Ambiguity Resolution in Precise Point Positioning: What Method should we use for Geosciences?

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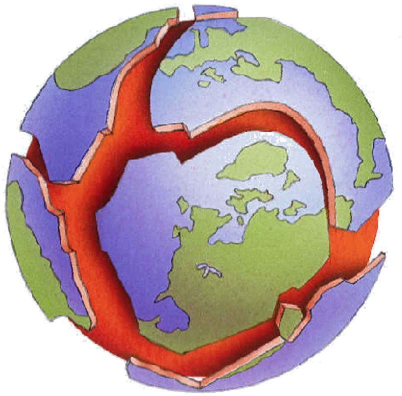
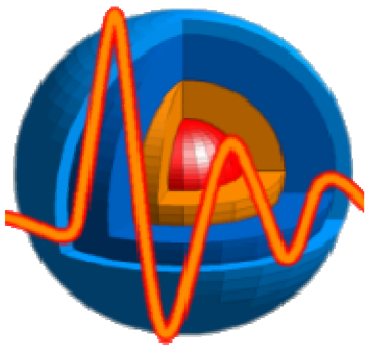
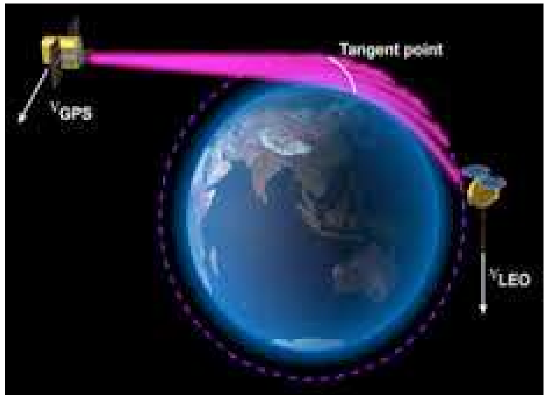
Positioning in the Geosciences

- One of the primary requirements for geoscientific studies is the accurate and precise determination of positions on either the Earth's surface or in space (e.g. LEO):
  - geodynamics, tectonics, seismology, volcanology, meteorology ...

- GNSS (Global Navigation Satellite Systems), in particular GPS, have become the essential tool for the millimetre to centimetre level positioning requirements within the geosciences

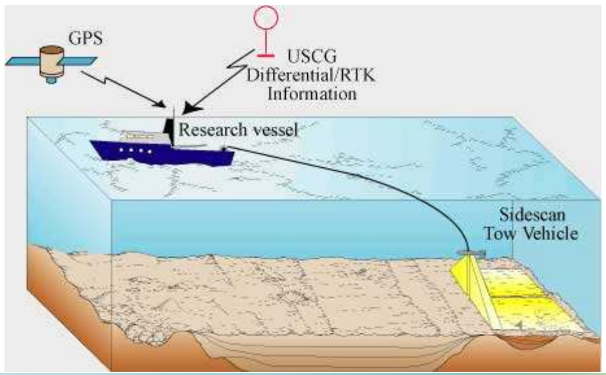


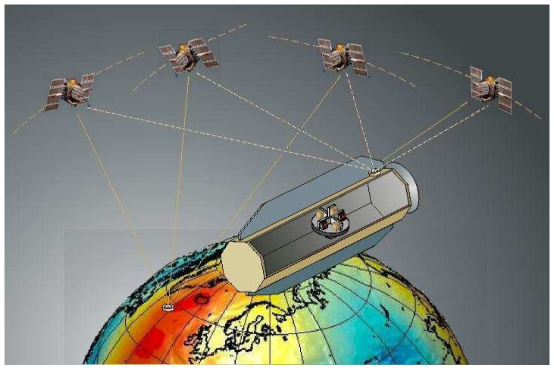




Network-solution strategy for GNSS positioning

- The conventional approach uses networks of GNSS stations for millimetre-level positioning, because until recently integer ambiguity resolution could only be performed between stations, i.e. for baselines
- Typical examples are
  - Double-differenced data processing (e.g. GAMIT/GLOBK and the Bernese GPS Software)
  - Un-differenced data processing, but ambiguity resolution is carried out within a GNSS network (e.g. GIPSY OASIS II (v 5.0 and earlier) and EPOS)
- However, some geoscientific applications require single-station ambiguity resolution to enable precise positioning, e.g. sea-floor geophysics, remote sensing from LEO ...
  - in some areas only few GNSS reference stations are available
  - Long baselines undermine the efficiency of ambiguity resolution





