NEDM and its potential use to improve IRI model for topside ionosphere and plasmasphere

M Mainul Hoque (1), and Fabricio S. Prol (2), Norbert Jakowski (1)

(1) German Aerospace Center (DLR)

(2) Finnish Geospatial Research Institute (FGI)

COSPAR IRI 2024 Workshop, 9 -13 Sep 2024, Kilifi, Kenya

IRI 2024 Workshop

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Neustrelitz Electron Density Model- NEDM2020

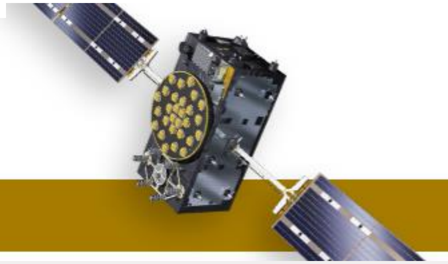
Hoque et al. 2022, SWSC

Neustrelitz Electron Density Model (NEDM)

	model	name	# coeff.	driving param	database	reference
TEC Model	Neustrelitz TEC Model	NTCM	12	F10.7	global TEC map (98 -06)	Jakowski et al., JoG [2011]
TEC Model	Neustrelitz TEC Broadcast Model	NTCM-BC	9	9 coeff.	daily GNSS data from 30 monitor stations	Hoque & Jakowski, JoG [2015]
TEC Model	NTCM driven by GPS Klobuchar parameter	NTCM-Klobpar	12	Klobpar	global TEC map (02 - 15)	Hoque et al., GPS Sol [2017]; Hoque et al., SWSC [2018]
TEC Model	NTCM driven by Galileo Az coefficients	NTCM-GlAzpar	12	GlAzpar	global TEC map (14 - 18)	Hoque et al., GPS Sol [2019]
NmF2	Neustrelitz Peak Density Model	NPDM	13	F10.7	Ionosonde, CHAMP (01-08), GRACE (08-10), COSMIC (06-10) IRO	Hoque & Jakowski, Radio Sci 2011
hmF2	Neustrelitz Peak Height Model	NPHM	13	F10.7	same as NPDM	Hoque & Jakowski, Annales Geophy. 2012
	Neustrelitz Plasmasphere Model	NPSM	40	F10.7	CHAMP topside recons. (00 -05)	Jakowski & Hoque, SWSC, 2018
	Neustrelitz Slab thickness Model	NSTM	13	F10.7	CHAMP, COSMIC RO, IGS TEC (01-18)	Jakowski and Hoque, SWSC, 2021

EUSPA European Union Agency for the Space Programme

European **GNSS** Service Centre



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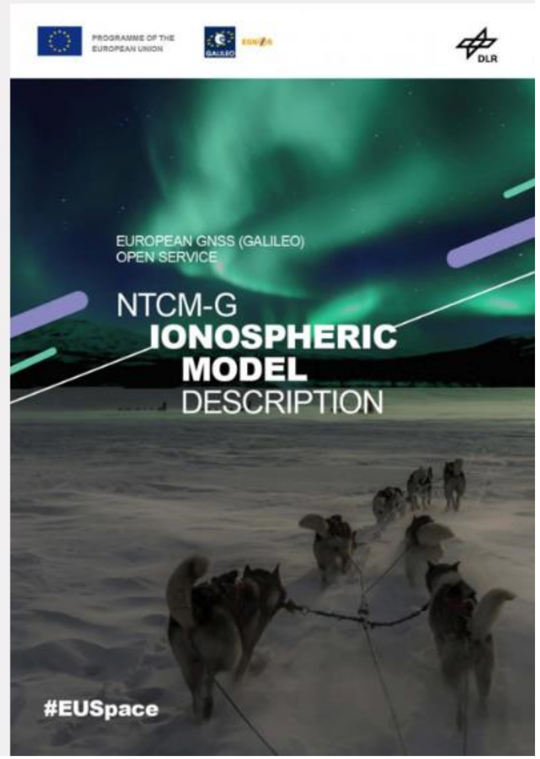
Good performance, less computation: A new ionospheric model for the Galileo Open Service

