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# Topside electron density from Irkutsk incoherent scatter radar, COSMIC/FORMOSAT-3 and International Reference Ionosphere

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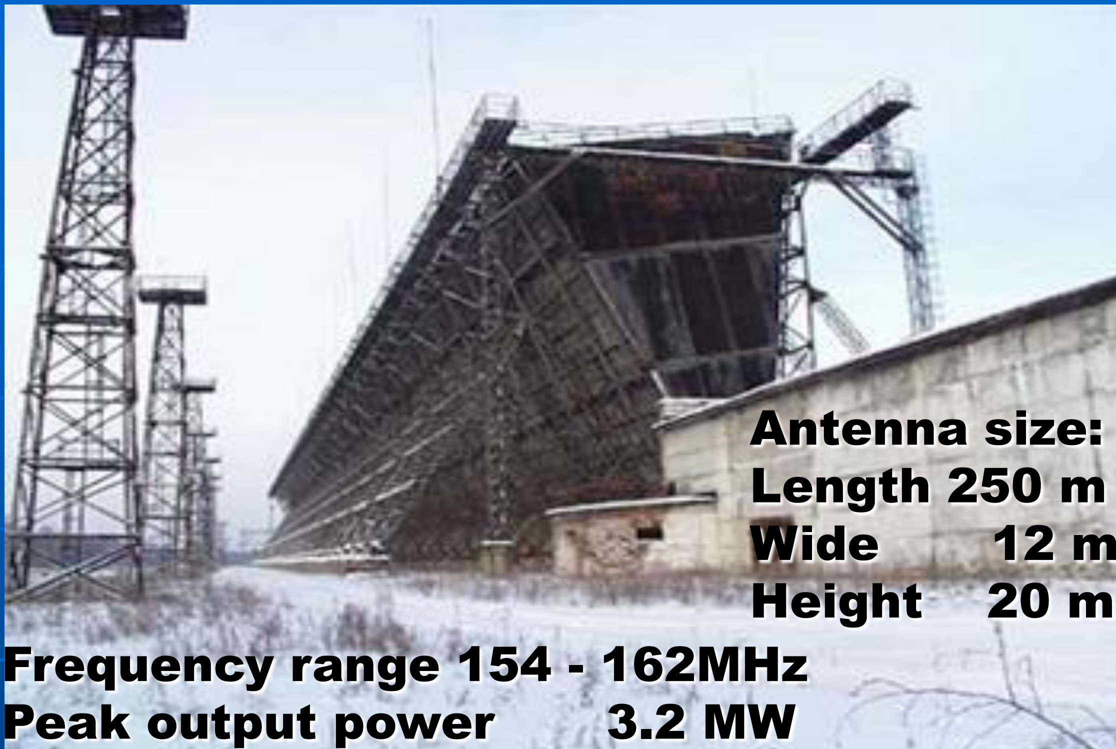
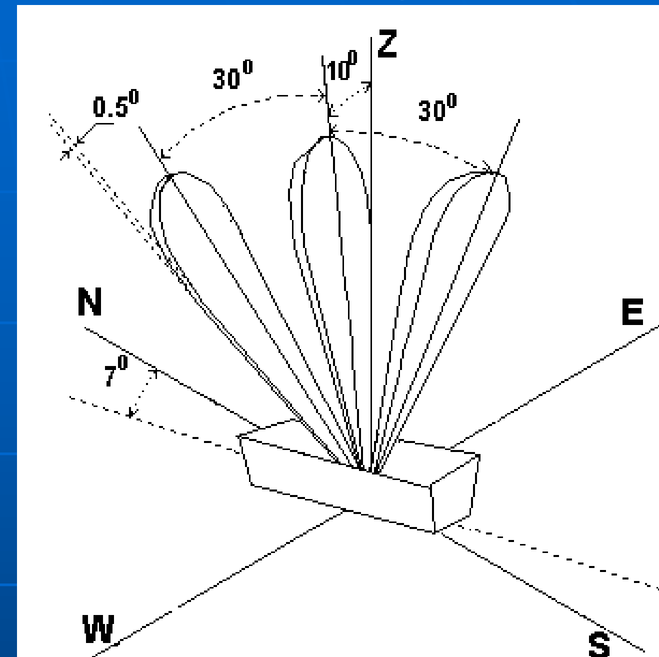
# Irkutsk Incoherent Scatter Radar (IISR) (52.9°N, 103.3°E)




Beam steering pattern




The main distinctive features:

(1) The IISR power profile is modulated by **Faraday rotation** due to radiating and receiving only one linear polarization. This feature allows eliminating the ionosonde calibration, but complicates the $N_e$ profile calculation technique.

