From igscb@igscb.jpl.nasa.gov Thu Jun 24 08:59:22 EDT 1999
Received: from igscb.jpl.nasa.gov (igscb.jpl.nasa.gov [128.149.70.171])
by maia.usno.navy.mil (8.8.6 (PHNE_17135)/8.8.6) with ESMTP id IAA16883;
Thu, 24 Jun 1999 08:59:21 -0400 (EDT)
Message-Id: <199906241259.IAA16883@maia.usno.navy.mil>
Received: by igscb.jpl.nasa.gov
(1.39.111.2/16.2) id AA095955513; Thu, 24 Jun 1999 04:58:33 -0700
Date: Thu, 24 Jun 1999 04:58:33 -0700
To: IGS Mail Recipients
From: IGS Mail Service
Reply-To: IGS Mail Administrator
Errors-To: IGS Mail Administrator
Sender: IGS Mail Administrator
Subject: No 2320: Handling mixed receiver types
Status: RO

****
IGS Electronic Mail   Thu Jun 24 4:58:32 PDT 1999   Message Number 2320
****

Author: Various (see below)
Subject: Handling mixed receiver types

Below is a draft position paper presented at the IGS AC Workshop on 10 June 1999. Even though the recommendations here have not yet been officially endorsed by the IGS, it is being circulated now to alert the IGS community to an emerging problem due to the mix of receiver types in the network. Station operators, in particular, should be aware of these complications when changing receiver types.

Regards,
--Jim Ray

Author: Various *
Subject: Recommendations for handling non-Rogue data
Date: 18 June 1999

* Various individuals have contributed to the development of this proposal, including J. Kouba, H. Dragert, J. Zumberge, R. Muellerschoen, L. Estey, W. Gurtner, and K. de Jong, although they do not necessarily endorse it. The text has primarily been written by J. Ray, H. Dragert, and J. Kouba, who are responsible for the contents.

Summary
=======
The transition of the IGS network from a core of Rogue/TurboRogue (TR) receivers to newer codeless tracking architectures is natural and beneficial. However, the new receivers provide pseudorange observables which can be biased compared with TRs. This is of no significance for data analysts who process only carrier phase observables. For analysts who use the pseudorange observations, their estimates for satellite clocks can depend on the receiver model and the RINEX translation process. To avoid mixing data with different satellite biases, which will degrade the IGS satellite clock products (and precise point positioning using them), recommendations are offerred for RINEXing and analysis procedures to maintain compatibility with the heritage TR tracking network until a

sufficient fraction of stations is upgraded. At a future date to be decided, a uniform switch of the IGS to the new observables can be made.

Rogue/TurboRogue Observables (CC type)

The AOA Rogue and TurboRogue (TR) receivers produce the following 4 observables:

```
C1      = C/A code at L1 freq.
L1(C1)  = C/A-based phase at L1 freq.
P2'     = codeless pseudorange at L2 freq.
L2'     = cross-correlated phase at L2 freq.
```

The P2' pseudorange-type observable and the L2' phase are actually formed by a process which tracks the cross-correlated (P2-P1) pseudorange and the (L2-L1) phase differences:

```
P2' = C1 + (P2-P1)
L2' = L1(C1) + (L2(P2)-L1(P1))
```

Analysis software then has available two pseudorange (C1, P2') and two phase (L1(C1), L2') observables which can be linearly combined to form an ionosphere-free pseudorange and phase observation for each receiver-satellite observation epoch. We denote these as CC (for cross-correlated) receiver and observable types.

Modern Codeless Observables (non-CC type)

Newer receiver models (e.g., Ashtech Z-XII, AOA Benchmark, AOA TurboRogues upgraded with ACT, etc.) provide direct measurements of P1 and P2 without the use of the Y-codes, with 6 (or more) observables available:

```
C1      = C/A code at L1 freq.
L1(C1)  = C/A-based phase at L1 freq.
P1      = Y1-codeless pseudorange at L1 freq.
L1(P1)  = Y1-codeless-based phase at L1 freq.
P2      = Y2-codeless pseudorange at L2 freq.
L2(P2)  = Y2-codeless-based phase at L2 freq.
```

The first 2 observables (C1, L1(C1)) correspond to the same quantities measured by the TurboRogues, but the others are not quite the same. Because it would be confusing to report two different L1 phase values (L1(C1), L1(P1)) in RINEX observation files, the one based on the higher SNR C/A-code is usually preferred. It should be noted however that the current default offload in Conan Binary, Conan ASCII, or RINEX format from the AOA BenchMark receiver provides L1(P1) instead of L1(C1), and does not provide C1.

