GPS and GNSS from the International Geosciences Perspective

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GPS and GNSS from the International Geosciences Perspective

- Geodesy and the International Association of Geodesy (IAG)
- Global Navigation Satellite Systems (GNSS)
- The International GNSS Service (IGS)
- MEO constellations and the 24 vs. 30 satellite configuration
- SLR reflectors on GNSS satellites (SLR)
- Summary

About Geodesy and IAG

Geodesy is based on three pillars

- ***geometry and kinematics of/on Earth and in its environment,***
- ***Earth orientation and rotation*, and**
- ***The Earth's gravity field including its variability***

Geodesy provides the metrological basis for positioning, navigation, surveying&mapping, global change studies.

IAG, the International Association of Geodesy, coordinates International activities related to the above pillars.

The space age brought a revolution in geodesy and led to the creation of four services relevant for GNSS,

- **International Earth Rotation Service (IERS) in 1989**
- **IGS (International GNSS Service) in 1991/1994**
- **ILRS (Intl. Laser Ranging Service) and**
- **IVS (Intl. VLBI Service) around the year 2000.**

About Geodesy and IAG

Global Navigation Satellite Systems (GNSS) play an essential role in geodesy to

- **maintain and densify the International Terrestrial Reference Frame (ITRF, issued by the IERS)**
- **monitoring Earth Rotation**
- **atmosphere monitoring**
- **Precise Orbit Determination (POD) of Low Earth Orbiters (LEOs)**

since 20 years & at least for the next 30 years.

The IGS (International GNSS Service) is acting on behalf of IAG for the exploitation of all available GNSS for highest accuracy applications.

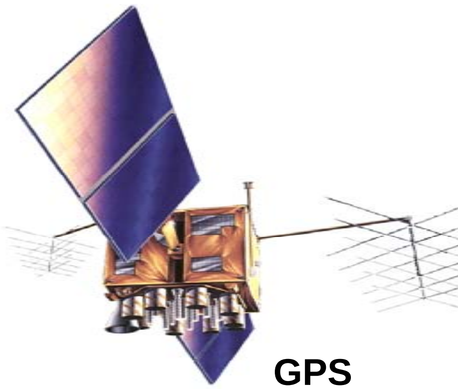
GNSS

GPS: USA , about 30 satellites in 6 planes

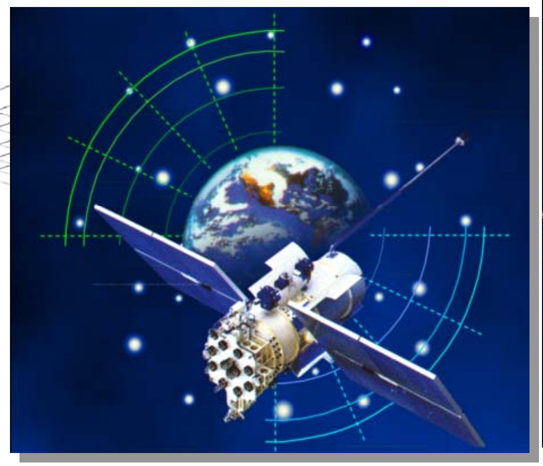
GLONASS: 10-17 satellites in 3 planes

GALILEO: 1 test satellite (GIOVE A) in orbit, eventually 27/30 sats in 3 planes

In addition China is developing a global/regional system COMPASS with 5 geostationary and 30 MEO satellites.



