GPS based total electron content (TEC) anomalies and their association with large magnitude earthquakes occurred around Indian region

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Overview of presentation

- Brief description of experimental setup used for TEC measurement.
- Data and method of analysis
- Statistical methods for detection of anomalous values of TEC.
- Results
- (i) Study of seismic effects on TEC for the duration of thirty months between 01 January, 2009 and 30 June, 2011.
- (ii) Comparative study of GIM TEC and observed GPS TEC.
- (iii) Results of anomalies in observed GPS TEC and GIM TEC corresponding to Wenchuan Earthquake.
- Conclusion

Experimental set up used at Agra for the measurement of TEC

GPS receiver system: GSV4004B

Receiver:
Novatel's Euro-PAK 3M

Antenna:
Novatel's GPS-702

The continuous observations are in progress since 24 June, 2006.

Data and analysis procedure to obtained daily diurnal curves of TEC data

- The TEC measurements are being carried out through combined frequencies (L1/L2) pseudorange and carrier phase measurements. The GSV4004B measures TEC using pseudorange measurements on the L1 and L2 frequencies.

- The receiver internal biases are also taken care of prior to final TEC calculations. This can be seen in the formula given below;

$$TEC = [9.483*(PR_{L2}-PR_{L1} - {}_{\Delta C/A\text{-}P,\ PRN}) + TEC_{RX} + TEC_{CAL}]\ TECU$$

where PR_{L2} is the L2 pseudo-range in meters, PR_{L1} is the L1 pseudo-range in meters, ΔC/A-P, PRN is the input bias between SV C/A- and P-code chip transition in meters. TEC_{RX} is the TEC result due to internal receiver L1/L2 delay and TEC_{CAL} is the user defined TEC offset.

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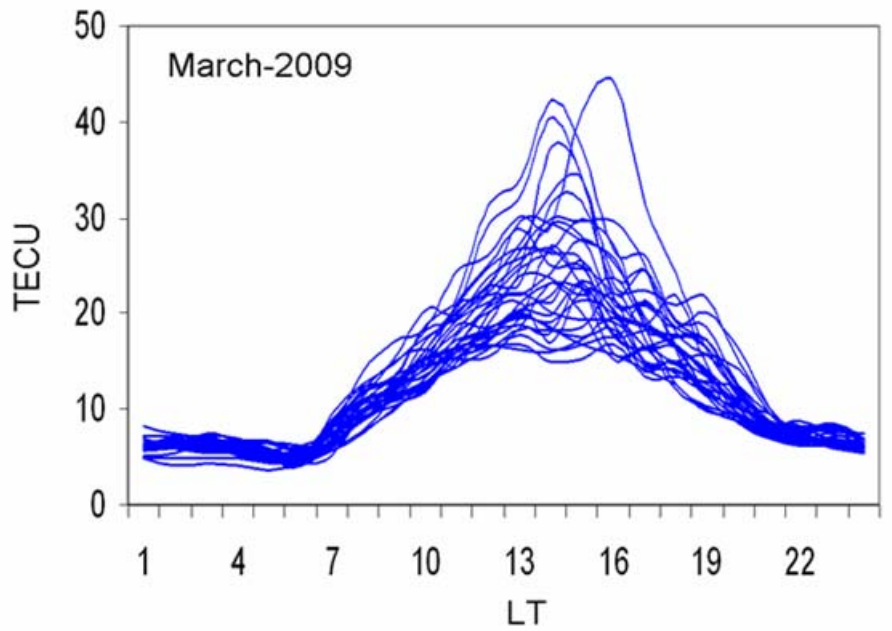
•Obtained vaules of TEC are slant TEC which are converted into vertical TEC (VTEC) using expression given by Mannucci et al. 1993.

$$S(E)=\frac{1}{\cos(z)}=\left\{1-\left(\frac{R_E \times \cos(E)}{R_E+h_S}\right)^2\right\}^{-0.5}$$

where R_E is the mean radius of the earth in km, h_S, the ionosphere (effective) height above the earth's surface, z, the zenith angle and E, the elevation angle in degrees. The effective ionospheric height of 350 km is used for determination of IPP locations.



To avoid the effect of multipath, troposcatter and water vapor at low elevation angles values of TEC are taken at higher elevation angles (>50^0).

Local Time (LT)=UT+0530 hrs

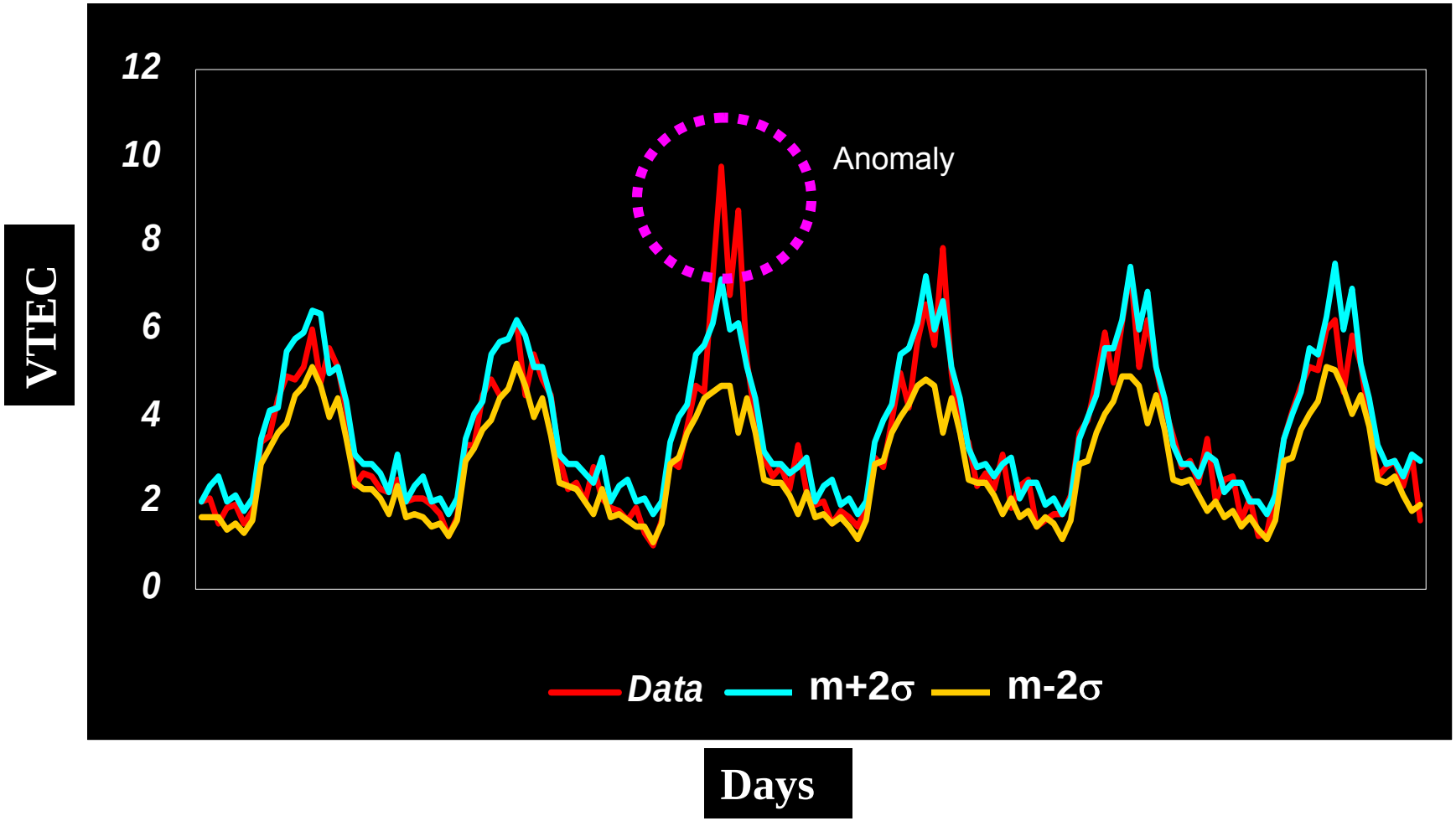
Statistical procedures to detect anomalous variations in daily diurnal curves of TEC data

- To detect anomalous variations in TEC data we applied the similar statistical procedures as adopted by earlier workers from Taiwan, Japan, etc. (Prof. Liu, Prof. Hayakawa, Prof. Hattori…..)

- **15 days backward running mean (m) and running standard deviation around mean (m±2σ)**

* The variation of VTEC is plotted between the curves of m ± 2σ.

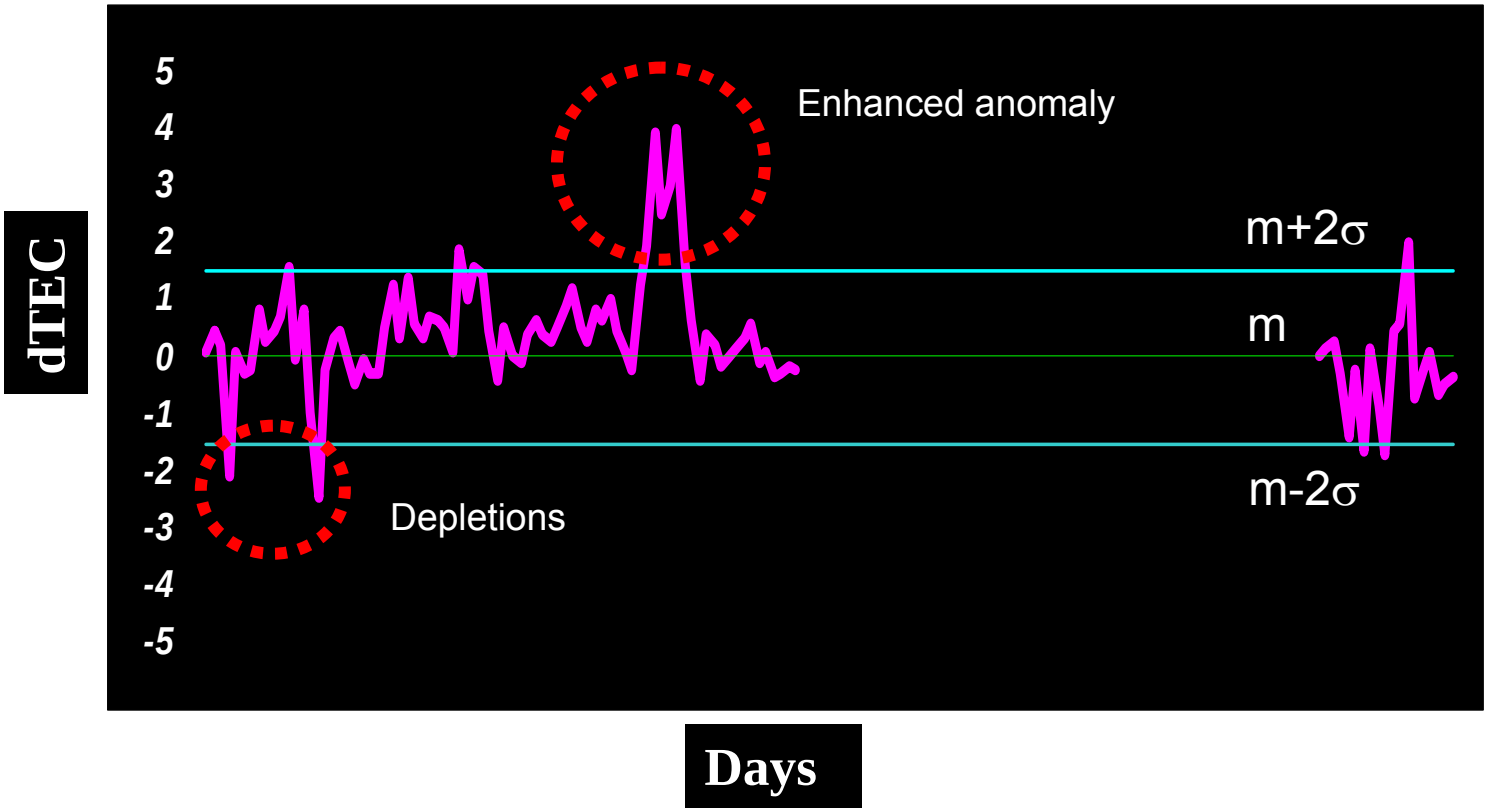
The values of VTEC crossing m ± 2σ curves are said to be abnormal.


