The realization of the origin of the terrestrial reference system

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Rationale

- Started as an examination of the treatment of “geocenter motion” in Conventions (2003)
- Conventions (2003) recognized to be inconsistent on this issue
- Investigation of several aspects implies a link with a host of other issues
  - some also covered in other Position Papers at this workshop
  - some (to be) covered in new version of Chapter 4 (TRS/TRF), under way
- Issues
  - Nomenclature for Terrestrial System and Frame
  - Definition of “geocenter motion”
  - Classification of effects that cause “geocenter motion”
  - Description of a conventional treatment for these effects

Goals

1. to describe the present situation in the IERS Conventions (2003)

2. to prepare the next edition of the IERS Conventions
   i. give directions for definitions and notations related to the geocenter and geocenter motion
   ii. describe, in a consistent manner, the practical implementation of the conventional procedures used by Analysis and Product centers, as much as is needed in the IERS Conventions

Discussion of ITRF goals

- Describe the time-varying positions of a network of points
- But cannot represent exactly (≅ the precision of geodetic techniques) the actual instantaneous positions, only to some level of approximation.

- As accuracy and resolution of geodetic data improves, demands for the ITRF also grow.

  ⇒improvement in the representation of regularized positions

  ⇒possible need for a more complex representation of the 'crust fixed' ITRF polyhedron with respect to Centre of Mass of the whole Earth
  - A low order spherical harmonic representation
  - Degree 1 terms are the topic of this talk: geocenter motion
  - Probably not independent of higher order terms

Nomenclature for Terrestrial System and Frame

WARNING: This viewgraph is not an authoritative reference

- Source for first three definitions: IAU WG "Nomenclature for Fundamental Astronomy"
- GTRS: "A system of geocentric space-time coordinates …"
- ITRS: "A specific GTRS ..."

- ITRF: "A realization of ITRS by a set of instantaneous coordinates and velocities of reference points …"
- TRF(t): A set of instantaneous coordinates of points, obtained over an interval centered on date t.

- The last two entities make explicit reference to coordinates, therefore the question of the origin of the system of coordinates is raised.
- Not the purpose of this talk to settle the discussions on what is a system vs. a frame

Geocentric Terrestrial Reference System (GTRS): a system of geocentric space-time coordinates within the framework of General Relativity, co-rotating with the Earth, and related to the GCRS by a spatial rotation which takes into account the Earth orientation parameters. It replaces the previously defined Conventional Terrestrial Reference System.

International Terrestrial Reference System (ITRS*)*: a specific GTRS for which the co-rotation condition is defined as no residual rotation with regard to the Earth's surface**,** and the geocenter is understood as the center of mass of the whole Earth system, including oceans and atmosphere (IUGG Resolution 2, Vienna 1991). It was aligned close to the mean equator of 1900 and the Greenwich meridian, for continuity with previous terrestrial reference systems. The ITRS is the recommended system to express positions on the Earth.

International Terrestrial Reference Frame (ITRF): a realization of ITRS by a set of instantaneous coordinates (and velocities) of reference points distributed on the topographic surface of the Earth (mainly space geodetic stations and related markers). Currently the ITRF provides a model for estimating, to high accuracy, the instantaneous positions of these points, which is the sum of conventional corrections provided by the IERS Convention center (solid Earth tides, pole tides, ...) and of a "regularized" position. At present, the latter is modeled by a piecewise linear function, the linear part accounting for such effects as tectonic plate motion, post-glacial rebound, and the piecewise aspect representing discontinuities such as seismic displacements. The initial orientation of the ITRF is that of the BIH Terrestrial System at epoch 1984.0.

Nomenclature for types of frame and their origin

WARNING: This viewgraph is not an authoritative reference

- Source: (Blewitt, 2003)
- Centre of Mass of the whole Earth (Solid + Fluid) (noted CM)

  Sensed by, and appropriate to describe, satellite dynamics
- Centre of Mass of the Solid Earth (noted CE)

  Natural frame to compute the dynamics of the solid Earth deformation
- Centre of Figure (noted CF)
  - Its origin is such that the surface integral of the displacement field is 0 (no net translation along any axis).
  - This origin is called Geocenter (also Dong et al, 1997; Greff, 2000)
  - Any center of network is just offset from the geocenter

- Name ‘geocenter’ often used for Center of Mass of whole Earth
  - E.g. in IUGG’1991 resolution (“the origin be the geocenter of Earth’s masses”), and because TRF is always said to be geocentric.

- Not the purpose of this talk to have definitive position, just to choose conventional use for the IERS Conventions.

