DETERMINATION OF EARTH ROTATION BY COMBINING VLBI AND RING LASER OBSERVATIONS

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ABSTRACT. We investigate the potential of combining VLBI data with ring laser gyroscope measurements. The formal errors of polar motion and UT1-UTC obtained from such a combination are estimated as function of the ring laser measurement accuracy. The possible improvements obtained by using data from three globally distributed ring lasers, instead of only one, is also investigated. It is shown that if three globally distributed ring lasers are used – all being one order of magnitude more accurate than the current Wettzell ring laser – the formal errors of the estimated Earth rotation parameters are reduced by more than 50%, compared to a VLBI only solution.

1. INTRODUCTION

In recent years large and very sensitive ring laser gyroscopes have been constructed which are able to measure the rotation of the Earth (Schreiber et al., 2009, 2011). Presently the ring laser accuracy is about one order of magnitude worse compared to space geodetic techniques such as Very Long Baseline Interferometry (VLBI) (Nilsson et al., 2012), but the accuracy is increasing rapidly (Schreiber et al., 2011). Common problems in ring lasers observations are however unknown offsets and drifts, making it difficult to obtain the absolute Earth rotation vector and its long term variations. The strength of the ring laser data is mainly to observe the high frequency variations, e.g. at sub-daily periods. Furthermore, since one single ring laser is only sensitive to one component of the Earth rotation vector, at least three ring lasers (with different orientation) would be needed in order to get all Earth rotation parameters.

In order to make the best use of the ring laser data it should be combined with another technique. In such a combination ring laser data will mainly help in resolving the high frequency Earth rotation variations. A first attempt was done by Nilsson et al. (2012), who combined data from the "G" ring laser in Wettzell, Germany, with simultaneous VLBI observations. It was found that the impact of the ring laser data in the combination was normally very low, which is not surprising given that VLBI is about one order of magnitude more accurate. Only for those VLBI sessions which have a low sensitivity to Earth rotation did the inclusion of ring laser data significantly affect the results. However, if the accuracy of the ring laser is improved – or more than one ring laser is used in the combination – its impact could be expected to be larger also for normal VLBI sessions. In this work we investigate the potential improvement obtained by using more accurate data from several globally distributed ring lasers.

2. THEORY

Here the ring laser measurements and the combination with VLBI are briefly described. For more details, see Nilsson et al. (2012).

In a ring laser gyroscope, two laser beams are transmitted in opposite directions in a ring. At the point where to two laser beams meet the Sagnac (beat) frequency f between the signals is measured. This frequency will depend on the rotation of the ring laser, i.e. the rotation of the Earth if the ring laser is fixed to the Earth's surface. The Sagnac frequency f is given by (Schreiber et al., 2009):

$$S_{rlg} = \frac{\delta f}{f_0} = \frac{\vec{\Omega}^T\,\hat{n}}{\vec{\Omega}_0^T\,\hat{n}_0} - 1 \tag{1}$$

S_{rlg} is called the relative Sagnac frequency, $\delta f = f - f_0$, $\vec{\Omega}$ the rotation vector of the Earth, and $\hat{n}$ the normal unit vector of the ring laser. $\vec{\Omega}_0$, $\hat{n}_0$, and f_0 are the nominal values of $\vec{\Omega}$, $\hat{n}$, and f, respectively.

The Earth rotation vector can be expressed as $\vec{\Omega} = \Omega_0\,[m_1,\, m_2,\, 1+m_3]^T$, where m_1, m_2, and m_3 are related to the polar motion (x_p and y_p) and DUT1 (UT1-UTC) normally measured by space geodetic techniques such as VLBI (Brzezinski and Capitaine, 1993):

$$m = p - \frac{\mathrm{i}}{\Omega}\frac{\partial p}{\partial t} \tag{2}$$

$$m_3 = \frac{\partial DUT1}{\partial t} \tag{3}$$

Here $m = m_1 + \mathrm{i}\, m_2$ and $p = x_p - \mathrm{i}\, y_p$.

