IGS Workshop 2018

29 October to 2 November

Wuhan, China

Multi-GNSS through Global Collaboration

Galileo un-differenced “integer” products: method, results and perspectives

Felix Perosanz, Sylvain Loyer, Georgia Katsigianni, Flavien Mercier, Laetitia Versini

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

CLS COLLECTE LOCALISATION SATELLITES

GÉOSCIENCES ENVIRONNEMENT TOULOUSE

GRGS GROUPE DE RECHERCHE DE GEODESIE SPATIALE

Introduction

The CNES-CLS IGS Analysis center:

- uses the Integer Recovery Clock (IRC) approach
- to processed un-differentiated iono-free phase observation
- and fix ambiguities to integer values for GPS L1, L2 measurements

We have investigated the capability to apply this methodology to Galileo E1,E5A

In this presentation:

- remind the two steps procedure to fix ambiguities (two frequencies approach)
- evaluate the stability of the Galileo satellite “hardware” biases
- present Galileo results: ambiguity success rate, clocks and orbits products consistency
- discuss potential applications and perspectives

Ambiguity fixing: step1

Melbourne-Wübbena Linear Combination

$$MW = \left(\frac{f_i}{f_i - f_j} L_i - \frac{f_j}{f_i - f_j} L_j\right) - \left(\frac{f_i}{f_i + f_j} P_i + \frac{f_j}{f_i + f_j} P_j\right)$$

$$= \lambda_{WL}(N_{WL} + WSB - WRB)$$

N_{WL} : Wide-Lane ambiguity
WSB: WL Satellite Bias
WRB: WL Receiver Bias

$$N_{WL} = N_j - N_i$$

NWL, WSB and WRB are 100% correlated

(Loyer, et al., 2012)

P,L: Range and phase observations

f_i, f_j : L_i and L_j frequencies

λ_{WL}: Wide-Lane wavelength

$$\lambda_{WL} = c/(f_i - f_j)$$

GNSS	λ_{WL} (m)
GPS ($L1$, $L2$)	0.862
Galileo ($E1$, $E5a$)	0.751

- examine WSB Stability ?
- if possible solve N_{WL}

Ambiguity fixing: step2

Iono-free Linear Combination

$$L_{IF} = \kappa_i L_i + \kappa_j L_j$$
$$= \rho \quad + \Delta h_L + \lambda_{NL} W - \lambda_{NL} N_i - \kappa_j \lambda_j N_{WL}$$

The precision on ρ (orbit and station coordinates) is critical

- solve for N_i
- hence also solving for N_j ($N_{WL} = N_j - N_i$)

L_{IF} : phase Iono-free LC

κ_i, κ_j - iono-free coefficients

$$\kappa_i = \frac{f_i^2}{f_i^2 - f_j^2} \quad , \quad \kappa_j = \frac{-f_j^2}{f_i^2 - f_j^2}$$

