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VLBI — A Vital Player in Global Observing Systems

How Can the Wettzell "G" Ring Laser Improve VLBI Measurements of Subdiurnal Earth Rotation Variations?

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Abstract. The orientation of the Earth in space and on the Earth, and the rotational speed change unpredictably in a rapid and irregular manner. The Wettzell "G" ring laser is about to sense the signatures of the ocean tidal effect on polar motion (and possibly length of day). We therefore analysed two Wettzell "G" ring laser data sets for detecting ocean tidal effects. Several amplitudes could be detected in the diurnal and semidiurnal tidal band. However, in order to validate the detection of ocean tidal effects upon the Wettzell "G" ring laser data, we need first to split up the model of the ocean tidal effect on polar motion of the celestial intermediate pole into its retrograde and prograde contributions, prior to applying the conversion to the polar motion of the instantaneous rotation pole. One major question needs to be resolved: what causes the high amplitude in the O1 tidal period of the ring laser residuals? A Kalman filter, which takes as input estimates of the Earth rotation based on Very Long Baseline Interferometry (VLBI) and Wettzell "G" ring laser, could be particularly useful for application to spacecraft navigation, reduction of geodetic data, and research into geophysical causes.

1. Introduction

In 1884, Küstner discovered the variation of latitude, and in 1891, Chandler explained it as polar motion. Until the mid-1960s, optical astrometry was the only source of Earth rotation information. At present, Very Long Baseline Interferometry (VLBI) technique provides the most complete high-accuracy observations for monitoring the rotation of the Earth, i.e., the motion of the

Celestial Intermediate Pole (CIP) w.r.t. both a Conventional Celestial Reference Frame (CCRF) and a Conventional Terrestrial Reference Frame (CTRF), in addition to Universal Time (UT1) variations w.r.t. the Universal Time Coordinated (UTC). For near real time considerations, electronic VLBI (e–VLBI) is nowadays able to provide UT1 with a time delay of less than one hour [5]). Since a few years, an emerging and more "exotic" instrument, the Wettzell "G" ring laser proved its ability in sensing variations in the Earth rotation [9]. Unlike VLBI, the Wettzell "G" ring laser responds directly to the instantaneous Earth rotation vector (ERV). In the case of VLBI, the latter is only a by-product, which is not required for geophysical interpretation: geophysical angular momentum functions are related to the polar motion of the CIP, and excess length of day (LOD). However, the Wettzell "G" ring laser generates observables with a temporal resolution of 30 minutes, which give access to the rate of change of precession-nutation (PN) of the CIP, to LOD variations, polar motion (PM) of the CIP and its rate of change [7]. The main contribution of the ring laser for the five Earth Orientation Parameters (EOP) lies in the spectrum from 1 to 48 hours. In terms of competitiveness, the question remains: how much does the Wettzell "G" ring laser sense considering Earth rotation signatures?

2. Ring Laser: Basic Equations Relating Observations to Earth Rotation

Fig. 1 gives a schematic overview of the PM of the CIP, the instantaneous rotation pole (IRP), and the geophysical pole G, which conveys the geophysical external torque-free equatorial part of Earth rotation.

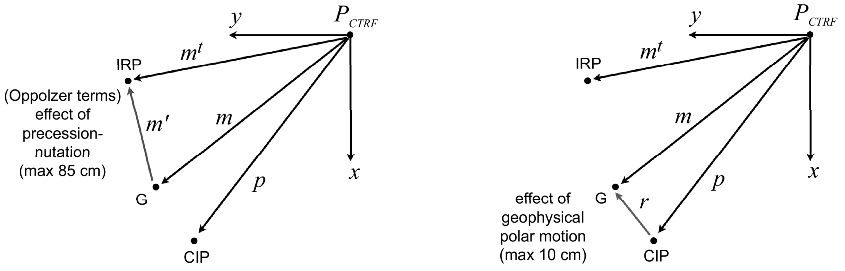

Figure 1. Schematic representation in a CTRF between the PM of the CIP p vs. PM of the IRP m^t, including the geophysical pole G, as well as the pole of the CTRF

The ERV w.r.t. a CTRF is given as:

$$\vec{\omega} = (\omega_1, \omega_2, \omega_3)^T = \omega_0 \cdot \left(m_1^t, m_2^t, 1 + m_3^t\right)^T, \tag{1}$$

where ω_0 is the mean angular speed of the sidereal rotation of the Earth, i.e.,

$7.2921150(1) \cdot 10^{-5}$ rad/s. The quantities m_1^t, m_2^t, and m_3^t represent the total terrestrial PM and axial motion of the IRP, respectively.

The total terrestrial PM of the IRP sums up as:

$$m^t = m + m' = m_1^t + i \cdot m_2^t, \tag{2}$$

where $i = \sqrt{-1}$, $m = m_1 + i \cdot m_2$ represents PM of the geophysical pole G, and $m' = m_1' + i \cdot m_2'$ being a function of the geodetic PN of the CIP. The geodetic PM of the CIP is denoted by $p = p_x - i \cdot p_y$.