NTCM G Source Code and Description



OSNMA Public Observation Test Phase

GNSS SIMULATION AND TESTING

Galileo Satellite Metadata

Galileo Compatible Devices

Ionospheric Correction Algorithms

- NeQuick G Source Code
- NTCM G Source Code

NTCM G Source Code

Download NTCM G source code

An implementation of NTCM G algorithm, an alternative to Nequick G algorithm, is now available for users. The NTCM G source code provides a portable and validated C/C++ version of the NTCM G model that can be easily deployed in different GNSS application and simulation environments. The NTCM G source code package is composed of:

- The NTCM G source code repository, which includes the reference implementation of the NTCM G,
- The Model Based Design (MDB) repository, which contains all the results and auxiliary information relying on the NTCM G routine according to MBD.
- The Application repository, which includes examples of applications built on top of the source code.
- The NTCM G Software Package User Guide

The NTCM G algorithm implementation is **available for registered users** upon access request.

Request access

NTCM G model for single frequency users

The Neustrelitz Total Electron Content Model for Galileo (NTCM G) is an empirical model that provides a practical and cost-effective solution for the determination of the global ionosphere Total Electron Content (TEC).

NTCM G is an alternative to the reference ionospheric correction algorithm NeQuick G. The model is less computationally demanding than the reference Nequick G model, so, it represents a good option for applications in which computational resources are limited.

Users shall follow indications provided in the reference document "NTCM-G Ionospheric Model Description" in order to implement the NTCM G algorithm for Galileo single frequency receivers. The document contains definitions, step-by-step procedures and guidelines for implementation of NTCM G in the receivers.

Resolution (spatial/temporal) and latency of model runs, standard 'outputs'

Driving parameter: F10.7

Input: user latitude, longitude, height, day of year, universal time

Spatial/temporal resolution: no interpolation, no limit

Output: electron density Ne

Forecast only in terms of F10.7

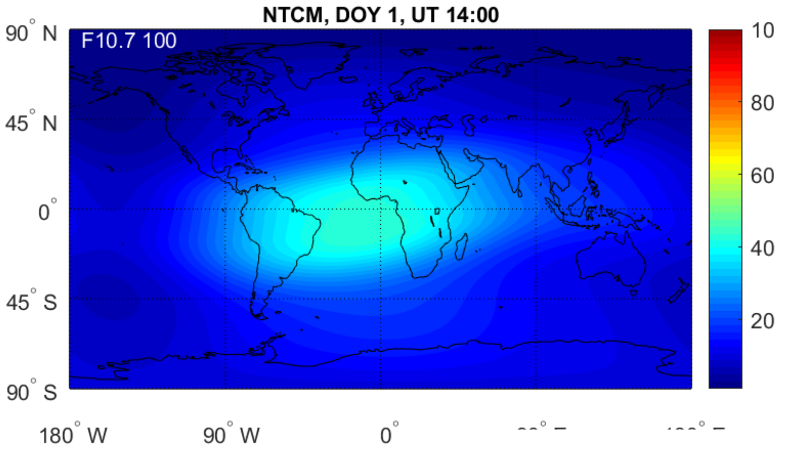
$$\text{TEC / NmF2 / hmF2} = F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5$$

