4-D observation of traveling ionospheric disturbances using a dense GPS receiver array

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Introduction

- Travelling Ionospheric Disturbances (TIDs) are wave-like structures observed in the Earth's plasma density.
- **Signatures in the ionosphere of:**
  - Atmospheric gravity waves (AGW) due to geomagnetic activity at high latitude, (as a result of Joule heating, Lorentz forces or particle precipitations, .e.g., **Valladares et al., 2009; Ding et al., 2007**).
  - Atmospheric gravity waves propagating from low – upper atmosphere (associated with atmospheric tides, tropospheric weather, volcanic explosions, earthquakes, rocket launches).

P. statement

❑ **Classification**:

❑ **Small-Scale (SS TIDs)**

- Period: 1-10 min
- Horizontal wavelength 0.1 to 1 km

❑ **Medium-Scale TIDs (MS TIDs)**

- velocities from 50 to 300 m/s
- Period: 20 - 60 min (e.g. **Hunsucker, 1982, Tsugawa et al. 2007**)
- Horizontal wavelength: < 1000 km.
- They are confined to mid and high-latitude zones (**Bruinsma and Forbes, 2008; Mayr et al., 1990**).

❑ **Large Scale TIDs (LS TIDs)**

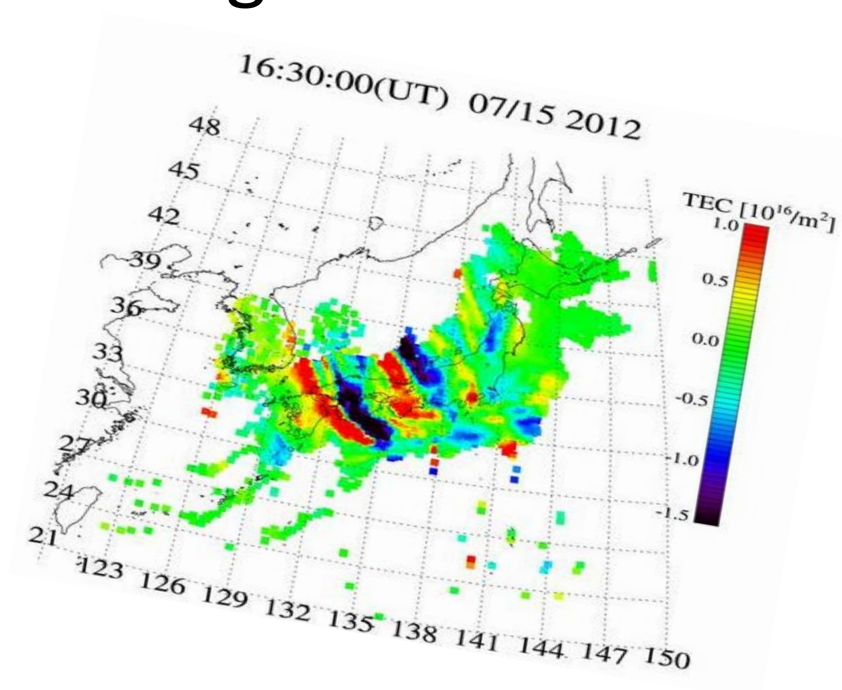
- 400 – 1000 m/s
- Period: > 1 hr
- Order of thousands of kilometers in horizontal scale.

- **Focus** is on MSTIDs that are characteristic wave phenomenon in the ionospheric F-region at mid-latitudes.

Problem

- Most studies have been limited two-dimensional imaging (2-D Total Electron Content, TEC, maps that infer information on the horizontal structuring of the electron density)

An example of a 2D TEC map.



Mainly:

- Due to the **paucity of Global Positioning System (GPS) receivers** and **limited projection angles.**

- Where, projection angle is the line integral along a given view.

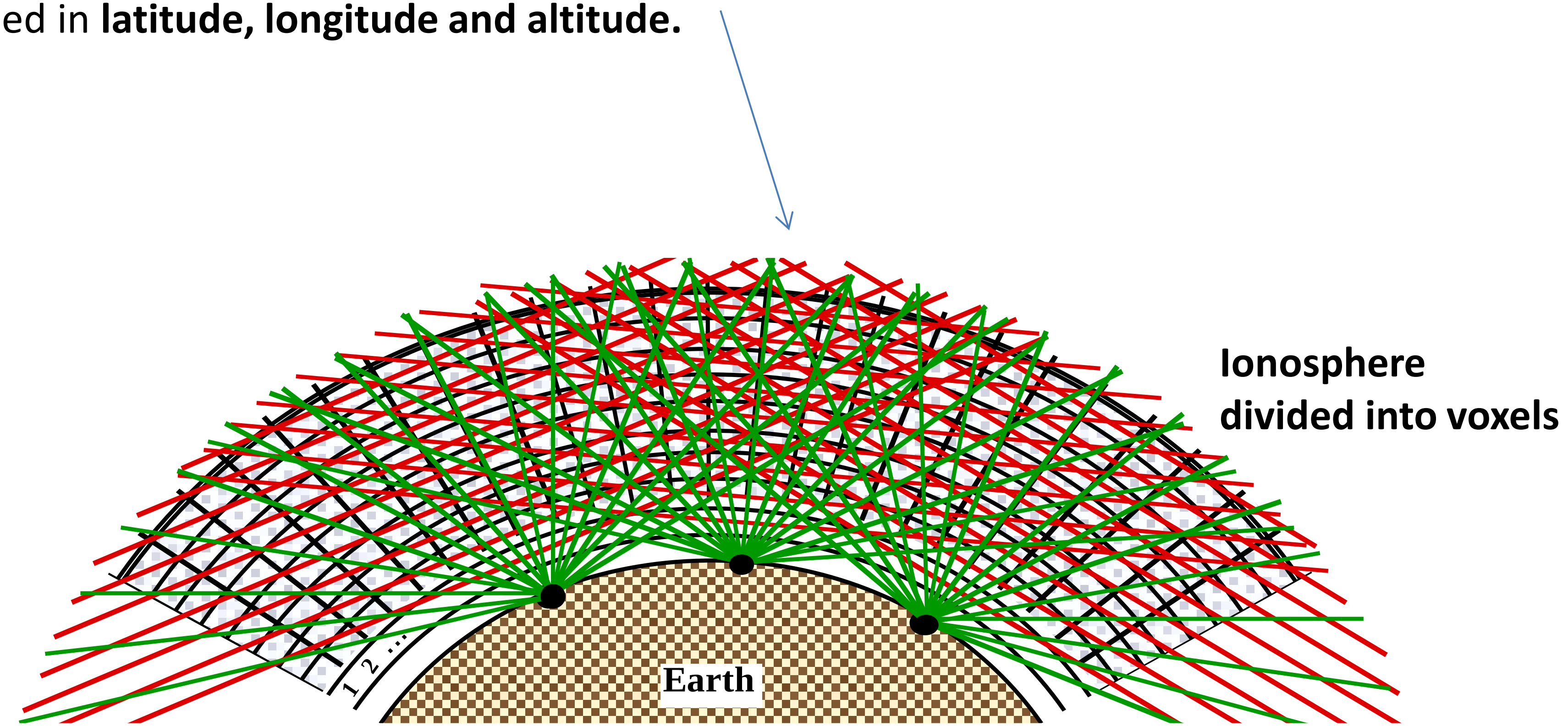
- Luckily, Japan has a GPS Earth Observation Network (GEONET) of more than 1000 receivers (with average distance between two neighbouring points being 25-30 km).

