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Preliminary analysis of ionosphere-corrected PPP-RTK user performance

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1. Introduction

The realization of the integer ambiguity resolution (IAR) enabled precise point positioning (PPP) method, the so-called **PPP-RTK**, is enabled by providing single-receiver PPP users with **satellite phase biases to recover the integerness of the user ambiguities**. Successful IAR can greatly reduce the solution convergence time. However, the unknown ionospheric delay parameters that are estimated by the PPP-RTK user (ionosphere-float model) do not allow for fast (or instantaneous) convergence to the centimeter level.

In this poster, we present a preliminary analysis on the improvement of PPP-RTK GPS dual-frequency user positioning performance **using precise ionospheric corrections**, which are expected to **greatly reduce the convergence time**. The ionospheric corrections used at the user level are determined by modeling PPP-RTK ionospheric slant delays computed from receivers of a regional network. The improvement of the PPP-IAR user performance is analyzed in terms of the required time to fix the integer ambiguities (TTFA) and the achieved convergence time to the 10 cm level.

2. PPP-RTK network system

The basis of the PPP-RTK network system is the **uncombined** GNSS code and carrier-phase observation equations:

$$E(p^s_{r,j}) = \rho^s_r + (dt_r - dt^s) + m^s_r\tau_r + \mu_j\iota^s_r + (d_{r,j} - d^s_{,j})$$
$$E(\phi^s_{r,j}) = \rho^s_r + (dt_r - dt^s) + m^s_r\tau_r - \mu_j\iota^s_r + \lambda_j(\delta_{r,j} - \delta^s_{,j} + a^s_{r,j})$$

Since not all the unknown parameters are unbiasedly estimable, we apply the S-system theory to eliminate the rank-deficiencies [1]. Assuming that precise orbits and clocks are used, the estimable parameters are:

$$\tilde{d}t_r = (dt_r + d_{r,\mathrm{IF}}) - (dt_p + d_{p,\mathrm{IF}}), \quad \forall\, r \neq p$$

(p: pivot rec./sat.)

$$\tilde{\iota}^s_r = \iota^s_r + d_{r,\mathrm{GF}} - d^s_{,\mathrm{GF}}, \quad \forall\, r, s$$

(IF: *ionosphere-free*)

$$\tilde{\delta}_{r,j} = \left(\delta_{r,j} - \frac{1}{\lambda_j}[d_{r,\mathrm{IF}} - \mu_j d_{r,\mathrm{GF}}] + a^p_{r,j}\right) - \left(\delta_{p,j} - \frac{1}{\lambda_j}[d_{p,\mathrm{IF}} - \mu_j d_{p,\mathrm{GF}}] + a^p_{p,j}\right), \quad \forall\, j, r \neq p$$

(GF: *geometry-free)*

$$\tilde{\delta}^s_{,j} = \left(\delta^s_{,j} - \frac{1}{\lambda_j}[d^s_{,\mathrm{IF}} - \mu_j d^s_{,\mathrm{GF}}]\right) - \left(\delta_{p,j} - \frac{1}{\lambda_j}[d_{p,\mathrm{IF}} - \mu_j d_{p,\mathrm{GF}}] + a^s_{p,j}\right), \quad \forall\, j, s$$

$$\tilde{a}^s_{r,j} = (a^s_{r,j} - a^p_{r,j}) - (a^s_{p,j} - a^p_{p,j}), \quad \forall\, j, r \neq p, s \neq p$$

3. PPP-RTK user system

The definition and estimability of the ionosphere-float PPP-RTK user parameters are the same as in the network component:

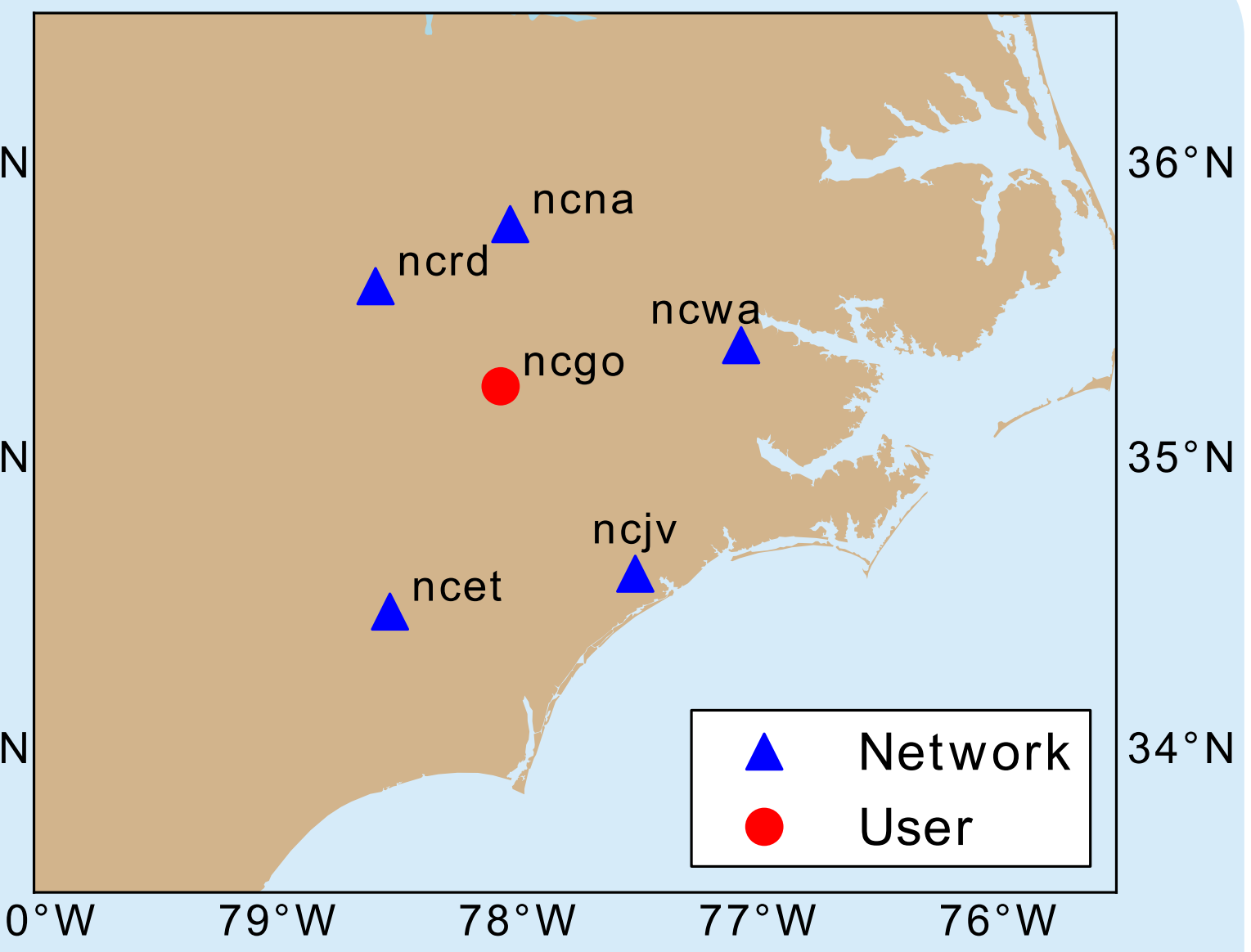
$$E(p^s_{u,j} + \tilde{d}t^s) = \rho^s_u + \tilde{d}t_u + m^s_u\tau_u + \mu_j\tilde{\iota}^s_u$$
$$E(\phi^s_{u,j} + \tilde{d}t^s + \lambda_j\tilde{\delta}^s_{,j}) = \rho^s_u + \tilde{d}t_u + m^s_u\tau_u - \mu_j\tilde{\iota}^s_u + \lambda_j(\tilde{\delta}_{u,j} + \tilde{a}^s_{u,j})$$

The user phase ambiguities are now double-differenced and therefore **integer**.

If ionospheric corrections are provided to the user, the **receiver code bias parameter** of the user becomes estimable.

4. Data – Processing strategy

For the network and user processing, a network in US with the **largest inter-station distance being ~170 km** was processed for 24 hours on February 15, 2014. **Dual-frequency GPS-only** 30 s data are used for the processing with an elevation mask of 10 degrees.

