EUROPEAN SPACE SOLUTIONS
BRINGING SPACE TO EARTH
30 MAY – 03 JUNE 2016, THE HAGUE

UNIVERSITI KEBANGSAAN MALAYSIA
The National University of Malaysia

European Space Solution, Bringing Space To Earth, 30 May- 03 June, The Hague, The Netherlands

Statistical approaches of ionospheric correction to improve the accuracy of the GPS positioning over Malaysia

M. Abdullah[1,2] , N.A. Elmunim[1], A.M. Hasbi[1,2] and S.A. Bahari[2]

[1]Department of Electrical, Electronic and System Engineering

[2]Space Science Center

Universiti Kebangsaan Malaysia (UKM)

- The National University of Malaysia

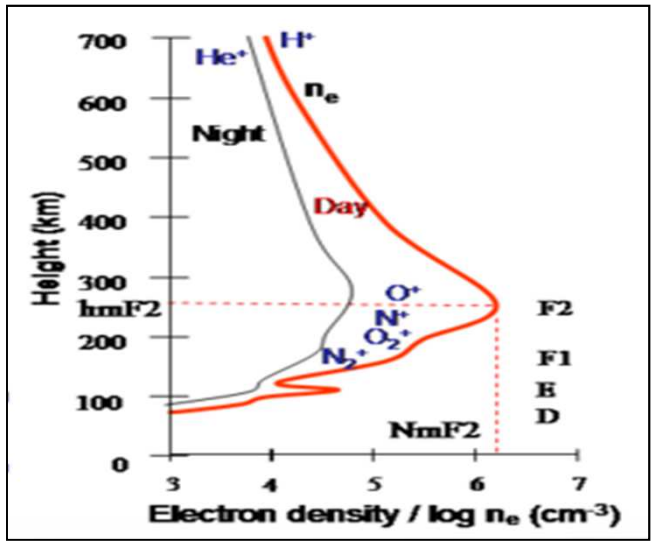
MALAYSIA

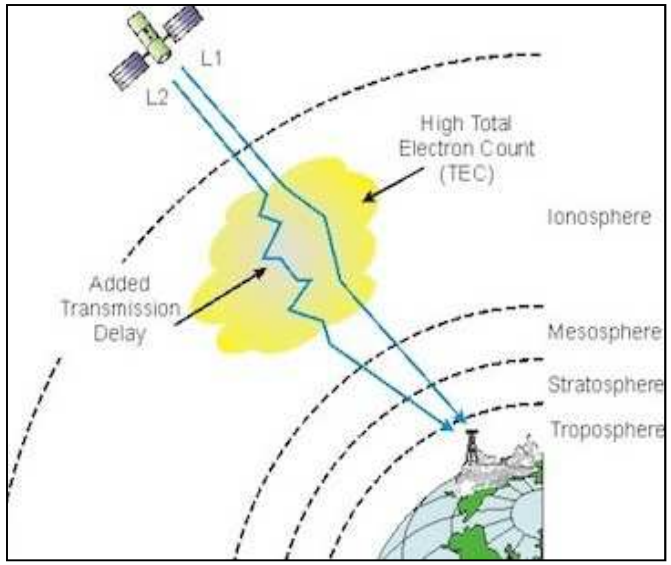
Outline

- Introduction
  - Ionosphere and TEC
  - Motivation
  - Objective
- Methodology
  - Data processing
- Results
  - Holt-winter model
  - IRI2012 with the topside options
- Conclusion

Introduction

- The ionosphere is a shell of electrons and electrically charged atoms and molecules that surround the Earth, stretching from a height of about 50 km to more than 1,000 km.
- The ionosphere varies to several factors such as diurnal variation, seasonal variation, solar cycle, geomagnetic effect, etc.→ geographical location
- The propagation of radio signals in the Earth's atmosphere is dominantly affected by the ionosphere due to its dispersive nature.
- Global positioning system (GPS) data provides relevant information that leads to the derivation of total electron content (TEC).
- The TEC is one of the most important parameters that describe the ionospheric state & structure.





Motivation

- Ionosphere is the main error source for the GPS signal
- Klobuchar model can only reduce 50% of the ionospheric error
- The study of the ionospheric delay forecasting is beneficial to improve and develop the ionospheric models.
- It is important to select the suitable prediction model that can correct the ionospheric delay errors to further improve the accuracy performance of GPS positioning

Objective

1. To analyse the short-term forecasting ionospheric delay using statistical Holt-Winter method

2. To Compare Holt-Winter method with IRI-2012

Methodology

- GPS Ionospheric Scintillation and TEC Monitor (GISTM), model GSV4004B by GPS Silicon Valley
- NovAtel Euro-3M dual-freq. receiver
- Measure amplitude and phase scintillation from the L1 frequency GPS signals
- TEC from the L1 and L2 frequency GPS signals.

