Detection of sinkhole precursors along the Dead Sea, Israel, by SAR interferometry

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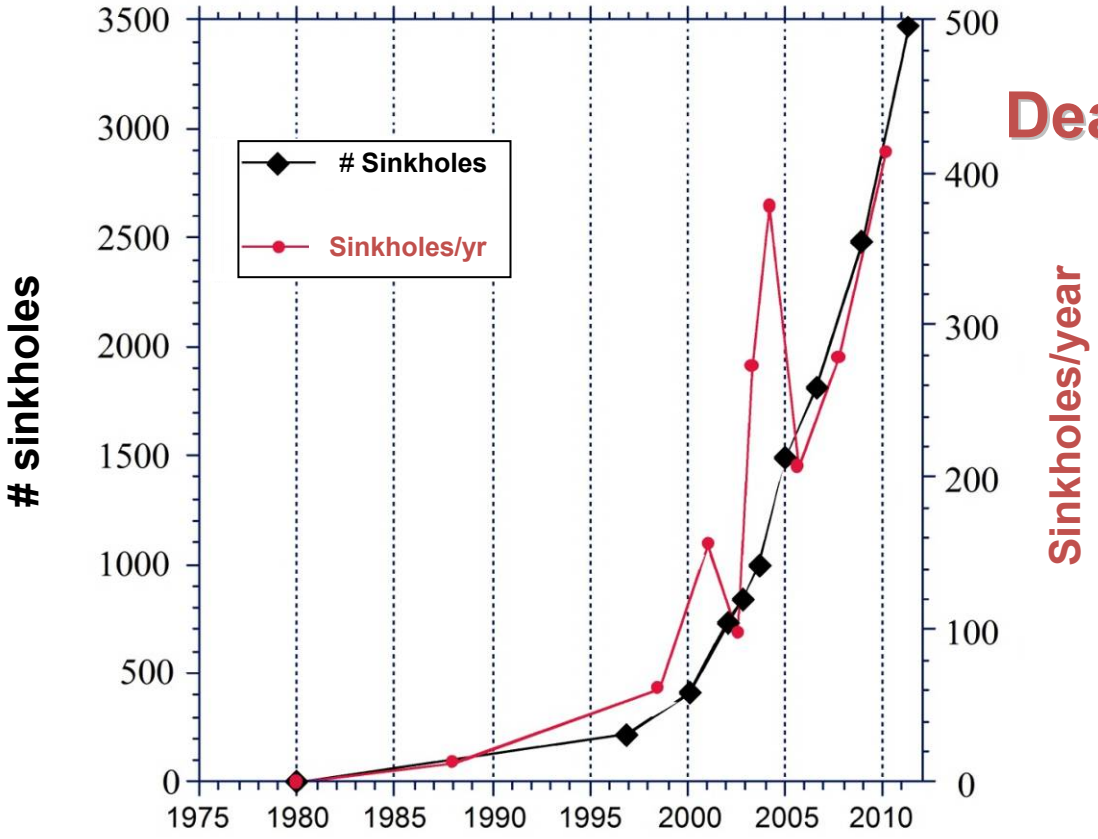
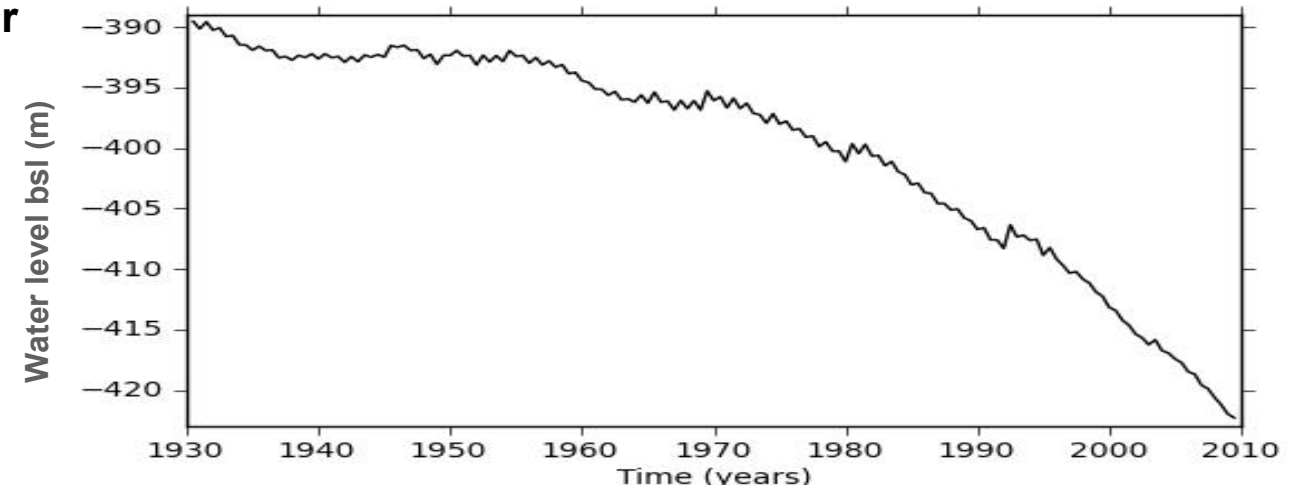
5 – INGV, Rome, Italy

