The New Characteristics of Ionospheric Total Electron Content (TEC) Disturbances prior to Four Large Earthquakes

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Outline

- **Introduction**
  - **Earthquake and earthquake prediction**
  - **Ionospheric disturbances prior to earthquake**
  - **Four large magnitude earthquakes**
  - **Database**
- **Characteristics of 5 new parameters**
  - **dTEC**
  - **ΔdTEC**
  - **TECR**
  - **Percentage of the variation**
  - **Power of the TECR**
- **Detection for disturbances**
  - **Existing method**
  - **New method**
  - **Reference values**
  - **Results**
- **Discussion and Summary**

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Earthquake

EQ and EQ Prediction

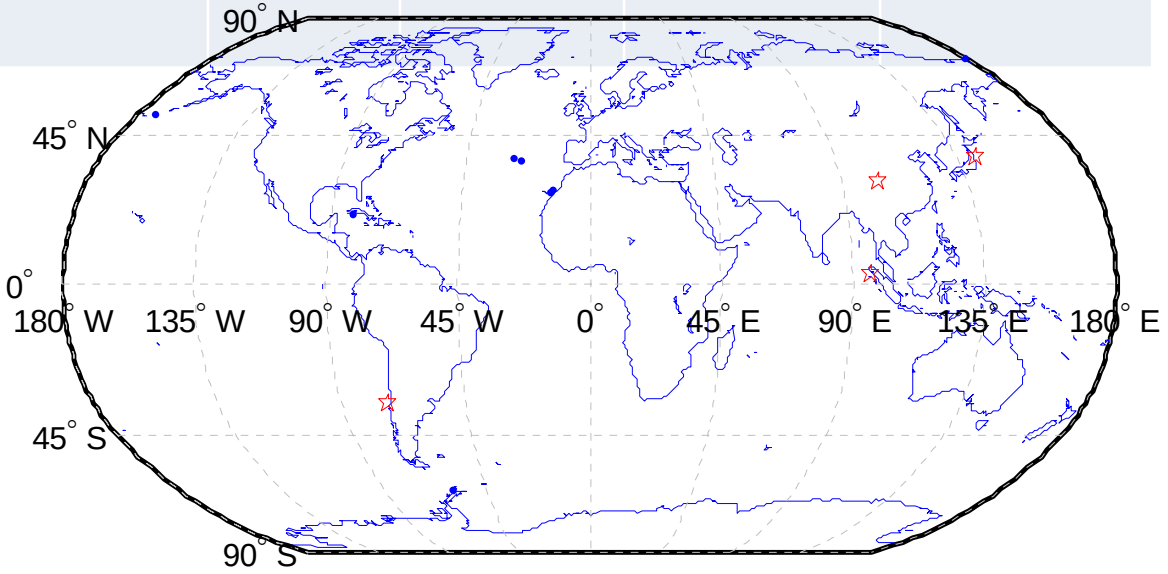
- There are a variety of geophysical precursors:
  - ground uplift and tilt
  - radon emissions increase
  - electric resistivity of rocks decrease
  - underground water level fluctuation
- Recently, many research indicate that ionospheric variations exist associated with the seismic activity and appearing a few days (1-15 days) or hours before the seismic shocks of large intensity (M>5) [Pulinets et al., 2003].

Ionospheric disturbances prior to EQ

- **Many researchers were concerned on the ionospheric anomaly in 1-30 days before the EQ , based on the ground-based ionosondes, satellite and ground-based GPS observations.**
- **The results show that ionospheric F_2 peak electron density N_mF_2, the critical frequency of F_2 layer f_0F_2 and the Total Electron Content (TEC) anomaly increased or reduced on 1-12 days before the earthquake [Liu et al., 2004].**
- **More study of the characteristics of the ionospheric variations prior to EQ are needed.**

Four large EQs

	Date	Time	Location	Magnitude
Sumatra	**26 Dec. 2004**	**00:58 UT**	**3.3°N 95.95°E**	**9.3**
Wenchuan	**12 May 2008**	**06:28 UT**	**30.986°N 103.364°E**	**8.0**
Chile	**27 Feb. 2010**	**06:34 UT**	**35.909°S 72.733°W**	**8.8**
Tohoku	**11 Mar. 2011**	**05:46 UT**	**38.322°N 142.369°E**	**9.0**



(http://earthquake.usgs.gov/earthquakes/eqarchives/epic/)

Ionospheric TEC Dataset -- GIM

- **The Global Ionospheric Maps (GIM) products generated from global positioning system (GPS) data, which is routinely published in a 2-hr interval. The spatial resolutions of the GIM on the ±87.5°N latitude and ±180°E longitude are 2.5° and 5°, respectively.**

(ftp://cddisa.gsfc.nasa.gov/pub/gps/products/ionex)

- **14 months TEC are analyzed**
  - **12-month before the EQ**
  - **2-month after the EQ**

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Definition of the parameters

We define 5 new parameters dTEC, ΔdTEC , TECR, Percentage (written as Per for abbreviation), and Power, which could represent the TEC disturbances,

- $dTEC_{DOY}=TEC_{DOY}-TEC_{DOY-3}$

  DOY means Day of Year.

- $\Delta dTEC_{DOY}=dTEC_{DOY}-dTEC_{DOY-3}$

the dTEC and ΔdTEC of earthquake day (EQ) contain the information of 3-day and 6-day prior to the earthquake.

Definition of the parameters

- $TECR_{DOY}=|TEC_{DOY}-TEC_{DOY\_1}|$

  $TECR_{DOY}$ represents the variations of TEC in 24 hours.