TEC = [9.483 * (PRL2 – PRL1 - C/A-P,PRN) + TECRX + TECCAL] TECU

PRL2 is the L2 pseudo-range in meters , PRL1 is the L1 pseudo-range in meters , C/A-P,PRN is the input bias between SV C/A- and P-code code chip transitions in meters , TECRX is the TEC result due to internal receiver L1/L2 delay , TECCAL is the user defined TEC offset

1.	**NovAtel GSV 4004B GPS receiver**
2 .	**GPS Antenna**
3,4,5,6.	**Connection cable (30 m maximum)**
7.	**PC processing data,**
8.	**UPS**

- GISTM provide slant TEC that can be converted to Vertical TEC

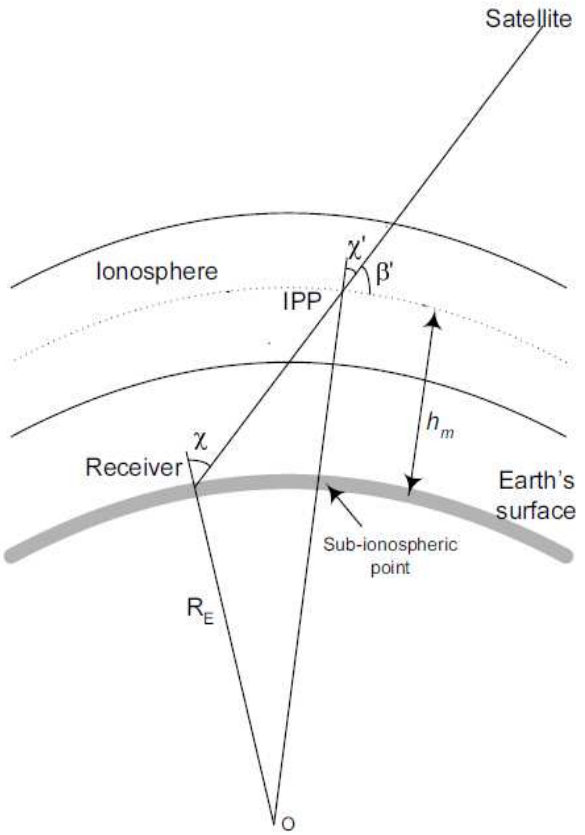
$$VTEC = STEC \cos \chi'$$

- Delay between the L1 and L2 signal

$$I_k^p = 40.3\text{VTEC}\left(\frac{1}{f_2^2} - \frac{1}{f_1^2}\right)$$

- Percentage deviation between the model and GPS-TEC

$$\%PD = \frac{VTEC_{\text{model}} - VTEC_{\text{GPS-TEC}}}{VTEC_{\text{GPS-TEC}}} \times 100$$



Ref: Abdullah M. 2004. Modelling and determination of ionospheric effects on relative GPS measurements, PhD thesis, Leeds University, UK and other references herein.

- **Holt-winter** is statistical method that can be used to forecast the ionospheric delay, producing short-term forecasting by employing level, trend and seasonal components at each period of the time-series.
- $F_{t+m} = (L_t + b_t m)S_{t-s+m}$

L_t, is the level; b_t, is the trend; S_t, is the seasonal; Y_t, is the VTEC, while t is the time period for the component of L_t,b_t, S_t and Y_t. F_t, is the forecasting value of a period ahead; F_{t+m}, is the forecasting time period. m, is the forecast period and s is the seasonal duration.

- Mean Absolute Percentage Error (MAPE) to measure the suitability and accuracy of a forecasting method

$$PE_t = \left(\frac{Y_t - F_t}{Y_t}\right) \times 100 \qquad \text{MAPE} = \frac{1}{n}\sum_{t=1}^{n} |PE_t|$$

PE is the percentage of error, Y_t, is the VTEC

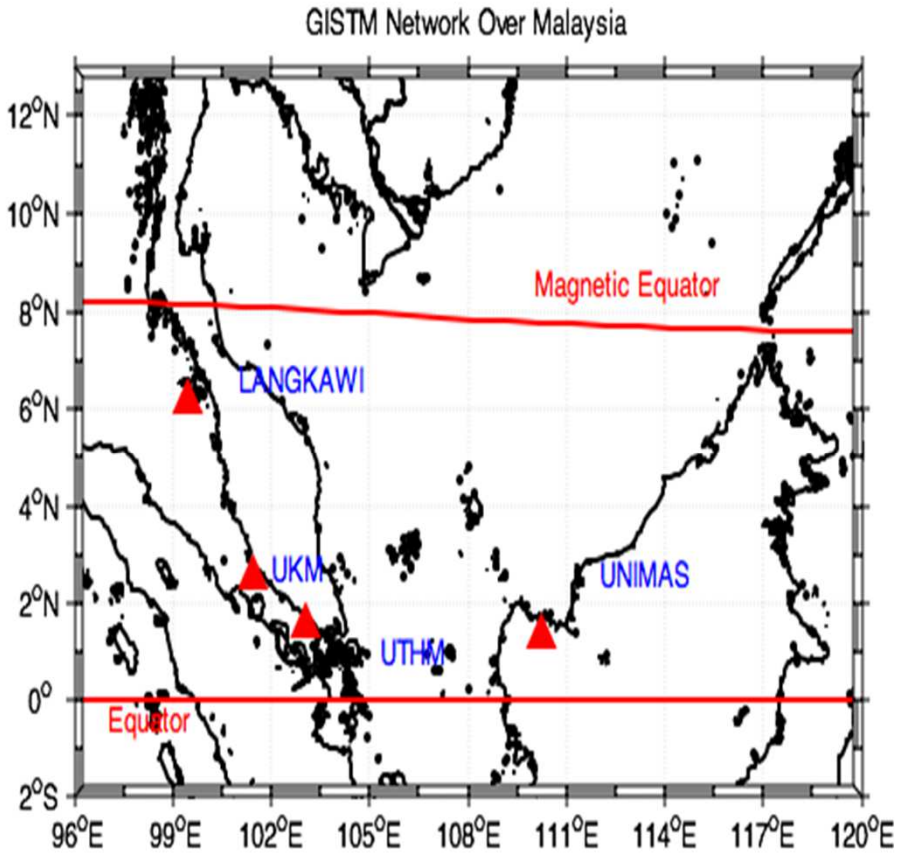
Ref:. *Suwantragul, S., Rakariyatham, P., Komolmis, T. and Sang-In, A., 2003. A modeling of ionospheric delay over Chiang Mai Province. Proc IEEE Int Symp Circuits Syst. 25(2), 340-343.*

