Multi-GNSS SPP simulation for various variants of systematic and random errors

Zofia Rzepecka, zofia.rzepecka@uwm.edu.pl

Jakub Kalita, jakub.kalita@tu.koszalin.pl

1. Abstract

The poster presents accuracy analysis of simulated SPP results. The results are obtained using GPS, GLONASS, Beidou and Galileo systems in various combinations. The simulations allowed to investigate different scenarios of errors, both systematic and random. Sources of errors in GNSS measurements were analyzed and on this basis the process of observations simulation was conducted.

The simulations were based on precise orbits of all available satellites and analysis of the various factors affecting the determined position, such as the ionosphere and troposphere.

Simulated observations were used instead of the actual, because this allowed for studies involving different satellite systems, not always available in the recorded observations from actual permanent stations.

To verify the simulation, the results obtained from simulated scenarios were compared with the actual observations taken from IGS stations.

Abstract (2)

Simulated observations were used instead of the actual, because this approach allowed for studies involving different satellite systems, not always available in the recorded observations from actual permanent stations.

In order to verify the simulation models, the results obtained from simulated observations were compared with the actual observations taken from IGS stations. Achieved average compliance is promising. The results of the study are maps of selected regions of the world showing the number of observed satellites, DOP factors, mean positioning errors, differences between computed and true positions, depending on various factors such as the size of systematic and random errors and the selection of GNSS systems used in the positioning.

2. Error sources and considered effects

- **Considered:**
  - Orbit
  - Satellite clocks
  - Troposphere
  - Ionosphere
- **Neglected in this elaboration (SPP vs PPP):**
  - Relativistic effects
  - Satellite orientaion
  - Phase windup
  - Etc. (see eg. Martin I., 2013)

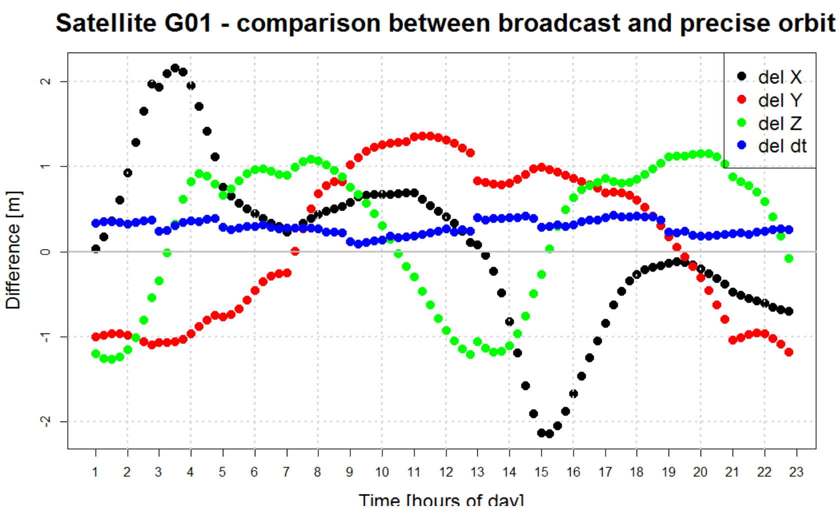
3. Assumed satellite orbit&clock accuracy

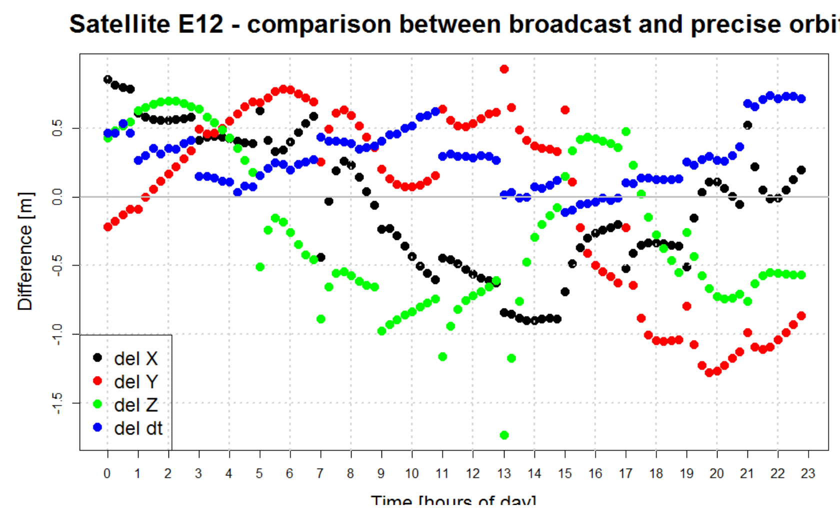
Type of source	Assumed position accuracy	Comments
Precise final	$\sim 2.5\ cm$	Available for G, R, E, C (1)
Precise predicted	$\sim 5\ cm$ (2)	Available for G (3)
Broadcast	GPS, Glonass, Galileo: $\sim 1m$ (2) Beidou: $\sim 10\ m$ (2)	Available for G, R, E, C (4)

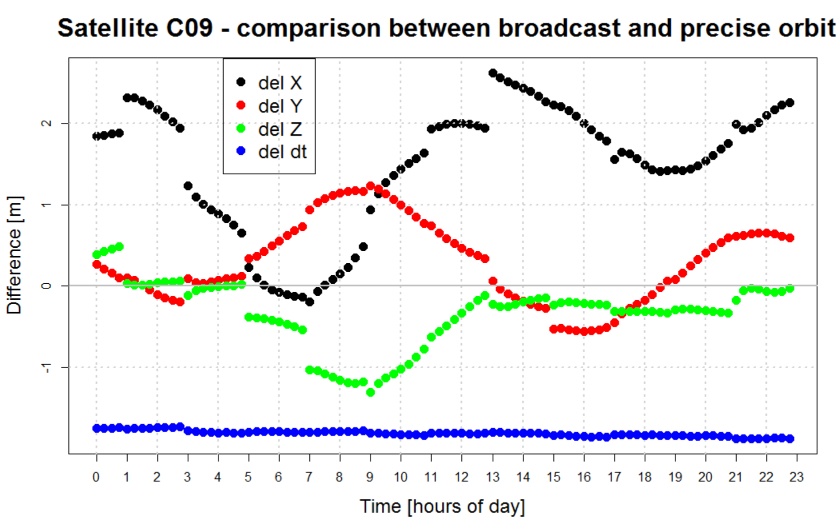
Type of source	Assumed clock accuracy	Comments
Precise final	$\sim 70\ ps\ (\sim 2\ cm)$	Available for G, R, E, C (1)
Precise predicted	$\sim 5\ cm$ (2)	Available for G (3)
Broadcast	GPS, Glonass, Galileo: $\sim 1m$ (~2.5 ns) (2) Beidou: $\sim 10\ m$ (2)	Available for G, R, E, C (4)

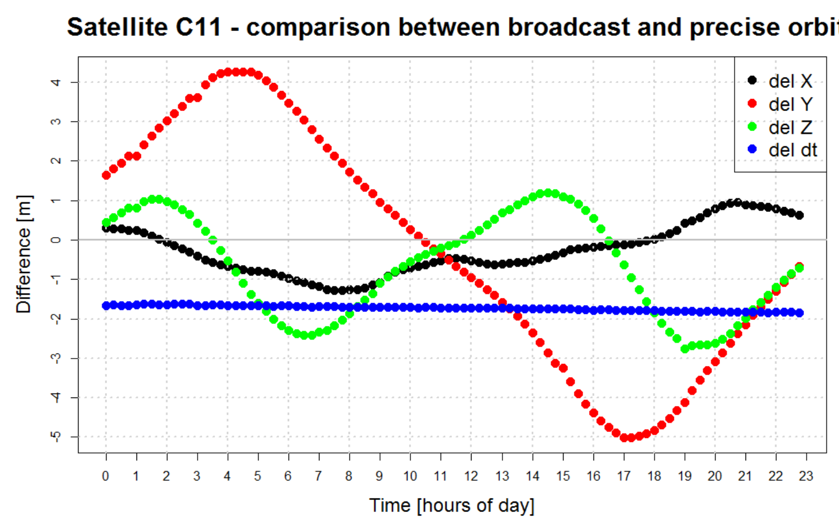
(1) - ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/ (Noll, 2010)
(2) - see example plots on next pages
(3) - ftp://cddis.gsfc.nasa.gov/pub/gps/products/ (IGS, 1992)
(4) - ftp://cddis.gsfc.nasa.gov/gnss/data/campaign/mgex/daily/rinex3/2016/001/16p/

