CHAPTER 1 NUMERICAL STANDARDS

The tables are organized into three columns: the item, the standard value, and comments. The comments note departures from the IAU values and direct the reader to the appropriate chapter for an expanded discussion or listing of values. In some cases, the succeeding chapters contain tutorial material that might prove helpful. Algorithms are, in some cases, provided to clarify a formulation.

References

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NUMERICAL STANDARDS

ITEM	RECOMMENDED VALUE	COMMENTS
ASTRONOMICAL CONSTANTS		
Defining Constants		
- Gaussian Gravitational Constant	$k = 0.01720209895$	
- Velocity of Light	$c = 2.99792458 \times 10^{8} ms^{-1}$	
Primary Constants		
- Astronomical Unit in Light-Seconds	$\tau_A = 499.00478353$ s	IAU (1976) Value = 499.004782 s.
- Equatorial Radius of the Earth	$a_e = 6378136.3$m	IAU Value = 6378140m. GEM T3 Value = 6378137m.
- Dynamical Form Factor for Earth	$J_2 = 0.0010826362$	GEM T3 Value = 0.0010826361
- Geocentric Constant of Gravitation	$GM_{\oplus} = 3.986004418 \times 10^{14} m^3 s^{-2}$ (TT Units) $= 3.986004415 \times 10^{14} m^3 s^{-2}$ (TCG Units)	IAU (1976) Value = $3.986005 \times 10^{14} m^3 s^{-2}$. GEMT3 Value = $3.98600436 \times 10^{14} m^3 s^{-2}$.
- Constant of Gravitation	$G = 6.67259 \times 10^{-11} m^3 kg^{-1} s^{-2}$	
- Earth-Moon Mass Ratio	$\mu = 0.012300034$	IAU (1976) Value = 0.01230002.
- General Precession in Longitude Per Century for J2000.0	$p = 5029''.0966$	
- Obliquity of the Ecliptic for J2000.0	$\epsilon_0 = 23° 26' 21''.4119$	IAU (1976) Value = $23° 26' 21''.448$. (see Chapter 5).
- Mean Angular Velocity of the Earth	$\omega = 7.292115 \times 10^{-5}$ rad s^{-1}	
Derived Constants		
- Astronomical Unit	$c\tau_A = 1.4959787061 \times 10^{11}$m	IAU (1976) Value = $1.49597870 \times 10^{11}$ m.
- Solar Parallax	$\pi_{\odot} = \sin^{-1}(a_e/A) = 8''.794142$	IAU (1976) Value = $8''.794148$.
- Earth Flattening	$f^{-1} = 298.257$	
- Heliocentric Constant for Gravitation	$GM_{\odot} = 1.32712440 \times 10^{20} m^3 s^{-2}$	IAU (1976) Value = $1.32712438 \times 10^{20} m^3 s^{-2}$.
- Ratio of the solar Mass to the Mass of the Earth	$M_{\odot}/M_{\oplus} = 332,946.045$	IAU (1976) Value = 332,946.0.
- Ratio of the Solar Mass to the Mass of the Earth-Moon System	$M_{\odot}/M_{\oplus}(1 + \mu) = 328,900.56$	IAU (1976) Value = 328,900.5.
- Solar Mass	$M_{\odot} = 1.9889 \times 10^{30}$kg	
System of Masses (See Chapter 4 for references and discussion) (Expressed in Reciprocal Solar Masses)		
- Mercury	6,023,600	IAU (1976) Value = 6,023,600
- Venus	408,523.71	IAU (1976) Value = 408,523.5

