A new GPS derived velocity field of the postglacial adjustment in Fennoscandia, and its implication for the maintenance of the European geodetic reference frame

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Outline

- The extended BIFROST network
- GPS analysis
- Time series analysis and data editing
- Evaluation of the velocity field
- Implications for European geodetic reference frame
- Conclusions

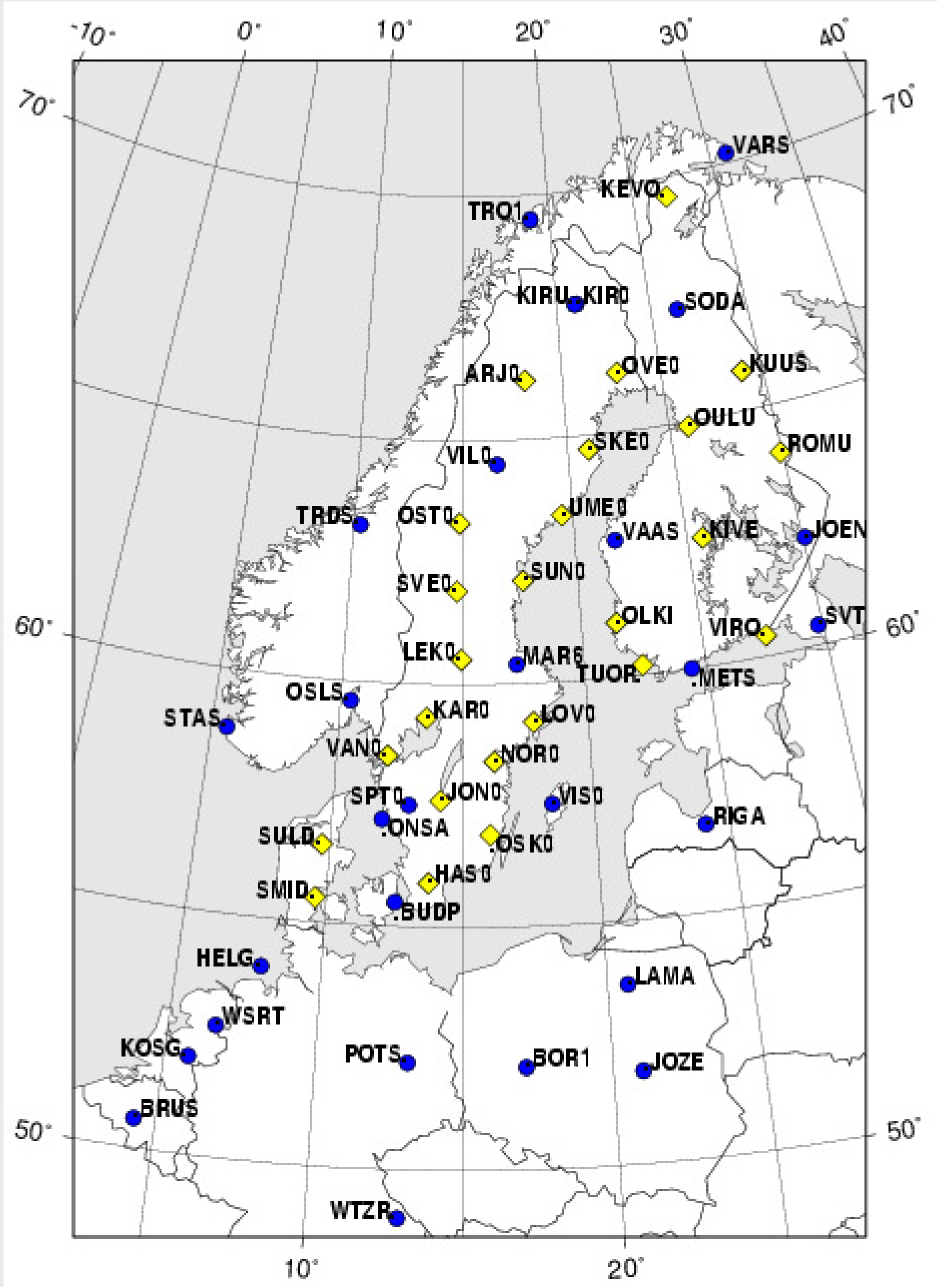
BIFROST

B aseline
I nferences for
F ennoscandian
R ebound
O bservations
S ea level and
T ectonics

The extended BIFROST network

Included GPS stations
(Jan 1996 – June 2004)

- EPN station in Northern Europe (blue •)
- Finland
- Sweden (21 concrete pillars)
- Norway
- Denmark



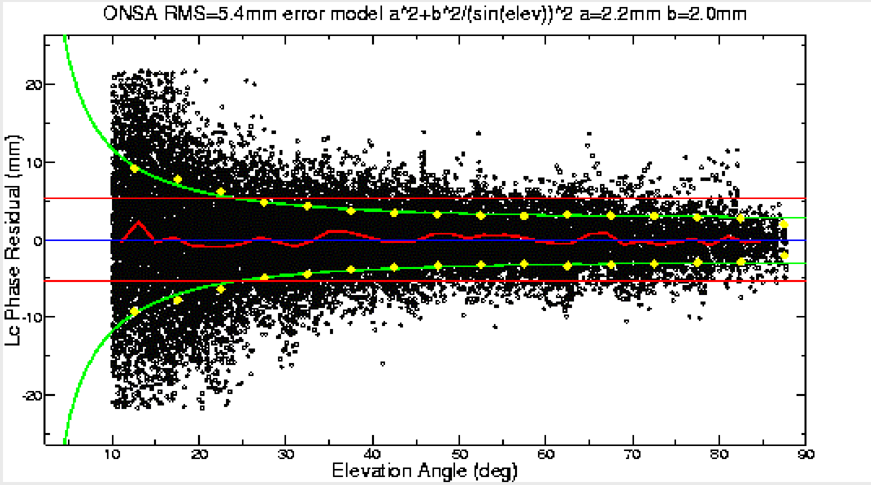
GPS analysis using GAMIT/GLOBK

GAMIT (GPS analysis)

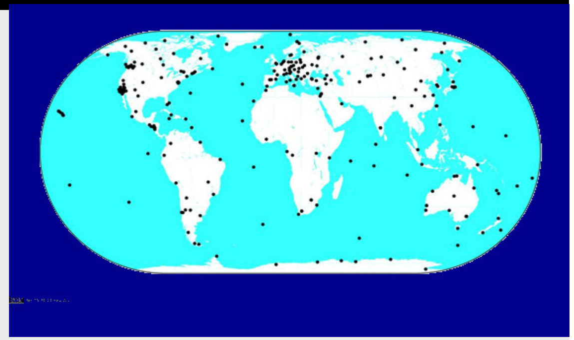
- 10° elevation cut off angle
- tropospheric zenith delay parameters every 2nd hour (piece-wise-linear)
- daily gradient parameters
- the Niell mapping functions
- solve for integer phase ambiguities
- a priori orbits from SCRIPPS Orbit and Permanent Array Center (SOPAC) (g-files)
- 5 regional sub-networks
- individual elevation dependent weighting based on preliminary analysis

GLOBK (combination & ref. frame)

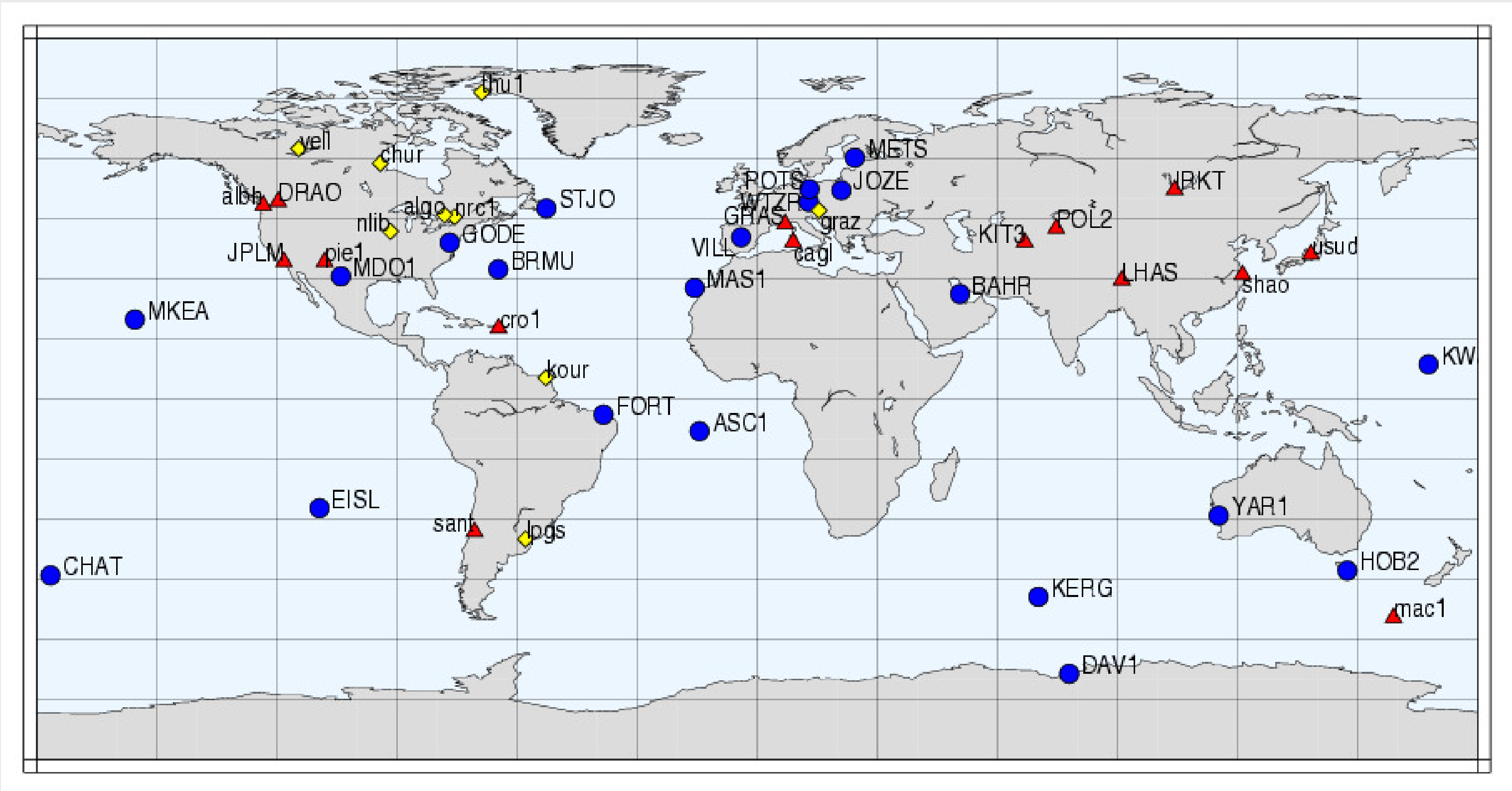
- is used for combination of sub-networks and reference frame realization.
- Combination of our regional analysis with global products from SCRIPPS.
- Satellite orbits are given loose constraints in the quasi-observations - final coordinates are not (so much) affected by a priori orbit information.



