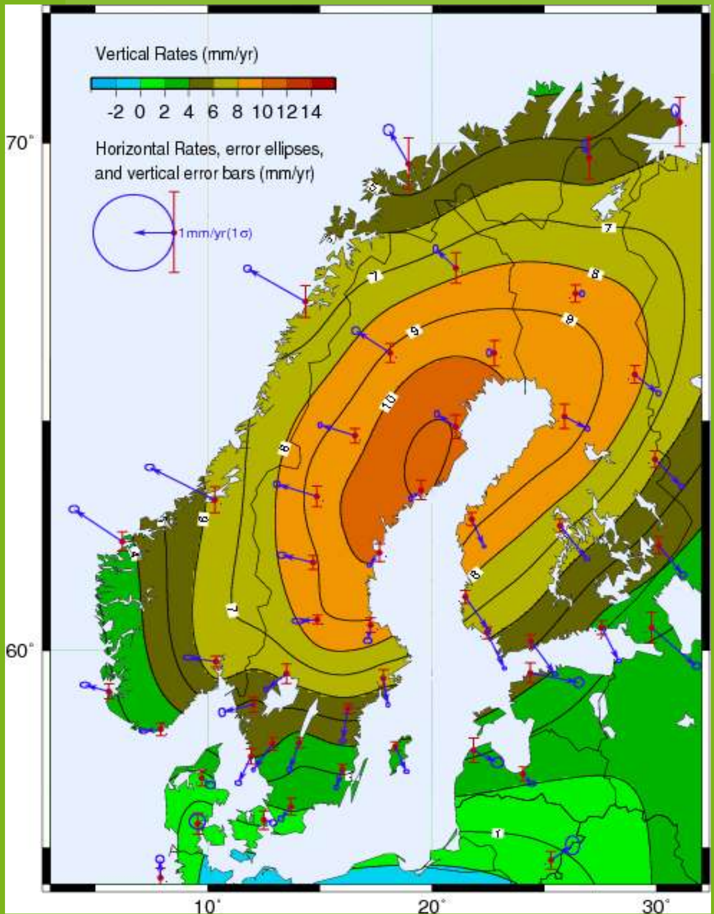
The search for the true crustal deformations in Fennoscandia from BIFROST



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CHALMERS

SP

LANTMÄTERIET

Outline

- The BIFROST GPS network
- The most recent BIFROST velocity solutions available
  - GPS analysis
  - Reference frame realization
  - Time series analysis and data editing
  - Evaluation of the velocity field and comparison to GIA model
- Considerations regarding modernization of the observation system
- Conclusions

BIFROST

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

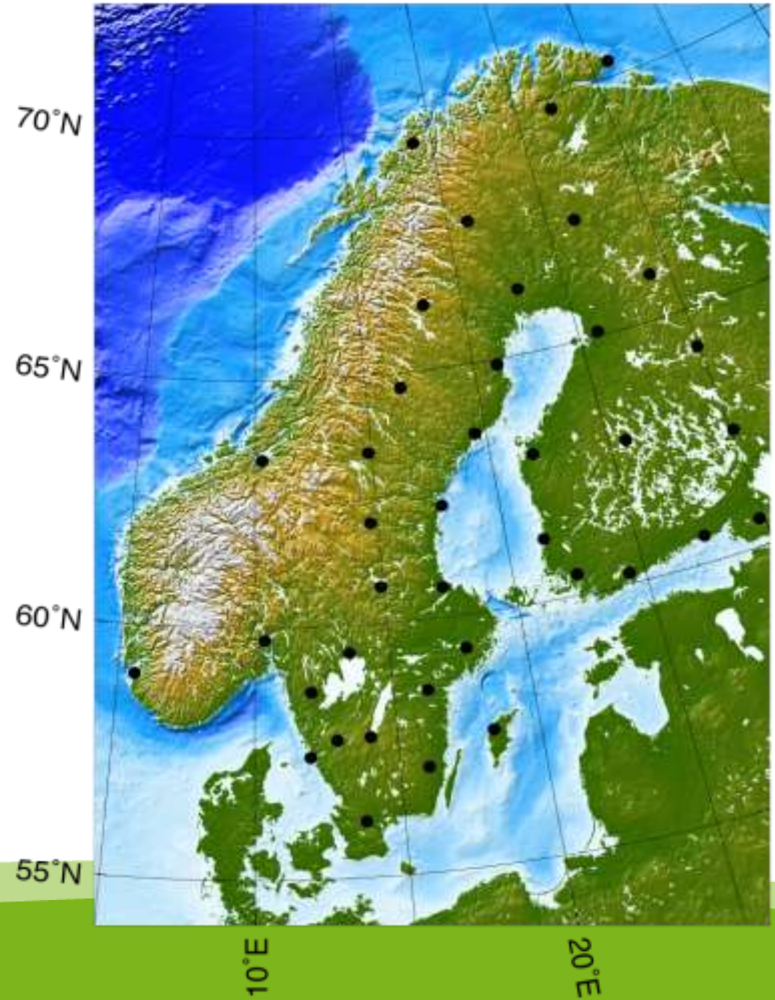
Determination of crustal deformations in Fennoscandia

First determination of the land uplift related to sea level
⇒ **apparent land uplift**

Determination of **horizontal rates** and **absolute land uplift** values;
⇒the purpose of **BIFROST**

BIFROST Project

- Permanent GPS systems across Norway, Sweden, and Finland
- First observations 1993
- Started with 16 sites, quickly increased to about 40 sites, ~100–200 km spacing
- First 3-D map of GIA (anywhere) produced 2001
- Most recent solution > 80 stations
- Next solution (August, 2010) will include > 200 stations



Example of GNSS monuments and antenna installation in the Nordic area

SWEPOS (Sweden)

Onsala (IGS site ONSA)

FinnRef (Finland)

SatRef (Norway)

GPS analysis strategy

GAMIT / GLOBK (2007, 2010)

GAMIT (GPS analysis)

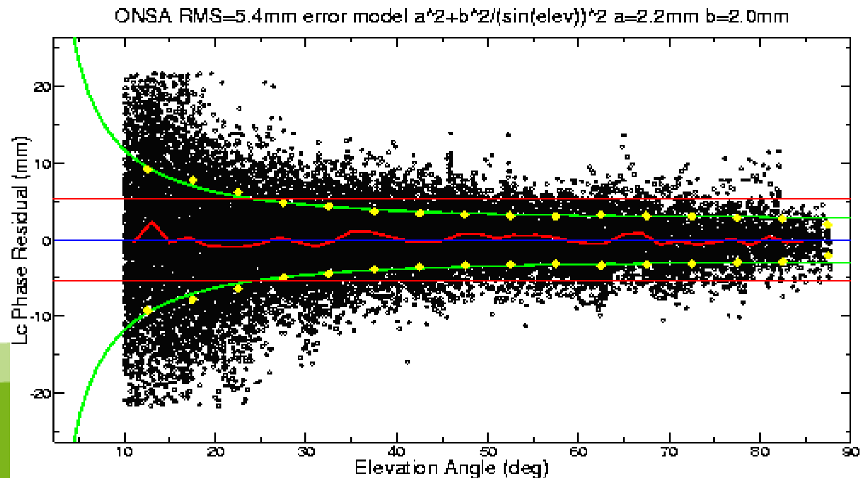
- Traditional analysis strategy
- 10° elevation cut off angle
- Trop. zenith delay & gradients
- the Niell 1996 mapping functions
- Relative antenna PCV values ("absolute" PCV not used so far)
- a priori orbits from SCRIPPS

GLOBK (combination & ref. frame)

- combination of sub-networks
- Combine the regional analysis with "complete IGS analysis" from SOPAC (GAMIT h-files).
- reference frame realization.
- Satellite orbits are given loose constraints in the quasi-observations.

