International Association of Oil & Gas Producers

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EPSG null and copy transformations to WGS 84

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Revision history

VERSION	DATE	AMENDMENTS
1.1	May 2022	Minor update
1.0	February 2022	First release

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Acknowledgements

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About

This Guidance Note explains aspects of the past and current policy for the inclusion in the EPSG Dataset of so-called null coordinate transformations to WGS 84 and limitations in the description of WGS 84 through coordinate reference system code EPSG:4326. It also describes the application of datum ensembles in the EPSG Dataset. It recommends appropriate usage of this data. The Guidance Note is aimed at application developers, data managers, operational surveyors and (GIS) end-users requiring decimetre to ~1-3m accuracy, especially those working in the oil, gas, and renewables industries, both in operating companies and for contractors/service providers.

Introduction

The overarching strategy for data population of the EPSG Dataset is to maintain geodetic rigour in definitions such that

i) users who require high spatial accuracy in their data can use the EPSG data without any degradation in their spatial referencing, and

ii) users who are able to work at low accuracy and wish to merge datasets referenced to multiple coordinate reference systems are able to do so efficiently.

Here 'low accuracy' means users who are able to ignore the secular motion of tectonic plates, so can accept 1-3m or worse spatial accuracy. To assist this second group of users, IOGP has a policy of introducing into the EPSG Dataset 'null' and 'copy' transformations and documenting 'datum ensembles'. These concepts are described in the following sections of this document. If misused, these transformations and datum ensembles can lead to degradation of spatial data integrity. The objective of this guidance note is to describe EPSG policy for populating null and copy transformations and datum ensembles, to highlight potential problems and provide recommendations for mitigation and avoidance.

WGS 84 is the operational reference frame for the GPS global navigation satellite system. Because GPS positioning is ubiquitous, WGS 84 is the most accessible of several global coordinate reference systems (CRSs). For many users, it is a natural choice for spatial referencing and for the integration of spatial data sets, particularly because it is generally used for Web Mapping. WGS 84 (EPSG:4326) has often been chosen for these purposes. However, there are issues with this choice that may have to be considered against end-user accuracy requirements:

- Most historic national CRSs are static (meaning that their coordinates do not change with time), while WGS 84 is dynamic (meaning that the coordinates of a stationary point on the surface of the Earth do change with time). Hence, the relationship of WGS 84 to most national CRSs changes with time.
- There have been multiple realizations of the WGS 84 reference frame and EPSG:4326 does not distinguish between these realizations.
- The EPSG policy of creating artificial 'null' and 'copy' transformations to EPSG:4326 involves approximations.
- Implementations and users often ignore transformation accuracy.

Because of these issues, EPSG:4326, together with projected CRSs based upon it, is not suitable for work requiring an accuracy of better than approximately 1-3 metres (depending on location, time frame of the project, and age of the data). This has not always been recognized by users. Advances in technology which will make sub-decimetre real-time positioning routinely available mean that approximations that were acceptable in past practices may no longer be appropriate in the future.

This guidance note describes the limitations embedded within EPSG:4326 and other CRSs based on the EPSG WGS 84 datum 6326[1], and recommends appropriate usage.

[1] The EPSG Dataset also contains a small number of EPSG-defined null and copy transformations that do not have WGS 84 as target CRS. Discussion of these transformations is beyond the scope of this Guidance Note.

1 EPSG null transformations

An EPSG null transformation is one created artificially by EPSG equating the coordinates of a location referenced to different CRSs. It ignores rigorous geodesy. Typically, it has been defined using the Geocentric translations method where all parameter values are zero, i.e., tX=tY=tZ=0.

The rationale underpinning the creation of these null transformations is:

- Direct transformations between CRSs will not always be available, and as a mitigation against this the EPSG Dataset content should support the hub transformation technique (see Appendix C).[2]
- WGS 84 has often been used as the CRS to which imagery has been georeferenced in web mapping applications.
- Modern geodetic CRSs almost always are defined with respect to geodetic science's best global CRS, the International Terrestrial Reference System (ITRS) through one of its ITRFyy frame realizations, usually being defined to be coincident with it at a specified epoch.
- Since 1994 and the introduction of WGS 84 (G730), the WGS 84 system has been approximately aligned with ITRS (see Section 3).
- When national and regional systems are aligned with ITRS, as WGS 84 is also aligned to ITRS, and as their reference ellipsoids are essentially the same, then as an approximation suitable for many practical purposes WGS 84 can be taken to be aligned with these national and regional systems.

However, there are issues with this notional equality of WGS 84 to a national or regional CRS:

- Although the reference frames are defined to be equal at some specified epoch, within the realizations of each reference frame the distortions differ, so this assumption of equality is an approximation.
- Differences between the various realizations of WGS 84 are ignored.
- Differences between various ITRF realizations and their frame reference epoch are ignored.
- WGS 84 is a dynamic reference frame. Most current national and regional systems are static. Static and dynamic CRSs move with respect to each other, typically by several centimetres per year (see Ref. [2] and [3] for more information).
  - These annual changes accumulate, so over a period of time the displacements may reach values that are significant to users.

To allow for these issues, null transformations to EPSG:4326 are given an accuracy of a nominal 1 metre. However, users should note that:

- For several tectonic plates, over a protracted period of time this 1 metre nominal value has been inadequate. In some cases, it has subsequently been increased.
- Transformation accuracy is often ignored by applications and users.

[2] Direct transformations between national and regional CRSs are currently (2022) more generally available than when EPSG implemented this policy. There is less reason to use hub concatenation techniques than once was the case.

2 EPSG copy transformations

EPSG copy transformations are the generalized case of the 'null' transformations described in the previous section. An historic national CRS may be related to a modern national CRS that is defined to be consistent with a realization of ITRF at some specified epoch. Examples include national CRSs in Europe being related to ETRS89 and in Australia AGD66 being related to GDA94. If the modern national CRS can be related to WGS 84 then the transformation from historic national to modern national may be concatenated with the transformation from modern national to WGS 84. When the latter is a 'null' transformation, the transformation from historic national to modern national may be taken as an approximate transformation from historic national CRS to WGS 84 – an EPSG copy transformation. This copy transformation provides a direct path from old national CRS to WGS 84. It is created only when no other direct path exists between the old national CRS and WGS 84.

