Multi–GNSS Processing

Position paper for the IGS Workshop
— DRAFT —

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1 Introduction

With the renaming of the IGS from the "International GPS Service" to the "International GNSS Service" the organization expressed its wish to extend activities from the well–established GPS to other active and planned systems. We expect the European Galileo system (and possibly the Chinese Compass) to become active in future.

Independent of these future systems we have today the Russian GLONASS as a second active GNSS. There is a continuously increasing number of stations in the IGS network tracking both, GPS and GLONASS data (see Section 2). Currently there are the following analysis centers providing orbit products for the GLONASS satellites:

- BKG: Bundesamt für Kartographie und Geodäsie, Frankfurt am Main, Germany
- CODE: Center for Orbit Determination in Europe, AIUB, Bern, Switzerland
- ESOC: European Space Operations Center, ESA, Darmstadt, Germany
- IAC: Information–Analytical Center, Russia

BKG and IAC solve only for GLONASS satellite orbits, introducing the information for the GPS satellites from the IGS solution as known. Since May 2003 CODE is providing orbits for GPS and GLONASS from a rigorous combined processing of the data from both GNSS. In January 2008 ESOC followed this strategy. GLONASS satellite clock corrections are only available from ESOC.

Even if the same software is used to combine the GPS as well as the GLONASS satellite orbits, the full consistency between systems is not guaranteed: the orbits of the satellites from the two GNSS are handled in independent procedures. The results are provided to the user community in separate files for each GNSS. Because there are only two centers submitting results for the rapid and ultra–rapid product lines only the combination for the GLONASS final orbits is possible today. Satellite clock corrections are not combined because of the lack of redundancy.

This position paper first documents the development of the combined GPS/GLONASS receivers in the IGS network (Section 2). The quality and accuracy of the GLONASS satellite orbits is discussed in Section 3.

In Section 4 we compare the global parameters from solutions of a GPS–only and a combined GPS/GLONASS processing using one year of data. After comparing the orbit characteristics and their consequences for the positioning in Section 5 we study the benefit of adding GLONASS measurements to the GPS observations for positioning in Section 6.

In Section 7 we review the existing file formats concerning their capability of covering all aspects of current and future multi–GNSS constellations.

2 The GNSS Subnetwork of the IGS

Figure 1 shows the number of stations in the IGS network providing GLONASS measurements. The number and distribution of IGS sites providing GPS and GLONASS data

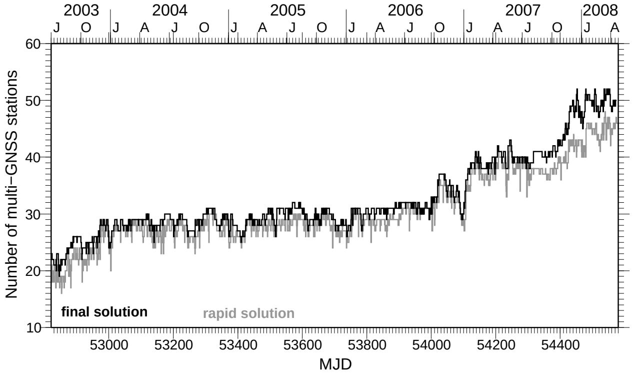


Figure 1: Number of sites in the IGS network providing GLONASS data, which were used for orbit determination in the CODE rapid (grey line) and final (black line) solution

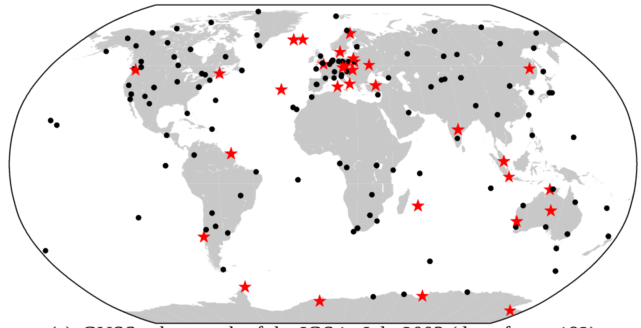
has significantly increased and improved since Spring 2003.

At the end of the IGEX campaign the IGS has terminated the generation of combined GLONASS satellite orbits since only two analysis centers did submit solutions. In May 2003 CODE started its activities in multi–GNSS processing providing GLONASS satellite orbits as the third analysis center at that time. This allowed the IGS to relaunch the combination of GLONASS orbits.

