Notes on December 2017 version of the ECLIPS subroutine

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In the previous *ECLIPS* subroutine version (*May 2017*), only a simple Beidou eclipsing, suggested by Montenbruck et al (2015), has been implemented. Namely, as soon as the angle β (the sun angle above, or below the orbital plane) felled below 4 degrees, the Beidou IGSO (Inclined Geosynchronous) and MEO (Mean Earth Orbit) satellite switched from the nominal yaw orientation to the so call Orbit Normal (ON) mode, where the +x body axis points in the satellite velocity direction and the yaw angle is equal to 0 deg. The Beidou geosynchronous (GEO) satellites always employ the ON mode. However, such switching can cause large jumps (up to $\pm$ 180 deg.) in the yaw angle, which is rather problematic, given the large Beidou body-x offset of 0.6 m. Using the reverse PPP, Dail at al. (2015) and Melachroinos et al (2017) have shown, that in order to minimize the yaw angle jumps, the actual switching from the nominal yaw steering (YS) to the ON mode and visa versa takes place for β close to $\pm$ 4 degrees, but only when the orbit angle u is near 90 deg. Then, the nominal yaw angle is small, equal to $-\beta$ and yaw angle jumps at YS/ON/YS switching are only ~ 4 degrees.

The new *Dec 2017 ECLIPS* version has implemented a more realistic YS/ON/YS switching, i.e., when the orbit angles are at or near 90 deg. Furthermore, now it also allows three additional input call parameters which, if nonzero, override the hard-coded yaw rate and yaw bias, and for a Beidou satellite specified by the new call parameter, it invokes the Galileo mode eclipsing. The changes and enhancements are described within the source by numerous comments. The following notes are intended to provide additional information on the changes/enhancements and testing of the new *Dec 2017 ECLIPS* version.

Beidou IGSO and MEO eclipsing

According to Melachroinos et al (2017), where numerous IGSO and MEO satellites eclipsing's have been studied during the 3 year period of 2014-2016, all the observed YS/ON/YS switching, indeed had β angles near $\pm$ 4 degrees and the orbit angles near 90 deg. Most of the YS/ON switching happened for $|\beta| < 4$ deg, however, a few switches were just before $|\beta|$ reached 4 deg., i.e., it was still slightly above 4 deg. Similarly for the ON/YS switching, most happed when $|\beta|$ was above 4 deg., though some have occurred even with $|\beta|$ still just below 4 deg. In all the cases, the orbit angles were close to 90 deg. to minimize the yaw angle jumps. Obviously, the YS/ON and ON/YS switching can already happen when the orbit angle u reaches 90 deg. and $|\beta|$ is very near the 4 deg. limit (within about 0.1 deg.).

Melachroinos et al (2017) suggested to the use of the orbit precision in the Beidou broadcast message to derive (somehow) the actual $|\beta|$ switching limit, replacing the nominal one of 4 deg. Since the broadcast message may not be readily available, or convenient for *ECLIPS* users, here new fixed $|\beta|$ limits have been adopted instead, namely 4.1 deg. for the YS/ON switching for a decreasing $|\beta|$ and 3.9 deg. for the ON/YS switching when $|\beta|$ is increasing. These fixed limits satisfy all the YS/ON/YS switching observed in Melachroinos et al (2017) during 2014 to 2016.

Using the 4.1 and 3.9 deg. limits for the YS/ON and ON/YS switching, regardless if $|\beta|$ is increasing or decreasing, and the change of β over one orbit revolution $|d\beta|$ (internal parameter *BETAE*), then the ON mode is used when

$$|\beta| < 4.1 - |d\beta|, \qquad (1)$$

for all IGSO (IBLK(IPRN)= 22) and MEO (IBLK (IPRN)= 21), as well as for all the GEO satellites. Similarly, the YS mode is used when

