International Civil Aviation Organization

THE FIFTH MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/5)

Okinawa, Japan, 16 – 18 February 2015

Agenda Item 4b: Task 2 – Iono Analysis

IONOSPHERIC DELAY GRADIENT ANALYSIS WITH THE SINGLE-FREQUENCY CARRIER-BASED AND CODE AIDED METHOD

(Presented by Japan)

SUMMARY

This paper presents the requirements in accuracy of relative positions of GNSS reference receiver antennas to apply the single-frequency carrier-based and code-aided method for precise ionospheric gradient estimation.

1. Introduction

1.1 ENRI developed a method to estimate ionospheric delay differences between two GNSS receivers based on single-frequency carrier-phase and code measurements, which is called “single-frequency carrier-based and code-aided (SF-CBCA) method [1, 2]. This method has been proposed to be one of the methods of ISTF data analysis to derive ionospheric delay gradients.

1.2 The method assumes that the relative positions of the pair of the GNSS receiver antennas are precisely known.

1.3 This paper presents the criteria of the accuracy in relative positions of the pair of GNSS receiver antennas so that the SF-CBCA method can be applied to the data from them.

2. Discussion

2.1 The SC-CBCA method estimates the ionospheric delay differences between a pair of GNSS receivers of which relative positions are well known.

2.2 Observables are the single-differences (between receivers) of carrier-phase measurements and code measurements. Unknowns are the single-differences of ionospheric delay, receiver clock offsets, and the integer ambiguity in carrier-phase measurements. The first step solutions (float solutions) are estimated by Kalman filtering. The final solutions (fix solutions) of the single-difference of ionospheric delays are obtained by fixing the double-difference (between a pair of receivers and a pair of satellites) of the integer ambiguity of carrier-phase measurements.

2.3 To achieve the resolution of some millimeters in the ionospheric delay difference, it is expected that the relative positions of the receiver antennas would also be accurate at the similar scale.

2.4 Performance of the SC-CBCA method was tested with the data from the GBAS reference receivers installed at the New Ishigaki Airport. The ratio of epochs when fixed solutions were obtained to all the epochs (fix rates) were compared for different position errors artificially added to the well-surveyed positions.

2.5 It was found that relative position accuracy of 1.5 cm is required to obtain fix rates greater than 95 %.

2.6 Details of the method and the analysis results are given in the **Aattachment1.**

3. Action required by the Meeting

3.1 The meeting is invited to do the following:

a) note the requirements to the accuracy of relative positions of a pair of GNSS receiver antennas to derive ionospheric delay gradients with the SF-CBCA method; and

b) discuss any relevant matters as appropriate.

4. References

[1] Fujita, S., T. Yoshihara, and S. Saito, Determination of ionospheric gradients in short baselines by using single frequency measurements, J. Aero. Astro. Avi., A- 42, 269–275, 2010.

[2] Saito, S., S. Fujita, and T. Yoshihara, Precise measurements of ionospheric delay gradient at short baselines associ- ated with low latitude ionospheric disturbances, Proc. ION ITM 2012, 2012.

5. Attachment

[1] Single-frequency carrier-based and code-aided method to derive ionospheric delay gradients

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Single-frequency carrier-based and code-aided method to derive ionospheric delay gradients

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ISTF/5, Ishigaki, Japan, 16-18 February 2015

Outiline

- Single-frequency carrier-based and code-aided (SF-CBCA) method for ionospheric delay gradient estimation
- Required position accuracy of a pair of GNSS receivers to apply the SF-CBCA method to the data from them

SF-CBCA method (I)

- Fujita et al., J. Aero. Astro. Avi., 2011
  - Estimates TEC difference between two receivers
  - Based on single frequency carrier-phase measurements aided by code measurements
  - Robust and free from inter-frequency bias problem

Carrier-phase

$$\Phi^p = \overset{\text{geometric range}}{r^p} + \overset{\text{receiver clock bias}}{b} - \overset{\text{satellite clock bias}}{B^p} - \overset{\text{ionospheric delay}}{\delta I^p} + \overset{\text{phase ambiguity}}{\lambda N^p} + \underset{\text{random error}}{\epsilon^p_\Phi}$$

