1 General definitions and numerical standards (16 November 2017)

This chapter provides definitions for some topics that are relevant to several chapters of the document, such as the tide systems in Section 1.1 and the units of relativistic time scales and associated quantities in Section 1.2. The latter section also provides the values of numerical standards that are used in the document. Those are based on the most recent reports of the appropriate working groups of the International Association of Geodesy (IAG) and the International Astronomical Union (IAU) which can be found in the references below Table 1.1.

1.1 Permanent tide

Some geodetic parameters are affected by tidal variations. The gravitational potential in the vicinity of the Earth, which is directly accessible to observation, is a combination of the tidal gravitational potential of external bodies (the Moon, the Sun, and the planets) and the Earth's own potential which is perturbed by the action of the tidal potential. The (external) tidal potential contains both time-independent (permanent) and time-dependent (periodic) parts, and so does the tide-induced part of the Earth's own potential. Similarly, the observed site positions are affected by displacements associated with solid Earth deformations produced by the tidal potential; these displacements also include permanent and time-dependent parts. Removing the time-dependent part of the tidal contributions from the observed site positions/potential, the resulting station positions are on the "mean tide" (or simply "mean") crust; and the potential which results is the "mean tide" potential. The permanent part of the deformation produced by the tidal potential is present in the mean crust; the associated permanent change in the geopotential, and also the permanent part of the tidal potential, are included in the mean tide geopotential. These correspond to the actual mean values, free of periodic variations due to tidal forces. The "mean tide" geoid, for example, would correspond to the mean ocean surface in the absence of non-gravitational disturbances (currents, winds). In general, quantities referred to as "mean tide" (*e.g.* flattening, dynamical form factor, equatorial radius, *etc.*) are defined in relation to the mean tide crust or the mean tide geoid.

If the deformation due to the permanent part of the tidal potential is removed from the mean tide crust, the result is the "tide free" crust. Regarding the potential, removal of the permanent part of the *external* potential from the mean tide potential results in the "zero tide" potential which is strictly a geopotential. The permanent part of the deformation-related contribution is still present; if that is also removed, the result is the "tide free" geopotential. It is important to note that unlike the case of the potential, the term "zero tide" as applied to the *crust* is synonymous with "mean tide."

In a "tide free" quantity, the total tidal effects have been removed with a model. Because the perturbing bodies are always present, a truly "tide free" quantity is unobservable. In this document, the tidal models used for the geopotential (Chapter 6) and for the displacement of points on the crust (Chapter 7) are based on nominal Love numbers; the reference geopotential model and the terrestrial reference frame, which are obtained by removal of tidal contributions using such models, are termed "conventional tide free." Because the deformational response to the permanent part of the tide generating potential is characterized actually by the secular (or fluid limit) Love numbers (Munk and MacDonald, 1960; Lambeck, 1980), which differ substantially from the nominal ones, "conventional tide free" values of quantities do *not* correspond to truly tide free values that would be observed if tidal perturbations were absent. The true effect of the permanent tide could be estimated using the fluid limit Love numbers for this purpose, but this calculation is not included in this document because it is not needed for the tidal correction procedure.

Resolution 16 of the 18th General Assembly of the IAG (1984), "recognizing the need for the uniform treatment of tidal corrections to various geodetic quantities such as gravity and station positions," recommended that "the indirect effect due to the permanent yielding of the Earth be not removed," *i.e.* recommends the use of "zero-tide" values for quantities associated with the geopotential and "mean-tide" values for quantities associated with station displacements. This recommendation, however, has not been implemented in the algorithms used for tide modeling by the geodesy community in the analysis of space geodetic data in general. As a consequence, the station coordinates that go with such analyses (see Chapter 4) are "conventional tide free" values.

The geopotential can be realized in three different cases (*i.e.*, mean tide, zero tide or tide free). For those parameters for which the difference is relevant, the values given in Table 1.1 are "zero-tide" values, according to the IAG Resolution.

The different notions related to the treatment of the permanent tide are shown pictorially in Figures 1.1 and 1.2.

