Multi-GNSS through Global Collaboration
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Improving Galileo orbit determination using zero-difference ambiguity resolution in a Multi-GNSS processing

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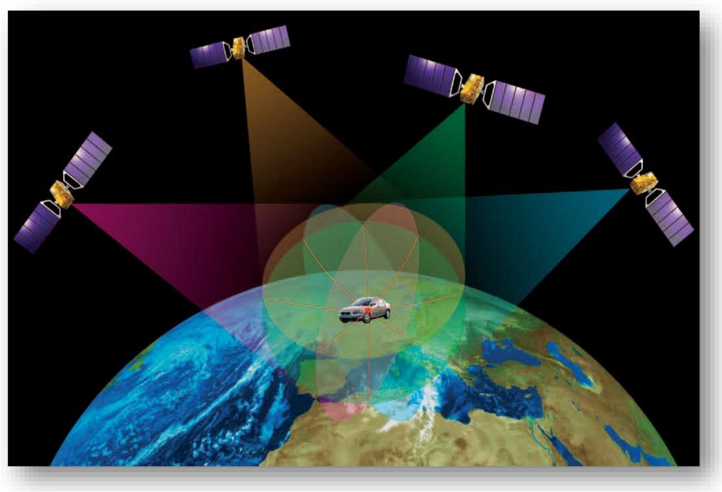
INTRODUCTION

CNES and CLS[1] are the GRG IGS Analysis Center (AC):

- ✓ They perform Multi-GNSS processing (GPS, Galileo & GLONASS) on a weekly basis.
- ✓ Undifferenced phase measurement ambiguities[2] are fixed for GPS observables within the daily computation of the delivery of products to the IGS service.
- ✓ Research was done for how to apply the same method for the Galileo system.



Main issue:

- ✓ Integer Ambiguity Resolution (AR) of GNSS phase measurements has to be done firstly at the level of orbit and clocks determination for the Galileo system.
- ✓ This will allow later Galileo integer precise positioning at the user level.

In this poster:

- ✓ We apply the method for fixing the undifferenced phase ambiguities for the Galileo system in a Multi-GNSS (Galileo + GPS) processing.
- ✓ We present a way to do integer ambiguity matrices comparison, as another way of AR validation.

METHOD

1) Wide-Lane (WL) ambiguity resolution

Estimate the unknowns μ^s and μ_r, fix the WL ambiguity $(\widetilde{N_{WL}})$[2,3,4]

$$f_{WL}(L_j, L_i, P_i, P_j) = \lambda_{WL}(L_j - L_i) - \lambda_{NL}(P_i/\lambda_i + P_j/\lambda_j) = \lambda_{WL}\widetilde{N_{WL}}$$

$$\widetilde{N_{WL}} = N_{WL} + \mu^s - \mu_r = N_j - N_i + \mu^s - \mu_r$$

$$\gamma = \lambda_j^2/\lambda_i^2 = f_i^2/f_j^2$$

2) Narrow-Lane (NL) ambiguity resolution

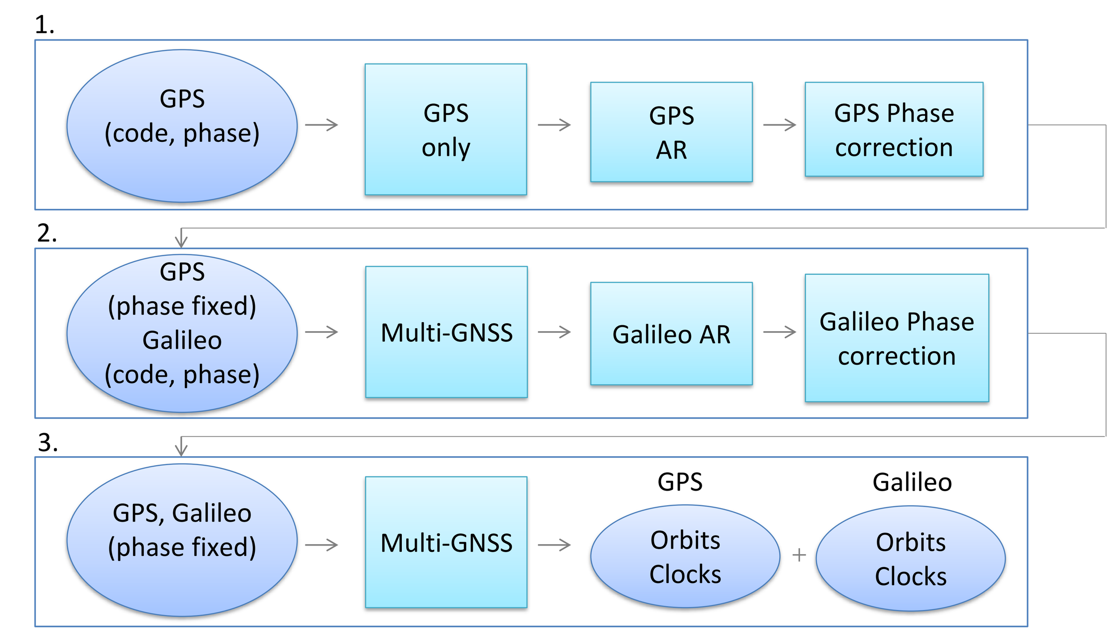
Iono-free combination, fix the NL ambiguity (N_i)

