Phase Biases of GPS L1/L2/L5 for the Purpose of Zero-difference Ambiguity Resolution and Initial Results on Galileo E1/E5a

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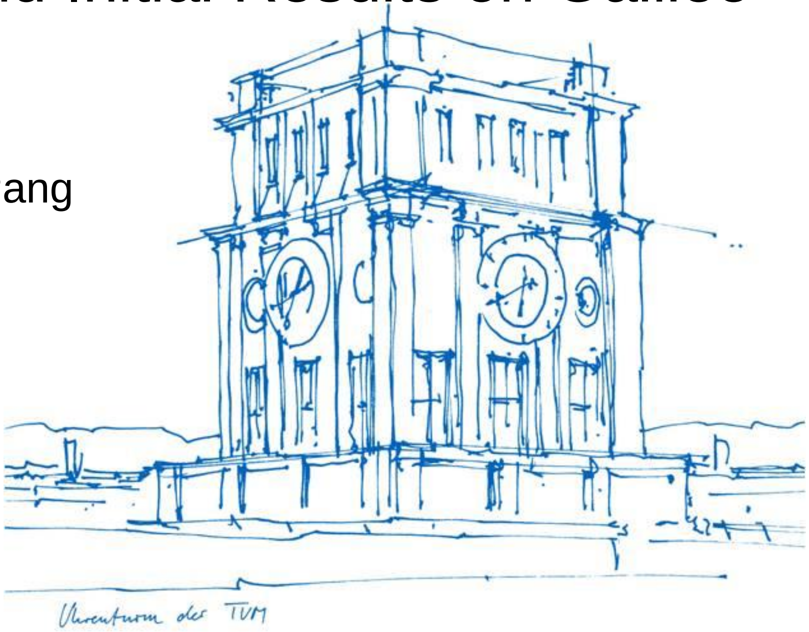


Background

Ambiguity resolution can significantly improve the quality of GNSS products and applications.

- Double-difference ambiguity resolution

  Most of the errors are canceled out or may be neglected

  At least two receivers are synchronously processed, miss clock info

- Zero-difference ambiguity resolution

  All the error sources must be considered

  Dedicated products are required → GPS L1/L2 products

- New frequencies and signals

  GPS L5Q/L5X, Galileo L5Q/L5X → Preliminary results

Theory

- **Phase equation of one single frequency**

Geometry distance, Ion-delay, Other corrections

$$L_{r,1}^{s} = \rho + c(dt_r - dt^s) - I_{r,1}^{s} + c(\delta_{r,1} - \delta_1^s) + \lambda_1 N_{r,1}^{s} + windup + corr$$

Phase obs, Clock offsets, Phase biases, Ambiguity

Numerous linear terms prevent direct access to the integer nature of ambiguity, double-difference can cancel out such terms fairly well

$$N_{r,1}^{s} = \widehat{N}_{r,1}^{s} + \varphi_{r,1}^{s} + \Delta$$

Integer value and initial shift

Theory

➢ **Ionosphere-free combination**

Ion-free combination is used to eliminate the first order of ion-delay

$$L_{r,IF}^{s} = \rho + c(dt_r - dt^s) + c(\delta_{r,IF} - \delta_{IF}^{s}) + \lambda_{IF} N_{r,IF}^{s} + windup + corr$$

Does not have integer character

$$N_{r,IF}^{s} = aN_{r,WL}^{s} + bN_{r,NL}^{s}$$

Fix wide-lane ambiguities

Fix narrow-lane ambiguities

Double difference or

Dedicated products(*CNES,GFZ,WUHN)

$$N_{r,WL}^{s} = Integer + \mu_{r,WL} - \mu_{WL}^{s}$$

$$N_{r,NL}^{s} = Integer + \mu_{r,NL} - \mu_{NL}^{s}$$

*Loyer S et al. (2012), Ge M et al. (2008), Li X et al. (2017)

Theory

- **Wide-lane biases Estimation**

Melbourne-Wuebbena (MW) (Geometry-free, Ionosphere-free)

