[EN-033] Diurnal and Seasonal Variation of Total Electron Content (TEC) at Chumphon and Bangkok, Thailand

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Abstract: This study presents the diurnal and seasonal variations of total electron content (TEC) for different seasons at the equatorial magnetic latitude at Chumphon, Thailand during 2009. The GPS-derived total electron content (GPS-TEC) is measured at Chumphon and Bangkok station, located near the magnetic equator. The slant TEC is converted into the delay in terms of distance relevant to aeronautical applications.

Keywords: total electron content, slant TEC, GBAS, SBAS, delay time

1. INTRODUCTION

Total electron content (TEC) is an important ionospheric parameter which directly affects the radio waves propagating through the ionosphere. The availability of TEC measurement data are required for the development of ionospheric models such as the International Reference Ionosphere (IRI) [1-2]. The increase in availability of TEC data over the last 10 years has largely come from a rapid increase in the number of Global Position System TEC data (GPS TEC) over land. It is well-known that at the low latitude regions, a characteristic of the ionosphere is symmetric peaks in electron density known as equatorial ionospheric anomaly (EIA). At the EIA regions, TEC is enhanced and peaks around $\pm 15^{\circ}$ from the magnetic equator. For the equatorial region, differential TEC contributes to the plasma bubble study [5].

Augmentations are necessary for the use of satellite-based navigation in aeronautical applications to provide very precise position determination. Two common types of augmentations: ground-based augmentation system (GBAS) and satellite-based augmentation system (SBAS) have been proposed and tested over the years.

One of the important sources of positional error is due to the ionospheric effects on the navigational signals. The ionospheric conditions vary depending on locations, time of year, solar activity and others, hence, they need to be well studied. The International Civil Aviation Organization (ICAO) has recently realized the importance of ionospheric effects on the global navigation satellite system (GNSS) [3].

In this work, we study the variation of TEC data at Chumphon and Bangkok, Thailand of some days in 2009. The monitoring of both stations is in proximity of the airport, in particular, the Bangkok station is only 5 kilometers from the Suvarnabhumi international airport. Both stations are a part of the South East Asia Low Latitude Ionosphere Observation Network (SEALION) [5] which is a joint project among the following institutions and countries: National Institute of Information and Communications Technology (NICT), Japan, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand, Chiang Mai University (CMU), Thailand, National Institute of Aeronautics and Space (LAPAN), Indonesia, Hanoi Institute of Geophysics (HIG), Vietnamese Academy of Science and Technology, Vietnam, Center for Space Science and Applied Research (CSSAR), Chinese Academy of Sciences, China, and Kyoto University, Japan, observes, monitors and forecasts the ionospheric variation in the Asia Pacific region near the magnetic equator.

2. THEORETICAL BACKGROUND

When the radio signal transmitted by the GPS satellites passes through the ionosphere, ionospheric effects cause a propagation delay that results in an error in the TEC measurement. Using the approximation for refractive index, the amount of group delay (Δt) imposed on a radio signal of frequency [5] is given by

$$\Delta t = \frac{e^2}{8\pi^2 m \varepsilon_0 c f^2} \int_s n ds \quad \text{(sec)}, \tag{1}$$

where e is the elementary charge (1.6022x10^{-19} C), m is the static electron mass (1.6605x10^{-31} kg), ε_0 is the permittivity of free space (8.8542x10^{-12} F/m) , c is the light speed in vacuum (2.9979x10^{8} m/s), f is the received GPS frequency and n is the electron density.

