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DISCONTINUITIES IN CLOCK ESTIMATES AT DAY BOUNDARIES

J.R. Ray, M.S. Carter, and J.R. Rohde
(U.S. Naval Observatory)

SUMMARY

Discontinuities in GPS-based clock estimates at day boundaries are an inevitable consequence of the standard strategy of processing the observational data in 24-hour batches. However, the discontinuities should be consistent with the standard errors of the clock estimates, normally about 0.2 ns, for realistic error estimates. We have observed that larger than expected discontinuities are sometimes obtained in global network solutions, at about the 1-ns level. It appears that these can usually be associated with a specific station rather than global causes (e.g., satellite orbits). The source(s) of such station-related discontinuities has not been positively identified although changes in local multipath environment seem the likeliest candidate.

OBSERVATIONS

As part of our participation in the IGS/BIPM GPS timing project, the IGS Associate Analysis Center at USNO posts clock solution results at the Web site http://maia.usno.navy.mil/gpsclocks/index.html. Plots of differential clock variations are provided for our "Rapid" solutions submitted for the IGS combined Rapid products; plots and RINEX-type solution files are provided for our "Final" clock solutions. The two types of analysis strategies are described at the above Web site. This report describes results from our Final clock solutions, which use the IGS Final orbits without adjustment. Unless unavailable, the IGS station "USNO" is always used as the fixed clock reference in our analyses.

GPS week 0987 (06-12 December 1998) is interesting in showing two distinct day-boundary discontinuities for all the usable H-maser stations. The magnitudes of the discontinuities at the midnight boundaries between adjacent days are shown in the table below:

ESTIMATED CLOCK DISCONTINUITIES (all units ns)
standard error estimates shown in ()

	GPS Week 0987	
	51157/51158	51158/51159
ALGO - USNO	-0.70 (0.20)	-0.97 (0.19)

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DRAO - USNO   -0.89 (0.20)    -0.88 (0.19)
IRKT - USNO   -1.32 (0.21)        ---
KOKB - USNO   -1.82 (0.23)    -1.21 (0.26)
MATE - USNO   -1.75 (0.20)    -0.70 (0.22)
NLIB - USNO   -1.08 (0.20)    -0.96 (0.19)
PIE1 - USNO   -1.64 (0.20) *  -0.84 (0.20) * odd tails at day-starts
TID2 - USNO   -2.05 (0.20)    -0.31 (0.21) * rapid variation near boundary
USNB - USNO   -1.02 (0.19)    -0.82 (0.19)
WES2 - USNO   -1.20 (0.20)     0.03 (0.19)
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 mean (RMS)   -1.33 (0.45)    -0.72 (0.37)
                              -0.83 (0.24) * excluding WES2
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Because "USNO" is common to all these differences, the ~1-ns discontinuities can be attributed mostly to that station rather than all the others. This expectation has been empirically demonstrated by reprocessing the Final clock solutions for week 0987 using "DRAO" as clock reference rather than "USNO". The results are available in the subdirectory http://maia.usno.navy.mil/gpsclocks/finals/0987/drao/. There it can be seen that the day-boundary discontinuities decrease by about the mean offsets: -1.3 ns for 51157/51158 and -.8 ns for 51158/51159. The residual discontinuities are then approximately consistent with the error estimates except for WES2 at 51158/51159, which could be another example of station-specific effects. "DRAO" itself is associated with another discontinuity of ~1 ns at 51156/51157.

STATION-SPECIFIC CAUSES

While we cannot offer a definitive explanation for the observed discontinuities, the evidence strongly indicates that they are associated specifically, in this case, with the station "USNO" rather than with a more general cause, such as orbit error or analysis strategy. The orbit error required would be ~30 cm averaged over the full constellation, compared with typical internal consistencies for individual IGS orbits at the 5 cm level or better. Moreover, if orbit errors were responsible then we would expect the effect to be nearly identical for "USNO" and "USNB" (the Swiss GeTT/Ashtech system temporarily deployed at USNO), which is not the case. These clock discontinuities are also similar for the USNO Rapid solutions (for the common stations), for which the satellite orbits are adjusted simultaneously with the clocks.

Another possible general cause could be a defect in the analysis strategy. However, USNO results for satellite clocks and other estimated parameters generally compare very favorably with the other IGS Analysis Centers in the IGS Rapid combination reports. The USNO clock residuals have a typical RMS of about 0.2 ns, compared with the IGS combined satellite clocks. Since receiver clock products are not yet compared within the IGS, it is possible that analysis defects exist which affect ground-based clock estimates much more than satellite clocks. However, this seems unlikely.

The simplest explanation seems to be that the discontinuities are station specific. A receiver-based effect is possible, particularly considering that "USNO" uses an AOA TurboRogue SNR-12 receiver while "USNB" uses a modified Ashtech Z-XII receiver. The tracking performance is quite different for these two, especially at L2 and at low elevation angles. However, it is difficult to imagine how ~1 ns (~30 cm) of clock difference could be obtained without affecting other

geodetic parameters unless the problem were restricted to receiver "clock" circuitry. In the latter case, there is no reason to expect the effects to show up preferentially at midnight epochs.

While we cannot demonstrate this, we believe that changes in the local multipath environment are probably the best explanation. In the geodetic method, the precision of clock variations is derived from the carrier phase observables. However, the "absolute" value for the clocks is derived from the time-averaged pseudorange observables, which are required in order to permit simultaneous estimation of the phase bias parameters. The pseudorange data are less precise and much more sensitive to multipath than the carrier phase data. Whether time-averaged daily differences in multipath at the 1-ns level are reasonable is unclear to us, although shorter term pseudorange variations at this level are common.

Even if the underlying cause is local multipath, the analysis strategy could be changed to attenuate the day-boundary discontinuities. Obviously, if the data were processed as a continuous stream or if constraints between 24-hour arcs were applied, the day-boundary shifts could be largely eliminated. However, such approaches would only be expected to redistributed the underlying error among other parameters rather than remove it. Implementation of phase cycle ambiguity resolution, which is not done in any of the USNO solutions, might be expected to be useful. However, that procedure essentially fixes the phase bias parameter at their estimated values and depends on the pseudorange data in the same way. The main benefit should be an improvement in clock precision, not accuracy.

Week 0987 (and neighboring weeks) was checked because of concerns about mechanical work being done on the roof of the building near the GPS antenna during that period (see IGS Mail #2150). At various times, significant amounts of sheet metal and other metal pieces have been moved around near the antenna. However, we have no specific records of these events to verify particular multipath circumstances. The week was unseasonably warm so there was no snow accumulation; there was significant rain on 08 December (51155) and 12-13 December (51159-51160) but not around the day-boundaries in question.

We invite comments from other groups who have investigated these or related effects.