Intergovernmental Committee for Surveying and Mapping (ICSM)

Handling of 4D coordinates in desktop GIS

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1 Introduction

1.1 Background

In 2019, ICSM contracted North Road (NR), with Mercury Project Solutions (MPS) in a Project Management role to perform the necessary updates to QGIS and some of its underlying libraries, to make QGIS' handling of GDA2020 coordinate transformations easier and more transparent to QGIS users, and also to use this as a 'best practice' example for commercial software vendors.

This work was completed in August 2019, delivering full GDA2020 compatibility and functionality to QGIS users, and the underlying libraries (PROJ and GDAL) that drive many other software applications.

The next step for ICSM's datum modernisation initiative is the implementation of a dynamic, time dependent datum, known as the Australian Terrestrial Reference Frame (ATRF).

It will be increasingly important to understand that latitude and longitude coordinates do not define a unique location unless the related time stamp is also identified. At best, a coordinate without datum is ambiguous and may even be meaningless. In 2020, the dynamic datum will establish a different kind of location reference system that will continually model the movement of the Australian continent.

The new dynamic (ATRF) datum will bring with it the need to create and work with time-tagged coordinates. New processes and tools to collect, manage, integrate and disseminate spatial information will therefore be required. This is in addition to, and cannot be seen separate from, the implementation of the new static datum, GDA2020, which is currently under way.

For a successful implementation, geospatial software will need to be able to manage and transform dataset with a time dependent (4D) datum.

1.2 Objectives and problem statement

While the initial work commissioned by ICSM was focused on the static GDA2020 datum, in the process of completing this work it was identified that research needed to be undertaken to ascertain the impact of a dynamic, time-dependent datum within geospatial software. Specifically, regarding the potential impacts this has on the day-to-day operation of geospatial desktop applications, and the underlying standards, formats and specifications which this depends upon.

Earlier research (van der Vlugt, 2018) indicates that the Australian dynamic datum (ATRF) will start having significant user impact from 2023 onwards. Thus, the question for ICSM is:

"After GDA2020 capability is made available to the Oceania community through QGIS, will a similar investment be required to get QGIS and/or other GIS desktop products to support time-based coordinates and ATRF in a timely manner, or will the market respond in time (i.e. by 2023) without the need for intervention?"

To answer this question, ICSM will need to know:

- The key use-cases for dealing with dynamic datums in desktop software
- The business and standards requirements to satisfy these use-cases
- The status of relevant technology products and standards, and whether they are likely to be ready for widespread adoption by 2023.

1.3 Methodology

To address these questions, we undertook a 5-stage approach:

1. **Define Use-Cases**

   This stage identified the key use-cases for time-dependent coordinate management within desktop GIS. It examined the user profiles, and typical workflows involving time-dependent coordinates.

2. **Identify Business and Standards requirements**

   From the use-cases, we derived Business Requirements (what capabilities should a desktop GIS need to satisfy the use-cases), and Standards Requirements (what, if any, standards would be needed to satisfy the use-cases).

3. **Validation of Use-cases and Requirements**

   To ensure the use-cases and requirements are validated, we conducted an online workshop with selected experts who are sufficiently across the subject matter.

4. **Technology Scan**

   Next, we undertook a desk-top study to understand the current status and expected product roadmap(s) of key software packages, such as software libraries (e.g. GDAL, PROJ6, open source tools (e.g. QGIS), COTS products, and geospatial standards. Information for the technology scan was accessed through the open source geospatial software community, consultation with Esri staff and publicly accessible roadmap and press releases from software vendors (see listing in Appendix 3).

5. **Recommendations to ICSM/PCC**

   Recommendations to ICSM/PCG regarding potential actions required to support the Oceania geospatial community in managing dynamic, time-dependent coordinate systems.

2 Use-cases & requirements

2.1 Use-cases and actors

The use-cases and associated requirements below were drafted, prioritised and validated in a workshop with selected experts and user representatives on 7 August 2019.

The actors in the use-cases are defined as

- **GIS Analyst:** A trained GIS analyst, conducting spatial analysis on a map-based desktop platform
- **Data Scientist:** A trained statistician or data scientist, with some geospatial knowledge, conducting spatial analysis in a non-map based statistical platform
- **Software Developer:** A software developer involved in the development of an application or library with a geospatial component
- **Spatial Data Manager:** A custodian or publisher of spatial data
- **Field User:** A worker involved in capturing or using spatial data in the field, usually via a mobile device. May be an expert in a non-spatial discipline and may not have any formal geospatial training or understanding.

Appendix 1 lists the full set of use-cases and associated requirements in detail. The high and medium priority use cases are summarised in the table below. They are in a format that allows identifying the actors, what the feature or capability is that they require, and for what purpose or benefit:

As a [actor], I want to [feature], so that [benefit]

Table 1 Priority use-cases

#	Use-case	Priority
1a	As a **GIS Analyst,** I want to import time dependent data (e.g. GNSS coordinates) that automatically align with my other layers (e.g. within my project), so that the layers in my project or map are all aligned to the same datum by default.	High
1b	As a **GIS Analyst** or **Data Scientist**, I want to query an existing dataset to determine the epoch currently assigned to the dataset so that I can populate metadata concerning the layer and include this reference information in reports and contextual descriptions of maps.	High
2	As a **GIS Analyst**, I want to assign an epoch to existing time-dependent coordinates, so that I can manage, transform, or correct time-dependent coordinates with no epoch (or the wrong epoch) defined.	High
3	As a **GIS Analyst**, I want to export ATRF based data with a user-defined epoch so that I can deliver data to third parties in an epoch of their choosing.	High

#	Use-case	Priority
4	As a **Software Developer**, I want to access a coordinate transformation library that natively and elegantly handles time dependent coordinates, so that my software handles time dependent coordinates accurately, correctly and consistently with other software implementations.	High
5	As a **Spatial Data Manager**, I want to publish a web-service that provides spatial data in ATRF so that consumers with GNSS-enabled devices can use base map data which is aligned with GNSS coordinates.	High-Medium
8	As a **GIS Analyst** or **Data Scientist**, I want to save a "project" today, including layers with a mix of different epochs, and be able to reload this project in 12 or more months' time and see the exact same map and results as I see today, so that I can justify decisions I made on past projects based on the spatial relationships of features exactly as they were at the time of analysis.	High
9a	As a **GIS Analyst** or **Data Scientist**, I want to conduct operations on a spatial layer, such as buffering, and trust the software to correctly save the result with the required CRS information or metadata concerning epoch, so that I don't need to consider this myself, yet be confident that transformed datasets are correctly tagged with an appropriate epoch as needed.	High
9b	As a **GIS Analyst** or **Data Scientist**, I want to conduct analysis on multiple layers (e.g. intersection, clips, union/aggregation), potentially with different epochs, and trust the software to transparently handle any required operations for accurate results, so that I can confidently conduct my analysis utilising any datasets provided without the need to pre-process these and manually ensure they have a common epoch.	High
10	As a **GIS Analyst**, I want to create a new dataset "from scratch" on my desktop, e.g. digitizing features from other sources, and utilise a modern time-dependent CRS for this data, ensuring it can be used accurately for many years to come.	Medium

2.2 Business Requirements

Analysis of the use-cases identified 16 Business Requirements that would be needed to satisfy the priority use-cases. These are summarised in the table below. The priority is derived from the respective use-case priorities.

The technology scan (section 3) assesses each of these in detail, if and how they are addressed by vendors and/or standards bodies, and any recommendations to ICSM.

