GAMIT/GLOBK for GNSS

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The promise …

- When GPS, Glonass, Beidou, and Galileo are deployed and modernized, there will be > 100 satellites and 12 distinct frequencies available for tracking
- Obvious advantages for kinematic positioning and atmospheric studies, but also a means to separate periodic signals due to aliasing in the GPS orbits
- Full deployment expected by 2020, but constellations > 20 SVs by mid-2018 should provide highly useful results

GNSS available in GAMIT/GLOBK

- As of GAMIT/GLOBK release 10.61 (2017-04-01), the following Global Navigation Satellite Systems (GNSSs) may be processed
  - ✔ GPS (USA), BeiDou (China), Galileo (Europe), IRNSS (India)
  - ✘ GLONASS (Russia), QZSS (Japan)
- GNSS code is in trial and we need testers
  - Bug-fixed and alpha-tested code is in the updates/source directory as gnss_170616.tar.gz, to be untarred at the gg level ***after*** the current incremental_updates.

  GNSS data must be processed *separately* for each system in GAMIT, i.e. one cannot process GPS data and Galileo data simultaneously

Why process separately?

- Dual-frequency observations are fundamental for GNSS to remove the ionosphere and are easily implemented under the current structure of GAMIT, but processing different systems across more than two frequencies simultaneously requires a different algorithmic approach and will take some time to implement
- Solution (h-) files from multiple systems (as with multiple sub-nets) can be rigorously combined in GLOBK to estimate site coordinates and velocities for static observations
- Based on research thus far, it is not clear that joint processing will Improve results for the long-sessions used for mm-level measurements, though that may change as the systems mature (improved orbits and knowledge of inter-system signal biases)

Processing GNSS in GAMIT/GLOBK

Version awareness and warnings

- A major change between GAMIT/GLOBK 10.5 and 10.6 was the format of many tables (e.g. dcb.dat, svnav.dat, etc.) to accommodate code changes for GNSS
- GAMIT/GLOBK 10.61 now builds upon the new file structures to deliver the data processing capability
- Given these major changes, many tables used in GAMIT/GLOBK 10.6 and 10.61 are *not* backwards compatible with GAMIT/GLOBK 10.5 and prior releases
- You *cannot* use many tables that came with GAMIT/GLOBK 10.5 and prior to process (GPS-only or GNSS) data using GAMIT/GLOBK 10.6 and later

Suggestions for processing strategies

- If you wish to combine data from different GNSS, process each system in a separate experiment directory, e.g. /2017g and /2017e for GPS and Galileo
- Download the RINEX files in advance to check for availability of GNSS signals
- For `sh_gamit` use the "`-gnss`" option to specify the GNSS; and COM1 for "-orbit" (IGSF ok for GPS)
- Check the orbit-fit rms files in the /igs directory to assess the orbit quality
- Combine the resulting h-files in GLOBK to produce a single result (time series or velocities)

RINEX files

- RINEX 2, which is still by far the most common format of RINEX file, was designed in an era when only GPS was viable for observation
- Since the redesign of GPS to broadcast a second code on L2 ("L2C") specifically for civilian use, the restoration of GLONASS and the introduction of other navigation satellite systems, RINEX 2 no longer suffices to track all available observations
- Be very careful with how you translate and use other people's RINEX 2 files with L2C (see Berglund et al., 2010; Blume et al., 2012; and http://kb.unavco.org/kb/article/the-effects-of-l2c-signal-tracking-on-high-precision-carrier-phase-gps-postioning-689.html)

GAMIT

- Several scripts now have an additional option ("`-gnss`") that sets the type of GNSS
  - Most likely to use directly: `sh_gamit`, `sh_get_orbits`, `sh_sp3fit`
  - Less likely to use directly: `sh_preproc`, `sh_bcfit`, `sh_rxscan`, `sh_get_times`, `sh_makexp`
- Valid arguments are (only one of)
  - `G` (GPS)
  - `R` (GLONASS; not yet coded or available to use)
  - `C` (BeiDou-2/COMPASS)
  - `E` (Galileo)
  - `J` (QZSS; not yet coded or available to use)
  - `I` (IRNSS)
- The default is still "G" (GPS)