VTEC
12
10
8
6
4
2
0
Anomaly
Data
m+2σ
m-2σ
Days

differential TEC (dTEC)

* dTEC = VTEC – 15 days backward running median of TEC at each epoch.
* The variation of dTEC is plotted between it's **fix mean** and standard deviation around. mean (m ± 2σ).

The values of dTEC crossing m+2σ or m-2σ lines are said to be abnormal.



- **Quartile-based statistical method**

* At first a **median (M) of every successive 15 days** of TEC is computed to find the deviation on 16^{th} day.

* **Two quartiles**, first (or lower) and third (or upper) are calculated which are denoted by **LQ** and **UQ** respectively. It has been shown by earlier workers (Klotz and Johnson, 1983; Liu et al., 2009) that under the assumption of a normal distribution with mean (m) and standard deviation (σ) for GPS TEC, the expected values of **M** and **LQ** or **UQ** are **m** and **1.34σ** respectively.

- **Finally**, the lower bound (LB) and upper bound (UB) are calculated as;

LB=M - 1.5 (M - LQ),

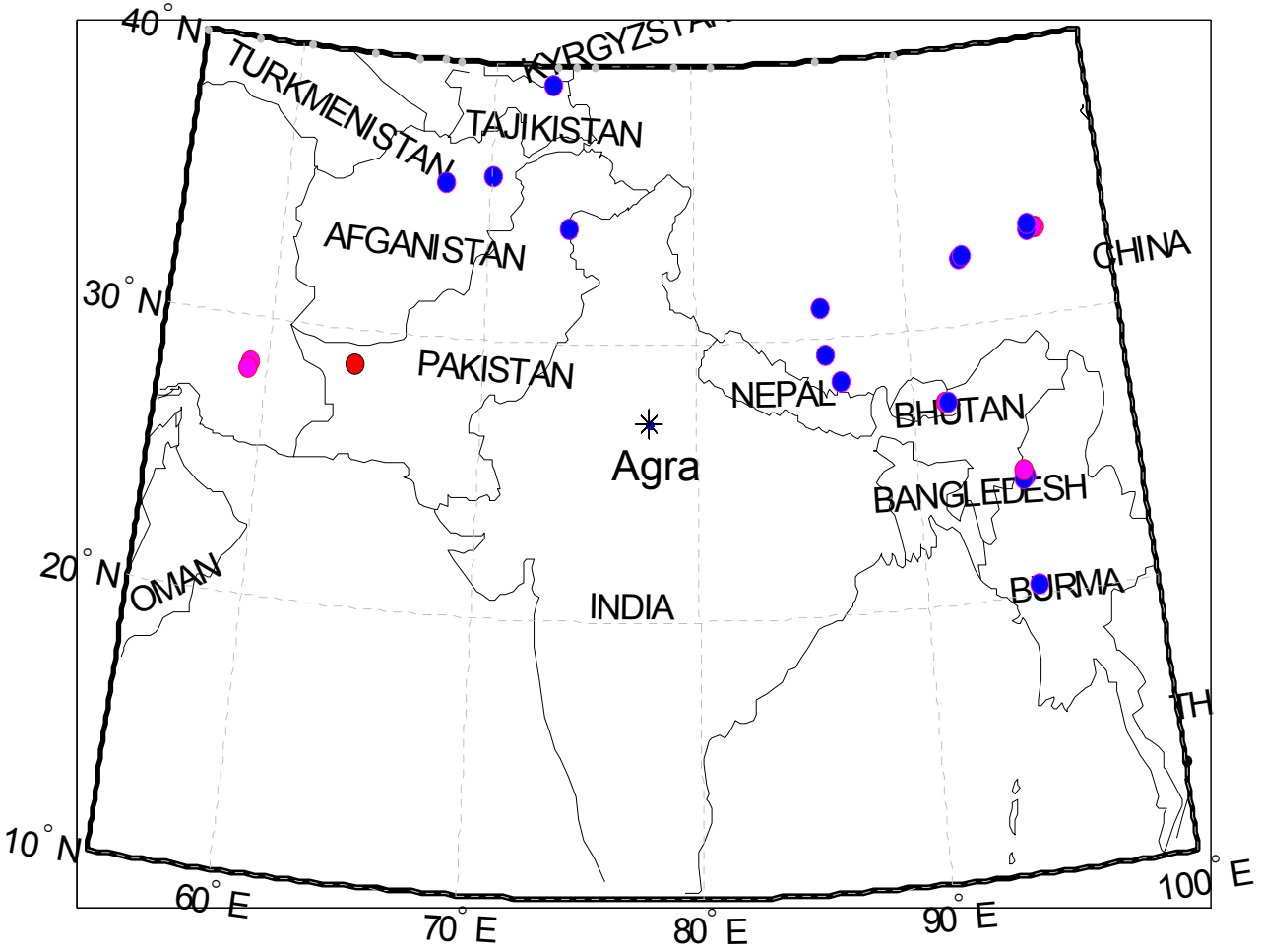
UB= M + 1.5 (UQ-M).

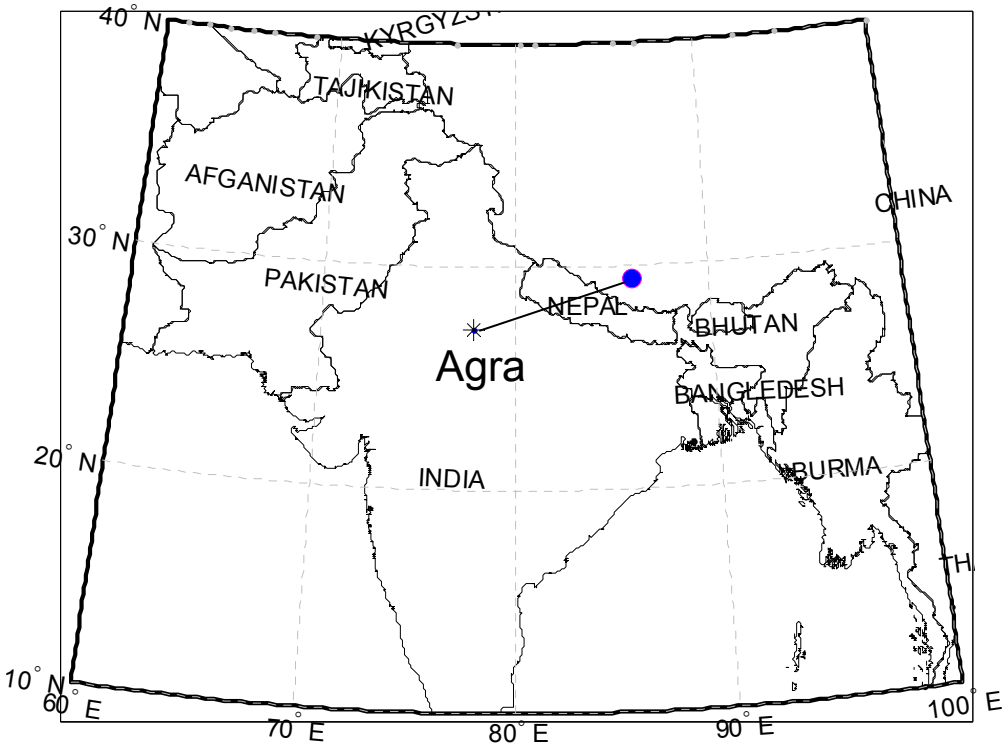
- ***The values of TEC crossing these LB and UB are detected as abnormal variation in TEC data***.

Results

Locations of the epicenters of earthquakes occurred around Indian region

(01 January, 2009 – 30 June, 2011)