Table 2 Business- and standards requirements to satisfy the priority use-cases

#	Requirement	Priority
1	GNSS or ATRF based datasets have a known epoch defined in its metadata using an agreed standard, using a machine-readable format.	High
2	The software can handle time-dependent coordinate transformations 'on the fly' (i.e. without user intervention or preparing datasets by hand), by performing the required time-dependent calculations in order to bring data which is in a “source” epoch into a different “destination” epoch as required.	High
3	When the epoch definition is not available through the dataset’s metadata, the user has a choice to (1) manually nominate an epoch (if they know the correct epoch date), or (2) leave the epoch as unknown (in which case the dataset’s CRS is considered unknown)	High
4	If a user manually nominates an epoch for a dataset when loading into a project, it is recorded for that dataset within the project, e.g. in the CRS metadata, so that it is respected whenever the project is re-opened	High
5	The GIS software shall allow users to query the epoch associated (if there is one) with an ATRF dataset, displaying this epoch in a human-readable or ISO date format.	High
6	The software has the capability to make a copy of an existing dataset (i.e. “save as”) with a new epoch assigned, without applying any transformation to coordinates	High
7	The software has the capability to make a copy of an existing dataset (“save as”) with a new epoch, applying the corresponding time-based transformation to coordinates as they are exported.	High
8	Web services are capable of applying time-dependent coordinate transformation on the fly while delivering data, ensuring that the data is delivered to clients in the epoch requested by that client.	Medium-High
9	The software is able to determine the correct epoch for ambiguous WGS84 based data, and standards exist for specifying the correct epoch for WGS84 based data	Low

#	Requirement	Priority
10	A particular project can have a user-defined epoch assigned to it (e.g. the date of creation, or another specific reference date such as ATRF 1/7/2023), and this date is used as the epoch when transforming data for display or analysis.	High
11	The software provides a tool (e.g. a time slider) to move coordinates in the CRS over time, by dynamically altering the project (or map displays) epoch and rendering features with an on-the-fly transformation to this epoch	Low
12	The software offers applicable choices of epoch to assign to output datasets in the case of data operation performed on a single layer (e.g. buffering an input dataset), and makes an intelligent choice for the initial value of this choice	High
13	The software makes an intelligent choice of epoch to assign to output datasets created as a result of a multi-layer operation involving layers with differing epochs (e.g. clipping or union operation)	High
14	The software allows users to choose the desired epoch when creating a new dataset, e.g. as part of the dataset's CRS selection	Medium
15	When adding new features to an existing dataset with a defined epoch, the software correctly performs a time dependent transformation of the data from the current project's epoch back to the reference epoch which the dataset is stored in	Medium
16	Standards exist for storage and retrieval of per-feature epoch within a single dataset, and the software correctly assigns the current epoch to newly created features	Very low

3 Technology scan

This section examines for each of the Business Requirements the underlying technology and standards status and expected future developments. It also identifies which, if any, actions ICSM could take to ensure ATRF readiness by 2023.

Information for the technology scan was accessed through the open source geospatial software community, consultation with Esri staff and publicly accessible roadmap and press releases from software vendors (see listing in Appendix 3).

Analysis of the Business Requirements shows that there are two primary requirements: Business Requirements 1 and 2. These encapsulate (1) the ability to store and read epoch metadata in a standard, machine readable format, and (2) the ability for software to automatically transform time dependent coordinates without user intervention. These two are fundamental to all capabilities implied in the remaining (secondary) Business Requirements.

3.1 Business Requirement 1

GNSS or ATRF based datasets have a known epoch defined in its metadata using an agreed standard, using a machine-readable format. (HIGH PRIORITY)

3.1.1 Summary

- This is a primary Business Requirement, on which many other Business Requirements are dependent
- Coordinate epoch is not part of a CRS definition, but rather a companion attribute to a dynamic CRS
- The WKT2:2019 standard exists to allow recording of dynamic CRS definitions and coordinate epochs, but is as of yet poorly supported and untested
- Existing software (such as PROJ 6.2) can read/write earlier versions of WKT2, but would need to be upgraded to be fully compatible with WKT2:2019
- Existing spatial data formats would need standard methods of storing WKT2:2019 CRS strings within (or alongside) datasets, or new data formats supporting this must be implemented
- The challenges involved in Business Requirement 1 are complex, and there will likely be very lengthy delays in resolving the standards gaps associated with this requirement
- This possibly may be short-cut or sidestepped in non-standards based, proprietary formats
- **Recommendation: ICSM should, through its international connections with OGC, advocate and promote accelerated maturing and testing of the WKT2:2019 standard, invest in upgrading the PROJ library to be fully compatible with WKT2:2019, as well as upgrading standard spatial data formats to allow support for WKT2:2019.**

3.1.2 Analysis

Existing Standards and the Well Known Text Format

The "*Well Known Text*" (WKT) format is a standard mechanism for encapsulating Coordinate Reference System (CRS) parameters and metadata within a machine-readable text string. This standard was ratified by the international standard *ISO 19111:2007* and *ISO 19111-2:2009* "*Geographic Information - Referencing by Coordinates*" (OGC 2019, https://www.opengeospatial.org/standards/wkt-crs), and has been widely used by geospatial software since its inception. For instance, the commonly used "Shapefile" data format records the CRS of a dataset in a ".prj" file as (an early variant of) a WKT text string (Kennedy 2014). Accordingly, it's safe to assume that all modern geospatial software which is capable of reading the Shapefile format is therefore capable of parsing some form of WKT CRS strings.

Unfortunately, early versions of the WKT specification were loosely defined, and numerous different variants of the format were implemented by different software packages (Kennedy 2014). Furthermore, the original WKT 2007/2009 standard had no provision for handling dynamic or epoch-based coordinate reference systems or datums, as is required by ATRF.

In 2019, a revision of the standard was accepted, and the ISO19111 "*Geographic Information - Referencing by Coordinates*" revision 2019 (https://www.iso.org/standard/74039.html, available via the OGC document library at http://docs.opengeospatial.org/is/18-010r7/18-010r7.html) now includes a standards based approach for encapsulating:

- The parameters relating to a dynamic transformation,
- The epoch of a static CRS definition, and
- The specific epoch associated with a CRS with a temporal component (such as ATRF).

Specifically, ISO19111:2019 describes a "*coordinate metadata*" keyword which can be used to record the epoch associated with coordinates (ISO 2019, sections 16.1 and 16.2). The specification states:

"Coordinate epoch is a mandatory attribute for a coordinate set that is referenced to a dynamic CRS. Coordinate epoch is not part of a CRS definition, it is additional metadata for the coordinates which is required to ensure that they are unambiguous when referenced to a dynamic CRS." (ISO 2019)

The important distinction here is that the epoch recorded in coordinate metadata is NOT a part of the CRS definition. Rather, for a dynamic CRS (such as ATRF), the CRS definition will encapsulate **only** the time-dependent parameters associated with transformation of the coordinates. In order to perform the actual transformation of the coordinates, both the time-dependent CRS definition **and** the additional coordinate metadata stating the actual epoch used by the coordinates are required. The CRS definition and the coordinate metadata are co-dependent and without both pieces of information the coordinates cannot be transformed or utilised.

The example WKT string included in the specification illustrates this relationship (ISO 2019):

```
COORDINATEMETADATA[
    GEOGCRS["WGS 84 (G1762)",
    DYNAMIC[FRAMEEPOCH[2005.0]],
    DATUM["World Geodetic System 1984 (G1762)",
      ELLIPSOID["WGS 84",6378137,298.257223563,LENGTHUNIT["metre",1.0]]
    ],
    CS[ellipsoidal,3],
      AXIS["(lat)",north,ANGLEUNIT["degree",0.0174532925199433]],
      AXIS["(lon)",east,ANGLEUNIT["degree",0.0174532925199433]],
      AXIS["ellipsoidal height (h)",up,LENGTHUNIT["metre",1.0]]
  ],
  EPOCH[2016.47]
]
```

Here we see a dynamic CRS, "*WGS84 (G1762)*", defined using the WKT "*GEOGCRS*" element, paired with the actual epoch utilised by the coordinate data of "2016.47".

Software support for WKT2 2019

Unfortunately, while the 2019 revision of the WKT specification (referred henceforth as *WKT2:2019*) provides a standard way of encapsulating the information required for ATRF based coordinates, the software and data format support for the revised specification is in its infancy.

