

# Is here still where it was? Changes in terrestrial reference frames in R spatial packages (2026-06-27 revision)

useR! 2026, Warsaw, Poland

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Roger Bivand

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Norwegian School of Economics, Bergen, Norway

[https://rsbivand.github.io/new\\_ref\\_systems](https://rsbivand.github.io/new_ref_systems)



Where is here?

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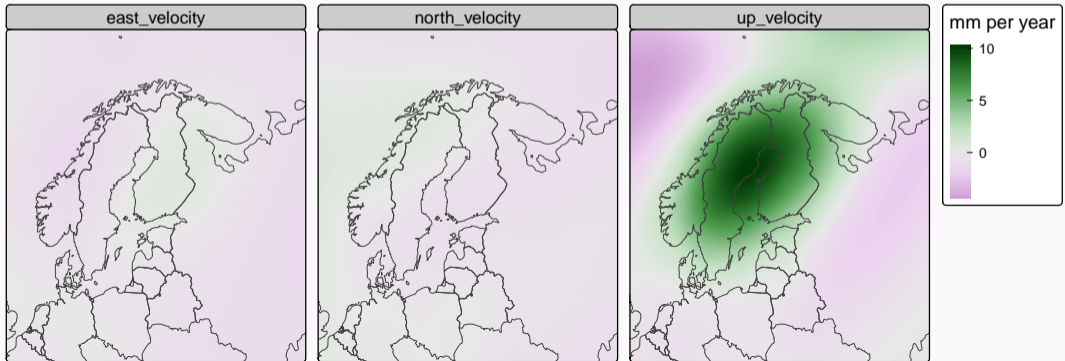
- When we represent or analyse spatial data, the position of observations matters
- Where objects of interest are, also in relation to each other, and how position is measured, are referenced through coordinate reference systems (CRS), including units of measurement
- Frequently used CRS rely on tabulated values, for example the axis lengths of an ellipsoid representing the Earth
- The tabulations crucially include *datums*, including the ellipsoid used in their definition
- Historical datums (typically tied to mean sea level at a well-known location) were established before continental drift was accepted (roughly 1960s)

## Continental drift

- The measurement of continental drift – plate tectonics – became feasible, and even obvious, when enough satellites could be used
- Geodetic measurements in metres from the 3D centre of the Earth are now the most reliable and accurate basis for recording object position
- “Stationary” objects move in geodetic terms when the tectonic plate on which they are located moves in any of the three axes
- Plate movements are given by date, so position measurements need to be dated to fix them in 3D+time
- “Here” in the view of one country’s mapping agency may not have the same coordinates as the same position viewed by a neighbouring country’s mapping agency, or the same country’s mapping agency at a different point in time

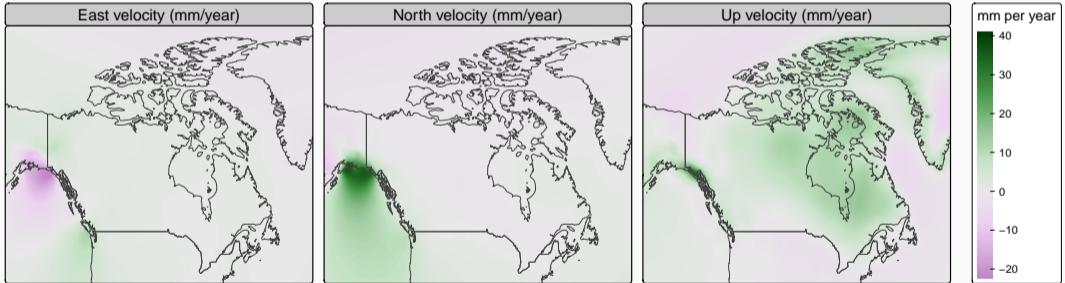
## Nordic-Baltic velocity grids

A velocity grid by the Nordic Geodetic Commission provides a deformation model covering the Nordic and Baltic countries, used in transformations between global reference frames and the local realizations of ETRS89 (European Terrestrial Reference System 1989) in the Nordic and Baltic countries ([https://cdn.proj.org/eur\\_nkg\\_README.txt](https://cdn.proj.org/eur_nkg_README.txt), Häkli et al. (2023)), read with `stars` (Pebesma 2026b) and displayed using `tmap` (Tennekes 2026)



# Canadian velocity grid

N2022v00VG.gvb is a beta release velocity grid, created prior to forthcoming changes in North America known as NATRF2022, [downloaded from \(login protected\) the Canadian Geodetic Survey](#)



## Preliminary take-home points

- Most legacy CRS did not take continental drift into account
- The demands on CRS for accuracy and measurable errors have increased greatly, especially with the general availability of GNSS receivers; errors at metre scale are now unacceptable, and sub-metre errors are undesirable
- Global CRS have to match global crustal movement, but regional/national CRS are most often fixed to the most appropriate tectonic plate
- Countries/jurisdictions adopt CRS for official purposes, and their mapping agencies often manage them differently
- Fitting different mapping agency practices balancing science with practical needs into a shared database involves complex trade-offs

## Definitions

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In Pebesma and Bivand (2023), page 22-3, “we follow(ed) Lott (2015) when defining the following concepts (*italics indicate literal quoting, here updated to Lott (2023a)*):

- a **coordinate system** (§4.1.8) is a *set of mathematical rules for specifying how coordinates are to be assigned to points,*
- a **datum** (§4.1.11) is a *parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system, (in Lott (2023a) (§3.1.12), referred to as a reference frame, a realization of a reference system)*
- a **geodetic datum** (§4.1.19) is a *datum describing the relationship of a two- or three-dimensional coordinate system to the Earth, and*

- a **coordinate reference system** (§4.1.7, **CRS**) is a *coordinate system that is related to an object by a datum; for geodetic and vertical datums, the object will be the Earth*; Lott (2023a) (§3.1.8) adds a note that geodetic and vertical datums are referred to as reference frames.

A readable text that further explains these concepts is(was) Iliffe and Lott (2008).”

## What is an *epoch* and a *datum ensemble*? i

- Iliffe and Lott (2008) do not discuss *epoch* or *datum ensemble*, which entered the European Petroleum Survey Group (EPSG) database at version v10 (September 2020) and subsequently, nor does Lott (2015), but Lott (2019) and Lott (2023a) do; Iliffe and Lott (2008) and Lott (2015) follow ISO 19111:2007 and ISO 19111-2:2009 which apply mainly to *static* CRS (dynamic is not mentioned in Lott (2015)), while Lott (2019) and Lott (2023a) elevate to 19111:2019 which also handles *dynamic* CRS (dynamic is mentioned 125 times in Lott (2023a))
- Lott (2023a) (§3.1.22) defines **epoch** as a “<geodesy> point in time, an epoch is expressed in the Gregorian calendar as a decimal year”; it expresses the moment at which a position in 2D or 3D is valid with respect to the realization of the reference system, geodetic datum

- (§7.7) “A CRS is *dynamic* if its reference frame is dynamic. In a *dynamic* CRS the coordinate values of a point on or near the surface of the Earth change with time. When a coordinate set is referenced to a dynamic CRS, to be unambiguous the coordinate set needs to additionally be referenced to a coordinate *epoch*.”

