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Simplified transformations from ITRF2014/IGS14 to ETRS89 for maritime applications

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1 Summary

Simple transformations using the 7-parameter transformation model between ITRF2008 current epoch and ETRS89 have been developed for the epochs 2012-2015 on request by maritime surveyors [Jivall 2012].

This PM presents an update with respect to the latest frame (ITRF2014) and the yearly epochs between 2015.5 – 2022.5.

The formulas are valid for maritime applications, but could also be used on land except for the central part of the Fennoscandian land uplift area.

Three sets of transformations have been defined – one for the stable part of Europe, excluding the Fennoscandian land uplift area, one for the Baltic Sea and one for southern part of Sweden (valid south of the line Oslo – Gävle) including lake Vänern. Yearly parameters have been estimated for year 2015-2022.

The general standard uncertainty of the transformation formulas is 1-3 cm in the chosen ETRF representing ETRS89, but national differences as well as some special areas like the Norwegian fjords and eastern Mediterranean get considerably larger differences. Maps with residuals give a hint of these areas. The effect of the plate tectonics would add up to 1.5 cm in horizontal if the epoch differs half a year from the specified epochs (which are defined in the middle of the summer, i.e. July 1st).

2 Introduction

Positions determined by the GNSS method Precise Point Positioning (PPP) are in the same reference frame as the orbits, i.e. usually a realization of ITRS[1], e.g. ITRF[2]yy, IGS[3]yy or WGS84[4], where "yy" represents the year of the realization. The coordinates change with time in the ITRS realizations, because of the plate tectonics – see Figure 1. Hence, the determined coordinates are given in the epoch of the observations.

Such ITRF coordinates could also be achieved by relative measurements from stations in the IGS-network.

For practical applications like mapping and referencing spatial data, a static system/frame, which does not change with time, is desired. For this purpose,

[1] International Terrestrial Reference System

[2] International Terrestrial Reference Frame

[3] International GNSS Service, IGS has own realizations of the ITRF

[4] World Geodetic System 1984, used by GPS

ETRS89 has been developed for Europe. ETRS89 coincides with ITRS at epoch 1989.0.

WGS84 has been connected to ITRS since 1994 and the latest update (October 2013) is aligned to ITRF2008, but we expect WGS 84 to be aligned to ITRF2014/IGS14 in the near future.

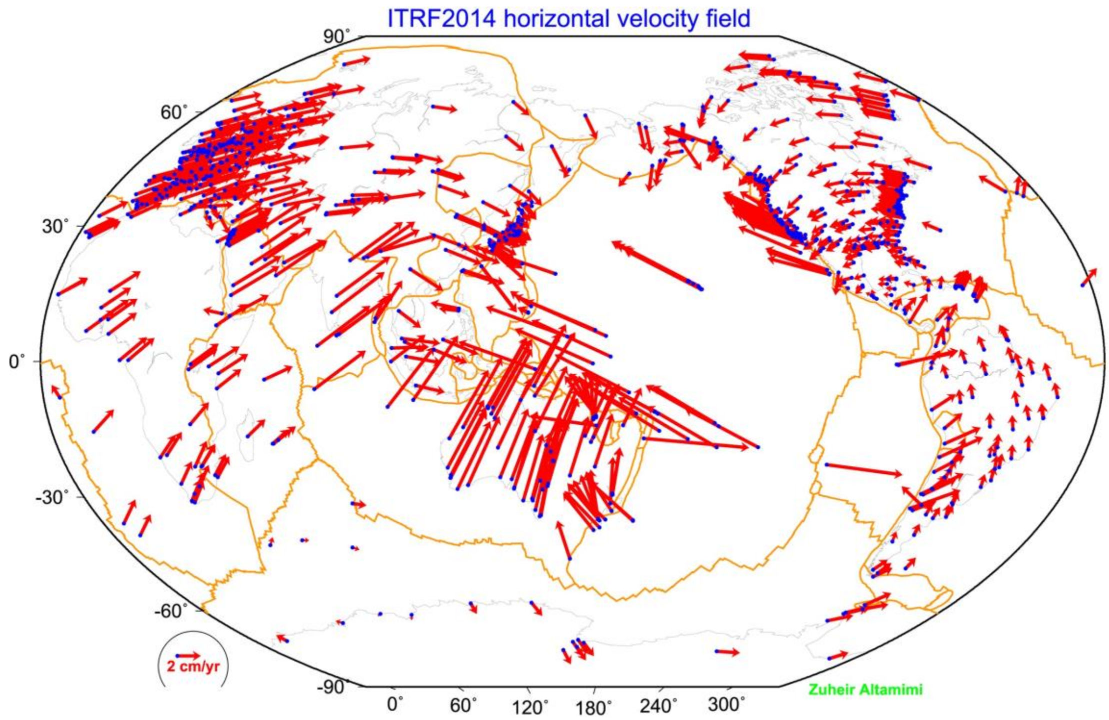

Figure 1: The plate tectonics described by the ITRF2014 velocity field [Altamimi et. al. 2016].

In [Altamimi 2017] the official EUREF-transformation from ITRFyy epoch yyyy.y to ETRFxx epoch yyyy.y is described. This transformation does not take the internal velocities within the European plate into account, i.e. the epoch yyyy.y remains. This means that stations close to the land uplift maximum will get errors up to 2 dm in height when transforming from a recent epoch (2018) in ITRF to ETRS89, compared to the Swedish or Finnish realization of ETRS89.

For the Nordic and Baltic area transformations from ITRF to the national ETRS89 realizations have been developed within the Nordic Geodetic Commission (NKG) [Häkli et. al. 2016, Nørbech et. al. 2006]. These transformations use grid files for interpolation of the deformations caused by the postglacial rebound. The vertical part of this model is shown in Figure 2.

For some applications, the official EUREF-transformation according to [Altamimi 2017] without taking internal deformations into account, is not sufficient and at the same time it is not possible to handle a gridded land uplift model. The request from maritime users is to use the 7-parameter similarity transformation (3D-Helmert-tranformation), which easily could be implemented. To account for the plate tectonics and the land uplift, different parameters could be solved for different years.

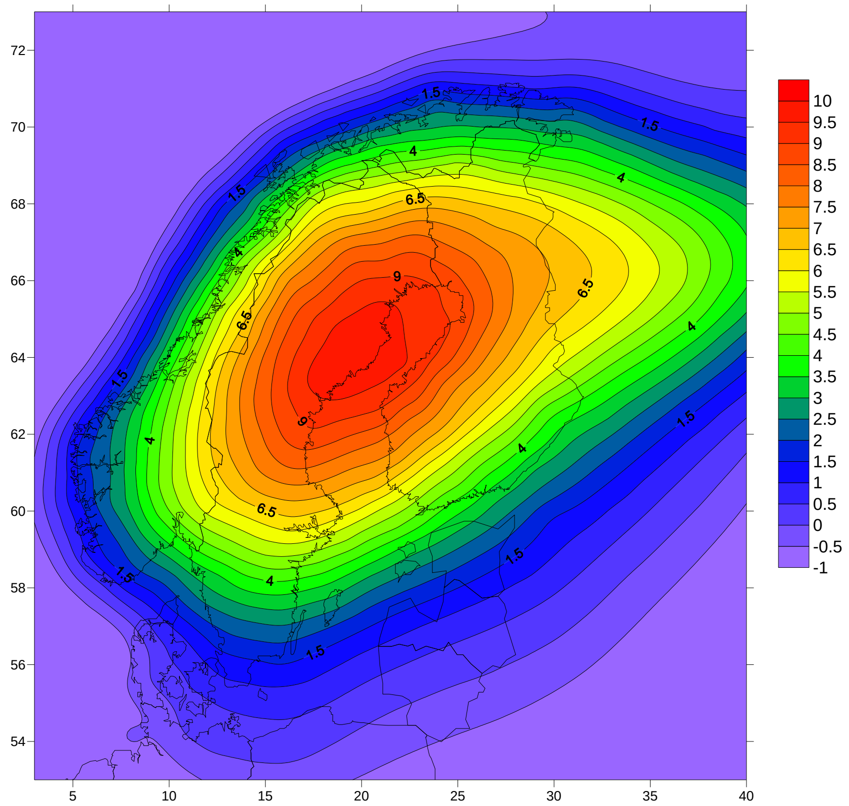

Figure 2: The vertical land uplift model NKG2005LU(ABS).

3 ITRF2014 and IGS14

ITRF2014 is today (2018) the latest realization of ITRS. It was released in January 2016 and the IGS-version of it, IGS14, was introduced into IGS- and EPN-processing in GPS-week 1934 (January 2017). This means that the IGS-products (orbits and clocks used e.g. for PPP) from this date are in IGS14.

IGS has adjusted each ITRFyy to be consistent with the GNSS-solutions. For the three latest ITRFs (ITRF2005, ITRF2008, ITRF2014) adjustments have also been made for the new antenna tables that have been introduced. The GPS-component for ITRF2014 has been processed with antenna models in the table igb08.atx, but when introducing the new frame into the IGS- and EPN-processing, a new updated antenna table, igs14.atx, is used. Stations with an updated antenna model have also got updated coordinates in IGS14 compared to ITRF2014.

In other words, IGS14 – the IGS-version of ITRF2014 – is fully consistent with the latest official antenna models (igs14.atx). When performing PPP with IGS-products and using antenna models from igs14.atx, the result will be in IGS14.

IGS14 does just have coordinates for IGS-stations fulfilling certain criteria on data span and number of discontinuities. The number of stations around the Baltic Sea, which is affected by the post glacial rebound, was not sufficient for estimating transformation parameters in this area. Therefore, the latest available EPN-densification of IGS14 (EPN_A_IGS14_C1980) was used for the realization of IGS14/ITRF2014.

EPN_A_IGS14_C1980 consists of coordinates and velocities for so called class A-stations. These are stations that could be used as reference stations for ETRS89 densifications. They should have at least 2 years of data and a velocity uncertainty less than 0.5 mm/yr in all components. Some stations have more than one set of coordinates. The reason for this is usually equipment change at the station that has introduced a shift into the coordinate time series. The most recent interval for each station has been used for the estimation of transformation parameters.

4 National ETRS89 coordinates and ETRFxx based on EPN-solutions

The ETRS89 is based on ITRS and is tied to the stable part of Europe. ETRS89 coincide with ITRS at epoch 1989.0. For each ITRFyy there exists a corresponding ETRFyy, but for realizations after ITRF2000, EUREF Governing board (GB) recommends the use of ETRF2000 as a conventional frame, e.g. ETRF2000(R08) is the corresponding ETRF to ITRF2008. For ITRF2014, EUREF GB leaves two options, either continue to use the recommended conventional frame ETRF2000 or to use the new ETRF2014. The origin of ETRF2014 coincides with the origin of ITRF2014, which is an advantage in some applications, but when the agreement between neighbouring countries is of concern, like geo-referencing, it is better to use ETRF2000. The coordinate differences between ETRF2014 and ETRF2000 may reach up to 7 cm.

The national realizations of ETRS89 are based on different ITRFs/ETRFs and have been established during a period of almost 20 years. Before the conventional frame ETRF2000 was introduced, there was often a shift between the ETRFs that could be up to a couple of cm in the more peripheral parts of Europe. In addition to this, the epoch of the observation campaign is important for areas which do not belong to the stable part of Europe (e.g. Fennoscandia). Furthermore, some countries have updated their coordinates when the old ones have become obsolete, e.g. by antenna replacement, while others have not.

