COSI-Corr v1.0 : Co-registration of Optically Sensed Images and Correlation

Toward an operational use of optical remotely sensed images for ground deformation measurements

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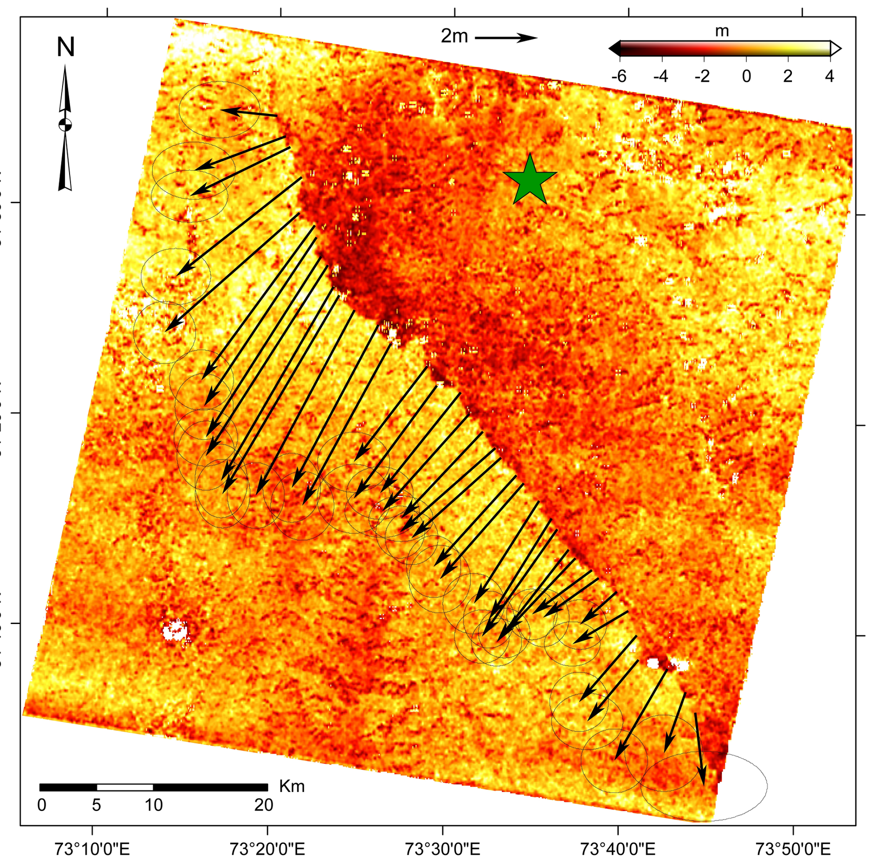
In complement to seismological records, the knowledge of the ruptured fault geometry and of the co-seismic ground deformation are key data to investigate the mechanics of seismic rupture. This information can be retrieved from sub-pixel correlation of pre- and post-earthquake remotely sensed optical 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, 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 images. Correlation on the ortho-rectified images then delivers the horizontal ground displacements to analyse.

As of November 2006, we are releasing a complete software package, COSI-Corr, developped in IDL and integrated under ENVI, that allows for such processing. In the following, we demonstrate its main capabilities, namely the processing of SPOT, ASTER and aerial images, the possibility of constraining aerial images with satellite derived measurements, and the convenient use of batch processing for intensive computations.

The 2005, Mw 7.6 Kashmir earthquake: Sub-pixel correlation of ASTER images



The color image represents the Northward ground displacements (positive to the north), determined from the correlation of ASTER images, 15-m ground resolution, taken on November 14, 2000 (AST_L1A.003:2003527667) and on October 27, 2005 (AST_L1A.003:2031572195). The incidence angle is 8.6° for both images. This correlation image was obtained with a sliding 32×32 pixels correlation window and 8-pixel step, leading to a ground resolution of 120 m. No measurement is assigned to white points, where the correlation is lost or where outliers (where the measured ground displacement was found to exceed 10 m) have been filtered out. Correlation is lost mainly due to landslides or variation of the snow cover.

