Revisiting the origin of GLONASS inter-frequency phase biases and its implication to IGS Bias-SINEX products

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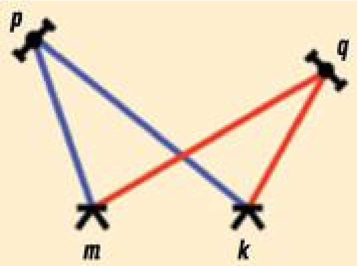
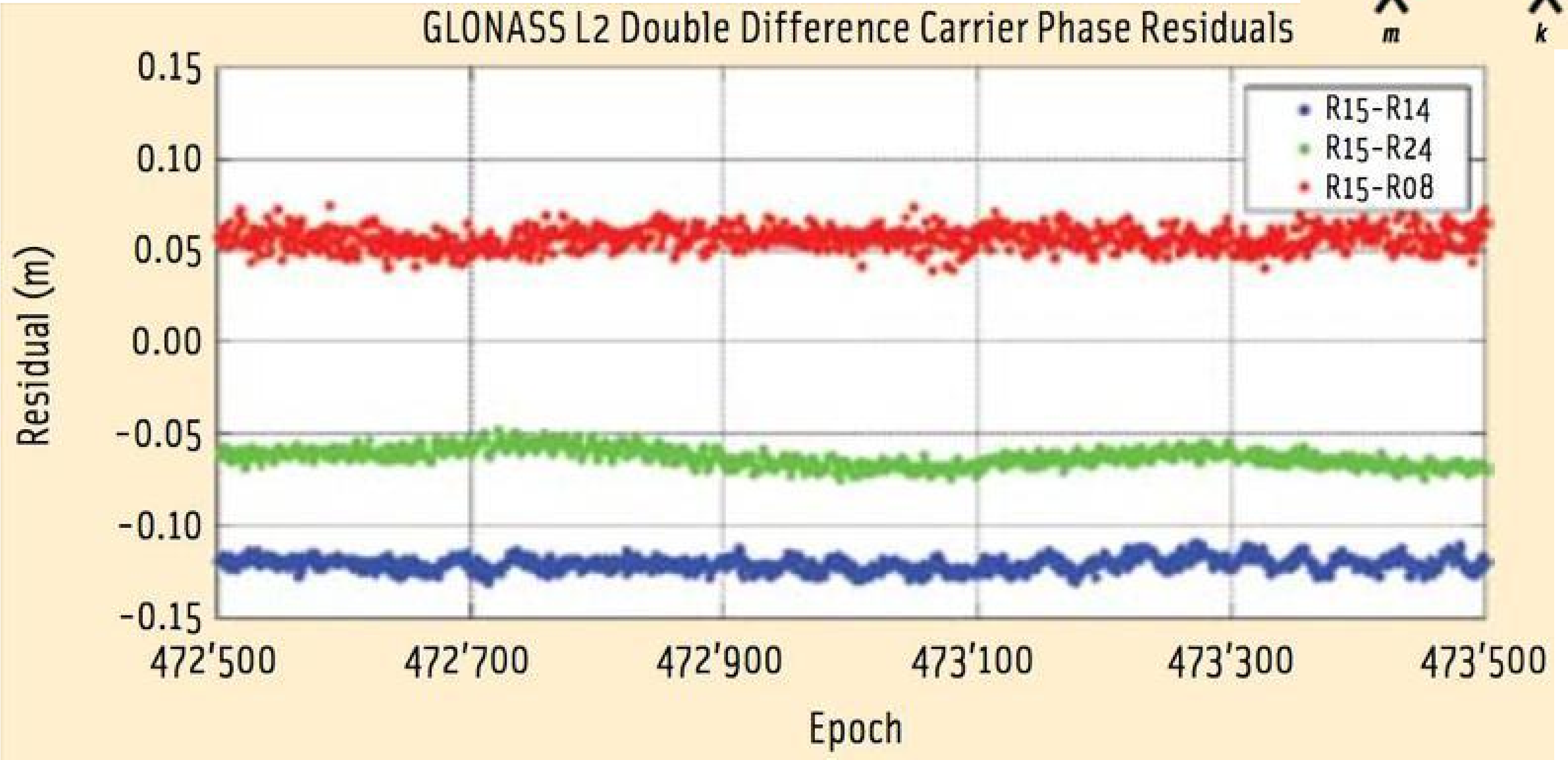
GLONASS ambiguity resolution is difficult!