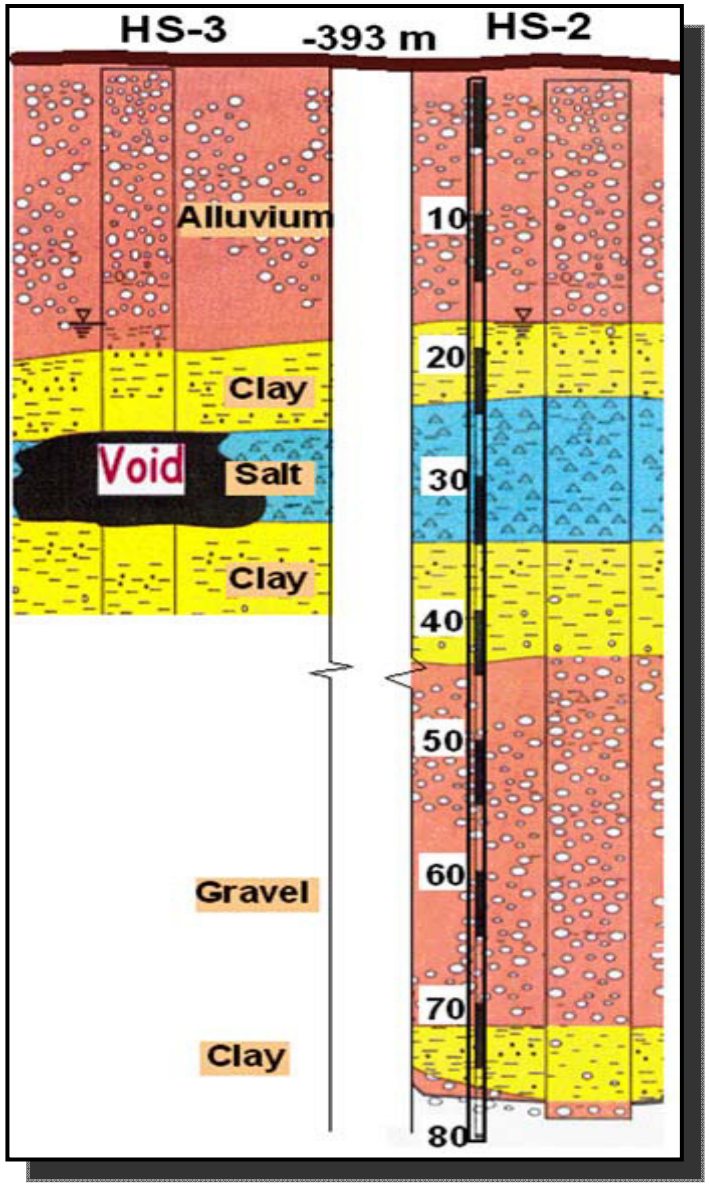
Dead Sea sinkhole evolution



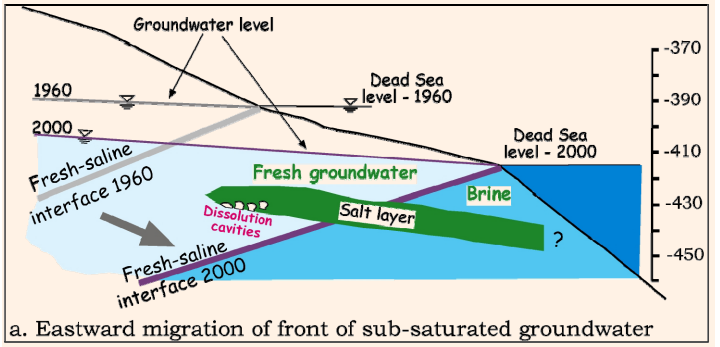
Dead Sea water level drop



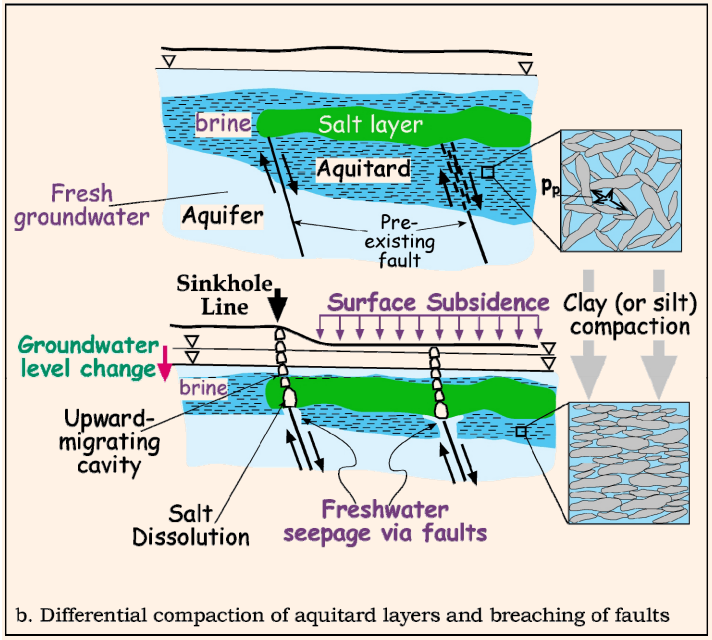
Formation mechanism



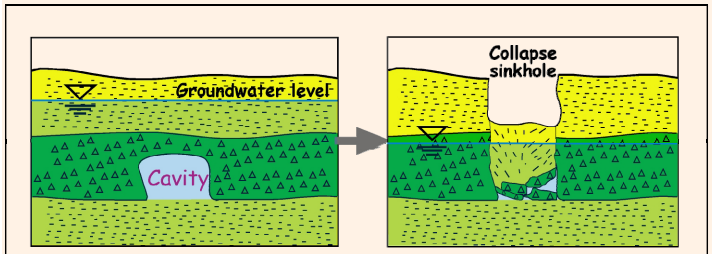
Ezersky et al., 2009



a. Eastward migration of front of sub-saturated groundwater

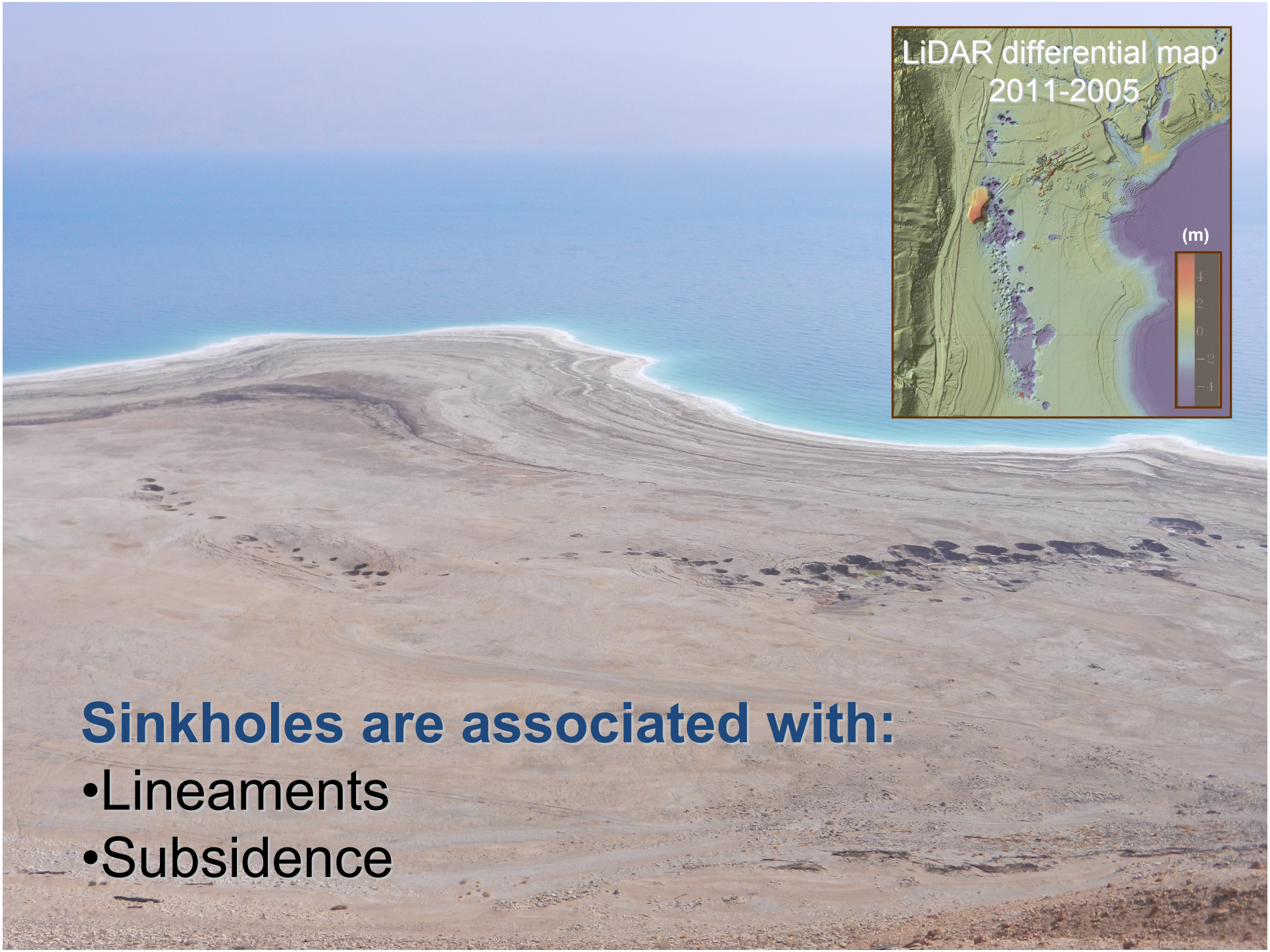


b. Differential compaction of aquitard layers and breaching of faults



c. Destabilization of cavities:
Decrease of groundwater level → Increase of effective stresses

Abelson et al., 2003

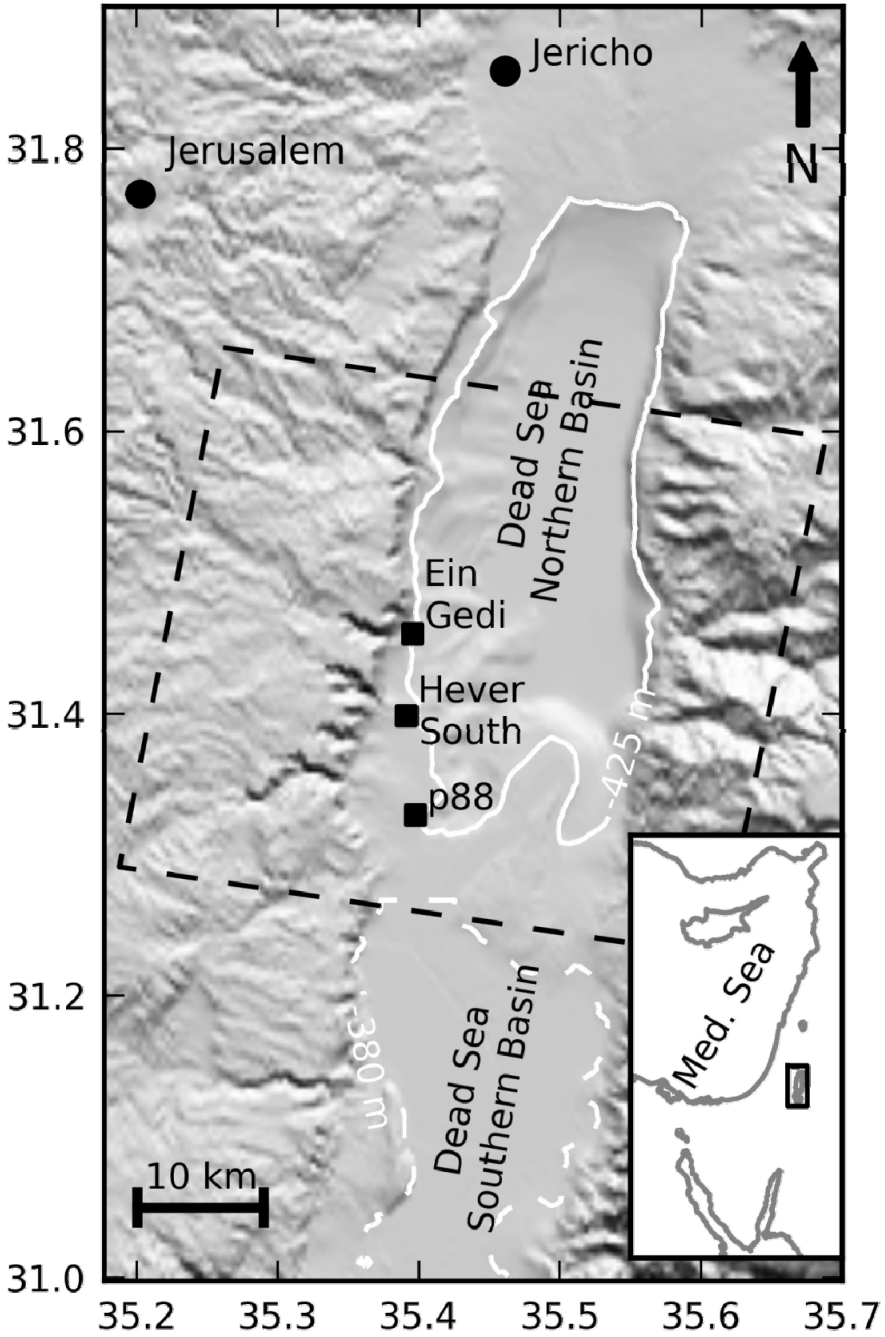


Sinkholes are associated with:

