

# Differences between Galileo and GPS coordinate estimates from separate and combined solutions

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# Overview

- Results here will be for the MIT IGS20 trial processing period starting GPS weeks 2222-2230
- Analysis types:
  - Separate GPS and Galileo solutions (separate site coordinates) and a combined solution where coordinates match between the two systems.
  - Satellite phase-center-offsets (PCO) values fixed to IGS20 values (fix20) and fully estimated (fre20)
  - Empirical radiation parameters (3 constant, 6 once-per-rev DYB axes, twice-per-rev Direct and four-per-rev Direct) all loosely constrained (daily) and with all but constant, B OPR and D 2PR estimated with process noise between days (set by overlaps and scatter of daily estimates) (backs).
  - Weekly solutions with radiation parameter process noise and selected terms (week with fixed and free PCO values).

# Results Presented

- Scatter of different solutions: Weighted root mean square scatter of position residuals about linear trends for the 9 weeks. (Precision)
- Comparison of mean differences in heights between single system and combined solutions to the IGS20 realization of ITRF2020 (some measure of accuracy)
- Comparison of mean height differences between combined and single system solutions: Weights of Galileo and GPS are now comparable (GPS still slightly higher weight) and so results will show Galileo minus combined solution. (GPS similar with opposite sign).

# Weekly and daily repeatability

- Solutions
- Full network is GPS and then GAL GNSS sites are selected
- All units are mm.
- Highlights show smallest weekly and daily values

Solution	# Sites	N 50%	E 50%	U 50%	N 95%	E 95%	U 95%
cmb.week_fix20	387	0.64	0.59	2.33	1.40	1.54	4.77
gps.week_fix20	389	0.59	0.67	2.47	1.61	1.64	5.43
gal.week_fix20	257	0.86	0.65	2.68	1.76	1.78	5.28
cmb.week_fre20	387	0.69	0.59	2.27	1.43	1.52	4.83
gps.week_fre20	389	0.61	0.67	2.40	1.60	1.54	4.94
gal.week_fre20	257	0.96	0.64	2.63	1.66	1.83	5.17
cmb.backs_fix20	388	1.23	1.21	4.42	2.16	2.42	8.25
gps.backs_fix20	388	1.24	1.30	4.55	2.26	2.51	8.43
gal.backs_fix20	256	1.65	1.72	5.42	2.65	3.03	10.21
cmb.daily_fix20	388	1.23	1.19	4.32	2.15	2.42	8.33
gps.daily_fix20	388	1.30	1.31	4.55	2.29	2.52	8.27
gal.daily_fix20	257	1.57	1.66	5.38	2.56	3.17	10.34
cmb.daily_fre20	388	1.20	1.19	4.57	2.15	2.44	8.43
gps.daily_fre20	388	1.31	1.31	4.88	2.25	2.52	8.67
gal.daily_fre20	257	1.59	1.68	5.63	2.58	3.14	10.58



# Summary of precision values

- Generally, the combined solution has lower RMS scatter in all components for both the PCO fixed and PCO free solutions (North weekly is exception: GPS 0.59 mm; Combined 0.64 mm).
- Analyses with PCO free have similar (and sometime better) daily solution repeatability.
- Best daily height RMS that contains 95% of the stations, is the combined with radiation parameter constraints (8.25 mm compared to 8.33 mm and 8.43 mm for fix20 and fre20. Median values for weekly solutions height are 4.42, 4.32 and 4.57 mm.

# Comparison between estimates

- Concentrate on height estimates since these are related to scale changes (although there are horizontal differences as well).
- Two type of comparison:
  - IGS20 comparisons normally with 45-130 sites (daily analyses used many of the IGS20 sites has reference frame sites).
  - Comparison at all sites between GPS and Galileo only and the combined solution with and without PCO and radiation parameter constraints (RMS of position estimates from these solutions earlier).

