An Abel inversion method assisted by an improved IRI model for ionospheric RO data

Mengjie Wu, Peng Guo, Naifeng Fu, Xiaogong Hu

Shanghai Astronomical Observatory
Chinese Academy of Sciences

2019.9.23

1. Background

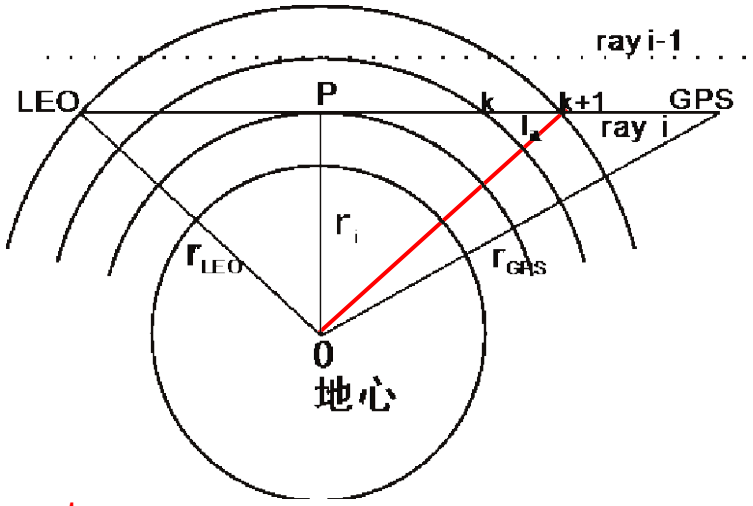
$$T = \int n_e \, dl = \frac{1}{40.3} \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} (L_1 - L_2)$$

$$T(r_0) = 2\int_{r_0}^{r_{LEO}} \frac{rN(r)}{\sqrt{r^2 - r_0}} dr$$

assumption of local spherical symmetry

$$N(r_0) = -\frac{1}{\pi}\int_{r_0}^{r_{LEO}} \frac{dT(r)/dr}{\sqrt{r^2 - r_0}} dr$$

GPS radio occultation

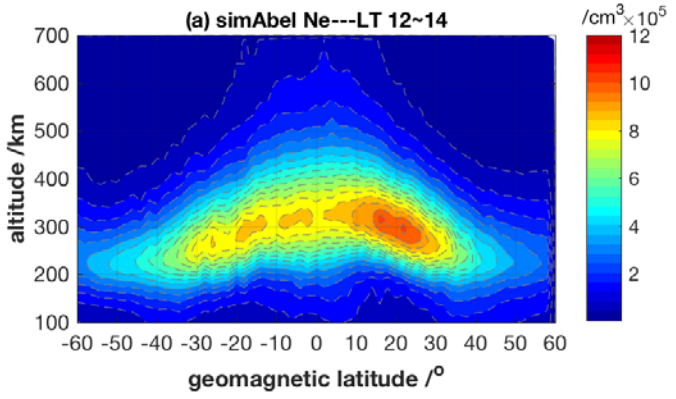


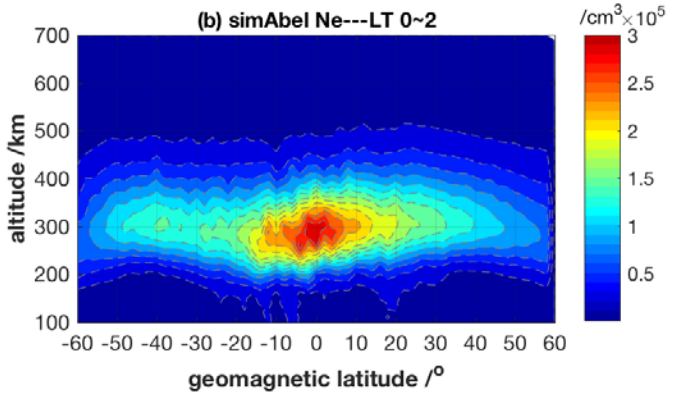
The most significant error of Abel inversion method to retrieve the radio occultation ionospheric observations is brought by the spherical symmetric assumption.

- The inversion error of F_2 layer peak density can reach about 20% with the classic Abel method.

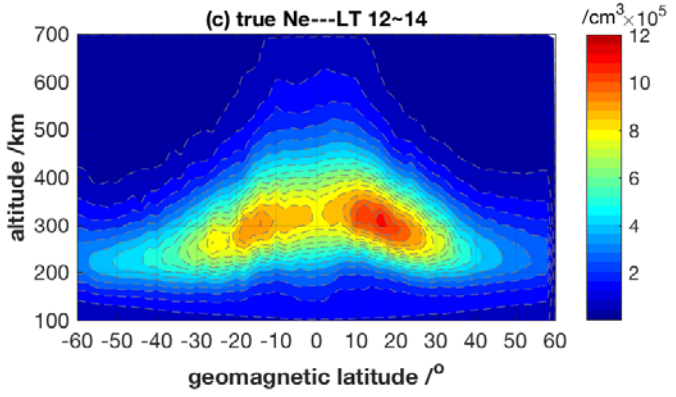
Equatorial ionization anomaly(EIA) artificial wave

