Phase bias product and open-source software for undifferenced ambiguity resolution at Wuhan University

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Wuhan China

GNSS biases and IGS Bias-SINEX file

- Code biases across GNSS systems, frequencies and observables.
  - Align pseudorange to obey IGS "conventions";
  - Resolve Melbourne-Wübbena ambiguities.
- IGS has been standardizing bias products since 2012 (Schaer 2018)
  - to address flourishing observables due to multi-GNSS;
  - to formulate IGS conventions on bias products.
- However, phase biases are seldom discussed.

SINEX_BIAS—Solution (Software/technique) INdependent EXchange Format for GNSS Biases Version 1.00

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June 29, 2011 (Draft Version 0.01)
December 7, 2016 (Finalized Version 1.00)
October 3, 2018

```
+BIAS/DESCRIPTION
*KEYWORD                                  VALUE (S)
 OBSERVATION_SAMPLING                          300
 PARAMETER_SPACING                           86400
 DETERMINATION_METHOD                    INTER-FREQUENCY_BIAS_ESTIMATION
 BIAS_MODE                               ABSOLUTE
 TIME_SYSTEM                             G
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES   G  C1W  C2W
 SATELLITE_CLOCK_REFERENCE_OBSERVABLES   R  C1P  C2P
-BIAS/DESCRIPTION
*-------------------------------------------------------------------------------
+BIAS/SOLUTION
*BIAS SVN_ PRN STATION__ OBS1 OBS2 BIAS_START____ BIAS_END_____ UNIT __ESTIMATED_VALUE____ _STD_DEV___
 OSB  G063 G01           C1C       2017:001:00000 2017:002:00000 ns              10.7141      0.0000
 OSB  G063 G01           C1W       2017:001:00000 2017:002:00000 ns              11.8171      0.0000
 OSB  G063 G01           C2C       2017:001:00000 2017:002:00000 ns              18.3161      0.0000
 OSB  G063 G01           C2W       2017:001:00000 2017:002:00000 ns              19.4621      0.0000
 OSB  G061 G02           C1C       2017:001:00000 2017:002:00000 ns             -12.5893      0.0000
 OSB  G061 G02           C1W       2017:001:00000 2017:002:00000 ns             -13.9193      0.0000
 OSB  G061 G02           C2W       2017:001:00000 2017:002:00000 ns             -22.9243      0.0000
 OSB  G069 G03           C1C       2017:001:00000 2017:002:00000 ns               5.6814      0.0000
 OSB  G069 G03           C1W       2017:001:00000 2017:002:00000 ns               7.2464      0.0000
 OSB  G069 G03           C2C       2017:001:00000 2017:002:00000 ns              12.2914      0.0000
 OSB  G069 G03           C2W       2017:001:00000 2017:002:00000 ns              11.9344      0.0000
 OSB  G034 G04           C1C       2017:001:00000 2017:002:00000 ns               0.3623      0.0000
 OSB  G034 G04           C1W       2017:001:00000 2017:002:00000 ns               0.7543      0.0000
 OSB  G034 G04           C2W       2017:001:00000 2017:002:00000 ns               1.2423      0.0000
 OSB  G050 G05           C1C       2017:001:00000 2017:002:00000 ns              -5.4140      0.0000
 OSB  G050 G05           C1W       2017:001:00000 2017:002:00000 ns              -4.2770      0.0000
 OSB  G050 G05           C2C       2017:001:00000 2017:002:00000 ns              -6.6360      0.0000
 OSB  G050 G05           C2W       2017:001:00000 2017:002:00000 ns              -7.0440      0.0000
 OSB  G067 G06           C1C       2017:001:00000 2017:002:00000 ns               8.3530      0.0000
 OSB  G067 G06           C1W       2017:001:00000 2017:002:00000 ns              10.0410      0.0000
```


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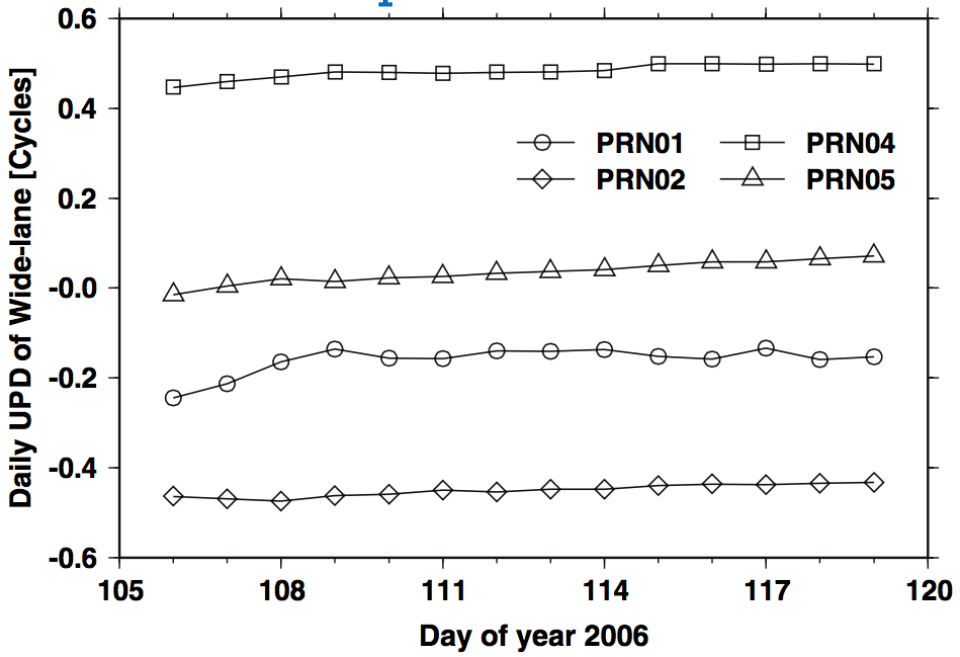
Phase biases

