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Impact of Limited Multi-GNSS Visibility on Vertical Land Movement Estimates

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Abstract

The number of GNSS satellites and their geometry directly affect the quality of positioning and derived satellite products. Accordingly, the International GNSS Service (IGS) recommends GNSS antennas to be installed away from natural and man-made surfaces and structures, which may affect the incoming signals through severe multipath or obstructions. Following these recommendations, continuous GNSS (cGNSS) stations are generally located in low multipath environments with minimal signal obstructions. However, some applications require GNSS antennas to be installed at specific locations in order to measure local processes. Hence, in support of sea level studies, cGNSS stations must be installed close to or at tide gauges in order to accurately monitor the local vertical land movements experienced by the sea level sensors. However, the environment at the tide gauge might not be optimal for GNSS observations due to the aforementioned station-specific effects, which degrade the quality of coordinate solutions.This first study investigates the impact of severe signal obstructions on long-term monitoring results by use of simulated and real observations for selected cGNSS stations, and evaluates if the use of multi-GNSS (GPS+GLONASS) constellations will benefit derived results. To investigate these effects, we implemented azimuth and elevation dependent masking in the Bernese GNSS Software version 5.2. We present our preliminary results on the impact of different obstruction scenarios and combined GPS and GLONASS solutions on coordinate and vertical land movement estimates.

Introduction

It is a well-known fact that GNSS positioning accuracy is dependent on the distribution of the observable satellites in the sky [eg Santerre, 1999]. Over time, launches and the decommissioning of satellites, as well as maneuvers, will change the constellation and, hence, the "geometry". These dynamical events are well handled by the International GNSS Service (IGS) Analysis Centers (ACs) such as the Center for Orbit determination in Europe (CODE), which make this information publically available [eg. Dach et al., 2007]. On the ground, man-made and natural objects can obstruct the satellite signals and can cause a compromised geometry. To avoid this, GNSS antennas have been installed away from objects of possible obstructions with a view of the sky as clear as possible. For high-precision applications the IGS and other organizations provide specific recommendations for the siting of GNSS antennas which take this into account.

However, some applications require the installation of GNSS antennas at specific locations, which may not be ideal for GNSS observations, in order to precisely measure local processes. For example, sea level studies require vertical land movements to be measured at or close to tide gauges (TG) in order to avoid costly leveling links between the antenna and the TG benchmarks. TGs are often located in harbours, providing an environment which can be harmful to the GNSS observations due to a number of effects [eg. Teferle et al., 2003]. Other examples of GNSS antennas being sited in less favorable locations may be found when monitoring mountain slopes prone to land slides.

In this initial study we have investigated the global IGS, Tide Gauge Benchmark Monitoring (TIGA) and UNAVCO Plate Boundary Observatory (PBO) networks for stations with severe obstructions. Figure 1 shows skyplots for six stations from these networks with a severly compromised geometry due to signal obstructions. We present the impact of severe signal obstructions on vertical land movement (VLM) estimates and investigate the benefits of using multi-GNSS (GPS+GLONASS) observations in such environments. Figure 2 shows the global and regional networks used in this study. Although other parameters, eg. zenith total delays and gradients, are impacted as well, results for these have not been included in this presentation.