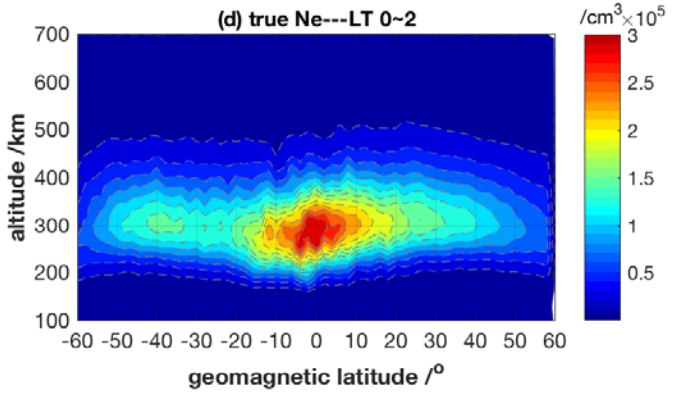
Retrieved field



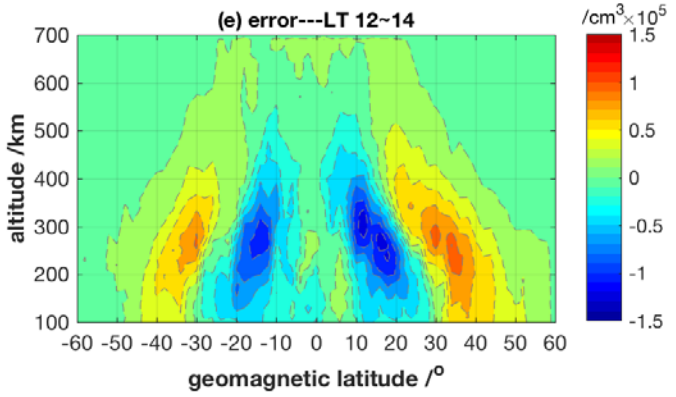


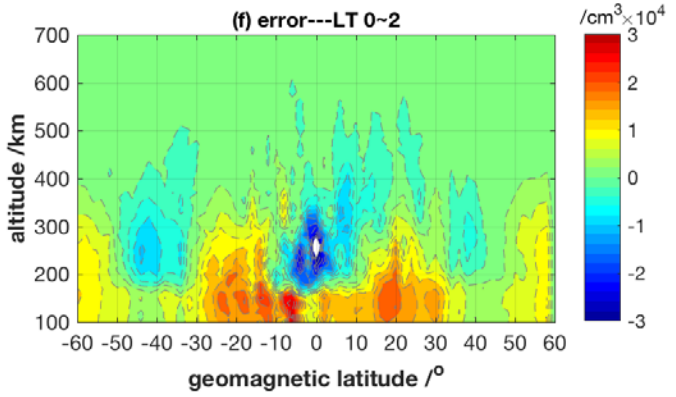
True field





Absolute error





The retrieved Ne underestimates the truth in the EIA crest (±10°~30°), while overestimates near the equator (~±10°) and in the north and south of crests (±30°~50°)

(Yue et al., 2010)

2. Improved Abel inversion

The ratio of T to T^{sph} (observational field) is considered equal to the ratio of T_{mod} to T_{mod}^{sph} (modeled TEC) *(Guo et al., 2015, JASTP)*.

$$N(r_0) = -\frac{1}{\pi}\int_{r_0}^{r_{LEO}} \frac{dT(r)/dr}{\sqrt{r^2 - r_0}} dr$$ （Abel inversion）

$$\frac{T}{T^{sph}} = \frac{T_{mod}}{T_{mod}^{sph}}$$

$$T_{mod} = \int_{\vec{r}_{LEO}}^{\vec{r}'_{LEO}} N_{mod} dl$$

$$T_{mod}^{sph}(r_0) = 2\int_{r_0}^{r_{LEO}} \frac{rN'_{mod}(r)}{\sqrt{r^2 - r_0}} dr$$

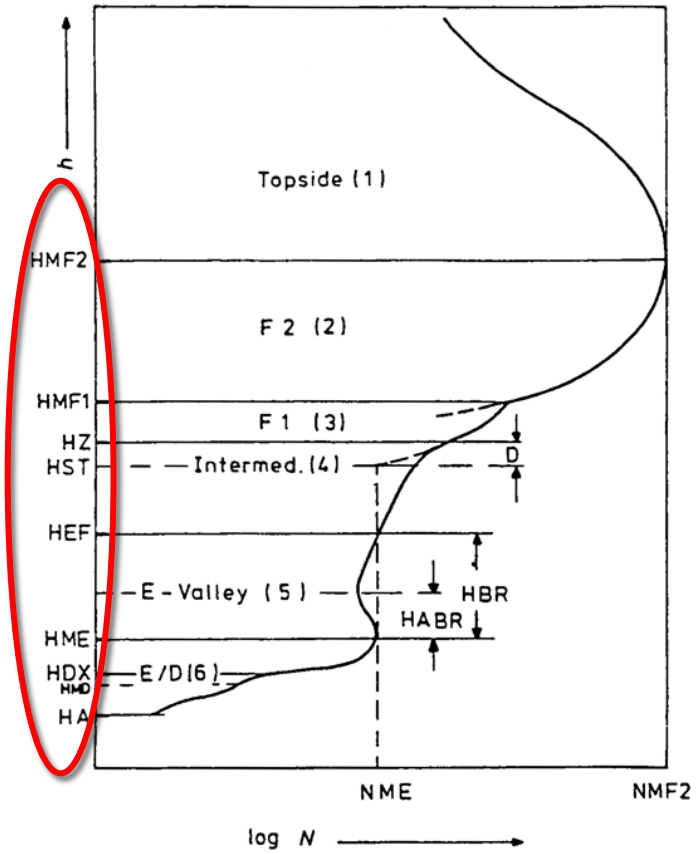
$$N^*(r_0) = -\frac{1}{\pi}\int_{r_0}^{r_{LEO}} \frac{dT^{sph}(r)/dr}{\sqrt{r^2 - r_0}} dr$$ **(improved approach)**

