InSAR Applications in Crustal Deformation Studies

EOSC 212, September 2008

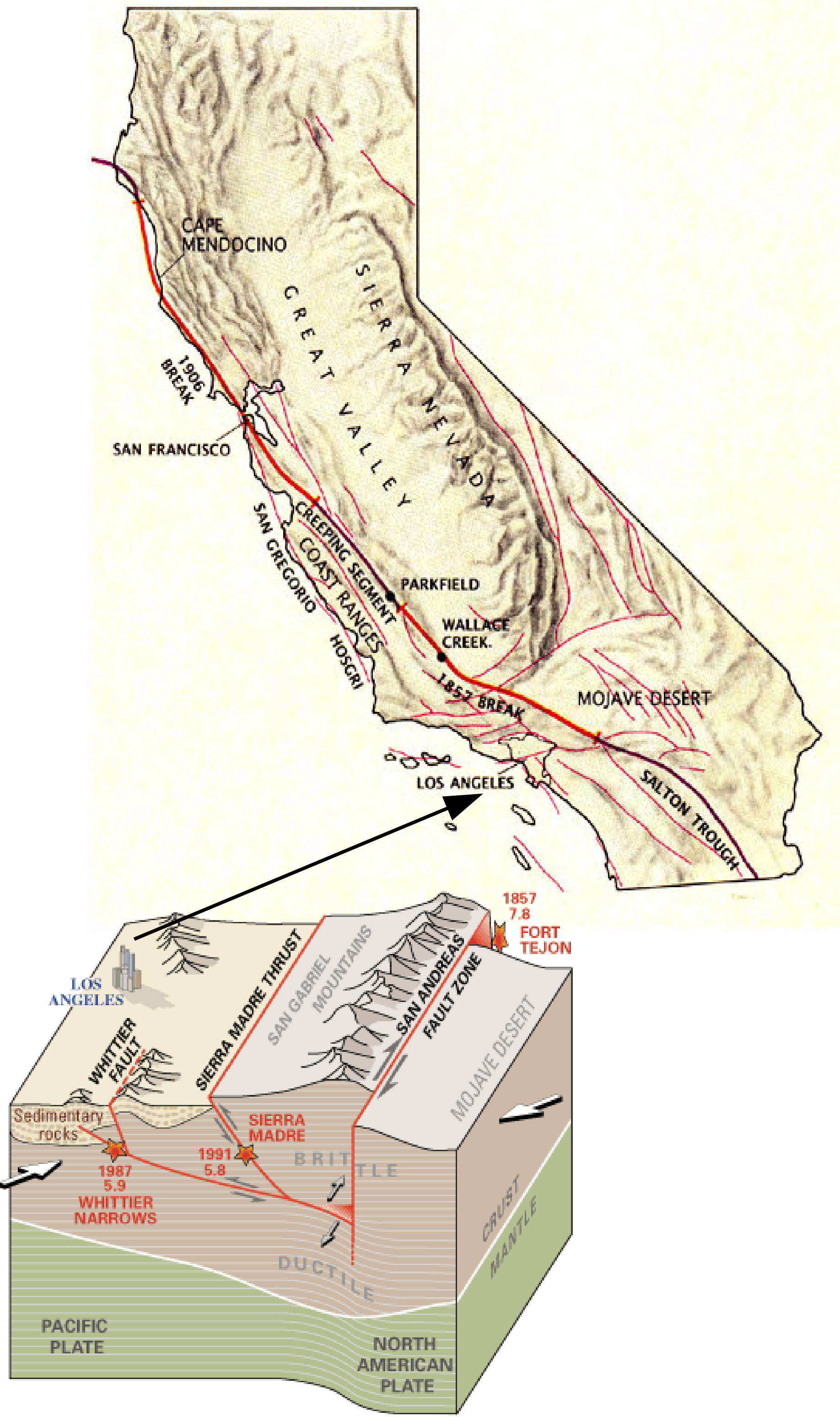
Yaron Finzi

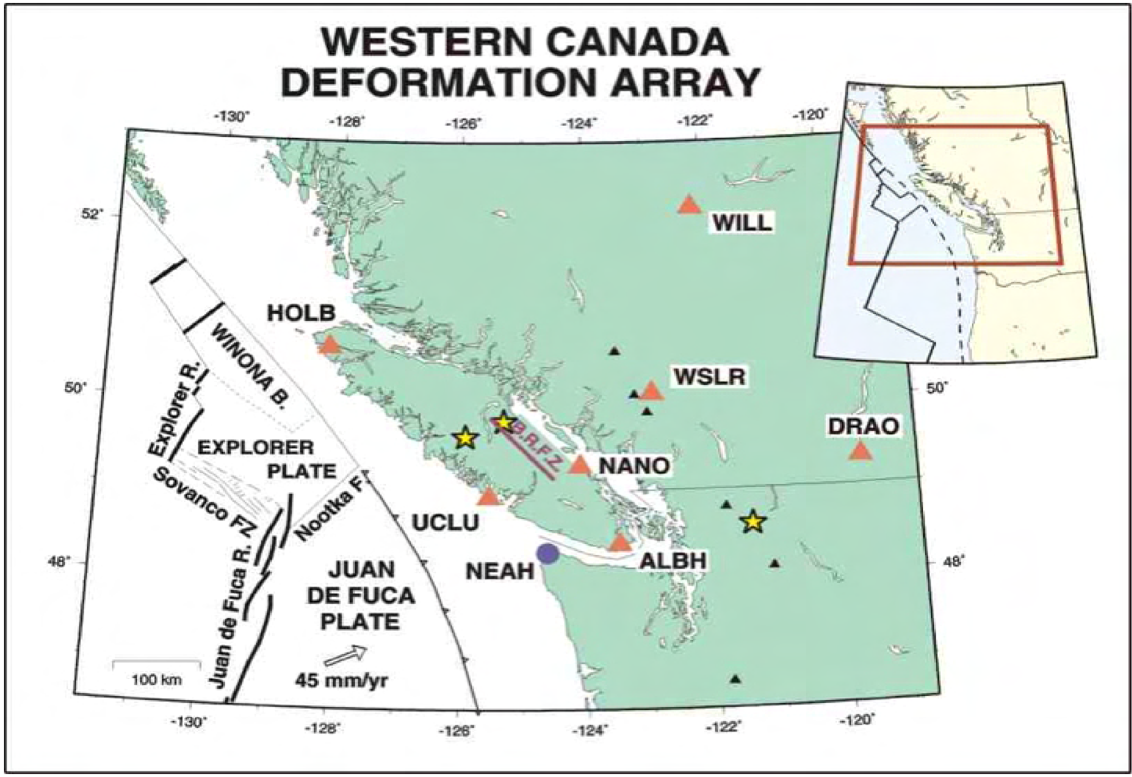
“*Shift Happens*”

Earthquakes

Stable slip (creep)

...We all have our faults...





InSAR and Crustal Deformation

Interferometric Synthetic Aperture Radar (InSAR)

Introduction

How to read and interpret interferograms

InSAR and GPS

Applications in crustal deformation studies

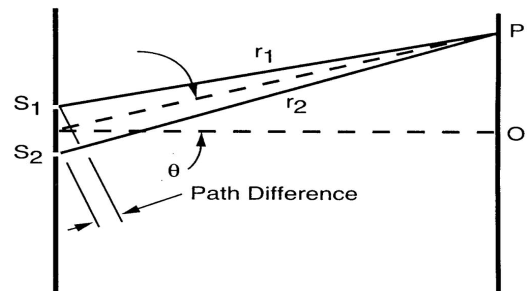
1. Monitoring surface deformation along active faults
2. Seismic hazard analysis

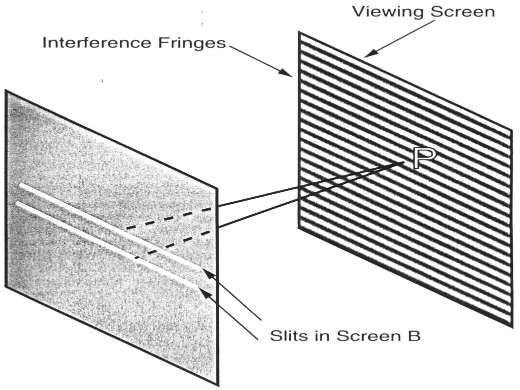
Advanced InSAR methods and applications

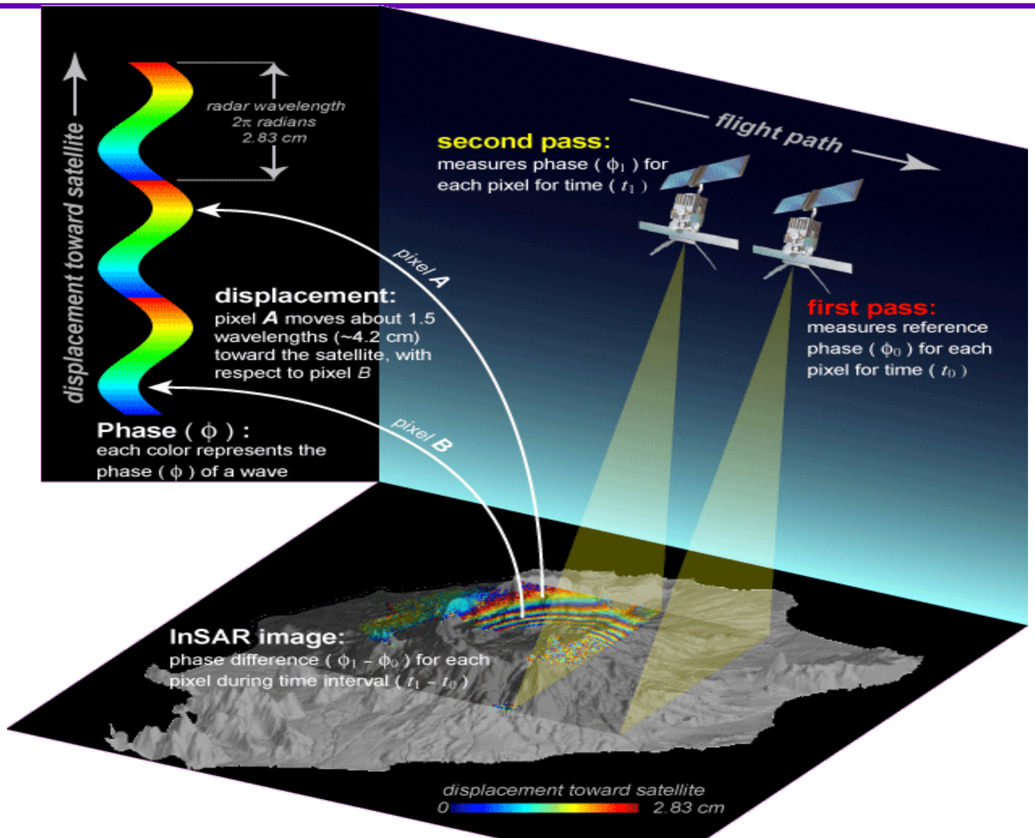
InSAR -

Interferometric Synthetic Aperture Radar

interference:



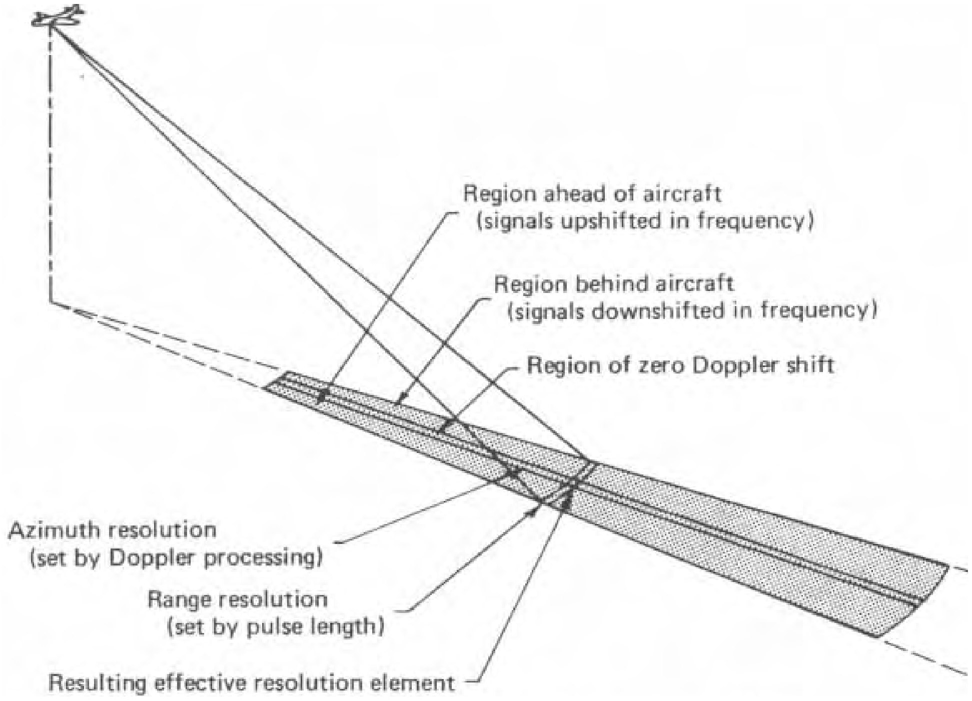


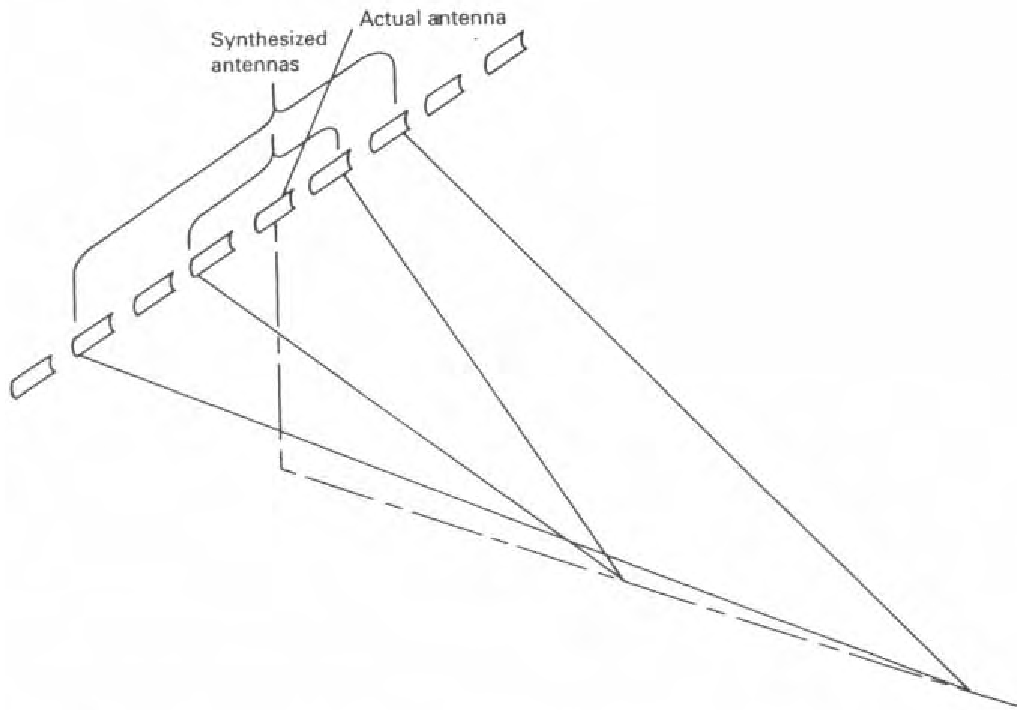


InSAR -
Interferometric Synthetic Aperture Radar

SAR: applying a moving antenna and doppler shift calculations

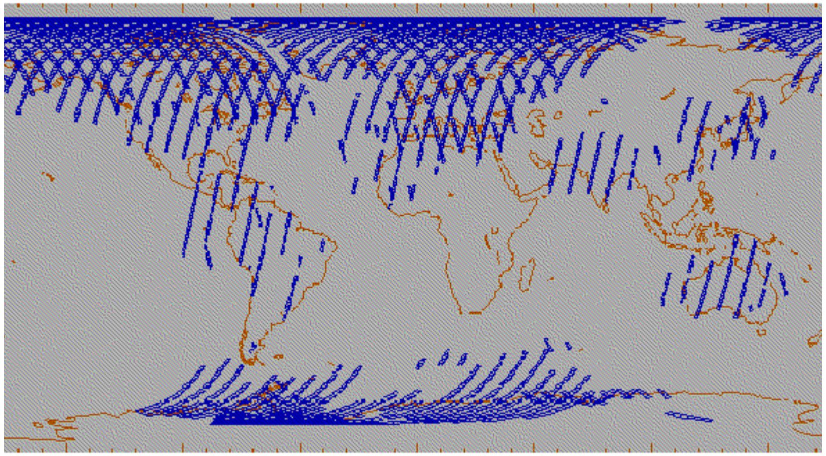
to improve spatial resolution





InSAR -
Interferometric Synthetic Aperture Radar

ESA satellites ERS 1,2:



Height: 800 km

Near polar orbits (ascend/descend)

Repeat interval ~35 days

InSAR -

Interferometric Synthetic Aperture Radar

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Height: 800 km

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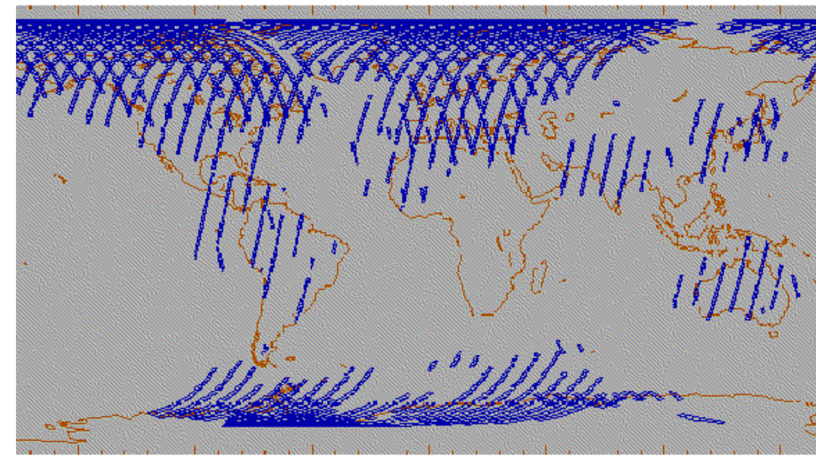
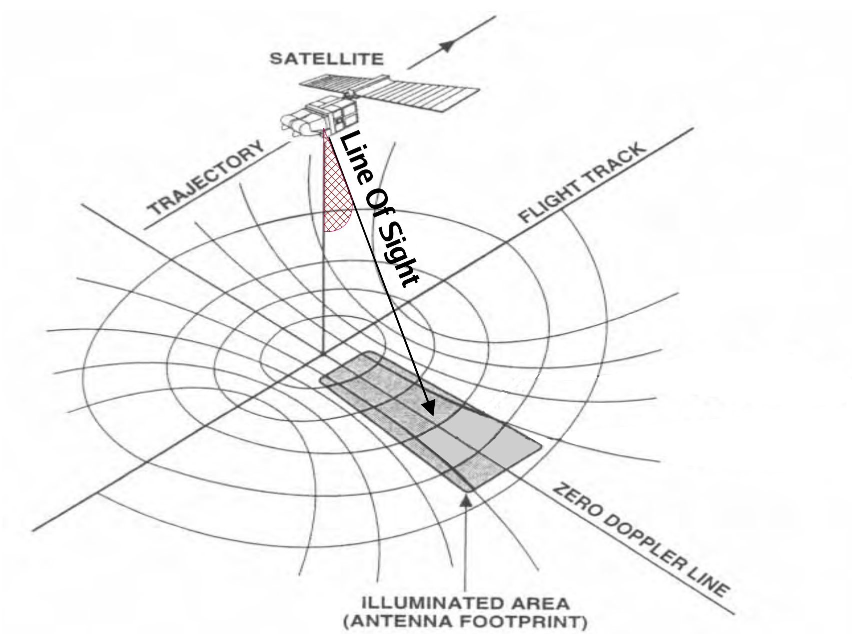




Flat earth

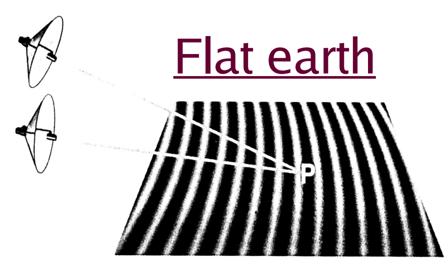


Figure 1.13 Two radar antennas producing interference patterns on the ground.