$$\frac{\gamma\lambda_i L_i - \lambda_j L_j - \lambda_j N_{WL}}{\gamma - 1} = \frac{\gamma D_{Li} - D_{Lj}}{\gamma - 1} + \lambda_{NL} W + \Delta h_L - \lambda_{NL} N_i$$

L	phase measurements
P	pseudo-range measurements
D_L	geometrical distances for the carrier phase
Δh_L	clock differences for carrier phase
i,j	two different frequencies
$\widetilde{N_{WL}}$	wide-lane ambiguity (over one pass)
μ^s	satellite hardware delays (also WL satellite biases - WSB)
μ_r	receiver hardware delays (also WL receiver biases - WRB)

Multi-GNSS with 31 GPS and 13 Galileo satellites

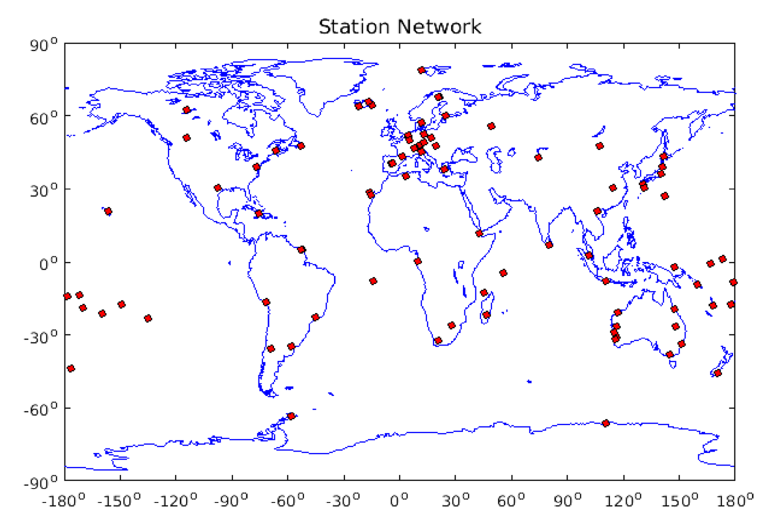
- ✓ ISB: 1 bias per station per day
- ✓ Equal weighting for GPS and Galileo