- Diverse frequencies across GLONASS L1/L2 bands
  - Inter-frequency phase biases (i.e. IFPB) at receivers
  - IFPBs don't cancel after differencing between satellit

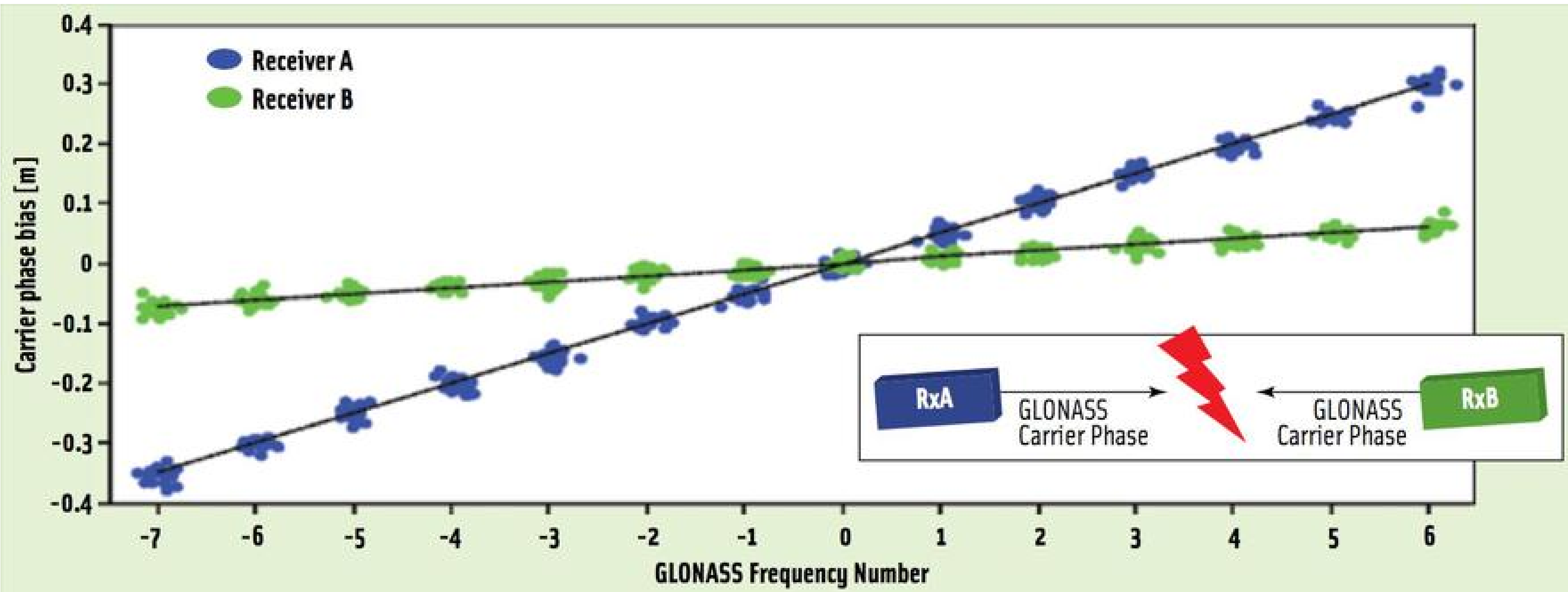




Takac et al. Inside GNSS 2009

Aha, inter-frequency biases can be corrected

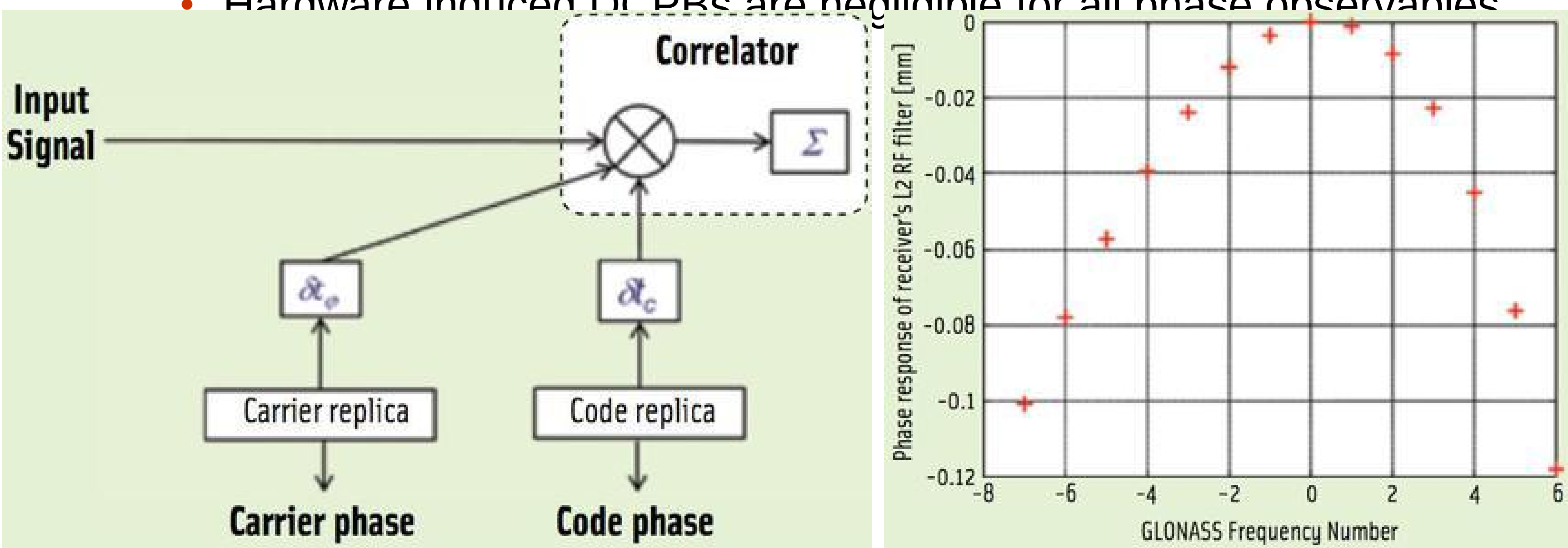
- IFPBs are linear function of frequency channel numbers
  - IFPBs appear to depend on receiver types/families
  - L1 and L2 signals seem to share identical IFPBs



