A CONTRIBUTION TO THE STANDARDIZATION OF GPS AND GLONASS TIME TRANSFERS

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Abstract

The international time metrology community has already succeeded in the implementation, in the almost all type of GPS time receivers, of uniform software for the treatment of raw data. For the GLONASS and GPS/GLONASS time receivers now arriving on the market, it was decided to adapt, roughly and for temporary use, standards devised for GPS. In this paper specific problems for these two new type receivers are identified and solutions for standards and format update are suggested. The paper also reports briefly on international decisions recognizing advantages of using of both systems.

So far, no standards address the difficulties experienced with time receiver hardware. The best-known hardware problem is sensitivity to external temperature. This paper suggests that the temperature of antennas be held constant by enclosing them in temperature-stabilized ovens.

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INTRODUCTION

Over a period of about 15 years the uncertainties quoted for GPS international time comparisons have improved, falling from a few tens of nanoseconds to a few nanoseconds. Recent progress has included the successful implementation of standards for software and data format.[1] The use of GLONASS for international time transfer was delayed until last year by the lack of commercial time receivers. Their recent appearance, plus knowledge accumulated during a decade of GPS practice, allowed rapid progress in the use of GLONASS for time transfer.[2] To speed up implementation of the GLONASS common-view technique, some standards devised for GPS by the CGGTTS[2] were adapted for temporary GLONASS use. This comes close to fulfilling immediate needs, but must be considered as a provisional solution because it does not address specific GLONASS issues such as the use of ionospheric and tropospheric corrections, relativistic corrections, satellites ephemerides, antenna coordinates, etc. A new family of dual-system GPS/GLONASS time receivers now available will create new opportunities, but will also call for technical directives to describe the use of two systems in a single receiver. Considering the above, the 13th meeting of the Comité International pour la Définition de la Seconde (CCDS) transformed the CCDS Group on GPS Time Transfer Standards (CGGTTS) into the CCDS sub-Group on GPS and GLONASS Time Transfer Standards (CGGTTS). Also, a CCDS recommendation and declaration addressed the issue of common use of GPS and GLONASS satellites and stressed the need for both systems to respect international standards for time reference and reference frames.

This paper identifies specific software problems to be standardized for GLONASS and GPS/GLONASS time transfers and suggest an adapted data output format. Until now no standards have been issued to address difficulties related to time receiver hardware. The best-known hardware problem is sensitivity to external temperature and this paper suggests that the use of temperature stabilized ovens be standardized for GPS and GLONASS antennas in use for high precision time-transfer applications.

BRINGING GPS AND GLONASS TOGETHER

The arrival of GLONASS underlines the need for Global Navigation Satellite Systems to adopt common system of reference. In fact, GPS and GLONASS use different systems for both positioning and timing. This does not preclude the interchangeable use of the 48 satellites composing the two constellations, but does complicate it. GPS already follows international standards, and its closeness to them is constantly improved. This is not the case for GLONASS, but a far-reaching and important recommendation, S 4 (1996), issued this year by two international committees, the Comité International des Poids et Mesures and its Consultative Committee CCDS[3], specifies a basis for harmonizing GPS, GLONASS, and other upcoming global navigation satellite systems. This recommends:

- the synchronization as close as possible to UTC the reference times of satellite navigation systems with global coverage (including GPS, GLONASS, INMARSAT, GNSS1, and GNSS2),
- the transformation of reference frames of these systems to be in conformity with the terrestrial reference frame (ITRF) maintained by the International Earth Rotation Service,
- the use of both GPS and GLONASS receivers at timing centers.

The recommendation does not make GLONASS depend on GPS or GPS on GLONASS, but requests that both systems follow internationally recognized standards for time and space. Given the increasing importance of civil applications, the Russian authorities are likely to consider more strict application of international standards to GLONASS.[4]

Also, the Executive Board of the United States Civil GPS Service Interface Committee (CGSIC), which is a forum for the exchange of GPS information between military and civilian elements, has recognized that the common use of GPS and GLONASS for civil applications is a very positive development. The CGSIC Executive Board is, however, well aware that the two systems use different references for timing and positioning, and fully supports the above named recommendation. The similar questions civil GLONASS users would like to bring to the attention of GLONASS authorities. However, the absence in Russia of a body similar to CGSIC nowadays limits interaction between civil users and military holders of GLONASS. Some Russian experts consider that Information Center of Russian Space Forces, so called CSIC (Coordinational Scientific Information Center), should play such a role.

The same CCDS meeting issued a declaration[3] which asks the CGGTTS:

- to contact manufacturers of receivers and request them to adapt their systems, both in hardware and software, to the time and frequency laboratory requirements so that these receivers can, for example, record signals of GPS and GLONASS satellites in the dual frequency mode, in multichannels, in a data format defined by the group, have internal calibration, and be as far as possible insensitive to environmental conditions,
- to maintain these contacts and keep time and frequency laboratories informed of their actions and of the specific and operational advantages of unifying these receivers.

REFERENCE FRAMES

It is now general practice for laboratories engaged in accurate GPS time transfer to express ground-antenna coordinates with decimetric uncertainties in the ITRF, the internationally recognized ultra-accurate terrestrial reference frame. Postprocessed GPS precise ephemerides are also expressed in the ITRF. Although actual GPS broadcast ephemerides are expressed in the WGS 84, the newest realization of this reference frame agrees to within one decimeter with the ITRF. Also, because standards established by the CGGTTS have now been implemented, it is possible to introduce antenna coordinates expressed in the x,y,z Cartesian form into GPS time receivers. This avoids the transformation of geodetic coordinates into Cartesian form, a transformation which was necessary in previous types of GPS time receiver and created a possible source of errors. To sum up: the use of coordinate reference frames for GPS time transfer is well defined, well practiced, and fulfills all recommendations and standards.

The situation is somewhat different for GLONASS. Its geodetic reference frame PZ-90 can differ by up to 20 m from ITRF on the surface of earth and no accurate relationship between PZ-90 and ITRF is yet known.[5,6] The simplest way to determine GLONASS antenna coordinates is to average a series of navigation solutions. But the uncertainties of such coordinates are no better than several meters and can have an impact on the accuracy of the common-view link of a few tens of nanoseconds. First users of GLONASS time receivers decided *ad hoc* to determine the GLONASS ground-antenna coordinates in the ITRF wherever this was possible. This has the obvious advantage of immediately providing the best possible consistency of antenna coordinates between various sites. At present the ITRF antenna coordinates introduced into R-100-type receivers are transformed to the PZ-90 reference frame to make them consistent with broadcast ephemerides. All R-100-type receivers now in operation use the same transformation formulae and parameters. If this practice is retained, a set of standard parmeters should be adopted and recorded in the file header; detailed changes are noted in Annex I.

