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Future of National Reference Frames – from static to kinematic?

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Abstract: Technical development, new applications and requests for increased accuracy in georeferencing are setting new demands for accuracy and reliability of reference frames. Due to crustal deformations and local movements of benchmarks, a static reference network deteriorates with time, thus eventually requiring update of the whole system. Technically, renewal of a reference frame is straightforward and should be done whenever enough new data or updated information exist to get an improvement in accuracy. An example is the International Terrestrial Reference Frame, ITRF, which is renewed regularly. The situation is more complicated with national reference frames which may have been given a legal status, and parameters defined by the national legislation. Even without that, renewal and implementation of such a frame is a multi-million euro project taking years to complete.

Crustal deformations and movements deteriorate static reference frames (defined by fixed/static coordinates of benchmarks) with time. Eventually, distortions in a static reference frame will become bigger than the uncertainties of GNSS measurements, thus deteriorating the obtainable accuracy of the measurement technique. Instead of a static reference frame, one can use semi-kinematic or kinematic approach where either the transformation from global to the national reference frame or the coordinates of reference frame benchmarks are time-dependent. In this paper we give a short overview of the topic, and discuss on technical issues and future aspects of the reference frames in the viewpoint of National Mapping and Cadastre Authorities (NMA) with an example on the national strategy in Finland.

Keywords: reference frames, kinematic reference frames, semi-kinematic reference frames, CORS, precise positioning

1. Introduction

In the geodetic terminology, a terrestrial reference system is a set of definitions and conventions how the system is ideally related to the Earth. Its realization on the actual Earth is the terrestrial reference frame defined by its origin, orientation and scale and their time derivatives. Accurate reference frames are the basis of georeferencing, geodetic and surveying measurements, studies of the global change, and utilization of Earth exploring and navigation satellites, among many other spatial data related applications. The applications cover e.g. GNSS-based positioning for surveying and civil engineering, industrial automation, agriculture, construction, automated transport systems, disaster monitoring and numerous other fields. The modern society is fully dependent of well-referenced, accurate and reliable spatial data and a general trend has been that accuracy demands are constantly increasing. This situation sets new challenges also for national mapping authorities (NMA) and increases importance of the accuracy, reliability and continuity of the reference frames.

Majority of current national reference frames maintained by NMAs are static and based on passive benchmarks, the coordinates of which have been measured once and typically kept unaltered ever since. All geospatial data are in this static (regional/national) reference frame and there is no time evolution for coordinates and typically no information of an epoch. Accuracy of such reference frames (and geospatial data in it) will be degraded with time relative to a global reference frame.

With traditional terrestrial geodetic measurement techniques the accuracy is good in local and relative sense and only local distortions were influencing on measurements. Modern space geodetic techniques, mainly GNSS, can provide good accuracy in the global sense and hence reveal/be affected also wide-area distortions or movements like the plate tectonics. In case of a deforming network and fixed static coordinates of benchmarks, also the coordinates of new points will be biased when measured relative to the static benchmarks. With ever increasing accuracy in measurements and accuracy demands of users, GNSS measurements can be more accurate than the reference frame in which the coordinates are estimated. It also means that one cannot make use of full accuracy of GNSS or other applications.

The lifetime or validity of such a static reference frame is depending on size of crustal motions as well as the accuracy of the used measurement technique (linked to the accuracy demands). Gradually the reference frame becomes too imprecise with respect to user expectations. An option is to renew the reference frame regularly by remeasuring the network of passive benchmarks, but in this case also the geospatial data in it must be transformed to the new reference frame. This process is slow and expensive. Depending on the accuracy requirements, one can estimate the time when renewal of the whole reference frame will be needed. In some areas movements are so large or abrupt that even a frequent update may not be enough. Another option is to consider crustal motions in the maintenance of a national reference frame.

