# ADVANCES IN INERTIAL EARTH ROTATION MEASUREMENTS - NEW DATA FROM THE WETTZELL G RING LASER

T. KLÜGEL[1], U. SCHREIBER[2], W. SCHLÜTER[1], A. VELIKOSELTSEV[2]
[1] Bundesamt für Kartographie und Geodäsie
Fundamentalstation Wettzell, Sackenrieder Str. 25, D-93444 Bad Kötzting
e-mail: thomas.kluegel@bkg.bund.de, wolfgang.schlueter@bkg.bund.de
[2] Forschungseinrichtung Satellitengeodäsie, TU München
Fundamentalstation Wettzell, Sackenrieder Str. 25, D-93444 Bad Kötzting
e-mail: schreiber@fs.wettzell.de, alex@fs.wettzell.de

## 1. INTRODUCTION

Ring lasers are a new type of instrument in geodesy to measure variations in Earth rotation. The scope is to obtain complementary measurements to the geodetic space techniques like VLBI (Very Long Baseline Interferometry), SLR (Satellite Laser Ranging), or GNSS (Global Navigation Satellite Systems). Employing a completely different type of measurement, they yield different components of the Earth's rotation. While the geodetic space techniques perform a relative measurement to determine the rotation matrix between the Earth and the observed objects, ring lasers measure the absolute spin rate and are sensitive to motions of the rotation axis with respect to the Earth. They are not sensitive to motions of the rotation axis in space. Thus ring lasers give direct access to polar motion. Other aspects comprise the high temporal resolution for a better sampling of subdaily variations, the continuous operation and the real time availability of the data.

## 2. THE WETTZELL RING LASER G

The Wettzell ring laser "G" is in operation since 2001. The basic principle and the technical realisation is described in Klügel et al. (2005) or at http://www.fs.wettzell.de/LKREISEL/G/LaserGyros.html. The unique resolution and stability was reached by a vastly expanded cavity size of 4 m x 4 m, an extreme mechanical and thermal stability resulting from the use of the glass ceramic Zerodur as base material, the use of low-loss dielectric supermirrors, and the operation in an underground installation.

However it was found that the long term stability of the Sagnac frequency suffered from a variable gain of the laser medium by outgassing of impurities like hydrogen or water from the inner stainless steel surfaces of the laser cavity enclosure. As a consequence the vacuum system has been modified in 2006 by replacing the old 50 mm tubes by 150 mm tubes in order to increase the ratio between gas volume an steel surface. In addition a getter tank has been installed to absorb gas impurities. Further modifications include the replacement of a rubidium frequency standard by a reference frequency coming from a hydrogen maser, and the stabilisation of the control loop steering the power of the laser excitation by installing it in a thermally stable environment.

## 3. THE NEW TIME SERIES

After the thermal perturbation due to the construction had died out, a continuous time series from August 2006 till March 2007 of outstanding quality was obtained. Varying drift rates and unregular excursions of the Sagnac signal, as could be observed in the former time series, are now strongly reduced (figure 1). The instrumental drift now changes gradually mostly due to thermal relaxation. The amplitude spectrum reveals a noise reduction in the entire spectral range (figure 2). The periodic signals around 1 and 2 cycles per day (cpd), being an effect of diurnal polar motion and local tidal tilts, come out with a much better signal to noise ratio.

For the acquisition and processing of the new time series, the following steps had been performed:

- Data acquisition using a frequency counter integrating over 30 minutes

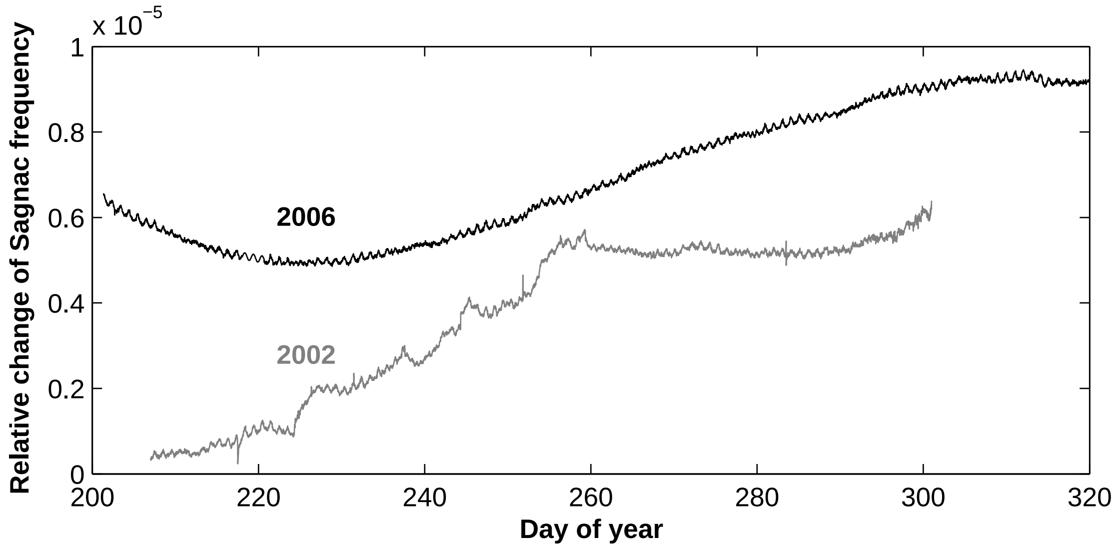


Figure 1: Ring laser time series before and after the modifications

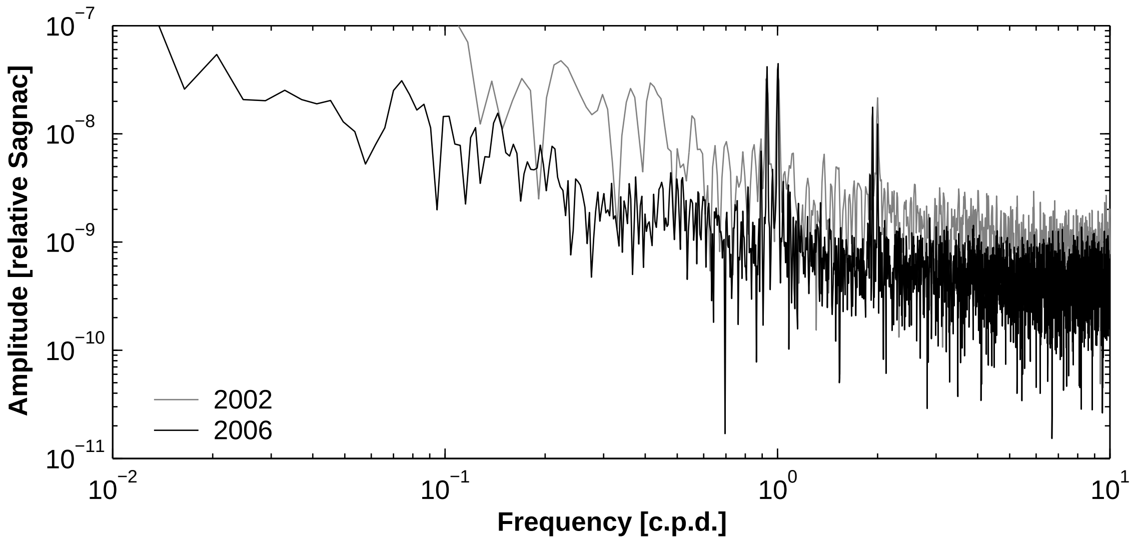


Figure 2: FFT amplitude spectrum demonstrates significant noise reduction in the entire spectral range

- Removal of outliers and resampling to 30 minutes
- Correction for local tilts using tiltmeters on top of the ring laser having a resolution of less than 0.1 mas, which themselves are corrected for tidal attraction and thermal effects
- Correction for instrumental effects like drifts due to pressure-induced temperature variations
- Spectral analysis using multiple Fourier transformations in order to increase frequency resolution
- Correction for diurnal polar motion, using the 21 largest terms from Brzezinski (1986), or
- Amplitude estimation of diurnal polar motion terms using (1) Matlab least square fit, (2) routine ERPEST of Bernese GPS software, (3) Eterna Earth tide analysis program

The amplitude spectrum of the raw time series (figure 3, left) shows that the 7 tidal components Q1, O1, M1, P1, K1, J1 and OO1 can be identified in the diurnal band. The amplitudes are generally somewhat bigger than the values taken from the Brzezinski (1986) polar motion model (plus signs). This is mainly an effect of local tidal tilts being responsible for the tidal signals in the semidiurnal band and a fraction of the signals in the diurnal band. After removing the tidal tilt by applying the tiltmeter correction, the tidal signals in the semidiurnal band nearly completely vanish, and the amplitudes in the diurnal band are reduced close to the model values (figure 3, right). The signal at exactly 2 cpd is assumed to be of atmospheric origin (see below and Schreiber et al. 2003). The reason for the remaining signal at 1.932 cpd (M2 tidal wave) is not yet clear; it can be either due to an incomplete tidal tilt correction, or an effect of the ocean tides on polar motion or rotation speed.

