National Technical University of Athens
School of Mining and Metallurgical Engineering
Laboratory of Engineering Geology and Hydrogeology

Land subsidence phenomena at the wide area of Thessaloniki detected by using radar interferometry techniques

Loupasakis C. [1], Raspini F. [2], Rozos D. [1] & Moretti S. [2]

[1]National Technical University of Athens,
School of Mining and Metallurgical Engineering,
Laboratory of Engineering Geology and Hydrogeology

[2] University of Firenze,
Department of Earth Sciences

UNIVERSITÀ DEGLI STUDI FIRENZE

TERRAFIRMA

esa

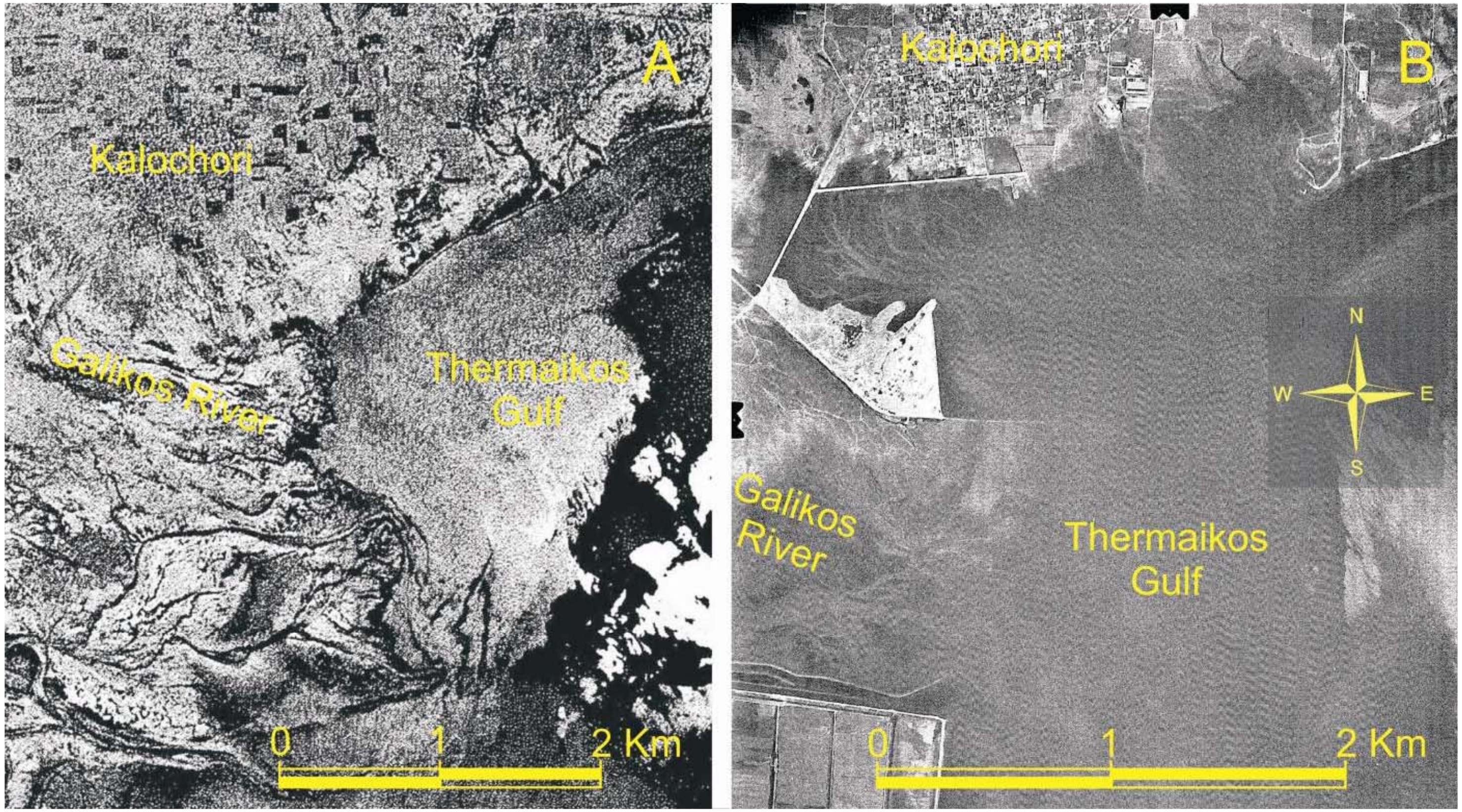
DLR

Kalochori Region

The Kalochori Village subsidence phenomena-Introduction - Historical Background

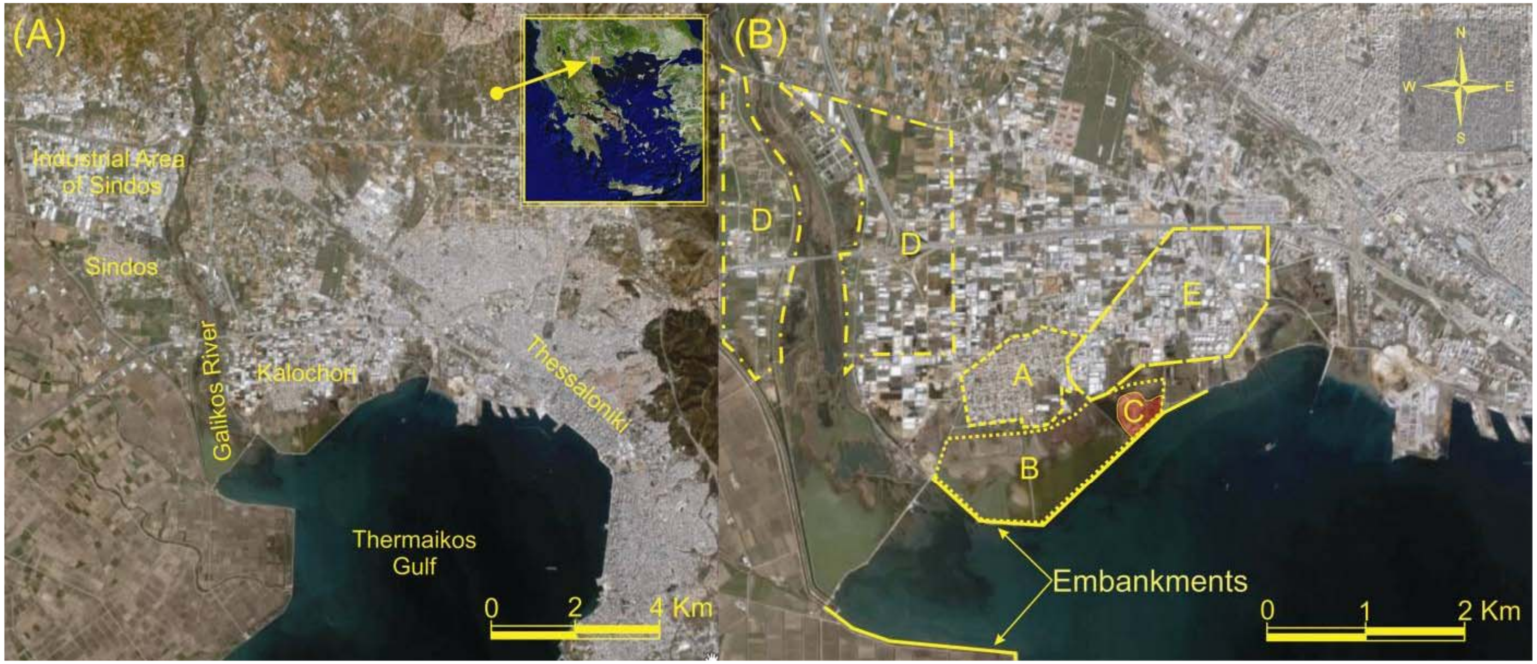
- Kalochori village was established in 1922, by refugees from Minor Asia.
- In the 1960`s the wider area became the main industrial centre of Thessaloniki.
- In 1965 progressive marine invasion (first subsidence signs).
- The morphological and the environmental setting of the region changed violently. The extreme land subsidence, exceeding 3m locally caused the sea invention reaching up to the first houses of the village.
- The embankments constructed for the protection of the village reclaimed some of the lost land and at the same time they allowed the generation of a shallow lagoon.
- Today, despite the environmental downgrading of the area, several industries damp their untreated fluid residuals into the lagoon. At the same time, the authorities use a part of the eastern border of the lagoon as a residential waste dumping site.

Kalochori Region



Old aerial-photographs taken in 1945 (A) and in 1975 (B). Picture (A) presents the coast line in 1945. The village is located at least 1km away from the sea. Picture (B) shows the flooded area reaching the first houses of the village after the collapse of the embankment in 1973

Kalochori Region



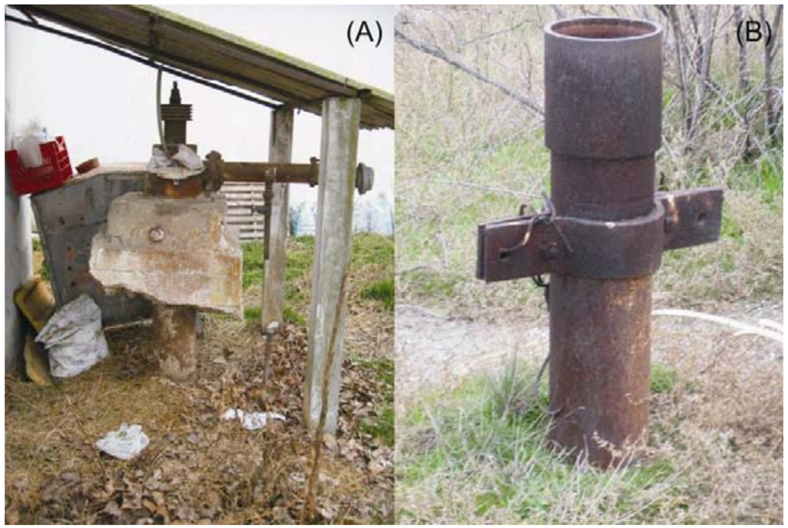
Satellite picture presenting the land use distribution in Kalochori. The outlines enclose the following areas: A: the residential area of Kalochori village, B: the lagoon - partly flooded area, C: the residential waste dumping site, D: areas containing the productive wells of the Water Company of Thessaloniki, E: the industrial area of Kalochori until the 1980`s.