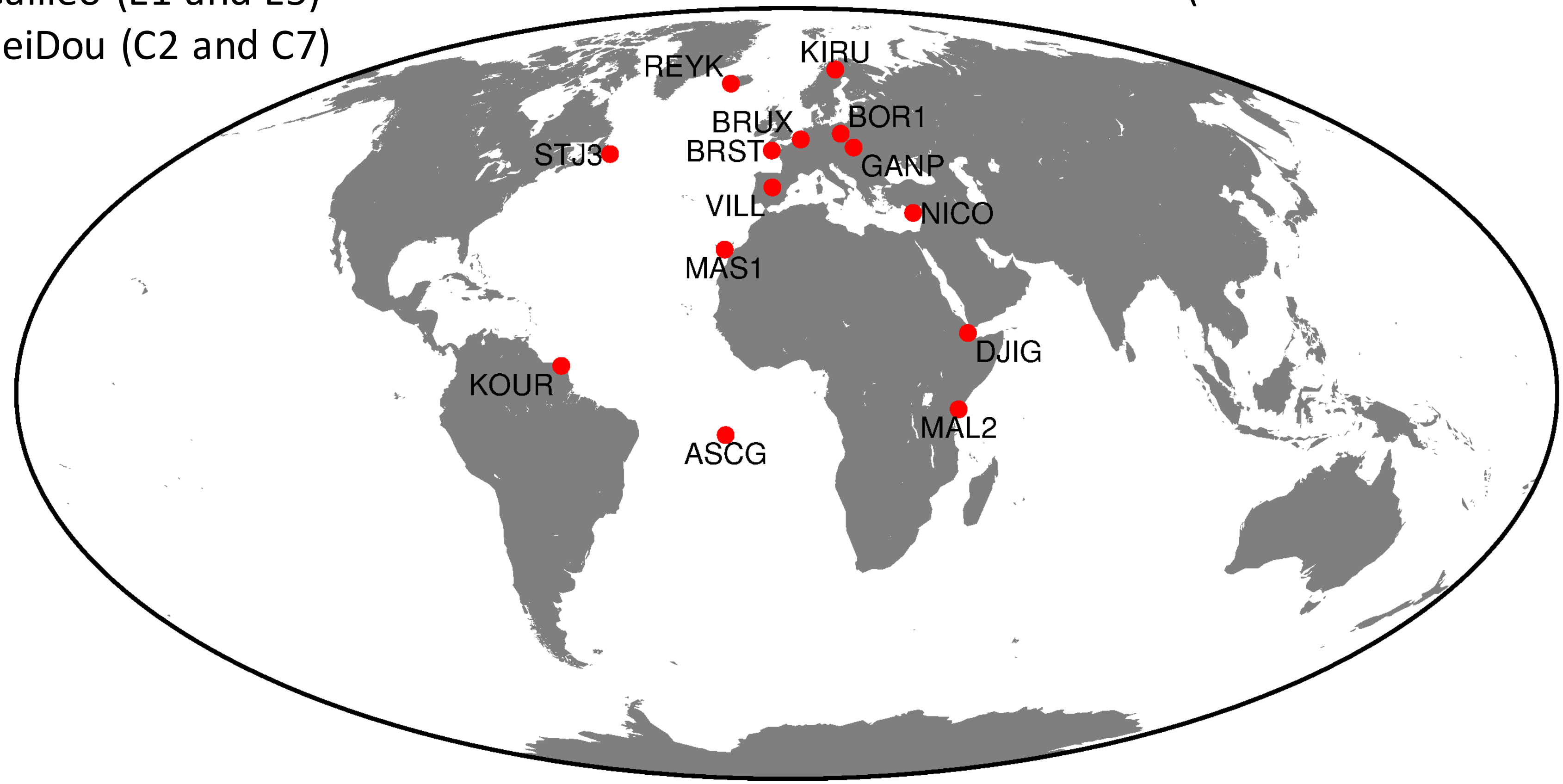
GLOBK

- GLOBK should work in the normal manner except that you cannot include orbits in the h-file (use BASELINE in GAMIT sestbl.)
- See GLOBK lectures, including those on creating time series using `glred` and combination or velocity solutions using `globk`

