Case study Europe (ETRS89 and EVRS)

-with examples from Sweden

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Outline

- Some words on EUREF – the organization for common reference frames in Europe
- Vertical reference frames, UELN and EVRS
- EUREF and the European Terrestrial Reference System 1989 (ETRS89)
- Example from the Nordic area (where crustal deformations are present)

What is EUREF?

- EUREF is the IAG Reference Frame Sub Commission for Europe
- Founded in 1987
- Members of EUREF are the European countries (following the IUGG membership rules)
- Contributors to EUREF are hundreds of agencies and institutions providing data, resources, and manpower on a voluntary basis
- EUREF provides all its products on the „best effort“ basis and free of charge to the public

IAG: International Association of Geodesy
IUGG: International Union of Geodesy and Geophysics

What is EUREF?

- Main objectives of EUREF are the maintenance of the
  - European Terrestrial Reference System (ETRS89)
  - European Vertical Reference System (EVRS)
- Basis and infrastructure for them are the
  - EUREF (GNSS) Permanent Network (EPN)
  - Unified European Levelling Network (UELN)
- → www.euref.eu

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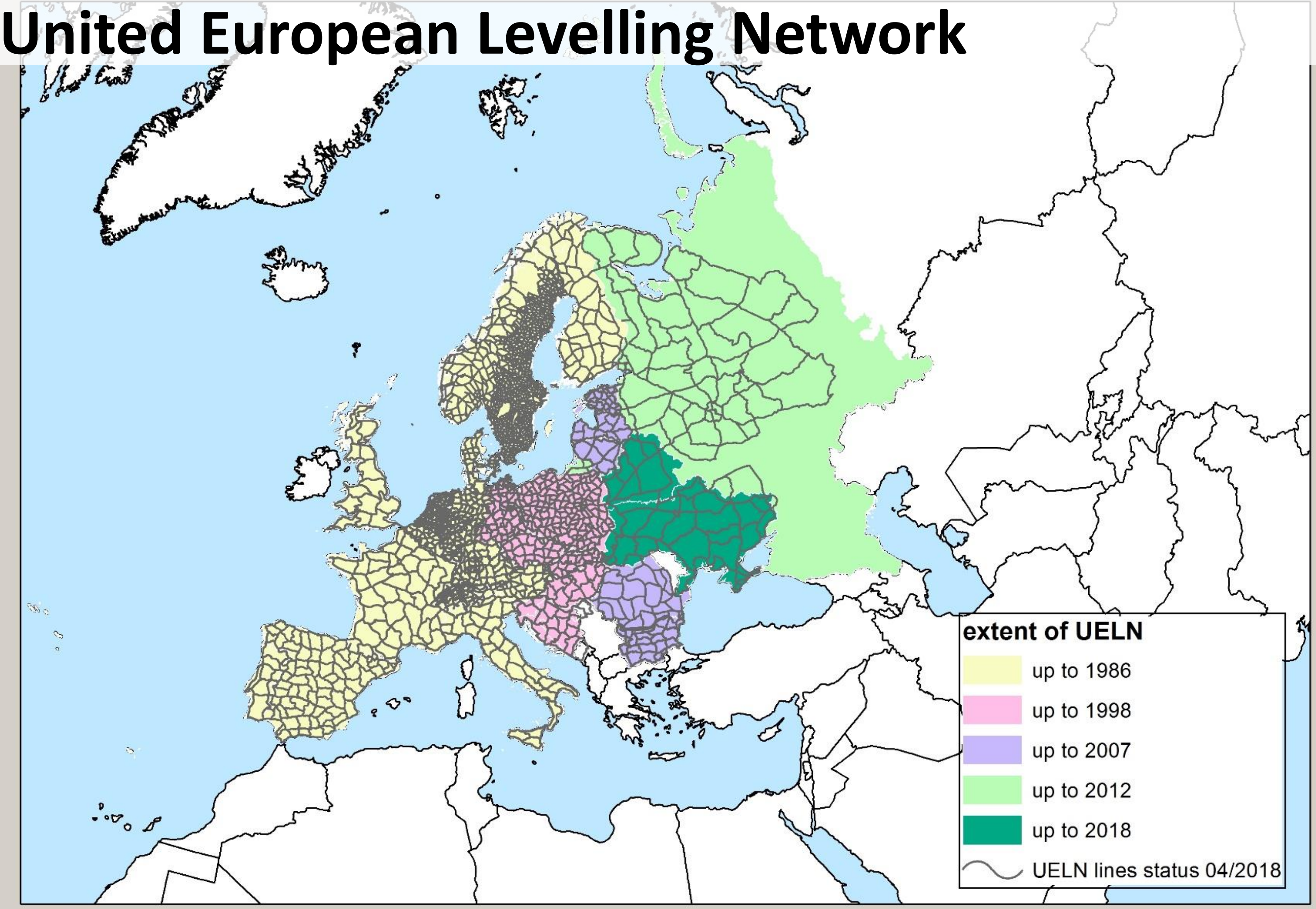
The United European Levelling Network, UELN

- Unification of national levelling networks in Europe
- The work done have been based on formal agreements/resolutions from IUGG, IAG or EUREF
- Basically three periods with more activity
  - 1954-1963
  - 1971-1986
  - 1994 - onwards
- Current work done under the umbrella of EUREF
- Ambition is a 1 cm uncertainty level for datum and network realization

The United European Levelling Network



Definition of EVRS - simplified formulation 1(2)

The European Vertical Reference System (EVRS) is a kinematical height reference system. The EVRS definitions fulfil the following four conventions:

1) The vertical datum is defined as the equipotential surface for which the Earth gravity field potential is constant:

$$W_0 = W_{0E} = const.$$

and which is in **the level of the Normaal Amsterdams Peil**.

2) The unit of length of the EVRS is the meter (SI). The unit of time is second (SI)...

Definition of EVRS - simplified formulation 2(2)

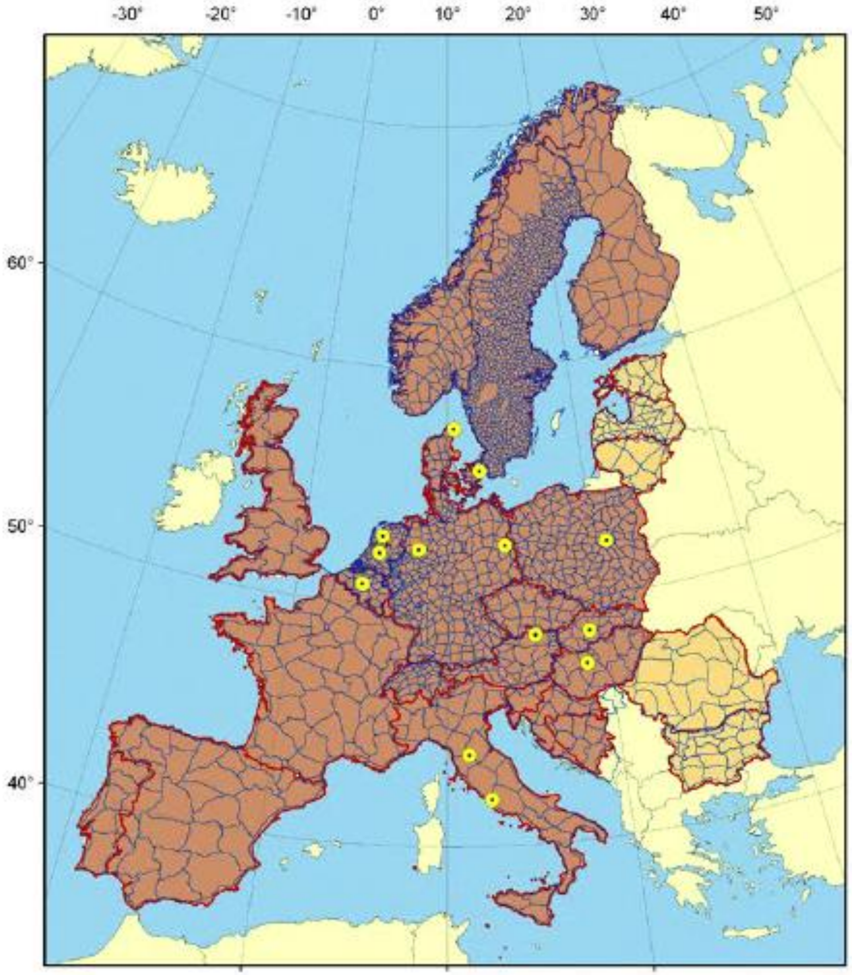
3) The height components are the differences ΔW_P between the potential W_P of the Earth gravity field through the considered points *P*, and the potential W_{0E} of the EVRS conventional zero level. The potential difference $-\Delta W_P$ is also designated as the geopotential number c_P

$$-\Delta W_P = c_P = W_{0E} - W_P$$

Normal heights are equivalent with geopotential numbers, provided that the reference gravity field is specified.