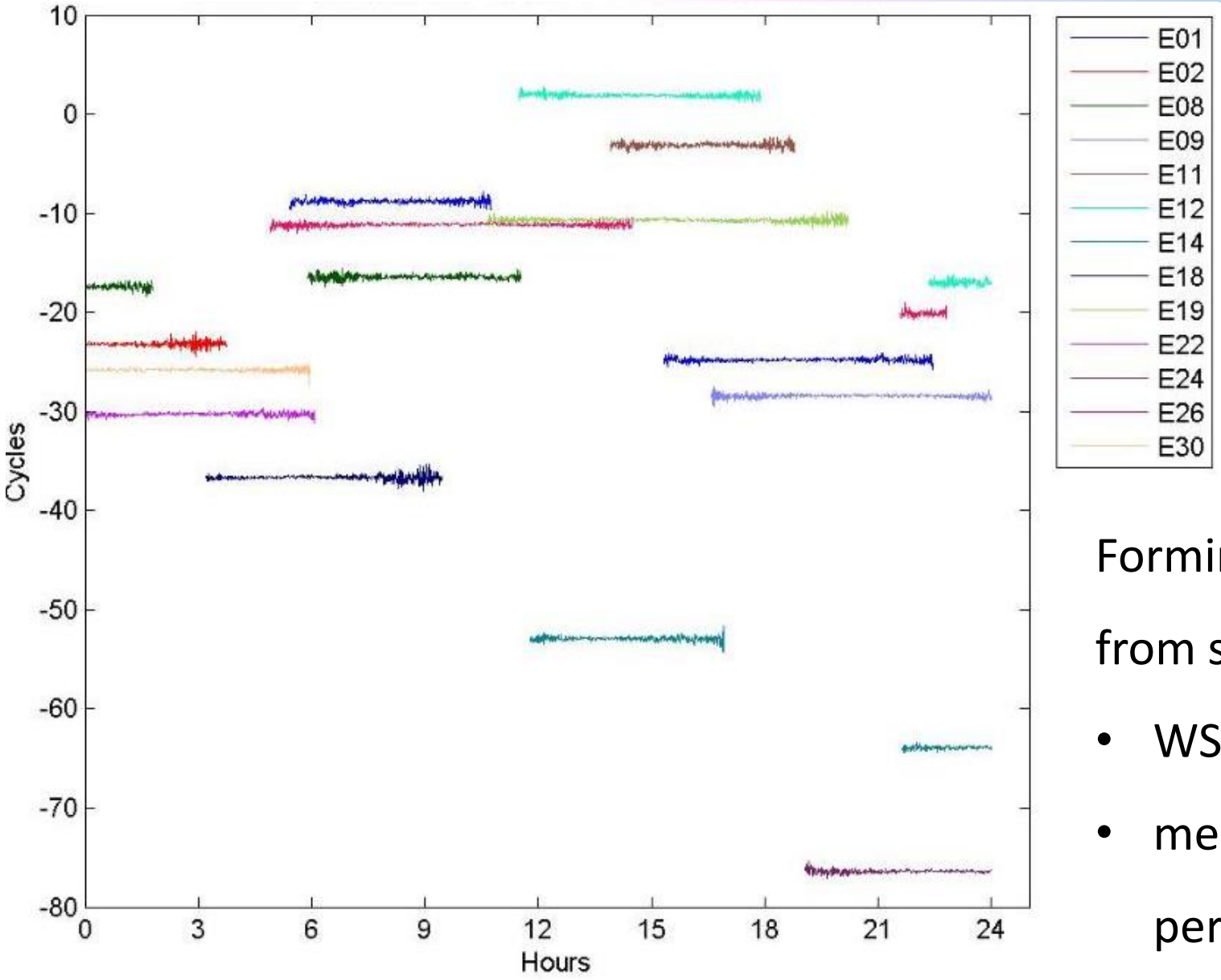
ρ : geometric distance

λ_{NL} - Narrow-Lane wavelength

N_{WL} - Wide-Lane ambiguity **from step 1**

GNSS	λ_{NL} (m)
GPS ($L1$, $L2$)	0.107
Galileo ($E1$, $E5a$)	0.109

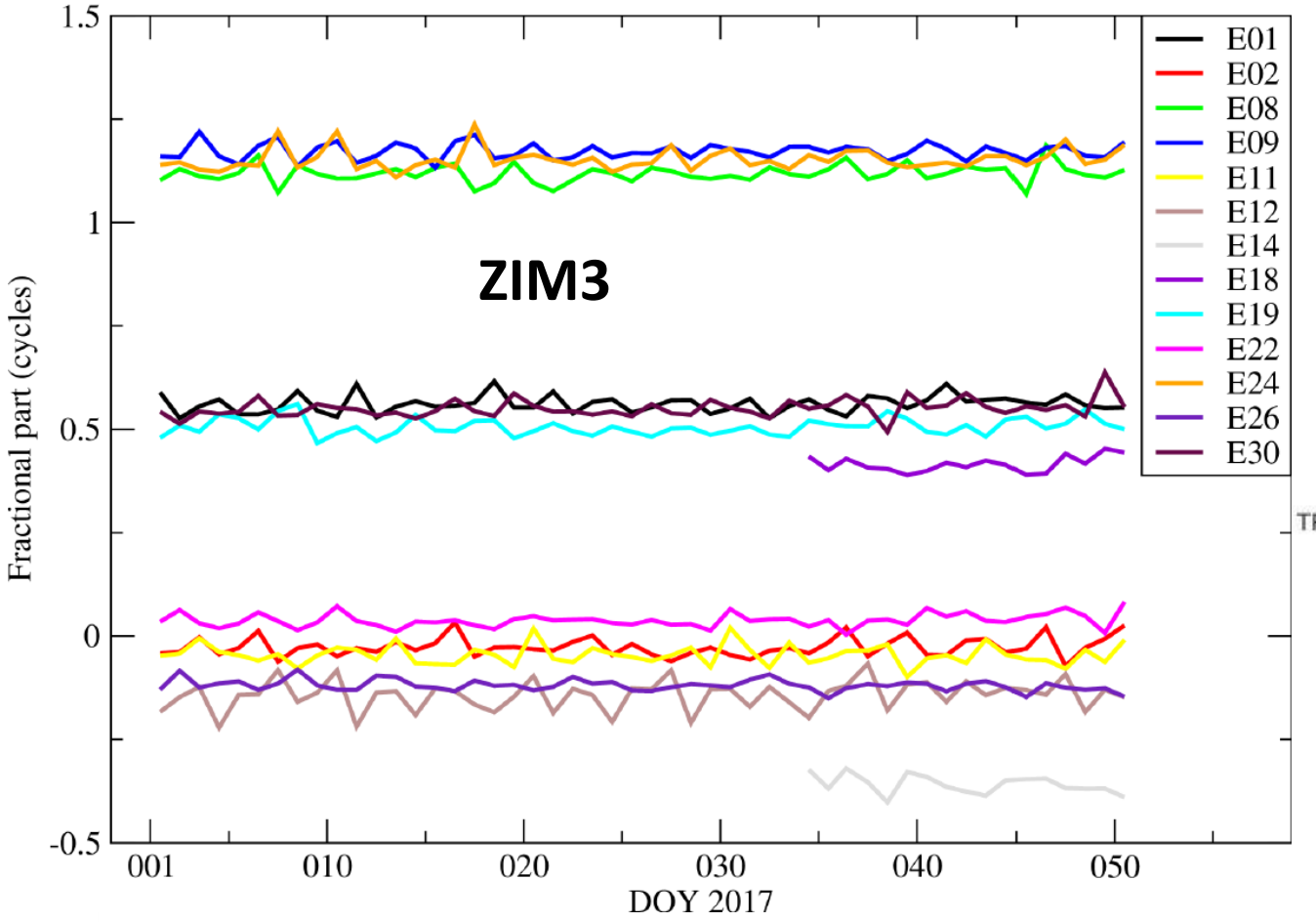
Galileo WSB measurement (1/2)

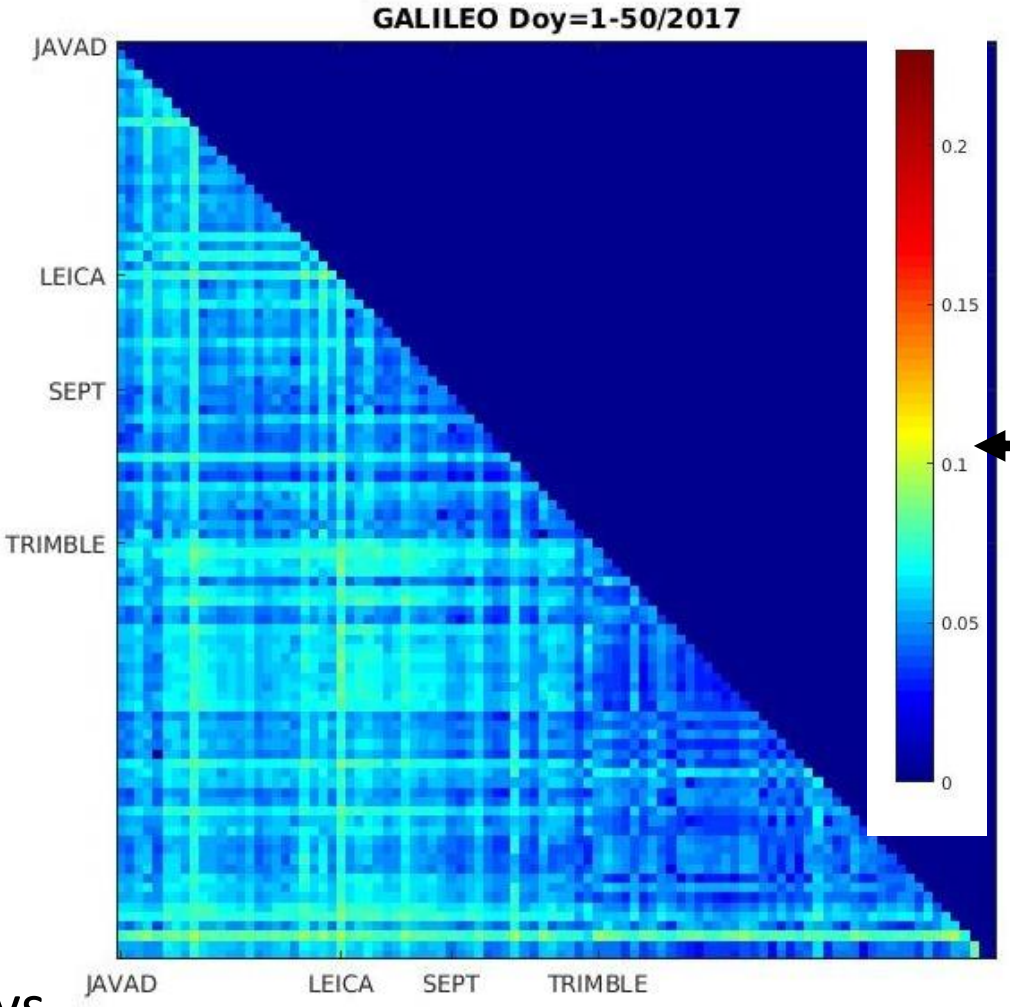


Forming MW per epoch and per satellite from station USN8 :

- WSB are stable (<< 1 WL cycle)
- mean fractional values can be calculated per pass

Galileo WSB measurement (2/2)





0.1 cycle

- Left: WSB per passes are stable even over 50 days
- Right: consistency of WSB between receiver manufacturers is below 0,1 cycle

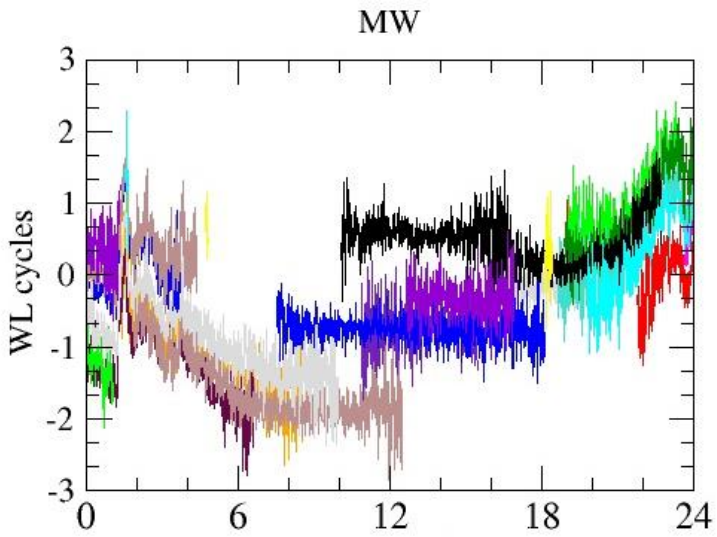
Conclusion: fixing WL ambiguities with Galileo must me feasible

