REALISING OF ETRS89 AS THE NATIONAL REFERENCE FRAME IN NORWAY – EUREF89

VZPOSTAVITEV ETRS89 KOT DRŽAVNEGA REFERENČNEGA SESTAVA NA NORVEŠKEM – EUREF89

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ABSTRACT

The introduction to a new geodetic reference frame EUREF89 in Norway is described. The further steps for a complete transition of data bases from the old system, Norwegian system, to the new EUREF89 are also briefly described. A status for the transition to EUREF89 in Norway is also given.

KEY WORDS

reference frames, transformation, ETRS89

IZVLEČEK

V prispevku je opisano uvajanje novega geodetskega referenčnega sestava EUREF89 na Norveškem. Na kratko so opisani tudi nadaljnji koraki za celoten prenos podatkovnih baz s starega norveškega sistema na novi sistem EUREF89. Opisano je tudi stanje za prehod v EUREF89 na Norveškem.

KLJUČNE BESEDE

referenčni sestavi, transformacija, ETRS89

1 INTRODUCTION

The establishment of a new national geodetic network was given priority in Part 3 of the Norwegian National Mapping Plan. This Plan was officially promulgated in Government White Paper Number 1984:4 under the sub-heading "Geodesy". Completing this task therefore became one of the objectives assigned to the Geodetic Institute, a division of the Norwegian Mapping and Cadastre Authority (NMCA), "Statens kartverk". However, in view of the dramatic changes taking place in satellite geodesy during the 1980's, it was difficult to select the best time to address this task.

A provisional datum for use by the offshore industry had meanwhile already been established early in 1989. This datum was called "WGS84*SEA" and was based on observations in the North Sea – Fennoscandia region using the TRANSIT Doppler Satellite System, the predecessor of GPS (Global Positioning System). WGS84*SEA became quite widely used for land purposes, even though it had been designed primarily to serve offshore needs.

In 1989, the Geodetic Institute participated in a major GPS campaign observing at 93 European stations, including seven in Norway. These were Eigeberg (Stavanger), Hønefoss, Vigra (Ålesund), Vassfjell (Trondheim), Rensåsen (Bodø), Tromsø and Domen near Vardø. Each of these stations was already, or has since been, connected to the national First Order Triangulation Network.

Meanwhile, at the EUREF Commission meetings in 1991 and 1992, it was recommended that the EUREF89 Reference System should be used as the European geodetic datum in the same way as the North American Datum 1983 (NAD83) had become accepted in North America.

Post-processing of the 1989 observation data was completed by two independent computing centres, which subsequently reported to the EUREF Commission, a sub-commission of the International Association of Geodesy (IAG). Solutions prepared by the Bern University Computing Centre were used as a basis for final adjustments, which were then accepted in the summer of 1992. The National Mapping Authority subsequently decided to establish EUREF89 as an official national geodetic datum from 1 January 1993. The objective then was that this datum would replace both of the existing datums, NGO1948 that had been used for technical and large scale mapping series, and ED50 that had been used for topographic and geographical mapping.

The EUREF Commission, however, recognising technical developments, arrived at a significant recommendation in 1993/94. This was that the improvements in GPS with its international tracking networks and reference frames should be employed to further refine and adjust EUREF89. Accordingly, the Geodetic Institute agreed to plan for major GPS activities in the late summer of 1994. All of the original Norwegian EUREF89 stations, except Vassfjell, were re-observed and in addition connected to the SATREF stations. The permanent stations for navigational and geodetic purposes in Norway are called SATREF stations. Observations at the Vassfjell station were now found to be impossible due to electro-magnetic interference.

The EUREF-NOR94 GPS Campaigns formed the basis for the initial establishment of the required new geodetic framework for Norway. The receivers during this campaign were placed at each site for at least three days, and data were collected for twenty-four hours each day. These sites are called 3D stations or "Base Stations". Later campaigns observing for 4–8 hours at stations in between the base stations resulted in so-called "Main Stations". These two kinds of stations comprise what is called the "Stamnett" in Norway. The terms "3D Station" and "Main Station" are used in the context of the new Norwegian national geodetic network so that they are clearly distinguished from the stations in the existing classical triangulation network, especially in respect to the methods used to determine their respective coordinates.

EUREF89 is thus the name of the new geodetic datum for Norway. However, in view of the very high accuracies now available from world wide satellite observations, these new stations' coordinates will eventually become imprecise due to tectonic plate motion, and in Scandinavia, post glacial rebound. EUREF89 must therefore be clearly understood to be a statement of the positions of the measured stations as they were at the beginning of 1989. Regional drift and land up-lift is of course being continually monitored for scientific purposes, and, with this knowledge, future measurements can be corrected back to the 1989 epoch.