Elmunim, N.A., Abdullah, M., Hasbi, A.M., Bahari, S.A., 2015. The comparison of statistical Holt-Winter models for forecasting the ionospheric delay using GPS observation. Indian Journal of Radio and Space Physics. 44, 28-34.

Elmunim, N.A., Abdullah, M., Hasbi, A.M., Bahari, S.A., 2016. Comparison of GPS TEC variations with Holt-Winter method and IRI-2012 over Langkawi, Malaysia. Submitted to Advance in Space Research

Data processing

- Use GISTM data located at:
  - Langkawi (6.19°N, 99.51°E)
  - UKM, Bangi (2.92° N, 101.78°)
- Period:
  - January to December 2011, 2014



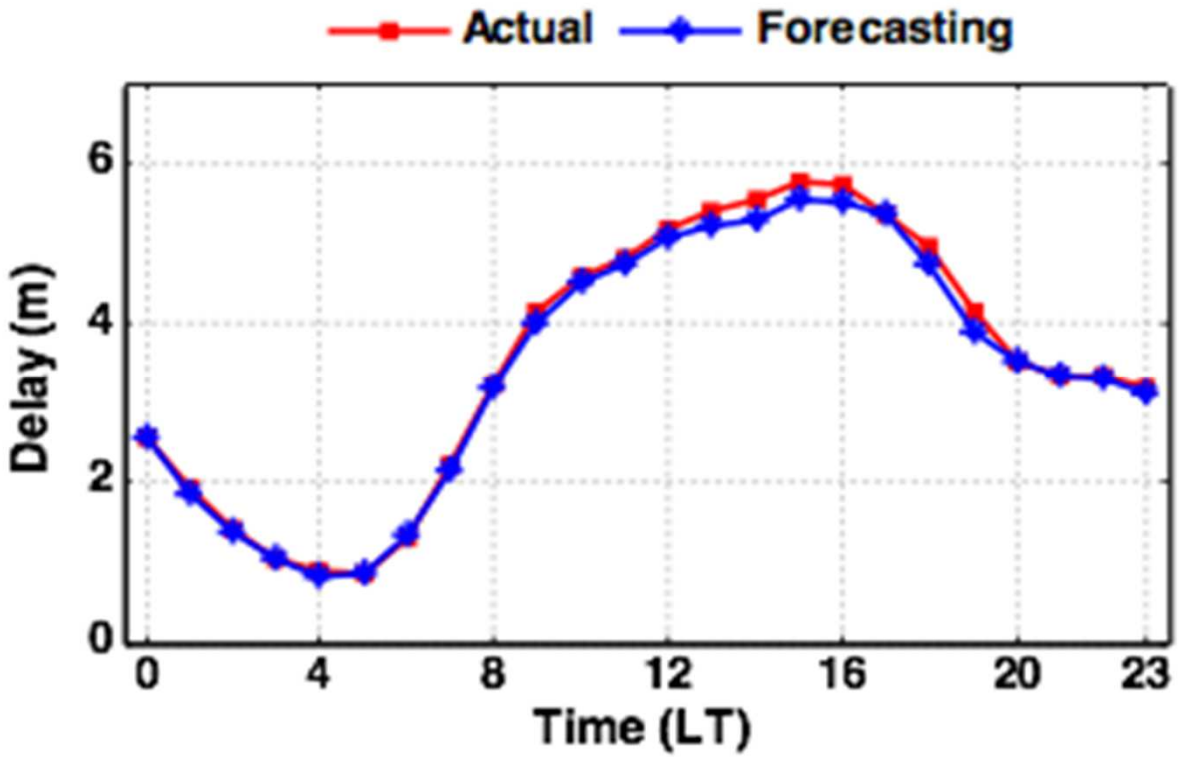
Results

Comparison of

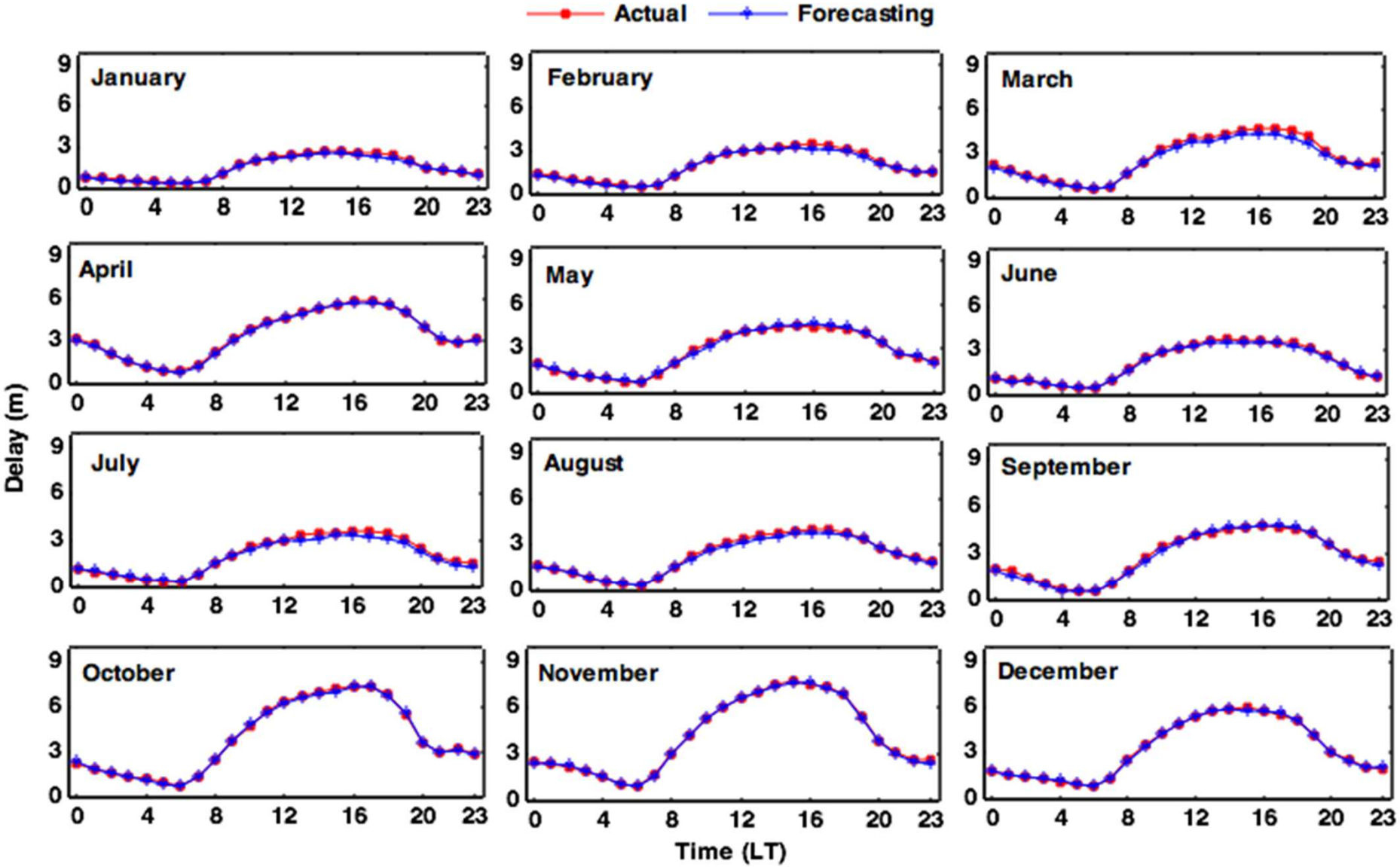
1. GPS TEC variations with Holt-Winter method and
2. With IRI-2012

- Diurnal
- Monthly
- Seasonal

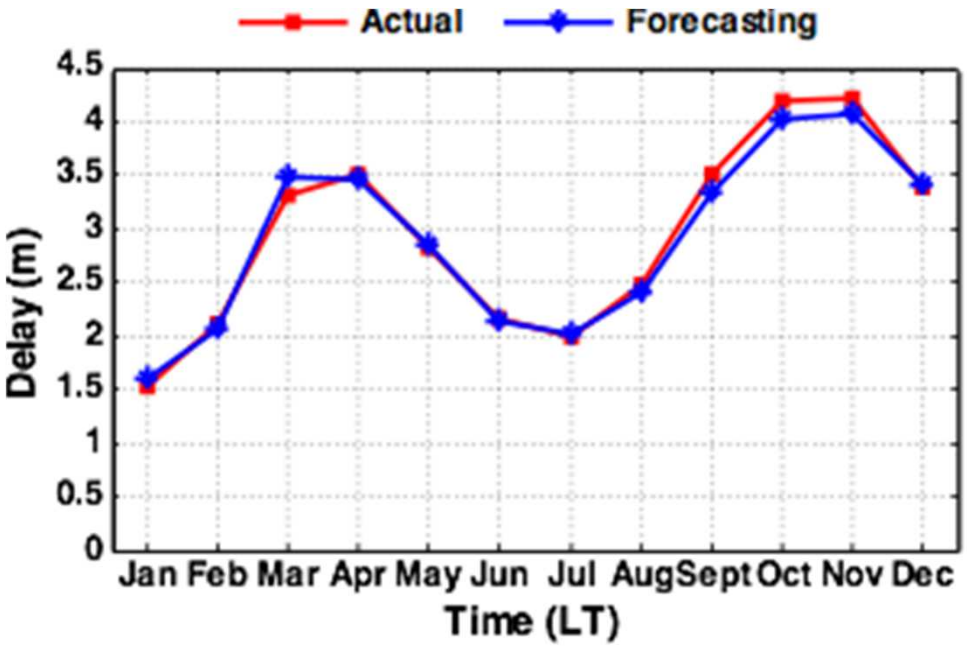
Diurnal variation of the actual and forecast ionospheric delay using the Holt-Winter method over UKM station during 7 April 2011



