Measuring Ground Deformation using Optical Imagery

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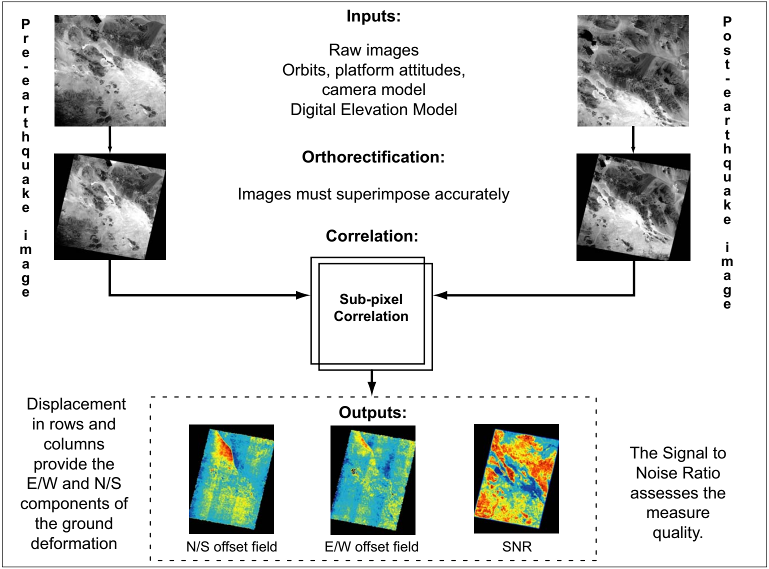
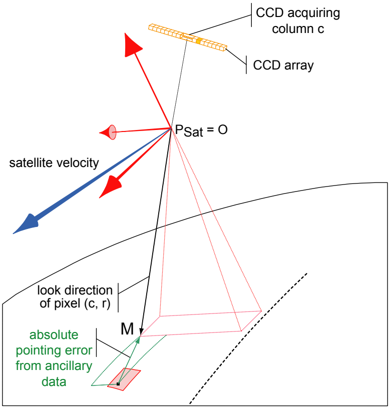
Measuring Horizontal Ground Displacement, Methodology Flow



Orthorectification Model

Pushbroom acquisition geometry



- O, optical center in space
- M, ground point seen by pixel p
- $\vec{u}_1$ pixel pointing model
- $R(p)$ 3D rotation matrix, roll, pitch, yaw at p
- $T(p)$ Terrestrial coordinates conversion
- $\vec{\delta}$ correction on the look directions to insure coregistration
- $\lambda > 0$

$$M(p) = O(p) + \lambda\left[T(p)R(p)\vec{u}_1(p) + \vec{\delta}(p)\right]$$

Image Correlation: local rigid translations

- Fourier Shift Theorem

$$i_2(x, y) = i_1(x - \Delta_x, y - \Delta_y)$$
$$I_2(\omega_x, \omega_y) = I_1(\omega_x, \omega_y) e^{-j(\omega_x \Delta_x + \omega_y \Delta_y)}$$

- Normalized Cross-spectrum

$$C_{i_1 i_2}(\omega_x, \omega_y) = \frac{I_1(\omega_x, \omega_y) I_2^*(\omega_x, \omega_y)}{|I_1(\omega_x, \omega_y) I_2^*(\omega_x, \omega_y)|} = e^{j(\omega_x \Delta_x + \omega_y \Delta_y)}$$