4) The EVRS is a **zero tidal system**, in agreement with the IAG Resolutions No. 9 and 16 adopted in Hamburg in 1983.

Datum points for EVRS



$$\sum_{i=1}^{13}\left(c_{UELN95/98} - c_{EVRS2007}\right) = 0$$

Since the NAP may have some instability, 13 specific markers in the network was selected as datum points with their geopotential values as achieved from the EVRF2000 realization

Datum points of EVRF2007

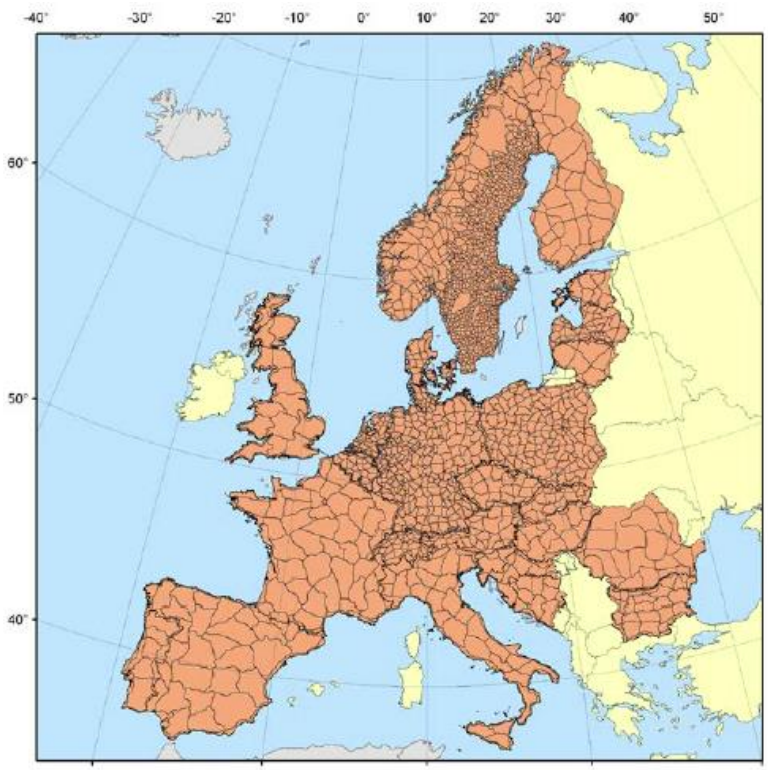
Extension of UELN

up to 1998

as from 2003

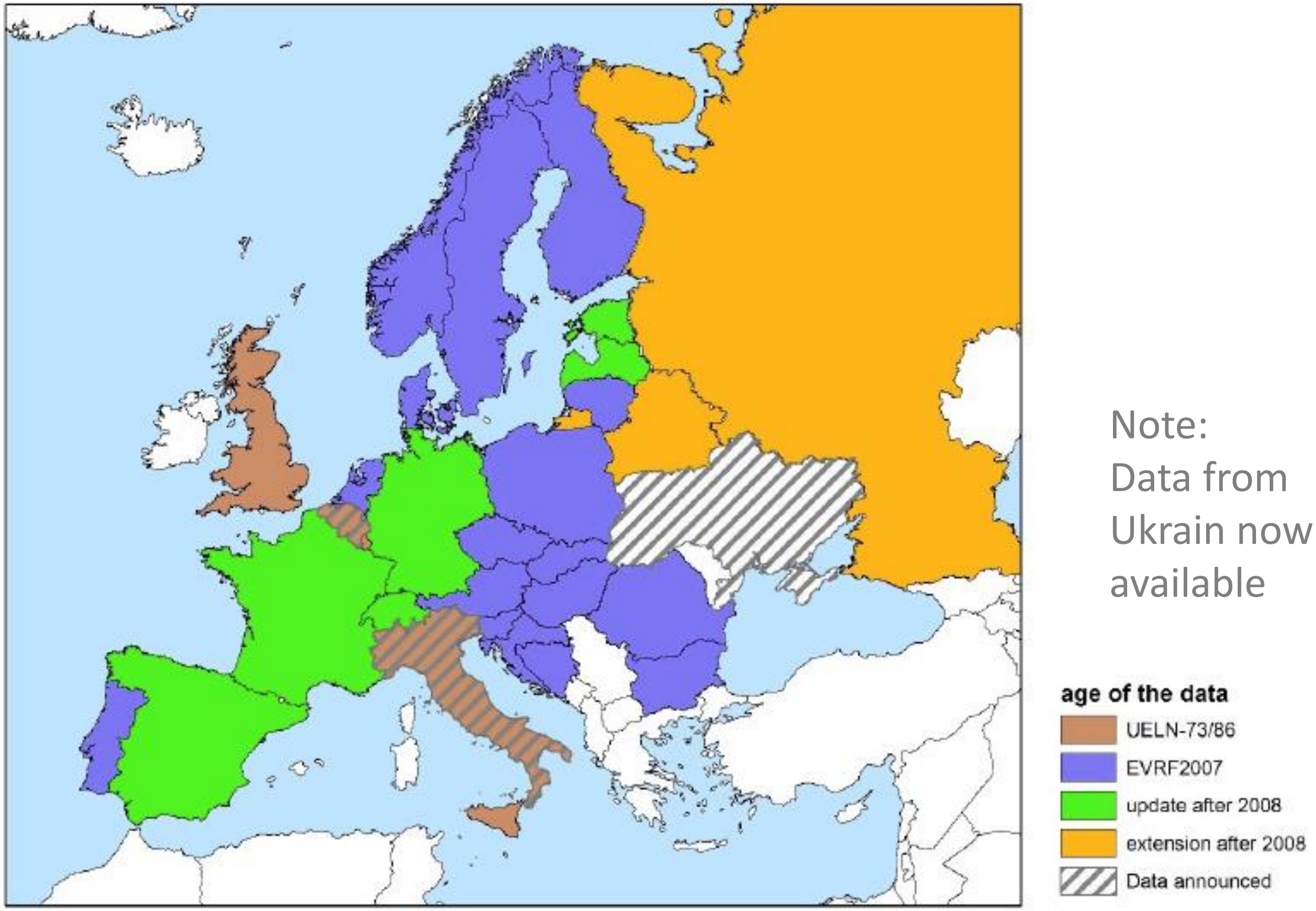
UELN lines

EVRF2007 – the current realization of EVRS



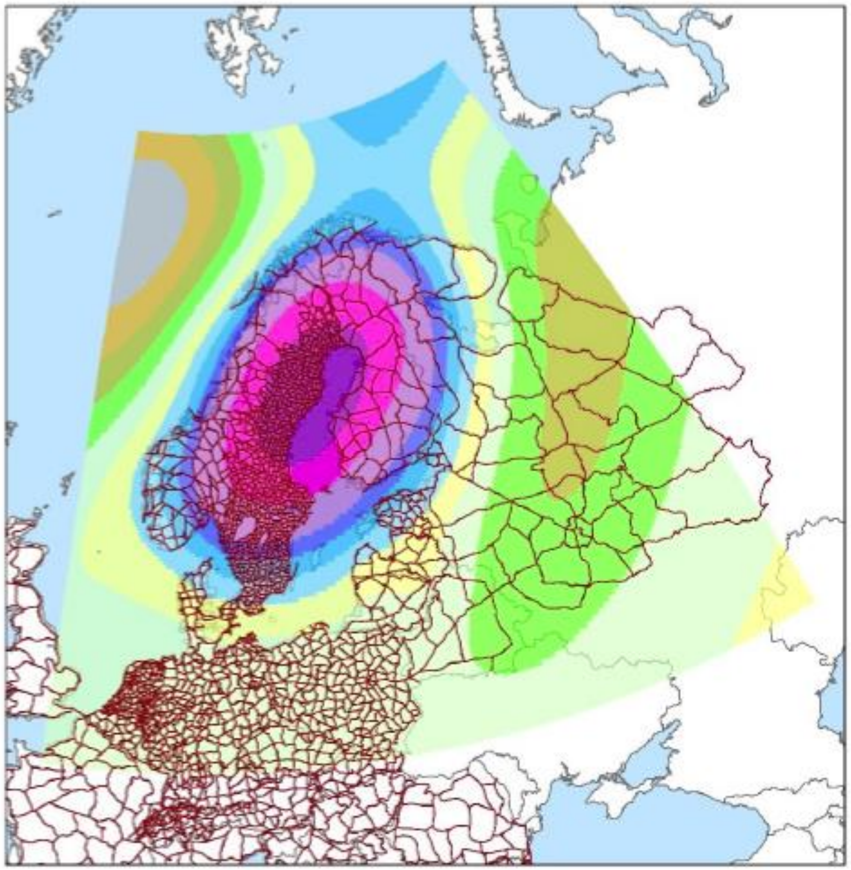
- 27 countries
- 13 datum points
- 7939 nodal points
- 10347 lines
- s_0 = 1.11 kgal.mm /√km
- Land uplift corrected in Nordic/Baltic area to epoch 2000.0
- Adopted by EUREF 2008
- New adjustments are performed when new data becomes available, but still in the EVRF2007 frame.

Status of levelling data



Note:
Data from
Ukrain now
available

New land uplift model NKG2016LU_lev



Vestøl et al: **NKG2016LU, an improved postglacial land uplift model over the Nordic-Baltic region.** *NKG meeting WG of Geoid and Height Systems. June 2016*

velocity in mm/year

- -2,99 - -2,00
- -1,99 - -1,00
- -0,99 - 0,00
- +0,01 - +1,00
- +1,01 - +2,00
- +2,01 - +3,00
- +3,01 - +4,00
- +4,01 - +6,00
- +6,01 - +8,00
- +8,01 - +9,63
- UELN lines status 03/2017

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EUREF and ETRS89

- At the global level we have the International Terrestrial Reference System and Frames (ITRS/ITRF)
- For Europe we have the European Terrestrial Reference System, ETRS89, and its realizations:
  - ETRS89 is by its definition **coincident with ITRS at epoch 1989.0**, and **fixed to the stable part of the Eurasian Plate**