Combination to get "global solution"

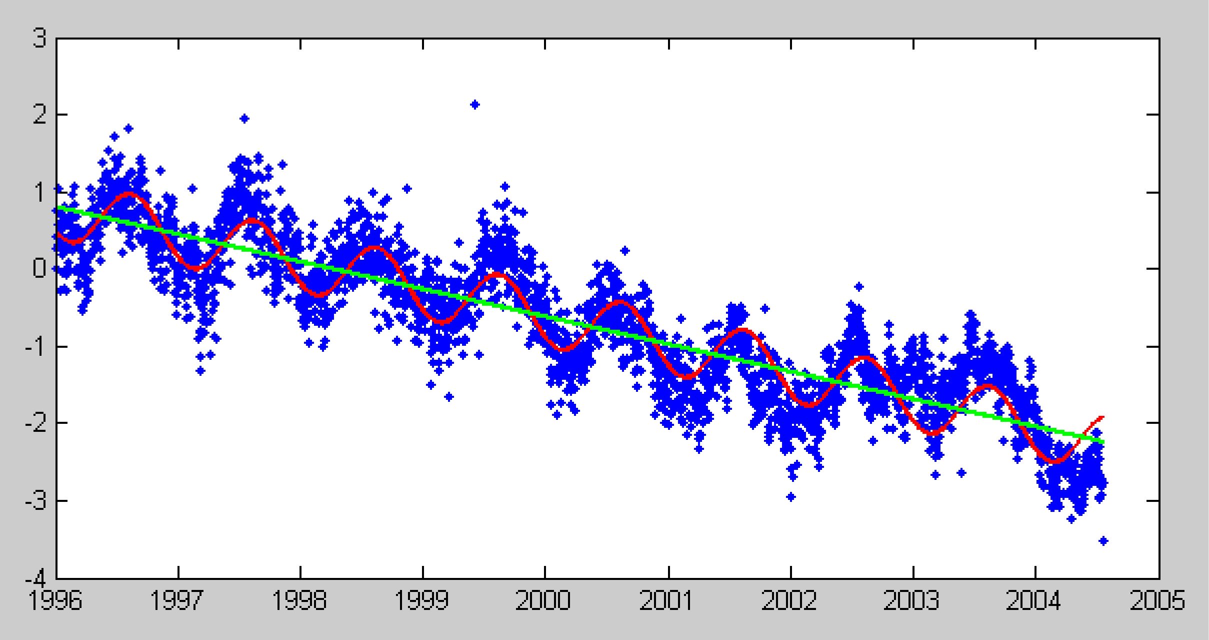


- Regional networks combined with global networks of "quasi-observations" from SOPAC
- stabilize to daily solutions in ITRF2000
- 44 "good" ITRF2000 stations used for stabilization
- 3 transl. + 3 rot. + 1 scale (daily)



The scale in the stabilization

(ppb)

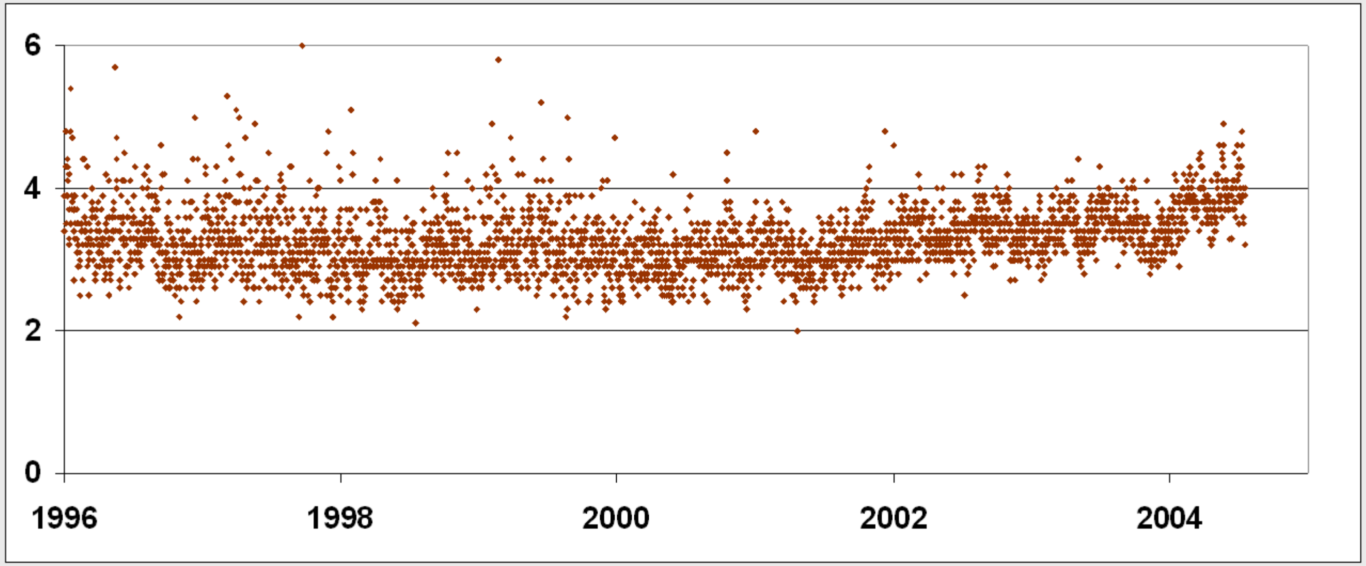


Periodic effects in GPS time series

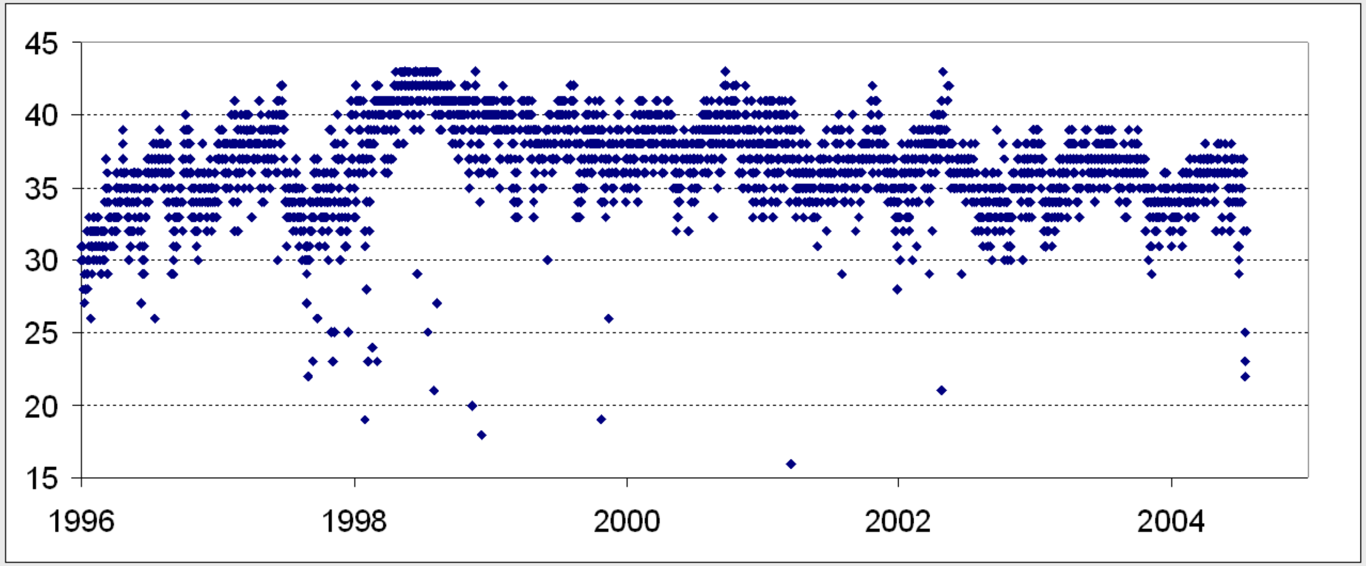
- Atmospheric mass loading
- Non-tidal ocean mass loading
- Snow and soil moisture mass loading
- Bedrock thermal expansion
- Glacier surge and internal ice flow
- Atmospheric modeling errors
- Phase center modeling and environmental influences

Result of stabilization

Post-fit RMS (mm)

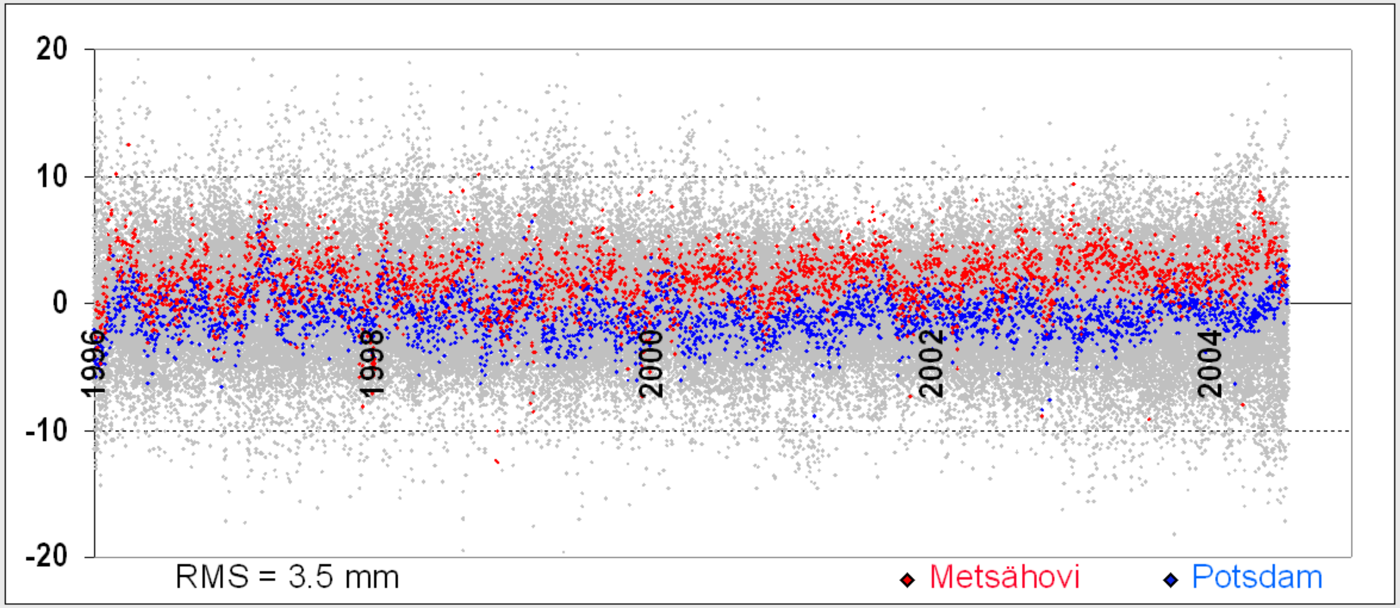


Number of sites used for stabilization

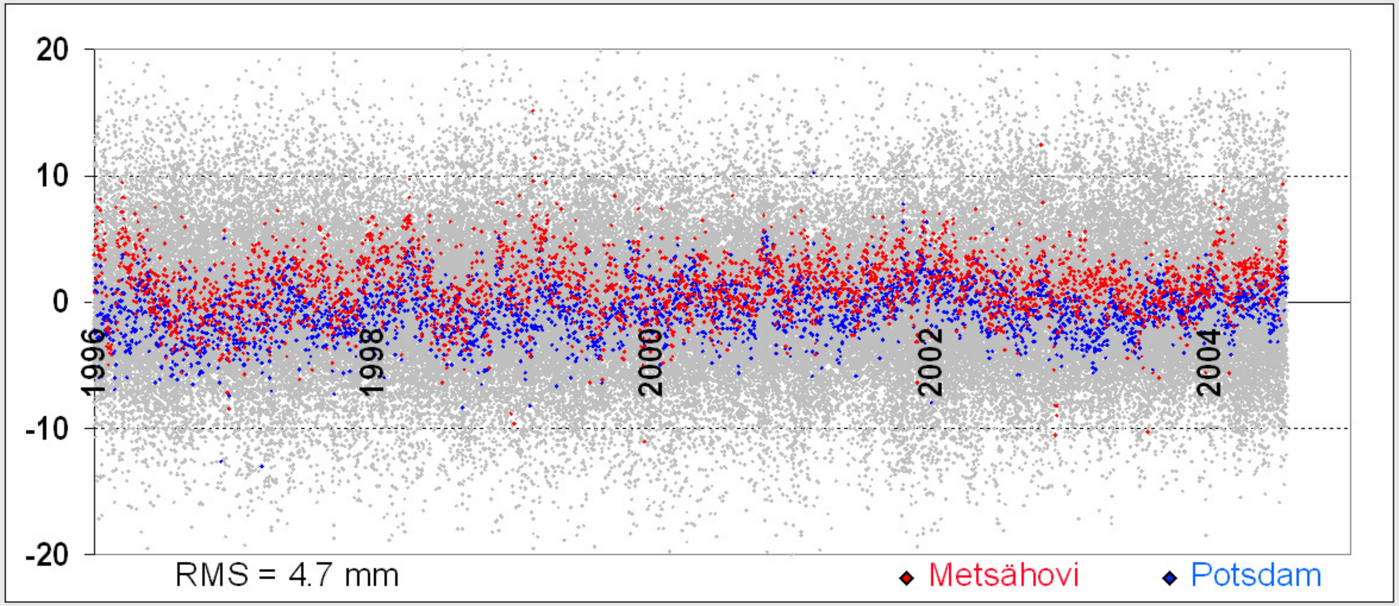


Residuals at stabilization sites

North (mm)



