LANTMÄTERIET

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PM

Simplified Transformations from ITRF2020/IGS20 to ETRS89 for Maritime Applications

Summary

Simplified transformations using the 7-parameter transformation model between ITRF2008/ITRF2014 current epoch and ETRS89 have earlier been developed for the epochs 2012.5-2022.5 on request by maritime surveyors [Jivall 2012], [Jivall 2018].

This PM presents an update with respect to the latest frame (ITRF2020) and the yearly epochs between 2022.5 – 2026.5.

The formulas are valid for maritime applications but could partly also be used on land except for the central part of the Fennoscandian land uplift area. It should be noted, that more accurate and general transformations (any epoch) are available for all Nordic and Baltic countries [Häkli et. al. 2023].

Five sets of transformations have been defined – for the stable part of Europe, excluding the Fennoscandian land uplift area, for the northern Baltic Sea, for southern Baltic Sea, for the area around Denmark and finally for the Norwegian coast. The latter two are considered as alternatives to the transformation for the stable part of Europe.

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 will 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).

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Abbreviations and Acronyms

Abbreviation or acronym	Explanation
EPN	EUREF Permanent Network
ETRS89	European Terrestrial Reference System
EUREF	IAG Reference Frame Sub-Commission for Europe
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAG	International Association of Geodesy
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
NKG	Nordic Geodetic Commission
SWEREF 99	Swedish realization of ETRS89
WGS 84	World Geodetic System 1984, used by GPS

1. 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 (International Terrestrial Reference System), e.g. ITRFyy, IGSyy or WGS84, 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 (International Terrestrial Reference Frame) 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, ETRS89 has been developed for Europe. ETRS89 coincides with ITRS at epoch 1989.0.

WGS84 (World Geodetic System 1984) has been connected to ITRS since 1994 and the latest update (January 2021) is aligned to ITRF2014/IGb14, but we expect WGS 84 to be aligned to ITRF2020/IGS20 in the near future.

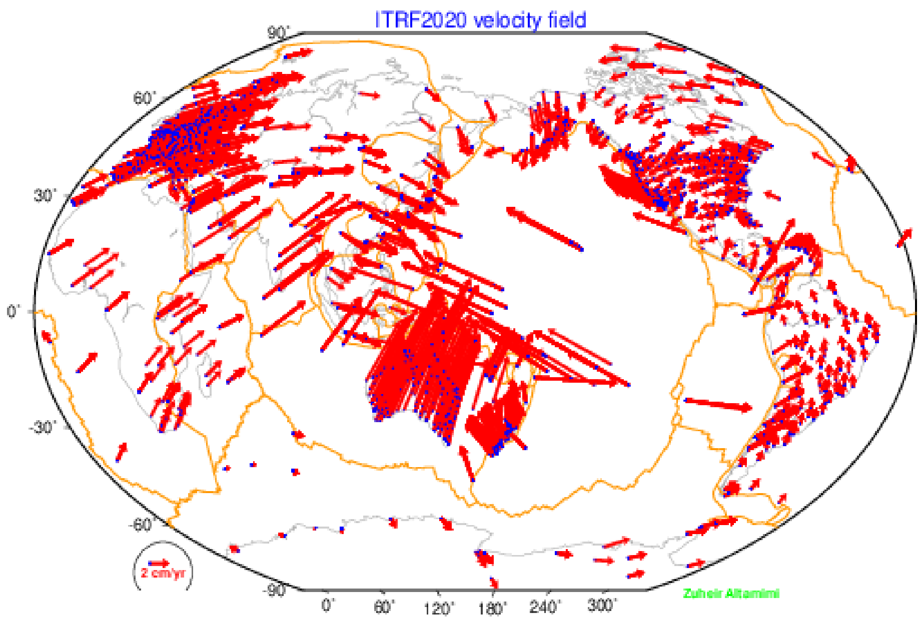

Figure 1: The plate tectonics described by the ITRF2020 velocity field [Altamimi et. al. 2022].

In Altamimi [2018] 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 25 cm in height when transforming from a recent epoch (2023) 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. 2023, Häkli et. al. 2016, Nørbech et. al. 2006]. These transformations use grid files for interpolation of the deformations caused by the postglacial rebound. The land uplift model used in the latest set of NKG-transformations, NKG_RF17vel, is shown in Figure 2.

For some applications, the official EUREF-transformation according to Altamimi [2018] without taking internal deformations into account, is not sufficient, but 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 and different areas.

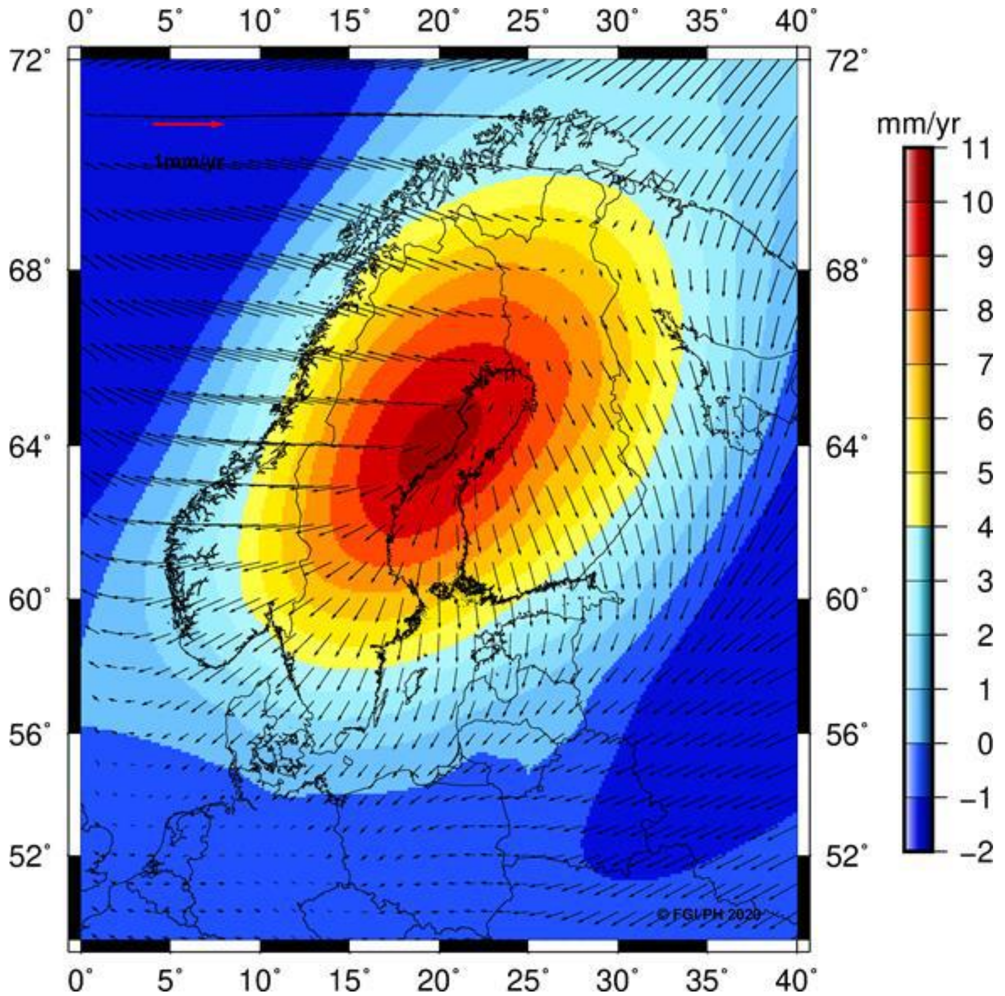

Figure 2: NKG_RF17vel model intraplate velocities. Black vectors denote horizontal velocities in ETRF2014. Vertical velocities shown with the colormap. Unit: mm/yr. [Häkli et. al., 2023]

2. ITRF2020 and IGS20

ITRF2020 is today (2023) the latest realization of ITRS. It was released in April 2022 and the IGS-version of it, IGS20, was introduced into IGS- and EPN-processing in GPS-week 2238 (November 27, 2022). This means that the IGS-products (orbits and clocks used e.g., for PPP) from this date are in IGS20.

IGS has adjusted each ITRFyy to be consistent with the GNSS-solutions. For the ITRFs between ITRF2005 and ITRF2014 adjustments have been made for the new antenna tables that have been introduced at the same as the new frames (igs05.atx, igs08.atx and igs14.atx). ITRF2020, which is based on IGS Repro3, did already use an updated antenna table (igsR3.atx), which for most receiver antenna types has the same models as igs20.atx. The satellite antenna offsets in igs20.atx have been adjusted (compared to igsR3.atx) to be consistent with ITRF2020. Stations with updated antenna model have also got updated coordinates in IGS20 compared to ITRF2020.

In other words, IGS20 – the IGS-version of ITRF2020 – is fully consistent with the latest official antenna models (igs20.atx). When performing PPP with IGS-products and using antenna models from igs20.atx, the result will be in IGS20.

3. 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. So far (April 2023) no national realization based on ETRF2014 has been endorsed by EUREF. No ETRF corresponding to ITRF2020 has been defined yet (April 2023).

The national realizations of ETRS89 are based on different ITRFs/ETRFs and have been established during a period of more than 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 cumulate IGSyy/ITRFyy solutions from the processing of the EPN-network, e.g. EPN_IGb14 (which can be found at ftp://ftp.epncb.oma.be/pub/product/cumulative/) could of course also be transformed with the EUREF-transformations [Altamimi 2018] to the conventional frame ETRF2000 (or any other ETRF).

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] and Jivall [2018] it was concluded to have different areas with different sets of transformation parameters – one for central Europe and one for the Baltic Sea.

The national ETRS89 coordinates were obtained directly from Elmar Brockmann as they could not be easily downloaded anymore. 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).

In total 30 European countries are included in the data set, but three of them have stated the epoch 1989.0, so those were not used when trying to find the most appropriate epoch to represent the national ETRS89-realizations.

For central Europe, the median epoch of the available national realizations is 2008. Most of the realizations are also based on the conventional frame ETRF2000. Hence **ETRF2000 epoch 2008.0 was chosen to represent the national ETRS89 in central Europe**. This epoch is also close to the national epoch of two countries (Greece and Italy) with large velocities within the European plate.

The **area around the Baltic Sea and Norway are affected by the postglacial rebound** and need special treatment, possibly divided into smaller areas to keep the accuracy when the deformation is growing with time. **SWEREF 99, the Swedish ETRS 89 realization, covers the whole area and has reasonable small differences to the national ETRS 89 realizations**.

Additionally, the epoch of SWEREF 99 (1999.5) is close to epoch of the Baltic Sea Chart Datum 2000 [Ågren et. al. 2023] (2000.0).

To give an idea about the differences between the national realizations and the selected frames to represent them, plots with differences are presented in Figure 3 - Figure 6.

Sweden and Finland, which are most affected by the post glacial rebound, are not included in the plots for central Europe (Figure 3 and Figure 4), but the other Nordic and Baltic countries are included in both comparisons. The national ETRS 89 realizations of Denmark and the Baltic countries agree slightly better with ETRF2000 epoch 2008 (based on EPN_IGb14_C2220) than with SWEREF 99.