  - i.e. **velocities** in ETRS89 are related to the “stable part” of the Eurasian Tectonic Plate
- ETRS89 is mandatory for data exchange under the INSPIRE directive within EU member countries.

ETRS89: Definition

- Coincides with ITRS at epoch 1989.0:
  - Definition at a reference epoch (1989.0)
  - The 7 parameters between ITRS and ETRS89 are zero at 1989.0
- Fixed to the stable part of the Eurasian plate
  - Co-moving with the plate: law of time evolution
  - Time derivatives of the transformation parameters are zero except the 3 rotation rates

Note that ETRS89 is thereby a kinematic system where intraplate deformations are visible, and vertical velocities in principle are identical to those in respective ITRF

The formula for transformation from ITRFyy to ETRFyy

For station position at epoch t

$$X_{yy}^{E}(t) = X_{yy}^{I}(t) + T_{yy} + \begin{pmatrix} 0 & -\dot{R}3_{yy} & \dot{R}2_{yy} \\ \dot{R}3_{yy} & 0 & -\dot{R}1_{yy} \\ -\dot{R}2_{yy} & \dot{R}1_{yy} & 0 \end{pmatrix} \times X_{yy}^{I}(t).(t - 1989.0)$$

For station velocities

$$\dot{X}_{yy}^{E} = \dot{X}_{yy}^{I} + \begin{pmatrix} 0 & -\dot{R}3_{yy} & \dot{R}2_{yy} \\ \dot{R}3_{yy} & 0 & -\dot{R}1_{yy} \\ -\dot{R}2_{yy} & \dot{R}1_{yy} & 0 \end{pmatrix} \times X_{yy}^{I}$$

EUREF Technical Note 1, available at:
(http://www.epncb.oma.be/_documentation/guidelines/)

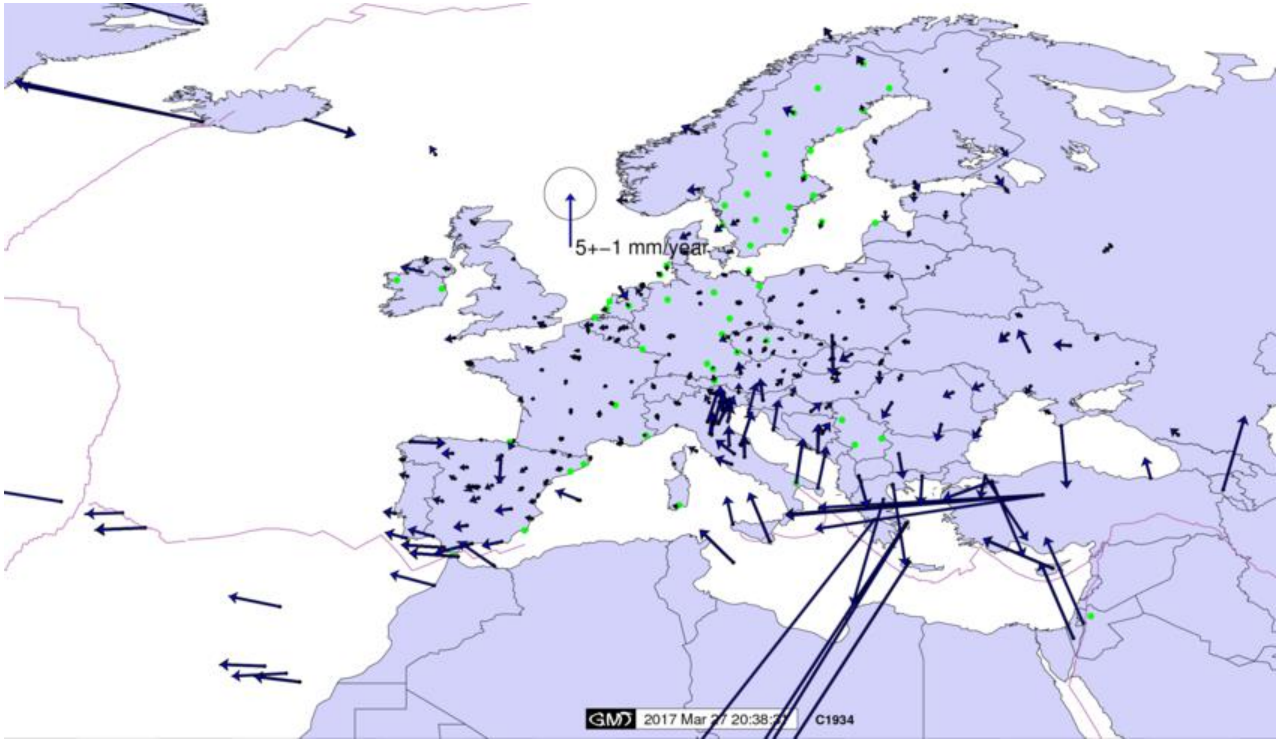
The EUREF Permanent Network (EPN)

The EPN is a science-driven network of permanent GNSS tracking stations (http://epncb.oma.be/). Through its daily and weekly computed network solutions it is used by EUREF to **realize** and **provide access** to the ETRS89. The EPN includes:

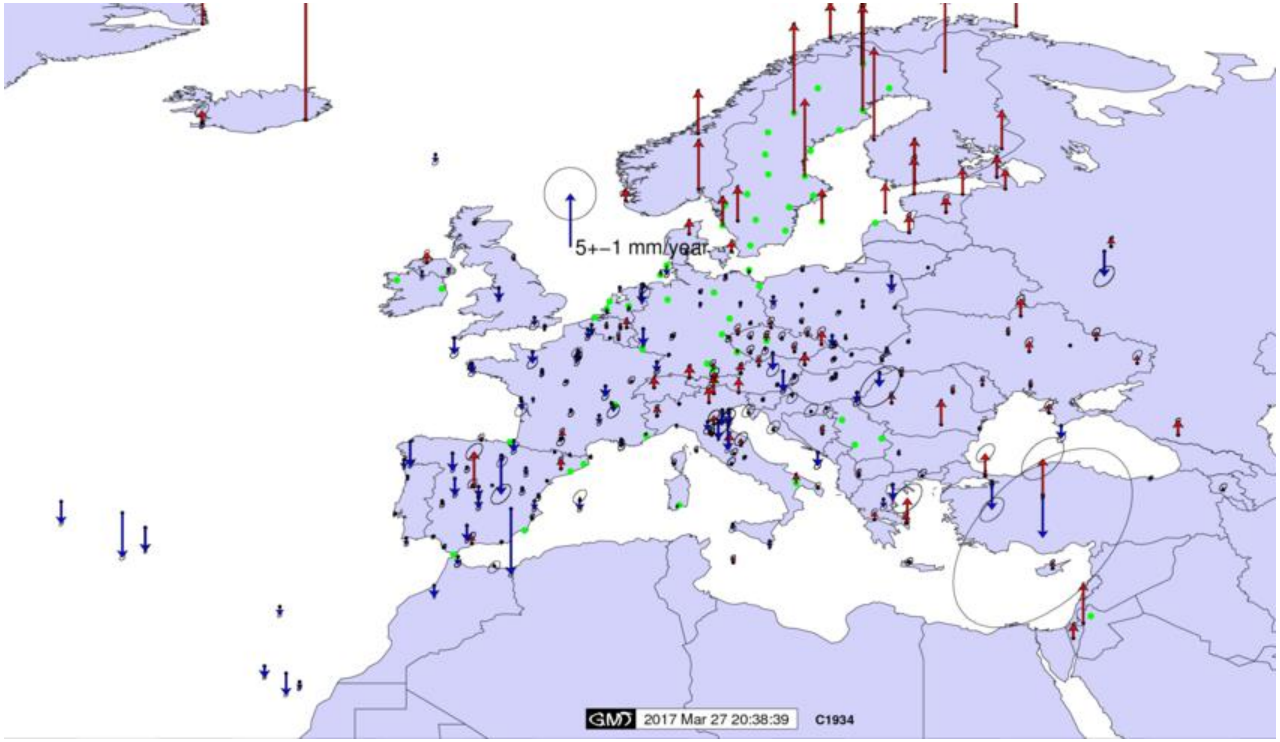
- a **network** of about 300 continuously operating GNSS stations,
- **data centers** providing access to the station data,
- **analysis centers** that routinely analyze the GNSS data,
- **product centers** and coordinators that generate the EPN products,
- and a **Central Bureau** that is responsible for the daily monitoring and management of the EPN.

The EUREF Permanent Network, EPN

EPN products – horizontal velocities



EPN products – vertical velocities



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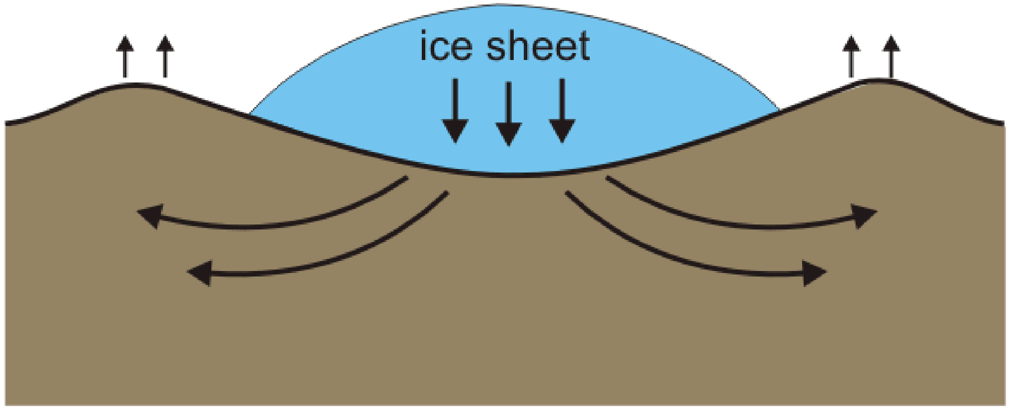
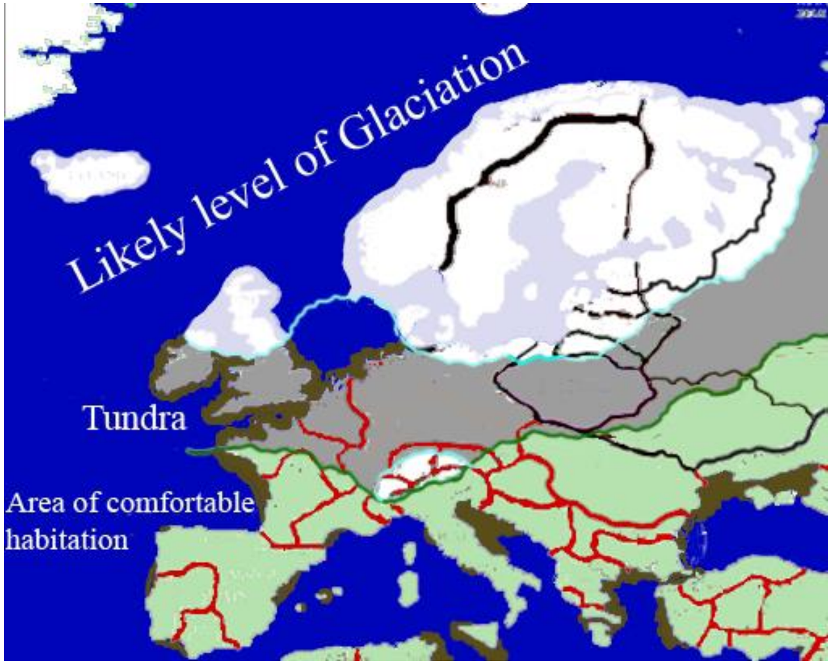
The Glacial Isostatic Adjustment (GIA) phenomenon





To note:

In presence of crustal deformations, the epoch is crucial.

Therefore:

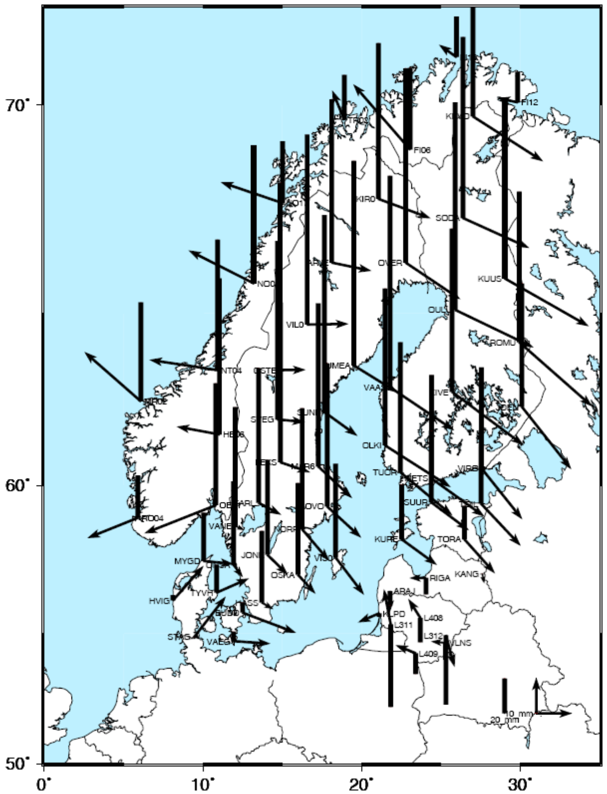
Time tag everything!