$$|\beta| > 3.9 + |d\beta|, \qquad (2)$$

for all IGSO and MEO satellites. Furthermore, for a decreasing $|\beta|$ the YS is used always when $|\beta| > 4.1$ deg. and for an increasing $|\beta|$ the ON mode is still used when $|\beta| < 3.9$ deg. $|d\beta|$, which depends on a particular satellite, can vary from 0.4 to about 1.0 deg./rev. It is initialized to 0.52 and 0.97 deg./rev. for MEO and IGSO satellites, respectively. However, for subsequent calls of a specific Beidou satellite when the initial β (the call parameter *BETAINI (IPRN)*) is nonzero, it is computed from the difference between the current and the initial β angles and the corresponding elapsed time difference. Finally, for IGSO or MEO satellites with decreasing $|\beta|$ between 4.1 and 4.1-$|d\beta|$ deg., the ON mode is used when the interpolated β value at the 90 deg. orbit angle is less than, or equal to 4.1 deg, i.e.,

$$[|\beta|+|d\beta| \ (u - 90)/360] \leq 4.1 \text{ deg.,} \quad (3)$$

and for increasing $|\beta|$ between 3.9 and 3.9+$|d\beta|$ deg, the YS mode is used when

$$[|\beta|-|d\beta| \ (u - 90)/360] \geq 3.9 \text{ deg.} \quad (4)$$

Here, the orbit angle u difference from 90 degrees (u - 90), if negative, is increased by 360 deg. The orbit angle $\underline{u}$ (the internal parameter *DET*) for Beidou satellites is approximated by the acute satellite-Earth-Sun angle B, since cos B (the call parameter *SVBCOS*) is also available for Beidou satellites, i.e.

$$u = 180 - B \text{, for yaw angles } \leq 90 \text{ deg. and } u = 180 + B \text{, for yaw angles } > 90 \text{ deg.,} \quad (5)$$

which is a good approximation, considering that it is used only for $|\beta|$ of about 4.9 deg. or less.

Note that, unlike in Melachroinos et al (2017), where the yaw angle of $-\beta$ is used for the ON mode (to achieve zero-yaw angle jumps for the YS/ON/YS switching), here zero-yaw angles are used for the ON mode, since 4 deg. yaw angle jumps are not considered significant.

In the above implementation, the first *ECLIPS* call of a specific satellite with $|\beta|$ between 3.1 and the 4.9 deg. (assuming the maximum $|d\beta|$ = 1 deg./rev.) may fail to switch to, or to use the ON mode and may retain the YS mode instead. This is so since the initial β, *(BETAINI(IPRN)),* is zero and thus it is not known if $|\beta|$ is increasing or decreasing. Consequently, the tests (3) and (4) cannot be used and the satellites with $|\beta|$ between 3.9+$|d\beta|$ and 4.1-$|d\beta|$ retain the YS mode, except for the GEO satellites (*IBLK(IPRN)* of 23 or 27), which always use the ON mode. Also, for the first call, the hard coded $|d\beta|$ may be in error by much as 0.5 deg./rev., resulting in a wrong YS/ON or ON/YS switching, specified by (1) and (2). However, for the second and subsequent calls of a particular satellite, the *BETAINI(IPRN)* and $|d\beta|$ are known and the proper switch tests (1) - (4) are applied.

Table 1. The sun β angles at the start (*ON Start*) and the end (*ON End*) of the Orbit Normal (ON) yaw mode for the IGSO and MEO Beidou satellites, when orbit angles are 90 deg. The switching β angles of the *ECLIPS* subroutine (*Beta Ecl*) are practically the same as the β angles (*Beta Mel*) of Melachroinos et al (2017).