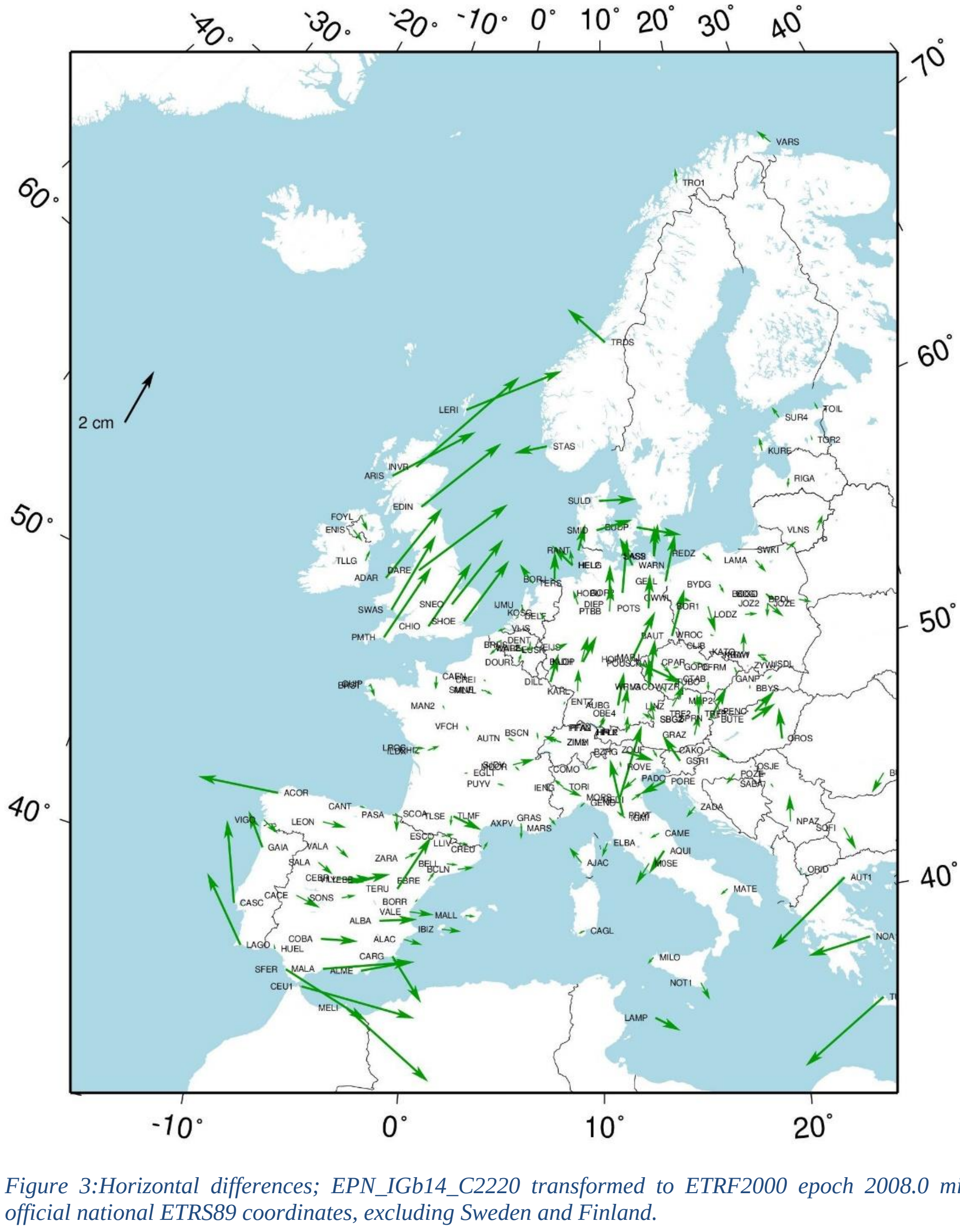

Figure 3:Horizontal differences; EPN_IGb14_C2220 transformed to ETRF2000 epoch 2008.0 minus official national ETRS89 coordinates, excluding Sweden and Finland.

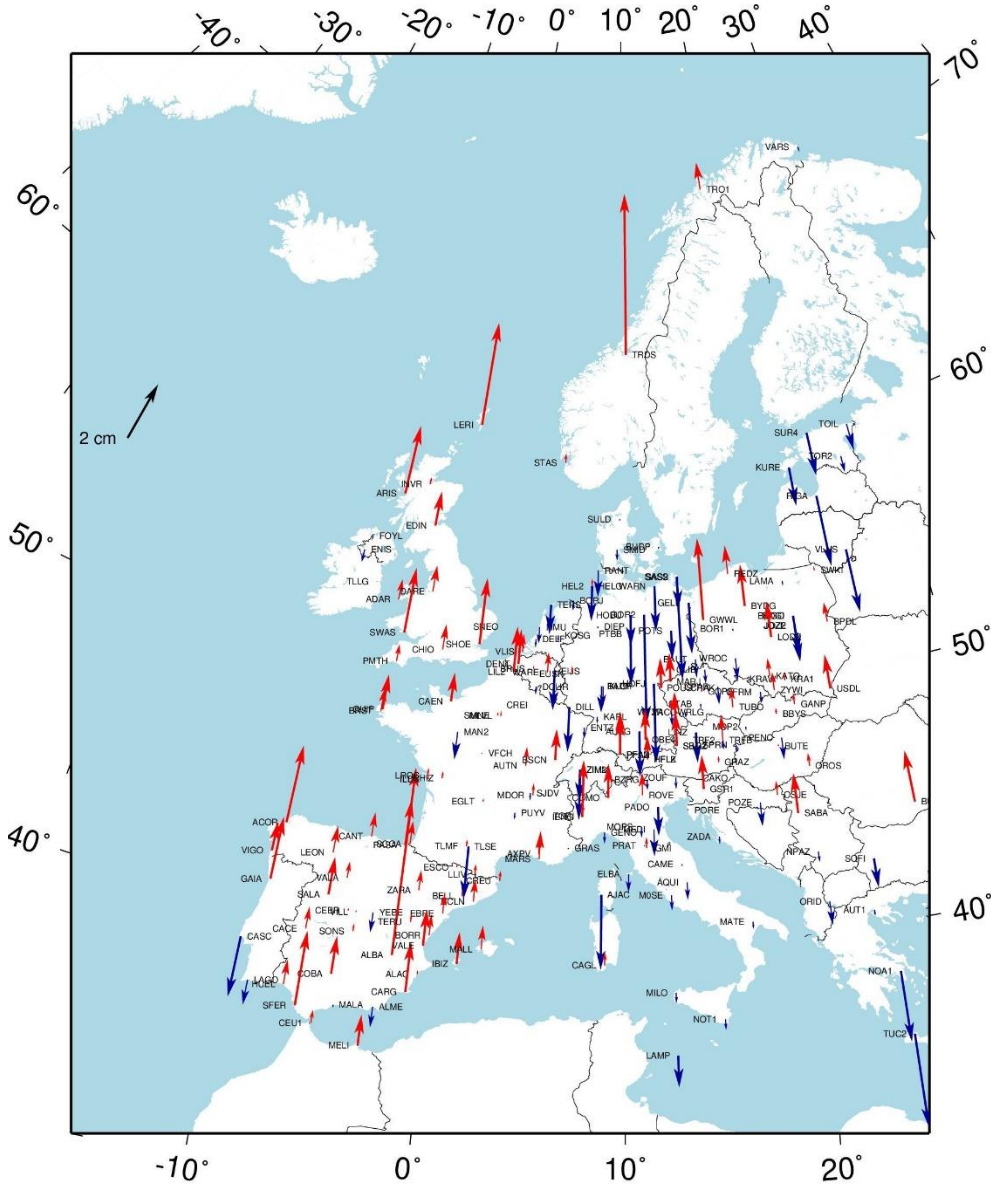

Figure 4:Vertical differences; EPN_IGb14_C2220 transformed to ETRF2000 epoch 2008.0 minus official national ETRS89 coordinates, excluding Sweden and Finland.

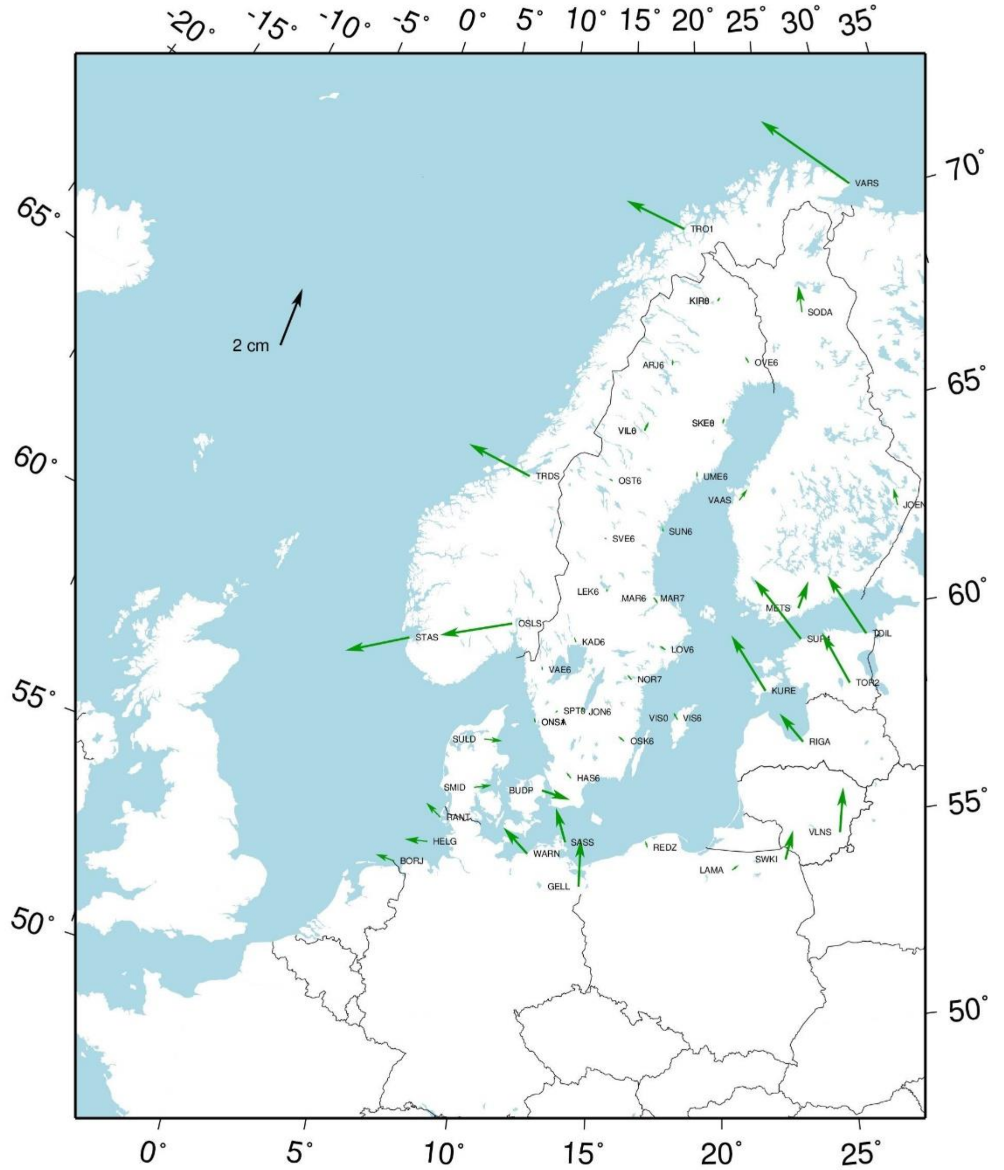

Figure 5: Horizontal differences; EPN_IGb14_C2220 transformed to SWEREF 99 with the NKG-transformation [Häkli et.al. 2023] minus official national ETRS89 coordinates for countries around the Baltic Sea and Norway.

