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Revisiting Past Earthquake and Seismo-Volcanic Crises using Declassified Optical Satellite Imagery

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ABSTRACT

In this study we demonstrate that the recently declassified Corona KH-9 images can be used to measure ground deformation due to seismotectonic and volcanic events from optical sub-pixel correlation. We use high resolution (6-9 m) satellite images, available from the USGS for a relatively small cost ($30 per image, swath measuring 250 x 125 km). The images are processed with the user-friendly software package COSI-Corr, which allows for automatic and precise ortho-rectification, co-registration, and sub-pixel correlation of pushbroom satellite and aerial images. Knowledge of the camera calibration information is required to determine the interior and exterior orientation parameters of the camera, which are in turn needed to successfully orthorectify and co-register the images using COSI-Corr. Because the camera information still remains classified, we follow the approach of Surazakov, et al., (2009), who conclude the Hexagon KH9 camera system is similar to the NASA Large Format Camera (LFC) system.

We successfully tested the approach on the 1999 Hector Mine, USA (Ms 7.4) and 1992 Landers, USA (Ms 7.5) earthquakes. Furthermore, we have been able to measure the surface deformation induced by the 1975-1984 Krafla rifting crisis in NE Iceland, by correlating a Hexagon image from 15th September 1977 with a SPOT5 image from 2002. During the period 1977-2002 we find an average E-W extension of 3±0.5 m across the rift, which extends NNE from Lake Myvatn in the south to Ásbyrgi canyon near the coast to the north (a distance of over 40 km) and were able to determine which faults were activated. The various examples discussed above highlight the potential for using inexpensive declassified Hexagon images to investigate tectonic deformation dating back to the onset of the KH9 program in 1973.

INTRODUCTION

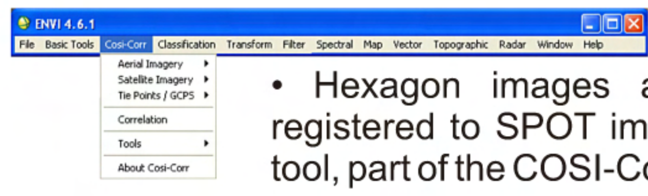
1 Co-registration and correlation of satellite images using COSI-Corr

• Recently declassified KH-9 Hexagon satellite images are available from the USGS for a fee of $30 per image. Each image measures 250 x 125 km, with a resolution of 6-9 m.

• Camera calibration information for KH-9 satellite images has not been declassified. However, Surazakhov (2009) recently demonstrated that KH-9 images were aquired with essentially the same system as the Large Format Camera (LFC), for which the calibration information is known.


LFC system

• We use the corner reseau grid marks as fiducial points, assuming no offset of the principal point, and a focal length of 0.305 m.



• Hexagon images are orthorectified and co-registered to SPOT images using the aerial photo tool, part of the COSI-Corr software.

• Hexagon images are then correlated with SPOT images to produce deformation maps (E-W and N-S components).

• Reseau marks may be found and film distortions corrected using the KH-9 Tools tool for ENVI (Surazhakov, 2009).

• We correlate Hexagon and SPOT images for the 1992 Landers and 1999 Hector Mine earthquakes, and the 1975-84 Krafla rifting crisis.

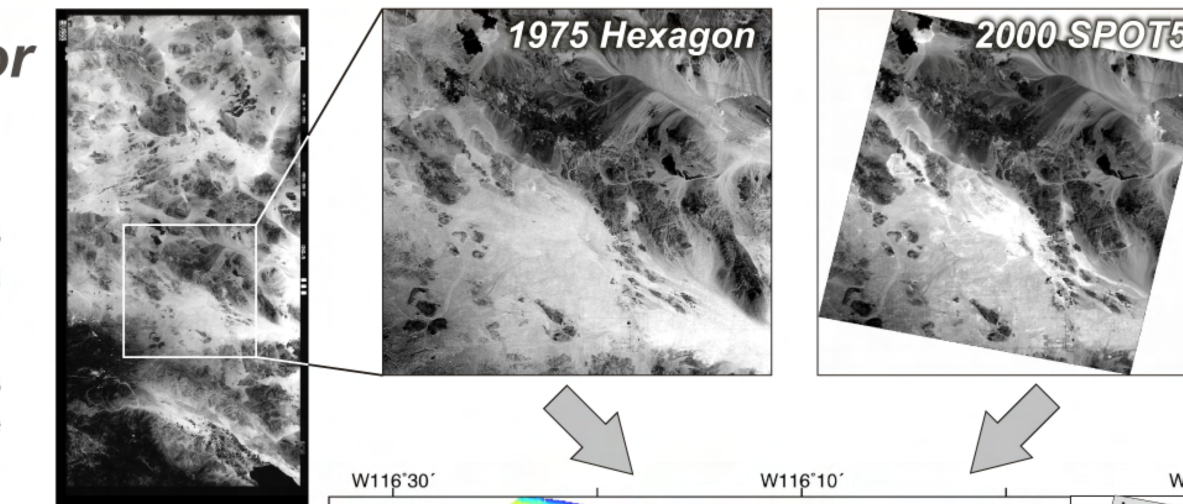
1992 LANDERS & 1999 HECTOR MINE EARTHQUAKES