- Accuracy of N_{mod} directly influence the result of TEC constraint, as well as the retrieved Ne.

3.Improved IRI

International Reference Ionosphere (**IRI**), describe the variation of electron density by means of a piecewise profile tied to the F_2-peak parameters: the peak electron density **NmF2** (or critical frequency foF2), the peak density height **hmF2** (or propagation factor M3000F2).

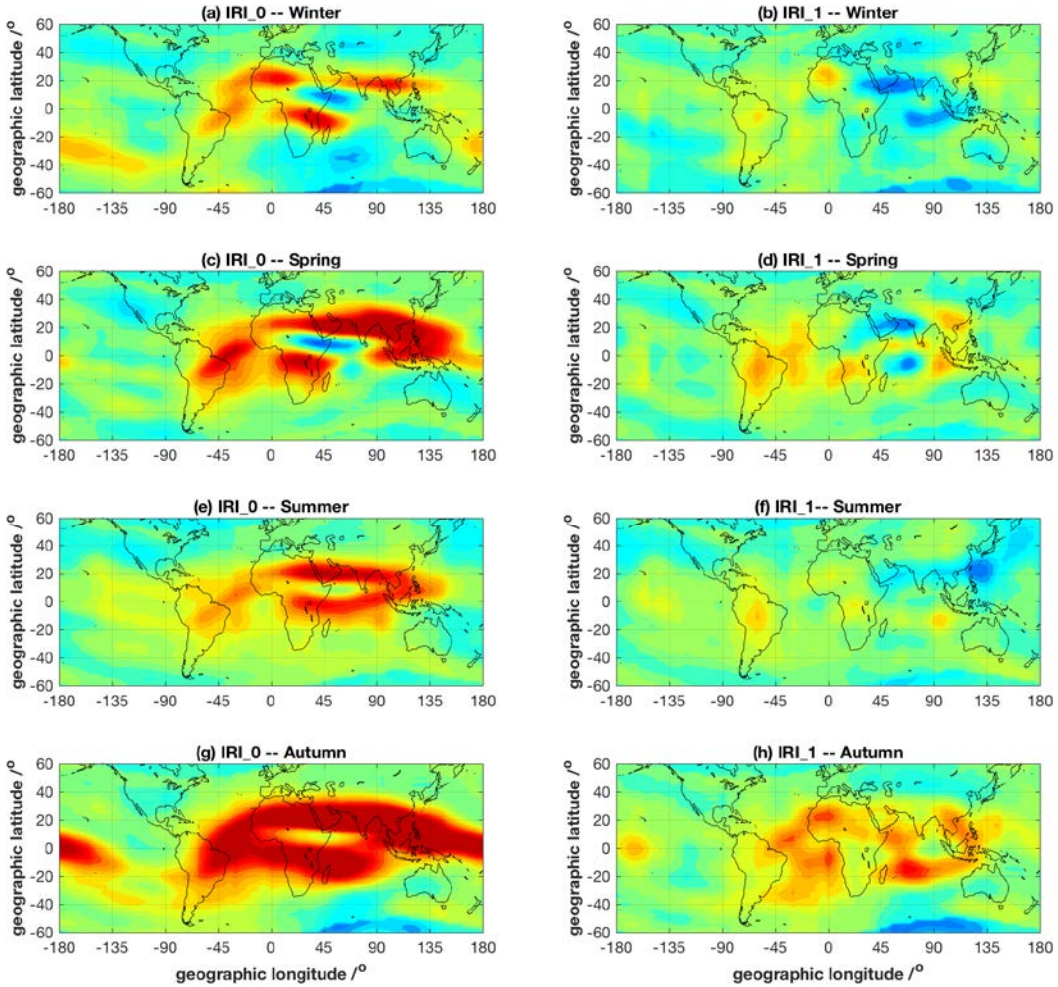
- IRI depends on ITU-R maps to get the parameters value.
- The accuracy of peak parameters is crucial for retrieving reliable electron density estimations.
- IRI is welcoming to involve the latest advanced observations to improve their current system.