The transformations between historic and modern national CRSs generally have an accuracy of decimetres to metres, mostly reflecting distortions caused by survey inaccuracies in the historic CRS. EPSG copy transformations are usually assigned an accuracy of the larger of (a) the EPSG null transformation accuracy, or (b) the accuracy of the historic to modern national transformation; the assigned accuracy value will therefore be less than the summation of the accuracies of the two transformations through WGS 84.

These copy transformations contain all of the limitations outlined in the previous Section on null transformations.

3 The evolution of WGS 84

The World Geodetic System of 1984 (WGS 84) is the operational reference frame for the GPS global navigation satellite system [1]. GPS was initially designed to support US military positioning requirements including medium scale (1:50,000) topographic mapping. System performance has significantly exceeded design criteria and, through subsequent advances in GNSS technology, sub-decimetre level real-time positioning will be available to the layman in the near future. These advances in positioning accuracy mean that, for some users, past practices associated with the use of WGS 84 may no longer be adequate.

3.1 WGS 84 realizations

The practical realization of the WGS 84 reference frame has evolved over time. It was first realized through the Doppler Transit satellite technology available in the late 1970s and early 1980s. This initial realization was based on the best positioning technology available at the time but was offset by about two metres from scientific geodesy's current best global reference system (the ITRS). The 2m value is a three-dimensional offset at the centre of the Earth; at the surface of the Earth its horizontal component varies with location but is typically 0.5 to 1.5 metres. Since 1994 six subsequent realizations of WGS 84 have been more closely aligned to the ITRS, initially at the decimetre level and more recently within a few centimetres. In practice, a realization of WGS 84 is accomplished by defining a set of station coordinates at a specified epoch. For each realization, these defining station coordinates have been refined. Such refinement manifests itself as changes in coordinates of locations derived through GPS direct positioning techniques, see Table 1.

Table 1 – WGS 84 realizations

Realization name	Date introduced[3]	Successive coordinate change
WGS 84 (Transit)	1987-01-01	n/a
WGS 84 (G730)	1994-06-29	1-2 m (average 0.7 m horizontal)
WGS 84 (G873)	1997-01-29	0.2 m
WGS 84 (G1150)	2002-01-20	0.06 m
WGS 84 (G1674)	2012-02-08	0.2 m
WGS 84 (G1762)	2013-10-16	0.05 m (0.02 m horizontal)
WGS 84 (G2139)	2021-01-03	0.03 m (0.01 m horizontal)

The name “WGS 84” is applied to the reference frame (datum) and was also used for the initial Transit realization before subsequent realizations existed. Although each realization now has its own name, “WGS 84” is now used without discrimination for any of the realizations, or for all realizations as a collective. For practical purposes the changes between realizations have been deemed to be within the positioning accuracy that the system was capable of delivering and no transformations between the earliest realizations have been published by the GPS system operator.

The WGS 84 reference frame and its realizations are dynamic: locations of stationary objects on the surface of the Earth move slowly through the WGS 84 coordinate space and their WGS 84 coordinates change with time. To be unambiguous, a WGS 84 position needs to be qualified by the WGS 84 realization and the coordinate epoch—a date-stamp for the coordinates—for example "WGS 84 (G2139) at epoch 2021.22". IOGP Geomatics Guidance Note 373-25 [2] and the IOGP Dynamic Coordinate Reference System video [3] provide further information on dynamic CRSs.

In the late 1980s and early 1990s, a collection of transformations between numerous national CRSs and WGS 84 was published in DMA TR8350.2 [4]. These transformations were related to the WGS 84 (Transit) realization, but because of their modest accuracy are also applied to the later realizations of WGS 84 [1]. These transformations are included in the EPSG Dataset.

3.2 The EPSG WGS 84 datum ensemble

The EPSG Dataset includes entries for each realization of WGS 84, and in addition CRSs based on a datum ensemble of all realizations. Datum ensembles and EPSG policy for them are outlined in Appendix A. Historically, the WGS 84 datum (EPSG code 6326) was implicitly defined as an ensemble through remarks in the datum record ("EPSG:6326 has been the then current realization. No distinction is made between the original and subsequent realizations of the WGS 84 frame"). From EPSG Dataset v10 (September 2020), which marked the introduction of an EPSG data model update, the datum code 6326 has been explicitly defined as a datum ensemble.

[3] Date when the GPS broadcast ephemeris signals available to civilian users were referenced to the new realization.

In the EPSG Dataset, datum ensemble 6326 has an ensemble accuracy of 2 metres, to cover the coordinate differences between all of the realizations described in the previous subsection. The offset of the Transit realization accounts for much of this 2 metres.

Per EPSG policy (Appendix A.2.2), CRSs associated with datum ensemble 6326 are treated as if they were static, despite the individual realizations of WGS 84 being dynamic.

Table 2 shows geodetic CRSs that are based on EPSG datum ensemble 6326. These geodetic CRSs, together with any projected CRSs based upon them, are not suitable for supporting applications requiring better than 1-3 metre accuracy.

Table 2 - Identifiers of geodetic CRSs utilizing EPSG WGS 84 datum ensemble 6326

Authority	Identifier	Geodetic CRS type
EPSG	4326	Geographic 2D
EPSG	4979	Geographic 3D
EPSG	4978	Geocentric
OGC[4]	CRS84	Geographic 2D
OGC	CRS84h	Geographic 3D

4 Transformation accuracy

Coordinate operation accuracy is an indicative number indicating the loss of accuracy in metres that applying the coordinate operation might bring to target coordinates. A small number of transformations are, by definition, taken to be exact. Application of these transformations introduces no error into the output coordinates. These have a coordinate operation accuracy of 0.