PRN	SV Type	ON Start	Beta Ecl	Beta Mel	ON End	Beta Ecl	Beta Mel
C06	IGSO-1	06-Apr-14	-3.70	-3.70	14-Apr-14	3.97	3.96
C07	IGSO-2	13-Jan-16	3.96	3.96	26-Jan-16	-4.45	-4.45
C08	IGSO-3	17-Dec-16	-3.50	-3.49	26-Dec-16	4.04	N/A
C09	IGSO-4	03-Oct-16	3.97	3.97	12-Oct-16	-4.74	-4.74
C10	IGSO-5	11-Jul-16	-4.02	-4.02	14-Apr-16	4.00	4.00
C11	MEO-3	16-Dec-15	-4.02	-4.01	26-Dec-15	3.99	4.00
C12	MEO-4	16-Dec-15	-3.70	-3.70	26-Dec-15	4.22	4.22
C14	MEO-6	23-Mar-16	-4.02	-4.01	14-Apr-16	4.02	4.01

In Tab. 1 the above *ECLIPS* implementation of Beidou satellites have been tested for five IGSO and three MEO satellites used by Melachroinos et al (2017). Here, the *ECLIPS* switching β angles (*Beta Ecl*) have been compared to the ones of Melachroinos et al (2017) (*Beta Mel*). From Tab. 1 one can see that the switching β angles of the *ECLIPS* subroutine (*Beta Ecl*) are practically the same as the β angles (*Beta Mel*) of Melachroinos et al (2017). From Tab. 1 one can also conclude that the YS/ON switching usually happens for $|\beta| < 4$ deg, but sometimes it happens even for $|\beta|$ slightly above 4 deg. On the other hand, the most of ON/YS switches were for $|\beta| > 4$ deg., but some can have $|\beta|$ slightly below 4 deg.

Using reverse kinematic PPP, Dilssner (2017) has noticed that the IGSO-6 (C13) satellite no longer switches to the ON mode when $|\beta|$ is about or smaller than 4 degrees. Instead, this new satellite keeps the YS mode until the critical $|\beta|$ = 2.8 deg. is reached, which for IGSO and MEO corresponds to the maximum hardware yaw rate (*YRATE*) of 0.085 and 0.158 deg./s, respectively. For $|\beta| < 2.8$ deg., the Beidou satellite appeared to follows quite closely the patented turn model of Ebert and Oesterlin (2008). Similarly, since October, 2016, MEO-6 (C14) and since March 2017 IGSO-1 (C06) have also abandoned the ON eclipsing mode in favour of the above Galileo-like YS eclipsing of Ebert and Oesterlin (2008) (Dilssner 2017). Furthermore, Dilssner (2017) has indicated that all the new Beidou 3 IGSO and MEO satellites may also use the Galileo- like YS, rather than the usual ON mode eclipsing. This is why a new call parameter *INPRN* has been introduced, which is valid only for Beidou (*IPRN* 101-136) and which if nonzero forces the official Galileo eclipsing noon and night turns models (Galileo Meta Data 2017), but with the critical β_y = 2.8 deg. instead of the Galileo limit of 2.0 deg. For both Galileo and Beidou, β_x = 15 deg. is used. The official rather than the patented Galileo model has been used here also for Beidou, since the use of the above patented eclipsing model may be problematic within a publicly available software and since the patented model does not differ much from the official Galileo eclipsing mode, namely by about 10 deg., see Fig.1. Note that for Galileo and Beidou satellites, the β_y (*BETA0*) is now recomputed from the hardware rate (*YRATE*) and from the actual satellite angular orbital velocity (*MURTE*).

