From Passive to Active Control Point Networks – Evaluation of Accuracy in Static GPS Surveying

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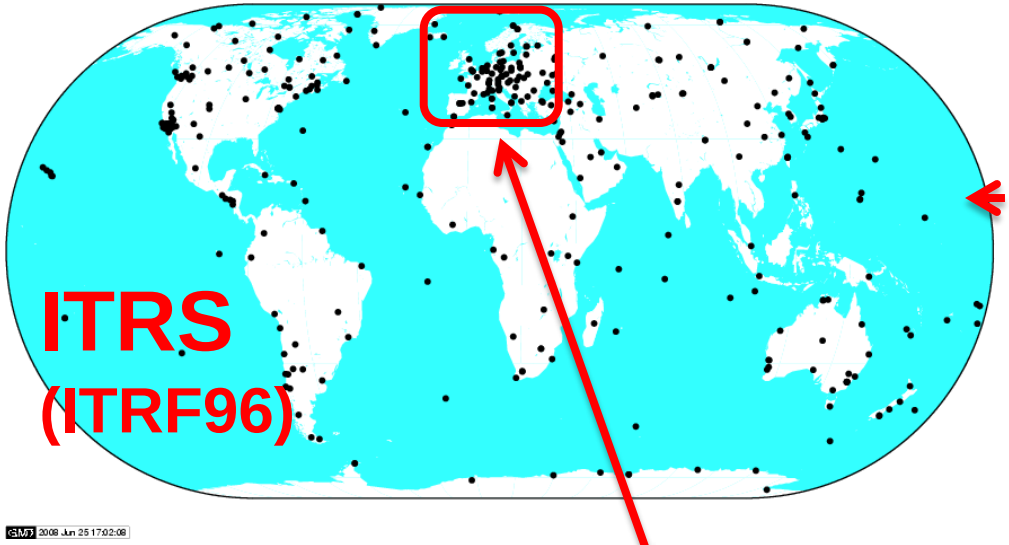
Background and motivation

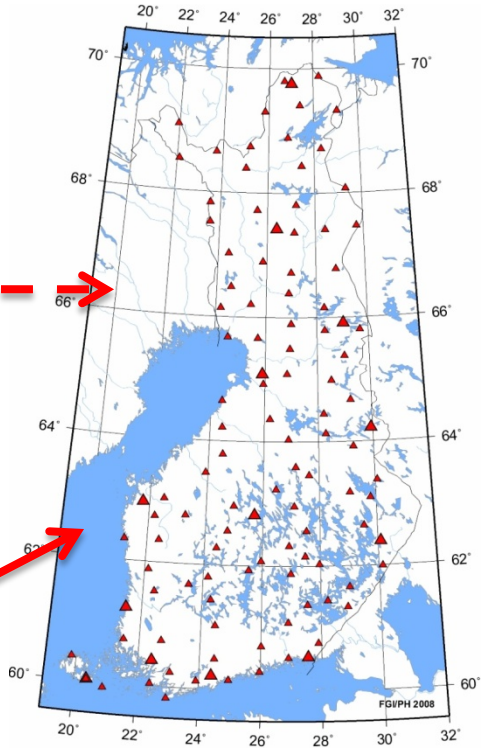
- Finnish Geodetic Institute (FGI) together with National Land Survey (NLS) responsible of creating and maintaining of Finnish reference frames
- In the past control point measurements made hierarchically in Finland (traditional way): first order network defines the RF, second order network tied directly to that, third order network tied to second order, etc. Measurements neglecting the hierarchy were not allowed.
- Situation has changed with satellite positioning: measurements not anymore dependent on distance between the points and new positioning services (network RTK) available:
  - + Cost-effective measurements
  - + One GNSS equipment enough
  - - Results do not have classification in EUREF-FIN
  - - Non-hierarchical measurements neglecting the EUREF-FIN hierarchy (points are not tied to the nearest points but further away to active stations from the area of interest)
  - → Compatibility with hierarchically measured control points?

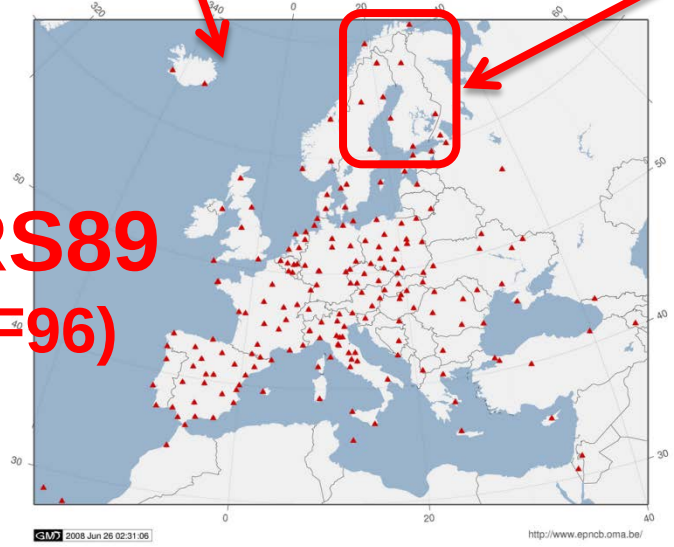
Control points

- Passive control points
  - Markers on the ground
  - Coordinates refer to some physical point on the marker
- Active control points
  - Permanently fixed GNSS equipment that collect GNSS observations continuously
  - Coordinates (usually) refer to antenna reference point (ARP)
    - Antenna-related
    - Accuracy may be destroyed/coordinates may change after equipment change or failure → requires monitoring