The International Terrestrial Reference Frame (ITRF) applies crustal motions. It is maintained by the International Earth Rotation and Reference Systems Service (IERS) of the International Association of Geodesy (IAG). ITRFs are comprised of long time series of data from several geodetic techniques observed all around the world by hundreds of stations and therefore provide the most accurate reference frame available. ITRFs are updated whenever enough new data exist and until now 13 versions of ITRFs have been published, latest being ITRF2014 (Altamimi et al., 2016). The cost of ITRF is that besides the coordinates, epoch of coordinates and their time evolution must be known and taken into account as well. Therefore it has, so far, not been considered suitable for practical purposes, e.g. in surveying or cadastre systems but used mainly for scientific applications.

However, rapidly increasing use of Continuously Operating Reference Stations (CORS) for accurate user positioning has changed the situation drastically. Referred as active benchmarks, they offer, with their continuous observations, the possibility to estimate the coordinates of the benchmarks in a global reference frame in real-time. Continuous observations enable estimation of motions in the reference frame as well. Most importantly, from users' point-of-view, CORS stations with associated positioning services, like network-RTK, provide cm-level accuracies substantially easier and cost-effectively compared to traditional techniques. As a consequence, these techniques have almost fully replaced the traditional measurements. However, such a positioning service requires accurate coordinates for the reference stations to fully benefit of the optimum accuracy. The coordinates of the reference stations need to be known in (near) real-time in the same global reference frame that GNSS satellites are using, in practice latest ITRF. This again implies that kinematic coordinates (and thus reference frame) are a prerequisite for positioning services.

Another emerging technique for widespread user positioning is the precise point positioning (PPP) that can provide accurate coordinates in a global reference frame at the epoch of observation without direct connections to reference stations. However, cm-level accurate real-time PPP is still dependent on dense network (especially in heights) to deliver signal propagation related corrections, and convergence times are still too long for common use. With new satellite positioning systems, foremost Galileo, one may expect a significant change in PPP usage.

Both these techniques challenge traditional static reference frames with their accuracy, as well as the hierarchy of the control points. On the other hand, associated kinematic coordinates have not been considered suitable for practical purposes, and therefore the advantage of active benchmarks has not been fully utilized on national level. In the following we discuss challenges and suitability of kinematic and semi-kinematic reference frames for basis of national reference frames.

2. Kinematic and semi-kinematic reference frames

Currently, there seems to be no common consensus on terminology. Quite often term "dynamic" is used instead of "kinematic" and "datum" instead of "reference frame" or some combination of these. In the case of geometric reference frames physics (forces or torques) or the reason for the movement is not required. Therefore, the term "kinematic" is more correct in the physical sense and consequently, we will use that in the following. Term "datum" is usually used in ISO/GIS communities while we prefer here IAG/geodetic terminology and use the term "reference frame" instead.

The main difference between a fully kinematic and semi-kinematic reference frame is the way how the coordinates are treated after observations. In both cases the coordinates are estimated in a kinematic (global) reference frame at the epoch of observations and in the kinematic frame, all coordinates are kept time-dependent, and at the epoch of the measurement. Slightly deviating definitions for a semi-kinematic reference frame (or semi-dynamic datum) exist but in all of these a static reference frame is derived for geospatial data (registers etc.).

Consequently, in both cases, the key element is the CORS network. It is needed for estimating kinematic coordinates and crustal motions and it is also the basis for positioning services providing access to the reference frame for most users. Therefore, from the reference frame point-of-view and closely inherent to semi-kinematic or kinematic reference frames, it is beneficial if the reference frame definition is based on active benchmarks instead of passive ones. CORS stations are providing accurate and up-to-date reference frame to users. Besides, need to maintain often numerous passive benchmarks and thus costs decrease notably. Challenges with such active benchmarks are related to instrument changes, changing conventions or global reference frame, etc.

2.1. Semi-kinematic reference frames

In cases where crustal motions are known for a sufficient level, an option is to utilize this information in maintenance of the reference frame. Instead of regular renewals of a static reference frame, one may prolong its lifetime substantially with adoption of the crustal motion information. We refer this approach to a semi-kinematic reference frame. In the semi-kinematic reference frame, positioning is made in a kinematic reference frame, like ITRF2014, at the epoch of observations (in real-time positioning services at current epoch). Transformation from the epoch and frame of observations to the static reference frame takes care of deformations and thus enables accurate link between the global and the national frame. Users will see fixed, time-independent coordinates in their national reference frame. A precise crustal motion model is needed to transfer measurements from one epoch to another, but most of this process can be kept invisible to the users.

