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# Assessment of the IRI-2016 and modified IRI 2016 models in China:

## Comparison with GNSS-TEC and ionosonde data

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# Outlines

- Background and motivation
- Method of the modified IRI 2016 model
- Experimental Data and Methodology
- Results and Discussion
- Summary and conclusions

# Background and motivation

- The IRI model is an empirical ionospheric model and provides the vertical total electron content(VTEC) and the altitude profiles of electron densities. The new version is the IRI-2016 model.
- The accuracy of the IRI model is not high enough in China due to the use of fewer data sources, and the validation and improvement of the IRI model are important as more data and sophisticated techniques become available.
- Many studies have been carried out to minimize the differences between IRI predictions of ionospheric parameters (e.g. TEC and electron density profiles) and different real observations from different measurement techniques (e.g. GNSS) that including assimilating measured data into the IRI model and adjusting the ionospheric and/or solar indices used in IRI model.

# Method of the modified IRI 2016 model

- This work aims at minimizing the differences between GNSS-derived TEC data and TEC data from the modified IRI2016 model updated by adjusting the 12 months running mean of sunspot number (R12) and global ionospheric effective solar index (IG12) . The NmF2 parameter is drived by IG12 index while the maximum height of the F2 layer (hmF2) parameter relies on R12 index within the IRI 2016 model (refer to Ssessanga et al.,2015, doi.org/10.3938/jkps.66.1599 ).
- The 2016 model has three options for hmF2 predictions: the AMTB2013, the shubin2015 and the M3000F2 options. An important contribution of this work is to investigate the performance of the IRI 2016 model with all three hmF2 options before and after the modification in China, and TEC values, electron density (Ne) profiles, hmF2 values from the standard and modified IRI 2016 models are compared with GNSS TEC and ionosonde data respectively.

