Standardizing Reference Frame Terms in Heliophysics

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We describe an effort by IVOA and Heliophysics representatives to develop a standard for reference frames and reference system terms. The objective of this effort is to provide a proposal for additions to the existing IVOA standard for reference frames.

Background

IVOA has Reference Frames (and also Coords-v1.0)

Many other similar lists exist (SPASE, TREPS, ...)

Term	Label	Description	Parent
AZ_EL	Azimuth/elevation	Local azimuth and elevation. (Ground-based observations; Azimuth from North through East.)	
BODY	Body Coordinates	Generic bodycentric coordinates. Data annotated in this way cannot be automatically combined with any other data. Use or create more specific terms if at all possible.	
ECLIPTIC	Ecliptic	Ecliptic coordinates; the ecliptic of J2000.0 is assumed.	
EQUATORIAL	Equatorial	Umbrella term of all equatorial frames. Only use for old, pre-FK4 equatorial coordinates.	
FK4	FK4	Positions based on the 4th Fundamental Katalog. If no equinox is defined with this frame, assume B1950.0.	#EQUATORIAL
FK5	FK5	Positions based on the 5th Fundamental Katalog. If no equinox is defined with this frame, assume J2000.0. Applications not requiring extremely high precision can identify FK5 at J2000 with ICRS.	#EQUATORIAL
GALACTIC	Galactic	Galactic coordinates, modern definition: Pole at precisely FK4 B1950 192.25, 27.4, origin at approximately FK4 B1950 265.55, -28.92. See 1960MNRAS.121..123B for details.	#GENERIC_GALACTIC
GALACTIC_I	Old Galactic	Old, pre-1958, Galactic coordinates. See 1960MNRAS.121..123B for details.	#GENERIC_GALACTIC
GENERIC_GALACTIC	Galactic	Umbrella term for Galactic coordinates. If at all possible, use a more specific term, as historically, many different conventions have been in use.	
ICRS	ICRS	International Celestial Reference System as defined by 1998AJ....116..516M.	#EQUATORIAL
SUPER_GALACTIC	Supergalactic	Supergalactic coordinates (pole at GALACTIC 47.37, +6.32, origin at GALACTIC 137.37, 0.	
UNKNOWN	Unknown reference frame	Unknown reference frame. Only to be used as a last resort or for simulations. Data annotated in this way cannot be automatically combined with any other data.	
barycentric (Deprecated)	ICRS/Bary	Old VOTable COOSYS term indicating ICRS at BARYCENTER reference position. In the modern VO, refpos and refframe are no longer represented together. Do not use this any more.	

Overall Objective

Ultimately, we want reproducibility. Many challenges:

- Although Reference Systems in Heliophysics (e.g., GEI, GSM, GSE) are agreed upon; acronyms are not (e.g, GEI, GEI_{2000}, J2000).
- Reference Frames (implementations of reference systems) are needed for reproducibility (e.g., ICRS = reference system; ICRF1, 2, 3 = reference frame)
- Long history of usage of some terms. Historical assumption is that differences in implementations are not significant relative to other measurement uncertainty.
- Ambiguous terminology: Coordinate System, Reference System, Reference Frame use in different was in Heliophysics, SPICE, Astronomy and Earth Science.

Overall Objective continued

Ultimately, we want reproducibility.

Many challenges:

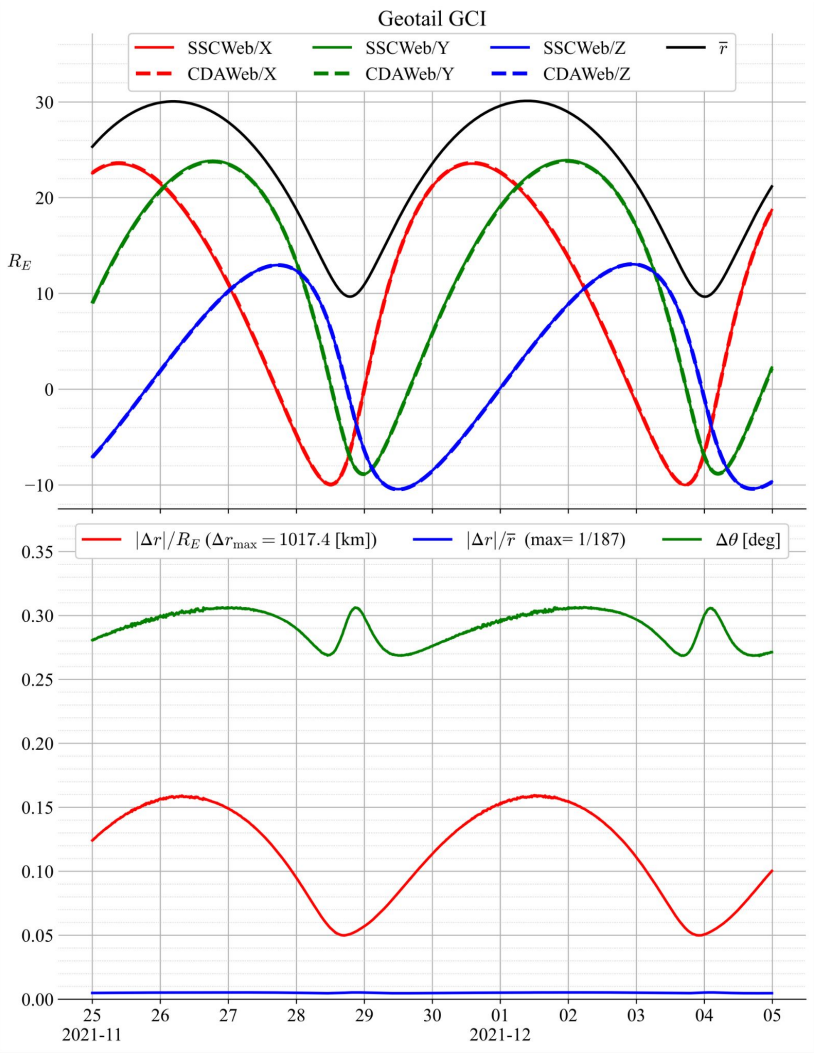
- Although we need a comprehensive standard for Reference Systems, much more is needed. Many lists exist.
- As a result of these challenges, a new list of definitions won't have much impact.
- Need also reference frame implementations (similar to ICRF1, 2, 3) and associated data for library developers and spacecraft science operation teams.

