The signicance of Ionospheric Modelling over the Equatorial Region (i.e. Malaysia)

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Presentation Outline

- Introduction
- Dynamic of the Ionosphere over Malaysia
- How to do Modelling - methods involved
- What’s ionospheric horizontal gradient?
- Application of GPS in Malaysia
- Wireless and Radio Science Research Centre in UTHM
- Challeges
- Conclusion
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- Acknowledgement

Introduction

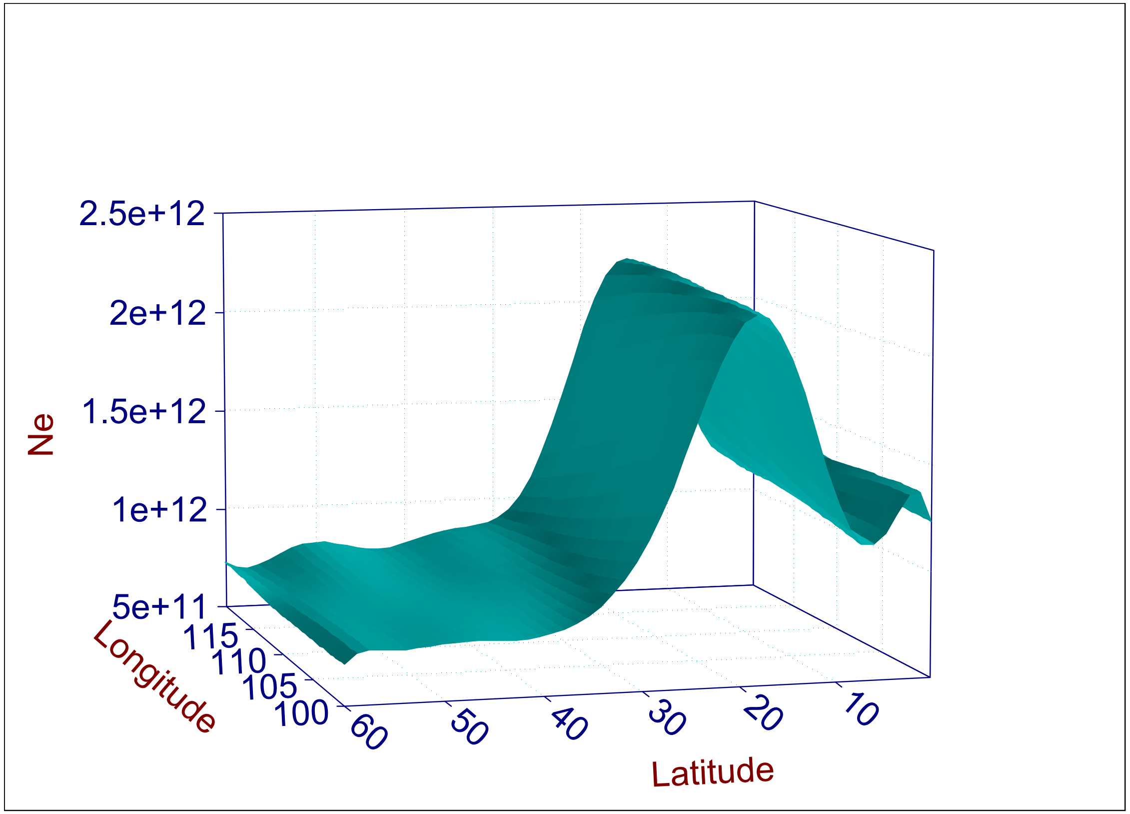
- Ionospheric delay - main source of error in GPS, especially over the equatorial region (i.e Malaysia) - termend equatorial ionospheric anomaly.

- Inhomogeneous formation of the ionosphere, complex ionospheric structure and large variation of Total Electron Content (TEC) in low latitudes

- A proper 3 dimensional model is necessary - to represent the ionospheric variation diurnaly, altitudinally, solar activity and latitudinally.

