Investigation of the difference between a preliminary national IHRS realisation for Sweden and the EVRS realisation RH 2000

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Background: IHRS and IHRF

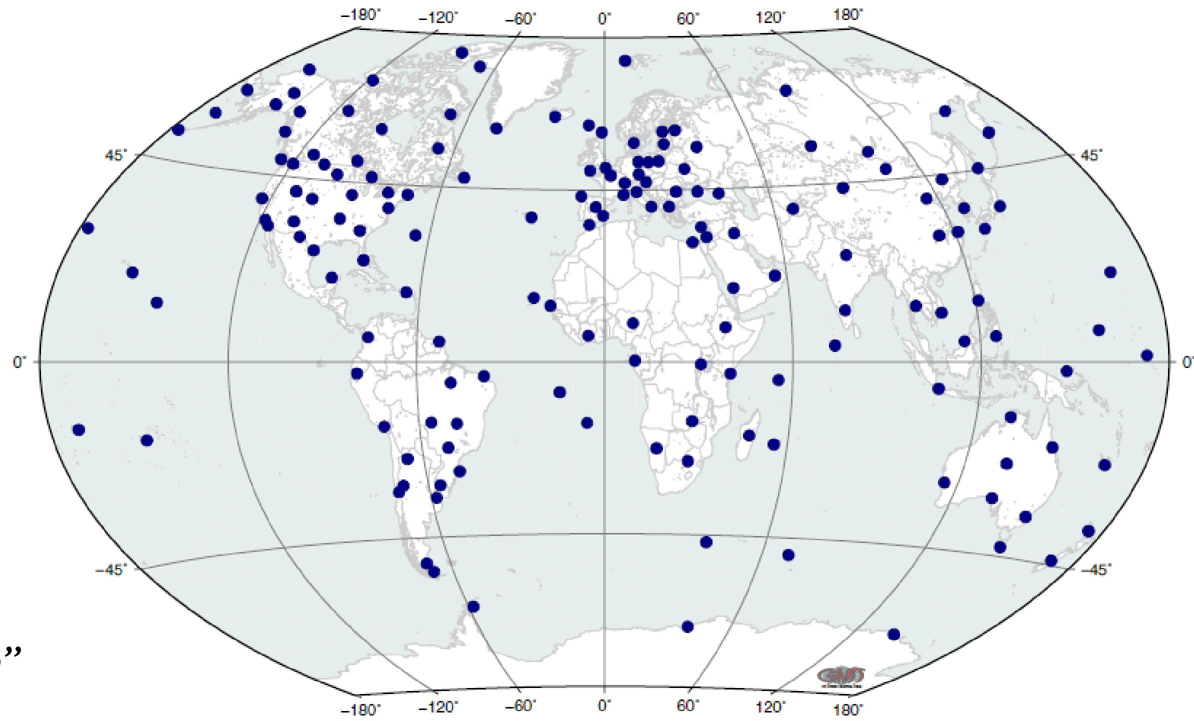
- The **International Height Reference System (IHRS)** was defined by the International Association of Geodesy (IAG) in 2015
- Since then, the international geodetic community is working on establishing the first **International Height Reference Frame (IHRF)**
- This frame will be realised primarily by **potential values** for the stations in the **global IHRF reference network**
- This, however, will not be sufficient for all practical use of IHRF, including the task to compute the best possible **transformations** to the existing regional/national height frames.
- There are currently only **three global stations** in the Nordic/Baltic region and there is only one such station in Sweden, **Onsala**
- IHRS will therefore have to be realised also by **national/regional realisations (densifications)** computed in accordance with the definition of IHRS and official conventions regarding the computation of IHRF

Global and national/regional realisation of IHRS

Sánchez, L., Ågren, J., Huang, J., Wang, Y.M., Mäkinen, J., Pail, R., Barzaghi, R., Vergos, G.S., Ahlgren, K., Liu, Q. (2021a) Strategy for the realisation of the International Height Reference System (IHRS), J Geod, 95(3). https://doi.org/10.1007/s00190-021-01481-0

IHRF will be "based on a worldwide homogeneously distributed set of reference stations including a **core network** and **regional/national densifications**"

- *"The **core network** has to be well materialized and maintained to ensure sustainability and long-term stability of the reference frame."*
- *"The **regional and national densifications** are to provide local accessibility to the global frame."*
- *"If regional ("quasi-)geoid models of high resolution are available, an IHRF reference station may be installed every 50 km or 100 km"*



Introduction

- The geopotential values *W(P)* of the **first static IHRF** will be computed based on
  - Spatial 3D-positions given in ITRF2014 with reference epoch 2021.04
  - Regional gravimetric (quasi-)geoid models or ultra-high degree EGMs (e.g., EGM2008, EIGEN-6C4, …)
- The method is specified in Sanchez et al. (2021b)