In order to harmonize GLONASS with GPS and avoid operations on ultra-precise ITRF coordinates, another approach would be to keep the ITRF coordinates unchanged in the receiver and transform broadcast ephemerides from PZ-90 into ITRF according to a standardized set of formulae and parameters. These parameters would be recorded in the file header; detailed changes are noted in Annex I.

We should also expect that future GLONASS postprocessed precise ephemerides will be expressed in ITRF coordinates.

TIME REFERENCES

For time reference, GPS relies for its 'GPS time' on UTC(USNO), Coordinated Universal Time (UTC) as realized by the USNO. GLONASS relies for its 'GLONASS time' on UTC(SU), UTC as realized by the Russian Federation. UTC is produced by the BIPM and is the internationally recognized time reference for the whole earth. The deviation of UTC(USNO) from the UTC generally remains within 20 ns. This closeness of approach is attributed to the 50 or so cesium atomic-beam clocks and 15 or so active-cavity hydrogen masers that form the USNO ensemble. In the Russian Federation, however, UTC(SU), which is derived from an ensemble of active-cavity hydrogen masers, is drifting from UTC. The deviation, [*UTC - UTC(SU)*] was approaching –8,000 ns in October 1996 (Fig. 1). Following the recommendation described above, however, the Russian authorities have, with effect 27 November 1996, brought the UTC(SU) into close alignment with UTC by applying a time step of 9,000 ns. The GLONASS Control System Center, which carries out the GLONASS operation, has been notified of this change, and it seems likely that GLONASS time will not be corrected.

The GPS operators keep GPS time within 100 ns (modulo 1 s) of UTC(USNO), and the actual value is generally much better than this. There have been a few exceptions, as in a period of about two weeks in December 1994 when, due to a malfunction, GPS time made an excursion from UTC(USNO) of about 270 ns (Fig. 2). But GPS broadcast a time correction allowing users to access UTC(USNO) with an uncertainty of 100 ns. This shows that the use of broadcast UTC(USNO) might be safer for some applications, as GPS time can always be subject to some anomaly.

For GLONASS, the difference between GLONASS Time and UTC in October 1996 was around 30,000 ns, and it is steadily drifting (Fig. 1). According to GLONASS ICD, the offset between GLONASS time and UTC(SU) should not exceed 1 millisecond. GLONASS does broadcast a time correction allowing users to access UTC(SU) with an uncertainty of 1,000 ns.

The differences between GPS time, GLONASS time, and UTC(SU) pointed above do not affect common-view time transfer, as readings of satellite clock vanish in the difference. This has only an effect during a common navigation solution from GPS and GLONASS. A single system navigation solution requires four satellites to determine four unknowns: position, x,y,z, and the user's clock bias. Present differences between GPS time and GLONASS time mean that a dual-system GPS/GLONASS navigation solution requires five satellites to determine position, x,y,z, the user's clock bias, and the clock offset between the two system times.

Reported in Fig. 1 are values of [*UTC - GLONASS time*] which were published in BIPM

Circular T according to observations performed at University of Leeds with a GPS/GLONASS receiver designed and built in-house. The same differences, derived from GLONASS observation at the BIPM with a R-100/10 receiver, differ by a constant of about 1,250 ns. See the table below.

	UTC - GLONASS time		
Date 1995	by Circ. T (ns)	by "R-100/10" (ns)	Circ. T - "R-100/10" (ns)
Aug 10	-19812	-21055	1243
Aug 20	-20188	-21421	1233
Aug 30	-20549	-21813	1264

We know that R-100 receivers are not calibrated absolutely. Similar differences were observed using other R-100 receivers at the VSL and the DLR.[7,8] We prefer to trust the Leeds values, because there the primary observations are [*GPS time - GLONASS time*]. The hardware delay is probably the same for GPS and GLONASS signals and should cancel in the difference.

Data from similar comparison with GLONASS data recorded with the Russian ASN-16-02 GLONASS receiver at the National Time and Frequency Service VNIIFTRI near Moscow are reported below.

	UTC - GLONASS time		
Date 1996	by Circ. T (ns)	by "ASN-16-02" (ns)	Cir. T - "ASN-16-02" (ns)
July 30	-30591	-30808	217
Aug 04	-30744	-30923	179
Aug 09	-30868	-31071	203
Aug 14	-31002	-31200	198
Aug 19	-31135	-31323	188
Aug 24	-31258	-31459	201

Here, we observe better agreement with the results from Leeds University published in Circular T, but it must be remembered that Russian receivers are also not absolutely calibrated and so do not provide an independent check.

Summing up, we note that, because GLONASS receivers are not calibrated absolutely, we know [*UTC - GLONASS time*] with an accuracy no better that 1 microsecond. GPS receivers are absolutely calibrated and [*UTC - GPS time*] is known with an accuracy of a few tens of nanoseconds. GLONASS provides worldwide real-time dissemination of UTC, as produced by the BIPM, to an average user with uncertainty of about 2 microseconds after recent improvement of the synchronization between UTC(SU) and UTC. GPS does the same with uncertainty of about 100 ns.

RECEIVER SOFTWARE

During a series of meetings at the beginning of 1990, the CCDS Group on GPS Time Transfer Standards developed a document called *Technical Directives for Standardization of GPS Time Receiver Software.*[1] This document lists nine explicit directives for the standardization of software for single-frequency C/A-Code GPS time receivers, possibly operating in tandem with an ionospheric measurement system. These directives have since been implemented in most GPS time receivers. This has had immediate consequences through improvement of the accuracy and precision of GPS time links.

Since that time, some major developments in timing equipment have taken place. These are mainly the arrival in 1994 and 1995 of one-channel GLONASS C/A-Code[9] and P-Code time receivers, and double-system multichannel GPS(C/A-Code)/GLONASS(P-Code)[2] time receivers. To allow rapid development of these receivers it was decided to adapt, roughly and for temporary use, some standards devised for GPS by the CGGTTS. There is a consequent need to extend more rigorously and formally the technical directives to the needs of these new devices which is reflected in the decisions of the most recent CCDS meeting.

Below we describe suggested updates. GPS Technical Directives 1 to 4 and 6 to 9, and Annex I can be applied strictly to GLONASS data. Directive 5, Annex II, and Annex III, should be updated for GLONASS.