# Method of the modified IRI 2016 model

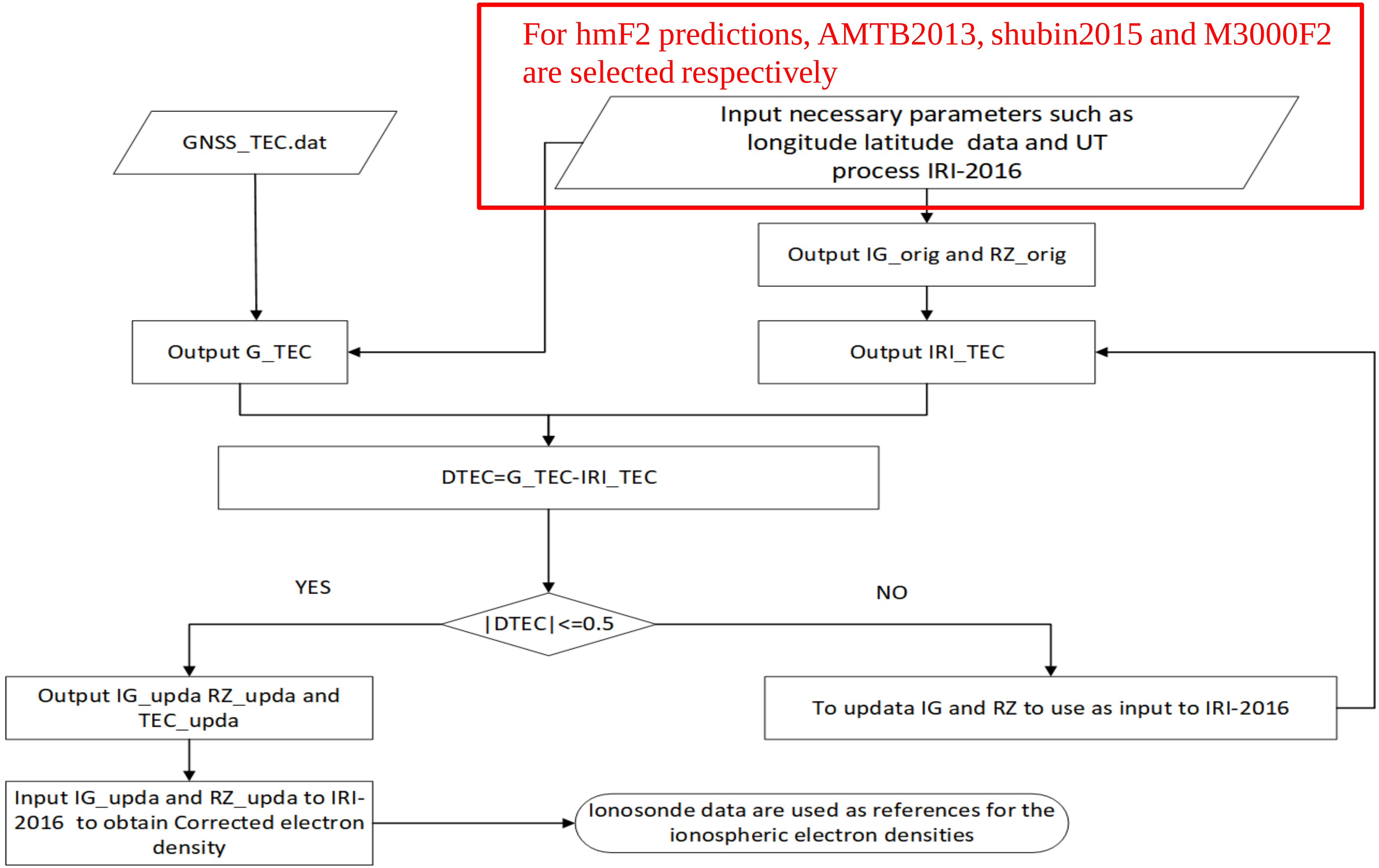



**Fig1. Diagram of the algorithm**

# Experimental Data and Methodology

- Ionospheric TEC estimated from GNSS data of the Crustal Movement Observation Network of China (CMONC) .
- Ionospheric electron densities (IED) from three ionosonde stations located at Beijing(BP440), Wuhan(WU430) and Sanya(SA418).
- Experimental data covered six days 1-6 in 2015 (high solar activity year ), and day 2-7 in 2019(low solar activity year).
- Ionospheric Electron Density (IED) profiles are presented from the modified and standard IRI-2016 model.
- RMSE and MAE values of NmF2, IED bottom-side profiles and hmF2 as well as TEC derived the modified and standard IRI-2016 model are compared with the ionosonde measurements and GPS TEC respectively.