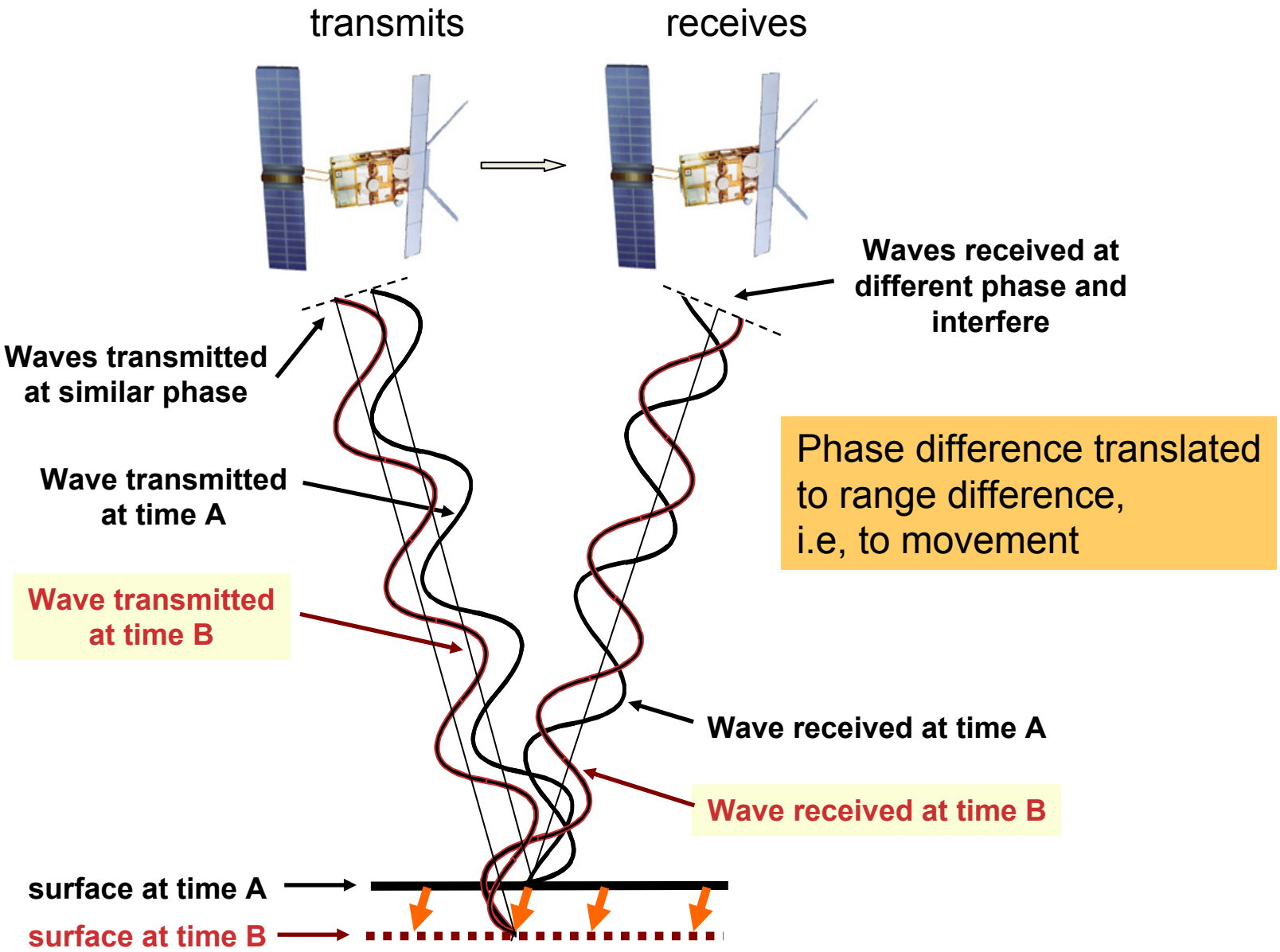
- Lineaments
- Subsidence

Objective:

Detect sinkhole – related precursory subsidence



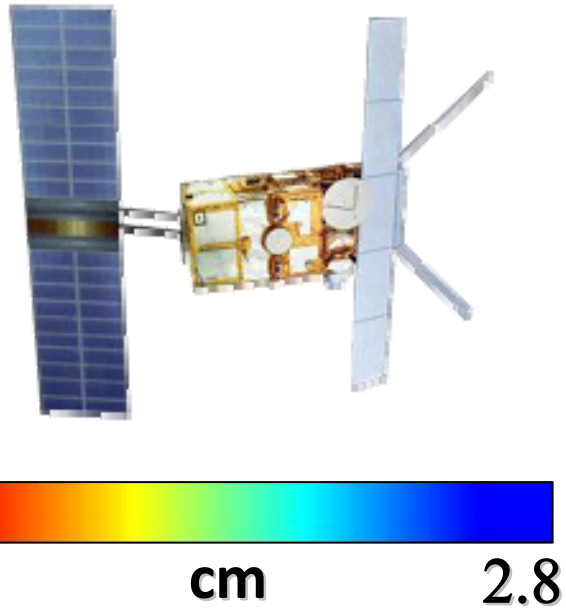
Method: Interferometric Synthetic Aperture Radar (InSAR)



1992 - 2011

Satellites:

ERS, ENVISAT
Wavelengths: 5.65 cm (C-band)
Incidence angles: 19° – 44°
Revisit time: 1 day, 35 days
Spatial resolution: 20x5 m/pixel
Altitude: ~800 km
European space agency

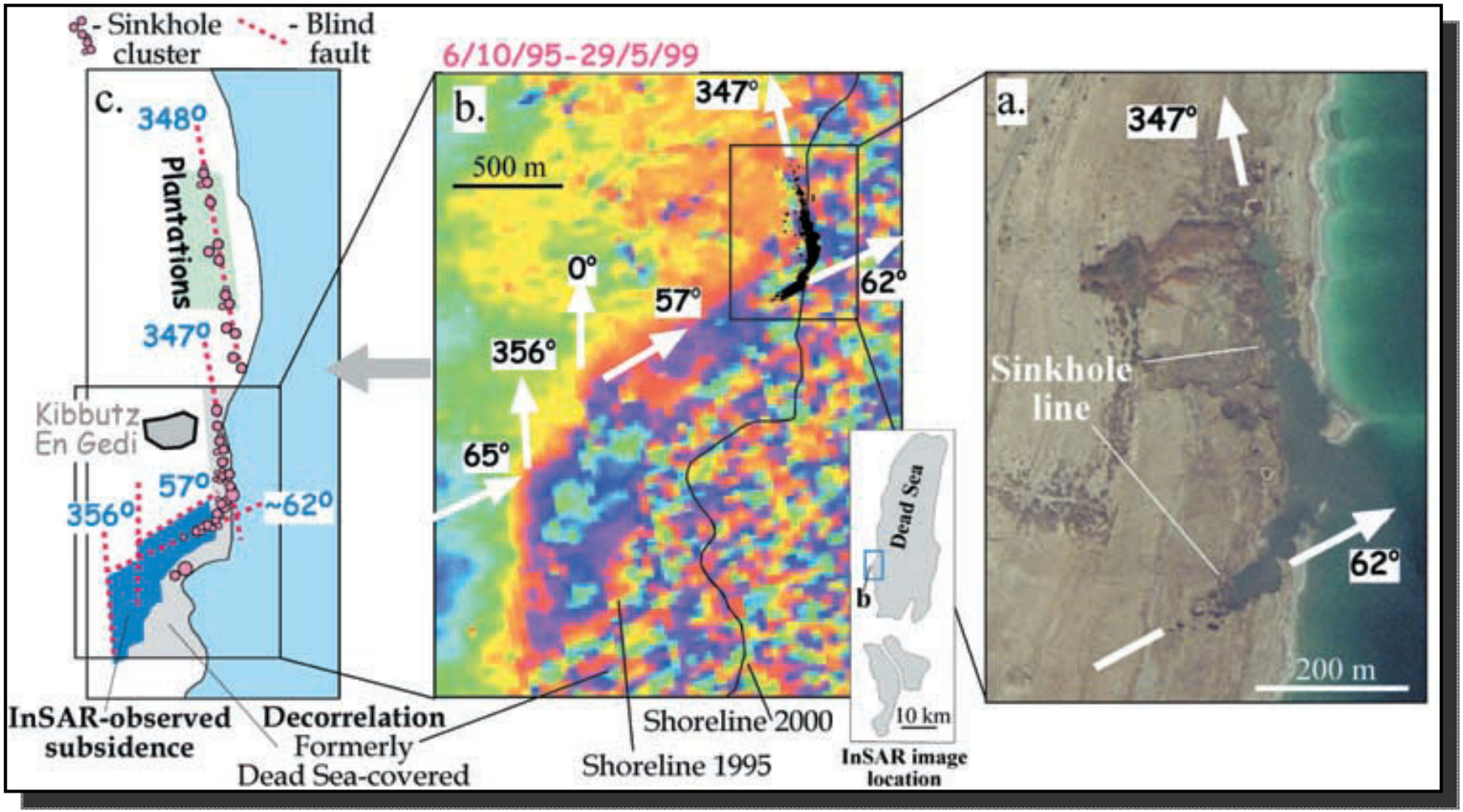


Digital Elevation Models:

ASTER GDEM: 30x30 m/pixel
SRTM: 90x90 m/pixel
Vertical error: 17 m

InSAR 1992 - 2011

Abelson et al., 2003



Sinkholes form at margins of gradual subsidence zones, fault controlled

Temporal relationships - undefined

2012-2013

Satellites:

COSMO SkyMed (CSK)

Wavelength: 3.12 cm (X-band)

Incidence angle: 41°

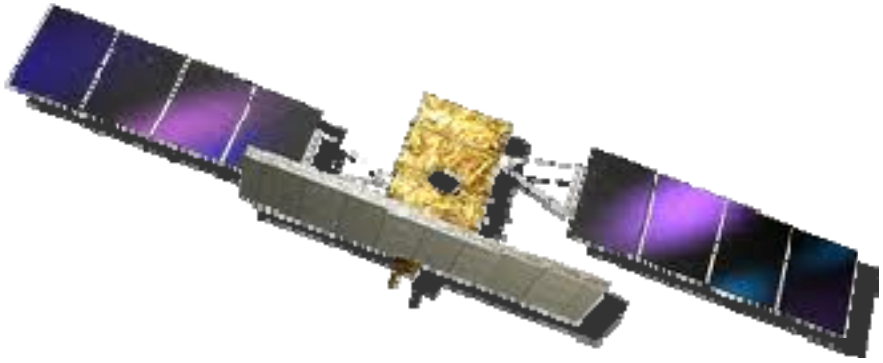
Revisit time: 1, 4, 8, 16 days

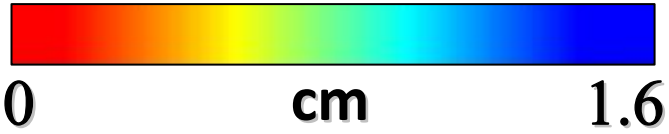
Spatial resolution: 3x3 m/pixel

Altitude: 620 km

constellation of 4 satellites

Italian space agency



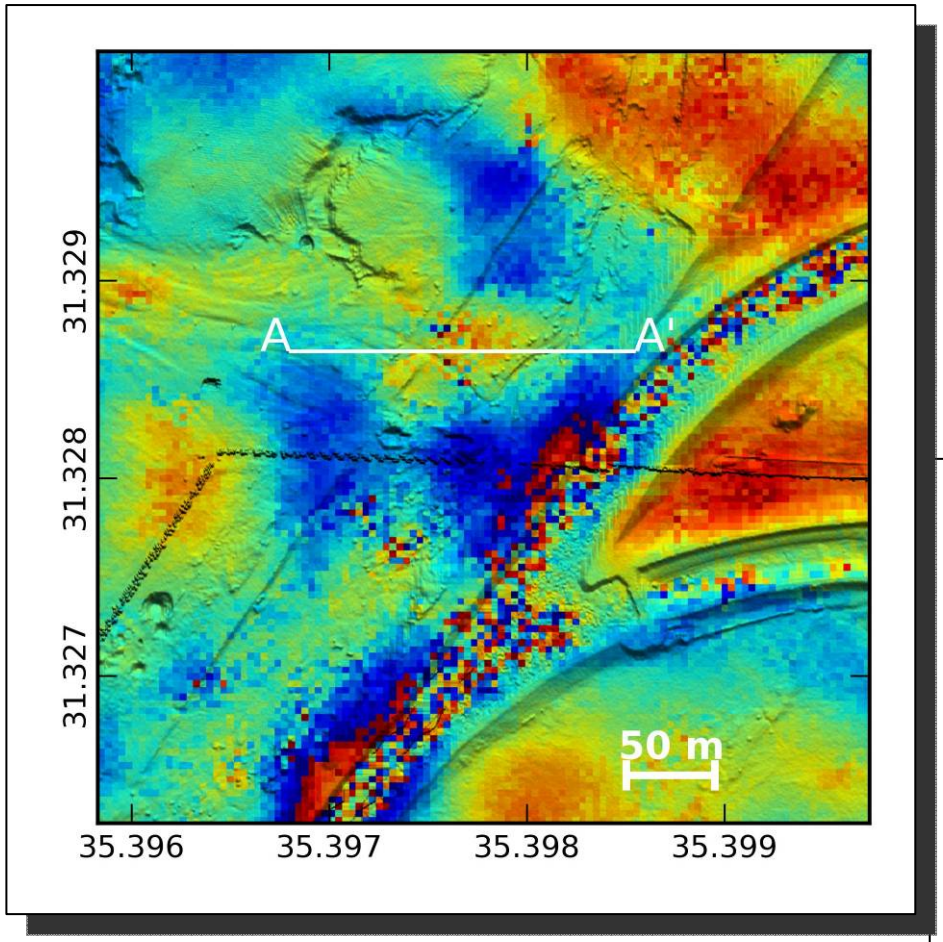


Digital Elevation Model:

Airborne LiDAR: 0.5x0.5 m/pixel

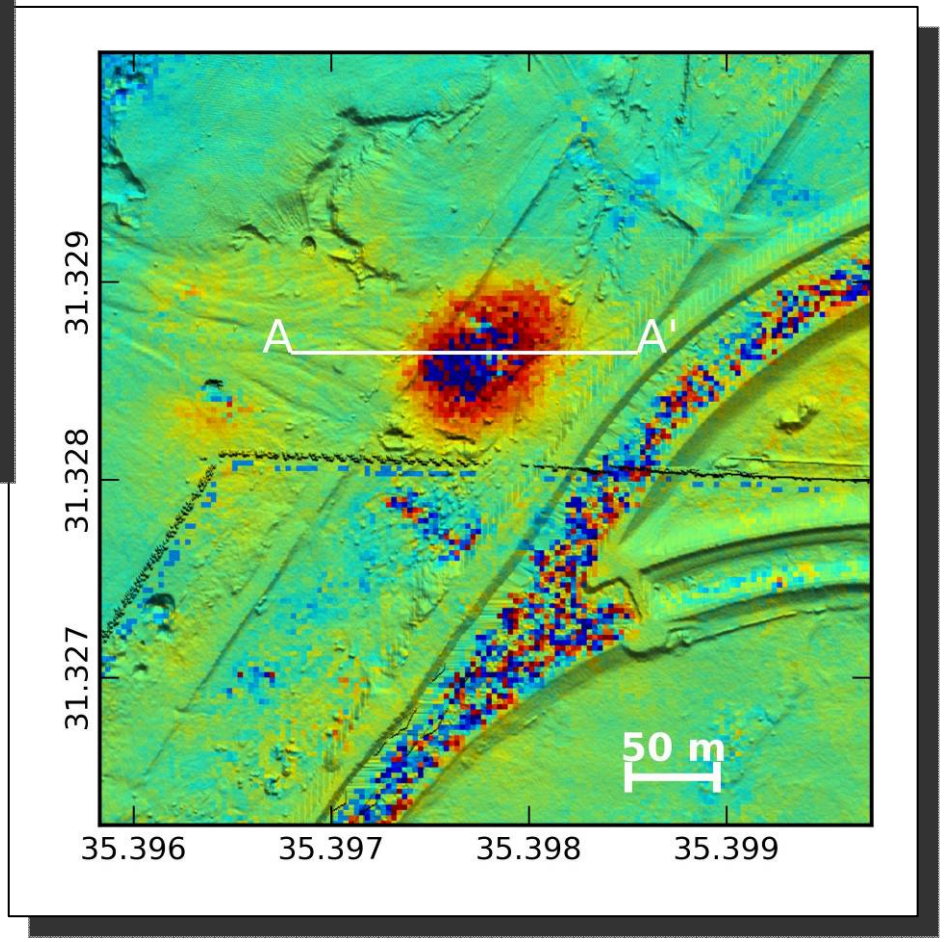
Vertical error: 0.35 m

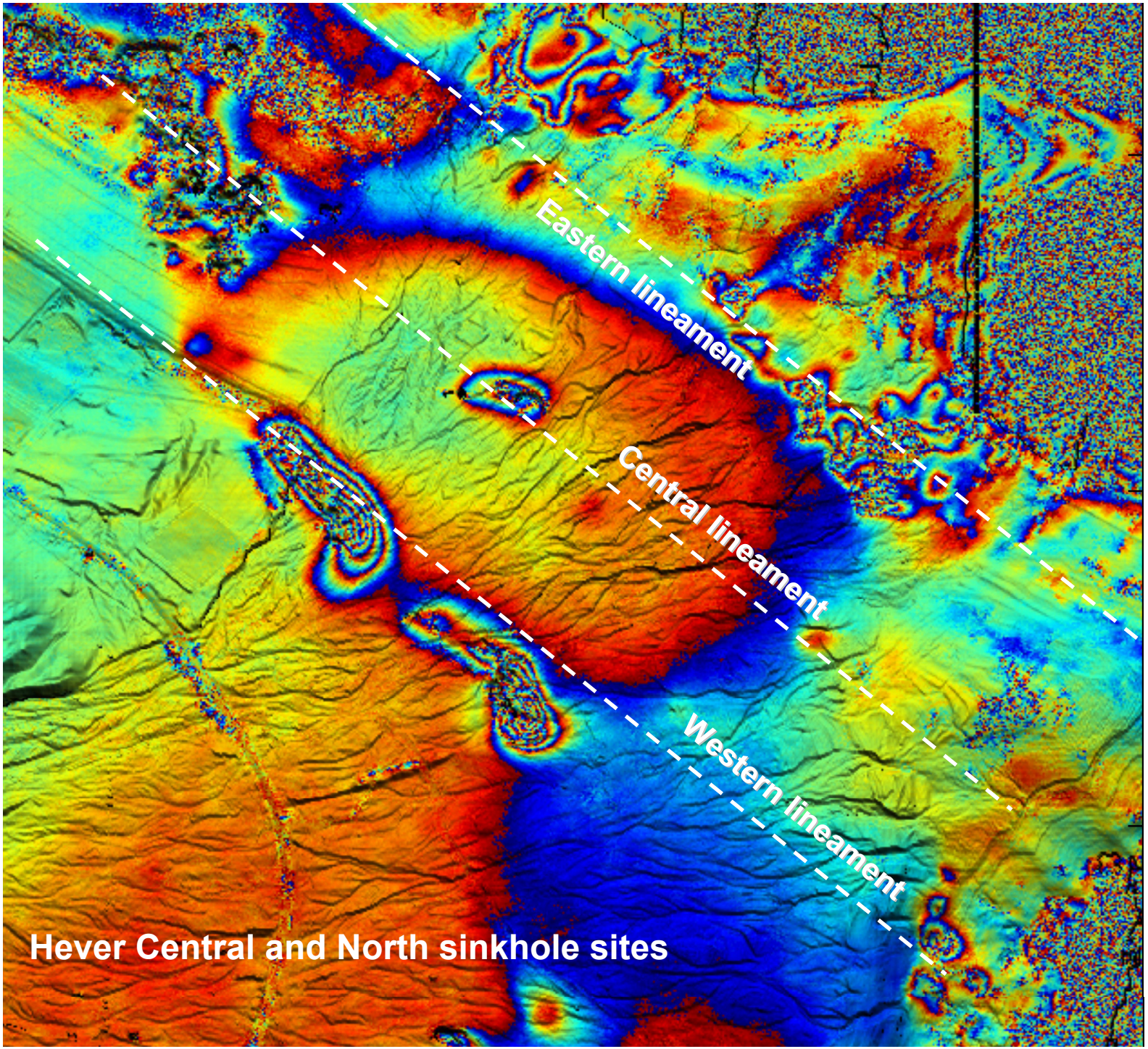
P-88 sinkhole site:
Increased resolution using different DEMs



ASTER GDEM (30m x 30m)

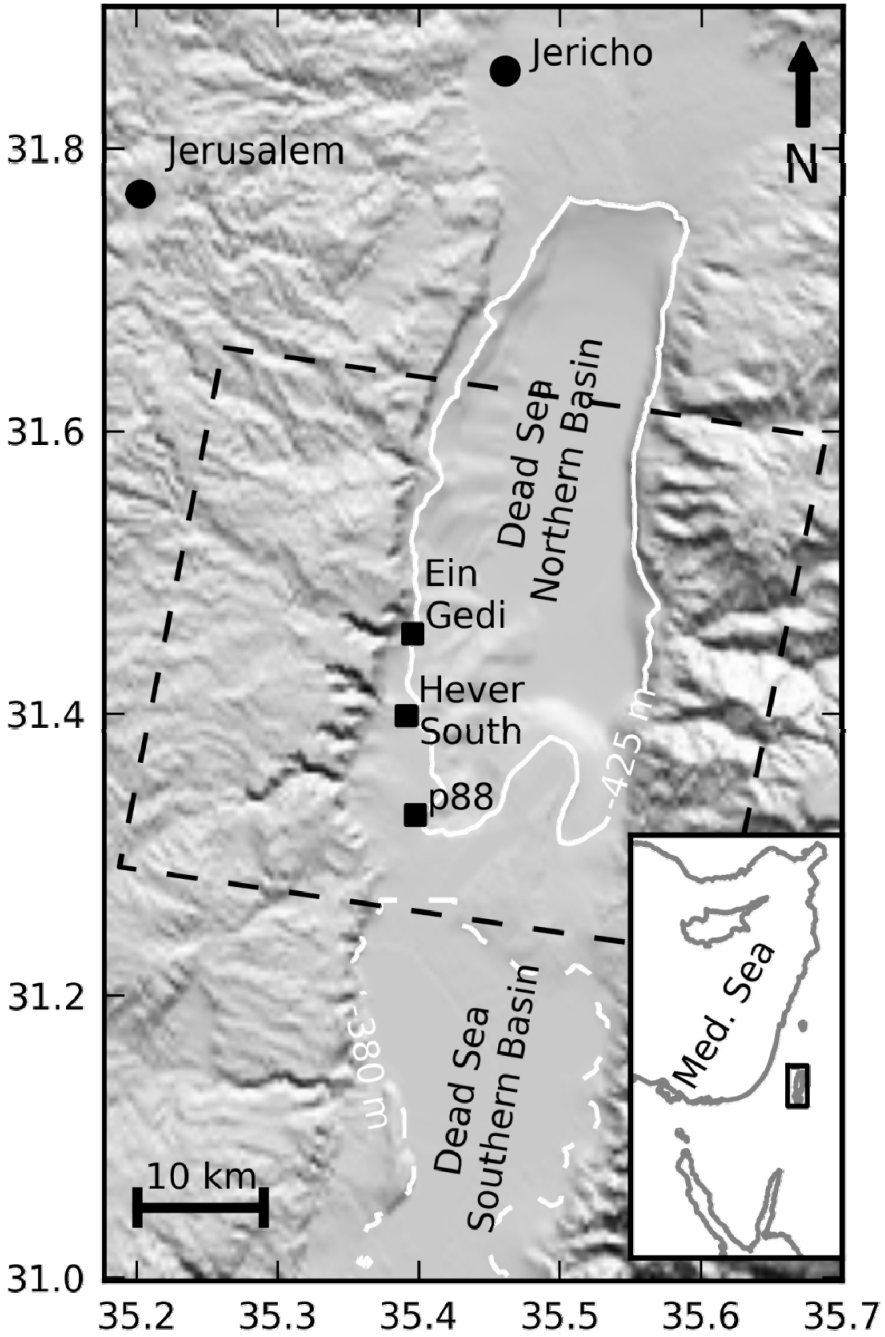
LiDAR (0.5m x 0.5m)