Comments on the adoption of GPS Technical Directive 5 for GLONASS:

GPS Technical Directive 5 requires that all modelled procedures, parameters, and constants needed in short-term data processing are deduced from the information given in the Interface Control Document (ICD) of the U.S. Department of Defense or in the NATO Standardization Agreement (STANAG). These are updated at each new issue. The GLONASS ICD does not include algorithms for the calculation of tropospheric and ionospheric corrections, nor does GLONASS broadcast ionospheric parameters. It is suggested, therefore, that in order to simplify common use of GPS and GLONASS for time transfer, that for GLONASS the same formulae for modelled tropospheric and ionospheric corrections be adopted as are used for GPS. However, the ionospheric correction for GLONASS should take into account the different GLONASS frequencies. In the case of dual-system GPS/GLONASS receivers, GPS broadcast ionospheric parameters should be applied to GLONASS ionospheric correction. For single-system GLONASS receivers, a set of adapted fixed parameters must be standardized. It has been verified experimentally that the use of fixed ionospheric parameters does not normally cause a deterioration of GLONASS data. This, however, cannot be true during strong solar activity.

Comments on the adoption of Annex II for GLONASS:

In GLONASS, as in GPS, the constant part of the relativistic correction to the frequency, consisting of the gravitational red shift and the second-order Doppler effect, is applied before launch to the satellite oscillators as a frequency offset (4.36×10^{-10} for GLONASS). Periodic relativistic corrections to take account of the eccentricity of the GLONASS satellite's orbit are applied when generating time and frequency corrections to the offset between satellite time and GLONASS time. These are uploaded to the satellite and transmitted in the navigation message. This implies that point (iii-5) of Annex II should not be applied to GLONASS data.

Most of the solutions suggested above are already applied to 3S Navigation-type receivers. On one point these receivers do not follow Technical Directive 9. This Directive requires that, for multichannel receivers, one data file should be created for each channel. 3S receivers put data from all channels and from two systems into one file. In practice, this way of handling data has proved to be very convenient and it is suggested that Directive 9 be changed to standardize the use of one file.

Suggested update of Annex III *GGTTS GPS Data Format Version 01* of Technical Directives is described in Annex I of this paper.

TEMPERATURE SENSITIVITY

It is now well documented and generally admitted that GPS time equipment is sensitive to external temperature. This sensitivity ranges from about 0.2 ns/°C to 2 ns/°C. Even for the lower value, the delay change can be the dominant contribution to the noise of time transfer by common view for periods of several days over short baselines of several hundred kilometers. The larger value makes it the dominant contributor to the noise of common-view time transfer even for intercontinental baselines. We illustrate this phenomenon for GPS equipment with the latest results recorded during calibration of a GPS reference receiver at the USNO covering a period of 11 months (Fig. 3). For GLONASS we the report the first ever comparison of two GLONASS time receivers recorded at the BIPM during a period of 10 months (Fig. 5).

It can be seen that the GPS and GLONASS receivers have similar behavior both over periods of several days and for the full period of comparison. Short periods are characterized by the correlation with external temperature (Fig. 4 and Fig. 6). A rough estimate of the correlation coefficient is 0.2 ns/°C for both GPS and GLONASS. No seasonal effect is evident.

The modified Allan deviation shows white phase noise for periods of several months. This makes possible to average differences between two pairs of receivers for the whole duration of comparison. Corresponding standard deviation is 2.5 ns for GPS and 4.0 ns for GLONASS. The larger value for GLONASS is attributed to the somewhat noisier results obtained from the of R-100/10 receiver, which were estimated by common-view comparisons with other laboratories.[2] We omit here the constant differences between the receivers, which are not of interest for this presentation.

The sensitivity to external temperature suggests an effect linked to the parts of time equipment located in the open air, that is to the antenna and its cable. The receiver itself is usually located in an air-conditioned room. For several years different hypotheses were considered to explain the temperature dependence of timing equipment. All linked the problem to the electronics of the antenna, but none were verified and proved. Experiments showed that the changes were not due to the changes in antenna cable[10], however length and material of the cables are important and must be considered.

As no practical way was found to resolve the problem electronically, another approach was suggested: the antenna should be protected by an oven with stabilized temperature.[11] The temperature of the oven used at the BIPM was set at 38°C. Initial observations show that temperature stabilization of the antenna assembly appears to reduce or even eliminate diurnal delay variation. It is thought that this is due to stabilization of the temperature of the filters and amplifiers rather than the antenna element itself. Thus, it is possible to make the preliminary recommendation that GPS, GLONASS, and GPS/GLONASS antenna electronics and outdoor in-line amplifiers be temperature stabilized when they are used for precision time applications. Further studies will be performed to further confirm this recommendation.

However, the development of a built-in calibration system for time receivers is a challenge for timing community. This solution is the most adapted to resolve present difficulties with delay stablility of GPS and GLONASS time equipment.

NEW DEVELOPMENTS

The accuracy of the GPS and GLONASS common-view time transfer could be improved by changing common practice in making common view observations. This section describes some of the suggestions that are likely to ultimately result in a considerable improvement in the accuracy of common-view time observations. Typical practice in making common-view time observations is for all receivers in an area to track a single satellite for 780 seconds according to the schedule published by the BIPM. The time difference between the local reference clock and the GPS or GLONASS constellation time is computed by an agreed real-time algorithm and these data are output to a text-editable file. There is then a delay of 180 seconds until the start of the next tracking period.

The method of single satellite observation over a 780-second integration period results largely from the receiver tracking channel, memory size, and data communication bandwidth limitations that existed at the time this technique was developed. The real-time algorithm fits a straight line to short-term effects, such as multipath and atmospheric path delay variations, that would probably be amenable to more sophisticated processing algorithms if a more complete data set were available. Observations based on simultaneous observation of several satellites may yield an improvement of time-transfer accuracy in rough proportion to the square root of the number of satellites tracked.

For this reason it suggested that common-view observations be made continuously and more often, and that all satellites in view (e.g. all-in-view) be observed. This can be done with multichannel receivers. The laboratories already equipped with such receivers could start experimentally to record all-in-view observations according to three possible schemes:

- with classical 780-second integration periods,
- with 15-second integration periods,
- at a rate of 1 per second; some laboratories already use this approach, known as Advanced Common View (ACS), on experimental basis.[12]

Existing time-transfer receivers typically discard carrier phase and pseudo-range data after the time-transfer algorithm is executed. If these data are retained, it is likely that postprocessing with more complete orbital data and more sophisticated algorithms will lead to a more accurate time-transfer result. Already several trials have shown the advantages of using carrier phase measurements for frequency comparisons.[13,14] The Receiver Independent Exchange Format (RINEX)[15] provides a convenient format for recording GPS and GLONASS carrier phase and pseudo-range data. If the receiver has the capability, it is suggested that a RINEX format carrier phase and pseudo-range data file be generated at 15-second intervals for all satellites in view. This data file can then be used for postprocessing of precision time and frequency data.