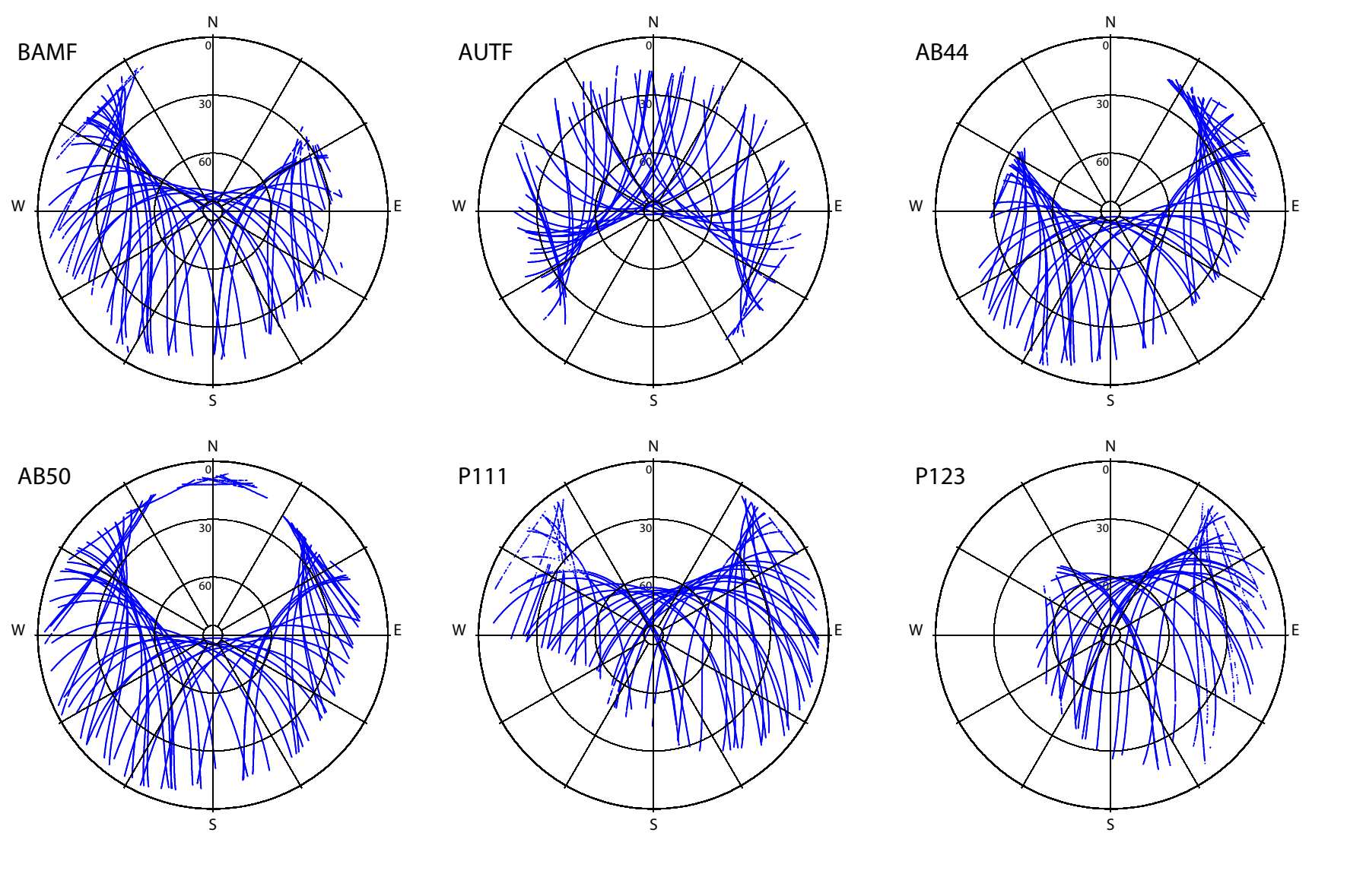


Figure 1: Skyplots of stations with severe obstructions from the IGS (BAMF), TIGA (AUTF) and UNAVCO/PBO (AB44, AB50, P111 and P123) networks. The obstruction masks derived from these are named after the stations.