East (mm)



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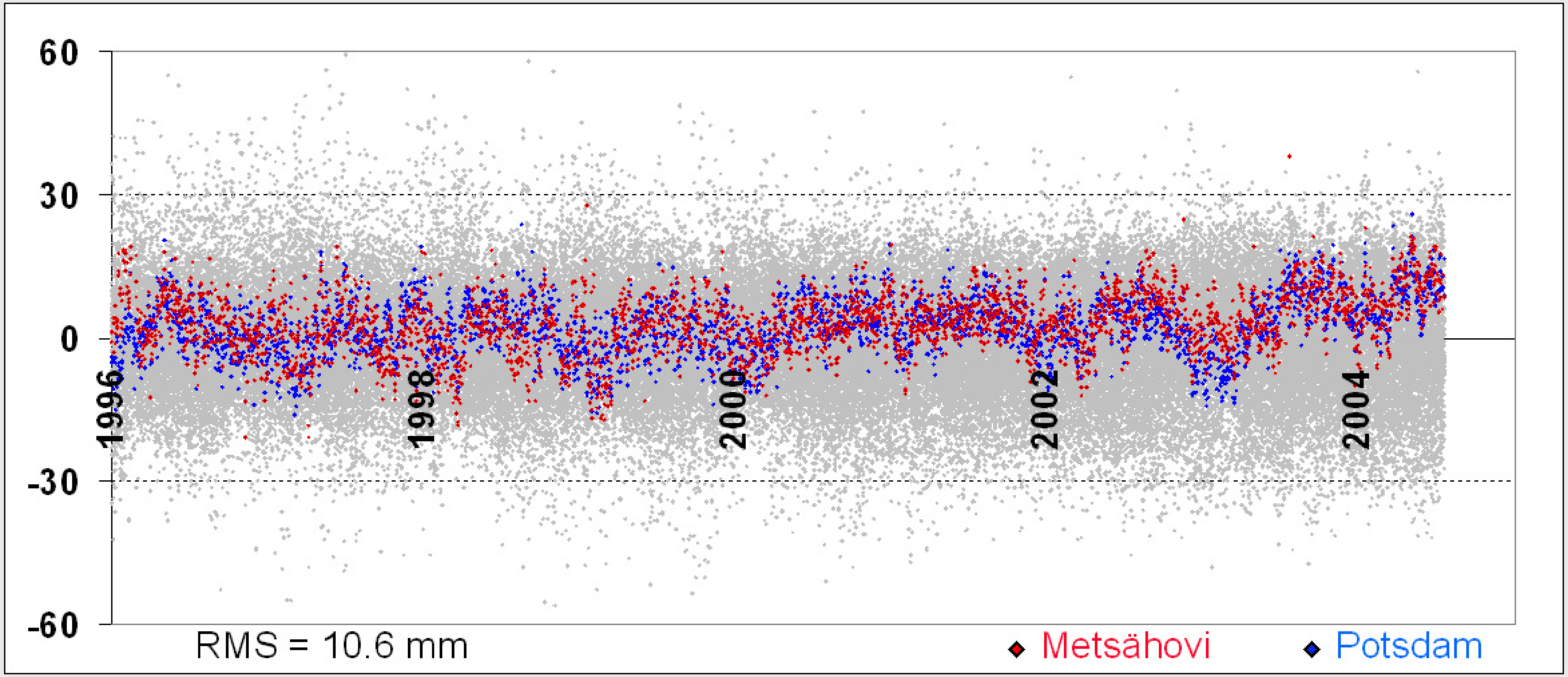
Residuals at stabilization sites

Up component (mm)



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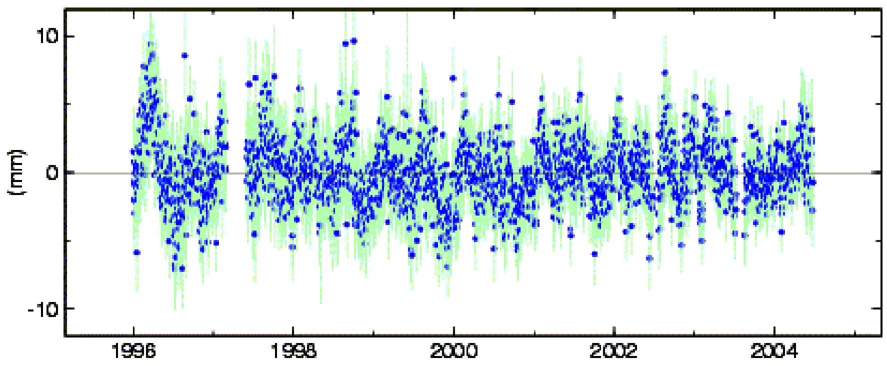
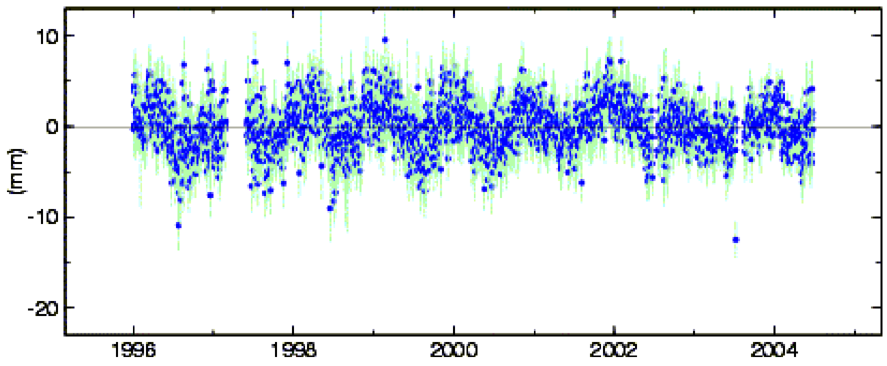
Time series of GPS positions before editing

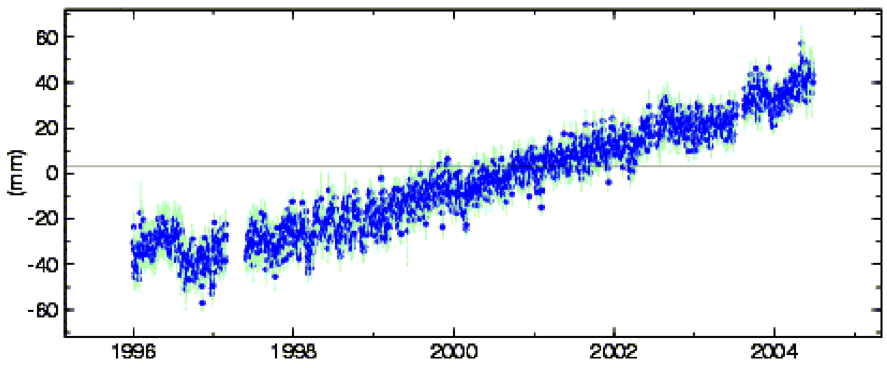
UMEO North Offset 7077486.006 m
rate(mm/yr)= 13.25 ± 0.02 nrms= 0.95 wrms= 2.0 mm # 2879



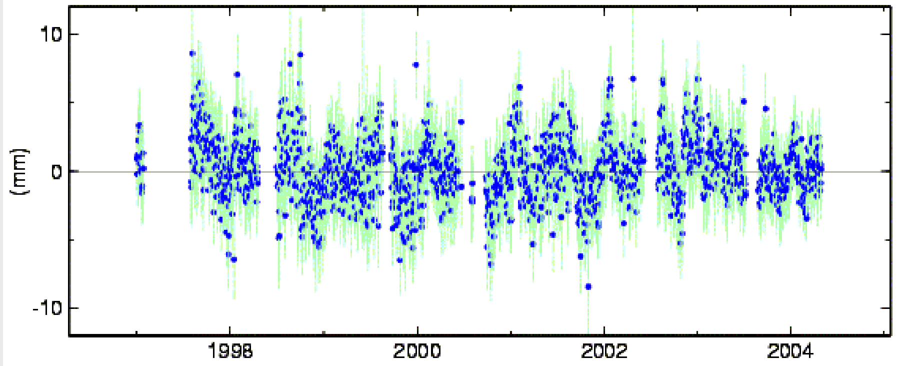
UMEO East Offset 966403.051 m
rate(mm/yr)= 17.38 ± 0.02 nrms= 1.00 wrms= 2.3 mm # 2879



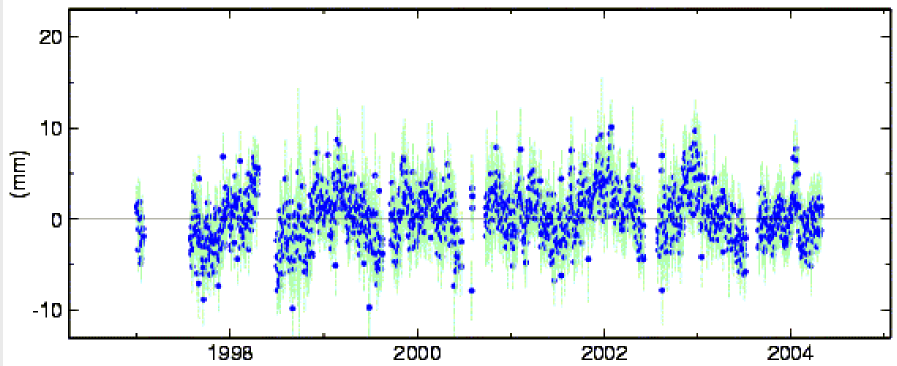
UMEO Up Offset 54.544 m
wmean(mm)= 3.40 ± 0.10 nrms= 4.46 wrms= 23.3 mm # 2879



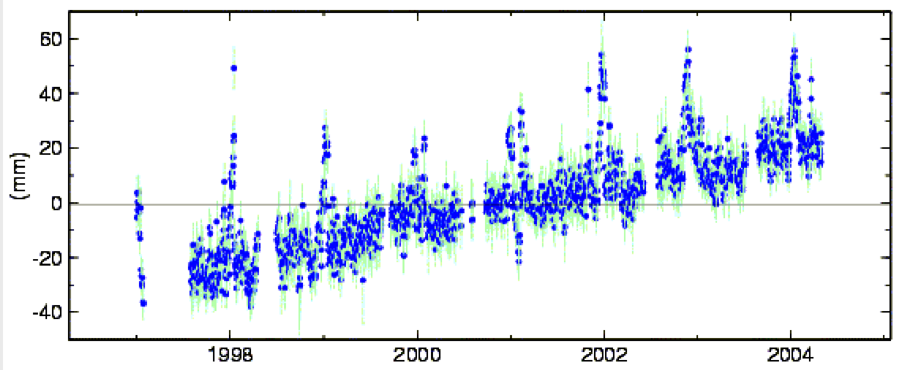
KIVE North Offset 6993076.287 m
rate(mm/yr)= 11.85 ± 0.03 nrms= 0.81 wrms= 2.0 mm # 1916



