THE ITRF AND ITS SCIENTIFIC APPLICATIONS

L. METIVIER[1], X. COLLILIEUX[1,2], Z. ALTAMIMI[1], D. LERCIER[1]
[1] IGN LAREG, Univ Paris Diderot, Sorbonne Paris Cité
5 rue Thomas Mann, 75205 Paris Cedex 13, France
e-mail: laurent.metivier@ign.fr, xavier.collilieux@ign.fr, zuheir.altamimi@ign.fr, daphne.lercier@ign.fr
[2] SYRTE, Observatoire de Paris, CNRS, UPMC,
61, avenue de l'Observatoire, 75014 Paris, France

ABSTRACT. The ability to assign accurate time-dependent coordinates to points on the Earth's surface is fundamental for many Earth observation applications. Point positions, to be meaningful and fully exploitable, have to be determined in a well-defined Terrestrial Reference Frame. All current global and regional reference frames rely on the availability of the International Terrestrial Reference Frame (ITRF), which is the most accurate realization of the International Terrestrial Reference System (ITRS). Positions and velocities in the last release of the ITRF, entitled ITRF2008, are determined with a precision better than a few millimeters and 1 mm/yr, respectively. This paper focuses on geophysical applications that benefited of the precision and stability of the ITRF. Sea level rise estimations, global plate tectonics, co/post-seismic deformation studies or the interpretation of displacements induced by postglacial rebound or recent ice melting all require an accurate reference frame. Conversely, the knowledge of the expected displacements from geophysical theories and external measurements allows providing constraints on the error budget of the ITRF defining parameters. For future releases of the ITRF, an estimation model that takes into account a more complex modeling of the seismic and loading displacements will be necessary.

1. INTRODUCTION

According to the two International Union of Geodesy and Geophysics (IUGG) resolutions 2 adopted in 1991 and 2007, the International Terrestrial Reference System (ITRS) is the recommended Terrestrial Reference System (ITRS) for Earth science applications. Twelve realizations of the ITRS, called International Terrestrial Reference Frame (ITRF), from ITRF88 to ITRF2008, have been computed since the creation of the International Earth Rotation and Reference Frames Service (IERS). They include the coordinates for several hundreds of stations derived from space geodesy measurements: Global Navigation Satellite System (GNSS), Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI) and Doppler Orbitography Integrated by Satellite (DORIS). Those measurements are analyzed by National Agencies or Universities, in relation with the Technique Services of the IERS. The estimated coordinates are then averaged rigorously combined to obtain long-term coordinates in a well defined TRF that verify ITRS specifications (Petit and Luzum, 2010): see for example Altamimi et al. (2011) for a whole description process of the most recent ITRF computation.

ITRF coordinates are not intended to include all Earth's deformation contributions. Indeed, a few corrections are necessary to restore instantaneous coordinates from ITRF coordinates, see chapter 7 of the IERS conventions (Petit and Luzum, 2010). These corrections mainly include high frequency coordinate variations while the first prerequisite is that corresponding models be available with a sufficient accuracy. Up to now, solid Earth tides, tidal ocean loading, pole tide or atmospheric tides are included in this list. Thus, ITRF coordinates include all residual deformations that could be modeled with piece-wise linear functions of time.

In this paper, we will review the geophysical processes that generate these residual variations and discontinuities in the ITRF coordinates. The study of ITRF coordinate variations and global scale geodynamic processes has revealed that both geophysical model and the ITRF itself could benefit from inter-comparison (Collilieux et al., 2013). While those analyses have been successful, the current level of precision reveals significant geophysical processes that are not yet modeled in ITRF coordinates and that should be considered for next ITRS realizations to comply with the user accuracy requirement.

2. ITRF AND GEOPHYSICAL MODELS

In the previous years, several studies have highlighted how the knowledge of the geophysical processes that take place at geodetic stations help to assess the TRF coordinate accuracy. A geophysical evaluation of the ITRF can be done, either by confronting station velocity estimations at regional scales, or by assessing the consistency between the frame parameters and ITRS specifications. For instance, the frame origin has to be at the Center of Mass of the Earth (CM) at long-period, and the scale is supposed to keep the same definition over time. While an extensive review and classifications of the studies and methods can be found in Collilieux et al. (2013), we review a few relevant examples here.