The PM of the geophysical pole G was derived by Gross [4] and Brzezinski and Capitaine [2]:

$$m = p - i \cdot \frac{\dot{p}}{\omega_0} = p + r. \tag{3}$$

The quantity m' was derived by Eubanks [3] and Brzezinski and Capitaine [2]:

$$m' = i \cdot \frac{\dot{N}}{\omega_0} \cdot e^{-i \cdot \theta}, \tag{4}$$

where the geodetic PN of the CIP reads

$$N = \delta\psi \cdot \sin\epsilon_0 + i \cdot \delta\epsilon = X + i \cdot Y, \tag{5}$$

and X, Y are the celestial coordinates of the CIP, $\delta\psi, \delta\epsilon$ being the corresponding geodetic PN angles, ϵ_0 the mean obliquity at epoch J2000.0, and θ the sidereal rotation angle.

Let us now turn our attention to the ring laser. For the most up-to-date description of the Wettzell “G” ring laser, we refer to [10]. The basic relation between the relative change in the Sagnac frequency [8], corrected for latitudinal tilt variations due to local effects, and the perturbation of the ERV, i.e., m_1^t, m_2^t, and m_3^t has been summarized [6]:

$$\Delta S_{RLG} = \cot\phi_0 \cdot \left[-m_1^t \cdot \cos\lambda_0 + m_2^t \cdot \sin\lambda_0\right] + m_3^t, \tag{6}$$

where ϕ_0 and λ_0 are the nominal latitude and longitude of Wettzell, respectively, and m_1^t, m_2^t, and m_3^t being expressed as:

$$m_1^t = \frac{1}{\omega_0} \cdot \left[\omega_0 \cdot p_x - \dot{p}_y + \dot{X}\sin\theta - \dot{Y}\cos\theta\right], \tag{7}$$

$$m_2^t = \frac{-1}{\omega_0} \cdot \left[\omega_0 \cdot p_y + \dot{p}_x - \dot{X}\cos\theta - \dot{Y}\sin\theta\right], \tag{8}$$

$$m_3^t = \frac{-\delta LOD}{T_0} = \frac{\partial(UT1 - UTC)}{\partial t}. \tag{9}$$

3. Results

In order to study the tidal signatures, possibly of oceanic origin, we analysed two Wettzell "G" ring laser data sets: the first one covered 40 days since Sep. 17, 2002 (MJD 52534), while the second included 144 days since Sep. 22, 2006 (MJD 54000), both having a temporal resolution of half an hour given in the time scale of UTC. In a first step, both data sets were corrected for local deformations induced by the solid Earth tides at station Wettzell, following the formalism described by Mendes Cerveira et al. [6]. Then the effect of the Oppolzer terms, denoted by the quantity $m^{\cdot}$, were reduced using the model of Brzezinski [1]. A program for removing jumps and breaks was applied, and then a high-pass smoothing filter of two days was applied to get rid of low frequency signals. In Fig. 2 the effect of the Oppolzer terms was restored for visualization purposes.

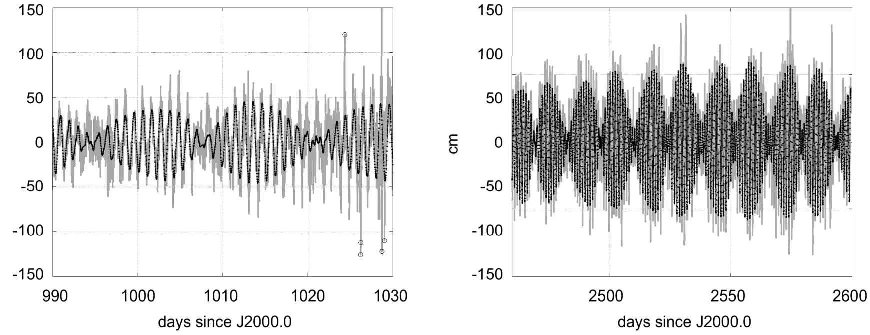

Figure 2. Pre-processed relative Sagnac frequency ring laser data (grey), and transformed model of Brzezinski [1] (black), both being projected to Earth's surface. Black circles are outliers. The ring laser data covers 40 days since Sep. 17, 2002 (MJD 52534), and 144 days since Sep. 22, 2006 (MJD 54000)

The next largest signatures in the ring laser data are the effect of ocean tides on PM and LOD, followed by the minor effect of tidal gravitation on PM for a non-rigid Earth. For this reason, we performed a least squares adjustment for the 71 waves included in the current correction of ocean tides on PM of the CIP (and LOD) to the residual relative Sagnac frequency variation. In addition, amplitudes of three further periods (8.28, 8.00, and 6.00 hours) were estimated, in order to check if the M3 tidal wave as well as both overtones could be detected. The standard deviation of unity weight of the complete adjustment is 13.7 cm. No significant amplitude ($\sim$ 6 mm) could be detected at the latter three periods. Amplitudes of such a magnitude can simply be generated by the noise level of 13.7 cm. Some constraints had to be applied, proportional to the ratio of the respective coefficients in the tidal potential, in order to separate all tidal waves, due to the short time span of the ring laser data. Tabl. 1 shows the residual amplitudes (processed ring laser obervations minus model by Brzezinski) of the most prominent tidal waves having an amplitude larger than 8 mm. An amplitude of ∼ 4 cm pops up for the O1 tidal wave: this is far too high to be explained solely by tidal oceanic effects and tidal gravitation. The next largest amplitude appears at the S2 tidal wave with ∼ 2 cm. Other significant amplitudes in the diurnal and semidiurnal band exist, e.g., for the P1 or M2 tidal waves.