GIPSY (2002, *2010*)

- Precise Point Positioning (PPP) using JPL products
- Ambiguity fixing (only 2010)
- Used to validate the GAMIT/GLOBK solution

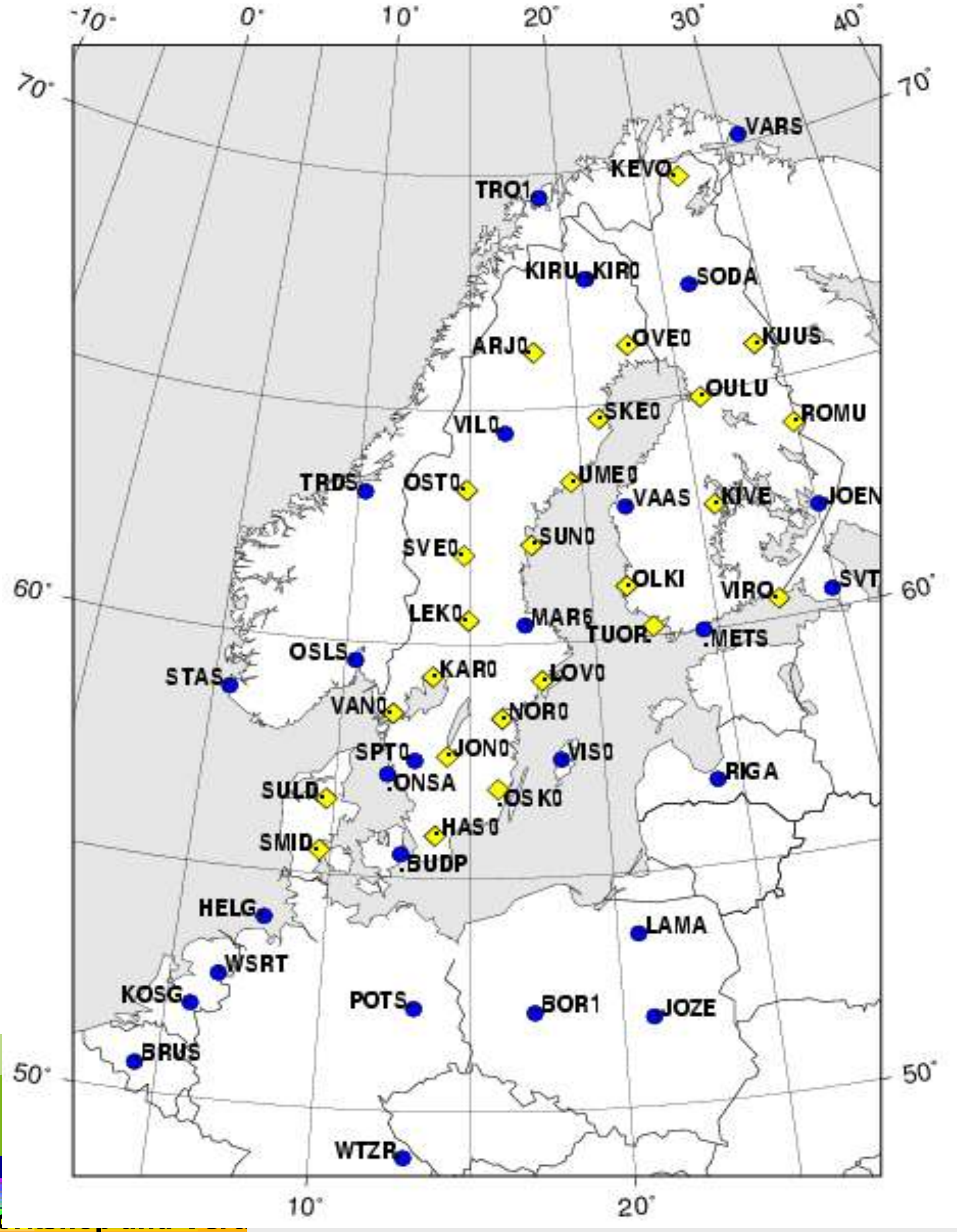


BIFROST network, GAMIT (2007)

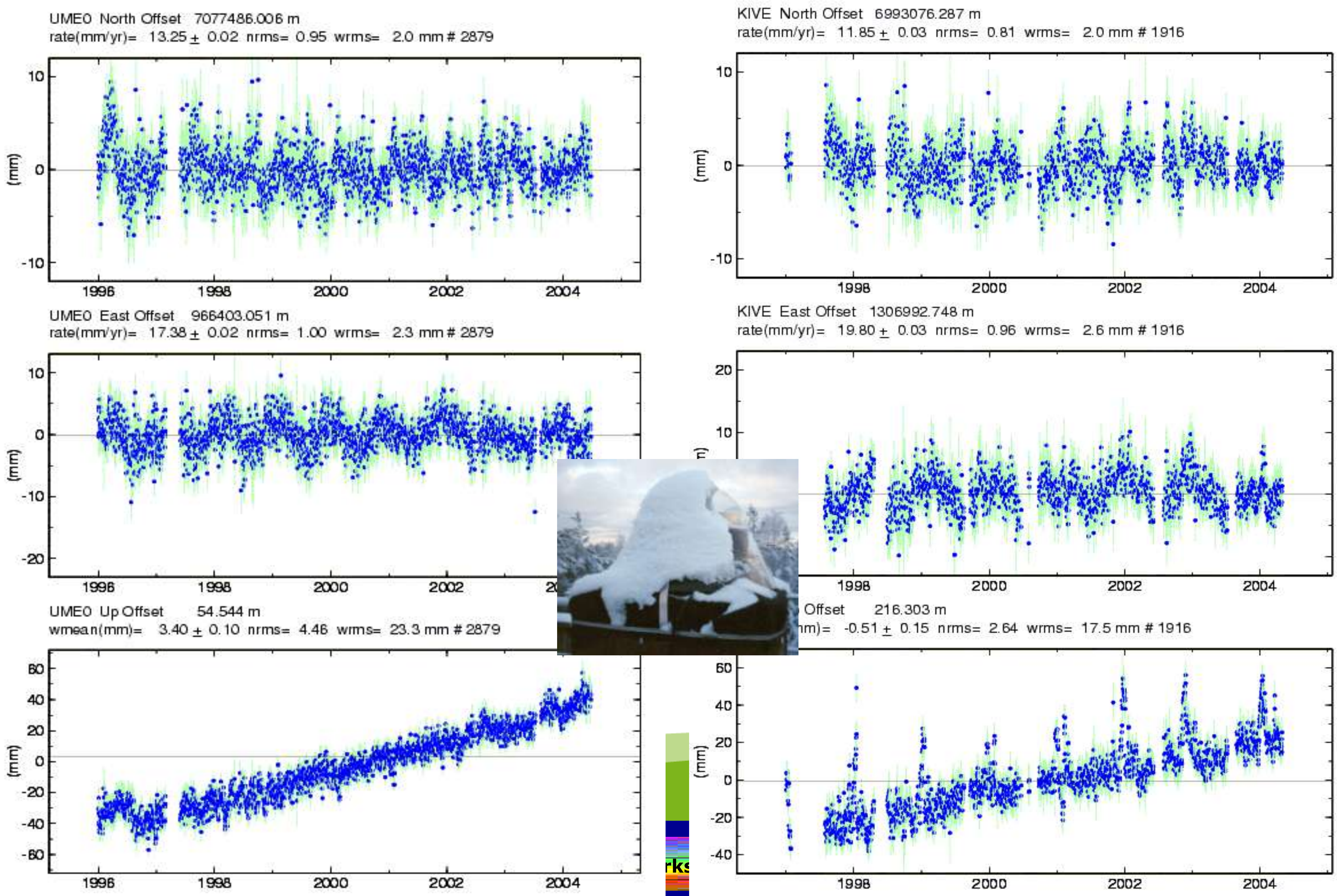
Included GPS stations (Jan 1996 – June 2004)

- EPN station in Northern Europe (blue dots •)
- Finland
- Sweden
- Norway
- Denmark

- GAMIT/GLOBK
- 53 sites + 44 global (SOPAC)
- Reported in J Geodesy 2007
- Velocities given in ITRF2000



