ON THE FEASIBILITY AND APPLICABILITY OF MULTIPATH MITIGATION MAPS AS AN IGS PRODUCT

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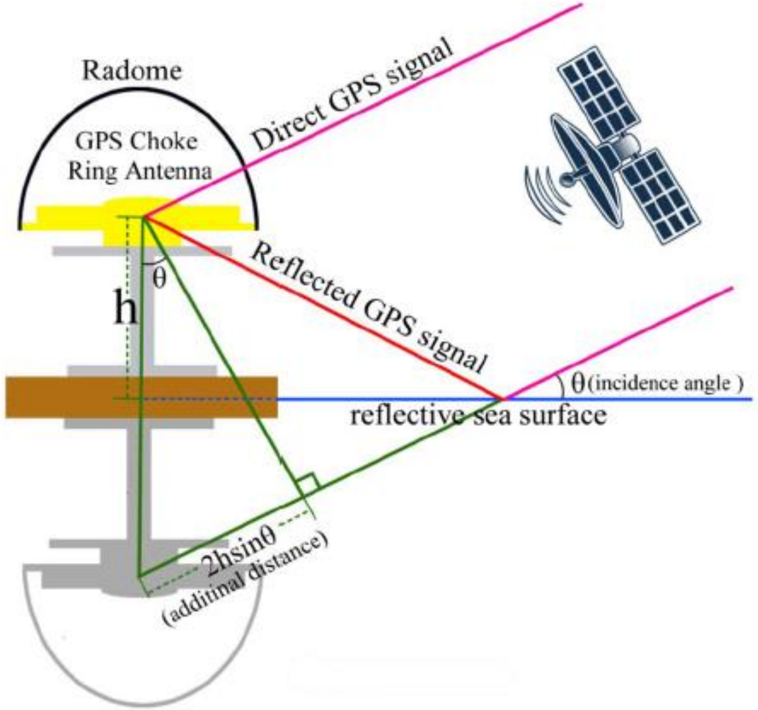
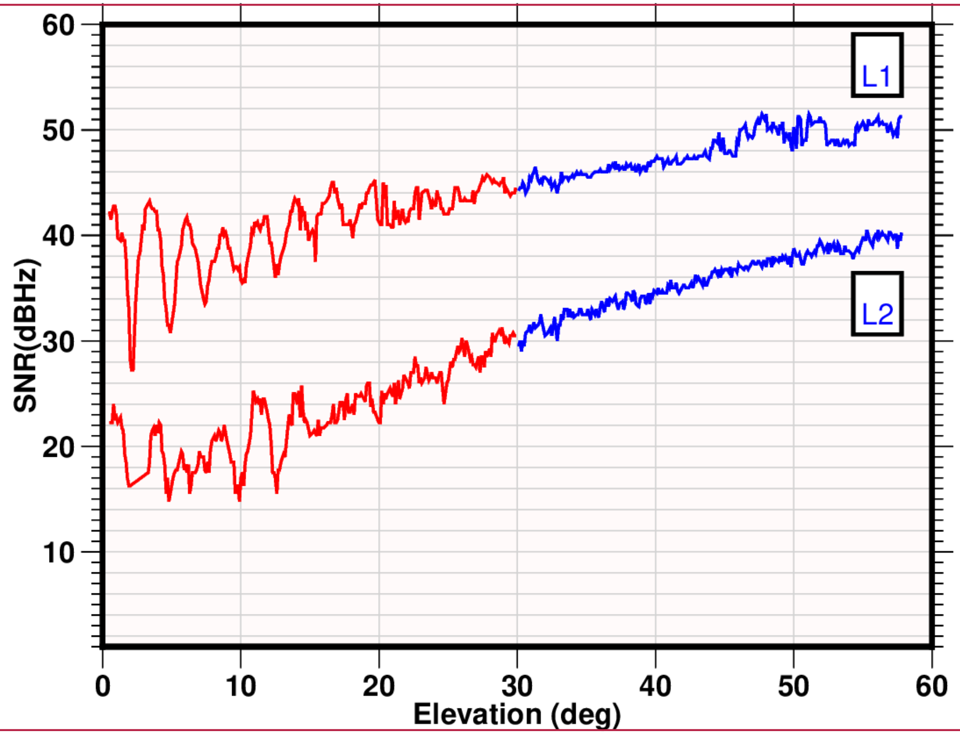
INTRODUCTION

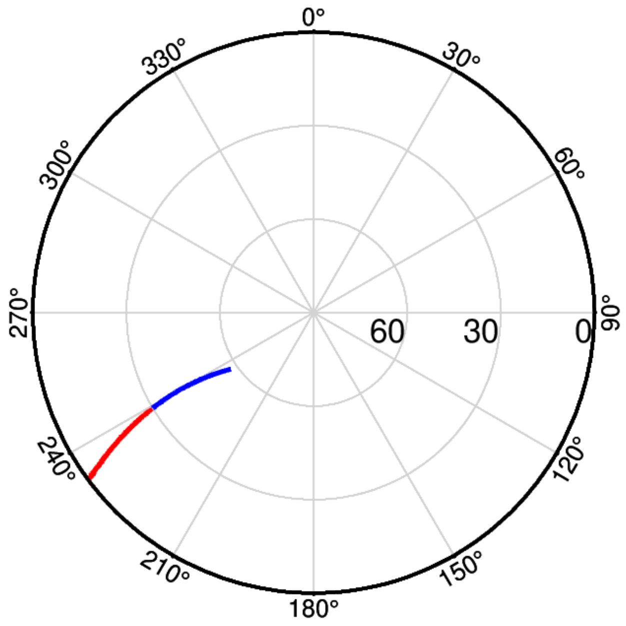
- Multipath introduce range error
- Multiple-path (multipath) effects are source of problems and opportunities for GNSS
- The composite signal received is a combinations of direct line-of-sight (LOS) signal and refracted and/or diffracted from near by object
- Multipath phase-carrier range error is up to $\frac{\lambda}{4}$, as high as 4.8 cm for the L1 and 6.1 cm for the L2



SIGNAL NOISE RATION CHARACTERISTICS

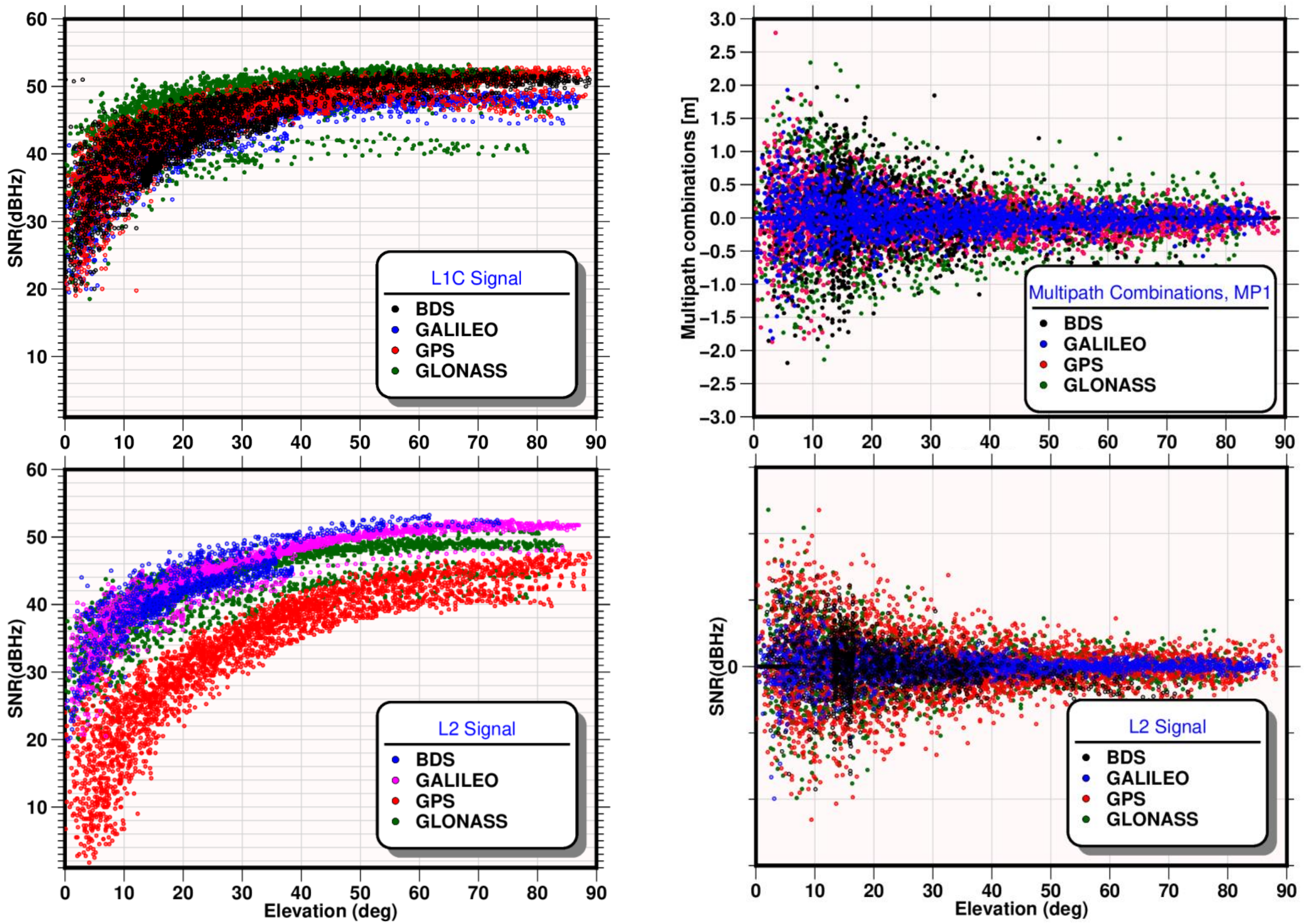
- **Signal-to-noise ratio (SNR)**
- **Understanding multipath error by mapping of SNR**
- **Correcting for multipath error for by modelling SNR**