F_2 layer: COSMIC EDPs (Electron Density Profiles) —spherical harmonics expansion→ ‘NmF2’, ‘hmF2’ model; ‘scale height’ model → IRI

Topside: COSMIC podTEC —empirical orthogonal functions→ adaptive topside model

VTEC mean error compared to GIM

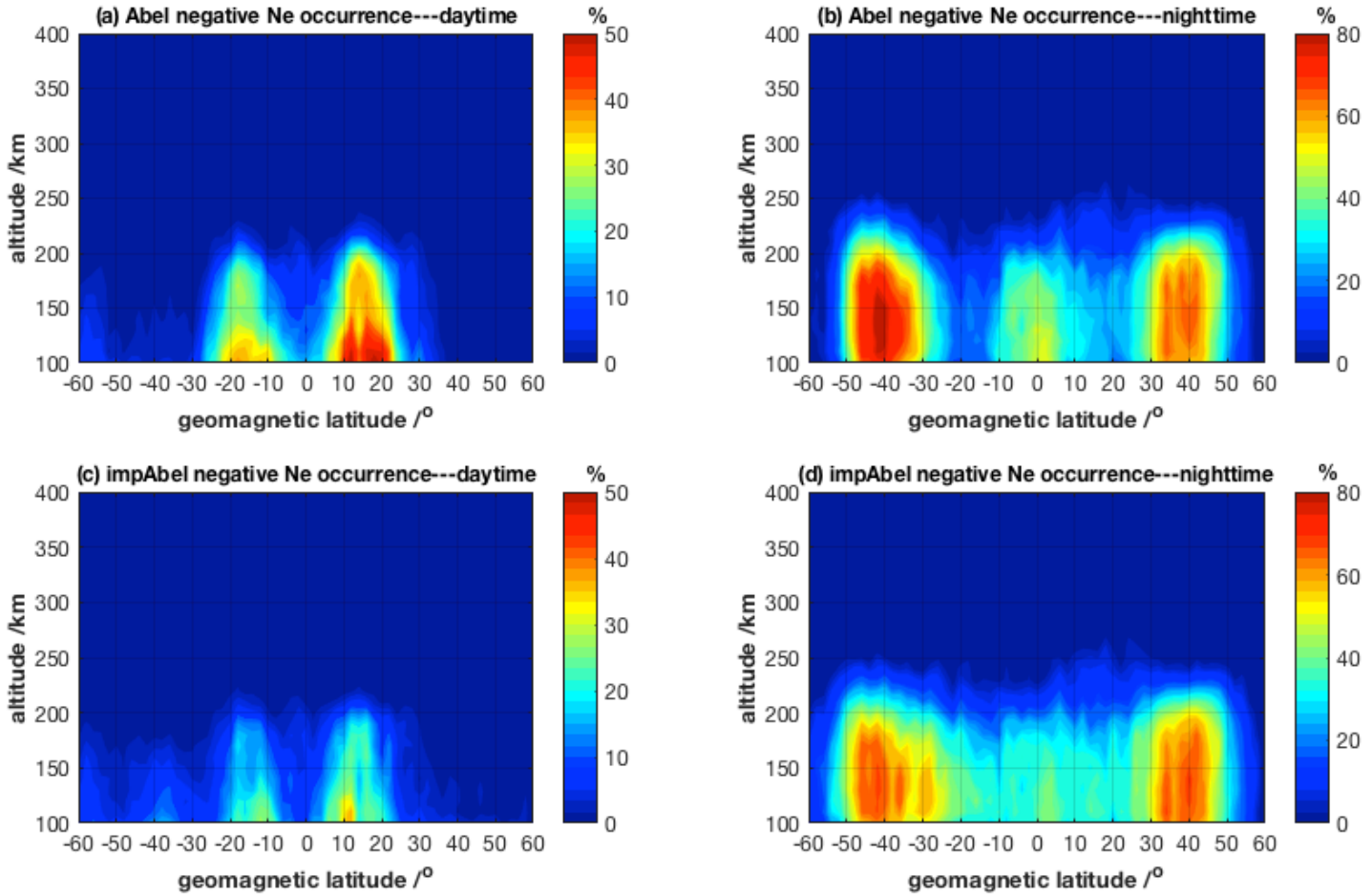


‘0’- IRI
‘1’- impIRI

(Wu et al., 2018, JGR)

4. Internal Validation

The occurrence of negative electron densities retrieved by Abel and improved Abel methods.



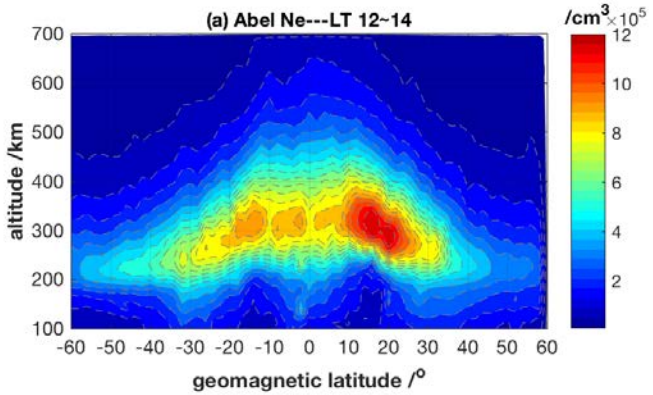
The number of unreasonable electron densities is largely decreased by about 26% in the day.

