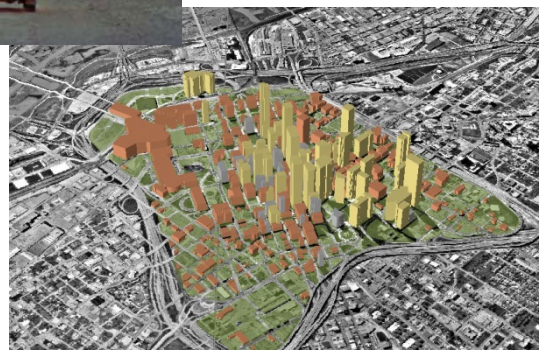
COSI-Corr Processing:

A Solution For Dense Image Registration, Ground Deformation Measurement, and DSM Generation



Sebastien Leprince
Francois Ayoub
Jiao Lin
Jean-Philippe Avouac

leprincs@caltech.edu

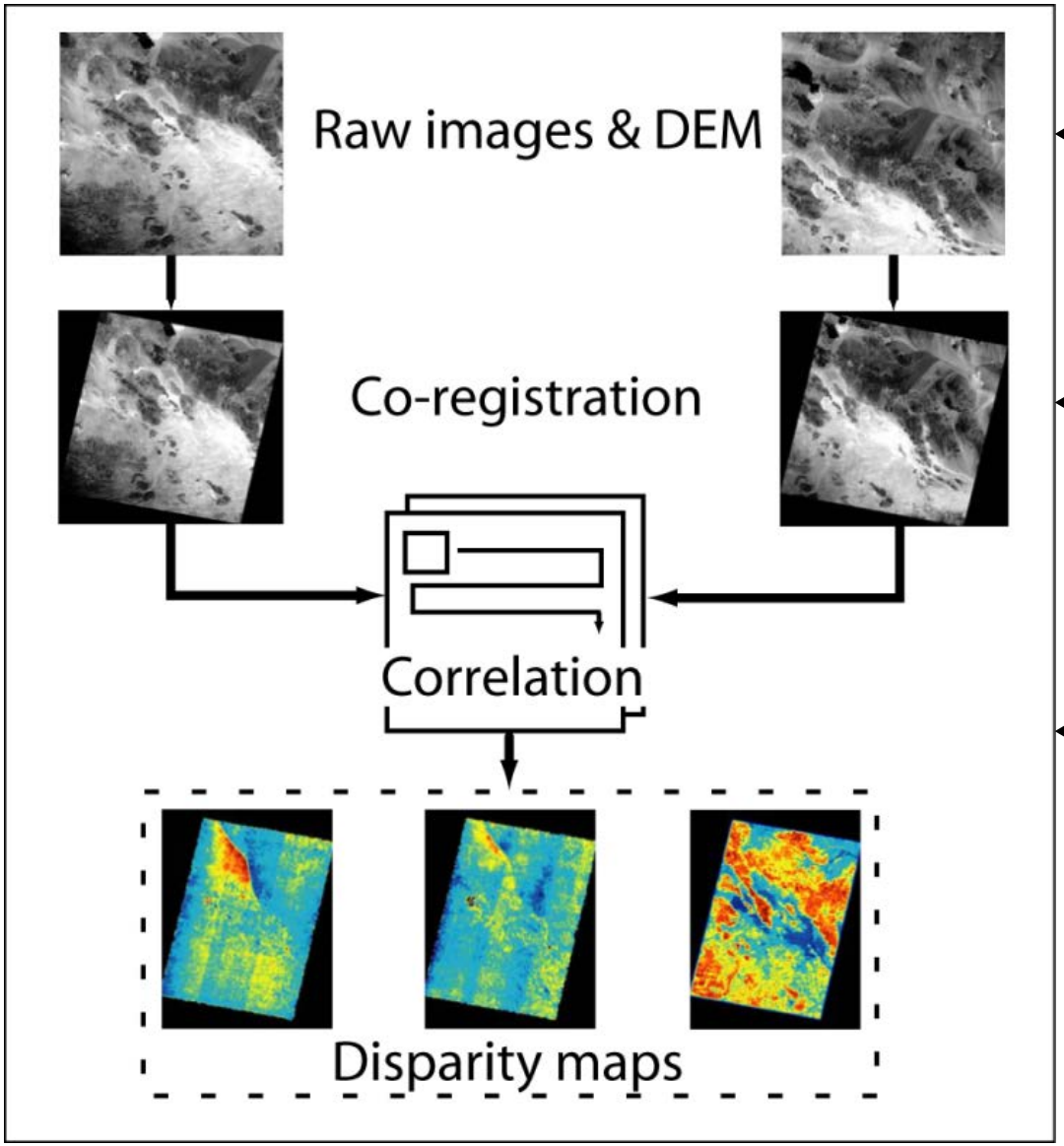
California Institute of Technology
Imagin' Labs Corporation

JACIE Workshop, April 18, 2013

Patent U.S. 8,121,433 B2
California Institute of Technology

imaginlabs.com

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



Raw imagery acquired at different time, at any resolution, and possibly by different imager s

Automatic registration of the imagery <u>with an accuracy of 1/10 of the pixel size</u> (sub-pixel accuracy)

Automatic comparison of the registered images to monitor any changes in the scene

COSI-Corr tool suite

Leprince et al., IEEE TGRS, 2007

http://www.tectonics.caltech.edu/slip_history/spot_coseis/

Sub-Pixel Image Correlation: Locally 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

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

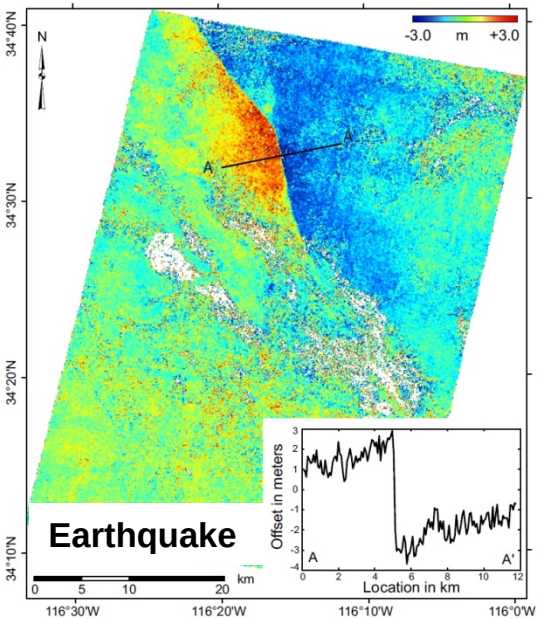
- Finding the relative displacement

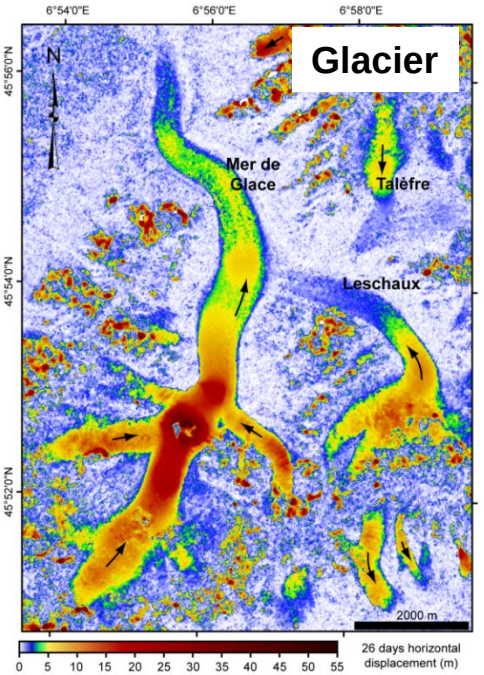
$$\phi(\Delta_x,\Delta_y) = \sum_{\omega_x=-\pi}^{\pi}\sum_{\omega_y=-\pi}^{\pi} W(\omega_x,\omega_y)|C_{i_1 i_2}(\omega_x,\omega_y) - e^{j(\omega_x\Delta_x+\omega_y\Delta_y)}|^2$$

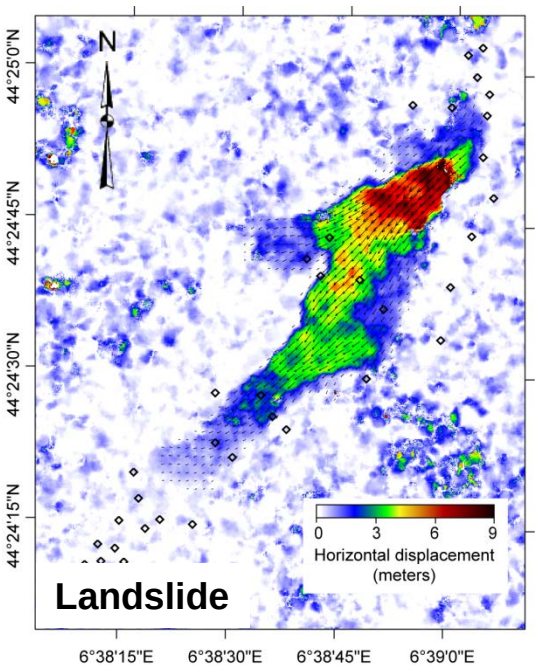
W weighting matrix. (Δ_x,Δ_y) such that ϕ minimum.