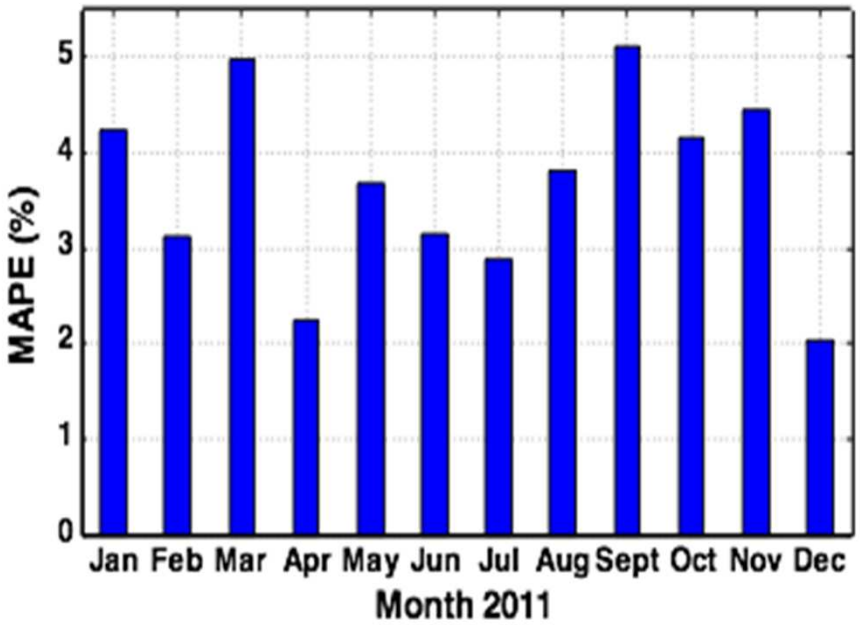
Monthly variation of the actual and forecast ionospheric delay using the Holt-Winter method during 2011 over UKM station



Month to month variation of the actual and forecast ionospheric delay using the Holt-Winter method