Oscillations with an amplitude of 3-4m and with a period of 5km have been removed from stacking. They were characteristic of attitude oscillations from ASTER.

Arrows represent the horizontal surface fault slip. They are determined from linear least sqaure adjustment, on each side of the fault and on each NS and EW images, of stacked profiles running perpendicularly to the rupture. Profiles are stacked over a width of 6 km and a length of 18 km. Ellipses show the 95% confidence intervals.

References:

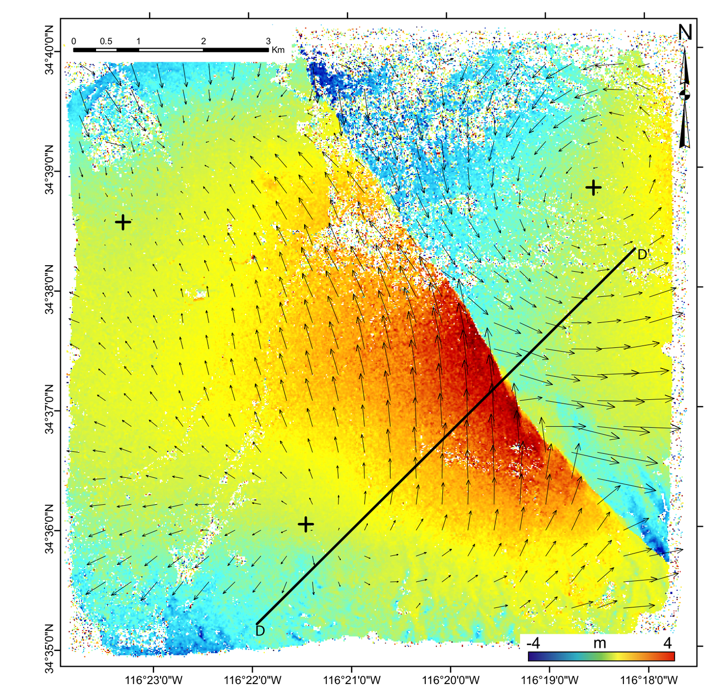
S. Leprince, S. Barbot, F. Ayoub and J. P. Avouac, "Automatic, Precise, Ortho-rectification and Coregistration for satellite Image Correlation, Application to Ground Deformation Measurements", IEEE Transactions on Geoscience and Remote Sensing, In Press 2006.

J. P. Avouac, F. Ayoub, S. Leprince, O. Konca and D. Helmberger, "The 2005, Mw 7.6 Kashmir earthquake, rupture kinematics from sub-pixel correlation of ASTER images and seismic waveforms analysis", Earth and Planetary Science Letters, vol. 249, no. 3-4, 2006, pp. 514-528.

F. Ayoub, S. Leprince and J.P. Avouac, "Aerial Photography for Seismic Ground Deformation Measurement",Submitted to ISPRS, 2006.

S. Leprince, A. Samanta and J.P. Avouac, "Edge Preserving Denoising of Optical Correlation Images, Applications to Ground Deformation Measurement", in preparation.

The 1999, Mw 7.1 Hector Mine earthquake: Using a priori information from Satellite images to better constrain Aerial images measurements



NS component of the correlation map. Three GCPs, located by the black crosses, are optimized to co-register the images without accounting for seismic ground displacement at their ground location. Arrows represent the ground displacement field accounting for both NS and EW components. Long wavelength distortions are introduced to satisfy the images co-registration.

