Measuring Horizontal Co-seismic Deformations from Optical Images, Method and Application to 1999 Hector Mine earthquake (Mw 7.1)

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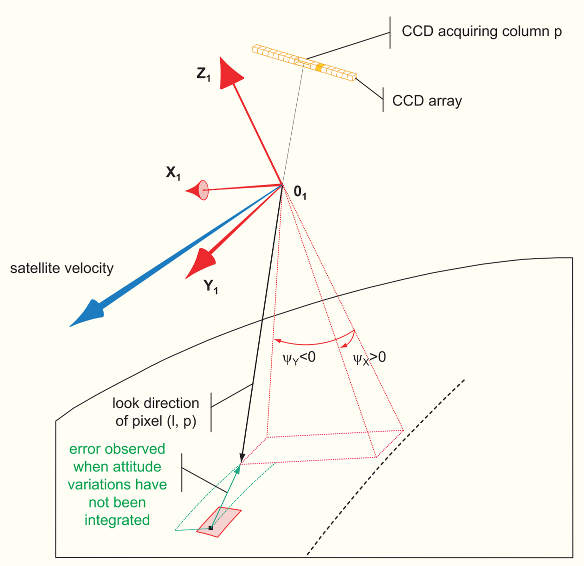
In complement to seismological records, the knowledge of the ruptured fault geometry and co-seismic ground displacements are key data to investigate the mechanics of seismic rupture. This information can be retrieved from sub-pixel correlation of optical images. We are investigating the use of SPOT satellites images and aerial images. When used together, precise measurements close and further away from the fault zone area can be delivered. The techniques developed here are attractive due to the operational status of a number of optical imaging programs and the availability of archived data. However, uncertainties on the imaging system itself and on its attitude dramatically limit the technique. We overcome these limitations by applying an iterative corrective process allowing for precise image registration that takes advantage of the availability of accurate Digital Elevation Models with global coverage (SRTM). This poster presents an application of this technique by showing accurate and dense horizontal co-seismic displacement field induced by the 1999 Hector-Mine earthquake in California (Mw 7.1).

Sub-pixel Correlation from SPOT Images

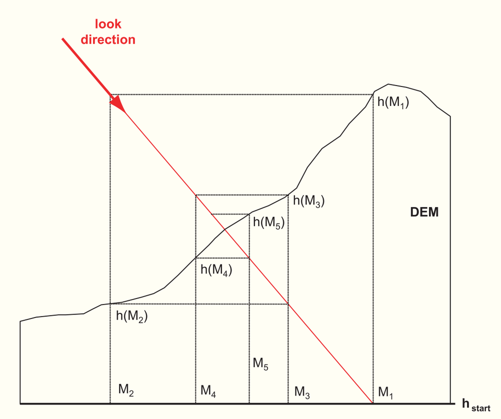
SPOT (Systeme pour l'Observation de la Terre) satellites are pushbroom imaging systems: all optical parts remain fixed during acquisition and the scanning is accomplished by the forward motion of the spacecraft. Each line in the image is then acquired at a different time and submitted to the different variations of the platform.

The orthorectification process consists in modeling and correcting these variations to produce cartographic distortion free images. It is then possible to accurately register images and look for their disparities using correlation techniques.



Attitude variations (roll, pitch, and yaw) during the scanning process have to be integrated in the image model.

Errors in correcting the satellite look directions will result in projecting the image pixels at the wrong location on the ground: important parallax artifacts will be seen when measuring displacement between two images.