Sánchez, L., Huang, J., Ågren, J., Barzaghi, R., & Vergos, G. S. (2021b). Recovering potential values from regional (quasi-)geoid models (Vol. 1, Issue 6)

Purpose

❖ The main purpose of this presentation is to describe the computation of a **preliminary national IHRS realisation** (densification) for Sweden and investigate how it **differs from the modern Swedish height system RH 2000**

❖ The preliminary computation of the three **Nordic/Baltic stations** in the global core network is also presented and analysed

Preliminary computation of potentials for the three Nordic/Baltic stations (Onsala, Metsähovi and Riga)

- Laura Sanchez is coordinating the work with IHRF and asked us to compute potential values for the three Nordic/Baltic global stations based on NKG2015
- The computation was made using of the ***purely gravimetric version of the Nordic geoid model NKG2015*** (quasigeoid computed using $W_0 = 62\ 636\ 853.400\ \mathrm{m^2s^{-2}}$, zero tide concept and postglacial land uplift epoch 2000.0)
- The preliminary potential values for Onsala, Metsähovi and Riga (and Svetloe) were delivered January 11th, 2022
- This computation will be updated and finalized as soon as the FAMOS-BSCD geoid project has been properly finalised

Onsala global IHRF station

NKG2015 gravimetric quasigeoid model

- The NKG2015 **gravimetric model** was computed using zero permanent tide ~~system~~ concept, land uplift epoch 2000.0 and the zero-degree term with W_0 = 62 636 853.4 m^{2}s^{-2} below as follows:

$$\zeta^{NKG2015}_{grav,zero,2000} = \frac{(GM_{GGM} - GM_{\mathrm{GRS\,80}})}{r \cdot \gamma} - \frac{(W_{0,IHRF} - U_{\mathrm{GRS\,80}})}{\gamma} + \frac{R}{4\pi\gamma}\iint_{\sigma_0} S^M(\psi)\,\Delta g\, d\sigma + \frac{R}{2\gamma}\sum_{n=2}^{M}(s_n + Q_n^M)\,\Delta g_n^{GGM} + \zeta_{DWC} + \delta\zeta_{ATM} + \delta\zeta_{ELL}$$

- Note here that the **released version** of NKG2015 was computed as follows

$$\zeta^{NKG2015}_{released} = \zeta^{NKG2015}_{grav,zero,2000} + \zeta_{1\text{-}par.} + \Delta h_{zero \to non-tidal}$$

- To correct for the **postglacial land uplift** of Fennoscandia, the NKG2015 gravimetric model is now converted from epoch 2000.0 to 2021.04 using the geoid change model of NKG2016LU (Vestøl et al., 2016),

$$\zeta^{NKG2015}_{grav,zero,2021.04} = \zeta^{NKG2015}_{grav,zero,2000} + \dot{N}_{NKG2016LU}(2021.04 - 2000.0)$$

Geopotential values from height anomalies

- Geopotential values are recovered with the height anomaly from a pure gravimetric (quasi-)geoid model (Sánchez et al., 2021a, b).

$$W(P) = W_0 - \left(h(P) - \zeta(P)\right) \cdot \bar{\gamma}_{QQ_0}$$

where W_0 is the fixed reference potential value, h(P) is the ellipsoidal height, ζ(P) is the height anomaly and $\bar{\gamma}_{QQ_0}$ is the mean normal gravity between the ellipsoid and the telluroid, given by:

$$\bar{\gamma}_{QQ_0} = \gamma_0 \cdot \left(1 - \frac{1}{a} \cdot \left(1 + f + m - 2f \cdot sin^2\varphi(P)\right) \cdot \left(h(P) - \zeta(P)\right)\right)$$

