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

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Content

- GPS, GLONASS, GALILEO: Status June 2011
  - GLONASS operational
  - „First“ GLONASS-only solutions based on global network
  - Galileo: GIOVE-A and –B, two IOV-Satellites in Space
- IGS = International *GNSS* Service
  - GPS & GLONASS Ephemerides and Clocks
  - IGS M GEX Experiment
- Galileo Science Advisory Committee
- Global Multi-GNSS Analyis
- SLR for the validation of different GNSS

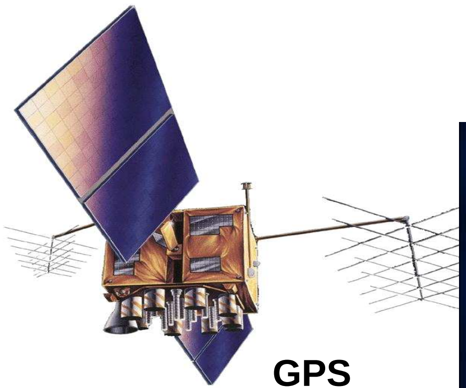
GPS, GLONASS and GALILEO

GPS: USA , 31 satellites in 6 planes
GLONASS: 24 satellites in 3 planes

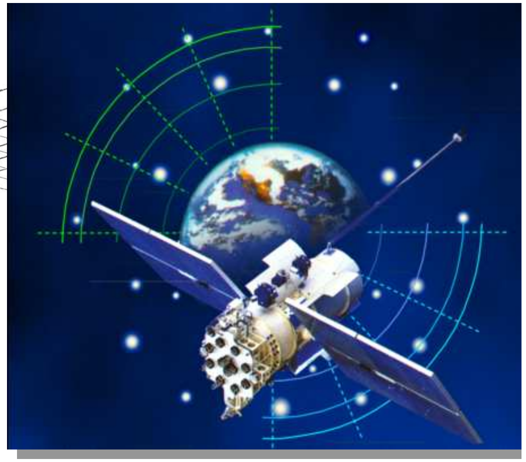
GALILEO: GIOVE-A, -B + 2 IOV-satellites in orbit

