http://topex.ucsd.edu/gmtsar

Scripps Institution of Oceanography Technical Report

GMTSAR: An InSAR Processing System Based on Generic Mapping Tools

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yesterday

HW2

1) Describe an algorithm to transform a point on the surface of the earth (longitude, latitude, elevation) into radar coordinates.

2) When a SAR image is focussed at zero Doppler, the radar coordinates of a point reflector correspond to the minimum range. Why?

3) Most SAR instruments emit a frequency modulated chirp rather than a short pulse. Why?

4) Make a plot of the real and imaginary parts of the function given in (B5) for a time interval of -2 to 2 seconds. Use $R_o = 850km$, $\dot{R}_o = 0$, $\ddot{R}_o = \frac{V^2}{R_o}$ where $V = 7125ms^{-1}$.

today

HW3

1) Give two reasons why the critical baseline for ALOS is more than 10 times longer than for ERS.

2) What happens to the phase of an interferogram in areas where the slope of the topography facing the radar exceeds the incidence angle of the radar?

3) Explain the terminology, master and slaves, reference and repeat.

4) Derive equation (C8)

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forming interferogram

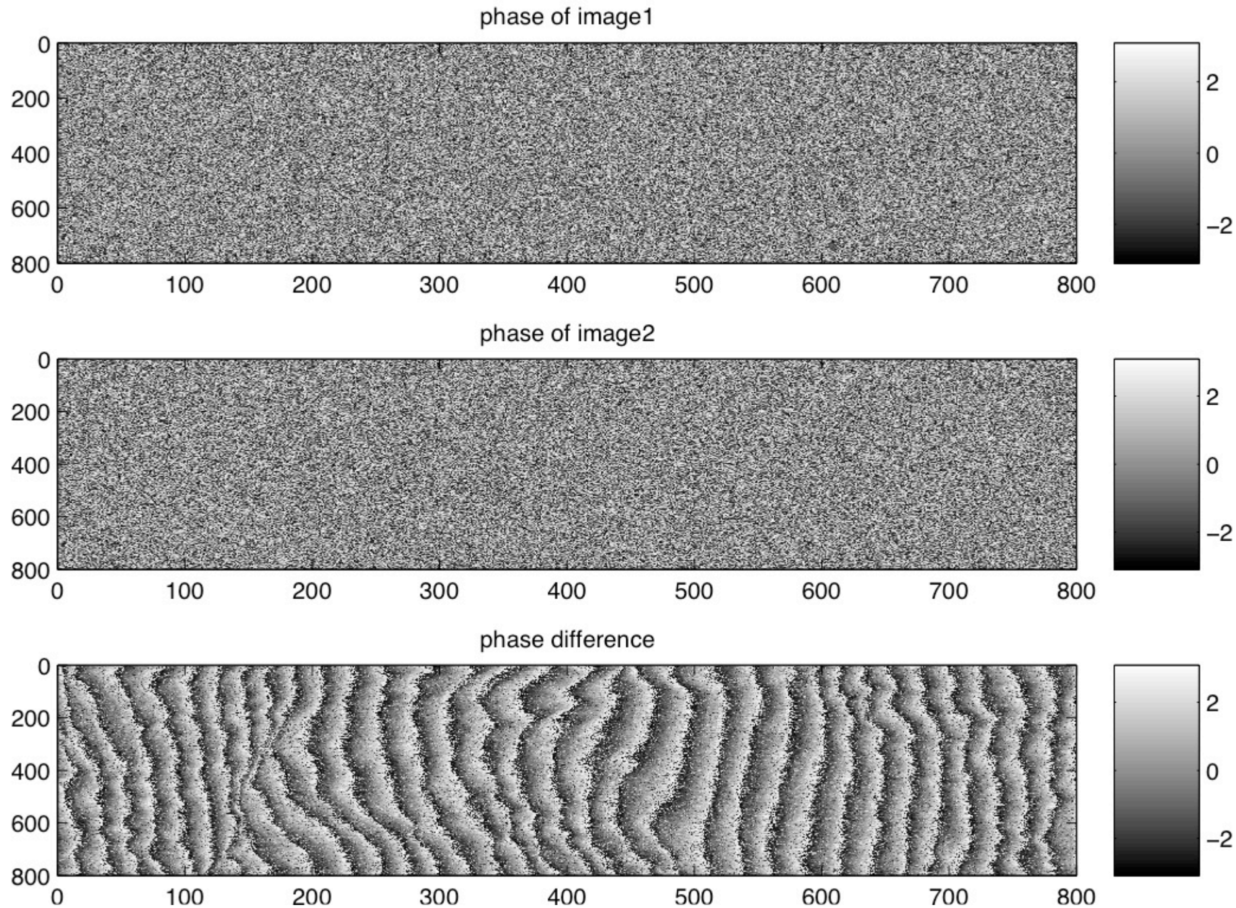
$$C(\mathbf{x}) = A(\mathbf{x})e^{i\phi(\mathbf{x})} \qquad \text{(C1)}$$

where $\mathbf{x} = (\rho, a)$ is the position vector consisting of range ρ and azimuth a. Their product is

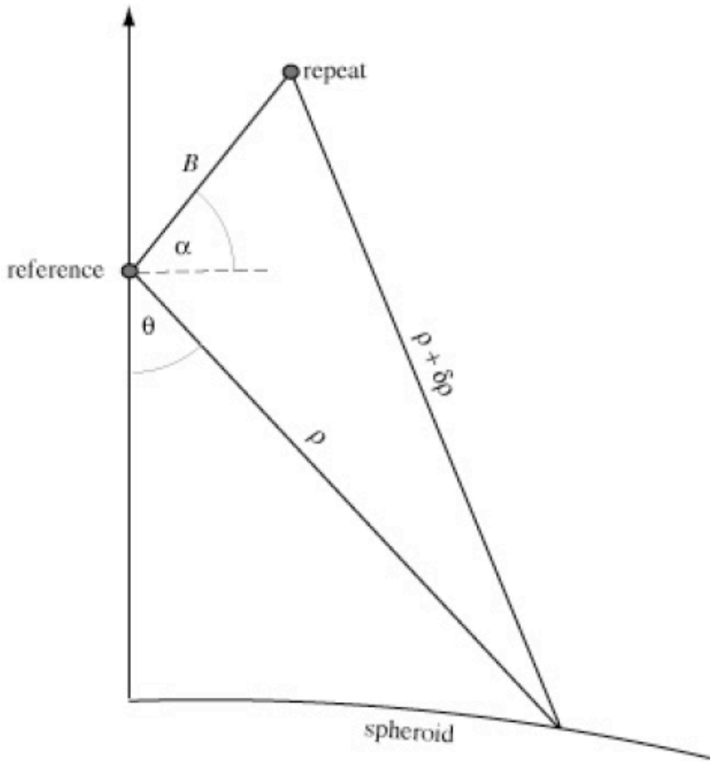
$$C_2C_1^* = A_1A_2e^{i(\phi_2-\phi_1)} = R(\mathbf{x}) + iI(\mathbf{x}). \qquad \text{(C2)}$$

The phase of the interferogram is extracted in the usual way.

$$(\phi_2 - \phi_1) = \tan^{-1}\left(\frac{I}{R}\right) \qquad \text{(C3)}$$



phase = **earth curvature** (almost a plane, known) +
topographic phase (broad spectrum) +
surface deformation (broad spectrum, unknown) +
orbit error (almost a plane, largely known) +
ionosphere delay (a plane or 40-km wavelength waves) +
troposphere delay (power law, unknown) +
phase noise (white spectrum, unknown)



$$(\rho + \delta\rho)^2 = \rho^2 + B^2 - 2\rho B \sin(\theta - \alpha) \tag{C7}$$

Next we make two standard approximations that are useful for introducing interferometric concepts but are unnecessary and also lead to inaccurate results. First we assume $\delta\rho << \rho$ so we have

$$\delta\rho = \frac{B^2}{2\rho} - B\sin(\theta - \alpha)\,. \tag{C8}$$

Furthermore since $B << \rho$ the parallel ray approximation yields.

$$\phi = \frac{-4\pi}{\lambda} B\sin(\theta - \alpha) \tag{C9}$$

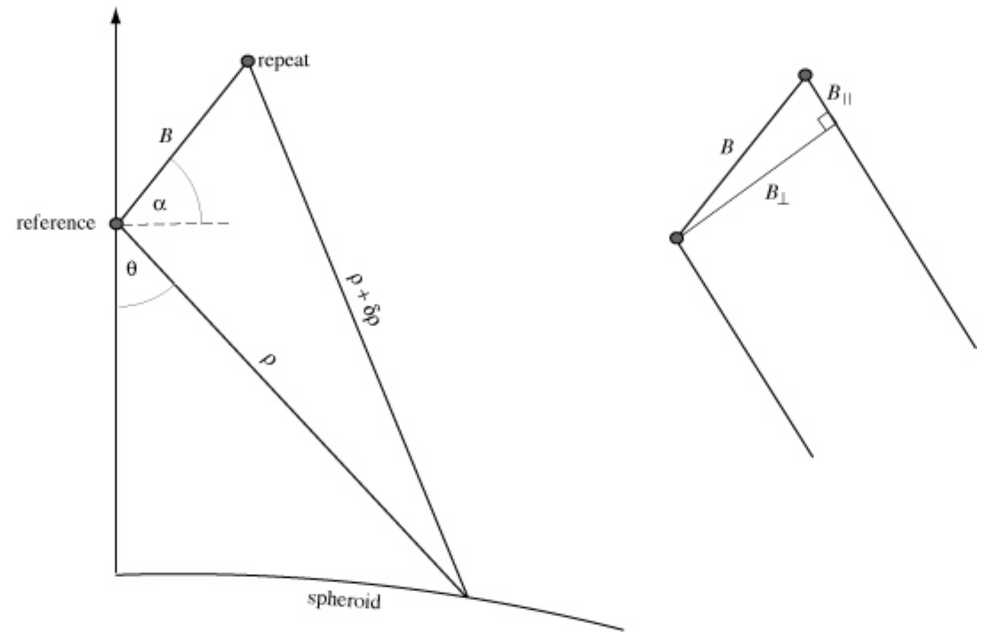
The phase difference depends on the parallel component of the baseline. The derivative of the phase with respect to range is

$$\frac{\partial\phi}{\partial\rho} = \frac{-4\pi}{\lambda} B\cos(\theta - \alpha)\frac{\partial\theta}{\partial\rho} \tag{C10}$$

