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

EXTREME IONOSPHERIC DELAY GRADIENT ASSOCIATED WITH PLASMA BUBBLE

(Presented by Japan)

SUMMARY

This paper presents results of analysis of an extreme ionospheric gradient event associated with a plasma bubble observed over Ishigaki, Japan. This paper also introduces how to estimate ionospheric threat model parameters relevant to GBAS.

1. Introduction

1.1 Plasma bubble is known to have extremely large ionospheric delay gradient.

1.2 To evaluate the ionospheric delay gradient associated with plasma bubbles, Electronic Navigation Research Institute (ENRI) is conducting ionospheric gradient observations with short baselines (80-1,551 m) in Ishigaki (24.3ºN, 124.2ºE, 19.6º Mag. Lat), Japan since 2008.

1.3 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].

1.4 This paper presents characteristics of an extreme gradient associated with a plasma bubble in terms of parameters relevant to GBAS ionospheric threat model.

2. Discussion

2.1 Associated with plasma bubbles which occurred on 8 April 2008, an extreme ionospheric delay gradient was observed. The maximum gradient was estimated as 518 mm/km with the SF-CBCF method [2]. This value exceeds the maximum gradient value that was used in the technical validation of the development baseline SARPs for GBAS service type D (GAST-D).

2.2 Characteristics of the extreme ionospheric gradient associated with the plasma bubble were examined with different method. The results are summarized as follows:

1) onospheric delay differences derived with dual-frequency linear combination, the maximum ionospheric delay gradient could be at least 818 mm/sec, although the results may be influenced by cycle-slips and inter-frequency bias.

2) Eastward velocity of the gradient derived from the time-lags of temporal variation of ionospheric delays observed at the sites is estimated to be 80 - 200 m/sec.

3) Scale size is estimated to be 7 km.

4) Depth of the plasma bubble is about 4.8 m, and that of the steepest part is about 2.4 m.

5) Reconstructed ionosperic delay gradient (1 min average) is estimated to be 380 mm/km.

6) Considering the results 1-4 above, the extreme ionospheric gradient of 518 mm/km derived by SF-CBCA method is considered to be real.

2.3 Important findings are the very large ionospheric gradient (518 mm/km) and the smaller scale size (7 km). Both are outside the ranges of values used in the technical validation of [3]. Large gradient may result in large range error. Gradients with smaller spatial scale may be detected neither by the ground nor the air.

2.4 The parameters estimated in this analysis is all relevant to GBAS ionospheric threat model. Detailed analysis and results are presented in the **Attachment 1** to this working paper.

3. Action required by the Meeting

3.1 The meeting is invited to do the following:

a) note the characteristics of the ionospheric delay gradient associated plasma bubble;

b) consider the analysis methodology as candidates of method to derive GBAS ionospheric threat model; and

c) 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.

[3] GBAS CAT II/III Development Baseline SARPs, ICAO Navigation Systems Panel Working Group of the Whole, 2010.

5. Attachment

[1] Extreme ionospheric gradient associated with plasma bubbles.

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Extreme ionospheric gradient associated with plasma bubble

