Global reference systems and Earth rotation

current realizations and scientific problems

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Satelitarne metody wyznaczania pozycji we współczesnej geodezji i nawigacji

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Contents

System and Frame

We need to make a distinction between reference system and reference frame

System

Reference system is ideal and conventional with specified mathematical and physical properties

Frame

Reference frame is a practical materialization of the system by means of coordinates of reference points obtained using observations

ICRS

The definition of the International Celestial Reference System follows 1991 IAU recommendations according to which:

- origin is located at the barycenter of the solar system through appropriate modeling of VLBI observations in the framework of general relativity
- pole is in direction defined by conventional IAU models of precession and nutation
- origin of right ascension is implicitly defined by fixing right ascension of quasar 3C273B to the FK5 value at epoch J2000.0

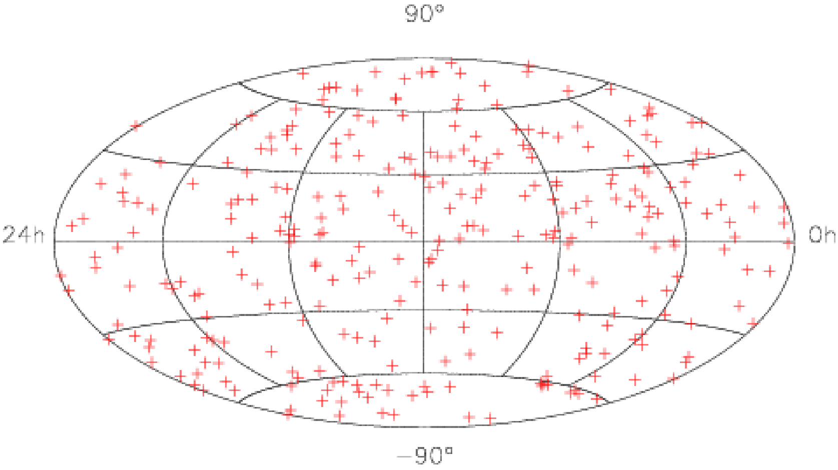
ICRF2

The ICRS is realized by VLBI estimates of equatorial coordinates of extragalactic reference radio sources. The realization is called International Celestial Reference Frame.

The current realization of ICRS at radio frequencies is ICRF2.

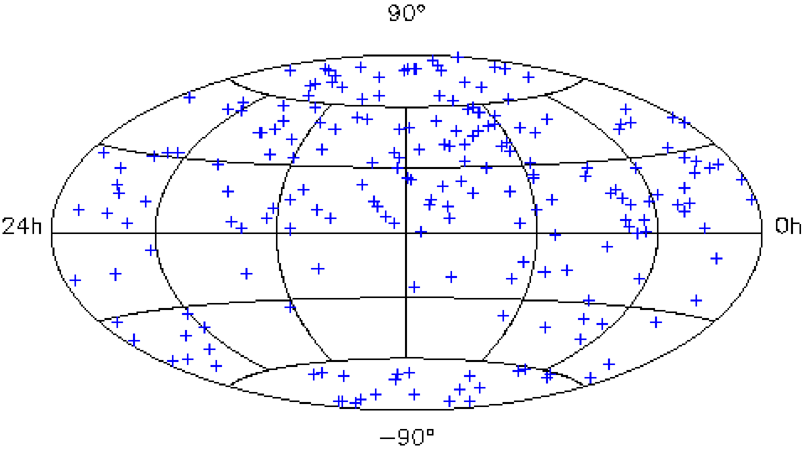
- adopted by IAU General Assmebly 2009
- ICRF2 became official on January 1, 2010.
- based on VLBI observations since 1979.0 to 2009.2.
- axis stability of the ICRF2 is ~ 10 μas (~ 30 μas for ICRF1)
- included 295 defining sources (212 in ICRF1)

ICRF2 – defining sources



295 defining sources (212 in ICRF1-ext2)

ICRF1-ext2 – defining sources



212 defining sources of ICRF1-ext2

International Terrestrial Reference System

The definition of the International Terrestrial Reference System (ITRS) fulfills the following conditions:

- origin in center of mass of the whole Earth, including oceans and atmosphere
- the unit of length is one meter SI (scale consistent with the geocentric coordinate time (TCG))
- orientation initially defined at epoch 1984.0 by Bureau International de l'Heure (BIH)
- orientation time evolution of the system is defined in such a way that there is no net rotation wrt. horizontal tectonic motions over the whole surface of the Earth

ITRF

International Terrestrial Reference Frame (ITRF) is a physical realization of the ITRS:

- it consists of number of physical points with precisely determined coordinates and velocities
- it is realized by means of 4 space geodetic techniques SLR, VLBI, GPS and DORIS (+ local ties)

ITRF2008 is realized in Terrestrial Time (TT) scale

ITRF Realizations

12 realizations have been produced by International Earth Rotation and Reference Systems Service (IERS) since 1988.

