Ambiguity resolution in precise point positioning (PPP): benefits and challenges from multi-constellation and multi-frequency GNSS signals

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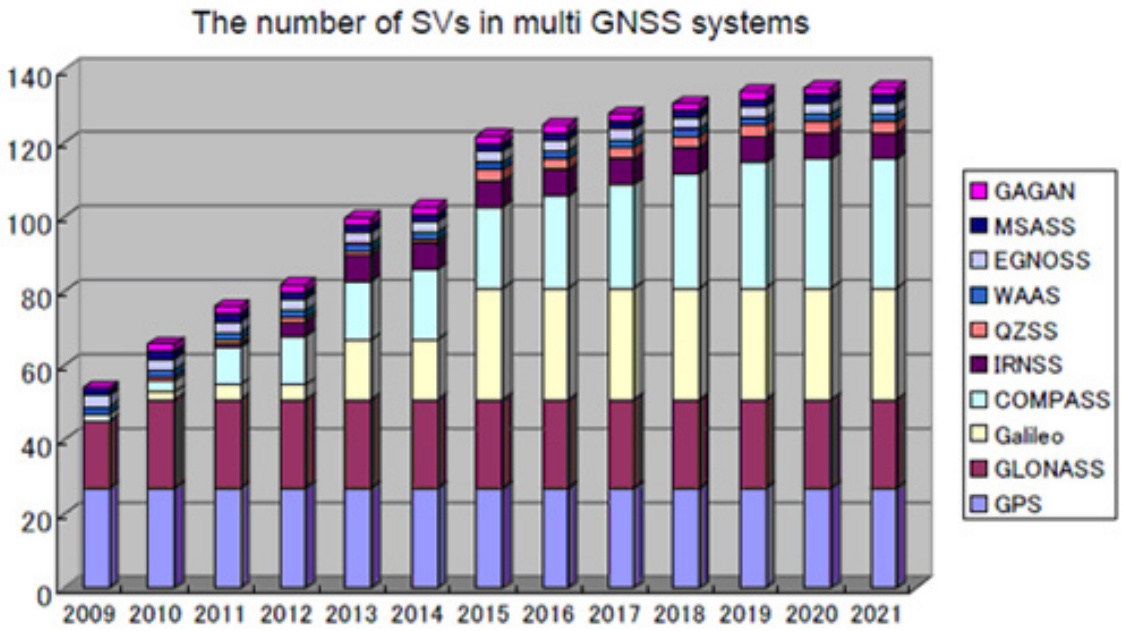
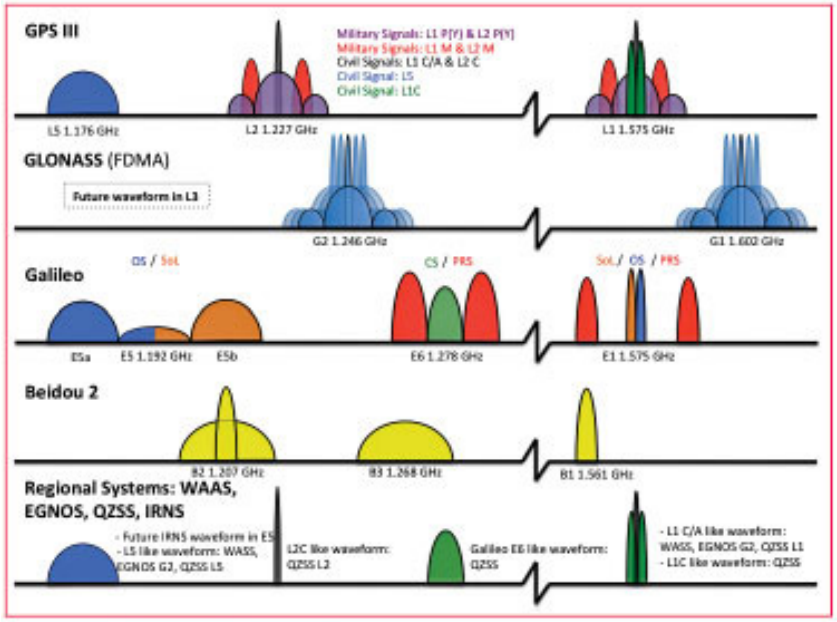
IGS Workshop June 23-27 Pasadena CA USA

GNSS in the next decade …





- What are the benefits and challenges of new signals to PPP?
- How do we use them exploit the benefits and resolve the challenges of the new signals?

Long bedeviling problems in dual-frequency PPP …

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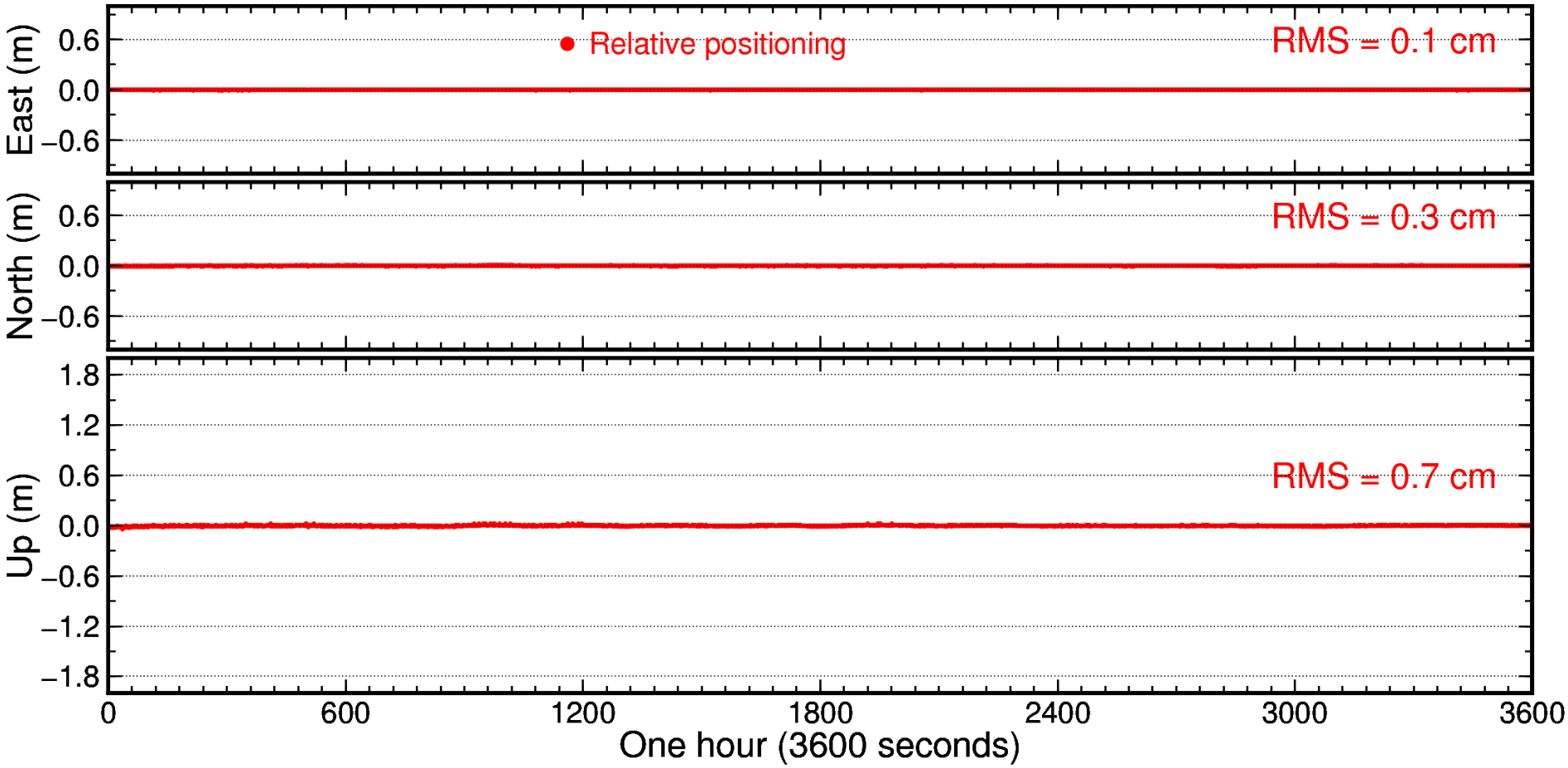

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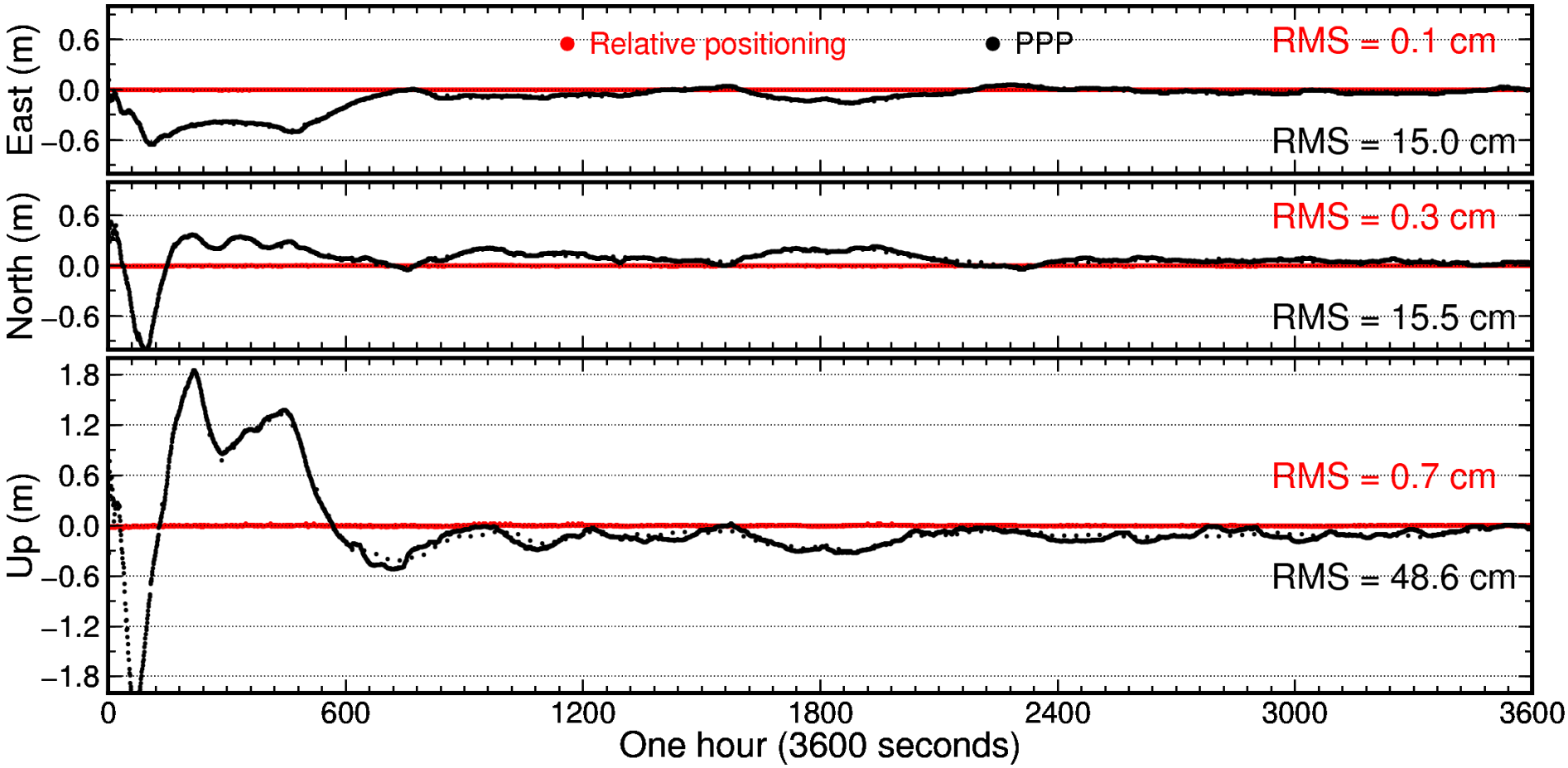