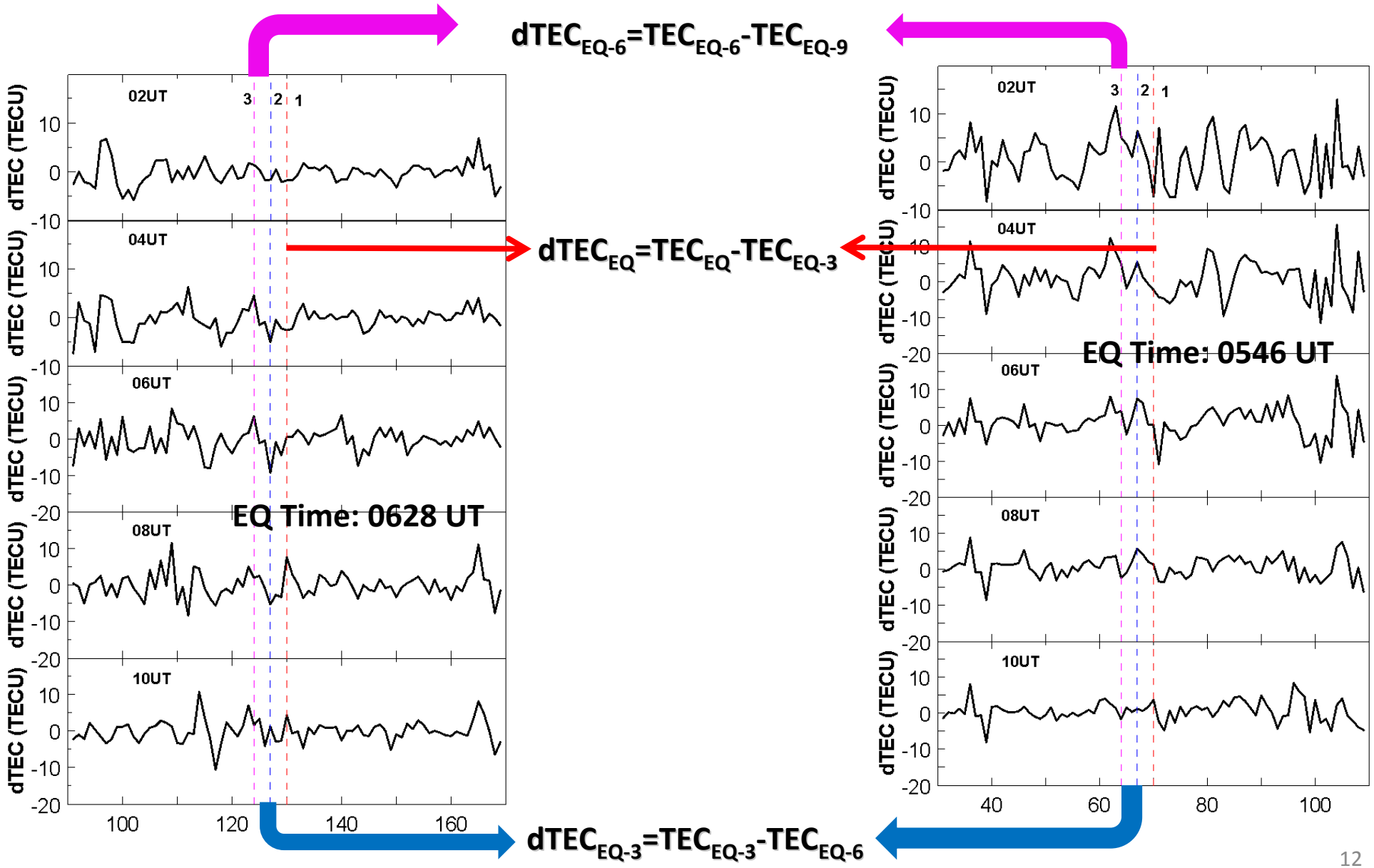
- $Per=\frac{TECR}{TEC}$

  Per represents the relative variation of the TEC

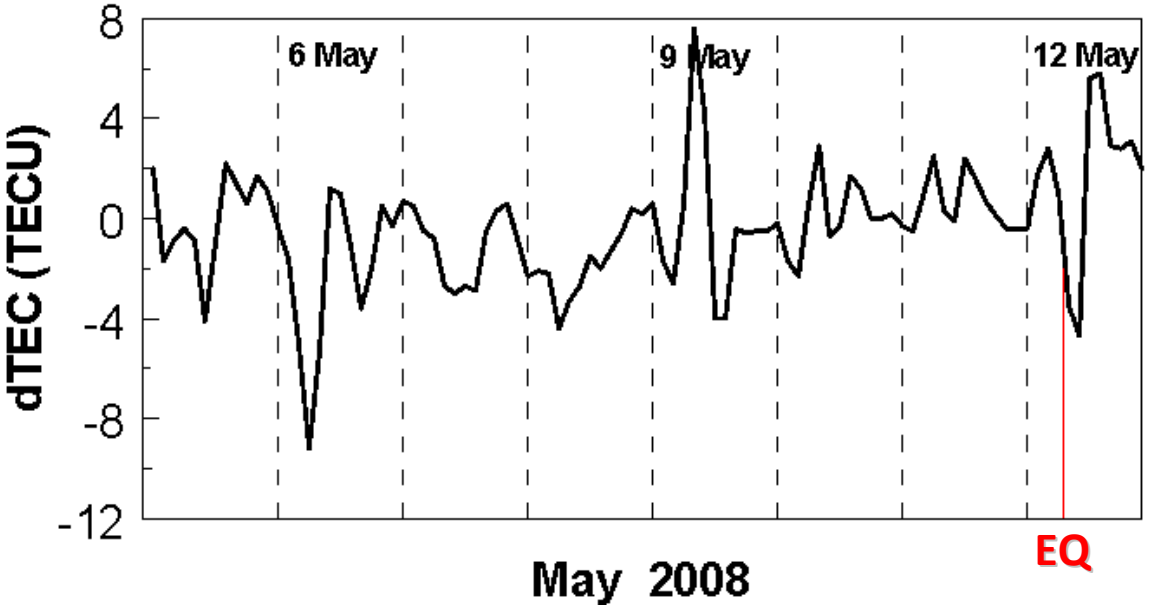
- $Power=\frac{\sum_1^n (TECR)^2}{n}$

  we take n=6

Characteristics of dTEC (I)