Code (pseudo-range)

$$\rho^p = r^p + b - B^p + \delta I^p + \underset{\text{random error}}{\epsilon^p_\rho}$$

Iono-free combination

$$L^p \equiv \frac{\Phi^p + \rho^p}{2}$$

Geometry-free single differences (SD) between receivers for each satellite

$$\underset{\text{observables}}{\boxed{\begin{array}{c}\tilde{\Phi}^p_{SD} \\ \\ \tilde{L}^p_{SD}\end{array}}} \quad \begin{array}{l} \equiv \Phi^p_{SD} - r^p_{SD} \\ = \underset{\text{unknowns}}{\boxed{b_{SD} - \delta I^p_{SD} + \lambda N^p_{SD}}} + \epsilon^p_{\Phi,SD} \\ \equiv L^p_{SD} - r^p_{SD} \\ = \underset{\text{unknowns}}{\boxed{b_{SD} + \frac{\lambda}{2} N^p_{SD}}} + \frac{\epsilon^p_{\Phi,SD} + \epsilon^p_{\rho,SD}}{2} \end{array}$$

SF-CBCA method (2)

$$\begin{bmatrix}\tilde{\mathbf{\Phi}}_{SD}\\ \tilde{\mathbf{L}}_{SD}\end{bmatrix} = \begin{bmatrix}\mathbf{1} & -\mathbf{I} & \lambda\mathbf{I}\\ \mathbf{1} & \mathbf{O} & \lambda\mathbf{I}\end{bmatrix}\begin{bmatrix} b_{SD}\\ \delta\mathbf{I}_{SD}\\ \mathbf{N}_{SD}\end{bmatrix} + \begin{bmatrix}\epsilon_{\Phi,SD}\\ \frac{\epsilon_{\Phi,SD}+\epsilon_{\rho,SD}}{2}\end{bmatrix}$$