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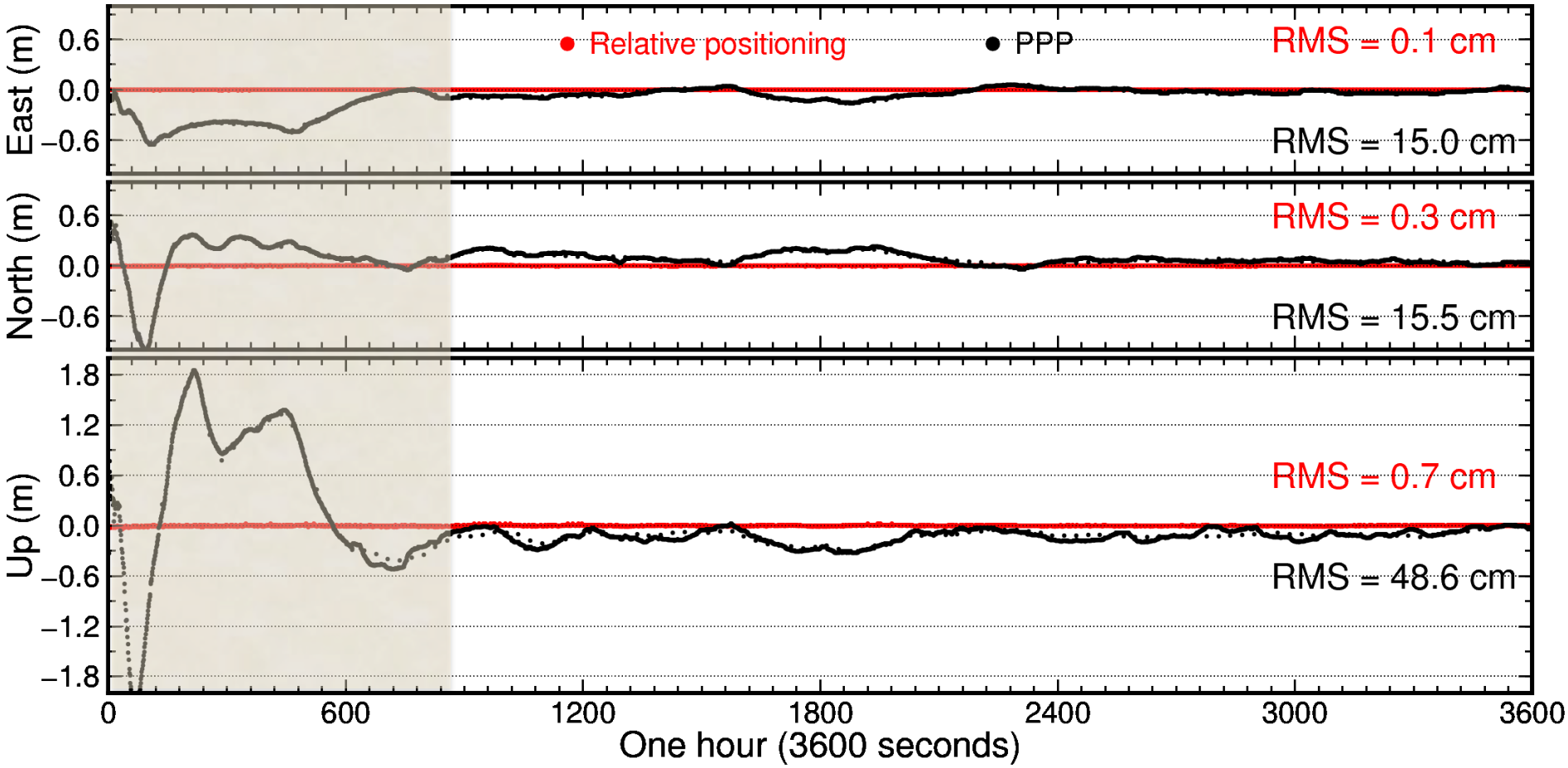

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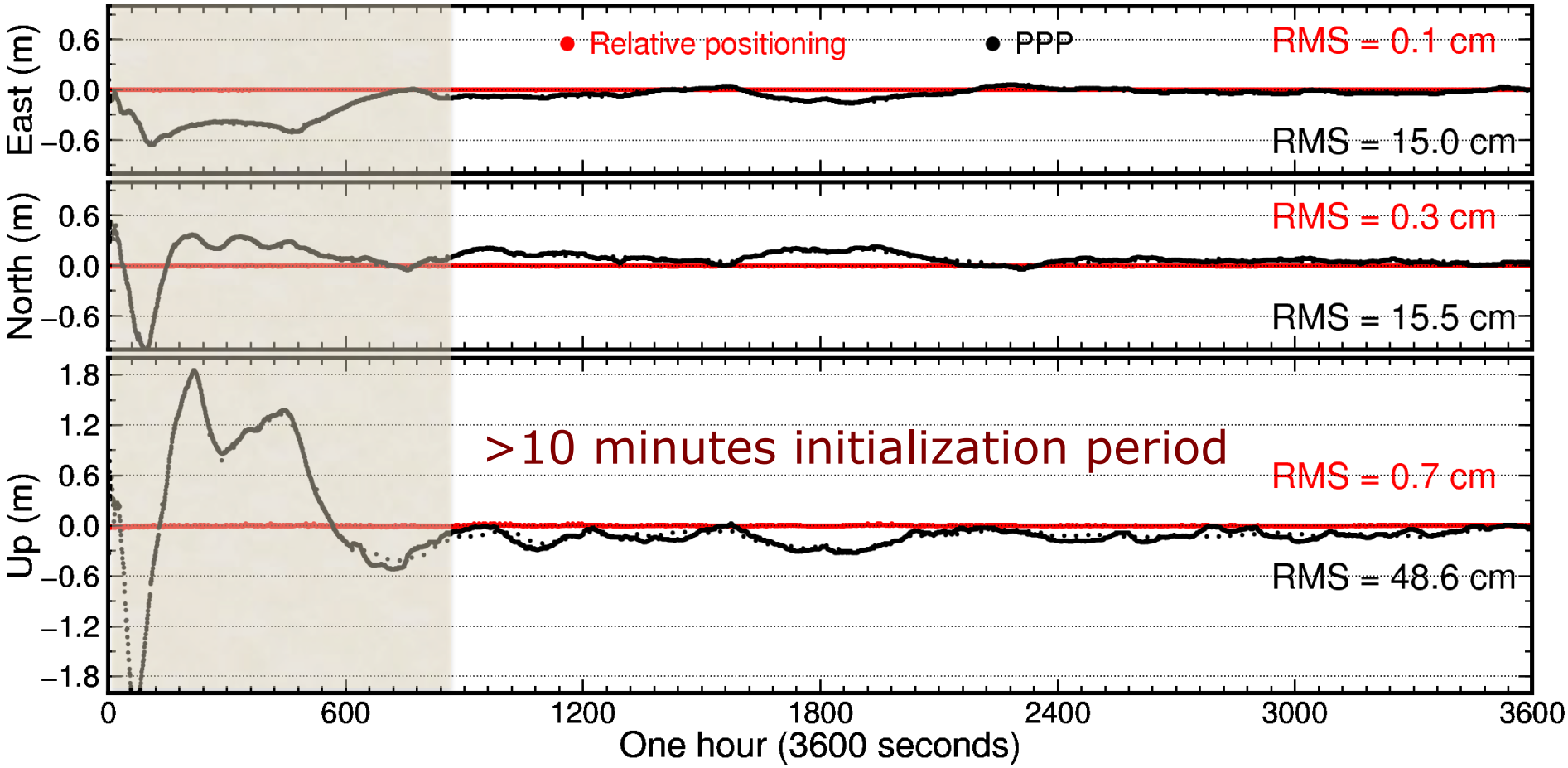

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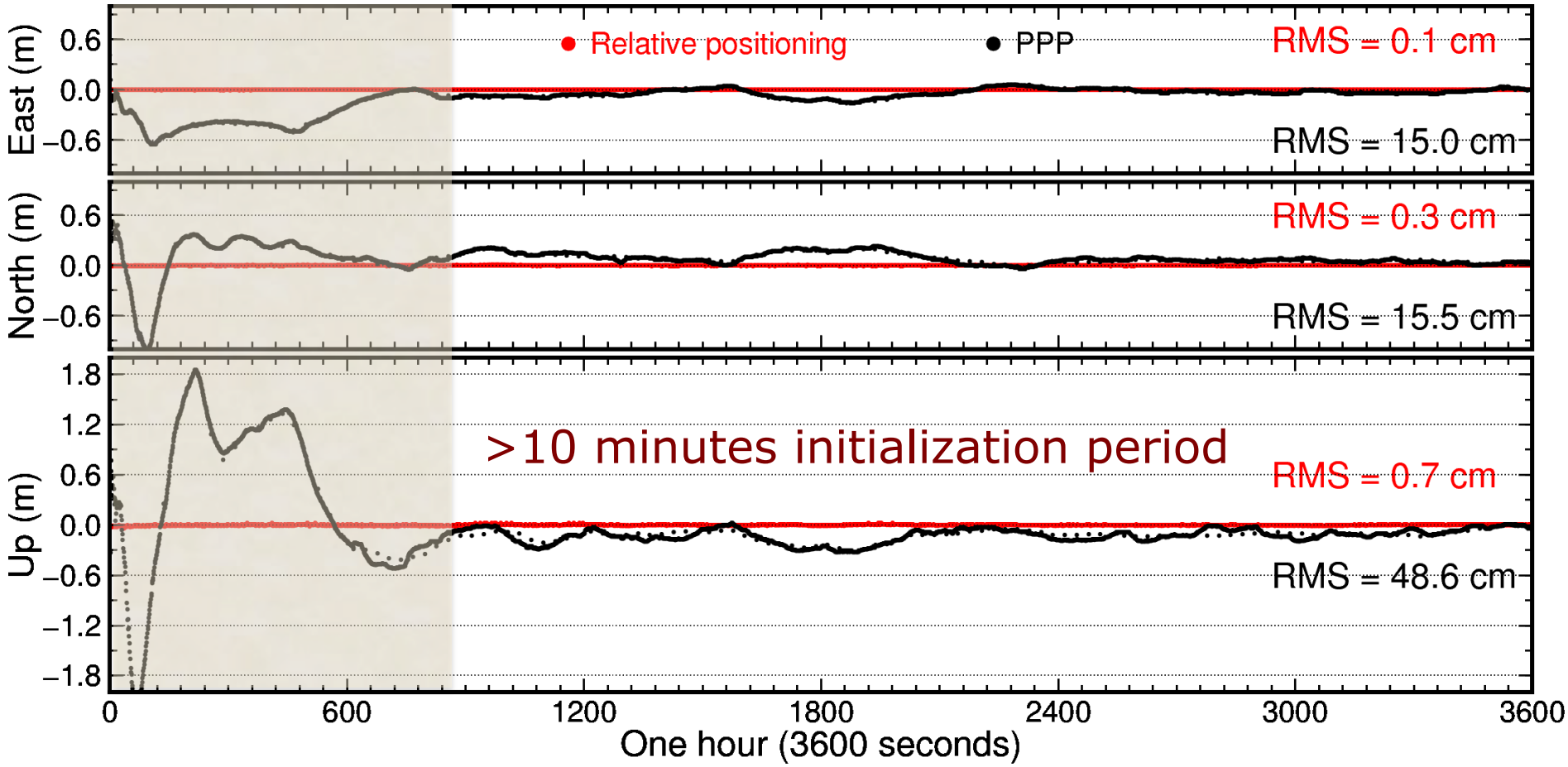
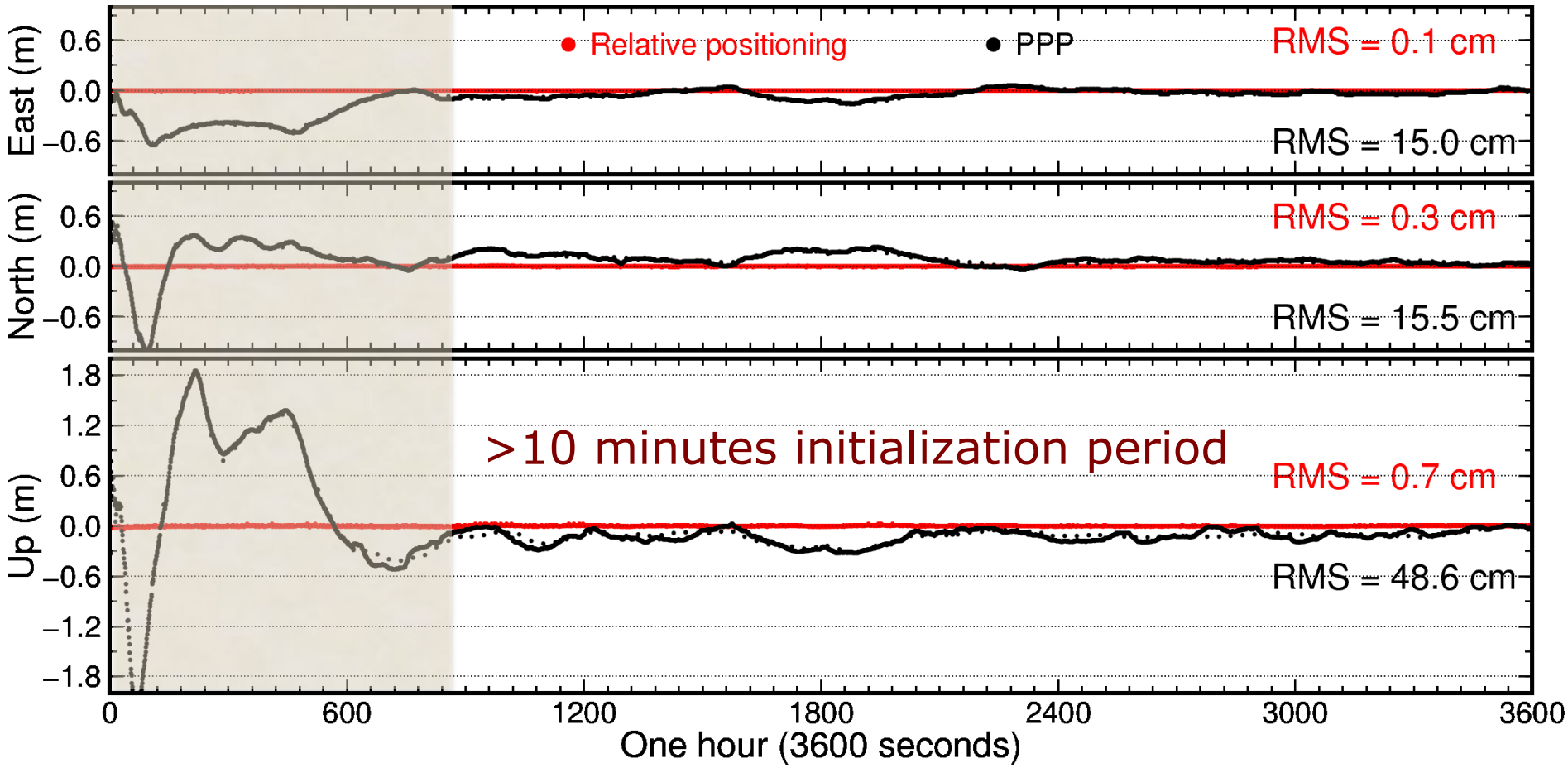


