
**Geographic information — Geodetic
references —**

Part 1:
**International terrestrial reference
system (ITRS)**

Information géographique — Références géodésiques —

Partie 1: Système international de référence terrestre (ITRS)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics*.

A list of all parts in the ISO 19161 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides the basic information and definitions related to the International Terrestrial Reference System (ITRS), its realizations and how to access these realizations. These are consistent with the conventions adopted by the international scientific organizations that created this concept, which are the International Union of Geodesy and Geophysics (IUGG), specifically its association in charge of geodesy, the International Association of Geodesy (IAG), and the International Astronomical Union (IAU).

The various realizations of ITRS are then presented as crust-based reference frames, which are global, regional or local, and as satellite ephemerides, such as those broadcasted by satellite navigation systems.

[Annex A](#) of this document describes the access methods to ITRS and the various processes required to determine positions expressed in this system.

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Geographic information — Geodetic references —

Part 1: International terrestrial reference system (ITRS)

1 Scope

This document provides the basic information and the requirements related to the International Terrestrial Reference System (ITRS), its definition, its realizations and how to access and use these realizations.

This document:

- describes ITRS following the definitions and terminology adopted by the International Union of Geodesy and Geophysics (IUGG), the International Association of Geodesy (IAG) and the International Astronomical Union (IAU);
- describes different categories of ITRS realizations: its primary realization, labelled the International Terrestrial Reference Frame (ITRF), other existing realizations of reference systems that are mathematically derived from the ITRS, and realizations that are aligned to the ITRF, such as GNSS-specific reference frames;
- categorizes procedures for realizing the ITRS.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 coordinate system

set of mathematical rules for specifying how coordinates are to be assigned to points

[SOURCE: ISO 19111:2019, 3.1.11]

3.2 geocentric terrestrial reference system GTRS

system of geocentric space-time coordinates within the framework of General Relativity, co-rotating with the Earth and related to the Geocentric Celestial Reference System by a spatial rotation which takes into account the Earth's orientation parameters

[SOURCE: IAG and IUGG resolutions of 1991 and 2007]

3.3

positioning process

computational process that determines, directly from measurements, the geodetic coordinates of points (absolute positioning), or that derives geodetic coordinates of points from previously determined geodetic coordinates (relative positioning)

3.4

satellite ephemeris

numerical representation of the trajectory of the centre of mass of an Earth orbiting artificial satellite expressed in an Earth centred *terrestrial reference frame* (3.5)

3.5

terrestrial reference frame

TRF

realization of a *terrestrial reference system* (TRS) (3.6), by specifying its origin, orientation, scale, and its time evolution

Note 1 to entry: The realization is achieved through a set of physical points with precisely determined coordinates in a specific *coordinate system* (3.1), which may include the rate of coordinate change.

Note 2 to entry: The realization is called static when no rates of coordinate change are defined, and kinematic when rates of coordinate change are defined without considering the underlying forces causing the motion. The realization may be called dynamic when these external forces are considered. "Dynamic" is also used colloquially to describe both the dynamic and kinematic cases without distinction.

[SOURCE: IERS Conventions 2010]

3.6

terrestrial reference system

TRS

set of conventions defining the origin, scale, orientation and time evolution of a spatial reference system co-rotating with the Earth in its diurnal motion in space

Note 1 to entry: The abstract concept of a TRS is realized through a *terrestrial reference frame* (3.5).

Note 2 to entry: In such a system, positions of points attached to the solid surface of the Earth have coordinates which undergo only small variations with time, due to geophysical effects (tectonic or tidal deformations). In the Newtonian framework, the physical space is considered as a Euclidean affine space of dimension 3, with an origin, a scale and an orientation.