Eastern lineament
Central lineament
Western lineament
Hever Central and North sinkhole sites

Test areas:

- P88
- Hever South
- Ein Gedi

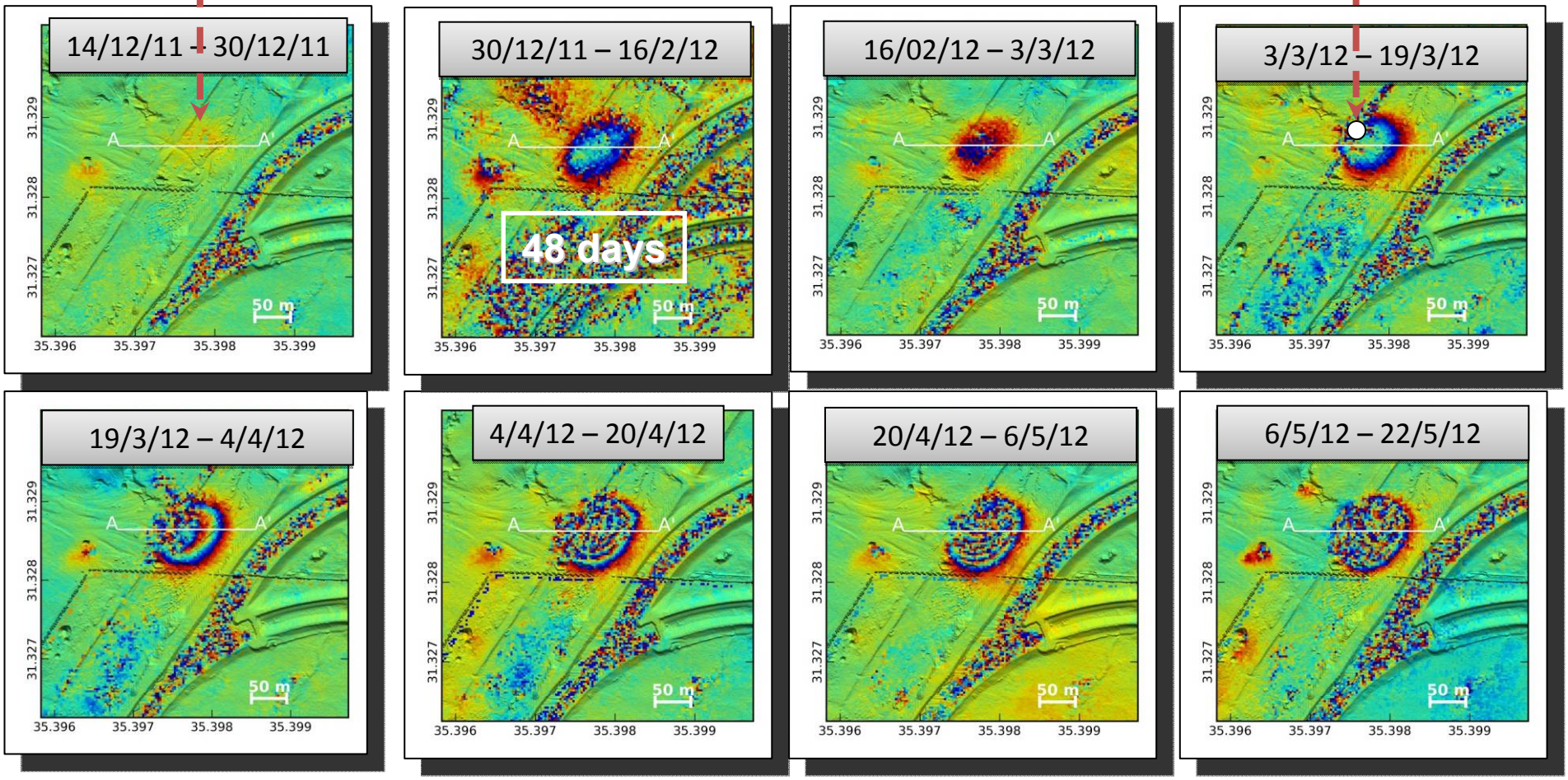


P-88 site: 19.3.2012

P – 88

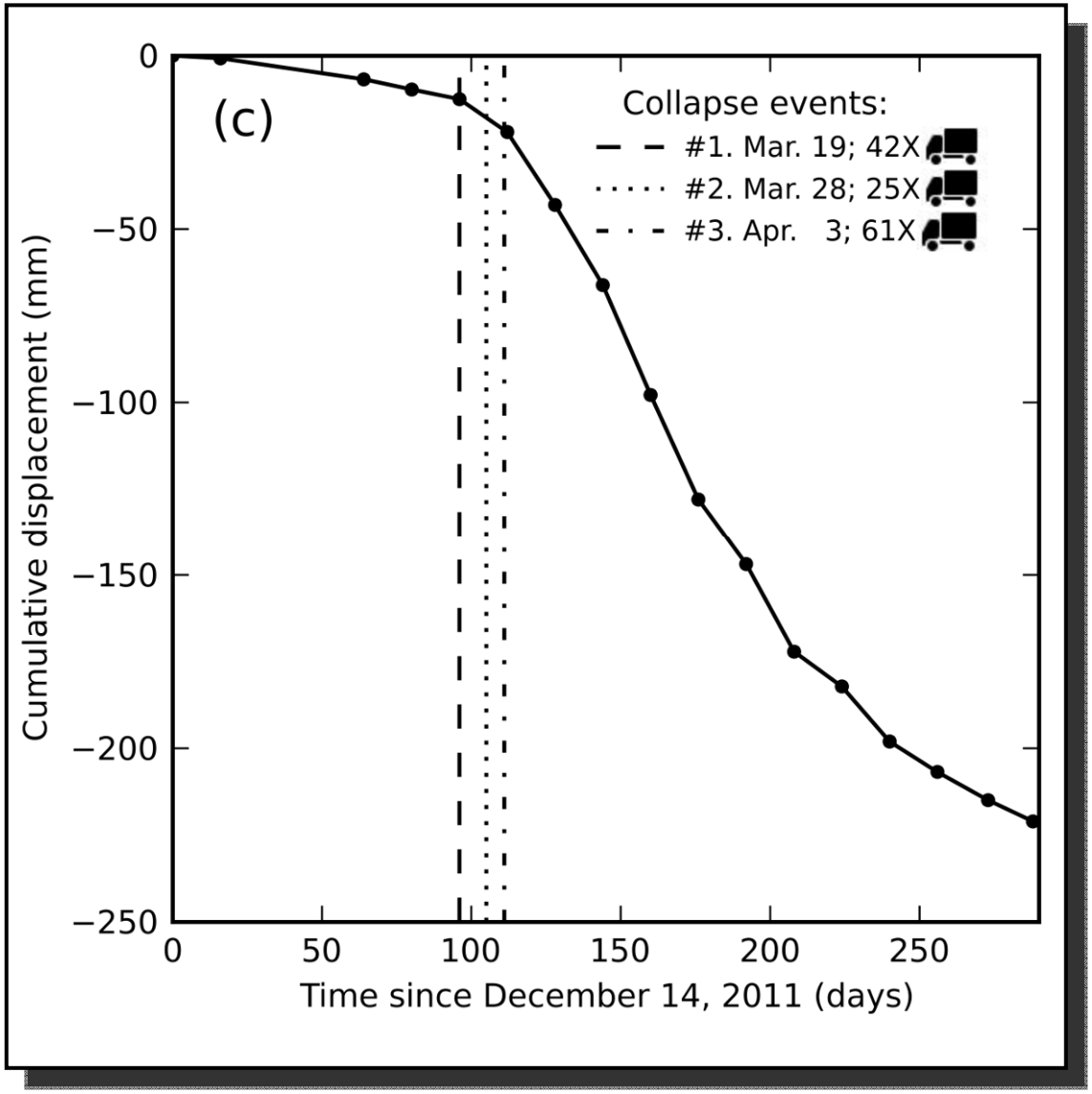