Investigation (Tomography)

The possibility of using a MART and Calibrated IRI model to observed TIDs

❑ With multiple ground stations each being able to "see" **6-8 GPS** satellites at time, tomography is possible.

❑To do this, we set up a three-dimensional grid of voxels (*i.e. volume* pixels), each bounded in **latitude, longitude and altitude.**



❑ Compute the length of each element of a satellite-to-receiver signal propagation path though each intersected voxel.

continued

- The contribution to the line integrals in each voxel is decomposed into a matrix, **A**.
- Given the measurements of these line integrals, **m (Slant-TEC)**, the problem becomes one of inverting **A** to solve for the unknown electron concentration, **x**.

$$\mathbf{Ax = m}$$

- **However**, the inverse problem is ill-posed and ill-conditioned.

To solve the inverse problem we use the MART (Multiplicative Algebraic Reconstruction Technique)

$$x_j^{k+1} = x_j^k * \left(\frac{m_i}{\langle \boldsymbol{A}^i, \boldsymbol{x}^k \rangle} \right)^{\dfrac{\lambda_k A_j^i}{A_{\max}}}, \quad j = 1, \ldots, N .$$

$A_{\max}$ is the maximum path-pixel intersection length in the grid.

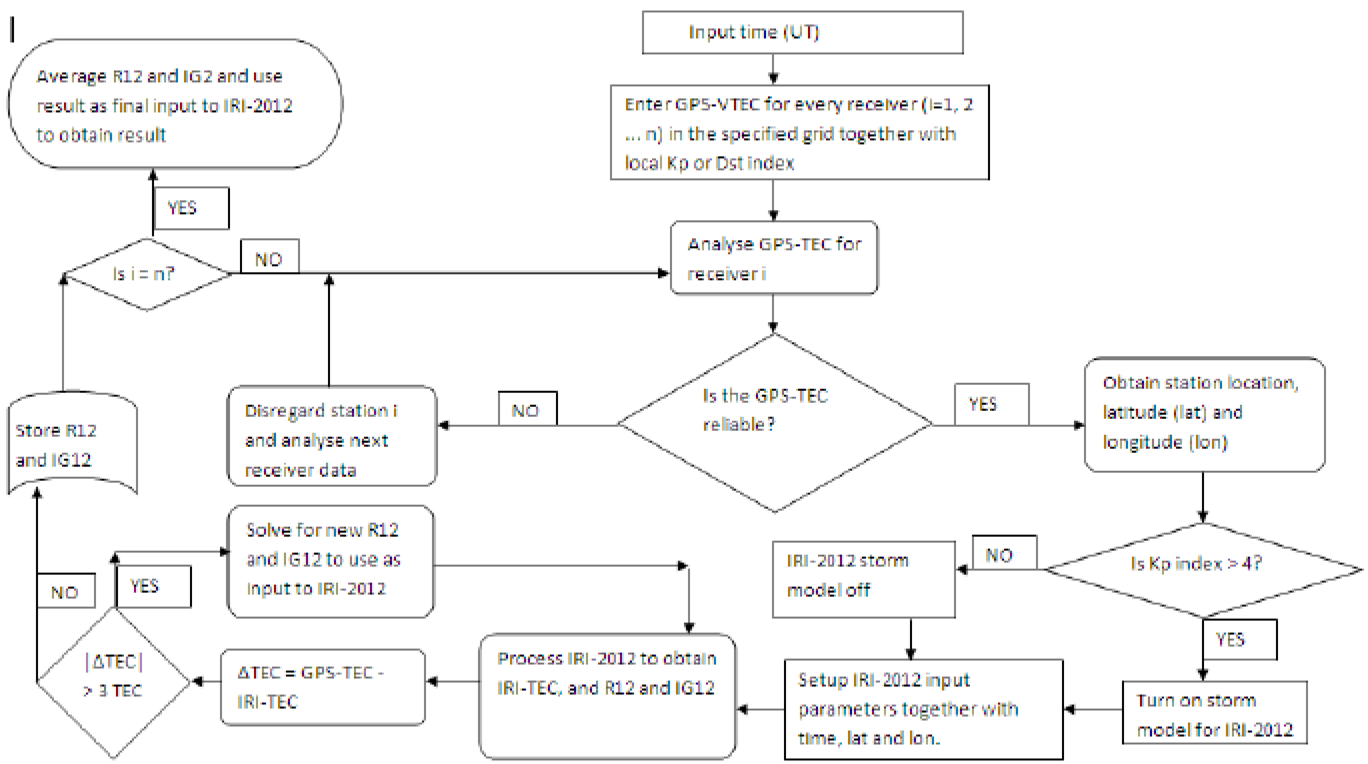
- **λ_k** is the relaxation parameter and controls the convergence of the algorithm, is bounded between 0 and 1 (Pryse et al., 1998; Raymund et la., 1990).
- **Advantage:** Low memory requirements , non negative electron density values.
- **However, MART is sensitive to the initial guess (xo),**

>>>> IRI-2012 model

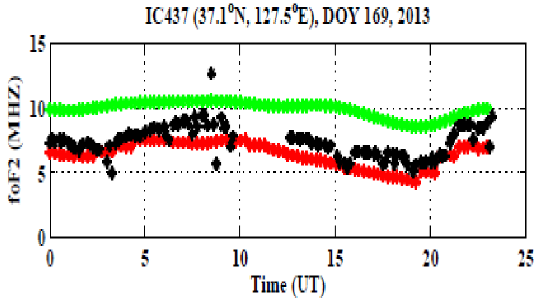
Calibrated IRI-2012 (Cal-IRI-2012)