This means that the national ETRS89 realizations do not form a fully homogeneous system, although it for many practical applications could be considered as one system. Furthermore, many national frames are not defined by any EPN-sites.

The IGSyy/ITRFyy solutions from the processing of the EPN-network, e.g. EPN_A_IGS14, could of course also be transformed with the EUREF-transformations [Altamimi 2017] to the conventional frame ETRF2000.

ETRF based on EPN-solutions is a more homogenous and updated system with a better coverage than the combination of the national realizations. For this reason, ETRF derived from EPN-solutions is a better choice to be used for the estimation of transformation parameters. However, in the end, ETRS89 is for many users usually understood as their national realization. Hence it is important to choose the ETRF-solution(s), for the estimation of transformation parameters, in such a way that the differences to the national realizations are small.

National ETRS89 coordinates for EPN-stations are available on the EPN web, if such exist and have been submitted to EUREF. These are used for the initiative "Monitoring of official national ETRF coordinates on EPN web" [Brockmann 2009].

In [Jivall 2012] it was concluded to have two areas with different sets of transformation parameters – one for central Europe and one for the Baltic Sea.

The national ETRS89 coordinates were downloaded from http://pnac.swisstopo.admin.ch/divers/etrf_monitor/ and the last/valid interval for all points were studied to decide the most suitable ETRFyy and epoch to represent ETRS89 for each area (central Europe and the Baltic Sea). There were not so many changes in the national ETRS89 coordinates since 2012, so it ended up with the same frames as in [Jivall 2012].

For central Europe, the median epoch of the available national realizations is 2007. Many of the realizations are also based on the conventional frame ETRF2000. Hence **ETRF2000 epoch 2007.0** was chosen to represent the national ETRS89 in central Europe.

The Swedish and Finnish national ETRS89 realizations, which have the longest coast line along the Baltic Sea and are most affected by the post glacial rebound, are based on ETRF97 epoch 1999.5 and ETRF96 epoch 1997.0, respectively. **ETRF97 epoch 1998.5** was chosen to represent ETRS89 in the area around the Baltic Sea.

To give an idea about the differences between the national realizations and the selected frames, plots with differences are presented in Figure 3 – Figure 6. In case of METS in Figure 6, the official national coordinates have not been updated for the antenna replacement in 2010. The official ETRS89 coordinates for Riga have quite large difference in height compared to ETRF97 epoch 1998.5. One part of the explanation is that the Latvian ETRS89 realization is based on ETRF2000, which has approximately 1-2 cm difference in height compared to ETRF97 in this area.

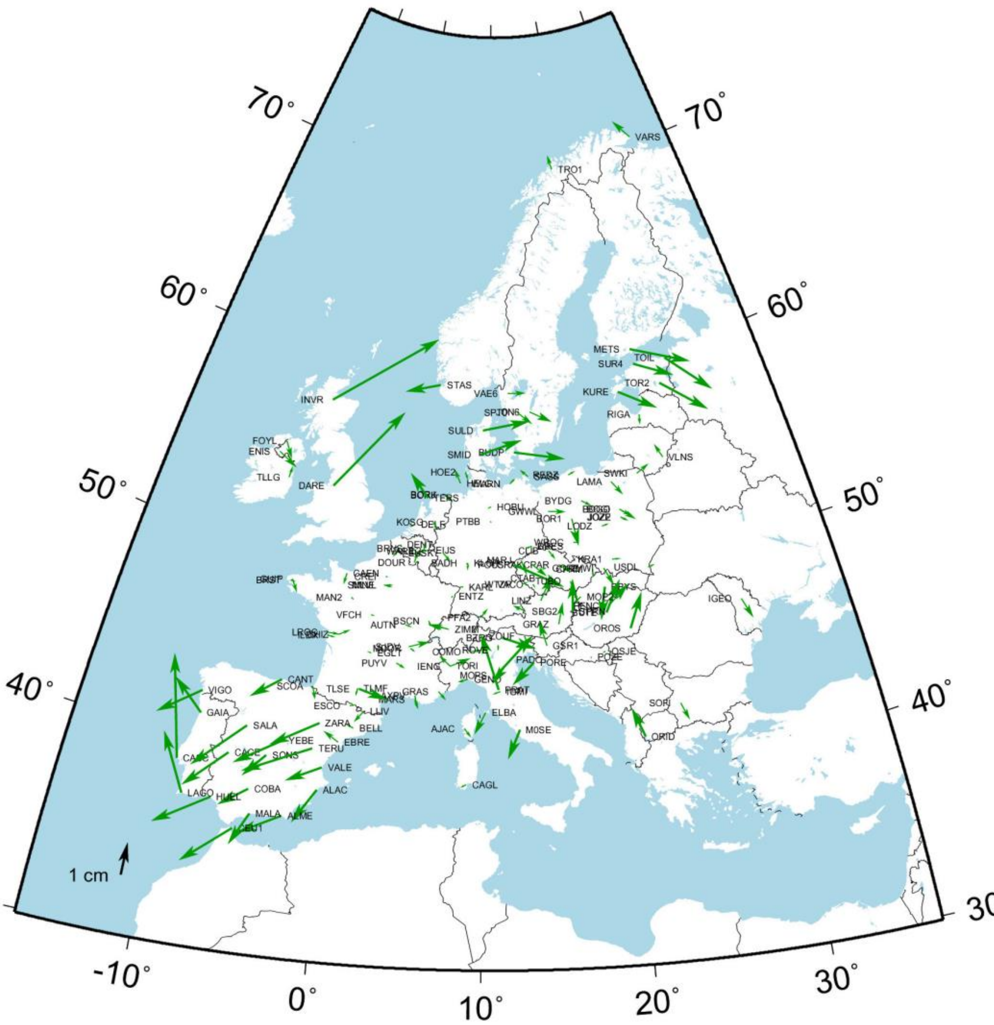

Figure 3: Horizontal differences; EPN_A_IGS14_C1980 transformed to ETRF2000 epoch 2007.0 minus official national ETRS89 coordinates, excluding the Fennoscandian land uplift area.

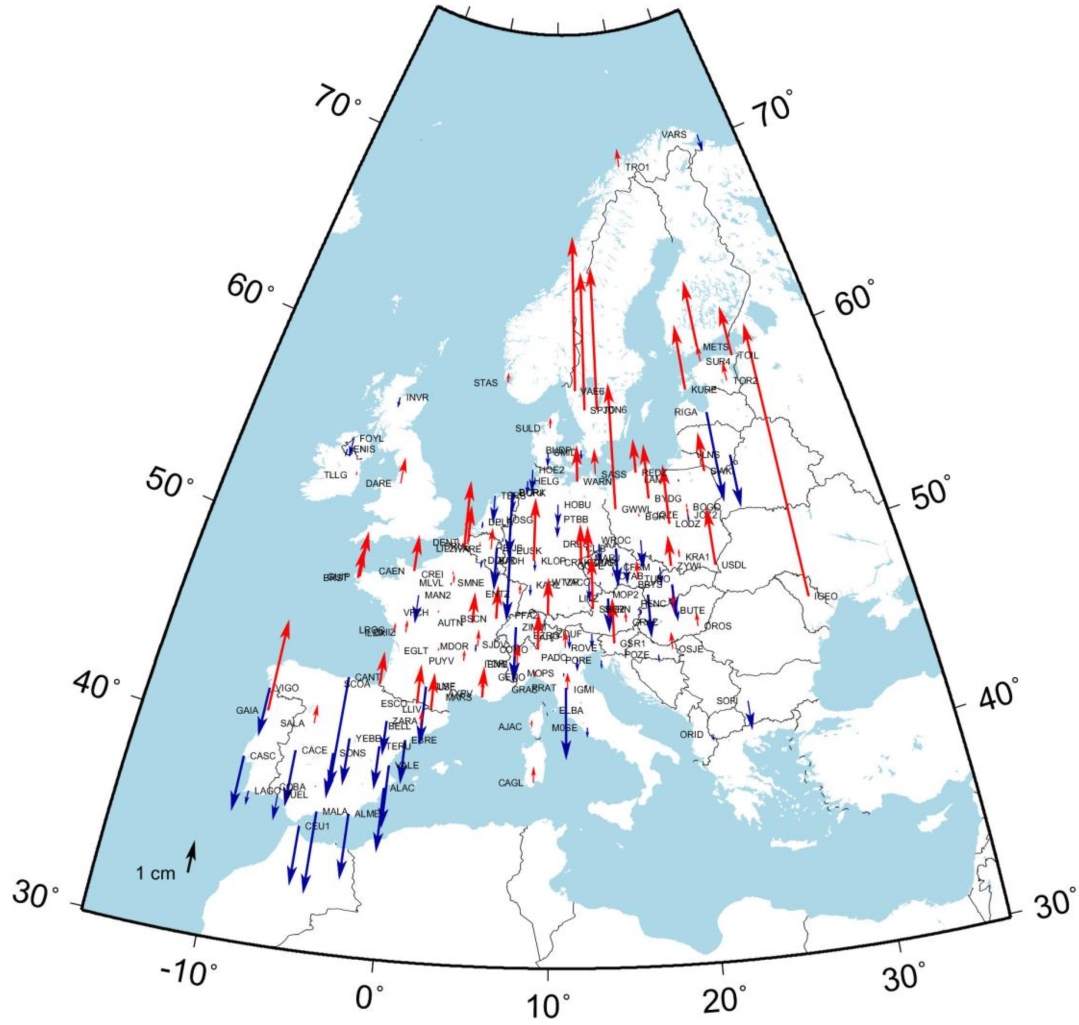

Figure 4: Vertical differences; EPN_A_IGS14_C1980 transformed to ETRF2000 epoch 2007.0 minus official national ETRS89 coordinates, excluding the Fennoscandian land uplift area.