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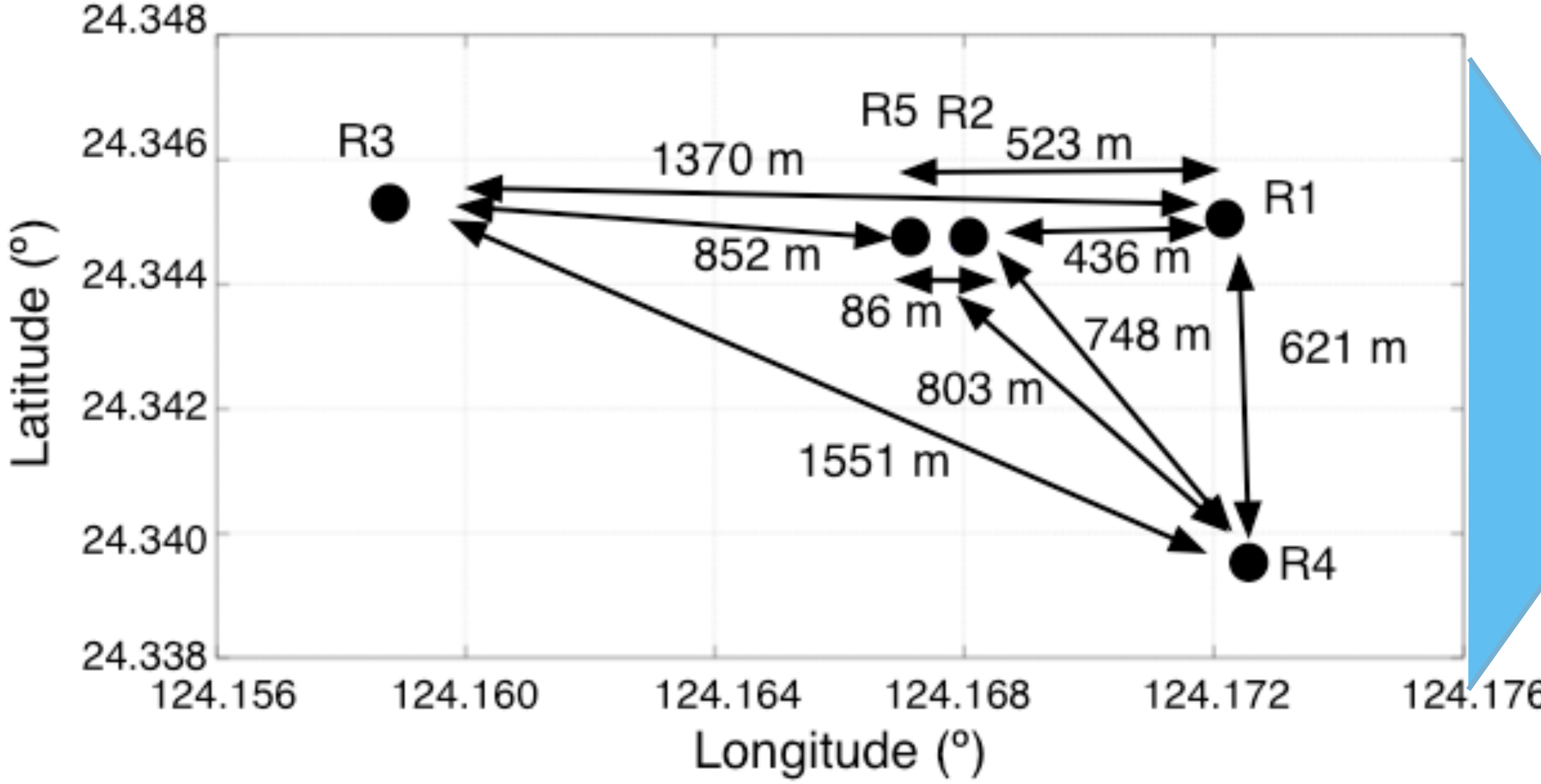
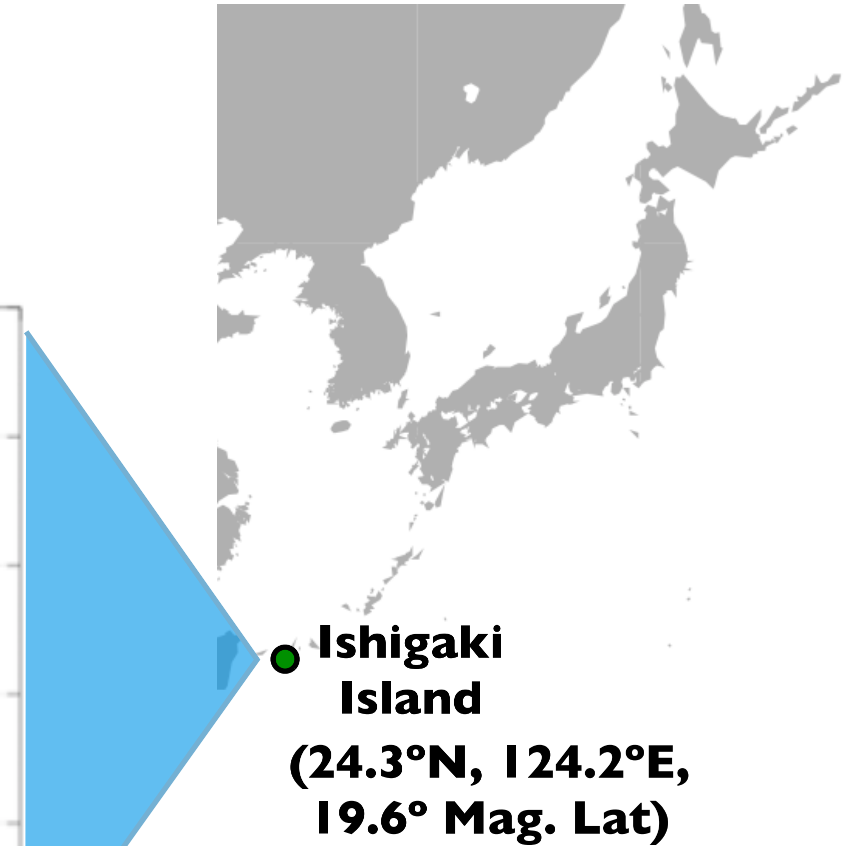
Outiline

* An extreme ionospheric gradient of 518 mm/km was observed in a plasma bubble event on 3 April 2008 at Ishigaki, Japan.
* Characteristics of this extreme event are further investigated.
  - Single-frequency carrier-based code-aided (SF-CBCA) gradient estimation
  - Dual-frequency ionospheric delay measurements
  - Velocity estimation
  - Spatial scale estimation