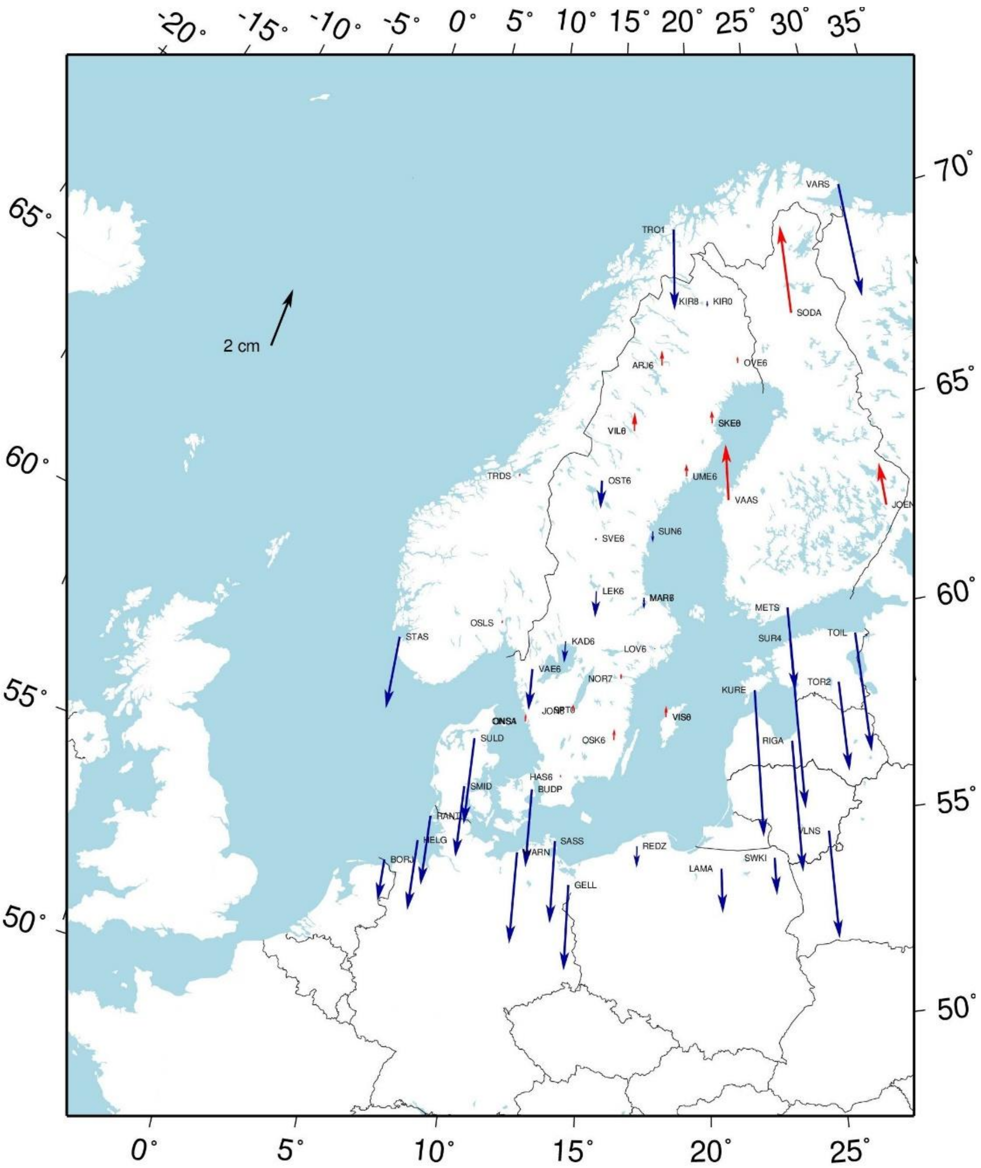

Figure 6: Vertical differences; EPN_IGb14_C2220 transformed to SWEREF 99 with the NKG-transformation [Häkli et.al. 2023] minus official national ETRS89 coordinates for countries around the Baltic Sea and Norway.

4. Basic model for the transformations

The request from the maritime surveyors 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 10.

The transformations are defined from ITRF2020 to ETRS89.

Transformation parameters are estimated based on fittings between ITRF 2020 in different epochs and the frame representing ETRS89 in different areas (ETRF2000 epoch 2008.0 or SWEREF 99 according to the previous section).

Earlier we have used physical fitting points in terms of EPN-stations included in the EPN cumulative solution that was chosen to represent ITRFyyyy. However, those stations are not always optimal placed (no stations in the sea) and with growing deformations a more dense set of points is needed. The access to official high accuracy transformations including deformation models has opened the possibility to define fictive fitting points in a grid and use the transformations to construct the data sets.

Yearly parameters have been solved, as ITRF changes with the plate tectonic (2-3 cm/yr in Eurpoe). The maximum error dependent on the epoch will be 1.5 cm in horizontal – see Figure 1.

The yearly epochs (2022.5 – 2026.5) 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 epoch has already passed, but it was decided to include it to continue the series and have a small overlap to the series in [Jivall 2018].

5. Central Europe

Fitting points were defined in a grid spanning over latitude 30°–70°N and longitude -12°–40°E, with the resolution 0.5° both in latitude and longitude. Only points in or close to the sea and on the Eurasian plate were used and points in the Baltic Sea were excluded. Totally 2576 fitting points were used (Figure 7).

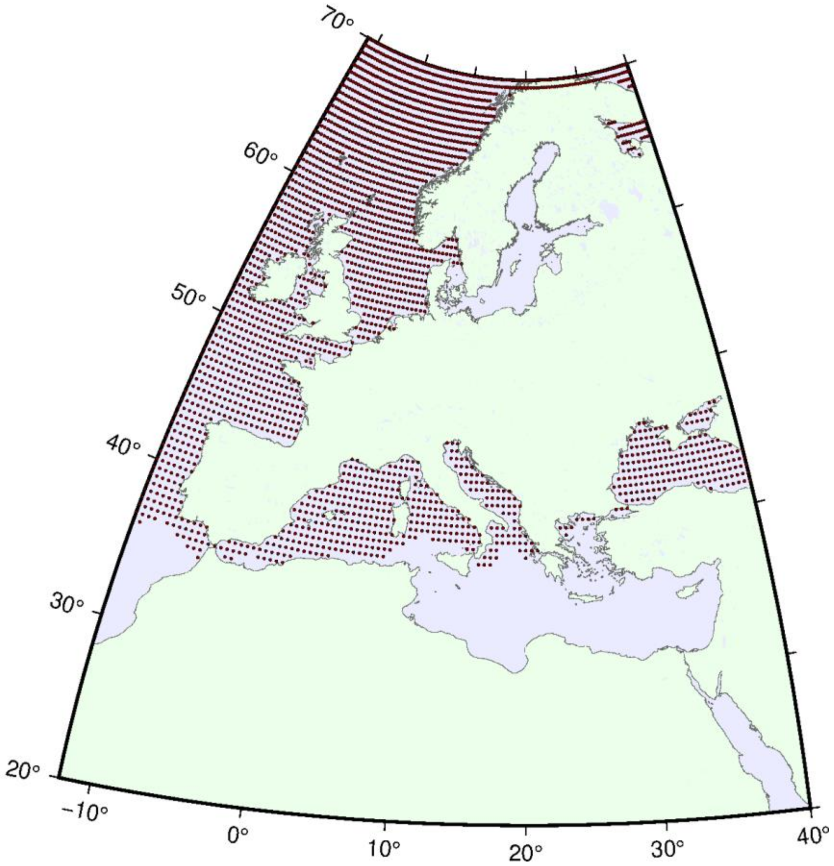

Figure 7: Fitting points for central Europe.

The coordinates for the fitting points were transformed from ITRF2020 (epoch 2022.5–2026.5) to ETRF2000 using the official EUREF-transformation [Altamimi 2018]. Finally, the epoch was reduced to epoch 2008 using the EUREF velocity field (EuVeM2022) [Steffen et.al., in preparation 2023].

Residuals for selected points are shown in Figure 8 – Figure 11.

The horizontal residuals are smaller than 1 cm for the main part of the area. Only in the Adriatic Sea, the strait of Gibraltar, the Black Sea and above all close to Greece, the residuals are considerable larger. The reason is local deformations which cannot be handled with a 7-parameter-transformtaion. In vertical we have the largest residuals close to the Norwegian coast, which are caused by the Post glacial rebound in Scandinavia. There are also some large residuals close to Iceland and southern Italy.

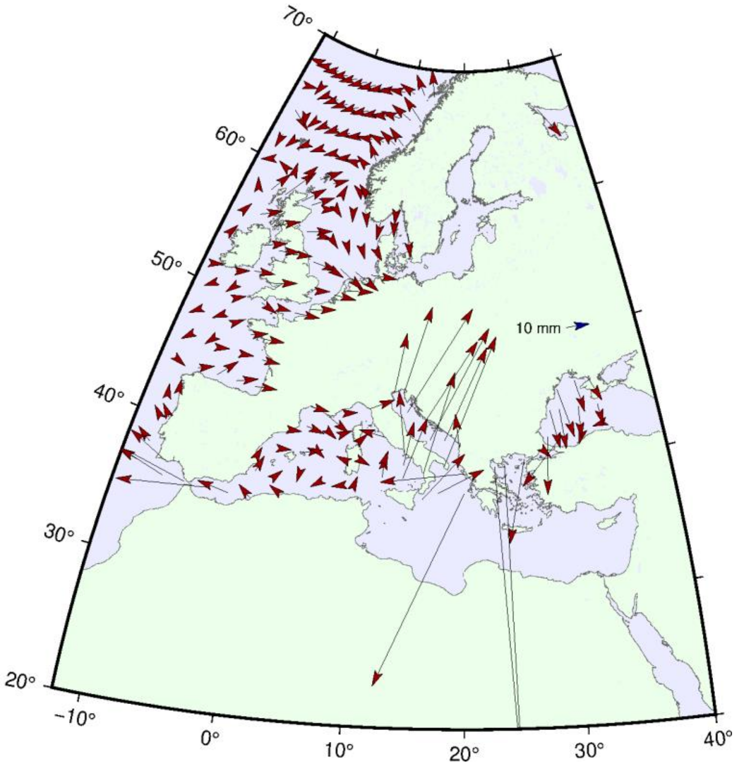

Figure 8: ITRF2000 epoch 2022.5 to ETRF2000 epoch 2008.0, horizontal residuals in the Helmert-transformation.