The relationship in (1) can be rewritten as

$$\Delta t = \frac{A}{cf^2} N_T \tag{2}$$

where $A = \dfrac{e^2}{8\pi^2 m \varepsilon_0}$ and $N_T = STEC = \int_s n ds.$

The parameter N_T is the electron density integrated over the propagation path length and is known as the slant total electron content (STEC). Thus, (2) becomes

$$\Delta t = \frac{40.3083}{cf^2} STEC \tag{3}$$

At each interval, more than one GPS satellites are typically visible. Group delay values can only be measured using beacon signals with two or more frequencies, modulated by some form of signal that serves as a time marker. We use difference in the group delay between two carriers of the L$_1$ signal (f_1= 1575.42 MHz) and L$_2$ signal (f_2 = 1227.60 MHz) to the group delay from

$$\Delta t = \frac{40.3083}{c} \left(\frac{1}{f_2^2} - \frac{1}{f_1^2} \right) \cdot TEC. \tag{4}$$

Therefore, the total electron content can be computed from

$$STEC = \frac{c}{40.3083} \left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2} \right) \Delta t \quad \text{(el/m}^2\text{)} \tag{5}$$

After removing the satellite and receiver biases from STEC, we obtain the absolute TEC (ATEC) as

$$ATEC = STEC - b_s - b_r \ , \tag{6}$$

where b_s and b_r are satellite and receiver biases, respectively.

The slant TEC (STEC) from a satellite to a receiver can be obtained from the difference between the pseudo ranges and the difference between the phases of the two signals (Blewitt, 1993). The slant TEC from phases is typically less noisy than that from pseudoranges, cycle slips need to be detected.

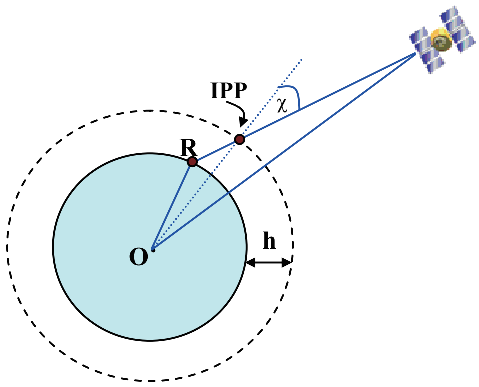


Figure 1 Geometry of GPS satellite

From (5), the elevation angle of the GPS satellite is not always zero to the GPS receivers, to compute the vertical TEC (VTEC) at the IPP point, we need to consider the zenith angle χ which can be computed from [6]

$$\chi = \arcsin \left(\frac{R_e \cos \alpha}{R_e + h} \right) \quad \text{(degrees)}, \tag{7}$$

where α is the elevation angle of the satellite, R_e is the mean radius of the Earth, and h is the height of the ionospheric layer. This height is typically assumed to be 400 km. For accurate values, …..

Finally, the VTEC values can be found from

$$VTEC = \frac{c}{40.3083} \left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2} \right) \Delta t \cdot \cos(\chi) \quad \text{(el/m}^2\text{)} \tag{8}$$

The measured distance (in meters) can be expressed as

$$d = d_0 + \delta_{ion} + \delta_{tropos} + c * \delta_t + w \quad , \tag{9}$$

where d_0 is an actual distance, $\delta_{ion}, \delta_{tropos}, \delta_t$ represent the errors due to ionosphere, troposphere and hardware clock, respectively, and w is the noise. The ionospheric delay δ_{ion} is related through the absolute TEC as

$$\delta_{ion} = \frac{40.3}{f^2} ATEC \quad \text{(m)} \tag{10}$$

For the L1 frequency at 1.57542 GHz, 1 TECU is about 16 cm delay.

3. THE EXPERIMENT SETUP

The TEC data were measured from the JAVAD GPS receiver in Chumphon (10.72 °N, 99.37 °E) and TOPCON GPS receiver in Bangkok (13.73 °N, 100.78 °E), Thailand. The TEC data are derived from the GPS signals. The GPS is a system in which signals transmitted by satellite are picked up by a ground based receiver, and these signals are used to determine the geographical position of the receiver. The GPS satellites broadcast the carriers at two frequencies: f_1= 1575.42 MHz and f_2 = 1227.60 MHz. The pseudo-ranges (P_1, P_2) and phases (L_1, L_2) can be computed at the receive side based on RINEX data.

