

# Ionospheric disturbances resulting from tsunami effects

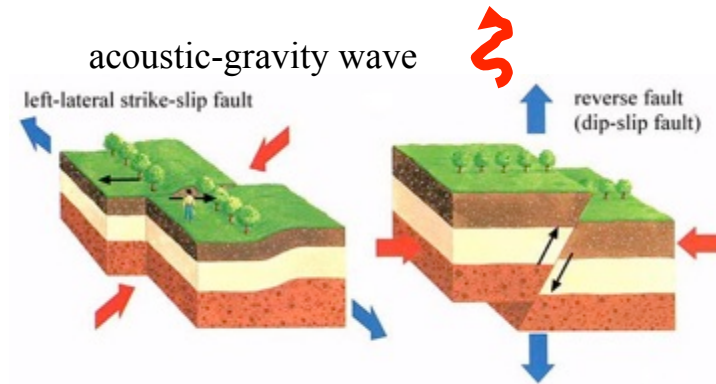
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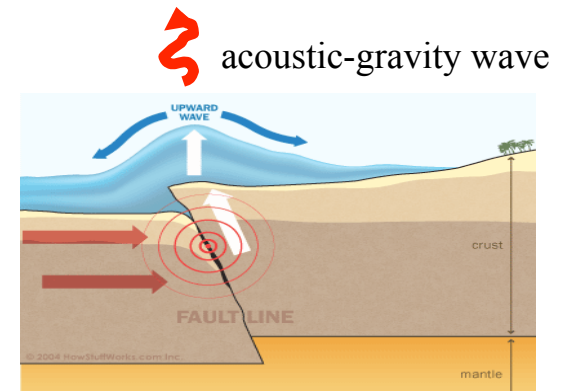
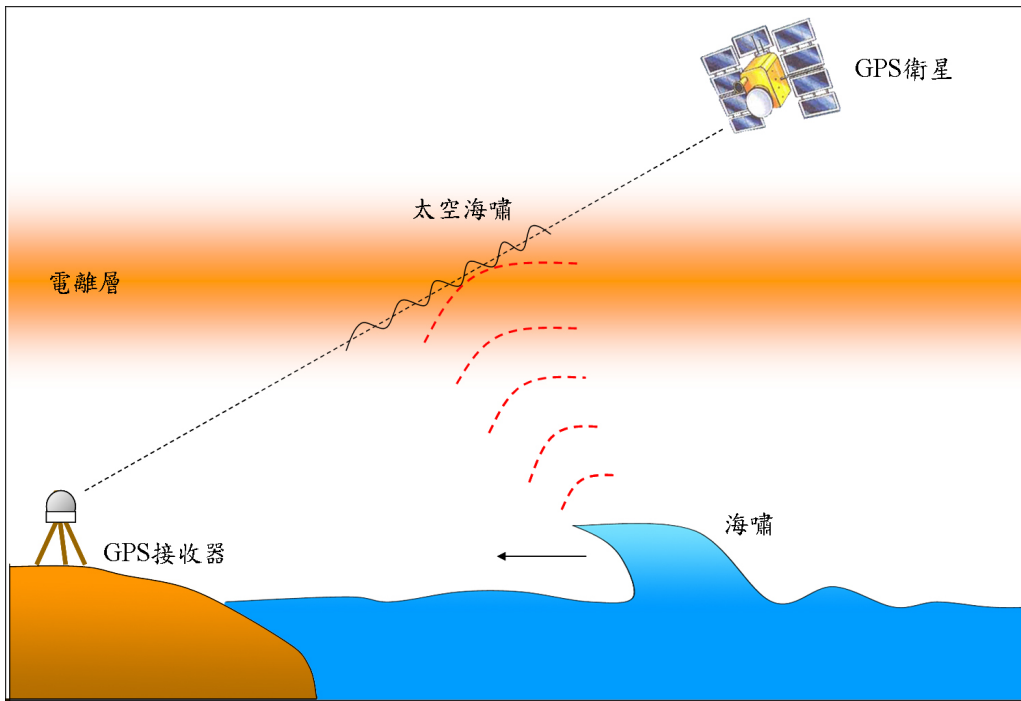
<sup>2</sup>Institute of Space Science, National Central University, Chung-Li, Taiwan

## (1) earthquake

ionosphere



## (2) tsunami

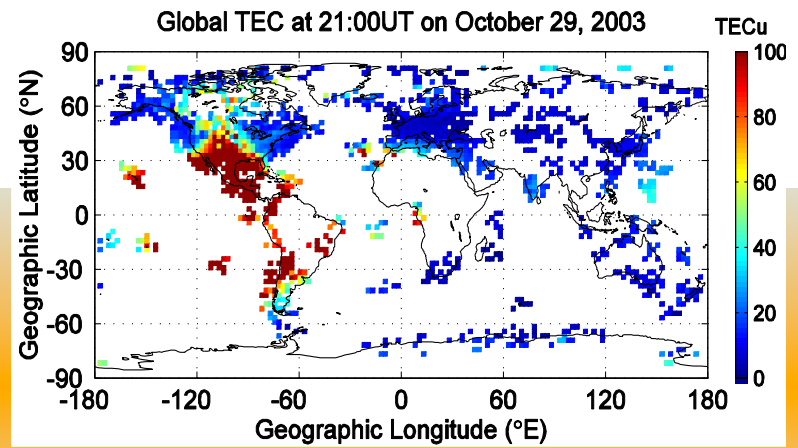
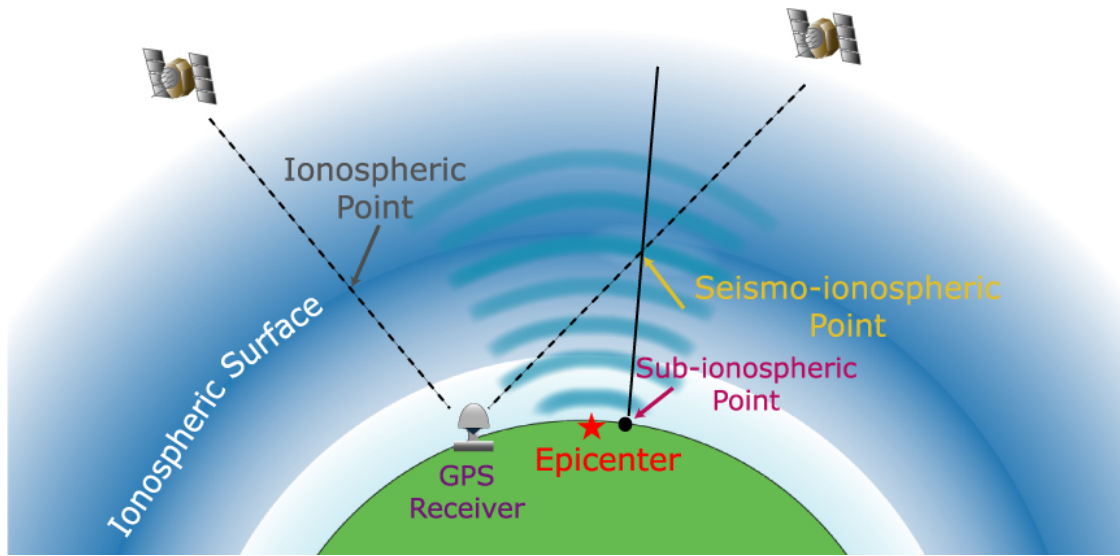
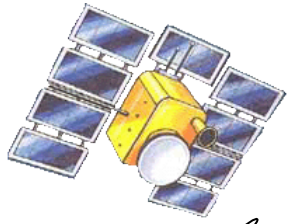


# Ionospheric total electron content (TEC) derived from GPS for studying ionospheric space weather effects and seismo-disturbance

$$n_g = n_p + f \frac{dn_p}{df} = 1 + \frac{40.3N}{f^2}$$

$$n_p = 1 - \frac{40.3N}{f^2}$$

$$S_g = \int_{Rx}^{Tx} n_g \cdot dl$$



## ionosphere

TEC (total electron content)  
unit: TECu ( $10^{16}$  ele/m<sup>2</sup>)

L1 : 1575.42 MHz (10.23 MHz\*154 )

L2 : 1227.60 MHz (10.23 MHz\*120)

C/A code (1.023 MHz)