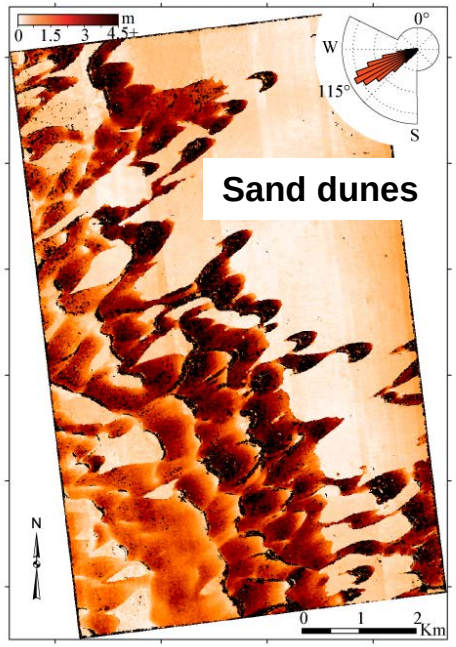
S. Leprince et al., IEEE TGRS, 2007

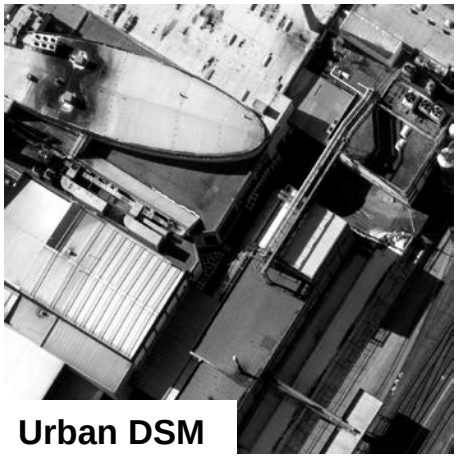
COSI-Corr: a wide range of applications



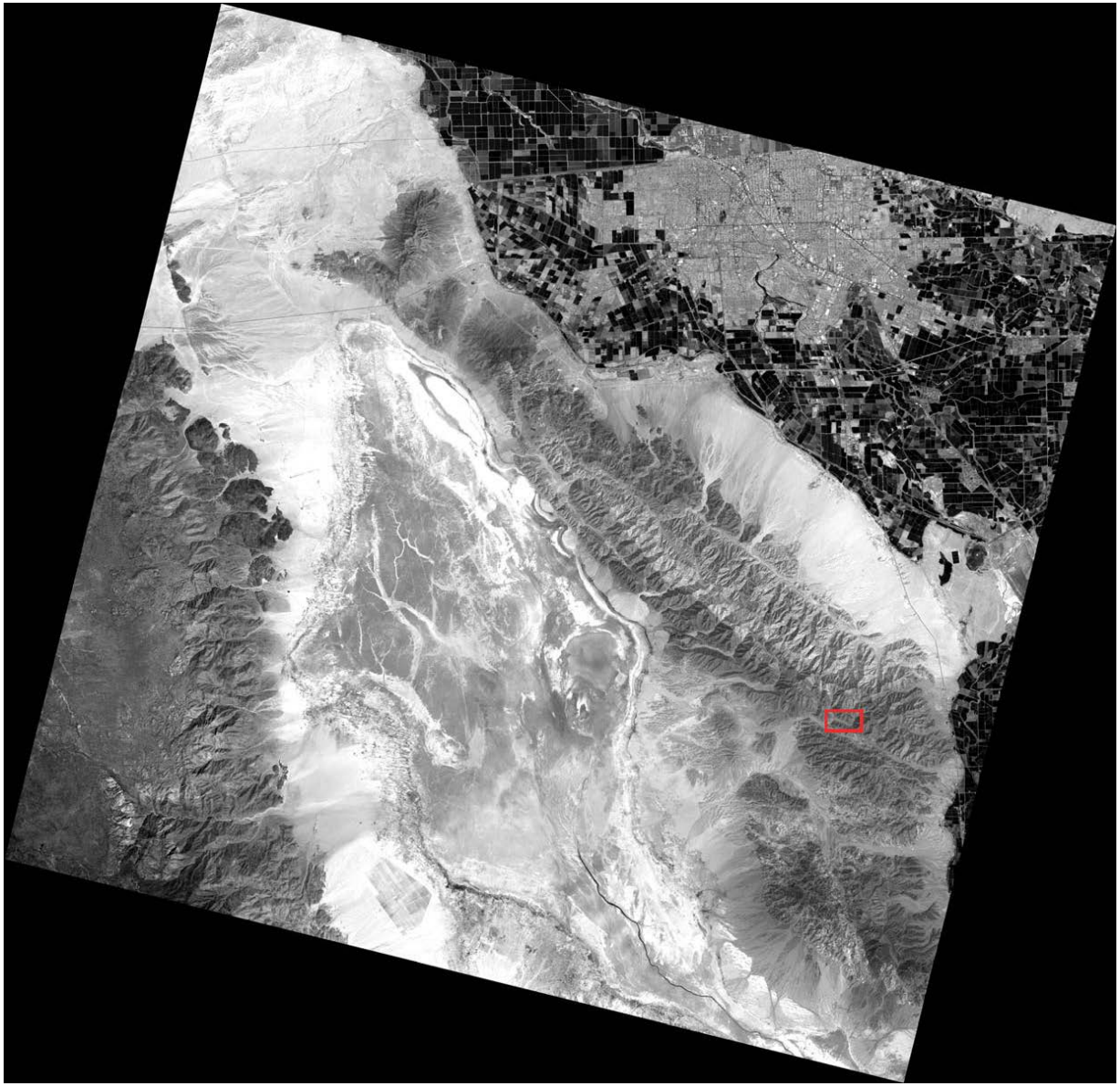








The April 2010 El-Mayor Cucapah Earthquake, Mw 7.2



SPOT 5 images
2.5 m GSD

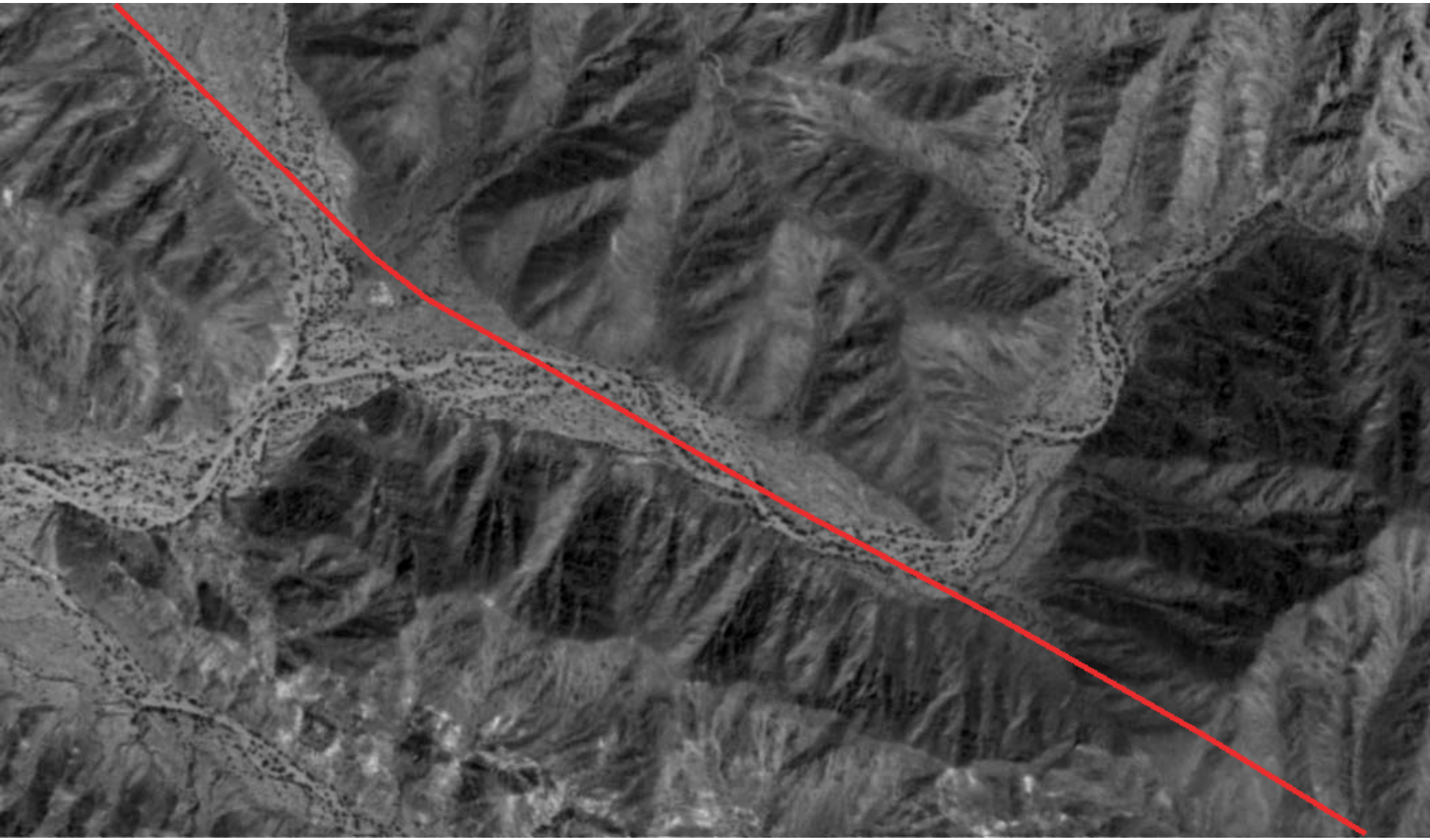
2009/05/26
2010/04/08

Images provided by
USGS
Rich Briggs
Ken Hudnut

Before/After Earthquake Imagery

Can you see the ground moving?

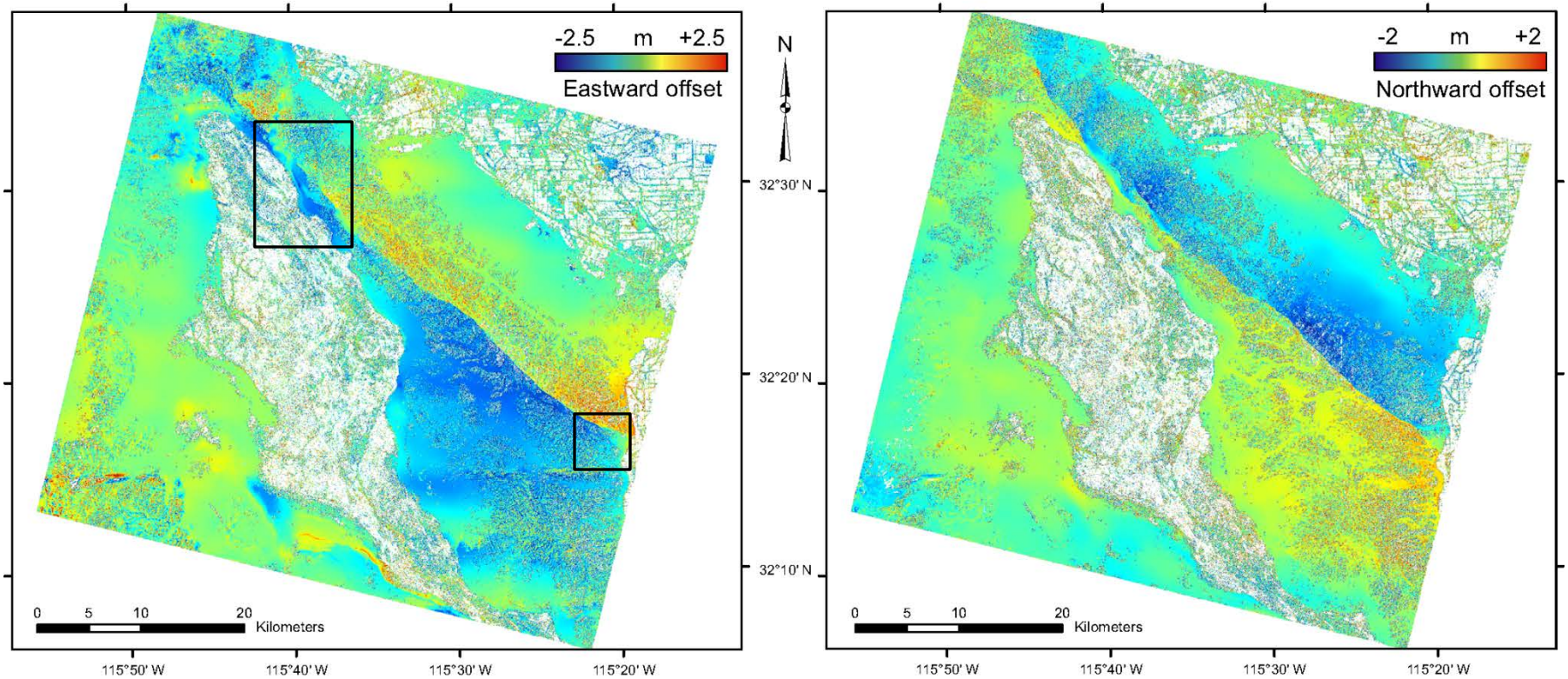
Before/After Earthquake Imagery



Can you see the ground moving?

Horizontal Displacement Field from SPOT Imagery:

Mw 7.2 El-Mayor Cucapah earthquake, April 2010

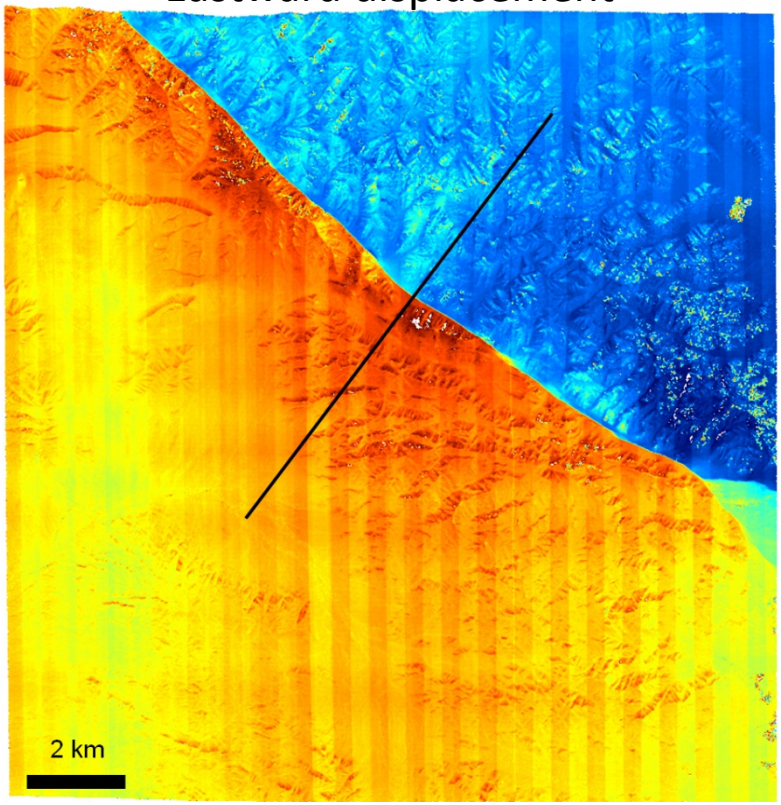


Ground rupture well identified and recovered with 1/10 pixel accuracy (~25 cm)

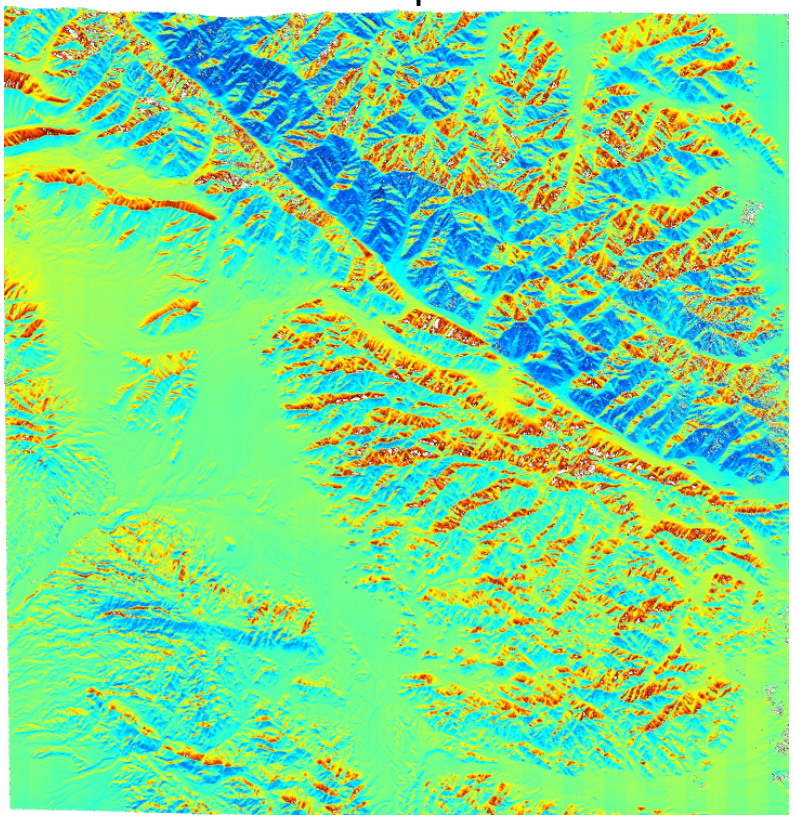
Wei et al., Nature Geoscience, 2011

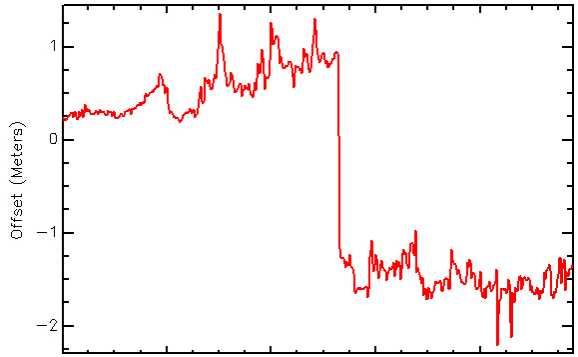
Horizontal Displacement using Worldview - 50 cm GSD

Eastward displacement



Northward displacement



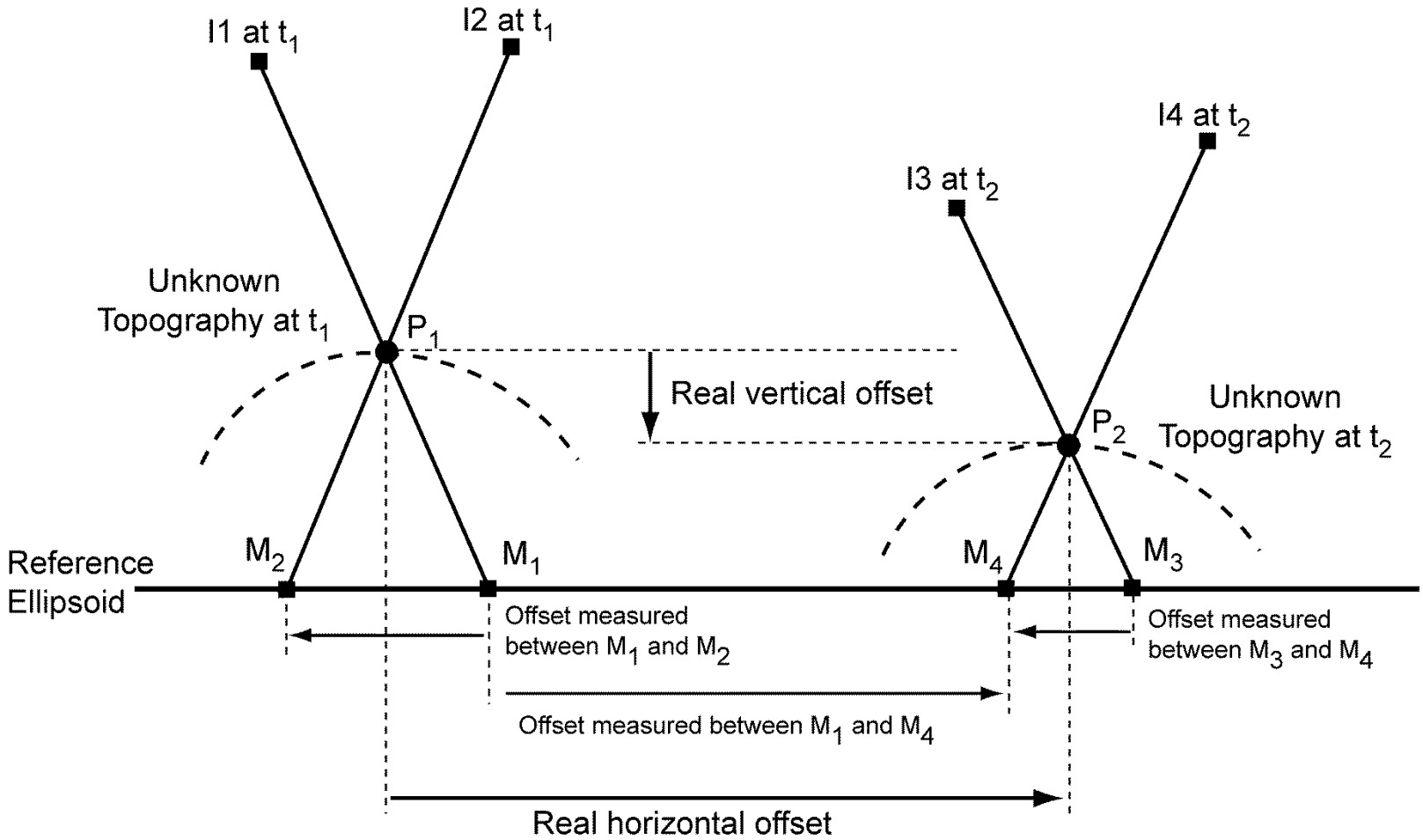


PB: large incidence angles bring topography residuals in parallax direction (here mostly Northward).