Sleewaegen et al. Inside GNSS 2012

In fact, it's differential code-phase bias that matters

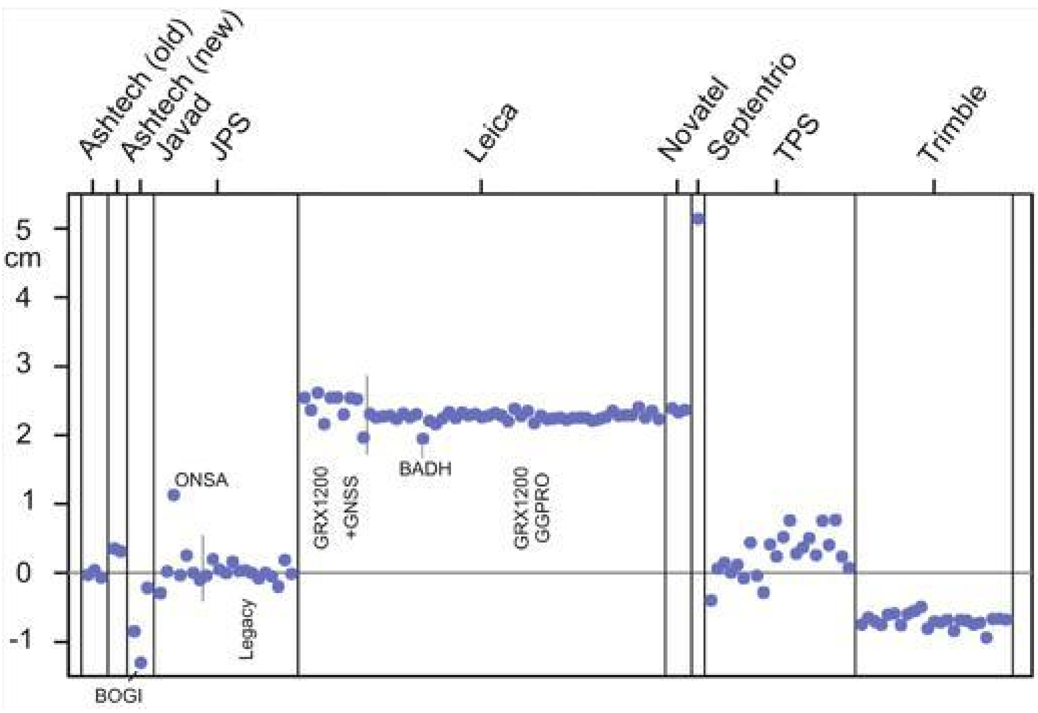
- Sleewaegen (2012) found that
  - Differential code-phase biases (DCPBs) are the physical origin of IFPBs
  - DCPBs consist of DSP and hardware induced parts
    - DSP induced DCPBs are fixed values for a specific receiver type
    - Hardware induced DCPBs are negligible for all phase observables

