# Quality Controlling RINEX Navigation Message Files

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## Abstract

As part of its operation, the NGS CORS Data Center, which also operates as an IGS regional data center, performs the routine task of creating cumulative hourly and daily global GPS and GLONASS navigation message files by combining site-specific navigation message files. With increasing frequency, incidents have occurred in which problematic navigation messages within site-specific files have corrupted these global files. To mitigate this issue, improved quality control for both the site-specific and global navigation message files has been implemented. That quality control can be broadly divided into three strategies:

- filter discrete format/data problems.
- comparison of time-adjacent messages for a satellite.
- comparison to an external source (namely an IGS precise, rapid or ultra-rapid ephemeris).

In this poster, each strategy will be described and its strengths and weaknesses delineated. In addition, summaries of some problems, their frequency and distribution within the IGS network will be provided.

## Introduction

When investigating problems reported by users of NGS products, the authors have occasionally identified the source as being a “bad” global RINEX broadcast navigation message file. Hereafter, “RINEX broadcast navigation message file” will be abbreviated simply as “file” in this presentation, and we take “global” file to mean a file created by combining files for a day from individual sites around the globe thereby creating a file that can be used anywhere. These global files are often called BRDC files because of the convention of using the string “brdc” as the four-character site identifier in the resulting RINEX file name. The problems caused by a bad BRDC file generally fall into two categories:

| | |
|---|---|
| user reports: | unexpectedly poor evaluation or processing of their data cause users to inquire if NGS is aware of any possible geophysical or GNSS causes. |
| OPUS logs: | the NGS Online Positioning User Service’s (OPUS) internal logs indicate an abnormal number of failures for a single day - usually in a limited region of a few hundred kilometers in diameter. |

Although these problems are infrequent, NGS undertook the challenge of preventing them entirely by implementing additional quality control (QC) tests for individual site and global files. To this end, all 2015 IGS network GPS and GLONASS daily site and global files from the Crustal Dynamics Data Information System (CDDIS) were evaluated using the QC tests described in the next section. The 2015 IGS GPS and GLONASS final ephemerides, also from the CDDIS, were used as “truth” in these tests. The CDDIS, which acts as an IGS global data center, was selected simply for convenience and this data set selected solely as a recent sample for this investigation. The authors do not mean to imply that the CDDIS, the data files it provides or the organizations that contribute those data files are better or worse than others by this selection. In point of fact, the IGS strives for consistency across its data centers, so the issues, or lack thereof, found in this sample should be representative of those found in the files of any IGS data center. And NGS has had a long and productive relationship with the CDDIS that we sincerely hope to continue. Over 200,000 files were downloaded for this investigation. It is certain that some of those downloads failed. Although any such problems were corrected when found, the results of some failed downloads probably remain in the sample; however, the authors do not believe the number is large enough to adversely affect these results. Currently, only GPS and GLONASS files are quality controlled and each system is handled separately (although there is almost complete sharing of source code, scripts and strategies between each system's QC tools) so that issues unique to each GNSS can be clearly identified. However, the plan is to consolidate these tools into a single set of tools/strategies applicable to all GNSS. The date for this consolidation has not been set, but will likely be in months - not days or years.

## The Quality Control Strategies

- **Filter:** Scan a file for discrete format problems. These include general RINEX formatting issues, truncated files, and the like.
  - Examples:
    - Missing RINEX headers or required header lines.
    - Inadvertently duplicated RINEX headers or header lines.
    - Corrupted or truncated files.
    - Nonsensical, often zero, values in header lines and messages, and some types of undesirable messages in an otherwise correctly formatted file.
  - Pros:
    - Most of these tests already exist in the NGS programming standards.
  - Cons:
    - Often a reactive response: a problem has to be encountered before source code is written to deal with it.

- **Internal consistency:** Comparison of values extrapolated to the mid-point in time between time-adjacent Times of Ephemeris messages for a satellite.
  - Examples:
    - Grossly incorrect messages.
  - Pros:
    - Capable of identifying broad categories of issues without the need of additional files or information.
    - Because this strategy requires no external "truth", it can be used on any file, at any time, any where.
  - Cons:
    - Incapable of identifying some systematic data issues such as leap second problems.
    - Implementation is the most complex of these strategies.

- **External comparison:** Comparison to an external source - namely an IGS precise, rapid or ultra-rapid ephemeris.
  - Examples:
    - Grossly incorrect messages.
    - Systematic problems such as an incorrect leap second.
  - Pros:
    - IGS products are the "gold" standard and are available (near) real-time.
    - Near real-time and later identification of navigation message position problems is effectively perfect.
  - Cons:
    - Requires an external source of "truth" access to which can, in some circumstances, be difficult.
    - IGS products sometimes have missing information, e.g. satellites excluded from ultra-rapid ephemerides, implying delays for the "best" results.
    - Currently, only position problems are tested, but some other types of information could be as well.

## Discussion

A selection of issues affecting many files in this sample are described and discussed, each in its own section. No speculations as to the root causes of these issues are provided, nor are remediations offered except trapping (identifying and removing) the offending data as part of these QC tests.

Even after limiting the sample to one year, the wealth of information prevents discussing individual sites in this format. To provide more detailed information, Excel® spreadsheets will be available for no less than six months at ftp://geodesy.noaa.gov/dist/MSchenewerk/IGS_2016_02.

A note about the statistics used. Many of the data sets described are simple counts of errors. Because the IGS as a whole performs quite well, those counts are usually near zero and their distribution skewed from a normal distribution; therefore, means and standard deviations computed from these data sets won't have precisely the meanings usually attributed to them. For this reason, the median and interquartile range (IQR) will be used in this presentation. Recall that the median is the midpoint value of an ordered population (numerically sorted in these cases). Literally half of the sample population values must be above the median; half below. If those ordered values are divided into quarters, the IQR is the third quarter value minus the first quarter value. This implies that 50% of the sample population falls within the IQR around the median. With a representative, normally distributed sample population: median ≅ mean; IQR ≅ $0.67\sigma$. But, again, normally distributed sets are not usually the case here.

A second note about dates. Unless a specific epoch is given, these are the days implied by the RINEX file names expressed as the GPS week and day-of-week. For example: abcd**160**0.**15**n implies 2015-160 = 2015-06-09 = 1848-2. To help with interpretation: the GPS week numbers for the first day of each month in 2015 are given below:

| Calendar Date | GPS Week-Day | GPS Week | Calendar Date | GPS Week-Day | GPS Week | Calendar Date | GPS Week-Day | GPS Week |
|---|---|---|---|---|---|---|---|---|
| 2015-01-01 | 1825-4 | 1825.57 | 2015-05-01 | 1842-5 | 1842.71 | 2015-09-01 | 1860-2 | 1860.29 |
| 2015-02-01 | 1830-0 | 1830.00 | 2015-06-01 | 1847-1 | 1847.14 | 2015-10-01 | 1864-4 | 1864.57 |
| 2015-03-01 | 1834-0 | 1834.00 | 2015-07-01 | 1851-3 | 1851.43 | 2015-11-01 | 1869-0 | 1869.00 |
| 2015-04-01 | 1838-3 | 1838.43 | 2015-08-01 | 1855-6 | 1855.86 | 2015-12-01 | 1873-2 | 1873.29 |