Practical positioning in the Norwegian area will in future be relative to the Stamnett, where the station coordinates are computed in the geodetic datum EUREF89. These coordinates will now remain unchanged for the foreseeable future. This means that coordinates which are computed for future Stamnett stations will also remain unchanged.

2 GPS CAMPAIGNS 1994–95

The work of creating the Stamnett began with the selection of the 3D Stations that would be occupied in 1994. These were negotiated and agreed on with the Flight Inspection Section (FIS) of the Norwegian Civil Aviation Administration (CAA (Norway)), and with the Directorate of Public Roads (DPR).

Detailed site requirements were issued well beforehand, while the Geodetic Institute designed how each station would be monumented in terms of foundations and type of fine mark. Some 70 marker bolts were produced by the Institute's workshops for this purpose. Each bolt was threaded so that a GPS antenna could be screwed onto it, thereby ensuring forced and repeatable centring.

Reconnaissance to select stations were carried out together with CAA (Norway) and NRD. The efforts at co-ordination had the additional benefit that the local authorities and CAA (Norway) offered to participate at their own expense in the actual station construction work. They also agreed to assist with the actual observation programs.

From the geodetic viewpoint, it was an absolute requirement that all stations would be built on bedrock, while there were clear needs for accessibility, security and a clear horizon at each station. Those who had previous knowledge of the areas made many excellent suggestions, and every effort was made to arrive at the most appropriate compromise solution in all cases. The final selections were made jointly by representatives from the Geodetic Institute, and from local authorities. Detailed building specifications and the necessary special bolts were of course provided to the points of contact at the NRD's offices and the county mapping offices as appropriate, for assistance in station construction work.

A total of 11 SNR-8100 TurboRogue GPS receivers with Dorne & Margolin T antennas were used during the first EUREF-NOR Campaign in 1994. These were borrowed from UNAVCO in USA. The receivers, together with the necessary associated equipment, were used to observe at 3D stations in a total number of 63.

The observation program for 3D stations continued the following year in the EUREF-NOR95 campaign lasting from late August to early October 1995. In this campaign 51 stations were included.

During the 1995 season, however, only eight TurboRogues were available, all of them coming from the Geodetic Institute's own resources. As in the previous year, the same Dorne & Margolin GPS antennas and observation procedure were used, and the observation time at each station was three days, 24 hours a day, starting at 00 GMT day one.

Apart from a few small changes, the whole observing campaign was completed according to plan. Station moves took place on schedule, with only few exceptions. The moves worked well in all but three cases where, for a variety of reasons, the receivers were not initialised until the following morning.

Equipment losses during the campaign were very small, only two compasses and a flashlight were found to be missing. More importantly, none of the small TurboRogue flash-cards were lost, implicitly indicating that none of the recorded observations were lost in transit between the observing sites and the point of downloading. Finally, the co-operation in the field between the various agencies involved went remarkably well.

TurboRogue receivers are arranged so that the observed data is recorded on flash-cards in the Turbo Binary format. The normal procedure then is for the data to be read into a PC. During the campaigns, data was read to a PC as near to the station as practicable for onward transfer by diskette. Otherwise, the flash-cards were used as the delivery medium. In some cases, it was possible to download the observed data to the Geodetic Institute through the county mapping offices' computer network. On arrival at the Institute's computers, the data were later converted into RINEX format.

Throughout the campaigns, observed data were recorded at 30 second sampling intervals, and with an elevation cut-off angle of 15 degrees.

It has already been mentioned that the object was to establish a new national reference frame, EUREF89, in Norway. Therefore it was important to connect the new measurements to the already existing EUREF89 stations in Europe. Accordingly, tracking data from 12 European IGS stations were obtained from the IGS Data Center at JPL in USA, all in RINEX format. Similarly, the tracking data from seven SATREF and five SWEPOS stations were obtained in RINEX format.

Picture 1*: Base station in Northern Norway.*

3 REALISING EUREF89 IN NORWAY

Coordinates from 15 stations in Europe were held fixed for defining EUREF89 from the results of the 1989 campaign. Each of these stations was on the European Tectonic Plate, and they consisted of seven VLBI and eight SLR sites. ITRF90 was used as the reference frame, and the epoch was 1989.0 (1 January 1989). This reference frame was given the name ETRF89 (European

Terrestrial Reference Frame 1989), and the associated reference system was called ETRS89 (European Terrestrial Reference System 1989).

The EUREF Commission (Boucher, 1994) recommended that the following procedure should be used to determine ETRS89, and to be able to include subsequent improvements both of GPS, international networks and the reference frame.