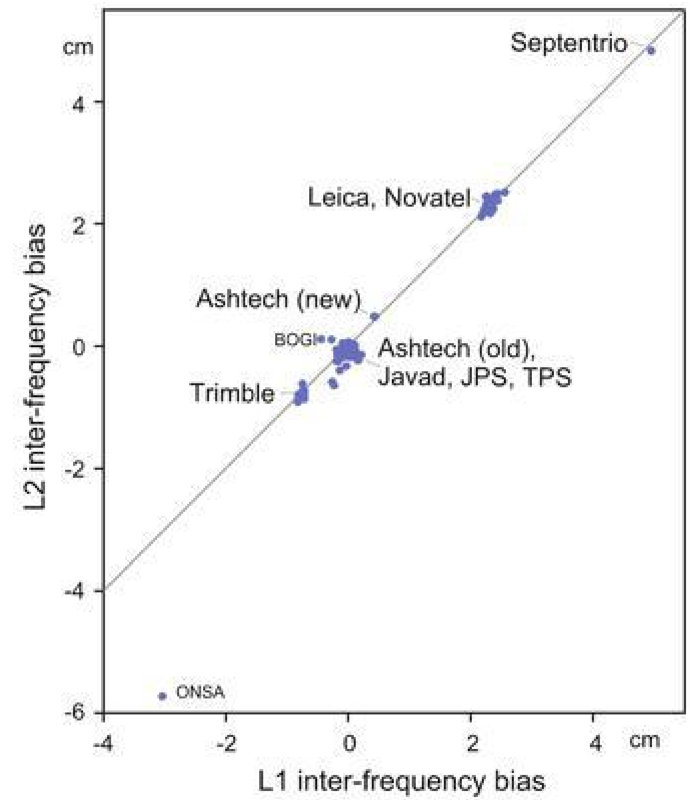


Sleewaegen et al. Inside GNSS 2012

Mysteries of IFPBs/DCPBs

- Question 1: Uncertainty of IFPB/DCPB estimates?
- Question 2: Receiver type specific IFPBs/DCPBs suffice or not?
- Question 3: One IFPB/DCPB for a receiver type suffice or not?





Wanninger Journal of Geodesy 2012

First, a little bit of math for DCPBs

- Pseudorange and carrier-phase have different clocks and hardware biases.

$$\begin{cases} \Delta P_g^i = \Delta\rho^i + c\Delta t_{\mathrm{P}} + c\Delta b_{\mathrm{P},g}^i \\ \Delta L_g^i = \Delta\rho^i + c\Delta t_{\mathrm{L}} + c\Delta b_{\mathrm{L},g}^i + \lambda_q^i \Delta N_q^i \end{cases}$$

- Therefore, a common clock assumption results in DCPBs,

$$\Delta L_g^i = \Delta\rho^i + c\Delta t_g + c\Delta B_g + \lambda_q^i \Delta N_q^i$$

- which consist of DSP and hardware induced parts.

$$\begin{cases} \Delta B_g = \Delta B_{\mathrm{DSP}} + \Delta B_{\mathrm{HW},g} \\ \Delta B_{\mathrm{DSP}} = \Delta t_{\mathrm{L}} - \Delta t_{\mathrm{P}} \\ \Delta B_{\mathrm{HW},g} = \Delta b_{\mathrm{L},g} - \Delta b_{\mathrm{P},g} \end{cases}$$

→ *Hardware and observable dependent*

In theory, how do DCPBs relate to different observables?

- DSP induced DCPBs ΔB_{DSP}
  - is constant for all observables (wide-lane, narrow-lane, etc.)
- Hardware induced DCPBs $\Delta B_{\mathrm{HW},g}$
  - is however observable dependent
- In fact, we have for ionosphere-free and wide-lane DCBPs that

$$\Delta B_{\mathrm{IF}} = 2.53125\Delta B_1 - 1.53125\Delta B_2$$

$$\Delta B_{\mathrm{w}} = 4.5\Delta B_1 - 3.5\Delta B_2$$

- Clearly, if

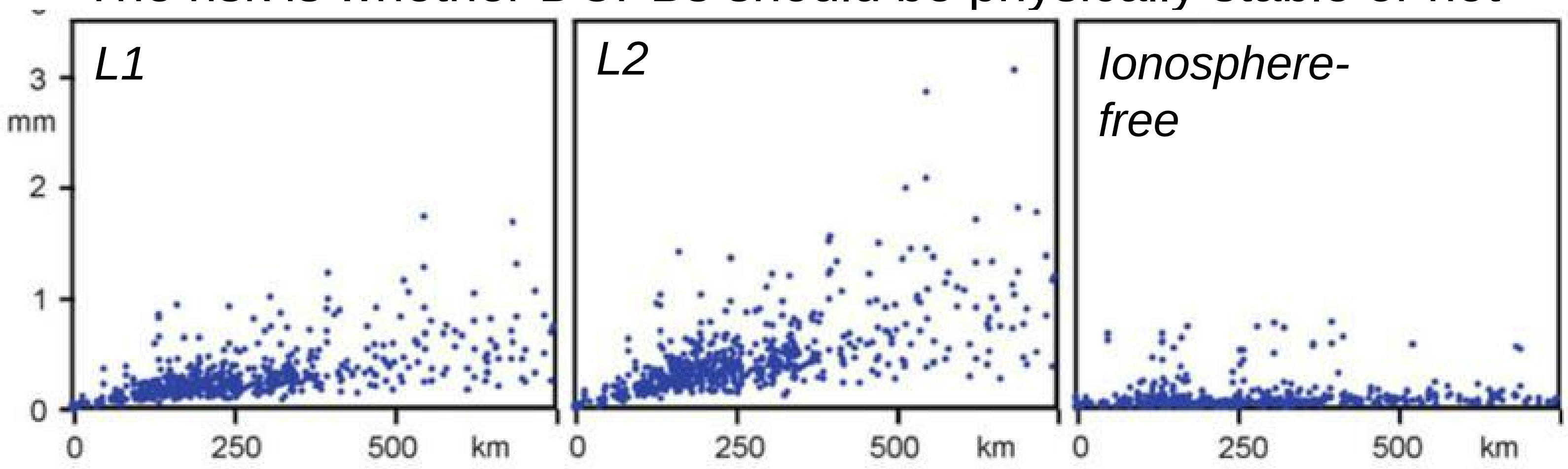
$$\Delta B_1 = \Delta B_2$$

$$\Delta B_1 = \Delta B_2 = \Delta B_{\mathrm{IF}} = \Delta B_{\mathrm{w}}$$

Is this true?