Precise Point Positioning (PPP) with ambiguity resolution

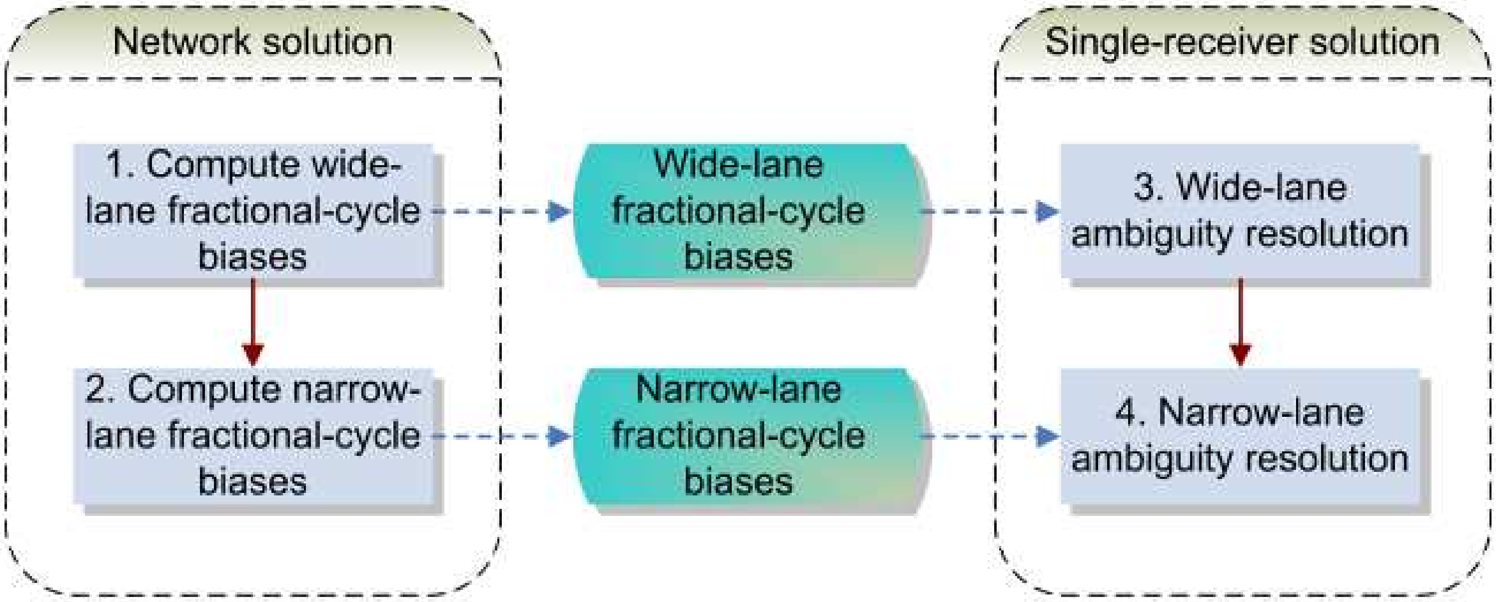
- PPP: precise positioning with only a single GNSS receiver
  - Precise satellite orbits and clocks are necessary
  - Conventionally, for un-differenced observations integer ambiguity resolution was impossible due to satellite and receiver hardware delays
  - This limited the positioning quality of PPP

- Methods for PPP ambiguity resolution
  - Estimate the fractional-cycle biases (FCB) that are common for all involved PPP ambiguity estimates (e.g. Gabor and Nerem 1999; Ge et al. 2008)
  - Estimate integer-recovery clocks (IRC) which absorb the above FCBs (e.g. Laurichesse et al. 2009; Collins et al. 2010)
  - Provide ambiguity estimates derived from a global network solution based on PPP (for GIPSY OASIS 6.0; Bertiger et al. 2010). In essence, double-difference ambiguities are fixed to integers in this method