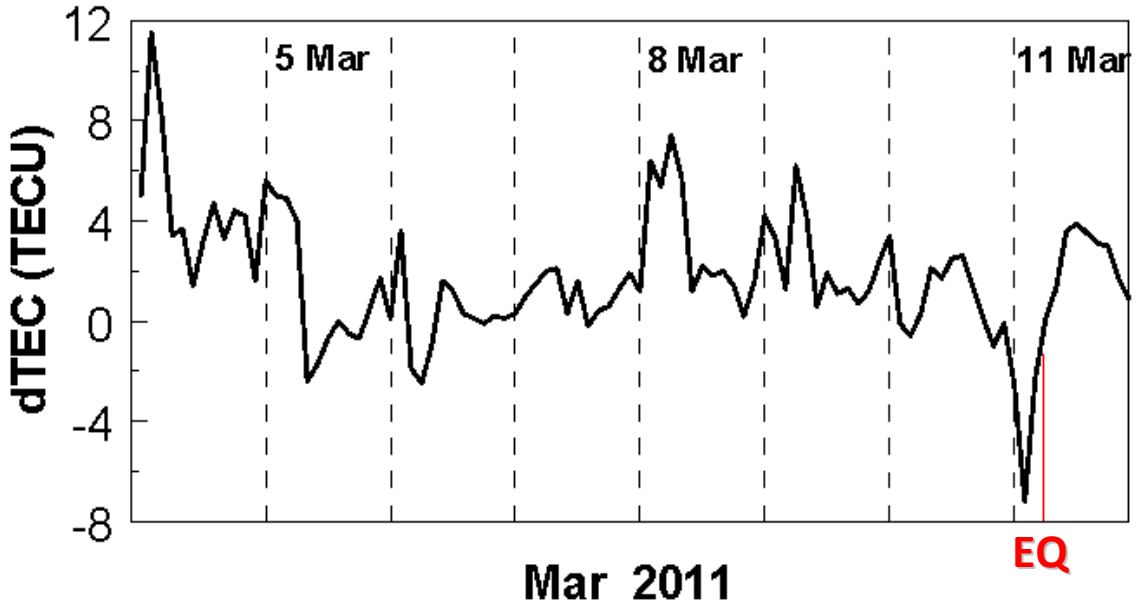


Characteristics of dTEC (II)



2008 Wenchuan EQ

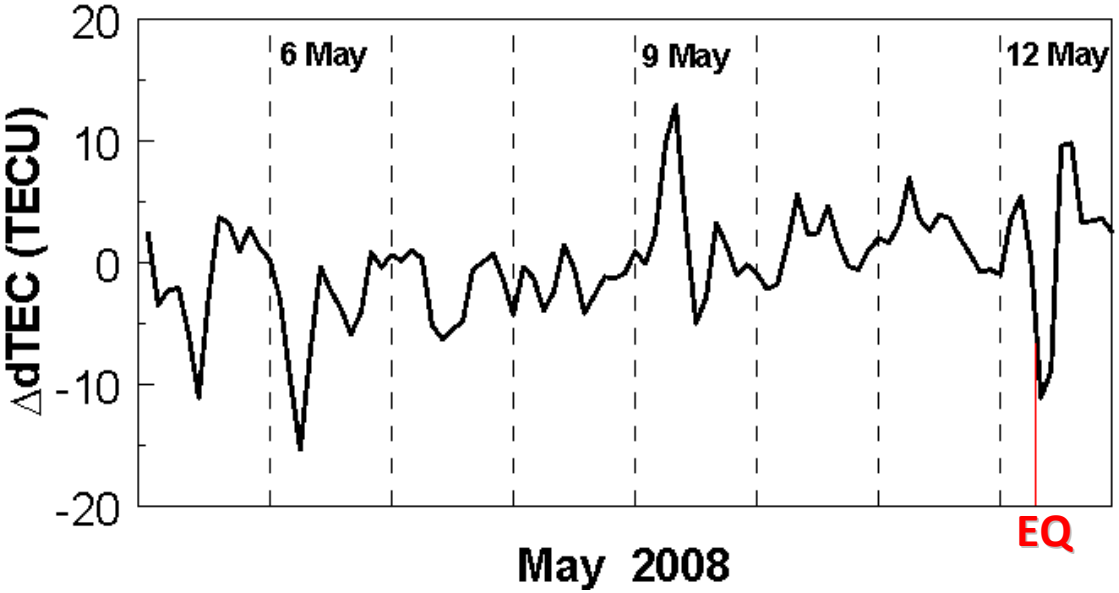
6 and 3 days prior to the EQ, there are obvious fluctuations



2011 Tohoku EQ

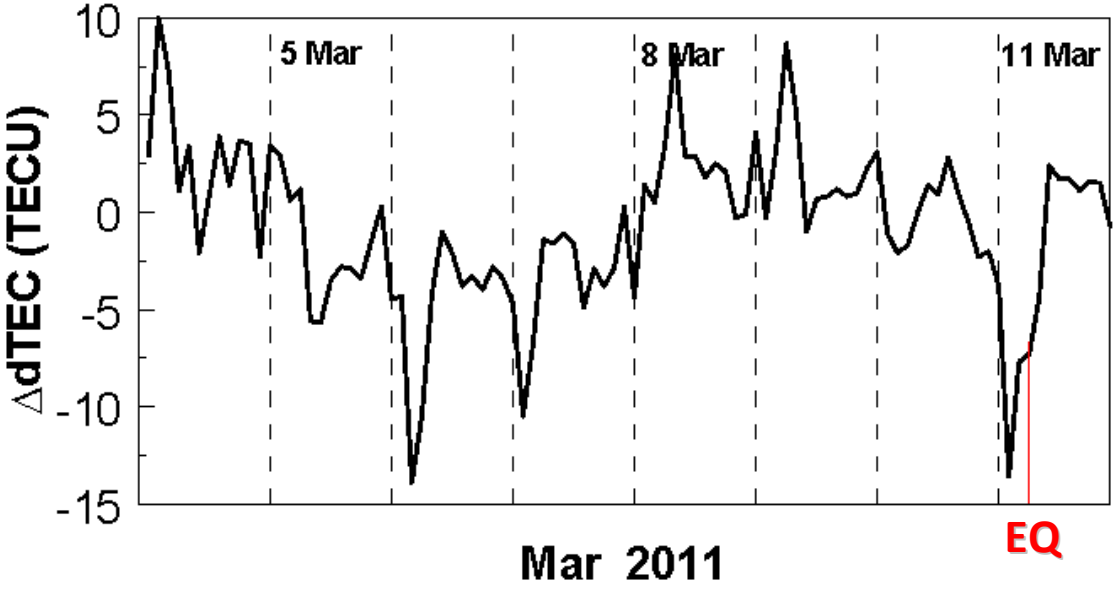
3 days prior to the EQ, there are obvious fluctuations