- Phase biases are relevant
  - not only in ambiguity resolution,
  - but also in highly accurate positions.
- Uncalibrated phase delays/fractional-cycle biases (UPD/FCB)
  - Satellite specific
  - for undifferenced ambiguity resolution.
- Code-phase biases (CPB) for GLONASS (Sleewaegen et al. 2012; Geng et al. 2017)
  - Station specific
  - for double-difference/undifferenced ambiguity resolution
  - See the poster by Pan et al. (PS06-04).
- Inter-system phase biases (ISPB) (Odijk et al. 2013; Geng et al. 2017)
  - Station specific
  - for double-difference/undifferenced ambiguity resolution.
- We focus on UPD/FCB, or simply phase bias for brevity, in this presentation.

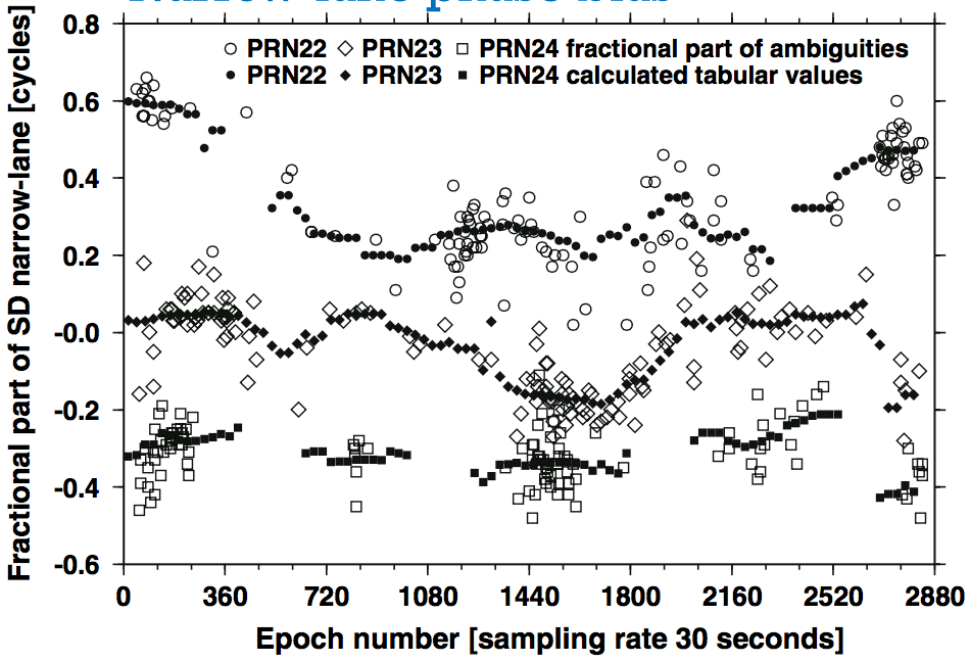
Problems with phase biases (UPDs/FCBs)

- Phase biases are not always stable over time.
  - Wide-lane phase biases are quite stable over days or even months;
  - But narrow-lane phase biases have significant subdaily signatures.
- In 2006, daily wide-lane and 15-min narrow-lane phase biases (Ge et al. 2006).

Wide-lane phase bias



Narrow-lane phase bias



Can we make phase biases always stable?