Observation setup



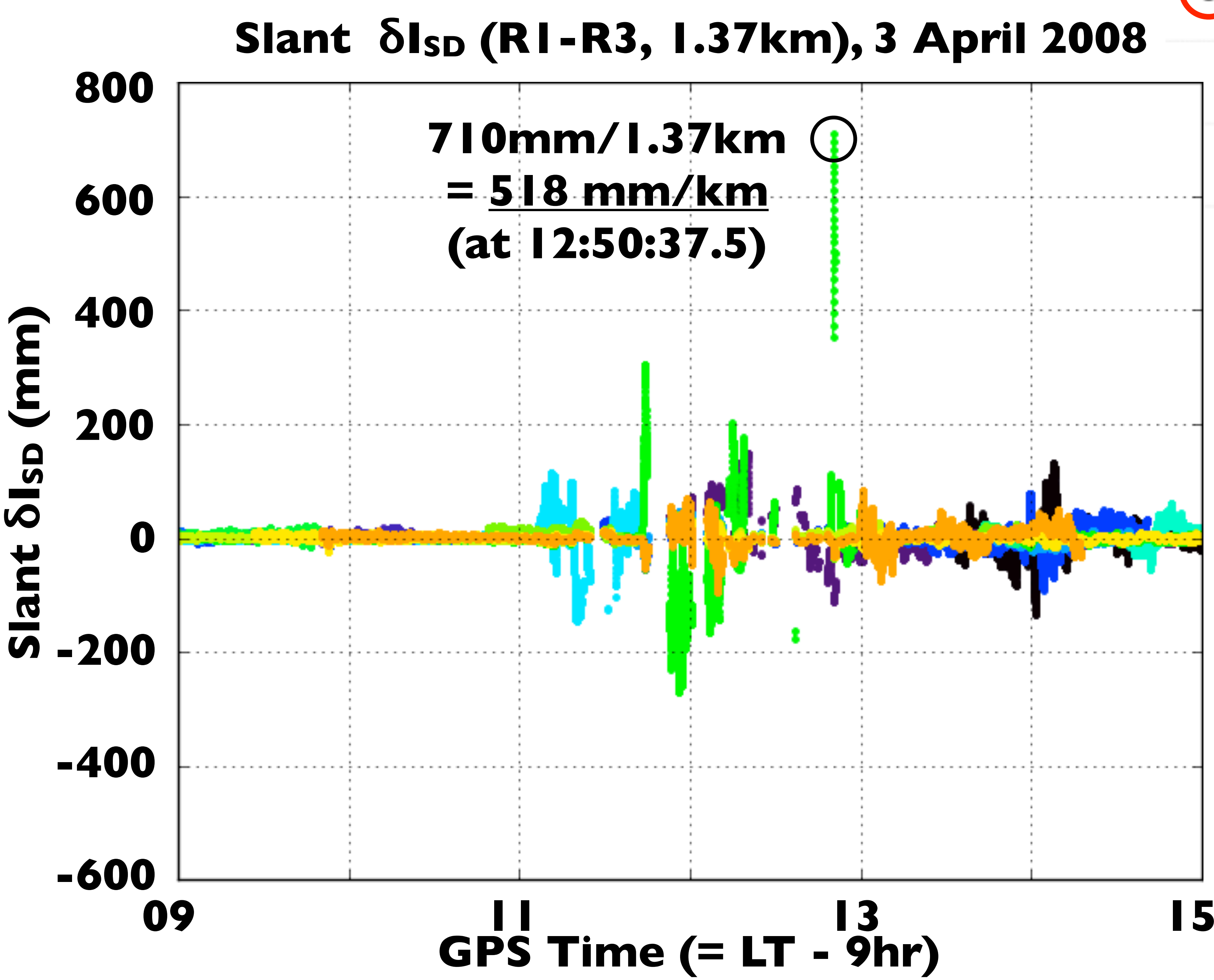


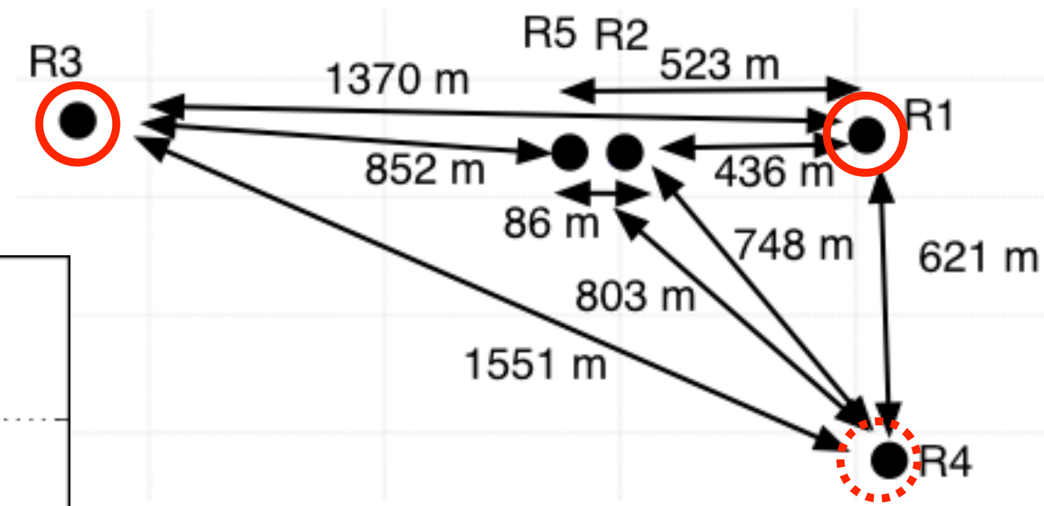
- Ishigaki Island in Southwest Japan (19.6° magnetic latitude) since 2008
- Five stations with distances 0.4-1.6 km
- Equipments
  - Receiver: NovAtel Euro-3, 2 Hz sampling
  - Antenna: NovAtel GPS-702-GG