However, most transformations are determined empirically from coordinates in both CRSs at a subset of stations in the two systems. Any network distortion embedded in those station coordinates is inherited by the empirically determined transformations. When applied at other locations with different distortion characteristics, the transformation introduces a small error in output coordinates.

Transformations in the EPSG Dataset carry a single coordinate operation accuracy figure which gives a representative value for the error that application of the transformation might introduce[5].

For concatenated operations, unless there is some reason to do otherwise, EPSG determines an operation accuracy from the square root of the sum of the squares of the individual operation accuracies.

[4] Open Geospatial Consortium, https://www.ogc.org/

[5] The accuracy for transformations in the DMA TR8350.2 transformation collection mentioned above is generally in the metres to tens of metres range – they are not suitable for purposes requiring high accuracy.

5 Practical issues with null transformations

5.1 Hub transformations

The hub concept is an appealing method of implementing a generalized coordinate transformation application and is sometimes found in GIS software. Refer to Appendix C for an overview of the technique. The limitations of null transformations applied in a hub setting are demonstrated by an example.

Two national static (plate-fixed) systems aligned to ITRS have been introduced in Australia:

- In 1994, GDA94 was aligned with ITRF92 at epoch 1994.00 (1st January 1994). At this time the then recently introduced realization of WGS 84, WGS 84 (G730), had also been aligned to ITRF92 at epoch 1994.00. Per policy, IOGP created null transformation, code EPSG:1150, equating GDA94 and WGS 84. A nominal transformation accuracy of 1 metre was assigned.
- In 2016, GDA2020 was aligned with ITRF2014 at epoch 2020.00 (1st January 2020). At this time the then current realization of WGS 84, WGS 84 (G1762), had been aligned to Igb08 at epoch 2005.00. The differences between ITRF2014 at epoch 2020.00 and Igb08 at epoch 2005.00 are small – approximately at the centimetre level – and considered insignificant for most purposes. IOGP created null transformation code EPSG:8450, equating GDA2020 and WGS 84. A nominal transformation accuracy of 1 metre was assigned.

The Australian national mapping agency has determined that GDA94 and GDA2020 are offset from each other by approximately 1.8 metres. Why this offset? GDA94 and GDA2020 are both aligned to ITRS. The changes between ITRF92 at epoch 1994.00 and ITRF2014 at epoch 2020.00 are small, at the centimetre level. But the Australian tectonic plate, to which both GDA94 and GDA2020 are fixed, is moving with respect to the earth-centred WGS 84 reference frame by approximately seven centimetres per year. The accumulated movement since 1994 is approaching two metres. Because the nominal accuracy of one metre originally assigned to GDA94 to WGS 84 null transformation EPSG:1150 was now outdated, it was increased to three metres. For consistency, the transformation accuracy for EPSG:8450 was also increased to three metres.

The illustration in Figure 1 below sketches the current situation. GDA94 and GDA2020 are known to be offset by 1.8 m. Through the artificial null transformations defined by EPSG, GDA94 is apparently equal to WGS 84, and GDA2020 is also apparently equal to WGS 84. The direct transformation between GDA94 and WGS 84 will correctly change coordinate values by 1.8 m. An indirect transformation between GDA94 and GDA2020 using a concatenation of the two null transformations EPSG:1150 and EPSG:8450 through WGS 84 (EPSG:4326) as the hub will result in no change of coordinates, incorrectly implying that GDA94 equals GDA2020.

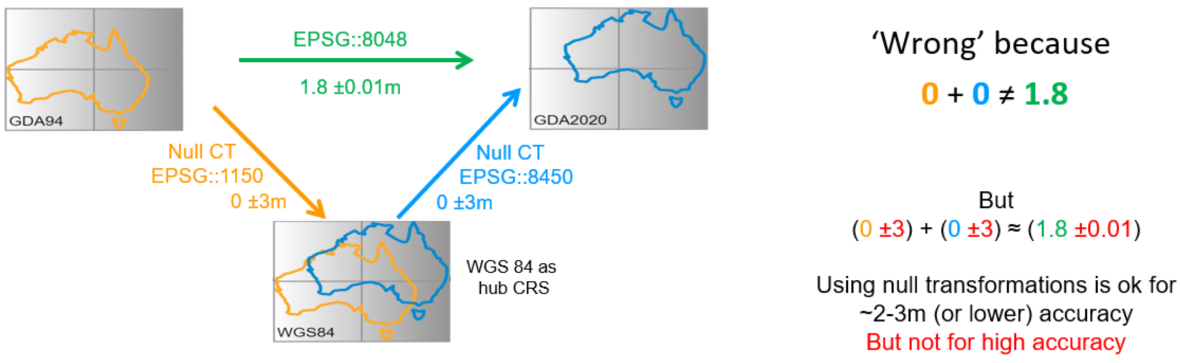


Figure 1 – Null transformations used in the hub concept

The most significant flaws in this scenario are that (i) tectonic plate motion is not accounted for in either of the null transformations EPSG:1150 and EPSG:8450, (ii) its accumulated change is no longer insignificant for high accuracy purposes, and (iii) the transformation accuracy has been ignored and the null transformations have been applied without recognition of their approximate nature.

These caveats regarding accuracy limitations of using EPSG:4326 and any CRS associated with datum ensemble 6326 apply equally to any spatial referencing, including web mapping, described in the next section.

The corollary is that EPSG-created null transformations to the WGS 84 ensemble datum should not be used for work requiring accuracy better than a metre or two.

A more accurate approach would be to assume that WGS 84 (G1762) is not significantly different to ITRF2014 or ATRF2014, and instead of using the null transformations use the known time-dependent relationships between ITRF/ATRF and GDA. This requires the coordinate epoch of the data to be known and application of a time-dependent transformation method.