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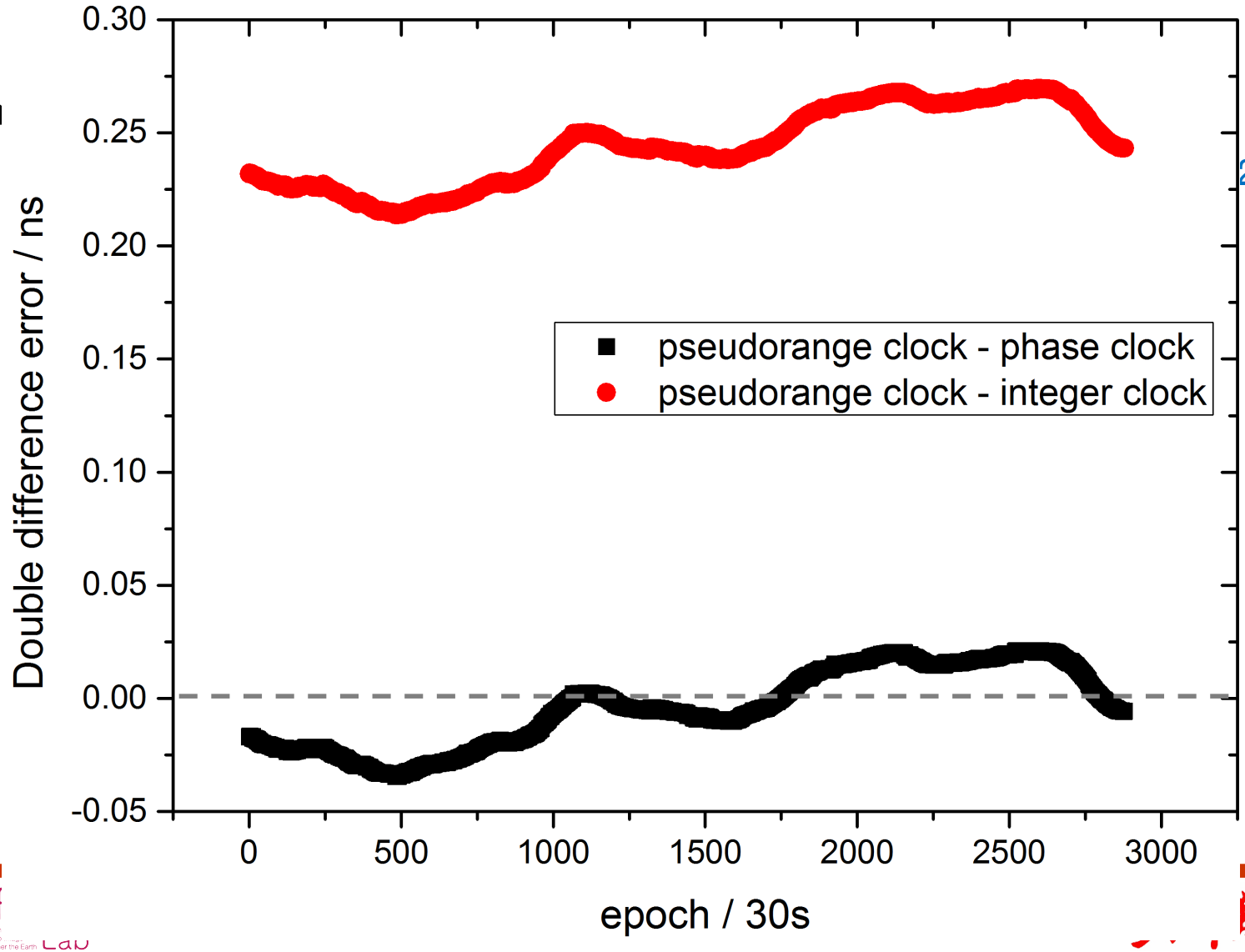
Solutions: "Better" clocks?

However, integer clocks are not compatible with legacy IGS code biases!

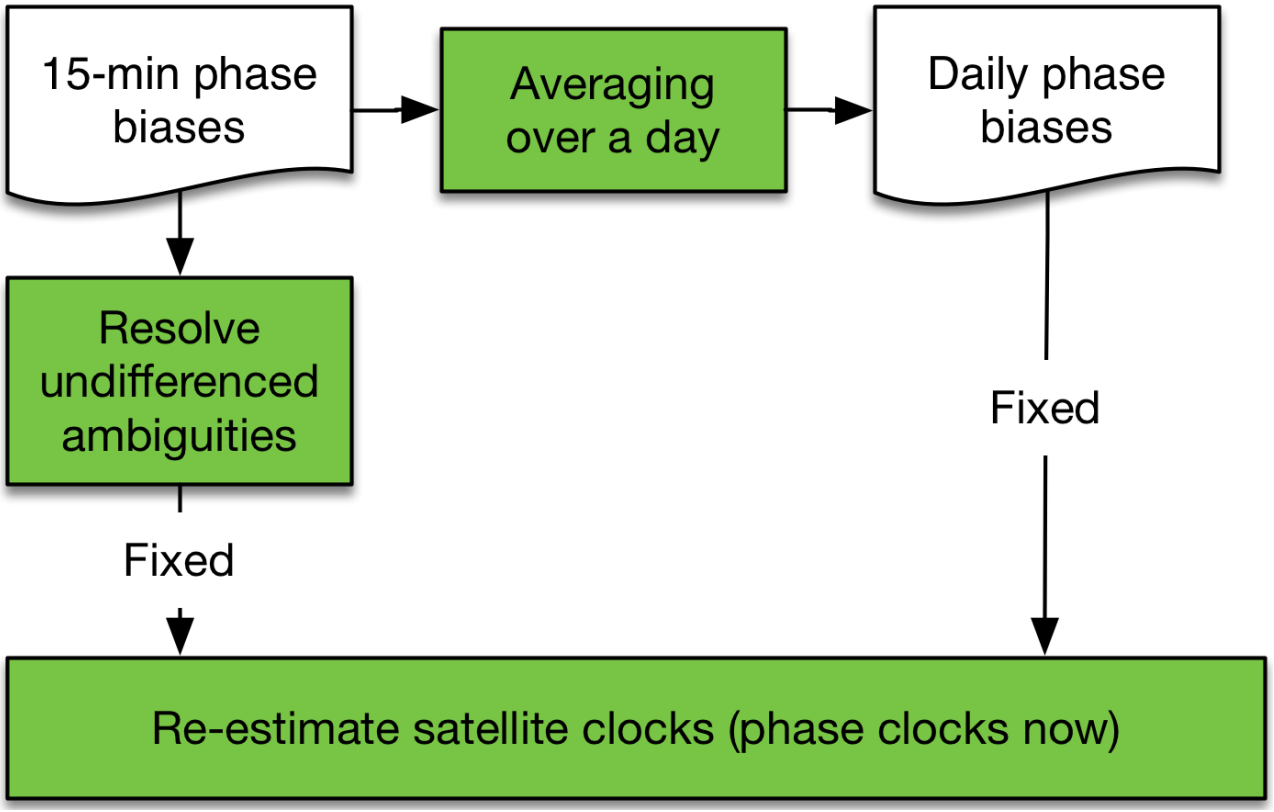
- Because legacy IGS clocks are aligned to pseudorange
- Wh