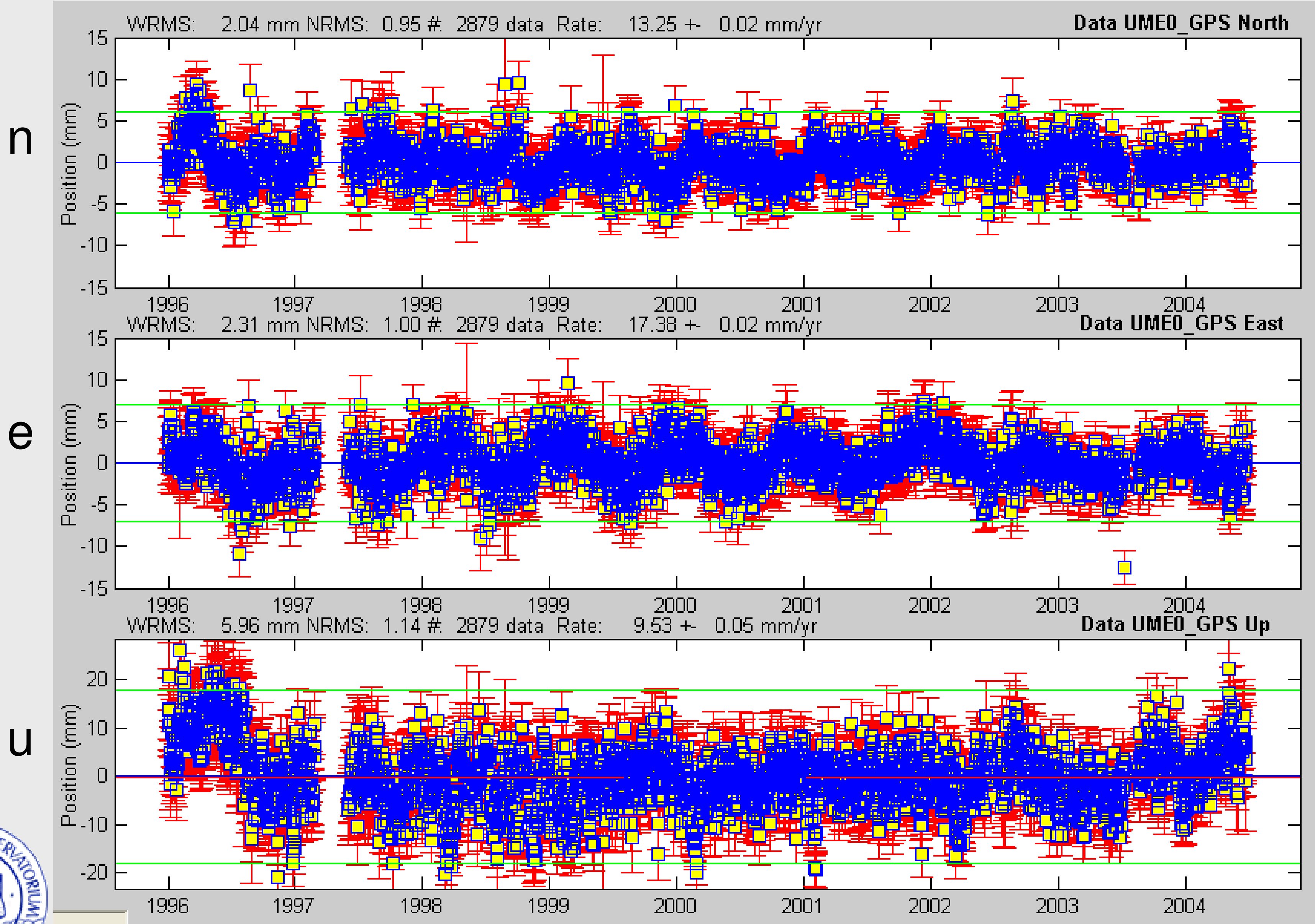
KIVE East Offset 1306992.748 m
rate(mm/yr)= 19.80 ± 0.03 nrms= 0.96 wrms= 2.6 mm # 1916



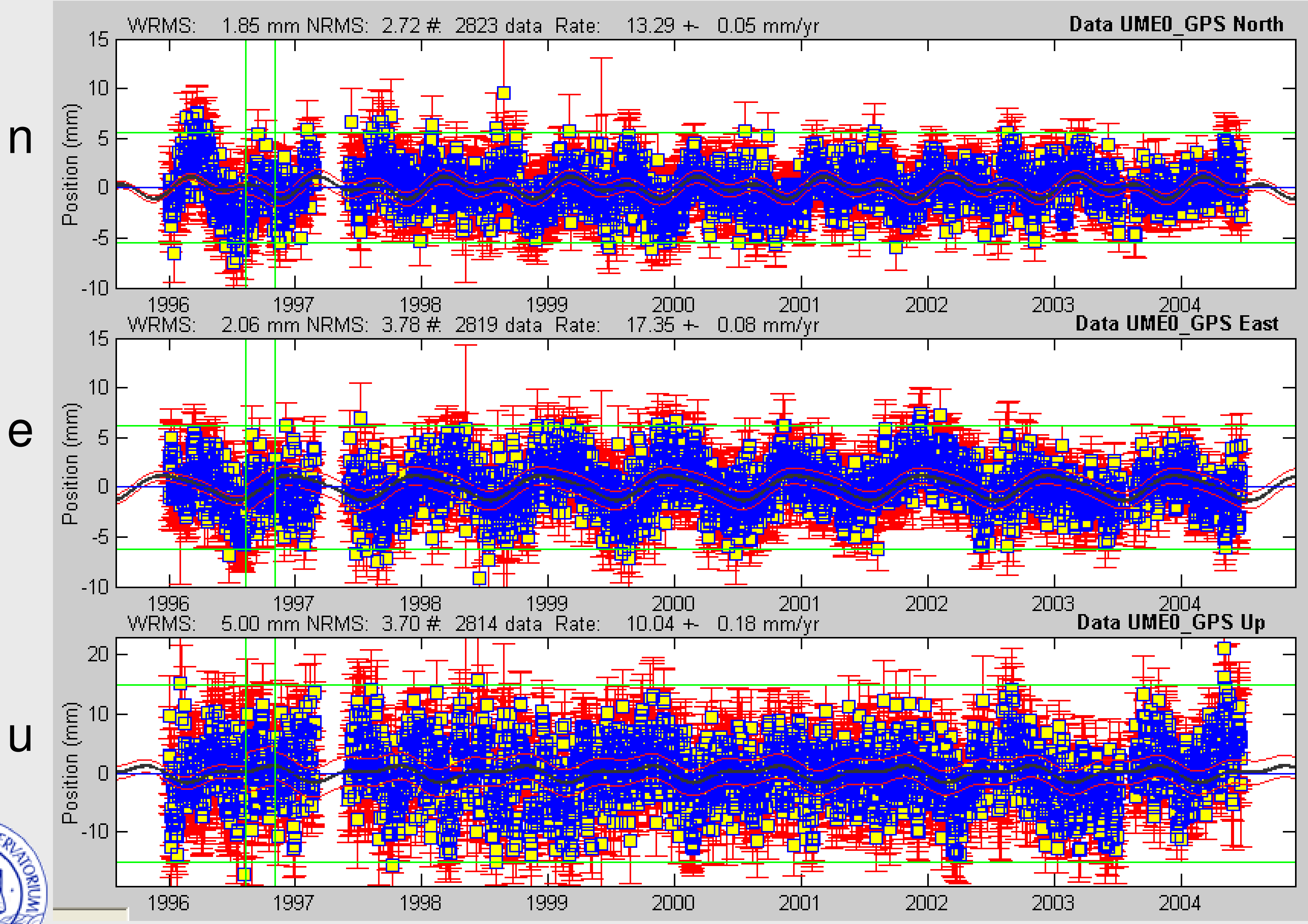
KIVE Up Offset 216.303 m
wmean(mm)= -0.51 ± 0.15 nrms= 2.64 wrms= 17.5 mm # 1916



Time series of Umeå



Time series of Umeå: seasonal cycles, realistic σ



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Estimating realistic velocity uncertainties

Least square solution

$$\hat{X} = (A^T C^{-1} A)^{-1} A^T C^{-1} Y$$

$$\hat{C}_X = \hat{\sigma}_0^2 (A^T C^{-1} A)^{-1}$$

Estimated σ_0^2

$$\hat{\sigma}_0^2 = \frac{V^T C^{-1} V}{N - np}$$

Assume 1st order GM process

$$v(i) = a * v(i-1) + w(i); \quad 0 < a < 1$$

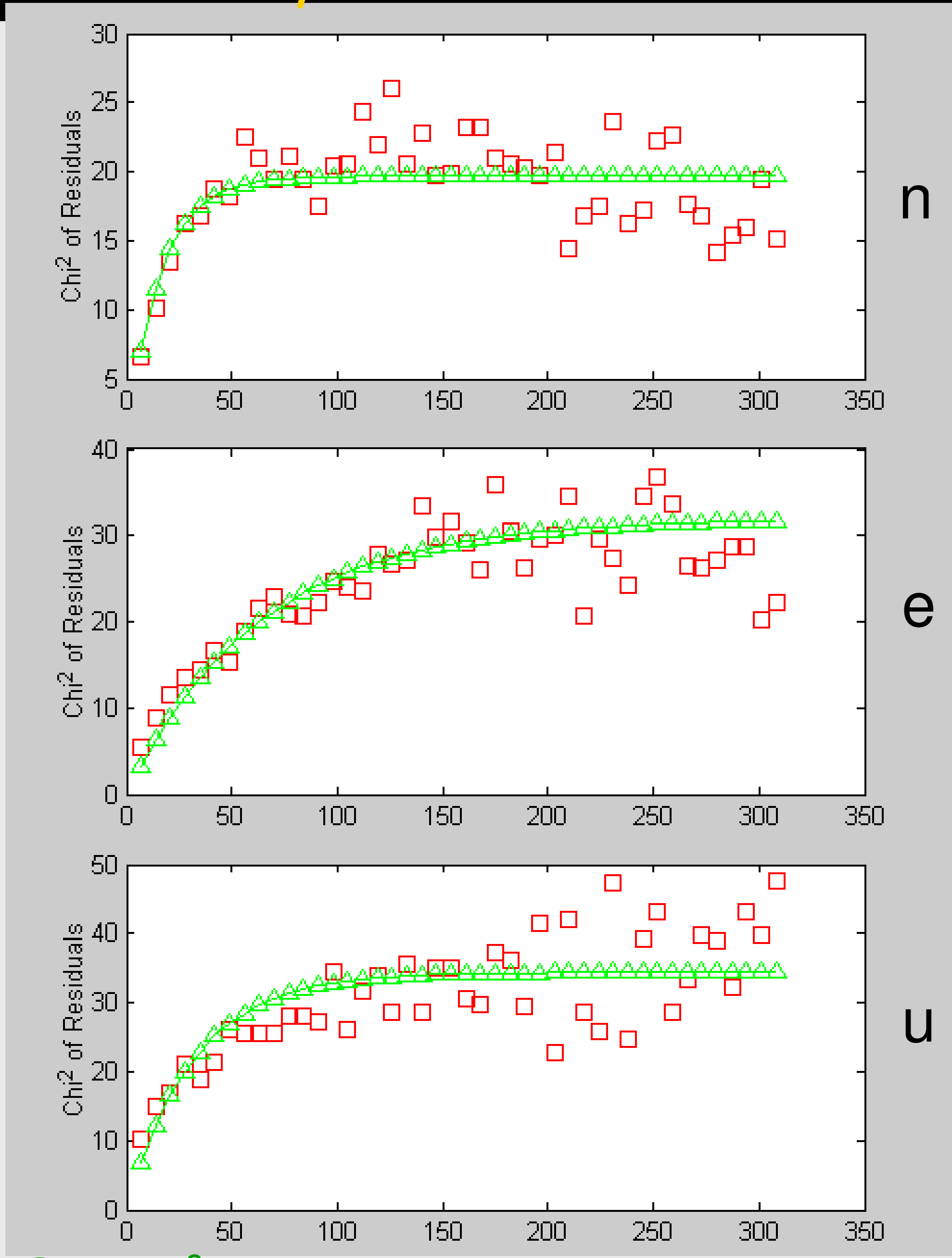
Compute weighted means of the residuals, including weights for the means;
- then compute weighted scatter of the weighted means