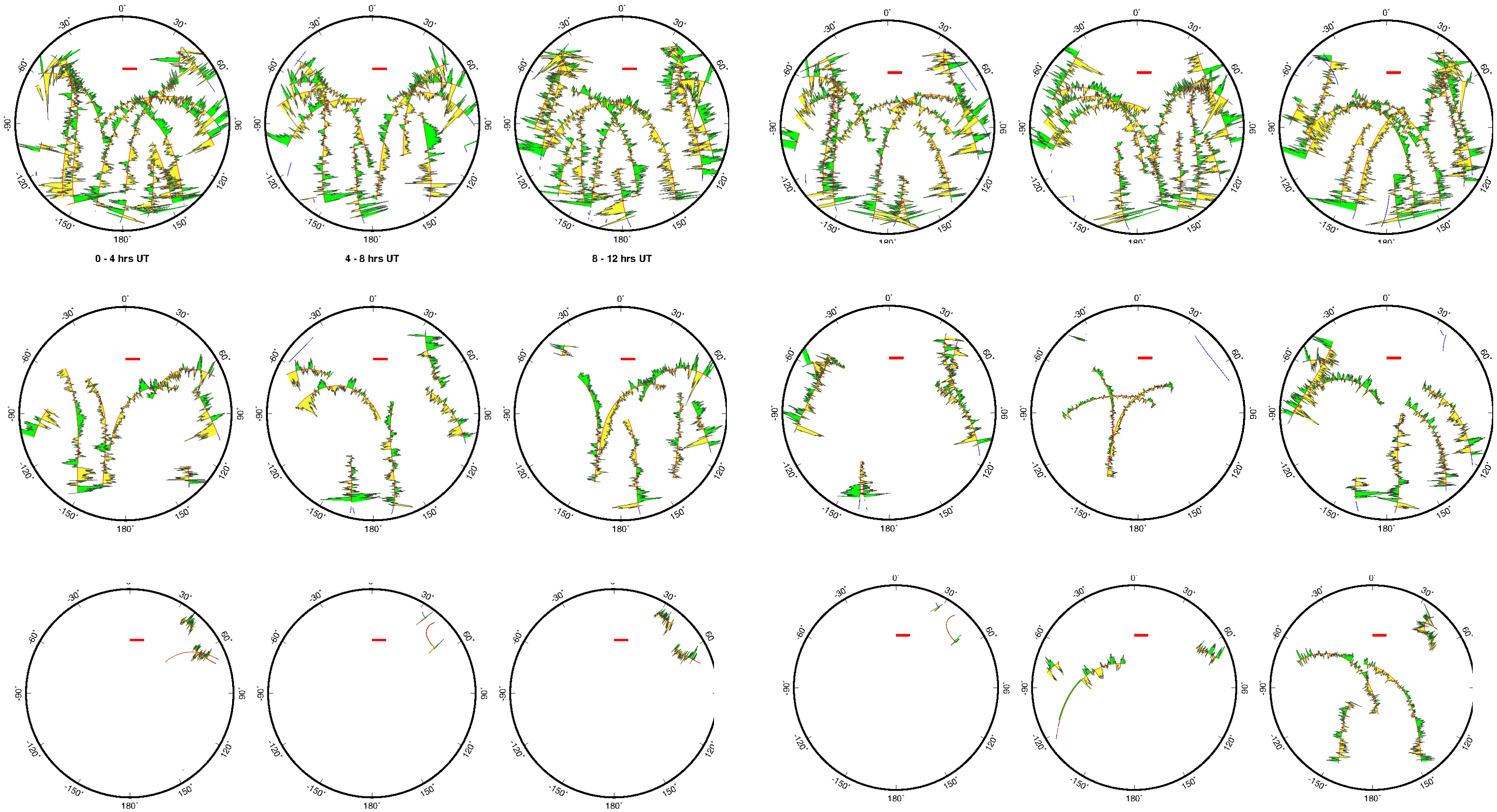
Results of initial tests

Systems processed:
GPS (L1 and L2)
Galileo (E1 and E5)
BeiDou (C2 and C7)

5 days processed
(2017-121 to 2017-125)



Sky tracks Day 121 at Spanish site VILL
Each circle covers a 4-hr window



GPS

Galileo

Beidou

Phase RMS (for 2017-121)

From sh_gamit_121[gec].summary (mm):

