CETC 中国电波传播研究所

# Ionospheric Forecast Based on Ingestion of GNSS Data into the NeQuick 2 Model

CHEN Liang
China Research Institute of Radiowave Propagation

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# CONTENTS

# Introduction

- GNSS ionospheric correction for single frequency user is usually realized by the combination of ionospheric model and TEC measurements

- NeQuick G is a semi-empirical profiler of the ionosphere that models electron density as a function of height, geographic latitude, geographic longitude, solar activity (specified by the Effective Ionization Level, Az), and time

- Study performed during in orbit validation (April 2013 to March 2014 ) showed approximately 70% removal of ionosphere-induced ranging errors for ground stations using NeQuick G (versus 50% using the GPS Klobuchar model)

- Introduction
- Confirmation of Data Ingestion Method
- *ER* Modeling with GNSS data
- Assessment Study
- Summary

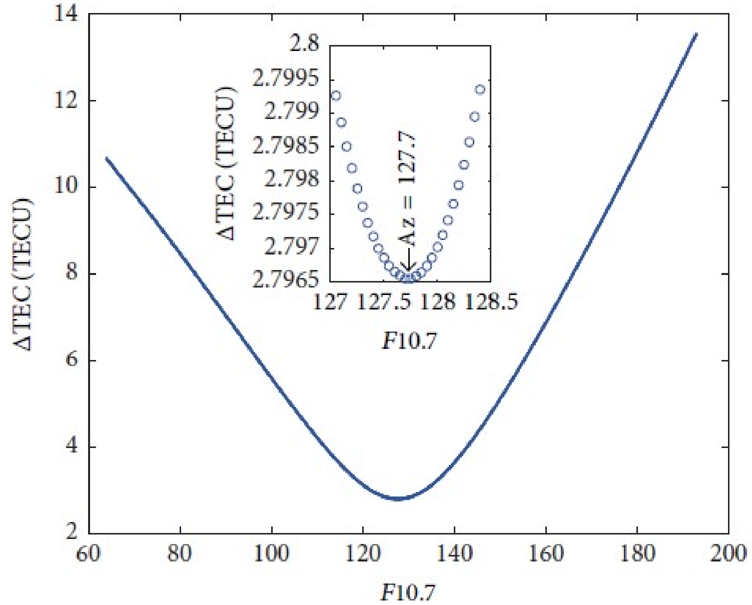
# Confirmation of Data Ingestion Method

•NeQuick 2 is optimized as a function of the daily effective ionization level to be adapted to the measured vTEC values.

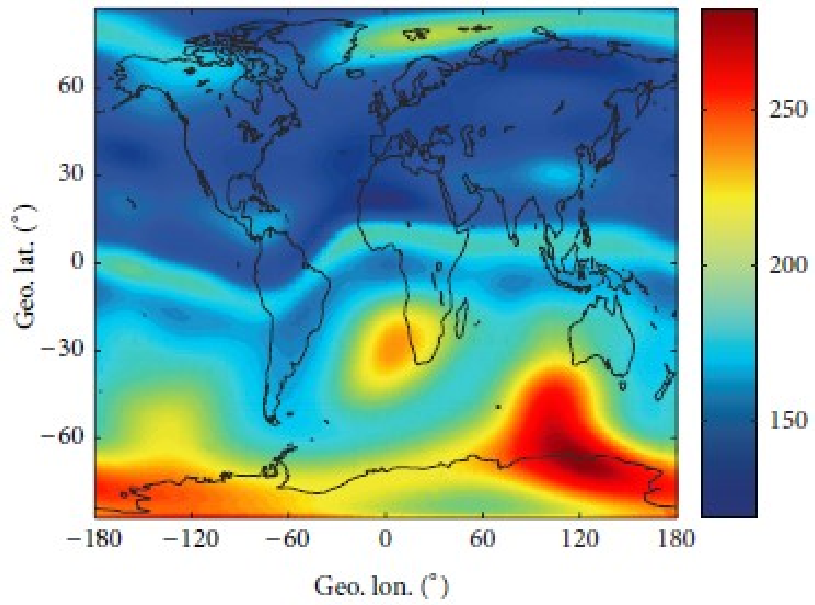
•The root mean square of TEC differences at a given grid point is defined as TEC residual errors . It is calculated as follows.

$$\Delta\mathrm{TEC} = \sqrt{\frac{\left(\sum_{i=1}^{N}\left(\mathrm{TEC}_{\mathrm{observed}} - \mathrm{TEC}_{\mathrm{modeled}}(F10.7)\right)^2\right)}{N}}.$$