Initial subsidence

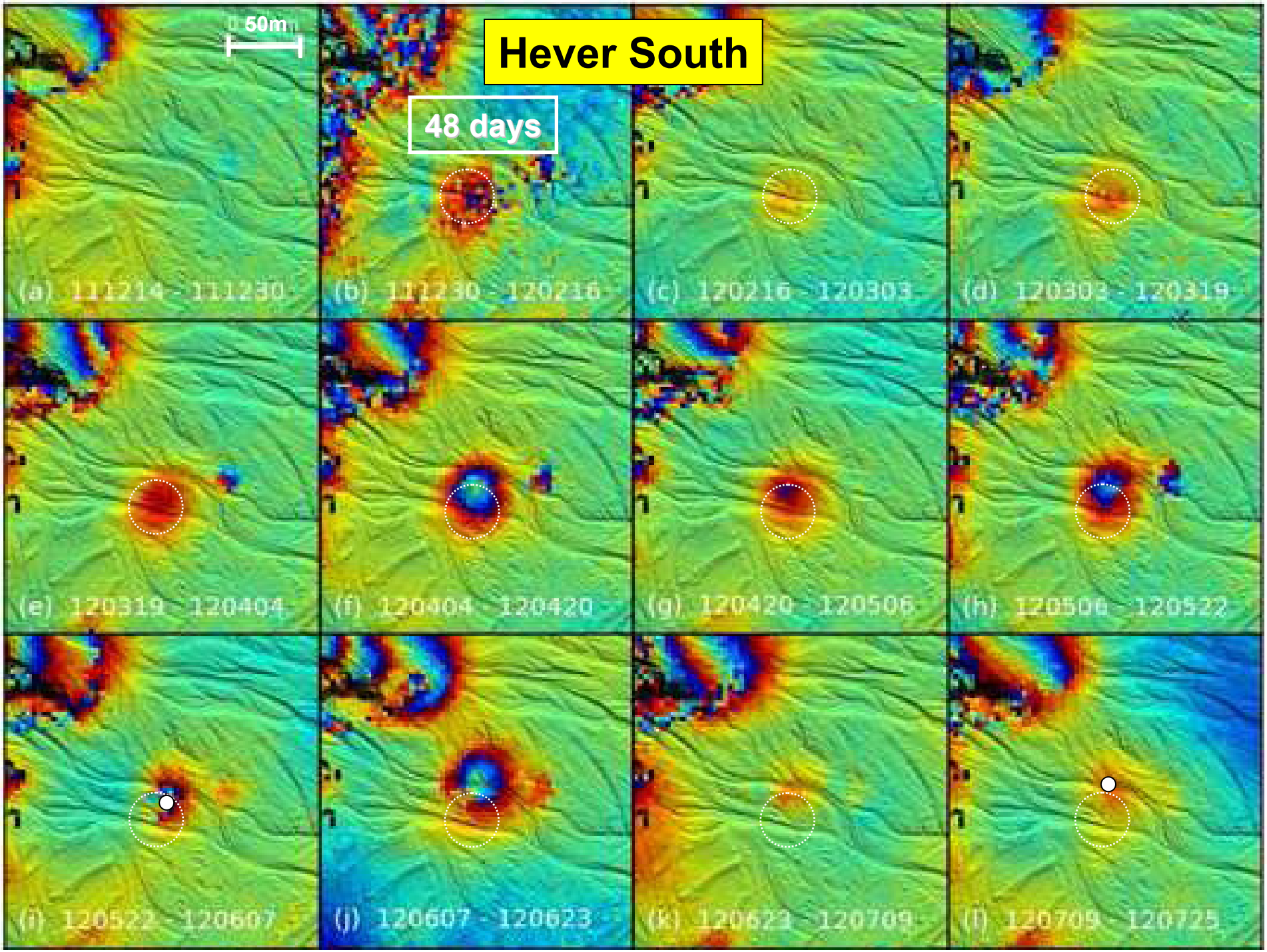
Sinkhole collapse

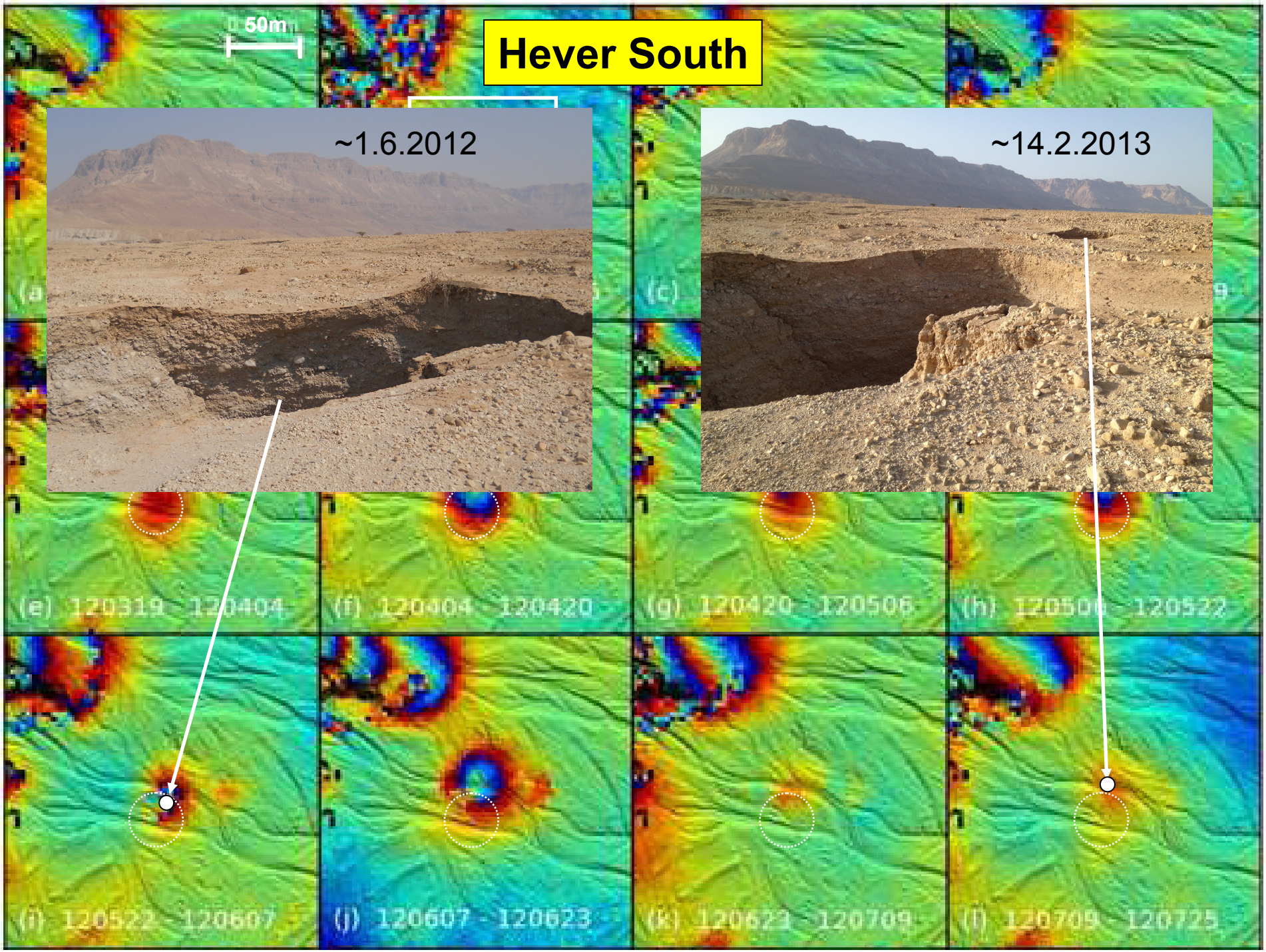


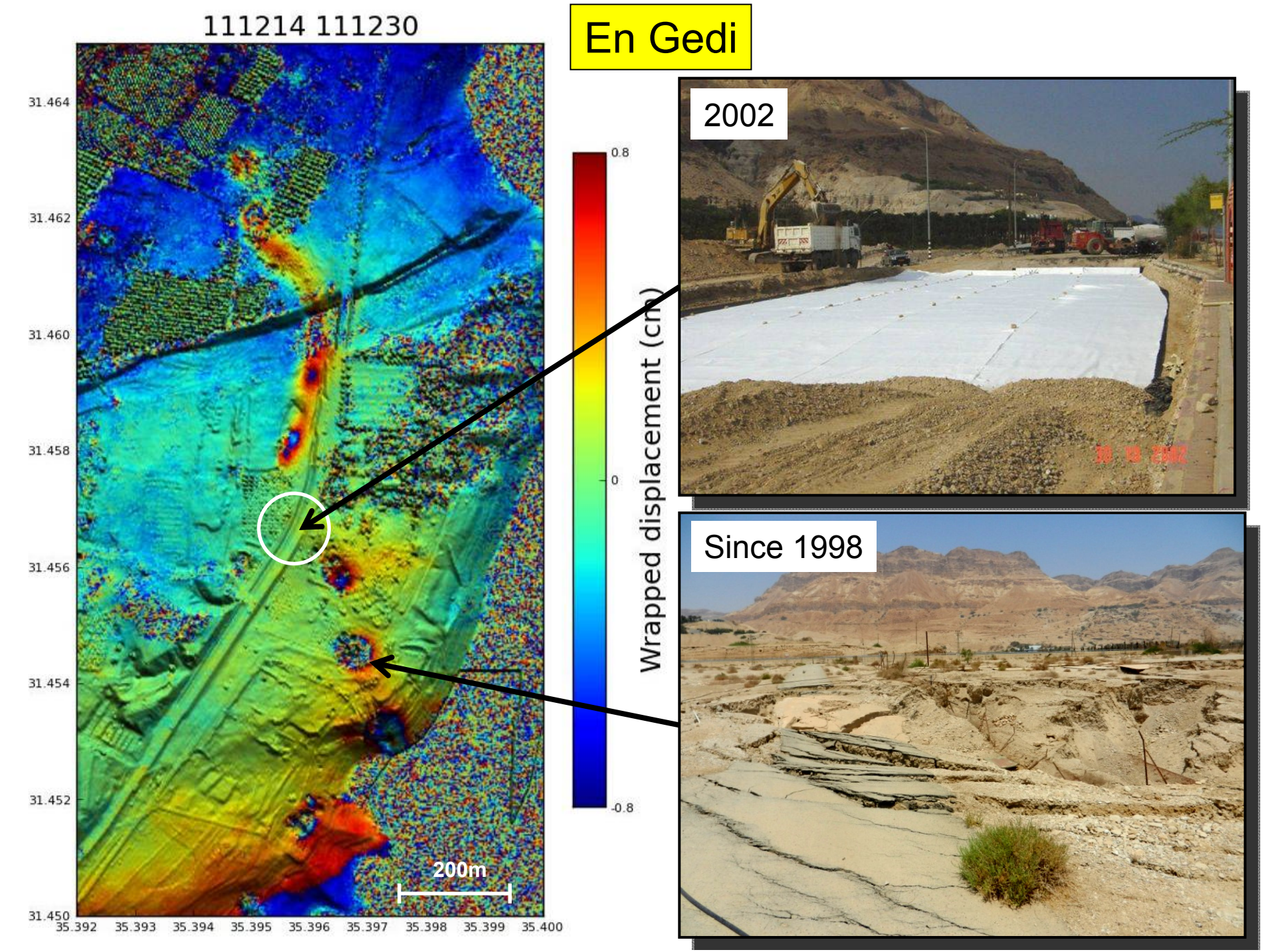
Subsidence time series: December 2011 – May 2012 (16 days intervals)