Receiver system

Antenna

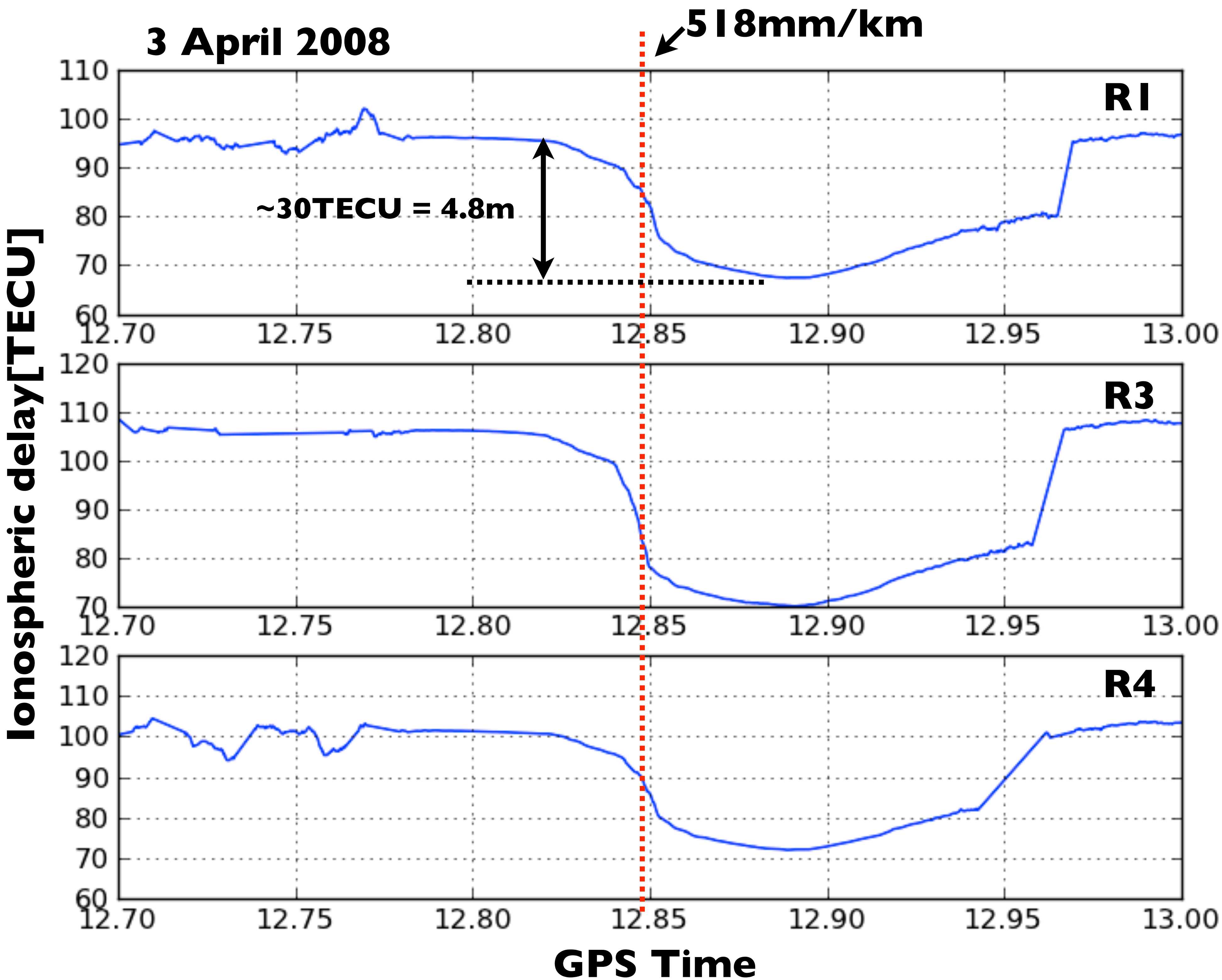
Single-frequency gradient estimation



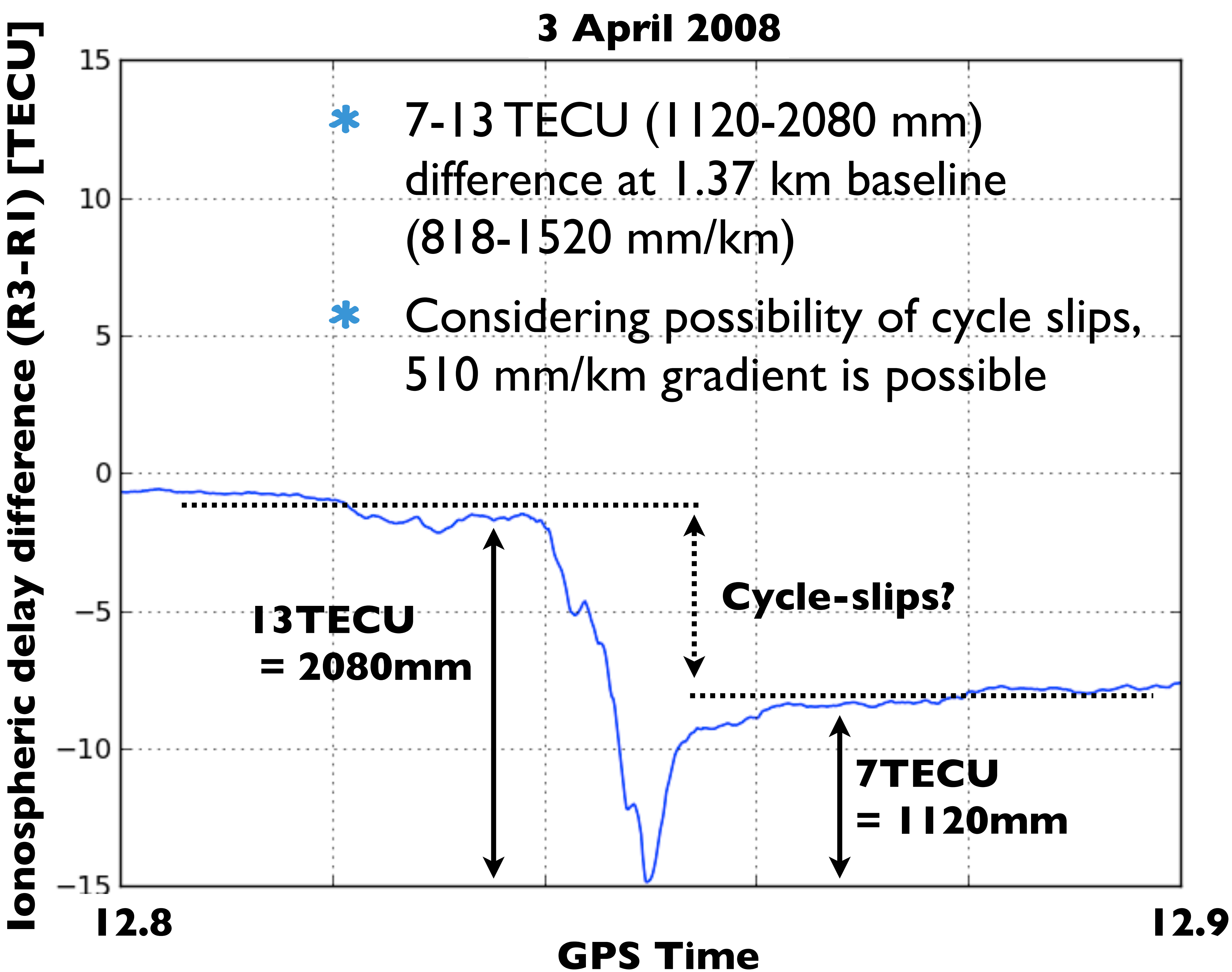


- Estimated by the single-frequency carrier-phase based and code-aided technique [Fujita et al., J. Aero. Astro. Avi., 2010]
- Ambiguity resolution is assured by consistency check with redundant measurements [Saito et al., ION GNSS 2012]