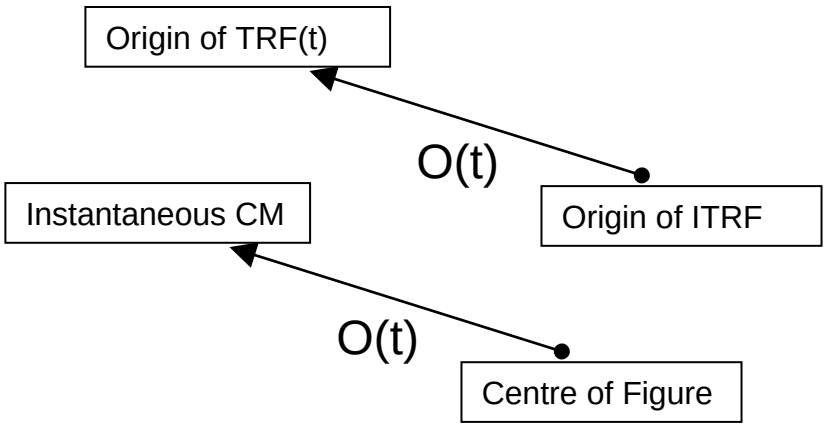
Definitions related to “geocenter motion” (1)

“When the solid Earth and fluid masses are considered as a system without any external forces acting upon it, the position of the common center of mass remains fixed in space. When a phenomenon (such as the ocean tides) causes displacements of fluid masses, the center of mass of the fluid masses moves and must be compensated by an opposite motion of the center of mass of the solid Earth. The stations, being fixed to the solid Earth, are subject to this counter-motion.”

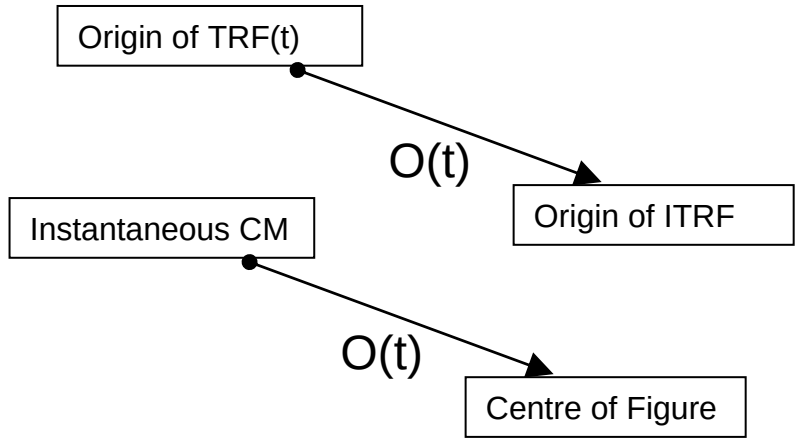
- Only one point has a not too unclear definition/realization, the (instantaneous) center of mass of the total (solid + fluid) Earth: It is realized by the modeling of satellite dynamics. This is CM(t).
- “Geophysicists” wishing to model the effects of mass displacement and “geodesists” wishing to specify coordinates of reference points define a number of geometrically defined frames, which origins can be generically called center of figure (CF).
- “Geocenter motion” is the translation (variable with t) between CM and CF, but in which orientation??

Definitions related to “geocenter motion” (2)

- Orientation of the vector is conventional but has to be specified!!
- Literal meaning of “geocenter motion” implies that geocenter is the arrow of the vector, where the vector describes the motion of the geocenter in some other frame.
- If the Center of Mass is taken as the geocenter, we have (Option 1)
- Blewitt (2003) recalls the variety of choices in the literature, prefers “to express translations with respect to CM, because CM is unperturbed by local redistribution and is the natural reference frame origin for modeling satellite dynamics”. (Option 2)