GPS



GLONASS

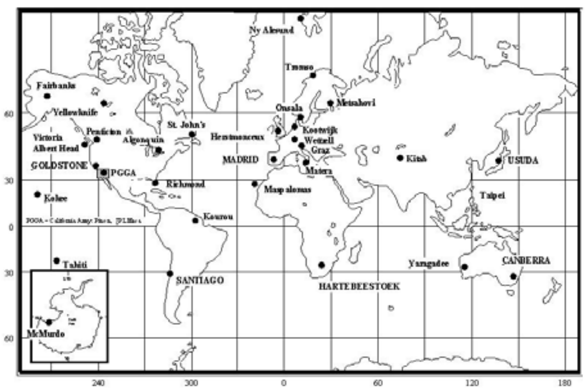
GALILEO

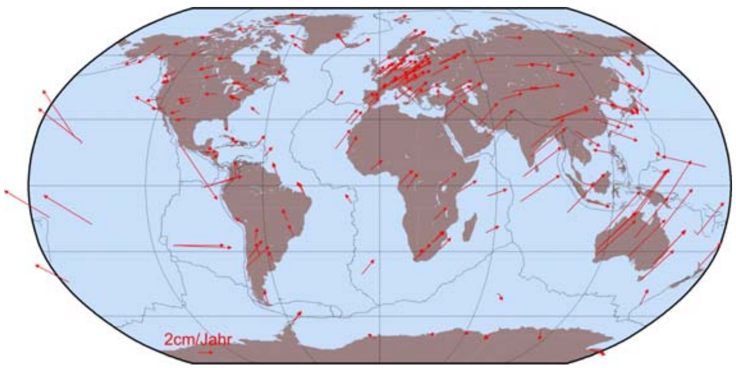
The IGS

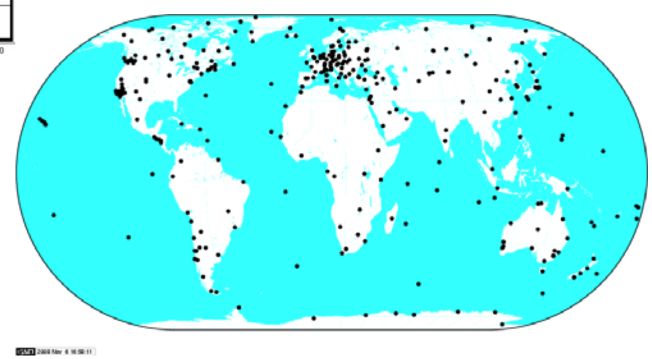
- The creation of the IGS was initiated in 1989 with I.I. Mueller, G. Mader, B. Melbourne, and Ruth Neilan as protagonists
- The IGS became an official IAG service in 1994.
- The IGS first was a pure GPS Service, it was renamed as the International GNSS Service in 2004.
- Today the IGS is a truly interdisciplinary service in support of Earth Sciences and Society committed to use the data from all GNSS.
- Since its creation the IGS Central Bureau is located in the USA with Ruth Neilan as director – who stand for providing continuity and leadership.

The IGS

Station Locations for the IGS Pilot Campaign, 1992







Monitor station motion in „real time“

IGS Network in March 2008

In 1992 the IGS was based on about 20 geodetic receivers, 400+ receivers are active and their data retrievable today

The IGS

In 1992 the IGS started off as an orbit determination service (dm accuracy) for about 20 GPS satellites.

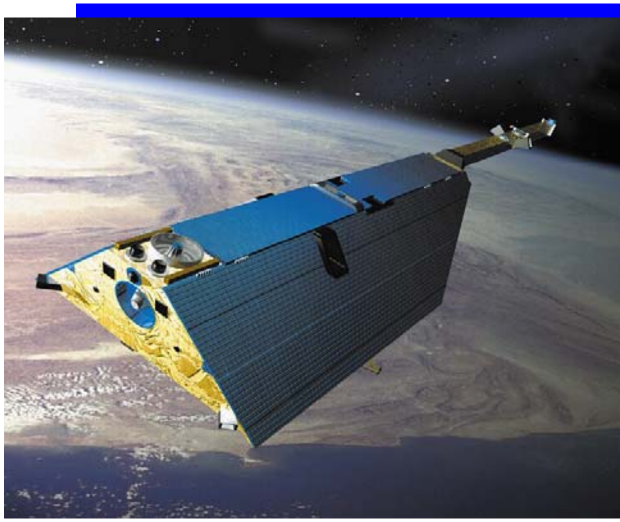
Today, the IGS provides ephemerides (accuracy of 2-4 cm) for about 30 GPS satellites and for all GLONASS satellites, i.e., for all currently active GNSS satellites.