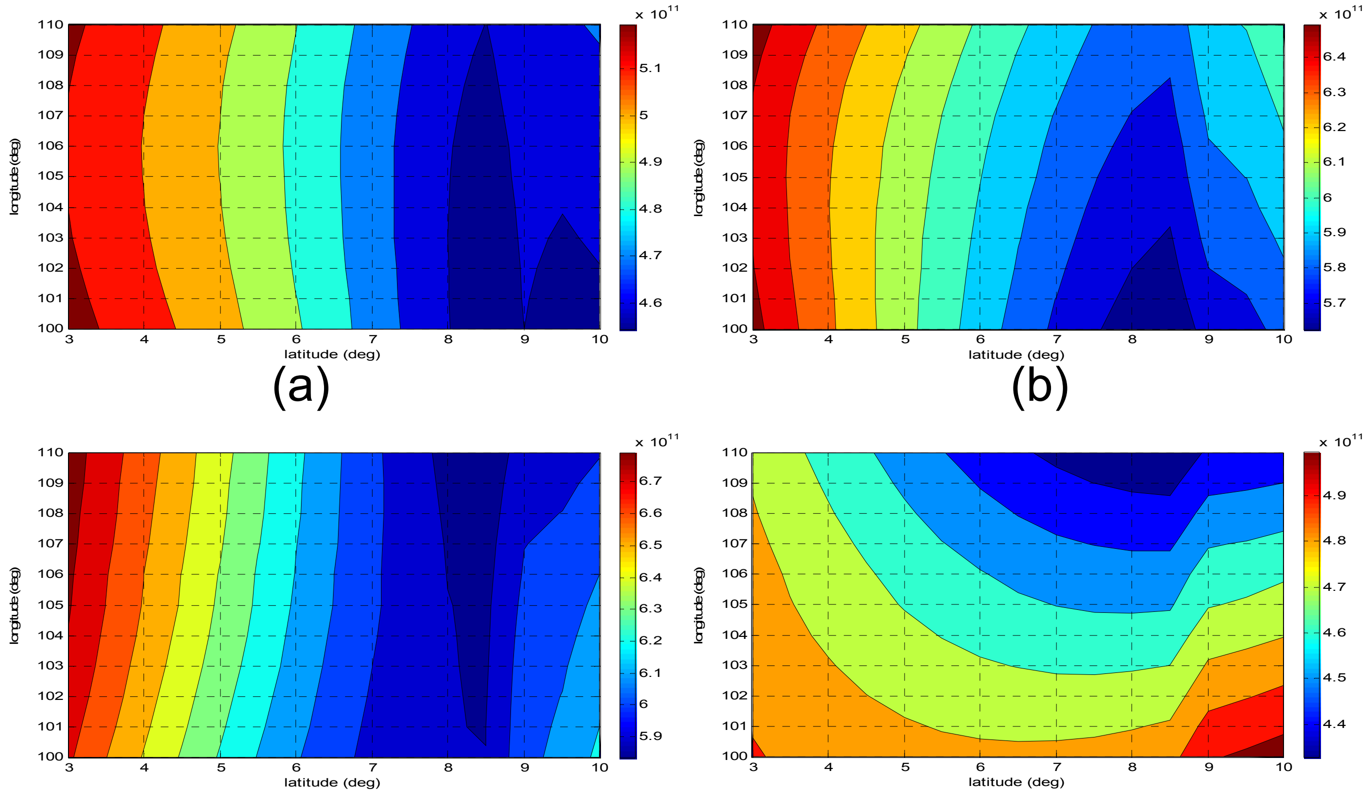
- Latitudinal variation – presence of ionospheric horizontal gradient very dominant

Latitudinal variation of the Ionosphere



Electron Density profile over a region of latitude and longitude at 350km

Diurnal variation of the Ionosphere

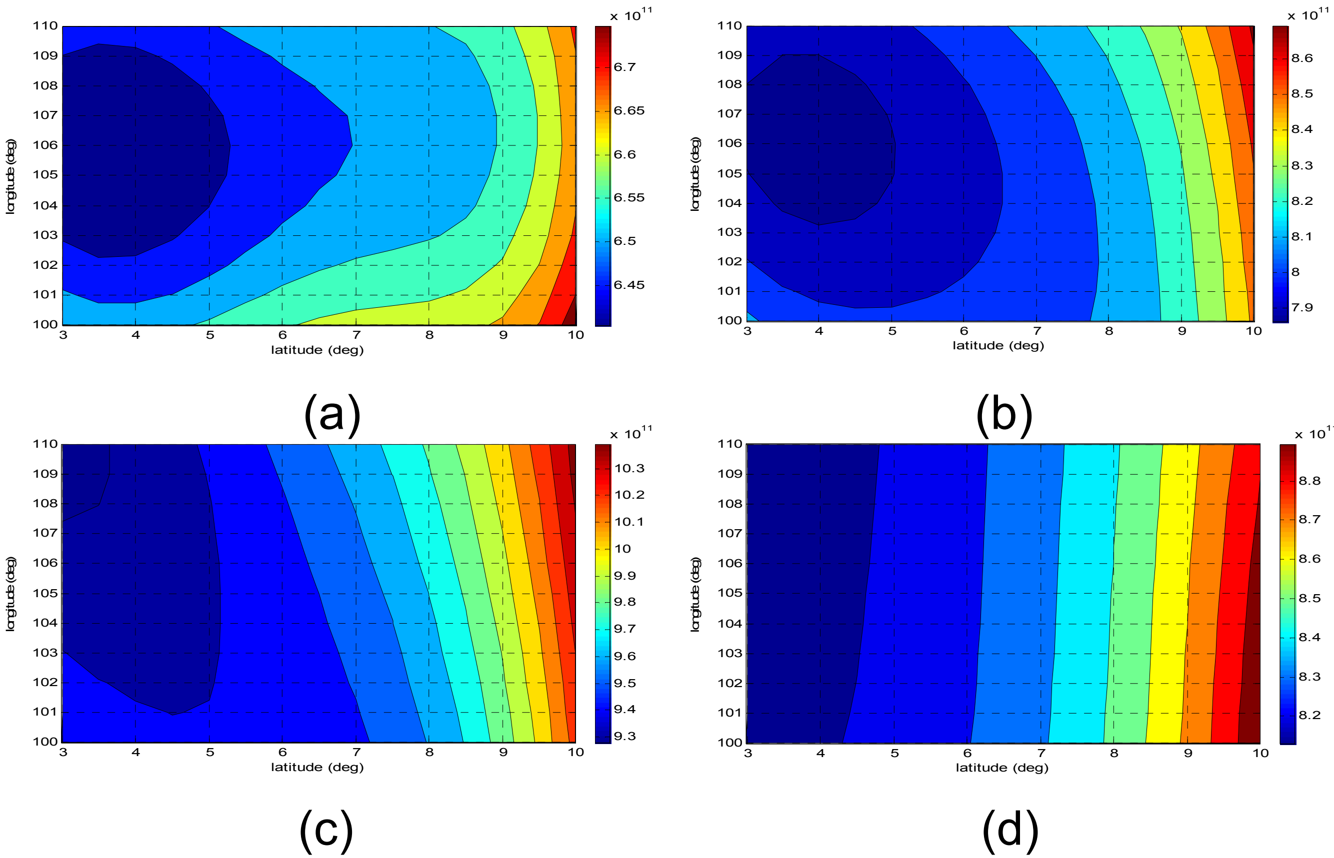


(a) (b) (c) (d)

Contour of electron density on 15th January 2008 at 350 km altitude for; (a) 1200 hours; (b) 1400 hours; (c) 1600 hours; and (d) 1800 hours.