5.2 Web mapping

In many web mapping applications, the default map projection used is referenced to WGS 84; EPSG:4326; see also Ref. [5] for a discussion of issues with the Web Mercator projection. If a null or copy transformation has been used to transform coordinates in a national CRS to EPSG:4326, then locations of spatial data in the web map are subject to the same problems of accuracy as demonstrated in the Australian example above. The only differences with Figure 1 above are to replace the text “WGS 84 as hub CRS” with “WGS 84 as base for Web Mercator” and reverse the direction of null transformation EPSG:8450!

Note that web mapping technology is capable of the highest accuracy. But web mapping using EPSG:4326 or any other CRS associated with datum ensemble 6326, or using EPSG null or copy transformations, is not suitable for uses requiring an accuracy of better than 1-3m.

For web mapping requiring an accuracy of better than 1-3m, do not use WGS 84 (EPSG:4326) or any projected CRS based on EPSG:4326 and its datum ensemble. Instead use either a static CRS, or a dynamic CRS at a specified single coordinate epoch. Any background imagery needs to be referenced to the same CRS and if that CRS is dynamic to the same epoch. This applies equally to all CRSs referred to in Table 2. Equally, for web mapping requiring an accuracy of better than 2-3 m, users should avoid CRS objects based on any ensemble and should not use null or copy transformations.

6 How to recognize a null or copy transformation in the EPSG dataset

To determine whether a transformation is an EPSG null or copy (and therefore ‘artificial'), the following criteria may be used:

a) The transformation scope will be "*(null/copy) Approximation for medium and low accuracy applications assuming equality between plate-fixed static and earth-fixed dynamic CRSs, ignoring static/dynamic CRS differences*”. This scope is used only for null and copy transformations in the EPSG Dataset.
   - The code for this scope is 1252.

b) The transformation remarks will usually contain:
   - (for null transformations) “Approximation at the *n*–metre level assuming ...”;
   - (for copy transformations) “Parameter values from ...”.

c) The information source for the transformation will be ‘EPSG’, 'OGP' or 'IOGP'. Note that:
   - The converse is not true. Some records that have an information source of ‘EPSG’, 'OGP' or 'IOGP' are not null or copy transformations.
   - The EPSG Dataset contains null and copy transformations that have been published by other information sources. These have the same characteristics and problems as do EPSG null and copy transformations. For these, the appropriate information source will be given.

The Data Source field cannot be used for determining whether the transformation is an EPSG null or copy as all records in the EPSG Dataset have a Data Source of ‘EPSG’.

7 Recommendations

This Report's recommendations and attention points are summarized below in table form for software developers, high and low accuracy users, as well as for geodesists, and data managers involved with project setup and lifecycle management.

Table 3 – Recommendations and attention points

<table>
<tr><td>1</td><td>The following items are attention points for all users, data managers, and developers:
Ensure that the accuracy of any coordinate transformation applied to data meets the application accuracy requirements, considering the lifetime of the project and coordinate epochs of data used in the project, in conjunction with the expected plate motion.
When transforming data between two CRSs, if a direct transformation between the two CRSs is available use it rather than a hub concatenation technique, or an implied ensemble transformation.
Be aware that EPSG null and copy transformations contain assumptions that may make these transformations unsuitable for high accuracy purposes.
For an automatically created indirect concatenated operation through the hub to be valid, the area of applicability for both steps forming the indirect concatenated transformation must embrace the area in which the coordinates lie.</td></tr>
<tr><td>2</td><td>For high accuracy applications, requiring better than a few metres accuracy over the project time span:
A geodetic CRS with an ensemble datum whose members are dynamic, or a projected CRS based on such a geodetic CRS, should not be used.
Be aware that EPSG:4326 ("WGS 84") is a geodetic CRS with an ensemble datum, as are geodetic CRSs EPSG:4979, EPSG:4978, OGC/1.3/CRS84 and OGC/1.3/CRS84h.
Preferably use a national geodetic CRS. If this is a dynamic CRS then, to maintain accuracy, ensure that:
either all data is referenced to a common coordinate epoch when loading,
or record the coordinate epochs with the coordinates and ensure that the application can apply a point motion operation to transform all coordinates to a common project epoch.
For web mapping (requiring long-term high accuracy), either a static CRS or a dynamic CRS at a single coordinate epoch should be used.</td></tr>
<tr><td>3</td><td>Low accuracy implies that plate motion (different coordinate epochs) and differences between realizations of a particular reference frame can be ignored for the purpose or duration of the project. CRSs based on a datum ensemble whose members are dynamic are suitable for such lower accuracy spatial referencing requirements. Transformation rules pertaining to ensembles should obey the following:
CRS to ensemble: Software should use the coordinate transformation from the specific source CRS to the target CRS.
Ensemble to ensemble with transformation: Software should use the transformation between the source and target CRSs.
Ensemble to ensemble without transformation: Software should search for the coordinate transformation between any source ensemble member and the target CRS (typically EPSG:4326).</td></tr>
<tr><td>4</td><td>The following items are aimed at developers, but also given for awareness for high and low accuracy users:
Special attention is needed for (background) imagery. For high accuracy project requirements, high-resolution accurately geo-located imagery should be referenced to the same specific CRS realization and epoch as the source project. This approach prevents the need to perform image resampling.
This may require setup of web mapping applications in such specific CRS and a re-tiling of the base data. In such high accuracy use cases any ensemble-based CRSs should be avoided.
If a projected CRS is used, for high accuracy geometric calculations appropriate survey corrections are required. This includes corrections for map projection scale error and elevation factor.</td></tr>
</table>

	• An audit trail which documents all implicit and explicit actions applied on coordinate data should be kept and be accessible to users. Where applicable the audit trail should include EPSG names and codes plus sufficient metadata to unambiguously describe the coordinate transformation including coordinate epoch; see Appendix D for an example.