The GPS receivers at both stations have received the signals from GPS satellites since 2003. The GPS receiver set consists of a microstrip antenna, an amplifier, a TEC Meter, and a personal computer. The microstrip antenna type is right-hand circularly polarized and receives two GPS signals. The amplified signal from the amplifier is then sent to the TEC Meter with built- in GPS receiver unit. TEC Meter works when it continuously receives 4 GPS signals or up to 12 GPS signals which are converted to the TEC values. The specification details of the GPS receiver are provided in Table 1.

4. RESULTS AND DISCUSSIONS

4.1 Vertical TEC at Chumphon and Bangkok station

Figure 2 shows the diurnal variation of GPS TEC (in TEC units of 10^{16}/ m^2 = TECU) at Chumphon station in 2009. The plotted TEC data are on 20 March 2009 (March equinox), 21 June 2009 (Summer solstice), 8 October 2009 (Autumnal equinox) and 21 December 2009 (Winter solstice), each representing the respective season. The local time (LT) is equal to UTC+7. It can be observed that the VTEC during Equinox is generally higher than the rest of the year. The VTEC increases in the morning (local time) and the peak occur at around

Table 1 JAVAD-GPS received measurement specification

Specification	GPS measurement
Frequencies	f_1 = 1575.42 MHz f_2 = 1227.60 MHz
Polarization	Right hand circular
Antenna	Microstrip antenna
LNA gain	26 dB

the around noontime. After sunset, the VTEC slowly decreases with the minima at around early morning. The missing curves at around 3-6 am indicate the outage of GPS signals or negative VTEC values due to the bias estimation. In Fig. 3, a VTEC plot is for Bangkok during the four seasons. We see similar trends to Chumphon data.

In [6], the diurnal and seasonal variation of TEC at Chumphon was studied during the period of 2004-2006. It was found that the IRI-2007 model generally underestimates the GPS-TEC. The largest deviation is upto 15 TECU. In 2006, the large difference is seen during sunset hours, but in 2004 and 2005, it is seen during midnight and morning hours instead.

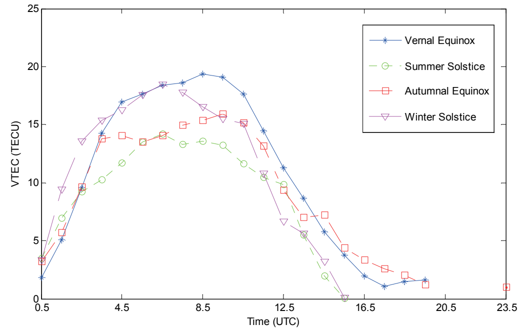


Figure 2 Diurnal variation of GPS-TEC at Chumphon station

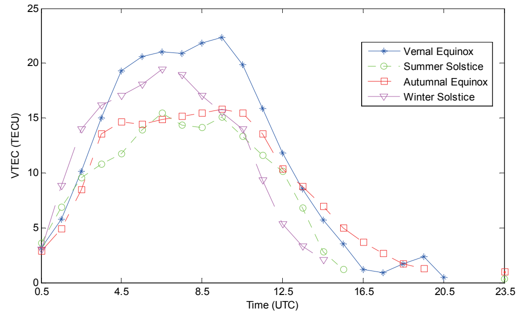
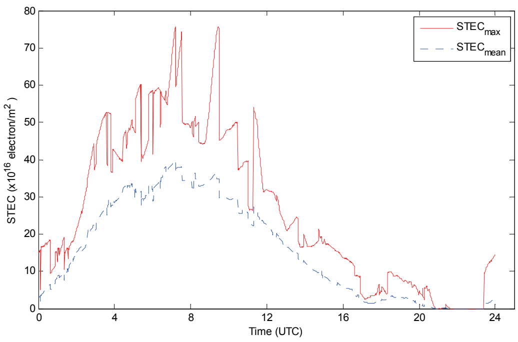


Figure 3 Diurnal variation of GPS-TEC at Bangkok station

4.2 Slant TEC at Bangkok and Chumphon station

Since slant TEC is used for computation of delay time, here we focus on the slant TEC (STEC) of Bangkok station and Chumphon station. In Fig. 4, the mean and maximum STEC values of Bangkok station are plotted. The maximum STEC is the maximum STEC values among received GPS signals at each time. The mean STEC ranges never exceed 40 TECU and the highest values occur during Vernal Equinox. The maximum STEC can go above 70 TECU except during Summer Solstice. The STEC data of Chumphon is shown in Fig. 5. It evident that the STEC during the equinoxes are higher than that during the solstices.



