X-RAY FLARE EFFECT ON GNSS VARIOMETRIC IN INDONESIA

Buldan Muslim[1], Asnawi[1], Anwar Santosa[1], Dyah R.M., M. Nur Cahyadi[2], Ririn Wuri Rahayu[2]

1

2

Space Science Center, LAPAN, Indonesia

Sepuluh Nopember Institute of Technology

X-RAY FLARE EFFECT ON GNSS VARIOMETRIC IN INDONESIA

The Important of the Topic:

1. **To date, one of the promising GNSS application for seismology is GNSS Variometric**
2. **This technique has been patented by Colosimo Gabriela (2010) and commercialized with the Leica VADASE product**
3. **As an institution engaged in research and space weather services we need to anticipate and identify the need for space weather information for GNSS seismology users using variometric technique**

Outline

1. Introduction
- Conventional GNSS application problems for earthquake monitoring
- GNSS Variometric can provide the solution
2. Data and Methodology
- X - Ray Flare
- Earthquake
- GNSS Rinex
- GNSS Variometric approach
3. Results and Discussion
4. Conclusion and Recommendation

1. INTRODUCTION:

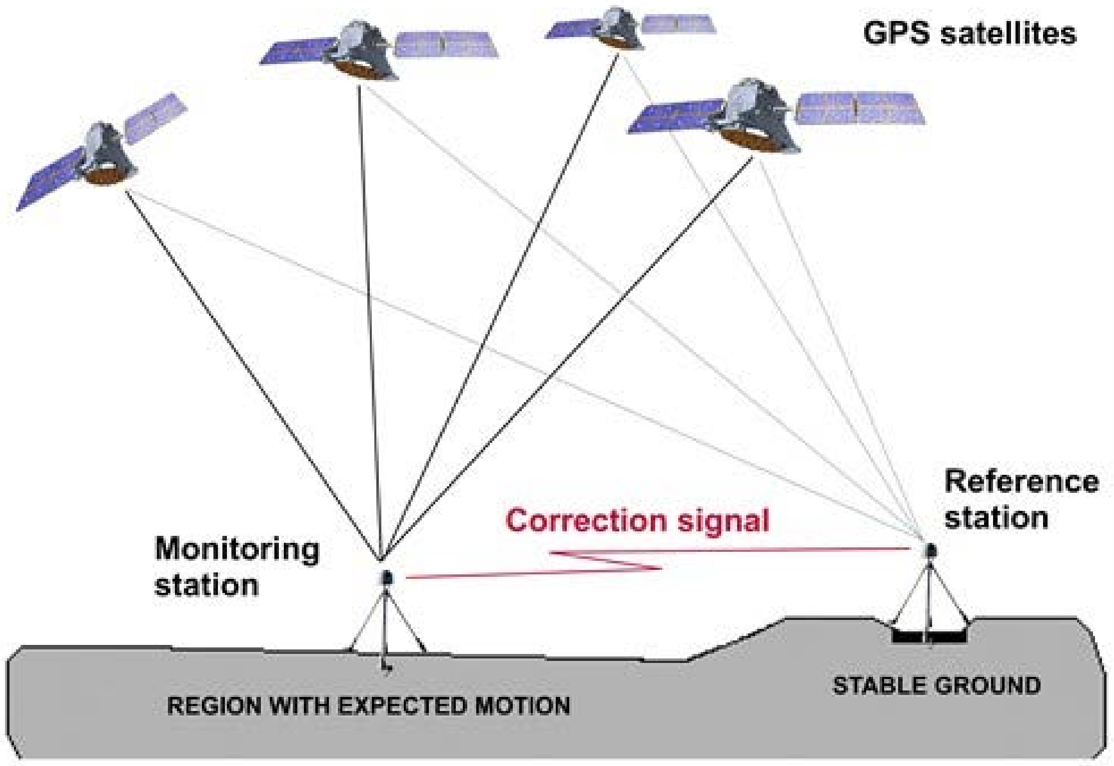
Two main approaches of GNSS positioning (Conventinal Methods)

- **Relative Positioning (Spatial Differential GNSS)**

  (used 2 GPS receiver (DGPS), Networked DGPS >=2)

- **Point Positioning (1 Receiver)**

Differential GNSS Conventional Problems for Earthquake Detection



- RS and MS experience displacements to some extend due to the same seismic event. The displacements estimated are affected by the displacement of the fixed station.
- May not be appropriate, in some cases, for earthquake monitoring, especially for large earthquakes.

GNSS PPP Conventional Method for Earthquake Detection

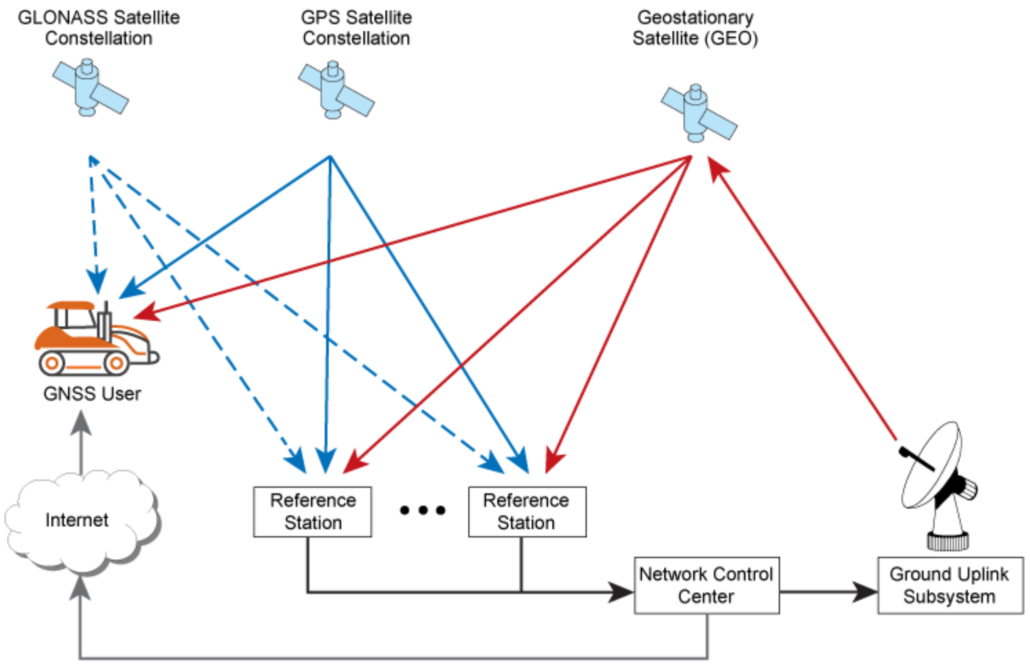


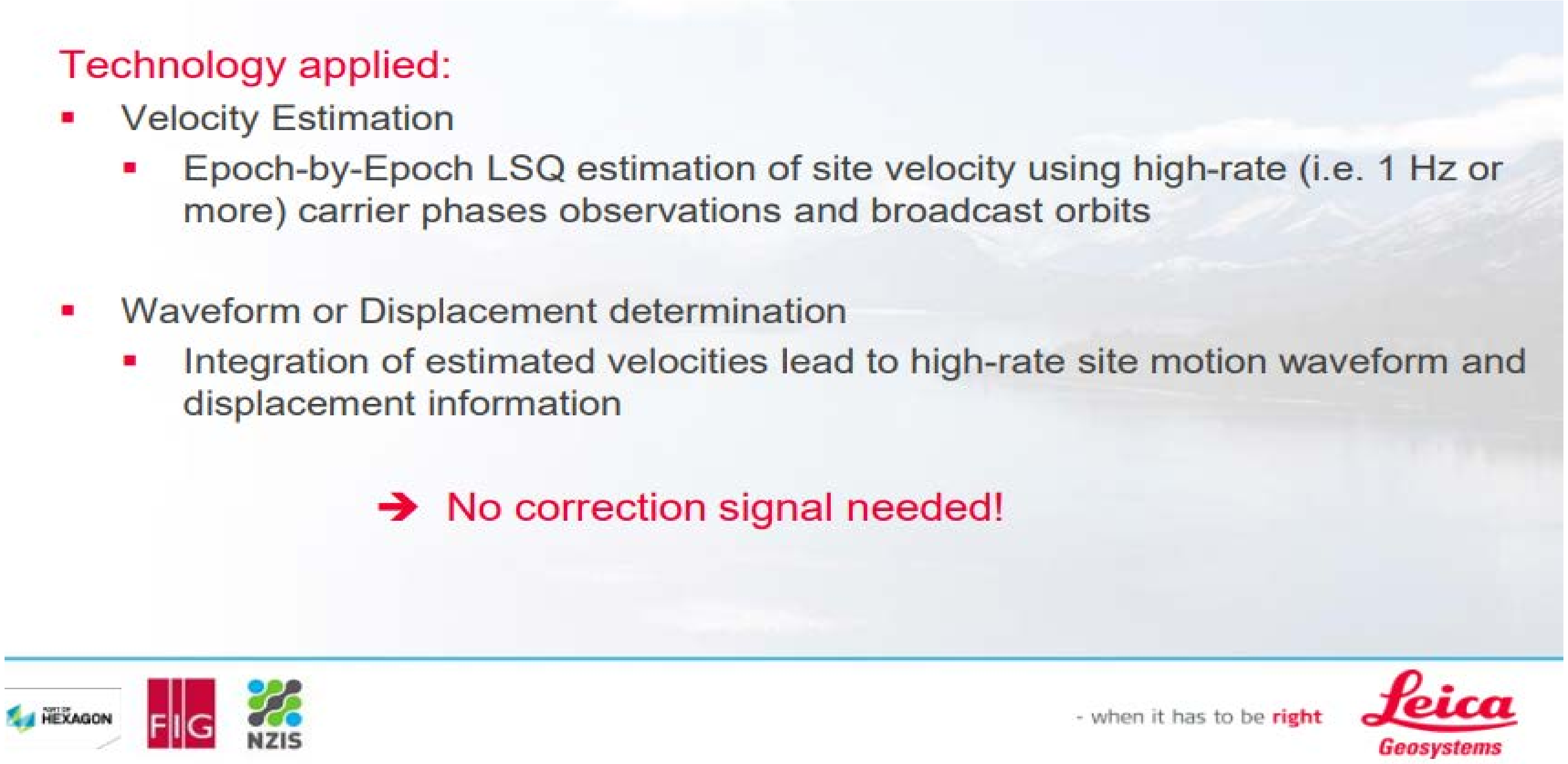
Figure 43 Precise Point Positioning (PPP) System Overview

- PPP can provide dynamic position estimation at millimeter to centimeter level accuracy with only a single GNSS receiver, and has been used as an effective approach to monitor displacements induced by earthquakes [Kouba, 2003]. However, conventional high-precision PPP depends on precise satellite orbits and clocks instead of the broadcast navigation ephemeris. The PPP problems for real time application: accuracy and convergence time.