Appendix A EPSG policy for defining datum ensembles

A.1 Introduction

Modern geodetic reference frames may be updated from time to time and the differences between successive realizations may be at the sub-decimetre level. For many users this is insignificant and dealing with multiple CRSs that are insignificantly different is an unwanted overhead. To address this issue, the EPSG data model supports the artificial concept of a datum ensemble.

A datum ensemble is a group of two or more closely related realizations of the same conventional reference system. It is modelled as a subtype of datum; the actual type of datum, whether geodetic or vertical, is inferred from the datum type of the ensemble members. Geodetic datums that are grouped within an ensemble all have identical ellipsoid and prime meridian attributes. A CRS may be associated with either a datum or with a datum ensemble.

A.2 EPSG policy

1. Datum ensembles will be added to the EPSG Dataset on a case-by-case basis. In general a datum ensemble will be created only when the authoritative organization (e.g., the national geodetic survey or mapping agency) has expressed that individual realizations may be treated as an ensemble, for example as is the case for WGS 84 and ETRS89.

2. In a datum ensemble with members that are dynamic, there is no single set of station velocities. Therefore, in the EPSG Dataset, ensembles consisting of members that are themselves dynamic are treated as if they were static[6].

3. When a datum ensemble exists in the EPSG Dataset, further realizations of the same conventional reference system issued by the authority will be added to the existing datum ensemble.

A.3 Discussion

Once data has been associated with a datum ensemble it may not be possible to identify the ensemble member to which the data would more accurately have been referenced. The inaccuracy introduced through the use of a datum ensemble is recorded as an ensemble accuracy value. This indicates the difference in coordinate values (at the same epoch) between the various realizations grouped into the ensemble. Datum ensembles should not be used in geodesy or other high accuracy applications; the appropriate individual reference frame should be identified and used.

Common practice using such ensembles is to ignore coordinate epoch and to not apply the time-dependent corrections on coordinates necessary when working with dynamic CRSs. By ignoring the time-dependent nature of the coordinates, accuracy is degraded further. This additional inaccuracy is not reflected in the ensemble accuracy value. Its value depends on the plate motion at the project location and time span of coordinates mixed in the ensemble, if not corrected to a common epoch.

As an important example, the WGS 84 datum ensemble (datum code EPSG:6326) currently has seven realizations as datum members. An ensemble accuracy of 2 metres has been assigned to cover the coordinate differences between these realizations. The offset of the

[6] For information on dynamic and static CRSs refer to IOGP Geomatics Guidance Note 25 and IOGP's Introduction to dynamic CRSs video, ref [2] and [3].

original WGS 84 (Transit) realization accounts for much of this 2 m. The 2 m value is the three-dimensional offset at the centre of the Earth; at the surface of the Earth its horizontal component varies with location but is typically 1 to 1.5 metres. Differences between coordinates for modern acquired data (say after the year 2000 when also positioning accuracy increased) is much smaller, say at decimetre level. However, to reiterate, this only accounts for differences in frame definition and assumes all coordinates are referenced to the same epoch.

Datasets that are referenced to datum ensemble members can be merged and co-visualized without transformation for low accuracy applications. Mathematically this is equivalent to performing a null transformation between the datum ensemble members. Datum ensembles are intended to avoid the creation of many null transformations between ensemble members, and between ensemble members and WGS 84 (and its ensemble members). If data is associated with a CRS based on a datum ensemble, the use of the ensemble name or code is not sufficient to identify the individual ensemble member. Consequently, data referenced directly to such a CRS is approximate to the stated ensemble accuracy. The user will need to track the original ensemble member independently if they want to exit the ensemble in the future.

Appendix B EPSG policy for defining null and copy transformations

B.1 Introduction

The strategy for population of the EPSG Dataset is to support:

1. Users who require high spatial accuracy such that they can reference the EPSG data without any degradation in their spatial referencing; and

2. Users who are able to work at low accuracy and wish to merge datasets referenced to multiple coordinate reference systems are able to do so efficiently. Here 'low accuracy' means users who are able to ignore the secular motion of tectonic plates, so can accept 1-3m or worse spatial accuracy.

To assist this second group of users by ensuring that most CRSs can be related to each other, the policy is to introduce ‘null’ and ‘copy’ transformations into the EPSG Dataset, where appropriate.

EPSG strategy assumes that WGS 84 is the global hub CRS. No distinction is made between specific realizations of WGS 84.

B.2 EPSG policy

Specific policy items are:

1. An EPSG null transformation to WGS 84 will be created when:
   - A national or regional geodetic CRS is defined to be aligned with the ITRS at some specified epoch.
   - No other transformation to WGS 84 or ITRS is available.
   - The datum of the national or regional geodetic CRS is not a member of a datum ensemble in which the CRS of another member is already related to WGS 84.

2. An EPSG copy transformation to WGS 84 will be created when:
   - A transformation exists relating ITRS to the national or regional geodetic CRS; and
   - No other transformation to WGS 84 is available.

3. EPSG null and copy transformations will be identified in the EPSG Dataset.

4. EPSG null transformations to WGS 84 are given an accuracy that is sufficient to cover secular plate motion over a period of 30-40 years. For most tectonic plates this is a nominal 1 metre. For some faster-moving tectonic plates the operation accuracy value assigned will be higher (making the transformation less accurate), typically 2-3 metres.
   - Note: Prior to 2019 (EPSG Dataset v9.9) the accuracy assigned to EPSG null transformations was always a nominal 1m. For the faster-moving tectonic plates, over a protracted period of time this 1 metre nominal value has been inadequate. In some cases it has subsequently been increased. This policy of increasing the operation accuracy value (making the transformation less accurate) will be maintained where appropriate.

5. EPSG copy transformations are given an accuracy of the accuracy of the copied transformation or sufficient to cover 30-40 years of secular plate motion (usually 1 metre), whichever is the greater.

B.3 Discussion

Many modern reference frames and coordinate reference systems are defined by a national authority with respect to the global standard: a realization of the International Earth Rotation Service Terrestrial Reference System (ITRS). At a geodetic level of significance, these ITRS realizations and national CRSs are all discrete. But at a practical accuracy level of 1-3 m, often satisfactory for GIS and subsurface oil and gas industry requirements, the differences between these national CRSs and ITRS realizations are not considered significant.