In addition the IGS provides

- archive of all globally relevant GNSS observations since 1991
- satellite and receiver clock corrections (sub-ns accuracy)
- polar motion (PM) and length of day (lod) (cm accuracy)
- coordinates and velocities for 200+ sites (cm / mm/y accuracy)
- atmosphere information

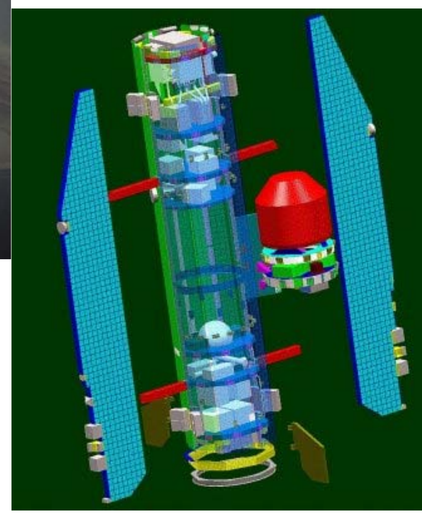
The IGS products are accurate, reliable and robust, available in a timely manner.

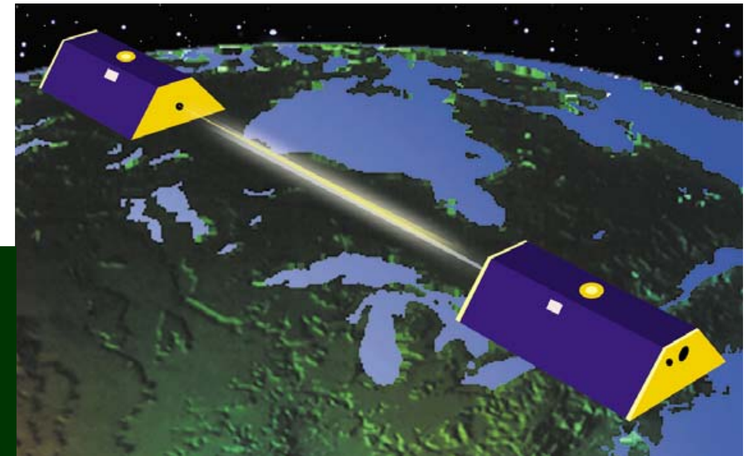
The IGS



CHAMP

GOCE



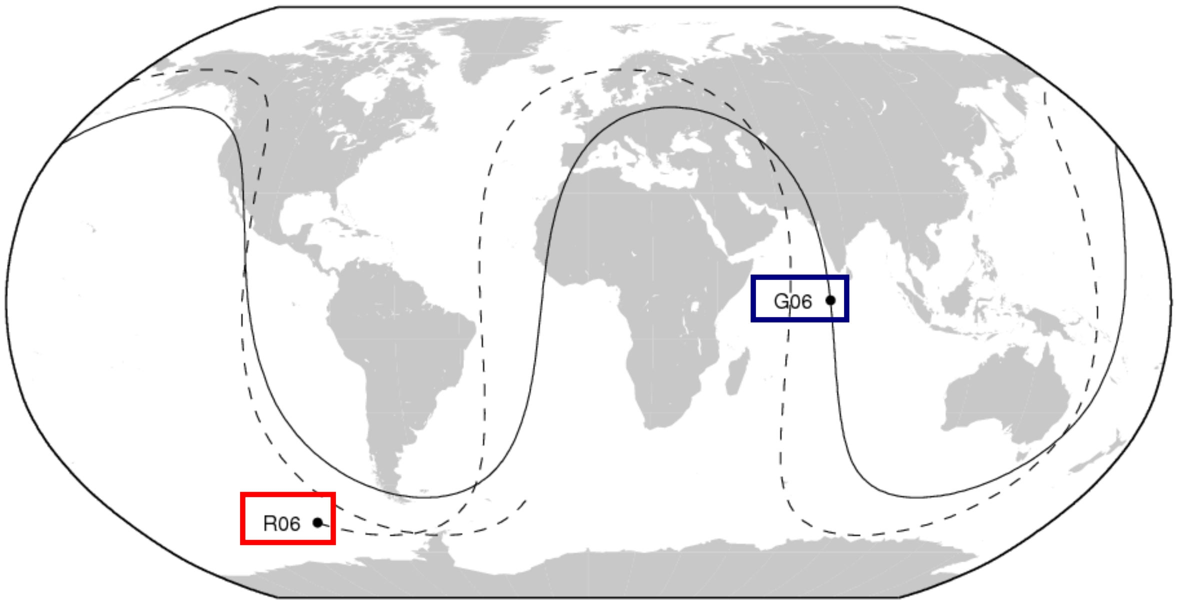


GRACE A and B

GNSS/IGS-derived positions contribute to gravity field estimation!
(lower degree & order harmonics)

The new age of gravity field determination was initiated with the launch of CHAMP in July 2000. GRACE, launched in 2002, explores the use of inter-satellite measurements (1-d-gradiometer) to study the time variability of the gravity field, GOCE will make use (starting 2007) of the 3-d-gradiometer to derive the „best possible“ stationary gravity field.

GNSS Constellations



July 7, 2006: sub-satellite tracks of:

GPS PRN 06, with daily repeat orbit and

GLONASS R06, orbit repeating after 8 days.

The GNSS constellations differ considerably (inclinations, daily vs. 8-day repeat orbits for GPS and GLONASS, respectively)

Different constellations improve the geometry, help to understand systematic errors