3.1 Compute the GPS data in ITRS at Epoch t_c

The latest version of ITRF was used. After the EUREF89-NOR94 campaign it was ITRF93, therefore ITRF93 has been used as the IERS reference frame in all the campaigns to materialise EUREF89. This entails obtaining the ITRF coordinates at epoch (t_0) from the IERS. These are then updated to the observation epoch (t_c) using velocity components for the IGS stations that had been used for transforming from a free adjustment to the ITRF. The velocity components are obtained from the ITRF Velocity Field, and new coordinates are computed using:

$$x_{ITRF93}(t_c) = x_{ITRF93}(t_0) + v_{ITRF93}(t_c\text{-}t_0)$$

3.2 Convert to ETRS89

This operation entails applying a systematic translation of the origin to ETRS89, but without altering the accurate ITRF scale. The EUREF Commission gives the following equation for this purpose (E=ETRF, I=ITRF):

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_E = \begin{pmatrix} x \\ y \\ z \end{pmatrix}^I_{t_c} + \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix} + \begin{pmatrix} 0 & -\dot{\theta}_z & \dot{\theta}_y \\ \dot{\theta}_z & 0 & -\dot{\theta}_x \\ -\dot{\theta}_y & \dot{\theta}_x & 0 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}^I_{t_c} \cdot (t_c - 1989.0)$$

The vector (t_x,t_y,t_z) gives the systematic translation of the origin here. The second part of the equation represents changes in the coordinates that have taken place in the period from January 1989 up to the time of observation resulting from tectonic plate movements.

When establishing the ITRF93 Velocity Field, the IERS used the latest geophysical tectonic plate model available – NUVEL-1A-NNR – for reference (Boucher, 1994). The rotation velocities tetadot correspond with the NUVEL-1A-NNR velocities corrected for the rotation velocity differences between ITRF93 and NUVEL-1A-NNR. The transformation parameters that were thus used in the conversion from ITRF93 to ETRS89 for the origin translation (t) and the derivatives of the rotations tetadot are given in Table 1.

$t_x(cm)$	$t_y(cm)$	$t_z(cm)$	$\dot{\theta}_x(0.001''/yr)$	$\dot{\theta}_y(0.001''/yr)$	$\dot{\theta}_z(0.001''/yr)$
1.9	5.3	-2.1	0.32	0.78	-0.67

***Table 1**: Parameters used for transformation between ITRF93 and ETRF89.*

3.3 Correct to 1989.0

All that now remains is to bring the co-ordinates to the true EUREF epoch on January 1, 1989 by correcting for post-glacial movements of the European tectonic plate. Data analysis from permanent GPS stations between June 1996 and January 2003 and campaign based data from 1994 to 2002 shows a significant three dimensional movement of Scandinavia relative to European plate. The size of this movement was not known in 1994/95 when we realised EUREF89 in Norway, and was therefore not included. The needed final Epoch 1989.0 co-ordinates can be obtained from the following expression:

$x_E(1989.0) = x_E(t_c) + v \bullet (1989.0 - t_c)$

4 ANALYSIS STRATEGY USED WHEN REALISING EUREF89 IN NORWAY

The results from the EUREF-NOR94 and EUREF-NOR95 campaigns were analysed based on a regional approach. Common to both campaigns, NOR94 and NOR95, are the use of precise GPS carrier phase and P-code pseudo-range measurements. In addition precise GPS ephemerides and GPS calculated Earth Orientation Parameters (EOP) value from one of the IGS analysis centres, namely NASA's JPL, were used. Data were processed with the JPL (Jet Propulsion Laboratory) GIPSY software.

In this regional analysis, IGS data from 14 sites in regional Europe were used together with the data from 11 mobile TurboRogue receivers at sites in Norway for the NOR94 data and 8 mobile TurboRogue receivers for the NOR95 data. In addition, data from respectively seven and five permanent tracking stations in Norway (SATREF) and Sweden (SWEPOS) were used. This provided a well distributed set of regional IGS sites from Ny-Ålesund, Svalbard in the north, Metsahovi, Finland in the east, Matera, Italy in the south-east and Mas Palomas on the Canary Islands in the south-west. The mobile receivers were placed at each site for at least three days, and data were collected for twenty-four hours each day. The GPS receiver type mounted on the European IGS sites was a mixture of TurboRogues and Rogues, and the antenna type was a mixture of Dorne & Margolin T, R and B antennas. In the analysis the station coordinates were solved for using weak constraints (10 and 100 meters).

Conversion from the free network results to ITRF93 was by transformation of each day's solution separately. For each daily free-network solution inner constraints were applied to the covariance matrix leaving the coordinates unchanged (Heflin et al., 1992). Five European IGS sites (Ny-Ålesund on Svalbard, Metsahovi in Finland, Wettzell in Germany, Madrid in Spain, and Matera in Italy) were used to estimate the transformation parameters. Statistical information from the transformed covariance matrix and the given standard deviations for ITRF93 were accounted for in this calculation. These selected sites define a strong geometrical network in Europe that can approximate a square of sites with Wettzell lying in the middle of Europe forming four triangles. All the mobile receivers lie in the two triangles in the north, which are Ny-Ålesund, Madrid and Wettzell in the west, and Ny-Ålesund, Metsahovi and Wettzell in the east. This implies that two of the IGS sites are very important sites in the materialization of EUREF89. These are Ny-Ålesund in the north and Metsahovi in the east.