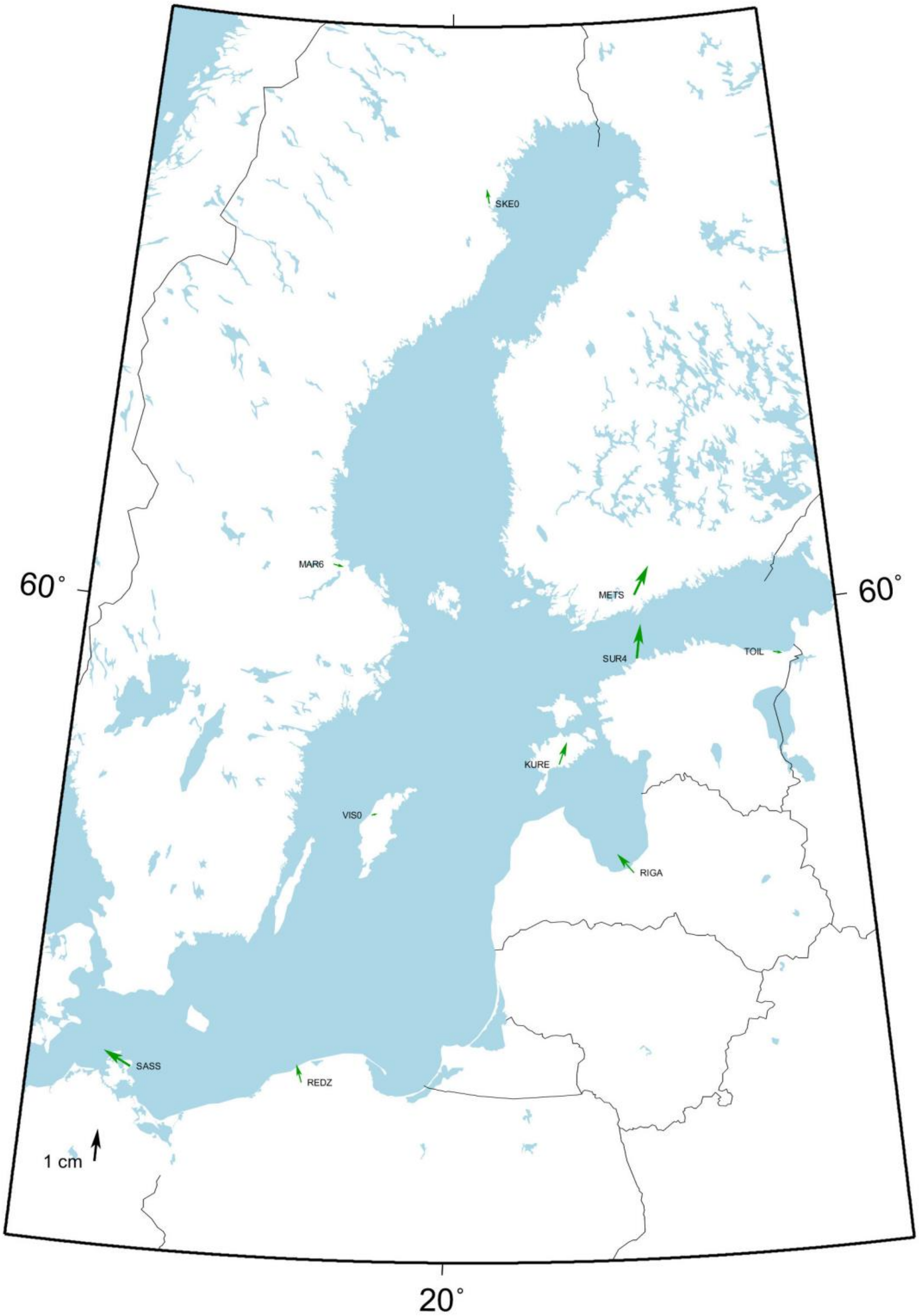

Figure 5: Horizontal differences; EPN_A_IGS14_C1980 transformed to ETRF97 epoch 1998.5 minus official national ETRS89 coordinates, for the Baltic Sea.

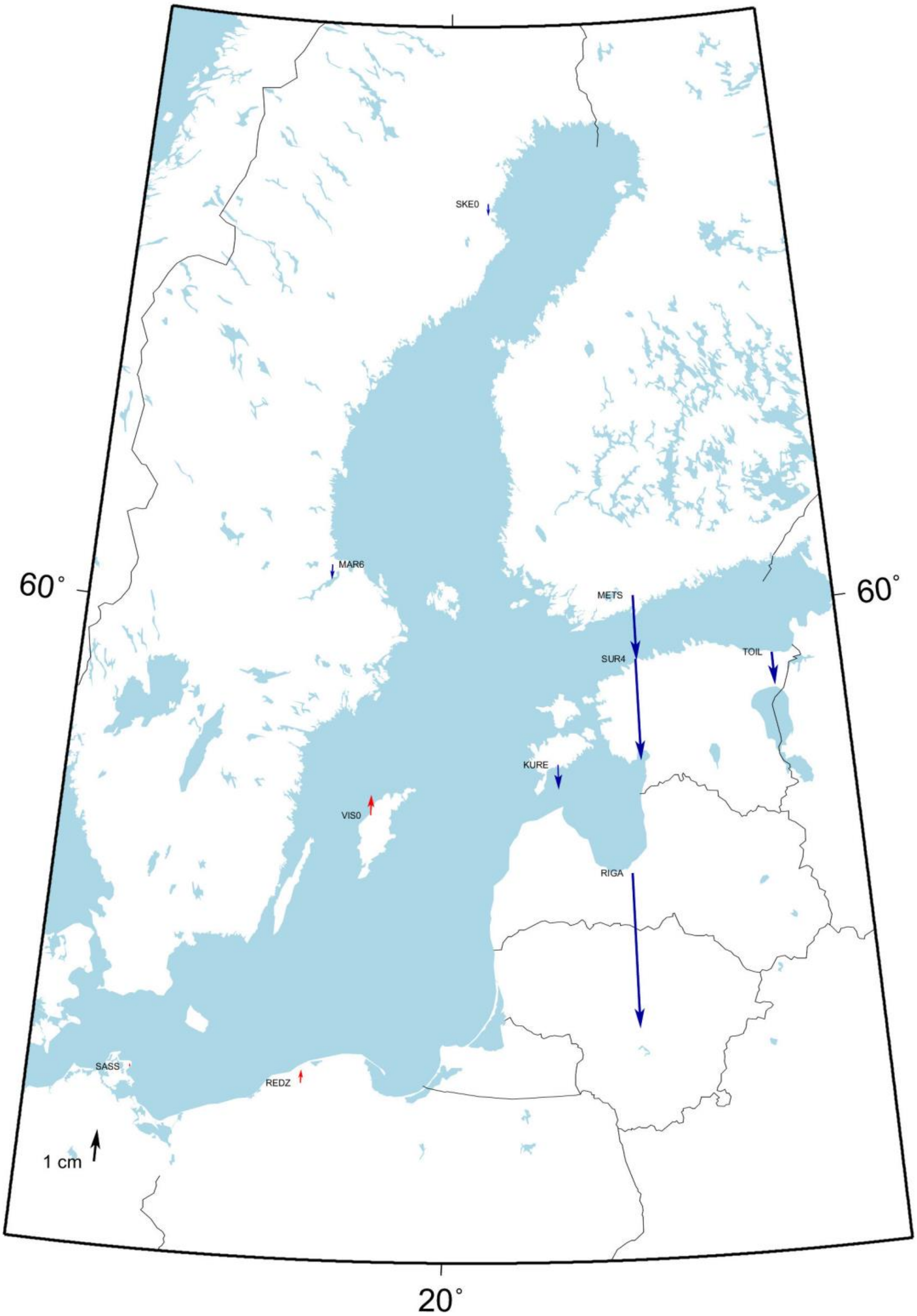

Figure 6: Vertical differences; EPN_A_IGS14_C1980 transformed to ETRF97 epoch 1998.5 minus official national ETRS89 coordinates, for the Baltic Sea.

5 Basic model for the transformations

The request was to use the 7-parameter similarity transformation formula, i.e. a 3D-Helmert transformation. This type of transformation could easily be implemented in many applications. The formulas are found in section 9.

The transformations are defined from ITRF2014 to ETRS89.

The EPN densified IGS14-solution (EPN_A_IGS14_1980), including coordinates and velocities represents ITRF2014. This solution transformed to ETRS89 according to the formulas and parameters in [Altamimi 2017] represents ETRS89 (ETRFxx, epoch yyyy.y). The xx and yyyy.y are dependent on the area, i.e. the dominant ETRS89 realization in the area (see section 4).

Yearly parameters have been solved, as ITRF changes with the plate tectonic (2-3 cm/yr). The maximum error dependent on the epoch will be 1.5 cm in horizontal – see Figure 1. The transformations in each area are described in Table 1. Coordinates in each epoch have been obtained by propagating the original coordinates (which are given in epoch 2010.0) with the velocities for each station.

Yearly epochs are chosen as the middle of the year since the main part of the measurements is expected to be performed during the summer. The first three epochs have already passed, but it was decided to include them to continue the series and have a small overlap to the series in [Jivall 2012].

Table 1: From- and to-system for the different 7-parameter transformations in an area. ETRFxx and the epoch yyyy.y are dependent on the area.

From-system	Epoch	To-system	Epoch
EPN_A_IGS14	2015.5	ETRFxx	yyyy.y
EPN_A_IGS14	2016.5	ETRFxx	yyyy.y
EPN_A_IGS14	2017.5	ETRFxx	yyyy.y
EPN_A_IGS14	2018.5	ETRFxx	yyyy.y
EPN_A_IGS14	2019.5	ETRFxx	yyyy.y
EPN_A_IGS14	2020.5	ETRFxx	yyyy.y
EPN_A_IGS14	2021.5	ETRFxx	yyyy.y
EPN_A_IGS14	2022.5	ETRFxx	yyyy.y

6 Transformation for central Europe

ETRF2000 epoch 2007.0 represents ETRS89 in the area.

This area includes whole Europe besides the areas affected by the Fennoscandian land uplift. The Norwegian coast is also covered as the land uplift there is close to zero. The fiords are however affected by land uplift and will get larger residuals in this transformation. The eastern part of the Mediterranean Sea does have large horizontal velocities with respect to the European plate, hence stations there do not fit so well.

The residuals for the transformation in epoch 2015.5 and 2022.5 are shown in Figure 7 – Figure 10.

The residuals give a picture of what accuracy could be expected when using the transformation in different parts of Europe.

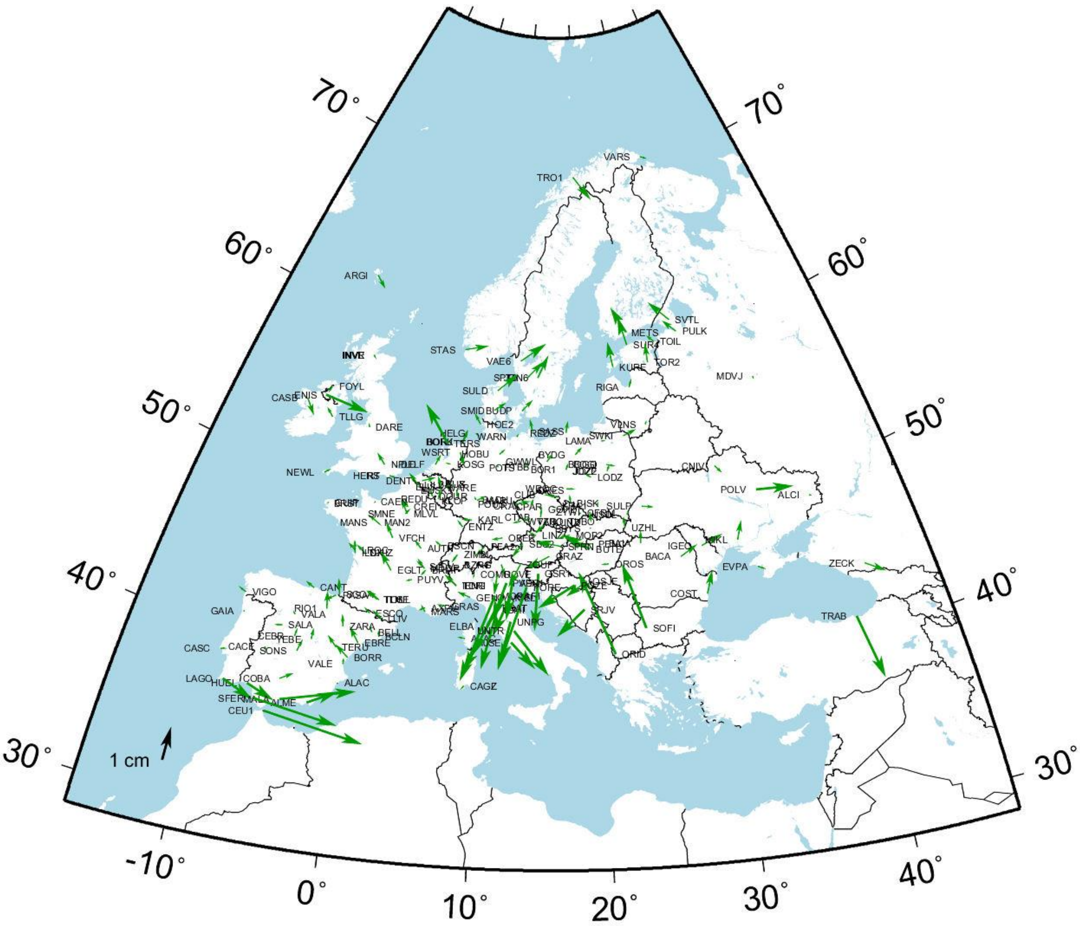

Figure 7: ITRF2014, epoch 2015.5 to ETRF2000 epoch 2007, horizontal residuals in the Helmert-transformation.