Variation due to Solar Activity

i. **Contour of electron density on 15 January 2004**



Contour of *Ne* on 15th January 2004 at;
(a) 1200 hours; (b) 1400 hours; (c) 1600 hours; and (d) 1800 hours

ii) Contour of electron density on 15 January 2008

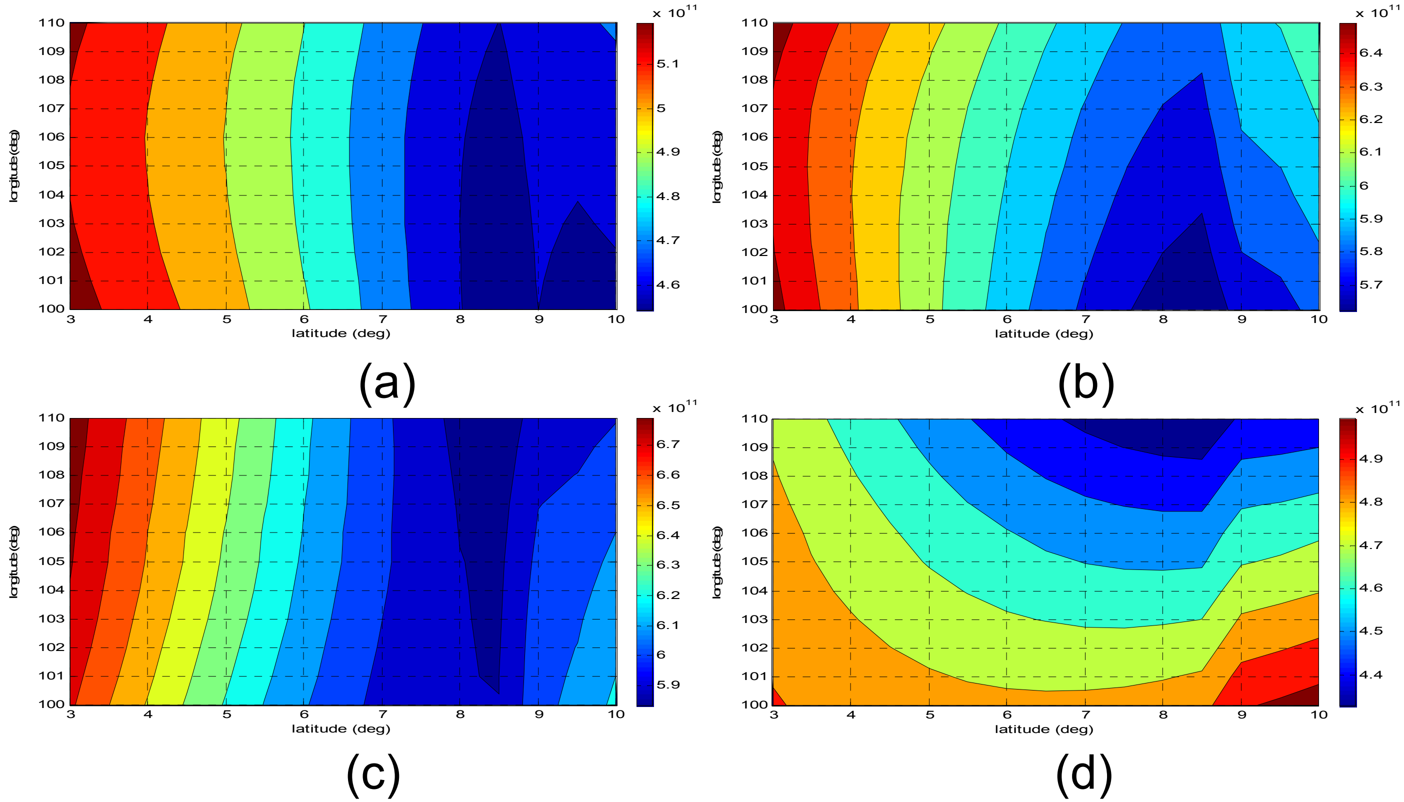


Figure 5: Contour of electron density on 15th January 2008 at;
(a) 1200 hours; (b) 1400 hours; (c) 1600 hours; and (d) 1800 hours

Modelling the Ionosphere

$$Ne(h,\theta,\phi) = \sum_{i=1}^{i=n} Ne_{\max_i} \exp\left(-\left\{\frac{h-h_{\max_i}}{s_{\max_i}}\right\}^2\right) \frac{f_i(\theta,\phi)}{f_i(\theta_{ref},\phi_{ref})}$$

where;

$Ne_{\max_i}$ = maximum of electron density of an exponential layer at the reference latitude and longitude at the i*th* layer

$h_{\max_i}$ = height of the maximum of an exponential layer at the i*th* layer

$s_{\max_i}$ = semithickness parameter of an exponential layer at the i*th* layer

$f_i(\theta,\phi)$ = the function of electron density for a region of latitude and longitude at the i*th* layer