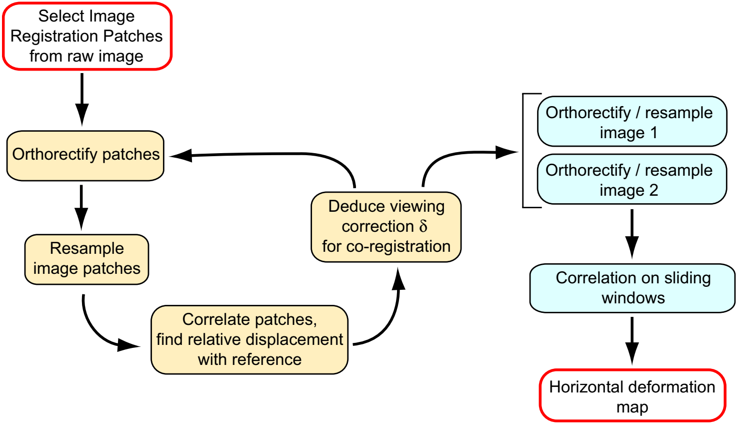
- Finding the relative displacement

$$\phi(\Delta_x, \Delta_y) = \sum_{\omega_x = -\pi}^{\pi} \sum_{\omega_y = -\pi}^{\pi} W(\omega_x, \omega_y) |C_{i_1 i_2}(\omega_x, \omega_y) - e^{j(\omega_x \Delta_x + \omega_y \Delta_y)}|^2$$

W weighting matrix. (Δ_x, Δ_y) such that ϕ minimum.

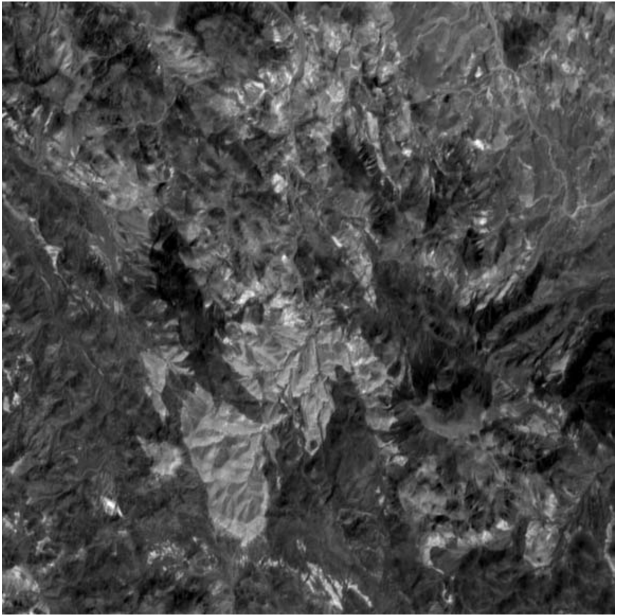
S. Leprince et al., IEEE TGRS, 2007

Processing Chain



S. Leprince et al., IEEE TGRS, 2007

1999 Mw 7.1 Hector Mine Earthquake, CA



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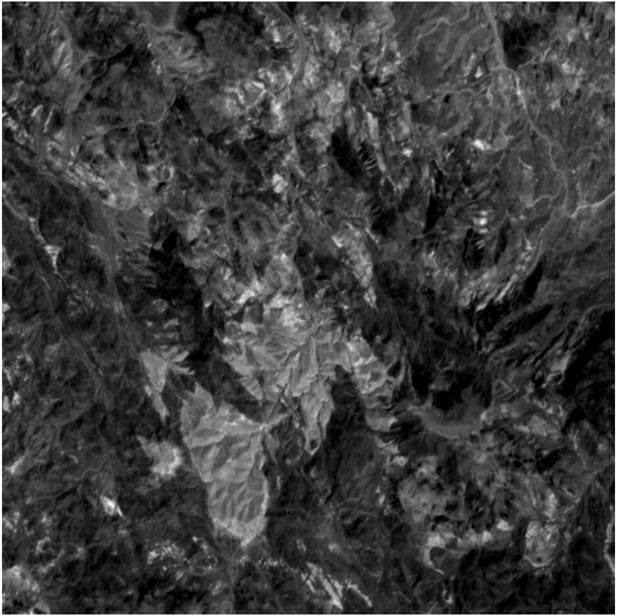

