From GPS-only to multi-GNSS: getting ready …

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National Space-Based Positioning, Navigation, And Timing (PNT) Advisory Board

Sheraton Crystal City Hotel

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Topics

- GPS, GLONASS, GALILEO: Status June 2011
- IGS = International *GNSS* Service
- Ultra-Precise Clocks in Space
- SLR for the validation of GNSS- and LEO-orbits

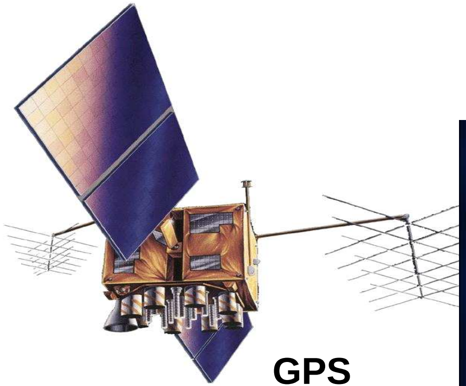
GPS, GLONASS, GALILEO

GPS: USA , 31 satellites in 6 planes
GLONASS: 23 satellites in 3 planes

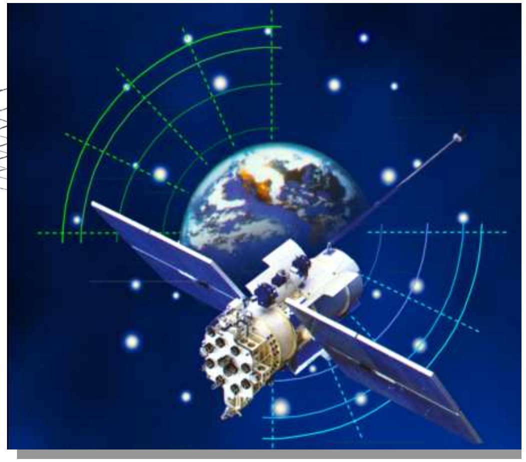
GALILEO: GIOVE-A, -B + 4 IOV-satellites to be launched from 2011 onwards