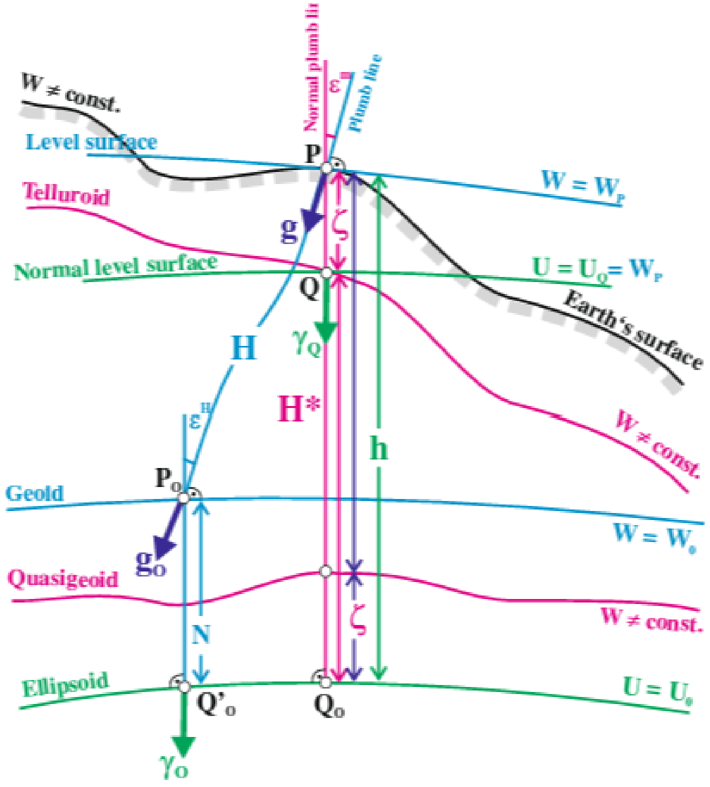
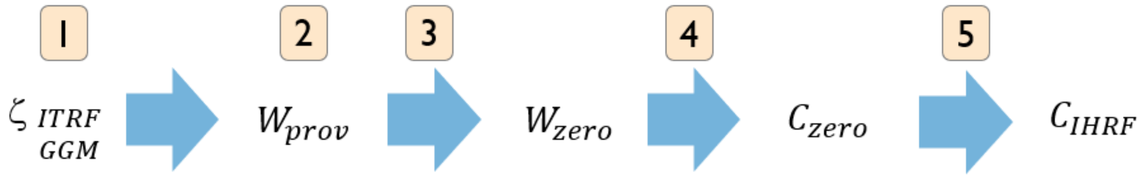


Figure from Sanchez et al. (2021a)

- The potential values are finally converted from to the mean permanent tide concept following Mäkinen (2021) as specified in Sanchez et al. (2021a,b),



Potential values delivered to Laura Sanchez January 11, 2022

- Potential values, geopotential numbers and normal heights in IHRF computed based on the **gravimetric NKG2015 quasigeoid model**

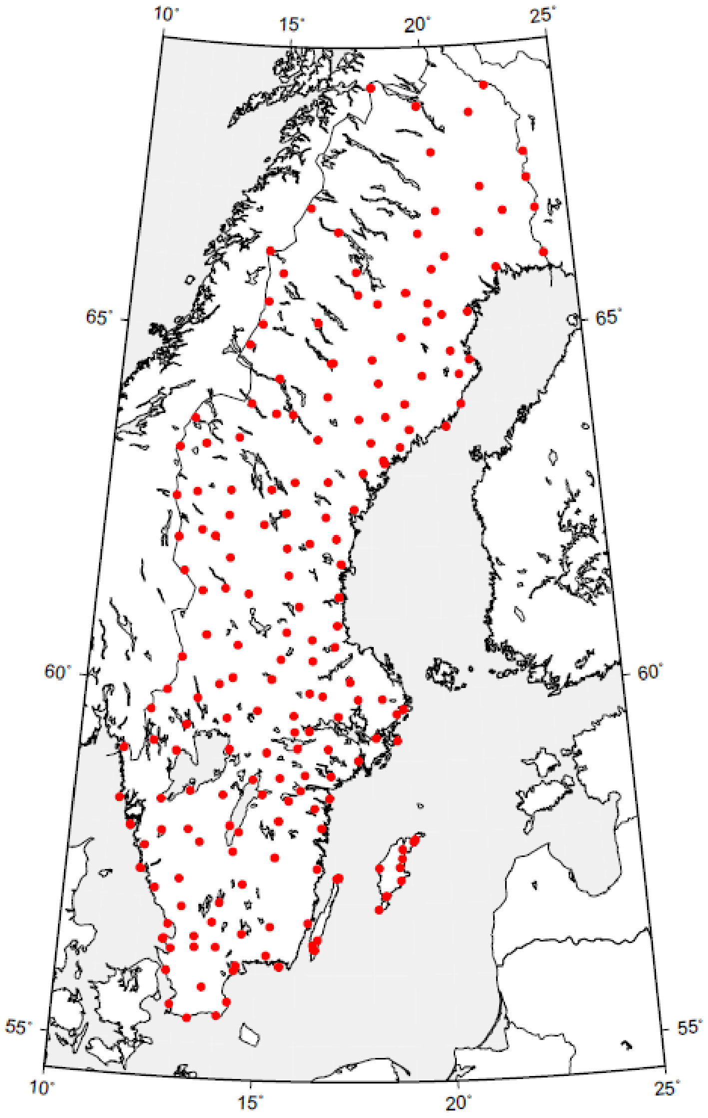
Station	ITRF2014, epoch 2021.04			NKG2015 (zt, 2021.04)	IHRF (Sanchez et al., 2021a, 2021b)		
	Latitude [Deg.]	Longitude [Deg.]	Ell. Height [m]	Height anomaly [m]	Normal height [m]	Geopotential number [m^2s^{-2}]	Potential [m^2s^{-2}]
METG10503	60.24196776	24.38417794	59.6998	19.1768	40.5709	398.378	62636455.022
RIGA12302	56.94862159	24.05877914	34.7296	21.3082	13.4634	132.166	62636721.234
ONSA10402	57.39530102	11.92552194	45.6181	36.8232	8.8377	86.760	62636766.640
SVTL12350	60.53286384	29.78088118	76.7160	15.7246	61.0398	599.380	62636254.020