5 FINAL ADJUSTMENT OF STAMNETT STATIONS

The final adjustment of the New Norwegian National Geodetic Network was carried out in May 1997. The coordinates computed for the Base Stations were used for fixed stations in the adjustments. This adjustment includes all the Main Stations in which measurements were carried out for 4–8 hours. Main Stations campaigns took place in primarily 1996 and 1997. All together some 3000 vectors were included in the adjustments.

The network adjustment of the Stamnett was carried out using the Gemini software in plane UTM map-coordinates.

Based on different statistical tests there were clear indications of having successfully achieved sub-centimetre quality in the Stamnett station coordinates. In total, the Stamnett thus consisted of 930 stations, distributed nation-wide, with well defined coordinates in EUREF89, as Norway covers 324 000 sq. km, that means an average of 19 km between the Stamnett stations.

6 DENSIFICATION OF THE NATIONAL NETWORK

This work is organised as a Geodata co-operation (Geovekst) between the main users under the leadership of NMCA. The final step of establishing the new reference frame is to densify the Stamnett according to the user requirements. The resulting network is called Landsnett and consists of 11 000 points with a density from one station per 10–25 sq. km in densely populated areas to less than one station per 100 sq. km in other areas.

The financial principle is based on the cooperation between NMCA, PRA and the municipalities. The progress of the project has been given priority according to rural areas where the infrastructure activities are highest. This work has been ongoing from 1997 and will be completed in 2008. A status of the Landsnett is shown in Figure 1.

With the Landsnett finished and ready for use, the final work with working out transformation formulas and the transition of all data to EUREF89 can be fulfilled.

Figure 1: *Status 2007 of Landsnettet.*

7 TRANSITION TO EUREF89

The work consists of the following elements

- Preparations, Analysis of existing network
- Start-up meeting, Geovekst agreement, schedule, economics
- Survey plan, local network
- Surveying, control points for transformations
- Transformation test results
- Develop local transformations

All these work packages are organised and coordinated by help of the GEOVEKST forum. At time being the activities concerning these work packages are intensified to reach the goal of having whole Norway covered with local transformations between old and the new EUREF89 within 2008. A status of the transition to EUREF89 in Norway is shown in Figure 2.

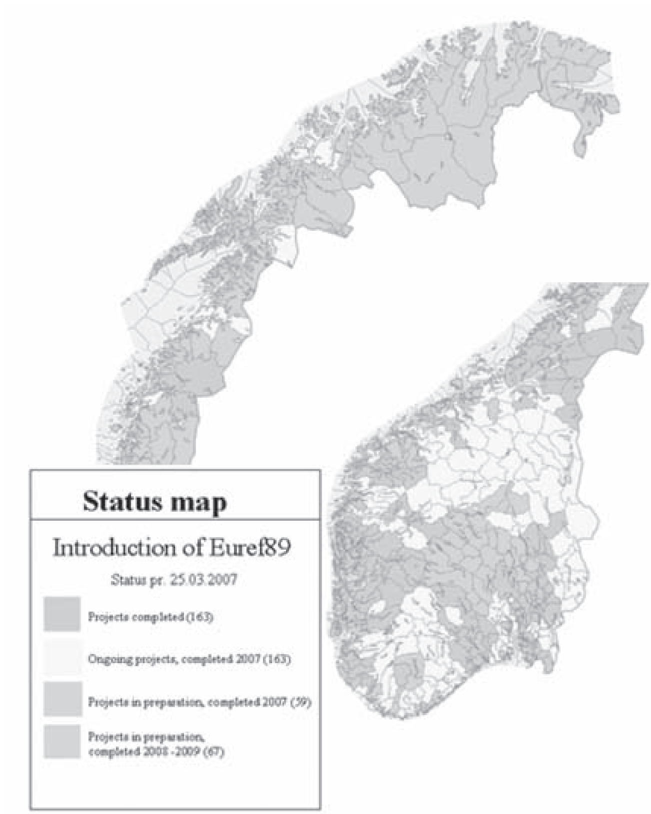

***Figure 2**: Status Local transformation 2007.*

The final technical work is to transform all data to EUREF89 by use of the local transformation formulas. Last but not least, a carefully prepared documentation and information plan has to be worked out to ensure the full benefit of this work to the users.

With this work done, the transition to EUREF89 in Norway is completed.

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