Comparison of GPS Derived TEC with the TEC Predicted by IRI 2012 Model Over the Eastern Africa Region

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Outline

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- Methodology
- Results and Discussion
- Summary

Introduction

- The ionosphere is a complex physical system that exhibit different features like diurnal, seasonal and spatial variability
- The low-latitude ionosphere is highly dynamic due to various processes like equatorial ionization anomaly (EIA), Equatorial Electrojet (EEJ), and equatorial spread-F (ESF) irregularities
- In order to understand the physics that controls the dynamics of the ionosphere, several ionospheric models have been developed during the last several decades

Intro…………

- Empirical models are among the types of ionospheric models that have been developed
- They give an average behavior of the ionosphere based on observational data
- Example:
  - NeQuick model
  - International Reference Ionosphere (IRI) model

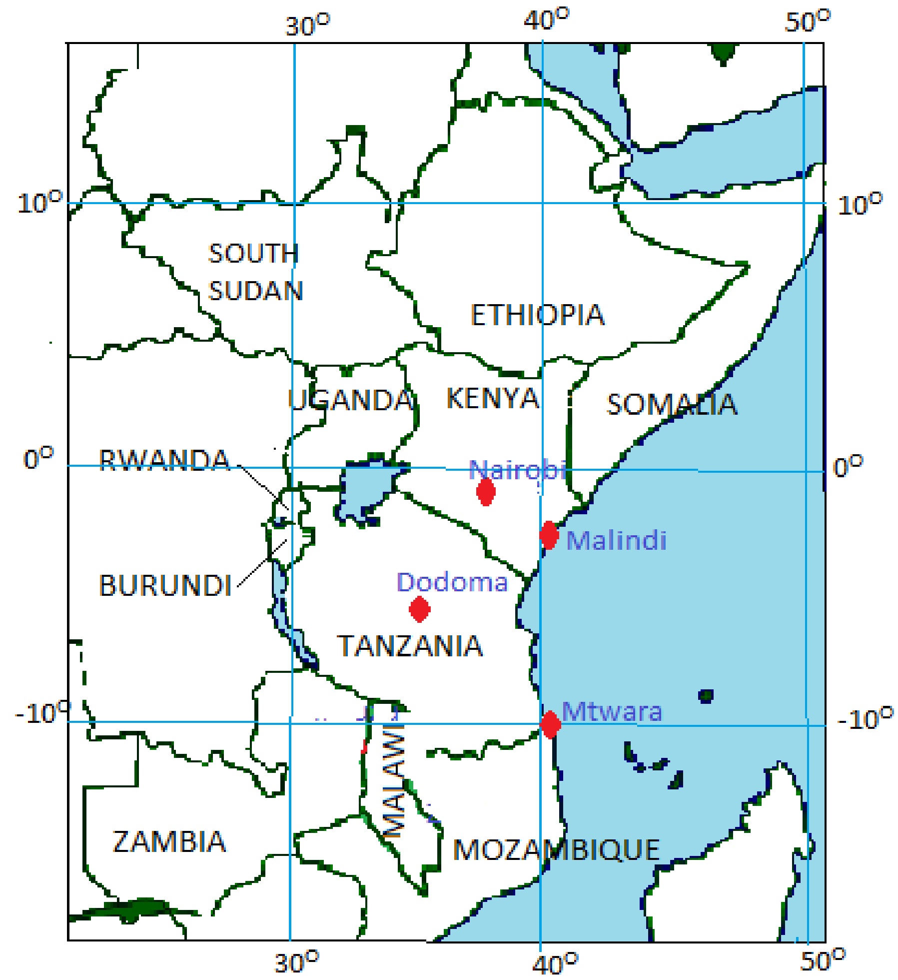
Intro………..

- The IRI model is based on experimental evidence using all available ground and space data sources
- It is continually upgraded as new data and new modeling approaches become available, and this process has resulted in several major editions of IRI

❖ The objective of this study was to validate the TEC obtained from the IRI-2012 model with the GPS derived TEC data recorded at four stations over the Eastern Africa region.

Methodology

- GPS-derived TEC data for 2012-2013 has been obtained from the Africa array and IGS network of ground based dual-frequency GPS receivers within the Eastern Africa region available at UNAVCO website (http://www.unavco.org/).



Method……….

- The slant TEC was obtained from the equation

$$TECs = \frac{1}{40.3}\left(\frac{f_1^{\,2} f_2^{\,2}}{f_1^{\,2} - f_2^{\,2}}\right)(P_1 - P_2)$$

where P_1 and P_2 are pseudoranges observable on L1 and L2 signals, f_1 and f_2 are the corresponding high and low GPS frequency respectively

- TECv is obtained from the TECs by use of a mapping function which takes the curvature of the Earth into account as;

$$TECv = M(e) \times TECs - (b_s + b_r + b_{rx})$$

Method……….

- where b_s is satellite bias, b_r is a receiver bias, b_{rx} is a receiver interchannel bias and

$$M(e) = \left[1 - \left(\frac{\cos(e)}{1 + h/R_E} \right)^2 \right]^{\frac{1}{2}}$$

- Here *e* is an elevation angle of a satellite, *h* is ionospheric shell height, and R_E is the Earth's mean radius

Method……….

- Validation of IRI 2012 model has been carried out by comparing GPS TEC with the TEC obtained from IRI 2012 model for the years 2012 and 2013
- A typical quite day of each month representing the four seasons (March equinox, June solstice, September equinox and December solstice) has been used in the analysis
- The three options for topside electron density have been used to compute the TEC from IRI 2012 model
- The IRI model is routinely updated and the latest available version is the IRI-2012, which is accessible from the IRI homepage (http://IRI.gsfc.nasa.gov)

Method.........

