ANALYSING THE LOCAL DEFORMATIONS AT OLKILUOTO USING GPS AND LEVELLING TIME SERIES

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INTRODUCTION

The Finnish Geodetic Institute has studied crustal deformations in co-operation with Posiva Oy at Olkiluoto since 1995:

- A local GPS network of 10 pillars observed twice a year
  - Baselines range from 0.5 to 3.5 km
- Precise levelling initiated in 2003 and repeated every second year to improve the vertical control of the network
- Also other measurement activity in the network
  - Baseline for electronic distance measurements to monitor the scale of the network
  - Centring measurements of the auxialary markes of the pillars to control the pillar stability

Here we concentrate on the relative movements of the GPS points, introduce the time series, and present the results of the deformation analysis using both GPS and levelling time series.

GPS TIME SERIES

Measurement

- Ashtech Z12 and μZ dual frequency receivers (Leica GX1230 series geodetic receivers since autumn 2009) and Ashtech Dorne Margolin Choke Ring antennas
- The same antenna set up on the same pillar every time
- 24h observation sessions

Data processing

- A total of 28 GPS campaigns (1996-2009) were processed uniformly (Kallio et al., 2010) using
  - Bernese 5.0 GPS software (Dach et al., 2007)
  - L1 frequency together with local ionosphere model
  - Ambiguity resolution using Sigma algorithm
- To get an insight into the variation of the GPS solutions the baseline lengths were computed from the 3-dimensional coordinates obtained from GPS processing (Figures 1 and 2)

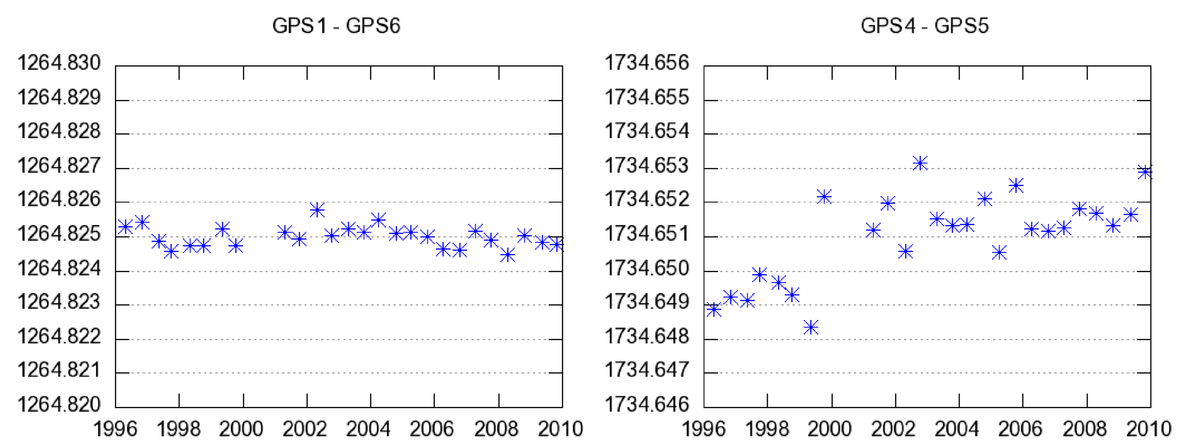

Figure 1. *Timeseries of baseline lengths in metres. The scatter of the solution in the best resolved vectors (left) is less than 1.0 mm. In the cases of problematic vectors (right) the results of the first campaigns deviate clearly from the others.*

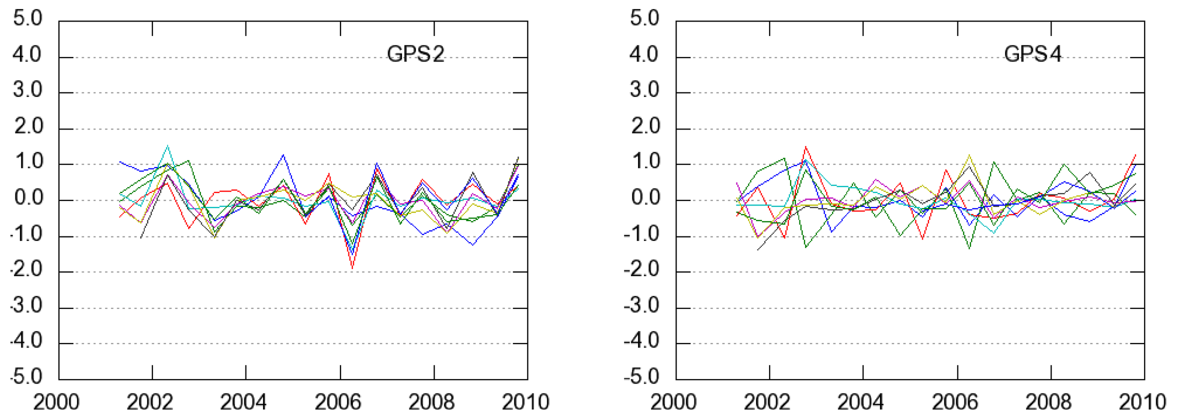

Figure 2. *Seasonal variation observed e.g. at GPS2 but not at every pillar.*

DEFORMATION ANALYSIS

Data

- GPS time series from the years 2001-2009 (GPS13 from 2005).
  - First observations excluded due to outlying behaviour in the baseline length time series
- Height time series include epochs: 2003, 2005, 2007 and 2009.