## What is an *epoch* and a *datum ensemble*? iii

- A **datum ensemble** (§3.1.13) is a “group of multiple realizations of the same terrestrial or vertical reference system that, for approximate spatial referencing purposes, are not significantly different”; Lott (2023a) notes that using WGS84 as example, “an undifferentiated group of realizations including WGS 84 (TRANSIT), WGS 84 (G730), WGS 84 (G873), WGS 84 (G1150), WGS 84 (G1674) and WGS 84 (G1762). At the surface of the Earth these have changed on average by 0.7 m between the TRANSIT and G730 realizations, a further 0.2 m between G730 and G873, 0.06 m between G873 and G1150, 0.2 m between G1150 and G1674 and 0.02 m between G1674 and G1762). It further notes that:”‘Approximate’ is for users to define but typically is in the order of under 1 decimetre but may be up to 2 metres”.  
G-numbers are [GPS weeks](#).

WGS84, also known as EPSG:4326, is perhaps the most frequently used CRS, but is an ensemble, retrieved from `sf::st_crs("EPSG:4326")` (Pebesma 2026a):

```
##      ENSEMBLE["World Geodetic System 1984 ensemble",
##            MEMBER["World Geodetic System 1984 (Transit)"],
##            MEMBER["World Geodetic System 1984 (G730)"],
##            MEMBER["World Geodetic System 1984 (G873)"],
##            MEMBER["World Geodetic System 1984 (G1150)"],
##            MEMBER["World Geodetic System 1984 (G1674)"],
##            MEMBER["World Geodetic System 1984 (G1762)"],
##            MEMBER["World Geodetic System 1984 (G2139)"],
##            MEMBER["World Geodetic System 1984 (G2296)"],
##            ELLIPSOID["WGS 84",6378137,298.257223563,
##            LENGTHUNIT["metre",1]],
##            ENSEMBLEACCURACY[2.0]],
```

Table 1: WGS84 iterations

Name	GEOD	GEOG	Epoch	Based.on	Implemented
WGS84(TRANSIT)	7815	7816	NA	BTS84	1987-01-01
WGS84(G730)	7656	7657	1994	ITRF92	1994-06-29
WGS84(G873)	7658	7659	1997	ITRF94	1997-01-29
WGS84(G1150)	7660	7661	2001	ITRF2000	2002-01-20
WGS84(G1674)	7662	7663	2005	ITRF2008/IGS08	2012-02-08
WGS84(G1762)	7664	7665	2005	ITRF2008/IGb08	2013-10-16
WGS84(G2139)	9753	9754	2016	ITRF2014/IGS14	2021-01-03
WGS84(G2296)	10604	10605	2024	ITRF2020/IGS20	2024-01-07

See also [ESRIs blog “WGS 1984 is not what you think!”](#), and Konyk et al. (2025)

The most recent update is aligned with ITRF2020, the most recent International Terrestrial Reference Frame (ITRF) realization; it is now defined as dynamic

```
## GEODCRS["WGS 84 (G2296)",  
##     DYNAMIC[  
##         FRAMEEPOCH[2024]],  
##     DATUM["World Geodetic System 1984 (G2296)",  
##         ELLIPSOID["WGS 84",6378137,298.257223563,  
##             LENGTHUNIT["metre",1]]],  
##     PRIMEM["Greenwich",0,  
##         ANGLEUNIT["degree",0.0174532925199433]],  
##     CS[Cartesian,3],  
##     AXIS["(X)",geocentricX,  
##         ORDER[1],  
##         LENGTHUNIT["metre",1]],
```

## WGS84 datum ensemble iv

```
##      AXIS["(Y)",geocentricY,  
##          ORDER[2],  
##          LENGTHUNIT["metre",1]],  
##      AXIS["(Z)",geocentricZ,  
##          ORDER[3],  
##          LENGTHUNIT["metre",1]],  
##      USAGE[  
##          SCOPE["Geodesy. Navigation and positioning using GPS satellite system."],  
##          AREA["World."],  
##          BBOX[-90,-180,90,180]],  
##      ID["EPSG",10604],  
##      REMARK["Replaces WGS 84 (G2139) (CRS code 9753) from 2024-01-07."]]
```

## From historical datums to reference frame realizations

- An International Terrestrial Reference Frame (ITRF) is a realization of the International Terrestrial Reference System (ITRS), which describes procedures for creating reference frames suitable for use with measurements on or near the Earth's surface
- Each realization attempts to improve on earlier iterations, as mathematical, computational and surveying techniques improve, and as measurements of the speed of shifts in the Earth's surface in relation to the geoid and ellipsoid surface advance; more accurate measurements of gravitation and magnetism contribute to this, through both satellite and terrestrial instrumentation
- Many grids are now available in the PROJ CDN to transform between epochs, based on other grids showing velocities of change between global reference frames and local realizations

## So what is a **FRAMEEPOCH**? i

- In **EPSG:10604**, WGS 84 (G2296), we see **FRAMEEPOCH**; here we need to lean on definitions given in Lott (2023b), annex B, pp. 83–87
- “Historically national and regional geodetic CRSs have been realized through the coordinates of points on the surface of the Earth. Those points move with the regional tectonic plate and to an observer situated on the tectonic plate the coordinates appear to be unchanging with time. This is called a *static reference frame*”

## So what is a **FRAMEEPOCH**? ii

- “Modern geodesy recognises that the surface of the Earth is deforming. The coordinates of points may change with time. The time evolution of coordinates may be included in the geodetic reference frame definition. Alternatively, or additionally, a crustal deformation model may be associated with the reference frame. A frame in which coordinates may change with time is called a *dynamic reference frame*”
- “When a reference frame and its coordinate reference system is fixed to the Earth as a whole, the individual tectonic plates move (albeit slowly, a few centimetres a year) within the system. To an observer on a tectonic plate the coordinates of his location within the earth-fixed Cartesian coordinate system change slowly with time – a dynamic reference frame. Examples include ITRF realizations and systems used by global satellite navigation systems such as WGS 84 used by GPS, PZ-90 by GLONASS, etc.”

## So what is a **FRAMEEPOCH**? iii

- “The tectonic plates may be subject to local crustal deformation caused by processes such as earthquake or post-glacial isostatic rebound. These deformations may be modelled, usually as a velocity grid. A CRS that has an associated deformation model is dynamic, regardless of whether it is plate-fixed or earth-fixed”
- “A CRS is dynamic either if it has a dynamic reference frame or if it is associated with a velocity model”
- “For practical application on a non-global basis, a dynamic CRS is not always convenient. Users prefer coordinates of locations on stable parts of tectonic plates to be constant. Regional and national reference frames may be defined to be fixed to the local tectonic plate with their definition adopting ITRF coordinate values at a chosen frame reference epoch”

## So what is a **FRAMEEPOCH**? iv

- “The coincidence of the two frames is only at the chosen epoch. Due to the motion of the tectonic plate to which the plate-fixed frame is fixed, the relationship between the global frame and the plate-fixed regional or national frame will then change slowly with time. Transformations between global and these national systems contain time evolution”
- What then is **ANCHOREPOCH** which we’ll see in the North America section? Lott (2023b), p. 57: “ANCHOREPOCH is the epoch at which a static reference frame matches a dynamic reference frame from which it has been derived. Note: Not to be confused with the frame reference epoch of dynamic geodetic and dynamic vertical reference frames. Nor with the epoch at which a reference frame is defined to be aligned with another reference frame; this information should be included in the datum anchor definition.”