FCB-based method for PPP ambiguity resolution

- Service providers: estimate satellite-dependent FCBs with un-differenced ambiguity estimates from a GNSS network solution, and deliver FCBs to users

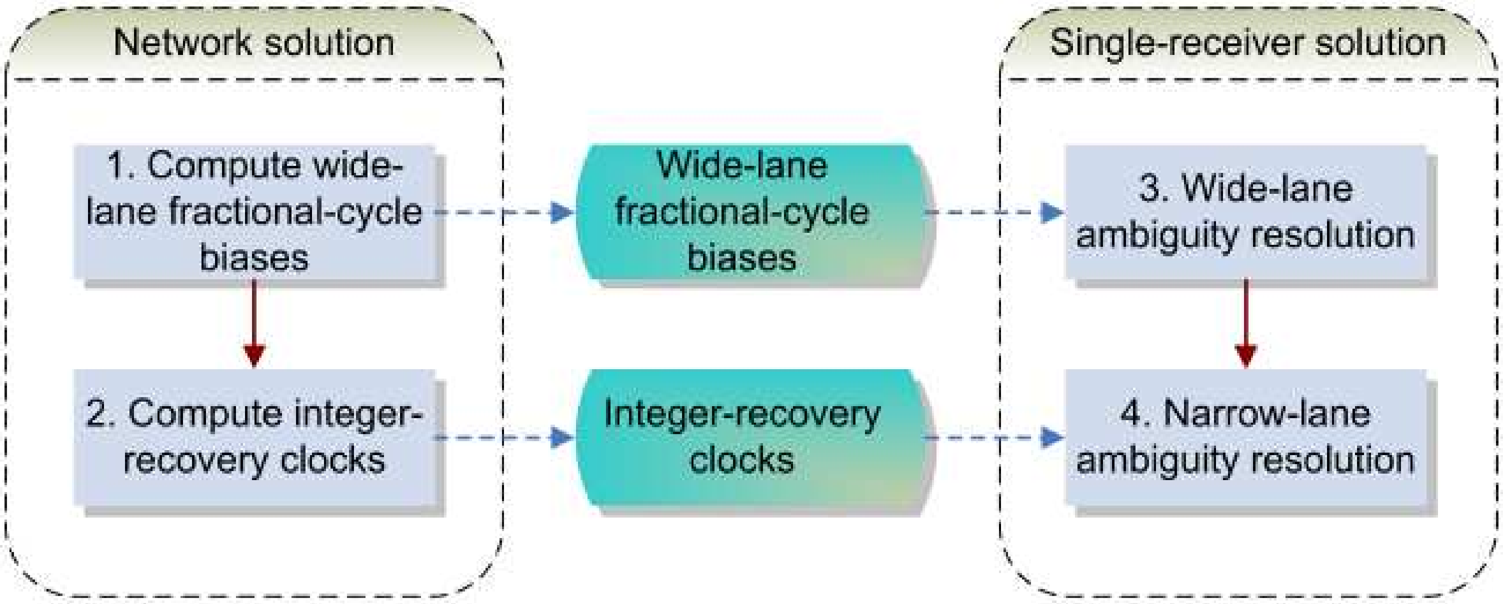
- PPP users: correct un-differenced ambiguity estimates with FCBs, and attempt integer resolution on un-differenced ambiguities



IRC-based method for PPP ambiguity resolution

- Service providers: estimate satellite IRCs by fixing un-differenced ambiguities to integers in advance in a GNSS network solution, and deliver these IRCs to users

- PPP users: apply IRCs, instead of the official clock products by IGS, in PPP data processing, and attempt integer resolution on un-differenced ambiguities



How do these two methods agree and differ?