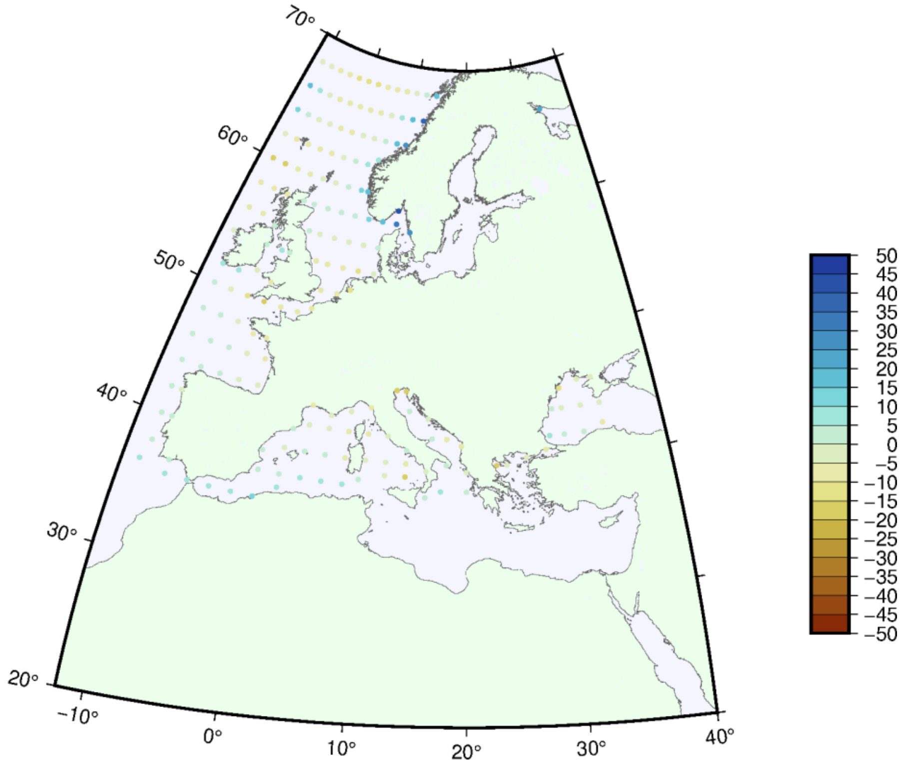

Figure 9: ITRF2000 epoch 2022.5 to ETRF2000 epoch 2008.0, vertical residuals in the Helmert-transformation.

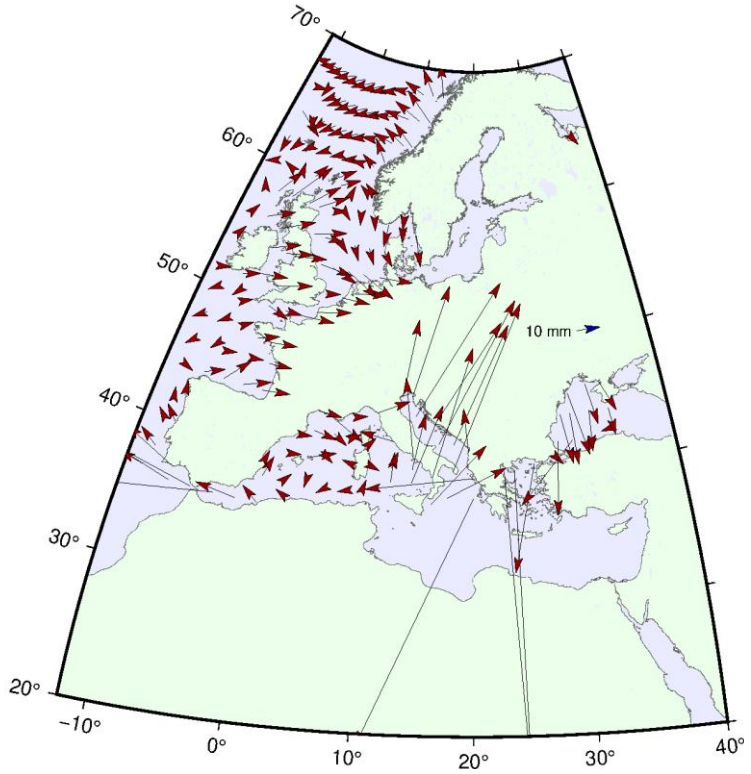

Figure 10: ITRF2000 epoch 2026.5 to ETRF2000 epoch 2008.0, horizontal residuals in the Helmert-transformation.

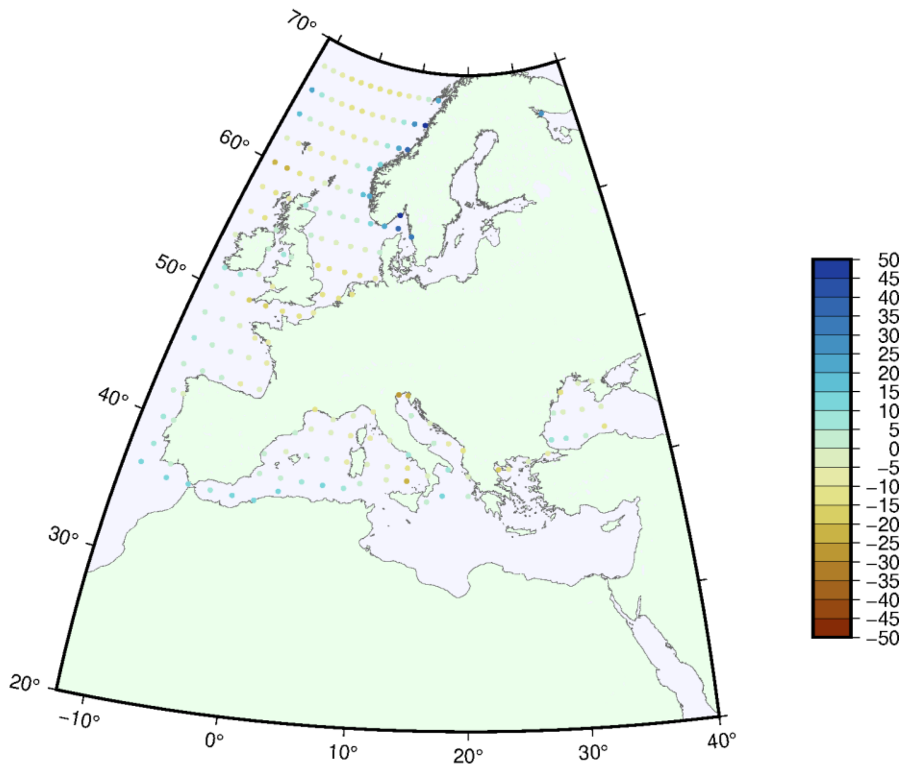

Figure 11: ITRF2000 epoch 2026.5 to ETRF2000 epoch 2008.0, vertical residuals in the Helmert-transformation.

As an attempt to avoid the quite large vertical residuals outside the Norwegian coast and north of Denmark (between Norway, Denmark and Sweden), alternative transformations were developed for those areas, see further section 8 and9. It is up to the user decide if the general transformation for central Europe or one of the more local sets is most appropriate for a certain task.

6. Northern Baltic Sea

Fitting points were selected using the same criteria as for central Europe, but just including points in or close to the Baltic Sea with the latitude larger than 60°. The fitting points are shown in Figure 12.

The coordinates of the fitting points were transformed from ITRF2020 (epoch 2022.5 – 2026.5) to SWEREF 99 via ITRF2014. The official global transformation between ITRF2020 and ITRF2014 was first used. Then the transformation to SWEREF 99 was performed with the NKG-transformation [Häkli et.al. 2023].

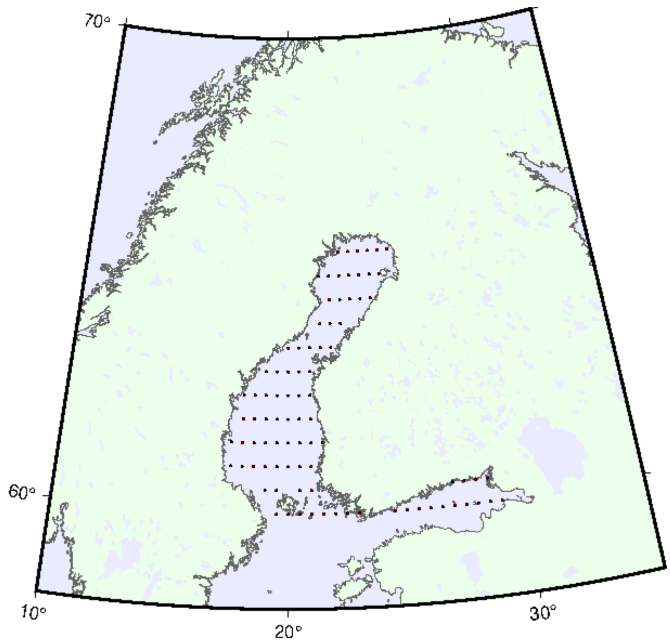

Figure 12: Fitting points for northern Baltic Sea.

Residuals for selected points are shown in Figure 13 – Figure 16.

The horizontal residuals are in general smaller than 1 cm. Vertically the residuals vary between -2.5 cm in the north and south parts of the area and +1.5 cm in the middle.

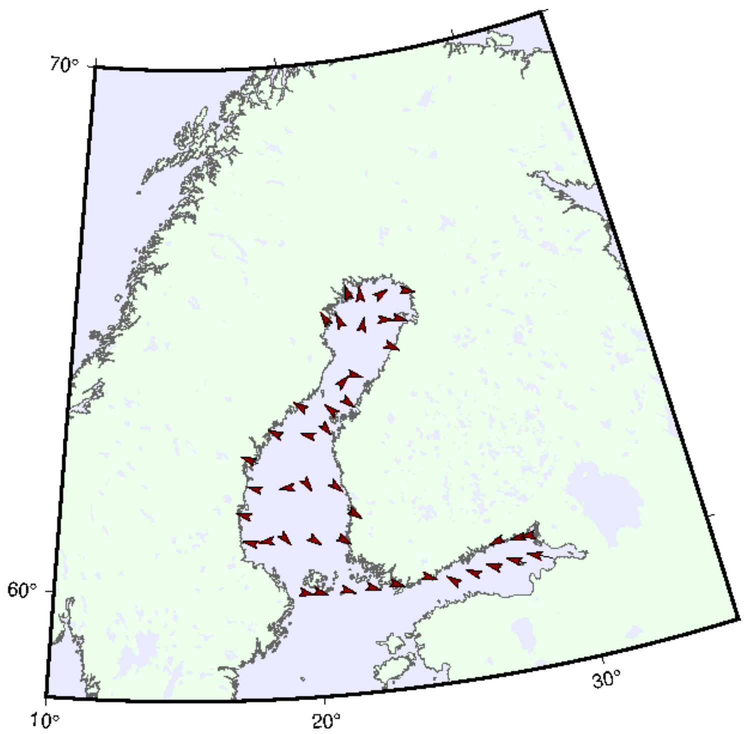

Figure 13: ITRF2000 epoch 2022.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