Site	GPS	Galileo	BeiDou
ASCG	7.8	9.1	4.8
BOR1	5.6	5.9	6.7
BRST	8.5	9.7	7.0
BRUX	4.4	5.0	4.7
DJIG	5.9	8.0	17.1
GANP	5.9	6.6	8.4
KIRU	6.8	8.0	10.7
KOUR	10.6	12.6	5.5

Site	GPS	Galileo	BeiDou
LAMP	4.5	6.2	6.2
MAL2	7.7	10.0	12.7
MAS1	7.1	8.1	3.1
NICO	6.1	9.1	22.1
REYK	8.4	11.1	8.3
STJ3	5.3	6.0	2.3
VILL	8.1	9.6	5.1
ALL	*7.1*	*8.6*	*11.3*

Ambiguity resolution

Best from sh_gamit_<DDD>[gec].summary:

System	Wide lane (WL)	Narrow lane (NL)
GPS	98%	91%
Galileo	99%	78%
BeiDou	80%	50%

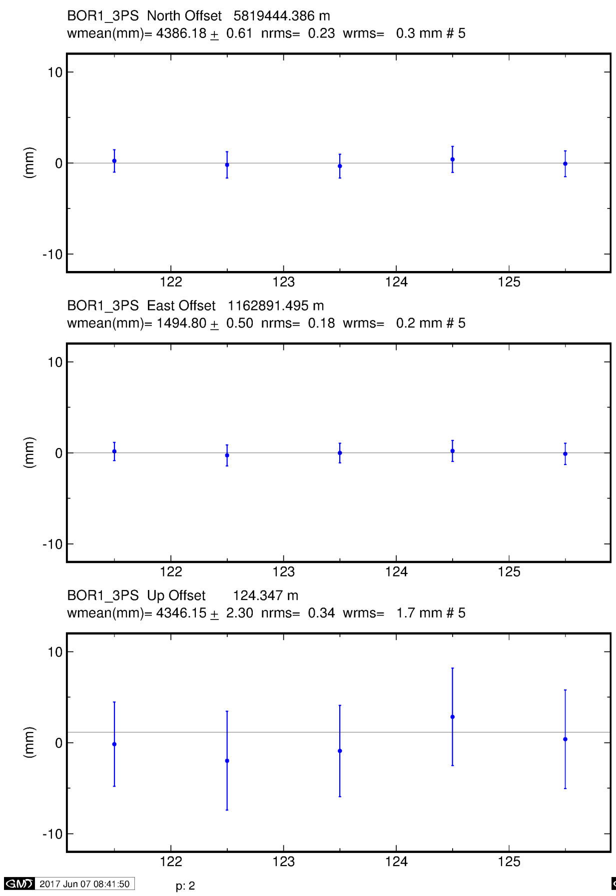
Time series stabilization

From “POS STAT” lines in .org-file(s) (mm:

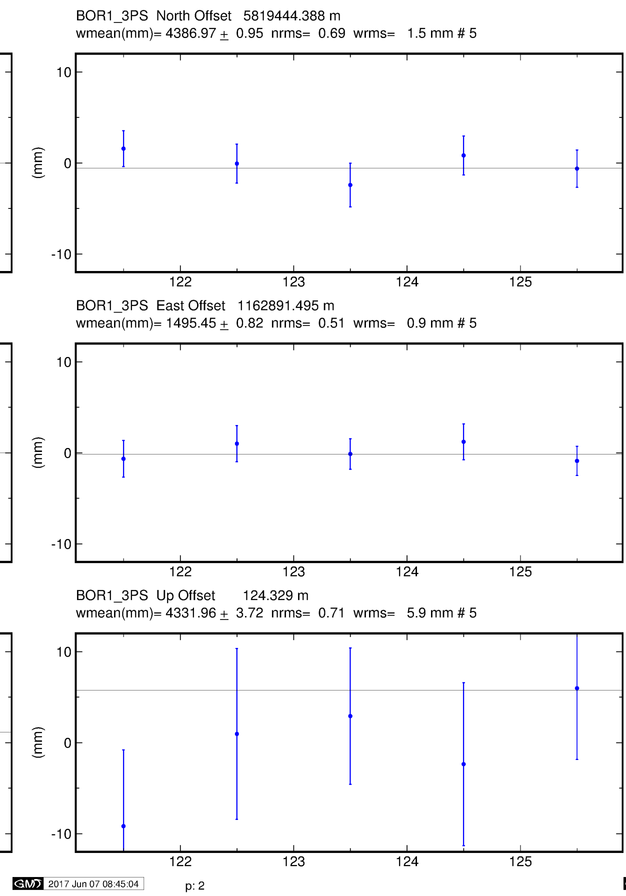
System	Sites	E	N	U
GPS	10	1-2	1–2	6–10
Galileo	9-10	2-3	2–4	11-16
BeiDou	6–9	1–7	3–9	6–18