Time series of GPS positions before editing



Comparing with previous BIFROST and GIA model

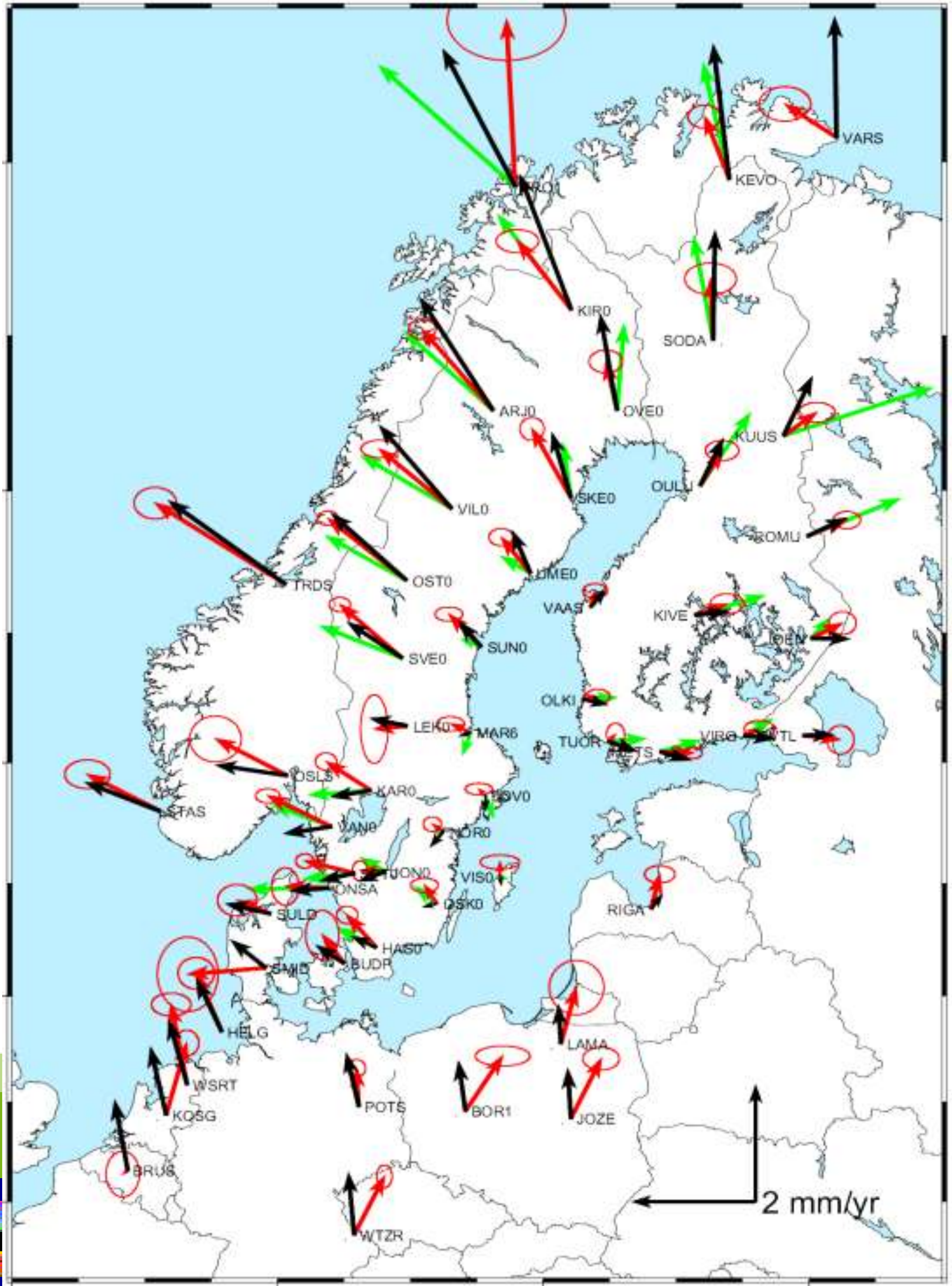
The **standard BIFROST solution** (GIPSY network solution - Johansson et al 2002, Scherneck et al 2002)

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

J Geodesy, 2007
- 1996-2004,
- GAMIT/GLOBK, ITRF2000

Gamit to model:
0.5 mm/yr (1σ) using all 53 sites
(BRUS, KIRU, KIR0, KEVO, TRO1, VARS) >**1 mm/yr**

6-par fit in velocity applied



Vertical velocity

Johansson et al 2002. JGR.

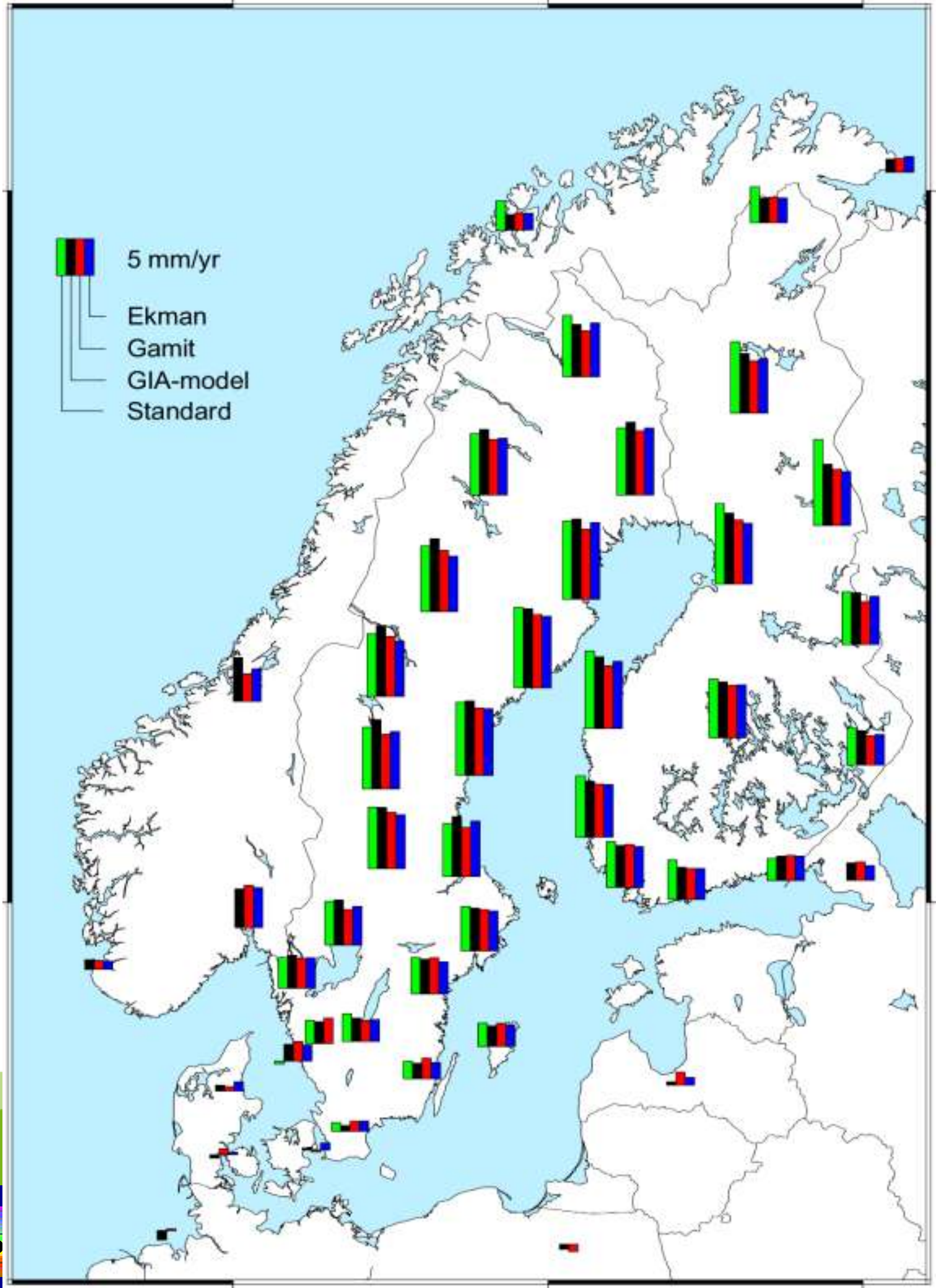
GIA model from Milne et al (2001)

This GAMIT/GLOBK solution (2007)

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

Comparison Ekman (1998) with GAMIT/GLOBK (ITRF2000) (mm/yr)

	mean	**RMS**
Ekman	0.1	0.5
Ekman best stn.	0.0	0.4



BIFROST analysis, GAMIT (2010)

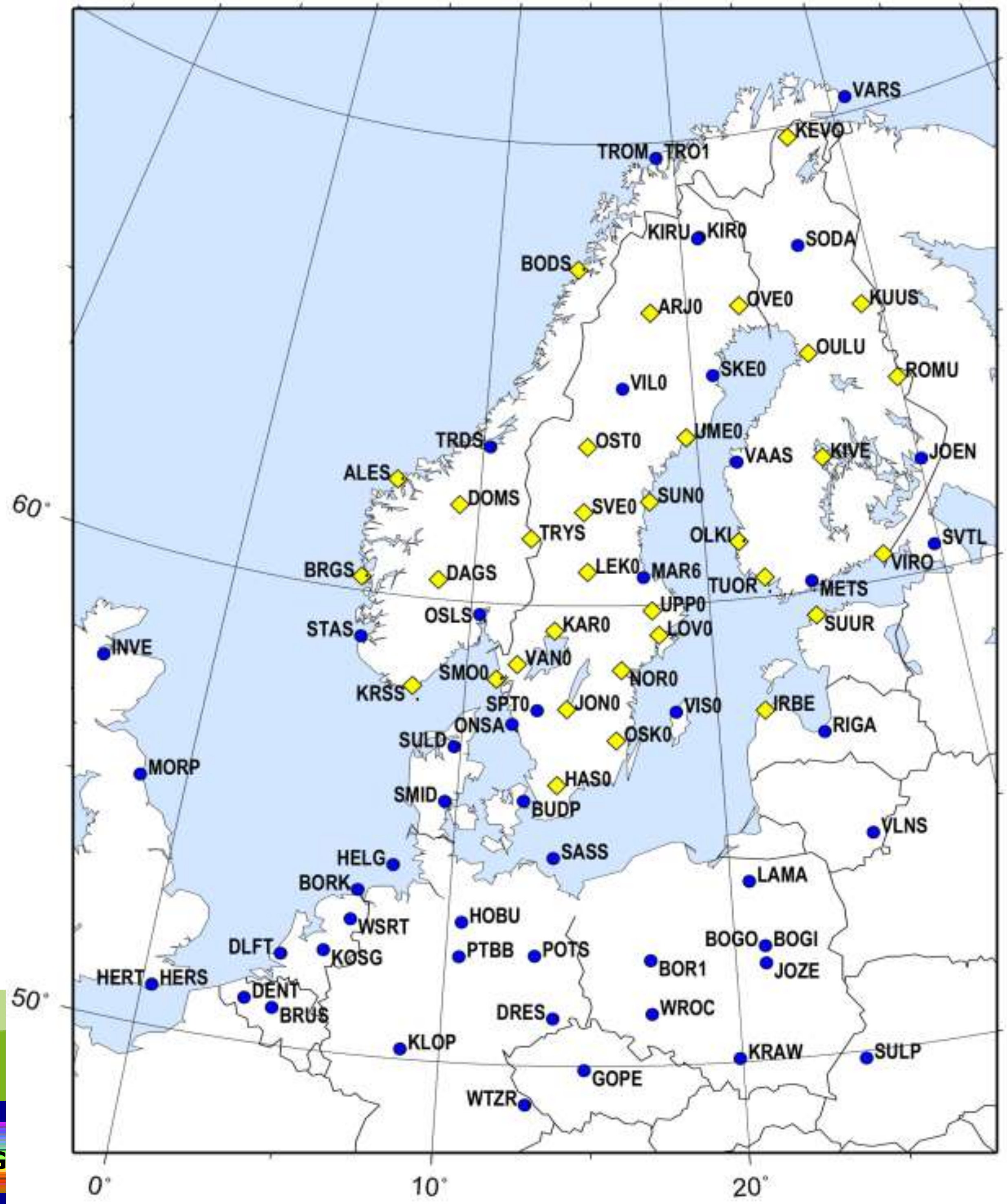
The analysis includes:

- Public sites from IGS and EPN (EUREF Permanent Network) (blue dots •)
- Local sites (yellow diamonds ◇)

Totally: 83 sites + 35 global sites

Period of analysis:
Aug. 1993 – Oct. 2006

Reported in:
- Lidberg PhD Thesis 2007
- J Geodynamics 2010, DynaQlim special issue



BIFROST project

Example of time series of GPS positions

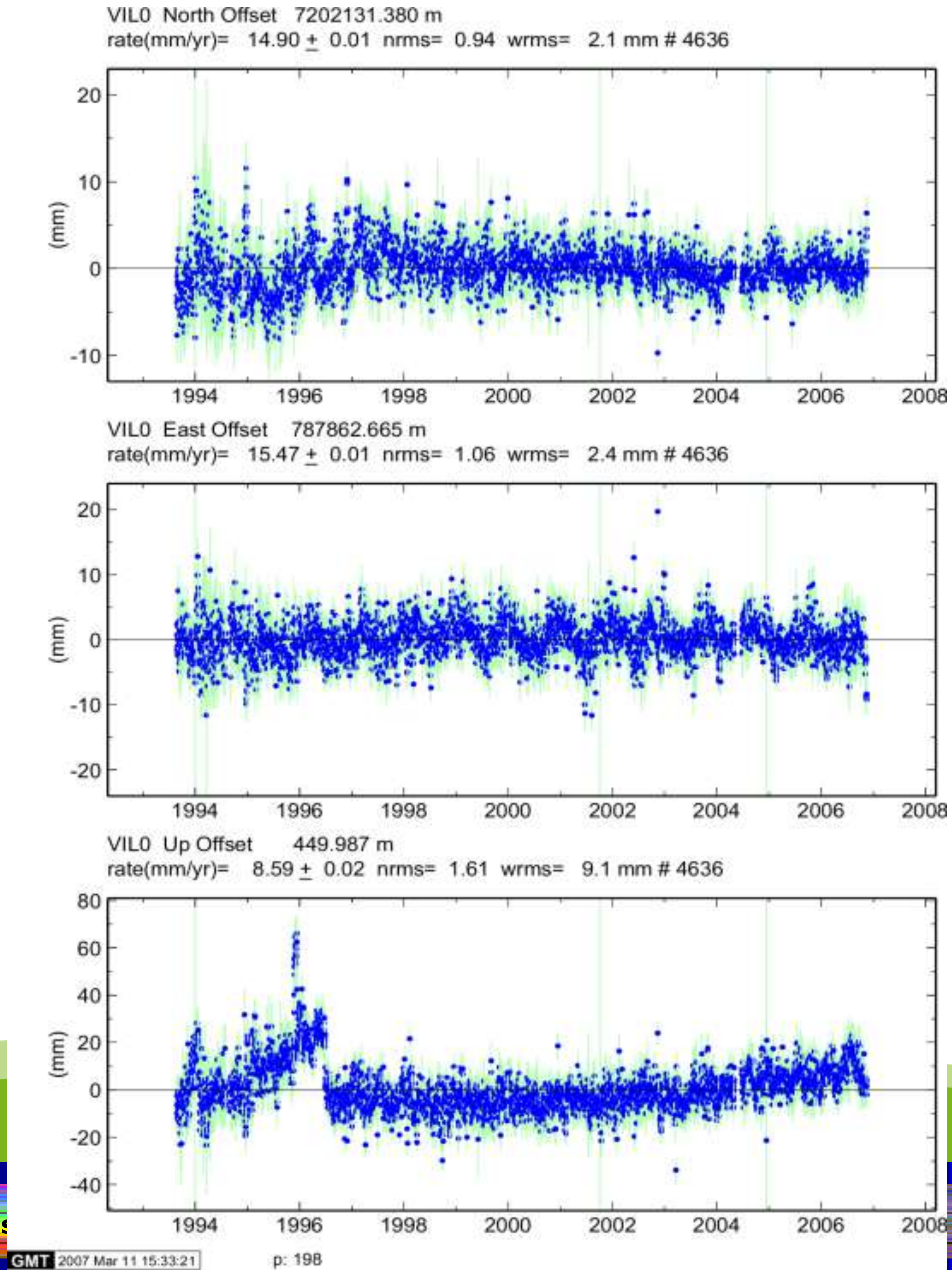
De-trended position time series from Vilhelmina (64º N) for the complete period
Aug. 1993 – Oct 2006

1993-1996:
- some "bad" antenna radoms

PROBLEMS !!!???
Non-linear time-series in the vertical:
- Bent "banana"-shape ???
- Or rate change by 2003 ???

Tide model problem??

Watson, Tregoning, Coleman (2006) "*Impact of solid earth tide models on GPS coord. and trop. time series*", GRL.

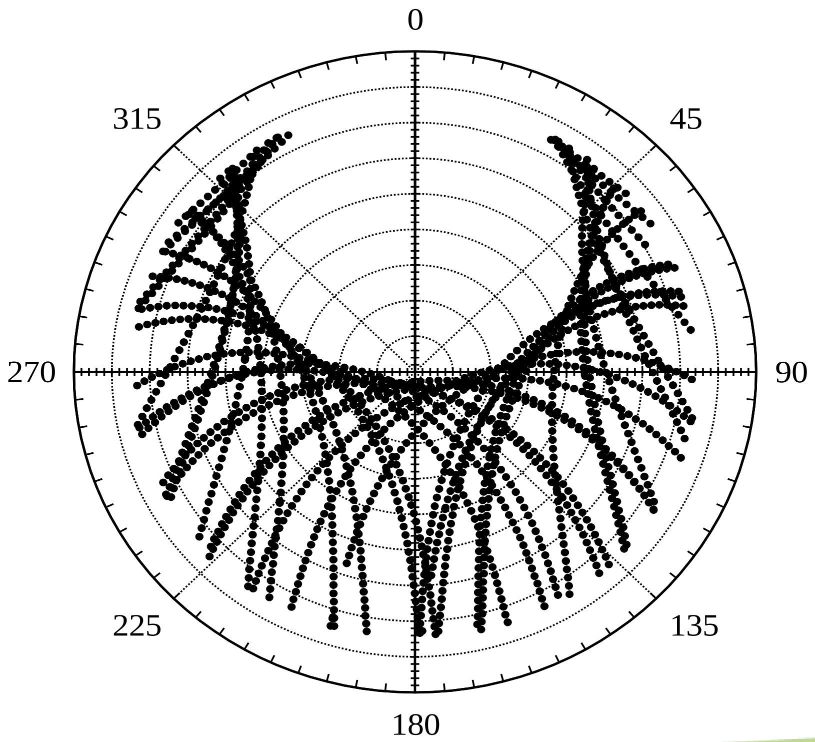


The "hole" in the sky plot at high latitude sites!