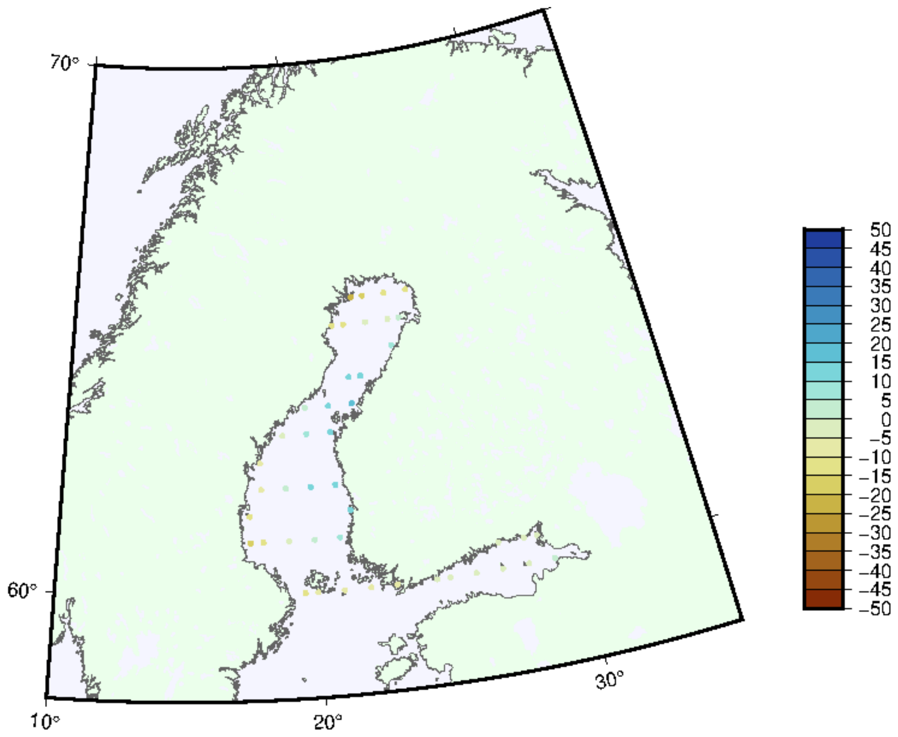

Figure 14: ITRF2000 epoch 2022.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

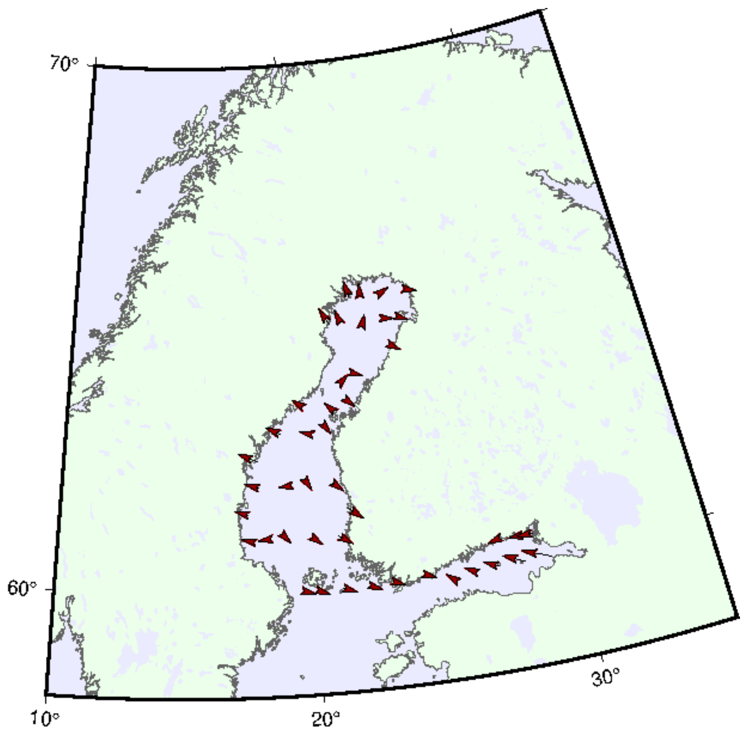

Figure 15: ITRF2000 epoch 2026.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

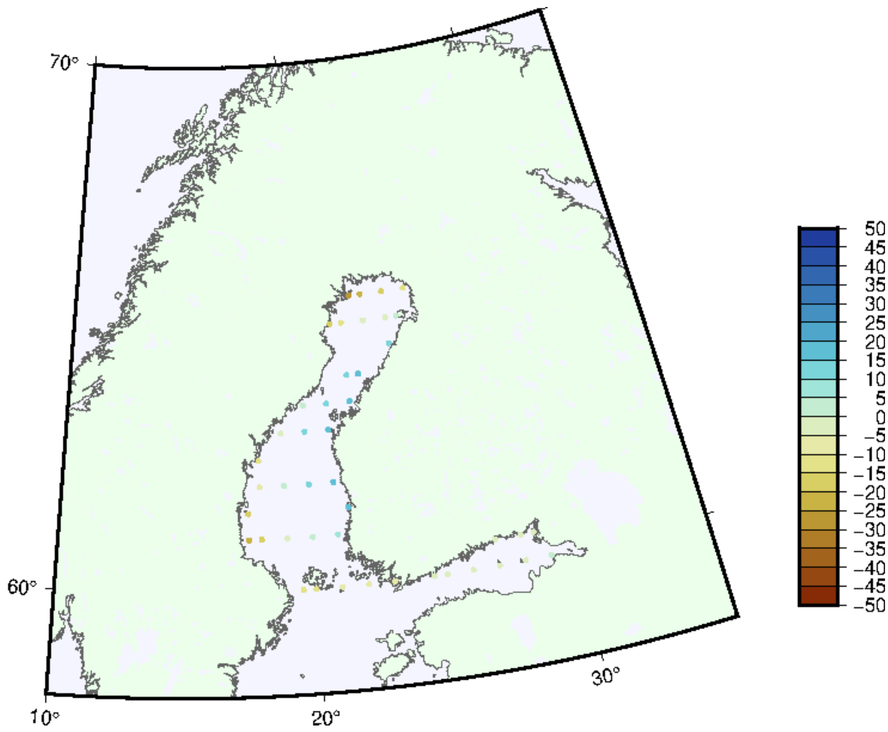

Figure 16: ITRF2000 epoch 2026.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

7. Southern Baltic Sea

Fitting points were selected using the same criteria as for central Europe, but just including points in or close to the Baltic Sea with the latitude smaller than 62° and longitude larger than 13°. The fitting points are shown in Figure 17.

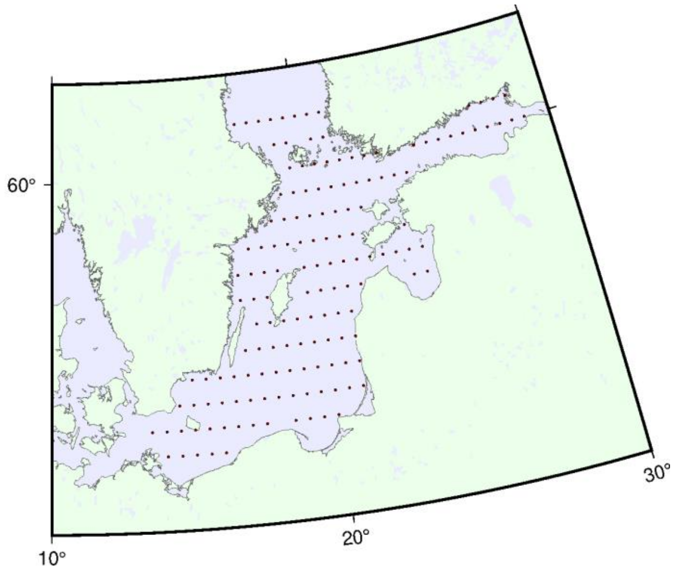

Figure 17: Fitting points for southern Baltic Sea.

The coordinates of the fitting points were transformed from ITRF2020 (epoch 2022.5 – 2026.5) to SWEREF 99 in the same was as for the northern Baltic Sea. Residuals for selected points are shown in Figure 18 – Figure 21.

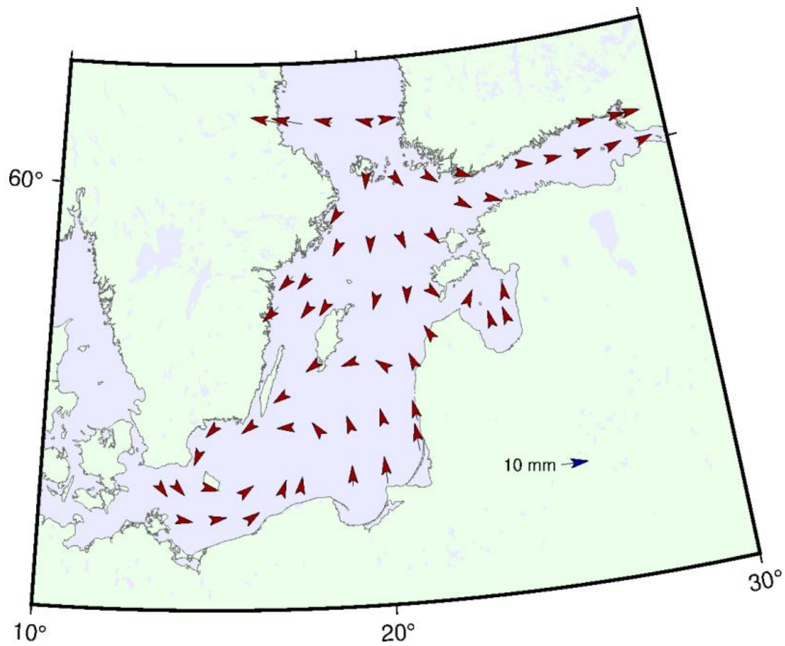

Figure 18: ITRF2000 epoch 2022.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

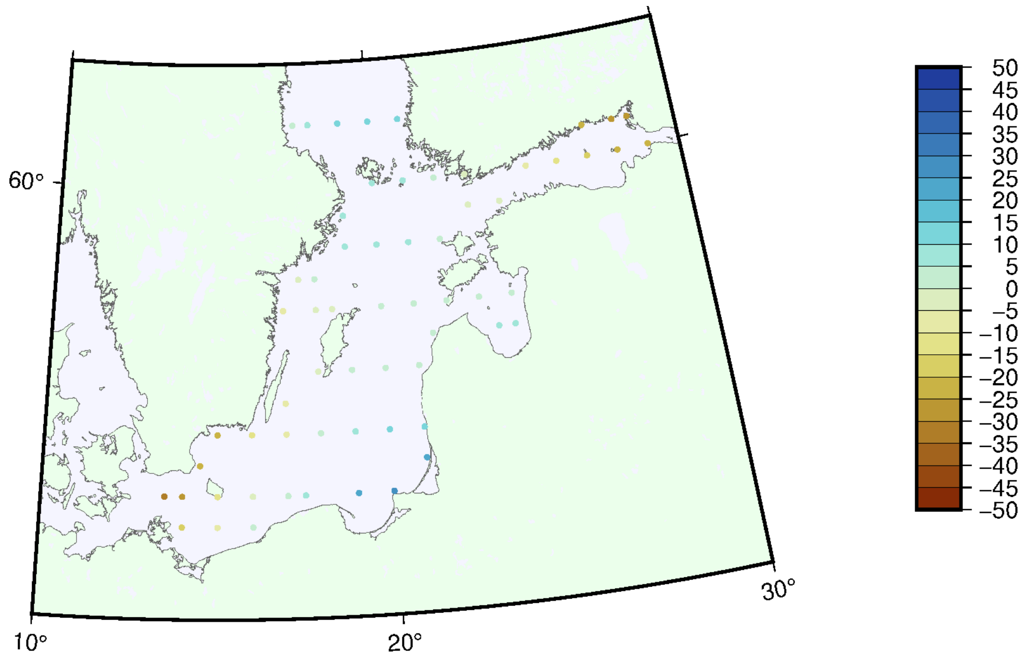

Figure 19: ITRF2000 epoch 2022.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