- Correlation Coefficients between the two sets of data, the Root-Mean Square Errors (RMSE) and the percentage RMSE of the IRI-TEC from the GPS-TEC have been computed using the following equations;

$$Correlation\ Coefficient = \frac{\sum_i (GPS_i - \overline{GPS}_i)(IRI_i - \overline{IRI}_i)}{\sum_i (GPS_i - \overline{GPS}_i)^2 \sum_i (IRI_i - \overline{IRI}_i)^2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (GPS_i - IRI_i)^2}{n}}$$

Method……….

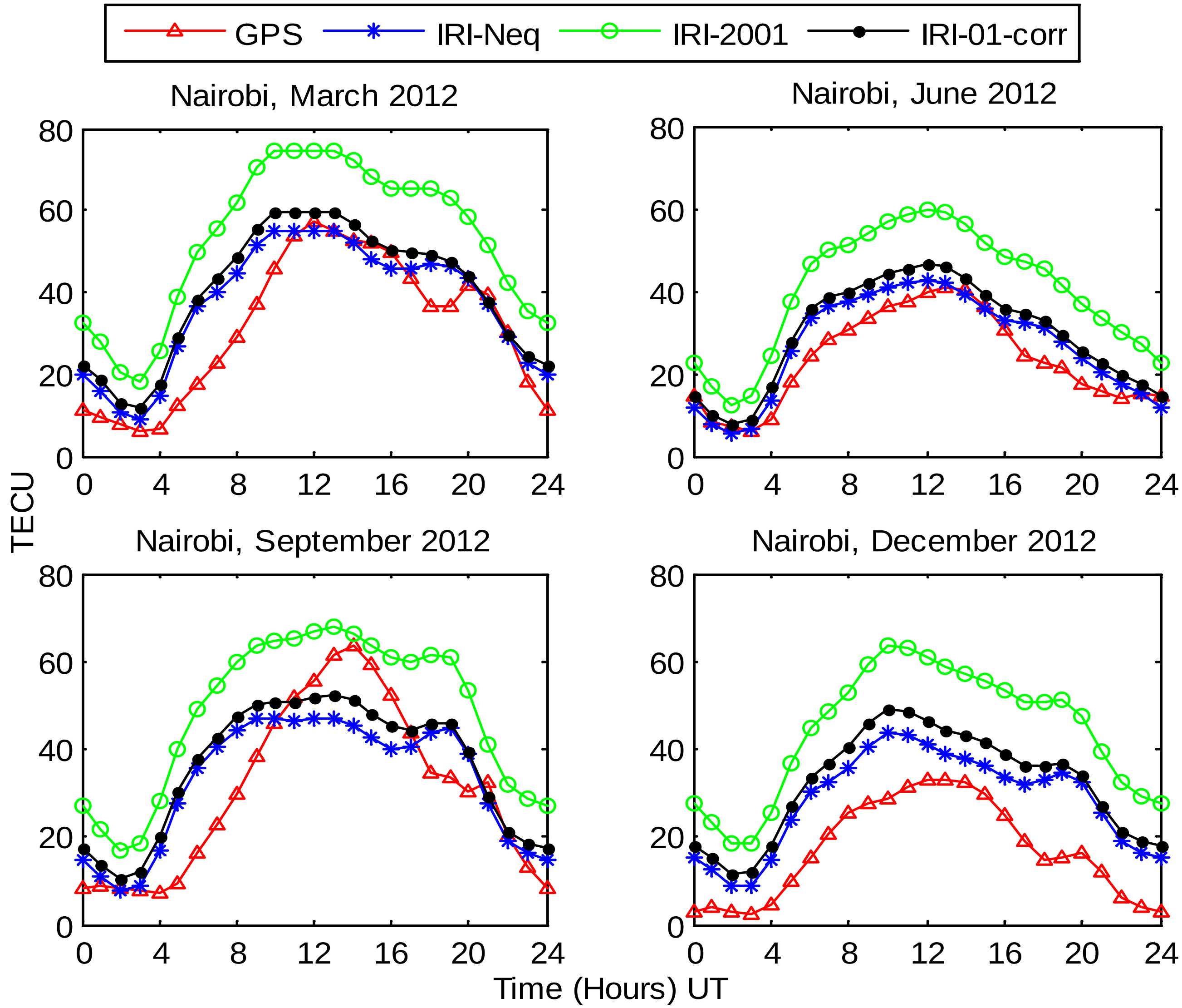
$$PRMSE = \frac{RMSE}{RMS_{GPS}} \times 100$$