P code (10.23 MHz)

$$S_o = [(x^i - x_j)^2 + (y^i - y_j)^2 + (z^i - z_j)^2]^{1/2}$$

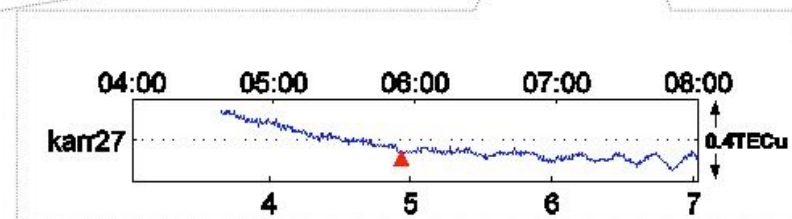
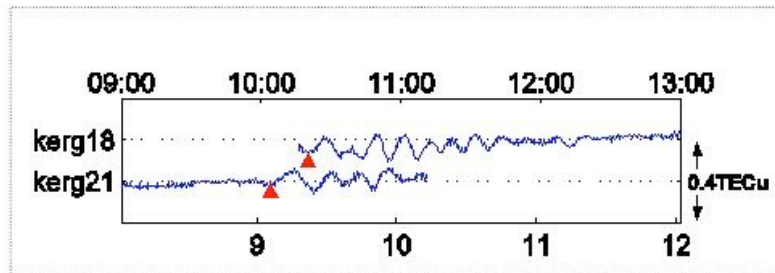
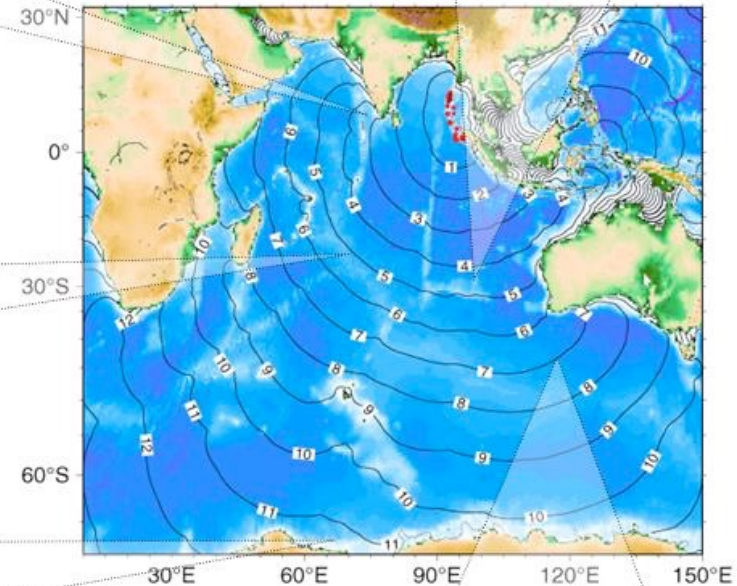
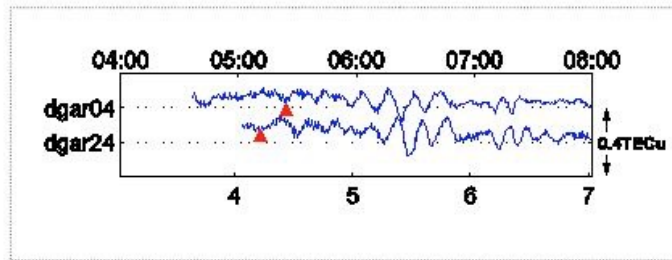
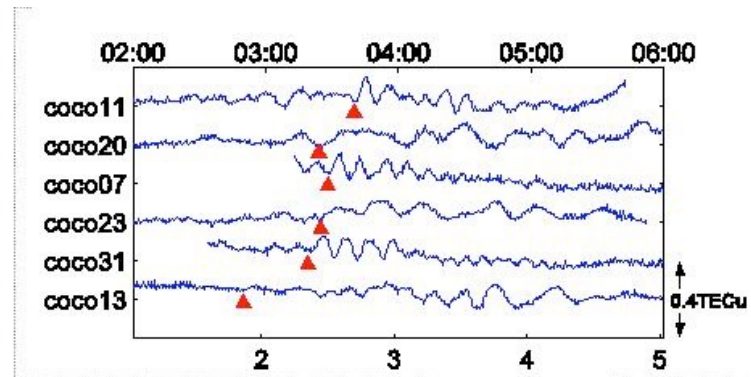
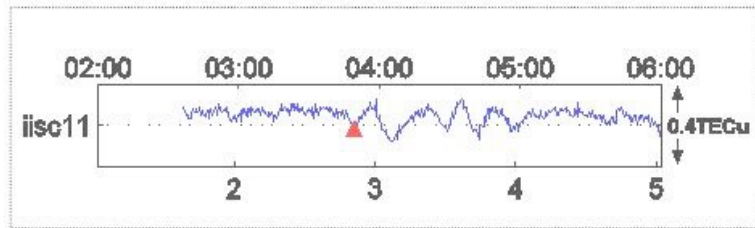
$(x_j, y_j, z_j)$



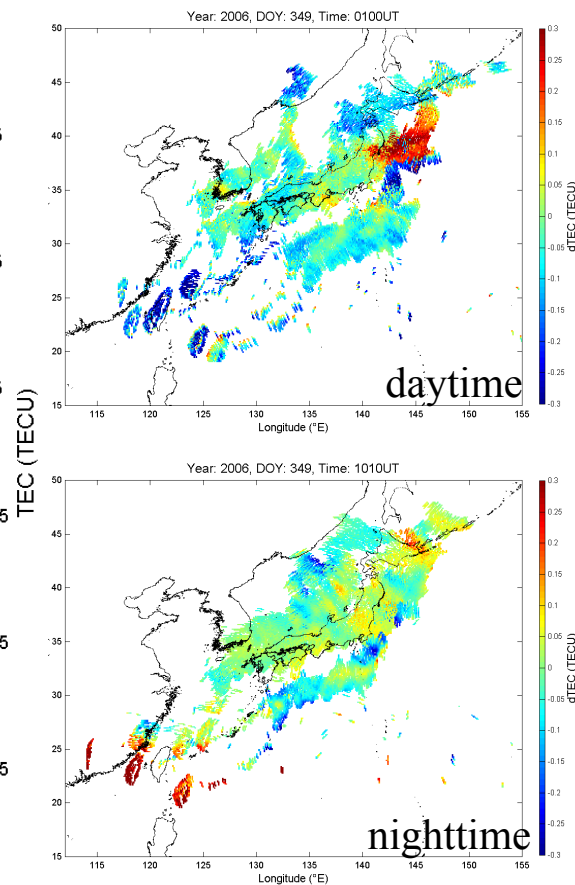
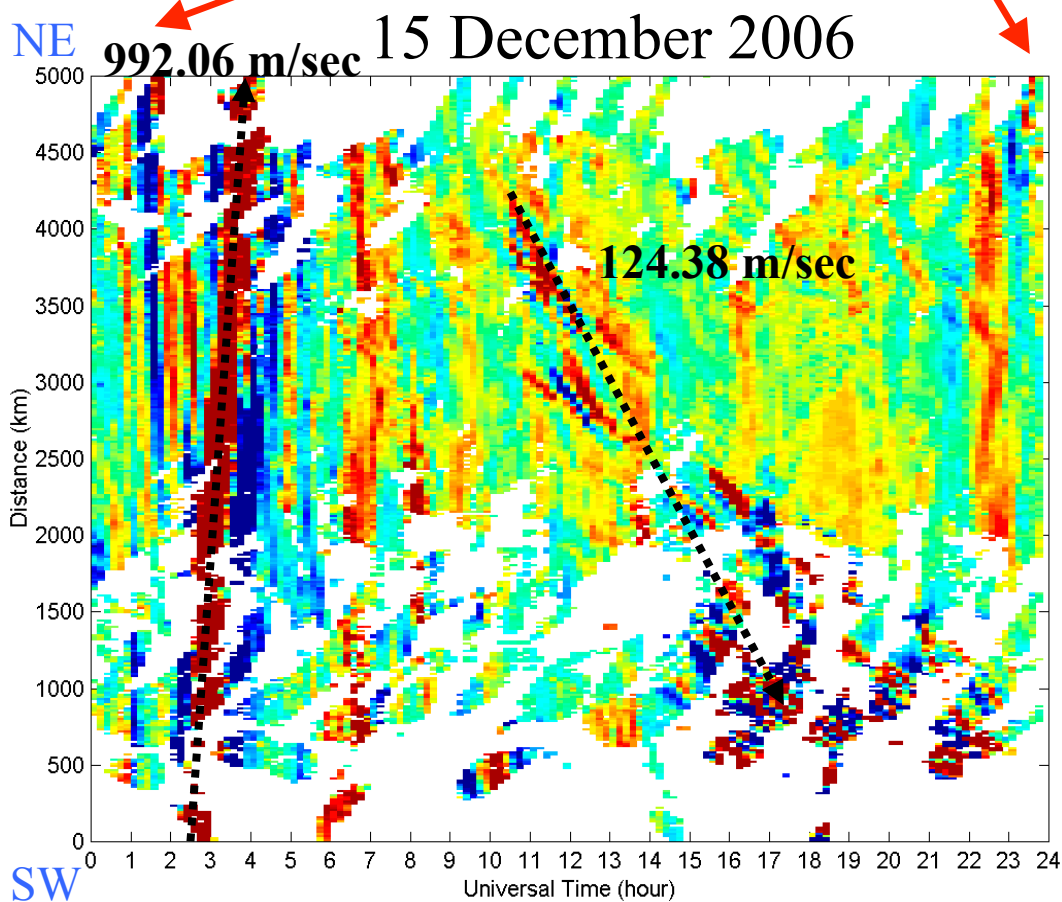
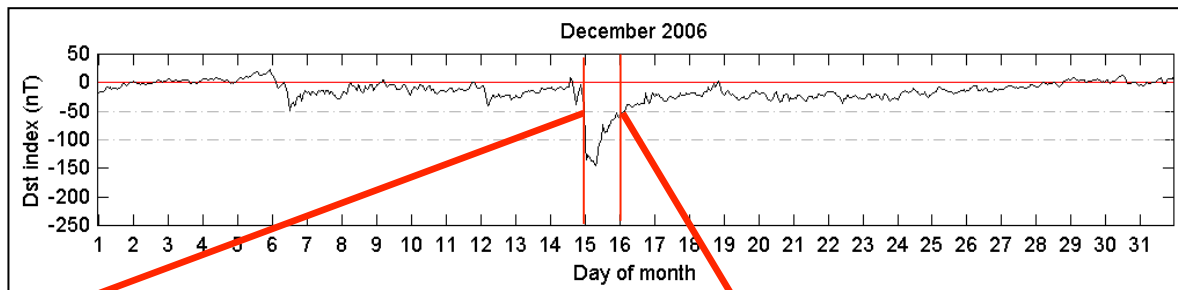
# Tsunamic-triggered wave in the Ionosphere