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
- Earth-Moon System	328,900.56	IAU (1976) Value = 328,900.5. (adjustable in LLR)
- Mars	3,098,708	IAU (1976) Value = 3,098,710
- Jupiter	1,047.3486	IAU (1976) Value = 1,047.355.
- Saturn	3,497. 90	IAU (1976) Value = 3,498.5.
- Uranus	22,902.94	IAU (1976) Value = 22,869.
- Neptune	19,412.24	IAU (1976) Value = 19,314
- Pluto-Charon	135,000,000	IAU (1976) Value = 3,000,000.
- Ceres	2.0×10^{9}	IAU (1976) Value = 1.7×10^{9}.
- Pallas	8×10^{9}	IAU (1976) Value = 9.1×10^{9}.
- Vesta	7×10^{9}	IAU (1976) Value = 8.3×10^{9}.
<u>Lunar Gravitational Parameters for LLR</u>		The values of these parameters are consistent with the DE200/LE200 ephemerides but they are adjustable in LLR.
$\gamma = (B-A)/C$	2.280043×10^{-4}	IAU (1976) Value = 2.278×10^{-4}.
$\beta = (C-A)/B$	6.316769×10^{-4}	IAU (1976) Value = 6.313×10^{-4}.
C/MR^{2*}	0.39053	IAU (1976) Value = 0.392.
I^*	5553".5	IAU (1976) Value = 5552".7 = 1° 32' 32".7.
GM^*	4902.7989 km^3/sec^2	
Love Number (k_2)	0.0222	
Rotational Dissipation (k_2T)	4.643×10^{5} days	
C_{20}	-2.02151×10^{-4}	IAU (1976) Value = -2.027×10^{-4}.
C_{22}^*	2.2302×10^{-5}	IAU (1976) Value = $+2.23 \times 10^{-5}$.
C_{30}	-8.626×10^{-6}	IAU (1976) Value = -6×10^{-6}.
C_{31}	3.071×10^{-5}	IAU (1976) Value = $+2.9 \times 10^{-5}$.
S_{31}	5.6107×10^{-6}	IAU (1976) Value = $+4 \times 10^{-6}$.
C_{32}	4.8348×10^{-6}	IAU (1976) Value = $+4.8 \times 10^{-6}$.
S_{32}	1.684×10^{-6}	IAU (1976) Value = $+1.7 \times 10^{-6}$.
C_{33}	1.436×10^{-6}	IAU (1976) Value = $+1.8 \times 10^{-6}$.
<u>Lunar Gravitational Parameters for LLR (continued)</u>		
S_{33}	-3.3435×10^{-7}	IAU (1976) Value = -1×10^{-6}.
C_{40}	1.5×10^{-7}	

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
C_{41}	-7.18×10^{-6}	
S_{41}	2.95×10^{-6}	
C_{42}	-1.440×10^{-6}	
S_{42}	-2.884×10^{-6}	
C_{43}	-8.5×10^{-8}	
S_{43}	-7.89×10^{-7}	
C_{44}	-1.549×10^{-7}	
S_{44}	5.64×10^{-8}	

*Derived Constants

DYNAMICAL MODELS

Geopotential		
- Laser Satellites		
Lageos	GEM-T3, truncated at degree and order 20	See Chapter 6.
GPS, Etalon	GEM-T3, truncated at degree and order 8	See Chapter 6.
- LLR	IAU (1976) zonals through degree 4 for DE200/LE200.	
Solid Earth Tides		
- Lageos, GPS, Etalon		See Chapter 7.
Ocean Tides		
- Lageos, GPS, Etalon	Schwiderski Ocean Tide Model	See Chapter 8.
Non-gravitational Force Parameters (Area and Mass)		
- Lageos	$A = 0.283 m^2$, $m = 407$ kg	
- Etalon-1, -2	$A = 1\ 315 m^2$, $m = 1346$kg	
- GPS (Satellite Dependent)		See Fliegel, *et al.* (1992)
Radiation Pressure		
	See Chapter 12.	
- Reflectance Model		See Chapter 12.
- Earth Radiation Pressure	Ignored	For GPS see Fliegel (1992).
- Penumbra Model	6 402 km	Radius of Earth for shadow model.
	1 738 km	Radius of Moon for shadow model.
	696 000 km	Radius of Sun for shadow model
Along-Track Force		
- Lageos, Etalon-1, -2	$C_T \times 10^{-12} ms^{-2}\bar{v}/v$ per unit mass	C_T is an adjusted parameter.
Other Non-gravitational Force		
- GPS	y-bias, C_Y	C^Y is an adjusted parameter for each satellite

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Relativistic Corrections		
- Propagation		
- LLR	Retardation due to Sun and Earth	See Chapter 14.
- VLBI	Retardation and bending due to Sun, Earth, and Moon	See Chapter 14.
- SLR	Retardation due to Earth	See Chapter 14.
- GPS	Retardation due to Earth	See Chapter 14
- Time Epoch and Interval		
- LLR, VLBI	Annual, diurnal, and other periodic terms	See Chapter 13.
- SLR, GPS	none	See Chapter 13.
- Dynamics		
- LLR	Barycentric (n-body) formulation ($\beta=\gamma=1$)	See Chapter 13.
- SLR	Geocentric (1-body) formulation ($\beta=\gamma=1$)	See Chapter 13.
- GPS	Geocentric (1-body) formulation ($\beta=\gamma=1$)	See Chapter 13.
Secular Acceleration of the Moon,	$\dot{n}$ = -24.9 arcsec cy^{-2}	$\dot{n}$ is an adjusted parameter in LLR. IAG (1991) Value.
MEASUREMENT MODEL		
Troposphere		
- SLR and LLR	Surface meteorology measurement plus Marini and Murray Model (1973).	See Chapter 11.
- VLBI		See Chapter 11. Water vapor radiometry if available-otherwise use model plus possible adjustment of vertical delay.
- GPS		See Chapter 11.