CONCLUSIONS

1) The use of a common format, standard formulae, and parameters would simplify worldwide time dissemination and time transfer by GPS and GLONASS.

2) Because there are no official formulae for several of the corrections required for GLONASS time transfer, it is suggested that the formulae adopted for GPS be used wherever this is possible.

3) It is suggested that a single output file be used for multichannel GPS and GLONASS time observations.

4) It is suggested that, if the receiver has the capability, it should record in RINEX format, in a separate file, carrier phase and pseudo-range data generated at 15-second intervals for

all satellites in view. It is recommended that the 15-second carrier phase and pseudo-range data be computed using the 15-second pseudo-range quadratic fit method given in Annex I and Annex II of the *Technical Directives for Standardization of GPS Time Receiver Software.*[1]

5) It is suggested that the ground antenna coordinates of GLONASS time receivers be expressed in the ITRF in Cartesian x,y,x form, and then transformed into PZ-90 using standard formulae and parameters adopted by all manufacturers.

Another suggested approach is to keep the ITRF coordinates unchanged in the receiver, and transform broadcast ephemerides from PZ-90 into ITRF according to a standardized set of formulae and parameters.

6) The time difference [*UTC - GLONASS time*] is known with an accuracy of about 1 microsecond, a poor value which results from the absence of absolutely calibrated GLONASS receivers. Such calibration is becoming urgent.

7) It is suggested that antennas electronic assemblies and any outdoor in-line amplifiers be temperature-stabilized. The use of temperature-stabilized enclosures should improve not only common-view time transfer and time dissemination, but also frequency comparisons by phase measurements.

8) The development of a built-in time calibration system for time receivers is a challenge for the timing community. This solution is the most adapted to resolve present difficulties with delay stablility of GPS and GLONASS time equipment.

9) Appearance of multichannel time receivers raise the question of replacing the present mode of scheduled common-view observations by "all satellites-in-view" common-view observations.

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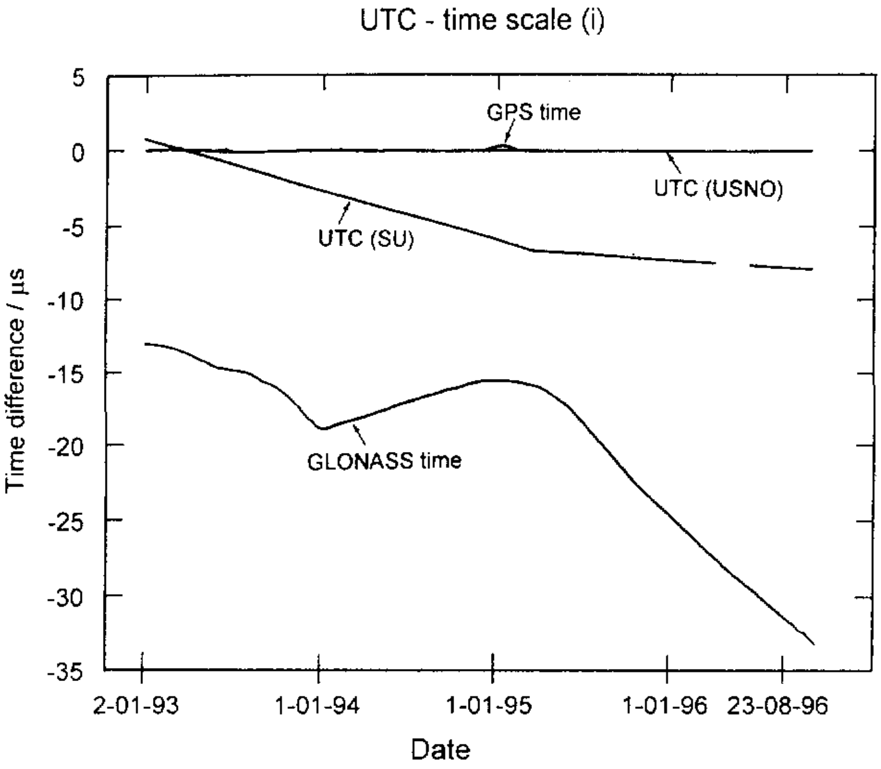

Figure 1: Deviation of UTC(USNO), UTC(SU), GPS time (modulo 1 s) and GLONASS time from UTC from 2 January 1993 to 28 Ocober 1996.

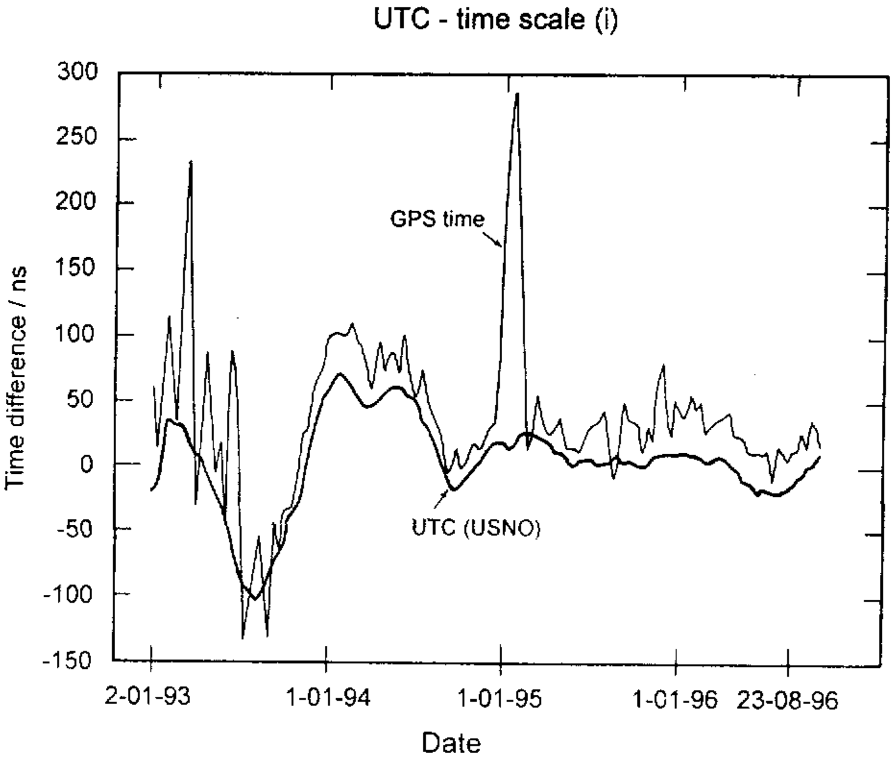

Figure 2: Expansion of Figure 5 highlighting the 270 nanosecond excursion of GPS time from UTC (modulo 1 s) at the end of 1994.

