Differential Code Bias Estimation for New Signals and Constellations

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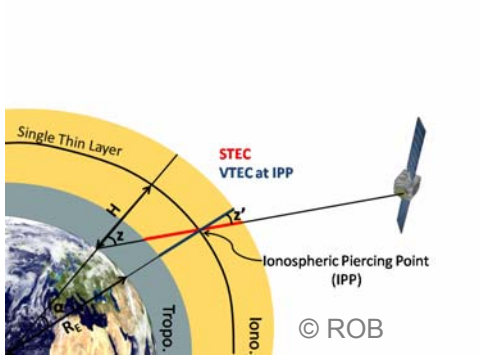
Motivation

- Differential Code Biases (DCBs) are required for
  - Code-based positioning
  - Ambiguity resolution using code observations
- Current DCB products (CODE) limited to GPS/GLONASS legacy signals
- New signal biases introduced by additional signals and tracking modes
- Broadcast TGD/BGD and ISC parameters do not include all possible tracking modes

- IGS needs to provide new multi-GNSS/multi-signal DCB product
- Multi-GNSS/multi-signal DCBs not presently supported in ionosphere+DCB processing
- Alternative, simplified method uses Global Ionosphere Maps for DCB estimation

DCB Determination using Global Ionosphere Maps

- DCB from ionosphere-corrected pseudorange difference
- Use of „known“ ionosphere based on global ionosphere maps
  - IGS IONEX product
  - Single-layer model
  - Limited accuracy

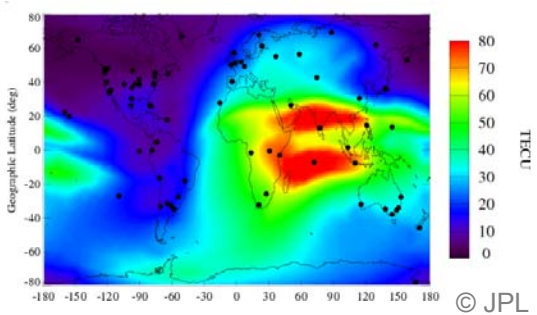


Averaged/ignored

$$P_{S_1} - P_{S_2} = (I_{S_1} - I_{S_2}) + (B_{S_1} - B_{S_2}) + (M_{S_1} - M_{S_2}) + (\varepsilon_{S_1} - \varepsilon_{S_2})$$

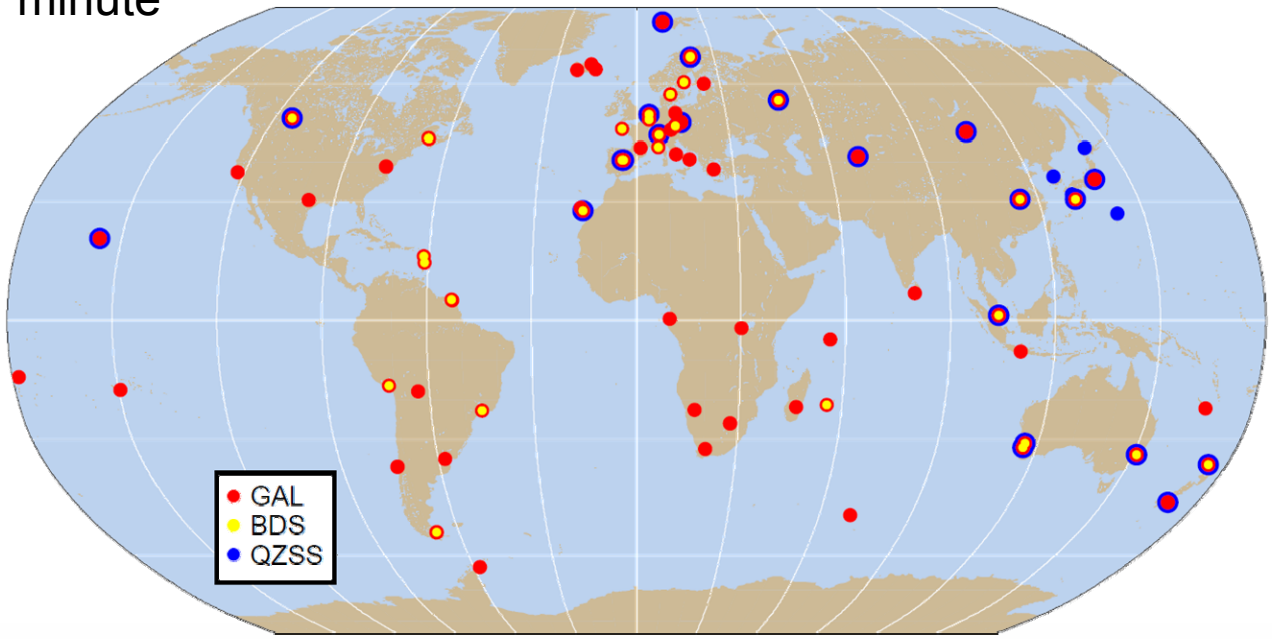
$$\approx 40.3 \cdot \mathrm{STEC} \cdot \left(\frac{1}{f_{S_1}^2} - \frac{1}{f_{S_2}^2} \right) + \mathrm{DCB}_{S_1 - S_2}^{\mathrm{sat+rcv}}$$

