Monitoring Earth Surface Dynamics with Optical Imagery

Sébastien Leprince(1), Etienne Berthier(2), François Ayoub(1), Christophe Delacourt(3), and Jean-Philippe Avouac(1)

(1) California Institute of Technology, Pasadena, CA 91125, USA, Email: leprincs@caltech.edu

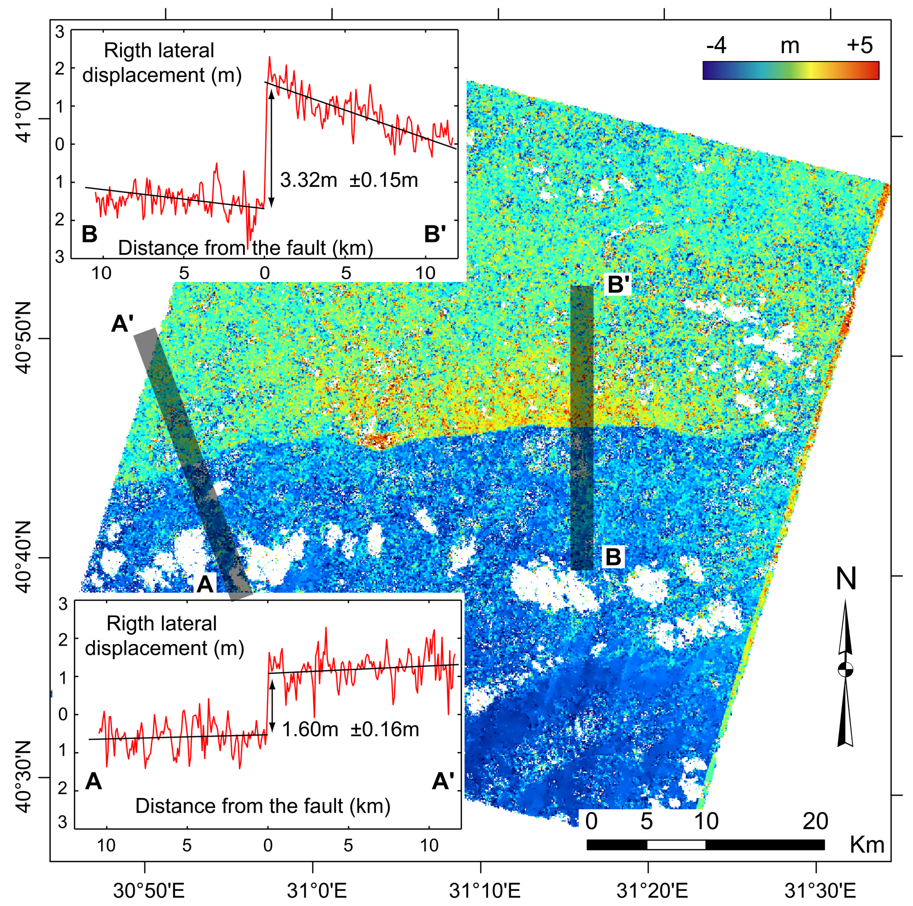
(2) CNRS-LEGOS, 14 av. Ed. Belin, 31400 Toulouse, France

(3) Domaines Océaniques, IUEM, Université de Bretagne Occidentale, Plouzané, France

The increasing availability of high quality optical satellite images should allow, in principle, continuous monitoring of Earth's surface changes due to geologic processes, climate change, or anthropic activity. For instance, sequential optical images have been used to measure displacements at the Earth's surface due to co-seismic ground deformation, ice-flow, sand-dune migration, and landsliding. Although the approach is simple in principle, it is still of limited use due to technical limitations - mainly geometric distortion of the images induced by the imaging system, biased correlation techniques, and implementation difficulties.