All GLONASS and GALILEO satellites are equipped with SLR reflectors

Only one GPS Satellite left in orbit with SLR reflectors



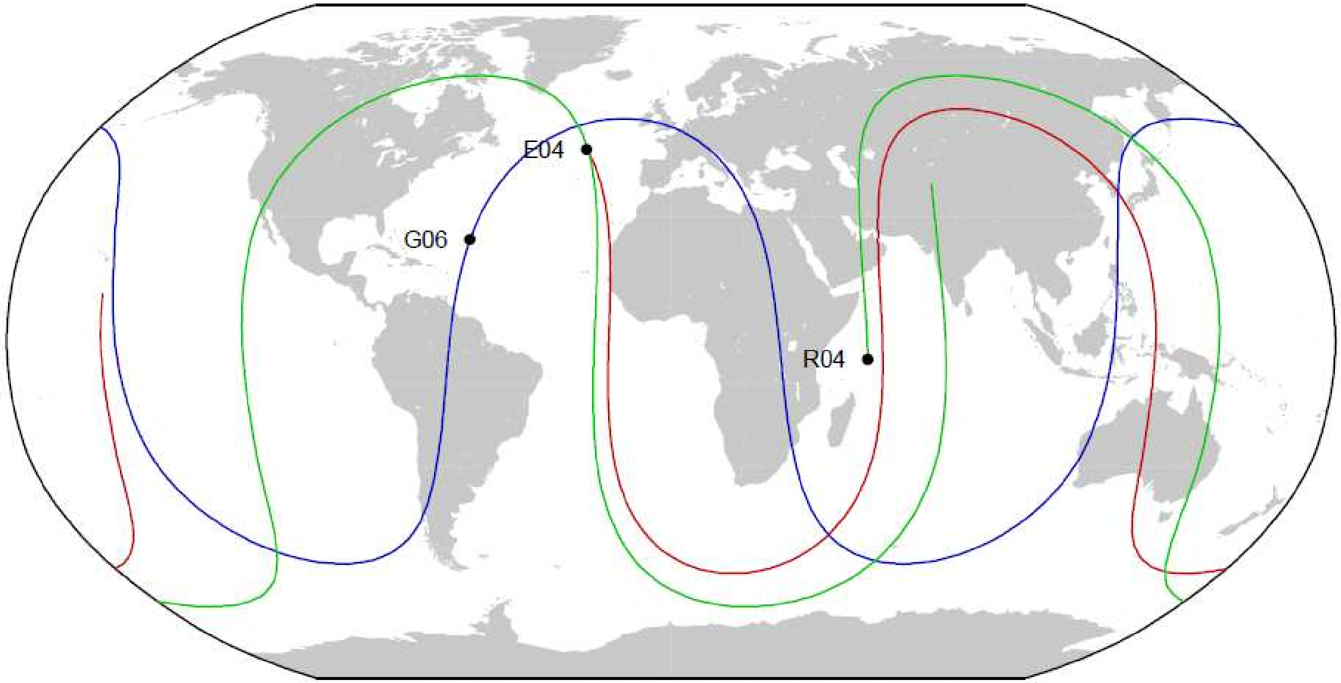
GPS



GLONASS

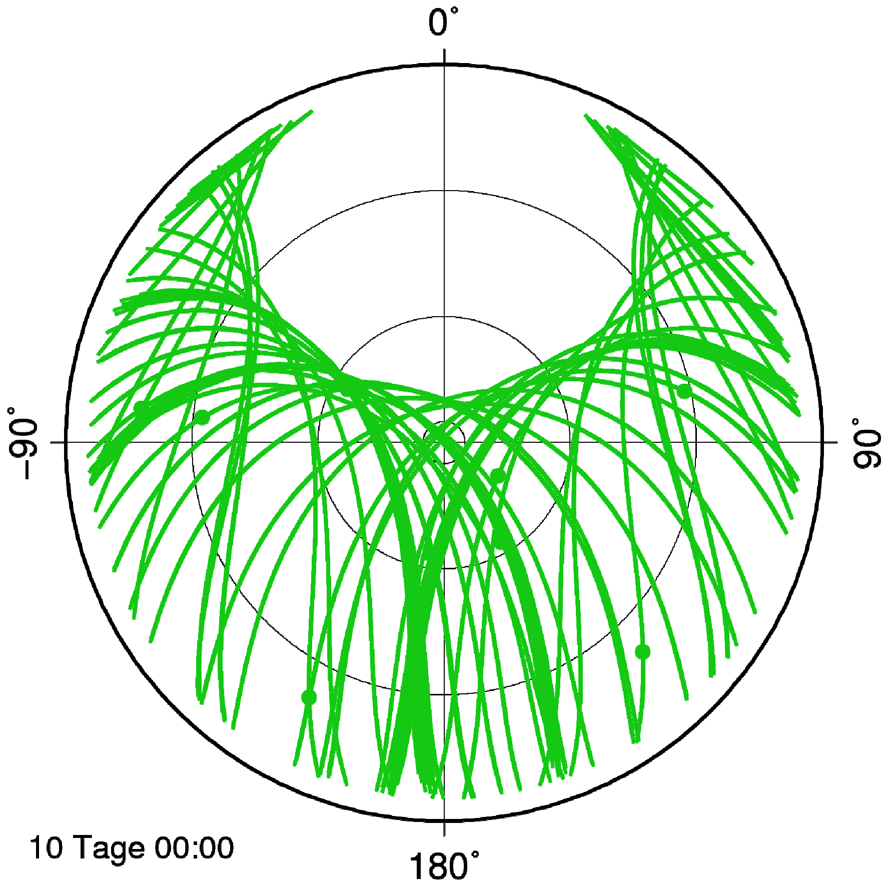
GALILEO

Groundtracks



Groundtracks of GPS, GLONASS and GALILEO over one day

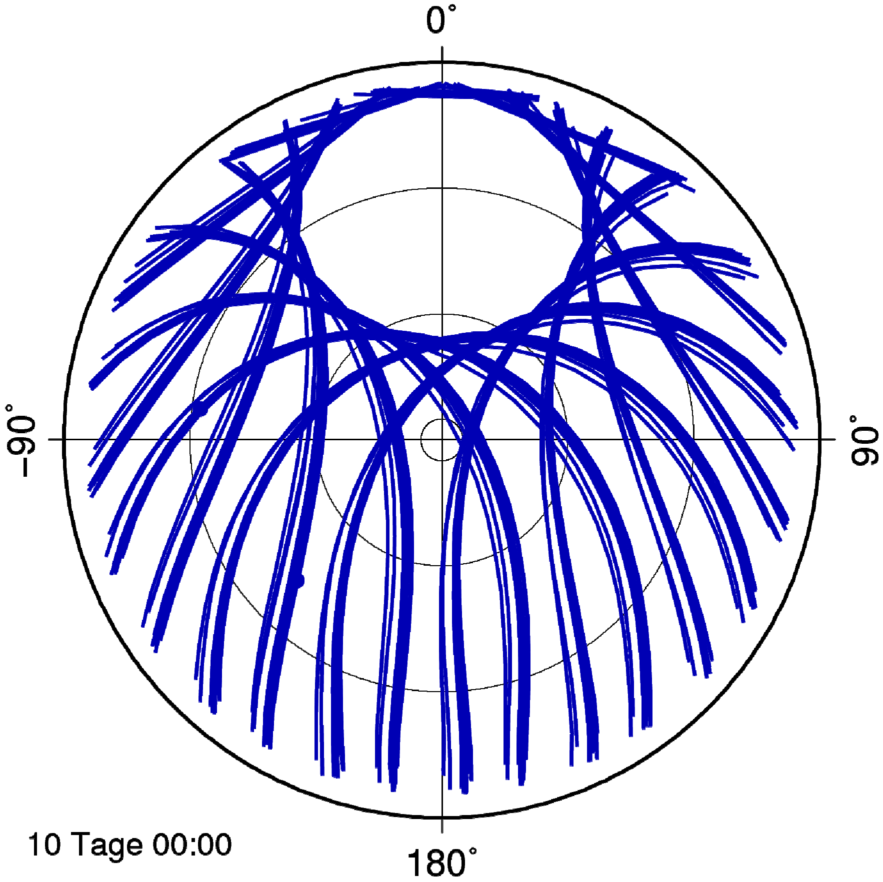
GPS visibility for a particular site



The 31 GPS satellite tracks repeat after one sidereal day (23h56m).

