

# X-RAY FLARE EFFECT ON GNSS VARIOMETRIC IN INDONESIA

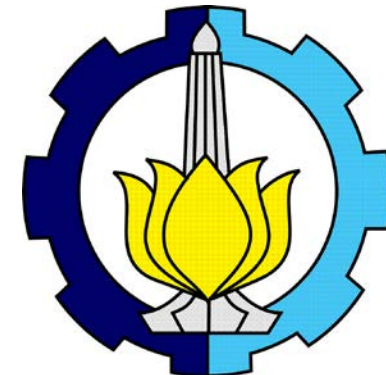
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# **X-RAY FLARE EFFECT ON GNSS VARIOMETRIC IN INDONESIA**

**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

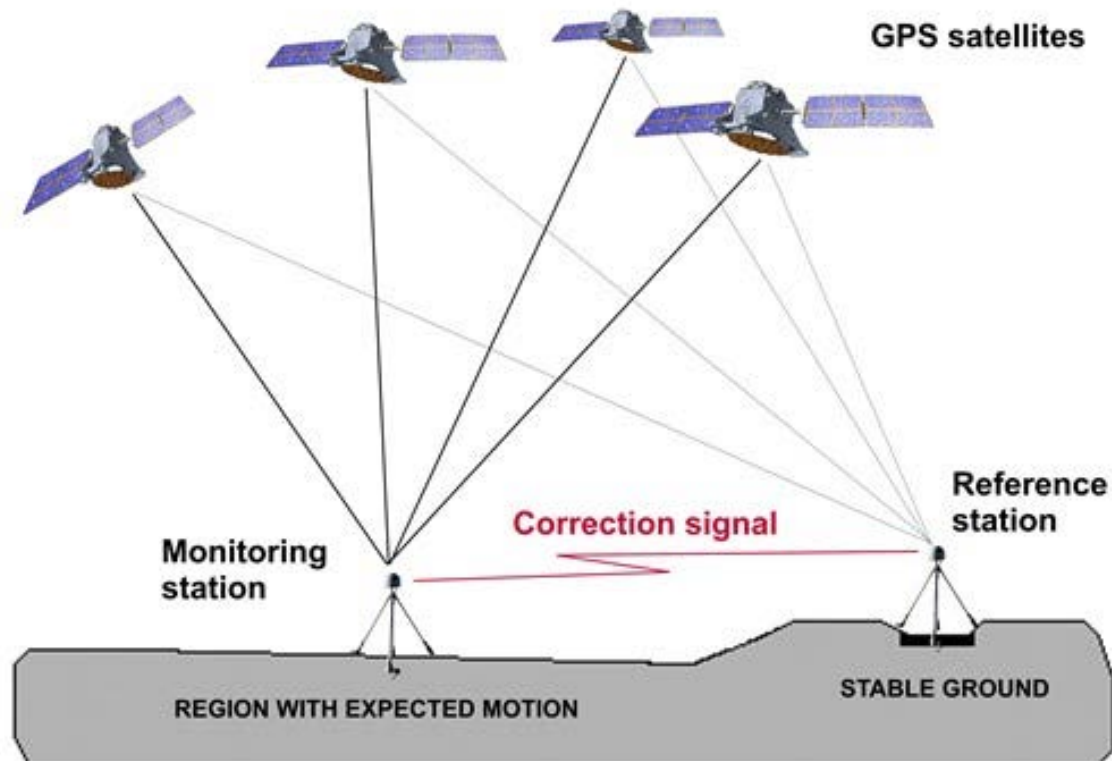
## 4. Conclusion and Recommendation

# **1. INTRODUCTION:**

**Two main approaches of GNSS positioning (Conventional Methods)**

- **Relative Positioning (Spatial Differential GNSS)  
(used 2 GPS receiver (DGPS), Networked DGPS  $\geq 2$  )**
- **Point Positioning (1 Receiver)**

# Differential GNSS Conventional Problems for Earthquake Detection



- RS and MS experience displacements to some extent 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

- 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.

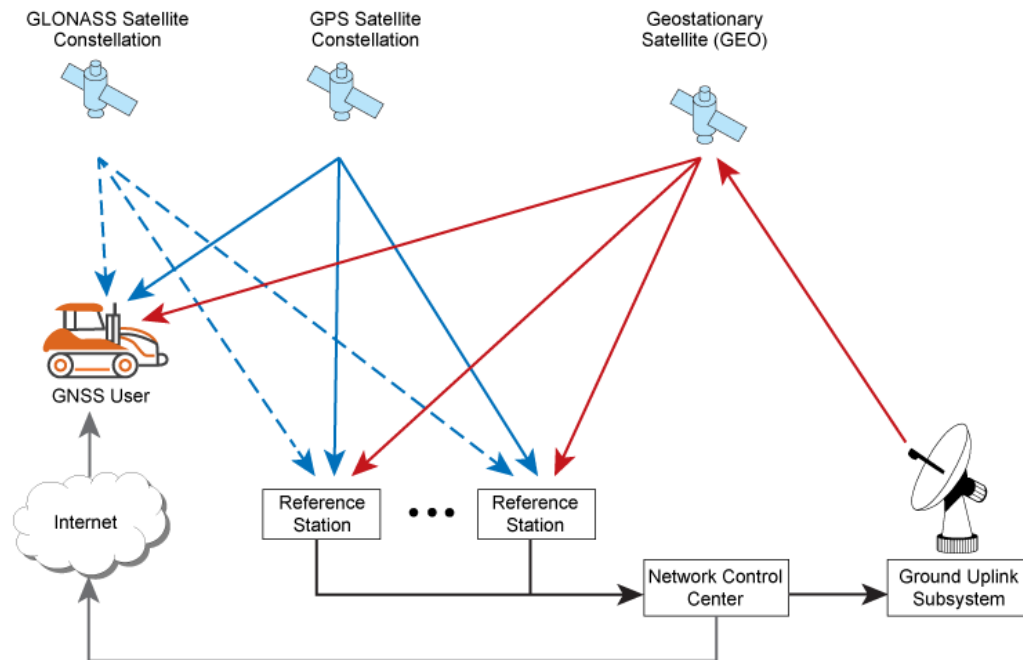


Figure 43 Precise Point Positioning (PPP) System Overview

# **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

## Technology applied:

- Velocity Estimation
  - Epoch-by-Epoch LSQ estimation of site velocity using high-rate (i.e. 1 Hz or more) carrier phases observations and broadcast orbits
- Waveform or Displacement determination
  - Integration of estimated velocities lead to high-rate site motion waveform and displacement information

→ No correction signal needed!



- when it has to be right





# GNSS Variometric errors

Temporal variation of ionosphere ( $\Delta\text{TEC}$ )

$\Delta\text{TEC}$ ,  $\Delta\text{troposphere model}$ ,  $\Delta\text{orbit}$ ,  $\Delta\text{satelit clock error}$ ,  
and  $\Delta\text{receiver clock errors}$ , etc

X-ray flare effect on ionosphere is sudden ionospheric disturbance, suddeng increasing of  $\Delta\text{TEC}$  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:

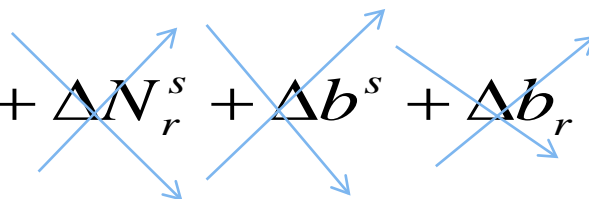
- GNSS RINEX (sopac)
- NTB Earthquake and Tohoku Earthquake
- X-ray flare during October 23-November 3, 2003

# GNSS Variometric from Carrier Phase Data

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

$$[\lambda\Phi_r^s(t+1)] - [\lambda\Phi_r^s(t)]$$

$$= \rho_r^s(t+1) - \rho_r^s(t) + c(\delta t_r(t+1) - \delta t_r(t)) - c(\delta t^s(t+1) - \delta t^s(t)) + T_r^s(t+1) - T_r^s(t) - (I_r^s(t+1) - I_r^s(t)) \dots$$

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


$$\Delta\rho_r^s = \Delta\rho_{rOR}^s + \Delta\rho_{rEtOl}^s + \vec{e}_r^s \cdot \xi_r^s$$

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


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

# Variometric using Carrier Phase Data

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

$$y = Ax + b$$

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

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

# goGPS GNSS Variometric

gui\_goGPS

Tools Help

## goGPS

open source positioning

**Mode**

Post-processing

Navigation

Least squares

Variometric approach fo...

Input file type

RINEX files

goGPS binary data

**Weighting model**

Same weights for all observ.