- Comparison with normal heights computed using the **preliminary FAMOS LM7F quasigeoid model** (Swedish computation centre)

Station	IHRF (Sanchez et al., 2021a, 2021b)		
	Normal height from NKG2015 [m]	Normal height from FAMOS LM7F [m]	Difference [m]
METG10503	40.5709	40.5638	0.0071
RIGA12302	13.4634	13.4624	0.0010
ONSA10402	8.8377	8.8409	-0.0032
SVTL12350	61.0398	61.0281	0.0117

Preliminary pointwise national realisation

- Computed using high-quality GNSS and a gravimetric geoid model (using the above methodology)
- The following data and models are used:
  - 196 high-quality GNSS/levelling observations given in SWEREF 99 and RH 2000
    - ❖ 48 hours observation time, processed in Bernese software, etc.
    - ❖ Dorne Margolin antennas
  - NKG 2015 gravimetric quasigeoid model (version modified in 2017 with some additional Swedish gravity data)
  - The SWEREF 99-ITRF 2014 transformation including the velocity model NKG_RF17vel (Häkli et al., 2016; Lantmäteriet, 2021)
  - The land uplift model NKG2016LU including the geoid change model (Vestøl et al., 2016)



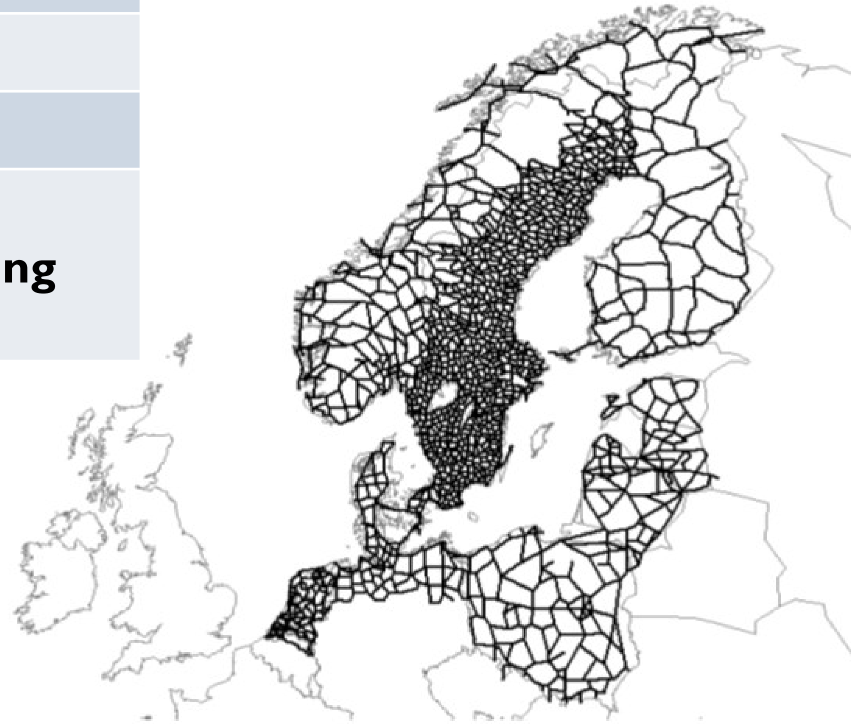
Difference between IHRS/IHRF and EVRS/RH 2000

	IHRS/IHRF	EVRS/RH 2000
Zero level	**W_0 = 62 636 853.4 m^{2}s^{-2}**	**NAP**
Permanent tide	**Mean**	**Zero**
Land uplift epoch	**2021.04***	**2000.0**
Primary way of realisation	**Space geodesy and gravity field (geoid) modelling**	**Geodetic levelling**