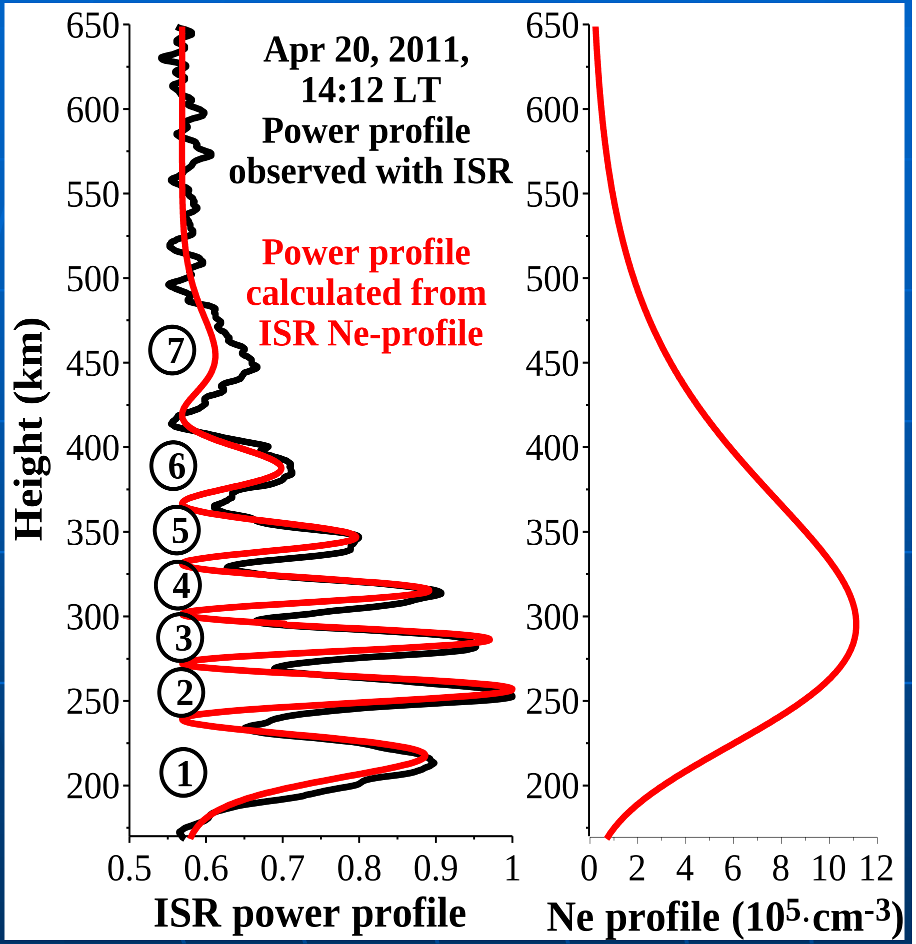
(2) IISR is only the mid-latitude radar located at **far-from-pole longitude zone** where difference between geographic and geomagnetic latitudes is the largest.

The long-duration Irkutsk incoherent scatter radar observations allowed collecting 337 electron density profiles obtained with ISR and COSMIC in the ISR vicinity (± 5º) . The COSMIC profiles were also compared with those from Digisonde, and IRI model.

| Observation periods | Number of Days | Number of Simultaneous cases | Yearly mean F10.7 (s.f.u.) |
|---|---|---|---|
| JUN 05 - JUN 19, 2007 | 15 | 46 | 73 |
| AUG 25 – SEP 28, 2008 | 35 | 44 | 69 |
| APR 01 – APR 18, 2009 | 16 | 32 | 71 |
| JAN 12 - FEB 28, 2010 | 48 | 62 | 80 |
| JAN 16 - FEB 16, 2011 | 32 | 28 | 114 |
| APR 12 - APR 21, 2011 | 10 | 6 | |
| JAN 18 - FEB 05, 2012 | 8 | 13 | 120 |
| APR 06 – APR 22, 2012 | 12 | 23 | |
| JAN 01 – JAN 21, 2013 | 19 | 49 | 123 |
| JUN 21 – JUN 30, 2013 | 9 | 24 | |
| DEC 25 - DEC 31, 2013 | 4 | 10 | |
| In total | 208 | 337 | |

We compare : peak electron density NmF2 , Bottomside Electron Content (170-300 km range), Topside Electron Content (300-600 km range) and ionospheric electron content (170-600 km range)

# Incoherent Scatter Radar (ISR) measurement technique




IISR radiates and receives only one linear polarization, and the received power profile *P* as function of *z* is modulated by the Faraday rotation

$$P(z) = A \cdot \frac{Ne(z)}{(z/\cos(\beta))^2} \cdot \cos^2(\varphi(z)) + B,$$

$$\varphi(z) = \frac{2\pi\cos(\theta)}{cf^2\cos(\beta)} \int_0^z f_p^2(z') f_H(z') dz'$$

Faraday modulation does not enable to calculate *Ne(z)* directly from *P(z)*, but allows obtaining *Ne(z)* without an ionosonde calibration.