$$chi^2/dof \text{ of mean} \sim \alpha \times (1\text{-exp}(-m/\tau))$$

$$new\, \hat{\sigma}_0^2 = \hat{\sigma}_0^2 \times \alpha$$

Averaging time

correlation time parameter

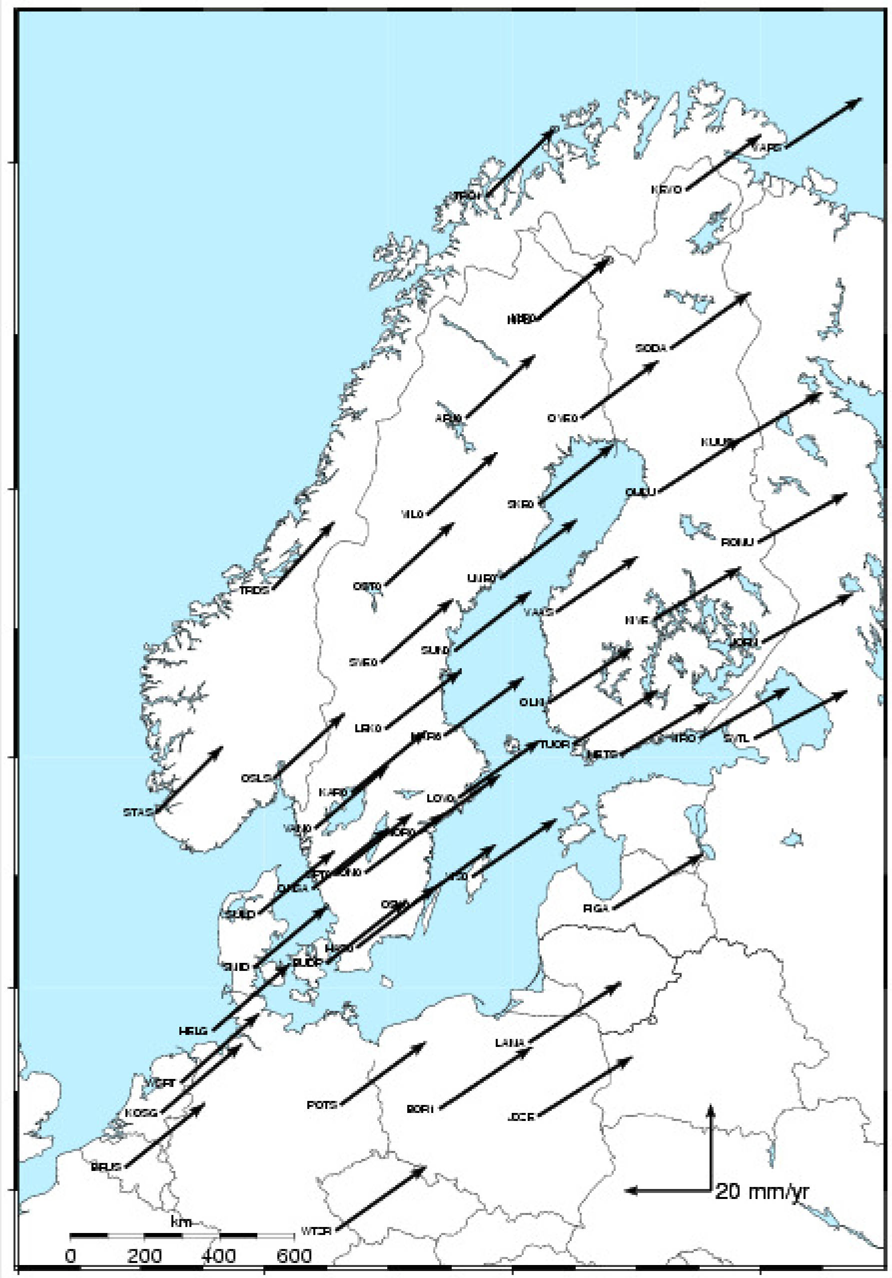


Ex. Umeå Averaging time (days)

Derived horizontal velocity field

Horizontal velocities in ITRF2000

we see the tectonic motion of the Eurasia tectonic plate



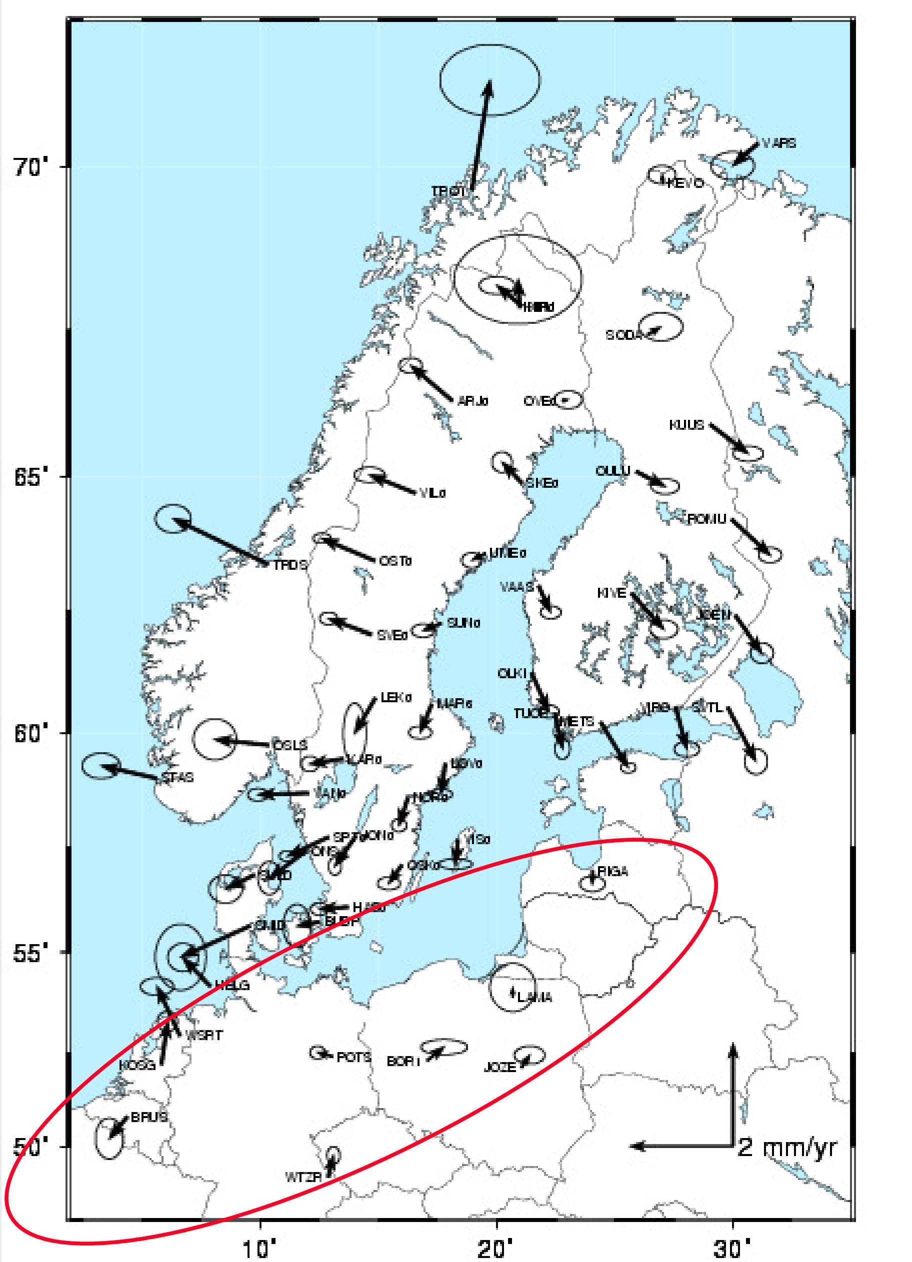
Derived velocity field relative to Eurasia

The Eurasia plate tectonic motion has been removed using the ITRF2000 Euler pole for Europe

RMS of velocity at 8 “stable European sites” 0.5 mm/yr

In case of:
- no deformations
- correct Euler pole fore Europe (formal error ~0.6 mm/yr)
- and no errors in the GPS derived velocity field

… the RMS value should have been =0



Comparing with previous BIFROST and a model

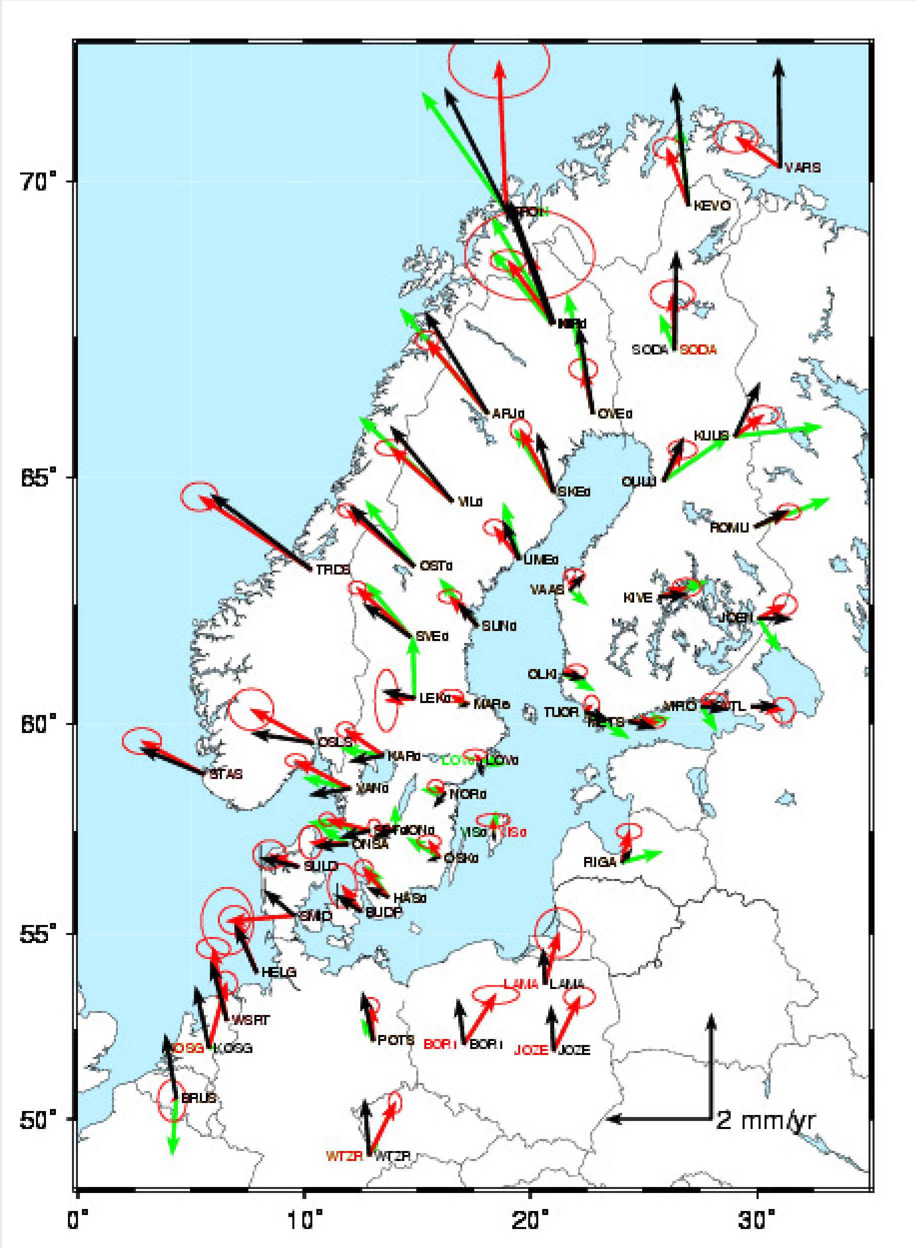
The winter edited version of previous BIFROST solution
(Johansson et al 2002, Scherneck et al 2002)