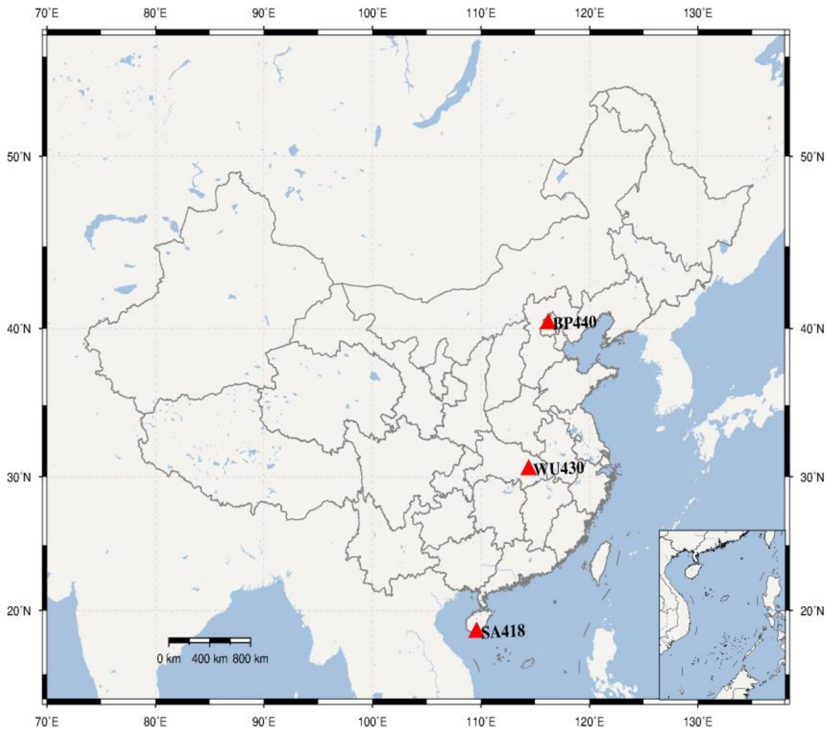
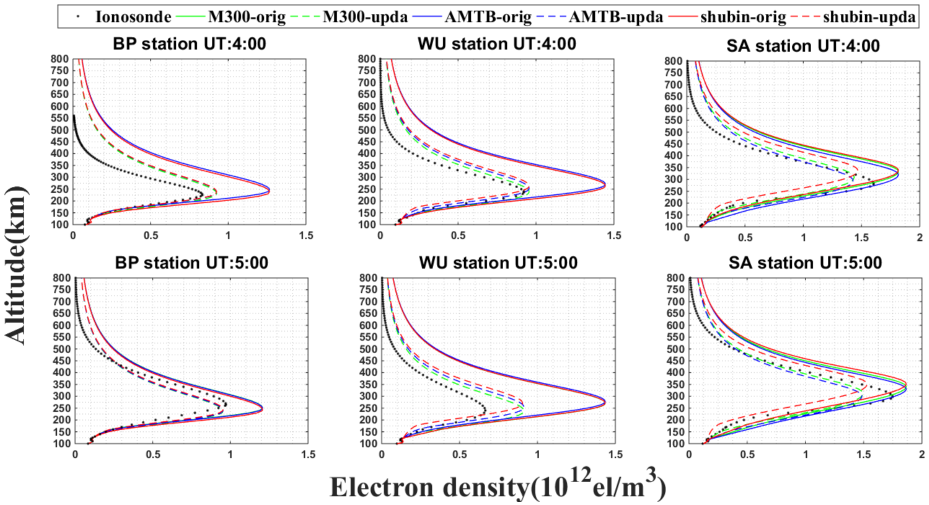


