Ionospheric Modeling with the Quadratic Approach: Results for the Super Storms

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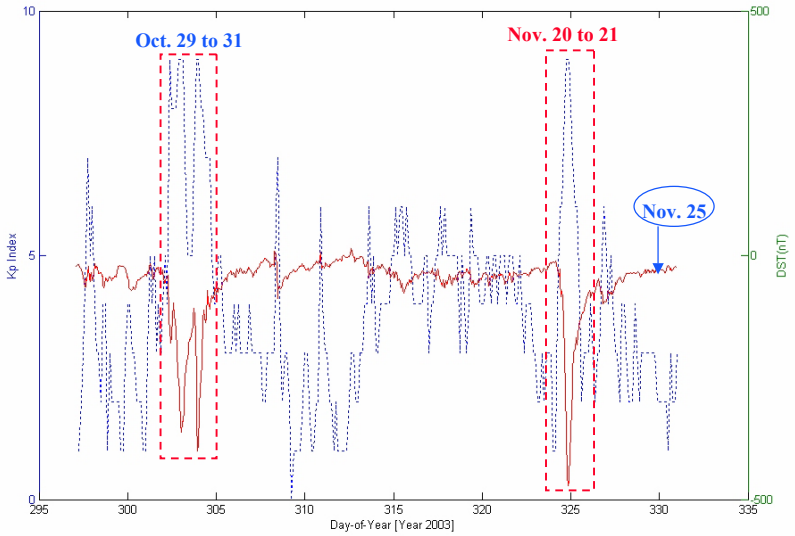
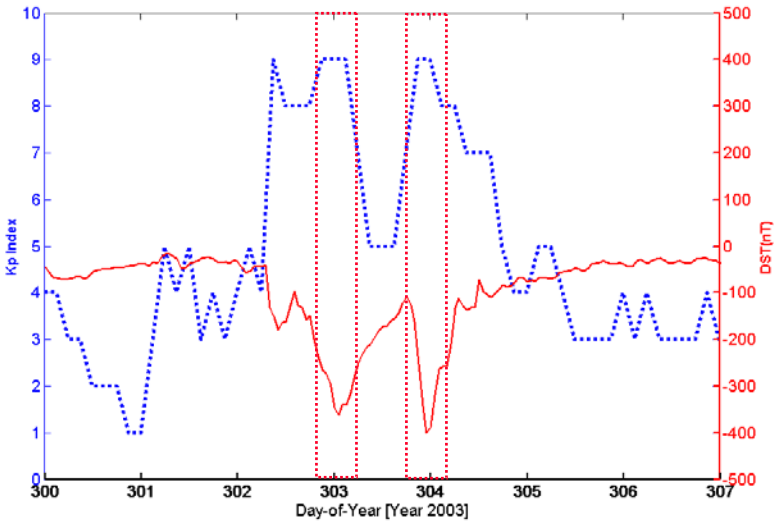
Introduction

- What are the effects of non-linear spatial variations in the ionosphere especially under geomagnetic storm conditions?
- Data: 48 stations in U.S.and southern Canada
- October 29-31, November 20 and November 25, 2003 used as ionospheric storm days and a quiet ionosphere day, respectively.

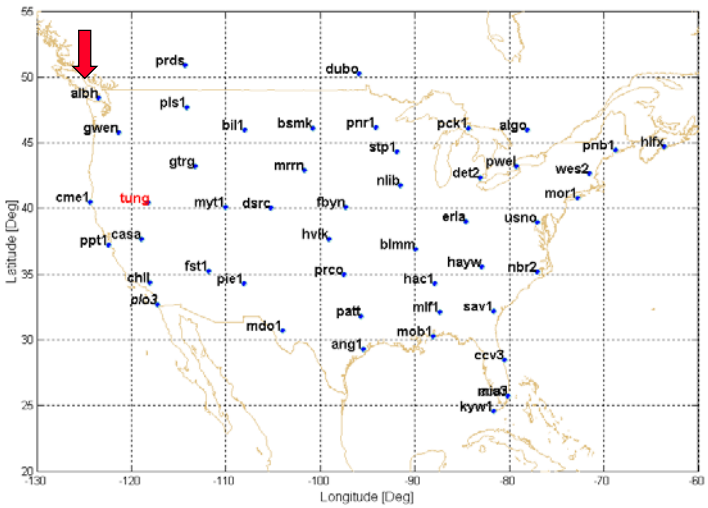
Selection of Data Sets
[One Month: Oct. 25 – Nov.25, 2003]