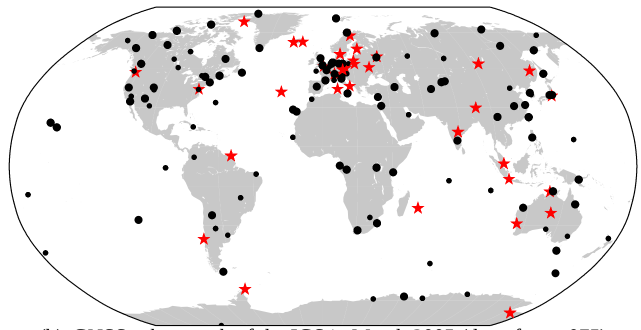
As a result of this event the number GLONASS tracking stations in the IGS network grew from about 20 to 30 till the end of the year 2003. The number of stations then remained stable for a long time. With the availability of a new generation of combined GPS/GLONASS receivers, produced by several well–known GPS receiver manufacturers in 2006/2007, the number of GLONASS tracking stations in the IGS network increased steadily and continues increasing today. The orbits for the GLONASS satellites may now be determined from the data of up to 50 tracking stations in the IGS network. For the ultra–rapid solution GLONASS tracking data from about 35 IGS stations may be used (the number is limited by the latency of the data). For orbit determination a good global distribution of observing sites is at least as important as their number.

In Summer 2003 the global coverage of IGS stations tracking GLONASS satellites was very inhomogeneous. Most of the 20 stations with GLONASS tracking capability were located in Europe (see Figure 2(a)). The 30 stations network available in the time interval 2003–2006 is in essence that shown in Figure 2(b). Figure 2(c) shows the current situation (early 2008). The relation between GPS–only (black dots) and combined GPS/GLONASS (grey stars) receivers is now balanced in all regions — except in the American continent, where GPS–only receivers still dominate. In summary we may, however, state that today orbit determination for the GLONASS satellites may be based on a truly global tracking network of geodetic–type receivers. This significant improvement is due to the efforts of many IGS station managers and their institutions.

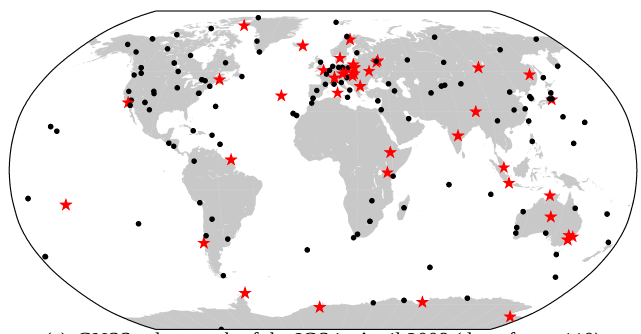
The number of active GLONASS satellites also grew considerably since 2003. Unfortunately, a large number



(a) GNSS subnetwork of the IGS in July 2003 (day of year 182)



(b) GNSS subnetwork of the IGS in March 2005 (day of year 075)



(c) GNSS subnetwork of the IGS in April 2008 (day of year 110)

Figure 2: Geographical distribution of multi–system GNSS receivers (grey stars) and GPS-only receivers (black dots) that are used for the CODE final processing.

of receivers was unable to track satellites flagged as "unusable", which reduced the number of receivers tracking these satellites. In 2007 GLONASS moved the frequency range of the system to a new frequency band (announced as a system update already in 2002). The frequencies of the 24 GLONASS satellites of the nominal constellation are no longer computed by the frequency numbers 1 to 12, but by -7 to $+6$. When the first satellites with frequency numbers ≤ 0 became active, several firmware upgrades were necessary to enable the receivers to provide data from these satellites.

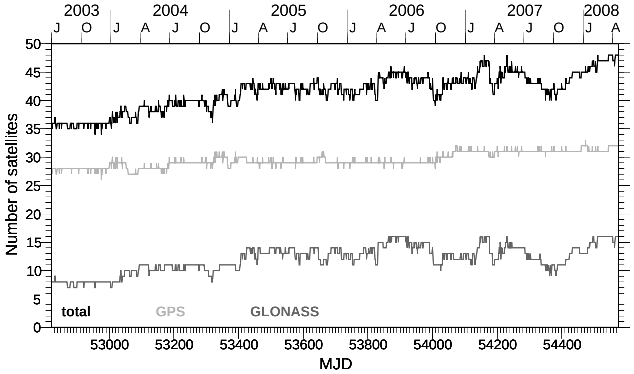


Figure 3: Number of satellites included in the CODE final orbit product since 2004.

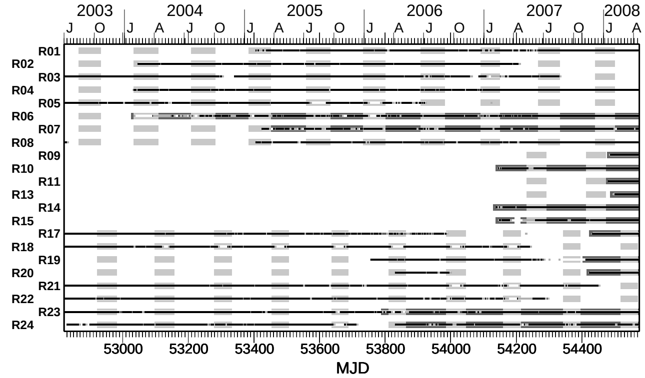


Figure 4: Days for which orbits of the individual GLONASS satellites are provided by CODE since July 2003 are indicated by black squares. If the orbit determination was not very reliable because of the lack of tracking data a grey square is used instead (in most cases the satellites are flagged as unusable in that time). Dark–grey bars indicate intervals where the PRN slot was occupied by a new GLONASS-M satellite. Light–grey bars indicate eclipsing periods for the satellites at a particular orbital plane.