## Who are the actors? i

- Perhaps changes are being driven by national or sub-national mapping agencies; [the British Ordnance Survey has a useful guide](#)
- In addition, supra-national coordinating bodies, for example in navigation, contribute; [Eurocontrol has a similar guide](#)
- Cartography and surveying have become much less important as users of position data, while navigation, construction and agriculture are more important civilian uses
- Integration and analysis of attribute data observed at recorded locations over time faces challenges if the CRS of the locations are changed

- There are several indeterminate decision levels, with tension between mapping agencies serving end users who prefer minimal change and geodesy which prefers scientific veracity, implying the correct representation of change, i.e. dynamism
- The mapping agencies are sovereign, but where jurisdictions meet, someone has to try to match borders, either between neighbouring agencies, or most helpfully through the IOGP/EPSG (<https://iogp.org>, <https://epsg.org> - Roger Lott is affiliated with the International Association of Oil & Gas Producers (IOGP), which makes major contributions to standards definition by Open Geospatial Consortium (OGC)), which has accumulated much practical experience through the decades

- The solutions to definition problems are then exposed in the EPSG geodetic parameter database, and through database values in PROJ, and on to software including R packages linking to PROJ
- The national mapping agencies also provide transformation definitions, grids, and sometimes also software that apply to the scope area, but which do not interoperate with other jurisdictions
- Writing per-jurisdiction plug-in software for R-packages for transformations is not practical, PROJ with the EPSG geodetic parameter is a much better choice, also for global use
- Finally, PROJ heuristics try to work around uncertainties, as end users need something that “works” to execute transformations

- The heuristics used in PROJ to find and order transformation pipelines only sometimes match the operation sequences proposed by national mapping agencies
- The comments in a PROJ [PR](#) help understand what appears to be the decision sequence

## Software implementation in R spatial packages

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- Most R geospatial packages (`sf`, `terra` (Hijmans et al. 2026), `gdalraster` (Toney and Sumner 2026), `vapour` (Sumner 2026), `gdalcubes` (Appel 2026)) use the `PROJ` external library (Evenden et al. 2026), its database `proj.db` and transformation grid files from the PROJ CDN (content download network) through the `GDAL` external library (Rouault et al. 2026); `geographiclib` (Sumner and Karney 2026) does not use `proj.db`
- This relationship between geospatial packages and `proj.db` has existed since GDAL ( $\geq 3$ ) and PROJ ( $\geq 6$ ) in 2019, and the PROJ CDN (<https://cdn.proj.org> from PROJ ( $\geq 7$ ) in 2020)
- The `proj.db` SQLite database contains tables from the EPSG geodetic parameter dataset; both the EPSG geodetic parameter dataset and the database layout are versioned, raising questions about handling backward compatibility

## Recent **proj.db** version information

Treating **proj.db** as an SQLite database, we can extract information from the **metadata** table. Version v12.029 is provided in PROJ 9.7.1 (December 2025) and 9.8.1 (April 2026, <https://proj.org/en/stable/news.html>), v12.049 was tried in 9.8.0 (March 2026) but caused trouble - more on this below, and the development version of PROJ (commit d258a97, 19 June) due for release in September 2026 provides currently v12.057:

**Table 2:** Recent PROJ **proj.db** characteristics

PROJ	epsg	layout_minor	tables
9.7.1	v12.029	6	47
9.8.0	v12.049	6	47
9.9.0	v12.057	7	48

The difference between the two newer databases is the addition of a new table: `derived_projected_crs`, causing an increment in the layout minor version. PROJ fails if the layout version of **proj.db** and that expected by the external library differ.

**proj.db** is updated at releases of PROJ, and made available both through package managers for Linux source installs, and through updates to R build trains for macOS and Windows (Rtools).

New standards are entering the EPSG database, so through PROJ and GDAL, enter R workflows, and as this happens, the same intended coordinate transformation may yield different results, depending on CRS definitions, EPSG versions and *epochs*

The adaptations to earlier changes in the PROJ external library described in section 4 of Bivand (2021) and Pebesma and Bivand (2023) may not be sufficient, see also [https://r-spatial.github.io/evolution/CRS\\_projections\\_transformations.html](https://r-spatial.github.io/evolution/CRS_projections_transformations.html), which is also no longer sufficient

EPSG table changes affect workflows

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## Prelude in Finland: **geofi** started failing with PROJ 9.6.0 i

- Before the release of PROJ 9.6.0 in March 2025, I was surprised to see an error in the R package **geofi** (Kainu et al. 2026) on running reverse dependency checks; **geofi** imports from **sf**
- **geofi** provides some saved geometries, including their CRS, and something had gone wrong with the intersection of a saved geometry and one freshly downloaded with a CRS instantiated from PROJ 9.6.0 - previously the CRS of the saved and freshly instantiated CRS were identical, now they differed
- At present, macOS binaries of **sf** are static built with PROJ 9.5.1, Windows with PROJ 9.7.1, COPR for RHEL/Fedora-rawhide PROJ 9.8.1, etc.

## Prelude in Finland: **geofi** started failing with PROJ 9.6.0 ii

- The issue was resolved (<https://github.com/rOpenGov/geofi/issues/52>), but the problem was caused by the National Land Survey of Finland changing the definition of the same EPSG 3067 code
- Pasi Häkli explained why they chose this alternative in a useful exchange on the PROJ mailing list; the underlying reason was connected to the emerging need to specify a datum ensemble member precisely (<https://lists.osgeo.org/pipermail/proj/2025-March/011787.htm>)
- Fortunately, there was a test in **geofi**, so the consequences of a change in **proj.db** stemming from an improvement made by a national mapping agency in a CRS definition were detected

## ETRS: ETRF iterations

Name	GEOD	GEOG3D	GEOG2D	Epoch	Based.on
ETRF89	7914	7915	9059	1989,0	ITRF89
ETRF90	7916	7917	9060	1989,0	ITRF90
ETRF91	7918	7919	9061	1989,0	ITRF91
ETRF92	7920	7921	9062	1989,0	ITRF92
ETRF93	7922	7923	9063	1989,0	ITRF93
ETRF94	7924	7925	9064	1989,0	ITRF94
ETRF96	7926	7927	9065	1989,0	ITRF96
ETRF97	7928	7929	9066	1989,0	ITRF97
ETRF2000	7930	7931	9067	1989,0	ITRF2000
ETRF2005	8397	8399	9068	1989,0	ITRF2005
ETRF2014	8401	8403	9069	1989,0	ITRF2014
ETRF2020	10569	10570	10571	1989,0	ITRF2020

GEOD: EPSG code, geocentric (m); GEOG3D: EPSG code, geographical with ellipsoidal height (m); GEOG2D: EPSG code, geographical

## Improved datum definitions affect searching for transformation pipelines i

The release of PROJ 9.8.0 on 2 March 2026 with EPSG database v12.049 including an in-place update to EPSG:4937, the European Terrestrial Reference System 1989 ensemble, things got complicated.