As presented in the Satellite picture today the industries occupy almost all the region besides the residential area (A) and the lagoon (B). Finally, the location of the embankments is also presented.

Kalochori Region

Submerged remnants of the old electricity network. Those poles were installed along the side of a road constructed in the SW of Kalochori in1975. The photo was taken in 2008.

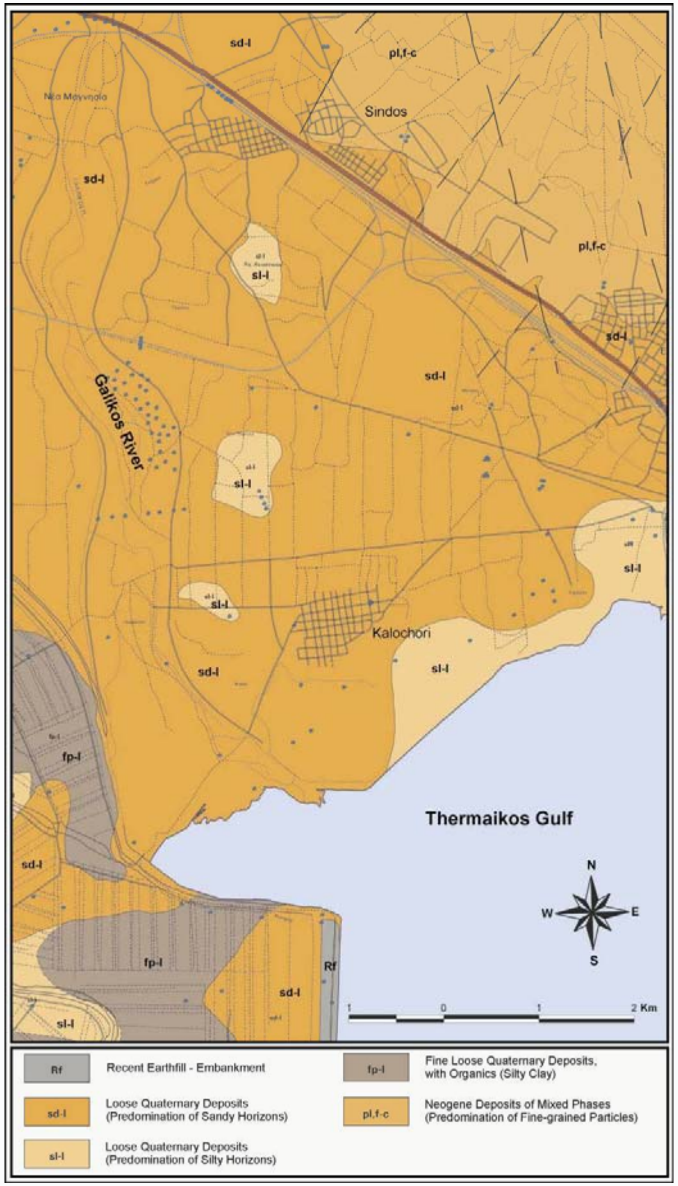
Emerged well pipes due to the subsidence phenomenon. (A) 100 m deep well located in the Institute of Wheat Cultivation (SW of Kalochori). The pipes have been extracted 0.9 m above the ground surface. (B) Well located near the Paleomana pumping station (SW of Kalochori). The pipes have been extracted 0.35 m above the ground surface. The photos were taken in 2008.



Kalochori Region

Views of the main embankment constructed at the South of Kalochori. (A) Front view of the embankment. The sea level is about 1m below the road level. Boulders have been installed as breakwater structures. (B) Back view of the embankment in the same location (note the transformer on the top of the wooden pillars). The lagoon water level is 4 to 5m bellow the road level. Comparing the pictures it becomes obvious that the inland is at least 4m below the sea level.

Kalochori Region



Geological and Geotechnical Setting of Kalochori Region

- The lowlands in the west of Thessaloniki constitute a tectonic graben covered by quaternary and neogene deposits of grate thickness.
- The upper formation of the study area is occupied by loose quaternary deposits, extending down to a depth varying from 150 to 400m.
- The deeper strata are occupied by neogene deposits reaching down to a maximum depth of 600-700m.

Kalochori Region

Hydrogeological Setting and Water Pumping History

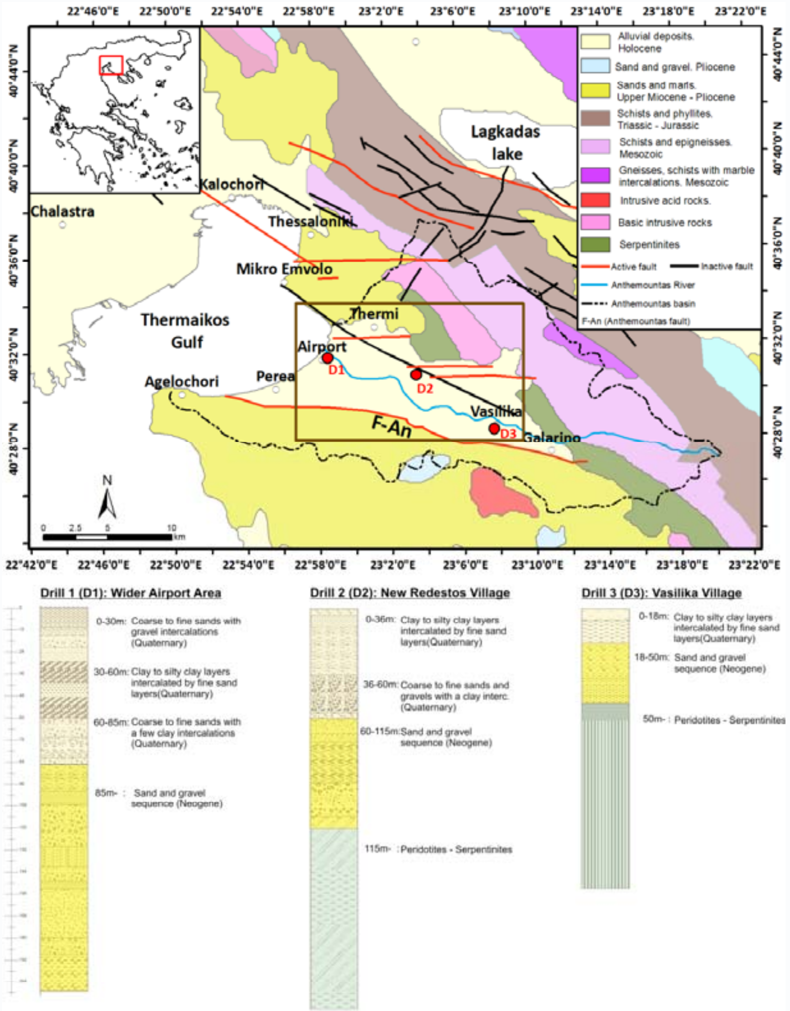
- The wide study area contain **one unconfined shallow aquifer** extending in the overlaying sands and **a system of successive confined - artesian aquifers** developing below the first impermeable black-gray silty sand layer.
- The water table depth of the unconfined shallow aquifer fluctuates from 1.5 to 3m, the aquifer reaches down to a depth of 10 to 15 m and the quality of the water is very poor.
- During the 50s, the piezometric surface of the aquifers was over the ground and the drills were artesian. In 1981, after 25 years of continues pumping, it fell 37m.
- In the early 1980`s the water company abandoned the majority of the drills. Unfortunately, the authorities could not control the industrial drills. Nevertheless, the reduction of the pumping wells led to the partial recovery of the piezometric surface level. According to measurements conducted during the period of 1997 – 2000 the piezometric surface's level in the Kalochori region varied from 20 to 30m, presenting an oscillation of 1 to 3 m.

The Anthemountas Basin subsidence phenomena-Introduction

- Anthemountas basin is located on the eastern side of Thessaloniki, named after the homonymous river. It extends with a NW-SE orientation from the Thermaikos gulf to the centre of the Chalkidiki peninsula
- This area draw the attention of the geo-scientists in 2005 when a series of fractures, causing damages to both buildings and roads, occurred at the Perea village, on the southern section of the basin`s coastal zone.
- From the beginning these fractures were attributed to the overexploitation of the aquifers, although they manifested along the active Anthemountas Fault.

Anthemountas basin

Anthemountas basin



Geological setting

The geological formations constituting the basin can be distinguished:

- on the **Mesozoic bedrock formations**, occupying the bordering mountains,
- the **Neogene** and the **Quaternary deposits** occupying the hilly and the plain areas.