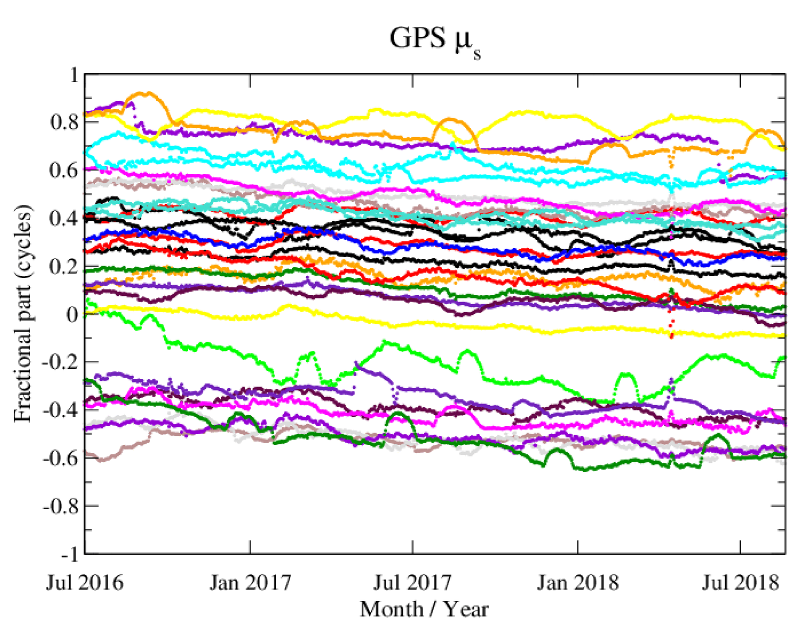


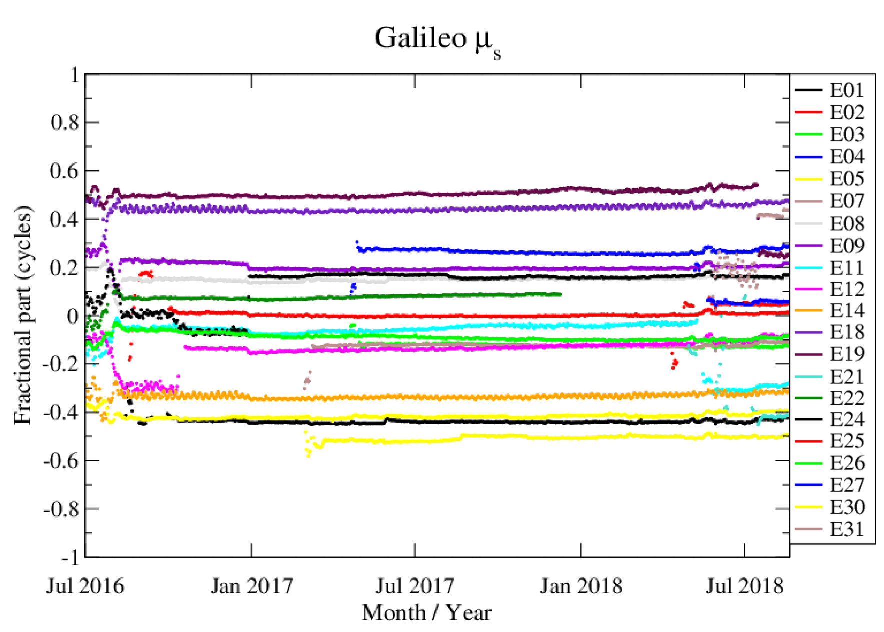
WL & NL FIXING

Network:

96 IGS MGEX stations (Galileo E1/E5a, GPS L1/L2)[4]. The fractional parts of μ^s and μ_r for each station were calculated. The values of μ^s are proven to be stable and can be estimated within 0,1 cycles. Comparison of GPS and Galileo showed that for Galileo, μ^s can be considered constant.

