Height changes of GNSS stations from the solutions of short vectors and PSI measurements

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Introduction (1)

PSI and GNSS

- totally independent observation techniques for the determination of height variations
- substantially differ in
  - source data used
  - acquiring and processing methods
  - spatial distribution
  - temporal resolution of the results
  - certainty of getting the correct results with the specified accuracy

Deformation from GNSS (permanent stations)

- very small spatial resolution
- high temporal resolution (most frequently 24 hours)
- high accuracy (at the level of 1 cm) of the determination of relative height variations independently on distance between stations
- no necessity of validation

Deformation from PSI

- very high spatial resolution ($10^3/km^2$)
- smaller temporal resolution (recently ca 11 days)
- increase of the phase unwrapping error propagation with a distance from the point of reference
- **need for external validation**

Introduction (2)

Different character of GNSS & PSI
in particular different advantages and disadvantages
in their use to the same purpose
make them complementary

Common use of GNSS & PSI
might be **beneficial for each of them**
in particular in terms of increasing reliability of the results

The **objective** of this work

to show that PSI data can be used to increase reliability and accuracy of height variations of permanent GNSS stations determined from GNSS data in case of correct processing of the phase unwrapping in large areas

Integration of both techniques may provide
height variation signal below the noise of GNSS solutions

Methods (1)

Precise determination of height changes from GNSS data (1)

Most accurate height variations using GNSS observations can be determined from permanent GNSS stations

- daily or weekly **network solutions**, e.g. IGS, EPN or regional network for station coordinates
- daily or weekly **short vector solutions**

Those solutions may indicate
- **local deformations** in the Earth' crust

or - **local seasonal changes** in atmosphere and hydrosphere

Very high accuracy of determined variations of station coordinates

- network solutions – **centimetre** accuracy
- solutions of short vectors – accuracy at the level of **single millimetres**

Their errors are frequently at the level of the signal determined

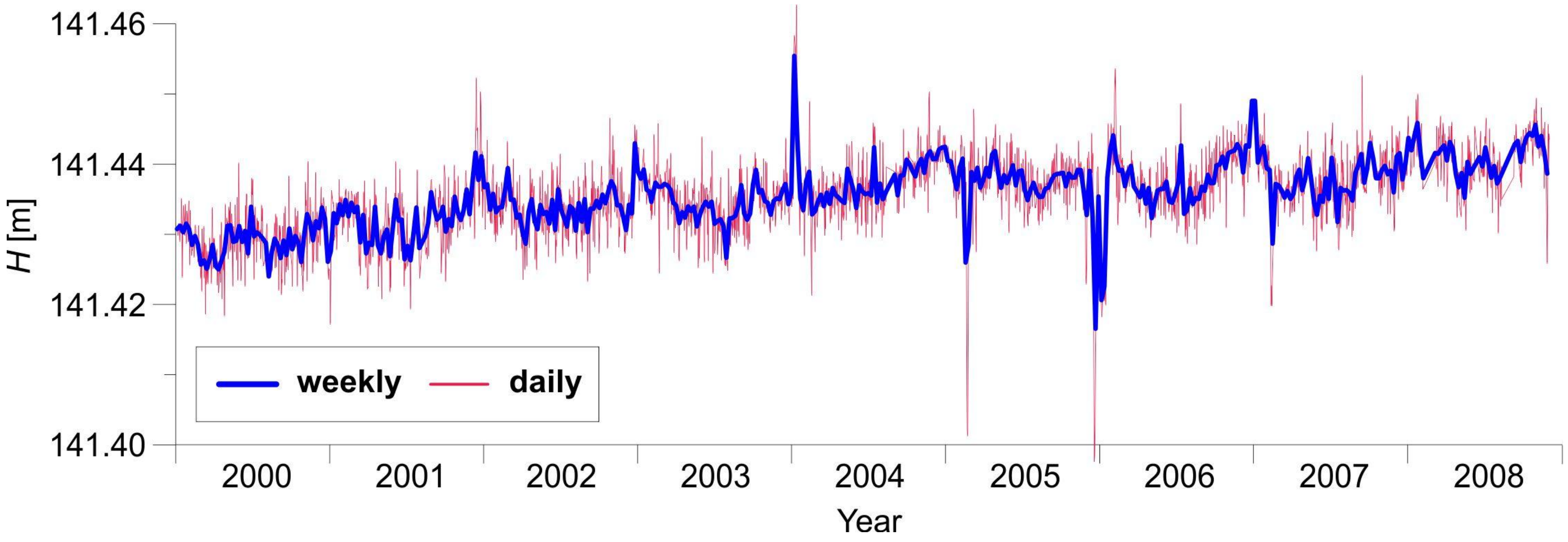
Deformations determined with the use of GNSS technique refer only to GNSS stations providing observations