- How do we improve PPP accuracy?

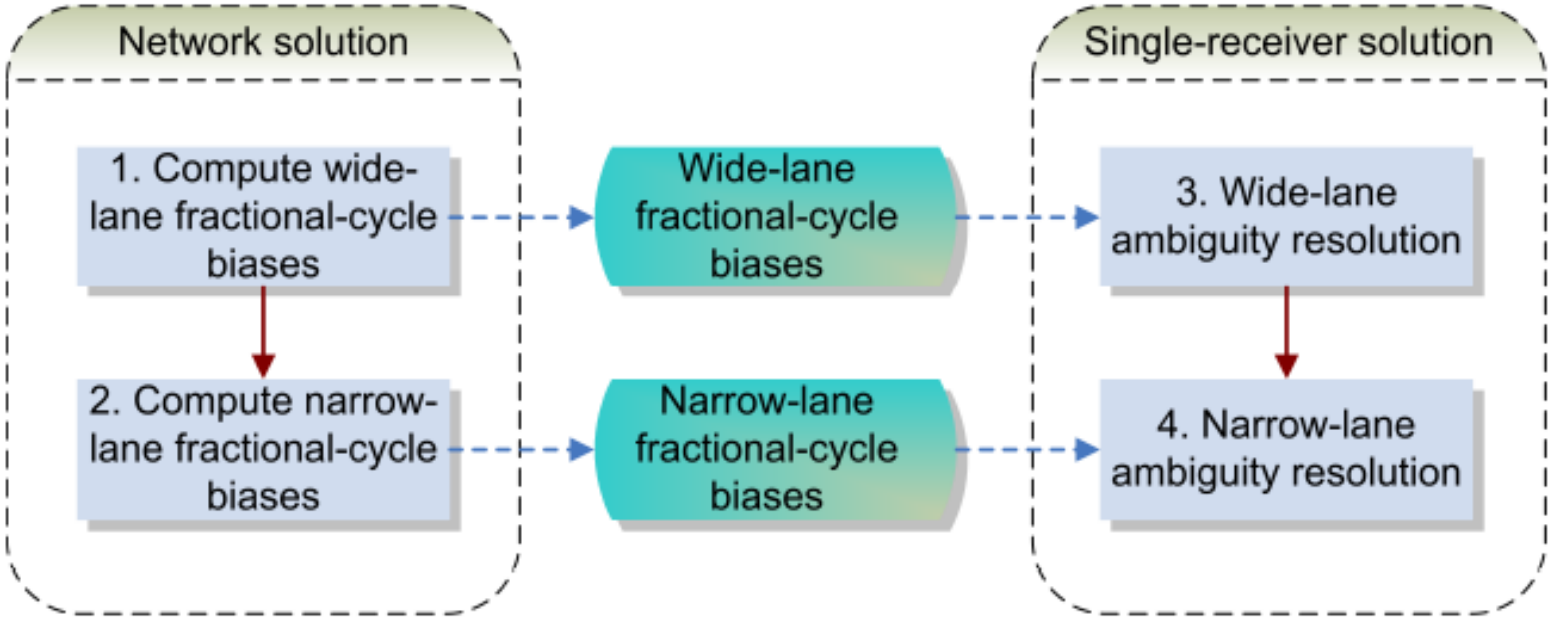
Long bedeviling problems in dual-frequency PPP …



- How do we improve PPP accuracy?
- How do we speed up PPP convergence (initialization)?

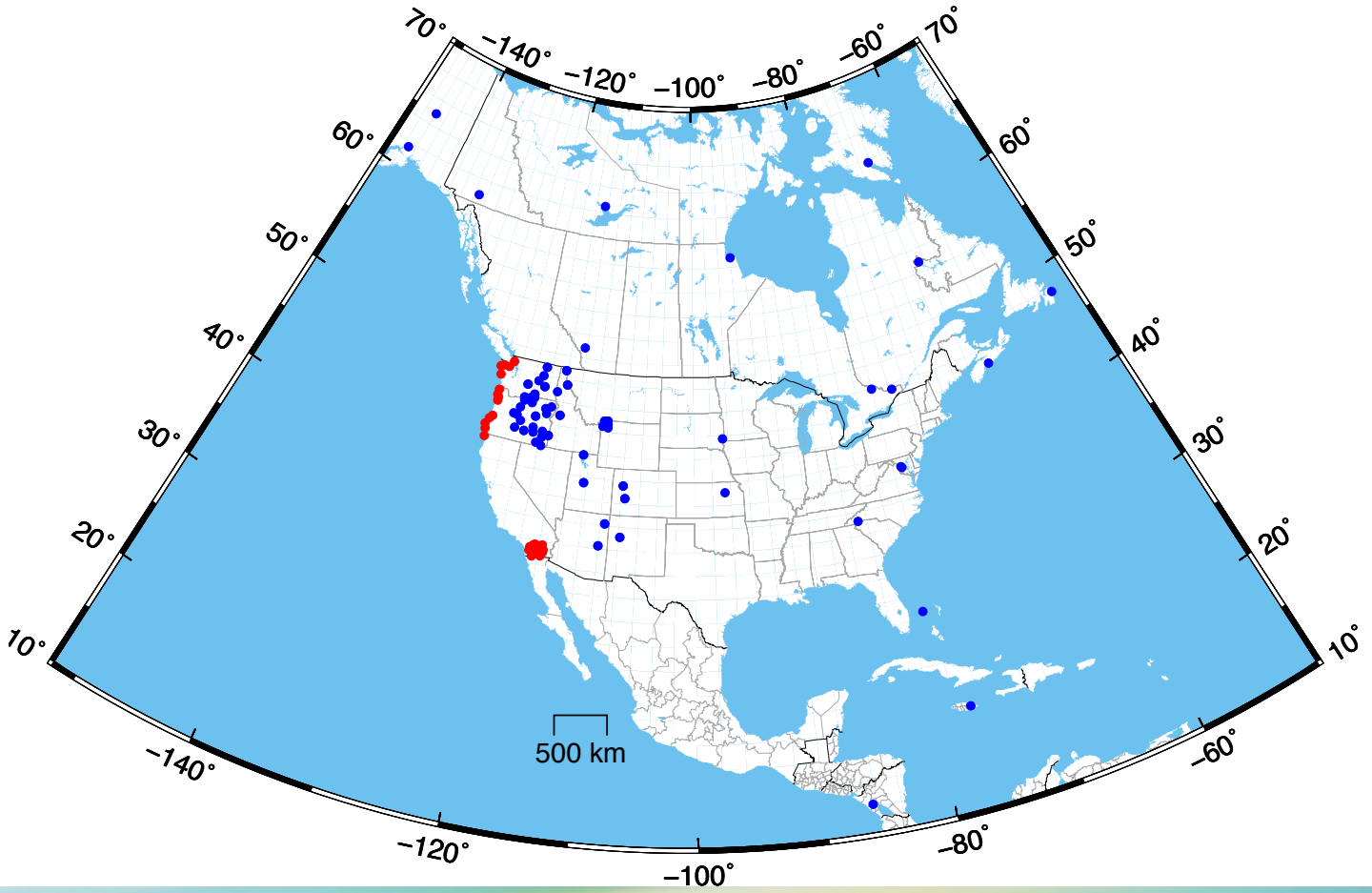
Ambiguity resolution & Atmosphere augmentation in dual-frequency PPP

- Improve PPP accuracy from decimeter to centimeter level
  - The key is to estimate the fractional-cycle biases (FCBs) of uncalibratedphase delays (UPDs) from the ambiguity estimates of a network of reference stations



Ambiguity resolution & Atmosphere augmentation in dual-frequency PPP

- Constrain the ionosphere and troposphere parameters
  - The performance highly depends on the accuracy of atmosphere information



