REPORT

JOINT EUREF AND EUROSDR WORKSHOP

GEOREFERENCING IN THE DIGITAL ERA

How To Increase Use of Spatial Data & Sharing Data Across Borders - Relating to Reference Frames.

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Abstract

The workshop «Georeferencing in the digital Era» has identified key problems relating to georeferencing geospatial observations and data. Important metadata regarding time and reference frame are often lost on the journey from the data collector via national database to the end user. This makes it difficult for the end users who must search up this information manually to use the geospatial information correctly. The workshop identified reasons for why unambiguous coordinate and time information are not preserved from the beginning to the end. The results show that the way forward is to collaborate on all levels, nationally, regionally and globally. This must be a collaboration between data collectors, National mapping and Cadastre Agencies (NMCA), standardization organisation, software developers and end users.

Content

Introduction

It has been argued that more than 80% of the information on the internet have a connection to a location. So, locations and possibilities to connect information using location is important.

In the same way, various information on precise information on location needs to be comparable. And the more precise your geographical data are, the more precise the framework for describing the location information needs to be. In the professional context these frameworks for precise positions are known as Geodetic Reference Systems, Geodetic Reference Frames and Coordinate Reference Systems (CRS).

The background for arranging a workshop on this subject is motivated by:

- the digitalization of the society where exchange of information machine-to-machine is one important component, and information on references for positions need to fulfil this
- the development in positioning technology and services, usually based on Global Navigation Satellite systems (GNSS), provide precise positioning also for the wider user community and non-specialists.
- The current situation with many different references for position in use and to some extent the limitations in the available descriptions of these references (meta-data) make the situation confusing for the users
- There are official standards on CRS available, and international registries describing them. The most used is the EPSG registry, which is a kind of de facto standard. Another is the ISO Geodetic Registry. The ISO standard “Referencing by coordinates” is widely used, However, there are limitations in the standard and therefore a revision has been initiated.

The invitation to this workshop had the title “How to increase use of spatial data & sharing data across borders – relating to reference frames”, later changed to “Georeferencing in the digital era”. This indicates well the ambition with the workshop. Basically, standardisation of data and CRS for position across borders/between countries is important only when data are exchanged across these borders. However, since the same tools and software are in use in many organizations and countries, data models and information on CRS needs to be harmonized and used correctly.

Currently (professional) suppliers and users of spatial data and positioning services do see limitations in the current situation with many “Coordinate Reference Systems” (CRS) and the available information on these CRS´s. But there are also new users that don’t have a background in positioning/geoinformation but may have a focus on other (innovative?) areas, where geodata is an important but minor component. The ambition is to “pave the way” also for these kinds of new user groups.

The main objective of the workshop is to make it easy to use and share geospatial data. Not only for the professionals, but for all potential users of geospatial data. The aim of this report is to convey discussions and themes that were raised during the workshop.

Concepts and Methods

The selected method for the project was to arrange a workshop to define problems, enhance collaboration among the participants and plan future work. The workshop was arranged in Tromsø, Norway 22-23 October 2024. In total 34 person from 10 different countries participated in the workshop. All in all, 14 different presentations divided into 4 different sessions where given:

- Background
- Today's situation
- Users' perspective
- solutions for the future.

All sessions included a breakout discussion. In the following a short description of the presentations and results from the breakout sessions will follow.

Brief description of presentation

Thomas Knudsen, *Danish Agency for Climate Data, Copenhagen, Denmark*
Title: Divided by a common language: Bridging the gap between the ideal world of geoinformatics and the messy realities of geodesy

Geodetic terminology is often inconsistent, focusing on practical reference frames and transformations, while geoinformatics, as per ISO-19100, uses strict, idealized terms. The ISO-19100 framework works well for decimeter-level accuracy within a single reference frame, but achieving higher accuracy across frames requires engaging with geodesy's complex realities. The future challenge is to harmonize geodesy with geoinformatics' strict terminology and integrate general geodetic transformations with geoinformatics' idealized concepts.

Javier Jimenez Shaw, *Pix4D*
Title: NTRIP Reference Systems: Is there a solution to the lack of data?