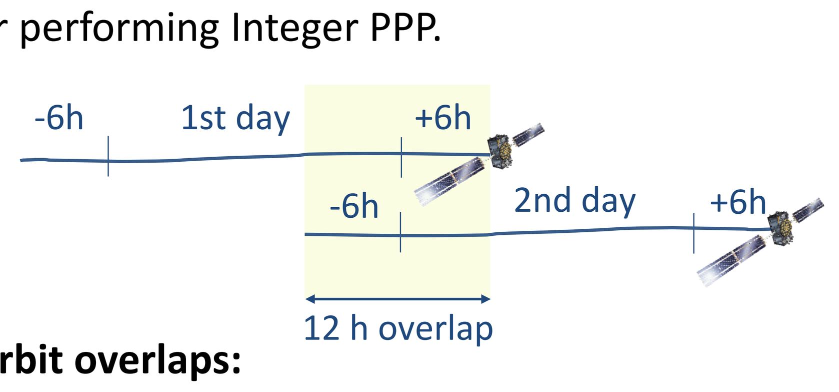


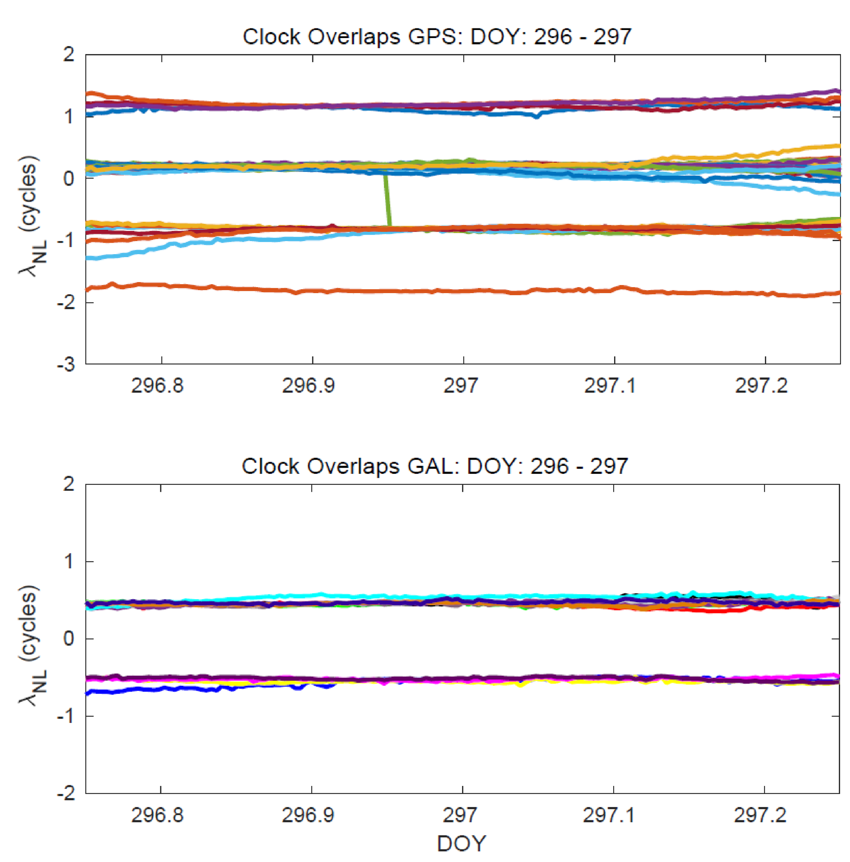




Integer Recovery Clock (IRC) overlaps:

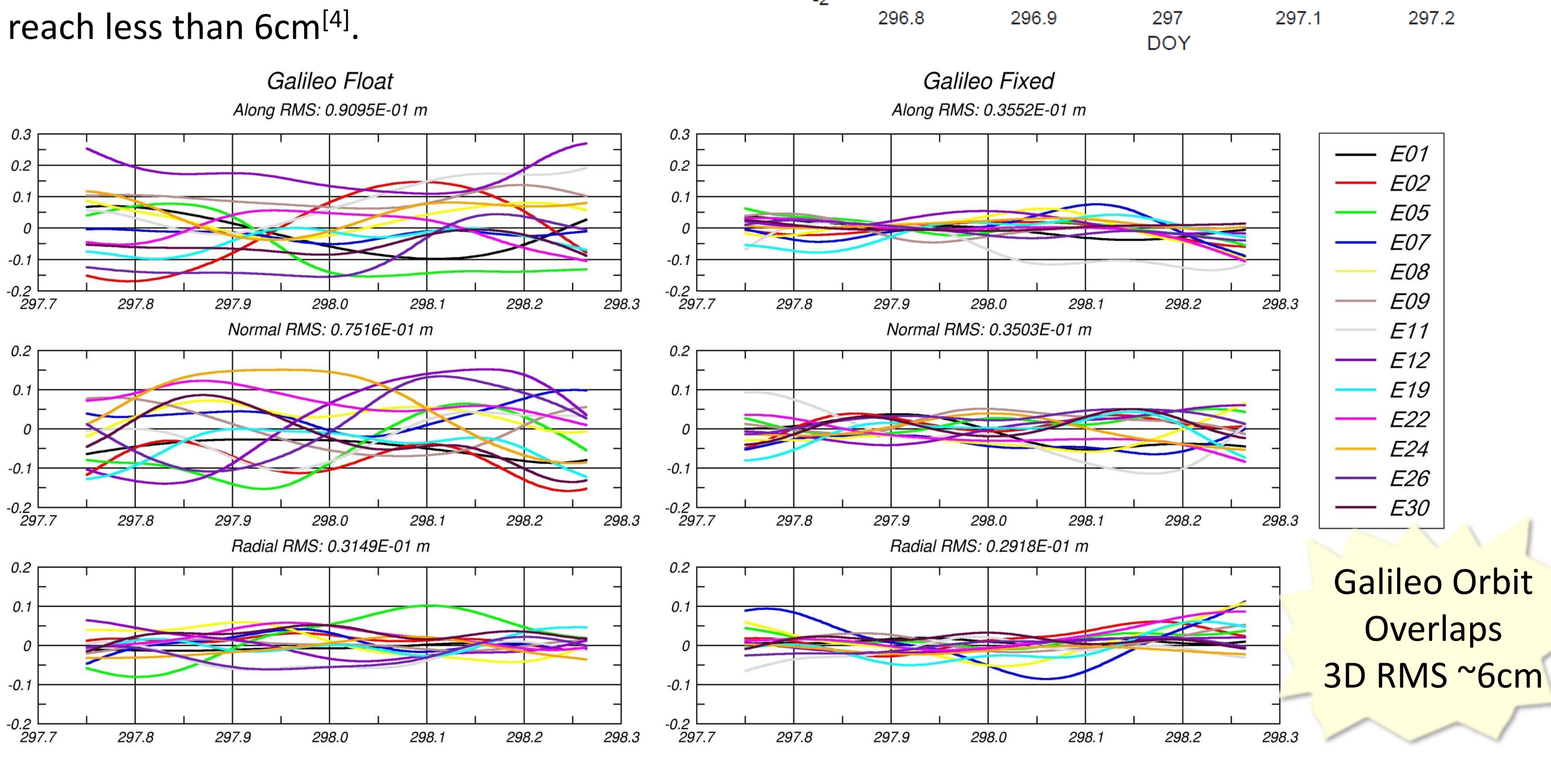
Clock products for consecutive days differ by an integer number of NL cycles (i.e. 0,107 m for GPS, 0,109 m for Galileo)[4]. This is necessary for performing Integer PPP.