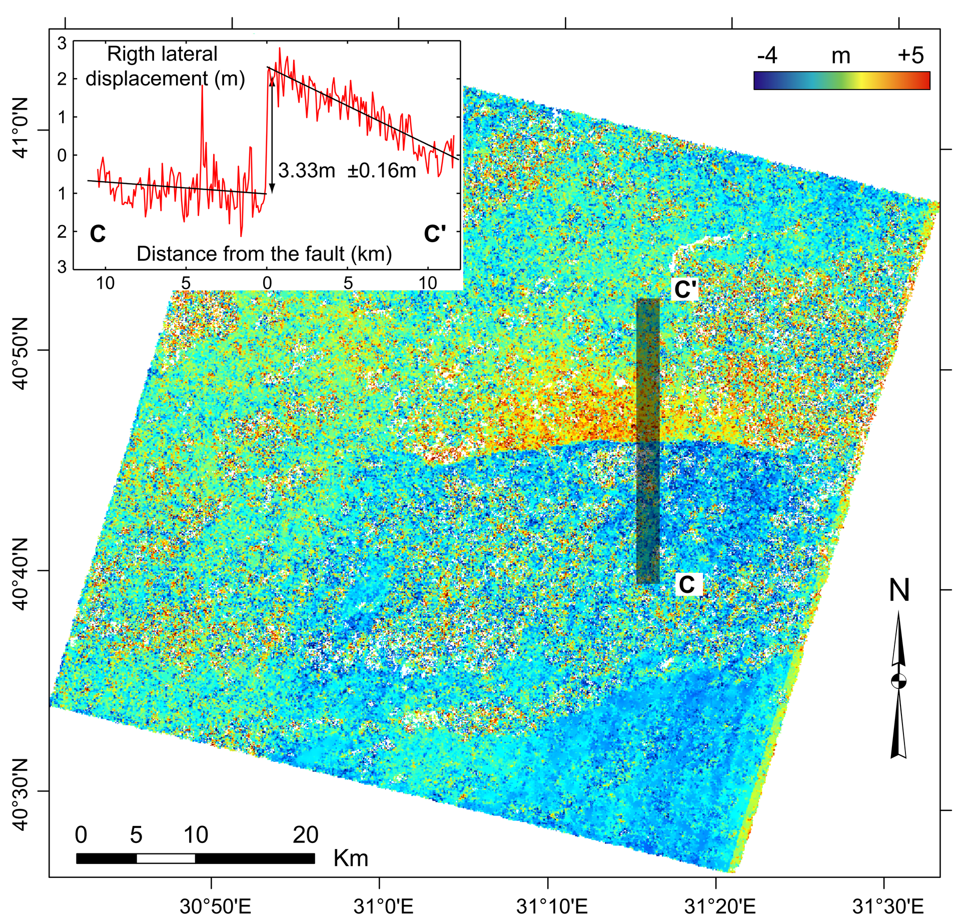
These obstacles were overcome thanks to recent methodological advances and the development of a user-friendly software package for Co-Registration of Optically Sensed Images and Correlation (COSI-Corr). The technique makes it possible to co-register images and to measure displacements at the Earth's surface with unprecedented ease and accuracy. We present here some examples of application, and point out the types of key thematic questions that can benefit from this approach.