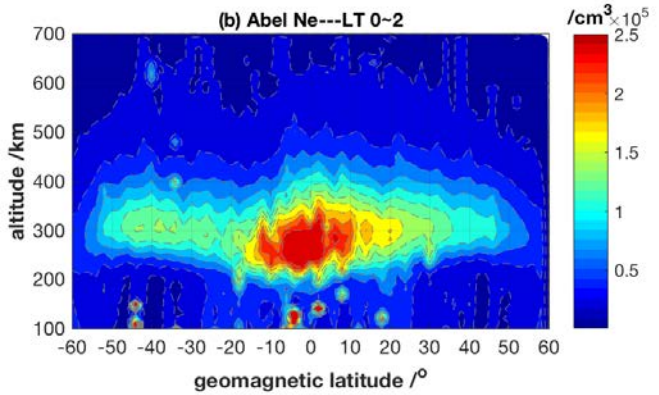
EIA artificial wave

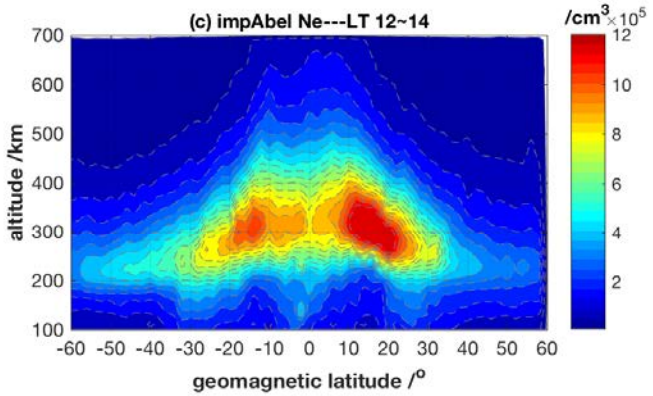
Abel

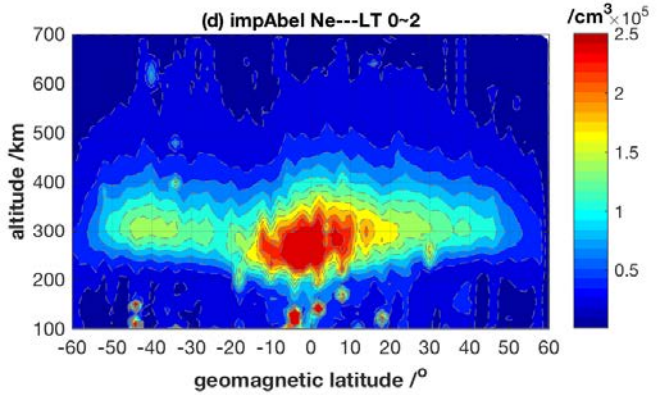
impAbel

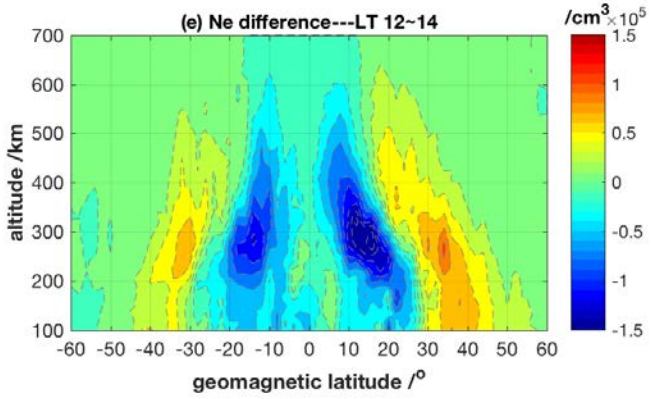
Abel - impAbel

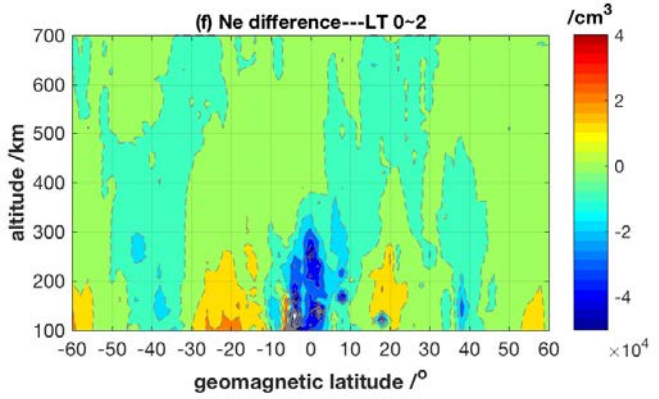


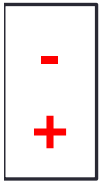