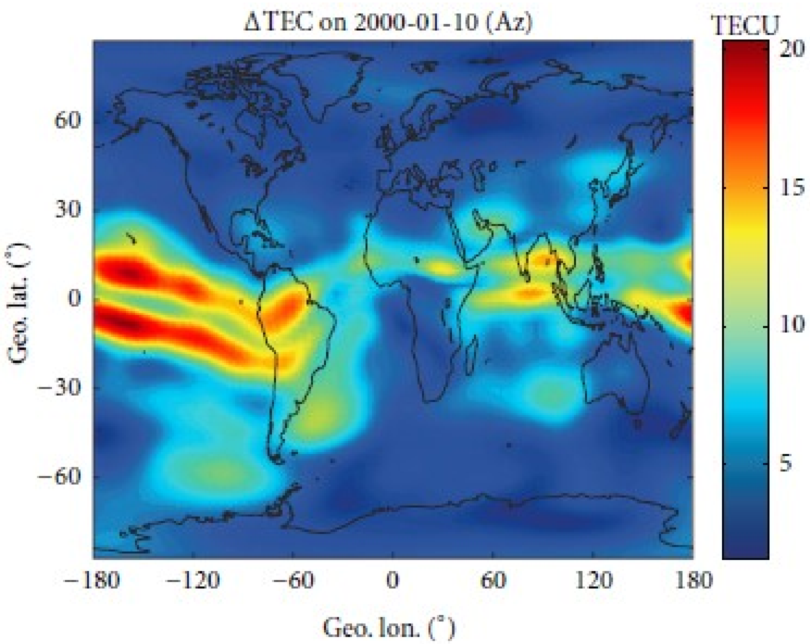
Az: Daily effective ionization lever parameter



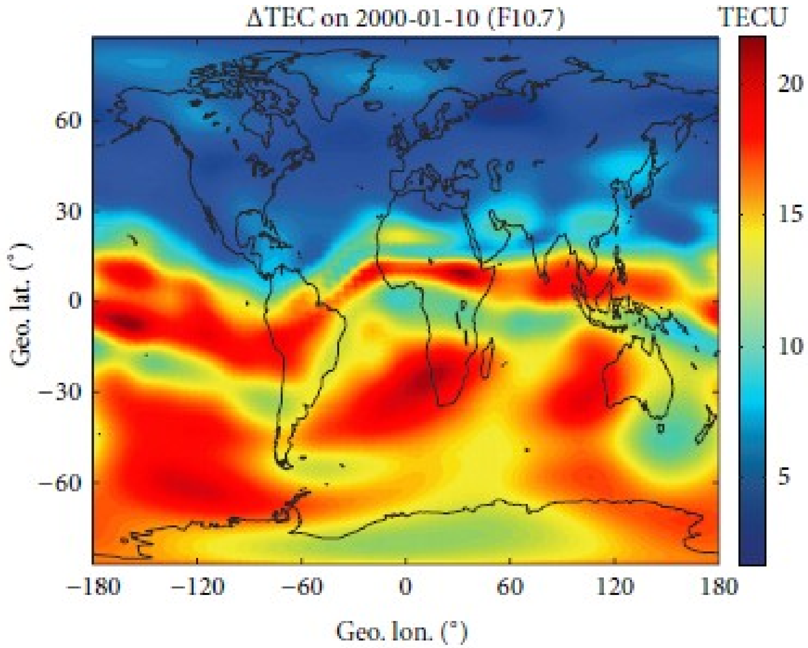

△TEC versus F10.7 at a grid point(45° N, 0° E) for 30 May 2004




Geographic Distribution of AZ after ingesting GIM data




Geographic distribution of TEC residual errors after ingesting GIMs into the NeQuick 2 model

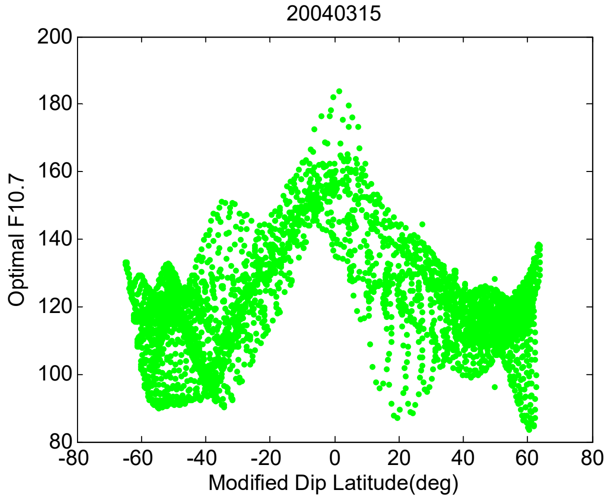



Geographic distribution of TEC residual errors when NeQuick 2 model is driven by F10.7