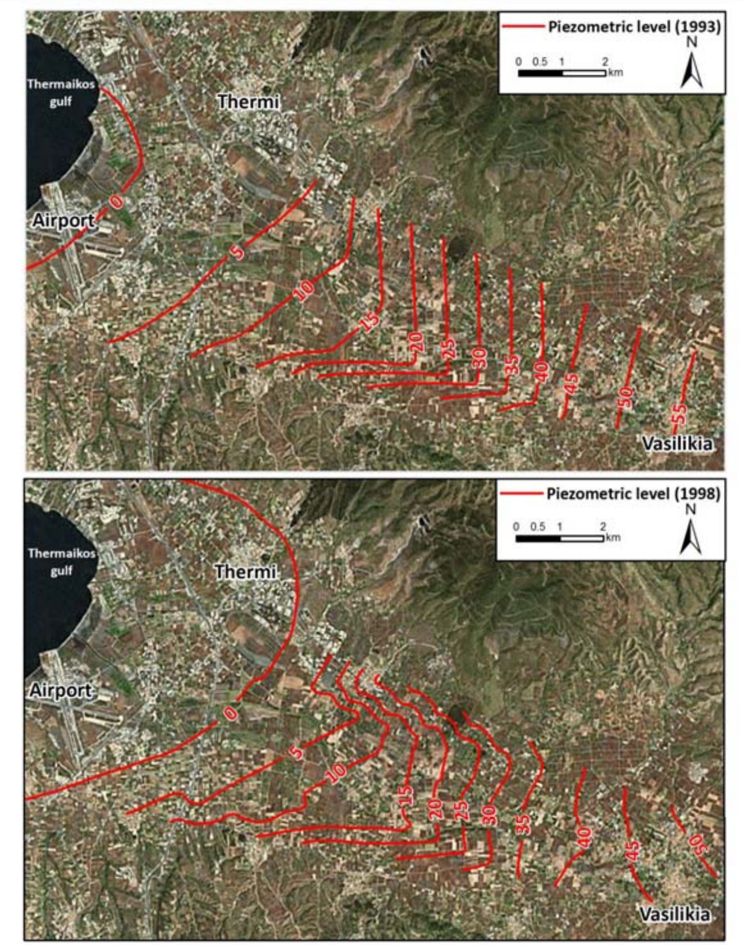
The **Neogene deposits** consist of two sequences:

- the **upper sand and gravel sequence** and
- the **lower sandy marls - red clays** sequence,

outcropping successively along the borders of the basin.

The Quaternary formations occupy the central part of the plain, with an **increasing thickness** towards the coastal area

Anthemountas basin



Hydrogeological Setting

Three aquifer systems can be distinguished in the abovementioned formations:

a) the **shallow phreatic aquifers system** occupying the upper coarse-grained Quaternary deposits extending to a maximum depth of 30m,

b) the **semi-confined alternating aquifers**, extending down to depths from 50 to more than 200m, occupying the lower Quaternary and the Neogene deposits as well as the fractured Mesozoic formations and

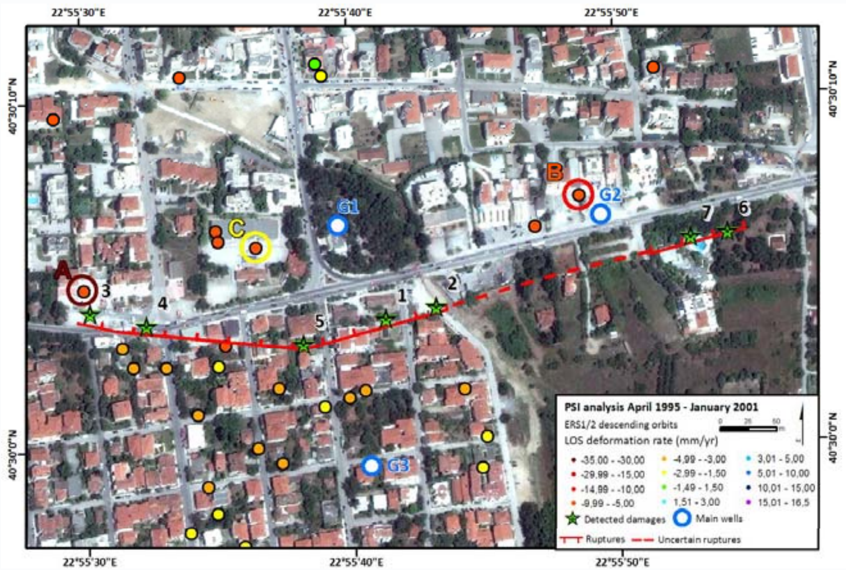
c) **Two deep confined (artesian) aquifers**, the one gushing out at the Souroti spring (sub-acidic sparkling mineral water rich in calcium and magnesium) and the other at the thermal springs of Thermi.

The continuously increasing demands on water are exclusively covered by the ground water exploitation. This resulted in the over-exploitation of the phreatic and the semi-confined aquifers. The ground water level degrade with a mean annual rate of 1,5 - 2m/yr.

Anthemountas basin

Land subsidence field observations

- In 2005 **a series of fractures damaged at the upper Perea village**.
- In **short distance three public wells** and an unknown number of private wells were **operating**.
- So, the operating wells with a 2,2m mean annual drawdown rate **generated an extra drawdown** and inside the limits of the intersecting depression cones of the wells the raptures occur.



Well-casing protrusion has also been reported northern to surface ruptures, at the same time period.

No other effects related to the groundwater withdrawal can be clearly detected since 2005 at the entire basin !!!

PSI Data

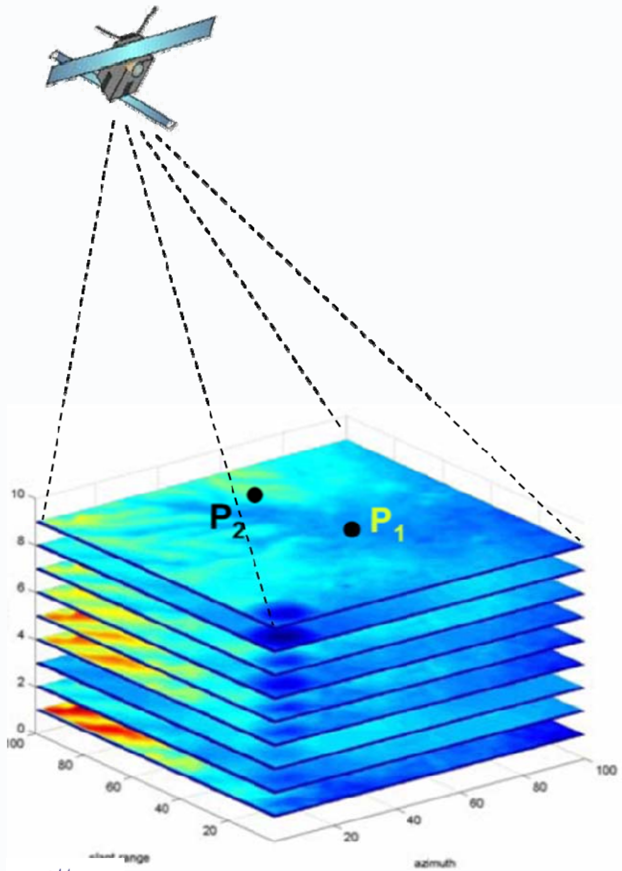
Persistent Scatterer Interferometry (PSI)

➢The PSI technique uses long stacks of radar dataset (more than 20).

➢Analyzes the electromagnetic signals backscattered from highly reflective point-wise targets (the so-called Permanent Scatterers, (PS) to estimate and remove atmospheric artifacts.

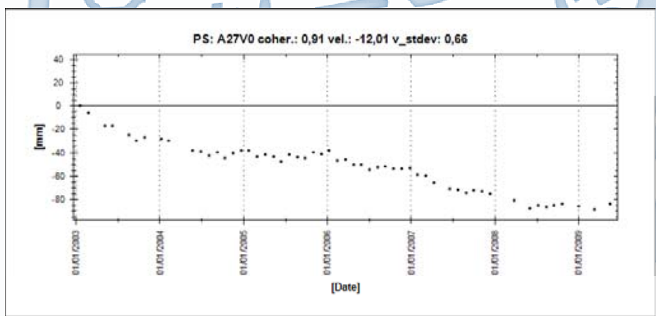
➢The electromagnetic returns are statistically processed and analyzed to retrieve the displacements occurred between different acquisitions .

➢The relevant LOS velocity can be estimated with extreme accuracy, up to a few mm/year.