The differences to official national coordinates are given by subtracting the residuals in the Helmert fits (in this and the next section) from the comparisons between ETRFxx epoch yyyy.y and the official national coordinates (in previous section).

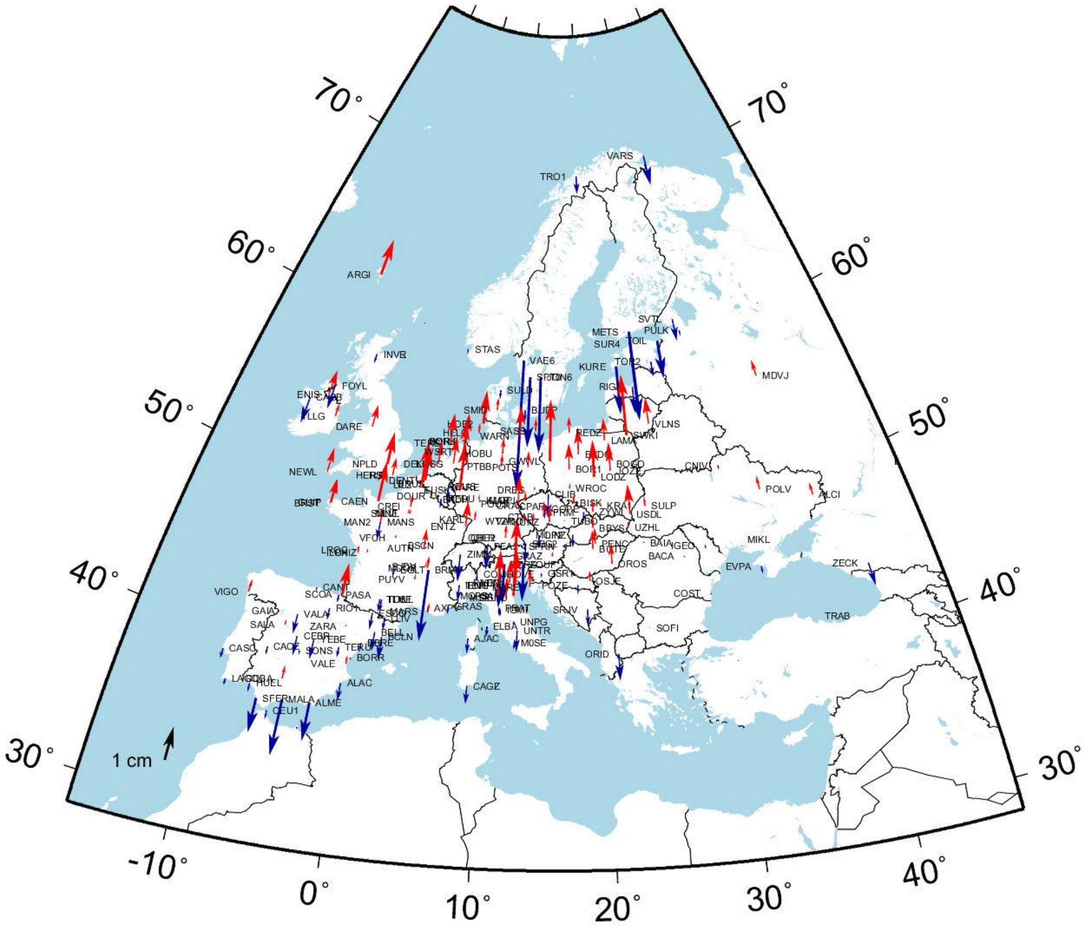

Figure 8: ITRF2014, epoch 2015.5 to ETRF2000 epoch 2007, vertical residuals in the Helmert-transformation. Red arrows are positive residuals and blue are negative.

In general, both the horizontal and vertical fits are better than the 1 cm level in epoch 2015.5, but there are some exceptions. The horizontal residuals are quite large in the eastern part of the Mediterranean, as well as Italy/Balkan and southern Spain, but the vertical looks OK.

The differences get larger when ITRF2014 is extrapolated to epoch 2022.5, see Figure 9 and Figure 10. For epoch 2022.5 the general level of the fit is 10-15 mm in all components.

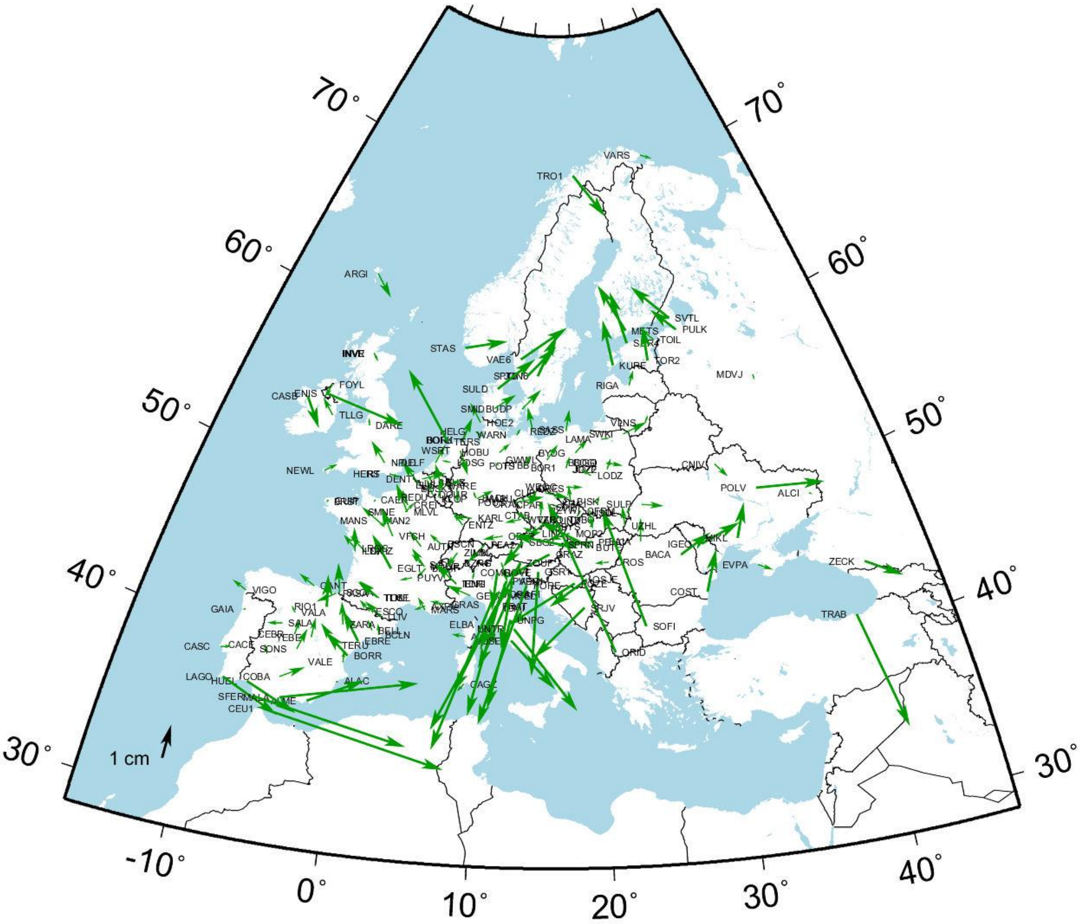

Figure 9 : ITRF2014, epoch 2022.5 to ETRF2000 epoch 2007, horizontal residuals in the Helmert-transformation.

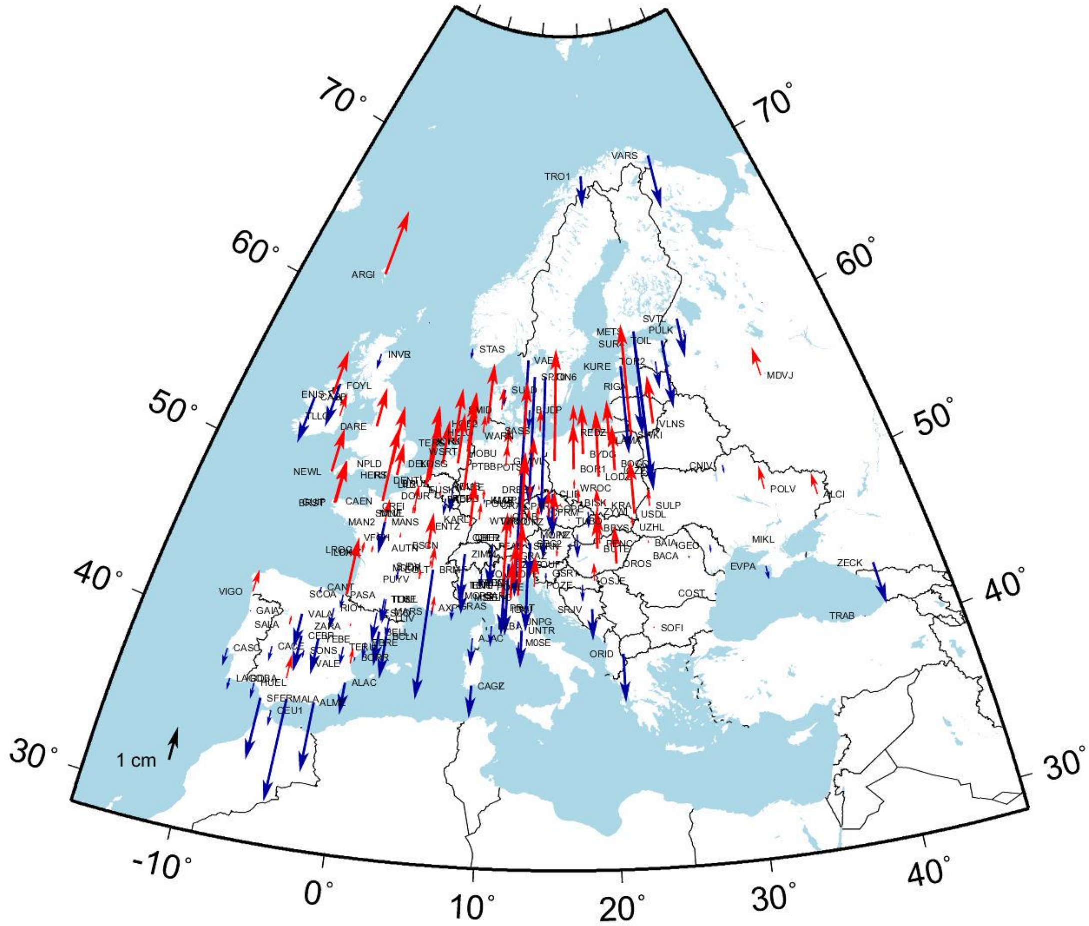

Figure 10: ITRF2014, epoch 2022.5 to ETRF2000 epoch 2007, vertical residuals in the Helmert-transformation.