The current realization, ITRF2008 was made available in May 2010 (*Altamimi et al., 2011, J. Geodesy*).

Realization details:

- origin of ITRF2008 defined by SLR technique
  - accuracy better than 1 cm, during the time span of SLR observations used
- scale of ITRF2008: mean value of SLR and VLBI solutions
  - accuracy 8 mm for entire time period of SLR and VLBI observations used
- orientation of ITRF2008 defined in that way that there is no rotation wrt. to ITRF2005 at epoch 2005.0 and there are null rotation rates

ITRF2008 – input data

ITRF2008 is based on reprocessed solutions from all 4 techniques. Data span of each technique used for ITRF2008 realization is given in table below:

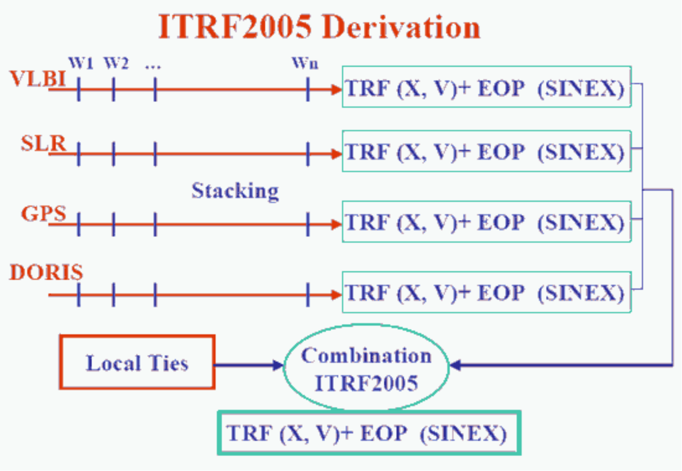
Technique	Data span	Solutions	Technique Center
VLBI	1980.0 – 2009.0	daily	IVS
SLR	1983.0 – 2009.0	weekly	ILRS
GPS	1997.0 – 2009.5	weekly	IGS
DORIS	1993.0 – 2009.5	weekly	IDS

ITRF 2008 – strategy

Since ITRF2005, all ITRF realizations, including the ITRF2008, are performed in two major steps:

1. stacking the individual time series for each technique independently to produce long term solutions. This allows to better handle discontinuities in time series and to remove outliers
2. combination of long term solutions from 4 techniques (step 1) together with the local ties at collocation sites

ITRF2008 – derivation

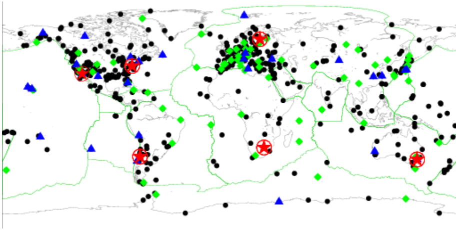


(source: IGN, France)

Local ties at co-location sites

Co-location sites are the key for succesfull combination of all 4 techniques together.
Co-location sites are defined in such way that two or more space geodetic instruments at very close locations wich are precisely surveyed in three dimensions using classical surveys or GPS technique, perform observations simultaneously.