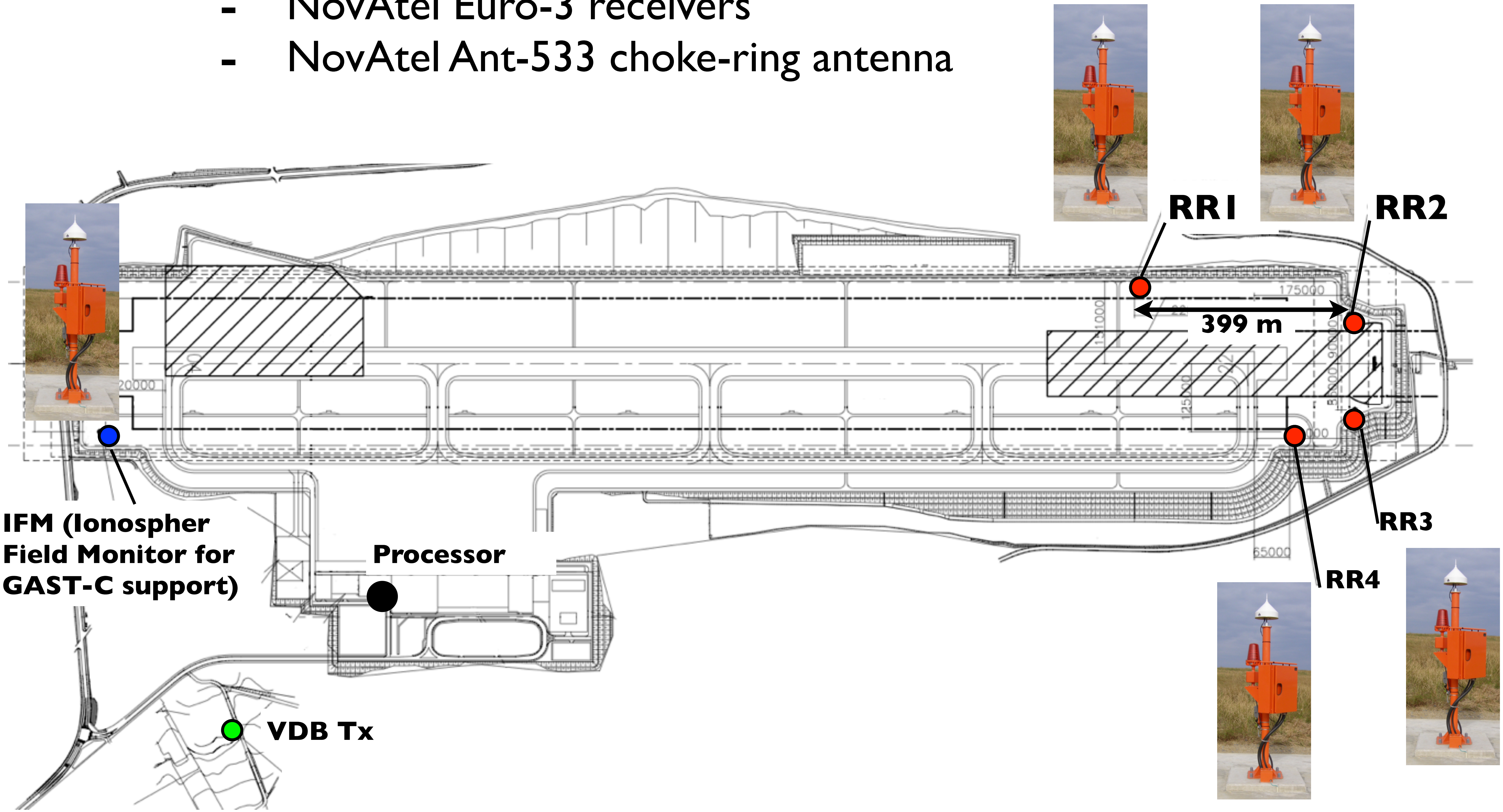
- SDs of clock bias, ionspheric delays and carrier-phase ambiguities are solved with Kalman filtering
  - Real number (float-value) solutions are obtained.

$$[b_{SD,float}, \delta\mathbf{I}_{SD,float}, \mathbf{N}_{SD,float}] \rightarrow [b_{SD,float}, \delta\mathbf{I}_{SD,fix}, \mathbf{N}_{DD,fix}]$$

- DDs of carrier-phase ambiguity should be integer values.
- Ambiguity values are fixed to integer values with the LAMBDA (Least-square ambiguity decorrelation adjustment) method.
  - Clock biases and Ionospheric delays are modified with the integer ambiguity values