# Comparison to IGS20

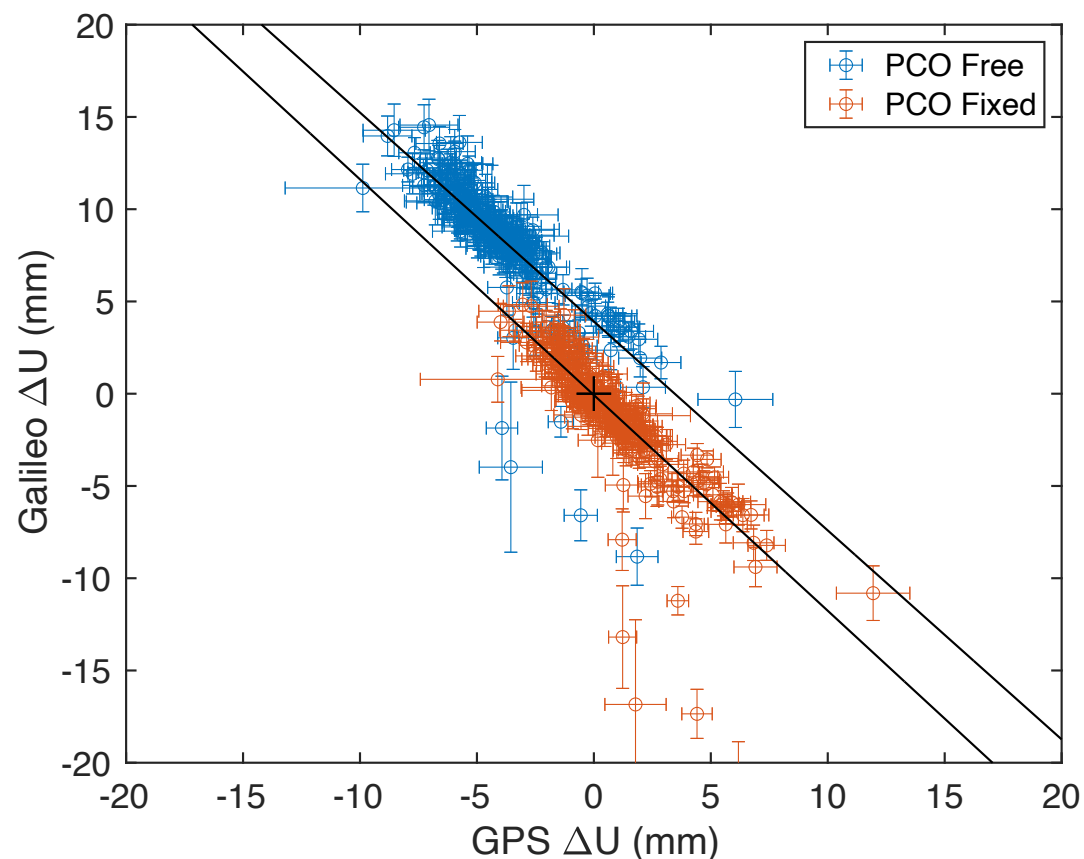
- Results with 40-130 reference frame sites from IGS20 lists
- With PCOs fixed, GPS and Galileo differ by 3.0 and 3.1 mm (GPS-Galileo) depending on radiation parameter treatment; with PCOs estimated differences are -10.9 and -10.7 mm.
- Radiation parameter treatment has little mean effect.

Solution	#	# site	$\Delta U$ (mm)
cmb.week fix20	9	46.2	-2.24
gps.week fix20	9	46.2	-0.78
gal.week fix20	9	42.3	-3.77
cmb.daily_fix20	63	134.8	-0.93
gps.daily_fix20	70	129.5	0.19
gal.daily_fix20	63	103.5	-2.95

Solution	#	# site	$\Delta U$ (mm)
cmb.week fre20	9	46.2	-0.34
gps.week fre20	9	46.2	-5.48
gal.week fre20	9	42.3	5.43
cmb.daily_fre20	63	134.9	0.64
gps.daily_fre20	70	129.5	-4.53
gal.daily_fre20	63	103.5	6.19