SNR CHARACTERISTICS AND MULTIPATH COMBINATIONS FROM MULTI-GNSS

Signal-to-noise ratio
From Multi-GNSS



Multipath combination (MP1)
of L1 signal from Multi-GNSS

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MULTIPATH MITIGATION APPROACH

Multipath mitigation Techniques

Antenna design & placement	Receiver proce-ssing algorithms	Site-specific multipath mapping	observation weighting
Site selection / monumentation	Equipment dependent	station calibration	Posfite Res. weighting
		Modelling of site environment	GNSS Analysis Strategies (E.g DD/PPP)
		Analysis of signal quality (E.g C/No)	
		Analysis of carrier phase residuals	

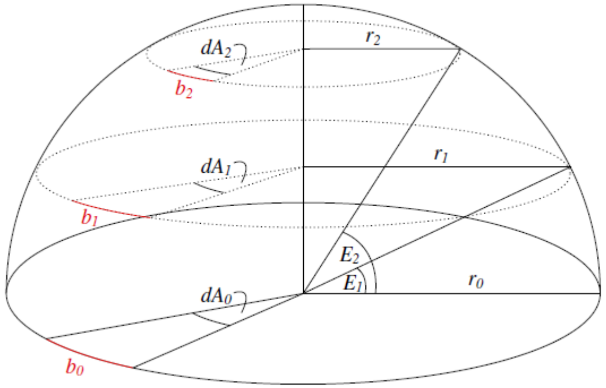
CONSTRUCTION OF MULTIPATH STACKING MAP (MPS)

- The GNSS post-fit phase residuals indicate the effect of unmodeled multipaths
- Here we use carrier phase residuals from GNSS data processing to derive combined PCV/multipath maps.
- Typically, residual stacked mapping of site specific process uses a constant approach to azimuth and elevation resolution → hence it strongly depends on the number of residuals per cell.
- For instance, Wanninger and May (2001), Lidberg et al. (2009) used constant azm, ele. $A = 5^0 \times 2^0$ resolution, and Wanninger and May (2001) and Wanninger and May (2001) and Iwabuchi et al. (2004) adopted $1^0 \times 1^0$.
- However, using constant elevation and azimuth resolution decrease the number of residuals stacking bin as the elevation angle increases (Fuhrmann et al.2015)

CONGRUENT GEOMETRY- SIMILAR SHAPE AND SIZE

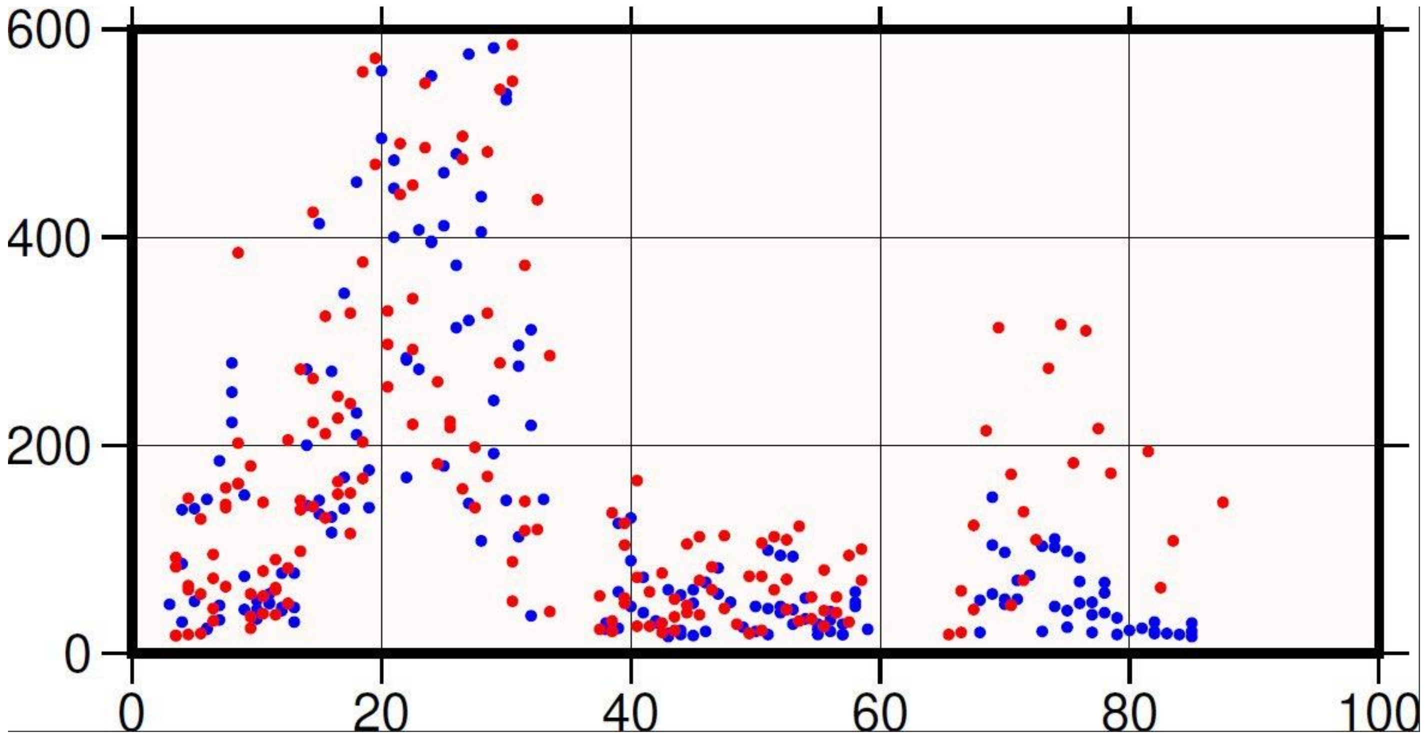
- Most common approaches for constructing grids use constant resolutions (fixed azimuth and elevation)
- Size of the grids decreases with increasing elevation -
  - leading to sparse residuals
- Fixed azimuth resolution, arc of horizontal circle decreases with elevation
- Congruent grid is proposed by Fuhrmann et al. (2015)
- Normally $b_o > b_1 > b_2$ for $dA_o = dA_1 = dA_2$

$$\mathrm{dA_i} = \frac{\mathrm{dA_o}}{\mathrm{cosE_i}}, \qquad C_i = \mathrm{ROUND}\left(\frac{360^o}{dA_i}\right)$$



Courtesy of Fuhrmann, et al. 2015
GPS Solutions

NUMBER OF RESIDUALS PER CELL



Fixed azimuthal resolution

Congruent cell resolution

MULTIPATH MAPPING

- For the residual stacking we make a running average of 21 days of past observations.
  - Corrections of present observations
- The resulting multipath maps contain mean of the impact of unmodelled PCV and multipath, measurement noise and unmodelled atmospheric delays.

