Global Electron Density (Ne) Observations from GPS-RO in the D- and E-Region Ionosphere

Dong L. Wu

NASA Goddard Space Flight Center

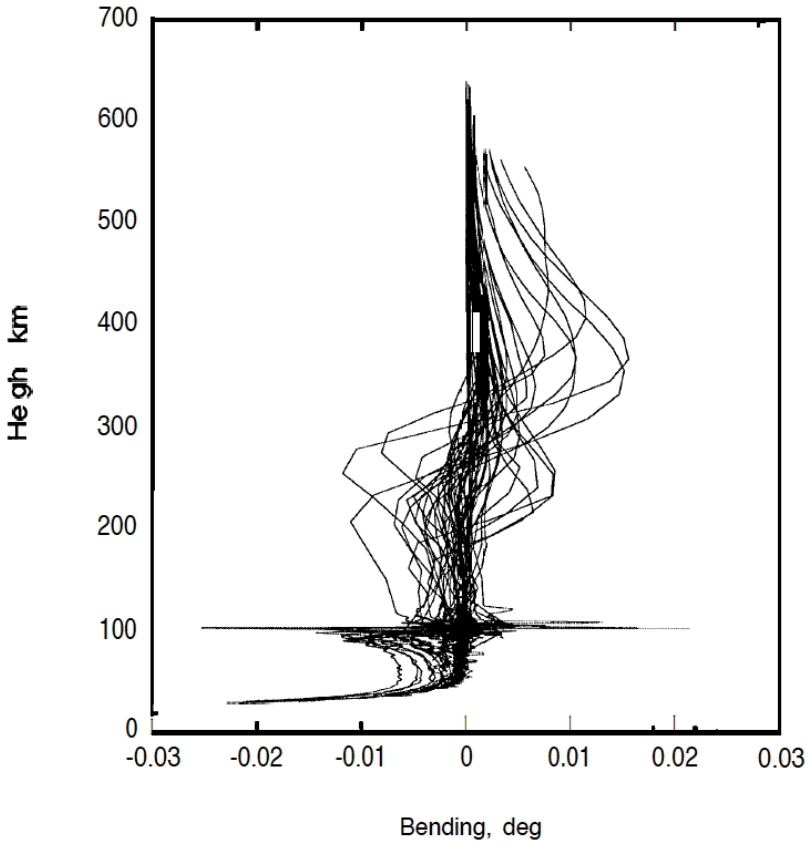
Outline

- Challenges in retrieving D- and E-region Ne from GPS-RO
- New algorithm
- Initial results
- Implications for energetic electron precipitation (EEP)

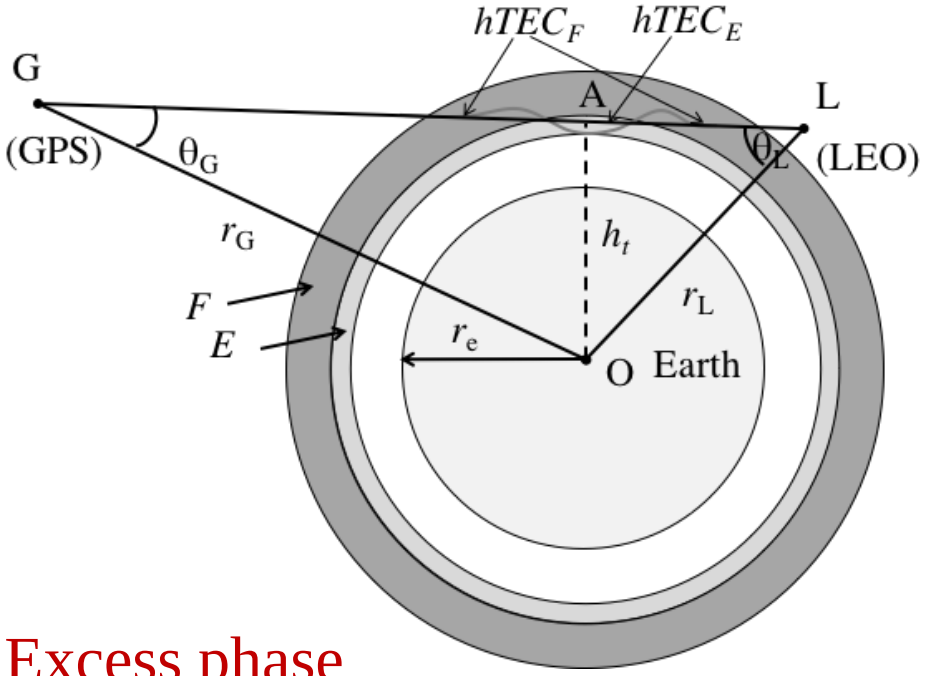
Wu (2017), JASTP, in press, 1–24. DOI: 10.1016/j.jastp.2017.07.013

Challenges in Retrieving E-Region Ne from RO (1)

Hajj and Romans (1998)



Can be asymmetric

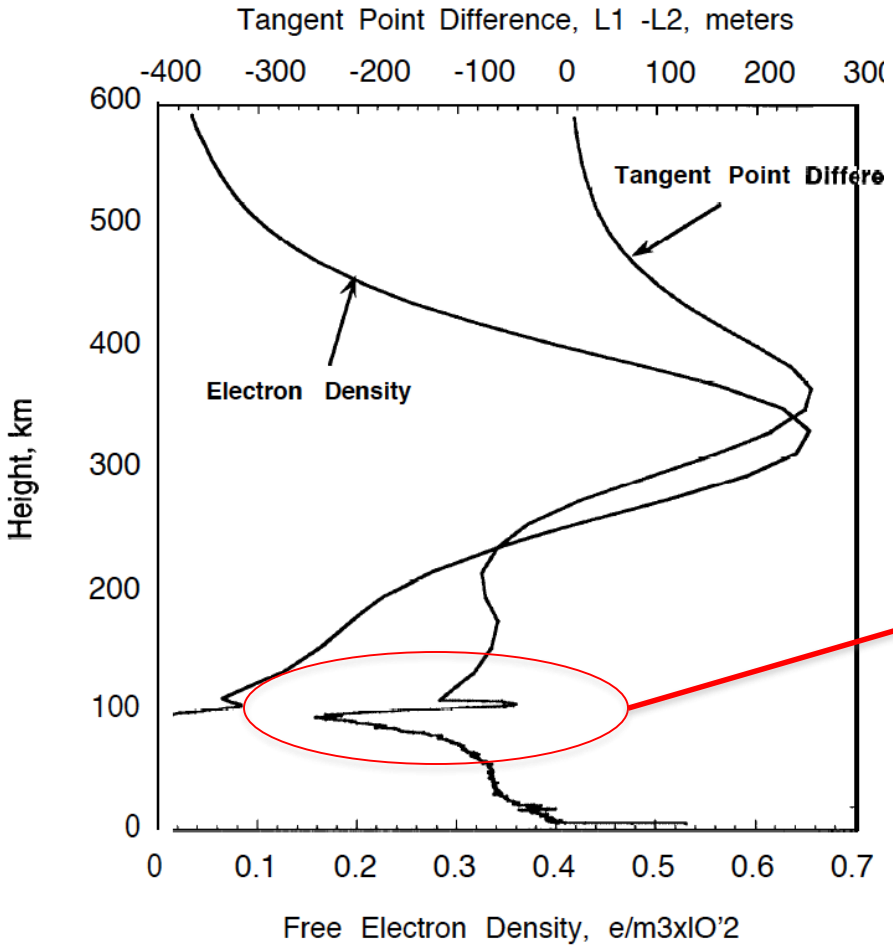


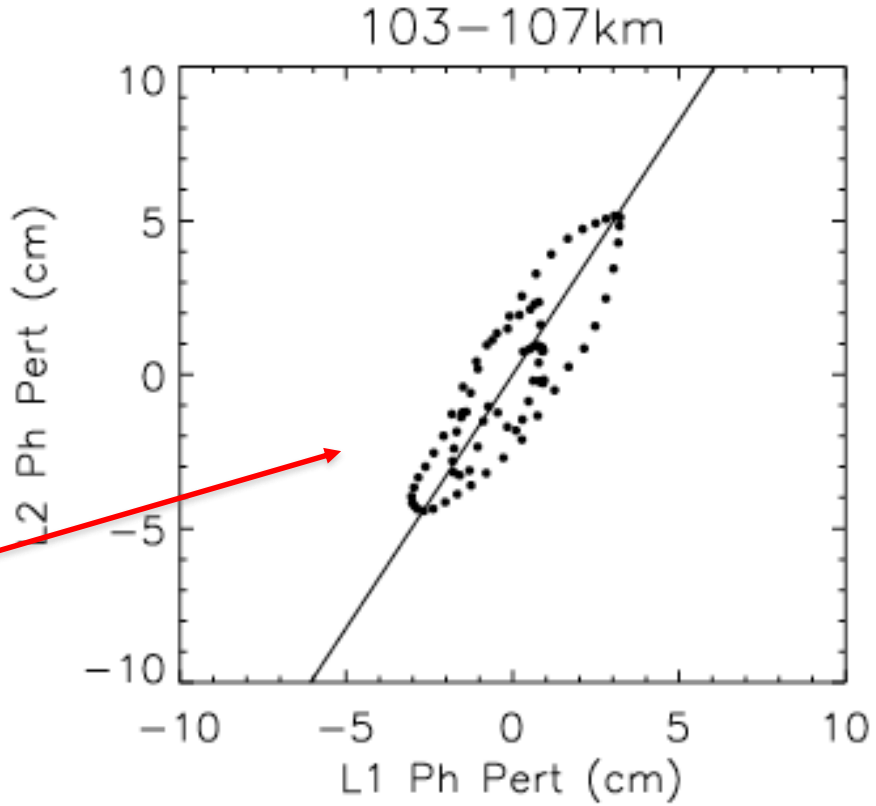
- Excess phase

$$\tau_{ex} = \tau_{bend} - \tau_p$$

- From bending: τ_{bend}
- From phase advance in plasma: τ_p

Challenges in Retrieving E-Region Ne from RO (2)