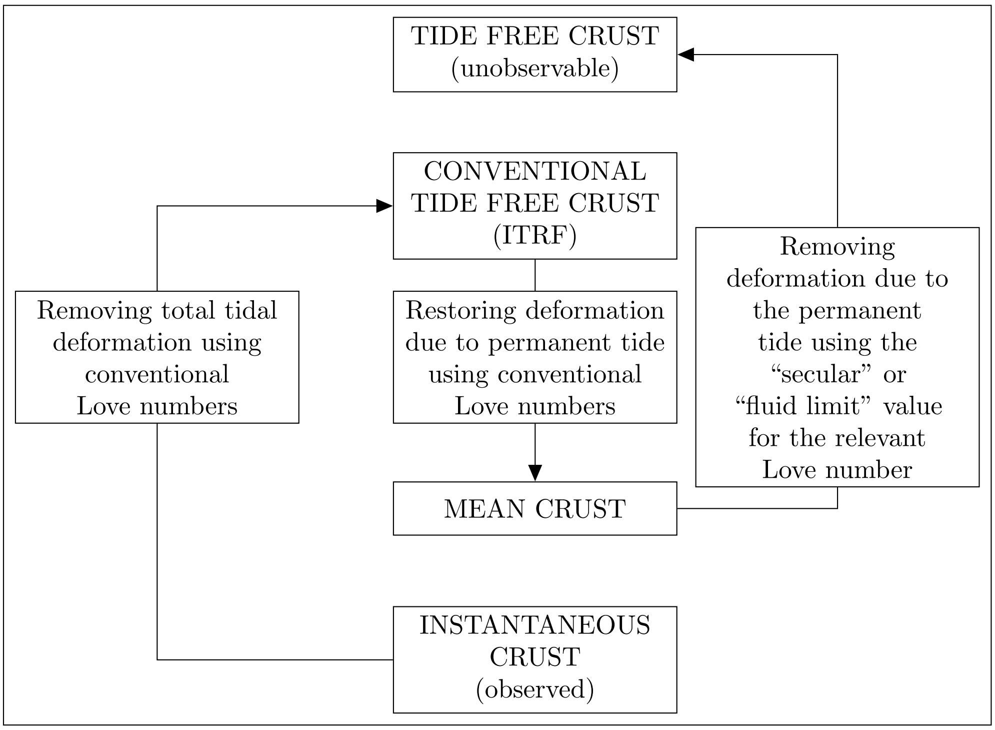

Figure 1.1: Treatment of observations to account for tidal deformations in terrestrial reference systems (see Chapters 4 and 7).

1.2 Numerical standards

Table 1.1, that lists adopted numerical standards, is organized into 5 columns: constant, value, uncertainty, reference, and description. Values of defining constants are provided without an uncertainty. The IAU (2009) System of Astronomical Constants (Luzum *et al.*, 2010) is adopted for all astronomical constants which do not appear in Table 1.1. Note that, except for defining constants, the values correspond to best estimates which are valid at the time of this publication and may be re-evaluated as needed. They should not be mistaken for conventional values, such as those of the Geodetic Reference System GRS80 (Moritz, 2000) shown in Table 1.2, which are, for example, used to express geographic coordinates (see Chapter 4).

Unless otherwise stated, the values in Table 1.1 are TCG-compatible or TCB-compatible, *i.e.* they are consistent with the use of Geocentric Coordinate Time TCG as a time coordinate for the geocentric system, and of Barycentric Coordinate Time TCB for the barycentric system. Note that for astronomical constants such as mass parameters GM of celestial bodies having the same value in BCRS and GCRS, the formulations "TCB-compatible" and "TCG-compatible" are equivalent and the values may be called "unscaled" (Klioner *et al.*, 2010). In this document some quantities are also given by TT-compatible values, having been determined using Terrestrial Time TT as a time

