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ORIGINAL ARTICLE

The impact of errors in polar motion and nutation on UT1 determinations from VLBI Intensive observations

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Abstract The earth's phase of rotation, expressed as Universal Time UT1, is the most variable component of the earth's rotation. Continuous monitoring of this quantity is realised through daily single-baseline VLBI observations which are interleaved with VLBI network observations. The accuracy of these single-baseline observations is established mainly through statistically determined standard deviations of the adjustment process although the results of these measurements are prone to systematic errors. The two major effects are caused by inaccuracies in the polar motion and nutation angles introduced as a priori values which propagate into the UT1 results. In this paper, we analyse the transfer of these components into UT1 depending on the two VLBI baselines being used for short duration UT1 monitoring. We develop transfer functions of the errors in polar motion and nutation into the UT1 estimates. Maximum values reach 30 [µs per milliarcsecond] which is quite large considering that observations of nutation offsets w.r.t. the state-of-the-art nutation model show deviations of as much as one milliarcsecond.

Keywords Universal Time UT1 · Geodetic VLBI · Intensive observations · Polar motion and nutation

1 Introduction

Among the earth orientation parameters, the daily earth rotation angle, represented as Universal Time UT1, is the most variable quantity with significant unpredictable variations. In order to monitor its behaviour and provide a timely base set for predictions, dense series of dedicated very long baseline interferometry (VLBI) observations with contemporary analysis have been carried out since 1985 (Robertson et al. 1985). The sole objective of these so-called *Intensive* observations is the daily measurement of UT1 with affordable logistics using only one VLBI baseline with about 1 h of observing time. A large east–west extension of the baseline is always necessary for a high sensitivity of UT1. Between April 1984 and February 1994 *Intensive* observations were carried out using the baseline Wettzell (Bavaria, Germany)–Westford (Massachusetts, USA), replaced by Wettzell–Green Bank (West Virginia, USA) from March 1994 to June 2000 (Eubanks et al. 1994). Since July 2000 the baseline Wettzell–Kokee Park (Hawaii, USA) has been in operation for these short-term single baseline *Intensive* sessions routinely. The observations (today called INT1) have usually been carried out four to five times a week on Mondays to Fridays with a special emphasis on quick data transfer and analysis.

Recognising the importance of a regular and dense monitoring of the rotation angle UT1, the International VLBI Service for Geodesy and Astrometry (IVS) (Schlüter and Behrend 2007) established a second baseline for *Intensive* VLBI observations in 2002. This second observation series, called INT2, using the baseline Wettzell–Tsukuba (Japan) is a temporal complement of the Wettzell–Kokee Park observations densifying the sequence of UT1 measurements on Saturdays and Sundays. An overview of the current organisation of both *Intensive* series is given in Table 1 with the geometry of the two *Intensive* baselines being depicted in Fig. 1.

The accuracy of the INT1 series has been evaluated previously on the basis of comparing them with coincident, multi-baseline 24-h VLBI determinations (Ray et al. 1995), or with respect to their sensitivity to the atmospheric delay model, and to the terrestrial and celestial reference frames

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Table 1 Overview of the current *Intensive* observing routines

	INT1	INT2
Stations	Wettzell (Germany) Kokee Park (Hawaii, USA)	Wettzell (Germany) Tsukuba (Japan)
Length of baseline (km)	10,357.4	8,445.0
East–West-dimension (km)	10,072	8,378
North–South-dimension (km)	2,414	1,064
Observing days	Monday to Friday	Saturday and Sunday
Time frame of observations	18.30 to 20.00 UT	07.30 to 09:00 UT
Recording technique	MARK 4/5	K4/K5 resp. MARK 4/5
Correlator	Washington MARK4/5 (NASA)	Tsukuba K4/K5 (GSI)
Scheduler	GSFC Washington DC	BKG Leipzig
Avg. number of scans		Before Aug. 2004:18.5/19.5
per session (obs./sched.)	16.3/17.0	After Aug. 2004:27.1/28.6