Where

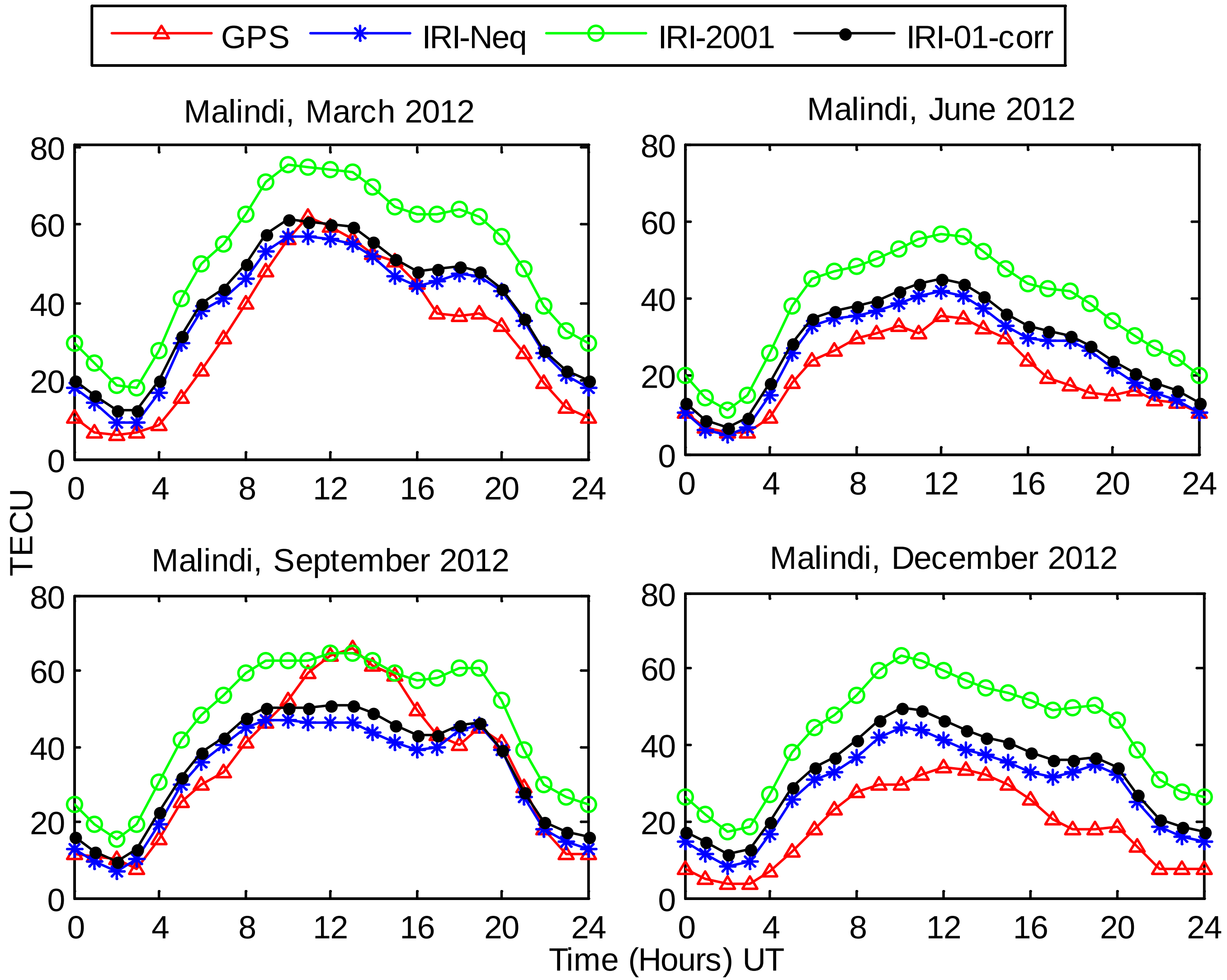
$$RMS_{GPS} = \sqrt{\frac{\sum_{i=1}^{n} (GPS_i)^2}{n}}$$

where GPS_i are GPS-TEC data, $\overline{GPS}_i$ is their mean, IRI_i are IRI-TEC data, $\overline{IRI}_i$ is their mean, and n is the number of them. RMS_{GPS} is the root-mean square value for the GPS-TEC data, and the subscripts 'i' denote numerical positions in the data, having integral values from *1 to n.*