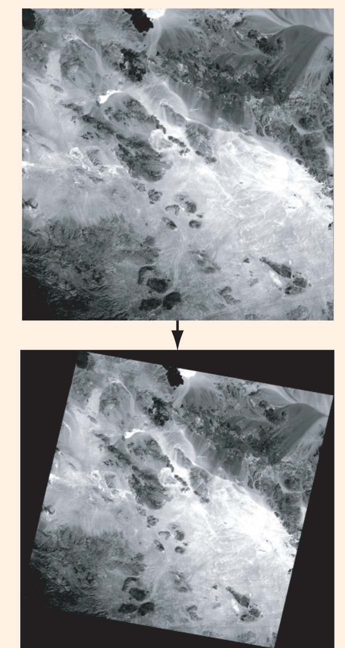
Exact pixel projection on the ground is achieved through an optimization algorithm that iteratively corrects the look directions by selecting ground control points. An accurate topography model has to be used.

Technique Limitations:

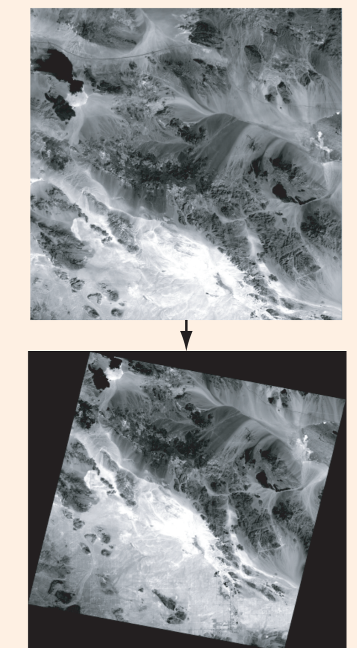
- DEM resolution
- Corrupted ancillary data
- CCD misalignements

Technique Flow Chart

Pre-earthquake image



Post-earthquake image



Inputs:

Pre and post-earthquake raw images
Acquisition parameters, platform attitude, camera model
Digital Elevation Model of the area

Rectification Stage:

Production of Level 3A orthorectified images
Both images must superimpose accurately:
GCPs may be necessary

Correlation Stage:

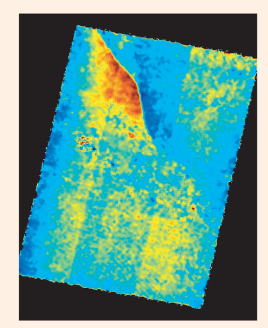
Sub-pixel Correlation

Corresponding sliding windows are successively correlated.

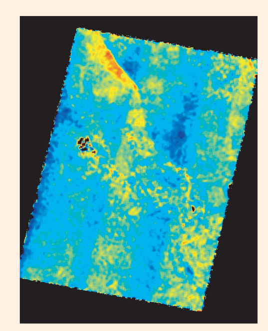
Displacement recovered by calculating the phase difference of the Fourier transform

Outputs:

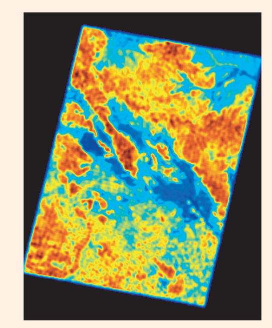
Offsets retrieved from the correlation: displacement in rows and columns provide the E/W and N/S components of the ground deformation