Jochem Lesparre on the PROJ mailing list (10 March 2026)- “transformations that used to give correct results (e.g. in PROJ 9.7.1) do no longer give results according to the official transformation” (<https://lists.osgeo.org/pipermail/proj/2026-March/012026.html>)

If we take the difference between ETRS89 (EPSG:4937) in v12.029 and v12.049, we see that 45 national/local realizations were added to the list of ensemble members (and one other line was edited):

## Improved datum definitions affect searching for transformation pipelines ii

```
## in v12.049, not in v12.029
##     MEMBER["ETRS89-DNK"],
##     MEMBER["Estonia 1997"],
##     MEMBER["Albanian Geodetic Reference Frame 2010"],
##     MEMBER["ETRS89-ALB [CORS]"],
##     MEMBER["ETRS89-AUT [2002]"],
##     MEMBER["Belgian Reference Frame 2002"],
##     MEMBER["Belgian Reference Frame 2011"],
##     MEMBER["BH_ETRS89"],
##     MEMBER["Bulgaria Geodetic System 2005"],
##     MEMBER["Croatian Terrestrial Reference System 1996"],
##     MEMBER["AGRS2010 (ETRF2000)"],
##     MEMBER["CROPOS"],
##     MEMBER["ETRF2000 Poland"],
##     MEMBER["ETRS89/DREF91 Realization 2016"],
##     MEMBER["ETRS89/DREF91 Realization 2025"],
##     MEMBER["ETRS89-CZE [2007]"],
```

## Improved datum definitions affect searching for transformation pipelines iii

```
## MEMBER["ETRS89-ESP [REGENTE]"],
## MEMBER["ETRS89-ESP [ERGNSS]"],
## MEMBER["ETRS89-FRO [2008]"],
## MEMBER["ETRS89-GRC [HTRS07]"],
## MEMBER["ETRS89-HUN [ETRF2000]"],
## MEMBER["ETRS89-IRE [ETRF2000]"],
## MEMBER["ETRS89-MKD [EUREF-MAK2010]"],
## MEMBER["ETRS89-NOR [EUREF89]"],
## MEMBER["ETRS89-PRT [1995]"],
## MEMBER["ETRS89-ROU [ETRF2000]"],
## MEMBER["ETRS89-SVK [SKTRF09]"],
## MEMBER["ETRS89-SVK [SKTRF2022]"],
## MEMBER["EUREF-FIN"],
## MEMBER["Istituto Geografico Militaire 1995"],
## MEMBER["Kosovo Reference System 2001"],
## MEMBER["Latvian geodetic coordinate system 1992"],
## MEMBER["Latvian coordinate system 2020"],
```

## Improved datum definitions affect searching for transformation pipelines iv

```
##      MEMBER["Lithuania 1994 (ETRS89)"],
##      MEMBER["MOLDREF99"],
##      MEMBER["OSNet v2009"],
##      MEMBER["Reseau Geodesique Francais 1993 v1"],
##      MEMBER["Reseau Geodesique Francais 1993 v2"],
##      MEMBER["Reseau Geodesique Francais 1993 v2b"],
##      MEMBER["Rete Dinamica Nazionale 2008"],
##      MEMBER["Serbian Reference Network 1998"],
##      MEMBER["Serbian Spatial Reference System 2000"],
##      MEMBER["Slovenia Geodetic Datum 1996"],
##      MEMBER["SWEREF 99"],
##      MEMBER["Swiss Terrestrial Reference Frame 1995"],
## in v12.029, not in v12.049
##      ID["EPSG",4937]]
```

Between v12.049 and v12.057, changes are more cosmetic:

## Improved datum definitions affect searching for transformation pipelines v

```
## in v12.049, not in v12.057
##     MEMBER["ETRS89-NOR [EUREF89]"],
##     MEMBER["Istituto Geografico Militaire 1995"],
## in v12.057, not in v12.049
##     MEMBER["EUREF89"],
##     MEMBER["Istituto Geografico Militaire 1995"],
##     MEMBER["ETRS89-LUX [ETRF2000]"],
##     MEMBER["Nordic Geodetic Commission ETRF14"],
```

The point raised by Jochem Lesparre applied not just to the changes in place in CRS definitions, but more crucially to the lack of synchronization engendered in transformation between CRS. Adding information to CRS to accommodate our understanding that they should more often be seen as dynamic is probably needed.

However, the growing complexity of datum definitions taking epoch into account has made the heuristics for choosing transformation pipelines (also from tables in `proj.db`) more challenging.

Legacy PROJ 4 used the (now) datum ensemble WGS84 as a static hub for coordinate transformation between a source and a target CRS, transforming from source datum to WGS84, then transforming again to the target datum reducing accuracy twice.

From PROJ 6, a transformation pipeline is used, directly from source to target or via varying intermediate steps (Knudsen and Evers 2017; Evers and Knudsen 2017).

Because the code used for searching for transformation pipelines may be updated between versions of PROJ itself, we need not only to track versions of EPSG, but also versions of PROJ.

## Improved datum definitions affect searching for transformation pipelines vii

The pipelines now need to be found by searching multiple table joins on the EPSG database in `proj.db`, ordering in terms of accuracy and whether transformation grids needed by the preferred pipelines are available, for example for on-demand download from the PROJ CDN.

Even Rouault commented 12 March: “There are situations where if you use the most complicated SQL requests it supports (and PROJ just limits itself to finding a single intermediate step...) you can end up with several hundreds or more potential transformation pipelines, with runtime of the order of second. While the execution of the pipeline is of the order of the microsecond for a coordinate. So before going to that, it checks if the results of less costly requests look to be good enough” (<https://lists.osgeo.org/pipermail/proj/2026-March/012037.html>).

Again on 10 May: “#PROJ challenge: propose a projinfo invocation searching operations between a source and target CRS and switches of your choice leading to the highest number of candidate operations. Record to beat: 717 (including ballpark operations) / 399 (without ballpark)” (<https://mastodon.social/@EvenRouault/116547361316876154>).

PROJ 9.8.0 and `proj.db` based on EPSG v12.049 was replaced by PROJ 9.8.1 with the same `proj.db` based on EPSG v12.029 published in PROJ 9.7.1.

PROJ PR <https://github.com/OSGeo/PROJ/pull/4773> merged 14 May adopts a hopefully less fragile logic for finding pipeline candidates affected by the ETRS89 ensemble changes in the EPSG database.

## Improved datum definitions affect searching for transformation pipelines ix

Does the remark by Jochem Lesparre (12 March) finding errors of up to 0.25 m affect R workflows when comparing coordinate transformation pipelines chosen in PROJ 9.7.1 and the troubled PROJ 9.8.0; is the problem mitigated in PROJ devel? See

<https://lists.osgeo.org/pipermail/proj/2026-March/012036.html>

Running the command to identify candidate transformation pipelines as in Jochem Lesparre's post: `sf::sf_proj_pipelines("EPSG:28992", "EPSG:4258", Use="INTERSECTION")` on these three versions of PROJ, we find that 9.7.1 returns 2 candidates, 9.8.0: 4 candidates, and 9.9.0: 9 candidates. So candidate counts increased as heuristics were modified to compensate for the added complexity of the epoch-based ETRS89 datum ensemble.