We denote these as non-CC receiver and observable types.

Since phase is inherently ambiguous and according to specifications (L1(C1)-L1(P1)) is a constant fraction of a carrier wavelength, the distinction between L2' in TurboRogues and L2(P2) in these receivers is not significant. However, the difference between the CC pseudorange pair (C1, P2') and the non-CC pseudorange pair (P1, P2) can be important for some applications, since the (C1-P1) pseudorange difference varies between satellites and can reach up to 2 ns (0.6 m).

Biased Pseudoranges and Their Consequences

The (C1-P1) pseudoranges from non-CC receivers are not zero-mean, but are biased up to ~ 2ns (see Appendix). The biases vary from satellite to satellite but tend to be relatively stable in time. These effects can be readily seen in data from modern receivers that output both L1 pseudorange observables. (Note that most CC type receivers also output both L1 observables under non-AS conditions.) Using the non-CC (P1, P2) pseudorange pair is not consistent and will be biased with respect to the CC pair (C1, P2') by (C1-P1) at both frequencies. Hence, the ionosphere-free pseudoranges will also be biased by (C1-P1), which will go directly into clock estimates. Note that since the biases change from satelite to satellite (unlike for phase observables) they will not be eliminated by double differencing.

If CC and standard non-CC pseudorange data are mixed, then estimates for the satellite clocks will be corrupted in a way that depends on the mix of receiver types and their geometric distribution. Considering that the IGS clock products have a precision at about 0.2 ns, this is highly undesirable. Point positioning using non-CC data and IGS/AS products that are based on CC-type data will also be correspondingly degraded.

On the other hand, data analyses which use only carrier phase observables, and therefore have no sensitivity to the absolute values of the satellite clocks, are not affected by these pseudorange biases. Pseudorange ionospheric estimates, whether based on (P2'-C1) for CC receivers or on (P2-P1) for non-CC receivers, are also unaffected.

Recommendations for Station Operators

For the time being, we strongly recommend RINEX translation procedures for non-CC receivers that provide sufficient pseudorange observables in order to allow CC-type pseudorange observables to be synthesized by the user. This will permit consistency within the IGS network to be preserved until the heritage core of TR receivers is largely replaced.

Specifically, station operators using modern non-CC receivers are asked to ensure that the C1 observable, if available, is reported in their RINEX files together with the P1 and P2 observables. This will allow RINEX users to form the synthetic observable

$$P2' = C1 + (P2-P1)$$

UNAVCO has kindly provided modifications to their `teqc' toolkit to support this need for certain receiver types; for further information please refer to http://www.unavco.ucar.edu/software/teqc/. Options for using teqc for particular non-CC receivers are given below.

AOA Benchmark & Upgraded TR

Data must be downloaded from the receiver in TurboBinary format. An offload of data in Conan Binary format from the BenchMark receiver will contain only the 4 observables P1, L1(P1), P2, L2(P2). The offload in TurboBinary however provides all six non-CC observables described above. (Note that the Turbo Binary files will be almost three times larger in size than the commensurate Conan Binary files.) Then the appropriate teqc option is

```
teqc -aoa tbY - O.obs L1L2C1P2P1S1S2
```