GAMIT-GLOBK PROCESSING

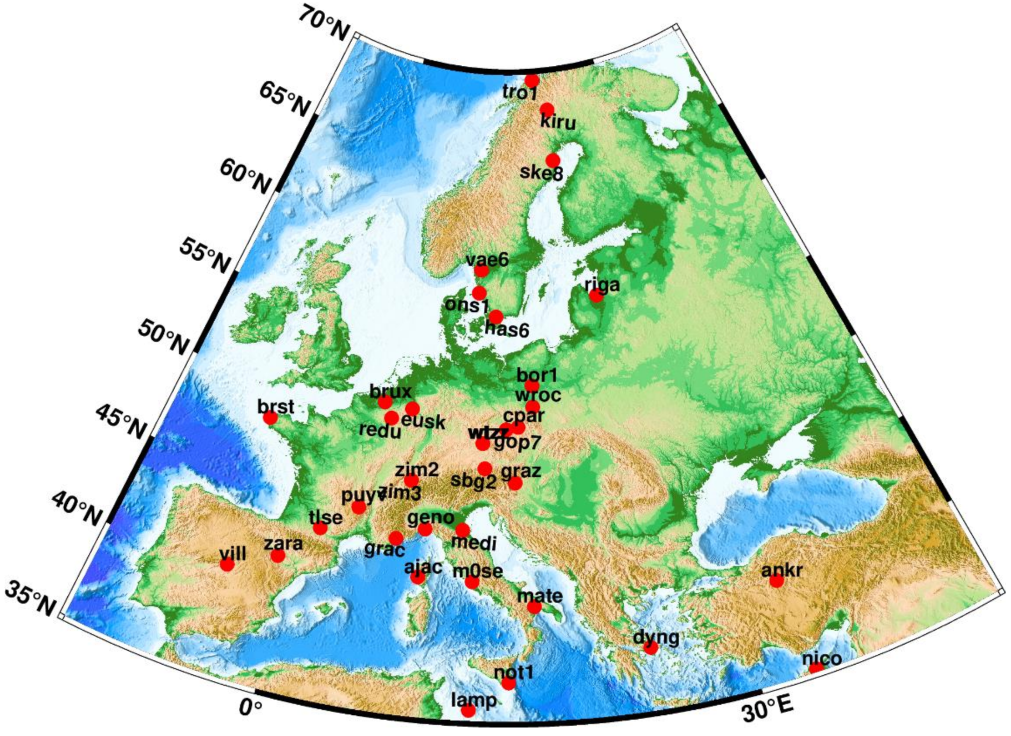
GAMIT-GLOBK capable of processing Multi-GNSS

- G (GPS)
- R (GLONASS
- C (BeiDou-2/COMPASS)
- E (Galileo)

GPS (L1 and L2), Galileo (E1 and E5), BeiDou (C2 and C7)

DATA PROCESSING AND INCLUDED STATIONS

- We have used 36 MGEX stations in Europe
- The selection is based on MGEX stations that can track all four GNSS system
- Data processed for one month from May to June, 2019
- We employed GAMIT-GLOBK V10.7
- Distance sites baselines more than 500km are included
- Elevation cutoff angle was set 3-degree
- Both dry and wet VMF1 mapping function was employed
- Ocean tidal loading effect corrected based on FES2004



Station distributions for available MGEX Stations.

EXAMPLES OF MULTIPATH STACKING MAPS

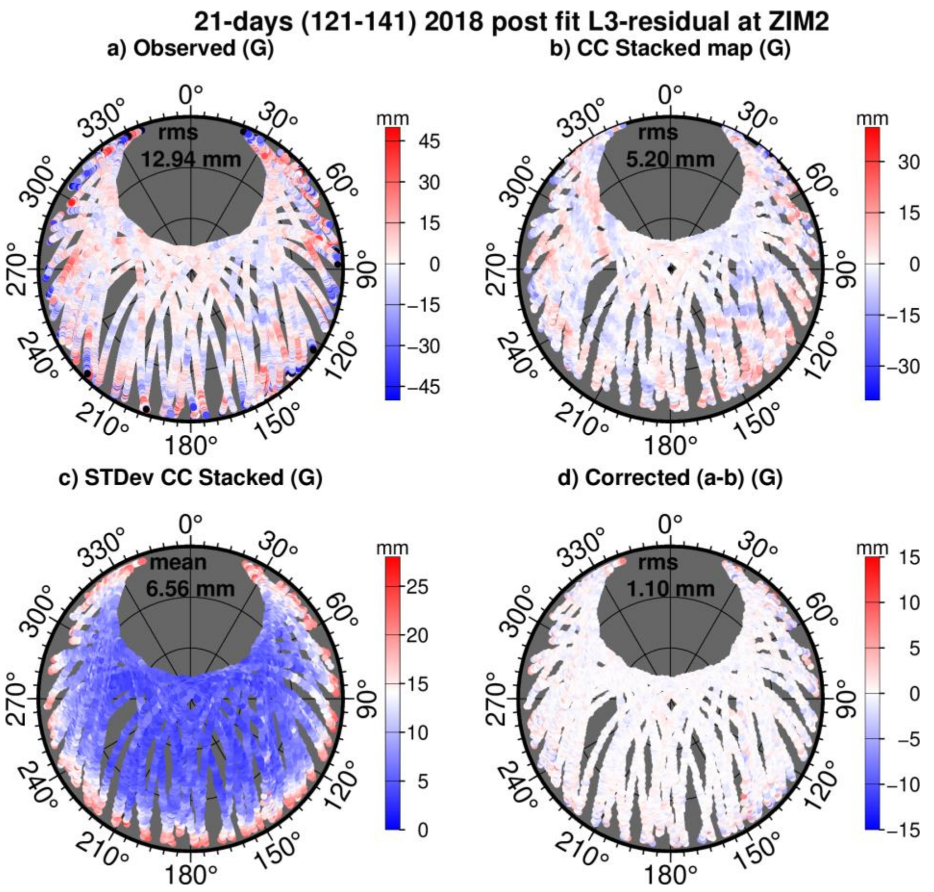
- Station with a larger post-fit residuals (station ZIM2, Zimmerwald, Switzerland)

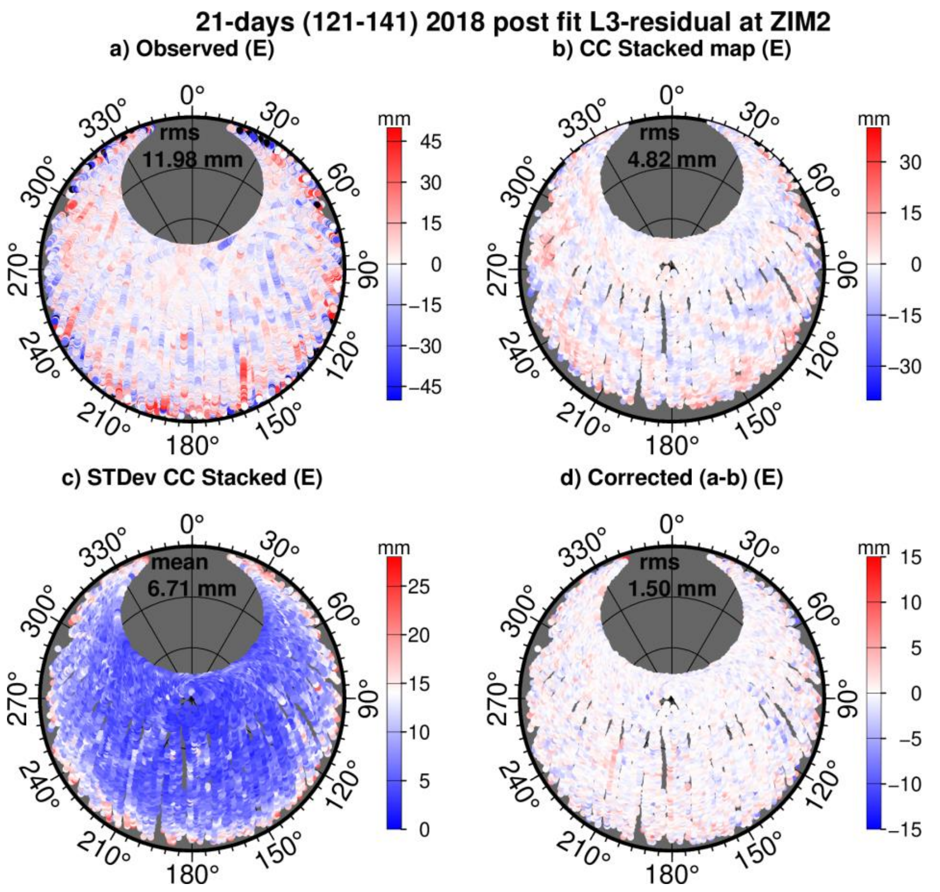
Receiver: Trimble NETR9, Antenna type: TRM59800.00 NONE