Precise & Broadcast orbit - comparisons

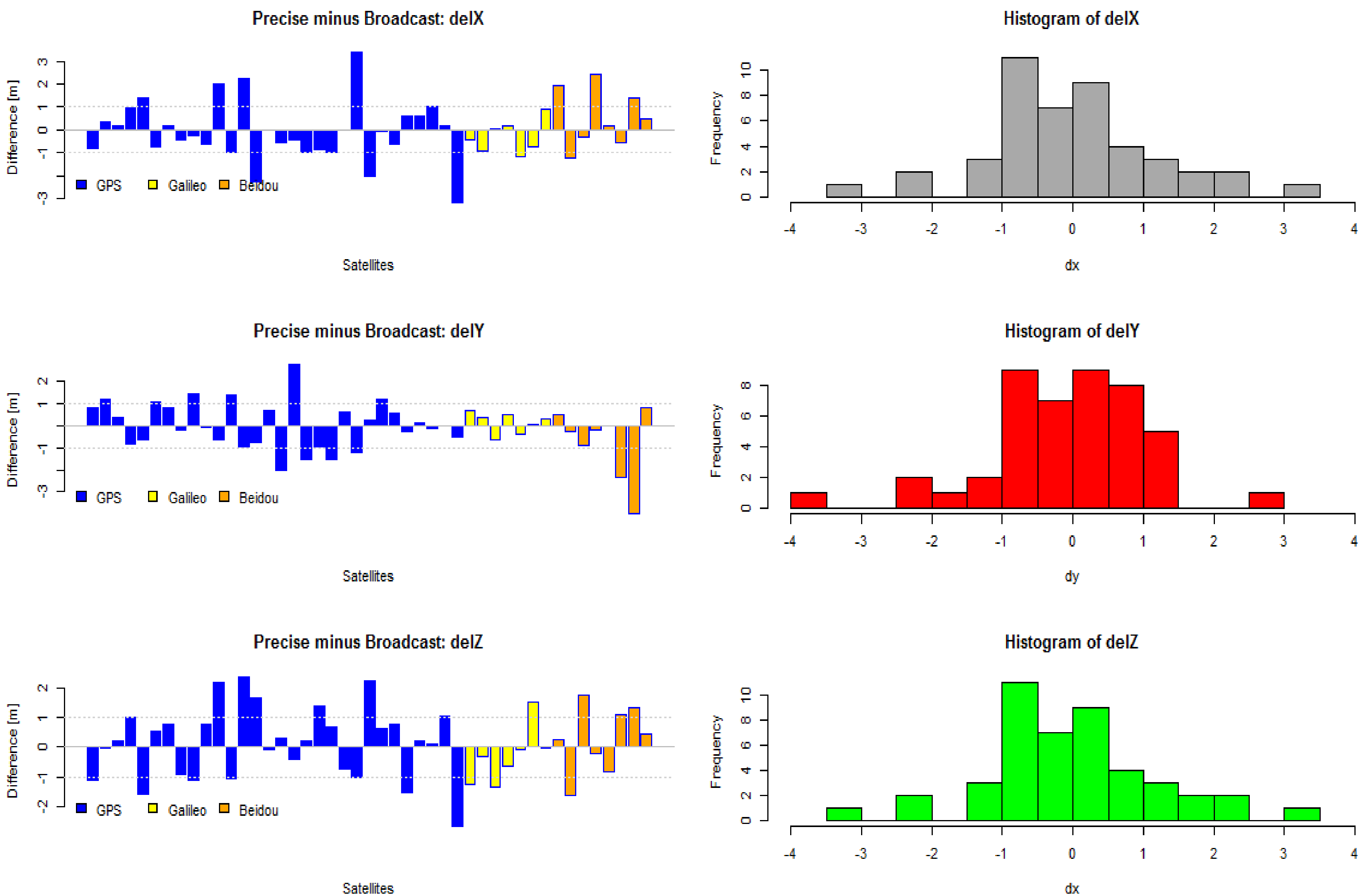








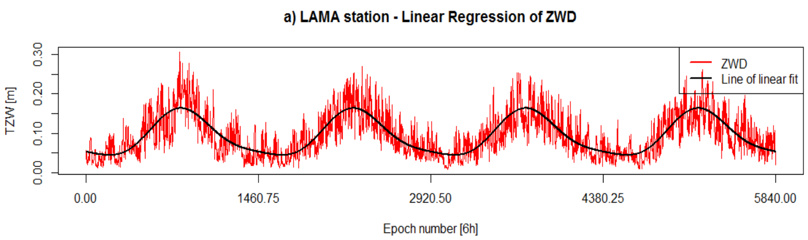
Precise & Broadcast – difference distributions at a given epoch (1.01.2016, 0h0m0s)

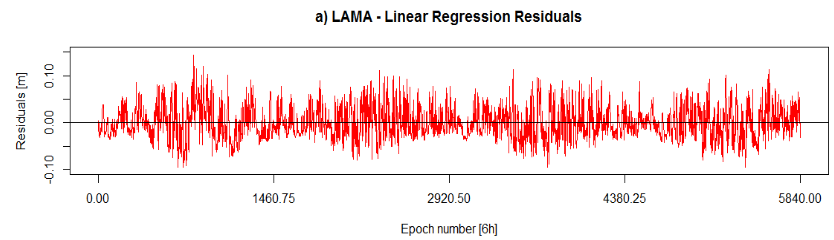


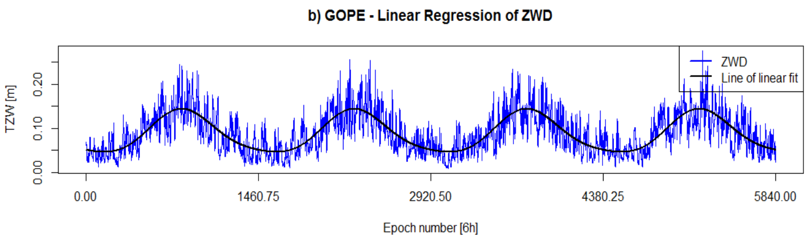
Tropospheric delay

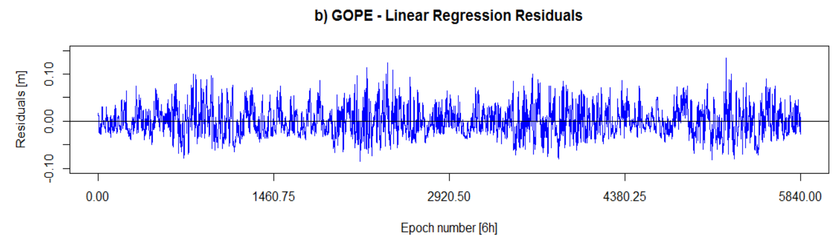
- To deal with a single parameter for all observed satellites, **zenith troposphere delay** (ZTD) is modeled
- ZTD is divided into the zenith **hydrostatic** delay (ZHD) and zenith **wet** delay (ZWD)
- The proportion of hydrostatic to wet delays is about 90% to 10%.
- The **slant tropospheric delay** (STD) is modeled using mapping functions for both ZHD and ZWD
- ZHD can be well determined from local meteorological measurements, while accuracy of **ZWD** is about 2.5-4.0 cm (Böhm et al 2015)