Analysis

- Based on the coordinate and height differences between adjacent pillars (determined automatically using Delaunay-triangulation)
- A least squares free network adjustment with station specific velocity parameters as additional parameters (Kallio et al., 2009)
- Relative movements (no fixed reference coordinates, heights or velocities used)

Results

- Maximum horizontal velocity 0.10 mm/a
  - The more measurement we have made, the smaller velocities obtained
- Maximum vertical velocity 0.18 mm/a
  - Change in the height difference between the points GPS6 and GPS13 potentially due to the construction work of the Olkiluoto 3 nuclear power station

Table 1. *Horizontal velocities from the GPS and vertical velocities from the levelling. Statistically significant velocities in bold.*

	North (mm/a)		East (mm/a)		Vertical (mm/a)	
Pillar	**Velocity**	**St.dev x3**	**Velocity**	**St.dev x3**	**Velocity**	**St.dev x3**
1	**-0.086**	**0.062**	0.035	0.048	0.011	0.077
2	**0.104**	**0.081**	0.048	0.063	-0.075	0.096
3	**-0.079**	**0.069**	0.014	0.053	0.064	0.085
4	0.018	0.060	0.017	0.047	**0.080**	**0.075**
5	-0.015	0.069	0.045	0.053	-	-
6	0.038	0.060	**0.064**	**0.046**	**0.162**	**0.073**
7	0.053	0.066	-0.004	0.051	0.016	0.080
8	-0.026	0.070	-0.036	0.054	-0.017	0.075
9	-0.042	0.079	**-0.103**	**0.061**	0.024	0.097
13	0.034	0.150	-0.080	0.116	**-0.176**	**0.125**
3216	levelling bench marks				**-0.087**	**0.077**
3217					0.030	0.070
3218					**-0.012**	**0.072**
5217					-0.021	0.111