Aerial Pre-earthquake image
USGS-NAPP, 7/25/89, 1m

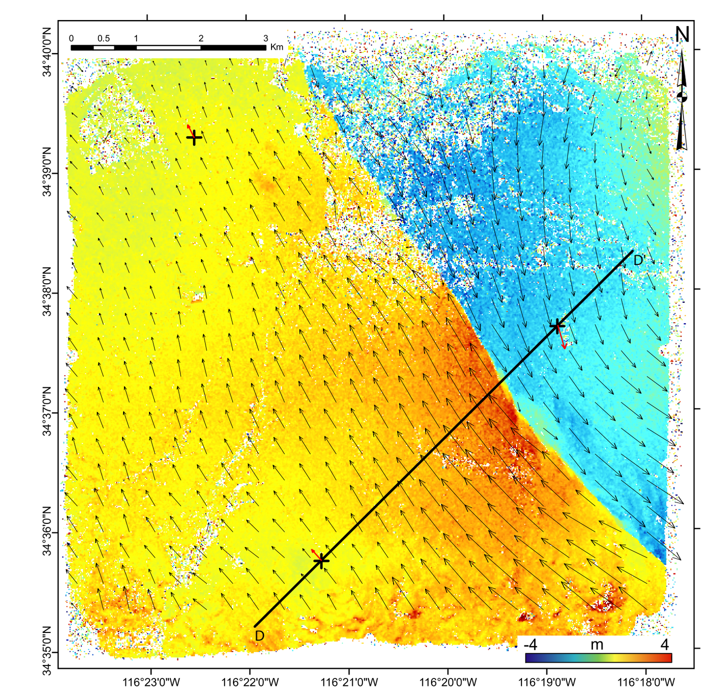
Aerial Post-earthquake image
USGS-NAPP, 06/01/02, 1m

Aerial Processing
- 128m x 128m correlation windows
- 16m between measurments

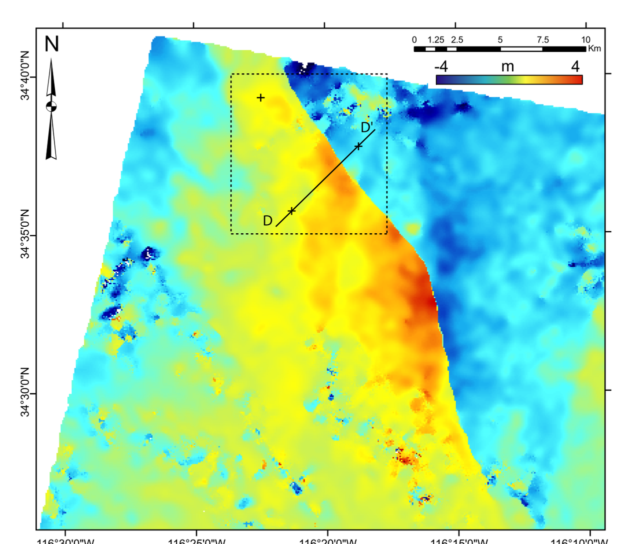
Satellite Pre-earthquake image
SPOT 4, 10m, 08-17-1998

Satellite Post-earthquake image
SPOT 2, 10m, 08-18-2000

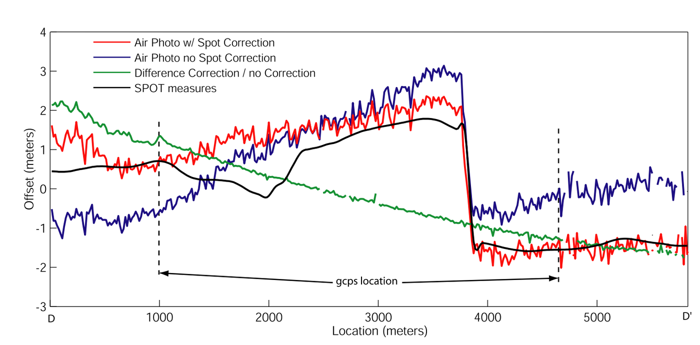
Satellite Processing
- 320m x 320m correlation windows
- 80m between measurements



NS component of the correlation map. The GCPs are optimized to co-register the images while accounting for ground displacement at their ground location (red arrow) from SPOT derived measures. Major long wavelength distortions are removed. Only may remain the long wavelength distortions caused by the SPOT correlation error, along with those introduced by film distortions.