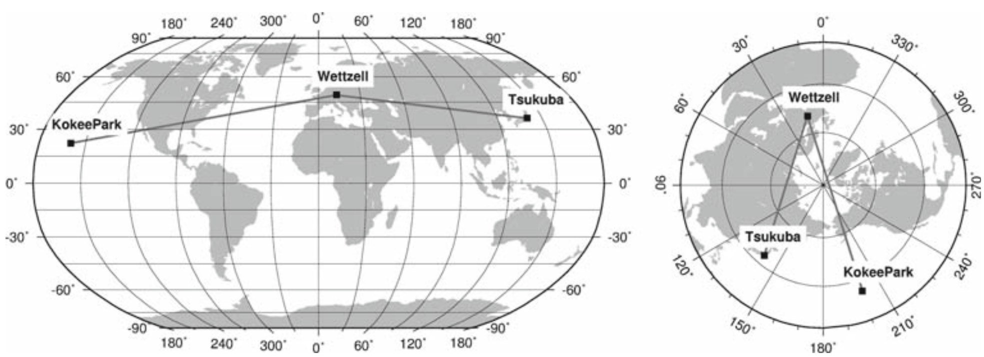

Fig. 1 Baseline geometry of current *Intensive* observations

(Hefty and Gontier 1997). Titov (2000) compared the effects of two nutation models, IAU1980 (Wahr 1981) and IERS1996 (Herring 1996), on the estimates of UT1.

Here, we concentrate on the geometric relations and on the impact of polar motion and nutation on the UT1 results. In general, the adjustment procedure of *Intensive* sessions requires that polar motion and nutation as well as the terrestrial and the celestial reference frame be introduced as known quantities. The advent of the second series, now, provides the opportunity for a detailed analysis of the sensitivity of the observations and of the geometric relations with the predefined "datum" of polar motion and nutation at the epoch of observation depending on the baseline employed. In this paper, we will, thus, investigate the differences in the effects which errors in fixed polar motion and nutation a prioris have on the UT1 estimates through their geometrical properties. Transfer functions will be developed which can be employed to approximate the effects of errors in polar motion and nutation angles on UT1 determinations.

As for all geodetic VLBI sessions, the analysis of the *Intensive* observations is carried out employing the standard VLBI observation equation for the delay τ of a baseline (e.g. Ma et al. 1990)

$$\tau = -\frac{1}{c}\, b_{i.6} W_{ij.} S_{ij.} N_{ij.} P_{ij.} k_{i.2} + T_0(t_0) + T_1(t - t_0) + \tau_{atm_1} - \tau_{atm_2} + \tau_{\text{corr}} \quad (1)$$

with

c	speed of light
$b_{i.6}$	baseline vector in a mean earth-fixed system (system S_6), e.g. ITRF2005
$W_{ij.}$	Rotation matrix of polar motion (wobble) de-composed in $R_x(y_p) R_y(x_p)$
$S_{ij.}$	Rotation matrix of UT1/sidereal time (spin)
$N_{ij.}$	Rotation matrix of nutation
$P_{ij.}$	Rotation matrix of precession
$k_{i.2}$	unit vector in source direction in mean space-fixed system at J2000.0 (system S_2), e.g. ICRF
T_0	clock offset between observatories
T_1	clock rate between observatories
t_0, t	reference and observation epoch, resp.
τ_{atm_i}	refraction parameter at station i (wet part)
τ_{corr}	other corrections (refractive, geophysical, instrumental, etc.)

Here, the notations of the systems S_2, mean space-fixed system at J2000.0, and S_6, mean earth-fixed system, with their intermediate systems S_3, S_4 and S_5 (true systems of date) used for the respective transformations follow the naming concept of Heitz (1976).

The parameters estimated for each *Intensive* observing session of 20–30 individual delay observations are normally limited to $UT1$, T_0, T_1, τ_{atm_1} and τ_{atm_2} while various corrections are applied and all other parameters, like those defining the datum including polar motion and nutation, have to be fixed to certain a priori values. In this paper we discuss the effects of the fixing of polar motion and nutation on the estimates of UT1. As a result, the effect of errors of these components on the accuracy of the UT1 estimates can be quantified.

