

# GNSS Positioning Performance Monitor

## *Getting Started Guide*

[GNSSPerformanceMonitor.com](http://GNSSPerformanceMonitor.com)

### **Background**

This website was an EECS Senior Design / Capstone project at Ohio University during the 2018-2019 Fall/Spring semesters.

The project started with background research in multi-constellation receiver technologies and key ideas in order to accomplish the following objectives:

- Develop a system to simultaneously collect and plot position data from each of the four major satellite navigation constellations (GPS, GLONASS, Galileo, BeiDou) individually.
- Develop a website to display the positioning performance of the constellations.

The ultimate goal of the project was to monitor the 4 major GNSS constellations (GPS, GLONASS, Galileo, and BeiDou) on an ongoing basis and display their typical performance in Athens, Ohio.

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# Website Features

The project's main features for users are the plots on the website and the ability to download our data.

## Plots

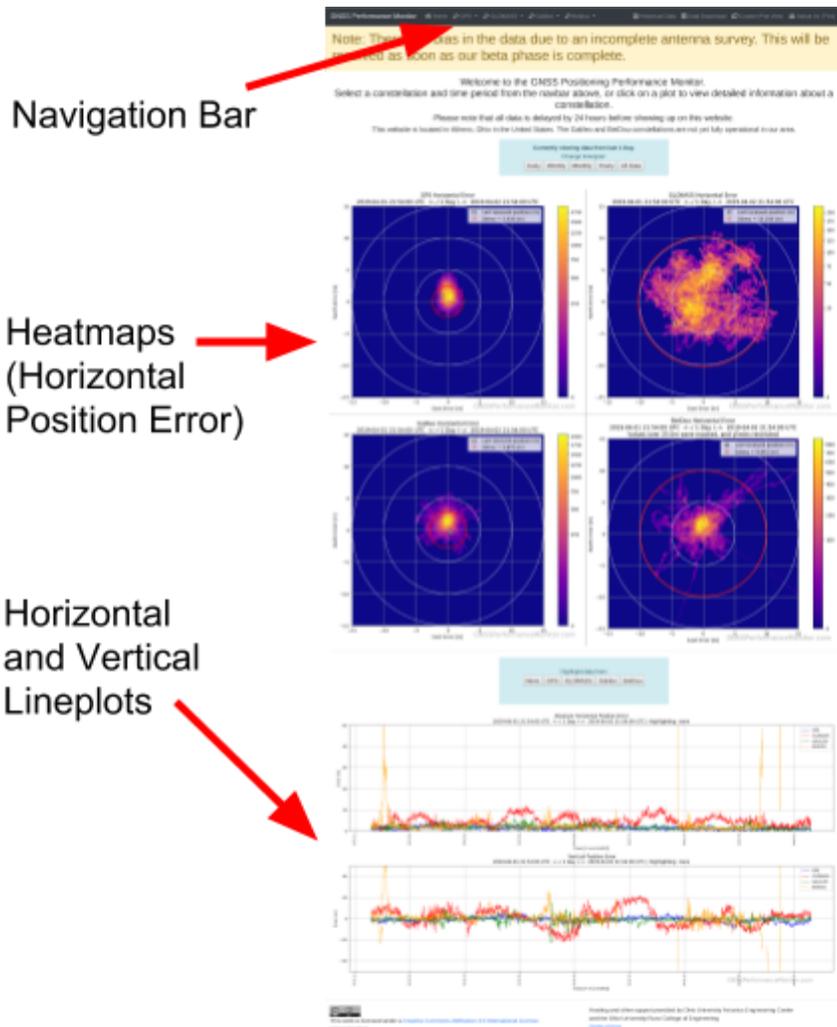
Every day, we generate over 300 plots. These are displayed on various pages including the homepage, the detailed view pages, custom plot pages, and the historical plot pages. Each of these is described below.

### Homepage

There are several different ways to view plots. First, users are presented with four heatmaps and a lineplot on our website's homepage.

The heatmaps show horizontal position error and frequency of error at each bin. For example, lighter areas indicate a position at that position more frequently than at darker areas.

The lineplot at the bottom of the page shows horizontal and vertical error for each constellation. There are buttons to highlight a specific constellation, which can be helpful in some circumstances.