3 GLONASS Orbit Determination

The number of GNSS satellites contained in the CODE[1] final solution is shown in Figure 3. The light–grey curve shows the number of available GPS satellites, which is quite stable around 30 since the year 2000. The number of GLONASS satellites tracked by a sufficient number of sites of the IGS network to allow for precise orbit determination is represented by the dark–grey curve in Figure 3. Currently (April 2008), 16 GLONASS satellites are active. Since two more triple–launches are announced for this year we can expect 22 active GLONASS satellites at the end of this year (or, more realistically, 20 satellites assuming that two satellites may be decommissioned during this year). In that case GLONASS will nearly have achieved its nominal constellation of 24 satellites.

Figure 3 shows that the number of active GLONASS satellites varies much more than the number of active GPS satellites: (1) during the maintenance phase a GPS satellite is flagged as unhealthy, but it continues to emit signals. GLONASS satellites, however, do not transmit signals for about 1 up to 3 days at irregular intervals. The duration and frequency of these events are comparable to the maintenance periods for GPS satellites. These GLONASS events are usually not announced by the system operators. Whereas GPS maintenance periods are often associated with repositioning events, no repositioning events were detected for GLONASS up today. It is thus possible to predict GLONASS orbits over long time intervals for the re–initialization of the orbit determination process, when the satellite is again tracked by the receivers in the IGS network — even if broadcast information is not yet available. (2) if an orbital plane is partially eclipsed, the GLONASS satellites were often switched off for a few weeks. When the satellite start to broadcast again after such a long time, a new initialization of the orbit determination process is required.

These system specific outages are compiled in Figure 4: Each day since May 2003 is marked by a black square, if the CODE final solution contained an accurate GLONASS satellite orbit. Grey squares mark days, where orbit determination was of poor quality due to a limited number of receivers tracking the satellite. Blank squares mark days were no orbit determination was possible, because of missing data (e.g., due to inactive satellites). Many gaps (blank squares) occur during the eclipsing phases marked by grey bars. Satellites R05, R18, or R21 illustrate the behavior.

In 2003 the first GLONASS–M satellite — a member of a new generation of GLONASS satellites — has been launched (R06 was running in a testing mode for several months in 2004). The replacement of an old–style by a modernized GLONASS satellite is indicated by dark bars in Figure 4. The current constellation mainly consists of modernized GLONASS satellites, because many of the older satellites have been decommissioned by now. R01 and R08 are the only active GLONASS satellites of the old generation. The new satellites continue operating during eclipse phases, which is a big advantage for orbit determination. Also the lifetime of the new generation of GLONASS satellites seems to be longer than for the old ones. Every few years the old generation GLONASS satellites needed to be replaced. This is another factor for the bigger variability in the GLONASS satellites constellation displayed in Figure 3.

Let us make the attempt to asses the precision of the GLONASS (and GPS) orbits provided by CODE. For this purpose we use the ephemerides of our final orbit series of three consecutive days. The positions, at a 15 minutes spacing, are used as pseudo–observations in an orbit determination process, where only six initial osculating elements and nine empirical parameters (three constant and six once–per revolution parameters in D−, Y−, and X−directions) were

[1]CODE is chosen as example because they provide orbits even if the number of tracking stations for a satellite is very limited.

set up. The RMS error of one satellite coordinate (referred to simply as RMS hereafter) is used as a precision indicator.

We do not want to include problems of marginally observed satellites and therefore display the median of the RMS over all GLONASS satellites for each day (black dots in Figure 5). For reference the corresponding values for the GPS satellites are given in light–grey. There is a clear correlation of the RMS with the number of stations tracking GLONASS satellites (see Figure 1): For a long time interval the median of the RMS for the GLONASS satellites was of the order of 8 to 10 cm. With the significantly increased number of GLONASS tracking stations in the IGS network this value was recently reduced to about 5 to 6 cm. Note that the median of the RMS error is much larger than the corresponding value for the GPS satellites. This mainly reflects the smaller number of tracking stations and the less optimal global distribution (compared to GPS). It is, however, remarkable that long time series of GLONASS ephemerides with sub–decimeter precision are now available. This precision is sufficient for many purposes of “everyday surveys”.

Because of the limited number of contributing analysis centers the consistency of the GLONASS satellite orbits from the combination (displayed in Figure 6) is not a very meaningful information to assess the quality of the orbits. Nevertheless an improvement of the consistency is evident — in particular after week 1400. Unfortunately, we cannot decide whether the network densification or the modelling refinements implemented into the processing caused this improvement. It is worth mentioning that since the beginning of 2008 — when ESOC started contributing with its new software package — a consistency level of 5 cm between the four analysis centers has been reached.