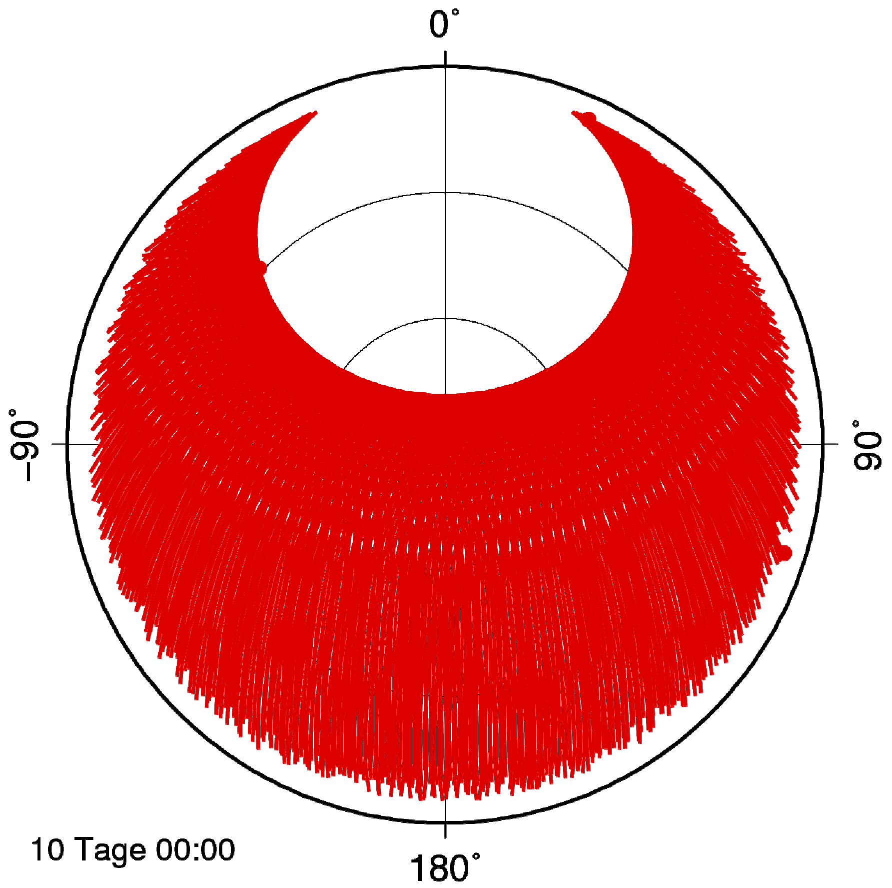
Azimuth-Elevation Plot of the GPS constellation as seen from Zimmer-wald(CH)

GLONASS visibility for a particular site



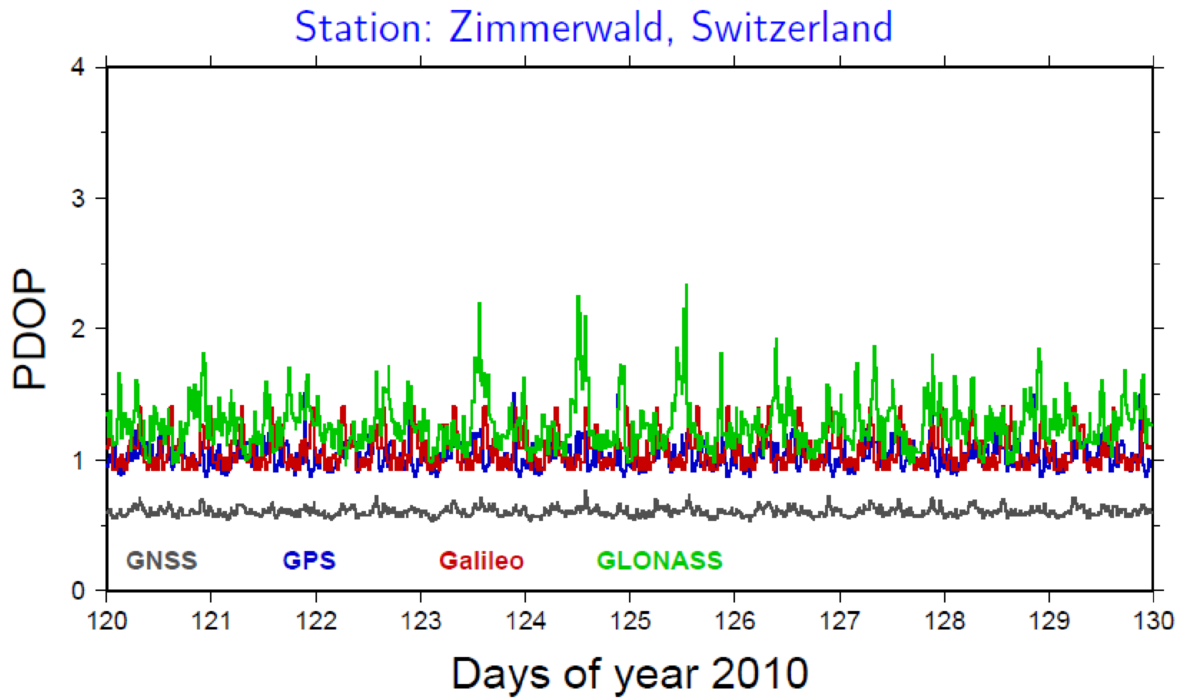
- The 23 GLONASS satellite tracks repeat after 8 sidereal days (17 revolutions).
- Smaller polar gap (compared to GPS, Galileo)
- Azimuth–Elevation Plot of the GLONASS constellation as seen from Zimmerwald(CH)
- Tracks over 10 days