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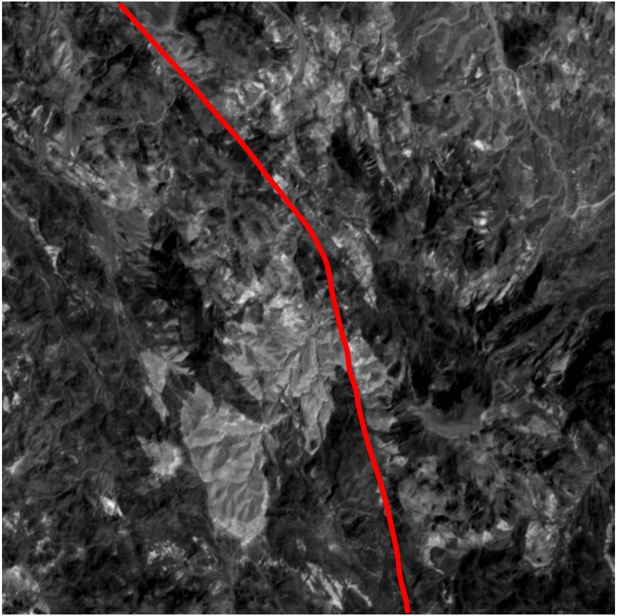
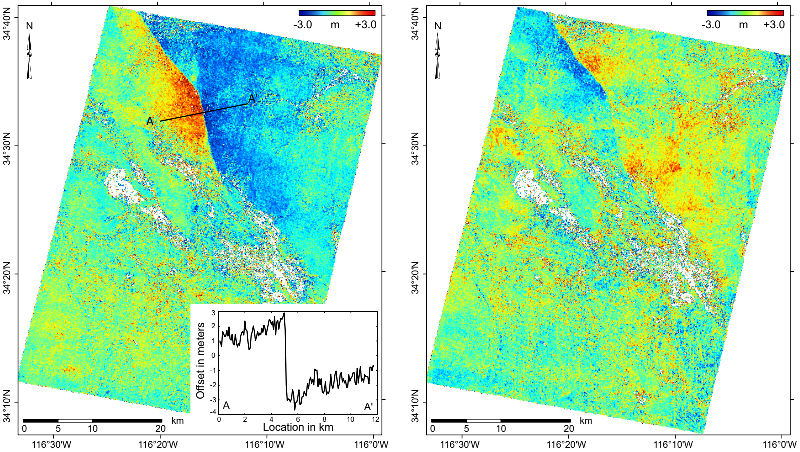
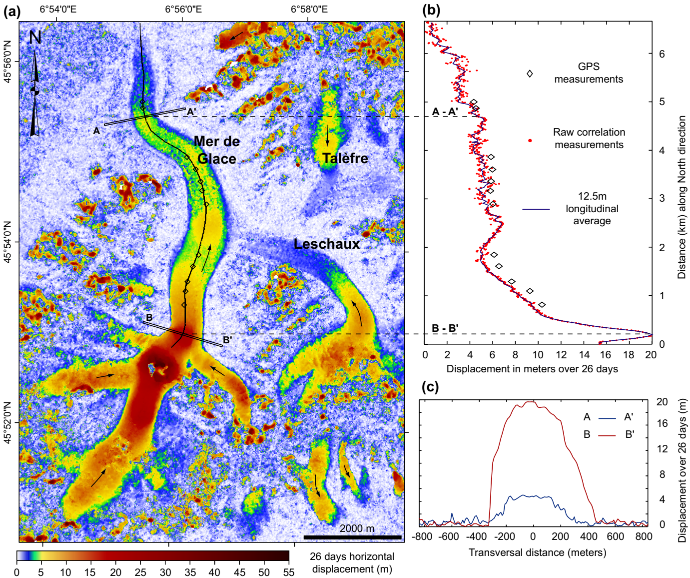