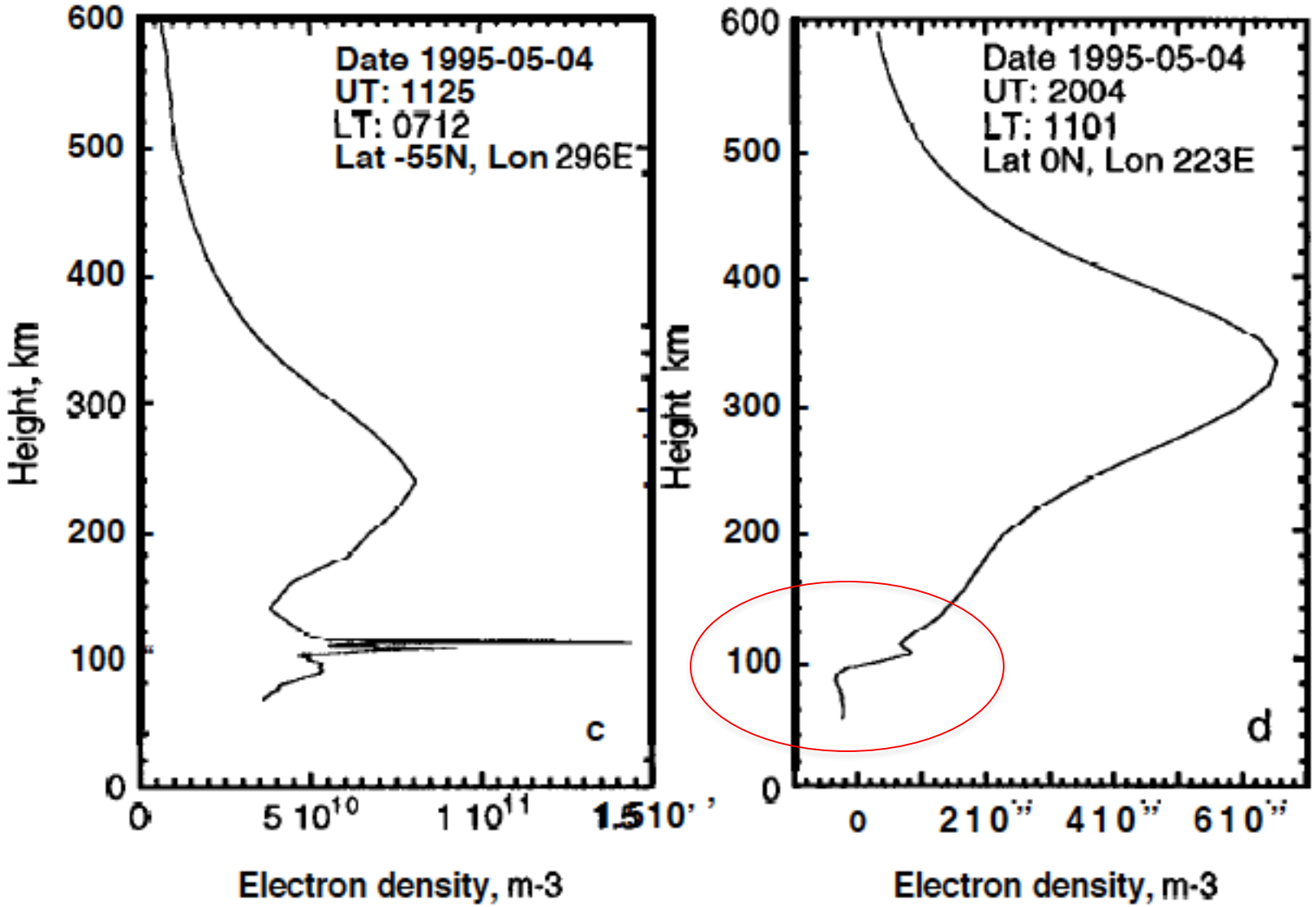


Hajj and Romans (1998)

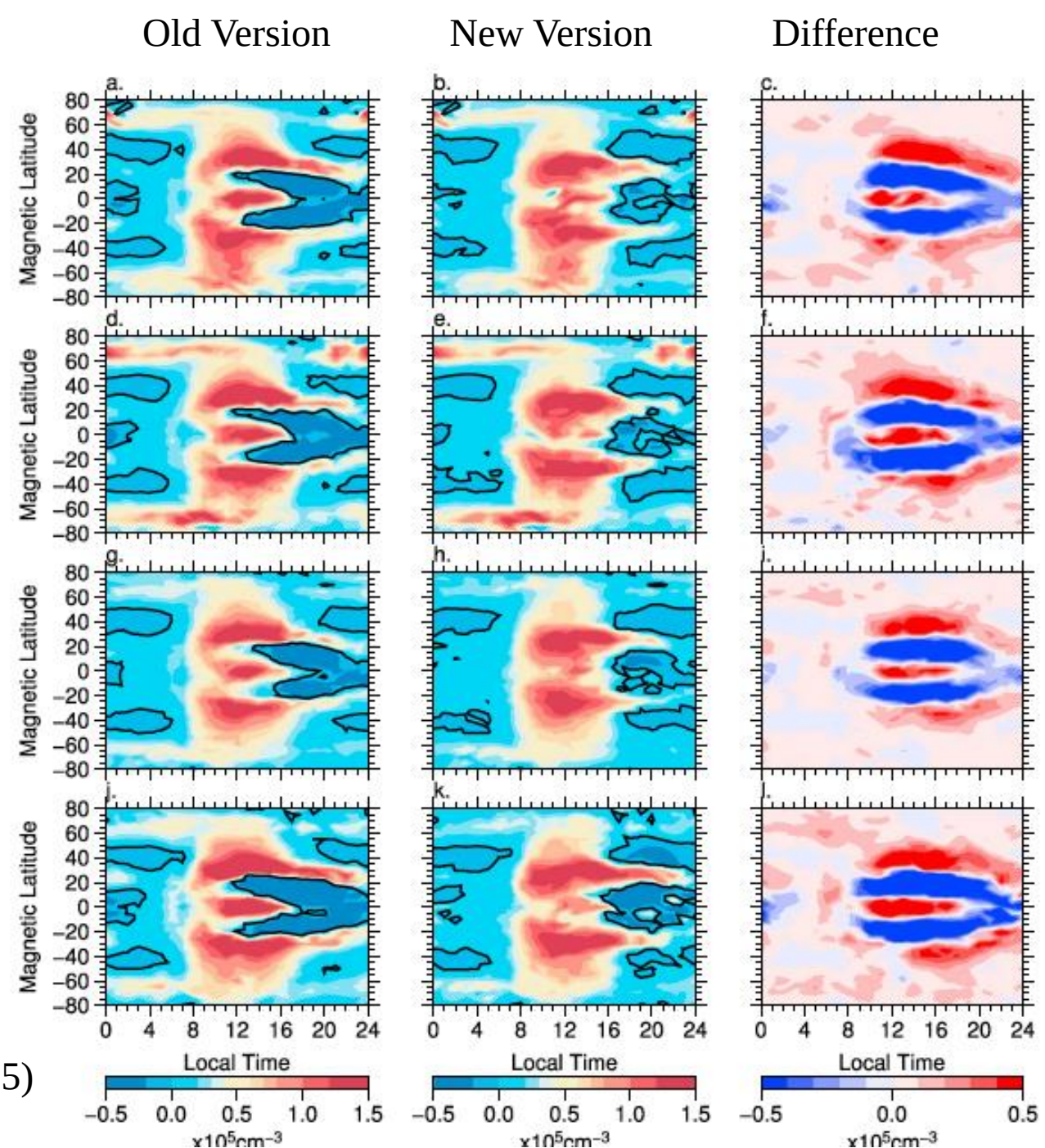
Wu et al. (2005)

Ne Retrievals from GPS/Met

Hajj and Romans (1998)