In this study we use the approximation of *Ne(z)* by the Chapman-like function:

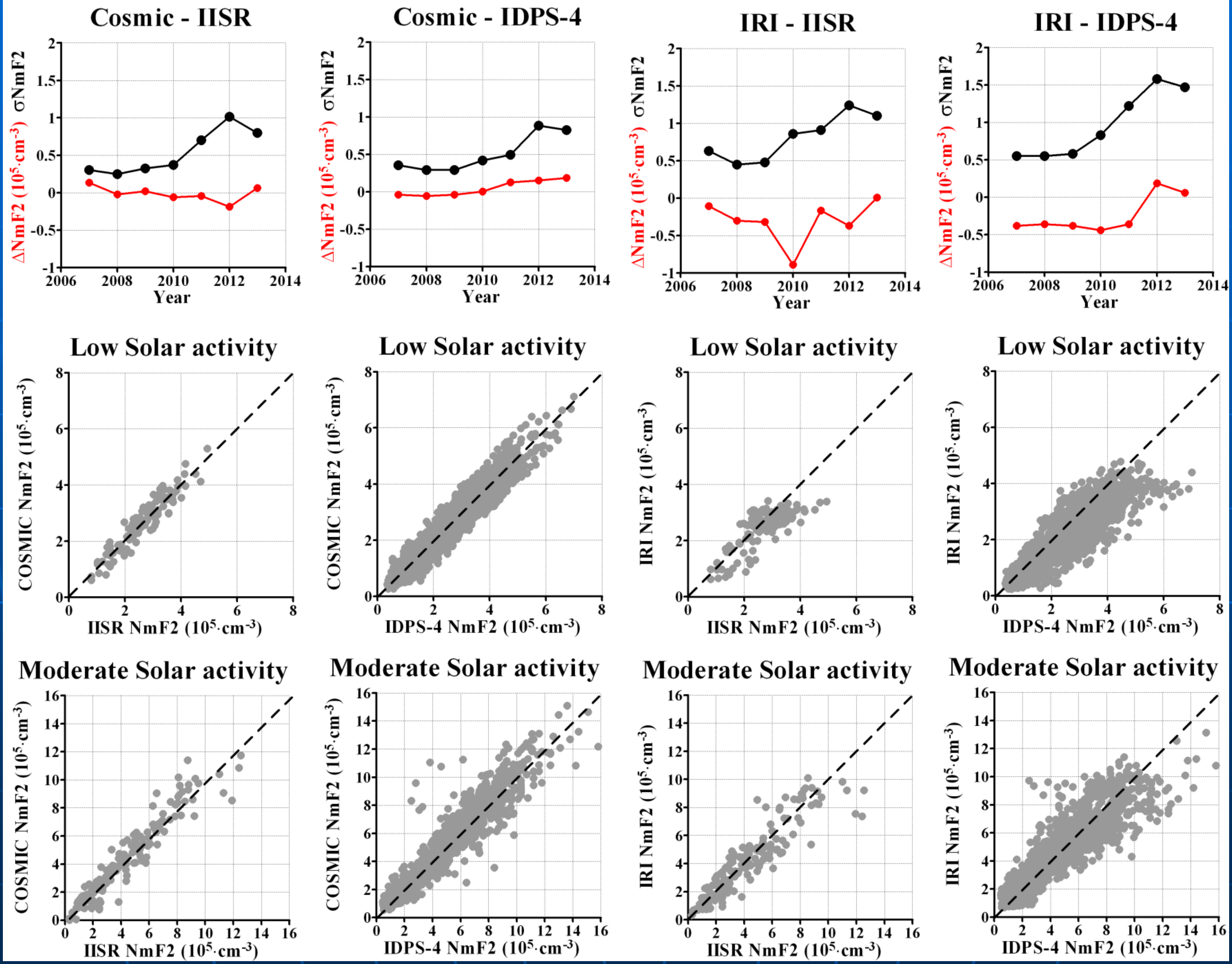
$$Ne(z) = NmF2 \cdot \exp(1 - x - \exp(-x)),$$

$$where\ \ x = (z - hmF2)/H_T \ \ at\ \ z > hmF2,$$

$$and\ \ \ \ x = (z - hmF2)/H_B \ \ at\ \ z < hmF2,$$

where $H_T$ and $H_B$ are the topside and bottomside scale heights, respectively. The Ne(z) profile characteristics (*NmF2*, *hmF2*, $H_T$ *and* $H_B$ ) as well as *A* and *B* were derived by least squares fit of the model *P(z)* to the received power profile.