GALILEO visibility for a particular site



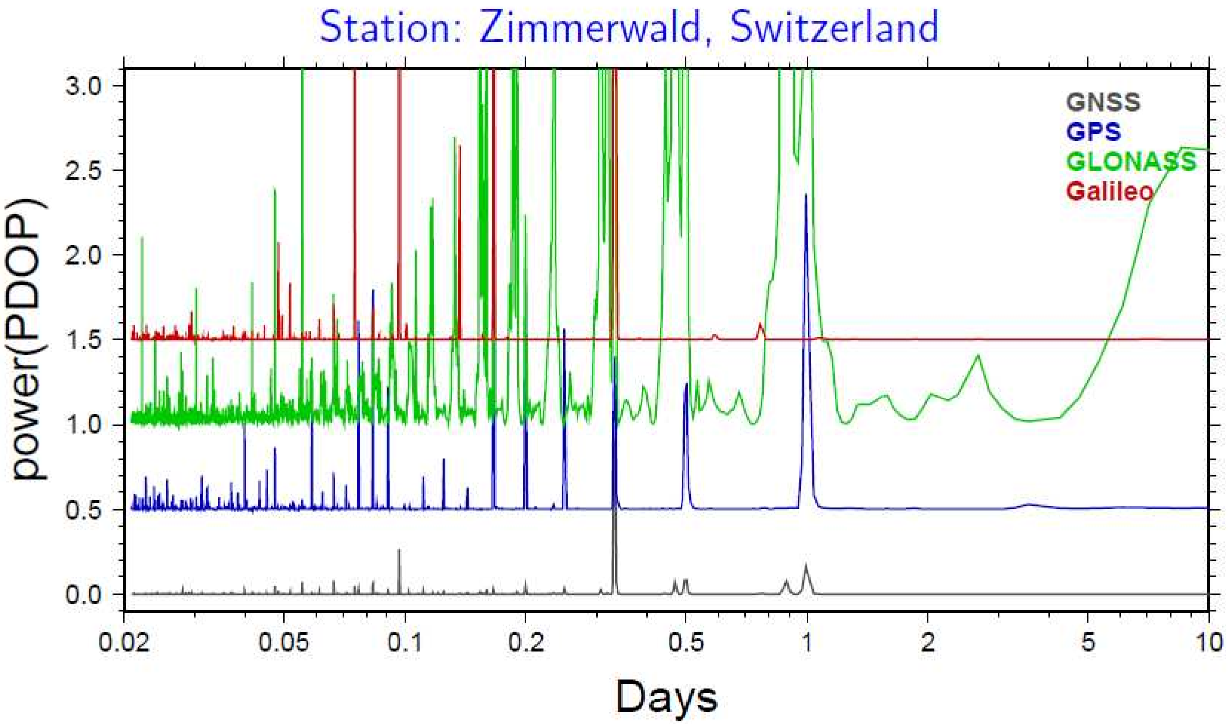
- The 27 Galileo satellite tracks repeat after 10 sidereal days of 23h56m (17 revolutions)
- Azimuth – Elevation Plot of the Galileo constel-lation as seen from Zimmerwald(CH)
- Polar gap approximately the same as that of GPS
- Tracks over 10 days

PDOP of GNSS



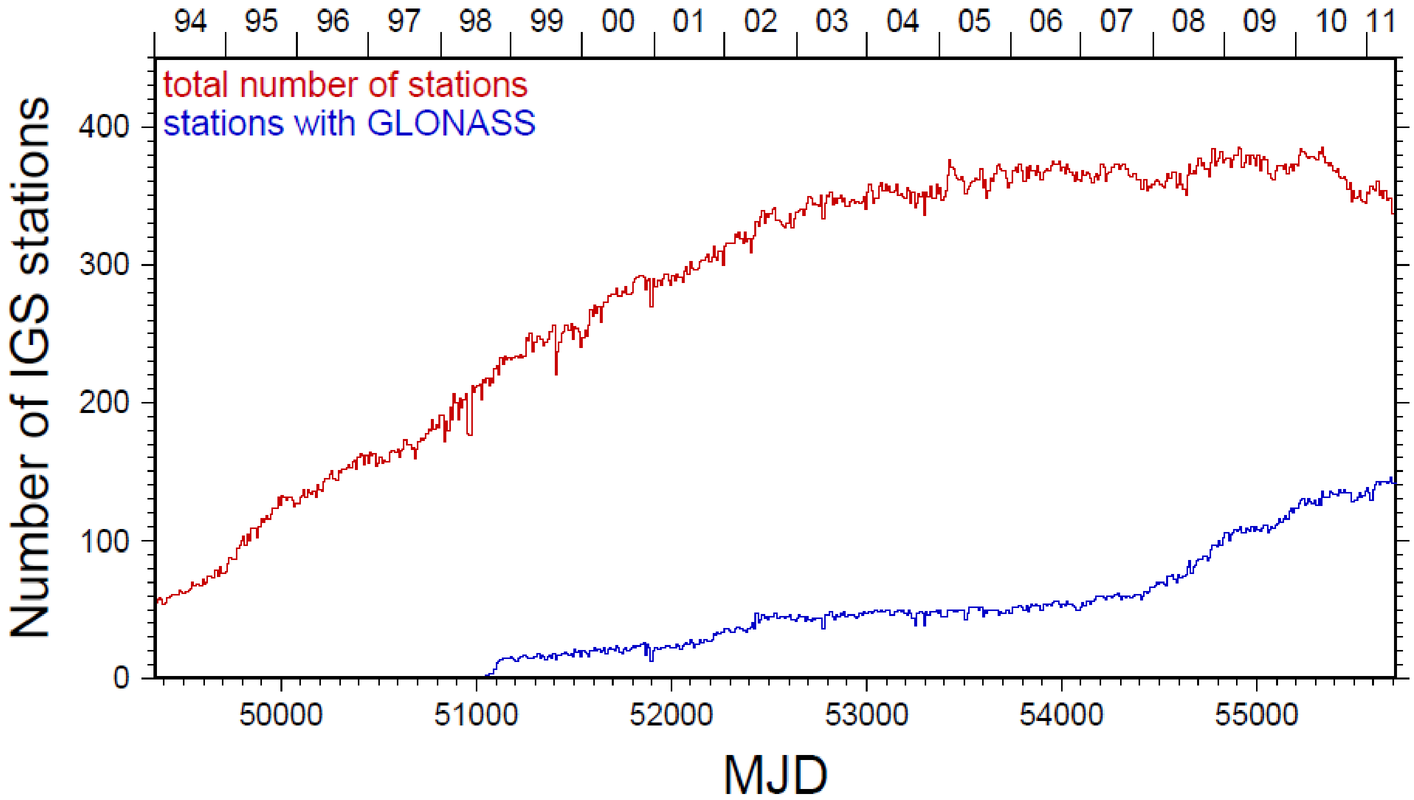
PDOP (Positional Dilution of Precision) for GPS, GLONASS, Galileo & combined over ten days.