Topography

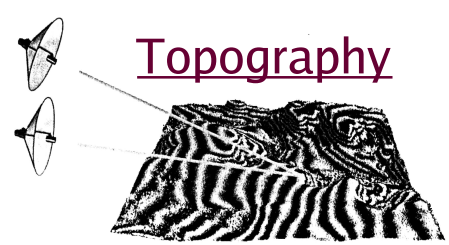
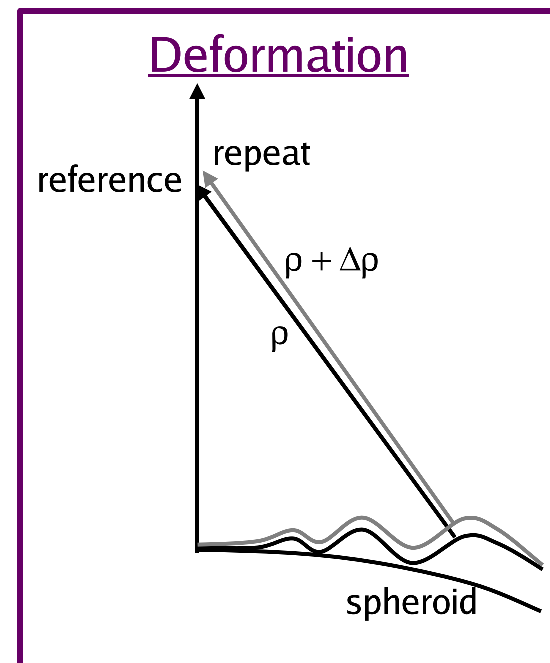
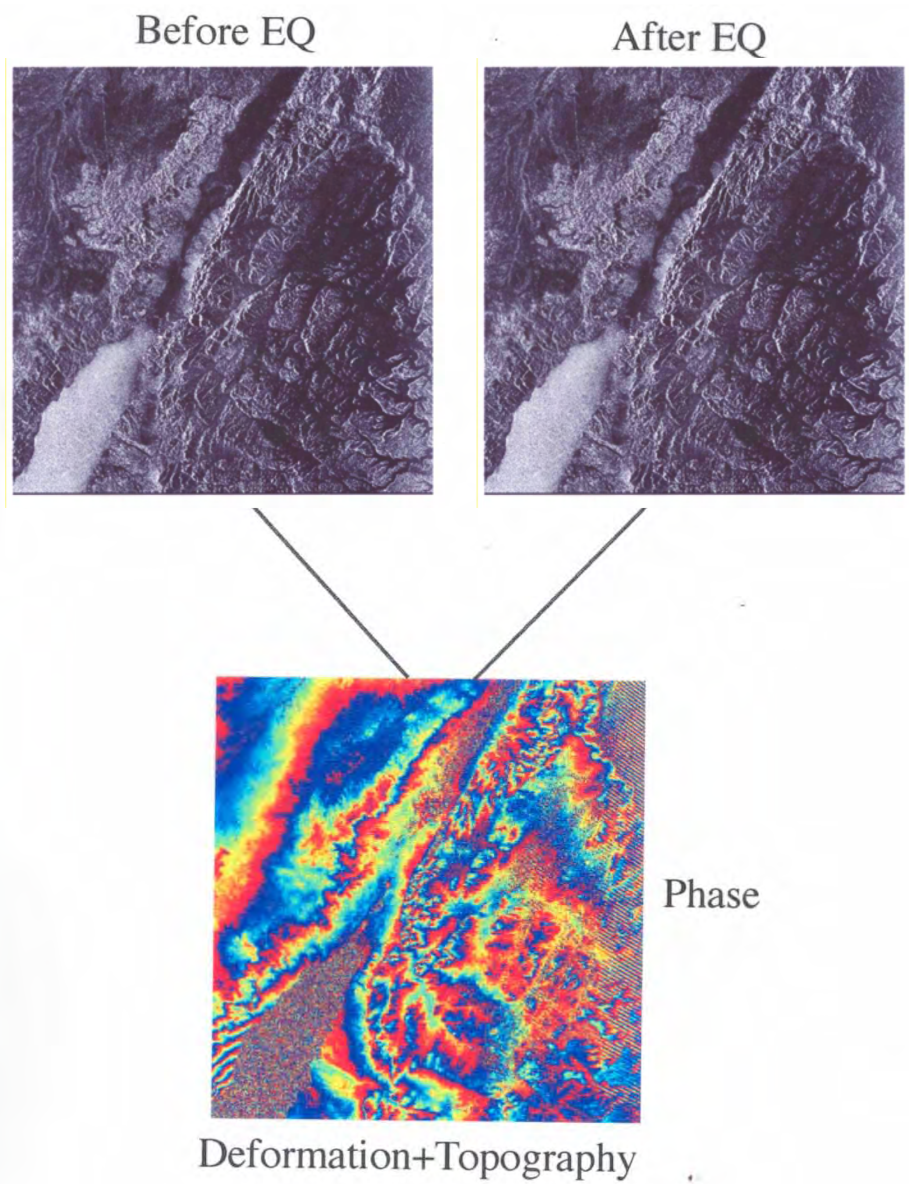


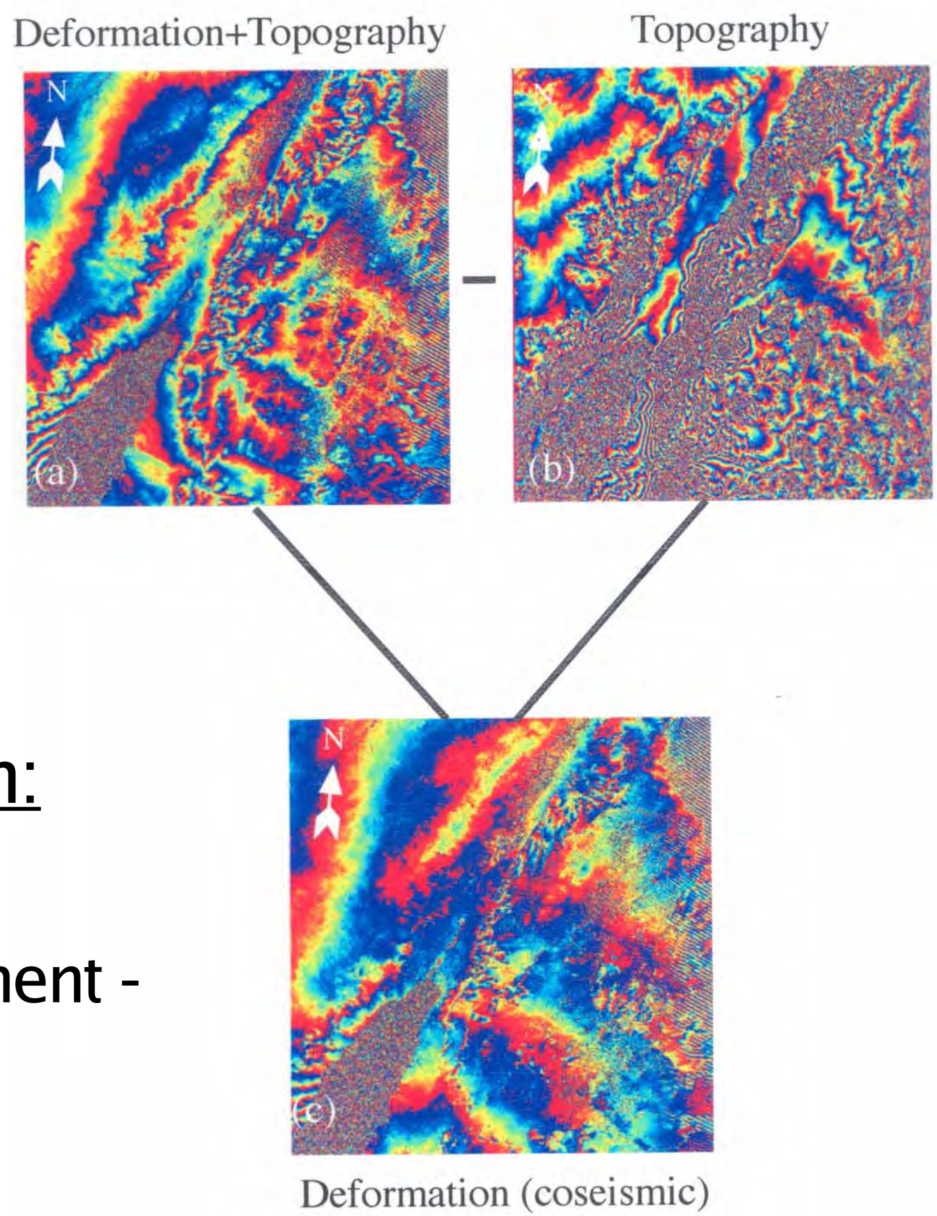
Figure 1.15 Typical interference pattern due to undulating terrain.



Making a Topographic + Deformation Interferogram



Remove topography, make a coseismic interferogram

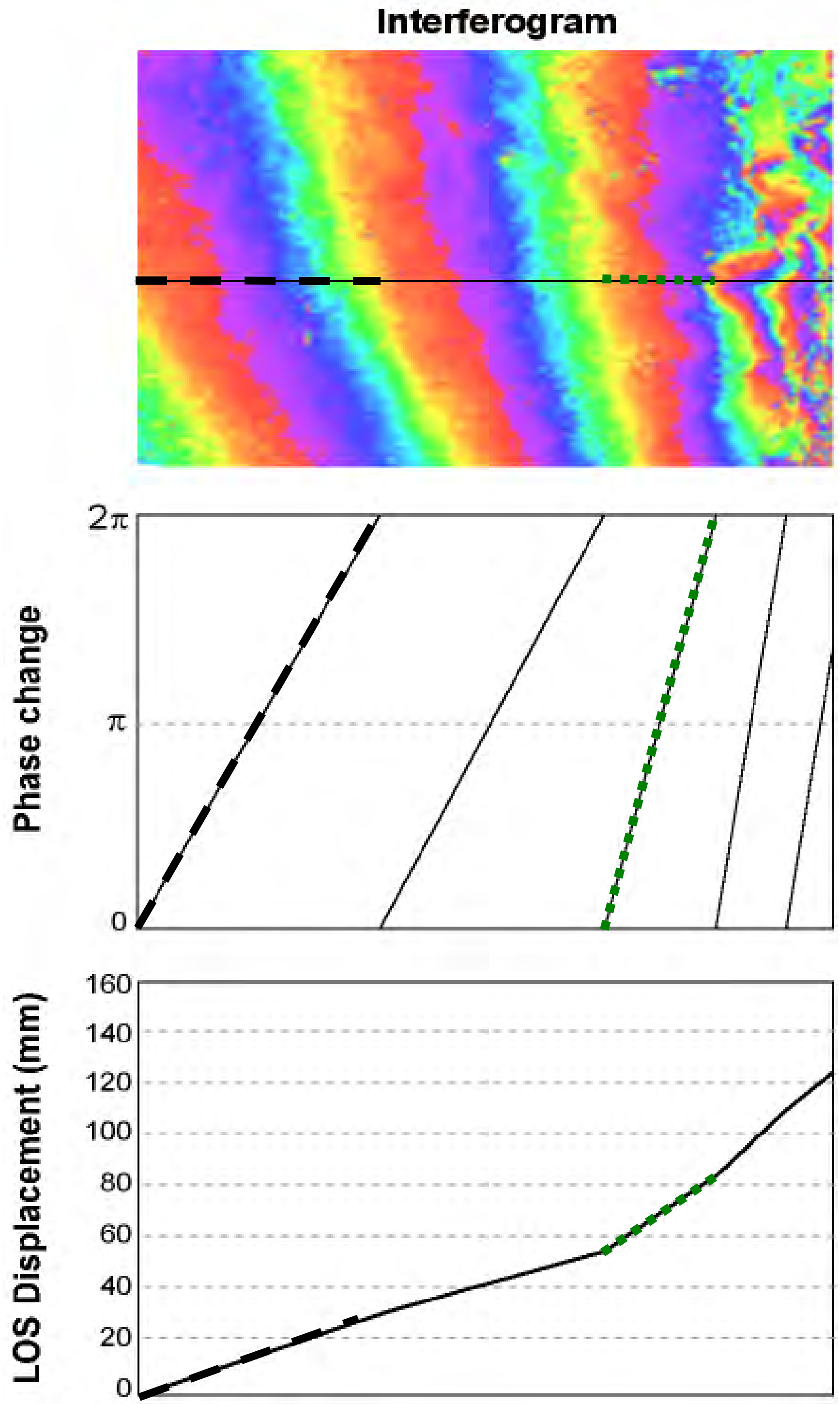


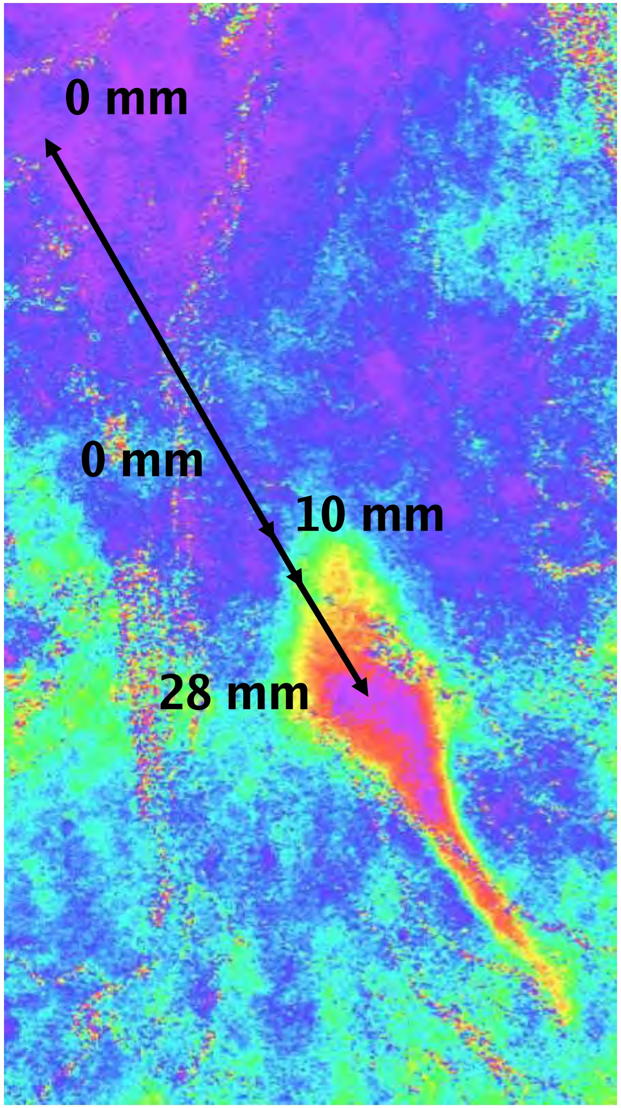
<u>interferogram:</u>

LOS Displacement -

contour map

Reading and Interpreting Interferograms

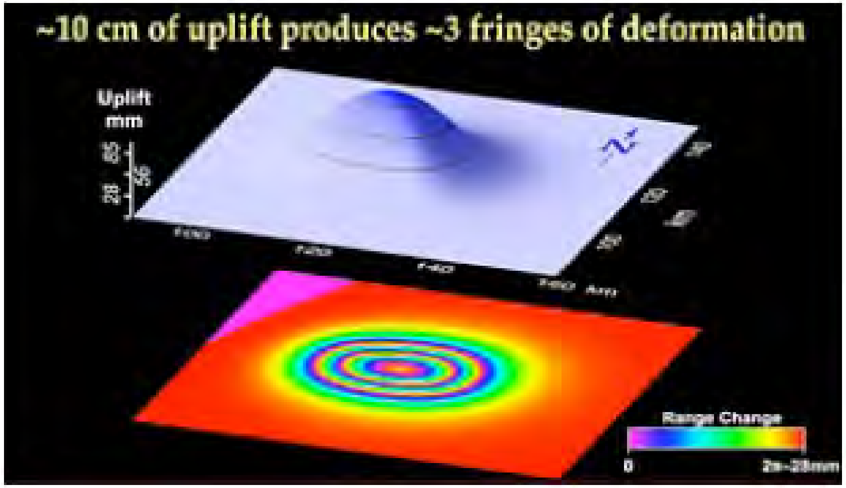


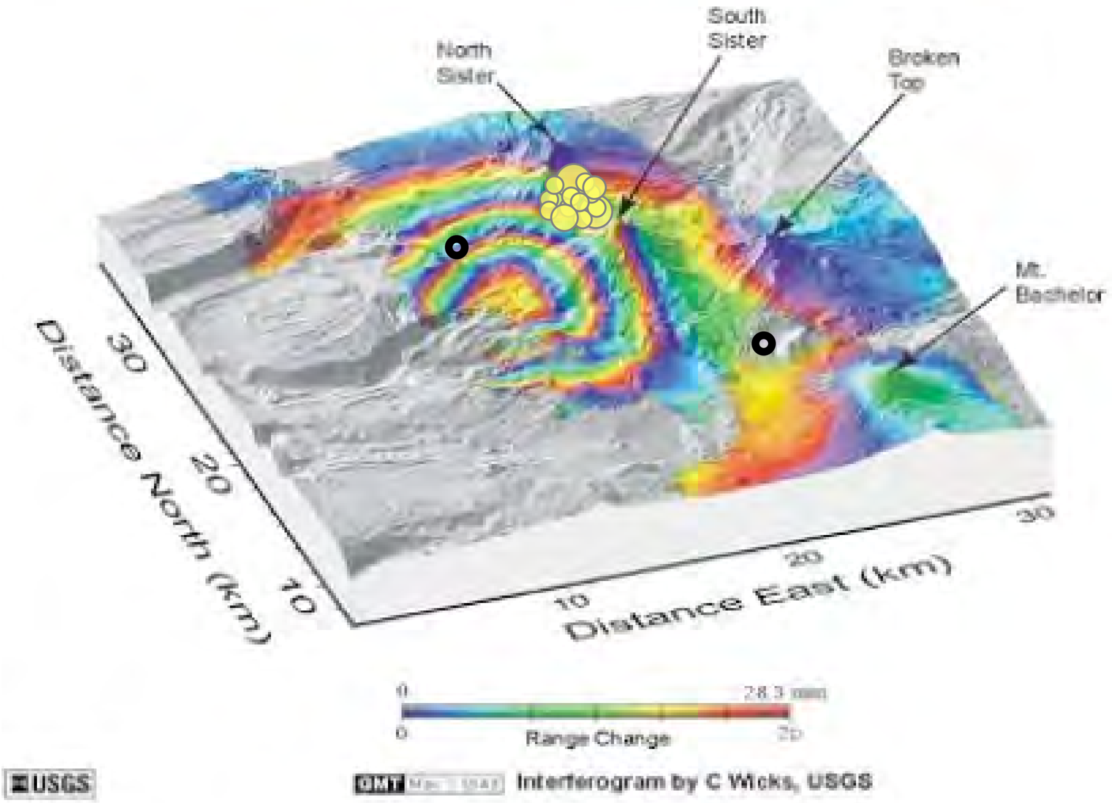


InSAR Disadvantage:

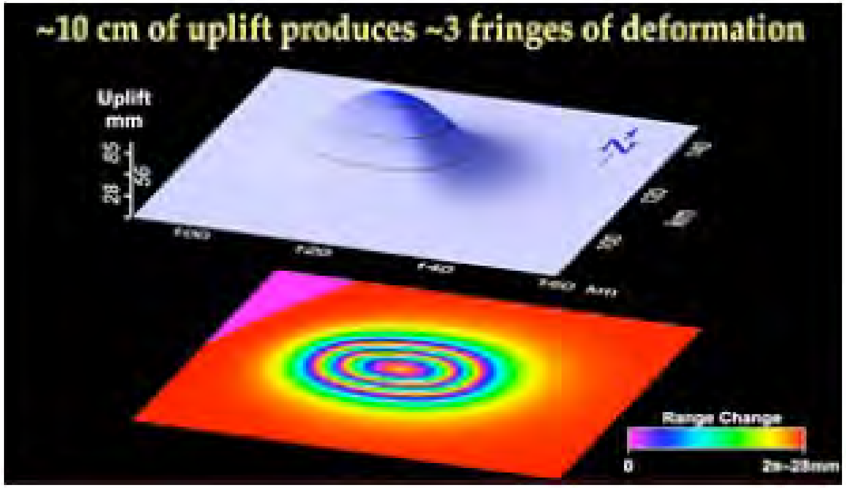
<u>1D measurement</u>

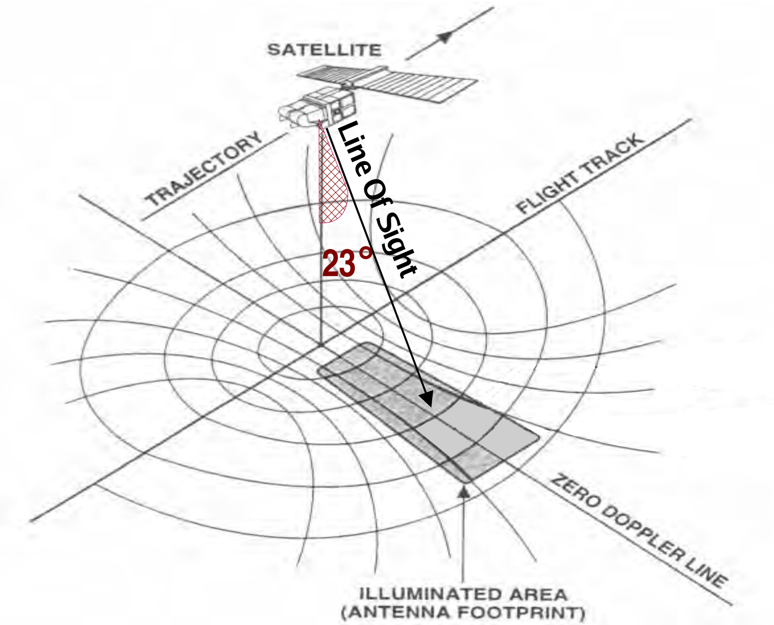
Reading and Interpreting Interferograms

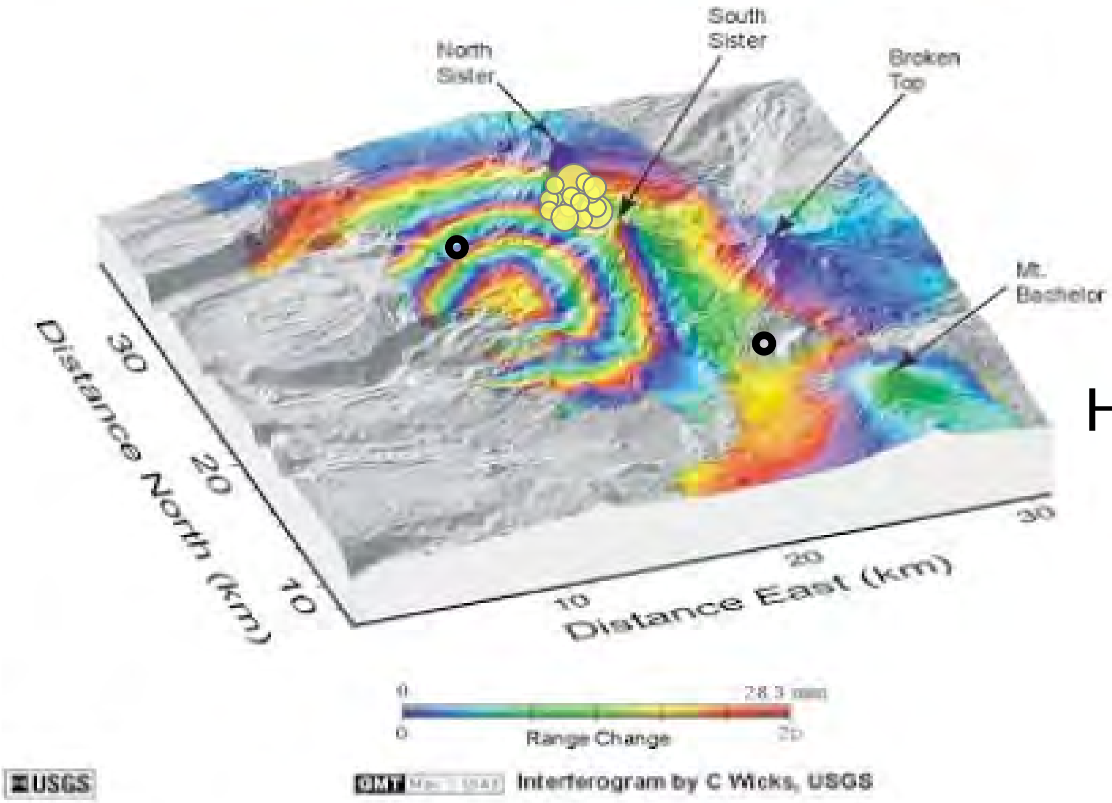




Reading and Interpreting Interferograms







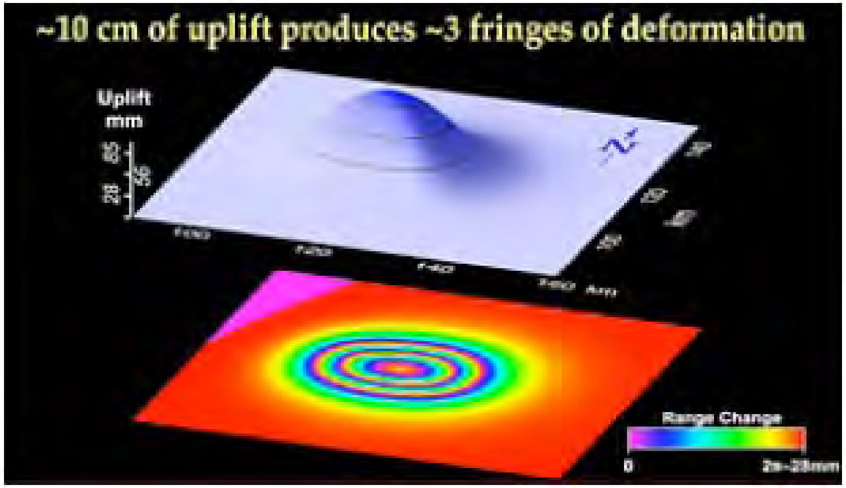
Question:

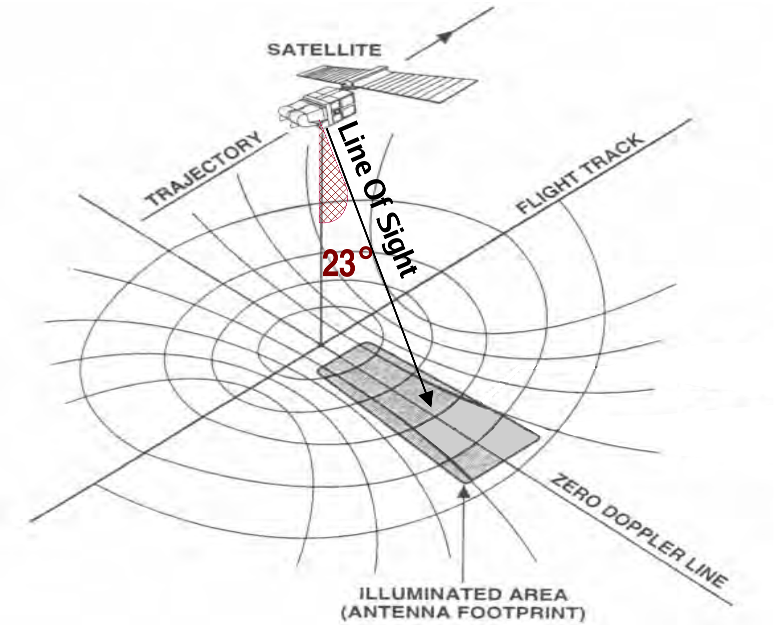
How do 3 fringes correlate to 10 cm of uplift ???

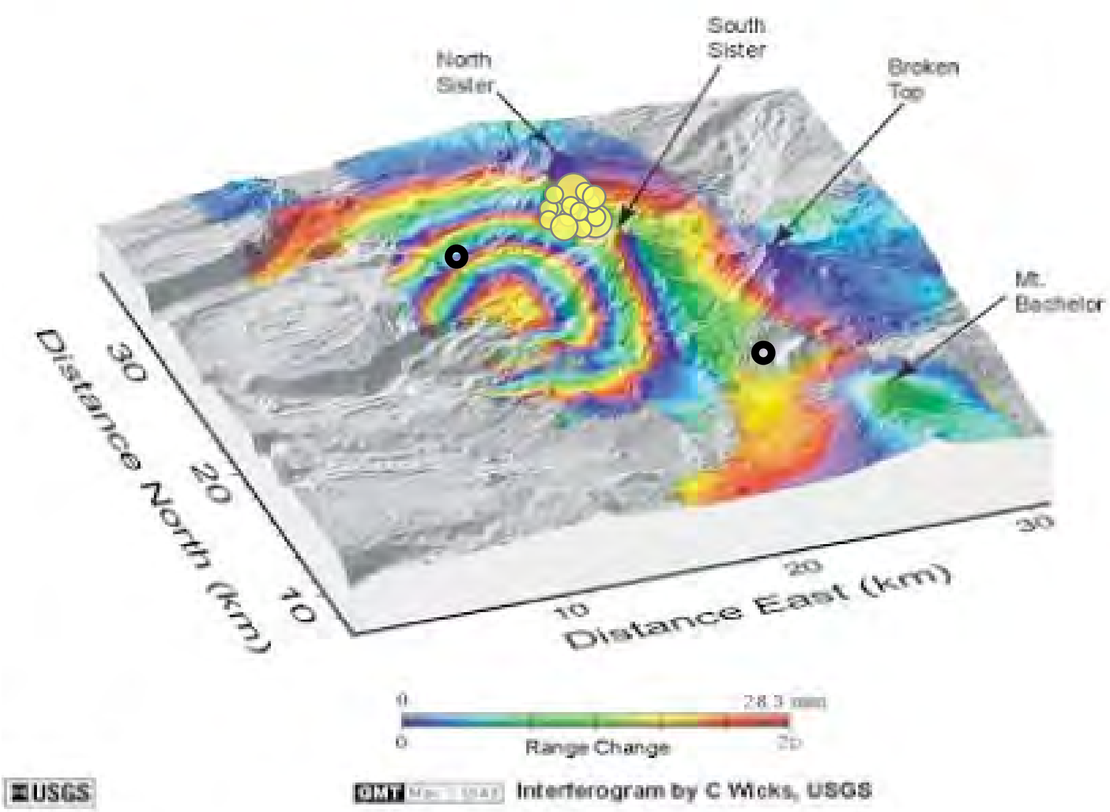
(hint: 1 fringe = 2.8cm of range change in the line of sight...

*and 3*2.83 is only ~8.5 cm)*

Reading and Interpreting Interferograms







Assumption:

Pure- vertical deformation !!!

How could we verify?

Ascending + descending interf.

GPS

InSAR -
Interferometric Synthetic Aperture Radar

pros:

Spatial Resolution (4x20m)

Accuracy (mm-cm scale)

Spatial coverage

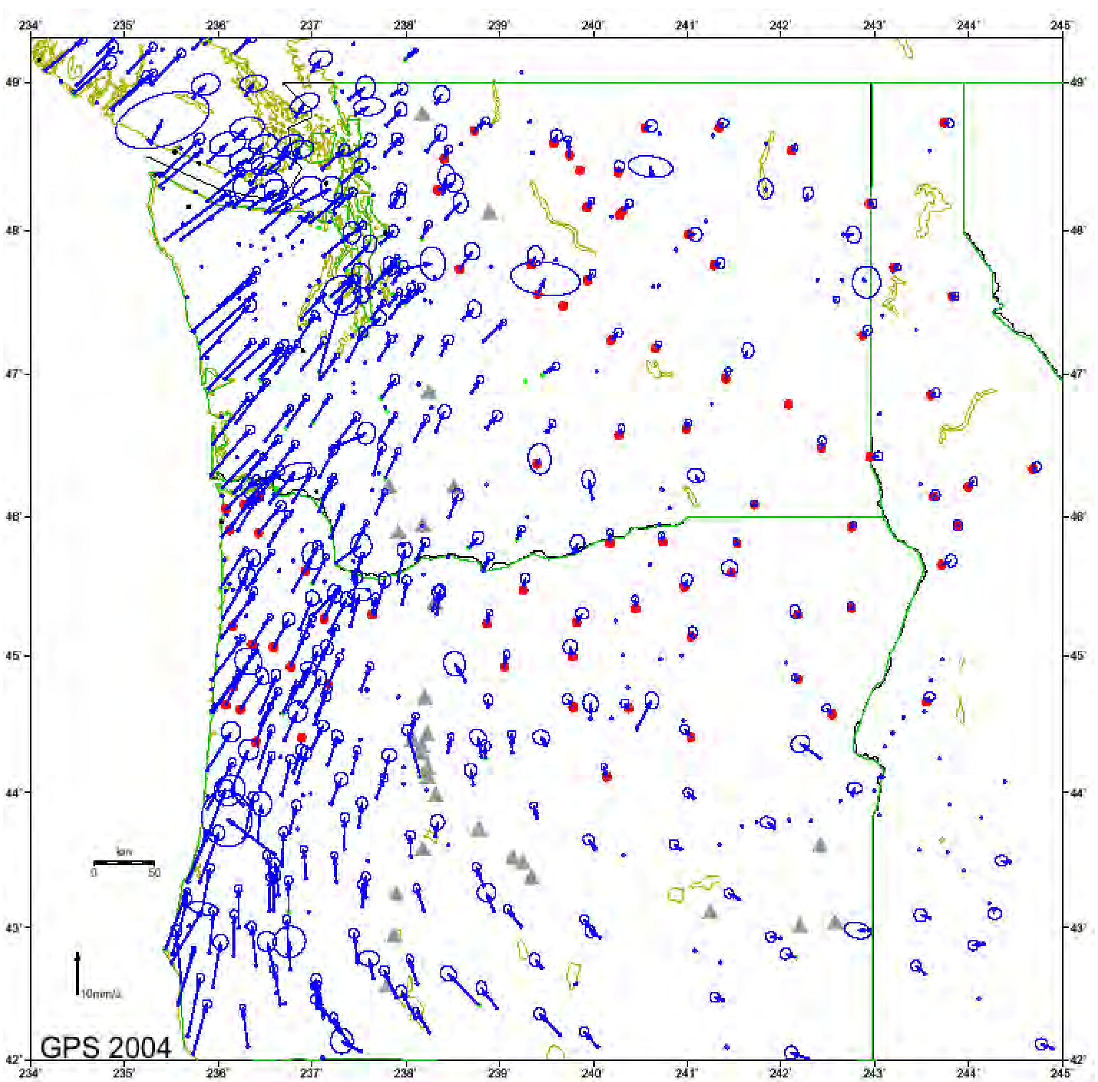
cons:

LOS ambiguity (1D measurement)

Decorrelation (slopes, vegetation, unstable ground, large deformation gradients, etc)

Low sensitivity to horizontal displacement parallel to trajectory

GPS:



McCaffrey et al., 2004

- GPS is typically more precise
- Measures 3 components (3D)

- Vertical GPS data less precise
- Sparse point measurements
- Expensive / labor intensive

InSAR & GPS complement each over

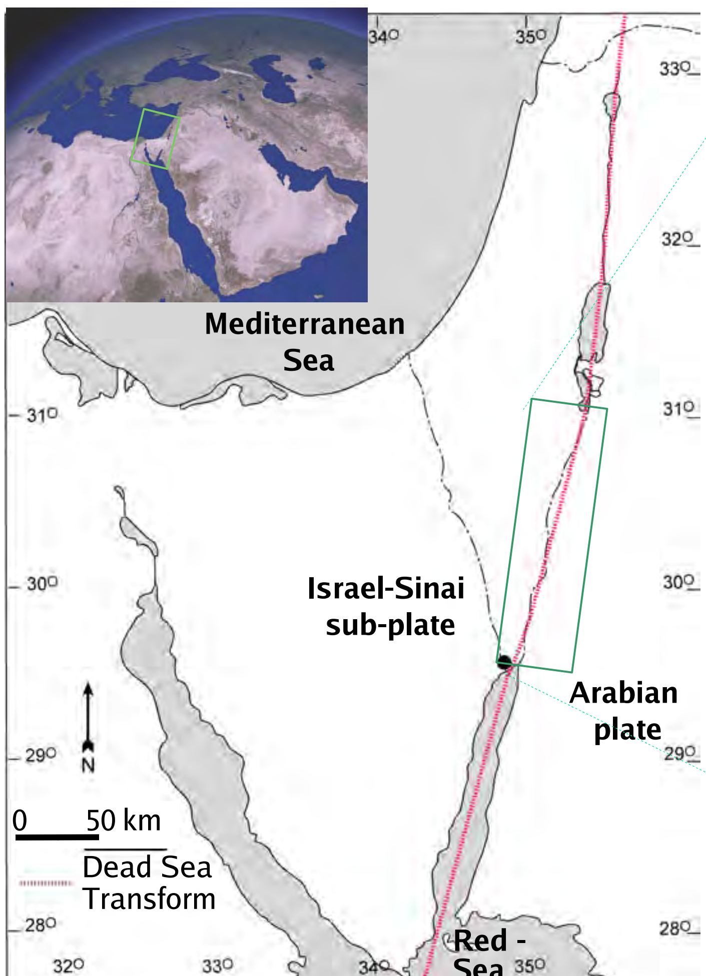
Applications in crustal deformation studies:

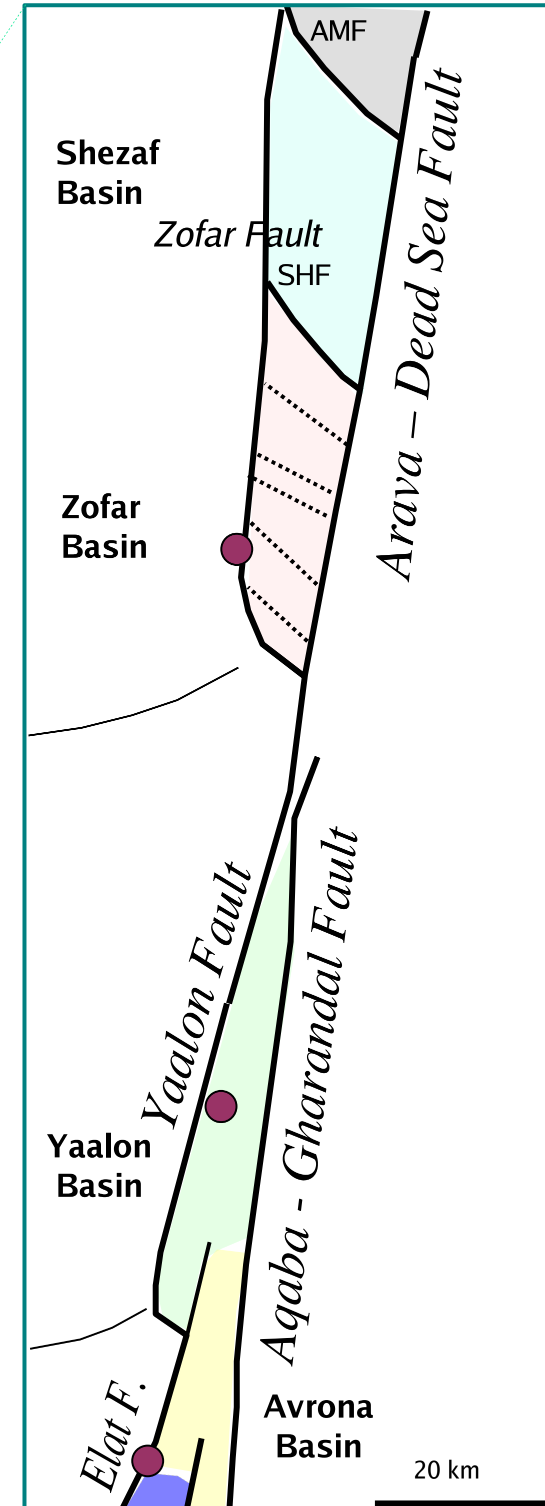
1. Monitoring Surface deformation

2. Seismic hazard analysis

Motivation:

- Apparent seismic gap along the Arava section of the Dead Sea Transform

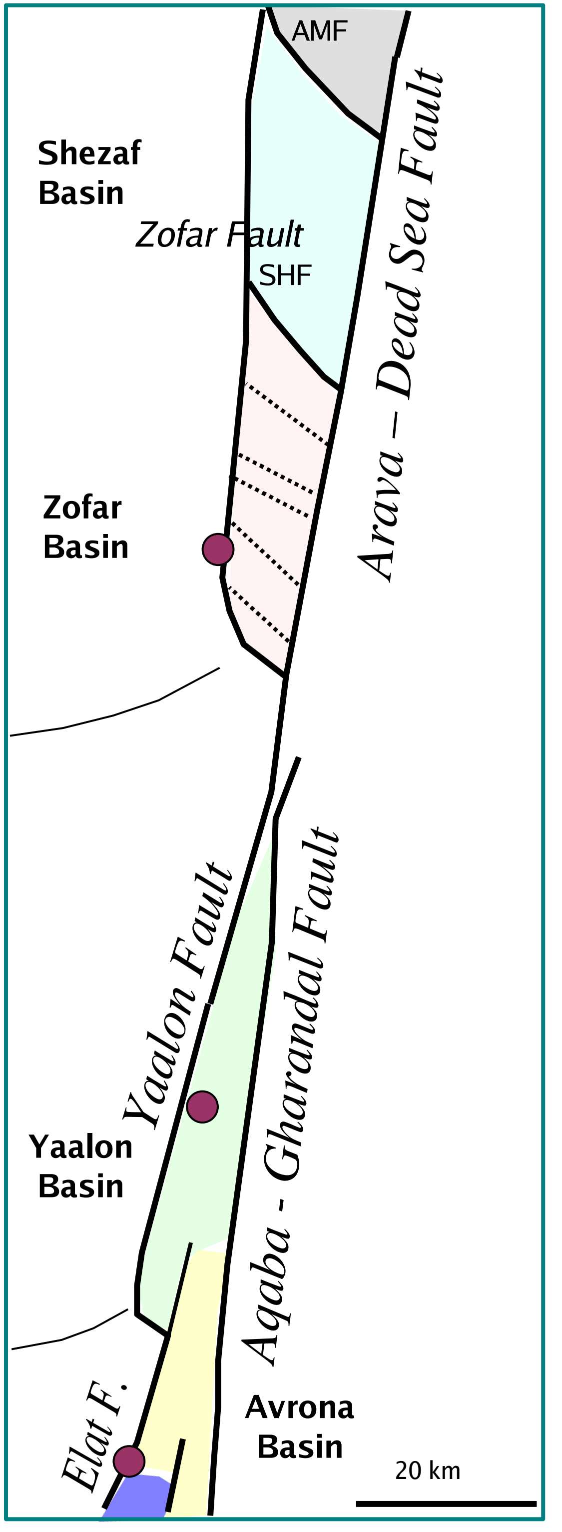




Motivation:

- Apparent seismic gap along the Arava section of the Dead Sea Transform

- Lack of geodetic and seismic record of processes within the Arava



Motivation:

- Apparent seismic gap along the Arava section of the Dead Sea Transform

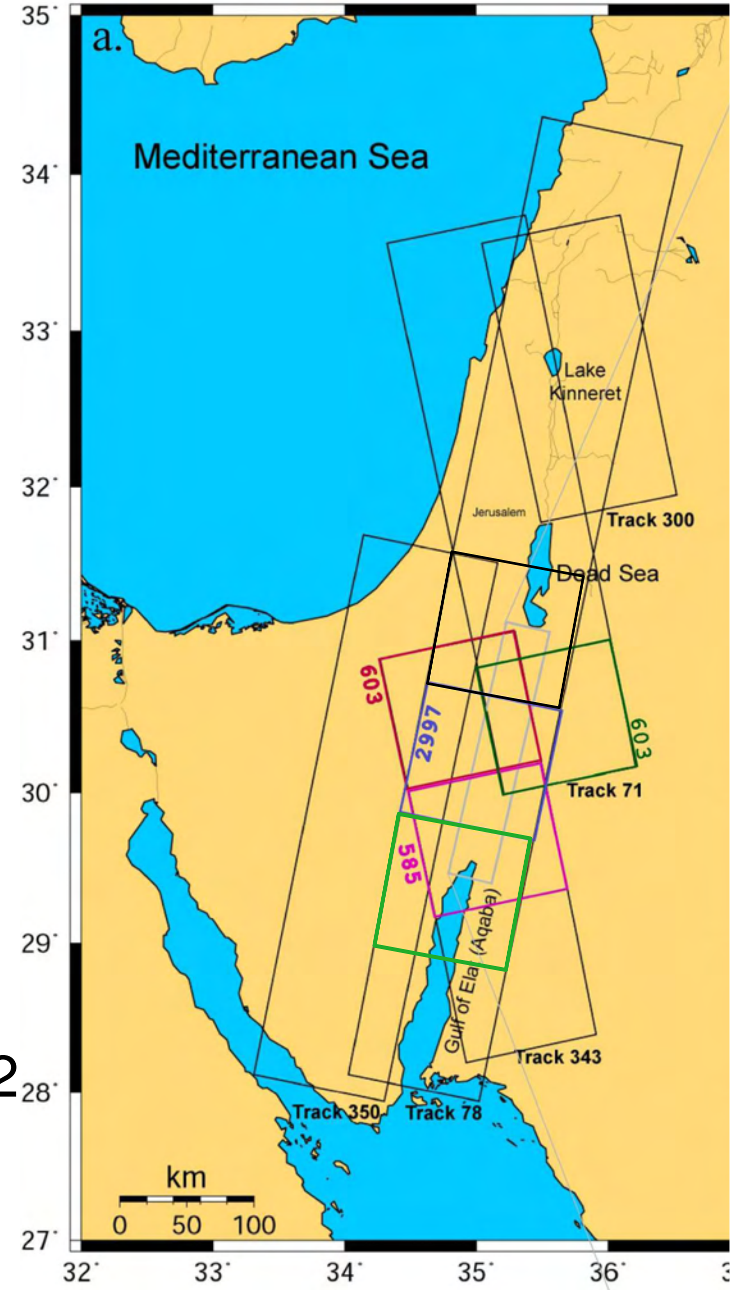
- Lack of geodetic and seismic record of processes within the Arava

Objectives:

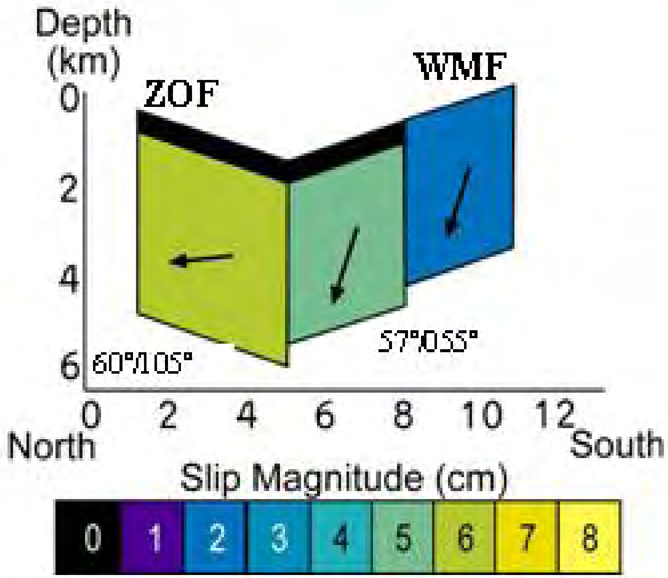
Measure current surface deformation

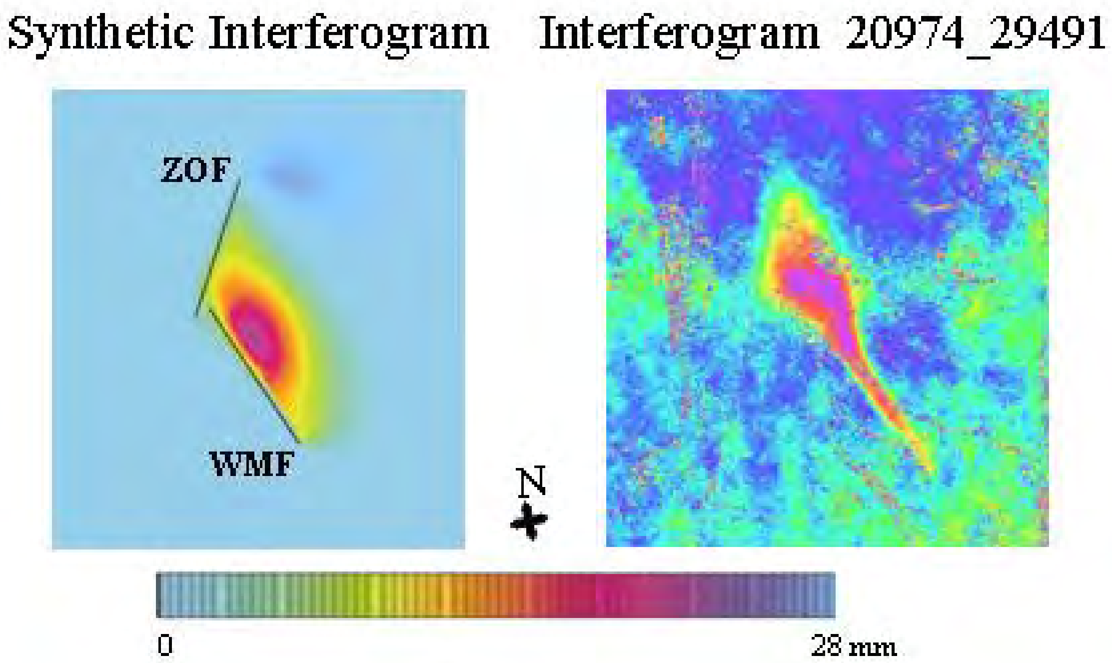
(~ 100 interferograms of 6 frames, 3/1995 - 11/2002)

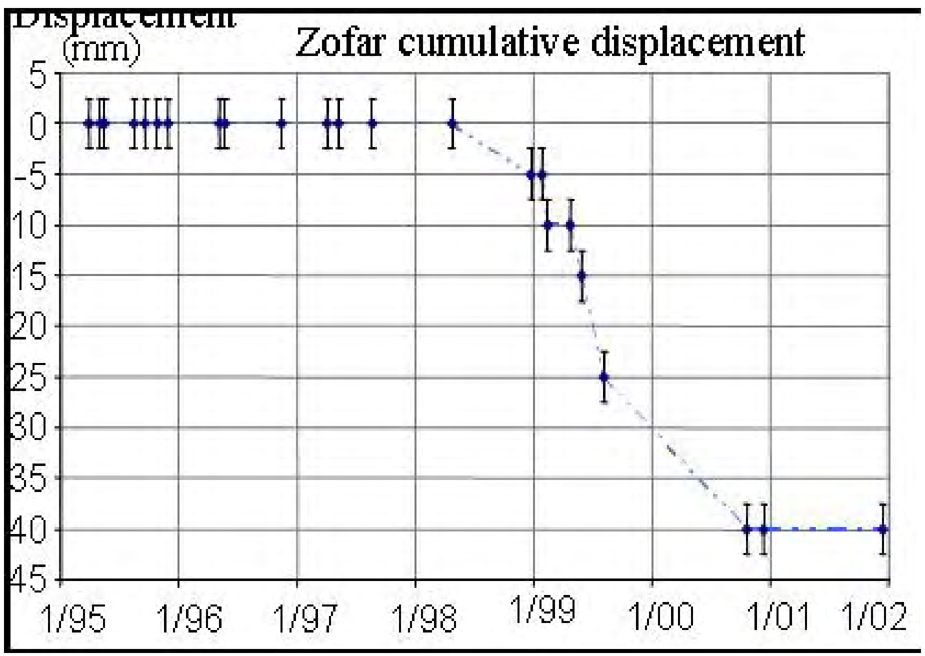
Analyze tectonic activity along the Arava



Results: Zofar Creep







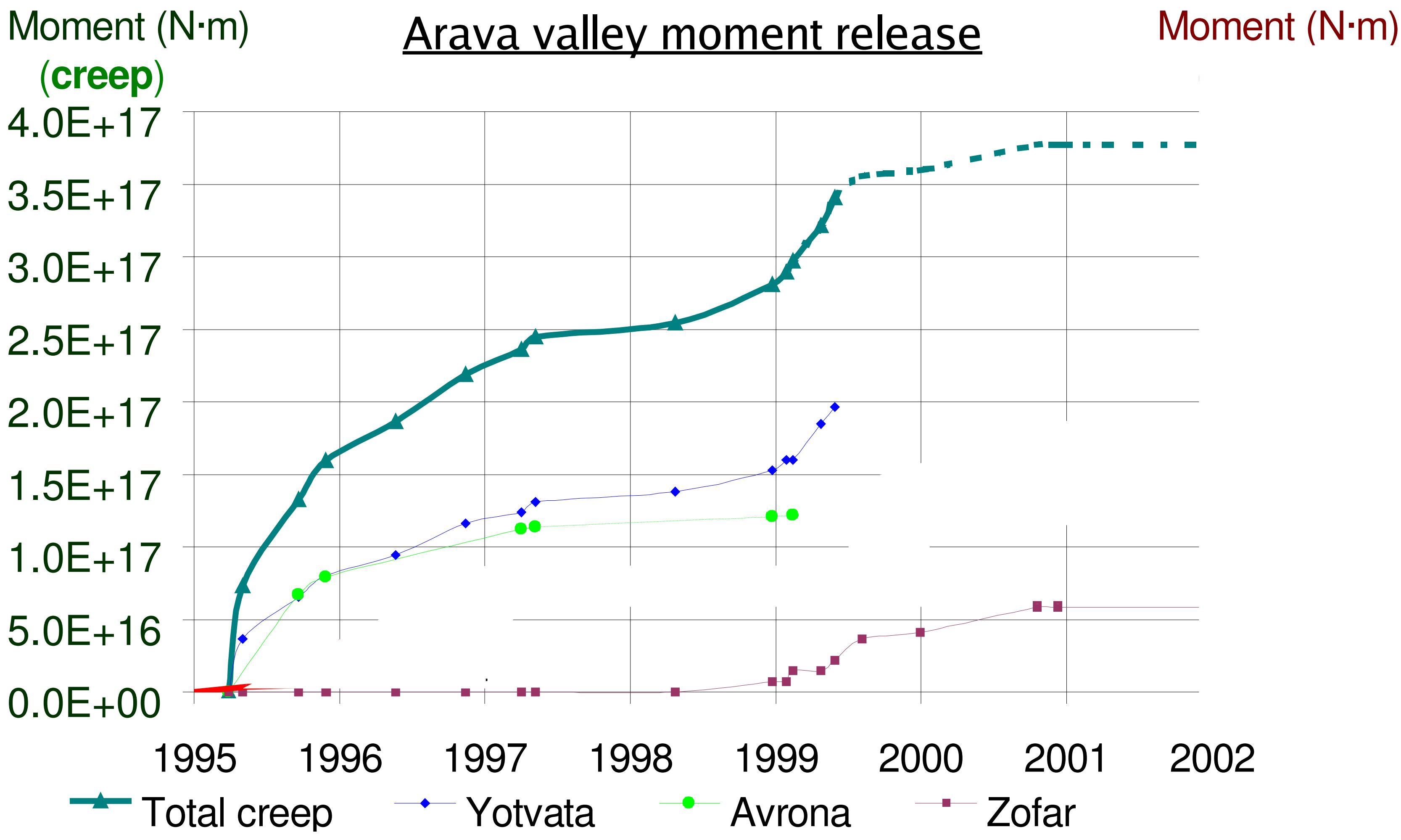
Zofar stable creep episode:

Moment release $5.9*10^{16}$ N*m

Equivalent Magnitude 5.2 (4.8 - 5.5)