[SOURCE: ISO 19111:2019, 3.1.66 — modified: Note 1 to entry has been modified, Note 2 to entry has been added from IERS Conventions 2010]

4 Symbols and abbreviated terms

BeiDou	Chinese satellite-based navigation system
BIH	Bureau International de l'Heure
CGCS2000	China Geodetic Coordinate System 2000
CTRS	Conventional Terrestrial Reference System
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
EOP	Earth Orientation Parameter(s)
EUREF	IAG Sub-Commission 1.3a, Reference Frame Sub-Commission for Europe
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema

GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GTRF	Galileo Terrestrial Reference Frame
GTRS	Geocentric Terrestrial Reference System
IAG	International Association of Geodesy
IAU	International Astronomical Union
IERS	International Earth Rotation and Reference Systems Service
IGS	International GNSS Service
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
JGS	Japan Satellite Navigation Geodetic System
LLR	Lunar Laser Ranging
PCV	Phase Centre Variations
PPP	Precise Point Positioning
PSD	Post-Seismic Deformation
PZ-90	Parametry Zemli 1990
QZSS	Quasi-Zenith Satellite System
RTK	Real Time Kinematic
SLR	Satellite Laser Ranging
TRF	Terrestrial Reference Frame
TRS	Terrestrial Reference System
VLBI	Very Long Baseline Interferometry
WGS 84	World Geodetic System 1984

5 ITRS: overview

The ITRS is defined jointly by the IAU and the IUGG. It is the spatial three-dimensional part of a specific Geocentric Terrestrial Reference System (GTRS) for which the orientation is maintained in continuity with past international agreements (the so-called BIH orientation).

Since 1988 both the monitoring of the definition of ITRS and the determination of its primary realizations, known as ITRF, have been the responsibility of the International Earth Rotation and Reference Systems Service (IERS).

A more detailed description of the ITRS, together with its effective origin, scale and orientation is available in [Annex B](#) (informative).

6 Realizations of ITRS

6.1 Description of a realization of ITRS

A realization of ITRS is any TRF product containing the required numerical information (e.g. a set of static coordinates, or coordinates and velocities) satisfying the definition of origin (centre of mass of the Earth), orientation (no net rotation with respect to the motions of the Earth's surface) and scale (based on the speed of light and the Earth's gravitational constant) of the ITRS and its time evolution.

EXAMPLE 1 A realization of ITRS consists of a set of static coordinates or a set of coordinates and their time evolution, of physical points on the topographical surface of the earth.

EXAMPLE 2 The coordinate sets in a realization of ITRS can refer to each satellite in a constellation.

6.2 Classification of realizations

6.2.1 General

Current ITRS realizations are obtained through processing and analysing datasets sourced from space geodetic techniques. Realizations may be determined using one or more of these techniques. All current realizations consist of a set of identifiers of physical points, with corresponding numerical coordinate information, expressed in a coordinate system (e.g. Cartesian, ellipsoidal).

In this document, the following categories of realizations are distinguished:

6.2.2 Primary realization of ITRS

It is a product created by the IERS under the generic name ITRF. This document does not define these primary realizations nor give any requirements for them, as they are the sole responsibility of IERS^[3] ^[5]. Only a general explanation is provided (see [Annex B](#)).

6.2.3 Secondary realization of ITRS

It is any of the other terrestrial reference frames that are aligned to the ITRF.

Alignment to a TRF uses a 7- or 14-parameter similarity transformation in which all parameter values are zero to give a solution with the same origin, scale, orientation and time evolution as an existing TRF.

For a TRF represented by a data set of estimated station positions, a 7-parameter similarity transformation is used, where the parameters represent the differences in the origin, orientation and scale with respect to an existing TRF.

For a TRF represented by a data set of estimated station positions and velocities, a 14-parameter similarity transformation is used, where the parameters represent the differences in the origin, orientation, scale and their time evolution with respect to an existing TRF at one or more given epoch(s).

Secondary realizations shall be realized or derived from an existing primary or secondary realization that is compliant with this document. They can be referred to as an "implementation" or a "densification" of ITRF.

[Annex C](#) summarizes some of these secondary realizations.

6.3 Types of TRF

6.3.1 General

A realization of ITRS may be represented as coordinates of points valid at a specified epoch, as time series of coordinates at regular epochs (e.g. daily, weekly), or as coordinates given as a function of time following linear and/or non-linear models. The two types of TRF are:

6.3.2 Crust-based TRF

In a crust based TRF, points refer to objects located on the topographic surface of the earth, e.g. geodetic markers or tracking instruments. The set of objects comprising a given TRF defines a geodetic network, which may have global, regional or national coverage.