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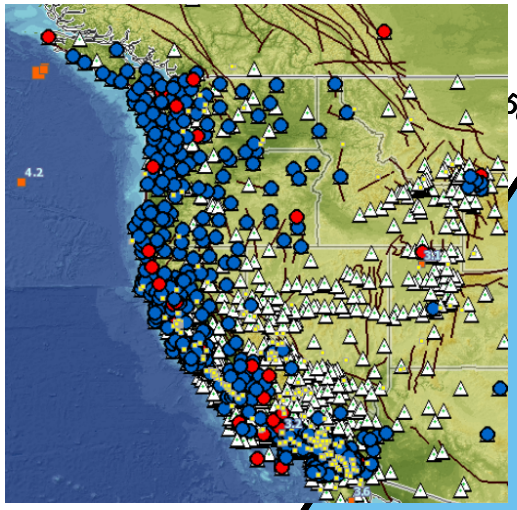
Dense GNSS network



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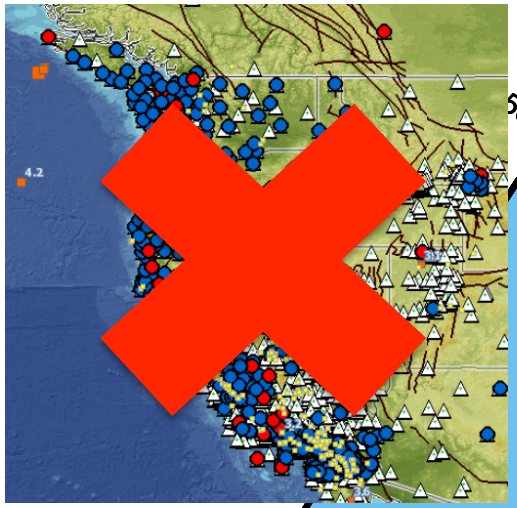

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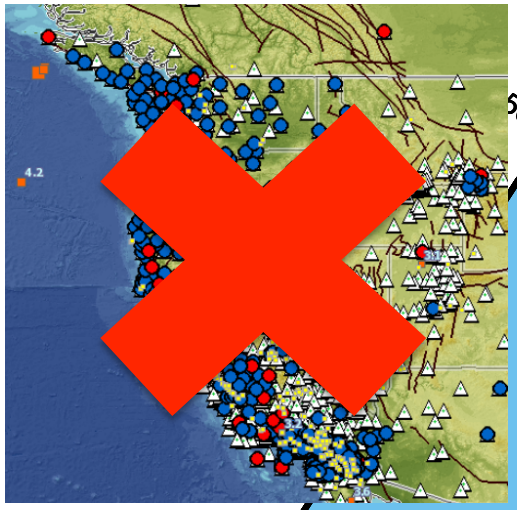

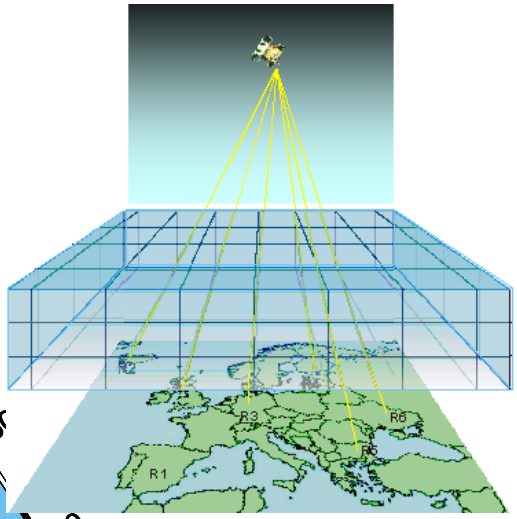

Global ionosphere map

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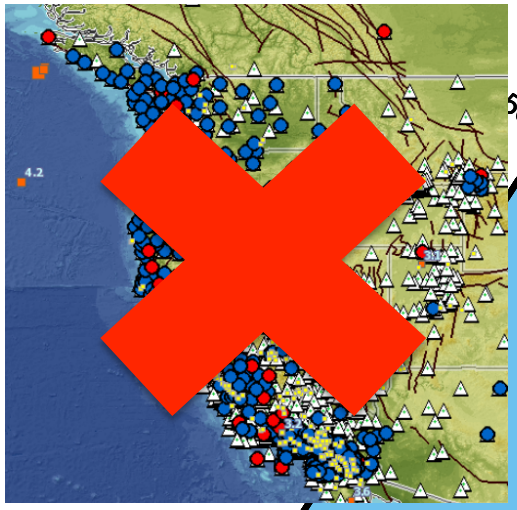
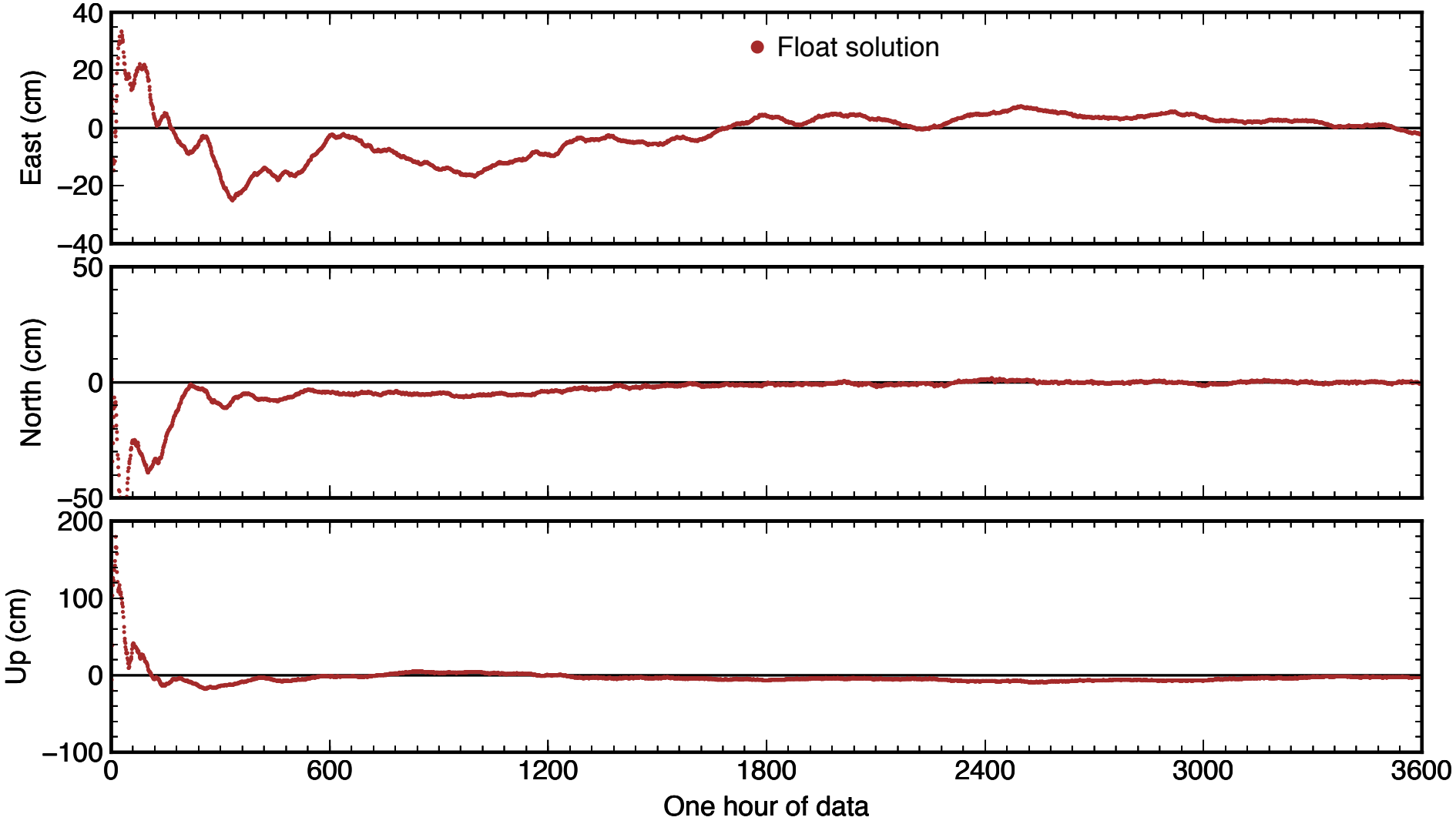


Global ionosphere map

NOAA GPS-Met predictions

Ambiguity resolution & Atmosphere augmentation in dual-frequency PPP



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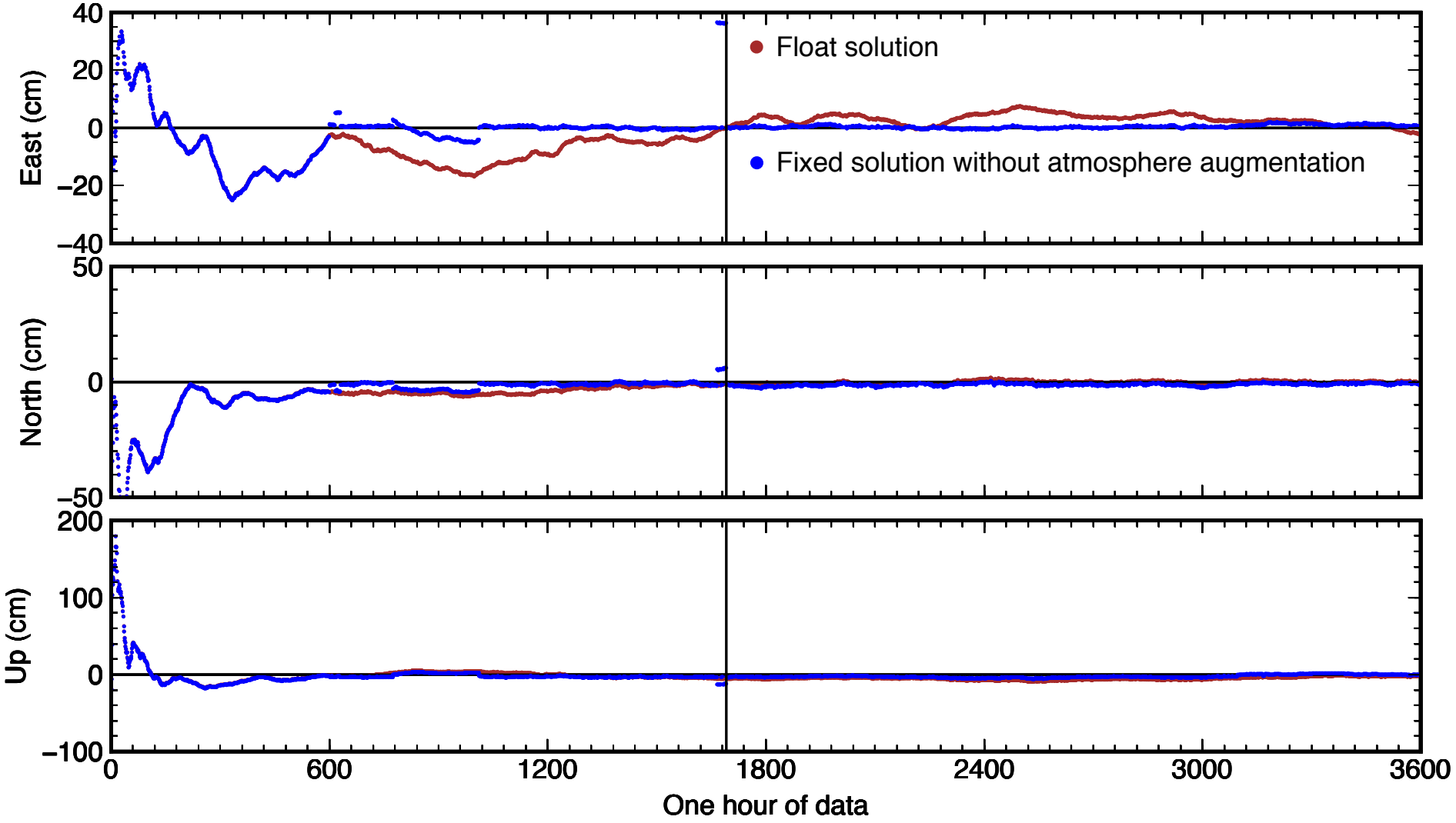