Satellite elevation ( $1/\sin(e)^2$ )

Satellite elevation (exp)

SNR (u-blox only)

Satellite elevation and SNR

**Input/Output files**

INI observation file

C:\Users\Asus\Downloads\goGPS\_v0.4.3\goC

RINEX rover observation file x 1  goGPS binary data input

RINEX master observation file  DTM path  PCO/PCV file

RINEX navigation file  Ref. path

goGPS data output folder  goGPS output prefix

../data/out yamatogawa

**Options**

Linear constraint

Reference path

Plot while processing

Draw skyplot & SNR graph

Google Earth overlay

Plot error ellipse

Plot master station

Plot ambiguities

Use NTRIP

Use Doppler for cycle slips

Apply EGNOS corrections

Direction estimation (stop-go-stop)

**Constellations**

GPS  BeiDou

GLONASS  QZSS

Galileo  SBAS

## Settings

**Kalman filter**

Error standard deviation

East	0.5	m	Code	0.3	m	Initial state	1	m
North	0.5	m	<b>Phase</b>	0.003	m	DTM (h)	1	m
Up	0.1	m	Velocity coord. (linear constraint)	1	m			

Elevation cut-off: 30 deg

SNR threshold: 0 dB

Cycle slip threshold: 2 cycles

Min. number of satellites: 2

Antenna height: 1 m

Integer ambiguity resolution

Try to solve ambiguities

Method: LAMBDA 2.0 - ILS, enum...

Ratio test threshold ( $\mu$ ): 0.5  auto

Fixed failure rate (P0): 0.001  default

Dynamic model: Const. velocity

Float ambiguity restart after anomalies: Least squares adjustment

**Master station**

Read master position from RTCM / RINEX

ECEF (X,Y,Z)

X		m	Lat		deg
Y		m	Lon		deg
Z		m	h		m

**Rover port and protocol**

# of rec.: 1 1 Hz

NA	UBX (u-blox)
NA	UBX (u-blox)
NA	UBX (u-blox)
NA	UBX (u-blox)

**Master server / NTRIP**

IP address: Username:

Port: 2101 Mountpoint: Password:

Approx. position Lat: 0 deg Lon: 0 deg h: 0 m

# goGPS GNSS Variometric

guiEditINI

## INI Editor

Edit the INI file to change the input file / parameters.  
You can lookup the fields that can be used in the INI, or press the button "browse 4 ..." to get a valid path to be pasted in the editor.

### Available Sections

Navigational

### Available Fields for this section

```
[Navigational]
isSP3 = 0
data_path = "insert a string"
file_name = "insert a string"
```

### Copy to clipboard a valid path

Browse 4 Rinex File

Browse 4 Ref File

Browse 4 Binary File

Browse 4 Generic File

Browse 4 Nav File

Browse for a Path

Input file C:\Users\Asus\Downloads\goGPS\_v0.4.3\goGPS\settings\bako307\_03\_InputFiles.ini

Browse

Output C:\Users\Asus\Downloads\goGPS\_v0.4.3\goGPS\settings\bako307\_03\_InputFiles.ini

Save

```
# define RINEX paths and file names
[Navigational]
isSP3 = 0
data_path = "../data/data_RINEX/"
file_name = "brdc3070.03n"

[Receivers]
nRec = 1
data_path = "../data/data_RINEX/"
file_name = "bako3070.03o"

[Bin]
data_path = "../data/data_goGPS/"
file_prefix = "yamatoogawa"

[PCO_PCV_file]
data_path = "../data/stations/"
file_name = "I08.ATX"

#[RefPath]
```

