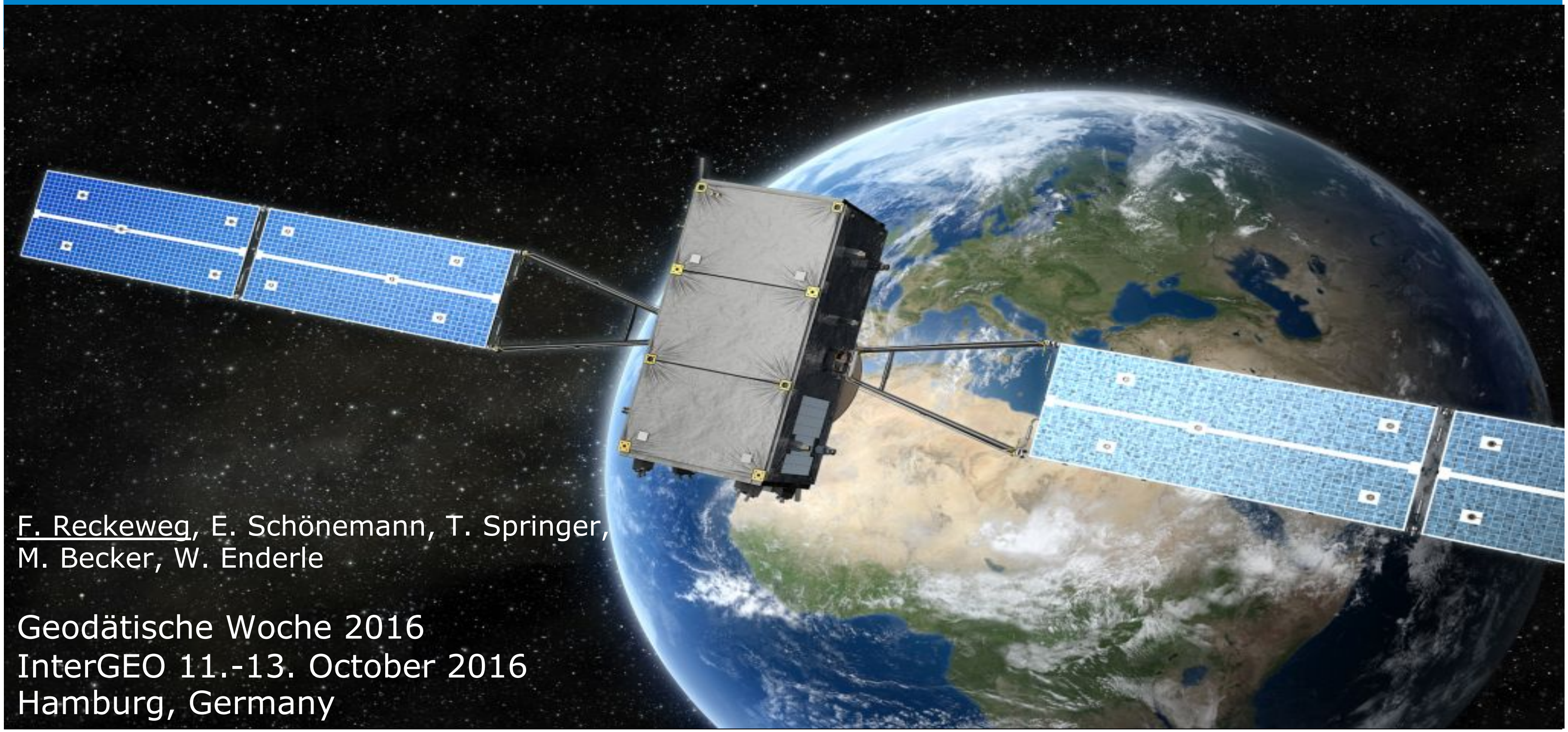
Multi-GNSS / Multi-Signal code bias determination from raw GNSS observations



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Content

Introduction

- What are Multi-GNSS/Multi-Signal code biases?
  Observation equation for a code measurement in RINEX 3.xx file:

$$C_r^s(ia) = \rho_r^s + c \cdot [dt_r - dt^s] + T_r^s + I_r^s(f_i) + \boxed{K_r(ia) - K^s(ia)} + \epsilon_C$$

  - (ia) is the frequency band number and tracking mode or channel as defined in the RINEX 3.xx format
  - K_r, K^s are uncalibrated hardware and software biases for receiver *r* and satellite *s*, also called *Uncalibrated Code Delays* (UCD)

Const.	Freq.	Signal	RINEX3
GPS	L1	C/A code	1C
GPS	L1	P(Y) code	1W
GPS	L2	P(Y) code	2W
GAL	E1	OS pilot	1C
GAL	E5a	pilot	5Q
GAL	E5b	pilot	7Q
GAL	E5	pilot	8Q