Characteristics of ΔdTEC



2008 Wenchuan EQ

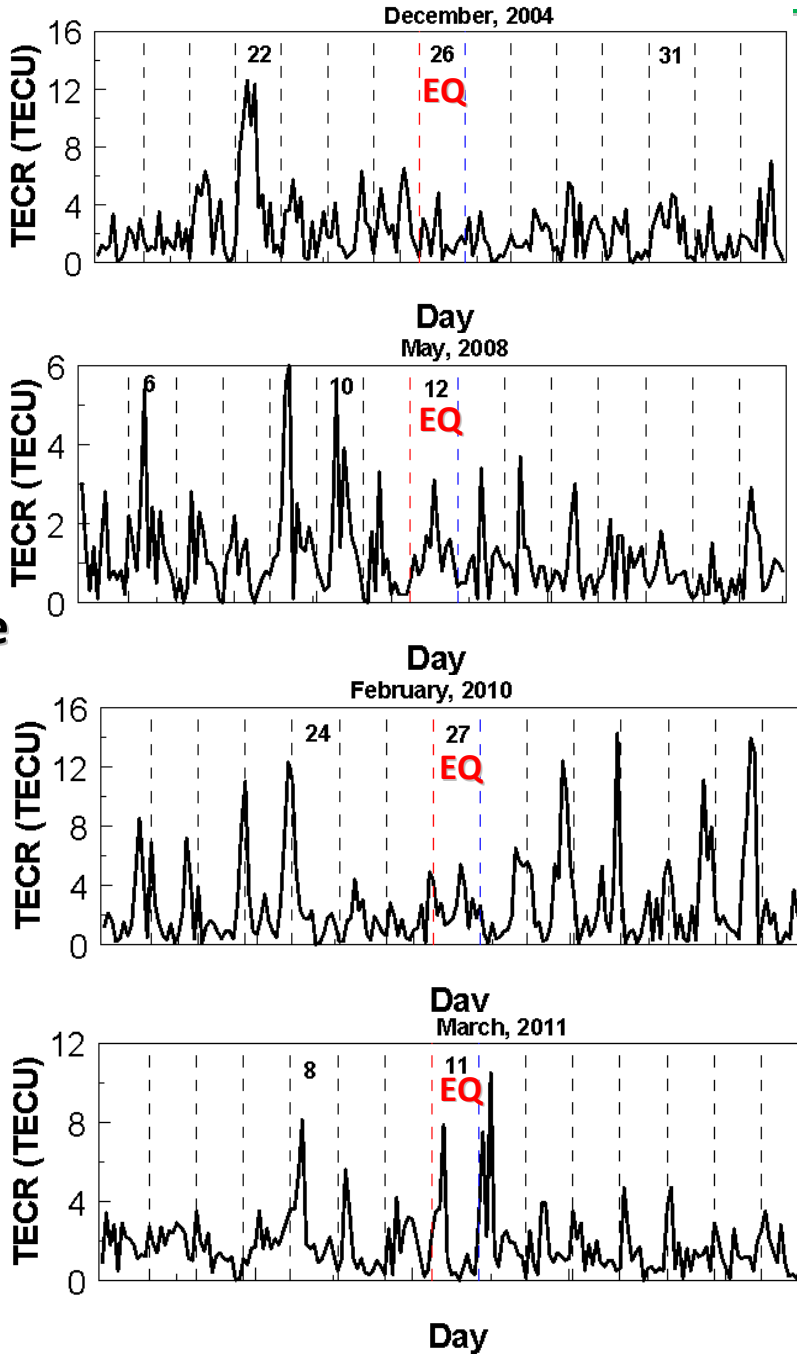
3 days prior to the EQ
there are obvious fluctuations