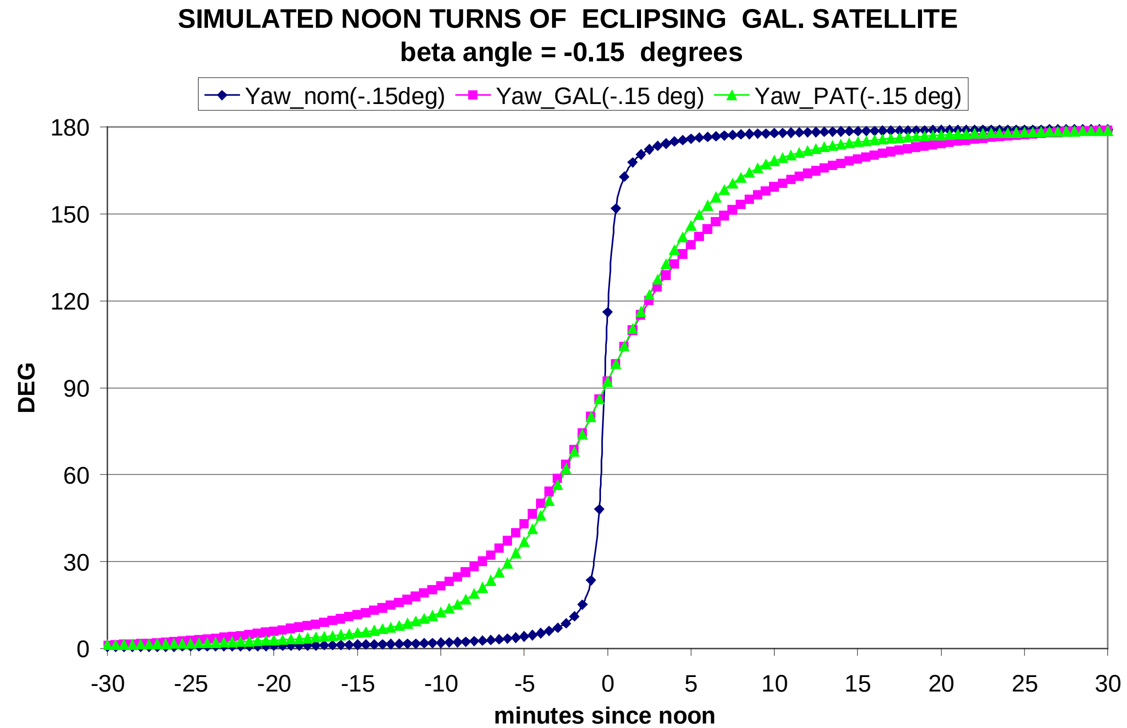

Fig. 1. Nominal yaw (*Yaw_nom*), the Galileo official model (Galileo Meta Data 2017) (*Yaw_GAL*) and the patented model (Ebert and Oesterlin 2008) (*Yaw_PAT*) simulated noon turn yaw angles for an eclipsing Galileo satellite with the small β of -0.15 deg. (*Yaw_GAL* and *Yaw_PAT* differ by up to 10 deg.).

In anticipation that the future (Beidou 3) IGSO and MEO satellites will likely employ the Galileo-like YS eclipsing, the *IBLK(IPRN)* = 25 or 26, which are used to specify the new Beidou 3 MEO and IGSO satellites, will reset nonzero *INPRN* to *IPRN* and thus also invokes the Galileo eclipsing for the Beidou 3 IGSO or MEO *IPRN* (101-136). However, *if the Beidou 3 ISO and MEO satellites will use the usual ON mode eclipsing, the following source-code statements of ECLIPS need to be deleted, or commented out*:

```
IF(IBLK(IPRN).EQ.25.OR.IBLK(IPRN).EQ.26) THEN
 IF(INPRN.EQ.0) INPRN=IPRN
END IF
```

Yaw rate and yaw bias parameter input for GPS satellites.

The correct maximum hardware yaw rates are in particular important for GPS Block II/IIA satellites. This is due to the significant body-x offset of 0.28m as well as the II/IIA shadow crossings regime, when the eclipsing satellite rotates with the maximum yaw rate in the direction of the (known) yaw bias. The Block II/IIA yaw rates are satellite dependent and can even change for the same satellite (Bar-Sever Y 1996). This is why a yaw rate estimation is recommended. In the *ECLIPS*, to accommodate analyses with no yaw rate estimation, long term weighted averages, listed in Tab. 2 are hard-coded. The Tab. 2 lists simple and weighted averages of JPL yaw rate solutions of all the Block II/IIA satellites operational during 1996-

2008. Also shown here are the corresponding residual RMS and the standard deviation of normalised residuals (*So*) with its *99%* Chi-square limits, based on the average *So* = 2.0, which is typically seen for formal solution sigma scaling in global GNSS solutions.