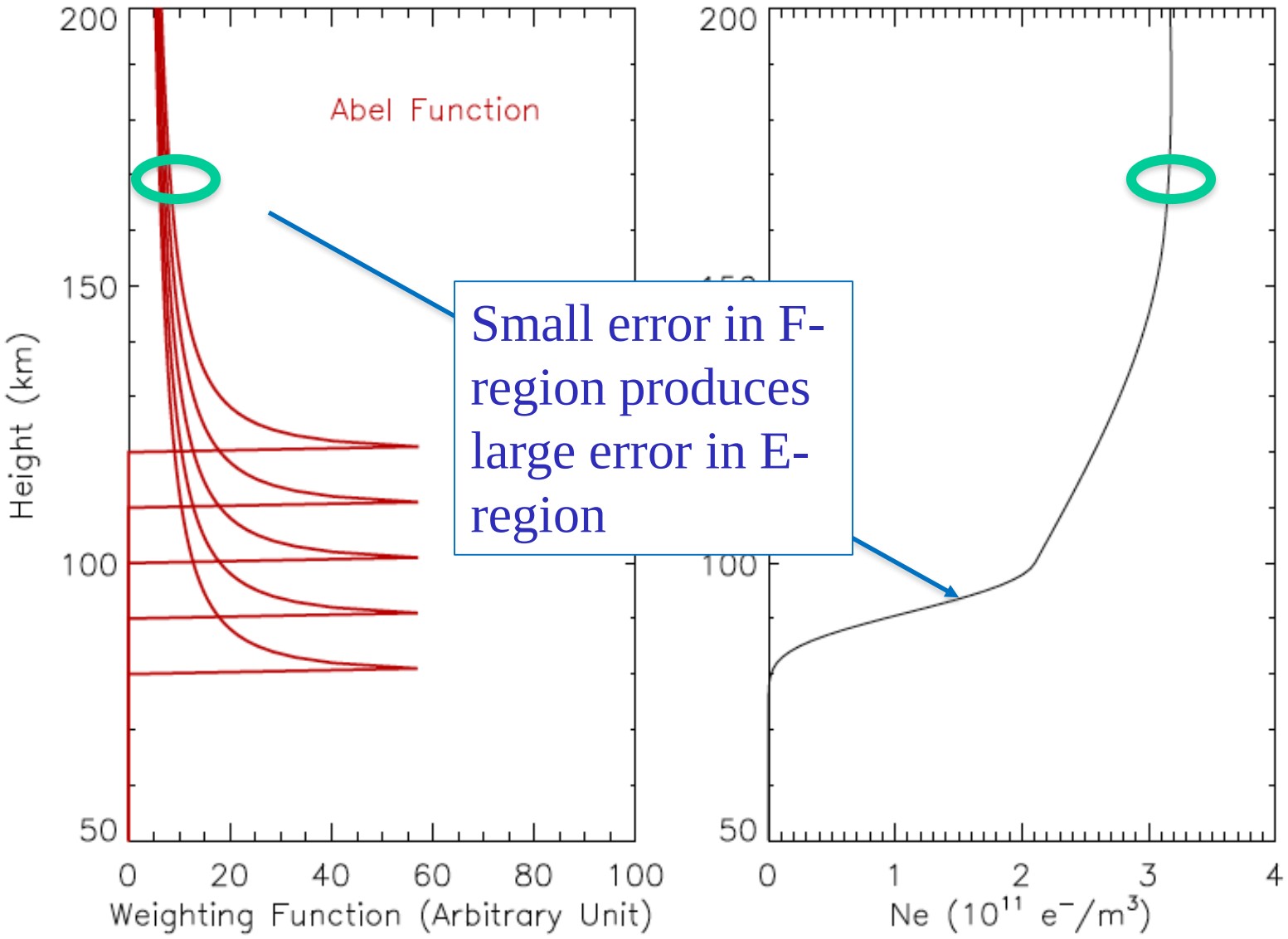


March Ne
at 100 km
(COSMIC)



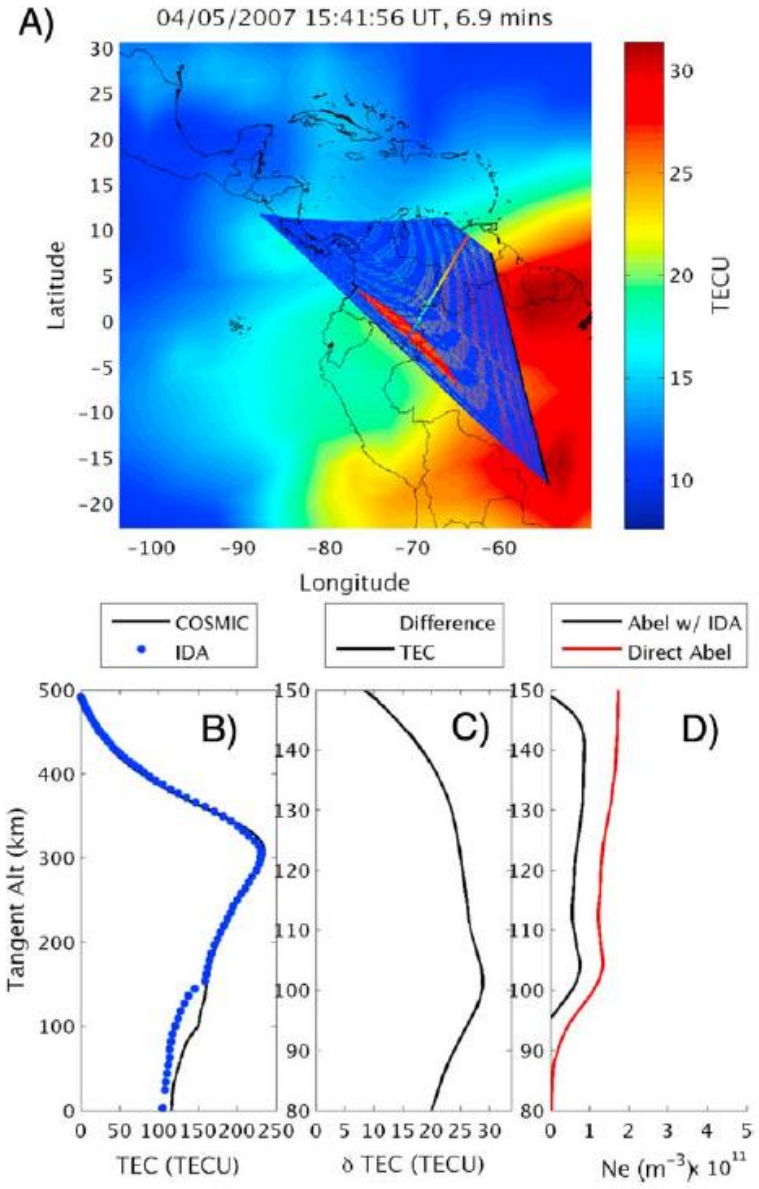
Pedatella et al. (2015)

Problems with the Abel Weighting Functions

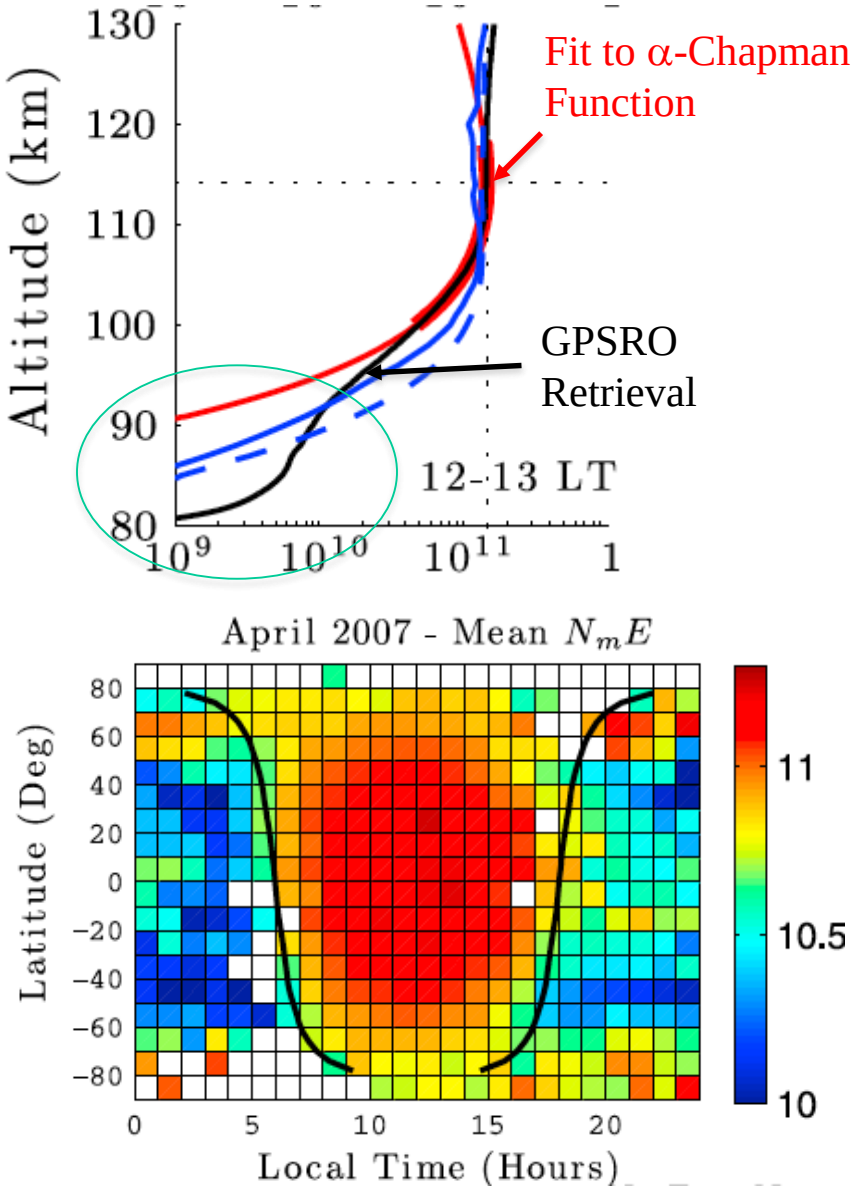


Model-Aided E-Region Ne Retrievals

Nicolls et al. (2009)

