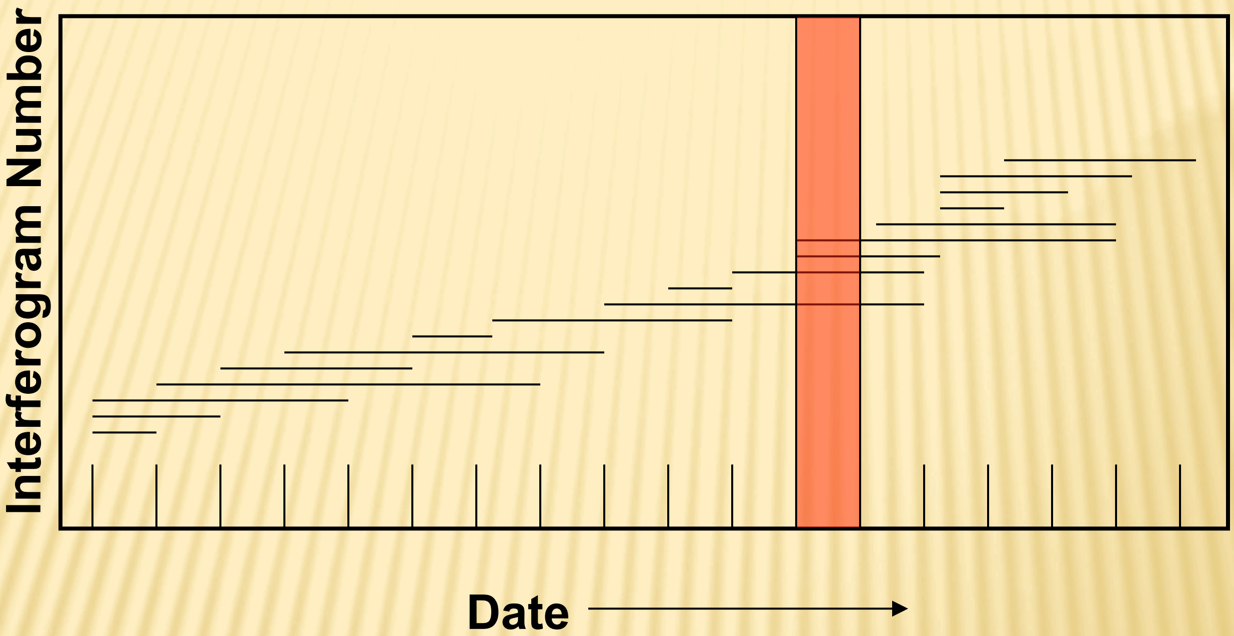
New techniques: Time series of interferograms

