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Challenges and Perspectives for TRF and CRF Determination

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Abstract

The improved and consistent determination of terrestrial and celestial reference frames has been the subject of many studies in the past and — due to technological innovations and new planned missions — is a topic of immediate interest today. We present and discuss challenges and perspectives which are tackled within three working groups of Sub-Commission 1.4 on the *Interaction of Celestial and Terrestrial Reference Frames* within the International Association of Geodesy (IAG), covering improved geophysical and astronomical models, rigorous combination strategies of space geodetic observations, new observation scenarios with radio telescopes to satellites, or the implication of the GAIA mission for the celestial reference frame.

1. Introduction

In recent years, significant progress has been made in astronomical and geophysical modeling for the analysis of space geodetic observations. Thus, there is a need to investigate the impact of those models on the terrestrial and celestial reference frames (TRF and CRF), and on the consistency between them and the Earth orientation parameters (EOP). Special attention needs to be paid to Very Long Baseline Interferometry (VLBI) observations, since it is the only technique to provide consistent sets of TRF/EOP/CRF. However, the present realization of the International Terrestrial Reference Frame (ITRF2008, Altamimi et al., 2011 [1]) is based on a combination of VLBI, Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), and Doppler Orbitography by Radiopositioning Integrated on Satellite (DORIS) observations, whereas the present realization of the International Celestial Reference Frame (ICRF2, Fey et al., 2009 [2]) is determined from a single VLBI solution. Consequently, research has to be carried out to integrate the ITRF and ICRF solutions, and also new options like VLBI observations to satellites should be considered for future improvement of the consistency. The Global Astrometry Interferometer for Astrophysics (GAIA) mission scheduled for launch in 2013 is expected to achieve an optical realization of the CRF with precision similar to or better than the ICRF2 and with at least an order of magnitude more objects. As the set of extragalactic objects suitable for both optical and radio observation is limited, such objects will have to be identified, and investigations will have to be carried out to permit the best possible connection between the radio and optical CRF realizations.

Many scientists and teams of researchers are working on those topics. As an overarching entity, the International Association of Geodesy (IAG) installed Sub-Commission 1.4 on the *Interaction of Celestial and Terrestrial Reference Frames* which is focusing on these tasks. Presently, three Working Groups are set up, and they are described with their goals below.

2. WG 1.4.1: Geophysical and Astronomical Effects and the Consistent Determination of Celestial and Terrestrial Reference Frames

Working Group 1.4.1 is created to promote and coordinate investigations of the impact of geophysical and astronomical modeling on the TRF and CRF, and the consistency between the reference frames and EOP. The primary attention will be given to VLBI as the only technique that can provide highly consistent global solutions for TRF, CRF, and EOP. Other techniques will also be considered when appropriate.

Theoretical studies, simulations, and processing of real data need to be carried out to better understand the impact of geophysical models on TRF, CRF, and EOP from VLBI observations. Particularly important is the mitigation of systematic errors. For example, the treatment of azimuthally asymmetric tropospheric delays by modeling and estimating gradient parameters is still critical to the estimation of celestial and terrestrial reference frames (Spicakova et al., 2012 [3]), in particular for VLBI observations before 1990. Furthermore, the description of non-linear station motions after earthquakes needs to be investigated and unified across all space geodetic techniques. An ongoing issue and challenge for the future is the poor geometry of stations as well as sources in the southern hemisphere which is affecting the estimation of TRF and CRF. Although the number of sources and their distribution has been improved with ICRF2 (Fey et al., 2009 [2]) the distribution of observations is still far from uniform.

Recent studies have revealed that the galactic rotation has to be considered in the analysis of VLBI observations (e.g., Titov, 2010 [5]) when applying a celestial reference frame that is tied to the barycenter. Upcoming challenges for the determination of the CRF are apparent source motions and source structure effects, which will have to be considered if better accuracies are to be reached. VLBI2010 observations (Petrachenko et al., 2009 [4]) will be more sensitive to those effects, but on the other hand better treatment of the effects will be available.

The investigation of the impact of astronomical and geophysical modeling on CRF, TRF, and EOP also requires better understanding of the procedures of the IVS global solution, including the impact of data weighting, noise models, or constraints. One goal is to develop practical recommendations for VLBI Analysis Centers and the Conventions Center of the International Earth Rotation and Reference Systems Service (IERS) on optimal models to be used during processing of VLBI observations, which are preferably applicable to other techniques as well.

3. WG 1.4.2: Co-location on Earth and in Space for the Determination of the Celestial Reference Frame

VLBI is the only space geodetic technique sensitive to the quasi-inertial celestial reference frame. The most recent realization of the International Celestial Reference System, the ICRF2, was determined in a VLBI-only solution (Fey et al., 2009 [2]). The other space geodetic techniques (GNSS, DORIS, and SLR) define a dynamical celestial reference frame based on satellite orbits, but all techniques are combined to determine the International Terrestrial Reference Frame (ITRF2008, Altamimi et al., 2011 [1]) without adding the estimation of sources to that combination. This causes small inconsistencies between the ICRF and the ITRF, in particular for the right ascension of VLBI Calibrator Sources (Manuela Seitz, personal communication).