TRE

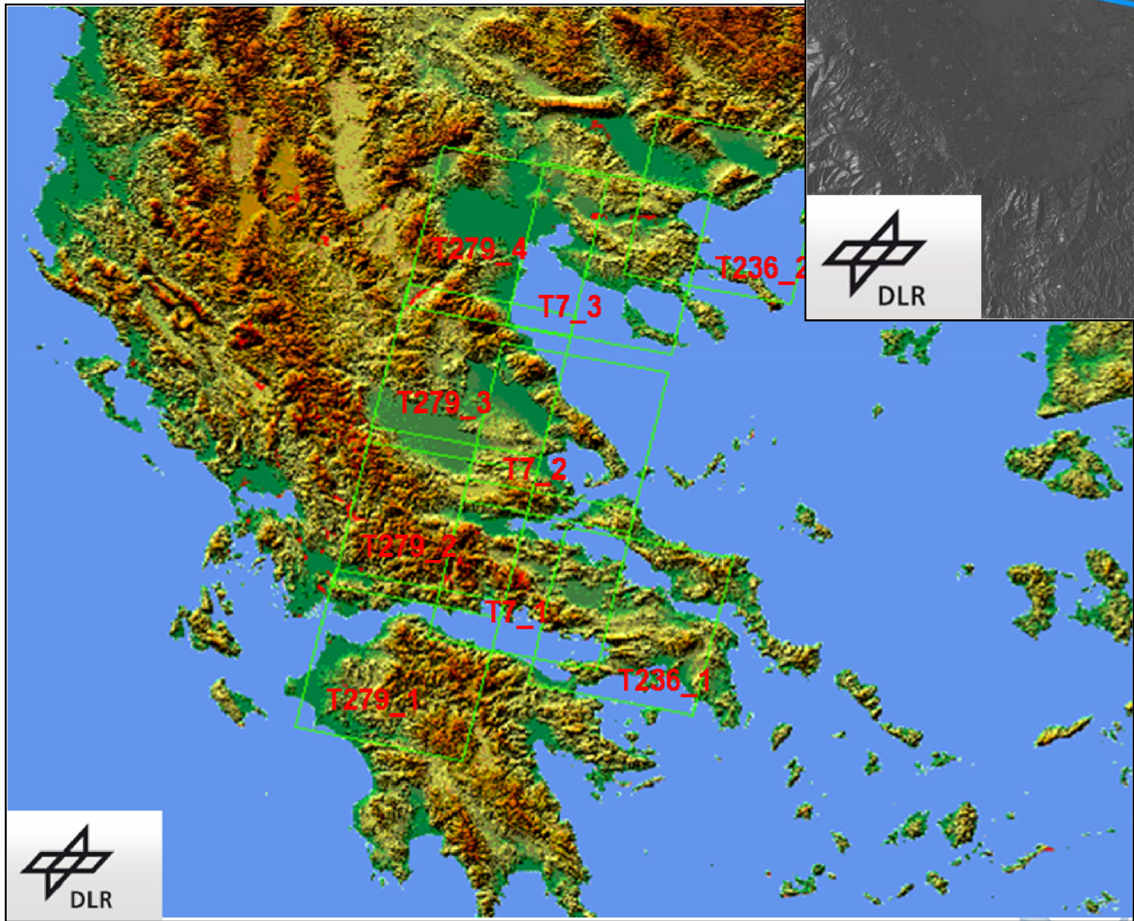
Dataset of SAR images

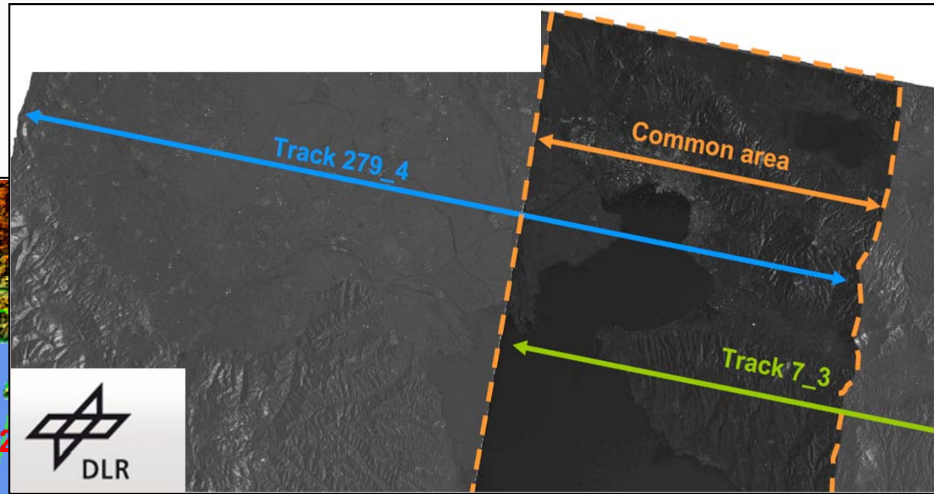


Displacement time-series on single radar benchmarks (precision ~ up to 1-3 mm on single measure)

PSI Data

Evaluated PSI data





Wide area product (WAP) PSI mapping provided by the German Space Agency (DLR)

Within the framework of the ESA GMES Terrafirma project (GMES - Global Monitoring for Environment and Security)