EUREF-FIN, Finnish ETRS89 realization







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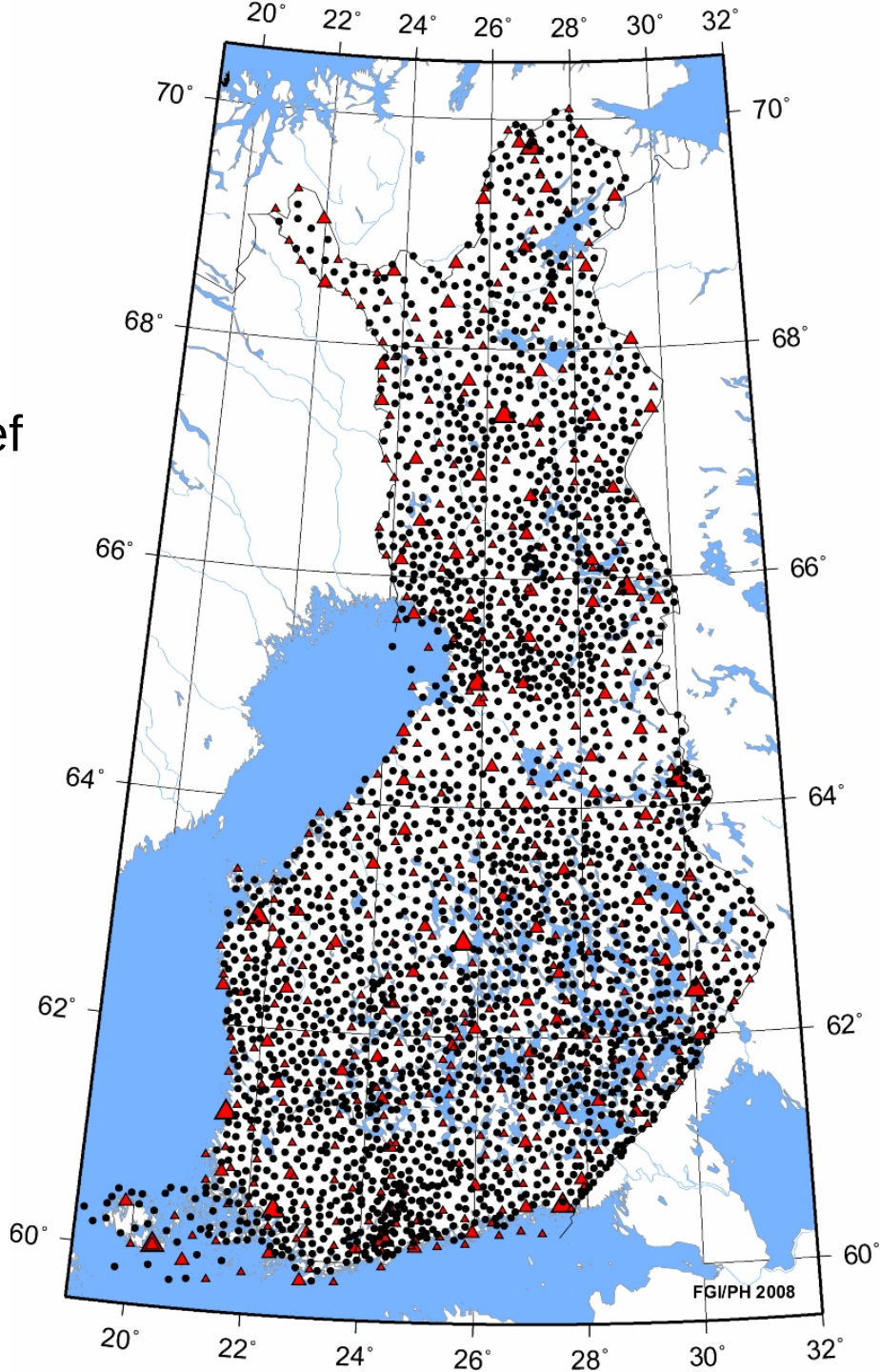
EUREF-FIN control point hierarchy

- E1 (first) order network
  - Permanent GPS network FinnRef
  - 100 passive control points
  - Measured 1996-97, defines the EUREF-FIN reference frame
- E1b order network
  - Densification 1998-99
  - 350 passive points
- E2 order network
  - Approx. 4800 passive points
- Thousands of local points in E3-E6