GIA model from Milne et al (2001)
Ice history model from Lambeck
120 km lithosphere,
upper mantle visc. $8{\times}10^{20}$ Pas
lower mantle visc. $1{\times}10^{22}$ Pas

This solution

Gamit to model:
0.5 mm/yr (1σ) using all 53 sites

(BRUS, KIRU, KIR0, KEVO, TRO1, VARS) >1 mm/yr



Vertical velocity

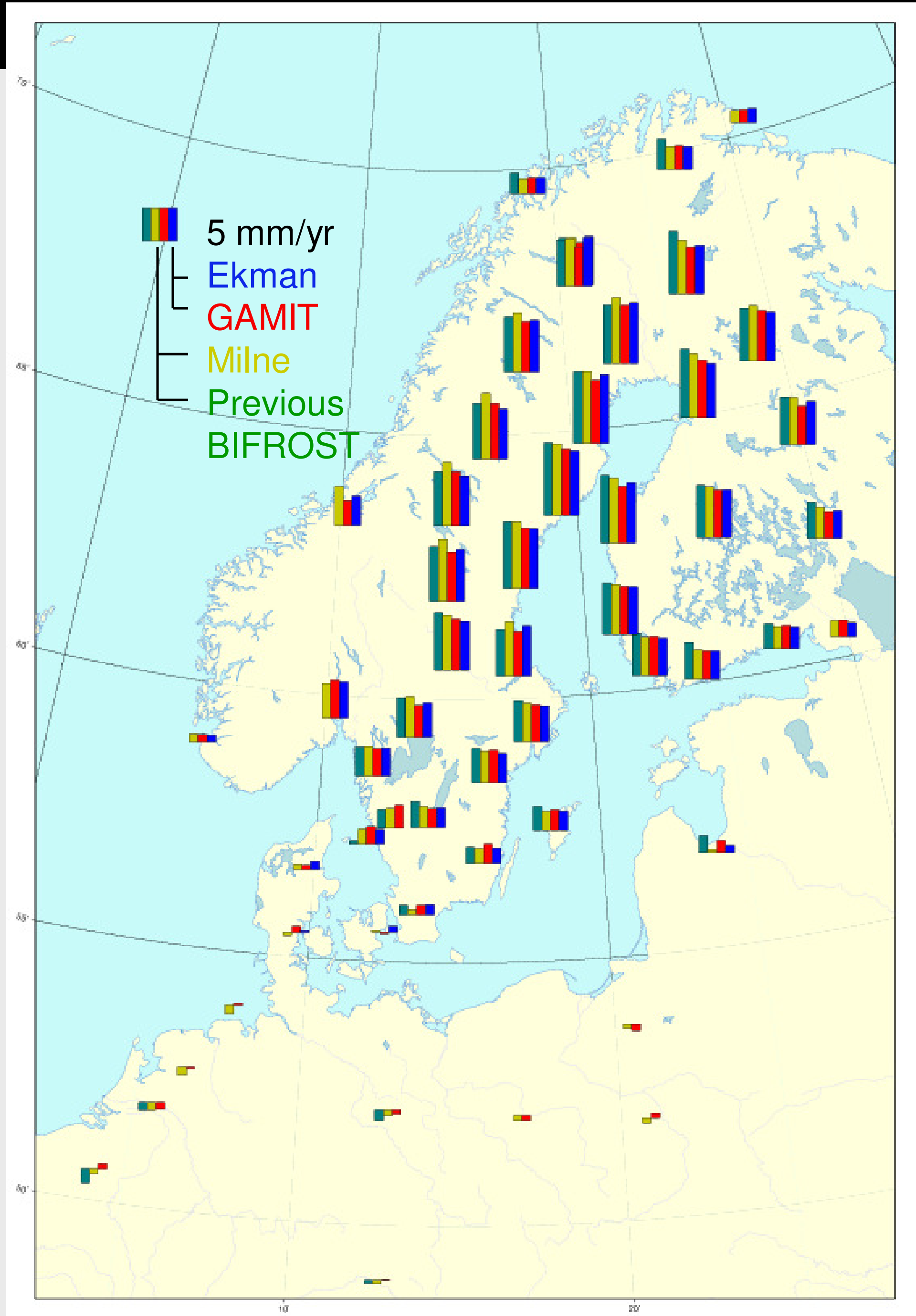
Comparing different land uplift estimates

The winter edited version of previous BIFROST solution
(Johansson et al 2002, Scherneck et al 2002)

GIA model from Milne et al (2001)
Ice history model from Lambeck
120 km lithosphere,
upper mantle visc. $8{\times}10^{20}$ Pas
lower mantle visc. $1{\times}10^{22}$ Pas

This solution

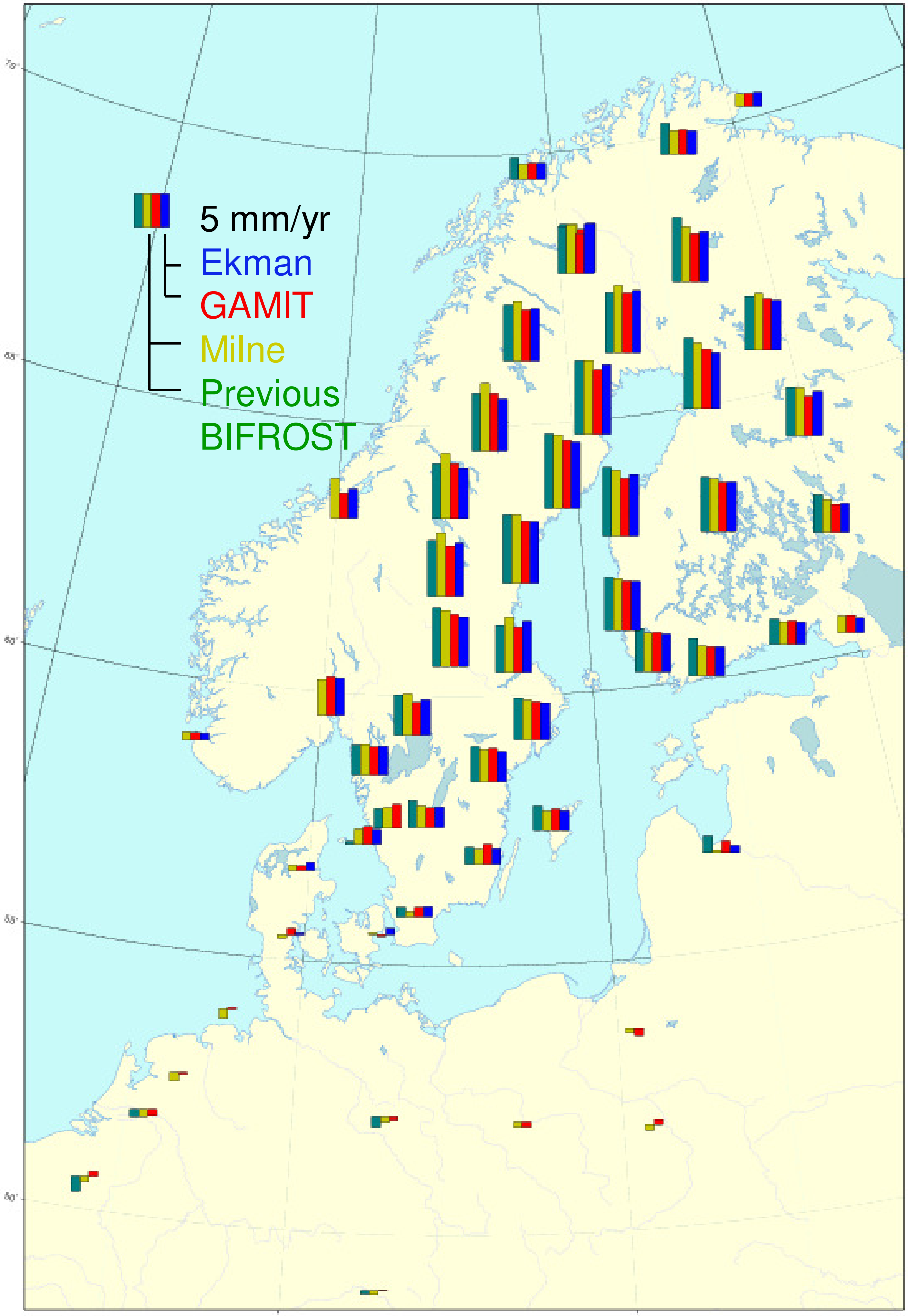
Ekman (1998) based on:
- mareographs and levellings,
- 1.2 mm/yr eustatic sea level rise
- change of the geoid based on Ekman & Mäkinen (1998)



Vertical velocity

Differences to the GAMIT solution (mm/yr)

	mean	RMS
Previous BIFROST	0.5	1.0
Milne GIA model	0.3	0.9
Ekman	0.1	0.5
Ekman best stn.	0	0.4