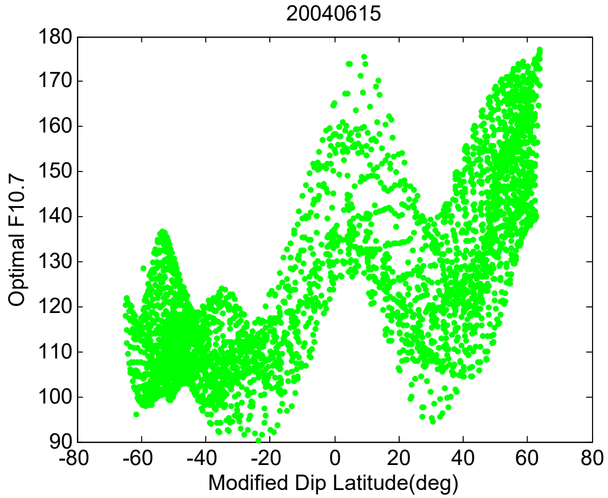
Data ingestion process would reduce the discrepancies through designating optimum F10.7

## Variation of daily effective ionization level with *MODIP in different seasons*

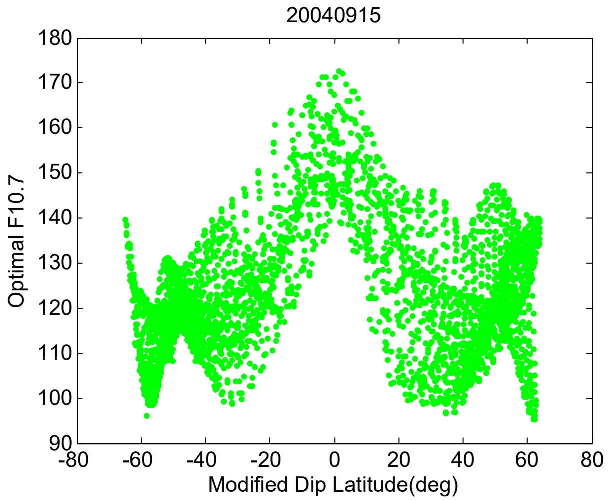
15th Mar.



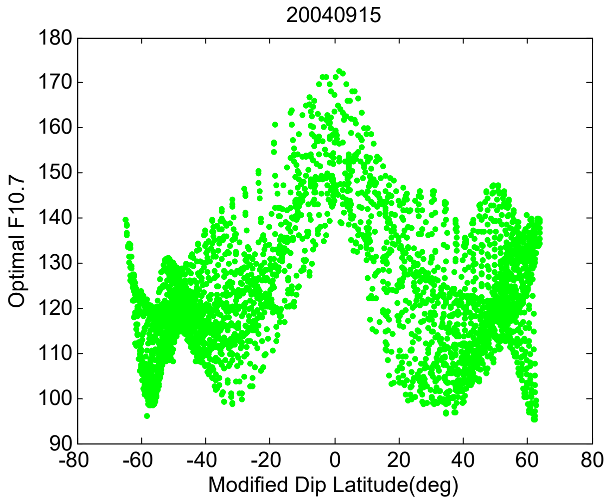

15th Jun.




15th Sep.




15th Dec.




The scatter points in all figures exhibit the wave-like variations.

- In the Galileo ICA, Az can be regressed as a second order polynomial function of modified dip latitude.

$$Az = a_0 + a_1 \cdot MODIP + a_2 \cdot MODIP^2$$

- To depict the wave-like variation of daily effective ionization level , the following model is constructed:

$$ER = a_0 + a_1 \cdot MODIP + a_2 \cdot MODIP^2 + a_3 \cdot MODIP \cdot \cos\left(a_4 \cdot MODIP + a_5\right)$$

# Variation of daily effective ionization level with *MODIP in different seasons*

15th Mar.