2010).



New phase bias & phase clock products

- We derive
  - stable phase biases (daily, instead of 15-min, calculations),
  - phase clocks (like integer clocks),
  - and compatibility with IGS code biases.



How do the new phase bias & phase clock work?

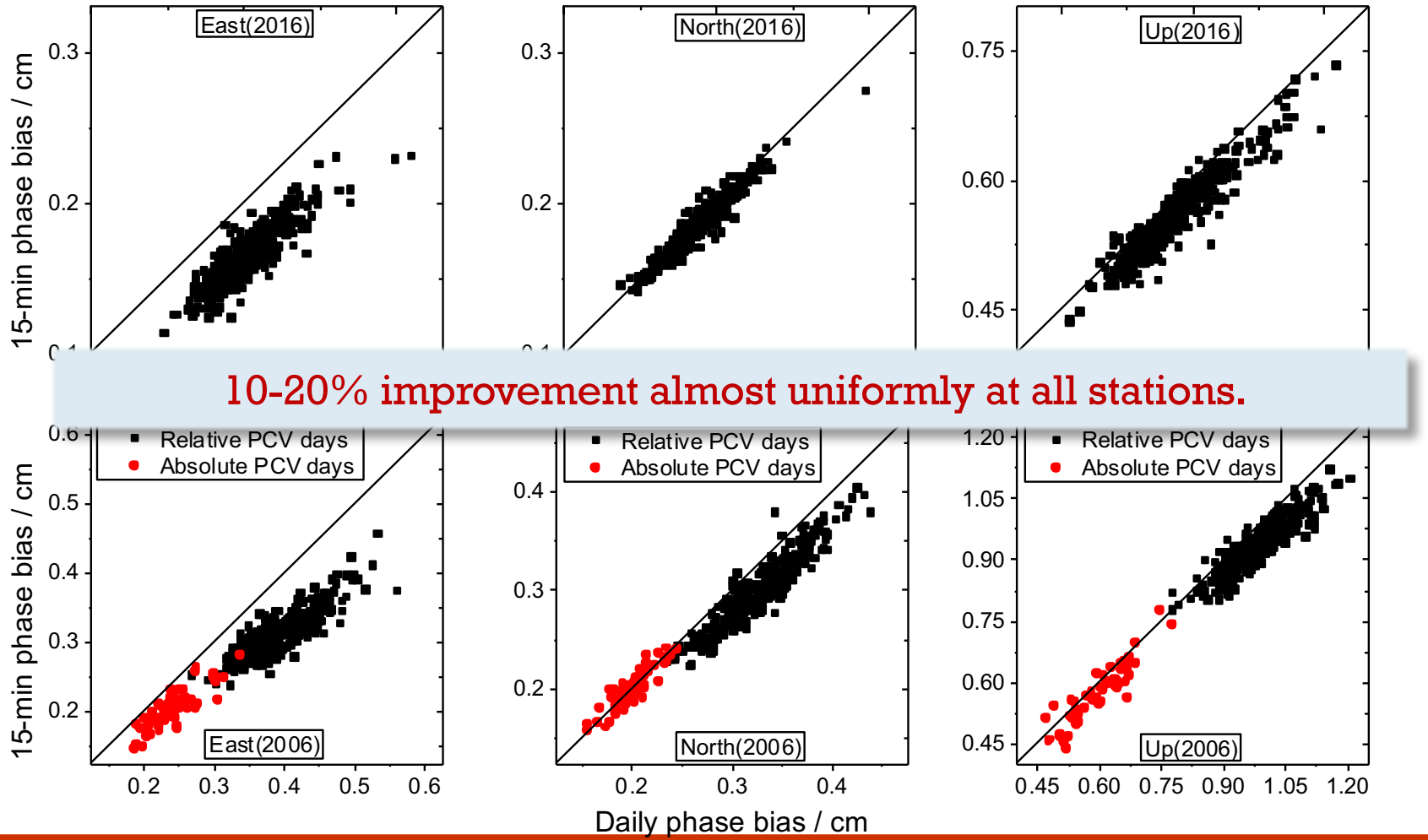
- 180-200 globally distributed stations
- Daily positions in 2006 & 2016 compared to IGS solutions

Solution types		2006 (mm)			2016 (mm)		
		East	North	Up	East	North	Up
Float	IGS clock	3.3	2.1	6.2	3.2	1.9	6.2
	Phase clock	3.3	2.1	6.1	3.2	1.9	6.1
Fixed	15-min phase bias	2.4	2.0	6.0	2.0	1.9	5.8
	Daily phase bias	2.1	2.0	5.8	1.6	1.8	5.6

10-20% improvement after applying daily phase biases and code-compatible phase clocks

How do the new phase bias & phase clock work?