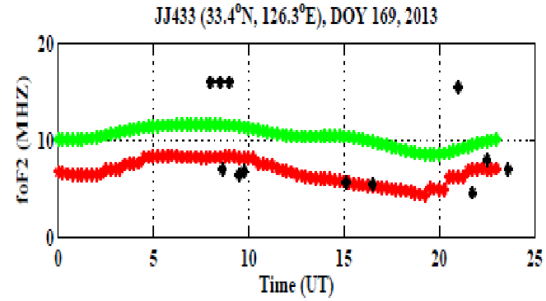
- The most recent version, IRI-2012, is used.
- Two input indices, **Sun Spot number** (SSN) and **Ionospheric index** (IG12), are adjusted in relation to derived GPS vertical TEC (VTEC).
- Only a few stations within the grid are need to reach the optimal solution.

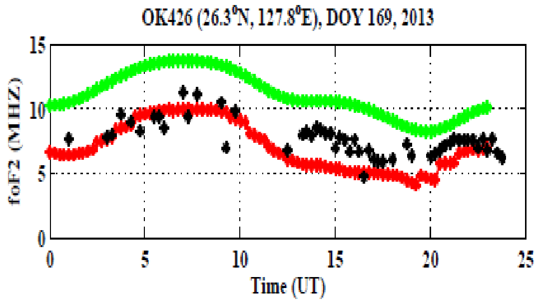
Algorithm

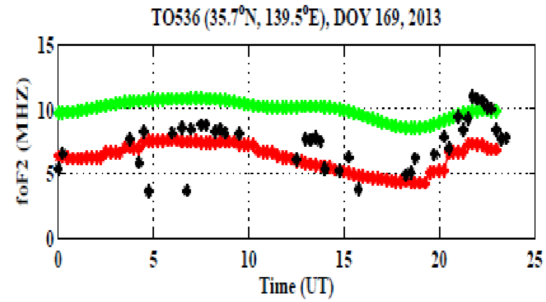

Input time (UT)
Enter GPS-VTEC for every receiver (i=1, 2 ... n) in the specified grid together with local Kp or Dst index
Analyse GPS-TEC for receiver i
Is the GPS-TEC reliable?
YES
NO
Obtain station location, latitude (lat) and longitude (lon)
Disregard station i and analyse next receiver data
Is Kp index > 4?
NO
YES
IRI-2012 storm model off
Turn on storm model for IRI-2012
Setup IRI-2012 input parameters together with time, lat and lon.
Process IRI-2012 to obtain IRI-TEC, and R12 and IG12
ΔTEC = GPS-TEC - IRI-TEC
|ΔTEC| > 3 TEC
YES
NO
Solve for new R12 and IG12 to use as input to IRI-2012
Store R12 and IG12
Is i = n?
NO
YES
Average R12 and IG2 and use result as final input to IRI-2012 to obtain result

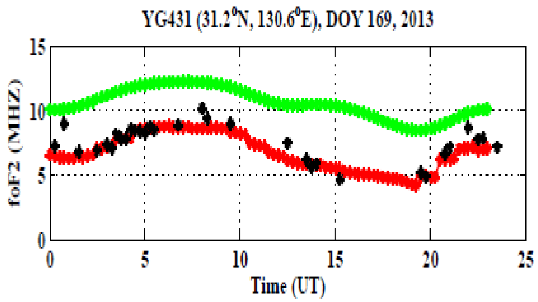
foF2 analysis











- ❑ **Use TEC to adjust foF2 values**

Table 3: RMSE at four ionosonde stations

Station	RMSE (MHz)	
	Cal-IRI-2012	IRI-2012
IC437 (37.1°N, 127.5°E)	1.3261	2.5213
OK426 (26.3°N, 127.8°E)	1.5620	3.0515
TO536 (35.7°N, 139.5°E)	1.9320	2.7574
YG431 (31.2°N, 130.6°E)	0.9285	3.2816
Average	1.4372	2.9030

❑**Percentage improvement = 50.5%**

***Regional optimization of IRI-2012 output (TEC, foF2) using derived GPS-TEC (Ssessanga Nicholas and Yong Ha Kim., In press)**

- We use Cal-IRI-2012 **(Xo)** as the initial guess.

Hence:

- Quick convergence
- A better solutions for resolving small scale structures.

Setup

Grid size

Latitude: 20° N : 1° : 50° N

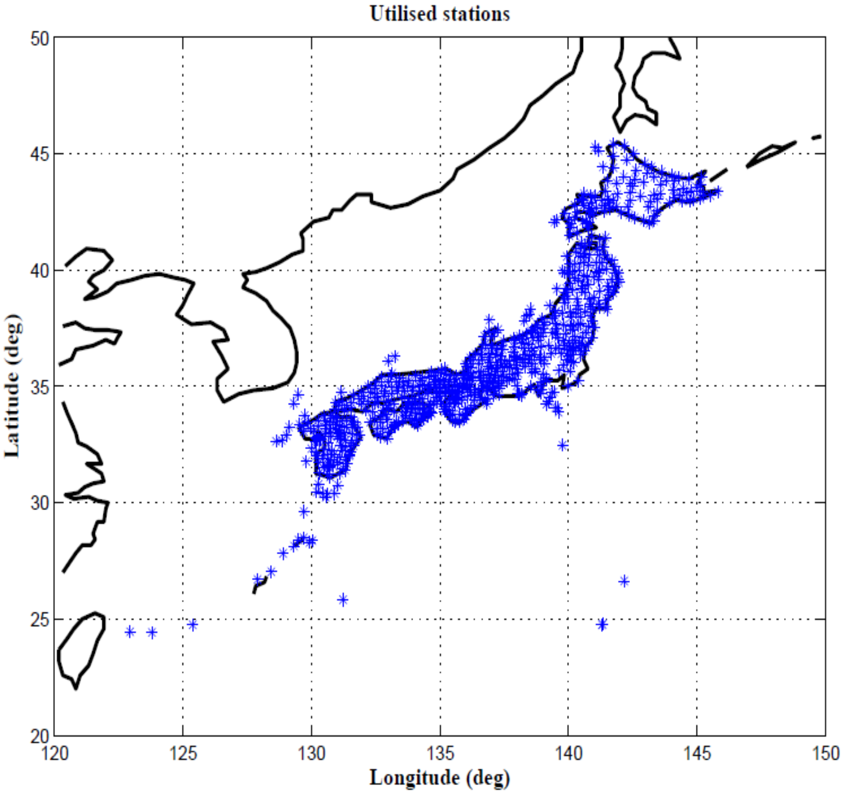
Longitude: 120° E : 1° : 150° E

Height: 100: 10 :1000 Km

Time resolution: (15 min)