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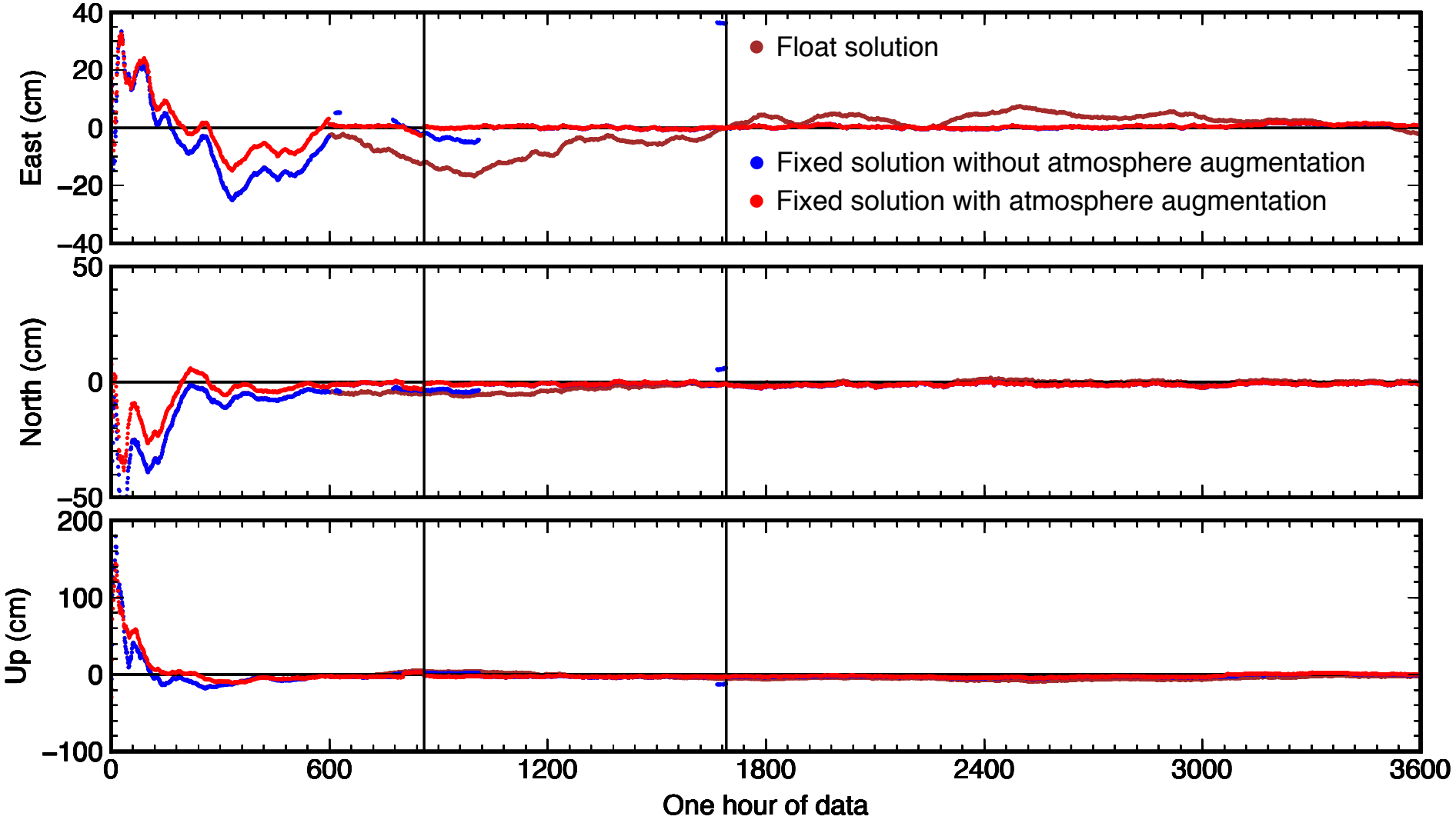

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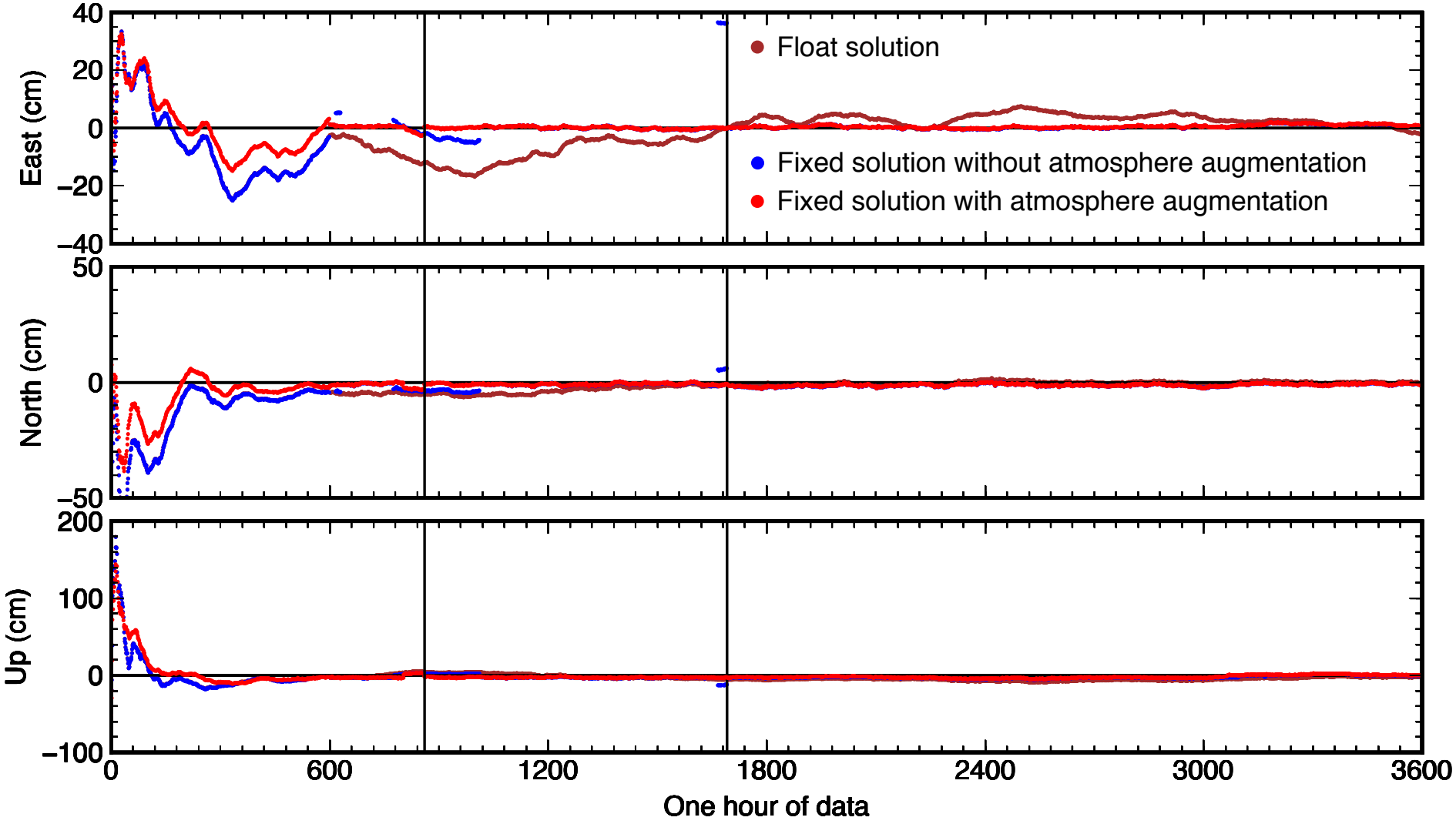
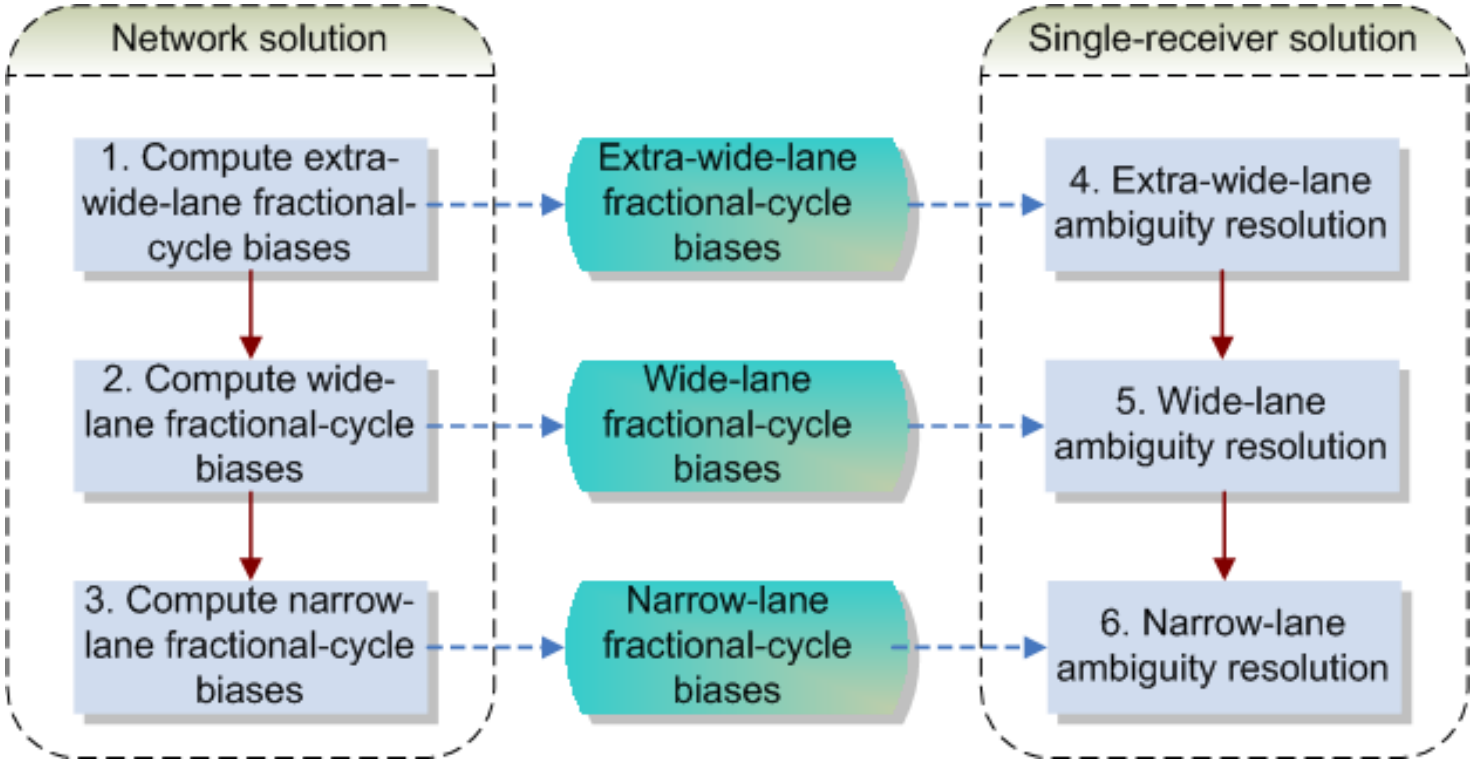


- On average convergences are only accelerated by about 2 min.

Will new signals help to resolve these problems?