Perpendicular baseline MATTERS!

$$B_{||} = B\sin(\theta - \alpha)$$

$$\boxed{B_{\perp} = B\cos(\theta - \alpha)}$$



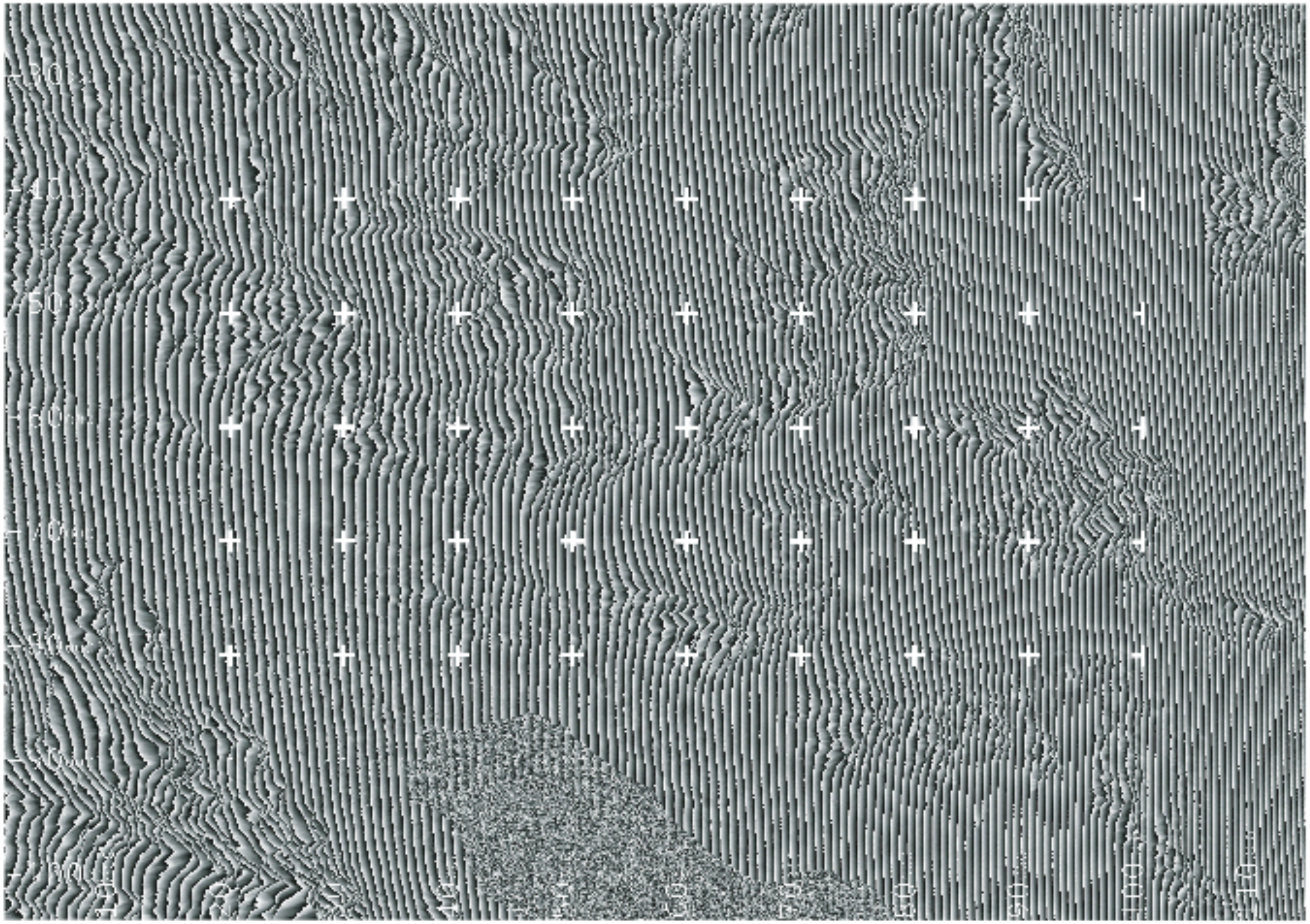
$$\frac{\partial\phi}{\partial\rho} = \frac{-4\pi}{\lambda\rho}\frac{\boxed{B\cos(\theta-\alpha)}}{\sin\theta}\left(\cos\theta - \frac{\rho}{b}\right)$$

phase due to curved earth

$$(\phi - \phi_e) \cong \frac{-4\pi r_e \boxed{B\cos(\theta-\alpha)}}{\lambda\rho b\sin\theta}(r - r_e)$$

phase due to topography

total phase



3) This is an interferogram made from ERS SAR data. One fringe represents 2 π phase change between the reference and repeat SAR acquisition. Count the fringes across the image and calculate the perpendicular baseline. You will need the look angle from the previous problem. The total change in slant range across the image is 50 km. Why does the fringe rate vary slightly across the image?

Phase from curved Earth

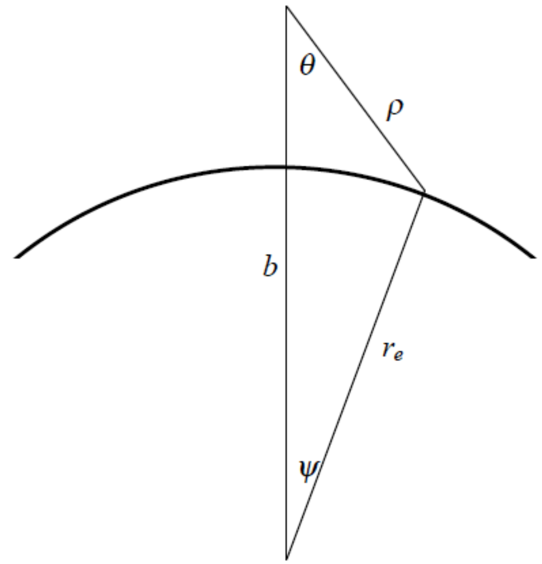


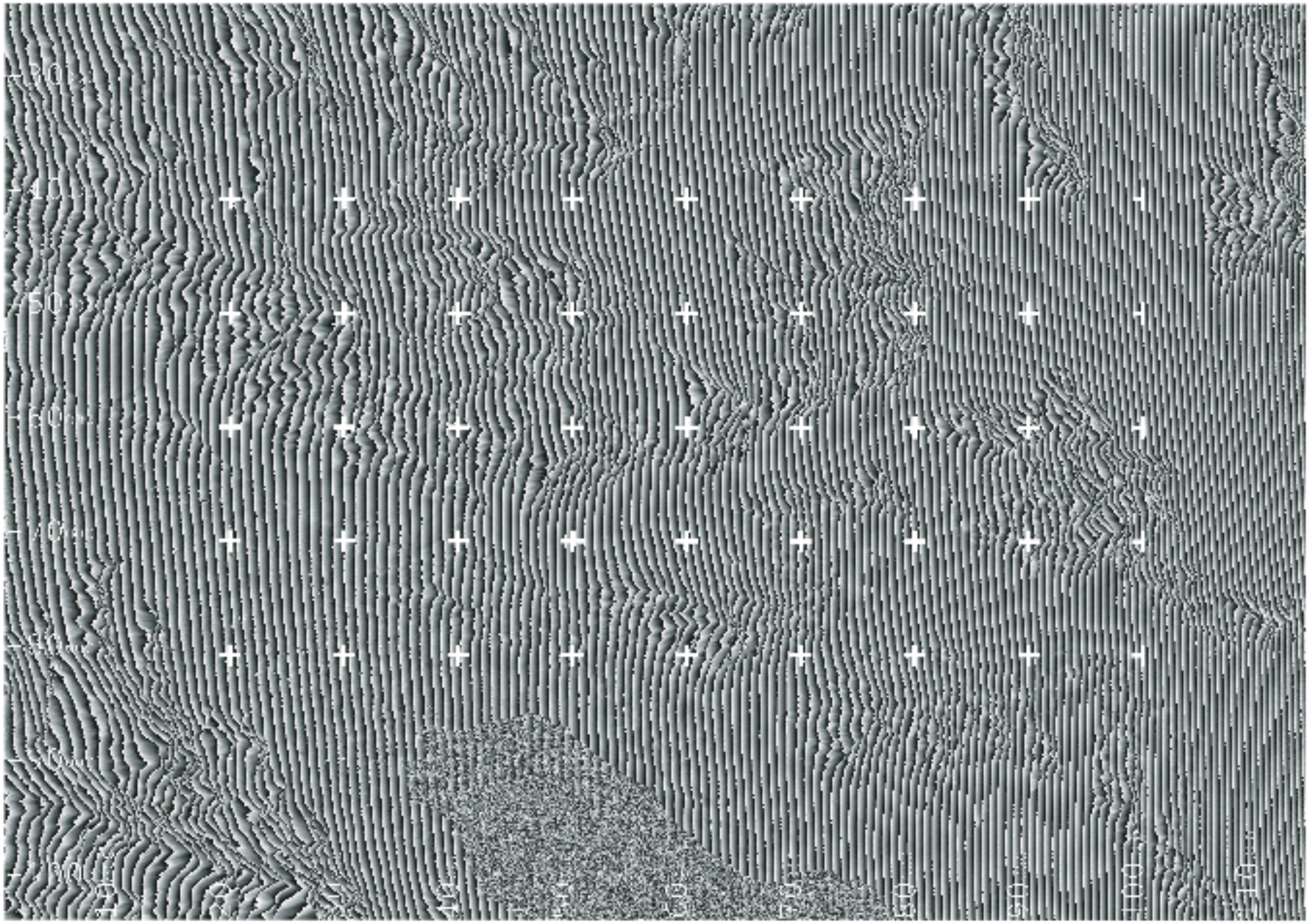
Figure C3 Triangle formed by the range ρ, radius of the earth r_e and spacecraft height b.