GNSS Variometric Provide Solution

- **Measurement of variation of GNSS position between epoch / velocity variation, not a position**
- **Differential GNSS in time, not of those used for Spatial Differential GNSS**

Variometric Solution for GNSS seismology



https://www.fig.net/resources/proceedings/fig_proceedings/fig2016/ppt/ts07b/TS07B_ashcroft_tawk_et_al_7952_ppt.pdf

GNSS Variometric errors

Temporal variation of ionosphere (ΔTEC)
ΔTEC, Δtroposphere model, Δorbit, Δsatelit clock error, and Δreceiver clock errors, etc

X-ray flare effect on ionosphere is sudden ionospheric disturbance, suddeng increasing of ΔTEC after x-ray flare (8 menit)

Objective

Find out the contribution of x-ray effect on GNSS variometric level errors and its comparison with level of site displacement due to earthquake

2. DATA AND METHODOLOGY

DATA:

- GNSS RINEX (sopac)
- NTB Earthquake and Tohoku Earthquake
- X-ray flare during October 23-Nopember 3, 2003

GNSS Variometric from Carrier Phase Data

$$\lambda\Phi_r^s = \rho_r^s + c\left(\delta t_r - \delta t^s\right) + T_r^s - I_r^s + N_r^s + b^s + b_r + m_r^s + \varepsilon_r^s$$

$$\left[\lambda\Phi_r^s(t+1)\right] - \left[\lambda\Phi_r^s(t)\right]$$
$$= \rho_r^s(t+1) - \rho_r^s(t+1) + c\left(\delta t_r(t+1) - \delta t_r(t)\right) - c\left(\delta t^s(t+1) - \delta t^s(t)\right) + T_r^s(t+1) - T_r^s(t) - \left(I_r^s(t+1) - I_r^s(t)\right)\ldots$$

$$\left[\lambda\Delta\Phi_r^s\right] = \Delta\rho_r^s + c\left(\Delta\delta t_r - \delta t^s\right) + \Delta T_r^s - \Delta I_r^s + \Delta N_r^s + \Delta b^s + \Delta b_r$$

$$\Delta\rho_r^s = \Delta\rho_{r\,OR}^s + \Delta\rho_{r\,EtOl}^s + \vec{e}_r^{\,s} \cdot \xi_r^s$$

$$\left[\lambda\Delta\Phi_r^s\right] = \vec{e}_r^{\,s}\xi_r^s + c\Delta\delta t_r + \Delta\rho_{r\,OR}^s - c\Delta\delta t^s + \Delta T_r^s - \Delta I_r^s + \Delta\rho_{r\,EtOl}^s$$

$$\left[\lambda\Delta\Phi_r^s\right] = \vec{e}_r^{\,s}\xi_r^s + c\Delta\delta t_r + \Delta\rho_{r\,OR}^s - c\Delta\delta t^s + \Delta T_r^s - \Delta I_r^s$$

Variometric using Carrier Phase Data

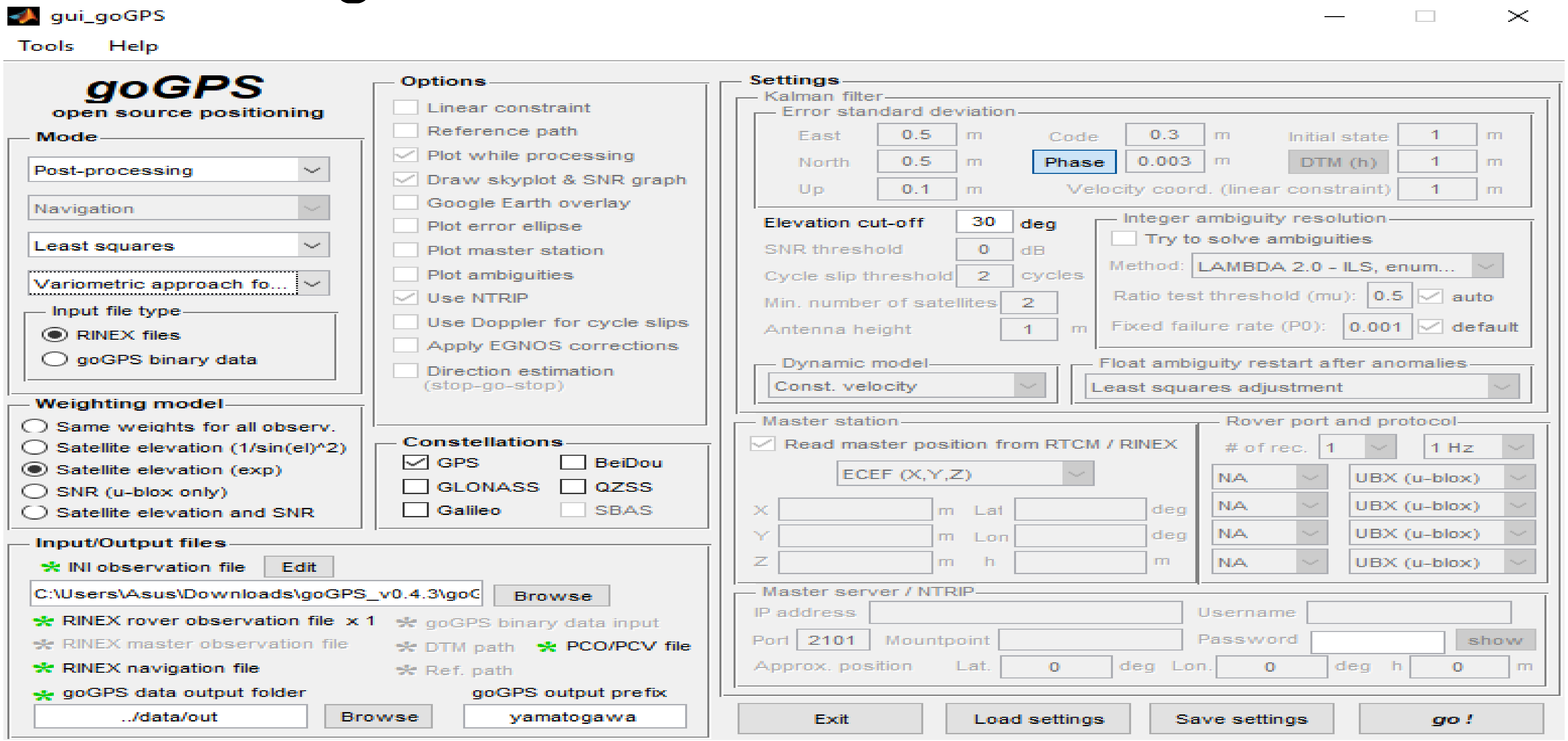
$$y_{n+1} = \begin{bmatrix} [\lambda\Delta\Phi_r^1] \\ [\lambda\Delta\Phi_r^2] \\ [\lambda\Delta\Phi_r^3] \\ \vdots \\ [\lambda\Delta\Phi_r^n] \end{bmatrix} \qquad A_{n+4} = \begin{bmatrix} e_{rX}^1 & e_{rY}^1 & e_{rZ}^1 & 1 \\ e_{rX}^2 & e_{rY}^2 & e_{rZ}^2 & 1 \\ \vdots & \vdots & \ddots & \vdots \\ e_{rX}^n & e_{rY}^n & e_{rZ}^n & 1 \end{bmatrix} \qquad x_4 = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \\ \Delta\delta t_r \end{bmatrix} \qquad b = \begin{bmatrix} [\Delta\rho_r^1]_{OR} + \Delta T_r^1 - c\Delta\delta t^1 \\ [\Delta\rho_r^2]_{OR} + \Delta T_r^2 - c\Delta\delta t^2 \\ \vdots \\ [\Delta\rho_r^n]_{OR} + \Delta T_r^n - c\Delta\delta t^n \end{bmatrix}$$

$$y = Ax + b$$

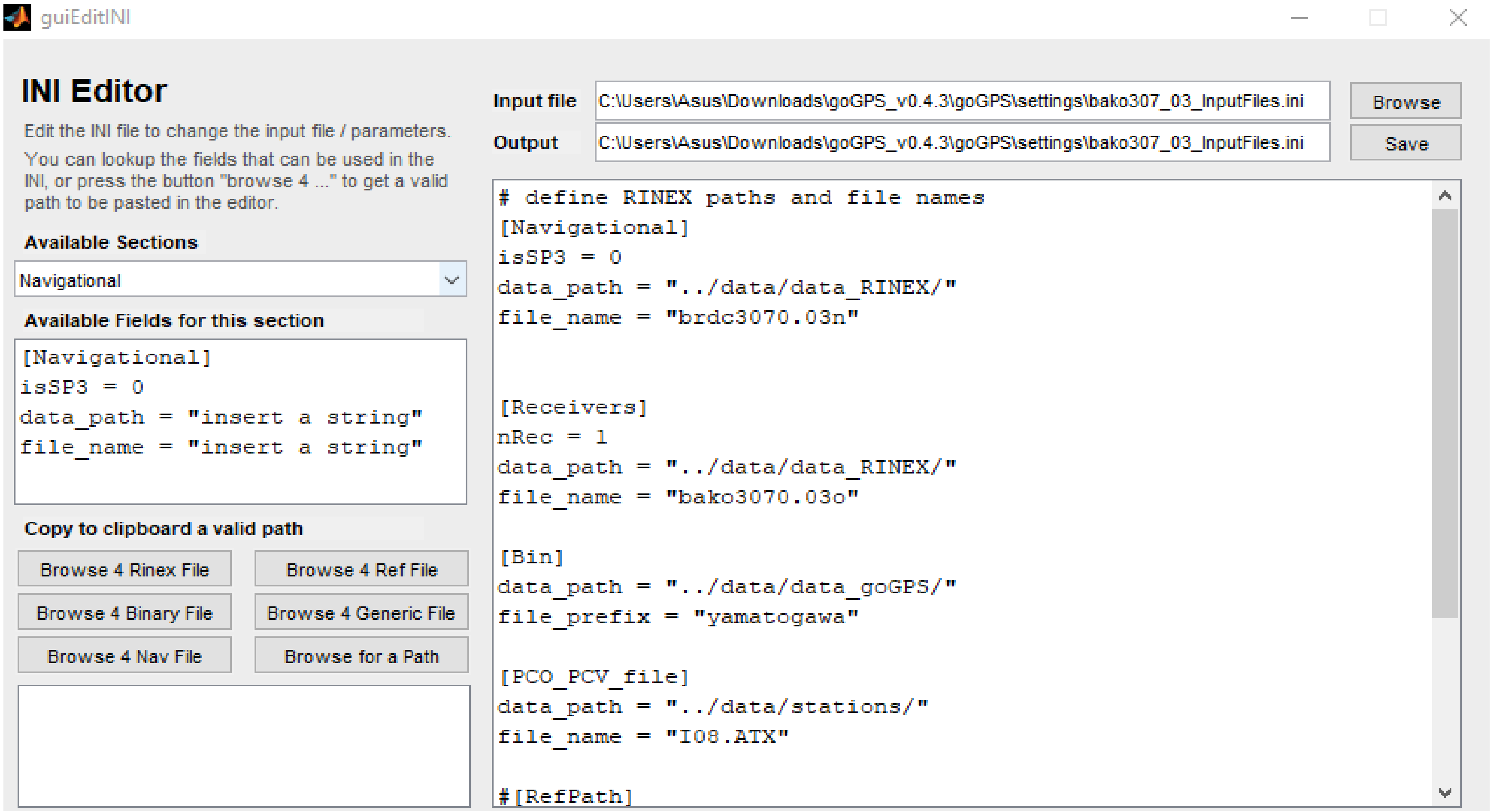
$$W_{nxn} = \begin{bmatrix} \cos^2(Z_r^1) & 0 & 0 & 0 \\ 0 & \cos^2(Z_r^2) & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \cos^2(Z_r^n) \end{bmatrix}$$