- Why are they relevant, or not?
  - Standard GPS L1, L2 **ionosphere free (IF)** processing
    →If same observation types are used for positioning and timing as in generation of GNSS orbits and clocks, code biases cancel
  - For any other processing approach
    → Code biases (UCDs) need to be considered

Introduction

- Future Multi-GNSS/Multi-Signal processing issue
  - Ionosphere Free processing
    - Decision of GNSS orbit and clock providers on which signals they use, will lead to the need of users to process exactly the same signals
  - RAW processing
    - Use signals ‘as they are‘ without forming any linear combination or observation differences
    - Users have free choice in terms of signal usage, but UCDs need to be considered
  - GNSS orbit and clock service providers either
    a) Stay with current dual frequency ionosphere free approach or
    b) Upgrade to Multi-Signal processing and provide biases

Processing Approach

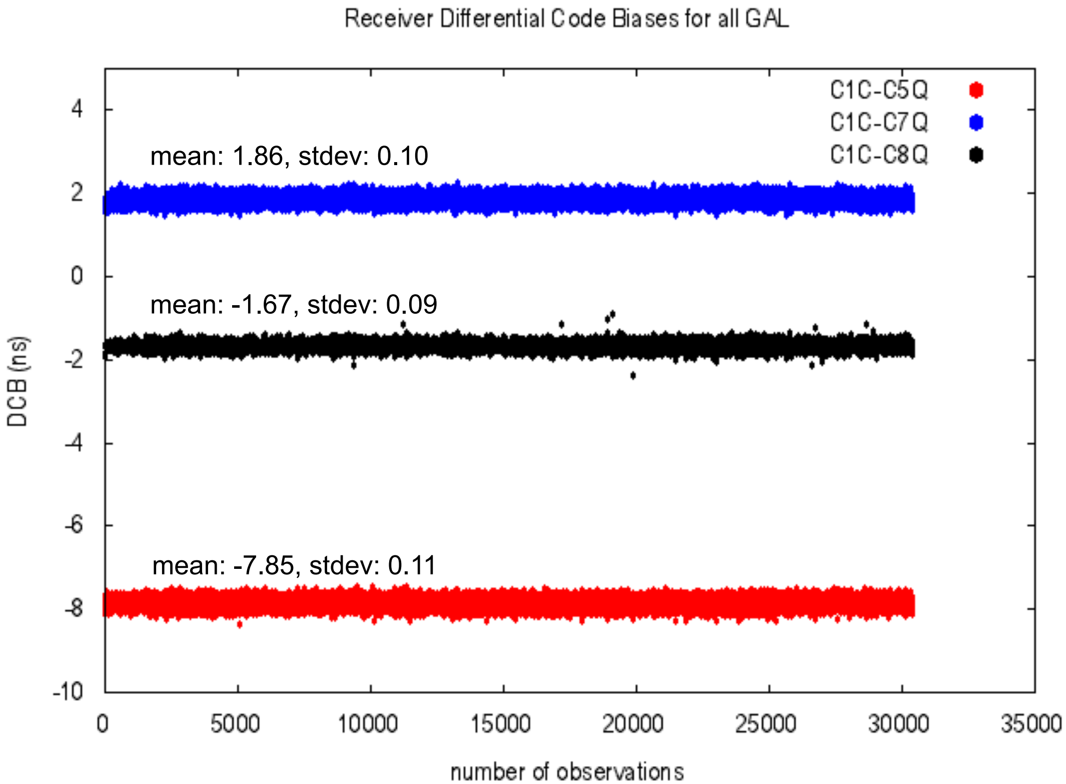
- Code Biases are commonly generated and distributed in form of *Differential Code Biases* (DCB)

$$DCB^s(ia, jb) = K^s(ia) - K^s(jb)$$

  - Navigation message contains
    - *Timing Group Delay* (TGD) ~ GPS DCB(1W,2W)
    - *Broadcast Group Delay* (BGD) ~ GAL DCB(1C,5Q) or ~ GAL DCB(1C,7Q)
- Common Multi-GNSS/Multi-Signal DCB generation strategy:
  - IGS IONEX: DCBs are side product of *Global Ionospheric Map* (GIM) estimation
  - MGEX (Multi-GNSS Experiment of IGS): DCB estimation with GIM information and by processing code observation differences
- Undifferenced Multi-GNSS/Multi-Signal UCD estimation
  - Direct UCD estimation from raw code observations without forming any linear combinations or observation differences