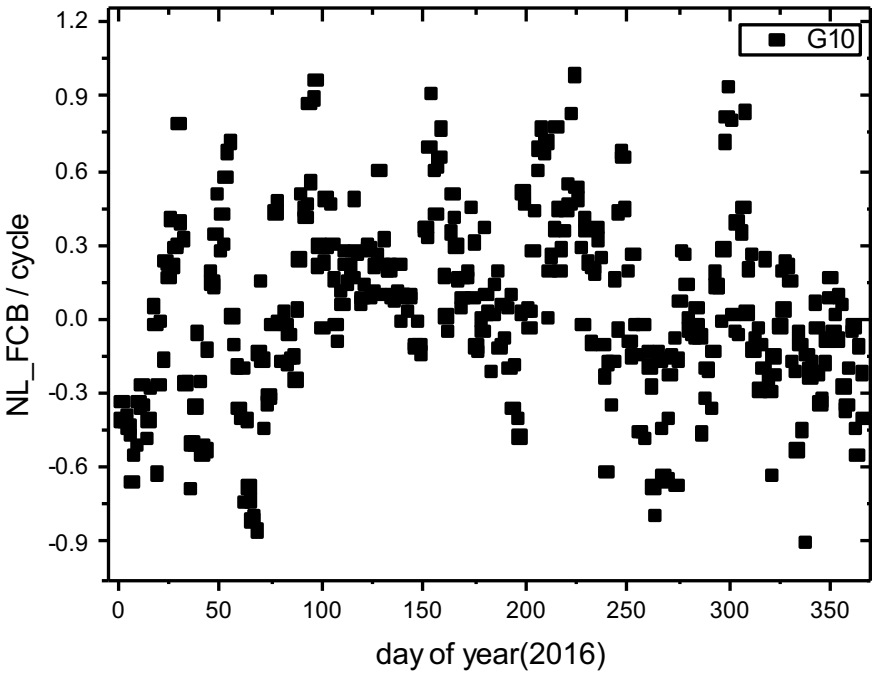
- 180-200 globally distributed stations
- Daily positions in 2006 & 2016 compared to IGS solutions

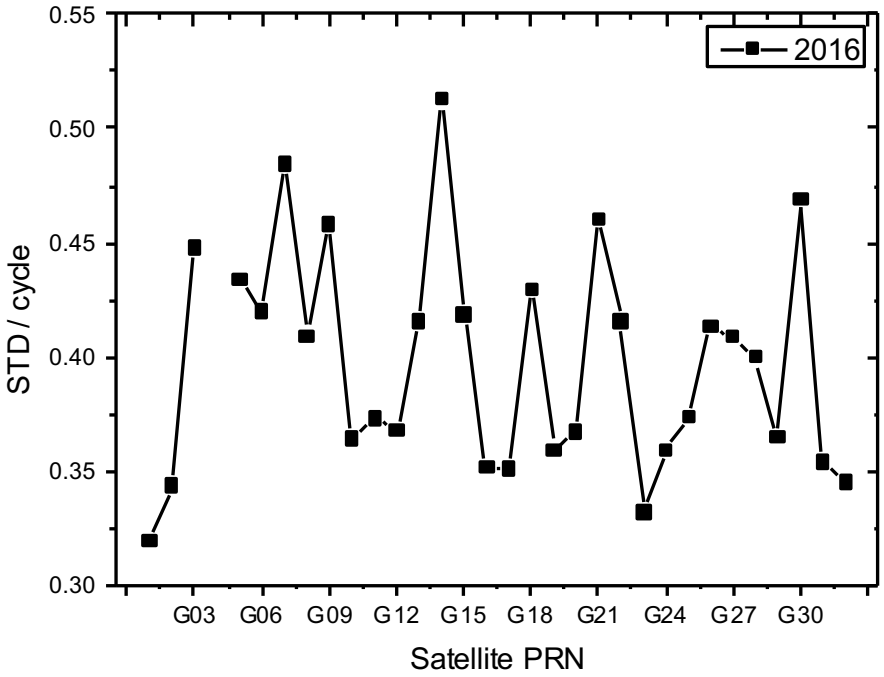


10-20% improvement almost uniformly at all stations.