$$x = \left(A^T W A\right)^{-1} A^T W [y - b]$$

goGPS GNSS Variometric



goGPS GNSS Variometric

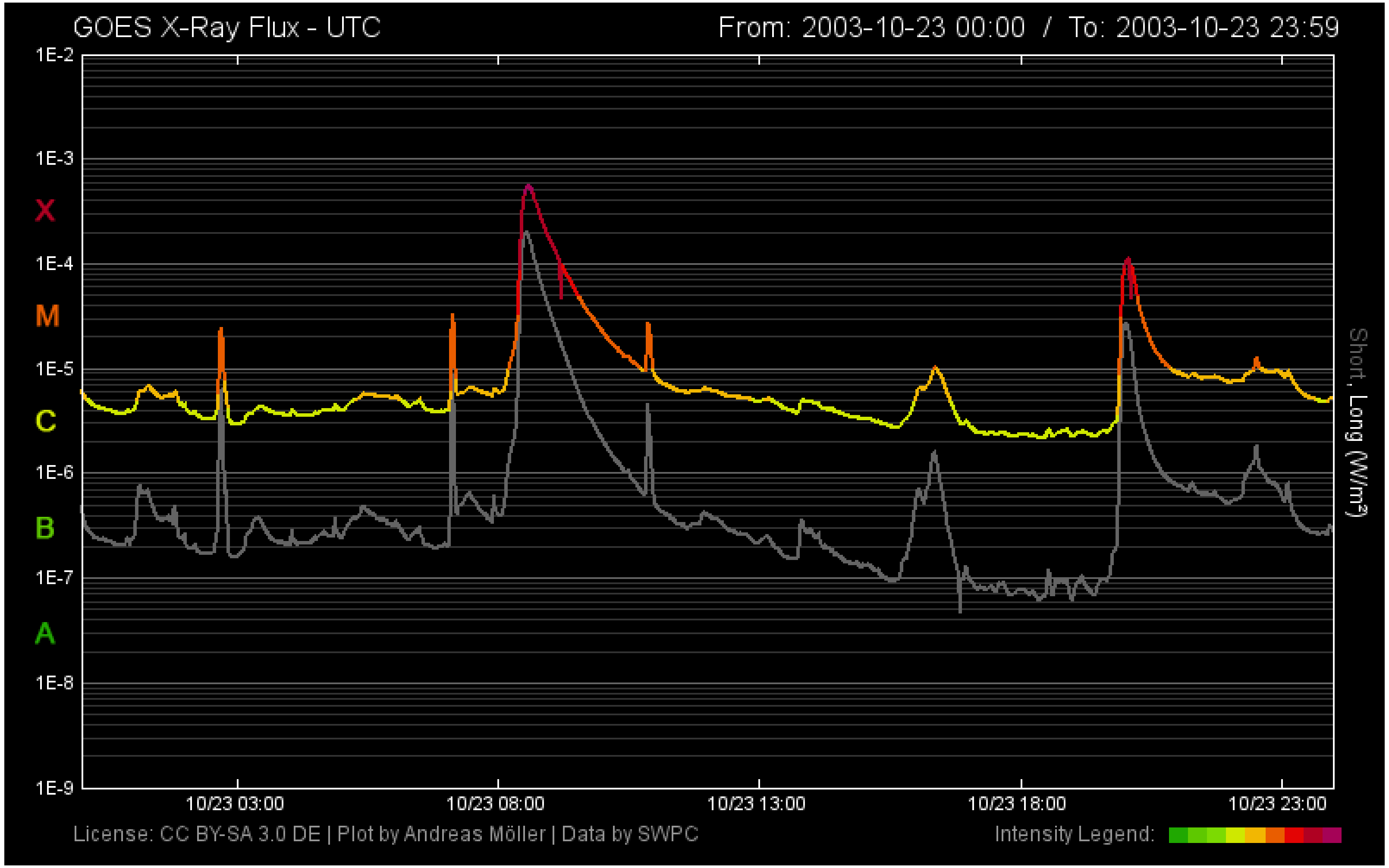


DVTEC calculation

- VTEC GOPI
- DVTEC = VTEC(t+1)-VTEC(t)