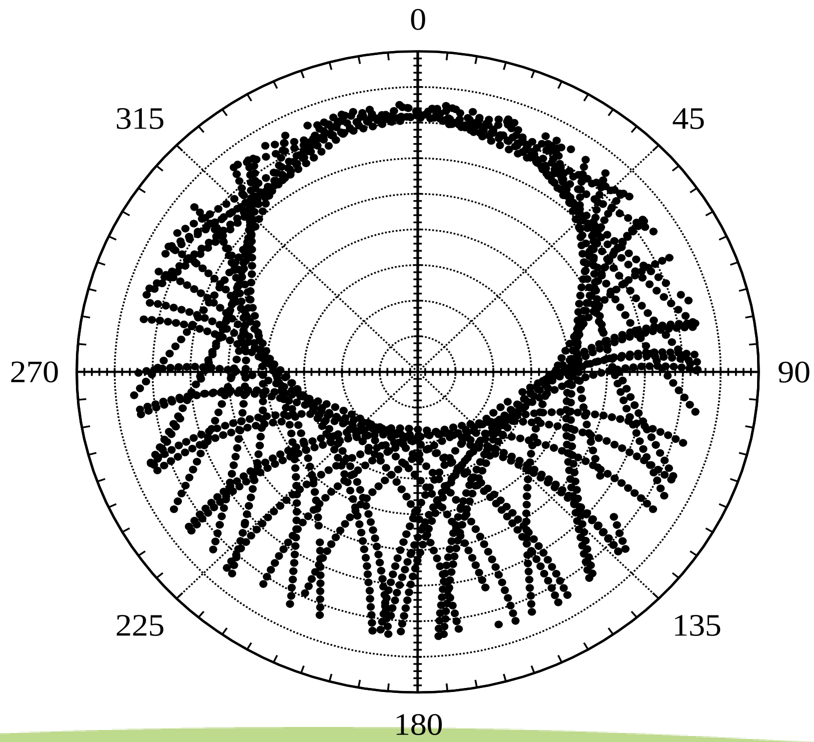
(looking for explanation to non-linear signatures in position time series..)

Satellite geometry at two locations:

Will this cause error in height, if e.g. elevation dependence (antenna models) and mapping functions are imperfect?



Borås: Lat. 57.7°



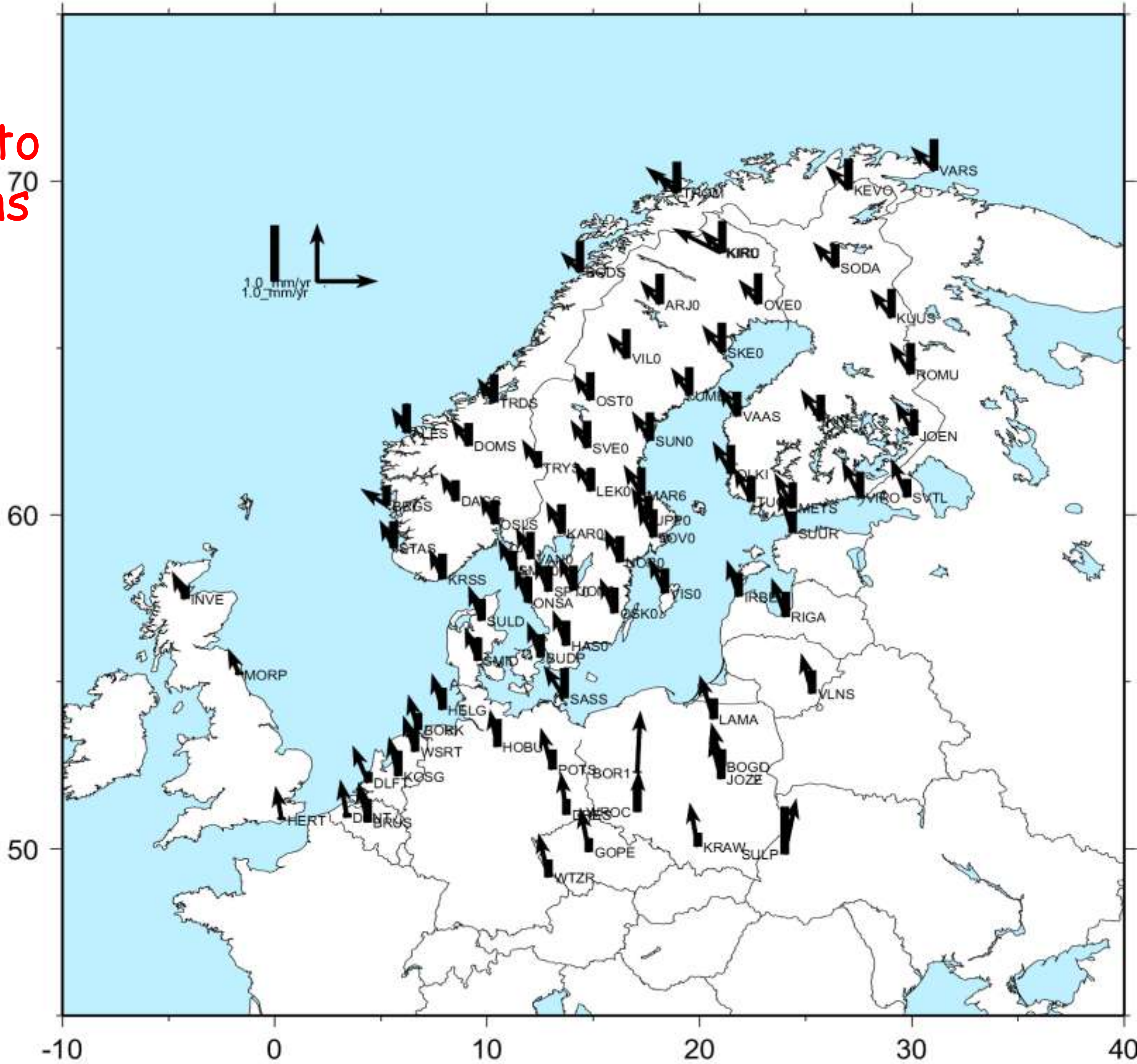
Kiruna: Lat. 67.9°

Velocity differences due to different versions of ITRF;

Station velocities based on:

ITRF2005 minus ITRF2000

Same data, Same GPS-processing, possibly small differences in editing



New GNSS solutions June 2010: Software and Analysis Strategy

- Early June 2010: Four alternative solutions, different elevation cut-offs 5°, 10°, 15°, 20°, (25°)
- JPL re-processed orbits and clocks
- ITRF2005 (IGS05)
- Absolute antenna models on SV and Ground
- Higher-order ionospheric terms
- Different mapping functions
- GIPSY-PPP with and without AMBIZAP (Blewitt)

Four-network hierarchy (always ≥ 3 sites in common):

1) Sweden 25 + Norway 12 + Finland 12
2) BE+NL+DE+DK+PL+LT+LV+EE 50
3) Southern Europe / Northern Africa
4) Global 50

August 2010: New official BIFROST solution: elev. Cut-off t.b.d.+ ambizap, data from 1996– 2009 (also 1993-1995)

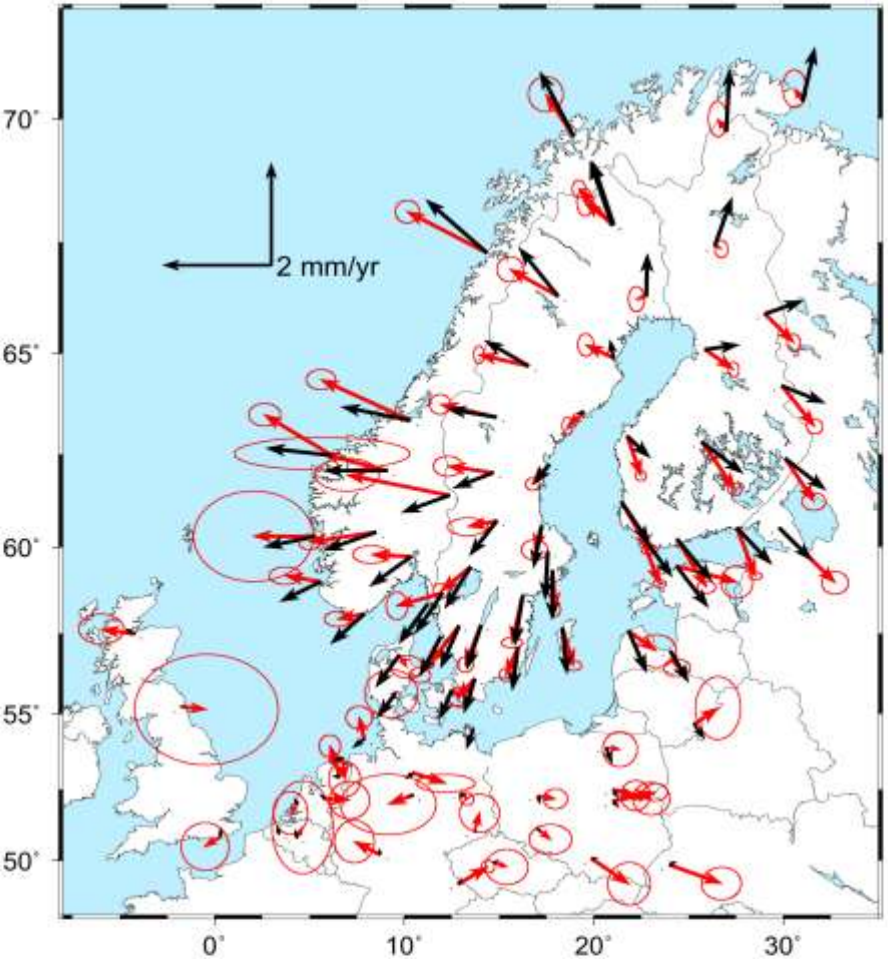
New GNSS solutions summer 2010:
The GNSS networks