Integer wide-lane ambiguity, noise

$$MW(P_{r,1}^{s}, P_{r,2}^{s}, L_{r,1}^{s}, L_{r,2}^{s}) = \lambda_{WL}\hat{N}_{r,WL}^{s} + \lambda_{WL}(\mu_{r,WL} - \mu_{WL}^{s}) + \varepsilon$$

Receiver bias (receiver dependent, epoch-wise)
Satellite bias (varies slowly with time, daily)

A zero-mean constraint of all satellite biases is added
Fix single-difference ambiguities between satellites for one receiver

Theory

- **Narrow-lane biases Estimation**

Introduce fixed wide-lane ambiguities into ion-free float solution
GPS satellite orbits and clocks are fixed to CODE products

A zero-mean constraint of all the satellite biases is added

$$L_{r,IF}^{s} = \rho' + c(dt_r + \delta_{r,IF}) + c\delta_{IF}^{s} + \lambda_{nl} N_{r,nl}^{s} + windup + corr$$

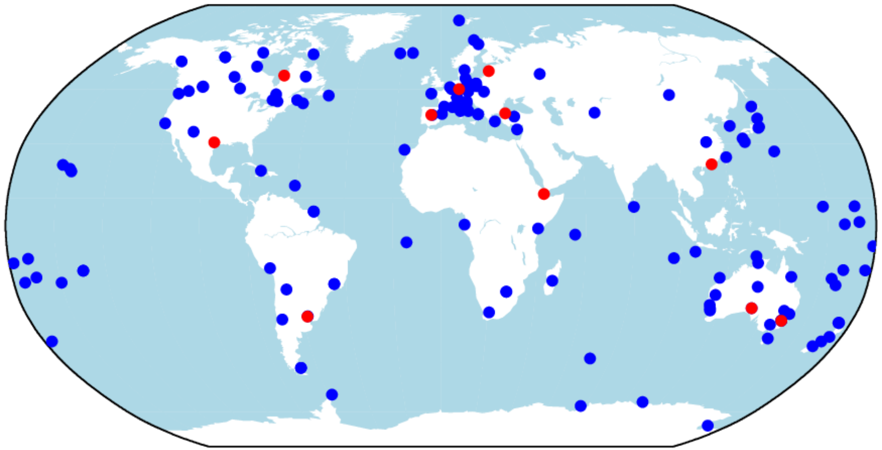
As one clock offset

A reference ambiguity is selected every station in one session
Fix single-difference ambiguities between satellites for one receiver

Products of GPS L1/L2

- **Settings and tracking stations**
  - **Bernese 5.3 is modified to support the estimation**
    - 150 +11 tracking stations (day 200 to day 300, 2017)
    - Obs type: C1C,L1C,C2W,L2W
    - DCB : C1W-C1C from CODE
    - Arc length: 1 day
    - Orbit&clock products: CODE
    - Antenna: ANTEX14
    - Ambiguity fixing approach: SIGMA