Galileo Wide-Lane ambiguities fixing

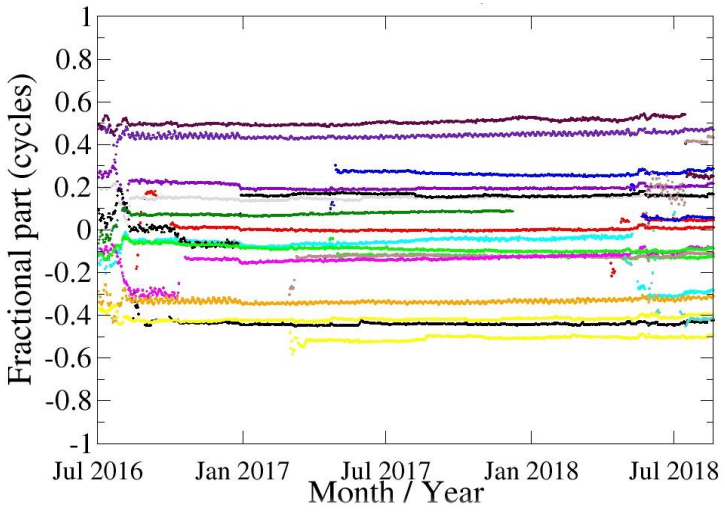
RINEX →

→ $N_{WL} = N_j - N_i$

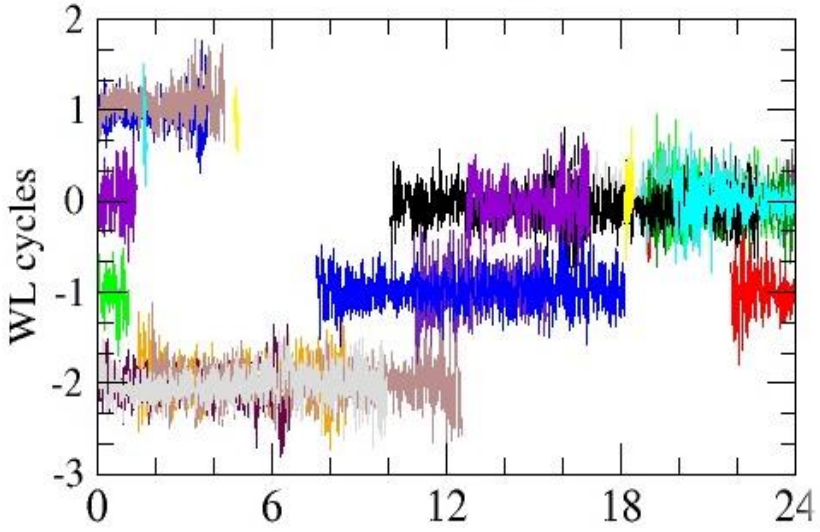
↑

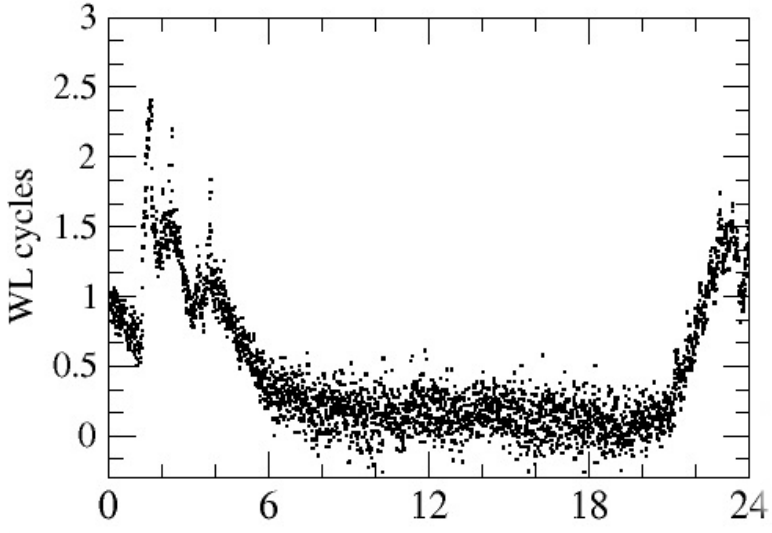


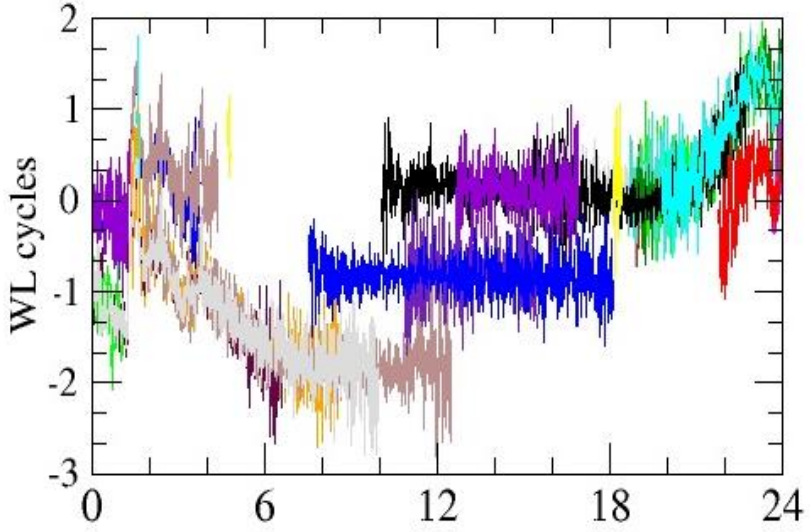
WSB



WRB(t)







Galileo Narrow-Lane ambiguities fixing

Success rates of AR for Nov. 2017

GPS+Galileo data processed simultaneously

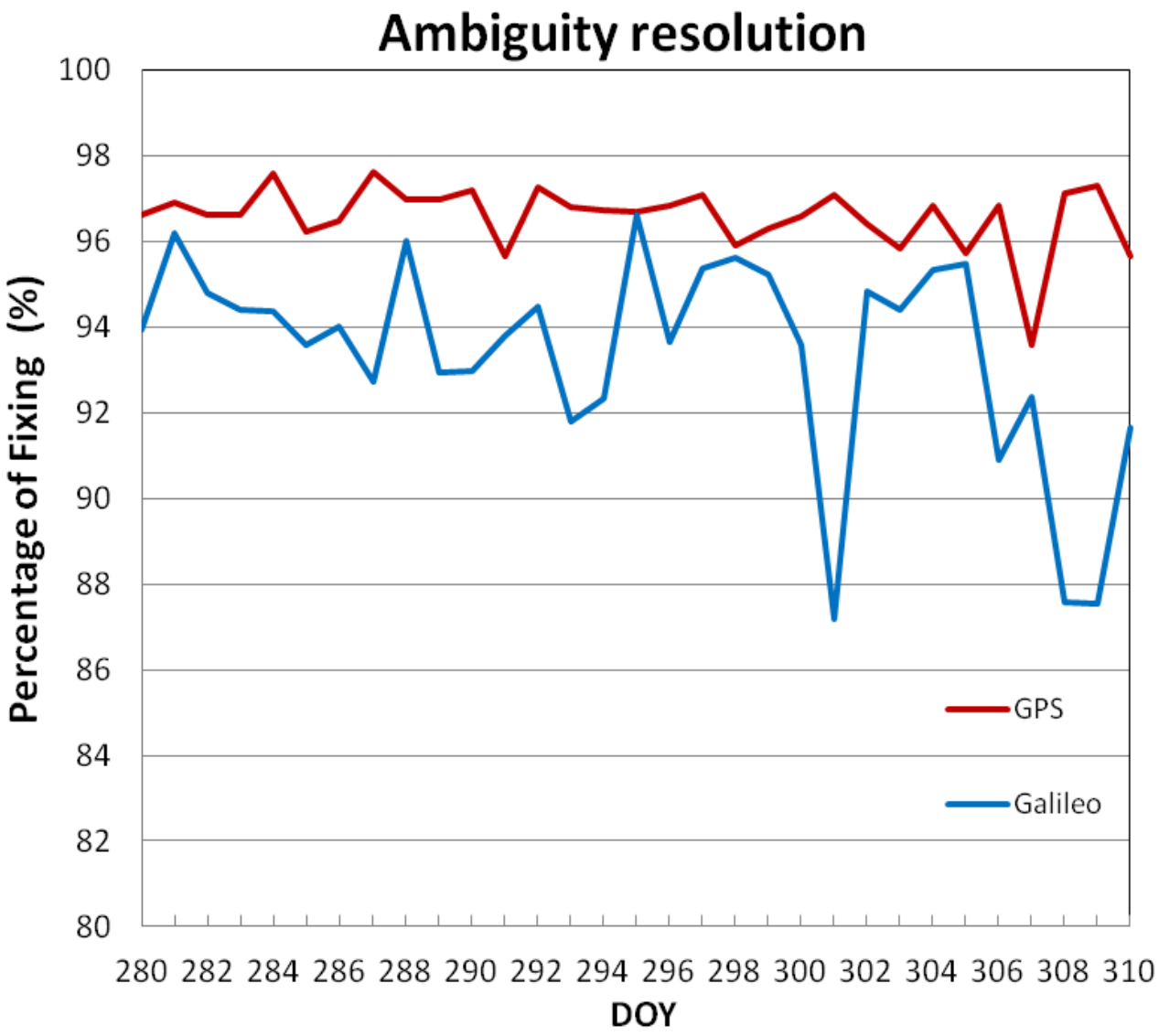
Common receiver clock bias + inter-system biais

Average success rates:

- 96% for GPS
- 93% for Galileo

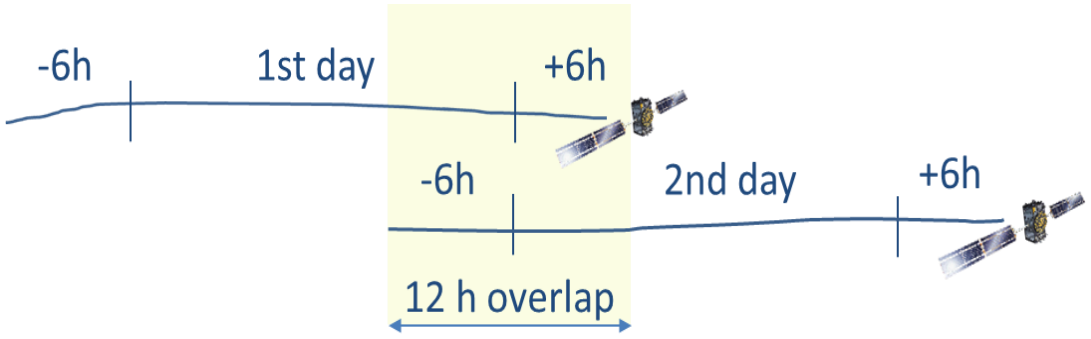
N_i resolved => also N_j

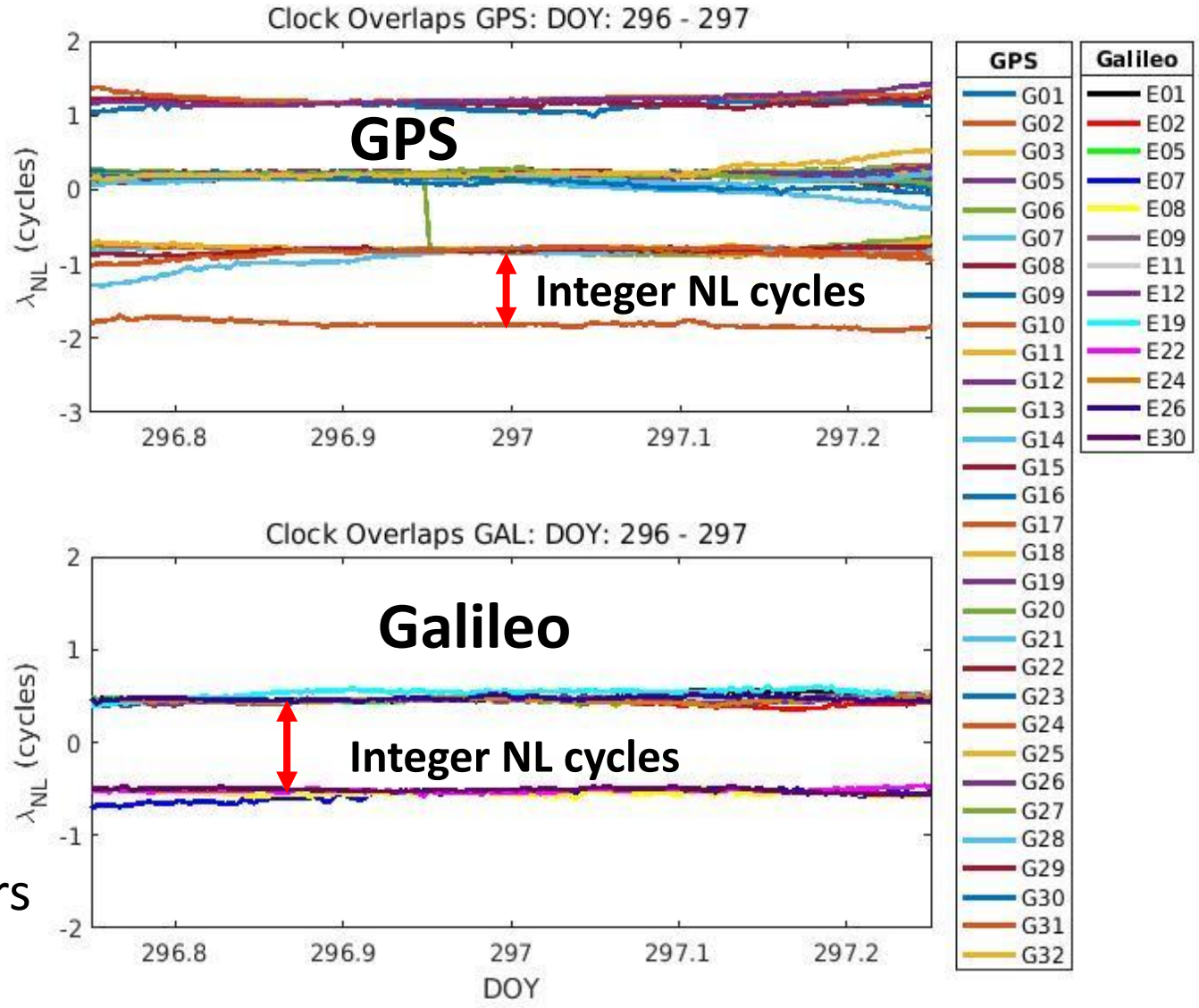
(Katsigianni, et al., 2018)



GPS + Galileo “Integer” clock solutions

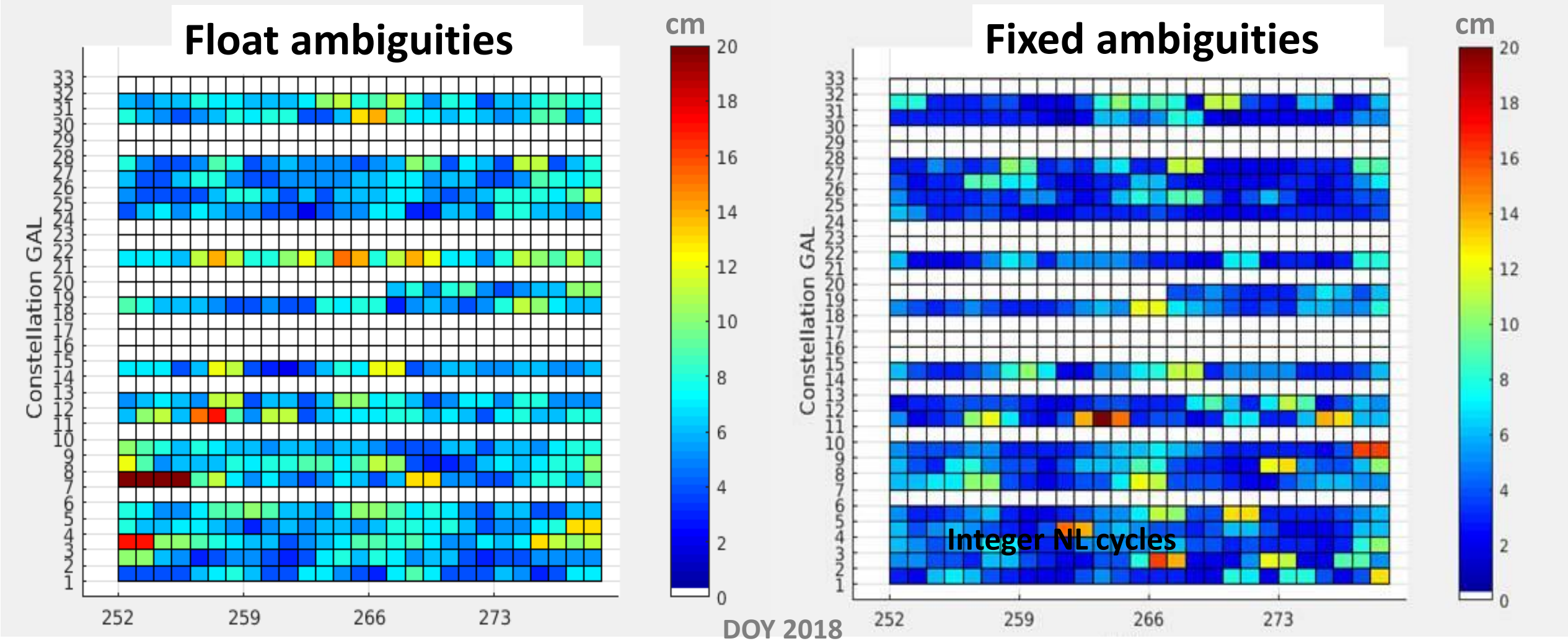
Integer Recovery Clock (IRC)





- aim to keep the «integer» nature of the phase clock solutions
- Easily produce continuous clock products
- useful properties for GPS and Galileo users

Galileo orbit overlap consistency



- 3D-RMS position comparison per satellite and per day (4 weeks from 2018/09/09)
- Fixing ambiguities clearly improves the orbit solution (down to 6 cm 3D-RMS)

Using “Integer” clocks (some GPS results)

- IPPP static and cinematic positioning (e.g. Barbu et al. 2018, ASR)
  - High accuracy even on remote stations
  - short CPU and easy to process in parallel
- Comparing atomic clocks frequency (e.g.. Petit et al. 2015, Metrologia)
  - Even if the clocks are distant
  - Continuity at arc boundaries ensured by overlapping passes with identical ambiguities: frequency comparison over months !
  - Could improve TAI time scale realization?
- Tracking LEO satellites (e.g. Montenbruck et al. 2018, JoG)
  - Without involving a ground network
  - Already TUM, ESA, CODE have successful results

… awaiting results based/including Galileo data !