A domain of applications that particularly needs ITRF accuracy is the measurement of sea level variations (Blewitt et al., 2011). The TRF coordinates are used either as a priori coordinates to compute altimeter satellite orbits or as a reference to correct tide gauges (TGs) measurements for land motion. While some potential reference frame deficiencies would map differently into sea level rise, residual errors cannot be excluded at the 0.1 mm/yr level (Collilieux and Wöppelmann, 2011). However, recent error analyses of the ITRF2008 velocity field, based on geophysical expectations, showed that the potential errors in the ITRF2008 origin motion is likely smaller than 0.5 mm/y along each component (Wu et al., 2011) and that the error in the scale rate is smaller than 0.2 mm/yr (Collilieux and Schmid, 2013). In addition, the assessment of GNSS-corrected TG series located within the same oceanographic region show much more consistent records (Santamaria et al., 2012), which informs about the quality of up to date GNSS and TRF results. In general, post-glacial rebound models are used for TG corrections instead of geodetic results when those are missing. But even for those studies, global velocity field as the one of ITRF2008 has been shown to be a valuable dataset to assess the postglacial rebound model itself. As an example, Métivier et al. (2012) showed that ITRF2008 vertical velocity comparisons with different geophysical models allow discussing some modeling issues and complements results from the GRACE mission. While the postglacial rebound signal is also present in the horizontal ITRF2008 velocity filed, it is shown not to affect drastically the determination of the global plate motion as demonstrated by Altamimi et al. (2012). See figure 1 illustrating the ITRF2008 velocity field.

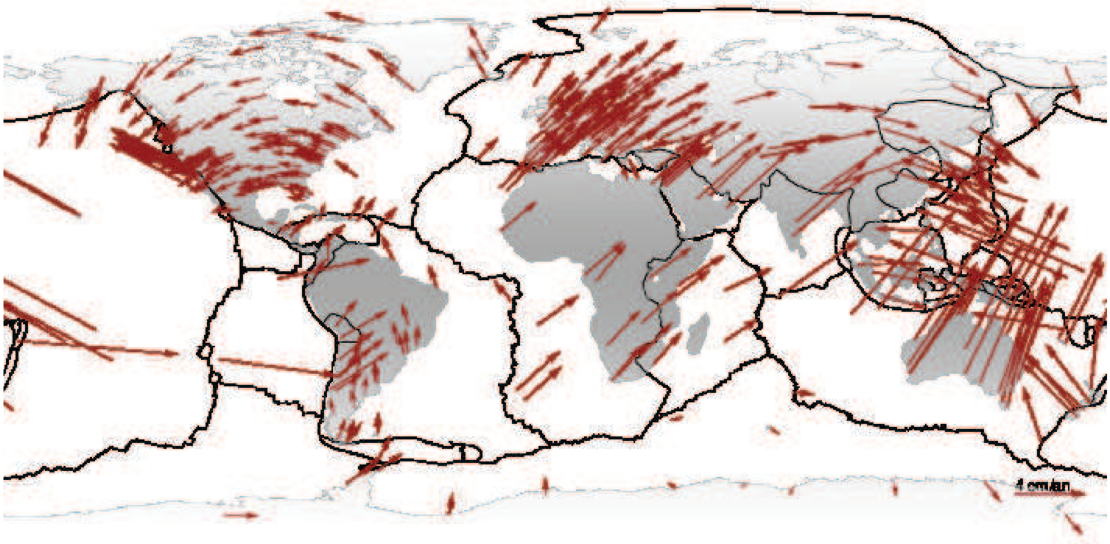

Figure 1: ITRF2008 horizontal velocities.