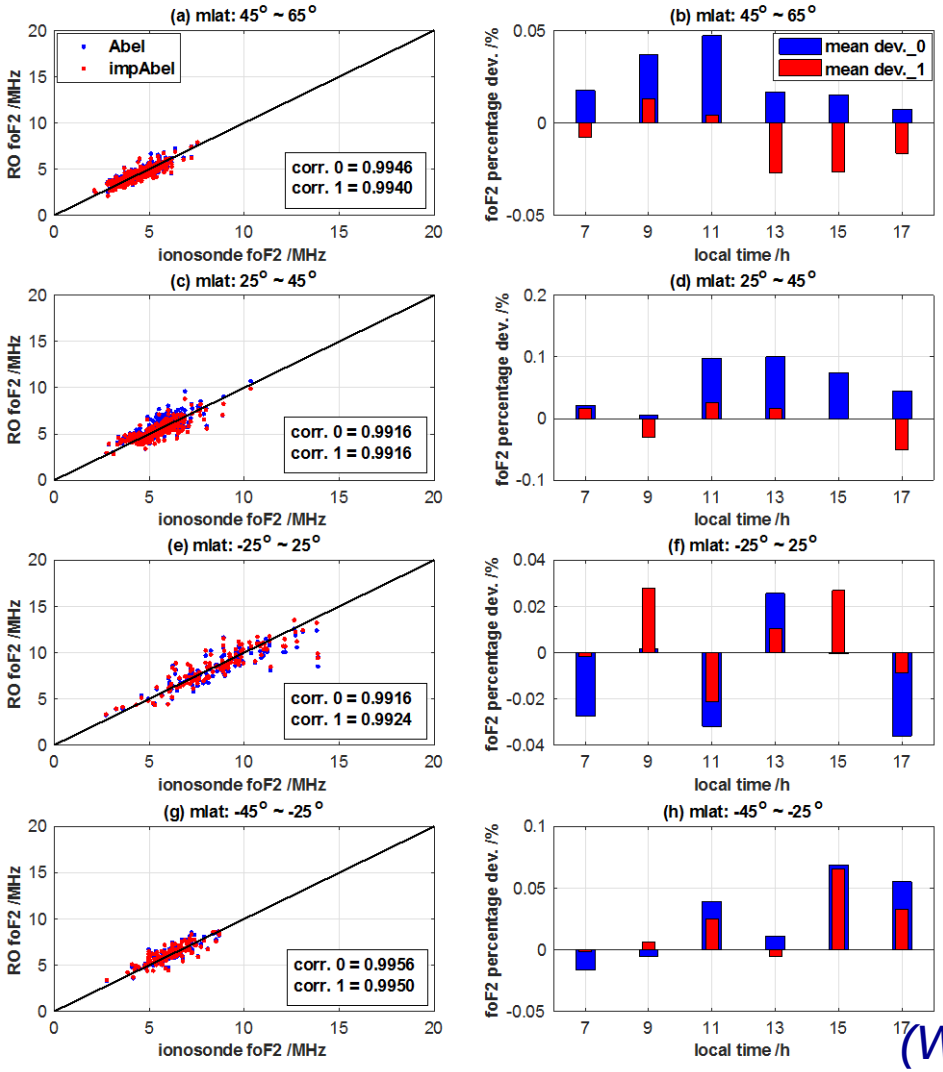






5. Validation by ionosonde

Match co-located RO events and ionosonde data within latitude ~2°, longitude ~10°, and 15 minutes. Equinox season.

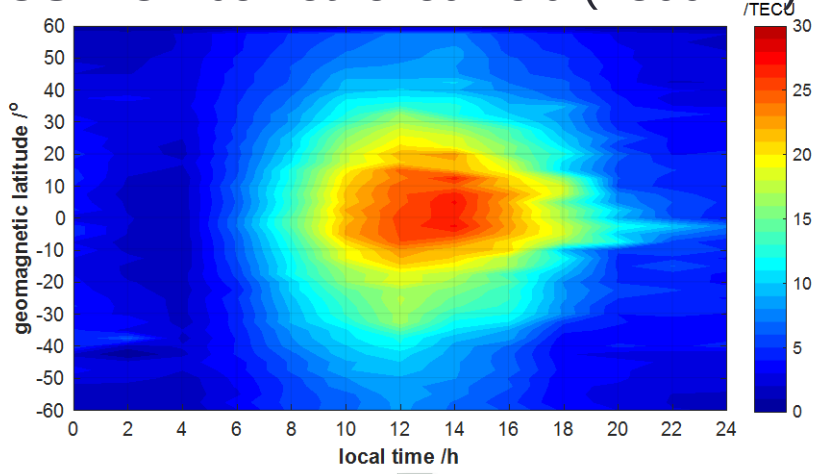


'0'- Abel
'1'-impAbel

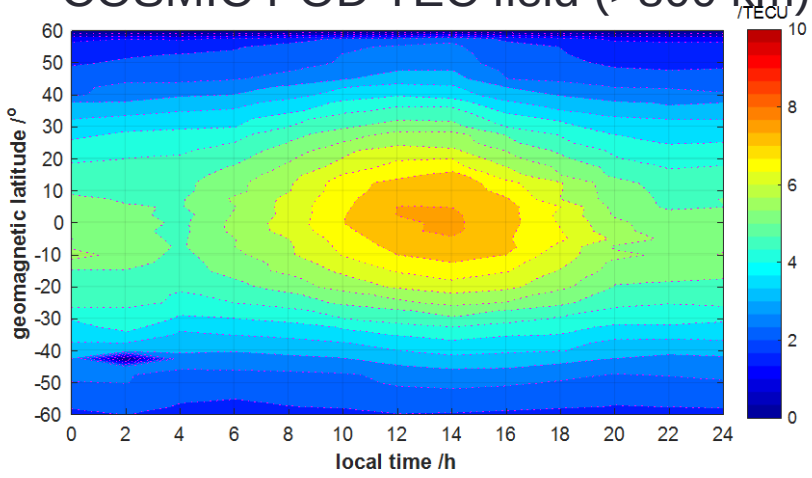
(Wu et al., 2019, JGR)