- Station with a smaller post-fit residuals (HAS6, Hassleholm, Sweden)

Receiver : TRIMBLE NETR9; Antenna type : LEIAR25.R3 LEIT

GPS(G) & GALILEO(E) POST-FIT RESIDUALS: ZIM2





GPS(G)

Galileo (E)

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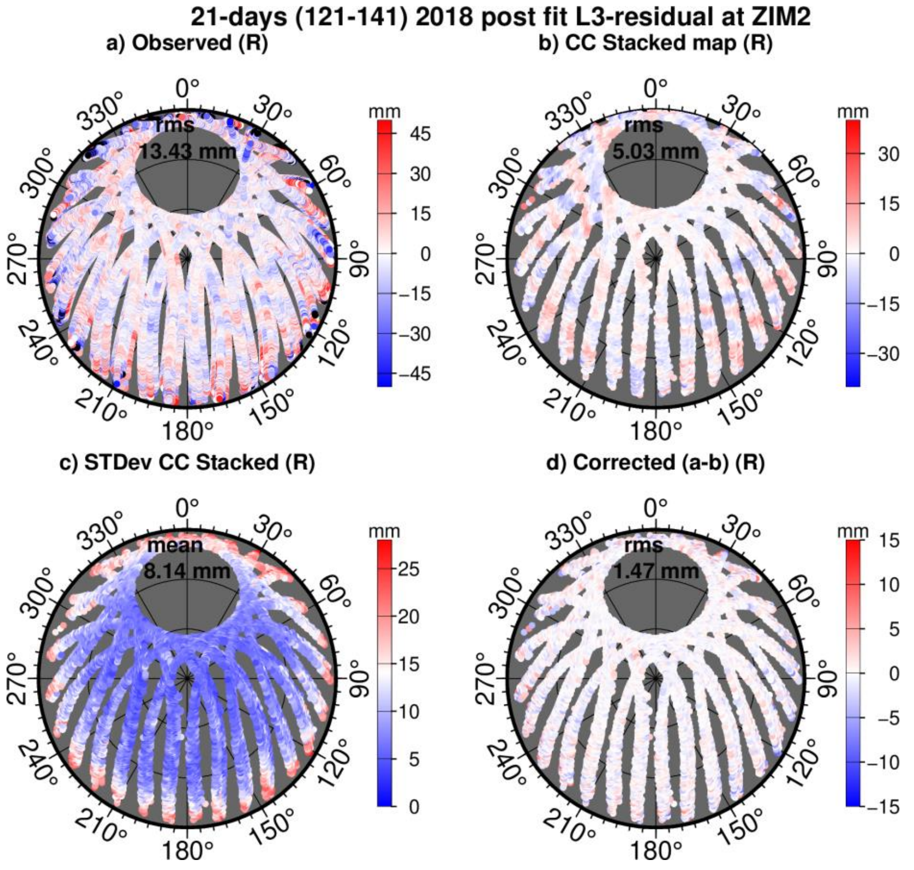
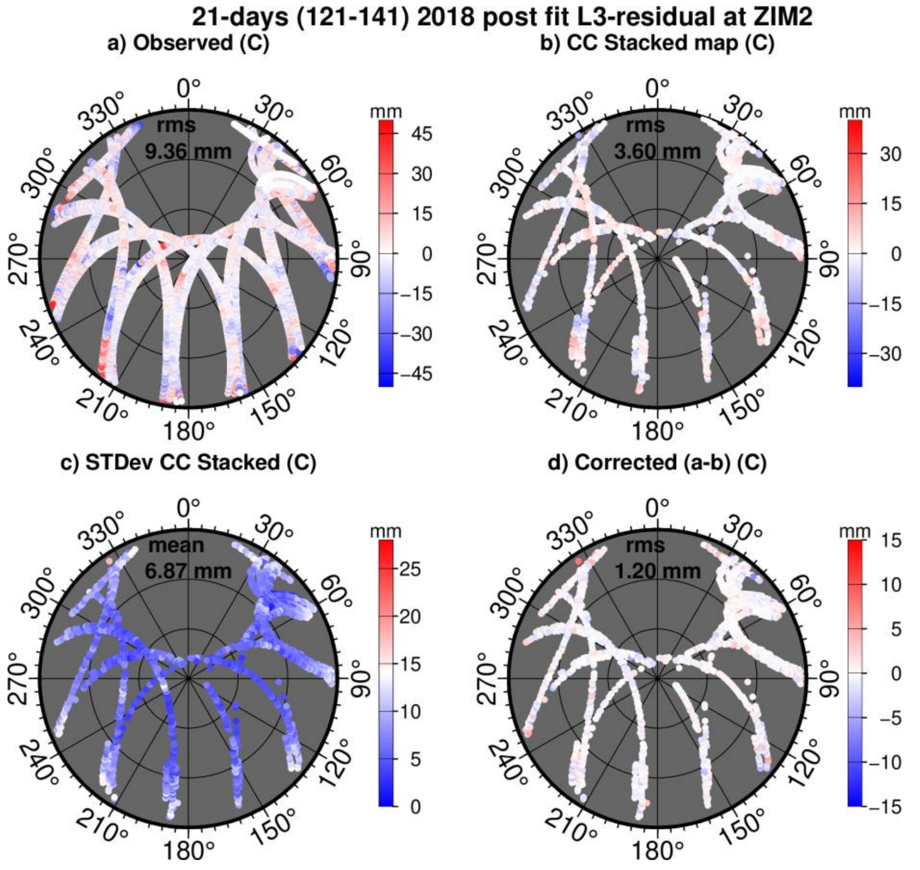
GLONASS (R) & **BDS(C)** POST-FIT RESIDUALS: **ZIM2**