7 Transformation for the Baltic Sea

A special set of transformations were developed for the Baltic Sea. The reason for this is that this area is affected by the post-glacial rebound. The transformations do not work for inland areas.

ETRF97 epoch 1998.5 represents ETRS89 in the area.

Residuals from the 7-parameter transformations for epoch 2015.5 and 2022.5 are found in Figure 11 – Figure 14.

The residuals of course grow larger with the later epoch 2022.5 and reflects the problems we have when trying to model a non-linear deformation with a linear model. The fit would be better if we could divide the area into two parts, but there are not enough fitting points in the northern part.

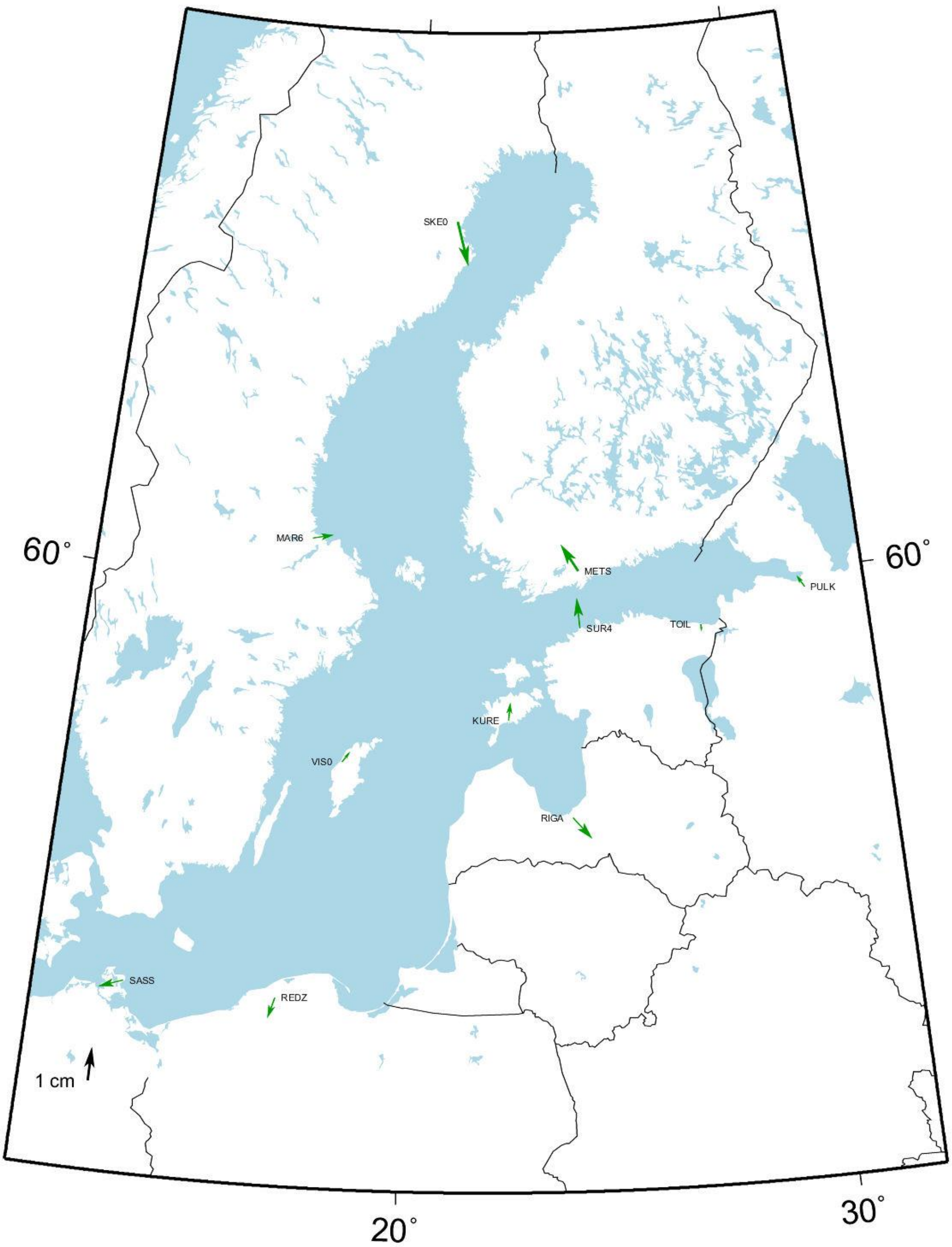

Figure 11: ITRF2014, epoch 2015.5 to ETRF97 epoch 1998.5, horizontal residuals in the Helmert-transformation.

The vertical residuals at Mårtsbo (MAR6), Riga (RIGA) and Sassnitz (SASS) are 24, 29 and 27 mm for epoch 2022.5. The maximum horizontal residual is 18 mm for Skellefteå (SKE0) in epoch 2022.5.

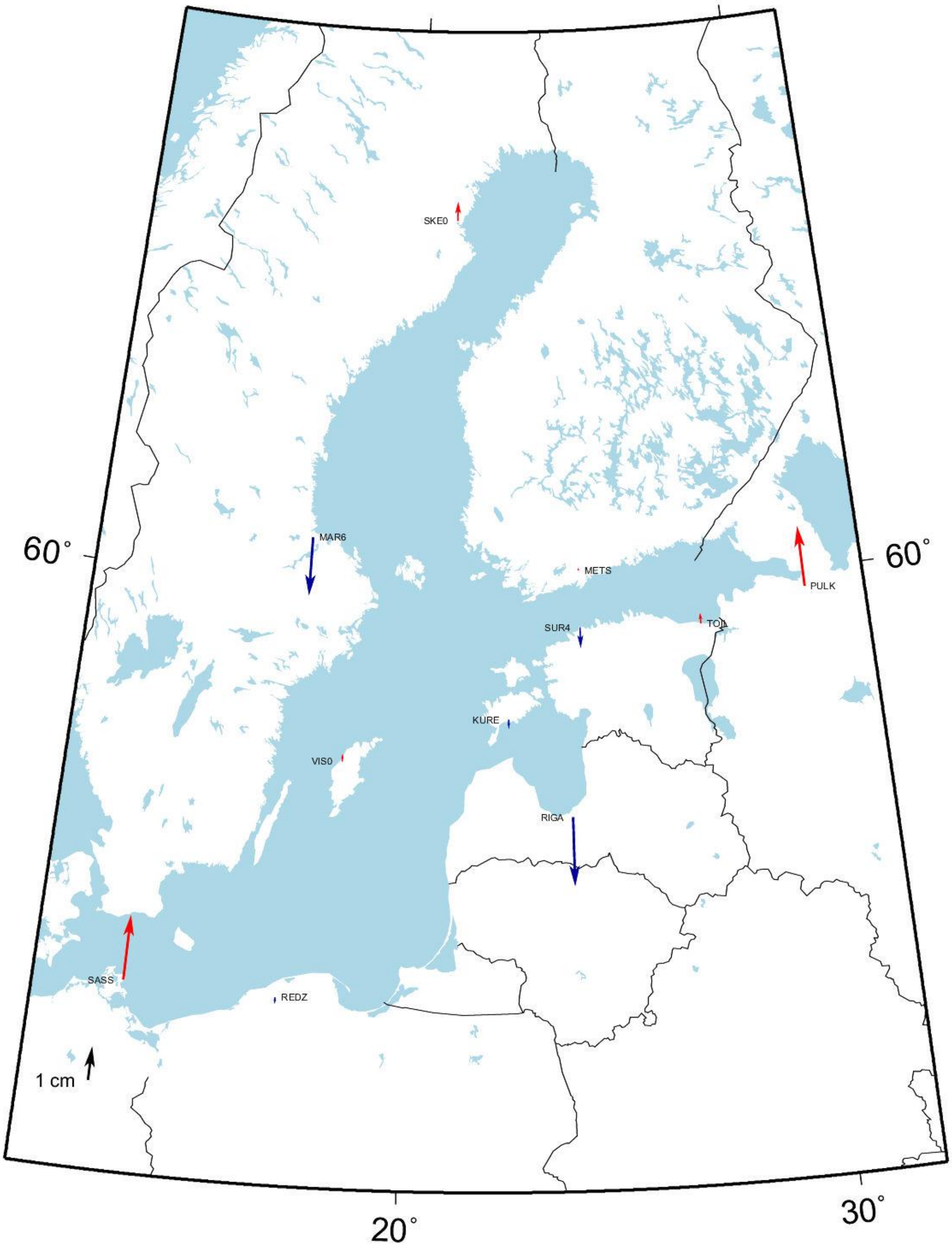

Figure 12: ITRF2014, epoch 2015.5 to ETRF97 epoch 1998.5, vertical residuals in the Helmert-transformation.

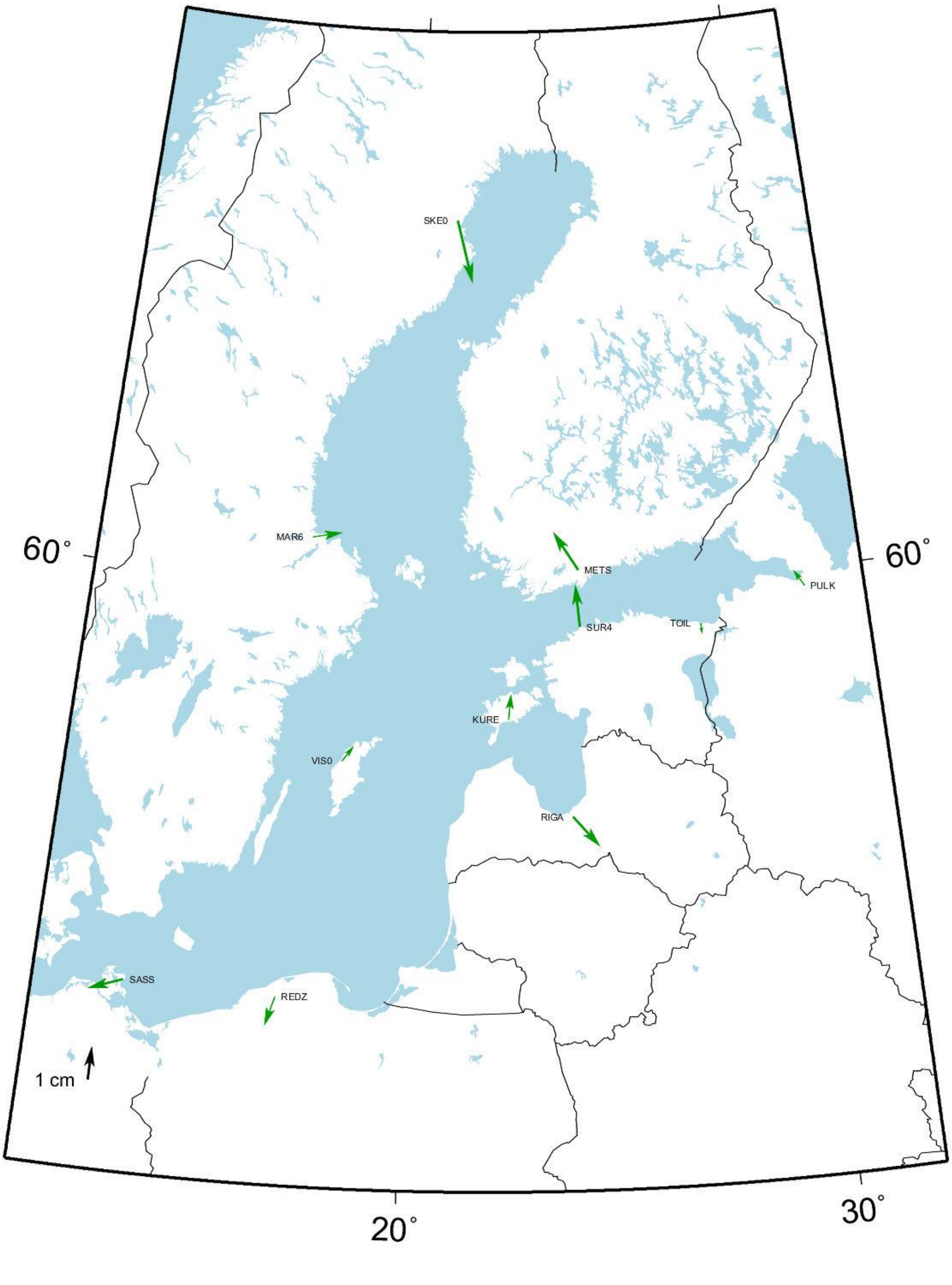

Figure 13: ITRF2014, epoch 2022.5 to ETRF97 epoch 1998.5, horizontal residuals in the Helmert-transformation.