The NTRIP protocol lacks information about the CRS used for corrections, which can significantly impact the accuracy of RTK measurements, now expected to be within a few centimeters. This issue complicates transformations to project-specific CRSs and is exacerbated by dynamic datums requiring time considerations, which most current software cannot handle. We propose a solution to collect and publish CRS information for NTRIP services, making it accessible and contributable by any provider.

Javier Jimenez Shaw, *Pix4D*
Title: User daily problems with Coordinate Reference Systems.

After years of developing georeferencing software, we've encountered many CRS-related issues due to user misunderstandings, incomplete information, and obfuscated software. This talk will highlight cases of inaccurate outputs and how professional behaviors, like those of surveyors, impact workflows. By presenting these problems from the user's perspective, we aim to find solutions and reduce mistakes.

Ivar Oveland, *EuroSDR/The Norwegian Mapping Authority*
Title: Importance of time

Everything occurs at a specific time, from life events to the construction and demolition of buildings, and the positions of celestial bodies. Different observations require varying levels of accuracy and resolution. The challenge is determining the most beneficial time resolution and presenting it in an unambiguous, machine-readable format (e.g., UTC, GPS time, Unix time…)

Jochem Lesparre, *Kadaster, Netherlands*
Title: Topology preservation of geo-information in different projections of reference frames

Even with 1 mm accurate coordinate transformations, different reference frames can cause topology issues, as projections can distort straight lines and geodesics. For short segments, this distortion is minimal, but for longer segments, it can become significant, such as a 2 cm intrusion over 750 m or a 200 m error over 85 km. To prevent misinterpretation, data suppliers should provide intermediate points along the geodesic with spacing that matches the data's accuracy.

Lennard Huisman, *NSGI – Kadaster, Netherlands*
presented by **Jochem Lesparre**, *Kadaster, Netherlands*
Title: Dutch Guidelines for Using CRS in the Exchange and Visualization of Geo-Information

Traditionally, correct CRS usage focused on geodata collection, but now it is essential at every stage, including the exchange and use of geo-information. This shift is driven by the increased use of spatial data in web applications and the need for accurate data integration across boundaries. Consequently, CRS has become a critical geo-information topic, requiring attention in information models, exchange mechanisms, and national facilities, with guidelines created to assist in these areas.

Jeffrey Verbeurgt, *UN-GGIM Europe*
Title: Simplifying Without Compromising: A Reference Frames Case Study

The growing reliance on geospatial data, especially in aviation, highlights the need to understand reference frames. This presentation discusses a EUROCONTROL publication that explains the differences between ITRS, WGS84, and ETRS89, providing practical guidance for basic users to ensure data consistency. By simplifying geodetic information, the publication aims to enhance the correct use of spatial data across Europe, improving operational efficiency and data accuracy.

Anders Alfredsson, *Lantmäteriet, Sweden*
Title: Height reference frames – current situation and future perspectives

National height reference systems vary due to system-related discrepancies and differences in their realizations. This presentation will examine the current state of height reference frames at national, European, and global scales, and discuss how the International Height Reference Frame (IHRF) can align these systems.

Kristian Evers, *Danish Agency for Climate Data, Copenhagen, Denmark*
Title: A Practical approach to vertical reference systems using PROJ and friends

Denmark has introduced new offshore vertical reference systems and updated its land-based height system, both registered as “datum ensembles” with the EPSG. This presentation explores these systems using publicly available data and demonstrates the capabilities of open-source software like PROJ and QGIS. It will highlight the complexities of combining data from a user perspective and the challenges faced by data providers.

Roger Lott, *IOGP, UK*
Title: EPSG Codes

This presentation explained the structure and management of the EPSG Dataset, clarified the nature of EPSG Codes, and offered suggestions for their use in merging data from different ETRF realizations. It also mentioned an International Standard for machine-readable coordinates, including reference frame, map projection, and epoch identification.

Martin Lidberg, *Lantmäteriet, Sweden*
Title Geodetic Reference Frames and the ETRS89

The presentation covered geodetic Terrestrial Reference Systems and Frames, including ITRS and ETRS89, and their realizations. It concluded with thoughts on the use of global versus regional/national reference frames and their connection to the development of positioning services.