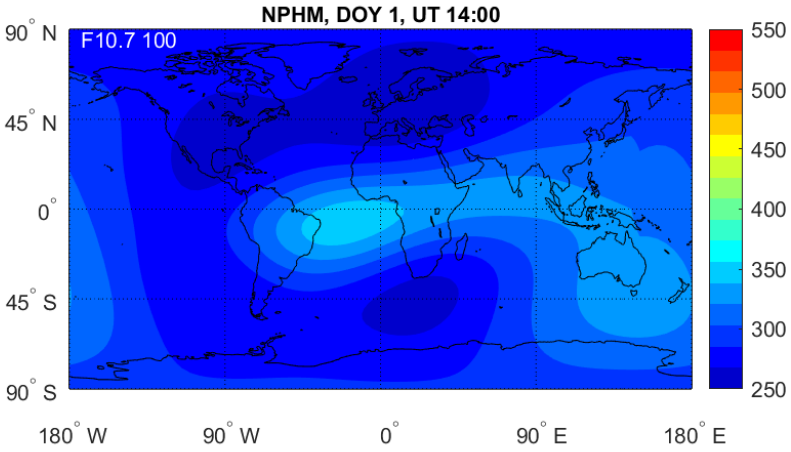
Diurnal, semi-diurnal, ter-diurnal variation	$F_1 = cos\chi^{***} + cos\chi^{**}(k_1 cosV_D + k_2 cosV_{SD} + k_3 sinV_{SD} + k_4 cosV_{TD} + k_5 sinV_{TD})$
Annual, semi-annual variation	$F_2 = 1 + k_6 cos(V_A) + +k_7 cos(V_{SA})$
Geomagnetic latitude variation	$F_3 = 1 + k_8 cos(\varphi_m)$
Equatorial anomaly	$F_4 = 1 + k_9 exp(EC_1) + k_{10} exp(EC_2)$
Solar cycle variation	$F_5 = k_{11} + k_{12}$**F10.7**

Each key parameter model has about 12/13 model coefficients, plasmasphere model has 40 model coefficents and few fixed parameters

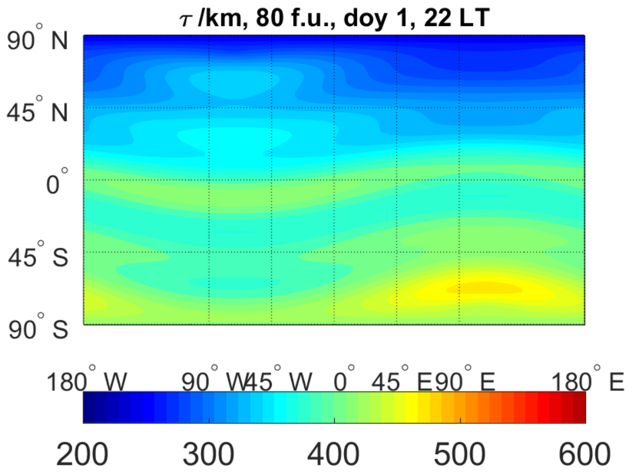
Ionosphere key parameters models

Neustrelitz Total Electron Content Model (NTCM) [Jakowski et al. 2011, JoG]