6.3.3 Satellite Ephemerides based TRF

A satellite-ephemerides-based TRF refers to any numerical representation of the trajectory of the centre of mass of one or more Earth orbiting artificial satellites, expressed in the ITRS.

6.4 Methods for secondary realizations of ITRS

In all secondary realizations of the ITRS, the main criterion to judge that they are compatible with the ITRS consists of demonstrable evidence that they are aligned to a primary or secondary ITRS realization that is compliant with this document.

The methods for determining a secondary realization are specified in the normative [Annex A](#).

7 Conformance of a secondary realization of ITRS

This conformance is achieved if the secondary realization of ITRS is consistent with the following requirements.

Requirement 1

Secondary ITRS realizations represented by a data set of estimated station positions and (if kinematic) velocities, whether static or kinematic, shall be aligned to a primary or secondary ITRS realization that is compliant with this document.

For a static secondary realization of ITRS, the numerical values of the 7 similarity-transformation parameters shall be zeros to the equivalent numerical resolution as the estimated station positions. The parameters shall represent the three-dimensional differences in the origin, orientation and scale, with respect to a primary or secondary ITRS realization that is compliant with this document.

For a kinematic secondary realization of ITRS, the numerical values of the 14 similarity-transformation parameters shall be zeros to the equivalent numerical resolution as the estimated station positions and velocities. The parameters shall represent the three-dimensional differences in the origin, orientation and scale and their temporal rates of change, with respect to a primary or secondary ITRS realization that is compliant with this document.

Requirement 2

For a secondary kinematic ITRS realization, a time series of at least 2,5 years of daily or weekly position solutions shall be used to reliably estimate station velocities^[9].

Requirement 3

For the absolute PPP method of position determination, a set of positions for a globally distributed set of ITRF/IGS stations shall also be estimated for the determination of 7 (for static realizations) or 14 (for kinematic realizations) transformation parameters to confirm alignment with a primary or secondary ITRS realization that is compliant with this document.

Requirement 4

Any GNSS-based secondary ITRS realization stemming from the methods presented in normative [Annex A](#) shall be accompanied with documentation that ensures its compliance with this document. As a minimum, the following items shall be described:

- the primary or secondary ITRS realization that is compliant with this document to which this secondary ITRS realization is aligned;
- the numerical values of the 7 transformation parameters are zeros at the equivalent numerical resolution as the estimated station positions at a defined epoch (possibly at any epoch). The parameters shall represent the three-dimensional differences in the origin, orientation and scale, with respect to the primary or secondary ITRS realization that is compliant with this document;
- input data: types of observations (space geodetic and/or terrestrial observations) and their timespans;
- data processing: software used, analysis strategy, estimated parameters and their standard deviations;
- accessible citation and/or documentation describing the relationship between the specific terrestrial reference frame and an ITRS realization (ITRF) including numerical examples of station coordinates and epochs in both terrestrial reference frames.

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Annex A (normative)

Methods of determining positions in an ITRS realization

A.1 Positioning methods

A.1.1

The ITRS is disseminated through its various primary and secondary realizations, which users have access to. Apart from specific scientific uses, the general use for these realizations is to determine positions that allow access to the ITRS.

There are three basic methods for determining the coordinates of points in either a primary or secondary ITRS realization. These methods can be classified as differential positioning methods, an absolute positioning method, or a 7- or 14-parameter transformation of existing coordinates from a non-ITRS realization to an ITRS realization. This annex describes each of these three methods, which are used to implement secondary ITRS realizations.

A.1.2 Differential positioning methods

There are two classes of differential or relative positioning methods: (1) using differential GNSS observations and, (2) using classical terrestrial measurements of distances and angles.

Differential GNSS methods are based on estimating the coordinate differences or baseline vectors between pairs of points using GNSS carrier phase measurements. Knowing the coordinates of one of a pair of points enables the determination of the coordinates of the other point using the estimated position difference through simple vector addition. There are many variations of this method for both static and real-time applications. In order to obtain positions in a realization of ITRS, the known coordinates must be in the same ITRS realization.

