A note on the December 2013 version of the *eclips.f* subroutine

Since September 2011, when the version of the eclipsing subroutine (*eclips.f*) has been made available to IGS, several details, mainly regarding to Block IIF GPS eclipsing have been noticed, or became available. More specifically, for small negative sun (β) angles > -0.9 deg, during noon turns, eclipsing IIF satellites have been observed by reverse PPP to rotate in a wrong (negative) direction. For small positive (β < 0.09 deg), no wrong noon turn directions have been observed (Dilssner et al 2011). Furthermore, thanks to an excerpt of the IIF USA AF document (kindly made available by Oscar Colombo in January 2013), which describes the specifics of IIF eclipsing, it became clear that the currently used IIF shadow eclipsing model is not correct (though it does not depart much from the correct one). According to the USAF document, at a shadow entry, IIF satellites compute the yaw rate, which ensures that at the shadow exit the nominal yaw rate is reached, so that no yaw angle recovery is needed at the shadow exit. IIF satellites, (like the IIA ones, made by the same manufacturer) employ a yaw bias. The IIF yaw bias is normally set to the default of –0.5 deg, but for shadow crossing it is assigned the same sign as the β angle at the shadow entry, i.e. the sign of the required night turn direction (the USAF document).

Recently, Kouba (2013) has investigated the anomalous IIF noon turns for small negative β angles and concluded that the negative yaw bias of –0.5 deg can fully explain the wrong noon turns for negative β between –0.5 and 0 deg. In addition, the negative bias delays the noon turn by up to 2 min, causing yaw errors up to 13 deg. Such a negative yaw bias does not affect positive noon rotations for small positive β, though in this case, the noon turn starts early, by up to about 2 min. Both cases, i.e. delayed wrong noon turn directions for small negative β and early, but correct, noon turn directions for small positive β have been observed (see Dilssner 2011). The –0.5 bias, however, cannot explained wrong noon turns observed for some IIF's with negative β down to about –0.9 deg. An IIF implementation or some hardware specifics could cause this anomaly. For example, if, due to some hardware peculiarities, the –0.5 deg yaw bias setting produces a larger effective (the actual) yaw bias of –0.9 deg, then the noon turns will also be in a wrong (negative) directions for negativeβ down to –0.9 deg. Or alternatively, some previous eclipsing cycle parameters, used internally by IIF satellites, may cause this change of the turn anomaly limit.

Since IIA satellites also employ a yaw bias, but with the opposite sign (+0.5 deg), all IIA's for small positiveβ < 0.5 deg should also have wrong (positive) noon turn directions. This also has been, very recently, confirmed for 3 IIA satellites (Dilssner priv. com. Dec. 19, 2013). The IIA's wrong noon turns have also been observed for positive β up to 0.9 deg. Finally, Weiss et al (2012) noticed an IIA PRN 23/SVN 23 negative night turn on Oct. 08, 2003. All IIA satellites, since Nov 17, 1995, are supposed to have the positive yaw bias of 0.5 deg, so should always turn in the positive direction during a shadow crossing, regardless of the sign of β (Bar-Saver 1996*)*. The above negative (wrong) night turn direction of the IIA PRN/SVN23 has been caused by a wrong (negative) yaw bias of –0.5 deg (Weiss, priv. comm. 2013). PRN 23/SVN 23 had also the bias set to +0.5 deg in November 1995, but developed various problems since then. The PRN23/SVN 23-yaw bias has been changed several times between Feb. 2002 and Feb 2004, when SVN23 has ceased operation as PRN 23. Since December 02, 2006, SVN 23 has assumed the PRN32 code and since then it has employed the correct IIA bias of 0.5 deg (for more details see ftp://sideshow.jpl.nasa.gov/pub/gipsy_files/gipsy_params/yaw_bias_table.gz).