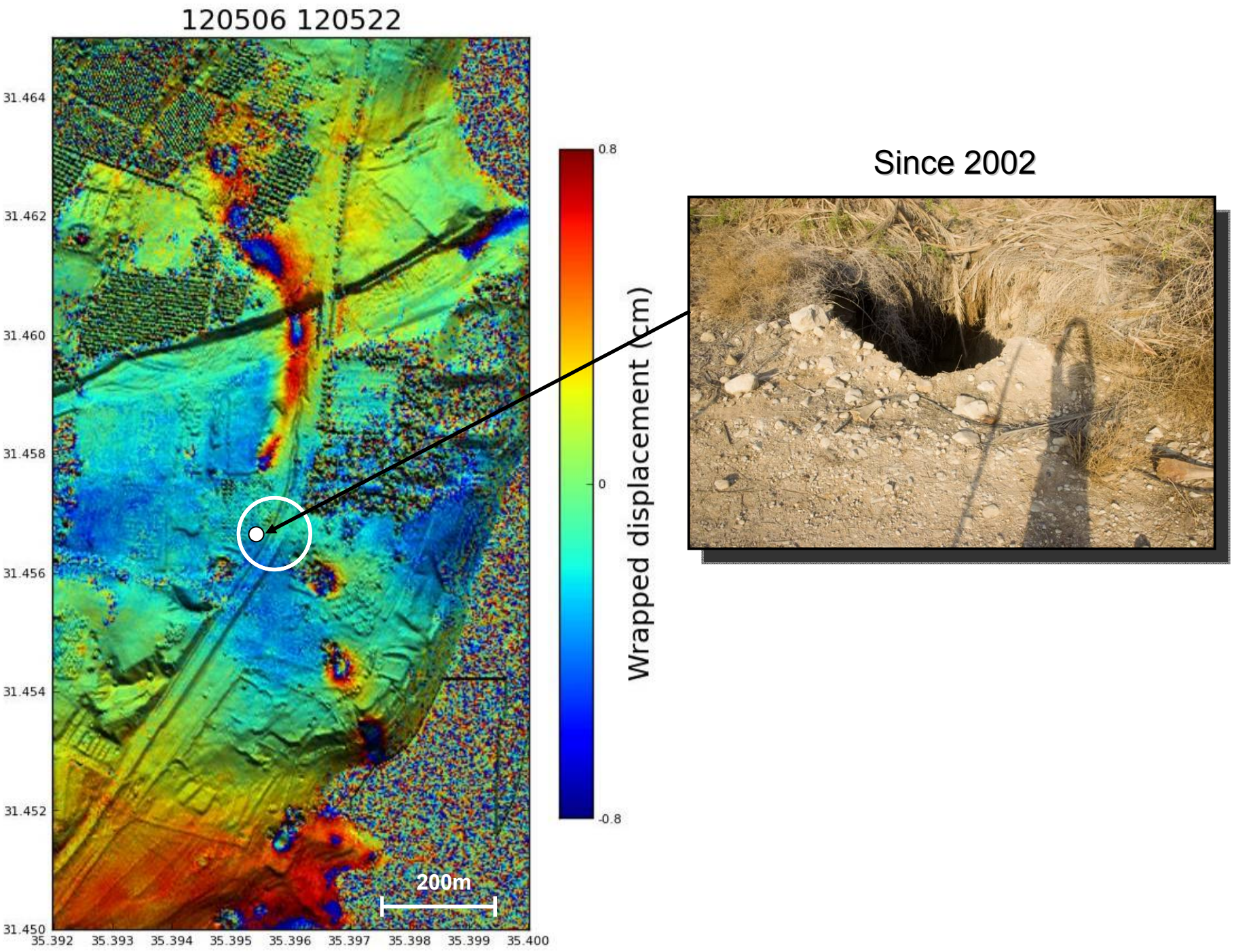
Subsidence acceleration after collapse

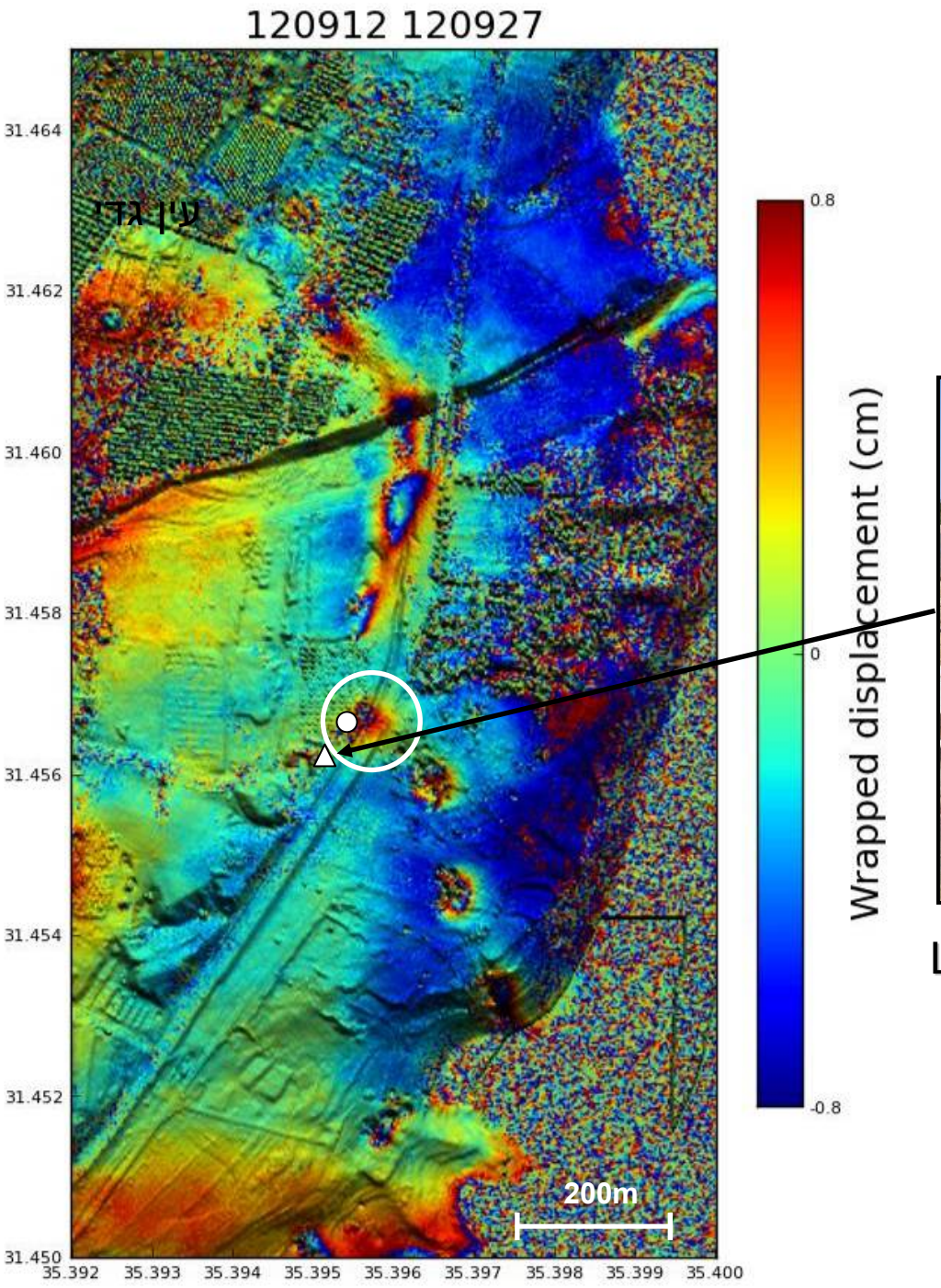



50m
Hever South
48 days
(a) 111214 - 111230
(b) 111230 - 120216
(c) 120216 - 120303
(d) 120303 - 120319
(e) 120319 - 120404
(f) 120404 - 120420
(g) 120420 - 120506
(h) 120506 - 120522
(i) 120522 - 120607
(j) 120607 - 120623
(k) 120623 - 120709
(l) 120709 - 120725


50m
Hever South
~1.6.2012
~14.2.2013
(e) 120319 - 120404
(f) 120404 - 120420
(g) 120420 - 120506
(h) 120506 - 120522
(i) 120522 - 120607
(j) 120607 - 120623
(k) 120623 - 120709
(l) 120709 - 120725