Measured | Modelled | Estimated



Network and Receivers

- MGEX Network (~80 stations) tracking GPS, GLO, GAL, (QZSS), BDS
- Challenge with modernized signals (GPS L2C+L5, Galileo E1+E5a):
  - Different receivers use different tracking modes
  - Example: GPS L5 pilot-only tracking or combined pilot+data tracking
- Period Jan. 1, 2013 – Mar 31, 2014
- Sampling period 1 minute



Processing Scheme

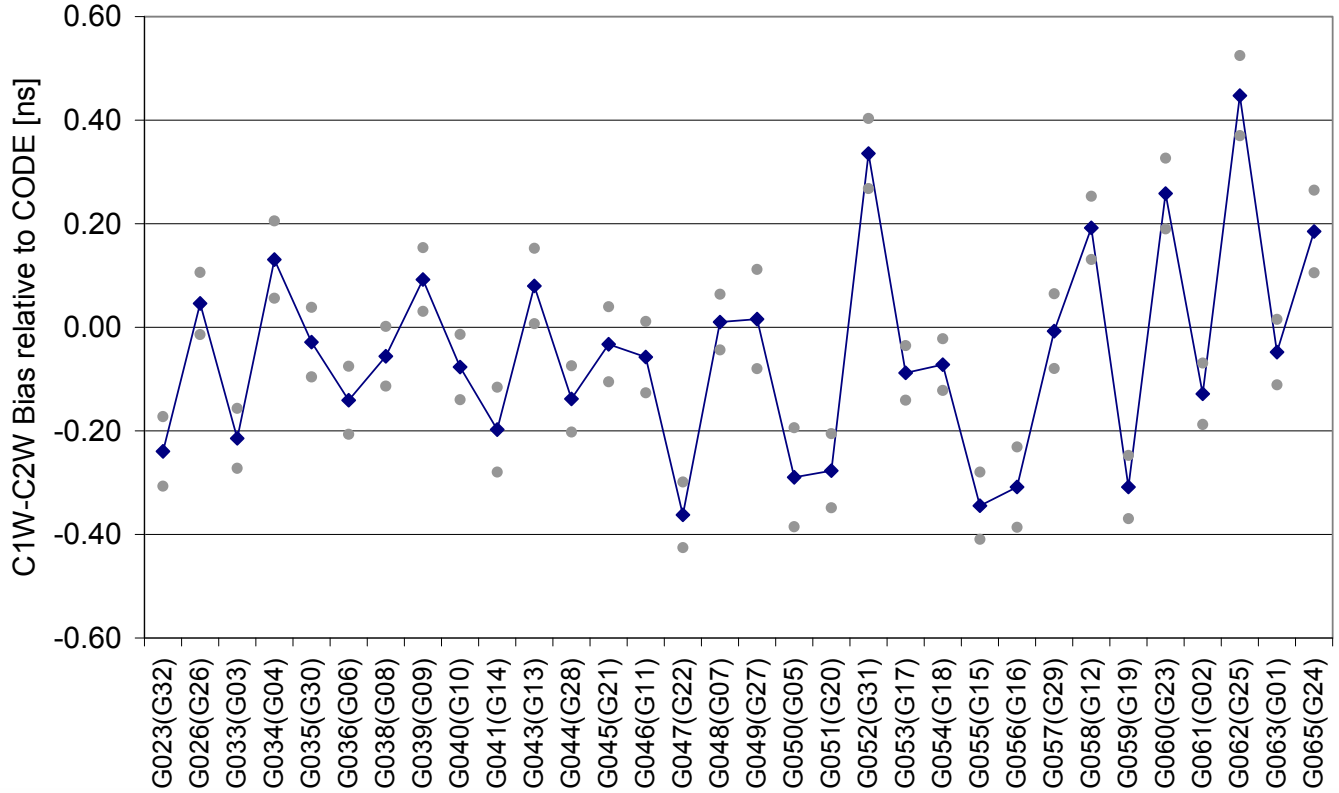
- Select signal pair (S_1,S_2)
- Determine satellite+receiver $DCB^{sat+rcv}$ from daily mean of ionosphere-corrected code difference
- Determine individual DCBs for each satellite and station from combined DCBs for all sites and satellites
  - assuming $DCB^{sat+rcv} = DCB^{sat}+DCB^{rcv}$
  - applying a zero-constellation-mean constraint