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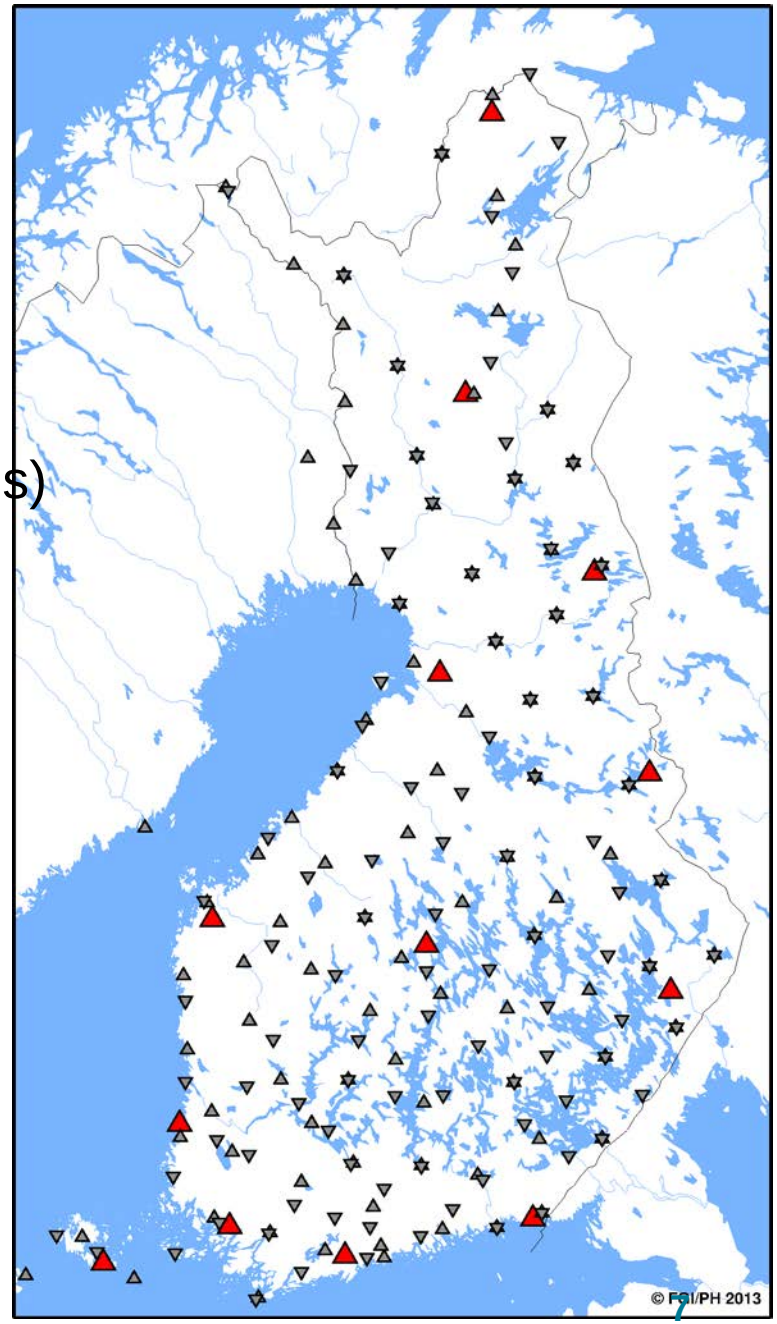
Active GNSS networks

- Scientific network FinnRef (governmental)
  - 13 stations since mid-90's (old stations)
  - 20 new stations to be GNSS capable
- Network RTK services (private companies)
  - Trimnet (previously VRSnet.fi)
    - Approx. 90 stations nationwide
    - Since 2000
  - SmartNet
    - Approx. 100 stations nationwide
    - Since 2011



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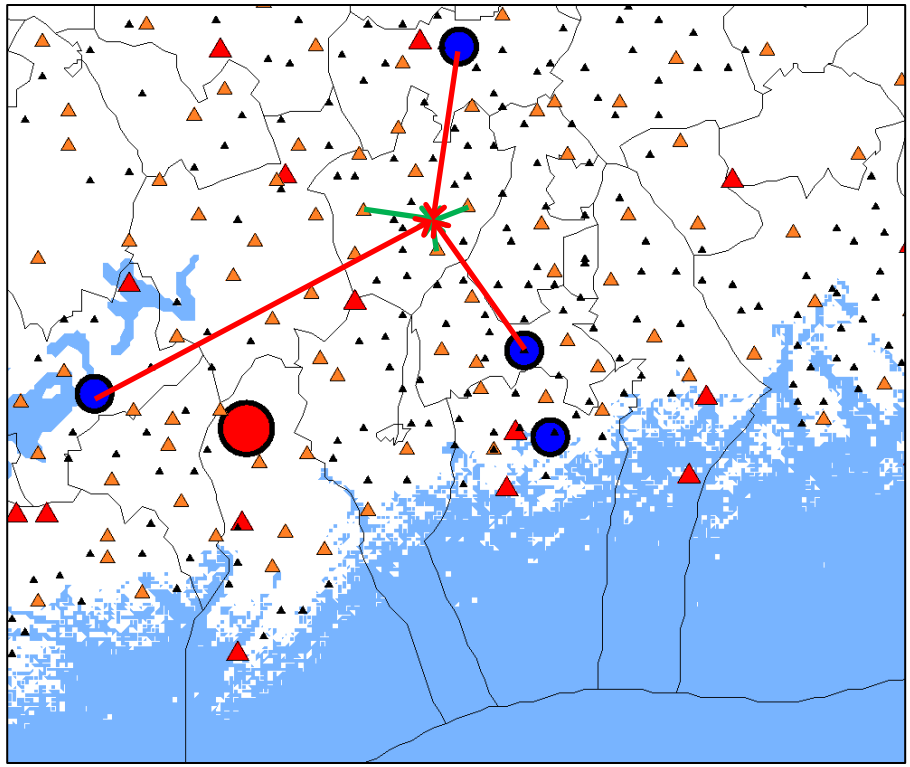
Hierarchical vs. non-hierarchical measurements

- Hierarchical measurement
  - Fixing to the nearest higher order points
- Non-hierarchical measurements
  - Fixing only to active stations → hierarchy of passive points neglected
  - Baselines to active stations much longer → requires longer occupation times
- Compatibility between the two ways of measuring?