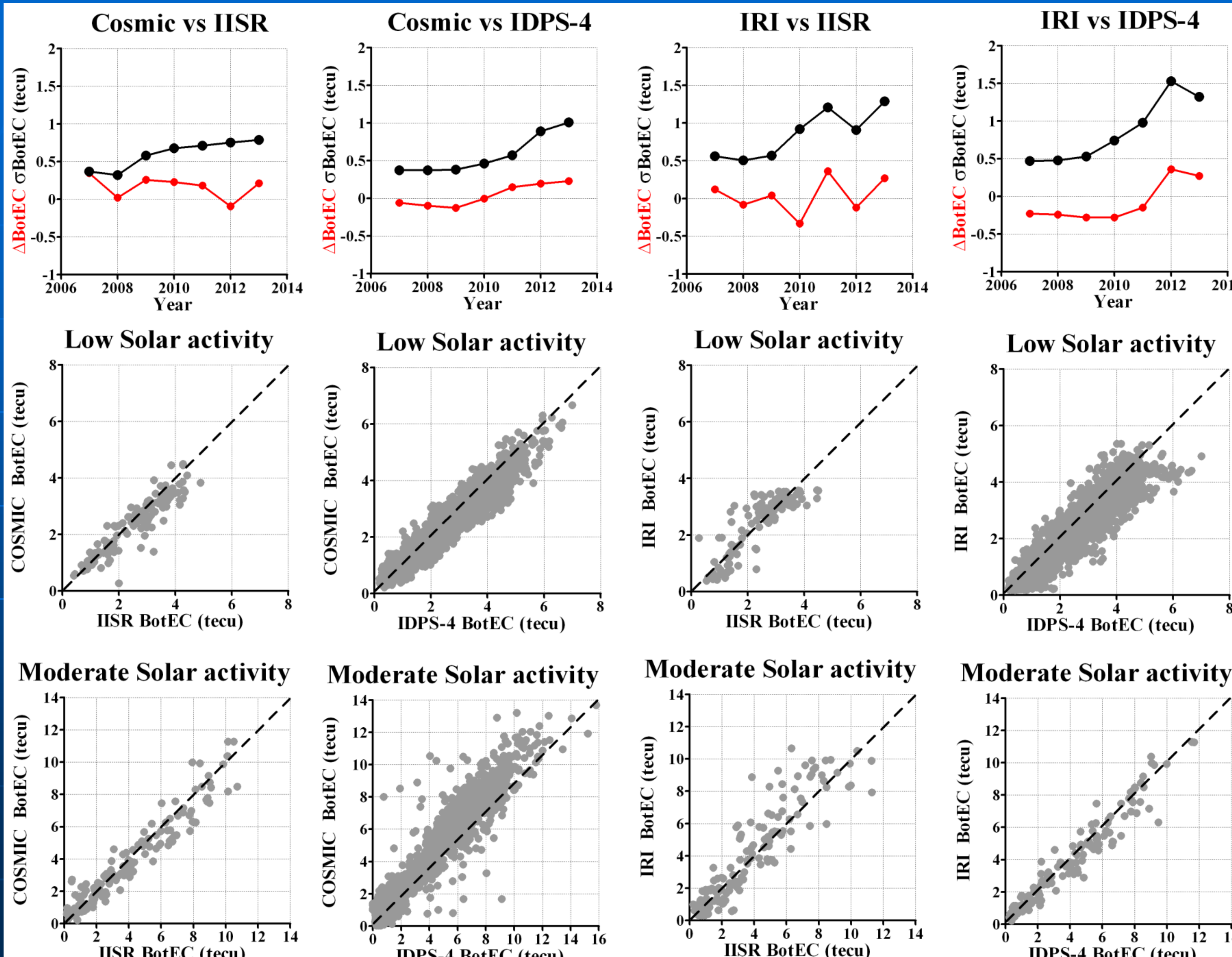
# Comparison of peak density (*NmF2*)