Morten Taraldsten Brunes and Sveinung Himle, *Norwegian Mapping Authority*
Title: Challenges with reference frames in Intelligent Transportation Systems (ITS)

The presentation covered the EU Horizon project MODI, which pave the way for automated freight transport through Europe. The project adresses challenges with reference frames, HD-maps and precise GNSS positions in cross border applications. The project has performed analysis to demonstrate coordinate differences between national realisations of ETRS89 and validated the results with GNSS RTK measurements on the border between Norway and Sweden.

Brief summary of breakout session

Session 1 - Background

In this first session the groups discussed how INSPIRE impacts sharing of spatial data and what role international standards have in simplifying the usage of geospatial data. The INSPIRE directive states that ETRS89 is to be used, which in practice means that all national realisation of ETRS89 are valid. This is a good solution for Europe that makes sharing of data across borders possible within an acceptable level of accuracy. Also, the data owner does not want their coordinates to change, and the change of coordinates comes with large expenses. It was stated that the INSPIRE directive contains much more than reference frames, i.e. open data directive and which datasets to be used. In hence of this, the INSPIRE directive is also made by the geospatial community and therefore have not taken into account the different realisations of ETRS89.

The groups agreed that there is a need for user guidelines to educate the geospatial community about geodesy. These guidelines should also contain use cases, and tools to transform coordinates should be provided.

Session 2 - Today's situation

The groups were asked to discuss technology, challenges with data sharing across borders, challenges with multiple EPSG codes within a single country and how national agencies and new technologies can streamline and simplify the use of EPSG codes.

One problem that was addressed when it comes to EPSG codes was that countries do not update/register their reference frames or transformations. This also apply for the Proj library, because Proj use the EPSG-database. Also, when it comes to EPSG codes, users have difficulties knowing which code to use, due to the high number of codes. Some groups argued that one solution could be "ensemble" CRS's (EPSG codes), but that would only be applicable/convenient for some users that does not need high accuracy.

The groups problematized that some agencies still use legacy formats or their own formats when sharing data. This could be handled with supporting open-source standards and using API's. Another problem is that metadata about the CRS is lost. Again, the groups addressed the importance of giving the users knowledge about reference frames and CRS's.

Session 3 – Users' perspective

In this session the groups were asked to discuss how sharing spatial data can be improved, how to ensure machine readable time information and how to standardize reference frames to improve sharing data across borders.

The groups addressed that using the same reference frame is more important than the reference frame itself and that there are needs for implementing time in metadata and standards. National reference frames or national realisations of ETRS89 should make it easy to use spatial data in a country. The challenge is that there are different realisations of ETRS89 in each European country, but the differences from country to country are

small. This is not visible for the users, that experience that the realisations are different reference frames (different EPSG codes).

There is a need for cooperation between geodesy and geospatial users to be able to make good solutions for using the same reference frame, and standards and metadata is necessary tools. Information about reference frames and practical use cases is too hard to locate today. When using transformations today, it is too easy to make errors which leads to less accuracy in the data, and the complexity of EPSG codes might add to the problem.

Session 4 - solution for the future

In the fourth session we asked the groups to consider if we actually have a problem.The groups agreed that we do have a problem. The aspects of the problem can be summarized to the following.

Geospatial users often struggle with reference frames because there are too many options, and it's hard to know which one provides the needed accuracy. Many reference frames are tied to specific time periods (epochs), and tectonic movements make older frames different from updated ones.

Most users don't want to think about reference frames; they want one simple solution that works for all situations. Collaboration between geodesists and geospatial users could help solve this issue.

Key Problems:

- General lack of knowledge about reference frame.
- Too many reference frames and EPSG codes cause confusion.
- Users lack clear and simple guidelines to choose the right frame.
- Sharing data across borders is difficult due to inconsistencies in reference frames.
- Sectors like construction, cadastre, maritime operations, and GIS already face big challenges with this.

Proposed Solutions:

1. Adopt a Fixed Version of ITRF
    a. Replace the current systems with one unified, high-resolution reference frame (ITRF) based on a fixed epoch.
    b. Include data about movements and deformations from national reference frames to avoid complex transformations.