The Basic Idea…



New techniques: Time series of interferograms

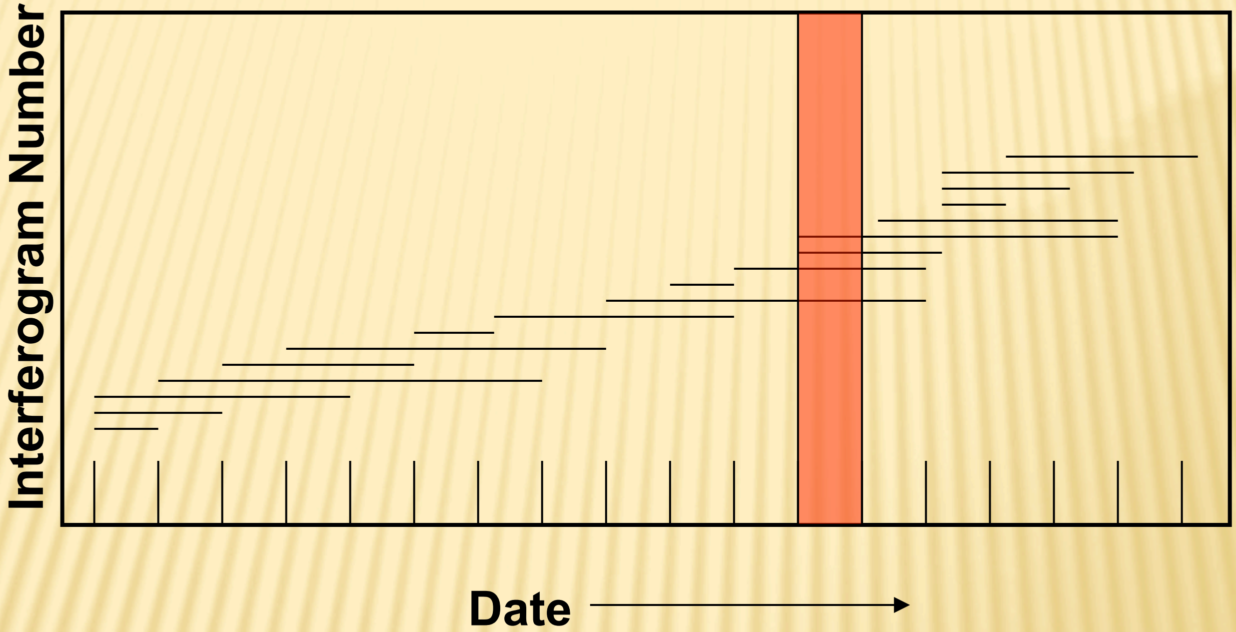
The Basic Idea…



A stack of interferograms provides multiple constraints on a given time interval

New techniques: Time series of interferograms

The Basic Idea…



Goal: Solve for the deformation history that, in a least-squared sense, fits the set of observations (i.e., interferograms),

Many different methods (e.g., Lundgren et al. (2001), Schmidt & Burgmann, 2003), but SBAS (Berardino et al. (2002)) is perhaps most common one

Persistent scatterers (PS or PSInSAR)

- Select pixels with stable scattering behavior over time

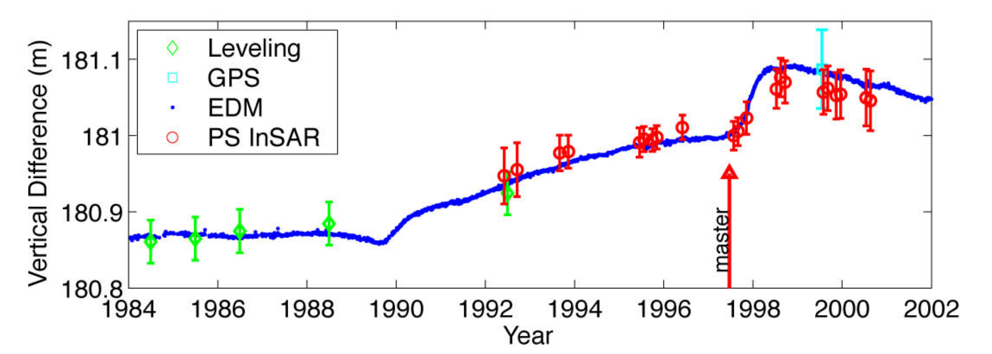
- Only focus on “good” pixels

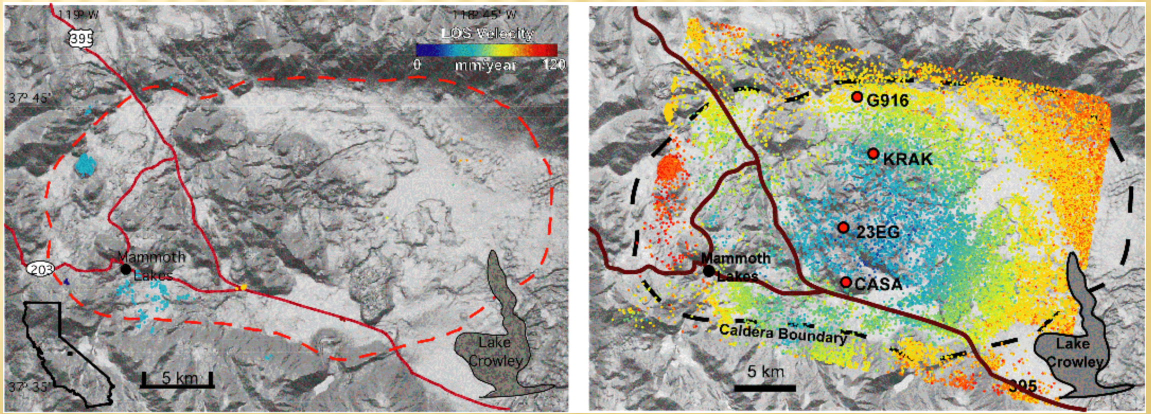
InSAR
- Spatial coherence @ 1 time
- Need neighborhoods of good pts