IOGP recognises that, at the lower level of accuracy requirement, in practice a direct transformation pathway is required "to WGS 84" in order to visualize data, for example for oil and gas subsurface applications that currently use the early-binding data model, and for many web mapping applications currently using WGS 84 (/ Web Mercator). IOGP facilitates this by the creation of artificial EPSG null and copy transformations. Such EPSG created artificial transformations may not be condoned by the originator of the national CRS. It should also be recognized that CRSs other than WGS 84 may be more appropriate as a hub. For example, in Europe the adoption of ETRS89 as a hub meets INSPIRE regulations.

Typical scenarios for IOGP to create an EPSG null or copy transformation

Figure B.1 below illustrates the current (2022) typical creation of EPSG null transformations. Imagine that at some point in time, a new national or regional realization is published by the authority. At this juncture, it is not known that a subsequent realization may be made in future. This system is defined with respect to a specific realization of ITRS at a specified epoch (t1), for example an "ITRF snapshot" and densification. Therefore, a transformation between ITRFxx@yyyy.yy and the national realization is available. It may or may not be null.

- If it is null, *and if no transformation to WGS 84 is provided by the Information Source*, then IOGP will create EPSG null transformation #1. This is done to ensure that the national realization can be used in hub transformations and in low accuracy web mapping using WGS 84.
- If the national realization is defined through a not-null transformation from ITRFxx, EPSG creates a copy transformation.

In both cases, the epoch at which this relation is valid may be noted through remarks.

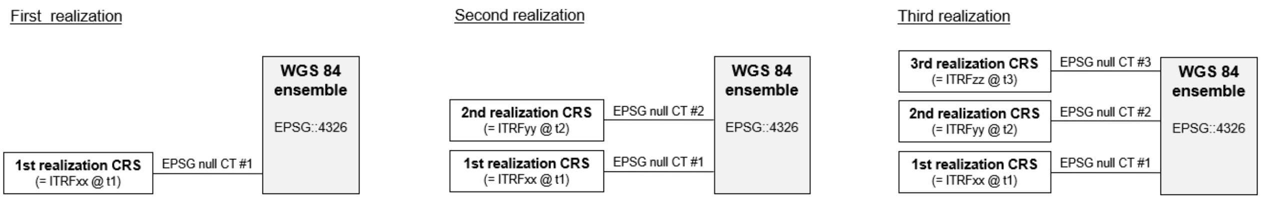


Figure B.1 – Creation of EPSG null transformations

Later, a second realization of the national system is made. The ITRF realization and/or the epoch at which the national realization is coincident with ITRF will very likely differ from the first national realization. A new EPSG null or copy transformation, #2, will now be created, as shown in the middle panel. This is the general policy principle: the EPSG Dataset aims to include a direct pathway from each realization to the WGS 84 ensemble to accommodate pragmatic lower accuracy usage.

Note that these two EPSG null transformations provide an indirect path for transforming between (the first and second) realizations via the WGS 84 ensemble. However, this transformation pathway should not be used if a direct transformation between the two realizations is available. A transformation documented directly between the two CRSs should always take priority over an indirect transformation.

The same process is repeated for further realizations as shown in the panel on the right for the third realization.

Local datum ensembles

The process described above is modified if the national CRS's datums are members of a datum ensemble (which is not common). Note that the local ensemble can only be created by IOGP after the second national realization has been published (also see the EPSG policy on datum ensemble creation).

In some circumstances the local ensemble (rather than any of its members) may have a transformation to WGS 84 (see Figure B.2[7]). All realization CRSs that do not have a direct transformation to WGS 84 should use ("inherit") this.

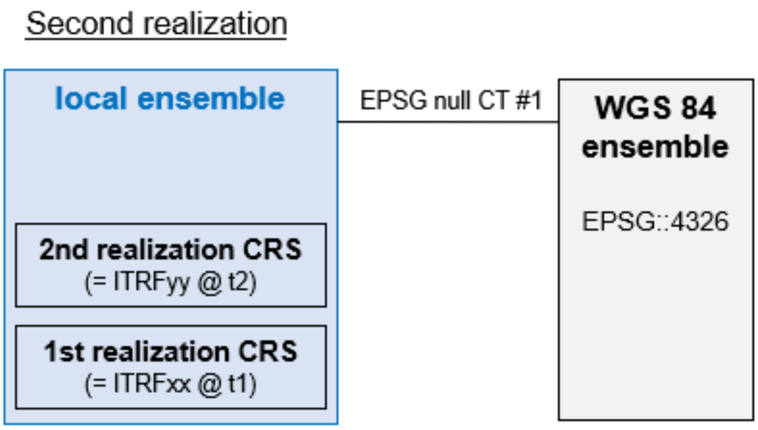


Figure B.2 - Local ensemble with transformation to WGS 84

In these circumstances software applications need to:

- Verify that the realization has no direct transformation to WGS 84.
- Verify that the realization's datum is a member of a datum ensemble.
- Recognise that a transformation from the CRS with datum ensemble to WGS 84 is available.
- Then utilise the transformation between the CRS with datum ensemble and WGS 84 to transform coordinates between the national realizations and WGS 84.

A more usual scenario is sketched in Figure B.3. When the second national realization is defined, the local ensemble does not yet exist but the first realization does. EPSG may define a local ensemble at this time. In this case it is important to realize that a null or copy CT to WGS 84 from the second realization **will not be created by EPSG.**

To transform the national realization to WGS 84 for use in hub transformations, or in low accuracy using WGS 84 (e.g., web mapping), null or copy CT #1 should be assumed to also apply to realization #2.

[7] For simplicity, figures B.2 and B.3 conflate CRSs and datum ensembles. Transformations operate between CRSs but datum ensemble members are the datums to which the CRSs are referenced.