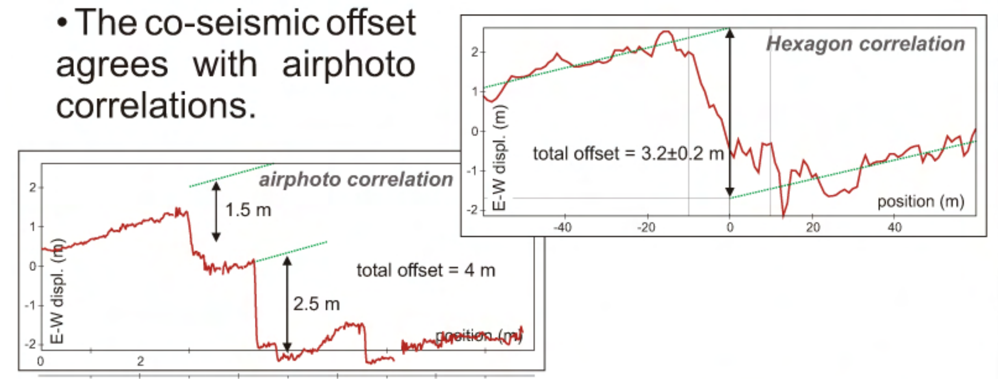
2 Landers and Hector Mine earthquakes

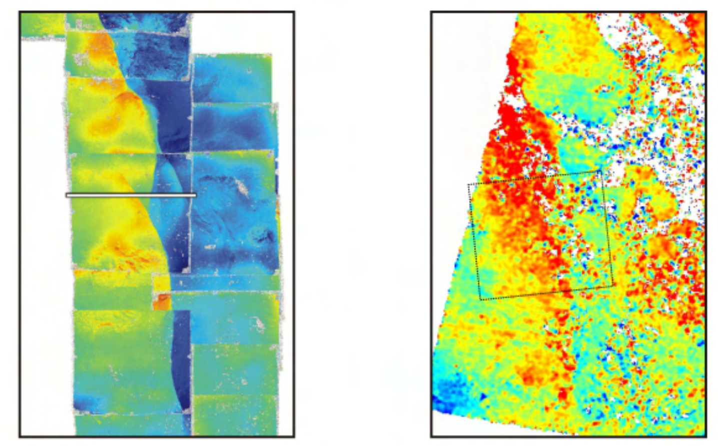
• A Hexagon image from 1975 was orthorectified and co-registered to a SPOT4 image from 2000.