2011 Tohoku EQ

3 days prior to the EQ
there are obvious fluctuations

Characteristics of TECR



In 7 days before the EQ, there are disturbances in all four EQs

2004 Sumatra EQ

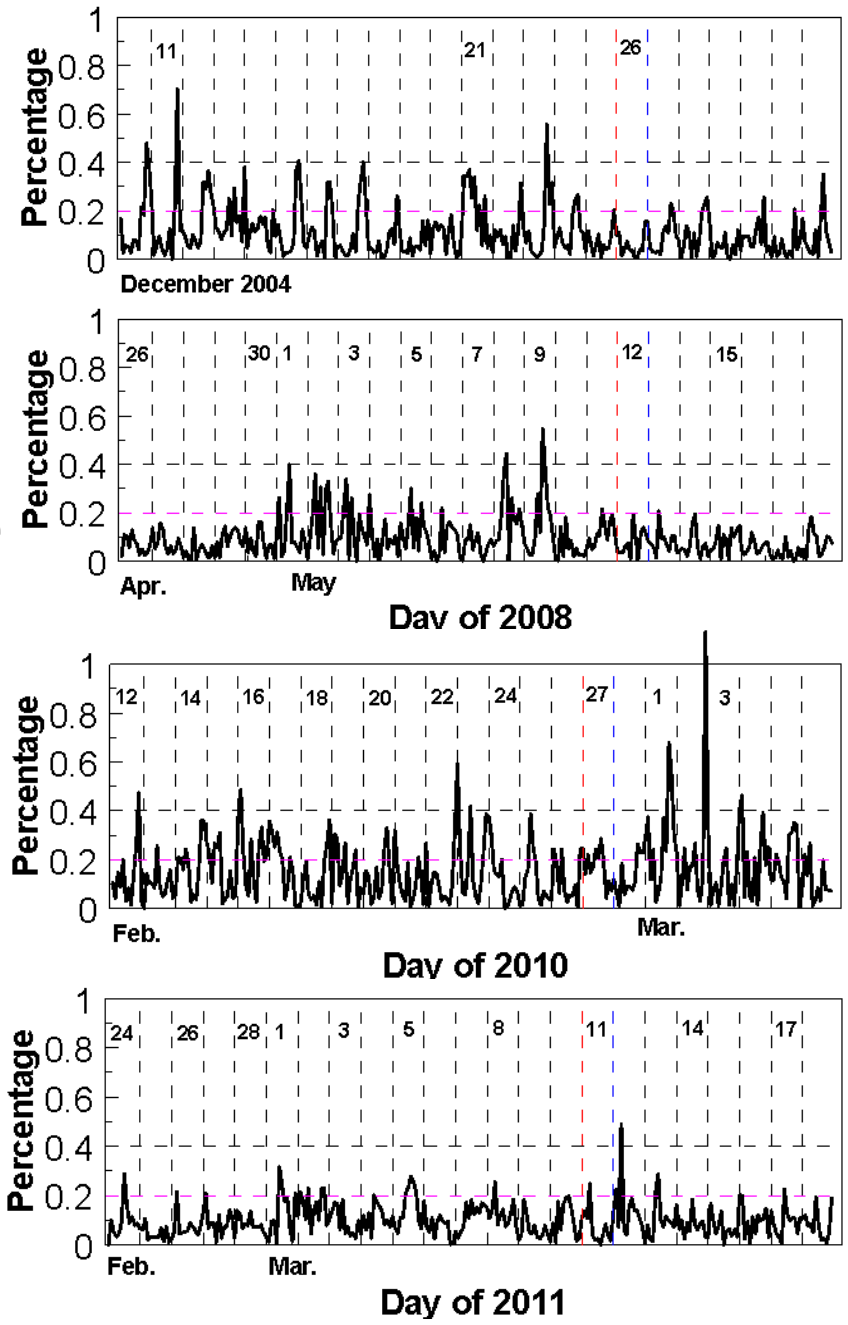
2008 Wenchuan EQ

2010 Chile EQ

2011 Tohoku EQ

Characteristics of Per

In 1-15 days before the EQ, there are disturbances in all four EQs



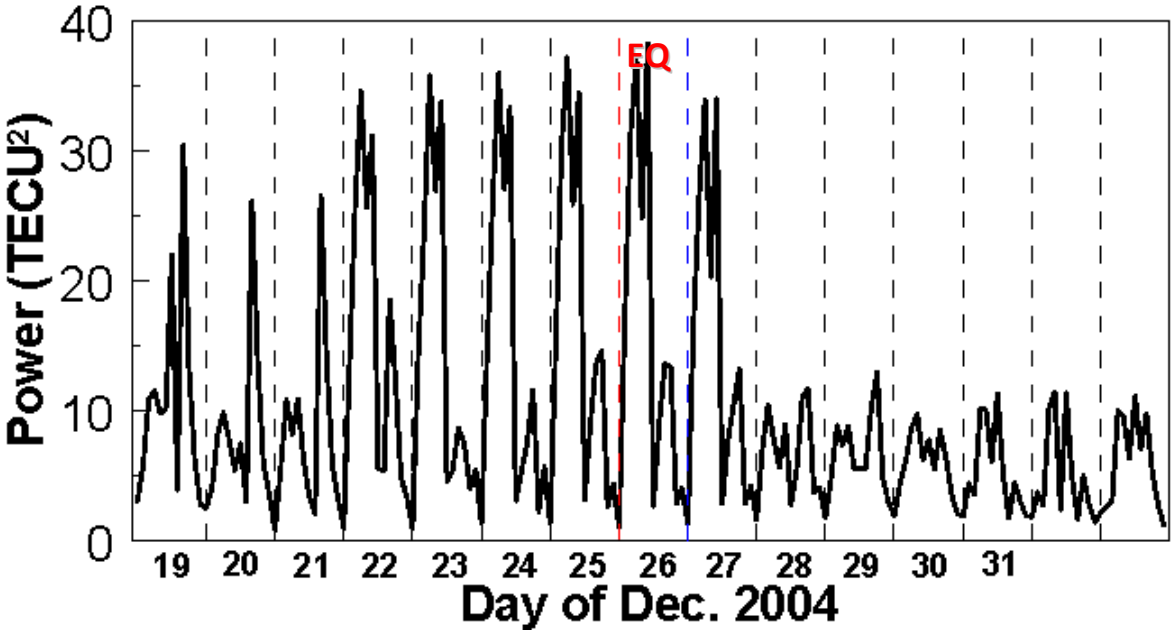
2004 Sumatra EQ

2008 Wenchuan EQ

2010 Chile EQ

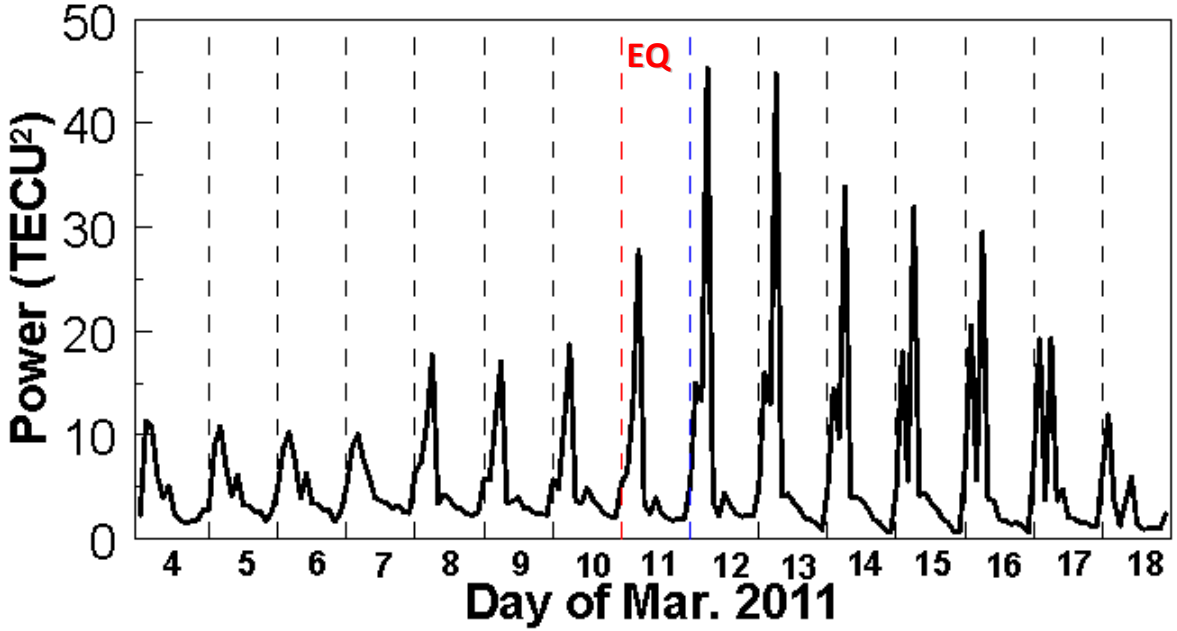
2011 Tohoku EQ

Characteristics of Power



2004 Sumatra EQ

The characteristics of the Power near the EQ are different from other days



2011 Tohoku EQ

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Existing Method

Quartile-based process

- Compute the median M of every successive 15 days of the TEC and find the deviation between the observed TEC on the 16^{th} day and M.
- Assume the distribution of TEC is a normal distribution (m ,σ), the expected value of M and LQ (the first quartiles) or UQ (the third quartiles) are m and 1.34σ, respectively.
- The lower bound: LB=M-1.5(M-LQ)

  The upper bound: UB=M+1.5(UQ-M)
- Thus when an observed TEC on the 16^{th} day is greater or smaller than UB or LB, one can declare an upper or lower abnormal TEC signal.

New Method

- **Using 5 new parameters dTEC, ΔdTEC, TECR, Per, and Power to detect ionospheric disturbances.**
- **Take the values of the window [EQ, EQ-6] as the references. Select a window [DOY, DOY+6] at two adjacent UT before and after the time earthquake occurred, and slide the window to compare with the reference.**
- **When the value exceeds the reference values, we define it is a disturbance.**

The reference values of Sumatra and Wenchuan EQs

For 2004 Sumatra earthquake, take the value of 4 UT and 6 UT as the reference.