3. CHALLENGES

As mentioned before, the ITRF2008 is based on a piece-wise linear model for the time evolution of station coordinates. Even if the linear model has proven its efficiency for global positioning on Earth until now, the continuous improvement in the precision of geodetic techniques imposes to realize more accurate and stable reference frames, raising the question of the adequacy of the reference frame model itself. Station position residual time series in ITRF2008 show clear non-linear behaviors that can be attributed to various geophysical phenomena, but also remaining technical systematic errors that would not need to be modeled if they were controlled.

Apart from tides, which are already corrected, the largest non-linear motions that can be observed in geodetic time series are abrupt discontinuities. They are typically due to equipment changes or earthquake ruptures and are generally taken into account in the pre-processing of terrestrial reference frame constructions. However the discontinuity detection remains usually empirical, i.e. mostly based on visual assumptions, which is today a limitation. For instance, it appears that co-seismic deformations may impact significantly GPS positions thousands of kilometers away from the earthquake epicenters, considering the current precision in GPS measurements (Tregoning et al., 2013). Unfortunately, small discontinuities are not always visible in time series due to the level of station seasonal displacements and due to the noise level in geodetic solutions, yet their presence in time series may affect the estimations of the station velocities. This issue calls for more investigations on the systematic treatment of discontinuities in geodetic time series. In addition, after a great earthquake, some of the geodetic stations impacted by the earthquake show non-linear relaxation motions during a few years due to post-seismic deformations. This non-linear behavior is today modeled in reference frame constructions as a piece-wise linear function, which is not accurate enough. At a shorter time scale, geodetic stations are affected by non-tidal loading deformations induced by the atmosphere, the oceans, the ice sheets and continental hydrology. They typically generate annual and semi-annual motions of geodetic stations up to 15 mm but also significant inter-annual displacements as a function of the regional climate (Valty et al., 2014). In addition, the last decade has shown a new class of station non-linear behavior in the form of global station accelerations in different regions. Fig. 2 shows the case of the GPS and DORIS stations located in Thule, in Greenland. These stations all present a net acceleration in their vertical components, probably due to the Greenland ice sheet retreat induced by recent global climate changes (Khan et al., 2010). The climate evolution also impact the position of the CM (Métivier et al., 2010, 2011), which might be a future issue for the determination of the ITRF origin if the effect is significant.

Considering the necessity today to gain one order of magnitude in reference frame precision, a major challenge will be to incorporate those non-linearity behaviors in the ITRF model for the time evolution of station coordinates and/or frame parameters. Different approaches may be investigated: either correcting the geodetic time series from geophysical models before the construction of the ITRF, which raises the issue of the models quality and their evaluation, or incorporating new degrees of freedom in the ITRF model in the form of non-linear parametric functions.

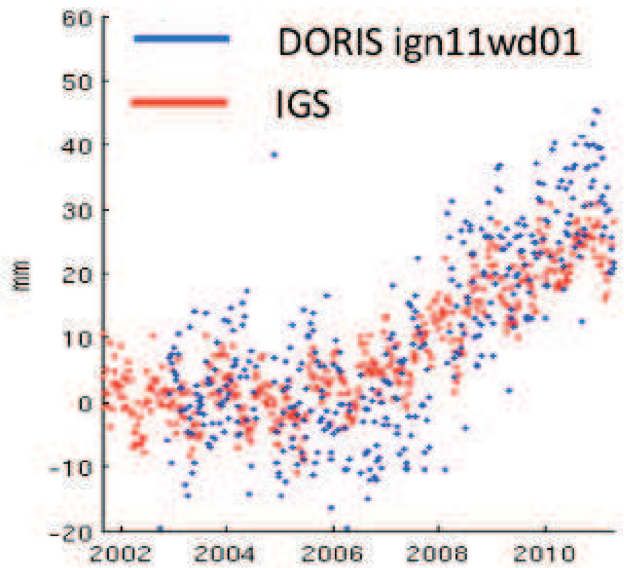

Figure 2: Thule GPS and DORIS Height displacements. The acceleration is related to recent ice melting as observed by (Khan et al., 2010).

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