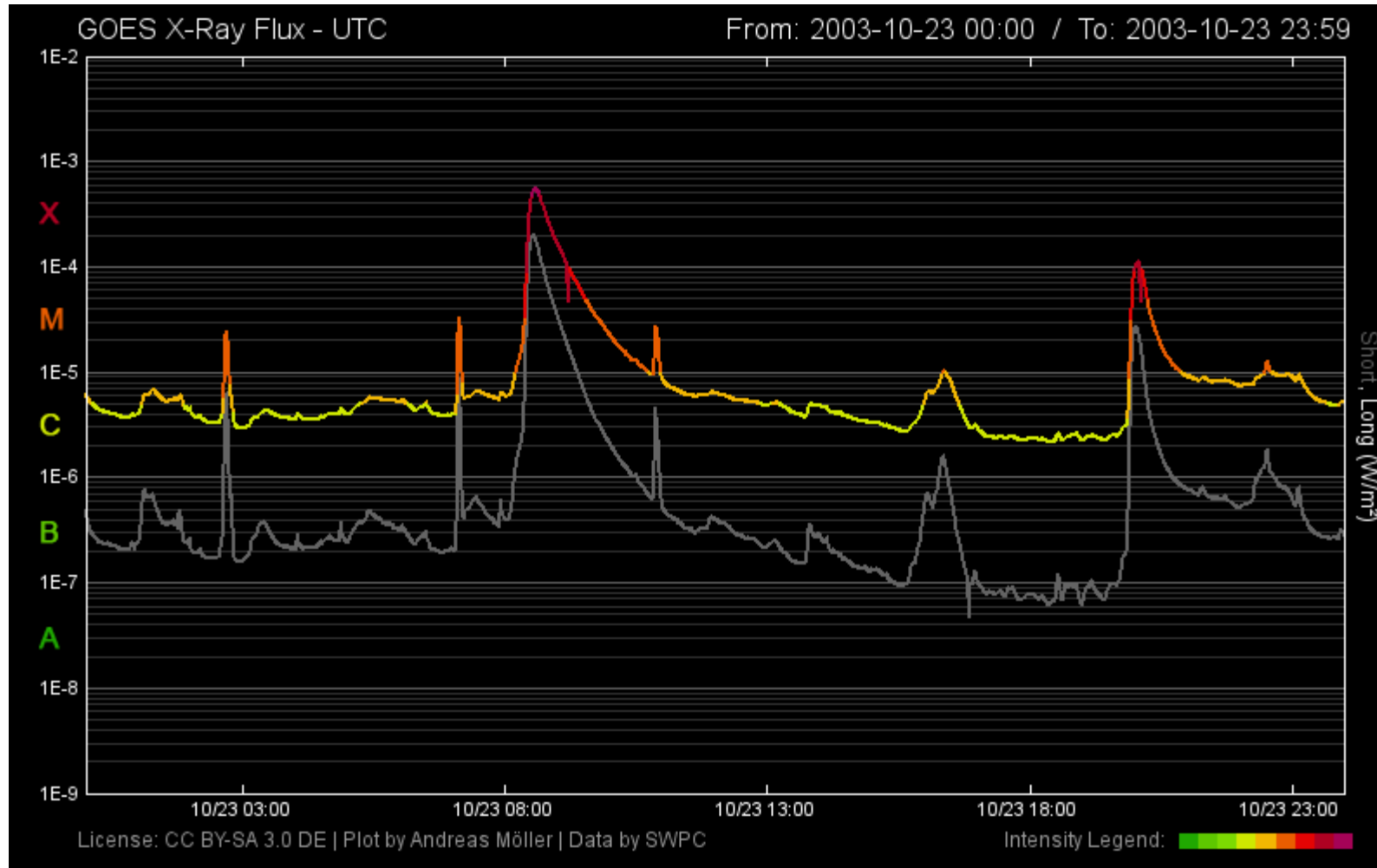


# DVTEC calculation

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

# 3. RESULTS AND DISCUSSION

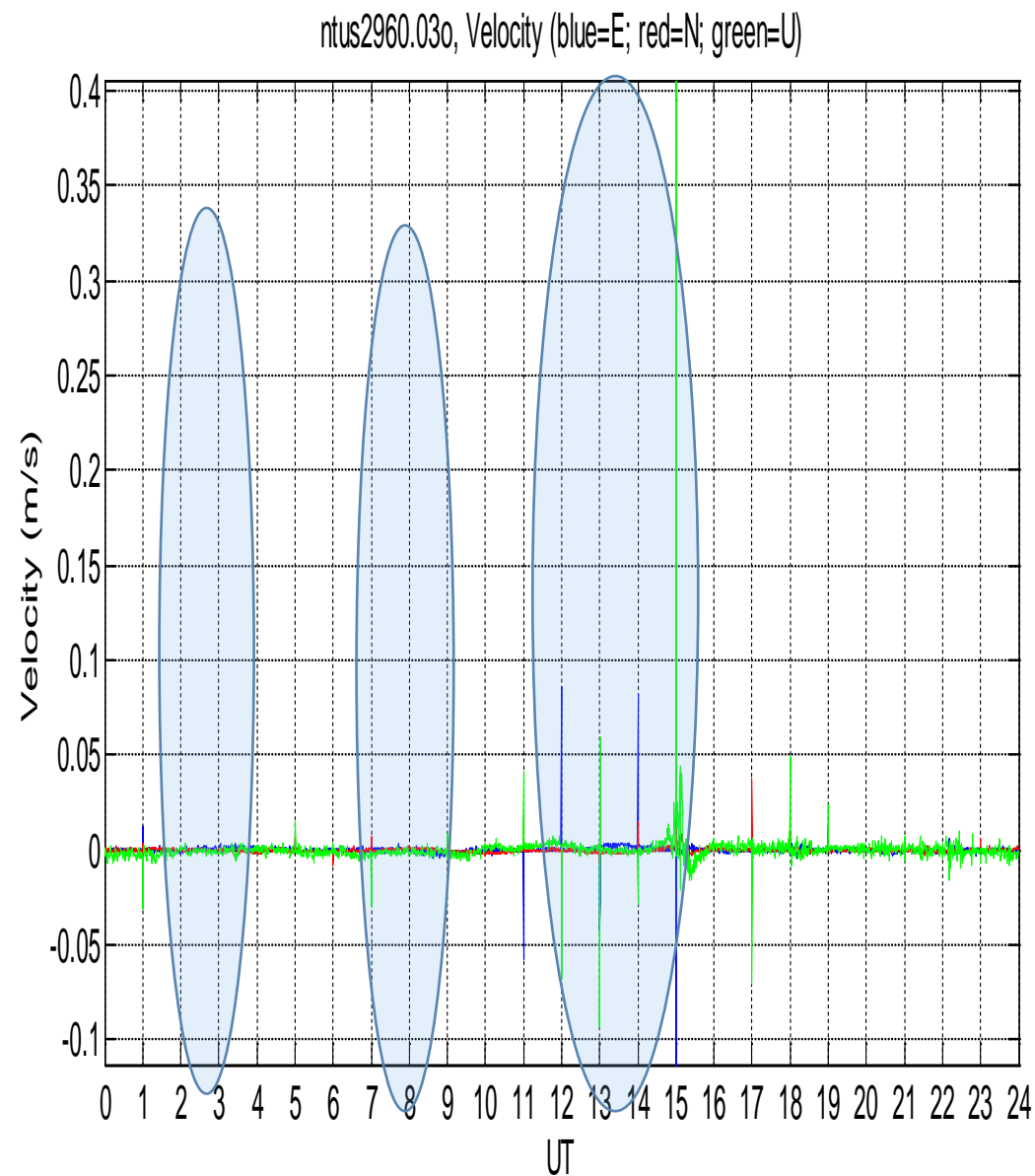
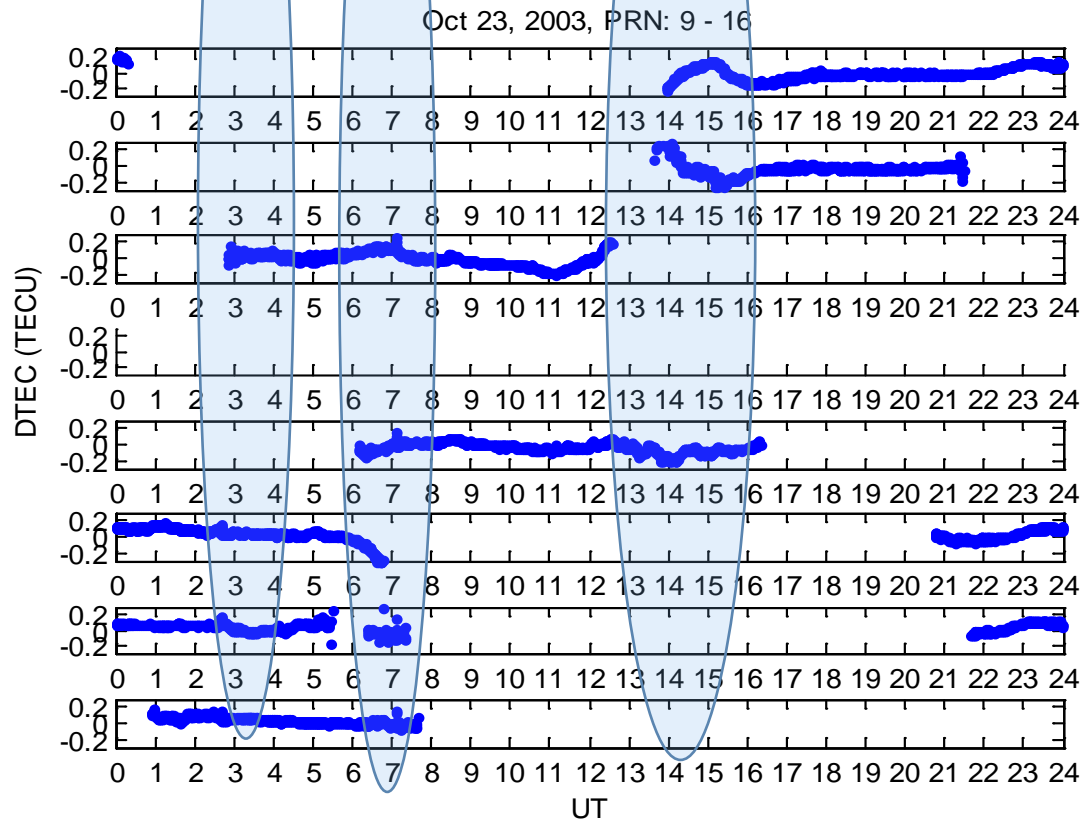
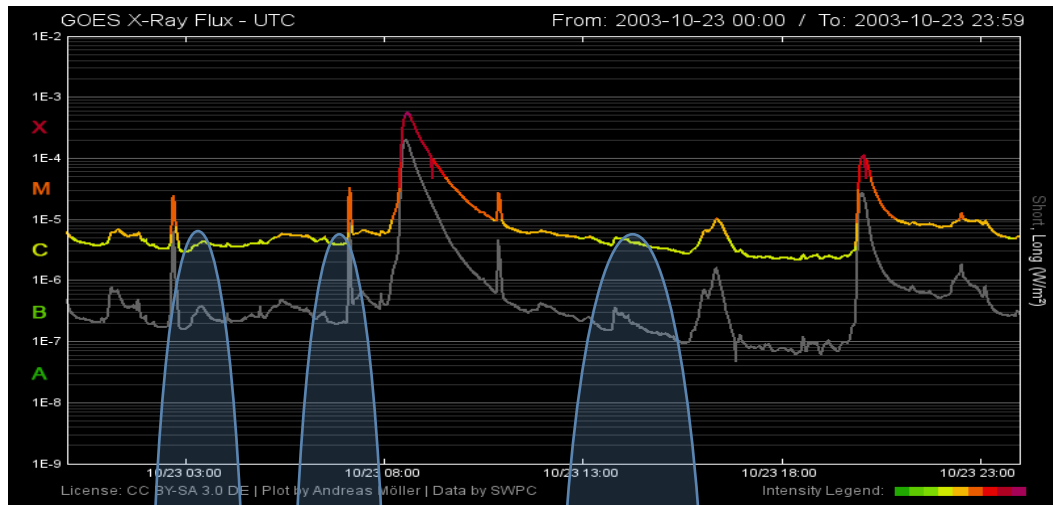
# October 23, 2003 X-ray flare

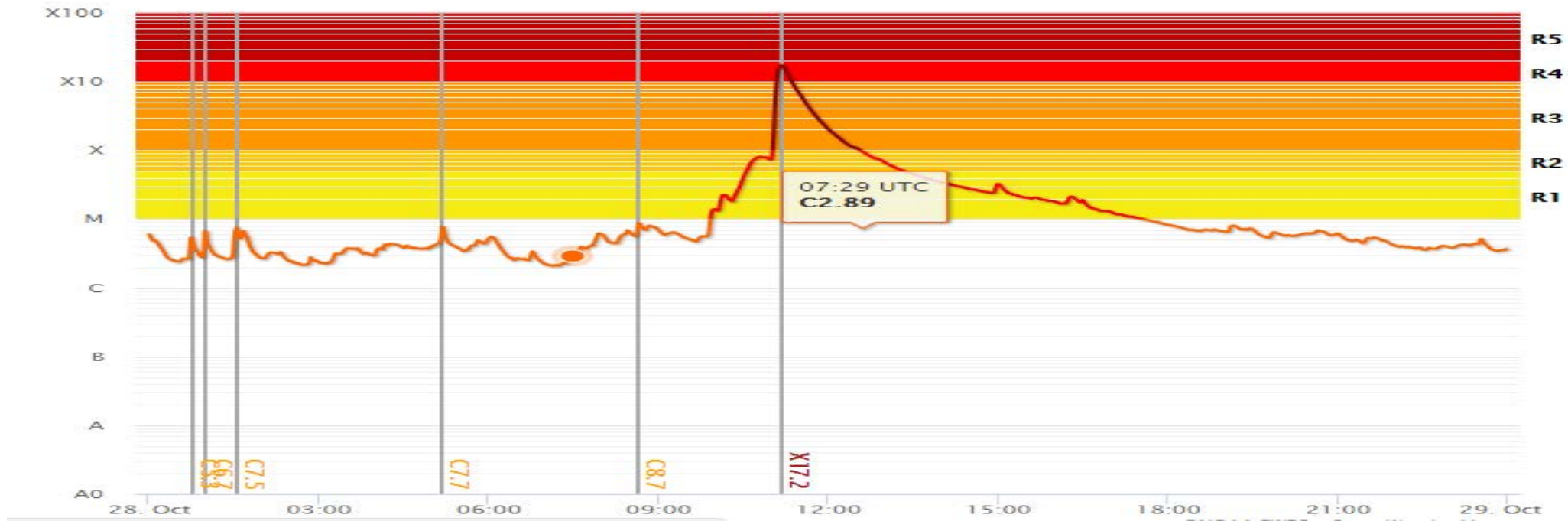


[http://www.polarlicht-vorhersage.de/goes\\_archive](http://www.polarlicht-vorhersage.de/goes_archive)