Notes:

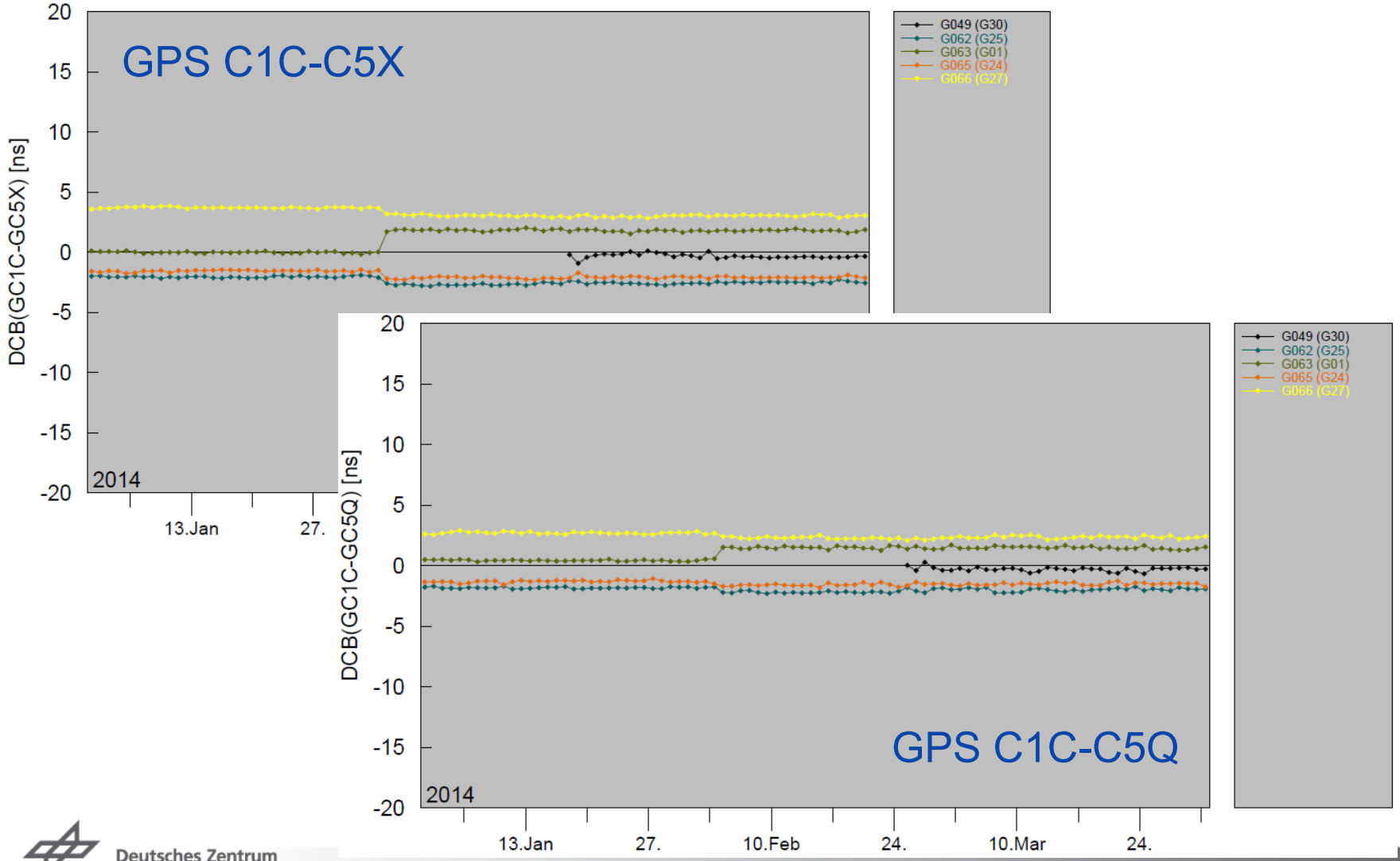
- Set of contributing stations depends on selected signals
- Prototype implementation (IONDCB) enables processing of „all“ constellations and dual-signal combinations but no combined adjustement of >2 signals (such as C1C, C1W, C2W)