The December 2013 version implementation

The implementation of the *correct IIF night turns* into the new (Dec 2013) *eclips* version was fairly straightforward, since the yaw angles at the shadow start and end as well as the corresponding times are available internally. During the shadow crossing, the yaw angle is computed from, the yaw rates computed as the difference of the shadow end and start yaw angles, divided by the corresponding time difference. No yaw angle recovery is needed at the shadow exit, since the yaw angle is already equal to the nominal one. Note that the sign of yaw bias has no effect on IIF shadow (night) turns (directions).

The implementation of the *anomalous IIF and IIA noon turns* for small negative and small positive β, respectively, is more complex, since the starts of the noon turns are also affected. Here, for the sake of simplicity, the noon start delays/advances have been neglected, which could introduce yaw angle errors at the 10-deg. level, which is still commensurate with the approximation level employed here. Similarly, the slightly different yaw rates observed by Dilssner et al (2011) for both IIF noon and night turns, depending on the β-sign, have also been neglected. This too, should be consistent with the approximation level used here. The observed β limit of 0.9 rather than the theoretical one of 0.5 deg has been implemented, so that most of the bad IIA/IIF noon turns could be captured and mitigated. In order to accommodate an anomalous yaw bias (such as the PRN23/SVN23 one), a separate *YBIAS* variable has been introduced and used (the sign only) for both IIA night turns and possible reversals of IIA and IIF noon turn directions. So the IIA and IIF noon turn direction reversal occurs for positive $\beta < 0.9$ deg and negative $\beta > -0.9$ deg, respectively. Note that the yaw bias has no effect on the IIF night turns, on the IIR noon/night turns (IIR yaw bias = 0 deg) and on the GLONASS noon/night turns. Currently, *YBIAS* is hard coded in the subroutine (=-0.5 deg for IIF, 0.5 deg for IIA (except for the PRN 23, for which it is –0.5 deg) and 0 deg for the remaining satellites (IIR and GLONASS). Ideally, the *YBIAS* variable should be included in the subroutine call statement, this way the *YBIAS* sign changes (such as for the IIA satellites prior November 17 1995, or the anomalous PRN23/SVN23 yaw bias changes prior 2002) could be properly accounted for. Note that the current IIF and IIA noon turn implementation allows *YBIAS*=0, in that case no reverse noon turns are applied even for $|\beta| < 0.9$ deg. In other words, *YBIAS*=0 switches off the noon the turn reversal (e.g., applicable, in case the future IIF yaw bias is set to 0 deg). Similarly, the currently hard-coded β limit can be more appropriately replaced with the variable (theoretical) limit equal to |*YBIAS*|, where different (effective) *YBIAS* values can be assigned (passed along in the subroutine call). This way, different small β limits can be used for different satellites. For example, some IIF satellites (such as PRN01/SVN63) were observed to have anomalous turn only for negative $\beta > -0.5$ deg (Dilssner priv. com. 2013). In the case it is useful, or required, all the above source code changes with respect the September 2011 *eclips* version have been annotated with the "*C Dec 12, 2013* " comment lines.

Conclusions

The new version of the subroutine *eclips.f* should show improved modelling of IIF shadow crossing as well as it should capture most of anomalous IIF and IIA noon turn directions observed for small β angles. The new subroutine version has been diligently tested for all satellite types (IIA, IIR, IIF and GLONASS), for both noon and night turns. For IIA/IIF, various combinations of small β noon turns have also been tested to ensure a proper functioning of the new noon turn reversal for small β. If there are questions or some problems are encountered, please notify the author.

Considering that all the above problems are most likely connected with yaw bias changes/problems, a regular monitoring of eclipsing and/or problem satellites with reverse PPP (as already recently proposed by O. Colombo) would be very useful, even essential for a proper yaw attitude modelling. Apart from verification or observations of (noon) turn directions, it can also be used to monitor the effective maximum yaw rates as well as effective yaw biases (e.g., as implied from the observed noon turn reversal β limits and/ore noon turn delays, or advances as discussed above). The effective yaw biases may be larger/smaller that the nominal ones typically set at +0.5 deg for IIA and –0.5 for IIF, respectively.

References

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