The 1999 Mw 7.1 Hector Mine Earthquake



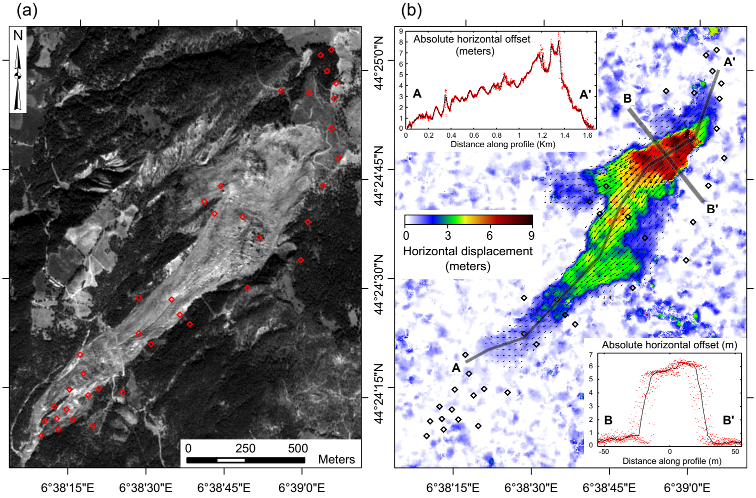
The Hector Mine horizontal coseismic field (NS and EW) once CCD distortions from SPOT4 and SPOT2 have been modeled during orthorectification. Accuracy better than 1/10 pixel.

The Mer de Glace Glacier, France



S. Leprince, et al., EOS, 2008

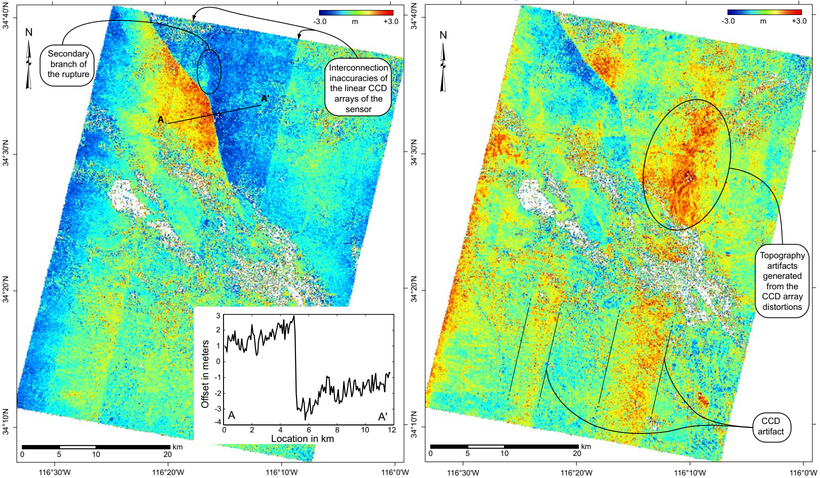
The La Valette Landslide, France



SPOT5 2.5m resolution images, 09/19/2003 - 08/22/2004

S. Leprince, et al., EOS, 2008

Geometrical Distortions: CCD misalignement

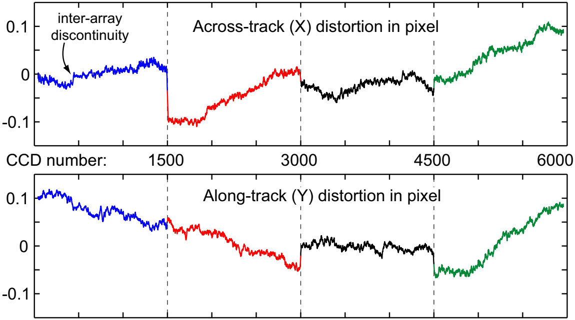


The Hector Mine horizontal coseismic field (NS and EW) showing linear artifacts due to CCD misalignment. The geometry of the CCD sensor has to be well modeled.