$f_i(\theta_{ref},\phi_{ref})$ = the function of electron density for the i*th* layer evaluated at the centre point of the modelled region of latitude and longitude (known as the reference location)

n = number of exponential layers used un the modelling

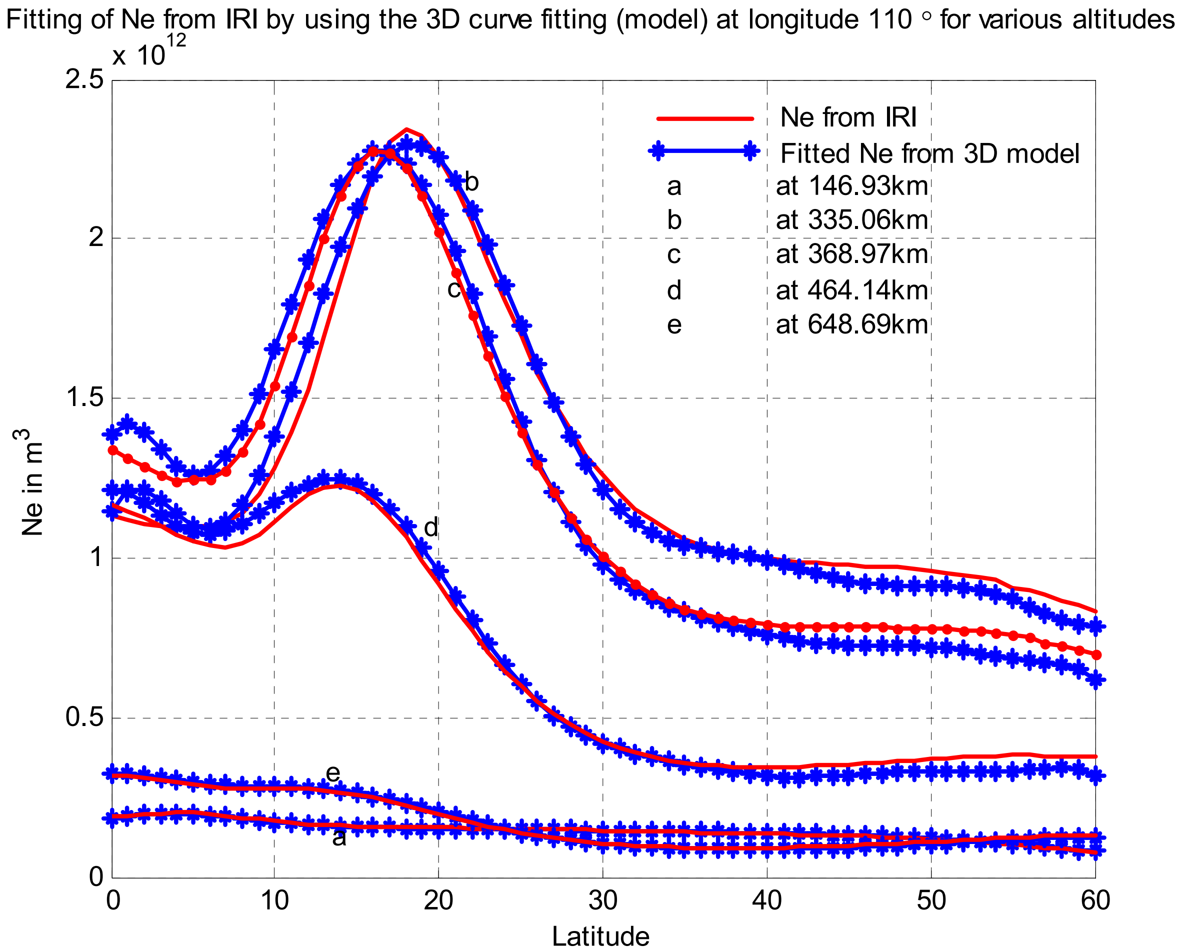
$$
\begin{aligned}
f(\theta,\phi)=\;& a+b\cos(\phi)+c\cos(\theta)+d\sin(\phi)+e\sin(\theta)+f\cos(2\phi)+g\cos(2\theta)+h\sin(2\phi)+i\sin(2\theta)+j\cos(3\phi)+k\cos(3\theta)+\\
& l\sin(3\phi)+m\sin(3\theta)+n\cos(4\phi)+o\cos(4\theta)+p\sin(4\phi)+q\sin(4\theta)+r\cos(5\phi)+s\cos(5\theta)+t\sin(5\phi)+u\sin(5\theta)+\\
& v\cos(\phi)\cos(\theta)+aa\cos(\phi)\sin(\theta)+ab\sin(\phi)\cos(\theta)+ac\cos(\phi)\cos(2\theta)+ad\cos(2\phi)\cos(\theta)+ae\cos(\phi)\sin(2\theta)+\\
& af\sin(2\phi)\cos(\theta)+ag\cos(\phi)\cos(3\theta)+ah\cos(3\phi)\cos(\theta)+ai\cos(\phi)\sin(3\theta)+aj\sin(3\phi)\cos(\theta)+ak\cos(\phi)\cos(4\theta)+\\
& al\cos(4\phi)\cos(\theta)+am\cos(\phi)\sin(4\theta)+an\sin(4\phi)\cos(\theta)+ao\sin(\phi)\sin(\theta)+ap\sin(\phi)\cos(2\phi)+aq\cos(2\phi)\sin(\theta)+\\
& ar\sin(\phi)\sin(2\theta)+as\sin(2\phi)\sin(\theta)+at\sin(\phi)\cos(3\theta)+au\cos(3\phi)\sin(\theta)+av\sin(\phi)\sin(3\theta)+ba\sin(3\phi)\sin(\theta)+\\
& bb\sin(\phi)\cos(4\theta)+bc\cos(4\phi)\sin(\theta)+bd\sin(\phi)\sin(4\theta)+be\sin(4\phi)\sin(\theta)+bf\cos(2\phi)\cos(2\theta)+bg\cos(2\phi)\sin(2\theta)+\\
& bh\sin(2\phi)\cos(2\theta)+bi\cos(2\phi)\cos(3\theta)+bj\cos(3\phi)\cos(2\theta)+bk\cos(2\phi)\sin(3\theta)+bl\sin(3\phi)\cos(2\theta)+bm\sin(2\phi)\sin(2\theta)+\\
& bn\sin(2\phi)\cos(3\theta)+bo\cos(3\phi)\sin(2\theta)+bp\sin(2\phi)\sin(3\theta)+bq\sin(3\phi)\sin(2\theta)
\end{aligned}
$$