Interstation distance for active stations (large circles) is much longer than for passive control points (triangles)

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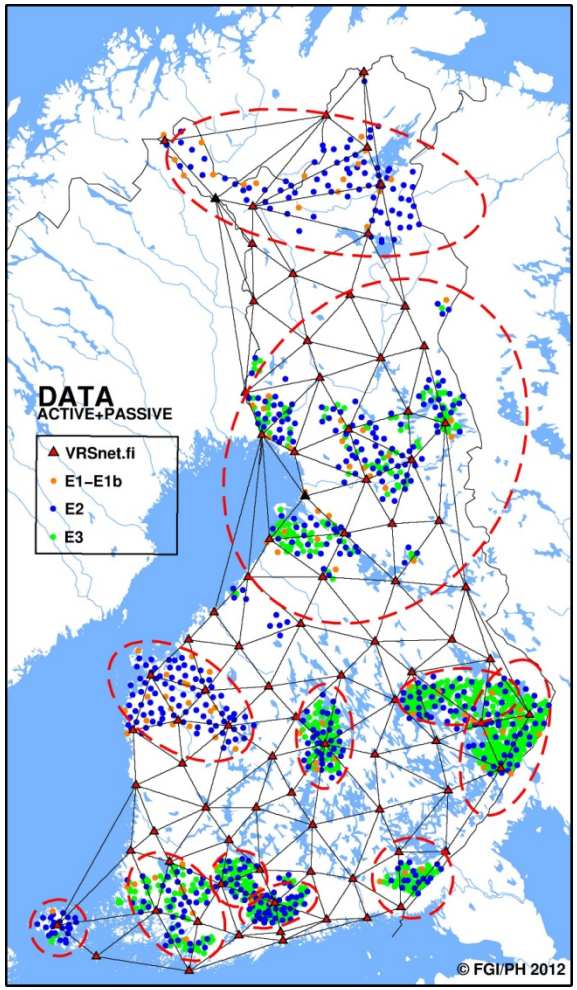
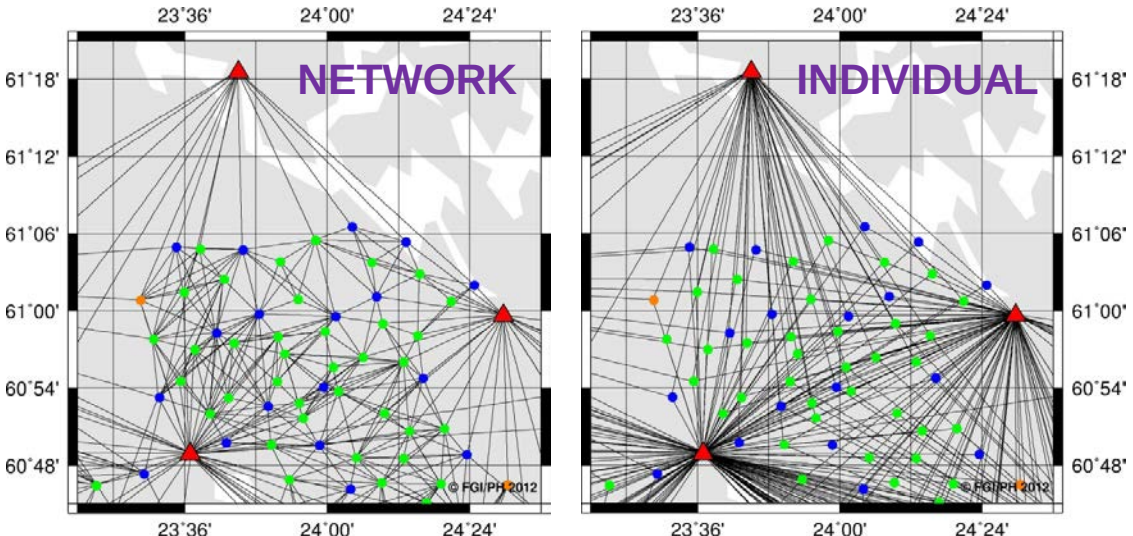
GPS data

- GPS measurements from 2006-2010
  - Approx. 1500 passive points in E1-E3
  - 11 separate subnets (dashed circles in the Figure)
- Original measurements done with hiearchical measurements i.e. reference coordinates for the points determined by fixing to the nearest higher order passive points
- Official coordinates for some E2-E3 points determined with the same data



GPS processing

- Standard/default settings with Trimble Total Control
  - IGS precise orbits, CODE global ionosphere maps,…
- Measurements fixed only to nearest active stations (VRSnet.fi)
- Sessions processed as network (closed loops) and individual (point-wise) solutions (Figures below)
  - Baseline lenghts 0.4-261km, averages: 18km (network solution) and 51km (individual solution)
  - Average occupation time 2-3h depending on solution type (minimum set to 30 minutes)
  - Approx. 10000 baselines for network soln and 7500 baselines for individual soln processed