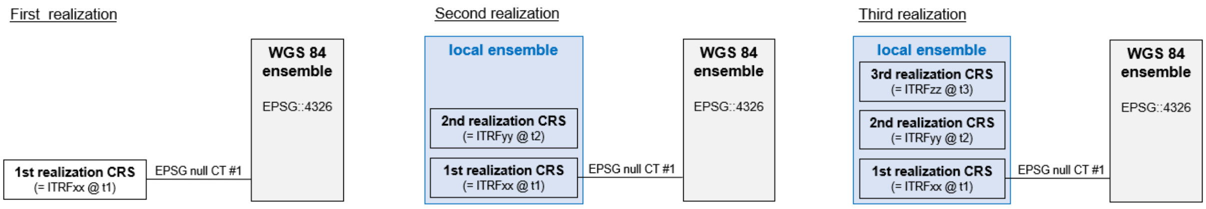


Figure B.3 - Local ensemble without transformation to WGS 84

Software applications need to associate the #1 member transform to WGS 84 with the second realization by recognizing that:

- The second realization has no transformation to WGS 84.
- The second realization's datum is a member of a datum ensemble.
- Another member of that datum ensemble (that for the first realization) has a CRS for which a transformation to WGS 84 is available.

Then:

- If there is a direct transformation between the first and second realizations, use a concatenation of this and the null or copy transformation from the first realization to WGS 84.
- If there is not a direct transformation between the first and second realizations, assume a null transformation between the second and first realizations and concatenated that with the null or copy transformation from the first realization to WGS 84.

Operation method used for EPSG null and copy transformations

In any scenario that requires the creation of an EPSG null transformation, the three-parameter geocentric translations method (EPSG operation code 9603) will generally be used, with all translation parameters set to 0 metres. Because each national or regional CRS that will be assigned a null transformation is aligned to an ITRF realization and shares the same (or practically the same) ellipsoid as the target WGS 84 ensemble, the net result of applying any null transformation will be no modification to any input coordinate values. Using this simplest method fits within the goals set forth for this guidance note, a given accuracy within 1-3 meters, and has the benefit of being supported by all major geospatial software packages.

Before reaching a decision to usually use the geocentric translation method, using an eight-parameter time-specific Helmert method was considered. These have the benefit of noting a reference date of coincidence between the regional/national system and a given ITRF realization. However, the eight-parameter methods do not fit the purpose of this guidance note when considering the inherent lower accuracy use cases associated with the null transformation concept, nor do they specifically define any velocity model to use at other epochs for higher accuracy. Similar considerations were also made for using a fifteen-parameter time-dependent transformation method. This transformation method will generally not be used because such an operation would falsely imply that there is a velocity model with null parameter values defined between the national/regional system and the WGS 84 ensemble which is considered to be static. Users would then seemingly have a mechanism for providing a time-based update to a coordinate epoch value that does not exist. This would not be appropriate. As a further consideration, currently neither of these time-based methods are generally supported by legacy geospatial software packages used by IOGP Members.

For EPSG copy transformations, the transformation method used will be that used in the copied transformation.

Appendix C Transformation concatenation – the 'hub' concept

Implicit concatenated operation techniques can be used to merge transformations. For example, if a transformation is required from CRS A to CRS B and none is found in the Dataset, it may be possible to transform indirectly via a third CRS, as shown diagrammatically in figure C.1. To be valid, the area of applicability for each of the steps forming the indirect concatenation must embrace the location in which the coordinates fall.

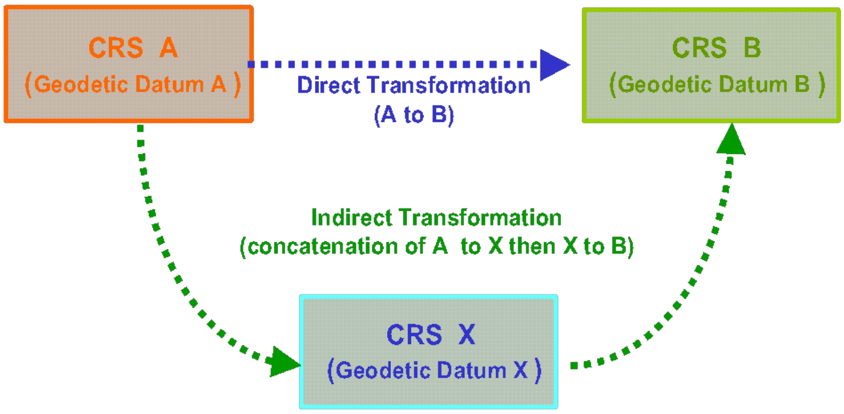
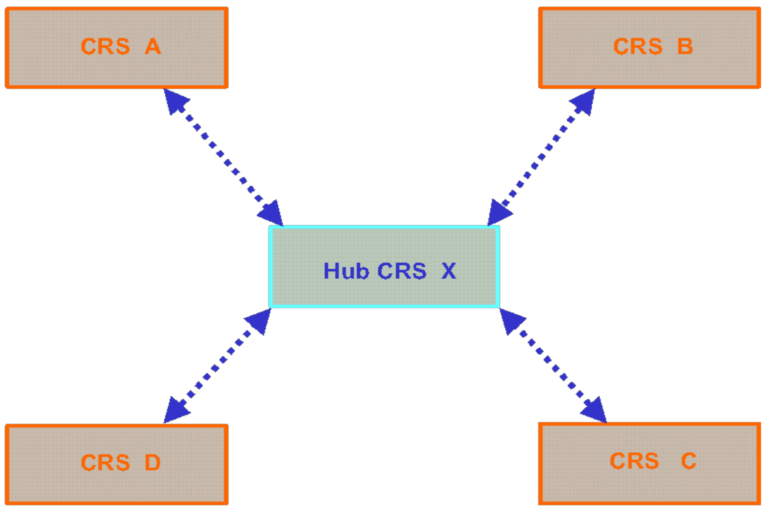


Figure C.1 – Direct and concatenated indirect transformations

It is possible to further extend this concept to a scheme in which a standard CRS is selected as a hub, shown in figure C.2:

Figure C.2 – The hub concept



The hub concept is an appealing way of implementing a generalized transformation application. However, there are several caveats:

- When a direct transformation is available it should take precedence over any artificially created indirect concatenated operation.
  - because it carries greater integrity.
  - because it will be more accurate.
- For an artificially created indirect concatenated operation through the hub to be valid, the area of applicability for both of the steps forming the indirect concatenated transformation must embrace the area in which the coordinates fall.