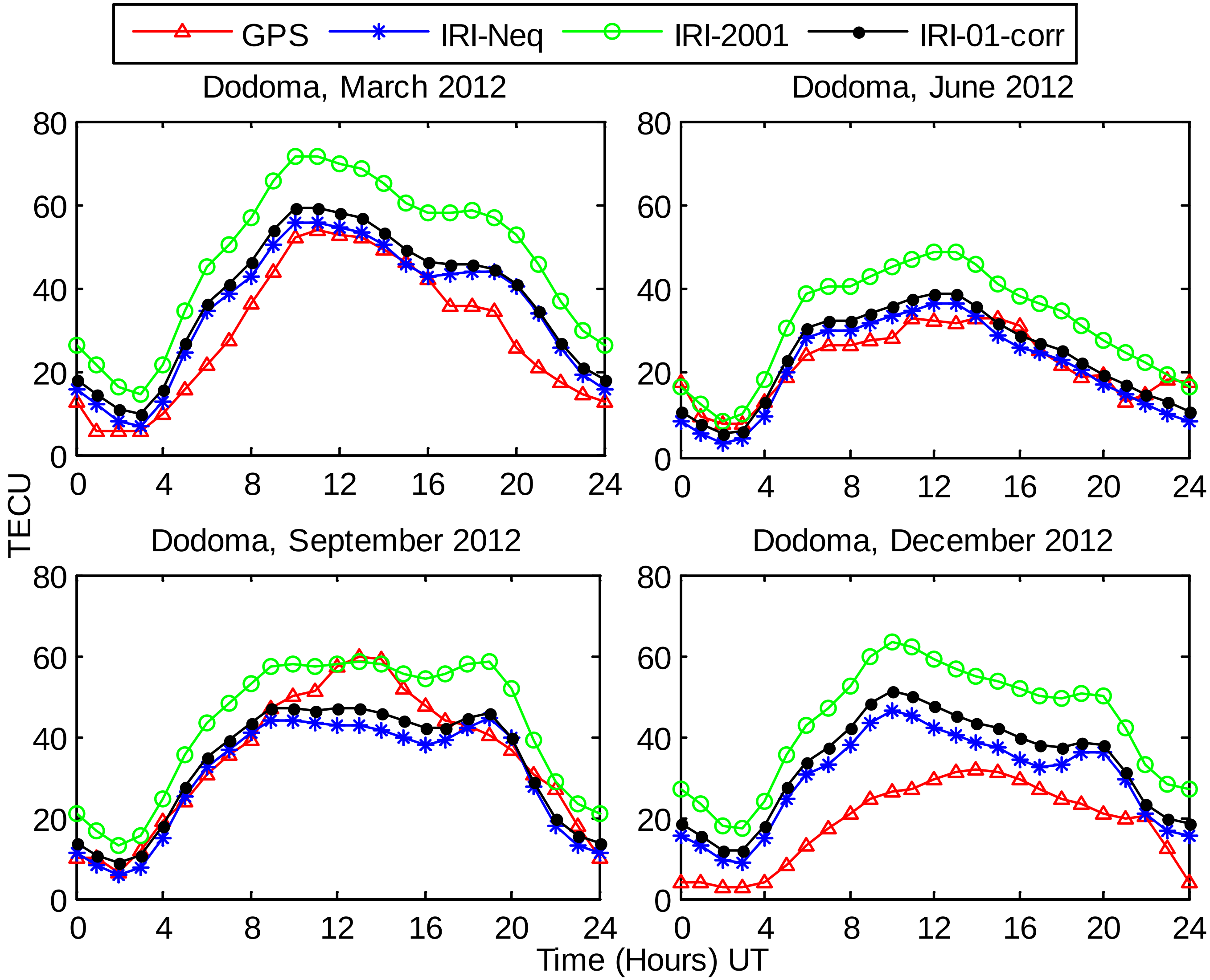
Results

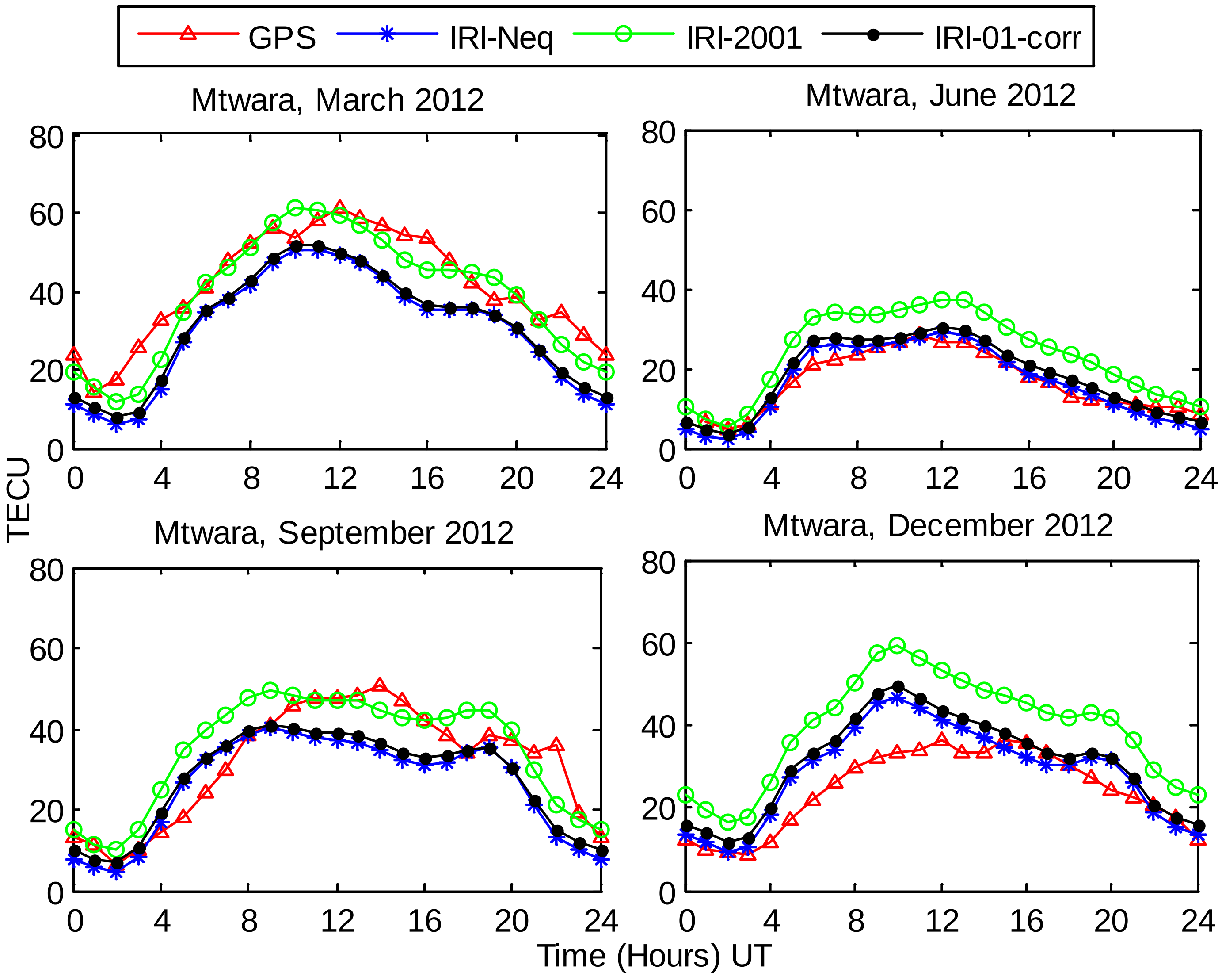


GPS
IRI-Neq
IRI-2001
IRI-01-corr
Nairobi, March 2012
Nairobi, June 2012
Nairobi, September 2012
Nairobi, December 2012
TECU
Time (Hours) UT
0
20
40
60
80
0
4
8
12
16
20
24