2 The impact of polar motion on *Intensive* UT1-UTC estimates

In order to quantify the impact of polar motion errors on the estimates of UT1, we first consider the geometry of the baseline employed. The components of polar motion, x_p and y_p, describe the direction of the true rotation axis (z_5 in system S_5, i.e. earth-fixed at time of observation) relative to the conventional (mean) terrestrial reference system (S_6), which is realised by the station coordinates (x_6, y_6, z_6). The coordinates of the observing stations are transformed from the conventional (S_6) into the true earth-fixed system of date (S_5) by

$$\begin{pmatrix} x_5 \\ y_5 \\ z_5 \end{pmatrix} = R_x(y_p) R_y(x_p) \begin{pmatrix} x_6 \\ y_6 \\ z_6 \end{pmatrix} = \begin{pmatrix} 1 & 0 & -x_p \\ 0 & 1 & y_p \\ x_p & -y_p & 1 \end{pmatrix} \begin{pmatrix} x_6 \\ y_6 \\ z_6 \end{pmatrix} \quad (2)$$

(Mueller 1969). Thus, a small change or mismodeling of the components of polar motion causes a small rotation of the *Intensive* baseline with respect to the axes of the conventional terrestrial reference system. Consequently, such a small baseline rotation is directly connected to a change of the estimated earth rotation phase, UT1.

As a zero-order approach for a geometrical quantification of the interdependencies between the determination of UT1 and the variations of the baseline, it may be permitted to consider only the baseline projection into the equatorial plane. Here, the direction of a baseline with respect to the system S_6 can be expressed by

$$\alpha = \arctan \frac{y_2 - y_1}{x_2 - x_1} \quad (3)$$

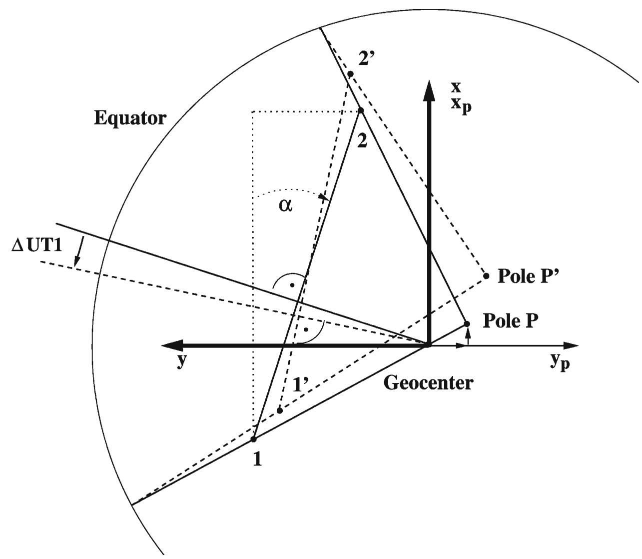

Fig. 2 Rotation of an *Intensive* baseline projection in the equatorial plane due to small corrections of polar motion components

where the station coordinates x_1, y_1, x_2, y_2 are given in the mean conventional terrestrial reference system S_6 with the indices standing for the eastern (index 1) and the western (index 2) end point of the baseline (Fig. 2).

If the pole P of the rotation axis is displaced to P' due to an inadequate a priori information of the pole components, first the positions of the observing stations ($1 \rightarrow 1'$, $2 \rightarrow 2'$) and consequently the direction α (Eq. 3) of the baseline are affected. The partial derivatives of Eq. 3 characterise the interrelation between the baseline direction and small changes of the station coordinates:

$$\frac{\partial \alpha}{\partial x_1} = \frac{y_2 - y_1}{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad (4)$$

$$\frac{\partial \alpha}{\partial x_2} = -\frac{y_2 - y_1}{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad (5)$$

$$\frac{\partial \alpha}{\partial y_1} = -\frac{x_2 - x_1}{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad (6)$$

$$\frac{\partial \alpha}{\partial y_2} = \frac{x_2 - x_1}{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad (7)$$