Table 1 The reference values for 2004 Sumatra earthquake, the units of TEC and Power are TECU and $TECU^2$

	dTEC	*dTEC*	Δ*dTEC*	Δ*dTEC*	TECR	Per_{EQ-3}	Power
4 UT	-9.5	7.6	-7	17.1	9.9	0.184	31.195
6 UT	-8.8	8.8	-4.8	14.5	12.6	0.491	37.178

For 2008 Wenchuan earthquake, take the value of 6 UT and 8 UT as the reference.

Table 2 The reference values for 2008 Wenchuan earthquake, the units of TEC and Power are TECU and $TECU^2$

	dTEC	*dTEC*	Δ*dTEC*	Δ*dTEC*	TECR	Per_{EQ-3}	Power
6 UT	-9.2	1	-15.4	9.8	2.6	0.176	19.36
8 UT	-5.3	7.6	-11.1	12.9	5.5	0.272	13.707

The reference values of Chile and Tohoku EQs

For 2010 Chile earthquake, take the value of 6 UT and 8 UT as the reference.

Table 3 The reference values for 2010 Chile earthquake, the units of TEC and Power are TECU and $TECU^2$

	dTEC	*dTEC*	*ΔdTEC*	*ΔdTEC*	TECR	Per_{EQ-3}	Power
6 UT	-5.2	1.2	-5.7	2.7	2.6	0.303	3.067
8 UT	-5.3	2.4	-6	4.3	2	0.254	5.21

For 2011 Tohoku earthquake, take the value of 4 UT and 6 UT as the reference.

Table 4 The reference values for 2011 Tohoku earthquake, the units of TEC and Power are TECU and $TECU^2$

	dTEC	*dTEC*	*ΔdTEC*	*ΔdTEC*	TECR	Per_{EQ-3}	Power
4 UT	-2.3	5.4	-7.7	0.6	5.3	0.184	12.885
6 UT	0.1	7.4	-7.3	3.4	8.1	0.255	27.878

2004 Sumatra EQ

The counts of the ionospheric disturbances in different UT regions on the basis of 5 parameters in 12 months before the EQ and 2 months after the EQ. (Do not including the disturbance associated with EQ)

Table 5 The results of the detection for the 2004 Sumatra earthquake

	0 UT	2 UT	4 UT	6 UT	8 UT	10 UT	12 UT	14 UT	16 UT	18 UT	20 UT	22 UT
dTEC & ΔdTEC & TECR & Per & Power	0	0	0	0	0	0	0	0	0	0	0	0

EQ Time: 00:58 UT

The numbers mean the count of detected disturbances.

Wenchuan, Chile and Tohoku EQs

Table 6 The results of the detection for the 2008 Wenchuan earthquake

	0 UT	2 UT	4 UT	6 UT	8 UT	10 UT	12 UT	14 UT	16 UT	18 UT	20 UT	22 UT
dTEC & ΔdTEC & TECR & Per & Power	0	0	0	4	1	4	0	0	0	0	0	0

EQ Time: 06:28 UT

Table 7 The results of the detection for the 2010 Chile earthquake

	0 UT	2 UT	4 UT	6 UT	8 UT	10 UT	12 UT	14 UT	16 UT	18 UT	20 UT	22 UT
dTEC & ΔdTEC & TECR & Per & Power	0	1	1	0	0	0	0	0	2	5	6	7

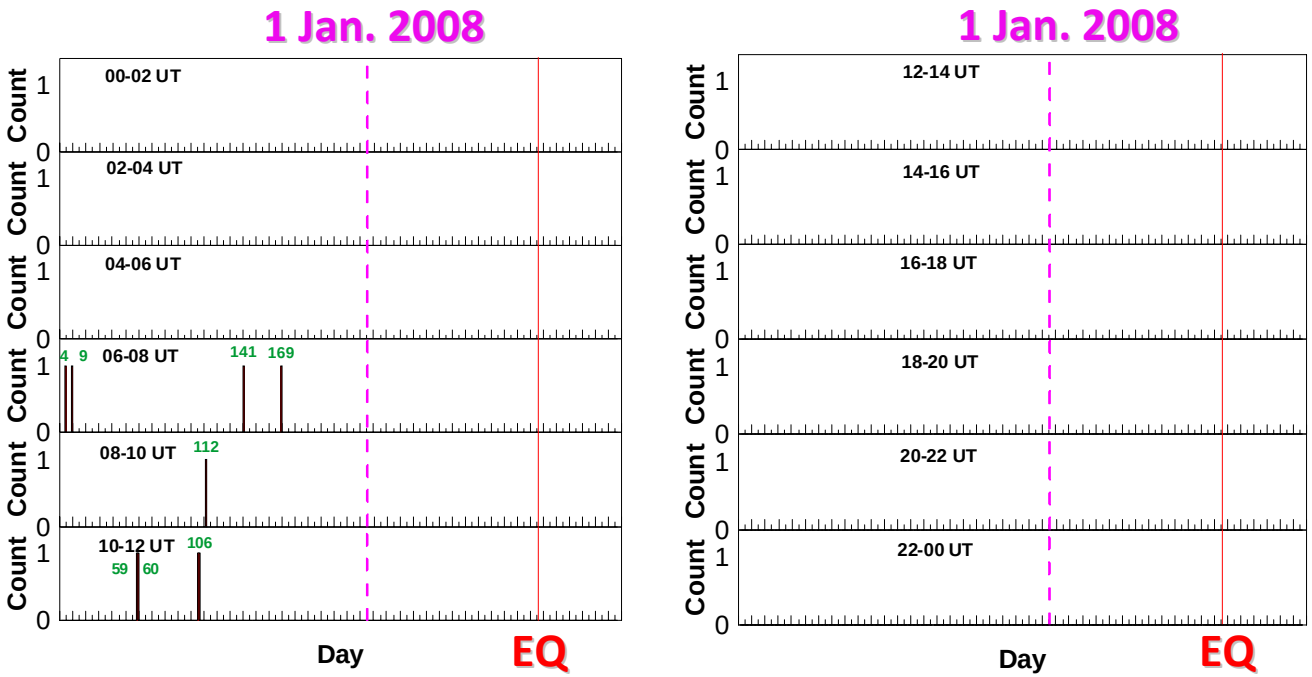
EQ Time: 06:34 UT

Table 8 The results of the detection for the 2011 Tohoku earthquake

	0 UT	2 UT	4 UT	6 UT	8 UT	10 UT	12 UT	14 UT	16 UT	18 UT	20 UT	22 UT
dTEC & ΔdTEC & TECR & Per & Power	0	9	6	4	1	3	5	0	0	0	0	0