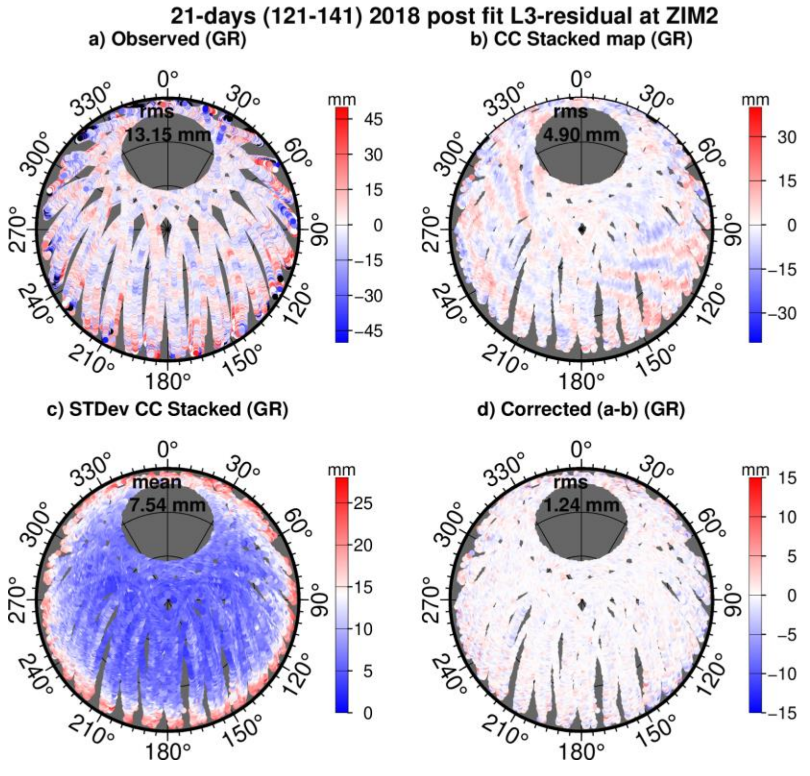


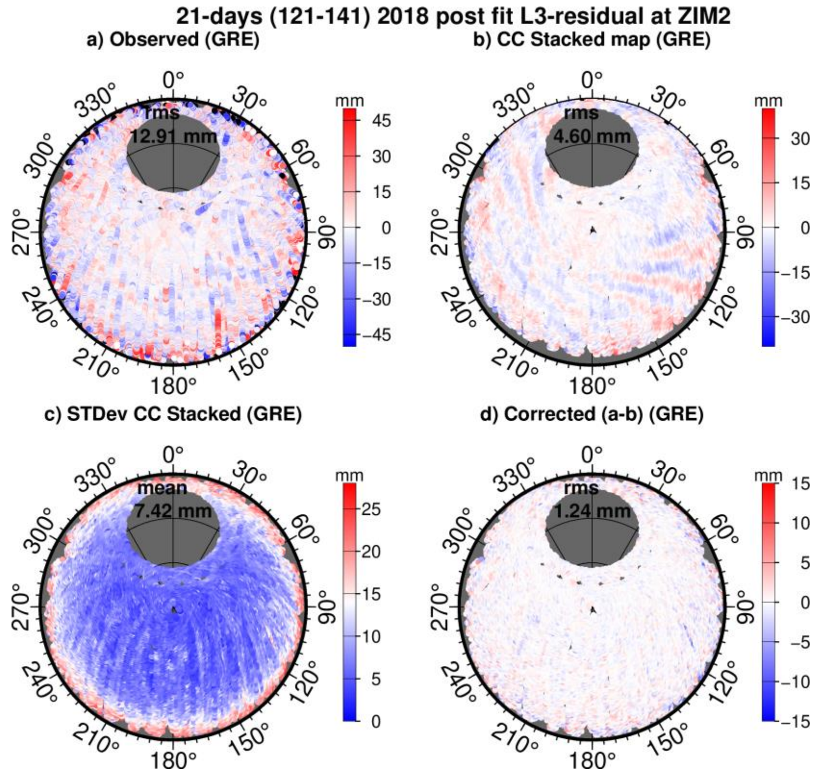
GLONASS (R)

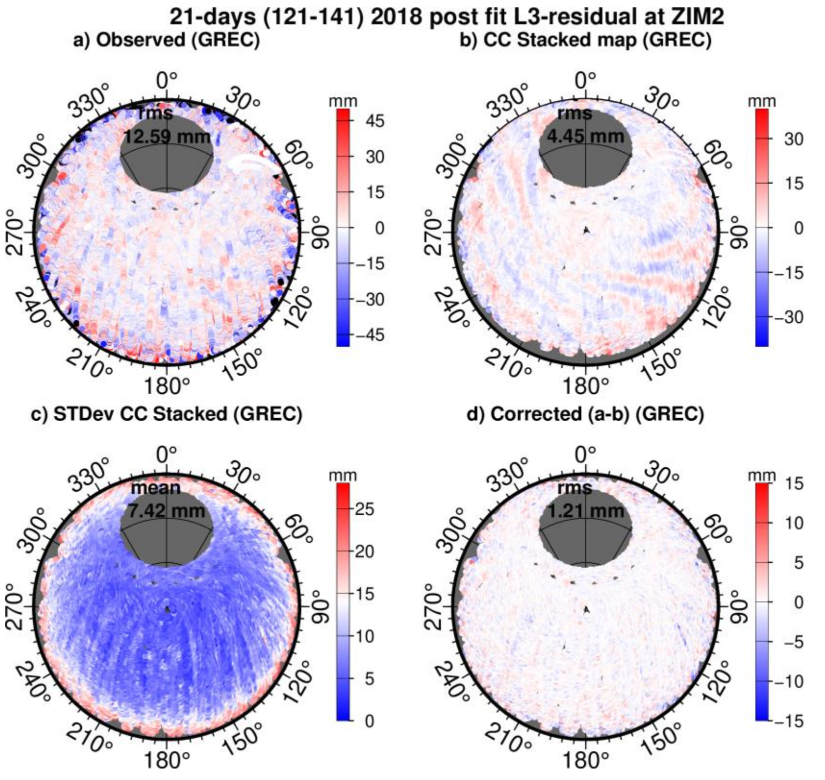


BDS(C)

MULTI-GNSS COMBINATIONS: **ZIM2**, ZIMMERWALD, SWITZERLAND







GPS +GLONASS

GPS +GLONASS+GALILEO

GPS +GLONASS+GALILEO+BDS

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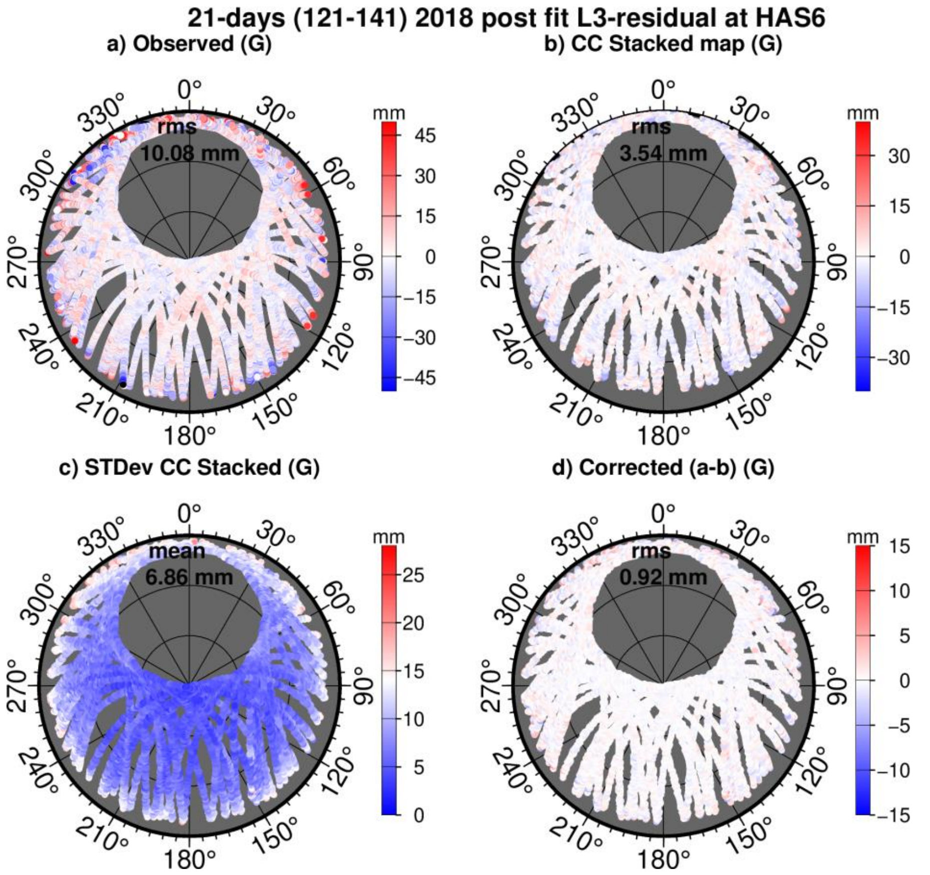
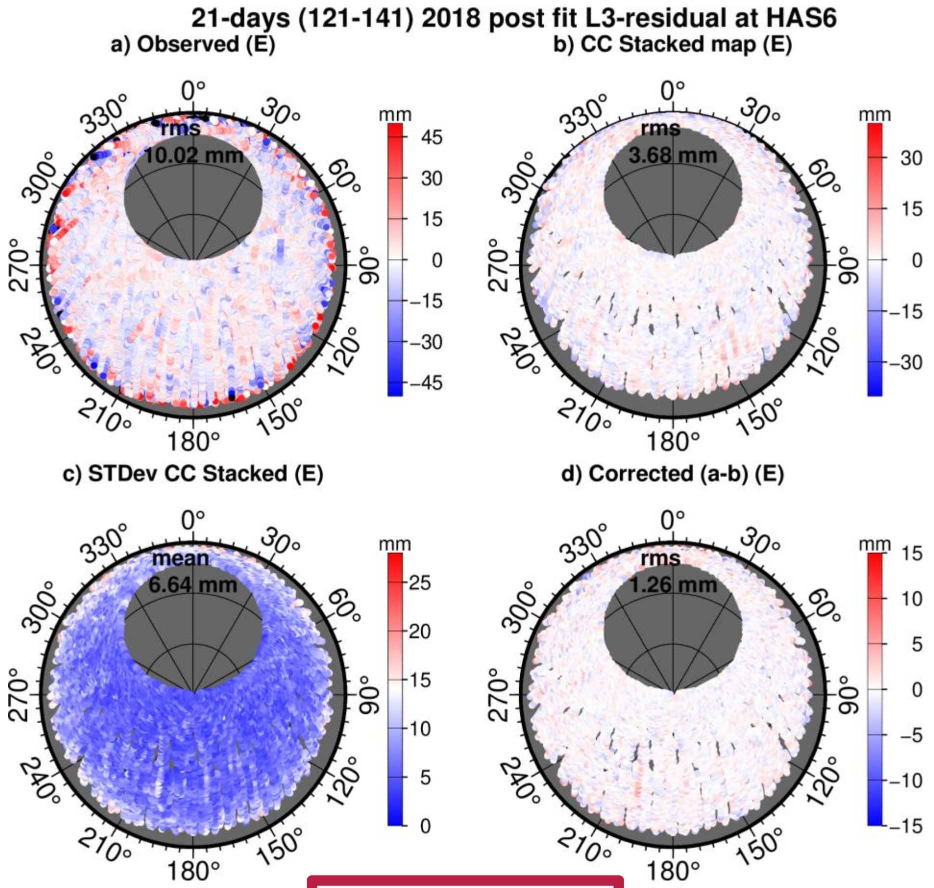
GALILEO(E) & GPS(G) POST-FIT RESIDUAL: HAS6