Solution: Use several images before and after the event.

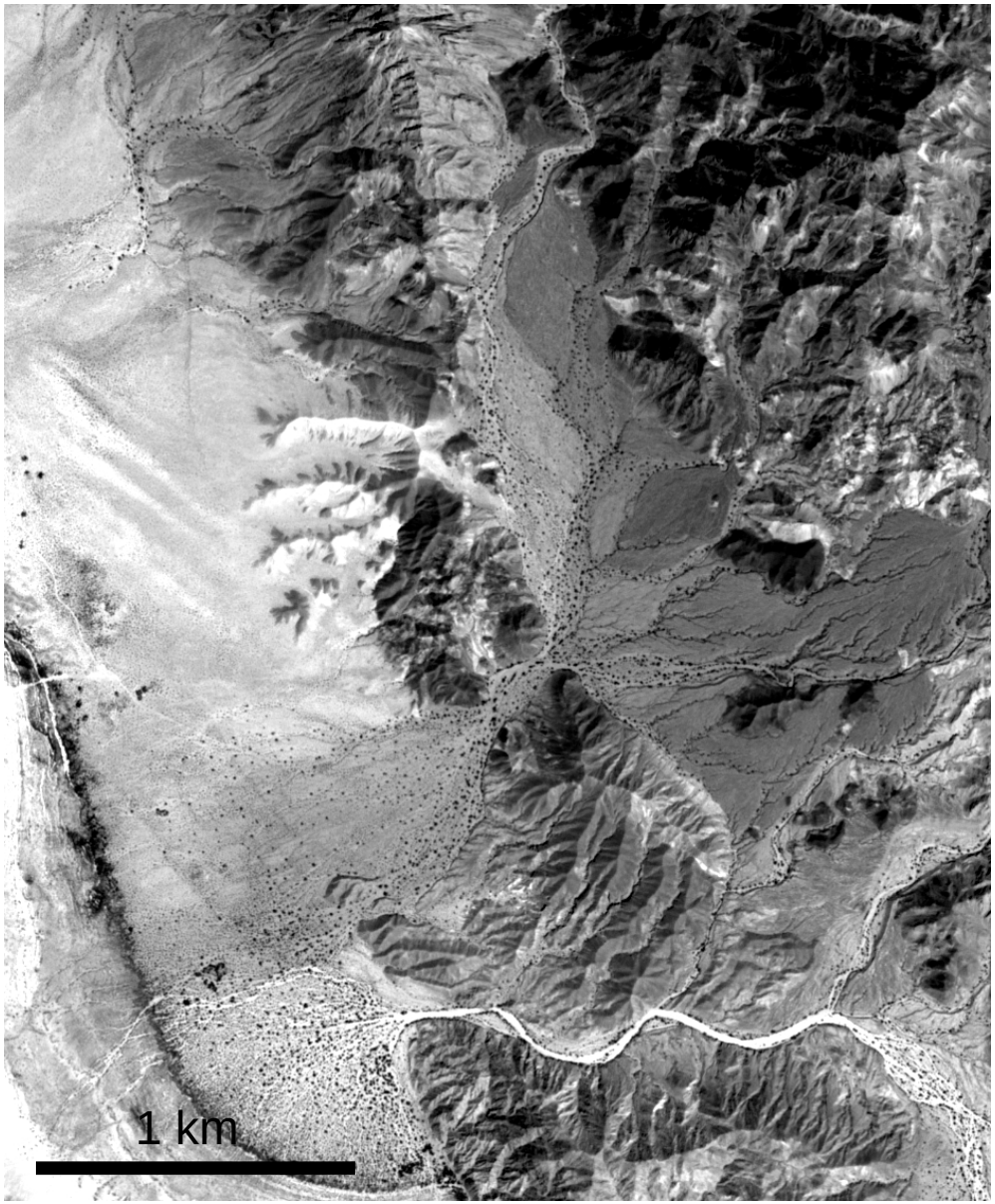
Artifacts from CCD misalignment.

Multiple Disparity Maps can be Triangulated to Retrieve 3D displacement field using Multiple Images



California Institute of Technology, Patent Pending, 2012

Northern Part of the Rupture, 3D displacement field



Pre-earthquake images:

- Quickbird **09/21/2006**,
  Along-track angle -1.23°
  Across-track angle -9.8°

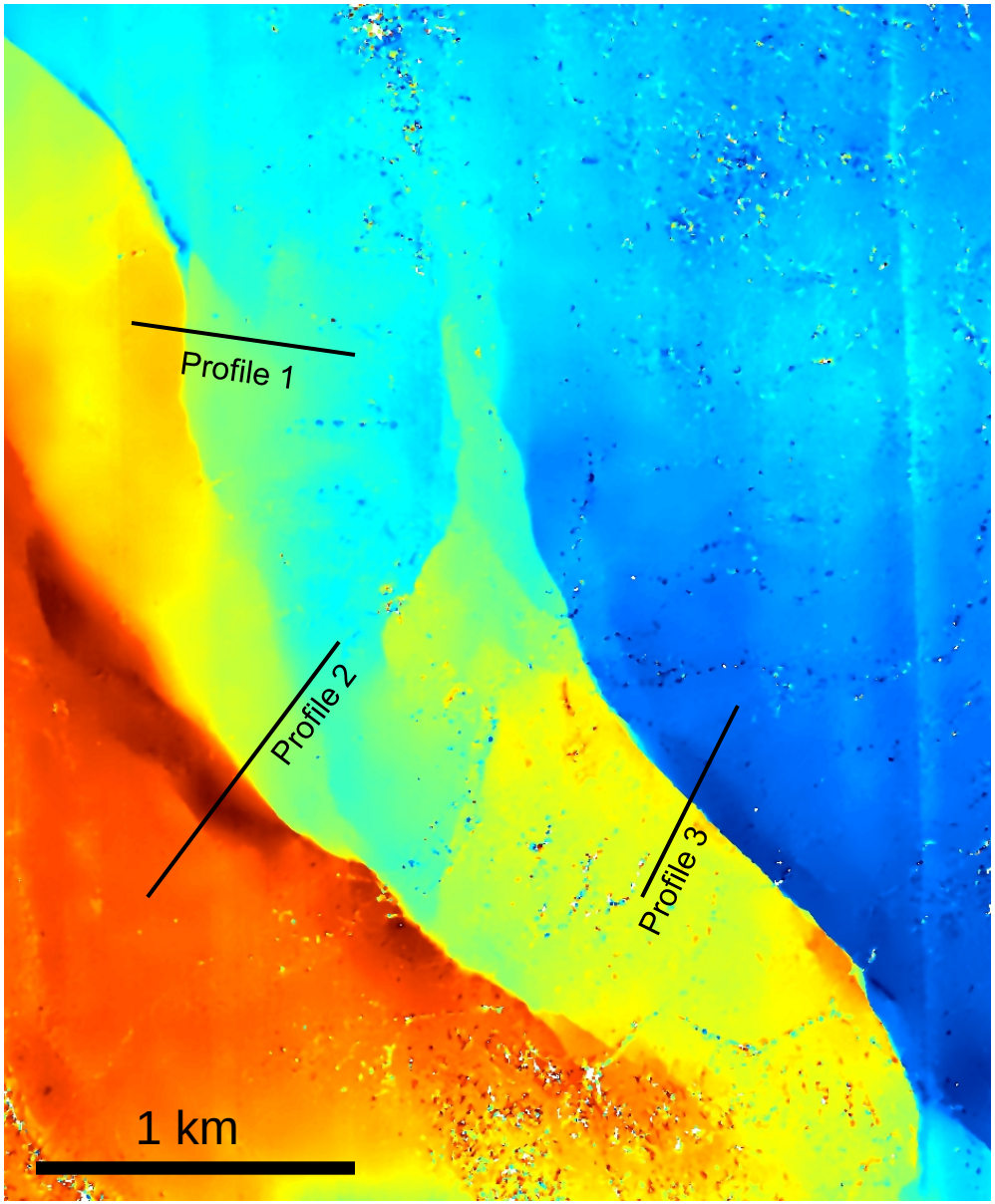
- Worldview **09/16/2008**,
  Along-track angle -10.8°
  Across-track angle 13.5°

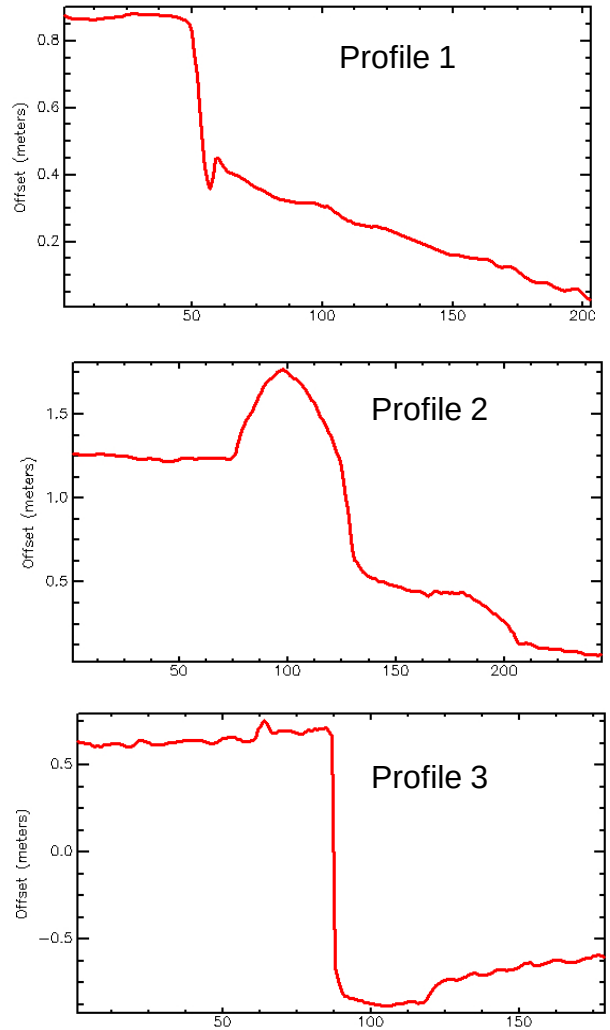
Post-earthquake images:

- Worldview **04/10/2011**,
  Along-track angle -13.8 °
  Across-track angle -22.5°

- Worldview **05/19/2011**,
  Along-track angle 14.1°
  Across-track angle 21.6°

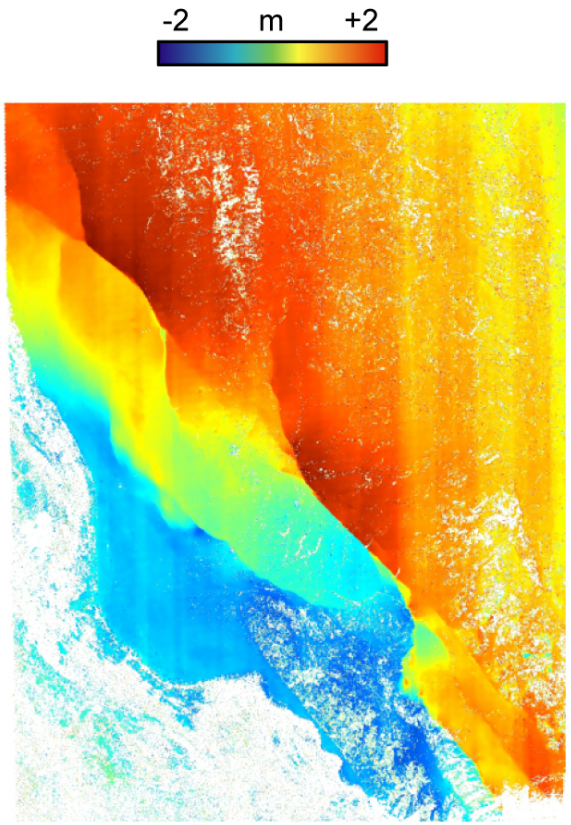
Northern Part of the Rupture (North/South displacement field)