Examples

Survey of ephemeris from four different sources CDAWeb, SSCWeb, AMDA, and JPL/Horizons.

Results are not always the same to numerical precision.

Some differences are large enough that they must be accounted for as a part of uncertainty.



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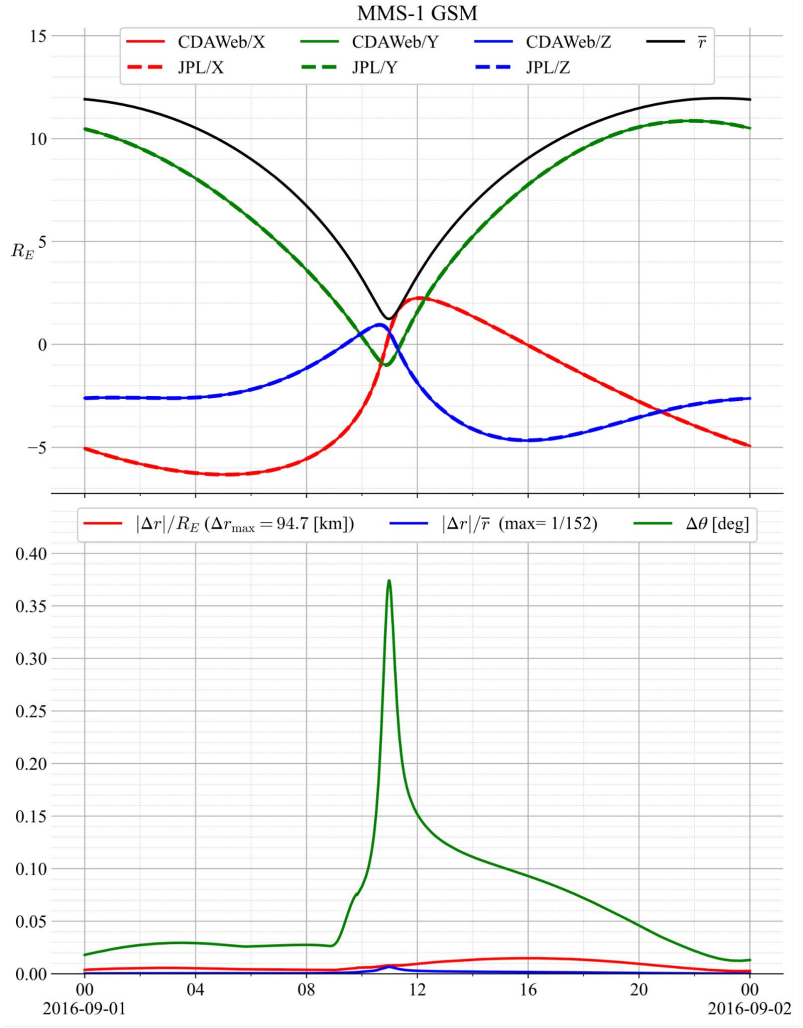

Examples

We see similar issues with coordinate transform libraries.

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

	x	y	z	magnitude	
Input (GSE):	3.46410162	3.46410162	3.46410162	6.00000000	
Output (GSM):					ang. [°] 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:	0.00410162	0.00659375	0.00701381	0.00445999	0.08717978
100*|max-min|/|max|:	0.1184%	0.2586%	0.1675%	0.0743%	0.7787%

Recommendations

1. A central authority maintains a citable database of reference data needed for common coordinate system transforms;
2. A standard set of acronyms and definitions for coordinate systems is developed for the reference implementations;
3. A central authority maintains the SPICE kernels for coordinate transforms used by space physics satellite missions to generate data products in different coordinate systems; and
4. Software developers provide explicit comparisons of their implementations with the results of 1. or 3. and documentation on implementation choices.

Status of Project

Circulation of draft of publication that provides justifications for the recommendations expected in late summer.

Documents differences in terminology, ephemeris datasets, and software that implements transforms.