Another signal is visible at exactly 3 cpd (8 hours). Signals having a period of 8 hours have also been reported in VLBI observations (e.g. Schuh 2007) or in GPS observations (e.g. Steigenberger 2007). Although there is strong evidence for air pressure effects (VLBI) or artefacts due to 24h binning (GPS), the origin of these signals is not definitely resolved. In the case of the ring laser the 8 hour signal can be removed by subtracting the ring laser temperature record, multiplied by an arbitrary factor, from the ring laser time series. As the air pressure is the main source of temperature variations in the ring laser lab, the 12 hour atmospheric oscillation and its harmonics (8 hours, 6 hours,..) are prominent in the temperature records. The local air pressure record however is not suitable to correct the ring laser time series due to the phase lag between air pressure and temperature. Hence the 8 hour signal is identified as an instrumental thermal effect of the ring laser.

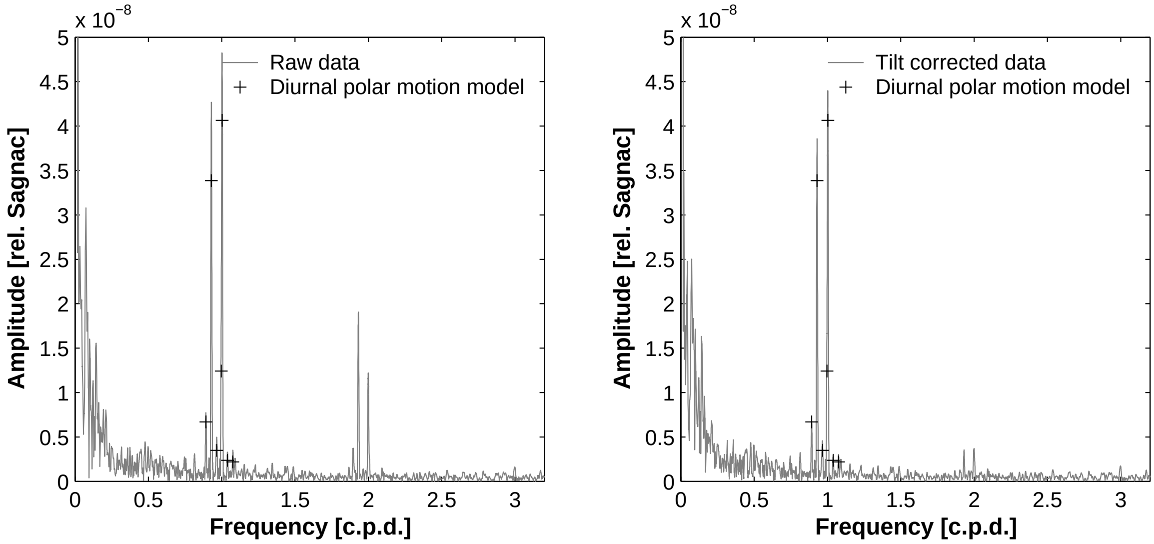


Figure 3: FFT amplitude spectrum of raw (left) and tilt corrected data (right), time series over 243 days

## 4. ESTIMATION OF DIURNAL POLAR MOTION TERMS

Because ring lasers are not sensitive to nutations in space, they have the unique capability to directly measure the quasi-diurnal motions of the instantaneous rotation axis with respect to the Earth's body due to the torques of Sun and Moon (Schreiber et al. 2004). The amplitude estimation of the 7 identified diurnal polar motion constituents (see above) has been done in terms of least squares fits of sinusoidal functions of given frequencies using different software tools. First the MatLab least square fit of Fourier type has been used. The resulting amplitudes of the tilt corrected time series are closer to the model values than those of the raw data (table 1). A previously injected signal having an amplitude of 1 mas and a frequency of 1.5 cpd came out with an amplitude of 1.01 mas after the fitting routine. This indicates that the fitting process works reliable. Second the Earth rotation parameter estimation routine ERPEST of the Bernese GPS software 5.0, which had been modified in order to process ring laser data, was applied. Third the Earth tide analysis package Eterna 3.4 has been used for the estimation of amplitudes and phase lags. For this purpose the ring laser time series was treated like a tidal potential just to get the amplitude and phase information, neglecting effects of tidal deformation.