Classical methods are also based on estimating the coordinate differences between points, but using instead terrestrial measurements (observations) of angles, distances and spirit levelling between points. Knowing the coordinates of a minimum number of points and/or the geodetic azimuth between at least one pair of points, the estimated coordinates of the other points can be determined using a least squares adjustment of observations (note that more than the required minimum number of observations are needed in order to perform a least squares adjustment). Due to the better accuracy and economy of using GNSS methods over longer distances, these classical terrestrial survey methods are used primarily for local surveys up to a few km and should not be used for the secondary realization of the ITRS.

Processing GNSS baseline observations of a local, national, regional or global network to produce station coordinates (static or kinematic) falls into this category and is seen as a densification of the ITRF. Such a solution generally includes non-ITRF stations, but a number of ITRF stations (preferably globally distributed) with well-known coordinates are included in the processing in order to facilitate and ensure the best alignment to the ITRF. GNSS satellite orbits and clock parameters, together with EOPs are usually fixed in the processing, but must be compatible with the ITRS defining parameters. General procedures on how to express station coordinates of a GNSS network in the ITRF using the IGS products can be found for instance in^[6], where the following steps are recommended:

- a) Selection of a reference set of known ITRF/IGS stations and collecting their GNSS observations from IGS data centres, covering the time-span of the implied observations. It is highly recommended to select a set of ITRF/IGS stations, as homogeneously and globally distributed as possible, in order to achieve accurate alignment to the current ITRF.

- b) Processing user station data together with data from the selected ITRF/IGS stations, using the preferred GNSS software. In this step, IGS orbits, clock parameters and EOPs should be fixed to the values consistent with the associated ITRF/IGS terrestrial reference frame. If non-IGS products are used, the resulting station coordinates should then be transformed into an ITRS realization. Fixing or tightly constraining ITRF/IGS reference station coordinates should be avoided. Doing so would potentially introduce distortion in the solution due to possible outdated ITRF/IGS station coordinates after some events, such as earthquakes or equipment changes. Moreover, as the ITRF is a kinematic frame, fixing or tightly constraining ITRF/IGS reference station coordinates would also inhibit the geophysical signal embedded in the transformed solution that one may want to preserve.
- c) Propagation of the selected ITRF/IGS station positions at the central epoch of the employed GNSS observations, using the published ITRF/IGS station velocities.
- d) Applications of minimum constraints approach, as detailed in^[6], which is implemented in major scientific software packages. The derived solution will be expressed in the ITRF/IGS frame that is consistent with the used IGS products.
- e) Comparison of the estimated ITRF/IGS reference station positions with the official published values, propagated to the central epoch of the employed observations in step (c), by fitting a similarity transformation of 3, 4 or 7 parameters selected in the minimum constraints application and checking for consistency. The estimated transformation parameters should all be zero. In addition, if large discrepancies (post-fit residuals of the similarity transformation) are found for some stations (exceeding a certain threshold, depending on the targeted accuracy), these stations should be rejected from the ITRF/IGS reference set and the processing chain should be iterated. Care should also be taken of the time interval of the validity of the used IGS/ITRF coordinates, taking into account station position discontinuities caused by earthquakes or equipment changes. In case of a regional or a national network, applying the minimum constraints approach on the three translation components can be sufficient. It is however advised to evaluate the performance (best fit of the similarity transformation) of at least the following three options: translation, translation and scale, all 7 parameters.
- f) The 5 steps described above are recommended when generating a static terrestrial reference frame solution (station coordinates only) using a short time span of GNSS observations (e.g. one day or one week). If the objective is to generate a longer-term kinematic terrestrial reference frame solution (station positions at a reference epoch and station velocities), then a time series of daily or weekly solutions covering at least 2,5 years of continuous observations is recommended^[9]. In that case, a 6th step is required which consists of combining (accumulating) the time series of daily or weekly solutions into a long-term kinematic solution.