All GLONASS and GALILEO satellites are equipped with SLR reflectors

Only one GPS Satellite left in orbit with SLR reflectors



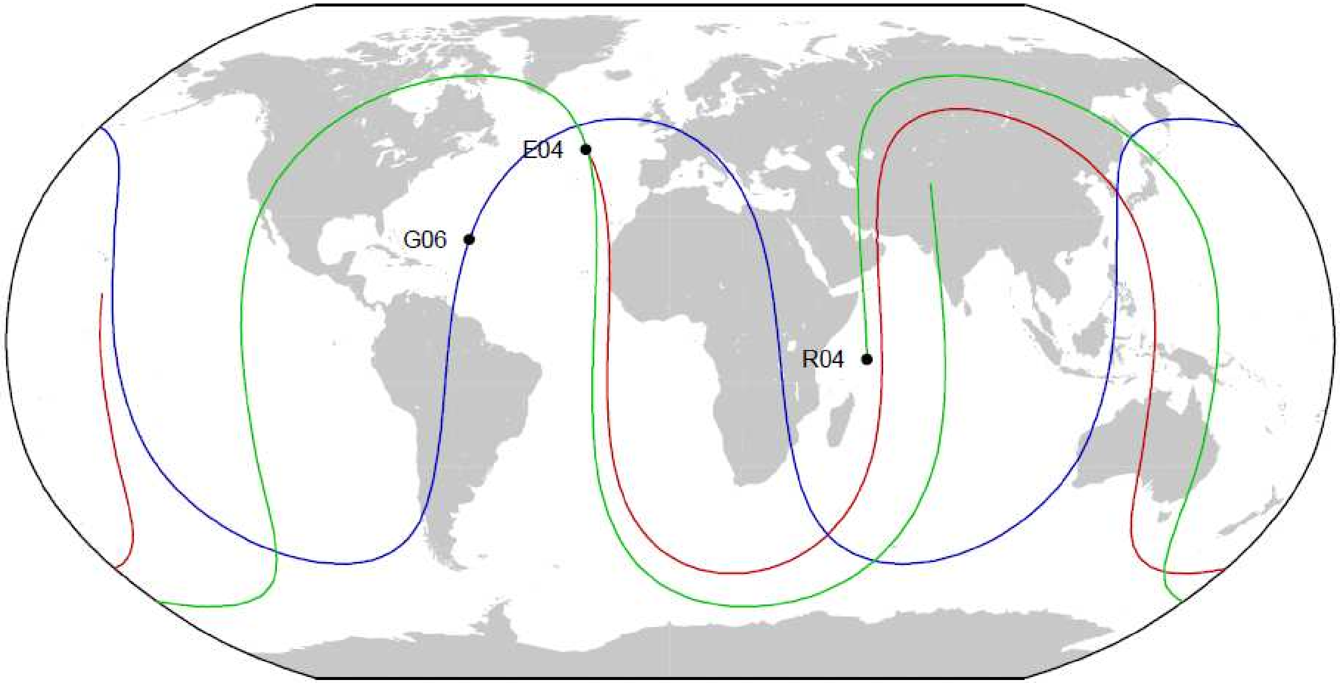
GPS



GLONASS

GALILEO

GPS, GLONASS and GALILEO



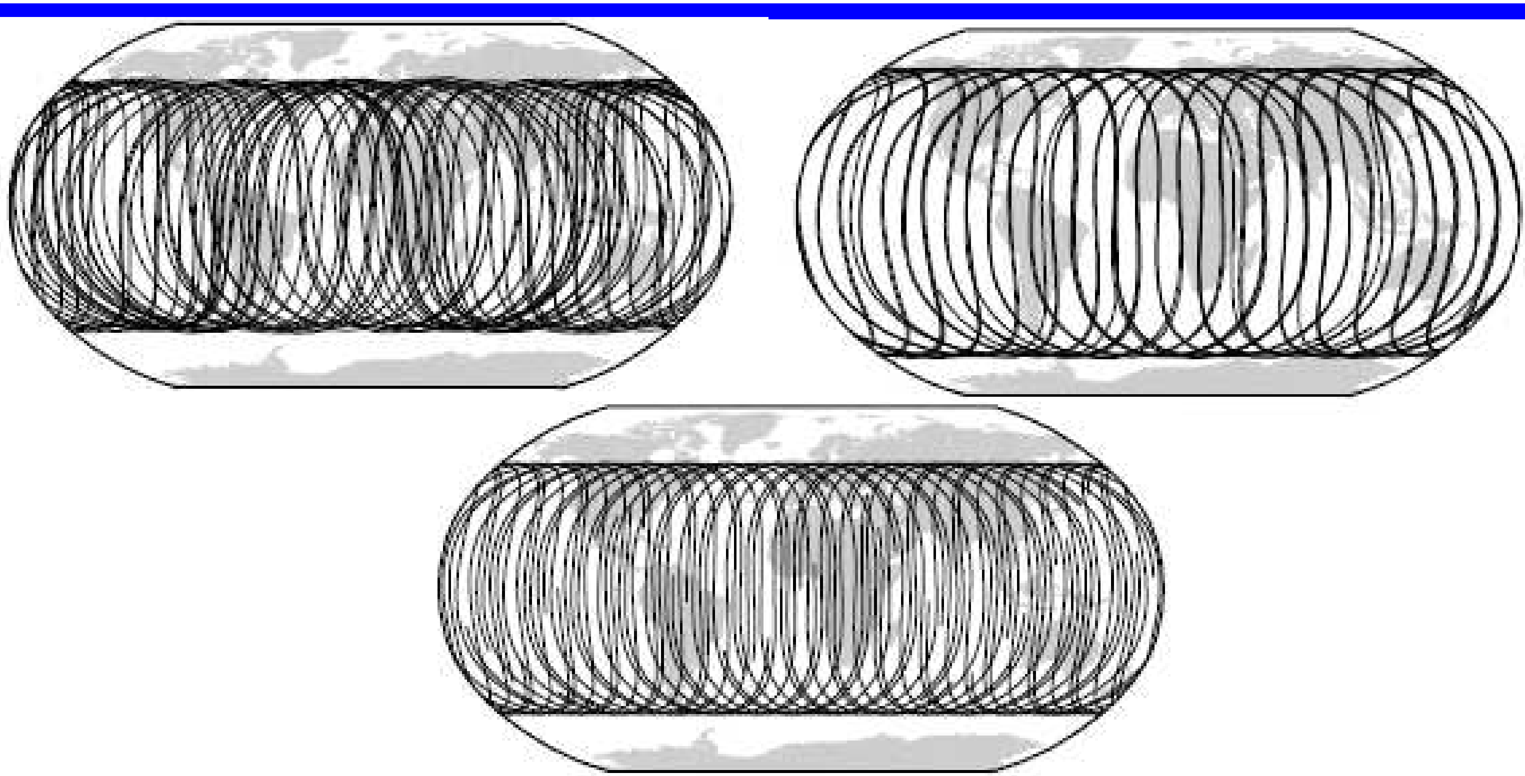
Groundtracks of GPS, GLONASS and GALILEO over one day