N/S offset field



E/W offset field

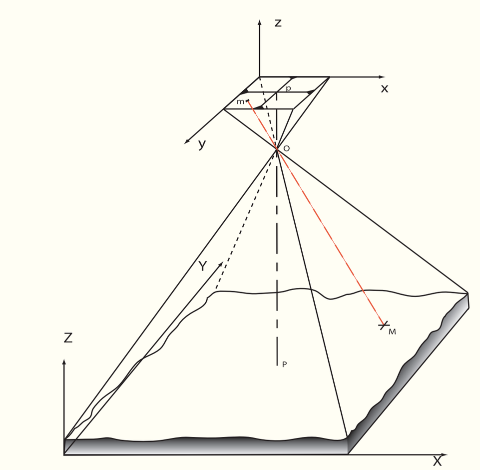


SNR

The Signal to Noise Ratio assess the measure quality. Value between 0 and 1

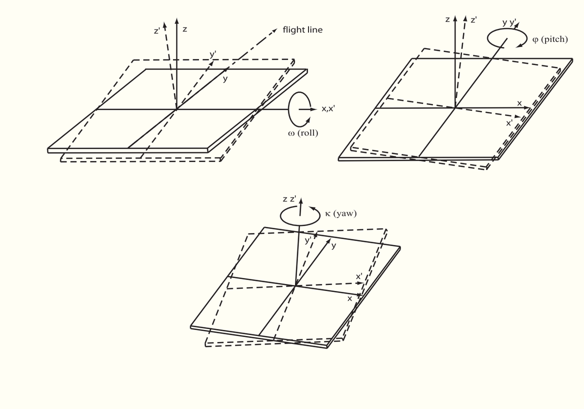
Sub-pixel Correlation from Aerial Images

Geometric model based on the collinearity relationship
OM ∧ Om = 0 ----→ $(x, y) = f(X, Y, Z)$



Internal Orientation :
Definition of the camera geometry
- focal lengh
- principal point location
- distortions correction (film shrink, lenses,...)

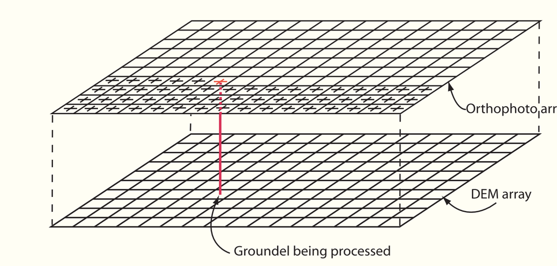
External Orientation :
Definition of the camera position and attitude
- exposure station position (Xo, Yo, Zo)
- attitude of the focal plane (ω, ϕ, κ)



Geographic coordinate system tranformation (λ, φ, h)

----→ $(x, y) = f_{Xo, Yo, Zo, \omega, \phi, \kappa}(\lambda, \varphi, h)$

Construction of the orthophoto by systematically appling the collinearity equation to each groundel of the DEM



Technique Limitations:

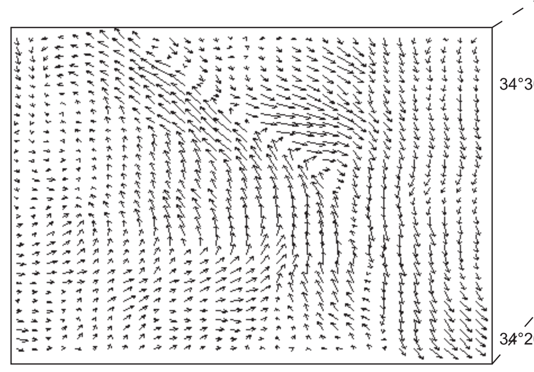
- DEM resolution
- Camera calibration report availability

The Hector Mine earthquake seen from SPOT images

Pre-earthquake image:
SPOT 4, acquisition date: 08-17-1998
Ground resolution: 10m