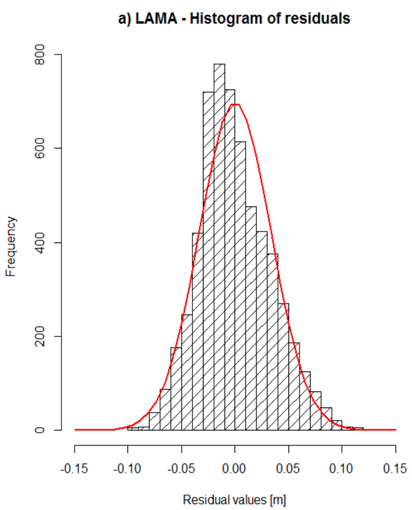
Examples of tropospheric ZWD data

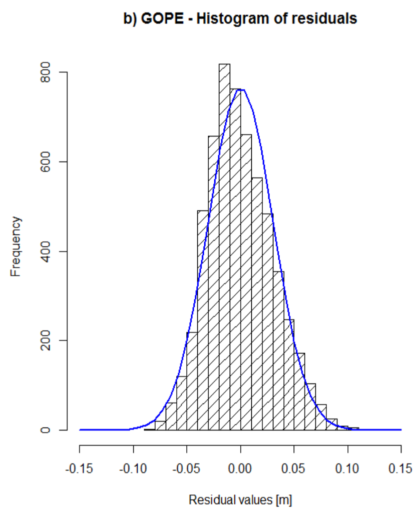












- ZWD data acquired from the service of Vienna Technical University: http://ggosatm.hg.tuwien.ac.at/DELAY
- IGS stations LAMA and GOPE are presented in the examples
- On the basis of (Rzepecka et al., 2015)

Ionospheric delay – considered cases

- **Total ionospheric effect** on GNSS signals is heavily dependent on state of the ionosphere, location of the station and local time
- Its absolute value, given in meters, **can reach ≈15 m** (at about 14-15 h of local time, on the equatorial regions, on disturbed days), see eg. (Stępniak et. al., 2014)
- On average, for computation of UERE it is often admitted that the bias caused by ionosphere is **of the order of 4 m** (Hofmann-Wellenhof et al., 2008)
- The simplest model, available via broadcast message, is **Klobuchar model**, it is assumed to reduce the effect by about 50% (Hofmann-Wellenhof et al., p. 123, Stępniak et al., 2014)

Ionospheric delay – considered cases

- Dual-frequency receiver users can take advantage of **ionosphere-free combination**
- It takes into account the **first order** effect of the refraction, leaving about 4 cm of unreduced error (Martin I., 2013)
- **Predicted ionosphere**: 1 h (accuracy order of 15 cm), 6-12 hour forecasts (accuracy of order of 45 cm) (Codrescu et al., 2012)

Goals of simulations

- Even better and fuller use of many products, eg. (IGS, 1992)
- Prediction may be made anywhere in the world
- It is anticipated that these simulations will provide the basis for a „**software generator**” of GNSS observables
- Which will help to test software, to decide which constelations to observe
- To predict accuracy of GNSS determinations under assumed conditions at any chosen location
- To analyze factors which mostly influence the results

Method of performing the simulations

- Using the last available **multi-GNSS precise orbit** and tested (arbitrary) location - calculation of set of ideal (considered as true) distances to all available (with elevations greater than admitted) satellites
- **deterioration** of ideal distances according to admitted models of errors (normal distribution, with assumed SD)
- Errors are divided into **elevation-dependent** (atmospheric) and elevation-independent (like orbital, clocks, observational)
- **Mapping** of atmospheric biases according to (simplified) mapping functions (here 1/sin(elev))
- Simulated user position recalcualtion, via (**one-epoch-SPP**)-like adjustment
- Comparison of both the positions (ideal and recalculated)
- Examination of accuracy estimation parameters

Method of performing the simulations

- **Calculations** can be performed for a chosen location or on a chosen grid of locations
- **Precise orbit used**: com18775.sp3, CODE MGEX ORBIT, available at: ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/1877/
- **Epoch:** 2016.01.01, 0h0m0s
- **Normal distribution** generating: sqrt(2*log(rand))*sin(2*pi*rand), sqrt(2*log(rand))*cos(2*pi*rand) (all math functions: according to MS Fortran 90 libraries)
- The computations were performed for cells of $10^0 x 10^0$
- Standard **LS adjustment**, utilizing deteriorated distances to satellites, deteriorated satellites positions and clocks

Example simulations assumptions

1. **Basic option** (available: broadcast orbit, Klobuchar, ZHD):
    1. Satellite coordinate errors ∈ $N(0, 1\ m)$
    2. Satellite clock errors ∈ $N(0, 0.5\ m)$ for G,R,E and ∈ $N(0, 1\ m)$ for C
    3. Ionosphere: ∈ $N(0, 1.5\ m)$, mapping ~1/sin(elev)
    4. Troposphere ZWD ∈ $N(0.1, 0.1\ m)$ ~1/sin(elev)
    5. Observational errors ∈ $N(0, 1\ m)$

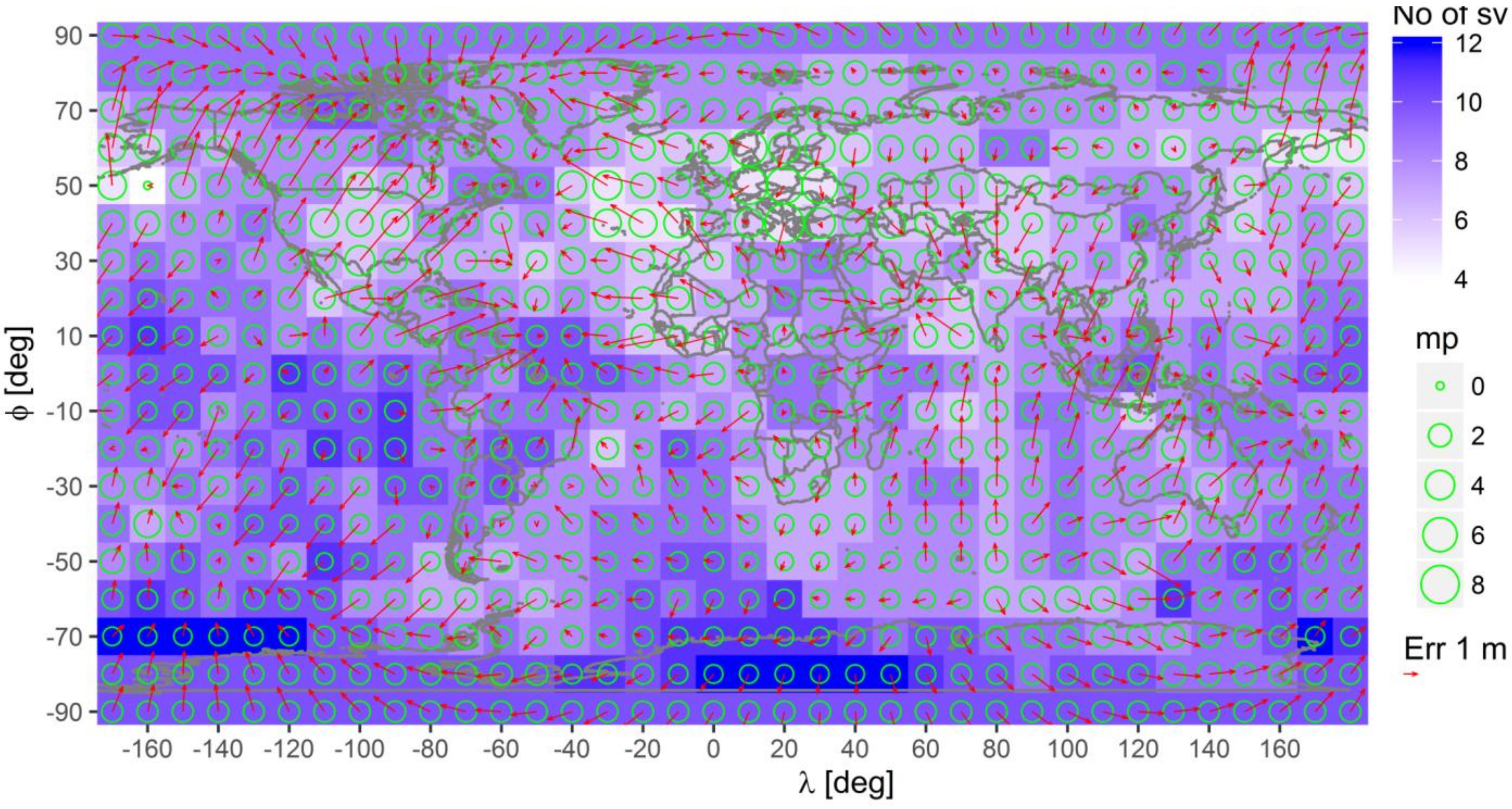
2. **Precise option** (available: predicted precise orbit and clock, ionosphere-free, ZHD, annual model of ZWD):
    1. Satellite coordinate errors ∈ $N(0,0.05\ m)$
    2. Satellite clock errors ∈ $N(0, 0.05\ m)$
    3. Ionosphere: ∈ $N(0, 0.04\ m)$~1/sin(elev)
    4. Troposphere ZWD ∈ $N(0, 0.05\ m)$~1/sin(elev)
    5. Observational errors ∈ $N(0, 0.01\ m)$