GNSS Constellations

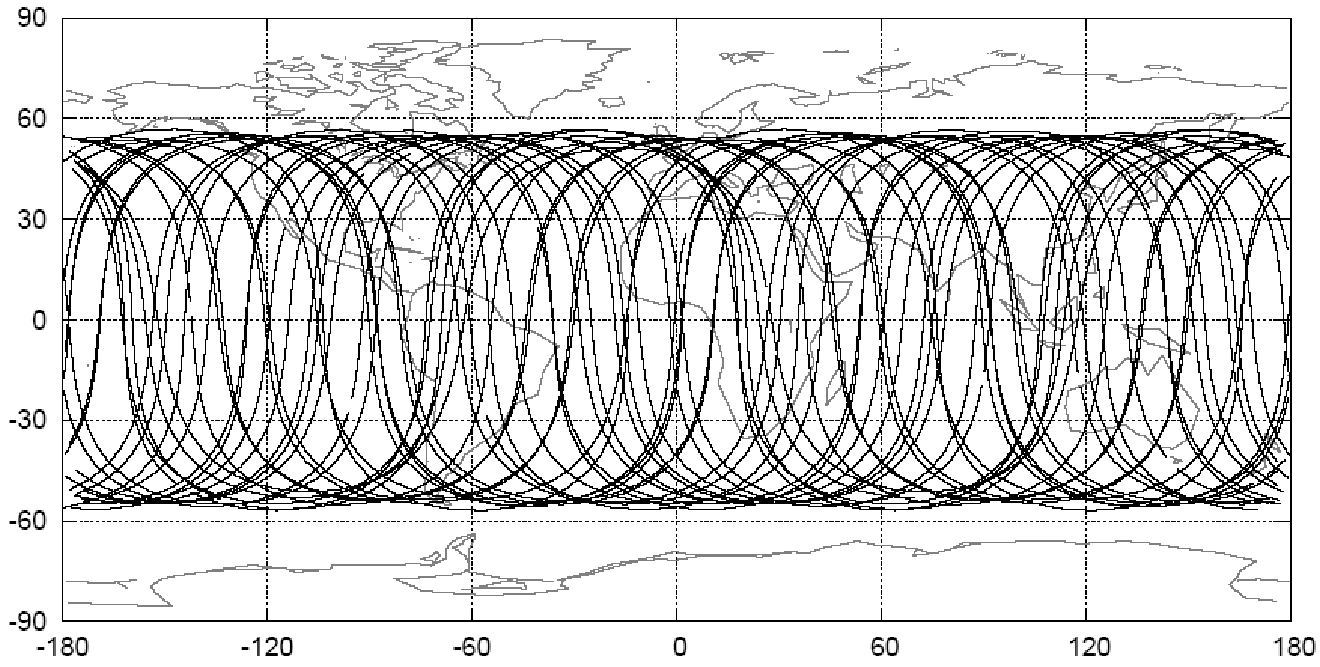
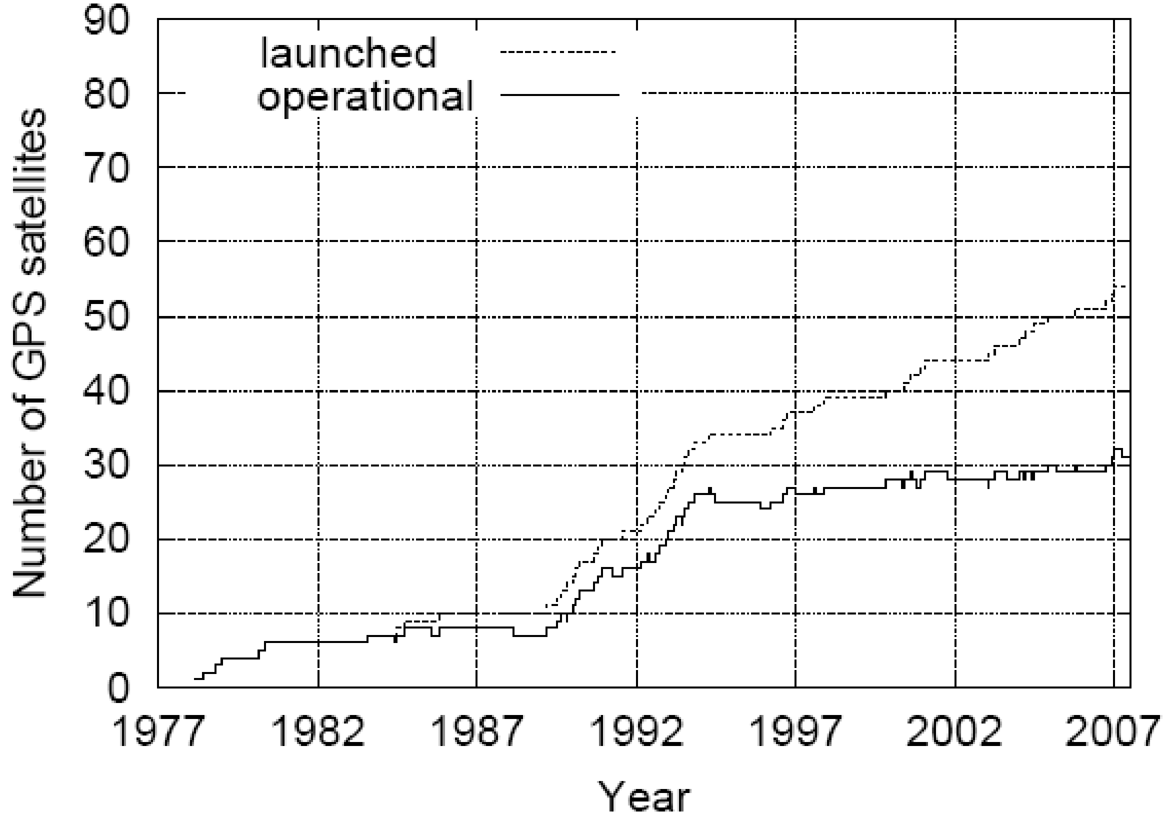


Figure 3.1: Ground-tracks of 30 GPS satellites over two orbital revolutions, for October 28, 2006

Mean observation geometry of a particular satellite, as viewed from a site at a particular latitude ϕ, is longitude-dependent.