PS
- Coherence @ 1 point
- Need > 15-20 scenes

- Added bonus: DEM errors!

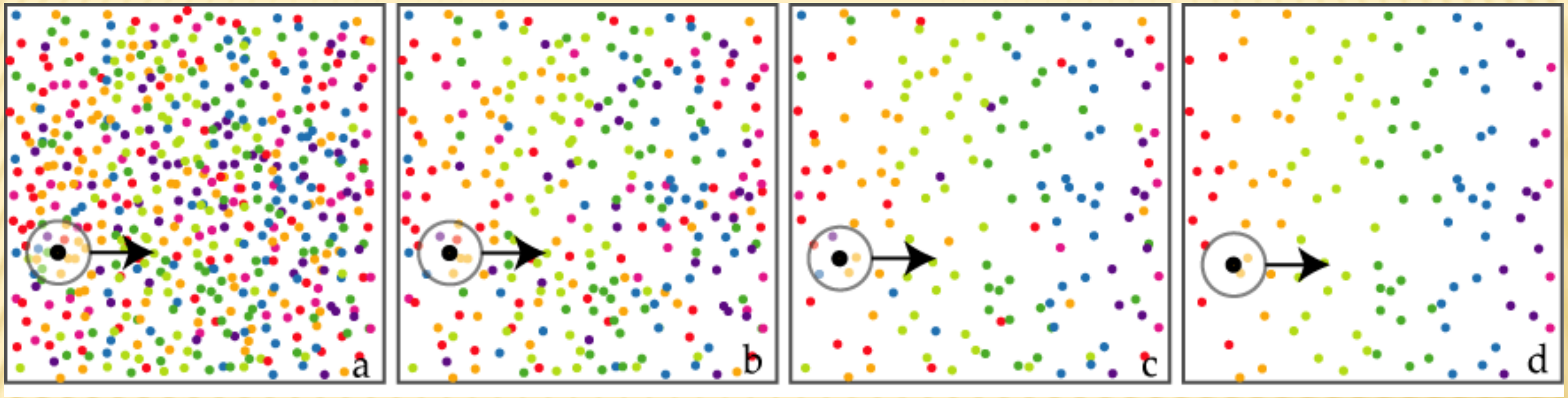
Long Valley Caldera, Hooper et al. 2004

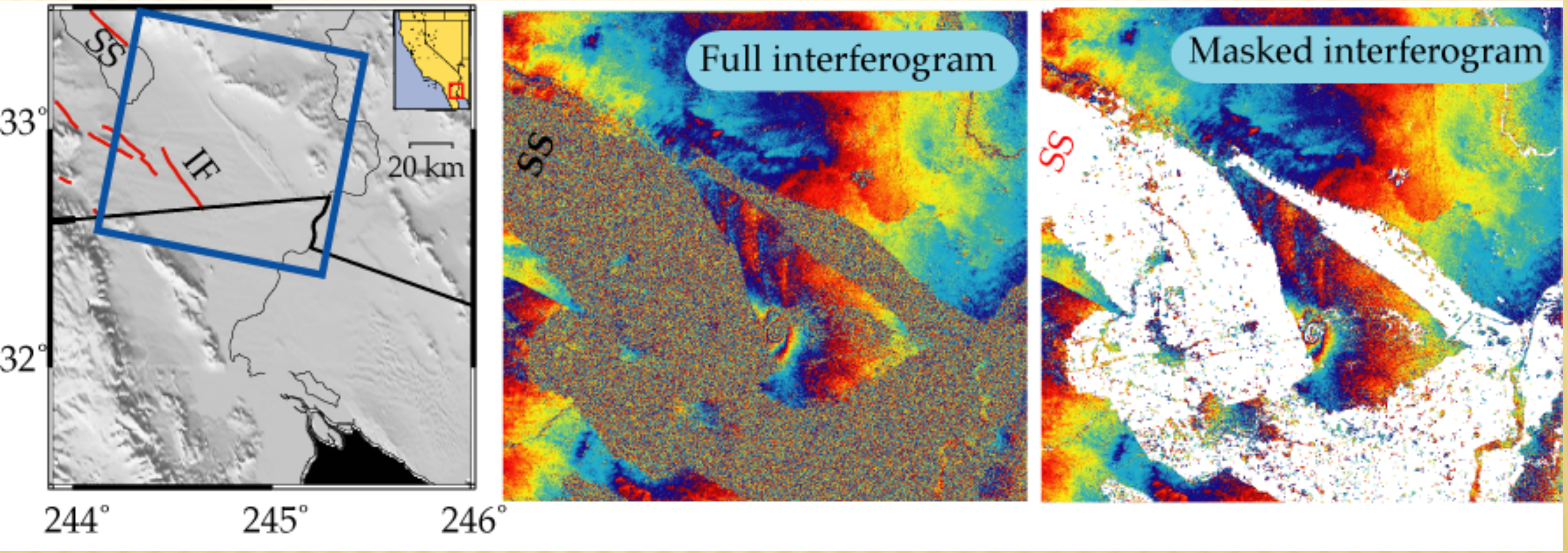




From: Rowena Lohman

StaMPS method (Hooper et al., 2004)