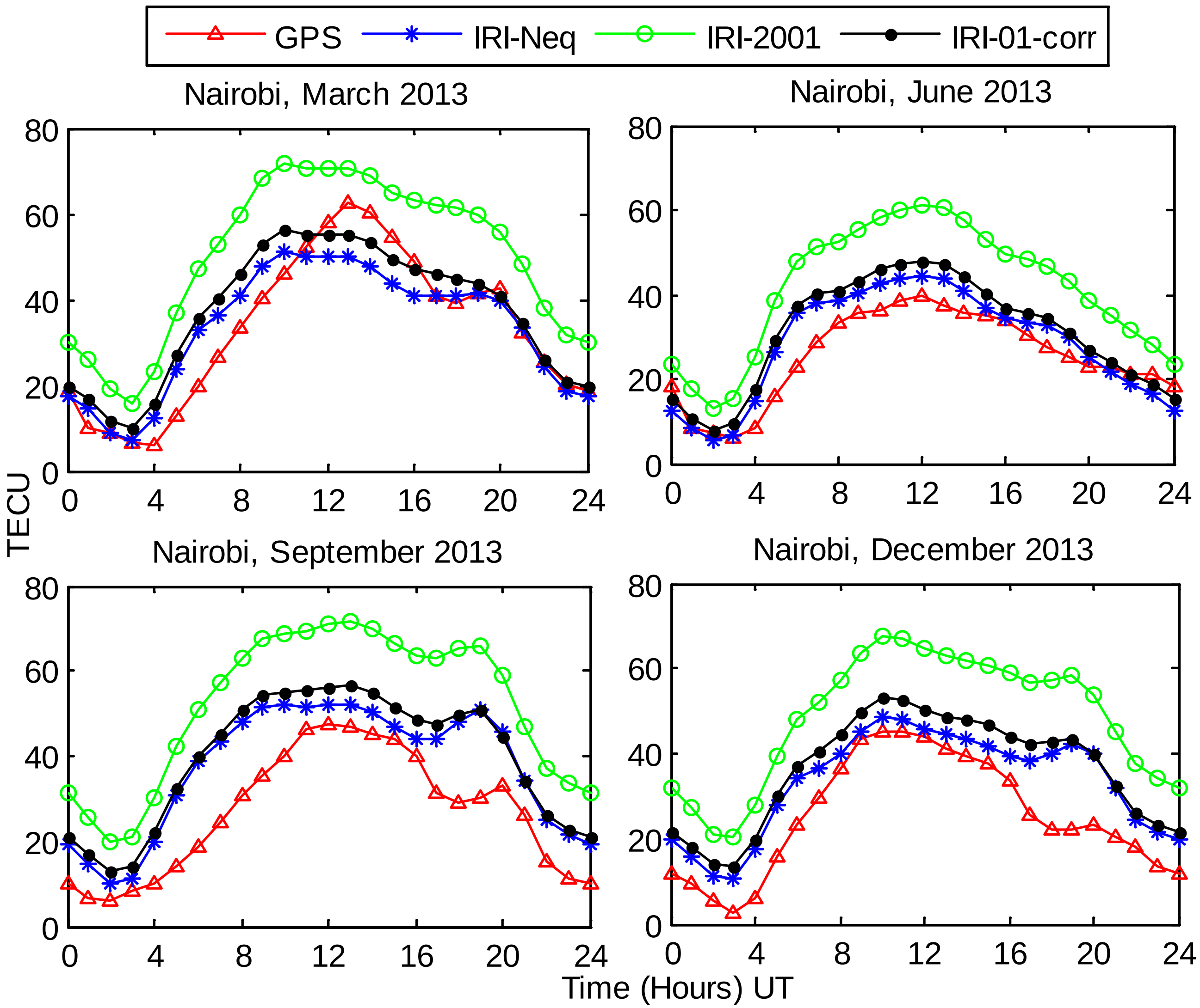


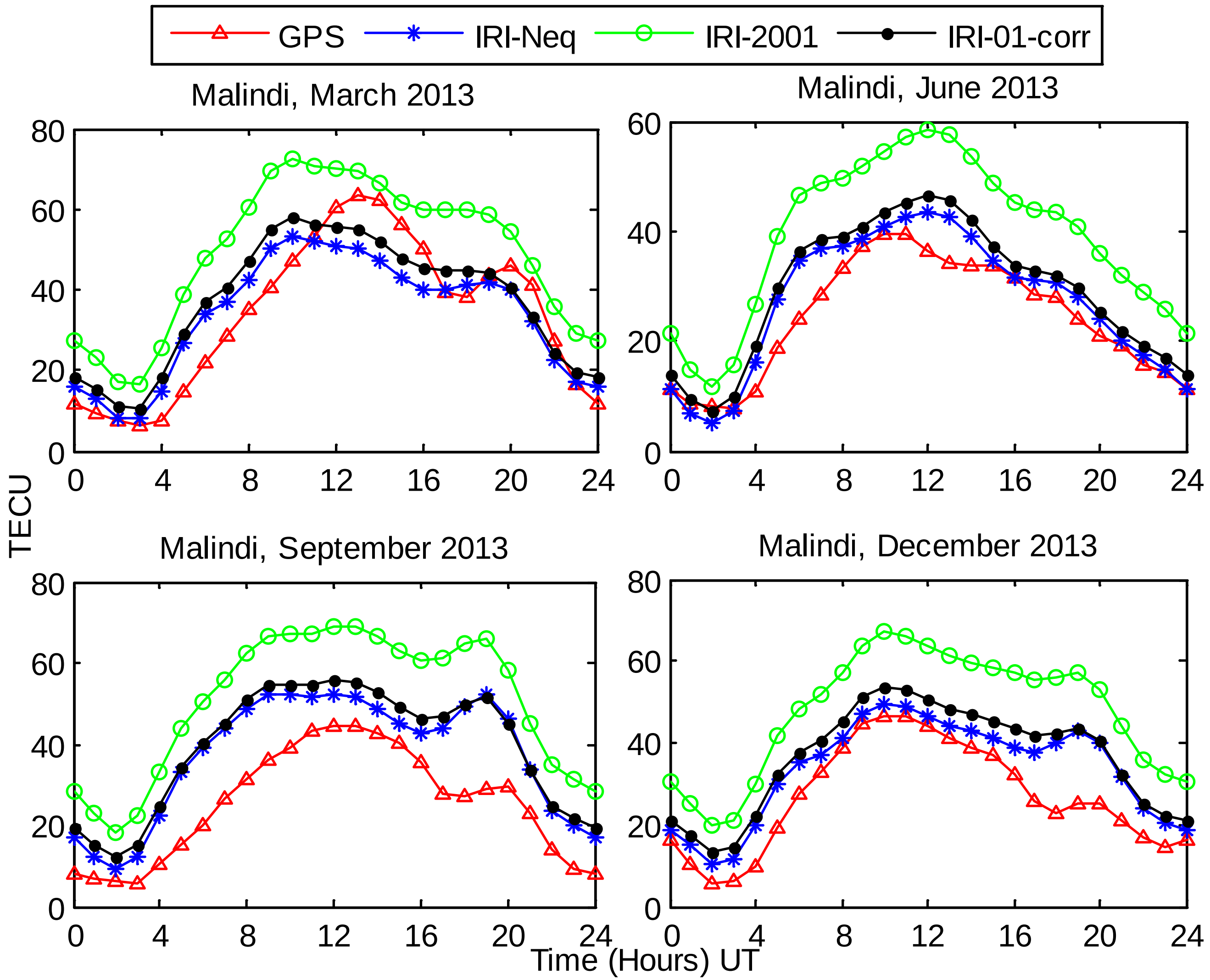
GPS
IRI-Neq
IRI-2001
IRI-01-corr
Malindi, March 2012
Malindi, June 2012
Malindi, September 2012
Malindi, December 2012
TECU
Time (Hours) UT