Example simulations performed

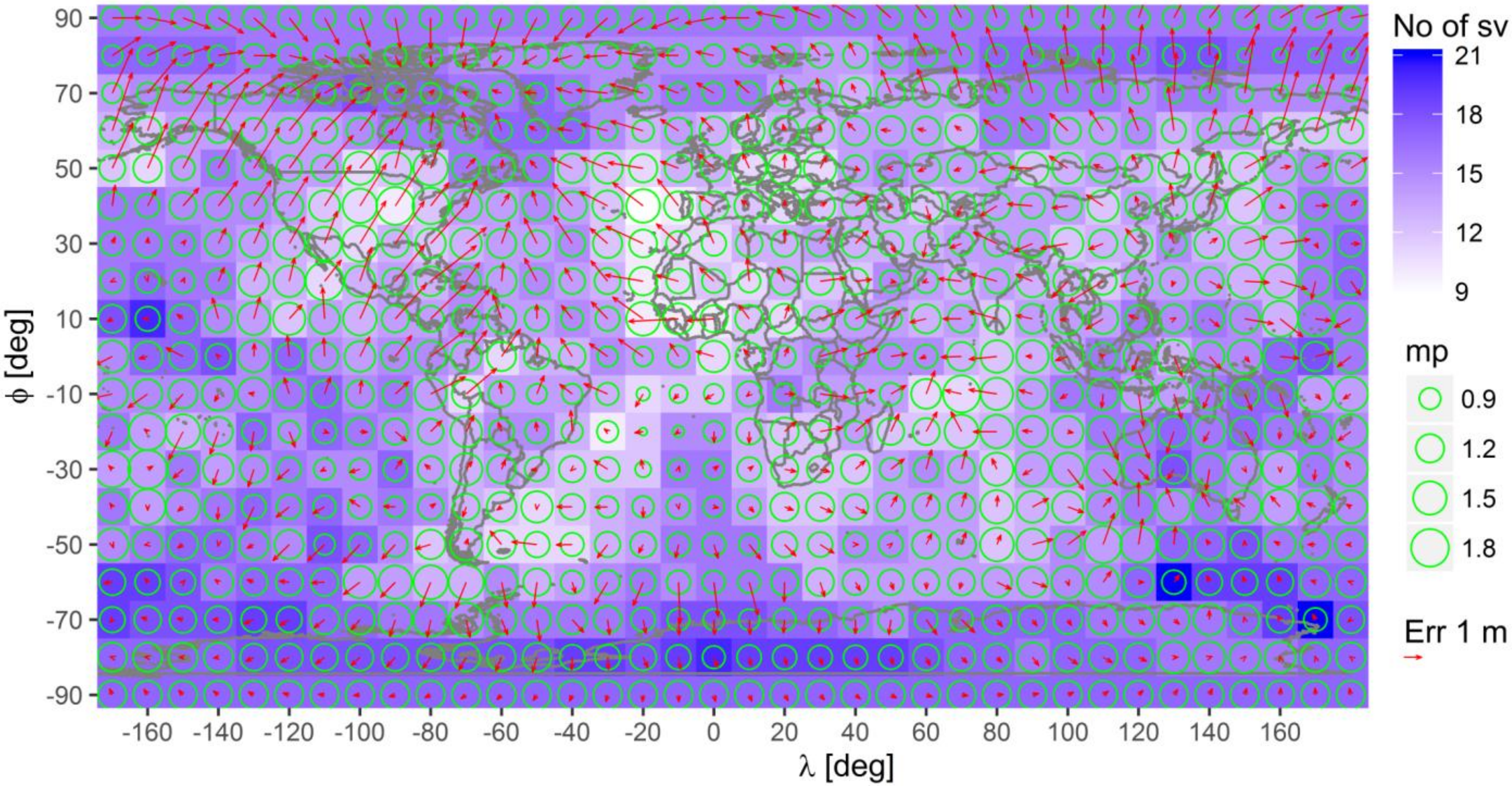
(see figures on slides 17-25; elevation cut-off angle of 15^0

1. GPS + basic (**G_bas**)
2. GPS+GLONASS+basic (**GR_bas**)
3. GPS+GLONASS+Galileo+COMPASS+basic (**GREC_bas**)
4. GPS + precise (**G_prec**)
5. GPS+GLONASS+precise (**GR_prec**)
6. GPS+GLONASS+Galileo+COMPASS+precise (**GREC_prec**)