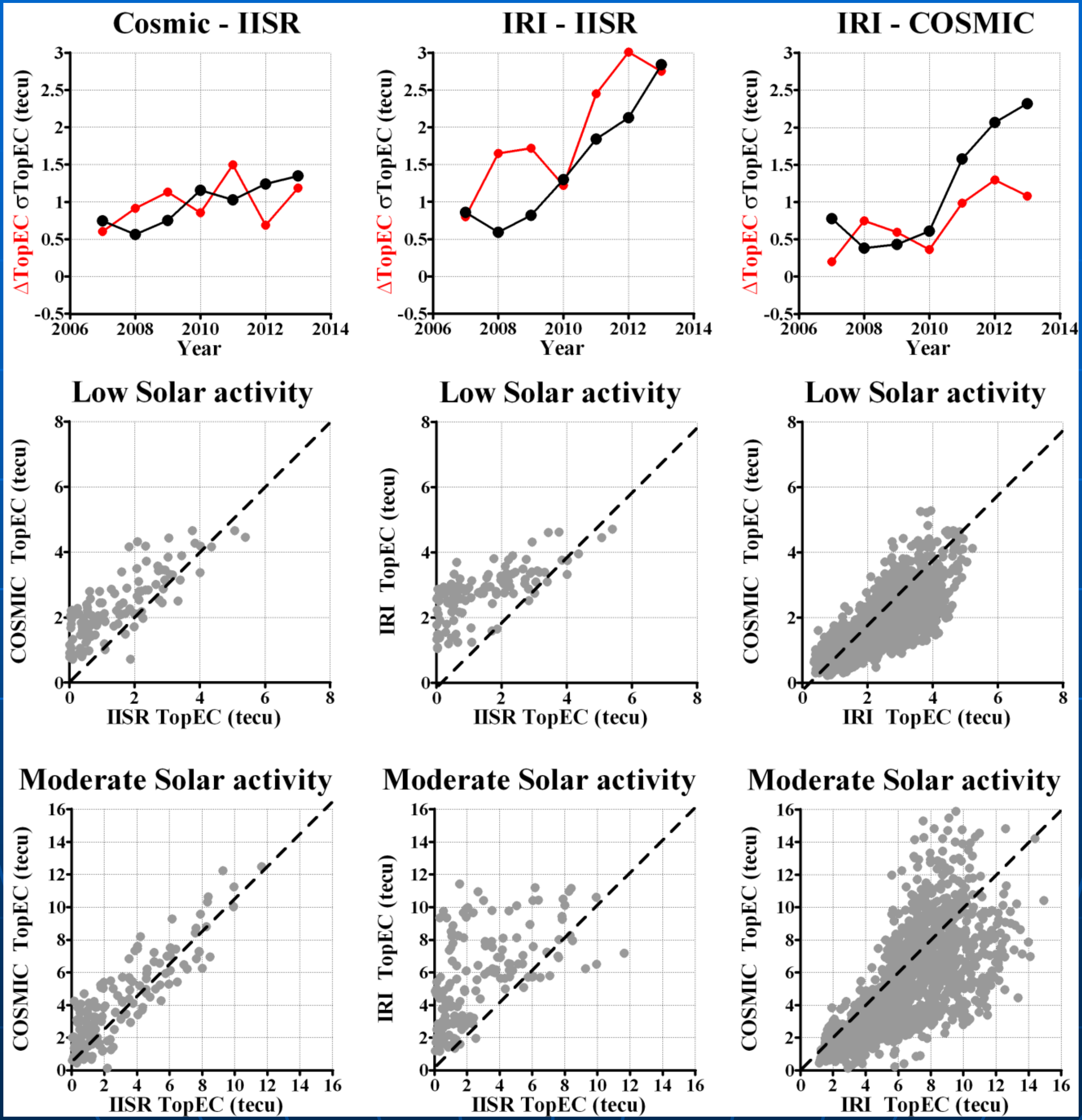
# Comparison with other validations of COSMIC

| Reference | Tool | Solar activity | σNmF2 ($10^5$ $cm^{-3}$) | ΔNmF2 ($10^5$ $cm^{-3}$) |
|---|---|---|---|---|
| This study | ISR, Digisonde | Low | 0.28 | 0.05 |
| | | Moderate | 0.85 | -0.05 |
| Agreement with tools located at latitudes near 50N or higher | | | | |
| Krankowski et al., J. Geod. 2011 | European Digisondes (36-55N, 0-20E) | Low | 0.20 | 0.01 |
| Cherniak and Zakharenkova, Adv. Space Res, 2014 | Kharkov ISR (50N, 26E) | Low | 0.28 | -0.09 |
| Hu et al., Ann. Geophys., 2014 | Mohe Digisonde (54N, 122E) | Moderate | 0.60 | 0.01 |
| Disagreement with tools located at latitudes near 40N or lower | | | | |
| Mikhailov et al., J. Space Weather Space Clim., 2014 | Millstone Hill ISR (42 N, 289E) | Low | 0.40 | 0.58 |
| Hu et al., Ann. Geophys., 2014 | Beijing Digisonde (40N, 116E) | Moderate | 1.70 | 1.30 |
| Hu et al., Ann. Geophys., 2014 | Wuhan Digisonde (31N, 114E) | Moderate | 3.60 | 2.00 |