Differential Code Bias Determination

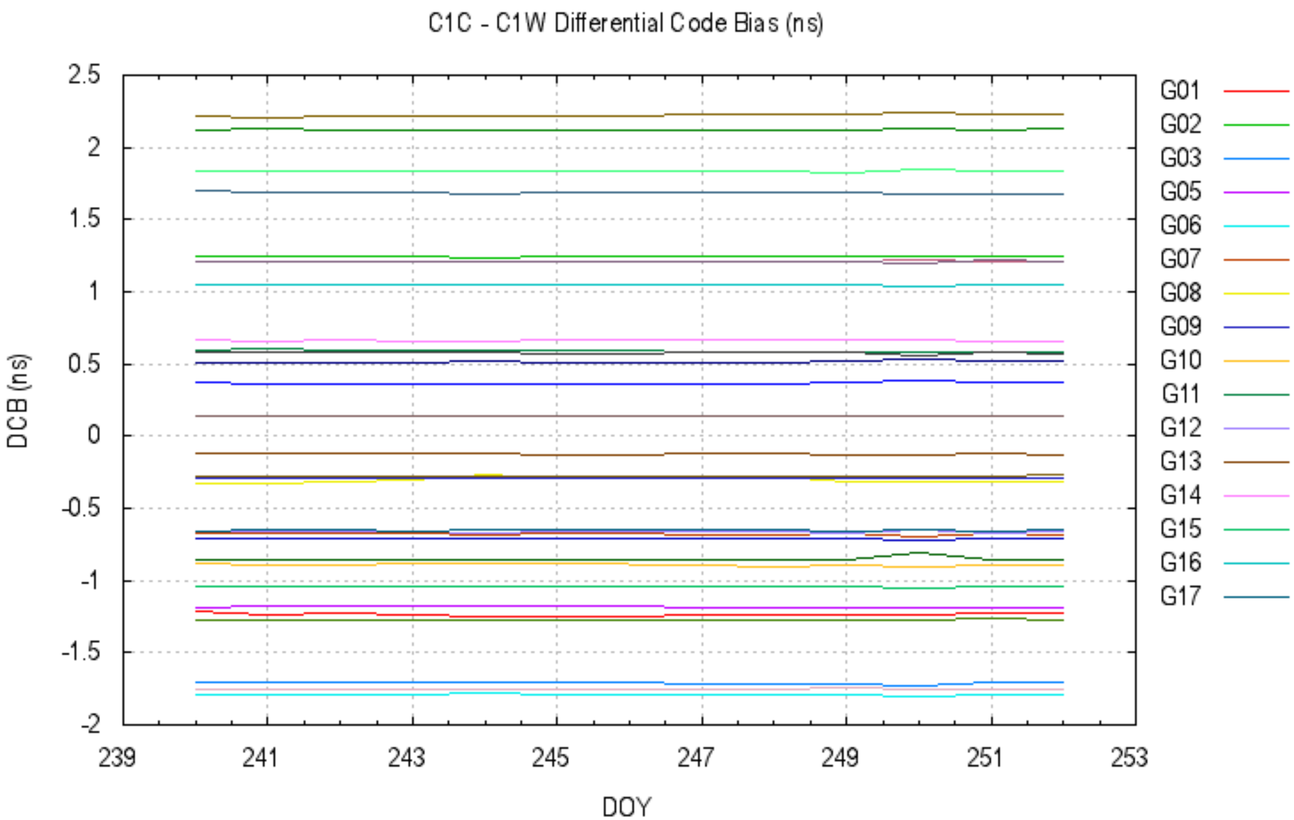
Simulator – Receiver DCB



- Simulated Galileo full constellation for 1 day
- No satellite errors
- No atmospheric effects
- Formed Galileo code observation differences
- UCD estimate differences from Network processing with same receiver type:
  - UCD(1C) – UCD(5Q): -9.00 ns
  - UCD(1C) – UCD(7Q): 2.33 ns
  - UCD(1C) – UCD(8Q): -1.71 ns