GNSS Constellations



Active GPS satellites and launches.

Since the year 2000 there are 30±2 GPS satellites available!

GNSS Constellations

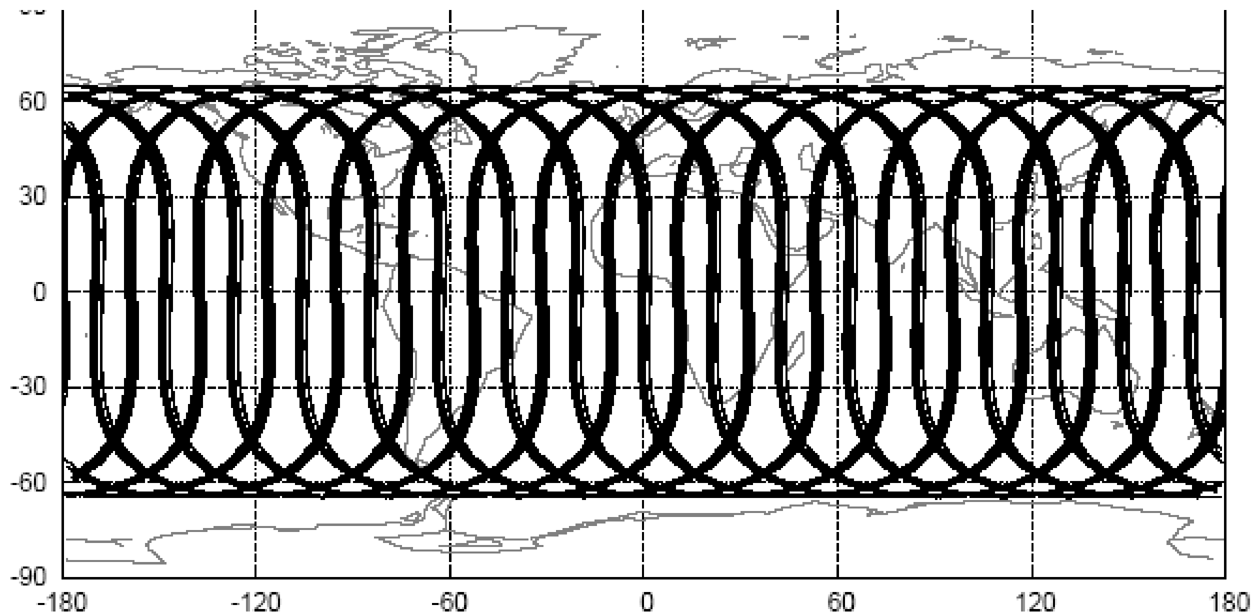
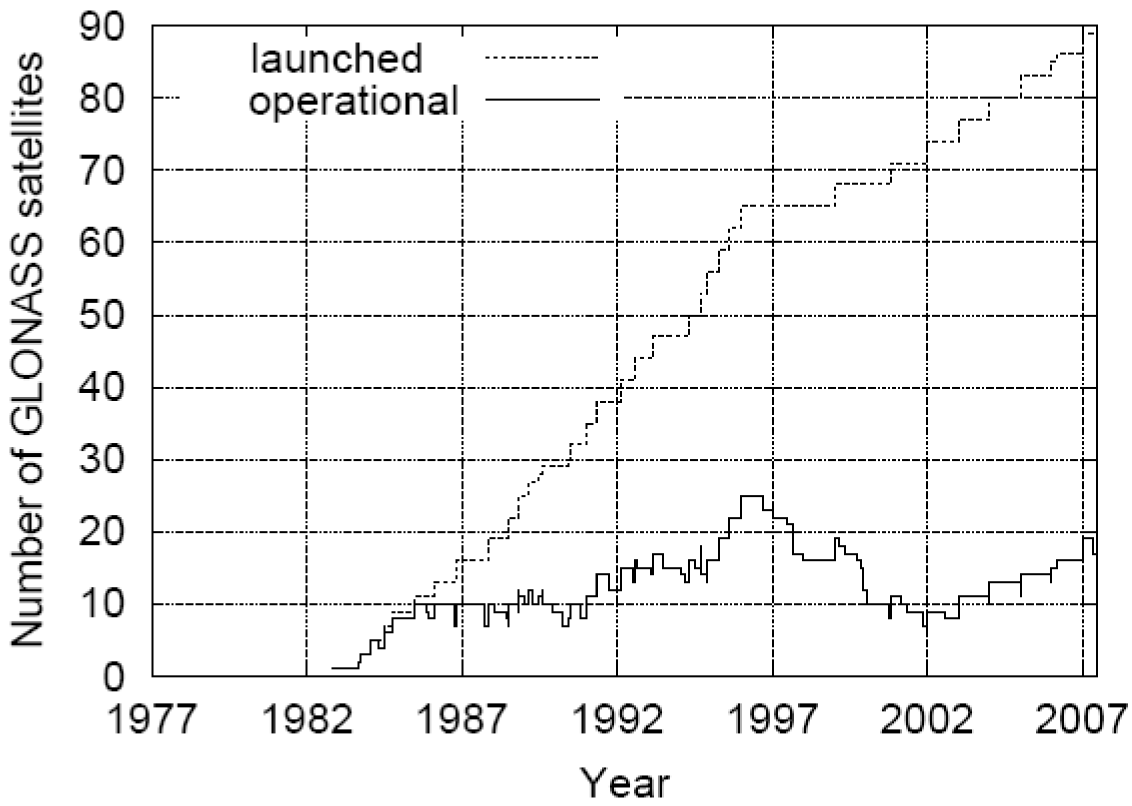