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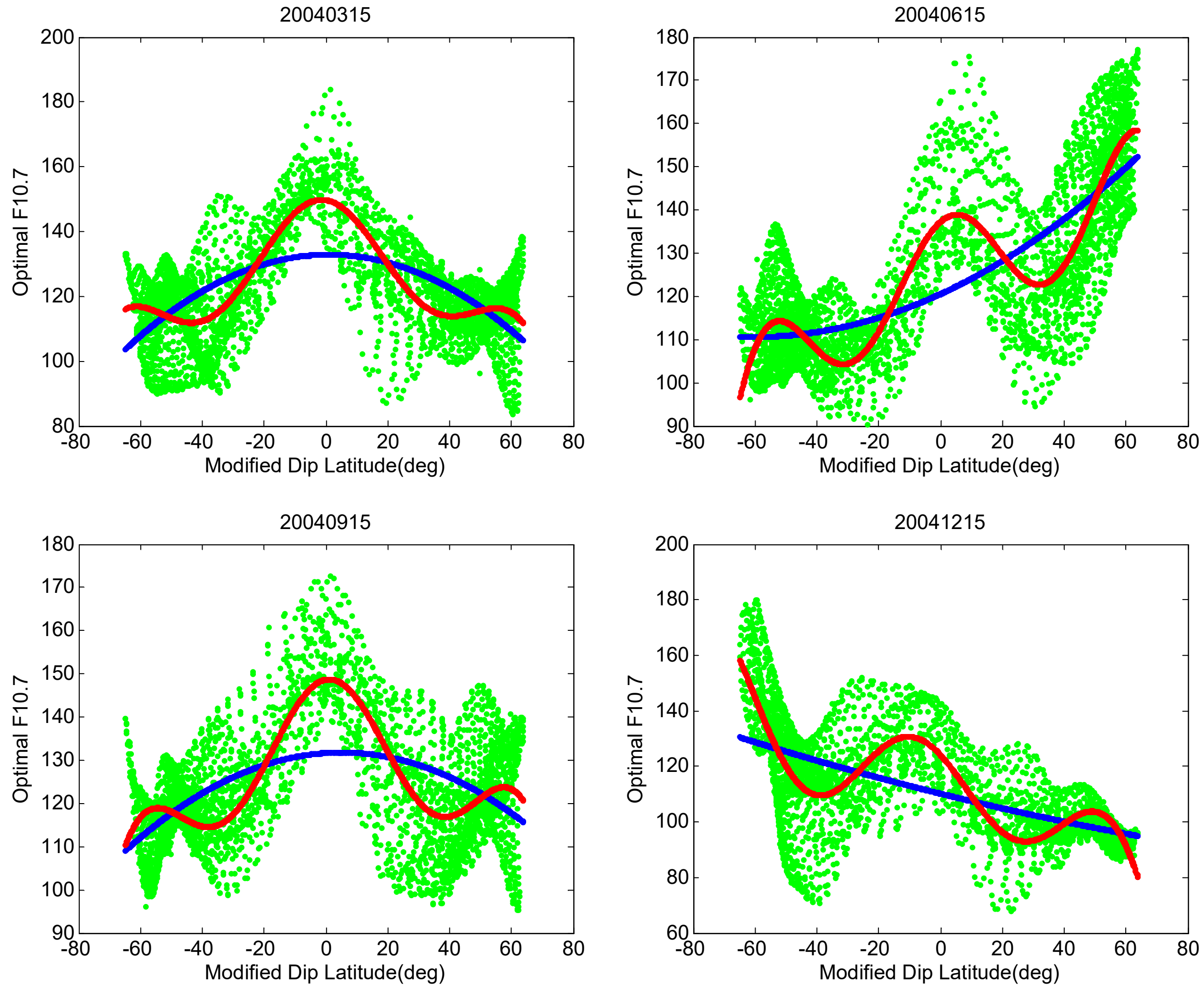


15th Sep.

15th Dec.

AZ

ER

It is clear that the ER model can reproduce the wave like shape of optimum F10.7 indexes better than Az model.

Correlation Coefficients between the two models and measurements

| | 20140315 | 20140615 | 20140915 | 20141215 |
|---|---|---|---|---|
| AZ | 0.51 | 0.74 | 0.42 | 0.61 |
| ER | 0.71 | 0.82 | 0.66 | 0.76 |

With respect to statistic result, the averages of correlation coefficients are 0.58 and 0.74 for the whole year 2014 .

The performance of the optimum F10.7 modeling is improved using ER model.

The ER model is selected to implement the ionospheric correction.