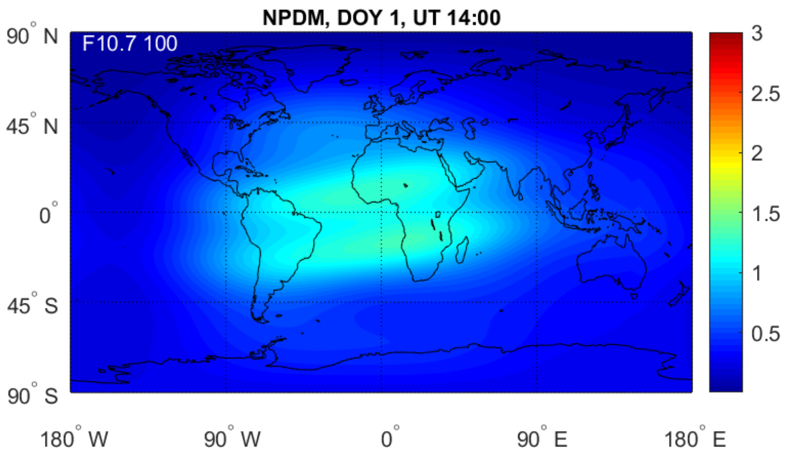


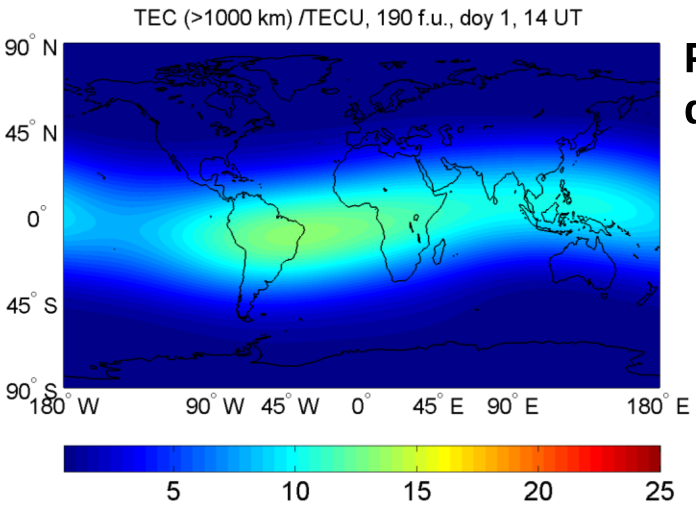
Neustrelitz Peak Height Model (NPDM)
[Hoque & Jakowski 2012, Ann. Geophy.]



Neustrelitz slab thickness model (NSTM) [Jakowski & Hoque 2021, swsc]

Neustrelitz Peak Density Moc
(NPDM)
[Hoque and Jakowski 2011, Radio Sci.



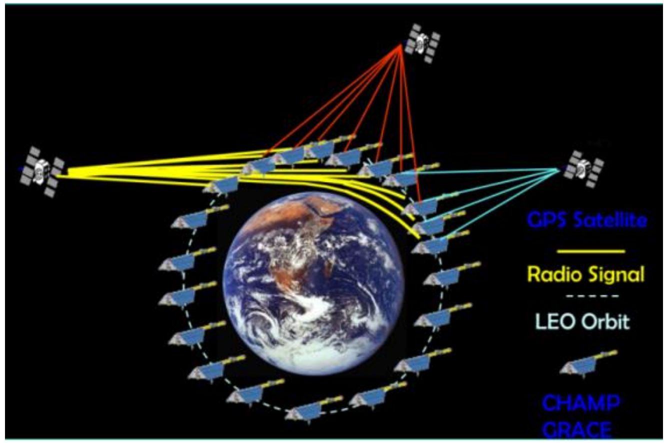


Plasmasphere density

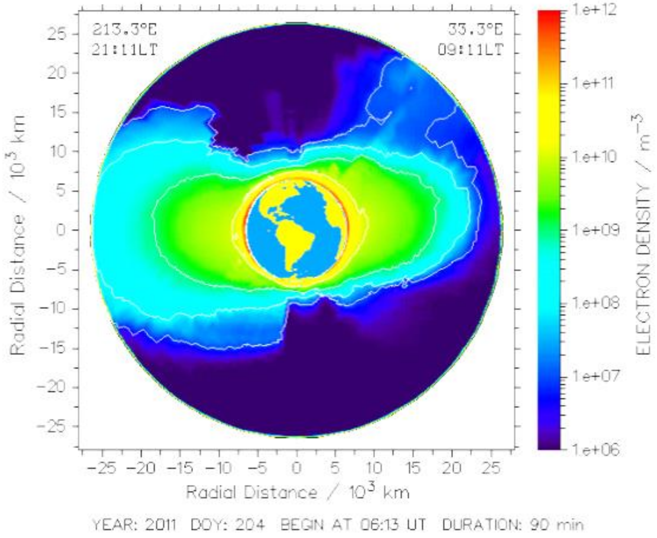
Neustrelitz plasmasphere model (NPSM) [Jakowski & Hoque 2018, swsc]

Neustrelitz Plasmasphere Model (NPSM)