$\Delta B_{\mathrm{HW},g}$ matters or not, subject to uncertainties of DCPBs

- How to estimate DCPBs
  - use wide-lane and narrow-lane ambiguity fixing,
  - but wide-lane fixing can be difficult over baselines of 1000+ km because
    - Melbourne-Wübbena combination doesn't work and
    - no precise ionosphere data for wide areas can be used
- Repeatabilities of DCPBs over a long period
  - The risk is whether DCPBs should be physically stable or not



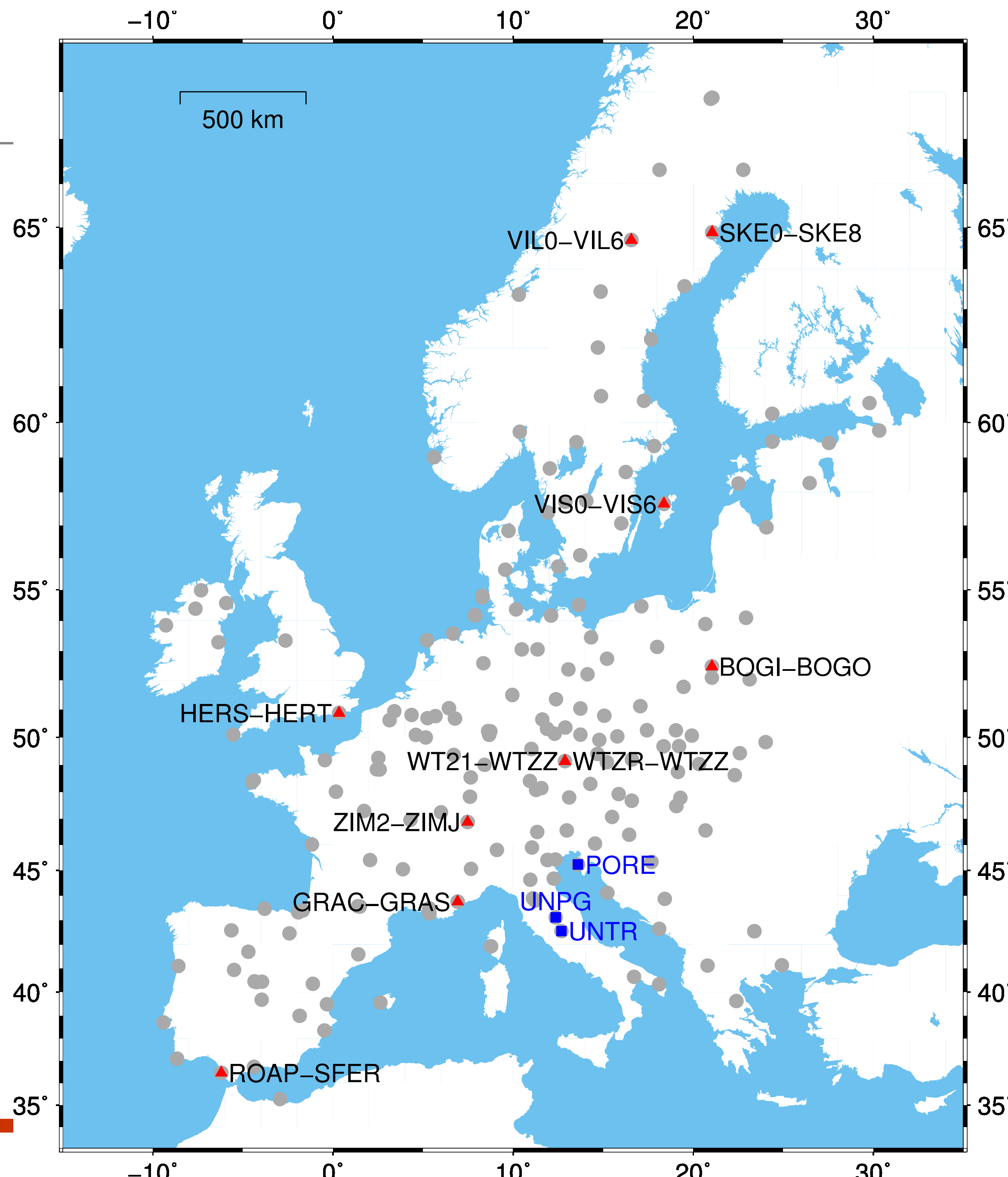
Wanninger Journal of Geodesy 2012

How to estimate DCPBs for a huge network

- An efficient method for huge networks (Banville 2016; Liu et al. 2016)
  - can be applied to a broad/global network of stations
  - use only ionosphere-free ambiguity fixing,
  - though its wavelength is only ~5.3 cm which
    - isn't a big problem on account of the quality of IGS final orbit products
  - Note that only ionosphere-free DCPBs can be estimated
- We compare these DCPB estimates with those from ultra-short baseline solutions
  - DCPBs from ultra-short baseline solutions are easily achievable and presumed as benchmarks
  - We can take this to assess the accuracy of DCPBs