From users' and national authorities' point-of-view, a semi-kinematic reference frame does not change much compared to a static reference frame. Spatial data is still in the same reference frame without need to transform them to a new one. Consequently notable savings are obtained. However, to achieve these, a prerequisite is an investment to dense enough CORS infrastructure and research to ensure qualified models for crustal motions, including abrupt and non-linear motions.

Some examples of semi-kinematic reference frames exist, e.g. in Nordic-Baltic countries and New Zealand. In Nordic-Baltic countries an approach called NKG transformation has been developed (Häkli et al., 2016). It can be used to access all the Nordic-Baltic ETRS89 realizations from any ITRF solution at an arbitrary epoch. The transformation makes use of the de facto transformation by EUREF (Boucher and Altamimi, 2011) with necessary amendments. The main addition is the model for crustal deformations taking care of the effect of the postglacial rebound (PGR). The residuals show that the national ETRS89 realizations can be accessed at a few millimetre level (1σ) for most of the area. This transformation can be seen as an option (but not necessarily as an official approach) for implementing a semi-kinematic datum in the Nordic-Baltic countries. Even if this transformation works well, major updates on it are underway. For example, a new PGR model is currently being developed and Nordic-Baltic CORS data is being reprocessed leading to new transformation parameters.

New Zealand national reference frame NZGD2000 is semi-kinematic, and a deformation model is applied to transform observations to the reference epoch (Blick and Donelly, 2016). NZGD2000 was originally aligned to ITRF96, epoch 2000.0. However, coordinates can be updated e.g. due to earthquakes, meaning that NZGD2000 does not strictly represent the position of a marker at the epoch 2000.0.

2.2. Fully kinematic reference frame

Another alternative is to replace the static reference frame and use only the kinematic (global) reference frame in all georeferencing activities. In a kinematic reference frame coordinates are time-dependent and position of a point is given with coordinates, velocity and a time tag.

If such a reference frame is taken in national use, also all geospatial data in registers should have at least three-dimensional coordinates and a time tag but preferably also the velocities. Velocities of geospatial data objects without continuous monitoring must be taken from velocity models. Consequently, it is important to note that similarly to a semi-kinematic reference frame, precise crustal motion model is needed to convert coordinates between epochs for comparison or analysis of different data sets. The difference is that the location of a newly measured point or real-time positioning of an object (e.g. vehicle) in a global reference frame is not transformed to another reference frame or epoch but instead the needed spatial data (e.g. road data in the case of a car positioning) is converted from the epoch of the original observation to the current one.

On the practical level, adoption of a kinematic reference frame would change the whole way of thinking and will set several challenges to the spatial data infrastructure. On one hand, registers should be capable of storing epoch of the observation (the time tag) and most probably also the associated velocity (or it could be taken from an up-to-date model whenever needed). On the other hand and in addition to practical issues with changing coordinates, there will be also legislation issues for example in cadastre work or any land-owning questions. Such issues must be solved for before the kinematic frame is taken in use. Another unsolved consideration regarding the kinematic reference frames relates to the physical heights where the global height system for kinematic heights is still missing.

Currently, fully kinematic reference frames are not used as national reference frames. Australia, however, has introduced a plan for a kinematic national reference frame (Australian Terrestrial Reference Frame, ATRF) which is aligned with the ITRF 2014 (Haasdyk et al., 2014). It is not fixed to the Australian plate and can be considered as a densification of ITRF. ATRF will be the stage two in the datum modernization in Australia and it will provide users a possibility to transit to a time-dependent reference frame. However, Australia has only recently released the stage one datum, a plate-fixed reference frame, GDA2020, and is strongly recommending local authorities to transit to it. Consequently, most likely these two reference frames will be used in parallel. ATRF will provide such a density of reference stations which is sufficient for practical work, like surveying measurements. The challenge will be the deformation model, its accuracy and implementation in practice.