→ **low resolution**

Methods (2)

Precise determination of height changes from GNSS data (2)

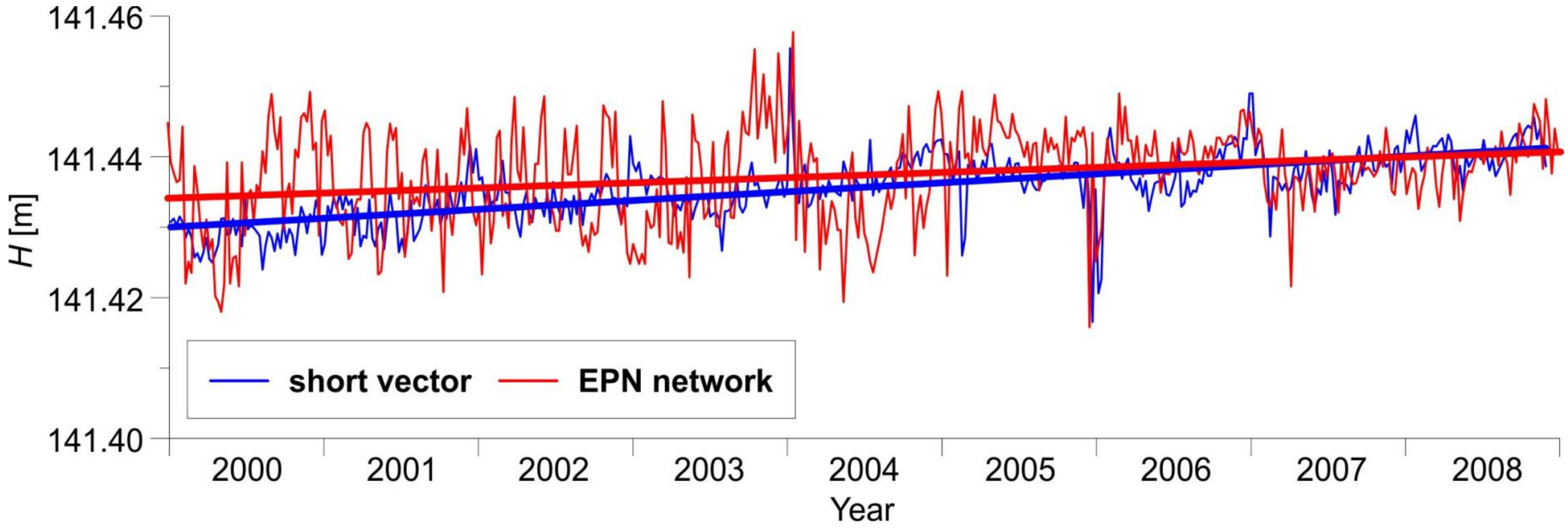
Height variations of JOZE station from daily and weekly solutions of the <u>short vector</u> BOGO - JOZE with reference station BOGO



Methods (3)

Precise determination of height changes from GNSS data (3)

Weekly solutions for height variations of JOZE station from the EPN network and the short vector BOGO - JOZE with reference station BOGO



	Mean	Max - Min	Std. dev.
EPN solution	141.437	0.042	0.007
Short vector weekly solution	141.436	0.039	0.005
Short vector daily solution	141.436	0.065	0.006

Methods (4)

Persistent Scatterer Interferometry (1)

Persistent Scatterer Radar Interferometry (PSI)

– one of multitemporal interferometric methods
– mainly applied for examining slow ground deformations using satellite data acquired from imaging SAR sensors

Radar interferometry (InSAR) was first time used to generate DTM (1988)

Its modification – **Differential Interferometry (DInSAR)** started to be applied for examining slow ground deformations (beginning of 1990.)

limitation of this method, caused by so-called temporal decorrelation

→ best results mainly for dry, semi-dry and rocky areas, characterized by high temporal stability of land cover and soil moisture conditions

Turning point - development of the Persistent Scatterer Interferometry (**PSI**)

in this method solely objects characterized by high stability of reflection and high phase coherence in a long period (persistent scatterers) are used.

In a temperate zone mainly anthropogenic objects fulfil these conditions

Methods (5)

Persistent Scatterer Interferometry (2)

Changes of the distance
between the ground and the satellite in two different time periods
are expressed as a part of wavelength recorded by the satellite sensor

The sensors record only the **phase of the last phase cycle**

→ the method enables to determine solely relative changes of height within the study area, and **accuracy** of final results is strictly related to the correctness of so-called phase unwrapping (*reconstruction of relative number of 2Pi cycles for each persistent scatterer*)

For each pixel representing **persistent scatterer**
the measured phase is related to the defined phase cycle

Interferometric phase is **affected** by

- deformations
- other factors (terrain relief, signal delay in atmosphere, change of land cover and change of dielectric constant)

generating **random noise**, called temporal decorrelation

→ determination of relative number of phase cycles for each pixel - not easy

Methods (6)