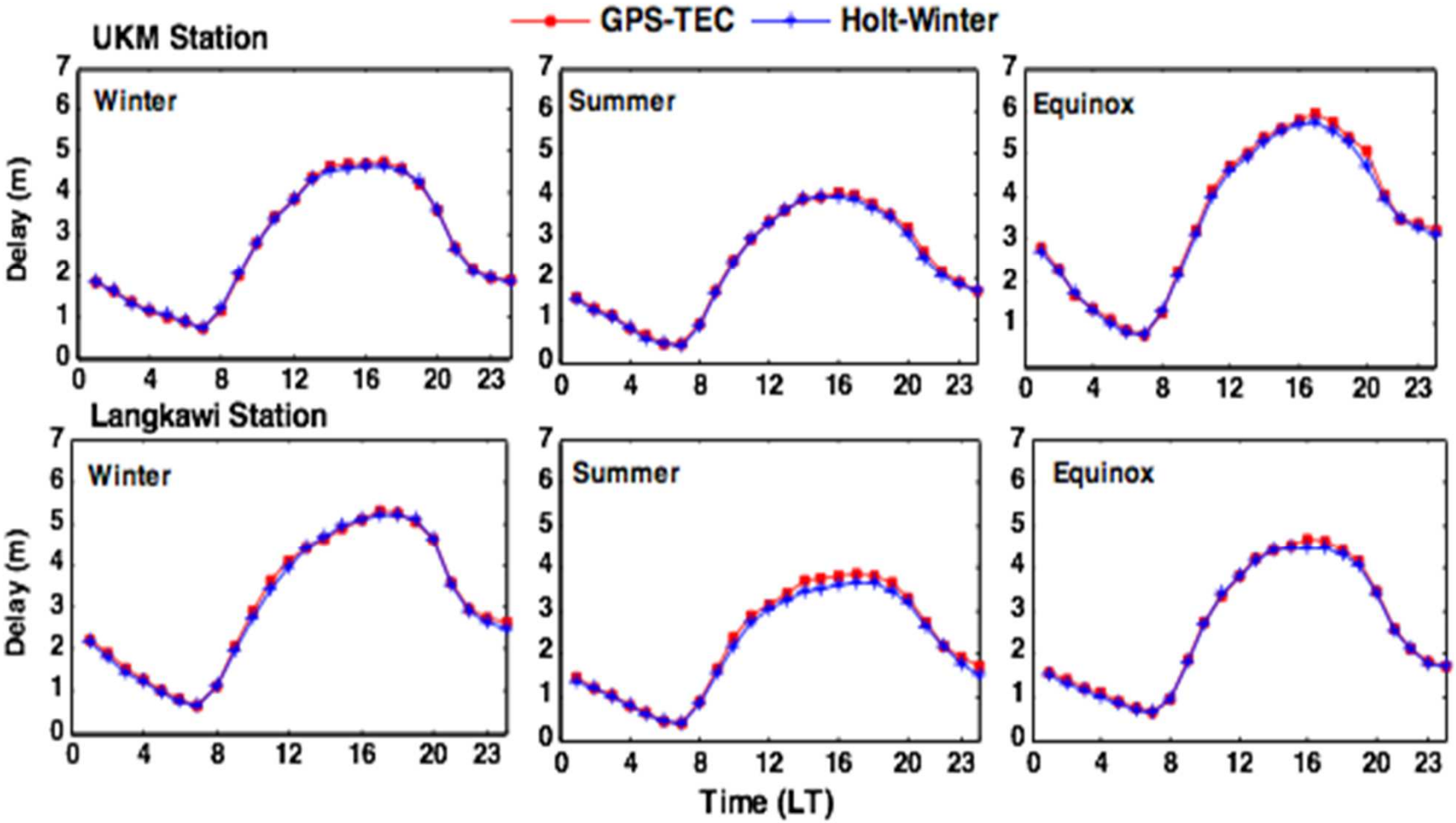


Variability of the error measurement MAPE

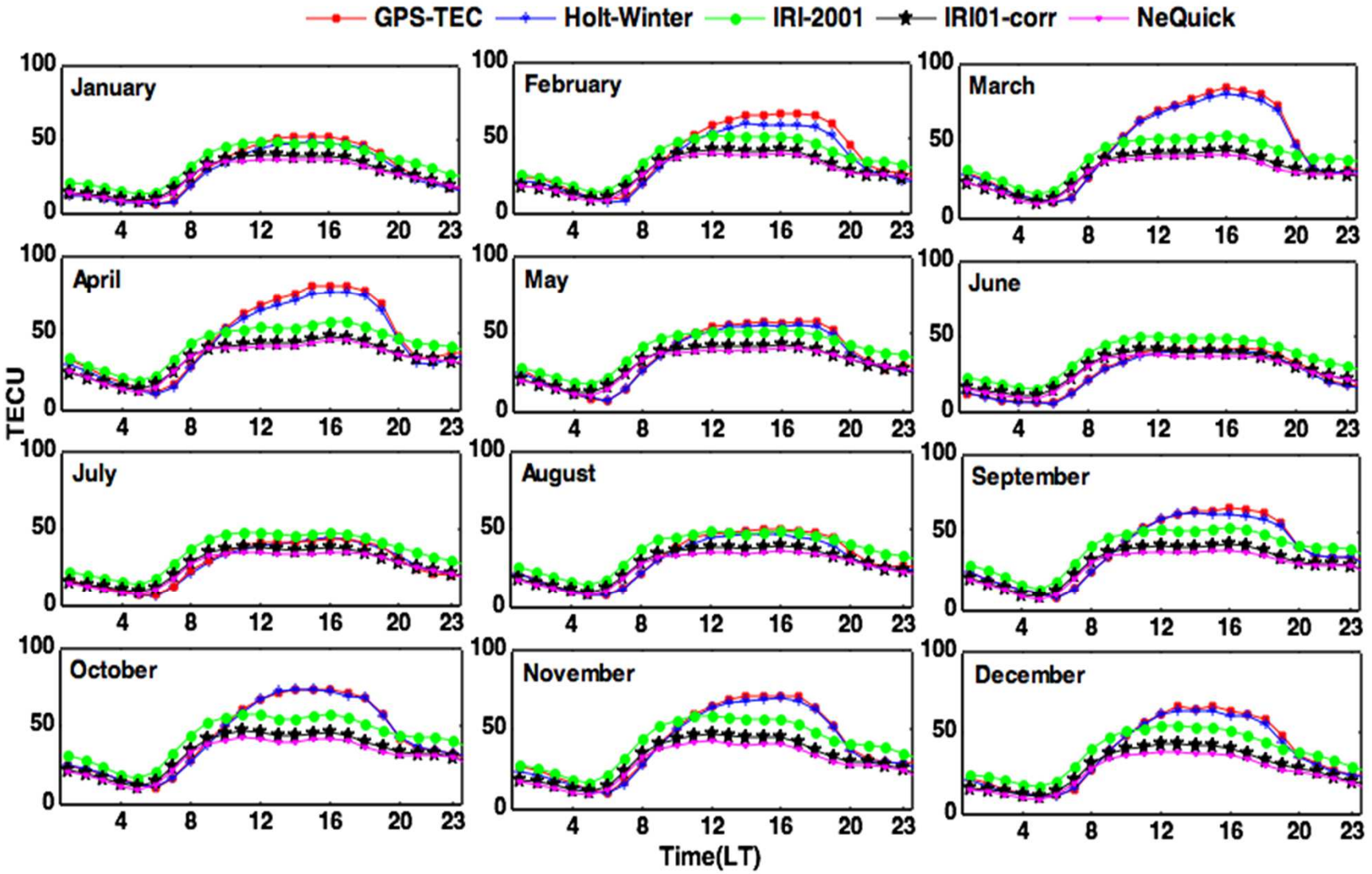


Seasonal variation over UKM and Langkawi station during 2011