Date: 07 November, 2009

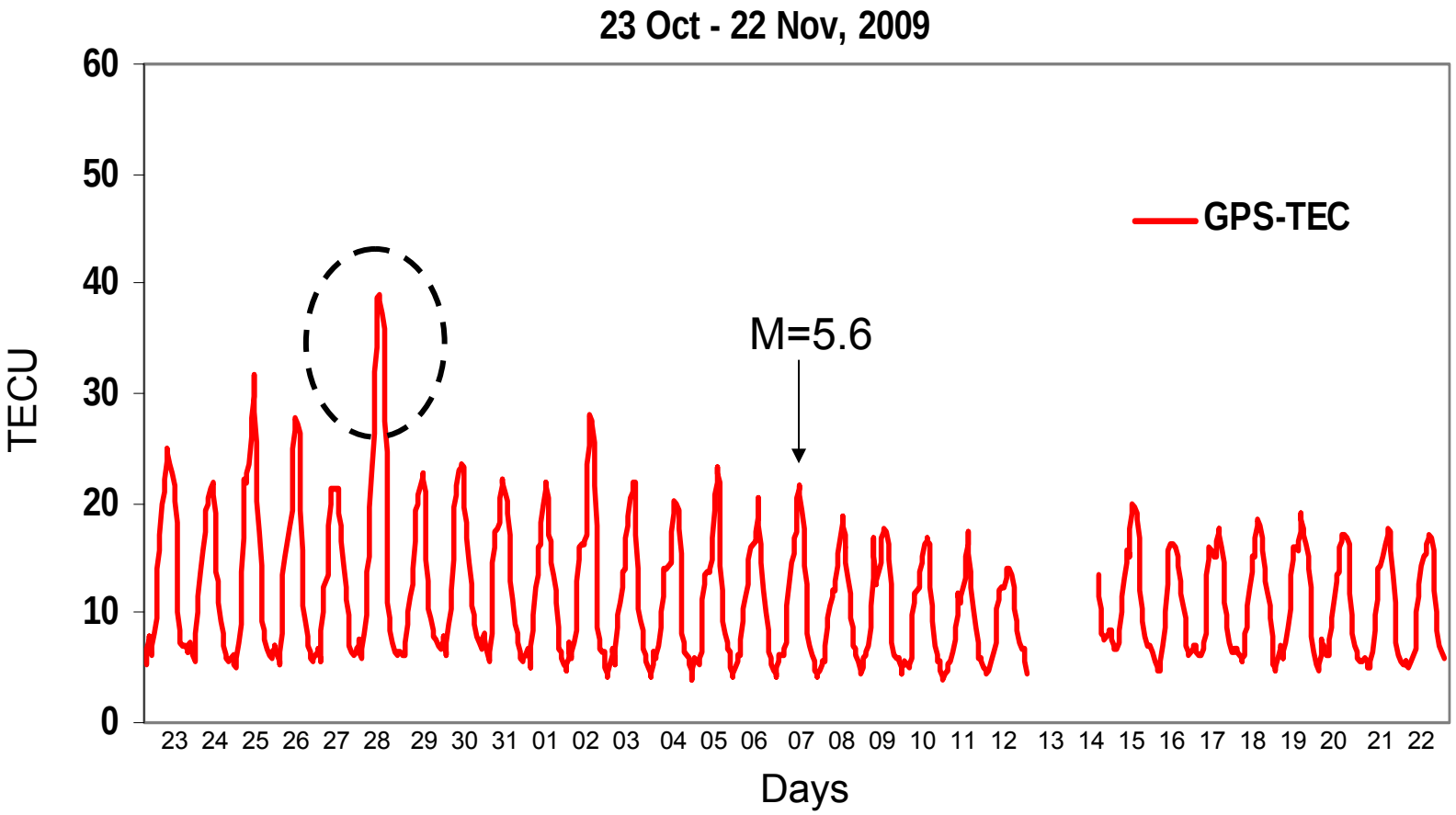
Magnitude = 5.5

Lat.=29.49^{0}N
Long.=86.01^{0}E

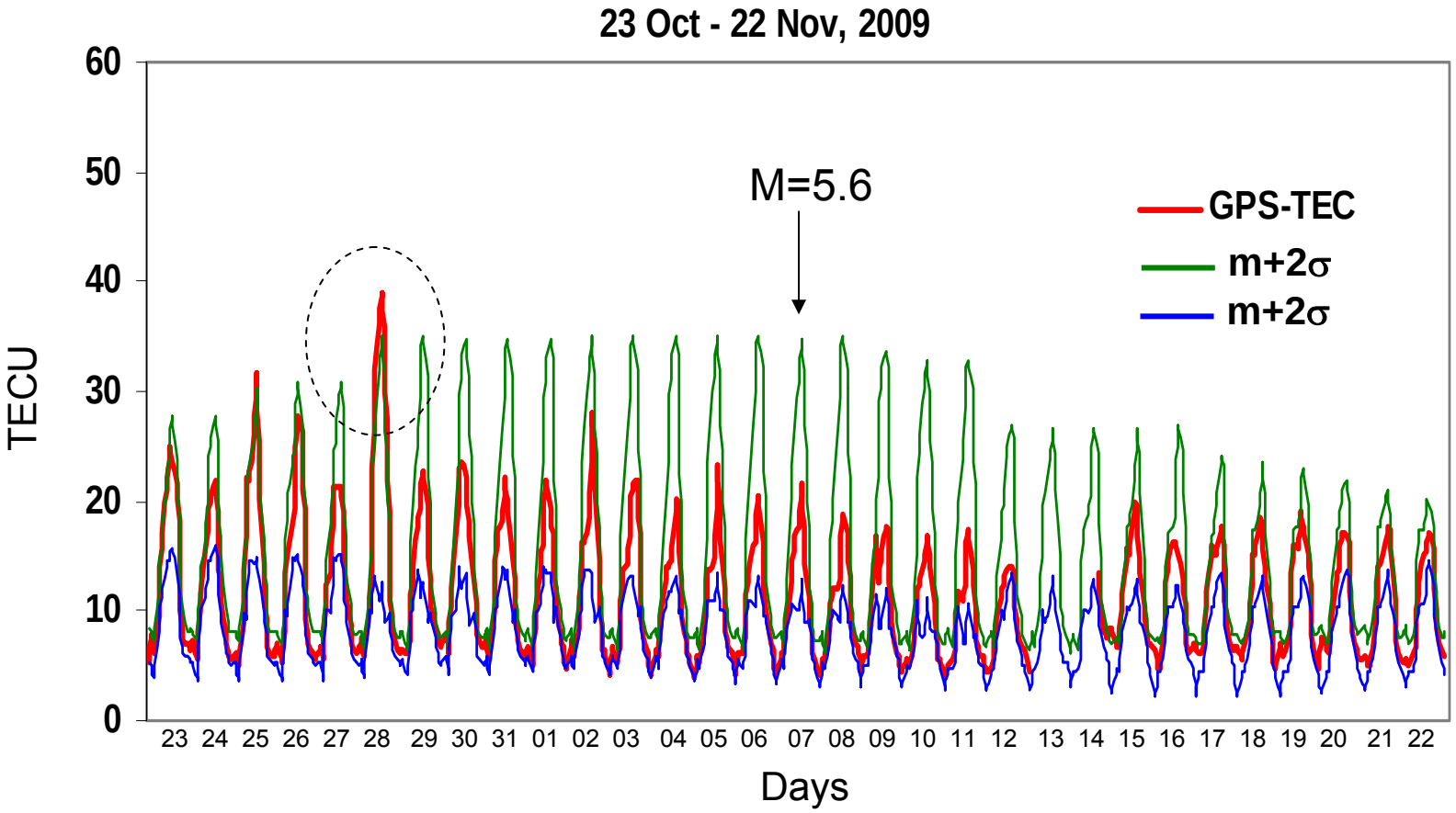
Distance from Agra=831 km

Depth=5 km

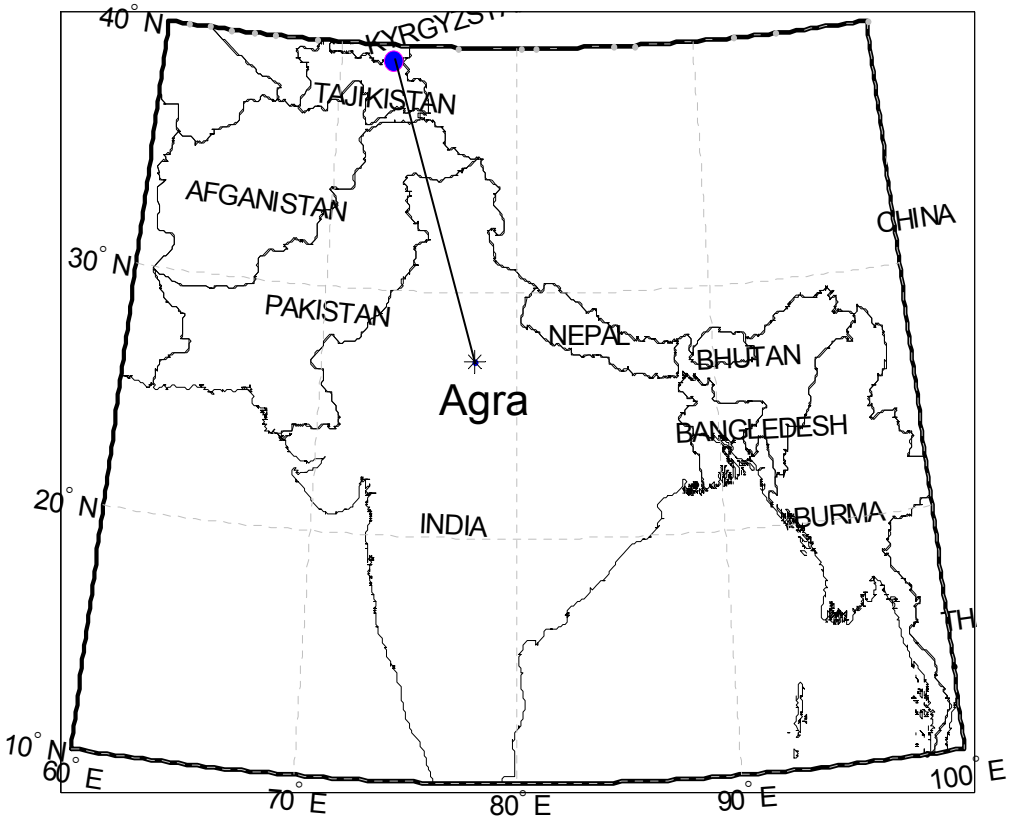
Day of the earthquake:07 November, 2009



Day of the earthquake:07 November, 2009



*To investigate the seismic effect on TEC we omitted the disturb days from all the data