Perspectives and challenges

- **GRM CNES-CLS Galileo Integer clocks are delivered to MGEX since week 2022**
- In the frame of REPRO-3 effort, CNES-CLS will provide “integer” clocks and WSB
  - ✓ *from may 2000 for GPS*
  - ✓ *from 2014 (TBC) for Galileo*
- Fixing un-differenced Galileo ambiguities is more and more accessible
- This is also true for Beidou *(e.g. X. Li et al. 2018, JoG)*
- What about producing combined clocks and biases from different ACs which keep the “integer” nature of phase ambiguities ?
  - ➢ *Should deserve an IGS Working Group ?*

More information in…

Posters:

- G. Katsigianni et al. Improving Galileo orbit determination using zero-difference ambiguity resolution in a Multi-GNSS processing
- S. Loyer et al. CNES/CLS IGS Analysis center: recent activities

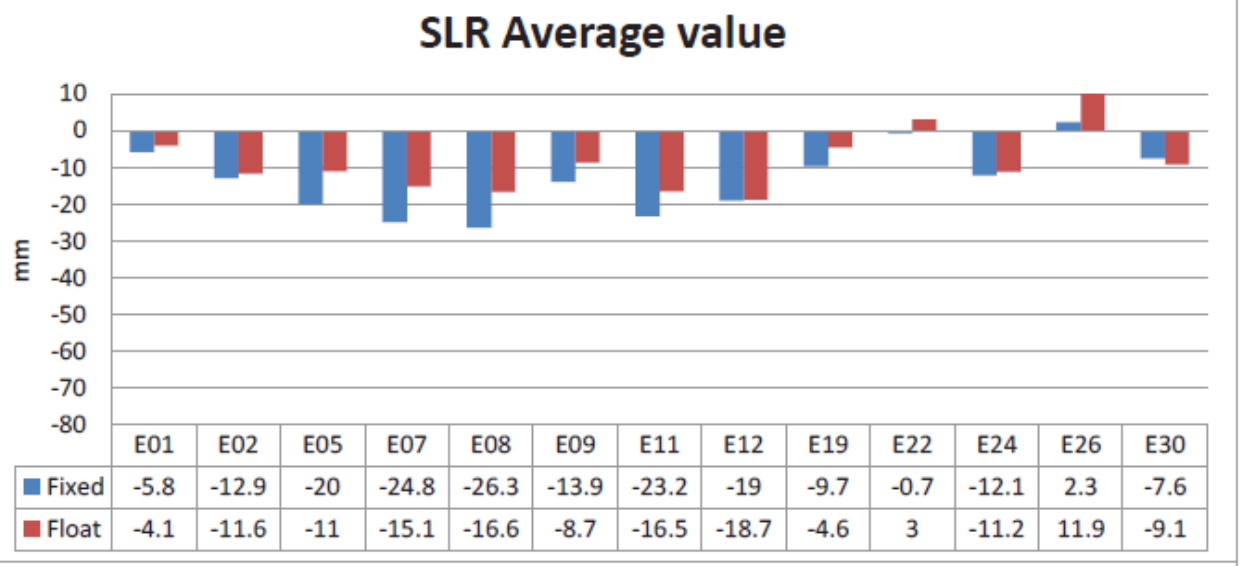
References:

- Katsigianni, G., Loyer S., Perosanz F., Mercier F., R. Zajdel, K. Sosnica, **Improving Galileo orbit determination using zero-difference ambiguity fixing in a Multi-GNSS** processing. Adv. Space Res. (2018),
- Barbu A., Laurent-Varin J., Perosanz F., Mercier F. and Marty JC., **Efficient QR Sequential Least Square algorithm for high frequency GNSS Precise Point Positioning seismic application**, Adv. Space Res. (2018)
- Montenbruck, O., Hackel, S. & Jäggi, A., **Precise orbit determination of the Sentinel-3A altimetry satellite using ambiguity-fixed GPS carrier phase observations**. Journal of Geodesy (2018)
- Li, X., Li, X., Yuan, Y. et al. **Multi-GNSS phase delay estimation and PPP ambiguity resolution: GPS, BDS, GLONASS, Galileo**. J Geod (2018)
- Petit, G., A. Kanj, S. Loyer, J. Delporte, F. Mercier and F. Perosanz. **1 × 10−16 frequency transfer by GPS PPP with integer ambiguity resolution**. Metrologia (2015)
- Loyer, S., Perosanz, F., Mercier, F., Capdeville, H. and Marty, J. C. **Zero-difference GPS ambiguity resolution at CNES-CLS IGS Analysis Center**. Journal of Geodesy (2012)

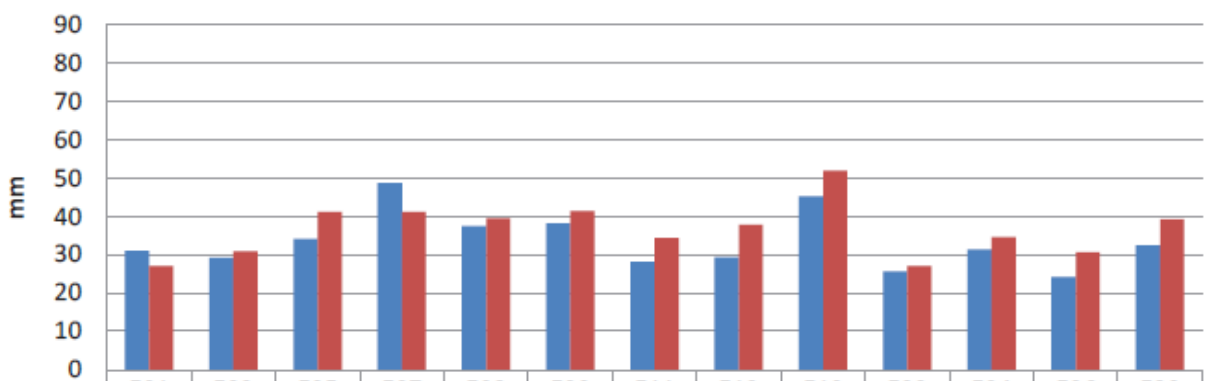
BONUS Slides

Narrow-Lane Fixing

- SLR residuals
  - SLR sensitive to radial direction
  - overall St.dev. is lower 5mm for fixed solution (15%)
  - Fixing ambiguities has a limited impact on the radial direction



	E01	E02	E05	E07	E08	E09	E11	E12	E19	E22	E24	E26	E30
Fixed	-5.8	-12.9	-20	-24.8	-26.3	-13.9	-23.2	-19	-9.7	-0.7	-12.1	2.3	-7.6
Float	-4.1	-11.6	-11	-15.1	-16.6	-8.7	-16.5	-18.7	-4.6	3	-11.2	11.9	-9.1



	E01	E02	E05	E07	E08	E09	E11	E12	E19	E22	E24	E26	E30
Fixed	31	29.2	34.1	48.7	37.5	38.2	28.1	29.3	45.2	25.6	31.4	24.1	32.4
Float	27.1	30.9	41.1	41.1	39.4	41.4	34.3	37.8	51.9	27.1	34.6	30.6	39.2