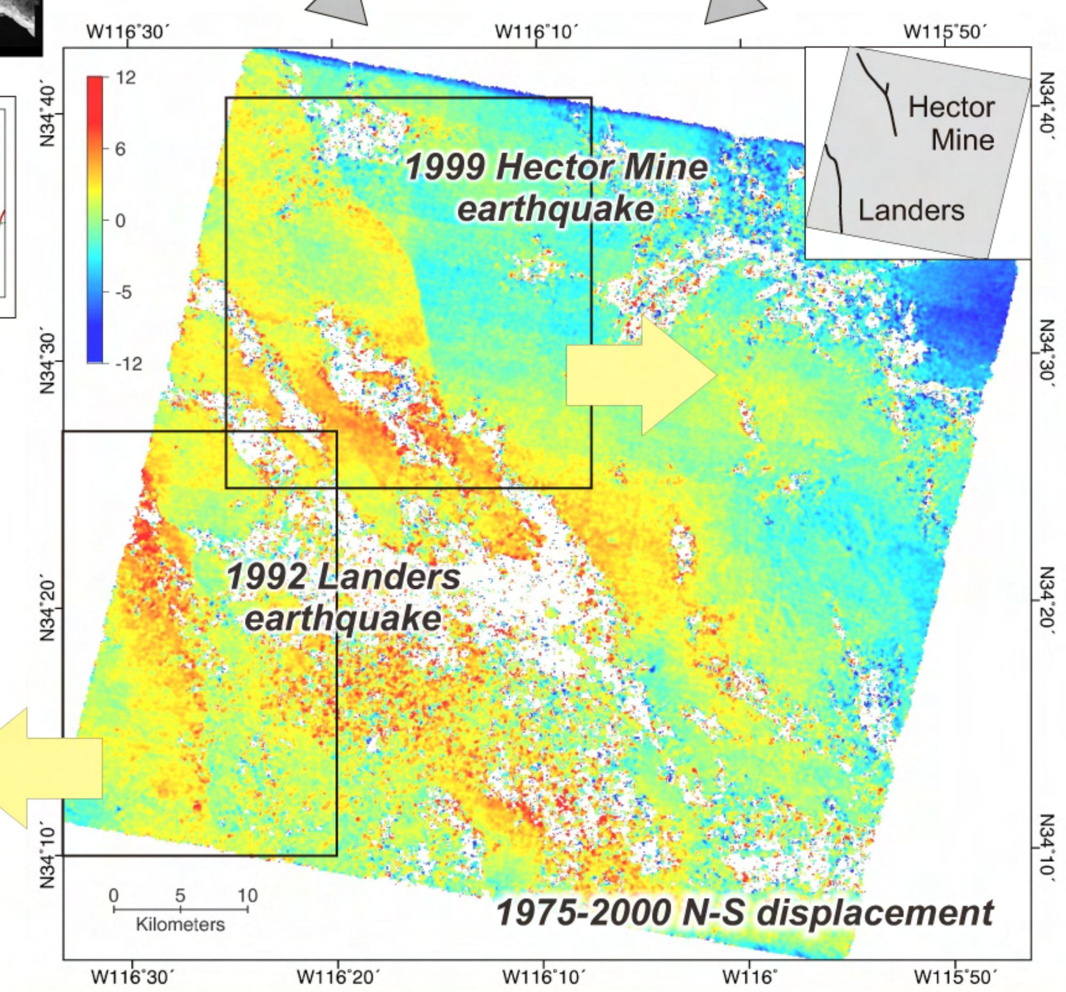
• Right-lateral slip in both earthquakes is clearly seen in the N-S component of the deformation map.

• The co-seismic offset agrees with airphoto correlations.





