CHANGING THE GEODETIC INFRASTRUCTURE

MIKAEL LILJE, SWEDEN

Key words: Reference Frame, ETRS89, EVRS2000, Permanent GNSS stations

SUMMARY

The national reference frames in Europe are going from being national and more or less unique to national realisations of the European reference frame ETRS 89. Sweden is e.g. changing from the reference system RT 90, which is based on Bessel ellipsoid 1841, to a national realisation of ETRS 89, called SWEREF 99. Sweden is also at the same time introducing a new height system called RH 2000, that is the national realisation of the European height system EVRS 2000.

The access to reference frames has traditionally been using points in a dense network spread over the region or nation and measurements from these. The introduction of permanent GPS station for surveying and mapping has also made the access to the reference frames much easier for the users. In Sweden, the net of permanent GPS stations is called SWEPOS™. Since the 1st of January 2004 Lantmäteriet introduced a network-RTK service over a large part of Sweden making it even easier for users to access the national reference frame.

CHANGING THE GEODETIC INFRASTRUCTURE

MIKAEL LILJE, SWEDEN

1 ABSTRACT

The international trend for national reference frames at the moment, mainly due to the introduction of techniques such as GPS, is the use of global adopted reference. The European countries have e.g. to a large extent introduced national realisation of ETRS 89 and several countries have even gone so far as starting to use their realisation as the national reference frame for surveying and mapping.

This paper will give an overview of the work done in Europe and then describe the work conducted in Sweden to go from the traditional reference frame to a more modern and globally aligned reference frame as SWEREF 99 is the Swedish realisation of ETRS 89. Also discussions will be made concerning connecting a map projection to SWEREF 99 and the present concerning shifting from RT 90 to SWEREF 99 for mapping and surveying.

Also, a new national height network will be introduced in Sweden during 2004 and the work to produce and implement the height network will be described.

The classical way has been to use physical points on the ground as the realisation of the national reference system. We are more and more changing from using these points to instead use active permanent GPS stations and the paper will also give an overview of the development of SWEPOS as well as the services connected to it.

2 INTRODUCTION

In Sweden, the responsibility for geodetic control networks is divided between local authorities (about 290 local authorities exists) and Lantmäteriet (National Land Survey of Sweden). The main cause for this is mostly different aims of the systems. The responsibility for Lantmäteriet is to establish ground control for official mapping in small scales. The local authorities establish control networks for urban developments.

Lantmäteriet is the national geodetic authority but has no power against municipalities and other authorities. Lantmäteriet cannot do anything other than give proposal and advice to the local authorities concerning their reference systems.

Lantmäteriet is responsible for all national geodetic networks. The local authorities are responsible for their own networks. There is an on-going discussion at Lantmäteriet about replacing our national reference frame RT 90, which is based on the Bessel ellipsoid 1841, with a globally aligned reference frame. It is important that the new reference frame will be appropriate for a long time.

Choosing an ETRS 89 solution approved by the IAG subcommission for Europe (EUREF) and originating from recent observation data, would give us good possibilities to get a reference frame that could last for a long time. Of course, the land uplift will continue, and even the new set of co-ordinates will be obsolete if we do not take it into account. Starting from the land uplift epoch 1999.5, which is the epoch for three-dimensional reference system SWEREF 99, will give us some more years to develop models for the movements within our country (and, not the least, methods to handle those models). SWEREF 99 was approved by EUREF in the year 2000 as a national realisation of ETRS 89.

Continuing to work in the traditionally reference frames will force the users to use transformation formulae when using GPS effectively in Sweden, that means in connection to our permanent GPS reference network SWEPOS. Using transformation formulae will always result in distorting the quality of the collected data since no transformation formulae are free from errors. Therefore, to benefit fully from satellite techniques and the high accuracy that the global reference frames have the three-dimensional reference system SWEREF 99 should preferably be used nationally for both surveying and mapping. Lantmäteriet also recommends that SWEREF 99 should be introduced locally and together with the local authorities and others. (Engberg et. al). Lantmäteriet decided in 2003 on a set of map projections that will fulfil the needs both nationally and locally.

Sweden is also introducing a new height system, RH 2000 during 2004. The new height system is the result of 25 years of motorised levelling covering about 50 000 km double run levelling and 50 000 points. Norway, Denmark and Finland are also introducing or will introduce new height systems within a few years and the Nordic Commission of Geodesy (NKG) has urged the countries to develop as common national height systems as possible. Therefore, the Nordic countries have decided to implement national realisations of EVRS 2000 as their national height systems.