A.1.3 Absolute positioning method: Precise Point Positioning (PPP)

Precise point positioning (PPP) is a GNSS-based method for determining individual station positions using known precise satellite orbits and clock corrections along with the code and phase observations of a multi-frequency GNSS receiver. The positions are effectively determined with respect to the known positions of the satellites (orbits). Consequently, the PPP coordinates are obtained in the same terrestrial reference frame as the satellite orbits. In order for the PPP-derived station coordinates to be compatible with an ITRS realization, the satellite orbits (coordinates) and clock corrections should themselves be expressed in the same ITRS realization. The IGS provides such orbit and clock products that are aligned to the latest primary ITRS realization. If non-IGS products are used, the resulting station coordinates should then be transformed into an ITRS realization.

This PPP method is generally used to determine individual station coordinates using 24 hours of GNSS observations.

A.1.4 Transformation method

This method of determining positions in an ITRS realization involves using a similarity transformation (in geodesy also referred to as a Helmert transformation) to realign coordinates in a GNSS-based non-

ITRS realization to an ITRS realization. The 7 transformation parameters (translations, rotations and scale change) may be known or adopted by authoritative sources beforehand or may be computed to provide a best fit of points in the transformed non-ITRS realization to the same known points in the ITRS realization.

When only static coordinates at a given epoch are to be transformed, 7 transformation parameters representing 3 translations, 3 rotations and a scale change at the same epoch are needed. When coordinates at a given epoch and their velocities are to be transformed, 14 parameters representing 3 translations, 3 rotations and a scale change at a given epoch in addition to their temporal rates of change are required.

A.2 Propagation of coordinates from one epoch to another

Station coordinates expressed in an ITRS realization at a given epoch can be propagated to another epoch using the temporal rates of change of the coordinates, representing the motion of the point in the ITRS realization. The motions are represented by a linear rate of change (velocities) and possibly non-linear motions. Non-linear motions can represent sudden discontinuous changes due to changes in equipment (e.g. antenna mounts) and earthquakes, periodic seasonal variations caused by changes in crustal loading (e.g. groundwater variations), and other more complicated motions such as those arising from post-seismic deformation.

The velocities and non-linear changes may be directly estimated for the station from a long time series of data, or they may be predicted from a model, usually representing current crustal motion with respect to the desired ITRS realization. Modelled velocity predictions can often be obtained from national mapping agencies as well as from the scientific literature, e.g [4] and [7].

Annex B (informative)

Description of ITRS and ITRF

B.1 ITRS description following the IERS Conventions (2010)

The IERS is responsible for defining, realizing and promoting the ITRS. The ITRS was formally adopted by the IUGG at its General Assembly in Perugia (2007), through its Resolution 2.

In summary, these texts (IAG and IUGG resolutions of 1991 and 2007, consistent with latest IAU Resolutions) state that:

- GTRS is to be defined from a geocentric non-rotating system by a spatial rotation leading to a quasi-Cartesian system. The geocentric non-rotating system is to be identical to the Geocentric Reference System (GRS) as defined in the IAU resolutions;
- The GTRS origin is the geocentre, considered for the whole Earth system body, including oceans and atmosphere;
- The GTRS time coordinate is TCG (Geocentric Coordinate Time). The scale of the spatial coordinates is consistent with this fact;
- The time evolution of the orientation of GTRS follows a no-net-rotation (NNR) condition with regards to the horizontal Earth surface.

The IAG Resolution of 1991, as well as various scientific and practical considerations, led explicitly to defining the ITRS as three-dimensional. For example, we note that accurate geophysical models are presently developed within the Newtonian framework and that all practical applications (mapping, navigation) consider ITRS as a three-dimensional system.

The IUGG Perugia (2007) text should be read in such a way that the ITRS is assimilated to the spatial part of GTRS (and not to a 4-dimensional coordinate system). The ITRS is therefore fully fixed, considering the statement that its orientation fulfils the international agreements [Bureau International de l'Heure (BIH) orientation]. The practical procedure adopted by the IERS at the beginning of its work led to the consideration that the ITRS orientation coincides with the previous BIH system (called BIH Terrestrial System) at the epoch 1984.0.

The ITRS definition fulfils the following conditions:

- a) It is geocentric, its origin being the centre of mass for the whole Earth, including oceans and atmosphere;
- b) The unit of length is the metre (SI). The scale is consistent with the TCG time coordinate for a geocentric local frame, in agreement with IAU and IUGG (1991) resolutions. This is obtained by appropriate relativistic modelling;
- c) Its orientation was initially given by the conventional BIH orientation at 1984.0;
- d) The time evolution of the orientation is ensured by using a no-net-rotation condition with regards to horizontal tectonic motions over the whole Earth.