To use a specific example, the PROJ library has support for parsing and interpreting dynamic CRS parameters recorded in WKT2:2019 strings. PROJ (https://proj.org/, previously known as "PROJ.4") is a "*generic coordinate transformation software that transforms geospatial coordinates from one Coordinate Reference System (CRS) to another*" (PROJ 2019). Since its initial release in the early 1980s (Evenden 1983), PROJ has become a mature, well-respected library, and is widely used as the backend for geographic transformation handling within many open-source and proprietary geospatial applications. Taking the sample WKT string from above (ISO 2019) as an example, PROJ version 6.0 (or later) is able to interpret the dynamic CRS component of the string, specifically:

```
GEOGCRS["WGS 84 (G1762)",
  DYNAMIC[FRAMEEPOCH[2005.0]],
  TRF["World Geodetic System 1984 (G1762)",
    ELLIPSOID["WGS 84",6378137,298.257223563,LENGTHUNIT["metre",1.0]
```

```
    ]
  ],
  CS[ellipsoidal,3],
    AXIS["(lat)",north,ANGLEUNIT["degree",0.0174532925199433]],
    AXIS["(lon)",east,ANGLEUNIT["degree",0.0174532925199433]],
    AXIS["ellipsoidal height (h)",up,LENGTHUNIT["metre",1.0]]
]
```

However, PROJ (as of version 6.2) lacks support for the COORDINATEMETADATA element and the second half of the dependent pair - the actual epoch corresponding to the coordinate data (Rouault 2019):

```
COORDINATEMETADATA[
   ...,
  EPOCH[2016.47]
]
```

As a prerequisite for satisfying this Business Requirement, the PROJ library would require investment and development to enable parsing of the coordinate metadata element, and new API for client applications to query and extract the coordinate epoch from a WKT2:2019 string.

Similarly, consultation with key ESRI staff indicates that whilst they have actively participated in the development and refinement of the ISO19111 2019 revision with the goal of addressing use cases like this, support for dynamic CRS definitions and epoch metadata is not implemented yet by the underlying Projection Engine library which drives their software, and thus is currently unused by ESRI client software (such as ArcGIS).

Accordingly, whilst the additions to the WKT specification were designed to address the requirements of standards like ATRF, they have not been road-tested in any real world, practical applications.

Data Formats

Furthermore, satisfaction of Business Requirement 1 requires that **spatial data formats themselves** also support the storage and retrieval of dynamic CRS definitions and any accompanying coordinate epochs.

While the 2019 additions to the WKT specification theoretically provide a standard for encapsulating the required information, spatial data formats would need a mechanism for storing WKT2:2019 CRS strings within (or alongside) datasets. These formats include (but are not limited to):

- **Disk-based vector spatial data formats**: Shapefiles, GeoPackage, GML, File GeoDatabases, etc
- Disk-based raster data formats: GeoTIFF, ECW, NetCDF, etc
- Disk-based mesh data formats: 2dm, grid, xmdf, dat, etc
- OGC Web Services (OWS): WMS, WFS, WCS, etc
- **Other, non-standards based web services:** such as the ESRI FeatureServer, MapServer and ImageServer REST services, amongst many others

The WKT string format has been designed to be backward compatible, so that any software library which is capable of reading and interpreting WKT strings complying to the 2019 revisions will inherently be capable of reading and interpreting earlier versions of the WKT specification (ISO 2019, section 6.7). However, the reverse is **not** true, and software which understands only earlier versions of the WKT specification may have undefined behavior or be completely unable to interpret a WKT2:2019 CRS string.

This presents a large technical difficulty and prevents WKT2:2019 strings from being utilised directly in place of older WKT strings in existing data formats. To do so would render these data files fragile and dangerous to use in older software. At best, the results would be inaccurate, and at worst, they could lead to crashes or software instability.

Taking the modern, standards-based GeoPackage format as an example, current versions of the format allow only for WKT2:2015 version strings (OGC 2017, section F.10) and do not allow the use of the 2019 additions required for dynamic reference systems such as ATRF.

Accordingly, revisions to the specifications for existing data formats and standards will be required to allow for use of WKT2:2019 strings, OR new data formats and standards will be required which are compatible with the WKT2:2019. This is a significant hurdle and may take many years to resolve.

The final component for satisfying Business Requirement 1 is support for handling changes to data formats (or new data formats) within the software libraries and applications responsible for reading these formats, such as the GDAL *Geospatial Data Abstraction Library* (https://gdal.org/). While this is dependent on the development and revisions of the formats themselves and cannot begin until this requirement is complete, it remains a significant undertaking which must be considered.

Non-standard Data Formats

An important distinction to make is that these difficulties apply to standards-based formats and software, and possibly may be short-cut or sidestepped in non-standards based, proprietary formats. These formats, such as the "*File GeoDatabase*" format widely used within ESRI software, are usually under the control of a single vendor and not necessarily subject to the same time periods for public review and comment as are standards-based formats. Given that vendors of proprietary formats are in control of both the data format and the software the data is used within, they may be able to deploy revisions on a much faster, more flexible timeline, and therefore be able to address Business Requirement 1 more easily.

Non-standard Storage of WKT2 Strings

Finally, in relation to the lack of WKT2:2019 support in existing data formats, it is possible that the software development community may proactively implement short-term workarounds to “patch” WKT2:2019 compatibility into existing data formats. For instance, a “sidecar” file containing the WKT2 string could be placed alongside the spatial data file with naming following some ad-hoc convention (much like the approach used by the Shapefile format of storing WKT1 CRS definitions in the .prj sidecar file). While this would potentially short cut any lengthy delays associated with revisions to the data format standards themselves, it would likely prove to be a fragile, short-term workaround dependent on an ad-hoc quasi standard only.

3.2 Business Requirement 2

The software can handle time-dependent coordinate transformations 'on the fly' (i.e. without user intervention or preparing datasets by hand), by performing the required time-dependent calculations in order to bring data which is in a “source” epoch into a different “destination” epoch as required. (HIGH PRIORITY)

3.2.1 Summary

- This is a primary Business Requirement, on which many other Business Requirements are dependent
- Existing software libraries such as PROJ 6.0 and the ESRI Projection Engine are capable of performing the mathematical operation of a 4-dimensional coordinate transformations required for ATRF
- Any client applications which utilise the PROJ library for coordinate transformations (such as the QGIS desktop application) would themselves also need to be updated in order to utilise PROJ’s 4-dimensional coordinate transformation API whenever required
- The capabilities are not widely user-tested and have not been exposed in client application
- The remaining components of requirement 2 are blocked by requirement 1
- Outside of ESRI, Blue Marble Geographics, and the open-source geospatial environment, it is unlikely that other software is implementing 4-dimensional transformation support within the near future
- **Recommendation: ICSM should actively liaise with Esri to ensure the availability of on-the-fly time-dependent coordinate transformations capability by 2023 and as part of ICSM's Datum Modernisation awareness program, encourage (or invest in) other client software developers to utilise this 4-D capability in their products, in order to meet the needs of Australian users.**

3.2.2 Analysis

In order to satisfy Business Requirement 2, the software must be capable of performing 4-dimensional, time dependent coordinate transformations.

In the specific case of ATRF, the time-dependent transformation is described by a 14-parameter Helmert transformation, using a 4-dimensional coordinate *(x, y, z, t)* as input to calculate a resultant 4-dimensional coordinate *(x, y, z, t)* (ICSM 2019, Australian Terrestrial Reference Frame (ATRF) Technical Implementation Plan). Accordingly, in order to correctly handle ATRF coordinate data, the software must be capable of performing a 14-parameter Helmert transformation based on predefined parameters (specifically, these are described in Table 2 in the Australian Terrestrial Reference Frame (ATRF) Technical Implementation Plan).