2004 Sumatra Earthquake

Liu et al. 2006

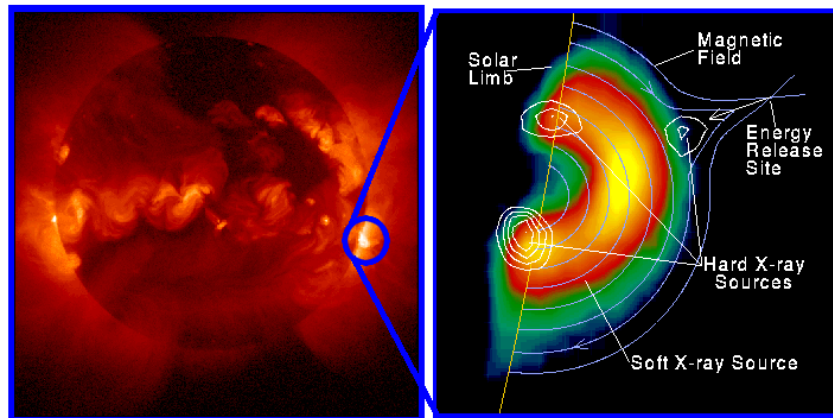


# How about the Space Weather effect? Can we distinguish the differences?

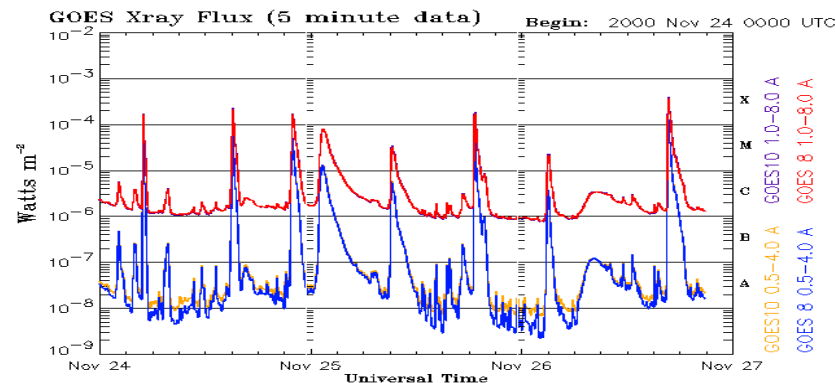




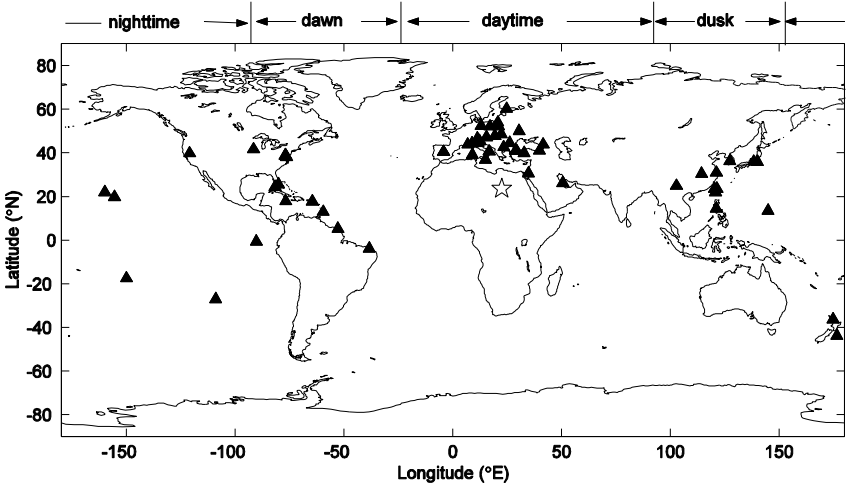
# Space Weather related signals in ionosphere: solar flare



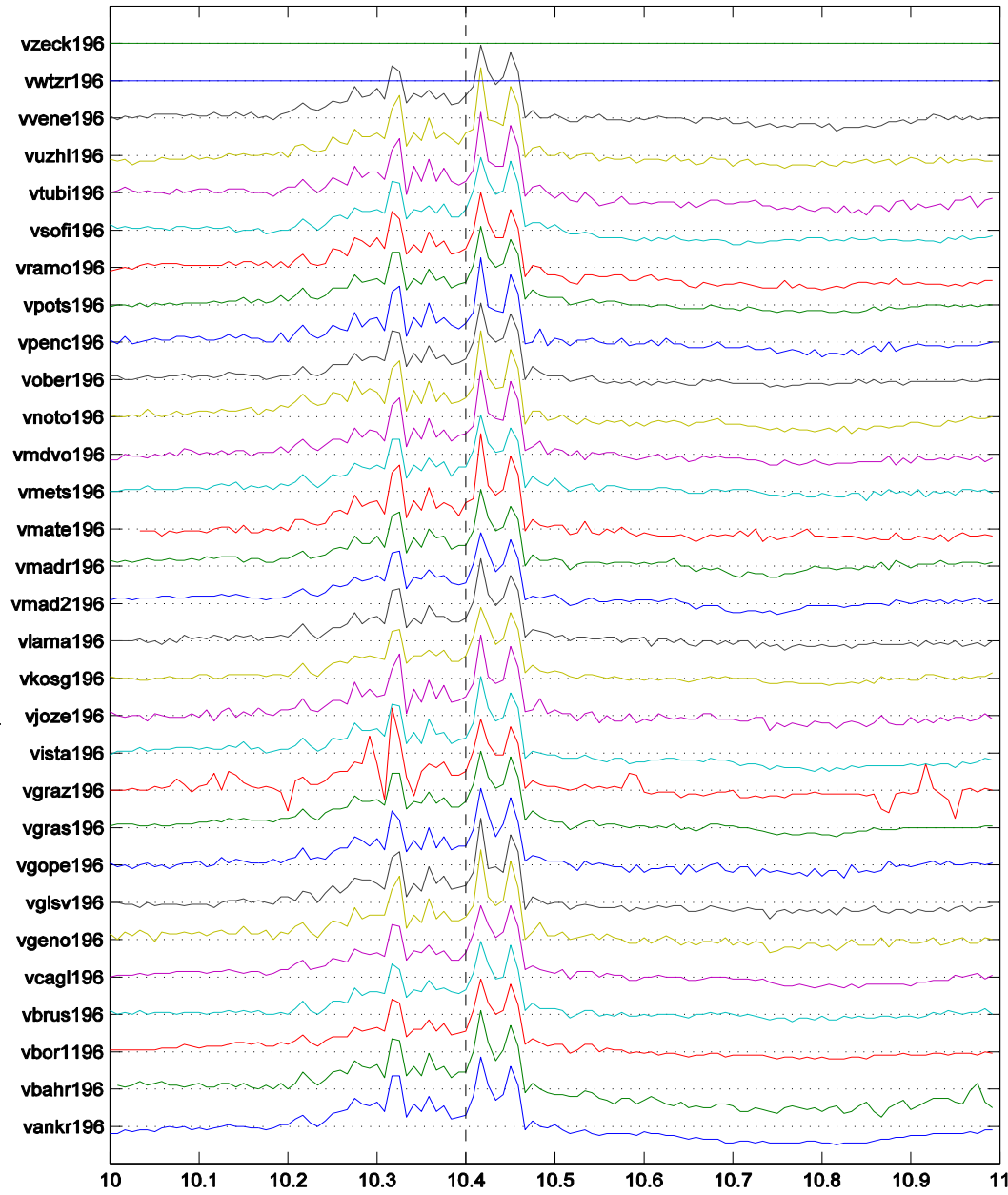
Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.



Updated 2000 Nov 26 20:59:04 UTC NOAA/SEC Boulder, CO USA

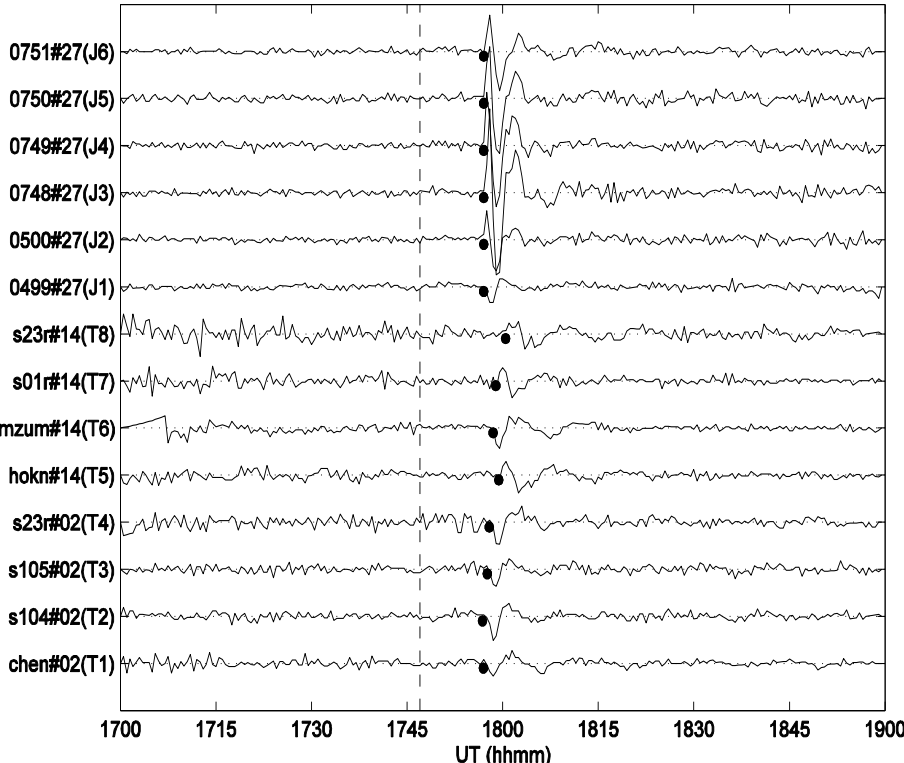
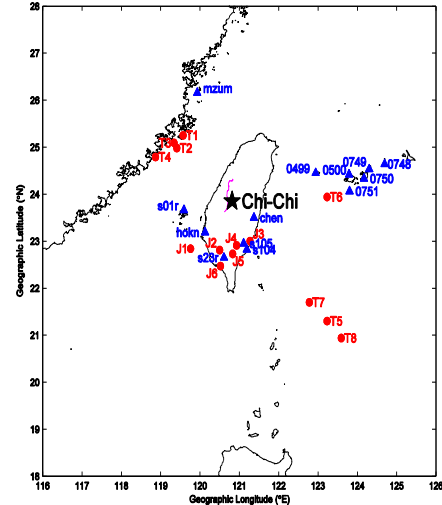