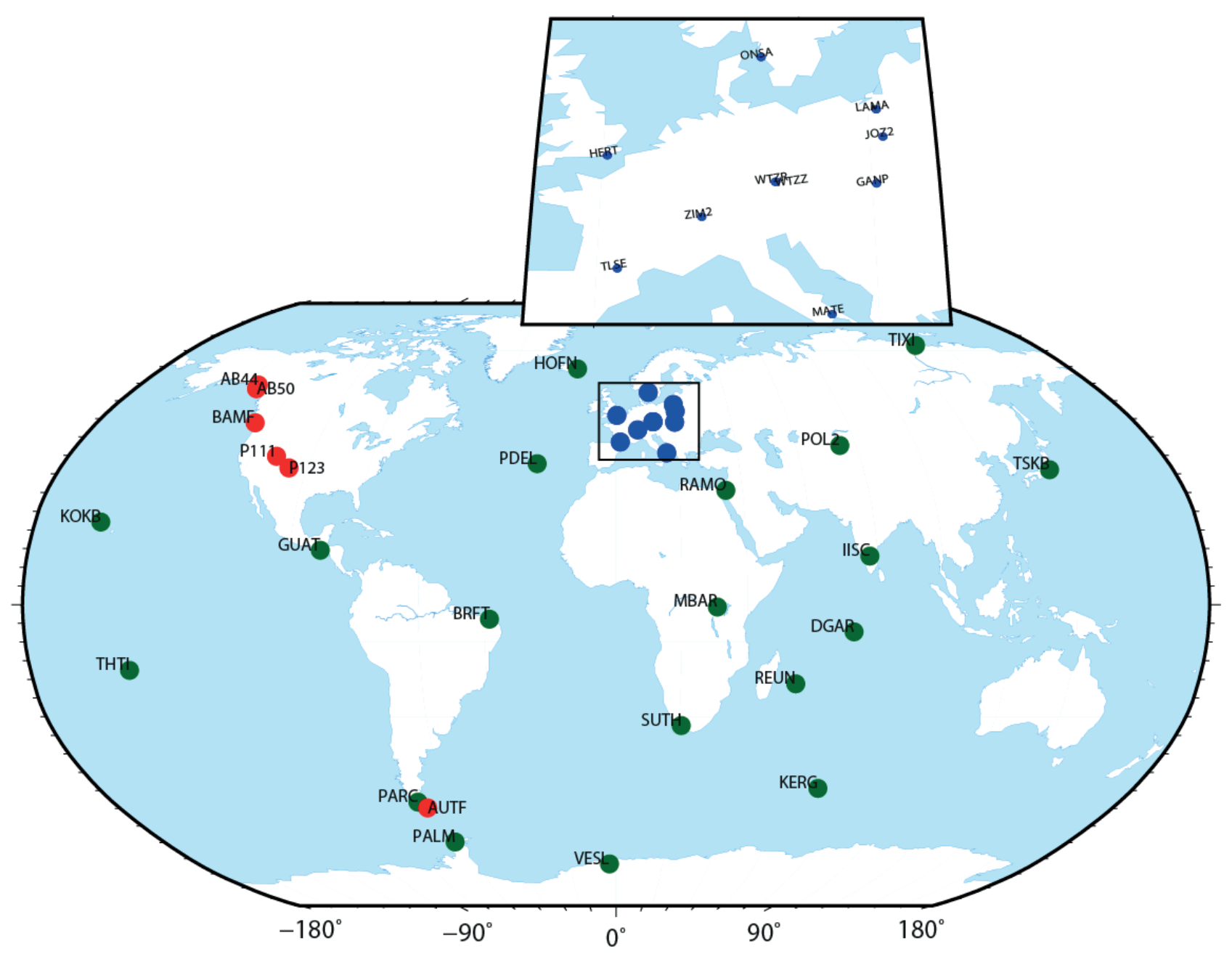
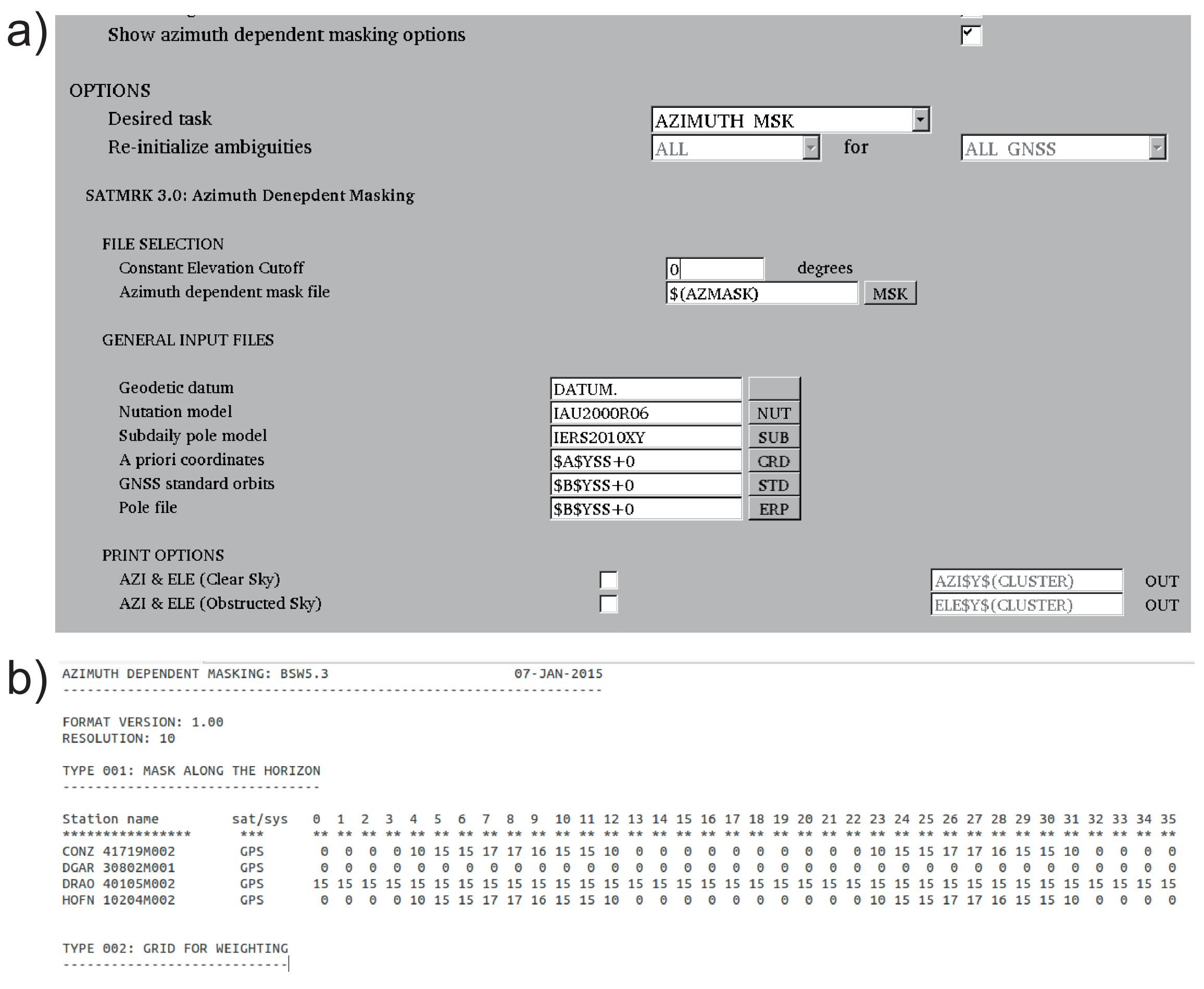


Figure 2: Map of stations used: stations in Figure 1 *(red dots)*, regional stations in Europe *(blue dots)* (see inset figure) used for the Precise Network Positioning (PNP) strategy, global stations *(green dots)* used for the Precise Point Positioning (PPP) strategy.