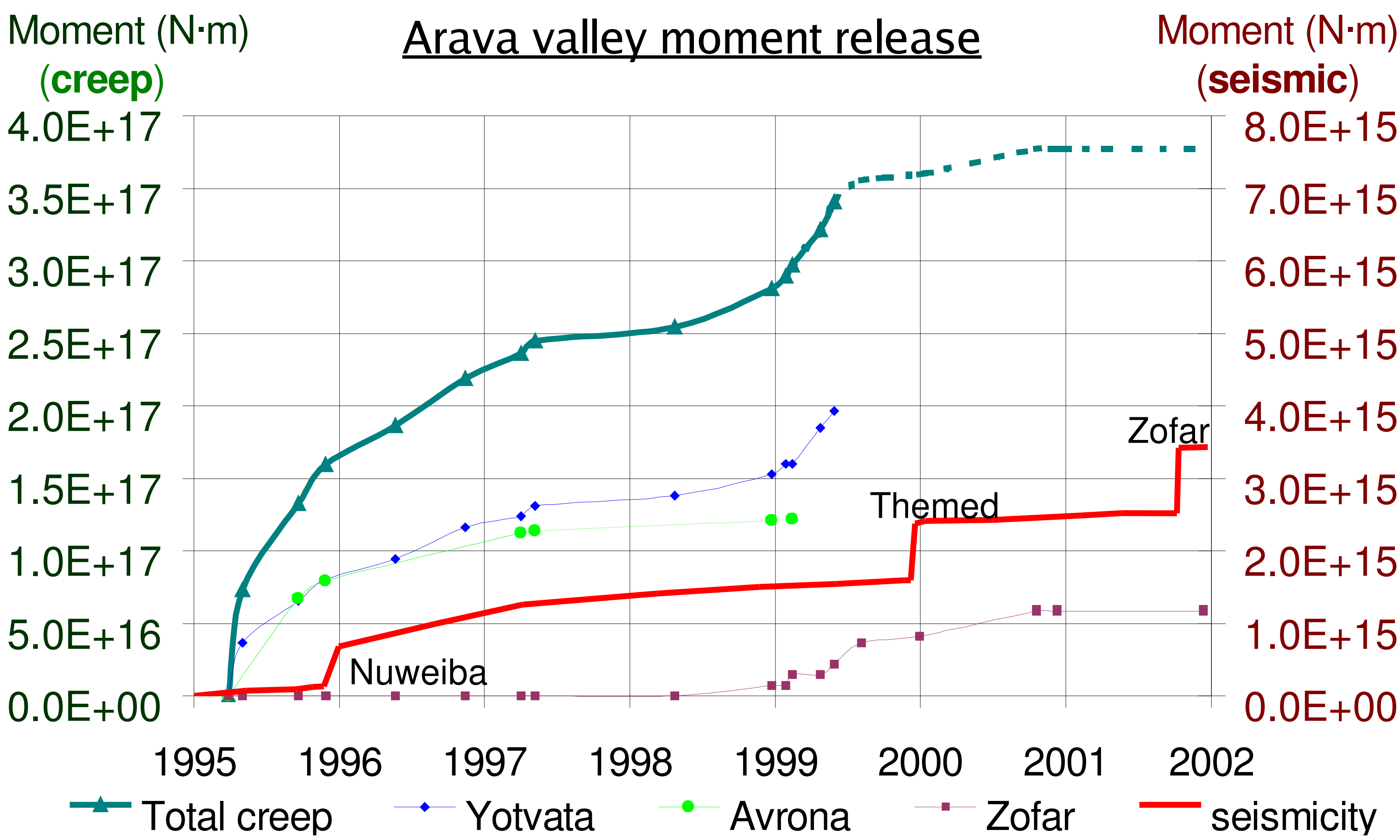
Arava Deformation - Conclusions

- Creep



Arava Deformation - Conclusions

- Creep
- Aseismic efficiency ~ 50%

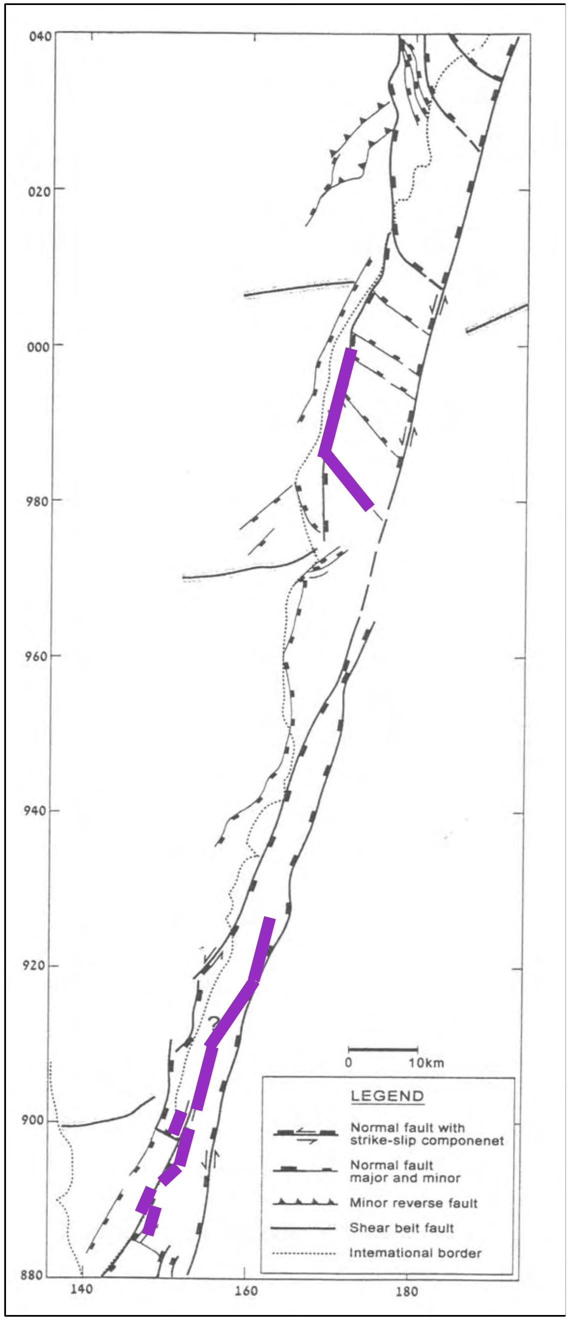


Arava Deformation - Conclusions

- Creep
- Aseismic efficiency ~ 50%
- Interseismic deformation at Arava stepovers

(upper 5-10 km of the crust)

Arava fault map from Frieslander, 2000

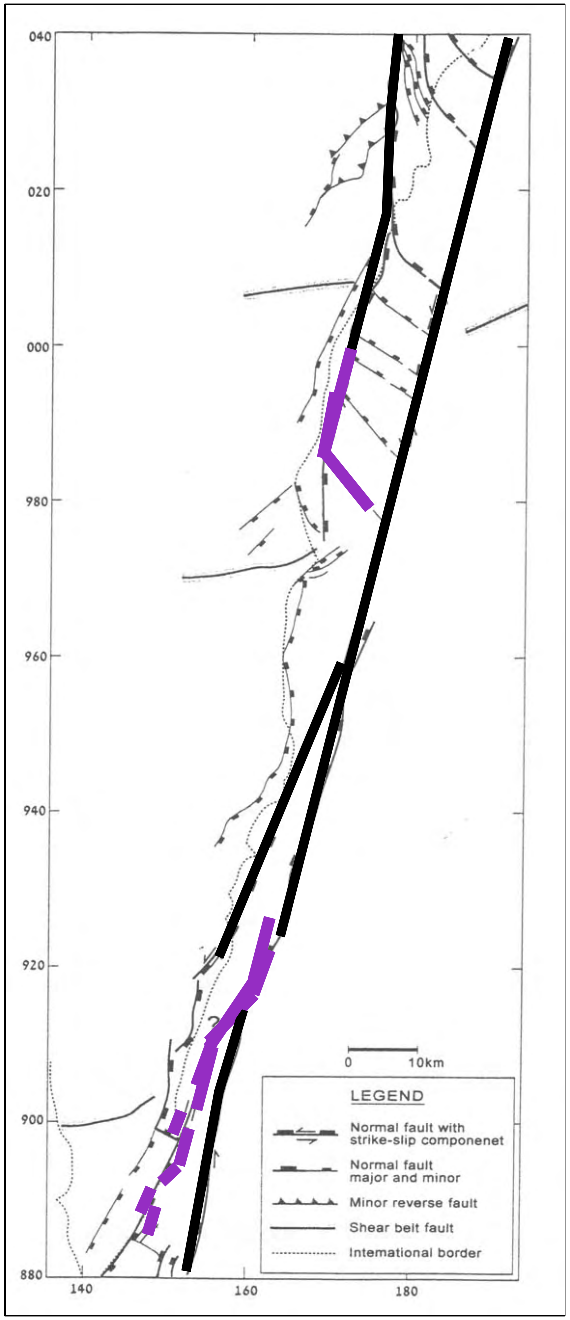


Arava Deformation - Conclusions

- Creep
- Aseismic efficiency ~ 50%
- Interseismic deformation at Arava stepovers
- Creep on intervening segments - undetected

(slip rate < 4 mm/yr)

AV map from Frieslander, 2000



Arava Deformation - Conclusions

- Creep
- Aseismic efficiency ~ 50%
- Interseismic deformation at Arava stepovers
- Creep on intervening segments - undetected

Summary

The Arava Valley is undergoing significant aseismic creep

and is therefore not a potential source for large earthquakes

Applications in crustal deformation studies:

1. Monitoring Surface deformation

2. Seismic hazard analysis

Seismic hazard analysis in California:

...Creeping VS. locked and loaded...

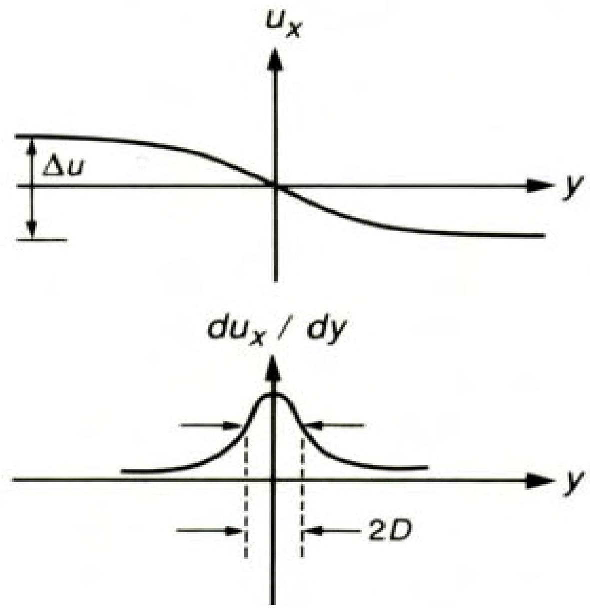
Elastic Rebound theory

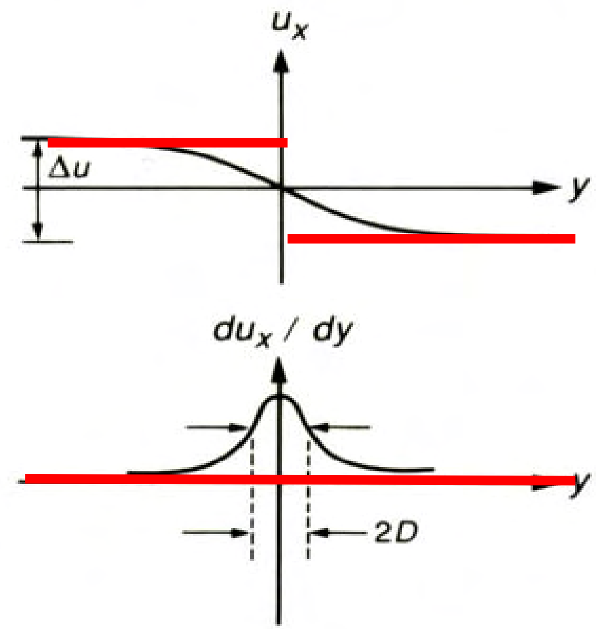
	Locked fault	creeping fault

<u>Interseismic stage:</u>

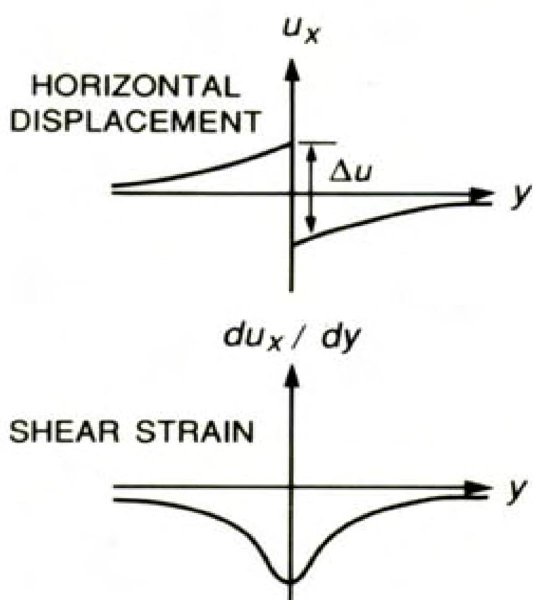
Horizontal displacement

Shear strain





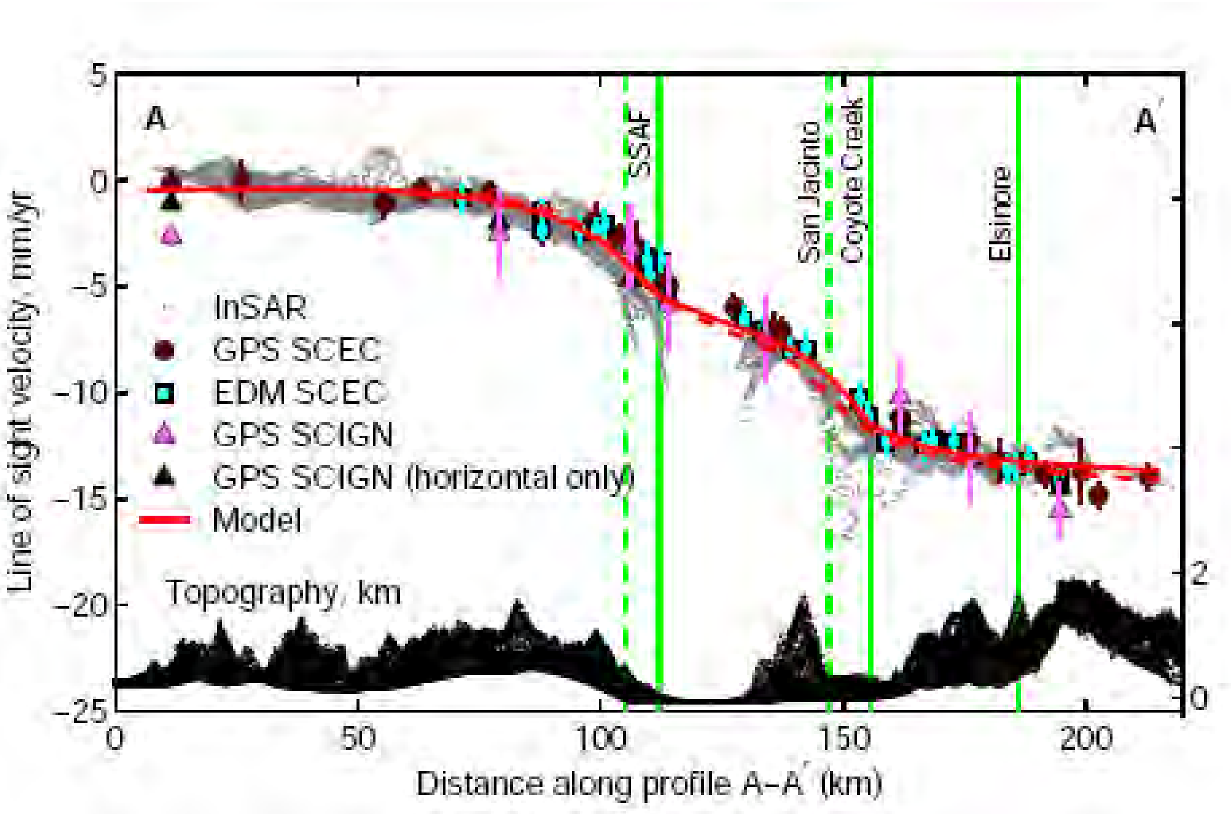
<u>Coseismic stage:</u>

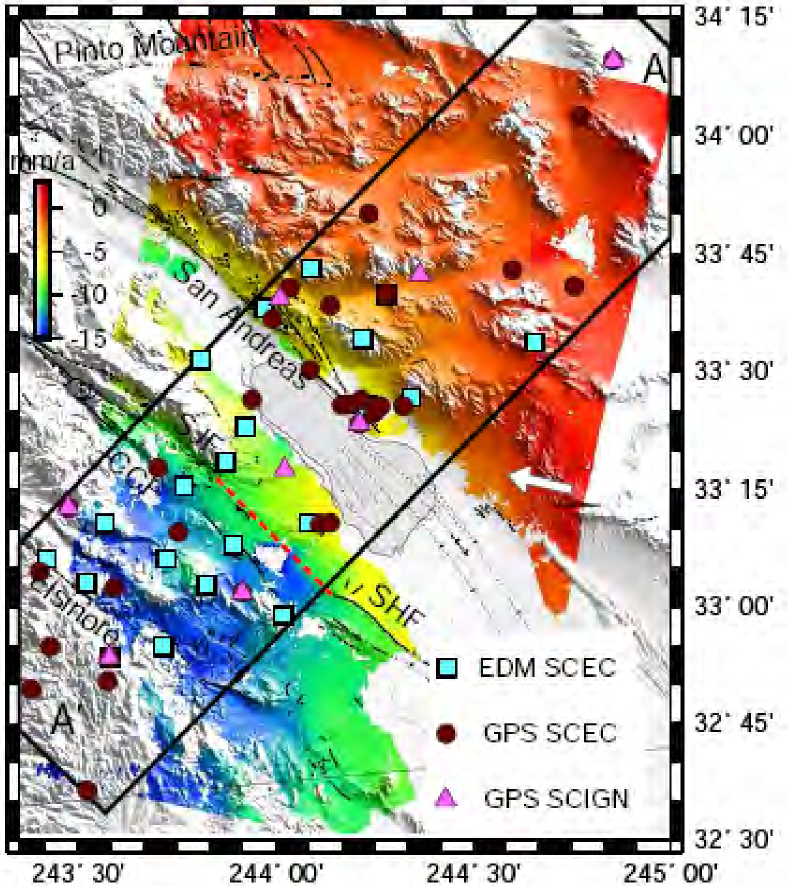


<u>No Coseismic stage!!!</u>

Interseismic strain accumulation and the earthquake potential on the southern San Andreas fault system

Yuri Fialko, Nature, 2006





1. Both the southern SAF and SJF are locked and loaded !

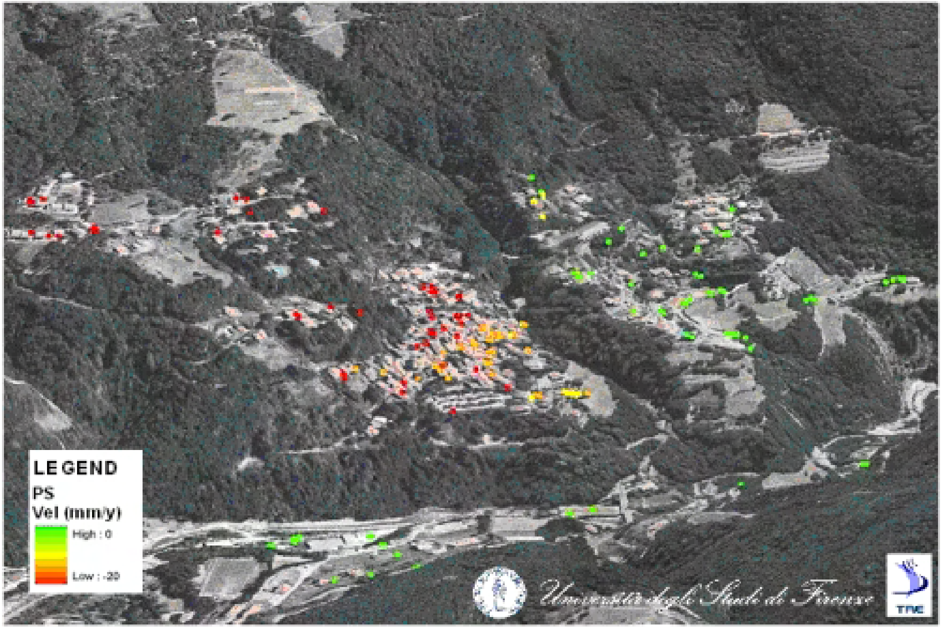
2. The southern SAF is likely in the late phase of its interseismic stage !!!