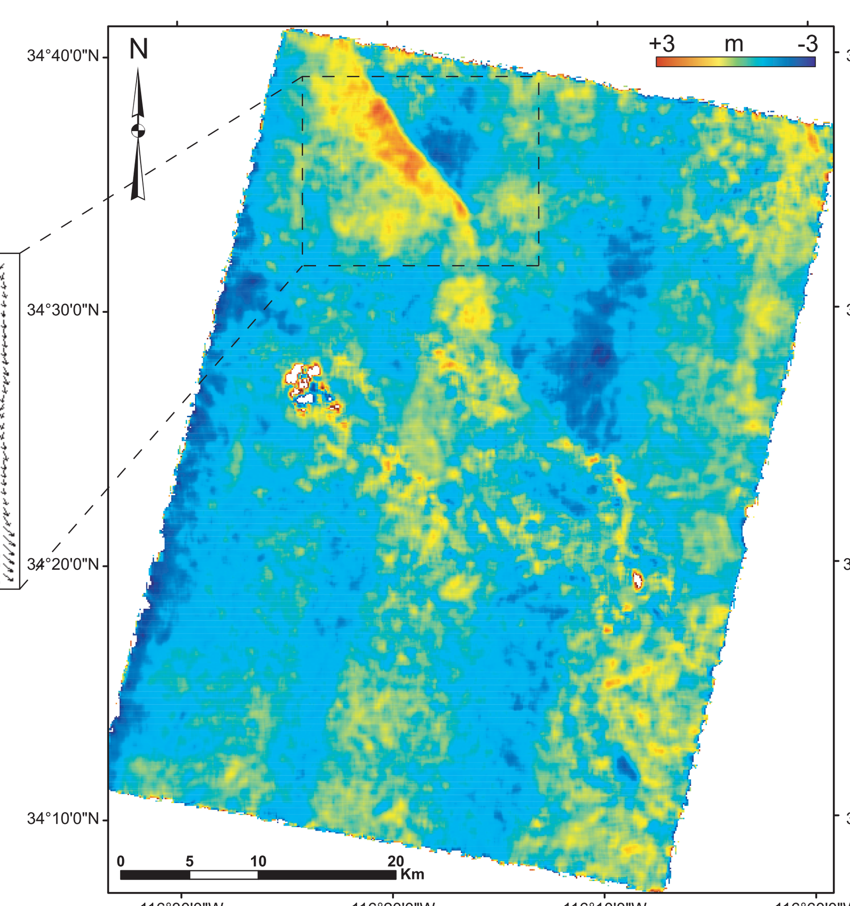
Post-earthquake image:
SPOT 2, acquisition date: 08-18-2000
Ground resolution: 10m

Offsets meaured from correlation:
Correspond to sub-pixel offsets in the raw images.
Correlation windows: 32 x 32 pixels
96m between two measurements