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# ER Modeling with GNSS Data

Observations (vertical TEC)

↓

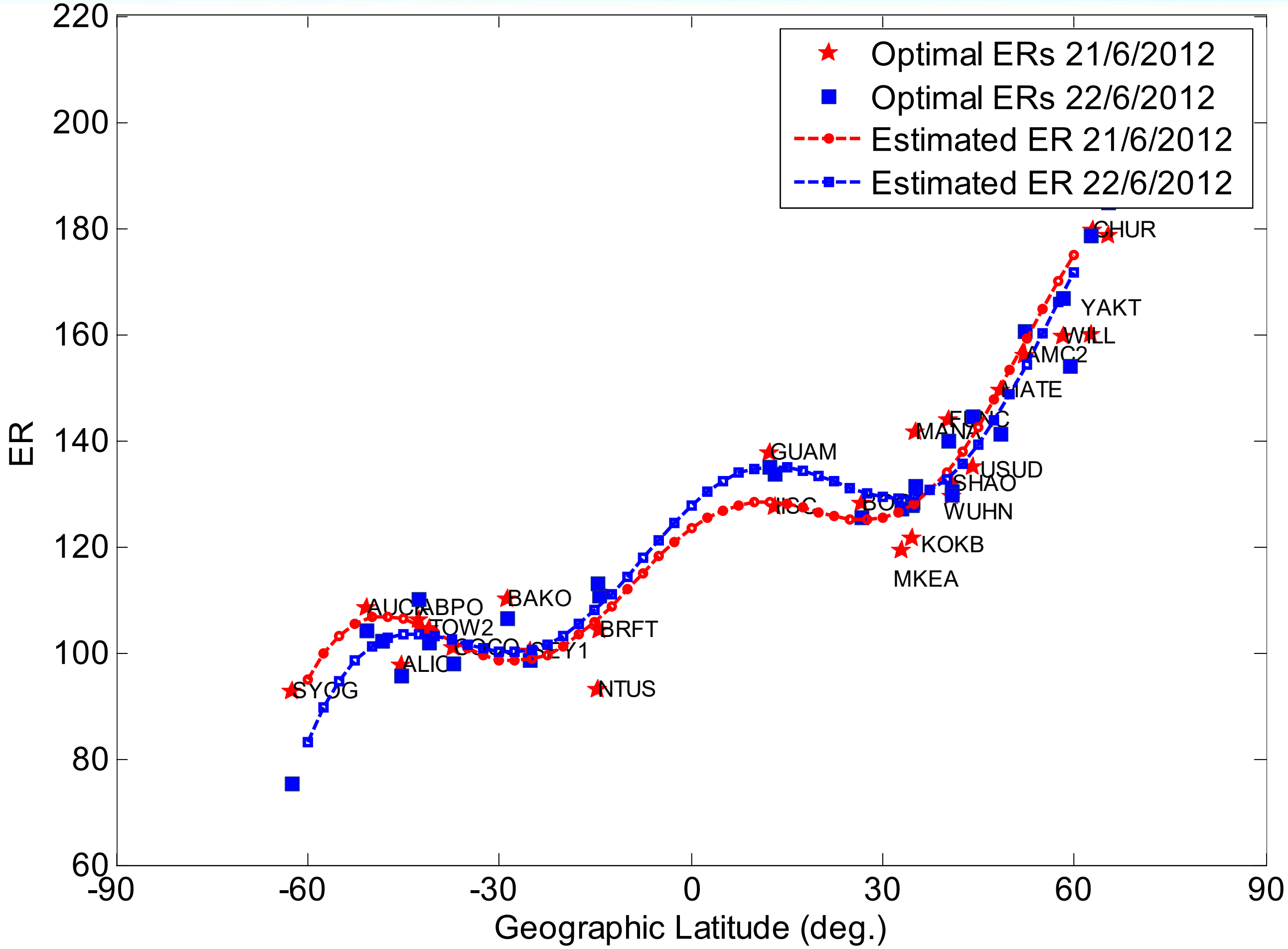
Optimize F10.7 for NeQuick to match observations

↓

MODIP of each station

↓

Coefficients of ER model is estimated in a least square




*ER* variation on two adjacent days

(red for 21st June 2012, and blue for 22nd June 2012).