**) The epoch of IHRF is so far only implicitly defined by the epoch of the provided ITRF2014 coordinates*

- Difference between the normal heights of (preliminary) IHRF and RH 2000 in the global station Onsala:

$$\Delta H_{IHRF-RH\ 2000} = H^N_{IHRF} - H^N_{RH\ 2000} = 8.8377 - 9.166 = -0.3283 \text{ m}$$



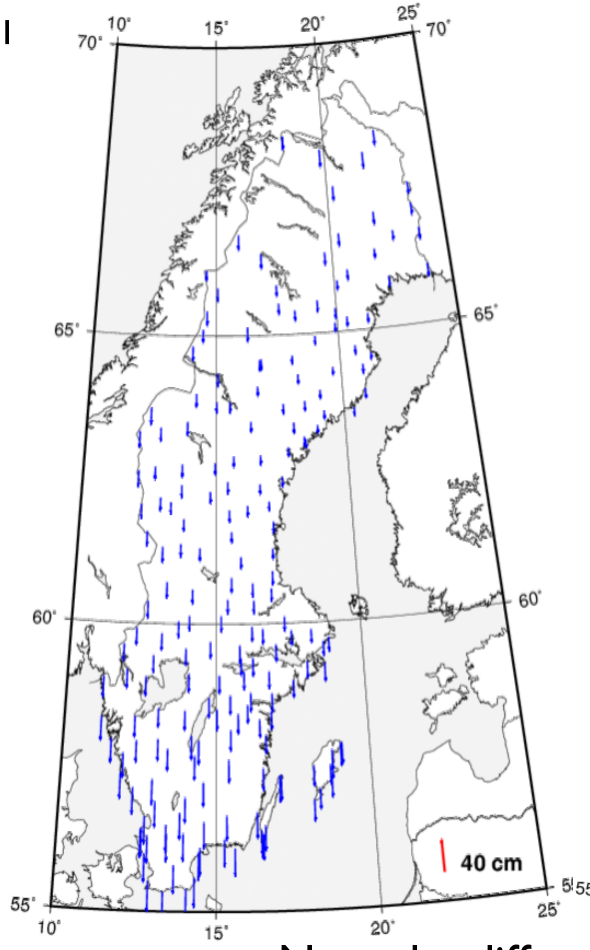
Baltic Levelling Ring (BLR)

Difference between IHRF and RH 2000

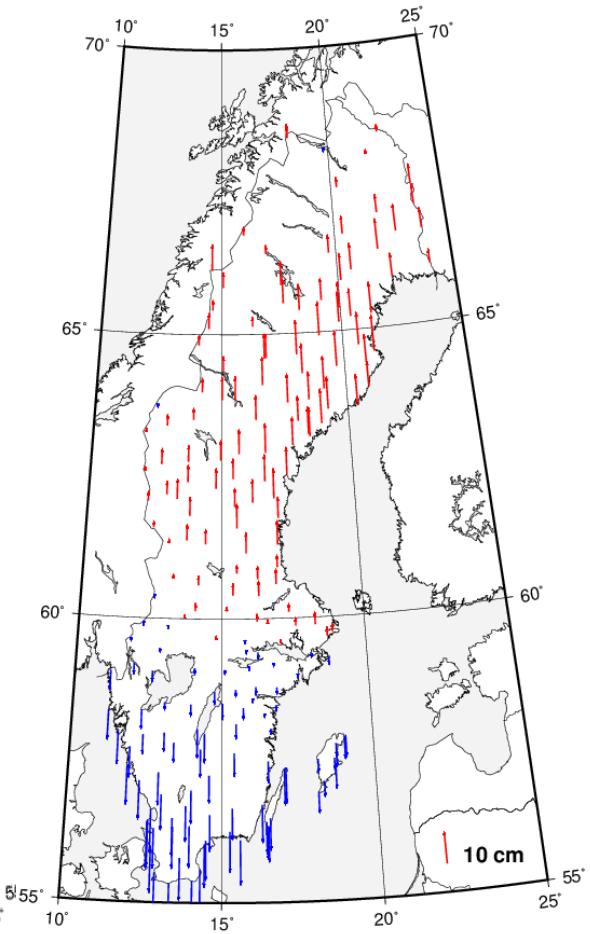
The potential numbers are converted to normal heights prior to the comparison

	Diff [mm]	IHRF shifted +207.9 mm [mm]
# Points	196	196
Mean	**-207.9**	0.0
Min	-385.0	-177.1
Max	-96.8	111.1
StdDev	75.2	75.2
RMS	221.0	75.0