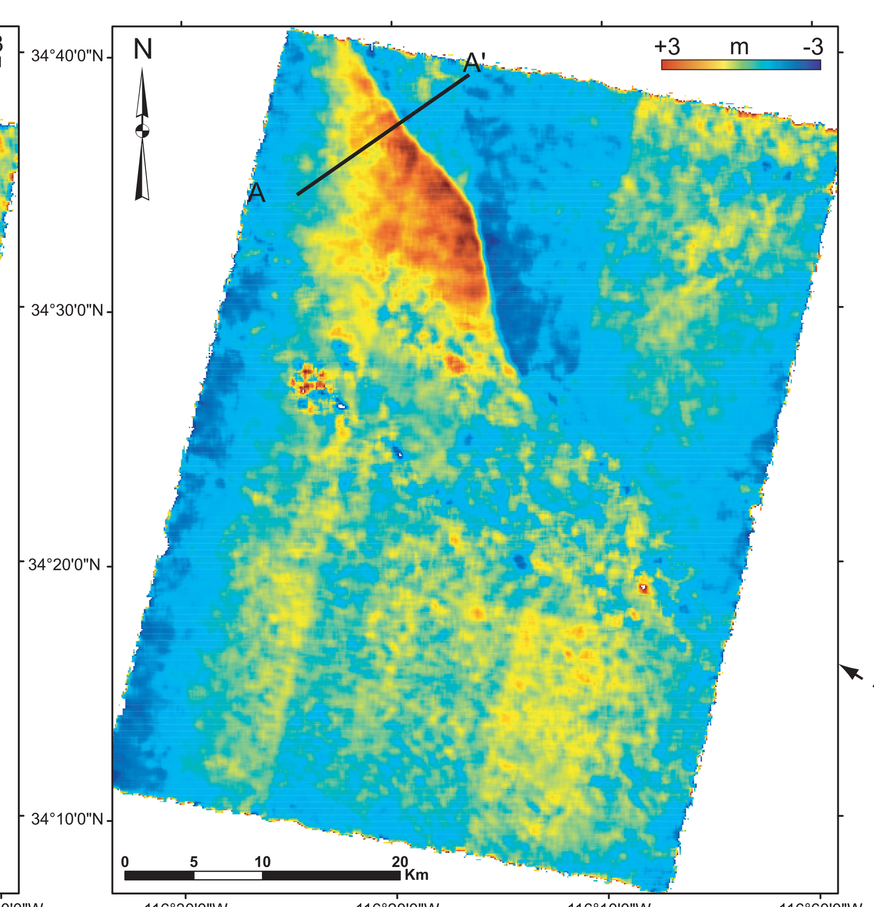


Vector field displacement

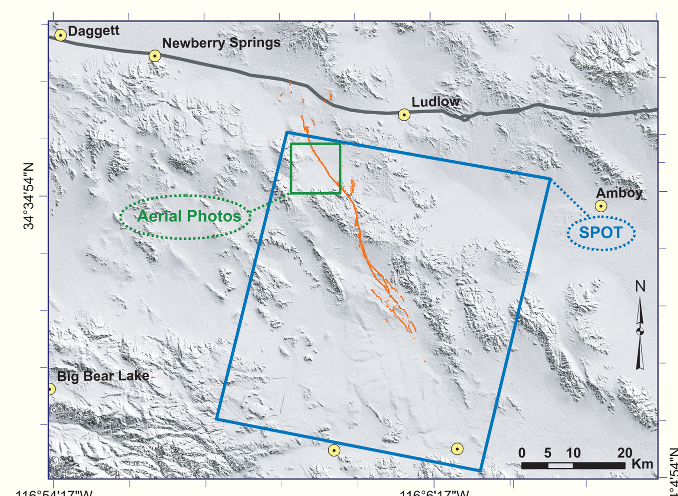
Filtered E/W Offsets



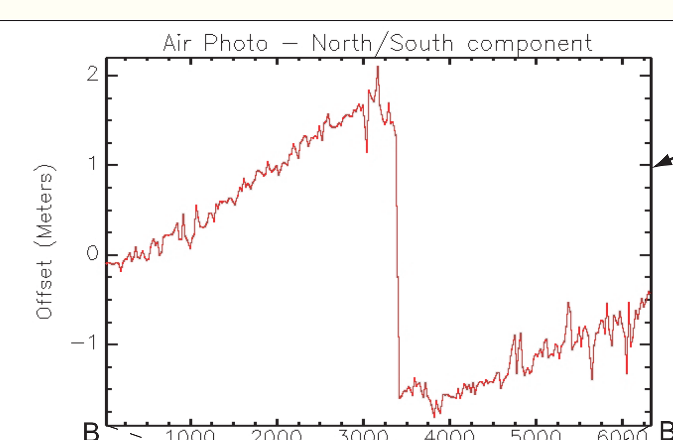
Filtered N/S Offsets

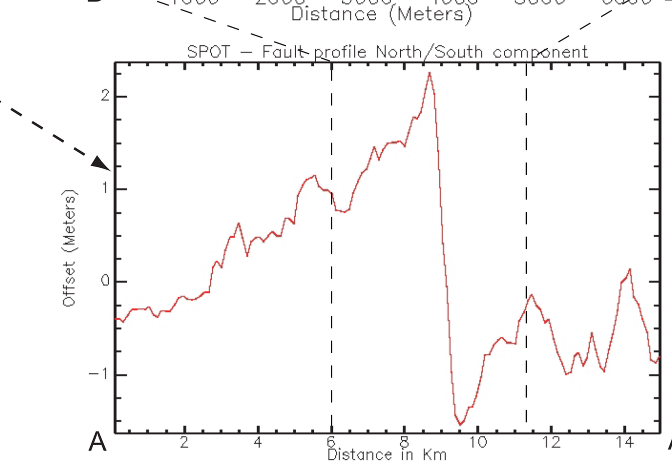


Filtered N/S and E/W horizontal SPOT offsets filtered using a 7x7 pixels sliding window (1 pixel is 96m)