Appendix D Audit trail examples

Table D1 - Example 1: Direct transformation using a null transformation

Action	Coordinate format	Audit Trail Content
Load Data & CRS selection	φ, λ	CRS = REGVEN (Geographic 2D), [EPSG CRS code 4189].
2D coordinate transformation		Transformation applied: REGVEN to SIRGAS 1995 (1) [EPSG transformation code 1767]; Geocentric translations (geog2D domain) method code 9603; null transformation, accuracy 0.02m.
Use data in desired CRS	φ, λ	CRS = SIRGAS 1995 (Geographic 2D), [EPSG CRS code 4170].

Table D2 - Example 2: Direct transformation using a null or copy when source or target CRS is based on a datum ensemble

Action	Coordinate format	Audit Trail Content
Load Data & CRS selection	φ, λ	CRS = SWEREF99 (Geographic 2D), [EPSG CRS code 4619].
2D coordinate transformation		Transformation applied: SWEREF99 to WGS 84 (1) [EPSG transformation code 1879]; Geocentric translations (geog2D domain) method code 9603; null transformation, accuracy 1m.
Use data in desired CRS	φ, λ	CRS = WGS 84 (Geographic 2D), [EPSG CRS code 4326], based on datum ensemble, accuracy 2m.

Table D3 - Example 3: Indirect transformation using a null or copy through a hub CRS

Action	Coordinate format	Audit Trail Content
Load Data & CRS selection	φ, λ	CRS = RGF93 v1 (Geographic 2D), [EPSG CRS code 1591].
2D Coordinate transformation to hub system		Transformation applied: RGF93 v1 to ETRS89 (1) [EPSG transformation code 1591]; Geocentric translations (geog2D domain) method code 9603; null transformation, accuracy 0.1m.
Data in hub CRS	φ, λ	CRS =ETRS89 (Geographic 2D), [EPSG CRS code 4285], based on datum ensemble, accuracy 0.1m.
2d Coordinate transformation from hub system		Transformation applied: RGF93 v2b to ETRS89 (1) [EPSG transformation code 9790 (reversed)]; Geocentric translations (geog2D domain) method code 9603; null transformation, accuracy 0.1m.
Use data in desired CRS	φ, λ	CRS = RGF93 v2b (Geographic 2D), [EPSG CRS code 9782].

Table D4 - Example 4: Direct Transformation using a CRS based on a datum ensemble with an implied ensemble transformation

Action	Coordinate Format	Audit Trail Content
Load Data & CRS selection	**X, Y, Z**	CRS = GDA2020 (Geocentric) [EPSG CRS code 7842]
3D coordinate transformation		Transformation applied: GDA2020 to WGS 84 (G1762) (1) [EPSG transformation code 8448]; Time-dependent Coordinate Frame rotation (geocen) method code 1056.
Data in CRS2	**X, Y, Z**	CRS = 7664 WGS 84 (G1762) (Dynamic Geocentric).
Coordinate Conversion		Conversion applied Geocentric to Geographic3D method [EPSG conversion code 15592].
Data in CRS3	**φ, λ, h**	CRS = 7665 WGS 84 (G1762) (Dynamic Geographic 3D)
Coordinate Conversion		Conversion applied Geographic3D to Geographic2D method [EPSG conversion code 15593].
Data in CRS4	**φ, λ**	CRS = 9057 WGS 84 (G1762) (Dynamic Geographic 2D).
Implicit CRS equality with datum ensemble (ensemble includes datum used in CRS4)		CRS WGS 84 (G1762) [EPSG code 9057] uses a base datum that is a member of World Geodetic System 1984 ensemble [EPSG datum code 6326]. Datum ensemble is base for CRS WGS 84 (Geographic 2D), [EPSG CRS code 4326].
Use data in desired CRS	**φ, λ**	CRS = WGS 84 (Geographic 2D), [EPSG CRS code 4326], based on datum ensemble, accuracy 2m.

Glossary

AGD66	Australian Geodetic Datum 1966
ATRF	Australian Terrestrial Reference Frame
CRS	Coordinate Reference System
CT	Coordinate Transformation
DMA	Defense Mapping Agency (United States)
EPSG	A database of geodetic parameters maintained by IOGP.
G730	GPS week 730
GDA94	Geocentric Datum of Australia 1994
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IGS (IGb)	International GNSS Service
IOGP	International Association of Oil and Gas Producers
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
OGC	Open Geospatial Consortium
WGS 84	World Geodetic System 1984

References

[1] "WORLD GEODETIC SYSTEM 1984, Its Definition and Relationships with Local Geodetic Systems", US Department of Defense, National Geospatial-Intelligence Agency (NGA), NGA.STND.0036_1.0.0_WGS84.

[2] IOGP Report 373-25 - *Geomatics Guidance Note 25 – Dynamic versus Static CRSs and Use of the ITRF*

[3] International Association of Oil and Gas Producers. "Dynamic Coordinate Reference Systems". https://www.youtube.com/watch?v=IKM-bR6SwVs .

[4] "Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems", US Defense Mapping Agency (DMA) Technical Report TR8350.2[8].

[5] IOGP Report 373-23 - *Geomatics Guidance Note 23 - Web Mercator*

[8] Superseded by NGA.STND.0036_1.0.0_WGS84, reference [1].

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