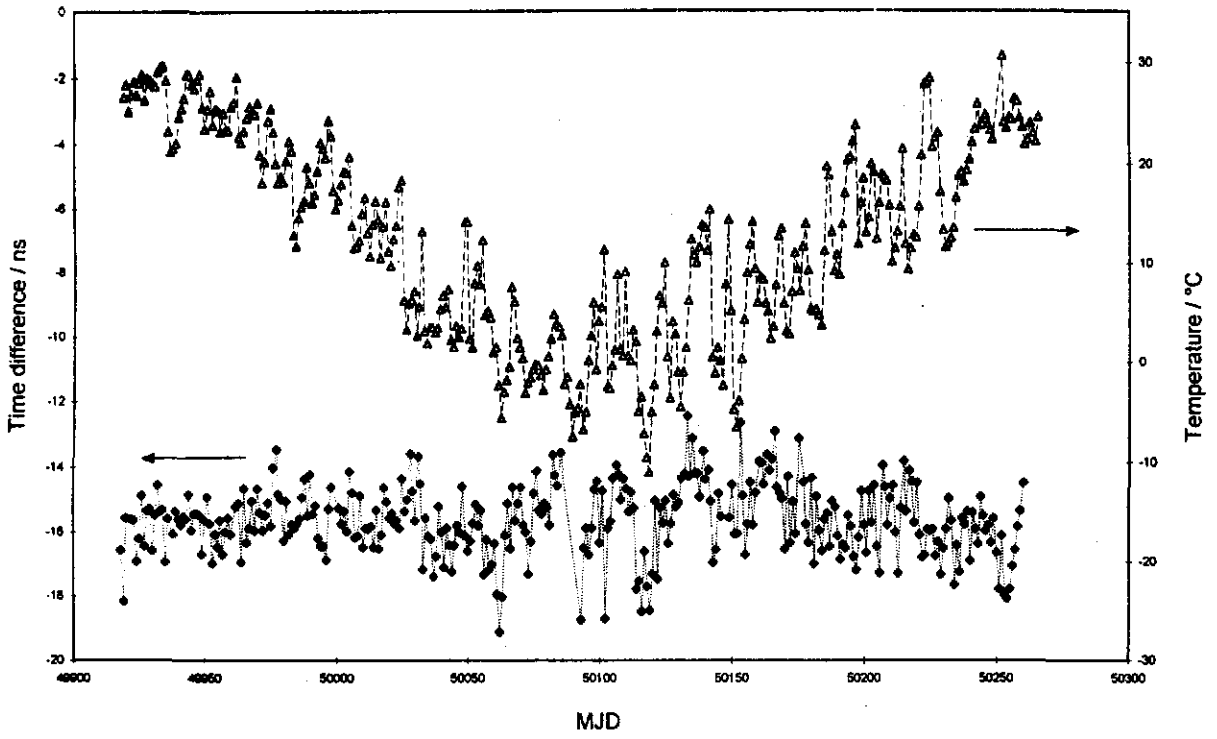

Figure 3. Daily averages of [*UTC(USNO) - GPS time*] by TTR6 - [*UTC(USNO) - GPS time*] by Stel502, and daily average temperature at USNO for a period of 11 months.

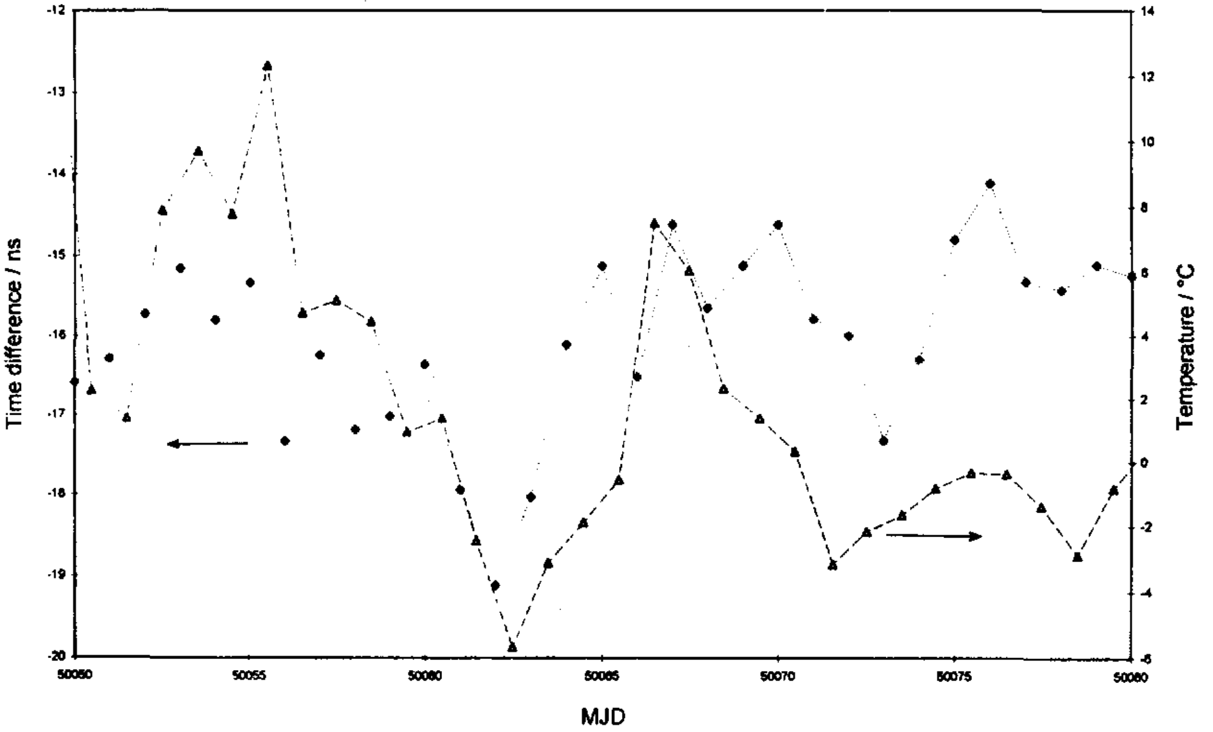

Figure 4. Daily averages of [*UTC(USNO) - GPS time*] by TTR6 - [*UTC(USNO) - GPS time*] by Stel502, and daily average temperature at USNO for a period of about 1 month.