- Cascade ambiguity resolution with multi-frequency signals
  - Speed up PPP convergences



Triple-frequency PPP with combination observables

- Raw observations

$$\begin{cases} P_g = \rho + \dfrac{\mu}{f_g^2} + b_g \\ L_g = \rho - \dfrac{\mu}{f_g^2} + \lambda_g(N_g + B_g), \quad g = 1, 2, 5 \end{cases}$$

- Extra-wide-lane observations: fast ambiguity resolution

$$L_{\mathrm{e}} = \frac{f_2 L_2 - f_5 L5}{f_2 - f_5} - \frac{f_2 P_2 + f_5 P_5}{f_2 + f_5}$$

$$= \lambda_{\mathrm{e}}(N_2 - N_5 + B_{\mathrm{e}}), \quad \lambda_{\mathrm{e}} = 5.86\mathrm{m}$$

Triple-frequency PPP with combination observables

- Wide-lane observation: fast ambiguity resolution for a 3.4m wavelength

$$
\begin{aligned}
L_{\mathrm{w}} =& \frac{f_1^2}{(f_1-f_2)(f_1-f_5)}L_1 - \frac{f_2^2}{(f_1-f_2)(f_2-f_5)}L_2 \\
&+ \frac{f_5^2}{(f_1-f_5)(f_2-f_5)}L_5 + \frac{f_5}{f_1-f_5}\lambda_{\mathrm{e}}N_{\mathrm{e}} \\
=& \rho + \frac{\lambda_{\mathrm{w}} f_1}{f_1-f_5}(N_1 - N_2 + B_{\mathrm{w}}), \quad \frac{\lambda_{\mathrm{w}} f_1}{f_1-f_5} = 3.4\mathrm{m}
\end{aligned}
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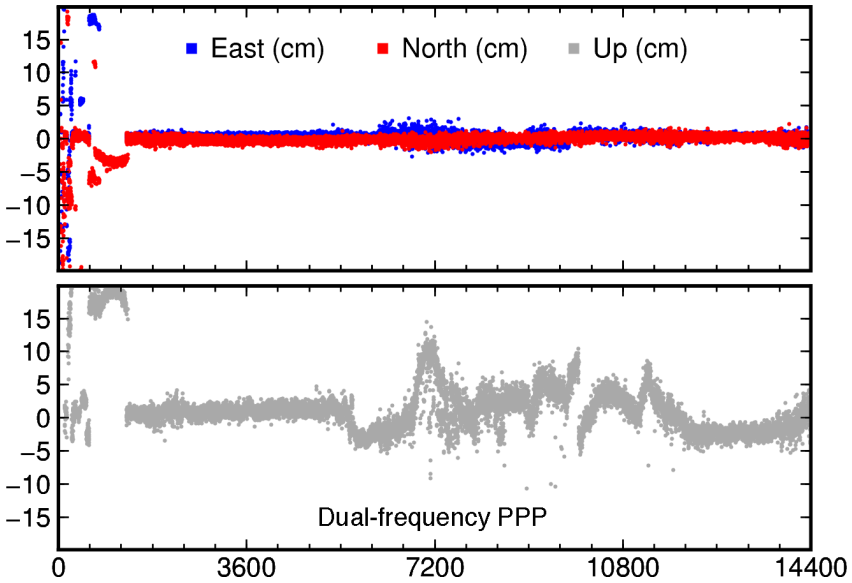
\end{aligned}
$$

- Narrow-lane observation: benefit from ambiguity-fixed wide-lane

$$
\begin{aligned}
L_{\mathrm{n}} =& \frac{f_1^2}{f_1^2-f_2^2}L_1 - \frac{f_2^2}{f_1^2-f_2^2}L_2 - \frac{\lambda_2 f_2^2}{f_1^2-f_2^2}(N_1 - N_2) \\
=& \rho + \lambda_{\mathrm{n}}(N_1 + B_{\mathrm{n}}), \quad \lambda_{\mathrm{n}} = 0.11\mathrm{m}
\end{aligned}
$$

Triple-frequency PPP with combination observables: Benefits

Convergence within a few minutes (Simulated GPS data with Spirent GSS8000)



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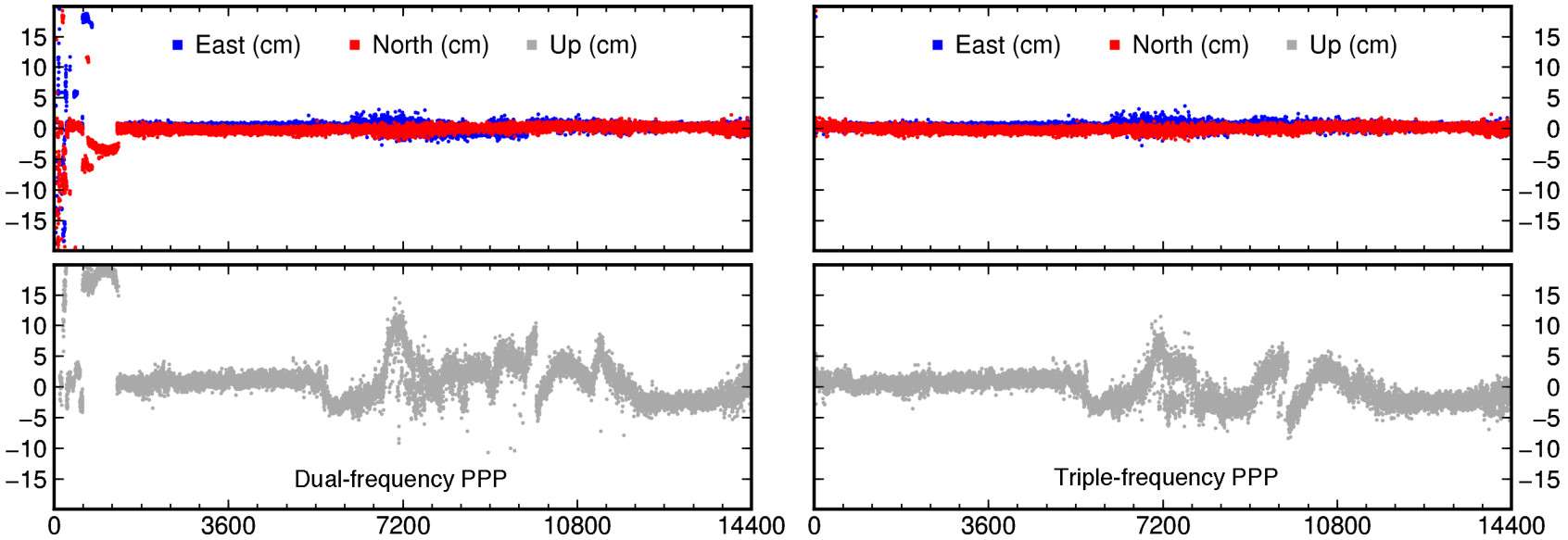

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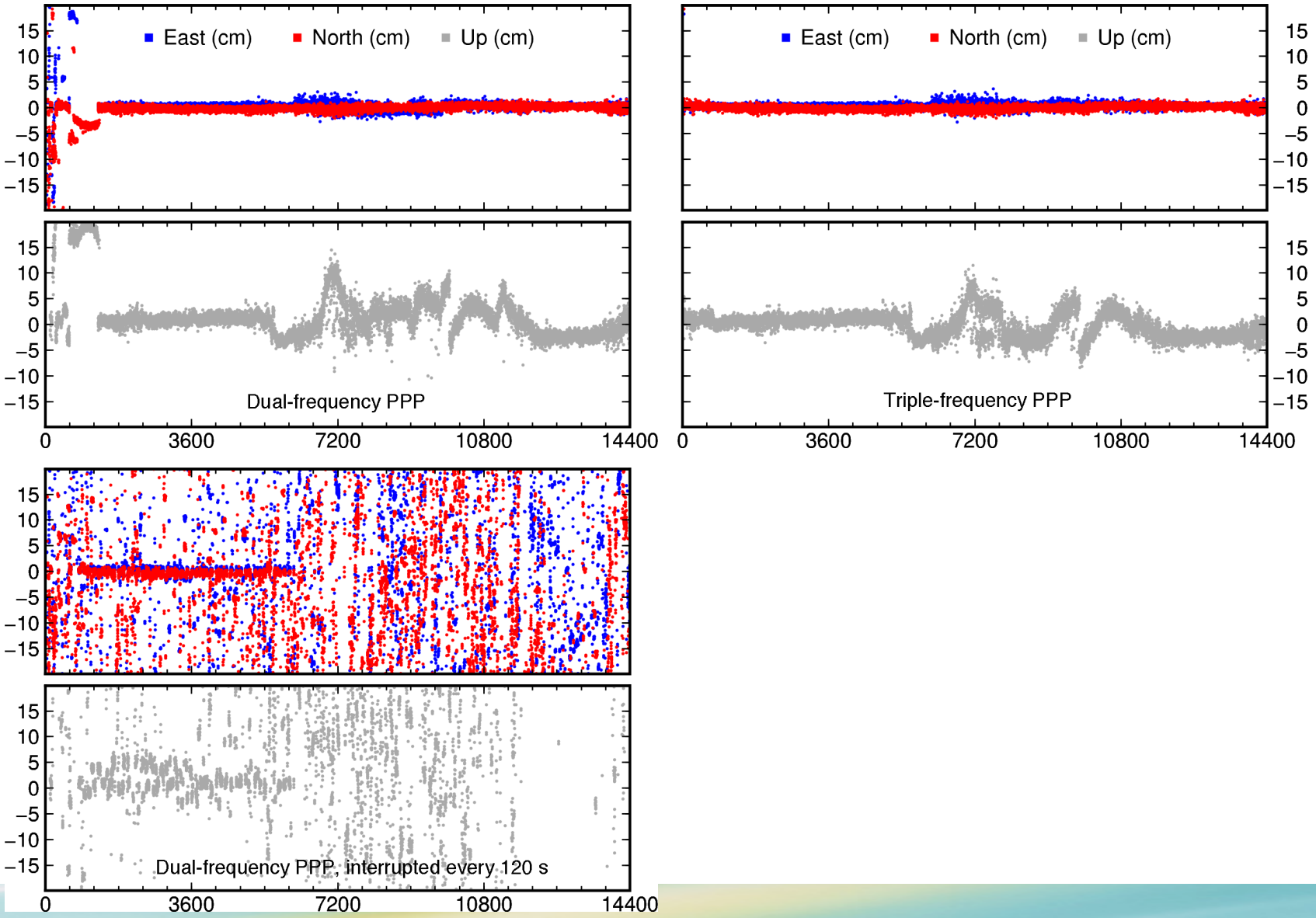