GPS, GLONASS and GALILEO

GPS, GLONASS, and Galileo (as of October 2011)

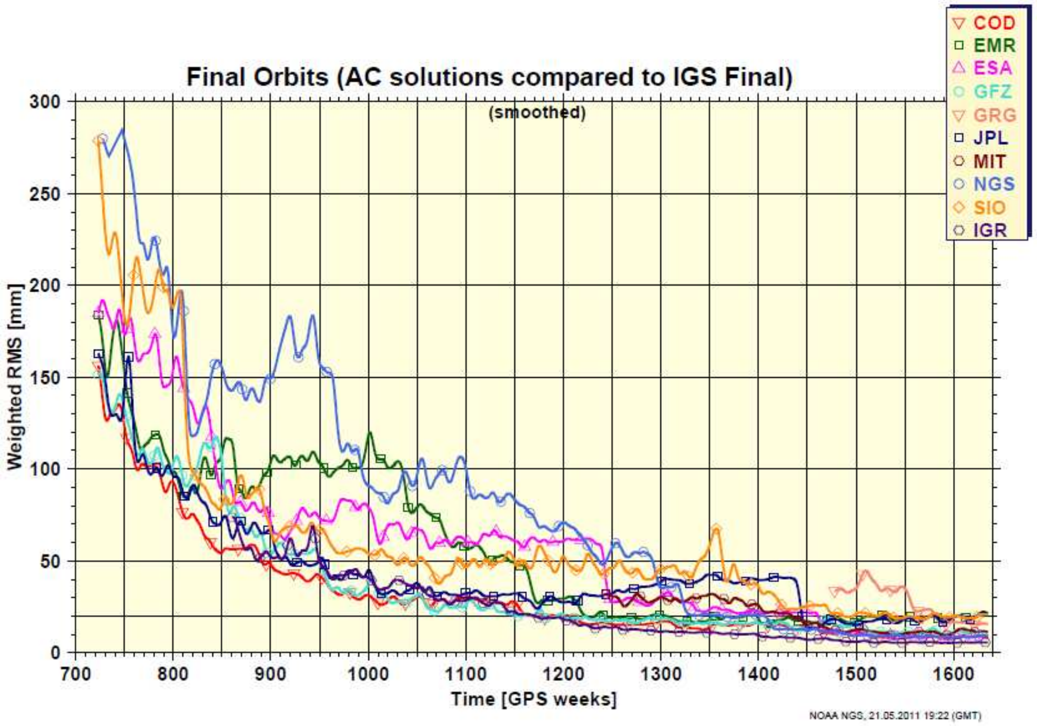
Constellation characteristic	GPS	GLONASS	Galileo
Walker designation	–	64.8°: 24/3/1	56°: 27/3/1
Orbital planes	6	3	3
Spacing of planes	60°	120°	120°
Number of satellites (nominal)	32 (24)	24 (24)	2 IOV (27)
Semi-major axis	26 500 km	25 510 km	29 600 km
Inclination	55°	64.8°	56°
Nodal drift per day	−0.0384°	−0.0336°	−0.0260°
Length of GNSS year	351.5 days	353.2 days	355.6 days
Revolution period	11 h 58 min ½ sidereal days	11 h 16 min 8/17 sidereal days	14 h 05 min 10/17 sidereal days
Repeat cycle (sidereal days)	1	8	10
Repeat cycle (orbital revolutions)	2	17	17