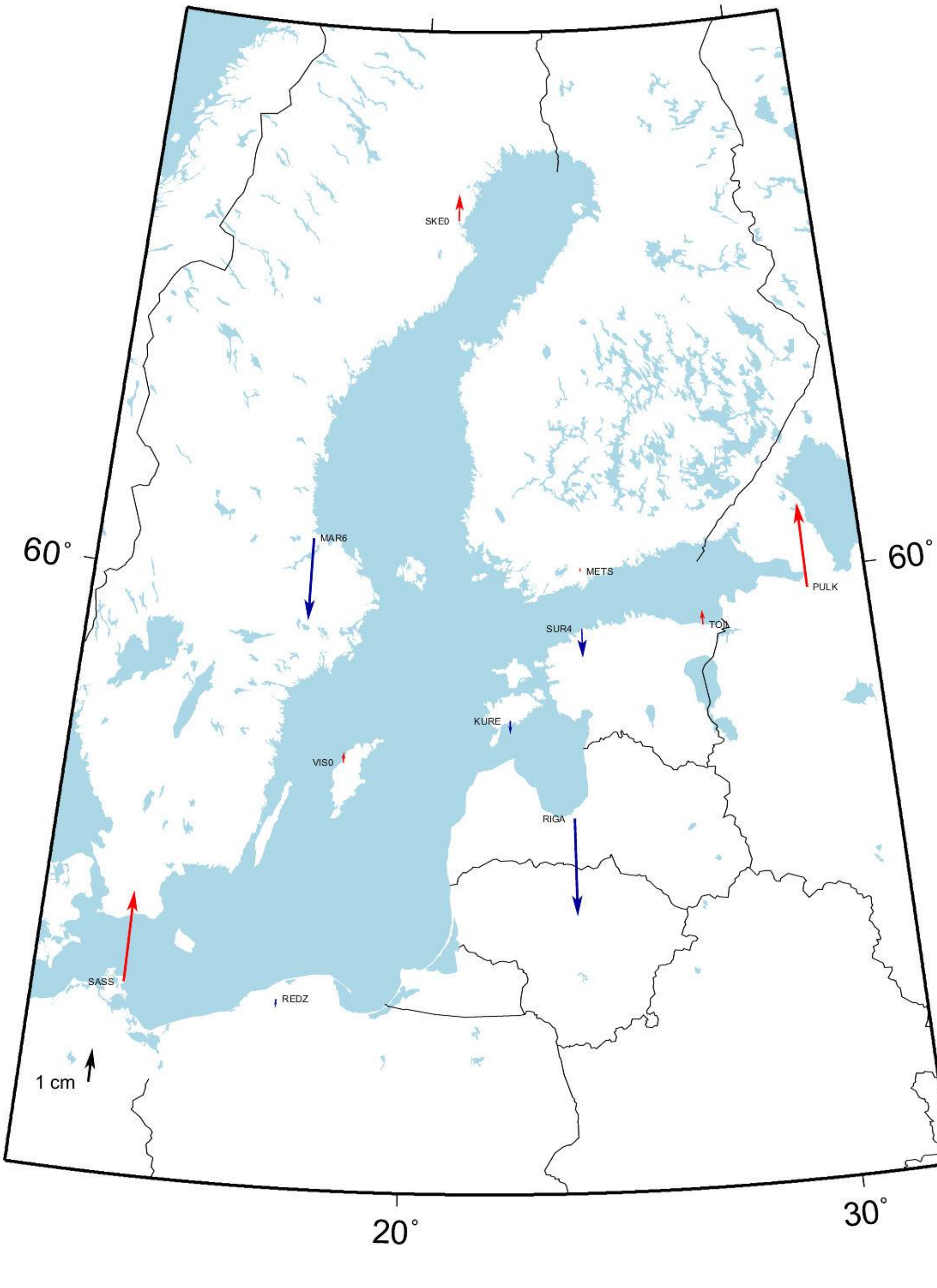

Figure 14: ITRF2014, epoch 2022.5 to ETRF97 epoch 1998.5, vertical residuals in the Helmert-transformation.

8 Transformation for southern part of Sweden including Lake Vänern

For the transformations in [Jivall 2012] no special transformation was given for Lake Vänern and southern part of Sweden (the transformation for the Baltic sea covered also this part). The deformation of the land due to the post-glacial rebound has increased with time, so now we need to create a separate transformation for the new time intervals 2015 – 2022. SWEREF 99 is the Swedish realization of ETRS89, and as the coverage area of this transformation is within Sweden, we define the transformation to SWEREF 99.

Residuals from the 7-parameter transformations for epoch 2015.5 and 2022.5 are found in Figure 15 – Figure 18.

The transformation is valid for Sweden south of the line Oslo – Gävle. The standard uncertainty is 1 cm or better both in horizontal and height for the defined epochs. The effect of the plate tectonics would add up to 1.5 cm if the epoch differs from the specified epochs (which are defined in the middle of the summer, i.e. July 1st).

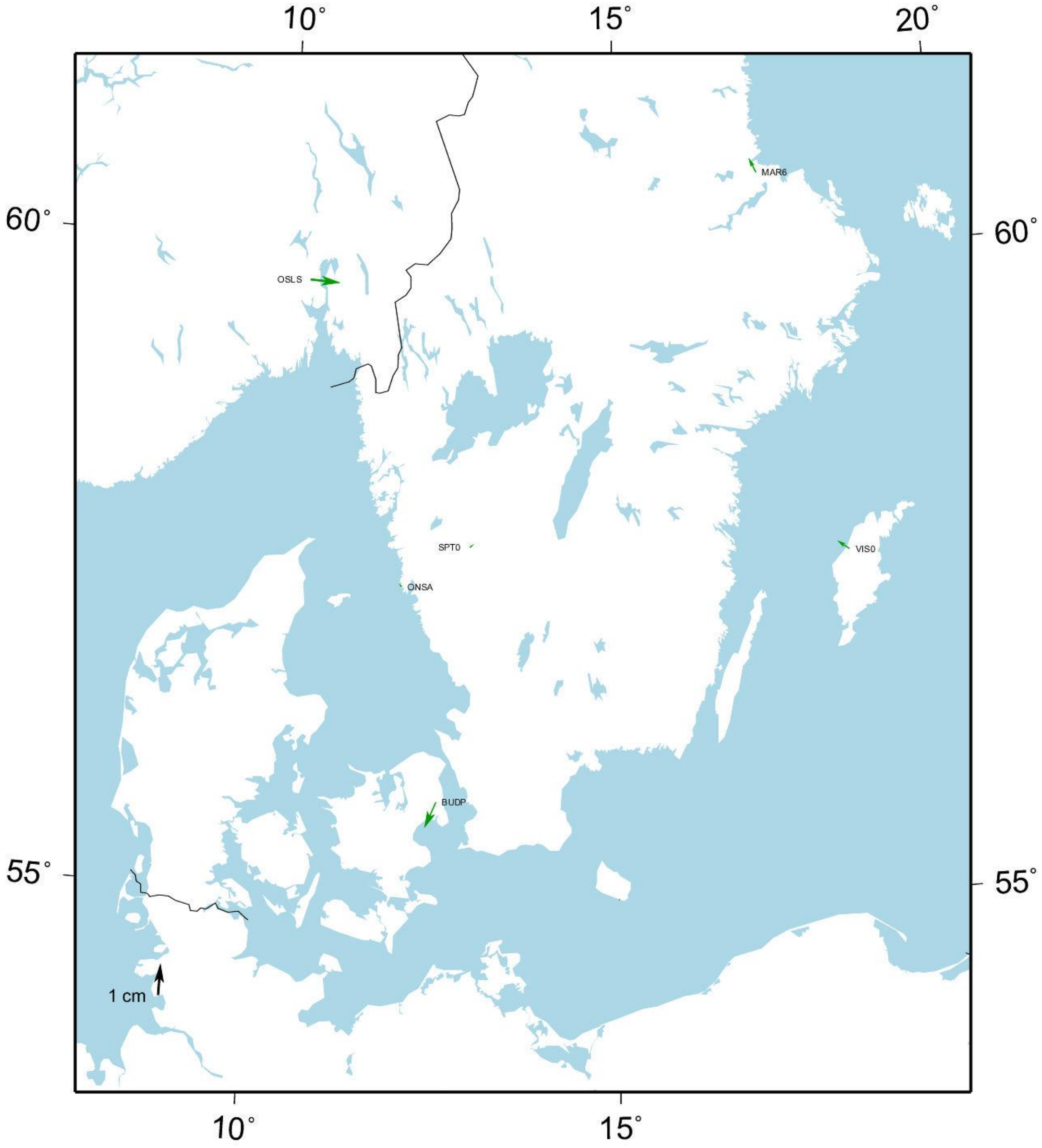

Figure 15: ITRF2014, epoch 2015.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