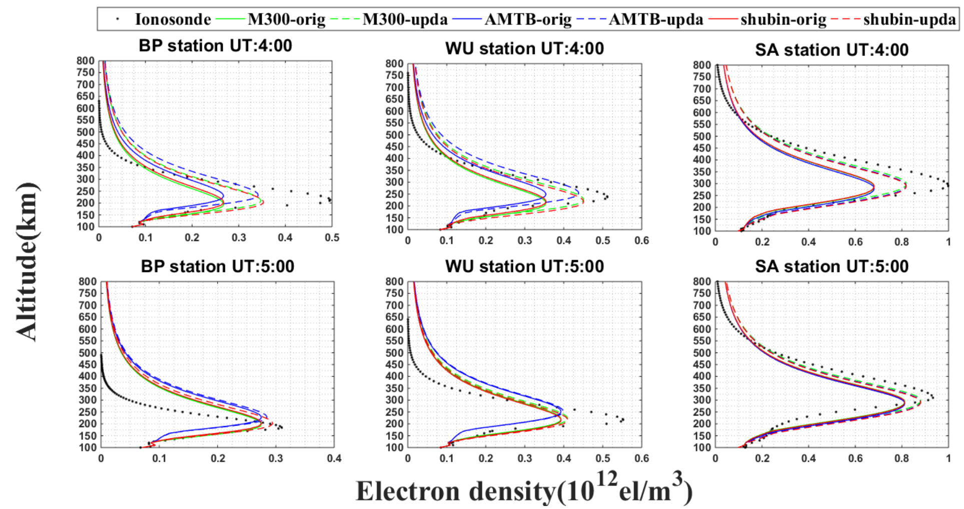

Fig2. Station location

# Results and Discussion

## (1) Ionospheric Electron Density (IED) profiles




Results on day 3 of 2015 as an example




Results on day 3 of 2019 as an example

Fig3. The IED profiles over BP, WU and SA stations at 4:00 and 5:00 UT

- The IED profiles derived from the modified IRI-2016 model match better with the IED profiles from the ionosonde data than those predicted from the standard IRI-2016 model.
- The IED profiles derived from the modified IRI-2016 model over BP and WU stations (middle latitudes) agree better with the ionosonde than those profiles over SA station(low latitude).

# Results and Discussion

## (2) Errors of peak electron densities(NmF2)

Table1(a). Root Mean Square Error of NmF2(RMSEN2) in 2015 / ($10^{12}$el/m$^3$)

| Station | IRI-2016 | | | upda-IRI-2016 | | |
|---|---|---|---|---|---|---|
| | M3000 | AMTB | shubin | M3000 | AMTB | shubin |
| BP | 0.215 | 0.215 | 0.215 | 0.151 | 0.151 | 0.151 |
| WU | 0.329 | 0.329 | 0.329 | 0.234 | 0.235 | 0.234 |
| SA | 0.351 | 0.351 | 0.351 | 0.339 | 0.338 | 0.342 |

Table1(b). Root Mean Square Error of NmF2 (RMSEN2) in 2019 / ($10^{12}$el/m$^3$)

| Station | IRI-2016 | | | upda-IRI-2016 | | |
|---|---|---|---|---|---|---|
| | M3000 | AMTB | shubin | M3000 | AMTB | shubin |
| BP | 0.136 | 0.136 | 0.136 | 0.071 | 0.067 | 0.066 |
| WU | 0.151 | 0.151 | 0.151 | 0.094 | 0.093 | 0.093 |
| SA | 0.267 | 0.267 | 0.267 | 0.226 | 0.226 | 0.226 |