Persistent Scatterer Interferometry (3)

Signal phase component responsible for terrain deformation
must be **separated**
from the **remaining components**
to correctly determine ground deformations

The process is done using methods of **statistical modelling**

Minimum 20-25 radar images recorded from the same orbit but at different time needed to determine ground deformation by the PSI method

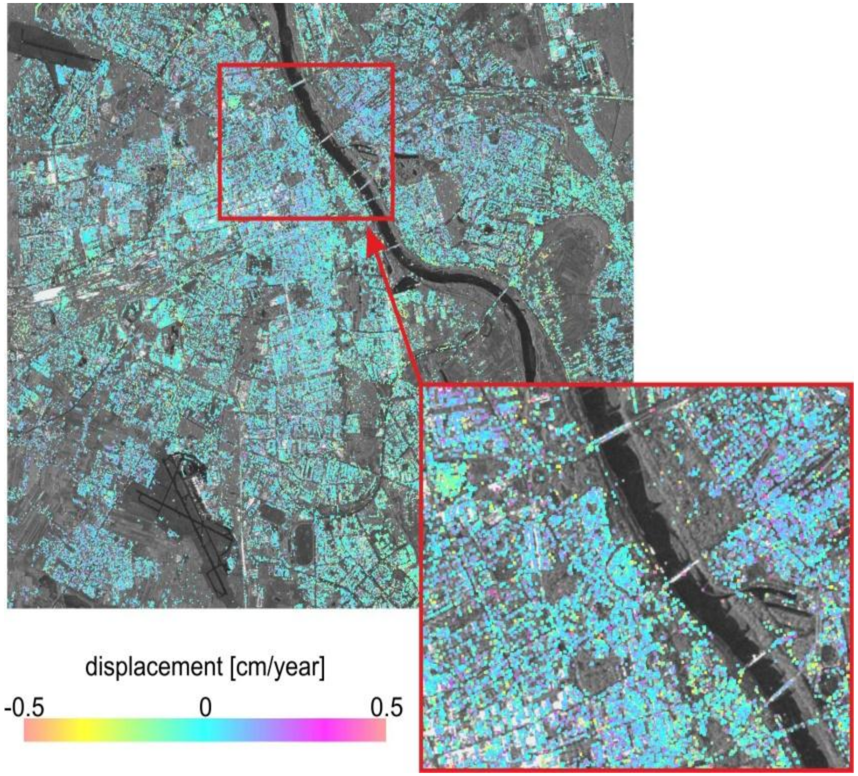
Two products are generated as a result of processing radar images with the use of PSI method:

- **mean deformation** at a given time period
- **deformation history** for each point identified as a persistent scatterer, which demonstrates height changes in relation to the zero epoch

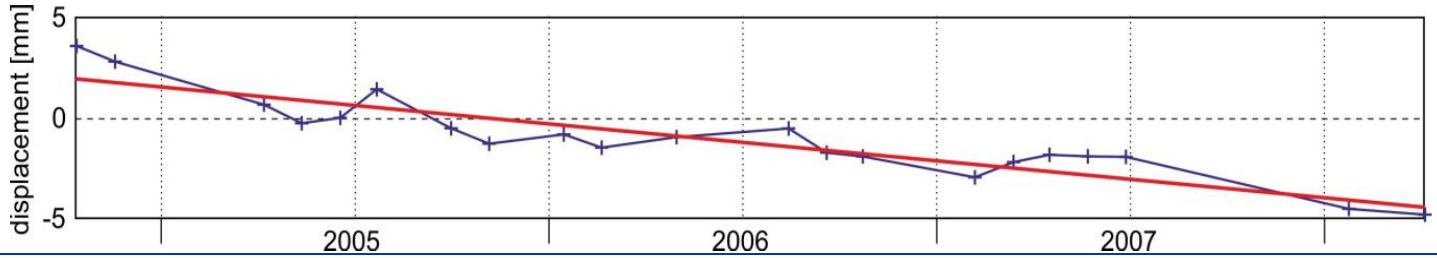
Methods (7)

Persistent Scatterer Interferometry (4)

Deformation map obtained as a result of processing radar images with the use of PSI method



The example of deformation history obtained as a result of processing radar images with the use of PSI method



Methods (8)

Persistent Scatterer Interferometry (5)

Accuracy of

- **mean deformation** can reach the level even below 1 mm/year
- **deformation history** it is assumed - is a few times lower

Final accuracy is affected by several factors

- resolution of images
- radar wavelength
- type of deformation (spatial extend, velocity and non-linearity in time)
- type of terrain and related quality of persistent scatterers
- correctness of the data processing

➡ **the results of PSI method should be validated with the use of independent measurement methods**