Orbit overlaps:

An example of orbit overlap for float and fixed Galileo orbits. Improvement in along and normal components. Orbit precision in 3D reach less than 6cm[4].



Galileo Orbit Overlaps 3D RMS ~6cm

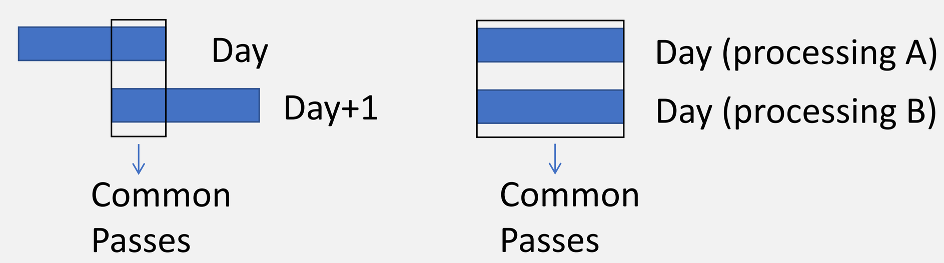
INTEGER AMBIGUITY MATRICES COMPARISON

Today there are no direct tools to know if ambiguity fixing is correct:

- Indirect tools used: % of fixing, improvement of orbits, clocks overlaps
- Hard to know when and where a false fixing may occur
- Need for comparisons & checks when changing processing models, weighting etc.

The idea: Check the agreement between 2 different integer AR matrices with common satellite passes

- ✓ From 2 successive days
- ✓ From the same day with different processing



The difficulty:

- The matrices are not the same (for a given integer solution there is an infinite number of "equivalent" matrices)
- Station and satellite data can have gaps

The algorithm:

1) Get File A & File B, find common passes
   - Organize **N** values in matrices (satellites × stations)