Example time series

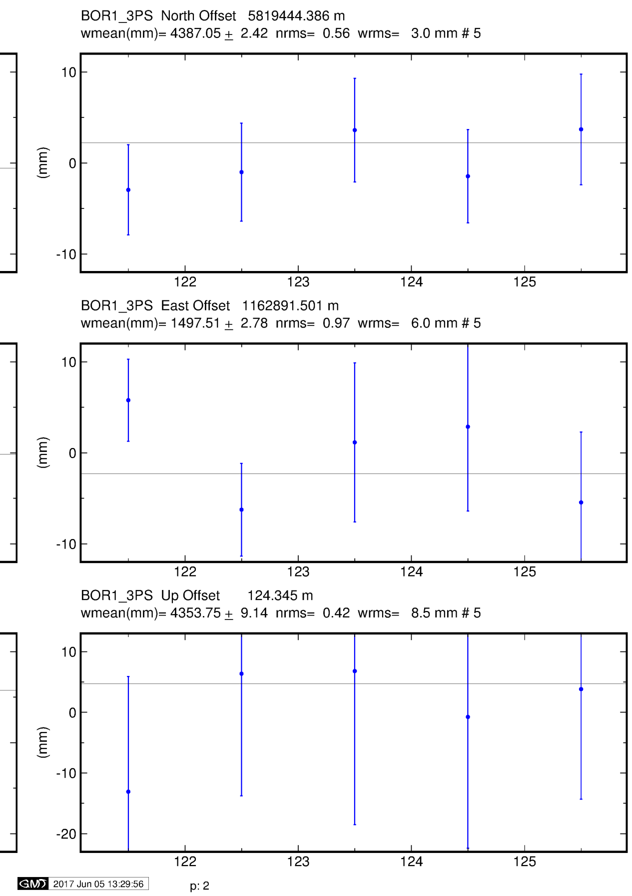
GPS



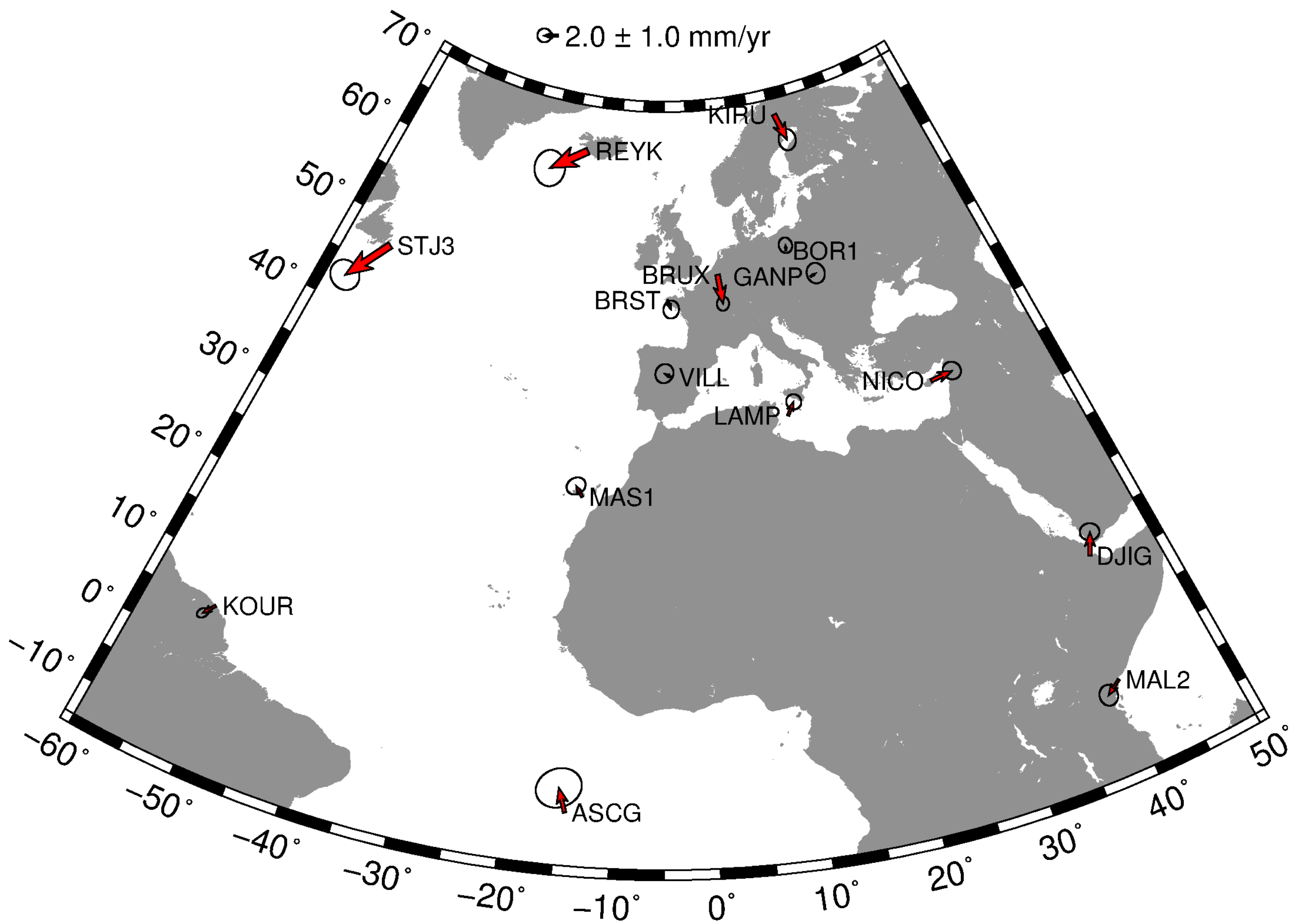
Galileo



BeiDou



Position differences (GPS versus Galileo)



Initial impressions

- Galileo has robust phase tracking and could, for small regional networks with good satellite coverage, now produce nearly GPS-quality results
- The Beidou constelletion will need to be filled out significantly, expected by mid-2018
- BeiDou also appears to be prone to single cycle slips, resulting in poor detection and cleaning of tracked phase
  - This may be improved by tuning autcln.cmd

Summary

- GAMIT/GLOBK is now (as of 10.61) capable of processing almost all GNSS data, except
  - GLONASS, which has variable frequencies and, as such, requires a redesign of the software's structure and flow
  - QZSS, which is a small, regional, high-altitude system of little use beyond the narrow design region or on a global scale (same is true of IRNSS, although this is coded)
- GNSS data are available but few users are actually collecting or processing such data
- As a result, global orbits are poorly constrained by ground stations with accurate coordinates in the terrestrial reference frame
  - Satellite orbital models and antenna designs are less well known than GPS
  - Many GNSSs other than GPS are in a similar "weak" state to where GPS was in the early 1990s before the advent of the IGS
- It is difficult to predict at what time the other systems will enhance rather than degrade GPS results but we should see rapid improvement with the launch of more satellites and the expansion of the tracking network in the next 18 months

References

Berglund, H., F. Blume, L. H. Estey, and A. A. Borsa (2010), The Effects of L2C Signal Tracking on High-Precision Carrier Phase GPS Positioning, Abstract G11B-0640 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Blume, F., H. Berglund, and L. Estey (2012), The Effects of L2C Signal Tracking on High-Precision Carrier Phase GPS Positioning: Implications for the Next Generation of GNSS Systems, Abstract G52B-07 presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec. [http://acc.igs.org/trf/agu12_blume_l2c.pdf]

http://kb.unavco.org/kb/article/the-effects-of-l2c-signal-tracking-on-high-precision-carrier-phase-gps-postioning-689.html

Montenbruck, O., R. Schmid, F. Mercier, P. Steigenberger, C. Noll, R. Fatkulin, S. Kogure, and A. S. Ganeshan (2015), *Adv. Space Res.*, 56, 1015–1029, doi:10.1016/j.asr.2015.06.019.