3. RESULTS AND DISCUSSION

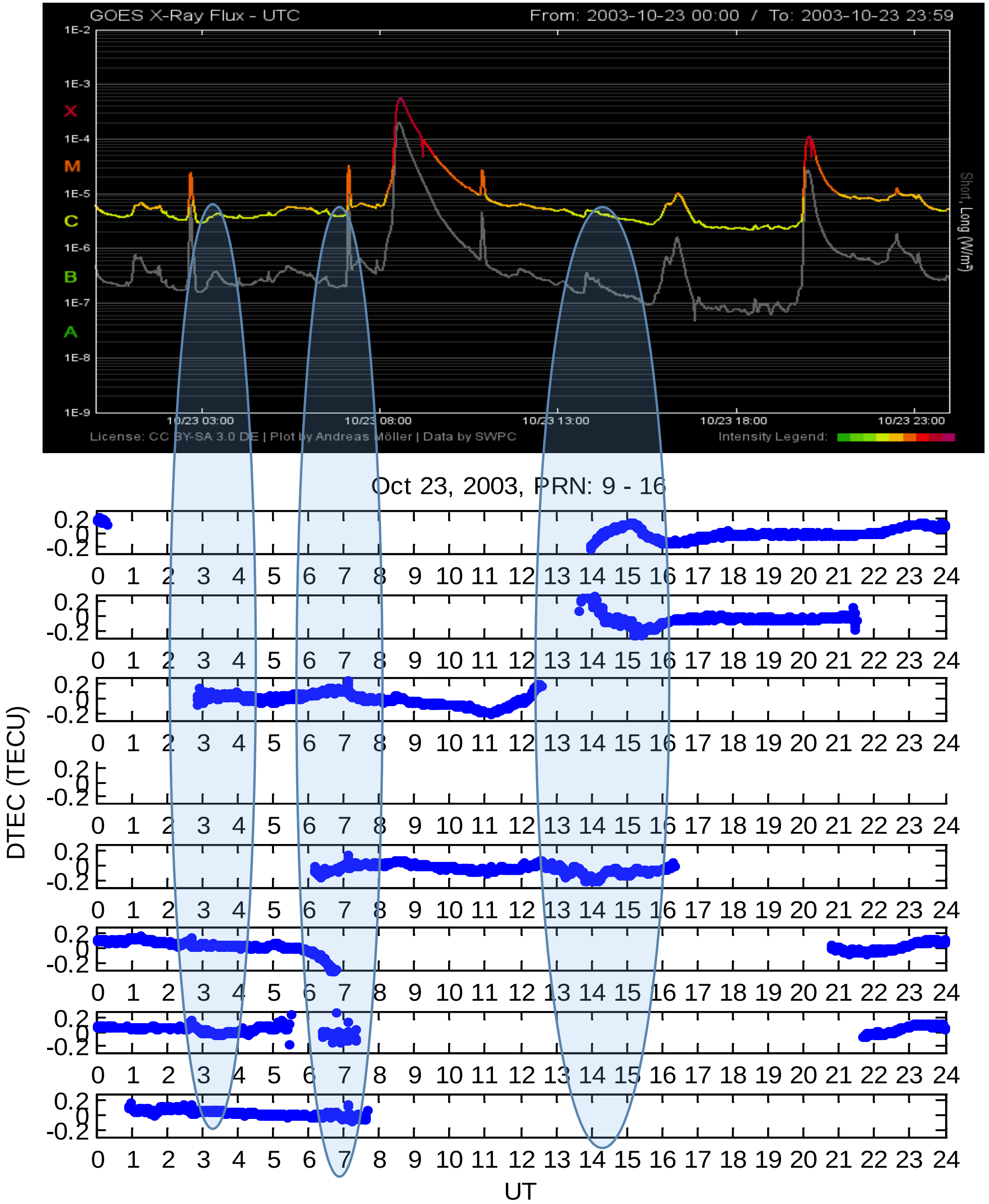
October 23, 2003 X-ray flare

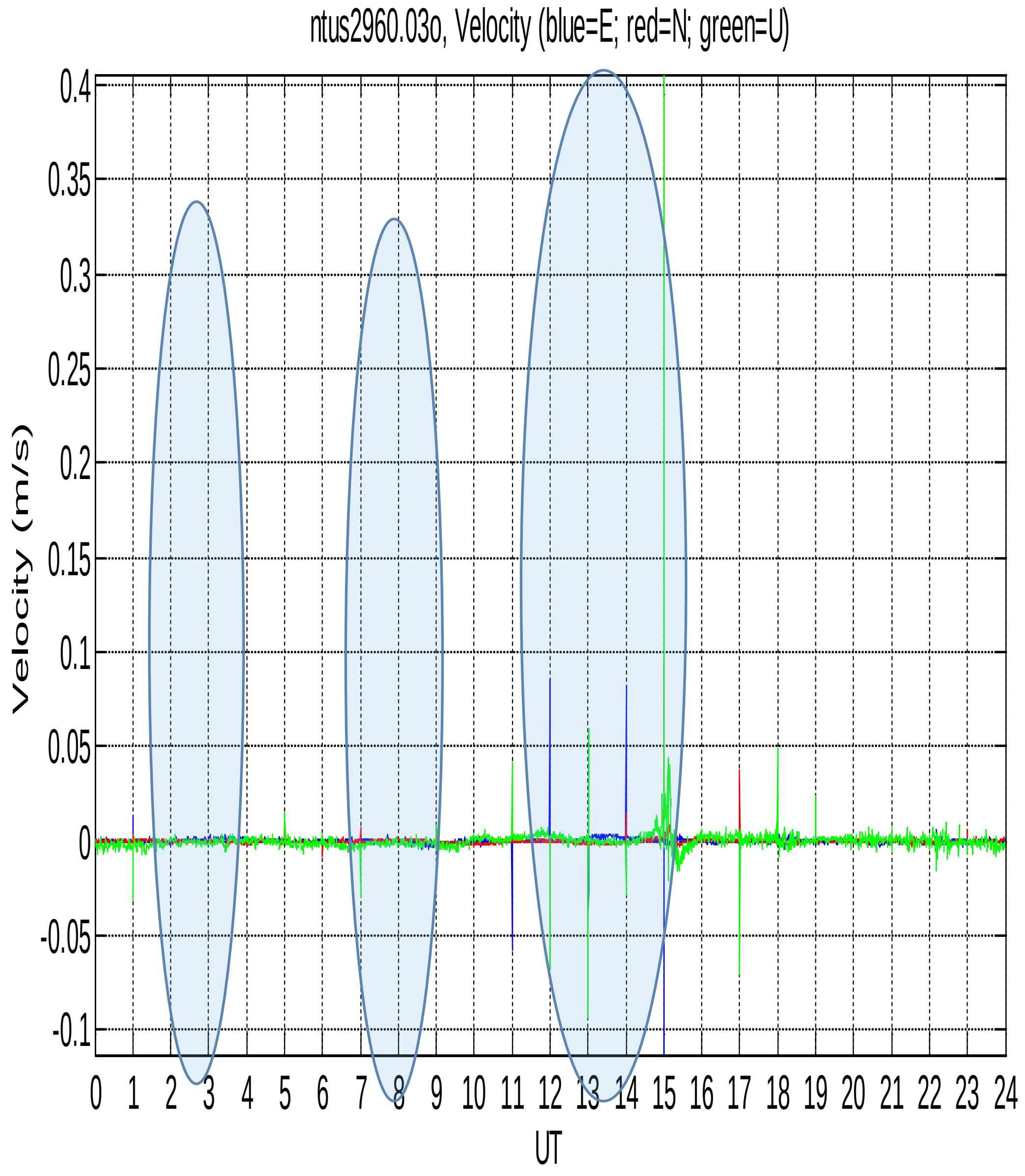


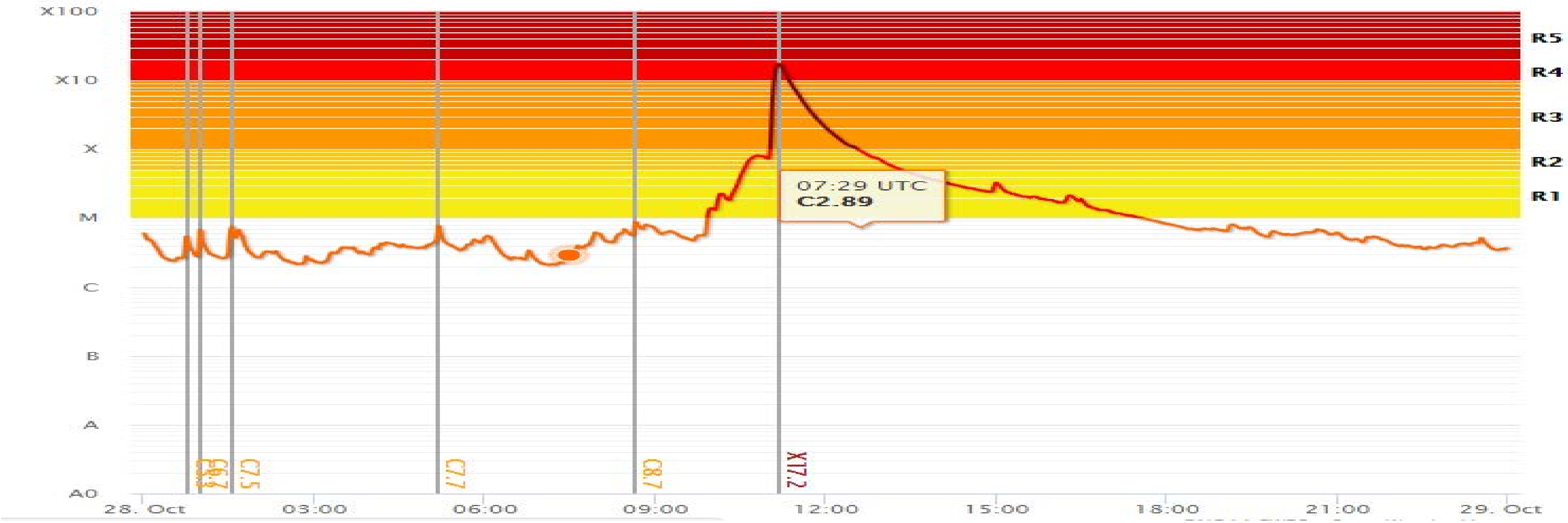
http://www.polarlicht-vorhersage.de/goes_archive

Solar flares

Region		Start	Maximum	End
0484	M2.4	02:35	02:41	02:44
0484	M3.2	07:02	07:08	07:10
0486	X5.4 Play	08:19	08:35	08:49
0484	M2.7	10:49	10:53	10:55
0486	X1.1 Play	19:50	20:04	20:14

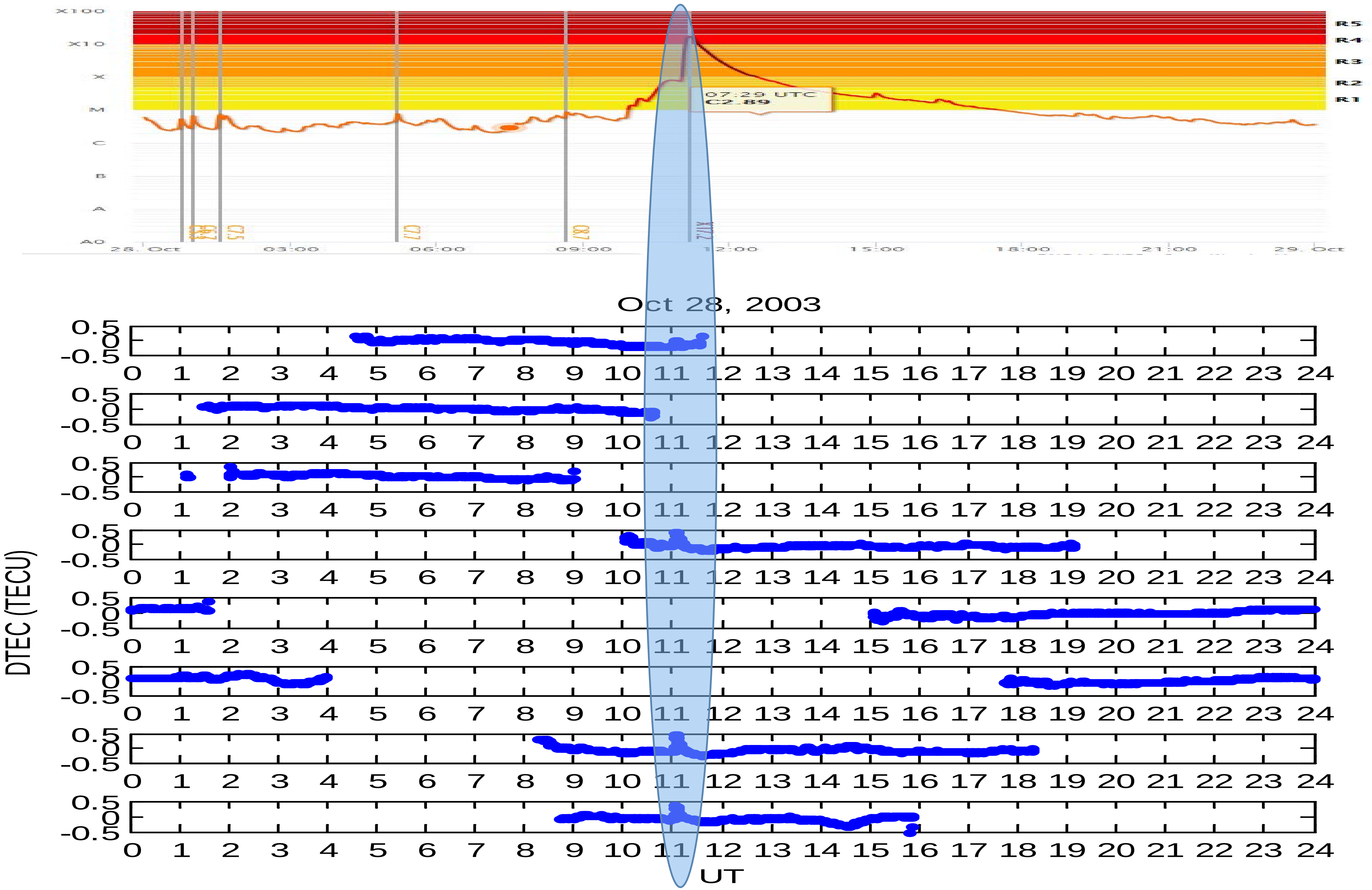

GOES X-Ray Flux - UTC
From: 2003-10-23 00:00 / To: 2003-10-23 23:59
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
X
M
C
B
A
10/23 03:00
10/23 08:00
10/23 13:00
10/23 18:00
10/23 23:00
Short, Long (W/m²)
License: CC BY-SA 3.0 DE | Plot by Andreas Möller | Data by SWPC
Intensity Legend:
Oct 23, 2003, PRN: 9 - 16
DTEC (TECU)
0.2
0
-0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
UT


ntus2960.03o, Velocity (blue=E; red=N; green=U)
Velocity (m/s)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
UT