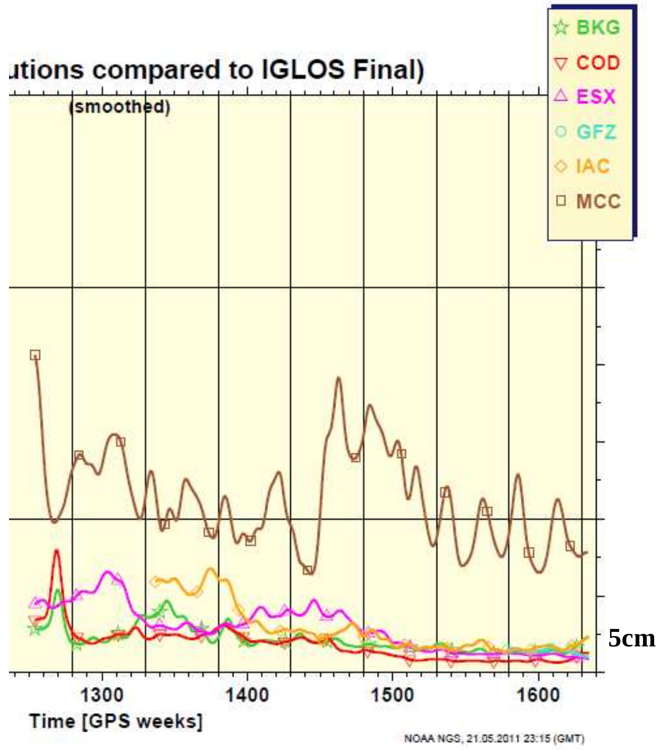
GPS, GLONASS, and Galileo



Ground tracks: top, left: GPS, one day; top right: Glonass, 8 days, bottom: Galileo, one day (!!)

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 M-GEX

International Global Navigation Satellite Systems Service

IGS
Multi-GNSS Experiment

IGS M-GEX

Call for Participation
www.igs.org

IGS M-GEX: History

IGS History as a GNSS Service

- 1991: CfP for creation of International GPS Service
- 1994: IGS becomes official IAG Service
- 1998: IGS CfP for IGEX (International GLONASS Experiment)
- 2003: GLONASS fully incorporated
- 2005: IGS = International GNSS Service
- 2011: IGS M-GEX CfP to take advantage of new systems, of new signals on existing GNSS

IGS M-GEX: Objectives

- **conduct a global multi-GNSS signals tracking experiment!**
- **focus on tracking the newly available GNSS signals**
- **Include modernized GPS, GLONASS, Galileo, Compass/BeiDou, QZSS, and augmentation systrems**
- **Top priority: collect and make available observation data**
- **A more definitive plan on the analysis will follow**
- **IGS and other Analysis Centers are encouraged to determine inter-system calibration biases**
- **development of multi-GNSS IGS products will be stimulated**
- **Eventually, a Multi-GNSS Pilot Project will be set up**

IGS M-GEX: Schedule

- August 2011: Distribution of Call for Participation
- October 30th: Proposals due (entities may propose and join at any time)
- December 15th Evaluation of proposals by Organizing Committee
- February 1st 2012: Experiment begins
- July 23 th – 27 th 2012 Evaluation of first results during IGS Workshop in Olsztyn, Poland
- August 31th 2012: Experiment ends

Multi-GNSS Pilot Project shall follow!

Galileo Science Advisory Committee (GSAC)

The Galileo Science Advisory Committy (GSAC) was set up to:

- **Recommend improvements to Galileo and EGNOS for scientific applications.**
- **Maintain the Galileo Science Opportunity Document (GSOD), highlighting scientific priorities.**
- **Support the preparation of announcements of opportunity (AO) for scientific studies.**
- **Advise on the use of Galileo and EGNOS data for scientific applications.**
- **Consider and review ESA-furnished documents related to the scientific use of GNSS signals.**

GSAC: Recent Activities

In September 2011 GSAC organized the 3rd International Colloquium – Scientific and Fundamental Aspects of the Galileo Programme, which was attended by more than 100 participants – despite the fact that Galileo still is in its infancy.