2. Better Education and Accessibility
    a. Create simple, user-friendly guides for different types of users, avoiding overly technical language.
    b. Ensure national reference frames are well-documented, with clear EPSG codes, transformation details and with reference to the ISO geodetic registry.
3. International Cooperation
    a. Introduce a shared reference frame for countries on the same tectonic plate or globally.
    b. Launch an EU project, led by larger countries with more resources, to drive standardization.
4. Workshops and Follow-Up
    a. Organize new workshops, like one planned for spring 2025, to bring in more participants and continue the efforts.
5. Cost-Benefit Analysis
    a. Assess the costs and benefits of switching to a single unified reference frame.

Simplifying reference frames and making them more accessible will lead to more accurate and efficient use of geospatial data across sectors like construction, maritime, and GIS.

Results

During the breakout sessions many different aspects were discussed. The discussions identified main problems regarding referencing geospatial data, seen from both f the data collector's, the national data manager's and to the end users' perspective.

Problem: Different user needs

Different users of geospatial data have different demands. An international organisation or multinational corporation needs a solution suitable for a global solution. On the other end of the scale, we have small building construction sites where a local coordinate system is more suitable.

Area of Interest	User Groups
Global	Multinational corporation software solutions, services and products
Region	European Union, Inspire, Open Data Directive
National	National Mapping and Cadaster Agencies (NMCA)
Local	Infrastructure and building contractors (from single buildings (BIM) to large railroad projects)

Different users have different requirements for the validity area

The area of interest will be decisive for both the choice and the use of a reference frame. The individual frames, transformations and projections have different capacities regarding area of validity. The same is true for accuracy. For low accuracy demand a reference frame with low accuracy potential is sufficient

Need of Accuracy	Examples of application
100 m	Weather observation, Environmental monitoring
10 m	Remote sensing, Satellite, Map with small scale
1 m	Map with medium scale
0.1 m	National geospatial databases, Map with large scale
0.01 m	National geospatial data capture, Cadaster
0.001 m	Geodesy, Ocean, Contractors

Different users have different requirements for accuracy

The individual frames, transformations and projections have different capacities regarding area of validity and accuracy. It is important to select the combination that best suits your needs.

EPSG code	Reference frame	Datum description	Crs type	Accuracy (metres)
EPSG:4326	WGS 84	World Geodetic System 1984 ensemble (merge 8 CRS)	Geodetic	2.0
EPSG:4937	ETRS89	European Terrestrial Reference System 1989 ensemble	Geodetic 3D	0.1
EPSG:10605	WGS 84 (G2296)	World Geodetic System 1984 (G2296)	Geodetic 3D, dynamic	~ 0.01
EPSG: 9989	ITRF2020	International Terrestrial Reference Frame 2020	Geodetic 3D, dynamic	~ 0.005

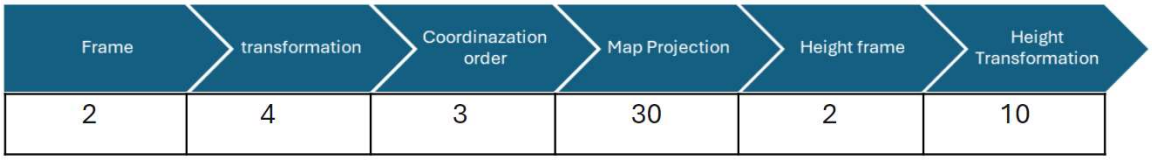
Different reference frames have different accuracy

A transformation to a reference frame with low accuracy may degrade the data.

Problem: High number of choices

An unambiguous defined georeferencing in a static frame is decided by multiple parameters. Some of the parameters are unknown for many users, but they still need to make a decision. Both trained and untrained users need to make active choices for all parameters. For 3-dimensional map projection geospatial data all the following parameters needs to be decided (today situation):

The theoretical number of options can be estimated by multiplying the available options for all topics. For a hypothetical example:



In this case we need 2*4*3*30*2*10 = 14 400 different EPSG codes to cover all options. For a new user without geodetic knowledge all options has to be consider. For a trained geospatial expert, the options will be narrowed down quite dramatically.

The number of EPSG codes makes it unclear for the user and difficult to select the correct code. Additionally, the description of the codes will for a non-geodetic user be difficult to understand the impact of.