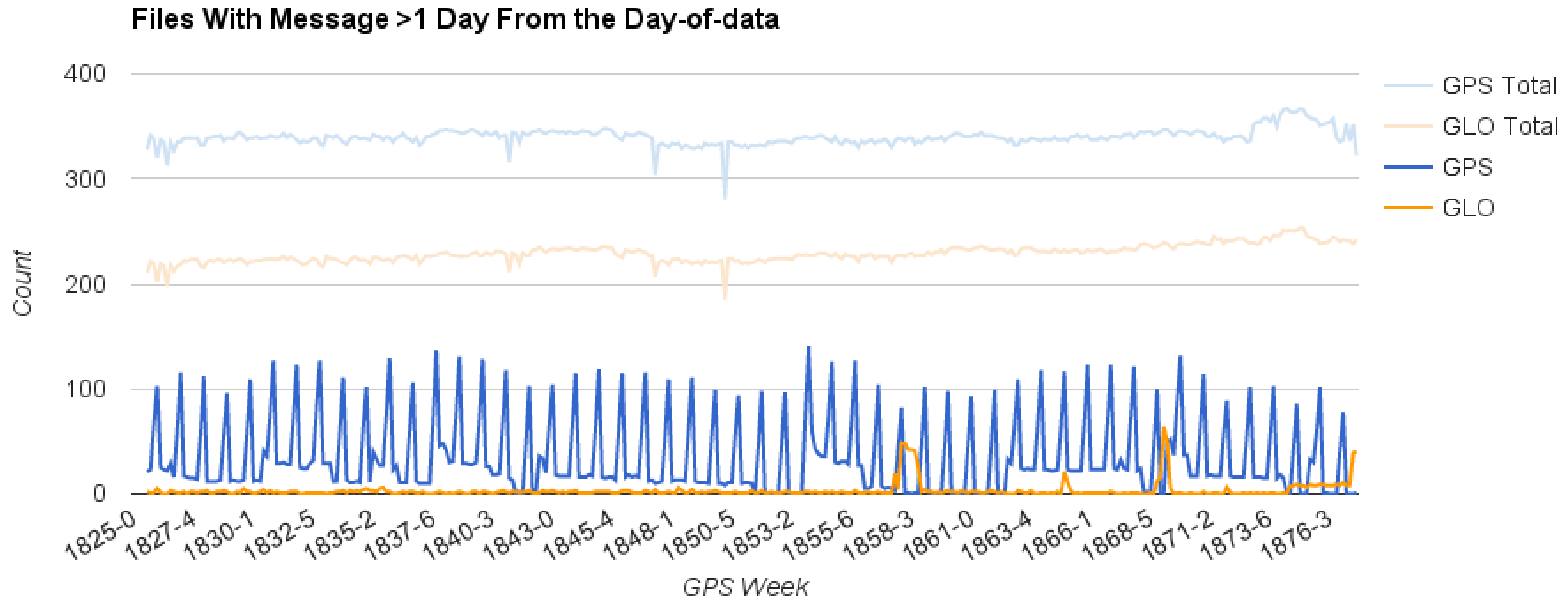
A limited amount of jargon and abbreviations will be used. Although the authors believe their meaning will be obvious and they will be described in the normal flow of the text, as one would expect, a glossary is provided here for convenience.

BRDC. . . . . . . . . global, combined broadcast navigation message file provided by IGS data centers.
day-of-data. . . . . the day of the data implied by the broadcast navigation message file's name.
external . . . . . . . external comparison strategy = compare message values to an external source of "truth" such an IGS final, rapid or ultra-rapid ephemeris.
file . . . . . . . . . . . unless explicitly stated, file will mean a RINEX broadcast navigation message file.
filter . . . . . . . . . . filter strategy = verify format and other broad characteristics such as meaningful appearing values.
GLO. . . . . . . . . . GLONASS.
internal. . . . . . . . internal consistency strategy = testing that values from similar or extrapolated from time-adjacent messages agree within reason.
IQR . . . . . . . . . . interquartile range.
message . . . . . . in individual RINEX broadcast navigation message block for a satellite.
QC. . . . . . . . . . . quality control.
trap. . . . . . . . . . identify and report (and remove operationally if instructed) broadcast navigation messages with errors.

## Messages Far Outside the Time Span Anticipated for a File

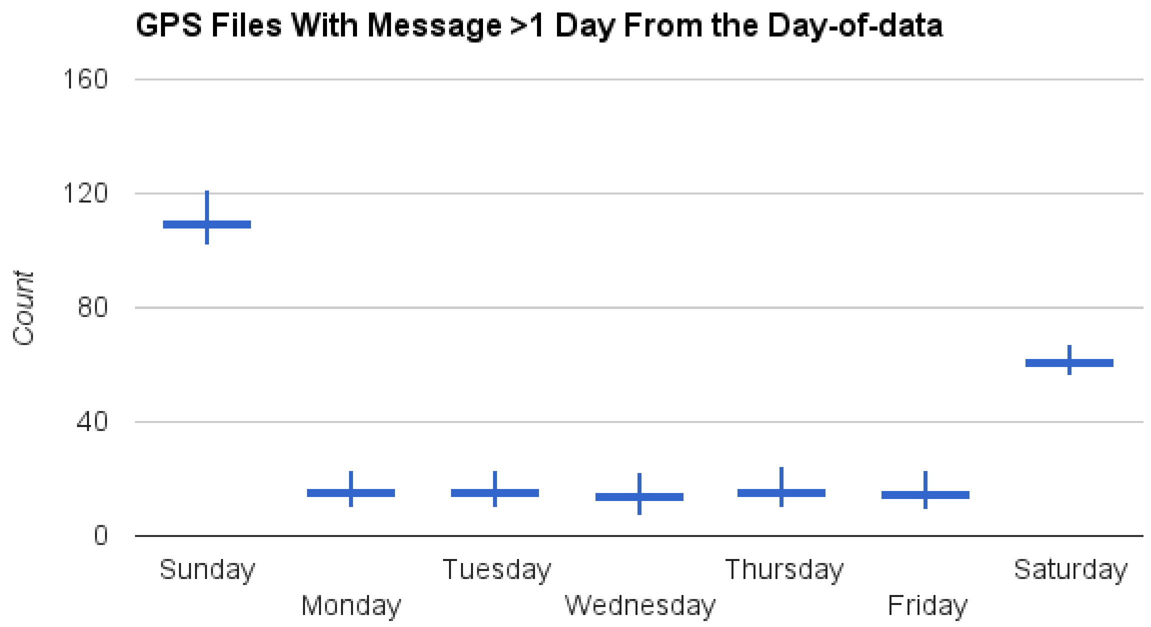
Messages shortly before and after the specific time span implied by the file's name are often included in a file. For example 48% (160 out of 332) of the GPS individual site files for 2015-160, plus the global file, contain messages from 2015-159T23:59:44 to 2015-161T00:00:00 GPS rather than strictly starting at 2015-160T00:00:00 GPS. Inclusion of any messages that would be considered meaningful for a day could be considered appropriate, but a definitive argument for or against this practice won't be offered here.

What was surprising was how often files include messages with Time of Ephemeris tags that were days or weeks or months before the day-of-data. Admittedly, these "stray" messages are unlikely to cause direct harm to any processing, but they could trigger warnings in software and potentially confuse users, and they unnecessarily increase file sizes.



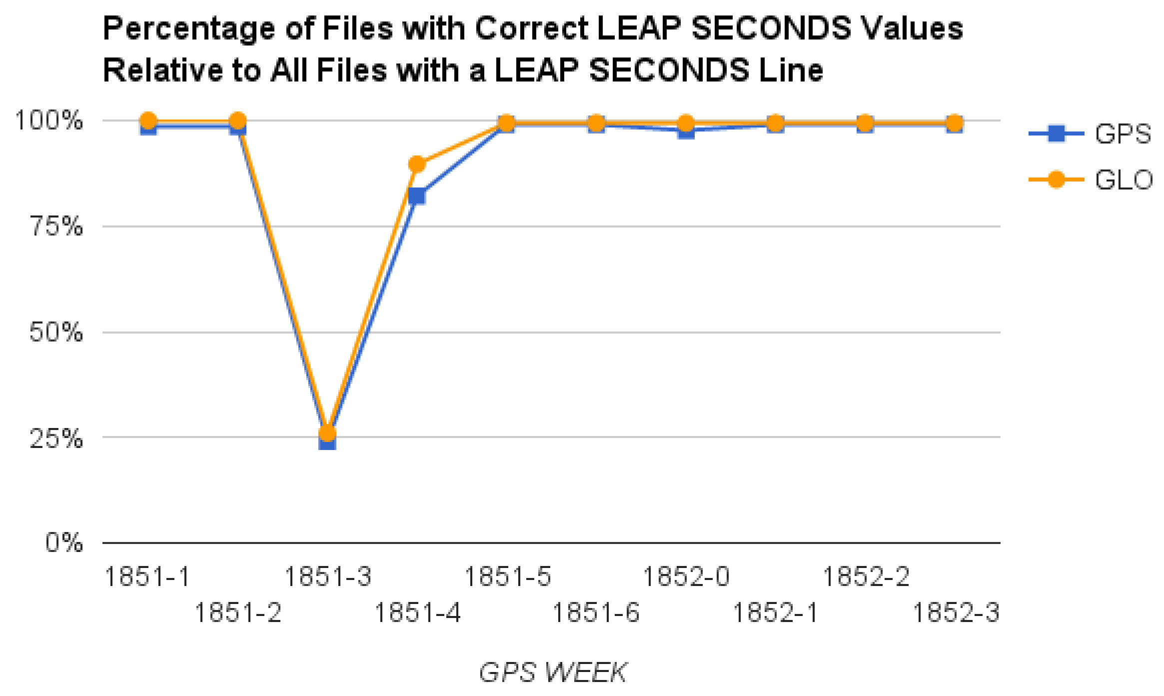

The plot to the left shows the counts-by-day of individual site files that contain navigation messages >1 day from the day-of-data implied by the file's name. Please note there will often be additional messages within 1 day of the day-of-data that were intentionally not counted for this plot. GPS counts are blue; GLO are orange. For comparison, the total number individual site files for each day is also shown: GPS in light-blue; GLO in light-orange. The number of GLO files with this issue is usually small, <1%, but the GPS files suffer more and present a pattern that appears to be a weekly cycle.