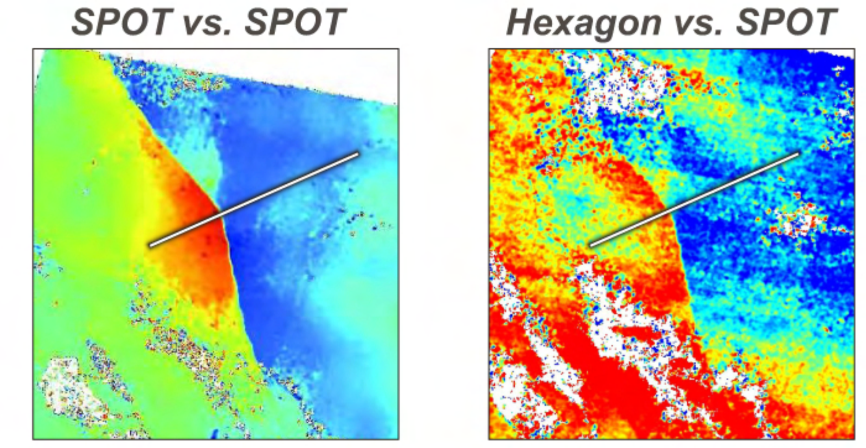




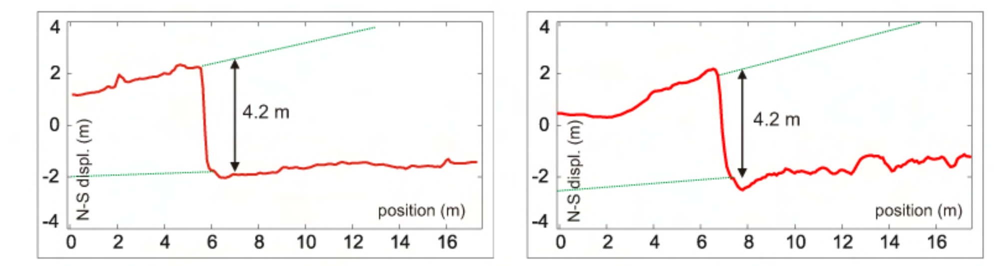
• Although Hexagon vs. SPOT correlations are typically noisy, the location of the fault rupture and the fault offset are consistent with SPOT vs. SPOT correlations.

• Scanning artifacts are clearly seen in the Hexagon vs SPOT correlations - these can be partly removed using the destriping tool in COSI-Corr.

• Despite 25 years between images, the arid desert environment of the Hector Mine region results in a good correlation.



• The fault offset (N-S component) for the Hector Mine earthquake, determined from Hexagon vs. SPOT4, is the same as SPOT vs. SPOT correlations.