where;

a,*b*,*c* … *bq* are the values of parameters which are obtained from 3D curve fitting software.

Its a **Numerical Method** approach

- The figure shows the latitudinal variation of electron density for 110 ° longitude at 5 different altitudes as a function of latitude as determined from the fitted formula and as given by the IRI model.

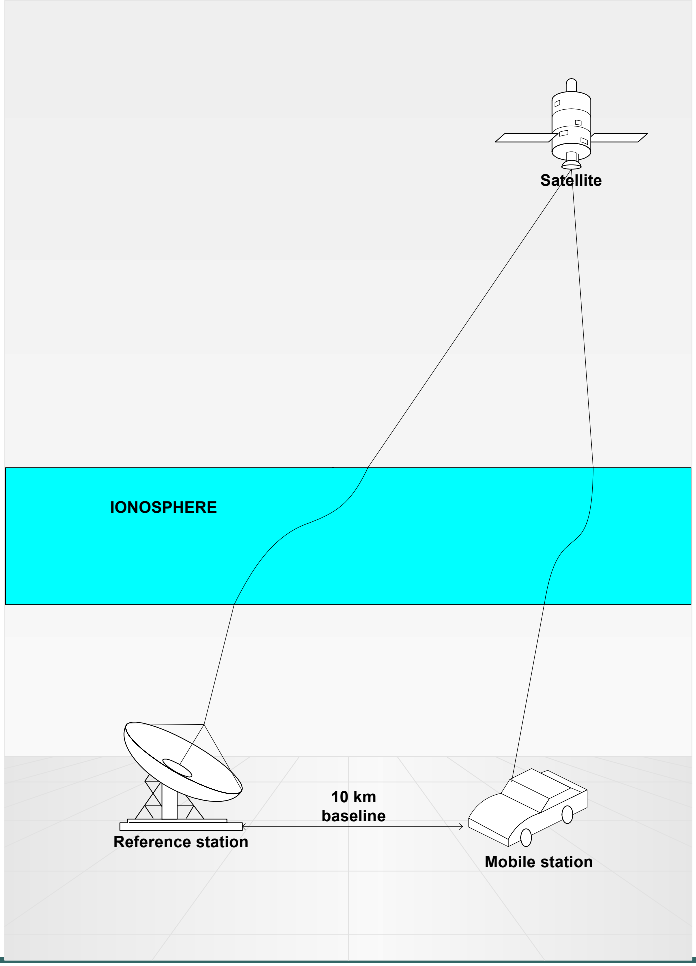


- However the modelling should be done using GPS observation data (better to use real time data) or any other highly accurate ionospheric representation data.
- However, using Dual Frequency Model to determine the ionospheric delay (or TEC) is not accurate enough. Even using the TEC value from Novatel Receiver – how to confirm its accurate enough as there are other errors also.

Methods to Determination Ionospheric Horizontal Gradient

- Jones 3D Ray Tracing approximation using DGPS method
- Magnitude of Ionospheric Horizontal Gradient from the Contour Plot
- Carrier phase levelling between carrier phase advance and group path delay in order to mitigate the carrier phase ambiguity and determine the gradient factor from the Carrier Phase advance.
- Etc..???

Analogy of DGPS method to determine the equation of ionospheric gradient Using Jones 3D Ray Tracing program **- Analytical Approach**



$$TEC_{slant} = \int Ne_{\max} \bullet \exp\left(-\left(\frac{h-h_{\max}}{s_{\max}}\right)^{200}\right) \bullet \left(1 + C\left(\theta - \theta_{ref}\right)\right)\sec(\beta)\ dh$$

$$C(in\,km) = \frac{C(in\,rad)}{6353.143\,km}$$

$$\text{variation in latitude}(in\,km) = \frac{h}{\tan(\beta)}$$

$$TEC_{slant}(C,\beta) = \frac{\left(\int Ne_{\max} \bullet \exp\left(-\left(\frac{h-h_{\max}}{s_{\max}}\right)^{200}\right) \bullet \left(1 + \frac{C}{6353.143}\left(\frac{h}{\tan(\beta)}\right)\right) dh\right)}{\cos(\beta)}$$