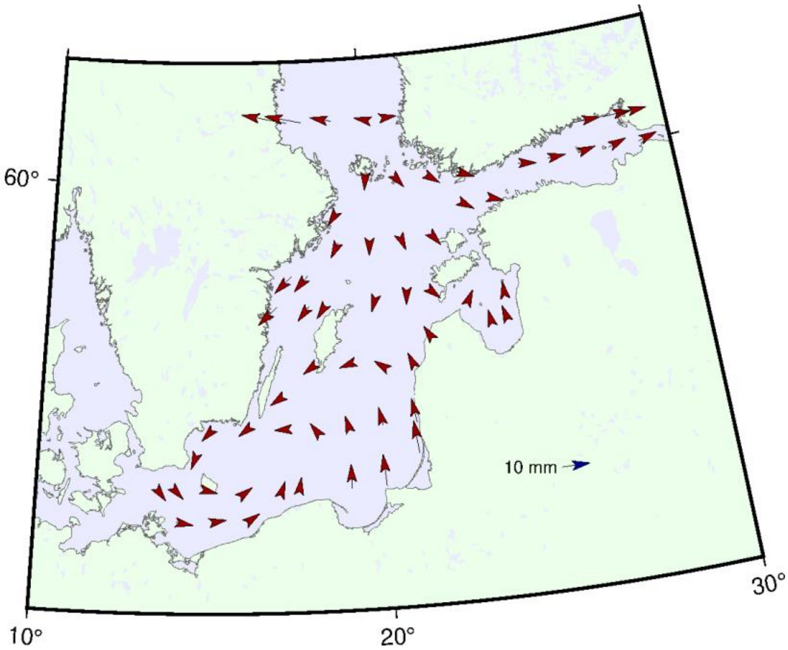

Figure 20: ITRF2000 epoch 2026.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

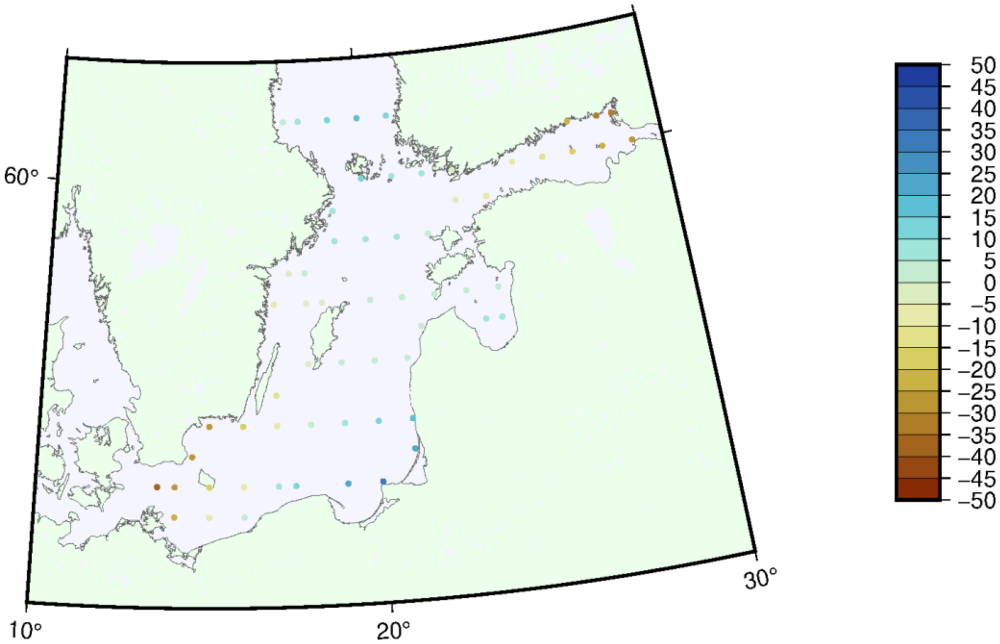

Figure 21: ITRF2000 epoch 2026.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

The horizontal residuals are in general smaller than 1.5 cm. the vertical residuals are in general smaller than 3 cm.

8. Denmark and outside southern Norway and western Sweden

This area is already covered by the transformations for central Europe (section 5), but to decrease the errors in height, a set of more local transformations was additionally calculated for this area. In this case SWEREF 99 is representing

ETRS89. The differences between SWEREF 99 and the national Danish and Norwegian ETRS89-realizations are shown for the EPN-sites in Figure 5 and Figure 6. The residuals in the figures below and the differences in Figure 5 and Figure 6 are added to get the difference between transformed values (from ITRF) to national coordinates, e.g. the Danish EPN-stations will be approximately 4 cm too low with the this transformation in 2026.5.

Fitting points were selected using the same criteria as for central Europe, but just including points in the following area: latitude between 54˚ and 61˚ and longitude between 3˚ and 14˚. The fitting points are shown in Figure 22.

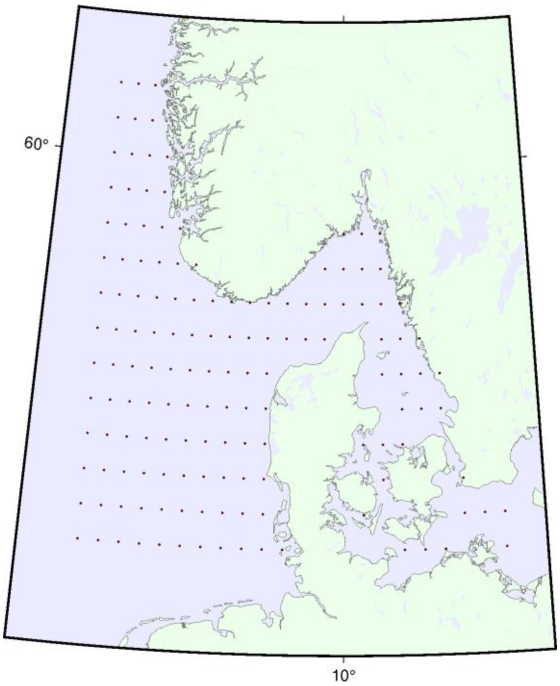

Figure 22: Fitting points for Denmark and southern Norway.

The coordinates of the fitting points were transformed from ITRF2020 (epoch 2022.5 – 2026.5) to SWEREF 99 in the same was as for the Baltic Sea. Residuals for selected points are shown in Figure 23 – Figure 26.

The horizontal residuals are in general smaller than 1 cm and the vertical smaller than 4 cm.

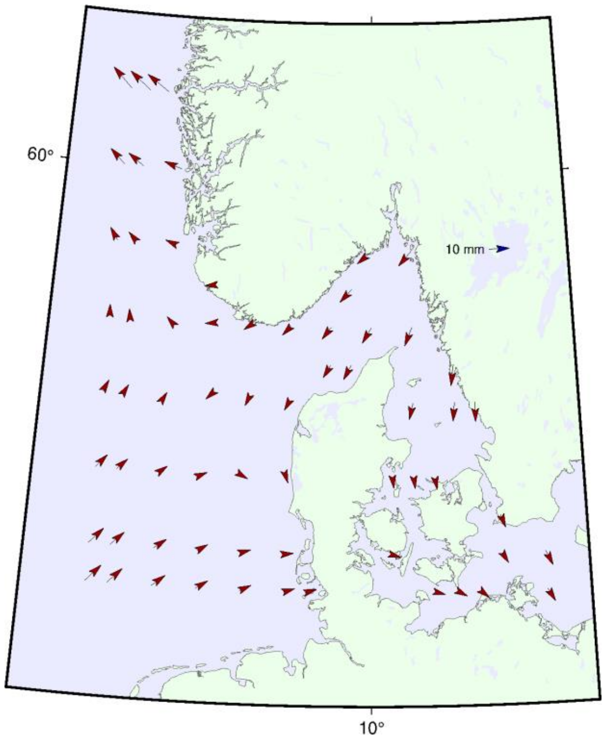

Figure 23: ITRF2000 epoch 2022.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

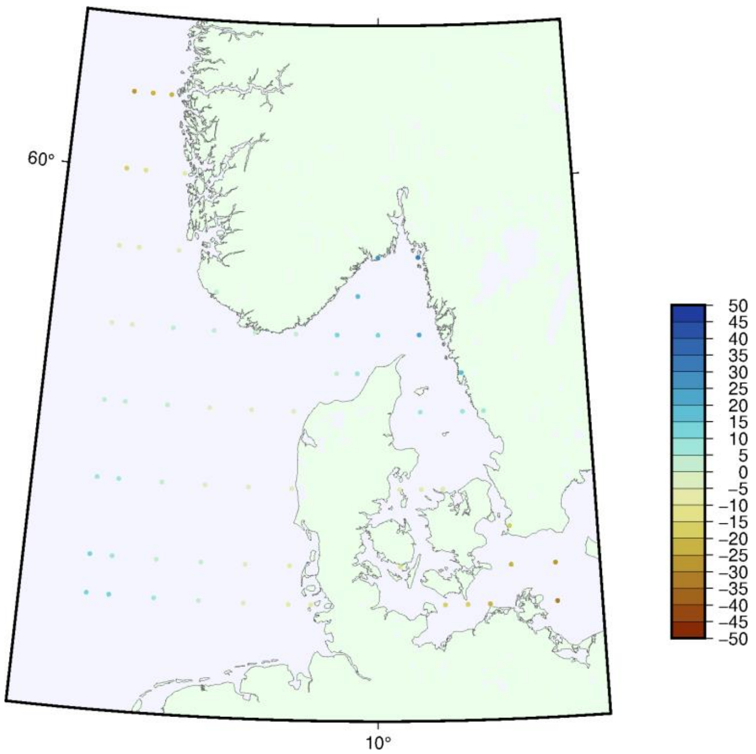

Figure 24: ITRF2000 epoch 2022.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

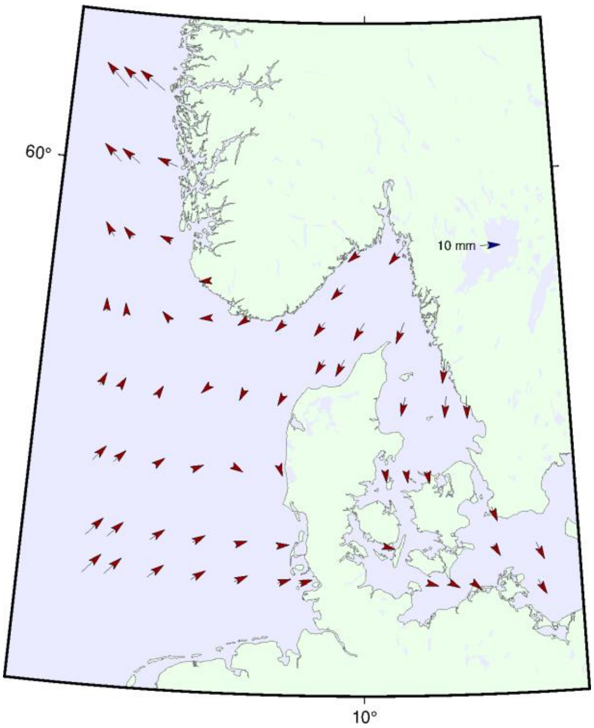

Figure 25: ITRF2000 epoch 2026.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