## Improved datum definitions affect searching for transformation pipelines x

```
> (m_71_80 <- match(ot_9.7.1_int[, "definition"], ot_9.8.0_int[, "definition"]))  
## [1] NA NA  
> (m_71_90 <- match(ot_9.7.1_int[, "definition"], ot_9.9.0_int[, "definition"]))  
## [1] 1 2  
> ot_9.9.0_int[m_71_90, "accuracy"]  
## [1] 0.101 0.350
```

Neither of the two pipelines found for 9.7.1 were found for 9.8.0, meaning that the change to the broader ETRS89 ensemble had confused the PROJ <= 9.8.0 heuristics for finding preferred pipelines.

The two 9.7.1 pipelines were found for 9.9.0, where the first gives high accuracy, using a modern grid `rdtrans2018` available from [https://cdn.proj.org/nl\\_nsgi\\_README.txt](https://cdn.proj.org/nl_nsgi_README.txt), the PROJ CDN:

## Improved datum definitions affect searching for transformation pipelines xi

```
## +proj=pipeline
## +step +inv +proj=sterea +lat_0=52.1561605555556 +lon_0=5.38763888888889 +k=0.9999079
## +x_0=155000 +y_0=463000 +ellps=bessel
## +step +proj=hgridshift +grids=nl_nsgi_rdtrans2018.tif
## +step +proj=unitconvert +xy_in=rad +xy_out=deg
```

The second pipeline is a Helmert transformation. All four 9.8.0 pipelines were found for 9.9.0, but none of them were in the most accurate position (ranked 1).

The first found pipeline for 9.8.0 used an out-dated grid not available from the PROJ CDN, the second a Molobadekas transformation, the third a Helmert transformation, and the fourth only has ballpark accuracy.

```
> (m_80_90 <- match(ot_9.8.0_int[, "definition"], ot_9.9.0_int[, "definition"]))
## [1] 3 4 5 8
```

## Improved datum definitions affect searching for transformation pipelines xii

Using the classical Meuse bank soil pollution data set in the `sp` package (Pebesma and Bivand 2026), with coordinates measured in EPSG:28992 and transforming to EPSG:4258 as in Jochem Lesparre's issue, we can track the average distances between transformations made with different versions of PROJ and the associated versions of the EPSG database.

We have 9.7.1 (under Windows, so a slightly different C math library) and 9.8.0 and 9.9.0 d258a97 (Fedora 44). 9.8.0 is about 12 cm off on average by comparison with 9.7.1 at the data location in the far south of the Netherlands. 9.9.0 has the same difference from 9.8.0.

```
> mean(diag(sf::st_distance(t1_9.7.1_cdn, t1_9.8.0_cdn)))  
## 0.12438 [m]  
> mean(diag(sf::st_distance(t1_9.8.0_cdn, t1_9.9.0_cdn)))  
## 0.12438 [m]
```

## Improved datum definitions affect searching for transformation pipelines xiii

Using the pipeline argument in `sf::st_transform`, the modern grid pipeline `rdtrans2018` can be replicated, as can the `molobadekas` pipeline. This demonstrates that 9.8.0 uses the `molobadekas` pipeline, 9.7.1 and 9.9.0 use the `rdtrans2018` pipeline, and that 9.7.1 and 9.9.0 differ by a minimal amount between Windows and Fedora C math libraries (the pipelines involve calls to trigonometry functions).

```
> mean(diag(sf::st_distance(molobadekas_sf, t1_9.8.0_cdn)))  
## 0 [m]  
> mean(diag(sf::st_distance(molobadekas_sf, rdtrans2018_sf)))  
## 0.12438 [m]  
> mean(diag(sf::st_distance(t1_9.9.0_cdn, rdtrans2018_sf)))  
## 0 [m]  
> mean(diag(sf::st_distance(t1_9.7.1_cdn, t1_9.9.0_cdn)))  
## 4.777793e-10 [m]
```

- So, yes, Jochem Lesparre's issue obviously would affect R spatial workflows if packages are built against PROJ 9.8.0
- Luckily, the problem was detected early within PROJ, and PROJ 9.8.1 was released with EPSG v12.029, stepping back from tracking current EPSG moves
- Work is continuing within PROJ to debate, test and implement improvements to heuristics for finding transformation pipelines and ordering them by accuracy
- *Epoch* and *datum ensemble* issues are unlikely to go away, as changes in North America are forthcoming
- Even Rouault on Mastodon (May 13): "Heard in a meeting: proprietary software tracks #PROJ changes to keep informed of changes in the EPSG dataset"  
<https://mastodon.social/@EvenRouault/116567675016927438>

North America

---

## Forthcoming changes in North America

- [Natural Resources Canada](#) reviews the background for Canadian Spatial Reference System (CSRS) modernization
- The North American Datum of 1983 (NAD83) was extended to create NAD83(CSRS) in the late 1990s as a three-dimensional reference system, and with subsequent enhancements improved the management of higher-accuracy positioning data (Craymer 2022)
- [The US National Geodetic Survey](#) will replace NAD83 with NSRS 2022 (NATRF2022), as NAD83 has shortcomings that are best addressed through defining new datums
- This has been coming for some time, see for example Smith (2010), where “up to 2 meters of error ... could cause incorrect lane determinations” (p. 7)

# Canadian Spatial Reference System

Name	Type	GEOG2D	Epoch	Based.on	Implemented	US.realization	US.epoch
NAD83(CSRS96)	Static	8232	NA	ITRF94	1996-01-01		NA
NAD83(CSRS)v2	Static	8237	1997	ITRF96	1998-01-01	NAD 83(CORS96)	1997
NAD83(CSRS)v3	Static	8240	1997	ITRF97	1999-01-01	NAD 83(CORS96)	1997
NAD83(CSRS)v4	Static	8246	2002	ITRF2000	2002-01-01	NAD 83(CORS96)	2002
NAD83(CSRS)v5	Dynamic	8249	2006	ITRF2005	2006-01-01		NA
NAD83(CSRS)v6	Dynamic	8252	2010	ITRF2008	2010-01-01	NAD 83(2011)	2010
NAD83(CSRS)v7	Dynamic	8255	2010	ITRF2014	2017-05-01	NAD 83(2011)	2010
NAD83(CSRS)v8	Dynamic	10414	2010	ITRF2020	2022-11-27		NA

- The North American Datum realizations are not grouped as a datum ensemble, but could have been, and present the same challenges
- In successive iterations, changes known as: High Accuracy Reference Network, Federal Base Network, Continuously Operating Reference Station Network, and National Spatial Reference System have been added to NAD83, which itself replaced NAD27
- NAD83 (like WGS84) uses the GRS80 global reference ellipsoid, while NAD27 used the Clarke 1866 ellipsoid (like the *maps* and *mapproj* R packages)