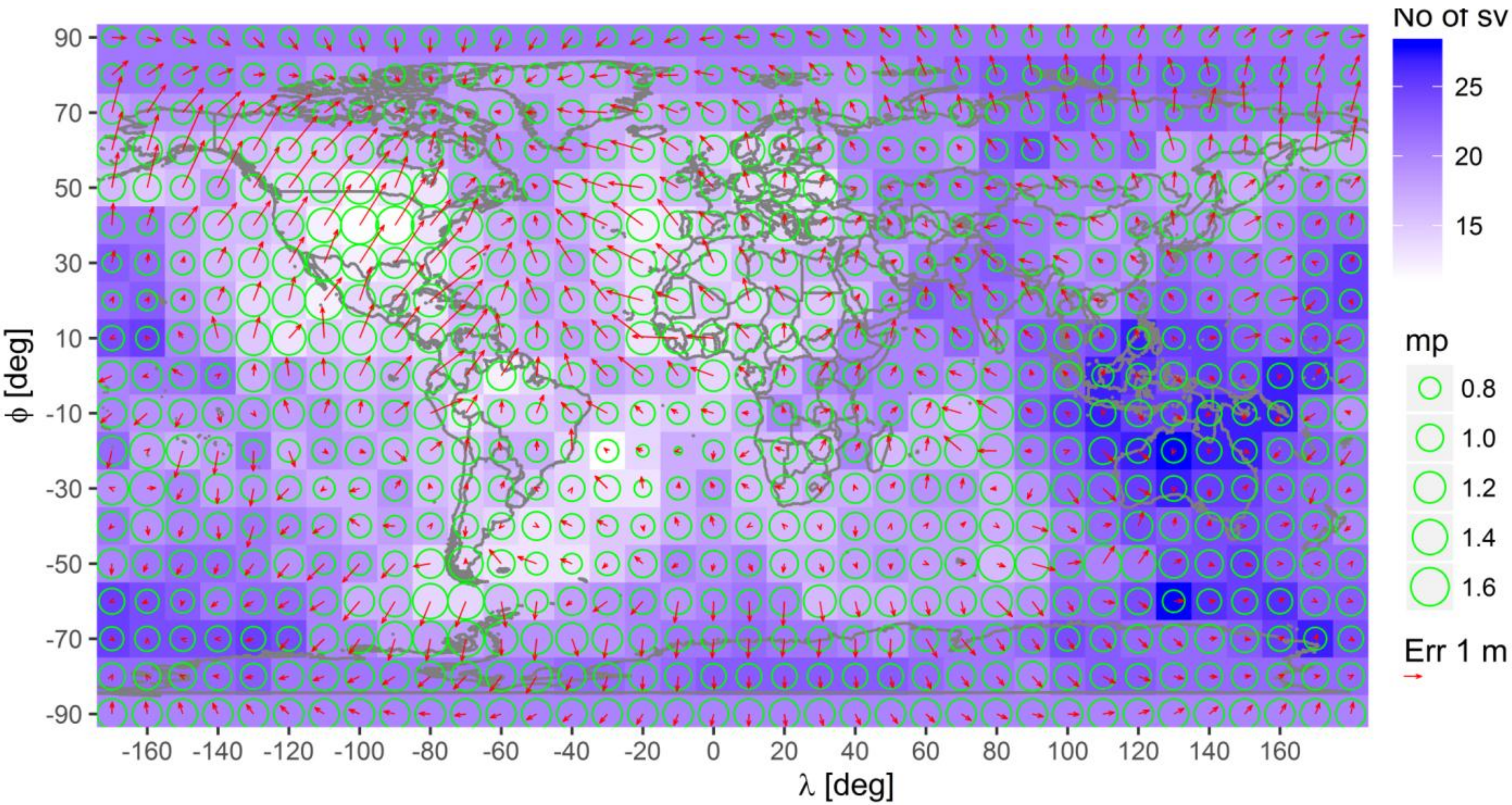
G_bas option: mp in meters, position differences (arrow lengths) reach 4.5 m



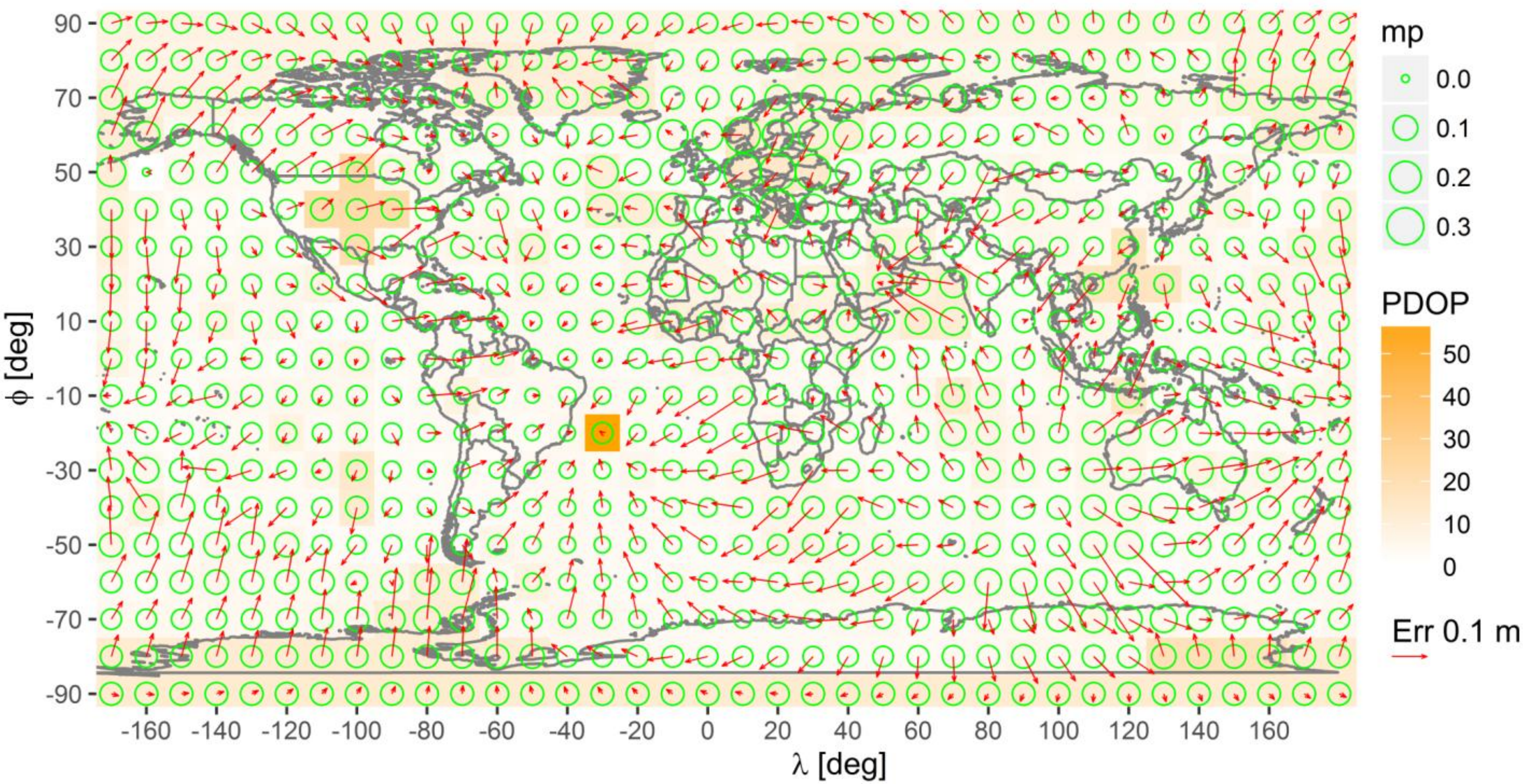
GR bas option: mp in meters, position differences (arrow lengths) range from 0.02 to 3.3 m