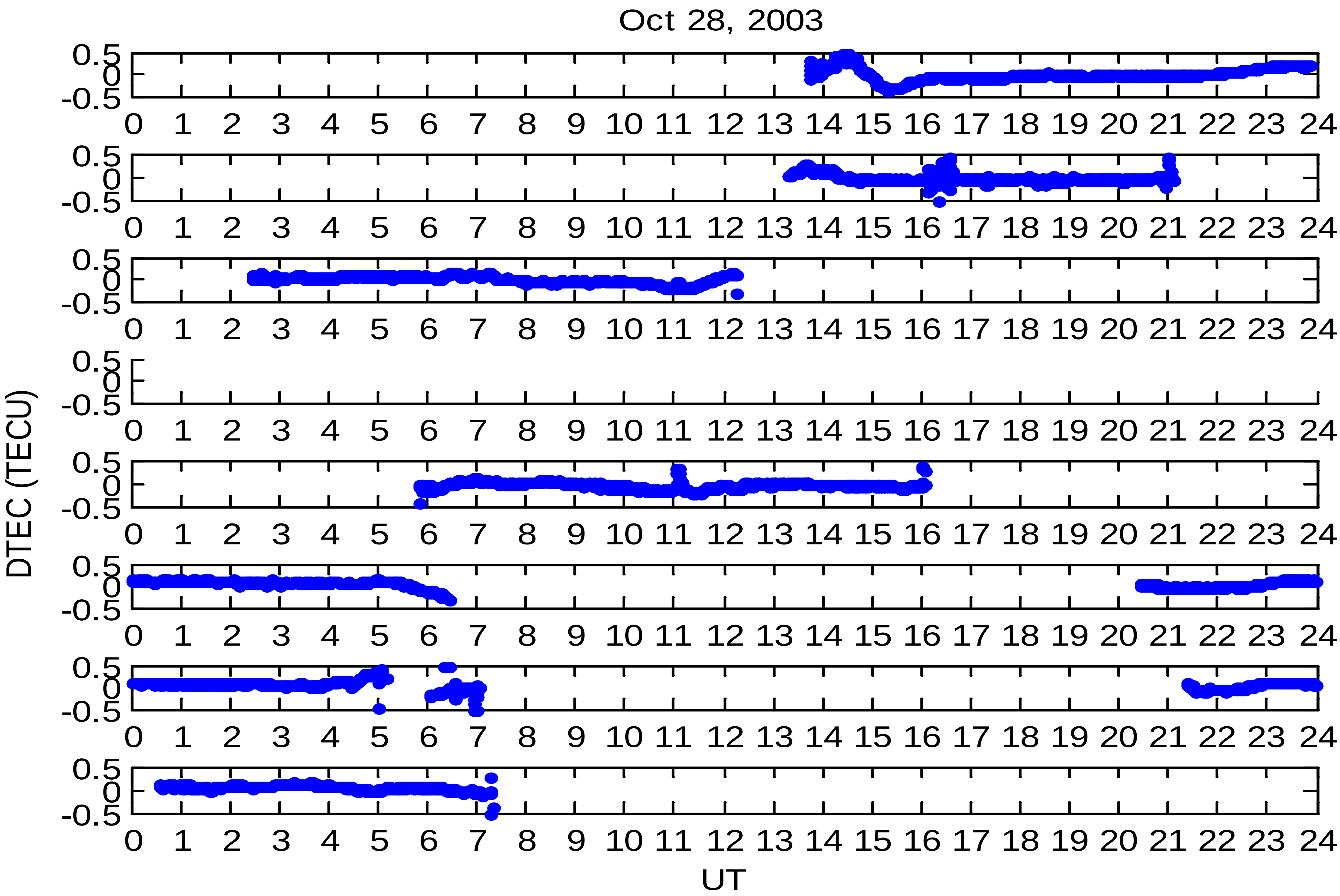


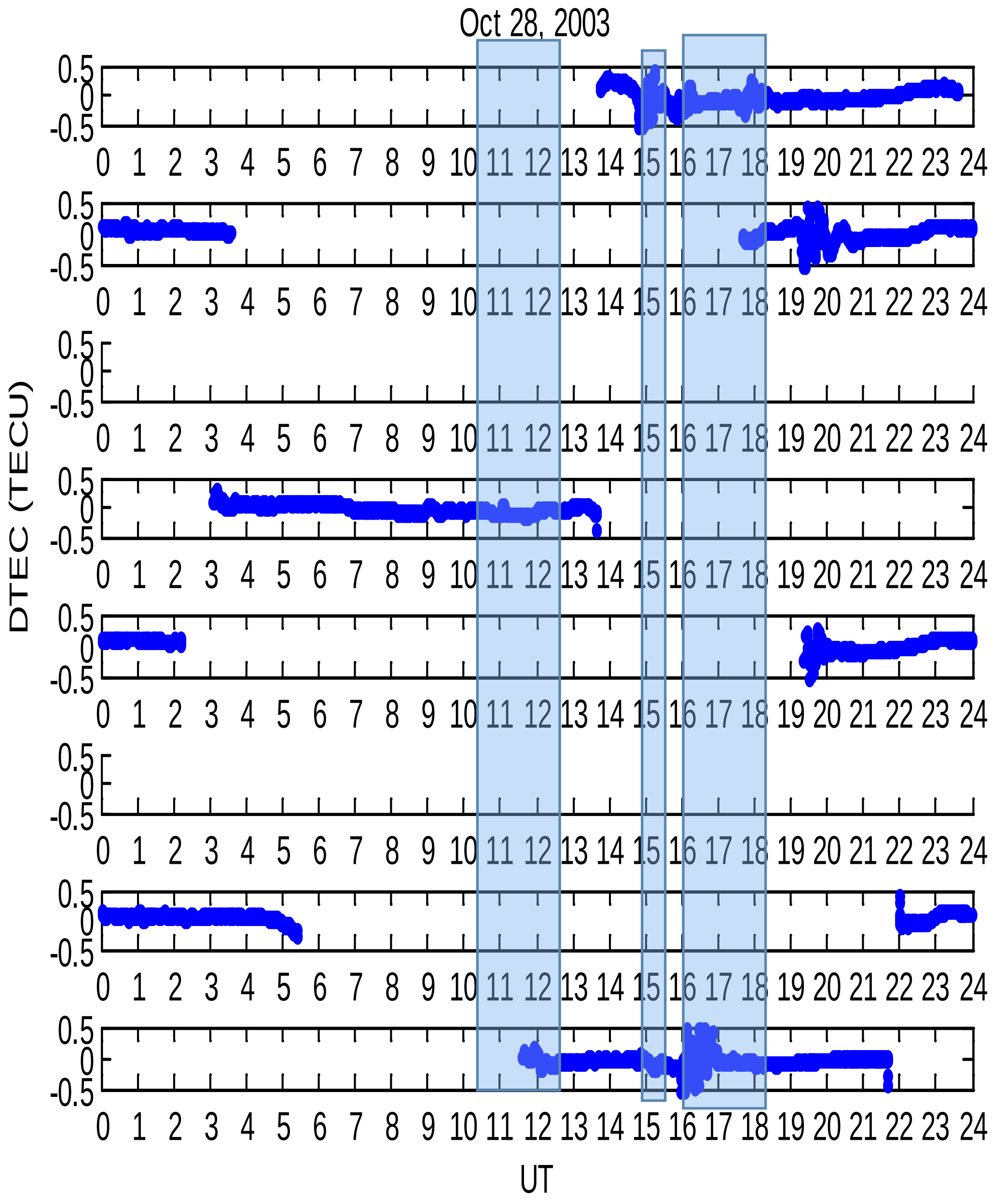
Solar flares

Region		Start	Maximum	End
0488	C5.3	00:41	00:45	00:48
0484	C6.7	00:56	00:59	01:02
0486	C7.5	01:27	01:33	01:45
0484	C7.7	05:07	05:11	05:14
0488	C8.7	08:35	08:39	08:44
0486	X17.2 Play	09:51	11:10	11:24