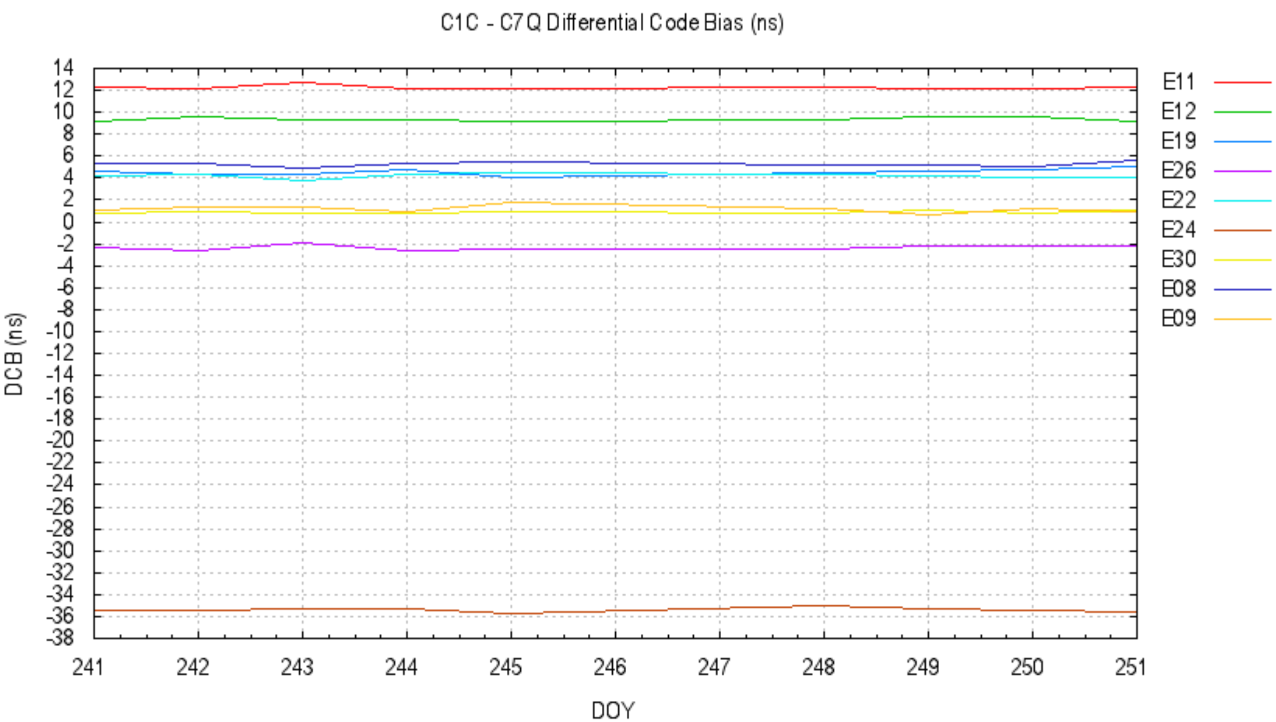
→ UCD estimates agree well with receiver bias as the dominant factor

Multi-GNSS ESA/ESOC Network GPS Satellite DCB



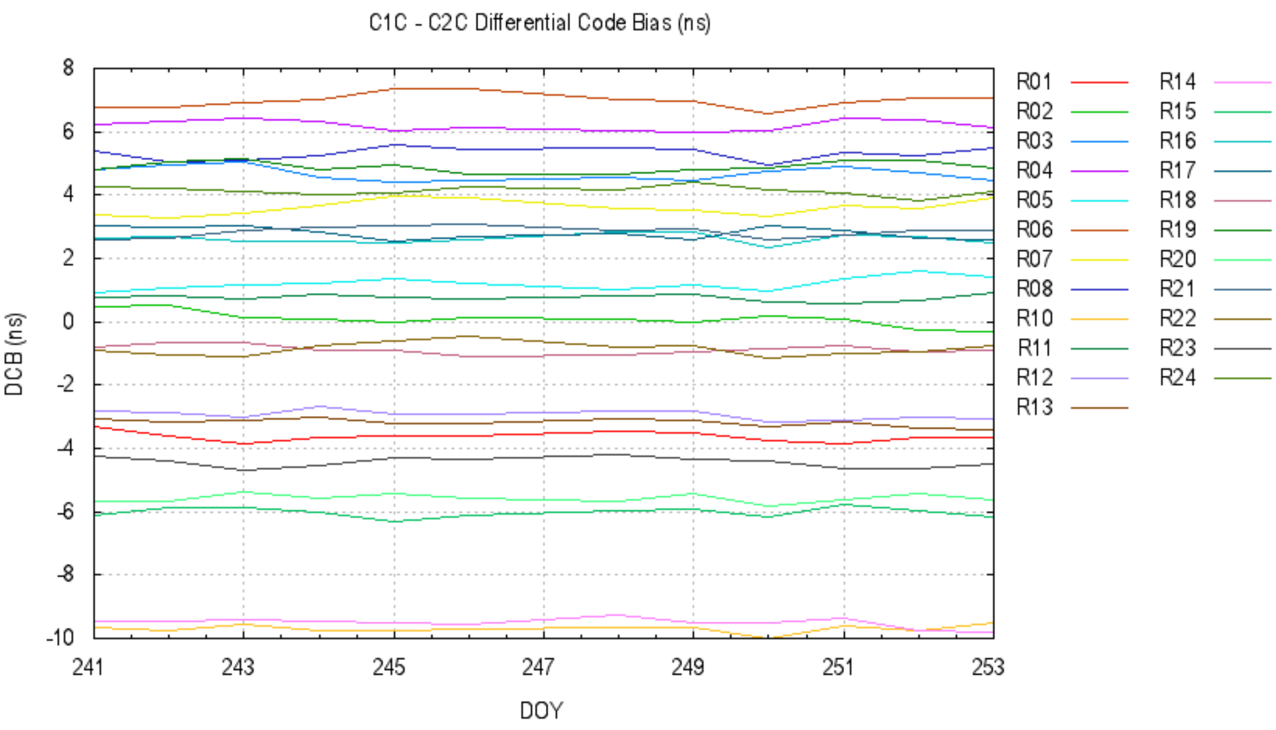
- GPS satellite UCD(1C)-UCD(1W) from RAW approach
- Mean daily repeatability: 0.02 ns
- Inter-frequency mean daily repeatability for UCD(1C)-UCD(2W): 0.16 ns