However, remaining problems with phase biases

- Discontinuity of our phase biases across days (Day-boundary jumps)

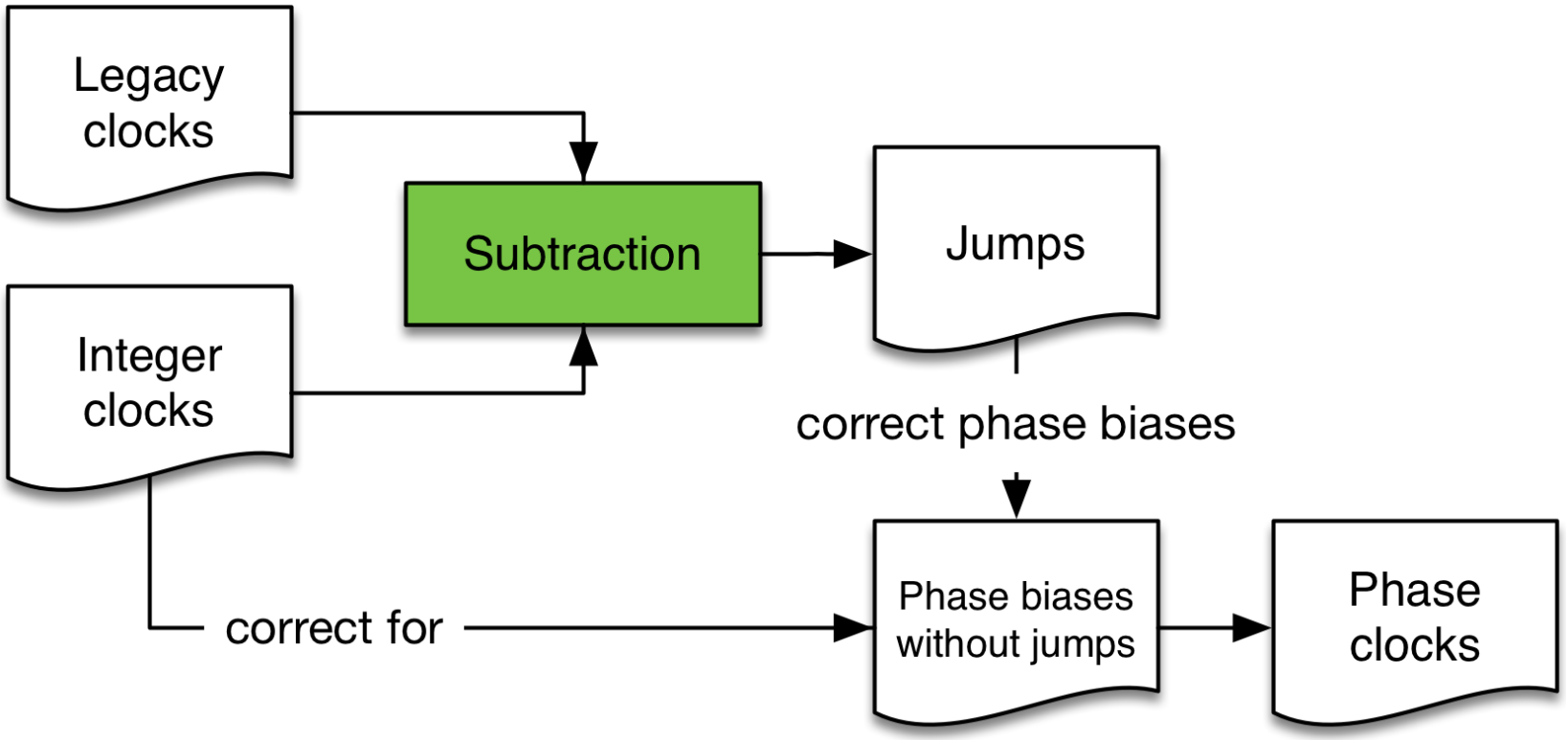




Day-to-day phase bias variations are due to pseudorange again.