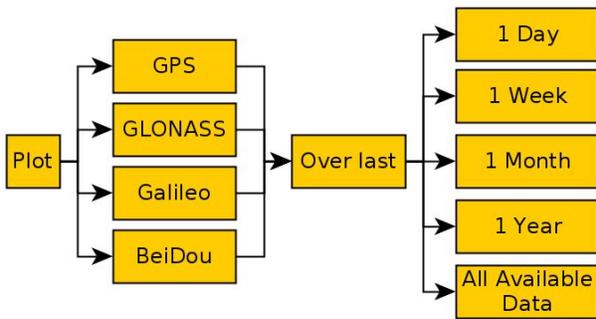


### Detailed View Pages

If a user would like to see more detailed information, they can either click on a heatmap or navigate to a specific constellation and timespan from the navbar above.

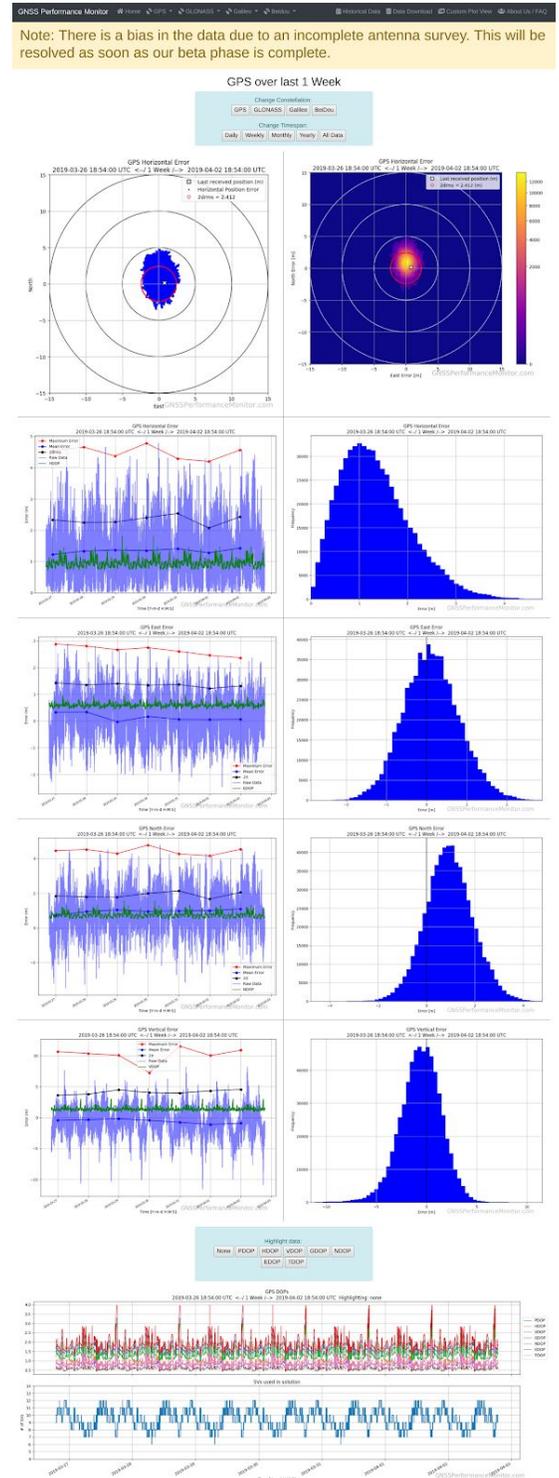
For each constellation, users can see data from these timespans:

- Last 1 Day
- Last 1 Week
- Last 1 Month
- Last 1 Year
- All Available Data



Some timespans have special features -- for example, 1-Day and 1-Week show a 3D Rotating Scatterplot video, whereas the All-available-data plot uses 1 and 24 hr averages instead of raw data.

These Detailed View Pages update regularly -- each timespan has a different update frequency (which varies depending on system load). If an issue occurs on the server and plots stop updating, a warning will appear above any stale plots warning that they have not been updated recently.



### Custom Plot Pages

The pages described above are somewhat inflexible, and sometimes a user may like to compare specific aspects of the four constellations. In this case, they can use our custom plot page creator.

The user can select which plots they want to compare, and with which timespan. If they chose to use 1-Day, they may also select a date to see plots for (using the historical plotter subsystem).

This page can be bookmarked or sent to someone else and it will always show the latest data.

Any plot generated for the website may be added to these custom pages. These include:

- Horizontal Position Error Scatter Plot
- Horizontal Position Error Heatmap Plot (2D Histogram)
- Horizontal Position Error Line Plot
- Horizontal Position Error Histogram
- East Position Error Line Plot
- East Position Error Histogram
- North Position Error Line Plot
- North Position Error Histogram
- Up Position Error Line Plot
- Up Position Error Histogram
- DOPs + Num of SVs used in Solution Lineplot
- Horizontal+Vertical GPS+GLONASS+Galileo+BeiDou Combined Lineplot

### Custom Plot Page Creator

This page will allow you to create a custom view to compare different aspects of each constellation. You can bookmark the resulting page and it will always have the latest plots when you load it.