Total difference



Difference after shifting IHRF with +207.9 mm



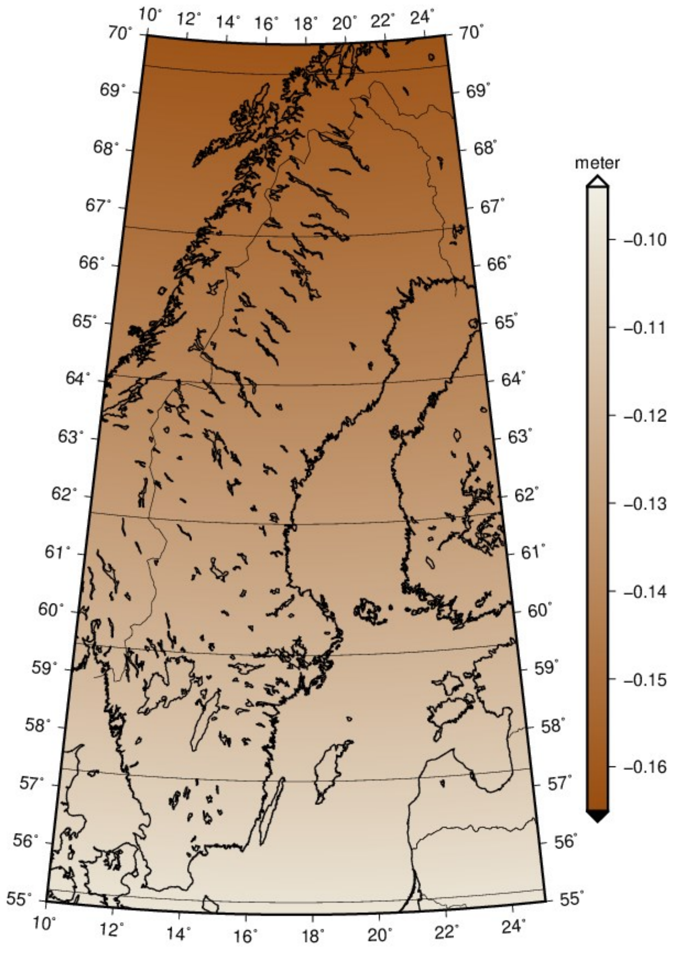
Note the different vector scales!

The differences are mainly due to different

- permanent tide concepts
- postglacial land uplift epochs
- zero levels

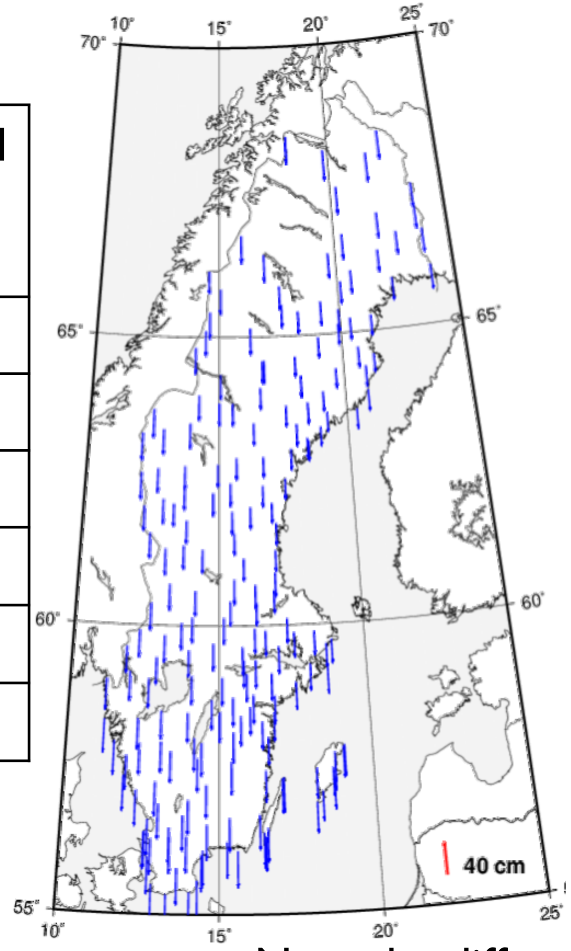
Difference between IHRF and RH 2000 after reduction of permanent tide effect