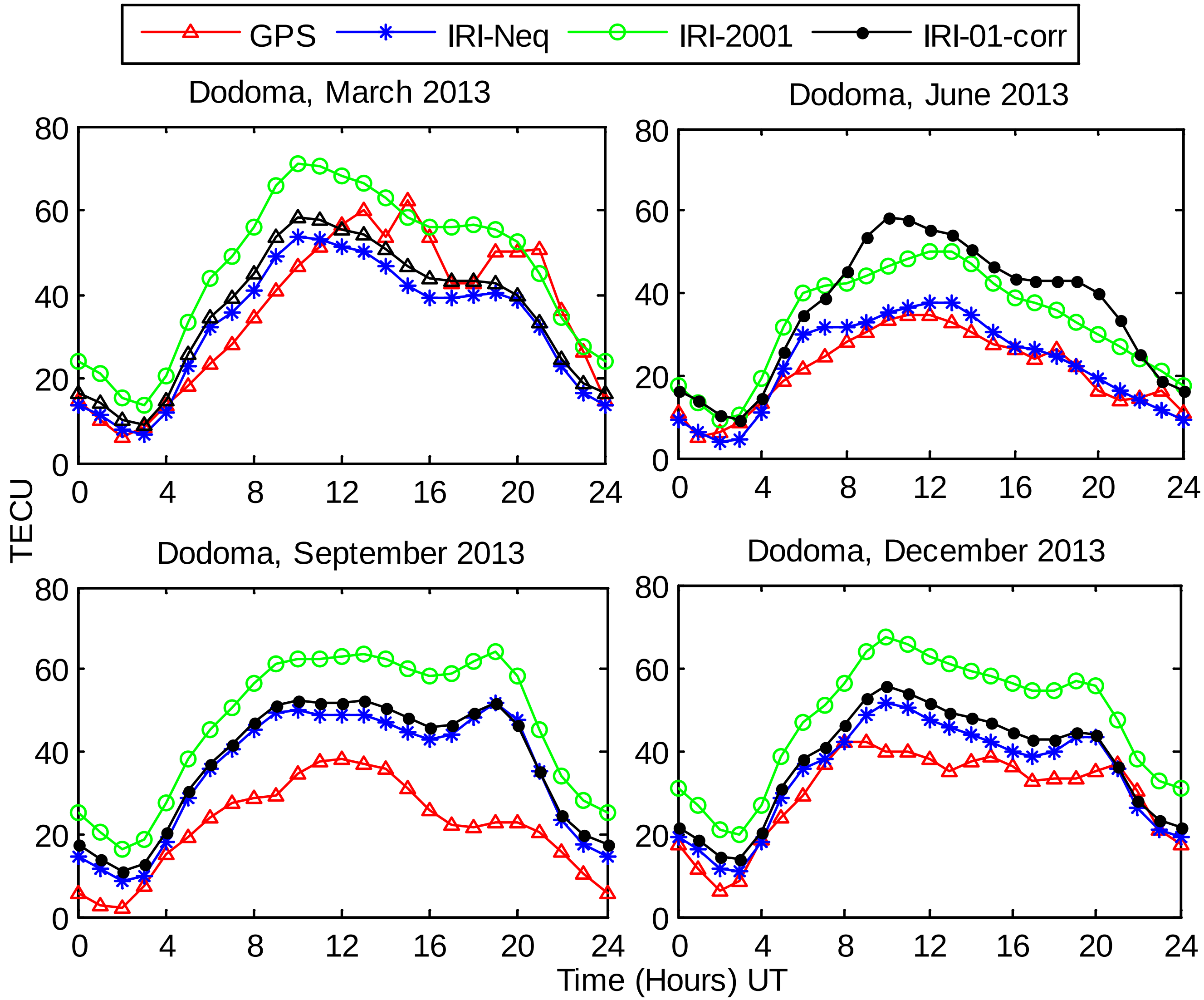

GPS
IRI-Neq
IRI-2001
IRI-01-corr
Dodoma, March 2012
Dodoma, June 2012
Dodoma, September 2012
Dodoma, December 2012
TECU
Time (Hours) UT
0
4
8
12
16
20
24
0
20
40
60
80