DCB-Results: GPS L1-L2 P(Y) legacy DCB

- L1-L2 P(Y) (C1W-C2W) DCBs compared to monthly CODE product for 01/2013
- Standard deviation of differences over entire constellation: 0.20 ns

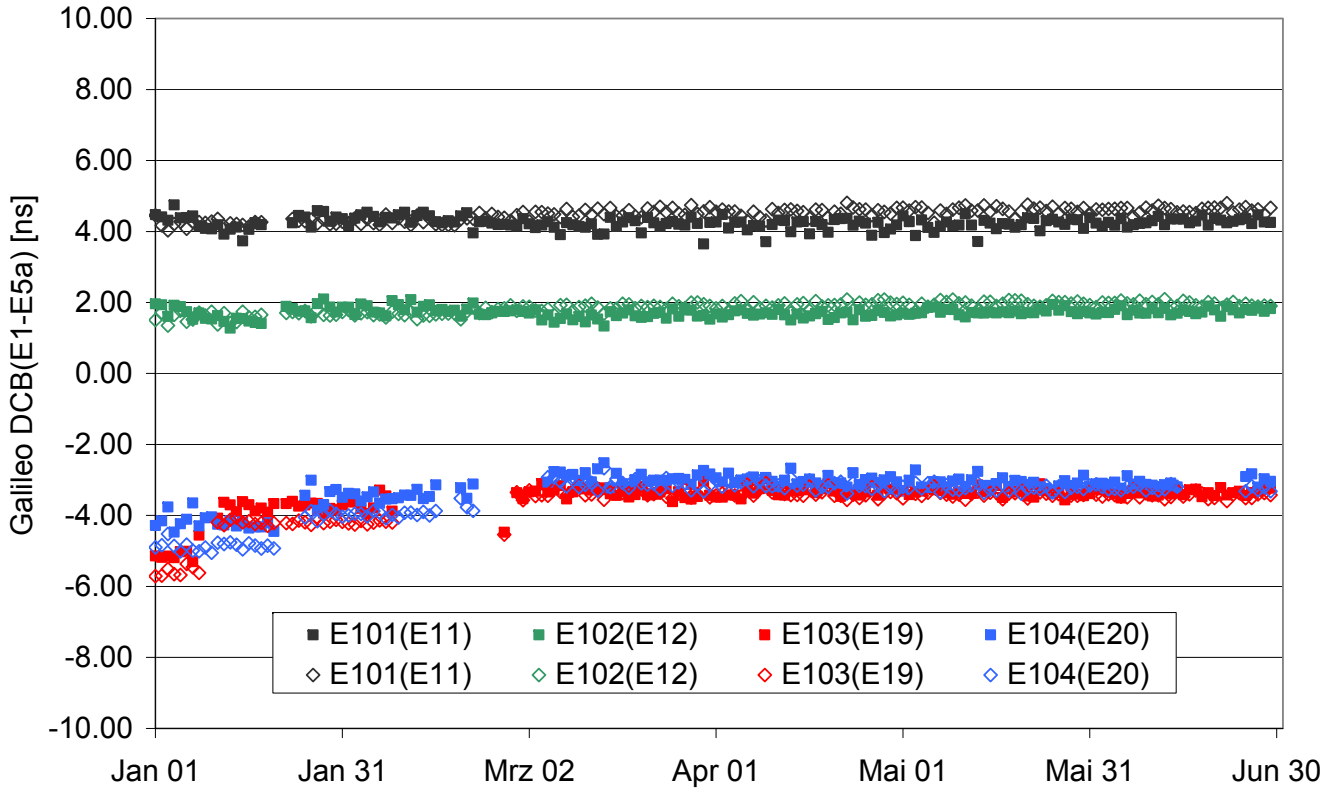


