Temporal and spatial anomalies of seismo-ionospheric GPS TEC

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Forecast Summary Questions

1. Describe a typical forecast:
   a. What area do they cover? Regional toward global area.
   b. What is the magnitude range? $M \geq 5.5$.
   c. How long is the time period? 1-6 day.
   d. Do you include a probability of an event during the forecast? Yes, in Taiwan and not yet for the globe.
   e. Do you include a confidence level in the forecast? Not yet but working on it.

2. Describe the process for making a forecast:
   a. Is it automatic or manual? Automatic for temporal and semi-automatic for spatial SIPs.
   b. What data are used? GPS TEC (local GPS and public GIM) + electrode, magnetometer,
      surface deformation, wall water level, infrasonic, atomistic E-filed, HF Doppler frequency
      shift, ionosonde, satellite sounding, etc.

3. Do you have a preference for which earthquake data should be used to test your forecasts?
   Regional + USGS earthquake catalogs.

4. Do you have a preferred testing method? Statistical analyses and ionospheric model.

5. What physical hypotheses about earthquake predictability have motivated your research?
   Lithosphere-Atmosphere-Ionosphere Coupling.
Content

• Introduction
  - iSTEP (integrate Search for Taiwan Earthquake Precursors)

• Seismo-ionospheric Precursors
  - Statistical results of $M \geq 5.0$ earthquakes in Taiwan
  - World Devastating Earthquake
  - the 16 October 1999 Mw7.1 Hector Mine earthquake

• Conclusion

• FORMOSAT-7 (lithosphere weather)

• SIP monitoring routine
Seismo-ionospheric anomalies in the GIM TEC at LA in April 2013.
M\geq 4.0 earthquakes in Taiwan 1900-2001.
1994-1999 M$\geq$5.0 184 EQKs

Liu et al. [JGR, 2006]
**Precursor Shape**

1994-1999: 2191 days

M\(\geq\) 5.0 EQK: 184 (170 days)

Ref: 15-day running MED & IQR

Below Lower Bound: 1200-1800 LT

Liu et al. [JGR, 2006]
170 EQKdays, 307 Pdays, 109 storm_days, Es -- > Ps: 74.1%; Ps -- > Es: 50.2%

Liu et al. [JGR, 2006]
Precursor Lead Time

416 Anomalies
307 Precursors
Lead Time: 0-5 days

Liu et al. [JGR, 2006]
Relation between the odds of $M \geq 5.0$ earthquakes with the foF2 PEIA in 5 days and the related magnitude and distance. $D \leq 40$ km, 93 EQK days.

Liu et al. [JGR, 2006]

\[ \log_{10} E \sim 1.4M + \text{constant} \]

(a) \[ \ln \left( \frac{p}{1-p} \right) = 1.50M - 6.96 \]

(b) \[ \ln \left( \frac{p}{1-p} \right) = \frac{29281.84}{d^2} \]
Statistical results

• The inter event time of $M \geq 5.0$ earthquakes in Taiwan is about 14 days. This implies the chance of observing an $M \geq 5.0$ earthquakes within next 1-5 days is about 35.7%.

• The chance of the 5.0 earthquakes being led by the SIPs within next 1-5 days is 74.1%.

• The chance of the SIPs being followed by the earthquakes within next 1-5 days is 50.2%.

Chen et al. [TAO, 2004]
iSTEP-1 (2003/4-2007/3)

Sub-project I
Seismological Variations

Sub-project II
Variations of the Geomagnetic and Gravity Fields

Sub-project III
Radar Interferometry for Detection of Surface Deformation

Sub-project IV
Ionospheric Variations

Sub-project V
Statistical Study

Overall

Integrated Search for Taiwan Earthquake Precursors
iSTEP-2 (2008/8-2012/7)

Sub-project I
Seismological Variations

Sub-project II
Measurement and Characterization of Crustal Deformation

Sub-project III
Lithosphere-Atmosphere-Ionosphere Coupling

Sub-project IV
Statistics for Earthquake Hazard

Overall

Integrated Study for Taiwan Earthquake Precursors

Program for Promoting University Academic Excellence - Research on Seismo-Electromagnetic Precursors of Earthquake
iSTEP-2 (2008/8-2012/7)

- Seismo-ionospheric Temporal and Spatial Precursors
- LAI Anomaly Monitoring (seismo-magnetic field, GPS surface deformation)
- Seismo-ionospheric Modeling
iSTEP-3 (2012/8-2016/7)

Earthquake Hazard Assessment

LAI monitoring

- Sub-project I: Seismological Variations
- Sub-project II: Measurement and Characterization of Crustal Deformation
- Sub-project III: Lithosphere-Atmosphere-Ionosphere Coupling
- Sub-project IV: Statistics for Earthquake Hazard