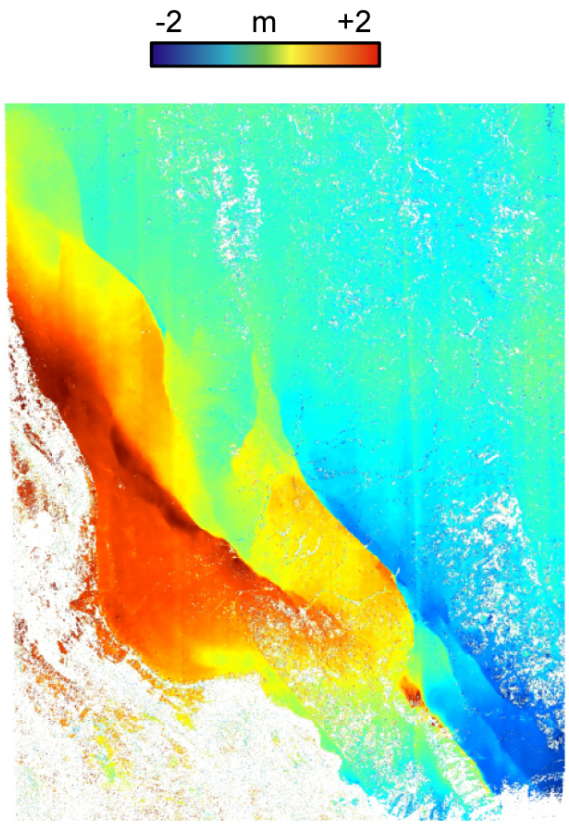


Measurement accuracy better than 10 cm

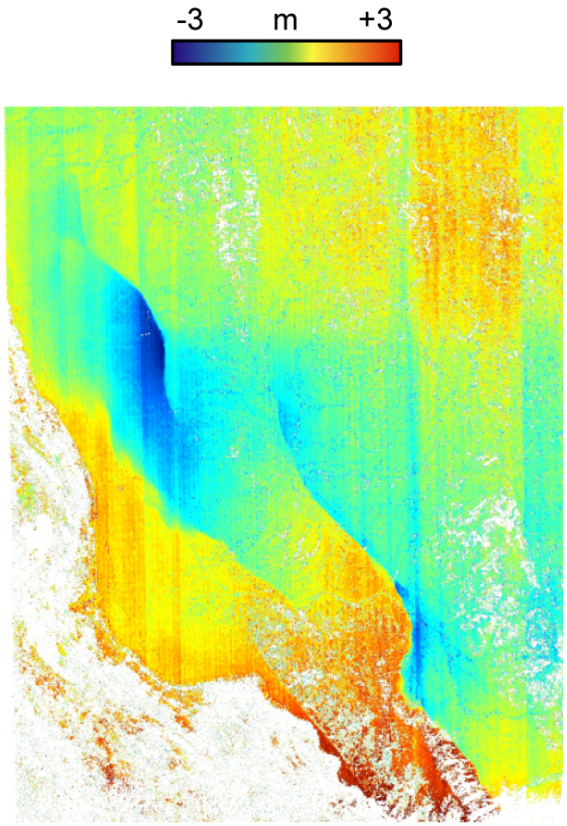
Northern Part of the Rupture (3D displacement field)



Eastward ground motion



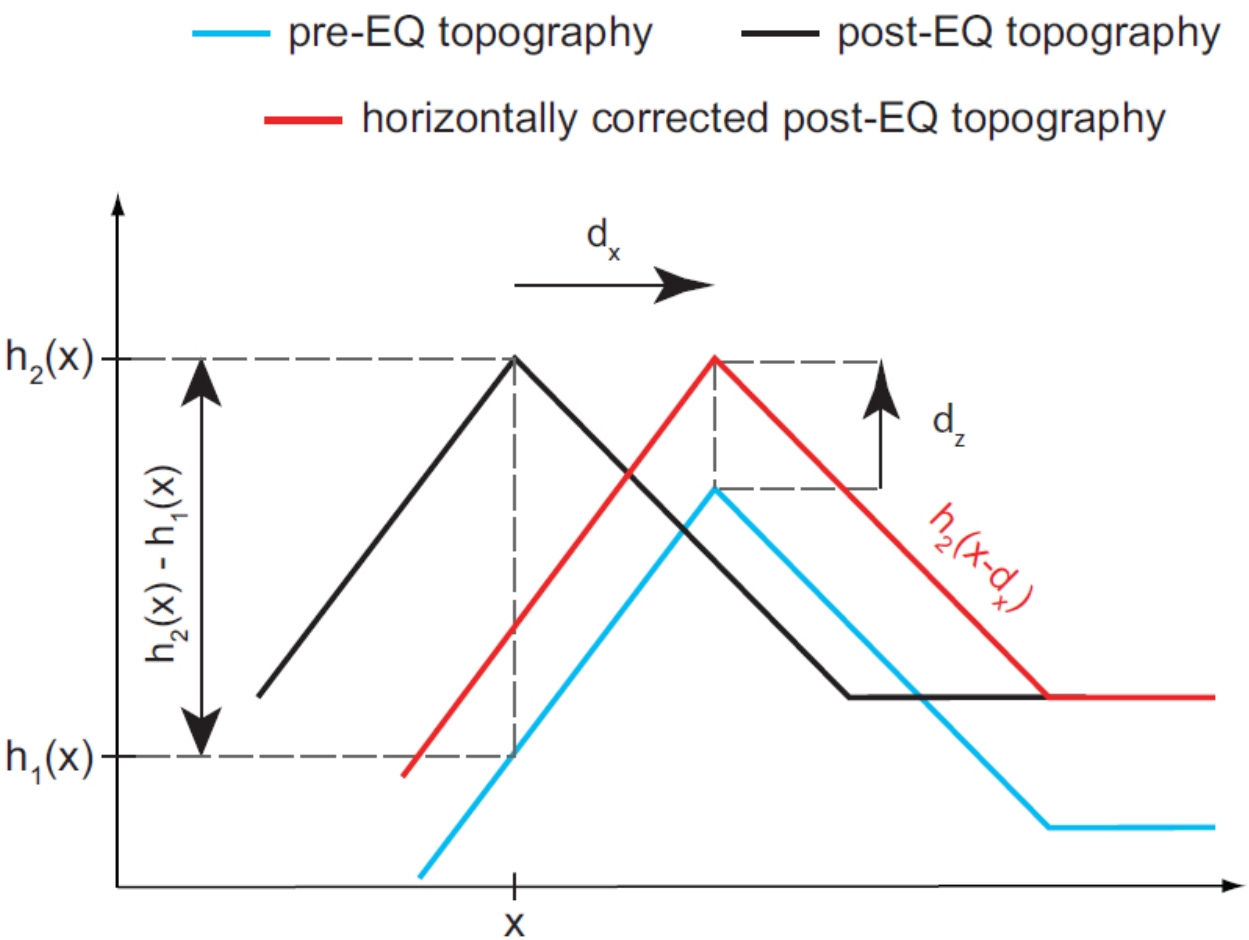
Northward ground motion



Vertical ground motion

Horizontal components noise stdev ~ 10 cm
Vertical component noise stdev ~ 25 cm
CCD and jitter artifacts largest source of bias

Retrieving 3D Ground Motion from Pre and Post- Earthquake LiDAR: El-Mayor Earthquake

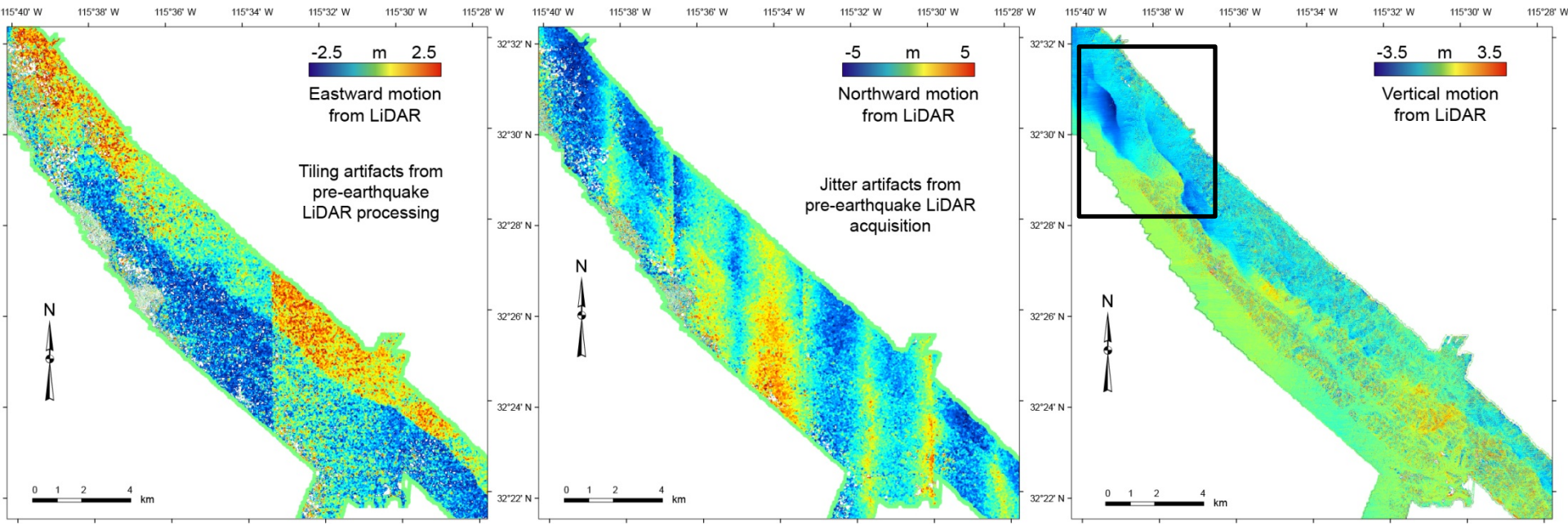


$$h_2(x) - h_1(x) = h_1'(x)d_x + d_z$$

$$h_2(x - d_x) - h_1(x) = d_z$$

- We use COSI-Corr to estimate and compensate the horizontal displacement between pre- and post-EQ LiDAR

Retrieving 3D Ground Motion from Pre and Post- Earthquake LiDAR: El-Mayor Earthquake

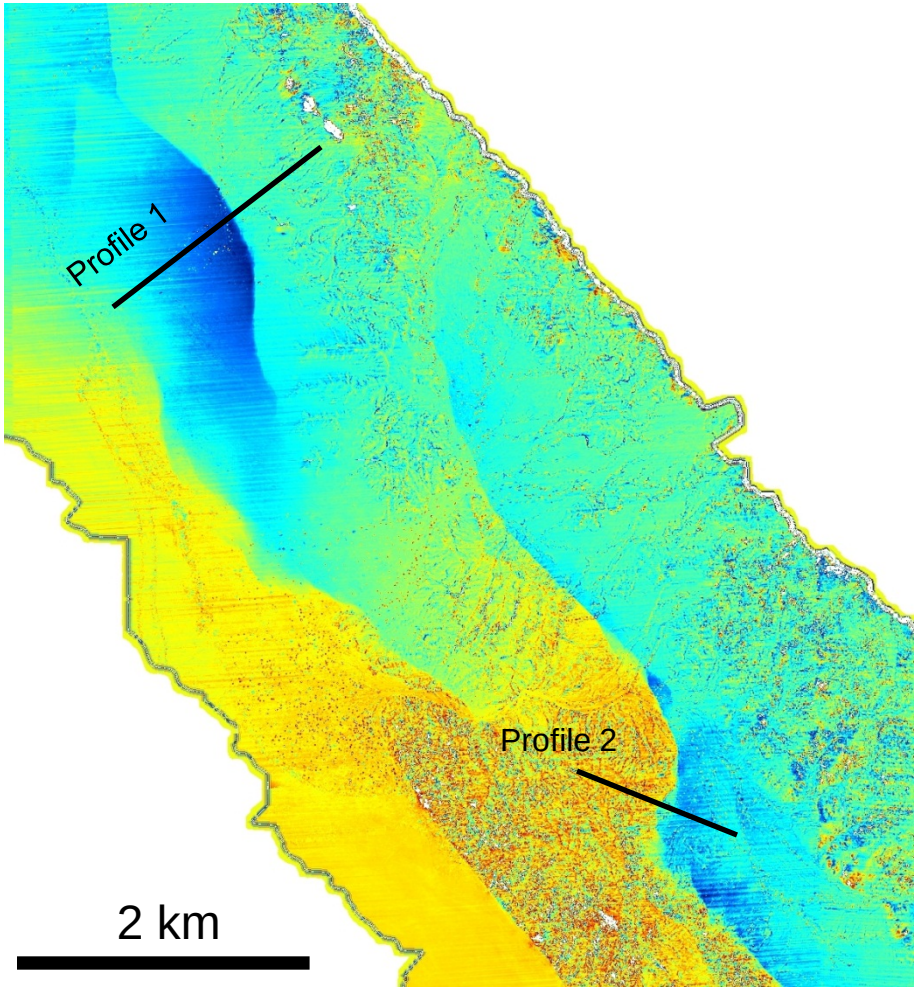


- Horizontal components retrieved from LiDAR suffer from jitter and tiling artifacts due to lower quality of pre-EQ data.
- High quality measurement of vertical offset using LiDAR (noise < 10 cm)
- Noise (not bias) on horizontal components could be reduced if correlation on LiDAR intensity could be performed.