where S1 and S2 are recommended to provide full-precision SNR values as additional observables; other suitable teqc options should also be included, normally in a configuration file. The output RINEX files should then contain the C1, P1, L1, P2, and L2 observables, as well as the SNR values. For the "-aoa" options, teqc already adds the appropriate comments to the RINEX header to indicate which observables

```
   have been formed.

   [actions needed for other receiver types ... still needs to be done]

   Ashtech Z-12
   ------------
   The ASHTORIN translator provides all the necessary pseudorange data.
   Of possible interest is the use of teqc to extract the L1(C1) phase
   from either the Ashtech B-file (as also Werner Gurtner's ASRINEXO
   translator does) or from an Ashtech MBEN/PBEN real-time data stream.
   The teqc option to set is "+Ashtech_CA_L1".  By default, teqc extracts
   the L1(P1) phase as its RINEX "L1" value.

   Leica
   -----
   does not output C1 observable ...

Recommendations for IGS Central Bureau
======================================
Because the RINEX format contains no specific indicator of the precise
nature of the pseudorange observables reported (whether the CC-style P2'
or the non-CC P2 observables are used), data users must rely on the
"REC # / TYPE / VERS" RINEX header recorder together with knowledge of
the generic types of the various receivers available.  This fact
underscores the vital importance of reliable RINEX headers, which the
IGS Central Bureau is asked to rigorously enforce.

In addition, it is necessary for the IGS Central Bureau, working with
receiver experts, to compile information characterizing all receiver
types as either CC or non-CC style.  This information should be readily
available and specifically linked with the various "official" receiver
names used by the IGS.

A preliminary partial list of receiver types follows:
[needs work here to verify and complete!!!]

   Cross-Correlation (CC) Style Receivers
   --------------------------------------
   ROGUE SNR-8*       (when AS is on)
   ROGUE SNR-12*      (when AS is on)
   TRIMBLE 4000*

   Non-Cross-Correlation (non-CC) Style Receivers
   ----------------------------------------------
   AOA SNR-12 ACT
   AOA BENCHMARK ACT
   ASHTECH Z-XII
   LEICA SR9500   (does not output C1 pseudorange)
   LEICA CRS1000  (does not output C1 pseudorange)
   JPS *
   TRIMBLE MS750

Recommendations for Data Analysts
=================================
The IGS Analysis Center Coordinator should ensure that IGS products
are as consistent as possible with either CC or non-CC observables.
This information should be readily available to all IGS data and
product users.

For the time being, it is recommended that the IGS adopt CC-style
```

observables as a standard. Observables, biases, and analysis products should be handled to ensure maximum consistency with this standard. Specifically, those Analysis Centers which process pseudorange data are strongly encouraged to: 1) Check their network mix and verify that the data RINEX from non-CC receivers being used are consistent with the recommendations above. 2) Use the (C1, P2') pseudorange pair, or the equivalent, rather than the (P1, P2) pair in their analyses. The 2nd recommendation can be accomplished in two possible ways:

a) Synthesize CC Style Observables

Use a utility to convert raw RINEX files to CC-style RINEX files by synthesizing the P2' = C1 + (P2-P1) observable and using the C1 pseudorange rather than P1. Obviously, this is only possible if the raw RINEX files hold all the necessary information.

A RINEX utility converter is available for ACs wishing to use this option (ftp://maia.usno.navy.mil/pub/noncc2cc.f). When a RINEX file is converted, the average (C1 - P1) bias values are printed out by satellite PRN.

b) Apply Satellite-based Bias Correction

Alternatively, corrections for the satellite-based biases can be applied based on empirical tabulations (such as have been compiled by the JPL group; see Appendix). In this case, the (P1, P2) pseudorange pair would be replaced by [P1 + f(i), P2 + f(i)], where f(i) is an empirically-determined function that represents the average value of (C1 - P1) as a function of GPS satellite PRNi. The Appendix describes results from Ron Muellerschoen at JPL.

A disadvantage of the synthesis approach (a) is that additional noise is introduced in forming the (C1, P2') pair that is not in the directly observed (P1, P2) pair. If temporal variations in the f(i) biases are small compared to the noise in the 30-s measurements of (C1 - P1), then using f(i) would introduce less error (approach b). On the other hand, if temporal variations in the f(i) biases are significant, then approach a) yields smaller errors. Approach (b) could also be applied in reverse, to convert CC-style observables to CC-type by subtracting f(i) from the usual (C1, P2') pair; this would be useful when the IGS eventually switches from a CC-based convention to non-CC.

Future Changes

As the IGS network continues to evolve these recommendations will be reviewed and modified. In particular, the IGS Analysis Center Coordinator may propose to end the CC-style standard and change to non-CC observables when that seems appropriate.

===

Appendix

Date: Wed, 14 Apr 1999 21:46:04 +0000
From: "Ronald J. Muellerschoen"
Subject: Re: handling TR and non-TR data

I've been periodically computing global solutions for CA-P code bias since

Oct of 97 with a network of 14 to 15 Ashtech Z-12 receivers. The variation over this period (in general) has been about 4-5 cm. The biggest change was prn 7 when the bias changed from 20 cm sometime between 12/22/97 and 4/12/98. I hadn't looked at these biases until almost a year later when I turned the process back on 3/18/99. The biggest change at this time was 8 cm for prn13, 7 cm for prn31, 6 cm for prn29 and prn 18, 5 cm for prns 15, 30,17 while all others were less than 4 cm.