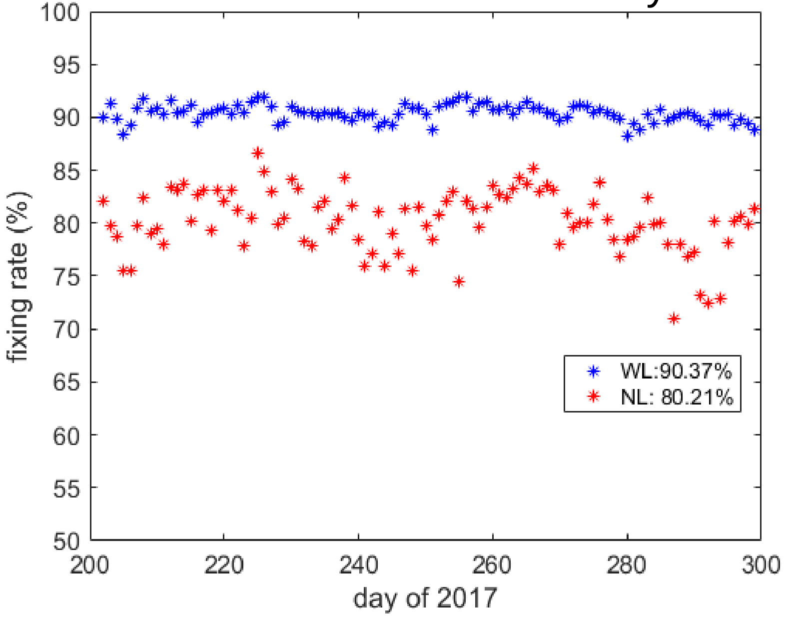
Blue for estimation, red for validation



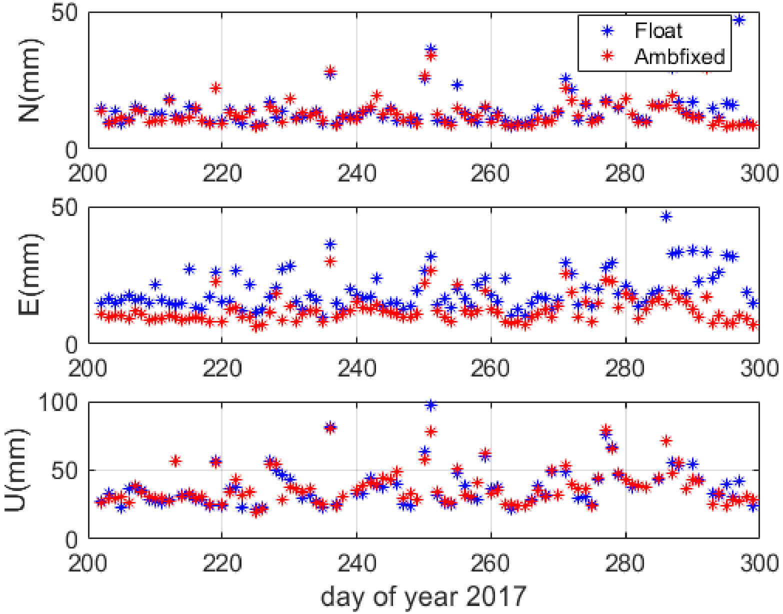
Products of GPS L1/L2

➢ **Application of ground tracking stations**

Averaged Ambiguity fixing rate of 11 sites in statistic solution over 100 days



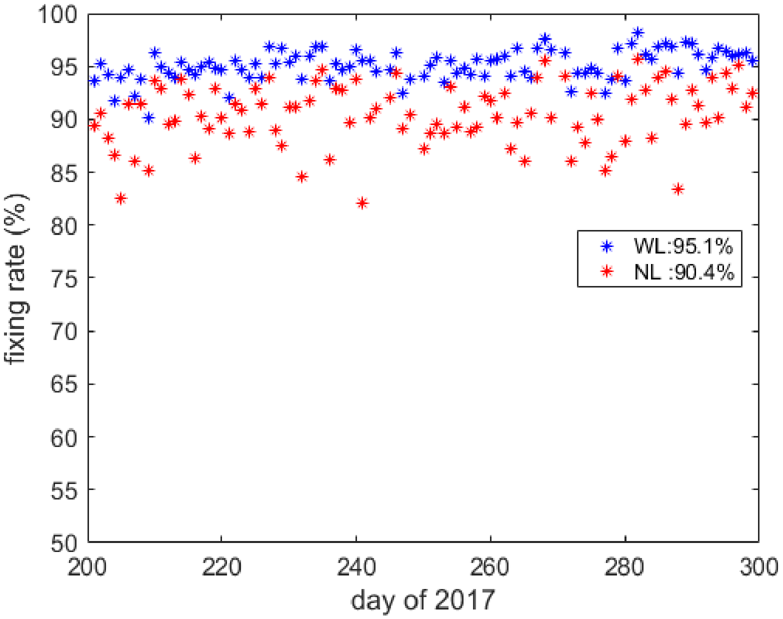
Average RMS of 11 stations over 100 days for kinematic solutions