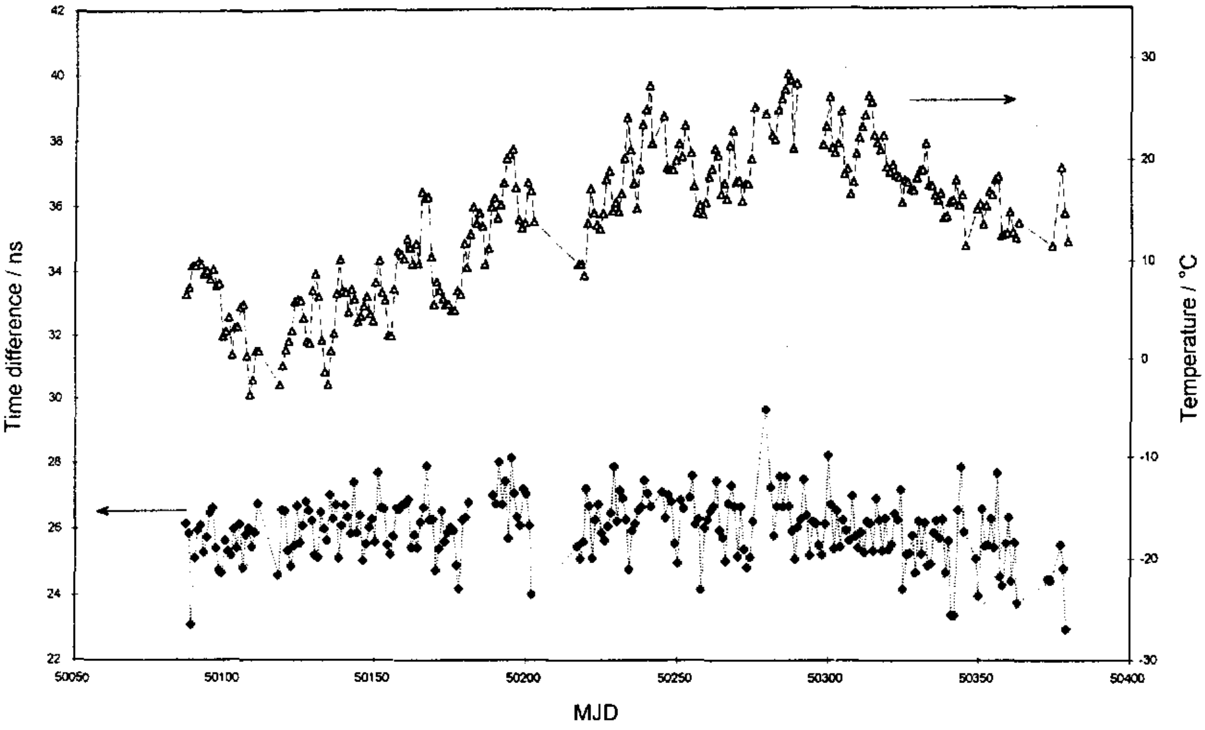

Figure 5. Daily averages of [*BIPM clock - GLONASS time*] by R-100/10 - [*BIPM clock - GLONASS time*] by R-100/30, and daily average temperature at BIPM for a period of 10 months.

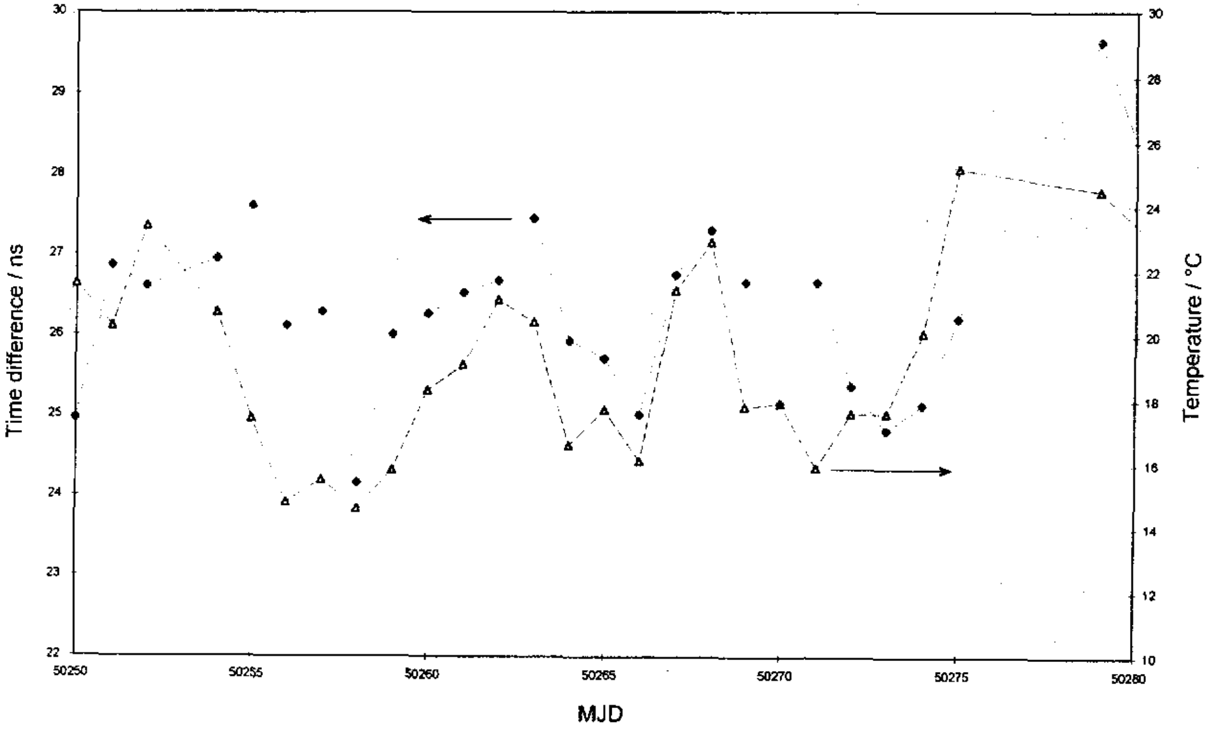

Figure 6. Daily averages of [*BIPM clock - GLONASS time*] by R-100/10 - [*BIPM clock - GLONASS time*] by R-100/30, and daily average temperature at BIPM for a period of about 1 month.

ANNEX I

A Suggested GPS Format Update for GPS/GLONASS

This is a suggested update of the CGGTTS GPS Data Format Version 01 as published in [1], for GPS/GLONASS, with suggested name CGGTTS GPS/GLONASS Data Format Version 02. Adopted notations are the same as for Version 01.

1. File header

Line 1-3: same as Version 01.

Line 4: "CH* = *" NUMBER OF CHANNELS
Number of receiver channels separately for GPS and GLONASS.
As many columns as necessary.