So the next earthquake will be soon (or big) !!!

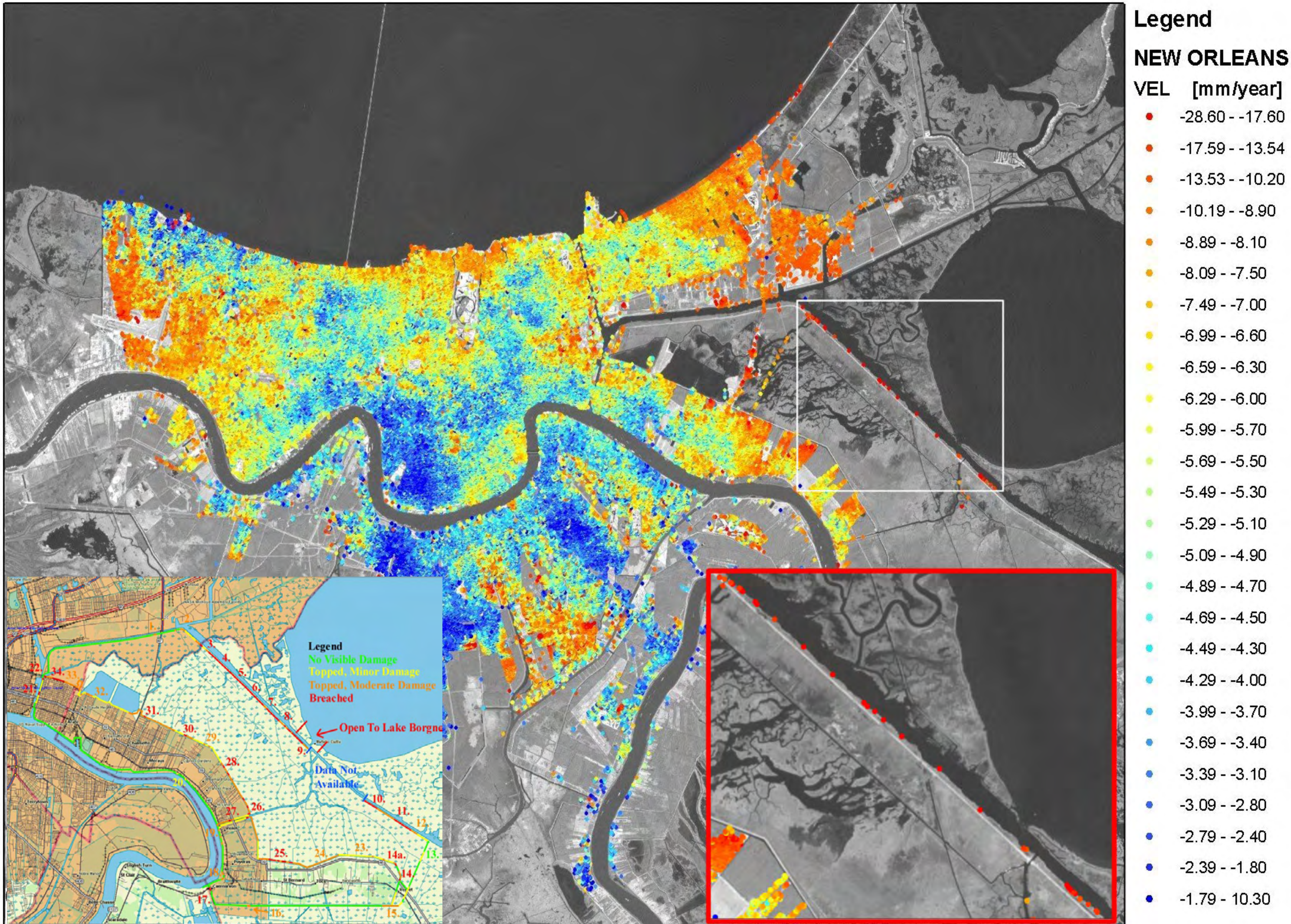
Advanced PSInSAR method and applications:

1. <u>Monitoring buildings and facilities:</u>
Detecting deterioration / instabilities
Real-time alert and on-site validation

2. <u>Slope stability:</u>
Detecting accelerations (instabilities)
Evaluating volume of future slides



Advanced PSInSAR method and applications:



The Future:

Driving Mission Requirements

- **Measurements of surface displacement:**
  - Interseismic strain requires long time series, very high displacement sensitivity
  - Transient and coseismic deformation and disaster response require high resolution and frequent access capability
  - Maintain maximum surface correlation → longer wavelength

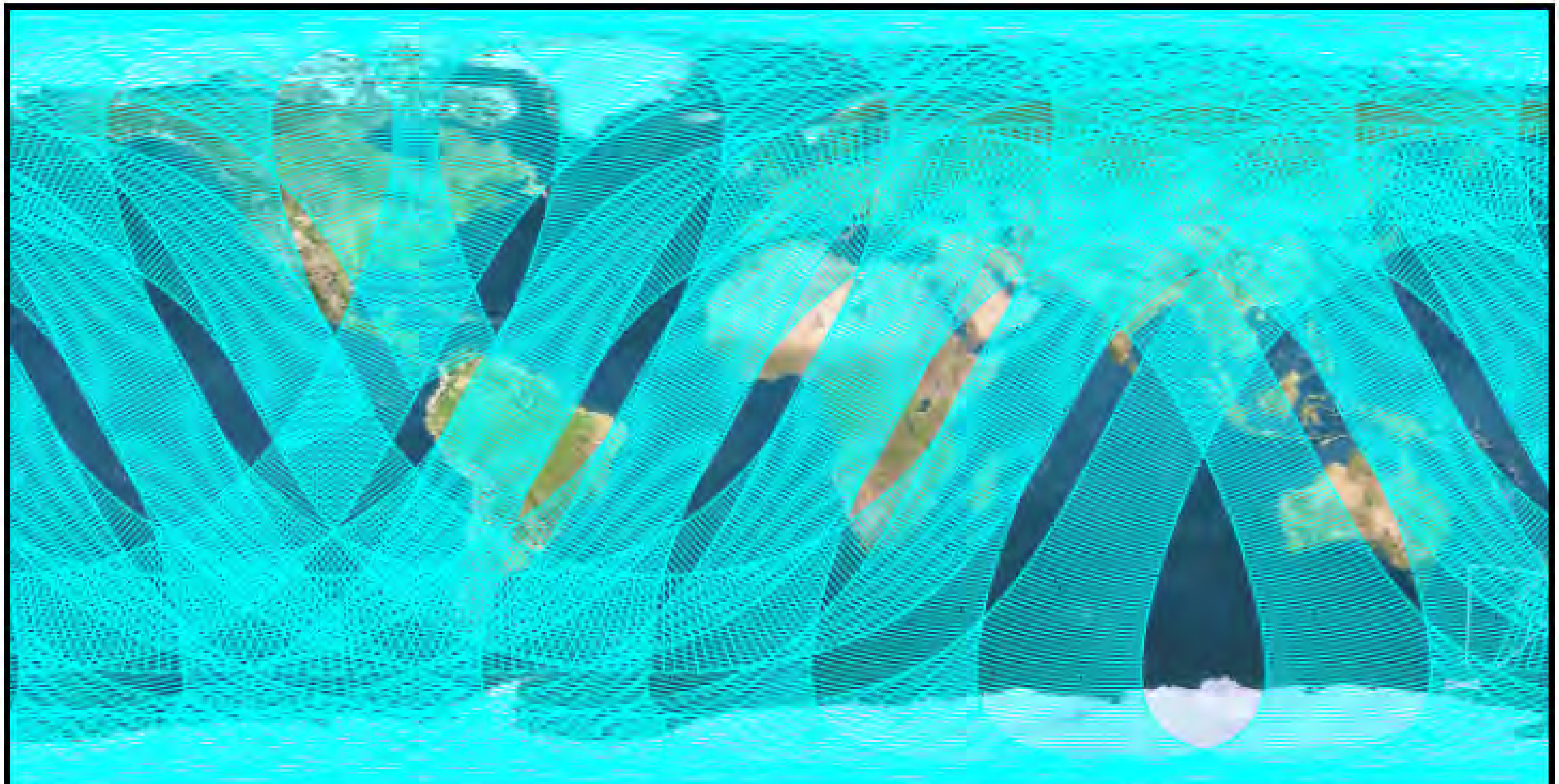
	Minimum	Goal
Displacement accuracy (1–D)	25 mm instantaneous	5 mm instantaneous
3–D displacement accuracy	50 mm (1 week)	10 mm (1 day)
Displacement rate	2 mm/year (over 10 yr)	1 mm/year (over 10 yr)
Repeat period	**8 days**	**1 day**
Daily coverage	6×10^6 km^2	Global (land)
Map region	±60° latitude	Global
Spatial resolution	50–100 m	3–30 m
Geo-location accuracy	25 m	3 m
Swath	100 km	500 km
Data latency in case of event	1 day	Minutes-hrs

The Future:

3000 km MEO Accessibility

Jet Propulsion Laboratory
California Institute of Technology

Nearly 90% of Earth surface accessible within 12 hours



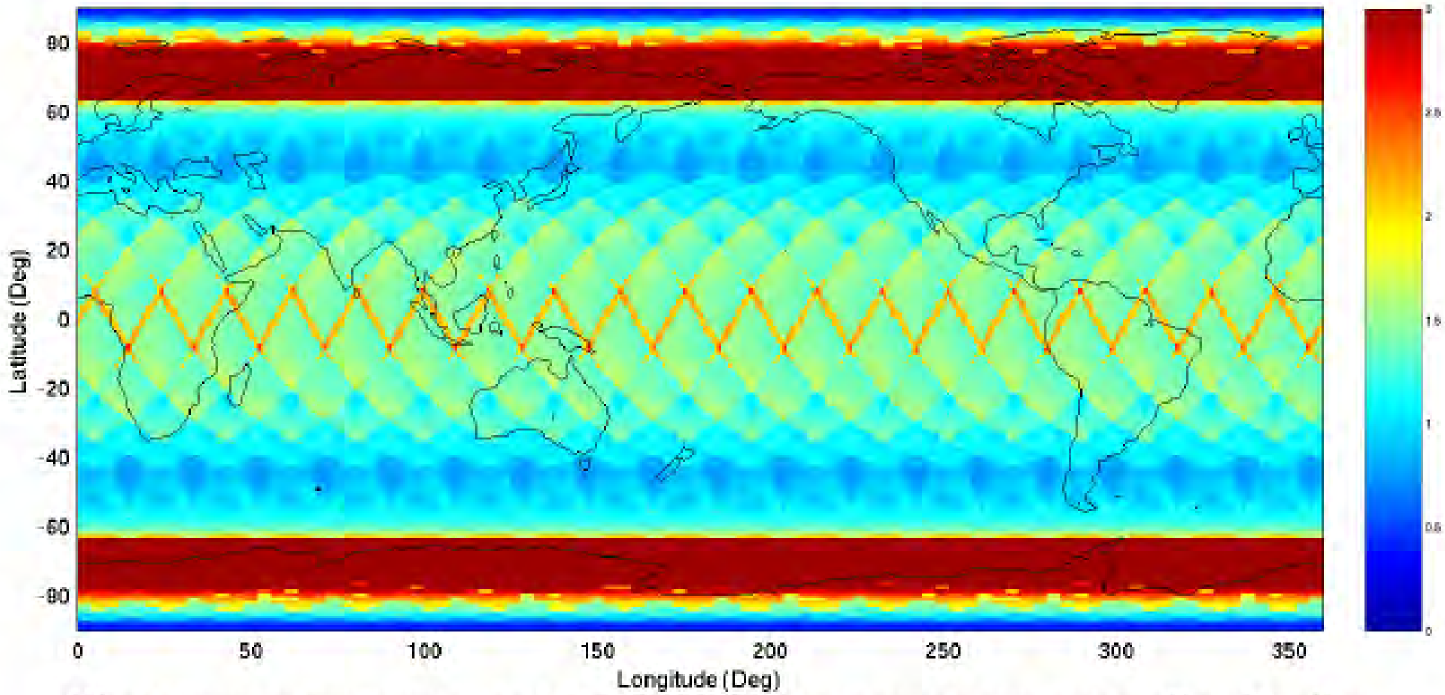
Accessibility for a single SAR at 3000 km altitude after 12 hours

The Future:

3-D Displacement Accuracy

Jet Propulsion Laboratory
California Institute of Technology

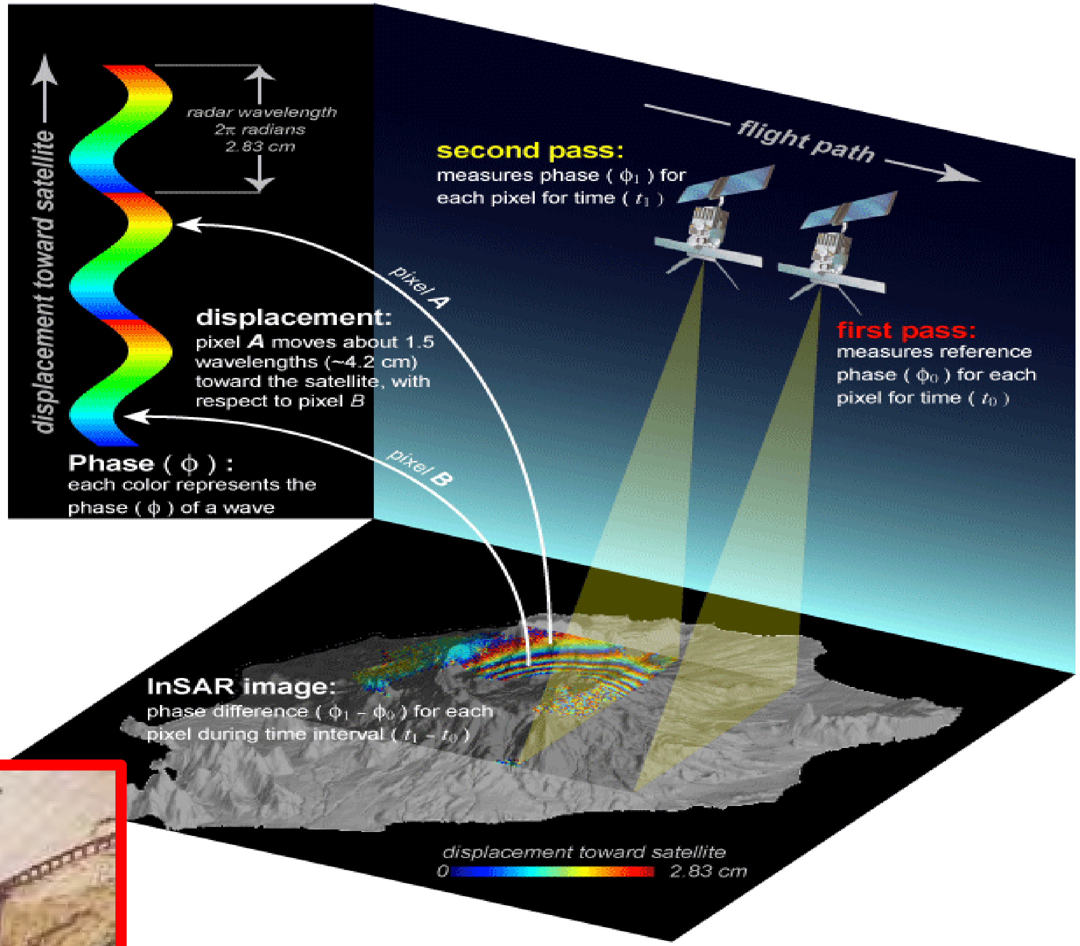
- Resolving vector components of surface motion requires diversity of viewing angles for each ground location
- Very good 3-D accuracy achievable with MEO design



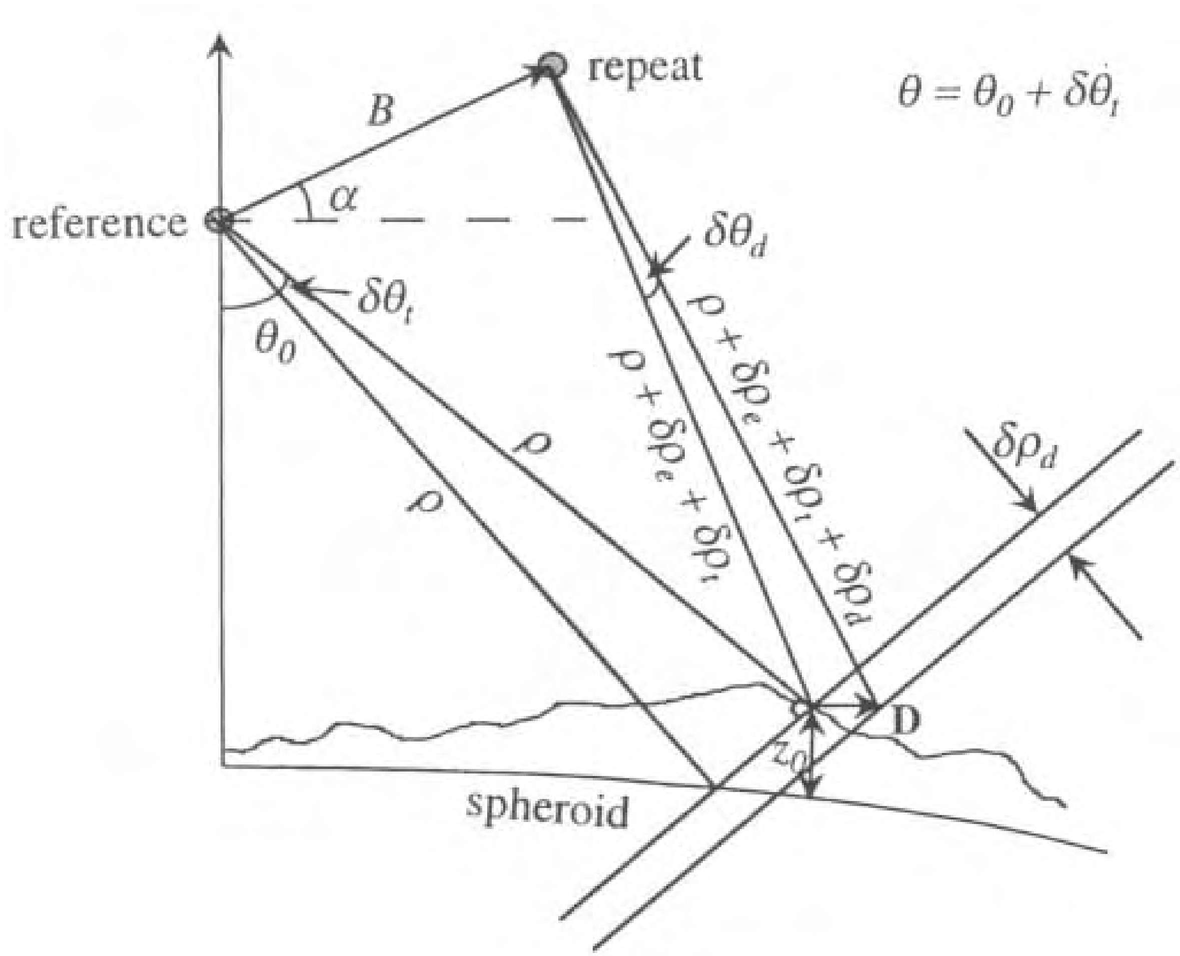
Worst vector component of 3-D displacement accuracy, normalized by line-of-sight accuracy, after incorporating all data from one repeat cycle

Thanks !