DCB-Results: Pilot vs. Pilot+Data Tracking GPS L5



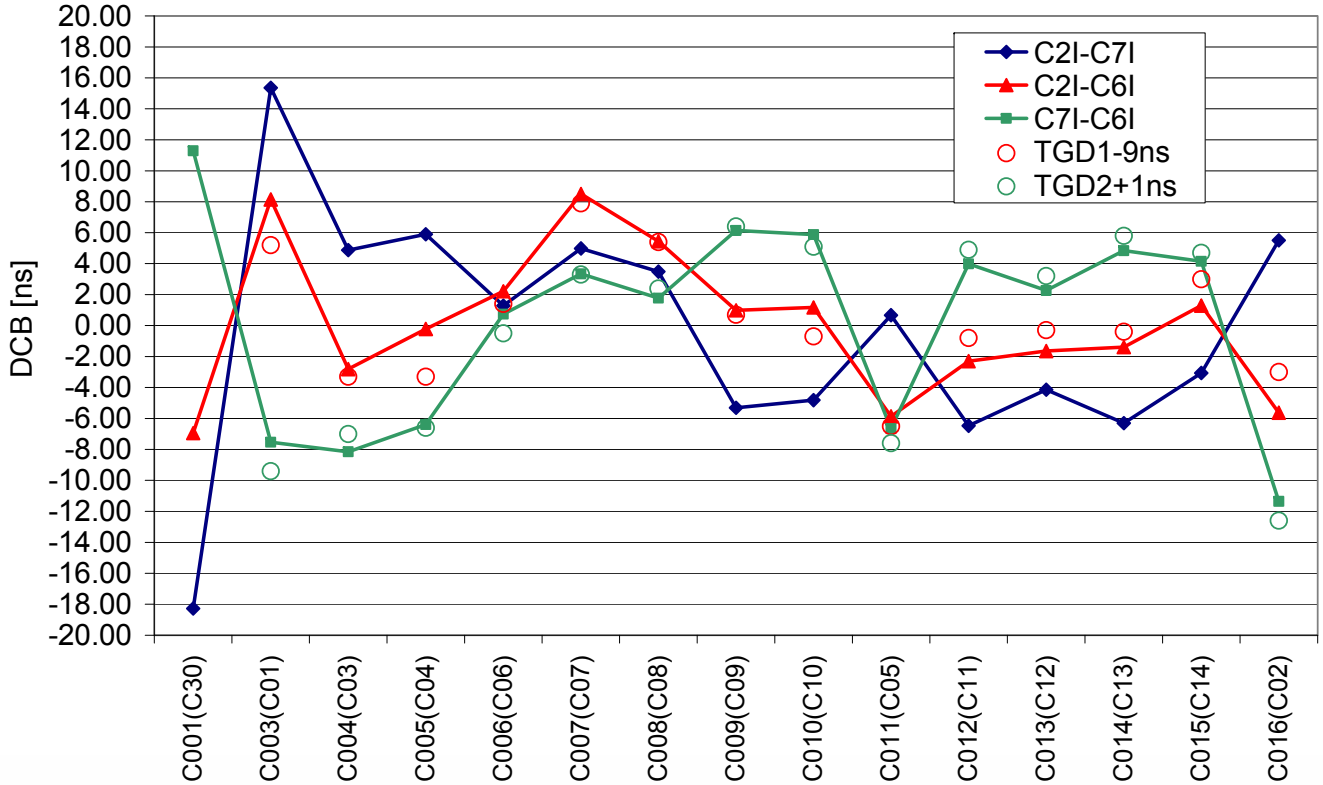
DCB-Results: Galileo

- Galileo E1-E5a DCBs (squares: pilot tracking, diamonds: data+pilot tracking)
- DCB variation observed for newly launched satellites E19 and E20