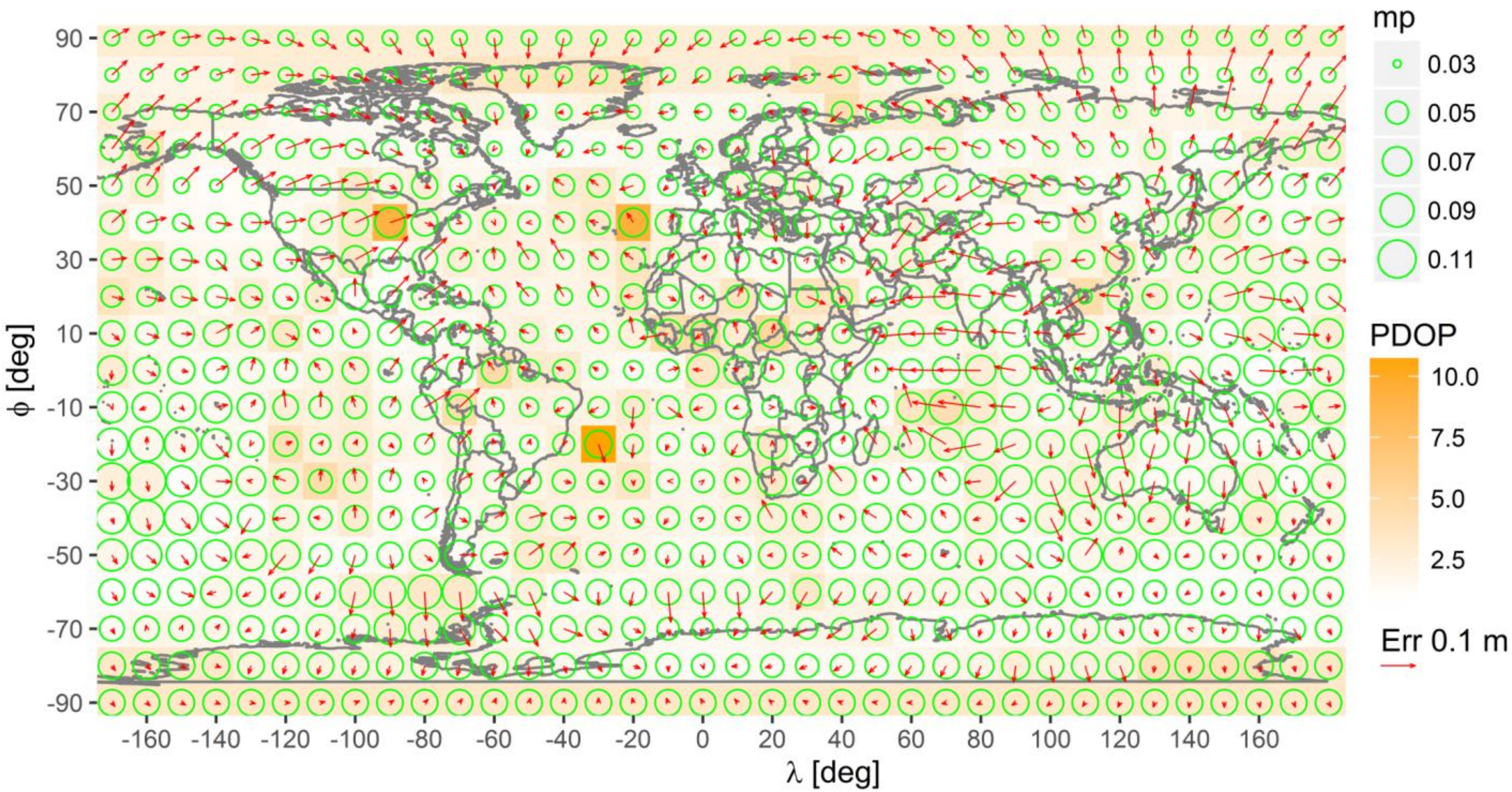
16. GREC bas option: mp in meters, position differences (arrow lengths) range from 0.03 to 3.2 m



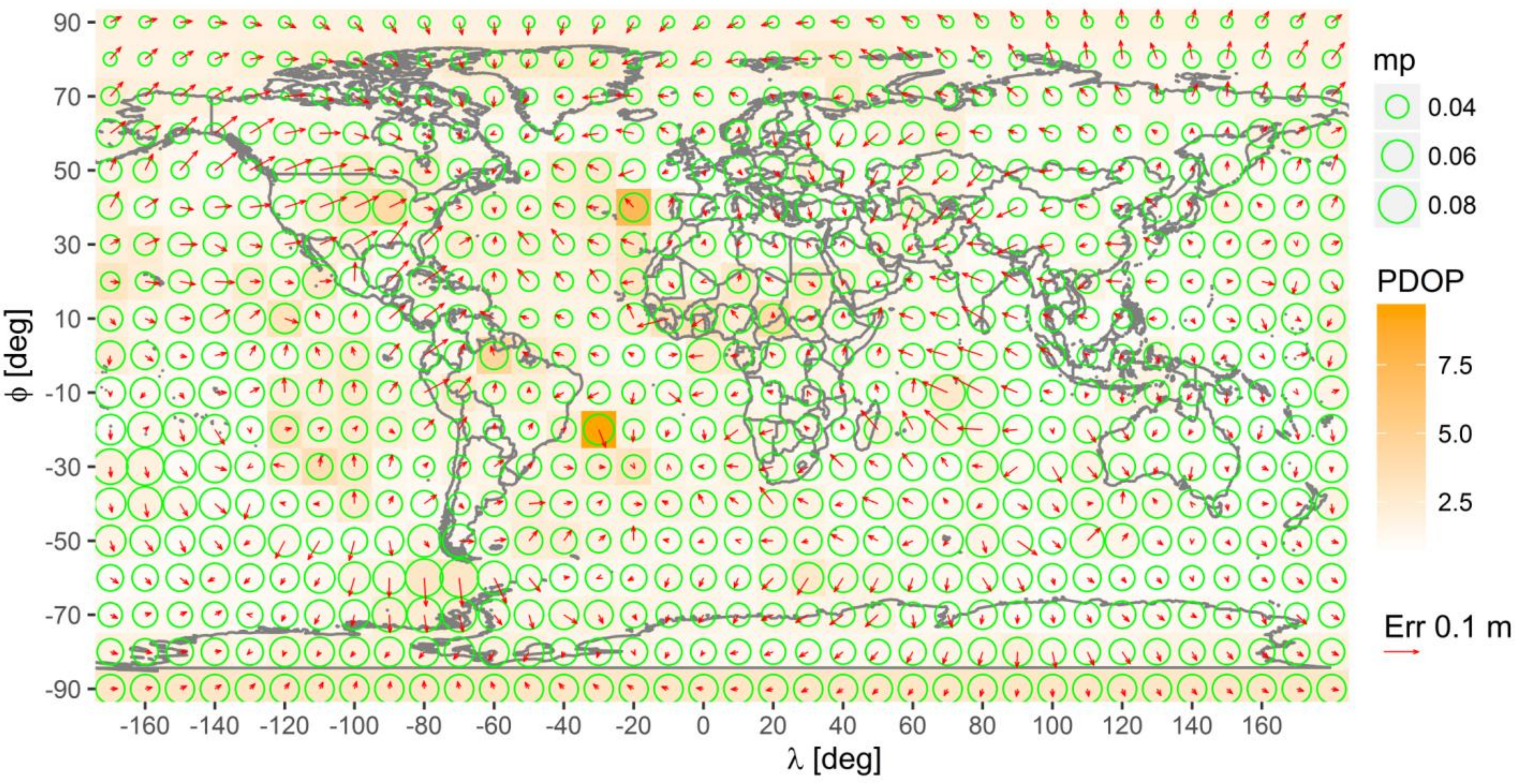
17. G_prec option: mp in meters, position differences (arrow lengths) reach 0.024 m