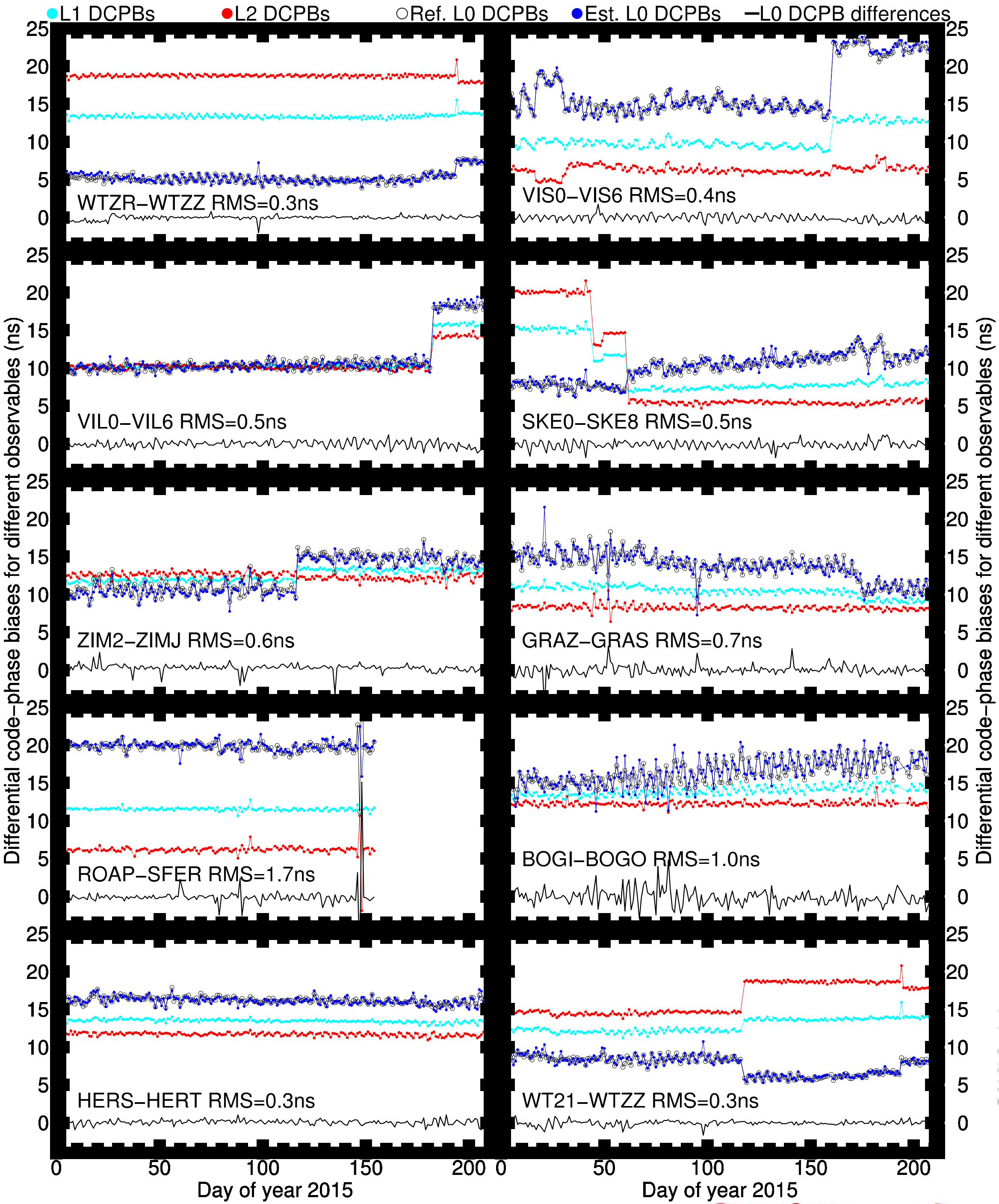
Data and processing

- 212 days of data in 2015
- 200 stations involved
  - DCPBs for ionosphere-free observables are estimated in a network solution
- 10 ultra-short baselines (<210m) across Europe
  - DCPBs on L1 and L2 are directly estimated