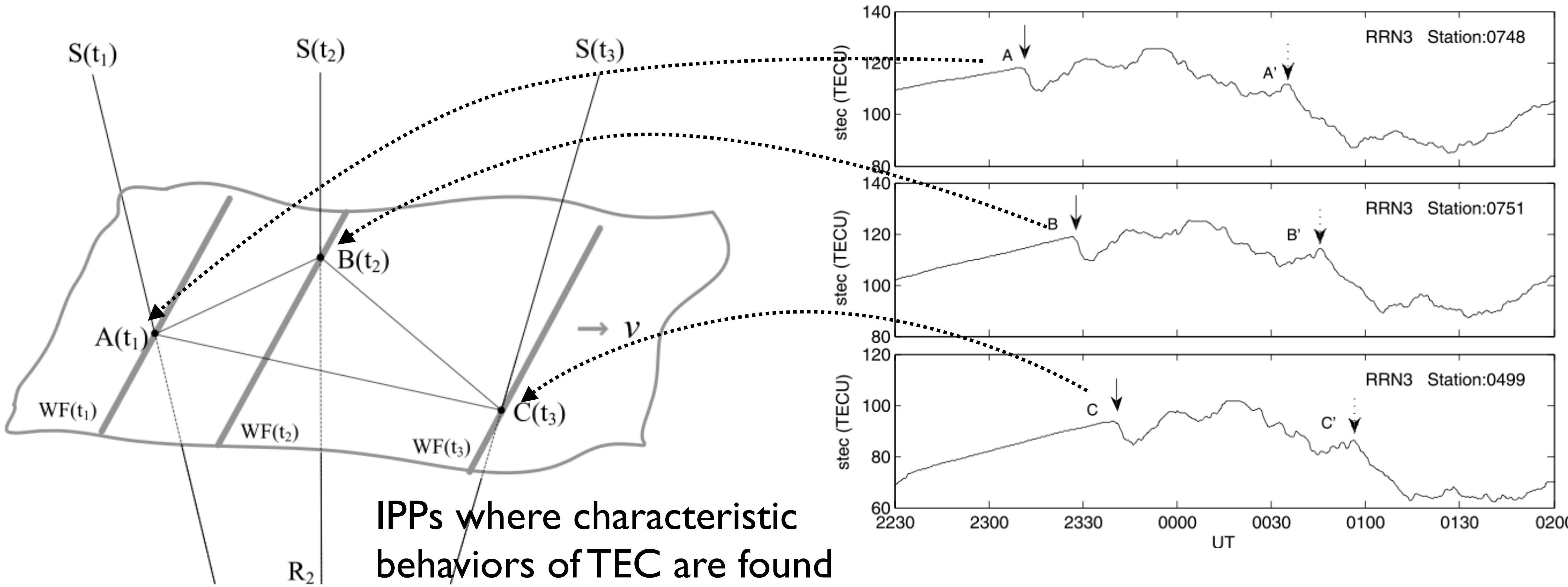
Dual-frequency results



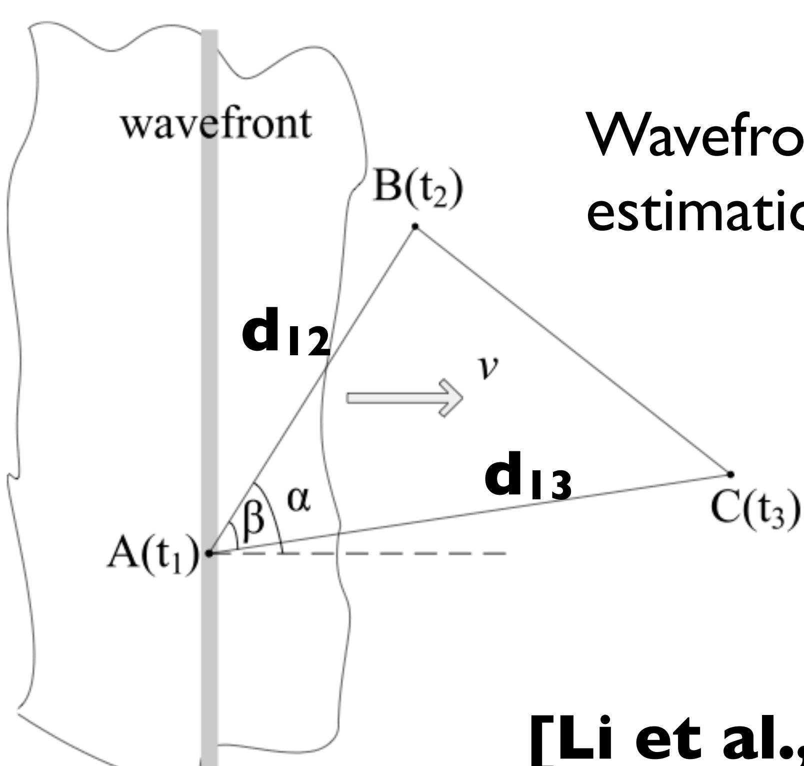
Gradient derived by dual-frequency measurements