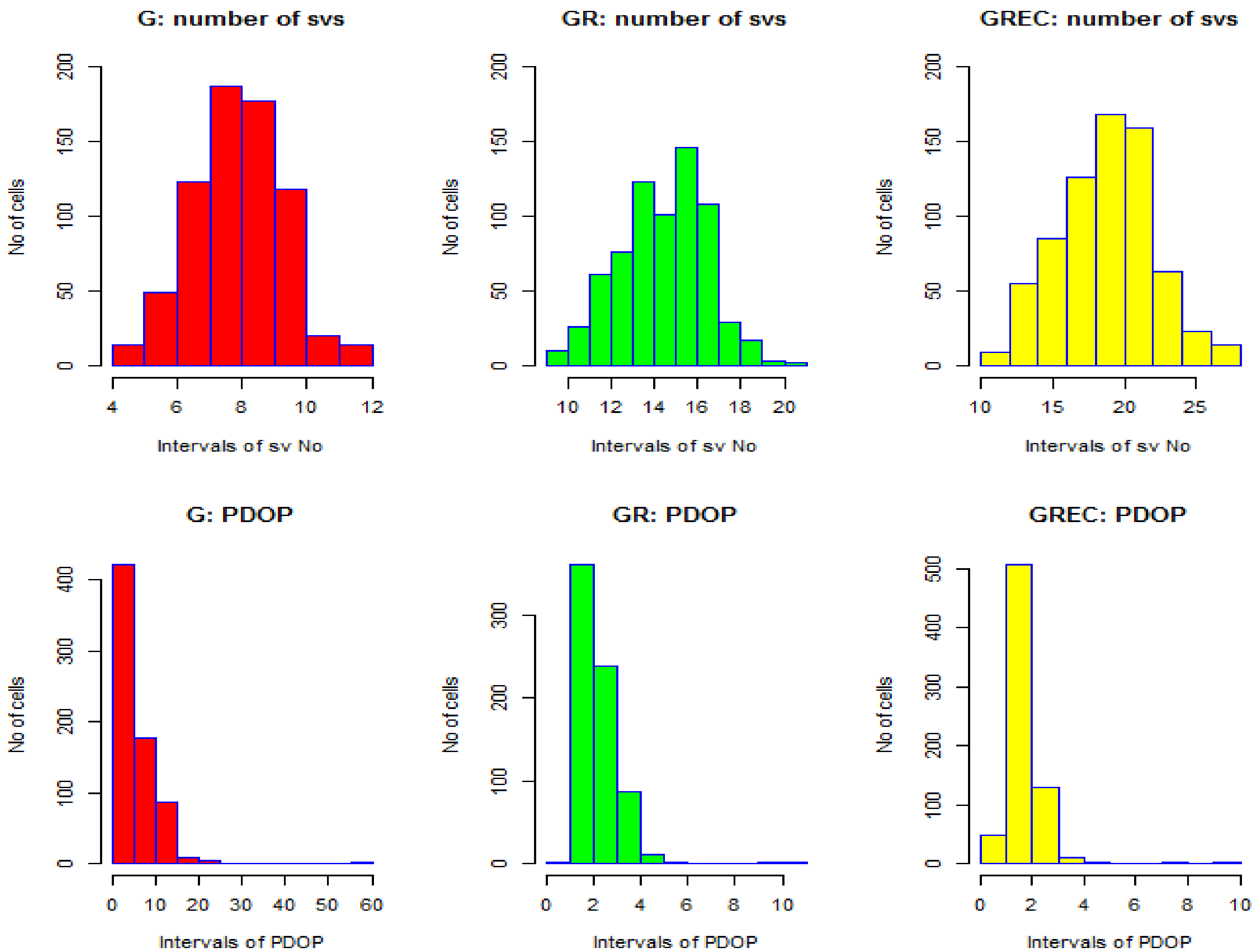
18. GR_prec option: mp in meters, position differences (arrow lengths) range from 0.0 to 0.13 m



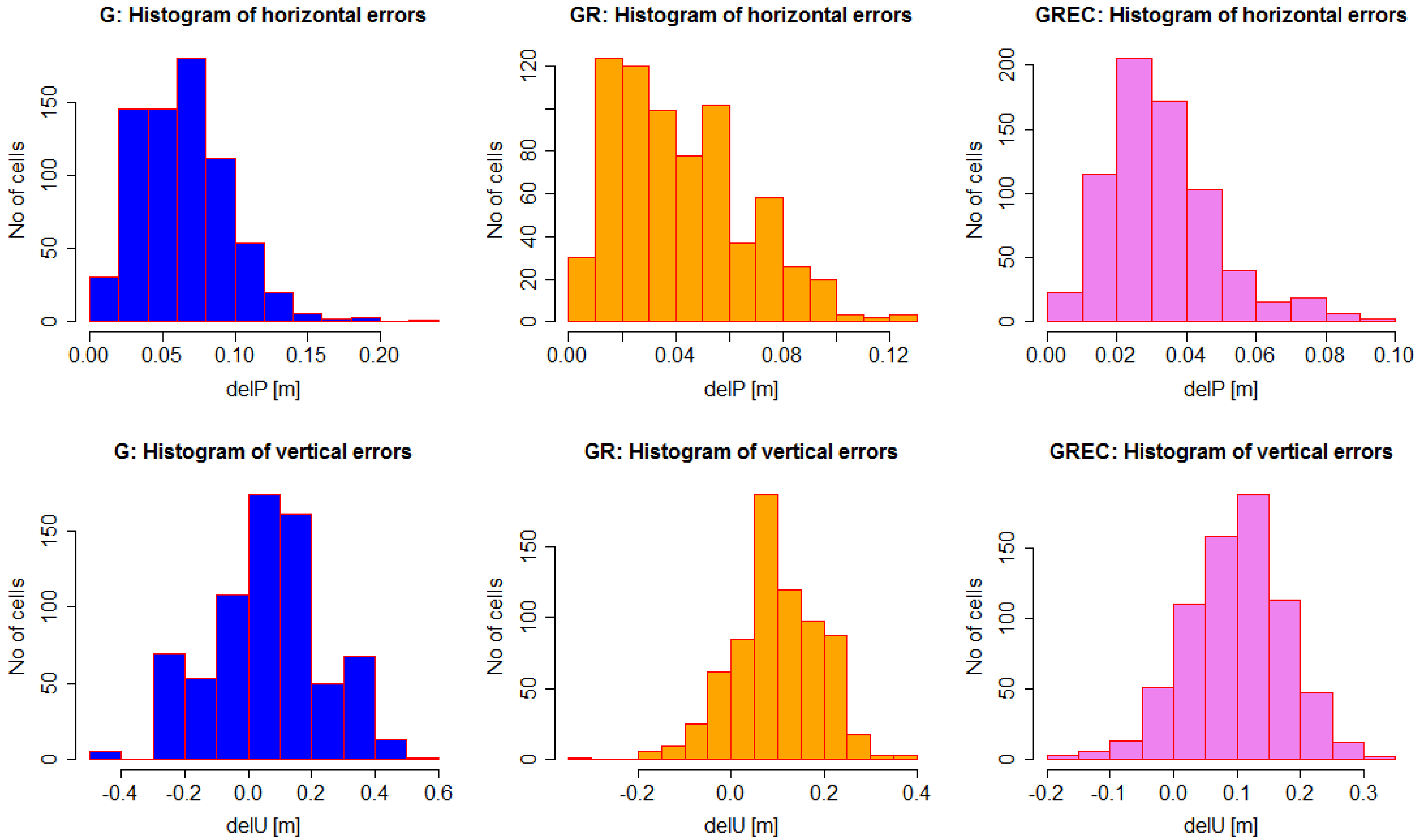
19. GREC prec option: mp in meters, position differences (arrow lengths) range from 0.0 to 0.09 m