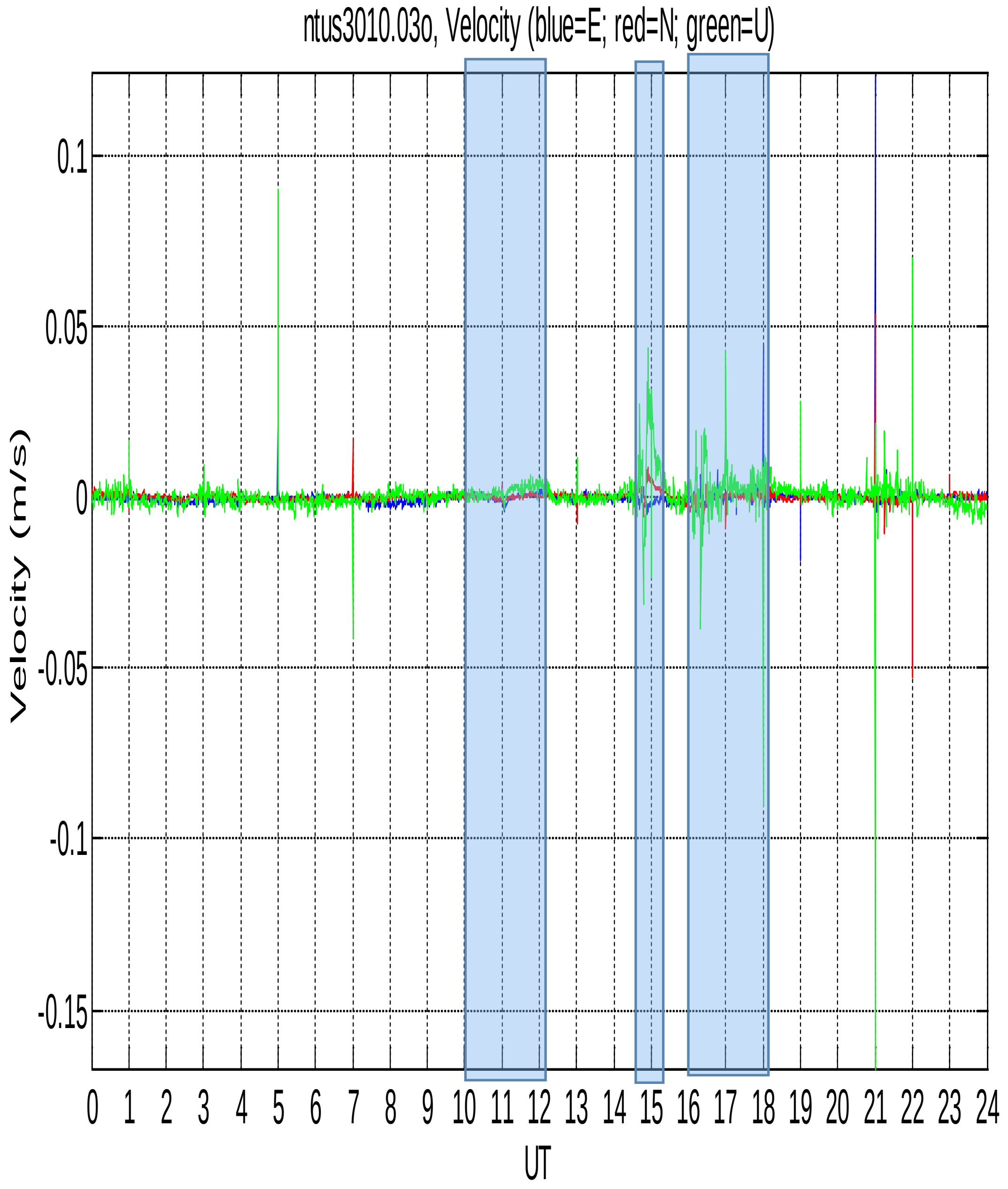


X100
X10
X
M
C
B
A
A0
R5
R4
R3
R2
R1
07:29 UTC
C2.89
28. Oct
03:00
06:00
09:00
12:00
15:00
18:00
21:00
29. Oct
Oct 28, 2003
DTEC (TECU)
UT

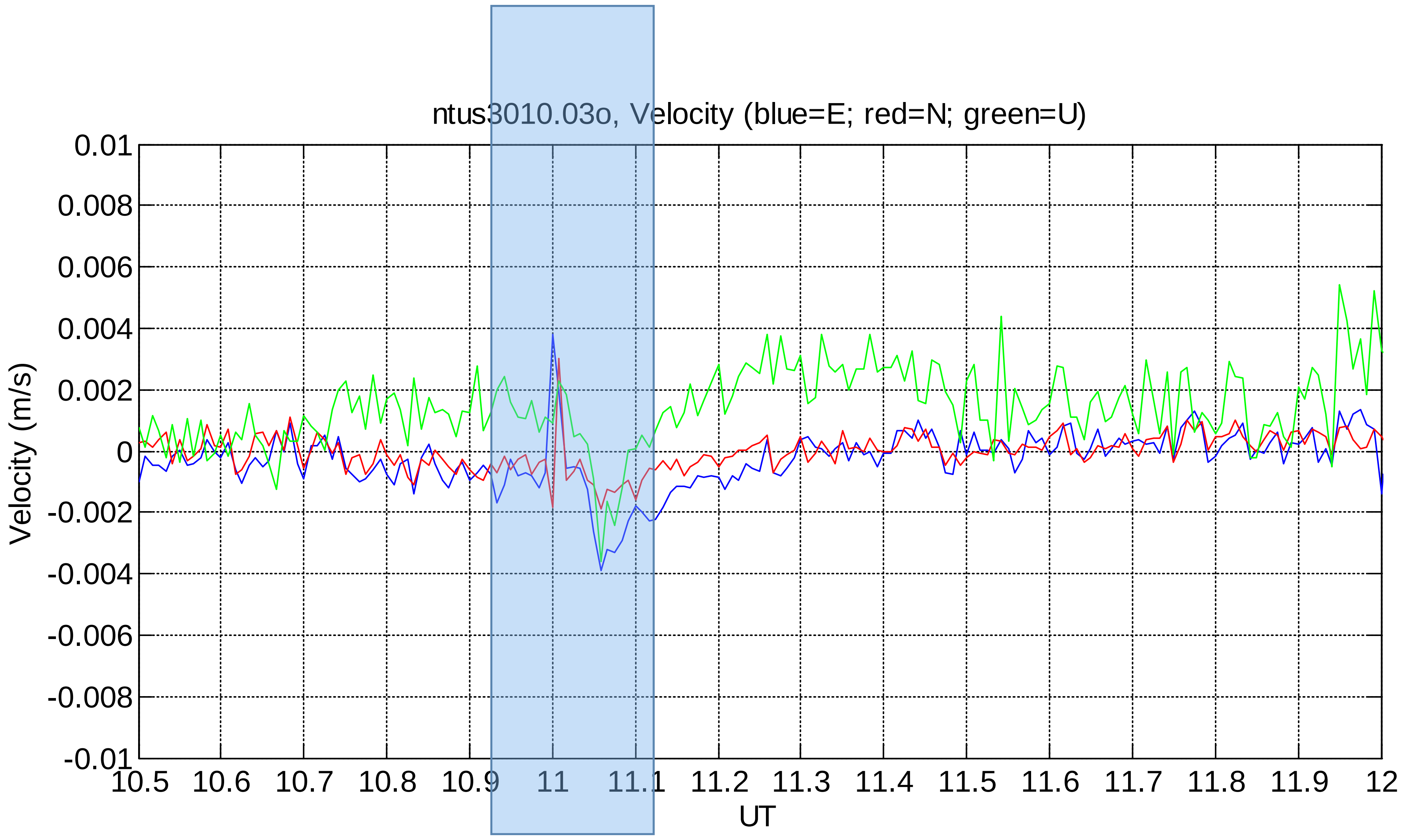

Oct 28, 2003
DTEC (TECU)
UT
0.5
0
-0.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24