Velocity Estimation



IPPs where characteristic behaviors of TEC are found



Wavefront and velocity estimation

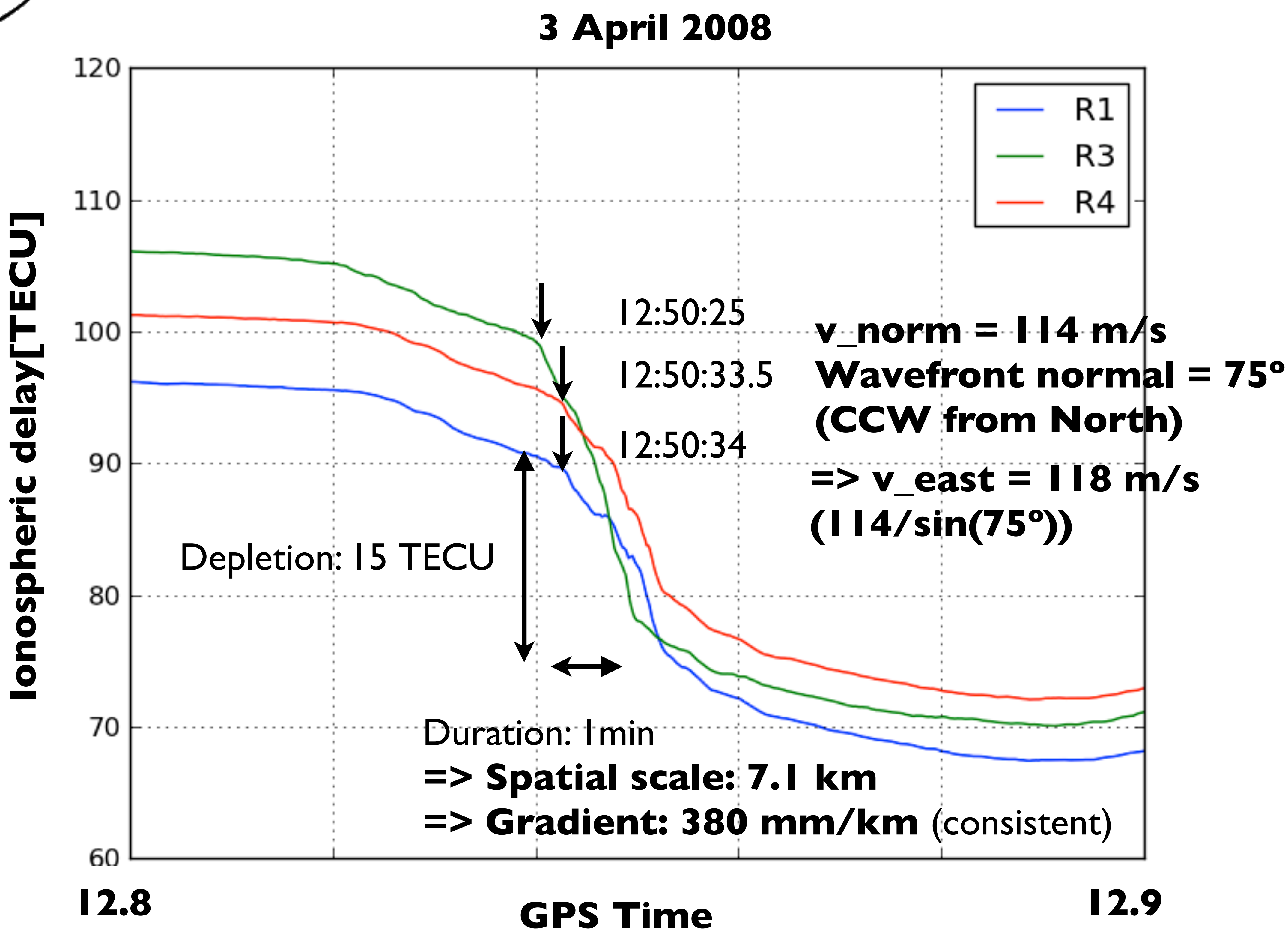
$$v = \frac{d_{12} cos\alpha}{t_2 - t_1}$$