Table 2: Averaged JPL reprocessing (JP1) yaw rate solutions, during 1996 - 2008 for all the GPS Block II/IIA satellites, operational during this period; unweighted (*avrg*) and weighted means (*Wavrg* - according the formal solution sigmas). Since no solutions were available for PRN 12 and 20, the JPL a priori values are listed. Also shown are single observation RMS (*rms, Wrms*). The formal sigmas of the means are much smaller, by about $\sqrt{(No - rej)}$. The 10-sigma residual rejection has been used. *So* is the standard deviation of the normalised residuals, ideally, it should be 1. The 99% column lists the 99% Chi-square limits, based on the average *So* of 2.0 (which is typical for a posteriori scaling of global GNSS solution sigmas). Here, the JP1 yaw rate solutions have been arbitrary selected (not all available were included), all a-priori solutions (sigma = 0.01deg/sec) have been excluded. Solution sigmas are usually well below 0.005 deg/sec. If available, specific, or improved yaw rates can now be input via the new call parameter *YRTIN* of the new *Dec 2017 ECLIPS* version, which, if nonzero, replaces the *YRATE* (*Wavrg*) values, hard-coded in *ECLIPS*.

prn	svn	blk	End	Wavrg	Wrms	avg	rms	So	99%	No	rej
1	32	IIA	Mar-2008	0.1211	0.0071	0.1189	0.0086	2.6	2.2	228	5
2	13	II	Feb-2004	0.1339	0.0036	0.1324	0.0072	1.4	2.6	35	4
3	33	IIA	Aug-2014	0.1230	0.0035	0.1216	0.0062	1.5	2.2	205	0
4	34	IIA	Nov-2015	0.1233	0.0021	0.1224	0.0038	1.2	2.2	190	0
5	35	IIA	Jan-2009	0.1180	0.0061	0.1195	0.0063	**2.4**	**2.3**	101	4
6	36	IIA	Feb-2013	0.1266	0.0036	0.1252	0.0077	1.7	2.2	212	0
7	37	IIA	Dec-2007	0.1269	0.0071	0.1262	0.0107	2.9	2.2	236	0
8	38	IIA	Oct-2014	0.1033	0.0027	0.1028	0.0039	1.7	2.4	62	0
9	39	IIA	Jul-2014	0.1278	0.0011	0.1275	0.0021	0.6	2.4	85	0
10	40	IIA	Jul-2015	0.0978	0.0066	0.0975	0.0069	2.4	2.3	175	0
12**	10	II	Mar-1996	0.1990							
14	14	II	Apr-2000	0.0815	0.0062	0.0820	0.0076	2.5	2.4	85	3
15	15	II	Mar-2007	0.1303	0.0084	0.1288	0.0062	3.3	2.3	145	2
16	16	II	Jul-2000	0.0838	0.0037	0.0830	0.0059	1.3	2.3	96	0
17	17	II	Feb-2005	0.1401	0.0064	0.1389	0.0054	2.7	2.3	94	1
18	18	II	Jun-2000	0.1069	0.0014	0.1063	0.0032	0.6	2.4	63	0
19	19	II	Sep-2001	0.0980	0.0009	0.0983	0.0016	0.6	2.6	31	0
20**	20	II	Jul-1996	0.1030							
21	21	II	Aug-2000	0.1366	0.0065	0.1355	0.0070	2.4	2.3	96	0
22	22	IIA	Aug-2003	0.1025	0.0097	0.1028	0.0092	4.0	2.5	44	1
23	23	IIA	Feb-2004	0.1140	0.0074	0.1163	0.0103	2.2	2.3	139	0
24	24	IIA	Nov-2011	0.1089	0.0073	0.1082	0.0067	3.1	2.3	175	10
25	25	IIA	Feb-2010	0.1001	0.0049	0.0995	0.0073	2.5	2.4	76	0
26	26	IIA	Jan-2015	0.1227	0.0047	0.1214	0.0061	1.8	2.2	238	0
27	27	IIA	Oct-2012	0.1194	0.0016	0.1189	0.0037	1.0	2.4	77	0
28	28	IIA	Nov-1996	0.1260	0.0002	0.1259	0.0004	0.1	2.6	25	0
29	29	IIA	Dec-2007	0.1228	0.0096	0.1223	0.0078	3.7	2.2	221	6
30	30	IIA	Jul-2011	0.1165	0.0080	0.1178	0.0071	3.0	2.3	112	0
31	31	IIA	Oct-2005	0.0969	0.0043	0.0962	0.0067	1.5	2.2	195	0
32*	23	IIA	Jan-2016	0.1152	0.0084	0.1139	0.0065	1.5	2.6	26	0
	avg			0.1176	0.0050	0.1147	0.0061			sum	
	rms			0.0217	0.0027	0.0151	0.0025	2.0	2.3	3441	36