Select which plots you would like to use for the comparison:

- Horizontal Position Error Scatter Plot [\[example\]](#)
- Horizontal Position Error Heatmap Plot (2D Histogram) [\[example\]](#)
- Horizontal Position Error Line Plot [\[example\]](#)
- Horizontal Position Error Histogram [\[example\]](#)
- East Position Error Line Plot [\[example\]](#)
- East Position Error Histogram [\[example\]](#)
- North Position Error Line Plot [\[example\]](#)
- North Position Error Histogram [\[example\]](#)
- Up Position Error Line Plot [\[example\]](#)
- Up Position Error Histogram [\[example\]](#)
- DOPs + Num of SVs used in Solution Lineplot [\[example\]](#)
- Horizontal+Vertical GPS+GLONASS+Galileo+BeiDou Combined Lineplot [\[example\]](#)

Timespan:

- 1 Day
- 1 Week
- 1 Month
- 1 Year
- All Available Data

Date Selector: (NOTE: This only works with a timespan of 1 Day!)

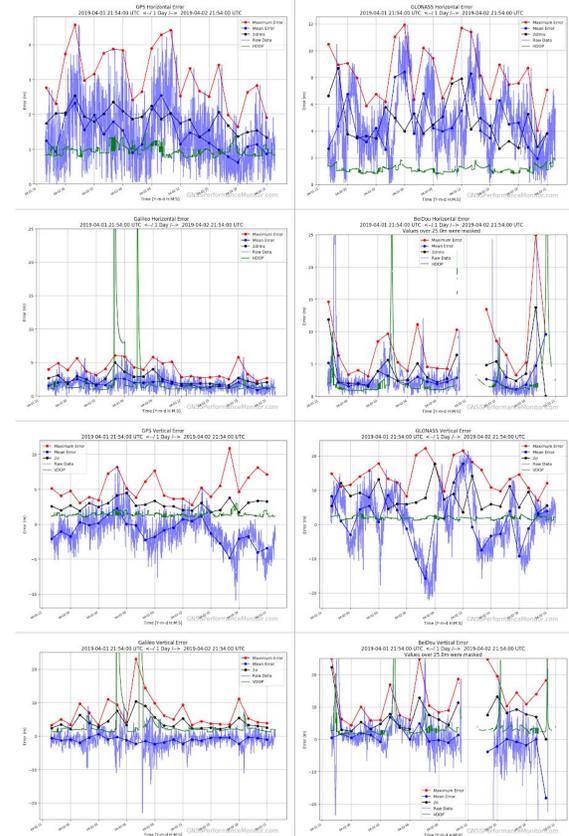
Date:  Format: YYYY-MM-DD

[Create custom plotting page](#)

GNSS Performance Monitor Home GPS GLONASS Galileo BeiDou Historical Data Data Download Custom Plot View About Us FAQ

Note: There is a bias in the data due to an incomplete antenna survey. This will be resolved as soon as our beta phase is complete.

Custom Plot Page - Last 1 Day View



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### *Historical Plots*

Finally, we wanted to let users see historical data and plots. This can be useful if they are interested in how a constellation changed over time (such as when more satellites are launched into orbit), or how performance was affected by a large event (such as a solar flare).

The historical plots are kept forever, and can be permanently linked to. For example, a journal paper could reference a historical plot page for a specific constellation and date, and that page will stay online as long as the website is online.

## Galileo On 2019-04-03

The image shows a web interface for viewing historical data. At the top, the title "Galileo On 2019-04-03" is displayed. Below the title is a light blue panel containing two sections: "Change Constellation:" and "Date Selector:". The "Change Constellation:" section has five buttons: "GPS", "GLONASS", "Galileo", "BeiDou", and "Compare GGGB". The "Date Selector:" section has a text input field containing "2019-04-03" and a "Go to Date" button. Below the input field are four buttons: "First Day of Data", "-1 Day", "+1 Day", and "Yesterday".

