BDSD 2021
Bern Data Science Day
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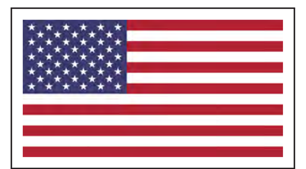
Science with GNSS: a multi-disciplinary challenge

The Satellite Geodesy Team of AIUB
Astronomical Institute, University of Bern, Switzerland

GNSS: Global Navigation Satellite Systems

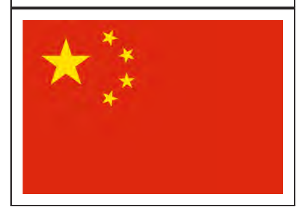
Currently the following GNSS are operational:



USA: GPS
Global Positioning System
Constellation consists of 32 active satellites.

Russia: GLONASS
Global Satellite Navigation System
Constellation consists of 24 satellites.

Europe: Galileo
Constellation consists of 24 active satellites.



P.R. of China: BeiDou
Constellation consists of more than 40 satellites in different orbits.

In addition some regional systems are established as well:

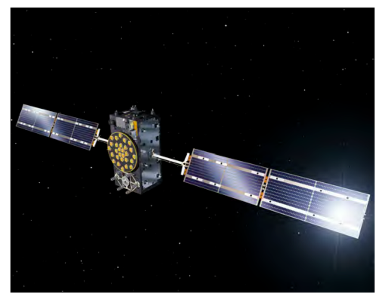
Japan: QZSS
Quasi Zenith Satellite System
Constellation consists of 4 active satellites.

India: NAVIC
Navigation with Indian Constellation
Constellation consists of 7 active satellites.

Overall, there are more than 130 satellites in orbit that support satelite-based navigation. In science the combined processing of as many satellites as possible is beneficial – given that the orbits of the space vehicle can be well modelled.
However, the diversity in properties and orbit characteristics among the different types of satellites creates a scientific challenge for orbit modelling on the centimeter level – field where AIUB takes a leading role.