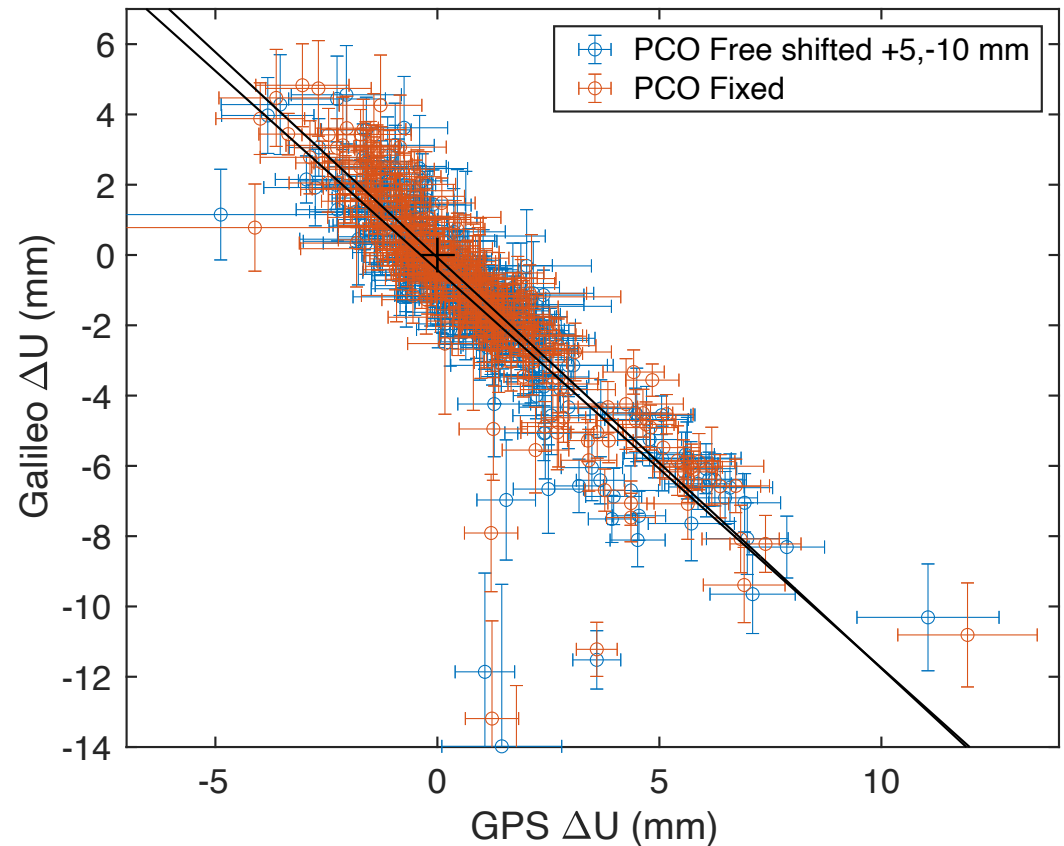
# Comparison of combined and individual solutions

- These are comparisons of the differences between GPS and Galileo only solution with the combined. Weekly solutions with PCO fixed and free.
- Slopes (black lines) are  $\sim -1.1$ - $1.2$  indicating Galileo and GPS have similar weights
- Large black + sign origin (0,0)



# Comparison of combined and individual solutions

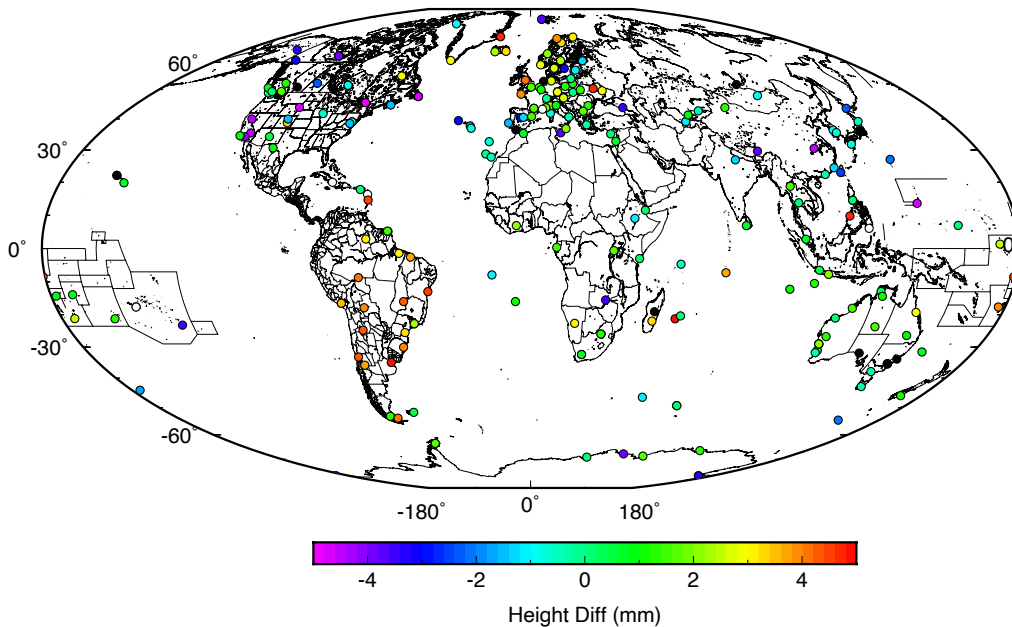
- These are comparisons of the differences between GPS and Galileo only solution with the combined. Use weekly solutions with PCO fixed and free.
- Offsetting PCO free and Fixed results show nearly identical patterns.