## Solar flares

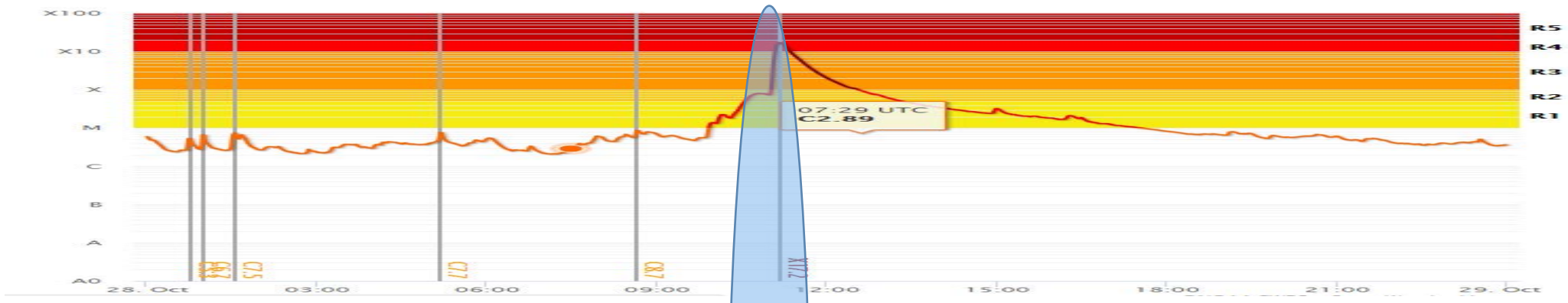
Region		Start	Maximum	End
0484	M2.4	02:35	02:41	02:44
0484	M3.2	07:02	07:08	07:10
0486	X5.4 <a href="#">Play</a>	08:19	08:35	08:49
0484	M2.7	10:49	10:53	10:55
0486	X1.1 <a href="#">Play</a>	19:50	20:04	20:14



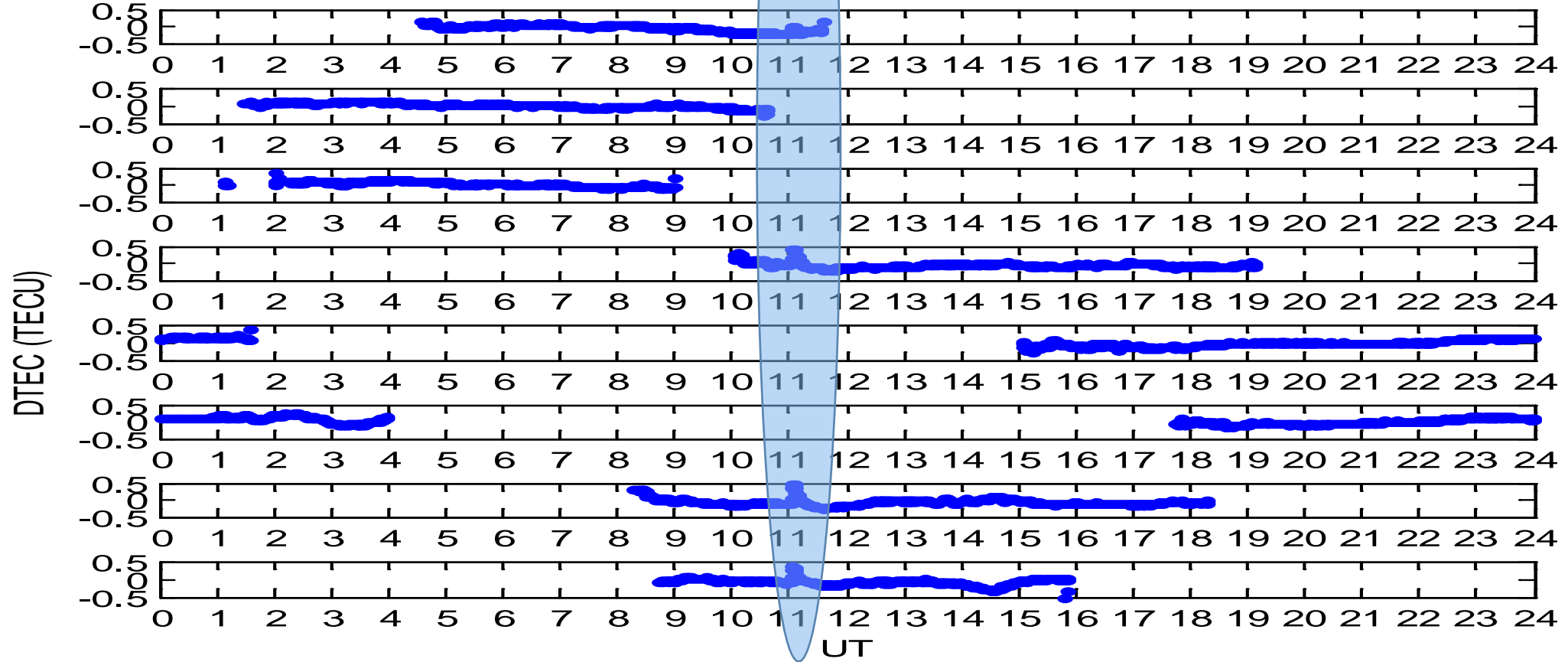


## Solar flares

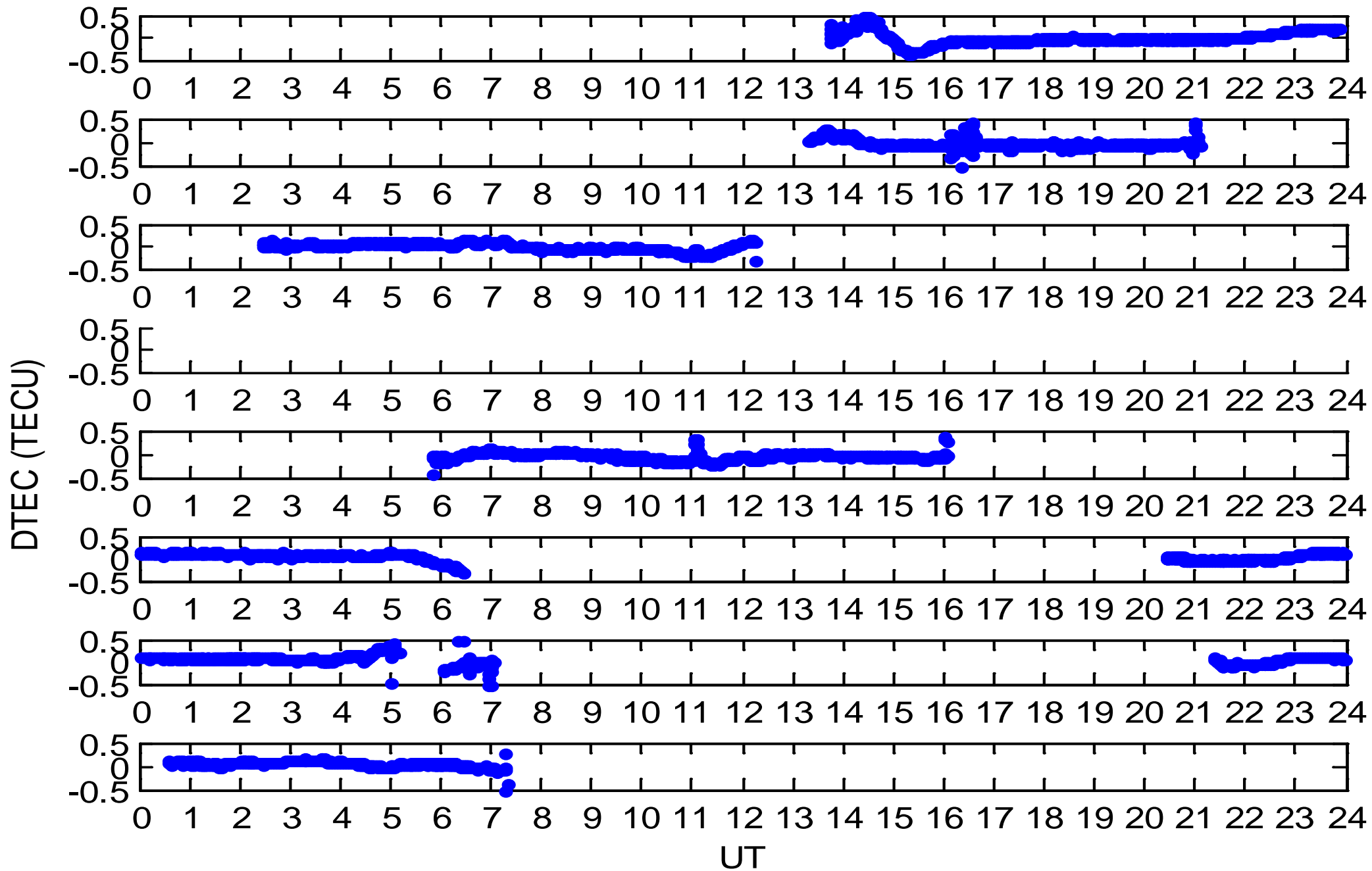
Region		Start	Maximum	End
0488	C5.3	00:41	00:45	00:48
0484	C6.7	00:56	00:59	01:02
0486	C7.5	01:27	01:33	01:45
0484	C7.7	05:07	05:11	05:14
0488	C8.7	08:35	08:39	08:44
0486	X17.2	09:51	11:10	11:24