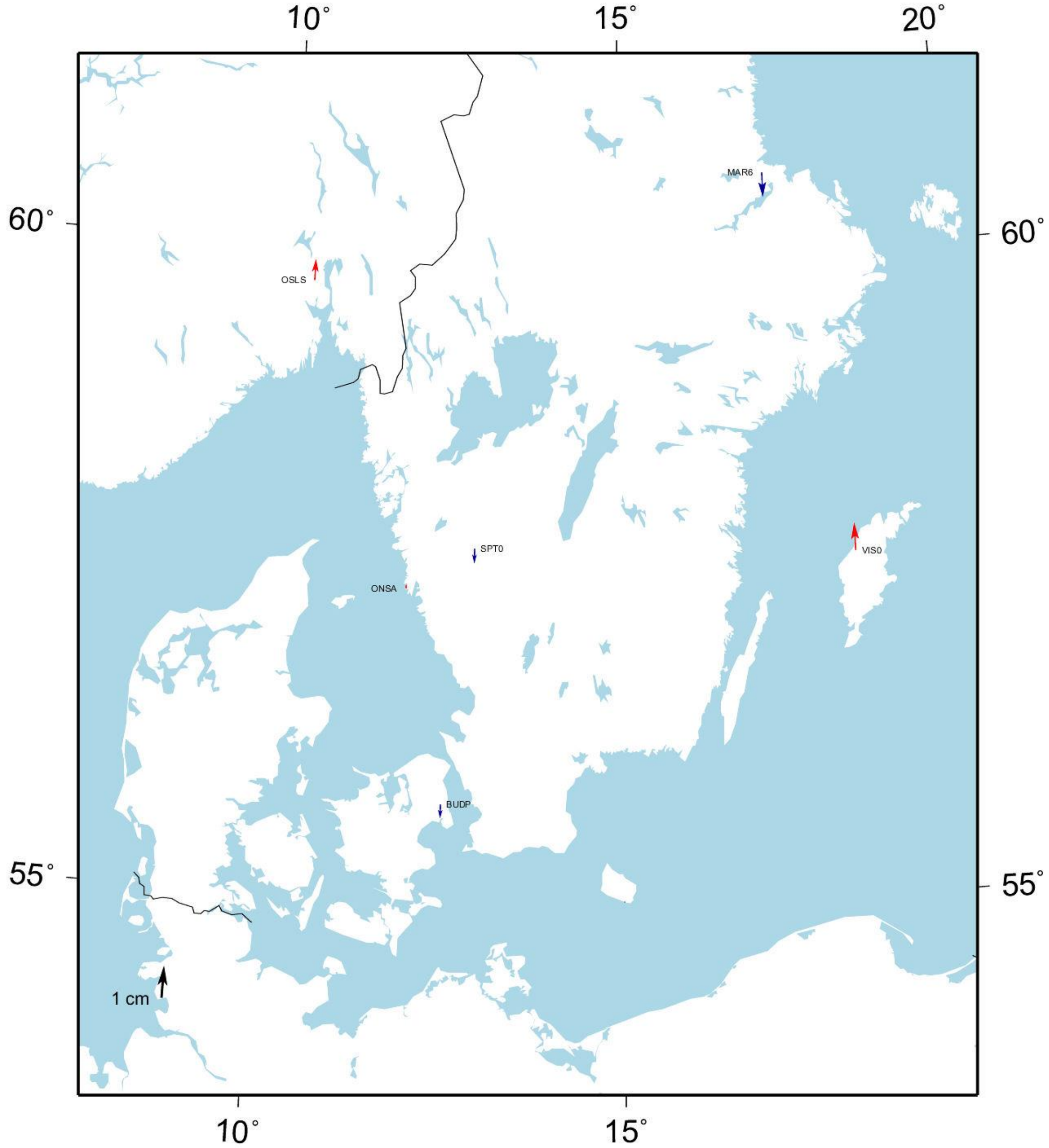

Figure 16: ITRF2014, epoch 2015.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

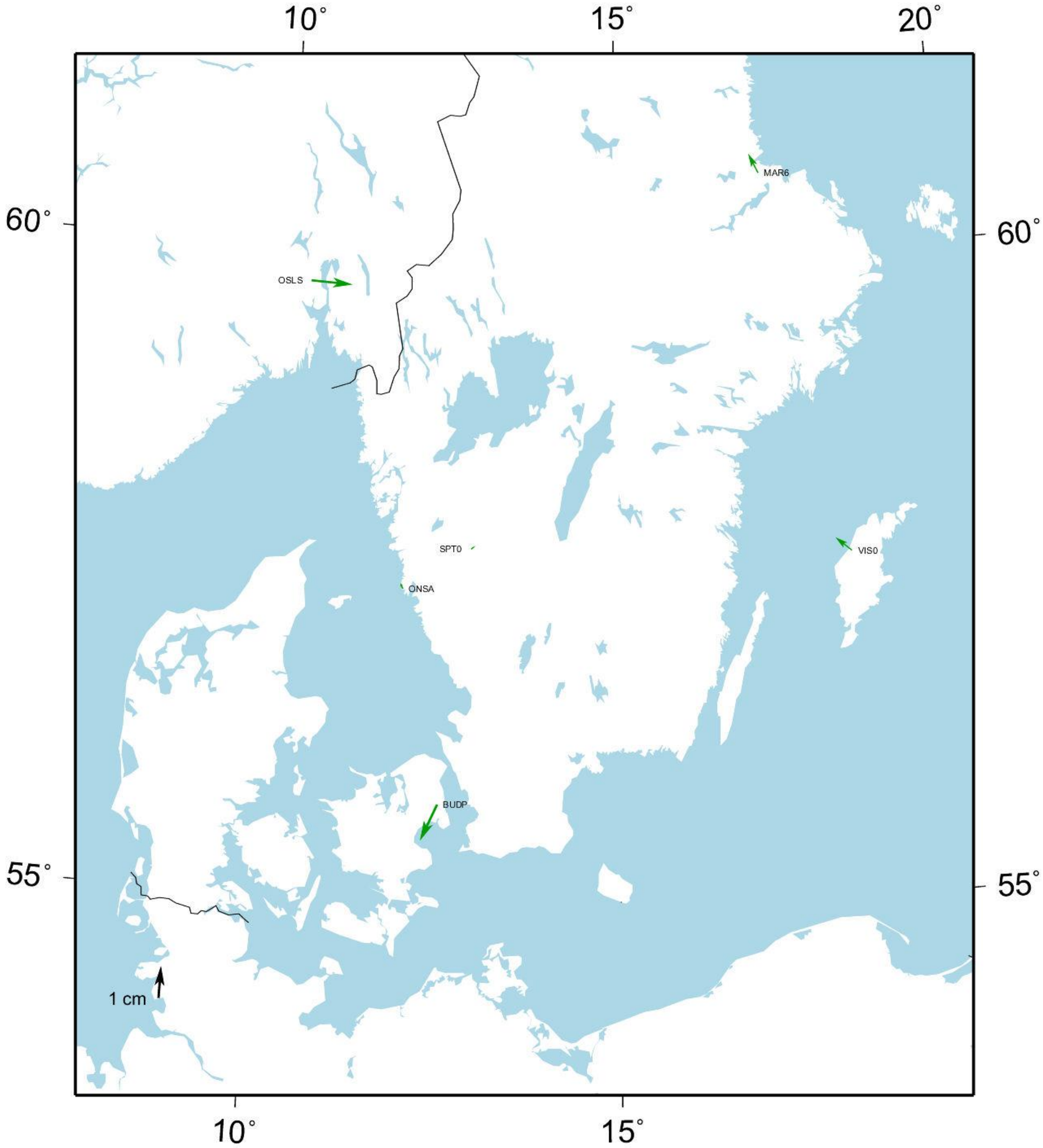

Figure 17: ITRF2014, epoch 2022.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

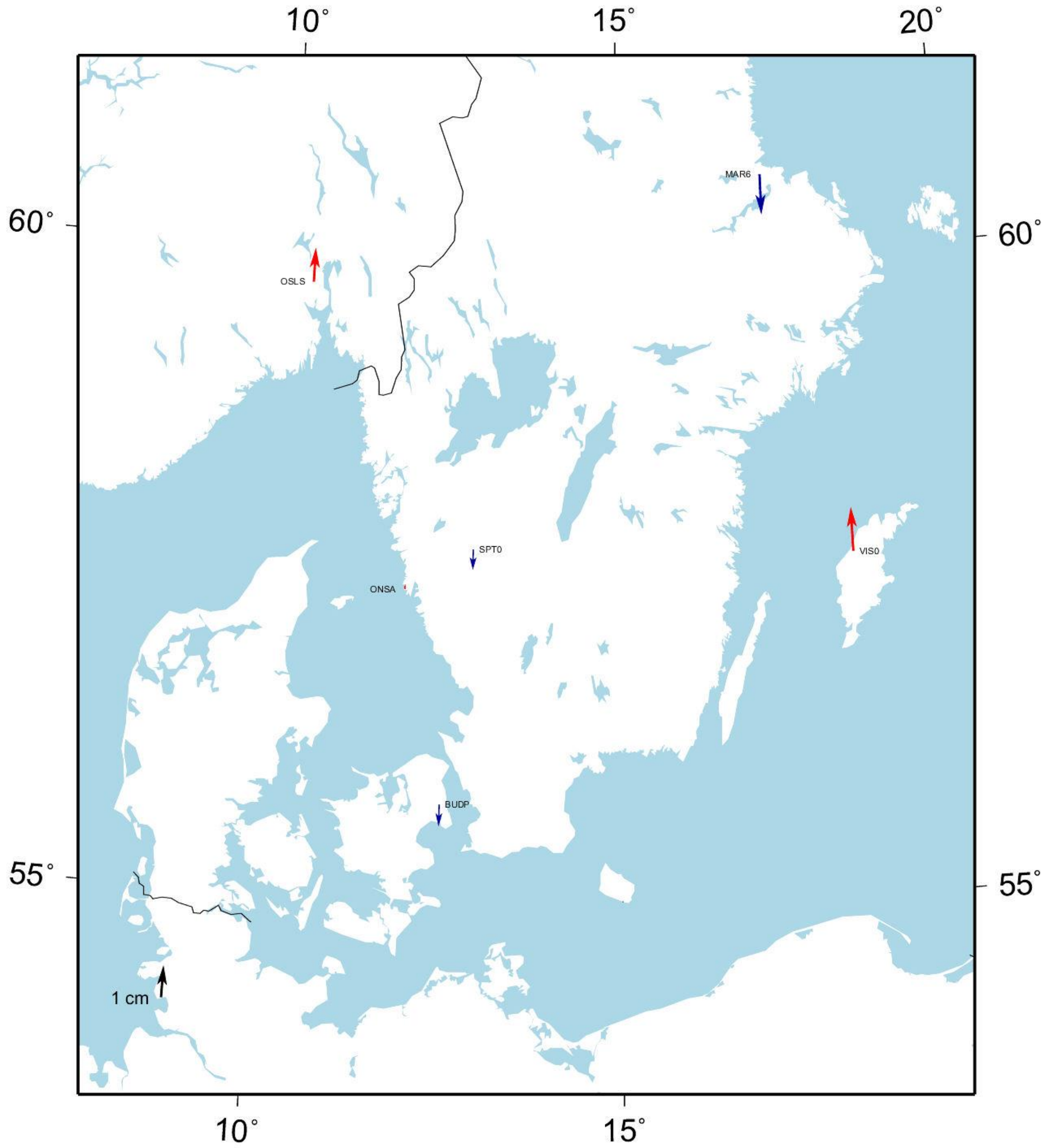

Figure 18: ITRF2014, epoch 2022.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

9 Transformation formulas and parameters

The 7-parameter similarity transformation, which also is called 3D-Helmert transformation, is used for the transformations. The parameters have been determined using formulas with the full rotation matrix (formula 1 and 2), but could also be used together with the linearized version (formula 1 and 3) without losing any precision as the rotations are small.

There are three sets of transformation parameters; one for central Europe including the British Islands and the sea outside Norway (Table 2), one for the Baltic Sea (Table 3) and one for southern Sweden and the lake Vänern, (Table 4). Parameters have been estimated for the yearly epochs 2015.5 – 2022.5, to be used for each corresponding year.