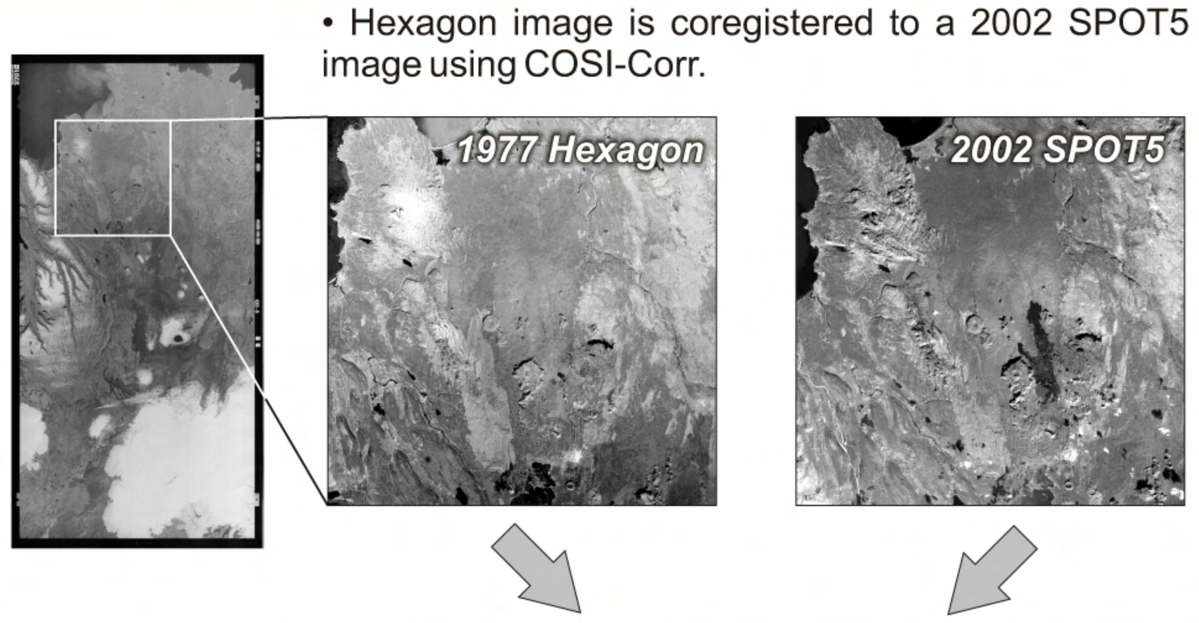
1975-84 KRAFLA RIFTING CRISIS

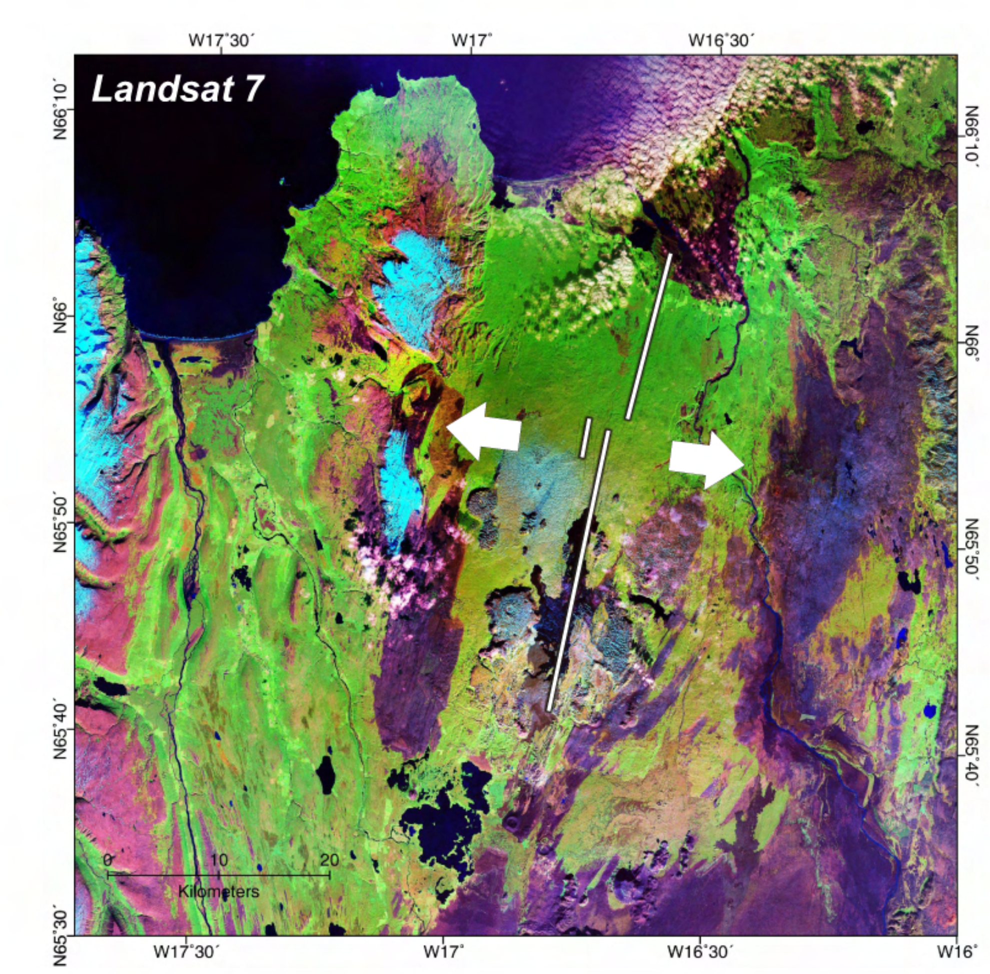
3 1975-1984 Krafla rift crisis

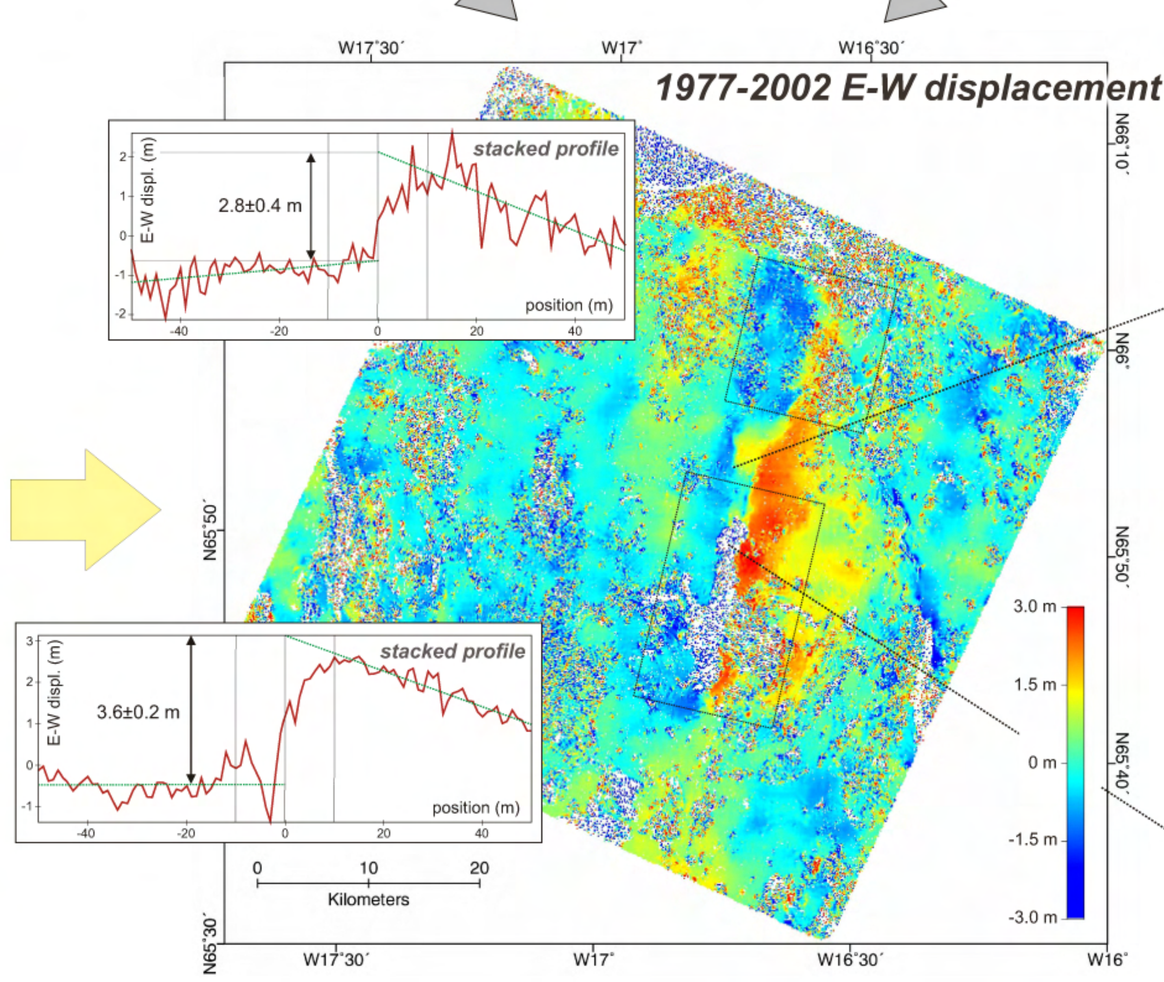
• A declassified 1977 Hexagon satellite image (6-9 m) was correlated with a 2002 SPOT5 image (2.5 m) of the Krafla