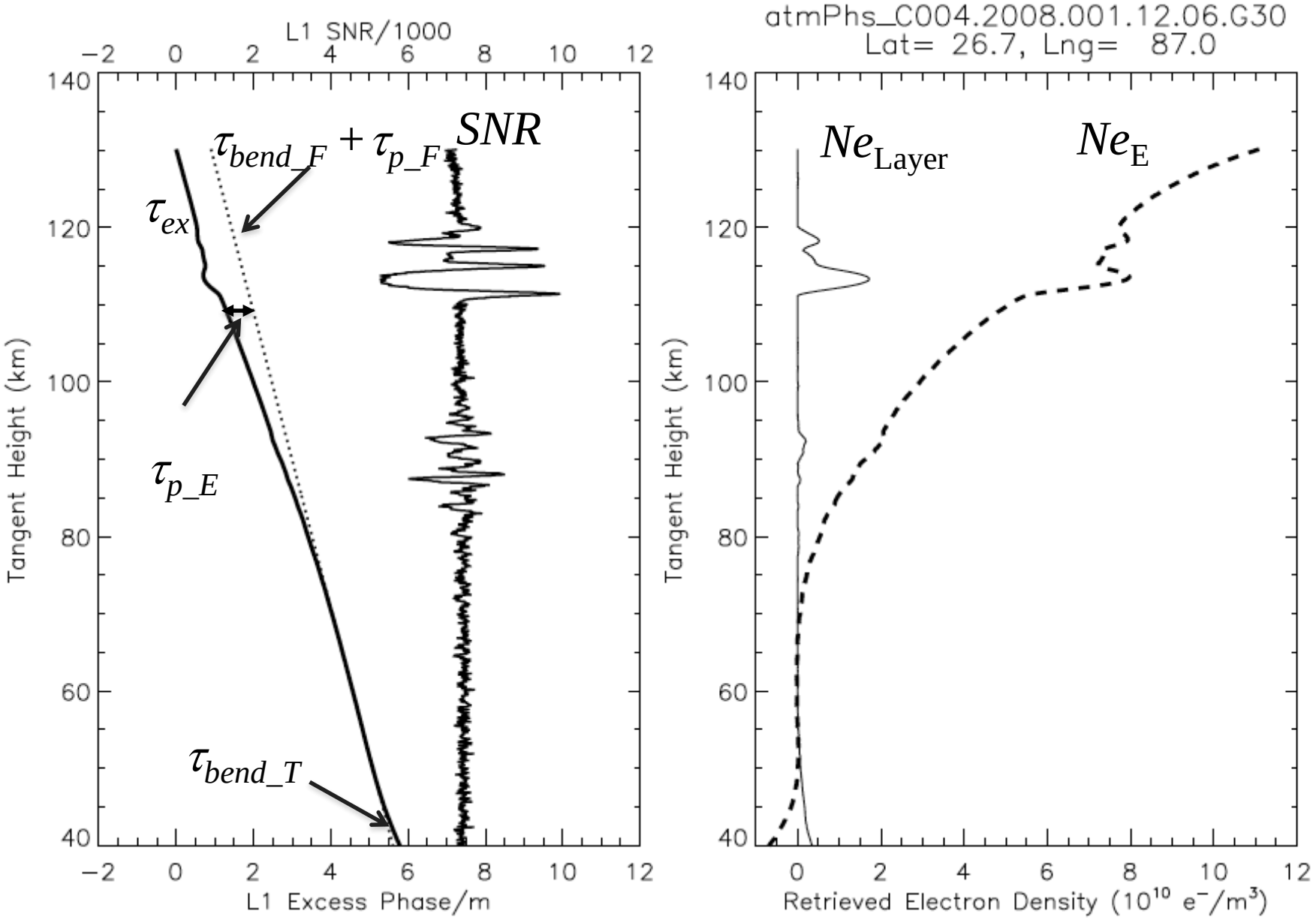


Nicolls et al. (2012)



This Work

- Self-sustained new retrieval method
  - No auxiliary inputs from model/data
  - Full utilization of good precision of L1 excess phase
- L1 50-Hz data only
  - Slowly-varying F-region contributions
  - Dominant phase advance due E-region Ne


L1 SNR/1000
−2 0 2 4 6 8 10 12
140 120 100 80 60 40
Tangent Height (km)
$\tau_{bend\_F} + \tau_{p\_F}$
SNR
τ_{ex}
τ_{p_E}
τ_{bend_T}
L1 Excess Phase/m
atmPhs_C004.2008.001.12.06.G30
Lat= 26.7, Lng= 87.0
Ne_{Layer}
Ne_{E}
Retrieved Electron Density (10^{10} e^{-}/m^{3})

Radio Wave Propagation in Plasma

Dispersion Relation $\omega^2 = c^2k^2 + \omega_c^2$

Critical Plasma Frequency $\omega_c = 56.4 \cdot N_e^{1/2}$ rad/s

Phase and Group Velocity $v_p \equiv \omega/k, v_g \equiv d\omega/dk,$

Phase and Group Refr Indices $n_p \equiv c/v_p \; n_g \equiv c/v_g$

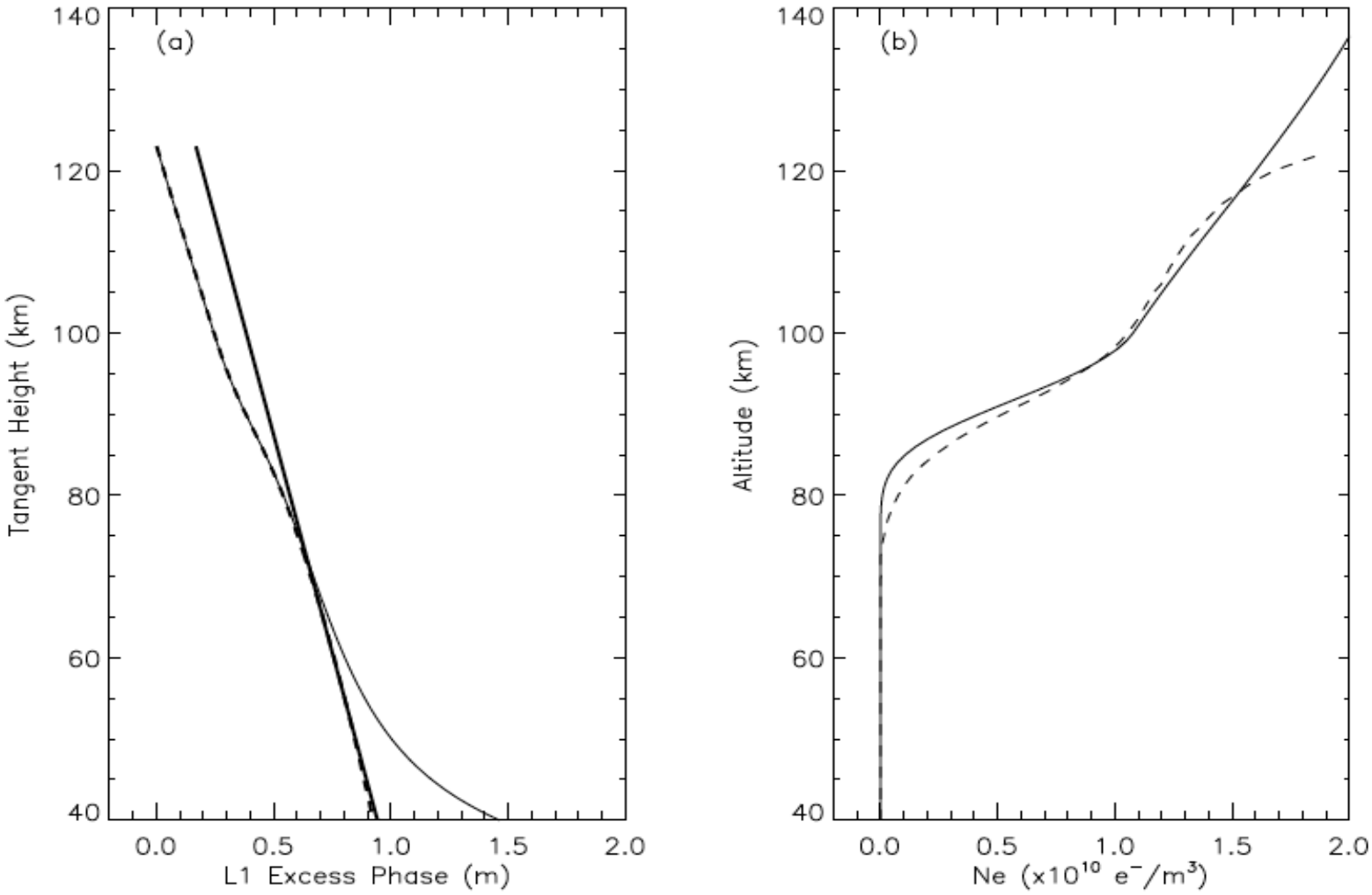
Advance $n_p = \sqrt{1-(f_c/f)^2} \approx 1 - 40.3 \cdot N_e/f^2$

Delay $n_g = 1/\sqrt{1-(f_c/f)^2} \approx 1 + 40.3 \cdot N_e/f^2$

Phase Delay from Bending $\tau_{bend\_I}(\lambda_i, h_t) \propto 1/f_i^2$

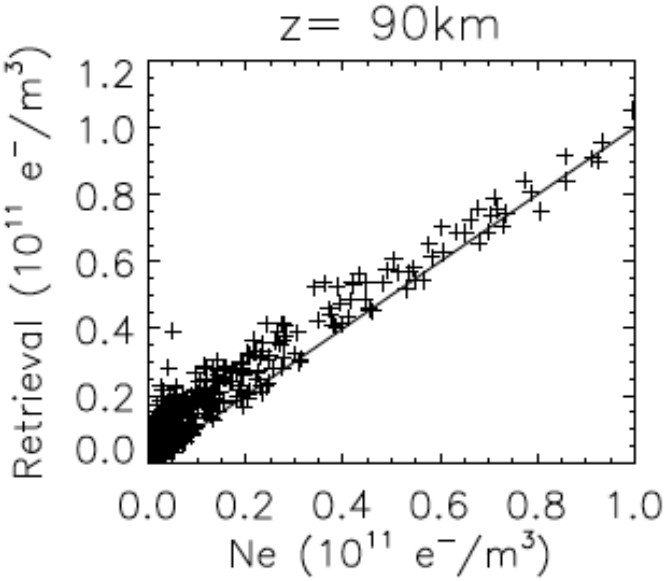
Delay due to F-region ionospheric bending is 1-2 m (Hoque and Jakowski, 2011)

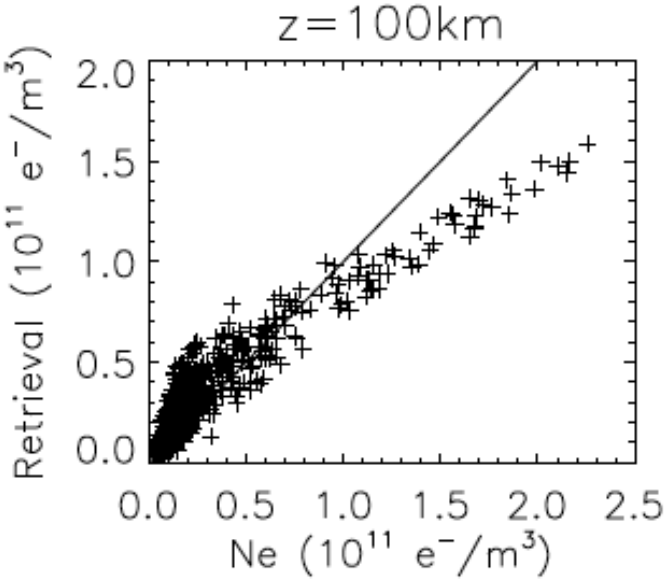
Ne Retrievals from Simulated Data (1/2)