- GPS plays major role in linking other 3 techniques



(source: IERS Conventions 2010)

Transformation btw. 2 TRFs

The transformation between two Terrestrial Reference Frames in linearized form is given below:

$$X_2 = X_1 + T + DX_1 + RX_1,$$

where: T – translation vector, D – scale difference, R – rotation matrix. Parameters of transformation are propagated to epoch t using their rates $P(t) = P(t_0) + \dot{P}(t - t_0)$
And for velocities:

$$\dot{X}_2 = \dot{X}_1 + \dot{T} + \dot{D}X_1 + \dot{R}X_1,$$

Trasformation in reverse direction (from frame '2' to '1') can be written as:

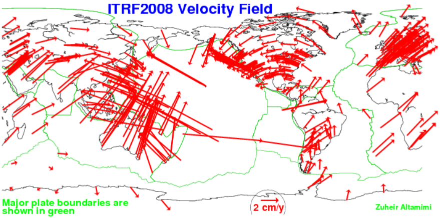
$$X_1 = X_2 - T - DX_2 - RX_2.$$

ITRF

Currently, the following linear model is adopted in ITRF for regularized position:

$$X(t) = X_0(t_0) + V \cdot (t - t_0)$$

where: $X_0(t)$ denotes catalogue coordinates of ITRF site at epoch of appropriate realization ($t_0 = 2005.0$ for ITRF2008), V is ITRF velocity of the site and t is epoch of observation.



source: http://itrf.ensg.ign.fr

ITRF is a conventional tide-free frame (station positions are also corrected for permanent tide).
Instantaneous position at epoch t may be written as:

$$X(t) = X_0(t_0) + V \cdot (t - t_0) + \sum \Delta x(t)$$

$\sum \Delta x(t)$ denotes modeled corrections of geophysical effects i.e. Earth tides, pole tide, ocean loading, atmospheric tidal loading and technique specific corrections which are recommended by IERS Convention 2010 (IERS TN 36).

ITRF

Non-linear motions of stations are not included in ITRF realizations. Seasonal variations are present in time series of coordinate changes.

Application of geophysical models for:

- atmospheric non-tidal loading
- continental water loading

Extended parametrization of seasonal station variations

Measuring and modeling Earth rotation

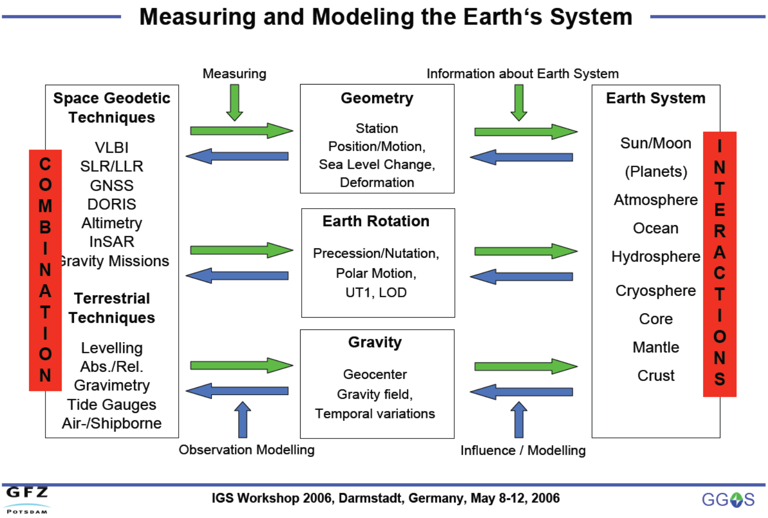
Why so important?

- Realization and maintenance of global reference systems
  - determination and forecasting of the parameters defining the transformation between the terrestrial and geocentric celestial reference systems (ITRS and GCRS, respectively)
- Determination of the Earth's shape, internal constitution and rheology
- Monitoring of large-scale processes taking place in geophysical fluids (atmosphere, ocean, land hydrology and liquid core) expressed by their total angular momentum

Important field of modern geodesy, astronomy and geophysics. The following scientific organizations deal with this subject

- Commission 19 IAU 'Rotation of the Earth'
- Commission 3 IAG 'Geodynamics and Earth rotation'
- IERS

Global Geodetic Observing System (GGOS)



Parametrization of Earth rotation

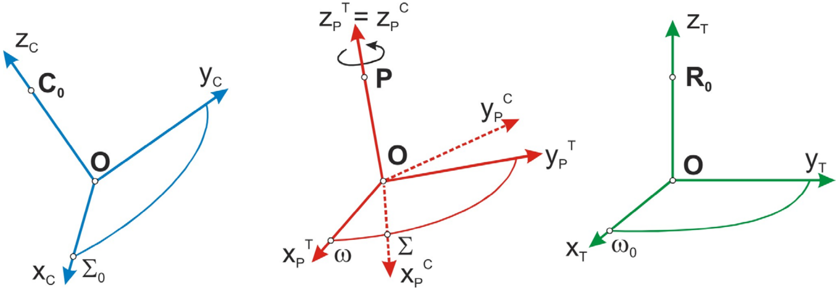
Time dependent transformation between ITRS and GCRS