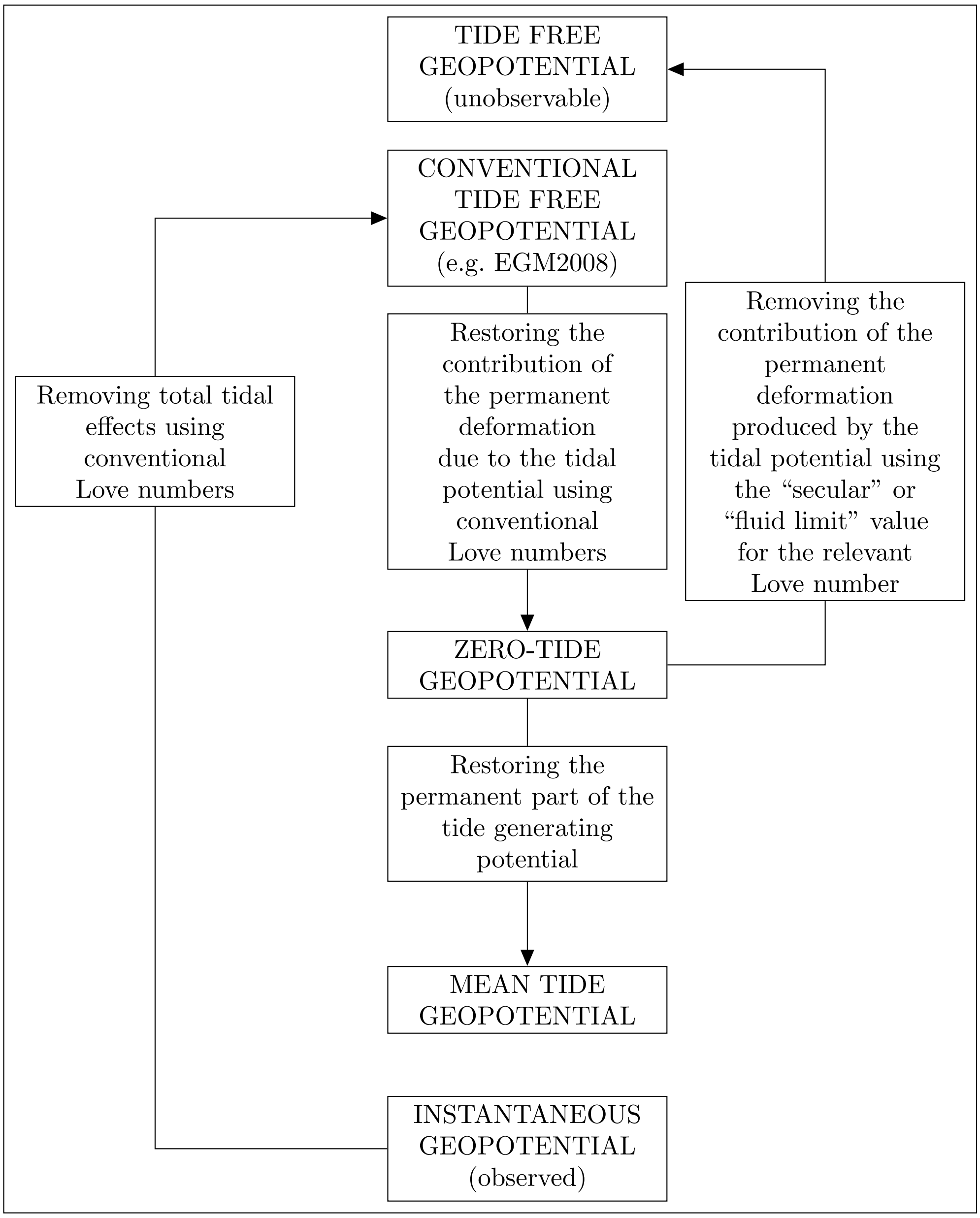

Figure 1.2: Treatme nt of observations to account for tidal effects in the geopotential (see Chapter 6).

coordinate for the geocentric system. See Chapter 10 for further details on the transformations between time scales and Chapter 3 for a discussion of the time scale used in the ephemerides.

Using SI units (*Le Système International d'Unités (SI)*, 2006) for proper quantities, coordinate quantities may be obtained as TCB-compatible when using TCB as coordinate time or as TDB-compatible when using TDB as a coordinate time (Klioner *et al.*, 2010). The two coordinate times differ in rate by $(1-L_B)$, where L_B is given in Table 1.1. Therefore a quantity x with the dimension of time or length has a TCB-compatible value x_{TCB} which differs from its TDB-compatible value x_{TDB} by

$$x_{TDB} = x_{TCB} \times (1 - L_B).$$

Table 1.1: IERS numerical standards.