The combination of the ring laser and VLBI data was performed at the normal equation level. First, the normal equation matrices for the VLBI data (N_{vlbi} and b_{vlbi}) were set up using the Vienna VLBI Software (VieVS, Böhm et al., 2011). Polar motion and DUT1 were modelled as piece-wise linear offsets in one hour intervals. Additionally, clock errors, tropospheric parameters, and station coordinates were estimated. Using exactly the same parametrisation for polar motion and DUT1 as in the VLBI analysis, normal equation matrices for the ring laser data acquired during the VLBI session were set up (N_{rlg} and b_{rlg}). Additionally for the ring laser data, one offset and one rate were estimated. Finally the normal equation matrices from VLBI and ring laser were stacked to obtain a common normal equation system:

$$N_{tot} = N_{vlbi} + N_{rlg} \tag{4}$$

$$b_{tot} = b_{vlbi} + b_{rlg} \tag{5}$$

By inverting the system, the unknown parameters (polar motion, DUT1, and additional parmaeters) are obtained. The variance-covariance matrix for the estimates, C_x, can be calculated by:

$$C_x = N_{tot}^{-1} \tag{6}$$

3. RESULTS

As shown by Nilsson et al. (2012) the impact of the ring laser data in the combination is presently very low. With future improvements of the ring laser technique and/or with more ring lasers being available the impact of the ring laser observations is expected to grow. One way of investigating the possible improvements is to look at the formal errors obtained from the variance-covariance matrix C_x (Equation 6). Since C_x does not depend on the observations, we can obtain the expected formal errors without having access to any actual observed data.

In these investigations we consider the combination of VLBI data from the session R1431 (17–18 May, 2010) with ring laser data. Figure 1 shows the median formal errors of polar motion and DUT1 as function of the ring laser accuracy, when one ring laser located in Wettzell (longitude: 12.9°, latitude: 49.1°) is used. The present accuracy of the relative Sagnac frequency S_{rlg} (Equation 1) is about 10^{-8} (Nilsson et al. 2012, Schreiber et al., 2011). We can note that the ring laser data only have a minor impact on the formal errors at this accuracy. However, as the accuracy increases the formal errors are reducing. It is interesting to note that when the accuracy of S_{rlg} is below 10^{-9} mainly the formal errors in y_p and DUT1 are affected, while for very accurate ring laser data (10^{-11}) the biggest reduction in formal error is in x_p. The reason for this is that a ring laser located in Wettzell will mainly be sensitive to the m_1 and m_3 components of the Earth rotation vector but not as much to m_2 (due to the small longitude of Wettzell). From Equation 2 we find that $m_1 = x_p - \frac{1}{\Omega}\frac{\partial y_p}{\partial t}$. When the accuracy is low the ring laser data mainly constrain the very high frequency (e.g. hourly) variations in m_1 which is mainly due to high frequncy variations in y_p. By more accurate ring laser data also the variations over relatively longer periods can be constrained, and these are more affected by the variations in x_p.

Figure 2 shows the effect of having data from more ring lasers in the combination. The formal errors of the hourly polar motion and DUT1 offsets are shown. One ring laser is assumed to be in Wettzell, one in East Brazil (longitude: 45.0°W, latitude: 23.5°S), and one in West Mexico (longitude: 115°W, latitude: 29.7°N). Having the ring lasers placed in these locations their normals will be almost perpendicular to each other, thus together they should have a good sensitivity to the full Earth rotation vector. We can see that when three ring lasers are used, similar reductions in formal errors are found for all three Earth rotation parameters. Two cases are shown, one with the accuracy of the ring lasers being equal to the current accuracy of the Wettzell ring laser, and one with accuracies being one order of magnitude better.