Validating usually with

- precise levelling - at a local scale related to single investments
- GNSS - for larger areas

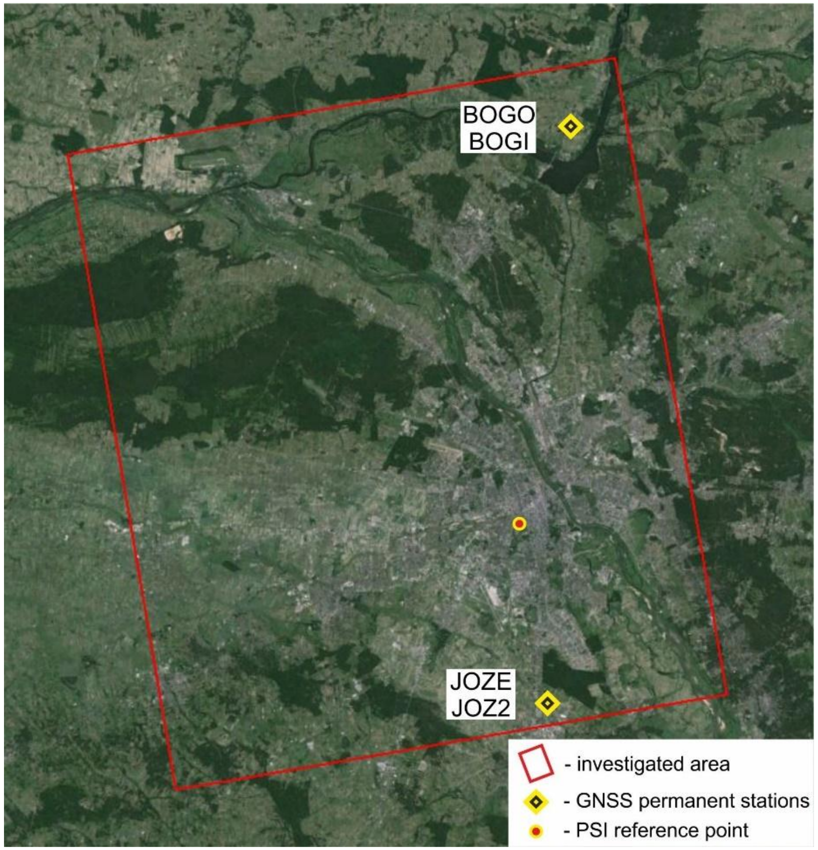
Study area and data (1)

Study area

Warsaw agglomeration

(central part of Mazowieckie Voivodship within the Warsaw Basin and cut by the Vistula River valley)

- in principle **geologically stable**
- observed **numerous deformations** associated probably mainly with the changes of hydrology within the Vistula River valley, Warsaw Escarpment and its surroundings



Local deformations are associated with

- the construction of the metro line
- the impact of various other investments in the subsoil

Study area and data (2)

GNSS data and products

Data from 2000–2008 (sampling rate 30 seconds)

- **BOGO** & **BOGI** stations
  (Geodetic-Geophysical Observatory Borowa Gora of IGiK)
- **JOZE** & **JOZ2** stations
  (Astrogeodetic Observatory Jozefoslaw of WUT)

Three vectors
- BOGO - BOGI
- BOGO - JOZE
- BOGO - JOZ2

have been processed with the **Bernese v.5.0** software using

- precise ephemeris and Earth rotation parameters (IGS)
- Earth tides model (IERS)
- ocean tide loading model coefficients (FES2004 model)
- absolute PCV model for antenna Phase Centre Variations (PCV)

Height variations of BOGI, JOZE, JOZ2 w.r.t. BOGO were determined

Study area and data (3)