$\Delta\text{TEC}/30\text{s}$  (0.2 TECU for Y grid)

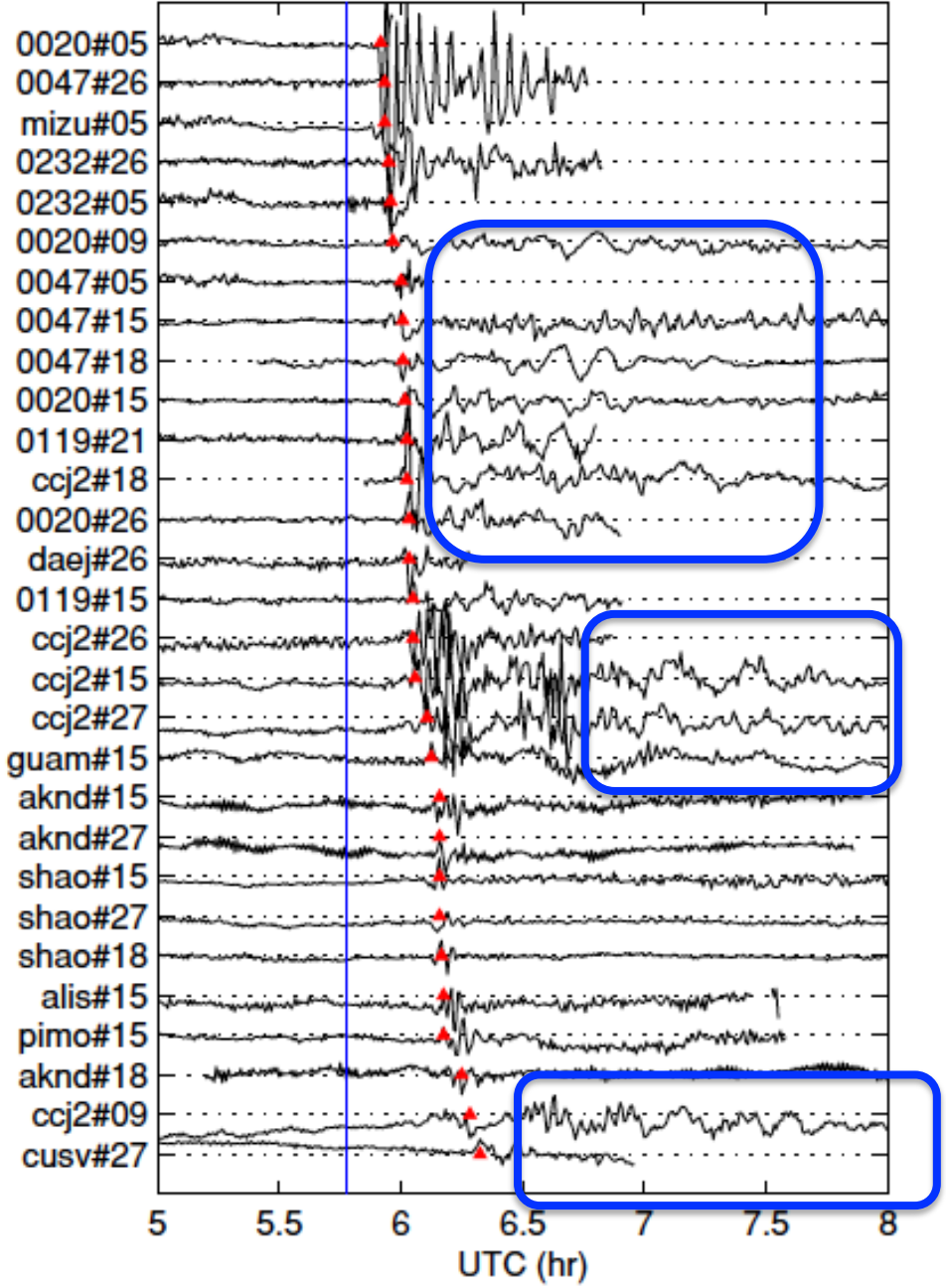


# Seismic related signal in ionosphere

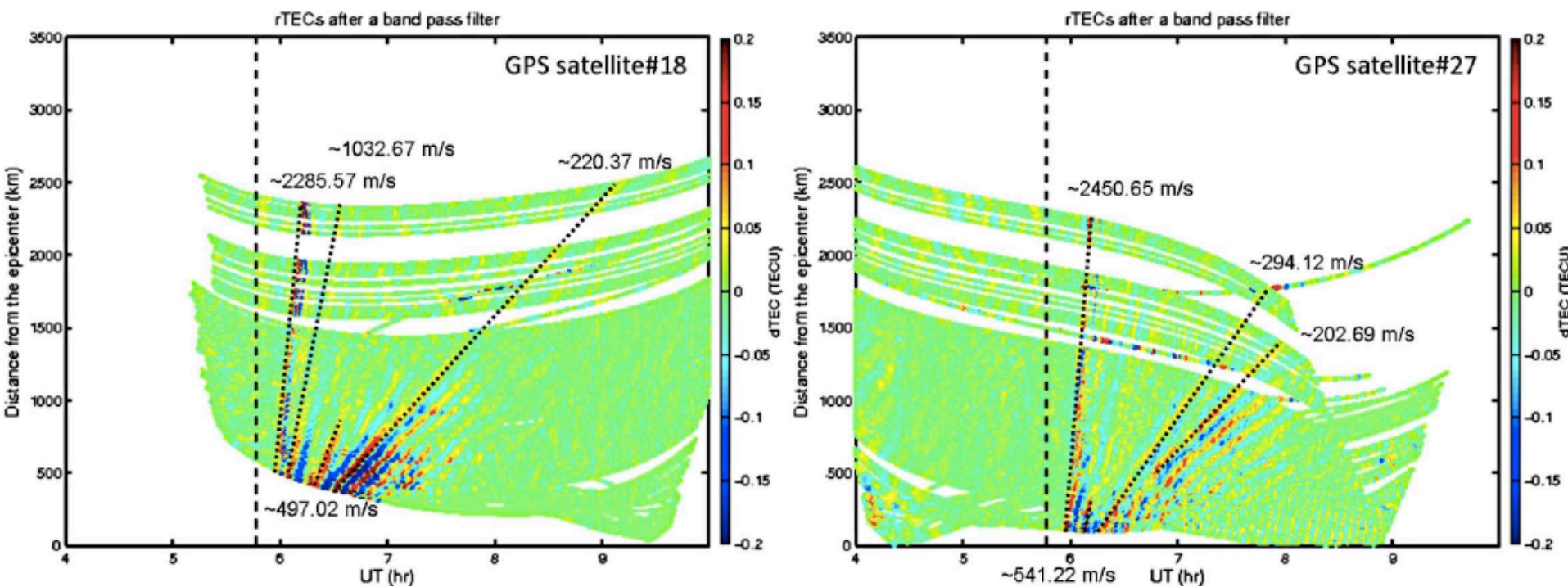
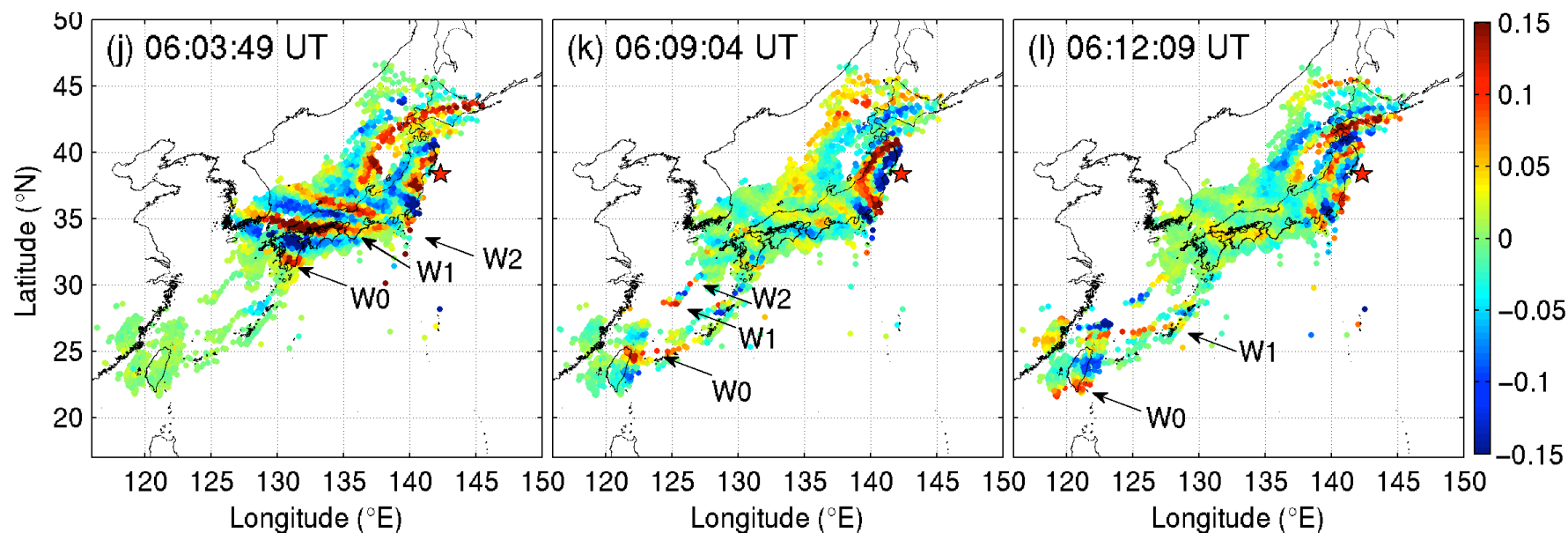
## Chi-Chi Earthquake Liu et al. 2010