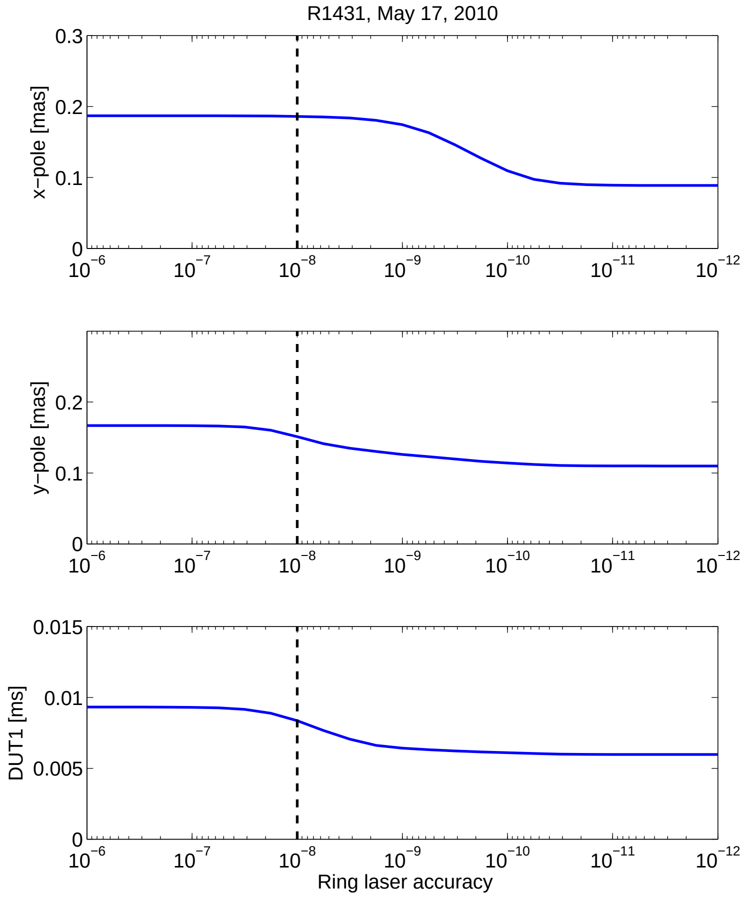

Figure 1: Median formal errors of polar motion and DUT1 estimated from combination of VLBI and ring laser data, as function of the accuracy of the ring laser measurements. The current accuracy of the Wettzell "G" ring laser is marked.

With three accurate ring lasers the formal errors are reduced by about 50% in both polar motion and DUT1, compared to using only VLBI data.

4. CONCLUSIONS

Currently, the Earth rotation parameters estimated in a VLBI – ring laser combination is only slightly more accurate than what is obtained by using only VLBI data. However, if the accuracy of the ring laser measurements can be improved by one order of magnitude or more, the improvement would be more significant, especially if data from several ring lasers distributed over the world is used. Over the last couple of years there has been a significant improvement in the ring laser accuracy (Schreiber et al., 2011). If the accuracy continues to improve at the current rate, the improvement by one order of magnitude will be reached in the not too distant future.

Acknowledgements. This work was funded by the German Science Foundation (DFG, Deutsche Forschungsgemeinschaft) within the Research Unit FOR584 Earth Rotation and Global Dynamic Processes, project number SCHU 1103/3-2.

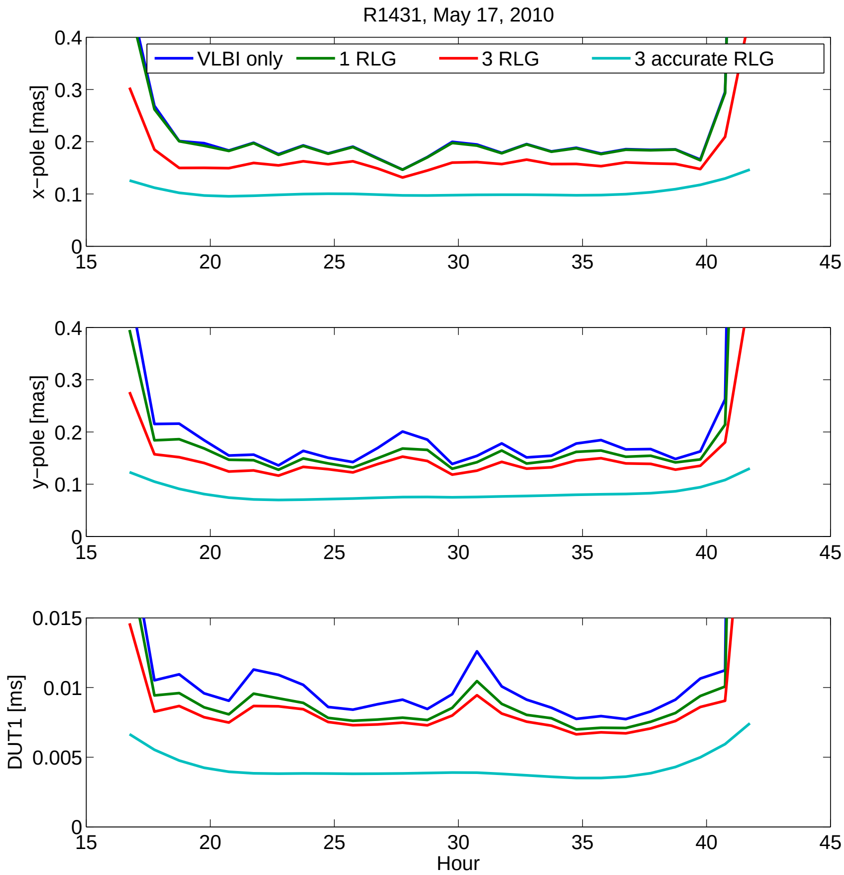

Figure 2: Formal errors of polar motion and DUT1 obtained using VLBI data, as well as from combining VLBI with data from one ring laser (Wettzell) or three globally distributed ring lasers. For the combination using three ring lasers two cases are considered: one case with the ring lasers all having the same accuracy as the current Wettzell ring laser, and one case with one order of magnitude more accurate ring laser data.

5. REFERENCES

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