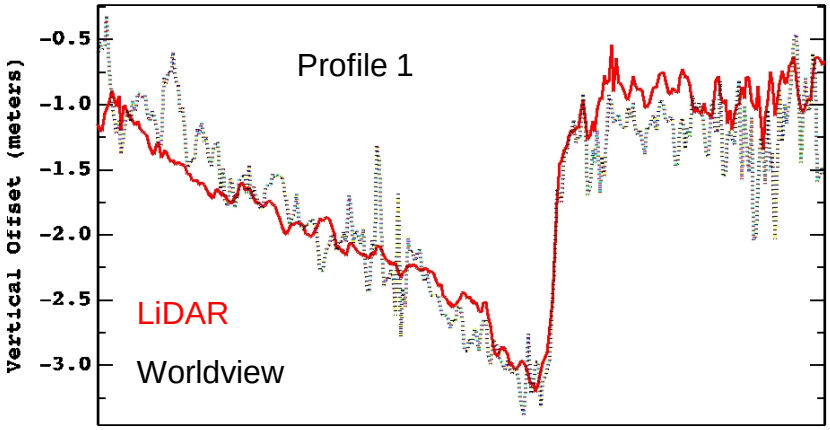
Results from work with K. W. Hudnut (U.S.G.S.), S. Akciz (UCI), A. Hinojosa Corona (CICESE), and J. M. Fletcher (CICESE)

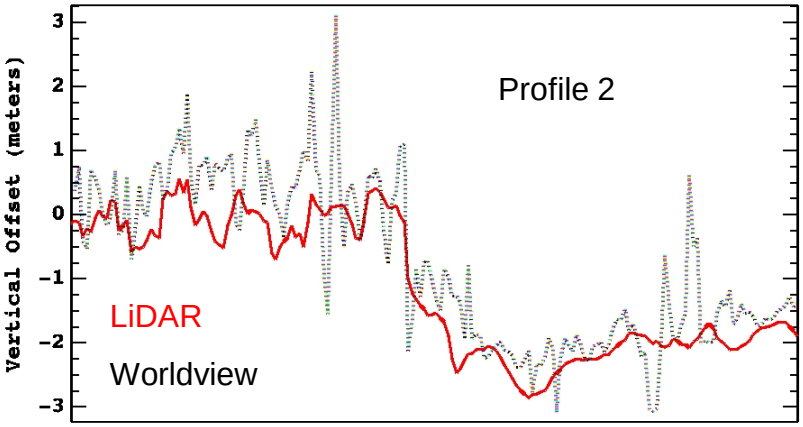
Comparison Worldview Stereo Imagery vs. LiDAR

LiDAR Vertical Offset



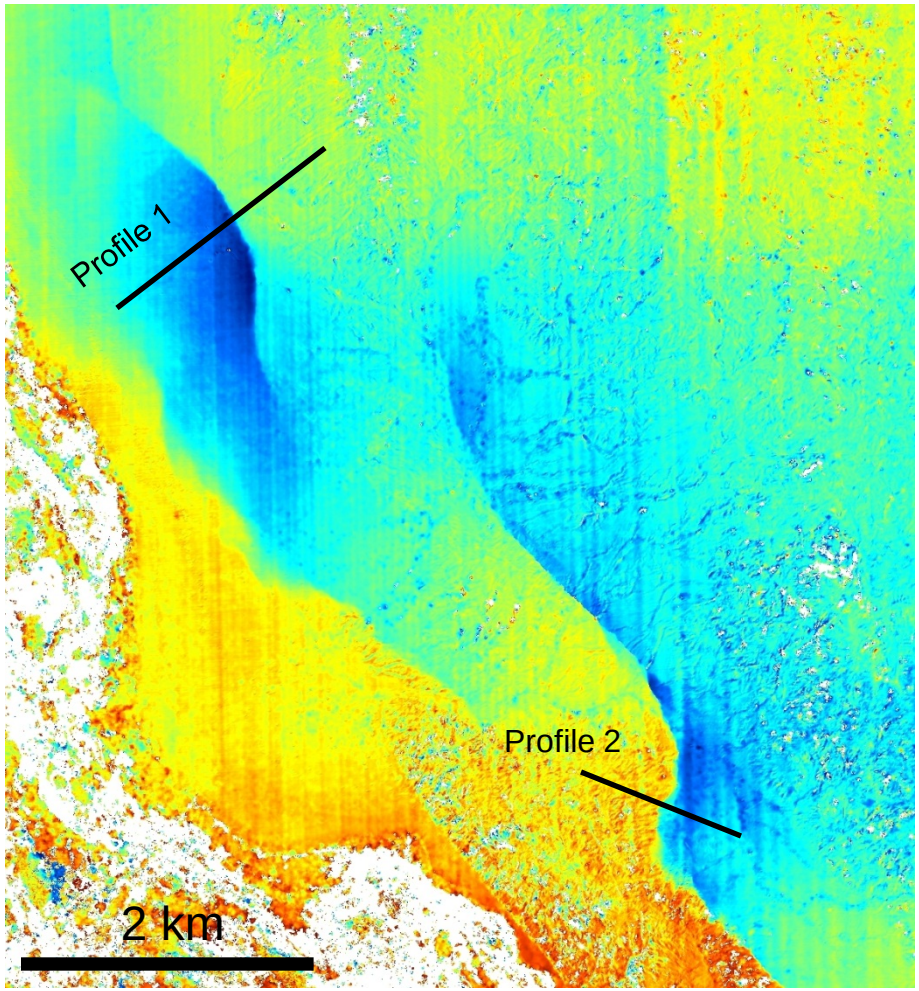
More noise on the stereo data, but good agreement between data set



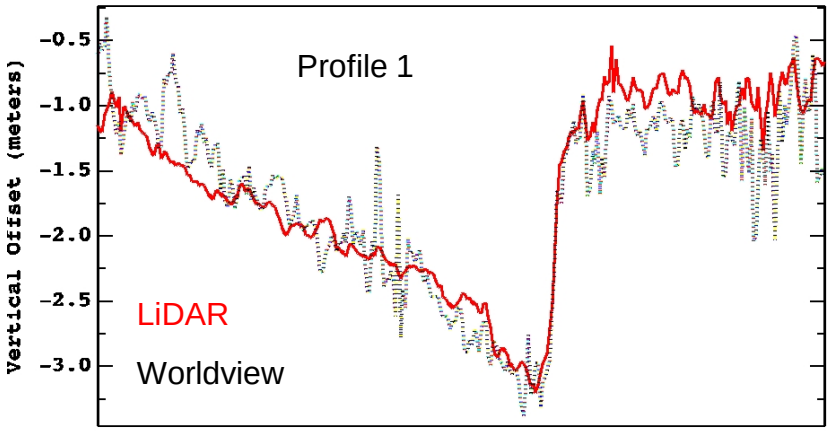


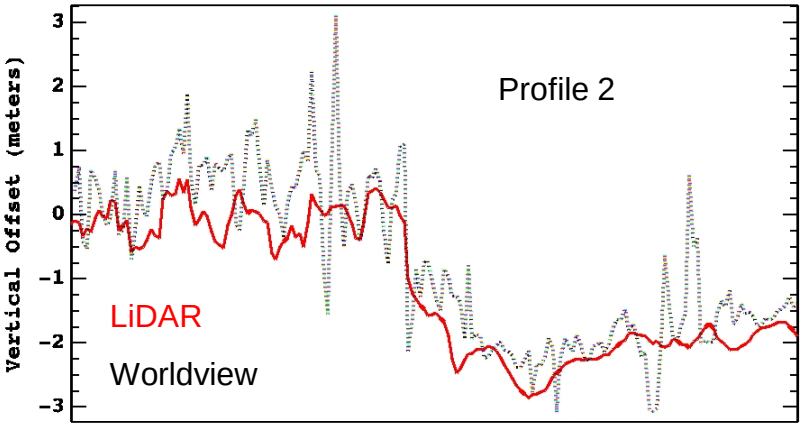
Comparison Worldview Stereo Imagery vs. LiDAR

Worldview Stereo Vertical Offset



More noise on the stereo data, but good agreement between data set





COSI-Corr and High Resolution DSM extraction:
The city of Christchurch, NZ

Data:

Worldview stereo-pairs (courtesy of DigitalGlobe):

- Acquired in September 2009
- Acquired in August 2011

LiDAR acquisitions (courtesy of GNS Science, NZ):

- 1m gridded LiDAR, 2010
- 1m gridded LiDAR, 2011

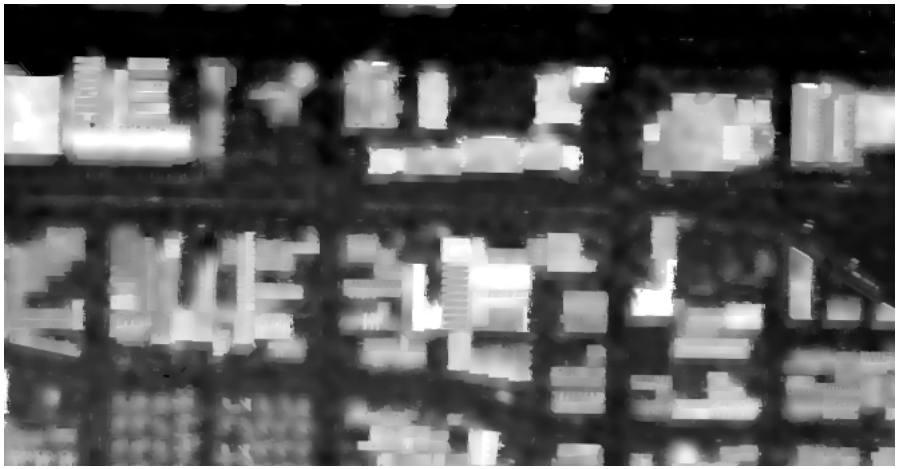
Goal:

Comparing the surface models produced using COSI-Corr on pairs of 0.5m stereo Worldview images with state-of-the-art airborne LiDAR acquisitions.

Applications:

City planning, urbanism, insurance, rapid response to catastrophic events (e.g., earthquakes, liquefactions).

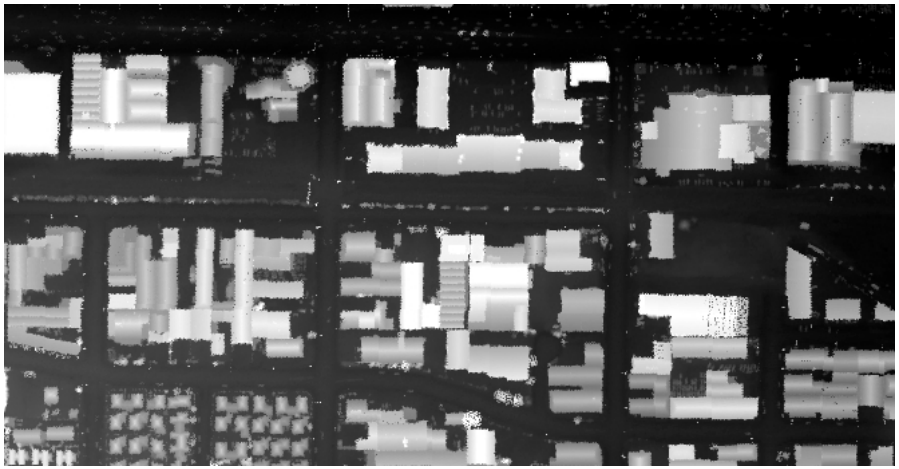
Eastern part of downtown Christchurch, NZ, zoom on a small 650x350m area



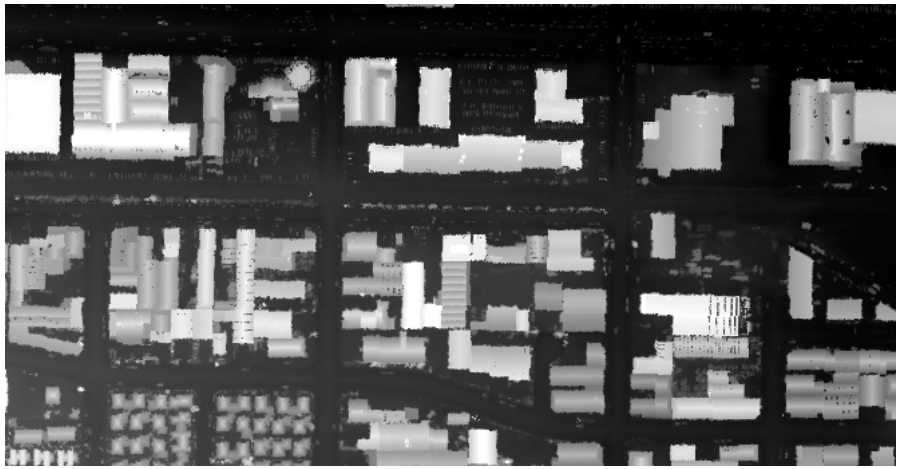
2009 Worldview DSM generated with COSI-Corr
1m GSD

2011 Worldview DSM generated with COSI-Corr
1m GSD

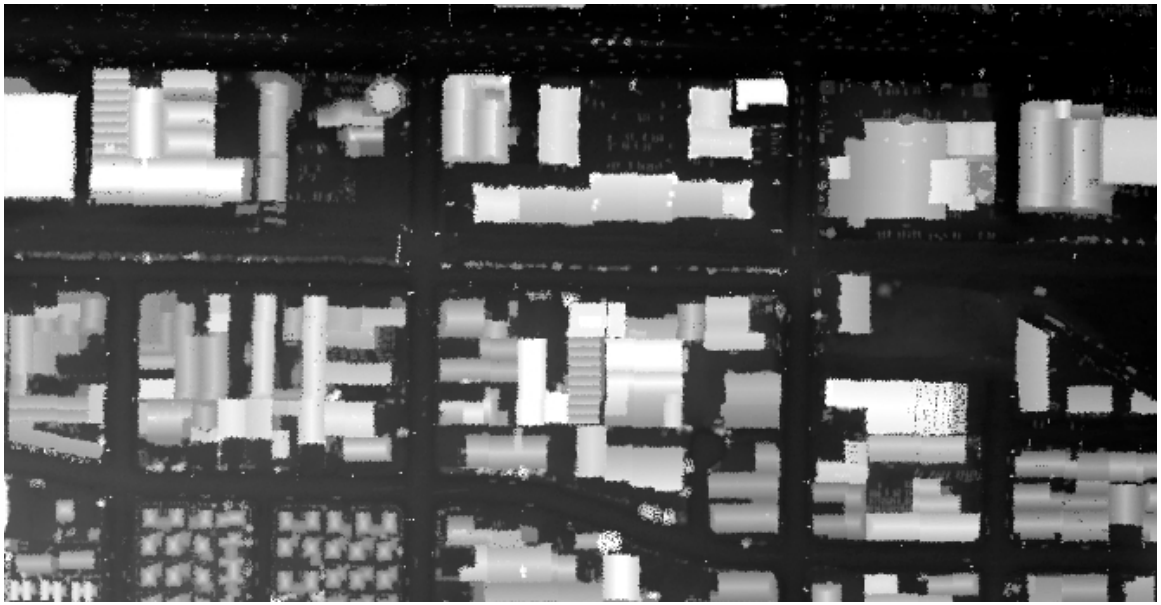
COSI-Corr DSM extraction using Worldview stereo imagery
competes with LiDAR