Using the Law of cosines one finds

$$\eta = \cos\theta = \frac{\left(b^2 + \rho^2 - r_e^2\right)}{2\rho b} \tag{C12}$$

$$\frac{\partial\phi}{\partial\rho} = \frac{-4\pi B}{\lambda\rho}\frac{\cos(\theta-\alpha)}{\sin\theta}\left(\cos\theta - \frac{\rho}{b}\right)$$

total phase



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Critical Baseline

$$\frac{\partial \phi}{\partial \rho} = \frac{-4\pi B_{\perp}}{\lambda \rho} \frac{\cos\theta}{\sin\theta} < \frac{2\pi}{\Delta \rho}$$

$$B_c = \frac{\lambda \rho}{C\tau} \tan\theta \quad . \qquad \text{(C16)}$$

For the parameters of the ERS satellite the critical baseline is 1100 m (Tabel 1). For topographic recovery, a baseline of about 1/4 critical is optimal. Of course for change detection, a zero baseline is optimal but not usually available.

Table 1. Comparison of critical baseline

look angle	23°	34°	41°
ERS/ENVISAT 16 MHz	1.1 km	2.0	2.9
ALOS FBD 14 MHz	3.6	6.5	9.6
ALOS FBS 28 MHz	7.3	13.1	18.6

ERS/ENVISAT - altitude = 790 km, wavelength = 56 mm
ALOS - altitude = 700 km, wavelength = 236 mm
Shaded area is most common mode for interferometry.

Phase from topography

$$\frac{\partial \phi}{\partial r}(r_e) = \frac{-4\pi r_e}{\lambda \rho b} \frac{B\cos(\theta_e - \alpha)}{\sin\theta_e}$$

where θ_e is the look angle to the spheroid (C12).

into elevation as a function of range is

$$(r - r_e) = \frac{-\lambda \rho b}{4\pi r_e} \frac{\sin\theta_e}{B\cos(\theta_e - \alpha)}(\phi - \phi_e)$$

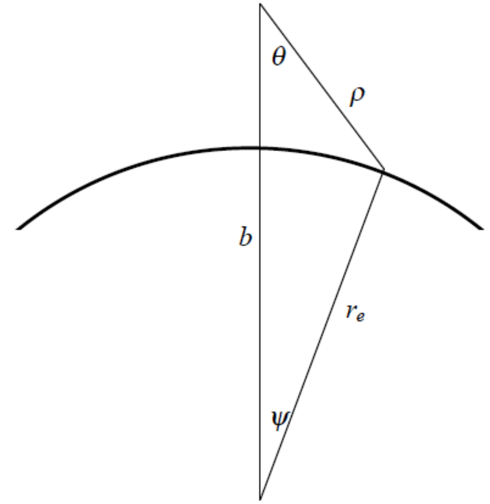


Figure C3 Triangle formed by the range ρ, radius of the earth r_e and spacecraft height b.

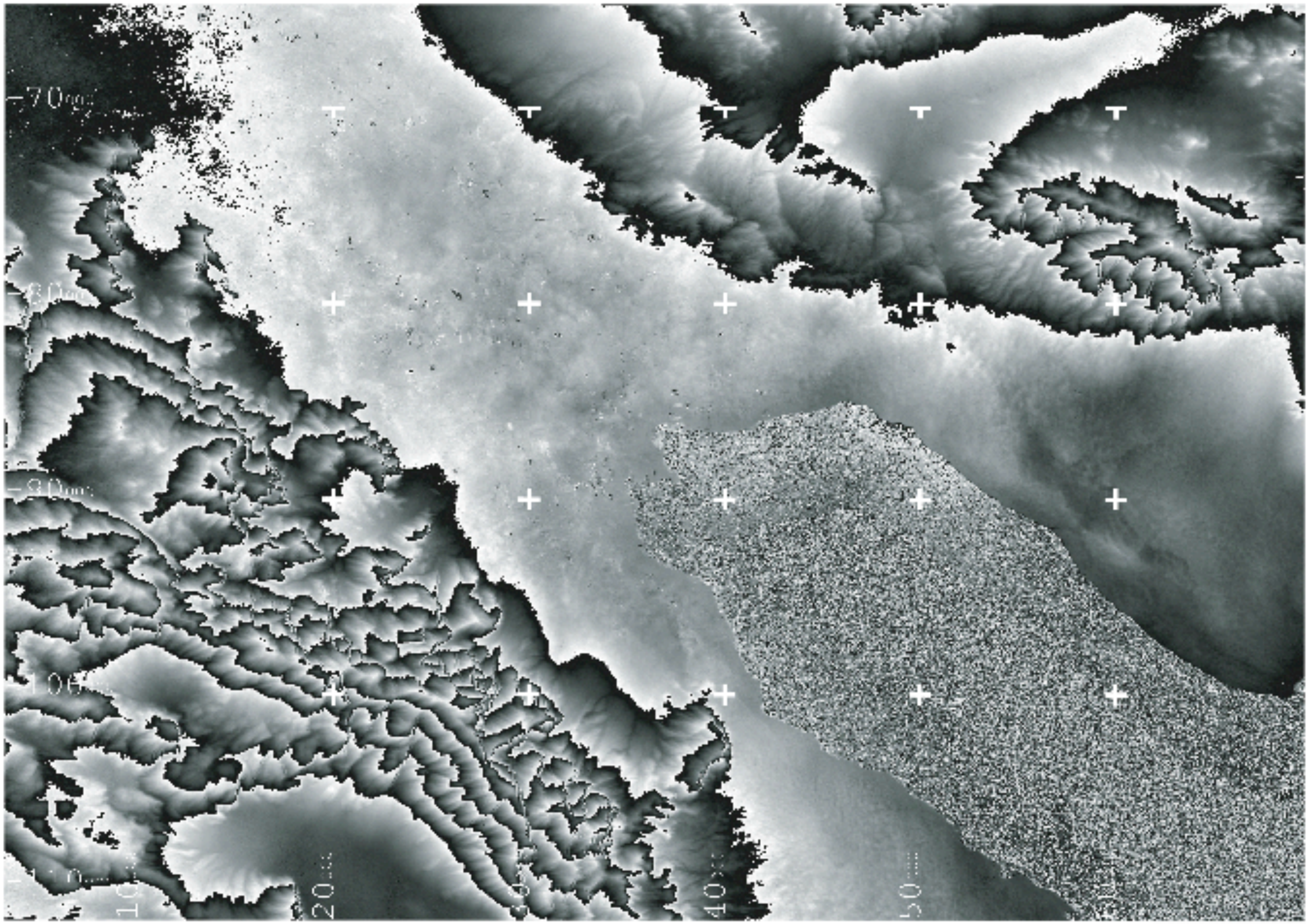
Using the Law of cosines one finds

$$\eta = \cos\theta = \frac{(b^2 + \rho^2 - r_e^2)}{2\rho b} \quad \text{(C1}$$

$$h_a = \frac{\lambda \rho \sin\theta_e}{2B_\perp} \quad \text{(C21)}$$

For the case of ERS with a perpendicular baseline of 100 m, this altitude of ambiguity is about 90 m. For change detection, a higher number is better.