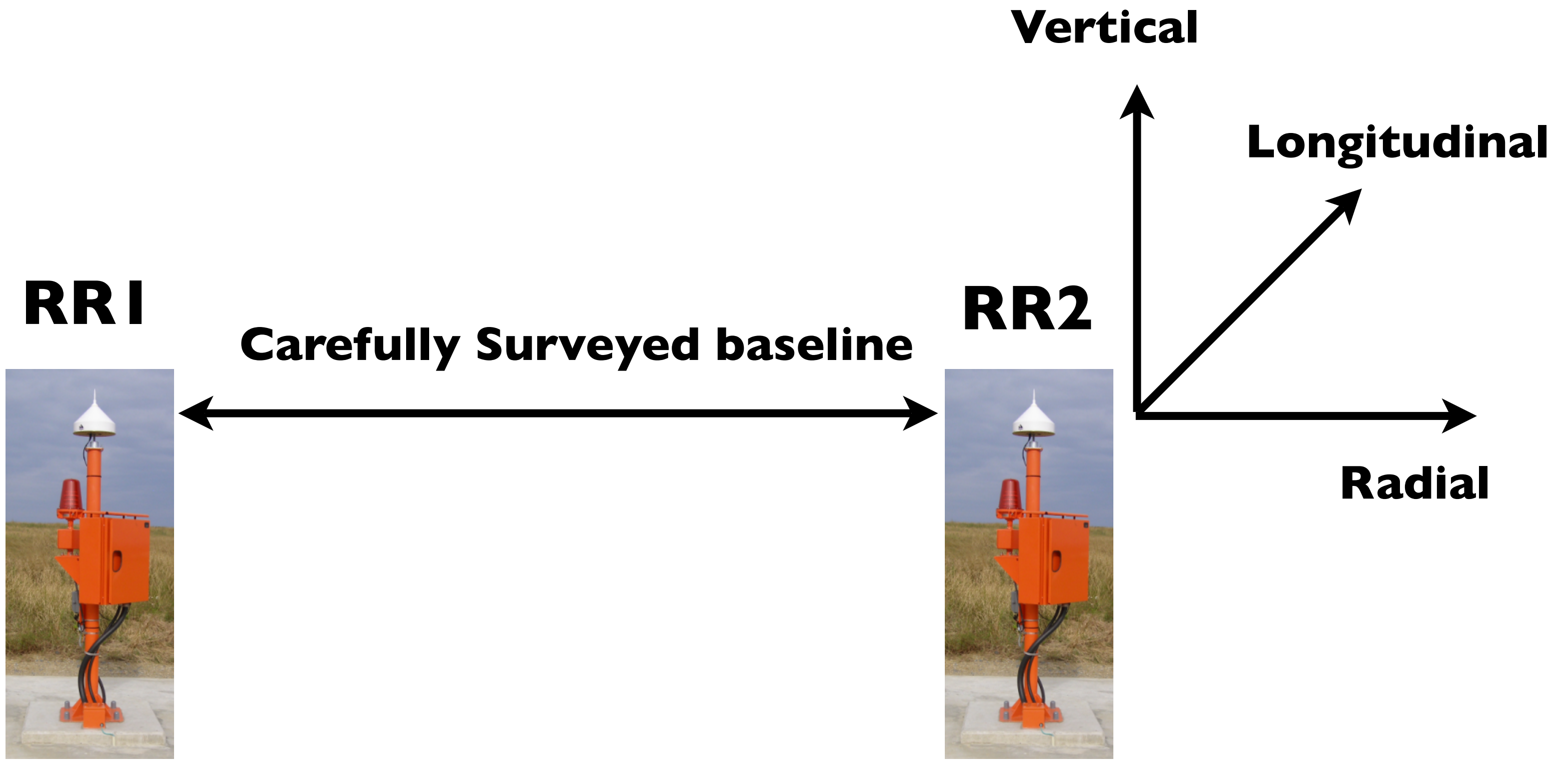
Data

- Two reference receivers (RR1 and RR2) of GAST-D (GBAS service type D) prototype at New Ishigaki Airport
  - NovAtel Euro-3 receivers
  - NovAtel Ant-533 choke-ring antenna



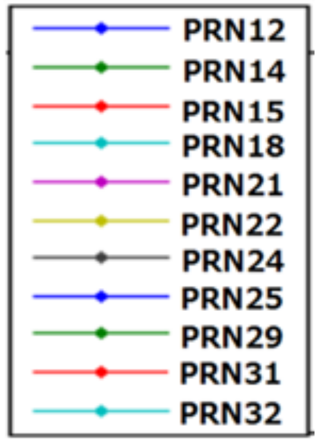
Evaluation methodology

- Add artificial position errors in three orthogonal directions
  - along-baseline, cross-baseline, and vertical
- Evaluation parameter
  - Fix rate = (# of epochs with fix solutions)/(# of all epochs)
  - Ratio test threshold: 3