At the same time, the station coordinates are affected by small changes $\mathrm{d}x_p$, $\mathrm{d}y_p$ of the pole components according to Eq. 2 by

$$\mathrm{d}x = -z\,\mathrm{d}x_p \quad \text{and} \quad \mathrm{d}y = z\,\mathrm{d}y_p. \quad (8)$$

Inserting these in Eqs. 4–7 leads to the dependencies of the baseline direction α on $\mathrm{d}x_p$ and $\mathrm{d}y_p$ (Eqs. 9 and 10). A rotation $\mathrm{d}\,\alpha$ of the baseline projection can also be interpreted as a rotation of the coordinate axes in opposite direction.

Table 2 Linear dependency of UT1 on the components of polar motion deduced from geometrical considerations as lower bounds of the transfer of polar motion uncertainties on UT1 estimates (mas = milliarcseconds, μs = microseconds)

Base	INT1 Wz-Kk (μs/mas)	INT2 Ts-Wz (μs/mas)
$\frac{\mathrm{dUT1}}{\mathrm{d}x_p}$	−4.74	2.40
$\frac{\mathrm{dUT1}}{\mathrm{d}y_p}$	−15.26	−8.12

Table 3 Empirical reaction of *Intensive* UT1 results to variations of the pole components

	Spread						Weighted Means	
	INT1 $[\frac{\mu s}{mas}]$			**INT2** $[\frac{\mu s}{mas}]$			**INT1** $[\frac{\mu s}{mas}]$	**INT2** $[\frac{\mu s}{mas}]$
$\frac{dUT1}{dx_p}$	-23.2	-	10.1	19.4	-	38.2	-8.7	30.8
$\frac{dUT1}{dy_p}$	-19.9	-	-9.5	-3.0	-	2.5	-14.0	0.3

Therefore, the influence of $\mathrm{d}x_\mathrm{p}$ and $\mathrm{d}y_\mathrm{p}$ on the UT1 estimates will be $\mathrm{d}\,\alpha = -\mathrm{dUT1}$.

$$\frac{\mathrm{d}\,\alpha}{\mathrm{d}\,x_\mathrm{p}} = \frac{(y_2-y_1)(z_2-z_1)}{(y_2-y_1)^2+(x_2-x_1)^2} = -\frac{\mathrm{dUT1}}{\mathrm{d}\,x_\mathrm{p}} \quad \text{and} \tag{9}$$

$$\frac{\mathrm{d}\,\alpha}{\mathrm{d}\,y_\mathrm{p}} = \frac{(x_2-x_1)(z_2-z_1)}{(y_2-y_1)^2+(x_2-x_1)^2} = -\frac{\mathrm{dUT1}}{\mathrm{d}\,y_\mathrm{p}}. \tag{10}$$

It is obvious that the theoretical impact of polar motion on the UT1 estimates is zero if both stations are of equal latitude ($z_1 = z_2$). Thus, a baseline's UT1 result is more affected by errors in the polar motion a prioris, the bigger its north–south component. In addition, the denominators of Eqs. 9 and 10 show that baselines with very large east–west dimensions are much more robust against polar motion insufficiencies than shorter ones. Assuming just these geometrical relationships, lower bounds can be computed for the effects of polar motion uncertainties on UT1 with Eqs. 9 and 10 (Table 2).

The numbers in Table 2 confirm that the UT1 determinations with the INT1 baseline which has a north–south extension more than twice as large are about twice as sensitive to errors in polar motion a prioris than those with the INT2 baseline. These dependencies are derived geometrically and, therefore, they only describe the apparent angular response of an interferometer geometry. However, since an *Intensive* session is composed of a set of observations of radio sources in various different directions with a variety of declinations, the geometric considerations alone will not cover the whole effect. Moreover, the influence of the variations in polar motion will also affect other parameters in the estimation process like clock and atmosphere parameters.