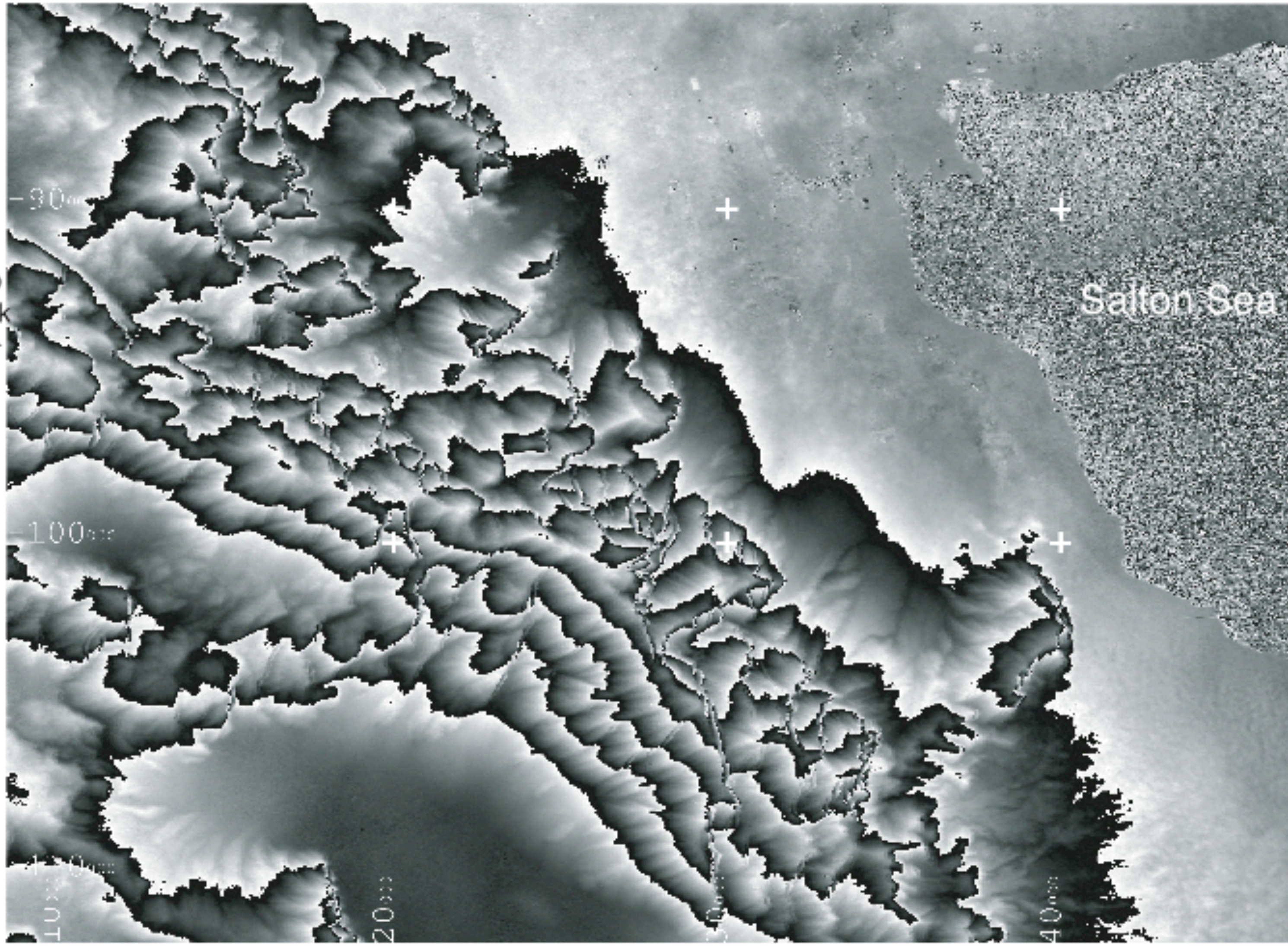
phase minus spherical earth



4) Interferogram with fringes due to geometry and Earth curvature removed. What are the cause(s) of the residual fringes? Why is the phase along the shoreline of the Salton Sea not exactly constant? (there are several possibilities).

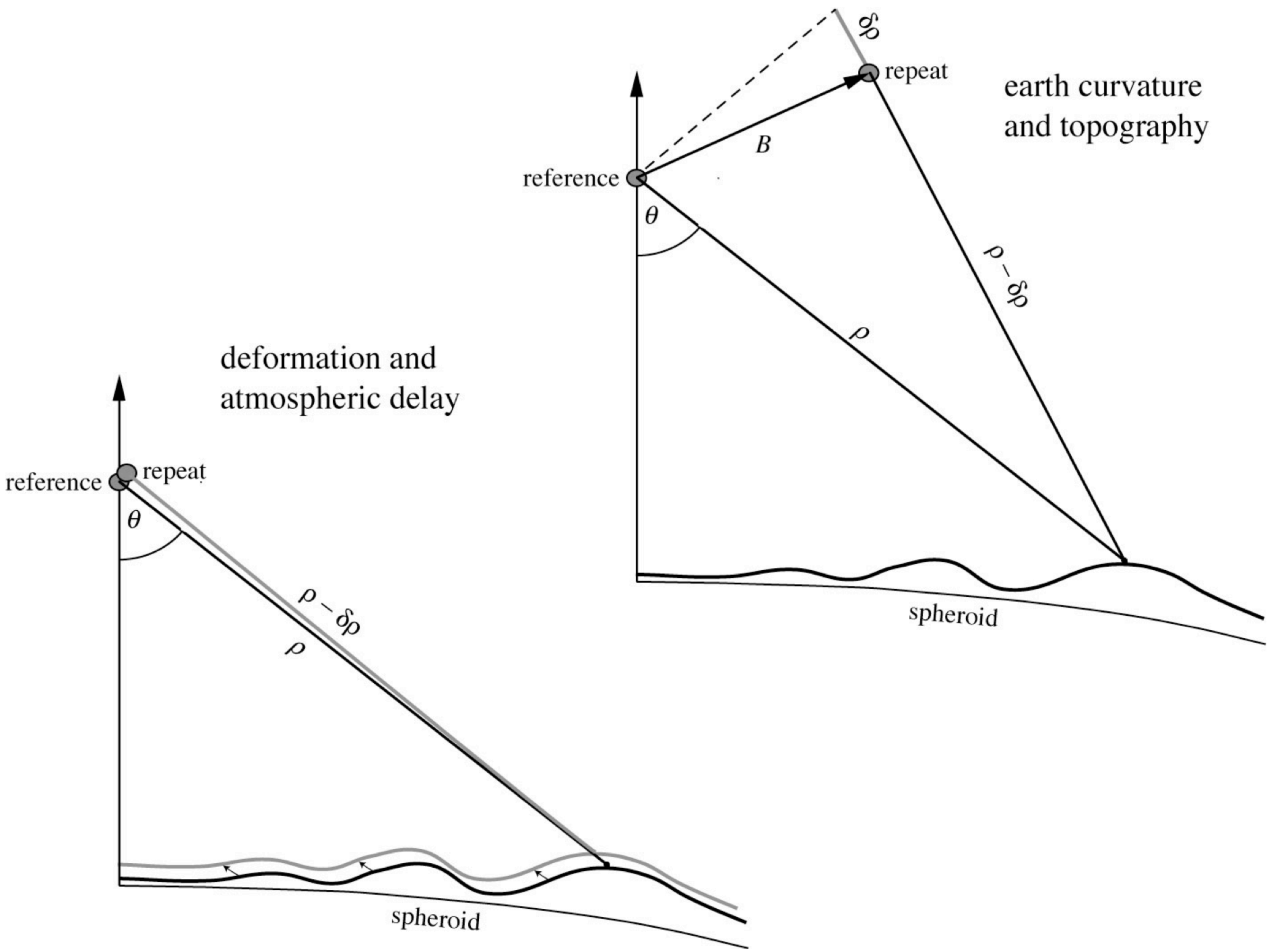
How high is Toro Peak?