Radar data and PSI produkt

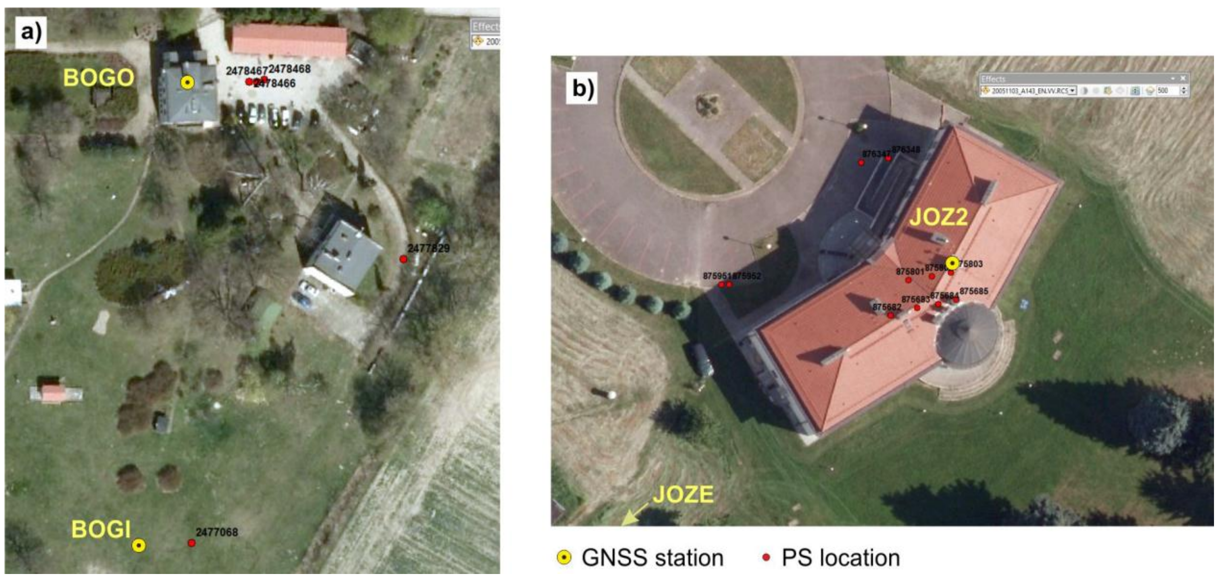
21 Envisat radar images from 2004.8–2008.3
(C-band; λ = 5.5 cm; 5 m × 20 m resolution; 60 days - average recording freq.)

Processing and analysis with the **Gamma Remote Sensing** software

Reference epoch: 2005-11-03

Reference point (phase unwrapping point) – Filtry (centre of Warsaw)

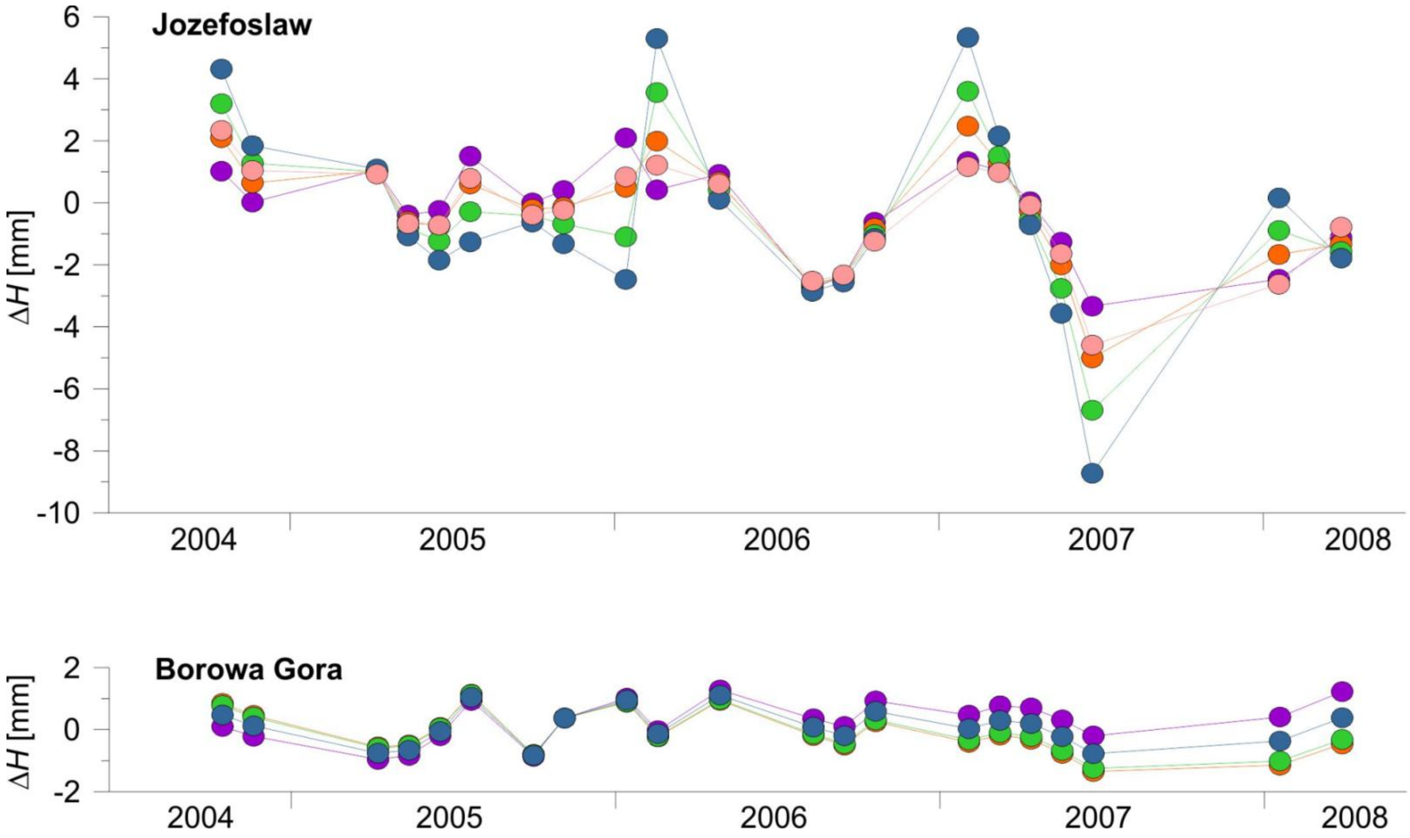
>10^6 natural persistent scatterers (including objects with GNSS stations)