results through GOVUS online service

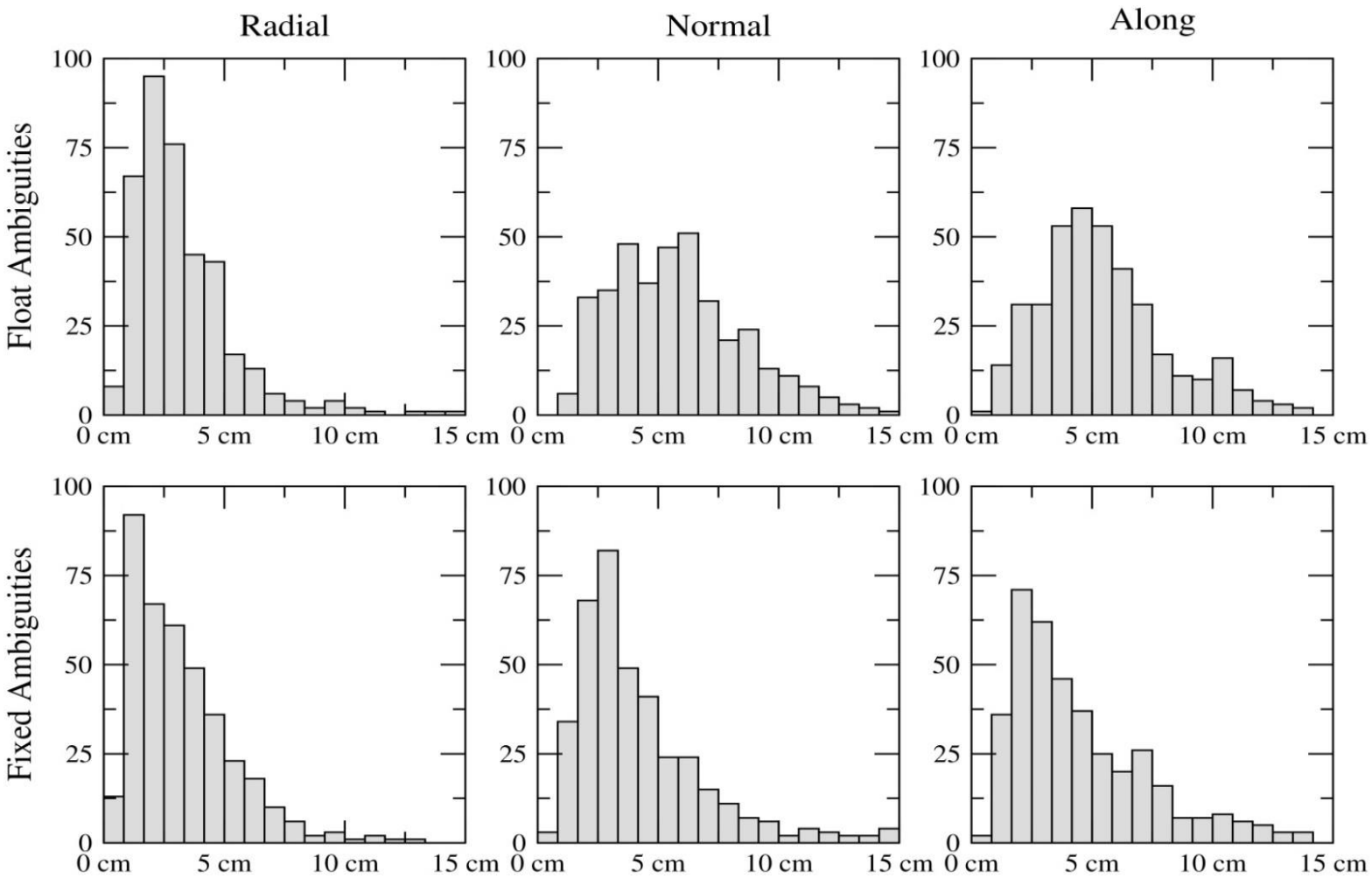
Zajdel, R., Sośnica, K., & Bury, G. (2017). A new online service for the validation of Multi-GNSS orbits using SLR. Remote Sensing 9(10), 1049. doi:10.3390/rs9101049

Narrow-Lane Fixing

Example of orbit overlaps (doy: 297/2017 – 298/2017):