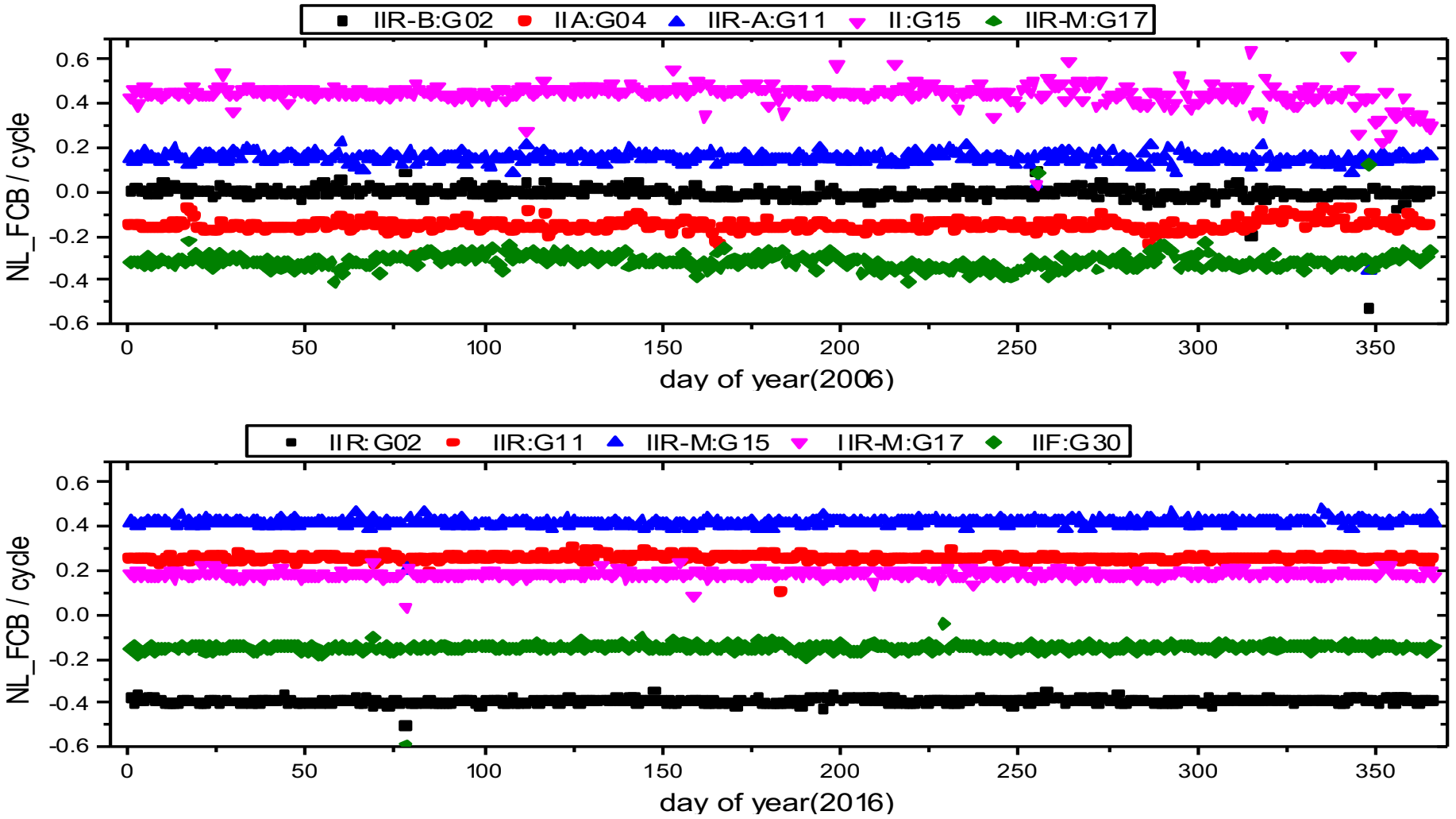
Day-boundary jumps: leveling phase biases

- Calculate the jumps using integer clocks and legacy clocks



How does the leveling work?

- Phase bias products in 2006 & 2016 without day-boundary jumps



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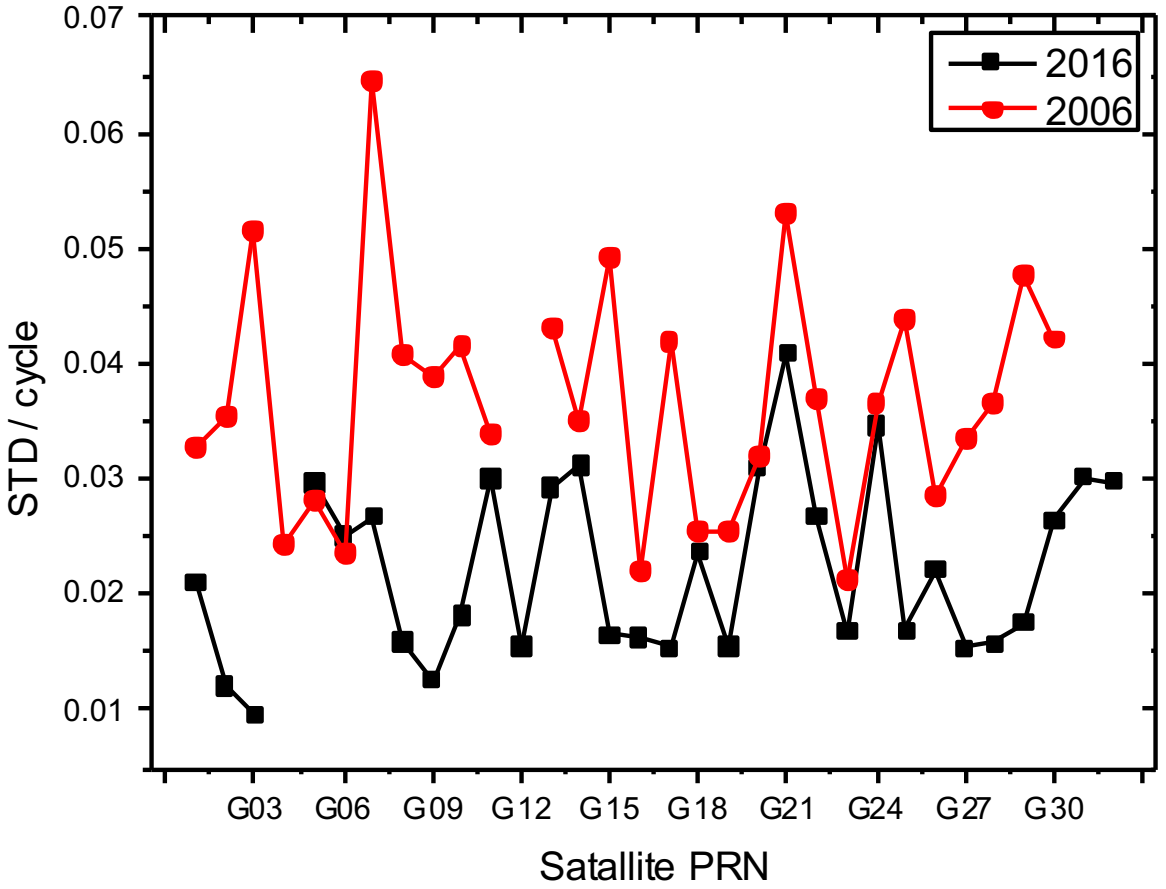
How does the leveling work?