4 Impact of GLONASS on the Global Products

ESOC has twice processed the data from the year 2007: a first time as a GPS–only solution and a second time as a combined GPS/GLONASS solution. In Figure 7 results from the following comparisons for the GPS satellites orbits are shown with the RMS of the differences and the median

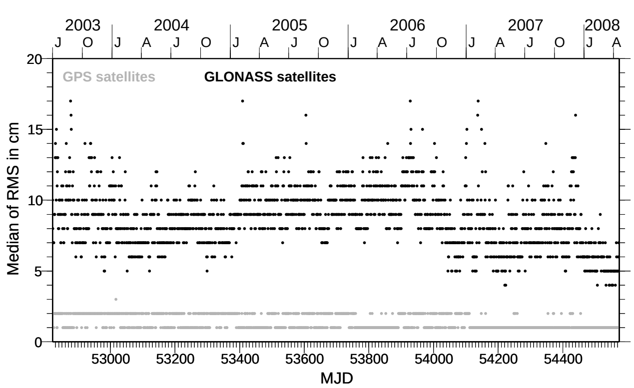


Figure 5: Median of the RMS for the fit of a three–day arc for the GPS (light–grey) and GLONASS (black) satellites obtained in the combined GPS/GLONASS processing at CODE since 2003.

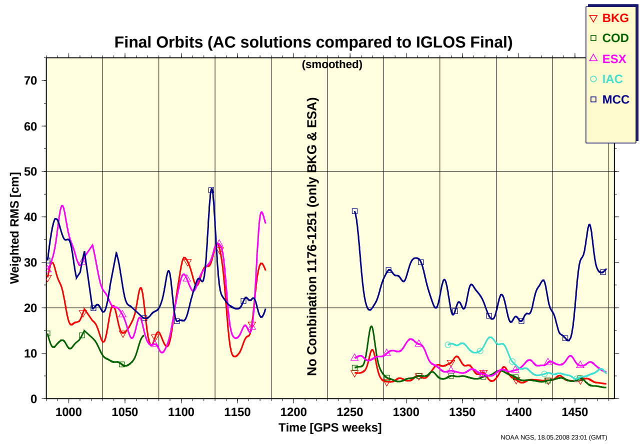


Figure 6: Consistency of the GLONASS satellite orbits accessed in the combination procedure (`http://www.ngs.noaa.gov/igsacc/WWW/`). (MCC is a solution based on SLR data for only three GLONASS satellites.)

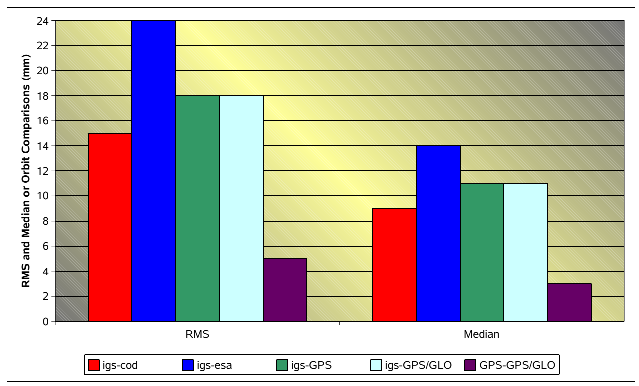


Figure 7: Comparison of the GPS–satellite orbits from a GPS–only and a combined GPS/GLONASS solution (computed from all days of year 2007).

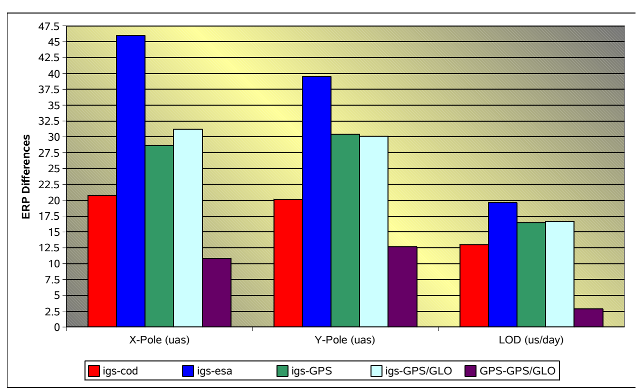


Figure 8: Comparison of the Earth rotation parameters from a GPS–only and a combined GPS/GLONASS solution (computed from all days of year 2007).

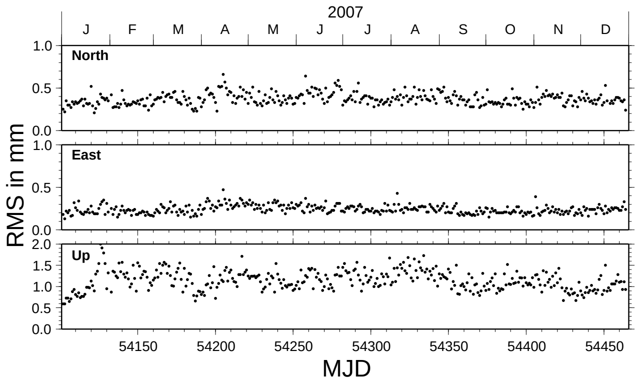


Figure 9: RMS of the coordinate differences obtained in daily GPS–only and combined GPS/GLONASS solutions in a global network during the year 2007, respectively

of the differences:

1. IGS combined orbits versus CODE final orbits
2. IGS combined orbits versus ESOC submitted final orbits generated by the old software package)
3. IGS combined orbits versus the orbits from a GPS–only solution generated with the new software package at ESOC
4. IGS combined orbits versus the orbits from a combined GPS/GLONASS solution generated with the new software package at ESOC
5. the GPS–only versus combined GPS/GLONASS solution both generated with the new software package at ESOC

In both solutions all relevant parameters were estimated: station coordinates, troposphere delays and gradients, Earth rotation parameters, orbit parameters, and ambiguity parameters that were not resolved to integer values.