Multi-GNSS ESA/ESOC Network
Galileo Satellite DCB



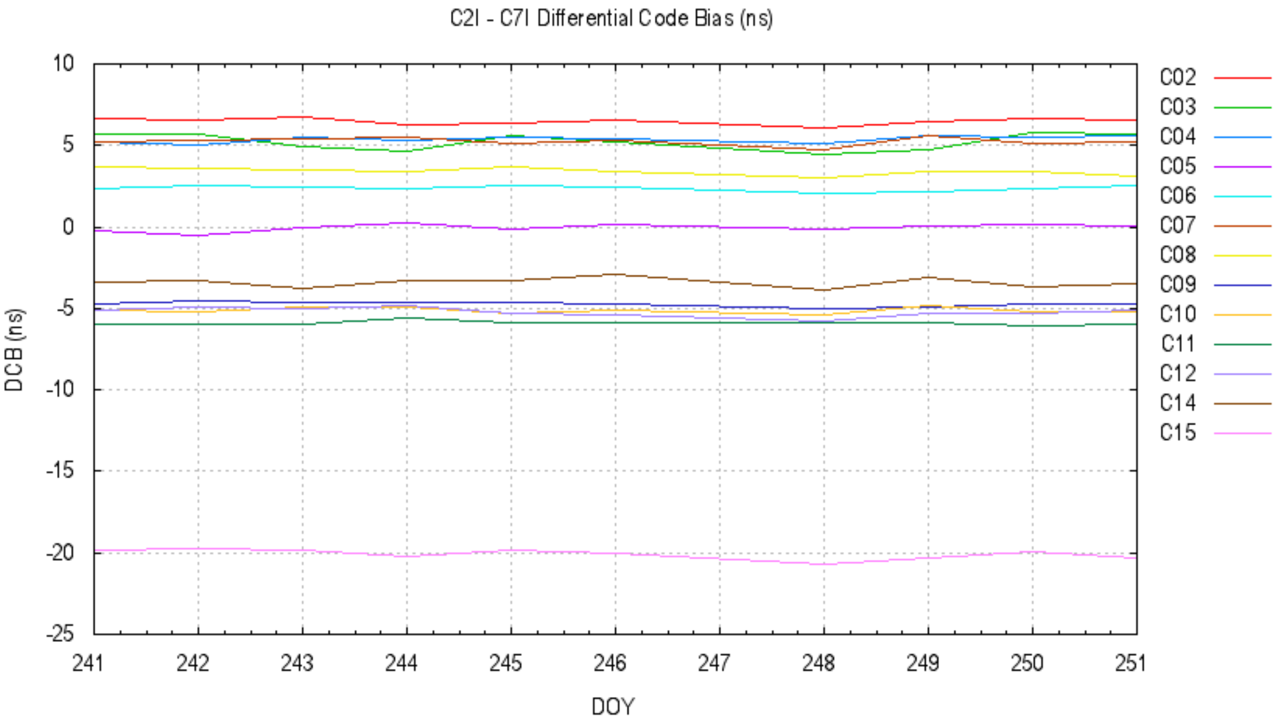
- Galileo satellite UCD(1C)-UCD(7Q) from RAW approach
- Mean daily repeatability: 0.21 ns

Multi-GNSS ESA/ESOC Network
GLONASS Satellite DCB



- GLONASS satellite UCD(1C)-UCD(2C) from RAW approach
- Mean daily repeatability: 0.17 ns

Multi-GNSS ESA/ESOC Network
Beidou Satellite DCB



- Beidou satellite UCD(2I)-UCD(7I) from RAW approach
- Mean daily repeatability: 0.24 ns

Undifferenced Code Bias Estimation & Application

Undifferenced Code Bias Estimation

(based on RAW approach)

TECHNISCHE UNIVERSITÄT DARMSTADT

- GNSS code observation equation based on satellite orbits and clocks generated with RAW approach

$$C_r^s(ia) = \rho_r^s + c \cdot [dt_r - dt^s] + T_r^s + I_r^s(f_i) + K_r(ia) - \underbrace{K^s(ia)}_{= UCD^s_{est,raw}(ia)} + \epsilon_C$$

- GNSS code observation equation based on satellite orbits and clocks generated with ionosphere free approach

$$C_r^s(ia) = \rho_r^s + c \cdot [dt_r - dt^s_{IF}] + T_r^s + I_r^s(f_i) + K_r(ia) - \underbrace{[K^s(ia) - K^s_{IF}]}_{= UCD^s_{est,IF}(ia)} + \epsilon_C$$