The below table are the results of hourly solutions of the CA-P code bias for the last three weeks. Note in all this I am assuming that the CA-P code bias at a particular station I have chosen is not changing. (To compute the solution I fix the CA-P code bias at this station to a particular value. A closer look at the values of CA-P code bias for the different prns all have a similar signature, which would indicate that the CA-P code bias at my reference station is not entirely stable.

Average (P1-C1) Biases over 3 weeks for 15 Ashtech Z-12 Receivers
(units are meters)

prn #	average	hi value	low value	spread	var. of ave.	numb.
prn 1	ave: -0.134	hi: -0.07	lw: -0.23	sp: 0.16	sigma: 0.030	n: 505
prn 2	ave: -0.378	hi: -0.31	lw: -0.45	sp: 0.14	sigma: 0.027	n: 505
prn 3	ave: -0.017	hi: 0.06	lw: -0.08	sp: 0.15	sigma: 0.029	n: 505
prn 4	ave: 0.358	hi: 0.43	lw: 0.29	sp: 0.14	sigma: 0.030	n: 505
prn 5	ave: -0.253	hi: -0.18	lw: -0.35	sp: 0.17	sigma: 0.030	n: 505
prn 6	ave: 0.099	hi: 0.17	lw: 0.03	sp: 0.14	sigma: 0.029	n: 505
prn 7	ave: -0.410	hi: -0.15	lw: -0.50	sp: 0.35	sigma: 0.060	n: 505
prn 8	ave: -0.324	hi: -0.23	lw: -0.40	sp: 0.16	sigma: 0.031	n: 505
prn 9	ave: 0.047	hi: 0.14	lw: -0.04	sp: 0.18	sigma: 0.035	n: 505
prn 10	ave: -0.588	hi: -0.52	lw: -0.65	sp: 0.13	sigma: 0.026	n: 505
prn 13	ave: 0.459	hi: 0.53	lw: 0.40	sp: 0.14	sigma: 0.029	n: 505
prn 14	ave: 0.057	hi: 0.14	lw: -0.03	sp: 0.17	sigma: 0.030	n: 505
prn 15	ave: -0.407	hi: -0.33	lw: -0.48	sp: 0.14	sigma: 0.028	n: 505
prn 16	ave: -0.290	hi: -0.22	lw: -0.36	sp: 0.14	sigma: 0.029	n: 505
prn 17	ave: -0.372	hi: -0.27	lw: -0.45	sp: 0.18	sigma: 0.037	n: 505
prn 18	ave: -0.038	hi: 0.03	lw: -0.12	sp: 0.15	sigma: 0.032	n: 505
prn 19	ave: 0.051	hi: 0.13	lw: -0.02	sp: 0.15	sigma: 0.032	n: 505
prn 21	ave: -0.171	hi: -0.10	lw: -0.24	sp: 0.14	sigma: 0.028	n: 505
prn 22	ave: -0.510	hi: -0.44	lw: -0.58	sp: 0.14	sigma: 0.029	n: 505
prn 23	ave: -0.206	hi: -0.14	lw: -0.27	sp: 0.13	sigma: 0.030	n: 505
prn 24	ave: 0.034	hi: 0.11	lw: -0.04	sp: 0.15	sigma: 0.029	n: 505
prn 25	ave: 0.176	hi: 0.28	lw: 0.09	sp: 0.19	sigma: 0.038	n: 505
prn 26	ave: 0.342	hi: 0.42	lw: 0.28	sp: 0.14	sigma: 0.027	n: 505
prn 27	ave: -0.067	hi: 0.02	lw: -0.16	sp: 0.17	sigma: 0.036	n: 505
prn 29	ave: 0.227	hi: 0.30	lw: 0.17	sp: 0.13	sigma: 0.029	n: 505
prn 30	ave: 0.470	hi: 0.53	lw: 0.40	sp: 0.14	sigma: 0.028	n: 505
prn 31	ave: -0.255	hi: -0.18	lw: -0.32	sp: 0.14	sigma: 0.029	n: 505

The "sp:" column (spread) is the hi value - low value, or the max variation of the estimates over the 3 week time span. The "sigma:" column is the variation of the estimates, n is the number of hourly solutions. Note prn 7 is again anomalous with the largest variation.

My convention is, to convert P code data to CA code data, subtract the above "ave:" value from range and phase. To convert back, (CA to P code) add the above "ave:" value. The widelane observable of course remains unchanged.

ron.

[Mailed From: Jim Ray (USNO 202-762-1444)]