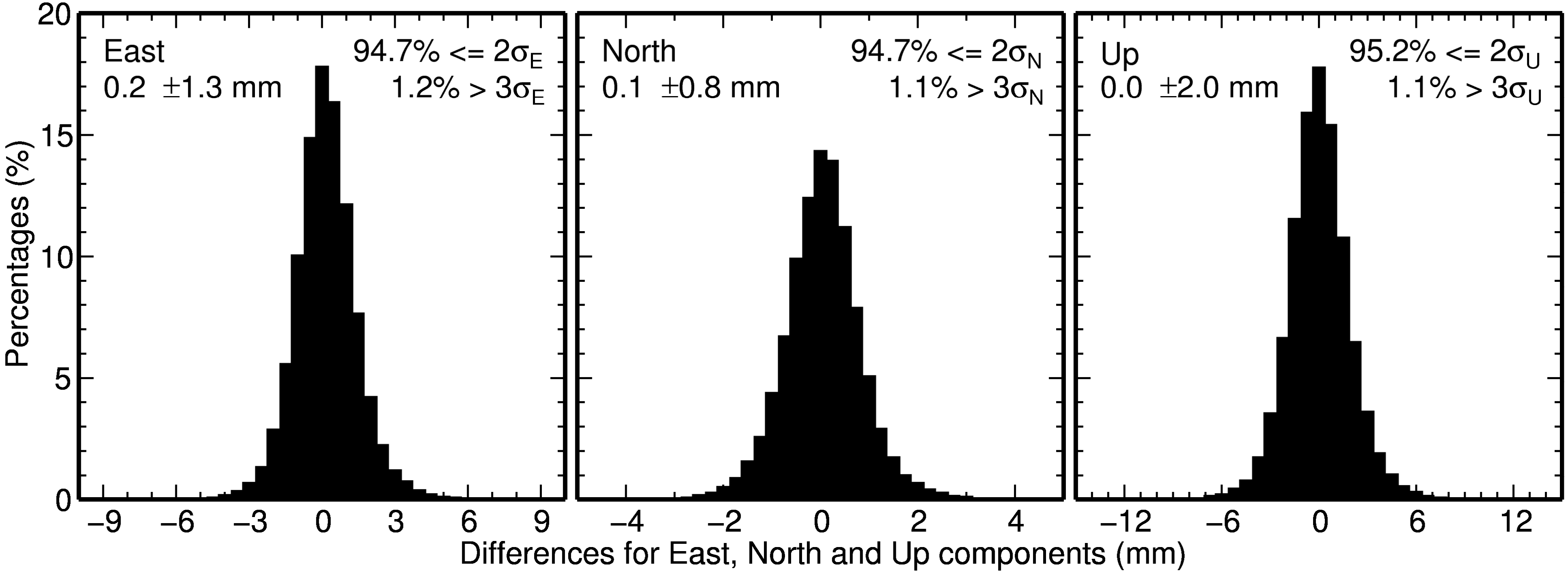
- In theory, the ambiguity-fixed estimates of these two methods are identical (Geng et al. 2010)

- The key difference between the two methods is the separation of the FCBs from the integer ambiguities
  - FCB-based method: average the fractional parts of all involved ambiguity estimates every 15 minutes to estimate FCBs
  - IRC-based method: assimilate the fractional parts of all involved ambiguity estimates to epoch-wise clocks to estimate IRCs