A more interesting representation of these GPS results is given in the plot to the right. This plot shows the median counts of individual files containing messages >1 day from the day-of-data (horizontal, blue lines) and the IQR associated with those medians (vertical, blue lines) plotted versus the day-of-week. The counts of files with this issue are usually about 5% of the total for weekdays, but 20% for Saturdays and 30% for Sundays. As stated at the start of the Discussion sections, the authors did not pursue any issue through hardware-firmware-software, but this plot suggests an issue with the transition from GPS week to week. The authors also offer that the affected files are derived from many receiver/firmware types.



## Leap Second

At the end of June 30, 2015 (= 2015-181 = GPS Week 1851-2), a leap second was added to UTC. Speaking for the NGS analysis and data center teams, these events always entail some trepidation, so there was no surprise to find issues across the IGS network on the days following the addition of the leap second.

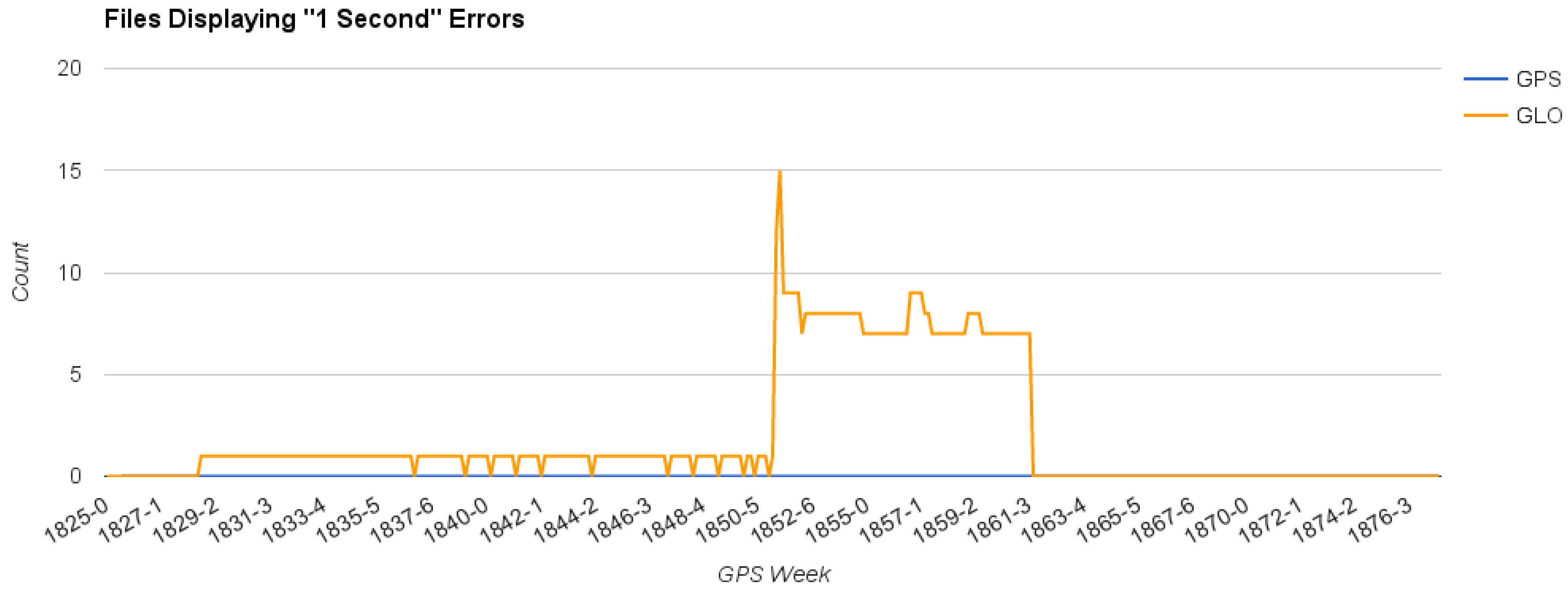



The plot to the left "zooms in" on just the few days around the addition of the leap second. We see that ~75% of the individual files that have a LEAP SECONDS line in their RINEX headers have an erroneous value the day after the leap second was added. For GPS, that is 159 out of 212 (there were a total of 329 individual site files for that day, but many do not include the optional LEAP SECONDS header line); for GLO, that is 122 out of 165 files (218 total files for this day). Fortunately, this issue is corrected within 48 hours. Most importantly, the BRDC files always have the correct values for the day-of-data**.**

Some interesting side notes are:

- There is no method for inserting modified header information amongst the messages in these files, so files that contain a LEAP SECONDS value are *likely* to have the wrong value for "stray" messages, i.e. messages whose Time of Ephemeris tag is not the day-of-data.
- 8 sites omit the LEAP SECONDS header line in their GPS files, but have it in their GLO files.
- 4 sites have correct values in their GPS files, but incorrect values in their GLO files on 1851-2.
- 2 GPS sites consistently have incorrect values the entire year.
- 1 GLO site persisted with the pre-June 30 value after the day of the leap second.

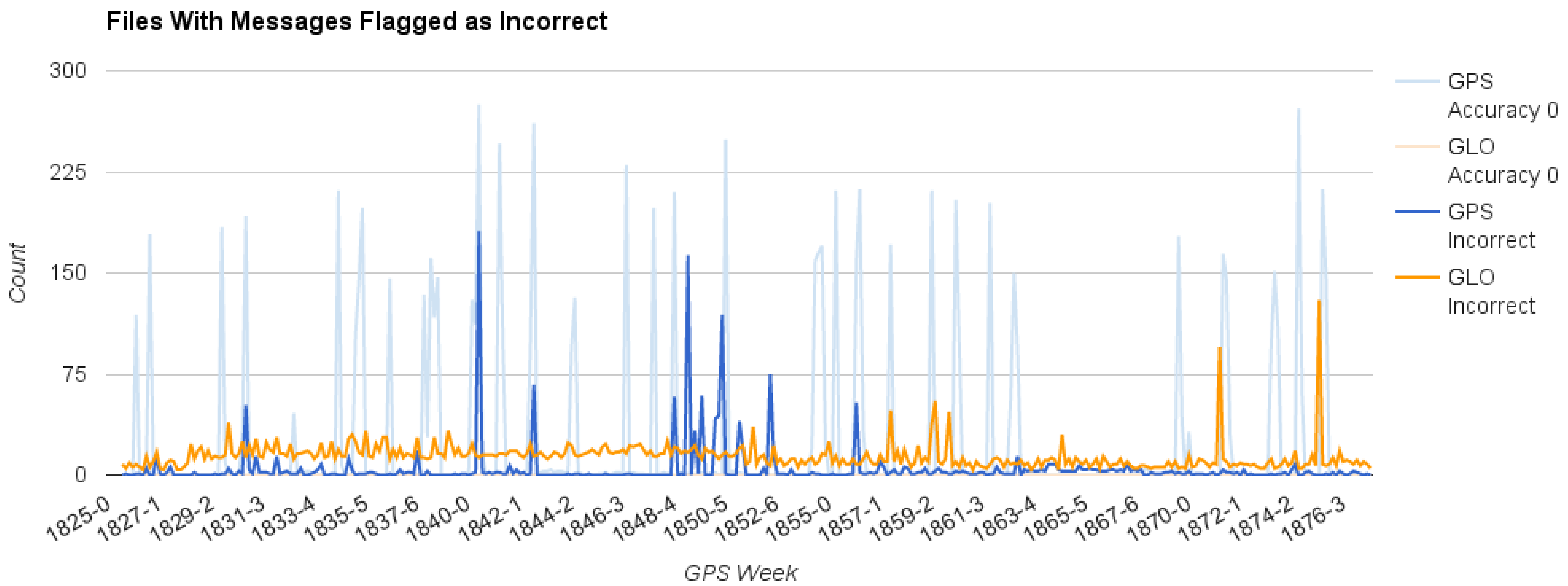
Another, more troubling issue occurred in the GLO files. In these cases, the Time of Ephemeris tags were "off" by 1 second relative to the ephemeris values in the message. Put another way, a message whose values were correct for 12:00:00 would have a Time of Ephemeris tag of 11:59:59 or 12:00:01. Generally, the number of files with this problem is very small, but that number, spiked for approximately 11 weeks after the leap second usually from a consistent subset of the network.



## Files With Incorrect Messages

Virtually all messages in these files are correct ... however, incorrect messages do occur that can result in a satellite position in error by thousands of kilometers. Excluding the leap second and formatting issues (discussed in other sections), these "incorrect" messages fall into two broad categories:

- messages inconsistent with an IGS ephemeris being used as "truth", but corresponding to time spans when zero accuracy codes (accuracy undetermined - satellite should be discarded or down-weighted) are reported in the ephemerides. The satellite position differences with respect to the corresponding ephemeris are almost always less than a few tens of kilometers. When this type of problem occurs, it affects all files with messages for the suspect satellite during the time span in question.
- messages whose data appear genuinely incorrect, i.e. inconsistent with the IGS ephemeris being used as "truth" and with time-adjacent messages. These can result in satellite position errors of thousands of kilometers.