3 EUREF, EC AND OTHER EUROPEAN INITIATIVE

EUREF has been working actively together with the national mapping agencies since the end of the 80´s with the realisation of the ETRS 89 and since the mid-90´s on the UELN (United European Levelling Network). However, European height systems have been calculated longer than that. National and regional GPS Campaigns have been measured more or less over whole of Europe and the results of the various campaigns are evaluated by the EUREF Technical Working group before acceptance as a national or regional implementation of ETRS 89 (Ihde et. al.). Figure 1 shows the status concerning EUREF sites and figure 2 shows the status of EVRS 2000. The area in figure 1 that is dark yellow is the region covered by campaigns. The light yellow (Moldavia) is the country most recently covered by campaigns. The blue area (Albania, Bosnia and Herzegovina and Yugoslavia) has performed campaign but final selection of points and publication of the co-ordinates pending. The green area (Ukraine) has performed a campaign but it is not possible to compute the co-ordinates because the GPS data has been kept by the local authorities (Torres, 2004).

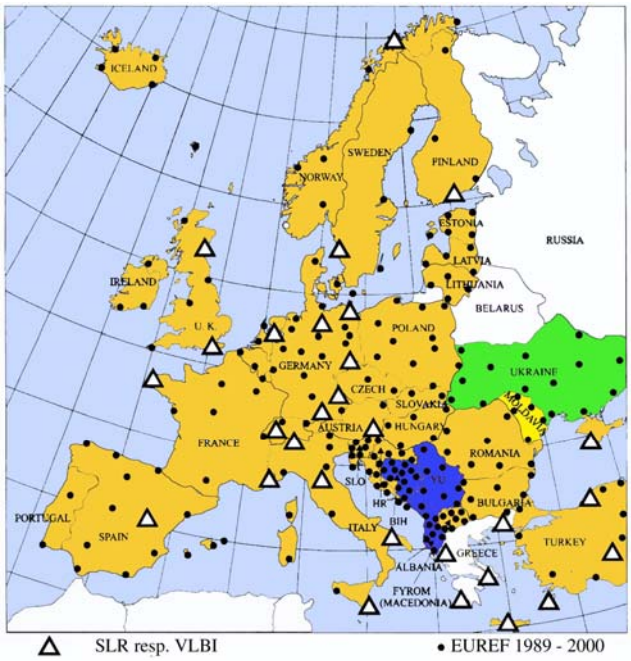

Figure 1. EUREF-sites

Figure 2. UELN-network

The extension of the EUREF-campaign has been done in the following order:

Between 1990 and 1999

- 24 campaigns validated by the EUREF Technical Working Group (146 sites)

Between 2000 and 2003

- EUREF-FIN-96/97 in Finland (sub-set of points)
- EUREF-Estonia-1997 in Estonia (sub-set of points)
- EUREF-Balkan-98 in Albania, Bosnia and Herzegovina, and Yugoslavia (final selection of points and publication of the co-ordinates pending)
- EUREF-Moldavia-99 in Moldavia (sub-set of points)
- EUREF-SWEREF-99 in Sweden (sub-set of points)
- EUREF-Balear-98 on the Balearic islands (Spain) (sub-set of points)
- EUREF-CRO-94/95/96 (re-computation)
- EUREF GB2001 in Great Britain
- EUREF campaigns in Slovenia in 94/95/96 (re-computation)

- EUREF-SK 2001 combined solution of campaigns in Slovakia
- HUNREF2002 campaign in Hungary

Several European countries, e.g. Denmark, Norway and Sweden have adopted their national ETRS 89-solution as their national reference system to be used for surveying and mapping.

The European Community (EC) has started to work in close co-operation with EUREF and other bodies concerning European co-ordinate reference system. Especially the Spatial Reference Workshop 15-16 November 1999 and the Cartographic Projection Workshop, 15-16 December 2000 in Marne-La-Vallée prepared the ground for the definition of a common European Coordinate Reference System (CRS). The workshops also prepared its use for geo-referencing of the data of the European Commission (EC) and for future specifications of the products to be delivered to the EC, within projects, contracts etc, and the promotion of the wider use within all member states by appropriate means. (http://crs.ifag.de/)

The Spatial Reference Workshop recommended that the European Commission (Annoni et. al):

European Geodetic Datum

- Adopts ETRS89 as the geodetic datum for the geo-references co-ordinates of its own data.
- Promotes the wider use of ETRS89 within all member states.

Geographical co-ordinate system

- Normally expresses positions related to ETRS89 datum in ellipsoidal type co-ordinates

European map projections

- Defines its various needs for map projection(s)/obtains further expert advise to determine the appropriate projections

European Vertical Datum

- Adopts the results of the EUVN/UELN initiatives when available, as definitions of vertical datum and gravity-related heights
- Promotes the wider use of European vertical reference system within all member states.