...and be careful out there...



Deformation



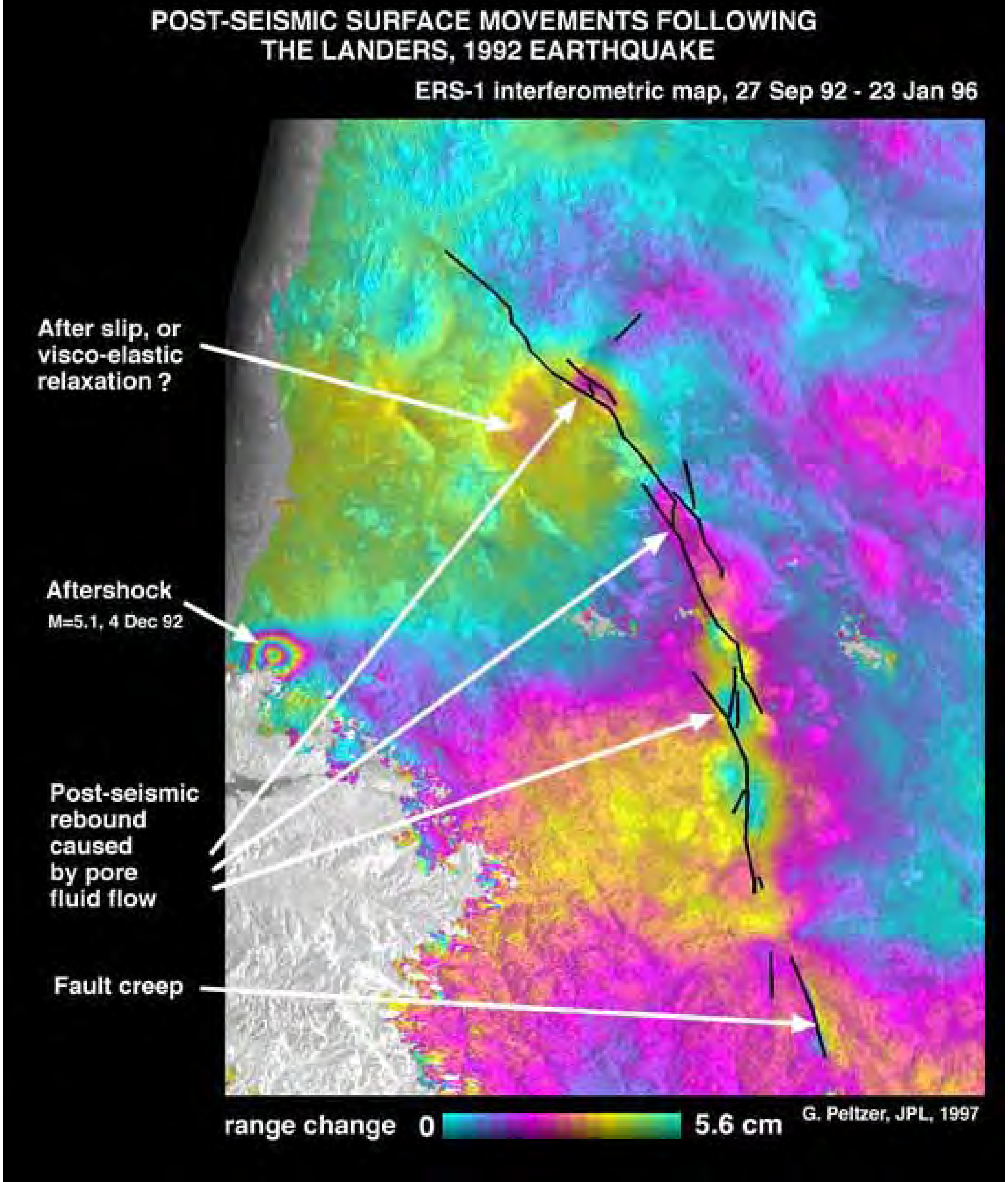
Phase change due to change in range (deformation):

$$\Phi_d = (2\pi/\lambda) 2\delta\rho_d$$

Line Of Sight (LOS) surface deformation:

$$2\delta\rho_d = \lambda\Phi_d/2\pi$$

Examples:

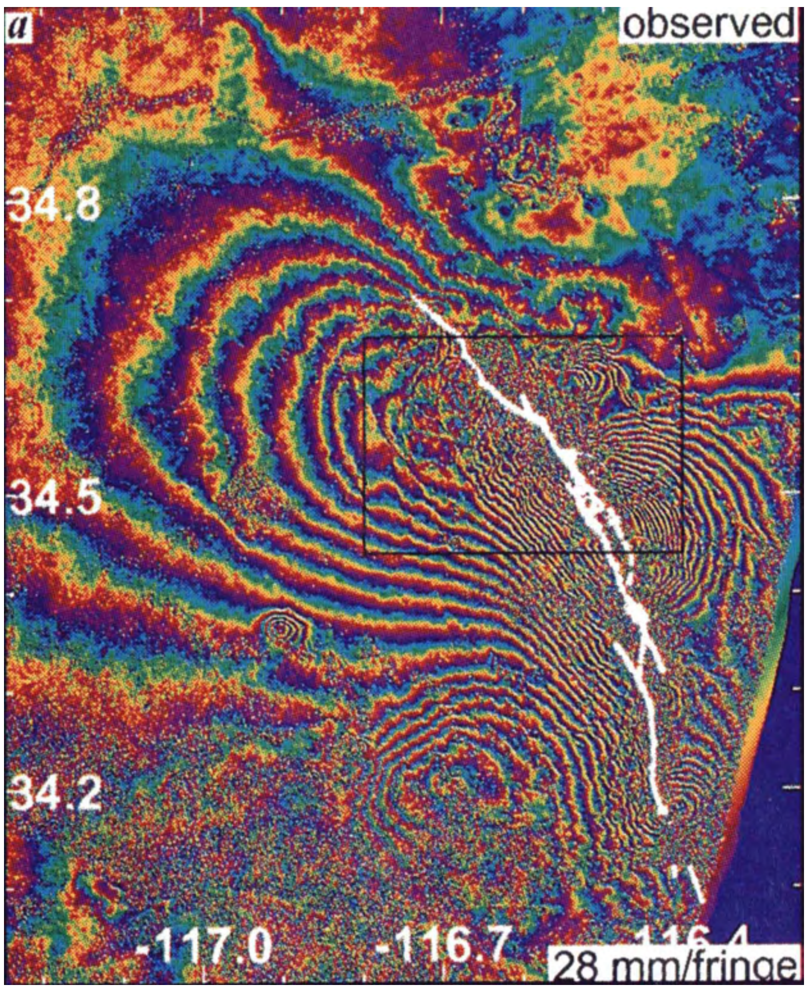


POST-SEISMIC SURFACE MOVEMENTS FOLLOWING
THE LANDERS, 1992 EARTHQUAKE
ERS-1 interferometric map, 27 Sep 92 - 23 Jan 96
After slip, or
visco-elastic
relaxation ?
Aftershock
M=5.1, 4 Dec 92
Post-seismic
rebound
caused
by pore
fluid flow
Fault creep
range change 0
5.6 cm
G. Peltzer, JPL, 1997

“Historic” coseismic interferograms:

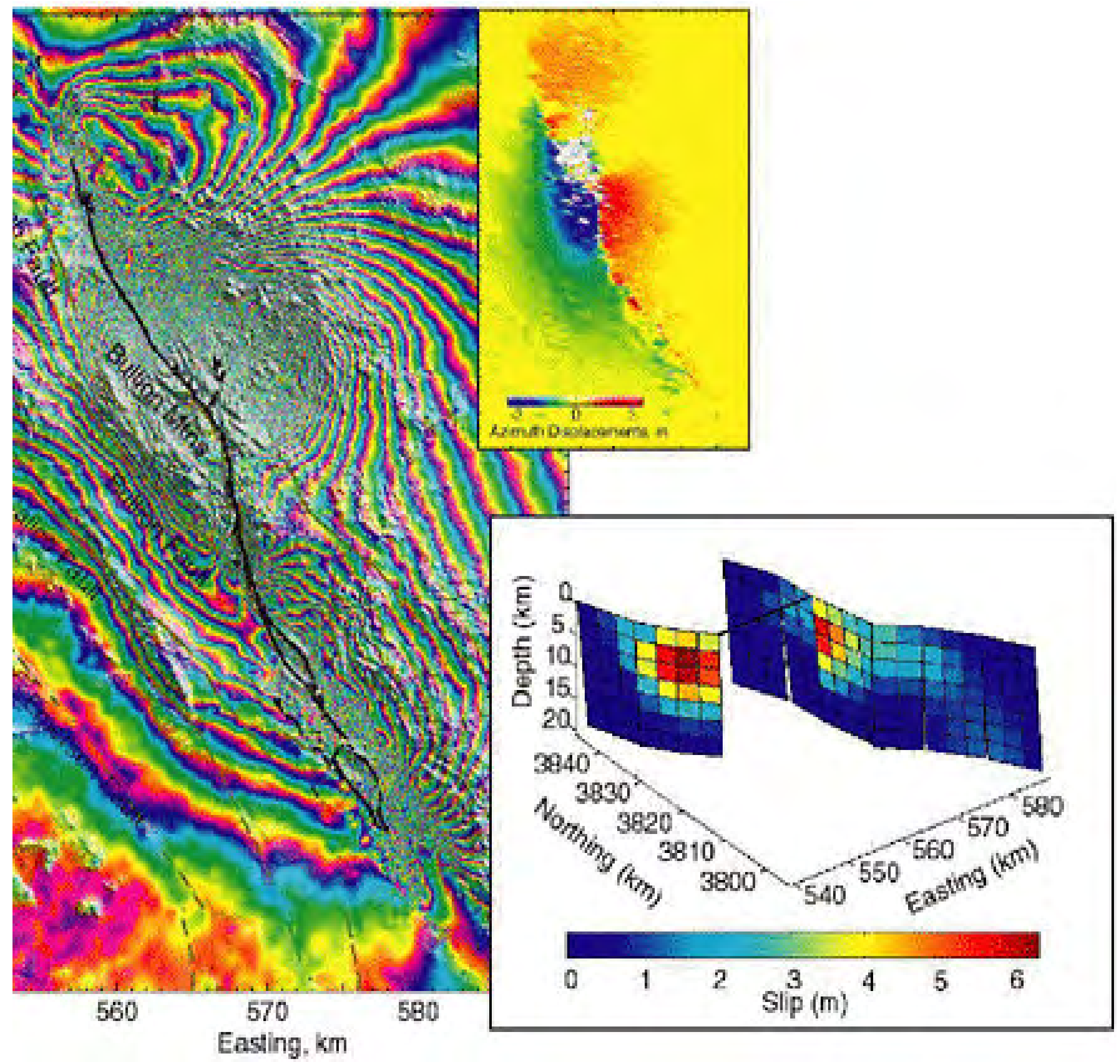
Landers (1992)

Landers (1992)

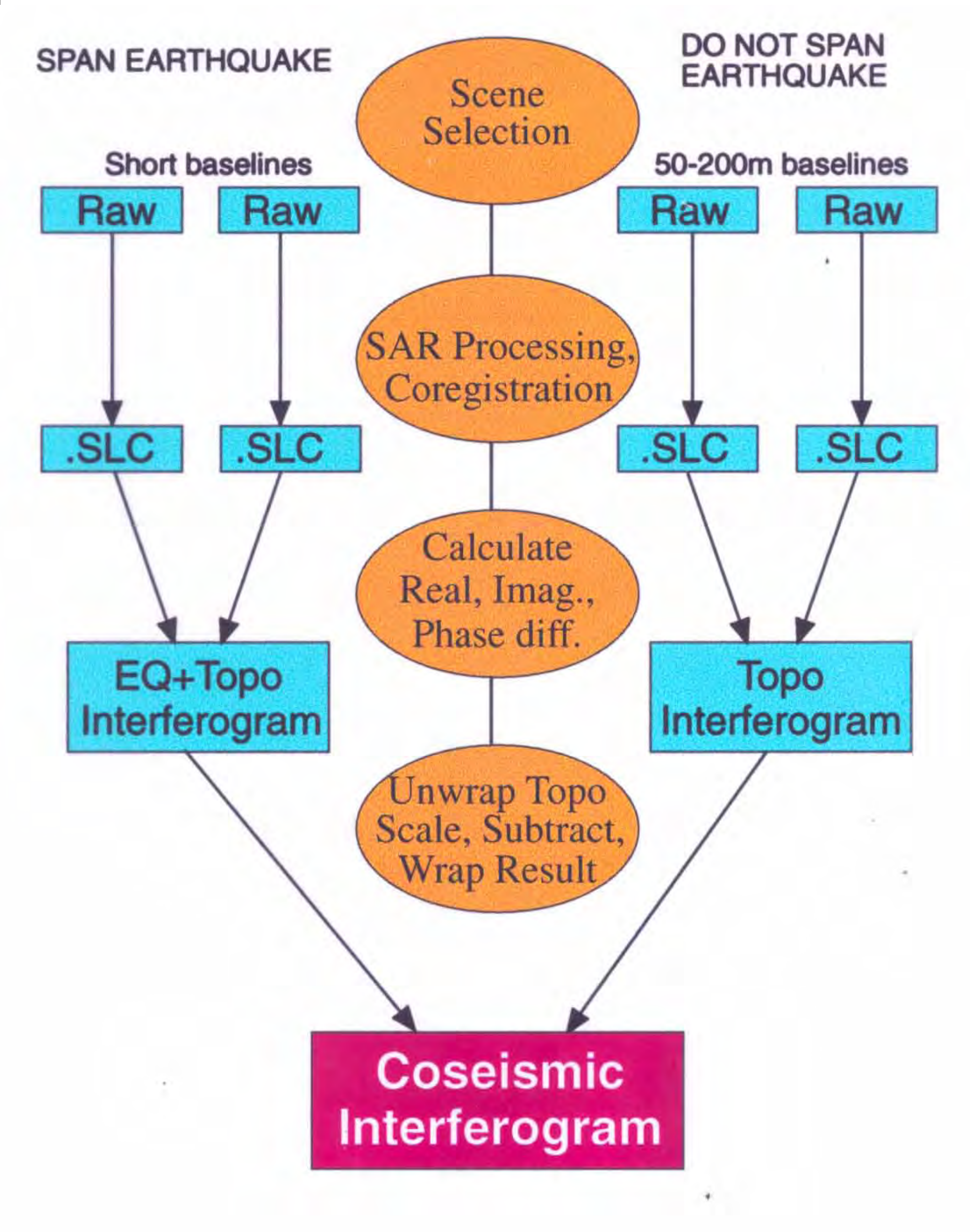


Hector Mines (1999)

Hector Mines (1999)



Making a Coseismic Interferogram



Main Phase contributions – Geoid, Topography, Deformation

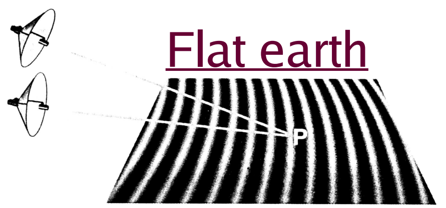


Figure 1.13 Two radar antennas producing interference patterns on the ground.

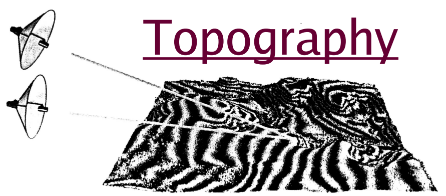
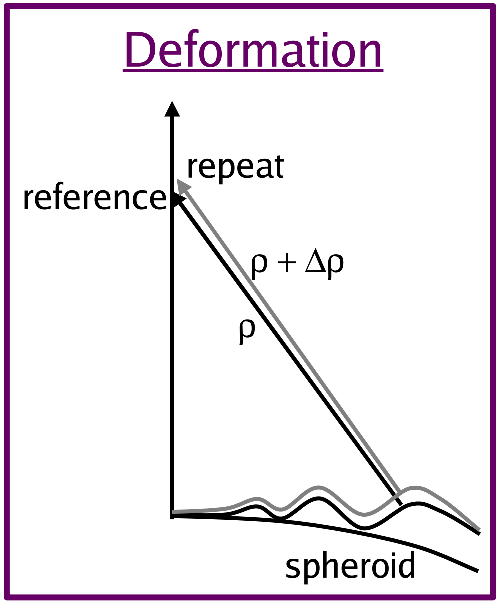
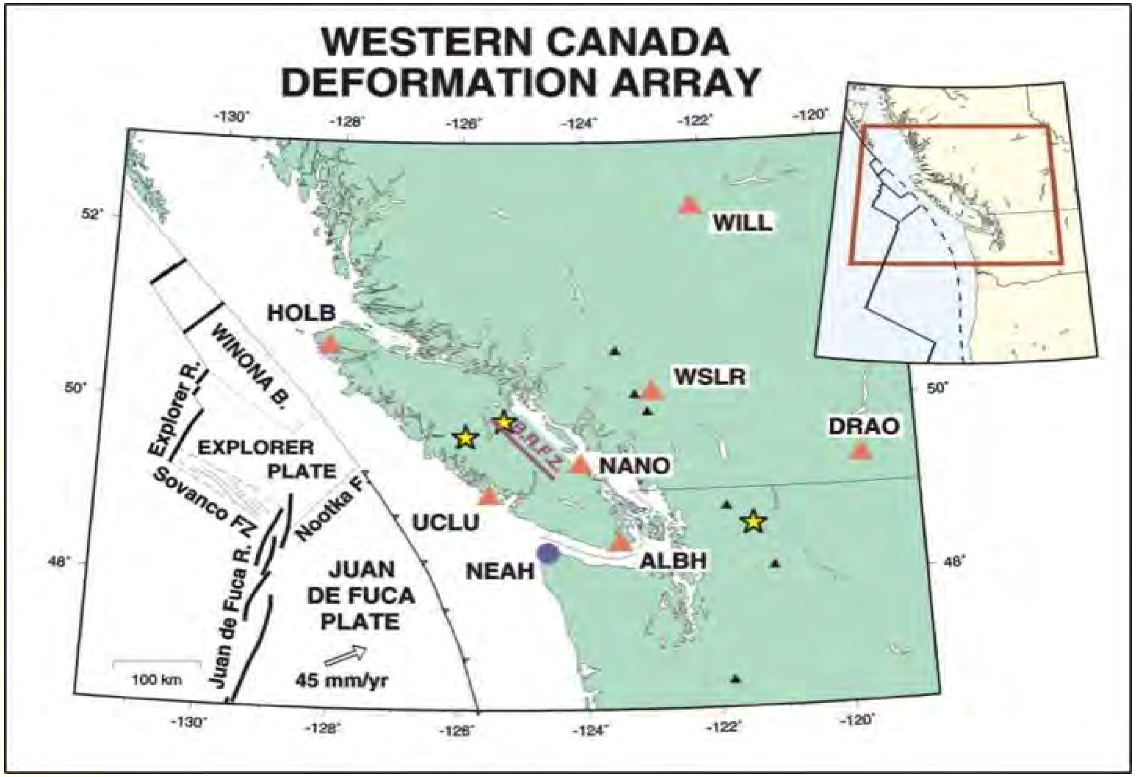
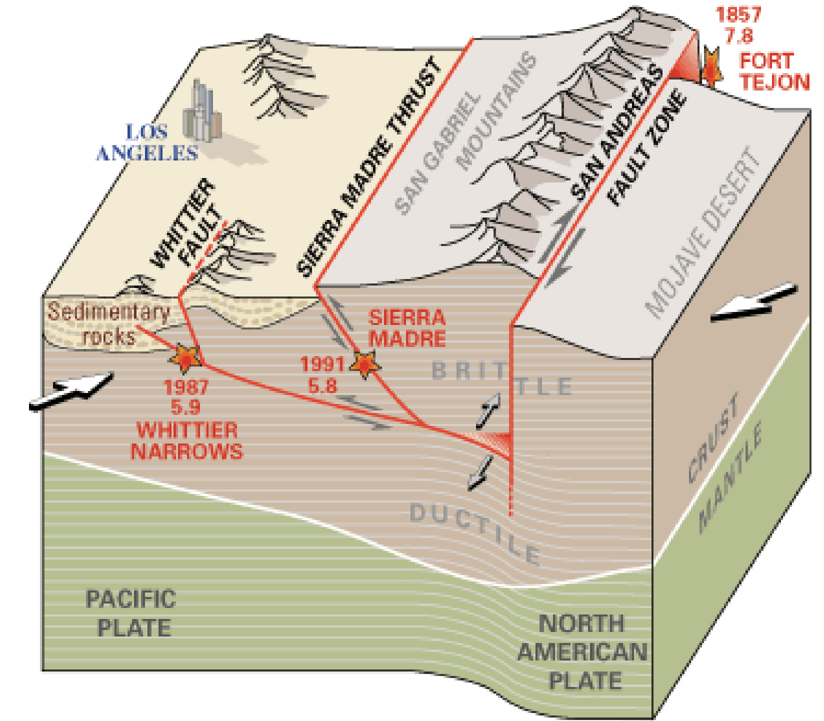


Figure 1.15 Typical interference pattern due to undulating terrain.