The plot to the left shows the by-day counts of files with incorrect messages. Leap second and formatting issues have been excluded to simplify the plot and because they are discussed in other sections.

Files whose "incorrect" messages can be attributed to ephemerides with zero accuracy codes were counted separately because of that uncertainty. Those counts are shown, but de-emphasized by using light-blue for GPS and light-orange for GLO.

Counts of files whose messages appear to be genuinely incorrect are shown using darker lines: GPS is in blue; GLO in orange.

If a "genuinely incorrect" message occurred, the median number of such messages in that file was 1 for GPS with an IQR of 2, and a median of 1 for GLO with an IQR of 1. In other words, if a file contained "genuinely incorrect" messages, usually there was only one such message in the file. When an incorrect message occurred, it usually, but not always, occurred in several (sometimes many) files creating the spikes seen in the plot. Remember that these "genuinely incorrect" messages are rare.

One note, in these files, it is most common for messages to have Time of Ephemeris tags precisely "on the minute", i.e. zero seconds before or after the minute. For GPS, a few other Time of Ephemeris seconds are also common: 44 s is the most common of these "odd" times, but 28 s and 12 s are also seen. An "odd" time might be startling, but is not a problem in itself.

## Formatting

### Formatting Programs

44 different programs or program versions for creating the files are reported. Some of these would be considered potentially out-of-date based upon the reported versions. For example, ~13% of the sites report using a TEQC version more than 5 years old. Of course, the age of the software does not guarantee that problems exist, but it is unsettling.

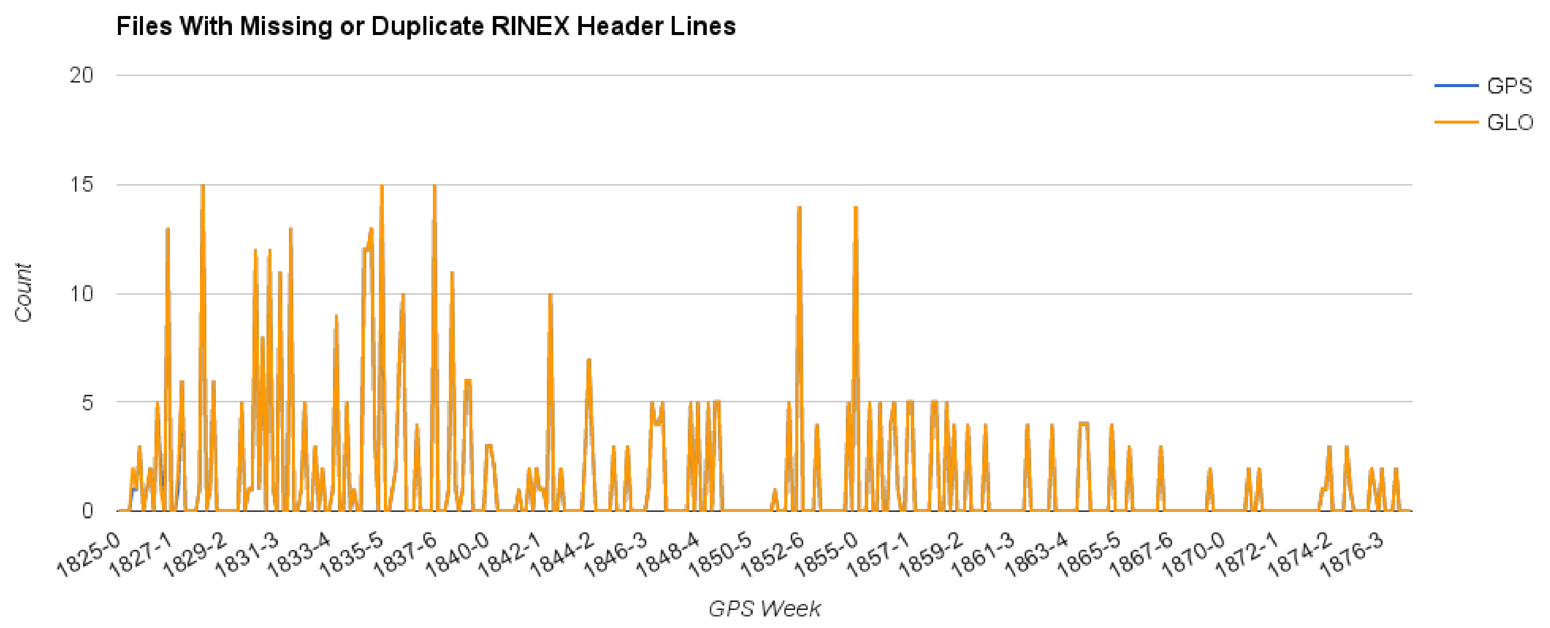
### RINEX format version:

- ❑ GPS: approximately 2.1% report as being RINEX 2, 0.0% as 2.01, 91.1% as 2.10 and 6.7% as 2.11.
- ❑ GLO: approximately 0.0% report as being RINEX 2, 1.6% as 2.01, 90.1% as 2.10 and 8.3% as 2.11.

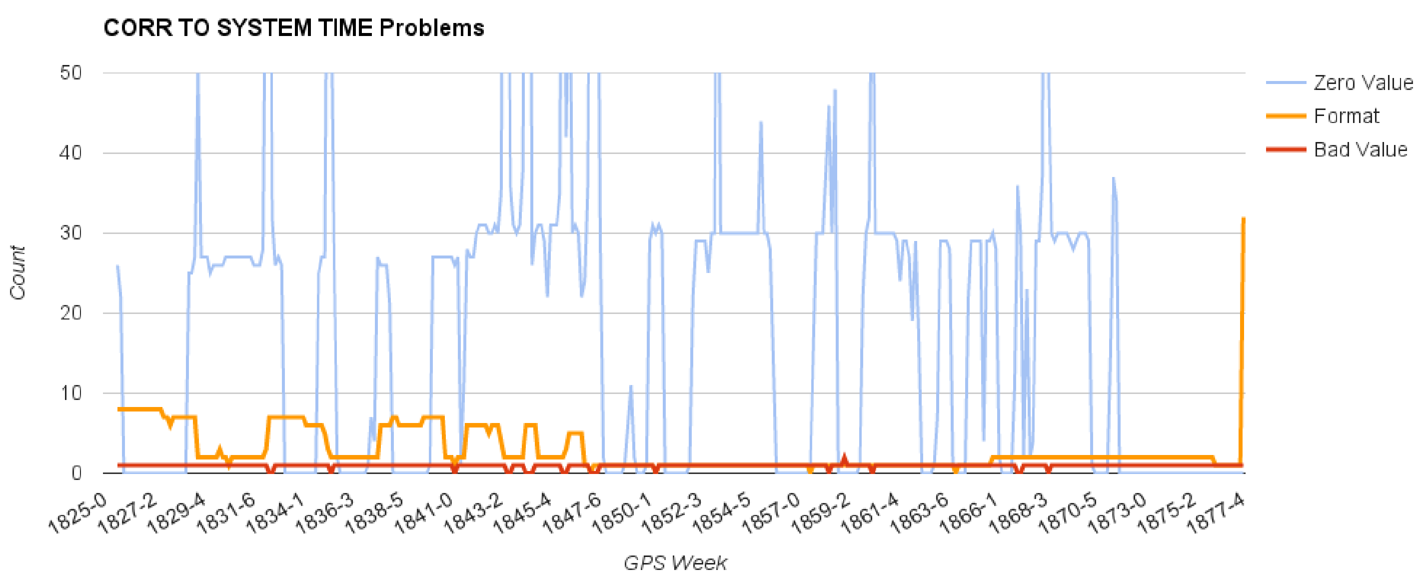
### Missing/Duplicate Header Lines:

The plot to the right summarizes the occurrences of header format errors: missing RINEX headers, duplicate headers, or missing or corrupted (required) header lines. GPS is in blue; GLO in orange. This figure is deceptive because the GPS and GLO counts are almost identical and the implication of this is true: namely that when this type of problem occurs, it occurs in both the GPS and GLO files if that site provides both.

Individual problem types are not broken out to keep the plot from being "too busy". Excluding LEAP SECONDS issues, missing headers are the most common problem by a wide margin.