PDOP of GNSS



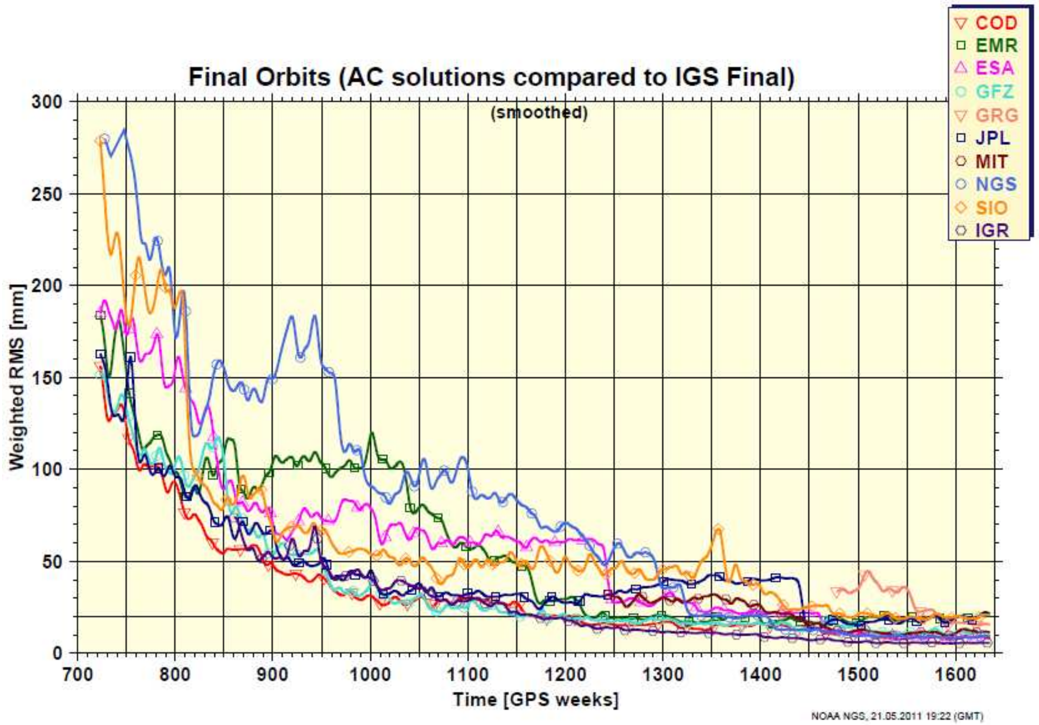
Spectral analysis of PDOP (Positional Dilution of Precision) for GPS, GLONASS, Galileo & combined → spectral lines are greatly reduced in the combination.

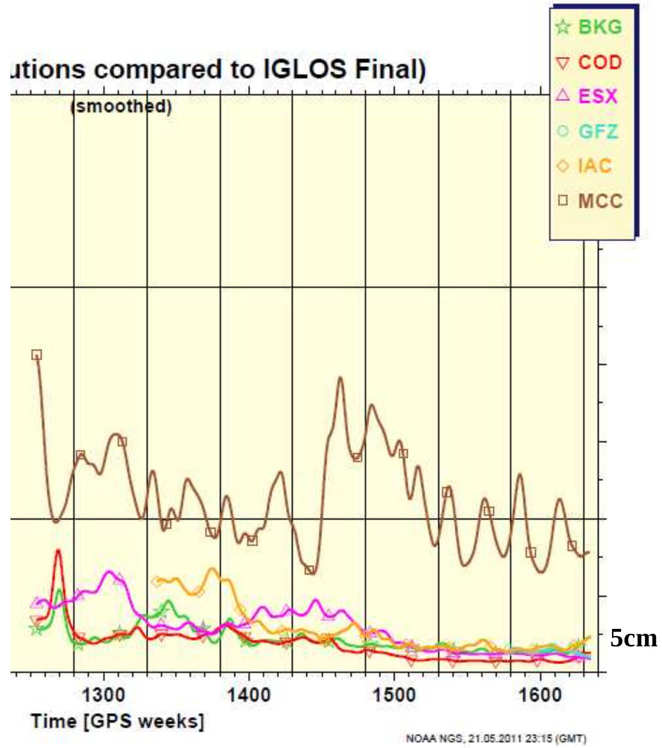
IGS: Combined GPS/GLONASS Analysis



In 1995 there were about 100 GPS receivers in the IGS net, today there are more than 300
In 1998 there were a few GLONASS receiver in the IGS net, today there are about 140.