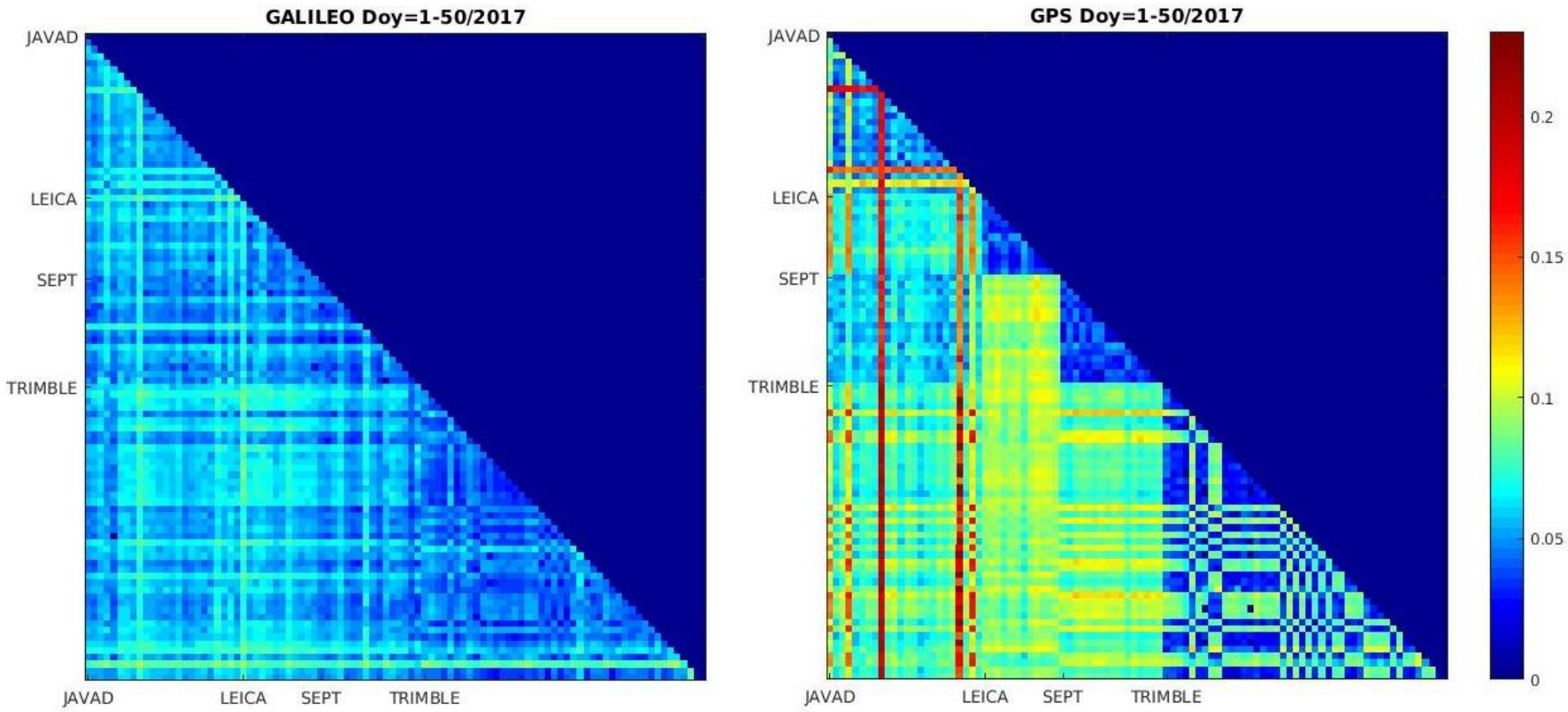
- 1 month period overlaps

	Float (cm)	Fixed (cm)
Radial	3.2	3.2
Normal	5.4	4.4
Along	5.6	4.1
3D	7.8	6.1



Wide-Lane Fixing

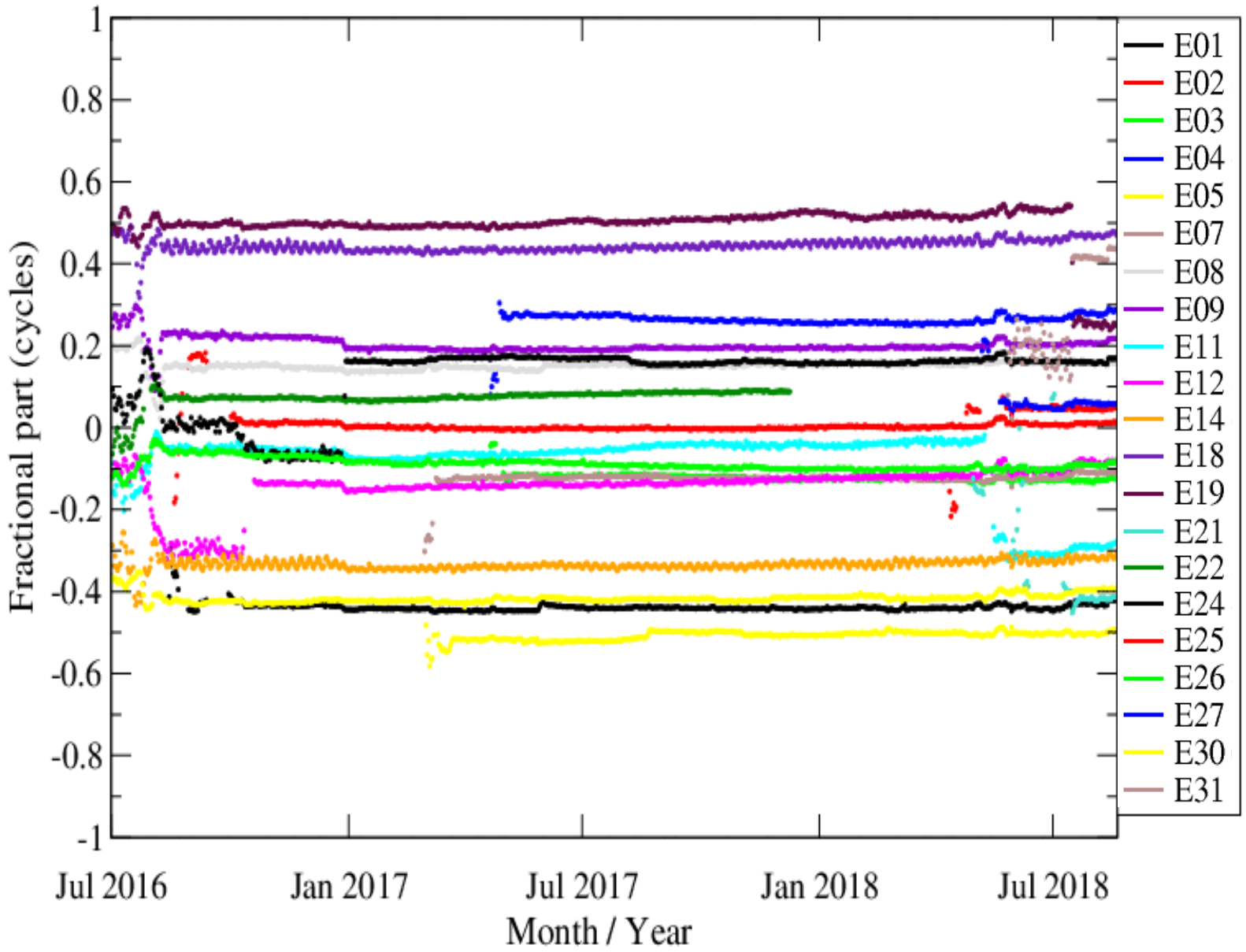
Comparison of WSB biases organized by receiver manufacturers



- Galileo below 0,08 cycles
- GPS up to 0,15 cycles

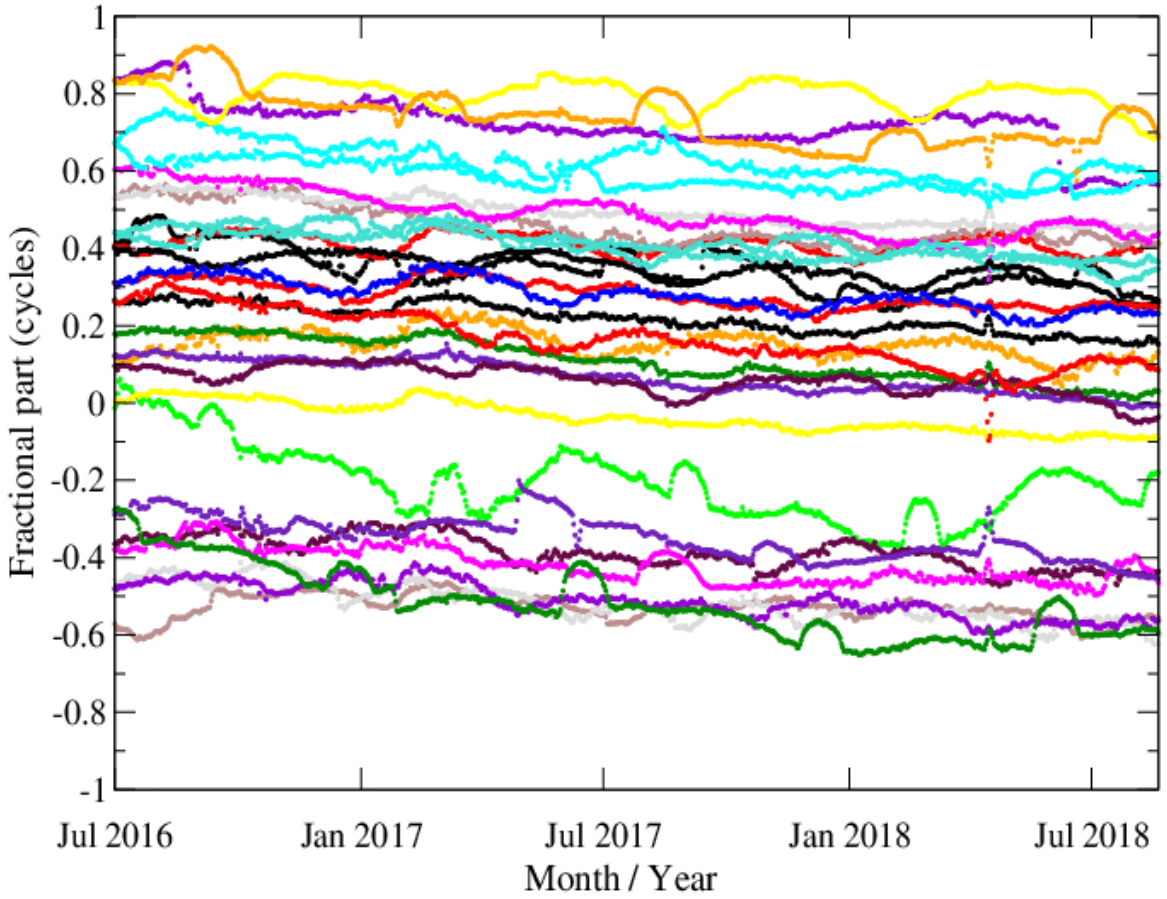
(Katsigianni, et al., 2018)

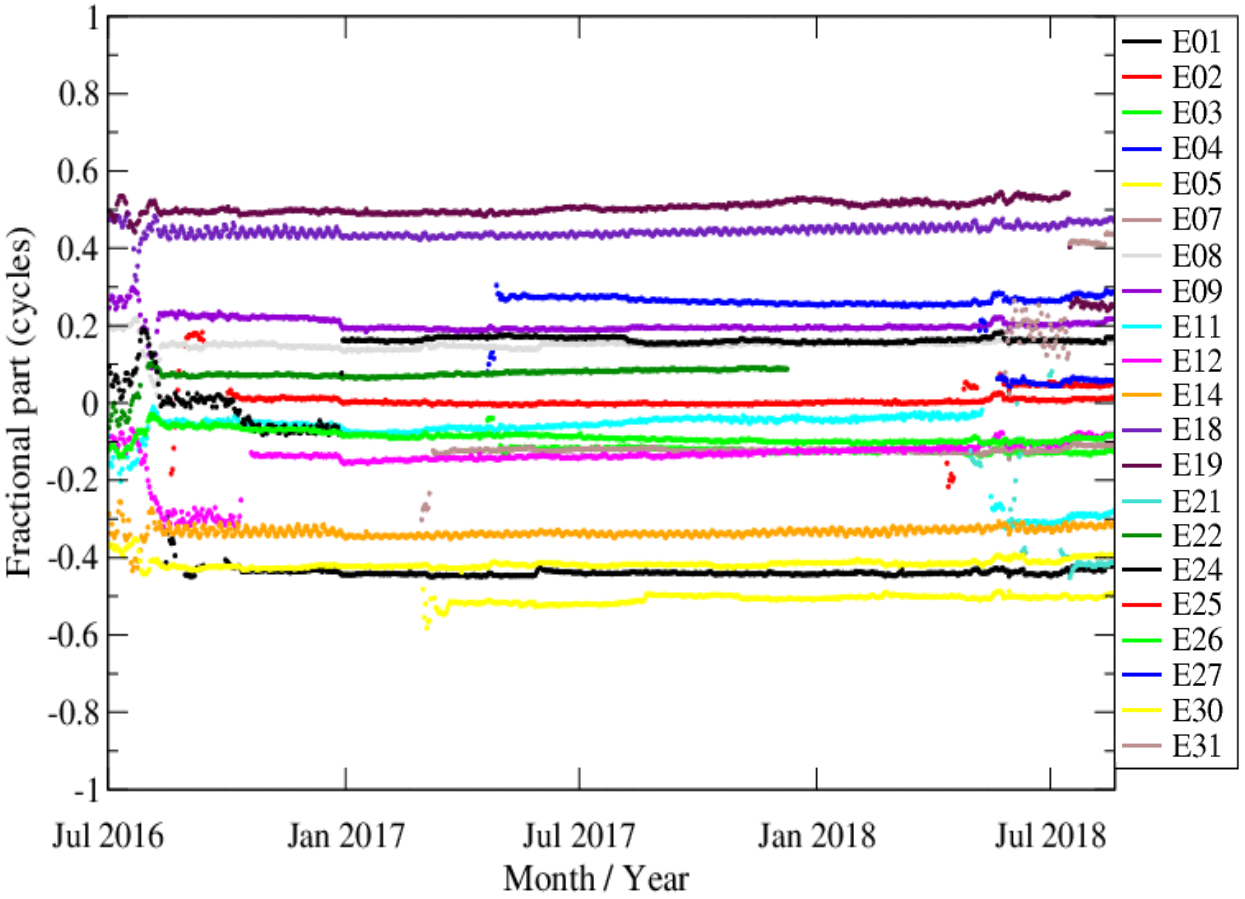
GPS and Galileo WSB from a global network