Realizations of ETRS89 in Fennoscandia

(the Nordic /Baltic countries)

Country	Country ID	Name of realization	Based on ITRFxx	Realization epoch
Denmark	DK	EUREF-DK94	ITRF92	1994.704
Estonia	EE	EUREF-EST97	ITRF96	1997.56
Faroe Islands	FO		ITRF2005 (ETRF2000)	2008.75
Finland	FI	EUREF-FIN	ITRF96	1997.0
Latvia	LV	LKS-92	ITRF89(?)	1992.75
Lithuania	LT	EUREF-NKG-2003	ITRF2000	2003.75
Norway	NO	EUREF89	ITRF93	1995.0
Sweden	SE	SWEREF 99	ITRF97	1999.5

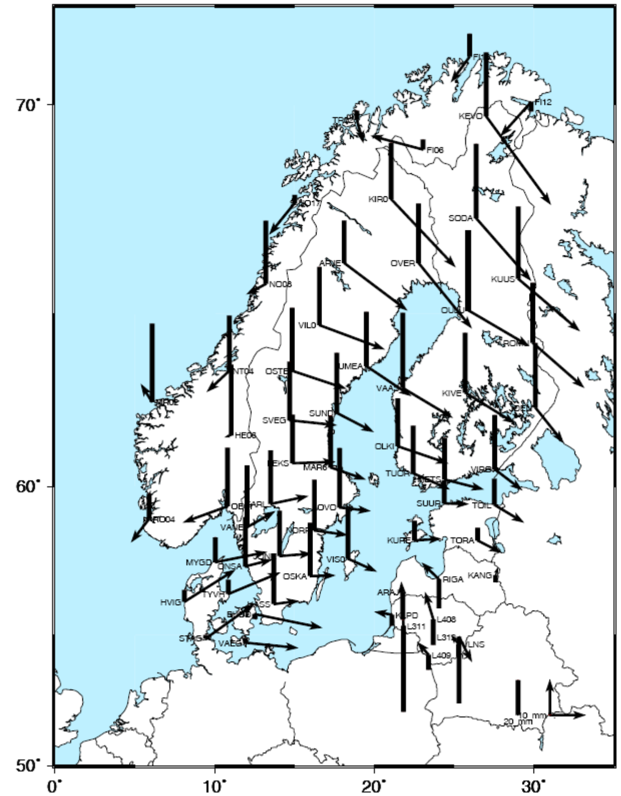
Comparing the national realizations of ETRS89 in Fennoscandia



The NKG2008 campaign in ETRF2000 compared to national realizations.

Left, @ epoch 2008.75.

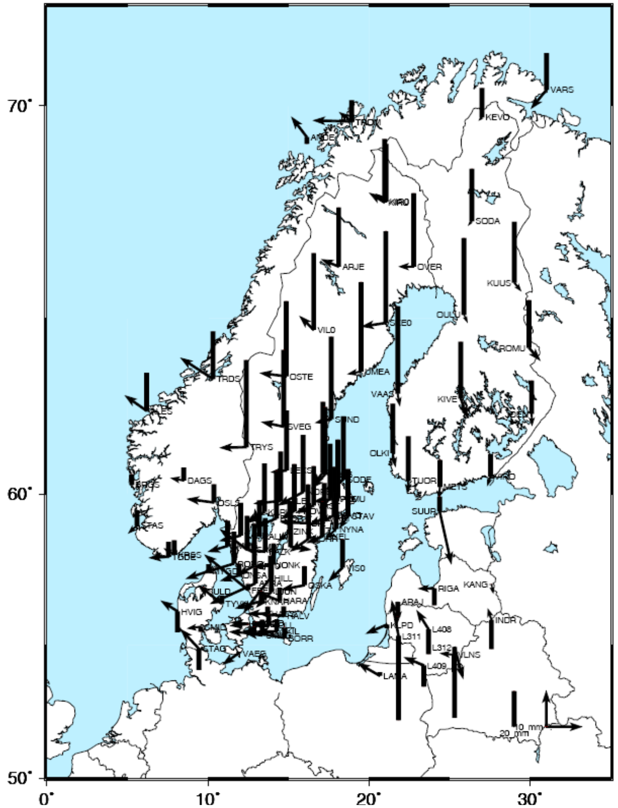
Right, @ epoch 2000.0, using a model for intraplate velocities (NKG_RF03vel)



Statistics:(n,e,u) in mm			
RMS	9	12	69
Mean	-4	5	53

Statistics:(n,e,u) in mm			
RMS	8	11	28
Mean	-3	7	19

Comparing the NKG2008, and the NKG2003 common campaigns. (in ETRF2000)



Statistics:(n,e,u) in mm			
RMS	4	5	24
Mean	-5	-4	16

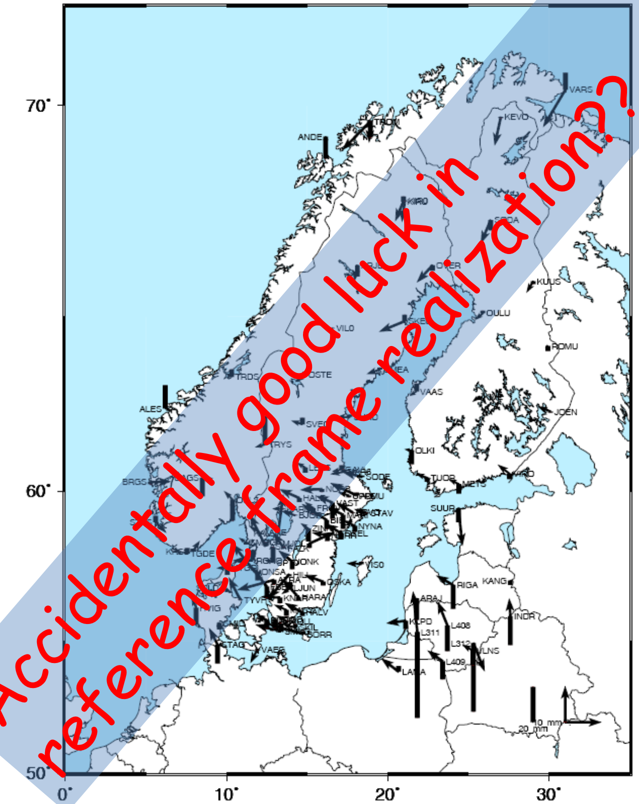
NKG2003 based on ITRF2000,

NKG2008 based on ITRF2005.

Left, NKG2008 @2008.75; NKG2003 @ 2003.75

Right, booth @ epoch 2003.75, using the model NKG_RF03vel

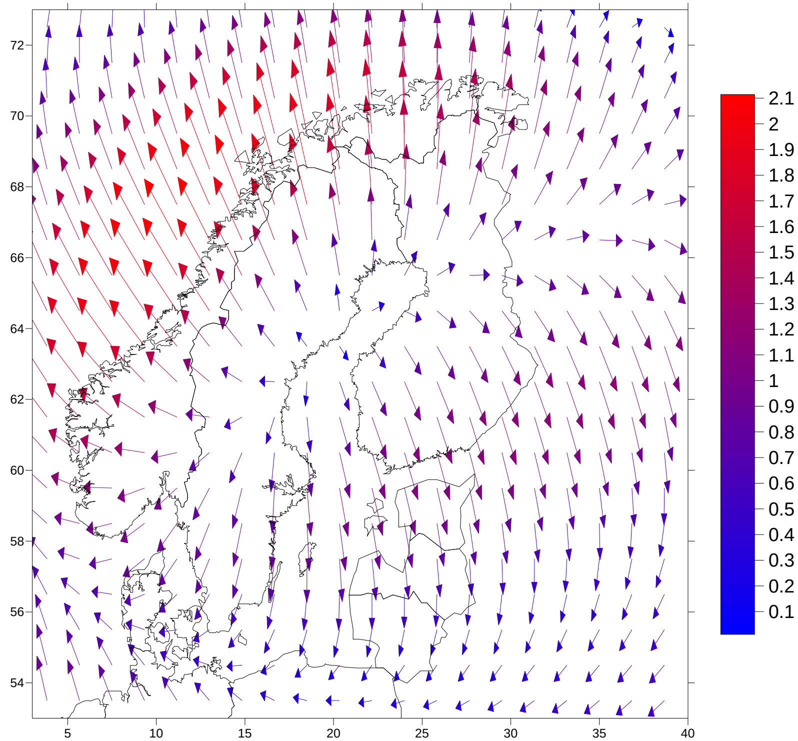
(No fit – just coordinate differences!)