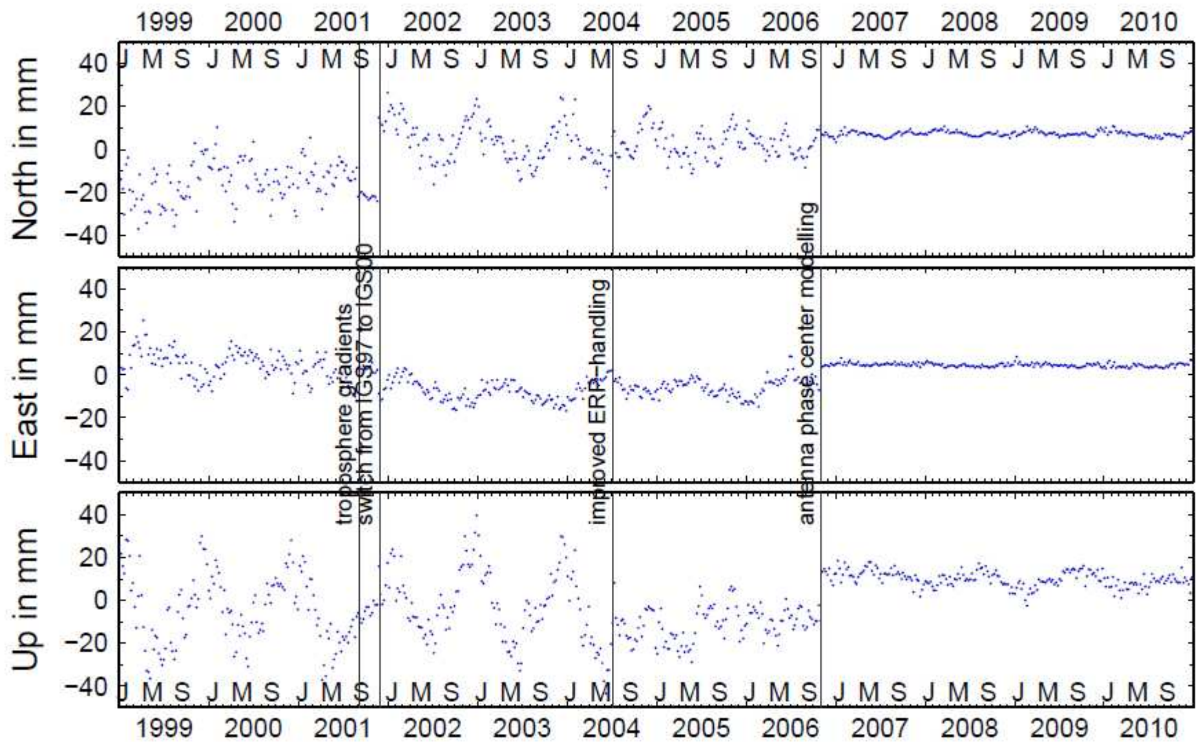
IGS: Combined GPS/GLONASS Analysis





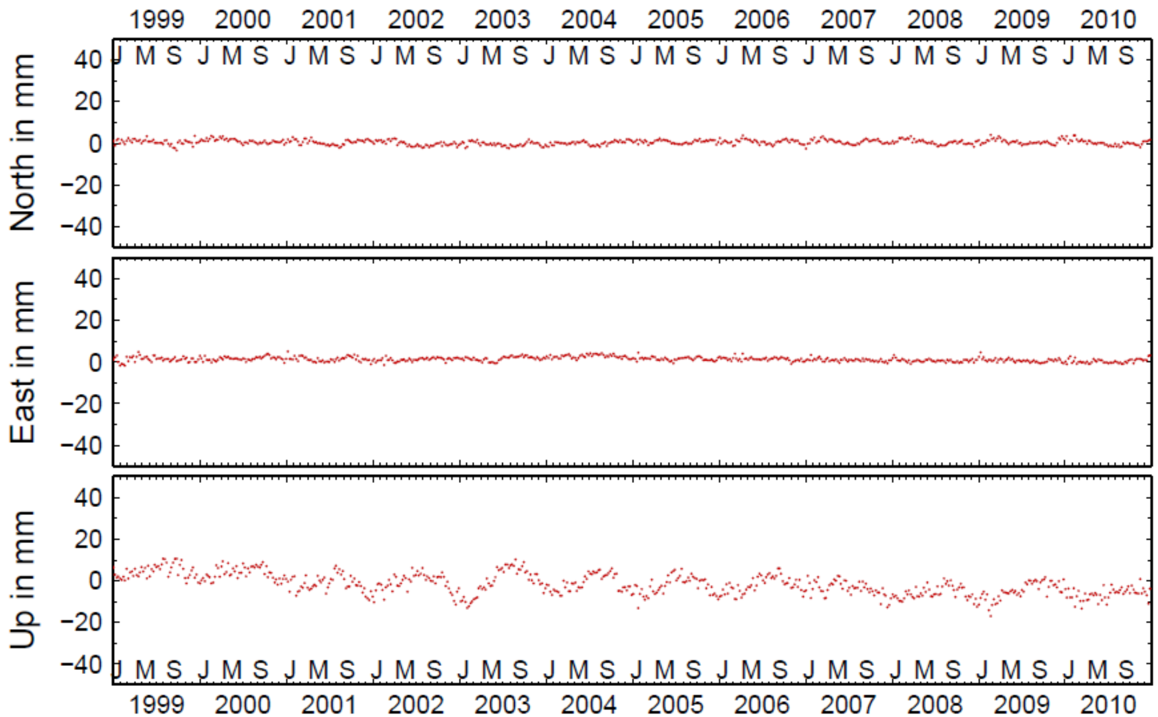
Consistency of IGS-derived GPS (left) and GLONASS (right) orbits: today both on the 1-2 cm level (weekly report of IGS ACC)

IGS: Reprocessing



Coordinate time series for the IGS sites based on original IGS solutions show systematic effects.

IGS: Reprocessing



Entire IGS dataset was re-analyzed using the latest software developments and models → no biases left in the solutions!

