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

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Sinkholes

## Dead Sea sinkhole evolution

![Graph showing the increase in sinkholes and sinkholes/year over time.](image1)

- **Sinkholes/year**
- **# sinkholes**

## Dead Sea water level drop

![Graph showing the decrease in Dead Sea water level over time.](image2)

- **Water level bsl (m)**: -390, -395, -400, -405, -410, -415, -420
Formation mechanism

Ezersky et al., 2009

Abelson et al., 2003
Sinkholes are associated with:

- Lineaments
- Subsidence
Objective:

Detect sinkhole – related precursory subsidence
Method: Interferometric Synthetic Aperture Radar (InSAR)

Waves transmitted at similar phase

Wave transmitted at time A

Wave transmitted at time B

Waves received at different phase and interfere

Phase difference translated to range difference, i.e., to movement

Waves received at time A

Waves received at time B
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
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)
Western lineament

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

![Graph showing subsidence acceleration over time]

Collapse events:
- #1. Mar. 19; 42X
- #2. Mar. 28; 25X
- #3. Apr. 3; 61X

Cumulative displacement (mm) vs. Time since December 14, 2011 (days)
Since 1998 En Gedi

2002

Wrapped displacement (cm)

Since 1998
Subsidence increases
Cumulative Displacement at 3 sites

(a) Sinkhole collapse

En Gedi

Hever south

LoC in BH

P-88 Cumulative displacement (mm)

Cumulative displacement other than #88 (mm)
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.