The PROJ library version 6.0 and later supports transformations between plate-fixed CRS (such as GDA2020) and Earth-fixed CRS (such as ITRF), using a time-dependent coordinate frame rotation/position vector transformation via a 14-parameter Helmert transformation (Rouault 2019). Accordingly, the PROJ library itself already satisfies the underlying technical requirements of Business Requirement 2.

However, while any client applications which utilise the PROJ library for coordinate transformations (such as the QGIS desktop application) have an API available through PROJ for performing these calculations, these individual applications would themselves also need to be updated in order to utilise PROJ's 4-dimensional coordinate transformation API whenever required.

As of September 2019, the only known application which publicly utilises this PROJ API is the GDAL library and command line tools (Rouault 2019). Furthermore, even within the GDAL tools, manual user intervention is required in order to perform 4-dimensional transformations. As outlined in Business Requirement 1, the PROJ library is not able to interpret coordinate epoch metadata associated with input datasets, and no spatial data formats currently exist which are capable of storing this information. Accordingly, users of GDAL must manually specify coordinate epoch when attempting these transformations.

Whilst FME, as of FME2020, will be utilising PROJ v6.0 as an underlying coordinate transformation engine and accordingly will also have access to PROJ's temporal transformation capabilities, Safe Software have not yet published any public roadmap or plans to expose this functionality to end users.

Similarly, consultation with key ESRI staff revealed that while the Projection Engine library which is utilised within the ESRI/ArcGIS ecosystem has support for temporal transformations, this support is unused and not exposed in any client-facing applications.

Blue Marble Geographics, the vendors of the widely-used "Global Mapper" software, added support for 14 parameter Helmert transformations in their GeoCalc SDK version 7.2 (Blue Marble Geographics 2016).

Outside of the open-source geospatial software community, ESRI, and Blue Marble Geographics, the technology scan revealed no other software vendors or applications planning to support this requirement (within publicly accessible roadmaps or press releases).

Indeed, the technology scan revealed that even support for the relatively simpler use case of the static GDA2020 datum is immature outside of the major GIS vendors and open-source community. Most more specialised tools or applications developed outside the geospatial industry have either no support for GDA2020, or rudimentary support utilising only the conformal transformation. Even widely used geospatial applications such as MapInfo Professional or AutoCAD Map 3D and AutoCAD Civil 3D require complicated manual post-installation steps to install the NTv2 grid shift files required for the conformal + distortion GDA2020 transformation (Pitney Bowes 2019, Autodesk 2018), and it is unlikely that these are widely in use, since they require motivated users to proactively seek out the installation steps and perform them. Accordingly, without active involvement from ICSM, it is highly unlikely that these vendors will have solutions in place to handle ATRF by the target rollout date.

3.3 Business Requirement 3

When the epoch definition is not available through the dataset's metadata, the user has a choice to (1) manually nominate an epoch (if they know the correct epoch date), or (2) leave the epoch as unknown (in which case the dataset's CRS is considered unknown) (HIGH PRIORITY)

3.3.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved
- A technology scan revealed no existing software support, or plans to support, this functionality.

3.3.2 Analysis

As discussed in Business Requirement 1, currently no end user software has support for storage or retrieval of epoch definitions from dataset metadata. However, this is not a pre-requisite for Business Requirement 3, as Business Requirement 3 relates specifically to the case when an epoch is **not** available or is undefined in a spatial dataset.

Satisfying this requirement relies on support within end-user applications and tools alone. It is envisaged by the authors that this choice would be presented to users in a similar method as the software currently handles datasets with an unknown or undefined CRS. For instance, in the case of the open-source QGIS desktop application, loading a dataset with no CRS information triggers a dialog presenting a searchable list of all known CRS definitions from which a user may manually select the correct CRS. If no CRS is selected, the software falls back to treating the coordinates from the data as purely planar, Cartesian coordinates, with no reference to actual geographic locations and no indication of coordinate units. Coordinate data effectively becomes abstract, purely numeric data.

A similar approach could be utilised by software in the case of data stored in a dynamic CRS for which no coordinate epoch is available. The software could present the user with a dialog prompting them to manually enter the coordinate epoch (e.g. via a calendar-based date selector). If the user makes a valid choice from this dialog, the selected epoch would be utilised whenever coordinates from the dataset are utilised. If no choice is made, the data would also become purely Cartesian, "non-Earth" coordinates.

3.4 Business Requirement 4

If a user manually nominates an epoch for a dataset when loading into a project, it is recorded for that dataset within the project, e.g. in the CRS metadata, so that it is respected whenever the project is re-opened (HIGH PRIORITY)

3.4.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved
- A technology scan revealed no existing software support, or plans to support, this functionality. However, if no issue exists with forward compatibility of projects in older software versions, this change is relatively trivial and can be considered "business as usual" for software developers and vendors.

3.4.2 Analysis

This Business Requirement flows directly from Business Requirement 3, in that it relates to datasets which have been loaded into a project in a client application with a manual, user-nominated epoch. Specifically, this requirement dictates that when a user re-opens a project containing these datasets with manually assigned epochs at a later date, the manually assigned epoch is respected and automatically re-assigned to the dataset.

Unlike the standard data formats used to store spatial data described in Business Requirement 1, no widely used standards exist for storage of spatial mapping "projects". (We define a mapping "project" as a document utilised by a geospatial software application containing one or more map layers, formatted and styled in a particular configuration as to fit the purposes of a single user task.) Rather, client applications define their own unique project formats specific to that particular application.

Accordingly, client applications are in control of their own project formats and are free to revise these project data formats as required. While some client applications may attempt to keep forward compatibility with their project data formats (e.g. allowing projects created in newer versions of the application to be opened in older versions of the application), this is less of a concern for the ATRF/dynamic CRS use case as older versions of the application have no handling or support for dynamic CRS transformations, and thus are inherently incompatible with projects utilising these CRS.

Given that the WKT2:2019 revision discussed in Business Requirement 1 provides a mechanism for encapsulating both the information required to describe a dynamic CRS and the associated coordinate epoch metadata, software applications could use WKT2:2019 internally for storing (and restoring) manually-assigned dataset epochs.

A technology scan revealed no existing software support, or plans to support, this functionality. However, if no issue exists with forward compatibility of projects in older software versions, this change is relatively trivial and can be considered "business as usual" for software developers and vendors.

3.5 Business Requirement 5

The GIS software shall allow users to query the epoch associated (if there is one) with an ATRF dataset, displaying this epoch in a human-readable or ISO date format. (HIGH PRIORITY)

3.5.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved
- This is a relatively trivial change, and ultimately is satisfied by adding an additional field to display next to the layer's CRS information and metadata
- A technology scan revealed no existing software support, or plans to support, this functionality.

3.5.2 Analysis

This Business Requirement is a natural extension of Business Requirements 1 and 3. Specifically, this Requirementstates that if a software application has internal knowledge of a dataset's epoch (either automatically via the dataset's CRS metadata or via a manual user-assigned epoch), that this information should also be visible to users in a human-readable format.

This is a relatively trivial change, and ultimately is satisfied by adding an additional field to display next to the layer's CRS information and metadata.

One concern raised during user workshops is that software must be careful to state that this coordinate epoch refers to the coordinate frame **only**, and is **unrelated** to the actual capture (or observation) date of data. For instance, aerial imagery captured on April 16th 2023 may be saved in a coordinate epoch of January 1st 2021. There is no requirement that the coordinate epoch and capture date have any relation to each other, and software must take care to present the coordinate epoch in an unambiguous way to avoid user misinterpretation or confusion. This may also require user re-education in order to inform users of the distinction between coordinate epoch and capture date.

A technology scan revealed no existing software support, or plans to support, this functionality.

3.6 Business Requirement 6

The software has the capability to make a copy of an existing dataset (i.e. "save as") with a new epoch assigned, without applying any transformation to coordinates (HIGH PRIORITY)

3.6.1 Summary

- This is a secondary Business Requirement

- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved
- A technology scan revealed no existing software support, or plans to support, this functionality.