Fennoscandian

Europe

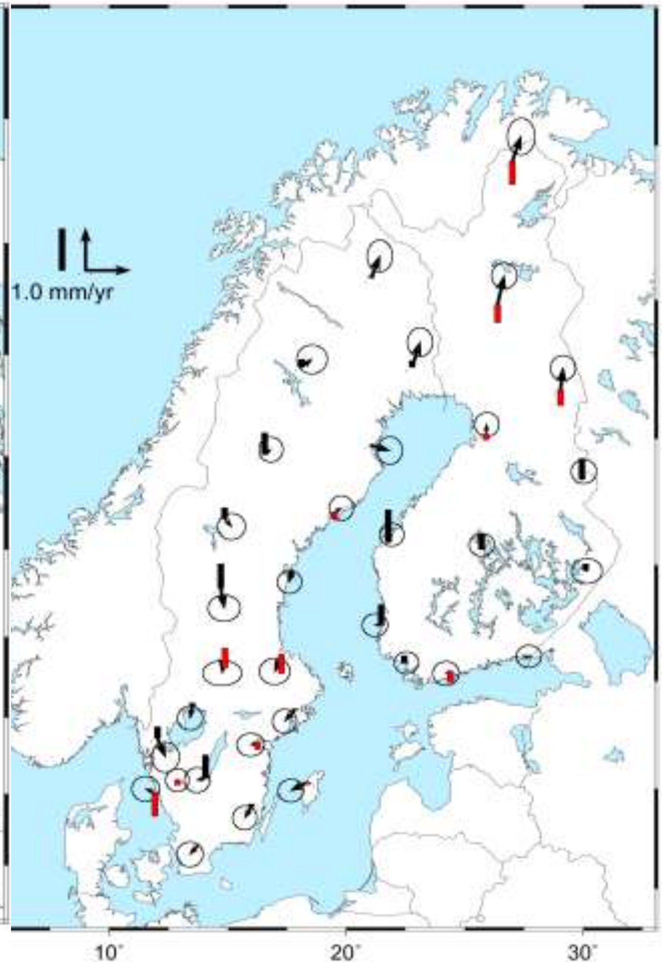
Evaluating the latest station velocity results

The new GAMIT/GLOBK solution (in ITRF2005) And GIA model



Validation using New GIPSY solution (0.1, 0.1, 0.2) (n,e,u) mm/yr
(after 6-par fit, applying rotation and translation rates)

New GIA model minus GPS, "best sites" (0.3, 0.2, 0.3) (n,e,u) mm/yr
(after 6-par fit, applying rotation and translation rates)



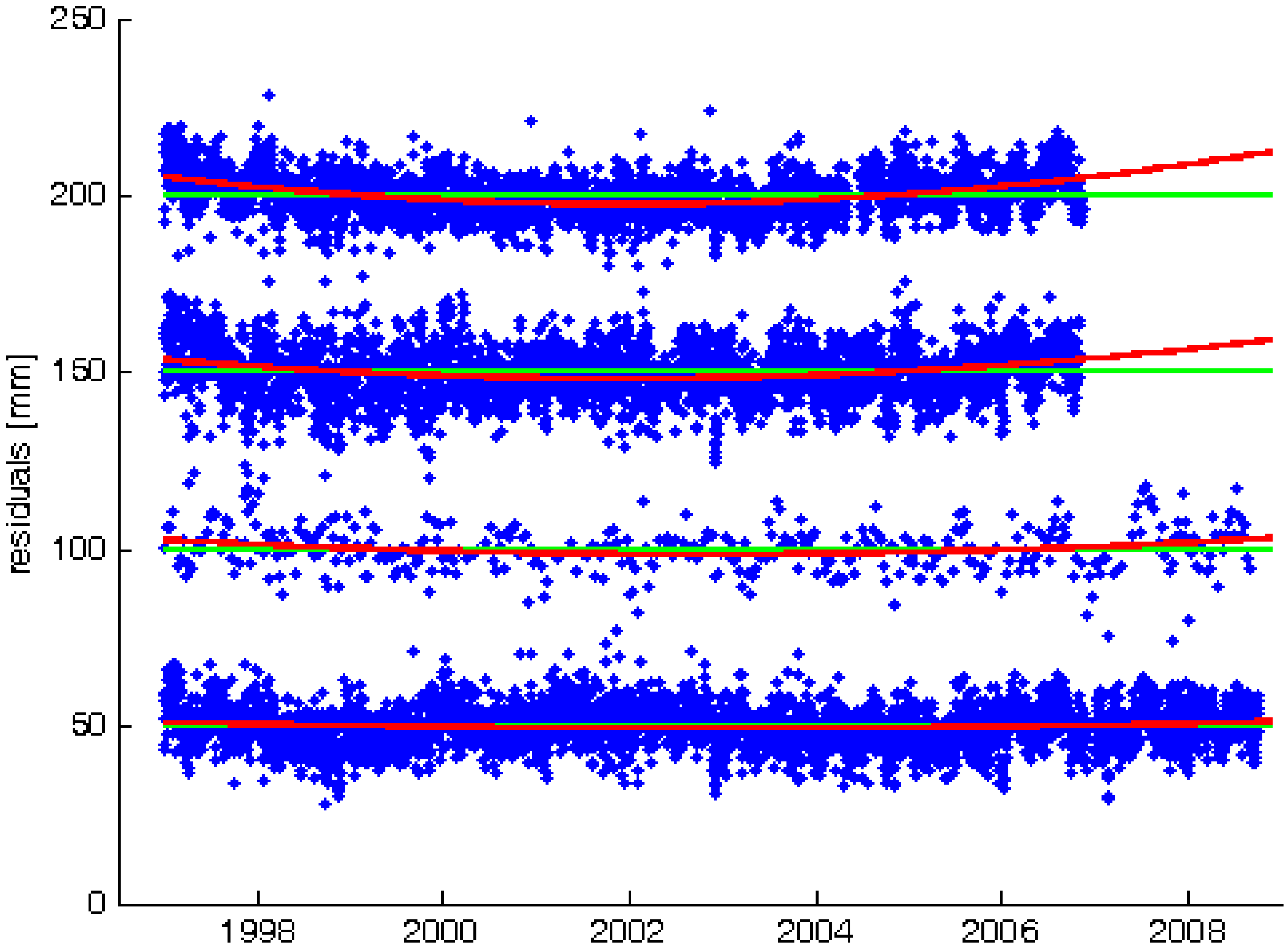
	standard error of single sample (mm) (white nose model)	The second order term, $\ddot{h}$ (mm/yr2)	Standard error in $\ddot{h}$ using white noise model. (mm/ yr^2)
VIL0 a, top	5.4	0.31	0.013
VIL0 b,	7.3	0.22	0.017
VIL0 c,	6.2	0.12	0.031
VIL0 d, bottom	5.8	0.05	0.009

JoG, 2007 (GAMIT)
Regional BIFROST +SOPAC

JoG, 2010 (GAMIT), Regional BIFROST +35 site global (mixed tide model)

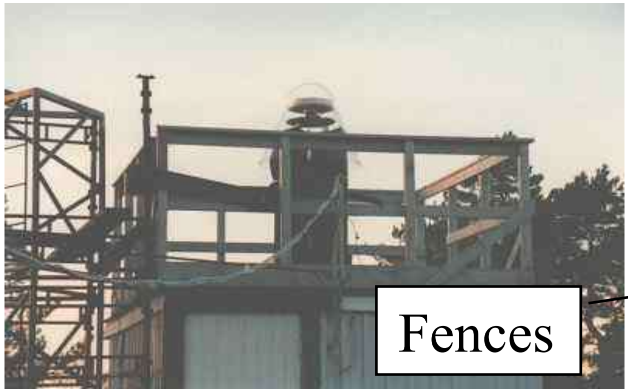
Sparse BIFROST +reprocessed SOPAC, absolute antenna models, GMF mapping function