# Comparison of bottomside (170-300 km) electron content (*BotEC*)



# Comparison of topside (300-600 km) electron content (*TopEC*)



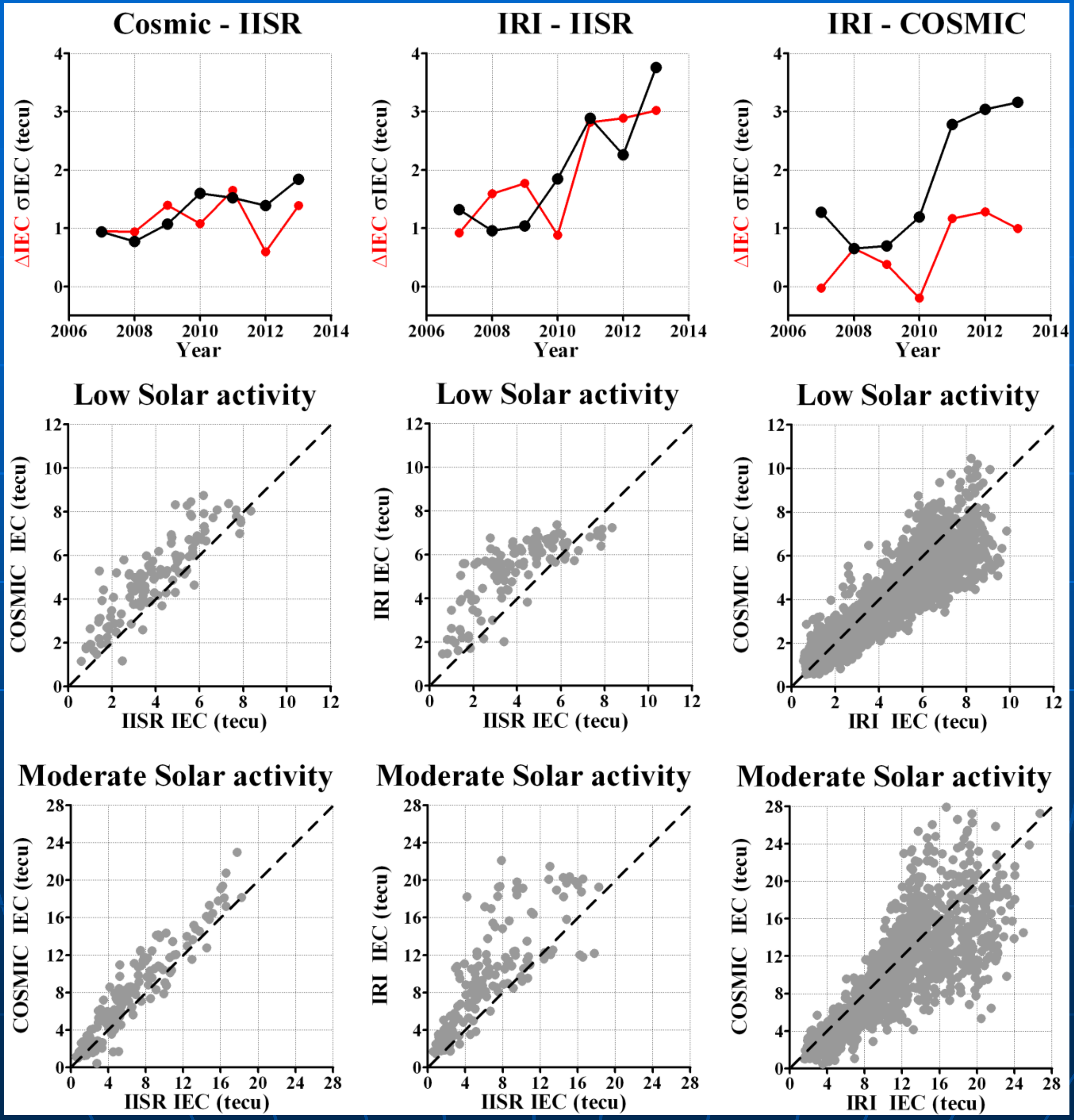
# Comparison with other validations of COSMIC

None of the previous incoherent scatter radar studies have reported that the COSMIC overestimates the topside electron density with a better agreement in the bottomside.