GPS


GLONASS


Galileo

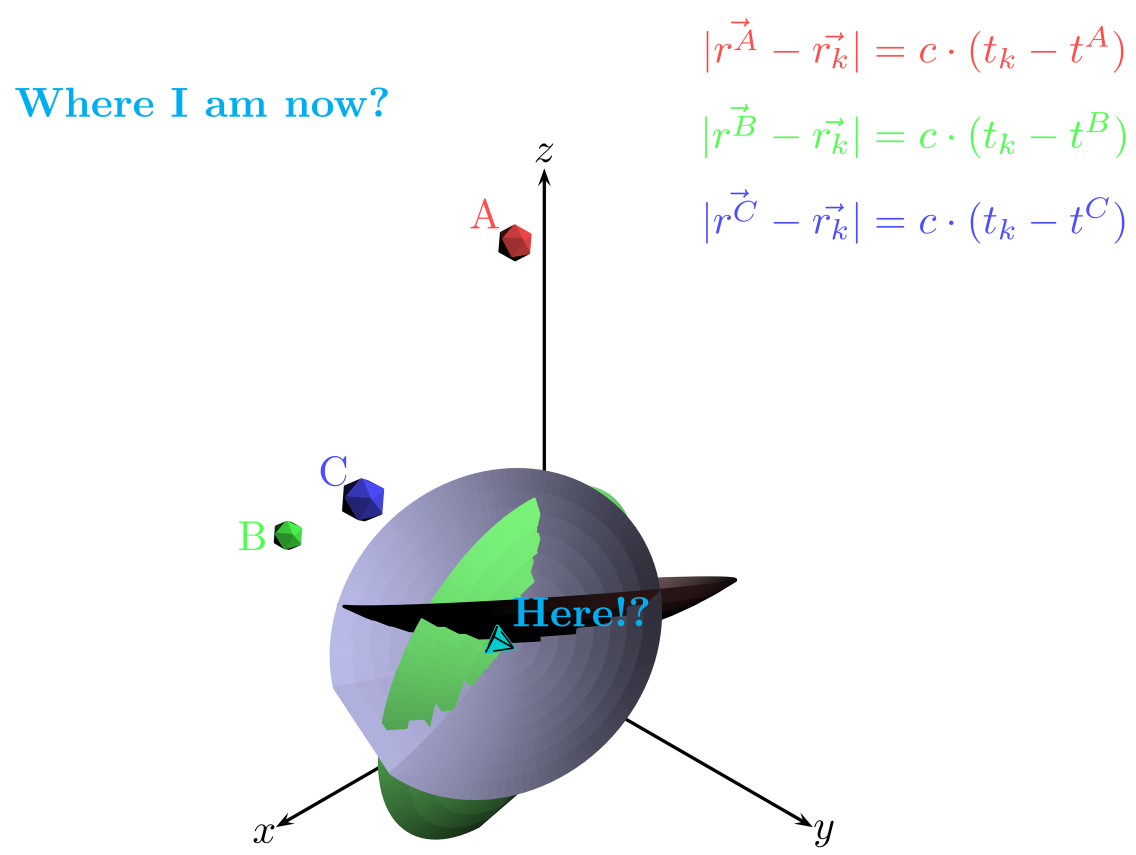

BeiDou


QZSS


NAVIC

How do GNSS work?

GNSS satellites permanently send out microwave signals on at least two frequencies (about 1.5 GHz and 1.2 GHz). The signals contain coded time stamps allowing a receiver to reconstruct the time of transmission at the satellite. With the help of the receiver clock, the signal travel time is obtained. Knowing the speed of light, the distance between satellite and the receiver may then be computed.
For a known satellite position, the receiver is per definition located somewhere on a sphere around the satellite with the radius beeing the distance between satellite and receiver. With several satellites an intersection point of the spheres can be computed with a certain redundancy, which is the position of the receiver:

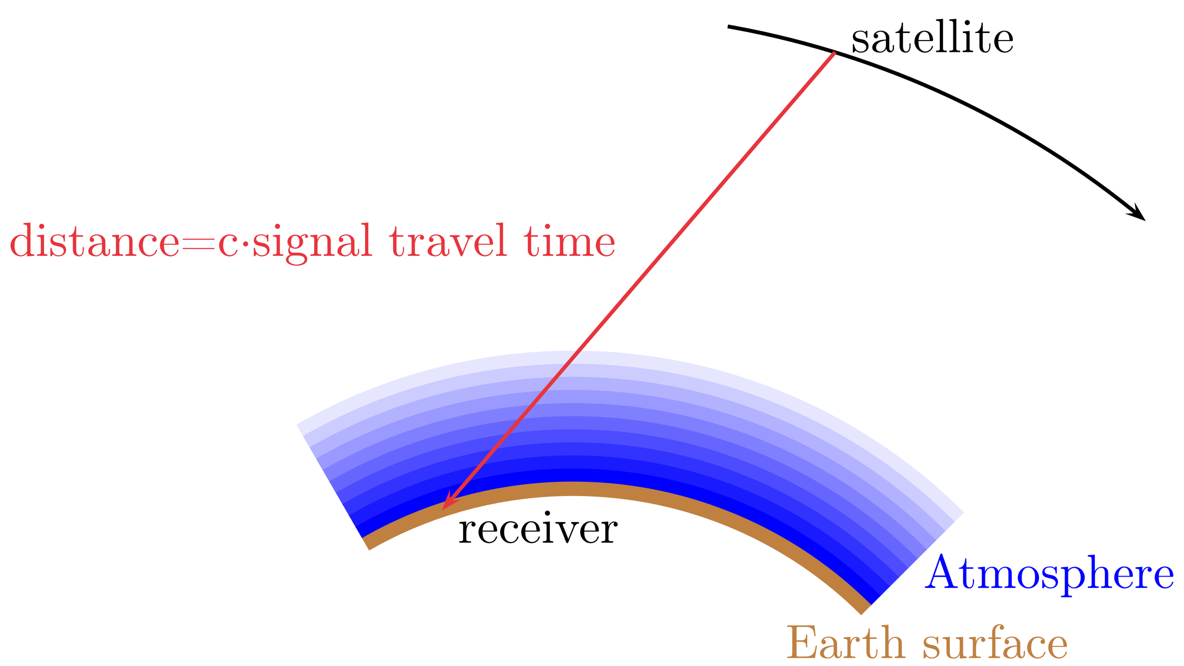


As the distance is measured based on the signal travel time, a clock synchronization between the satellite and receiver clock is necessary. Typically this is done by computing the related clock correction with respect to GPS-system time.

What can we learn from GNSS data?

Coordinates for high-end GNSS receivers may be computed with accuracy of up to the millimeter level, which allows a wide range of applications in science and society:

- monitoring of global crustal movements: plate tectonics; crustal deformation due to loading effects (ocean, atmosphere, ice shields)
- surveilling of local crustal deformations, e.g., glacier movements, volcanic activities, landslides, tide gauges
- cadastral and engineering surveying tasks
- Earthquake monitoring (even for Tsunami Early Warning Systems)
- precise positioning of any object (e.g., even low flying satellites)



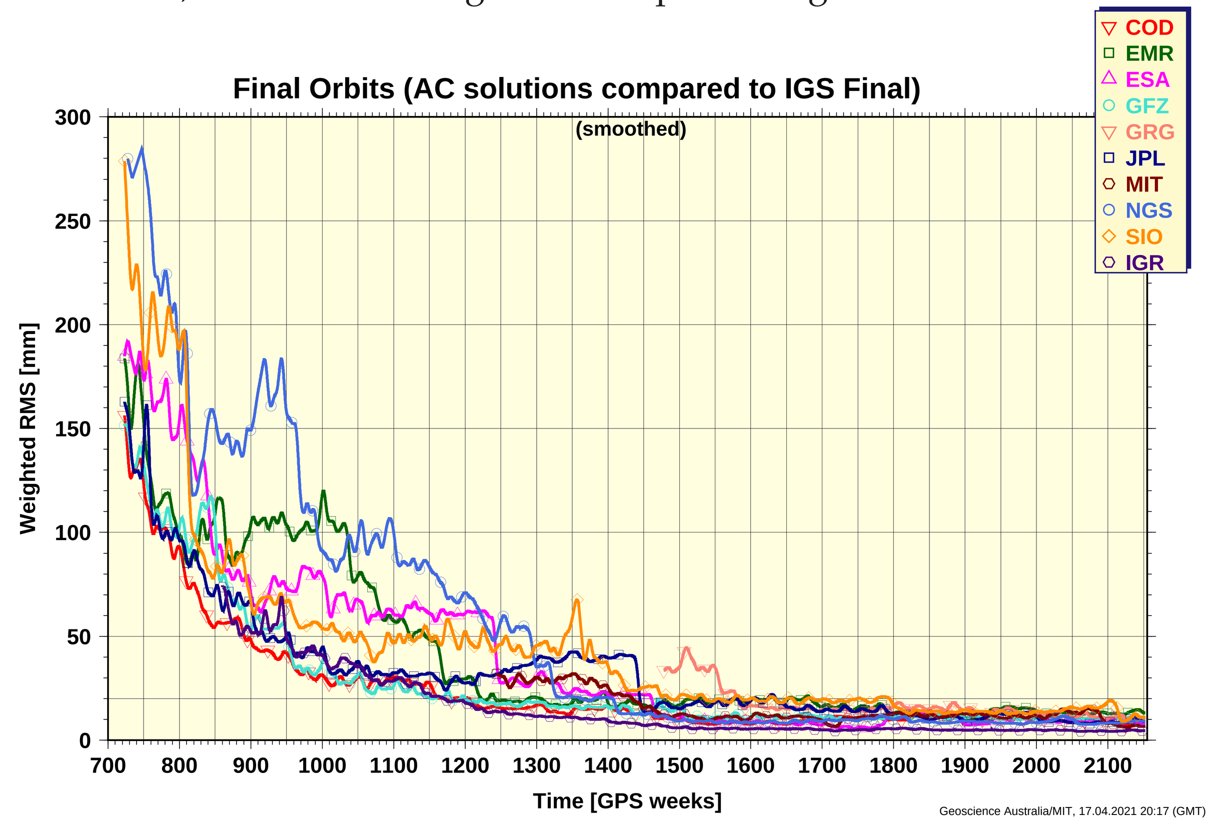
Addional applications make use of all effects acting on GNSS measurements:

- comparison of clocks connected to two receivers over long distances
- troposphere monitoring, even for weather forecast
- ionosphere modelling (Space weather)
- monitoring of the Earth rotation

This list of applications just provides selected examples but is by far not complete.

IGS: International GNSS Service

The IGS is a voluntary federation of over 200 self-funding agencies, universities, and research institutions from more than 100 countries. They contribute to a global network of GNSS tracking stations, various solution series, and with defining the GNSS processing standards and formats.



About 10 analysis centers compute solutions for all relevant GNSS parameters: satellite orbits, Earth rotation parameters, troposphere and ionosphere corrections, station coordinates, and receiver/satellite clock corrections. These results are compared by a so-called analysis center coordinator. The comparison provides a regular feedback to the analysis centers, which inspires a culture of *friendly competition* resulting in a continuous improvement of the products. This may be illustrated by the GPS orbit accuracy, which improved from about 30 cm at the beginning of the IGS activity in 1994 down to below 2 cm nowadays.

The products from the IGS groups are used world-wide to establish numerous GNSS-based applications with different quality and latency requirements.

AIUB contribution to the IGS

The AIUB hosts one of the analysis centers of the IGS (label COD in the above graphic) contributing to several product lines:

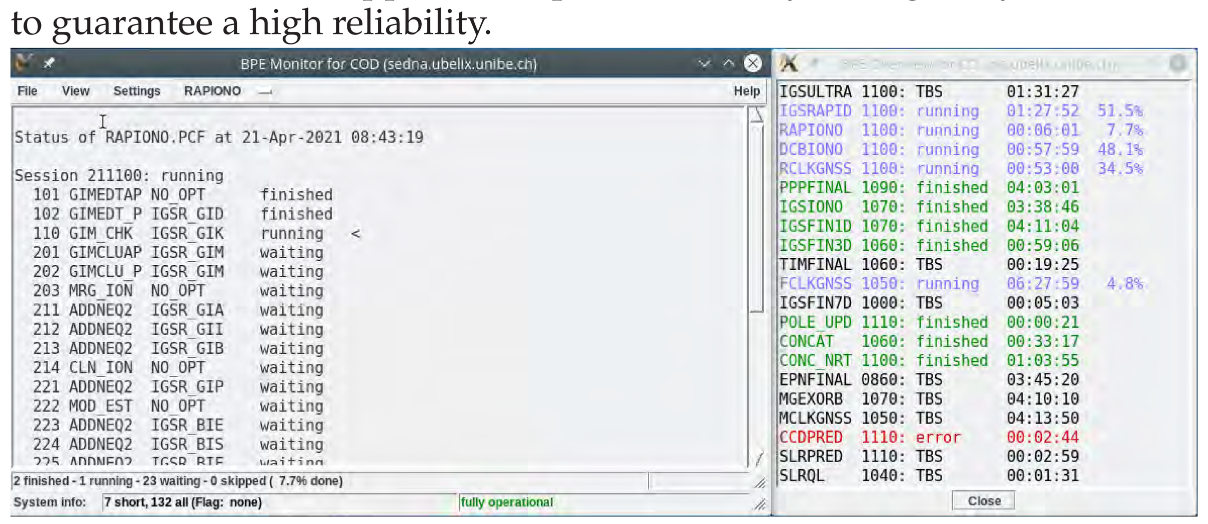
ultra-rapid solution: near real-time solution providing estimated and predicted orbits for real-time and near real-time applications. Eight updates per day are computed within about 2 hours.