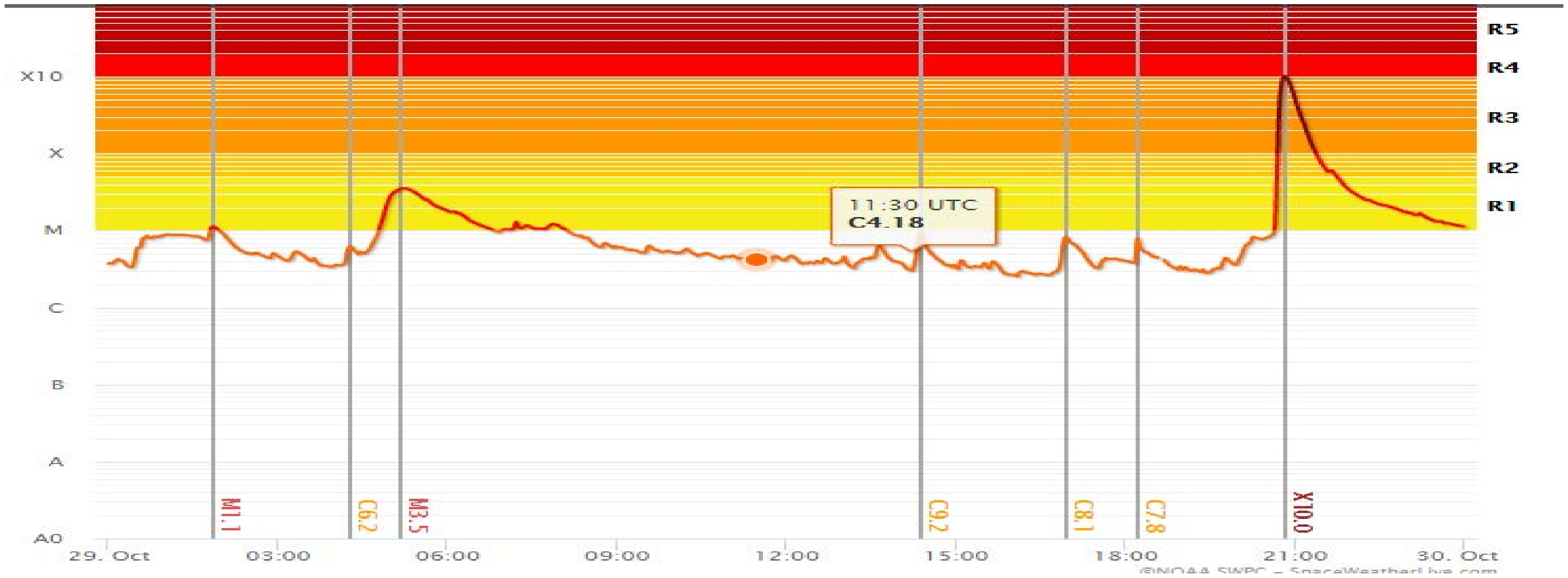
Oct 28, 2003
DTEC (TECU)
UT



ntus3010.03o, Velocity (blue=E; red=N; green=U)
Velocity (m/s)
UT

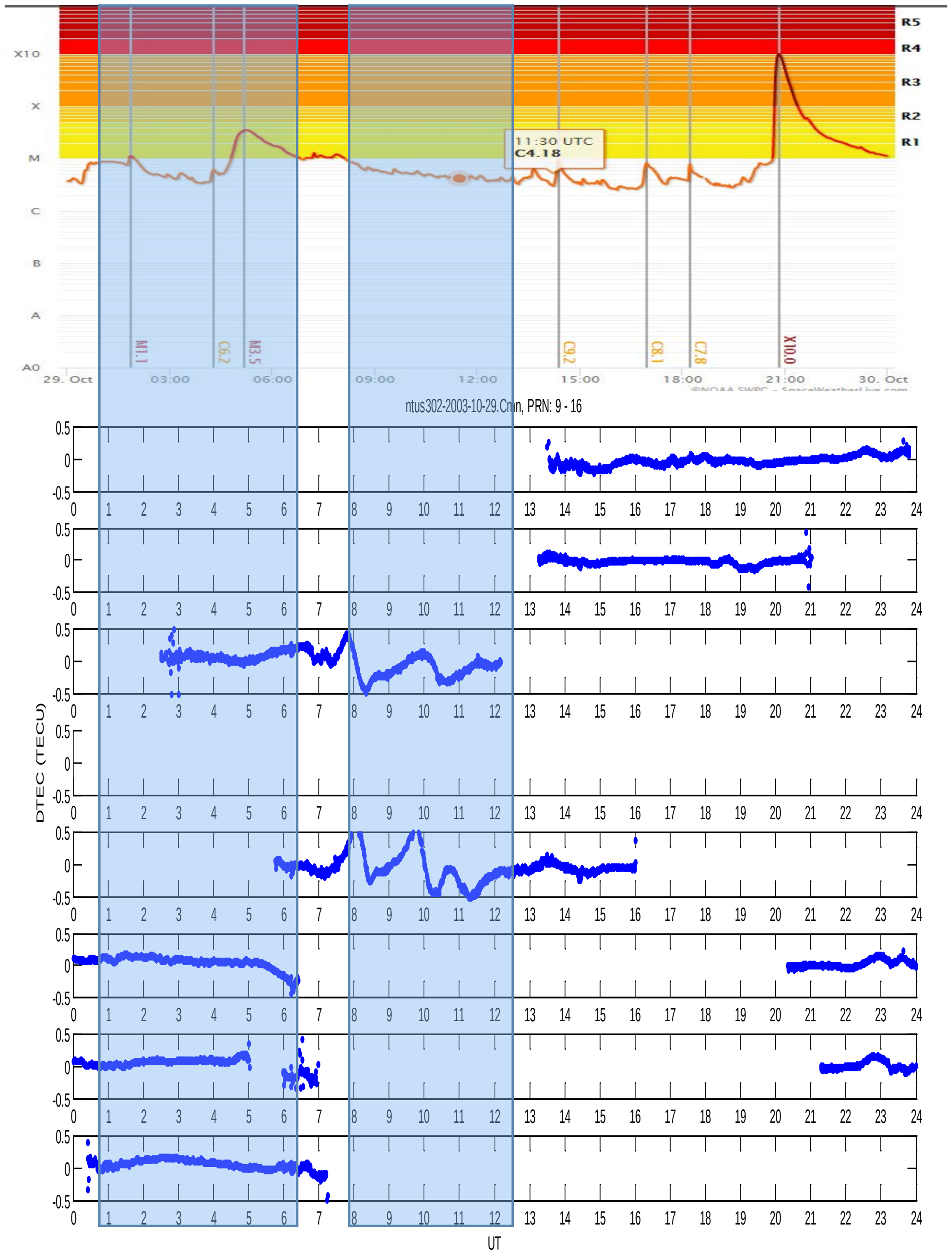


ntus3010.03o, Velocity (blue=E; red=N; green=U)
Velocity (m/s)
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
10.5
10.6
10.7
10.8
10.9
11
11.1
11.2
11.3
11.4
11.5
11.6
11.7
11.8
11.9
12
UT

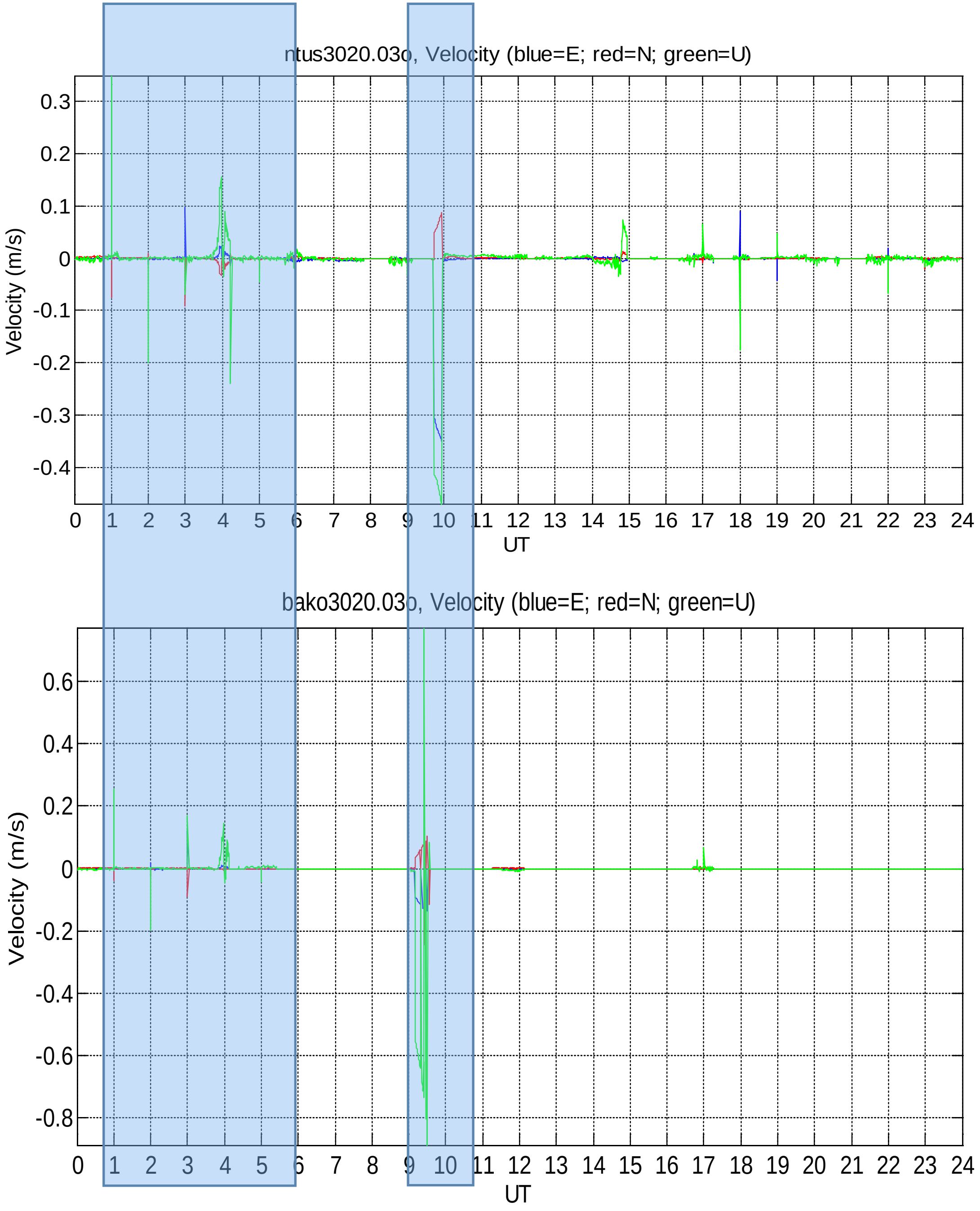


Solar flares

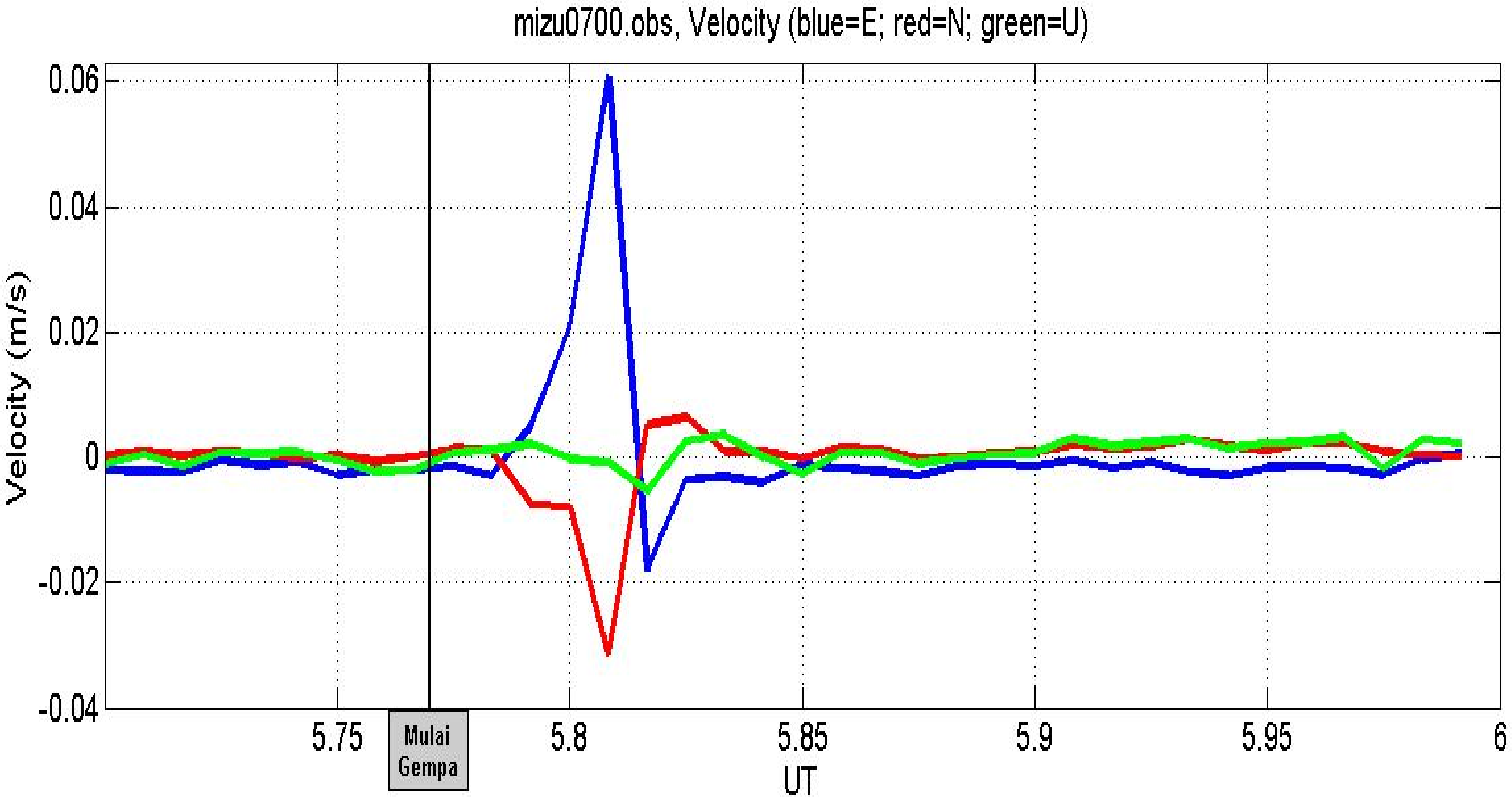
Region		Start	Maximum	End
0486	M1.1	00:26	01:51	02:08
-	C6.2	04:10	04:17	04:25
0486	M3.5	04:08	05:11	05:54
0486	C9.2	14:15	14:22	14:28
0486	C8.1	16:49	16:57	17:12
0488	C7.8	18:10	18:13	18:17
0486	X10.0 Play	20:37	20:49	21:01