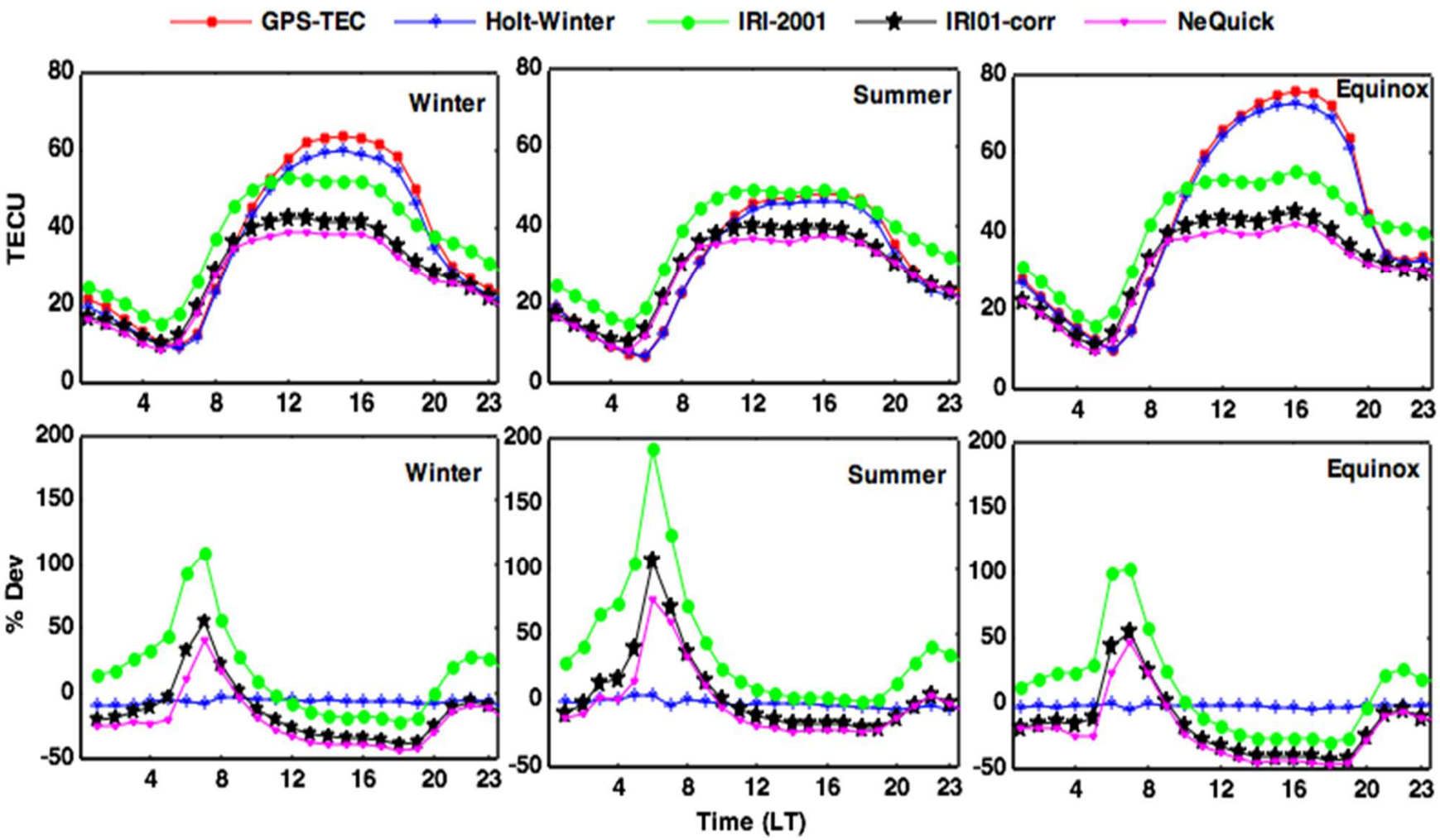
Winter (January, February, November, December) , Summer (May, June, July, August)
Equinox (March, April, September, October)