The last bar shows the differences between the two solutions (with and without GLONASS) are of the order of 5 mm (violet bar). On the other hand, comparing both solutions to the combined IGS orbits (green and cyan bars) no advantage for one or the other solution can be detected. The figure confirms the (expected) improvement of the ESOC solution due to the transition to the new software package for the orbit products (blue and cyan bars).

The same kind of comparisons are provided for the Earth rotation parameters in Figure 8. The last bar (violet) indicates some differences between the GPS–only and combined GPS/GLONASS solutions. As for the orbits the comparison to the combined IGS ERP–solution shows no significant differences (green and cyan bars) between both solutions with and without including the GLONASS measurements. The same conclusion can be drawn for the station coordinates from this study at ESOC.

An similar study has been carried out at the CODE analysis center. The results confirm in general the findings of the experiment performed by ESOC. Figure 9 shows the daily RMS values in the North, East, Up components of the coordinate differences between two solutions with and without using GLONASS observations. About 150 sites are included in the global analysis. The processing corresponds closely to the CODE analysis strategy. Figure 9 provides a simple message: The global reference frame is only marginally affected when adding GLONASS measurements to the processing.

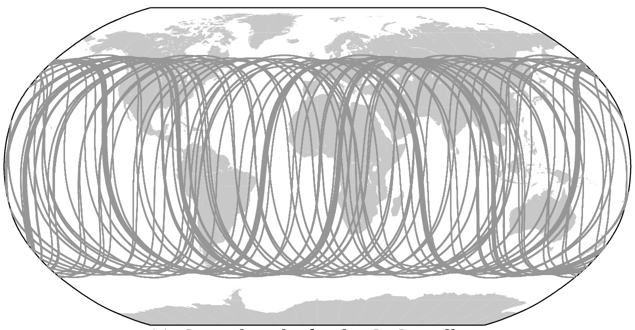
5 GPS and GLONASS Orbit Characteristics

The sub–satellite track of one particular GPS satellite repeats every day. It is therefore possible to show all sub–satellite tracks for the entire GPS constellation using one day as an example. As long as the satellites are not moved to a different position within the orbital plane, the same ground tracks result for each day. Figure 10(a) shows the ground tracks for all GPS satellites during ten days in February 2008. The GPS–specific ground tracks show that a particular satellite follows the same azimuth–elevation paths (at maximum two visibility intervals per day) for one and the same site. This implies in particular that the observation scenarios of particular GPS satellites are — for a given latitude — longitude–dependent. As the IGS network is not really global and homogeneous, this fact implies that different GPS satellites are most likely not observed with the same "intensity" and with the same quality. Figure 11(a) shows an example for the site Zimmerwald at a Northern latitude of about 45°. Note that the ground track actually corresponds to 10 days, which proves that the particular GPS satellite follows the same track day after day. Only one GPS track, culminating almost at 90° elevation results in this case. A site at the same latitude as Zimmerwald, but separated in longitude by $\pm 90^\circ$ would observe two tracks of the same GPS satellite per day, culminating at lower elevations, one in the East and one in the West.

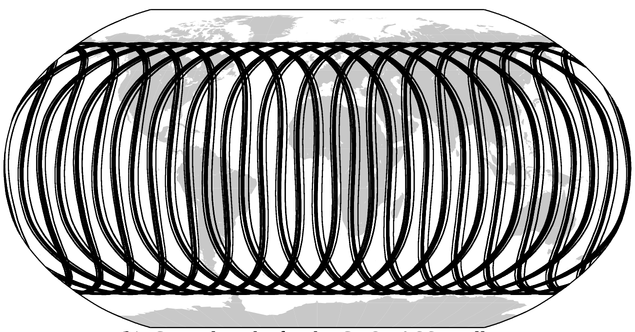
GLONASS ground tracks are repeated after 8 sidereal days (which corresponds to a $17:8$ commensurability with Earth rotation). The ground tracks of all 16 GLONASS satellites active on the same days in 2008 are shown in Figure 10(b). The ground track of a particular satellite is shifted by 45° in longitude per day. As the satellites in one and the same orbital plane are separated by 45° in the full nominal constellation, the ground track generated by one particular satellite on day i is the same as the ground track of its two neighbors on days $i \pm 1$. Therefore, one orbital plane of the GLONASS in essence generates one ground track, where all ground tracks are much steeper than the GPS ground tracks as a consequence of the 8 sidereal day repeat cycle. From the scientific perspective it is unfortunate that the arguments of latitude of the satellites in the three orbital planes are defined in such a way that the satellites in the three orbital planes all generate one and the same ground track. This characteristic may be attractive for the system operators (it reduces the number of necessary control stations) but it would be better from the scientific point of view to have a less regular pattern.