- The unknown IF satellite code bias $K^s{}_{IF}$ should be the same for all signals when derived from UCD estimates by

$$K^s_{IF} = UCD^s_{est,raw}(ia) - UCD^s_{est,IF}(ia) \quad (1)$$

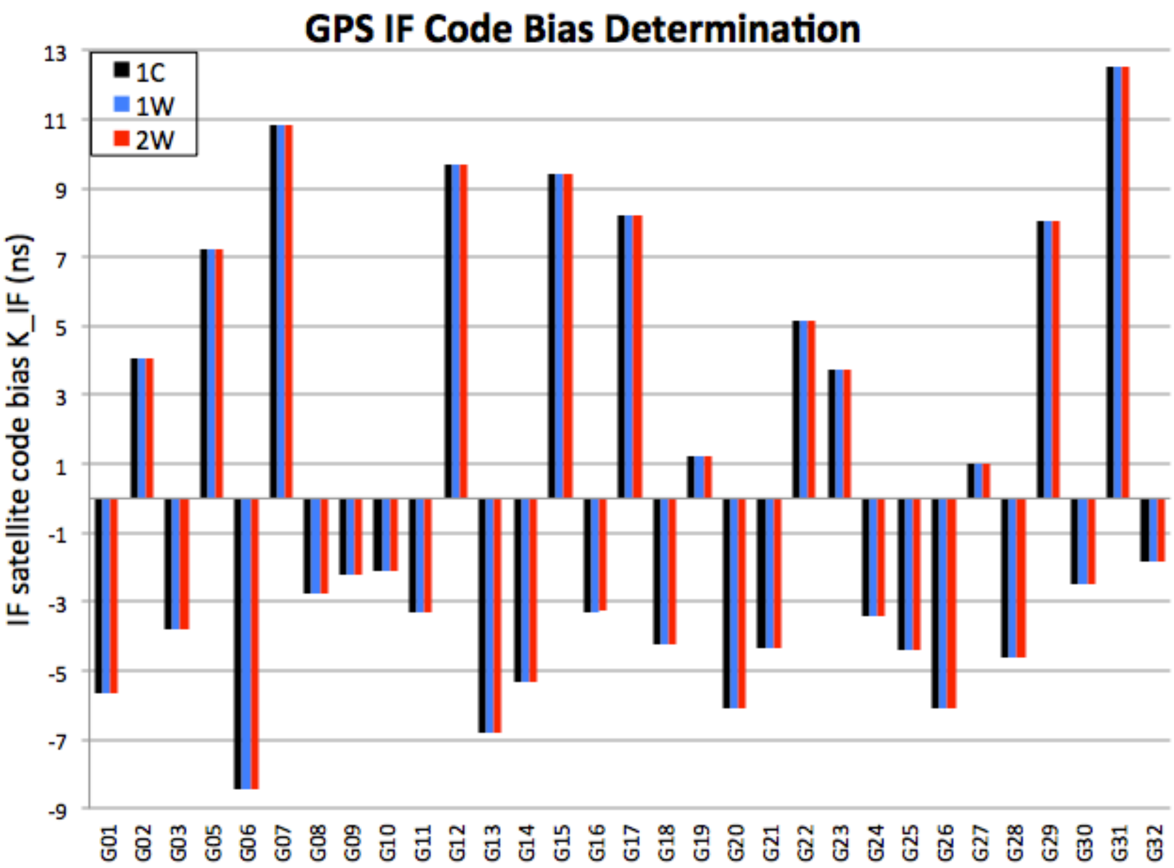
$$c \cdot \delta t^s_{IF} = c \cdot \delta t^s + K^s_{IF}$$

- Arbitrary IF satellite code biases can be derived from $UCD^s{}_{raw}$ estimates

$$K^s_{IF}(ia, jb) = \frac{f_i^2 \cdot UCD^s_{est,raw}(ia) - f_j^2 \cdot UCD^s_{est,raw}(jb)}{f_i^2 - f_j^2}$$

(should be identical to $K^s{}_{IF}$ in (1), if the same signals *ia, jb* are used as in IF clock generation)