PSI Data

Track 7_3: ERS descending PSI data

SAR data: ERS1 – ERS2

Period: 02.05.1992 - 30.12.2003

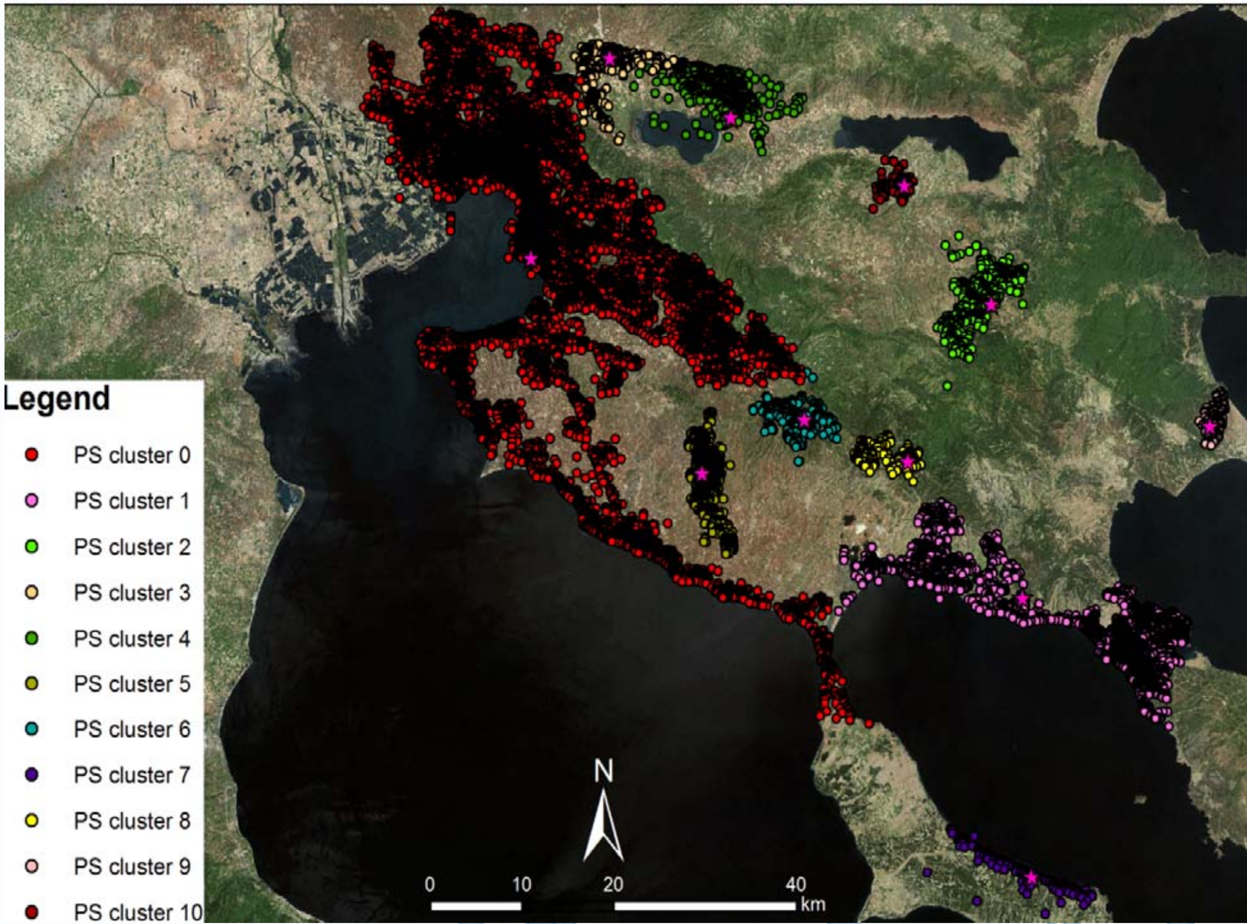
Master scene: 31.12.1996

Number of scenes: 63

Area: 6.733 km^2

PS-points: 49.286

Density: 7,3 PS/km^2



PSI Data

Track 274_4: ERS descending PSI data

SAR data: ERS1 – ERS2

Period: 12.11.1992 - 05.10.2003

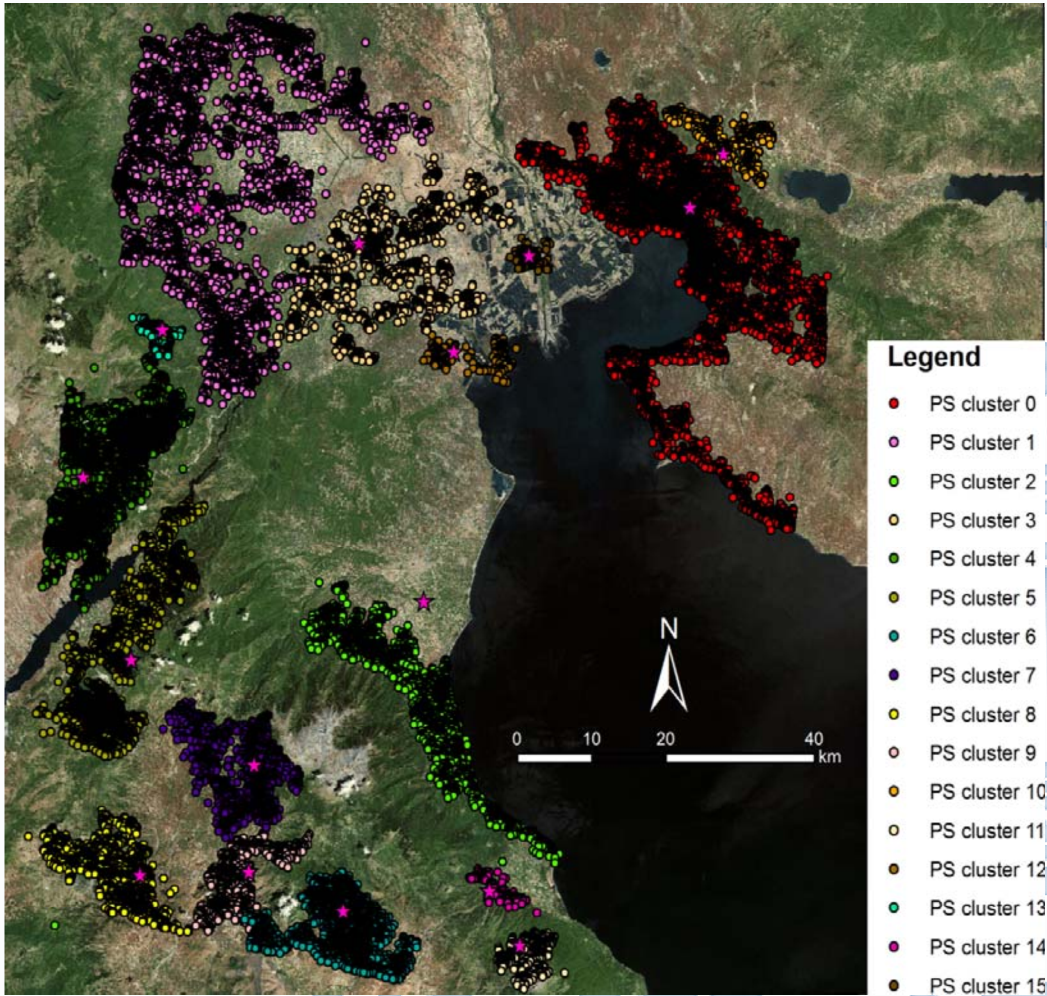
Master scene: 02.08.1998

Number of scenes: 51

Area: 9.786 km^2

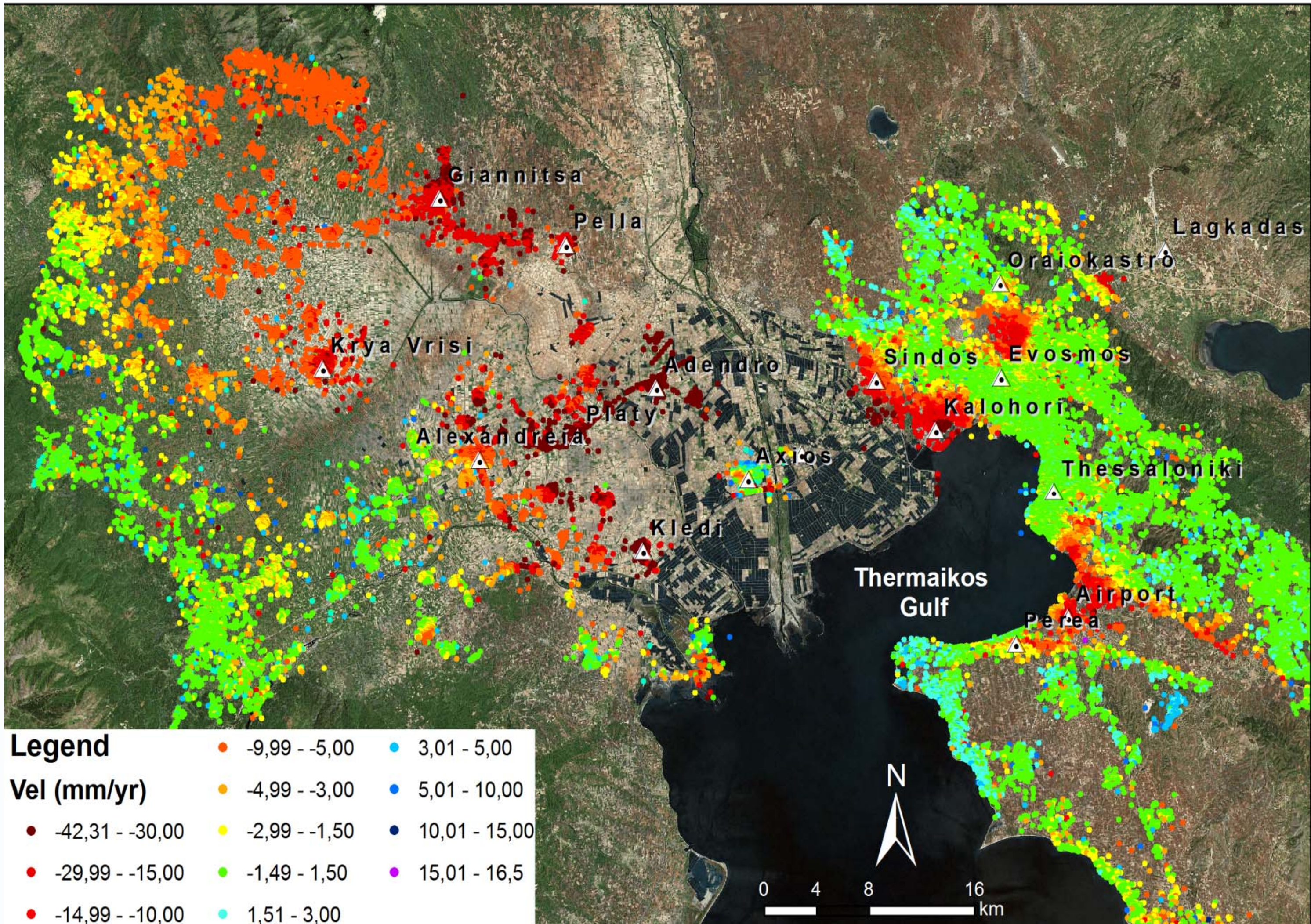
PS-points: 83.966

Density: 8,58 PS/km2



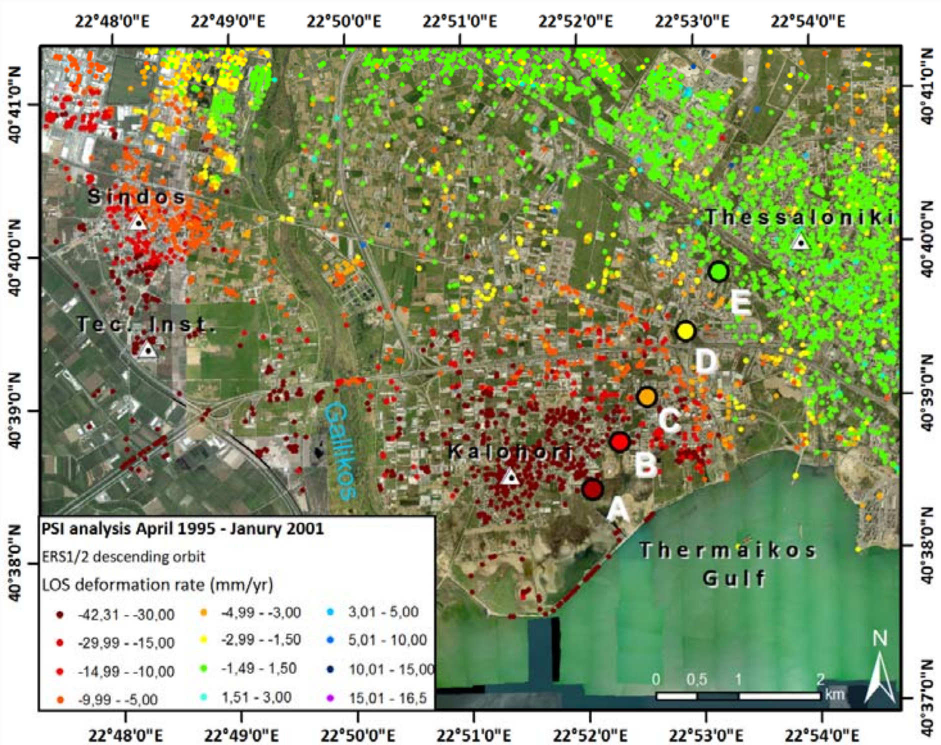
PSI Data Evaluation

Average displacement rates along the LOS

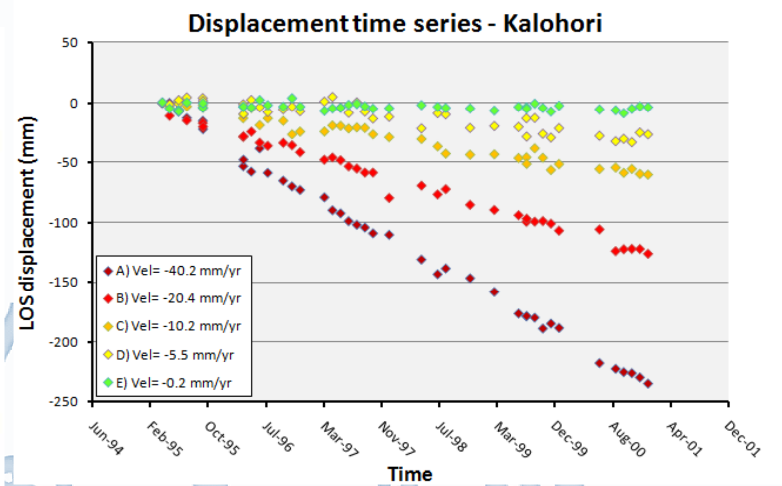


PSI Data Evaluation

Evaluation of the PSI data yielded for the Kalochori region



The LOS deformation rates between 1995 and 2001.