EQ Time: 05:46 UT

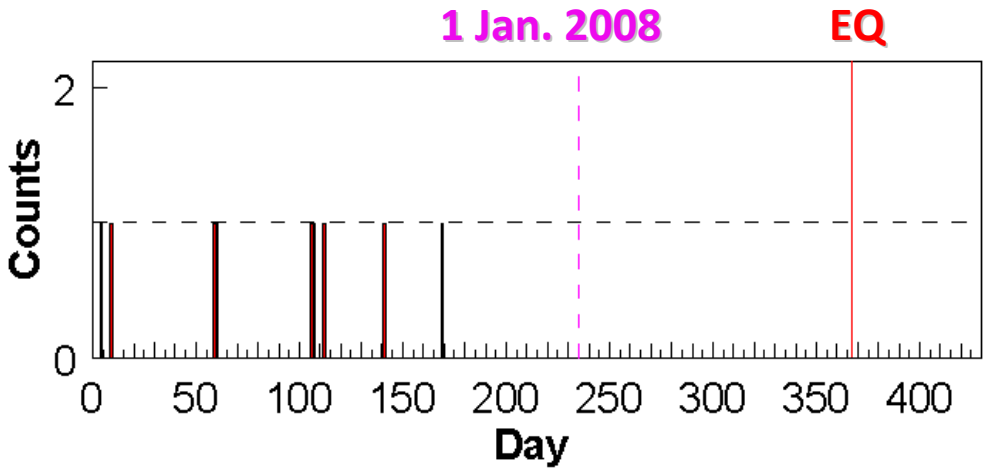
2008 Wenchuan EQ



There is no disturbance in 1-month before the EQ at all UTs
But disturbance occurred on EQ day

There is no disturbance in 12-month before the EQ at 00-06 UT and 12-24 UT

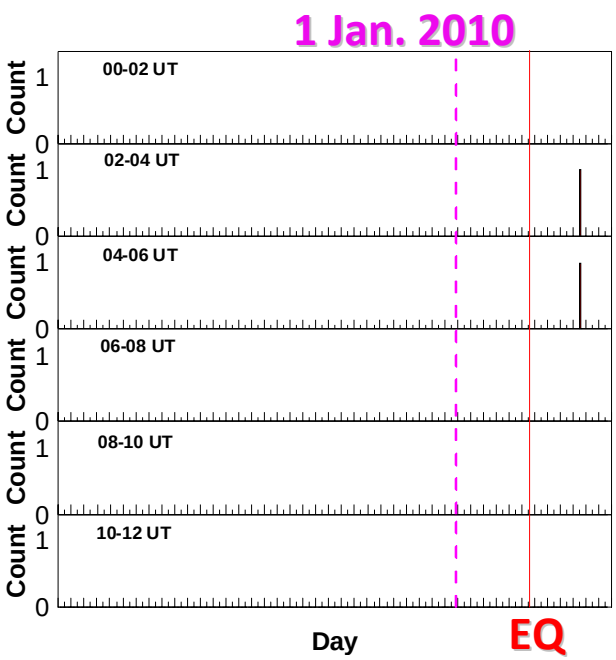
The distribution of the disturbance day at different UT times.

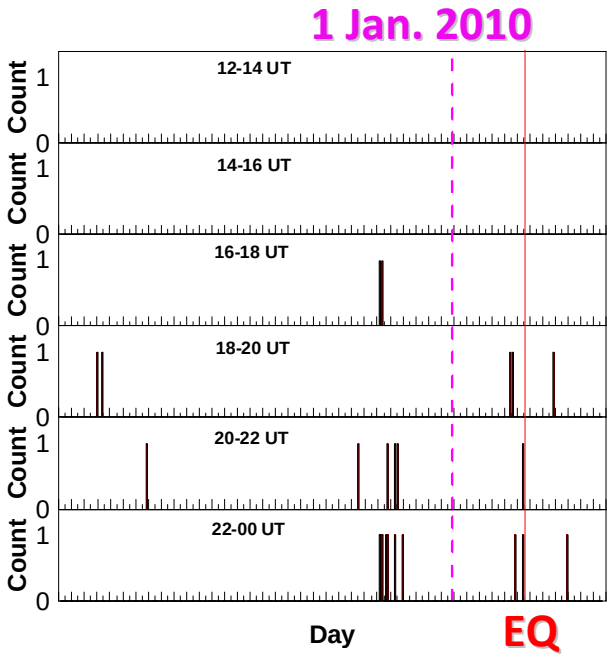


The disturbance occurred 7-month before the EQ at 06 UT

The distribution of the counts of the disturbance in a day.