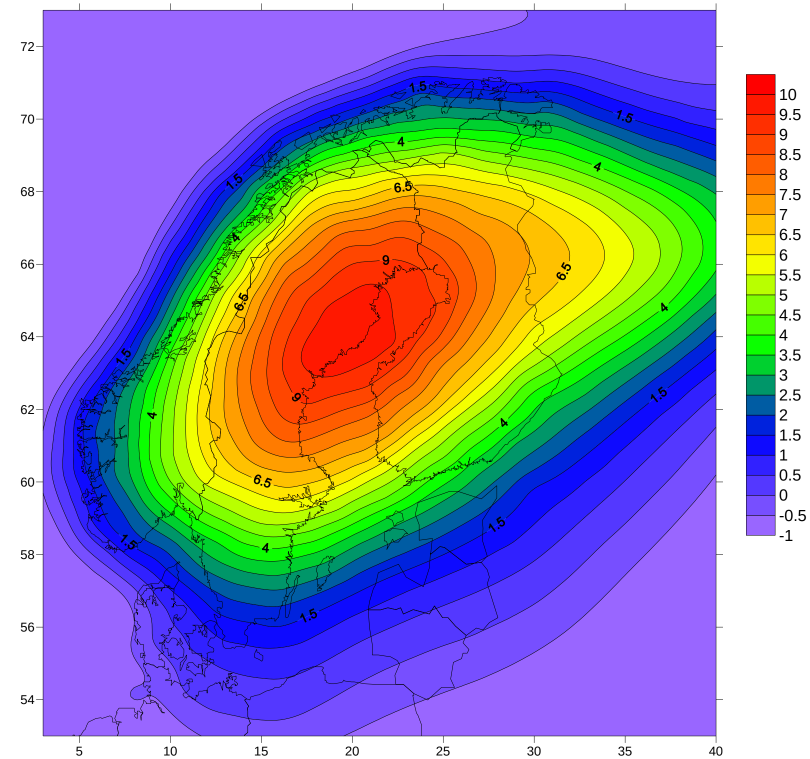
Accidentally good luck in reference frame realization??

Statistics:(n,e,u) in mm			
RMS	4	4	8
Mean	0	-3	-3

The NKG_RF2003_vel velocity model



Horizontal (0 to 2 mm/yr):
The GIA model in Milne 2001 transformed to the GPS-velocities (in Lidberg 2007).



Vertical (-1 to 10 mm/yr):
The NKG2005LU(ABS) model
Based on: TG, repeated levelling, and GPS. (Ågren & Svensson 2006)

Some formulas for the use of the model of crustal (intraplate) deformation

From velocities to coordinate differences

$$\begin{pmatrix} dX \\ dY \\ dZ \end{pmatrix} = \left(t_{target\_epoch} - t_{observation\_epoch}\right) \begin{pmatrix} V_{X_{intra}} \\ V_{Y_{intra}} \\ V_{Z_{intra}} \end{pmatrix}_{NKG\_RF03vel}$$

From velocities in (n,e,u) to (X,Y,Z) frame

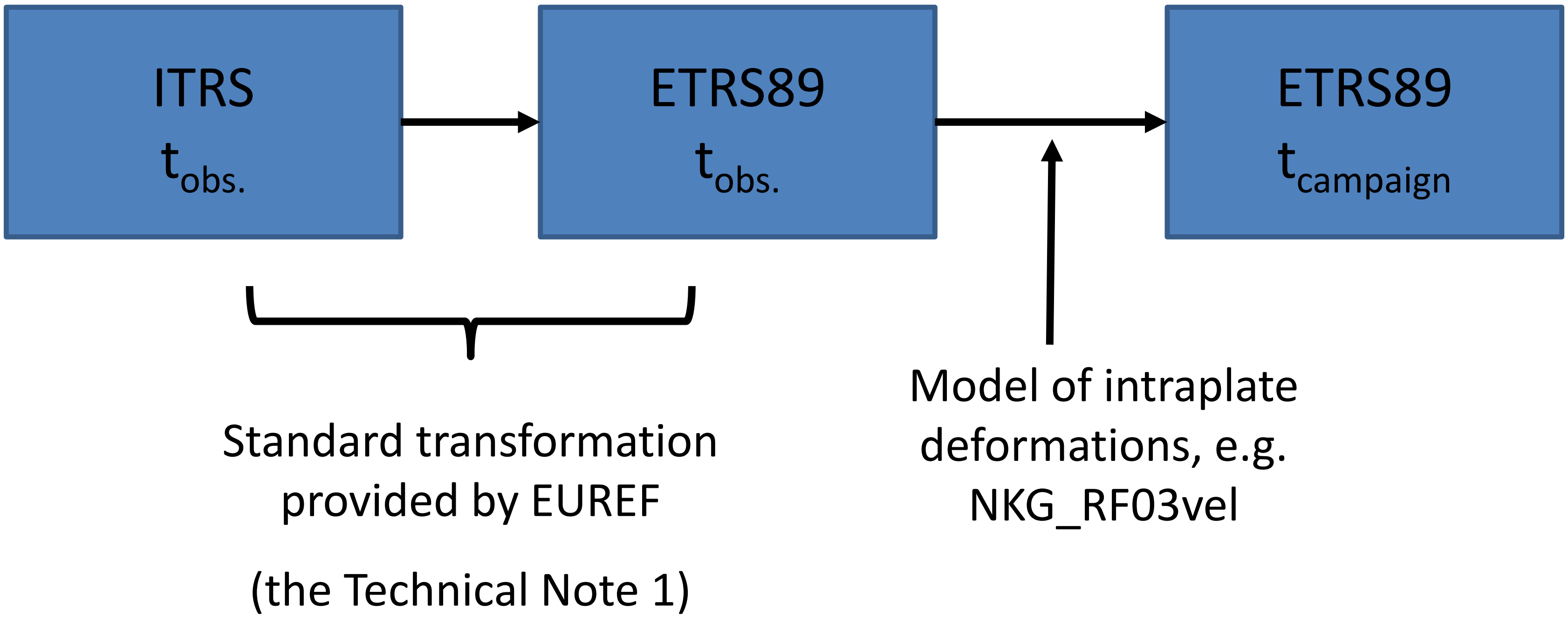
$$\begin{cases} \dot{X} = \dfrac{-Z}{R}\dfrac{X}{P}\dot{n} + \dfrac{-Y}{P}\dot{e} + \dfrac{X}{R}\dot{u} \\ \dot{Y} = \dfrac{-Z}{R}\dfrac{Y}{P}\dot{n} + \dfrac{X}{P}\dot{e} + \dfrac{Y}{R}\dot{u} \\ \dot{Z} = \dfrac{P}{R}\dot{n} + \dfrac{Z}{R}\dot{u} \end{cases}$$

