FIG Working Week 2008
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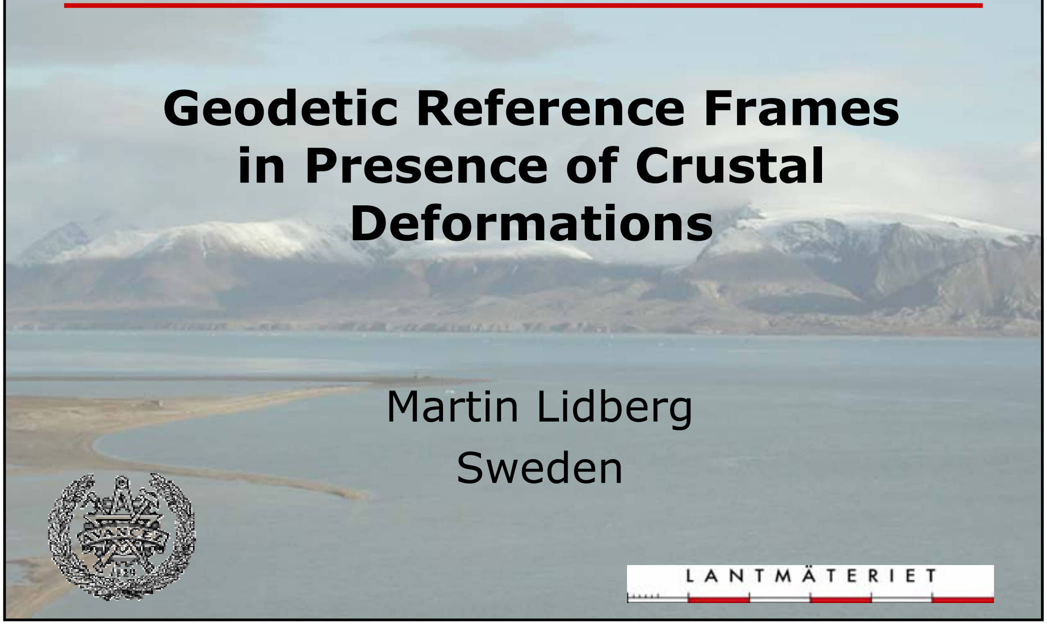

Geodetic Reference Frames in Presence of Crustal Deformations

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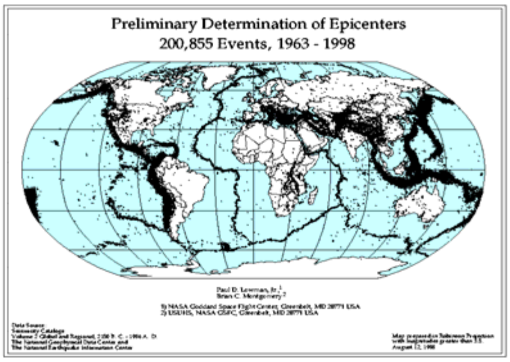
Sweden

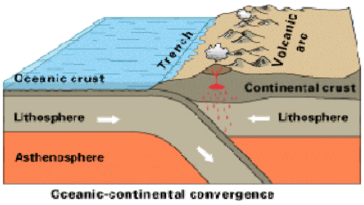
Outline

- Crustal deformations
- Consequences for reference frame management
- Principles for handling the problem
- Case study from the Nordic area
- Summary

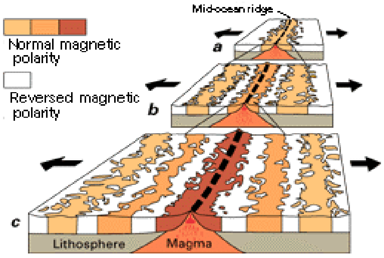
Our dynamic planet (1)



Earthquakes at borders between tectonic plates



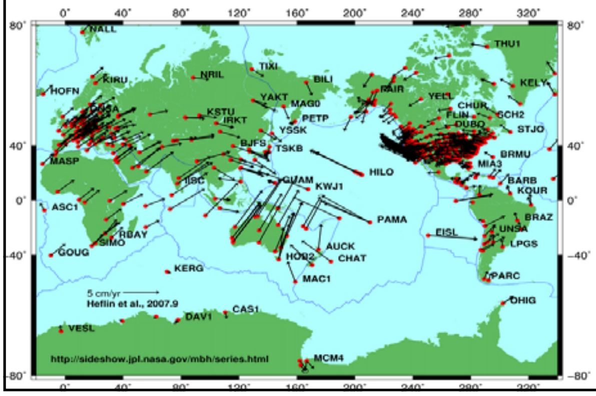
Subduction zone;
Oceanic Ridge

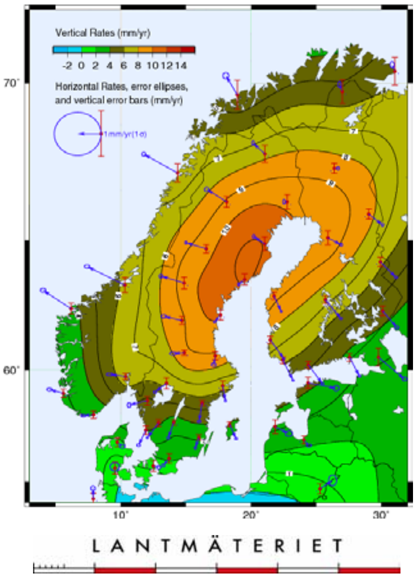


Our dynamic planet (2)