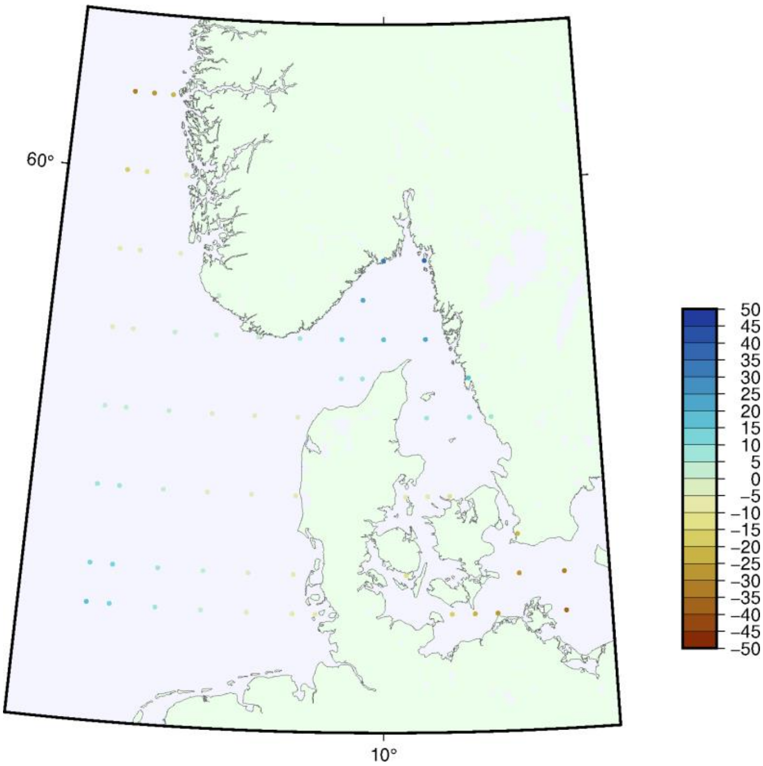

Figure 26: ITRF2000 epoch 2026.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

9. The Norwegian coast (partly)

This area is already covered by the transformations for central Europe, but to decrease the errors especially in height, a set of more local transformations was additionally calculated for this area. In this case SWEREF 99 is representing ETRS89. The differences between SWEREF 99 and the national Norwegian ETRS89-realizations are shown for the EPN-sites in Figure 5 and Figure 6. The residuals in the figures below and the differences in Figure 5 and Figure 6 are added to get the difference between transformed values (from ITRF) to national coordinates.

Fitting points were selected using the same criteria as for central Europe, but just including points outside Norway in the following area: latitude between 59˚ and 70˚ and longitude between -3˚ and 20˚. The fitting points are shown in Figure 27.

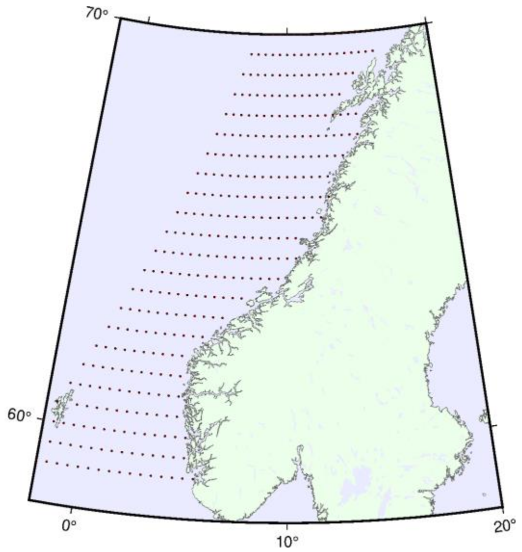

Figure 27: ITRF2000 epoch 2022.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

The coordinates of the fitting points were transformed from ITRF2020 (epoch 2022.5 – 2026.5) to SWEREF 99 in the same was as for the Baltic Sea and Denmark. Residuals for selected points are shown in

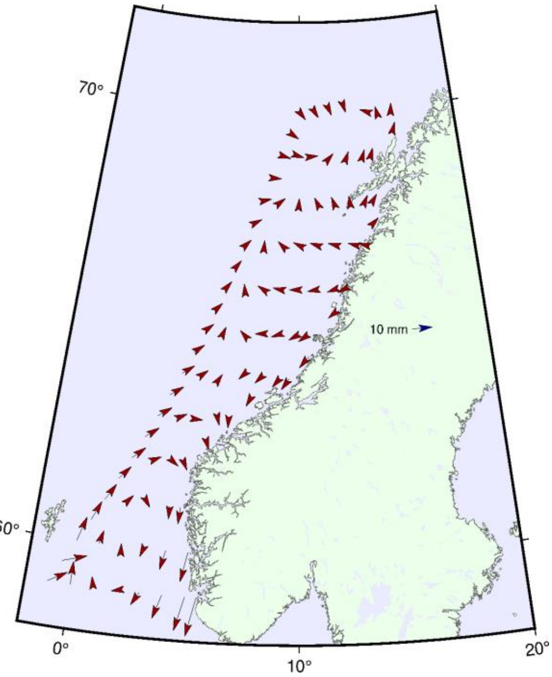

Figure 28: ITRF2000 epoch 2022.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

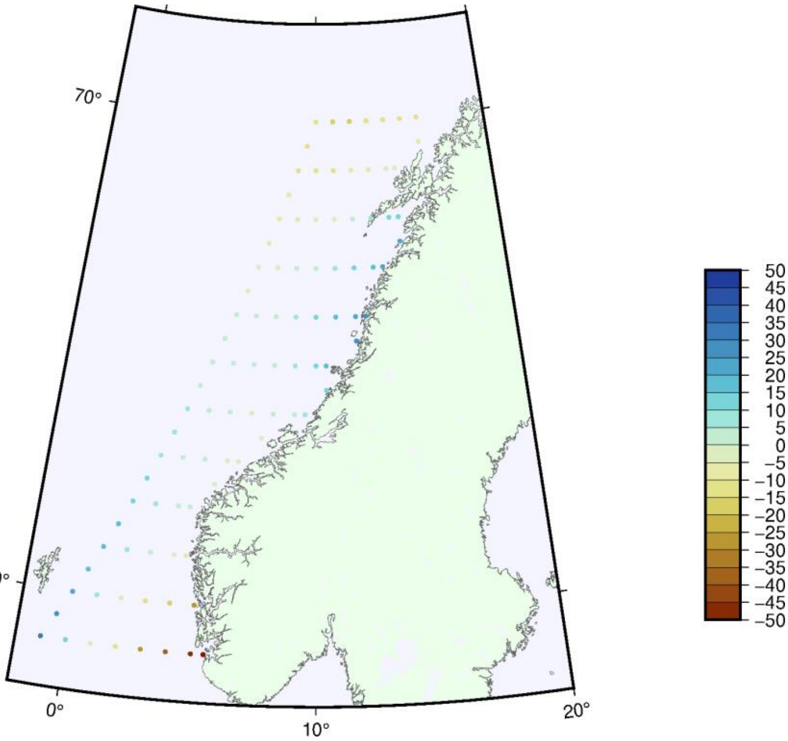

Figure 29: ITRF2000 epoch 2022.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

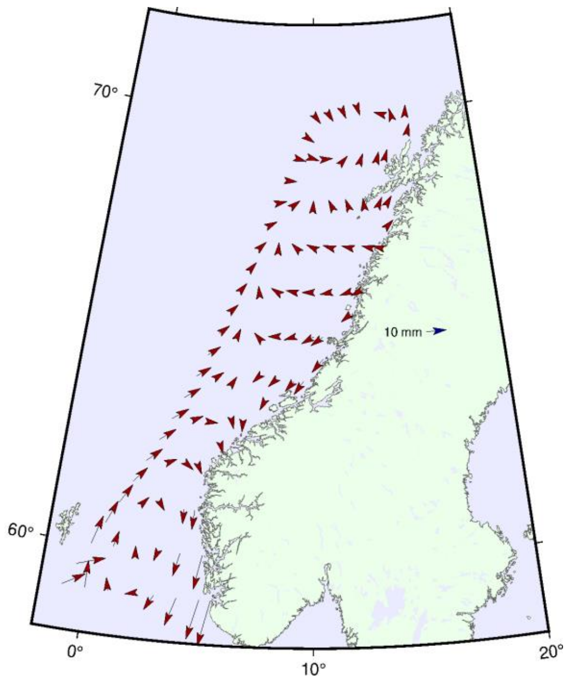

Figure 30: ITRF2000 epoch 2026.5 to SWEREF 99, horizontal residuals in the Helmert-transformation.

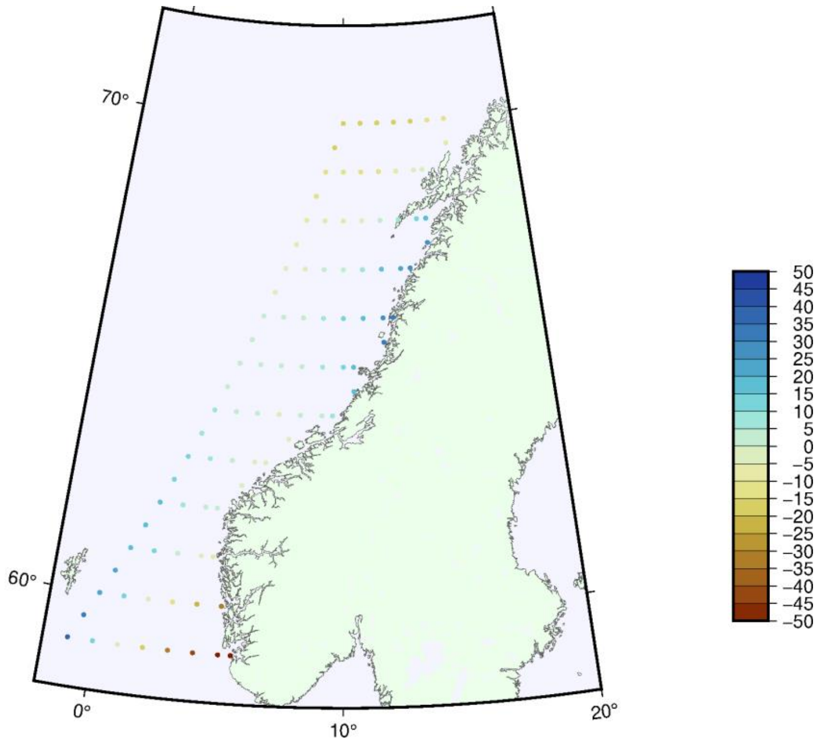

Figure 31: ITRF2000 epoch 2026.5 to SWEREF 99, vertical residuals in the Helmert-transformation.

10. 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 five sets of transformation parameters; one for central Europe including the British Islands and the sea outside Norway (Table 1), two for the Baltic Sea (Table 2 for the north part and Table 3for the south part) and two additional sets to enhance the accuracy around Denmark and along the Norwegian coast (Table 4 and Table 5). Parameters have been estimated for the yearly epochs 2022.5 – 2026.5, to be used for each corresponding year.

The residual plots from the estimation of the parameters (see sections 5 – 9) in combination with the differences between the national realizations and the frame representing them (see section 3) give an idea about the accuracy of the transformations in different areas. (The differences and residuals should be added to give the total error.)