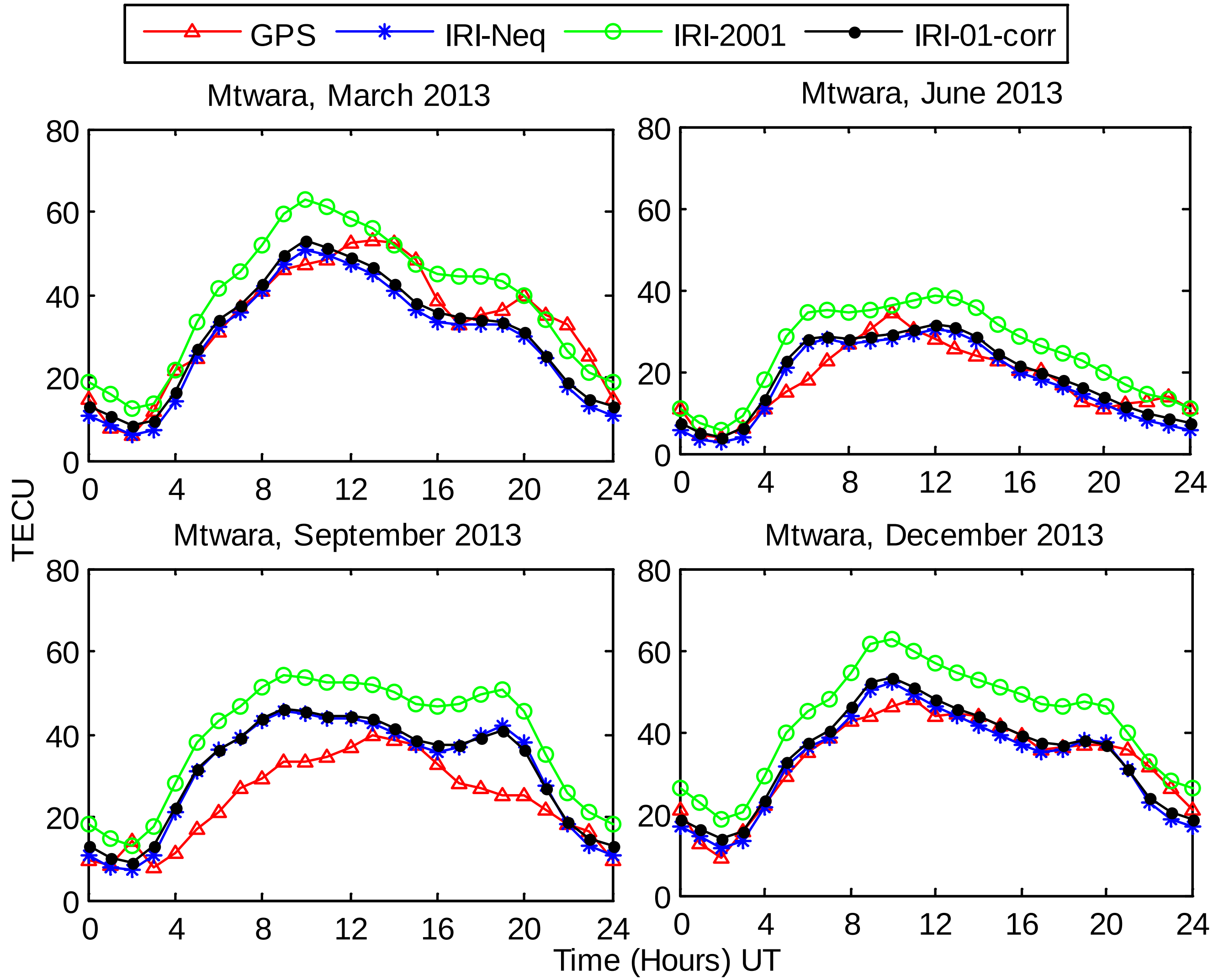
GPS
IRI-Neq
IRI-2001
IRI-01-corr
Mtwara, March 2012
Mtwara, June 2012
Mtwara, September 2012
Mtwara, December 2012
TECU
Time (Hours) UT
0
20
40
60
80
0
4
8
12
16
20
24


GPS
IRI-Neq
IRI-2001
IRI-01-corr
Nairobi, March 2013
Nairobi, June 2013
Nairobi, September 2013
Nairobi, December 2013
TECU
Time (Hours) UT
0
4
8
12
16
20
24
0
20
40
60
80


GPS
IRI-Neq
IRI-2001
IRI-01-corr
Malindi, March 2013
Malindi, June 2013
Malindi, September 2013
Malindi, December 2013
TECU
Time (Hours) UT



GPS
IRI-Neq
IRI-2001
IRI-01-corr
Dodoma, March 2013
Dodoma, June 2013
Dodoma, September 2013
Dodoma, December 2013
TECU
Time (Hours) UT


GPS
IRI-Neq
IRI-2001
IRI-01-corr
Mtwara, March 2013
Mtwara, June 2013
Mtwara, September 2013
Mtwara, December 2013
TECU
Time (Hours) UT
0
20
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0
4
8
12
16
20
24

- The disagreements of the GPS TEC values and those estimated by IRI 2012 model is due to the relatively small amount of data from the region considered in developing the model, the Eastern Africa region

- **Bilitza and Reinisch (2008);** "*the scarcity of ionospheric data over the African Equatorial region is a factor that contributes to the diminished accuracies of the IRI predictions over this region*"

Correlation coefficients

2012 Corr. coeff

		Dodoma	Mtwara	Malindi	Nairobi
March Equinox	IRI-Neq	0.9658	0.9580	0.9642	0.9220
	IRI-2001	0.9712	0.9591	0.9702	0.9301
	IRI-01-Corr	0.9757	0.9607	0.9736	0.9223
June Solstice	IRI-Neq	0.9340	0.9825	0.9640	0.9569
	IRI-2001	0.9406	0.9757	0.9623	0.9626
	IRI-01-Corr	0.9369	0.9805	0.9693	0.9650
September Equinox	IRI-Neq	0.9345	0.8491	0.9229	0.8416
	IRI-2001	0.9512	0.8695	0.9465	0.8850
	IRI-01-Corr	0.9516	0.8546	0.9425	0.8718
December Solstice	IRI-Neq	0.8952	0.9059	0.9528	0.9427
	IRI-2001	0.9185	0.9307	0.9607	0.9509
	IRI-01-Corr	0.9009	0.9126	0.9667	0.9607