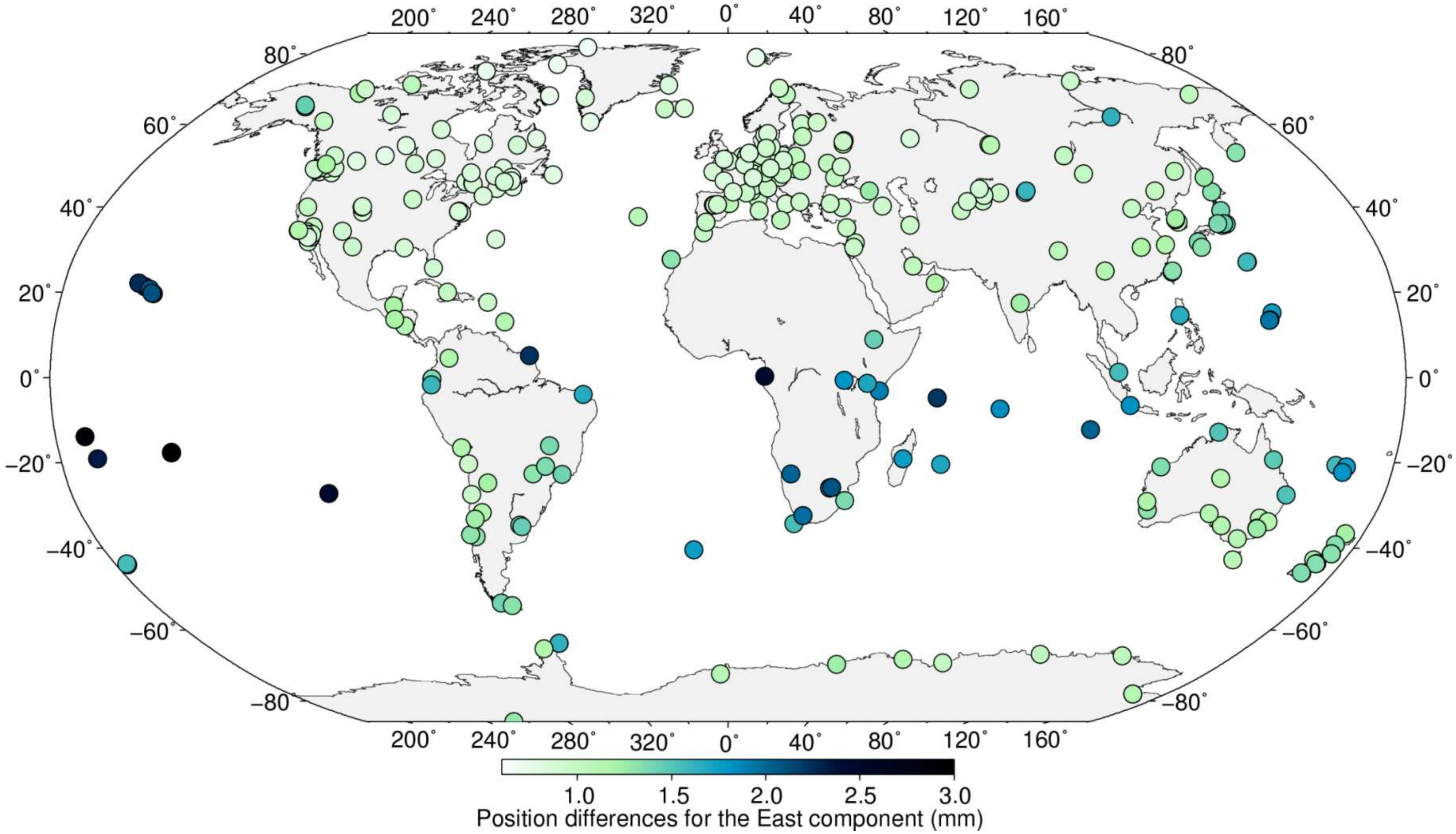
- What is the impact of this difference on the positioning quality which is critical to the geosciences?
- To investigate ambiguity-fixed positions, we use
  - One year (2008) of GPS data from 350 globally-distributed stations
  - CODE satellite orbits
  - Estimate daily positions, hourly zenith troposphere delays and 12-hourly horizontal troposphere gradients

Position differences between the FCB and IRC methods

>100,000 differences	East (mm)	North (mm)	Up (mm)
Bias	0.2	0.1	0.0
Standard deviation	1.3	0.8	2.0
RMS	1.3	0.8	2.0