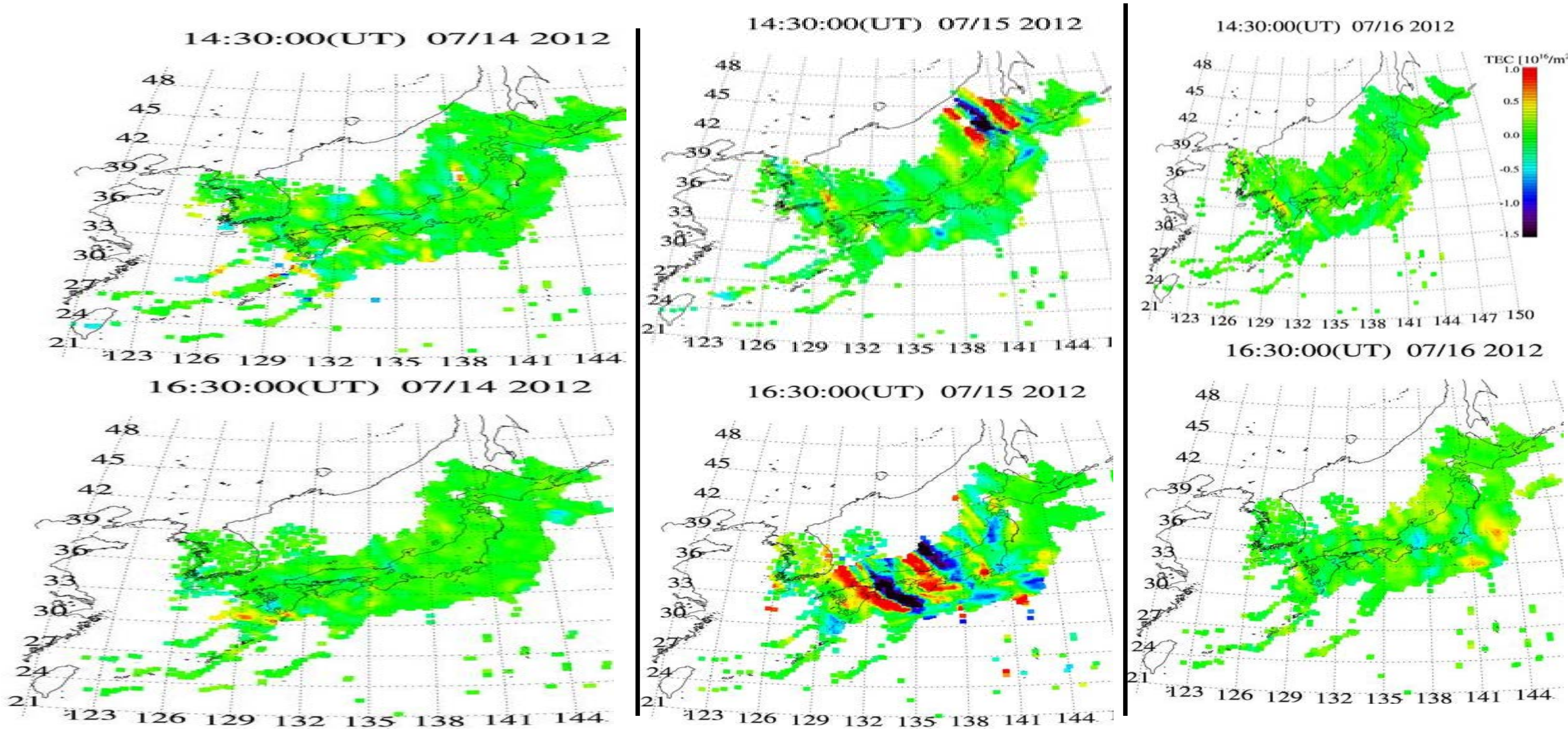
utilised stations: 700

A plot of utilised stations



Day of Analysis

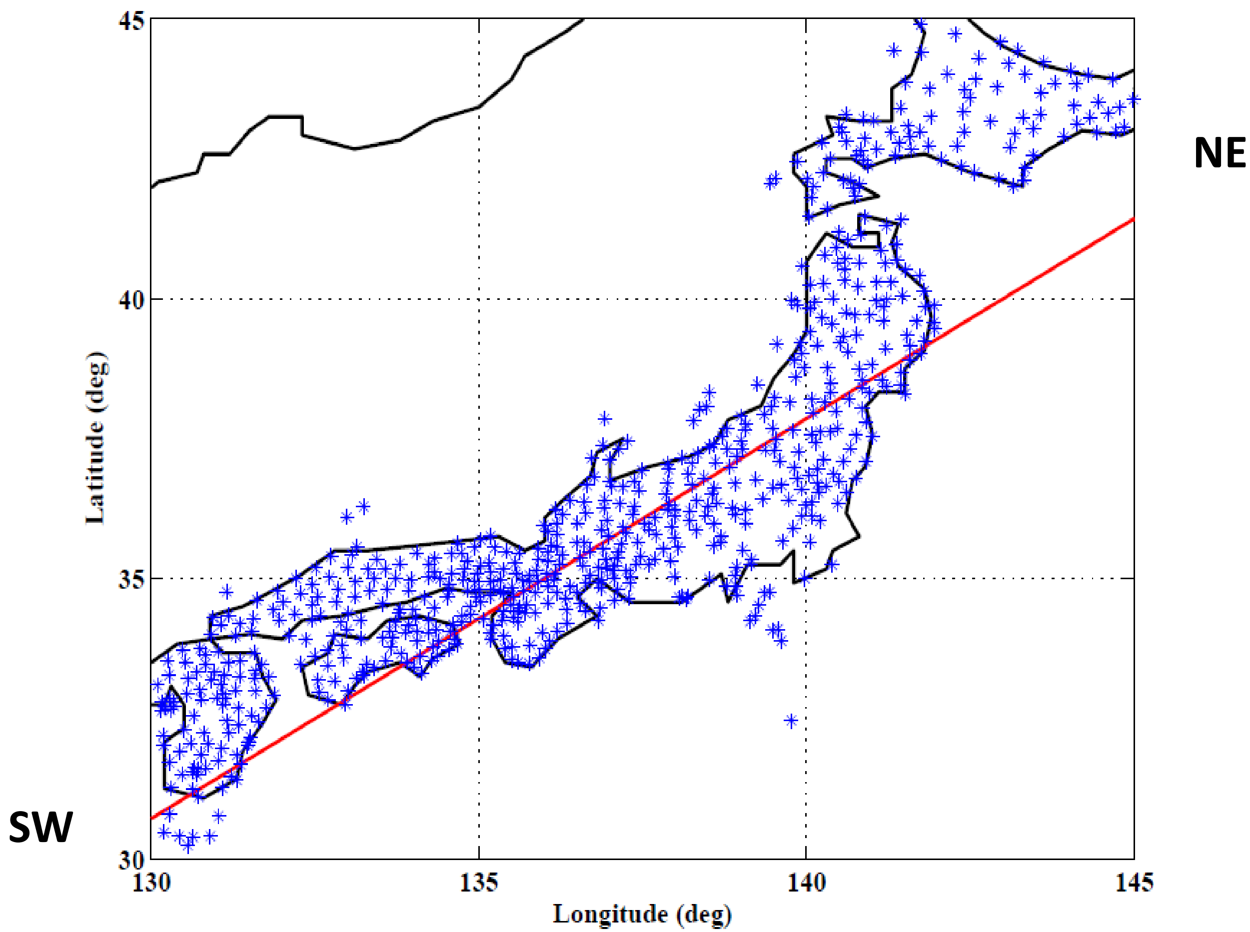
2D dTEC Maps, 14-16, July 2012



- ❑The selection was done through a **visual examination** of these sequences of maps. If there were TIDs passing by, there would be regularly moving **band-like structures**.
- ❑The perturbation components of TEC values were derived by subtracting a trend of the TEC values that is a 30-min running average.
- ❑ The data from satellite receiver paths with low elevation angles below 30^o were not included. (using a program a from NICT)