ER is applicable for a period of 24 hours forecasting

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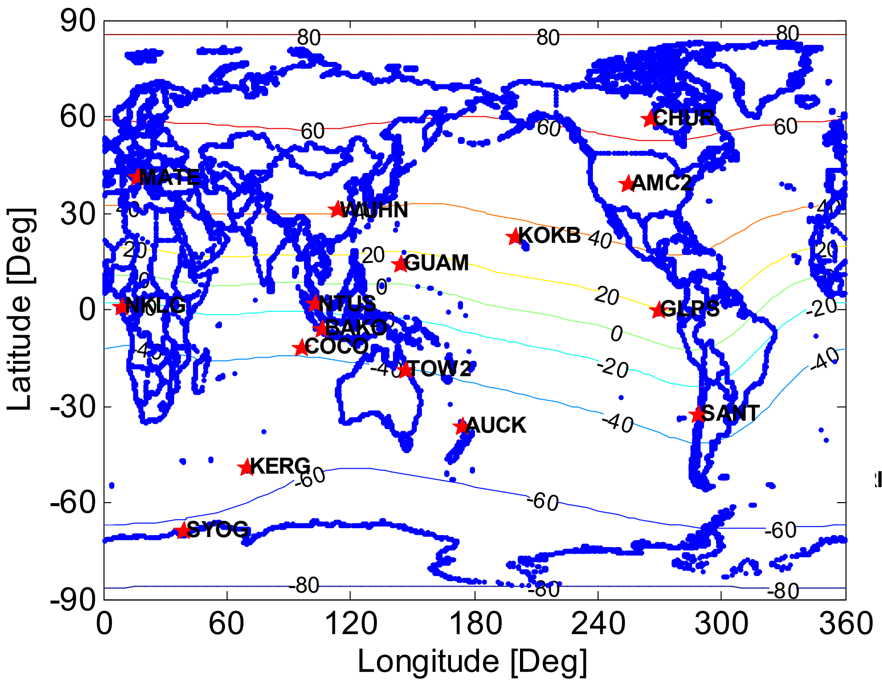
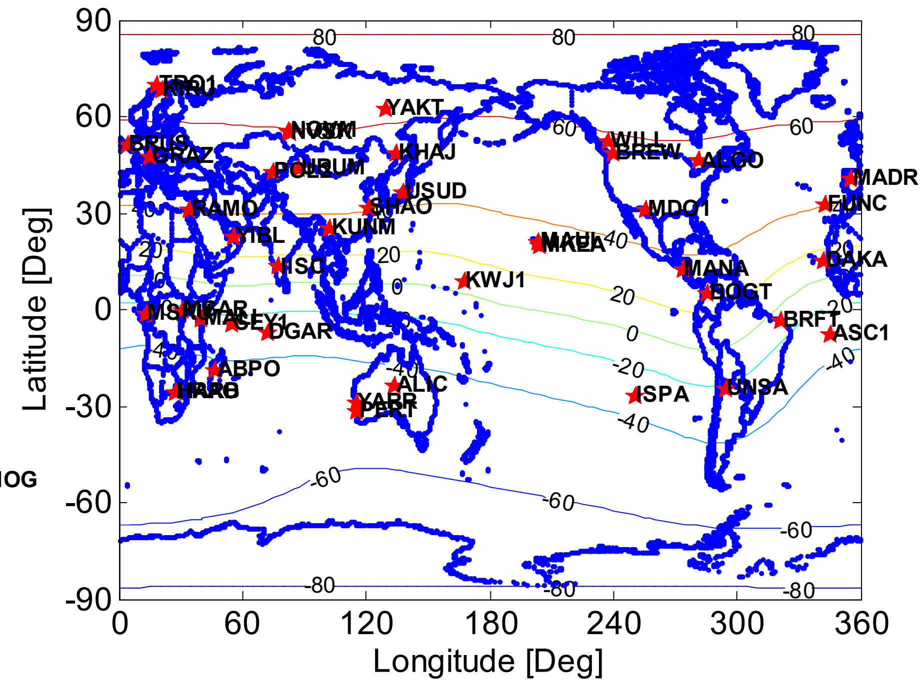
# Assessment Study