- The Fennoscandia Post Glacial Rebound →
- GPS-observed station velocities

↓





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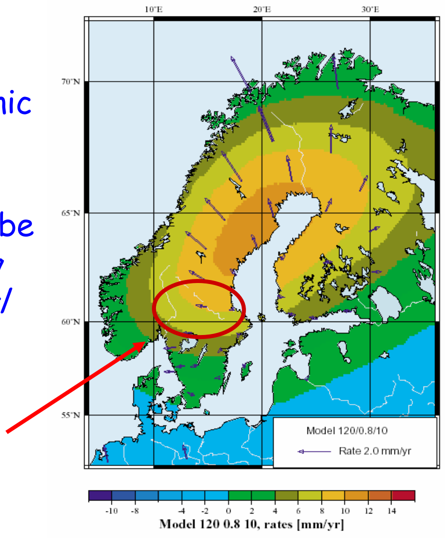
Glacial Isostatic Adjustment (GIA) - or how works the land uplift?

(From Bergstrand, 2002)

a) The relaxed earth
b) The earth surface are depressed due to the load from the (1-3 km) ice-sheet (100 000 yr).
c) The earth rebounds when the ice-load disappeared (10 000 yr)

Consequences for Management of Geodetic Reference Frame

- Position ***and*** velocities for global reference frames (e.g ITRFxx)
- Regional frames follow the tectonic plate in question (e.g ETRS89 in Europe)
- Intraplate deformations need to be considered (*frames defined using permanent GNSS stations several 100 km apart*)
- For Sweden, 1 cm degradation in positioning over 20 years if Fennoscandian GIA ignored!
- 25 M€ to change geodetic reference frame in Sweden.



Principles for handling the problem

- "Time tag everything!"
- National geodetic reference frame "stable in time" *(users happy!)* but with well defined epoch of validity
- Correct precise measurements from epoch of observation to epoch of the reference frame using a **Velocity Model**
- Estimate the crustal deformations - usually at permanent GNSS sites
- Develop a **Velocity Model** of the deformations *(to interpolate and filter the observed velocities).* Geo-physical model preferred!
- Never use estimated station velocities without modelling for "epoch transformation" !

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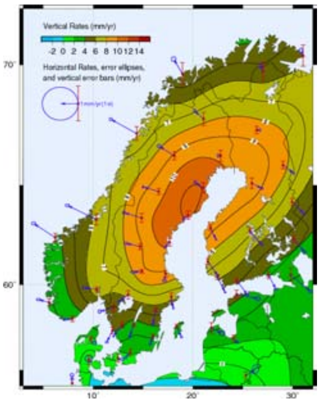
Case study: Nordic area

Official national ETRS89:

- Tectonic epoch 1989.0
- Internal deformations ignored (1 cm vertical, 2mm horizontal)

Country	epoch	based on ITRFxx
Denmark	1994.707	ITRF92
Finland	1997.0	ITRF96
Norway	1994.665	ITRF93
Sweden	1999.5	ITRF97



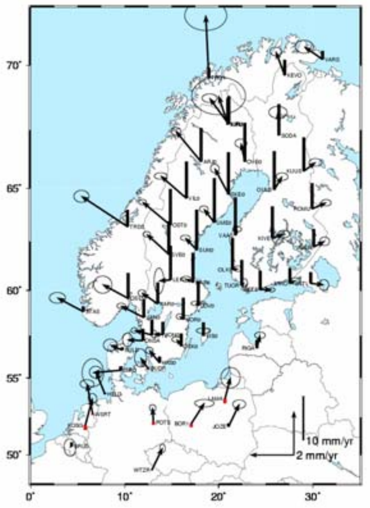
$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{Tepoch}^{ITRF\,2000} = \begin{pmatrix} Y \\ Y \\ Z \end{pmatrix}_{2003.75}^{ITRF\,2000} + (Tepoch - 2003.75) \begin{pmatrix} vX_{INTRA} \\ vY_{INTRA} \\ vZ_{INTRA} \end{pmatrix}_{MODEL}^{ITRF\,/\,ETRS}$$