S. Leprince et al., IEEE TGRS, 2008

Geometrical Distortions: CCD misalignement

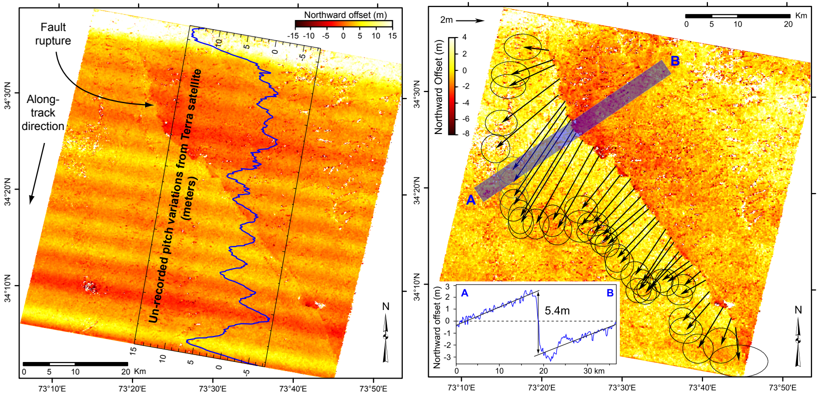
SPOT CCD distortions



- CCD Calibration model (1/100 pixel accurate) for SPOT 4-HRV1

S. Leprince et al., IEEE TGRS, 2008

ASTER attitude variations: The 2005 Mw 7.6 Kashmir Earthquake



Northward component of the correlation from 15m ASTER images acquired on 11/14/2000 and 10/27/2005. Before, and after removing pitch artifacts (destripping). Deformation mostly perpendicular to the fault that could not be measured on the field

Leprince et al., IGARSS 2007 / Avouac et al., EPSL, 2006

Topography error: modeling

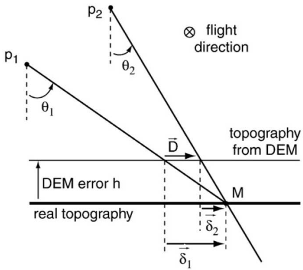


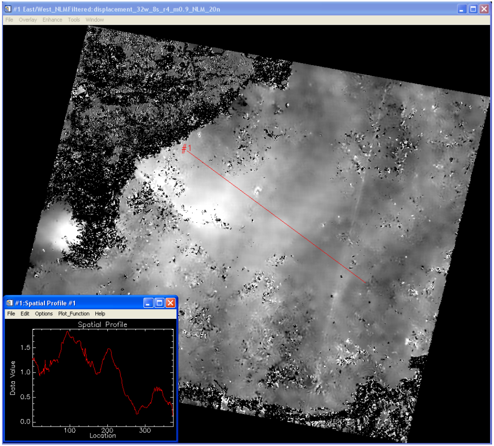
Fig. 2. Effect of DEM-error on displacement measurements. Assume a pixel p_1 from an image I_1 acquired at a date t_1 sees the ground point M, and a pixel p_2 from an image I_2 acquired at a date t_2 sees the same point M on the ground, and that both images are orthorectified and co-registered according to a DEM with an elevation error h. For simplicity, it is assumed that locally, around the ground point M, the topography and the elevation error are well approximated by constants. θ_1 and θ_2 are the angles between the line of sight of pixels p_1 and p_2, and the vertical. When the orthorectified images I_1 and I_2 are correlated, a disparity $D=\delta_1-\delta_2$, induced by the elevation error h, is measured.

Scherler et al., RSE 2008

$$D = h(\tan(\theta_1) - \tan(\theta_2))$$

- The measurement error $\vec{D}$ results from a trade-off between a well resolved topography and incidence angles difference.
- $\vec{D}$ lives in the plane $(p_1 M p_2)$, called the epipolar plane. For pushbroom systems, this plane is generally in the across-track direction, hence EW components are usually affected the most by topo biases.

Aliasing effects in deformation maps: 2001 Bhuj earthquake using SPOT images



- Optical images often aliased (CCD do not properly sample instrument PSF)
- Aliasing effects produce white noise when acquisitions have different viewing geometry
- Aliasing strongly bias subpixel measurement when images have similar viewing geometry
- Image de-aliasing or single image super-resolution still an open problem and area of active research

Future challenge for large scale monitoring

- Thus far:
  - Semi-automatic processing: manual selection of registration points. Sufficient for studies with a few dozen of images
  - Only a handful of registration points is necessary per image
- The key to large scale processing:
  - Automatic determination of a few “robust” registration points per image
    - Techniques such as SIFT can be useful to achieve this goal
    - Tricky problem when dealing with ground displacement, because registration points should be selected on stable ground