In order to check this, an empirical test has been carried out with 24 sessions each of both *Intensive* series scattered over the whole range of sidereal times. In repeated adjustments, both components of the polar motion angles have been modified systematically in both *Intensive* series by 0.1, 0.5, 1.0 and 3.0 mas each. The main result was that the UT1 estimates always changed directly proportional to the variations in the pole compenents. However, the dependencies of the UT1 estimates on the pole coordinates are not uniform but vary by observing day as a consequence of the different observing schedules, i.e. the different radio sources at different areas of the sky. In Table 3 the spread within the two series is listed together with the weighted mean.

It is immediately obvious that in general the scatter is fairly large and an agreement with the purely geometrical relationships in Table 2 would be rather accidental. It can, therefore, be stated that the dependencies of the UT1 estimates on the polar motion errors heavily depend on the observation geometries of the individual observing session and only marginally on the geometric relationship of Eqs. 9 and 10. It should be mentioned that a larger sample would affect the means and the scatter of the results only by fractions of the overall numbers. It is more important that the whole range of sidereal time epochs is well covered to check whether any systematic variations are discernible which is not the case.

Assuming that the accuracy of polar motion components published by the International Earth Rotation and Reference Systems Service (IERS) is at the level of 100 μas (1σ) an upper bound of 2.3 μs can be given for the polar motion induced error of INT1 and 3.8 μs of INT2 by scaling the maxima in Table 3 by 1/10 (conversion from 1 mas to 100 μas). Even though the geometric considerations alone are not sufficient to explain any dependencies, the approach chosen here will have a direct application when considering the impact of nutation errors on UT1 estimates as will be shown in the next section.

3 The impact of nutation

A similar scenario of interdependencies also applies to nutation as Titov (2000) already showed significant differences between *Intensive* solutions for observations on the Wettzell–Green Bank baseline based on two different nutation models applying empirical comparisons. In our study, we start with an empirical test as well. Using the complete data set of the *Intensive* sessions of the year 2005, a constant offset of 1 mas has been added separately to $\Delta\psi$ and $\Delta\varepsilon$ and the differences in the UT1 results have been computed w.r.t. the standard solution. The data points in Figs. 3 and 4 depict the individual observing sessions representing the UT1 differences induced by the enforced nutation offsets.

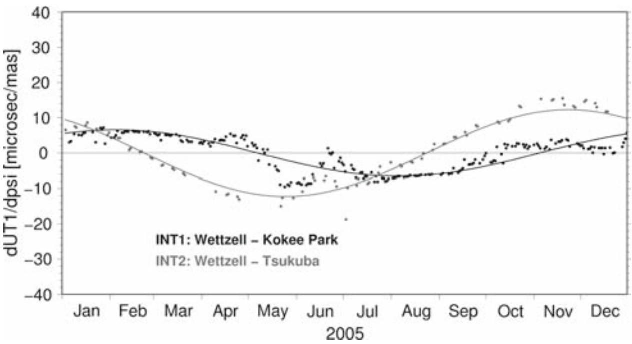

Fig. 3 Differences of UT1 results induced by an enforced constant 1 mas difference of the nutation in longitude (*dotted*). The *solid lines* represent the impacts as expected theoretically

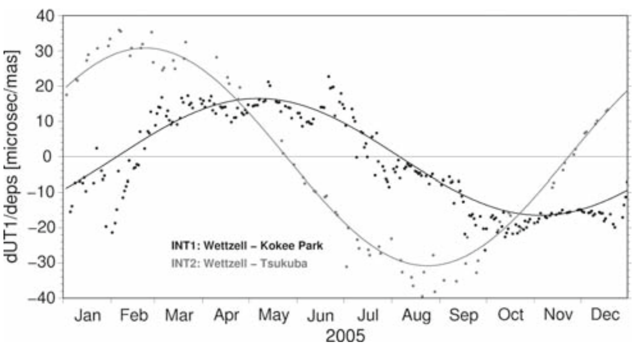

Fig. 4 Differences of UT1 results induced by an enforced constant 1 mas difference of the nutation in obliquity (*dotted*). The *solid lines* denote the impacts as expected theoretically

Even without the solid lines included in the graph, one can already discern that all components in Figs. 3 and 4 reveal a sinusoidal behaviour with an annual period. Any further small scale systematics beyond arbitrary scattering can be attributed mainly to the individual VLBI observing schedules. In certain periods of time the schedules often use similar sets of radio sources and these, in turn, are affected by offsets in the nutation angles depending on their right ascensions.