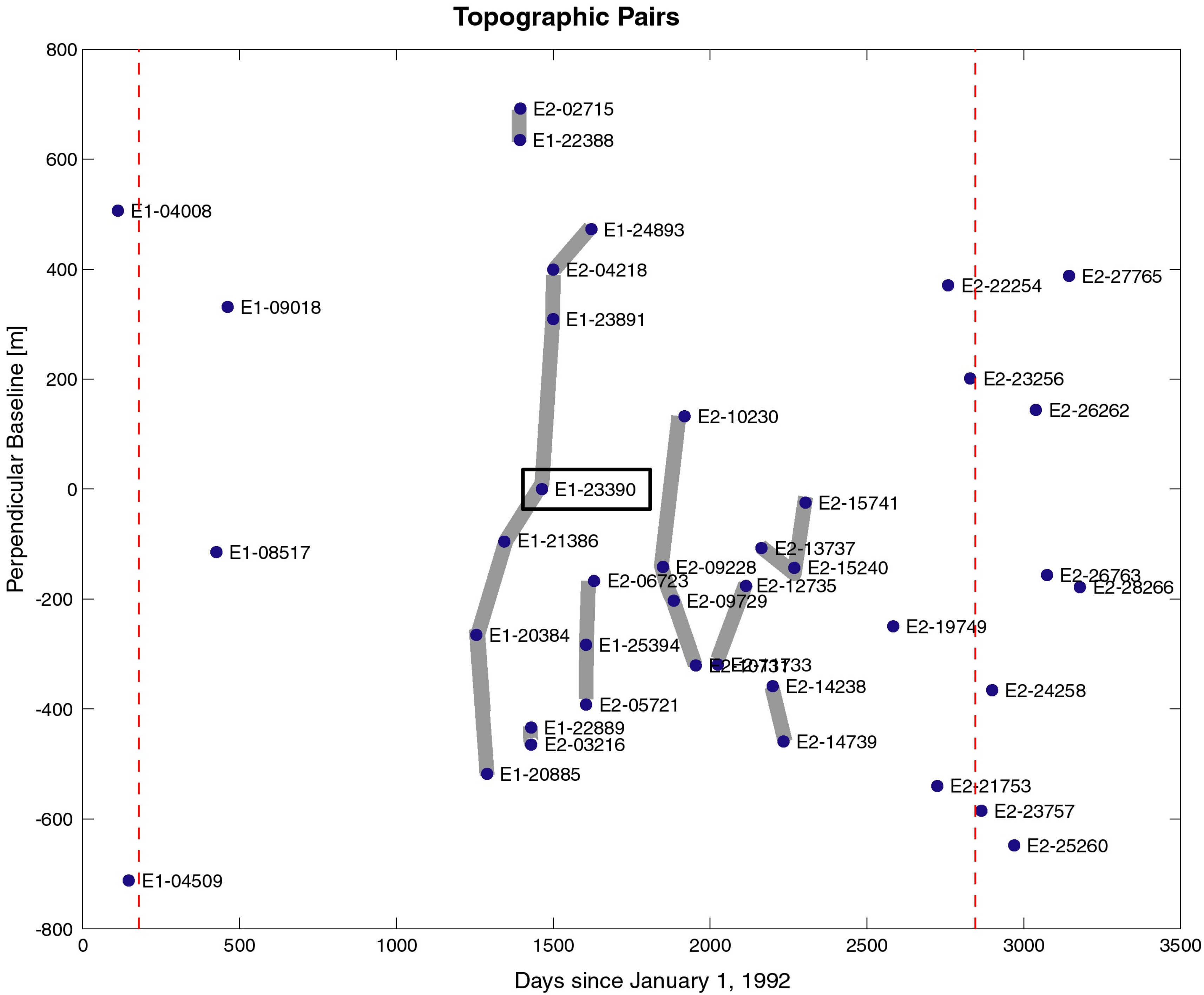
Toro Peak



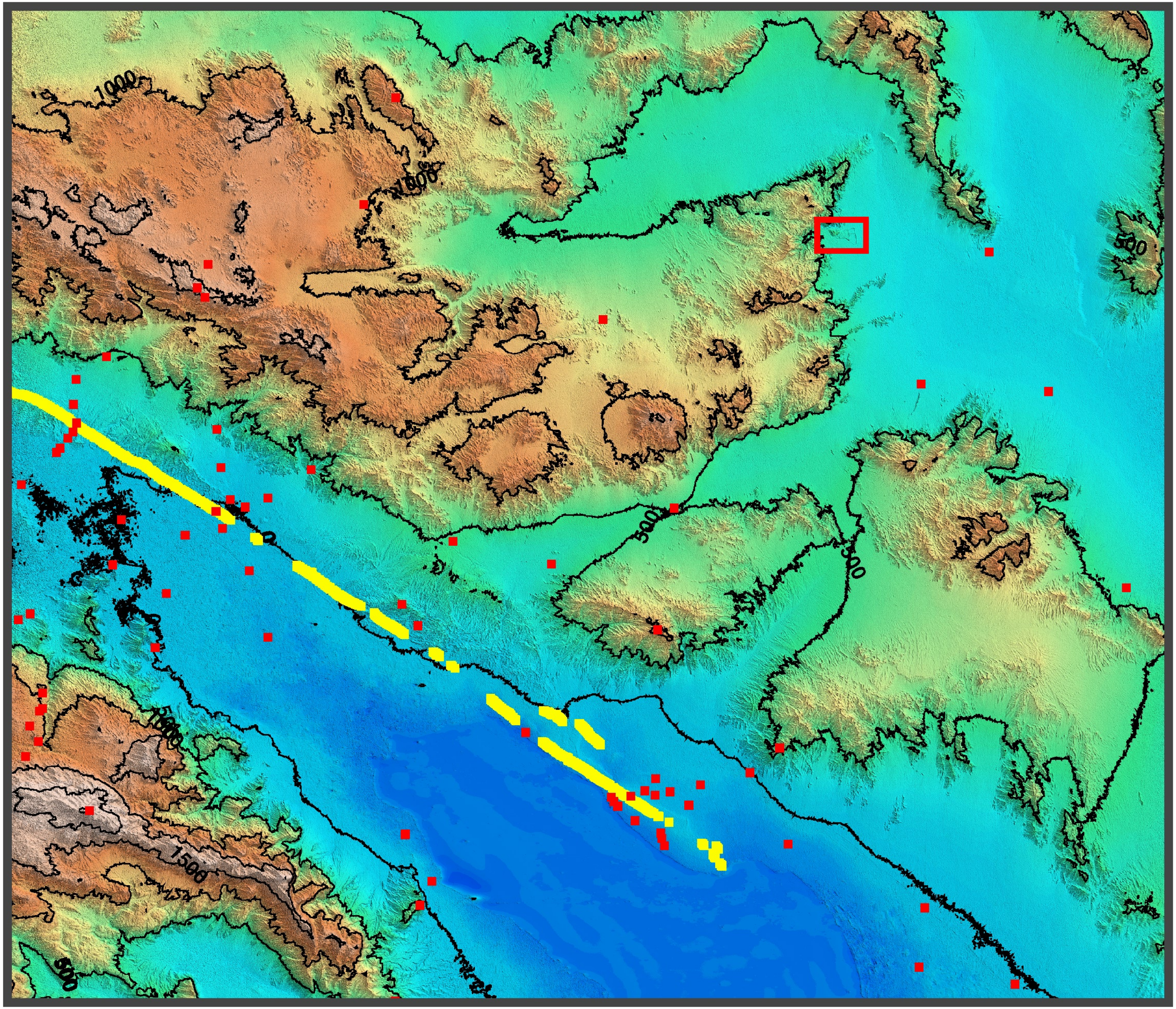
5) This is a zoom of the previous interferogram. Estimate the height difference between Toro Peak and the Salton Sea. Identify areas of layover?