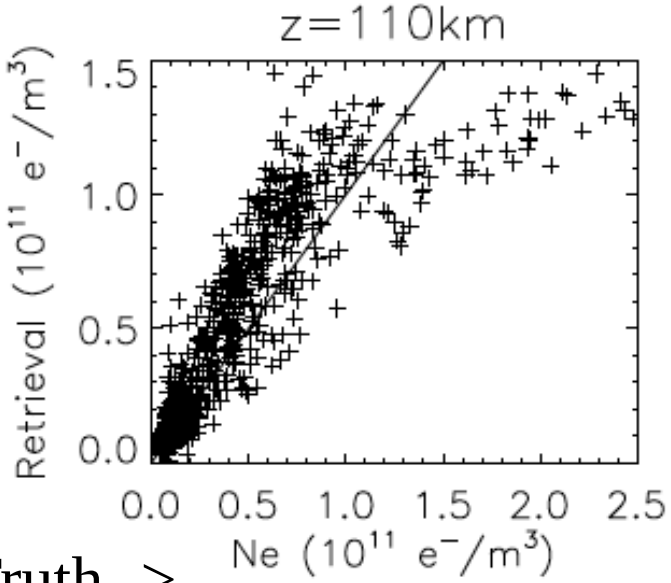


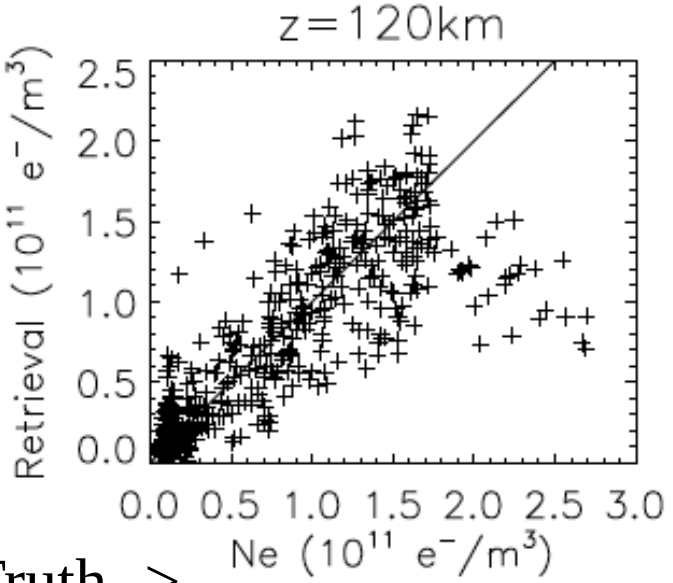
Courtesy of X. Yue for the simulated data from UCAR

Ne Retrievals from Simulated Data (2/2)





