Standardisation of Geodetic Reference Frames for GNSS based on ITRF

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What is a Terrestrial Reference System (TRS)?

• Stations positions are neither directly observable nor absolute quantities: they have to be determined with respect to some reference

• **TRS**: mathematical model for a physical Earth in which point positions are expressed and have small temporal variations due to geophysical effects (plate motion, Earth tides, etc.)

• It is a spatial reference system co-rotating with the Earth in its diurnal motion in space
International Terrestrial Reference System (ITRS): Definition

- **Origin**: Center of mass of the whole Earth, including oceans and atmosphere
- **Unit of length**: metre SI, consistent with TCG (Geocentric Coordinate Time)
- **Orientation**: consistent with BIH (Bureau International de l’Heure) orientation at 1984.0.
- **Orientation time evolution**: ensured by using a No-Net-Rotation-Condition w.r.t. horizontal tectonic motions over the whole Earth
How a TRS is realized?

- Access to point positions requires measurements (observations) allowing their link to the mathematical object
- **TRF**: Set of physical points with determined coordinates
- The TRF is a realization of the TRS, making use of Space Geodetic observations
- Each technique and data analysis realizes its own TRS
- Many TRF’s exist
Coordinate Systems

- Cartesian: X, Y, Z
- Ellipsoidal: $\lambda$, $\varphi$, $h$
- Mapping: E, N, h
- Spherical: $R$, $\theta$, $\lambda$
- Cylindrical: $l$, $\lambda$, $Z$
The instantaneous position of a point on Earth Crust at epoch $t$ could be written as:

$$X(t) = X_0 + \dot{X}(t - t_0) + \sum_i \Delta X_i(t)$$

- $X_0$: point position at a reference epoch $t_0$
- $\dot{X}$: point linear velocity
- $\Delta X_i(t)$: high frequency time variations:
  - solid Earth tide
  - ocean loading
  - atmosphere loading
  - geocentre motion
Space Geodesy Techniques

• GNSS (GPS, GLONASS, Galileo, …)
• Very Long Baseline Interferometry (VLBI)
• Lunar Laser Ranging (LLR)
• Satellite Laser Ranging (SLR)
• DORIS
International Association of Geodesy
Associated Space Geodesy Services

- International GNSS Service (IGS) (1994)
- International Laser Ranging Service (ILRS) (1998)
- International VLBI Service (IVS) (1999)


- http://www.iag-aig.org
Current Space Geodesy Networks (1999.0 onward)
International Earth Rotation and Reference Systems Service (IERS)

Established 1 January 1988 by IAU and IUGG to realize/maintain/provide:

– The International Celestial Reference System (ICRS)
– The International Terrestrial Reference System (ITRS)
– Earth Orientation Parameters (EOP)
– Geophysical data to interpret time/space variations in the ICRF, ITRF & EOP
– Standards, constants and models (“IERS Conventions”)

http://www.iers.org/
International Terrestrial Reference System (ITRS)

- Realized and maintained by ITRS Product Center of the IERS
- Its realization is called International Terrestrial Reference Frame (ITRF)
- Set of station positions and velocities, estimated by combination of VLBI, LLR, SLR, GPS and DORIS individual TRF solutions
- Based on Co-location sites
- More than 800 stations located on more than 500 sites
- Available: ITRF88, 89,…,2000, latest is ITRF2005

http://www.ensg.ign.fr/ITRF/
Co-location Site

- Site where two or more space geodesy close instruments (hundred metres) are operating
- Precisely surveyed in three dimensions, using classical or GPS geodesy
- Differential coordinates (DX, DY, DZ) are available
ITRF2005 Co-locations

1 Technique (48)  2 Techniques (25)  3 Techniques (6)
Positioning Performance
WRMS range per technique
(Internal Precision – Repeatability)