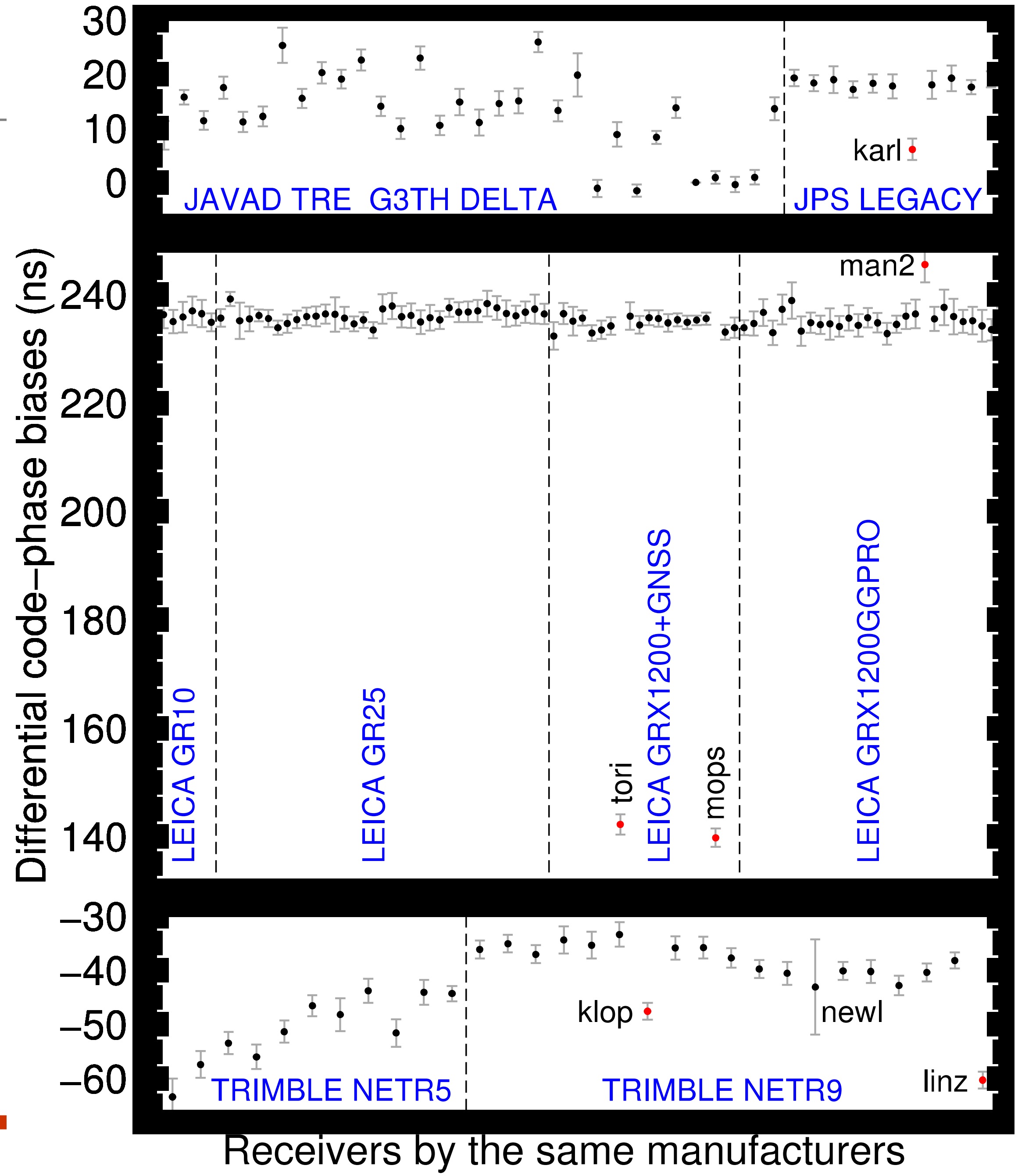
Uncertainties of DCPBs

- 0.7 ns (RMS) for ionosphere-free DCPBs against L1/L2 DCPBs
- L1/L2 DCPBs can be quite different
  - DCPBs are actually observable dependent
- DCPBs vary with time which can be significant
  - Repeatabilities will then be problematic to quantify DCPB precisions



DCPBs specific to receiver types or stations?

- DCPBs can be quite different among the same types of receivers by up to 30 ns
  - These differences are statistically significant
  - The differences are subject to not only receiver types, but also antennas, domes, firmware, etc.



How will the "30 ns" affect ambiguity resolution?