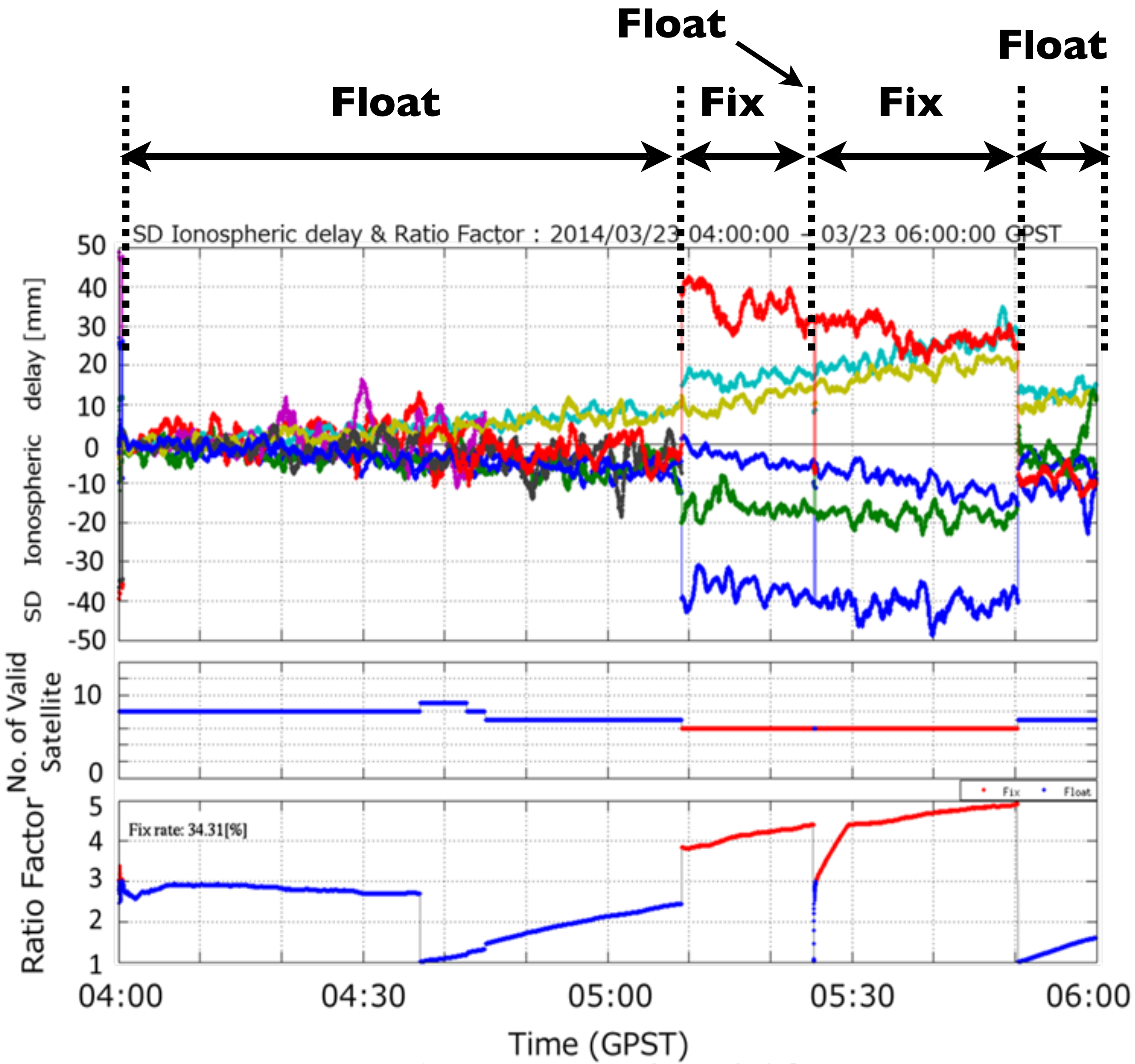


Example of results

Estimated ionospheric delay differences (RR1 - RR2)
04-06 GPST on 23 March 2014

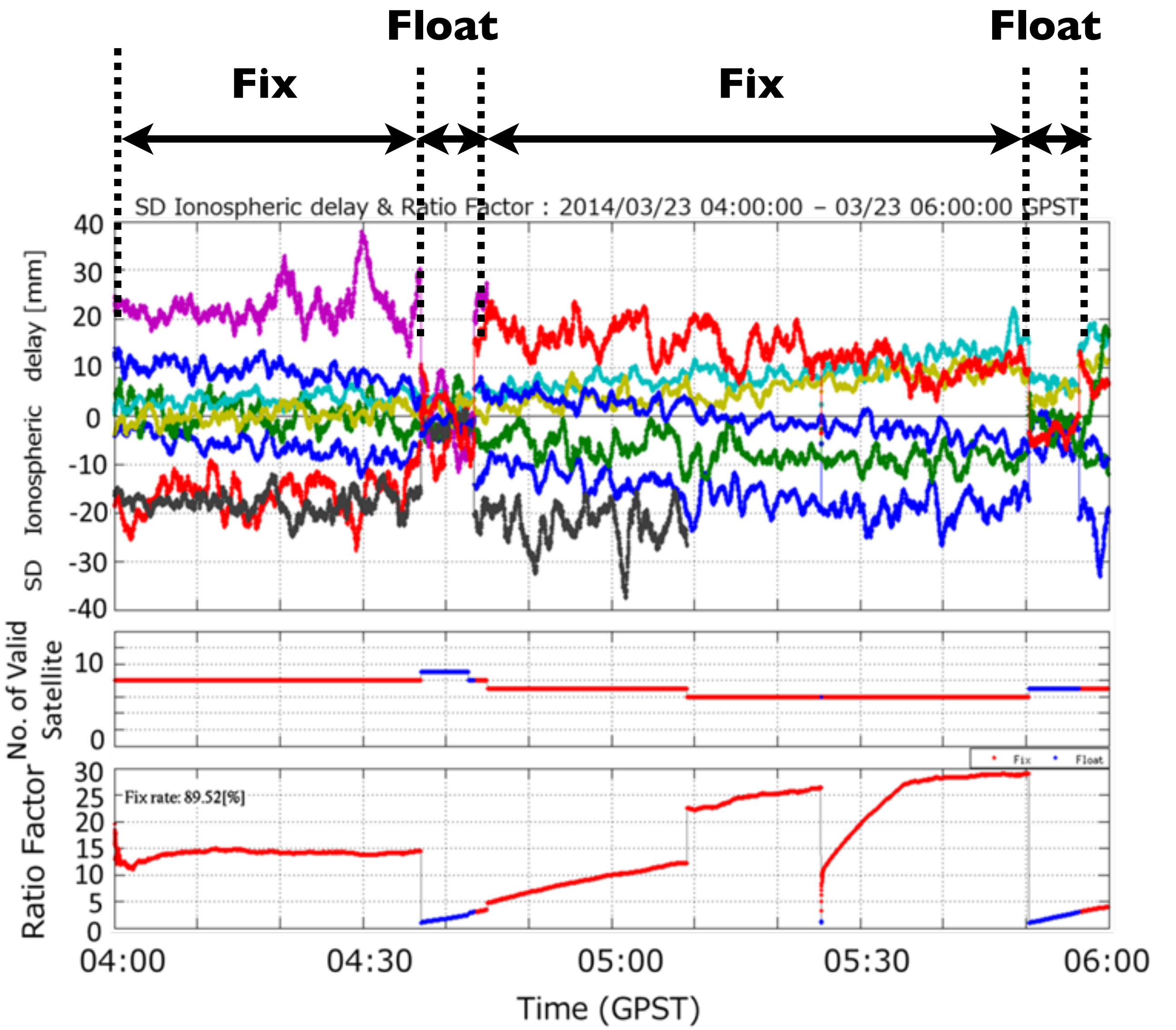


radial position error: +5cm


Float
Float
Fix
Fix
Float

Fix rate: 34.3%

radial position error: +2cm


Float
Float
Fix
Fix

Fix rate: 89.5%

Baseline errors and fix rates

Fix Rate	Radial error	Longitudinal error	Vertical error
95%	1.5cm	1.5cm	3.5cm
90%	2.3cm	2.2cm	5.2cm
80%	3.8cm	3.3cm	7.8cm

- Fix rate is relatively insensitive to vertical error
- Fix rate may not only the parameters to evaluate performance
  - Offsets and standard deviations
  - Cross-check with dual-frequency TEC difference (assuming zero mean TEC difference)