Problem: Short-, medium- and Long-term approaches

Information from the presentations and group discussions shows that there are different points of view and opinions on how to proceed. Depending on profession and the challenges they meet in their everyday work the perspective may be different. To embrace and showcase all points of view they are summarized and grouped into short, medium and long-term indicating the timeframe to work with the challenges.

Short term

- EPSG has some challenges:
  - There are missing codes for reference frames and transformations in the EPSG registry
  - One code might describe several CRS's
  - Not enough available codes to describe all CRS's and transformations
  - Unknown terminology, for example ensemble and compound, for many users
- Lack of tools to help users to choose the correct CRS and transformation
- Missing guidelines and information to end users on how to use coordinate reference systems correctly
  - Valid both horizontally and vertically
  - Users are informed about the challenges, but not given a solution on how to deal with it
  - The guidelines for EUROCONTROL are a good example
- The latest NTRIP MSM holds information about the coordinate reference system, but the positioning service providers don't use it.

Medium term

- There is an increasing difference between plate fixed systems in Europe (ETRS89) compared to global systems (ITRS) due to plate tectonics
- There is not a unified system to handle intraplate deformation and postglacial rebound
- Lacking awareness of the importance of having information about CRS in the metadata
- Not all standards for geospatial data force the users to add coordinate reference system to metadata

Long term

- There is to many reference systems to choose from for an end user
  - reducing complexity is important
  - reducing number of reference frames
  - different epochs for national realisations of ETRS89
  - differences between national realisations of ETRS89
  - move as much complexity to geodesy sector as possible
  - Cost-benefit of different options are important

- Many possibilities for transformation from one system to another which gives different results
- IT infrastructure for geospatial data do not
  - handle time sufficiently (4D coordinate)
  - support regular alignment to current epoch
- Standardisation
  - do not support 4D coordinate reference systems
  - unclear relationship between EPSG, ISO GR and CRS-EU
    unknown where the responsibility for standardisation will be in the future
  - alignment between geodesy standardisation and geospatial software

Problem: Difficult to understand how EPSG works and the meaning of expression like ensemble, compound etc.

The IOGP's EPSG Geodetic Parameter Dataset contains definitions of coordinate reference systems and coordinate transformations which may be global, regional, national or local in application. It is maintained by the Geodesy Subcommittee of the IOGP Geomatics Committee.

The EPSG Dataset is the de facto standard in the geospatial industry, initiated in 1985 and first made public in 1993, as described in the **History of the EPSG Dataset**. For more information about its content and usage, see the **Guidance Notes** under “Support Documentation”.

All entities in the EPSG registry have a certain EPSG code. The EPSG codes will have a number in an interval between 1024 and 32767, where the codes could be Transformations, Coordinate Reference Systems, Extents, Ellipsoids, Projections and so on.

Examples of EPSG codes.

EPSG code	Type of object	Name
1352	Extent	Norway - onshore
7019	Ellipsoid	GRS 1980
9991	Coordinate transformation	ITRF2014 to ITRF2020 (1)
9656	Coordinate method	Cartesian Grid Offsets
6326	Datum	World Geodetic System 1984 ensemble
9905	Coordinate Axis	Depth
5972	Coordinate Reference System (compound)	ETRS89 / UTM zone 32N + NN2000 height

Coordinate Reference System in EPSG registry are defined in different Crs types.

Type of Crs	Remarks
Projected	Projected coordinate system such as UTM, TM, Lambert etc.
Geocentric	
Geographic 2D	
Geographic 3D	
Vertical	
Compound	Compound of Geographic 2D and Vertical, or Projected and Vertical

As mentioned above both Crs's and transformations are registered with EPSG codes, and transformation methods, parameters and resources are available in the EPSG registry. That means Compounded Crs's are composites of a horizontal EPSG and a vertical EPSG code. Example:

EPSG:5942 (ETRS89 + NN2000 height) = EPSG:4258 (ETRS89) + EPSG:5941 (NN2000 height)

Ensemble is a collection of different reference frame that fulfil the accuracy stated in the description. A god example is EPSG:3857 also called "Google Mercator" or "Web Mercator" used a default frame in Leaflet.