Due to the fact that the nutation modeling itself is a composition of numerous individual harmonic oscillations, a possible incorrectness of the model would have a certain periodic behaviour, with periods shorter than 1 year and amplitudes below half a milliarcsecond, too, which should be superimposed on the annual period of the UT1 impact displayed. For clarity, however, these periodicities of the nutation terms themselves are neglected here and are considered to be part of the overall error.

In order to develop a model for the admittance of the UT1 estimates to uncertainties in the nutation angles, some geometrical considerations are to be applied again. In general, nutation in longitude is embedded in the relation between the true and the mean vernal equinox and, thus, the conversion of the observed apparent sidereal time at Greenwich (GAST = Θ) into the mean sidereal time (GMST). Due to the derivation of UT1 from GMST by

$$\mathrm{UT1} = \mathrm{GMST} - \alpha_{\mathrm{mSu}} + 12h \tag{11}$$

$$= \Theta - \Delta\psi \cdot \cos\varepsilon_0 - \alpha_{\mathrm{mSu}} + 12h, \tag{12}$$

a change or insufficiency of the used nutation model, therefore, directly influences the definition of UT1. α_{mSu} is the right ascension of the mean sun, ε_0 is the mean obliquity of the ecliptic and $\Delta\psi$ is the nutation in longitude. Furthermore, the nutation in obliquity also has an impact on the results of *Intensive* sessions because VLBI observations are of course sensitive to the complete rotational position of the earth relative to the space-fixed celestial reference system. The geometrical relationship of the mean earth-fixed system (S_6) and the space-fixed system at any epoch can be described by just three angles and there cannot be a distinction between polar motion and nutation. This also applies to the 1-h observing period which is still too short for a reliable separation (Thaller et al. 2007). For this reason it may be safely assumed that within *Intensive* sessions the impact of nutation on UT1 estimates is geometrically identical to the impact of polar motion. In other words, small changes of nutation angles can also be functionally expressed as changes of pole components, whose impact on UT1 is already known from the previous section.

In general, changes of the nutation model associate with changes of the pole components in the form

$$\mathrm{d}x_{\mathrm{p}} = \quad \mathrm{d}\Delta\varepsilon \sin\Theta + \mathrm{d}\Delta\psi \sin\varepsilon_0 \cos\Theta \tag{13}$$

$$\mathrm{d}y_{\mathrm{p}} = -\mathrm{d}\Delta\varepsilon \cos\Theta + \mathrm{d}\Delta\psi \sin\varepsilon_0 \sin\Theta. \tag{14}$$

with $\mathrm{d}x_{\mathrm{p}}$, $\mathrm{d}y_{\mathrm{p}}$ being the changes of the pole components related to small nutation differences $\mathrm{d}\Delta\psi$ and $\mathrm{d}\Delta\varepsilon$ (Zhu and Mueller 1983).

In order to quantify the effect of nutation on UT1 determinations, an analogy can be drawn with the effect of polar motion as explained above. If we consider an observing epoch when the zero meridian points towards the equinox, a tilt in nutation has the same effect on the observing geometry as a tilt in the terrestrial pole but with opposite signs. Therefore, the impact of nutation angles on the estimates of UT1 can be formulated as

$$\frac{\mathrm{dUT1}}{\mathrm{d}\Delta\psi} = \frac{\mathrm{dUT1}}{(-\mathrm{d}x_{\mathrm{p}})}\frac{\mathrm{d}x_{\mathrm{p}}}{\mathrm{d}\Delta\psi} + \frac{\mathrm{dUT1}}{(-\mathrm{d}y_{\mathrm{p}})}\frac{\mathrm{d}y_{\mathrm{p}}}{\mathrm{d}\Delta\psi}$$