rift zone, NE Iceland to determine the displacement field associated with the 1975-84 Krafla rifting crisis.

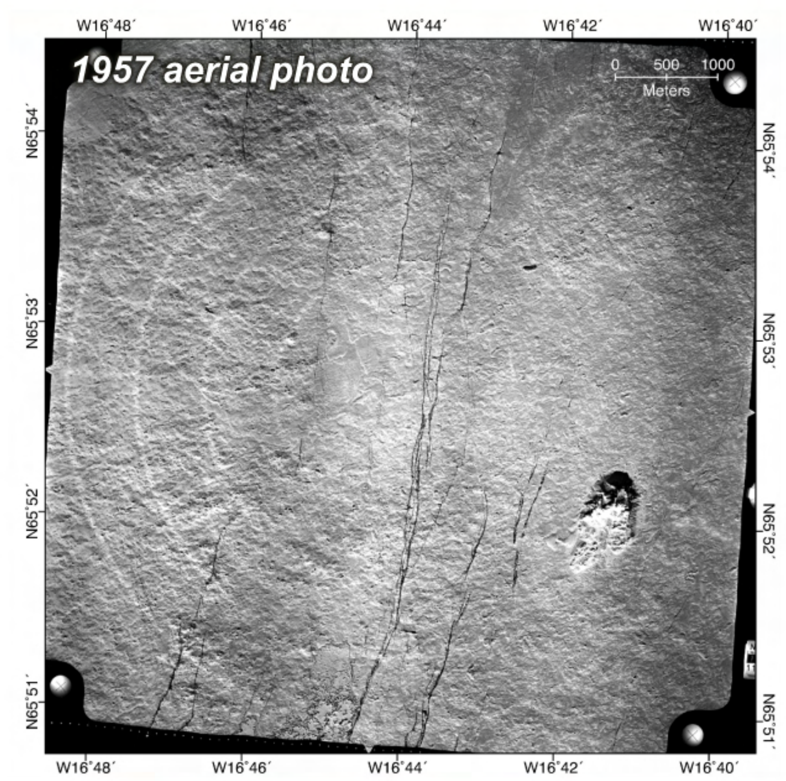
• E-W extension occurs on normal faults (overlying intruding dikes); between 1977-2002, ~3 m E-W extension occurred, which extended north to the coast.