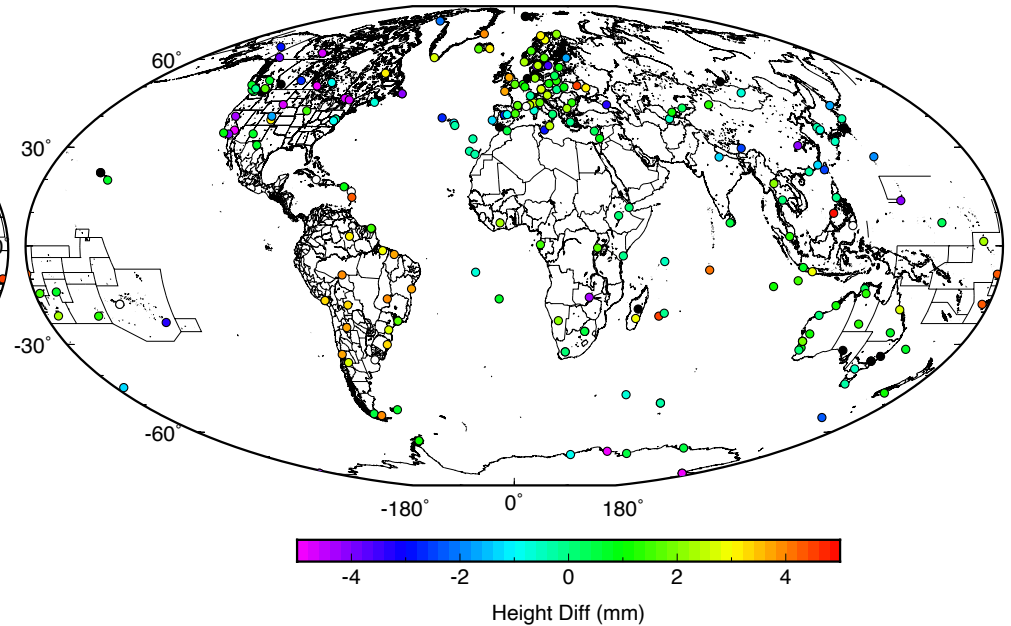
# Maps of GAL-CMB (fixed and free PCO)

- Means of -1.33 and 8.23 mm removed from fixed and free PCO.

PCO Fixed IGS20



PCO Free



# Analysis

- Large differences between GPS and Galileo only solutions for some sites seen and relative pattern remains the same when PCOs are estimated. The differences are shifted for GPS and Galileo.
- When mean offsets are removed (equivalent to global scale change) the spatial pattern of the differences is very similar in location and magnitude.
- Treatment of radiation parameters has some effect, but majority seems to arise from ground stations: Check antenna calibration and antenna installation.
- Examine short baselines where all non-site-specific errors should be eliminated.

# Antennas

- One very clear pattern is the AOAD/M\_T-B antenna with only G01 and G02 calibrations have -4 to -17 mm Galileo differences from combined solution when PCOs fixed. E X20: Galileo Fixed PCO; E R20 Galileo Free PCO

Site	Longitude	Latitude	E X20	E R20	Antenna		Radome	Frequencies			
CEDU	133.809840	-31.866660	-17.35	-6.59	AOAD/M_T	NONE	NONE	G01	G02	R01	R02
YAR2	115.346980	-29.046550	-11.22	-1.52	AOAD/M_T	NONE	NONE	G01	G02	R01	R02
USUD	138.362050	36.133110	-10.81	-0.31	AOAD/M_T	JPLA	NONE	G01	G02	R01	R02
GODE	283.173170	39.021730	-8.22	1.69	AOAD/M_T	JPLA	NONE	G01	G02	R01	R02
...											
NYAL	11.865090	78.929590	-5.04	3.13	AOAD/M_B	DOME	NONE	G01	G02		
..											
VIS0	18.367320	57.653870	-4.50	4.75	AOAD/M_T	OSOD	NONE	G01	G02	R01	R02
MADR	355.750340	40.429160	-4.24	5.45	AOAD/M_T	NONE	NONE	G01	G02	R01	R02

- Not all 22 sites shown. There are differences but all negative and ~10 mm offset between PCO fixed and free.



