GNSS Orbit Determination
Question and Answer Document
September 8, 2022

Q: Is NGS then the only Federal entity who publishes orbit solutions? Or are there many? If many, is this awareness communicated with collaboration taking place? (if appropriate, of course)
A: No. The broadcast orbits are orbit solutions that are generated by the Department of Defense and “published” by the control segment and transmitted by the satellites themselves. There are several U.S. institutions that also do their own orbit determination using post-processing. These include: the U.S. Naval Observatory, MIT, JPL, and Scripps. Yes, all of these organizations collaborate under the umbrella of the International GNSS Service (IGS).

Q: Could you quantify the magnitude of the effect of the masses of Mars and Jupiter on orbit determinations?
A: The accelerations due to other planets are negligible on GPS satellites, several orders of magnitude smaller than the point mass effects of the sun and moon, which are of order 5e-6 meters per second squared. Other forces associated with solar radiation pressure, Earth tides, and albedo pressure are more important than the point mass accelerations from the planets.

Q: Could you address the issue of how good an orbit needs to be in order to satisfy baseline accuracy requirements? That is, if I observe a project with baselines no greater than 25km can’t I achieve a 2cm accuracy with the Ultra-Rapid orbits?
A: The rule of thumb for baseline solutions is that the ratio of baseline error to baseline length is proportional to the ratio of orbit error to satellite altitude.

Q: How do we not know all of the forces acting on the satellites affecting their orbits? Do we know what we don't know yet or is it a complete mystery?
A: One of the most difficult to quantify of the known forces that act on GNSS satellites is an acceleration known as solar radiation pressure. When photons emitted by the sun (and also those reflected back into space by the Earth) impact GNSS satellites they exert a force on the satellite. The force is a function of the shape and material properties of the satellite and the intensity of the solar radiation. However, because the satellites do not have a simple shape (like a sphere), and since the material properties of the satellites are not made public, this phenomenon is difficult to model in a physically

realistic way. Furthermore, we do not know the magnitude of the solar radiation pressure with high precision, because solar radiation has a random component to it. We therefore have to estimate the accelerations associated with solar radiation pressure. These estimated accelerations are fairly general, and could absorb other unknown forces acting on the satellites, if they exist. But to the best of our knowledge other forces such as atmospheric drag, gravitational attraction of major planets (e.g., Jupiter), or other unknown forces are thought to be negligible relative to solar radiation pressure.

Q: For how orbit errors affect baselines, I refer to this rule-of-thumb proportion in Alfred Leick's "GPS Satellite Surveying" 3rd ed. (section 5.3.5) db/b = ds/s db = relative error in baseline b = baseline length ds = error in base station (or satellite ephemeris) positions = range from satellite to receivers, Will you cover that concept? Particularly how 2.5 cm orbit error doesn't mean 2.5 cm relative error in baseline. Or correct me? Thanks.
A: The true relationship is more accurately db/b = C ds/s , where C is a constant of proportionality, but you can use the Leick equation for order of magnitude.

Q: do we actively use satellites track (follow) another satellite to observe the wandering in the orbit to achieve an tighter fix (heights)
A: GPS signals are commonly used to track satellites in low Earth orbit (LEO). Also, because the half-beamwidth of GPS signals is broad enough, GPS signals may also be used to track spacecraft outside the GPS constellation. The range of altitudes above Earth in which GPS may be used to track spacecraft, 3000 km to 36000 km, is referred to as the Space Service Volume (in contrast to the Terrestrial Service Volume which extends from Earth's surface to 3000 km). GPS satellites are not currently used to track one another.

Q: Is this a Kalman filtering solution to produce the precise orbits?
A: No, we do not use a Kalman filter approach. We collect all the observation and constraint equations and perform a single global least squares adjustment.

Q:On the interference,does ocean loading affect orbit determination? If yes, please kindly share more about it. Which tide types have the greatest impact on the orbits? Thank you. Bruno (From Uganda-Africa)
A: The solid Earth tide affects the positions of the stations in the ground tracking network. In order to solve for the orbits, we have to "fix" or tightly constrain a subset of stations in the ground network. So we have to account for the solid Earth tide when fixing the positions of these stations.