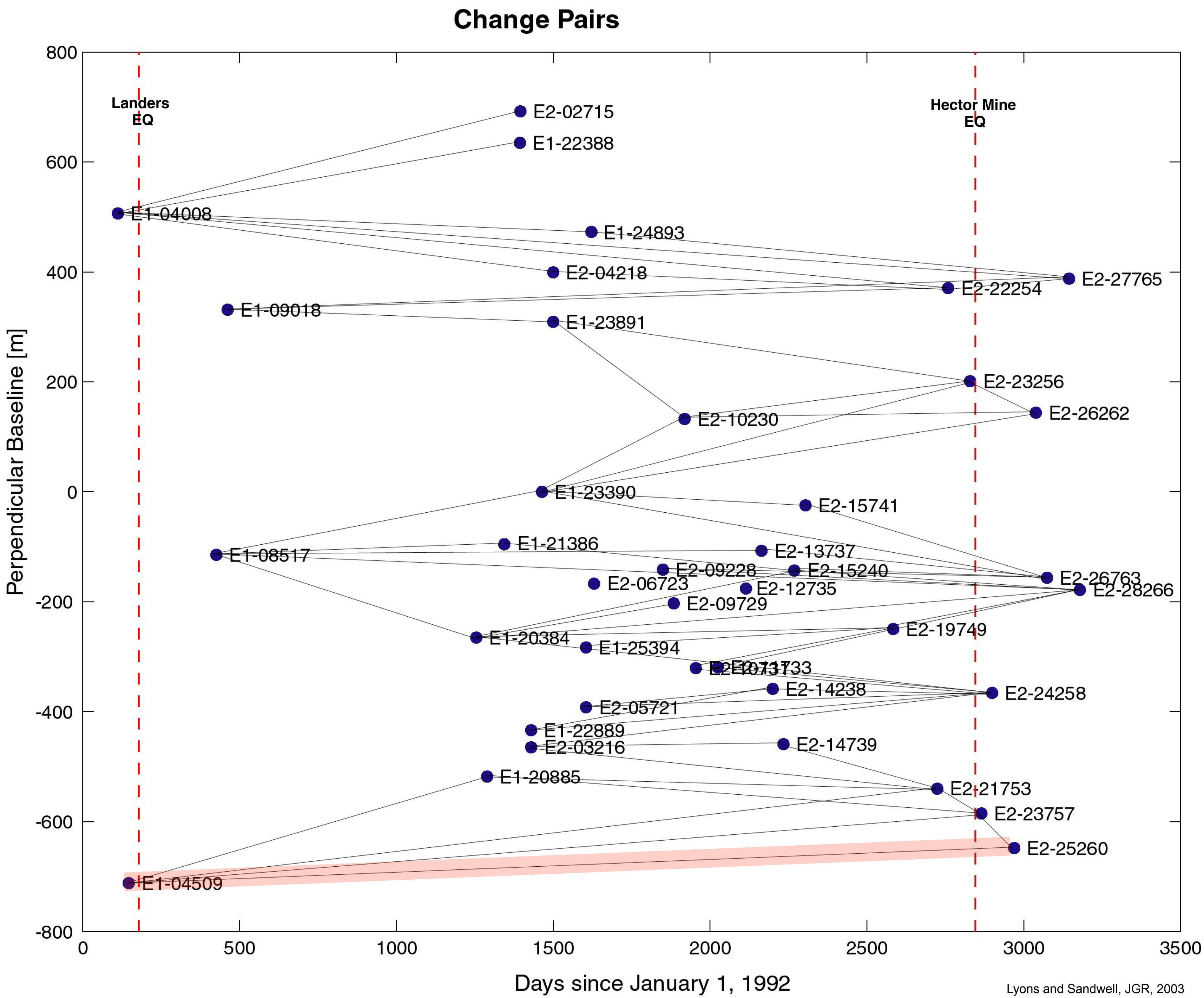
deformation and topography





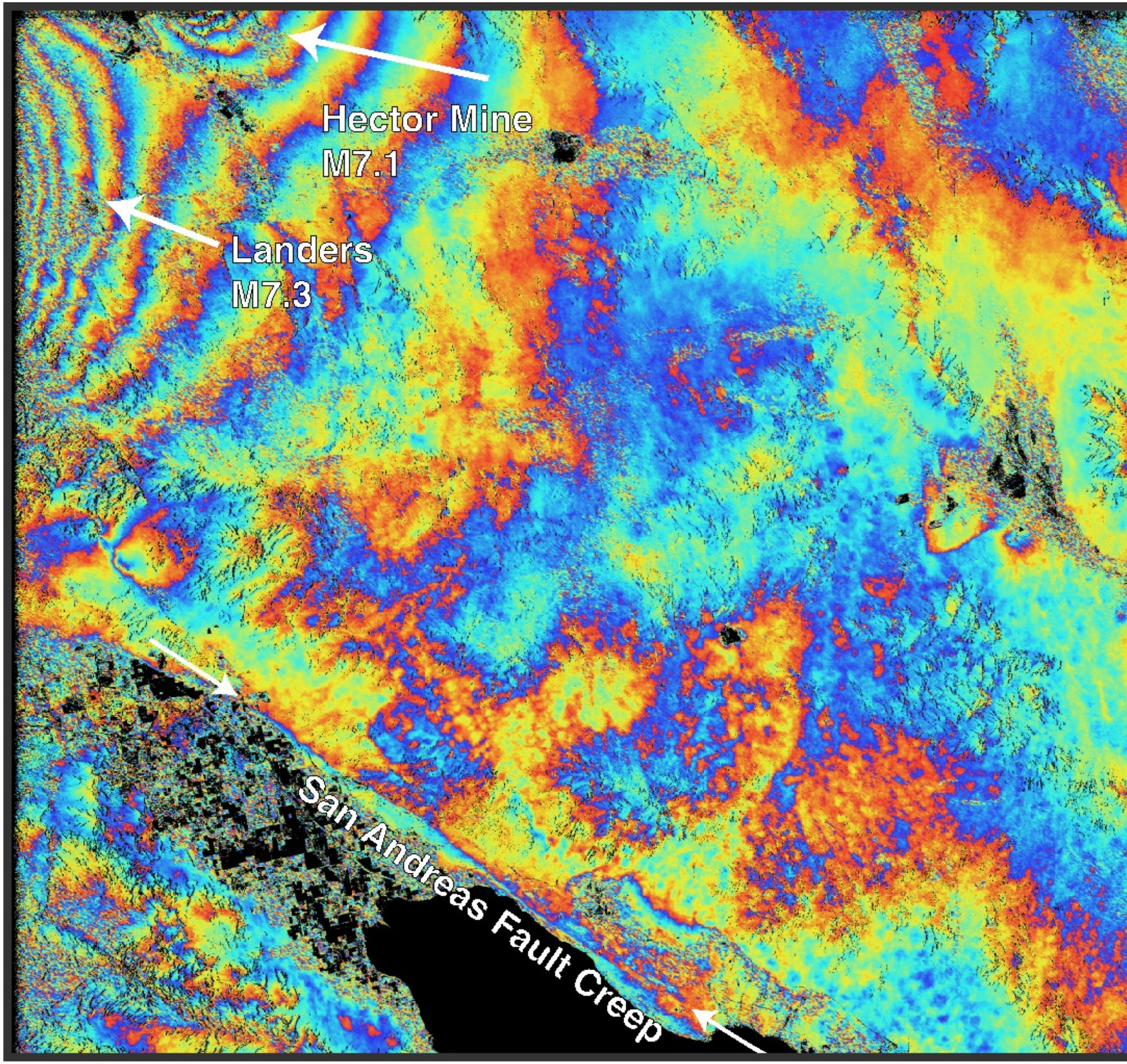
Topographic Pairs
Perpendicular Baseline [m]
Days since January 1, 1992
800
600
400
200
0
-200
-400
-600
-800
0
500
1000
1500
2000
2500
3000
3500
E2-02715
E1-22388
E1-04008
E1-24893
E2-04218
E1-09018
E1-23891
E2-22254
E2-27765
E2-23256
E2-26262
E2-10230
E1-23390
E2-15741
E1-21386
E1-08517
E2-13737
E2-09228
E2-15240
E2-06723
E2-12735
E2-09729
E2-26763
E2-28266
E1-20384
E1-25394
E2-19749
E2-14238
E2-24258
E2-05721
E1-22889
E2-03216
E2-14739
E1-20885
E2-21753
E2-23757
E2-25260
E1-04509


1000
1000
500
500
500
1000
1500
500



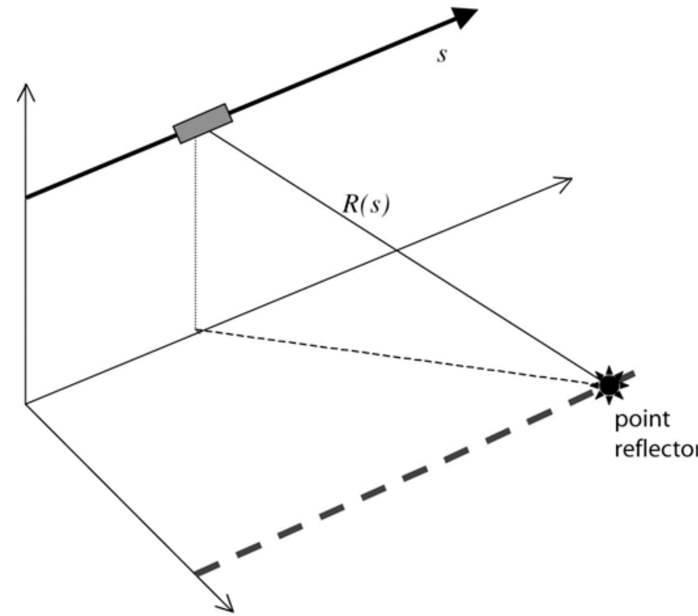
Lyons and Sandwell, JGR, 2003

Triggered slip on Southern San Andreas Fault



Need for Precise Orbits

1. proper focus
2. transform from geographic radar coordinates
3. image alignment
4. flattening interferogram



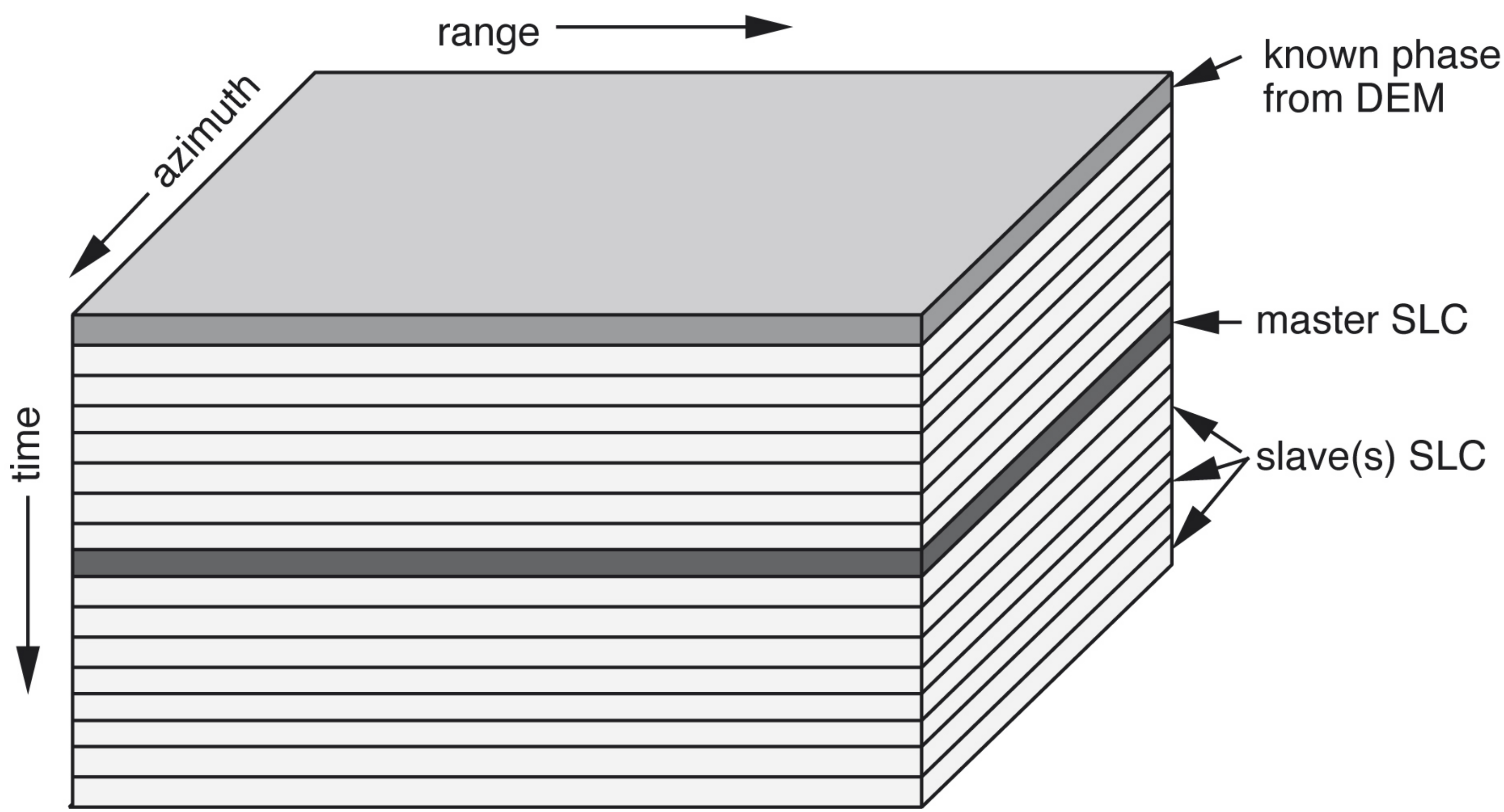
Brute force algorithm given precise orbit subroutine