Another ongoing example is the Nordic collaboration project for "Dynamic reference frame in Iceland" (DRF-Iceland). Directors of Nordic Mapping Authorities gave a task to the Nordic Geodetic Commission (NKG) to study a possibility to create a kinematic reference frame for Iceland. NKG has initiated a pilot project to define specifications and requirements for a kinematic frame with an outcome a plan for a new reference frame in Iceland. (Kierulf et al., 2017).

3. Challenges for maintaining time-(in)variable reference frames

As explained above, it is obvious that the time tag is mandatory as the fourth coordinate in the most accurate positioning. It is essential to know the motions of the reference points in addition to the epoch of their coordinates. Effects of crustal deformations cannot be estimated without a time tag and thus the uncertainties of coordinates may be much worse than expected. In practice, understanding the motions is necessary for all kinds of reference frames: for a static (time-invariable) reference frame it gives an estimate of deformations (or current accuracy of the frame), for a kinematic (time-variable) reference frame this information is needed to convert spatial data to current or common epoch for data analysis or comparison and for a semi-kinematic reference frame this is needed for transforming coordinates in a global reference frame to national/local static reference frame (or vice versa).

There exist crustal movements on all scales from global to local or movement of just one point. The most notable cases are:

1. Plate tectonics. Continents are moving a few cm/year which implies that the absolute position of a point on the Earth is changed.
2. Intraplate wide area movements. As an example of such movement is the post-glacial rebound in Fennoscandia and Canada. Also deformations at plate-margin areas can be counted as such.
3. Local abrupt movements, like earthquakes or landslides.
4. Local slow movements, like subsidence, local tectonics, volcanoes.

Plate tectonics is dominating in a global scale while other movements are mostly regional or local. On regional and local networks rigid plate motions can be minimized but otherwise all other movements may exist. Case 1 and partly case 2 can be predicted and taken into account but cases 3 and 4 cannot be extrapolated in the future.

Estimation of crustal deformations is one of the fundamental geodetic challenges and study areas. Several groups are working on different levels; from global to local movements. As an example on the European level, activities within the EUREF Permanent GNSS network (EPN, 2017) is an attempt to obtain a precise kinematic velocity model. Introducing geophysical modelling will add a dynamical aspect (e.g. Kierulf et al., 2014, Vestol et al., 2016) and allow better estimation of velocities at areas of missing observations. To manage the temporal variation in the reference frame, one should know any movements better than 0.5 mm/year to achieve the anticipated 0.1 mm/year on the global scale (Plag and Pearlman, 2009).

Global plate tectonic motions are estimated for each ITRF with an associated plate motion model (PMM). These models are estimated as plate angular velocities (or rotation poles) inverted from station velocities and they represent a rigid plate motion of major tectonic plates in the associated ITRF. The precision level of the latest models is 0.3 mm/year (Altamimi et al., 2012, 2017).

Rigid plate motion models can be supplemented by residual/intraplate deformation models derived using CORS station velocities (see e.g. Lidberg et al., 2007, 2010, Stanaway et al., 2015). Intraplate (including plate boundary) deformations may be caused by e.g. the Glacial Isostatic Adjustment (GIA, or often referred as the post-glacial rebound, PGR), transform, divergent or convergent plate boundaries implying different mechanisms behind the motion. An example from Europe can be seen in Figure 1 where the intraplate movements are shown with respect to the rigid motion of the Eurasian plate. It demonstrates that deformation and therefore needs and means for maintenance of the reference frame are different at different areas. Most of the northern and central part of Europe is quite stable when one considers horizontal movement, whereas at the Mediterranean area large tectonic-based movements can exist. They are often abrupt and/or very local of nature. On vertical, the situation is almost opposite: the postglacial rebound in the north dominates height changes.