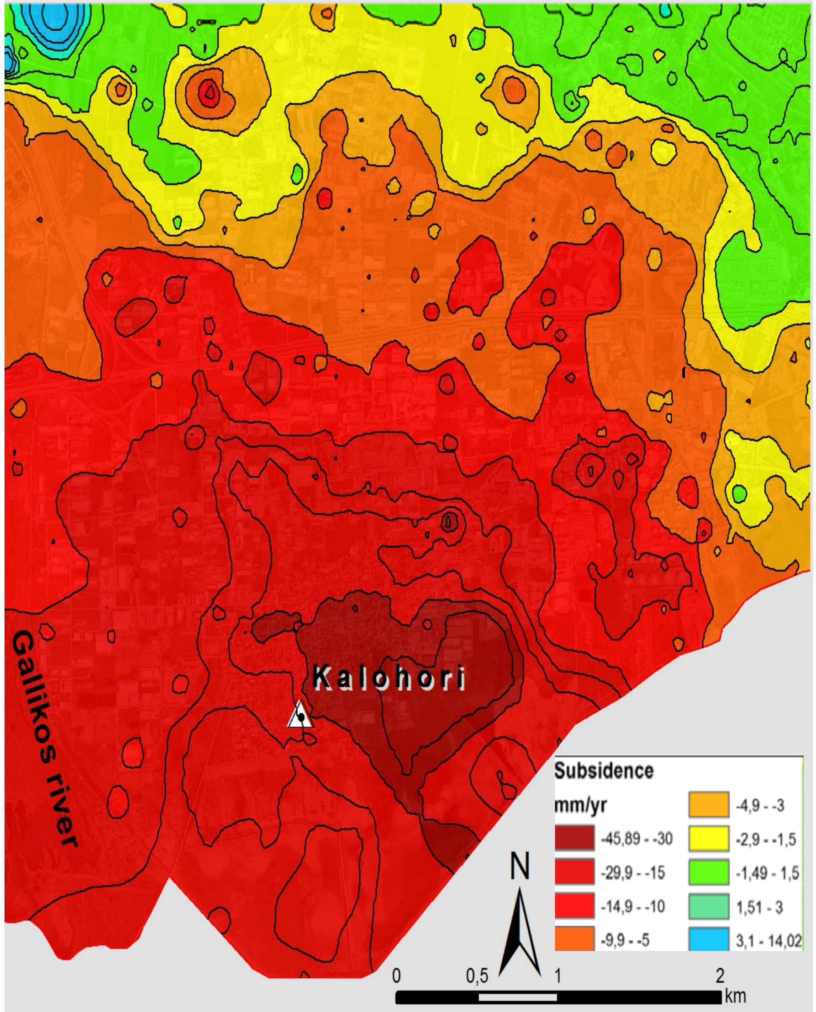


LOS displacement time series and yearly velocities of PS A, B, C, D and E

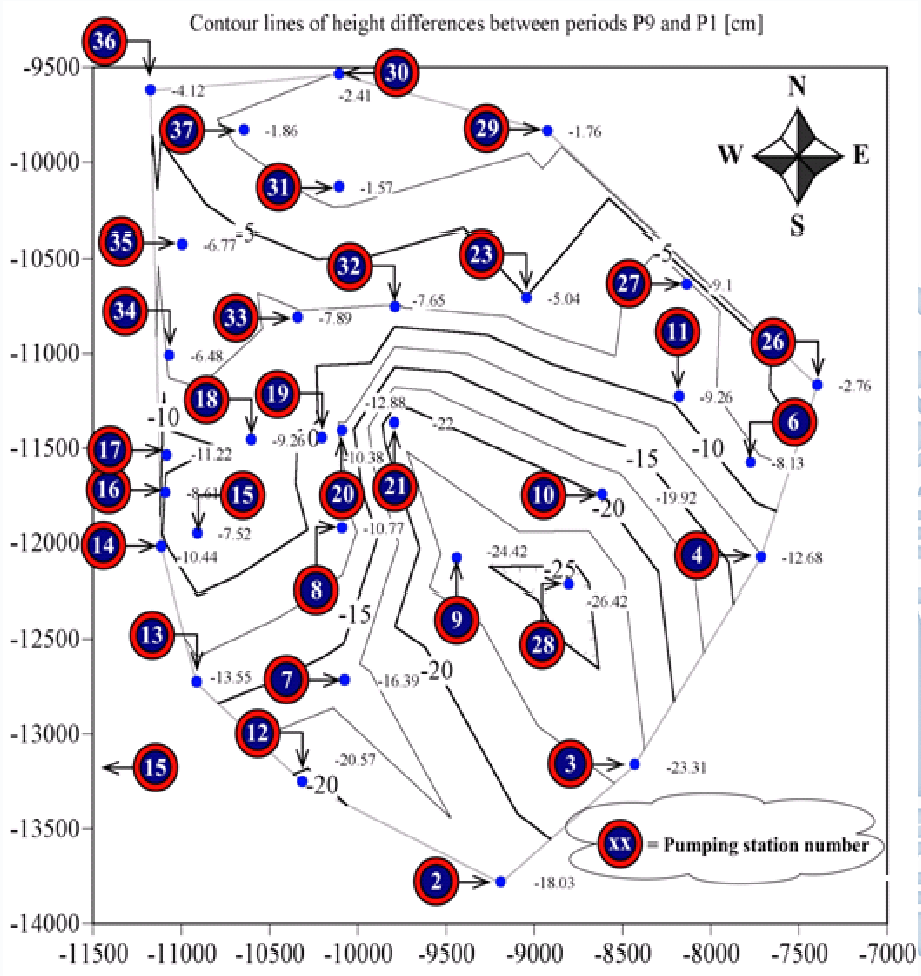
Land subsidence can be clearly identified in the coastal area of Kalochori. The highest LOS velocities range between 15 and 25 mm/yr in 1992-2003, with peaks of 40 mm/yr recorded in the SW of the village.

PSI Data Evaluation

PSI data (Apr 1995 – Jan 2001)



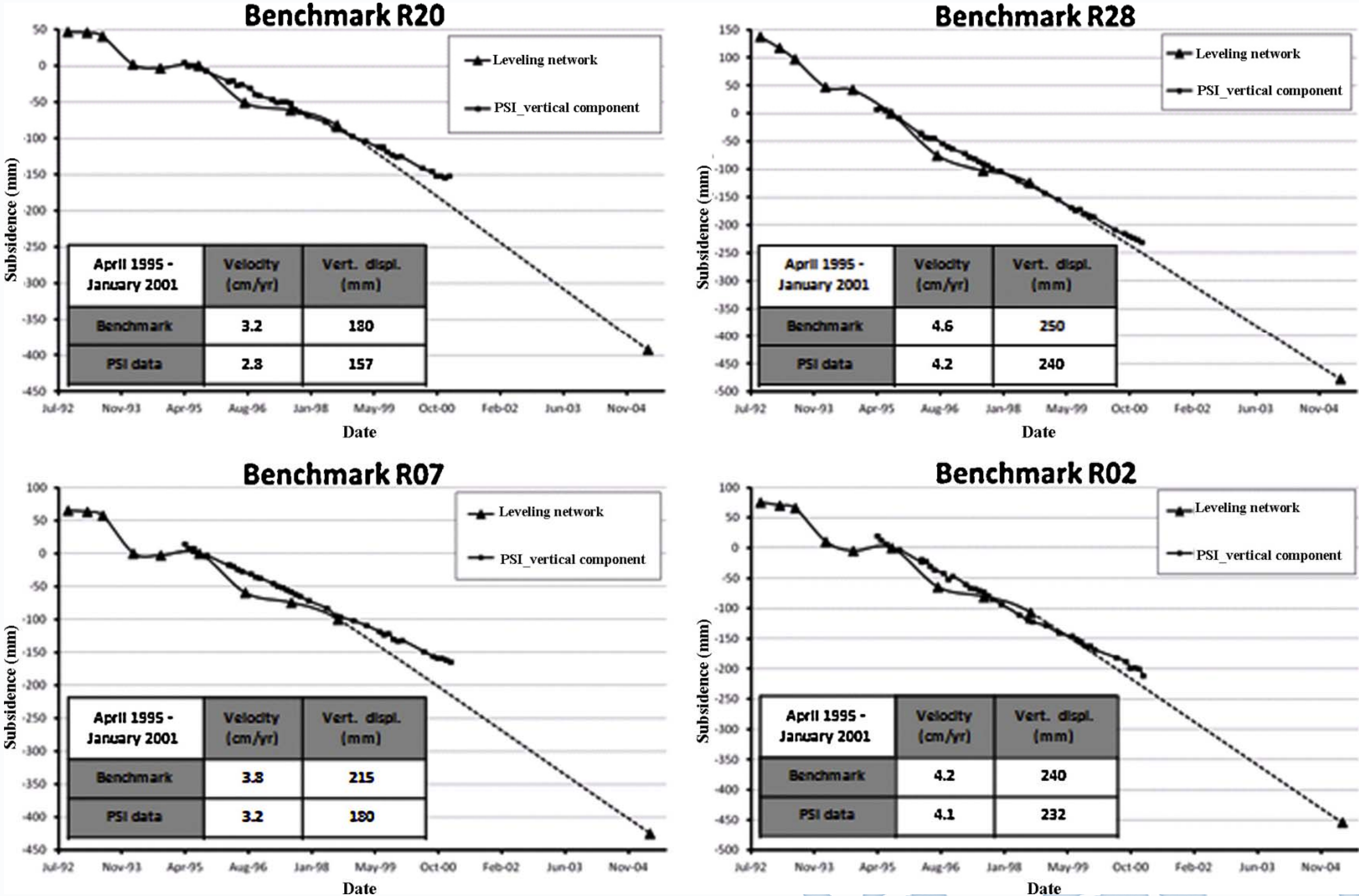
Levelling network (Sept 1992 – Oct 1998)



From Doukas et al., 2004

PSI Data Evaluation

Comparison between the vertical component of PSI measures and leveling data at benchmark R20, R28, R07 and R02.