# 2011 Tohoku earthquake Tsai et al. 2011



# 2011 Tohoku Earthquake



# Whole Atmospheric Disturbance Model (WADM)

- Time-dependent, three-dimensional, non-linear, non-hydrostatic, compressible, neutral, numerical model

## Ionosphere

$$\text{Number density} \quad \frac{\partial n_i}{\partial t} = -(\vec{u}_i \cdot \nabla)n_i - n_i(\nabla \cdot \vec{u}_i) + P_i - \beta n_i$$

$$\text{Momentum} \quad 0 = en_i(\vec{E} + \vec{u}_i \times \vec{B}) - \nabla p_i + m_i n_i \vec{g} + m_i n_i \nu_{in}(\vec{u}_n - \vec{u}_i)$$

$$\text{Internal energy} \quad T_i = T_n + \frac{m_i}{3k_B}(\vec{u}_i - \vec{u}_n)^2$$

## Neutral atmosphere

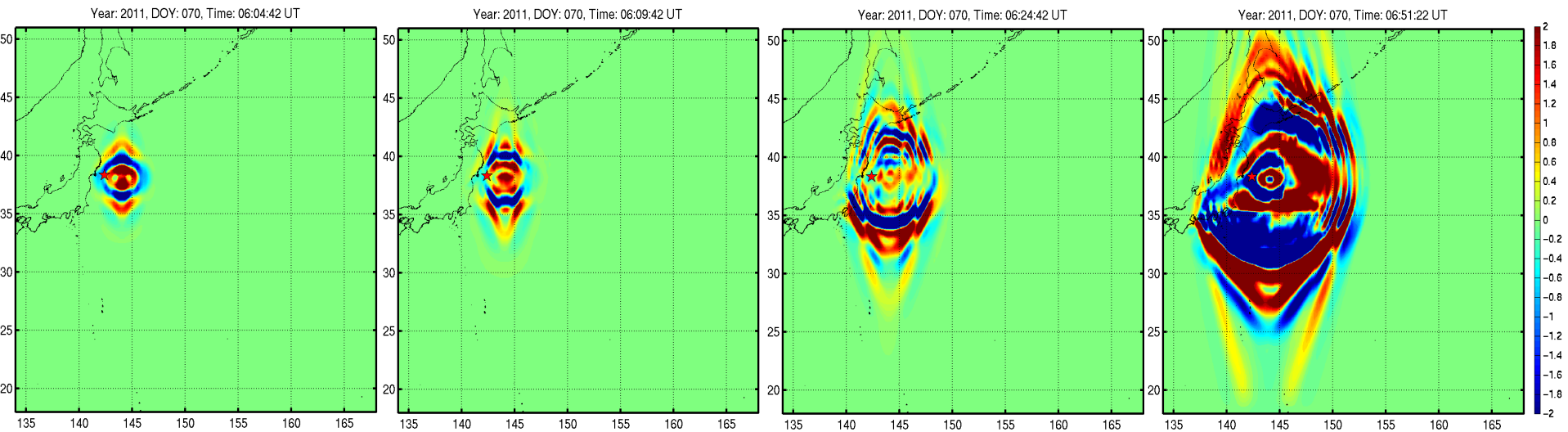
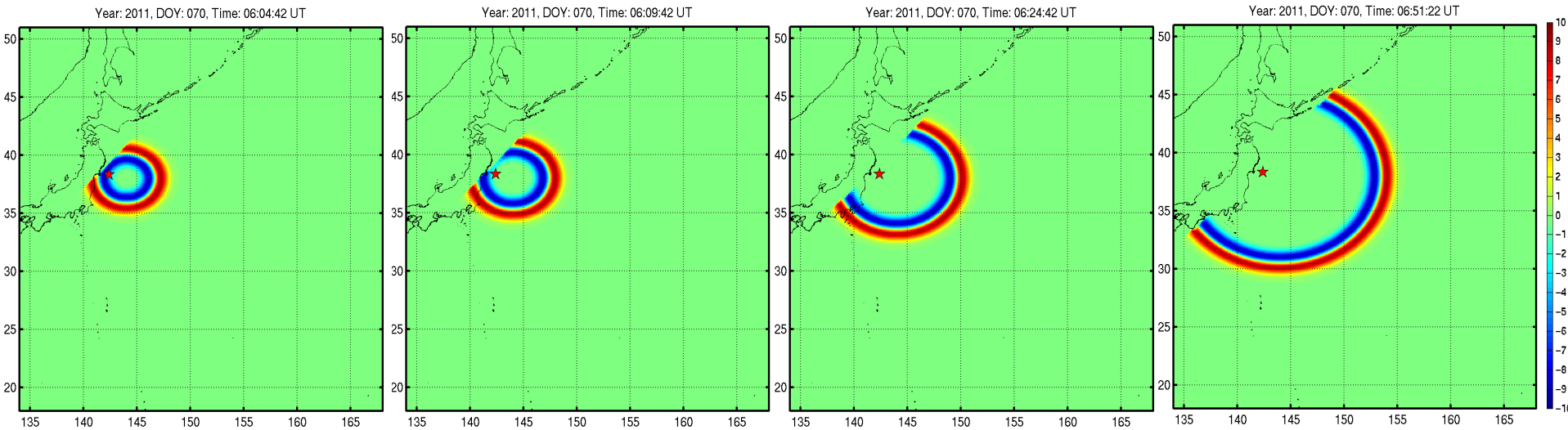
$$\text{Mass density} \quad \frac{\partial \rho_n}{\partial t} = -(\vec{u}_n \cdot \nabla)\rho_n - \rho_n(\nabla \cdot \vec{u}_n)$$

$$\text{Momentum} \quad \frac{\partial \vec{u}_n}{\partial t} = -(\vec{u}_n \cdot \nabla)\vec{u}_n - \frac{1}{\rho_n} \nabla p_n - \vec{g} + \frac{1}{\rho_n} \nabla \cdot (\eta \nabla \vec{u}_n) - \nu_{ni}(\vec{u}_n - \vec{u}_i)$$

$$\text{Internal energy} \quad \frac{\partial T_n}{\partial t} = -(\vec{u}_n \cdot \nabla)T_n - \frac{k_B T_n}{m_n c_v} (\nabla \cdot \vec{u}_n) + \frac{1}{\rho_n c_v} \nabla \cdot (\kappa \nabla T_n) - \frac{3\nu_{ni} k_B}{m_n c_v} (T_n - T_i)$$



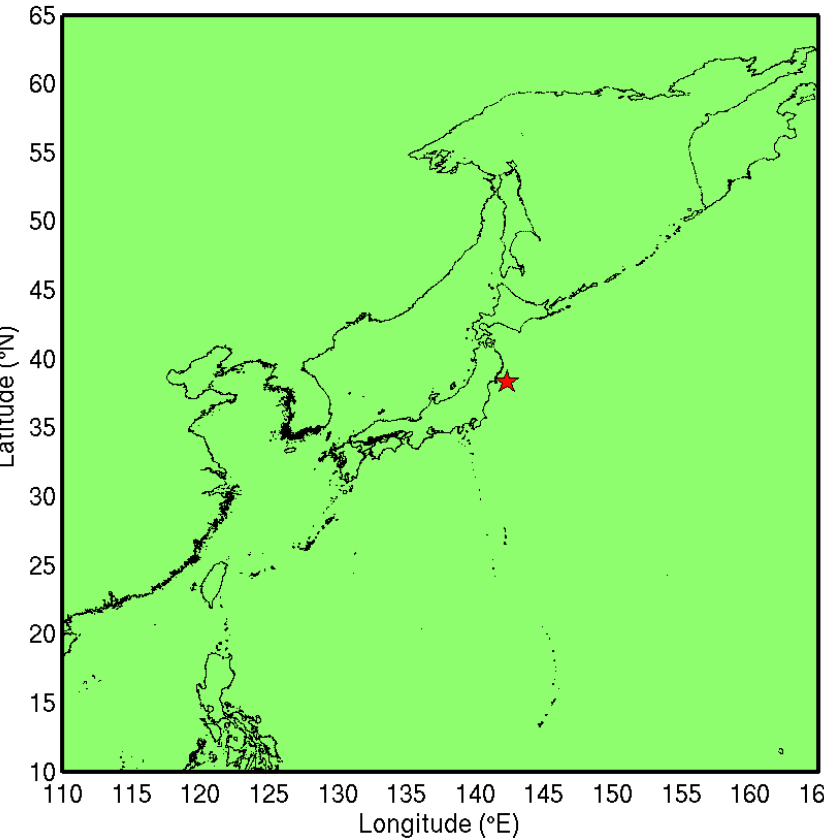
# Simulations of tsunami – ionospheric disturbances