Geomagnetic Indices
[Oct. 28 – Oct. 31, 2003]



Reference Stations [48 Stations]



Model Descriptions: *Bi-Linear Model*

- **Observation equation:**

$$I(t) = M(e)\,[a_0(t) + a_1(t)\,d\lambda + a_2(t)\,d\phi\,] + b^s + b_r$$

I (t)	**L1-L2 phase-levelled ionospheric measurement,**
$a_0(t)$, $a_1(t)$, $a_2(t)$	**coefficients of the spatial linear approximation of TEC estimated using a Kalman filter approach,**
$b^s + b_r$	**satellite+receiver differential delays,**
M(e)	**elevation angle mapping function.**

- **Single layer ionospheric model computed for each station:**

  Ionospheric shell height fixed: 350 km,

  Elevation cut-off angle: 15 degrees.

Model Descriptions: *Quadratic Model*

- **Observation equation:**

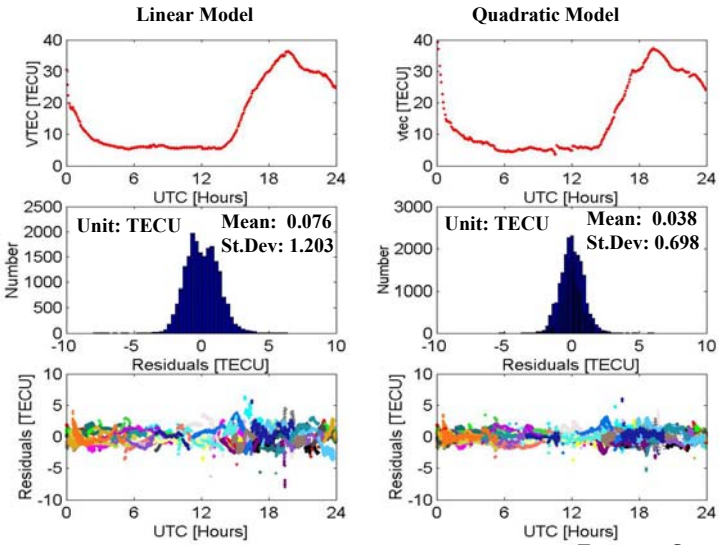
$$I(t) = M(e)\,[a_0(t) + a_1(t)\,d\lambda + a_2(t)\,d\lambda^2 + a_3(t)\,d\phi + a_4(t)\,d\phi^2 + a_5(t)\,(d\phi * d\lambda)] + b^s + b_r$$

$I(t)$	L1-L2 phase-levelled ionospheric measurement,
$a_0(t)$, $a_1(t)$, $a_2(t)$, $a_3(t)$, $a_4(t)$, $a_5(t)$	coefficients of the spatial quadratic approximation of TEC estimated using a Kalman filter approach,
$b^s + b_r$	satellite+receiver differential delays,
$M(e)$	elevation angle mapping function.