Date: 08 December, 2010

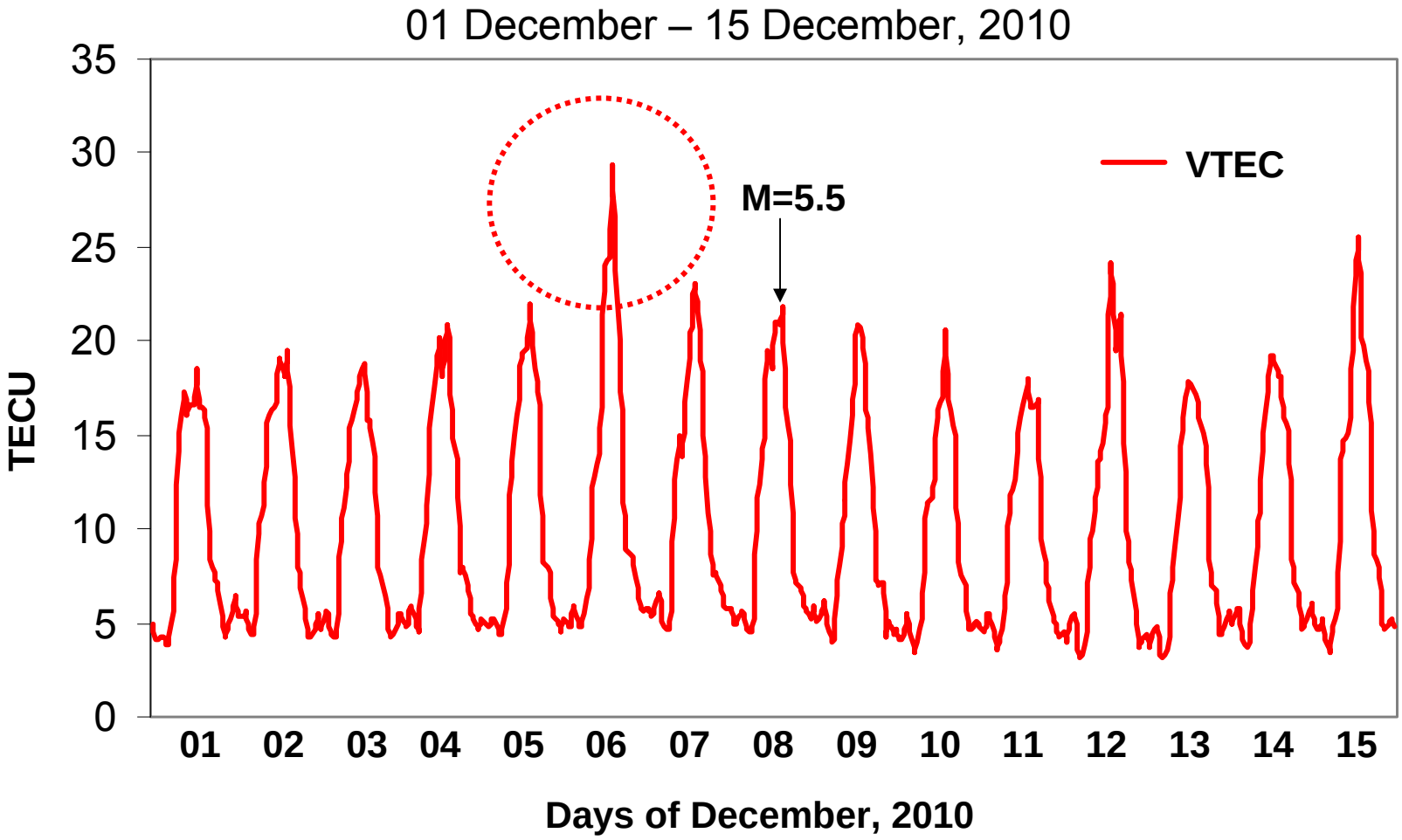
Magnitude = 5.5

Lat.=39.36^{0}N
Long.=72.86^{0}E

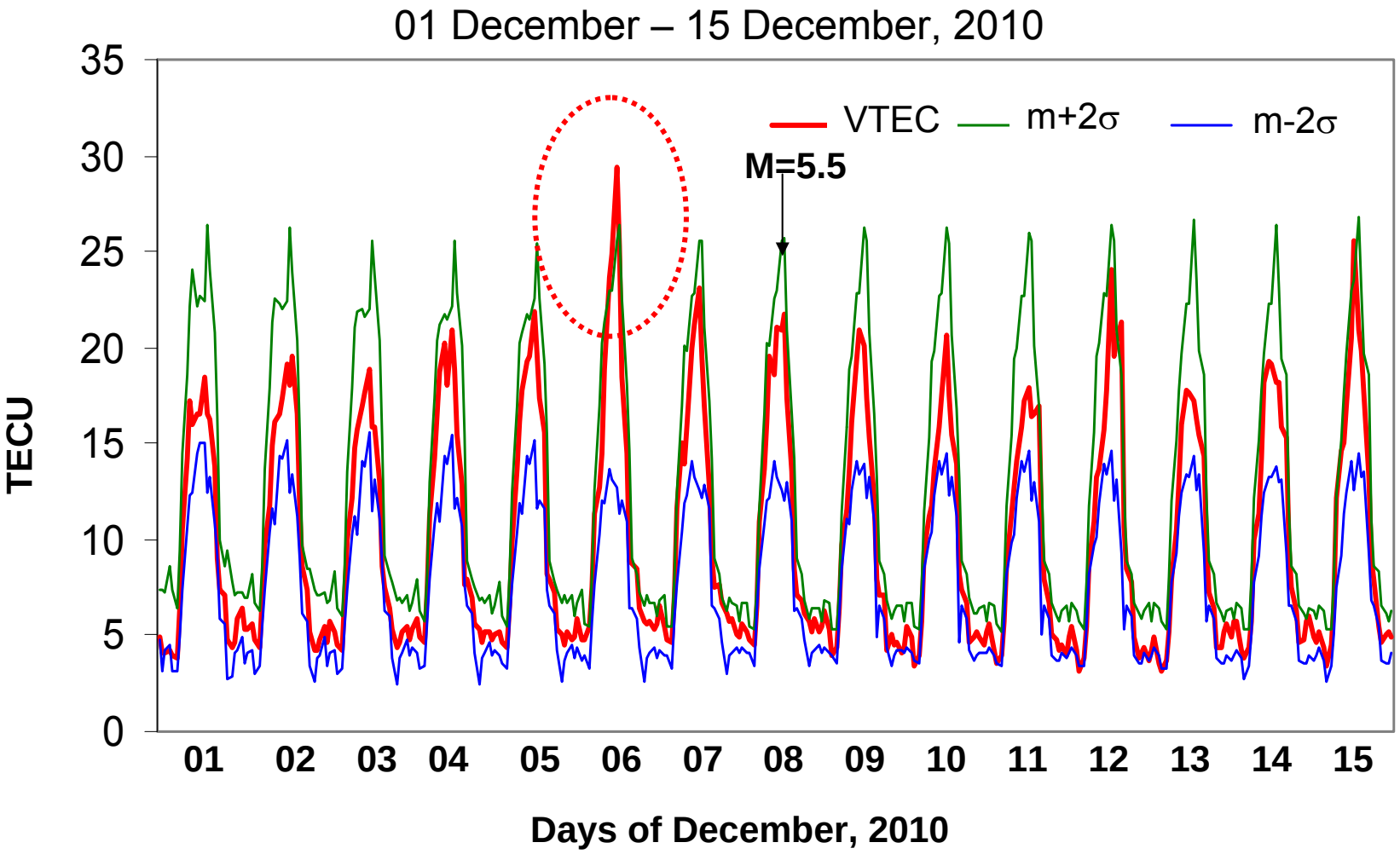
Distance from Agra=1450 km

Depth=10 km

Day of the earthquake: 08 December, 2010

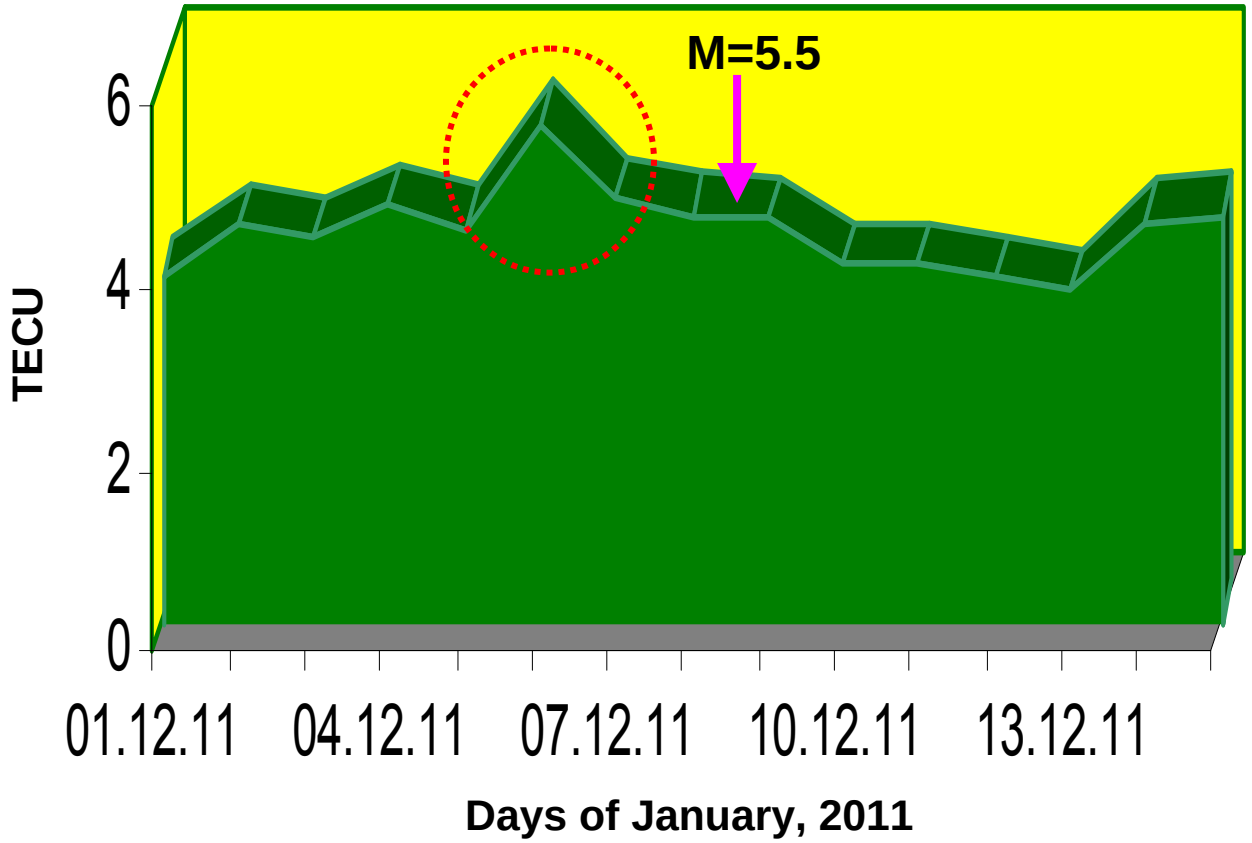


Day of the earthquake: 08 December, 2010



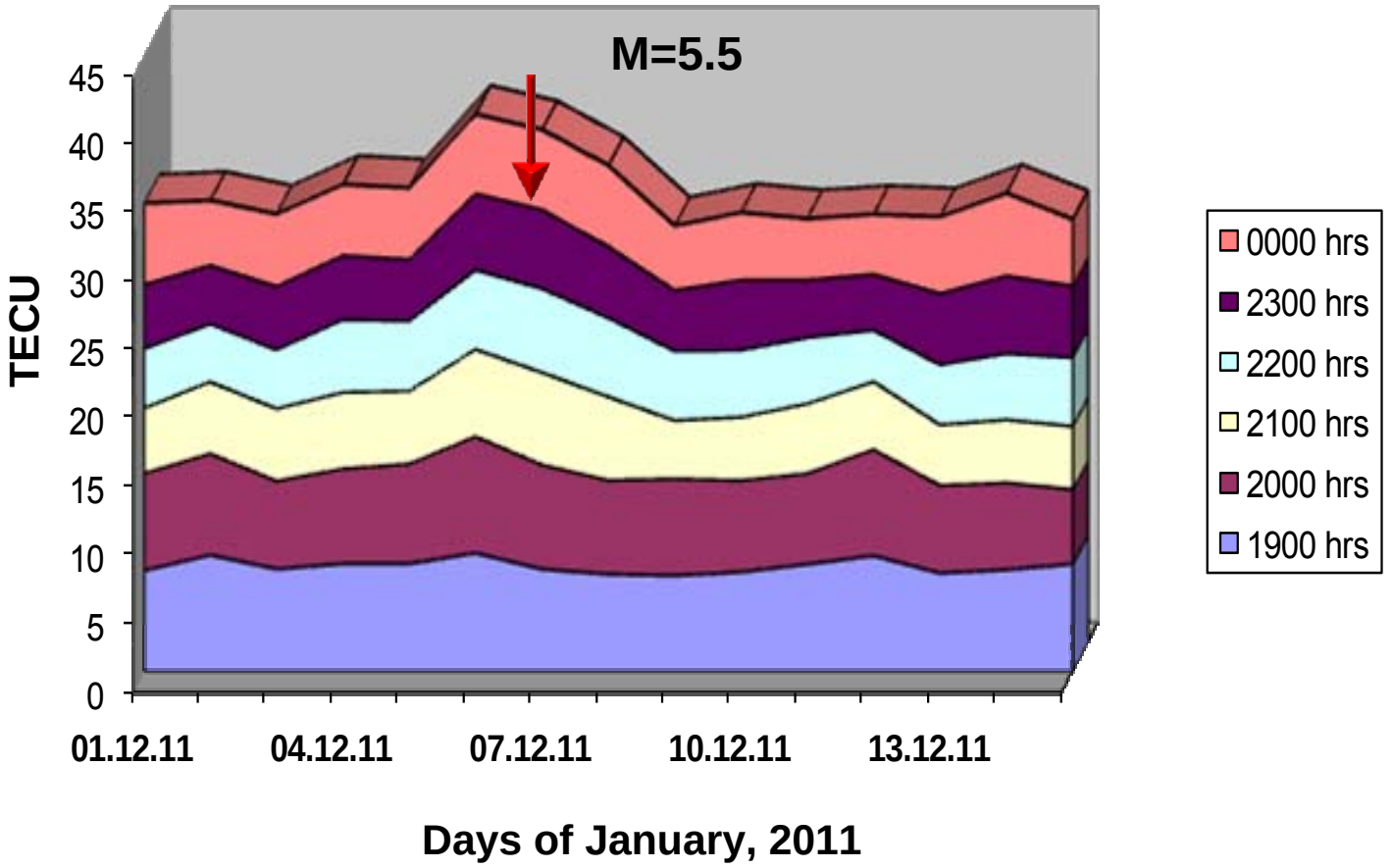
01 December – 15 December, 2010

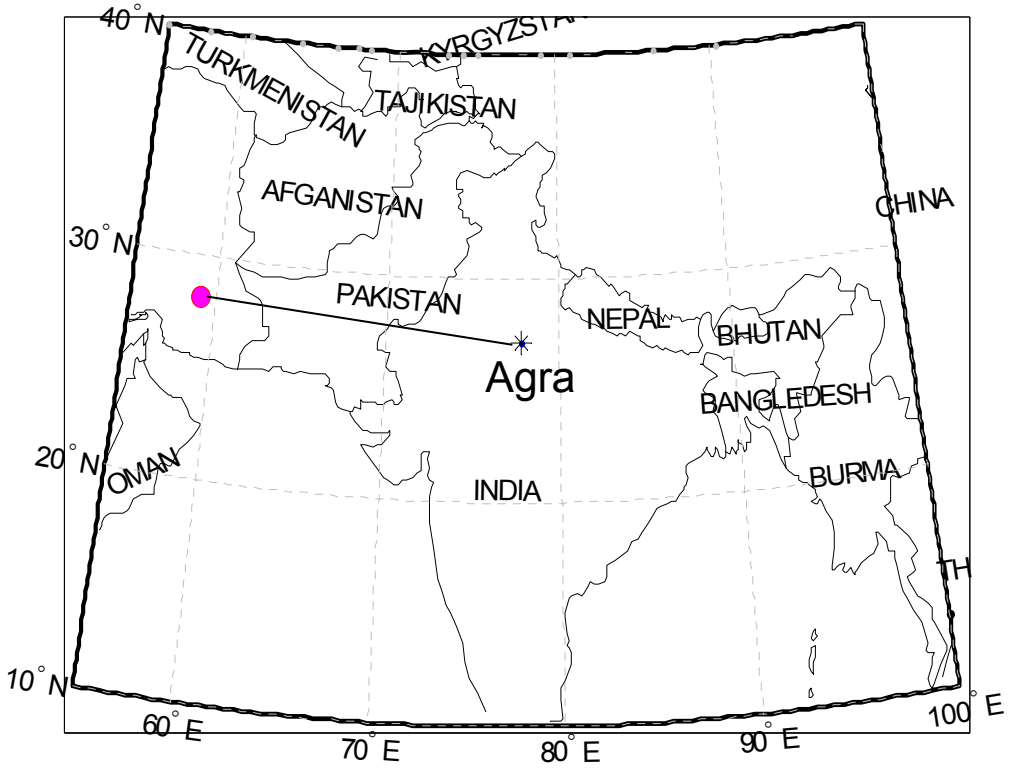
Variation of VTEC at 0600 hrs local time