Topics of the Colloquium:

- **Earth Science (geodesy, geodynamics, atmosphere, climatology, reflectometry, etc.)**
- **Physics (general relativity and beyond, fundamental constants, etc.)**
- **Metrology (atomic clocks, time scales and time comparison, inter-satellite links, time & orbit determination, etc)**

Combined analysis of different GNSS was a major issue at the Colloquium.

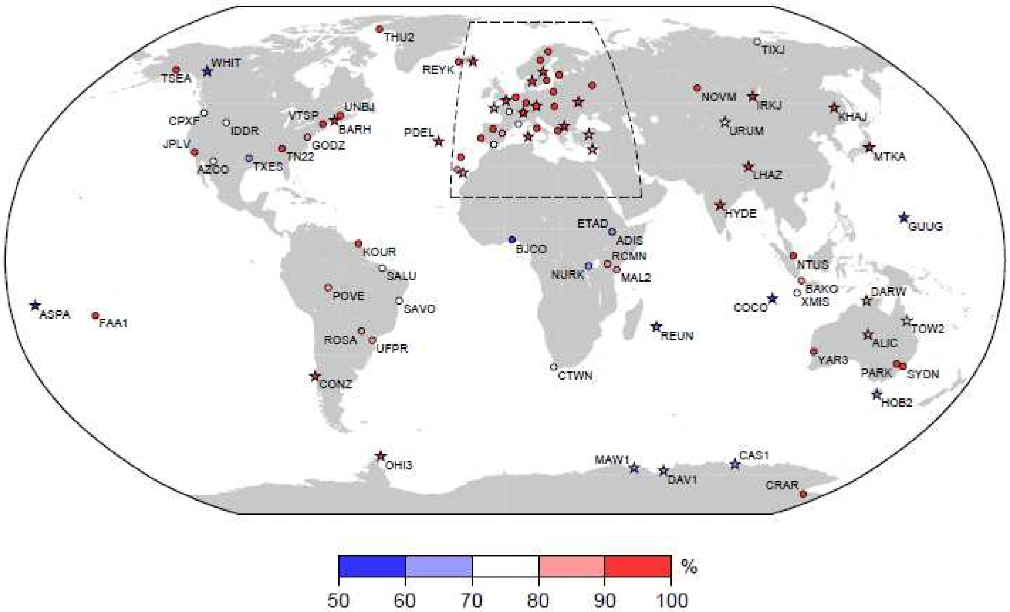
Global Multi-GNSS Analysis

- **Determine**
  - **Satellite ephemerides**
  - **Satellite clock corrections**
  - **Polar motion length-of-day**
  - **Ionosphere maps**
  - **Calibration data**
- **using data from a global tracking network of combined GNSS receivers**
- **in single GNSS and combined GNSS modes**

The following example is taken from

M. Meindl (2011) „Combined Analysis of Observations from Different Global Navigation Satellite Systems“, Ph.D. Thesis, University of Bern, Switzerland

Global Multi-GNSS Analysis



No science fiction for GPS and GLONASS!

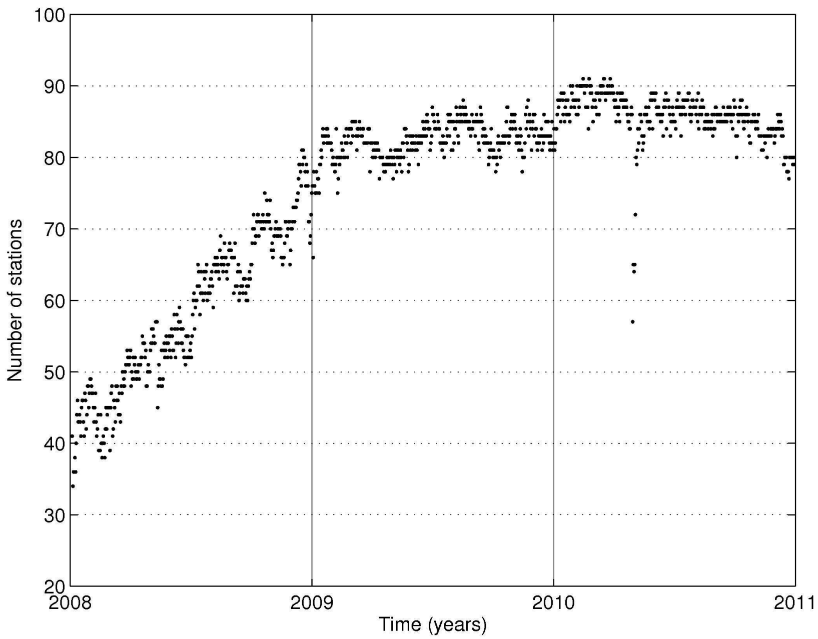
Three years of data analyzed by M. Meindl