All three kinds of fitting procedures give similar results. The Eterna fit yields somewhat smaller amplitudes, but the estimated errors are bigger and seem to be more realistic than the formal Bernese errors. With the exception of the tidal wave O1, all model amplitudes are within the $2\sigma$ error bar of the estimated polar motion amplitudes. The model amplitudes represent not the denoted constituent alone, but comprise the sum of all model amplitudes within +/- 0.002 cpd around the constituent frequency. The reason is that the frequency resolution of the time series is 0.004 cpd, being the sampling interval (48 per day) divided by the number of samples (11664). Thus all constituents within this interval contribute to the estimated amplitude.

| Astronomical arguments | | | | | | Darwin | Fre- | MatLab | | Bernese | | Eterna | | Model |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $l$ | $l'$ | $F$ | $D$ | $\Omega$ | $\Theta$ | symbol | quency | raw data | tilt cor. | tilt corrected | | tilt corrected | | |
| | | | | | | | [c.p.d.] | ampl. | ampl. | ampl. | rms | ampl. | stdev | |
| 1 | 0 | 2 | 0 | 2 | -1 | Q1 | 0.8932 | 1.82 | 1.61 | 1.53 | 0.07 | 1.24 | 0.16 | 1.59 |
| 0 | 0 | 2 | 0 | 2 | -1 | O1 | 0.9295 | 9.78 | 8.83 | 8.65 | 0.07 | 7.51 | 0.16 | 8.08 |
| 1 | 0 | 0 | 0 | 0 | -1 | M1 | 0.9664 | 1.32 | 1.24 | 1.19 | 0.07 | 0.84 | 0.12 | 0.83 |
| 0 | 0 | 2 | -2 | 2 | -1 | P1 | 0.9973 | 3.18 | 2.87 | 2.94 | 0.07 | 2.70 | 0.19 | 2.96 |
| 0 | 0 | 0 | 0 | 0 | -1 | K1 | 1.0027 | 10.60 | 9.66 | 10.06 | 0.07 | 9.28 | 0.17 | 9.69 |
| -1 | 0 | 0 | 0 | 0 | -1 | J1 | 1.0390 | 0.78 | 0.63 | 0.66 | 0.07 | 0.89 | 0.16 | 0.57 |
| 0 | 0 | -2 | 0 | -2 | -1 | OO1 | 1.0759 | 0.89 | 0.78 | 0.67 | 0.07 | 0.45 | 0.09 | 0.52 |
| Synthetic signal (1 mas) | | | | | | | 1.5000 | 1.03 | 1.01 | | | | | |

Table 1: Estimated amplitudes in milliarcseconds of 7 diurnal polar motion terms

## 5. SUMMARY AND OUTLOOK

The performance of the Wettzell ring laser has been significantly improved in 2006. The average noise level at subdaily frequencies is less than $10^{-9}$. The recent detection limit for subdaily signals is 0.4 milliarcseconds (2 nanorad) for polar motion or 0.15 milliseconds for length of day. The amplitudes of the 7 diurnal polar motion terms Q1, O1, M1, P1, K1, J1 and OO1 has been reliably determined with formal errors less than 0.1 mas (Bernese) or 0.2 mas (Eterna).

Regarding the technical feasibility for further improvements like the stabilization of the optical frequency, there is still potential for an increase in resolution and stability, that the determination of diurnal polar motion terms with higher precision and the detection of high frequency UT1 variations due to ocean tides or atmosphere might be possible in future.

## 6. REFERENCES


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

Klügel T., Schlüter W., Schreiber U., and Schneider M., 2005, "Grossringlaser zur kontinuierlichen Beobachtung der Erdrotation", Zeitschrift für Vermessungswesen, 130(2), pp. 99–108.

Schreiber, U., Klügel, T., Stedman, G. E., 2003, "Earth tide and tilt detection by a ring laser gyroscope", J. Geophys. Res. , 108 (B2), 10.1029/2001JB000569.

Schreiber U., Velikoseltsev A., Rothacher M., Klügel T., Stedman G.E., and Wiltshire D.L., 2004, "Direct measurement of diurnal polar motion by ring laser gyroscopes", J. Geophys. Res. , 109 (B6), 10.1029/2003JB002803, B06405.

Schuh H., 2007, "The intricacies of high-frequency polar motion and universal time variations: status report of the SPEED project", Status seminar Earth Rotation and Global Dynamic Processes, Dresden.

Steigenberger, P., 2007, "GPS-derived long time series of sub-daily Earth rotation parameters", Status seminar Earth Rotation and Global Dynamic Processes, Dresden.