Permanent tide correction

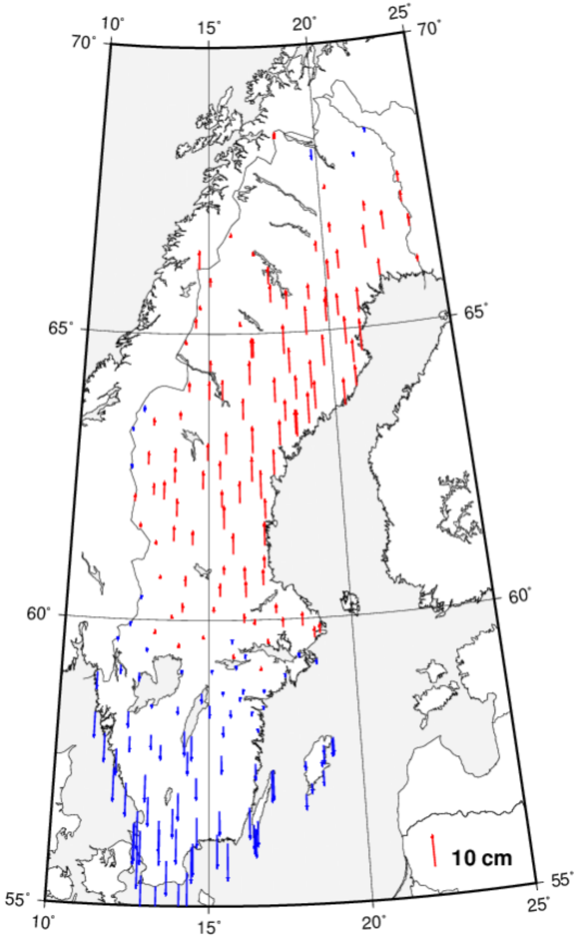


	Diff [mm]	IHRF shifted +334.2 mm [mm]
# Points	196	196
Mean	**-334.2**	0.0
Min	-486.5	-152.3
Max	-238.5	95.7
StDev	62.7	62.7
RMS	340.0	62.6

Difference



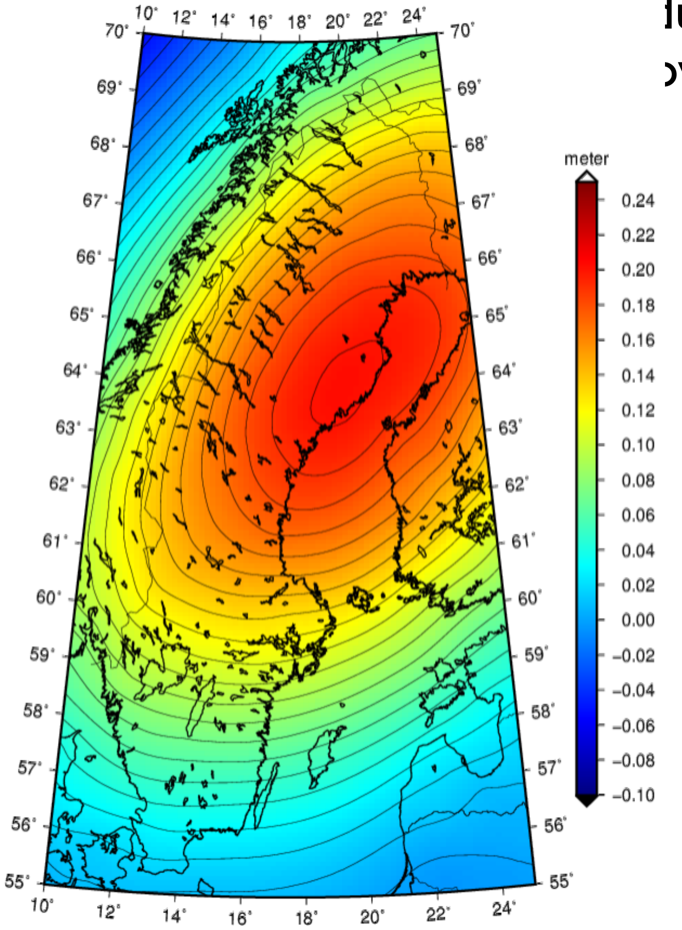
Difference after shifting IHRF with +334.2 mm



Note the different vector scales!

Difference between IHRF and RH 2000 after reduction of permanent tide and land uplift effects