Methods of data integration (1)

Deformations with respect to phase unwrapping point were obtained for each of chosen persistent scatterers for 21 days in the period of 2004 – 2008

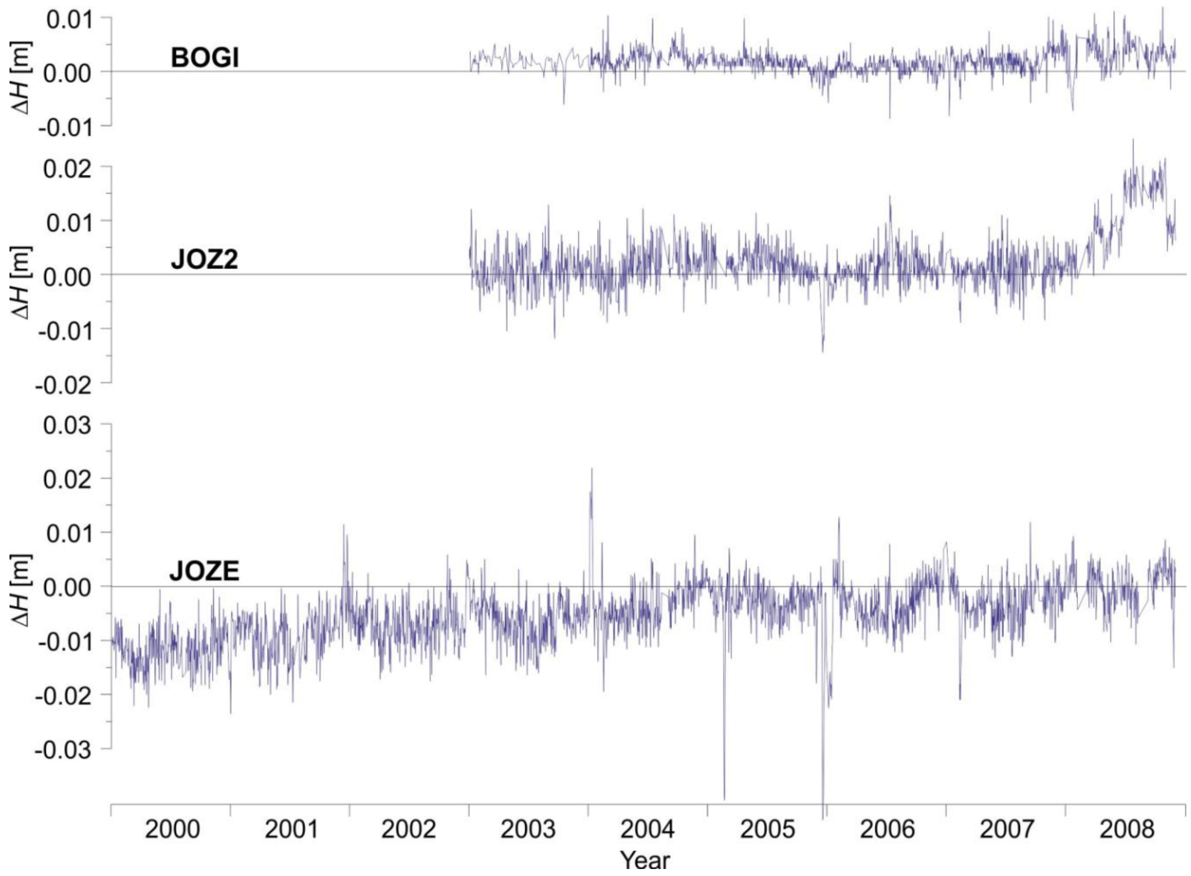
Relative deformations in Borowa Gora and Jozefoslaw form PSI data [mm]



Methods of data integration (2)