6. Validation by GIM

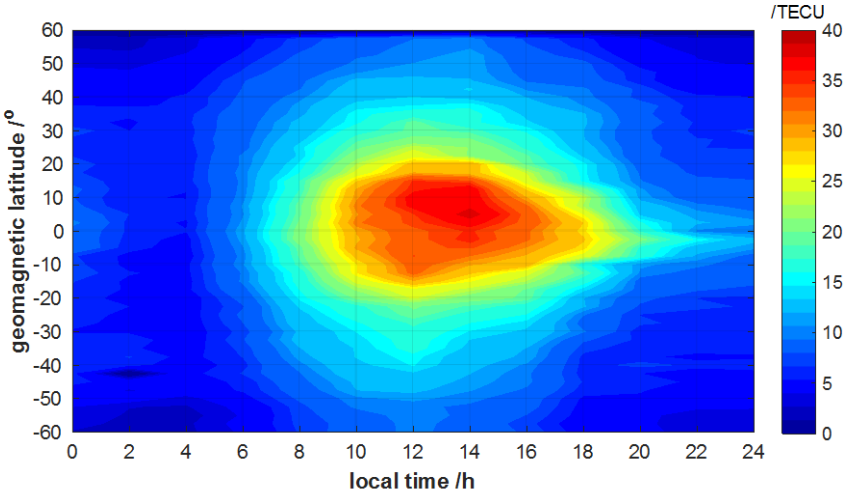
COSMIC Abel retrieved field (~800 km)



COSMIC POD TEC field (>800 km)

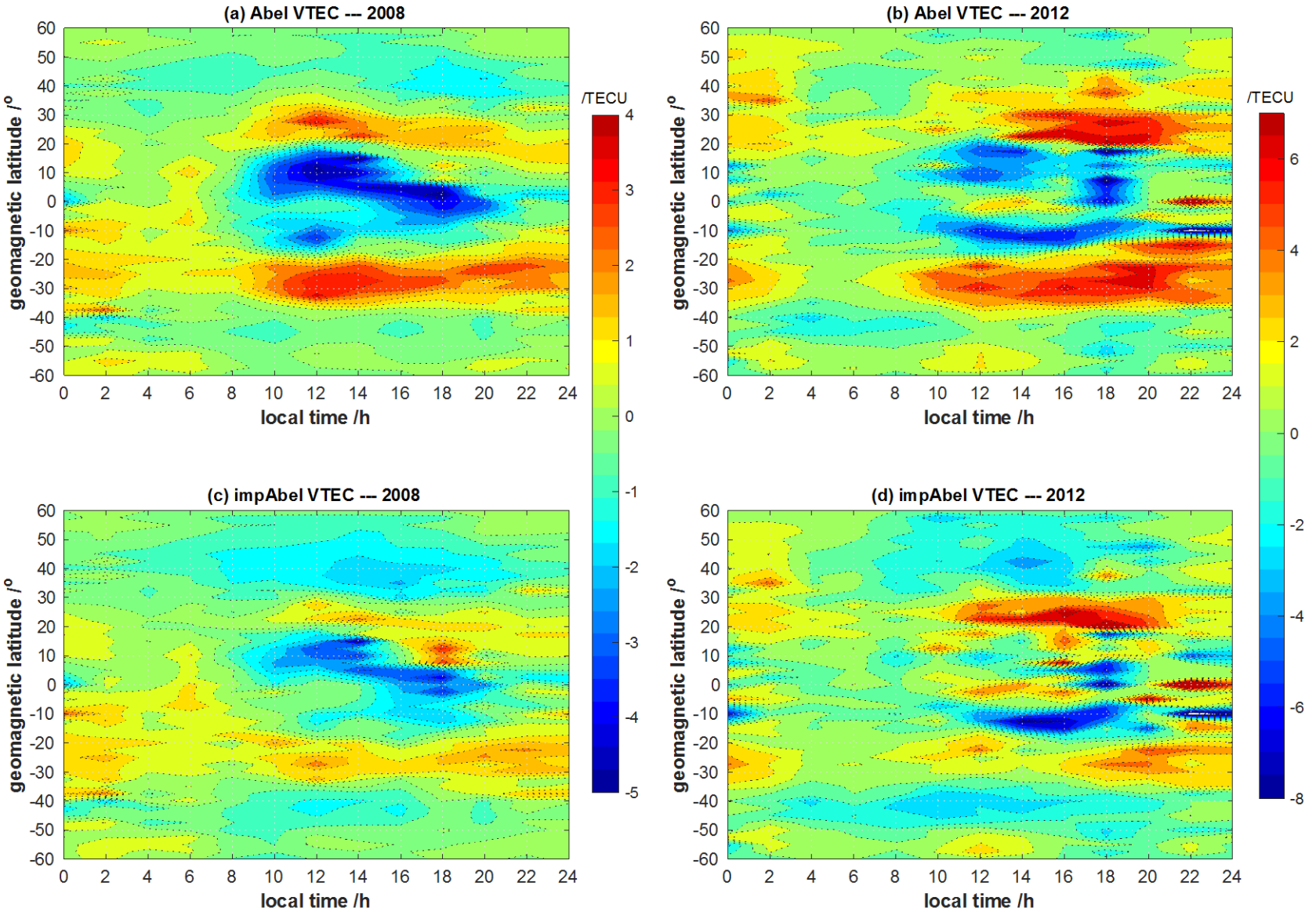


GIM VTEC field (~20200 km)