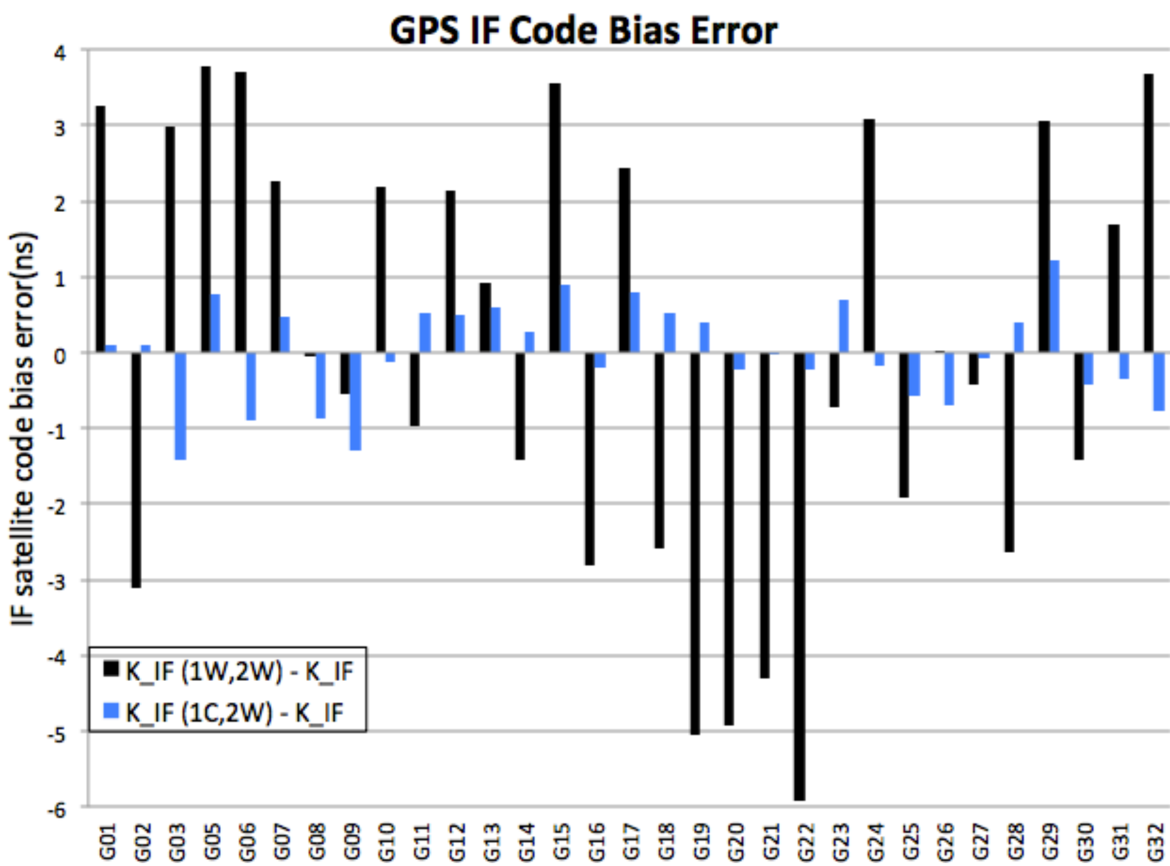
GPS IF satellite code bias



- GPS IF satellite code biases K^s_{IF} are the same, although derived from different signal UCD estimates

-9 ns to 13 ns
(-2.7 m to 3.9 m)