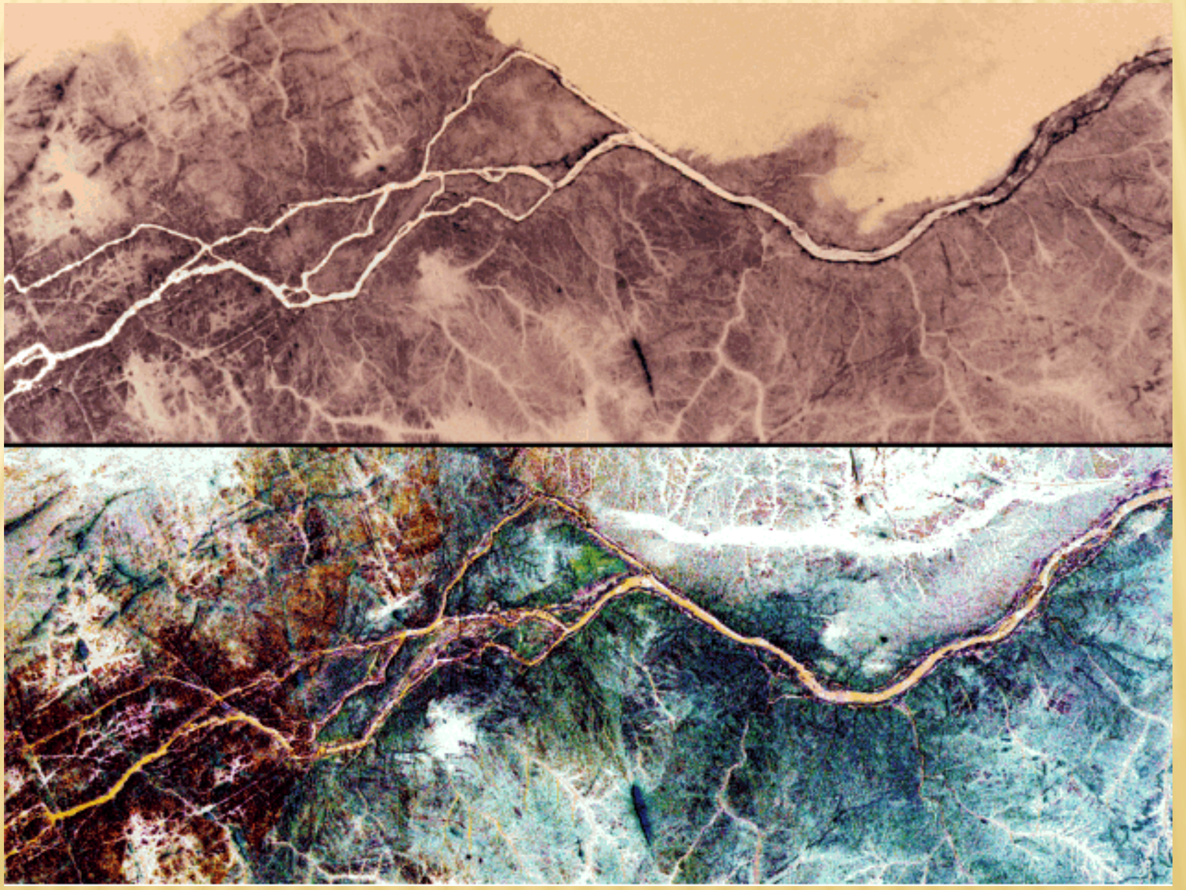
Example: Imperial Valley, CA

Matt Pritchard

From: Rowena Lohman

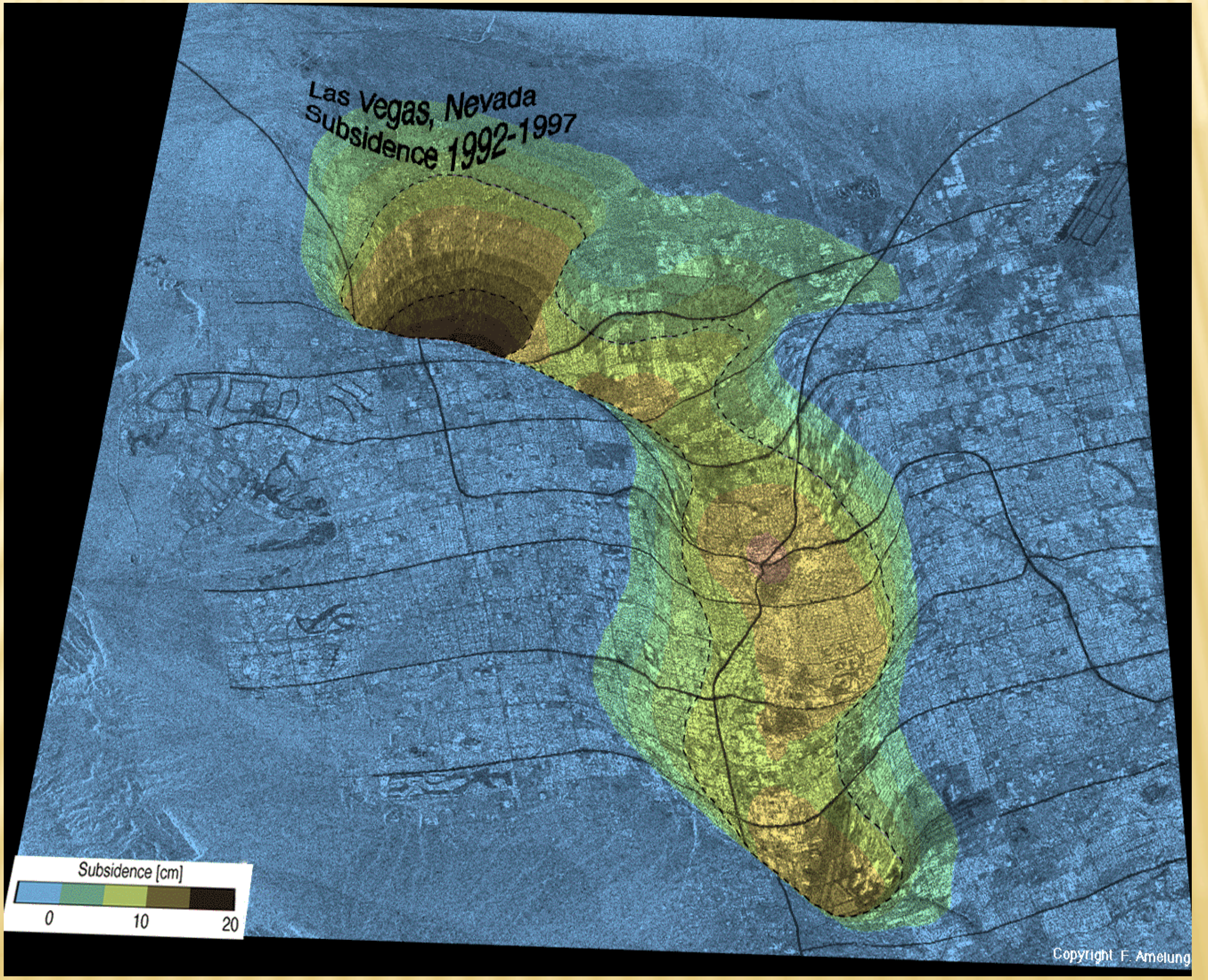
SIR-C image of Nile Paleochannel, Sudan

- The top image is a photograph taken with color infrared. The radar image at the bottom is a SIR-C/X-SAR image. The thick, white band in the top right of the radar image is an ancient channel of the Nile that is now buried under layers of sand. This channel cannot be seen in the photograph and its existence was not known before this radar image was processed.



Murchison

SUBSIDENCE DUE TO GROUND WATER WITHDRAWAL. (PRESENTATION HAS EXTREME VERTICAL EXAGGERATION)



I think this is from Amelung

REVIEW: WILL INSAR WORK FOR YOU?

- What is the local rate of deformation?
  - Sensitivity of single igram ~1cm
  - How many years to get signal this big and will it be overcome by noise?
  - Can you stack several igrams together?
- What is the scale of deformation?
  - Pixel size ~10m, but generally need to average many together
  - Image size is ~100 km, but if too broad worry about precision of orbits
- What is the local noise?