Be this as it may: It is an important difference of the GLONASS w.r.t. the GPS constellation that, on the average over 8 sidereal days, all sites at one and the same latitude observe each GLONASS satellite in essence in the same way (shifted only by a time offset governed by the longitude difference). Figure 11(b), which was generated in the same way as Figure 11(a) covering the time interval of 10 days, illustrates this behavior. One GLONASS satellite in essence fills the entire azimuth–elevation plot (except for the hole in the North, caused by the satellites' inclination of 65°). Due to the special selection of the arguments of latitude in the three orbital planes, Figure 11(b) also characterizes the ground tracks of all GLONASS satellites. As a matter of fact this leads to an eight–hour repeat cycle in the satellite geometry for the stations.

As each GLONASS satellite transmits its signal on an individual frequency the impact of frequency–dependent effects such as multipath on station–specific parameters (such as coordinates and troposphere) should be reduced for this constellation. For such issues we expect a period of four sidereal days (as opposed to one sidereal day for the GPS), because GLONASS satellites separated by $180°$ in the orbital plane use the same frequencies.

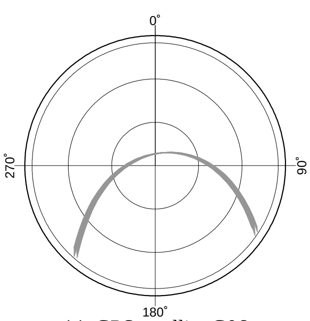


(a) Ground tracks for the GPS satellites

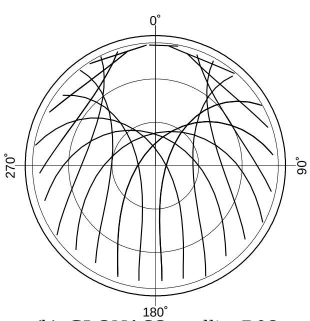


(b) Ground tracks for the GLONASS satellites

Figure 10: Ground tracks of the GPS (top) and GLONASS (bottom) constellation for 10 days (day 60 to 69 of year 2008) in February 2008.



(a) GPS satellite G06



(b) GLONASS satellite R06

Figure 11: Sky plot for one GPS (left) and one GLONASS (right) satellite for Zimmerwald, Switzerland, covering 10 days (day 60 to 69 of year 2008) in February 2008.

6 Benefit of the Combined GNSS Products on Navigation and Rapid Positioning

The global distribution of the PDOP for a GPS–only constellation is shown in Figure 12 (left). The current GLONASS constellation consists of only 16 active satellites (13 in November 2007). From these numbers we may expect an accuracy gain of the combined system for navigation and for positioning using short (few minutes) time spans of about $\sqrt{31/16} \approx \sqrt{1.5} \approx 1.22$ in a least squares adjustment. Figure 12 (right) shows the gain according to the different latitudes: about 10% in equatorial regions, about 20% in mid–latitude regions and nearly 30% in the polar regions. The higher improvement in the polar regions is a consequence of the higher inclination of the GLONASS satellites (55° for GPS; 65° for GLONASS).

The PDOP value in essence gives the average of the mean errors in the three orthogonal directions North, East, Up of a position determination assuming code observations of the accuracy of one meter (remember that smaller PDOP values correspond to better satellite geometry ...). The same PDOP may be used for phase observations with resolved ambiguities, where the unit would be mm. The expected accuracy gain is not dramatic. With the full 24 satellite constellation the gain will be $\sqrt{(32+24)/32} \approx 1.32$. More important, but more difficult to illustrate is the gain in robustness of the solution, e.g., the higher redundancy for the preprocessing in case of kinematic solutions.

This improvement in the PDOP by adding the GLONASS data seems to be in contradiction to the conclusions of Section 4. The PDOP reflects the satellite geometry for the location of a receiver for a specific epoch, which is mainly relevant for a kinematic positioning. So we carried out the following experiment: The European network solution, the CODE contribution to the EPN (European Permanent Network, [Bruyninx and Roosbeek, 2007]), was processed in daily batches, for a two month interval. The orbits and the coordinates of the reference stations were introduced from the official CODE contribution to the IGS (final so-