## North American Datum realizations EPSG remarks

```
## NAD27 [4267]: Replaced by NAD27(76) (code 4608) in Ontario, CGQ77 (code 4609) in Quebec,  
## Mexican Datum of 1993 (code 4483) in Mexico, NAD83 (code 4269) in Canada (excl.  
## Ontario & Quebec) & USA.  
## NAD83 [4269]: The adjustment included connections to Greenland and Mexico but the system  
## was not adopted there. For applications with an accuracy of better than 1m replaced  
## by NAD83(HARN) in the US and PRVI and by NAD83(CSRS) in Canada.  
## NAD83(HARN) [4152]: Replaced by NAD83(FBN) in CONUS, American Samoa and Guam / NMI, by  
## NAD83(NSRS2007) in Alaska, by NAD83(PA11) in Hawaii and by NAD83(HARN Corrected) in  
## PRVI.  
## NAD83(FBN) [8542]: In Continental US, Puerto Rico and US Virgin Islands replaced by  
## NAD83(NSRS2007). In American Samoa and Hawaii replaced by NAD83(PA11). In Guam/NMI  
## replaced by NAD83(MA11).  
## NAD83(NSRS2007) [4759]: Replaces NAD83(HARN) and NAD83(FBN). Replaced by NAD83(2011).  
## NAD83(CORS96) [6783]: Replaced by NAD83(2011) (CRS code 6318) from 2011-09-06.  
## NAD83(2011) [6318]: Replaces NAD83(CORS96) and NAD83(NSRS2007) (CRS codes 6783 and 4759).
```

To transform from NAD83 to NAD83(2011), lots of steps are required; this also applies to [ArcGIS](#)

```
## [1] "https://cdn.proj.org"  
## Candidate coordinate operations found: 3  
## Strict containment: FALSE  
## Axis order auth compl: TRUE  
## Source: EPSG:4269  
## Target: EPSG:6318  
## Best instantiable operation has accuracy: 0.1 m  
## Description: NAD83 to NAD83(2011) (NADCON5, CONUS)  
## Definition: +proj=pipeline +step +proj=axisswap +order=2,1 +step +proj=unitconvert  
## +xy_in=deg +xy_out=rad +step +proj=gridshift  
## +grids=us_noaa_nadcon5_nad83_1986_nad83_harn_conus.tif +step  
## +proj=gridshift +no_z_transform  
## +grids=us_noaa_nadcon5_nad83_harn_nad83_fbn_conus.tif +step  
## +proj=gridshift +no_z_transform  
## +grids=us_noaa_nadcon5_nad83_fbn_nad83_2007_conus.tif +step  
## +proj=gridshift +no_z_transform  
## +grids=us_noaa_nadcon5_nad83_2007_nad83_2011_conus.tif +step  
## +proj=unitconvert +xy_in=rad +xy_out=deg +step +proj=axisswap  
## +order=2,1
```

## North American Terrestrial Reference Frame 2022 going forward

- Since early 2025, beta versions of the modernized US NSRS have been made available, accommodating now known velocities of movements in 3 dimensions; the velocities and pre-existing inaccuracies justify modernization
- A vote on approving the modernized NSRS may occur in early to mid 2026; watch <https://geodesy.noaa.gov/datums/newdatums/index.shtml>
- Javier Jimenez Shaw contributed infrastructure to test the modernized NSRS in late April 2025, <https://github.com/jjimenezshaw/NSRS-2022-PROJ>, including a WASM option
- This makes it possible for users of US data to try to check their workflows for vulnerabilities to forthcoming changes

In the case of US data where integration of post-transition to NATRF2022 position data with pre-transition position data, it will be necessary to transform first to NAD83(2011):

```
## GEOGCRS["NAD83(2011)",  
##     DATUM["NAD83 (National Spatial Reference System 2011)",  
##         ELLIPSOID["GRS 1980",6378137,298.257222101,  
##             LENGTHUNIT["metre",1]],  
##         ANCHOREPOCH[2010]],  
##     PRIMEM["Greenwich",0,  
##         ANGLEUNIT["degree",0.0174532925199433]],  
##     CS[ellipsoidal,2],  
##         AXIS["geodetic latitude (Lat)",north,  
##             ORDER[1],  
##             ANGLEUNIT["degree",0.0174532925199433]],  
##         AXIS["geodetic longitude (Lon)",east,  
##             ORDER[2],
```

```
##           ANGLEUNIT["degree",0.0174532925199433]],
##  USAGE[
##           SCOPE["Horizontal component of 3D system."],
##           AREA["Puerto Rico - onshore and offshore. United States (USA) onshore and offshore - Alabama;
##           BBOX[14.92,167.65,74.71,-63.88]],
##  ID["EPSG",6318],
##  REMARK["Note: this CRS includes longitudes which are POSITIVE EAST. Replaces NAD83(CORS96) and NAD83(2011)"]]
```

The NATRF2022 2D CRS definition is (for now from Javier Jimenez Shaw's test infrastructure, as yet with no assigned EPSG code) - note that it is now dynamic, but the usage block is as yet incomplete:

```
## GEOGCRS["NATRF2022",
##     DYNAMIC[
##         FRAMEEPOCH[2020]],
##     DATUM["North American Terrestrial Reference Frame 2022",
##         ELLIPSOID["GRS 1980",6378137,298.257222101,
##             LENGTHUNIT["metre",1]]],
##     PRIMEM["Greenwich",0,
##         ANGLEUNIT["degree",0.0174532925199433]],
##     CS[ellipsoidal,2],
##         AXIS["geodetic latitude (Lat)",north,
##             ORDER[1],
##             ANGLEUNIT["degree",0.0174532925199433]],
```

```
##      AXIS["geodetic longitude (Lon)",east,  
##      ORDER[2],  
##      ANGLEUNIT["degree",0.0174532925199433]],  
##  USAGE[  
##      SCOPE["Not known."],  
##      AREA["World."],  
##      BBOX[-90,-180,90,180]],  
##  ID["NSRS","NATRF2022_2D"],  
##  REMARK["NATRF2022"]]
```

## Testing modernized NSRS NATRF2022 in `proj.db` i

EPSG v12.057 and earlier (including v12.029) include initial versions of “so-called” EPSG:10968 - here from v12.029 (not dynamic but with an epoch anchored to a matching reference frame):

```
## GEOGCRS["NATRF2022",  
##     DATUM["North American Terrestrial Reference Frame of 2022",  
##         ELLIPSOID["GRS 1980",6378137,298.257222101,  
##             LENGTHUNIT["metre",1]],  
##         ANCHOREPOCH[2020]],  
##     PRIMEM["Greenwich",0,  
##         ANGLEUNIT["degree",0.0174532925199433]],  
##     CS[ellipsoidal,2],  
##         AXIS["geodetic latitude (Lat)",north,  
##             ORDER[1],  
##             ANGLEUNIT["degree",0.0174532925199433]],  
##         AXIS["geodetic longitude (Lon)",east,  
##             ORDER[2],
```

## Testing modernized NSRS NATRF2022 in `proj.db` ii

```
##           ANGLEUNIT["degree",0.0174532925199433]],  
##   USAGE[  
##     SCOPE["Horizontal component of 3D system."],  
##     AREA["North America - onshore and offshore: Canada - Alberta; British Columbia; Manitoba; New  
##     BBOX[23.81,167.65,86.46,-40.73]],  
##     ID["EPSG",10968]]
```

from v12.049, which cautiously remarks - This data has been added to the EPSG Dataset prior to official adoption to facilitate software testing and evaluation. In the unlikely event that definitions change, the record will be deprecated and replaced with a new EPSG code:

## Testing modernized NSRS NATRF2022 in **proj.db** iii

```
## GEOGCRS["NATRF2022",
##     DATUM["North American Terrestrial Reference Frame of 2022",
##         ELLIPSOID["GRS 1980",6378137,298.257222101,
##             LENGTHUNIT["metre",1]],
##         ANCHOREPOCH[2020]],
##     PRIMEM["Greenwich",0,
##         ANGLEUNIT["degree",0.0174532925199433]],
##     CS[ellipsoidal,2],
##         AXIS["geodetic latitude (Lat)",north,
##             ORDER[1],
##             ANGLEUNIT["degree",0.0174532925199433]],
##         AXIS["geodetic longitude (Lon)",east,
##             ORDER[2],
##             ANGLEUNIT["degree",0.0174532925199433]],
##     USAGE[
##         SCOPE["Horizontal component of 3D system."],
##         AREA["North America - onshore and offshore: Canada - Alberta; British Columbia; Manitoba; New
```

## Testing modernized NSRS NATRF2022 in **proj.db** iv

```
##          BBOX[23.81,167.65,86.46,-40.73]],
##          ID["EPSG",10968],
##          REMARK["CAUTION: Preliminary data from NGS beta website (https://beta.ngs.noaa.gov/). This data ha
```

and v12.057, now without the remark, but with a new name - NATRF2022e2020, for the 2020 epoch:

```
## GEOGCRS["NATRF2022e2020",
##          DATUM["North American Terrestrial Reference Frame of 2022 epoch 2020.00",
##          ELLIPSOID["GRS 1980",6378137,298.257222101,
##          LENGTHUNIT["metre",1]],
##          ANCHOREPOCH[2020]],
##          PRIMEM["Greenwich",0,
##          ANGLEUNIT["degree",0.0174532925199433]],
##          CS[ellipsoidal,2],
##          AXIS["geodetic latitude (Lat)",north,
##          ORDER[1],
##          ANGLEUNIT["degree",0.0174532925199433]],
```

## Testing modernized NSRS NATRF2022 in **proj.db** v

```
##      AXIS["geodetic longitude (Lon)",east,  
##          ORDER[2],  
##          ANGLEUNIT["degree",0.0174532925199433]],  
##  USAGE[  
##      SCOPE["Horizontal component of 3D system."],  
##      AREA["North America - onshore and offshore: Canada; United States (USA) - Alaska, conterminous  
##      BBOX[23.81,167.65,86.46,-40.73]],  
##      ID["EPSG",10968]]
```

## Testing modernized NSRS - transformation pipeline i

Again, using Javier Jimenez Shaw's test infrastructure, we can access a preliminary transformation pipeline definition from NAD83(2011) to NATRF2022\_2D (at the moment the axis order of the position data must be authority compliant as the test infrastructure or its use in `sf::st_transform` has not been generalized to support longitude, latitude order):

```
## Candidate coordinate operations found: 1
## Strict containment: FALSE
## Axis order auth compl: TRUE
## Source: EPSG:6318
## Target: NSRS:NATRF2022_2D
## Best instantiable operation has accuracy: 0.01 m
## Description: Conversion from NAD83(2011) (geog2D) to NAD83(2011) (geocentric) + Inverse of
## ITRF2020 to NAD83(2011) (1) + ITRF2020 to NATRF2022 + Conversion
## from NATRF2022 (geocentric) to NATRF2022 (geog2D)
## Definition: +proj=pipeline +step +proj=axisswap +order=2,1 +step +proj=unitconvert
```

## Testing modernized NSRS - transformation pipeline ii

```
##      +xy_in=deg +xy_out=rad +step +proj=cart +ellps=GRS80 +step +inv
##      +proj=helmert +x=1.0039 +y=-1.90961 +z=-0.54117 +rx=0.02678138
##      +ry=-0.00042027 +rz=0.01093206 +s=-5.109e-05 +dx=0.00079
##      +dy=-0.0007 +dz=-0.00124 +drx=6.667e-05 +dry=-0.00075744
##      +drz=-5.133e-05 +ds=-7.201e-05 +t_epoch=2010
##      +convention=coordinate_frame +step +proj=helmert +x=0 +y=0 +z=0
##      +rx=0 +ry=0 +rz=0 +s=0 +dx=0 +dy=0 +dz=0 +drx=4.6e-05
##      +dry=-0.000704 +drz=-4.7e-05 +ds=0 +t_epoch=2020
##      +convention=coordinate_frame +step +inv +proj=cart +ellps=GRS80
##      +step +proj=unitconvert +xy_in=rad +xy_out=deg +step
##      +proj=axiswap +order=2,1
```

v12.029 returns a `noop` for NAD83(2011) to NATRF2022:

```
## Candidate coordinate operations found: 1
## Strict containment: FALSE
## Axis order auth compl: TRUE
## Source: EPSG:6318
## Target: EPSG:10968
## Best instantiable operation has accuracy: 3 m
## Description: NAD83(2011) to WGS 84 (1) + Inverse of NATRF2022 to WGS 84 (1)
## Definition: +proj=noop +ellps=GRS80
```

as does v12.049:

## Testing modernized NSRS transformation pipelines in `proj.db` ii

```
## Candidate coordinate operations found: 1
## Strict containment:      FALSE
## Axis order auth compl:  TRUE
## Source:  EPSG:6318
## Target:  EPSG:10968
## Best instantiable operation has accuracy: 3 m
## Description: NAD83(2011) to WGS 84 (1) + Inverse of NATRF2022 to WGS 84 (1)
## Definition:  +proj=noop +ellps=GRS80
```

while v12.057 offers the `noop` and two similar pipelines with reported minimal loss of accuracy naming the target as `NATRF2022e2020`; the chosen pipeline is the same as that returned by Javier Jimenez Shaw's test infrastructure:

## Testing modernized NSRS transformation pipelines in `proj.db` iii

```
## Candidate coordinate operations found: 3
## Strict containment:      FALSE
## Axis order auth compl:  TRUE
## Source:  EPSG:6318
## Target:  EPSG:10968
## Best instantiable operation has accuracy: 0 m
## Description: Conversion from NAD83(2011) (geog2D) to NAD83(2011) (geocentric) + Inverse of
##              ITRF2020 to NAD83(2011) (1) + ITRF2020 to NATRF2022e2020 (1) +
##              Conversion from NATRF2022e2020 (geocentric) to NATRF2022e2020
##              (geog2D)
## Definition:  +proj=pipeline +step +proj=axisswap +order=2,1 +step +proj=unitconvert
##              +xy_in=deg +xy_out=rad +step +proj=cart +ellps=GRS80 +step +inv
##              +proj=helmert +x=1.0039 +y=-1.90961 +z=-0.54117 +rx=0.02678138
##              +ry=-0.00042027 +rz=0.01093206 +s=-5.109e-05 +dx=0.00079
##              +dy=-0.0007 +dz=-0.00124 +drx=6.667e-05 +dry=-0.00075744
##              +drz=-5.133e-05 +ds=-7.201e-05 +t_epoch=2010
##              +convention=coordinate_frame +step +proj=helmert +x=0 +y=0 +z=0
```