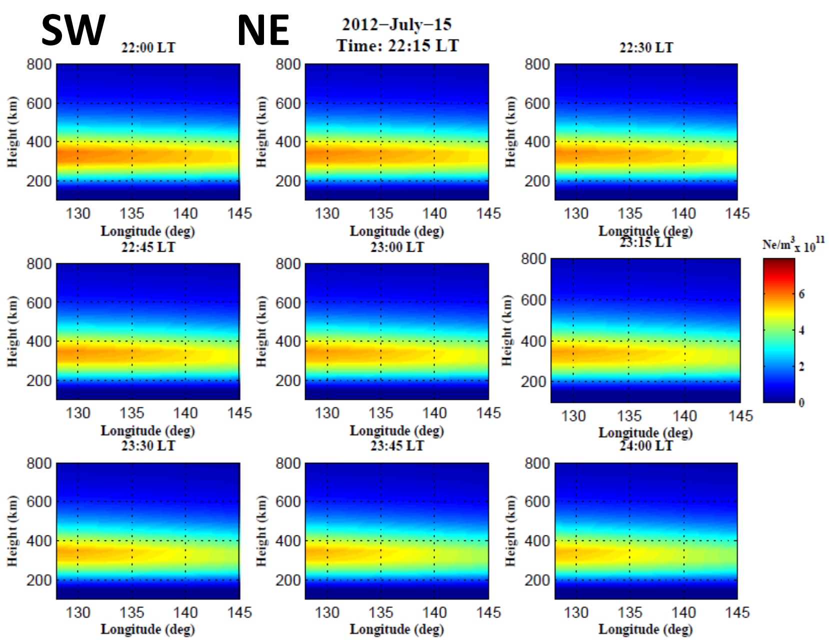
Results

Spatial representation

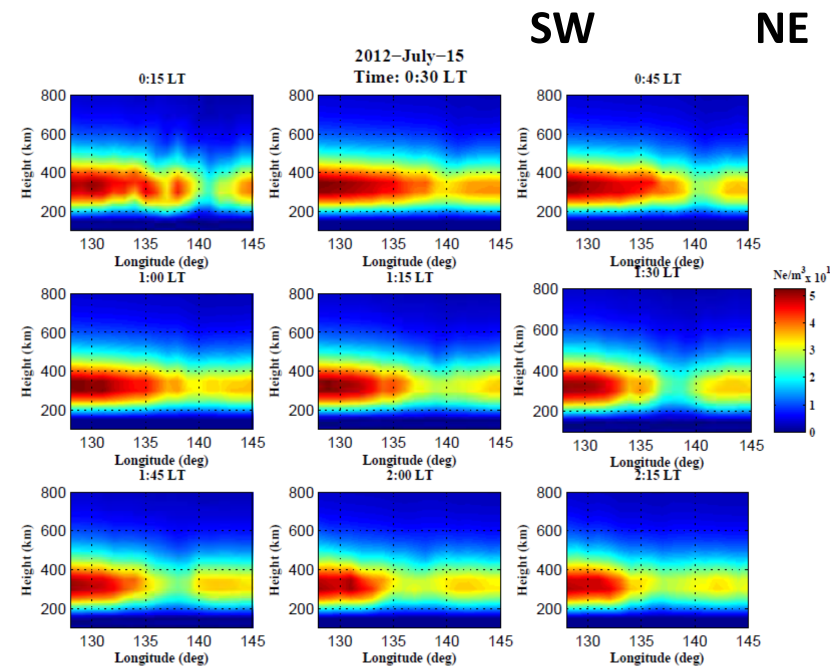


- Slice a vertical plane with most number of data points

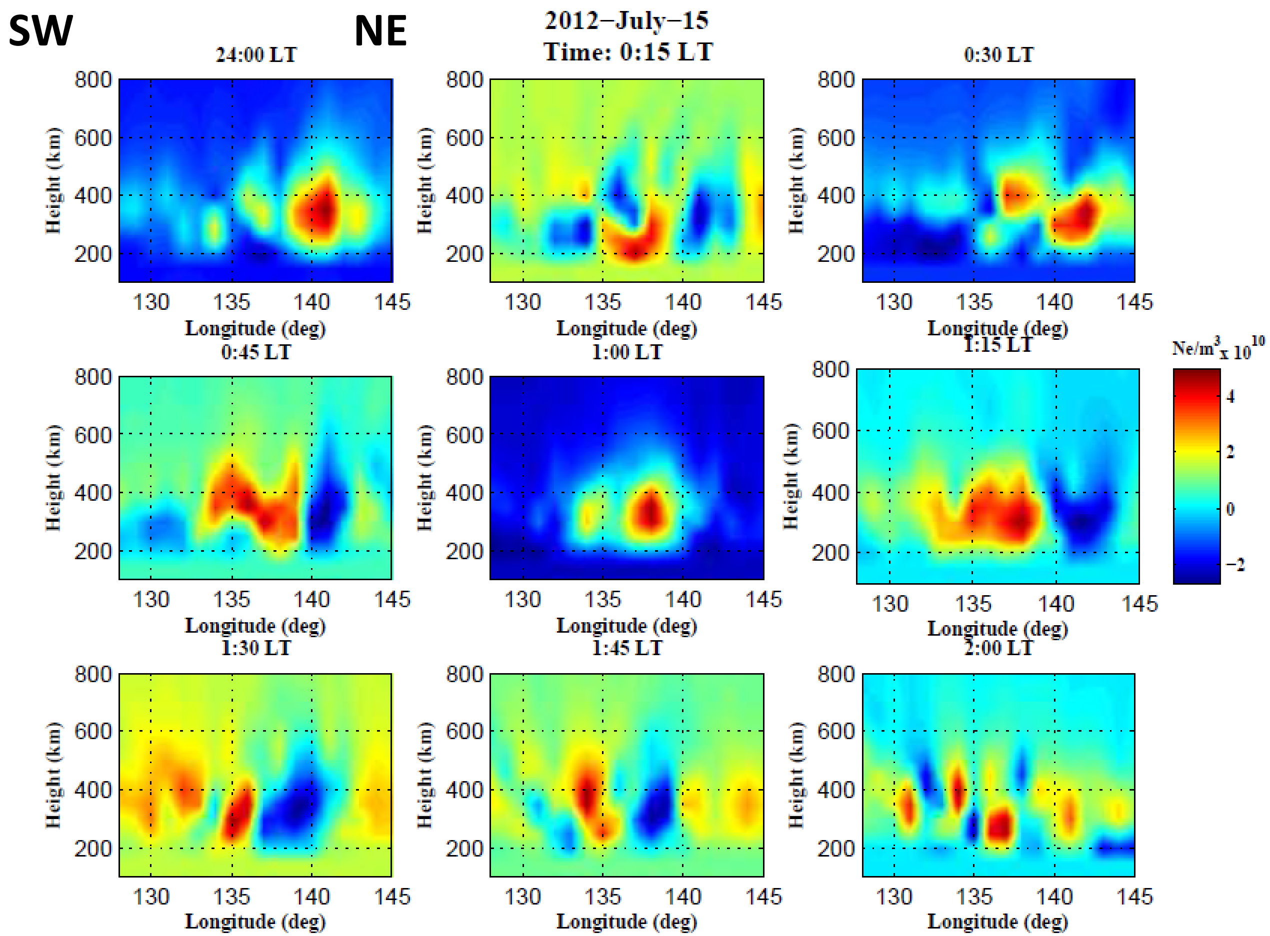