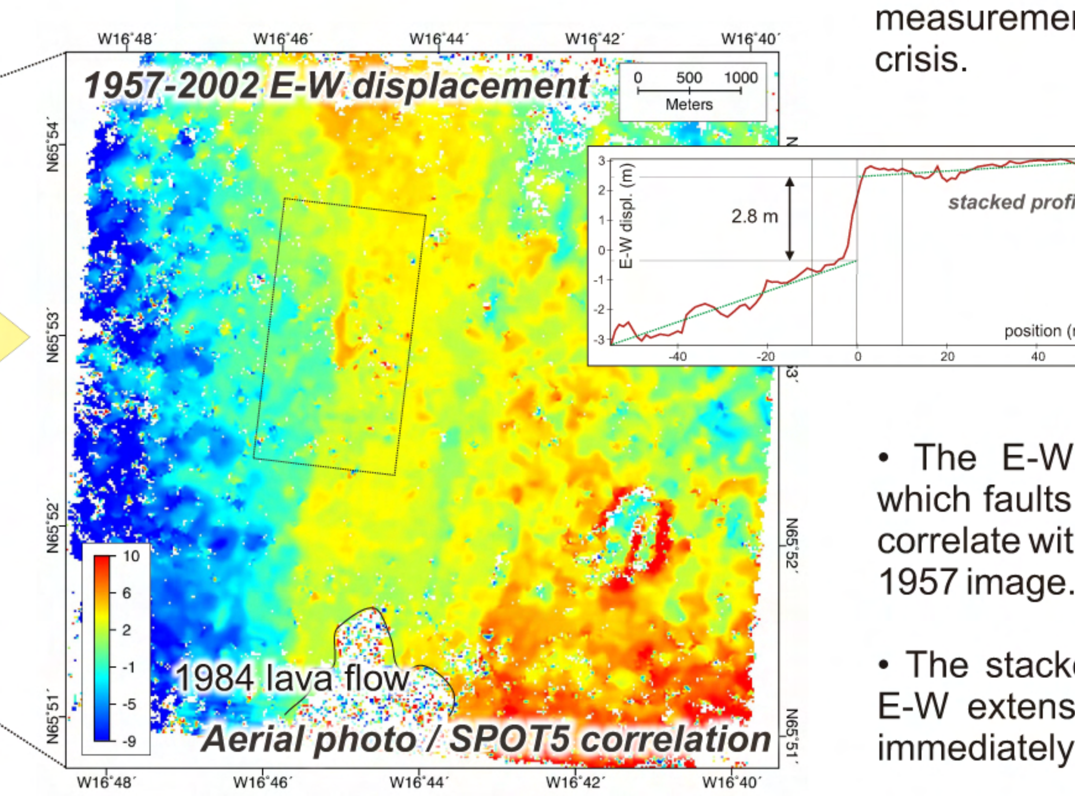
• Hexagon image is coregistered to a 2002 SPOT5 image using COSI-Corr.