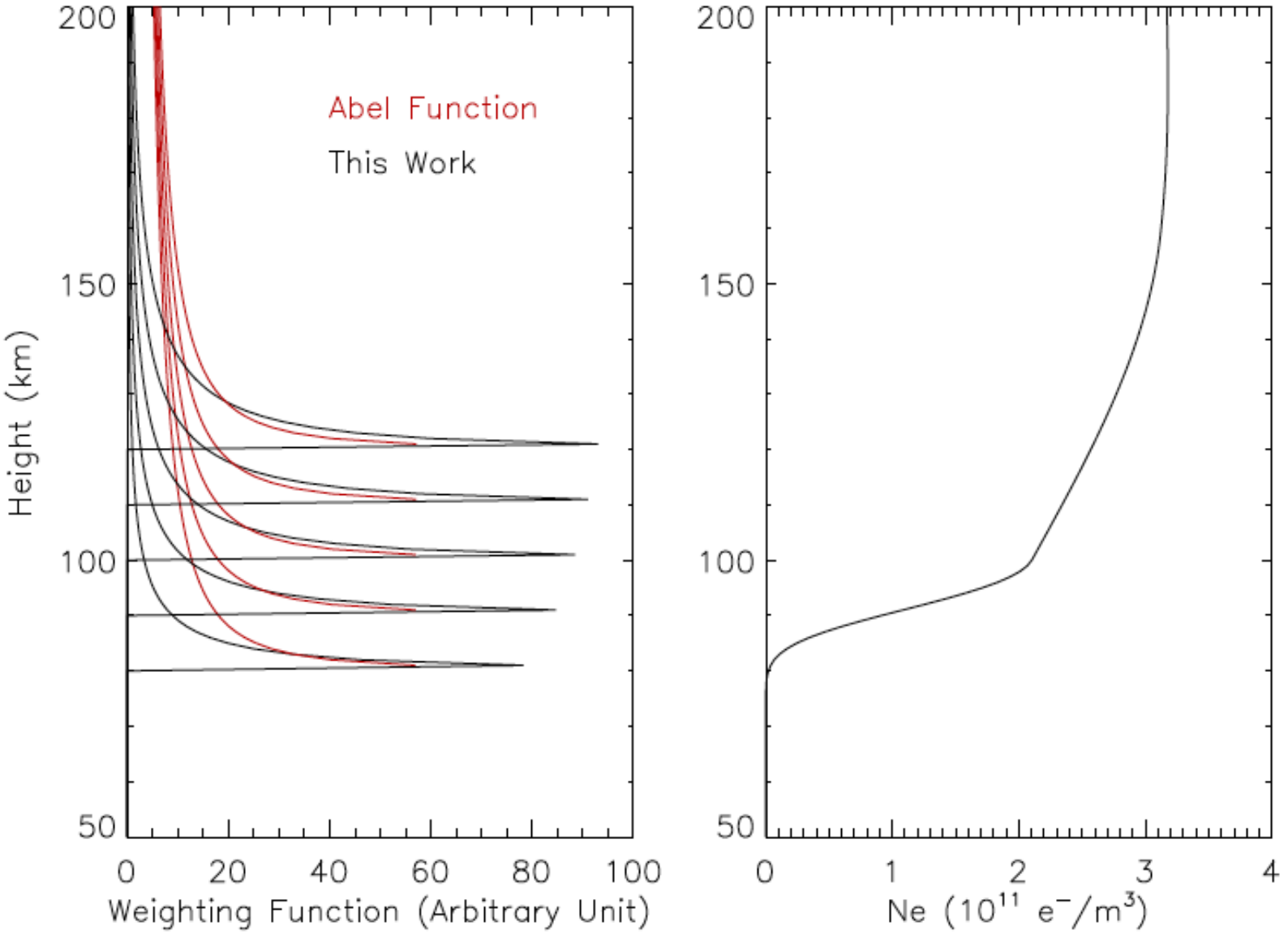




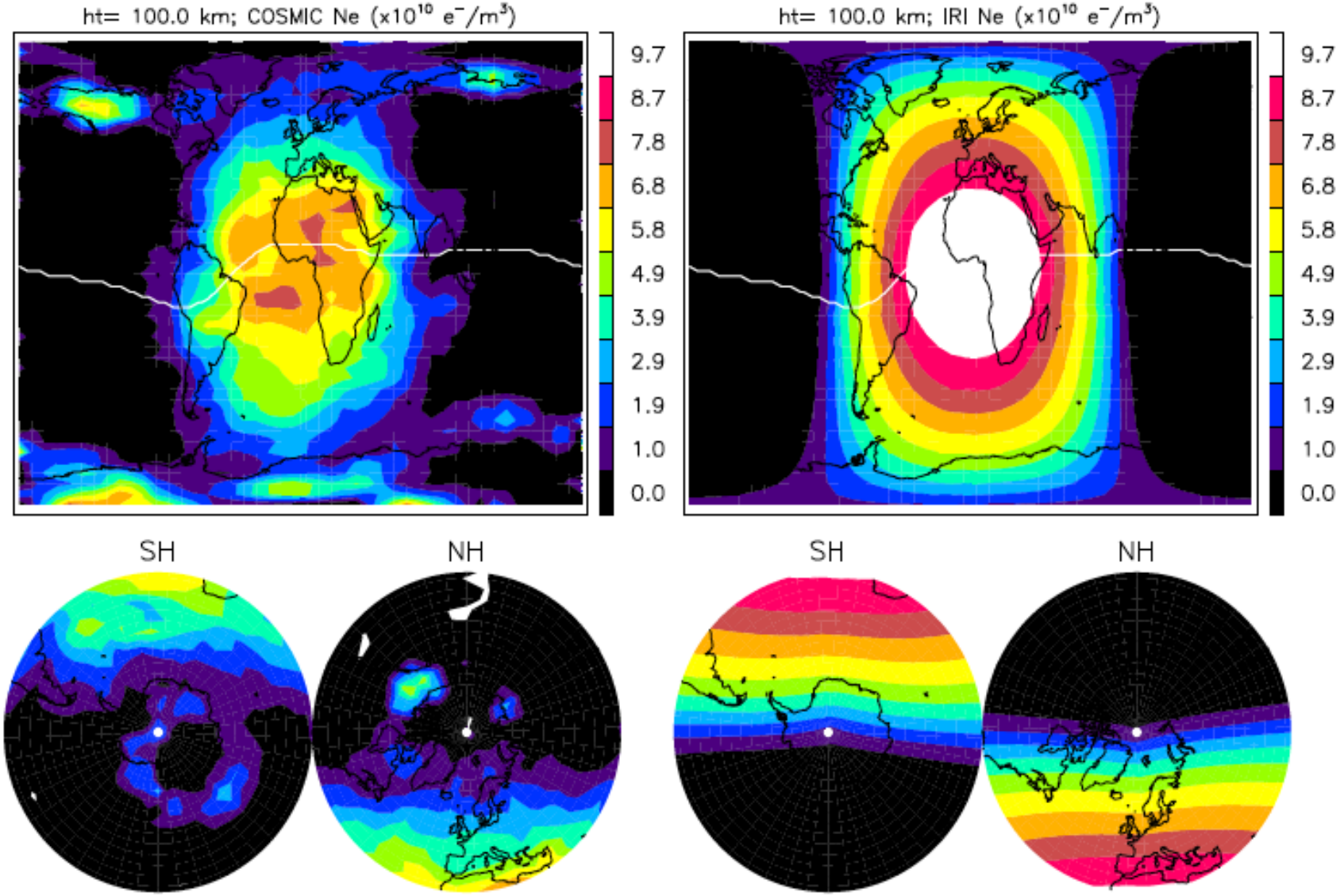
Truth ->

Truth ->

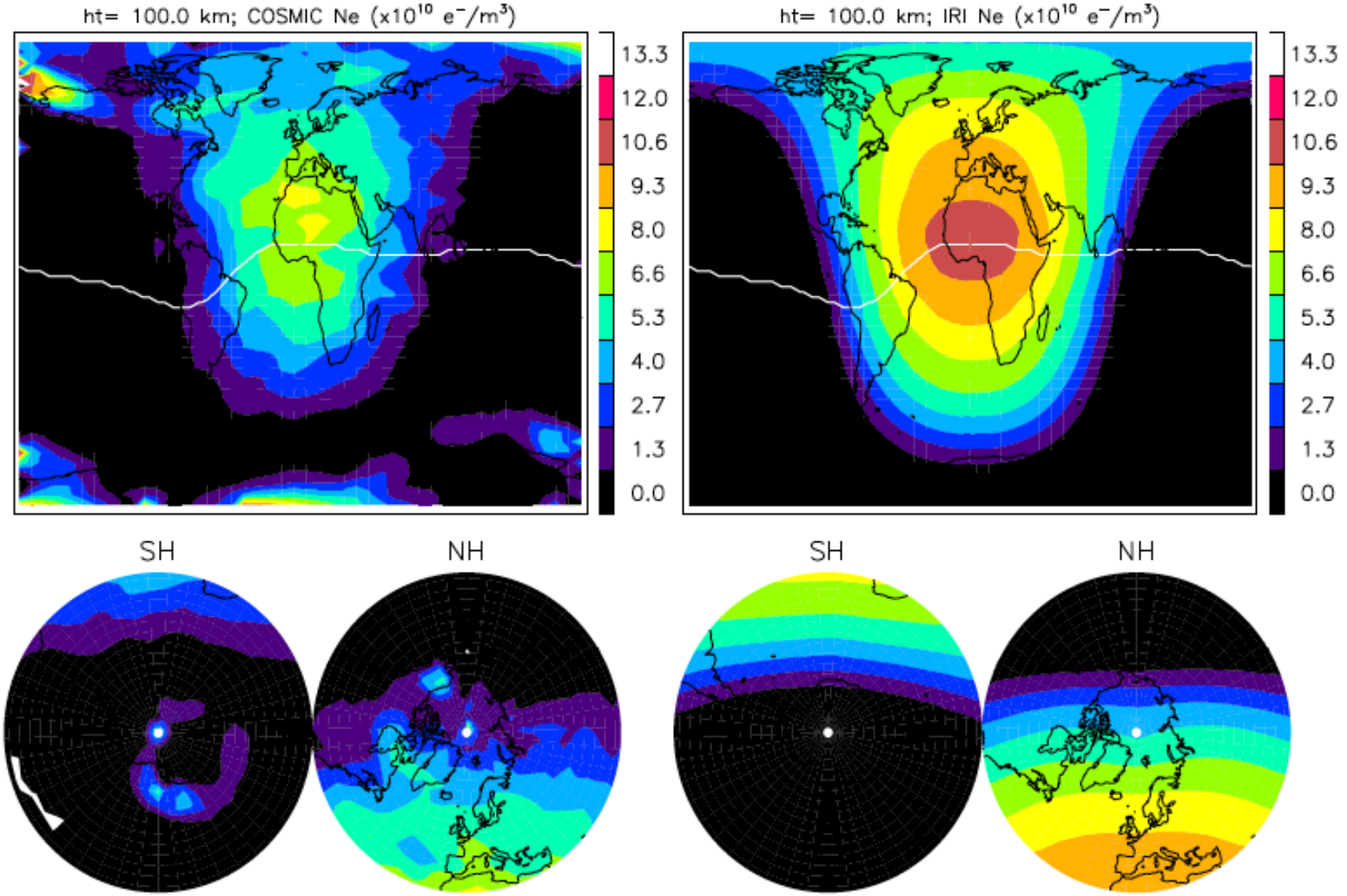
New Weighting Functions



March 2008


ht= 100.0 km; COSMIC Ne (x10^10 e^-/m^3)
ht= 100.0 km; IRI Ne (x10^10 e^-/m^3)
9.7
8.7
7.8
6.8
5.8
4.9
3.9
2.9
1.9
1.0
0.0
SH
NH
SH
NH
COSMIC Ne (UTC=10:00–14:00)
IRI2016 Ne (UTC=12:00)

July 2008

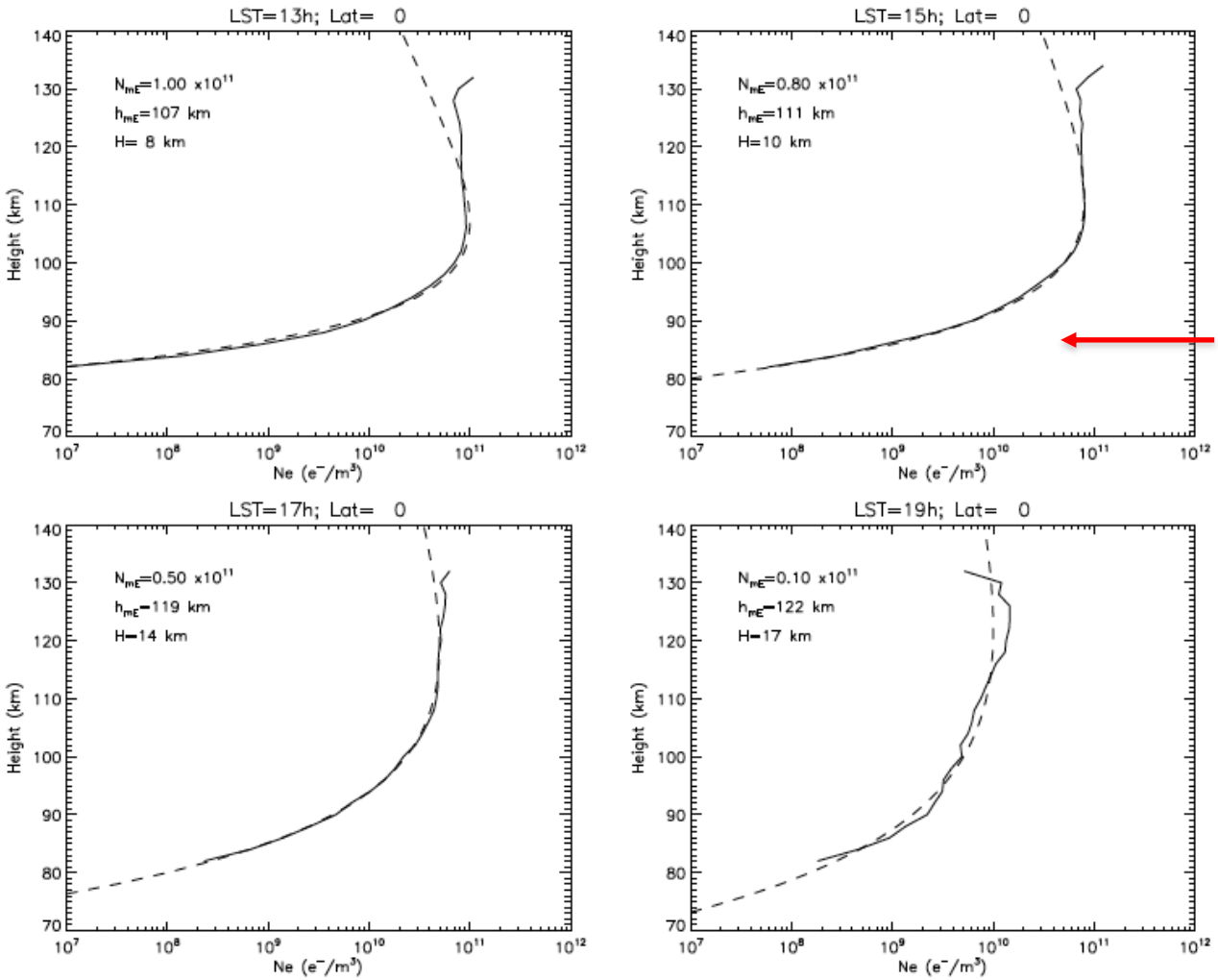


COSMIC Ne (UTC=10:00–14:00)

IRI2016 Ne (UTC=12:00)

α-Chapman Function

$$N_e(z) = N_{mE} e^{\{0.5 \cdot (1 - z' - e^{-z'})\}} \qquad z' = (z - h_{mE})/H$$