Methodology

In this study, we have simulated several artificial obstruction scenarios (no results shown here) and extracted scenarios from stations with severe obstructions (Figure 1). The obtained observation masks were then applied to un-obstructed IGS sites (green dots Figure 1) to investigate the impact of the limited visibility. In order to implement these different obstruction scenarios, we have added a new feature (Figure 3a) to the Bernese GNSS Software Version 5.2 (BSW52). This is done by providing azimuth-dependent masking information for stations of interest using a fixed-column format (Figure 3b). The current version of the masking information file (version 1.00) is with a resolution of 10º and 1º in azimuth and elevation, respectively. The masking information is implemented after the RINEX files are converted into the BSW52-formatted observations and before forming baselines (Figure 3c).

Furthermore, we used two different processing strategies, precise network processing (PNP) and precise point positioning (PPP). The PNP strategy is performed on GPS-only and multi-GNSS (GPS+GLONASS) observations, while PPP is based on GPS observations only.



a)

Show azimuth dependent masking options ☑

OPTIONS
Desired task: AZIMUTH MSK
Re-initialize ambiguities: ALL for ALL GNSS

SATMRK 3.0: Azimuth Denepdent Masking

FILE SELECTION
Constant Elevation Cutoff: 0 degrees
Azimuth dependent mask file: $(AZMASK) MSK

GENERAL INPUT FILES
Geodetic datum: DATUM.
Nutation model: IAU2000R06 NUT
Subdaily pole model: IERS2010XY SUB
A priori coordinates: AYSS+0 CRD
GNSS standard orbits: BYSS+0 STD
Pole file: BYSS+0 ERP

PRINT OPTIONS
AZI & ELE (Clear Sky) ☐ AZIY(CLUSTER) OUT
AZI & ELE (Obstructed Sky) ☐ ELEY(CLUSTER) OUT