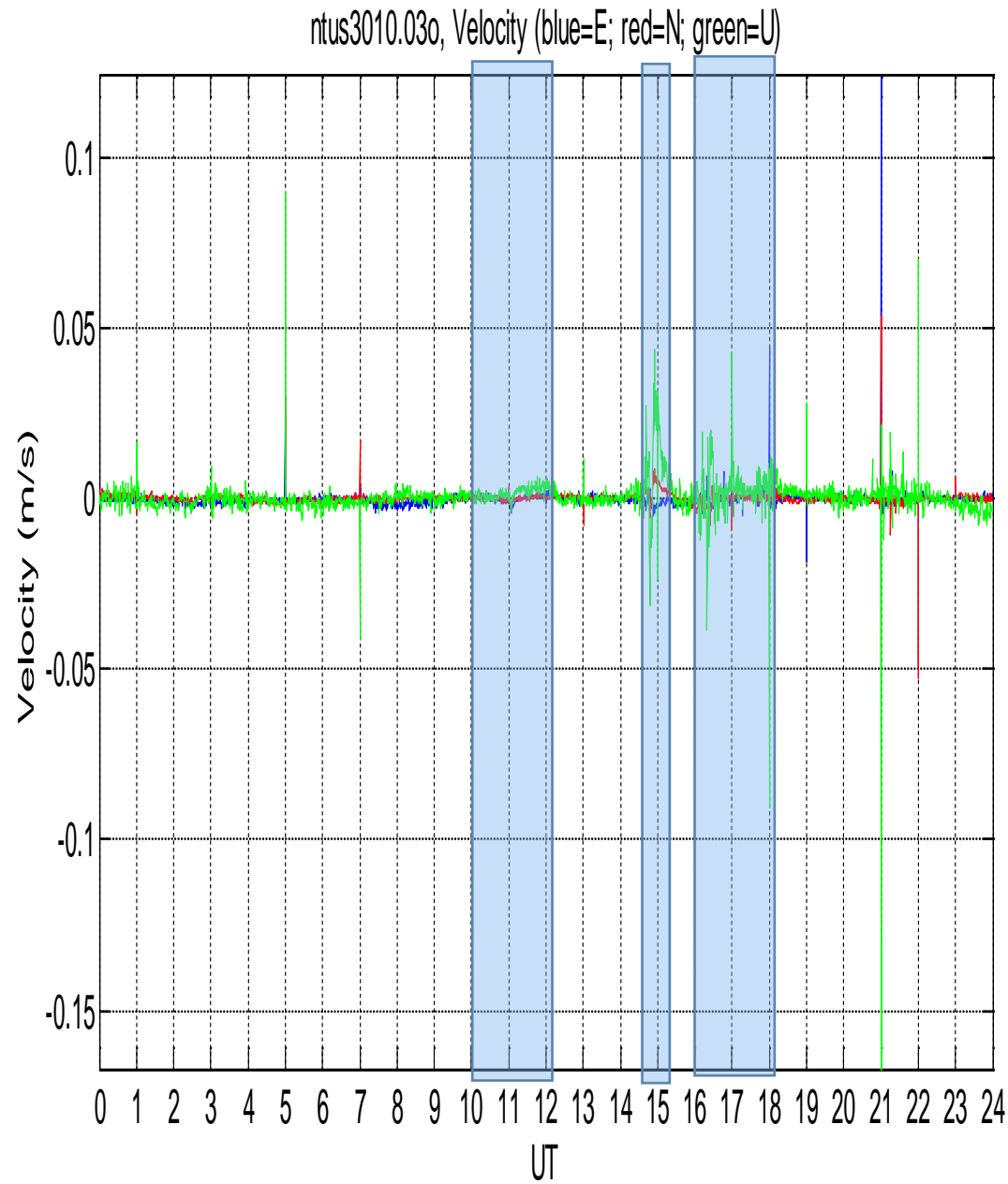
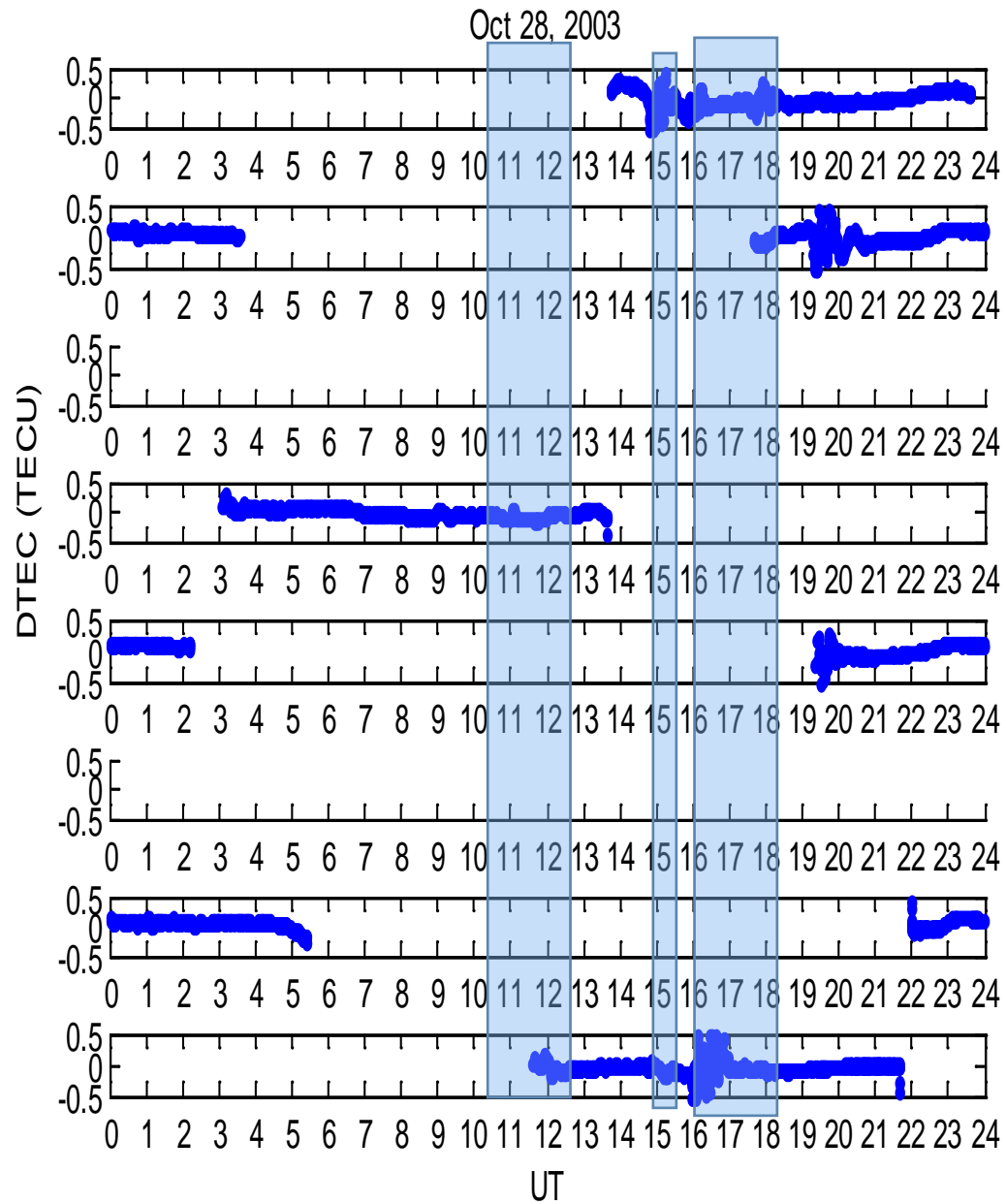
Oct 28, 2003