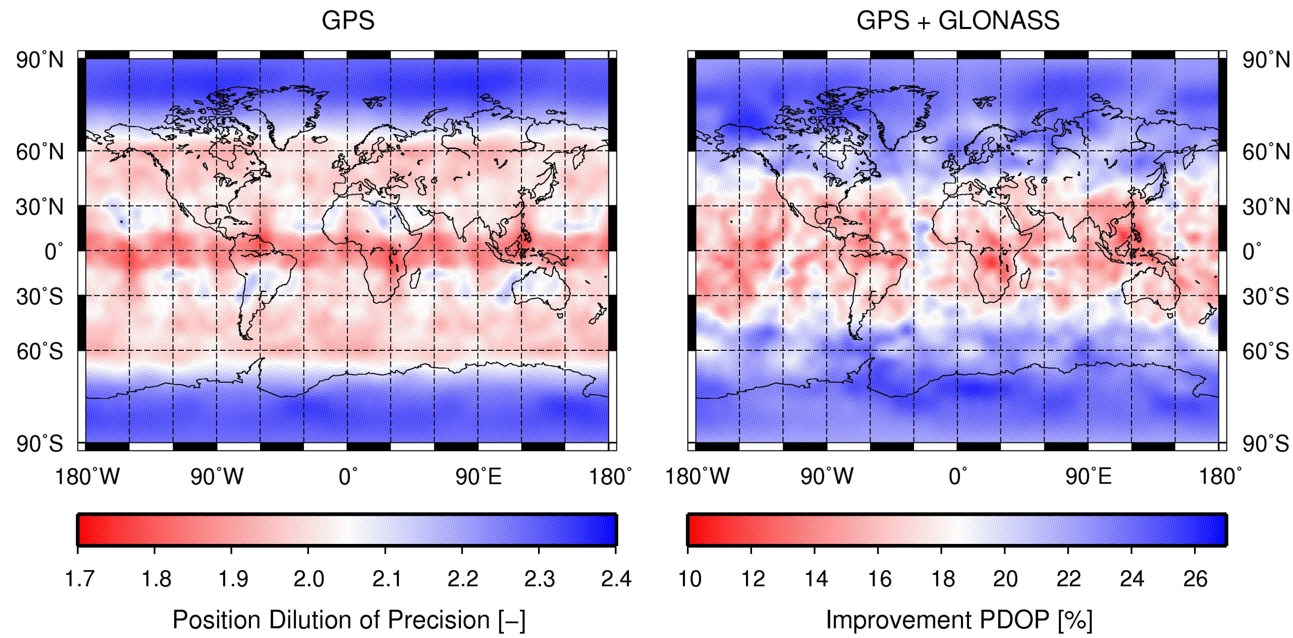
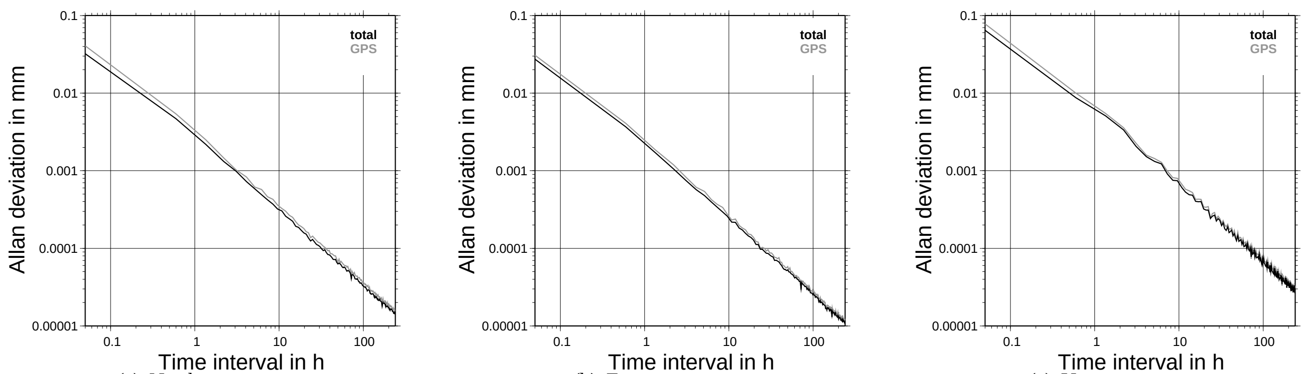


Figure 12: The PDOP for a GPS–only constellation (left) and the improvement of the PDOP by adding the GLONASS constellation (as it was available in November 2007)



(a) North component

(b) East component

(c) Up component

Figure 13: Allan deviations of the kinematic positions (at 3-minute intervals over 60 days) of the combined GPS/GLONASS receiver in Zimmerwald (ZIM2) using only GPS measurements (grey line) and observations from both GNSS (black line), respectively.

lution) and to the EPN. The coordinates of the other sites and the troposphere parameters were adjusted in the experiment. The combined GPS/GLONASS receiver at Zimmerwald observatory (ZIM2) was considered as "mildly kinematic", i.e., coordinates were determined at 3 minute intervals whereas the ambiguities were introduced as known from the standard network processing. Only the GPS observations were used for all stations in the solution in the first part of the experiment, all observations (GPS and GLONASS) were used in the second part. It would have been attractive to generate a third solution using only the GLONASS measurements. In view of the limited number of simultaneously visible GLONASS satellites, such a solution makes little sense.