- **Single layer ionospheric model computed for each station:**
  Ionospheric shell height fixed: 350 km
  Elevation cut-off angle: 15 degrees

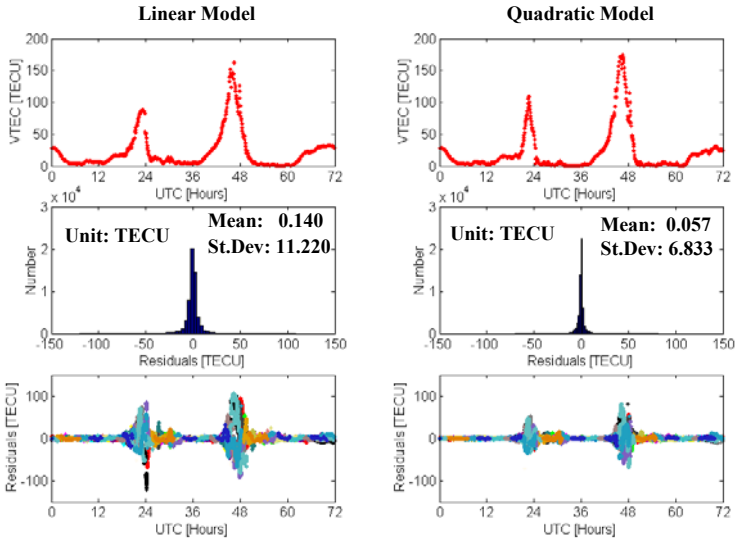
Sensitivity Tests

Sensitivity Test I:
Quiet Day (Nov. 25, 2003), TUNG

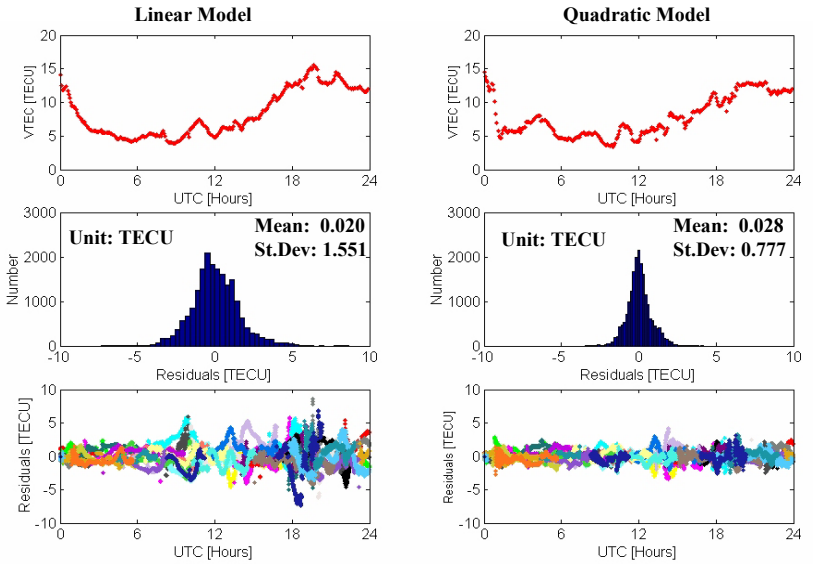


Tungsten: Oreana, Nevada

Sensitivity Test II
Storm Days (Oct. 29 – Oct. 31, 2003), TUNG

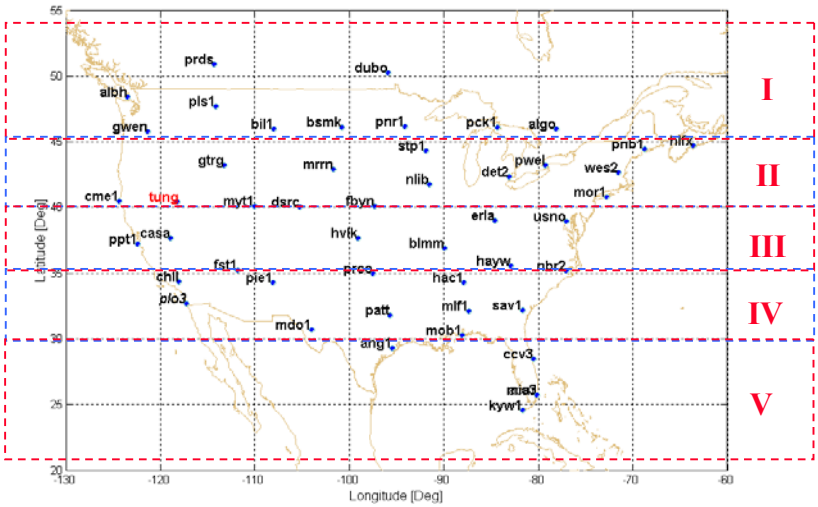


Sensitivity Test III: Storm Day (Nov. 20, 2003), TUNG



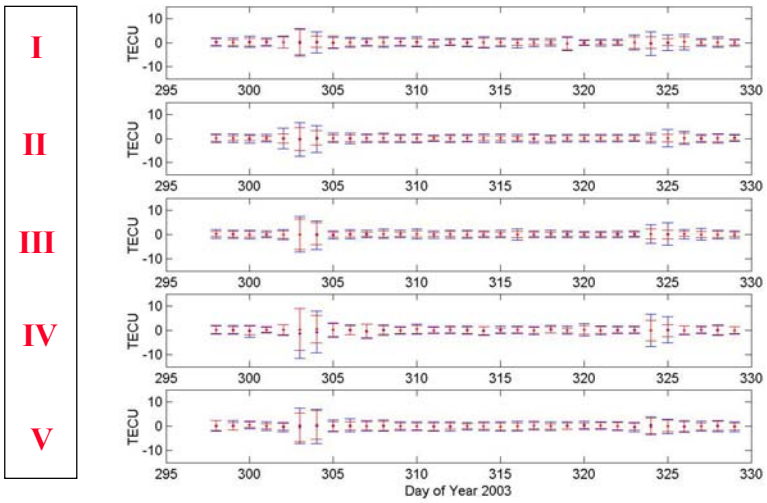
Results and Statistics

Divide into Sections for Statistics: Latitude Variations



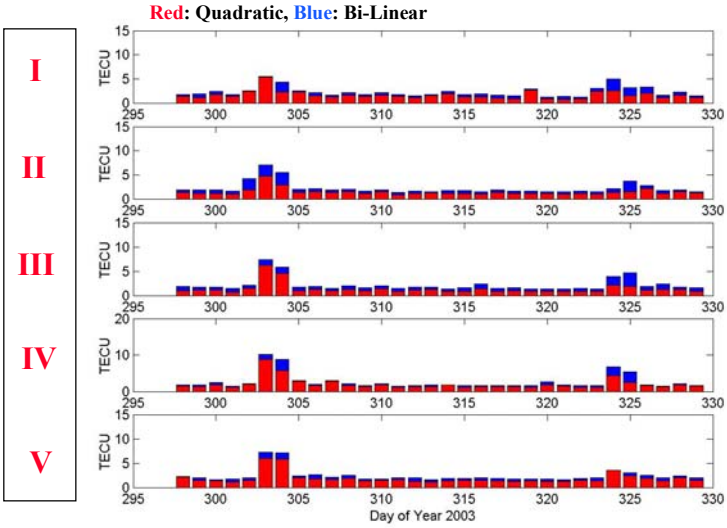
Comparison Between Bi-linear and Quadratic results: Mean and St. Dev

Red: Quadratic, Blue: Bi-Linear



Comparison Between Bi-linear and Quadratic results: Daily RMS

Red: Quadratic, **Blue**: Bi-Linear



Conclusions

- Generally, the overall trend of daily means have good agreement between both the bi-linear and quadratic models.
- We saw the greatest improvement for the quadratic approach in the rms of residuals.
- In quiet conditions, the improvement of daily rms of residuals is at about 1 TECU level or less.
- The maximum improvement in rms of residuals happens when the ionosphere was significantly disturbed; the level of improvement was 1 to 3 TECU.

Thanks

- ***Natural Sciences and Engineering Research Council of Canada***

- ***UNB Faculty of Computer Science - To allow us to use their "super computer" (164-processor Sun Microsystems V60 cluster).***

- ***U.S. Continuously Operating Reference Stations (CORS) and Scripps Orbit and Permanent Array Center (SOPAC)*** **for the** ***GPS data.***