Smooth Ionosphere - Cal-IRI 2012



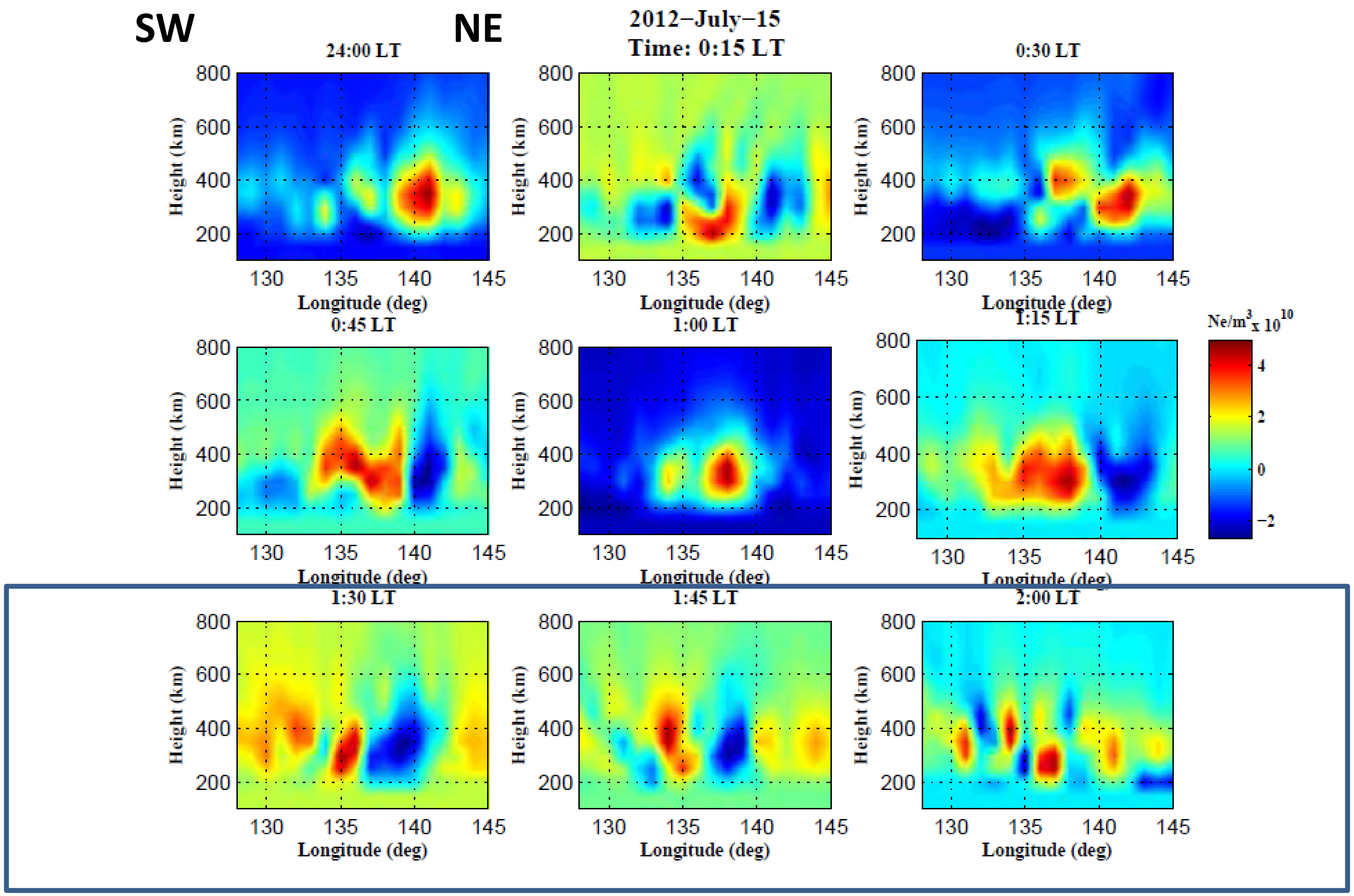
Results from algorithm



- 15 minute resolution , spatial representation
- The ionosphere is quite moderately modulated by the TIDs