Allan deviations (see [Allan, 1987]) were generated with the two sets of three minutes solutions for the Zimmerwald station (all in all 30'240 data points within 63 days). The Allan deviations referring to a spacing of τ between data points are given by

$$\sigma(\tau) = \sqrt{\frac{1}{2(N-2)\tau^2} \cdot \sum_{i=1}^{N-2} \left(x_i - 2x_{i+1} + x_{i+2}\right)^2} \,,$$

where the data values x_k, $k = i, i+1, i+2$ refer to epochs separated by τ.

The black line in Figure 13 refers to the combined processing of GPS and GLONASS measurements, whereas the grey line is obtained from the GPS–only solution. For short time intervals (up to a few minutes) the Allan deviation is dominated by the noise of the carrier phase (see also [Dach et al., 2007]). In this domain the additional GLONASS measurements help according to the $\sqrt{n}$–law to reduce the noise of the kinematic positions by 20 to 30%. For longer intervals — let us say half an hour or more — the improvement becomes very small. For intervals of one hour and longer the difference between both curves is even smaller, but the black one (GPS/GLONASS solution) remains slightly below the grey line (GPS–only solution).

This behavior might — at least partially — be explained by the higher variability in the satellite geometry of the incomplete GLONASS constellation.

7 Reviewing file formats concerning multi–GNSS

In this section we discuss whether the currently used file formats cover the needs for the current (GPS/GLONASS) and future (GPS/GLONASS/Galileo/Compass) multi–GNSS constellations. We also want to summarize the status of the current developments:

RINEX The new RINEX 3 is defined and covers all needs for the multi–GNSS processing in future. Unfortunately it is not really in use within the IGS.

SINEX The current format covers all needs of a routinely multi–GNSS analysis.

Troposphere SINEX No adaption for a multi–GNSS processing is necessary.

clock RINEX Station clocks must be separable for different GNSS because some receivers show more than only an offset between the systems (see [Schaer, 2007]).

SP3c In the current format there are not enough positions for the satellites from all expected GNSS. A corresponding format extension is under discussion.

ERP The current format meets all needs of a multi–GNSS processing.

DCB Today we have for GPS only P1−C1, P2−C2, P1−P2 code biases and the 1/4–cycle–phase shift for a very limited number of receivers. For GLONASS one GPS–GLONASS receiver clock bias as well as GLONASS inter–frequency code biases need to be considered ([Dach et al., 2006]).
Much more biases have to be expected considering to have three GPS and GLONASS respective five Galileo frequencies in future. This aspect should be addressed and solved in the working group on "biases and calibrations".

8 Summary: Perspective of Multi–GNSS in the IGS

The IGS has promised to become a GNSS service by changing its name two years ago. Nevertheless, in practice it is still a GPS service today — with a marginal extension to GLONASS. On the other hand, there are commercial companies providing real multi–GNSS products on at least a comparable quality level as the IGS product lines. In this section we describe the current status and the expected development within the IGS in the near future. We also describe what would be necessary to develop the IGS into a full GNSS service.

Network: An increasing number of multi–GNSS receivers is expected in the IGS network. Because not only the receiver but also the antenna needs to be changed in order to guarantee optimum performance, the station managers are asked to consider options that help to retain the stability of the reference frame (e.g., by providing data from the old and new receiver in parallel as far as possible — according to the general recommendations of the IGS).
Concerning Galileo: the exchange of the equipment within the network may take place more rapidly than the transition from a GPS–only to a combined GPS/GLONASS network observed today. This may enhance the problem of the stability of the reference frame.
To become an International GNSS Service: Replacements of receivers in the IGS network have to be associated with the transition to modern multi–GNSS stations. New IGS–sites are only accepted if they provide the observations from all active GNSS.

Processing: Since the beginning of 2008 ESOC provides fully consistent GPS/GLONASS products from a rigorously combined processing comparable to the approach CODE follows since May 2003. There are plans for including GLONASS into the processing at the CNES–CLS analysis center. Unfortunately there are no activities in view by the established analysis centers of the IGS to contribute to GLONASS orbits neither in a separate nor in a fully combined mode. On the other hand, nearly all analysis centers announced an interest in processing of Galileo data.
To become an International GNSS Service: All (or at least a substantial number) analysis centers have to provide combined products from all active GNSS. In the current situation it means that the ACs included into the combination have to provide combined GPS/GLONASS products after a development phase of in maximum two years.

Combination: Since we have now two ACs providing fully combined and consistent orbits we need not a GPS–only plus an experimental, independent GLONASS–only combination but a combined

GPS/GLONASS orbit combination procedure (with an alternative GPS–only combination or — better — an extraction of orbits).

To become an International GNSS Service: a rigorous combined analysis of the satellites from all active GNSS is required. A corresponding update of the combination software should not only consider GLONASS as the second active GNSS today but it should be open to all future GNSS.

Validation: Let us finally mention that the only two GPS satellites carying SLR reflectors are very old and their decommissioning is expected in the near future. An independent validation of the GNSS orbits derived from the microwave signals will only be possible with non–GPS satellites (in near future GLONASS but later also Galileo or possibly Compass). Systematic studies (e.g. [Urschl et al., 2007]) have demonstrated the importance of this validation.

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