* Starts in Dec 2006

******JPL a priori values

From Tab. 2, one can conclude that, with some notable exceptions, most the II/IIA satellites pass the 99% Chi-square test, indicating that for most satellites, the variation of yaw rate solutions was not statistically significant and the variation was consistent with the formal solution sigmas, scaled by *So* = 2. Nevertheless, a yaw rate call parameter input should be useful, to be able to override the hard coded values when better ones are available, since for some II/IIA satellites the yaw rates can indeed vary significantly from eclipsing to eclipsing. This is why in the *Dec 2017 ECLIPS* version a new *YRTIN* parameter has been introduced, which, when nonzero, overrides the hard-coded *YRATE* value for a particular satellite. The *YRTIN* input is useful only for GPS Block II/IIA satellites, since for the remaining GPS Block and the other GNSS satellites the yaw rates seem to be known and well behaved.

Table 3. Comparison of JPL a priori (*JPL YR*) yaw rates and the (1996 - 2008) weighted averages of the first JPL reprocessing yaw rate solutions (*Wavrg* of Tab. 2), hard-coded in the subroutine *ECLIPS*. Except for five satellites (PRN 5, 15, 22, 24 and 29) the *Wavrg* rates agree quite well with the JPL a priori ones. Interestingly, the above five satellites also fail the 99% Chi-square test, see Tab. 2.