GPS IF satellite code bias

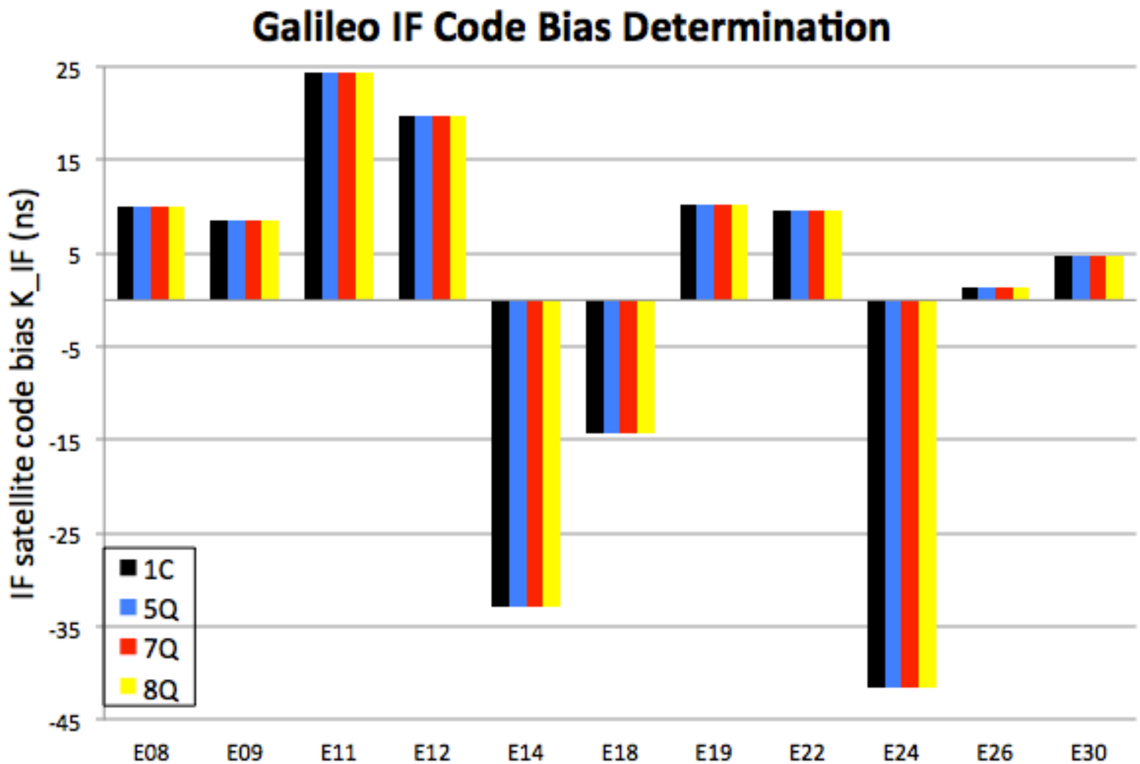


- Signal combination 1C, 2W was (primarily) used in generation of orbits and clocks with IF approach
- Introduced code bias error for IF linear combination when signals 1W, 2W are used instead:

  \- 6 ns to 4 ns

  (- 1.8 m to 1.2 m)

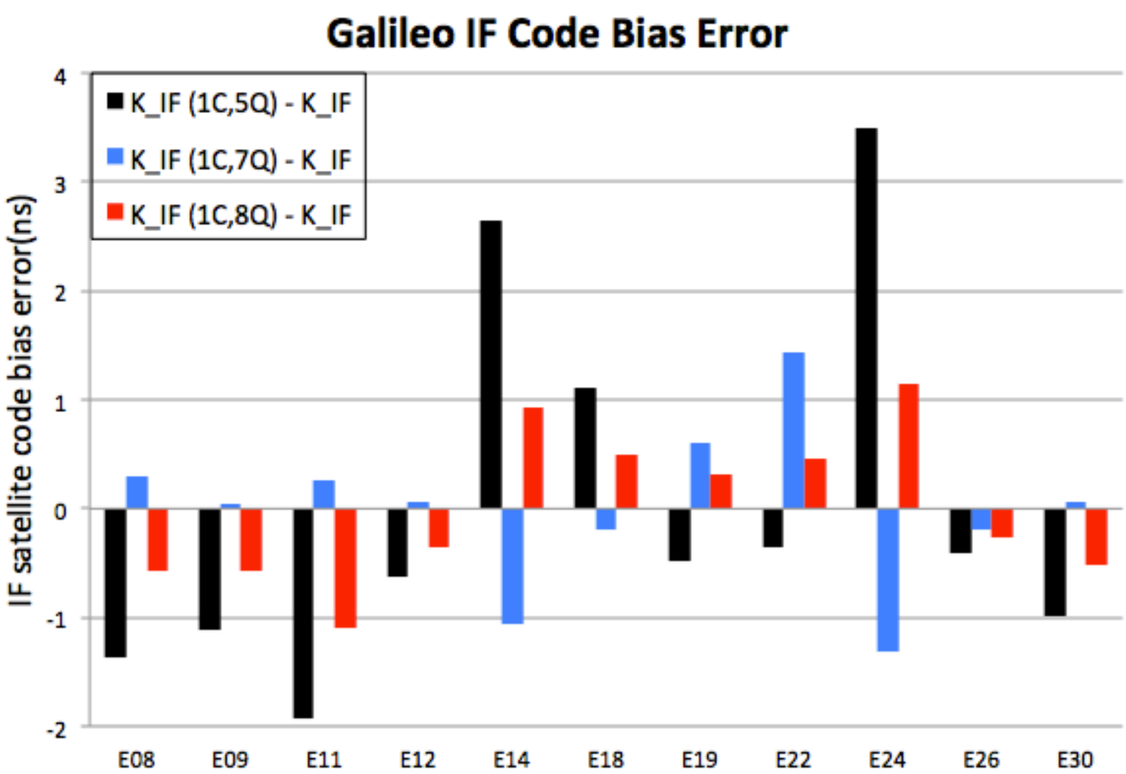
Galileo IF satellite code bias



- Galileo IF satellite code biases K^s_{IF} are the same, although derived from different signal UCD estimates

-41 ns to 25 ns
(-12.3 m to 7.5 m)

Galileo IF satellite code bias



- Signal combination 1C, 7Q was (primarily) used in generation of orbits and clocks with IF approach
- Introduced code bias error for IF linear combination when signals 1C, 5Q are used instead:

  - 2 ns to 3.5 ns

  (- 0.6 m to 1 m)

Summary and Conclusion

- The GNSS RAW processing approach allows Multi-GNSS/Multi-Signal users to have free choice in terms of frequency and signal usage
  - Code biases need to be considered
- Receiver UCD estimates from RAW approach agree well with receiver bias determined in GNSS signal simulator campaign
- The RAW approach can be used to directly estimate code biases (UCDs) rather than the commonly used differential code biases (DCBs)
- Satellite UCD estimates were used to show that ionosphere free code bias errors can reach up to 1.8 m, if a ‘wrong‘ signal combination is used