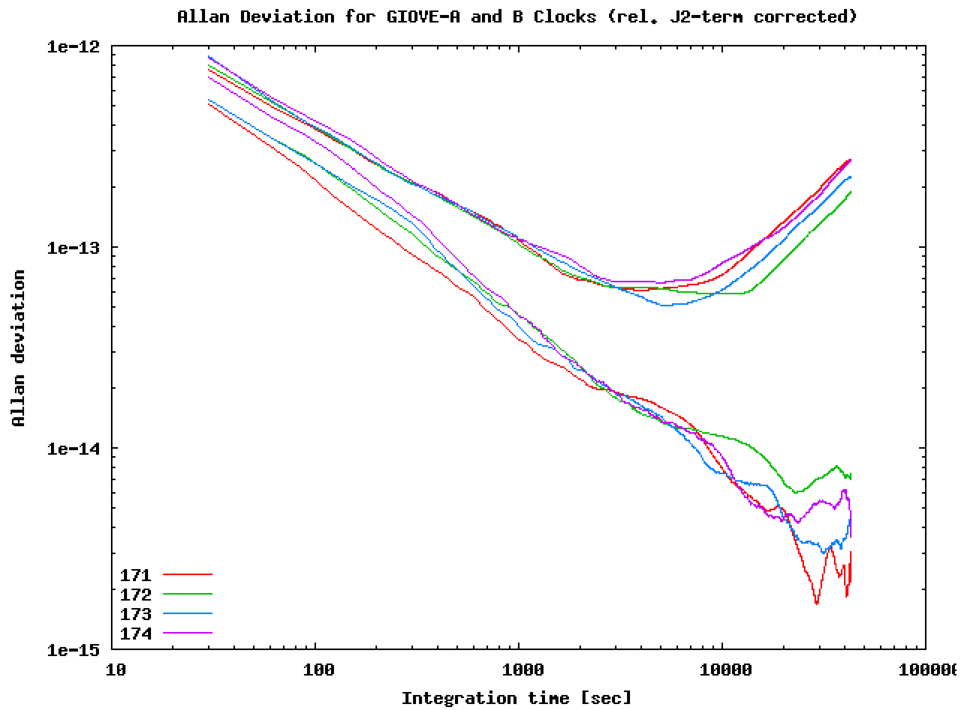
High-Accuracy Clocks in Space

In 1984 G. Beutler et al. wrote:

„*In the authors' opinion, the best way of modelling the clocks is the following: define a statistical model of clock performances using available information on clock offset, drift, jitter. This leads to a simple stochastic differential equation ... for the clock synchronization error as a function of time* ...“

From: G. Beutler, D.A. Davidson, R.B. Langley, R. Santerre, P. Vanicek, D.E. Wells (1984) „*Some theoretical and practical aspects of geodetic positioning using carrier phase difference observations of GPS satellites*“, Technical Report, Dept. Of Surveying Engineering, University of New Brunswick

High-Accuracy Clocks in Space



Potential impact:

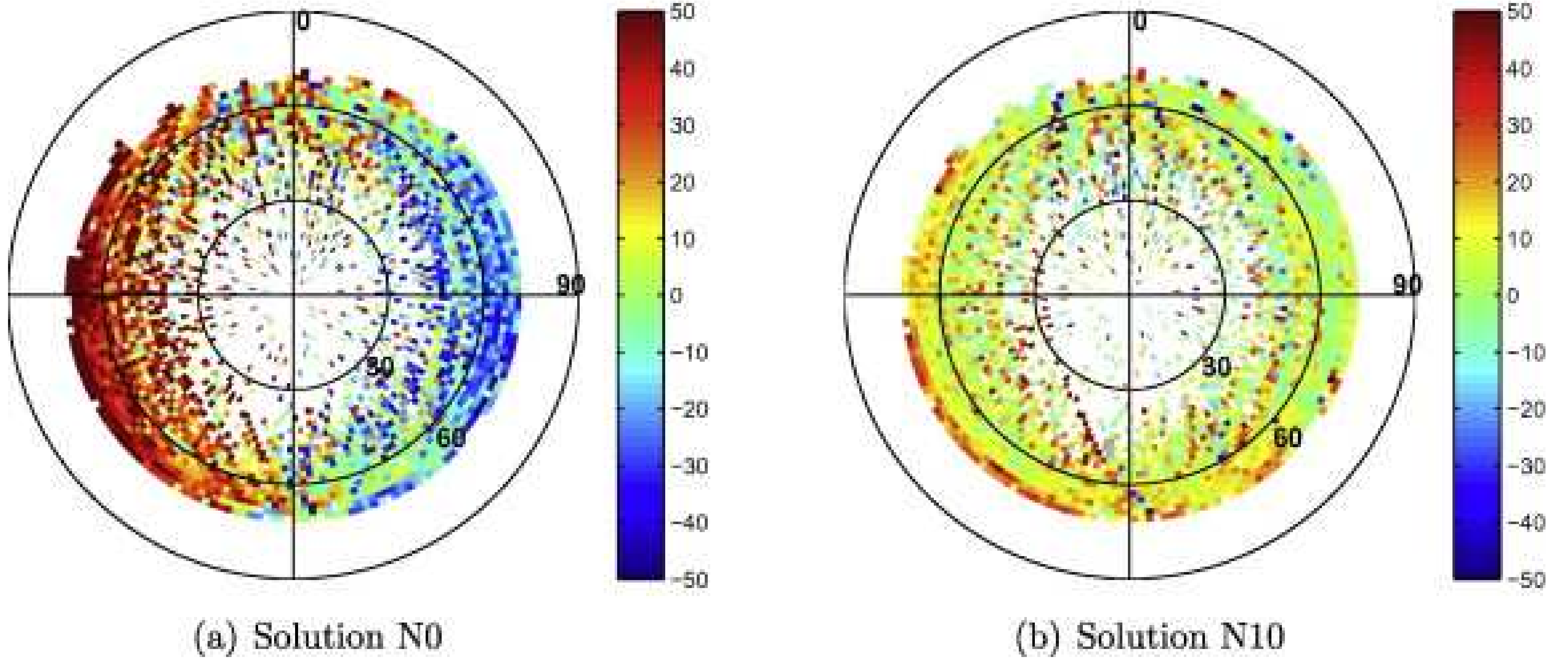
Clock prediction for real-time applications: Orbit errors might become the limiting factor for prediction.