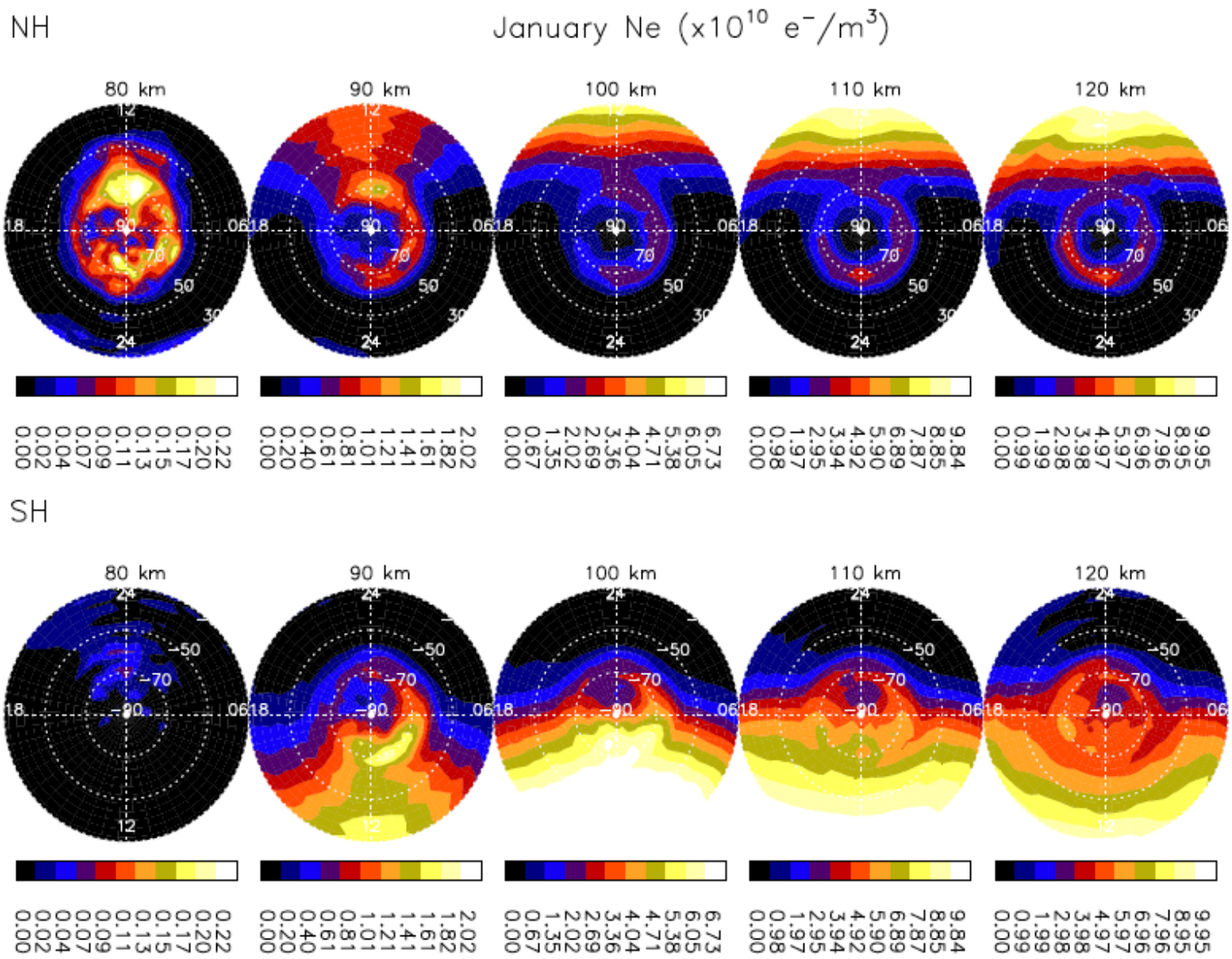


Good fit

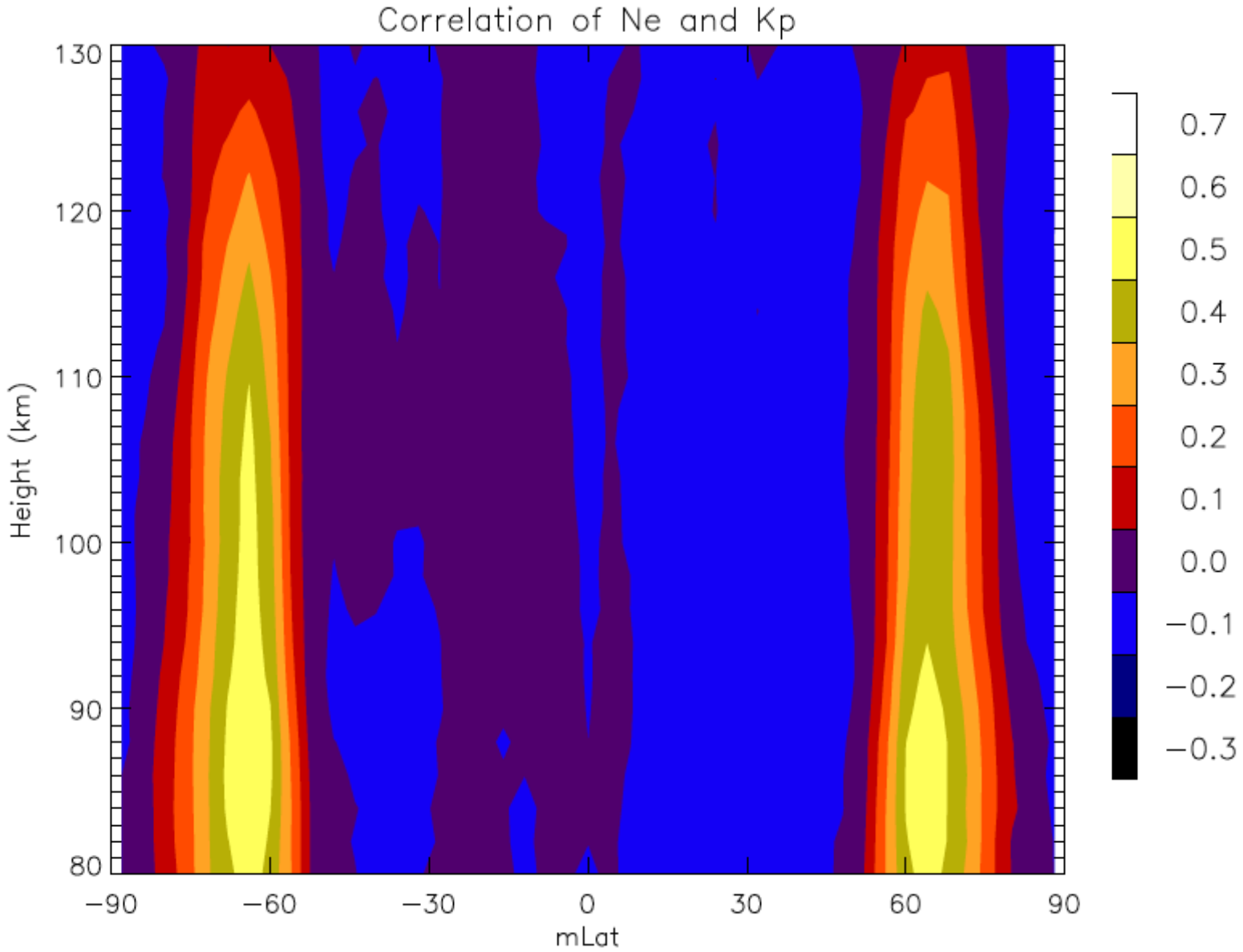
Science Applications

- Ionosphere-atmosphere coupling
  - Auroral electron and energetic electron precipitation, and their impacts on O3 chemistry
  - Planetary and gravity wave disturbances
  - Global electric circuit
- Ionosphere-magnetosphere coupling
  - Solar impacts
  - Storm-time electron density disturbances

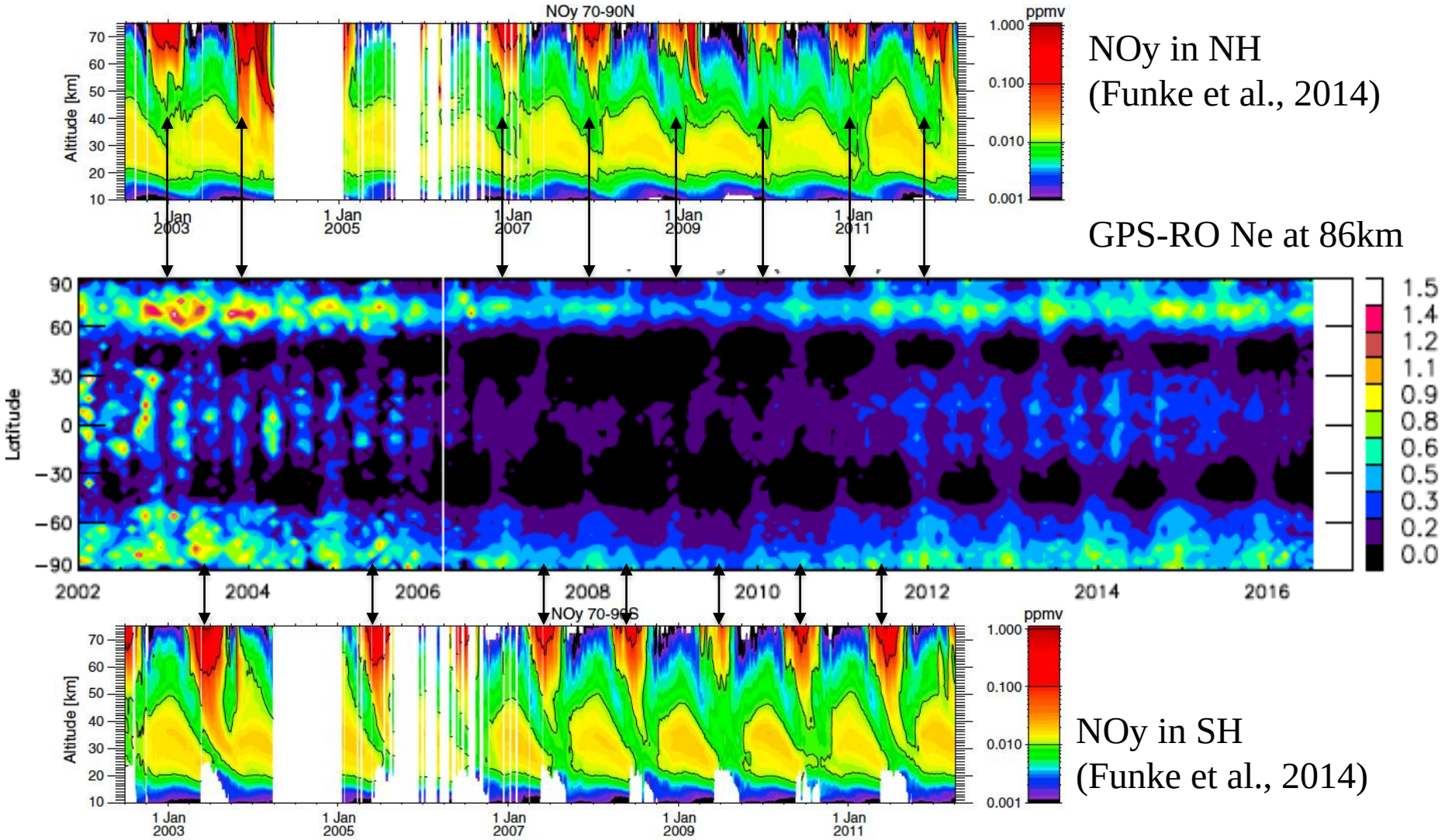
Wu (2017)