2013 corr. coeff

		Dodoma	Mtwara	Malindi	Nairobi
March Equinox	IRI-Neq	0.8843	0.9348	0.9177	0.9288
	IRI-2001	0.8887	0.9368	0.9209	0.9356
	IRI-01-Corr	0.8746	0.9304	0.9136	0.9296
June Solstice	IRI-Neq	0.9699	0.9193	0.9645	0.9386
	IRI-2001	0.9719	0.9177	0.9677	0.9514
	IRI-01-Corr	0.9543	0.9173	0.9649	0.9403
September Equinox	IRI-Neq	0.9098	0.8863	0.9278	0.9220
	IRI-2001	0.9107	0.9042	0.9494	0.9466
	IRI-01-Corr	0.9262	0.9002	0.9492	0.9431
December Solstice	IRI-Neq	0.9513	0.9620	0.9320	0.9317
	IRI-2001	0.9501	0.9697	0.9392	0.9417
	IRI-01-Corr	0.9457	0.9591	0.9507	0.9524

Root mean square error

2012 RMSE

		Dodoma	Mtwara	Malindi	Nairobi
March Equinox	IRI-Neq	7.0394	11.8846	7.6203	8.8151
	IRI-2001	18.7052	5.1983	20.3765	22.4399
	IRI-01-Corr	8.8990	10.6746	9.3361	10.9402
June Solstice	IRI-Neq	4.4586	2.3552	6.3971	4.9335
	IRI-2001	11.0446	7.9947	18.1688	17.4543
	IRI-01-Corr	4.7016	2.8911	8.5440	6.9939
September Equinox	IRI-Neq	7.4150	9.2449	8.5678	10.6777
	IRI-2001	9.6483	7.6776	12.7612	19.5970
	IRI-01-Corr	5.5755	8.3049	7.2067	10.8830
December Solstice	IRI-Neq	12.1939	6.3971	10.3760	12.0212
	IRI-2001	25.5359	15.4960	25.0495	27.6262
	IRI-01-Corr	15.6402	8.0559	13.8202	15.5996

2013 RMSE

		Dodoma	Mtwara	Malindi	Nairobi
March Equinox	IRI-Neq	8.8819	6.6941	7.8438	6.7995
	IRI-2001	13.1987	7.6904	16.9541	18.0007
	IRI-01-Corr	8.5175	5.8187	8.4719	7.6408
June Solstice	IRI-Neq	3.4565	3.8572	4.5811	5.4889
	IRI-2001	12.3032	8.0880	15.7490	17.3808
	IRI-01-Corr	16.2479	3.9413	6.3336	7.2867
September Equinox	IRI-Neq	14.9219	9.1770	13.0904	12.0779
	IRI-2001	26.3483	16.2024	25.9766	26.0263
	IRI-01-Corr	16.5440	9.2781	14.7582	13.9603
December Solstice	IRI-Neq	6.2052	3.4914	8.1272	9.4701
	IRI-2001	18.5705	9.9675	21.5065	23.7732
	IRI-01-Corr	8.7880	3.6418	10.3754	11.8766

Percentage root mean square error

2012 PRMSE

		Dodoma	Mtwara	Malindi	Nairobi
March Equinox	IRI-Neq	21.1064	27.3449	20.8434	24.6164
	IRI-2001	56.0840	11.9605	55.7349	62.6638
	IRI-01-Corr	26.6821	24.5607	25.5366	30.5506
June Solstice	IRI-Neq	18.9500	13.0869	28.4987	18.9987
	IRI-2001	46.9419	44.4224	80.9406	67.2155
	IRI-01-Corr	19.9830	16.0647	38.0629	26.9332
September Equinox	IRI-Neq	19.4248	26.8329	21.4097	29.6567
	IRI-2001	25.2754	22.2838	31.8885	54.4294
	IRI-01-Corr	14.6059	24.1045	18.0086	30.2269
December Solstice	IRI-Neq	58.0083	24.4315	48.8205	59.9534
	IRI-2001	121.4782	59.1821	117.8612	137.7800
	IRI-01-Corr	74.4029	30.7668	65.0257	77.7996

2013 PRMSE

		Dodoma	Mtwara	Malindi	Nairobi
March Equinox	IRI-Neq	22.2750	18.5023	20.4140	18.2128
	IRI-2001	33.1010	21.2562	44.1245	48.2162
	IRI-01-Corr	21.3612	16.0829	22.0487	20.4663
June Solstice	IRI-Neq	14.9110	19.6298	17.4887	20.1324
	IRI-2001	53.0744	41.1610	60.1232	63.7500
	IRI-01-Corr	70.0918	20.0578	24.1791	26.7264
September Equinox	IRI-Neq	61.1206	35.0459	46.1351	40.2714
	IRI-2001	107.9232	61.8748	91.5510	86.7795
	IRI-01-Corr	67.7648	35.4320	52.0133	46.5477
December Solstice	IRI-Neq	19.7552	9.9406	27.5177	33.2097
	IRI-2001	59.1226	28.3788	72.8186	83.3681
	IRI-01-Corr	27.9783	10.3688	35.1300	41.6490

The largest discrepancy in TEC can be associated with a poor estimation of the hmF2 and foF2 from the coefficients

Summary

- The general structure of the diurnal variations curves from GPS TEC and from all the three options of the IRI-2012 model are quite similar
- Generally, IRI-2012 model with all three options overestimates the GPS-TEC
- IRI-2001 overestimates GPS-TEC more compared with other options at most of the stations
- GPS-TEC values and IRI-TEC values using all the three topside Ne options show very good correlation
- TEC using IRI-Neq and IRI-01- corr had small deviations from the GPS measured TEC compared to the IRI-2001

- **Acknowledgement**
  - BSS-2016 organizers
  - UNAVCO
  - My University

THANK YOU