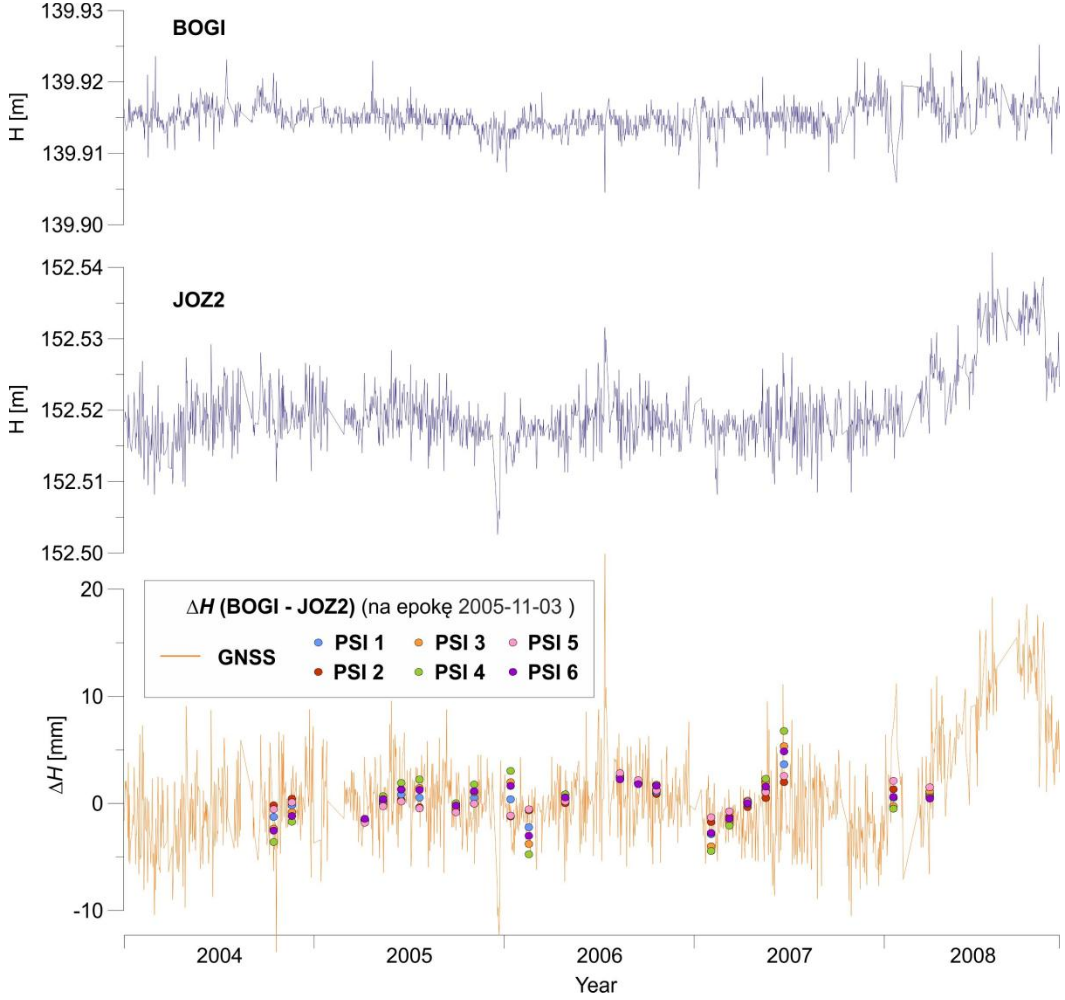
Same reference epoch for both data types (PSI & GNSS) needed

Deformations at BOGI, JOZ2 and JOZE relative to BOGO from GNSS data referred to epoch 2005-11-03 [mm]



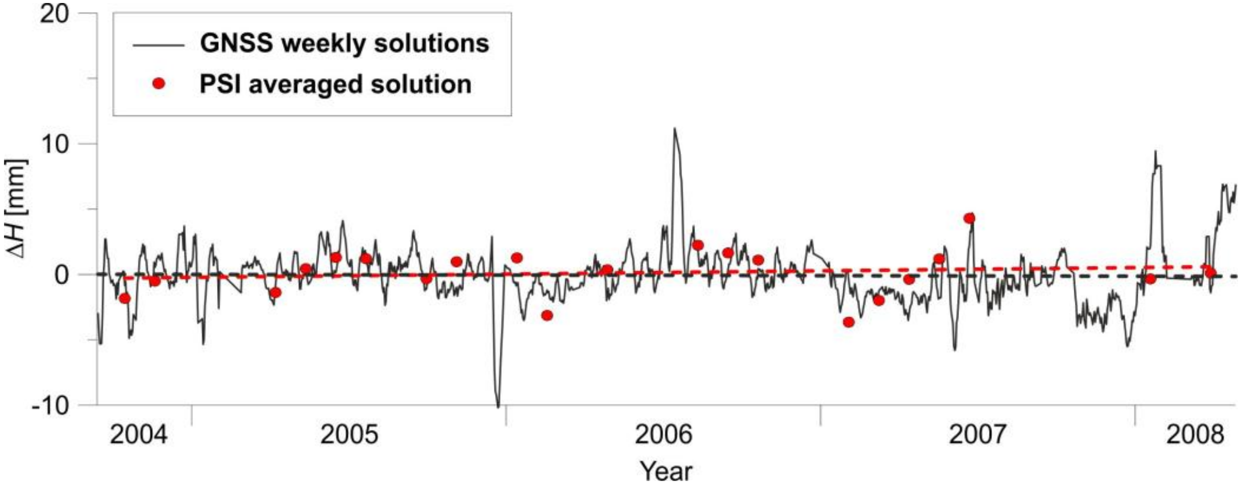
Methods of data integration (3)