The 1999, Mw7.4 Izmit and Mw 7.2 Duzce earthquakes, Turkey



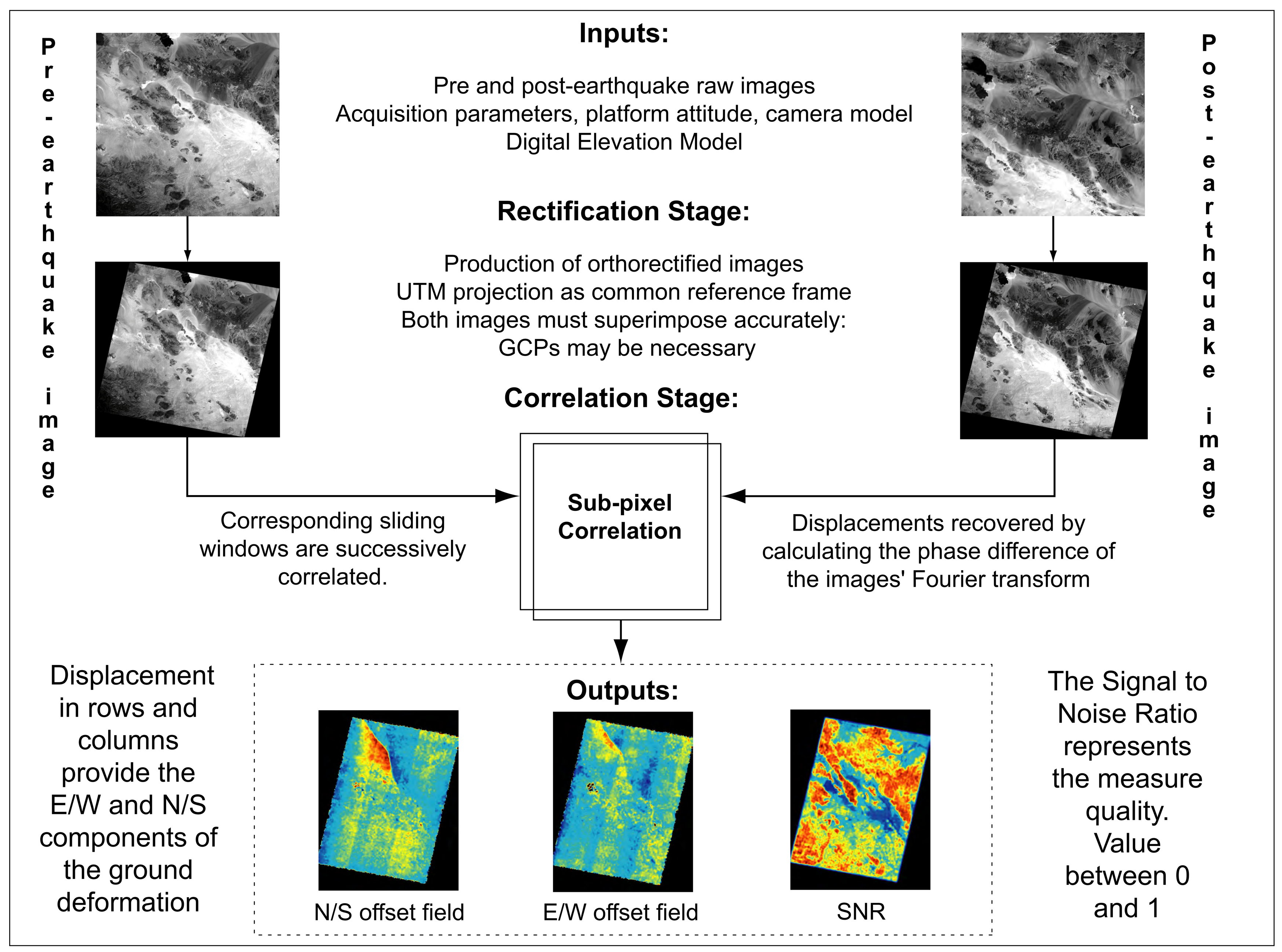
East-West component (eastward positive) of the ground displacement measured between a SPOT 1 image acquired on the 06/26/1999, and a SPOT 4 image acquired on the 07/12/2000. The Izmit earthquake occured on the 08/17/1999, and the Duzce earthquake on the 11/15/1999. This image then represents the cumulative coseismic displacement due to both events. The continuity of the ruptures is here evident, and the ground rupture can be traced all the way east where it has been missed during field surveys.