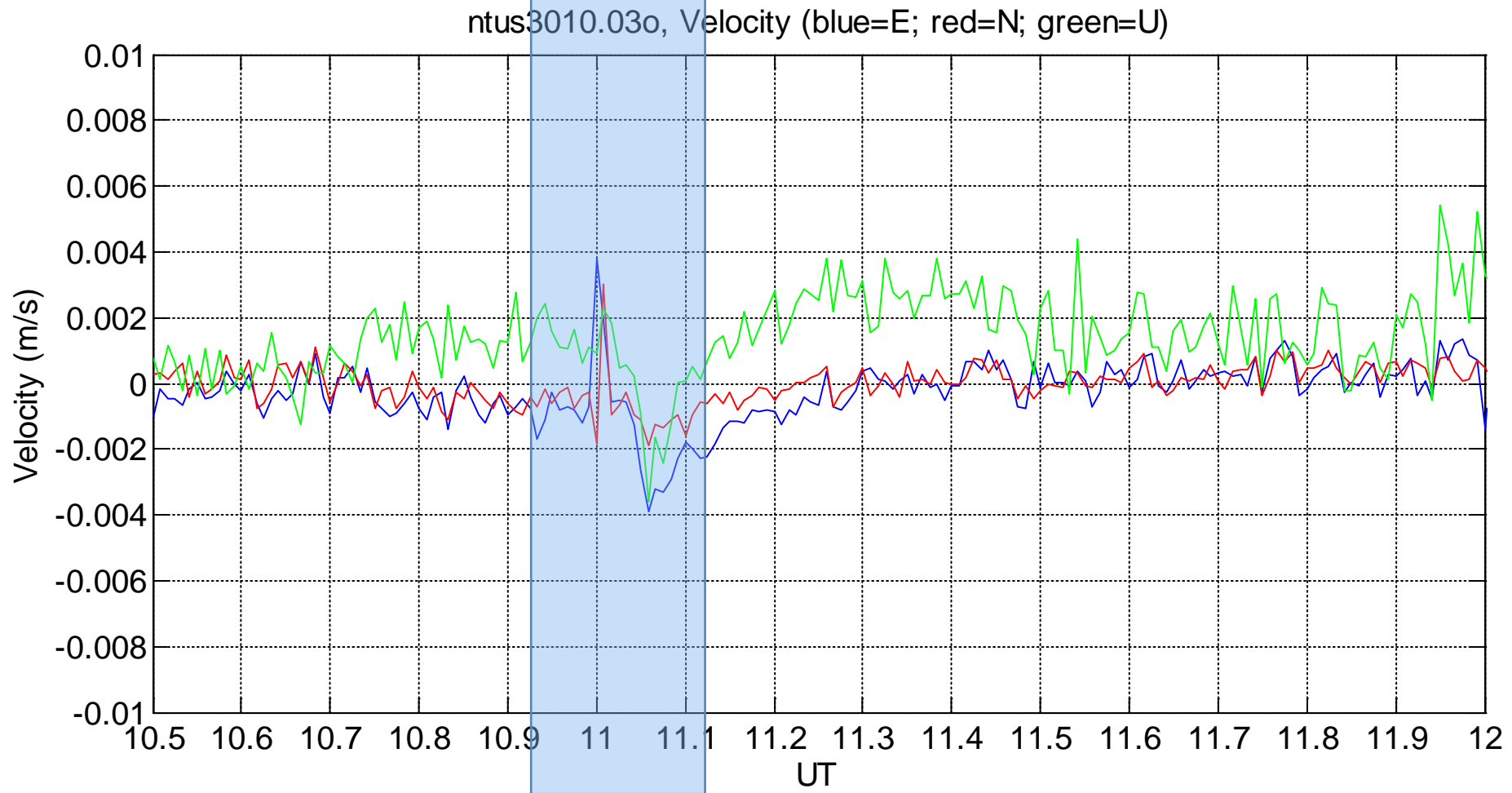


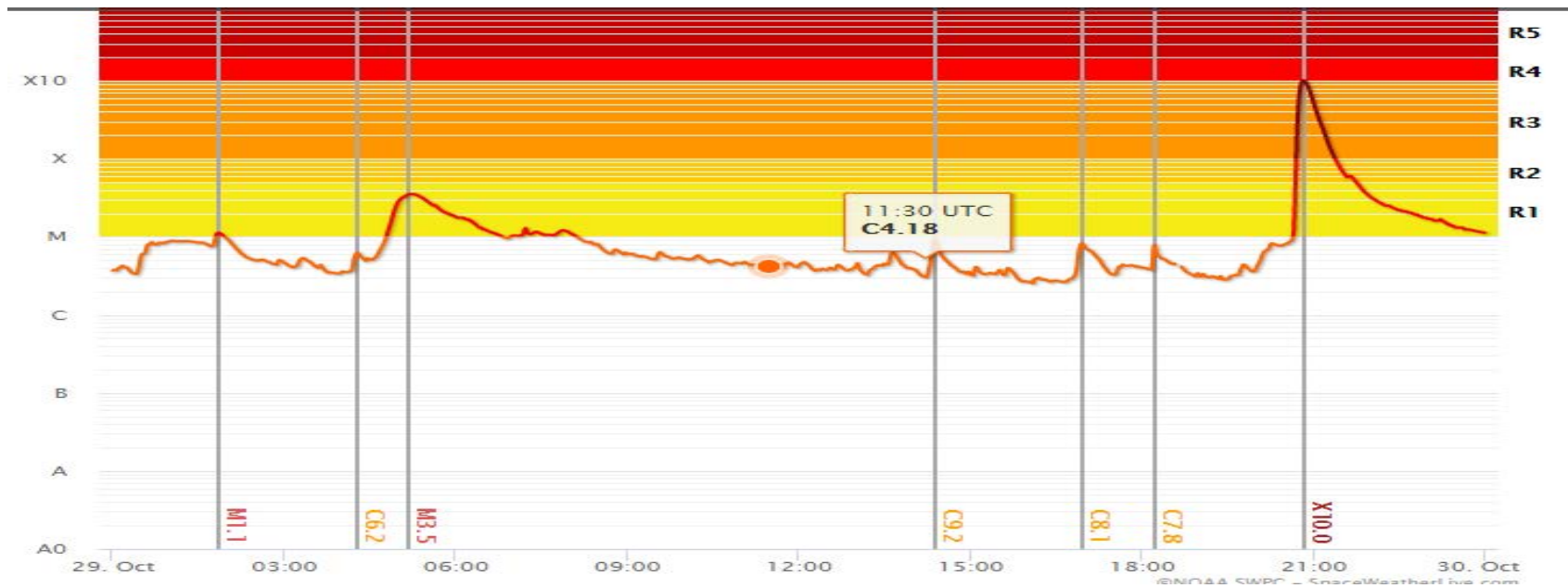
Oct 28, 2003





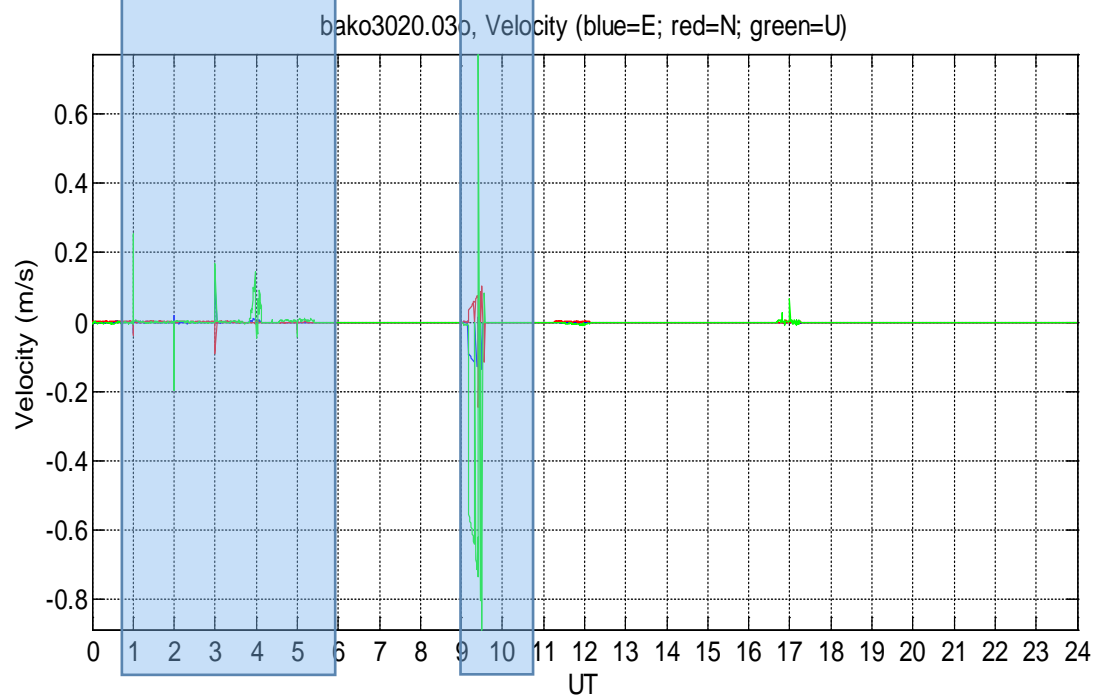