- Biases on ambiguities in cycles due to DCB ΔB_g

$$\xi_g = \Delta B_g \left(h^i - h^j\right) \Delta f_q$$

Frequency spacing (for Δf_q)

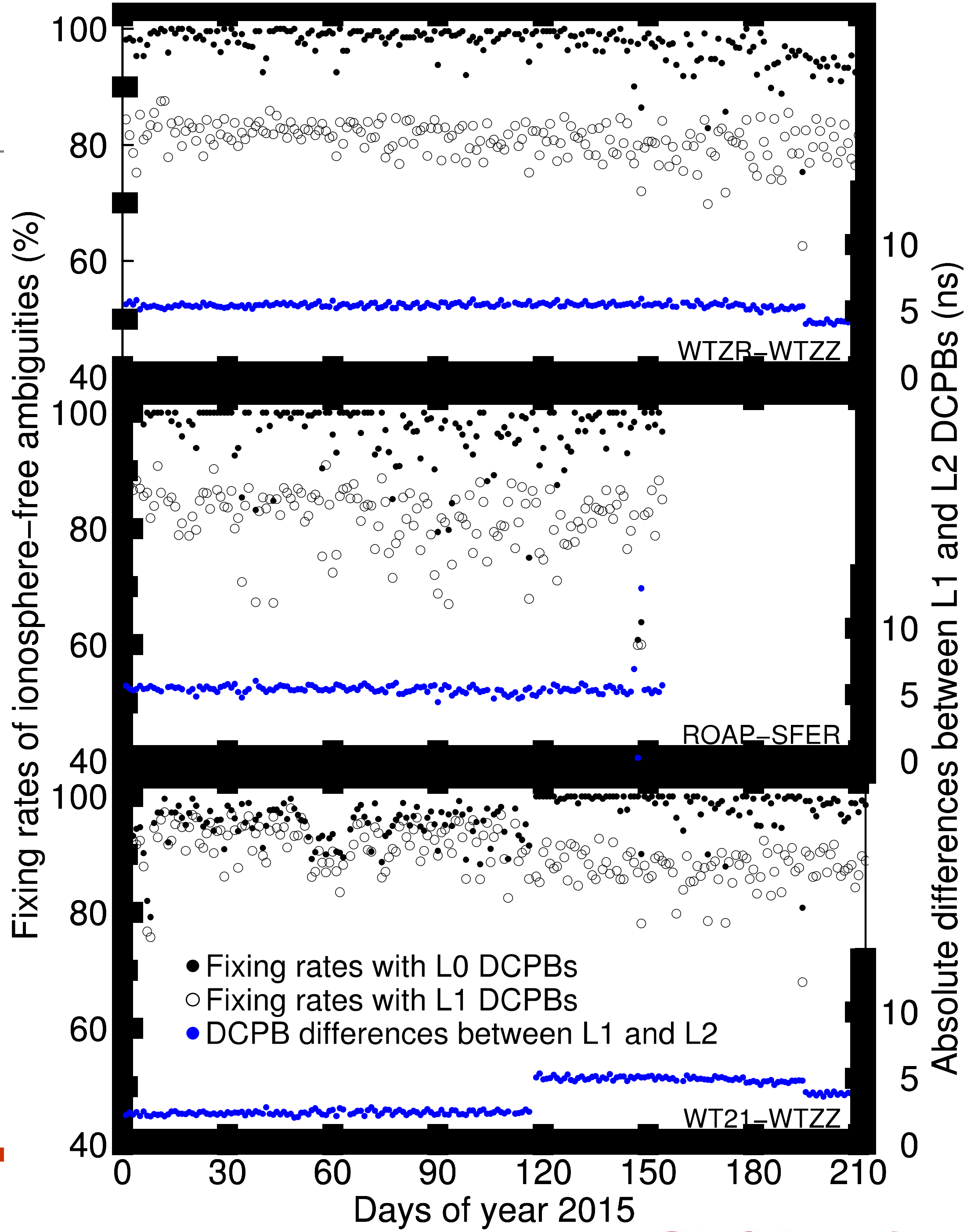
Channel number difference (at most 13) (for $h^i - h^j$)

$$\begin{cases} \xi_1 \rightarrow 0.22 \text{ cycle} \\ \xi_2 \rightarrow 0.17 \text{ cycle} \\ \xi_{\mathrm{w}} \rightarrow 0.05 \text{ cycle} \\ \xi_{\mathrm{n}} \rightarrow 0.39 \text{ cycle} \\ \xi_{\mathrm{en}} \rightarrow 0.78 \text{ cycle} \end{cases}$$

Wide-lane is little affected while ionosphere-free is most

Which observable specific DCPBs to provide for users?

- DCPBs on L1 and L2 signals can differ by up to 10 ns
  - What if we use L1 DCPBs for ionosphere-free ambiguity resolution?
- Ionosphere-free DCPBs are preferred
  - High efficiency to compute
  - L1, L2 and wide-lane are more resistant to DCPB errors



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Implications to IGS Bias-SINEX products

- DCPBs of sub-ns accuracy can be achieved over a large network by efficiently resolving ionosphere-free ambiguities;
- DCPBs should be estimated and applied on account of their station and observable specific properties, especially for ambiguities of short wavelengths.
  - DCPBs can differ significantly by up to 30 ns for the same types of receivers
  - Provide both L1 and L2 DCPBs if possible, otherwise ionosphere-free DCPBs are preferred. Their difference can be up to 10 ns
- More details and interesting aspects refer to
  - Geng et al. (2017) A review on the inter-frequency biases of GLONASS carrier-phase data. Journal of Geodesy

Thanks for your attention

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