Figure 3.5: Ground-tracks of 12 GLONASS satellites over 17 orbital revolutions, for October 28 - November 4, 2006

Only two (of three) orbital planes filled with satellites in 2006.

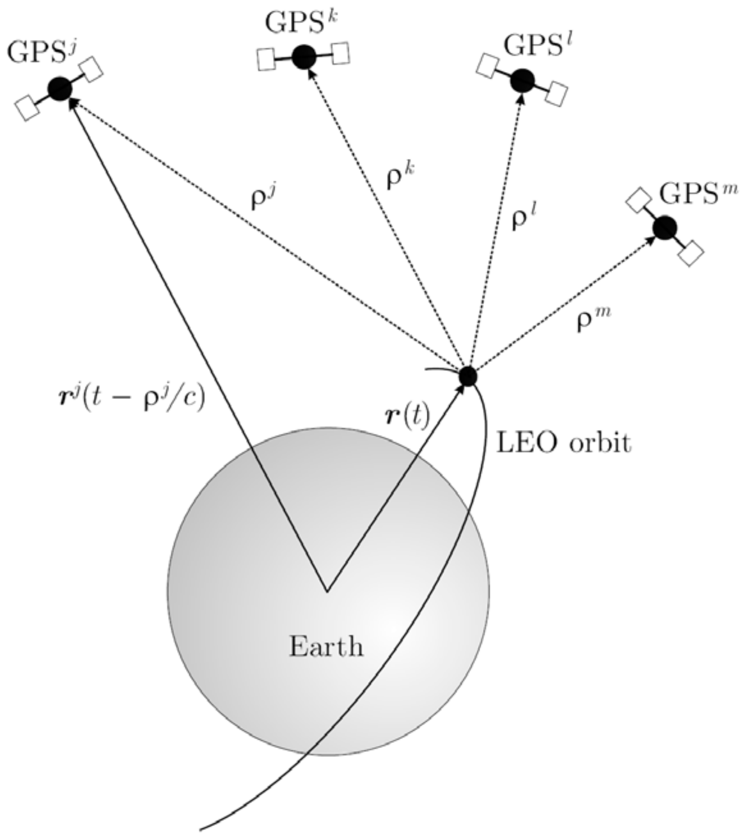
Mean observation geometry of a particular satellite (in the average over 8 (or more) days), as viewed from a site at a particular latitude ϕ, is (almost) longitude-independent.