The goal is to investigate the impact on the ICRF when combining VLBI observations with those from satellite techniques. Historically, this combination is based on local tie information at

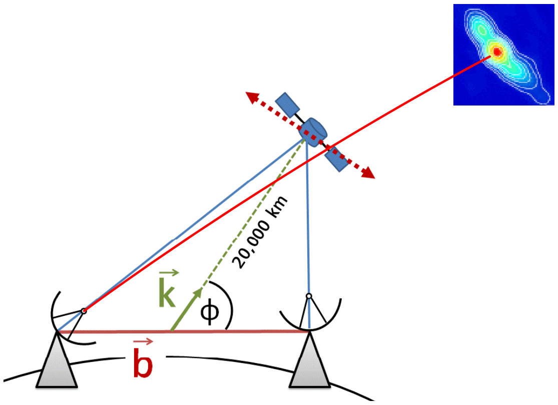

Figure 1. VLBI observation to a quasar and to a GNSS satellite in VLBI mode. The observations can be scheduled to use close encounters between satellites and quasars to mitigate tropospheric effects.

the co-location sites, but in the future troposphere ties (Krügel et al., 2007 [6]) and even space ties could also be used, i.e., observing the GNSS constellation (Tornatore et al., 2009 [7]) or a dedicated micro satellite like GRASP with VLBI, so that a fully consistent system would be created. Figure 1 shows the concept of observing a satellite in VLBI-mode, i.e., the difference of arrival times at the stations is used as the main observable. In that case it would be sufficient if the satellite transmits weak white noise similar to quasars. Alternatively, VLBI radio telescopes could also observe modulated signals from satellites in GNSS-mode, which means that essentially the travel time from the satellite to the telescope is measured.

As illustrated in Figure 1, VLBI telescopes could observe quasars and satellites alternately. The link between the dynamical reference frame realized with satellites and the kinematic reference frame realized with quasars can be strengthened if the observations to satellites and quasars are close in space and time, because effects due to tropospheric turbulence could then be reduced. Figure 2 shows the simulated effect on the slant wet delay at 30^o elevation as a function of the separation angle when switching between quasar and satellite every 15 seconds. The tropospheric turbulence that was assumed for this simulation was rather high ($Cn = 2.5 \times 10^{-7} m^{-1/3}$, $H = 2km$). With VLBI2010 and the availability of twin telescopes there will be even more possible observing strategies to provide improved and consistent TRF and CRF.

4. WG 1.4.3: Maintenance of Celestial Reference Frames and the Link to the New GAIA Frame

The GAIA (Global Astrometry Interferometer for Astrophysics) mission scheduled for launch in 2013 is expected to achieve an optical realization of the CRF with precision similar to or better than the ICRF2 and with at least an order of magnitude more objects. However, as the set of extragalactic objects suitable for both optical and radio observation is limited, one goal of the Working Group is to identify such objects, oversee the relevant observations, and analyze the data to permit the best possible connection between the radio and optical CRF realizations.

For geodetic use the CRF realization must be accessible from the ground. For the foreseeable future this connection will be through VLBI observations. In cooperation with the IVS and

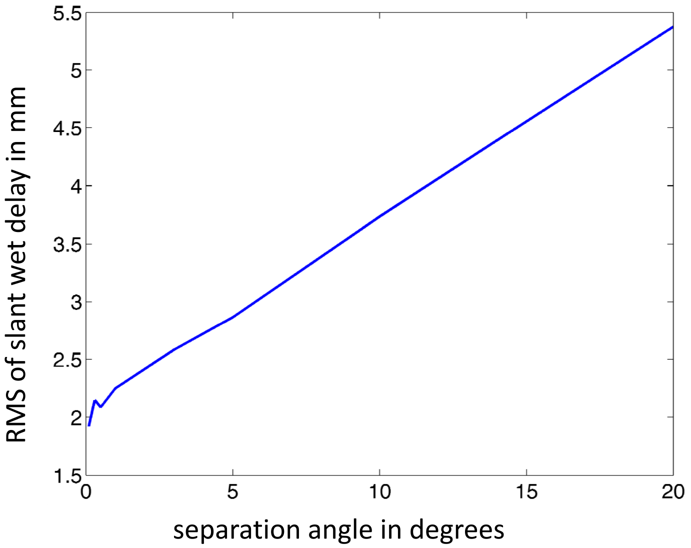

Figure 2. RMS of slant wet delay at 30^o elevation as a function of the separation angle between quasar and satellite when switching every 15 seconds. The tropospheric turbulence was simulated with $Cn = 2.5 \times 10^{-7} m^{-1/3}$ and $H = 2km$.

the IERS, this Working Group will oversee the maintenance and improvement of the ICRF2, in particular the set of sources used for geodetic observations and the ICRF2 defining sources.

5. Outlook

New space missions and technological advances provide great perspectives for the determination of improved and consistent terrestrial and celestial reference frames. These perspectives not only include improved measurement accuracies but also new concepts for linking the frames.

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