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Results

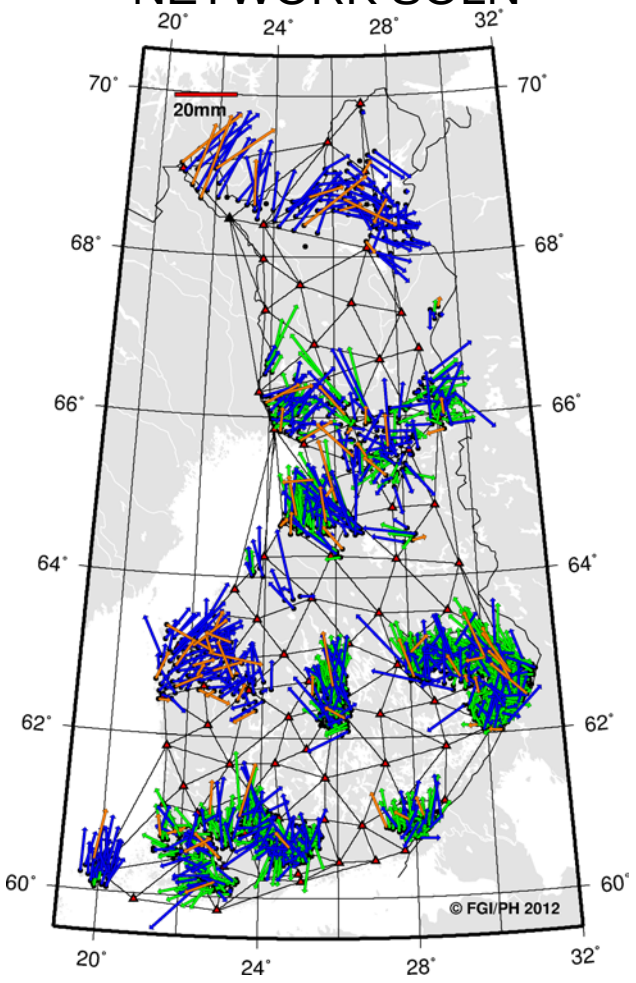
- Some preprocessing (e.g. outliers removed,…)
- Additional verification of occupation times
- Results compared to official, hierarchically measured, coordinates

	Network solution (*n*=1400)			**Individual solution** (*n*=1401)		
	N (mm)	E (mm)	U (mm)	N (mm)	E (mm)	U (mm)
Min	-15.40	-17.60	-79.80	-20.90	-21.70	-73.00
Max	27.40	20.10	60.10	27.30	20.10	66.40
Mean	4.68	-0.34	-14.32	5.10	-0.30	-13.07
Stdev	±6.64	±6.02	±21.09	±7.21	±6.42	±23.55
Rms	**±8.13**	**±6.03**	**±25.50**	**±8.83**	**±6.43**	**±26.93**
95%	**±16.20**	**±12.20**	**±49.20**	**±17.59**	**±13.10**	**±52.00**

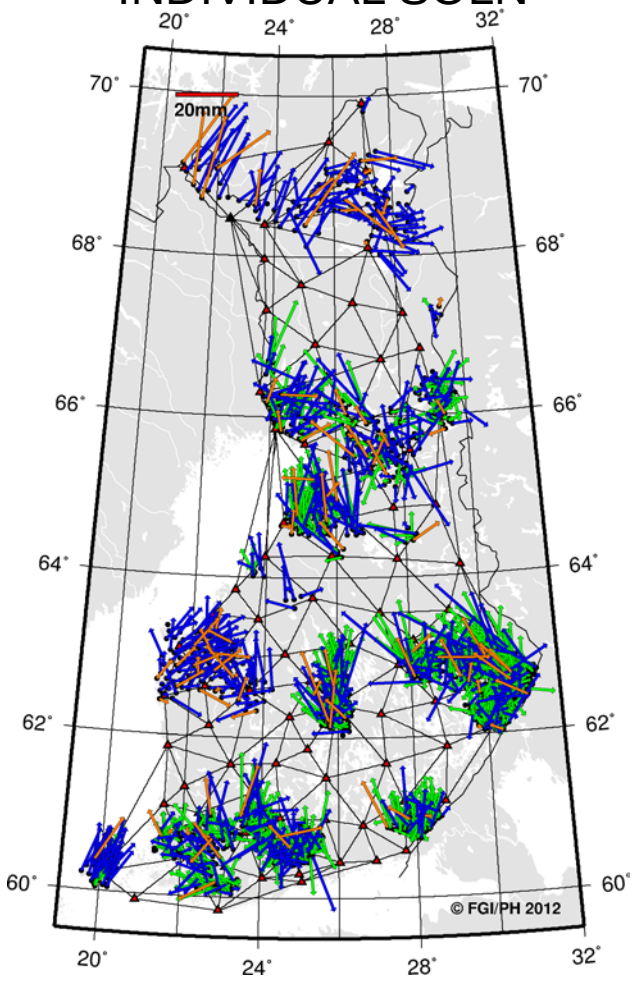
- Results from different solution types (network/individual) quite equal – network solution only slightly better
- Rms roughly 1cm in horizontal coordinates and 3cm in height (ellipsoidal)