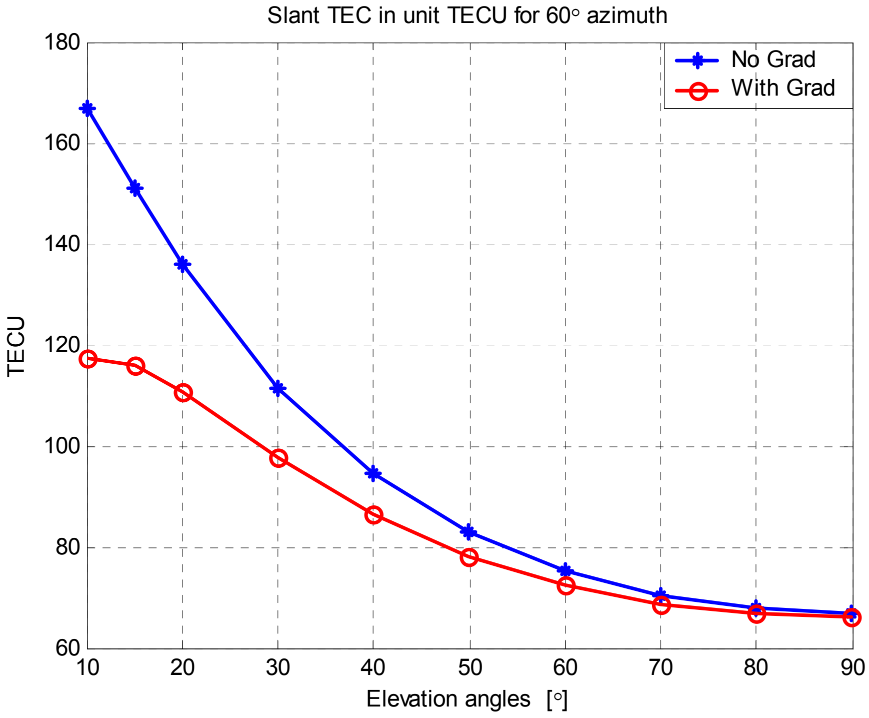
β is the elevation angle, C is fractional increase or decrease in electron density per radian away from θ_{ref} the reference latitude.

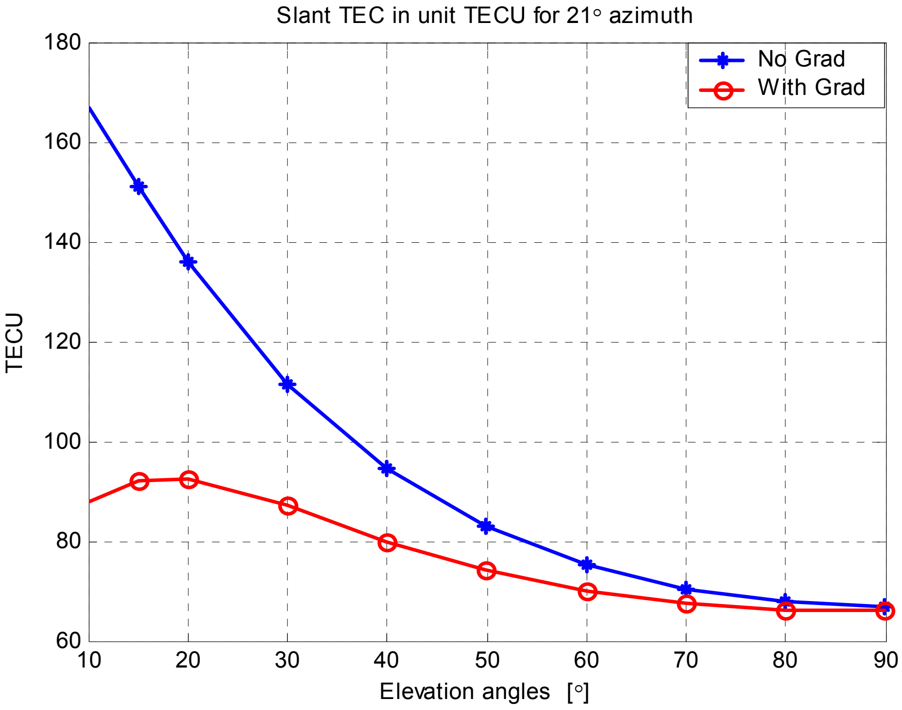
$$Diff\ in\ slant\ TEC = TEC_{ref} - TEC_{mob}$$

$$Effect\ of\ Gradient = (TEC_{ref} - TEC_{mob})_{WG} - (TEC_{ref} - TEC_{mob})_{NG(C=0.0)}$$

Significant of Ionospheric Horizontal gradient

1) Can be determined from the Jones 3D ray tracing program





2a)GPSurvey (Trimble) also has been used to show the significant in positioning improvement by mitigating the ionospheric horizontal gradient.

2b)Eight satellites location has been fixed using ray tracing program from a fixed reference station location (i.e. 5º, 110º). Then, the range measurements at the reference station and the user / mobile station will be obtained.

2c)A user station was fixed at 21º azimuth and 10 km away from the reference station.

Location of Satellites – from reference station

Eight sets of elevation and azimuth angles at the reference station for the reception of group delay range measurements from 8 different GPS satellites.

Satellite	Elevation (°)	Azimuth (°)
1	20	295
2	25	60
3	45	275
4	55	330
5	15	10
6	40	110
7	60	210
8	35	45

Location of Satellites – from user station

Eight sets of elevation and azimuth angles at the user location for the reception of group delay Measurements from 8 GPS satellites, as at the reference station.