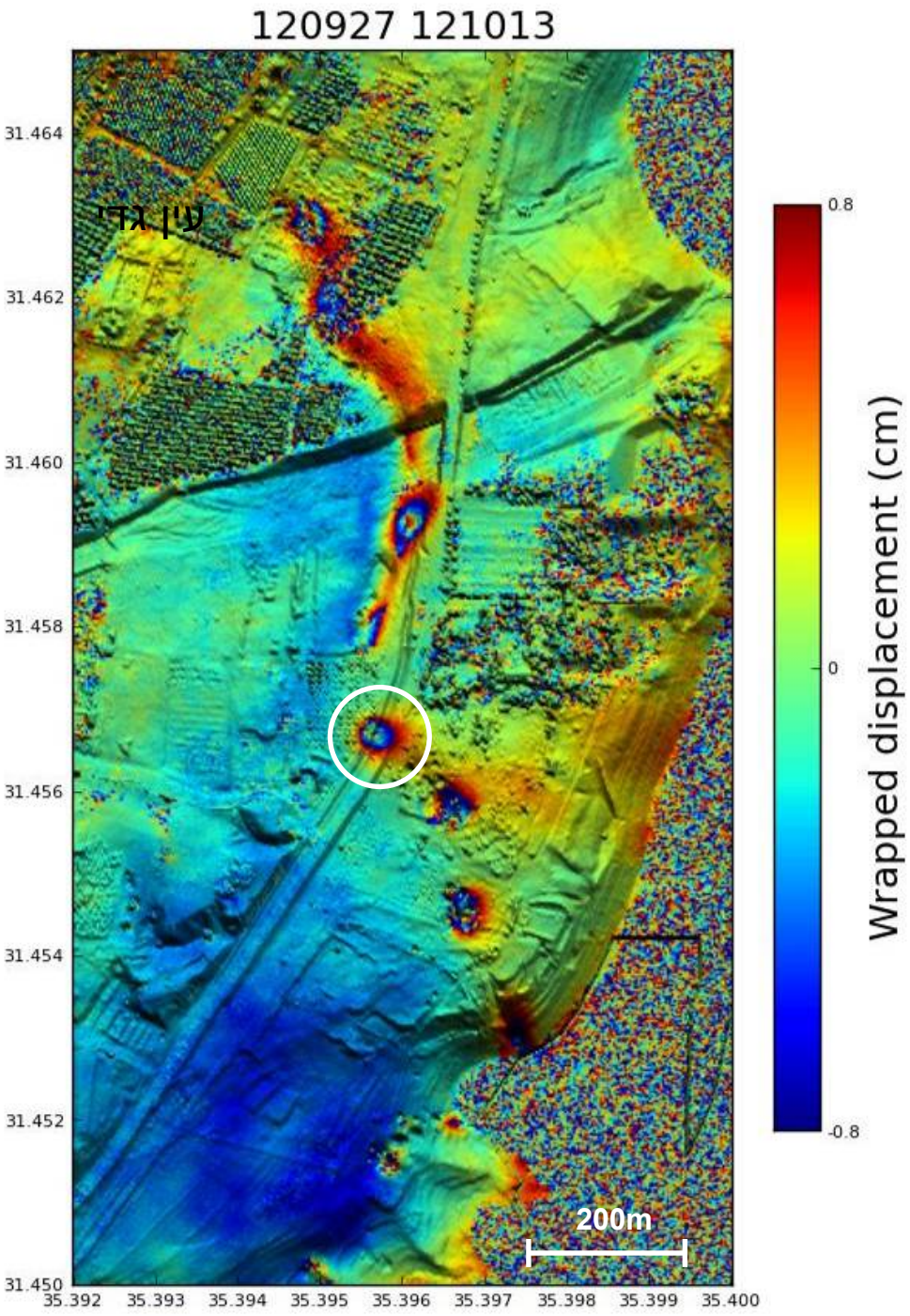

111214 111230
En Gedi
2002
Since 1998
Wrapped displacement (cm)
0.8
0
-0.8
200m
31.464
31.462
31.460
31.458
31.456
31.454
31.452
31.450
35.392
35.393
35.394
35.395
35.396
35.397
35.398
35.399
35.400


120506 120522
31.464
31.462
31.460
31.458
31.456
31.454
31.452
31.450
35.392
35.393
35.394
35.395
35.396
35.397
35.398
35.399
35.400
200m
0.8
0
-0.8
Wrapped displacement (cm)
Since 2002

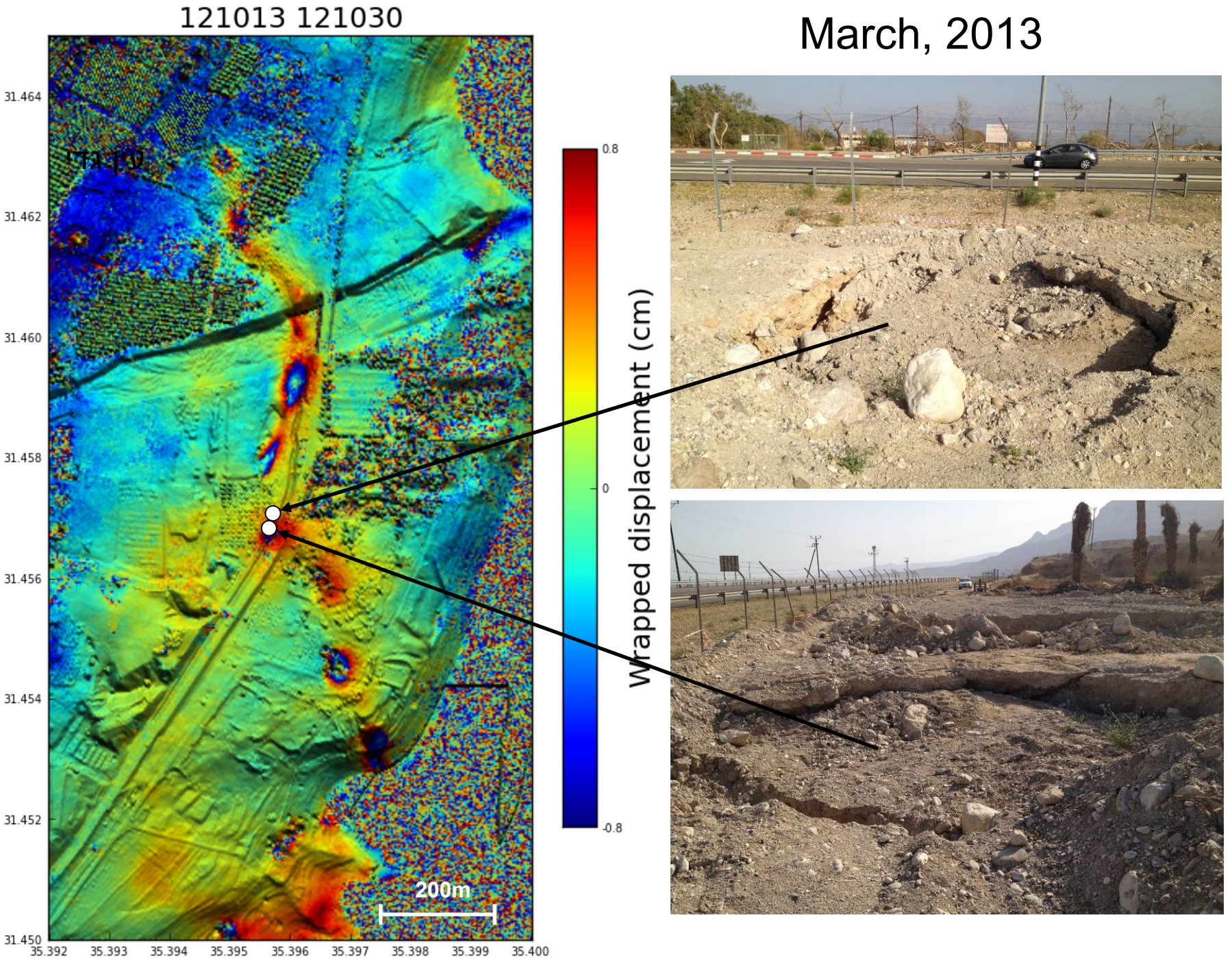


Borehole, August 23, 2012

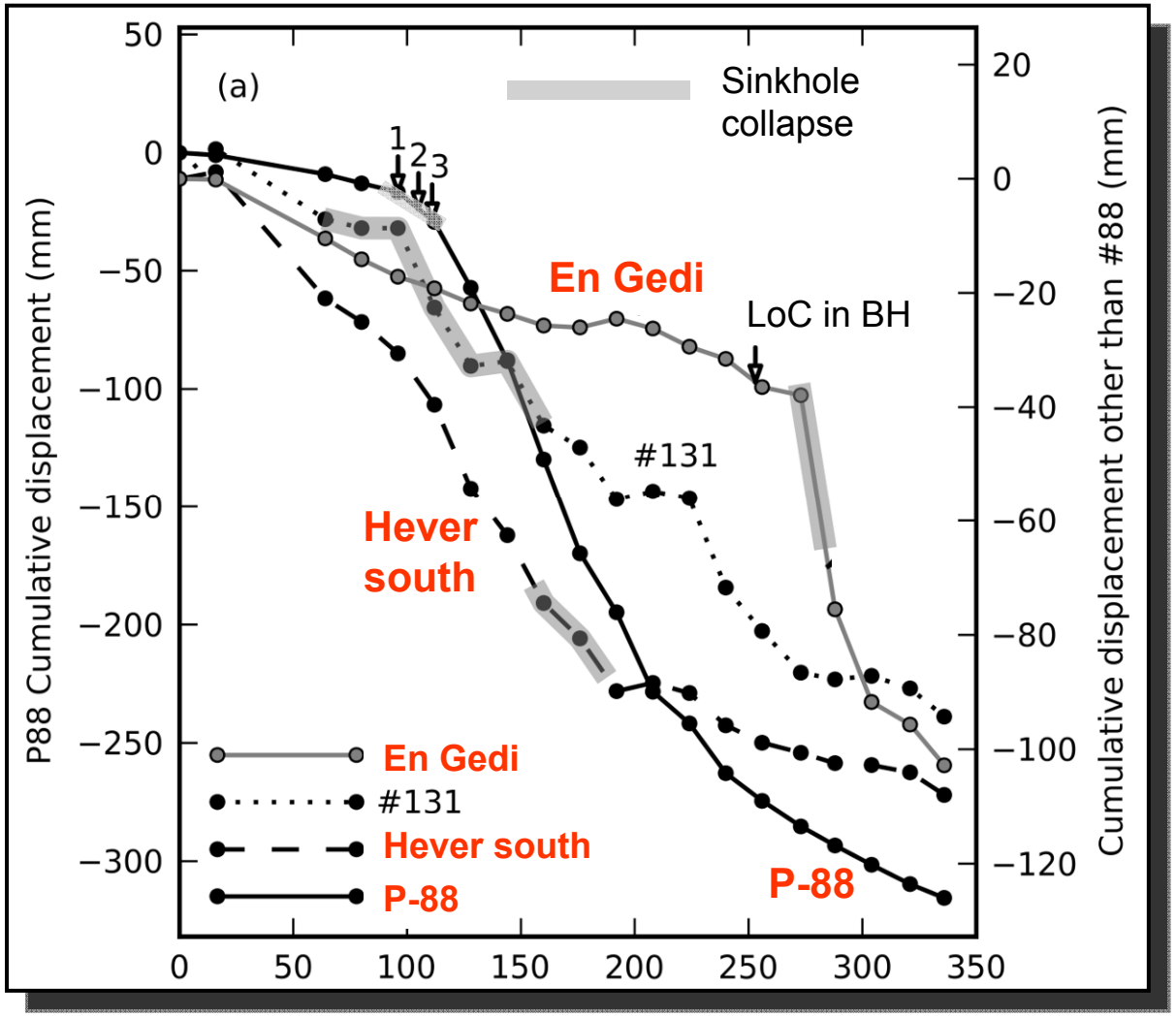
Loss of circulation: September 9-18



Subsidence increases


121013 121030
March, 2013
31.464
31.462
31.460
31.458
31.456
31.454
31.452
31.450
35.392
35.393
35.394
35.395
35.396
35.397
35.398
35.399
35.400
200m
0.8
0
-0.8
Wrapped displacement (cm)

Cumulative Displacement at 3 sites



Summary

- High resolution interferograms and LiDAR DEM reveal mm-scale precursory subsidence a few months before sinkhole collapse.
- Subsiding zones and sinkholes migrate with time.
- Post-collapse gravel fill at P88 site, possibly induced subsidence acceleration.
- Non-disturbed natural environment (Hever South) show accelerated subsidence before sinkhole collapse and deceleration thereafter.
- At En-Gedi site, subsidence and sinkhole collapse were most likely triggered by mud injection at the nearby borehole.


Thank you !
INGV
אוניברסיטת תל-אביב
TEL AVIV UNIVERSITY
Dead Sea & Arava Science Center
מרכז מדע ים המלח והערבה