Where: $R = \sqrt{X^2 + Y^2 + Z^2}$

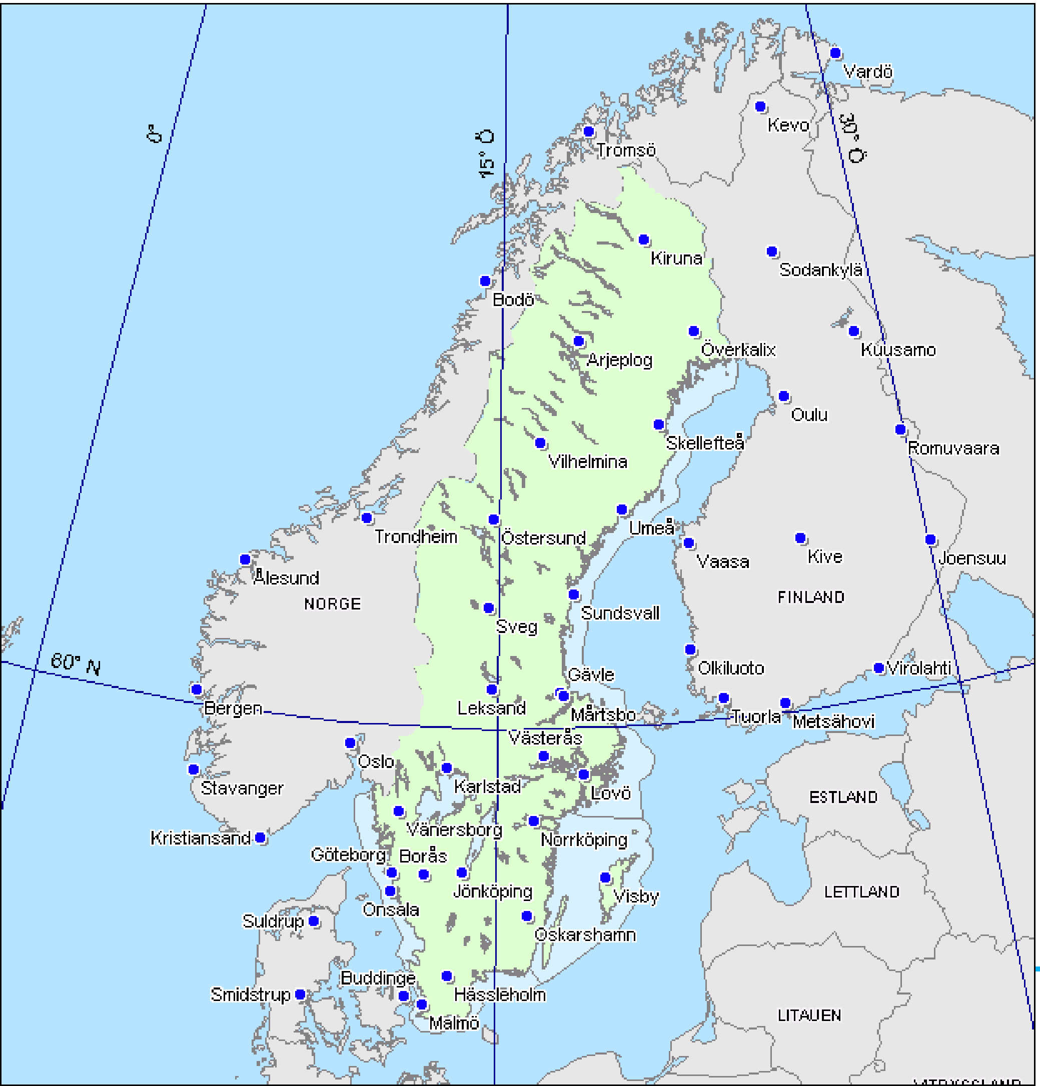
And: $P = \sqrt{X^2 + Y^2}$

(assuming a spherical earth)

Principle transformation scheme from ITRFs to national realization of ETRS89, (including deformation model)



Example from Sweden



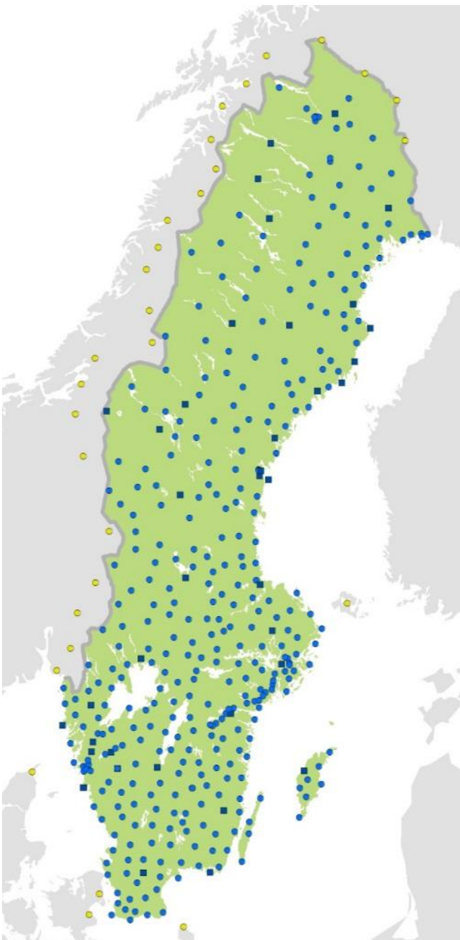
SWEREF 99

Epoch 1999.5

Class B densification of ETRS89 validated by EUREF

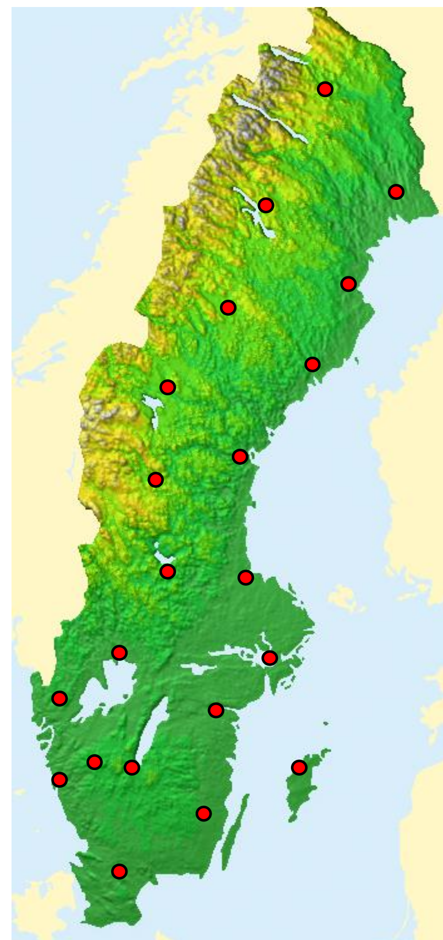
Used as the national geodetic reference frame in Sweden.