3.6.2 Analysis

This Business Requirement has a prerequisite on Business Requirement 1, in that it relates specifically to creating a new copy of an existing dataset with a specific epoch assigned to the coordinates. This requirement is analogous to the functionality exposed in applications such as QGIS' "*Assign Projection*" tool, which allows users to create a copy of an existing dataset to a new file with a particular CRS assigned, but without performing ANY transformation of coordinates. These tools are designed to allow users to correct a dataset which has been assigned an incorrect CRS definition, for instance a dataset with coordinates in GDA2020 latitude/longitude values (EPSG:7844) but with metadata describing the coordinates as GDA2020 MGA zone 56 (EPSG:7856).

Business Requirement 6 extends this existing functionality, by allowing users to create a copy of an existing dataset into a new file with a different, manually assigned coordinate epoch, without any transformation of coordinates. Since no actual transformation of coordinates is performed, this requirement is NOT dependent on Business Requirement 2.

It is envisaged that the functionality could be exposed in client applications in a similar way to their existing "*assign projection*" tools, with the addition of a calendar-based widget for selecting the desired output coordinate epoch.

A technology scan revealed no existing software support, or plans to support, this functionality.

3.7 Business Requirement 7

The software has the capability to make a export of an existing dataset ("save as") with a new epoch, applying the corresponding time-based transformation to coordinates as they are exported. (HIGH PRIORITY)

3.7.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved
- A technology scan revealed no existing software support, or plans to support, this functionality.

3.7.2 Analysis

Much like Business Requirement 6, this requirement has a prerequisite on Business Requirement 1, in that it depends on the ability for software to store a coordinate epoch into a layer's metadata.

The important distinction from Business Requirement 6 is that unlike requirement 6, coordinates will be transformed using a 4-dimensional, time-dependent transformation during the copy. This requirement is the time-dependent, dynamic equivalent to QGIS' "*Reproject Layer*" tool, or ArcGIS' "*Project*" tool.

Business Requirement 7 further extends this existing functionality by allowing users to create an export of an existing dataset into a new file with a different, manually assigned coordinate epoch, with coordinates transformed from their source position to the equivalent position at the destination epoch. Since a 4-dimensional transformation is required, this Business Requirement is dependent on Business Requirement 2.

It is envisaged that the functionality could be exposed in client applications in a similar way to their existing "*reproject*" tools, with the addition of a calendar-based widget for selecting the desired output coordinate epoch.

Consultation with ESRI staff, and material published from their 2018 user conference (Kennedy 2018) has revealed that ESRI plans on adding this functionality to their ArcGIS Pro desktop application, however this implementation is likely internally blocked by Business Requirement 1.

Outside of ESRI, a technology scan revealed that the only other tool currently partially handling this requirement is the GDAL command line suite of utilities. GDAL version 3.0 allows users to perform a 4-dimensional time-dependent transformation of an input dataset, however users must manually specify the input coordinate epoch and the output dataset does **not** include the destination epoch anywhere in its automatically-generated metadata (Rouault 2019). This functionality is blocked by Business Requirement 1.

The technology scan revealed no existing software support, or plans to support, this functionality.

3.8 Business Requirement 8

Web services are capable of applying time-dependent coordinate transformation on the fly while delivering data, ensuring that the data is delivered to clients in the epoch requested by that client. (MEDIUM-HIGH PRIORITY)

3.8.1 Summary

- This is a secondary Business Requirement
- It is critical for the dissemination of 4D datasets through geospatial web services
- Current versions of standard web-service specifications have no concept of dynamic CRS definitions, or time-dependent transformations
- The technology scan revealed no existing plans to amend web service standard specifications to handle this requirement, and no server software vendor plans to implement this functionality in their software
- This requirement likely being deferred until the underlying issues described in Business Requirement 1 are resolved, specifically revisions to existing web service standards

3.8.2 Analysis

Many web services are implemented using standard specifications ratified by the OGC. These include Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS) services, amongst many others. Current versions of these specifications have no concept of dynamic CRS definitions, or time-dependent transformations.

At a minimum, in order to utilise ATRF coordinates with these web services, would require the existing standards to be updated to allow the use of dynamic CRS definitions for available datasets and their associated coordinate epoch (such as via the WKT2:2019 standard discussed in Business Requirement 1.

Business Requirement 8 extends on this by requiring that web services are capable of performing on-the-fly transformations on the server-side and delivering the resultant datasets to clients in a coordinate epoch of the client’s choice.

This adds additional functional requirements to future revisions of the WxS service standards, providing a standard method for web service clients to:

- Query a list of available coordinate epochs at which the service is capable of providing data, or determine whether the service is capable of transforming on-the-fly to any desired coordinate epoch
- Specify the desired coordinate epoch when requesting data from the service

Additionally, the many server implementations of these standards provided from different software projects and vendors would require updates to handle the newer versions of the specifications and expose this functionality to clients.

The technology scan revealed no existing plans to amend web service standard specifications to handle this requirement, and no server software vendor plans to implement this functionality in their software.

While vendors of proprietary, non-standards based web services (such as the ESRI REST services) may have internal plans to address this requirement in future versions of their server software, the technology scan did not reveal any publicly released plans for this.

3.9 Business Requirement 9

The software is able to determine the correct epoch for ambiguous WGS84 based data, and standards exist for specifying the correct epoch for WGS84 based data (LOW PRIORITY)

3.9.1 Summary

- This is a secondary Business Requirement
- There are extreme technical challenges and ambiguity associated with this Business Requirement
- This requirement is not satisfied by any existing software and is dependent on development of international standards for ensemble datums, updates to registries

such as the EPSG registry to handle these, and updates to both the underlying software libraries (such as PROJ) and client applications to expose these datums.

- **Recommendation: we defer any final recommendations regarding ICSM involvement or investment on this requirement to other bodies of work which are underway and are focussed solely on this particular issue.**

3.9.2 Analysis

Unfortunately, for existing datasets stored within WGS84, the actual coordinate epoch has been permanently lost and cannot be retrieved without manual intervention. In some cases, the epoch may be available via additional textual metadata associated with the dataset, however even when this information **is** available, it is not available in a machine-readable format and it would be dependent on a user manually sourcing the correct epoch and assigning it to the dataset.

Accordingly, due to the extreme technical challenges and ambiguity associated with this Business Requirement, it has been classified as a low priority. Correctly handling this use cases is dependent on other bodies of work, such as development of "*ensemble datums*" (see https://www.opengeospatial.org/blog/3045) and standards and specifications for storing and handling these.

The technology scan revealed no existing software support, or plans to support, this functionality.

3.10 Business Requirement 10

A particular project can have a user-defined epoch assigned to it (e.g. the date of creation, or another specific reference date such as ATRF 1/7/2023), and this date is used as the epoch when transforming data for display or analysis. (HIGH PRIORITY)

3.10.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved

3.10.2 Analysis

The authors envisage that this functionality would be exposed to users alongside the software's existing ability to specify a particular CRS for a project or map frame. A new, calendar-based, widget would be shown whenever a dynamic CRS is selected, allowing users to pick the desired coordinate epoch for viewing the project or map frame. This epoch would be saved into the project and retrieved when the project is restored at a later date.

This functionality is dependent on Business Requirements 1 and 2, as it requires that the coordinate epoch of individual map layers in the project is available, and that the software is able to project coordinates from the source layer's coordinate epoch to the project (or map frame's) coordinate epoch on-the-fly.

As described in Business Requirement 4, vendors and software developers have the flexibility to adapt their project formats as required. Accordingly, there should not be any standards-based issues for software applications to allow projects to be created, saved, and restored with a dynamic datum with a particular, user-assigned coordinate epoch.

A technology scan revealed no existing software support, or plans to support, this functionality. Consultation with key ESRI staff revealed that they did not have any existing plans to allow control over project coordinate epochs, however, it is possible that they will be revising their approach following the workshop.