Option 1



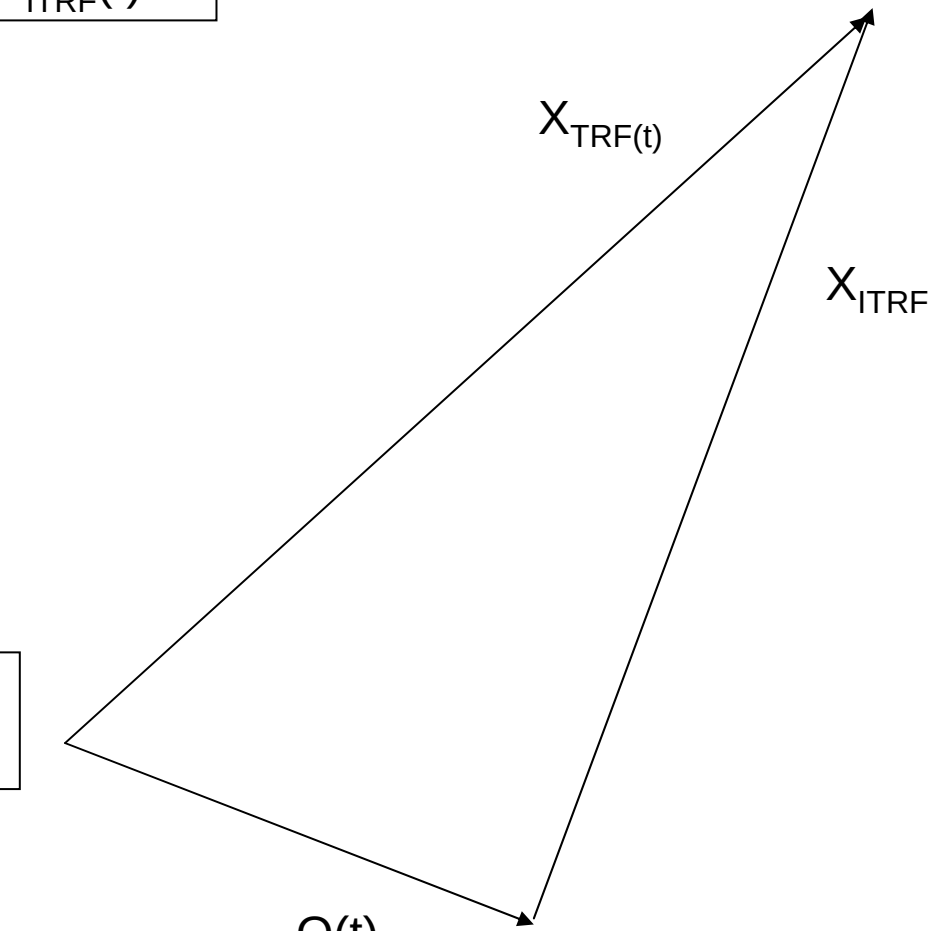
Option 2

Definitions related to “geocenter motion” (3)

- In the IERS context:
  - Ray (1999) chose option 1. This is referenced in IERS Conventions (2003).
  - IGS combination (Ferland et al., 2000) uses Option 2.
  - ITRF product center always uses the translation T that allows to go from ITRF coordinates to obtain TRF(t) (i.e. CM) coordinates: $X_{TRF(t)} = X_{ITRF} + T + \ldots$ therefore Option 2 is used.
  - Chapter 7 update of 25 Nov. 2006 (Section 7.1.1 Ocean loading) introduces vector dX representing the ‘crust-frame translation due to ocan tidal mass’, following convention in the ocean loading service by M.S. Bos and H.-G. Scherneck (http://www.oso.chalmers.se/~loading/). This is Option 2.

- A practical solution: The vector that IERS mentions in documents and data exchange is defined as option 2: From the instantaneous Center of Mass to the origin of the frame of interest. It is conventionally called ”origin translation”.

$X_{TRF(t)} = O(t) + X_{ITRF}(t)$



Classification of effects that cause “geocenter motion”

[These are generic terms, not to be taken too literally]

- Tidal, mostly in the diurnal and semidiurnal bands
  - magnitude is of order 2 mm (ocean loading part, computed from http://www.oso.chalmers.se/~loading/)
- Seasonal (or non-tidal, non-secular)
  - magnitude estimated to be 2-4 mm amplitude for yearly term (see below)
- Long-term / secular
  - magnitude estimated 0.2-0.5 mm/yr (e.g. Greff-Lefftz, 2000)
- Separation between categories not always obvious

Conventional treatment for these effects

	Characteristic time	Models	Conventional Treatment
Tidal	Mostly 0.5 – 1 day (Some long-period)	Available	Model applied at observation level
Seasonal	Mostly 0.5 – 1 year	Available, under study	Removed by long-term average
Long-term	>Decades	Not complete	Included in the time evolution of coordinates.