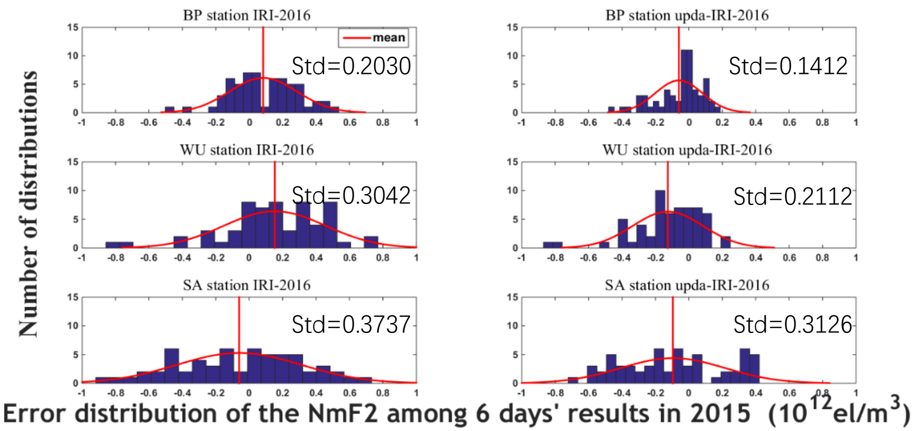



Fig4.NmF2 error distribution in 2015

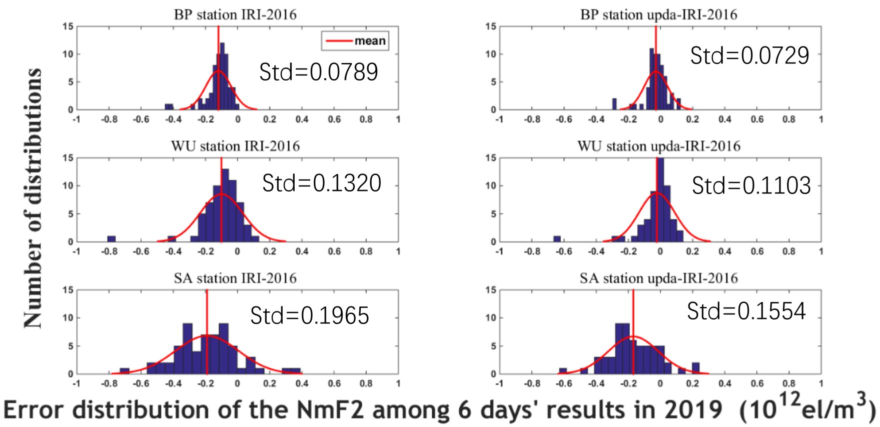



Fig5.NmF2 error distribution in 2019

- The NmF2 predicted results are not affected by the different hmF2 models including the AMTB2013, the shubin2015 and the M3000F2 options.
- Compared to the ionosonde NmF2 measurements, the NmF2 errors estimated by the modified IRI-2016 is smaller than that predicted by the standard IRI-2016 model.
- The NmF2 errors over SA station(low latitude) are larger than those over BP and WU stations (middle latitudes) .
- The NmF2 errors in 2015 (high solar activity year) are more dispersed than those in 2019(low solar activity year).