pick target point

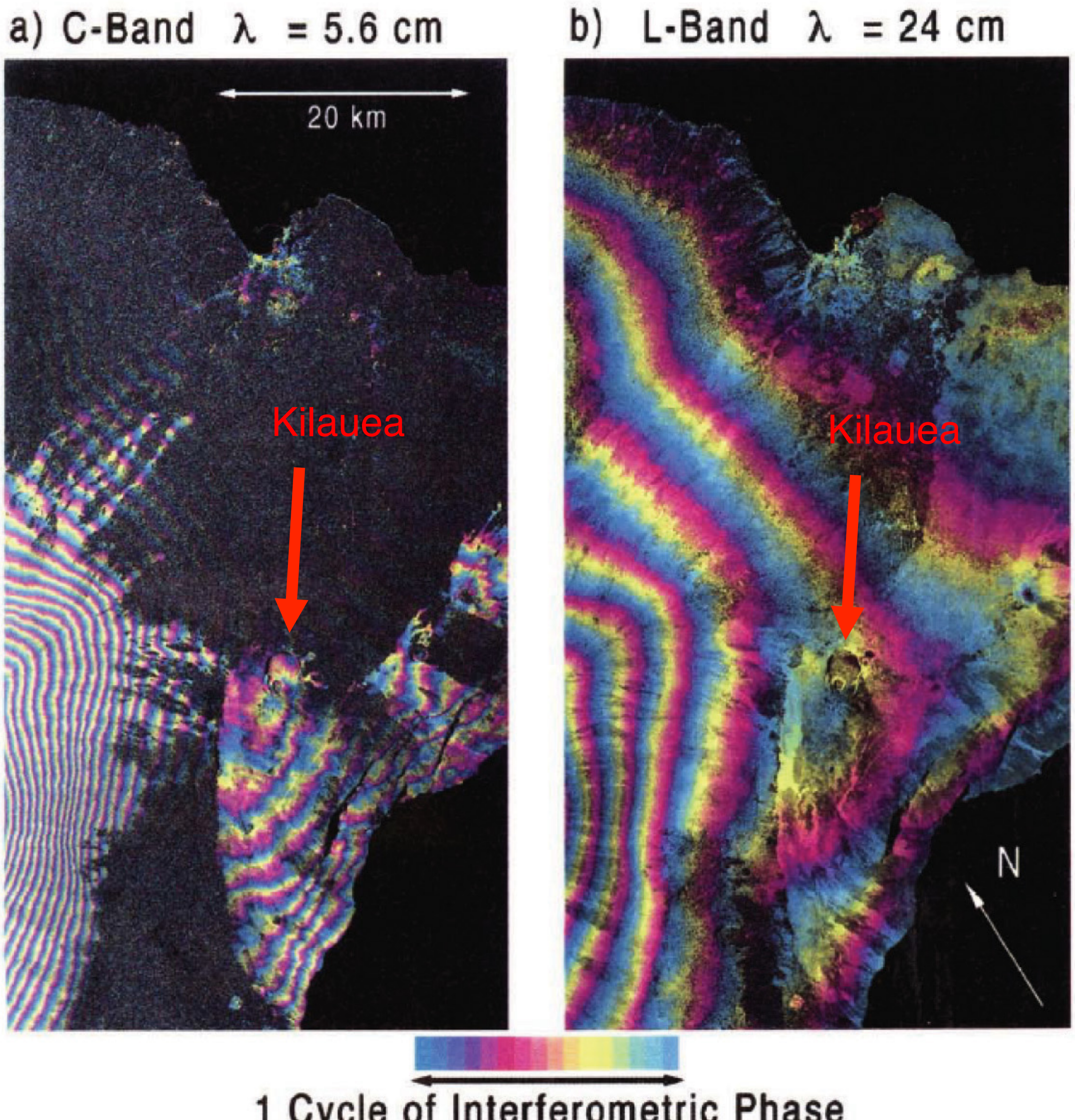
fly satellite along orbit and identify point of closest approach

(This is inefficient but computers are fast so don't waste time coding.)

Batch processing for time series



L-band vs. C-band



improved coherence

[Rosen et al., JGR, 1996]

lower fringe rate =
lower range precision?,
easier phase unwrapping

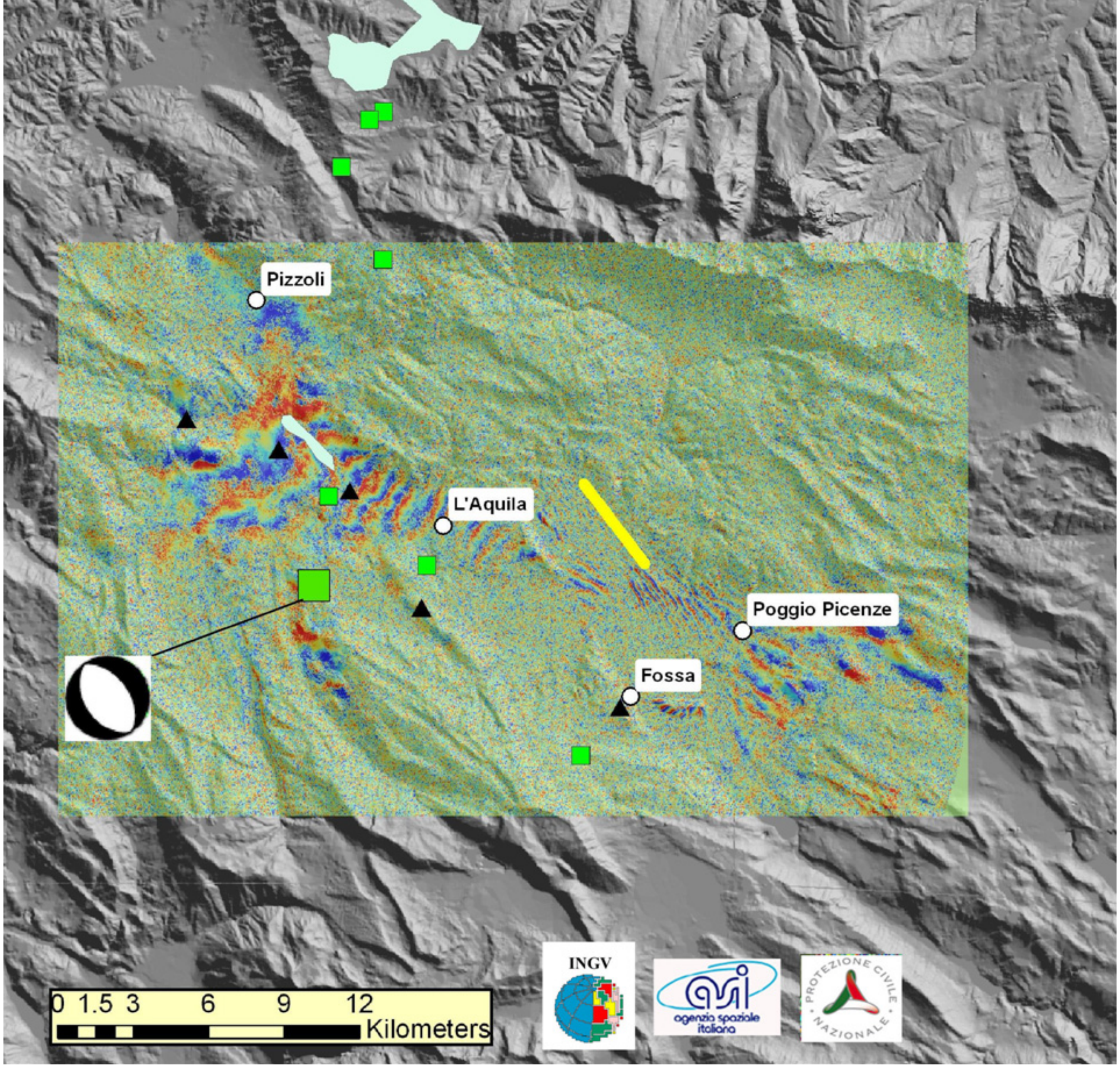
ionospheric delay 16x worse at L-band

X-band

3 cm
TerraSAR

COSMO-SkyMed interferogram using data from 19 February 2009 and 9 April 2009. Perpendicular baseline is 480 m, and the satellite's right-looking angle is 37 degrees. The large green square represents the Mw 6.3 main shock, smaller green squares represent the Mw > 5 aftershocks, the yellow line marks the observed co-seismic surface breaks and the black triangles represent GPS stations used for SAR validation.