Position differences for the East component for each station

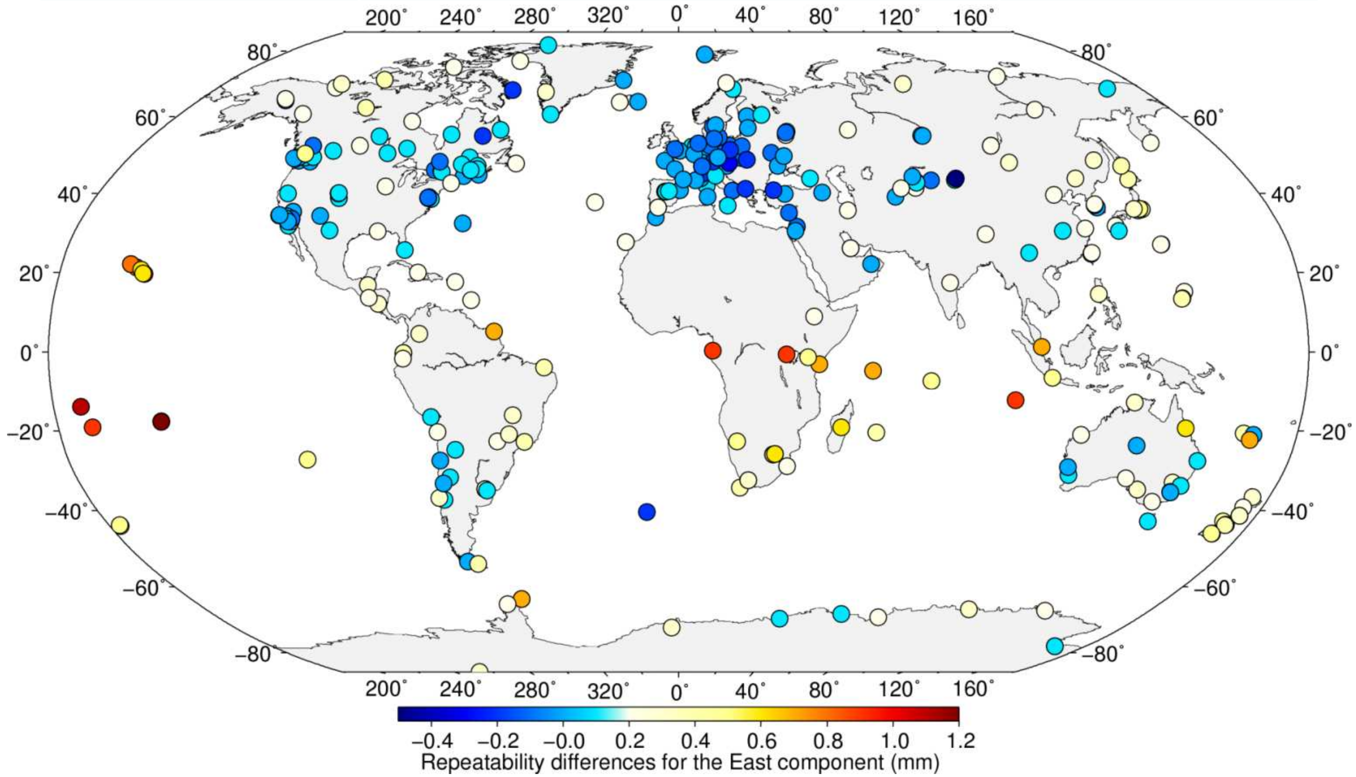


- Small differences are present mainly in Europe and North America (<2mm)
- Large differences are present for sparse networks, e.g. oceanic islands, Africa (>1.5mm)
- Also visible for the North and Up components

Position repeatability differences between FCB and IRC methods for East component