01 December – 15 December, 2010

Variation of VTEC in nighttime sector





Date: 27 January, 2011

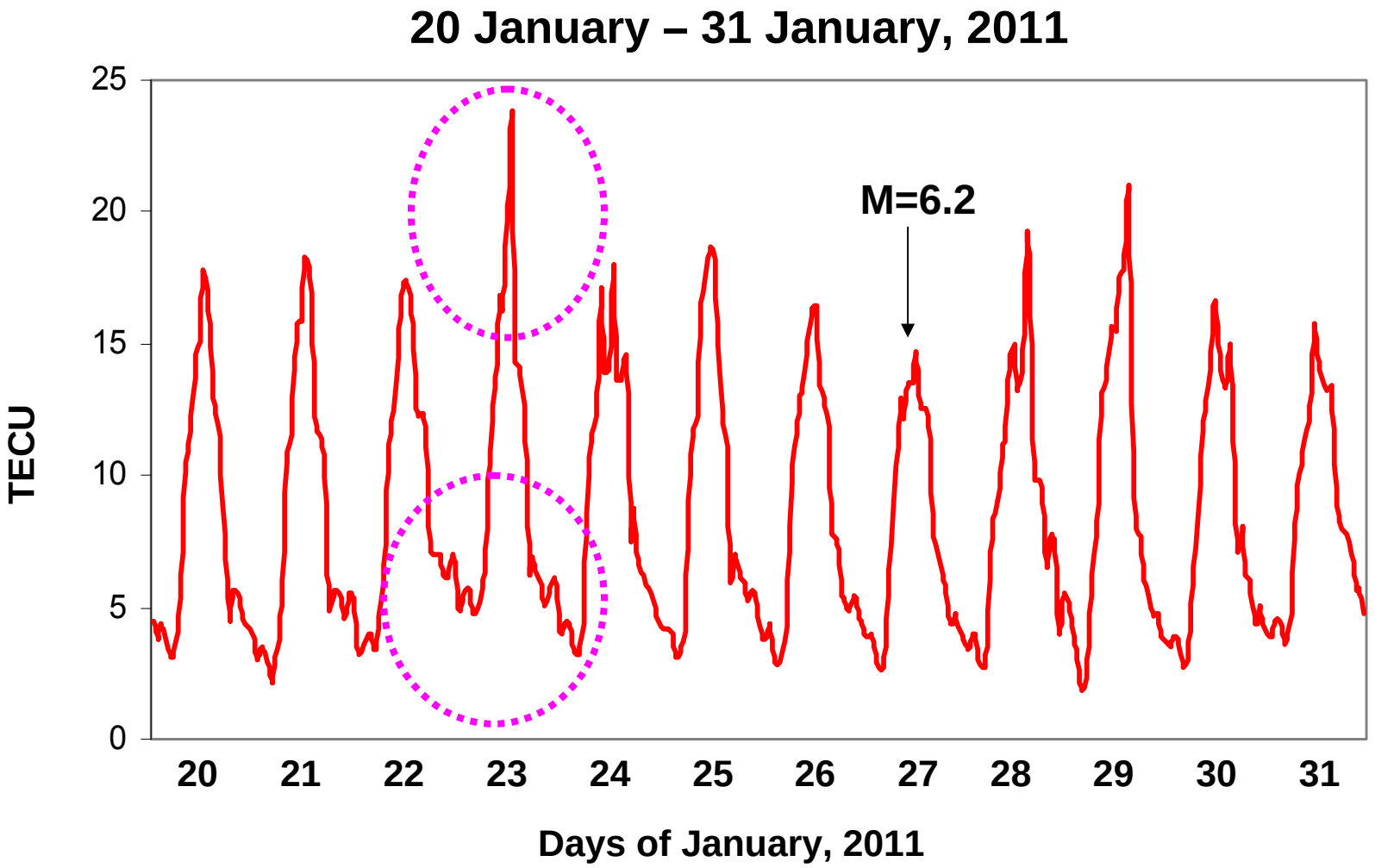
Magnitude = 6.2

Lat.=28.19^{0}N
Long.=59.01^{0}E

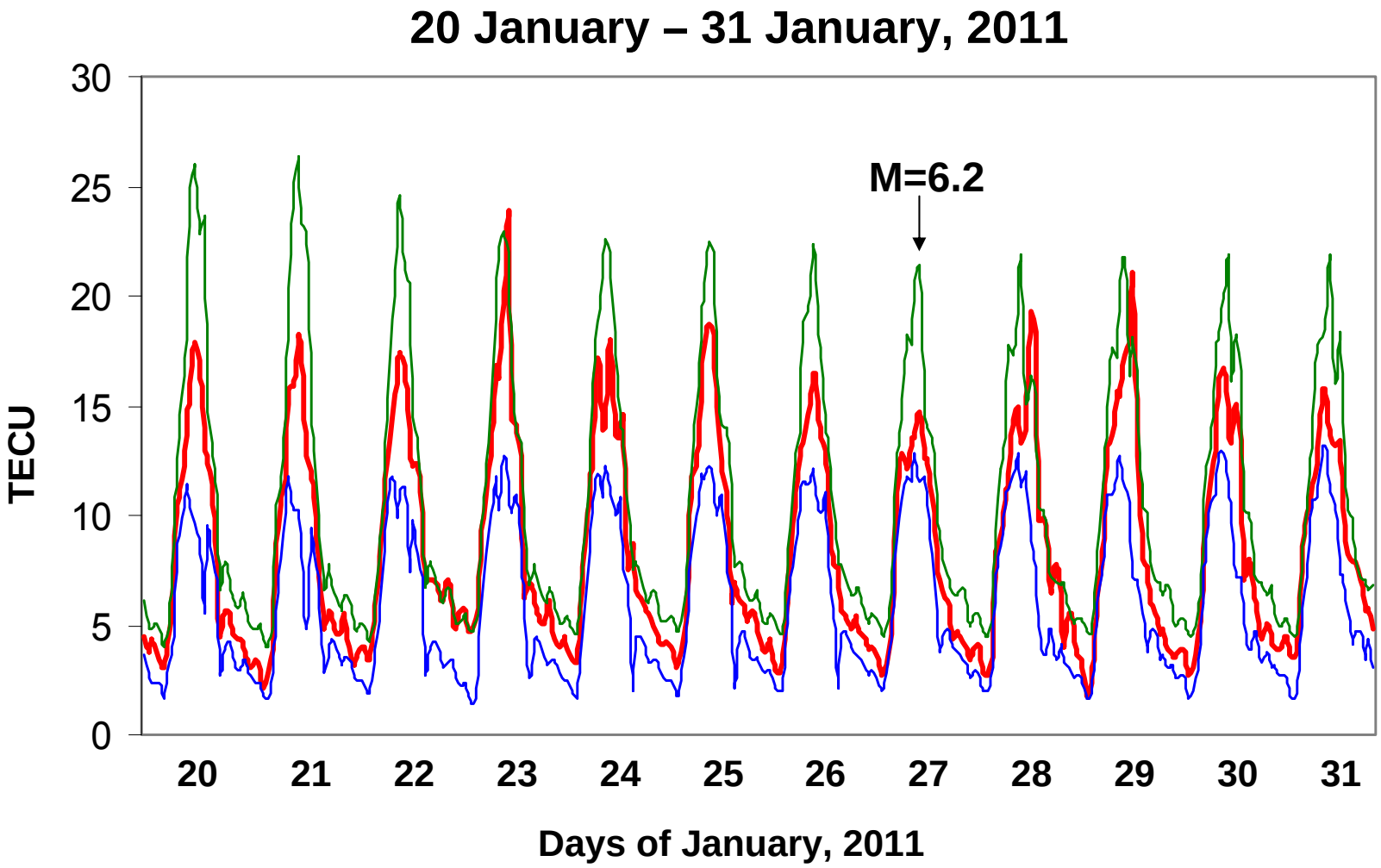
Distance from Agra=1875 km

Depth=12 km

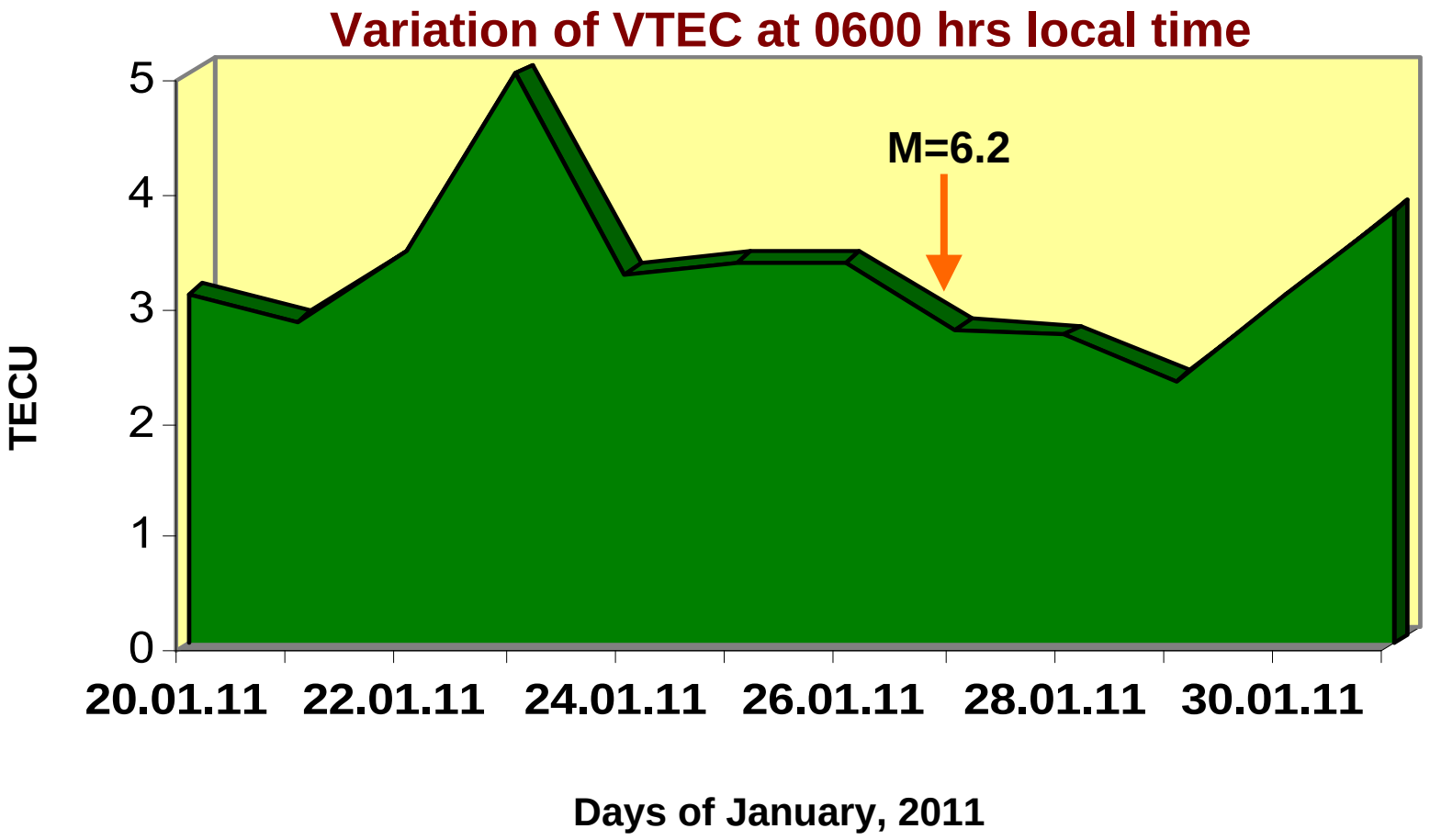
Day of the earthquake: 27 January, 2011