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Satellite Center of Mass Correction		
- Lageos	0.251 m	This may vary depending on detection type for site.
- Etalon-1, -2	0.558 m	
- GPS Block I	dx = 0.210 m dy = 0.0 m dz = 0.854 m	dx, dy, dz are given in the satellite body-fixed coordinate frame (Fliegel, 1991).
-GPS Block II	dx = 0.2794 m dy = 0.0 m dz = ~~1.0229~~ m 0.9519 m	dx, dy, dz are given in the satellite body-fixed coordinate frame (Fliegel, 1991). Unit vectors for the body fixed coordinates are given by $\hat{k}$, defined as a unit vector pointing from the satellite center of mass to the center of the Earth; $\hat{j}$, defined by $\hat{j} = \hat{k} \times \hat{S}$, where $\hat{S}$ is a unit vector pointing from the center of mass of the satellite to the Sun, assuming the cross product is not zero; and $\hat{i}$, determined by $\hat{i} = \hat{j} \times \hat{k}$. Within 3 degrees of Earth-Sun-satellite line, only the correction to the x-coordinate is made
Solid Earth Tides Displacement	Wahr Solid Tide Model	See Chapter 7.
Ocean Loading Site Displacement	Schwiderski tides	See Chapter 10.
REFERENCE SYSTEMS	1984 Conventions except as noted.	
Conventional Inertial System	Mean equinox and equator of J2000.0	See Chapter 2.
Time Synchronization	UTC as given by BIPM	If using UTC(USNO), then use UTC(USNO)-UTC(BIPM) as published by BIPM to correct to UTC(BIPM).
Precession	IAU 1976	See Lieske, *et al.* (1977) for application.
Nutation	IAU 1980	Based on Wahr Theory. Reference pole is the Celestial Ephemeris Pole (CEP). See Chapter 4.
Terrestrial Reference Frame		See Chapter 3.
Tidal Variations in UT1		See Chapter 10.
VLBI Radio Source Positions and Designations		See Chapter 2.
Tectonic Motion	NUVEL No Net Rotation	See Chapter 3.

ITEM	RECOMMENDED VALUE	COMMENT
Ephemeris System	Astronomical Almanac, 1984 (DE200/LE200).	Uses the Equinox and Equator of J2000.0. Origin in right ascension is set equal to the dynamical equinox of J2000.0. See Chapter 5.
Lunar Reference Frame		
- Retro-Reflector Coordinates (meters)		These coordinates are consistent with the DE200/LE200 ephemeris system but they are adjustable in LLR.

Apollo 11

	X1	X2	X3
PA	1592012.174	690605.998	21006.310
ME	1591752.786	691221.955	20394.850
	R	LONG	LAT
PA	1735477.073	23.45093088	.69352820
ME	1735477.073	23.47299617	.67333975

Apollo 14

	X1	X2	X3
PA	1652662.237	-521095.647	-109727.640
ME	1652821.419	-520455.963	-110364.156
	R	LONG	LAT
PA	1736339.050	-17.50041767	-3.62321101
ME	1736339.050	-17.47866283	-3.64425710

Apollo 15

	X1	X2	X3
PA	1554686.268	98004.046	765010.082
ME	1554942.413	98604.650	764412.078
	R	LONG	LAT
PA	1735481.089	3.60702873	26.15530389
ME	1735481.089	3.62847880	26.13331104

ITEM	RECOMMENDED VALUE				COMMENT
Lunakhod 2					
		X1	X2	X3	
	PA	1339413.779	801793.356	756361.607	
	ME	1339394.295	802310.618	755847.426	
		R	LONG	LAT	
	PA	1734642.539	30.90537743	25.85105146	
	ME	1734642.539	30.92203167	25.83218088	

PA = Principal Axis Coordinates
ME = Mean Earth Coordinates

Rotation Angles between mean Earth and principal axis coordinates are tau = 79.815, P1 = -79.350, P2 = 0.295 arcseconds.