rapid solution: high quality solution using the observations from the day before

final solution: high quality solution without restrictions in processing time to generate the best possible and most complete solution

reprocessing solution: a series of final solutions computed back to 1994 using the latest models; to be done from time to time to produce consistent time series of products

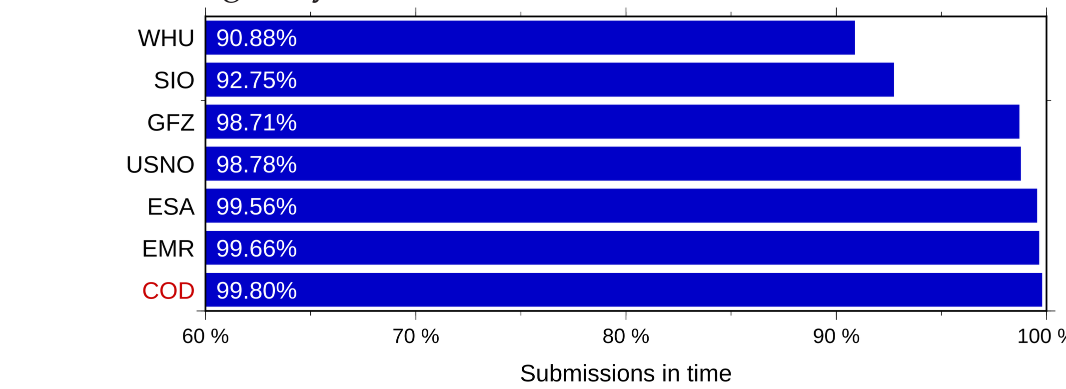
Numerous jobs automatically launched from crontab are computed on UBELIX in order to support these processes. They are regularly monitored to guarantee a high reliability.