Q: Is the NGS computing orbits for other constellations? If so, will these be productized? If not, what are the best sources for orbit products for other constellations?
A: At present, no, NGS is not computing orbits for GNSS constellations other than GPS. We are working toward being able to compute orbits for at least Glonass and Galileo once our M-PAGE software is ready. If you need precise orbits for other constellations, the IGS MGEX products are a great place to start:
https://cddis.nasa.gov/Data_and_Derived_Products/GNSS/gnss_mgex_products.html

Q: Why are USNO orbits offset from the other Analysis centers? Is it related to their timing activities?
A: Our team reached out to USNO regarding this question and we received the following response: *The USNO IGS Analysis Center acknowledges the bias of USNO contributions in comparison to the IGS combination products and are testing updates to processing to improve our contributions. The bias is not related to any timing activities.*

Q: Will M-PAGES improve the time to determine the orbits?
A: No. Although incorporation of data from an increasing number of GNSS satellites in the processing will increase data volume and thus processing time, we anticipate that the latency of the orbital products will continue to be primarily due to the latency of the relevant ancillary information. For the rapid orbits, we wait until the following day to make sure we can collect a sufficient number of RINEX data from the ground station tracking network. For the final orbits, we wait even longer to make sure we get RINEX data from the core ground tracking network as well as updated Earth-orientation parameters.

Q: What is the status of the CORS sites in Benin?
A: We are awaiting an answer on this, and will get back directly to the questioner.

Q: Is there a relationship between gravity variations and orbit "modelling?
A: The primary force acting on the GPS satellites is Earth's gravity field. At very large distances, Earth's gravity field can be effectively modeled by a point source, as if all of Earth's mass was located at its center. However, closer to Earth the gravity field is more complex in both space and time, due to the complex distribution of density within the solid Earth, and to the changes in the continuous redistribution of fluid masses over Earth's surface over time. Because the gravitational attraction between masses decreases as the inverse squared distance, the effects of complex internal density structure and surface fluid movements (including terrestrial and ocean water/ice, and atmospheric mass movements) are smaller at greater distance from the Earth. GPS satellites orbit at an elevation of ~20,000 km so they are not affected by small scale

variations in the Earth's gravity field. For our orbits, we consider only large scale variations that occur over thousands of kilometers (up to degree and order 12)

Q: Will there be a new and more accurate ellipsoid to replace GRS-80/WGS84?
A: One of the first decisions that NGS made with regard to the modernized NSRS is that it will continue to use GRS-80. Part of the reason for this is that the ellipsoid is a mere convention, and having a "best fit" ellipsoid to the geoid as part of a geodetic reference system is no longer a necessity. The degree 0 terms which reflect the difference between GRS-80 and the geoid are accounted for in the modernized NSRS. As for WGS84, that system is regularly updated by NGA, though they have never updated their ellipsoid shape parameters. We are not aware of any plans by NGA to change the WGS84 ellipsoid.

Q: The near future ephemerides solution could be available 5 minutes ? 1 minute?
A: At present, if your application requires low latency orbits (e.g. 5 minutes or less) the best you will be able to do is either the IGS ultra-rapid predicted orbits or the broadcast orbits.

Q: When will a new realization of the WGS84 will be released compatible with the new ITRF2020??
A: The National Geospatial Intelligence Agency (NGA) is responsible for defining, maintaining and providing access to WGS84. If they have plans for updating it, they have not shared those plans with our group.

Q: on slide 21, you showed the # of satellites for other countries, but how many for the US????
A: 32 active satellites. You can check on the status of the GPS constellation here: https://www.navcen.uscg.gov/gps-constellation

Q: In traditional geodesy we calculated a quantity known as "strength of figure." Is your selection of baselines based on a similar concept? How high a priority is improving coverage in areas without sites?
A: For our orbits, we select the ground tracking network based on the stability of the stations over many years. We then use a simple Delaunay triangulation algorithm to form baselines based on the stations we have selected.

Q: Can you confirm the precision of the rapid orbits are comparable at the several centimeter level with the precise orbits that are available 2 weeks later?

A: Yes, this is true. The rapid orbits have become quite good over the years. Their precision is now comparable with that of the final orbits**.**

Q: What does AC stand for?
A: IGS analysis center.

Q: any issues with RINEX4.0?
A: My understanding is that RINEX v4.0 is quite similar to v3.0. The main difference, as I understand it, is that RINEX v4.0 has expanded fields to hold additional information. Once we modify our software to ingest RINEX v3.4 we should be able to bring in RINEX v4.0 with only minor modifications.

Q: Why does OPUS-S have large east residuals in the Caribbean Region?
A: We will need more information to help you with this specific question. We suggest you contact the OPUS team at ngs.opus@noaa.gov and send them a few of your data files in RINEX format for testing in OPUS-S. Generally speaking, solutions from OPUS-S are based on three baselines that are post-processed from three CORSs to the rover. It's possible that your solutions from OPUS-S are based on one or two CORSs in the region that have larger errors in their published coordinates, but we need more information to truly analyze your situation or give you better advice.

Q: Can you share any documentation that explains the baseline length to satellite orbit ratio? Minimum baseline length constraints are somewhat black box.
A: We will get back directly to the questioner on this one.