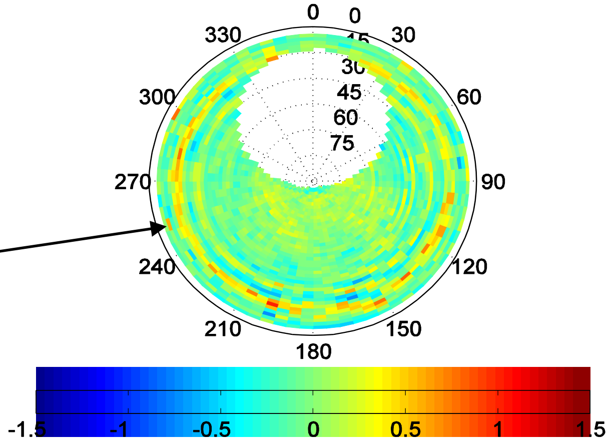
GIPSY re-processed. Absolute antenna models, higher order iono…

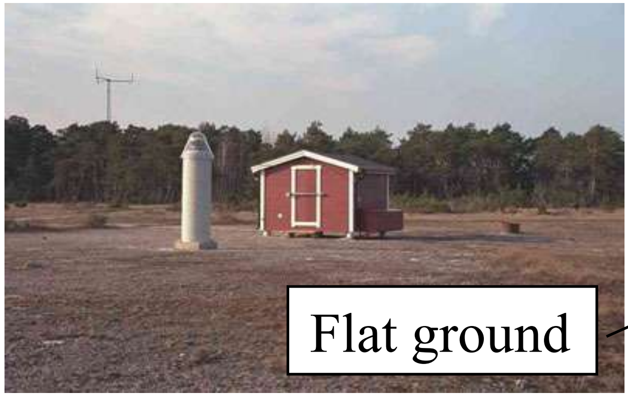


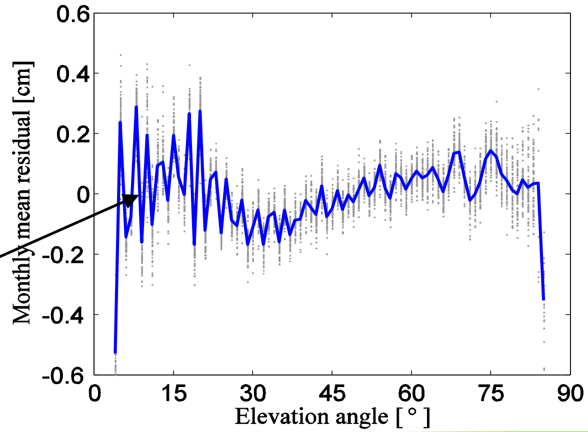
BIFROST proje

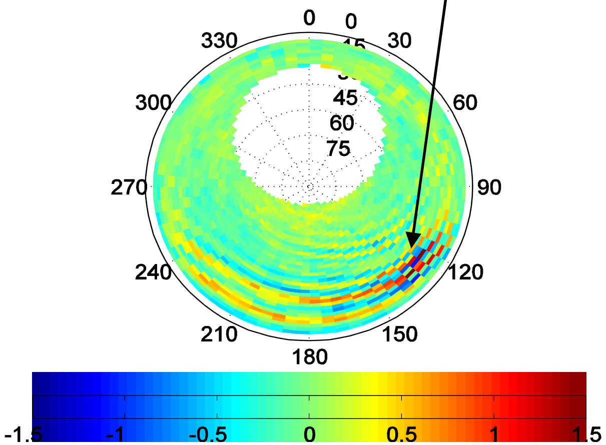
Special Effects and Possible Causes











What about the observing system (ground segment) in the view of Galileo and modernized GPS and GLONASS?

- Some (many?) existing GNSS antennas in IGS and regional networks are not able to track new signals (L5)
- Many of our monuments and antenna installations were done >10 years ago => before we got experience from IGS. Can we do better today?
- How should the upgrade of the observation system be done to meet stability requirements?
  - Change antenna at the existing monument/platform?
  - Keep the existing antenna and add a second monument for the modern antenna?

Conclusion and outlook

The velocity solutions presented here are preliminary.

However, GPS-velocities and GIA-model agree at

- 0.4 mm/yr level (1σ) horizontal
- 0.5 mm/yr level (1σ) vertically

$\Rightarrow$ The velocities observed in northern Europe can be explained by the GIA model to the 0.5 mm/yr level!!

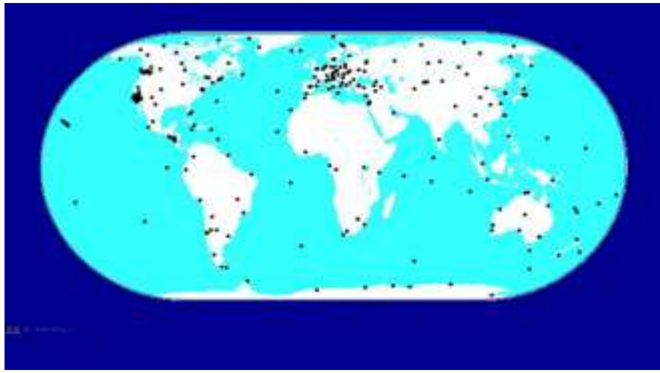
1. GPS-results may still suffer from limitations in applied models (tide models, antenna models, atmospheric effects, site dep. effects)
   $\Rightarrow$ *Re-processing is on-going for BIFROST*
2. GPS-results are highly dependent on the used reference frame
   - ITRF2000 and ITRF2005 differ in vertical velocity by 1-2mm/yr
   $\Rightarrow$ *ITRF2008 will hopefully solve possible doubts*

So, for high accuracy applications aiming at 0.1 mm/yr level (like sea level work, GIA modeling, etc), there is more to do about:

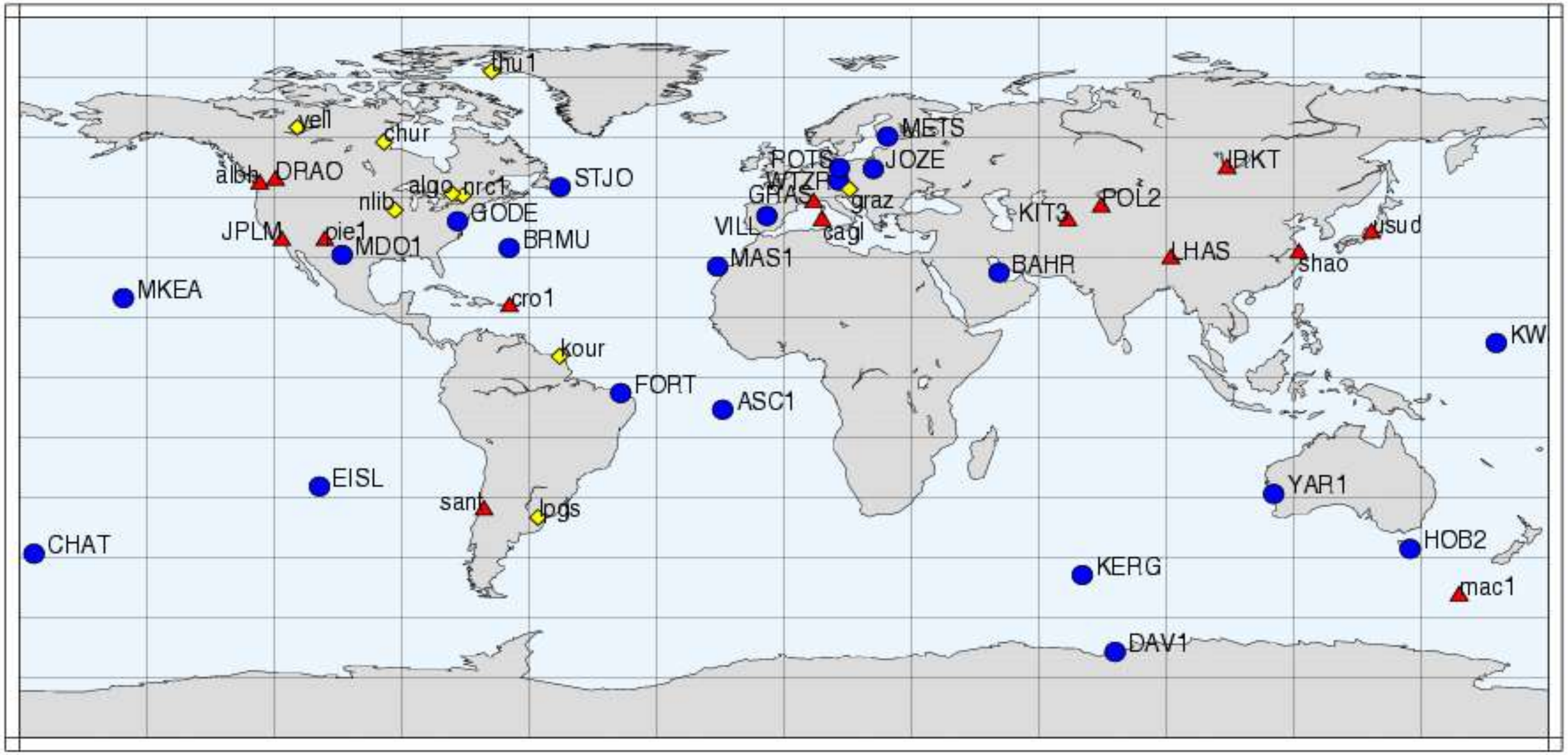
-"long term stability in GNSS results"

- the stability in the geodetic terrestrial reference frame

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)



Global analysis by Lidberg et al.