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Conclusion:

- The technique has broad applications and is valuable to measure many different surface processes, e.g, glacier flow, landslides, sand dunes migration, volcanoes
- Generally valuable to any change detection application, whenever precise co-registration of images and/or spectral bands is required (vegetation, agriculture, land monitoring, etc...)
- Could envision operational high resolution global monitoring of Earth surface changes using current satellite image databases for, e.g, large scale monitoring of mountainous glaciers, desertification, deforestation, etc...
- Optical imaging satellites have not been designed for measuring ground deformation. New applications might put new constraints on the design of future missions (tighter geometric constraints, higher image sampling, etc...)

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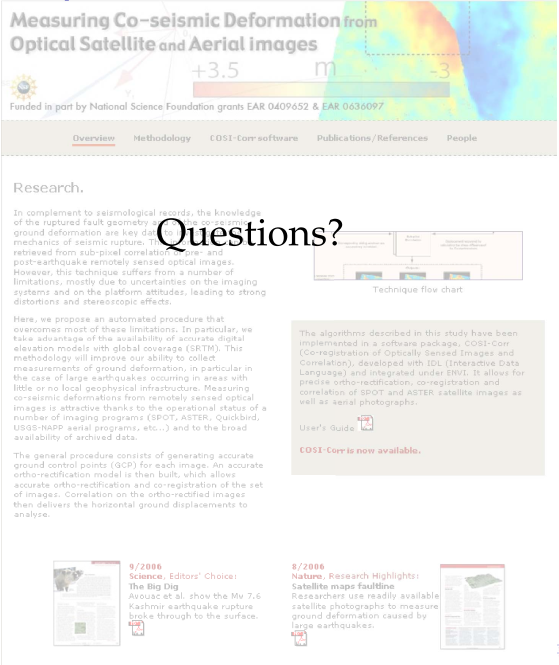
The End: Thank you!



Measuring Co-seismic Deformation from Optical Satellite and Aerial images

+3.5 m -3

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Overview Methodology COSI-Corr software Publications/References People

Research.

In complement to seismological records, the knowledge of the ruptured fault geometry and of the co-seismic ground deformation are key data to investigate the mechanics of seismic rupture. These data can be retrieved from sub-pixel correlation of pre- and post-earthquake remotely sensed optical images. However, this technique suffers from a number of limitations, mostly due to uncertainties on the imaging systems and on the platform attitudes, leading to strong distortions and stereoscopic effects.

Here, we propose an automated procedure that overcomes most of these limitations. In particular, we take advantage of the availability of accurate digital elevation models with global coverage (SRTM). This methodology will improve our ability to collect measurements of ground deformation, in particular in the case of large earthquakes occurring in areas with little or no local geophysical infrastructure. Measuring co-seismic deformations from remotely sensed optical images is attractive thanks to the operational status of a number of imaging programs (SPOT, ASTER, Quickbird, USGS-NAPP aerial programs, etc...) and to the broad availability of archived data.

The general procedure consists of generating accurate ground control points (GCP) for each image. An accurate ortho-rectification model is then built, which allows accurate ortho-rectification and co-registration of the set of images. Correlation on the ortho-rectified images then delivers the horizontal ground displacements to analyse.

Technique flow chart

The algorithms described in this study have been implemented in a software package, COSI-Corr (Co-registration of Optically Sensed Images and Correlation), developed with IDL (Interactive Data Language) and integrated under ENVI. It allows for precise ortho-rectification, co-registration and correlation of SPOT and ASTER satellite images as well as aerial photographs.

User's Guide

COSI-Corr is now available.

9/2006
Science, Editors' Choice:
The Big Dig
Avouac et al. show the Mw 7.6 Kashmir earthquake rupture broke through to the surface.

8/2006
Nature, Research Highlights:
Satellite maps faultline
Researchers use readily available satellite photographs to measure ground deformation caused by large earthquakes.

Questions?