<table>
<thead>
<tr>
<th>Solution</th>
<th>2-D WRMS mm</th>
<th>Up WRMS mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLBI</td>
<td>2-3</td>
<td>5-7</td>
</tr>
<tr>
<td>SLR</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>GPS</td>
<td>2-3</td>
<td>5-6</td>
</tr>
<tr>
<td>DORIS</td>
<td>12-25</td>
<td>10-25</td>
</tr>
</tbody>
</table>

WARNING! These are indicative numbers and are station dependant
Seasonal Variations GPS/IGS Sites

BAHR Annual Amplitude and Phase (mm)

DRAO Annual Amplitude and Phase (mm)

IRKT Annual Amplitude and Phase (mm)

BAHR

DRAO

IRKT

Second Meeting of the ICG
Bangalore, India, 4-7 September 2007
Access to ITRS

• Direct use of ITRF coordinates
• Use of IGS Products (Orbits, Clocks): all related to ITRF
• Fixing or constraining some ITRF station coordinates in the analysis of GPS measurements
• Use of transformation formulae
World Geodetic System 84 (WGS 84)

- Collection of models including Earth Gravity model, geoid, transformation formulae and set of coordinates of permanent DoD GPS monitor stations
- WGS 60…66…72…84
- Originally based on TRANSIT satellite Doppler data
WGS 84

- TRS of GPS Broadcast Ephemerides
- Recent WGS 84 realizations based on GPS data:
  - G730 in 1994
  - G873 in 1996
  - G1150 in 2002 (NGA used data from 49 IGS stations, fixed with their ITRF2000 coordinates)
- Now coincides with ITRF at few cm level
- For most applications “WGS 84 = ITRF2000”, but ITRF is better realized (a few mm)
GLONASS Reference Frame PZ-90

- IGS monitors daily the transformation between the GLONASS Broadcast message and ITRF (IGS)
- Variations of metres, day to day
- Improved version PZ-90.02 will be applied to GLONASS starting September 20, 2007. “On switching to the International Terrestrial Reference Frame ITRF2000, PZ-90.02 transformation parameters will contain only origin shift along X, Y, Z by -36 cm, +8 cm, +18 cm respectively” (Announcement of 31.8.2007)
Galileo Terrestrial Reference Frame (GTRF)

- Galileo Geodesy Service Provider (GGSP) Prototype
- GGSP Consortium (GFZ, AIUB, ESOC, BKG, IGN) under contract to GSA:
  - Define, realize and maintain the GTRF
  - GTRF to be compatible with the ITRF
  - Liaison with IERS, IGS, ILRS
- GTRF is a realization of the ITRS
- Similar to IGS/GPS: Galileo Orbits, Clocks will be expressed in GTRF (= ITRF to some mm)
GTRF Implementation

• Initial GSS positions and velocities will be provided using GPS observations
• Subsequent GTRF versions will use GPS & Galileo observations
• Weekly solutions will be performed for the long-term maintenance of the GTRF
  – independent solutions by the 3 Analysis Centres of the GGSP consortium (GFZ, AIUB, ESOC)
  – Analysis of the 3 solutions by IGN:
    • Comparison and quality evaluation
    • Combination and alignment to the ITRF
Reference Frames for Global Navigation Satellite Systems

- GPS Broadcast Message uses WGS-84, which is now well-aligned to ITRF
- GLONASS is adopting a new version of PZ-90 which is becoming closer to the ITRF
- Galileo will use a GTRF which will have cm alignment to ITRF
- Japanese, Indian, Chinese systems …?
- IGS currently monitors routinely the GPS and GLONASS reference frames, others in the future
Concluding Remarks

- IAG Services play a major role in realising the ITRS
- GPS and GLONASS are now using reference frames which are gradually approaching ITRF
- Galileo will enhance the ITRF in the future
- Inter-operability: need for standardisation of GNSS reference frames
- Specifically, all future GNSS’s should aim to realise the ITRS at the few cm level or better
- IGS is in a good position to monitor reference frame offsets and stability on routine basis
- Proposal for a WG in ICG, to be discussed in WG-D