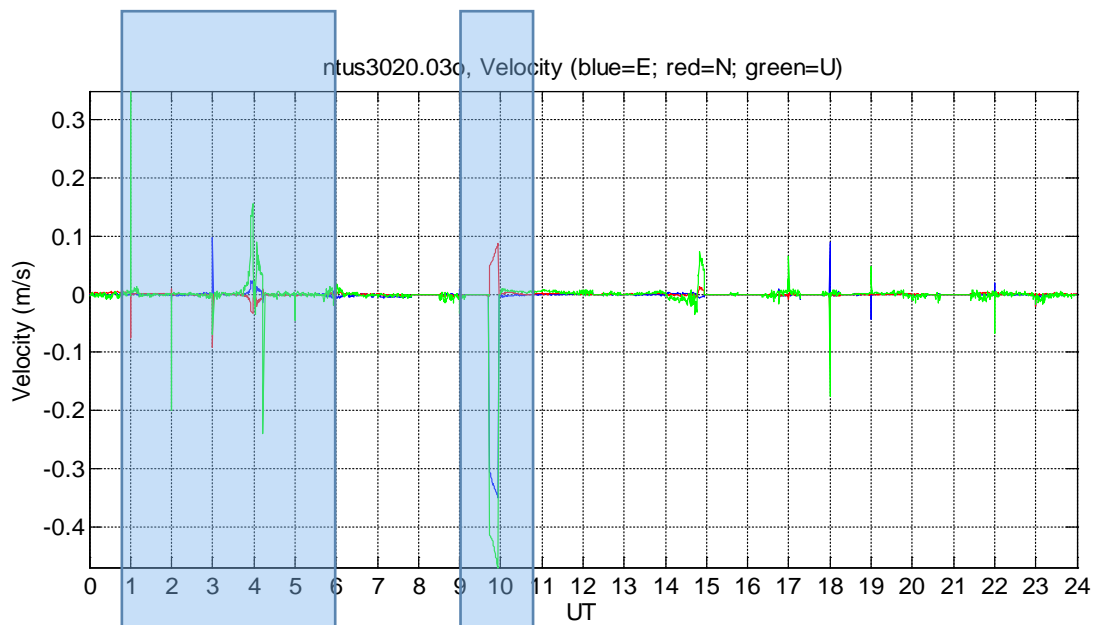
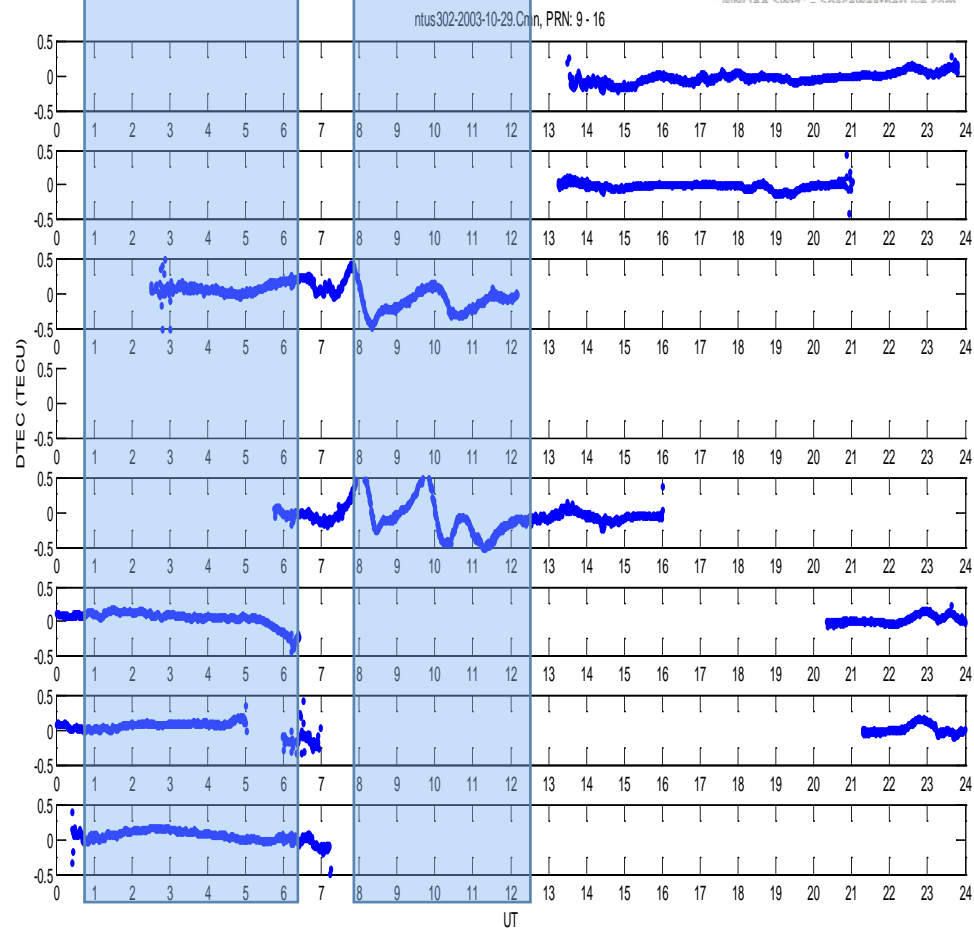
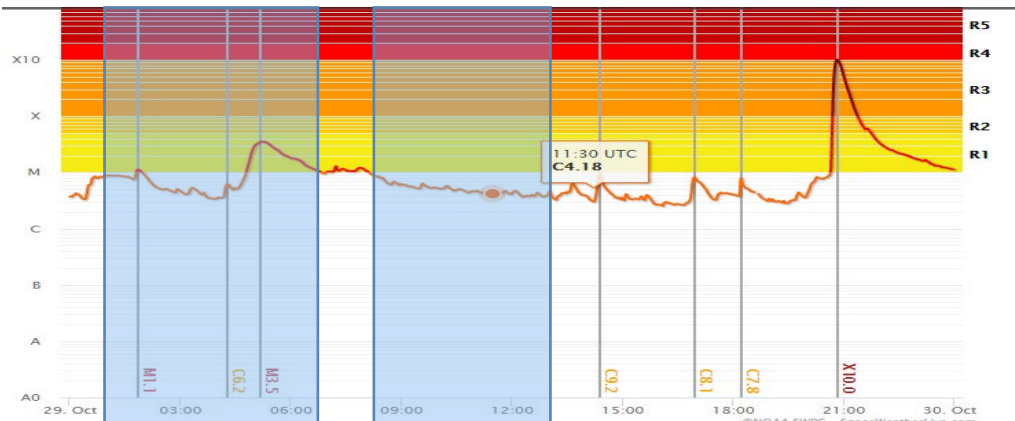