Methods	East (mm)	North (mm)	Up (mm)
FCB-based	2.4	2.2	7.7
IRC-based	2.2	2.3	7.6

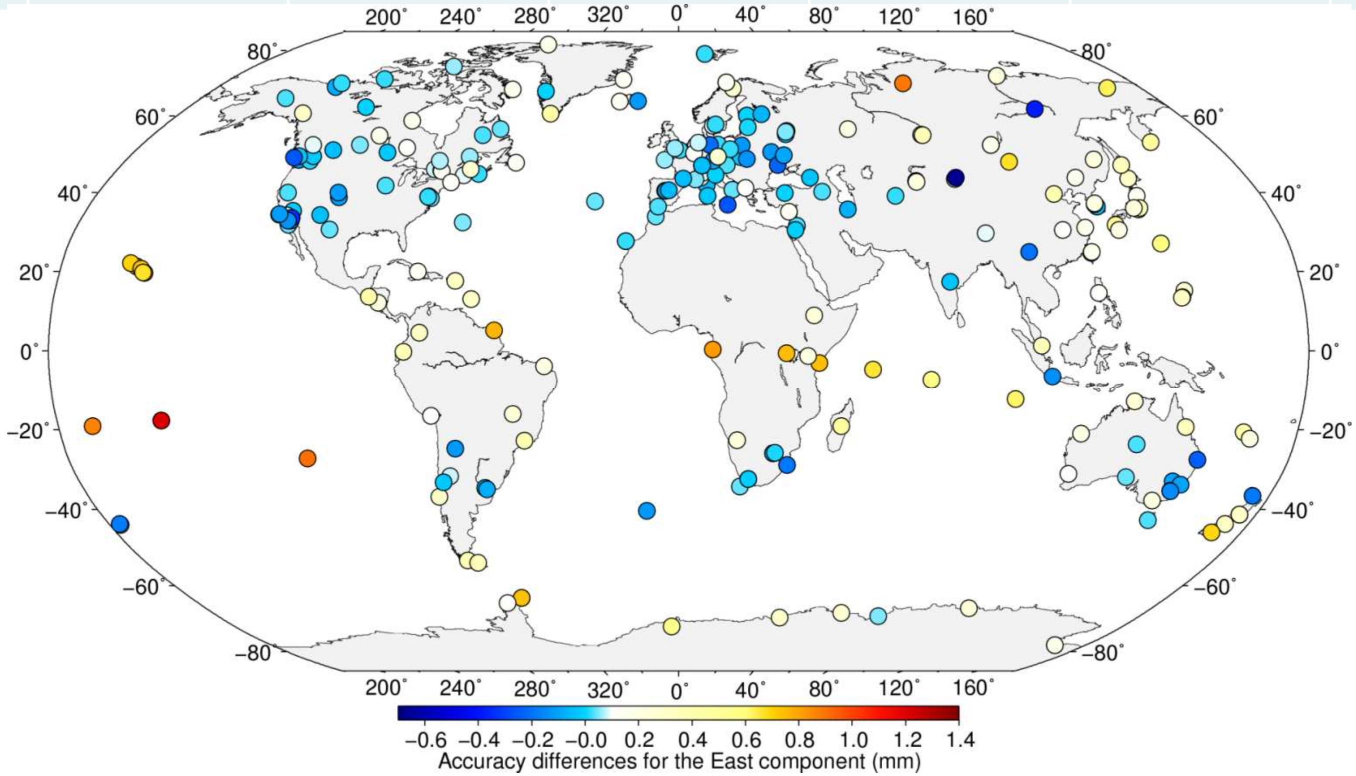
within 0.2mm!



- FCB-based method outperforms IRC-based method over dense networks (<0.5mm)
- IRC-based method even more outperforms FCB-based method over sparse networks (>0.5mm)
- Not visible for the North and Up components