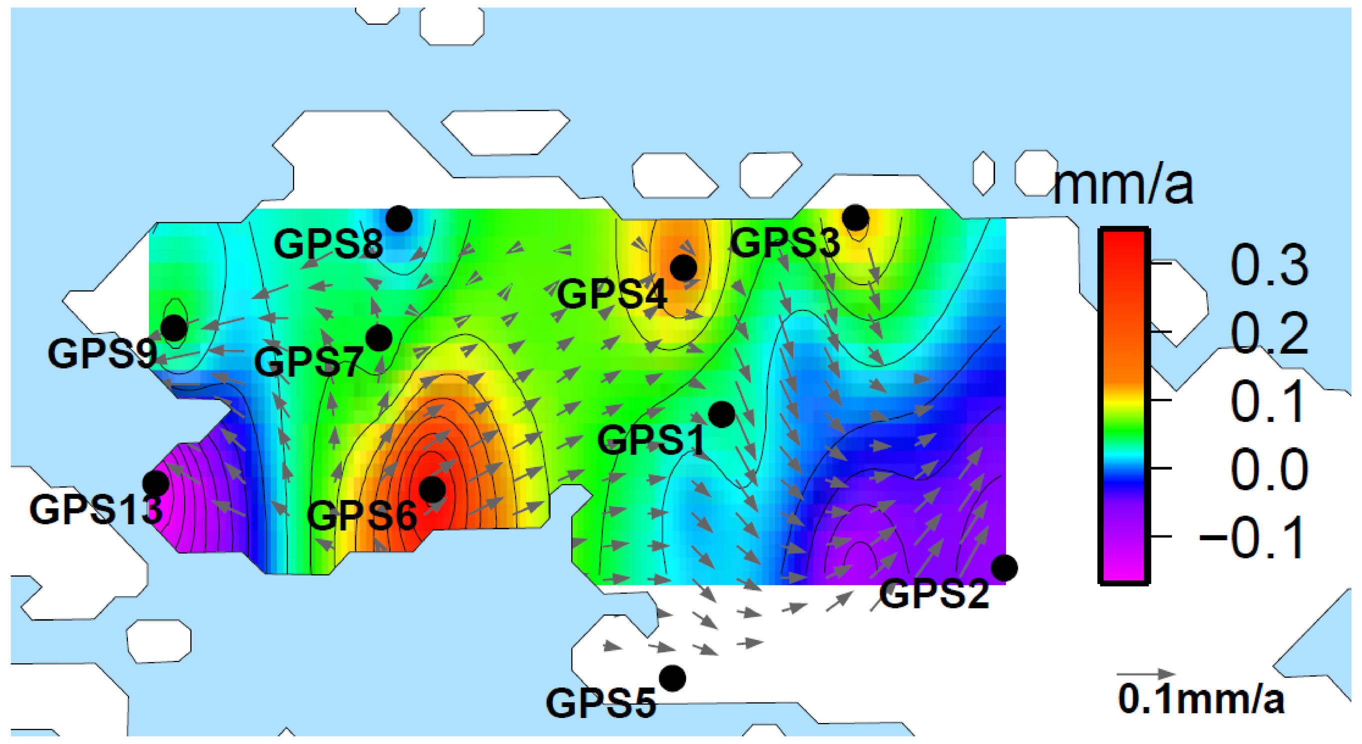

Figure 4. *Horizontal and vertical velocities at Olkiluoto interpolated in a grid from the stations values. The contour lines are at 0.02 mm/a interval.*

LEVELLING TIME SERIES

- The same method used as in the Third Precise Levelling of Finland (1978-2004)
- Digital levelling system Zeiss DiNi12 and Zeiss Nedo LD13 bar code invar rods
- Levelling of the GPS network (Lehmuskoski, 2008) consisted of reserve marks of eight GPS pillars and four levelling bench marks
  - Also some micro loops levelled onto the ONKALO (Underground Rock Characterisation Facility) excavations, but those observations are not included in this analysis
- The time series of the height differences point by point in order get to an idea of the nature of the changes (Figure 3).

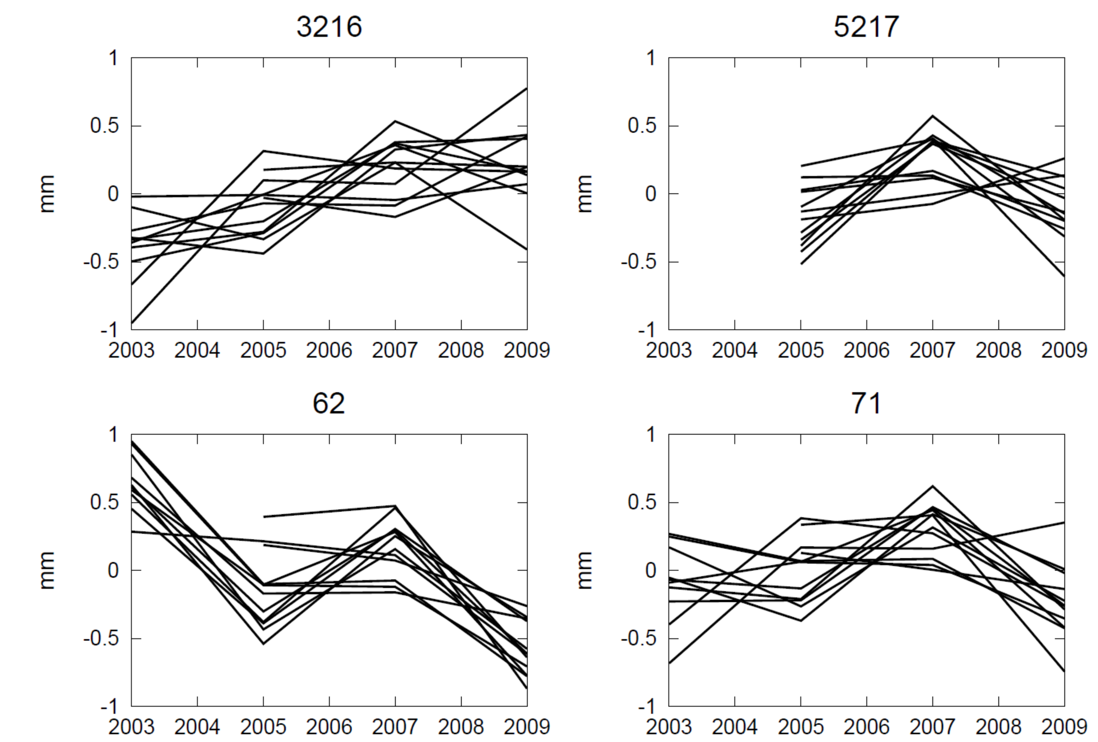

Figure 3. *Change in height difference from the levelling bench marks 3216 and 5217 and the reserve marks of points GPS 6 (62) and GPS7 (71) to the other points of the network. Deviation from the mean in millimetres.*

CONCLUSIONS

- Horizontal movements larger than 0.3 mm/a can be excluded on the basis of ten years GPS measurements.
- The vertical velocities are more uncertain because of fewer measurements and shorter time series.
- In future the structure of the GPS network will improve, when new permanent stations will be established at Olkiluoto. After a few years of continuous observations we will achieve the current precision level of the horizontal velocities for the new pillars.
- Regular precise levelling campaigns will also be continued.
- The joint analysis of the GPS and levelling results may reveal potential interesting sub-areas for the further analysis and interpretation.

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