### CORR TO SYSTEM TIME Problems:




Although not a required RINEX header line, the CORR TO SYSTEM TIME, a correction from GLONASS system time to UTC(SU), is critical for highest accuracies when using the GLO files. For this reason, special attention was paid to this record when it was included. Grossly incorrect values and some formatting errors which would cause grossly incorrect values to be read, can cause errors of kilometers or more. In the plot on the left, one sees that the most common problem was a zero (0) value for the correction. During 2015, the magnitude of this correction was small (e.g. $10^{-8}$ s to $10^{-10}$ s), so a value of zero does not significantly affect the satellite positions, but it could point to other problems. Similarly, the dates in the CORR TO SYSTEM TIME lines could be off by a few days and affect the positions less than a millimeter. But one amusing special case: on December 31 (2015-365 = 1877-4), 31 files reported the year as 2105 rather than 2015. This "typo" was counted as a Format issue in the plot.

## GPS Latency

Although not within the purview of this investigation, information about the latency of the files was collected. Here, latency is determined by the modification time of a file. While this is not a perfect or perfectly reliable measure of latency, it should serve as a good surrogate. The results for GPS files are given in the table below. The columns repeat in groups of four: the four-character site ID, the median latency in days, the IQR of the latency in days, and the reliability of a site providing a file as a percentage the total number of days of the year. There is an empty spacer column between four-column groups. The top row contains labels for the columns. Every row thereafter gives information about a site. Every tenth row is shaded light gray to aid in navigation. Gray or white median and IQR cells have a latency ≤ 1 day. Yellow cells: ≤ 7 days. Red cells > 7 days. The authors freely admit the table below is difficult to read, but a “feel” for the overall latency should be evident by the color coding. The point, of course, is that most of the table is without yellow or red shading. The overall median latency is 0 days with an IQR of 0 days with a reliability of 84%. Excellent! The BRDC latency is 10 days with an IQR of 23 days.

| | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ABPO | 0 | 0 | 100% | CHIL | 0 | 0 | 100% | GANP | 0 | 0 | 99% | JPLM | 0 | 0 | 99% |
| ADIS | 0 | 0 | 92% | CHPG | 0 | 0 | 100% | GENO | 0 | 0 | 99% | KARR | 0 | 0 | 79% |
| AIRA | 2 | 1 | 99% | CHPI | 0 | 0 | 89% | GLDR | 0 | 0 | 83% | KAT1 | 0 | 0 | 97% |
| ALBH | 0 | 0 | 98% | CHU2 | 0 | 15 | 100% | GLPS | 0 | 1 | 96% | KAT2 | 0 | 0 | 79% |
| ALG2 | 0 | 0 | 56% | CHUM | 0 | 0 | 98% | GLSV | 0 | 0 | 99% | KAZA | 29 | 23 | 88% |
| ALG3 | 0 | 0 | 98% | CHUR | 0 | 0 | 100% | GMSD | 0 | 0 | 94% | KELY | 0 | 0 | 100% |
| ALGO | 0 | 0 | 100% | CHWK | 0 | 0 | 97% | GODE | 0 | 0 | 99% | KERG | 0 | 0 | 100% |
| ALIC | 0 | 0 | 100% | CIT1 | 0 | 0 | 99% | GODN | 0 | 0 | 70% | KGNI | 0 | 0 | 14% |
| ALRT | 0 | 0 | 99% | CKIS | 0 | 0 | 100% | GODS | 0 | 0 | 70% | KHAR | 0 | 0 | 84% |
| AMC2 | 0 | 0 | 100% | CLAR | 0 | 0 | 100% | GODZ | 0 | 0 | 98% | KIR0 | 0 | 0 | 99% |
| AMU2 | 0 | 1 | 100% | CLRS | 0 | 0 | 100% | GOL2 | 0 | 0 | 100% | KIR8 | 1 | 1.5 | 6% |
| ANKR | 0 | 0 | 100% | CMP9 | 0 | 0 | 98% | GOLD | 0 | 0 | 100% | KIRI | 0 | 0 | 68% |
| AREG | 0 | 0 | 100% | CNMR | 0 | 0 | 89% | GOPE | 0 | 0 | 99% | KOKB | 0 | 0 | 100% |
| AREQ | 0 | 0 | 99% | COCO | 0 | 0 | 100% | GORO | 8 | 10 | 98% | KOKC | 0 | 0 | 2% |
| AREV | 0 | 0 | 99% | CONZ | 0 | 0 | 26% | GRAS | 0 | 0 | 100% | KOKV | 0 | 0 | 100% |
| ARUC | 0 | 0 | 99% | CORD | 0 | 0 | 98% | GRNB | 0 | 77 | 100% | KOUC | 8 | 10 | 98% |
| ASCG | 1 | 1 | 28% | COSO | 0 | 0 | 22% | GUAM | 0 | 0 | 99% | KOUG | 0 | 0 | 100% |
| ASPA | 0 | 3 | 96% | CPVG | 0 | 1 | 74% | GUAO | 0 | 0 | 21% | KRGG | 0 | 0 | 97% |
| AZU1 | 0 | 0 | 98% | CRAO | 0 | 0 | 91% | GUUG | 0 | 0 | 99% | KSMV | 0 | 0 | 14% |
| BADG | 0 | 0 | 99% | CRAR | 0 | 0 | 94% | HALY | 48 | 37 | 21% | KUUJ | 0 | 0 | 100% |
| BAIE | 0 | 0 | 98% | CRFP | 0 | 0 | 98% | HARB | 0 | 0 | 96% | LAUT | 14 | 2 | 1% |
| BAKE | 0 | 0 | 99% | CRO1 | 0 | 0 | 92% | HERS | 0 | 0 | 100% | LBCH | 0 | 0 | 100% |
| BAMF | 0 | 0 | 100% | CUSV | 0 | 0 | 45% | HERT | 0 | 0 | 99% | LCAP | 8 | 10 | 93% |
| BARH | 0 | 0 | 92% | DAEJ | 0 | 0 | 99% | HGHN | 8 | 10 | 91% | LCK3 | 2 | 3 | 39% |
| BCOV | 0 | 0 | 100% | DAKR | 1 | 3 | 98% | HKSL | 3 | 3.5 | 5% | LCK4 | 2 | 3 | 39% |
| BHR3 | 0 | 0 | 8% | DARW | 0 | 0 | 98% | HKWS | 3 | 3.5 | 5% | LEIJ | 0 | 0 | 99% |
| BHR4 | 0 | 0 | 7% | DAV1 | 0 | 0 | 100% | HLFX | 0 | 0 | 100% | LFOA | 8 | 10 | 94% |
| BILL | 0 | 0 | 100% | DGAR | 0 | 0 | 77% | HLOU | 8 | 10.5 | 96% | LHAZ | 0 | 0 | 99% |
| BJCO | 0 | 1 | 95% | DGAV | 0 | 0 | 77% | HNPT | 0 | 0 | 100% | LPAL | 0 | 0 | 100% |
| BJFS | 1 | 2 | 94% | DJIG | 1 | 5 | 46% | HOB2 | 0 | 0 | 100% | LPIL | 8 | 10 | 95% |
| BJNM | 0 | 14.75 | 33% | DRA3 | 0 | 18 | 97% | HOFN | 0 | 0 | 100% | LPOC | 0 | 0 | 100% |
| BLCL | 0 | 10 | 78% | DRA4 | 0 | 18 | 97% | HOLB | 0 | 0 | 100% | MAC1 | 0 | 0 | 100% |
| BLYT | 0 | 0 | 100% | DRAO | 0 | 0 | 100% | HOLM | 0 | 0 | 100% | MAD2 | 0 | 0 | 99% |
| BOGI | 0 | 0 | 97% | DUBO | 0 | 0 | 98% | HOLP | 0 | 0 | 100% | MADR | 0 | 0 | 100% |
| BOGT | 0 | 0 | 73% | DYNG | 0 | 0 | 99% | HRAC | 0 | 0 | 100% | MAJU | 0 | 0 | 50% |
| BOR1 | 0 | 0 | 100% | EIL3 | 0 | 0 | 8% | HRAO | 0 | 0 | 100% | MANA | 0 | 0 | 98% |
| BREW | 0 | 0 | 100% | EIL4 | 0 | 0 | 7% | HUEG | 0 | 0 | 100% | MAR6 | 0 | 0 | 99% |
| BRFT | 3.5 | 11 | 28% | ELIZ | 0 | 0 | 100% | IENG | 0 | 0 | 99% | MAR7 | 1 | 1.5 | 6% |
| BRMU | 0 | 0 | 99% | ESCU | 0 | 0 | 97% | IISC | 0 | 0 | 98% | MAT1 | 0 | 0 | 99% |
| BRUX | 0 | 0 | 100% | EUR2 | 0 | 0 | 100% | INVK | 0 | 0 | 100% | MATE | 0 | 0 | 100% |
| BSHM | 0 | 0 | 100% | FAIC | 0 | 0 | 100% | IQAL | 0 | 0 | 100% | MAW1 | 0 | 0 | 100% |
| BUCU | 0 | 0 | 99% | FAIR | 0 | 0 | 100% | IQUI | 0 | 5 | 95% | MAYG | 0 | 0 | 99% |
| BZRG | 0 | 0 | 99% | FAIV | 0 | 0 | 100% | IRKJ | 0 | 0 | 96% | MBAR | 0 | 4.25 | 50% |
| CAGS | 0 | 0 | 100% | FALK | 0 | 0 | 100% | ISBA | 0 | 0 | 65% | MCHL | 11 | 98.5 | 99% |
| CALL | 0 | 0 | 75% | FFMJ | 0 | 0 | 100% | ISCO | 0 | 1 | 53% | MCIL | 1 | 1 | 99% |
| CAS1 | 0 | 0 | 100% | FLIN | 0 | 0 | 100% | ISPA | 0 | 0 | 100% | MCM4 | 0 | 0 | 98% |
| CCJ2 | 2 | 1 | 99% | FLRS | 0 | 0 | 99% | ISTA | 0 | 0 | 96% | MCMC | 0 | 0 | 98% |
| CEDU | 0 | 0 | 100% | FRDN | 0 | 0 | 97% | JFNG | 0 | 0 | 100% | MDVJ | 0 | 0 | 100% |
| CGGN | 0 | 5 | 51% | FTNA | 0 | 0 | 94% | JOZ2 | 0 | 0 | 99% | MEDI | 0 | 0 | 89% |
| CHAN | 0 | 0 | 99% | FUNC | 0 | 0 | 96% | JOZE | 0 | 0 | 99% | MELI | 0 | 0 | 72% |

| | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| METG | 0 | 0 | 100% | PGC5 | 0 | 0 | 100% | SHAO | 0 | 2 | 5% | TWTF | 0 | 1 | 51% |
| MIKL | 0 | 0 | 98% | PGEN | 3 | 5.5 | 10% | SHE2 | 0 | 0 | 100% | UACO | 8 | 10 | 96% |
| MKEA | 0 | 0 | 73% | PICL | 0 | 0 | 88% | SMST | 0 | 0 | 96% | UCLP | 0 | 0 | 88% |
| MOBS | 0 | 0 | 100% | PIE1 | 0 | 0 | 99% | SNI1 | 0 | 0 | 100% | UCLU | 0 | 0 | 100% |
| MOIU | 0 | 0 | 67% | PIMO | 0 | 0 | 95% | SOFI | 0 | 0 | 99% | UNB3 | 0 | 0 | 99% |
| MORP | 0 | 0 | 99% | PMBT | 8 | 10.75 | 98% | SOLA | 4 | 4 | 82% | UNBJ | 0 | 0 | 100% |
| MRL1 | 0 | 0 | 8% | PNGM | 0 | 0 | 50% | SOLO | 19.5 | 32.5 | 18% | URUS | 0 | 0 | 93% |
| MRL2 | 0 | 0 | 7% | PODG | 32.5 | 21.75 | 77% | SPK1 | 0 | 0 | 100% | USN7 | 0 | 0 | 100% |
| MTKA | 2 | 1 | 79% | POHN | 0 | 0 | 100% | SPT0 | 0 | 1 | 99% | USUD | 0 | 0 | 100% |
| MTV1 | 0 | 0 | 8% | POL2 | 0 | 0 | 100% | SSIA | 0 | 0 | 89% | UZHL | 0 | 0 | 99% |
| MTV2 | 0 | 0 | 7% | POLV | 0 | 1 | 100% | STHL | 0 | 0 | 98% | VACS | 0 | 0 | 100% |
| NAIN | 0 | 0 | 81% | POUM | 8 | 11 | 97% | STJ2 | 0 | 0 | 100% | VALD | 0 | 0 | 100% |
| NANO | 0 | 0 | 100% | PPPC | 0.5 | 4.25 | 13% | STJO | 0 | 0 | 100% | VIS0 | 0 | 0 | 100% |
| NAS0 | 0 | 0 | 99% | PRD2 | 0 | 15 | 100% | STK2 | 2 | 1 | 99% | VNDP | 0 | 0 | 100% |
| NAUR | 0 | 2 | 89% | PRD3 | 0 | 15 | 100% | STR1 | 0 | 0 | 100% | WARN | 0 | 0 | 98% |
| NICO | 0 | 0 | 100% | PRDS | 0 | 0 | 100% | STR2 | 0 | 0 | 100% | WDC5 | 0 | 0 | 7% |
| NIST | 0 | 0 | 100% | PRE3 | 0 | 0 | 8% | SULP | 0 | 0 | 100% | WDC6 | 0 | 0 | 7% |
| NIUM | 0 | 0 | 100% | PRE4 | 0 | 0 | 7% | SUMK | 0 | 1 | 100% | WES2 | 0 | 0 | 53% |
| NKLG | 0 | 0 | 100% | PTAG | 0 | 1 | 36% | SUTH | 0 | 0 | 95% | WHC1 | 0 | 0 | 100% |
| NLIB | 0 | 0 | 93% | PTAL | 0 | 0 | 100% | SUTV | 0 | 0 | 95% | WHIT | 0 | 0 | 100% |
| NMEA | 8 | 11 | 99% | PTBB | 0 | 0 | 99% | SUWN | 1 | 1 | 80% | WIDC | 0 | 0 | 100% |
| NOT1 | 0 | 0 | 99% | PTGG | 0 | 1 | 75% | SVTL | 0 | 0 | 97% | WILL | 0 | 0 | 100% |
| NOVM | 0 | 0 | 99% | PTRF | 0 | 0 | 100% | SYOG | 2 | 2 | 99% | WLSN | 0 | 0 | 95% |
| NRC1 | 0 | 0 | 100% | QIKI | 0 | 0 | 100% | TABL | 0 | 0 | 100% | WROC | 0 | 0 | 98% |
| NRL1 | 0 | 0 | 98% | QUAD | 0 | 0 | 100% | TABV | 0 | 0 | 97% | WSLR | 0 | 0 | 100% |
| NRMD | 10 | 9 | 74% | QUI3 | 0 | 0 | 7% | TAH1 | 0 | 0 | 57% | WSRT | 0 | 0 | 100% |
| NTKA | 0 | 0 | 100% | QUI4 | 0 | 0 | 7% | TAH2 | 0 | 0 | 57% | WTZA | 0 | 0 | 99% |
| NTUS | 0 | 0 | 26% | QUIN | 0 | 0 | 99% | TANA | 0 | 0 | 24% | WTZR | 0 | 0 | 100% |
| NVSK | 4 | 3 | 97% | RABT | 0 | 0 | 95% | TEHN | 5 | 4 | 8% | WTZS | 0 | 0 | 98% |
| NYA1 | 1 | 45 | 100% | RCMN | 1 | 0 | 72% | TFNO | 0 | 0 | 100% | WTZZ | 0 | 0 | 97% |
| NYAL | 1 | 45 | 100% | RDSD | 90.5 | 180.5 | 100% | THIO | 8 | 10 | 93% | WUHN | 0 | 0 | 43% |
| OAK1 | 0 | 0 | 8% | RESO | 0 | 0 | 99% | THTG | 0 | 0 | 100% | XMIS | 0 | 0 | 100% |
| OAK2 | 0 | 0 | 7% | REYK | 0 | 0 | 100% | THTI | 0 | 0 | 100% | YAR2 | 0 | 66.25 | 94% |
| OHI2 | 0 | 0 | 100% | RGDG | 0 | 0 | 100% | TID1 | 0 | 0 | 100% | YAR3 | 0 | 0 | 100% |
| OHI3 | 0 | 0 | 99% | RIGA | 0 | 0 | 100% | TIDB | 0 | 0 | 100% | YARR | 0 | 0 | 98% |
| ONS1 | 1 | 1.5 | 6% | RIOP | 0 | 0 | 94% | TIT2 | 0 | 0 | 100% | YATE | 8 | 10 | 94% |
| ONSA | 0 | 1 | 87% | ROAP | 0 | 0 | 72% | TITG | 5 | 8 | 5% | YCBA | 0 | 0 | 95% |
| ORID | 0 | 0 | 100% | ROCK | 0 | 0 | 100% | TITZ | 0 | 0 | 44% | YEBE | 0 | 0 | 99% |
| OSN3 | 0 | 0 | 8% | ROTH | 29 | 120 | 100% | TLSE | 0 | 0 | 99% | YEL2 | 0 | 5 | 42% |
| OSN4 | 0 | 0 | 7% | SANT | 0 | 0 | 71% | TLSG | 0 | 2.5 | 42% | YEL3 | 0 | 15.25 | 100% |
| OWNG | 0 | 1 | 78% | SASK | 0 | 0 | 100% | TONG | 0 | 0 | 100% | YELL | 0 | 0 | 100% |
| PADO | 0 | 0 | 99% | SASS | 0 | 0 | 98% | TORP | 0 | 0 | 100% | YIBL | 4 | 8 | 96% |
| PALM | 0 | 0 | 100% | SC04 | 0 | 0 | 100% | TOW2 | 0 | 0 | 100% | YKRO | 0 | 0 | 100% |
| PALV | 0 | 0 | 100% | SCH2 | 0 | 0 | 99% | TRO1 | 1 | 45 | 100% | YONS | 0 | 1 | 95% |
| PBR2 | 2 | 3 | 39% | SCRZ | 1 | 1 | 76% | TSK2 | 2 | 1 | 99% | ZAMB | 0 | 0 | 42% |
| PBRI | 2 | 3 | 39% | SEJN | 0 | 0 | 64% | TSKB | 1 | 1 | 97% | ZECK | 0 | 0 | 100% |
| PDEL | 0 | 0 | 98% | SEY1 | 0 | 0 | 92% | TTTA | 8 | 9 | 94% | ZIM2 | 0 | 0 | 99% |
| PDME | 8 | 10 | 98% | SEYG | 0 | 0 | 99% | TUBI | 1 | 1 | 98% | ZIMJ | 0 | 0 | 100% |
| PEBO | 7 | 15.25 | 61% | SFDM | 0 | 0 | 100% | TUKT | 0.5 | 13 | 71% | ZIMM | 0 | 0 | 100% |
| PERT | 0 | 0 | 100% | SFER | 0 | 0 | 96% | TUVA | 0 | 32 | 100% | ZWE2 | 0 | 0 | 100% |