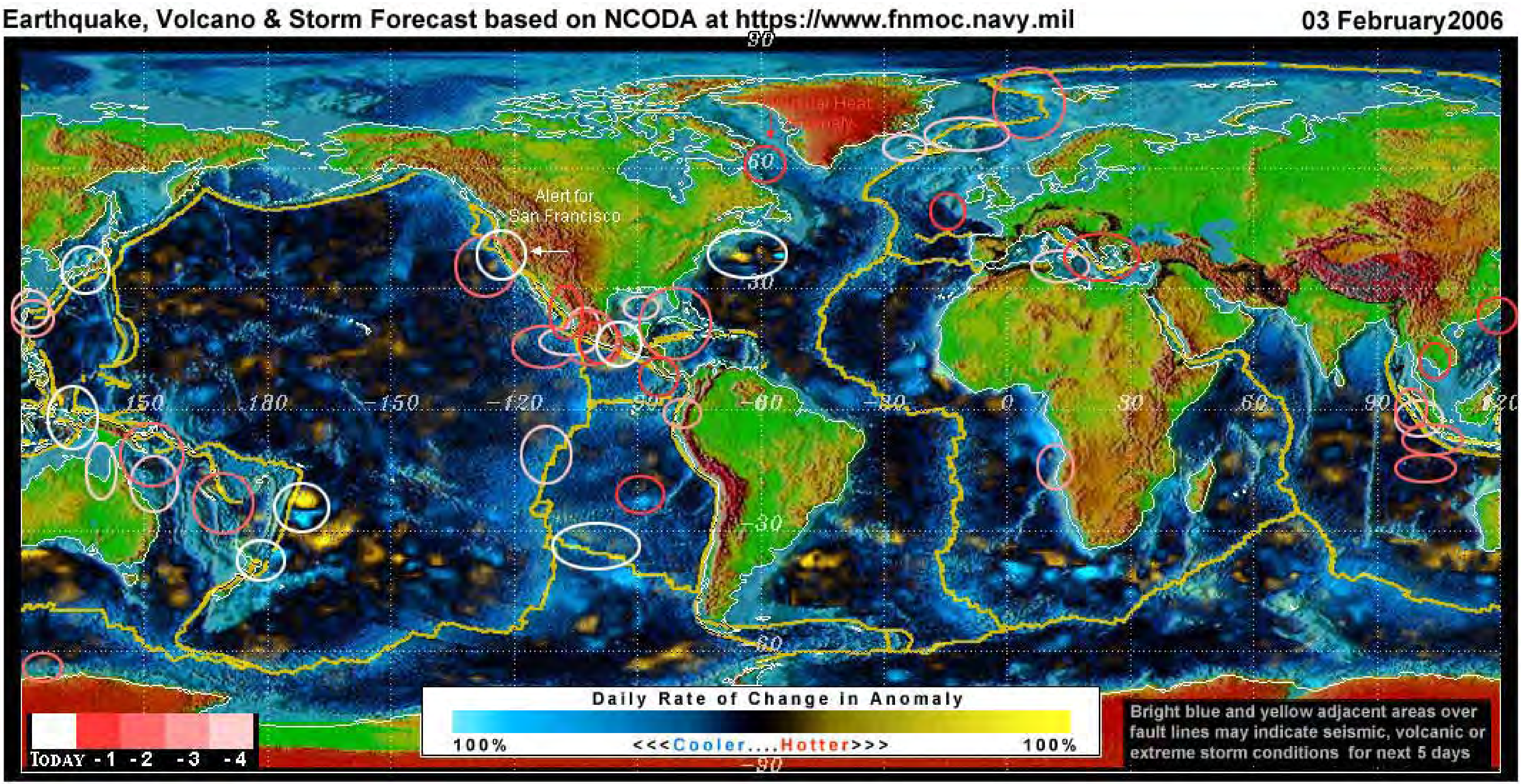
...We all have our faults...



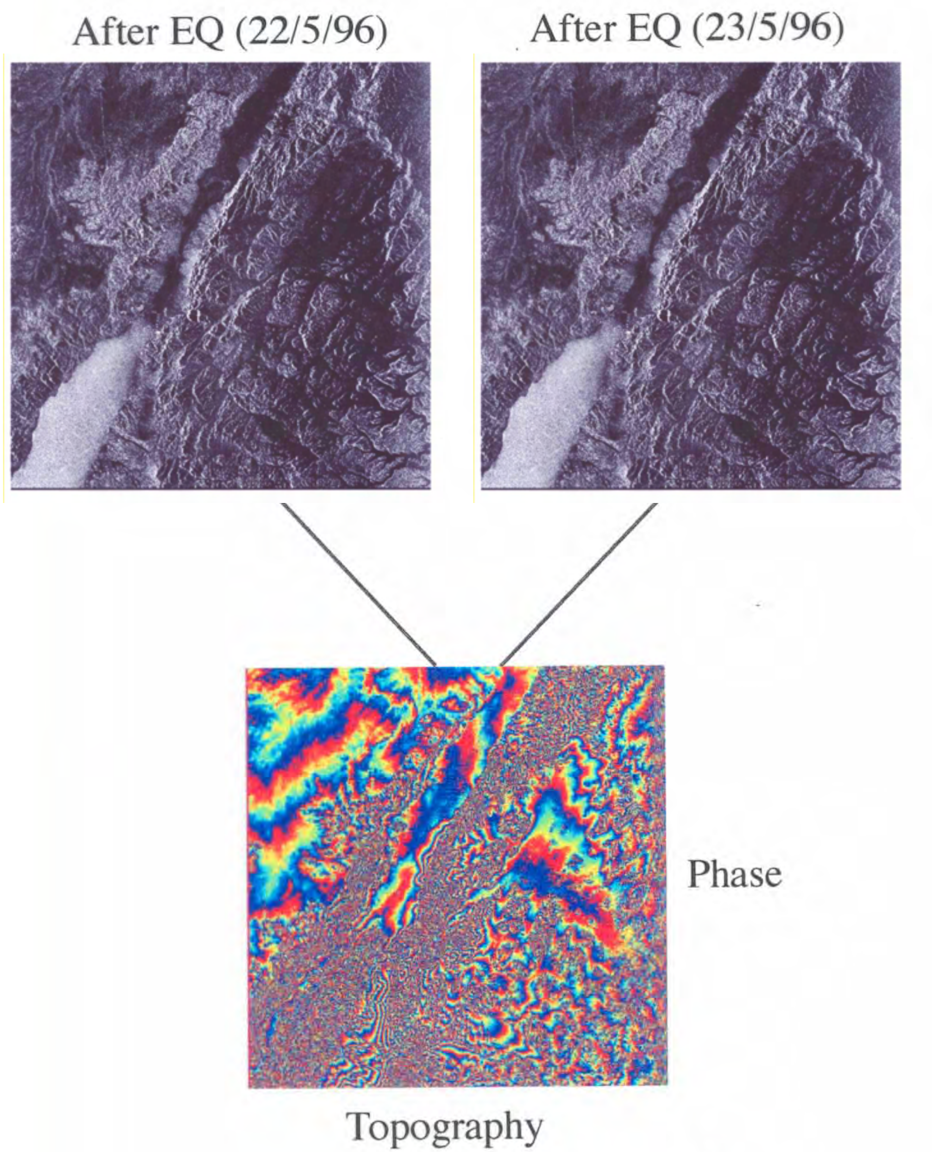


But still - EQ prediction is currently not reliable !!!

...and *"non-predictions"* should be ignored...



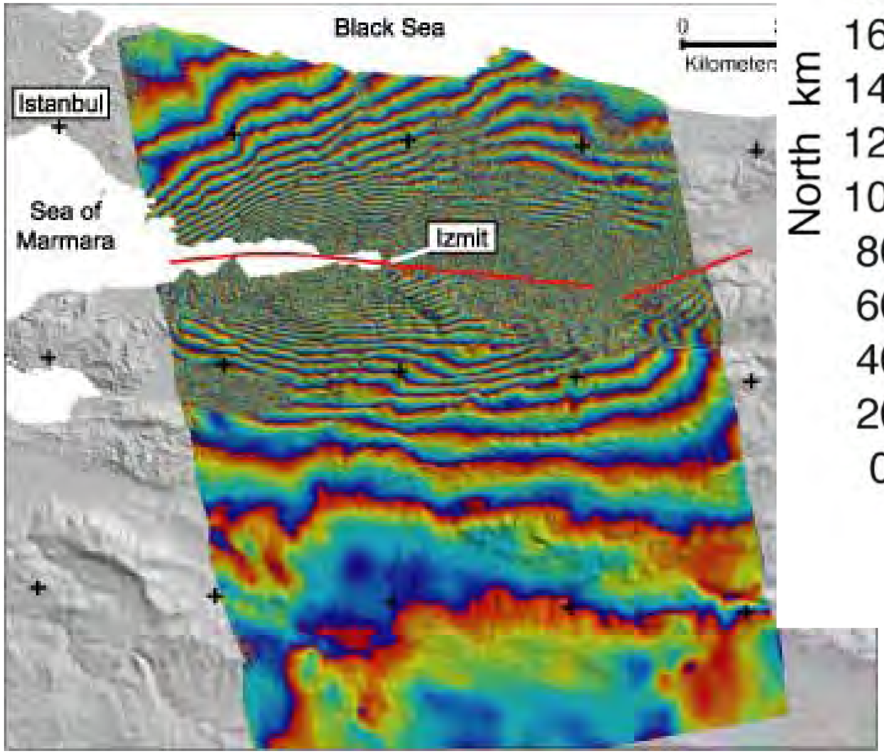
Resolving the topographic phase contribution



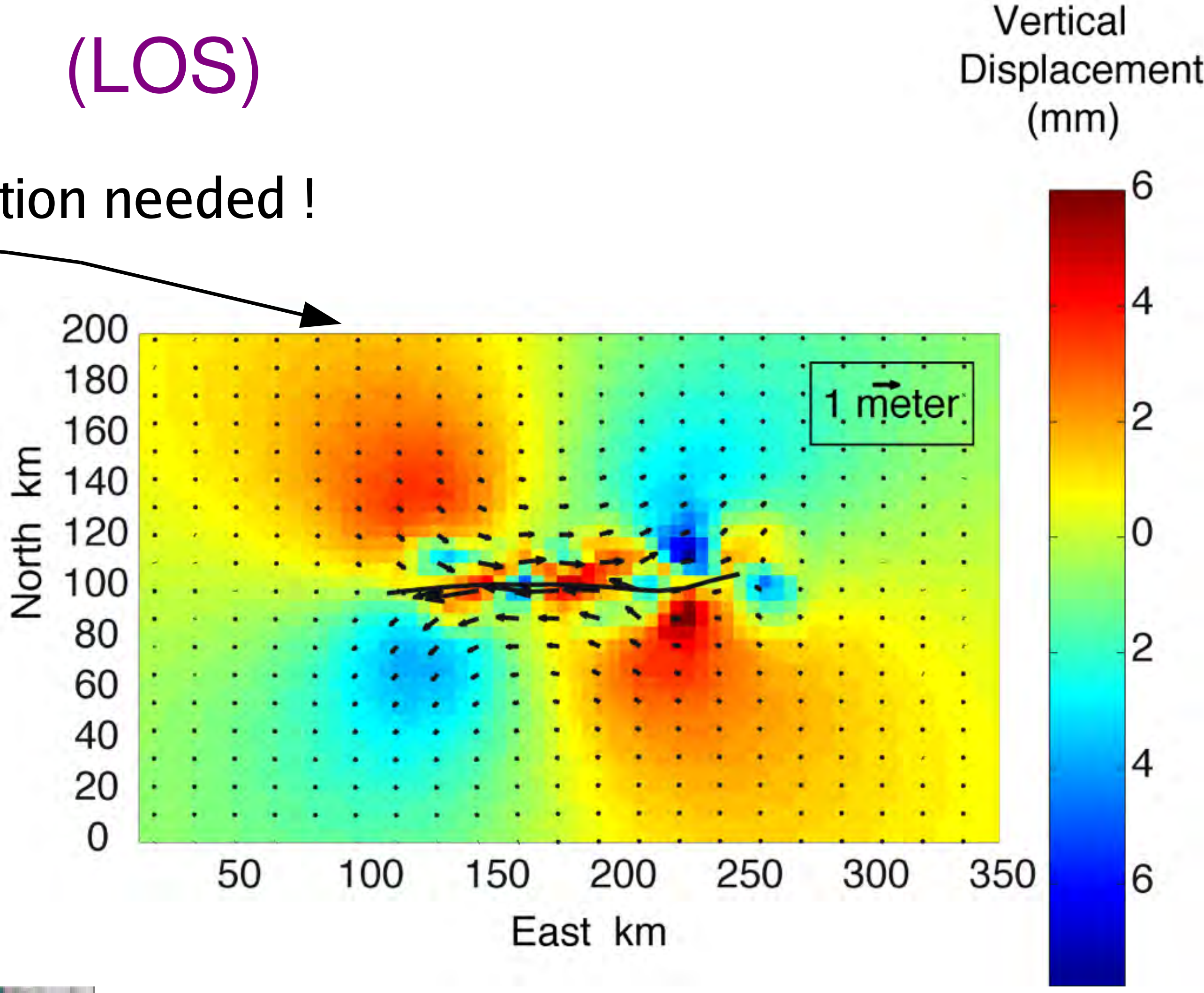
Alternatively – use a Digital Elevation Model (DEM)

InSAR: like having thousands of moderately accurate GPS sites, measuring just one direction (LOS)

Additional information needed !



wrapped interferogram (LOS)

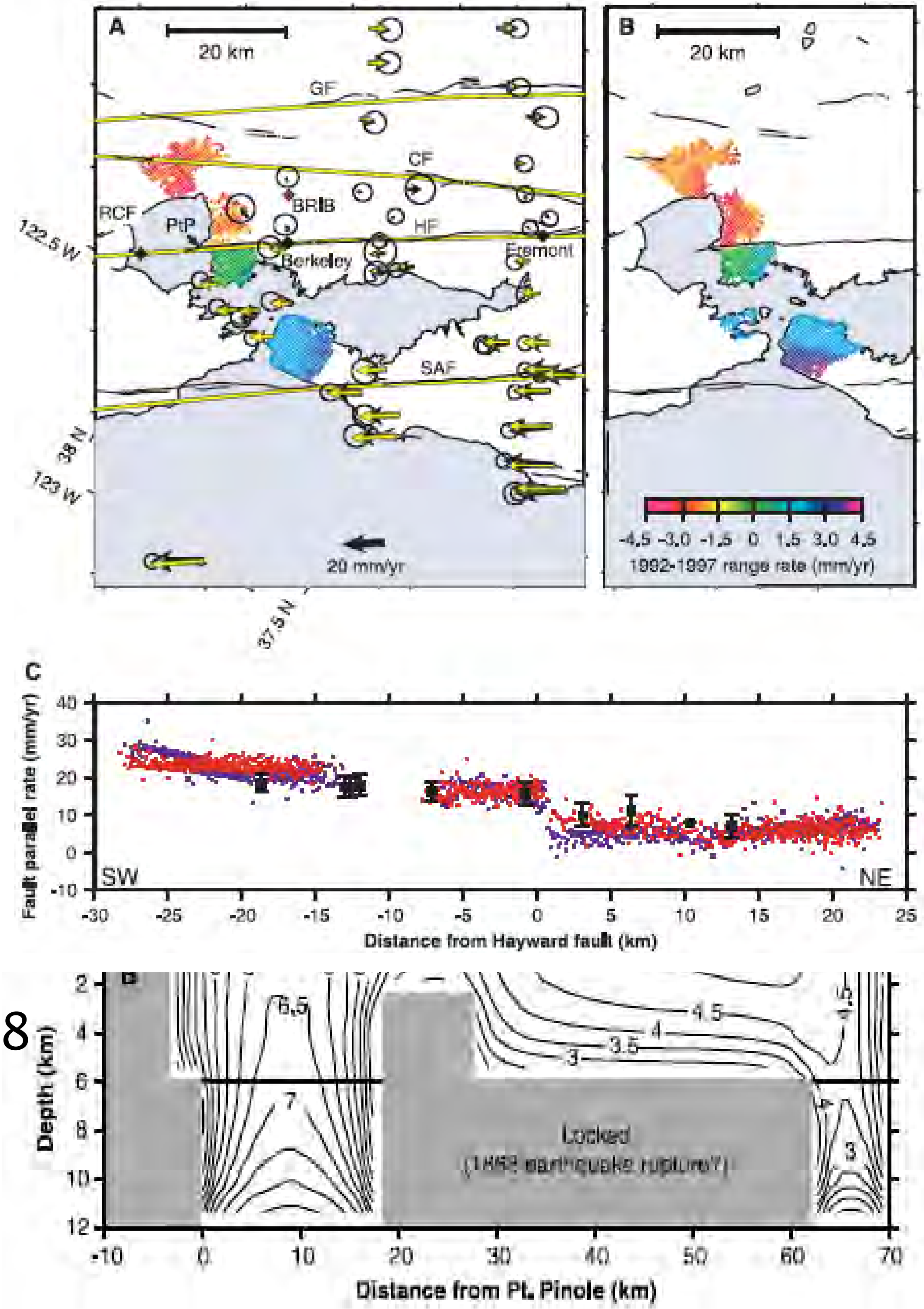


Earthquake potential along the Northern Hayward Fault, California

Burgmann et al., Science, 2000

1. HF & CF display significant creep:

Rates of 30-60% of tectonic rate



2. Seismic hazard implication:

N-HF should not be considered as a source for large earthquakes

S-HF is locked at depth where the 1868 earthquake occurred (M~7)