SWEPOS – the national CORS network in Sweden



Right:
The 21 Fundamental stations

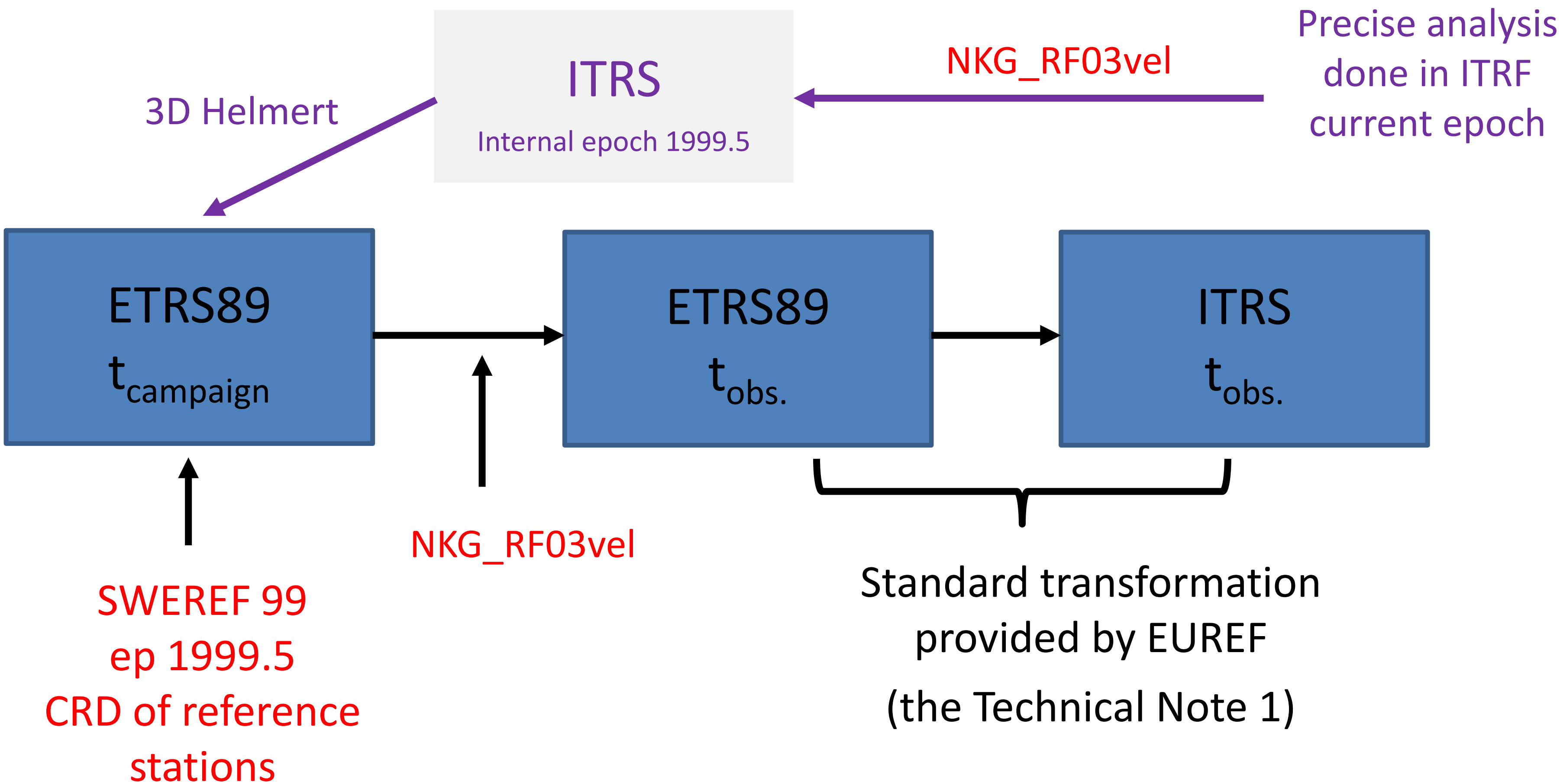
Left:
Some 400 stations for the RTK service



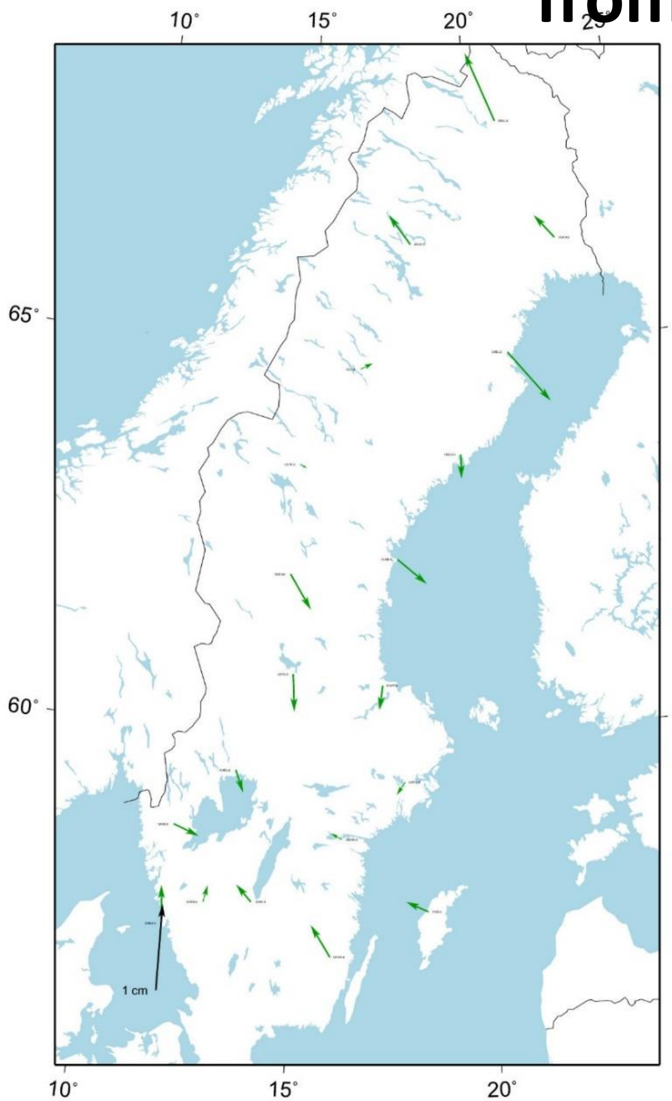
Also used for management of the geodetic infrastructure and the geodetic reference frame

Most (all?) precise applications in SWEREF 99 is done relative to the permanent GNSS stations!

Practical transformation scheme while connecting to known permanent GNSS stations – example SWEPOS



Agreement between a modern analysis using data from 2016, and SWEREF 99

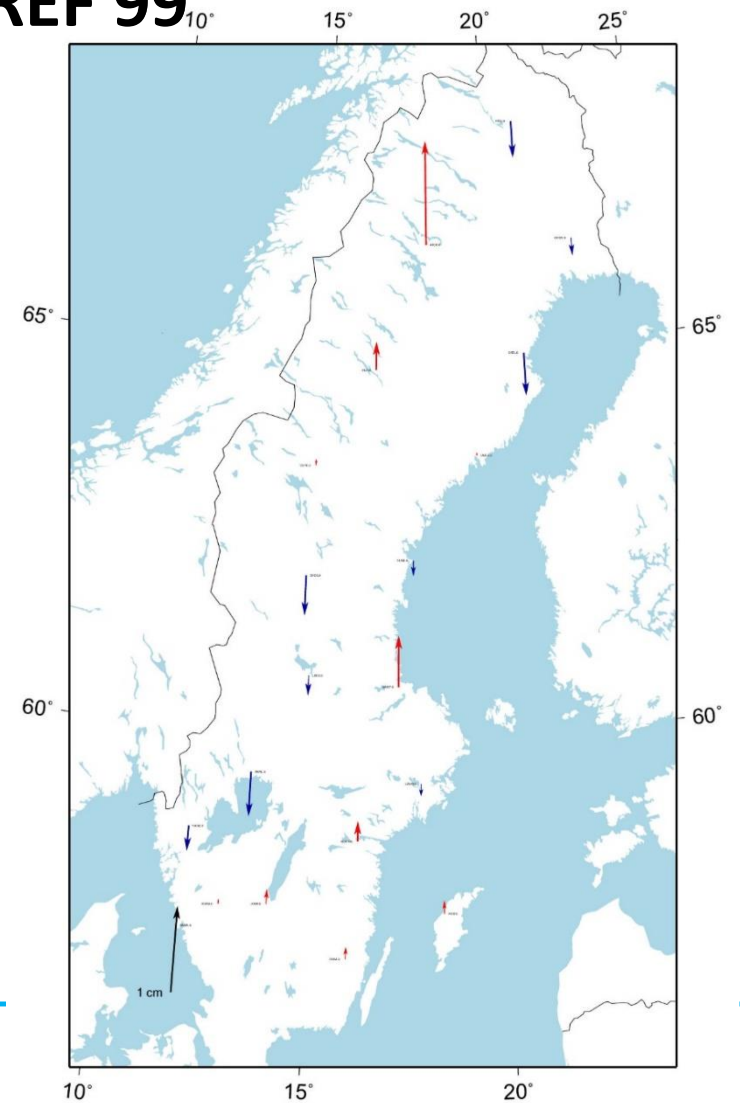


Statistics:

RMS (mm)
n : 3.5
e : 2.2
u : 4.1

Example from our internal weekly solution April 10-16, 2016

NKG_RF03vel model applied!



Thanks for your attention!

Discussions?