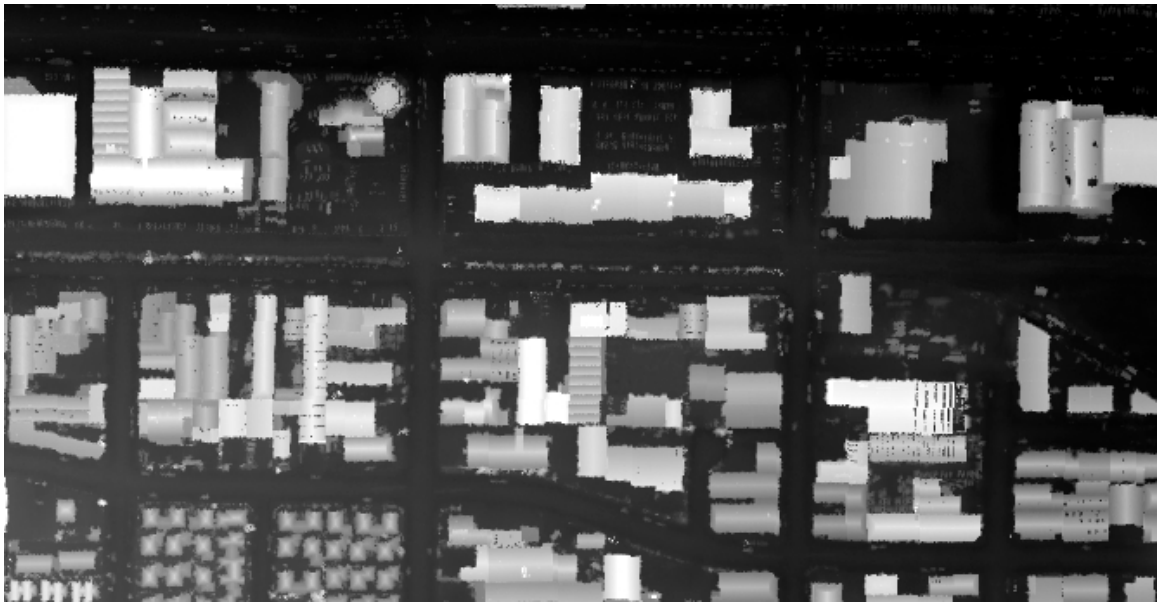
2010 LiDAR DSM, 1m GSD



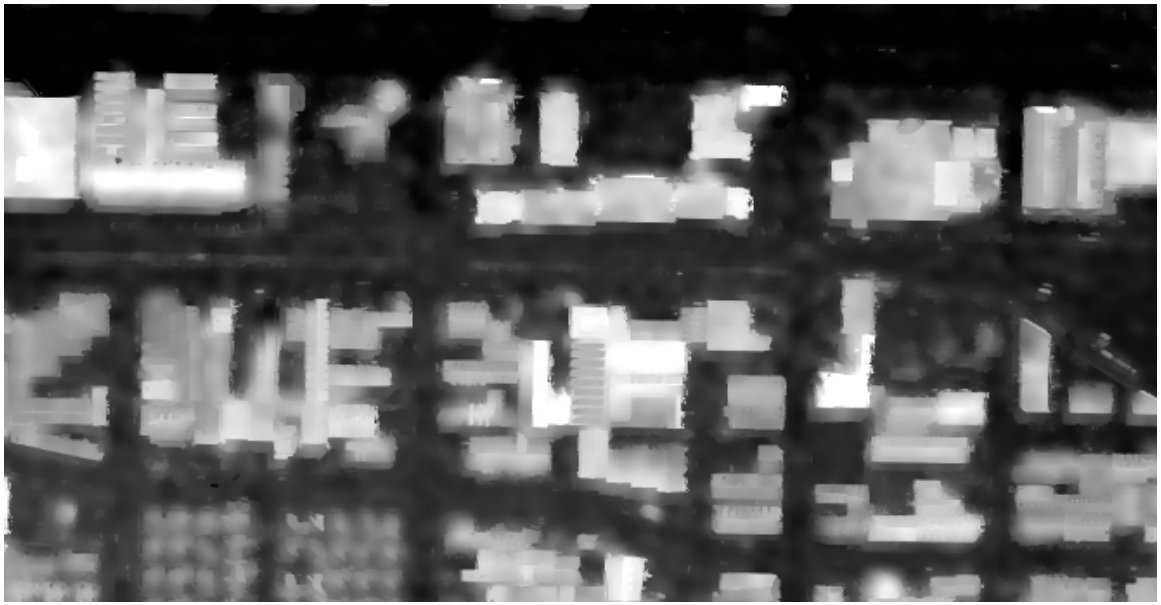
2011 LiDAR DSM, 1m GSD



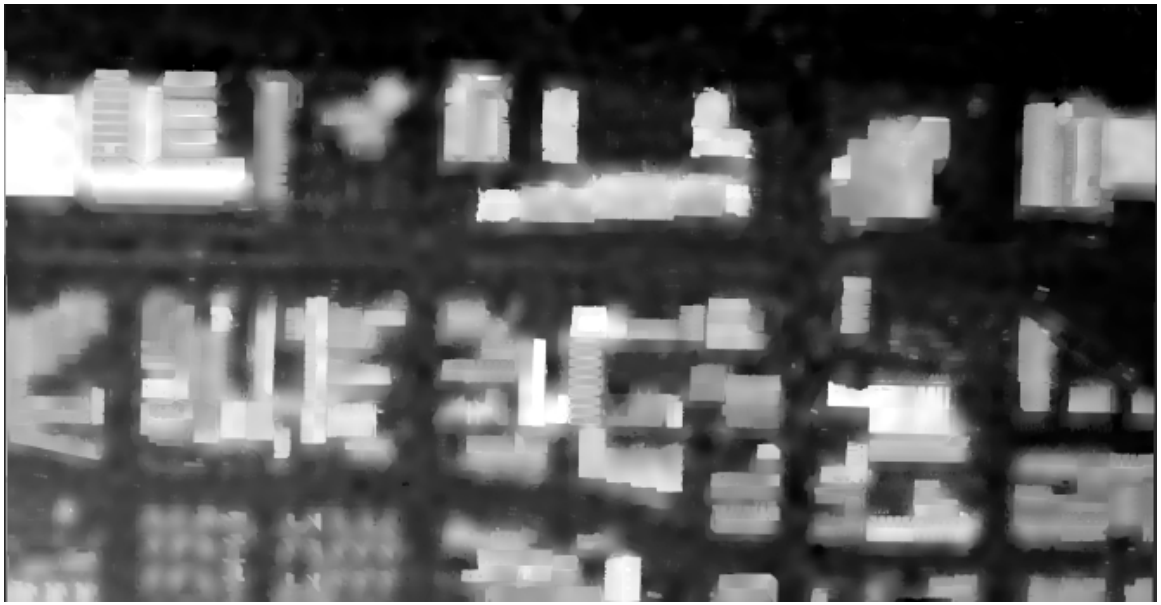
2010 LiDAR DSM
1m GSD



2011 LiDAR DSM
1m GSD

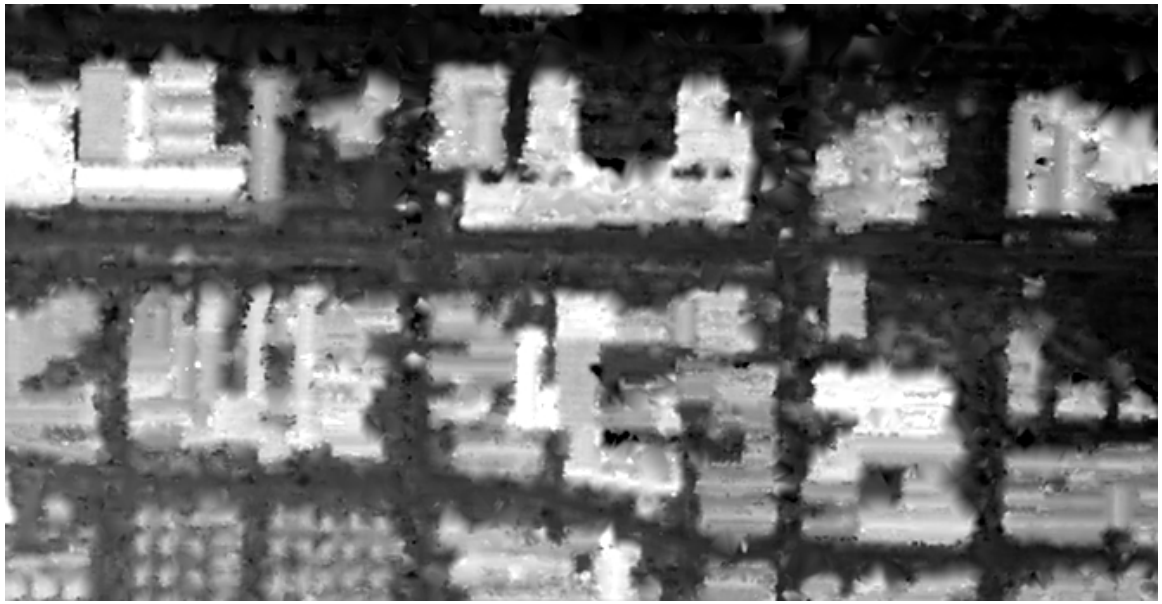


2009 Worldview DSM
generated with COSI-Corr
1m GSD



2011 Worldview DSM
generated with COSI-Corr
1m GSD

Comparison with other Software (2011 data): ERDAS LPS - eATE



2011 Worldview DSM generated
with **ERDAS LPS eATE 2013**
1m GSD

Comparison with other Software (2011 data): ERDAS LPS - eATE

2011 Worldview DSM
generated with **COSI-Corr**
1m GSD

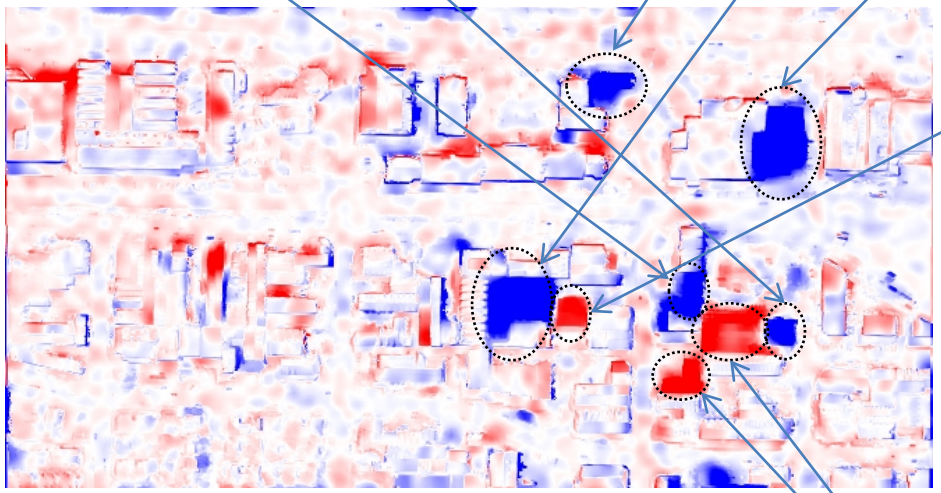
Documenting Building Height/Volume Change

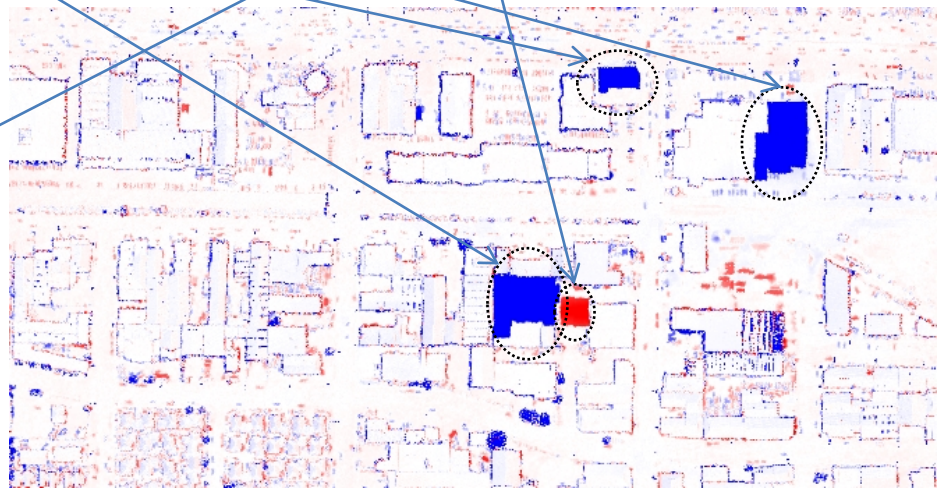
Blue areas are negative changes in height in excess of 3m (building destruction)
Red areas are positive changes in height in excess of 3m (building construction)

Building destruction after the Sept. 2010 Canterbury earthquake?

Building destruction after the Feb. 2011 Christchurch earthquake

Building construction after the Feb. 2011 Christchurch earthquake





2009/2011 Difference between Worldview DEM generated by COSI-Corr

2010/2011 Difference between LiDAR DSM

Building construction after the Sept. 2010 Canterbury earthquake

COSI-Corr and Automatic Dense Sub-Pixel Registration:

High Value for Automatic Change Detection

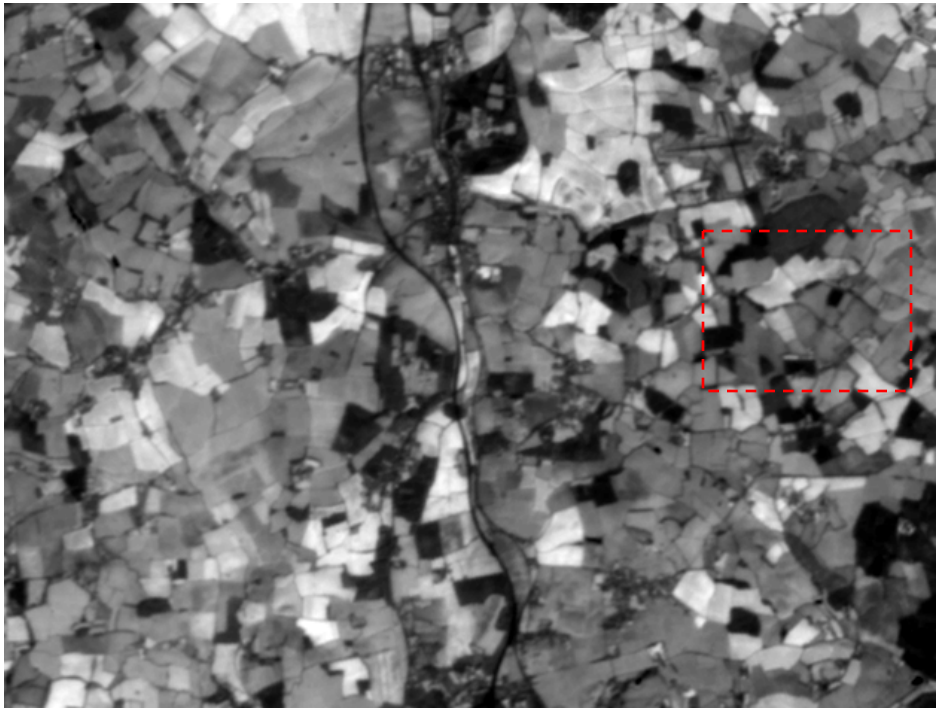
Study Cases:

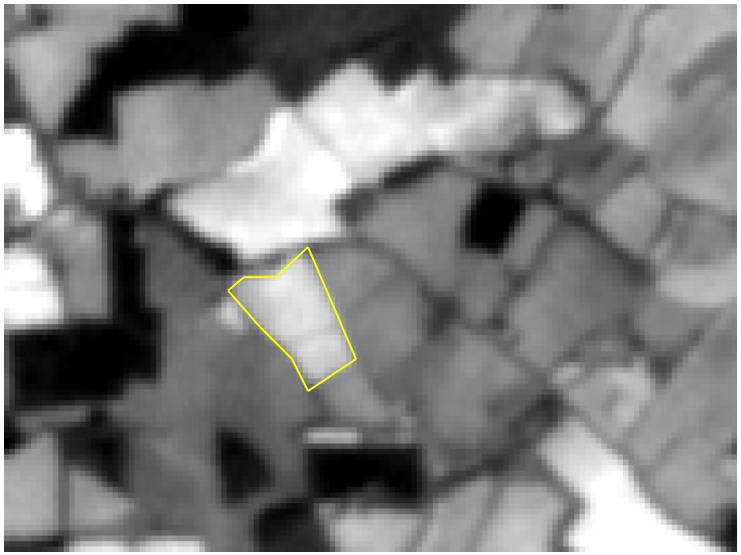
- Agriculture Monitoring (growing season)
- War Monitoring / Crater Detection
- Landslide Assessment

Image registration for agriculture monitoring

Multi-source and multi-spectral image registration

Image registration for agriculture monitoring



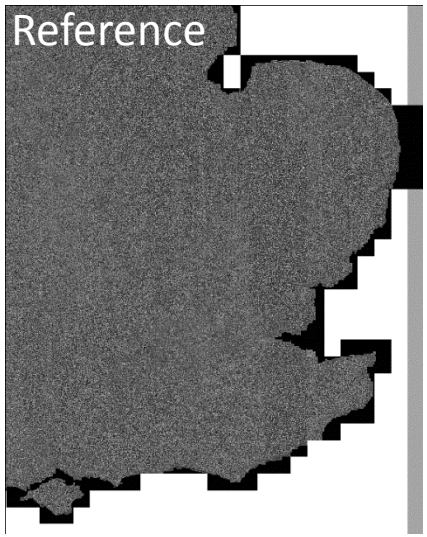


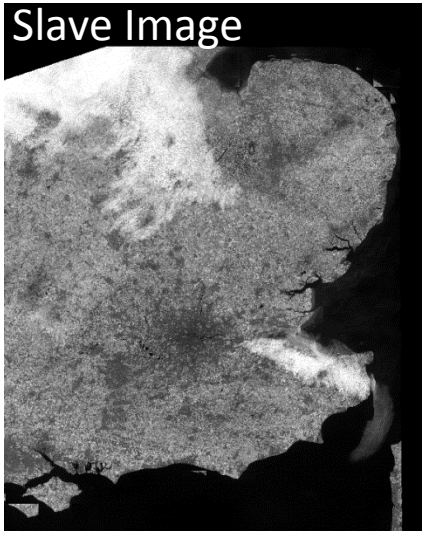
Zoom view

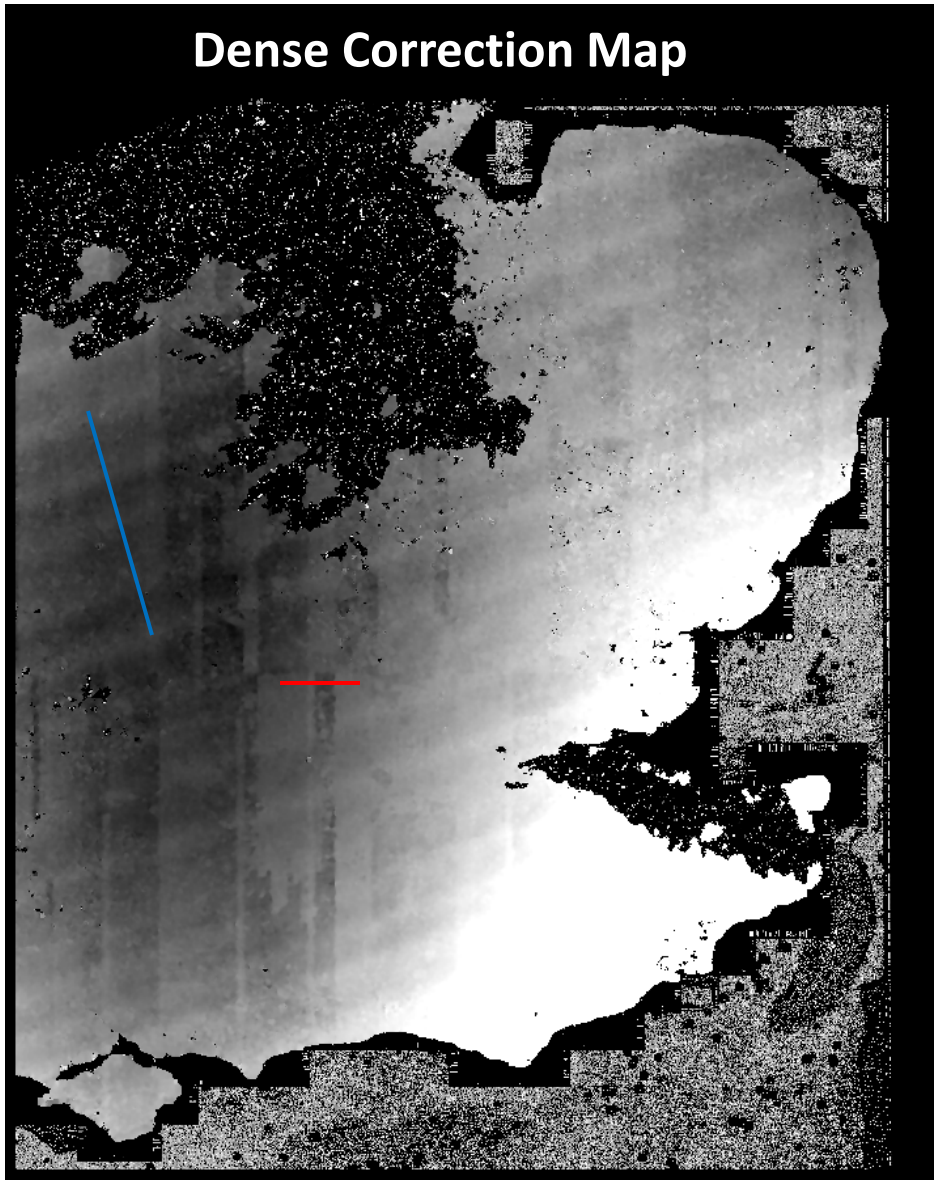
Reference: Panchromatic aerial mosaic (1999)
Layer: UK2 (2010), DEIMOS (2010)

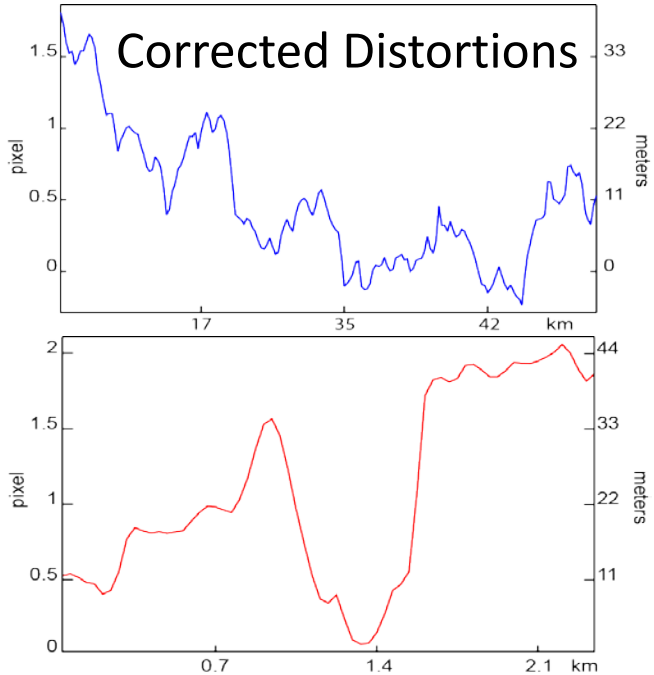
In-season crop monitoring at scale of a parcel

GEOSYS Growing agriculture









GEOSYS Growing agriculture

Automatic web-based sub-pixel registration service for agriculture processing

Bombing Detection: City of Anadan, Syria

Data:

Worldview panchromatic image pair, standard ortho processing level (courtesy of DigitalGlobe):

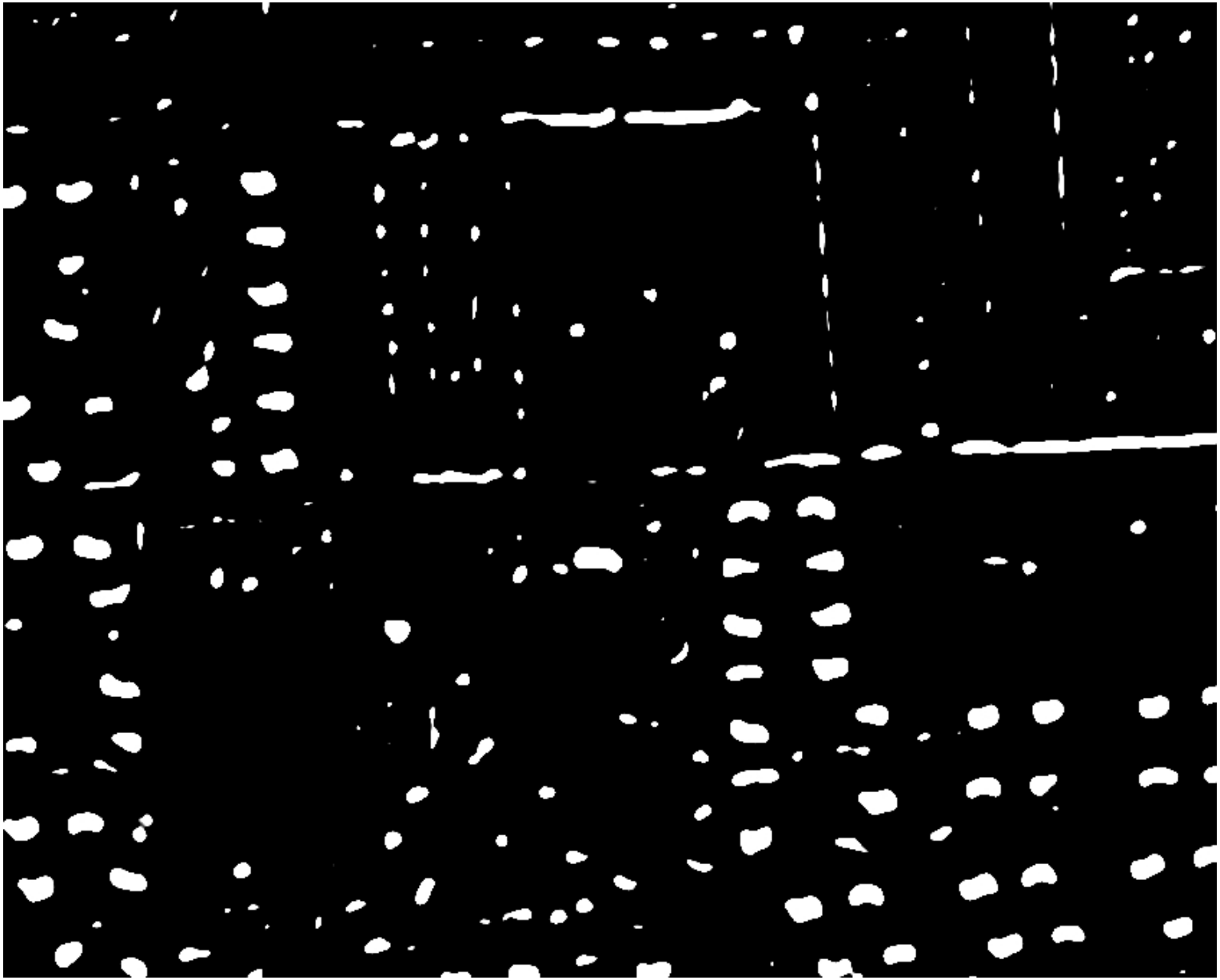
- Image 1 acquired on July 1, 2012

- Image 2 acquired on July 31, 2012

Goal:

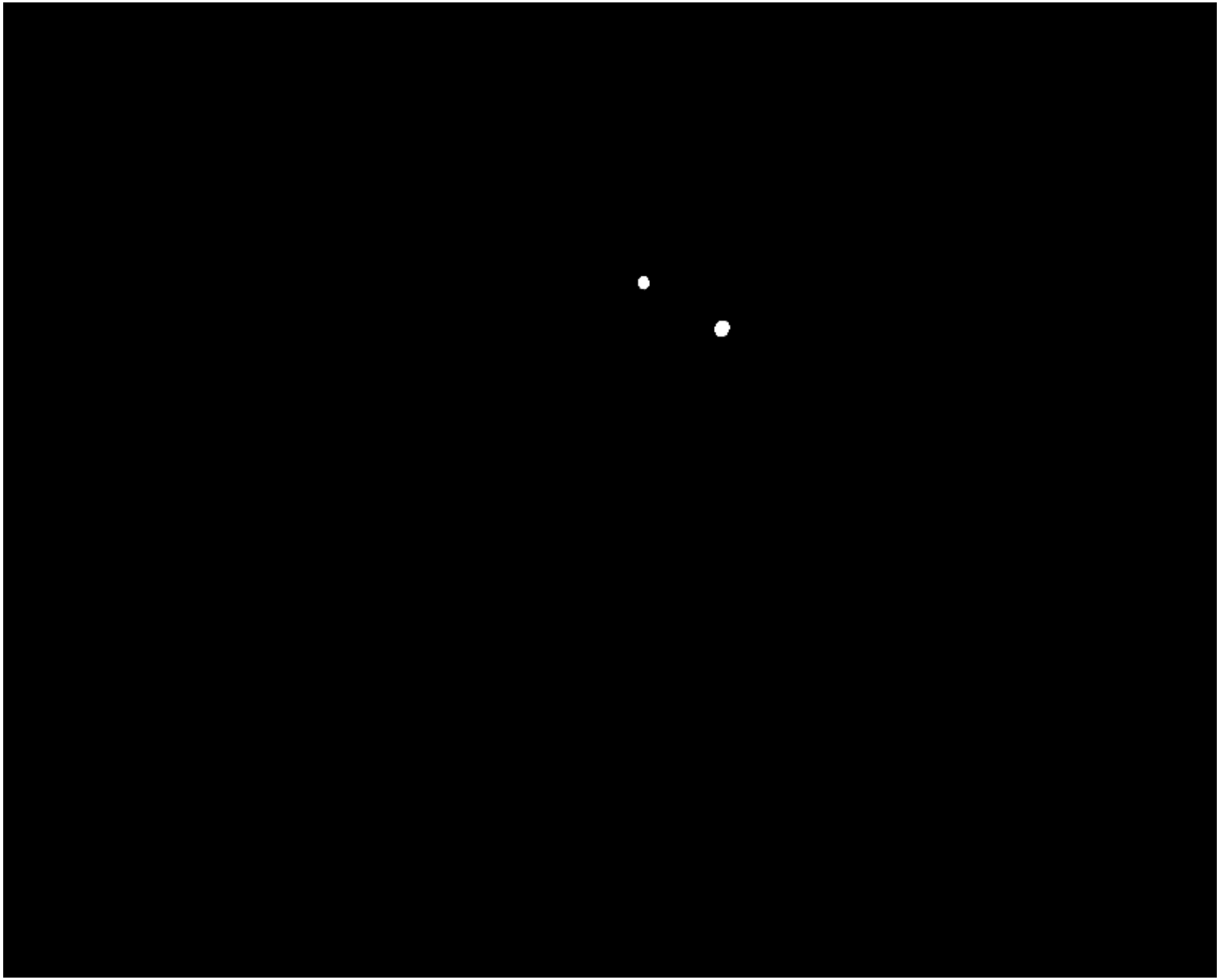
Detecting and counting the craters produced during the battle of Anadan, July 29th, 2012

Before/After standard ortho images. Notice lack of registration.