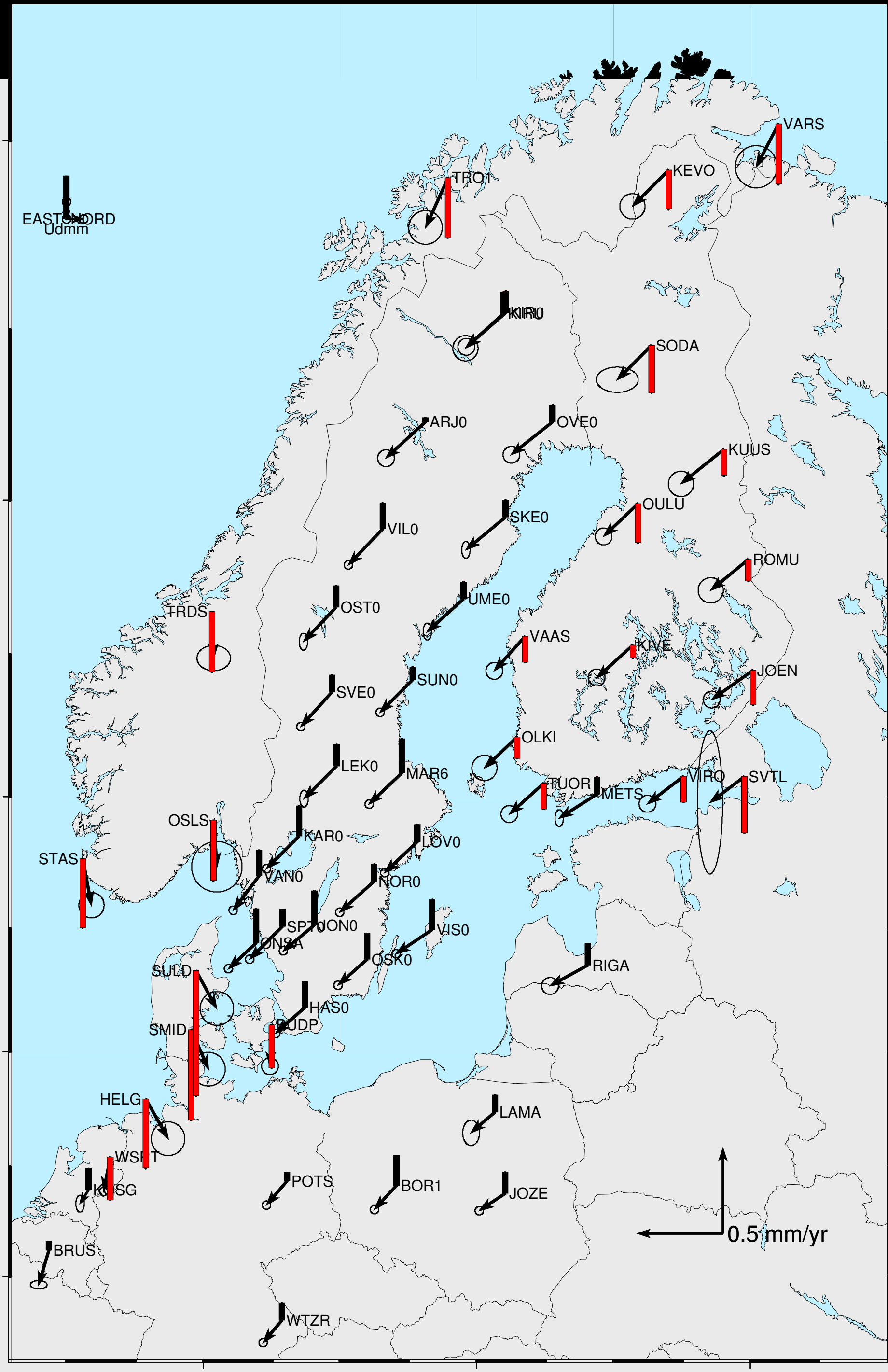


44 vs. 21 stabilization sites

Comparison between using 44 or 21 sites for reference frame realization,

Horizontal: ~ 0.2 mm/yr
Vertical: ~ 0.1 mm/yr

However, systematic differences due to length of time series.



Conclusion and outlook

- A new GPS derived 3D velocity field for the Fennoscandian GIA area presented
- Global adaptation to the ITRF2000 velocity field at sub-mm/yr level
- external assessment indicate
  - 0.2 mm/yr level (1σ) horizontal
  - 0.5 mm/yr level (1σ) vertically

EUREF implications:

- Vertical station velocities used in land uplift modeling for Nordic leveling work (Mäkinen, session 5)
- The signal (10 mm/yr) of the Fennoscandia GIA process can be modeled to 1mm/yr (90%), and better models foreseen;
- Intraplate deformations should be considered in future ETRS89 realizations, but is 1989 a good target epoch for this (Norway 1995, Finland 1997, Sweden 1999.5)??

Next step:

- GPS analysis: 1993 to 2005, absolute calibrated antennas, higher order ionosphere effects, GIPSY (PPP and amb. Fix.), extended noise analysis…
- adjusting the GIA model using the improved velocity field.

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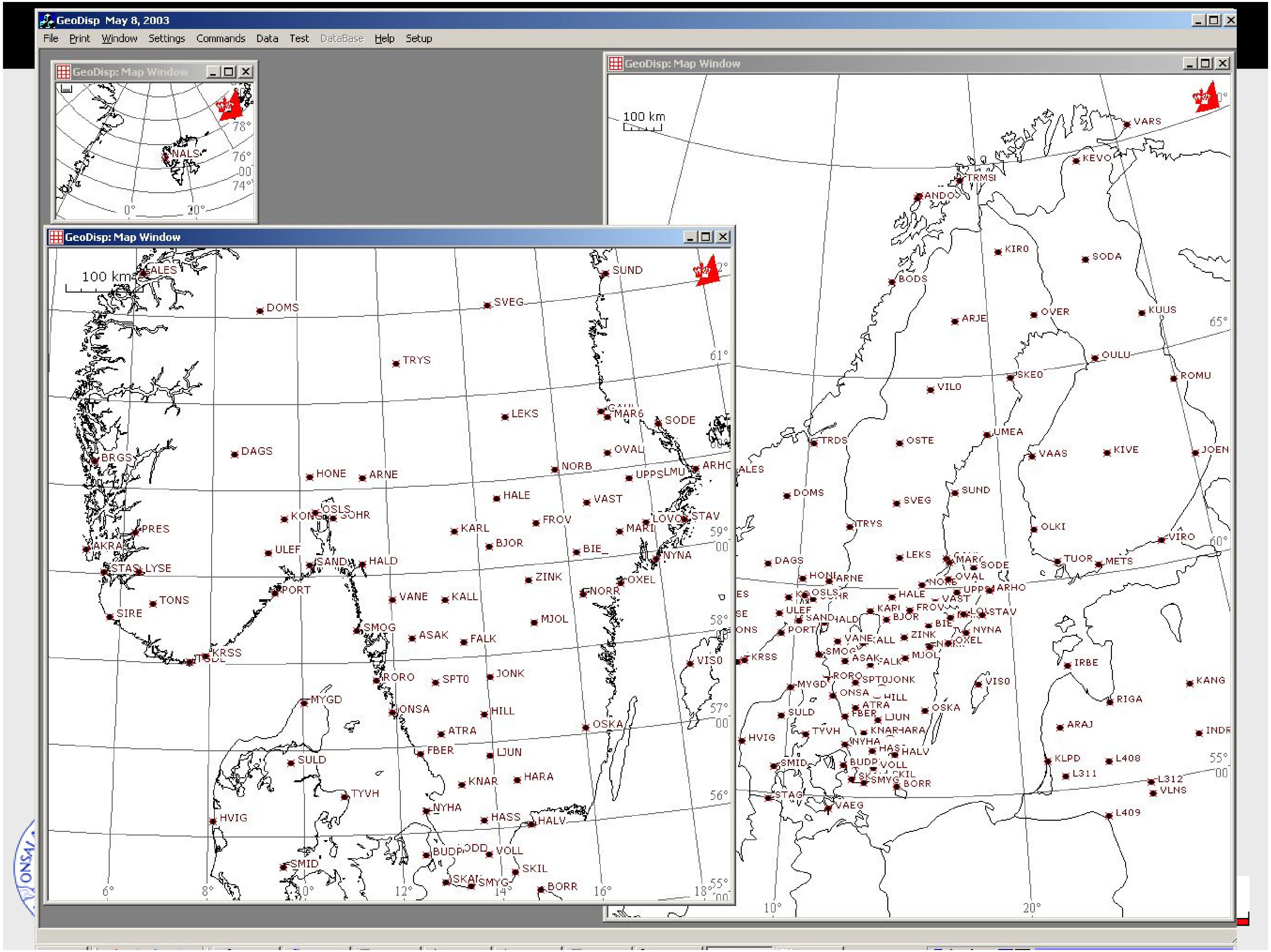
GeoDisp May 8, 2003
File Print Window Settings Commands Data Test DataBase Help Setup
GeoDisp: Map Window
NALS
78°
76°
74°
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GeoDisp: Map Window
100 km
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VLNS
L409
STAG
VAEG
10°
20°

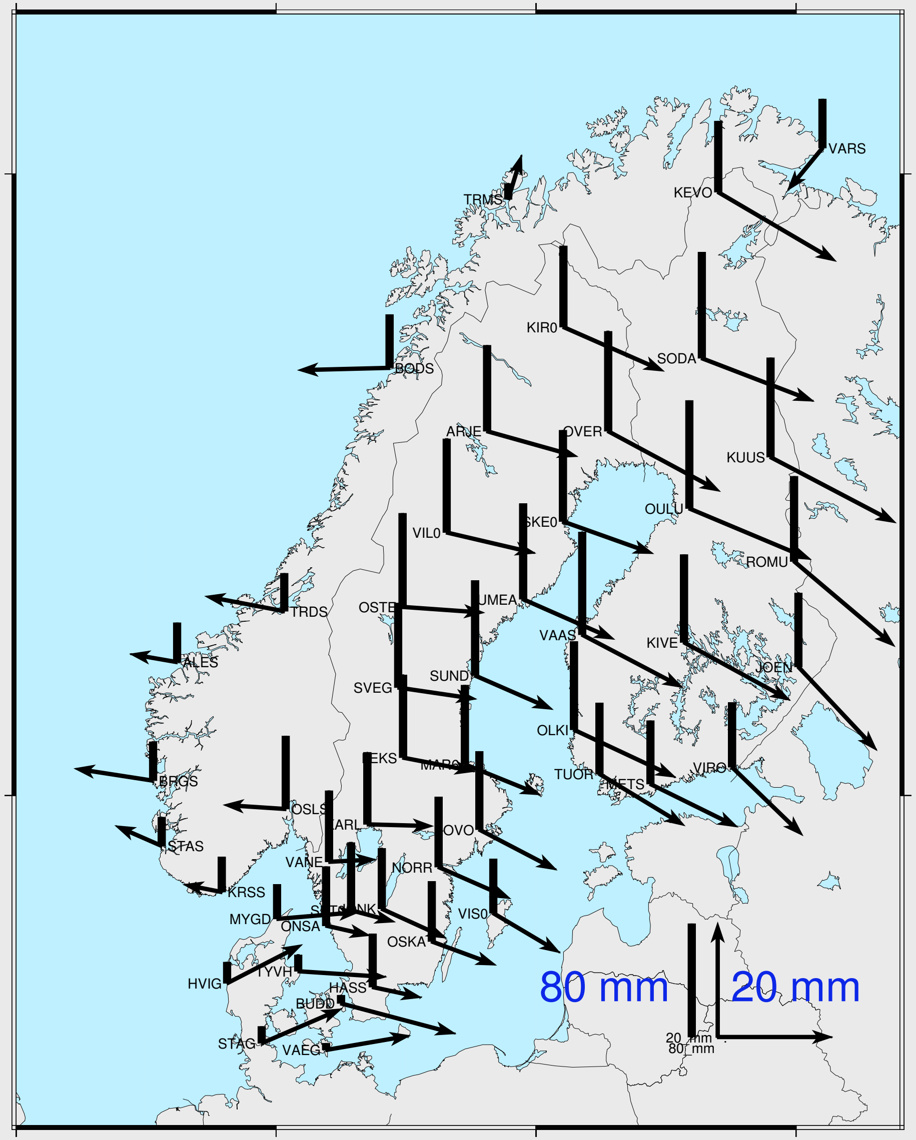
NKG 2003 vs. official ETRS89 realizations

The NKG 2003 GPS campaign

- in ETRS89
  (Boucher & Altamimi MEMO)

- compared to official ETRS89
  realizations

RMS n = 10 mm
RMS e = 19 mm
RMS u = 52 mm



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NKG 2003 vs. official ETRS89 (with internal deformations)