# Simulation of the 2011 Tohoku Tsunami

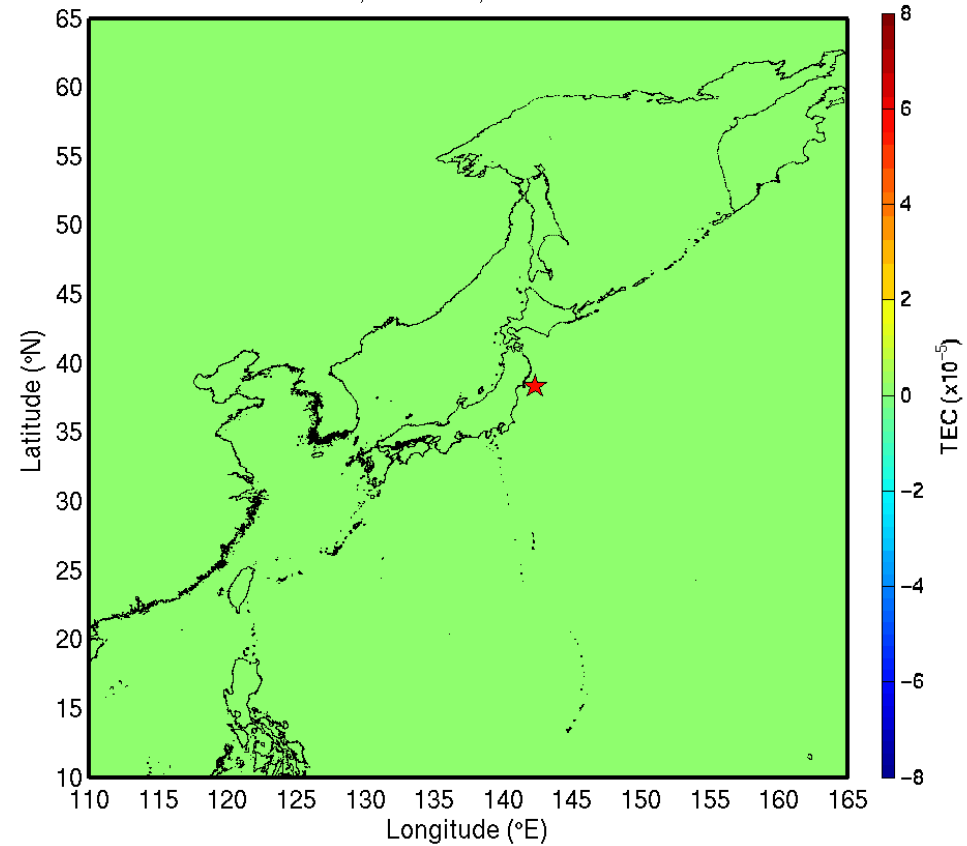
## Sea Surface Displacements Provided by Prof. Wu