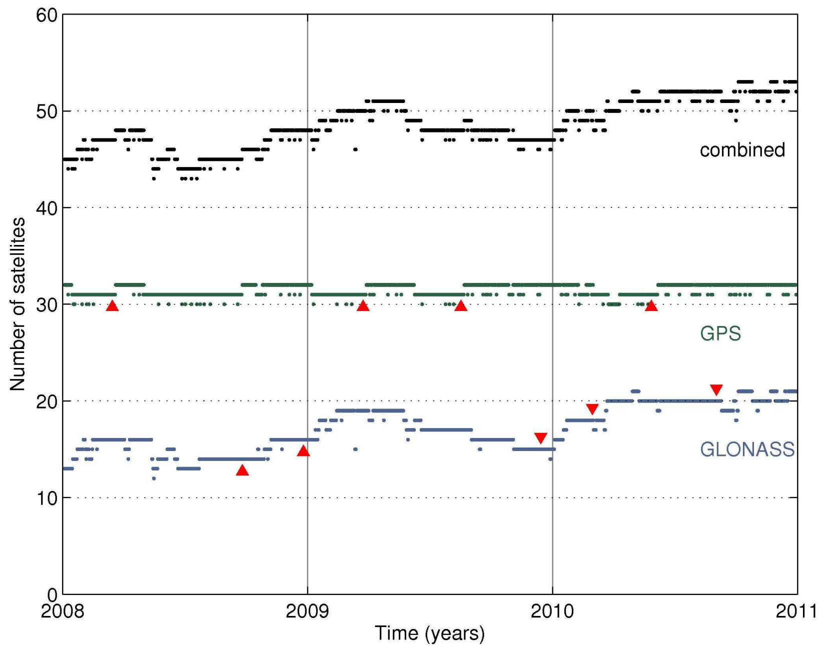
Tracking network of 92 sites equipped with GPS / GLONASS receivers, availability of data generally > 75%

Data span: Calendar years 2008-2010

On the average 32 GPS satellites and 16 GLONASS satellites

Global Multi-GNSS Analysis





Number of Stations

Number of Satellites

Global Multi-GNSS Analysis

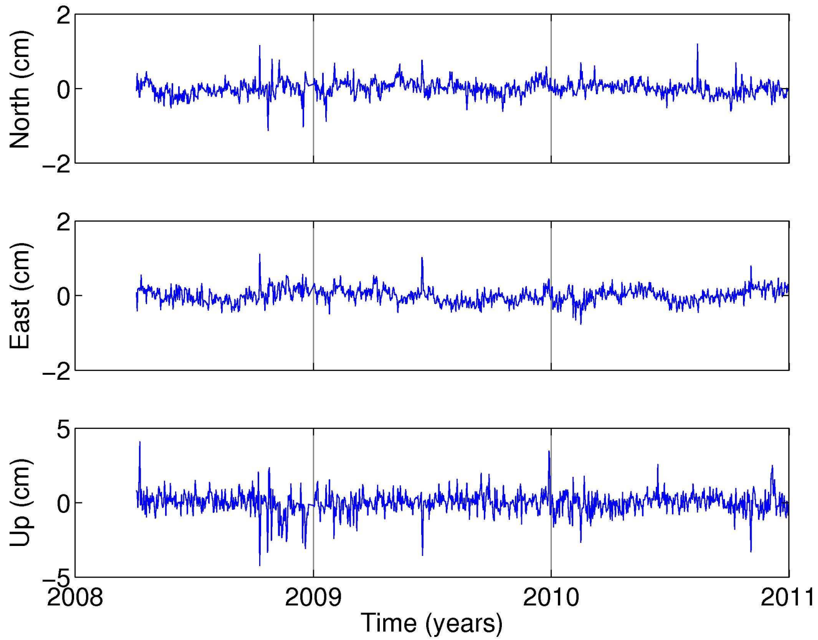
Table 3. Solution identifiers and characteristics.