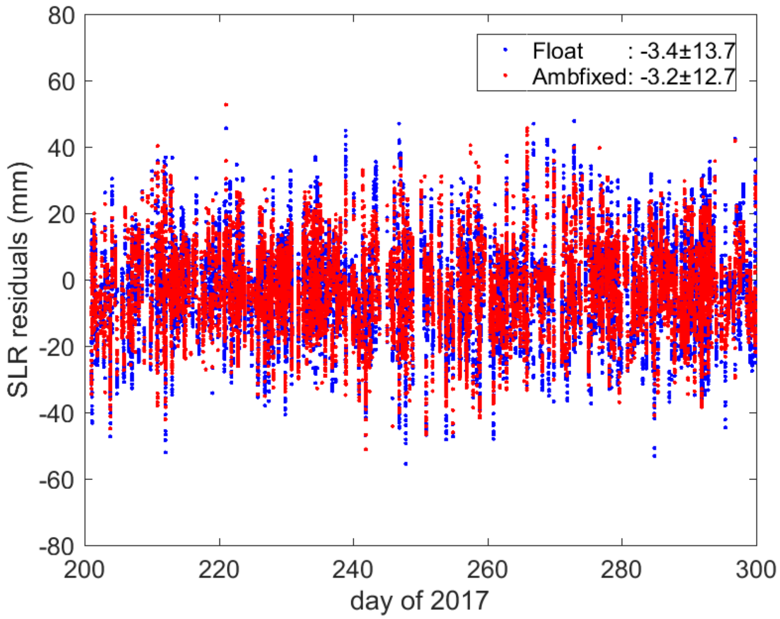
Products of GPS L1/L2

➢ **Application of SENTINEL-3A satellite**

Ambiguity fixing rate



SLR residuals of reduced dynamic orbits



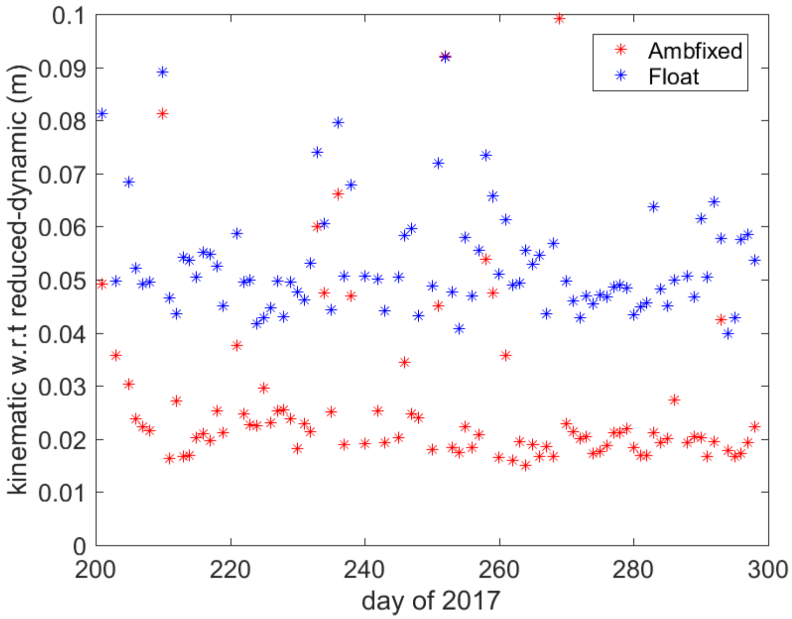
Products of GPS L1/L2

➢ **Application of SENTINEL-3A satellite**

Ambiguity fixed reduced-dynamic solutions are taken as reference

By comparing to reduced-dynamic solutions ambiguity fixed kinematic solutions mark an improvement of more than a factor of two over the float kinematic solutions

3D difference



Initial results of GPS L1/L5 and Galileo E1/E5a

➢ Issues before ambiguity resolution

1. GPS L1/L2 satellite clocks are not the same as GPS L1/L5 clocks
(Oliver Montenbruck et al. (2011)) → Estimate L1/L5 clocks

2. LEICA, SEPT : L5Q
TRIMBLE, JAVAD : L5X (I+Q) → Process together?

3. PCO/PCV for GPS L5 are not clear
PCO/PCV of receivers for the GPS L1/L5 and Galileo E1/E5a

↓

Assumed to be the same as GPS L1/L2

Initial results of GPS L1/L5 and Galileo E1/E5a

➢ Settings and tracking stations

Satellite : 12 GPS IIF, 17 Galileo

Blue : 42 TRIMBLE with C5X/L5X
Red : 35 JAVAD with C5X/L5X
Yellow : 45 LEICA&SEPT with C5Q/L5Q