Line 5-6: same as Version 01.

Line 7-9: same as Version 01, but "GPS antenna" should be replaced by "GPS/GLONASS antenna"

Line 10: Designation of the reference frames, and if necessary transformation parameters between GLONASS and GPS frames.
As many columns as necessary.

Line 11: same as Version 01.

Line 12: "INT*DLY* = *" INTERNAL DELAY "*ns*(GPS)," INTERNAL DELAY "*ns*(GLO)"
Internal delays entered in the receiver separately for GPS and GLONASS, in ns and given with 1 decimal.
As many columns as necessary.

Line 13: "CAB*DLY* = *" CABLE DELAY "*ns*(GPS)," CABLE DELAY "*ns*(GLO)"
Delays from the antenna to the main unit including delays in the antenna element, filters, electronics and cable length, entered in the receiver separately for GPS and GLONASS, in ns and given with 1 decimal.
As many columns as necessary.

Line 14-17: same as Version 01.

2. Line header

2.1 No measured ionospheric delays available

For no ionospheric measurements available line header update is as follows:

Line 18.1: "SAT*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV***** REFSYS****SRSYS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*FR*HC*FRC*CK"
The acronyms are explained in Section 4 below. 113 columns.

2.2 Measured ionospheric delays available

With ionospheric measurements available line header update is as follows:

Line 18.2: "SAT*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV***** REFSYS****SRSYS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*MSIO*SMSI*ISG* FR*HC*FRC*CK"

The acronyms are explained in Section 4 below. 127 columns.

3. Unit header

Same as Version 01.

4. Data line

Line 20, columns 1-3: "123" SAT GPS or GLONASS satellite identification number.
a. GPS satellite PRN number, 1 to 38. No unit.
b. GLONASS almanac slot number plus 100, 101 to 124. No unit.

Line 20, columns 4-53: same as Version 01.

Line 20, columns 54-64: "+1234567890" REFSYS
Title changed from " REFGPS" to indicate reference to either constellation.
Data content same as Version 01.

Line 20, column 65: same as Version 01.

Line 20, columns 66-71: "+12345" SRSYS
Title changed from " SRGPS" to indicate slope for either constellation.
Data content same as Version 01.

Line 20, columns 72-101: same as Version 01.

4.1 No measured ionospheric delays available.

Line 20, columns 102-103: "12" FR
GLONASS transmission frequency channel number. 1 to 24. For GPS set to 0. No unit.

Line 20, column 104: space, ASCII value 20 (hexadecimal).

Line 20, columns 105-106: "12" HC
Receiver hardware channel number. 0 to 99. No unit.

Line 20, column 107: space, ASCII value 20 (hexadecimal).

Line 20, columns 108-110: "123" FRC
Frequency and Code type used for pseudo-range measurement, where:
L1C - L1 C/A code,
L1P - L1 P code,
L2C - L2 C/A code (GLONASS future capability),
L2P - L2 P code.

Line 20, column 111: space, ASCII value 20 (hexadecimal).

Line 20, columns 112-113: "12" CK
Data line check-sum for columns 1 to 111. Check-sum algorithm as defined for Version 01.

Line 20, columns 114-140: "123456789012345678901234567"
Optional comments on the data line, constituted of characters which are not included in the line check-sum CK.

4.2 Measured ionospheric delays available

Line 20, columns 102-115: same as Version 01.

Line 20, columns 116-117: "12" FR

GLONASS transmission frequency channel number. 1 to 24. For GPS set to 0. No unit.

Line 20, column 118: space, ASCII value 20 (hexadecimal).

Line 20, columns 119-120: "12" HC

Receiver hardware channel number. 0 to 99. No unit.

Line 20, column 121: space, ASCII value 20 (hexadecimal).

Line 20, columns 122-124: "123" FRC

Frequency and Code type used for pseudo-range measurement, where:
L1C - L1 C/A code,
L1P - L1 P code,
L2C - L2 C/A code (GLONASS future capability),
L2P - L2 P code.

Line 20, column 125: space, ASCII value 20 (hexadecimal).

Line 20, columns 126-127: "12" CK

Data line check-sum for columns 1 to 125. Check-sum algorithm as defined for Version 01.

Line 20, columns 128-140: "1234567890123"

Optional comments on the data line, constitued of characters which are not included in the line check-sum CK.

5. Example of Proposed Standard Format (fictitious data)

5.1 No measured ionospheric delays available, separate reference frames for GPS and GLONASS

```
CGGTTS GPS/GLONASS DATA FORMAT VERSION = 02
REV DATE = 1996-10-20
RCVR = 3S Navigation, R-100/10 L1 GLONASS 2 CH, S/N 00102 Rev 002 1996-10-20
CH = 1 (GPS), 1 (GLONASS)
IMS = 99999
LAB = 3S
X = -2473157.78 m (GPS),  -2473171.90 m (GLONASS)
Y = -4706094.09 m (GPS),  -4706086.67 m (GLONASS)
Z = +3512042.48 m (GPS),  +3512038.48 m (GLONASS)
FRAME = ITRF for GPS, PZ-90 for GLONASS
COMMENTS = NO COMMENTS
INT DLY = 1366.0 ns (GPS), 1312.0 ns (GLONASS)
CAB DLY =  100.0 ns (GPS),  105.0 ns (GLONASS)
REF DLY = 30.0 ns
REF = 3S
CKSUM = FE

SAT CL  MJD  STTIME TRKL ELV AZTH   REFSV      SRSV     REFSYS    SRSYS  DSG IOE MDTR SMDT MDIO SMDI FR HC FRC CK
             hhmmss  s  .1dg .1dg    .1ns     .1ps/s     .1ns    .1ps/s .1ns     .1ns.1ps/s.1ns.1ps/s
107 34 50367 231000  780 273 3287    +903734    +114       +1906     +69   41   9  177  -46  218  -34 21  1 L1C C1
107 34 50367 232300  180 273 3287    +903764    +105       +1936     +60   42   9  156  -33  201  -30 21  1 L1C B9
  9 18 50367 232600  780 428 2719    +491057     -63       +2120     -72   29   9  119   -8  174  -16  0  0 L1C 4A
107 18 50367 232600  780 348 3257    +903854     +87       +1926     +41   42   9  142  -27  188  -28 21  1 L1C BF
```