# Results and Discussion

## (3) Error statistics of IED bottom-side profiles

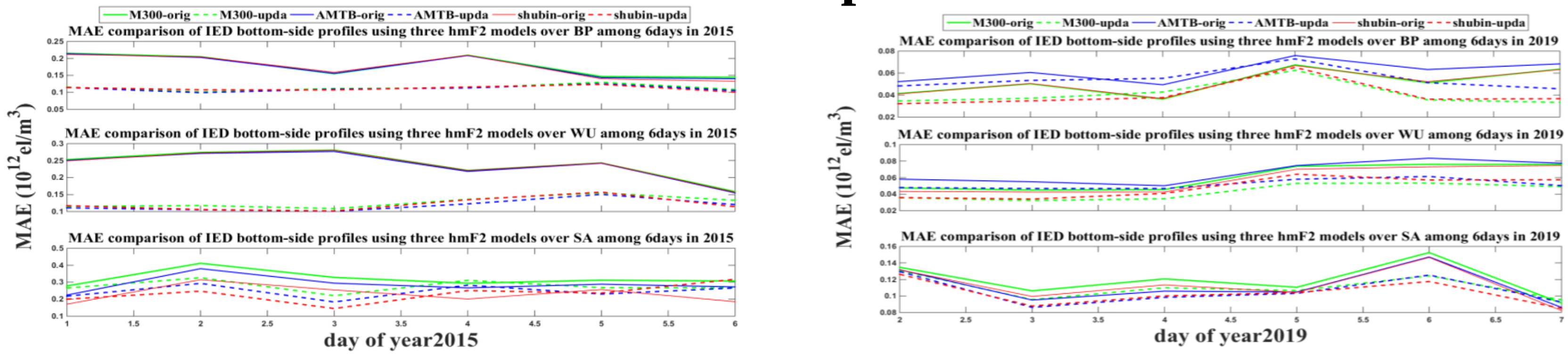



Fig6. Mean Absolute Error(MAE) of electron density profiles

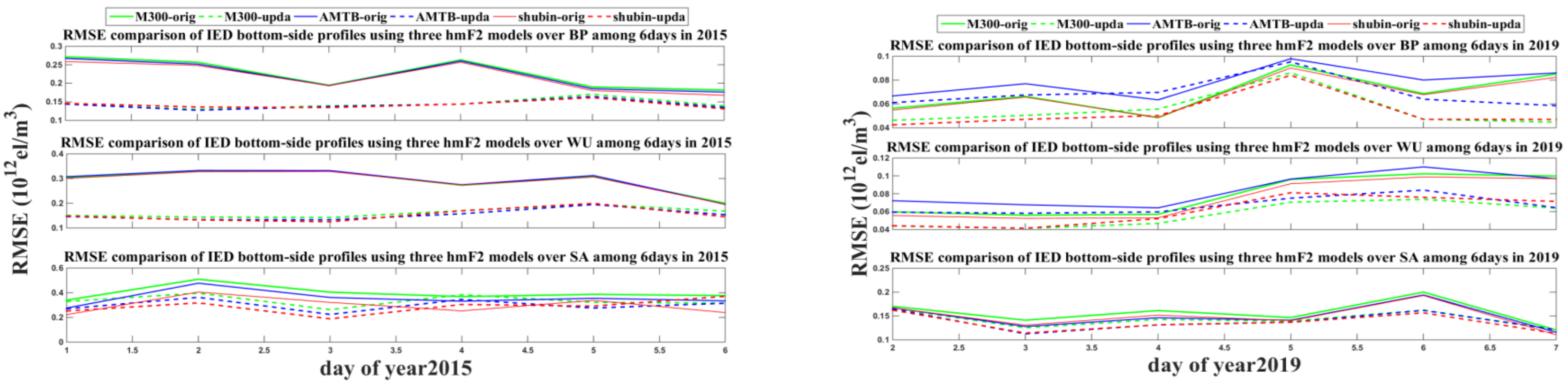



Fig7.Root Mean Square Error (RMSE) of electron density profiles

- The IED bottom-side profiles are affected by the different hmF2 models, and the IED bottom-side profiles based on the shubin2015 model have better agreement with the ionosonde measurements than those based on M3000F2 and AMTB2013 models.
- Compared to the ionosonde measurements, the RMSE and MAE values estimated by the modified IRI-2016 is smaller than that predicted by the standard IRI-2016 model.
- The RMSE and MAE values over SA station(low latitude) are larger than those over BP and WU stations (middle latitudes) .
- The RMSE and MAE values in 2015 (high solar activity year) are larger than those in 2019(low solar activity year).

# Results and Discussion

## (4) Errors of the peak density height (hmF2)

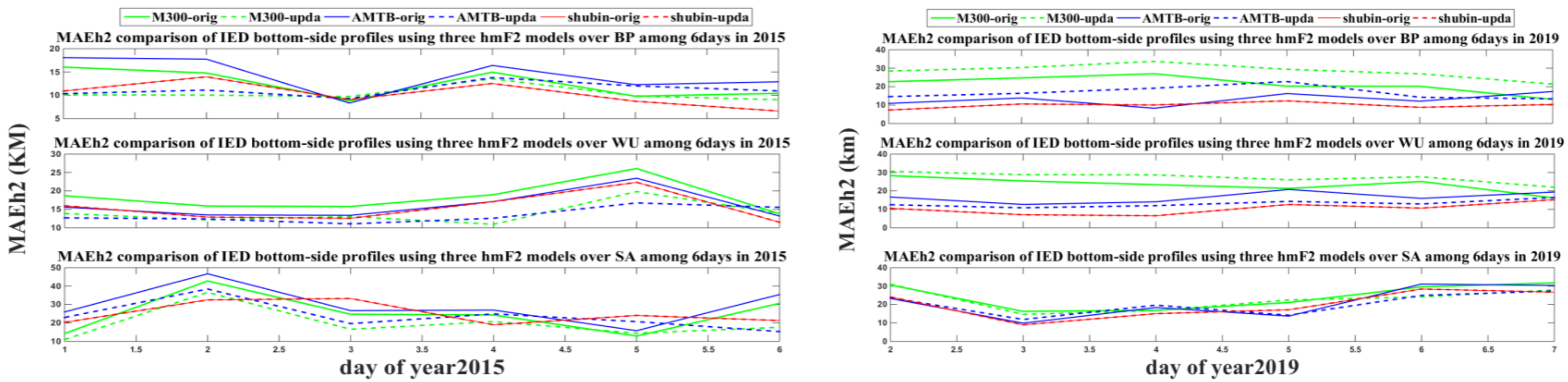



Fig8. Mean Absolute Error of hmF2 (MAEh2)