Satellite orbit/clock estimation ← Station related parameters are fixed on GPS L1/L2 PPP

↓

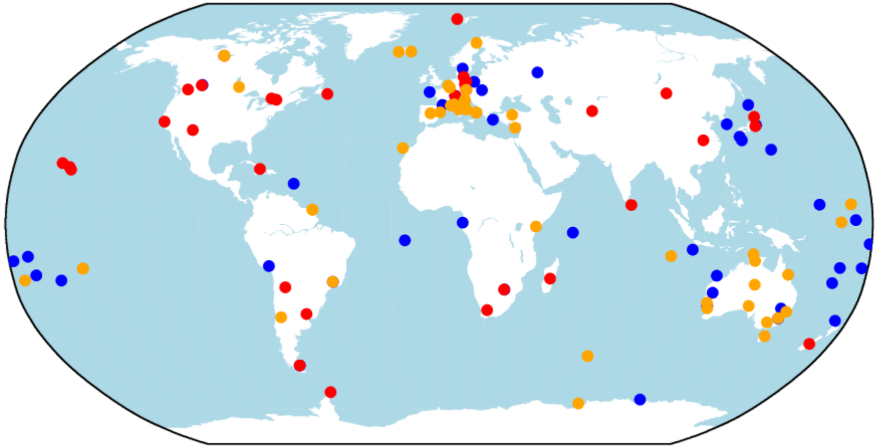
Wide-lane ambiguity

↓

Narrow-lane ambiguity

→ Cluster processing :

- L1C/L5Q (40)
- L1X/L5X (40)
- Mix L5Q/L5X (40)



Initial results of GPS L1/L5 and Galileo E1/E5a

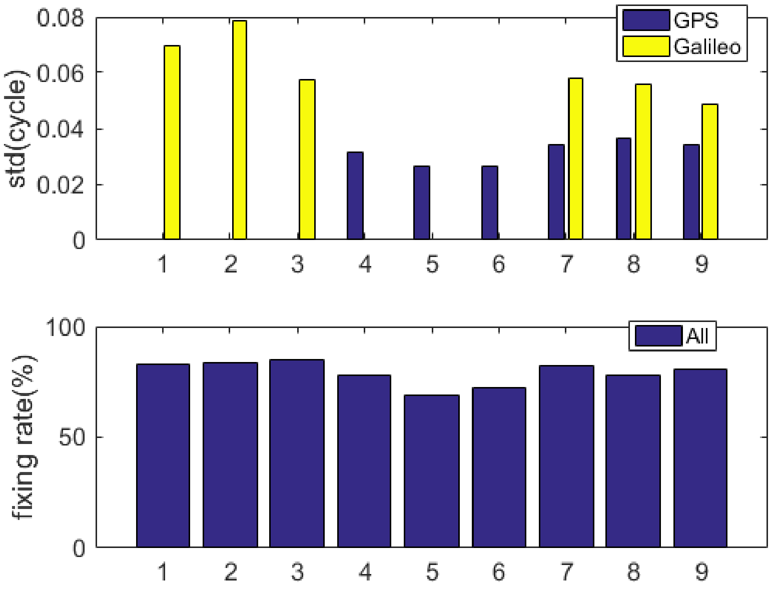
➢ Wide-lane biases estimation

Estimations using individual obs types

Ambiguity fixing between G and E is allowed

1. Galileo L5Q
2. Galileo L5X
3. Galileo L5Q+L5X
4. GPS L5Q
5. GPS L5X
6. GPS L5Q+L5X
7. Galileo+GPS IIF L5Q
8. Galileo+GPS IIF L5X
9. Galileo+GPS IIF L5Q+L5X