## GLO Latency

The motivation for and description of the GLO table are identical to the GPS Latency table. Recall that gray or white median and IQR cells have a latency ≤ 1 day. Yellow cells: ≤ 7 days. Red cells > 7 days. Here, again, the point is that most of the table is without yellow or red shading. The overall median latency is 0 days with an IQR of 0 days with a reliability of 84%. Excellent again! The BRDC latency is 1 days with an IQR of 0 days

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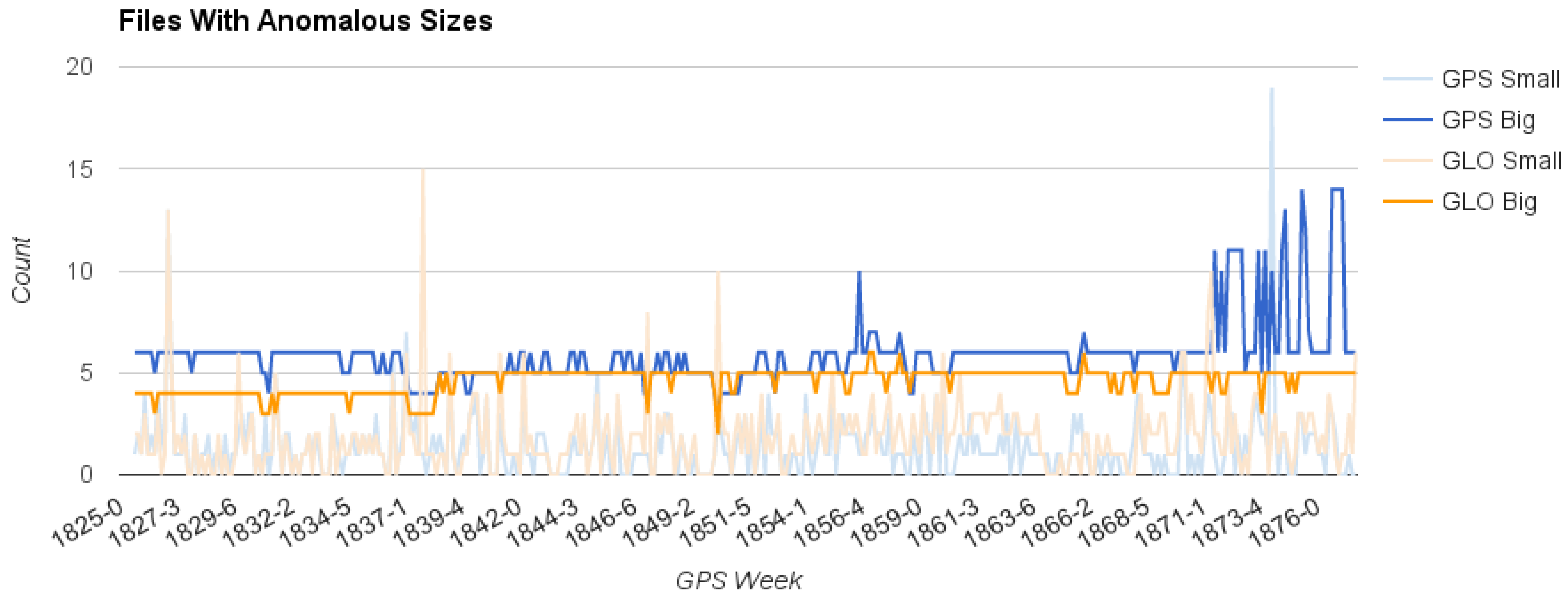
| | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI | | MEDIAN | IQR | RELI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADIS | 0 | 0 | 92% | DARW | 0 | 0 | 98% | JFNG | 0 | 0 | 100% | NIUM | 0 | 0 | 100% | SEY1 | 0 | 0 | 92% | WHIT | 0 | 0 | 100% |
| AIRA | 2 | 1 | 99% | DAV1 | 0 | 0 | 100% | JOZ2 | 0 | 0 | 99% | NKLG | 0 | 0 | 100% | SEYG | 0 | 0 | 99% | WIDC | 0 | 0 | 100% |
| ALBH | 0 | 0 | 29% | DGAV | 0 | 0 | 77% | JPLM | 0 | 0 | 99% | NMEA | 8 | 11 | 99% | SFER | 0 | 0 | 96% | WILL | 0 | 0 | 100% |
| ALG2 | 0 | 0 | 56% | DJIG | 1 | 5 | 46% | KARR | 0 | 0 | 79% | NNOR | 0 | 0 | 99% | SNI1 | 0 | 0 | 12% | WLSN | 0 | 1 | 12% |
| ALG3 | 0 | 0 | 98% | DRA3 | 0 | 18 | 97% | KAT1 | 0 | 0 | 97% | NOVM | 0 | 0 | 100% | SOFI | 0 | 0 | 99% | WROC | 0 | 0 | 99% |
| ALGO | 0 | 0 | 100% | DRA4 | 0 | 18 | 97% | KAT2 | 0 | 0 | 79% | NRC1 | 0 | 0 | 100% | SOLO | 19.5 | 32.5 | 18% | WTZR | 0 | 0 | 100% |
| ALIC | 0 | 0 | 100% | DRAO | 0 | 0 | 100% | KERG | 0 | 0 | 100% | NRMD | 10 | 9 | 74% | SPK1 | 0 | 0 | 12% | WTZZ | 0 | 0 | 97% |
| ANKR | 0 | 0 | 100% | DUBO | 0 | 0 | 98% | KHAR | 0 | 0 | 84% | NTUS | 0 | 0 | 26% | SPT0 | 0 | 1 | 99% | WUHN | 0 | 0 | 43% |
| AREG | 0 | 0 | 100% | DYNG | 0 | 0 | 99% | KIR0 | 0 | 0 | 99% | OHI2 | 0 | 0 | 100% | STHL | 0 | 0 | 98% | XMIS | 0 | 0 | 100% |
| AREV | 0 | 0 | 99% | EUR2 | 0 | 0 | 99% | KIR8 | 1 | 1.5 | 6% | OHI3 | 0 | 0 | 99% | STJ2 | 0 | 0 | 100% | YAR2 | 0 | 75 | 85% |
| ASCG | 1 | 1 | 28% | FAIV | 0 | 0 | 100% | KIRI | 0 | 14.25 | 98% | ONS1 | 1 | 1.5 | 6% | STJO | 0 | 0 | 100% | YAR3 | 0 | 0 | 100% |
| ASPA | 0 | 3 | 96% | FFMJ | 0 | 0 | 100% | KIRU | 0 | 0 | 100% | ONSA | 0 | 1 | 87% | STK2 | 2 | 1 | 99% | YATE | 8 | 11 | 95% |
| BADG | 0 | 0 | 99% | FLIN | 0 | 0 | 100% | KOKV | 0 | 0 | 100% | ORID | 0 | 0 | 100% | STR1 | 0 | 0 | 100% | YCBA | 0 | 0 | 95% |
| BAKE | 0 | 0 | 99% | FLRS | 0 | 0 | 99% | KOUC | 8 | 10 | 98% | OWNG | 0 | 1 | 78% | STR2 | 0 | 0 | 100% | YEL2 | 0 | 5 | 42% |
| BARH | 0 | 0 | 92% | FRDN | 0 | 0 | 97% | KOUG | 0 | 0 | 100% | PADO | 0 | 0 | 98% | SULP | 0 | 0 | 100% | YEL3 | 0 | 15.25 | 100% |
| BJCO | 0 | 1 | 95% | FTNA | 0 | 0 | 94% | KOUR | 0 | 0 | 100% | PALV | 0 | 0 | 100% | SUTV | 0 | 0 | 95% | YELL | 0 | 0 | 100% |
| BJFS | 1 | 2 | 94% | FUNC | 0 | 0 | 96% | KRGG | 0 | 0 | 97% | PBR2 | 2 | 3 | 39% | SUWN | 1 | 1 | 80% | YONS | 0 | 1 | 95% |
| BJNM | 0 | 14.75 | 33% | GANP | 0 | 0 | 99% | KUUJ | 0 | 0 | 100% | PBRI | 2 | 3 | 39% | SVTL | 0 | 0 | 98% | ZECK | 0 | 0 | 100% |
| BLCL | 0 | 10 | 78% | GLPS | 0 | 4 | 36% | LAUT | 14.5 | 6.25 | 2% | PDEL | 0 | 0 | 98% | SYOG | 2 | 2 | 99% | ZIM2 | 0 | 0 | 99% |
| BOGI | 0 | 0 | 98% | GLSV | 0 | 0 | 99% | LCAP | 8 | 10 | 93% | PDME | 8 | 10 | 98% | TABL | 0 | 0 | 100% | ZIMJ | 0 | 0 | 100% |
| BOGT | 8 | 16.5 | 10% | GMSD | 0 | 0 | 94% | LCK3 | 2 | 3 | 39% | PEBO | 7 | 15.25 | 61% | TABV | 0 | 0 | 97% | | | | |
| BRMU | 0 | 0 | 99% | GODN | 0 | 0 | 70% | LCK4 | 2 | 3 | 39% | PERT | 0 | 0 | 100% | TANA | 0 | 0 | 24% | | | | |
| BSHM | 0 | 0 | 100% | GODS | 0 | 0 | 70% | LEIJ | 0 | 0 | 100% | PGEN | 3 | 5 | 10% | THIO | 8 | 10 | 93% | | | | |
| BUCU | 0 | 0 | 99% | GODZ | 0 | 0 | 98% | LFOA | 8 | 10 | 95% | PIE1 | 0 | 0 | 99% | THTG | 0 | 0 | 100% | | | | |
| BZRG | 0 | 0 | 99% | GOLD | 0 | 0 | 100% | LHAZ | 0 | 0 | 99% | PIMO | 0 | 0 | 95% | THTI | 0 | 0 | 100% | | | | |