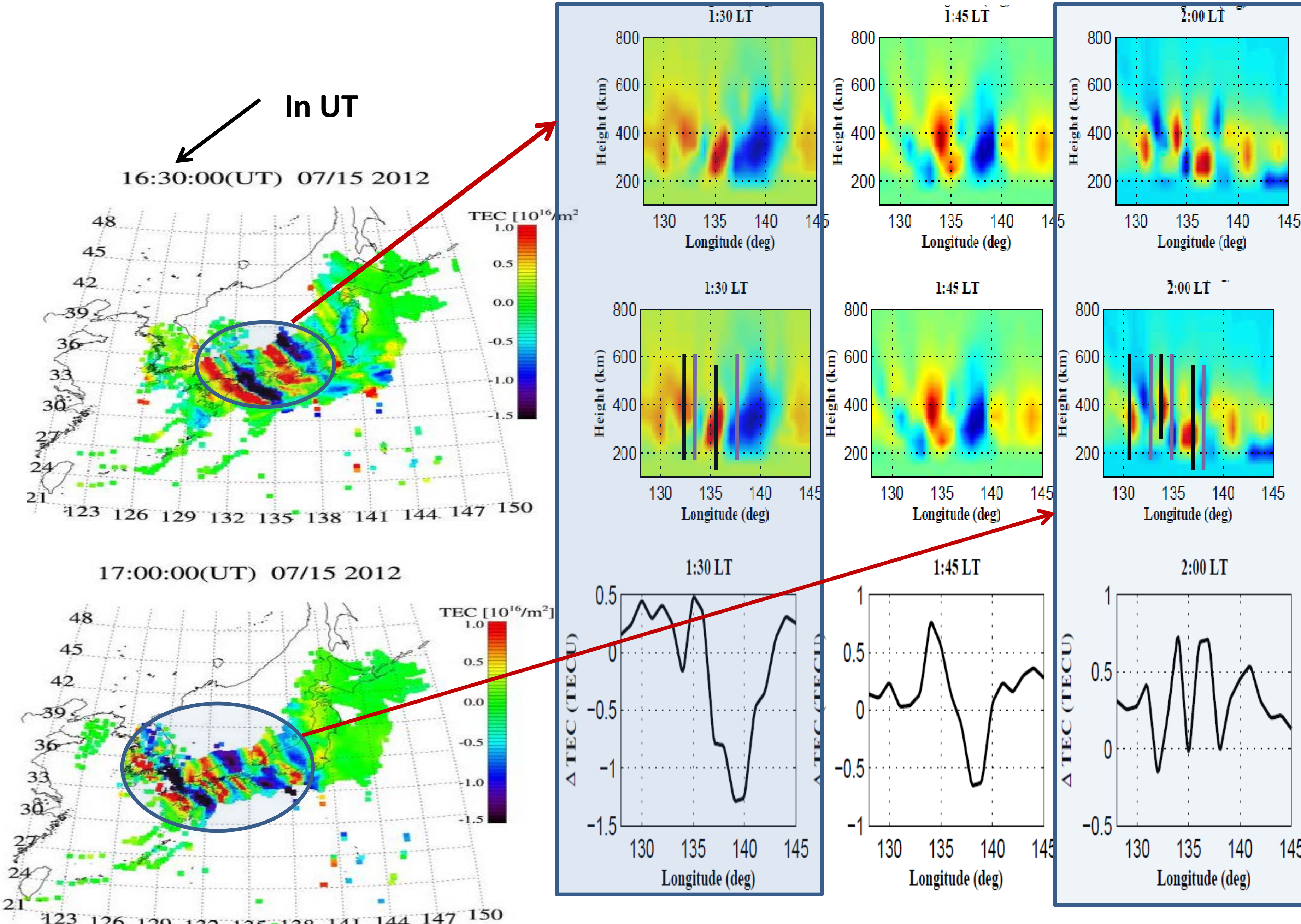


- In local time = UT + 9



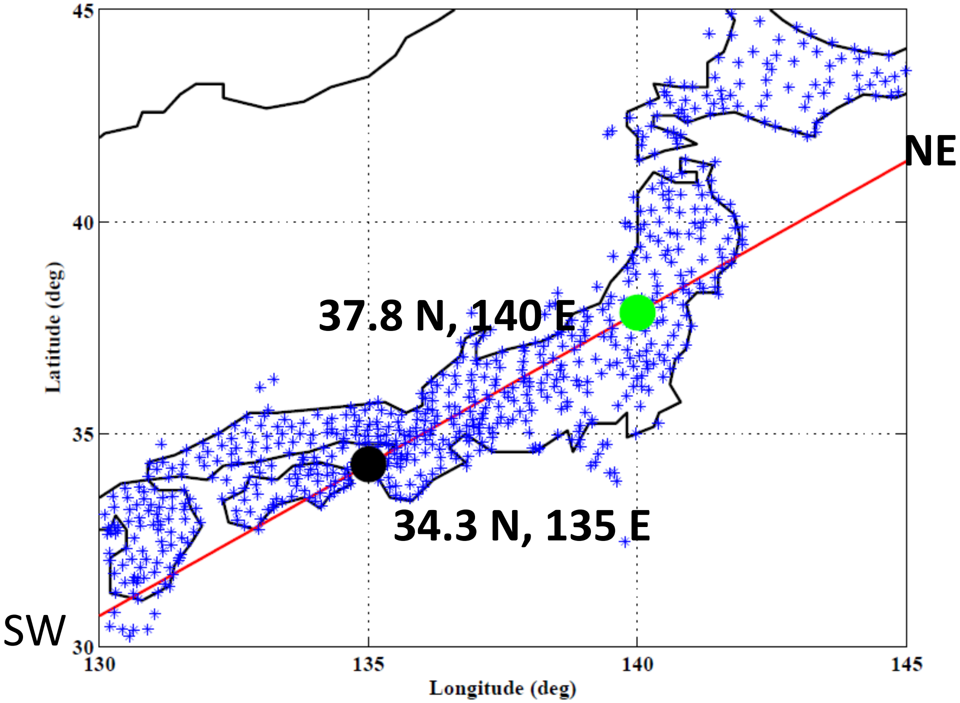
- In local time = UT + 9

In local time(LT) = UT+9

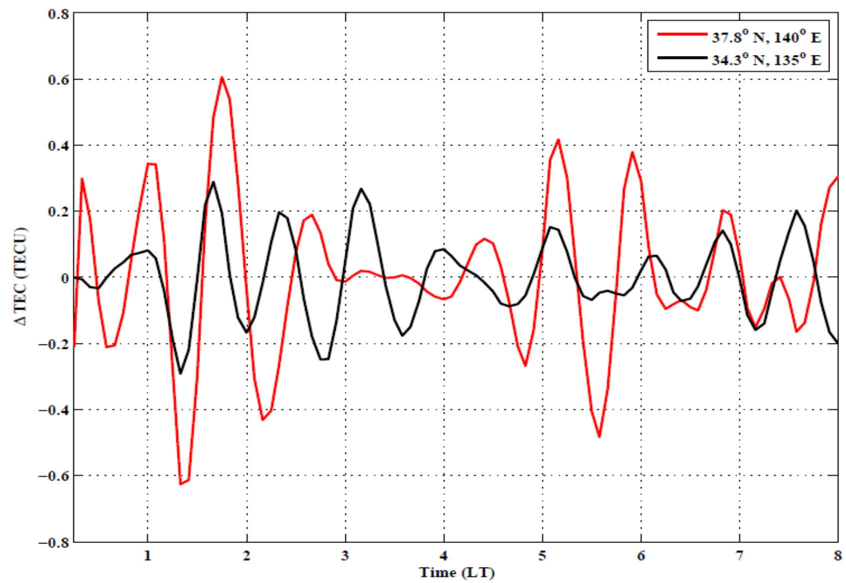


Spatial period ≈ 333.6 Km

Choose two points along the plane

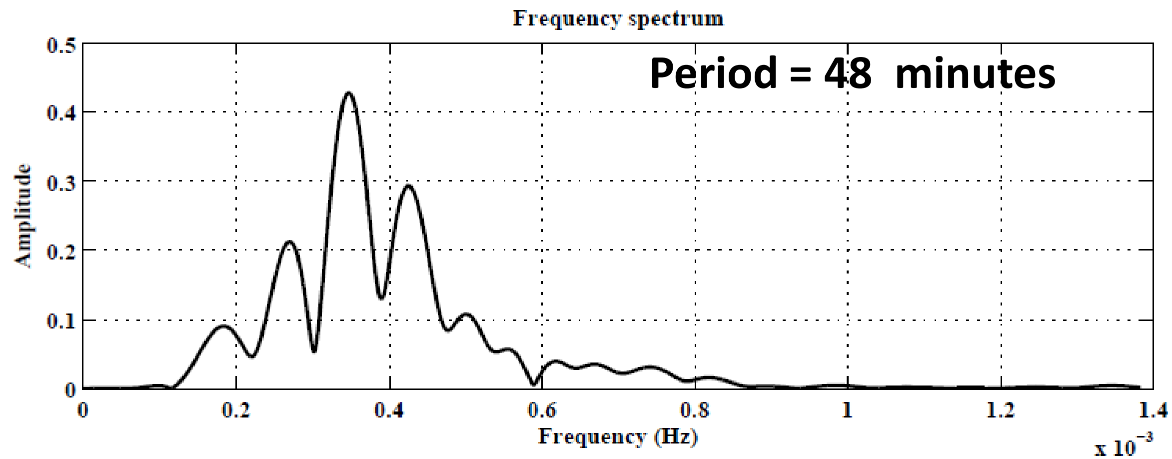


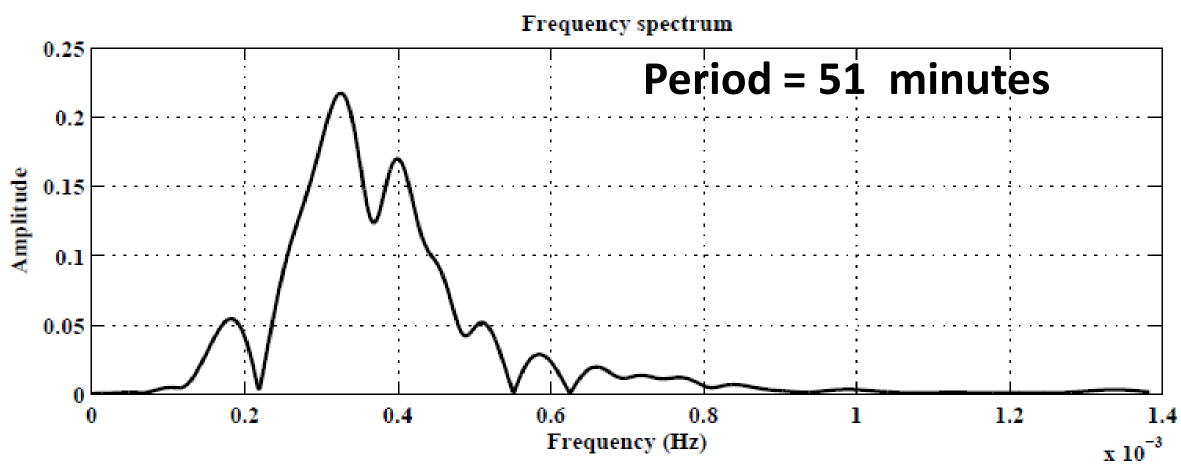
Time series variation at each point



- ❑ Distance between the two points = 594.4 km
- ❑ Use cross correlation to determine time lag = 3436.6s
- ❑ Velocity of TID = [Distance/ time lag] = 173 m/s

Take FFT of the two signals and determine average period





Average period ≈ 49.6 minutes

- **Medium-Scale TIDs (MS TIDs)**
  - velocities from 50 to 300 m/s **(≈ 173 m/s)**
  - Period: 20 - 60 min **(≈ 49 min)**
  - Horizontal wavelength: < 1000 km **(≈ 333.6 Km)**

- Summary:

❑ This investigative procedure has provided promising results,

➢ that a dense network of GPS receivers could be used to infer further information about the vertical structure of TIDs.

THANKS