Automatic crater detection. Lack of registration produces tremendous errors.

Before/After standard ortho images AFTER automatic registration.



The automatic registration allows perfect detection of new craters

Landslide Detection: Storms in Los Angeles, Hollywood Reservoir, 2005

Data:

Quickbird panchromatic image pair, standard ortho processing level (courtesy of DigitalGlobe):

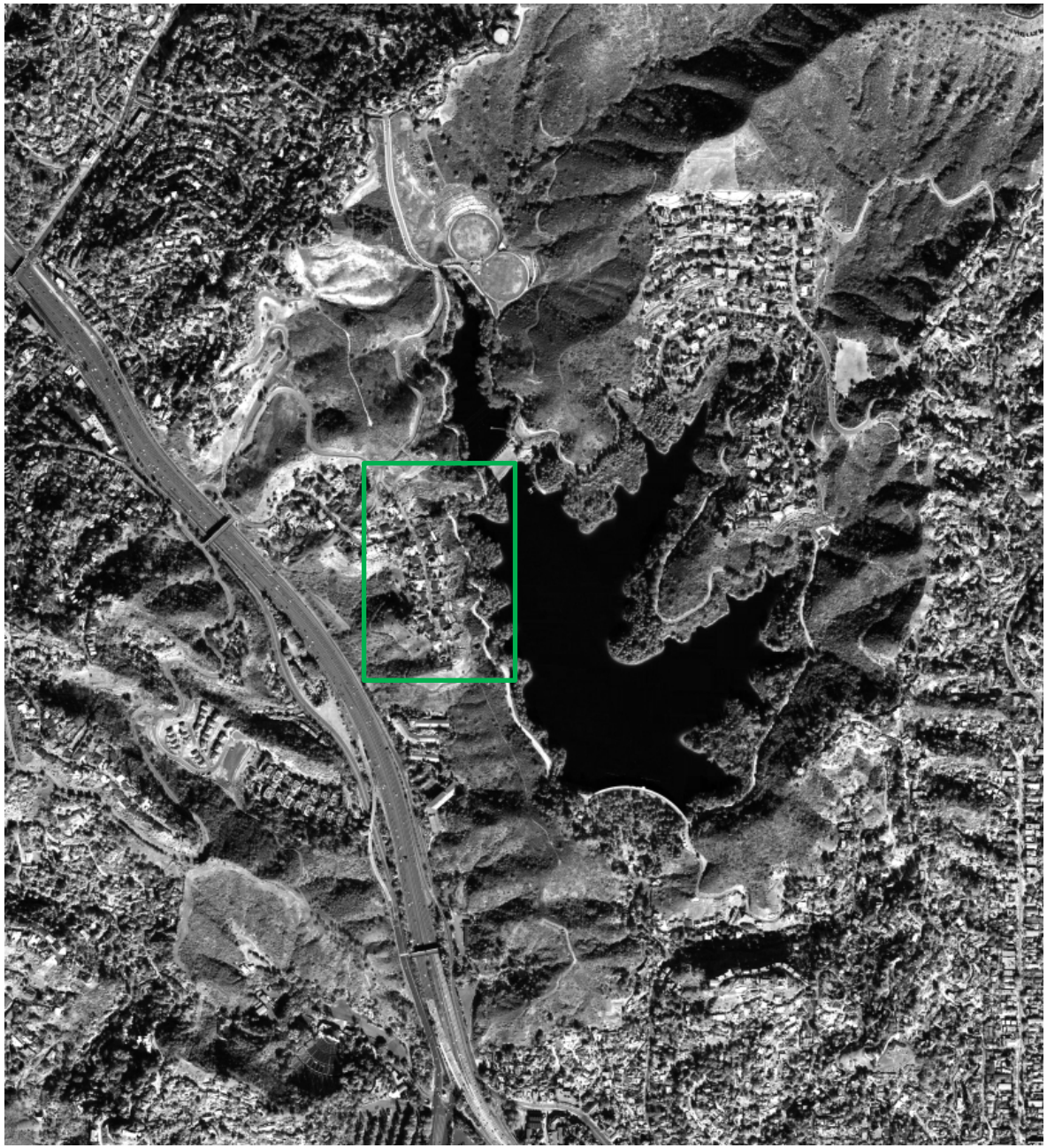
- Image 1 acquired on December 19, 2004

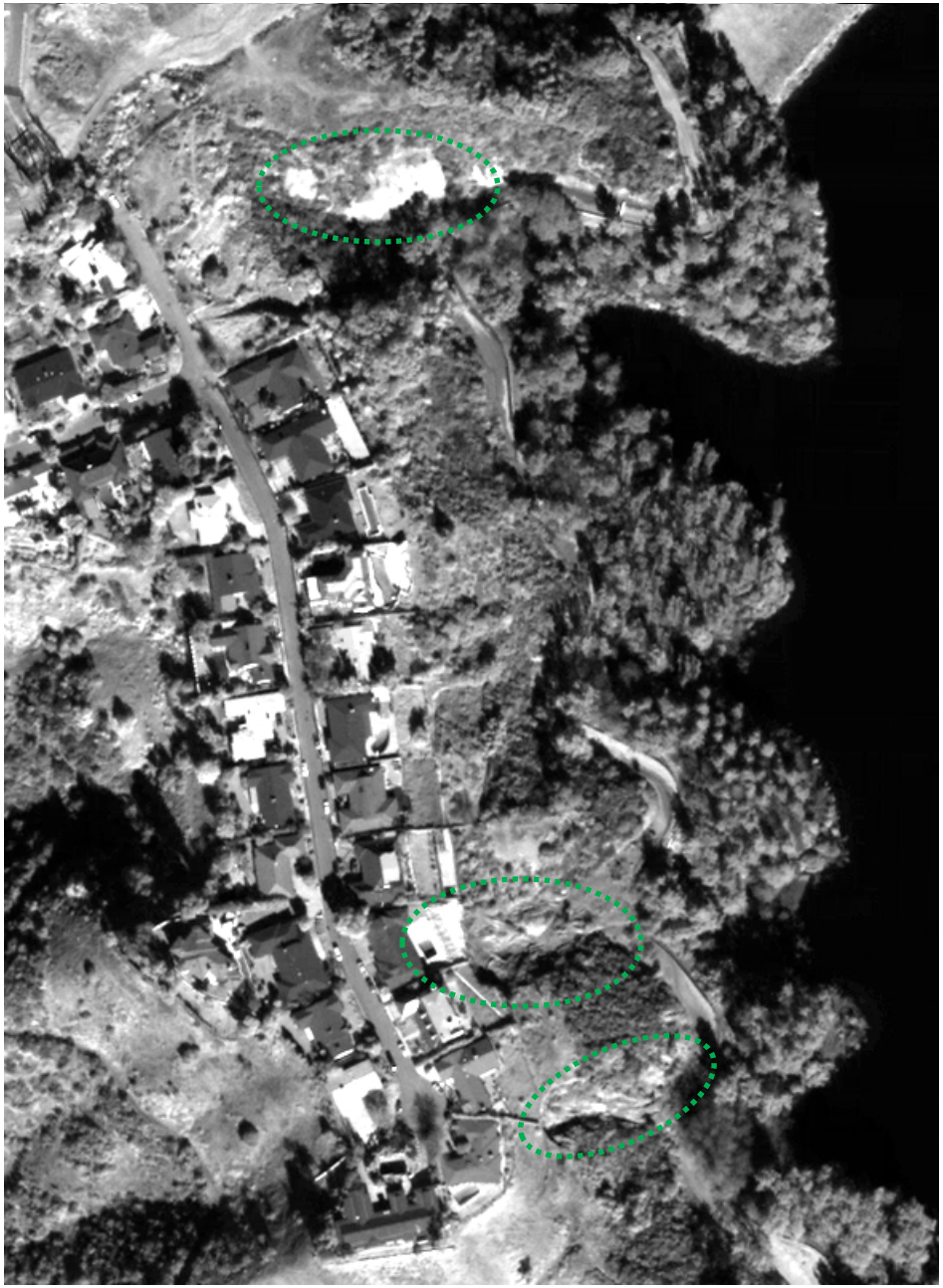
- Image 2 acquired on January 19, 2005

Goal:

Identify the location of landslides and related ground changes.

Hollywood Reservoir, Los Angeles:





Dec 2004 – Jan 2005 standard ortho images.

Parallax effect due to topography residuals (DEM too coarse).

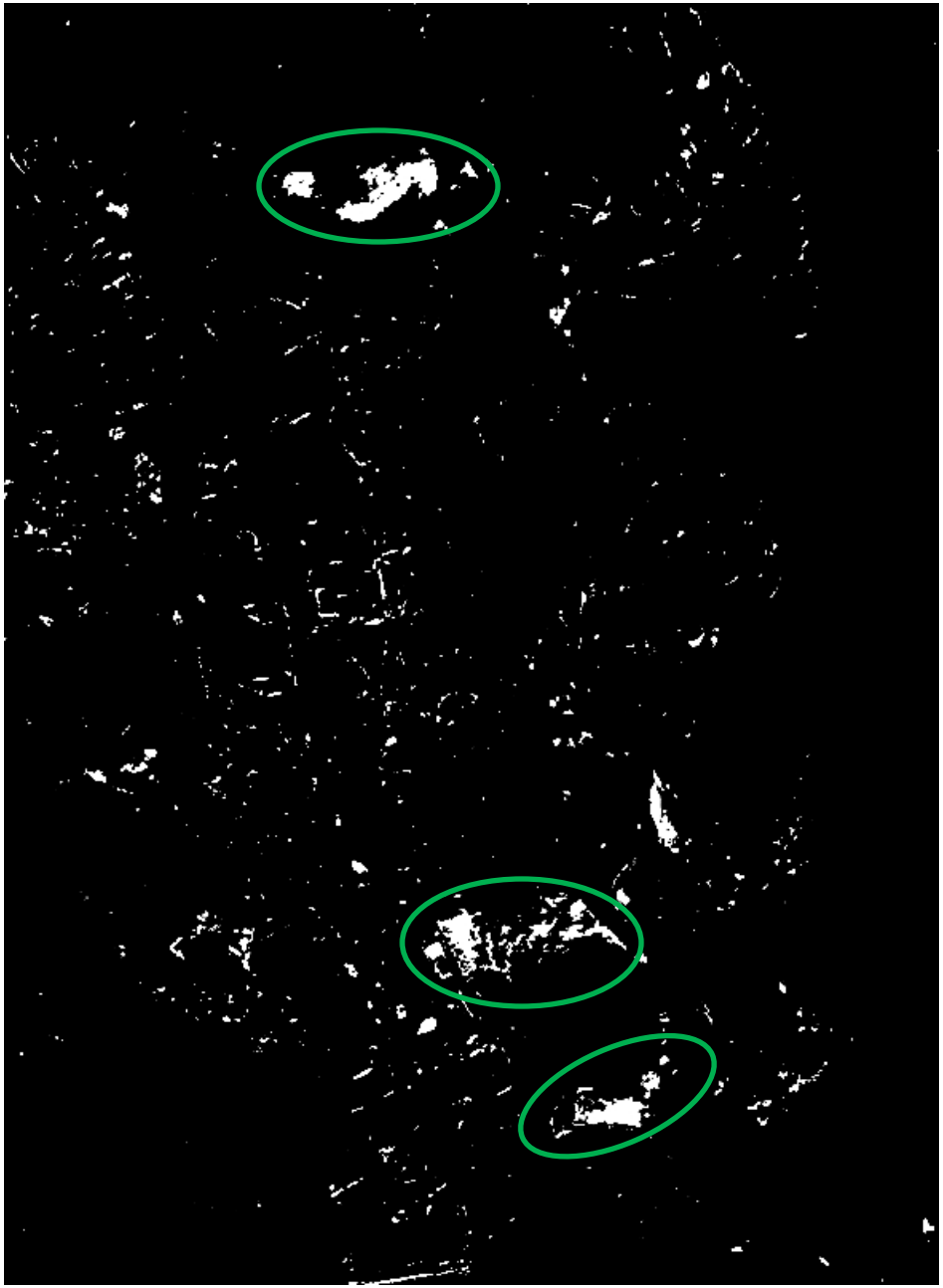
Better registration would be achieved with better DEM, but better DEM not always available in rapid response situations.

Automatic detection of ground changes.

Registration errors induce large errors in automatic change detection.

Dec 2004 – Jan 2005 standard ortho images AFTER dense registration.

Parallax residual is removed



Automatic detection of ground changes using registered images.

Automatic change detection identifies well the affected areas.

Conclusions

- Rigorous methods to measure 3D ground deformation,
- Generic methods to monitor a variety of surface processes (fault rupture, landslides, sand dune migration, glaciers, etc.),
- COSI-Corr processing of Worldview stereo-pairs can compete with LiDAR DSM acquisitions,
- Automatic registration enhances automatic change detection capabilities,
- COSI-Corr also processes LiDAR data with sub-pixel accuracy,
- Typical applications: disaster monitoring and assessment, city planning, mining, engineering projects, etc.