Problem: Summary of various topics

- Many older, outdated reference frames are still in use in legislation and regulations.
- The EPSG Register is not complete. User often select the closest EPSG when the needed code is not presents. This has the potential to degrade the geospatial information.
- Problem related to dynamic frames
    - How is a zero meridian defined for a dynamic reference frame? As the central meridian moves, the scale of the UTM coordinate will vary with time.
    - In a dynamic frame one must have epoch together with coordinate. How can we convey the epoch together with the coordinate.
- In geospatial analyses, there is an increased demand for observation times. This is critical in change detection analyses. In general, the need for current epoch information from geospatial analyses and dynamic reference frame coincides. How can we unambiguously communicate the time of observation together with the coordinate value from the data collector to the end user?
- Most geospatial software are based on coordinate representation with only 3 values (x,y,z). To add more information at a coordinate level will require massive changes to the geospatial software but also to the databases at the national mapping agencies.
- Lack of collaboration and trust in hence of reference realization and transformation establishment in between countries.

Discussion and further work

The result from the workshop identified key problems in hence of georeferencing geospatial observations and data. It became clear that different users have different needs. One of the challenges with the use of reference frames is the user confusion due to the too many reference frames and EPSG codes to deal with, and the limited knowledge among the common user about which reference frame to use for specific needs. The users wish for a single and simple solution, but in the everyday life they are faced with multiple and complex choices. While geodesists recognize the problem, there are still a way to go when it comes to standardization and guidelines.

The workshop conclude that further work is needed to find solutions to the identified problems. Together, it was decided to have a follow-up workshop in 2025. This is supported by the EuroSDR community. Based on the described results the workshop community has identified potential topics for the next meeting. The overall objective is to come one step closer to solutions. There is a common understanding that there is no short and simple solution to the problems we face. The action plan should therefore be divided into a short- medium- and long-term actions.

The following topics are recommended for the next workshop:

- Can WKT2-2019 (ISO 19162:2019) be used as a machine-readable information carrier from data collector to end user
- How do we design the IT Architecture of the future to ensure that time and reference frame information are taken care of - Architecture in the new digital Era?
- New map database designs pre-defined reference fame to WGS84, EPSG:4326 (Leaflet, H3 indexing, OpenStreetMap, DuckDB). How do we ensure correct indexing and preserve geospatial accuracy?
- New dataformat with pre-defined reference fame (flatgeobuf, geojson (default CRS is WGS84,EPSG:4326), FGjson (good support for multi CRS) ISO 19111 – What is needed to make everyday life easier - For data collectors - data managers and end users.
- To what extend is EPSG an implementation of ISO 19111? If we would like to harmonize EPSG and ISO GR how would the roadmap towards this ambition look like? How can we make the systems robust with regard to continuity of staffing?
- Only Global reference systems at national level, how could it be implemented?
- Two frames approach working with both static and dynamic frames at national level?
- How can we implement time at the coordinate level (from data capture to end user).

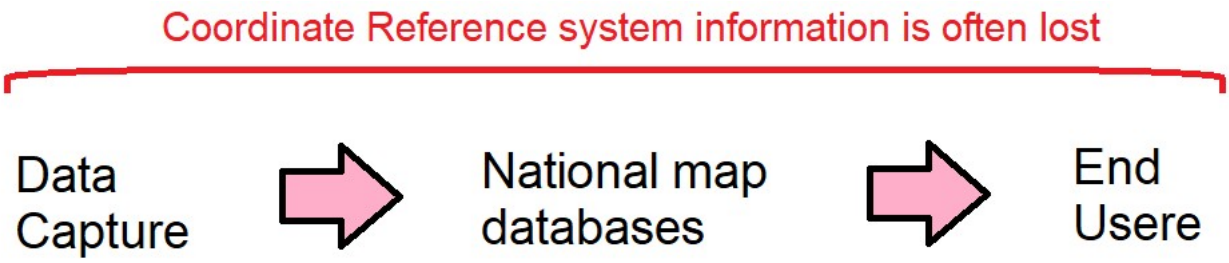
- How do we describe a *dream coordinate*? An unambiguous coordinate contains an unambiguous description. For example, a dream coordinate in 4 dimensions might have 14 values:
    - Coordinate values in 3 dimensions
    - Uncertainties in 3 dimensions, this is required because the accuracy might change during transformation
    - Geodetic reference frame
    - Transformation
    - Coordinate order
    - Map projection
    - Geodetic height frame
    - Height transformation
    - Time of observation
    - Time frame
- Apply for EU funded project.
- Prepare extensive information material for various users, about the characteristics of the different reference frames, the dependency of time.
- Identify and invite numerous data collectors, national mapping agencies, GIS software developers and user groups.
- How can we benefit from ISO19111 and ISO 6709:2022?