The 1999, Mw 7.2 Duzce earthquake, Turkey



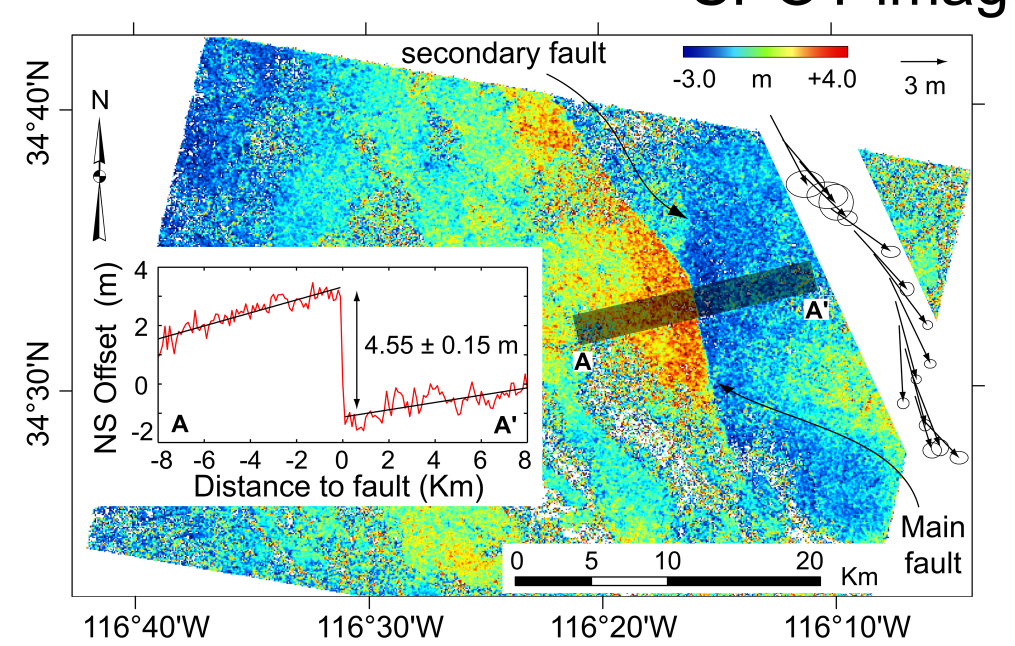
East-West component (eastward positive) of the ground displacement measured between a SPOT 1 image acquired on the 10/03/1999, and a SPOT 4 image acquired on the 07/12/2000. These images bracket only the Duzce event, so that only the coseismic displacement induced by the Duzce earthquake is analysed. This correlation image clearly indicates where the Duzce rupture starts. The profiles BB' and CC' also highlight the consistency of the measurements

The COSI-Corr Flow Chart and Methodology



The precise orthorectification procedure relies on the automatic generation of precise ground control points (GCPs). They are generated such that the correction they imply on the viewing geometry of the observing platform allows for precise ortho-rectification and co-registration of the images. We generate a precise set of GCPs from a raw image (slave), with respect to an already ortho-rectified image (master), by iteratively refining a rough selection of GCPs. Image patches from the raw slave image are orthorectified and their misregistration with the master orthoimage are estimated from correlation.

The 1999, Mw 7.1 Hector Mine earthquake, from ASTER and SPOT images



North-South component (northward positive) of the coseismic displacement field due to the 1999 Hector Mine earthquake, California. The pre-earthquake image is a 10m SPOT 4 acquisition from 08/17/1998, and the post-earthquake image is a 15m VNIR 2 ASTER acquisition from 05/10/2000. Decorrelation occurs mainly because of white sandy areas that saturate the images, or are due to differences in the spectral sensitivities. A secondary branch of the rupture that accounts for about 1m right lateral displacement is also visible. The standard deviation on individual measurements is around 1.3m.

References:

S. Leprince, F. Ayoub, Y. Klinger, and J. P. Avouac, "Co-Registration of Optically Sensed Images and Correlation (COSI-Corr): an Operational Methodology for Ground Deformation Measurements", IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2007), Barcelona July 2007.