3.11 Business Requirement 11

The software provides a tool (e.g. a time slider) to move coordinates in the CRS over time, by dynamically altering the project (or map displays) epoch and rendering features with an on-the-fly transformation to this epoch (LOW PRIORITY)

3.11.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved

3.11.2 Analysis

This requirement is an extension of Business Requirement 10. Specifically, it builds upon the functionality described in requirement 10 by exposing the project or map frame's coordinate epoch via an interactive "*time slider*" widget. As users interact with this widget, the coordinate epoch associated with the map view will be updated, and the map reprojected into the new epoch. Accordingly, it is also dependent on Business Requirements 1 and 2.

Many geospatial desktop applications (e.g. QGIS, ArcMap) already expose a "time slider" widget which allows users to interactive explore temporal data. These sliders currently alter a map view by toggling the visibility of features based on a timestamp (or epoch) associated with features, usually via an attribute assigned to each feature. For instance, if features have a "start date" and "end date" attribute, the feature will be visible whenever the slider position sits between these dates. It is possible that these existing interactive time-slider controls could be updated to also dynamically alter the map view's coordinate epoch.

A technology scan revealed no existing software support, or plans to support, this functionality.

3.12 Business Requirement 12

The software offers applicable choices of epoch to assign to output datasets in the case of data operation performed on a single layer (e.g. buffering an input dataset), and makes an intelligent choice for the initial value of this choice (HIGH PRIORITY)

3.12.1 Summary

- This is a secondary Business Requirement

- This requirement is dependent on Business Requirement 1, and in a situation where the destination coordinate epoch does not match the input coordinate epoch, Business Requirement 4.
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirements 1 and 4 are resolved

3.12.2 Analysis

This requirement relates to the common GIS analyst task of performing a spatial operation on a single input dataset. For instance, buffering a layer by a fixed distance, or converting a polygon layer to a centroid point layer. In the case that a user performs these operations on a source layer which is stored in a dynamic CRS with a particular coordinate epoch, the software (or user) must make a choice about what epoch to store the output dataset in.

Possible approaches could consist of:

- Using the same dynamic CRS and coordinate epoch as the input dataset
- Using the project's defined dynamic CRS and coordinate epoch (as described in Business Requirement 10)
- Using some other default, manually user-specified epoch (e.g. an epoch selected by the user from the software applications "Options" dialog)

This requirement is dependent on Business Requirement 1, and in a situation where the destination coordinate epoch does not match the input coordinate epoch, Business Requirement 4.

A technology scan revealed no existing software support, or plans to support, this functionality. Effectively, since no software applications can currently handle Business Requirement 1, if any datasets with a coordinate epoch are processed using existing software applications, the output will always be in the same coordinate epoch as the input dataset.

3.13 Business Requirement 13

The software makes an intelligent choice of epoch to assign to output datasets created as a result of a multi-layer operation involving layers with differing epochs (e.g. clipping or union operation). (HIGH PRIORITY)

3.13.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved
- A technology scan revealed no existing software support, or plans to support, this functionality.

3.13.2 Analysis

In addition to the situation described in Business Requirement 12, GIS analysts also regularly perform spatial operations which utilise multiple input datasets. Examples of these tasks include clipping a set of layers against a polygon layer or joining attributes from one layer to another through the use of a spatial join. For these operations, the input datasets used may not necessarily all be stored in an identical CRS or coordinate epoch.

Typically, software applications already handle the use of multiple inputs with different static CRS by performing an on-the-fly reprojection of the input datasets in order to bring them all into a common CRS for processing. In the case of input datasets which utilise dynamic CRS and differing coordinate epochs, it will be necessary for the software to also perform the 4-dimensional transformations required to align input datasets into a matching coordinate epoch. Accordingly, this requirement is dependent on both Business Requirements 1 and 2.

The software must make an intelligent choice of epoch to utilise for the output dataset, or require users to manually make this choice of epoch. Possible approaches are similar to those described in Business Requirement 12, and include:

- Using the same dynamic CRS and coordinate epoch as just one of the input datasets (e.g. the first dataset selected in the tool)
- Using the project's defined dynamic CRS and coordinate epoch (as described in Business Requirement 10)
- Using some other default, manually user-specified epoch (e.g. an epoch selected by the user from the software applications "Options" dialog)

A technology scan revealed no existing software support, or plans to support, this functionality.

3.14 Business Requirement 14

The software allows users to choose the desired epoch when creating a new dataset, e.g. as part of the dataset's CRS selection (MEDIUM PRIORITY)

3.14.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved

3.14.2 Analysis

This requirement is a natural extension to Business Requirements 6 and 7, but unlike those requirements, it relates to the use case of a user creating a brand-new dataset within the software application.

Geospatial applications currently expose the choice of static CRS to users when creating a new dataset. This is commonly done via a graphical widget which allows users to pick from a list of known CRS definitions (such as those available from the EPSG registry). In order to accommodate the creation of a new dataset in a dynamic CRS, such as ATRF, it will be necessary for users to also select the corresponding coordinate epoch associated with the data which will be stored in the layer.

This requirement is dependent on Business Requirement 1, or in limited use cases (where a dataset will only be utilised from a single project), Business Requirement 4. It is envisaged that this choice would be exposed via a similar method as Business Requirement 3, e.g. via a calendar widget which requires users to select the desired coordinate epoch.

A technology scan revealed no existing software support, or plans to support, this functionality.

3.15 Business Requirement 15

When adding new features to an existing dataset with a defined epoch, the software correctly performs a time dependent transformation of the data from the current project's epoch back to the reference epoch which the dataset is stored in. (MEDIUM PRIORITY)

3.15.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software, and is likely being deferred until the underlying issues described in Business Requirement 1 are resolved

3.15.2 Analysis

A common task performed by desktop GIS analysts is populating an existing dataset by digitizing features over a map. For instance, tracing the footprints of buildings over a reference aerial image.

In the case that a user is storing these features into a dataset with a particular coordinate epoch, the software must take careful consideration of how to appropriately transform and handle digitized features during their storage in the destination dataset. As an example, if a user is tracing features from a map displayed in a coordinate epoch of January 1 2026, the digitized coordinates cannot be directly stored into a dataset with a coordinate epoch of September 15 2023. Rather, these coordinates must be transformed via a 4-dimensional, temporal transformation in order to ensure that the coordinate values stored in the destination dataset are also in the September 15 2023 coordinate epoch.

Accordingly, the software must perform an on-the-fly temporal transformation from the project or map frame's coordinate epoch at which the features have been digitized (dependent on Business Requirement 10) to the destination dataset's coordinate epoch (dependent on Business Requirement 2).

A technology scan revealed no existing software support, or plans to support, this functionality.

It is likely that user education is also required in this situation, to avoid confusion when a user digitises a point using a particular x/y value and later queries the actual stored coordinate, which has a different x/y value.

3.16 Business Requirement 16

Standards exist for storage and retrieval of per-feature epoch within a single dataset, and the software correctly assigns the current epoch to newly created features (VERY LOW PRIORITY)

3.16.1 Summary

- This is a secondary Business Requirement
- This requirement is not satisfied by any existing software and standards
- There are extremely complex technical challenges preventing implementation of this requirement
- This is likely a “red herring” or “dead end” track, and epochs will be assigned on a dataset level (e.g. all features in a single dataset share a common epoch)

3.16.2 Analysis

While theoretically interesting, this is not a practical requirement. The use-cases are relatively rare, largely revolving around GNSS data capture over prolonged periods of time. In those cases, it is good practice anyway to collect data in ‘batches’ with their own epochs, which can be harmonised upon aggregation.

The technical, standards, and storage complexities to meet this requirement are an order of magnitude higher than for dataset-level epochs, and in our opinion outweigh the marginal use-case benefits. These difficulties include, but are not limited to:

No standards exist for per-feature storage of epoch (or timestamp), and support amongst existing vector data formats is incomplete. Whilst some formats (such as GPX) contain a timestamp attribute, this timestamp is not necessarily related to the coordinate epoch and care must be taken not to incorrectly equate these two.