## Data

We collect data using four identical GNSS receivers, connected to the same rooftop antenna using a signal splitter. This is a very brief explanation - more information is available on the website on the “About Us” page. **Important: All data is delayed by 24.0 hours before showing up on the website.**

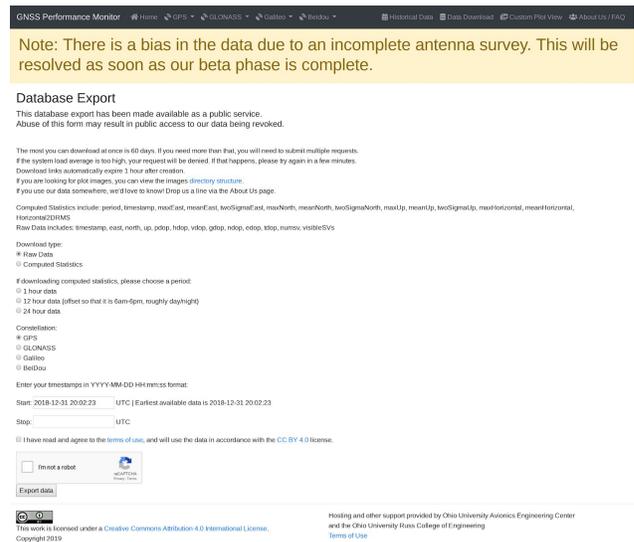


The data collected includes position error in east, north, and vertical directions, as well as Dilution of Precision values which are a numerical value representing precision due to satellite constellation geometry.

We decided early on to make our data available to download. There are very few sources where researchers can access long term performance data about GNSS constellations, and most of them require a great deal of processing and work to be useful. Access to our data is unrestricted with the hope that it spurs more research and work on long term GNSS performance monitoring.

Sometimes, using the raw data is not the best option -- for example, a year of our data would be ~30GB for all 4 constellations. Therefore, it's helpful to precompute some aggregate statistics for standard performance metrics. These include mean, max,  $2 \cdot \sigma$  (~95%), and  $2\text{drms}$  values. These are also available for download.

To export data, you need to pick whether you want raw data or precomputed statistics (and if so, a period), a constellation, and start and stop timestamps. Within a minute or so, you will have a compressed CSV file containing all applicable data.



## FAQ

More questions and answers are available on the website under “About Us / FAQ”.

### Q: Why are some constellations better than others?

**A:** GPS, GLONASS, Galileo, and BeiDou are all similar but have important differences. Each system has satellites in different orbits, use different coding methods for their signals, have different number of satellites, and have other differences.

### Q: What signals do your receivers track?

**A:** We used u-blox NEO-M8N receivers for our project. According to the manufacturer, these are “professional grade”. We do not use any satellite augmentation systems. We track these signals:

- GPS L1 C/A (**No SBAS/WAAS**)
- GLONASS L1OF
- Galileo E1-B/C
- BeiDou B1I

### Q: Why not use a higher quality receiver that has better performance?

**A:** There are two main reasons for this.

- First, we did not have a large budget for our project, so we were essentially limited to a single higher-performance receiver that could potentially do multiple constellations simultaneously, or we could do four lower-grade receivers and dedicate a receiver to each constellation.
- Secondly, the goal of the project was not to show how good GNSS can be under ideal conditions, but rather the typical performance of a widely used, low cost receiver in Athens, Ohio.

### Q: What causes errors in the position calculations?

**A:** Position errors come from a variety of sources. These include tropospheric delay, ionospheric delay, receiver noise, orbit errors, and multipath:

- Tropospheric Delay
  - Changes in temperature, humidity, and air pressure within the layer of the atmosphere closest to the Earth’s crust causes the receiver to receive the signals from the satellites at inconsistent time delays. By using a simple model, approximately 90% of the tropospheric delay can be removed.

- Ionospheric Delay
  - The ionosphere is a layer of the Earth's atmosphere that contains a high concentration of ions and free electrons, and affects radio waves as a function of their frequency. Ionospheric delay is a function of the frequency of the signal, elevation angle, and the total electron content in the ionosphere. Receivers which only receive one signal (i.e. L1) must use simplified mathematical models to reduce this error. Unfortunately, since the total electron content of the ionosphere is very dynamic, these models are not as effective at removing the delay error as the tropospheric model. These delays can cause up to (+/-) 5 meter errors.
- Multipath
  - Multipath errors occur when the signal that is sent from the satellites reflects off another surface before being received by the antenna/receiver. Long delays are handled by the receiver, where as the short delays are handled by the antenna. The best way to mitigate these errors is to mount the antenna in a location with little to no reflective surfaces around.
- Orbit Error
  - Although the orbital paths that satellites travel are very precise, the satellites are able to drift slightly. Ground stations monitor these satellites and are able to send corrections when drifting occurs. However, even with the corrections, orbit errors can affect the positioning performance by roughly (+/-) 2.5 meter errors.
- Receiver Noise
  - These errors are due to the quality of the receiver hardware and processing software. It is expected that high performance GNSS receivers have less of these errors, where as consumer grade receivers (like the u-blox NEO-M8N) will experience more of these errors.