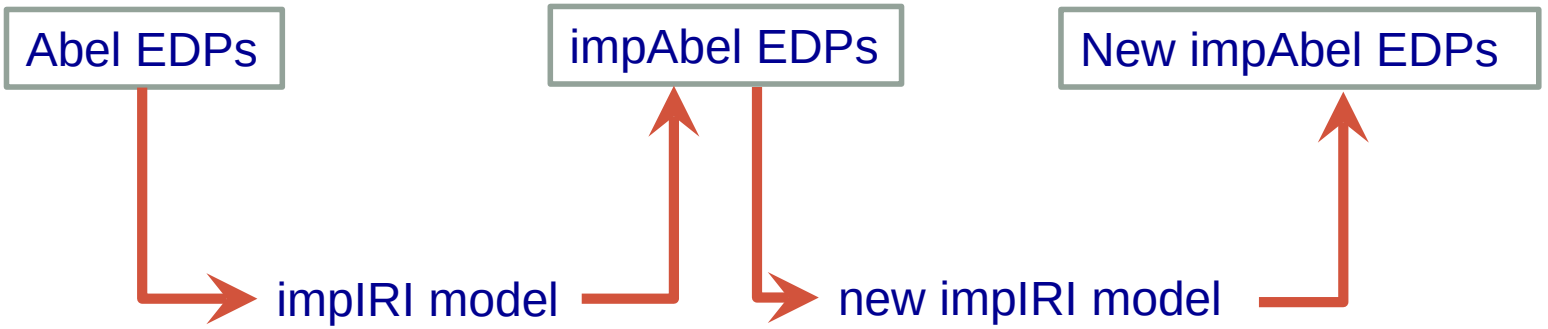
Observations

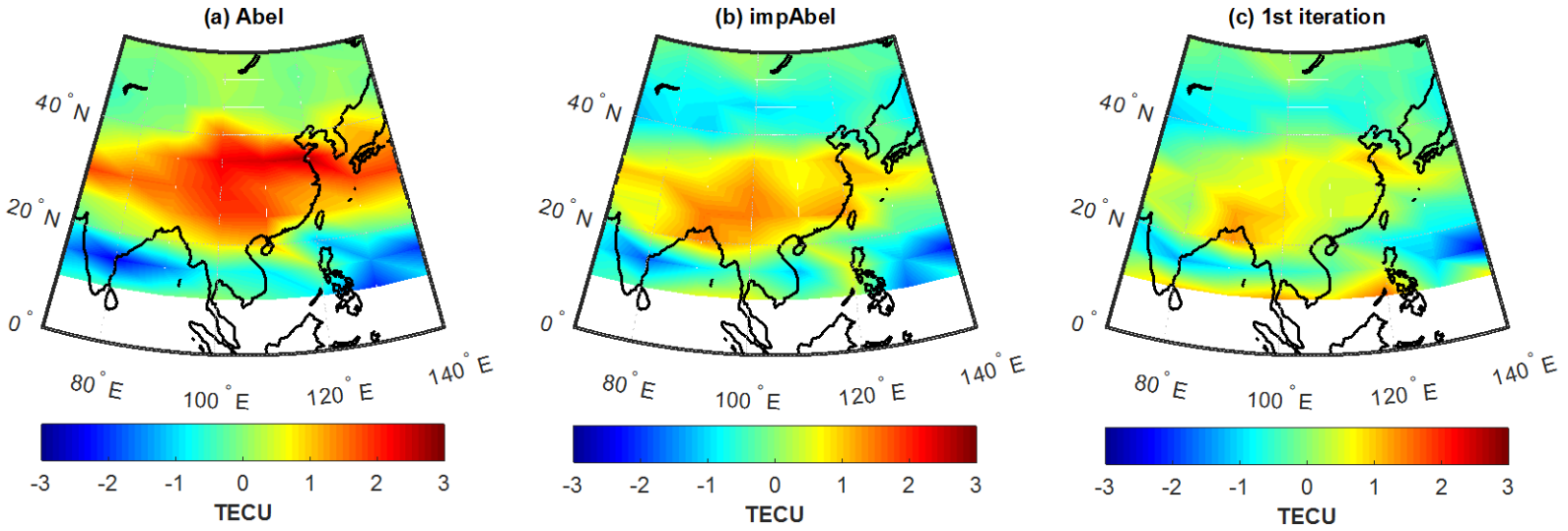
VTEC error



The VTEC mean deviation is decreased from 0.384 to −0.115 TECU in 2008, and more than 1 TECU in 2012.

7. Summary





RMS: 2.77 2.36 2.31 TECU

Thanks!