2010 Chile EQ

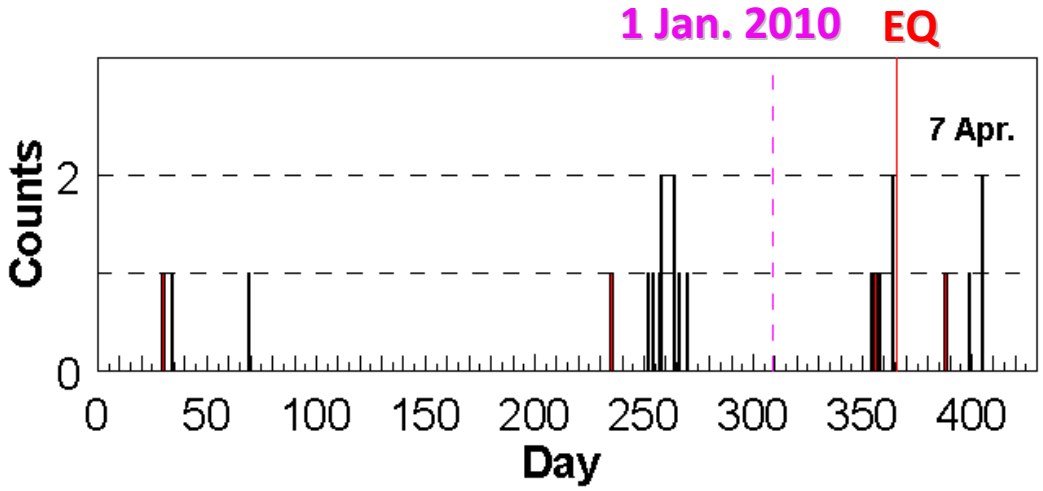




There is no disturbance in 12-month before the EQ during 00-16 UT

There is disturbance in 2-10 days before the EQ during 18-24 UT

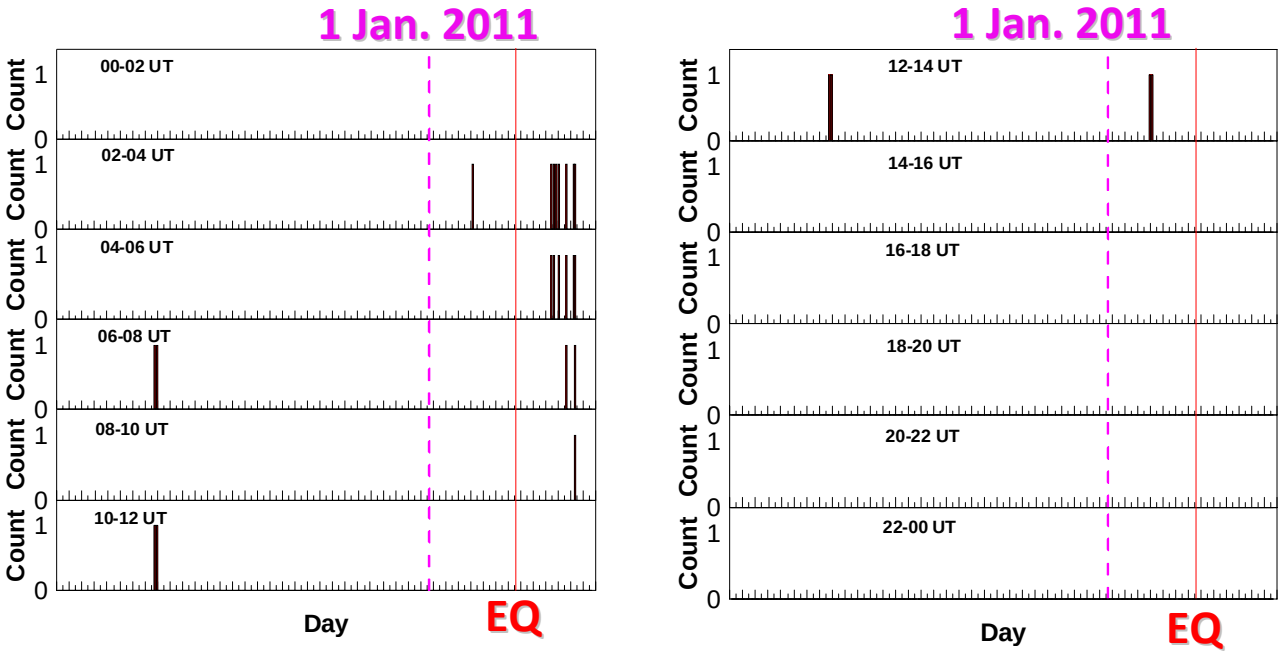
The distribution of the disturbance day at different UT times.



The disturbance occurred 2-day before the EQ at 20 UT and 22 UT

The distribution of the counts of the disturbance in a day.

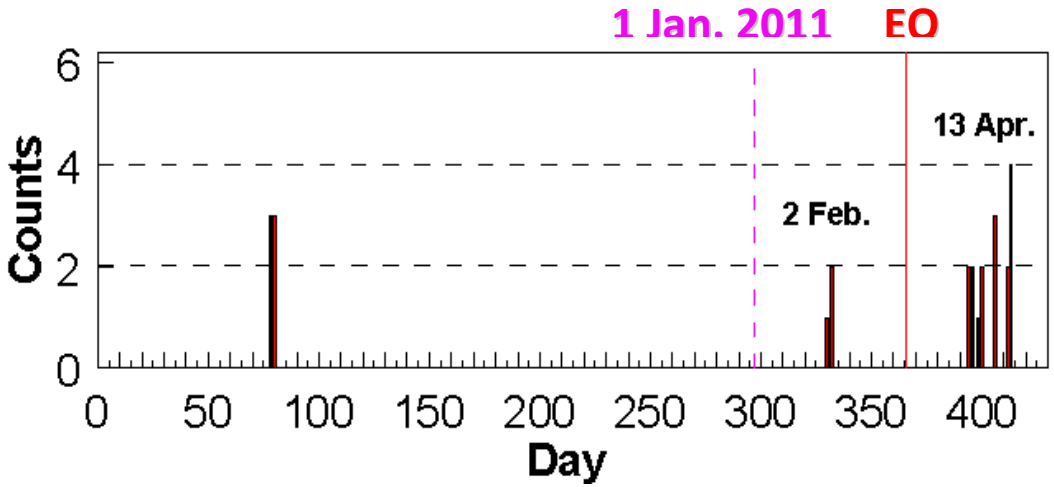
2011 Tohoku EQ



There is no disturbance in 1-month before the EQ at all UTs

There is no disturbance in 12-month before the EQ at 08-10 UT and 14-24 UT

The distribution of the disturbance day at different UT times.



The disturbance occurred 1-month before the EQ at 02 UT and 12 UT

The distribution of the counts of the disturbance in a day.

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Possible reason for TEC disturbances

- **Geomagnetic condition**
- **From upper atmosphere**

- **Electric field. Electric field would impact the distribution of the electron density and cause the TEC disturbances.**
- **Interplanetary Magetic Field (IMF). Fluctuations of IMF Bz may cause the ionospheric disturbances and contribute to the TEC fluctuations.**

- **From lower atmosphere**

- **Gravity Wave. Travelling Ionospheric Disturbance (TID)**

Summary

- There are ionospheric disturbances in some days prior to large magnitude earthquakes. The peak-to-peak amplitude of the differential TEC between the earthquake day and 3-day (or 5-day) before the EQ day could be above 10 TECU.
- The absolute differential TEC between the two adjacent days could reach 12 TECU prior to the earthquake.
- The percentage of the variation of TEC in 6-days before the EQ could be about 30~40%.

Summary

- There is no disturbance in some months prior to EQ detected by 5 parameters.

	2004 Sumatara	2008 Wenchuan	2010 Chile	2011 Tohoku
No ionospheric disturbances' months prior to EQ	12	12(except 06-12UT) 7(06 UT)	12(00-16 UT) 2-10 days (18-24 UT)	12 (14-24 UT) 1 (02 and 12 UT)

- The new parameters may be used to detect the ionospheric disturbances associated with earthquakes.

The end

Thanks for your attention !