Space-Time Coordinate Transform Standards Working Group

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Background

Space Time Coordinate Transform (STCT) Standards Working Group

- Meeting Notes
- Email list: https://groups.io/g/hdrl-stct/
- Contact rweigel@gmu.edu for bi-weekly (Thursday @ noon) telecon invite

Small NASA/HDRL-supported IHDEA working group project; started in October 2023.

Result of HDRL Conclave break-out session in January, 2023.

A funny image to make a point

We have a clear understanding of the *problems*.

We are looking for criticism on our proposed solutions to some of the problems.

Outline

1. Motivation
2. Initial Objectives
3. Examples of Issues - Definitions
    a. GEI
    b. GSM
    c. Conclusions
4. Examples of Issues - Implementations
    a. CDAWeb vs SSCWeb
    b. Differences in Coordinate Transform Library Results
    c. Conclusions
5. Plan

Motivation

Experience with 1. HAPI and 2. Research Analysis

1. HAPI metadata is minimal - it relies on pointing to existing standards for interpretation of unit and coordinate system strings in HAPI metadata.

   Several standards exist for coordinate system name/definition pairs. (More details in Baptiste's linked data talk tomorrow.)

Motivation

2. In projects over past 5 years, my students and I have used 6 different libraries for coordinate transforms.
    - Not one library worked as-needed for all projects due to speed, compilation/interfacing issues, up-to-date IGRF, needed transforms, and bugs.
    - Libraries usually give similar results (< 0.1% angular). This is usually “good enough”, until it isn’t and one tries to figure out why.
    - There are also issues with differences due to definitions.
    - Our experience is not unique. I have also seen questions in community forums related to numerical differences, primarily due to implementation assumptions.

Initial Objective

The working group identified three needs and planned to address them in the following order:

1. The development of a comprehensive standard for coordinate system acronyms and definitions,
2. the implementation of comprehensive software, services, and unit tests for coordinate transforms;
3. and understanding the uncertainty of transforms due to implementation choices.

In this presentation, I'll describe a revision to this plan based on research into these items.

Examples of Definition Issues - GEI and ilk

- In the early days, only “GEI” (Geocentric Equatorial Inertial) was used. Significant ambiguity: “The Z-axis is parallel to Earth’s rotation axis” - However, Earth’s rotation axis varies due to obliquity, precession, nutation (and other factors).
- “Geocentric Equatorial Inertial” - has also been referred to as “Geocentric Earth Equatorial” (Franz and Harper, 2002; 2017), perhaps to account for fact that some definitions of GEI are not inertial.

Examples of Definition Issues - GEI and ilk continued

- SpacePy has “GEI”, “ECI2000”, “ECITOD”, and “ECIMOD” (ECI = Earth Centered Inertial), which address some of the ambiguity regarding if obliquity, precession, and nutation is accounted for.
- Franz and Harper use “GEI_J2000”, “GEI_D”, and “GEI_T”
- SSCWeb uses “GEI” and “J2000”
- SPICE Toolkit documentation: “J2000, also known as EME 2000, and is generally used in SPICE to refer to the ICRF”

Examples of Definition Issues - GSM

There are similar issues with GSM, which depends on the location of Earth's dipole in the geographic coordinate system.

- What model was used for the dipole?
- IGRF model coefficients apply to a 5-year period. Was interpolation performed? If so, on location of dipole or on coefficients?
- Commonly used model coefficients can change - IGRF provides preliminary coefficients, so saying IGRF was used is ambiguous - need to state what version of IGRF coefficient table was used or list values of coefficients.

Defining acronyms for each of the possibilities that exist or could exist is not feasible.

Conclusions

1. We have identified 8 standards, papers, and frequently used web pages that provide a list of coordinate frames and definitions that that include a frame related to GEI. Creating another list may exacerbate the problem by creating more noise, and it is unlikely that existing code and web services will be modified to use the new acronyms.
2. Even with precise definitions and definitions that cover all common cases, not enough information can be put in the definition to ensure **reproducibility**. For example, the “true-of-date” GEI depends on a precession and nutation model. Multiple models exist for each. Enumerating all possible permutations is not feasible and standard would need to be updated when new models are released.

Examples of Implementation Issues

Non-trivial variation in results from different implementations.

Geotail GSE, and GSM; Max differences on the order of 1000 km (⅙ of an RE) on `2021-11-25T00:00:00.000Z`

```
         X_GSE [km]     Y_GSE [km]     Z_GSE [km]
CDAWeb:  -96913.678     112140.816     -64398.839     Using dataset GE_OR_DEF/GSE
SSCWeb:  -97844.503     111984.683     -64344.178     Using dataset geotail/GSE

         X_GSM [km]     Y_GSM [km]     Z_GSM [km]
CDAWeb:  -96913.678     110822.349     -66642.180     Using dataset GE_OR_DEF/GSM
SSCWeb:  -97844.503     110030.273     -67631.954     Using dataset geotail/GSM
```

Examples of Implementation Issues

Non-trivial variation in results from different implementations

```
Time: [2015, 12, 30, 0, 0, 0]
                            x           y           z       magnitude
-------------------------------------------------------------------------------
Input (GSE):           3.46410162  3.46410162  3.46410162  6.00000000
Output (GSM):                                                      ∠° wrt Input
-------------------------------------------------------------------------------
cxform
geopack_08_dp
pyspedas
spacepy
spacepy-irbem
spiceypy1
spiceypy2
sscweb
sunpy
```

Examples of Implementation Issues

Non-trivial variation in results from different implementations

Time: [2015, 12, 30, 0, 0, 0]

	x	y	z	magnitude	
Input (GSE):	3.46410162	3.46410162	3.46410162	6.00000000	
Output (GSM):					∠° wrt Input
cxform	3.46410162	2.54340625	4.18701381	6.00000000	11.19612022
geopack_08_dp	3.46410162	2.54785114	4.18431052	6.00000000	11.14656002
pyspedas	3.46410162	2.54785080	4.18431073	6.00000000	11.14656386
spacepy	3.46410162	2.54710195	4.18476662	6.00000000	11.15491581
spacepy-irbem	3.46410162	2.54566083	4.18535391	5.99979803	11.16945855
spiceypy1	3.46410162	2.54651712	4.18512252	6.00000000	11.16143772
spiceypy2	3.46410162	2.54725501	4.18467345	6.00000000	11.15320876
sscweb	3.46	2.55	4.18	5.99554001	11.10894044
sunpy	3.46395412	2.54785162	4.18443234	6.00000000	11.14727882

max-min: 0.08717978

100*|max-min|/|max|: 0.7787%

If x, y, z are in R_E, then max-min angle corresponds to 58 km

Plan

1. Write a paper summarizing issues/results discussed here (in progress) - use terms/definitions in paper for standard.
2. Develop a continuously updated dataset (at CDAWeb as files) that contains the information needed for certain transforms (transform matrix elements). If you cite the data set, another user can exactly reproduce your transformation. (If you cite software used for transform, it is unlikely that software, or the exact version, will be runnable in future.)

   The advantage of a dataset is that it can be used with any programming language. The disadvantage is a dependency on external data. However, Python users can avoid the data download by using the Python package that generates the dataset (in progress).

Revised Objectives

4. Engage and support the developers of commonly used transform code to participate in the development of the dataset. This will increase the likelihood they will actually provide an option to use the data for transforms in their library.