North/South component of the denoised SPOT correlation map. The GCPs are located away from the fault to assume a null ground displacement. Images are orthorectified on a 10 m resolution grid and correlated using a 32 × 32 pixels window with a 8 pixels step. The dotted square represents the air photo footprint, and black cross indicates the location of the air photo GCPs.



Profile DD'. GCPs correction brings a 2nd order polynomial correction in each NS and EW directions. High frequency signal (displacement at the fault) is not affected however.

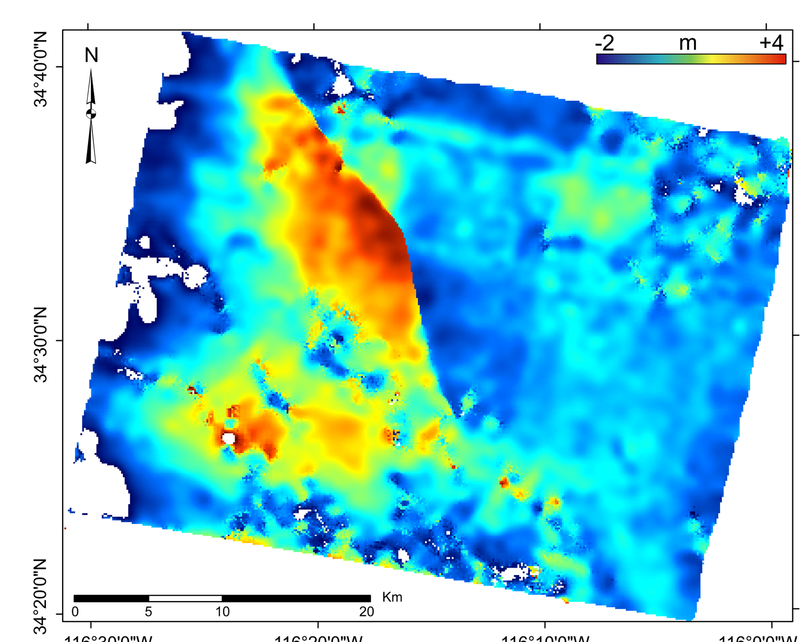
The 1999, Mw 7.1 Hector Mine earthquake: Cross-correlating SPOT and ASTER images

COSI-Corr allows the co-registration and correlation of several kinds of data. Here is an example where the co-seismic displacement of the Hector Mine earthquaue is accurately retrieved from the cross-correlation of SPOT and ASTER images. Here, only the NS compenent of the displacement is shown. The correlation map has been denoised.