  - How much vegetation/precipitation/water vapor/human cultivation?
  - Can you only make igrams with data from the same seasons?
  - Can you get L-band data and find persistent scatterers?
- What data is available?
- Is there data from multiple satellites and/or imaging geometries?
- Is a digital elevation model available?
- Do you need rapid response for hazard assessment?

Matt Pritchard

REVIEW: HOW TO SET UP INSAR CAPABILITY?

1) Establish access to data
   - Main sources: see next slide

   - How? Can be purchased commercially. Lower cost/no-cost data available with restrictions. In Europe, through ESA. In U.S., through ASF and UNAVCO. Some foreign access is allowed to UNAVCO

   Can useful interferograms be made with available data? Worry about ground conditions, radar wavelength, frequency of observations, perpendicular baseline, availability of advanced processing techniques

2) Purchase/Install software to process and visualize data
   - Open source: ROI_PAC, DORIS, RAT and IDIOT (TU Berlin)
   - Commercial: Gamma, TR Europa, Vexcel/Atlantis, DIAPASON, SARscape

3) Download/create DEM (SRTM is only +/- 60 degrees latitude, but ASTER G-DEM in 2009)

4) Download precise orbital information & instrument files (Only ERS & Envisat)

5) Interpret results, create stacks, time series, persistent scatterers. May need to buy/download/create new software

6) Publish new discoveries and software tools!

FOR MORE INFORMATION:

- Good overview of classical & space based geodesy (but no InSAR): John Wahr's online textbook http://samizdat.mines.edu/geodesy

- Introductions to InSAR:
  - 2 page overview from Physics Today http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/matt/vol59no7p68_69.pdf
  - Overviews of applications: Massonnet & Feigl, Rev. Geophys., 1998; Burgmann et al., AREPS, 2000.

- More advanced InSAR:
  - The definitive SAR book: Curlander & Mcdonough, 1990
  - More technical reviews: Rosen et al., IEEE 2000; Hanssen's Radar Interferometry book, 2001; Simons & Rosen, Treatise on Geophysics, 2007;
  - Time series analysis: Berardino et al., IEEE, 2002; Schmidt & Burgmann, JGR, 2003
  - Persistent scatterers: Ferretti IEEE, 2001; Hooper et al., GRL, 2004; Kampes' Persistent Scatterers book, 2006