The Workshop recommended to the European National Mapping Agencies that:

Relationship with National co-ordinate Reference Systems

- National transformation parameters and algorithms to and from ETRS89 providing co-ordinates of accuracy at the 1-2 m level should be placed in the public domain. The availability of more accurate transformations should also be indicated (with the achievable accuracy's) and the official source of information.

On the WebPages http://crs.ifag.de/ it is possible to find information about the European and national reference frames as well as transformation parameters. The information system on the WebPages is a common initiative of EuroGeographics, EUREF and as acting institution the Bundesamt für Kartographie und Geodäsie (BKG). The information system is based on the convention of ISO 19111 Spatial referencing by co-ordinates standard. The National Mapping Agencies or comparable Institutions/Organisations provided the information for the descriptions of the national Coordinate Reference Systems and for the transformation parameters between the national Coordinate Reference Systems and the European Coordinate Reference System ETRS89.

INSPIRE (Infrastructure for Spatial Information in Europe) is a recent initiative launched by the EC and developed in collaboration with Member States and accession countries. It aims at making available relevant, harmonised and quality geographic information to support formulation, implementation, monitoring and evaluation of Community policies with a territorial dimension or impact. INSPIRE has written a position paper on *Reference Data and Metadata,* which is accessible on the WebPage http://www.ec-gis.org/inspire/, where common aspects on the reference data is described. Concerning geodetic Reference System and projections, INSPIRE has recognised that ETRS89 is the most appropriate geodetic datum to use. Also that EVRF2000 should be used for expressing orthometric heights. The INSPIRE document has gone further concerning map projections for spatial information in Europe and has the following recommendation:

- Use ETRS89 Lambert Azimuthal Equal Area coordinate reference frame of 2001 (ETRS-LAEA), for statistical analysis and display
- Use ETRS89 Lambert Conic Conformal coordinate reference frame of 2001 (ETRS-LCC) for conformal pan-European mapping at scales smaller or equal to 1:500000.
- Use ETRS89 Transverse Mercator coordinate reference systems (ETRS-TMzn), for conformal pan-European mapping at scales larger than 1:500000

This project show that what EUREF has done is important not only for the geodetic community but also for the whole community regarding geographical information. An IAG subcommission has had and will have great influence in the geodetic work within Europe, an influence that will be shown also in the work for everyone working with spatial information.

More and more users will be able to benefit from using geographical information for different types of analysis. The existence of positions in various forms for the spatial data is vital for the user. The use of modern technology as GPS and mobile telephones also gives private persons the possibility for accurate positioning in geographical reference systems. This will also put demand on interesting information used together with the positioning systems; the same geographical reference system must be used. Unification of the reference frames will be necessary. Many users of handhold GPS receivers have bad experience when trying to mark the position of the GPS on a printed map. If GPS gives co-ordinate in a global reference frame and the printed map is using a national reference frame, this would easily lead to errors in the order of 200-300 metres in Sweden.

4 NEW THREE DIMENSIONAL SYSTEM IN SWEDEN, SWEREF 99

The reference system used nationally must meet several criteria. It must be modern in such way that positioning using modern technologies should be possible without destroying the high accuracy that using modern instrument can achieve. It should make it possibly to exchange data with neighbouring countries and other users within the country easy and efficient, that means the connection must be well known or we should work in the same reference frame.

The introduction of SWEREF 99 as the national reference system for GPS in Sweden was done during 2001. This means that positioning in relation to the permanent Swedish GPS stations is done in an accurate reference system well connected to our neighbouring countries and major part of Europe. This is not the case with RT 90.

Lantmäteriet recommended to the government that SWEREF 99 is to be our official reference system for surveying and mapping. A decision was made in the autumn 2003 that Lantmäteriet is going to use SWEREF 99 together with the map projection described below for surveying and mapping. The change will be done as soon as it is possible. Several governmental agencies and municipalities will adopt this decision into their own databases.

Locally, we have today several hundreds of different reference systems. Lantmäteriet recommends the local authorities to tie their local networks to the nationally or, preferably, change to use the national reference frame. To help the users today, we have a project running called RIX 95 that will calculate transformation parameters between the SWEREF 99 and the local networks.

5 CHOICE OF MAP PROJECTION TO SWEREF 99

A pre study was carried out at Lantmäteriet during 2001, including both technical discussions of suitable map projections and an inventory on activities at Lantmäteriet dependent of co-ordinate or map projection. The outcome of the technical discussions was that the Transverse Mercator projection should be used and that several zones are needed for local surveying.