# Yarragadee: Three sites

- Galileo differences: Long/Lat 115.346980 -29.046550

Site	E X20	E R20	Antenna	
YAR2	-11.22	-1.52	AOAD/M_T	NONE
YARR	0.73	10.07	LEIAT504	NONE
YAR3	3.42	13.06	LEIAR25	NONE

- Site Frequencies

YAR2 G01 G02 R01 R02

YARR G01 E01 J01 S01 C01 G02 J02 G05 E05 J05  
C05 S05 I05 R01 R04 R02 R06 E06 J06 E07 C07  
E08 C08 C02 C06

YAR3 G01 E01 J01 S01 C01 G02 J02 G05 E05 J05  
C05 S05 I05 R01 R04 R02 R06 E06 J06 E07 C07  
E08 C08 C02 C06

YAR2



YARR



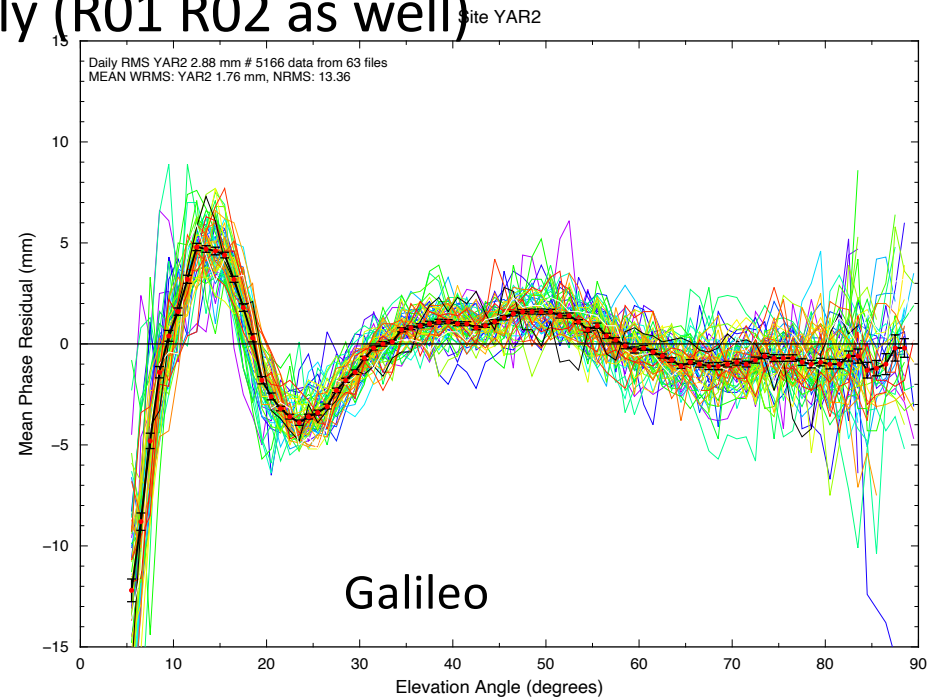
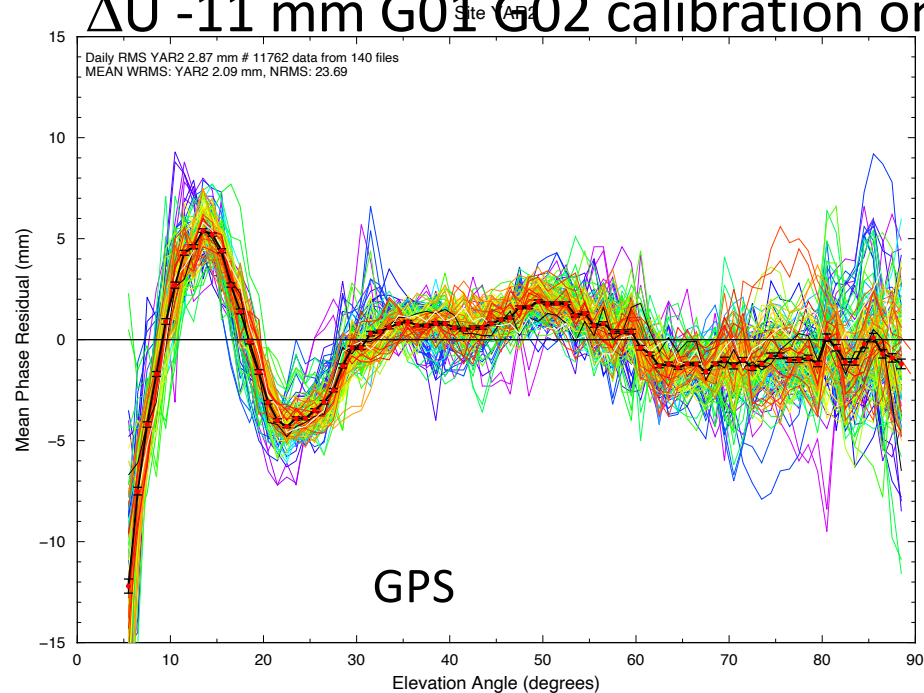
YAR3