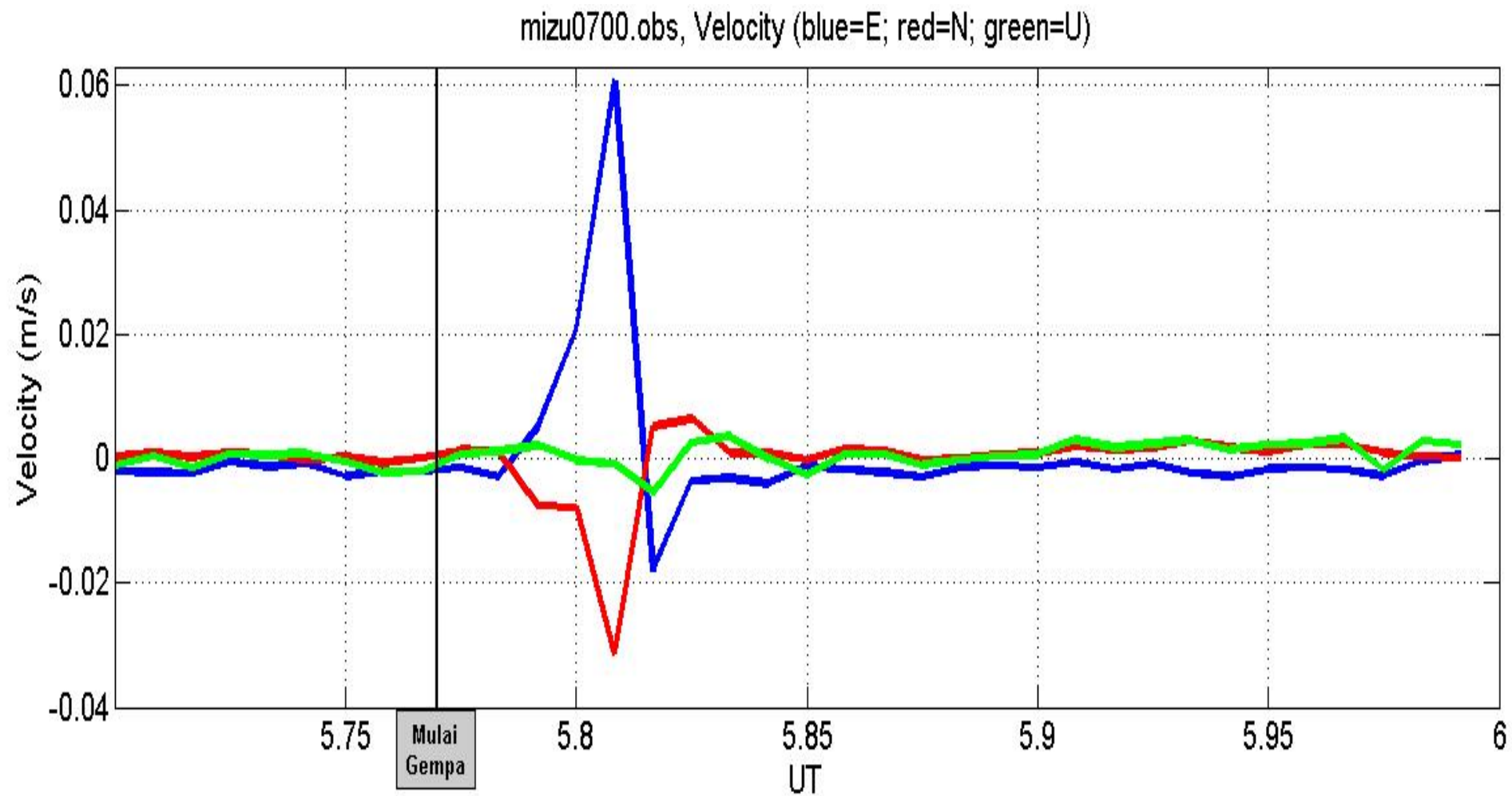




## Solar flares

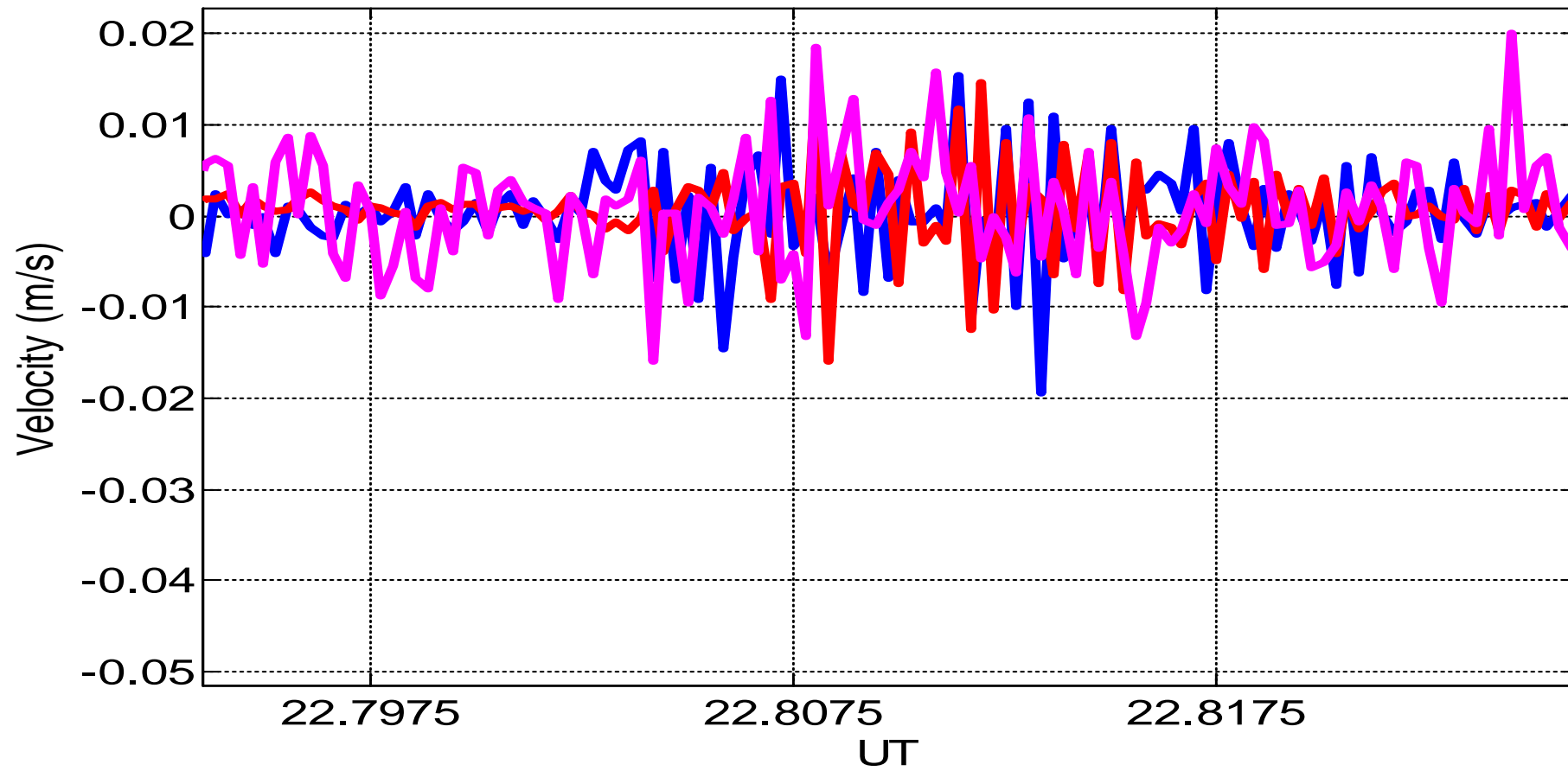
Region		Start	Maximum	End
0486	M1.1	00:26	01:51	02:08
-	C6.2	04:10	04:17	04:25
0486	M3.5	04:08	05:11	05:54
0486	C9.2	14:15	14:22	14:28
0486	C8.1	16:49	16:57	17:12
0488	C7.8	18:10	18:13	18:17
0486	X10.0 <a href="#">Play</a>	20:37	20:49	21:01



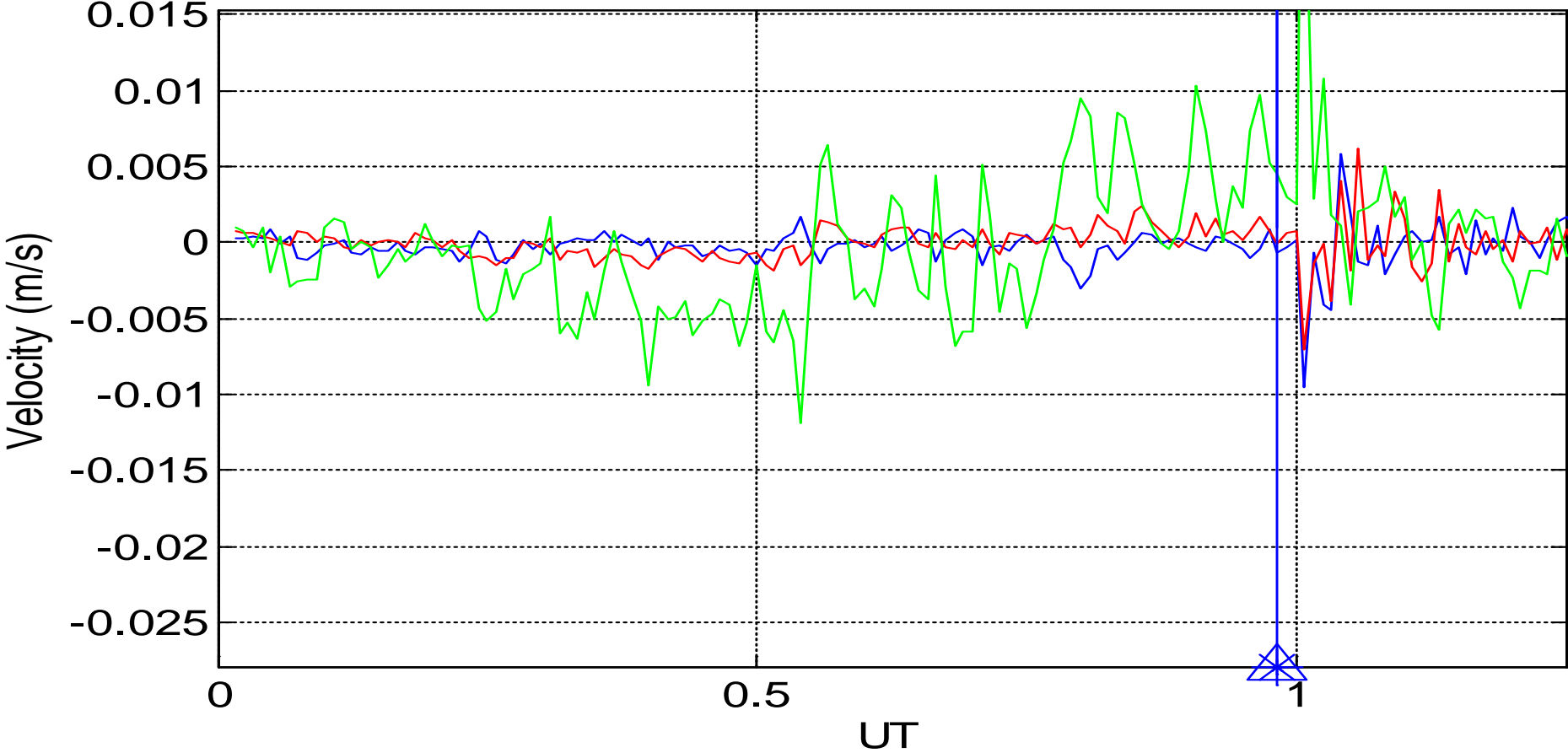


MIZU station is about 142 km from Tohoku earthquake epicenter, detect earthquake using variometric (6 cm displacement) after of about 1 minute

cmat209w.18o, Velocity (blue=E; red=N; pink=U)



samp3610.04o, Velocity (blue=E; red=N; green=U)



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 linear 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 during scintillation
2. Research deeply and broader of ionospheric scintillation effect on GNSS variometric

Thank You For Your  
Attention