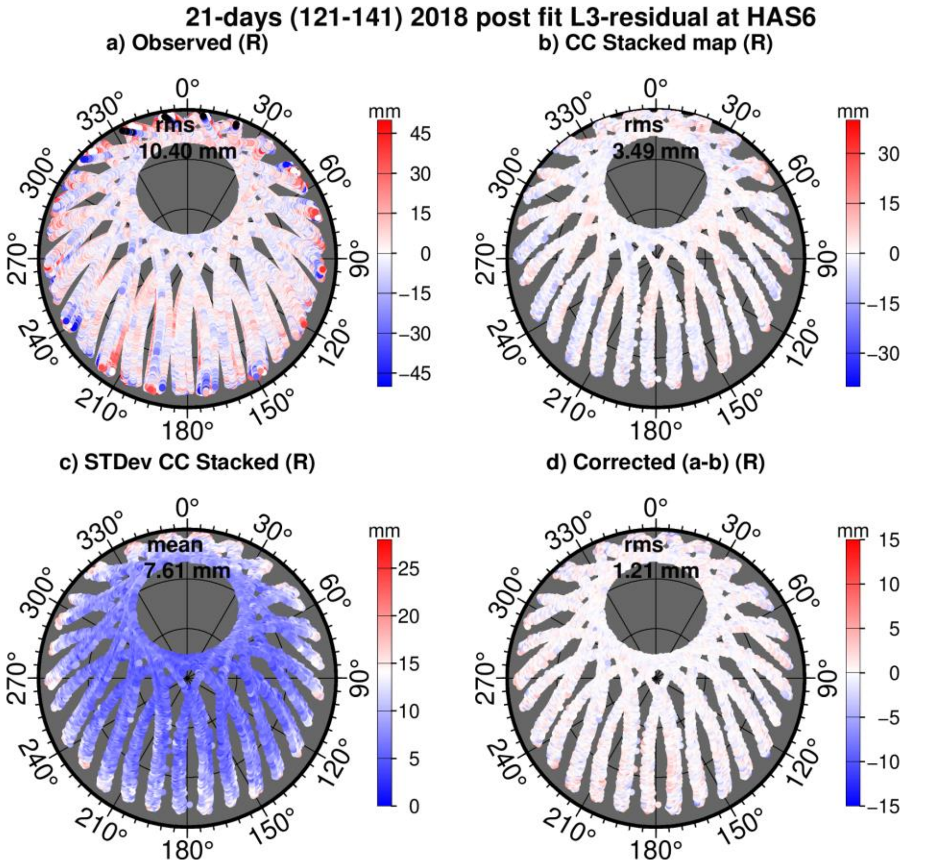


GPS

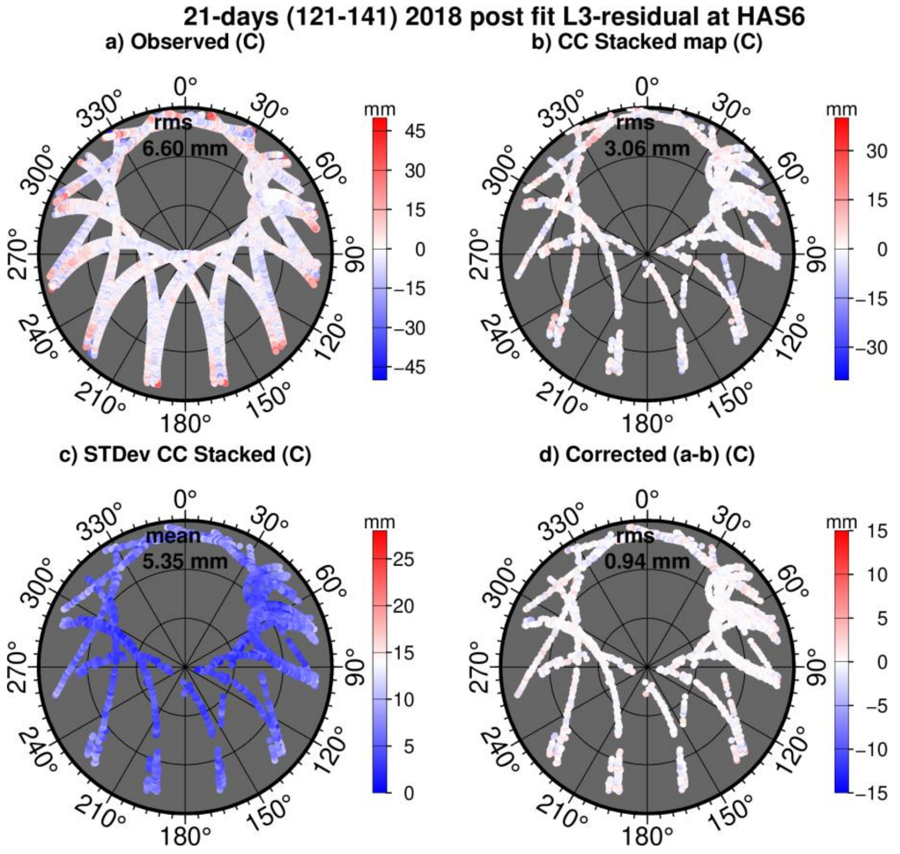


GALILEO

GLONASS (R) & **BDS(C)** POST-FIT RESIDUAL : HAS6



GLONASS (R)



BDS(C)