Satellite	**Elevation (º)**	**Azimuth (º)**
1	20.00679991883	295
2	25.0780183344	60
3	44.9699315534	275
4	55.0705298062	330
5	15.0943621050	10
6	40.0017645250	110
7	59.8876371233	210
8	35.09561502982	45

Jones 3D Ray Tracing program is used to determine the group path measurements for with and without gradient cases.

After that, the differential corrected ranges will be obtained.

However, these differential corrected ranges still consist of the range error due to the presence of the ionospheric horizontal gradient.

Finally, Least Square Minimization (LSM) technique will be used to determine the improvement in the user positioning in DGPS.

$$improved\ positional\ error = \sqrt{\left(x_{ori} - x_{pred}\right)^2 + \left(y_{ori} - y_{pred}\right)^2 + \left(z_{ori} - z_{pred}\right)^2}$$

GROUP DELAY MEASUREMENTS AT THE USER STATION BEFORE AND AFTER THE ERROR CORRECTIONS

Satellite	Differential corrected range (m)	Range after horizontal gradient correction (m)
1	23707639.0655	23707639.11453
2	23236093.0247	23236093.11440
3	21683112.0003	21683112.00843
4	21095988.4575	21095988.49574
5	24189588.7333	24189588.80628
6	22023382.7028	22023382.70367
7	20866780.1912	20866780.16973
8	22391426.2073	22391426.28067

IMPROVEMENT IN THE FINAL POSITIONAL ERROR AT THE USER BEFORE AND AFTER CORRECTIONS USING GROUP DELAY MEASUREMENTS

Correction	Error in the positioning (cm)
Differential	7.5366
Horizontal gradient	0.4141

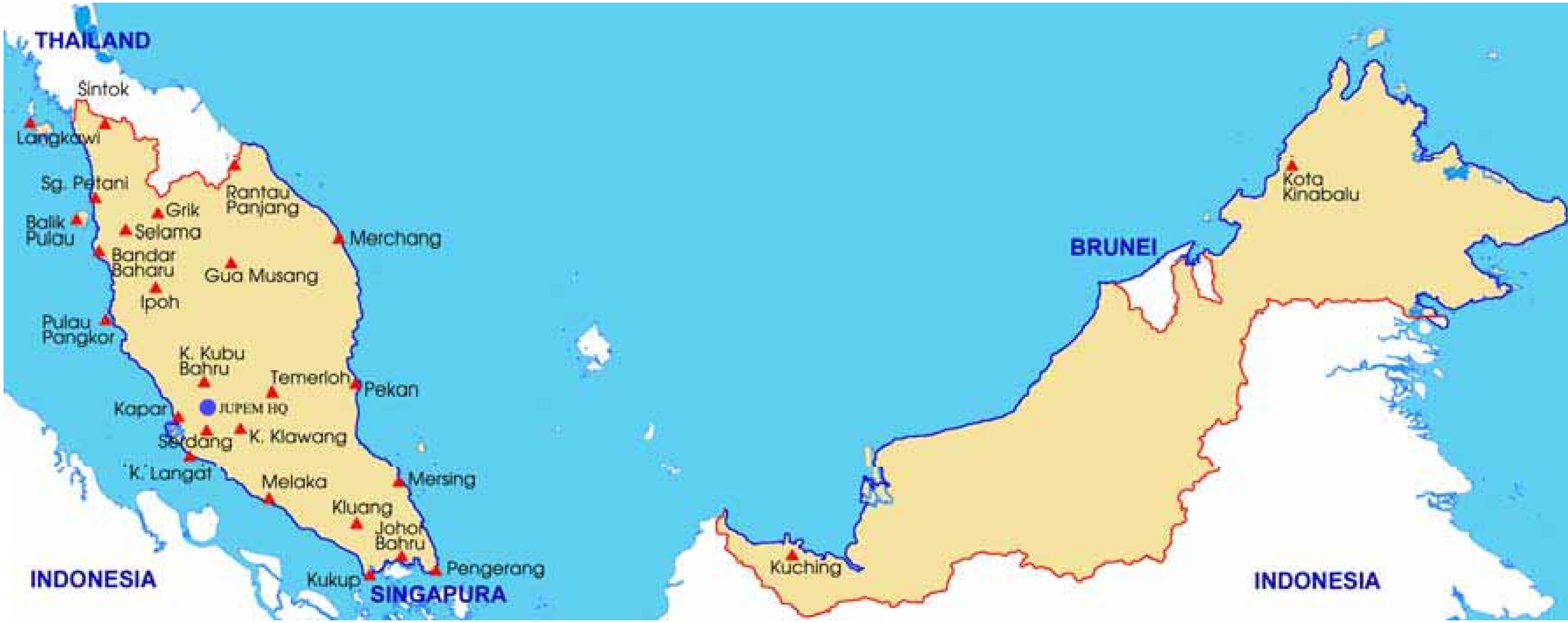
Though the improvement is very minimal, however, for applications that require high precision in positioning such as surveying, mapping, military, etc, this approximation is very important.