Exposing a per-feature epoch via software greatly complicates user interfaces and would necessitate educational campaigns to inform users that two features from the same dataset, with identical coordinates, are NOT necessarily located in the same place!

Adding per-feature epoch to large (e.g. multimillion/billion point) datasets would dramatically increase the memory and processing requirements for handling this data -- instead of storing 2 coordinates to represent a 2-dimensional point feature, 2 coordinate + epoch would be required. In addition, the software would no longer be able to perform optimisations like preparing a single coordinate transform to use for an entire dataset in advance and would instead be forced to create and process epoch-based coordinate transforms per feature (or, strictly speaking, per unique epoch in the input dataset).

4 Summary and recommendations

This section summarises the findings from the technology scan of the prioritised use-cases, associated requirements and our understanding of the product- and standard roadmaps. The recommendations are aimed at addressing any issues and risks to the Australian datum modernisation program in a timely manner.

4.1 Key findings

ATRF is the second stage of Australia's datum modernisation program, after GDA2020. As such, it represents a paradigm shift. Fundamentally GDA2020 is a more accurate, and spatially adjusted, datum, in relation to previous datums such as GDA94, whereas ATRF adds a temporal (4^{th}) dimension.

This means the changes required in spatial standards, data format and software are significantly more complex for enabling ATRF, than they are for enabling GDA2020.

To analyse the required changes to enable ATRF use in desktop GIS, we identified 12 priority use cases, which translate into 16 Business Requirements, i.e. the capabilities GIS software tools, data and standards would need to include to fully support ATRF.

Analysis of the Business Requirements shows that there are two primary requirements: Business Requirements 1 and 2. These encapsulate

1. the ability to store and read epoch metadata in a standard, machine readable format, and
2. the ability for software to automatically transform time dependent coordinates without user intervention.

These two are fundamental to all capabilities implied in the remaining (secondary) Business Requirements.

The other (secondary) requirements are largely solution specific. It is our assessment that these are likely to be relatively quickly and easily implemented after the primary requirements are completed.

The primary requirements must therefore be resolved with urgency and priority, as a prerequisite for ATRF adoption in Australia. Earlier research indicates that ATRF will start having significant user impact from 2023 onwards.

4.2 Risk to ICSM

A key risk to the ICSM datum modernisation program is that when ATRF becomes relevant to users (i.e. from 2023 onwards), there are no mainstream GIS tools available to them. This would have major impact on the program, its credibility and potentially the long-term viability of ATRF.

The technology scan shows that the challenges involved in Business Requirement 1 are complex, and there will likely be very lengthy delays in resolving the standards gaps associated with this requirement. With all the other requirements dependent on it, there is a medium to high likelihood that without ICSM intervention, ATRF capability will not be widely available to mainstream users in Australia by 2023.

4.3 Recommendations

It is recommended that ICSM take the lead in a coordinated effort to accelerate Business Requirements 1 and 2 as a risk mitigation strategy to be ATRF ready by 2023.

Specifically, we recommend that:

- ICSM should, through its international connections with OGC, advocate and promote accelerated maturing and testing of the WKT2:2019 standard, invest in upgrading the PROJ library to be fully compatible with WKT2:2019, as well as upgrading standard spatial data formats to allow support for WKT2:2019.
- ICSM should actively liaise with Esri to ensure the availability of on-the-fly time-dependent coordinate transformations capability by 2023 and as part of ICSM's Datum Modernisation awareness program, encourage (or invest in) other client software developers to utilise this 4-D capability in their products, in order to meet the needs of Australian users.

5 Appendix 1: Use-cases

The use-cases and associated requirements below were drafted, prioritised and validated in a workshop with selected experts and user representatives on 7 August 2019.

The actors in the use-cases are defined as

- **GIS Analyst:** A trained GIS analyst, conducting spatial analysis on a map-based desktop platform
- **Data Scientist:** A trained statistician or data scientist, with some geospatial knowledge, conducting spatial analysis in a non-map based statistical platform
- **Software Developer:** A software developer involved in the development of an application or library with a geospatial component
- **Spatial Data Manager:** A custodian or publisher of spatial data
- **Field User:** A worker involved in capturing or using spatial data in the field, usually via a mobile device. May be an expert in a non-spatial discipline and may not have any formal geospatial training or understanding.

For each use case, we identified the associated Business Requirements that are needed to satisfy the use-case.

5.1 Use Case 1a

As a **GIS Analyst,** I want to import time dependent data (e.g. GNSS coordinates) that automatically align with my other layers (e.g. within my project), so that the layers in my project or map are all aligned to the same datum by default.

Business Requirements

- GNSS or ATRF based data has a known epoch defined in its metadata, or when this information is not available, the user has a choice to (1) nominate an epoch (if they know the correct date), or (2) not nominate an epoch (dataset CRS is considered part of a 'datum ensemble').
- If a user nominates an epoch, it is flagged as such in the CRS metadata (?)
- The software can handle time-dependent coordinate transformations 'on the fly'

Priority: high

5.2 Use Case 1b

As a **GIS Analyst** or **Data Scientist**, I want to query an existing dataset to determine the epoch currently assigned to the dataset so that I can populate metadata concerning the layer and include this reference information in reports and contextual descriptions of maps.

Business Requirements

- GNSS or ATRF based data has a known epoch assigned (as per UC1), and standards exist for storing epoch metadata.

- The GIS software shall allow user to query the epoch associated (if there is one) with an ATRF dataset

Priority: high (part of 1a)

5.3 Use Case 2

As a **GIS Analyst**, I want to assign an epoch to existing time-dependent coordinates, so that I can manage, transform, or correct time-dependent coordinates with no epoch (or the wrong epoch) defined.

Business Requirements

- The software has the capability to make a copy of existing data ("save as") with a new epoch, without applying any transformation to coordinates
- Standards exist for storing epoch metadata (as per UC1b)

Priority: high

5.4 Use Case 3

As a **GIS Analyst**, I want to export ATRF based data with a user-defined epoch so that I can deliver data to third parties in an epoch of their choosing.

Business Requirements

- The software has the capability to make a copy of existing data ("save as") with a new epoch, applying the corresponding time-based transformation to coordinates as they are exported
- Standards exist for storing epoch metadata (as per UC1b)
- The software can handle time-dependent coordinate transformations 'on the fly' (as per UC1)

Priority: high

5.5 Use Case 4

As a **Software Developer**, I want to access a coordinate transformation library that natively and elegantly handles time dependent coordinates, so that my software handles time dependent coordinates accurately, correctly and consistently with other software implementations.

Business Requirements

- The software can handle time-dependent coordinate transformations 'on the fly' (as per UC1)