PRN	SVN	Valid_From	Valid_To	JPL YR [deg/s]	Wavrg [deg/s]	diff. [deg/s]	M	_Bias [deg]	Comment
12	G010	1984:252:00	0000:000:00	0.199	0.1990*		U	0	GPS-I
2	G013	1995:321:00	1998:335:00	0.134	0.1340	0.0000	P	0.5	GPS-II
2	G013	1998:335:00	0000:000:00	0.134	0.1340	0.0000	P	4	GPS-II
14	G014	1995:321:00	0000:000:00	0.081	0.0815	0.0005	P	0.5	GPS-II
15	G015	1995:321:00	1999:179:00	**0.134**	**0.1303**	**-0.0037**	P	0.5	GPS-II
15	G015	1999:179:00	2001:005:75	**0.134**	**0.1303**	**-0.0037**	P	0.5	GPS-II
15	G015	2001:005:75	0000:000:00	**0.134**	**0.1303**	**-0.0037**	P	0.5	GPS-II
16	G016	1995:321:00	0000:000:00	0.084	0.0838	-0.0002	P	0.5	GPS-II
17	G017	1995:321:00	0000:000:00	0.142	0.1401	-0.0019	P	0.5	GPS-II
18	G018	1995:321:00	0000:000:00	0.107	0.1069	-0.0001	P	0.5	GPS-II
19	G019	1995:295:00	0000:000:00	0.098	0.0980	0.0000	P	0.5	GPS-II
20	G020	1995:321:00	0000:000:00	0.103	0.1030*		P	0.5	GPS-II
21	G021	1995:321:00	0000:000:00	0.137	0.1366	-0.0004	P	0.5	GPS-II
22	G022	1995:321:00	0000:000:00	**0.107**	**0.1025**	**-0.0045**	P	0.5	GPS-IIA
23	G023	1995:321:00	2002:021:00	0.114	0.1140	0.0000	P	0.5	GPS-IIA
23	G023	2002:021:00	2007:001:00	0.114	0.1140	0.0000	N	3.5	GPS-IIA
32	G023	2007:001:00	0000:000:00	0.114	0.1140	0.0000	P	0.5	GPS-IIA
24	G024	1995:321:00	0000:000:00	**0.112**	**0.1089**	**-0.0031**	P	0.5	GPS-IIA
25	G025	1995:295:00	0000:000:00	0.101	0.1001	-0.0009	P	0.5	GPS-IIA
26	G026	1995:267:76	0000:000:00	0.123	0.1227	-0.0003	P	0.5	GPS-IIA
27	G027	1995:295:00	0000:000:00	0.12	0.1194	-0.0006	P	0.5	GPS-IIA
28	G028	1995:244:00	0000:000:00	0.126	0.1260	0.0000	P	0.5	GPS-IIA
29	G029	1995:009:76	1996:256:00	**0.127**	**0.1228**	**-0.0042**	P	0.5	GPS-IIA
30	G030	1996:256:00	0000:000:00	0.119	0.1165	-0.0025	P	0.5	GPS-IIA
31	G031	1995:244:00	0000:000:00	0.097	0.0969	-0.0001	P	0.5	GPS-IIA
1	G032	1995:267:19	0000:000:00	0.123	0.1211	-0.0019	P	0.5	GPS-IIA
3	G033	1996:088:00	0000:000:00	0.123	0.1230	0.0000	P	0.5	GPS-IIA
4	G034	1995:321:00	0000:000:00	0.123	0.1233	0.0003	P	0.5	GPS-IIA
5	G035	1995:321:00	0000:000:00	**0.122**	**0.1180**	**-0.0040**	P	0.5	GPS-IIA
6	G036	1995:244:00	0000:000:00	0.127	0.1266	-0.0004	P	0.5	GPS-IIA
7	G037	1995:244:00	0000:000:00	0.128	0.1269	-0.0011	P	0.5	GPS-IIA
8	G038	1997:310:00	0000:000:00	0.103	0.1033	0.0003	P	0.5	GPS-IIA
9	G039	1995:295:00	2013:030:00	0.128	0.1278	-0.0002	P	0.5	GPS-IIA
9	G039	2013:030:00	2013:078:00	0.128	0.1278	-0.0002	N	0.5	GPS-IIA
9	G039	2013:078:00	0000:000:00	0.128	0.1278	-0.0002	P	0.5	GPS-IIA
10	G040	1996:198:00	0000:000:00	0.098	0.0978	-0.0002	P	0.5	GPS-IIA

Improved II/IIA yaw rates may become readily available, thanks to the SINEX extension, proposed by IGS, which accommodates coding of yaw rates and biases for specific satellites with specific intervals of validity. The Tab. 3 was compiled from the proposed SINEX extension (Montenbruck, per. com, the proposal for SINEX extensions, emailed *Nov. 19, 2017*), where JPL a priori yaw rates (*JPL YR*) and yaw biases (*BIAS*) were coded as a practical example of the usage of the new format extension. For comparisons, an additional column has been added, labeled *Wavrg*, It contains the weighted averaged rates of Tab. 2, hard-coded in the *ECLIPS* subroutine. From Tab. 3 one can observe a very good agreement between the JPL a priori rates and the *ECLIPS* average rate, with a notable exception of five satellites (PRN 5, 15, 22, 24 and 29), with significant differences of about 0.004 deg./s. Such large yaw rate differences can cause yaw angle errors exceeding 10 deg. after a II/IIA shadow crossing. Interestingly, the above five satellites also failed the statistical limits in Tab. 2. The statistical failures of Tab. 2 and the large differences seen in Tab. 3 may justify, or necessitate using an improved *YRATE* (if available), which is may now be possible thanks to the new call parameter *YRTIN*.