- *No impact*
- WSB a-priori taken from the day before
- WSB a-priori are stable unless they change

GPS and Galileo WSB from a global network





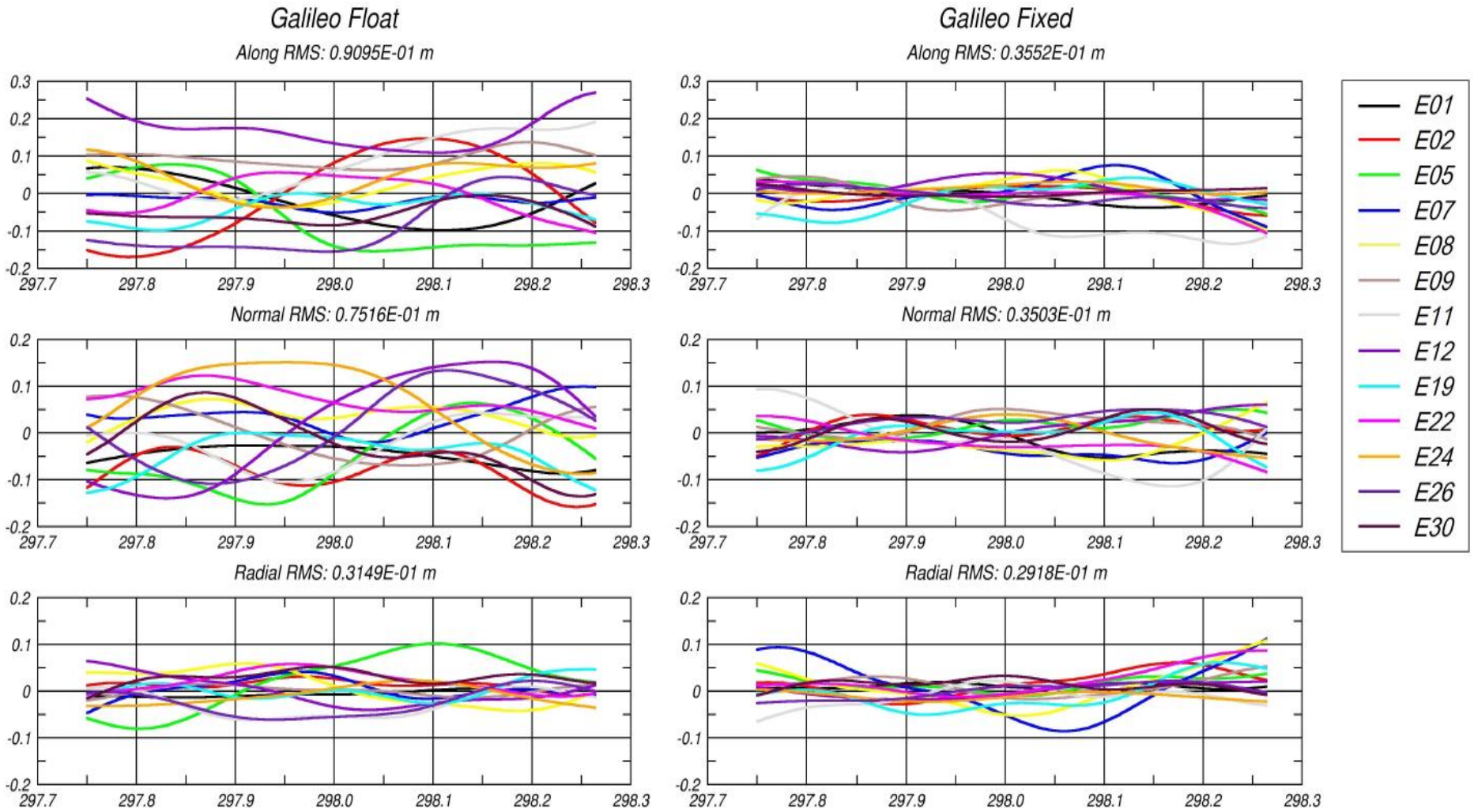
- WSB a-priori taken from the day before
- WSB a-priori are stable unless they change

Narrow-Lane Fixing

Orbit overlaps for Float and Fixed solution DOY 297-298

- along, normal improvements
- very small for radial

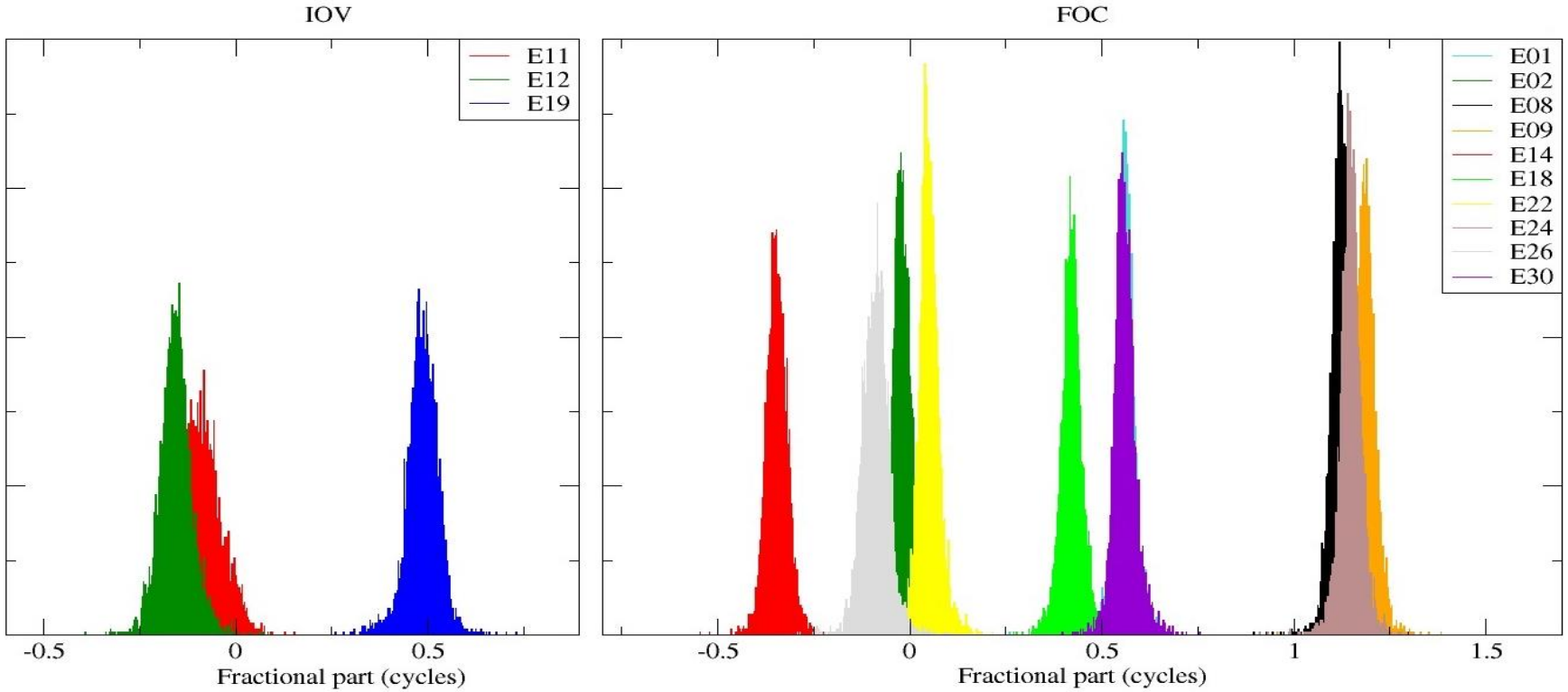
3D RMS ~6cm



(Katsigianni, et al., 2018)

Wide-Lane Fixing

Histograms of WSB for IOV and FOC satellites



-symmetric single peaked and bell-shaped distributions
-small difference between IOV and FOC due to different manufacturers