Table2(a). Root Mean Square Error of hmF2 (RMSEh2) in 2015 / ( km)

| Station | IRI-2016 | | | upda-IRI-2016 | | |
|---|---|---|---|---|---|---|
| | M3000 | AMTB | shubin | M3000 | AMTB | shubin |
| BP | 15.4 | 17.2 | 12.4 | 13.4 | 14.5 | 12.4 |
| WU | 22.1 | 19.4 | 18.9 | 17.2 | 17.2 | 18.9 |
| SA | 31.6 | 34.0 | 25.1 | 28.6 | 30.1 | 28.6 |

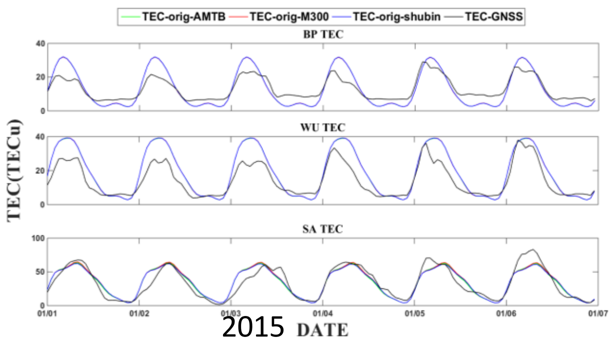
Table2(b). Root Mean Square Error of hmF2 (RMSEh2) in 2019 / ( km)

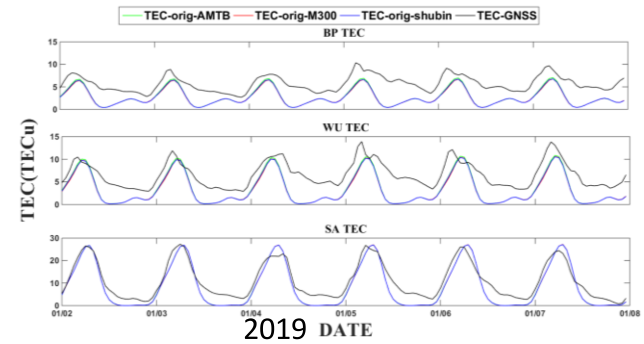
| Station | IRI-2016 | | | upda-IRI-2016 | | |
|---|---|---|---|---|---|---|
| | M3000 | AMTB | shubin | M3000 | AMTB | shubin |
| BP | 23.8 | 16.9 | 11.6 | 20.8 | 21.1 | 11.6 |
| WU | 27.0 | 20.8 | 12.8 | 30.9 | 16.3 | 12.8 |
| SA | 29.3 | 27.2 | 25.1 | 28.0 | 24.9 | 25.1 |

- For the hmF2, the performance of the Shubin 2015 model is not affect by adjusting the R12 index, however, the performance of AMTB2013 and the M3000F2 models in the modified IRI-2016 model is improved with the comparison to the ionosonde measurements in 2015 (the high solar activity year).
- For the hmF2, the performance of the Shubin 2015 model is the best in the standard IRI-2016 model, however, the performance of the Shubin 2015 model in 2015 (the high solar activity year) is worse than that of AMTB2013 and the M3000F2 models by adjusting the R12 index in the modified IRI-2016 model .
- The performance of hmF2 modes over SA station is better than that over BP and WU stations.