Situation in the IERS Conventions (2003) Chapter 4

- 4.1.4: Provide a realization of ITRS following IUGG Resolution 2 (1991): origin is the geocenter of Earth's masses including oceans and atmosphere, i.e. a CM frame.
- 4.2.4: ITRF should be considered as a figure origin related to the crust (i.e. a CF frame). Geocenter motion vector relates ITRF and ITRS coordinates.
- 4.1.3: It is stated that the instantaneous vector position X(t) of a point on the Earth's surface can be expressed in the ITRF as X(t) = X_R(t) + Sum{ delta X_i(t) }, where X_R(t) are regularized coordinates and where delta X_i(t) are site-specific conventional corrections to be presented in Chapter 7 for solid Earth tides, ocean tidal loading, pole tide, atmosphere loading and geocenter motion. However in Chapter 7, conventional expressions for the last two cannot be found.

- Last two statements imply that ITRF and ITRS have different types and differ by the geocenter motion.

Situation in the IERS Conventions (2003) Chapter 5

- Coordinate transformation from the TRS to the CRS at the epoch t is:

  $CRS = Q(t)R(t)W(t)\ TRS$ (Equation 1)

- Section 5.10 states that Equation (1) provides the transformation from ITRS to GCRS. It implies that the EOPs in the matrix W are referenced to the CM, and that the same convention should be used when determining EOPs.
- This is formally consistent with the writing in Chapter 4, where ITRS is defined as 'CM'.The application is unclear, as it may be applied using ITRF instead of ITRS and because the definition of ITRF is ambiguous (see above).

Situation in the IERS Conventions (2003) chapter 7

- Conventions (2003) did not mention anything on geocenter.
- Section 7.1.1 (Ocean loading) updated 25 Nov. 2006
  - "For observing techniques that rely upon the dynamical motions of satellites, which respond to the center of mass of the total Earth system, the modeled motions of crust-fixed stations should include the "geocenter motion" contributions that counterbalance the effects of the fluid components. For other observing techniques, such as VLBI, neglect of geocenter motion should have no observable consequences."
  - i.e. in the first case, the coordinates obtained from / used in the analysis are CM; in the second case, the coordinates are CF.
  - This distinction is implemented in the ocean loading service computation (http://www.oso.chalmers.se/~loading/)
  - The formula to compute the ['origin translation'] is also provided.

    $dX(t) = \sum_{(k=1,11)} [X_{in}(k) \cos(\chi_k(t)) + X_{cr}(k) \sin(\chi_k(t))]$
  - This correction should be applied, for instance, in the transformation of GPS orbits from the center-of-mass to the crust-fixed frame expected in sp3 format:

    $$X_{CF} = X_{CM} - dX,$$
  - Note that dX has same convention as our 'origin translation' vector.

Recommendations for future edition of IERS Conventions

- Chapter 4 (TRS/TRF):
  - No term accounting for geocenter motion to appear between ITRS and ITRF.
  - Geocenter motion effects explicitly mentioned in ‘conventional corrections to station coordinates’.
  - Describe the conventional treatment for seasonal effects used for ITRF:

    During the stacking of the SLR weekly solutions, time series of the 7 weekly transformation parameters are estimated with respect to the long-term solution. The time series of the weekly translation components (‘origin translation’) are considered to represent the geocenter motion.

Recommendations for future edition of IERS Conventions

- Chapter 5 (Transformation CRF-TRF):
  - The coordinate transformation [CRS = Q(t)R(t)W(t) TRS] from the TRS to the CRS at the epoch t is more precisely between ITRS and GCRS. When applying it, one must understand that
    - The EOPs in matrix W are referenced to the ITRF origin.
    - ITRF coordinates should be used. $X_{ITRF}(t) = X_{TRF(t)} - O(t)$.
    - [If ICRF coordinates are needed, relativistic coordinate transformations from GCRS to BCRS should be applied.]

- Chapter 7 (Conventional corrections to station coordinates):
  - For all loading effects, indicate how to compute the vector « origin translation », following the example of Ocean loading (update of 25/11/2006).
  - Recommend to use CM frame for all applications? **(To Be Discussed)**

Suggestions / Recommendations

- Form a working group on Nomenclature.

- For IERS applications
  - In dealing with geocenter motion (translation between frames, comparison of models to observed effects etc…), use the vector from the instantaneous center of mass to the center of the geometric frame of interest; name this vector « origin translation ».
  - The "Tidal" component of the origin translation associated to all modeled loading effects should be modeled at the observation level, following the procedure used for Ocean loading in the update 25/11/2006 of Conventions.
  - The "Seasonal" component of the origin translation is to be dealt in the elaboration of ITRF. Chapter 4 of next edition should describe the current conventional procedure.
  - EOP formulation: In the transformation TRS⇒CRS, the EOPs used are referenced to the ITRF origin, and ITRF coordinates should be used.