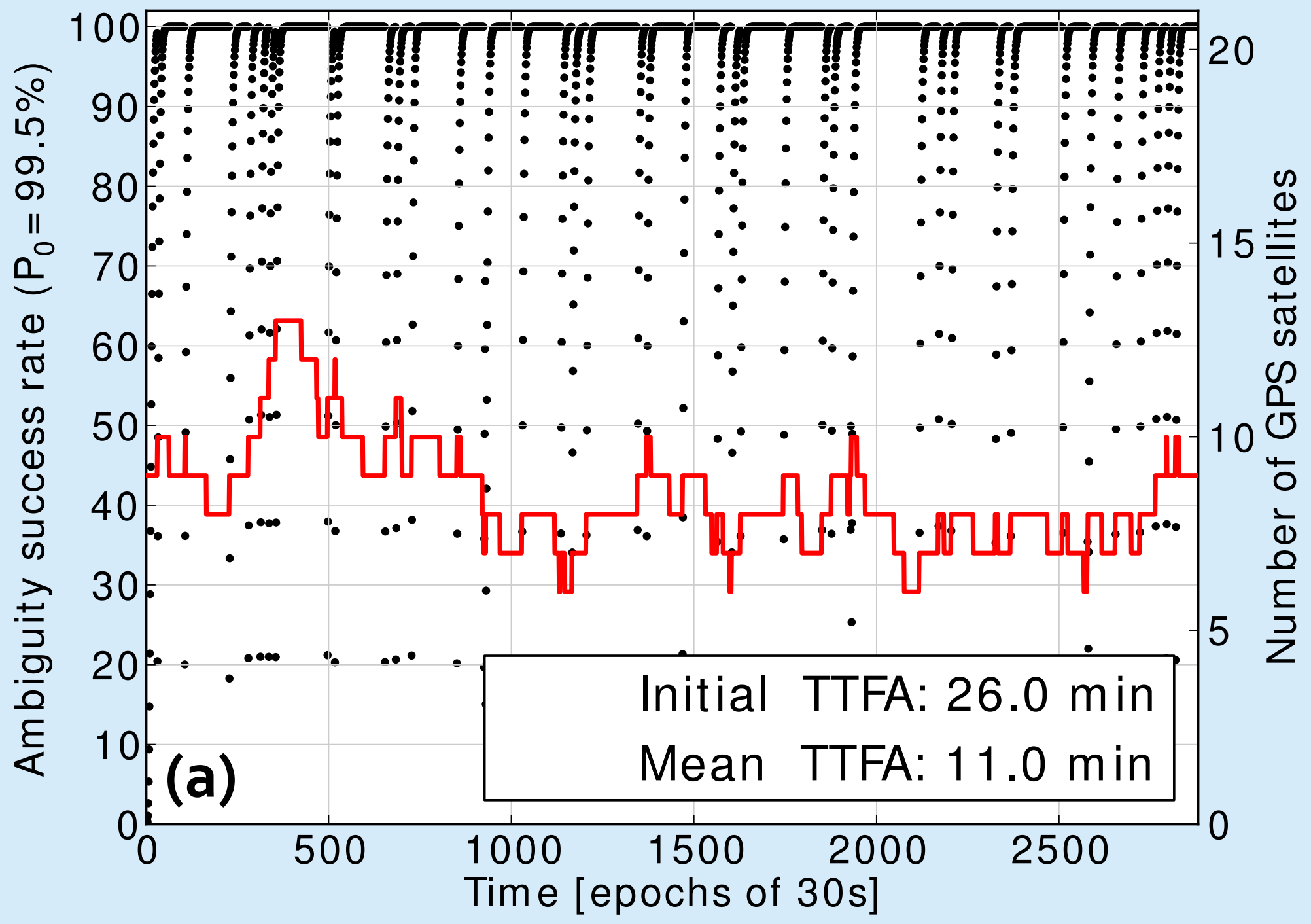


- Meas. noise at zenith: 30cm / 3mm for code / phase
- Parameter estimation using **Kalman filter**
- Full integer ambiguity resolution using **LAMBDA** [2]
- **User-specific ionospheric slant delays are determined** using the least-squares collocation [3] and the best linear unbiased prediction model [4].