BIFROST project

GNSS stations velocities

GNSS station velocities

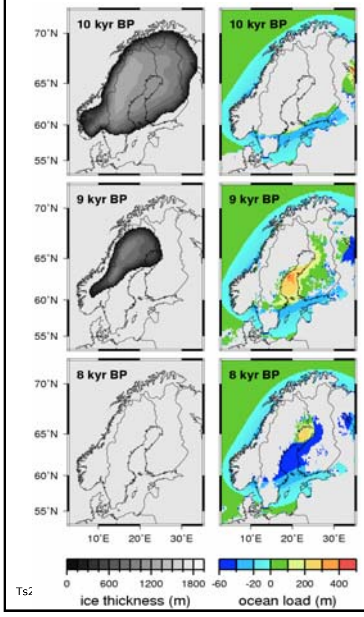
- 83 permanent GNSS sites in northern Europe
- Aug 1993–Oct 2006
- GAMIT/GLOBK software
- “checked” using GIPSY software
- *Details in the proceeding paper*



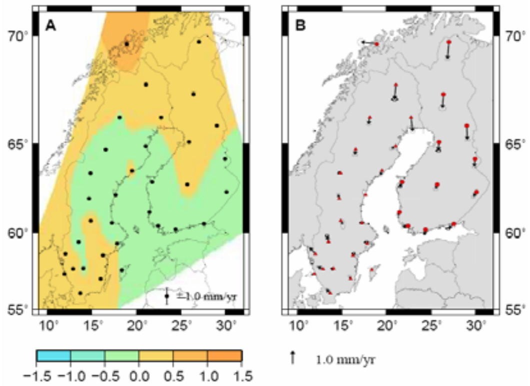
The BIFROST effort:

- Lantmäteriet
- Onsala Space Observatory
- University of Durham
- Finnish Geodetic Institute
- Toronto University
- Smithsonian CfA @ Harvard

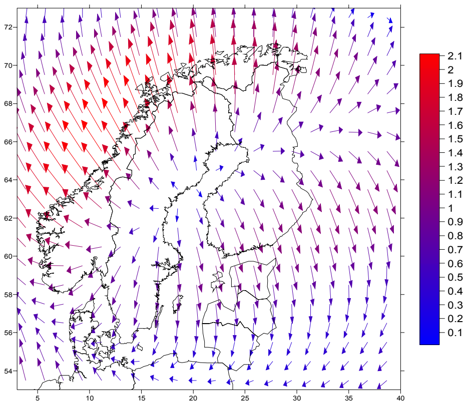
Glacial isostatic adjustment (GIA) model



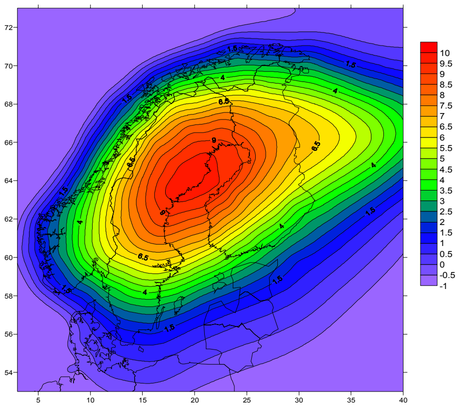
- Ice-load history model (Lambeck 1998)
- 3D GPS station velocities
- Find best fitting (0.5 mm/yr, 1σ) values of:
  - →Lithosphere thickness: 120 km
  - →upper mantle visc. 5×10^{20} Pas
  - →lower mantle visc. 5×10^{21} Pas



Velocity model in grid-format (*.gri)



Horizontal (0 to 2 mm/yr):
GIA model transformed to the
GPS station velocities

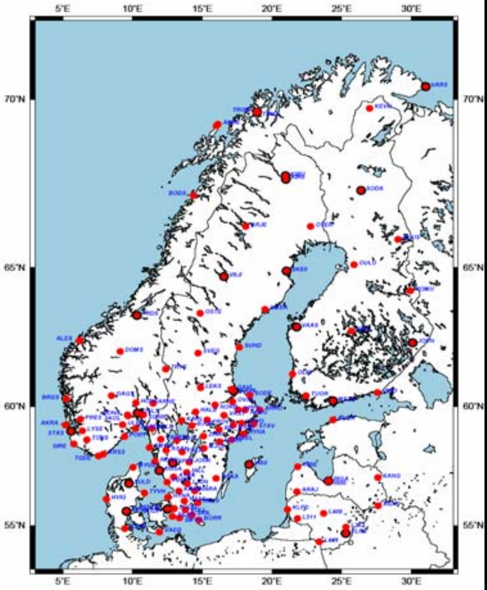


Vertical (-1 to 10 mm/yr):
NKG2005LU(ABS),
Based on: tide gauge, levelling, GPS
NKG w.g. Height determination

Common campaign to compare the Nordic ETRS89 realizations

Common GPS-campaign:

- "NKG 2003" (Nordic Geodetic Commission)
- 133 stations (Nordic and Baltic area – also Iceland, Greenland and Svalbard)
- GPS week 1238 (w 40, 2003)
- Software: GIPSY, GAMIT, Bernese
- Result in ITRF2000, ep 2003.75
- Coordinated by the NKG w.g. Positioning and Reference Frames

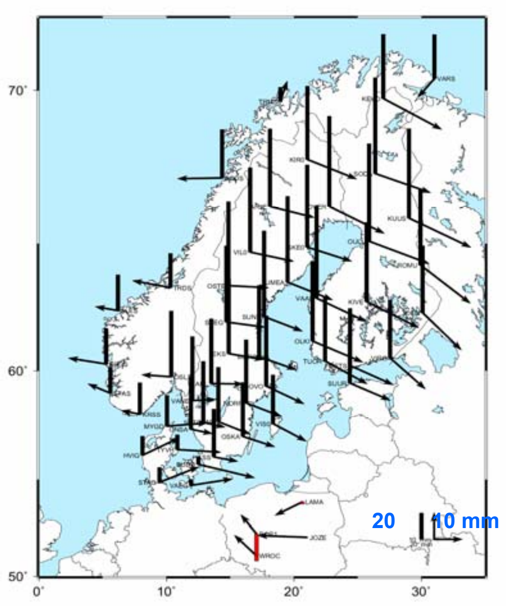


NKG 2003 vs. official ETRS89 realizations

The NKG 2003 GPS campaign

- in ETRS89
  (Boucher & Altamimi MEMO)
- Land uplift ignored
- compared to official national
  ETRS89 realizations

	Mean	RMS (mm)
north	- 4	7
east	9	14
up	42	48

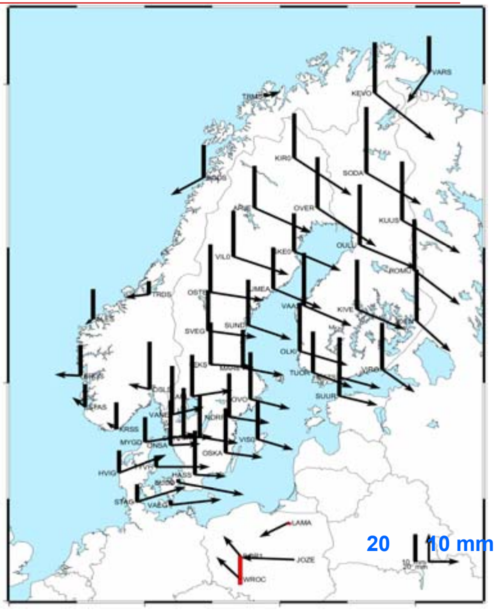


NKG 2003 vs. official ETRS89 (with internal deformations)

The NKG 2003 GPS campaign

- in ETRS89
  (Boucher & Altamimi MEMO)
- internal deformations reduced
  to year 2000 using the
  velocity models
- compared to official national
  ETRS89 realizations

	Mean	RMS (mm)
north	- 3	7
east	10	14
up	25	29

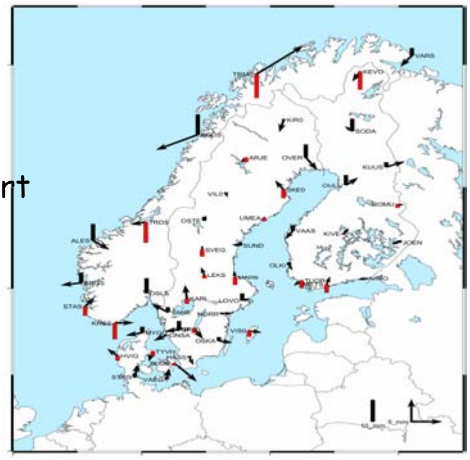


Each national ETRS89 transformed till NKG 2003

Internal deformations of
NKG 2003 GPS campaign
reduced to epoch 2000.0

Residuals after 7-parameter Helmert transformation:

RMS (mm)		**north**	**east**	**up**
Denmark	(1994.7):	2.5	2.0	1.8
Finland	(1997.0):	1.3	1.4	3.7
Norway	(1994.6):	2.7	3.9	7.5
Sweden	(1999.5):	1.5	1.3	2.5



Conclusion and outlook

- Crustal deformations must be considered in management of modern Geodetic Reference Frames
- Use a velocity model that **explain** (not only quantify) the crustal deformations
- Model of GIA in Fennoscandia **explain** station velocities based on GPS observations to the 0.5 mm/yr level (1σ) !
- Internal accuracy of the GPS campaigns fulfil ~1-2mm horizontal, and ~5mm vertical
- The challenge is not in the internal geometry of a GNSS network, but in intraplate deformations and reference frame realization!

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