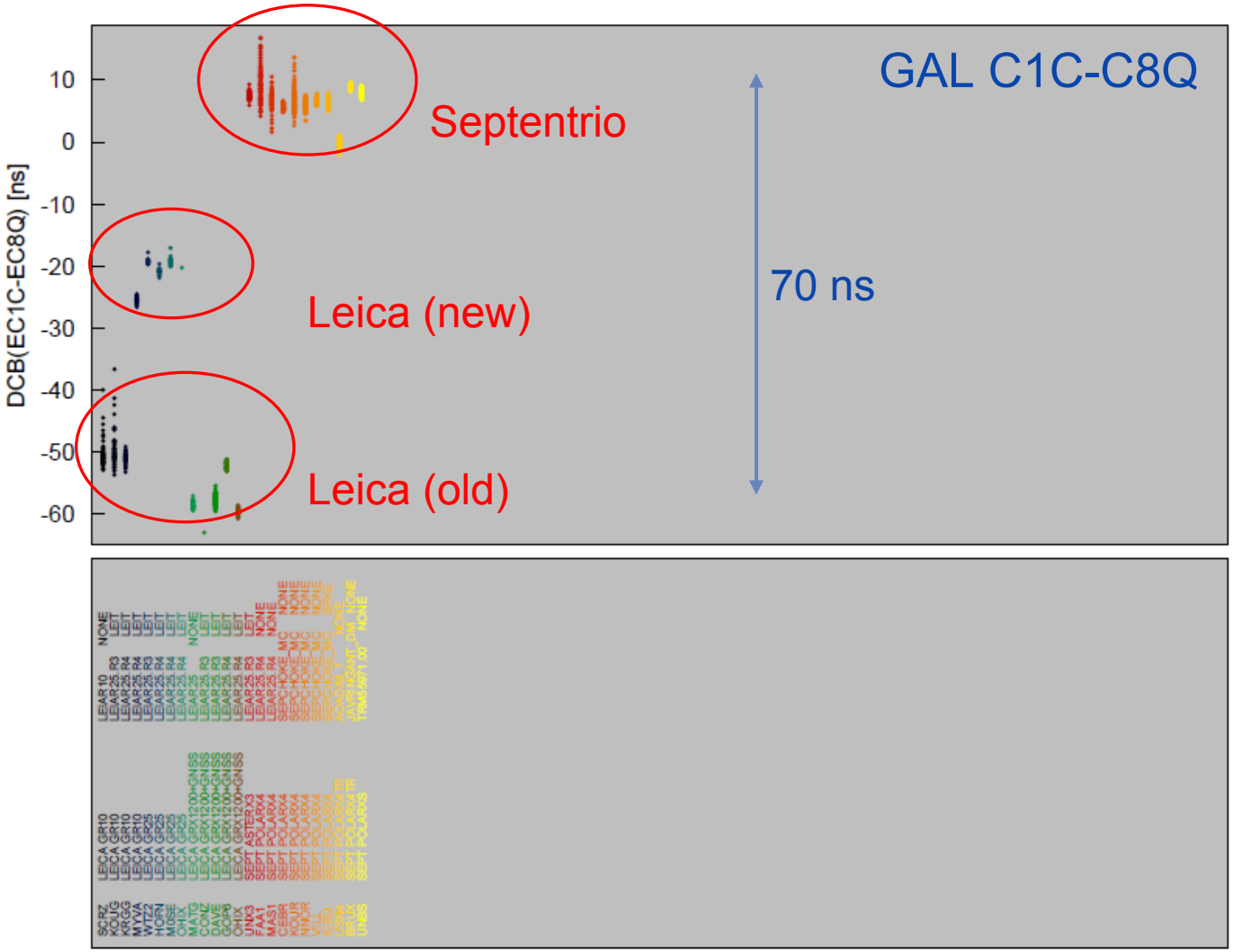


DCB-Results: BeiDou

- DCBs for combinations of signals on bands B1 (C2I), B2 (C7I) and B3 (C6I)
- Monthly DCB solution and broadcast values for January 2013
- Consistency limited to 2ns



Site DCBs – Example Galileo



IGS MGEX DCB Product

- Available at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/dcb
- Supported constellations and signals
  - GPS (C1C, C1W, C2W, C2X/L/S, C5Q/X)
  - GLO (C1C, C1P, C2C, C2P)
  - GAL (C1C/X, C5Q/X, C7Q/X, C8Q/X)
  - BDS (C2I, C7I, C6I)
- Prototype Bias SINEX format
- Two products
  - MGEXyyyy.bsx Satellite-only biases (weekly averages)
  - MGEXyyyy_all.bsx Satellite and station biases (daily values)