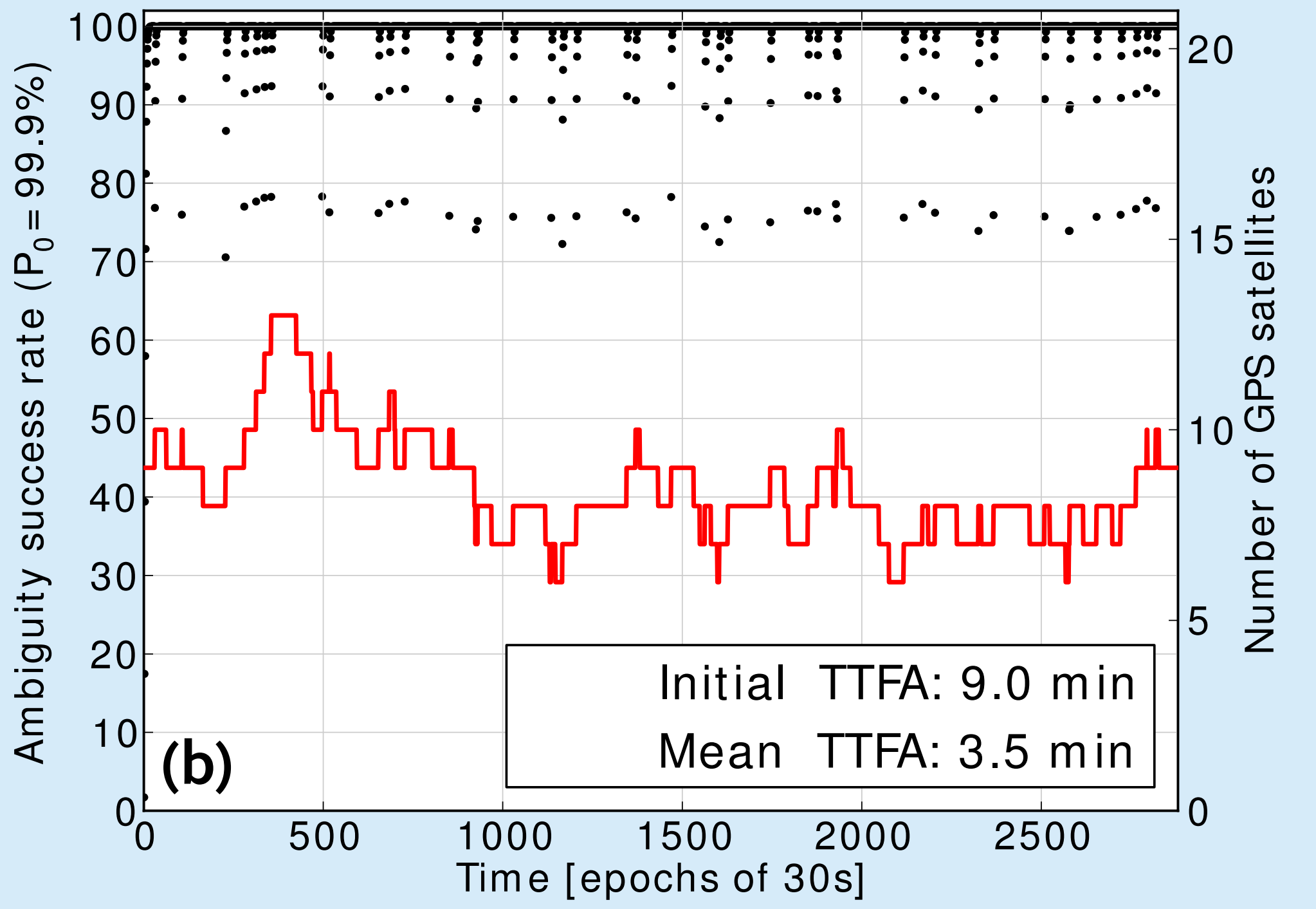
5. Results

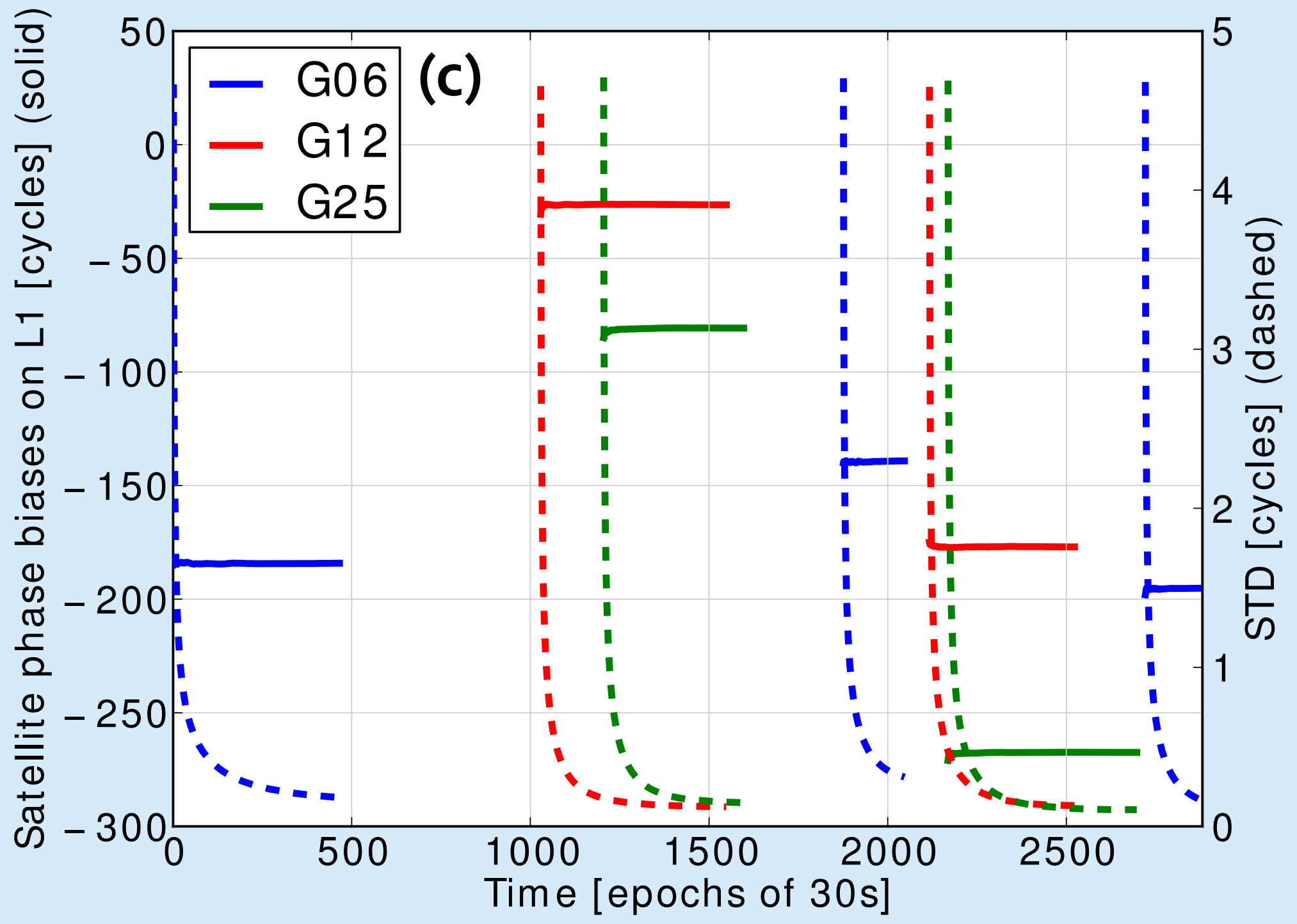
- When precise ionospheric corrections are provided to the user, **the model becomes stronger** than before leading to **more precise phase ambiguities** and, therefore, to higher ambiguity success rates and **shorter TTFAs**, see (a) and (b).
- The quite stable satellite phase biases, see (c), allow for realizing PPP-RTK. When **ionospheric corrections** are further used, the **convergence time** drops to **only 9 minutes**, see (d).
- The estimable **receiver code bias** shows a **stability over time**, with its daily variation not exceeding 20 cm, see (e).