Overall

Integrated Study for Taiwan Earthquake Precursors

Program for Promoting University Academic Excellence - Research on Seismo-Electromagnetic Precursors of Earthquake
**iSTEP-3 (20012/8-2016/7)**

- SAS (seismo-ionospheric, atmospheric, and lithospheric anomalous signals) observations
- LAIC model development
- Temporal/spatial SIP (seismo-ionospheric precursor) monitoring system
- Earthquake hazard statistics
iSTEP-3 (2012/8-2016/7)

- International Cooperation (Russia, Japan, USA, China, France, etc.)
- Ground-based LAI observation networks (Electrode, Infrasounder, Atmospheric E-field, FM tuner, Doppler Sounder, ionosonde, magnetometer, GPS receiver), etc. 11 stations, 52 instruments
- Satellite: FORMOSAT-3, -5, -7
- Model Simulation
- Tsunami Early Warning
Seismo-ionospheric Precursors
Ionospheric total electron content (TEC) derived from GPS

Receiver: YMSM (North Taiwan)

TEC (total electron content) unit: TECu (10^{16} \text{ ele/m}^2)

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)
SIP observed by GPS TEC
LLT maps

Liu et al. [GRL, 2001]
September 1999

TECu

Day

P

100

50

0

1 2 3 4 5 6 7 8 9 10

11 12 13 14 15 16 17 18 19 20

21 22 23 24 25 26 27 28 29 30

Program for Promoting University Academic Excellence - Research on Seismo-Electromagnetic Precursors of Earthquake
Difference between Observations and the Median of NmF2 and GPSTEC for $M_L \geq 5.0$ Earthquakes
Difference between Observations and the Median of NmF2 and GPSTEC for $M_L \geq 6.0$ Earthquakes
$M \geq 5.0$
$M \geq 5.5$
$M \geq 6.5$
World Devastating Earthquake

• 1999 M7.6 Chi-Chi earthquake (Ne+TEC) 
  Liu et al. (GRL 2000, GRL 2001)
• 2004 M9.3 Sumatra Earthquake (Stochastic test) 
  Liu et al. (JGR 2010)
• 2008 M8.0 Wenchuan Earthquake 
  (FORMOSAT-3 observation) 
  Liu et al. (JGR 2009)
• 2010 M7.0 Haiti Earthquake (Model simulation) 
  Liu et al. (JGR 2011)
• 2011 M9.0 Tohoku Earthquake (????)
Global Ionosphere Map of the GPS TEC
16 October 1999 M7.1 Hector Mine earthquake
The Hector Mine area and two reference areas.
Figure 3.

Northward TEC Gradient

Hector Mine (35°N, -116°E)

Europe (45°N, 10°E)

Japan (37°N, 140°E)

October 1999
(a) GIM TEC over Hector Mine Earthquake

(b) Northward TEC Gradient

October 1999

1999/10/11

(c) Map showing the location of the Hector Mine Earthquake with time stamps 07:00 - 23:00 UT and 01:00 - 09:00 UT.
Decrease anomaly
Conclusion

• To discriminate anomalies caused by global effects, such as solar radiations, magnetic storms, etc., and local effects, such as earthquake, both temporal and spatial anomaly analyses are required.

• A global search by using the TEC of GIM (global ionosphere map) shows that the TEC increase and decrease anomalies continuously and specifically appear around the epicenter day 5 before 1999 Mw7.1 Hector Mine the earthquake.

• A region index, spatial gradient seems to be helpful/useful to discriminate global and local effects.

• Temporal anomalies – Forecast, spatial anomalies – Prediction.

• CSEP-Taiwan???
FORMOSAT-3/COSMIC

- **FORMOSAT-3/COSMIC Constellation** was launched at 01:40 UTC, April 14, 2006 (Taiwan Time: April 15, 2006) at Vandenberg Air Force Base, CA. Minotaur Launch

- Maneuvered into six different orbital planes (inclination ~72°) for optimal global coverage (at ~800 km altitude).

- 5 out of 6 satellites are in good health and providing science data.
FORMOSAT-3/COSMIC

Profiling the Troposphere, Stratosphere and Ionosphere by Radio Occultation
GOX

Electron Density Profile

2006.7.14 1018 UT density profile

Plasma Frequency (MHz)

Altitude (km)
What is future impact of F7/C2 on ionospheric research?

With 6 satellites + GPS, 60 minutes
About 80-100 profiles per hour

With 12 satellites + GPS, 60 minutes
About 400 profiles per hour
• Solar activity variations
• Seasonal variations
• Monthly variations
• Tidal effects
• Diurnal variations
• Semi-diurnal variations
• Disturbed period effects
• Other temporal variations
• Irregularities

Could it be advanced by F7/C2?
Simulated F7/C2 observations at 08:00 UT within 1 hour x 1 day accumulation period

12 satellites,
28 GPS and
24 GLONAAA
敬請批評指教 Thank you!!!