In a report to the government prepared during the autumn 2001 and after consultation with the Association of Local Authorities, Lantmäteriet proposed SWEREF 99 as a replacement of RT 90 in all official mapping activities. The decision taken at Lantmäteriet during autumn 2003 concerning our national map projection (small scale maps) is:

- Transverse Mercator with central meridian, λ_0=15°, and scale reduction factor, k_0 = 0.9996. The system is called SWEREF 99 TM
- For local surveying, a system of zones with 1° 30' between central meridians and k_0 = 1 is recommended. A system is called SWEREF 99 DD MM, where DD and MM is the degree and minutes related to Greenwich.

The decision means that SWEREF 99 TM will be used for surveying and mapping in the organisation and that all our databases should be stored in this system as soon as it is

appropriate. Work has started to go through our routines for checking in and out data to our databases as well as our routines for surveying and mapping.

6 LOCAL SYSTEMS VS. NATIONAL SYSTEM

6.1 Local systems

As mentioned earlier, the responsibility for geodetic control networks is divided between local authorities and Lantmäteriet mainly due to different aims. The responsibility for Lantmäteriet is to establish ground control for official mapping in small scales and the local authorities have to establish control networks for urban developments. Lantmäteriet can only recommend and advise local authorities regarding geodetic work.

Some 40 out of the 290 municipalities that exist in Sweden have however started to improve the quality of their local systems and this is mainly in co-operation with Lantmäteriet. The improvement is necessary if they want to take full advantage of the GPS technique as well as making the best out of the change of reference system for their local systems to a SWEREF 99 based system. A good base for the improvement is the outcome from the project RIX 95.

6.2 Project RIX 95

Since 1995, the project RIX 95, that involve GPS measurements on triangulation stations and selected local control points, has been in operation. The project is supported by a group of national agencies and the municipalities. The principal aims are to establish transformation formulas between local coordinate systems and the national reference systems (SWEREF 99 and RT 90), and to establish new points easily accessible for local GPS measurements. The project also gives a good start for the evaluation of the quality of the local systems and further on for the change to SWEREF 99-system as a local system.

7 NEW HEIGHT SYSTEM IN SWEDEN, RH 2000

The third precise levelling of Sweden is progressing according to plan that means that the new national height network should be calculated during 2004. The final network will consist of about 50 000 bench marks representing roughly 50 000 km double run precise levelling measured using the motorised levelling technique.

Preparation for the final adjustment of a new height system is under way. Within the Nordic Geodetic Commission Working Group on Height Determination, work is focused on calculating a Nordic Height block including the height networks from Denmark, Finland, Norway and Sweden. The purpose is to set up an EVRS2000 realisation in the Nordic countries based on Normaal Amsterdam Peil, zero tidal system and the epoch 2000.0. Much work is also spent on finding a suitable land uplift model for the Nordic area. Several existing land uplift models are investigated such as the Bifrost-model, Ekman-model, Lambeck-model as well as using repeated levelling.

Figure 3: RH 2000

8 PASSIVE VERSUS ACTIVE REFERENCE POINTS

8.1 Passive versus active points

Traditionally, the horizontal reference systems in Sweden have been made up by points situated on hills with as clear view between them as possible. The reason was of course due to the measuring techniques used when sighting between points where important. GPS only needs to have a clear view to the sky, which means that we can place these points more or less anywhere as long as the environment is suitable for GPS measurements. GPS also makes it very easy to measure new points very accurate using GPS permanent stations from hundreds of kilometres from the point.

Using permanent stations as the carrier of the reference frame will automatically make the surveying easier for the users since they do not need to find their own reference points for there surveying. Sweden has built up a network of permanent GPS stations called SWEPOS.

The situation for reference points for heights is different since GPS is not as accurate as levelling on shorter distances. Therefore, at least in Sweden, we have decided that maintenance in the future must be done for the points in the new height system RH 2000 but not for the points in SWEREF 99.

8.2 SWEPOS

The SWEPOS network of GPS reference stations began as a co-operation between Lantmäteriet and Onsala Space Observatory. The early design phases of SWEPOS were made in 1992. It was then stated that the purposes of the network were to be both scientific and of practical benefit to the professional users and the public. The purposes of SWEPOS are to (Jonsson):

- Provide L1 and L2 raw data to post-processing users.
- Provide DGPS and RTK corrections to real-time users.
- Act as high-precision control points for Swedish GPS users.
- Provide data for scientific studies of crustal motion.
- Monitor the integrity of the GPS system.

Today SWEPOS is used as the basis for the Swedish national reference system, SWEREF 99 and besides many surveying and navigation applications SWEPOS is also used for meteorology and timing applications.