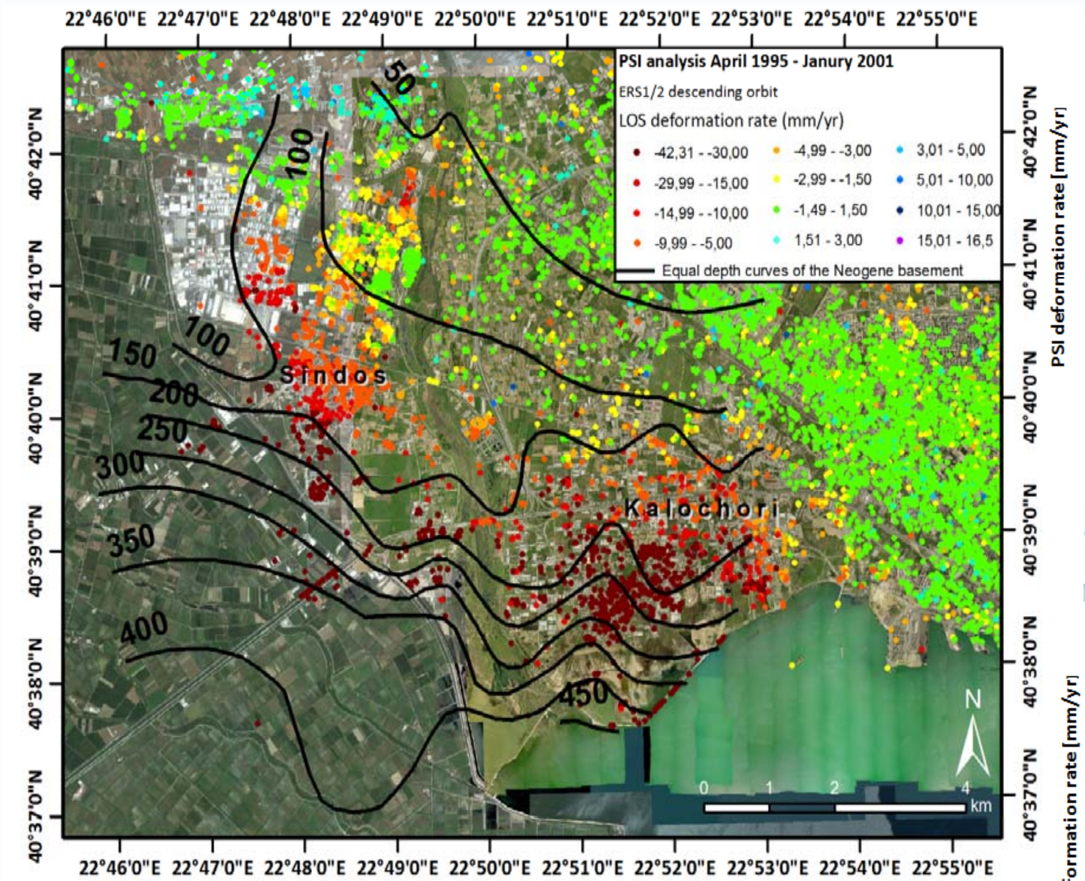


Levelling data from Savvaidis et al., 2006

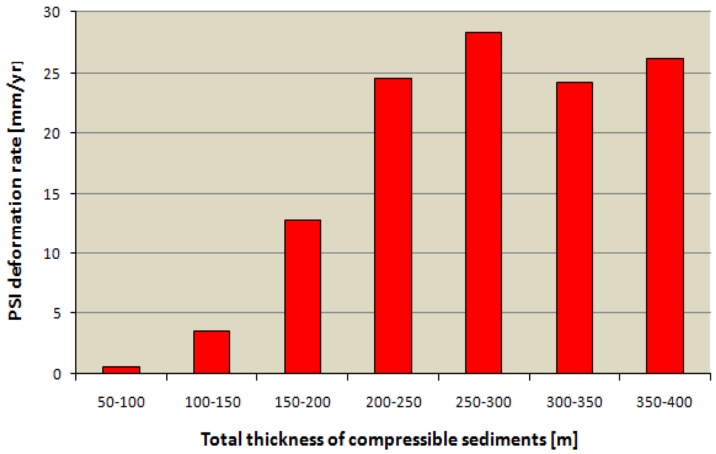
School of Mining and Metallurgical Engineering

Laboratory of Engineering Geology and Hydrogeology

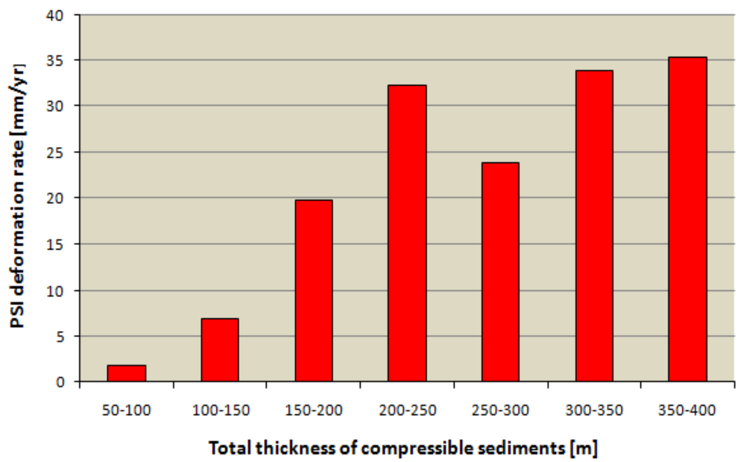
PSI Data Evaluation



Kalochori

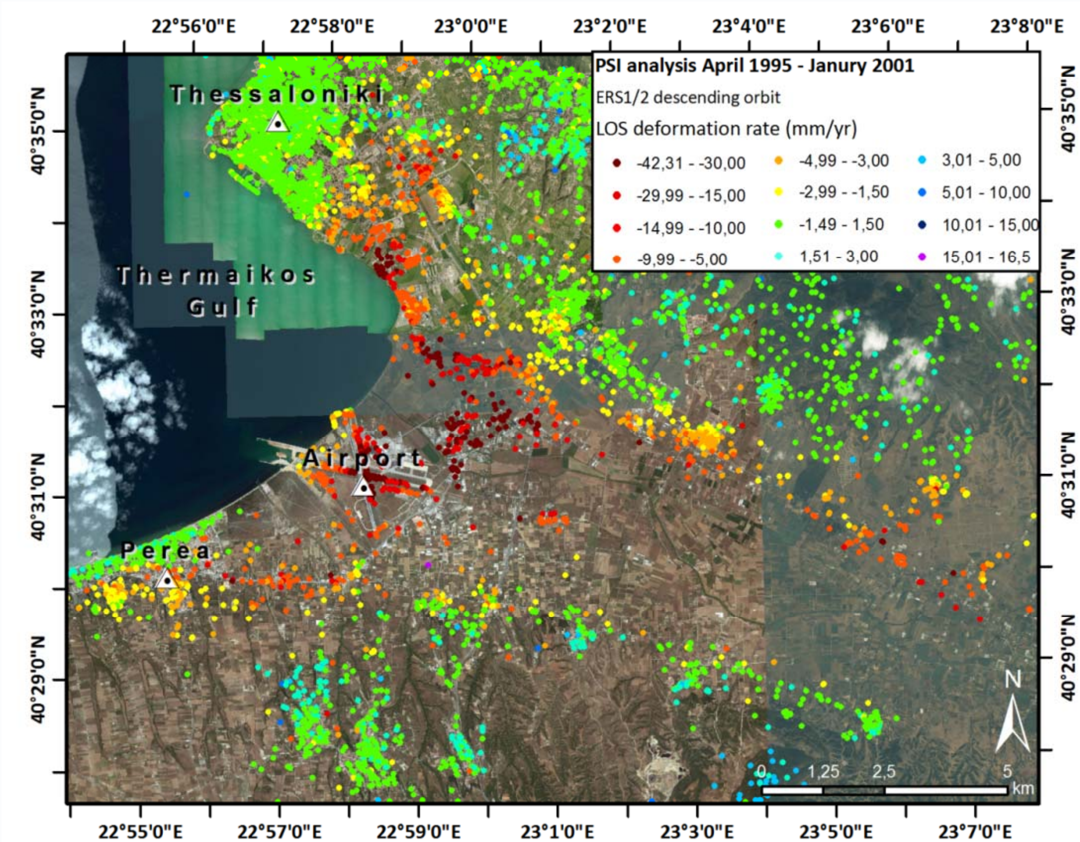


Sindos



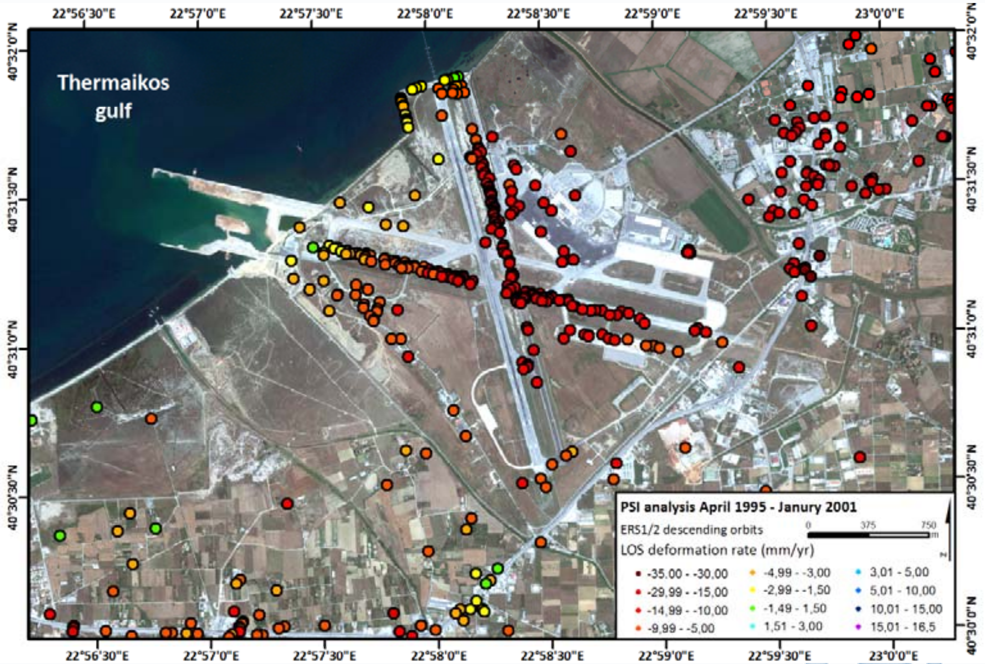
For both investigated areas (Sindos and Kalochori) it is observed that the thicker the cumulate compressible deposits the higher the estimated subsidence rates.