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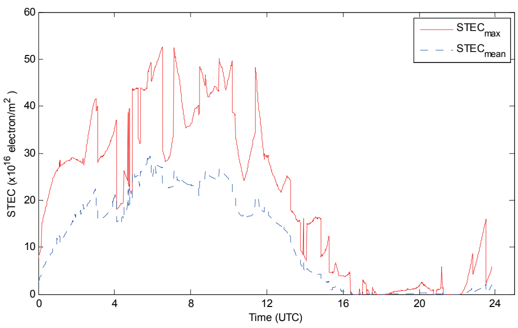

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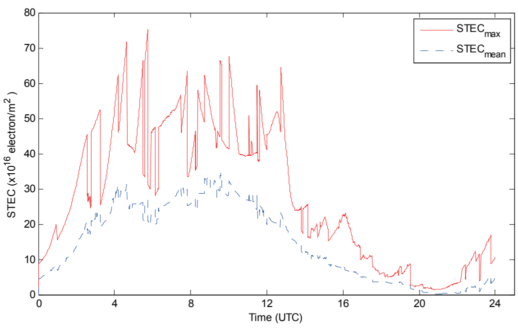

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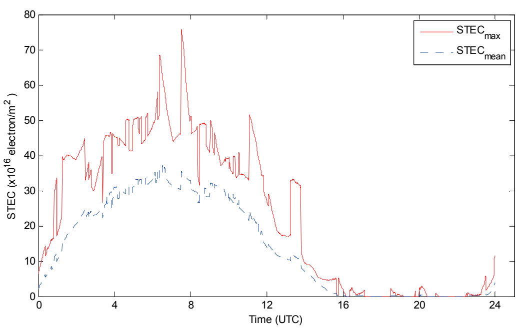
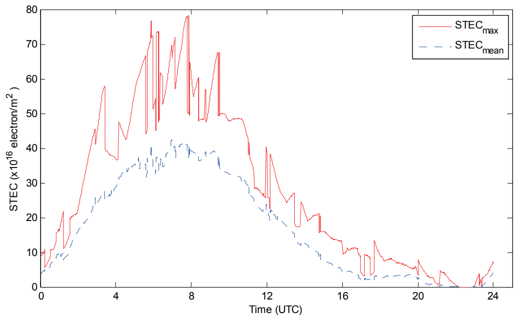


(d)

Figure 4 Slant TEC of Bangkok station in 2009 (a) Vernal equinox (b) Summer Solstice (c) Autumnal equinox (d) Winter solstice



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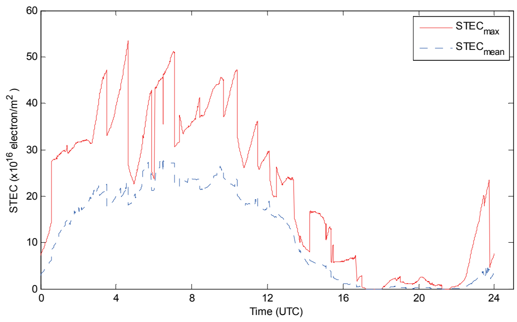

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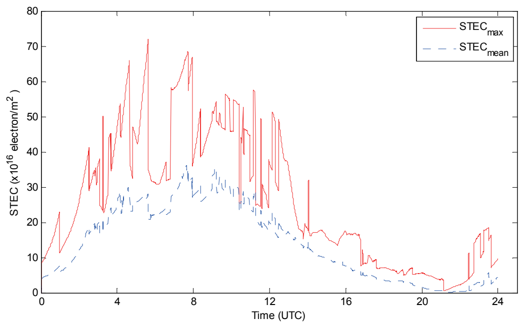