b)

```
AZIMUTH DEPENDENT MASKING: BSW5.3                    07-JAN-2015
-------------------------------------------------------------------

FORMAT VERSION: 1.00
RESOLUTION: 10

TYPE 001: MASK ALONG THE HORIZON
--------------------------------

Station name         sat/sys   0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
****************      ***     ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
CONZ 41719M002        GPS      0  0  0  0 10 15 15 17 17 16 15 15 10  0  0  0  0  0  0  0  0  0  0 10 15 15 17 17 16 15 15 10  0  0  0  0
DGAR 30802M001        GPS      0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
DRAO 40105M002        GPS     15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15
HOFN 10204M002        GPS      0  0  0  0 10 15 15 17 17 16 15 15 10  0  0  0  0  0  0  0  0  0  0 10 15 15 17 17 16 15 15 10  0  0  0  0


TYPE 002: GRID FOR WEIGHTING
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c)

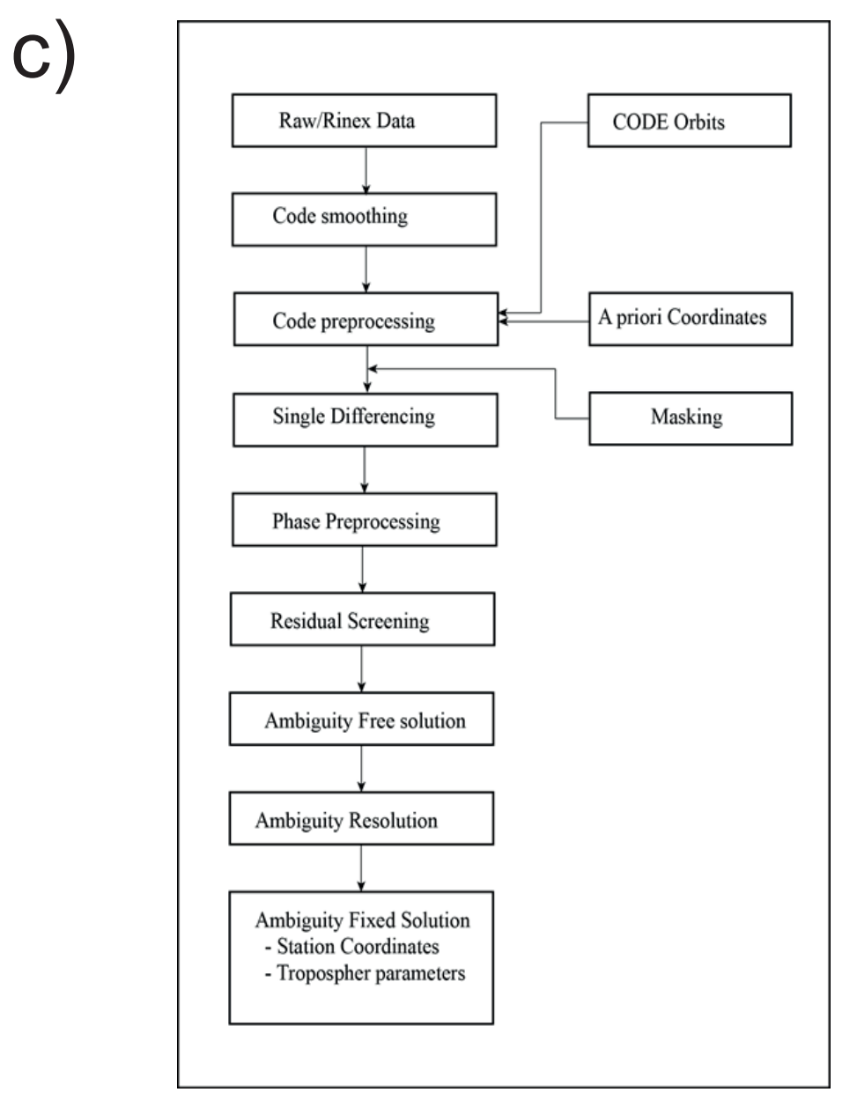

Figure 3: a) GUI of the new feature added to implement masking in BSW52; b) fixed-column formatted file containing masking information; c) a simple PNP strategy with the new masking feature

Effects on Coordinate Time Series

We have processed two PPP solutions from 2008 to 2014. The first solution is based on the real (unobstructed) observations while the second one is based on the same observations but with the applied obstruction scenario P111 (as an example). To investigate the effect of the obstructions, position differences time series between the unobstructed and obstructed solutions were computed. We assume that all common signals and