GNSS Constellations



Active GLONASS satellites and launches

GNSS Constellations



It takes **four** simultaneously visible **GNSS satellites for positioning** ((*x*-,*y*-,*z*-) coordinates of receiver and ist synchronization error Δt w.r.t. system time have to be determined).

No redundancy and **no error control** are possible with only four satellites!

For precise and for security-relevant applications **5+ simultaneously visible satellites are a minimum**.

GNSS Constellations

The number of orbital planes, the number & distribution of satellites in the orbital planes, and the inclination of orbits w.r.t. the equatorial plane are the key entries to calculate the number of satellites simultaneously visible from a particular receiver on / near the surface of the Earth.

The calculated performance difference (number of simultaneously visible satellites at 9x% of time in a latitude band of ±xy degrees) between the actually maintained 30 satellite configuration and the guaranteed 24 satellite constellation is significant and makes GPS look bad in theoretical performance statisitics comparing the different GNSS.

SLR Reflectors on GNSS Satellites

The observed pseudorange of a receiver is given by

$$c\,(t_e - t^s) = \rho + c\,(\Delta t_e - \Delta t^s) + \Delta\rho_i + \Delta\rho_t\ ,$$

where

- **the distance ρ „contains“ the position of the receiver and the orbit of the satellite.**
- **the term $c\,(\Delta t_e - \Delta t^s)$ is used to synchronize clocks.**
- **$\Delta\rho_I$, the signal delay caused by the free electrons in the atmosphere is used for ionosphere modeling or eliminated by forming linear combinations.**
- **$\Delta\rho_t$, the signal delay caused by the troposphere, is used for GPS meteorology (e.g., determination of the total water vapor content in the atmosphere).**

The orbit parameters are determined together with a huge number of other parameters →

Independent accuracy checks are a requirement, not a luxury.

SLR Reflectors on GNSS Satellites

SLR provides the only independent check (in the radial direction) of GNSS orbits – determined with the GNSS signals and carriers.

SLR is important for cross-validation of GNSSs in future.

The payload required to enable SLR tracking is minor (about 10 kg, the SLA on Compass has 2.5 kg), the costs marginal.

SLR tracking to GNSS, internationally coordinated by the ILRS, was successfully performed for

- **GPS (PRN 05 & 06)**
- **All GLONASS satellites**
- **GIOVE-A (GALILEO)**
- **COMPASS-M1 (launched in spring 2007)**

SLR Reflectors on GNSS Satellites

GPS SLR reflector arrays (diameter about 20cm) on PRN 05 and 06. GLONASS SLR arrays have 60 cm diameters.

SLR Reflectors on GNSS Satellites

Size	31.6×28 cm
Diameter of corner cube	33mm
Number	42
Reflective area	360cm^2
Material	fused silica
Weight	2.5 kg

The corner cubes are uncoated both front and back surfaces

The LRA on Compass M1

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SLR Reflectors on GNSS Satellites

In view of the foreseeable decommissioning of the GPS satellites PRN 05 and 06, the ILRS just launched the *"last"* internationally coordinated GPS tracking campaign.

For more information concerning issues related to the SLR tracking of GNSS satellites consult

- The ILRS, International Laser Ranging Service, in particular http://ilrs.gsfc.nasa.gov/
- Dr. Michael Pearlman (from SAO, US), Director of the ILRS Central Bureau.

Summary

The scientific community, organized in IAG, is committed to exploit the full potential of *all* Global Navigation Satellite Systems

- by combining the measurements of all systems in the same analysis
- stemming from combined GPS/GLONASS/GALILEO receivers.

The IGS provides the leadership in the scientific exploitation of the GPS and other GNSS for more than 15 years.

This IGS role should be acknowledged and the US/GPS contribution to the IGS strengthened (PNT Advisory Board recommendations)

The issues of

- SLR on GPS/GNSS satellites
- 30+ GPS constellation

are important considerations for GPS accuracy, assured availability & integrity (PNT Advisory Board recommendations)