Day of the earthquake: 27 January, 2011

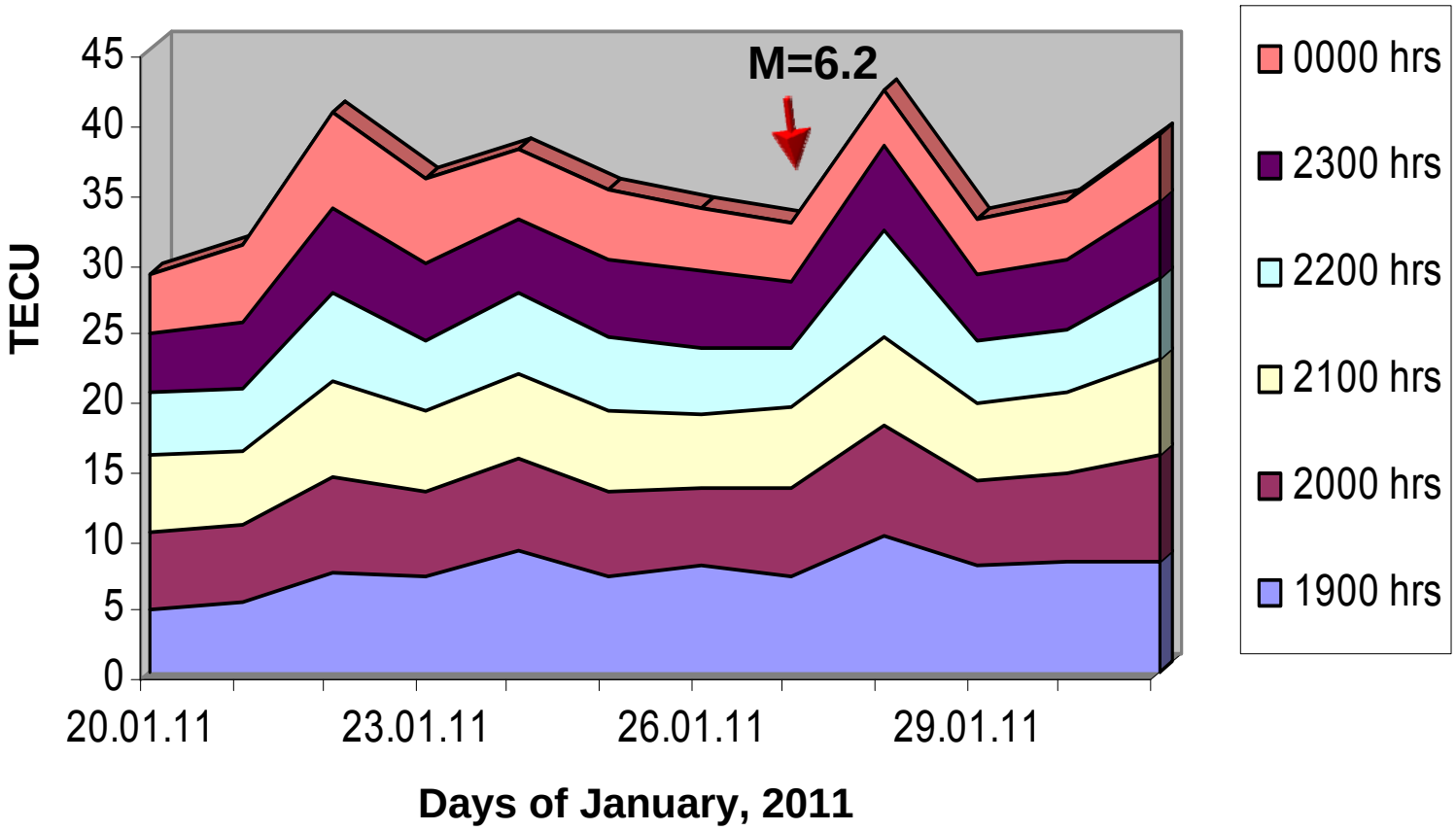


20 January – 31 January, 2011



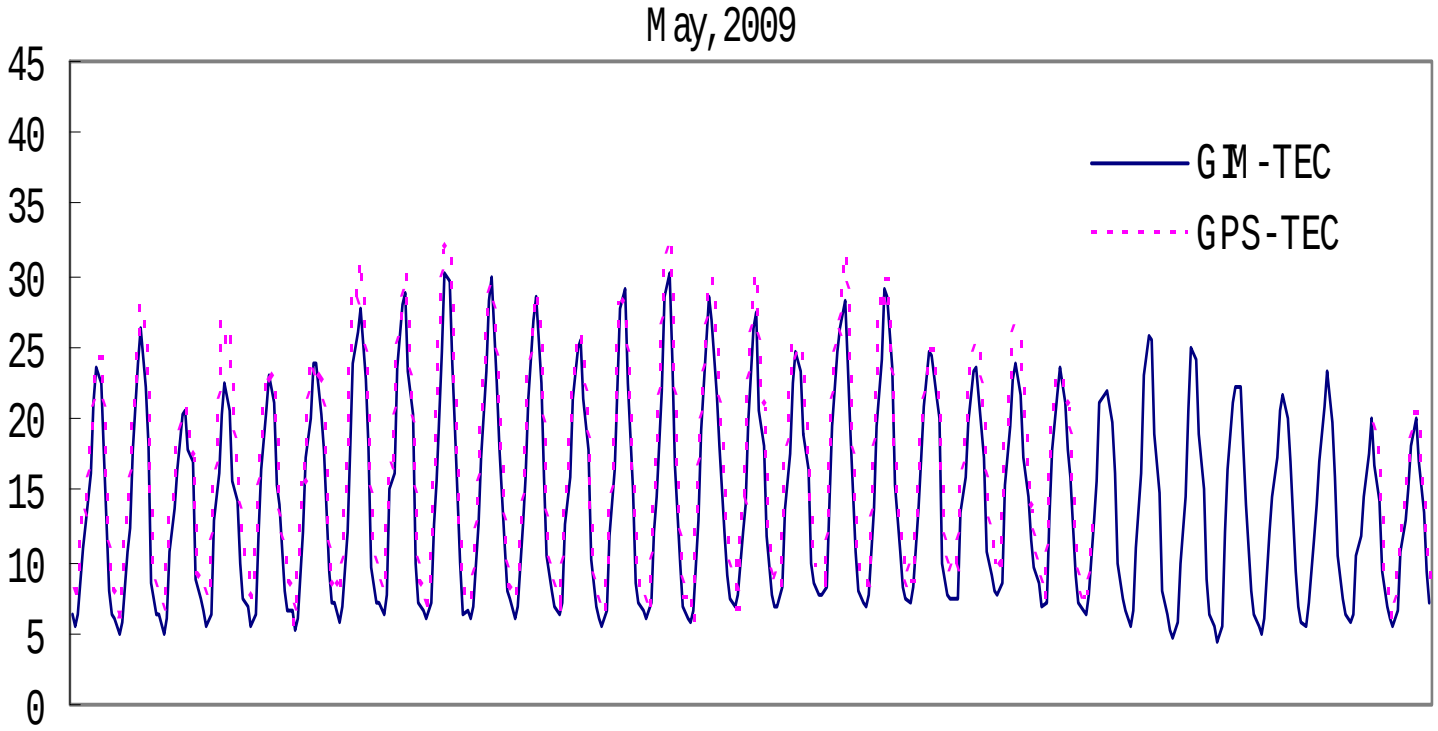
20 January – 31 January, 2011

Variation of VTEC in nighttime sector



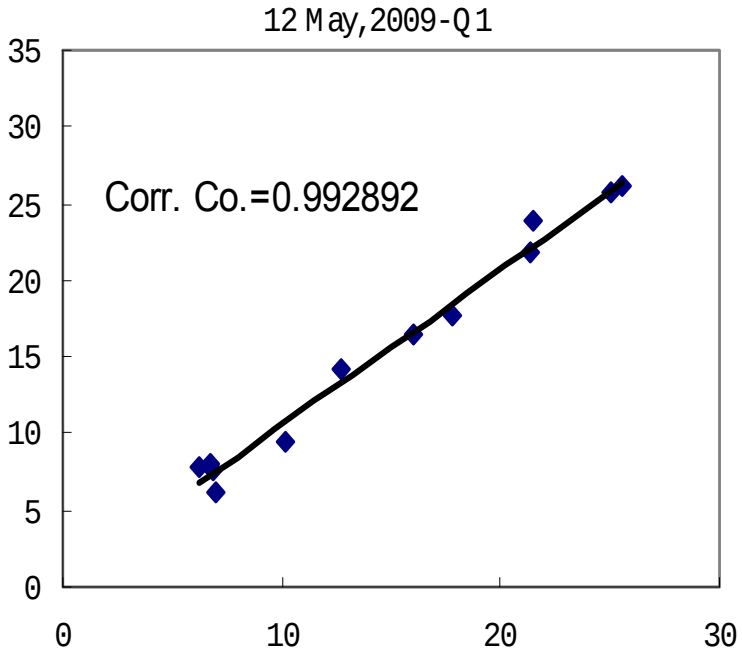
Study of GIM-TEC data and its comparison with GPS-TEC data at Agra