biases will cancel from the difference, highlighting the effect of the obstruction scenario. Figure 4 shows the coordinate difference time series of the up component for 11 selected stations. The figure shows, that the effect varies from station to station. Constant up biases (removed from the difference time series) caused by the obstructions reach 10 mm for nearly all stations. Rate estimates for the difference time series range from -1.43 mm/yr (TIXI) to -0.00 mm/yr (DGAR).

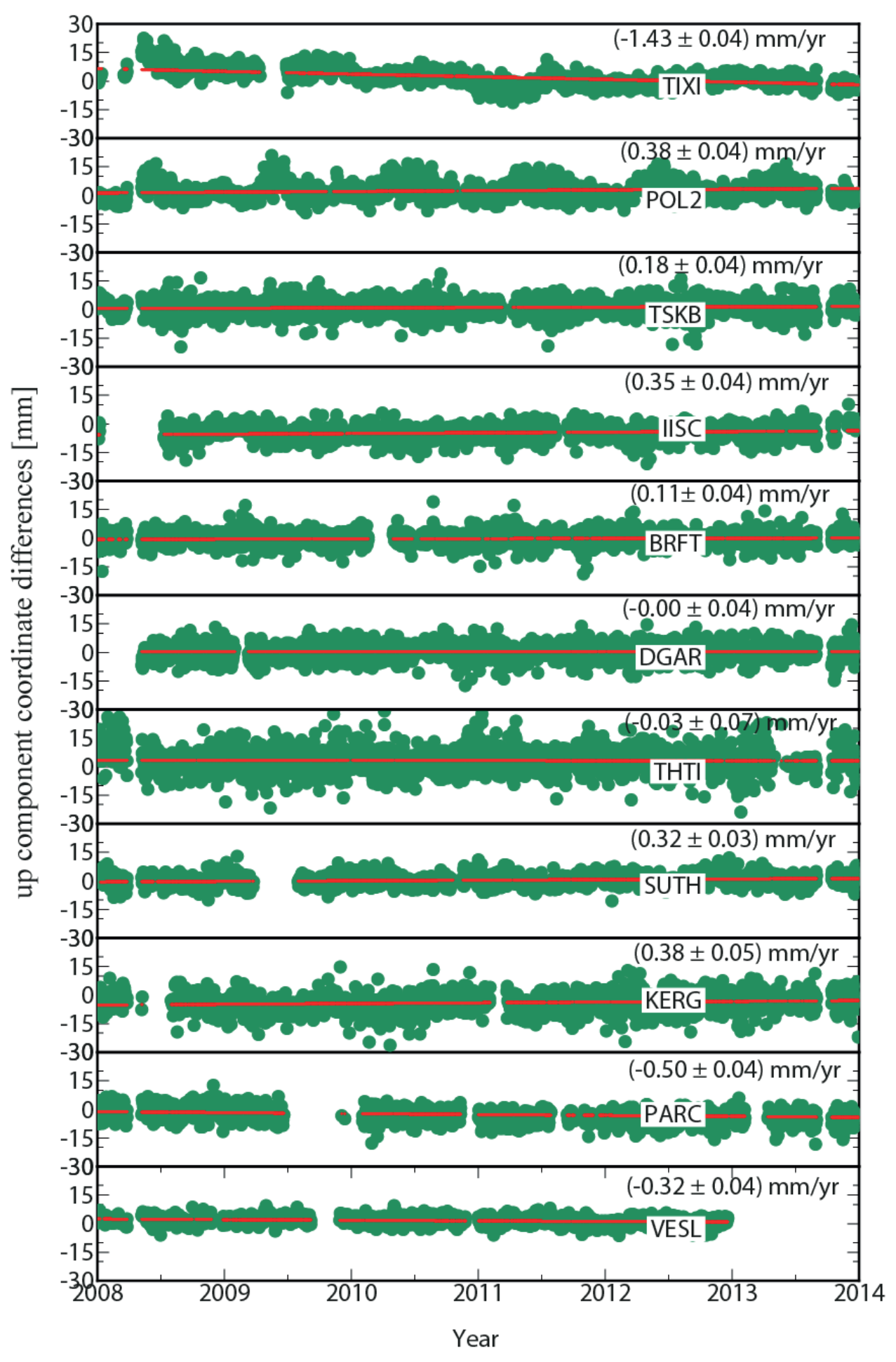

Figure 4: Up difference time series for selected stations (Figure 2, green stations). *Green dots* and *red line* are the daily up differences and the rate of the difference time series, respectively. The values on the upper right corner are the rate estimates and their associated uncertainty.

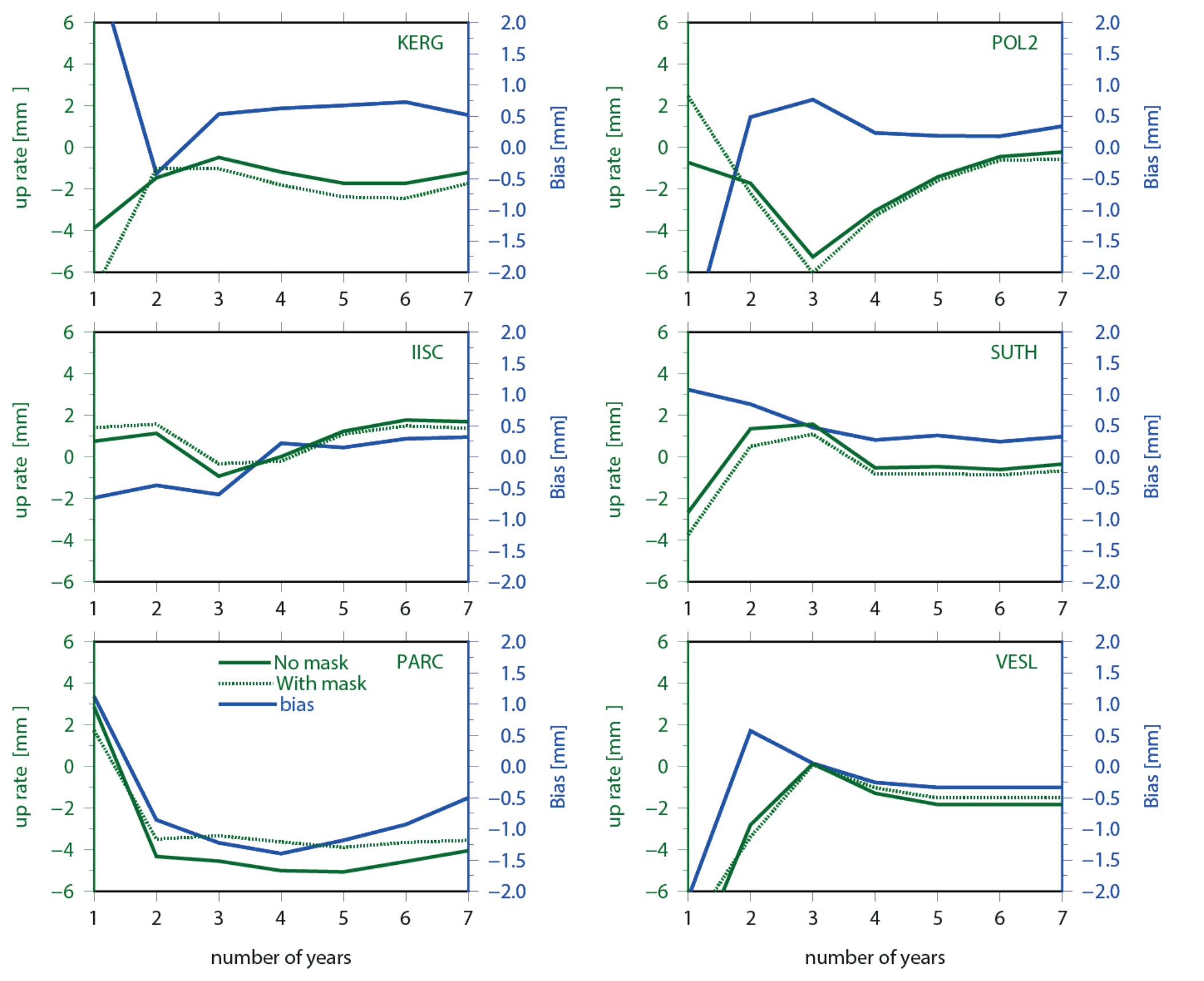

Figure 5: Rate bias of the up component of the stations due to the obstruction scenario. The *green solid line* (no mask) is the rate estimate of the stations without obstructions for years 1 to 7, the *dotted green line* (with mask) is the rate estimate of the stations with obstruction scenario. The *blue line* is the bias of the rate estimates due to the obstruction scenario.

As expected the effect of the obstruction scenario depends on how severe they are and where the obstructing objects are located relative to the GNSS antenna. There is a latitude-dependency which can vary from station to station. In general, we showed that a certain obstruction produces a coordinate bias and increases the day-to-day scatter, which results in a bias in the rate estimates (Figure 5). Naturally with short time series this effect is substantially larger (not shown). Figure 5 indicates that the rate biases can reach ±0.5 mm/yr for most of the stations even for time series of seven years.