Results – horizontal accuracy

NETWORK SOLN



INDIVIDUAL SOLN



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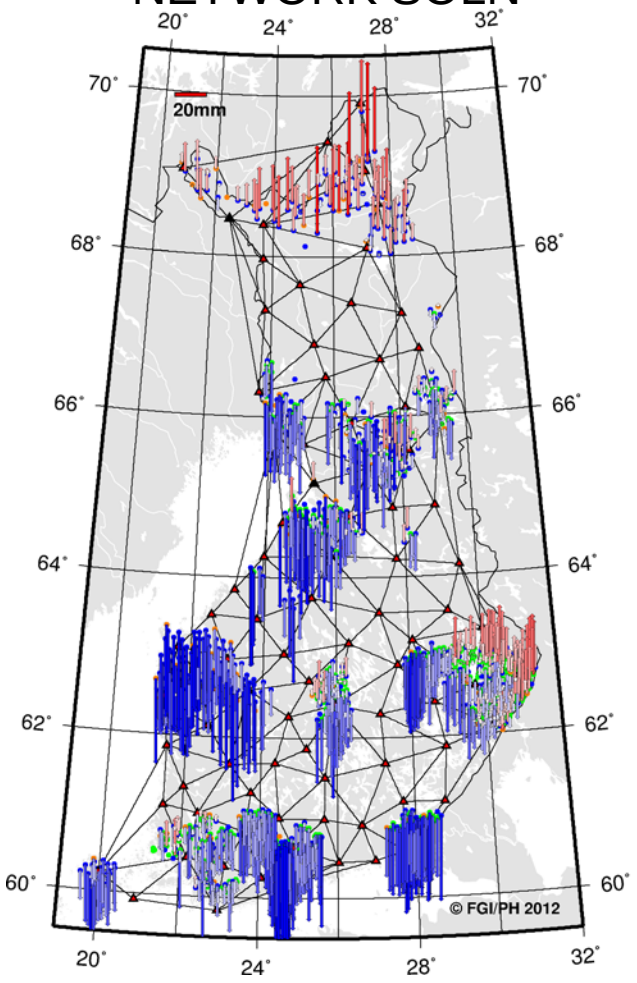
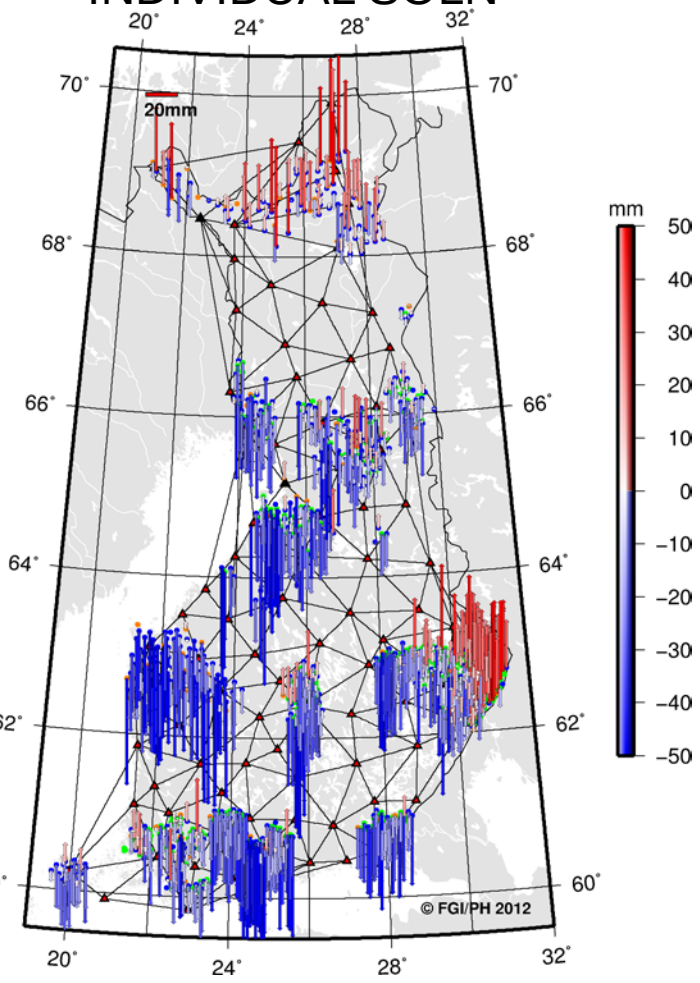
Results – vertical accuracy

NETWORK SOLN



INDIVIDUAL SOLN



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Analysis – solution type

- Results from different solution types (network/individual) quite equal – network solution only slightly better
- Correlation between solutions high ($R^2 \approx 0.7$)

→ roughly 2/3 of the errors can be attributed to some common sources (and only 1/3 to differences caused by the solution types)