•Distribution of sites used for assessment




Monitor sites used for establish ER model

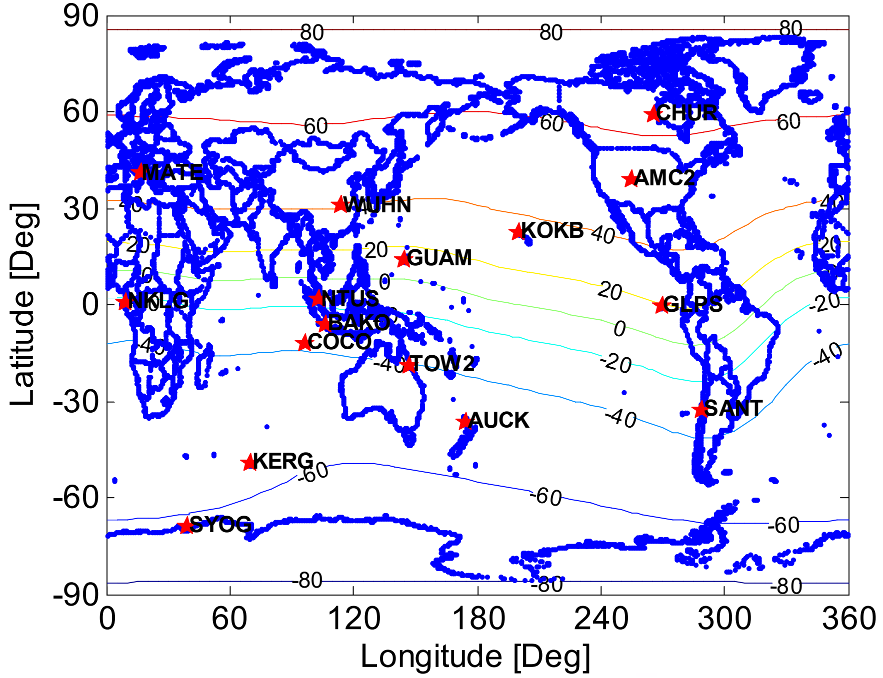



Test sites used for assessing the ionospheric correction algorithm

Step 1:

Coefficients of *ER* model estimated in a least square method based on measurements from monitor sites

$$ER = a_0 + a_1 \cdot MODIP + a_2 \cdot MODIP^2 + a_3 \cdot MODIP \cdot \cos\left(a_4 \cdot MODIP + a_5\right)$$



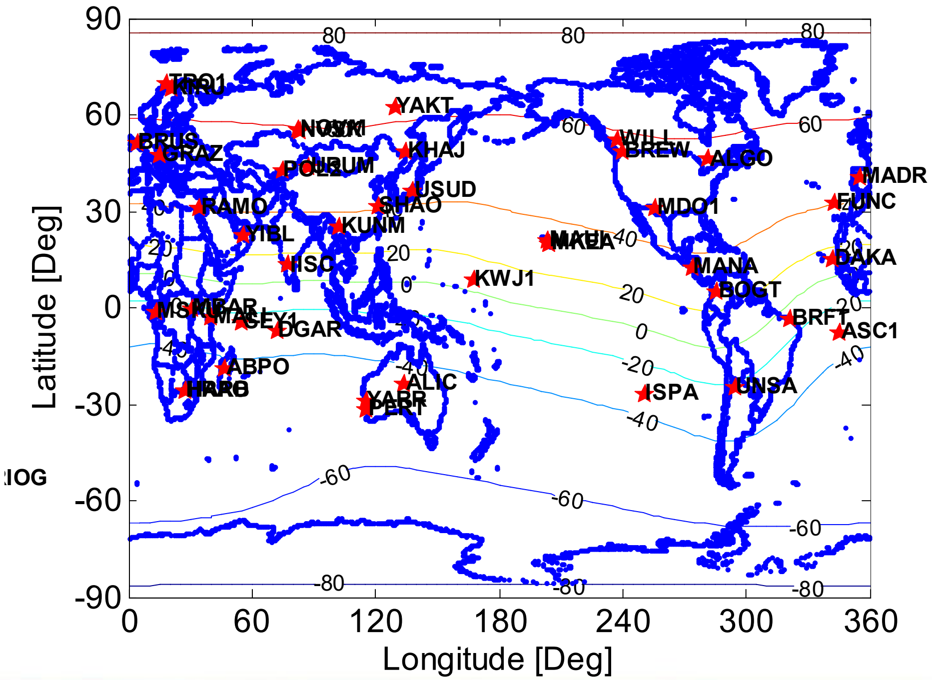

Monitor sites used for establish ER model

Step 2:

Modips of the test sites acquired

Step 3:

*ER* of every test site obtained ($ER_f$) with ER model



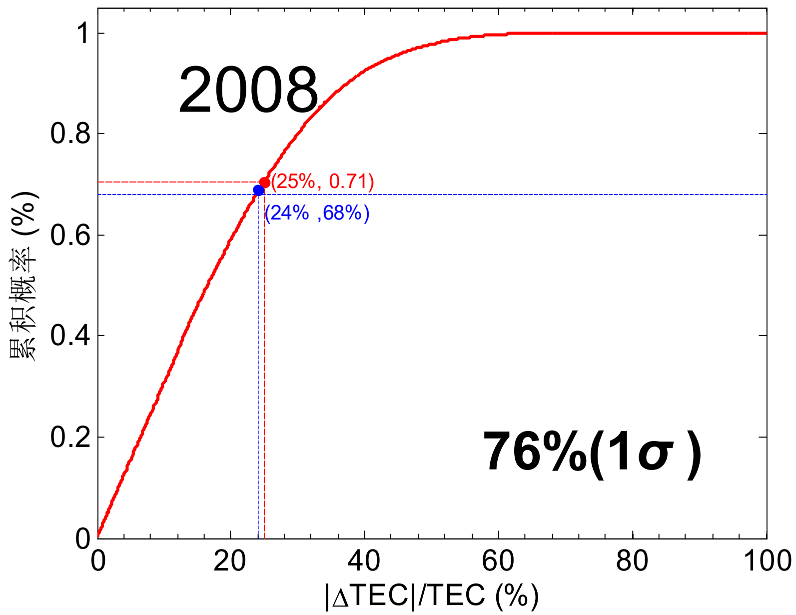

Test sites used for assessing the ionspheric model

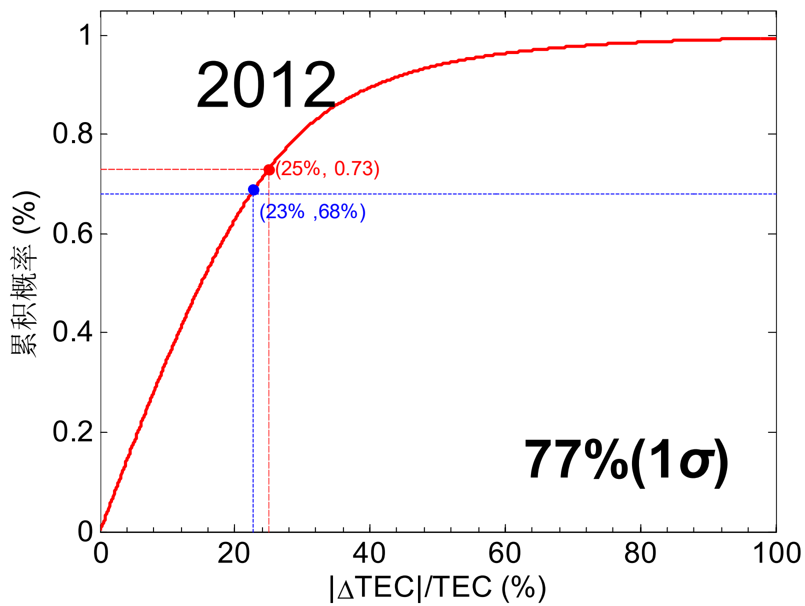
Step 4: TEC of the ionospheric model calculated as model result of the following day of test sites

Step 5: TEC of the test sites calculated as observation result of the following day

Step 6: To make comparison between model result and observation result

• Cumulative probability distribution of relative error for driven NeQuick model



## •Statistic result

| year | Yearly Average of sunspot number | Correction percent（%） | average（TECU） | std（TECU） | rms（TECU） | Total samplin g points | Total sampling days |
|---|---|---|---|---|---|---|---|
| 2002 | 110 | 74 | -0.23 | 12.62 | 12.62 | 1956665 | 60 |
| 2003 | 65.65 | 73 | -1.05 | 12.14 | 12.19 | 2190237 | 96 |
| 2005 | 28.916 | 76 | 0.04 | 7.20 | 7.20 | 500649 | 25 |
| 2006 | 16.075 | 78 | 0.39 | 5.82 | 5.84 | 831945 | 65 |
| 2008 | 2.85 | 76 | 1.08 | 3.98 | 4.12 | 64840 | 18 |
| 2009 | 4.2 | 75 | 0.47 | 5.37 | 5.39 | 162804 | 20 |
| 2010 | 17.5333 | 80 | -0.07 | 5.36 | 5.56 | 1263792 | 70 |
| 2011 | 50.3250 | 79 | -0.23 | 7.13 | 7.13 | 2445737 | 70 |
| 2012 | 69.4167 | 77 | -0.25 | 7.97 | 7.97 | 2543936 | 84 |
| mean | 40.5518 | 76 | 0.02 | 7.51 | 7.56 | 1328956 | 56 |

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# Summary

- Designating a much higher (sometimes lower ) solar flux input than real F10.7 index, data ingestion process would reduce the discrepancies of Nequick 2 .
- ER model depicts the optimum F10.7 variation better than AZ model
- ER is applicable for a period of 24 hours forecasting.
- Assessment study with IGS measurements shows that, the correction present of the NeQuick 2 using *ER model* could be ~76%, which would be better than NeQuick G used in Galileo system for single frequency receivers.
- Further assessment with more TEC measurements and assessment of performance at different latitudes need to be studied.

# *Thanks for all your attention!*

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