Benefits from Multi-GNSS Solutions

To assess the benefits of the GPS+GLONASS solution, we have selected 10 stations in a regional network (Figure 2, blue stations) and processed the whole network by implementing scenario P123 at one station at a time. For this test we used the PNP strategy as described in Figure 3c.

A reduction of the daily formal errros for the up component is observed as the number of GLONASS satellites increases in the GPS+GLONASS solution (Figure 6). The lower part of Figure 6 indicataes that the reduction of the errors is more pronounced when the station is obstructed. For obstructed stations, the apparent periodic variations and scatter increases. The large formal errors in Figures 6 and 7 from the GPS+GLONASS solution on some days are due to the failures in GLONASS ambiguity resolution.

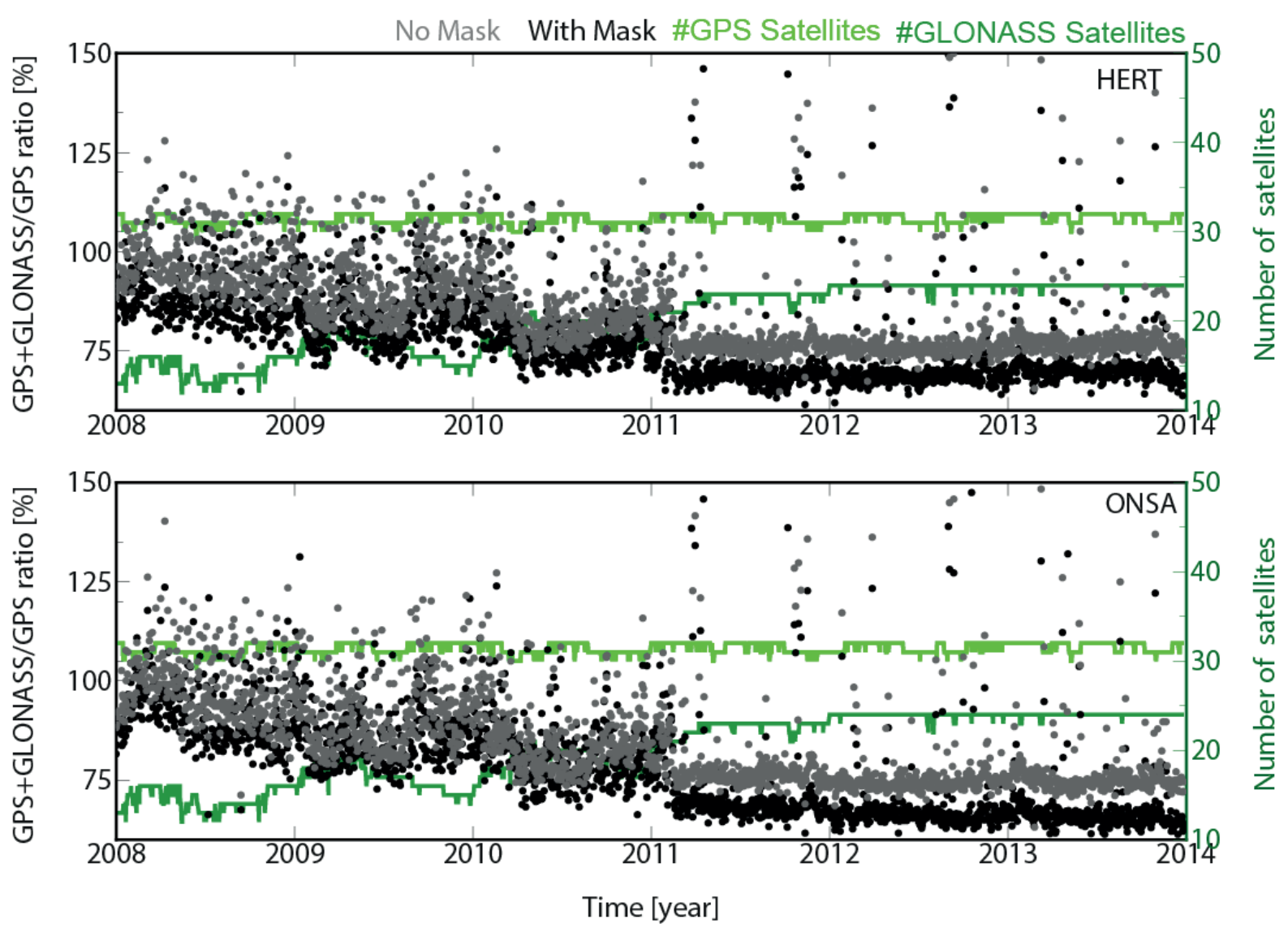

Figure 7: Ratio of formal errors for the up component for GPS-only and GPS+GLONASS solutions. *Light* and *dark green lines* are the number of GPS and GLONASS satellites, respectively. *Blue* and *red lines* are the ratio with and without obstruction scenario P123.

Figure 7 shows the ratio of the formal errors for the GPS-only and GPS+GLONASS solutions. The figure confirms that the reduction of the erros due to the inclusion of GLONASS is more pronounced for obstructed stations. Without the obstruction the daily error reduction for the up component reaches on average 0.3 mm, which is in agreement with Fritsche et al. (2014). However, for obstructed stations (obstruction scenario P123), the average daily error reduction for the up component reaches 1 mm (Table 1).