Evaluation of the PSI data yielded for the Anthemounta region

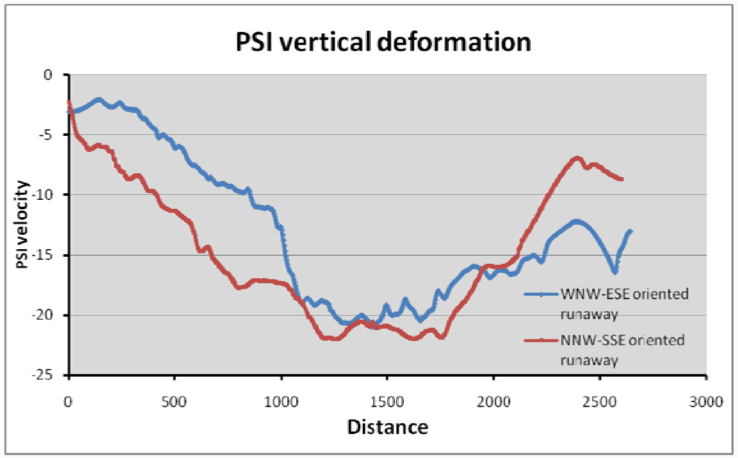


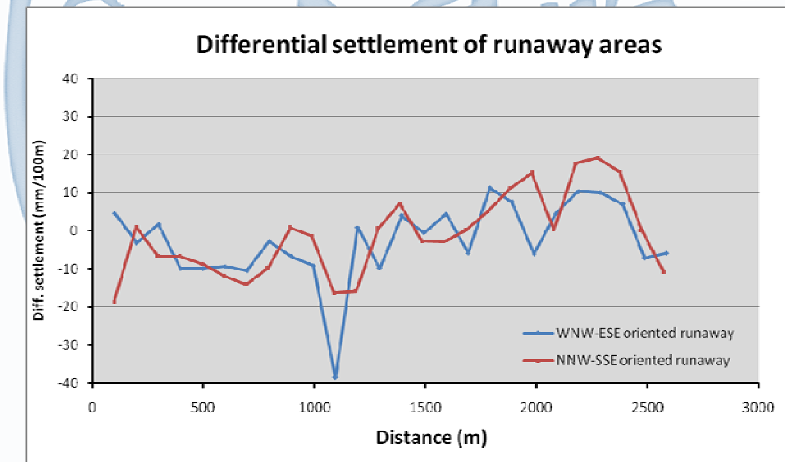
- Land subsidence can be clearly **<u>identified in the wide Anthemountas basin area</u>** with a mean deformation rate of 10mm/yr.
- The main "classical" subsidence bowl (elongate pattern), corresponding to intense groundwater extraction, **<u>affects mostly the central part of the basin</u>**. The measured subsidence rates seem to **<u>increase towards the coastline</u>**, where the thickest sequences of compressible Quaternary layers crop out.

PSI Data Evaluation

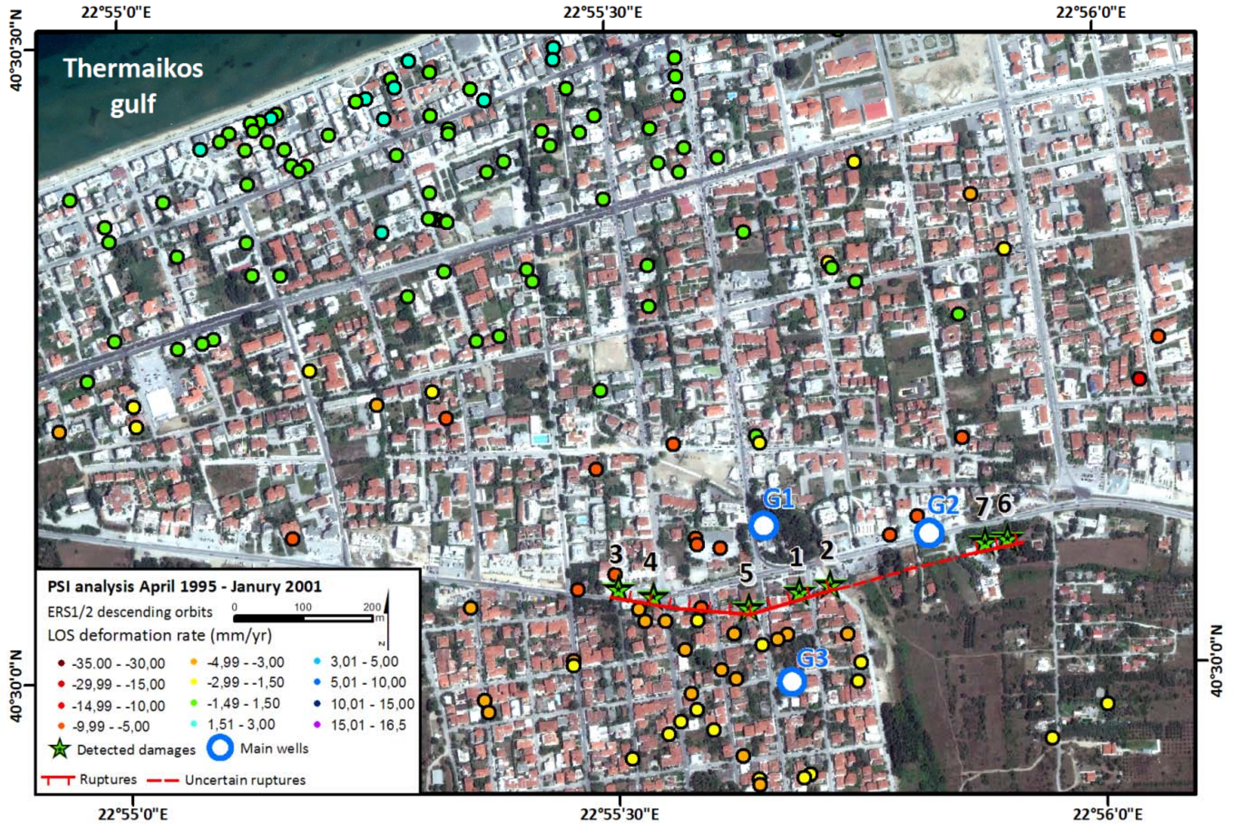


- In **<u>the airport area, observed LOS subsidence rates are 5–15mm/yr</u>**, with several points exceeding 20 mm/yr along the NNW-SSE oriented runaway area.





PSI Data Evaluation



- PSI results reveal that **the coastal area of the Perea village shows very low LOS deformation rates**, indicating relatively stable ground conditions since 1995.
- In **the southern part of the urban area subsidence can be observed, with maximum LOS deformation rates up to 10–15 mm/yr**.

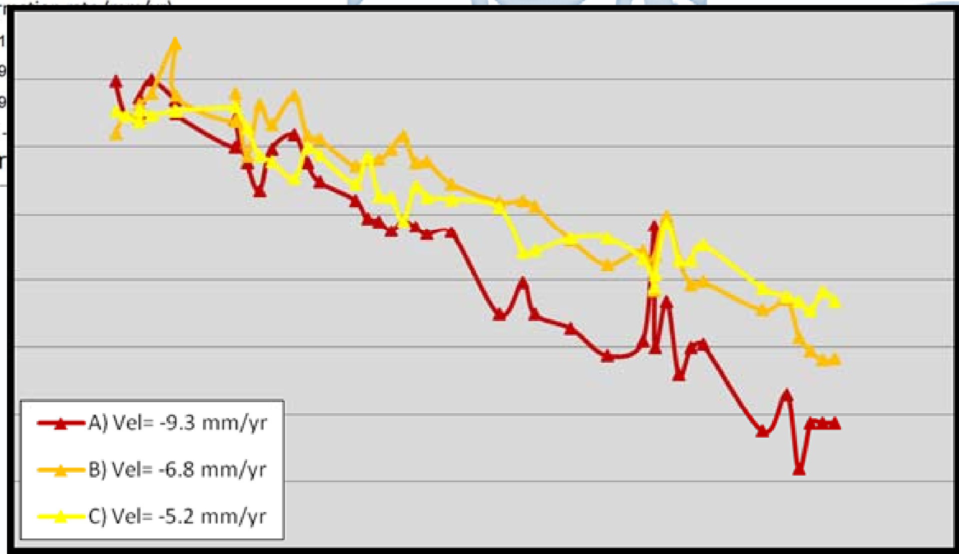
This fact supports the theory claiming that they were caused by the local overexploitation of the aquifers inside the intersecting depression cones.

School of Mining and Metallurgical Engineering

Laboratory of Engineering Geology and Hydrogeology

PSI Data Evaluation

Close-up of PSI data for Perea village. Green stars indicate surveyed points A, B and C.



Displacement time series and yearly velocities of PS A, B, and C, located close to the damaged area of Perea village.

Conclusions

- The PSI results provided substantial information about the actual extent of the land subsidence phenomenon.
- The detection of the phenomena at an initial stage is extremely important, as further extension of the affected area and damages on settlements and infrastructure can be prevented.
- The information provided by this study can give rise to focused geotechnical and hydrogeological studies aiming to stop the phenomenon before it becomes an actual problem for the area.
- This study proved that the repeat-pass satellite SAR interferometry can be exploited not only to map the extension of affected areas at a regional (basin) level but at a local level also, as it was proved valuable for the study of the phenomenon at the narrow airport or upper Perea region.

THANK YOU FOR YOUR ATTENTION !!!