5.2 Measured ionospheric delays available, GLONASS satellite position transformed

```
CGGTTS GPS/GLONASS DATA FORMAT VERSION = 02
REV DATE = 1996-10-20
RCVR = 3S Navigation, R-100/30, L1 GPS 12 CH, L1/L2 GLONASS 2 CH, S/N 00020 Rev 004 1996-10-01
CH = 7 (GPS), 7 (GLONASS)
IMS = R-100/30
LAB = 3S
X = -2473157.78 m (GPS,GLONASS)
Y = -4706094.09 m (GPS,GLONASS)
Z = +3512042.48 m (GPS,GLONASS)
FRAME = ITRF, PZ-90->ITRF Dx = 0.0 m, Dy = 0.0 m, Dz = 4.0 m, ds = 0.0, Rx = 0.0, Ry = 0.0, Rz = -0.000003
COMMENTS = NO COMMENTS
INT DLY = 1366.0 ns (GPS), 1312.0 ns (GLONASS)
CAB DLY =  100.0 ns (GPS),  105.0 ns (GLONASS)
REF DLY = 0.0 ns
REF = 3S
CKSUM = 86

SAT CL  MJD  STTIME TRKL ELV AZTH   REFSV      SRSV     REFSYS    SRSYS  DSG IOE MDTR SMDT MDIO SMDI MSIO SMSI ISG FR HC FRC CK
             hhmmss  s  .1dg .1dg    .1ns     .1ps/s     .1ns    .1ps/s .1ns     .1ns.1ps/s.1ns.1ps/s.1ns.1ps/s.1ns
107 34 50367 231000  780 273 3287    +903734    +114       +1906     +69   41   9  177  -46  218  -34  225  -10  09 21  1 L1C C1
107 34 50367 232300  180 273 3287    +903764    +105       +1936     +60   42   9  156  -33  201  -30  189  -40  20 21  1 L1C B9
  9 18 50367 232600  780 428 2719    +491057     -63       +2120     -72   29   9  119   -8  174  -16 9999 9999 999  0  0 L1C 4A
107 18 50367 232600  780 348 3257    +903854     +87       +1926     +41   42   9  142  -27  188  -28  202  -30  17 21  1 L1C BF
```

ANNEX I

A Suggested GPS Format Update for GPS/GLONASS

This is a suggested update of the CGGTTS GPS Data Format Version 01 as published in [1], for GPS/GLONASS, with suggested name CGGTTS GPS/GLONASS Data Format Version 02. Adopted notations are the same as for Version 01.

1. File header

Line 1-3: same as Version 01.

Line 4: "CH* = *" NUMBER OF CHANNELS
Number of receiver channels separately for GPS and GLONASS.
As many columns as necessary.

Line 5-6: same as Version 01.

Line 7-9: same as Version 01, but "GPS antenna" should be replaced by "GPS/GLONASS antenna"

Line 10: Designation of the reference frames, and if necessary transformation parameters between GLONASS and GPS frames.
As many columns as necessary.

Line 11: same as Version 01.

Line 12: "INT*DLY* = *" INTERNAL DELAY "*ns*(GPS)," INTERNAL DELAY "*ns*(GLO)"
Internal delays entered in the receiver separately for GPS and GLONASS, in ns and given with 1 decimal.
As many columns as necessary.

Line 13: "CAB*DLY* = *" CABLE DELAY "*ns*(GPS)," CABLE DELAY "*ns*(GLO)"
Delays from the antenna to the main unit including delays in the antenna element, filters, electronics and cable length, entered in the receiver separately for GPS and GLONASS, in ns and given with 1 decimal.
As many columns as necessary.

Line 14-17: same as Version 01.

2. Line header

2.1 No measured ionospheric delays available

For no ionospheric measurements available line header update is as follows:

Line 18.1: "SAT*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV***** REFSYS****SRSYS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*FR*HC*FRC*CK"
The acronyms are explained in Section 4 below. 113 columns.

2.2 Measured ionospheric delays available

With ionospheric measurements available line header update is as follows:

Line 18.2: "SAT*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV***** REFSYS****SRSYS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*MSIO*SMSI*ISG* FR*HC*FRC*CK"

The acronyms are explained in Section 4 below. 127 columns.

3. Unit header

Same as Version 01.

4. Data line

Line 20, columns 1-3: "123" SAT GPS or GLONASS satellite identification number.
a. GPS satellite PRN number, 1 to 38. No unit.
b. GLONASS almanac slot number plus 100, 101 to 124. No unit.

Line 20, columns 4-53: same as Version 01.

Line 20, columns 54-64: "+1234567890" REFSYS
Title changed from " REFGPS" to indicate reference to either constellation.
Data content same as Version 01.

Line 20, column 65: same as Version 01.

Line 20, columns 66-71: "+12345" SRSYS
Title changed from " SRGPS" to indicate slope for either constellation.
Data content same as Version 01.

Line 20, columns 72-101: same as Version 01.

4.1 No measured ionospheric delays available.

Line 20, columns 102-103: "12" FR
GLONASS transmission frequency channel number. 1 to 24. For GPS set to 0. No unit.

Line 20, column 104: space, ASCII value 20 (hexadecimal).

Line 20, columns 105-106: "12" HC
Receiver hardware channel number. 0 to 99. No unit.

Line 20, column 107: space, ASCII value 20 (hexadecimal).

Line 20, columns 108-110: "123" FRC
Frequency and Code type used for pseudo-range measurement, where:
L1C - L1 C/A code,
L1P - L1 P code,
L2C - L2 C/A code (GLONASS future capability),
L2P - L2 P code.

Line 20, column 111: space, ASCII value 20 (hexadecimal).

Line 20, columns 112-113: "12" CK
Data line check-sum for columns 1 to 111. Check-sum algorithm as defined for Version 01.

Line 20, columns 114-140: "123456789012345678901234567"
Optional comments on the data line, constituted of characters which are not included in the line check-sum CK.

4.2 Measured ionospheric delays available

Line 20, columns 102-115: same as Version 01.

Line 20, columns 116-117: "12" FR
GLONASS transmission frequency channel number. 1 to 24. For GPS set to 0. No unit.

Line 20, column 118: space, ASCII value 20 (hexadecimal).

Line 20, columns 119-120: "12" HC
Receiver hardware channel number. 0 to 99. No unit.

Line 20, column 121: space, ASCII value 20 (hexadecimal).

Line 20, columns 122-124: "123" FRC
Frequency and Code type used for pseudo-range measurement, where:
L1C - L1 C/A code,
L1P - L1 P code,
L2C - L2 C/A code (GLONASS future capability),
L2P - L2 P code.

Line 20, column 125: space, ASCII value 20 (hexadecimal).

Line 20, columns 126-127: "12" CK
Data line check-sum for columns 1 to 125. Check-sum algorithm as defined for Version 01.

Line 20, columns 128-140: "1234567890123"
Optional comments on the data line, constitued of characters which are not included in the line check-sum CK.