Year: 2011, DOY: 070, Time: 05:46:23 UT

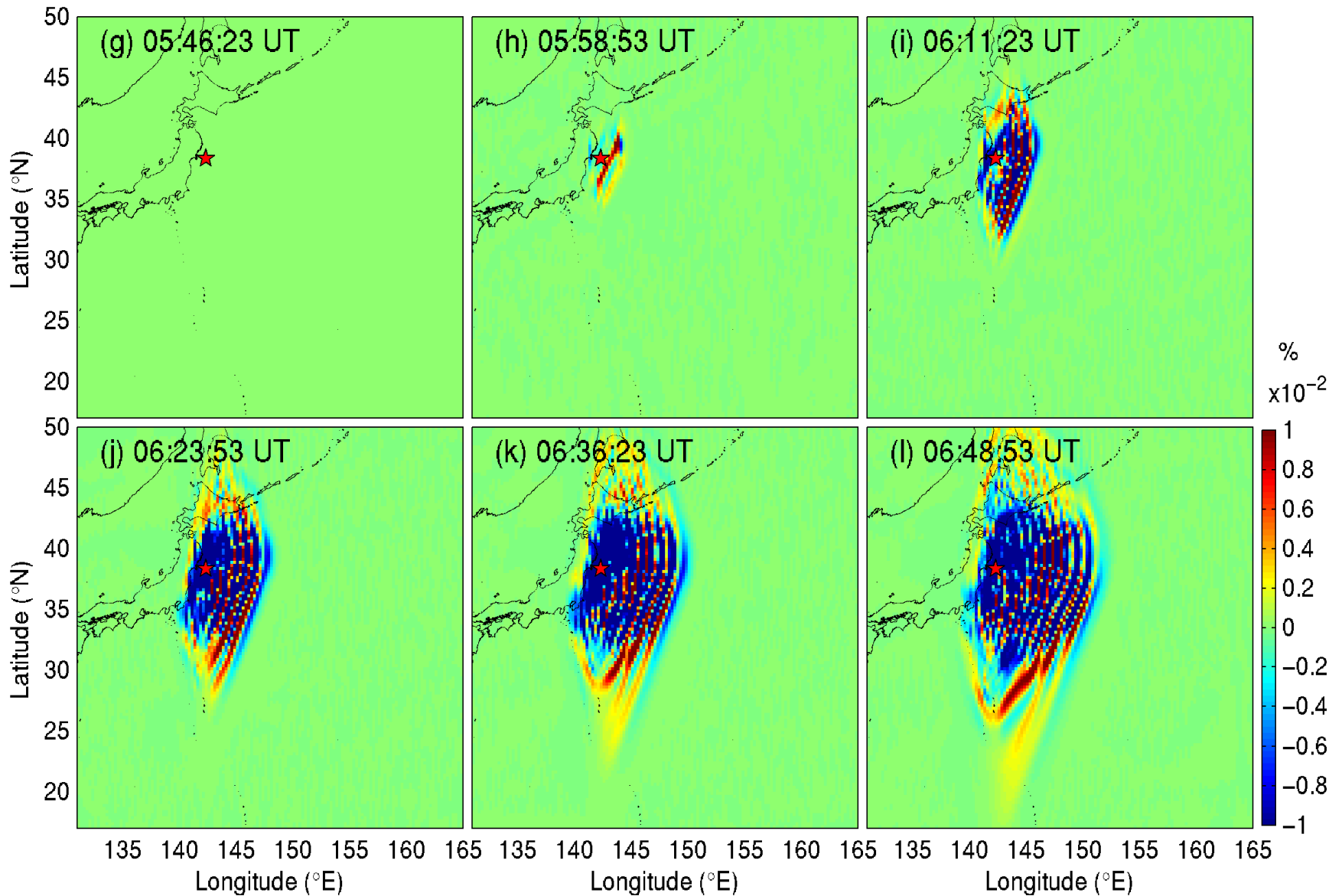


## Ionosphere disturbances

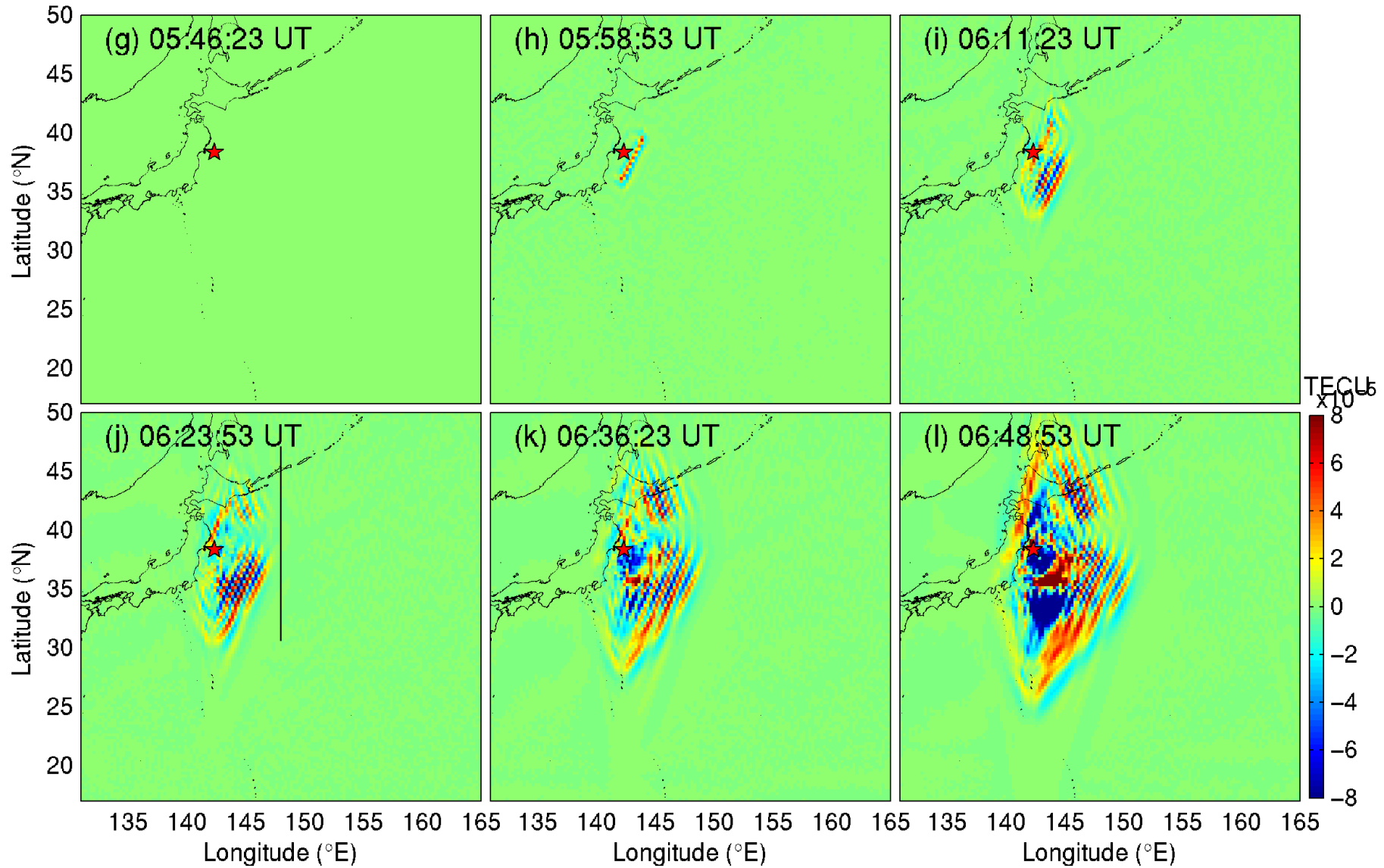
Year: 2011, DOY: 070, Time: 05:46:23 UT



# 2011 Tohoku Earthquake Tsunami effect (neutral density @ 200 km)



# 2011 Tohoku Earthquake Tsunami effect ( $\Sigma$ electron density)

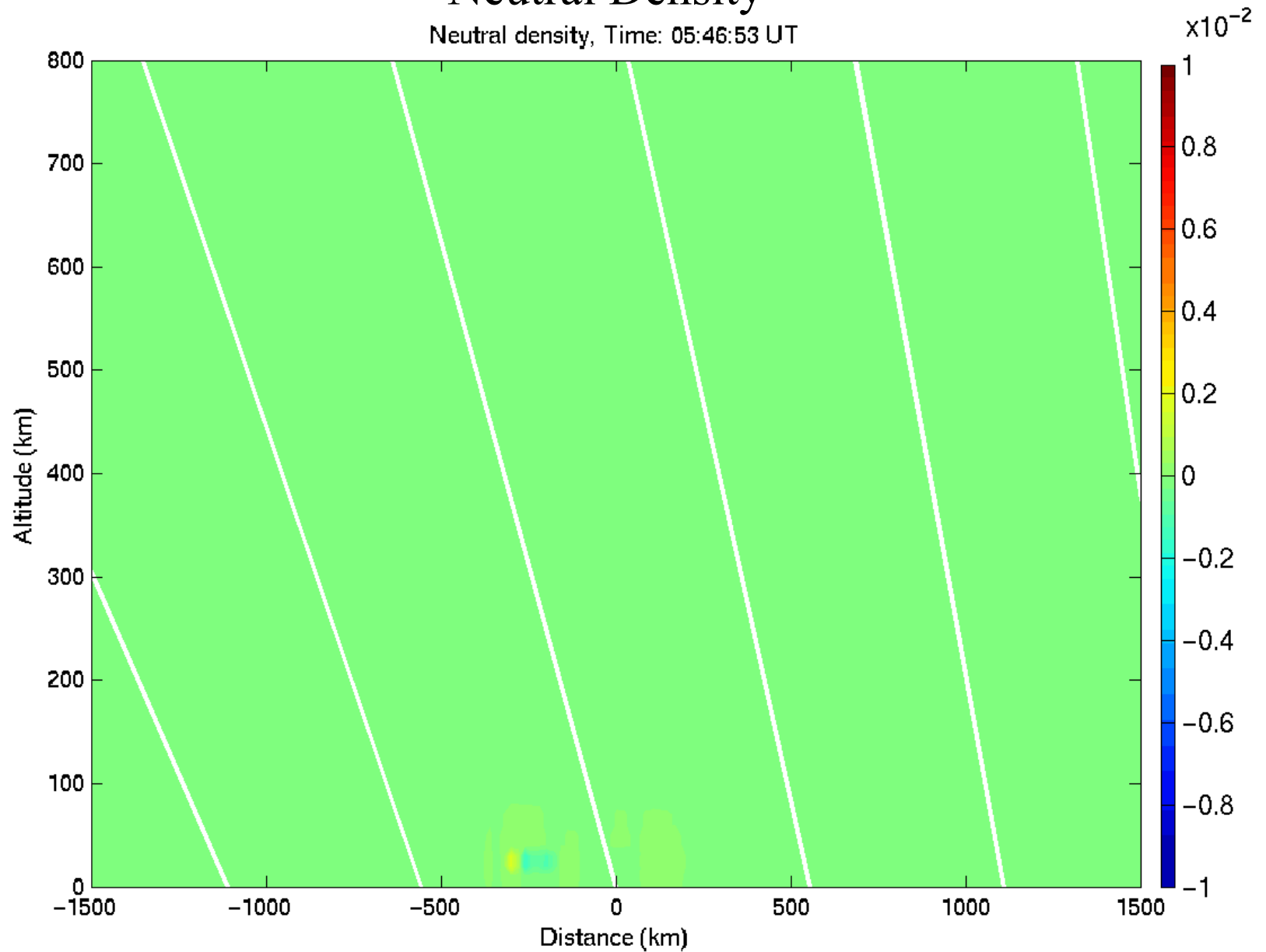




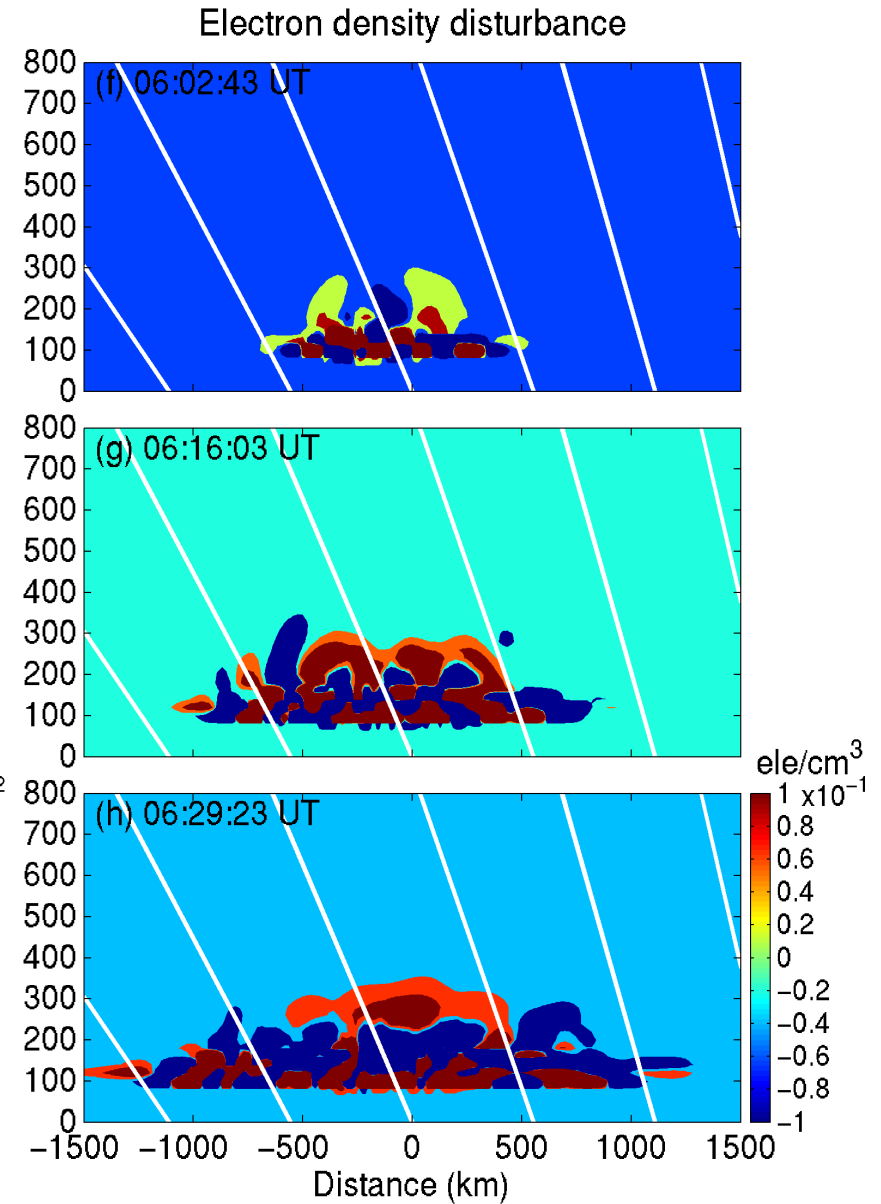
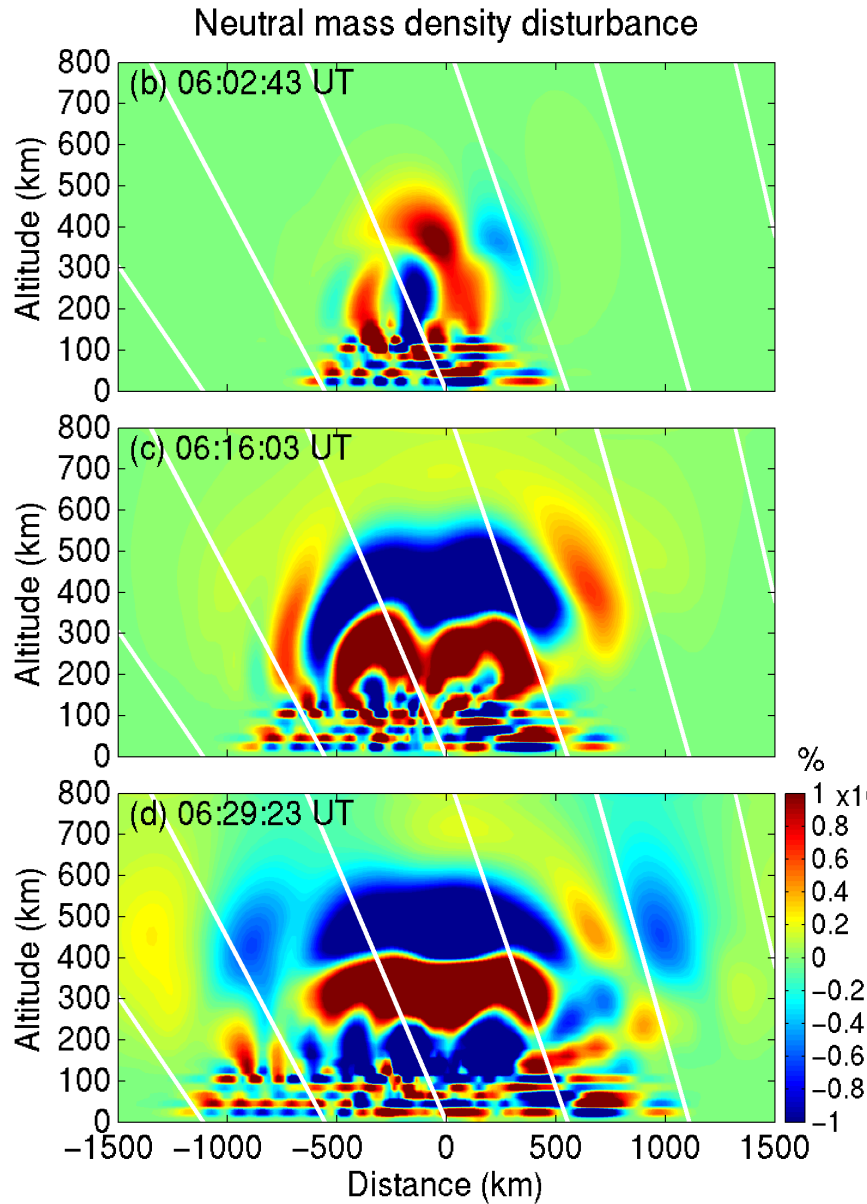
# 2011 Tohoku Earthquake Tsunami Effect