NH
January Ne (x10^10 e⁻/m³)
80 km
90 km
100 km
110 km
120 km
SH
80 km
90 km
100 km
110 km
120 km

Sensitivity of Ne to Magnetosphere Substorms



Impacts on Medium-Level Electron on NOy

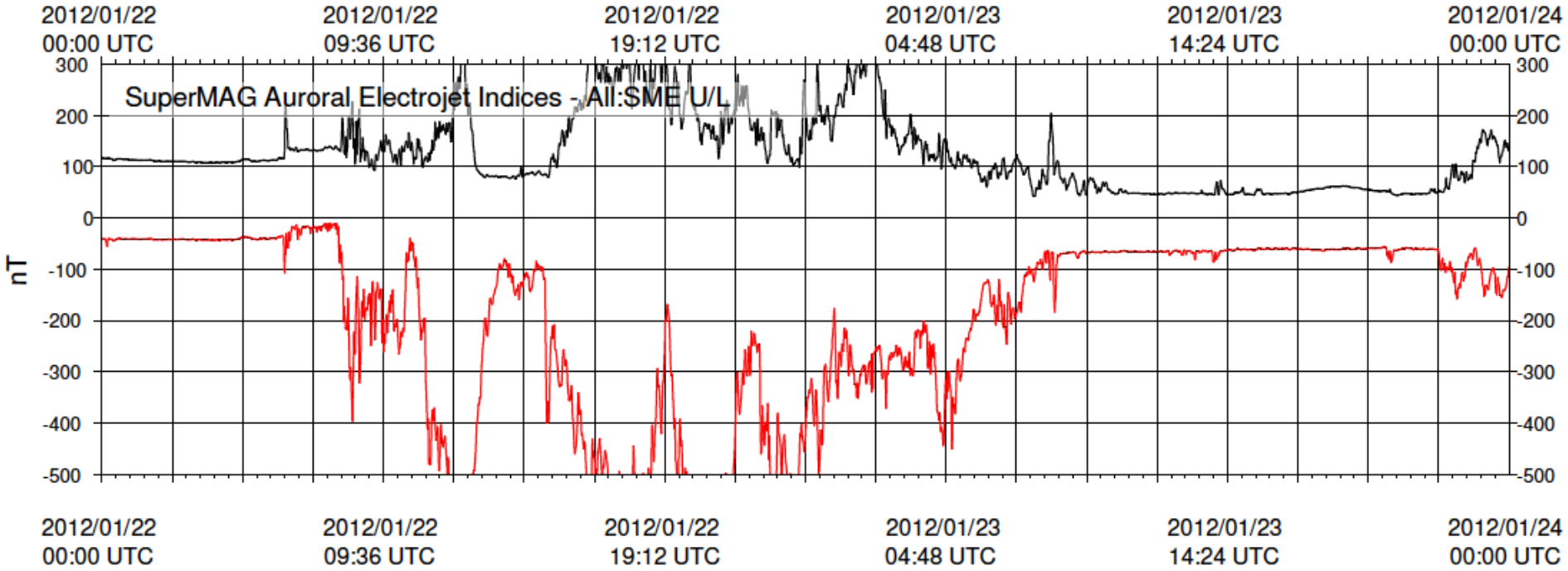


NOy in NH
(Funke et al., 2014)

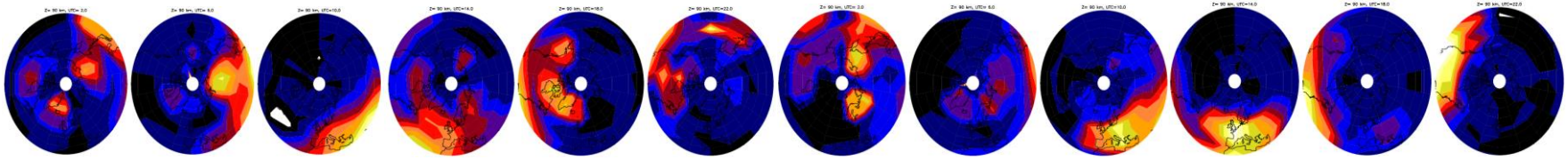
GPS-RO Ne at 86km

NOy in SH
(Funke et al., 2014)

Sensitivity of Ne to Energetic Particle Precipitation



SuperMAG Aurora Index *SME U/L*

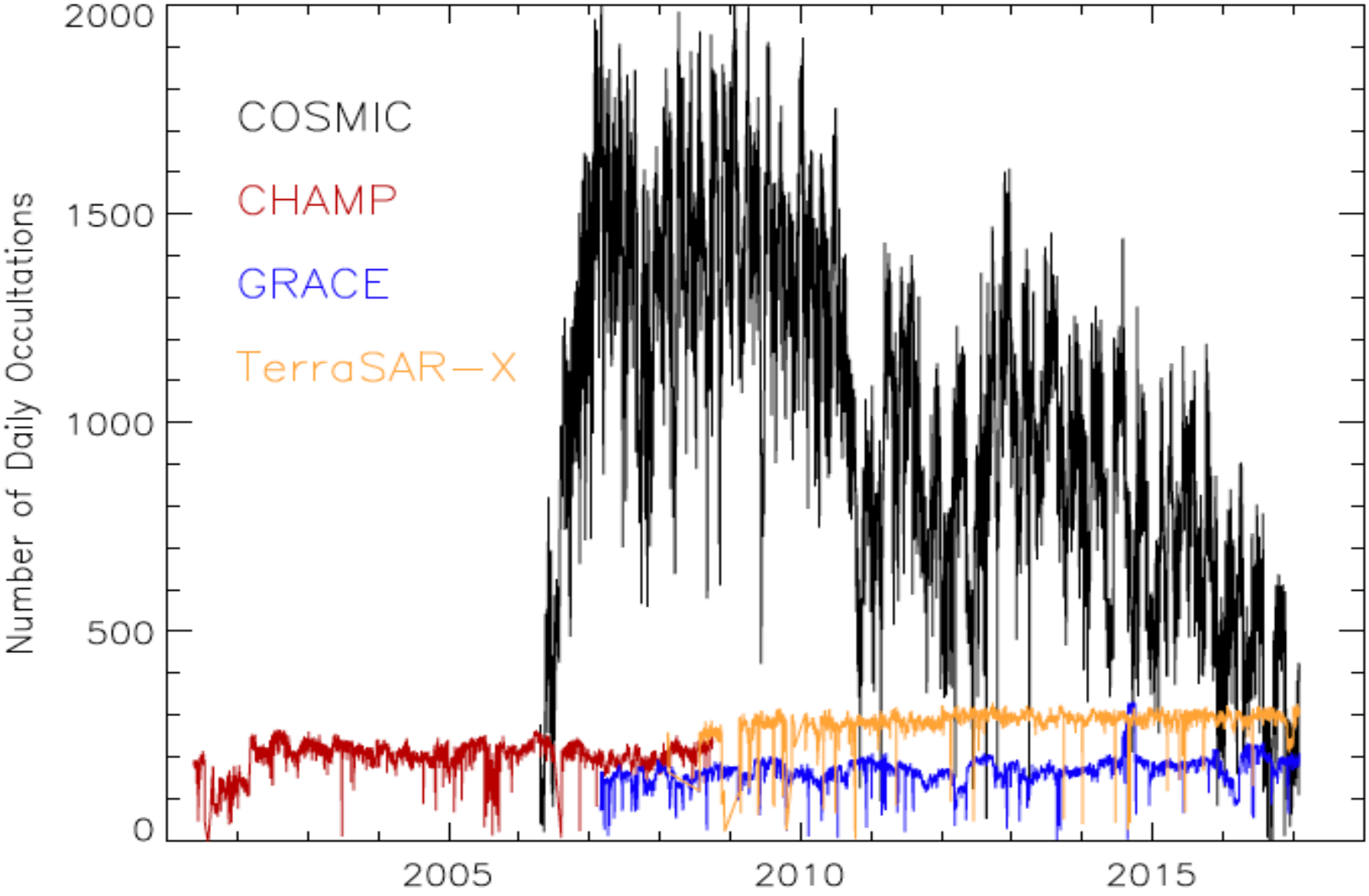


GPS-RO *Ne*

Top Height of GPS-RO Data

120+ km	< 85 km
CHAMP	SAC-C
COSMIC-1	MetOp-A, -B, -C
C/NOFS	KOMPSat5
GRACE	
TerraSAR-X	

Courtesy of CDAAC



Summary

- New “bottom-up” method provides sharper weighting functions than Abel. Key assumptions:
  - F-region contributions varying slowly at low tangent heights
  - Excess phase due to the advance of E-region Ne
- The technique works with 50-Hz RO if reached 80-120 km, but not all operation RO data go above 85km;
- Initial Ne retrievals at 80-120 km show good agreement with IRI-2016 but with auroral electron;
- GPS-RO Ne data provide a critical source for studying energetic electron precipitation and its impacts on the upper atmosphere