- expressed as sequence of elementary rotations around the axes of intermediate Cartesian systems
- rotation angles are combinations of the models and the Earth Orientation Parameters (EOP) which are determined from observations

Models

- adopted international standards recommended for use in reductions of space geodetic observations
  - important components defined by resolutions of the IAU General Assemblies (2000, 2006), then confirmed by the IUGG GA's
- computational procedures described in the IERS Conventions (2010) and made available via Internet as computer programs
- programs are also available via Internet in the SOFA (Standards Of Fundamental Astronomy) package

Transformation between GCRS and ITRS



GCRS

Intermediate
Reference Systems

ITRS

$$GCRS = Q(t)R(t)W(t)ITRS$$

$Q(t)$ – celestial motion of the reference pole
$R(t)$ – rotation angle
$W(t)$ – terrestrial motion of the reference pole

Parametrization of Earth rotation

Classification of the IERS models (IERS Conventions 2010)

- class 1: (“reduction”)
  - recommended to be used *a priori* in the reduction of raw space geodetic data; as a rule based on geophysical theories (e.g. precession-nutation model IAU 2000/2006)
- class 2: (“conventional”)
  - models eliminating an observational singularity; as a rule purely conventional in nature (e.g. models defining rotation parameters of ITRF)
- class 3: (“useful”)
  - models, that are not required as either class 1 or 2, nevertheless may be useful in the research (e.g. model of tidal variations in UT1/LOD)

in generation of the IERS products all class 1 models and specified class 2 effects should be applied; class 3 effects should never be included

Parametrization of Earth rotation

Sec.	Cl.	Phenomenon	Amplitude of effect	Conventions 2003	Conventions 2010	Accuracy & difference/improvement between Conventions
5	**Transformation between the ITRS and GCRS**					
5.5.1	1	libration in polar motion	tens of μas	No specific routine	Brzezinski PMSDNUT2 model	Specific routine
5.5.3	1	libration in the axial component of rotation	several μs in UT1	Not available	Brzezinski & Capitaine (2003) UTLIBR model	New model
5.5.4	1	precession-nutation of the CIP	tens of as/yr and tens of as for the periodic part in X and Y	IAU2000 PN	IAU2006/2000 PN	100 μas/c. + 7 mas/c.^{2} in X; 500 μas/c. in Y
5.5.5	3	FCN	Few hundred μas	not available	Lambert model	Accuracy: 50 μas rms, 100 μas at one year extrapolation
5.5.6	1	space motion of the CIO	mas/c.	IAU2000 PN	IAU2006/2000 PN	no change larger than 1 μas after one century

Source: IERS Conventions (2010) – http://www.iers.org

Parametrization of Earth rotation

Detailed description of the transformation between the celestial and terrestrial reference systems can be found in the literature:

- *IERS Conventions (2010)*, (eds.) Gérard Petit and Brian Luzum, IERS Technical Note No. 36, Verlags des Bundesamtes für Kartographie und Geodäsie, Frankfurt am Main 2010.
    - takes into account IAU resolutions (2006, 2009) and recommendations of the IAU Working Group on Nomenclature and Standards in Fundamental Astronomy (NSFA WG)
- *Nowe obowiązujące niebieskie i ziemski systemy i układy odniesienia oraz ich wzajemne relacje*, pod redakcją Jana Kryńskiego, Inst. Geodezji i Kartografii, Seria Monograficzna nr 10, Warszawa 2004. (in Polish)
    - consistent with the IERS Conventions (2003) and resolutions of the IAU GA (2000)

Selected scientific problems

- Improvement of the EOP predictions, particularly those in time scales of days and hours
  - important for global adjustment of space geodetic observatins
  - EOP prediction comparison campaigns
- Diurnal and subdiurnal signals in EOP
  - conventional model of the ocean tide contribution needs improvement
  - irregular geophysical signals in PM and UT1 need monitoring
- Development of the global geophysical models (atmosphere, oceans) and related excitation data (AAM, OAM)
- Development of the monitoring techniques
  - VLBI 2010
  - ring laser