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

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

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

Table 1:Parameters for different epochs to be used in central Europe, the British Islands and outside the Norwegian coast. See further section 5. Note that there are two additional sets of parameters that also cover the waters around Denmark and parts of the Norwegian coast. See further section 8 and 9 as well as Table 4 and Table 5.

Central Europe					
Parameter	2022.5	2023.5	2024.5	2025.5	2026.5
ΔX (m)	0.09532	0.09823	0.10114	0.10405	0.10697
ΔY (m)	0.05389	0.05403	0.05417	0.05432	0.05446
ΔZ (m)	-0.12704	-0.13096	-0.13487	-0.13878	-0.14270
ω_x (mas)	-2.470	-2.534	-2.598	-2.663	-2.727
ω_y (mas)	-14.680	-15.051	-15.421	-15.792	-16.162
ω_z (mas)	26.326	27.104	27.882	28.660	29.438
δ (ppb)	2.502	2.572	2.643	2.713	2.783

Table 2:Parameters for different epochs to be used in the northern part of the Baltic Sea (latitude > 60°).

Baltic Sea Northern Part					
Parameter	2022.5	2023.5	2024.5	2025.5	2026.5
ΔX (m)	0.61064	0.63592	0.66121	0.68649	0.71177
ΔY (m)	1.81267	1.88945	1.96623	2.04301	2.11980
ΔZ (m)	-0.55295	-0.57347	-0.59398	-0.61449	-0.63501
ω_x (mas)	-57.546	-59.947	-62.349	-64.750	-67.152
ω_y (mas)	5.939	6.446	6.954	7.461	7.968
ω_z (mas)	46.290	48.017	49.743	51.470	53.196
δ (ppb)	-47.773	-49.963	-52.152	-54.341	-56.531

Table 3:Parameters for different epochs to be used in the southern part of the Baltic Sea (latitude < 62° and longitude > 13°).

Baltic Sea Southern Part					
Parameter	2022.5	2023.5	2024.5	2025.5	2026.5
ΔX (m)	1.12288	1.17044	1.21799	1.26555	1.31310
ΔY (m)	1.42375	1.48362	1.54349	1.60336	1.66324
ΔZ (m)	-1.04268	-1.08449	-1.12629	-1.16810	-1.20990
ω_x (mas)	-49.629	-51.686	-53.743	-55.800	-57.858
ω_y (mas)	27.667	29.119	30.571	32.023	33.475
ω_z (mas)	37.330	38.667	40.004	41.341	42.678
δ (ppb)	-5.697	-6.057	-6.416	-6.776	-7.136

Table 4:Optional parameters for different epochs to be used around Denmark, southern Norway and western Sweden. See chapter 8 for coverage.

Denmark and outside southern Norway and western Sweden					
Parameter	2022.5	2023.5	2024.5	2025.5	2026.5
ΔX (m)	0.59116	0.61559	0.64003	0.66447	0.68890
ΔY (m)	-0.43588	-0.45686	-0.47784	-0.49883	-0.51981
ΔZ (m)	-0.41041	-0.42472	-0.43904	-0.45335	-0.46767
ω_x (mas)	8.509	8.980	9.450	9.921	10.391
ω_y (mas)	3.462	3.862	4.261	4.661	5.060
ω_z (mas)	14.719	15.073	15.427	15.780	16.134
δ (ppb)	-0.006	-0.119	-0.231	-0.344	-0.457

Table 5:Optional parameters for different epochs to be used outside the middle part of the Norwegian coast. See chapter 9 for coverage.

Norwegian coast (partly)					
Parameter	2022.5	2023.5	2024.5	2025.5	2026.5
ΔX (m)	-0.63818	-0.66720	-0.69621	-0.72523	-0.75424
ΔY (m)	-2.02243	-2.11240	-2.20236	-2.29232	-2.38228
ΔZ (m)	0.31854	0.33592	0.35329	0.37067	0.38805
ω_X (mas)	58.692	61.344	63.996	66.649	69.301
ω_Y (mas)	-42.995	-44.615	-46.235	-47.856	-49.476
ω_Z (mas)	-1.659	-2.018	-2.376	-2.734	-3.092
δ (ppb)	5.670	5.804	5.938	6.073	6.207

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:

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

11. Test example

For testing the implementation of the transformations, a test example has been prepared – see Table 6 and Table 7. Note that the ITRF2020-coordinates are the same for all epochs, which means that it is not the same point. The coordinates refer to a point in southern Baltic Sea, between Skåne in Sweden and Rügen in Germany. Note that it not really makes sense to transform this point with all transformation sets, but it works for testing the implementation of the transformations.

The difference between the two applicable transformations for this point (central Europe and Baltic Sea South) differ about 4 cm in height, which mainly depend on the different ETRS89 realizations (ETRF2000 epoch 2008 and SWEREF 99), but also on the residuals in the 7-parameter fits. The difference was similar in [Jivall 2018].

The test point is the same as used in [Jivall 2018]. For the epoch 2022.5 the coordinate difference is just over 1 cm compared to the corresponding transformations in [Jivall 2018] (Central Europe and Baltic Sea, respectively).

Table 6:Cartesian coordinates for testing the transformations.

Reference frame	X	Y	Z
ITRF2020 epoch 2022.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Eur. (2022.5)	3565285.5837	855948.5387	5201382.6425
ETRS89, Baltic Sea N (2022.5)	3565285.4826	855948.5205	5201382.5400
ETRS89, Baltic Sea S (2022.5)	3565285.5598	855948.5221	5201382.6119
ETRS89, Denmark (2022.5)	3565285.5649	855948.5243	5201382.6141
ETRS89, Norw. coast (2022.5)	3565285.4594	855948.4911	5201382.3613
ITRF2020 epoch 2023.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Eur. (2023.5)	3565285.5994	855948.5238	5201382.6328
ETRS89, Baltic Sea N (2023.5)	3565285.4945	855948.5050	5201382.5268
ETRS89, Baltic Sea S (2023.5)	3565285.5750	855948.5067	5201382.6018
ETRS89, Denmark (2023.5)	3565285.5803	855948.5090	5201382.6042
ETRS89, Norw. coast (2023.5)	3565285.4702	855948.4744	5201382.3404
ITRF2020 epoch 2024.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Eur. (2024.5)	3565285.6151	855948.5090	5201382.6231
ETRS89, Baltic Sea N (2024.5)	3565285.5063	855948.4895	5201382.5137
ETRS89, Baltic Sea S (2024.5)	3565285.5902	855948.4913	5201382.5918
ETRS89, Denmark (2024.5)	3565285.5958	855948.4936	5201382.5942
ETRS89, Norw. coast (2024.5)	3565285.4810	855948.4576	5201382.3194
ITRF2020 epoch 2025.5	3565285.0000	855949.0000	5201383.0000
ETRS89, central Eur. (2025.5)	3565285.6309	855948.4941	5201382.6134
ETRS89, Baltic Sea N (2025.5)	3565285.5182	855948.4740	5201382.5005
ETRS89, Baltic Sea S (2025.5)	3565285.6054	855948.4759	5201382.5817
ETRS89, Denmark (2025.5)	3565285.6112	855948.4783	5201382.5843
ETRS89, Norw. coast (2025.5)	3565285.4919	855948.4408	5201382.2985
ITRF2020 epoch 2026.5	3565285.0000	855949.0000	5201383.0000

Reference frame	X	Y	Z
ETRS89, central Eur. (2026.5)	3565285.6466	855948.4792	5201382.6037
ETRS89, Baltic Sea N 2026.5)	3565285.5300	855948.4585	5201382.4873
ETRS89, Baltic Sea S (2026.5)	3565285.6206	855948.4604	5201382.5717
ETRS89, Denmark (2026.5)	3565285.6266	855948.4630	5201382.5743
ETRS89, Norw. coast (2026.5)	3565285.5027	855948.4240	5201382.2776

Table 7: Geodetic coordinates for testing the transformations.

Reference frame	Latitude	Longitude	Height
ITRF2020 epoch 2022.5	54 59 59.998378	13 29 59.989138	-0.6034
ETRS89, central Eur. (2022.5)	54 59 59.979564	13 29 59.956239	-0.6325
ETRS89, Baltic Sea N (2022.5)	54 59 59.980380	13 29 59.956571	-0.7753
ETRS89, Baltic Sea S (2022.5)	54 59 59.979715	13 29 59.955645	-0.6731
ETRS89, Denmark (2022.5)	54 59 59.979611	13 29 59.955698	-0.6682
ETRS89, Norw. coast (2022.5)	54 59 59.977844	13 29 59.955268	-0.9386
ITRF2020 epoch 2023.5	54 59 59.998378	13 29 59.989138	-0.6034
ETRS89, central Eur. (2023.5)	54 59 59.979072	13 29 59.955218	-0.6337
ETRS89, Baltic Sea N (2023.5)	54 59 59.979924	13 29 59.955567	-0.7815
ETRS89, Baltic Sea S (2023.5)	54 59 59.979231	13 29 59.954603	-0.6750
ETRS89, Denmark (2023.5)	54 59 59.979125	13 29 59.954659	-0.6698
ETRS89, Norw. coast (2023.5)	54 59 59.977282	13 29 59.954213	-0.9519
ITRF2020 epoch 2024.5	54 59 59.998378	13 29 59.989138	-0.6034
ETRS89, central Eur. (2024.5)	54 59 59.978579	13 29 59.954202	-0.6349
ETRS89, Baltic Sea N (2024.5)	54 59 59.979473	13 29 59.954564	-0.7878
ETRS89, Baltic Sea S (2024.5)	54 59 59.978750	13 29 59.953561	-0.6768
ETRS89, Denmark (2024.5)	54 59 59.978636	13 29 59.953613	-0.6714
ETRS89, Norw. coast (2024.5)	54 59 59.976718	13 29 59.953152	-0.9653

Reference frame	Latitude	Longitude	Height
ITRF2020 epoch 2025.5	54 59 59.998378	13 29 59.989138	-0.6034
ETRS89, central Eur. (2025.5)	54 59 59.978084	13 29 59.953180	-0.6360
ETRS89, Baltic Sea N (2025.5)	54 59 59.979018	13 29 59.953560	-0.7940
ETRS89, Baltic Sea S (2025.5)	54 59 59.978266	13 29 59.952519	-0.6786
ETRS89, Denmark (2025.5)	54 59 59.978150	13 29 59.952574	-0.6729
ETRS89, Norw. coast (2025.5)	54 59 59.976154	13 29 59.952090	-0.9786
ITRF2020 epoch 2026.5	54 59 59.998378	13 29 59.989138	-0.6034
ETRS89, central Eur. (2026.5)	54 59 59.977592	13 29 59.952159	-0.6372
ETRS89, Baltic Sea N 2026.5)	54 59 59.978565	13 29 59.952557	-0.8003
ETRS89, Baltic Sea S (2026.5)	54 59 59.977785	13 29 59.951472	-0.6804
ETRS89, Denmark (2026.5)	54 59 59.977662	13 29 59.951535	-0.6746
ETRS89, Norw. coast (2026.5)	54 59 59.975592	13 29 59.951029	-0.9920

12. Used software

In-house Matlab-scripts were used to compute the transformation parameters and for the transformation of ITRF2020 to ETRF2000 epoch 2008.0. The maps were generated using the Generic Mapping Tools (GMT) [Wessel 2013]. The coordinates in the test example were produced with an in-house FORTRAN program (SEVENPAR_FULL).

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