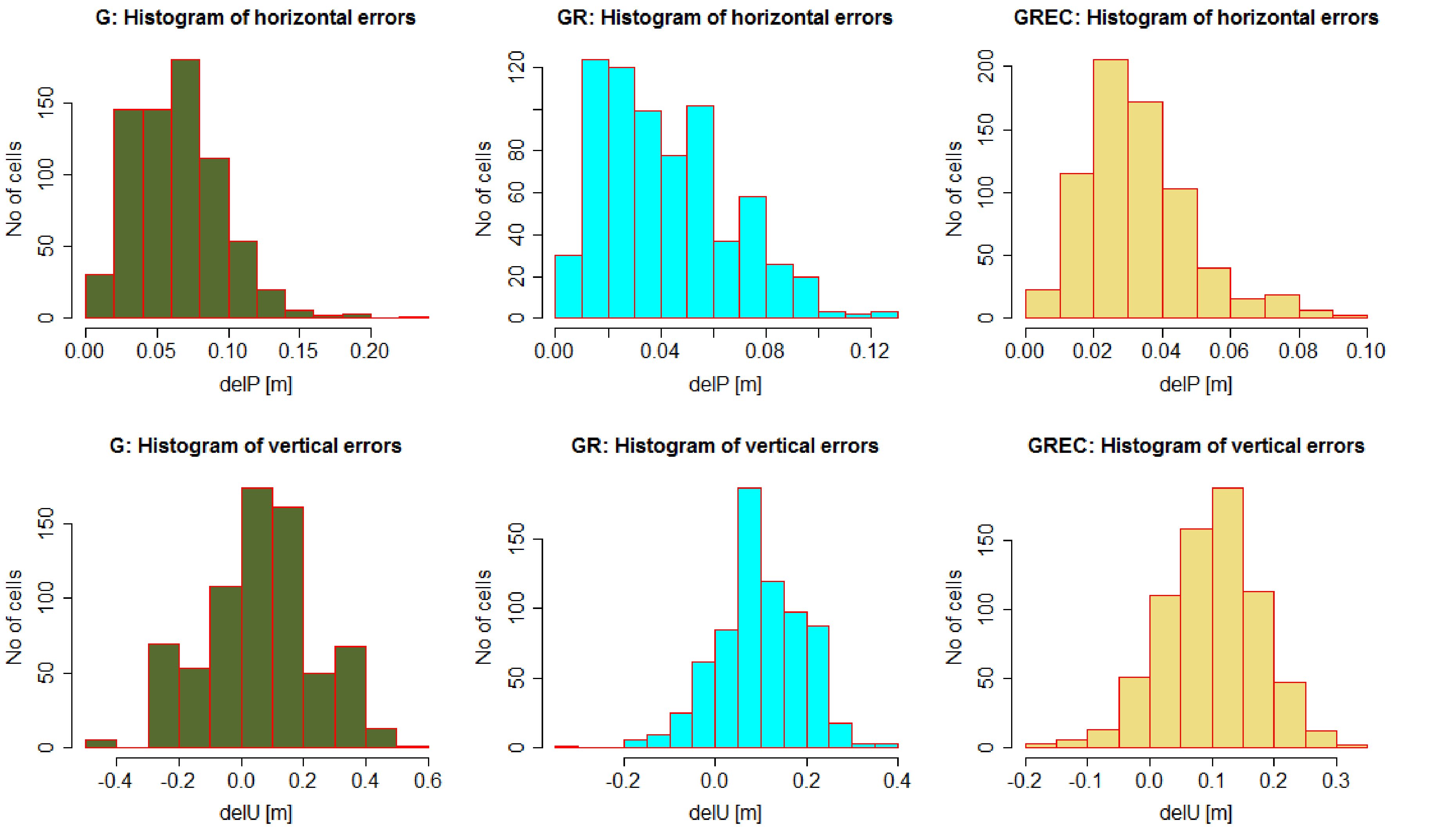
20. No of satellites and PDOP



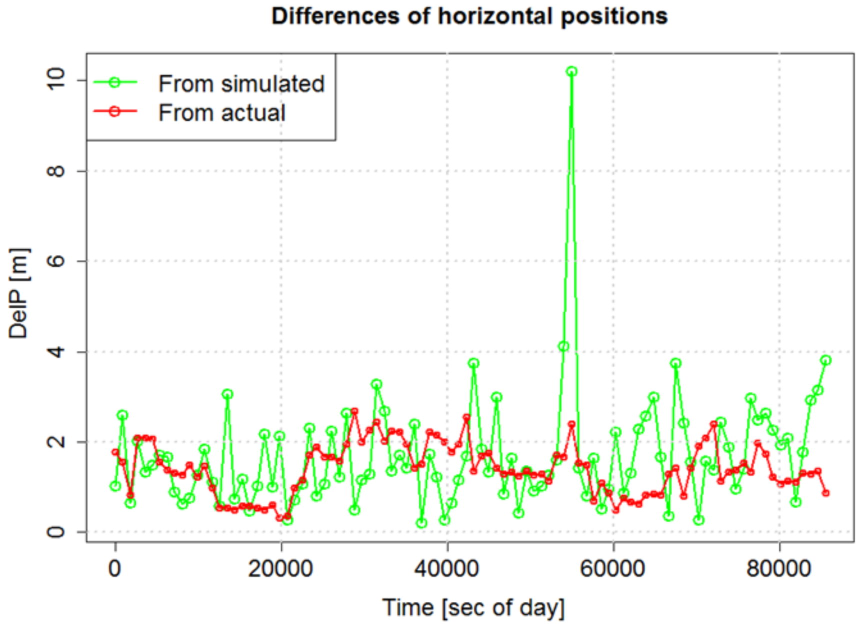
21. Errors: – basic options, whole world

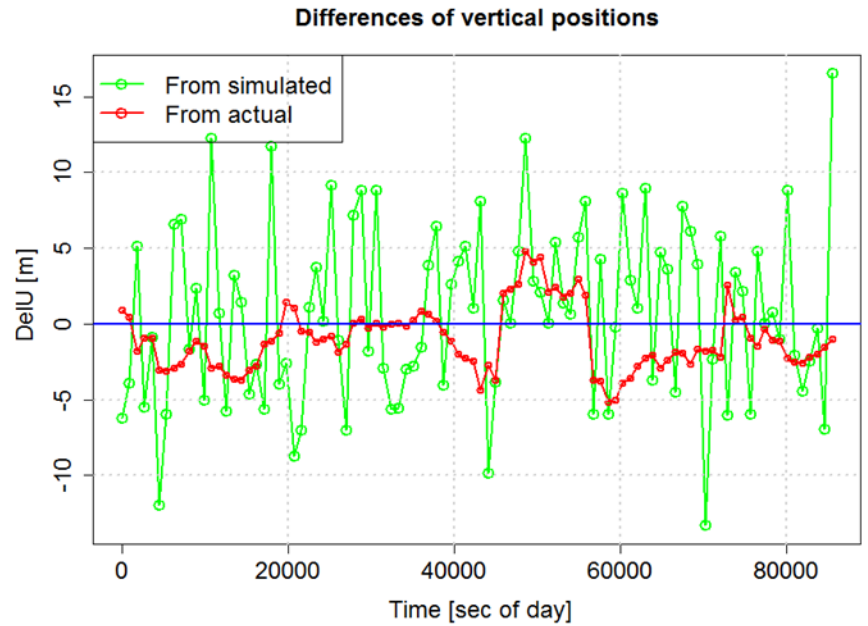


22. Errors: – precise options, whole world



23. Comparison to actual observation





- Actual observations: wroc0010.16o , brdm0010.16p (IGS, 1992)
- Software: RTKLIB ver.2.4.1 (Takadu, Yasuda, 2009)
- RTKLIB run options: pos mode : single, elev mask : 15.0 deg, ionos opt : broadcast, tropo opt : Saastamoinen, ephemeris : broadcast
- Only GPS satellites were processed
- RTKLIB results obtained using a filter, in contrast - the simulated results are independent for every epoch
- In spite of that, there can be seen quite a promising compliance between the computed sets

Summary

- **A tool** was developed for quick and easy simulations of results obtained on the basis of chosen satellite constellation(s)
- **The simulations** may be performed anywhere in the world, regardless of whether there are available real observations from that place or not
- The simulations are performed on the basis of a precise multi-constellation orbit
- **Errors** are simulated according to the normal distribution and admitted standard deviations
- **In contrast** to other tools, which generally use only geometrical information and DOP factors for position accuracy predictions, the presented tool also considers satellite elevations and mapped atmospheric effects influence on the derived positions
- In the future, it is planned to develop this tool to build a **„software generator of simulated GNSS observations"**

Conclusions

- In the case shown in this presentation, **spatial distributions** of DOP factors values, number of visible satellites, predicted errors of positioning, both horizontal and vertical can be analyzed
- **Time distributions** for a given location can also be analyzed, like for the WROC station
- The results obtained for $10^0 x 10^0$ grid for the **whole world**, can be analyzed in the form of histograms or other graphical or analytic methods
- The results can be **easily obtained** for an arbitrary region at freely admitted resolution
- It failed to carry out **proper comparisons** between results computed from actual and simulated observations (lack of a good multi-GNSS software at the moment)
- However, comparisons performed for GPS constellation **seem promising**
- This issue will be worked out in the near future

Literature

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