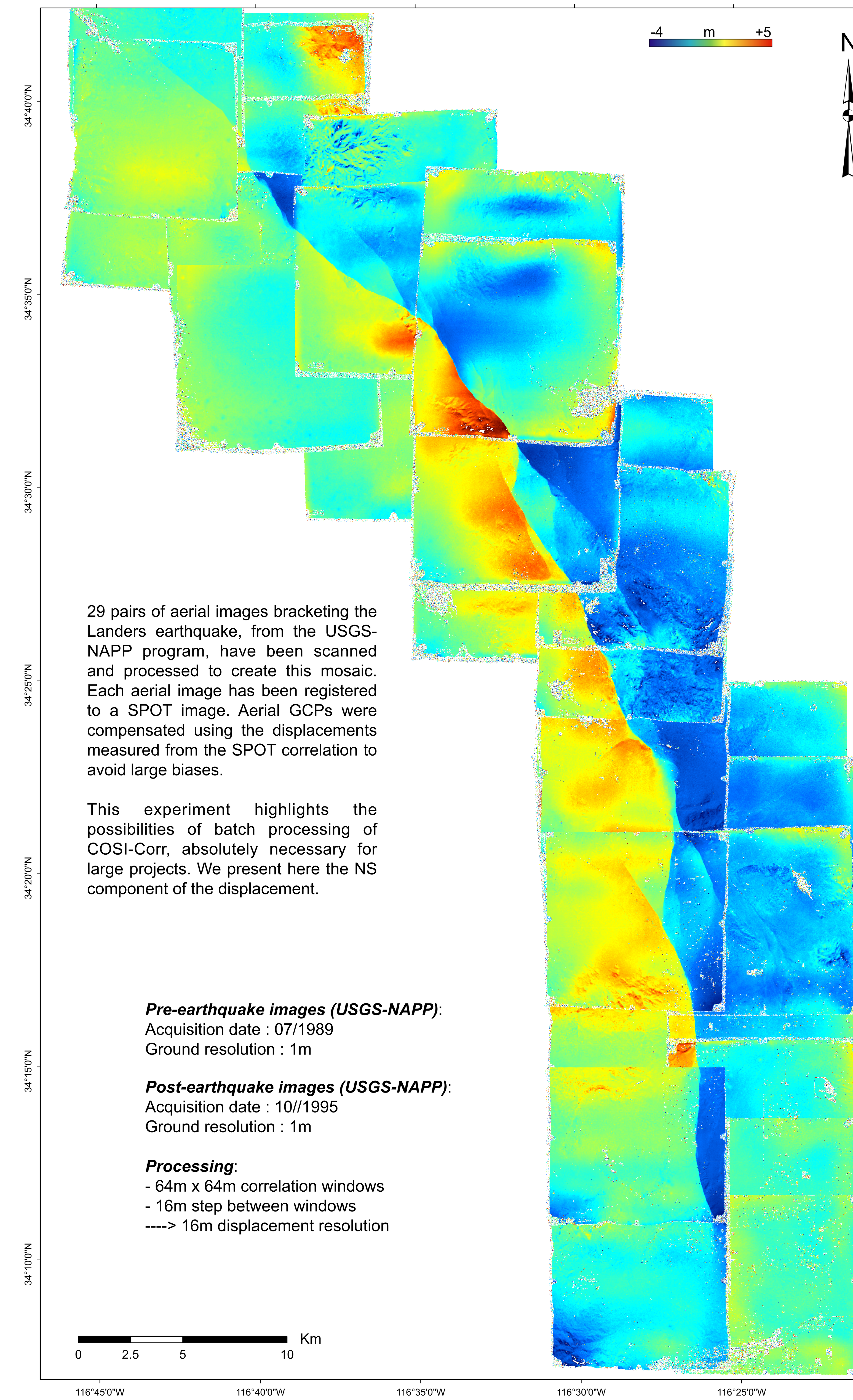
Satellite Pre-earthquake image
SPOT 4, 10m, 08-17-1998

Satellite Post-earthquake image
ASTER, 15m, 04-24-2000

Processing
- Each image is ortho-rectified at 15m
- 480m x 480m correlation windows
- 120m between measurements
- Waves artifacts due to the pitch oscillations of ASTER have been removed by stacking



The 1992, Mw 7.3 Landers earthquake from Aerial images, batch processing. SPOT images taken as reference.



29 pairs of aerial images bracketing the Landers earthquake, from the USGS-NAPP program, have been scanned and processed to create this mosaic. Each aerial image has been registered to a SPOT image. Aerial GCPs were compensated using the displacements measured from the SPOT correlation to avoid large biases.

This experiment highlights the possibilities of batch processing of COSI-Corr, absolutely necessary for large projects. We present here the NS component of the displacement.

Pre-earthquake images (USGS-NAPP):
Acquisition date : 07/1989
Ground resolution : 1m

Post-earthquake images (USGS-NAPP):
Acquisition date : 10//1995
Ground resolution : 1m

Processing:
- 64m x 64m correlation windows
- 16m step between windows
----> 16m displacement resolution

Work in progress, collaboration with Yann Klinger, IPGP, France