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

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GSAC (ESA)

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National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board
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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 Analysis
- 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 and GALILEO

Groundtracks of GPS, GLONASS and GALILEO over one day
### GPS, GLONASS, and GALILEO

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

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

IGS
Multi-GNSS Experiment

*IGS M-GEX*

Call for Participation
www.igs.org

International Association of Geodesy
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 systems
- 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 23rd – 27th 2012 Evaluation of first results during IGS Workshop in Olsztyn, Poland
- August 31st 2012: Experiment ends

Multi-GNSS Pilot Project shall follow!

International Association of Geodesy
Galileo Science Advisory Committee (GSAC)

The Galileo Science Advisory Committee (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

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.

<table>
<thead>
<tr>
<th>ID</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS/G</td>
<td>GPS-only</td>
</tr>
<tr>
<td>GLO/R</td>
<td>GLONASS-only</td>
</tr>
<tr>
<td>CMB/C</td>
<td>Combined on observation level (one ISB)</td>
</tr>
<tr>
<td>NEC/N</td>
<td>Combined on NEQ level (epoch-wise ISBs)</td>
</tr>
</tbody>
</table>

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

![Graphs showing repeatability of daily coordinate estimates for GPS and GLONASS over the years 2008 to 2011.](image)
Global Multi-GNSS Analysis

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

<table>
<thead>
<tr>
<th></th>
<th>CMB/GPS</th>
<th>CMB/GLO</th>
<th>GPS/GLO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>1.1</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Expected</td>
<td>1.2</td>
<td>1.7</td>
<td>1.4</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Session</th>
<th>CMB</th>
<th>NEC</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG</td>
<td>5.8</td>
<td>5.9</td>
<td>6.1</td>
</tr>
<tr>
<td>DAY</td>
<td>5.9</td>
<td>6.0</td>
<td>6.2</td>
</tr>
<tr>
<td>GPS</td>
<td>5.8</td>
<td>5.9</td>
<td>6.0</td>
</tr>
<tr>
<td>GLO</td>
<td>6.1</td>
<td>6.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CMB</th>
<th>NEC</th>
<th>GLO</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0</td>
<td>11.1</td>
<td>12.4</td>
</tr>
<tr>
<td>9.3</td>
<td>11.6</td>
<td>13.3</td>
</tr>
<tr>
<td>9.4</td>
<td>11.6</td>
<td>13.2</td>
</tr>
<tr>
<td>9.9</td>
<td>12.6</td>
<td>14.4</td>
</tr>
</tbody>
</table>

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!