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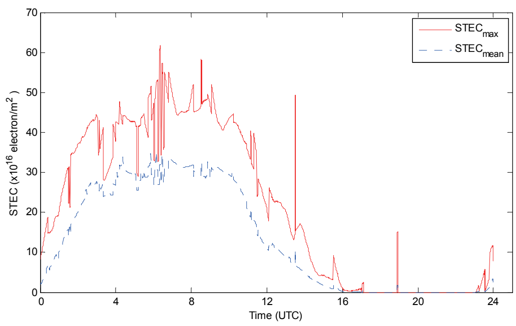

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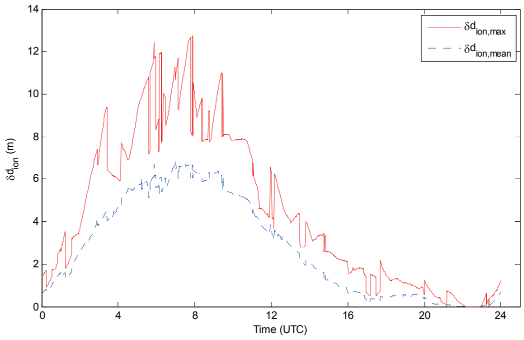
Figure 5 Slant TEC of Chumphon station in 2009 (a) Vernal equinox (b) Summer Solstice (c) Autumnal equinox (d) Winter solstice



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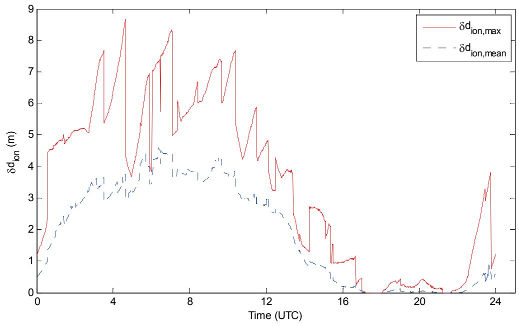

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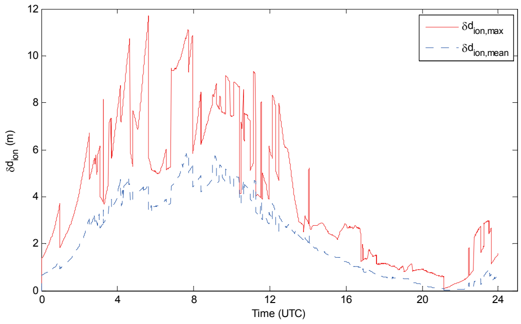

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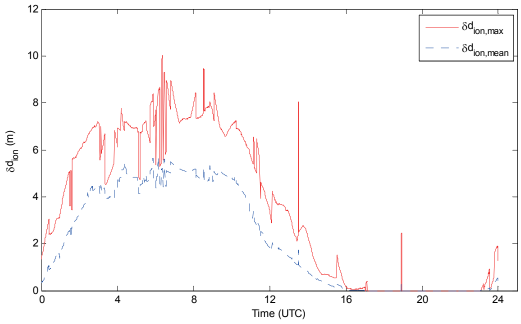
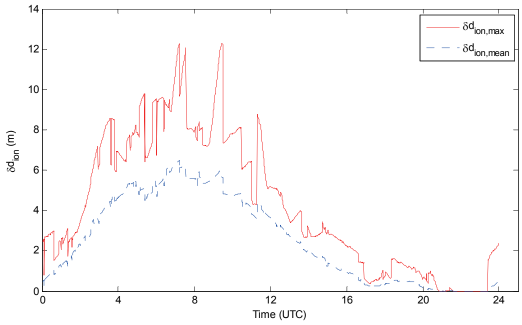


(d)

Figure 6 Ionospheric delay time of Bangkok station in 2009 (a) Vernal equinox (b) Summer Solstice (c) Autumnal equinox (d) Winter solstice