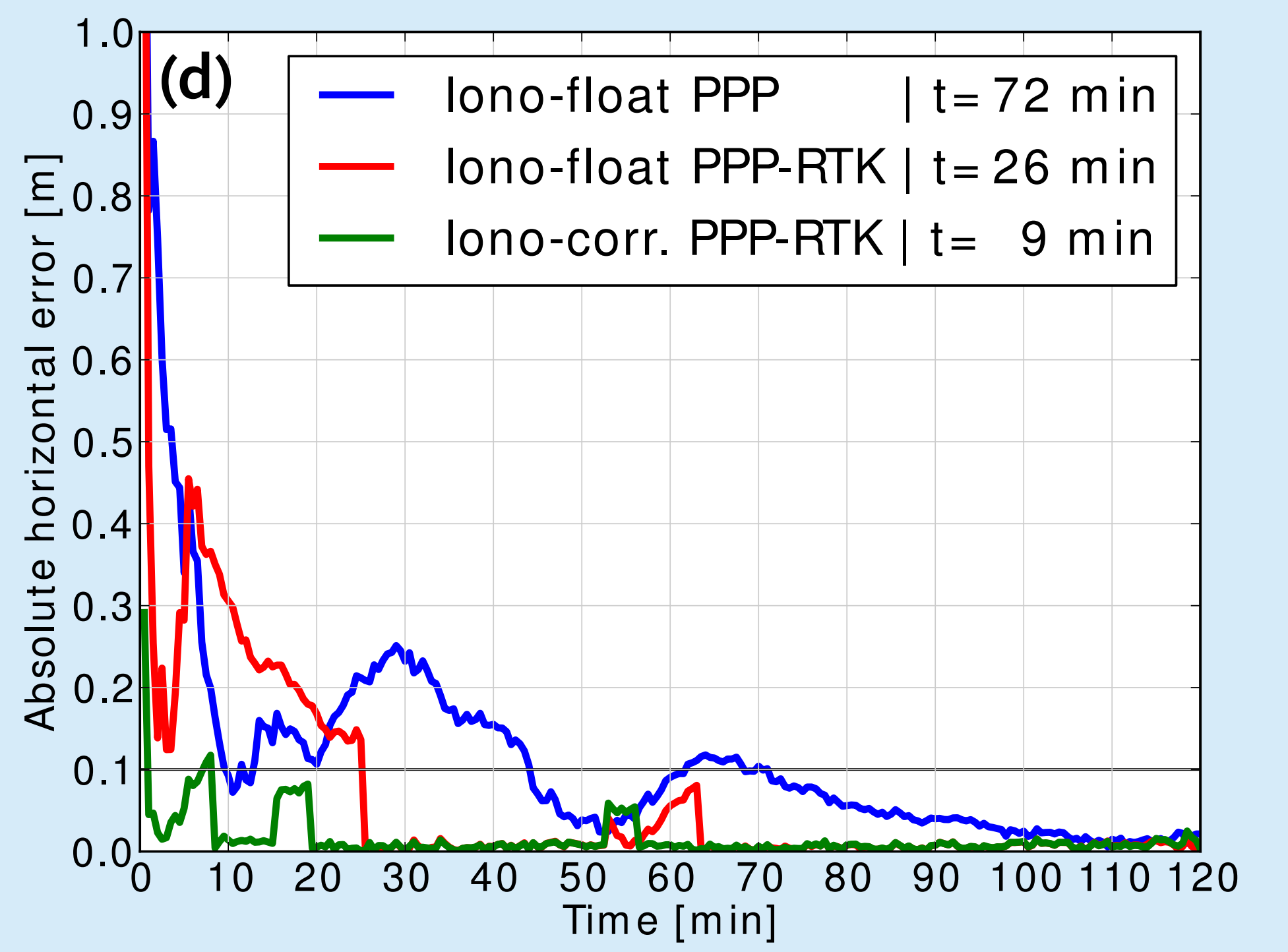
Ionosphere-float PPP-RTK user

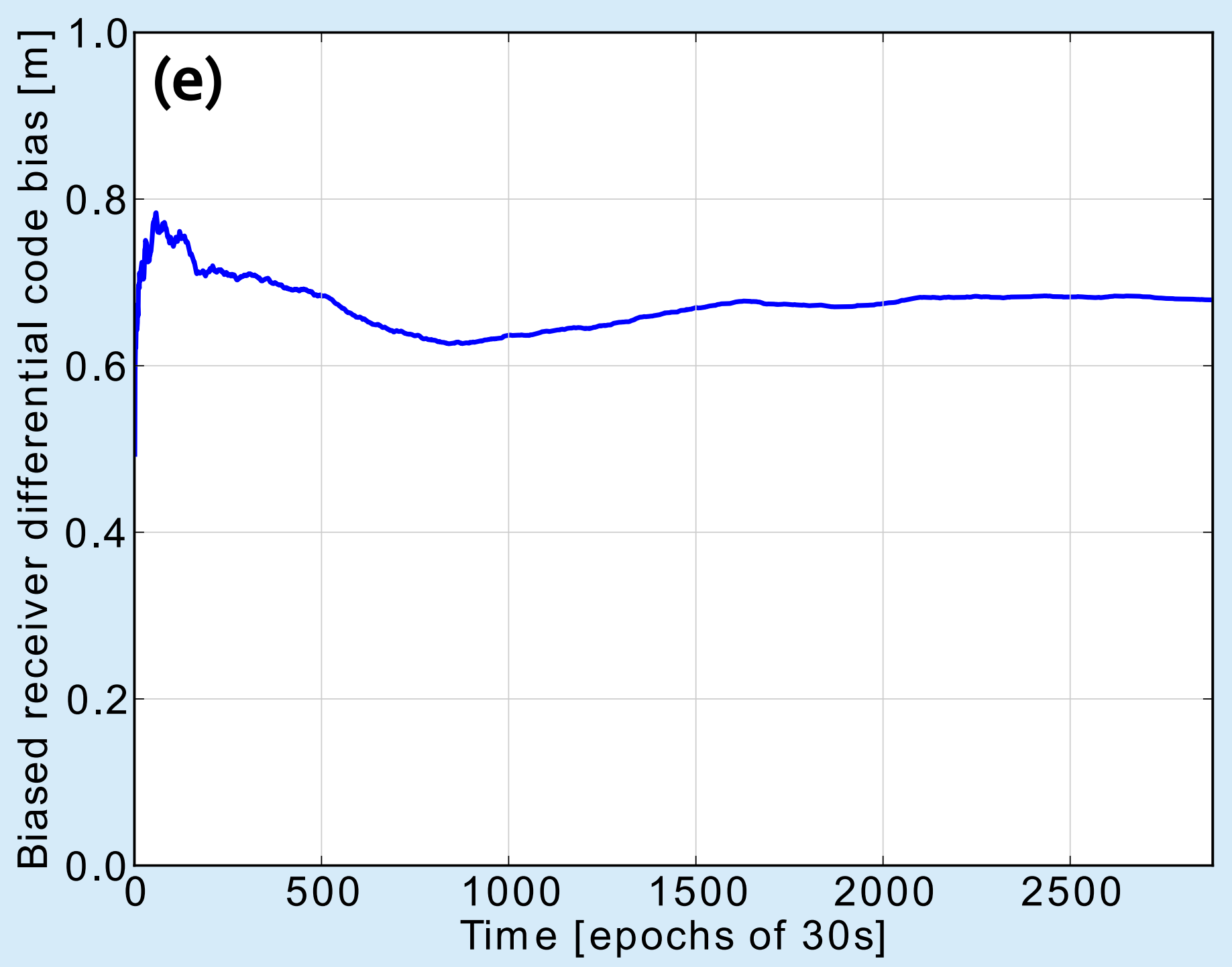


Ionosphere-corrected PPP-RTK user









6. Conclusions

- The **ionosphere-float model is weak in terms of IAR** due to the increased number of unknown parameters.
- **Precise ionospheric corrections** can significantly reduce the convergence time.

Outlook: A large number of sample data will be processed to infer the **distribution of the achieved convergence times**, due to the **random nature of the GNSS data**.

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Photography encouraged