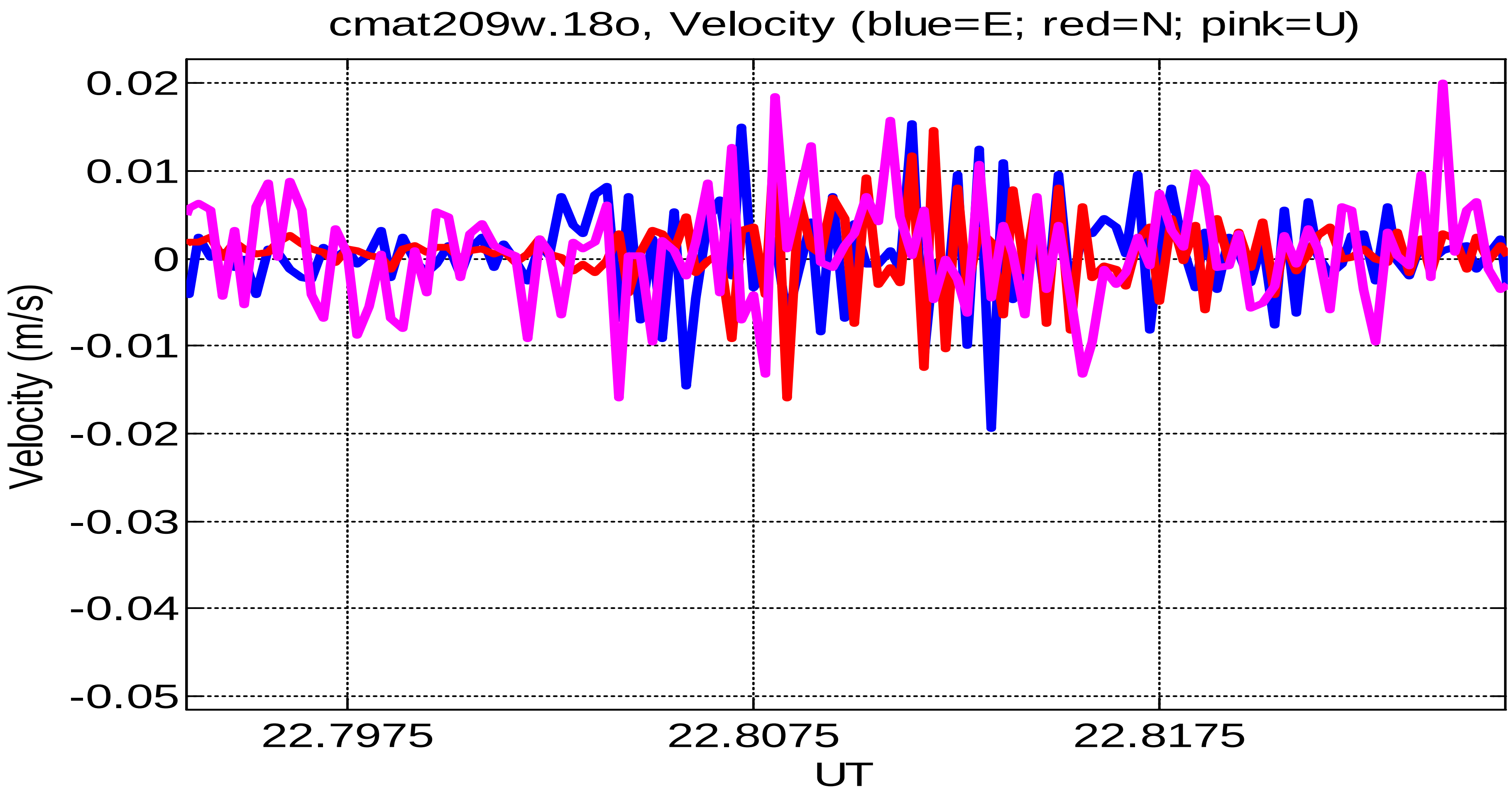
R5
R4
R3
R2
R1
X10
X
M
C
B
A
A0
M1.1
C6.2
M3.5
11:30 UTC
C4.18
C9.2
C8.1
C7.8
X10.0
29. Oct
03:00
06:00
09:00
12:00
15:00
18:00
21:00
30. Oct
ntus302-2003-10-29.Cmn, PRN: 9 - 16
DTEC (TECU)
UT

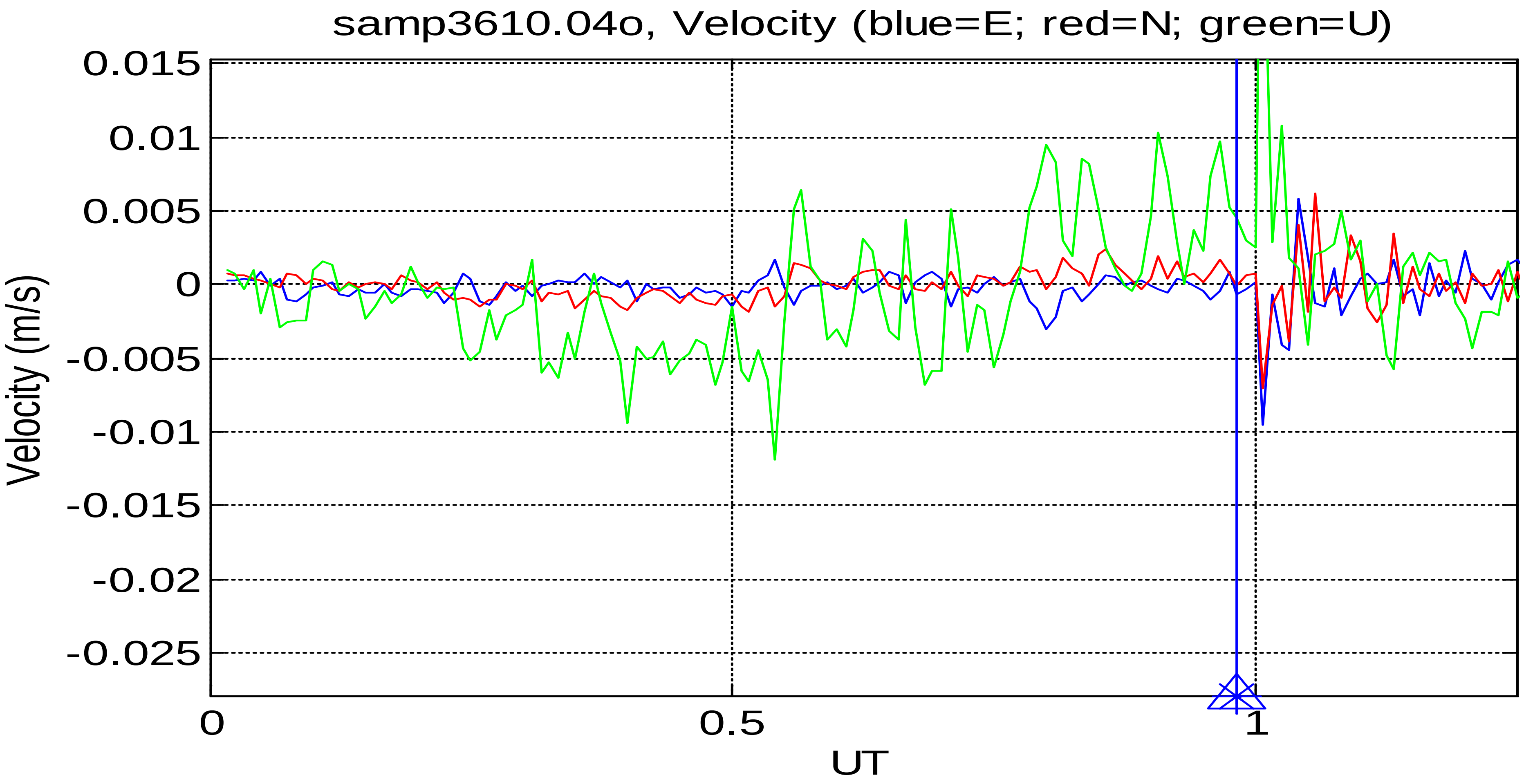


ntus3020.03o, Velocity (blue=E; red=N; green=U)
Velocity (m/s)
UT
bako3020.03o, Velocity (blue=E; red=N; green=U)
Velocity (m/s)
UT



MIZU station is about 142 km from Tohoku earthquake epicenter, detect earhquake using variometric (6 cm displacement) after of about 1 minute


cmat209w.18o, Velocity (blue=E; red=N; pink=U)
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
Velocity (m/s)
22.7975
22.8075
22.8175
UT



samp3610.04o, Velocity (blue=E; red=N; green=U)
Velocity (m/s)
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
0
0.5
1
UT

Variometric errors level comparison of x-ray flare, TID, scintillation and displacement due to earthquake

X-ray flare	Class	DVTEC (TECU)	Variometric errors level
October 23	M2.4	0.15	mm
	M3.2	0.20	mm
	X5.4	0.10	mm
		0.2 (Scintillation)	cm
October 28	X17.2	0.5	mm
		1 (-0.5-0.5) (scintillation)	cm
October 29	M1.1	-	-
	M3.5	-	-
		1 TECU (TID daytime)	cm
Earthquake	Magnitude		Site displacement
Tohoku	9		6 cm
NTB	7		2 cm
Aceh	9		1.5 cm

Conclusion and Recommendation

Conclusion of X - Ray Flare Effect on GNSS Variometric:

1. Not direct effect but through sudden ionospheric disturbance
2. Not linier but depend also to local time of x-ray flare events, morning time x-ray flares have more significant effect rather than afternoon time x-ray flare
3. Only few mm - cm equivalent to one to ten order of sudden increasing TEC (0.01-0.5 TECU)
4. Although only few mm - cm, the x-ray flare effect should be considered for seismology application of GNSS variometric
5. Rapid TEC fluctuation or ionospheric scintillation and TID effect on GNSS variometric is more pronounced compared to x-ray effect

Recommendation:

1. Using detrended TEC (TEC(t+1) - TEC(t)) for mitigating indirect x-ray flare effect on GNSS variometric through sudden ionospheric disturbance model or observation and mitigating TEC fluctuation durung scintillation
2. Research deeply and broader of ionosheric sintillation effect on GNSS variometric

Thank You For Your Attention