B.2 Realization through single or multi-technique

This category designates an ITRS realization obtained using observations (raw data) from one or more space geodesy techniques, along with conventional models (following IERS Conventions). The

estimated parameters may include, but are not limited to station coordinates, satellite orbits, and Earth Orientation Parameters (EOPs) that are all consistent and compatible with the ITRS defining parameters. They are supplied in the form of (1) static coordinates at a given epoch, (2) time series of station coordinates or (3) a long-term solution, such as station coordinates at a given epoch together with linear (and possibly) nonlinear variations with time. The typical space geodesy techniques used in this category are DORIS, GNSS, SLR (including LLR) and VLBI.

B.3 Realization through combination

Several data sets stemming from single or multi-techniques are combined using a mathematical combination model to produce a combined solution satisfying the ITRS defining parameters. The immediate example of such a realization is the ITRF where individual technique (DORIS, GNSS, SLR, and VLBI) solutions are combined together. Another example would be the combined orbit(s) of one or more satellites.

B.4 ITRF description

Primary realizations of the ITRS are produced by the IERS ITRS Centre under the name ITRF. Thirteen ITRF versions have been produced to date, starting with ITRF88 and currently ending with ITRF2014. ITRF2000 and prior solutions used long-term global solutions (comprising station positions and velocities) from four space geodetic techniques (VLBI, SLR, GNSS and DORIS) as input for ITRF generation. Beginning with ITRF2005, time series of station positions and Earth Orientation Parameters (EOPs) are used as input data for the ITRF construction. The current procedure is to combine the technique TRF solutions using a combination model that involves a similarity transformation of 14 parameters. The combination method makes use of local ties in co-location sites where two or more space geodetic techniques are operated. The local ties are used as additional observations with proper variances. They are usually derived from local surveys using either classical geodesy or the global navigation satellite systems (GNSS). As they represent a key element of the ITRF combination, they should be more accurate than, or at least as accurate as, the individual space geodesy solutions incorporated in the ITRF combination.

ITRF solutions are published by the ITRS Centre in Technical Notes, but also in peer reviewed articles [1],[2],[3],[5]. The number following the ITRF designation specifies the last year for which data was used for the formation of the frame. Hence, ITRF2014 designates the frame of a globally distributed set of station positions and velocities constructed in 2015 using data available until the end of 2014 (but until February 14, 2015 for GNSS).

By definition, the ITRF is a secular/linear frame, which is accessible to the users through station positions (X) at a given epoch (t_0) and station velocities (\dot{X}), so that a station position at any epoch (t) is obtained by

$$X(t) = X(t_0) + (t - t_0) \cdot \dot{X}$$

At the time of preparation of this document, the current ITRF version is ITRF2014, whose construction involved two main innovations dealing with the modelling of station nonlinear motions, namely (1) the seasonal (annual and semi-annual) signals present in the time series of station positions and (2) post-seismic deformations (PSD) for 117 sites that were subject to major earthquakes.

Modelling the station seasonal signals is accomplished by adding to the combination model the appropriate parameters (coefficients) of sinusoidal functions, while the PSDs were accounted for, before the stacking, by applying parametric models that were first fitted to IGS daily station position time series. Corrections, predicted by the GNSS fitted models to the nearby stations of the three other techniques (DORIS, SLR and VLBI) at earthquake co-location sites, were then applied before stacking their respective time series.

The main motivation for modelling the periodic (annual and semi-annual) signals is to ensure the most robust estimation of site linear velocities, and therefore they do not form part of the ITRF2014

products. The fitted PSD parametric models, however, do form part of the ITRF2014 products and the users should be aware of their importance and usage, depending on their applications. Failing to do so would introduce position errors at the decimetre level for many stations impacted by PSDs. Full details of the PSD functions and usage are available in^[5] and at the ITRF2014 website (http://itrf.ign.fr/ITRF_solutions/2014/).