A next step should therefore split up the model of ocean tidal effect on PM of the CIP into the retrograde and prograde contributions prior to apply the conversion to the PM of the IRP, and then apply this model as a correction to the Wettzell "G" ring laser data.

Table 1. Difference in amplitude between the CIP and the IRP and the model of Brzezinski. Temporal reference for the phase is J2000.0. Asin and Acos represent the amplitudes in the sine and cosine components, respectively. Mean solar day is denoted by msd, and the standard deviation of the amplitude by sA

Name *Doodson*	Period, hours	Period, msd	Asin, mm	Acos, mm	A, mm	sA, mm
SIG1	27.848	1.1603	−2.5	8.2	8.6	2.3
Q1	26.868	1.1195	−8.8	1.0	8.9	2.3
RO1	26.723	1.1134	10.1	3.2	10.6	2.3
	25.823	1.0759	5.2	6.4	8.2	0.6
O1	25.819	1.0758	26.5	35.2	44.0	2.4
TAU1	25.668	1.0695	11.8	7.9	14.2	2.2
	24.974	1.0406	3.4	9.2	9.8	2.3
P1	24.065	1.0027	−12.4	−8.8	15.2	3.1
SO1	22.420	0.9341	10.6	3.9	11.3	2.2
OO1	22.306	0.9294	13.5	5.6	14.7	2.7
	22.303	0.9292	8.6	3.6	9.3	1.7
V1	21.578	0.8990	−12.1	−12.3	17.3	2.2
	21.575	0.8989	−7.7	−7.9	11.0	1.4
NI2	12.626	0.5260	−0.8	8.4	8.5	2.0
M2	12.420	0.5175	1.8	8.9	9.1	2.7
S2	12.000	0.5000	7.1	17.2	18.6	2.1
ETA2	11.754	0.4897	−7.2	4.6	8.5	2.3

4. Discussion and Conclusions

A dynamical model, i.e., the Euler-Liouville equation, is available for Earth rotation. VLBI delivers EOP with a certain time delay. The Wettzell "G" ring laser produces integrated 30 minutes observables, and apparently senses the effects of ocean tides on PM. For this reason, a software based on the Kalman filter approach will be developed for monitoring and predicting Earth rotation for near real time applications from VLBI and ring laser observations. But first, the high amplitude in the O1 tidal wave in the residuals of the Wettzell "G" ring laser data should be elucidated.

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References

[1] Brzezinski A. Contribution to the theory of polar motion for an elastic earth with liquid core. Manuscripta Geodaetica, v. 11, 226–241, 1986.

[2] Brzezinski A., N. Capitaine. The use of the precise observations of the Celestial Ephemeris Pole in the analysis of geophysical excitation of Earth rotation. J. Geophys. Res., v. 98 (B4), 6667–6675, 1993.

[3] Eubanks T.M., Variations in the Orientation of the Earth. Geodynamic Series, v. 24, 1–54, 1993.

[4] Gross R.S., Correspondence between theory and observations of polar motion. Geophys. J. Int., v. 109, 162–170, 1992.

[5] Haas R., J. Wagner, J. Ritakari, et al. Report on the Fennoscandian-Japanese Project for Near real-time UT1-Observations with e–VLBI. Submitted to Proc. Journées Systèmes de Référence Spatio-Temporels 2007, 2008.

[6] Mendes Cerveira P.J., H. Spicakova, H. Schuh, et al. Earth rotation parameters from Very Long Baseline Interferometry and ring laser observables. Accepted to Advances in Geosciences, 2008.

[7] Mendes Cerveira P.J., J. Böhm, H. Schuh, et al. Using Very Long Baseline Interferometry and Ring Laser for Monitoring Earth Rotation. Submitted to Journal of Geodesy, 2008.

[8] Post E.J. Sagnac Effect. Reviews of Modern Physics, v. 39 (2), 475–493, 1967.

[9] Schreiber K.U., A. Velikoseltsev, M. Rothacher, et al. Direct measurement of diurnal polar motion by ring laser gyroscopes. J. Geophys. Res., v. 109 (B06405), DOI 10.1029/2003JB002803, 2004.

[10] Schreiber K.U., T. Klügel, A. Velikoseltsev, et al. The Large ring laser G for Continuous Earth Rotation Monitoring. Submitted to Journal of Geodesy, 2008.