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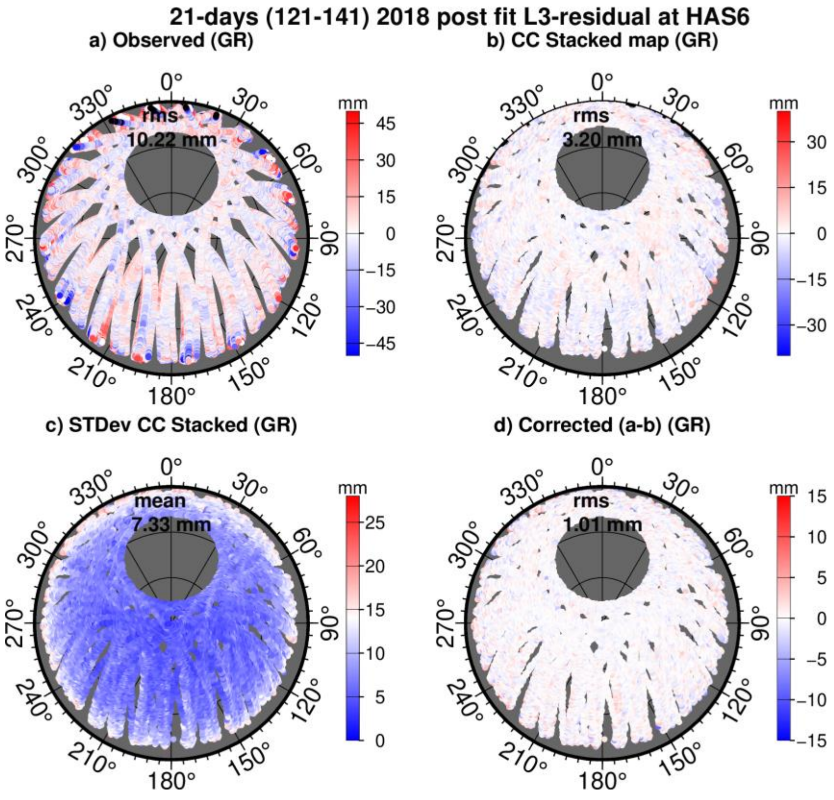
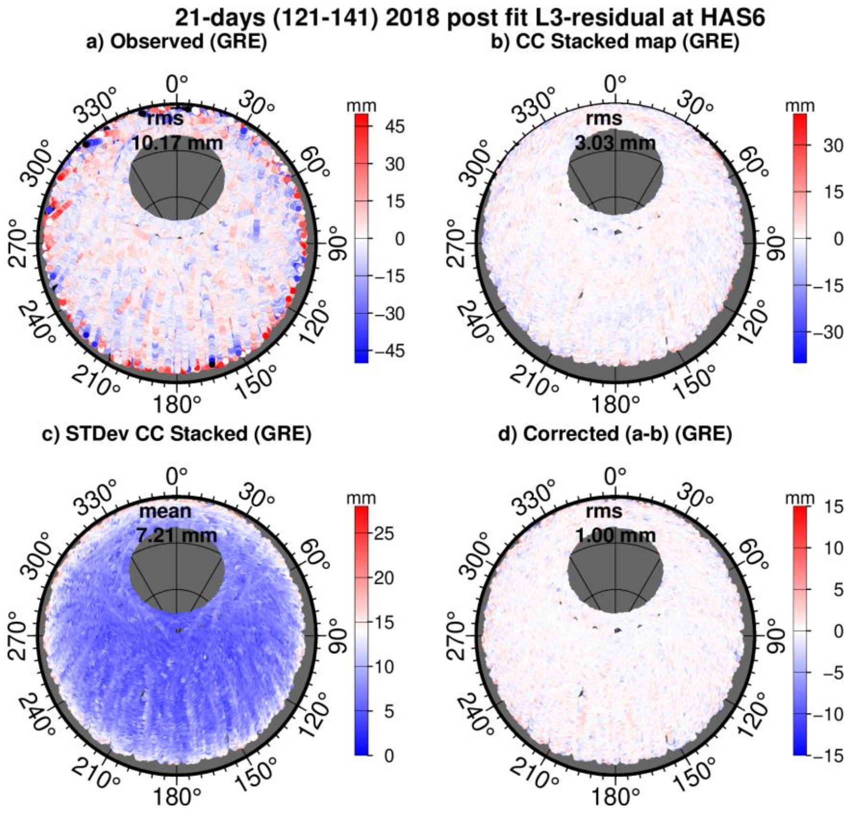
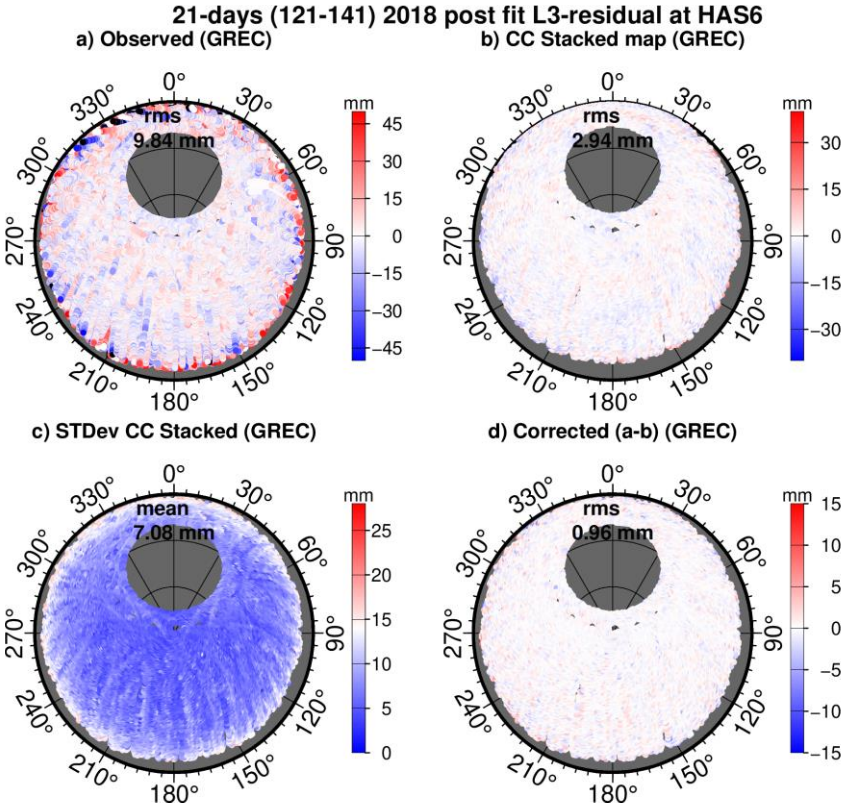
MULTI-GNSS COMBINATIONS: **HAS6,** HASSLEHOLM, SWEDEN



GPS +GLONASS



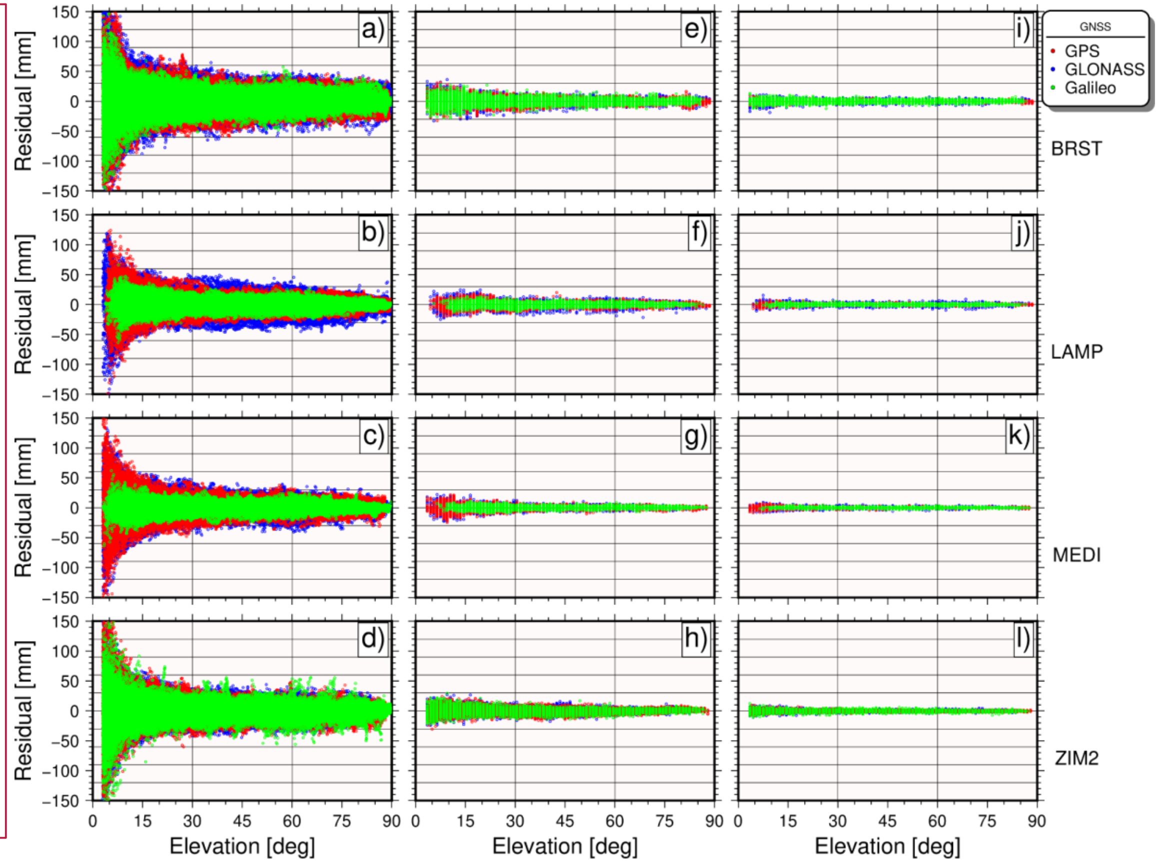
GPS +GLONASS+GALILEO



GPS +GLONASS+GALILEO+BDS

ELEVATION DEPENDENT ONE WAY POST-FIT RESIDUALS AND STACKED RESIDUALS

- **(a-d)** 30 seconds LC post-fit residual from GAMIT-GLOBK processing
- **(e-h)** a stacked bin blocked median of LC post-fit residual
- **(i-l)** Mean difference between observed LC post-fit residuals and stacked block median for each grid cell.