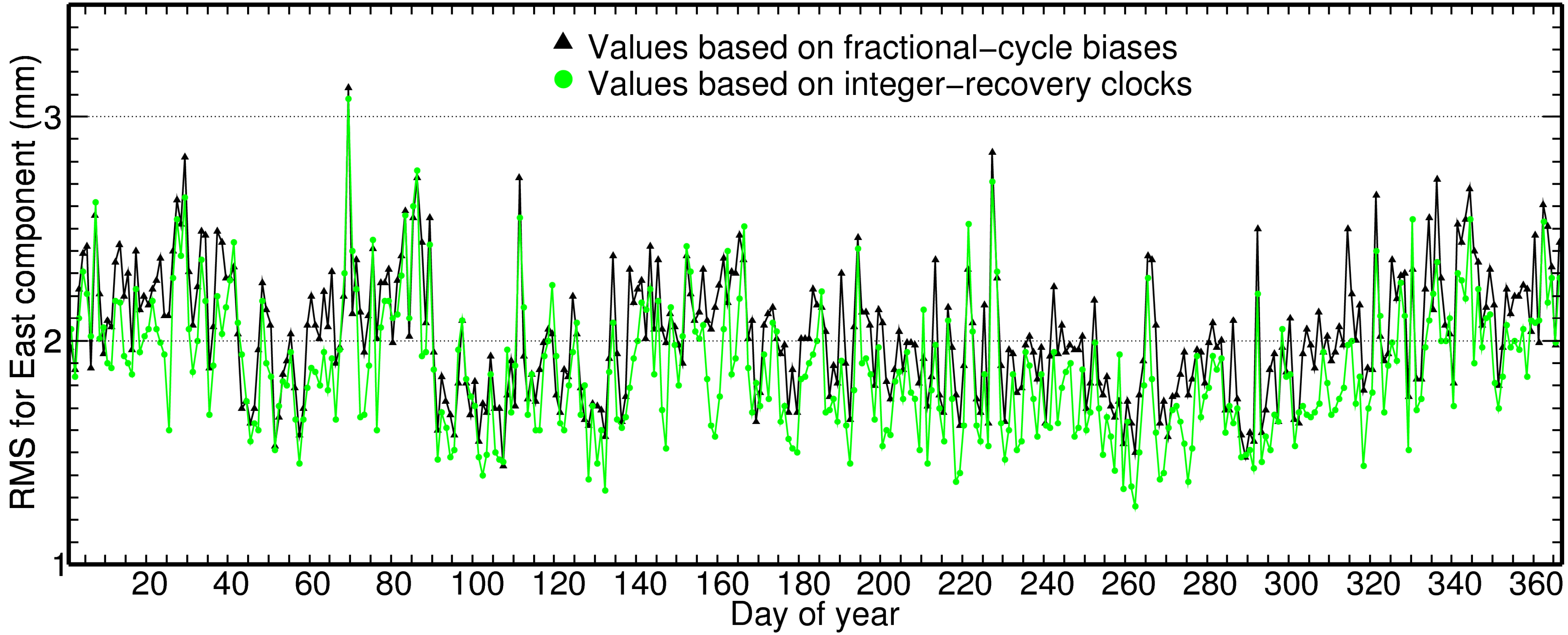
Comparison with IGS weekly solutions: differences in East

	Ambiguity-float solutions (mm)			Ambiguity-fixed solutions (mm)		
	East	North	Up	East	North	Up
FCB-based	3.4	2.2	6.2	2.0	2.1	5.9
IRC-based	3.5	2.3	6.3	1.9	2.1	5.8



- FCB-based method outperforms IRC-based method over dense networks (<0.7mm)
- IRC-based method outperforms even more over sparse networks (up to 1.4mm)
- Not visible for North and Up components

Comparison with IGS weekly solutions: daily RMS of residuals (East)



- For most days in 2008, IRC-based position estimates are closer to IGS weekly solutions than FCB-based ones
- Not visible for the North and Up components, presumably due to their lower correlation with ambiguities

Discussion

- Slightly inferior performance of the FCB-based method may be due to the averaging operation over 15 minutes, rather than every epoch

- Epoch-wise FCBs + IGS clocks = IRCs?
  - In this case, it would not be necessary to separate FCB and clock products in the FCB-based method. They can be combined.
- FCB-based method is compatible with current official clock-generation methods within IGS
  - Users can apply the current IGS clock products + the FCB product

- IRC-based method is not compatible
  - Users apply the IRC clock products
- But IRC-based method can lead to slightly better positioning quality (at the sub-millimetre to millimetre level)

Conclusions

- Millimetre-level positioning errors are critical in contemporary geoscience applications
- For PPP ambiguity resolution, the FCB-based and IRC-based methods agree to within 2 mm for daily position estimates
- Globally, the FCB-based method outperforms the IRC-based method over dense networks of stations by less than 0.5 mm
- IRC-based method can outperform the FCB-based method over sparse networks by over 1 mm
- The FCB-based method may be improved if epoch-wise FCBs are estimated
- The IRC-based method may be more appropriate for the Geosciences

Thanks for your attention!

See “Geng J, Meng X, Dodson AH, Teferle FN (2010) Integer ambiguity resolution in precise point positioning: Method comparison. Journal of Geodesy 84(9):569-581”

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