ID	Characteristic
GPS/G	GPS-only
GLO/R	GLONASS-only
CMB/C	Combined on observation level (one ISB)
NEC/N	Combined on NEQ level (epoch-wise ISBs)

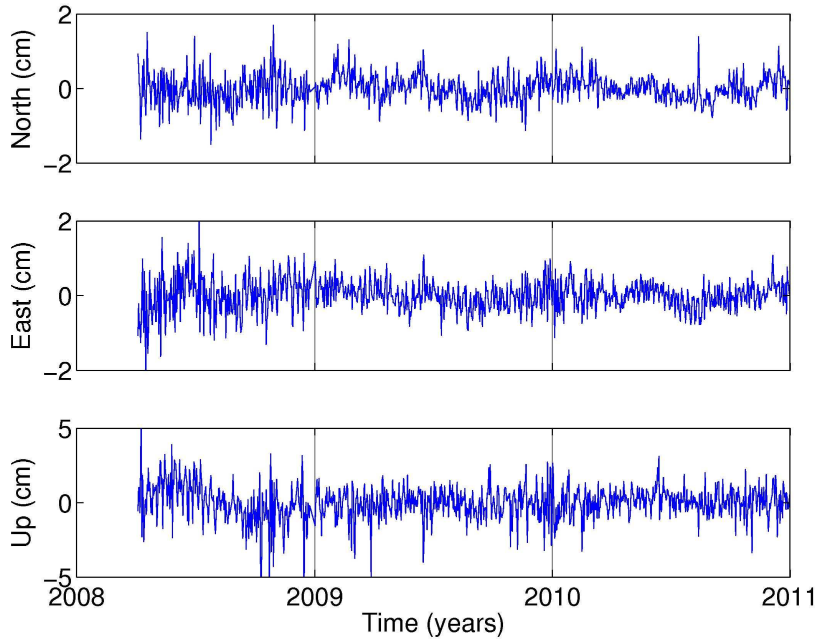
GPS-only, GLONASS-only, and combined solutions (on observation level and on the NEQ-level) were generated – all with four different session lengths.

Global Multi-GNSS Analysis

- **Repeatability of Daily Coordinate Estimates**



GPS



GLONASS

Global Multi-GNSS Analysis

Table 6. Mean improvement for different solutions (observed and expected from square-root-law).

	CMB/GPS	CMB/GLO	GPS/GLO
Observed	1.1	2.0	1.8
Expected	1.2	1.7	1.4

For statistical reasons (rms should decrease with square root of the number of satellites (or observations)) one would expect the improvements in the second line of the above table. The expected and the achieved improvements agree quite well – where one should take into account that the GLONASS observation scenario is not „saturated".

Global Multi-GNSS Analysis

Table 7. Mean absolute orbit overlap errors (in cm).

Session	GPS satellites CMB	GPS satellites NEC	GPS satellites GPS	GLONASS satellites CMB	GLONASS satellites NEC	GLONASS satellites GLO
LNG	5.8	5.9	6.1	9.0	11.1	12.4
DAY	5.9	6.0	6.2	9.3	11.6	13.3
GPS	5.8	5.9	6.0	9.4	11.6	13.2
GLO	6.1	6.2	6.4	9.9	12.6	14.4

At the session boundaries one may compare the satellite positions from two adjacent arcs.

- **Small improvement for GPS in the combined solutions, major improvements for GLONASS.**
- **CMB solutions clearly better than NEC solution – in particular for GLONASS**

The Case for SLR Reflectors on GNSS

- 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 of distances between observers on the Earth's surface and the satellites (no ambiguities, „no“ 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 have/ will have SLR reflectors
- **All future GPS satellites should be equipped with SLR reflectors!**