$$= -\frac{\mathrm{dUT1}}{\mathrm{d}x_{\mathrm{p}}}\sin\varepsilon_0\cos\Theta - \frac{\mathrm{dUT1}}{\mathrm{d}y_{\mathrm{p}}}\sin\varepsilon_0\sin\Theta \tag{15}$$

$$\frac{\mathrm{dUT1}}{\mathrm{d}\Delta\varepsilon} = \frac{\mathrm{dUT1}}{(-\mathrm{d}x_{\mathrm{p}})}\frac{\mathrm{d}x_{\mathrm{p}}}{\mathrm{d}\Delta\varepsilon} + \frac{\mathrm{dUT1}}{(-\mathrm{d}y_{\mathrm{p}})}\frac{\mathrm{d}y_{\mathrm{p}}}{\mathrm{d}\Delta\varepsilon}$$

$$= -\frac{\mathrm{dUT1}}{\mathrm{d}x_{\mathrm{p}}}\sin\Theta + \frac{\mathrm{dUT1}}{\mathrm{d}y_{\mathrm{p}}}\cos\Theta. \tag{16}$$

Owing to the dependency on Θ, the impact of a change of the nutation model on the UT1 estimates varies periodically with a cycle duration of one sidereal day. Due to the fact that INT1 sessions are observed between 18.00 and 20.00 UT and INT2 sessions between 07.30 and 09.00 UT, a mismodeling of the nutation would affect the UT1 estimates with a phase difference of about 10 h. Furthermore, it has to be taken into account that the observing times of the *Intensives* are fixed to solar time and thus the sidereal time of the sessions varies from day to day by the difference between a solar and a sidereal day, which is about 4 min per day. Therefore, with observing time fixed at specific solar epochs for each baseline, the influence of the nutation depends on the day of the year. Here, sidereal time Θ then comprises both, the orientation of the baseline and the solar time of the observations, which lead to an equivalent phase shift in the annual representation.

Now, returning to the empirical computations at the beginning of this section, we should be able to match the empirical results with the model of formulas 15 and 16 applying 1 mas nutation errors. The resulting sinosoids by far exceed what we found in the empirical test (not shown here). However, if we assume the mean values of $\frac{\mathrm{dUT1}}{\mathrm{d}x_\mathrm{p}}$ and $\frac{\mathrm{dUT1}}{\mathrm{d}y_\mathrm{p}}$ according to Table 3 and apply them to formulas 15 and 16, the theoretical impact of $\mathrm{d}\Delta\varepsilon$ and $\mathrm{d}\Delta\psi$ matches the empirical results very well, i.e. less than 4 µs WRMS (solid lines in Figs. 3, 4). If we would estimate annual periods from the empirical data of Figs. 3 and 4 we would probably reach a slightly better fit for $\frac{\mathrm{dUT1}}{\mathrm{d}x_\mathrm{p}}$ and $\frac{\mathrm{dUT1}}{\mathrm{d}y_\mathrm{p}}$. However, the values of Table 3 really represent the admittance of the individual baselines and should, thus, be preferred.

From visual inspection of the results of current observations of nutation offsets w.r.t the state-of-the-art nutation model, i.e. IAU2000A (Mathews et al. 2002) as published by the International VLBI Service for Geodesy and Astrometry (IVS), uncertainties of the model of as much as 0.3 mas in addition to a clear annual signal and possible other periods can be identified (IVS 2007a).

Assumed to remain mismodeling of about 0.3 mas for both nutation components after the nutation model has been corrected scales the impact level to about 30% of that depicted in Figs. 3 and 4. Consequently, these induce an error component of about 10 µs in the UT1 results from INT2 and about 6 µs from INT1 for $\Delta\varepsilon$ and about 4 and 3 µs for $\Delta\psi$, respectively.