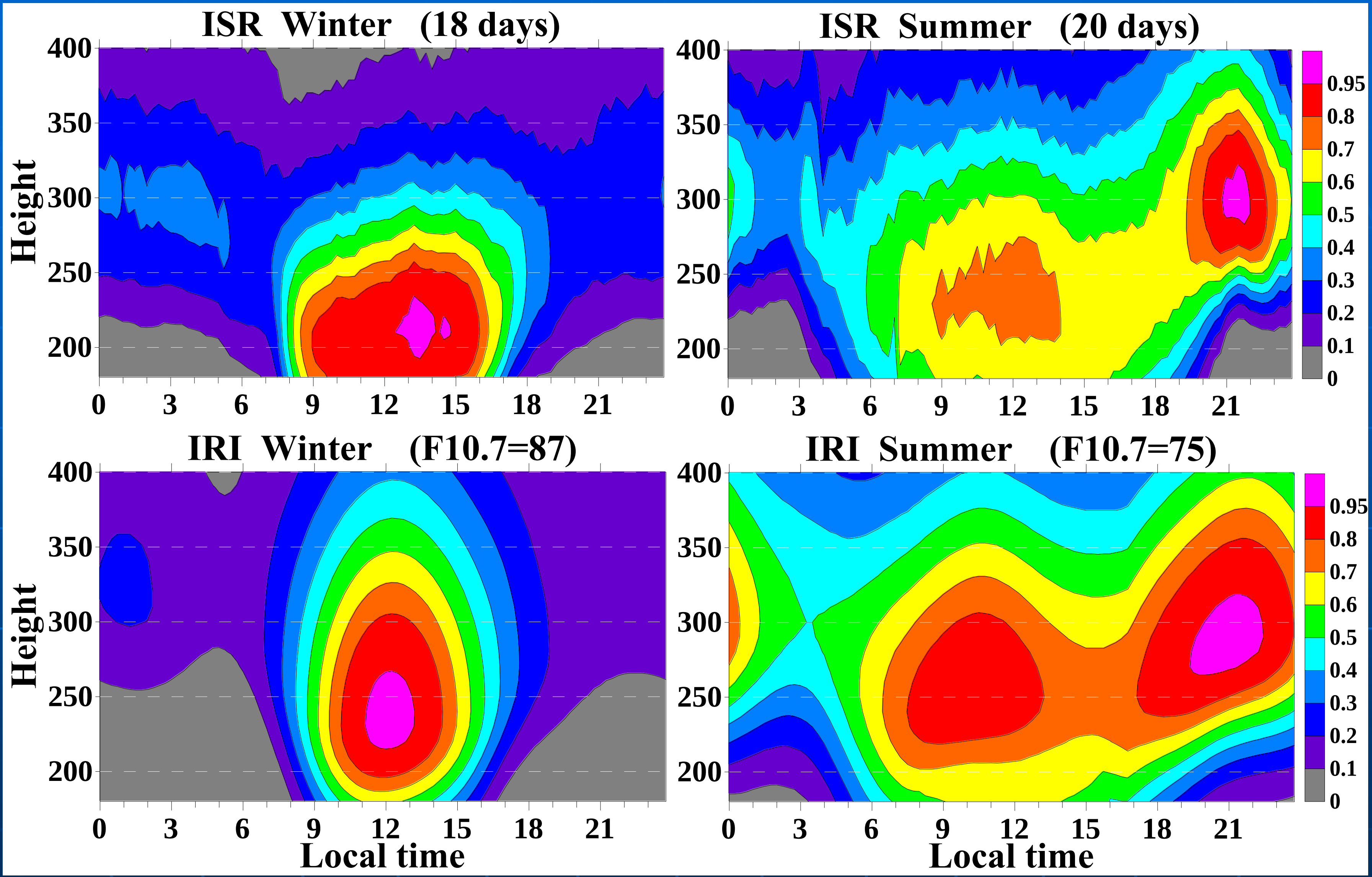
Cherniak and Zakharenkova ( Adv. Space Res, 2014) concluded that the topside profile shape showed rather good agreement between the COSMIC and the Kharkov incoherent scatter radar.

Mikhailov et al. (J. Space Weather Space Clim, 2014) concluded that in the majority of cases the COSMIC topside profile coincided fairly well with the Millstone Hill incoherent scatter radar observations, while the coincidence in the bottomside profile was not good for the 40% of the analyzed cases. Their result is opposite to our findings. Possibly, the comparison results strongly depend on the ground-based facility location, at least the mentioned above ionosonde comparisons show that this may be the case.