Constant	Value	Uncertainty	Ref.	Description
	Natural defining constants			
c	$299792458\ \mathrm{ms}^{-1}$	Defining	[1]	Speed of light
	Auxiliary defining constants			
k	$1.720209895 \times 10^{-2}$	Defining	[2]	Gaussian gravitational constant
L_G	$6.969290134 \times 10^{-10}$	Defining	[3]	1−d(TT)/d(TCG)
L_B	$1.550519768 \times 10^{-8}$	Defining	[4]	1−d(TDB)/d(TCB)
TDB_0	-6.55×10^{-5} s	Defining	[4]	TDB−TCB at JD 2443144.5 TAI
θ_0	0.7790572732640 rev	Defining	[3]	Earth Rotation Angle (ERA) at J2000.0
$d\theta/dt$	1.00273781191135448 rev/UT1day	Defining	[3]	Rate of advance of ERA
	Natural measurable constant			
G	$6.67428 \times 10^{-11}\ \mathrm{m^3kg^{-1}s^{-2}}$	$6.7 \times 10^{-15}\ \mathrm{m^3kg^{-1}s^{-2}}$	[1]	Constant of gravitation
	Body constants			
$GM_\odot$ #	$1.32712442099 \times 10^{20}\ \mathrm{m^3s^{-2}}$	$1 \times 10^{10}\ \mathrm{m^3s^{-2}}$	[5]	Heliocentric gravitational constant
$J_{2\odot}$	2.0×10^{-7}	(adopted for DE421)	[5]	Dynamical form factor of the Sun
μ	0.0123000371	4×10^{-10}	[6]	Moon-Earth mass ratio
	Earth constants			
$GM_\oplus$ †	$3.986004418 \times 10^{14}\ \mathrm{m^3s^{-2}}$	$8 \times 10^{5}\ \mathrm{m^3s^{-2}}$	[7]	Geocentric gravitational constant
a_E †‡	6378136.6 m	0.1 m	[8]	Equatorial radius of the Earth
$J_{2\oplus}$ ‡	1.0826359×10^{-3}	1×10^{-10}	[8]	Dynamical form factor of the Earth
$1/f$ ‡	298.25642	0.00001	[8]	Flattening factor of the Earth
g_E †‡	$9.7803278\ \mathrm{ms}^{-2}$	$1 \times 10^{-6}\ \mathrm{ms}^{-2}$	[8]	Mean equatorial gravity
2017/11/06 W_0	$62636853.4\ \mathrm{m^2s^{-2}}$	$0.02\ \mathrm{m^2s^{-2}}$	[10]	Potential of the geoid
R_0 †	6363672.6 m	0.1 m	[8]	Geopotential scale factor ($GM_\oplus/W_0$)
H	3273795×10^{-9}	1×10^{-9}	[9]	Dynamical flattening
	Initial value at J2000.0			
ϵ_0	$84381.406''$	$0.001''$	[4]	Obliquity of the ecliptic at J2000.0
	Other constants			
au ††	$1.49597870700 \times 10^{11}$ m	3 m	[6]	Astronomical unit
L_C	$1.48082686741 \times 10^{-8}$	2×10^{-17}	[3]	Average value of 1−d(TCG)/d(TCB)

TCB-compatible value, computed from the TDB-compatible value in [5].

† The value for $GM_\oplus$ is TCG-compatible. For a_E, g_E and R_0 the difference between TCG-compatible and TT-compatible is not relevant with respect to the uncertainty.

‡ The values for a_E, $1/f$, $J_{2\oplus}$ and g_E are "zero tide" values (see the discussion in Section 1.1 above). Values according to other conventions may be found in reference [8].

†† TDB-compatible value. An accepted definition for the TCB-compatible value of au is still under discussion.

[1] Mohr *et al.*, 2008.

[2] Resolution adopted at the IAU XVI General Assembly (Müller and Jappel, 1977), see `http://www.iau.org/administration/resolutions/general_assemblies/`.

[3] Resolution adopted at the IAU XXIV General Assembly (Rickman, 2001), see `http://www.iau.org/administration/resolutions/general_assemblies/`.

[4] Resolution adopted at the IAU XXVI General Assembly (van der Hucht, 2008), see `http://www.iau.org/administration/resolutions/general_assemblies/`.

[5] Folkner *et al.*, 2008.

[6] Pitjeva and Standish, 2009.

[7] Ries *et al.*, 1992. Recent studies (Ries, 2007) indicate an uncertainty of $4 \times 10^5\ \mathrm{m^3s^{-2}}$.

[8] Groten, 2004.

[9] Value and uncertainty consistent with the IAU2006/2000 precession-nutation model, see (Capitaine *et al.*, 2003).

2017/11/06 **[10]** Resolution No. 1 adopted at the IAG (2015), see `https://iag.dgfi.tum.de/fileadmin/IAG-docs/IAG_Resolutions_2015.pdf`.

Table 1.2: Parameters of the Geodetic Reference System GRS80

Constant	Value	Description
$GM_\oplus$	3.986005×10^{14} m^{3}s^{-2}	Geocentric gravitational constant
a_E	6378137 m	Equatorial radius of the Earth
$J_{2\oplus}$	1.08263×10^{-3}	Dynamical form factor
ω	7.292115×10^{-5} rads^{-1}	Nominal mean Earth's angular velocity
$1/f$	298.257222101	Flattening factor of the Earth

Similarly, a TCG-compatible value x_{TCG} differs from a TT-compatible value x_{TT} by

$$x_{TT} = x_{TCG} \times (1 - L_G),$$

where L_G is given in Table 1.1.

As an example, the TT-compatible geocentric gravitational constant is $3.986004415 \times 10^{14}$ m^{3}s^{-2}, as obtained from the above equation applied to the TCG-compatible value from Table 1.1. It shall be used to compute orbits in a TT-compatible reference frame, see Chapter 6. Most ITRS realizations are given in TT-compatible coordinates (except ITRF94, 96 and 97), see Chapter 4.

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