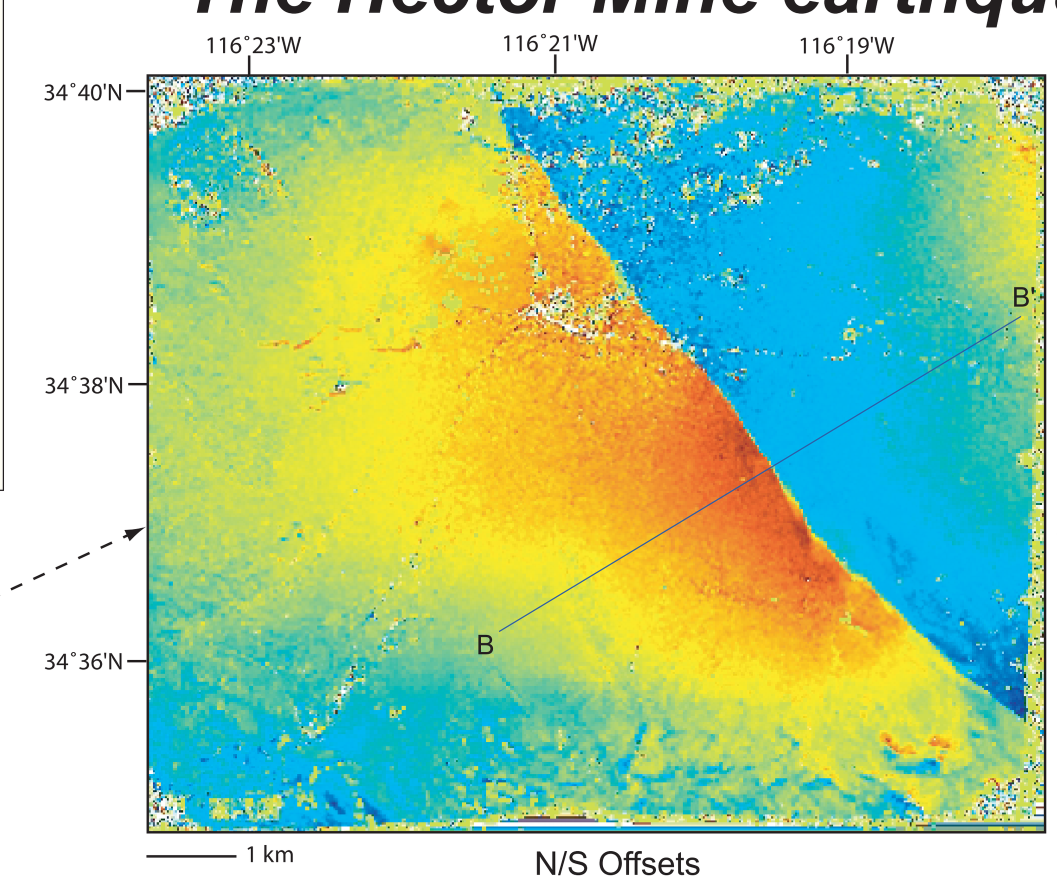


Location of the Hectormine rupture from field measurements

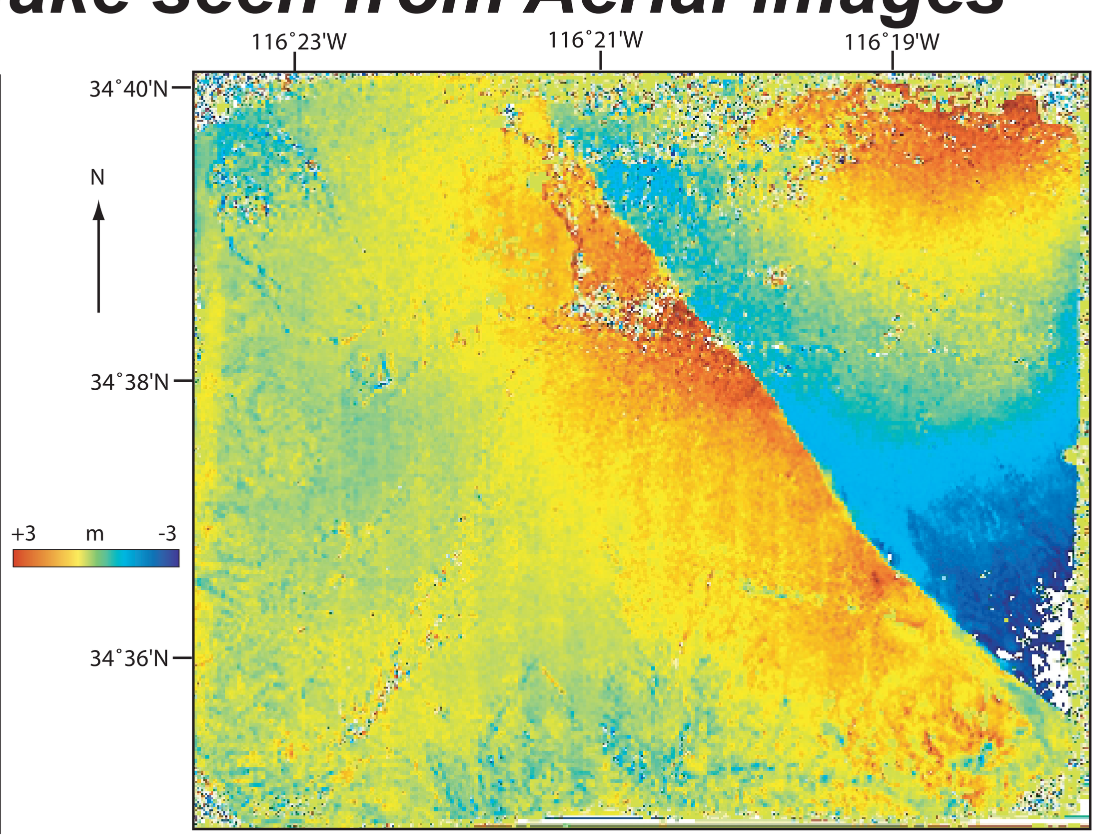




The Hector Mine earthquake seen from Aerial images



N/S Offsets

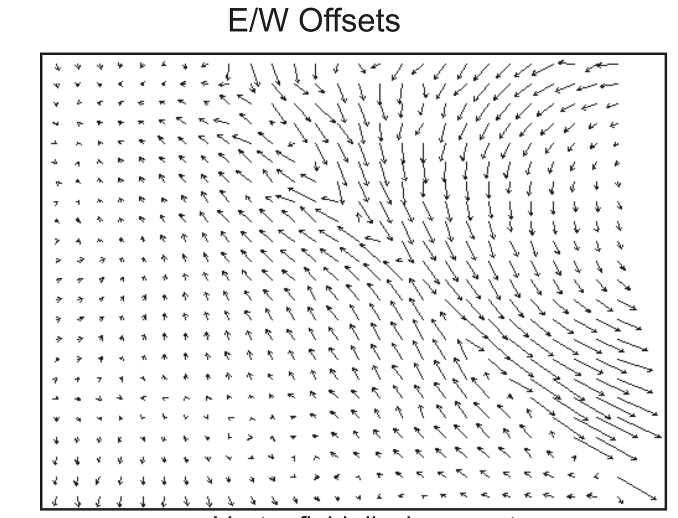


E/W Offsets

Pre-earthquake image (USGS-NAPP):
acquisition date : 7/25/89
resolution : 75cm

Post-earthquake image (USGS-NAPP):
acquisition date : 06/01/02
resolution : 75cm

Correlation image :
- 50m x 50m correlation windows
- 25m step between windows
----→ 25m displacement resolution



Vector field displacement