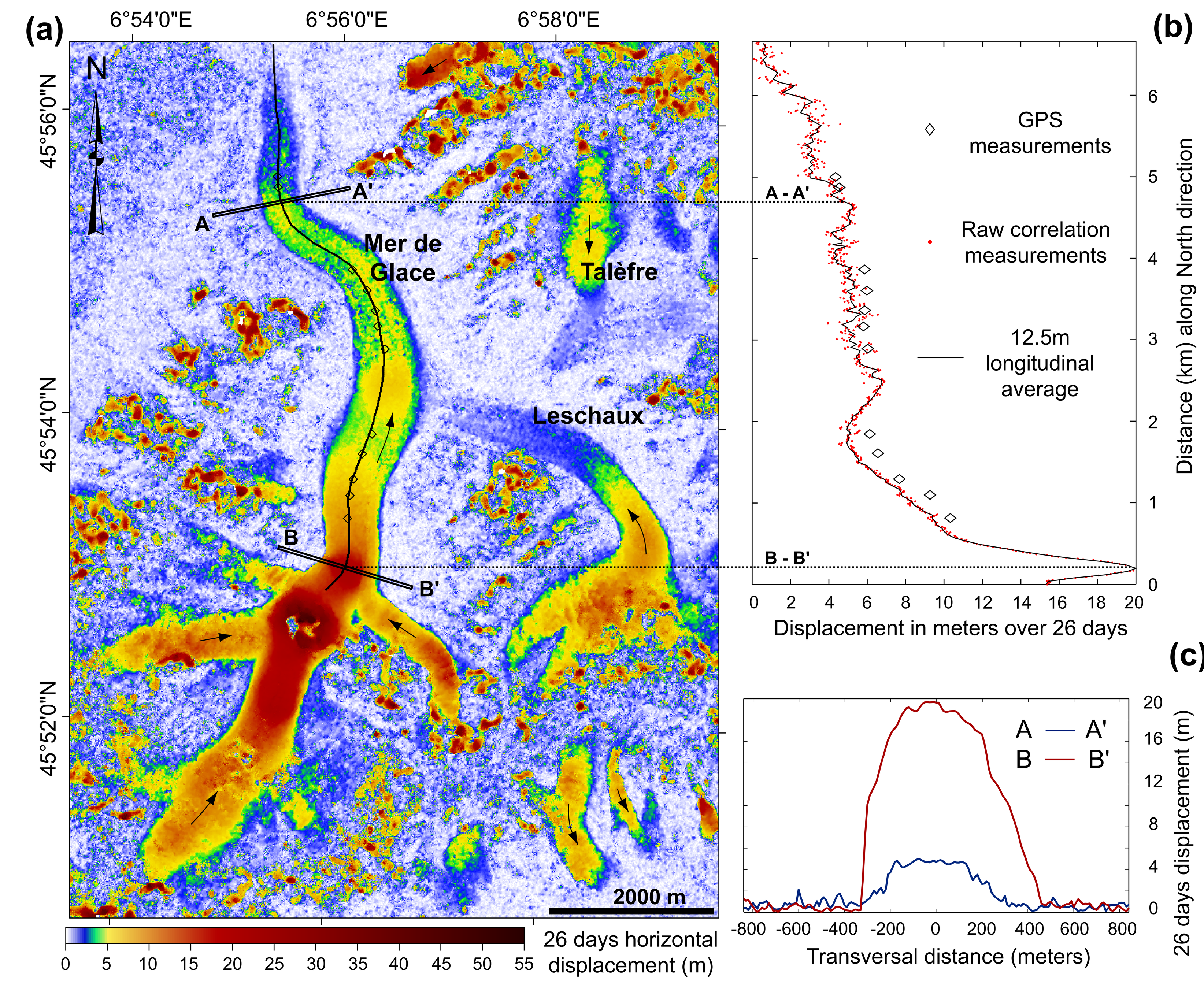
S. Leprince, S. Barbot, F. Ayoub and J. P. Avouac, "Automatic and Precise Ortho-rectification, Coregistration, and Subpixel Correlation of Satellite Images, Application to Ground Deformation Measurements", IEEE Transactions on Geoscience and Remote Sensing, Vol.45, No.6, June 2007.

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, "Measuring Ground Deformation from Air Photography Using COSI-Corr", Submitted 2007.