| CALL | 0 | 0 | 75% | GOPE | 0 | 0 | 99% | LPAL | 0 | 0 | 100% | PMBT | 8 | 10.75 | 98% | TID1 | 0 | 0 | 100% | | | | |
| CAS1 | 0 | 0 | 100% | GORO | 8 | 10 | 98% | LPIL | 8 | 10 | 95% | PNGM | 0 | 0 | 50% | TIT2 | 0 | 0 | 100% | | | | |
| CCJ2 | 2 | 1 | 99% | GRAS | 0 | 0 | 100% | MAC1 | 0 | 0 | 100% | POHN | 0 | 0 | 100% | TITG | 5 | 8 | 5% | | | | |
| CEBR | 0 | 0 | 100% | GRNB | 0 | 77 | 100% | MADR | 0 | 0 | 100% | POLV | 0 | 1 | 100% | TITZ | 0 | 0 | 44% | | | | |
| CEDU | 0 | 0 | 100% | GUAM | 0 | 0 | 99% | MAJU | 0 | 0 | 50% | POUM | 8 | 11 | 98% | TLSE | 0 | 0 | 99% | | | | |
| CGGN | 0 | 5 | 51% | GUUG | 0 | 0 | 99% | MAL2 | 0 | 0 | 97% | PPPC | 0.5 | 4.25 | 13% | TLSG | 0 | 3 | 43% | | | | |
| CHIL | 0 | 0 | 68% | HARB | 0 | 0 | 96% | MAR6 | 0 | 0 | 99% | PRD2 | 0 | 15 | 100% | TONG | 0 | 0 | 100% | | | | |
| CHPG | 0 | 0 | 100% | HERS | 0 | 0 | 100% | MAR7 | 1 | 1.5 | 6% | PRD3 | 0 | 15 | 100% | TORP | 0 | 0 | 12% | | | | |
| CHPI | 0 | 0 | 89% | HERT | 0 | 0 | 99% | MAS1 | 0 | 0 | 100% | PRDS | 0 | 0 | 100% | TOW2 | 0 | 0 | 100% | | | | |
| CHU2 | 0 | 15 | 100% | HGHN | 8 | 10 | 91% | MATE | 0 | 0 | 100% | PTAG | 0 | 1 | 36% | TSK2 | 2 | 1 | 99% | | | | |
| CHUR | 0 | 0 | 100% | HKSL | 3 | 3.5 | 5% | MAW1 | 0 | 0 | 100% | PTGG | 0 | 1 | 75% | TTTA | 8 | 9 | 94% | | | | |
| CIT1 | 0 | 0 | 99% | HKWS | 3 | 3.5 | 5% | MAYG | 0 | 0 | 99% | RCMN | 1 | 0 | 72% | TUVA | 0 | 32 | 100% | | | | |
| CKIS | 0 | 0 | 100% | HLFX | 0 | 0 | 100% | MBAR | 0 | 4.25 | 50% | RDSD | 90.5 | 180.5 | 100% | UACO | 8 | 10 | 98% | | | | |
| CLAR | 0 | 0 | 68% | HLOU | 8 | 11 | 96% | MCHL | 11 | 98.5 | 99% | REDU | 0 | 0 | 100% | UCLP | 0 | 0 | 1% | | | | |
| CMP9 | 0 | 0 | 13% | HNPT | 0 | 0 | 100% | MDVJ | 0 | 0 | 100% | REYK | 0 | 0 | 100% | UNB3 | 0 | 0 | 99% | | | | |
| CNMR | 0 | 0 | 89% | HOB2 | 0 | 0 | 100% | MELI | 0 | 0 | 73% | RGDG | 0 | 0 | 100% | UNBJ | 0 | 0 | 100% | | | | |
| COCO | 0 | 0 | 100% | HOFN | 0 | 0 | 99% | METG | 0 | 0 | 100% | RIGA | 0 | 0 | 100% | URUS | 0 | 0 | 93% | | | | |
| CONZ | 0 | 0 | 26% | HOLB | 0 | 0 | 100% | MGUE | 0 | 0 | 100% | ROAP | 0 | 0 | 72% | UZHL | 0 | 0 | 99% | | | | |
| CORD | 0 | 0 | 98% | HOLP | 0 | 0 | 68% | MKEA | 0 | 0 | 73% | ROCK | 0 | 0 | 12% | VALD | 0 | 0 | 100% | | | | |
| CPVG | 0 | 1 | 74% | HRAO | 0 | 0 | 100% | MOBS | 0 | 0 | 100% | ROTH | 29 | 120 | 100% | VILL | 0 | 0 | 97% | | | | |
| CRAR | 0 | 0 | 94% | HUEG | 0 | 0 | 100% | MOIU | 0 | 0 | 67% | SASK | 0 | 0 | 100% | VIS0 | 0 | 0 | 99% | | | | |
| CRFP | 0 | 0 | 98% | IQAL | 0 | 0 | 100% | MTKA | 2 | 1 | 79% | SASS | 0 | 0 | 98% | VNDP | 0 | 0 | 3% | | | | |
| CUSV | 13.5 | 7.5 | 4% | IQUI | 0 | 5 | 95% | NANO | 0 | 0 | 100% | SCH2 | 0 | 0 | 99% | WARN | 0 | 0 | 98% | | | | |
| DAEJ | 0 | 0 | 99% | IRKJ | 0 | 0 | 97% | NAUR | 0 | 2 | 89% | SCRZ | 1 | 1 | 76% | WES2 | 0 | 0 | 53% | | | | |
| DAKR | 1 | 3 | 97% | ISBA | 0 | 0 | 65% | NICO | 0 | 0 | 100% | SEJN | 0 | 0 | 64% | WHC1 | 0 | 0 | 8% | | | | |

## File Sizes

The plot to the right shows the by-day counts of files considered too big and too small: GPS in blue; GLO in orange. Files greater than twice the median size were considered too big; less than one-half the median file size were considered too small. This range is about 10× the IQR for both GPS and GLO. Because there are many potential issues outside a site's or the data center's control that could truncate files, the "too small" counts have been de-emphasized, but are still shown for completeness.

Five GPS sites have provided files for almost the entire year that are "too big"; four GLO sites have done so. Both the GPS and GLO files from one of these sites are "too big"; the other three GLO sites also contribute GPS files, but their GPS files were not flagged as being "too big". Spot checking a few of these files suggests the cause to be duplicate messages. Seven different receiver types from three different manufacturers were used to create these persistently "too big" files.

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