http://www.esa.int/esaEO/SEM4PJ9NJTF_index_1.html

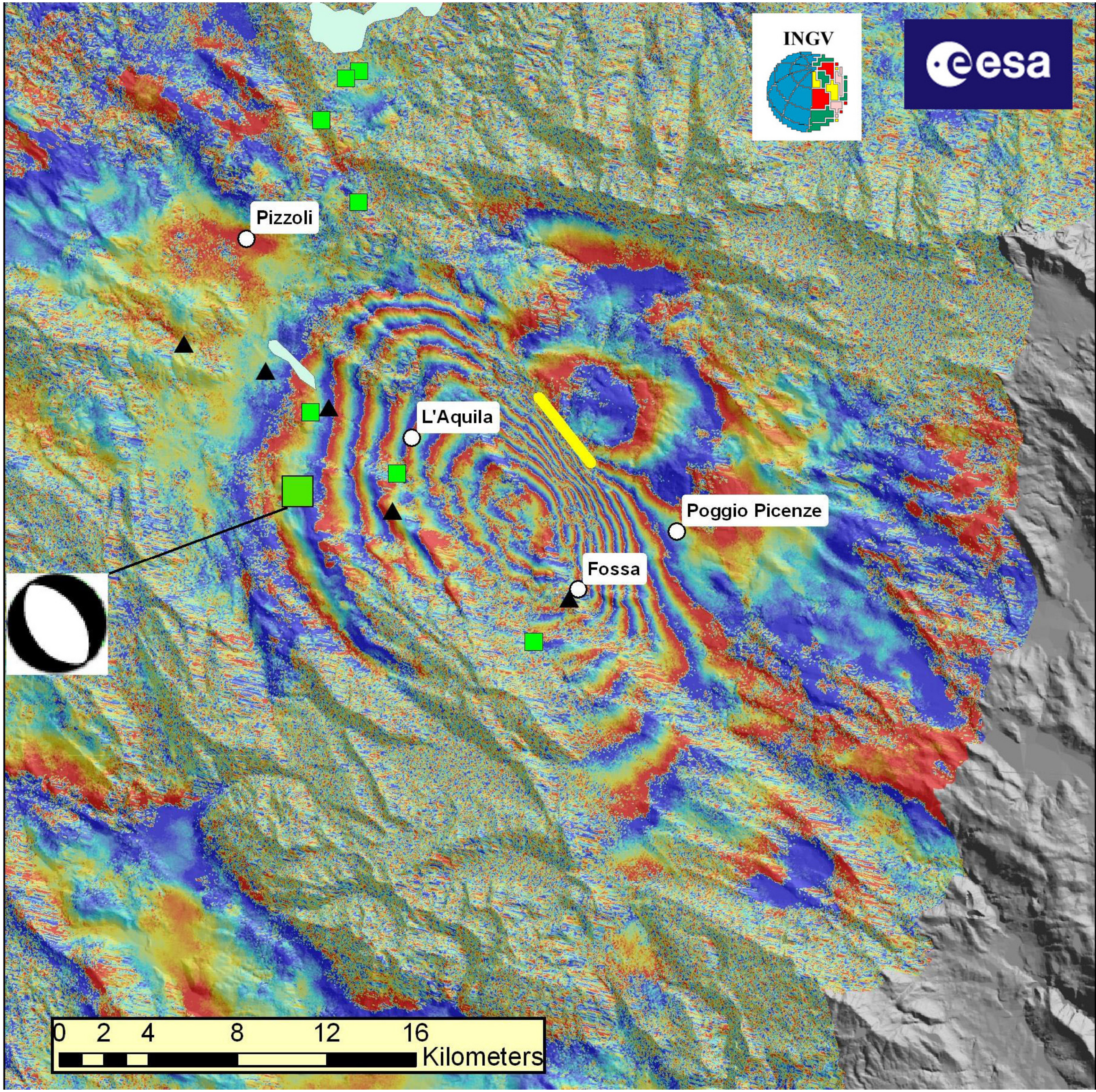


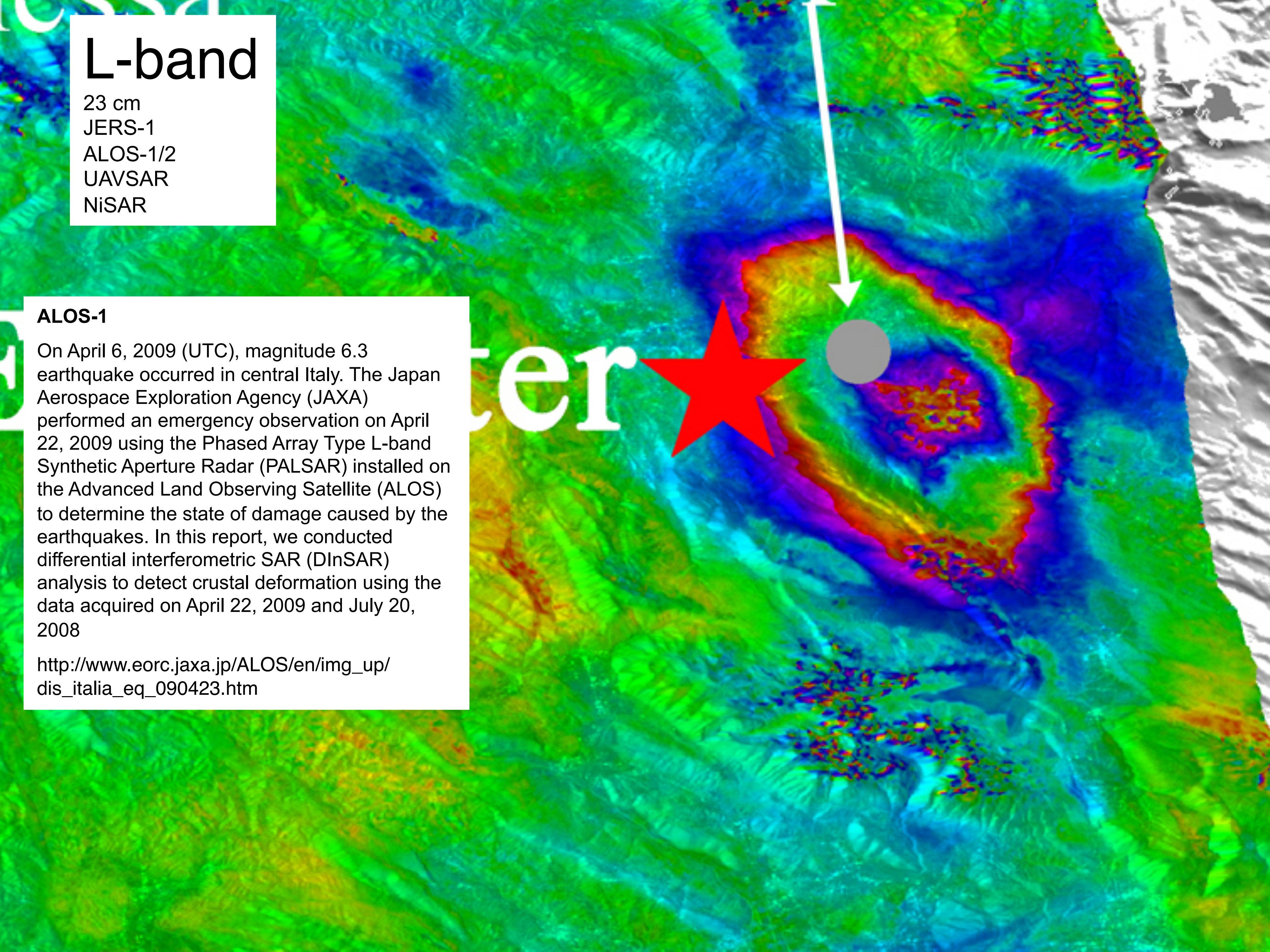
C-band

6 cm
ERS-1/2
Radarsat-1/2
Envisat
Sentinel

Envisat interferogram interpretation by Italy's Istituto Nazionale di Geofisica e Vulcanologia (INGV). The large green square represents the Mw 6.3 main shock, the smaller green squares represent the Mw > 5 aftershocks and the black triangles represent GPS stations used for SAR validation. The yellow line east of L'Aquila shows the location of a ~4 km–long alignment of co-seismic surface breaks observed in the field by INGV researchers. This alignment corresponds to a northwest - southeast strip where the spatial fringe rate seems to exceed the limit for interferometric correlation. This may indicate that the fault dislocation reached, or was very close to, the surface along this line. The observed pattern of ground displacement is in very good agreement with the earthquake source mechanism (the 'beach ball'), confirming that the earthquake source is a normal fault striking 144 degrees (clockwise from north), and dipping to the southwest.

http://www.esa.int/esaEO/SEM4PJ9NJTF_index_1.html





L-band

23 cm
JERS-1
ALOS-1/2
UAVSAR
NiSAR

ALOS-1

On April 6, 2009 (UTC), magnitude 6.3 earthquake occurred in central Italy. The Japan Aerospace Exploration Agency (JAXA) performed an emergency observation on April 22, 2009 using the Phased Array Type L-band Synthetic Aperture Radar (PALSAR) installed on the Advanced Land Observing Satellite (ALOS) to determine the state of damage caused by the earthquakes. In this report, we conducted differential interferometric SAR (DInSAR) analysis to detect crustal deformation using the data acquired on April 22, 2009 and July 20, 2008

http://www.eorc.jaxa.jp/ALOS/en/img_up/dis_italia_eq_090423.htm

HW3

1) Give two reasons why the critical baseline for ALOS is more than 10 times longer than for ERS.

2) What happens to the phase of an interferogram in areas where the slope of the topography facing the radar exceeds the incidence angle of the radar?

3) Explain the terminology, master and slaves, reference and repeat.

4) Derive equation (C8)