The user should recall that by definition, and by construction, the ITRF is a linear (secular) frame, and so the coordinates vary only linearly, with the station velocities provided, even for earthquake sites that have significant post seismic deformation. However, for ITRF2014, the user interested in station positions during the post-seismic trajectory, $X_{PSD}(t)$, of a station subject to PSD, should then add the sum of all PSD corrections to the linearly propagated position, using the following formula:

$$X_{PSD}(t) = X(t_0) + (t - t_0) \cdot \dot{X} + \delta X_{PSD}(t)$$

where $\delta X_{PSD}(t)$ is the total sum of PSD corrections at epoch t .

The ITRF2014 PSD parametric models, together with all equations required to compute the PSD correction, $X_{PSD}(t)$, and Fortran subroutines are available at the ITRF2014 website (http://itrf.ign.fr/ITRF_solutions/2014/).

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Annex C (informative)

Major reference frames aligned to primary and secondary ITRS realizations

C.1 GNSS-specific terrestrial reference frames

To precisely determine satellite orbits of each GNSS constellation, a specific terrestrial reference frame should be determined and maintained over time. The coordinates of the GNSS-specific ground segment control stations should be expressed in this frame. The orbits computed are then transmitted to the users via the GNSS navigation message that allows for the determination of the user location(s), consistent with those orbits.

In an effort to ensure GNSS interoperability, all currently existing GNSS-specific frames are nominally aligned to ITRS realizations, using different versions of the ITRF: WGS 84 for GPS, PZ-90 for GLONASS, the GTRF for Galileo, CGCS2000 for BeiDou, and the JGS for QZSS.

According to the ICG (International Committee on GNSS) meeting reports (<http://www.unoosa.org/oosa/en/ourwork/icg/icg.html>), all recent and up-to-date GNSS-specific terrestrial reference frames are aligned to a primary ITRS realization.

GNSS-specific frames, other than the GTRF series (described hereafter), are built using GNSS data with short time spans (a few days or one week of data) and are, therefore, consistent with each other and with the ITRF at the level of a few decimetres. However, this level of agreement is certainly well below the inherent and typical uncertainty of the broadcast orbits.

All GNSS-specific terrestrial reference frames are briefly described at the ICG website: <http://www.unoosa.org/oosa/en/ourwork/icg/resources/Regl-ref.html>.

CGCS2000. The China Geodetic Coordinate System 2000 is realized by the China Terrestrial Reference Frame 2000 (CTRF2000) and aligned to ITRF97^[22]. Future plans are to update the CTRF2000 based on ITRF2008.

GTRF. The main requirement for the Galileo Terrestrial Reference Frame (GTRF) is to be compatible with the ITRF at the level of 3 cm^[14]. A series of GTRF versions were determined since the start of the Galileo project, the newest one at the time of preparation of this document is designated as GTRF19v01 and aligned to the ITRF2014. The GTRF frames are represented as station positions and linear velocities, and are aligned to the ITRF, at the level of a few mm and less than 1 mm/yr^[15].

IGS Terrestrial Reference Frames. Since its inception, the IGS has adopted the ITRS defining parameters (origin, scale, orientation and their time evolution) as the basis for its own products (orbits, clocks and Earth Rotation Parameters), through the adoption and usage of ITRF solutions. A series of IGS frames labelled IGSyy (or IGbyy) have been formed by extracting GNSS station coordinates from the corresponding ITRFyy solutions and applying corrections to some ITRF GNSS station coordinates to account for antenna phase centre variations (PCV). Indeed, starting with GPS week 1400 (2006-11-5), the IGS switched from using relative to absolute model PCV corrections. More details about IGS frame elaboration are available in^[19].

At the time of preparation of this document, the most recent IGS terrestrial reference frame available is IGS14, in effect since GPS week 1934 (2017-01-29) and is available at <ftp://igs-rf.ign.fr/pub/IGS14>. It is highly important to understand that IGSyy (or IGbyy) station coordinates inherit and share the same ITRFyy defining parameters (origin, scale, orientation and their time evolution). Therefore in GNSS data processing, when IGSyy (or IGbyy) station coordinates corrected for PCVs are used instead of ITRFyy, the results are still consistent with this document.