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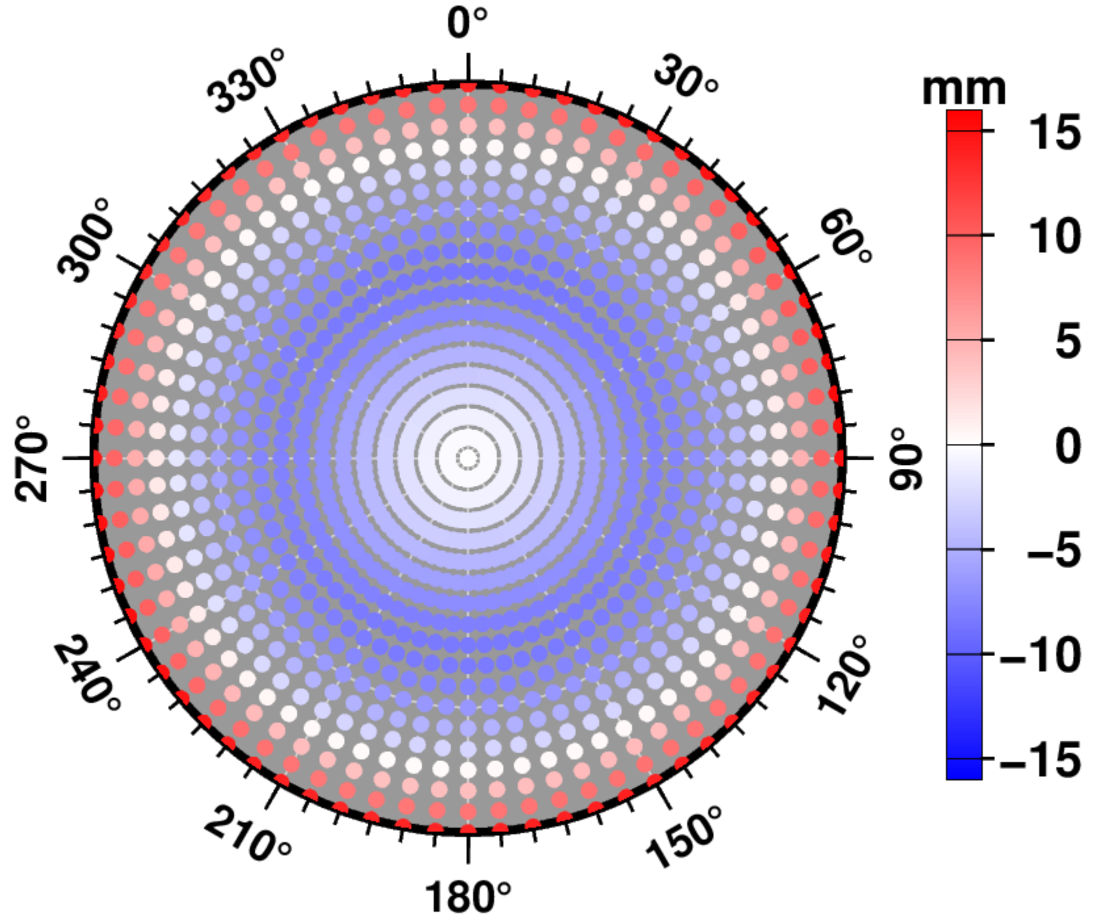
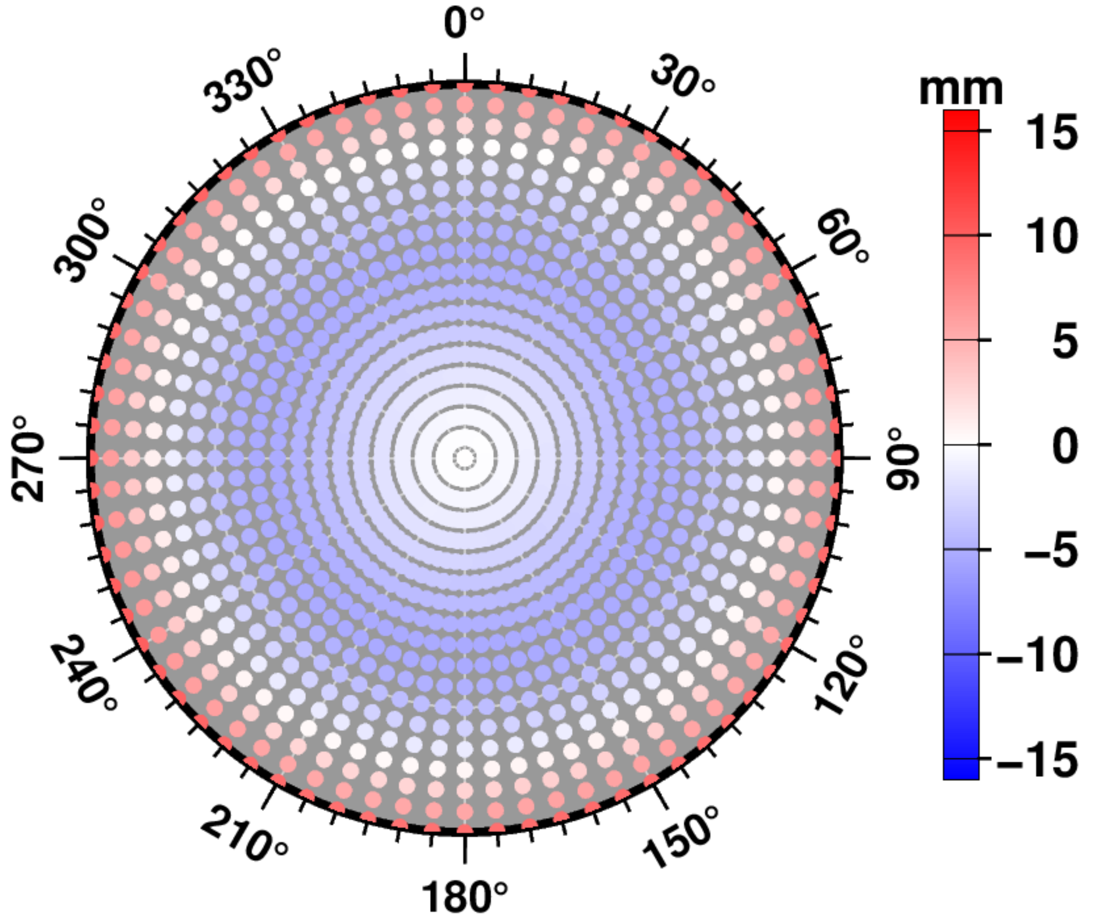
RMS FOR DIFFERENT MEGX STATIONS FOR MULIT-GNSS COMBINATIONS

Station	G	GR	GRE	GREC
AJAC	5.66	5.51	5.07	4.92
ANKR	7.51	7.19	6.37	6.14
BOR1	4.11	5.07	4.62	4.44
BRST	5.98	5.79	5.20	4.98
DYNG	5.47	6.25	5.53	5.30
EUSK	5.54	5.14	4.85	4.73
GENO	5.96	5.76	5.10	4.94
GOP7	6.19	5.79	5.38	5.19
GRAC	5.32	5.45	4.83	4.67
HAS6	3.86	3.54	3.36	3.27
LAMP	4.41	4.44	3.83	3.66
M0SE	7.48	6.80	5.86	5.74
MATE	4.82	5.04	4.39	4.36
MEDI	3.71	3.72	3.21	3.10
NICO	7.65	7.51	6.28	6.06
ONS1	4.91	4.68	4.44	4.26
NOT1	4.38	4.60	3.98	3.84
PUYV	5.52	5.08	4.46	4.35
SBG2	5.39	5.01	4.67	4.58
SKE8	5.97	5.38	5.19	5.06
TLSE	7.18	6.84	6.36	6.21
TRO1	7.85	7.08	6.98	6.82
VAE6	5.51	5.12	4.74	4.56
WTZR	6.41	6.16	5.68	5.49
ZARA	5.31	4.71	4.08	3.95
ZIM2	5.42	5.14	4.72	4.57
ZIM3	5.39	5.10	4.71	4.58

PHASE CENTER VARIATIONS CORRECTIONS FOR L1 (GPS)



PCV at station (ASH700936A_M NONE), station @AJAC



PCV after MPS corrections(ASH700936A_M NONE) , station @AJAC

CONCLUSIONS

- Raw (unfiltered) residual manifest large fluctuations below around 15 degree elevations
- Multi-GNSS stacking further reduce the multipath effects
- The residual MPS map RMS improves when GPS+GLONASS+GALILEO+ BDS are combined
- Galileo show the smallest RMS
- One can provide in-situ correction products similar to the PCV correction tables for all IGS stations