An example of the diurnal variation of GIM-TEC and GPS-TEC data

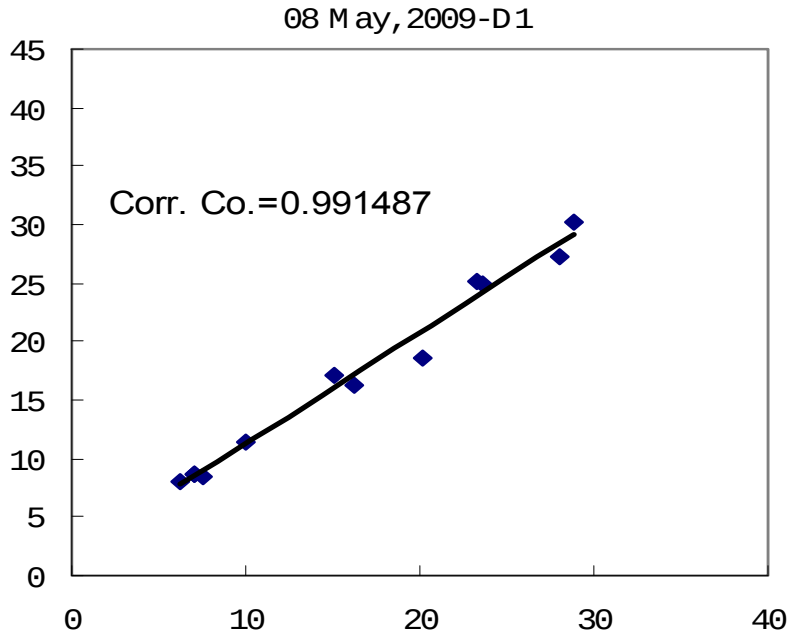


An example of the correlation between GIM-TEC and GPS-TEC data

Quiet Day

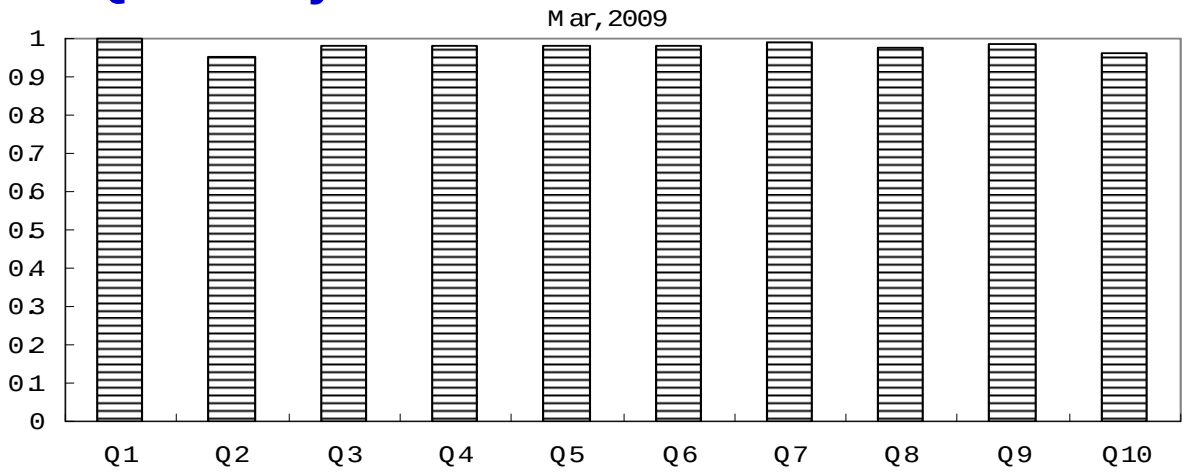


Disturb Day

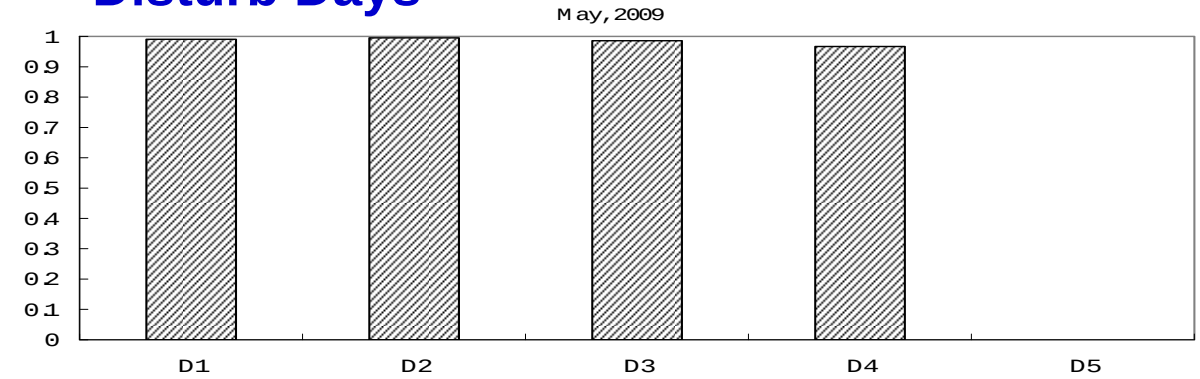


An example of the correlation between GIM-TEC and GPS-TEC data

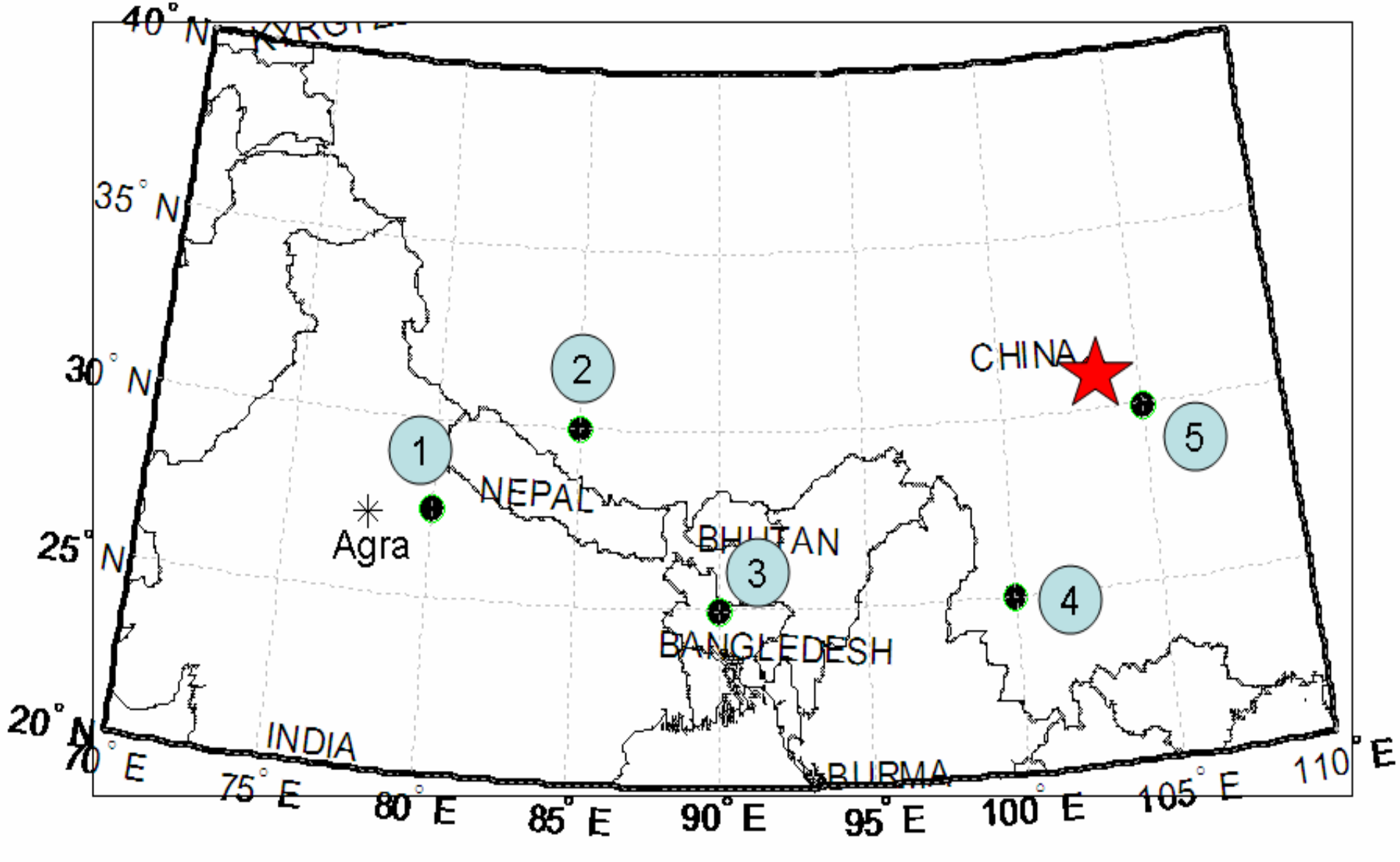
Quiet Days

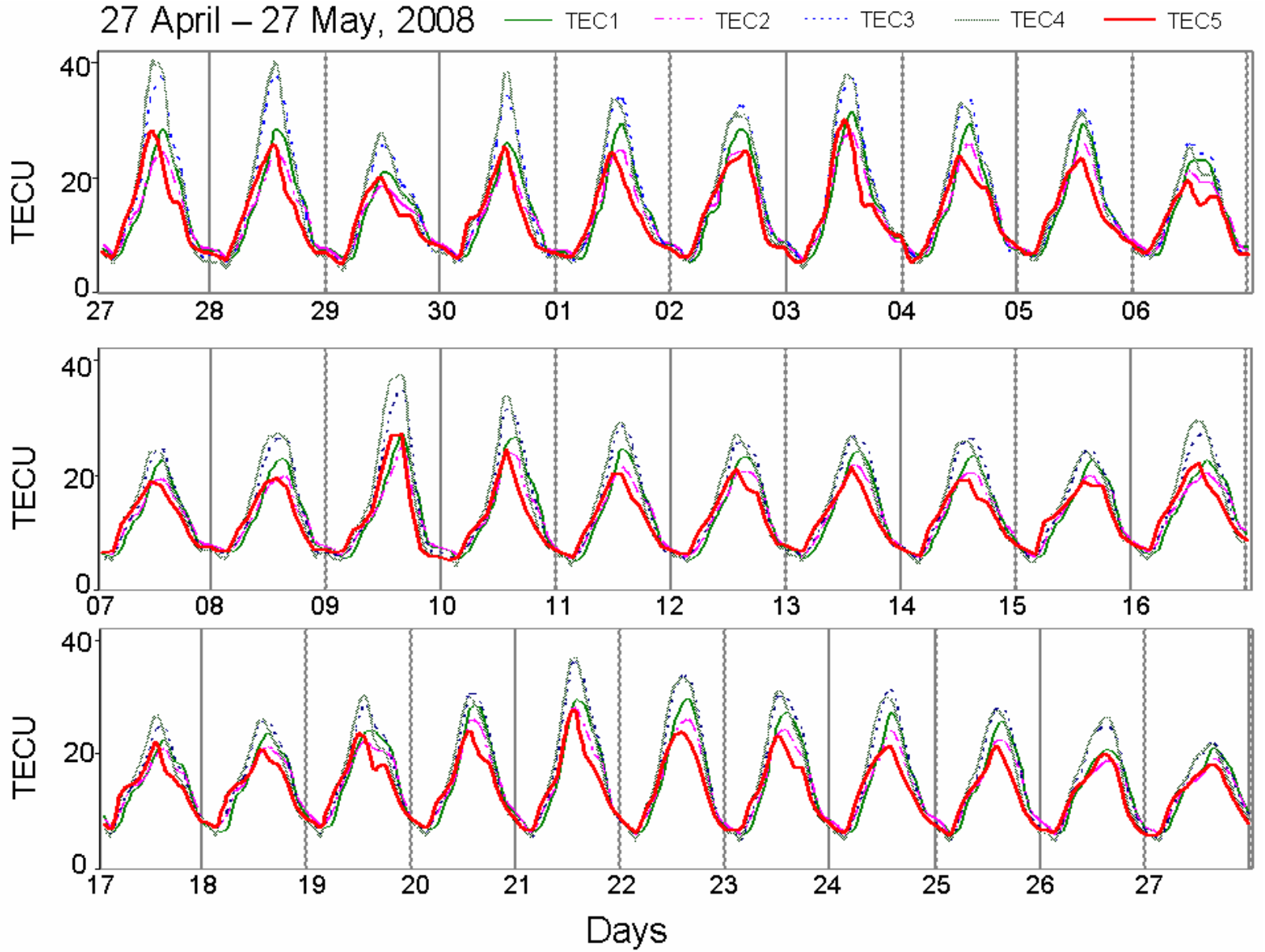


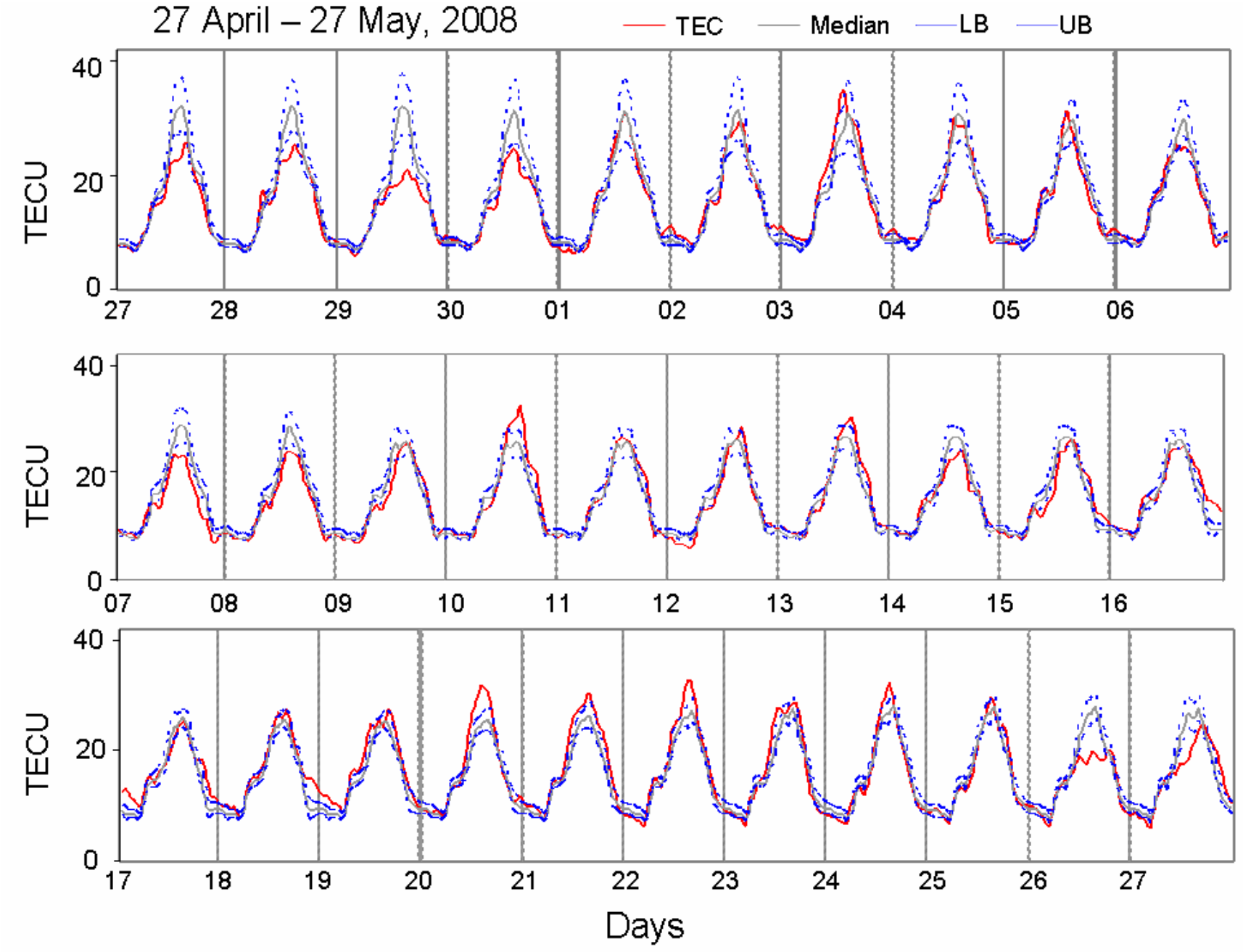
Disturb Days

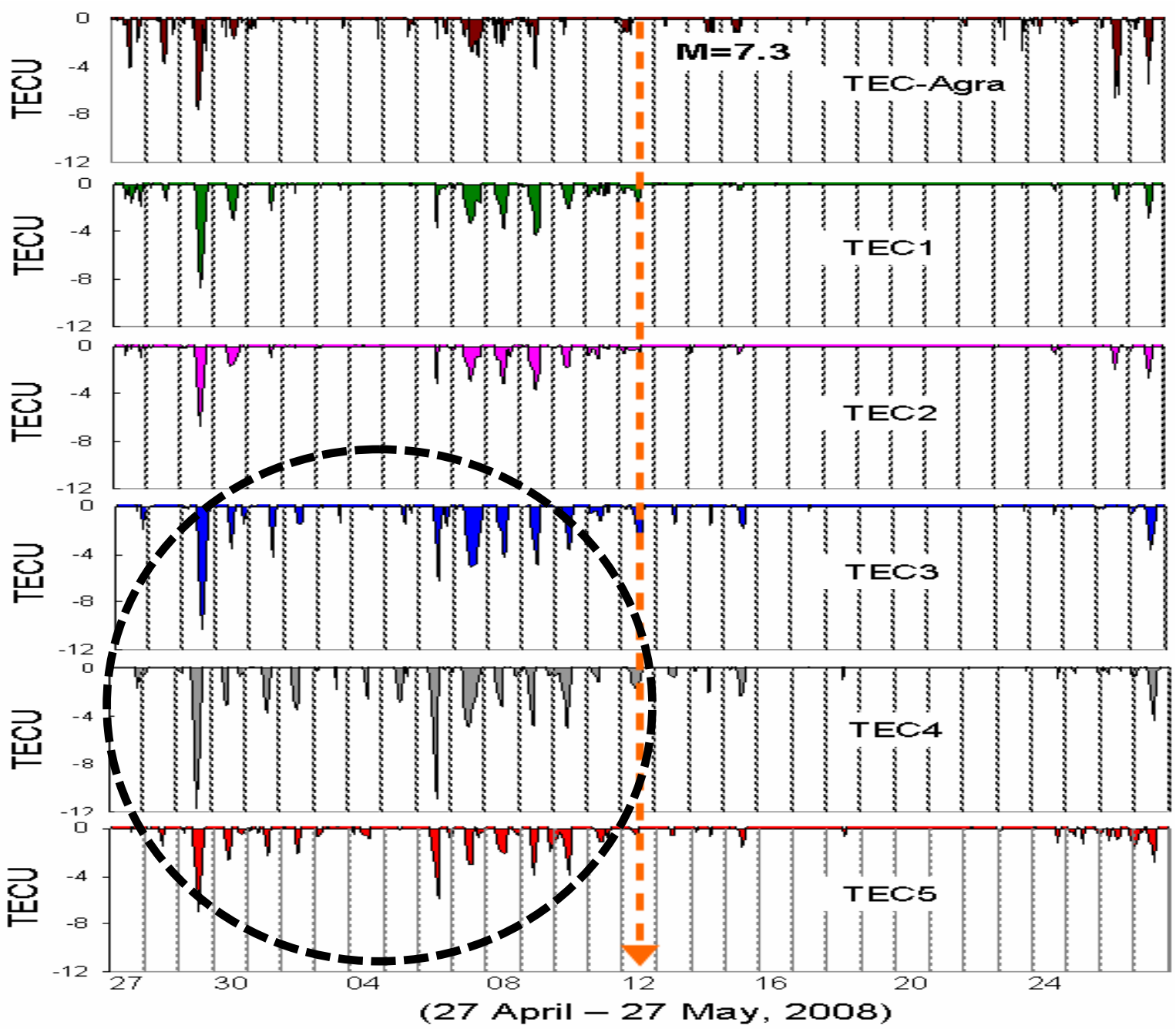


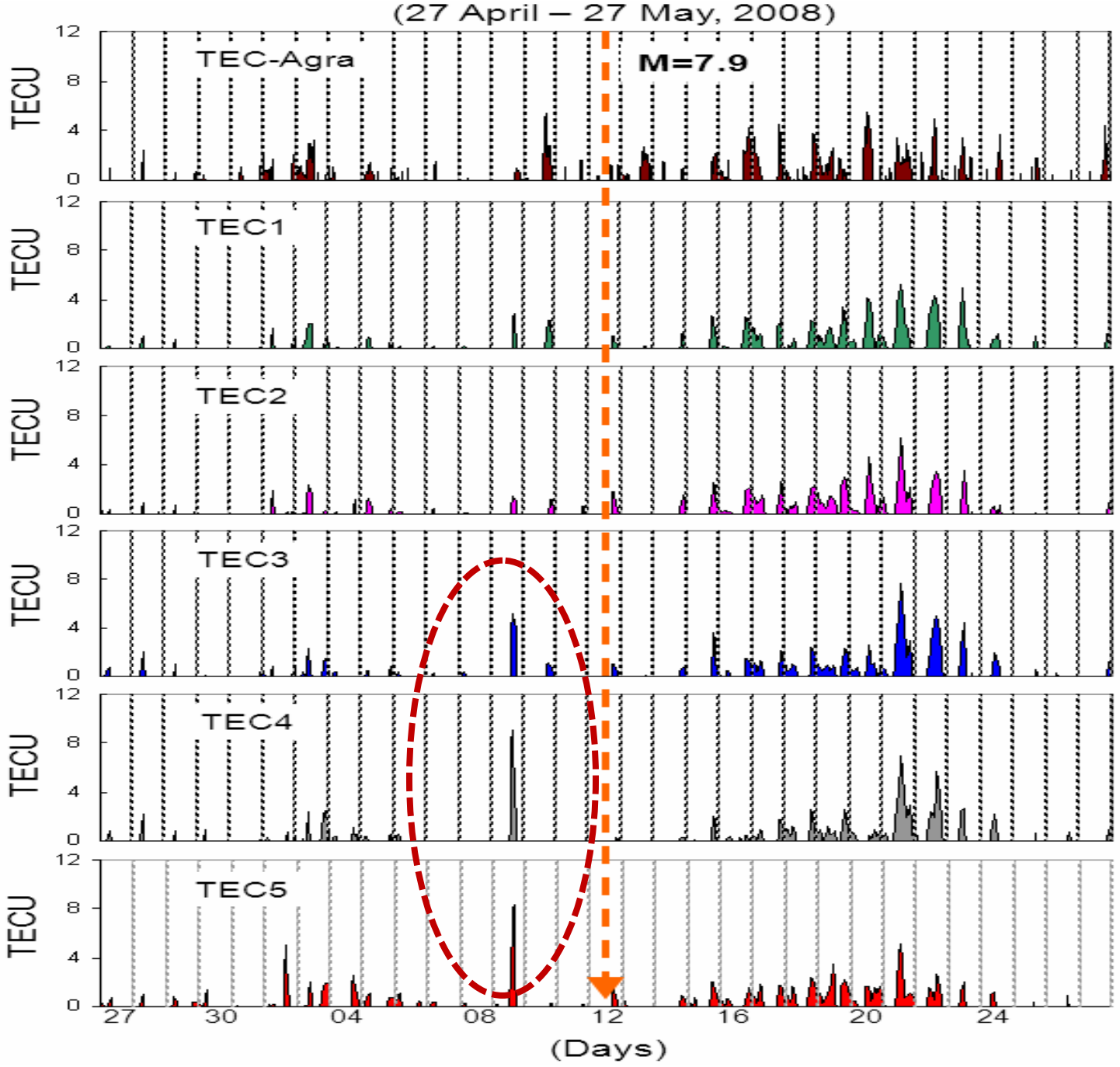
Wenchuan Earthquake (M=7.3)




27 April – 27 May, 2008
TEC1
TEC2
TEC3
TEC4
TEC5
TECU
40
20
0
27
28
29
30
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
Days


27 April – 27 May, 2008
TEC
Median
LB
UB
TECU
40
20
0
27
28
29
30
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
Days


M=7.3
TEC-Agra
TEC1
TEC2
TEC3
TEC4
TEC5
TECU
0
-4
-8
-12
27
30
04
08
12
16
20
24
(27 April — 27 May, 2008)


(27 April – 27 May, 2008)
TEC-Agra
M=7.9
TEC1
TEC2
TEC3
TEC4
TEC5
TECU
0
4
8
12
27
30
04
08
12
16
20
24
(Days)

Conclusion

1. The GPS based TEC measurements are analyzed for the period of 30 months from 01 January, 2009 to 30 June, 2011 in the light of magnetic storms and earthquakes. The large magnitude earthquakes (M≥5.5) which occurred within an epicentral distance of 2000 km from the observing station Agra are considered for this study.

2. Anomalous variations in TEC, in the form of enhancements and depletions, are observed in almost all the cases of earthquakes examined with precursory period lying between 0 and 10 days.

3. The GPS-TEC data obtained at Agra station are also compared with global ionospheric maps (GIMs) of TEC and a very good correlation is found between the two. .

4. The GPS-TEC data and GIM TEC data at five different locations are analysed corresponding to the Wenchuan earthquake (M=7.9) occurred on 12 May, 2008 in China region. The anomalies in TEC data are investigated by using quartile based statistical method. It has been found that TEC data obtained at Agra and other locations show anomalous depletions 02 to 13 days before and anomalous enhancements 03 to 10 days prior to the occurrence of earthquake. It has also been found that the level of anomalies are more distinct near the epicenter than at the Agra station and they appeared earlier at the location near the epicenter than other locations.

3. Since to investigate the seismic effects on TEC data the data on disturebed days are omitted hence the observed anomalies in TEC data may be due to the considered seismic events.

Thank you