The residual plots from the estimation of the parameters, see sections 6 – 8, give an idea about the accuracy of the transformations.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{ETRS89} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} + (1+\delta)\ \mathbf{R} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{ITRF} \tag{1}$$

$$\mathbf{R} = \mathbf{R}_Z \mathbf{R}_Y \mathbf{R}_X = \begin{pmatrix} \cos\omega_Z & \sin\omega_Z & 0 \\ -\sin\omega_Z & \cos\omega_Z & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\omega_Y & 0 & -\sin\omega_Y \\ 0 & 1 & 0 \\ \sin\omega_Y & 0 & \cos\omega_Y \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\omega_X & \sin\omega_X \\ 0 & -\sin\omega_X & \cos\omega_X \end{pmatrix} \tag{2}$$

$$\mathbf{R} = \mathbf{R}_Z \mathbf{R}_Y \mathbf{R}_X = \begin{pmatrix} 1 & \omega_Z & -\omega_Y \\ -\omega_Z & 1 & \omega_X \\ \omega_Y & -\omega_X & 1 \end{pmatrix} \tag{3}$$

*Table 2: Parameters for different epochs to be used in **central Europe, the British Islands and outside the Norwegian coast**.*

Parameter	2015.5	2016.5	2017.5	2018.5	2019.5	2020.5	2021.5	2022.5
ΔX (m)	0.08502	0.08863	0.09223	0.09584	0.09944	0.10305	0.10665	0.11025
ΔY (m)	0.06024	0.06123	0.06220	0.06318	0.06416	0.06515	0.06613	0.06711
ΔZ (m)	-0.10375	-0.10792	-0.11208	-0.11624	-0.12040	-0.12457	-0.12873	-0.13289
ω_x (mas)	-2.601	-2.736	-2.871	-3.005	-3.139	-3.274	-3.409	-3.543
ω_y (mas)	-11.893	-12.256	-12.617	-12.979	-13.340	-13.703	-14.065	-14.426
ω_z (mas)	20.673	21.430	22.185	22.940	23.695	24.452	25.207	25.962
δ (ppb)	2.62	2.72	2.81	2.91	3.01	3.11	3.20	3.30

Table 3: Parameters for different epochs to be used in the ***Baltic Sea****.*

Parameter	2015.5	2016.5	2017.5	2018.5	2019.5	2020.5	2021.5	2022.5
ΔX (m)	0.73384	0.77433	0.81473	0.85509	0.89548	0.93597	0.97637	1.01673
ΔY (m)	0.88328	0.93267	0.98187	1.03107	1.08027	1.12966	1.17886	1.22806
ΔZ (m)	-0.62780	-0.66050	-0.69304	-0.72563	-0.75818	-0.79088	-0.82343	-0.85601
ω_x (mas)	-29.958	-31.613	-33.262	-34.911	-36.560	-38.216	-39.864	-41.514
ω_y (mas)	14.279	15.402	16.521	17.640	18.759	19.882	21.001	22.120
ω_z (mas)	28.179	29.479	30.775	32.070	33.366	34.665	35.961	37.257
δ (ppb)	-9.58	-10.28	-10.99	-11.69	-12.40	-13.10	-13.81	-14.52

Table 4: Parameters for different epochs to be used in ***southern Sweden including lake Vänern****.*

Parameter	2015.5	2016.5	2017.5	2018.5	2019.5	2020.5	2021.5	2022.5
ΔX (m)	0.97431	1.03446	1.09438	1.15423	1.21415	1.27430	1.33422	1.39407
ΔY (m)	0.20937	0.21334	0.21723	0.22095	0.22475	0.22873	0.23261	0.23633
ΔZ (m)	-0.57881	-0.61125	-0.64355	-0.67572	-0.70805	-0.74048	-0.77278	-0.80496
ω_x (mas)	-10.665	-11.000	-11.334	-11.662	-11.994	-12.330	-12.663	-12.991
ω_y (mas)	20.241	21.921	23.594	25.262	26.936	28.616	30.289	31.958
ω_z (mas)	16.463	17.012	17.558	18.101	18.643	19.192	19.738	20.281
δ (ppb)	-19.38	-20.58	-21.78	-22.99	-24.18	-25.38	-26.58	-27.78

Note the definition of the rotations in formula 2 and 3 and change signs if necessary. The rotations need to be converted to radians by multiplication with the following factor:

$$\frac{0.001 \cdot \pi}{3600 \cdot 180} \tag{4}$$

10 Test example

For testing the implementation of the transformations, a test example has been prepared – see Table 5 and Table 6. Note that the ITRF2014-coordinates are the same for all epochs, which means that it is not the same point. The points are approximately in the middle between Skåne and Rügen, so in principle both the transformation for central Europe and the one for the Baltic sea would be applicable. The difference between the two transformations in epoch 2015.5 is 8 mm in horizontal and 32 mm in height and in 2022.5 the differences are 11 mm in horizontal and 40 mm in height. The differences partly reflect the difference between ETRF2000 epoch 2007 and ETRF97 epoch 1998.5, but also the residuals in the fit for the Baltic sea where we try to model a non-linear deformation with a linear model. The test point between Skåne and Rügen agrees on 1-2 cm level between the transformation for southern Sweden and the transformation for central Europe, in both epochs 2015.5 and 2022.5.

Table 5: Cartesian coordinates for testing of the transformations.

Reference frame	X	Y	Z
ITRF2014 epoch 2015.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2015.5)	3565285.4801	855948.6396	5201382.7151
ETRS89, Baltic Sea (2015.5)	3565285.4565	855948.6326	5201382.6935
SWEREF99, southern Sweden (2015.5)	3565285.4631	855948.6393	5201382.7145
ITRF2014 epoch 2016.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2016.5)	3565285.4963	855948.6241	5201382.7057
ETRS89, Baltic Sea (2016.5)	3565285.4716	855948.6171	5201382.6834
SWEREF99, southern Sweden (2016.5)	3565285.4789	855948.6243	5201382.7063
ITRF2014 epoch 2017.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2017.5)	3565285.5125	855948.6087	5201382.6964
ETRS89, Baltic Sea (2017.5)	3565285.4866	855948.6017	5201382.6734
SWEREF99, southern Sweden (2017.5)	3565285.4946	855948.6093	5201382.6980
ITRF2014 epoch 2018.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2018.5)	3565285.5287	855948.5934	5201382.6870
ETRS89, Baltic Sea (2018.5)	3565285.5017	855948.5864	5201382.6633
SWEREF99, southern Sweden (2018.5)	3565285.5103	855948.5943	5201382.6897
ITRF2014 epoch 2019.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2019.5)	3565285.5449	855948.5780	5201382.6777
ETRS89, Baltic Sea (2019.5)	3565285.5167	855948.5710	5201382.6533
SWEREF99, southern Sweden (2019.5)	3565285.5261	855948.5794	5201382.6815
ITRF2014 epoch 2020.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2020.5)	3565285.5612	855948.5626	5201382.6683
ETRS89, Baltic Sea (2020.5)	3565285.5318	855948.5556	5201382.6432
SWEREF99, southern Sweden (2020.5)	3565285.5418	855948.5643	5201382.6733
ITRF2014 epoch 2021.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2021.5)	3565285.5773	855948.5472	5201382.6589
ETRS89, Baltic Sea (2021.5)	3565285.5468	855948.5402	5201382.6332
SWEREF99, southern Sweden (2021.5)	3565285.5576	855948.5494	5201382.6651
ITRF2014 epoch 2022.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Europe (2022.5)	3565285.5935	855948.5318	5201382.6496
ETRS89, Baltic Sea (2022.5)	3565285.5618	855948.5248	5201382.6231
SWEREF99, southern Sweden (2022.5)	3565285.5733	855948.5344	5201382.6568

Table 6: Geodetic coordinates for testing of the transformations.

Reference frame	Latitude	LongitudeY	Ell. Height
ITRF2014 epoch 2015.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2015.5)	54°59'59''982955	13°29'59.963119	-0.6173
ETRS89, Baltic Sea (2015.5)	54°59'59''983206	13°29'59.963046	-0.6491
SWEREF99, southern Sweden (2015.5)	54°59'59''983384	13°29'59.963326	-0.6273
ITRF2014 epoch 2016.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2016.5)	54°59'59''982460	13°29'59.962059	-0.6181
ETRS89, Baltic Sea (2016.5)	54°59'59''982725	13°29'59.962000	-0.6510
SWEREF99, southern Sweden (2016.5)	54°59'59''982918	13°29'59.962298	-0.6272
ITRF2014 epoch 2017.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2017.5)	54°59'59''981965	13°29'59.961003	-0.6187
ETRS89, Baltic Sea (2017.5)	54°59'59''982249	13°29'59.960961	-0.6529
SWEREF99, southern Sweden (2017.5)	54°59'59''982452	13°29'59.961271	-0.6273
ITRF2014 epoch 2018.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2018.5)	54°59'59''981468	13°29'59.959954	-0.6194
ETRS89, Baltic Sea (2018.5)	54°59'59''981767	13°29'59.959925	-0.6548
SWEREF99, southern Sweden (2018.5)	54°59'59''981987	13°29'59.960245	-0.6273
ITRF2014 epoch 2019.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2019.5)	54°59'59''980974	13°29'59.958899	-0.6201
ETRS89, Baltic Sea (2019.5)	54°59'59''981291	13°29'59.958886	-0.6567
SWEREF99, southern Sweden (2019.5)	54°59'59''981520	13°29'59.959222	-0.6272
ITRF2014 epoch 2020.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2020.5)	54°59'59''980475	13°29'59.957842	-0.6207
ETRS89, Baltic Sea (2020.5)	54°59'59''980810	13°29'59.957845	-0.6586
SWEREF99, southern Sweden (2020.5)	54°59'59''981056	13°29'59.958190	-0.6272
ITRF2014 epoch 2021.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2021.5)	54°59'59''979981	13°29'59.956788	-0.6215
ETRS89, Baltic Sea (2021.5)	54°59'59''980333	13°29'59.956806	-0.6605
SWEREF99, southern Sweden (2021.5)	54°59'59''980590	13°29'59.957167	-0.6271
ITRF2014 epoch 2022.5	54°59'59''998378	13°29'59.989138	-0.6034
ETRS89, central Europe (2022.5)	54°59'59''979486	13°29'59.955733	-0.6222
ETRS89, Baltic Sea (2022.5)	54°59'59''979854	13°29'59.955767	-0.6625
SWEREF99, southern Sweden (2022.5)	54°59'59''980124	13°29'59.956141	-0.6272

The coordinates in epoch 2015.5 of the transformed test point were also compared to the transformations in [Jivall 2012]. When using the transformation for central Europe, the differences were below 1 mm in horizontal and 4 mm in height, and when using the transformation for the Baltic Sea, the differences were 2, 1 and 8 mm for north, east and up. The transformation for southern Sweden to SWEREF 99 was tested by transforming a weekly solution of SWEPOS in IGS14 epoch 2017.5. The difference to official SWEREF 99-coordinates were below 15 mm in height and 10 mm in horizontal for all stations in the coverage area.

11 Used software

The transformation parameters were computed using the program HELMR1 in the Bernese GNSS Software [AIUB 2013] and the maps were generated using the Generic Mapping Tools (GMT) [Wessel 2013]. For the transformation of ITRF2014 to ETRF97 epoch 1998.0 the transformation tool at http://www.epncb.oma.be/_productsservices/coord_trans/ was used. The coordinates in the test example were produced with a small in-house program (SEVENPAR_FULL).

12 References

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