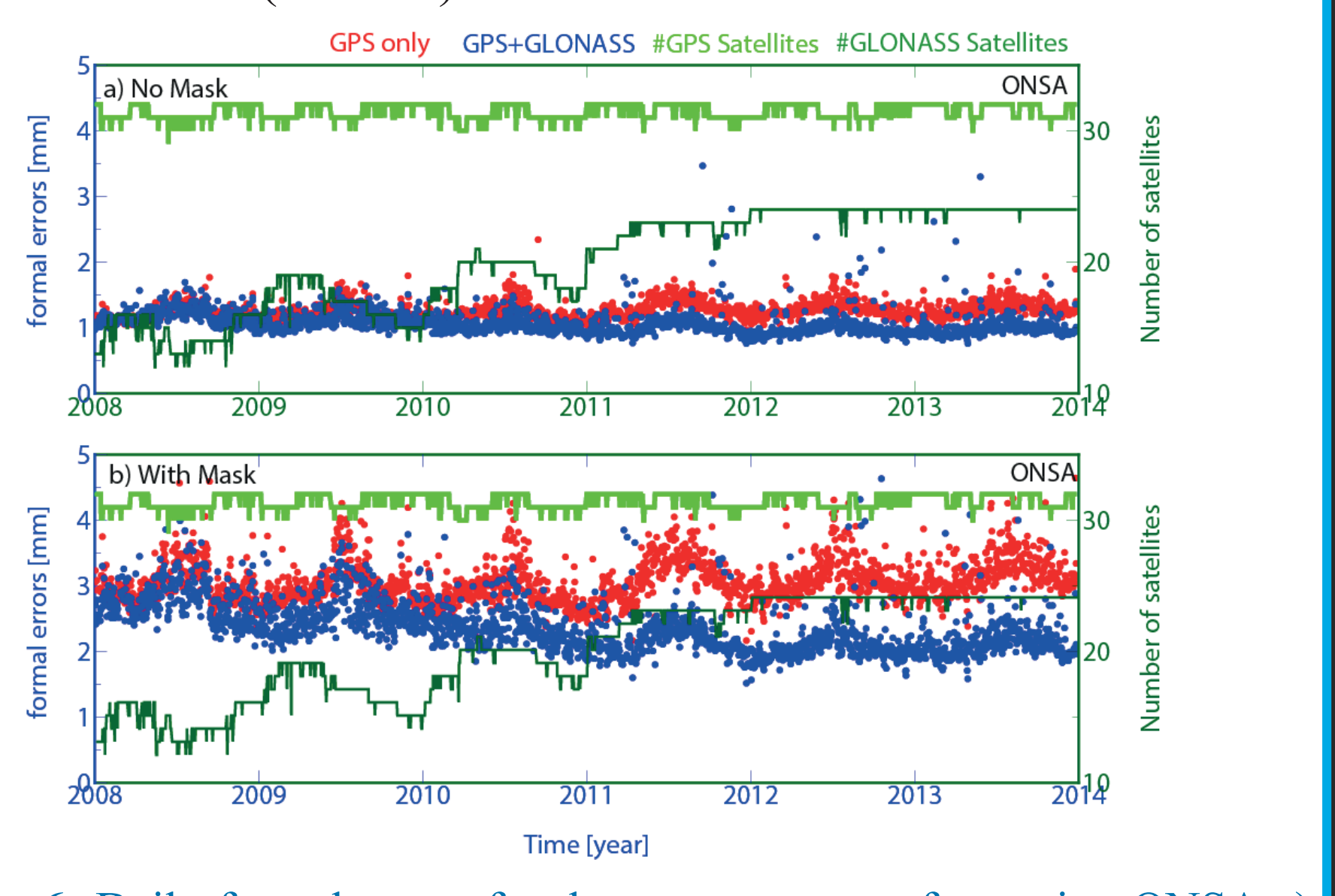

Figure 6: Daily formal errors for the up component for station ONSA a) without obstruction scenario b) with obstruction scenario P123. *Light* and *dark green lines* are the number of GPS and GLONASS satellites, respectively. The *red* and *blue lines* are the formal error values for GPS-only and GPS+GLONASS solutions, respectively.

year	# Satellites GLONASS	RMS Reduction (mm) Without Mask	With Mask
2008	13	0.02	0.3
2009	17	0.1	0.4
2010	19	0.2	0.6
2011	22	0.3	0.8
2012	24	0.3	1.0
2013	24	0.3	1.0

Table 1: Daily formal error reduction for up component for station ONSA with and without obstruction scenario P123.

Conclusions:

An investigation of the effect of signal obstructions using simulated and real obstruction scenarios has been performed. The preliminary results confirm that the effect of the obstructions is to a large degree site-specific and latitude-dependent. The obstructing objects cause a compromised satellite geometry, increase scatter of the position time series, cause coordinate biases and may lead to biases in the rate estimates. The use of GPS+GLONASS observations instead of GPS-only observations benefits both un-obstructed and obstructed stations with the improvement being more significant for the latter. More work is needed to better quantify the current results and to include observations from Galileo and BeiDou.

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