# Results and Discussion

## (5)Comparison of IRI-2016 TEC with GPS TEC



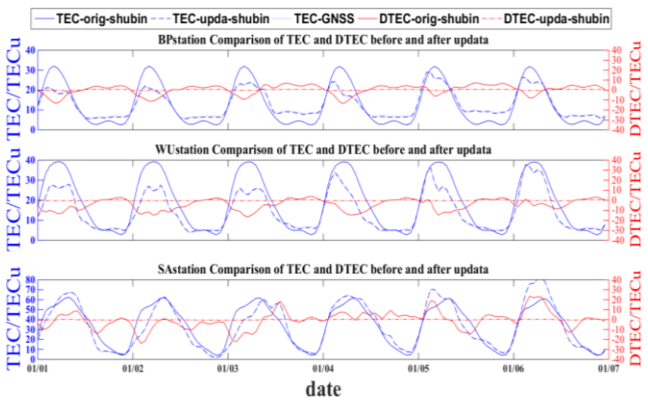




Fig9.TEC and DTEC of 1-6 days
in the high solar year using Shubin model (2015)

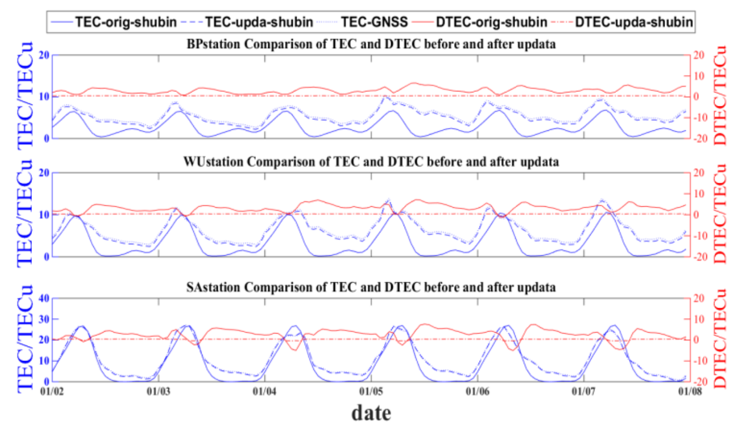



Fig10.TEC and DTEC of 2-7 days
in the low solar year using Shubin model (2019)

- There is no almost difference of TEC for the IRI-2016 model with different hmF2 options.
- The IRI-2016 model TEC agrees with GPS-TEC strongly over SA station (lower latitudes) than BP and WU stations (middle latitudes).
- There is a good consistency between the modified IRI-2016 TEC predictions and GPS TEC, and the improved DTEC is almost zero.

# Summary and conclusions

An important component of this work is the validation of the modified and standard IRI-2016 model by using the ionosonde electron density (Ne) profiles and GPS TEC in China.

I. The predicted electron densities from the modified IRI-2016 model have better agreement with the ionosonde measurements than those from the standard IRI-2016 model, and the IED profiles over middle latitudes agree better with the ionosonde than those profiles over low latitude before and after modifying the IRI-2016 model by changing the IG index and R12 index.

II. For the hmF2, the performance of the Shubin 2015 model is the best in the standard IRI-2016 model, however, the performance of the Shubin 2015 model is worse than that of AMTB2013 and the M3000F2 in the modified IRI-2016 model in the high solar activity year .

III. The performance of hmF2 modes over low latitude is better than that over middle latitudes.

IV. There is a good consistency between the modified IRI-2016 TEC predictions and GPS TEC.

# Acknowledge

We acknowledge the use of GNSS data provided by Crustal Movement Observation Network of China (CMONOC) for providing access to GNSS data, and Ionosonde data provided by Beijing National Observatory of Space Environment, Institute of Geology and Geophysics Chinese Academy of Sciences through the Geophysics center, National Earth System Science Data Center (http://wdc.geophys.ac.cn)

The IRI - 2016 Fortran source code can be downloaded from the IRI official website (http://www.irimodel.org)

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**Thanks for your attention**

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