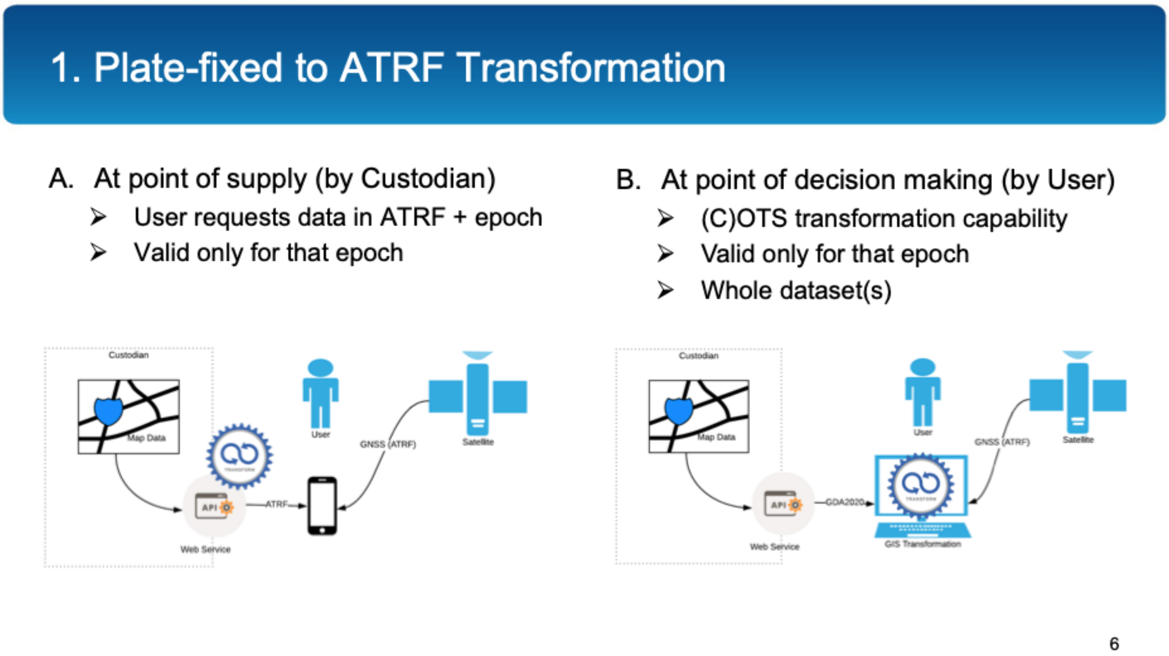
Priority: high

5.6 Use Case 5

As a **Spatial Data Manager**, I want to publish a web-service that provides spatial data in ATRF so that consumers with GNSS-enabled devices can use base map data which is aligned with GNSS coordinates.

Business Requirements

- The web service is capable of applying time-dependent coordinate transformation on the fly while delivering data.
- The epoch for exported data defaults to “today” (consider whether a user can request a specific non-today epoch?)
- WxS standard needs to allow for epoch-based query



Priority: high-medium

5.7 Use Case 6

As a **GIS Analyst** or **Data Scientist**, I want to use spatial datasets that have a known accuracy, datum and (where necessary) epoch, so that I know if data with different datums and/or epochs are 'equivalent', and my software can perform any required transformations without my intervention.

Business Requirements

- The software can handle time-dependent coordinate transformations 'on the fly' (as per UC1)
- Standards exist for storing epoch metadata (as per UC1b)

Priority: low (could be redundant)

5.8 Use Case 7

As a **GIS Analyst** I want to accurately handle and align data in a WGS84 reference frame so that the layers in my project or map are all aligned to the same datum by default.

Business Requirements

- The software can handle time-dependent coordinate transformations 'on the fly' (as per UC1)
- The software is able to determine the correct epoch for ambiguous WGS84 based data, and standards exist for specifying the correct epoch for WGS84 based data

Priority: low

5.9 Use Case 8

As a **GIS Analyst** or **Data Scientist**, I want to save a "project" today, including layers with a mix of different epochs, and be able to reload this project in 12 or more months' time and see the exact same map and results as I see today, so that I can justify decisions I made on past projects based on the spatial relationships of features exactly as they were at the time of analysis.

Business Requirements

- GNSS or ATRF based data has a known epoch defined in its metadata (as per UC1)
- The software can handle time-dependent coordinate transformations 'on the fly' (as per UC1)
- Standards exist for storing epoch metadata (as per UC1b)
- A particular project can have a user-defined epoch assigned to it (e.g. the date of creation, or another specific reference date such as ATRF 1/7/2023), and this date is recovered and used as the epoch when transforming data for display or analysis.

Priority: high

5.10 Use Case 8b

As a **GIS Analyst** or **Data Scientist**, I want to be able to move forward and backward in time (e.g. with a time slider) for an ATRF dataset, to see how its position changes.

Business Requirements

- GNSS or ATRF based data has a known epoch defined in its metadata (as per UC1)
- The software can handle time-dependent coordinate transformations 'on the fly' (as per UC1)

- Standards exist for storing epoch metadata (as per UC1b)
- A particular project can have a user-defined epoch assigned to it (e.g. the date of creation, or another specific reference date such as ATRF 1/7/2023), and this date is recovered and used as the epoch when transforming data for display or analysis.
- The software provides a tool (e.g. time slider) to move coordinates in the CRS over time

Priority: low

5.11 Use Case 9

As a **GIS Analyst** or **Data Scientist**, I want to conduct operations on a spatial layer, such as buffering, and trust the software to correctly save the result with the required CRS information or metadata concerning epoch, so that I don't need to consider this myself, yet be confident that transformed datasets are correctly tagged with an appropriate epoch as needed.

Business Requirements

- GNSS or ATRF based data has a known epoch defined in its metadata (as per UC1)
- Standards exist for storing epoch metadata (as per UC1b)
- The software can handle time-dependent coordinate transformations 'on the fly' (as per UC1)
- The software makes an intelligent choice of epoch to assign to output datasets (e.g. use the same CRS/epoch as input dataset, or use the project CRS/epoch)

Priority: high

5.12 Use Case 9b

As a **GIS Analyst** or **Data Scientist**, I want to conduct analysis on multiple layers (e.g. intersection, clips, union/aggregation), potentially with different epochs, and trust the software to transparently handle any required operations for accurate results, so that I can confidently conduct my analysis utilising any datasets provided without the need to pre-process these and manually ensure they have a common epoch.

Business Requirements

- GNSS or ATRF based data has a known epoch defined in its metadata (as per UC1)
- Standards exist for storing epoch metadata (as per UC1b)
- The software makes an intelligent choice of epoch to assign to output datasets (e.g. use the same CRS/epoch as input datasets, or use the project CRS/epoch)

Priority: High

5.13 Use Case 10

As a **GIS Analyst**, I want to create a new dataset "from scratch" on my desktop, e.g. digitizing features from other sources, and utilise a modern time-dependent CRS for this data, ensuring it can be used accurately for many years to come.

Business Requirements

- The software allows users to choose the desired epoch when creating a new dataset
- Standards exist for storing epoch metadata (as per UC1b)
- When adding new features to the dataset, either:
- The software correctly performs a time dependent transformation of the data from the date of digitization (or other appropriate epoch) back to the reference epoch for the dataset
- Or, standards exist for storage and retrieval of per-feature epoch within a single dataset, and the software correctly assigns the current epoch to newly created features
- Use the PROJECT’S reference epoch as the feature-level epoch while digitizing, and project back or forward in time BEFORE storing these coordinates into the actual dataset itself.

Priority: medium

5.14 Use Case 11

As a **Field User**, I want to collect data in the field over an extended (multi year?) period of time, using a mobile app or GNSS device and for later use on a desktop, so that I can harmonise the data points collected at different times to a common epoch.

Business Requirements

- Standards exist for storage and retrieval of per-feature epoch within a single dataset, and the software correctly assigns the current epoch to newly created features (as per UC11)

Priority: very low

5.15 Use Case 12

As a **GIS Analyst**, I want to import data from a large database where features have been collected over a lengthy period of time (e.g. OpenStreetMap) and have these features accurately positioned so that I can utilise this data with a sub-meter (or greater) accuracy.

Business Requirements

- Standards exist for retrieval of per-feature epoch within a single dataset, and the software correctly transforms features with different epochs (as per UC11)

Priority: out of scope

6 Appendix 2: Workshop participants

The workshop was held on 7 August 2019, to validate and prioritise the use-cases and requirements underpinning dynamic date support in desktop GIS. Workshop participants are listed in the table below.

Table 3 Workshop participants

Participant	Title	Affiliation
Kevin Kelly	Geodesist	Esri Inc.
Melissa Daley	Team Leader - Business Intelligence	Sutherland Shire Council
Scott Strong	Program Manager Geodetic System	DPIPWE Tasmania / ICSM
Joel Haasdyk	GDA2020 Implementation Program Manager	NSW Spatial Services
Mark McLean	CTO	L&M Spatial
Nyall Dawson	CEO	North Road
Maurits van der Vlugt	Director, Location Solutions	Mercury Project Solutions

7 Appendix 3: References

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