→ some systematics (biases) in data

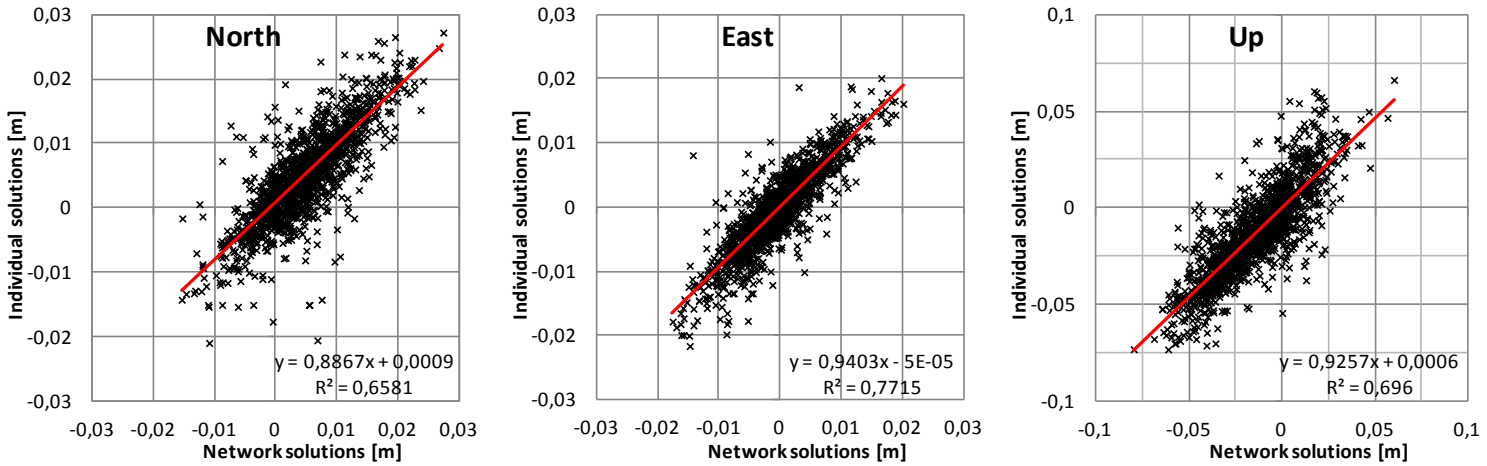
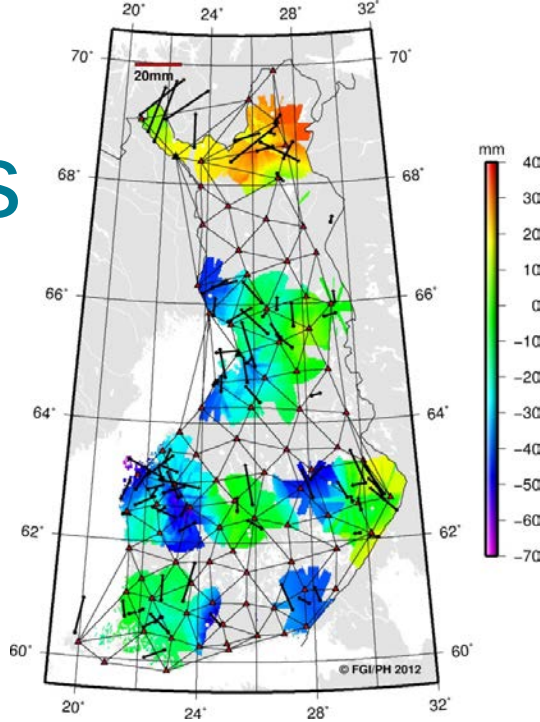
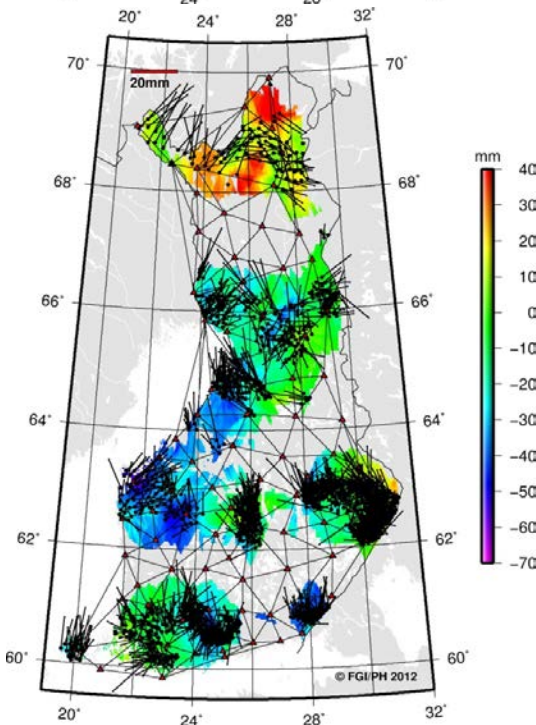


Figure 6. Correlation between network and individual solutions for North (left), East (middle) and up (right) components.

Analysis – coordinate class

- Official E1 coordinates define the EUREF-FIN reference frame → residuals at E1 points should reveal possible differences in the active GNSS network and defining passive control points
- Residuals similar between the E1 and E2-E3 coordinate classes (Figures: E1 on top, E2-E3 below, vectors: horizontal residuals, color map: vertical) → suggests that most of the residuals at E2-E3 points originate from E1 or fiducial (active) points