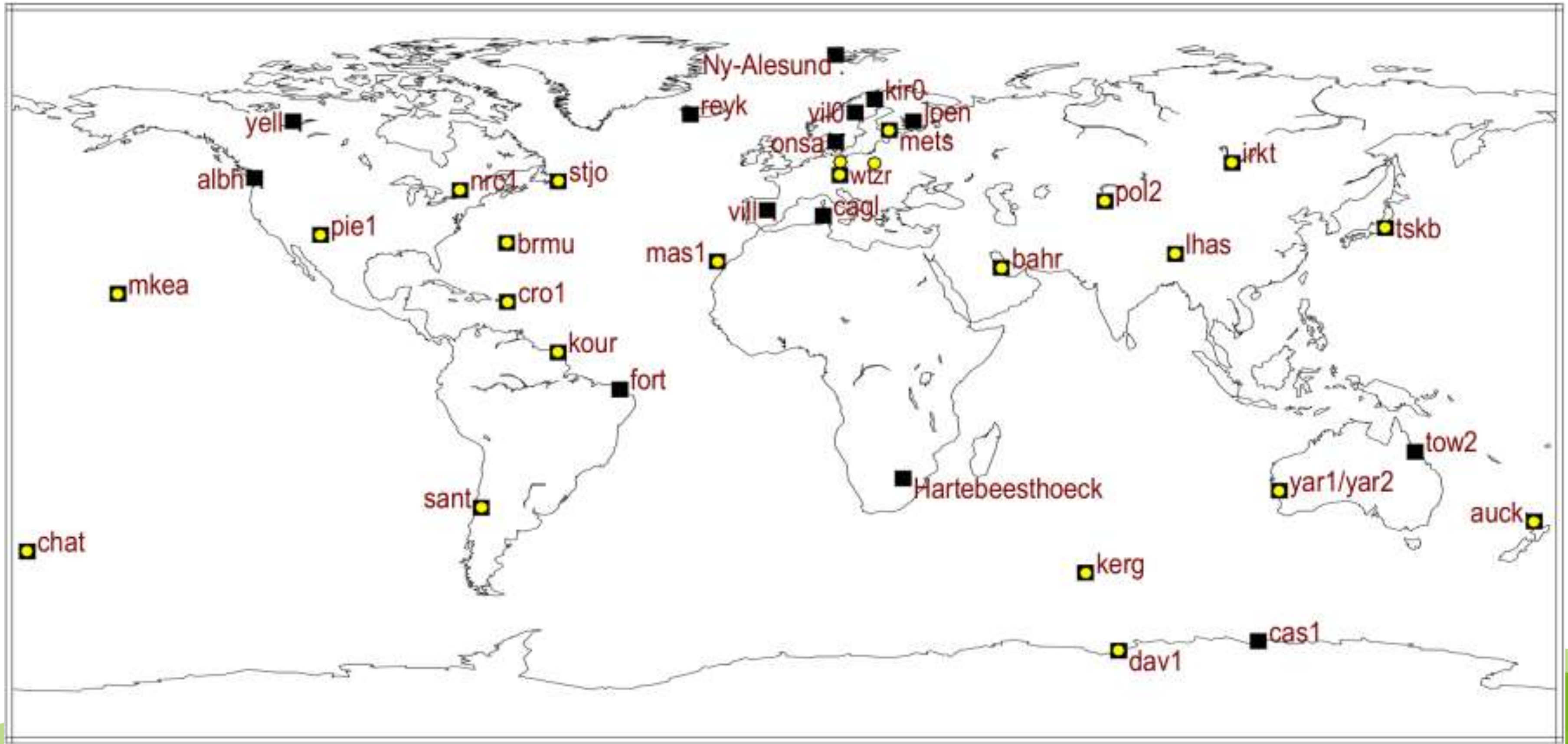
The global network:

35 selected sites. (black squares ■)

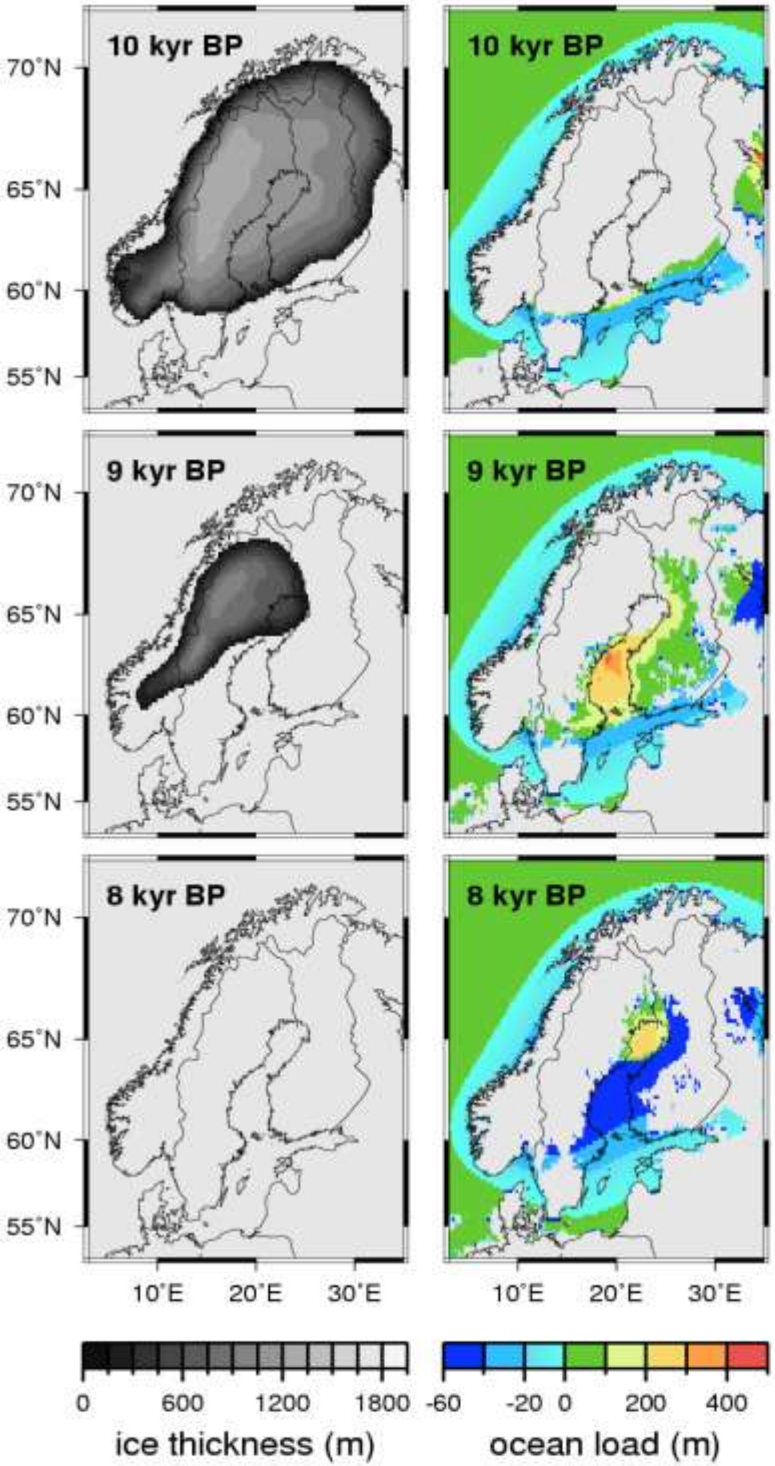
- Cover the globe - Connect regional & global analysis
- Include "good" sites for reference frame realization

Reference frame sites:

23 sites as candidates (yellow circles ●)



Glacial Isostatic Adjustment (GIA) model



Update of the GIA model developed by (Milne et al Science 2001).

Ice history and method is identical but the new GPS velocity solution (Lidberg et al, 2007) is used for constraining the model, and not the solution in (Johansson et al JGR 2002).

Ice history model from Lambeck

120 km lithosphere,
upper mantle visc. 5×10^{20} Pas
lower mantle visc. 5×10^{21} Pas

Thanks to Glenn Milne, Maaria Nordman, Pippa Whitehouse!!