# Comparison of ionospheric (170-600 km) electron content (*IEC*)

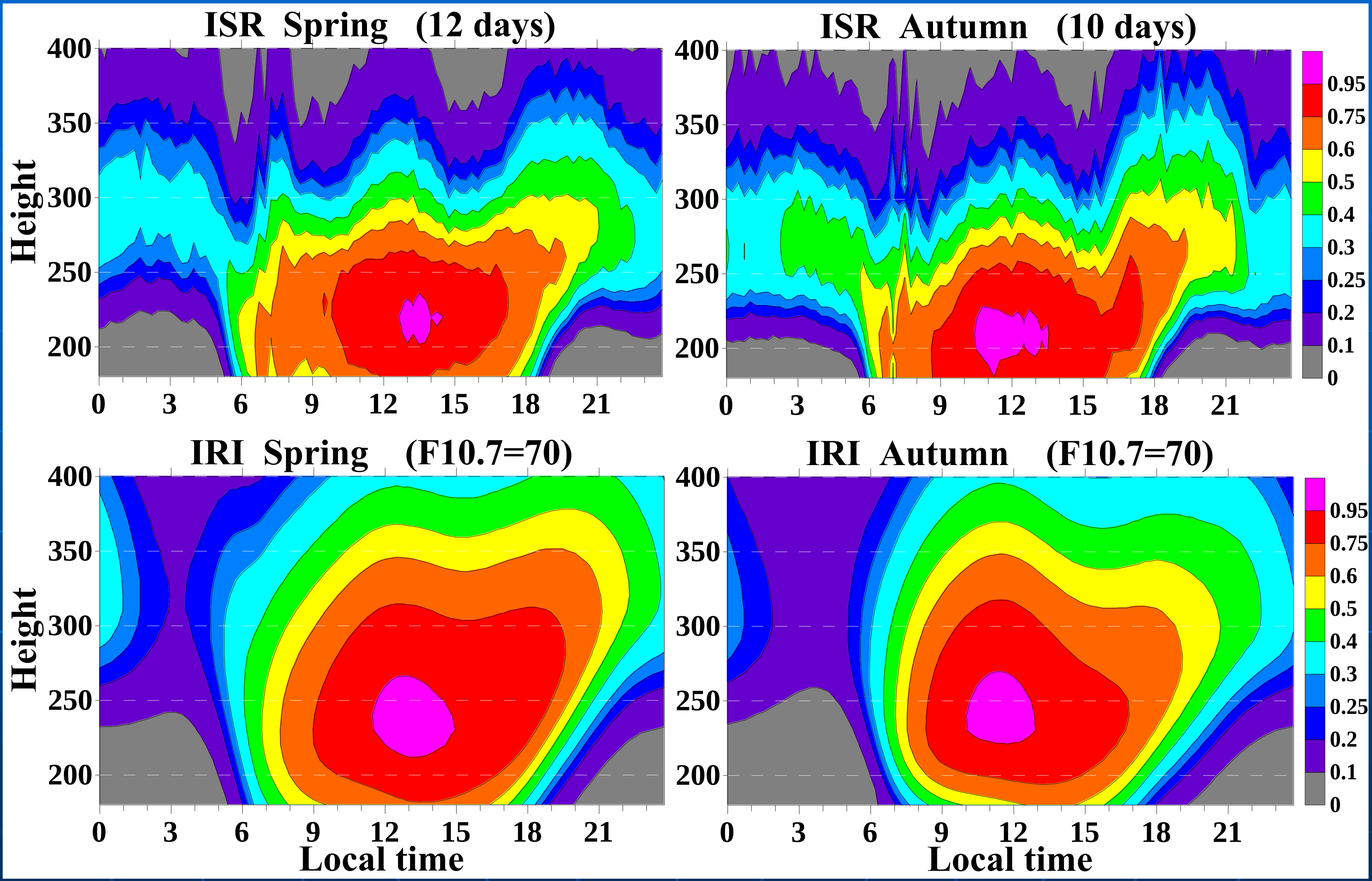


# Comparison of ISR ~ monthly averaged Ne and IRI prediction




Agreement in Summer is reasonable, while in the winter daytime IRI overestimates the ISR topside Ne by 3-4 times.

# Comparison of ISR ~ monthly averaged Ne and IRI prediction




**IRI overestimates the ISR topside Ne on the whole and does not reproduce a multi-peak variations of the ISR Ne at ~ 300 km and above .**

# Summary

- Our comparison included 4 seasons and 2 solar activity levels (low and moderate), and the number of simultaneous cases was ~10 times more than in the previous incoherent scatter radar comparisons.

- In the case of the bottomside characteristics (peak density and bottomside electron content), the deviations between the COSMIC and the ground-based facilities data may be interpreted as the COSMIC measurement errors without significant systematic biases and with root-mean-square values that are ~1.4-1.6 times smaller those that from the IRI model prediction. The rise in the root-mean-square errors with increasing solar activity may be explained by the corresponding rise in latitudinal and longitudinal gradients of the electron density. Our comparison agrees closely with the tools located at about 50ºN latitude, while differs from the comparisons at latitudes near 40ºN or lower.

- In the case of the topside characteristics (topside electron content and ionospheric electron content), the IRI model overestimates the COSMIC data by 0.6-0.8 tecu on average, and the COSMIC overestimates the Irkutsk incoherent scatter radar data by 1.0-1.1 tecu on average. In terms of the root-mean-square deviation, the COSMIC and the radar agree better than each of them agrees with the IRI model. None of the previous incoherent scatter radar studies have reported that the COSMIC overestimates the topside electron density with a better agreement in the bottomside. Possibly, the comparison results strongly depend on the ground-based facility location, as it is seen from the comparisons of NmF2.