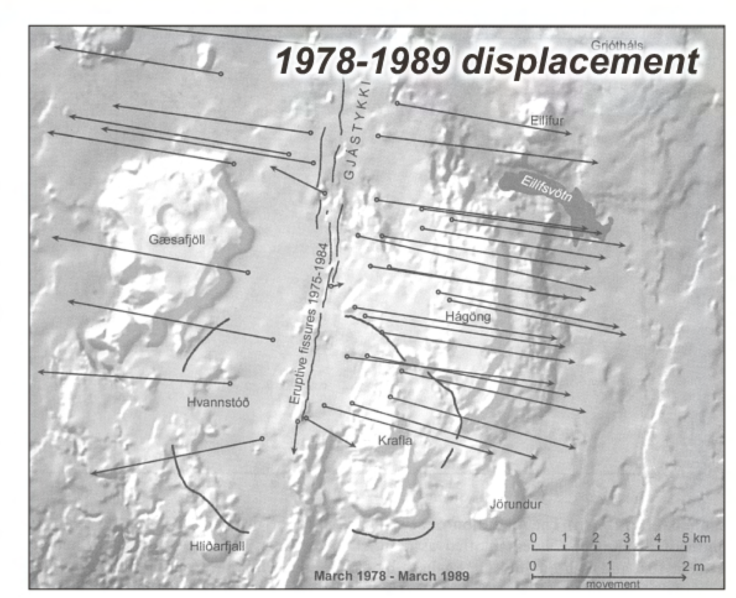












• The displacement field estimated from the correlation of Hexagon and SPOT5 images is consistent with geodetic (EDM) measurements made during the time of the crisis.

• Aerial photos from 1957 can also be correlated with the 2002 SPOT5 image to determine exactly which faults moved during the Krafla rifting crisis.

• The E-W displacement map highlights which faults moved during the crisis. These correlate with pre-existing faults visible in the 1957 image.

• The stacked profile above indicates 3 m E-W extension on the western-most fault, immediately north of the 1984 erupted lavas.

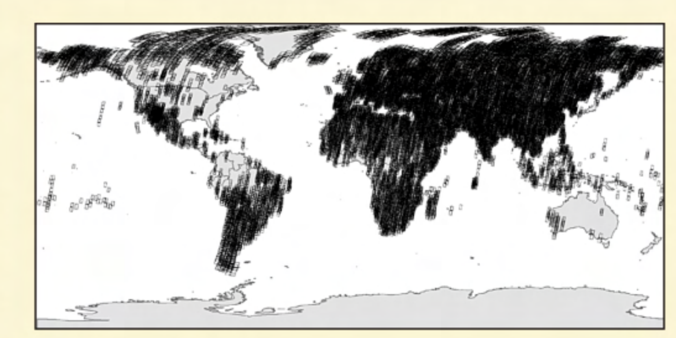
DISCUSSION / CONCLUSIONS

4

• We demonstrate that declassified KH-9 Hexagon images may be orthorectified and precisely co-registered to SPOT satellite images. Sub-pixel correlation of these two images reveals the location and magnitude of past tectonic deformation.

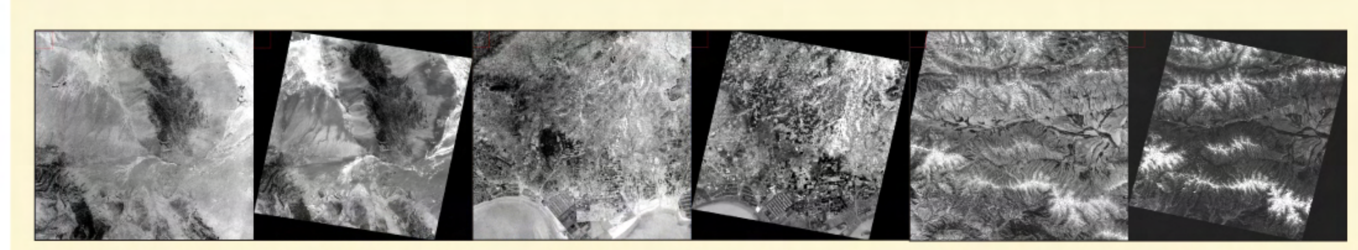
• Hexagon images offer huge potential for monitoring movement of the Earth's surface from 1973 to the present day.

• Images are inexpensive ($30), and offer global coverage; 29,000 images were acquired between 1973-1980.



• Large earthquakes which ruptured the Earth's surface during the pre-InSAR period may now be investigated by correlating Hexagon images with either SPOT or ASTER data.

• Further studies investigating the location and magnitude of coseismic surface ruptures associated with the 1979 Khuli-Buniabad, 1976 Tangshan and 1992 Suusamyr earthquakes are ongoing.


1979 Khuli-Buniabad (Mw 7.1) 1976 Tangshan (Ms 7.8) 1992 Suusamyr (Ms 7.3)

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