The proposed SINEX extension shown in Tab. 3 also includes yaw angle biases (*BIAS*). The yaw angle biases, which are relevant only for GPS Block II/IIA and IIF satellites, are also hard-coded (*YBIAS*) in *ECLIPS* as the II/IIA yaw bias of +0.5 and (about) -0.7 deg. has been used for (nearly) all the Block II/IIA (since Nov 5, 1995 only) and all the IIF satellites, respectively. Note the II/IIA yaw bias determines the direction of the maximum yaw rate rotation during a shadow crossing (Bar-Sever 1996). The IIF and IIA biases can also cause the anomalous noon turns for small $|\beta| \leq |YBIAS|$ (Kouba 2013), consequently *YBIAS* is also used to detect and model the anomalous turns for small positive II/IIA and negative IIF β angles. An additional yaw rate parameter call parameter input, *YBSIN* has also been implemented, *s*ince a yaw bias input may be useful for II/IIA satellites prior Nov. 5, 1995, or even after this date for some anomalous satellites (see Tab. 3, PRN 2 and 23), or simply to switch the anomalous IIF noon turns by using *YBIAS* = 0. The new call parameter *YBSIN* if nonzero replaces the hard-coded the II/IIA or IIF *YBIAS*. If |*YBSIN*| < 0.01 deg, the *YBIAS* is set 0 deg., which switches off the anomalous IIF and IIA noon turns, while still using the positive yaw rotation for IIA shadow crossing (since the Fortran SIGN(x, 0) function return a positive x). Alternatively, the IIF hard-coded *YBIAS* of -0.7 deg., used as a limit for the anomalous IIF noon turns, can also be changed (increased/decreased) for a particular Block IIF satellite, if required, by means of the *YBSIN* input parameter.

Warning: *The default Block II/IIA shadow eclipsing model is valid only after* ***Nov 5, 1995*** *when practically all the II/IIA yaw angles have been biased by +0.5 deg. and consequently their shadow behaviour is known.* ***Prior this date, shadow- crossing data should not be used,*** *unless the yaw bias is known and input via the new call parameter YBSIN.*

Conclusions

A more realistic Beidou eclipsing model has been implemented. It minimizes the yaw angle jumps by applying the YS to ON and ON to YS mode only when the orbit angle is 90 deg. Furthermore, to accommodate anomalous Beidou (and perhaps the future Beidou 3 IGSO and MEO) satellites, the new input call parameter *INPRN* has been implemented. *INPRN*, if nonzero, invokes the Galileo YS eclipsing with β_y *of* 2.8 deg., as it has been recently suggested by Dilssner (2017) for IGSO-6 (C13), IGSO-1 (C06) and MEO-6 (C14) Beidou satellites. Currently, the Galileo YS eclipsing has also been implemented for all Beidou 3 IGSO and MEO satellites (*IBLK* of 26 and 25, respectively). This, however, needs to be verified if the future Beidou 3 IGSO and MEO satellites will indeed use the Galileo-like YS eclipsing mode, or changed (as indicated above), if the Bedou 3 satellite will also employ the usual ON mode eclipsing.

The call input parameters now also include the yaw rate input (*YRTIN*) as well as yaw bias input (*YBSIN*), both of which if nonzero, for a specific satellite, allow to override the hard coded values. This may prove useful, if improved II/IIA yaw rates and II/IIA/IIF biases become available, thanks to the proposed SINEX format extensions, accommodating yaw rates and biases. |*YBSIN*| < 0.01 deg. resets the *YBIAS* to zero, which switches the anomalous IIF or IIA noon turns for small negative or positive β angles ($|\beta| \leq |YBIAS|$), respectively.

The current *ECLIPS* version (*Dec 2017*), apart from the above enhanced Beidou and potentially more precise and more flexible GPS Block II/IIA and IIF satellite eclipsing, (like the previous version) also models the eclipsing of GPS Block IIR, GLONASS and Galileo satellites, using the official (GPS IIR and Galileo), or commonly accepted (GLONASS) eclipsing models.

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