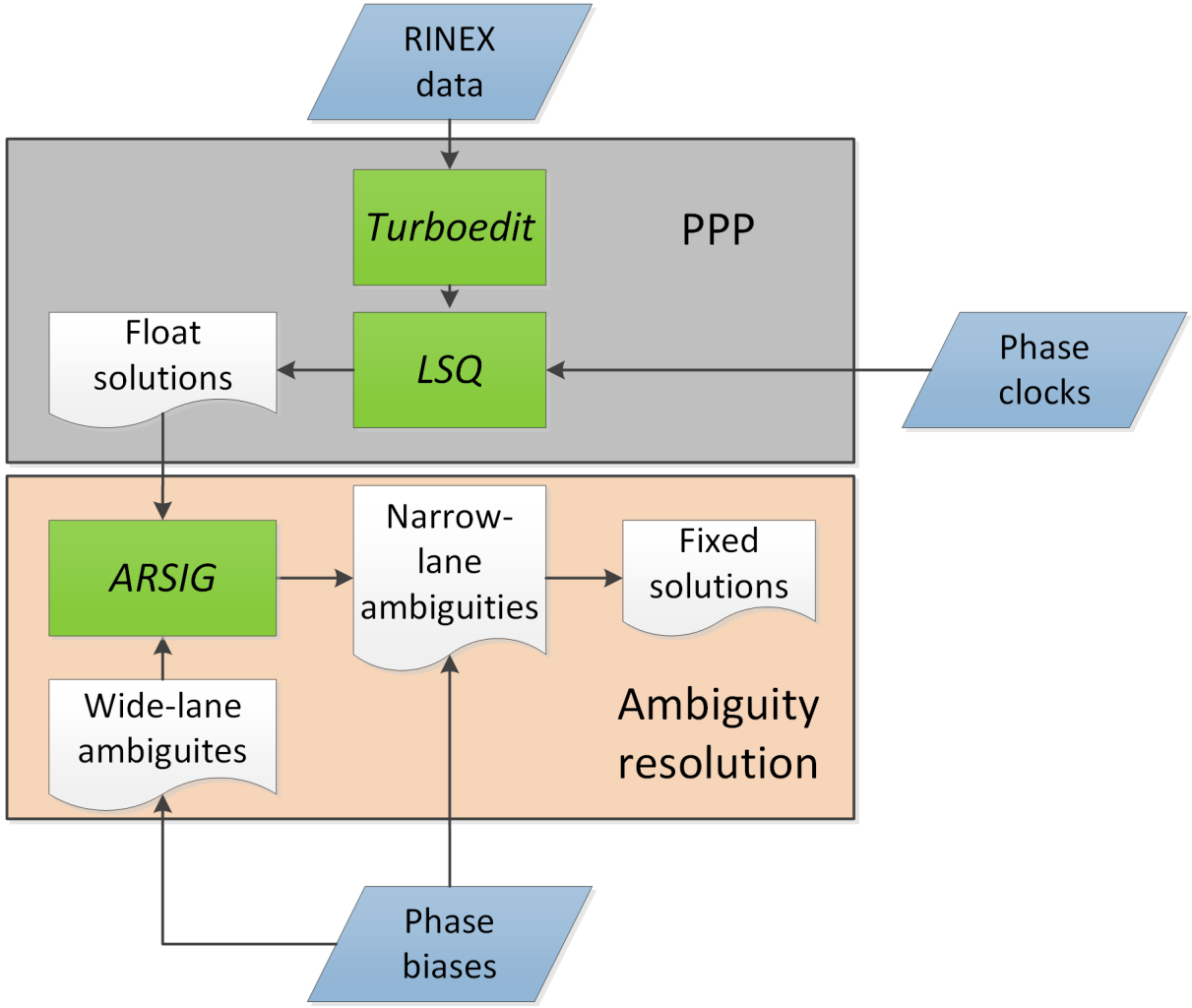
- The yearly STDs of daily phase biases are reduced below 0.1 cycles



The leveling does not impact the positioning performance

Open-source software for undifferenced ambiguity resolution

- Package name: "PRIDE PPP-AR" in Fortran 95



Summary and outlook

- 10-year (2006-2016) GPS phase bias and phase clock products at Wuhan
  - In the form of L1 & L2 biases
  - Under final validation using PRIDE PPP-AR software
  - Preliminary release of products and software before 2019
  - Also include GLONASS DCPBs, BeiDou, Galileo phase bias on the way
  - News on http://pride.whu.edu.cn
- Phase bias products
  - Daily values
  - No day-boundary jumps
- Phase clocks
  - Compatible with IGS code biases
  - Identical performance to "integer clocks"
- Positioning differences from IGS solutions in terms of RMS
  - 1.6mm, 1.8mm and 5.6mm for the east, north and up components
- Remaining questions: how to combine phase products from different ACs?
  - New "PPP-AR WG" for phase biases/phase clocks

Thank you!

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