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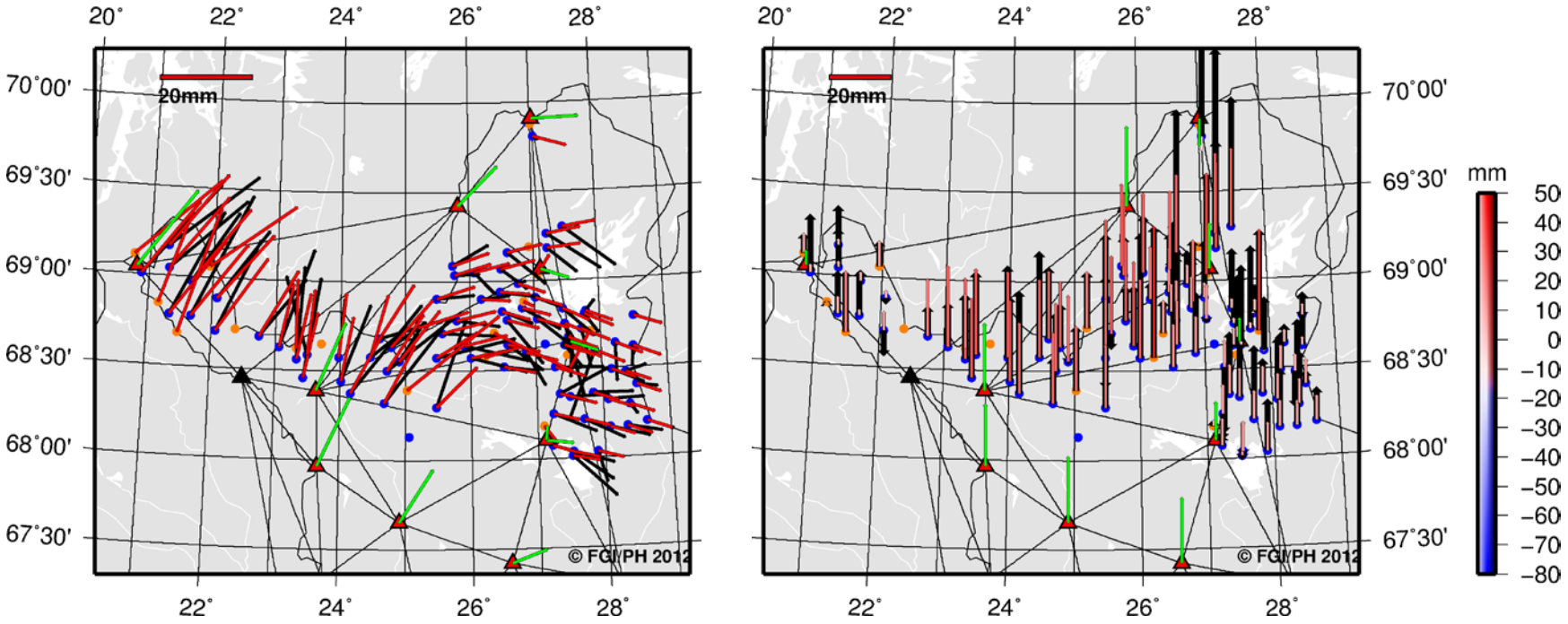
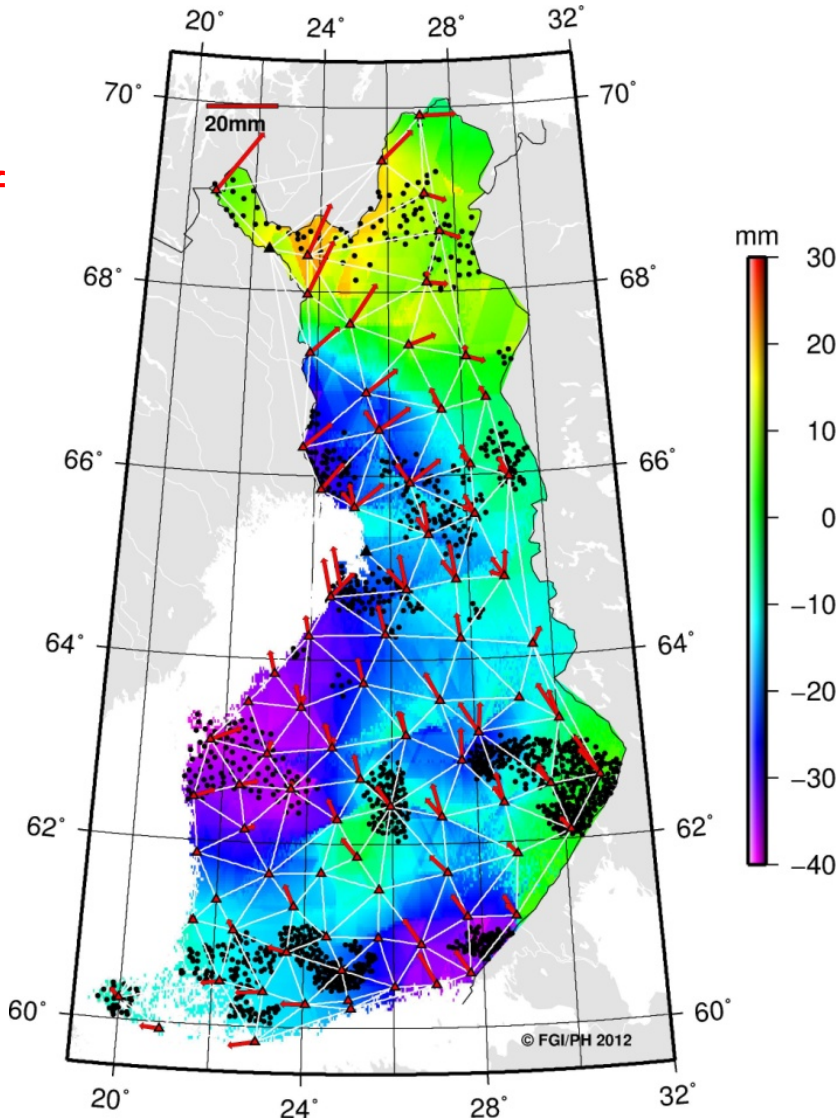
Analysis – simulations (1/2)

- Simulation done by constraining the official E1 coordinates and propagating E1 residuals to the other points (E2-E3 and fiducial active stations)



Analysis – simulations (2/2)

- The simulation suggests that the agreement between active and passive network is in the order of 5-10mm in horizontal and 25mm in vertical coordinates
- For horizontal part this is a good result but for vertical coordinates some improvements could be made
- Most likely reason for the small disagreement in vertical coordinates is the post-glacial rebound effect



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Conclusions

- Ignoring the coordinate hierarchy one may expect approx. 1cm accuracy (rms) in horizontal and 2-3cm accuracy in vertical coordinates
- Some systematics remain between passive and active networks that are most likely caused by post-glacial rebound. By correcting this effect accuracy could be improved.

- The results were utilized when official guidelines in Finland were renewed – good compatibility means that now also active stations can be used as fiducial stations

Thanks!

- More information:
  - *Häkli, P., U. Kallio and J. Puupponen (2013):* From Passive to Active Control Point Networks – Evaluation of Accuracy in Static GPS Surveying. Environment for Sustainability, FIG Working Week 2013, Abuja, Nigeria, 6–10 May 2013.
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