4 Conclusions

The second *Intensive* series INT2 using the baseline Wettzell–Tsukuba, carried out regularly since April 2003, is a complement of the traditional, long-standing Wettzell–Kokee Park series INT1 enabling monitoring of UT1 on a daily basis. When reporting UT1 (in the form of UT1–UTC) the uncertainties are given as standard deviations (1σ) computed from the least squares adjustment process. These formal errors are reported by the IVS Analysis Centers in the range of 7–10 µs for the INT1 sessions and 6–8 µs for the INT2 series (IVS 2007b). Although the formal errors of both *Intensive* series are of equal order of magnitude, significant baseline-dependent elements of uncertainty through uncertainties in fixed polar motion and nutation have been identified. These geometry and time-dependent impacts affect the relative, i.e. between neighbouring epochs, as well as the absolute accuracy of the results of any *Intensive* observations.

As demonstrated in this paper, these contributions are not negligible but rather have the same level as the formal errors of the UT1 estimates, i.e. between 6 and 12 µs. They have to be taken into account when addressing the question of accuracy of the UT1 determinations from *Intensive* observing sessions. Therefore, empirical tests have produced admittance factors for the effects of errors in polar motion on the estimates of UT1 (Table 4). Although the scatter is quite large as can be seen in Table 3, the mean values can safely be used as good estimates for the conversion of errors in polar motion a prioris into systematic errors of UT1. The main argument is that these factors also best match the empirical test of the impact of nutation. With the x pole component of the INT2 baseline having a maximum deviation of 38 [µs/mas] and the error in polar motion being below 100 µas, the maximum effect is about 3.8 µs. This is already a significant contribution compared to the standard deviations which are reported by the IVS Analysis Centers to be between 6 and 10 µs resulting purely from the fit of the observations itself (IVS 2007b).

The transfer of the nutation errors into the UT1 estimates may safely be based on applying a functional model to the empirical values of Table 4. Since the error in UT1 caused by nutation mismodelling is dependent on the sidereal time of the observation, the transfer has to be computed with:

$$\frac{\mathrm{dUT1}}{\mathrm{d}\Delta\psi} = -\frac{\mathrm{dUT1}}{\mathrm{d}x_\mathrm{p}} \sin\varepsilon_0 \cos\Theta - \frac{\mathrm{dUT1}}{\mathrm{d}y_\mathrm{p}} \sin\varepsilon_0 \sin\Theta \qquad (17)$$

$$\frac{\mathrm{dUT1}}{\mathrm{d}\Delta\varepsilon} = -\frac{\mathrm{dUT1}}{\mathrm{d}x_\mathrm{p}} \sin\Theta + \frac{\mathrm{dUT1}}{\mathrm{d}y_\mathrm{p}} \cos\Theta . \qquad (18)$$

Again, sidereal time Θ comprises both, the orientation of the baseline and the solar time of the observations. For the x pole component in INT2 the impact, consequently, varies between +30 and −30 (µs/mas). However, in contrast to polar

Table 4 Admittance factors of *Intensive* UT1 results to variations of the pole components

	Admittance factors	
	INT1 (µs/mas)	INT2 (µs/mas)
$\frac{\mathrm{dUT1}}{\mathrm{d}x_\mathrm{p}}$	−8.7	30.8
$\frac{\mathrm{dUT1}}{\mathrm{d}y_\mathrm{p}}$	−14.0	0.3

motion, errors in nutation may still be as large as 1 mas (IVS 2007b).

In contrast to VLBI network sessions of 24 h duration from which polar motion, UT1 and nutation can be estimated simultaneously, *Intensive* observing sessions heavily depend on a priori information of polar motion and nutation. It has been demonstrated here that both contributions, the a prioris of polar motion and of nutation, introduce significant systematic deviations in the UT1 results. When assessing the accuracy of the UT1 results from single baseline *Intensive* observing sessions, it is, therefore, of paramount importance to take these effects into account by applying the numbers of Table 4 and Eqs. 17 and 18 in an root-sum-squared sense.

Another consequence of these investigations should be a more elaborate procedure for the introduction of the nutation a prioris in the data analysis of *Intensive* observing sessions: it is not sufficient to just introduce nutation angles according to the IAU2000A model but corrections predicted from previous VLBI network observations have to be added as well. Prediction will be even more important when the VLBI bitstreams of the *Intensive* observations will be transferred to the correlators by electronic networks and the latency between observations and analysis will be shortened to only a few hours.

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