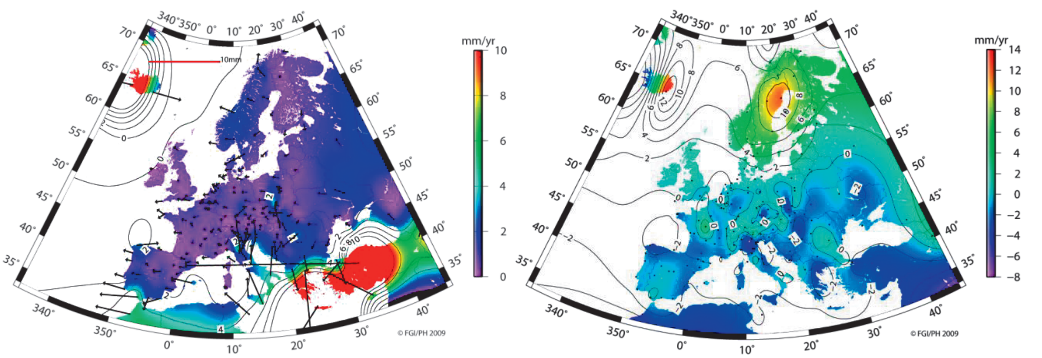

Fig. 1. Crustal movements in Europe. Left hand side picture shows the horizontal movements and the right hand side vertical movements (data source: EPN, 2010)

Postglacial rebound is predictable and can be taken into account in deformation models. The effect of GIA in the Fennoscandian region has been studied for a long time. Some of the most recent results have been published under the umbrellas of the BIFROST project (see e.g. Johansson et al., 2002, Lidberg et al., 2010) and the Nordic Geodetic Commission (NKG). The NKG has published deformation models that are combined from observations of several geodetic techniques and GIA modelling, the most recent one being NKG2016LU (Vestol et al., 2016).

Even if some of these intraplate wide area movements are well estimated, they are seldom adopted to the reference frame definition at least in the global scale. At regional or national level, some practical examples of such models exist, (see e.g. Blick et al., 2016, and Häkli et al., 2016). Such models mostly include linear velocities or coordinate shifts that are usually gridded using e.g. kriging or least-squares collocation.

Local effects (cases 3 and 4 in the above list) are even more difficult to adopt in the positioning, not to mention maintenance of the reference frame itself. A step forward is a post-seismic deformation (PSD) model that was introduced to account for post-seismic relaxation of tectonic events in the latest ITRF2014 (Altamimi et al., 2016). However, one problem with PSD models is that deformations are determined for observing stations (GNSS, SLR, VLBI and DORIS) but for practical use also inter-station deformations should be estimated somehow. Some emerging techniques have shown potential for estimating local movements; one of the most interesting one is SAR interferometry.

4. Future national reference frames in Finland

4.1. Current situation

In Europe, the Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE, 2017) requires that common Implementing Rules are adopted in a number of specific fields, including the reference systems. As stated in the INSPIRE Technical Guidelines, the European Terrestrial Reference System 1989 (ETRS89) shall be used, and for elevations, i.e. gravity-related heights, the European Vertical Reference System (EVRS) shall be the system. It is notable, that INSPIRE is defining only the system, not the realization.

EUREF permanent GNSS Network, EPN, is the basis for the access to and densification of the ETRS89 realizations through Europe (Ihde et al., 2014). Similarly, Finnish national ETRS89 realisation, EUREF-FIN, is based on CORS stations in Finland (FinnRef, 2017), but also on passive benchmarks (Koivula et al., 2012). From practical, i.e. users' point-of-view, EUREF-FIN is considered as static in its current form but in some specific applications it is not accurate enough anymore. In the Fennoscandian area the postglacial rebound causes deformations, the magnitude reaching up to about 1 cm/yr in vertical, and some millimetres a year in horizontal direction, see e.g. Lidberg et al. 2010.

EUREF-FIN was established with a GPS measurement campaign in 1996-97, meaning already 20 years of deformations compared to the present-day coordinates. The original homogeneous 5 mm precision (rms) of the EUREF-FIN has deteriorated (deformed) due to the PGR to about 35 mm in horizontal and 125 mm in vertical coordinates on the nationwide scale up to now. Therefore it is obvious that in most accurate georeferencing applications, like determining coordinates for reference stations of network-RTK service, EUREF-FIN cannot be used as purely static but instead a semi-kinematic approach must be considered. For these applications we use the NKG transformation approach (Häkli et al., 2016).