Related activities on UBELIX

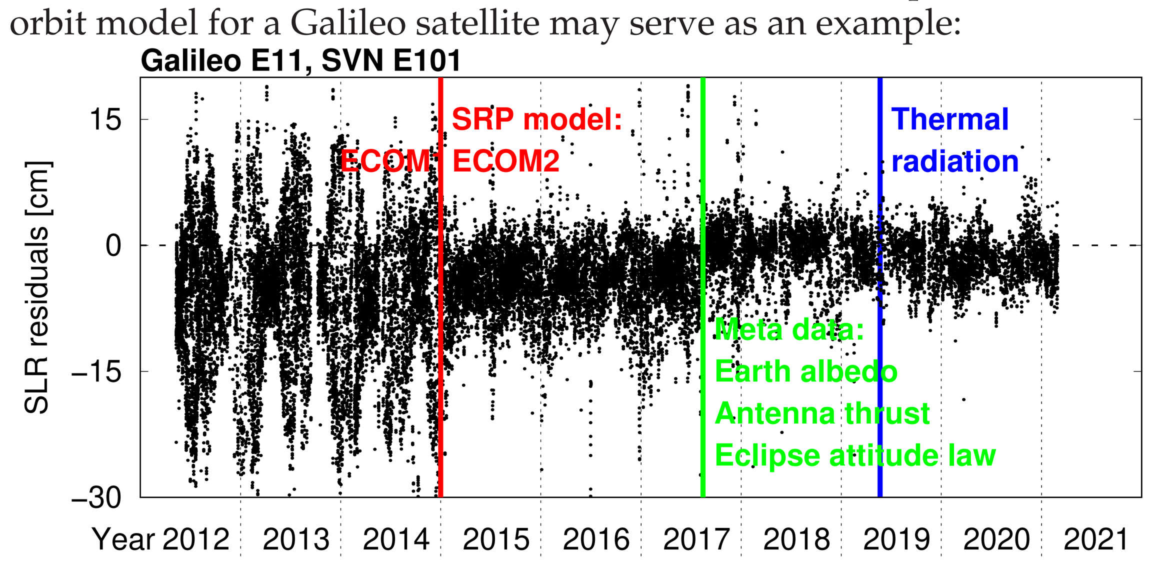
Ultra-rapid solutions

A high reliability of the ultra-rapid solutions is only possible with a high availability of the computer system. Only six out of 2939 submission were missed during the years 2019 and 2020.

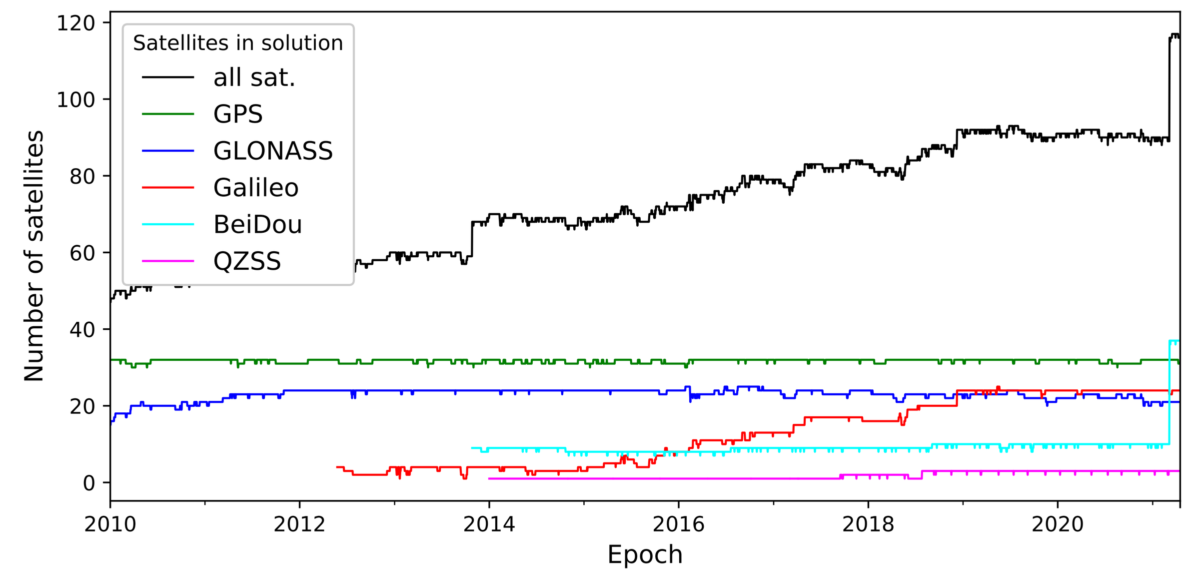


Development of new orbit models

Within the last years significant progress in modelling the forces acting on the GNSS satellites has been achieved at AIUB. The performace of the orbit model for a Galileo satellite may serve as an example:



The launch of new satellite systems bring new satellite types and features. By developing the related orbit models, the AIUB was able to increase the number of satellites considered in our IGS solutions.



Reprocessing solution

One day of a typical final solution as computed by AIUB at the UBELIX inludes the measurements from about 250 tracking stations from up to 120 satellites from different navigation satellite systems. Meaning, from 2 million individual observations about 120,000 parameters are determined with several iterations.
In a reprocessing solution, these numbers from one day have to be scaled to 25 years: 4 TB of observation files have been analyised to obtain 15 TB of result files by using about 300,000 CPU hours.

Acknowledgement

We want take the opportunity to thank the UBELIX team for their exceptional flexibility and high motivation in maintaining the system. We hope to continue the close cooperation in future.

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