STD of wide-lane biases and average fixing rate over two weeks



Initial results of GPS L1/L5 and Galileo E1/E5a

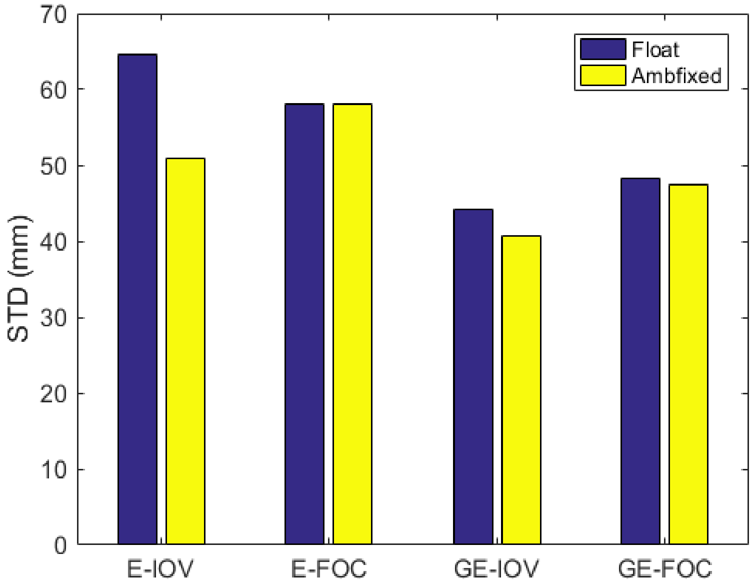
➢ Orbit validation

Galileo and Galileo+GPS L1C/L5Q
Ambiguity fixing between G and E is allowed

1. E-IOV only Galileo
2. E-FOC only Galileo
3. GE-IOV GPS IIF + Galileo
4. GE-FOC GPS IIF +Galileo

Galileo+GPS IIF results are in general better than only Galileo
Ambiguity resolution reduces the STD of SLR residuals, especially for Galileo IOV satellites

STD of SLR residuals of Galileo orbits over two weeks



Initial results of GPS L1/L5 and Galileo E1/E5a

➢ Orbit validation

Galileo+GPS L1X/L5X

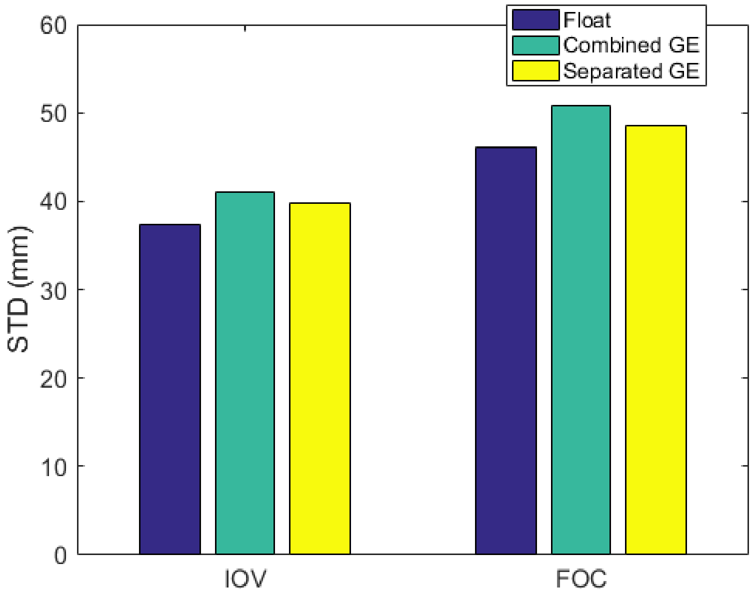
Ambiguity fixing between G and E ? Y/N

1. Combined GE Y
2. Separated GE N

Ambiguity fixing does not improve Galileo orbits by using L1X/L5X observation types

Ambiguity resolution between G and E makes results even slightly worse than the separate case

STD of SLR residuals of Galileo orbits over two weeks



Summery and plans

1. GPS L1/L2 phase biases in TUM proves to work fairly well in zero difference ambiguity resolution.
2. Joint processing of GPS IIF and Galileo satellites with respect to the frequency L1/L5, E1/E5a improves the accuracy of Galileo orbits.
3. Ambiguity resolution between GPS and Galileo with respect to the signal L5Q and L5X needs more analysis.
4. It will be good if we can provide Galileo and GPS L1/L5 satellite orbit and clock products, or even the wide-lane biases for the purpose of zero-difference ambiguity resolution