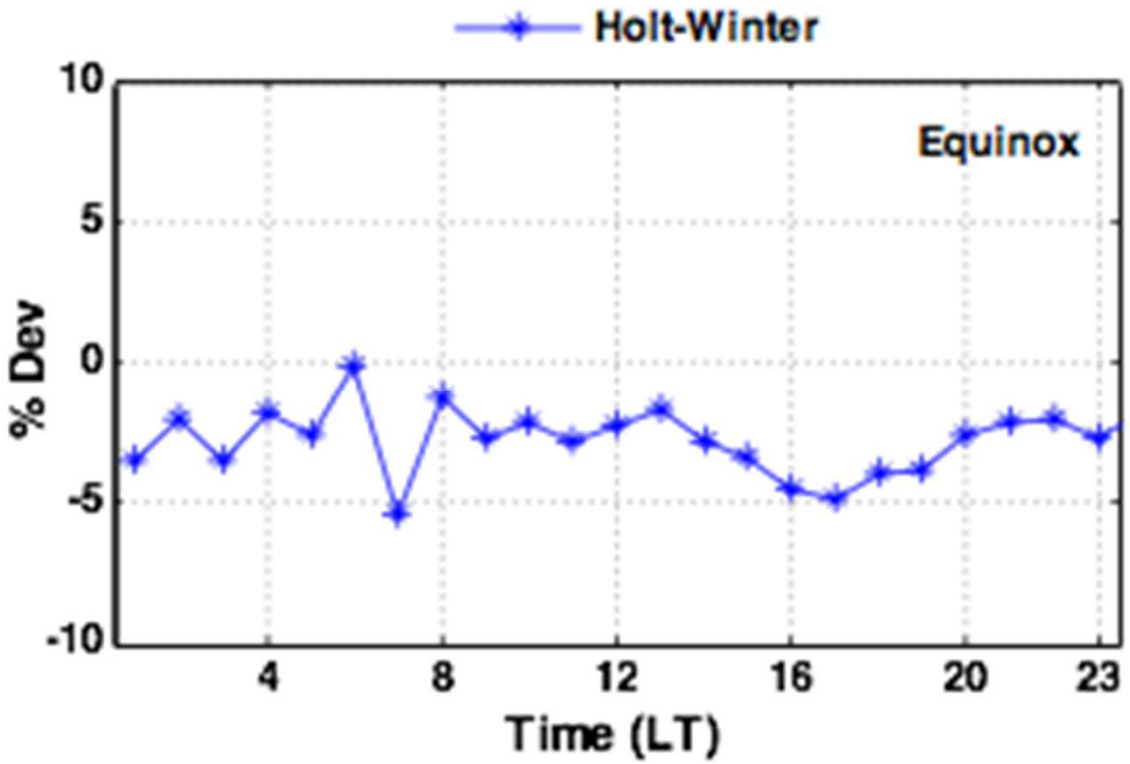
Comparison of the Holt-Winter method with IRI-2012 over Langkawi station in 2014



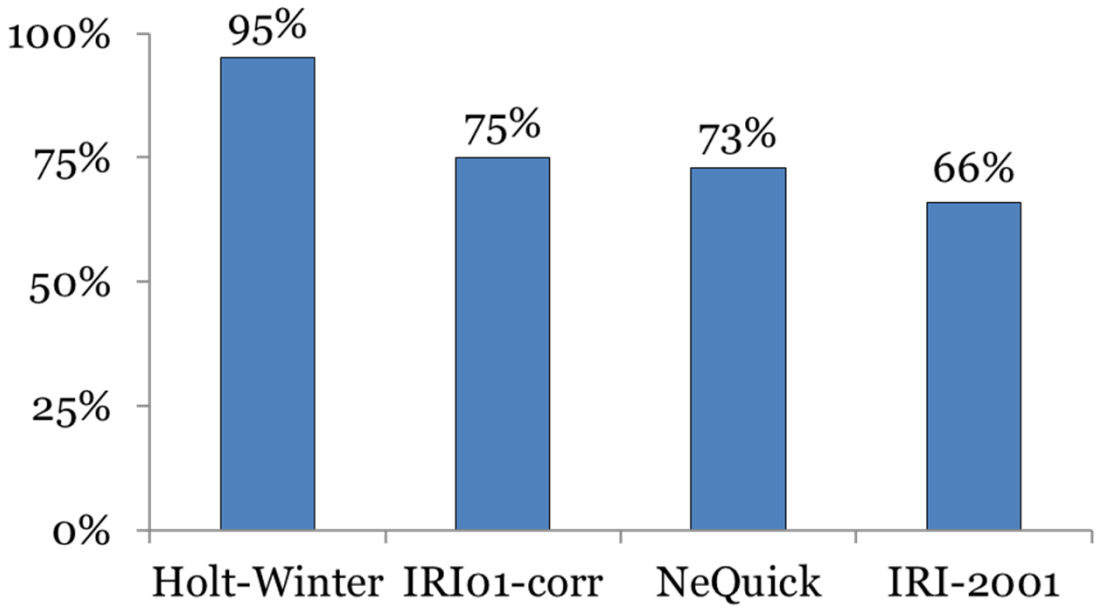
Comparison of the seasonal VTEC from GPS-TEC with IRI-2012 topside options and Holt-Winter method and their %Dev



Closer inspection to illustrate the %Dev of the Holt-Winter method during the time period from 10:00 to 19:00 LT.



Accuracy of prediction model



- That can be conclude that the Holt-Winter method indicates high performance and better estimate of the VTEC prediction

Conclusion

- Holt-Winter can be used to forecast ionospheric delay and show higher accuracy compare to the IRI-2012 model
- Help to mitigate ionospheric error in GPS positioning for better accuracy

Acknowledgment

- National Space Agency through the Langkawi National Observatory for the installation and maintenance of GISTM in Langkawi

- UNOOSA through ICG for the financial support

Thank you