Explicit/Implicit Double-difference approach may have to be left.

But: The algorithms have to be kept maneagable for the user! → Challenge

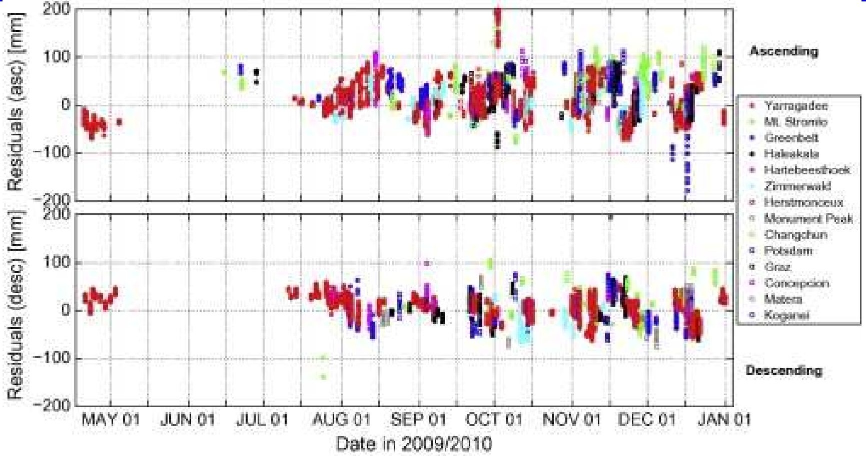
From Hugentobler et al. (2010) „Evaluation of GIOVE Satellite Clocks using the CONGO Network “. Allan deviations derived from an orbit & clock analysis using the data of the CONGO network of GNSS receivers (deployed by DLR and BKG, Germany).

The Case for SLR Reflectors on GNSS and LEO Satellites

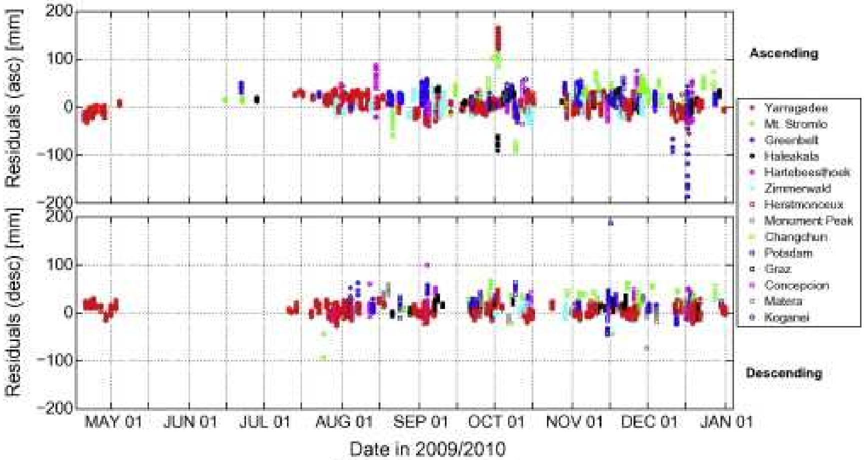


Modeling the Phase Center Variations on the GOCE satellite. Mean Residuals of SLR Observations in 2 x 2 deg bins in the satellite-fixed reference frame before (left) and after (right) PCV modelling. Scale in mm.

The Case for SLR Reflectors on GNSS and LEO Satellites



(a) Solution N0



(b) Solution N10

SLR Residuals based on Orbit without (top) and with (bottom) PCVs.

→ SLR provided an external validation of the determined PCV model

Figures from Bock, H., A. Jäggi, U. Meyer, R. Dach, G. Beutler; 2011: Impact of GPS antenna phase center variations on precise orbits of the GOCE satellite. Advances in Space Research, vol. 47(11), pp. 1885-1893, DOI 10.1016/j.asr.2011.01.017.

The Case for SLR Reflectors on GNSS and LEO Satellites

- SLR reflectors on board GNSS and other satellites allow it to validate their orbits, which were determined using the GNSS observables (Code and Carrier Phase).
- SLR provides an absolute measurement between observers on the Earth‘s surface and the satellites (no ambiguities, no wet tropospheric refraction)
- All current and future GLONASS satellites have/will have Laser reflectors → orbit models can be easily validated
- GIOVE-A and –B have SLR SLR reflectors
- All Galileo IOV satellites will have SLR reflectors
- All future GPS satellites should be equipped with SLR reflectors!

Acknowledgements

International GNSS Service
on the step to the multi-GNSS age

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Satellite methods for positioning in modern geodesy and navigation
Satelitarne metody wyznaczania pozycji we współczesnej geodezji i nawigacji
Wrocław, 02. June 2011

Material from the above presentation by Rolf Dach (head of CODE AC of the IGS) and Urs Hugentobler (Chair of IGS Governing Board) was used in this presentation.