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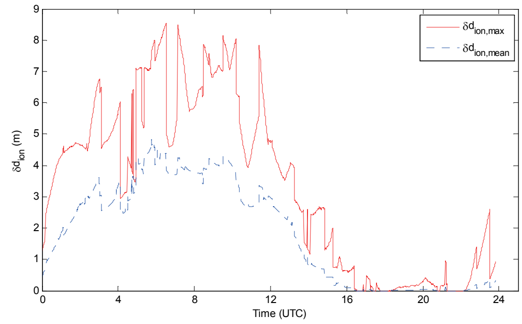

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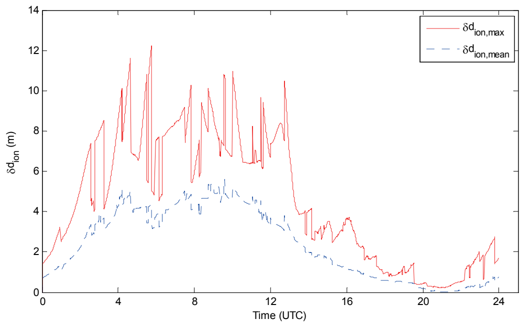

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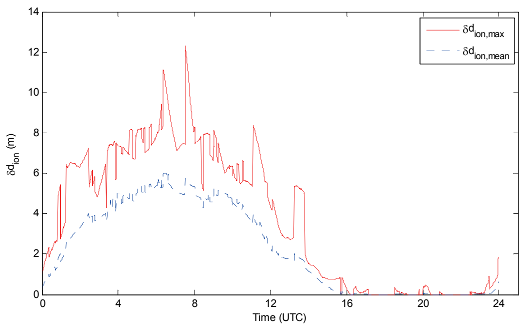

(d)

Figure 7 Ionospheric delay time of Bangkok station in 2009 (a) Vernal equinox (b) Summer Solstice (c) Autumnal equinox (d) Winter solstice

4.3 Delay at Chumphon and Bangkok station

Based on the relationship between the STEC and delay time, we plot the computed mean and maximum delay times in Fig. 6 and 7. We plot the maximum and mean of $\delta_{d,ion}$ at Bangkok station. The maximum value is among all from all the received GPS signals at one time. The mean is the average value. In this plot, the received signal with Flag 6 is not used. The maximum ionospheric delay time is the maximum ones among the received GPS signals at each time. The mean delay time at Bangkok station can be higher than 10 meters during the equinoxes. For Chumphon, all seasons except summer solstice can exhibit this high level of delay time.

In the future, we plan to perform the TEC monitoring at several stations near an airport and analyze the characteristics of the spatial TEC distribution. At present, there exist some GPS-TEC monitoring stations near the Thai international airport. We have recently cooperated with Aeronautical Thailand (AeroThai) and other agencies to acquire such TEC data.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] D.Bilitza, "International Reference Ionosphere 2000," Radio Sci. 36 (#2),261–275, 2001.

[2] D. Bilitza and B.W. Reinisch, "International Reference Ionosphere 2007: Improvements and new parameters," Adv. Space Res. 42, 599–609, 2008.

[3] Resolution for ionosphere issues in implementing GNSS, Working paper, CNS/MET SG/14 – WP/43, 19 July 2010.

[4] S. Saito, T.Yoshihara and N. Fujii, "Study of effects of the plasma bubble on GBAS by a three-dimensional ionospheric delay model," Proceedings of ION GNSS 2009.

[5] T. Maruyama, M. Kawamura, S. Saito, K. Nozaki, H. Kato, N. Hemmakorn, T. Boonchuk, T. Komolmis, C. Ha Duyen, "Low latitude ionosphere-thermosphere dynamics studies with ionosonde chain in Southeast Asia," Ann. Geophys., vol. 25, pp. 1569-1577, 2007.

[6] P. Kenpankho, P. Supnithi, T. Tsugawa and T. Maruyama, "Comparison of GPS TEC measurements with IRI TEC prediction at an equatorial latitude station, Chumphon, Thailand," Earth Planets Space, *submitted,* 2010.

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