## Testing modernized NSRS transformation pipelines in **proj.db** iv

```
##          +rx=0 +ry=0 +rz=0 +s=0 +dx=0 +dy=0 +dz=0 +drx=4.6e-05
##          +dry=-0.000704 +drz=-4.7e-05 +ds=0 +t_epoch=2020
##          +convention=coordinate_frame +step +inv +proj=cart +ellps=GRS80
##          +step +proj=unitconvert +xy_in=rad +xy_out=deg +step
##          +proj=axiswap +order=2,1
```

## Testing modernized NSRS - Boston bounding box coordinates by CRS

Using this on the Boston census tract NAD27 data set in `spData` (Bivand et al. 2026), after first transforming to NAD83 then NAD83(2011), we can see that the coordinate values are changed, most for the big NAD27 to NAD83 step (NAD27 used the Clarke 1866 legacy ellipsoid, NAD83 GRS80 also with different datums); v12.057 gives the same transformation output as Javier Jimenez Shaw's test infrastructure:

CRS	Geodetic latitude min	Geodetic longitude min	Geodetic latitude max	Geodetic longitude max
NAD27	42.00304794	- 71.52310944	42.67307281	- 70.63822937
NAD83	42.0031502	- 71.52261635	42.6731655	- 70.63771032
NAD83(2011)	42.00315072	- 71.52261689	42.67316488	- 70.63771176
NATRF2022	42.00316021	- 71.52262028	42.67317448	- 70.63771483
NATRF2022e2020	42.00316021	- 71.52262028	42.67317448	- 70.63771483

## Testing modernized NSRS - distances between Boston points by CRS

Approximating with `s2` (Dunnington et al. 2026) the distances between south-west bounding box coordinates, we can see that the modernization from NAD83(2011) to NATRF2022 causes a shift of just over a metre ([PR 4775](#) probably caused the NATRF2022(PROJ 9.8)-NATRF2022e2020(PROJ 9.9) difference):

CRS	NAD27	NAD83	NAD83.2011.	NATRF2022	NATRF2022e2020
NAD27	0.00000 [m]	42.30085734 [m]	42.27365820 [m]	4.230290e+01 [m]	4.230290e+01 [m]
NAD83	42.30086 [m]	0.00000000 [m]	0.07227717 [m]	1.158747e+00 [m]	1.158747e+00 [m]
NAD83(2011)	42.27366 [m]	0.07227717 [m]	0.00000000 [m]	1.091805e+00 [m]	1.091805e+00 [m]
NATRF2022	42.30290 [m]	1.15874745 [m]	1.09180478 [m]	0.000000e+00 [m]	1.015817e-09 [m]
NATRF2022e2020	42.30290 [m]	1.15874745 [m]	1.09180478 [m]	1.015817e-09 [m]	0.000000e+00 [m]

## Summary

---

## Preliminary take-home points

- Most legacy CRS did not take continental drift into account
- The demands on CRS for accuracy and measurable errors have increased greatly, especially with the general availability of GNSS receivers; errors at metre scale are now unacceptable, and sub-metre errors are undesirable
- Global CRS have to match global crustal movement, but regional/national CRS are most often fixed to the most appropriate tectonic plate
- Countries/jurisdictions adopt CRS for official purposes, and their mapping agencies often manage them differently
- Fitting different mapping agency practices balancing science with practical needs into a shared database involves complex trade-offs

## Concluding take-home points

- Adaptation to new CRS will be required as public mapping agencies modernize their standards
- There are many public mapping agencies, and their adaptations may impact users in unexpected ways - also unexpected for the agencies
- The EPSG database is where much of the coordination of these adaptations has to take place, and EPSG/PROJ cooperation can provide both with useful experience of what works in practice
- As could be seen from the NATRF2022e2020 example, EPSG registration has to feel its way forward cautiously to provide advanced access to mapping agency thinking, so caution and feedback from users such as us will also contribute

- All of the issues raised here apply to software using PROJ, and PROJ through GDAL
- These include other interactive environments such as Python and Julia
- They also include desktop GIS such as QGIS, GRASS, and web mapping applications
- So hopefully these notes are not only relevant for R packages

# sessionInfo i

```
> sessionInfo()
```

```
R version 4.6.0 (2026-04-24)
```

```
Platform: x86_64-pc-linux-gnu
```

```
Running under: Fedora Linux 44 (Workstation Edition)
```

```
Matrix products: default
```

```
BLAS/LAPACK: FlexiBLAS LIBFLEXIBLAS_OPENBLAS-SERIAL.SO; LAPACK version 3.12.1
```

```
locale:
```

```
[1] LC_CTYPE=en_GB.UTF-8      LC_NUMERIC=C              LC_TIME=en_GB.UTF-8
[4] LC_COLLATE=en_GB.UTF-8   LC_MONETARY=en_GB.UTF-8  LC_MESSAGES=en_GB.UTF-8
[7] LC_PAPER=en_GB.UTF-8     LC_NAME=C                 LC_ADDRESS=C
[10] LC_TELEPHONE=C           LC_MEASUREMENT=en_GB.UTF-8 LC_IDENTIFICATION=C
```

```
time zone: Europe/Oslo
```

```
tzcode source: system (glibc)
```

```
attached base packages:
```

```
[1] stats      graphics  grDevices  utils      datasets  methods    base
```

```
other attached packages:
```

```
[1] tinytable_0.16.0
```

loaded via a namespace (and not attached):

[1] s2_1.1.11	class_7.3-23	lwgeom_0.2-16	KernSmooth_2.23-26
[5] lattice_0.22-9	digest_0.6.39	magrittr_2.0.5	evaluate_1.0.5
[9] grid_4.6.0	fastmap_1.2.0	tmap_4.4	jsonlite_2.0.0
[13] e1071_1.7-17	leafsync_0.1.0	DBI_1.3.0	tinytex_0.60
[17] crosstalk_1.2.2	cols4all_0.10	XML_3.99-0.23	codetools_0.2-20
[21] microbenchmark_1.5.0	abind_1.4-8	cli_3.6.6	rlang_1.2.0
[25] units_1.0-1	tmertools_3.3	litedown_0.9	base64enc_0.1-6
[29] yaml_2.3.12	otel_0.2.0	leaflet_1.2.8	tools_4.6.0
[33] raster_3.6-32	parallel_4.6.0	maptiles_0.11.0	colorspace_2.1-2
[37] spacesXYZ_1.6-0	logger_0.4.2	R6_2.6.1	png_0.1-9
[41] proxy_0.4-29	classInt_0.4-11	leaflet_2.2.3	htmlwidgets_1.6.4
[45] terra_1.9-34	data.table_1.18.4	glue_1.8.1	Rcpp_1.1.1-1.1
[49] sf_1.1-1	rnaturalearthdata_1.0.0	xfun_0.59	knitr_1.51
[53] htmltools_0.5.9	rmarkdown_2.31	leaflet_0.2.5	wk_0.9.5
[57] compiler_4.6.0	sp_2.2-1	stars_0.7-2	

## Aftermatter

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