# Average Elevation angles dependent residuals

- YAR2: Colors are different days over 9 weeks; Red line average.

$\Delta U$  -11 mm G01 G02 calibration only (R01 R02 as well)



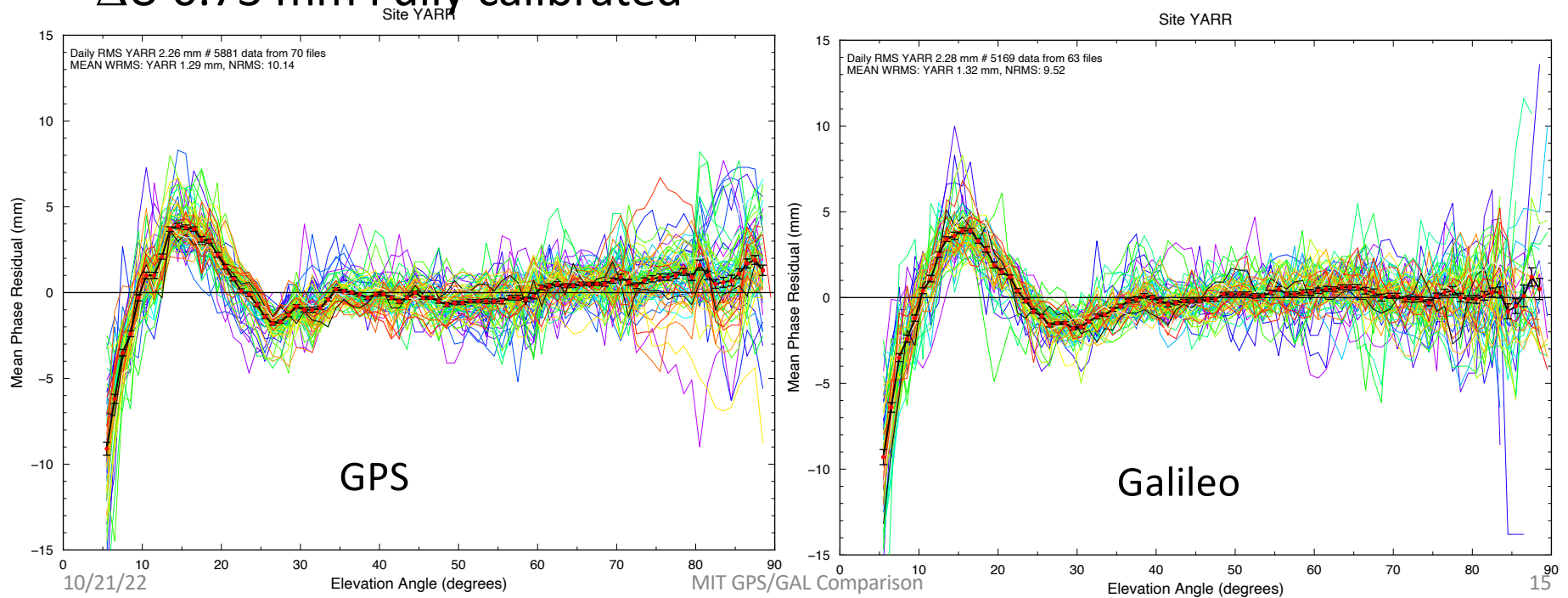
10/21/22

MIT GPS/GAL Comparison

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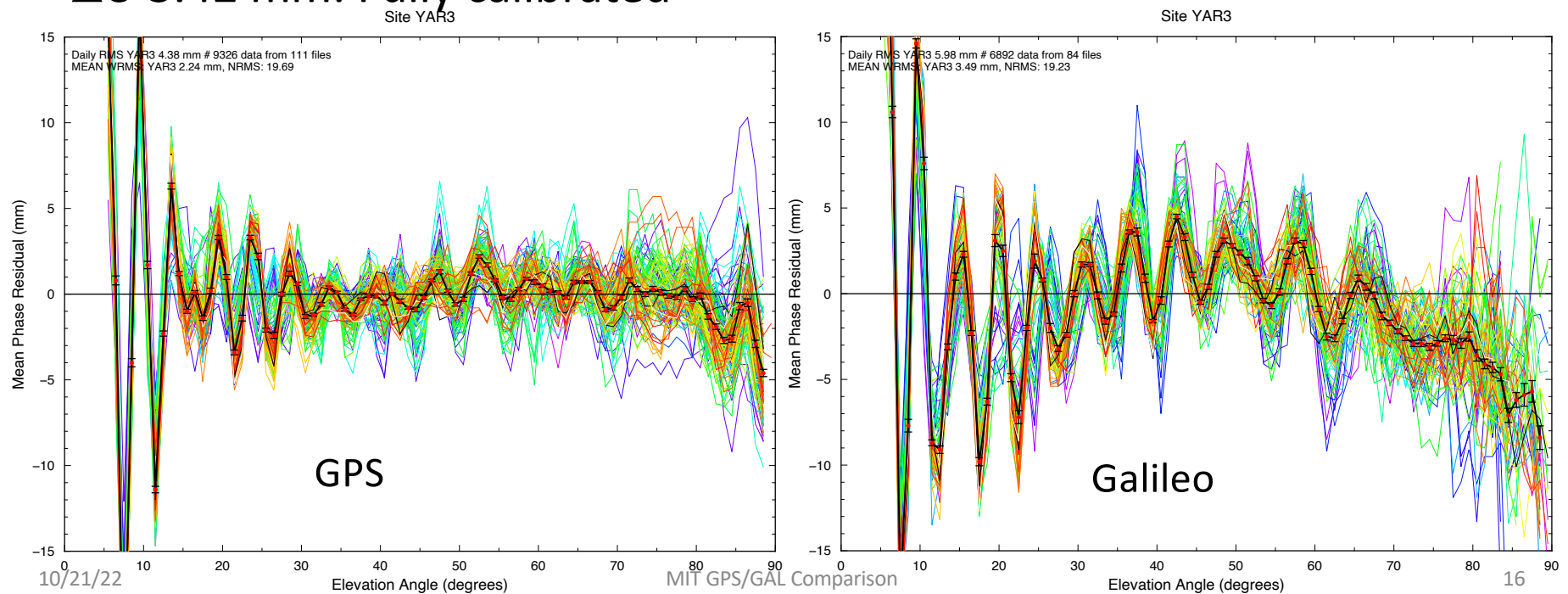
# Average Elevation angles dependent residuals

- YARR: Colors are different days over 9 weeks; Red line average.  
 $\Delta U$  0.73 mm Fully calibrated



# Average Elevation angles dependent residuals

- YAR3: Colors are different days over 9 weeks; Red line average.  
 $\Delta U$  3.42 mm: Fully calibrated



# Conclusions

- There are systematic differences between Galileo and GPS position estimates which are enhanced when satellite phase center offsets are estimated.
- Mean difference between GPS and Galileo heights are close to zero when IGS20 PCO values held fixed, but this is expected based on the scaling used to create IGS20.
- Treatment of radiation parameters has some impact but is probably not the main contributor.
- Some **but not all** antenna types with only G01 and G02 calibration have negative bias of Galileo height estimates.
- Fully calibrated antennas also have biases (**but not all**) and these biases seem to arise from local effects at the antenna installation.
- Concentrated in this talk on heights, but systematic differences in horizontal components as well.
- **Recommendation:** Development of *insitu* absolute calibration method with repeat surveys to verify environmental change effects.