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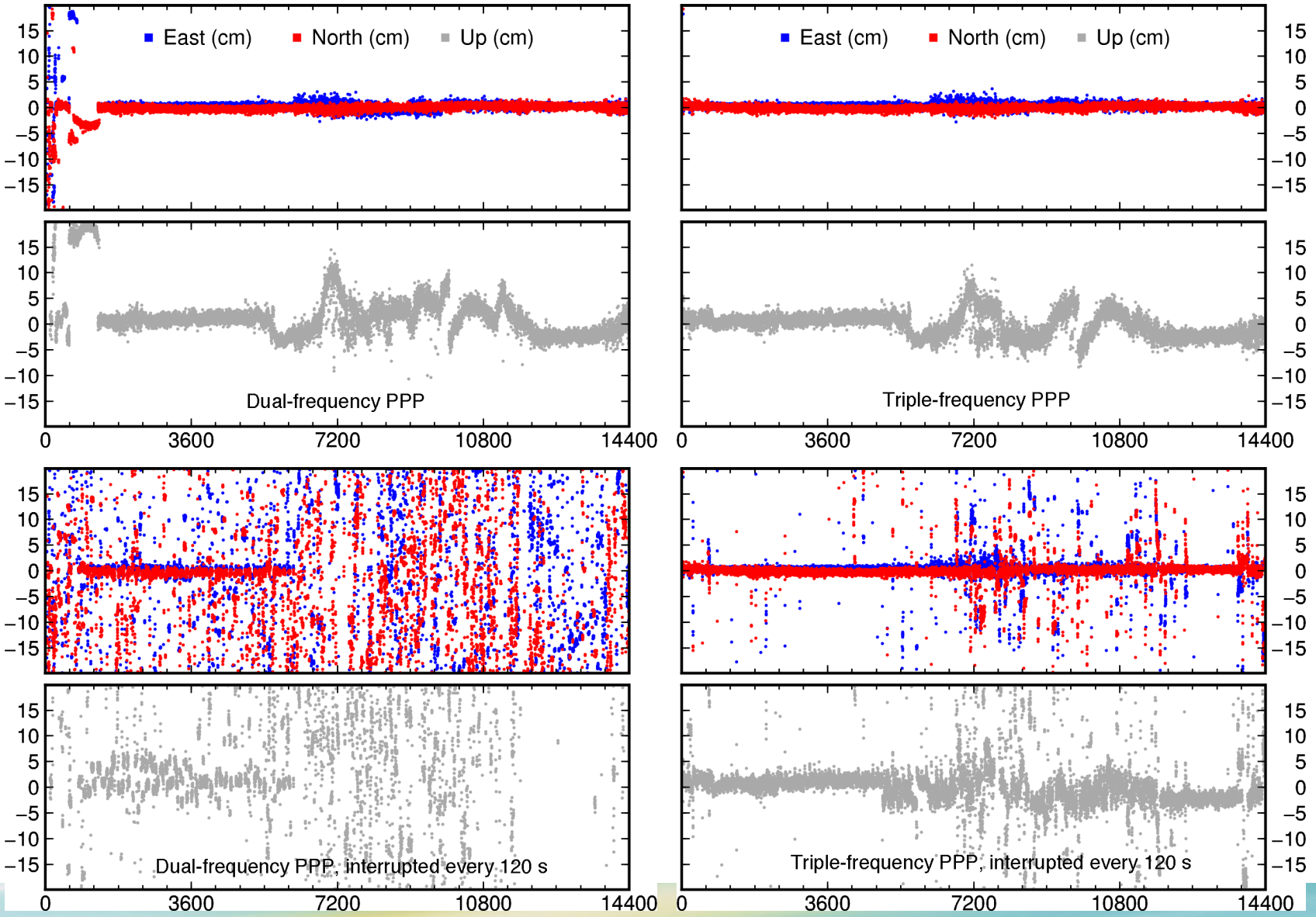

Triple-frequency PPP with combination observables: Challenges

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    - Longer wavelength, lower noise, reduced ionosphere?
  - Do we really have to use ionosphere-free observables?
    - Otherwise ionosphere needs to be estimated
  - How do we keep the flexibility for users in selecting their preferable combination observables?
    - *Your best combination may be not my best*

What if avoid searching for the 'best-combination'?

- PPP directly with raw observables (*Gu et al. 2013*)

$$\begin{cases} P_g = \rho + \dfrac{\mu}{f_g^2} + b_g \\ L_g = \rho - \dfrac{\mu}{f_g^2} + \lambda_g(N_g + B_g), \quad g = 1, 2, 5 \end{cases}$$

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$$\begin{cases} \sum\limits_{\text{all satellites}} b_g = 0 \quad \text{for } g = 1, 2, 5 \\ \sum\limits_{\text{all satellites}} B_g = 0 \quad \text{for } g = 1, 2, 5 \\ b_1 = 0 \quad \text{for all receivers} \\ b_1 = 0 \quad \text{for all satellites} \end{cases}$$

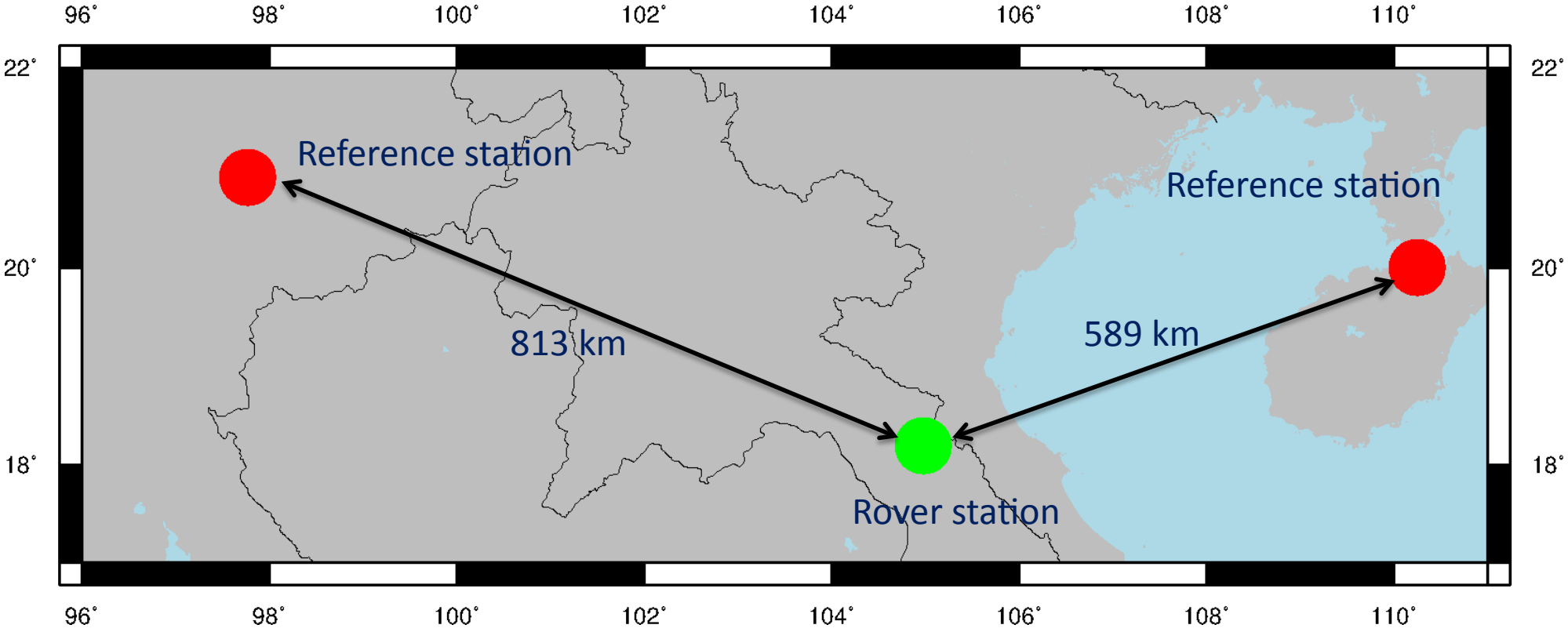
Triple-frequency PPP with raw observables

- Integer resolution with ambiguity estimates on raw observables

$$
\begin{aligned}
&\text{Extra-wide-lane} && N_2 - N_5 + \tilde{B}_{\mathrm{e}} \\
&&& \Downarrow \\
&\text{Wide-lane} && N_1 - N_2 + \tilde{B}_{\mathrm{w}} \\
&&& \Downarrow \\
&\text{Narrow-lane} && N_1 + \tilde{B}_{\mathrm{n}}
\end{aligned}
$$

Triple-frequency PPP with raw observables: BeiDou

- BeiDou triple-frequency data spanning 13 days in 2013
- Precise orbit and clock produced by Wuhan University
  - 10 cm IGSO/MEO and 50 cm GEO orbits
- Trimble R9 receivers at 3 stations (Preliminary results)
- Narrow-lane ambiguity-fixing is not easy …



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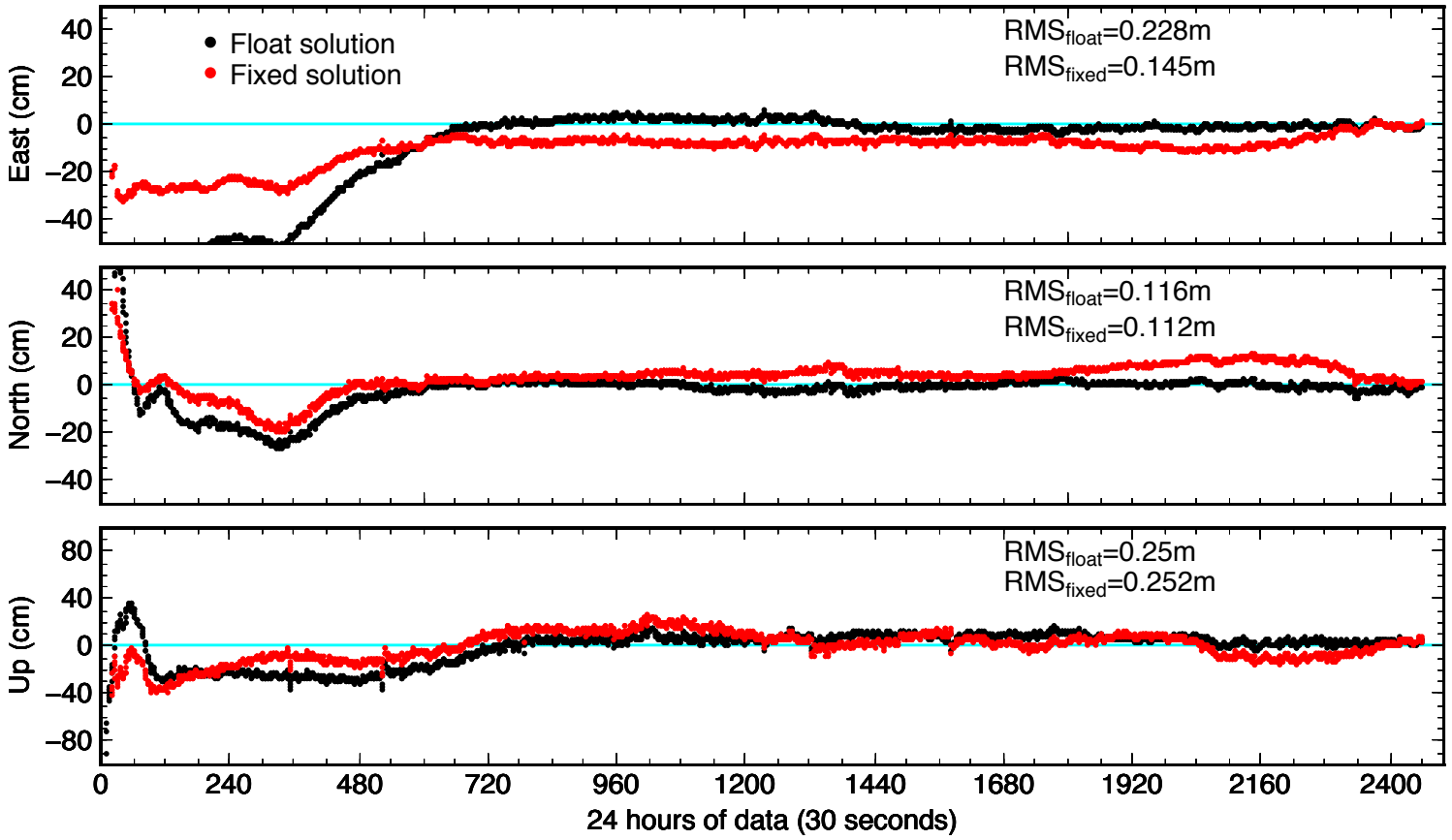