Conclusion

The workshop 22-23 October «Georeferencing in the digital era» has successfully identified significant problems related to georeferencing. There is no short-term solution to the discovered problems so further work is needed. In a short-term perspective, there is a strong need for clear and accessible guidelines to help the users understand the basics when it comes to reference frames (dynamic and static). Guidelines and educational resources should reach a broad audience, from professionals to the occasional users, that means guidelines without overwhelming technical detail. Further, national reference frames should be documented and accessible, with consistent EPSG codes and information about transformations, so that we have reliable use of data across borders and sectors.

In the long term the reference frames and how we handle them, should be done simpler and more reliable for all users. Clear guidelines, better software integration and improved accessibility will ensure both more and accurate use. This will give more effective use across diverse fields like construction, maritime applications and GIS.

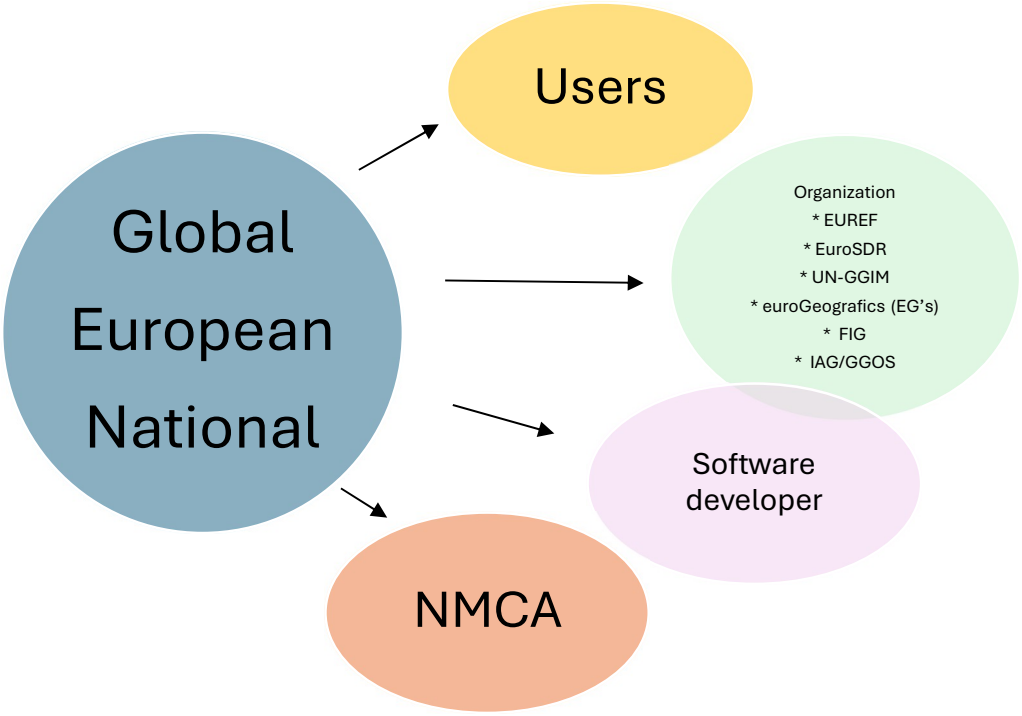
The overall goal is to ensure that unambiguous coordinates and time information are preserved from the data collector, national database to the end user.



How can we preserve unambiguous coordinates and time information from the beginning to the end?

Two different approaches

One solution is to narrow down the options in hence to reference frame, transformation, coordinate order, map projections, height frame, height transformation and time frame. Another approach is to make the information machine readable. Based on the identified problem a solution would be somewhere between. Both approaches require extensive collaboration. From the discussion the way forward is to collaborate on wide level. The needed collaboration needs to be addressed on a national, European and global level. This must be done together with National mapping and Cadastre Agencies (NMCA), organisation, software developer and user.



A solution is only possible through collaboration

Acknowledgments

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