In its current stage, EUREF-FIN is a hybrid reference frame; partly used as a static and partly as a semi-kinematic reference frame. Also positioning with predominant measurement techniques like network-RTK cannot be performed at some centimetre level accurately in a purely static reference frame without accounting for the deformations. However, with more local ("traditional") measurement techniques sufficient accuracy may be achieved relative to other data points in the vicinity. Measurements in both cases have been instructed in the national recommendations of the public administration number 184 (JHS 184, see Poutanen et al., 2012). This is the trade-off of the modern techniques and will eventually lead to the need of complete renewal of the current static reference frame.

4.2. Implications on spatial data – cadastral data as an example

To examine consequences of different types of reference frames, we take the Finnish cadastre data as an example. Cadastre data can be considered to be comprised of four main pillars: precise positioning (measurement of an object) and the reference frame (as the basis for the coordinates) in which the data are stored in a register, existing data in the register and legal regulations. Fig. 2 illustrates consequences of different types of reference frames for cadastre data compared to the present situation ("now/static" in the figure).

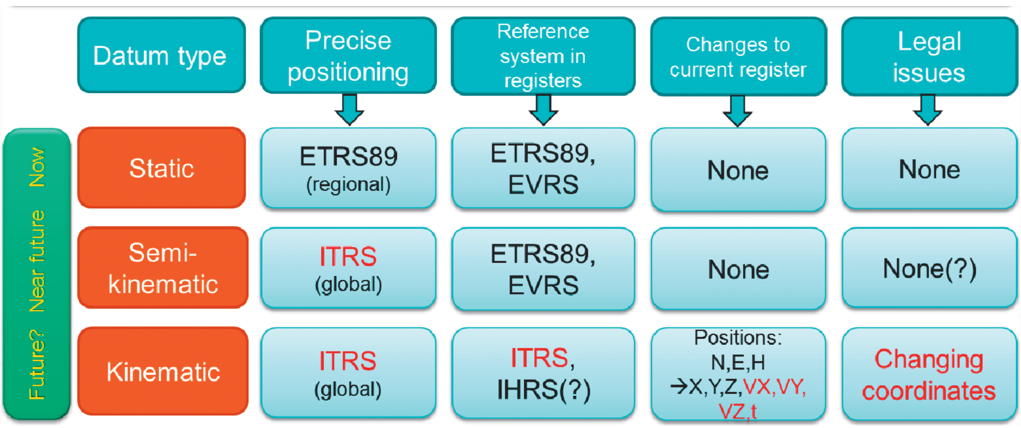

Fig. 2. Impacts in practice, or changes needed in the case of static, semi-kinematic and kinematic reference frame

Currently, data are collected, stored and compared/analysed with other existing data in ETRS89- and EVRS-based coordinates (with static, time-invariable coordinates). All the legislation is enacted for this situation. Cadastre data has different accuracy expectations in different areas (from city centre to rural areas) varying from centimetres to several decimetres. It is obvious that the current static reference frame cannot fulfil all these accuracy requirements.

In the case of a change to the semi-kinematic reference frame, most probably the only difference is that the measurement is made in the global kinematic reference frame and transformed accurately enough to the national reference frame. Updating of the transformation (and crustal motion model) or some other associated conventions may change slightly the resulting coordinates and thus may need some considerations on the legislation level. In the end, changes on the user level are minimal.

In the kinematic approach everything is in a global kinematic reference frame and having information on epoch of observation (time tag) and velocity information in addition to the three-dimensional coordinates. Currently, even the height component is often omitted unless there is a special need for a 3D-cadastre. It means that the cadastre system should be able to store and handle this extra data. Even more challenging is probably the transformation of the existing data to the kinematic reference frame and legal land owning issues.

Technical readiness (NKG transformation) to change to the semi-kinematic reference frame exist but other considerations like transformation tools, impact on existing data etc. are still lacking. Besides, the current approach will have a major update in the near future by means of new improved PGR model and reprocessed Nordic-Baltic CORS data. Considering all these, change to a semi-kinematic reference frame would require a minimum a few years to be in use. Fully kinematic reference frame instead, would require even longer time.