$$v = \frac{d_{13} cos(\alpha - \beta)}{t_3 - t_1}$$

$$\rightarrow v, \alpha$$

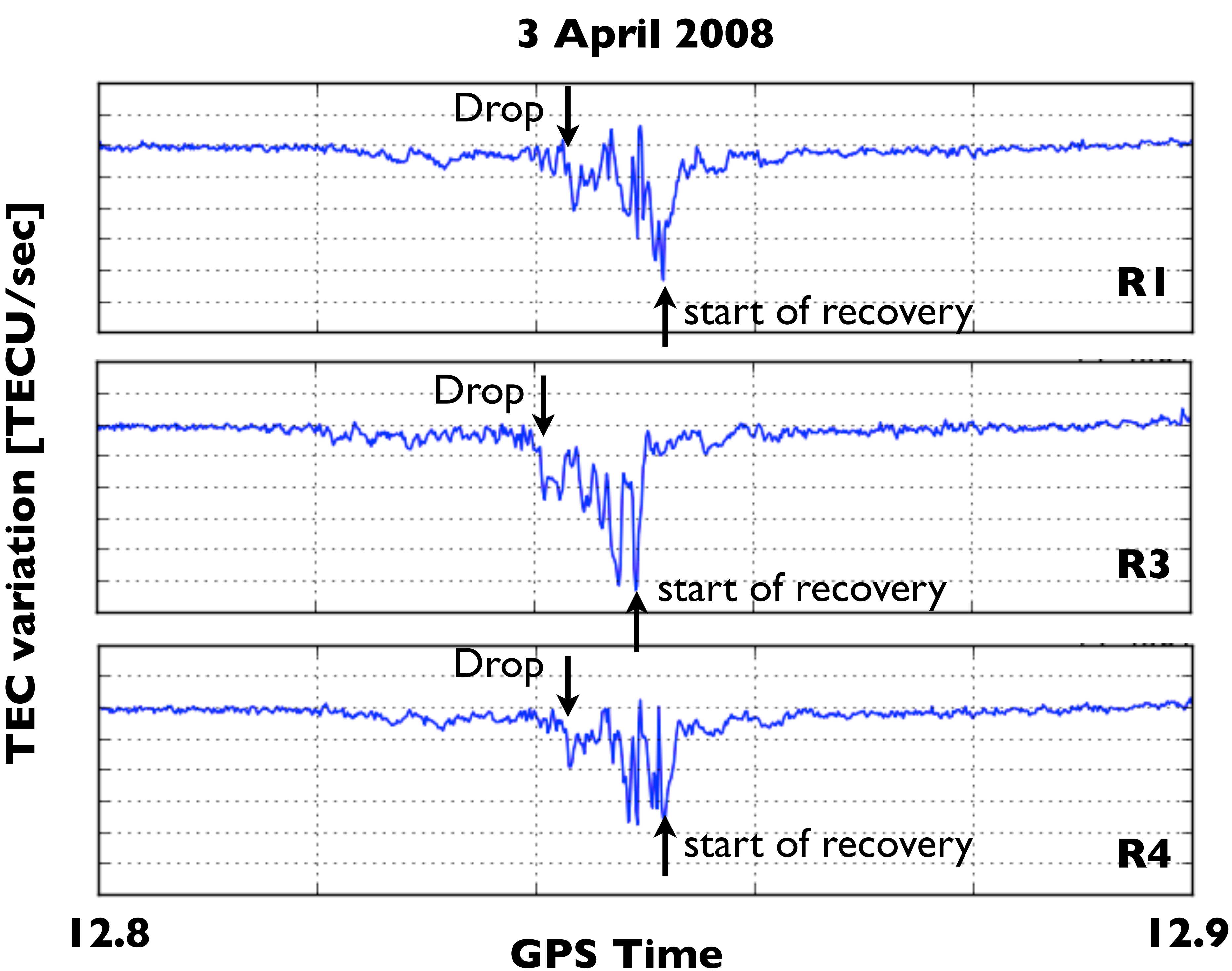
[Li et al., J. Geophys. Res., 2012]

Characteristic Points with TEC variation



* Not easy to determine the characteristic points

Characteristic Points with TEC variation rate (AATR)



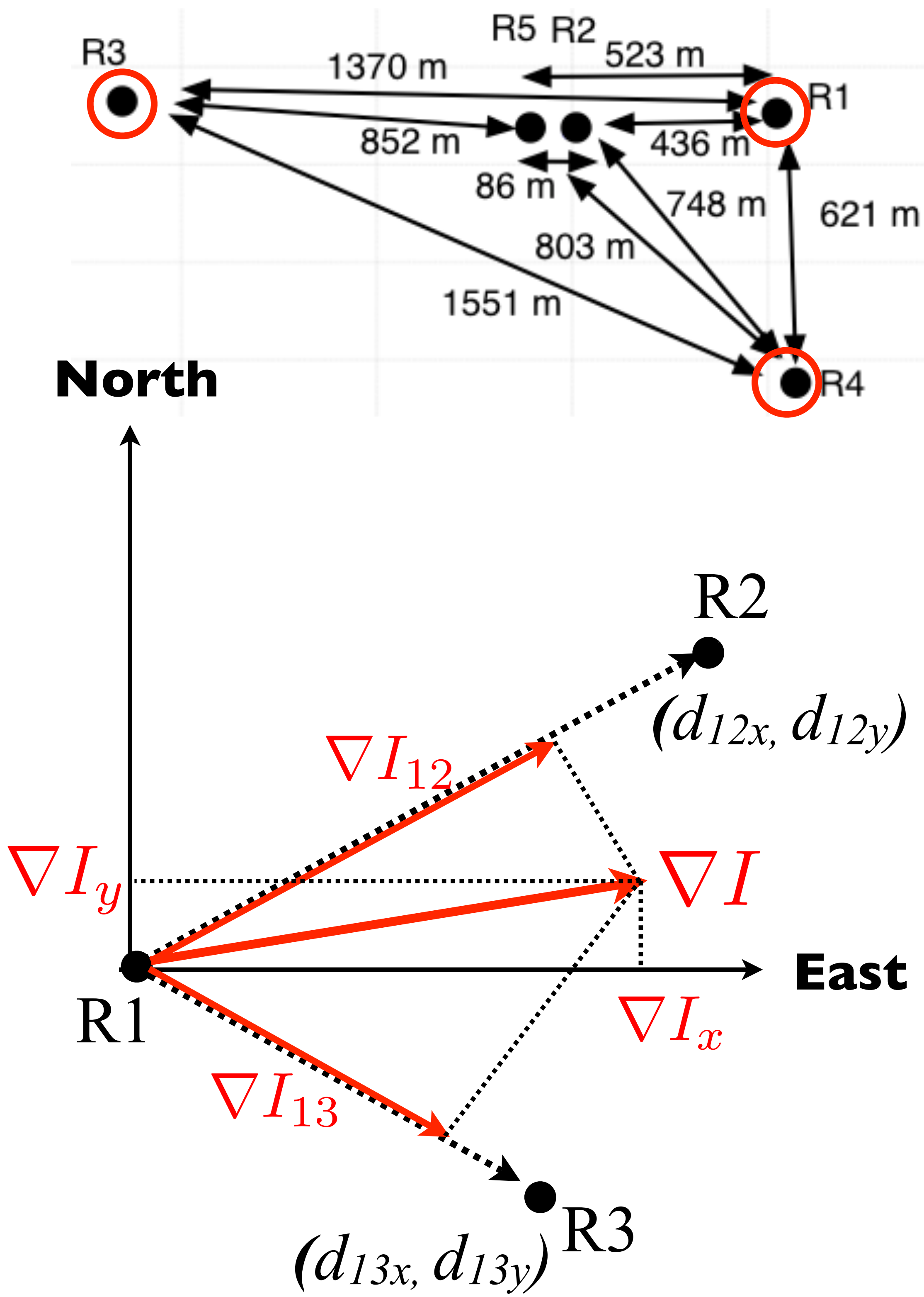
AATR Drop
- R1: 12:50:34.5
- R2: 12:50:25.5
- R3: 12:50:33.5