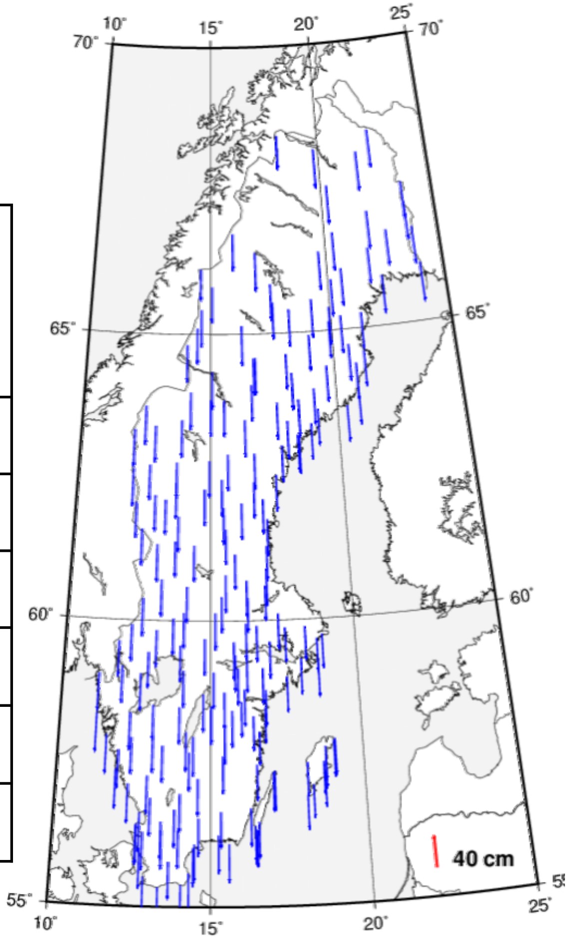
NKG2016LU_LEV (21.04 years)



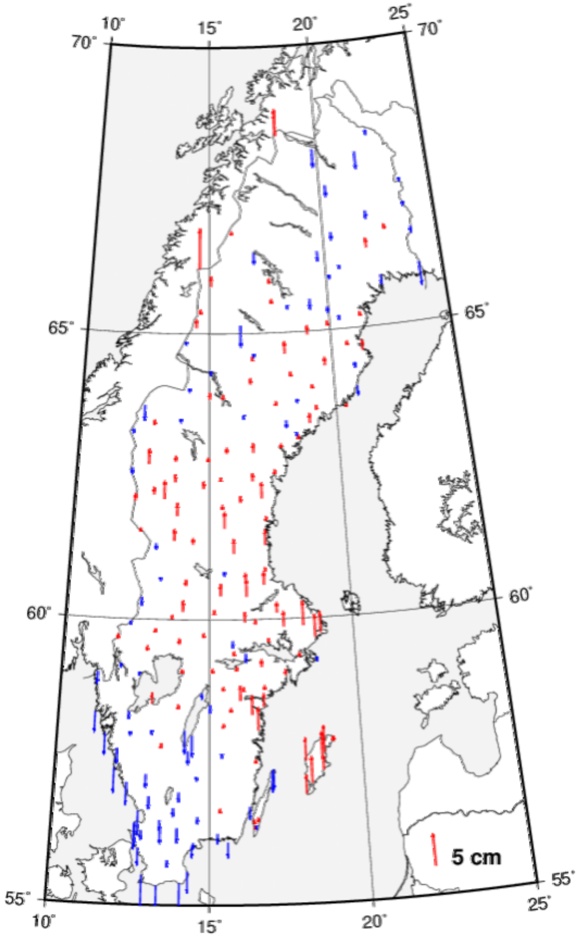
The land uplift during 21.04 years is
luced by subtracting the values
wn to the left.

	Diff [mm]	IHRF shifted +454.5 mm [mm]
# Points	196	196
Mean	**-454.5**	0.0
Min	-504.5	-50.0
Max	-392.5	+62.0
StDev	19.0	19.0
RMS	454.9	19.0

Difference



Difference after shifting IHRF with +454.5 mm



Note the different vector scales!

Discussion

- The main part of the difference between preliminary IHRF and RH 2000 is due to the different permanents tide concepts, postglacial land uplift epochs and zero levels
  - After correcting for these effects, the remaining residuals are close to the existing smooth residual surface used for the Swedish height correction model SWEN17_RH2000
  - The standard deviation for the difference is reduced from 0.0752 m to 0.0190 m after permanent tide and land uplift correction
- The corresponding mean differences are –0.2079 m and –0.4545 m, respectively
  - The absolute value of the mean difference thus increases when the corrections in question are applied
- The (uncorrected) minimum and maximum differences are –0.3850 and –0.0968 m,
  - After another 10 years of land uplift, the difference will reach zero along the northern coast of the Gulf of Bothnia
- The difference in the global IHRF station Onsala (–0.3283 m) is not very representative for the whole of Sweden

Outlook

- This work was made as an early step in the PhD project of Anders Alfredsson (financed by Lantmäteriet, at HiG, with Jonas Ågren as main supervisor)
- Next, the focus will mainly be on
  - how precise levelling can/should be utilised to improve a national/regional realisation
  - gravimetric gravity field modelling for IHRS realisation
  - recommendations for regional and national realization (densification) of IHRF (and transformations)
  - a possible regional Nordic/Baltic NKG realisation? (we should discuss this)