At the moment, the GIS world is not ready for kinematic coordinates and no supporting widespread applications are available. However, kinematic coordinates are starting to get attention in geospatial software development due to e.g. the announcement of a new kinematic datum in Australia. For example PROJ.4 library is undergoing development to be capable to handle kinematic coordinates (Evers and Knudsen, 2017). However, it is still a long way to have even technical readiness, not to mention other aspects in kinematic coordinates in practical work.

4.3. Future

According to the newly released 10-year national geodetic strategy, Finland will have an active, semi-kinematic reference frame in all georeferencing applications in 2026. The main reason for this choice is that crustal motions in the Fennoscandian region are secular without abrupt events and they are already well-modelled. With this choice, the main efforts will be to further improve the crustal motion models in the region and to provide users an accurate and seamless access to the national reference frame through the GNSS positioning services. The main benefit is that existing heterogeneous data registers need not to be upgraded at once but more time to prepare for future challenges are gained. This includes investigations on requirements of a fully kinematic national reference frame that will be carried out simultaneously with the implementation of a semi-kinematic reference frame.

During next years, terms and conditions for such a change must be studied, not only in the technical point of view, but also the changes in legislation and practical implementation, e.g. on geoinformation databases and cadastral data.

5. Conclusion and recommendations

User requests together with increasing accuracy of GNSS positioning will set new demands for national (practical) reference frames and their timeliness. Misalignment between local and global reference frames becomes more and more apparent with time. At some point the discrepancy becomes so large that a complete renewal of the local reference frame must be done. This, however, is a slow and very expensive process which cannot be done very often. It is a huge task to update all registers and databases, create transparent systems to users for transforming coordinates between the old and new frame, and assure quality and accuracy of the transformations.

In case of deformations, a static reference frame and passive benchmarks defining the frame have shown to be the limiting factor. Reference frames intended for scientific purposes are already providing a solution but they are, however, not easily adoptable for practical applications.

For any time-dependent coordinates, their time evolution is mandatory and should be known in a sufficient accuracy level. For CORS data with sufficient data (long uninterrupted time series) and dense network this information can be retrieved but for other spatial (passive) objects time evolution must be defined otherwise. In practice, time evolution is determined by modelling from existing station velocities. In modelling, the main challenge is that CORS network is usually sparse and/or spacing with heterogeneous location of stations. Furthermore, some of the tectonic processes are causing non-linear velocities and abrupt motions that are difficult to model.

The first step is to create a good enough regional velocity field of CORS stations, enabling semi-kinematic and/or kinematic reference frame approaches. For some regions, such models exist or projects are underway to create a precise velocity field. Only after that one can build up a set of rules and conventions for NMAs to join the reference frame. There are several technical and conceptual solutions, but no conventions nor consensus currently exist how these should be adopted at the level of NMAs who maintain national reference networks. It should be a task of EUREF and other similar regional organizations to create and adopt such conventions.

We have discussed and given some examples on kinematic and semi-kinematic approaches which are either solving or diminishing the problem. However, many geodetic and GIS challenges still exist with the adoption of time-dependent coordinates, accurate 3D crustal motion models as well as tying new measurements to the old ones or with existing reference frame.

According to the newly released 10-year national geodetic strategy, Finland has decided to change to an active semi-kinematic reference frame in all georeferencing applications by 2026. At more general level the conclusion is that there is no single solution for a future reference frame. For scientific work, it is obvious and even mandatory to use the best possible global reference frame that considers crustal motions. However, for practical and national use the case is not that simple and expectations are even contradicting. On one hand users are expecting static coordinates and compatibility at borders to the reference frames of the neighbouring countries. On the other hand they expect best possible accuracy.

No standardized solution exist, and in many cases there seems to be a gap between scientific and practical world. Besides, the situation is different in different regions of a continent with varying crustal motions. Nevertheless, modern measurement techniques have led to a situation where strictly static reference frames are in most cases no longer sufficient (or their lifetime is short) and other solutions are needed. Research and development in the whole range from science (e.g. geodynamics) to user level (e.g. GIS software) are needed to be prepared for a kinematic world.

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