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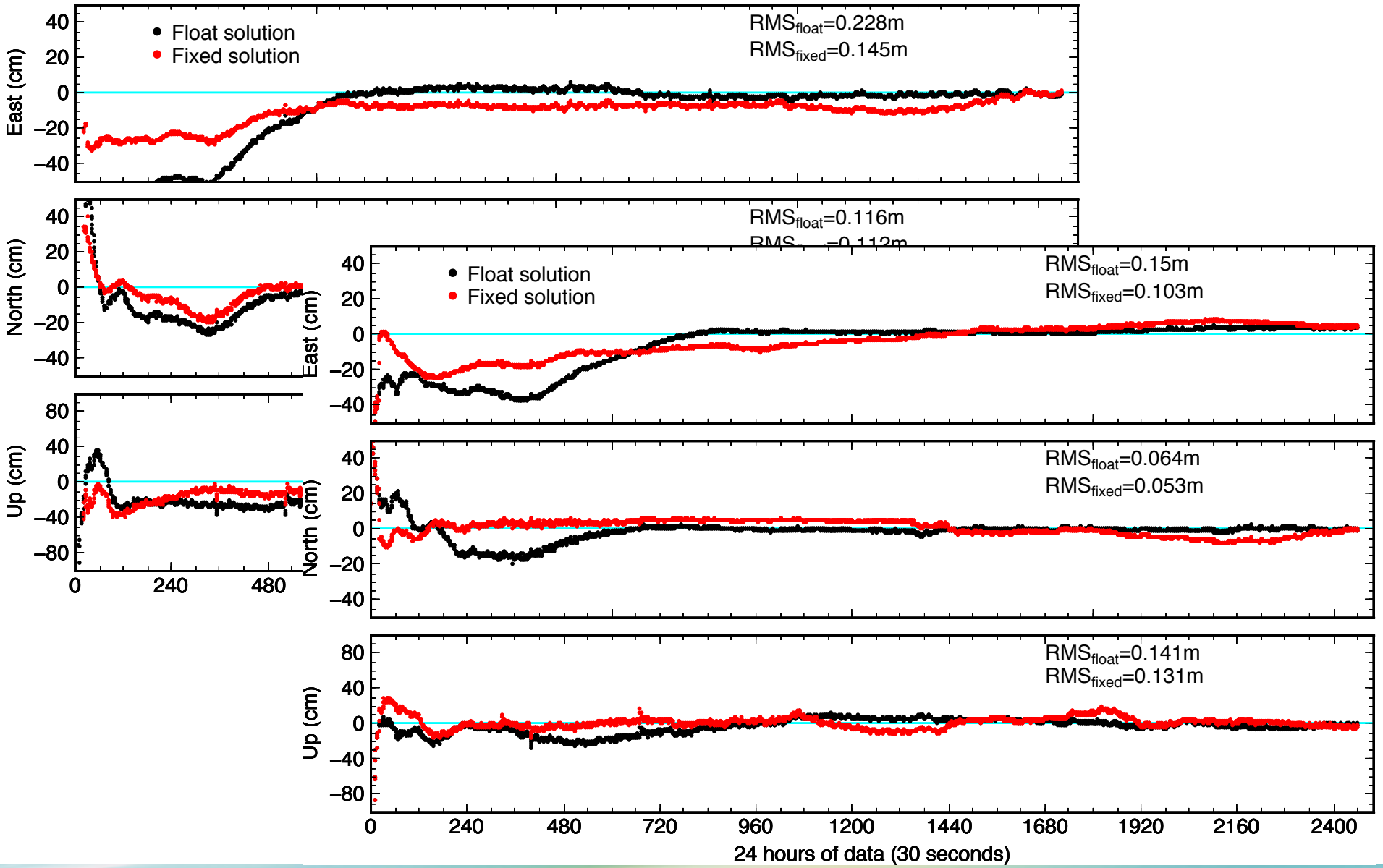

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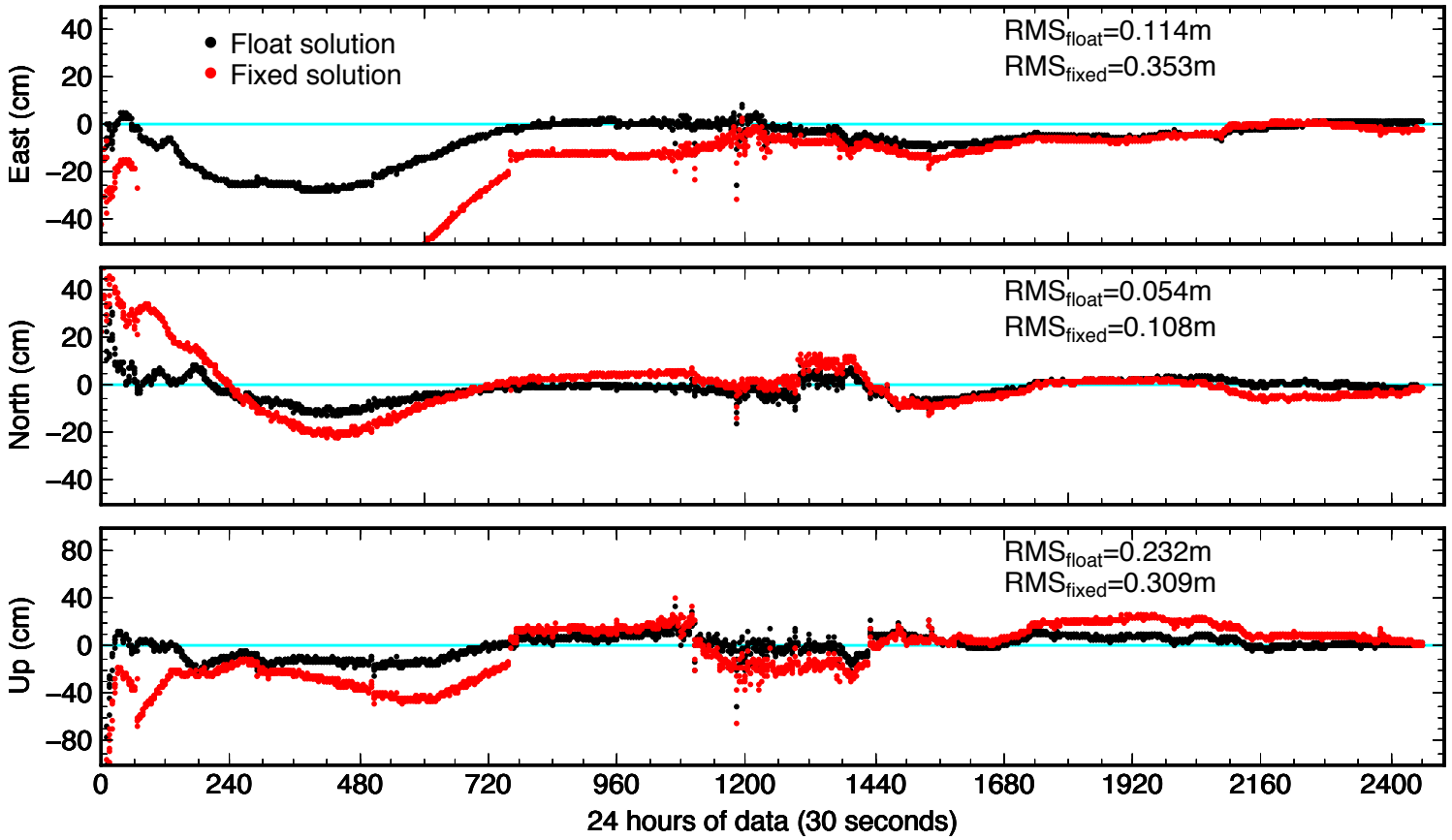

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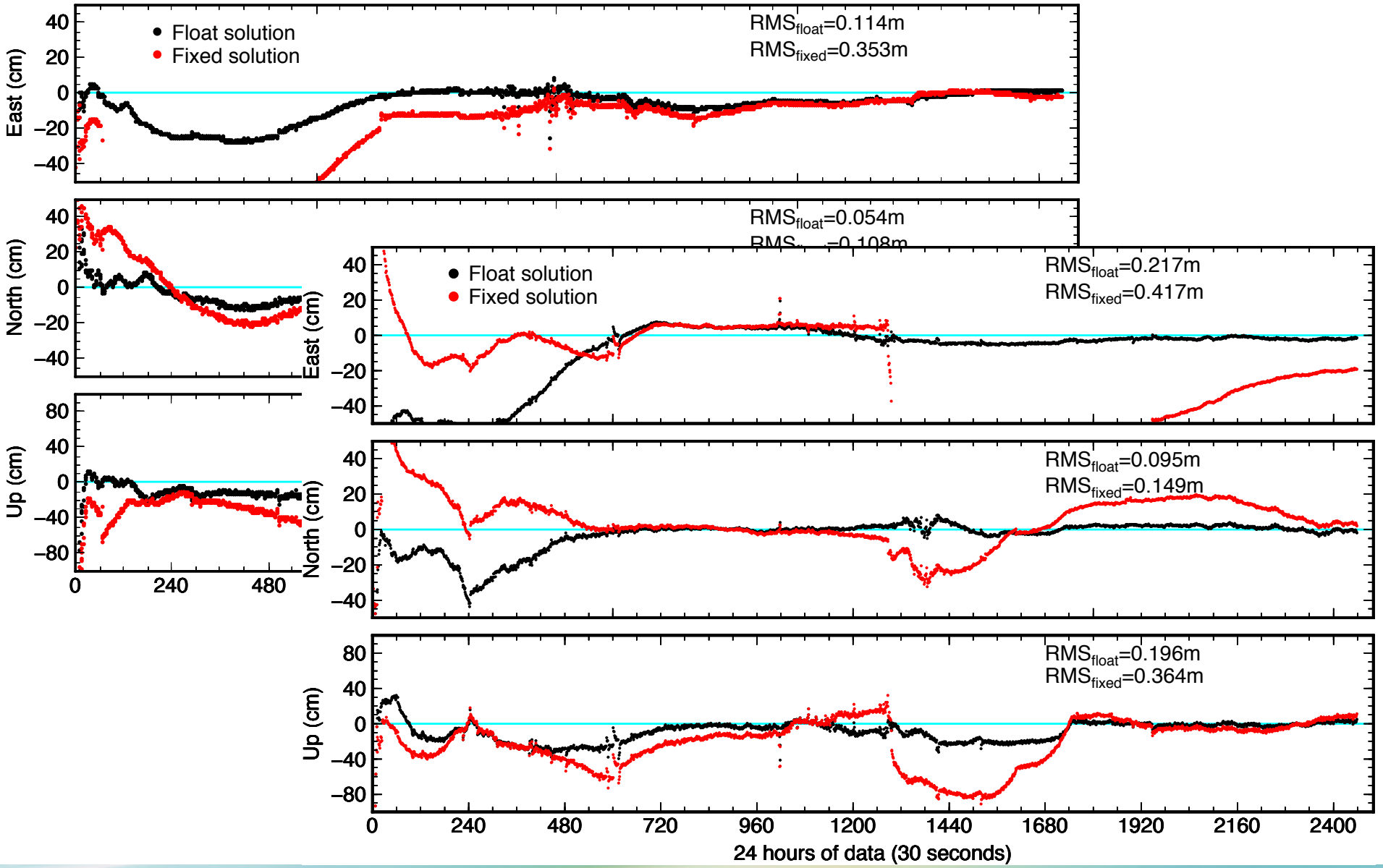

Triple-frequency PPP with raw observables: Challenges

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  - Poor BeiDou orbit and clock accuracy, compared to GPS
  - Receiver and satellite hardware issues?

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- Much more parameters to be estimated in network solutions
  - For m receivers, n satellites and k observables, $(m+n)\times k$ bias parameters and almost $m\times n$ ionosphere parameters

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  - For *m* receivers, *n* satellites and *k* observables, $(m+n)\times k$ bias parameters and almost $m\times n$ ionosphere parameters

- Ambiguity resolution is still based on the 'cascade' concept
  - Ionosphere parameters cannot be constrained tightly
  - Is it then still necessary to look for the 'best combinations'?

Summary

- Rapid ambiguity resolution is still challenging in dual-frequency PPP. Precise atmosphere predictions are unavailable at present;
- Rapid convergences will benefit from multi-frequency GNSS. It's expected ambiguity resolution within a few minutes can be achieved;
- Multi-frequency PPP based on combination observables is easy to handle, but challenged by the search for the optimum combinations;
- Multi-frequency PPP based on raw observables is clear and direct, but computation burden is heavy and ambiguity resolution is still based on the cascade concept.

Thank you for your attention!

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