Application of GPS in Msia

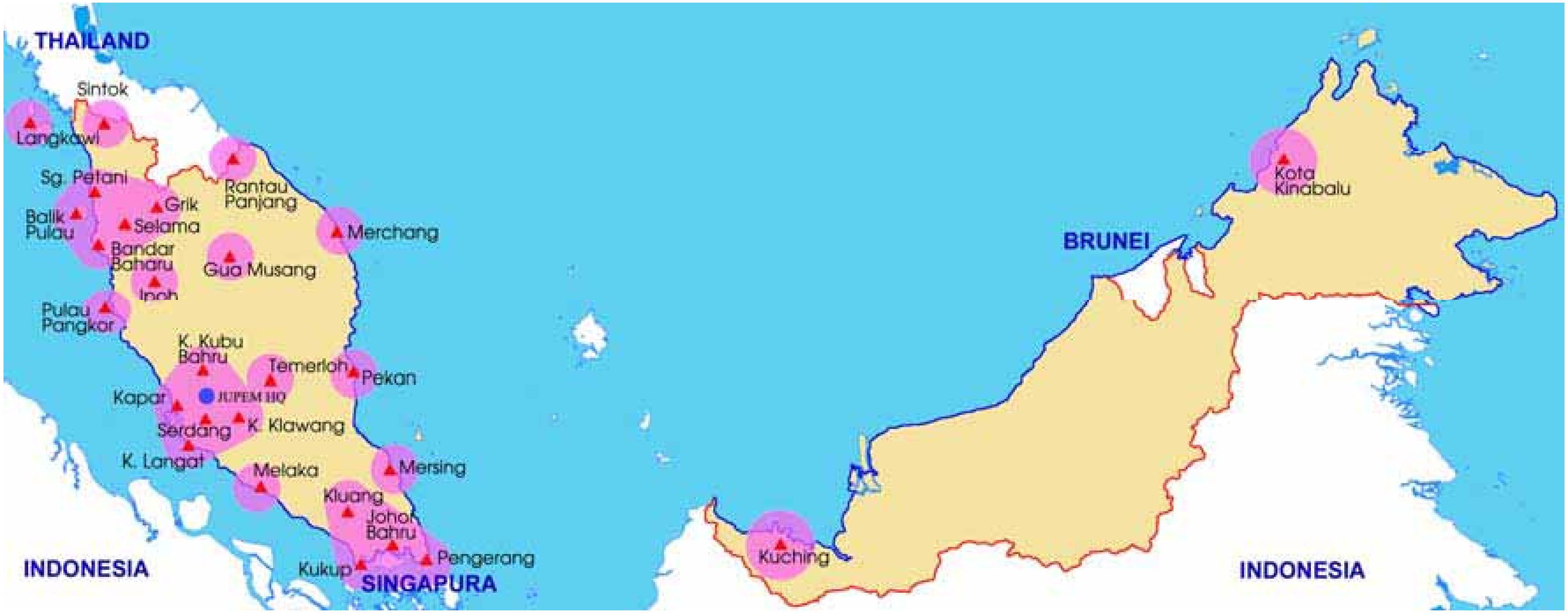
- Navigation, Mapping, Mobile phone, Vehicle (i.e Transportation Lorry) Tracking, Surveying, Fertilizing in Agriculture (i.e Oil Palm Estate),Marine, Navy, Military, Jungle Trekking, Container Handling in the port, deformation monitoring - it was not in Malaysia 10 years ago – but now very common
- Department of Survey and Mapping Malaysia (DSMM)
- Malaysia Metrological Department (MMD) introduces MyRTKnet in 2005 – start to use GPS data to update on weather over Malaysia.
- Ionospheric correction has to looked into and have to give higher priority for that.

- Get the GPS observation data from MMD or any other relevant department – to model the variation of the ionosphere in real time

GPS data from MMD Malaysia



MyRTKNet Distributions



MyRTKNet Coverage in Malaysia

UTHM – Wireless and Radio Science Laboratory

- A research centre was established in UTHM to conduct research in the area Communications Engineering as Space Science and Space Communication as one of its Research Unit.
- At the moment, only consist of 3 active researchers.
- Quite some graduates so far; 2 PhDs and few Masters – but none of them pursue further as lack of opportunity in terms of job spec etc.
- Collaboration – UKM (Angkasa), ANGKASA MOSTI and SUPARCO
- Lack of funding and lack of support from relevant organization.

Vertical and Oblique Ionosonde System
Model: CADI 1993-01 SIL

GPS Ionospheric Scintilllation & TEC monitor

Model: GSV 4004B

- Magnetometre – to do research on the magnetic field

Research Grants Received So far

- Science Fund by Ministry of Science, Technology and Innovation (MOSTI) Malaysia – *Realibilty Study on Ionosphere Model for SBAS System* - Project Member
- FRGS by then Ministry of Higher Education (MOHE) Malaysia – *Fundamental Analysis on the Variations of the Ionosphere Over the Equatorial Region and Its Effect to GPS Positioning* – Project Head

Challenges

- Lack of funding / human assistance / support from relevant agencies
- Lack of knowledge and interest on the importance of space science and knowing space weather
- Lack of research knowledge
- GPS observation data – lack of data and the charge by MMD is very expensive (i.e RM 10 for 1 hour access) ~ Euro 2.50
- Etc…

- Meeting with International Civil Aviation Organization – representative from ANGKASA MOSTI – attended it in Bangkok on 5 – 6th May 2011 – Workshop on Ionospheric Data Collection, Analysis and Sharing in Support of GNSS Implementation - was never invited

- But one of the latest / important reason to model the ionosphere over Malaysia

- Effect of Geomagnetic Field to Transmission Grid Line, Satellites over the geomagnetic equator (close to geographic equator) – by Head, J., and H. Haubold (2012)

Conclusions

- Being over the equatorial region, it is very important for Malaysia to have its own ionospheric model which take account all the terms and conditions.
- This is will be very much useful and can be embedded into the GPS positioning application.
- However, those challenges mentioned above have to be tackled in order to obtain a model with highly in precision and accuracy.

List of References

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Thank You For the Attention

Q & A