Bias SINEX DCB Format Example

```
%=BIA 0.01 IGS 14:110:29859 IGS 14:001:00000 00:000:00000 P 00000 0
*-------------------------------------------------------------------------------------------------------
* Solution INdependent EXchange Format (SINEX)
*-------------------------------------------------------------------------------------------------------
*-------------------------------------------------------------------------------------------------------
+BIAS/SOLUTION
*BIAS SVN_ PRN SITE DOMES____ OBS1 OBS2 BIAS_START__ BIAS_END____ UNIT __ESTIMATED_VALUE____ _STD_DEV___
...
 DCB  E101 E11               C1C  C5Q  14:001:00000 14:005:00000 ns                 4.2518      0.0496
 DCB  E101 E11               C1C  C5Q  14:005:00000 14:012:00000 ns                 4.2838      0.0845
 DCB  E101 E11               C1C  C5Q  14:012:00000 14:019:00000 ns                 4.2881      0.0725
 DCB  E101 E11               C1C  C5Q  14:019:00000 14:026:00000 ns                 4.2985      0.1644
 DCB  E101 E11               C1C  C5Q  14:026:00000 14:033:00000 ns                 4.3621      0.1399
 DCB  E101 E11               C1C  C5Q  14:033:00000 14:040:00000 ns                 4.2716      0.1454
 DCB  E101 E11               C1C  C5Q  14:040:00000 14:047:00000 ns                 3.9937      0.0000
 DCB  E101 E11               C1C  C5Q  14:047:00000 14:054:00000 ns                 4.4921      0.1809
 DCB  E101 E11               C1C  C5Q  14:054:00000 14:061:00000 ns                 4.0552      0.5291
 DCB  E101 E11               C1C  C5Q  14:061:00000 14:068:00000 ns                 4.2821      0.2117
 DCB  E101 E11               C1C  C5Q  14:068:00000 14:075:00000 ns                 4.1911      0.1618
 DCB  E101 E11               C1C  C5Q  14:075:00000 14:082:00000 ns                 4.1363      0.1770
 DCB  E101 E11               C1C  C5Q  14:082:00000 14:089:00000 ns                 4.1988      0.1490
 DCB  E101 E11               C1C  C5Q  14:089:00000 00:000:00000 ns                 4.2597      0.0780
 DCB  E101 E11               C1C  C7Q  14:001:00000 14:005:00000 ns                 4.5851      0.0738
 DCB  E101 E11               C1C  C7Q  14:005:00000 14:012:00000 ns                 4.6154      0.1071
 DCB  E101 E11               C1C  C7Q  14:012:00000 14:019:00000 ns                 4.5895      0.0769
 DCB  E101 E11               C1C  C7Q  14:019:00000 14:026:00000 ns                 4.6393      0.1322
 DCB  E101 E11               C1C  C7Q  14:026:00000 14:033:00000 ns                 4.6416      0.1322
...
-BIAS/SOLUTION
*-------------------------------------------------------------------------------------------------------
%=ENDBIA
```

DCB Product – Problems

- Improper compensation of ionospheric delays using GIMs
- Independence of DCBs for pilot-only vs. pilot+data tracking (no common receivers)
- Lack of observations for analysis of pilot-minus-data DCBs
- Lacking self-consistency,
  i.e. DCB(a-b)+DCB(b-c) ≠DCB(a-c)
  - Receiver dependence of satellite biases
  - Impact of multipath

- BIAS SINEX is no standard (just prototype v0.01)

Summary and Conclusions

- Simplified DCB estimation process based on differenced code observations
- Ionospheric delay eliminated using slant TEC from global ionospheric-map
  - Simpler algorithm than combined ionosphere and bias estimation
  - Potentially less accurate
- Allows computation of DCBs for modernized signals and new constellations
- Good agreement of legacy L1-L2-P(Y) bias with CODE DCBs (σ=0.2ns)
- Different biases are estimated for different tracking modes
  - Potentially station-dependent effects
  - Dependence on tracking mode / signal type still to be assessed
- Comparison of DCBs with corresponding parameters of broadcast data
  - Good agreement for GPS and Galileo (<0.2 ns)
  - Larger differences (0-12 ns) for BeiDou (further assessment required)