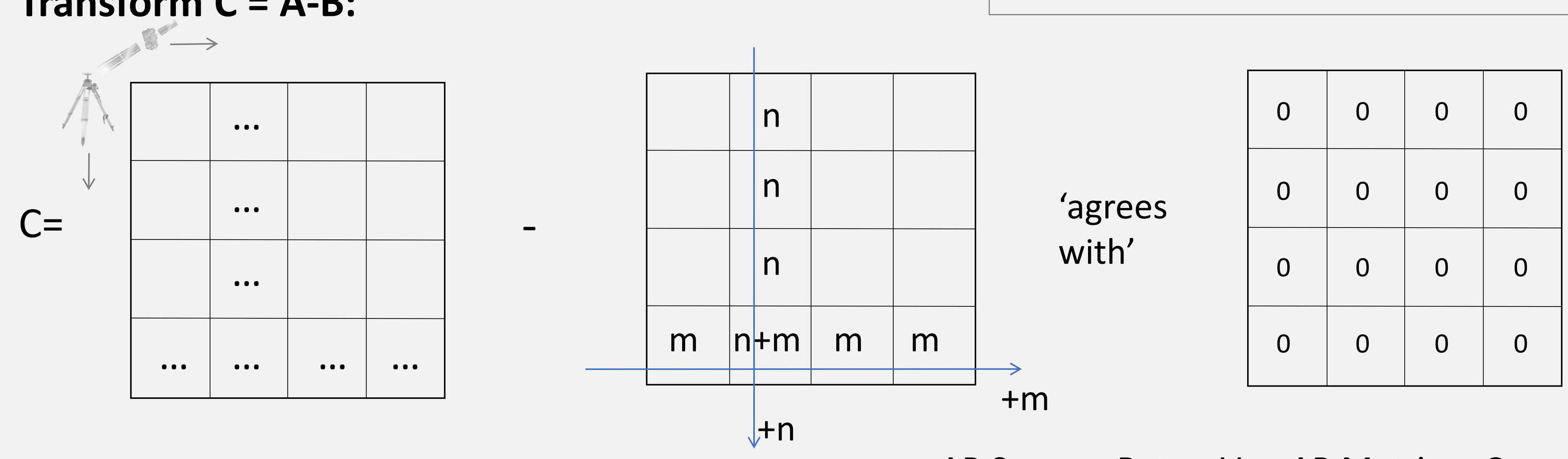
2) Subtract C = A-B

3) Check data gaps:
   - Perform a bubble sorting
   - Find stations with gaps and make them as if they were 2,3, etc.

4) Transform matrix C
   - For every line, find most frequent non-zero value, subtract from the entire line
   - Do the same for every column
   - Percentage of non zero elements
   - Repeat until C can not change anymore

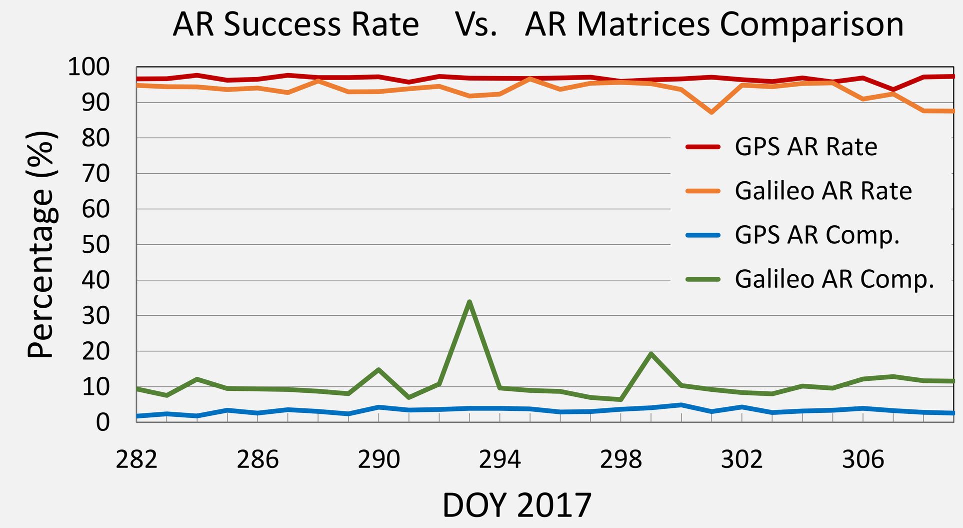
5) Find disagreements and do statistics

Transform C = A-B:



Example:

- AR Rates: GPS ~ 96%, Galileo ~ 93%
- Comparison: GPS ~ 3%, Galileo ~ 10%
- High % of AR does not guarantee correct integer AR
- Ideally: 100% success rate with 0% matrices comparison disagreement



CONCLUSIONS

- WL satellite biases μ^s are stable over time and can be estimated within approx. 0,1 cycles
- A-priori values of μ^s are stable over time (compared to GPS, where an a-priori value is needed every day)
- Undifferenced ambiguity fixing of Galileo is possible in a Multi-GNSS processing. Percentages of fixation is approx. 93 %
- Galileo phase fixed clocks have an integer property (IRC)
- Phase fixed orbits improved in along and normal directions, with 3D RMS of overlaps around 6cm
- A way to compare directly integer ambiguity solutions was presented

[1] igsac-cnes.cls.fr
[2] Laurichesse D, Mercier F (2007) Integer ambiguity resolution on undifferenced GPS phase measurements and its application to PPP. ION GNSS 2007, Fort Worth, TX
[3] Loyer S, et al. (2012) Zero-difference GPS ambiguity resolution at CNES-CLS IGS Analysis Center. J. Geod
[4] Katsigianni G, et al. (2018) Improving Galileo orbit determination using zero-difference ambiguity fixing in a Multi-GNSS . Adv. Space Res.
Photos: esa.int