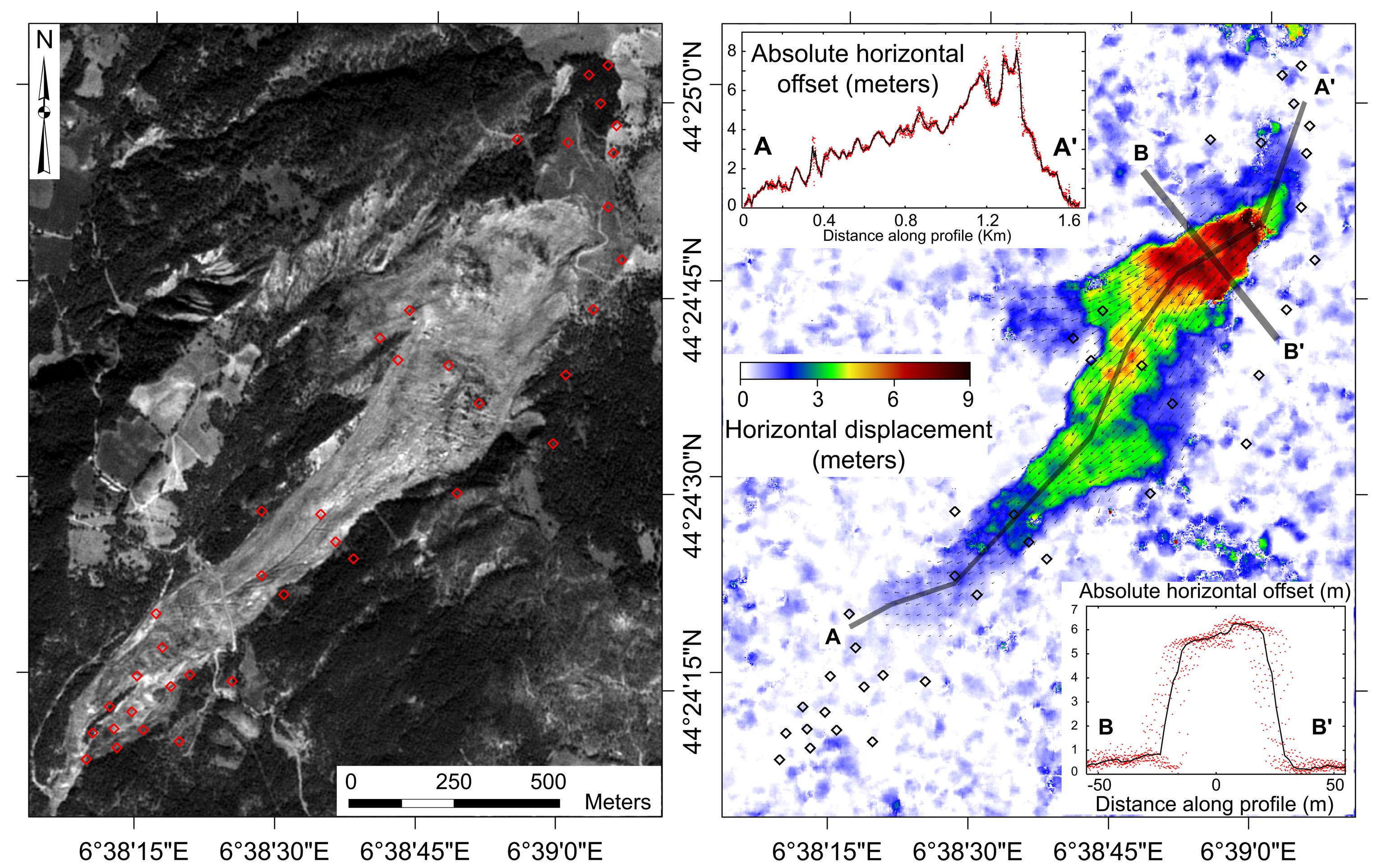
N. Van Puymbroeck, R. Michel, R. Binet, J.P. Avouac, and J. Taboury, "Measuring earthquakes from optical satellite images," Appl. Opt., vol. 39, no. 20, pp. 3486–3494, 2000.

Ice-flow monitoring using SPOT5: the Mer de Glace glacier



(a) Amplitude of horizontal displacement over the Mer de Glace area from 08/23/2003 to 09/18/2003, from two 2.5m SPOT 5 images. Displacements below 2.5m appear in blue to highlight the subpixel capabilities and the low noise level of the measurements. Displacements as high as 55m (about 800 m/yr) are recorded over this 26-day period. (b) Displacements along a central flow line of the Mer de Glace measured from SPOT5 images and from GPS campaign. The time period covered by the GPS (08/12/2003 to 09/03/2003) starts slightly earlier in the summer and includes the August 2003 European heat wave, explaining the faster velocities observed over this period. (c) Displacement along transverse profiles AA' and BB'. No topography or baseline artifacts are noticed.

La Valette landslide (French Alps) monitoring using SPOT5



(left) Orthorectified SPOT image of the La Valette landslide. The red diamonds show the geodetic benchmarks for field survey. (right) Absolute horizontal displacement and displacement vectors as imaged from the correlation of two 2.5m SPOT 5 images acquired on 09/19/2003 and 08/22/2004. The black diamonds indicate the geodetic benchmarks. The displacement field revealed from the correlation would have been unnoticed in the geodetic measurements.