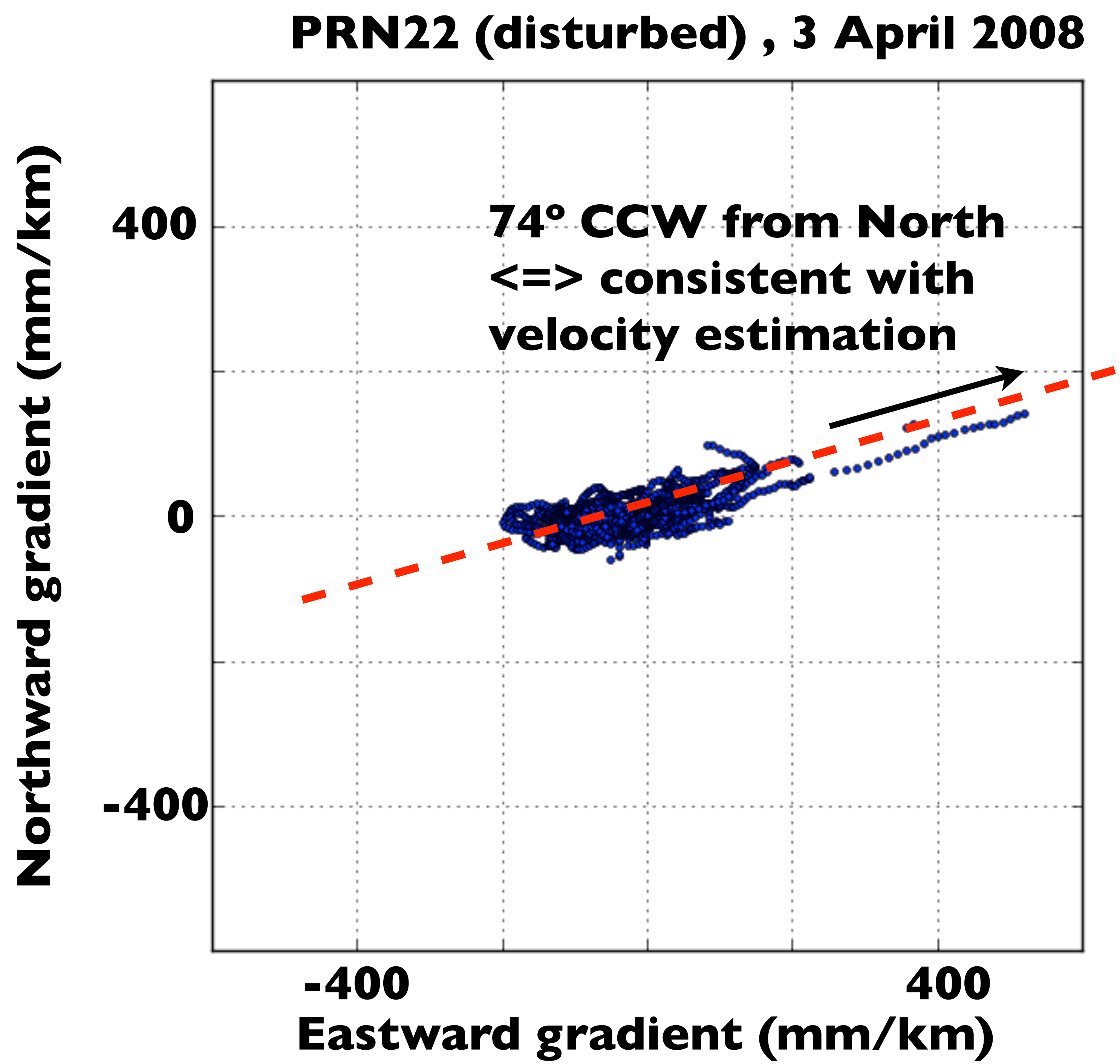
Start of AATR recovery
- R1: 12:51:05.5
- R2: 12:50:57
- R3: 12:51:06

Velocity estimation with TEC variation rate (AATR)

* AATR drop points (close to the time of largest gradient)
  - v_norm = 76 m/s
  - wavefront normal = 67°
  - v_east = 83 m/s (= 76/sin(67°))
* Start of AATR recovery points
  - v_norm = 203 m/s
  - wavefront normal = 94°
  - v_east = 203 m/s (= 203/sin(94°))
* Very sharp TEC drop occurred in about 1 min
  - Spatial scale: 4.6-12.2 km
  - Gradient (1 min average): 200-521 mm/km
    - ➡ Obtained gradient is consistent with those obtained with other methods

Gradient vector obtained by SF-CBCA





Summary

* An extreme ionospheric gradient of 518 mm/km observed in a plasma bubble event on 3 April 2008 at Ishigaki, Japan was further investigated by using dual-frequency data.
  - Dual-frequency ionospheric delay difference results support the plausibility of the large gradient
  - Wavefront direction and velocity were estimated by using temporal variation patterns of ionospheric delay
    - Eastward velocity: 105 m/s
      - Wavefront normal direction is consistent with the direction of gradient
    - Spatial scale: 6.3 km
    - Reconstructed gradient: 380 mm/km (1 min average)
* The ionospheric gradient of 518 mm/km observed in a plasma bubble event on 3 April 2008 at Ishigaki, Japan is quite plausible.