## Neutral Density

Neutral density, Time: 05:46:53 UT

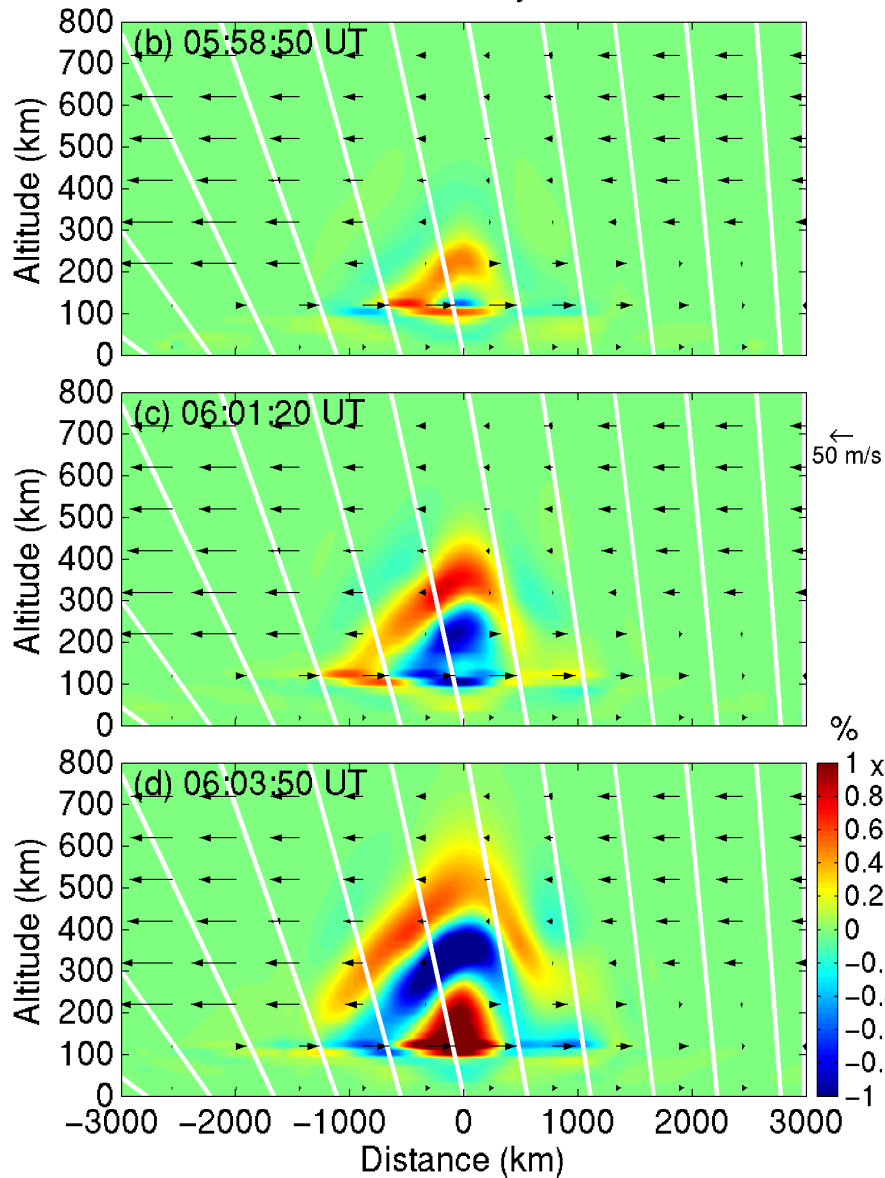


# 2011 Tohoku Earthquake Tsunami effect

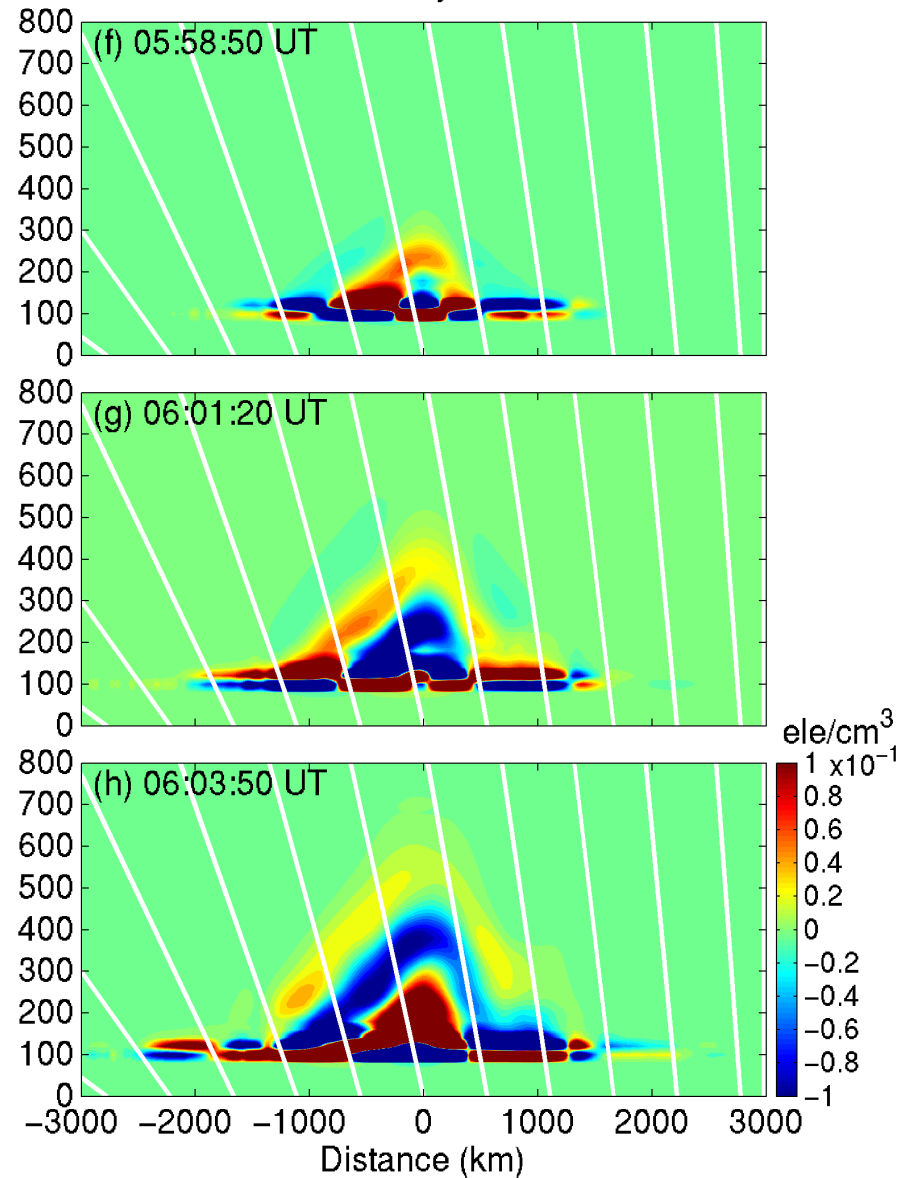


# The Earthquake Related Effect

Neutral mass density disturbance



Electron density disturbance



# Summary:

1. Tsunami triggered ionospheric electron density disturbances has longer period compared with that triggered by earthquake.
2. From our previous space weather related studies, we could identify the disturbances coming from Tsunami or space weather triggered disturbances.
3. Numerical simulation could be done by specifying the tsunami displacements at the lower boundary.
4. For the simulation of 2011 Tohoku earthquake triggered tsunami, the neutral and ionospheric disturbances propagating in North-South direction travel faster than tsunami, whereas the East-West direction disturbances travel slower than tsunami.
5. Background atmosphere conditions as well as Earth's magnetic field play important roles in affecting the propagation characters of ionospheric disturbances.