Comparison of relative deformations in height component between Borowa Gora and Jozefoslaw obtained from GNSS (daily solutions) and PSI data



Results of PSI vs results of GNSS (1)

Comparison of relative deformations in height component between Borowa Gora and Jozefoslaw obtained from GNSS (weekly solutions) and PSI (average) data

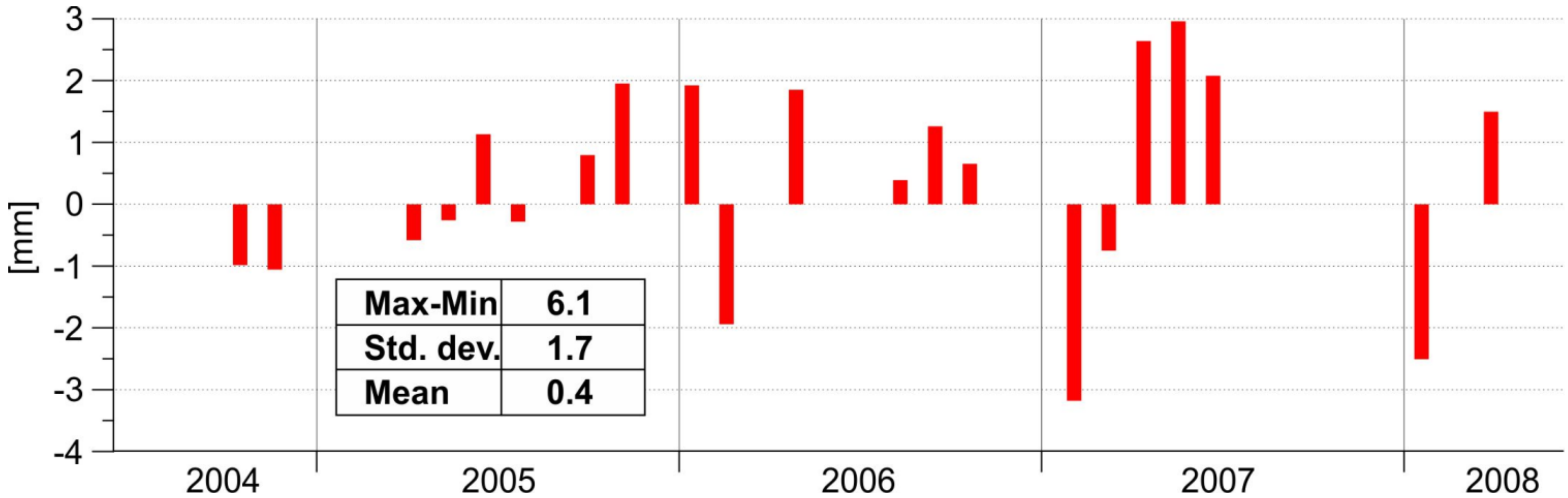


Statistics of relative deformations in height component between Borowa Gora and Jozefoslaw obtained from GNSS and PSI data [mm]

	PSI	GNSS	
		daily	weekly
Mean	0.1	-0.1	-0.1
Std. dev.	1.8	3.4	2.2
Max-Min	7.9	37.2	21.4

Results of PSI vs results of GNSS (2)

Differences between relative deformations in height component of BOGI and JOZ2 stations obtained from GNSS and PSI and their statistics



Summary and conclusions

- **The use** of mutually complementing observation techniques for monitoring deformations in the investigated area, such as GNSS and PSI can substantially increase reliability of the interpretation of the results obtained
- **Common use of both techniques** allows in the variations considered as noise observation to extract the signal of height changes that is below the limit of measurement error
- Simultaneously, the **analysis of results of two completely independent observation techniques** leads to the increase of reliability of results obtained using each of these methods
- Archive radar data of a relatively small spatial as well as temporal resolution were used in this work. The results obtained are, however, promising.

  It should be expected that comparing the results of the GNSS data with PSI data of higher spatial resolution, and in particular of higher temporal resolution, e.g. Cosmo-SkyMed or Sentinel-1 data, should give better results and allow the extract larger signal of height changes from the observed variations of vertical component of the GNSS station

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