In the first phase, SWEPOS consisted of 21 stations situated on bedrock in 1996 covering the whole of Sweden with on average 200 kilometre distances between the stations. The control centre has been located at Lantmäteriet from the beginning.

In the SWEPOS network the stations are of two types, complete and simplified ones. On the complete stations all equipment is doubled and the stations are mounted on bedrock, while the simplified ones have only one set of equipment and is usually mounted on buildings.

Figure 4: Complete station

Figure 5: Simplified station

In connection with the development of a Network-RTK-service, additional stations have been established. These new stations are mostly established on the top of buildings, typically belonging to local authorities.

8.3 SWEPOS SERVICES

Data from the SWEPOS network is available for the end-user via the following services:

- Post-processing data through a WWW/FTP service
- An Automatic Computation Service on the SWEPOS Web
- The DGPS-service Epos run by the Swedish company Cartesia
- The global WADGPS-service Omnistar run by the multi-national company Fugro
- Network-RTK

8.4 A National Network-RTK Positioning Service

During the years 1999-2003, several pre-study and prototype Network-RTK projects were carried out in different parts of Sweden, as collaboration projects between Lantmäteriet, local authorities, governmental agencies, universities and private companies. In total, almost 50 new SWEPOS stations were built. On 1 January 2004 a Network-RTK service started. Cellular telephones are currently used for the distribution of the Network-RTK corrections. Lantmäteriet expects to have 200 users connected to the Network-RTK server during 2004. In five years, some 1500 users are expected.

Figure 6: SWEPOS-network

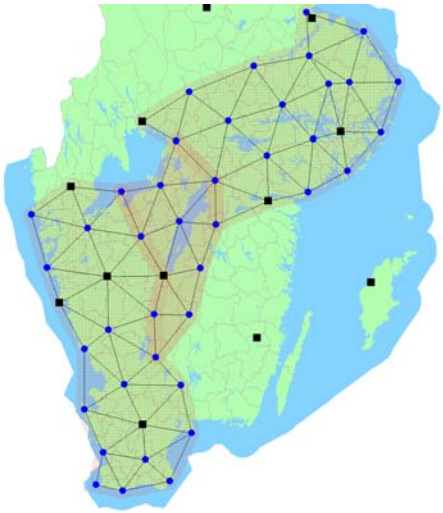

Figure 7: Area of Network-RTK-service as Feb. 2004

9 CONCLUSIONS

As many other European countries, Sweden is changing from the traditional more or less local reference frames to a global reference frame. The new reference frame is more homogeneous and of better quality than the older systems. The change is going rapidly and will improve the exchange of spatial data within the country as well as international exchange of data. One of the major driving forces for the local authorities to change reference frame is the introduction and use of GPS in their daily work. GPS-measurements have high quality and are easily distorted if we want to keep the older local reference frames. To help the users to use GPS, Lantmäteriet has developed a network of permanent GPS stations called SWEPOS. Using these stations will help the users to work in a homogeneous reference frame that at the same time is well connected to the surrounding countries. The latest development is the Network-RTK-service that started 1st of January 2004 in southern parts of Sweden.

REFERENCES

Annoni A., Luzet C. (2000): Spatial Reference Workshop, Short Proceeding Conclusions and Recommendations, Marne-la-Vallée, 29-30 November 1999, (http://crs.ifag.de/crs_reference.php)

Engberg L E, Lilje M (2002): A New Co-ordinate System for Sweden, Presented at FIG Congress, Washington, 2002.

Ihde et.al., European Spatial Reference System. (http://crs.ifag.de/crs_reference.php)

Jonsson Bo et al (2003): SWEPOS Network-RTK services – status, applications and experiences, Presented at ION, 2003

Torres J (2004): Personal communication, Presentation at IUGG-meeting, Sapporo, July, 2003

http://www.ec-gis.org/inspire/

http://www.swepos.com

BIOGRAPHICAL NOTES

Mr. Lilje graduated as a land surveyor from The Royal Institute of Technology, Stockholm, Sweden in 1993 with main subjects concerning Geodesy and Photogrammetry and GIS. He has worked at the National Land Survey since 1994. He is the head of a section concerning reference frame at the Geodetic Research Division. Mr. Lilje was the secretary for FIG Commission 5 during 1998 – 2002 and is currently the co-chair of FIG Working Group 5.2 (Reference Frame in Practise).

CONTACTS

Mikael Lilje

Lantmäteriet

SE-801 82 Gävle

SWEDEN

Tel. +46 26 63 37 42

Fax + 46 26 61 06 76

Email: mikael.lilje@lm.se

Web site: www.lantmateriet.se