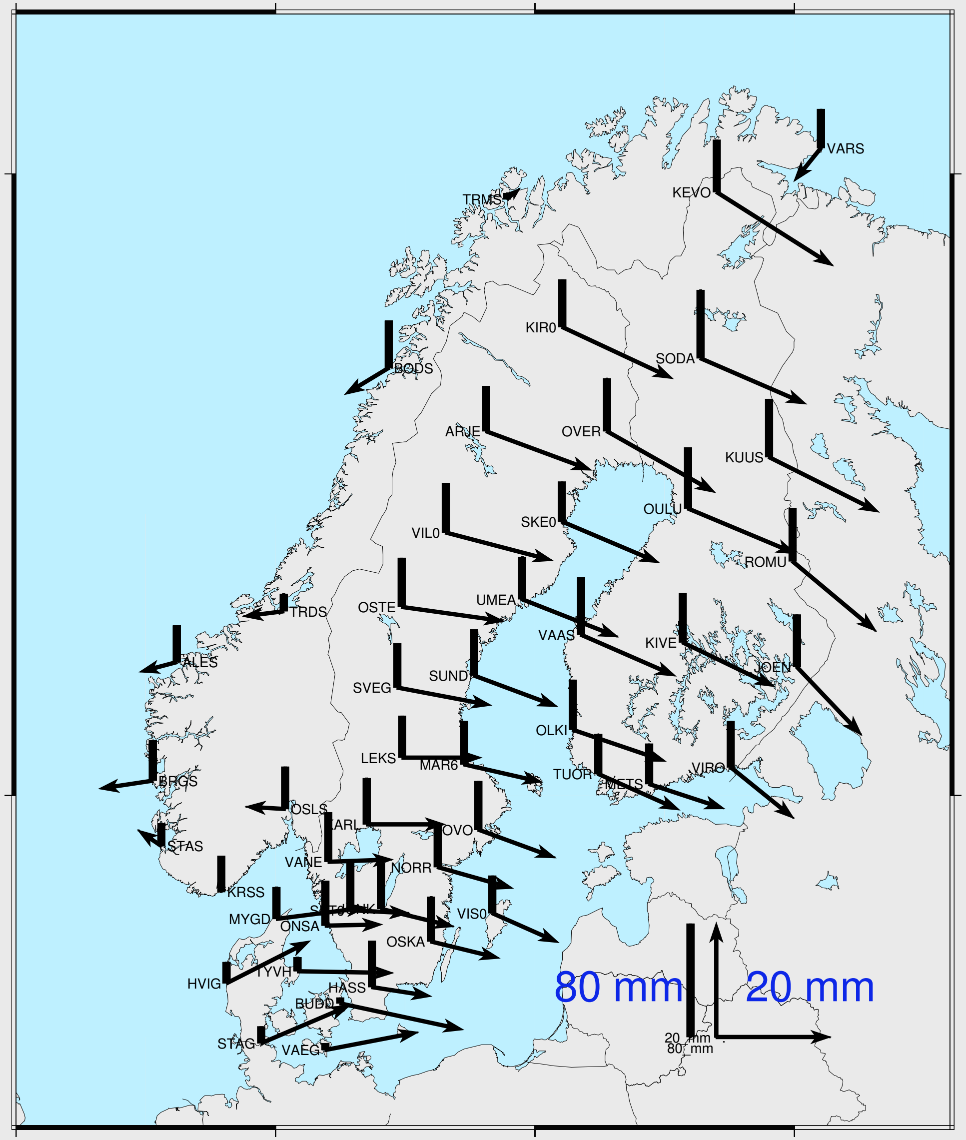
The NKG 2003 GPS campaign

- in ETRS89
  (Boucher & Altamimi MEMO)

- internal deformations reduced
  to year 2000 using computed
  station velocities

- compared to official ETRS89
  realizations

RMS n = 6 mm
RMS e = 14 mm
RMS u = 30 mm



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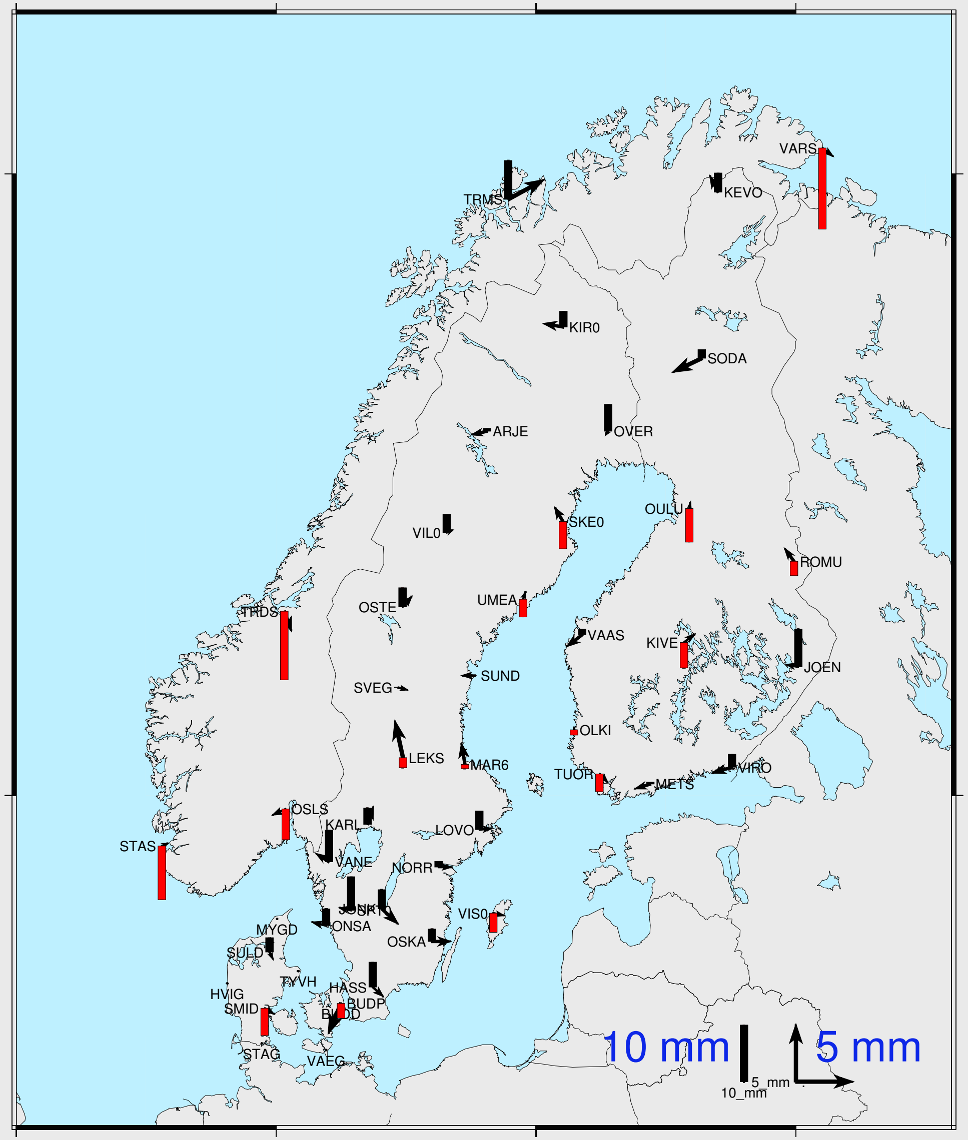
NKG 2003 vs. SWEREF 99 (station velocities 2003.75 – 1999.5)

The NKG 2003 GPS campaign

- internal deformations reduced to 1999.5 using computed station velocities

- transformed (7-par.) to the SWEREF 99 GPS campaign

RMS n = 1.1mm
RMS e = 1.2 mm
RMS u = 5.2 mm



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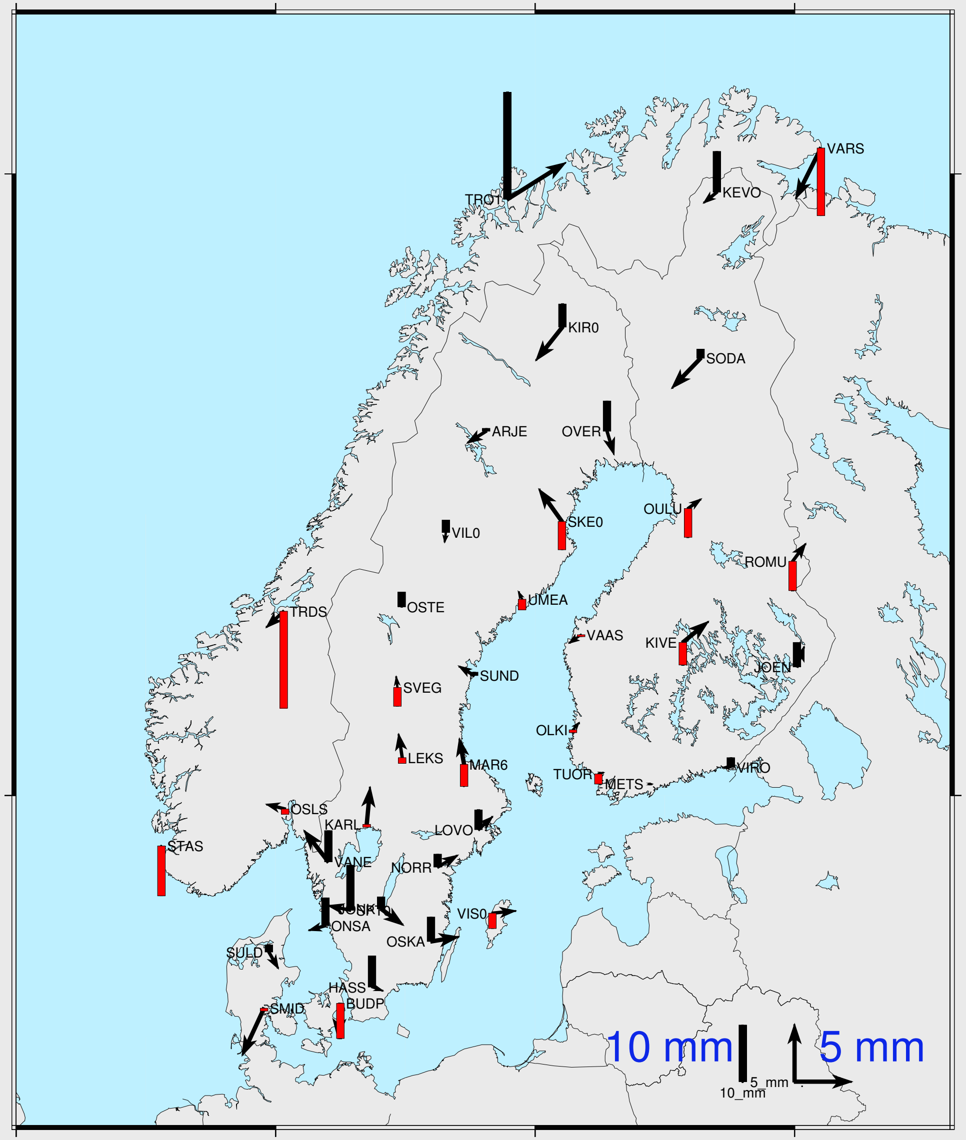
NKG 2003 vs. SWEREF 99 (GIA model 2003.75 - 1999.5)

The NKG 2003 GPS campaign

- internal deformations reduced to 1999.5 using GIA model (Milne et al 2001)

- transformed (7-par.) to the SWEREF 99 GPS campaign

RMS n = 1.9 mm
RMS e = 1.6 mm
RMS u = 5.9 mm



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EUREF implications:

- Correction for internal deformations needed
- Due to (ignored) internal deformations,
  and height system epoch of year 2000:
  - an epoch of intraplate deformations of ETRS89 at year 2000 may better suit users of ETRS89

Next step:

- GPS analysis: 1993 to 2005, absolute calibrated antennas, higher order ionosphere effects, GIPSY (PPP and amb. Fix.)
- adjusting the GIA model using the improved velocity field.

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