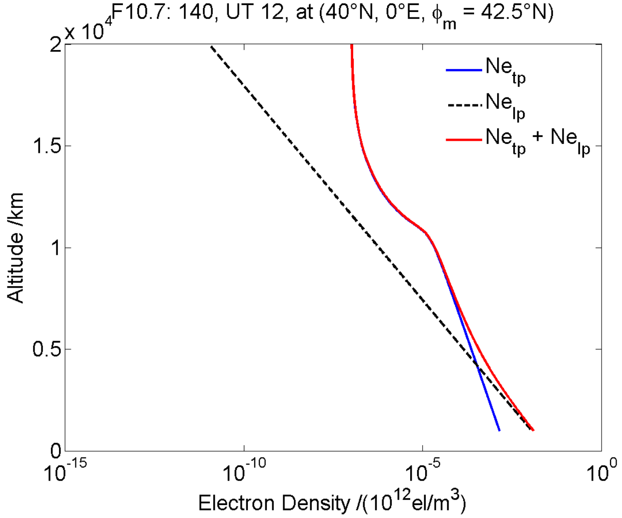
GNSS navigation data abroad CHAMP



topside ionosphere /plasmasphere



NPSM approach



- GNSS navigation data from LEO satellites enable the reconstruction of the 3D electron density distribution of the topside ionosphere /plasmasphere in the vicinity of the satellite orbit

A high altitude part (blue curve) where plasmaspheric processes related to plasmapause and magnetosphere dominate and a lower part (black curve) where ionospheric coupling is taken into account. The resultant plasmaspheric electron density is represented by the red curve.

Jakowski N. and M.M. Hoque (2018) A new electron density model of the plasmasphere for operational applications and services, J. Space Weather Space Clim., 8, A16

Neustrelitz Plasmasphere Model (NPSM)

The NPSM approach consists of two parts, a high altitude part where plasmaspheric processes related to plasmapause and magnetosphere dominate and a lower part where ionospheric coupling is taken into account.

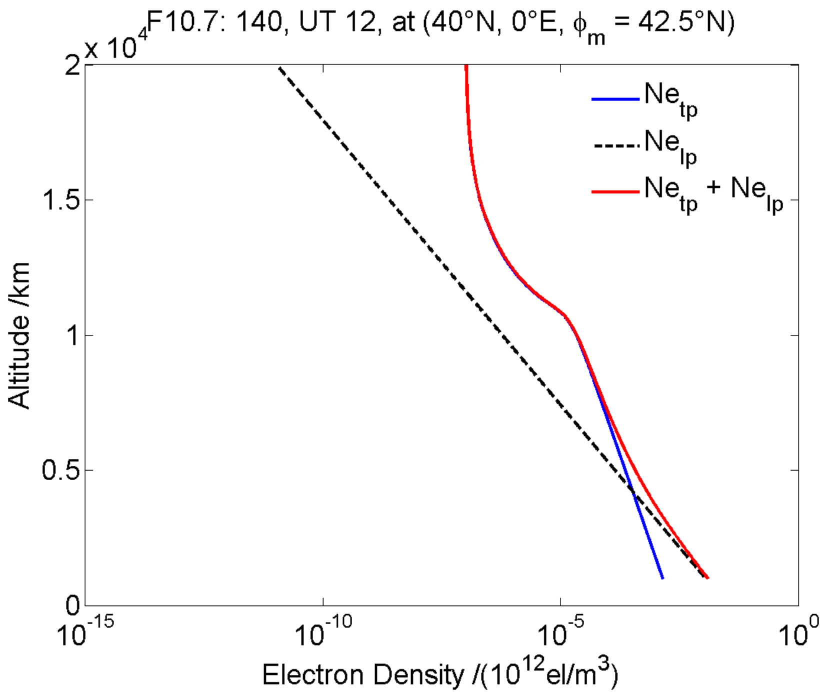
$$Ne = Ne_{tp} + Ne_{lp}$$

High altitude part:

$$Ne_{tp} = Np0_{tp} \cdot F_{pp} \cdot \exp\left(-\frac{R_E(L-1)}{Hp_{tp}}\right) + N_{ms}$$

Lower part:

$$Ne_{lp} = Np0_{lp} \cdot \exp\left(-\frac{h}{Hp_{lp}}\right)$$

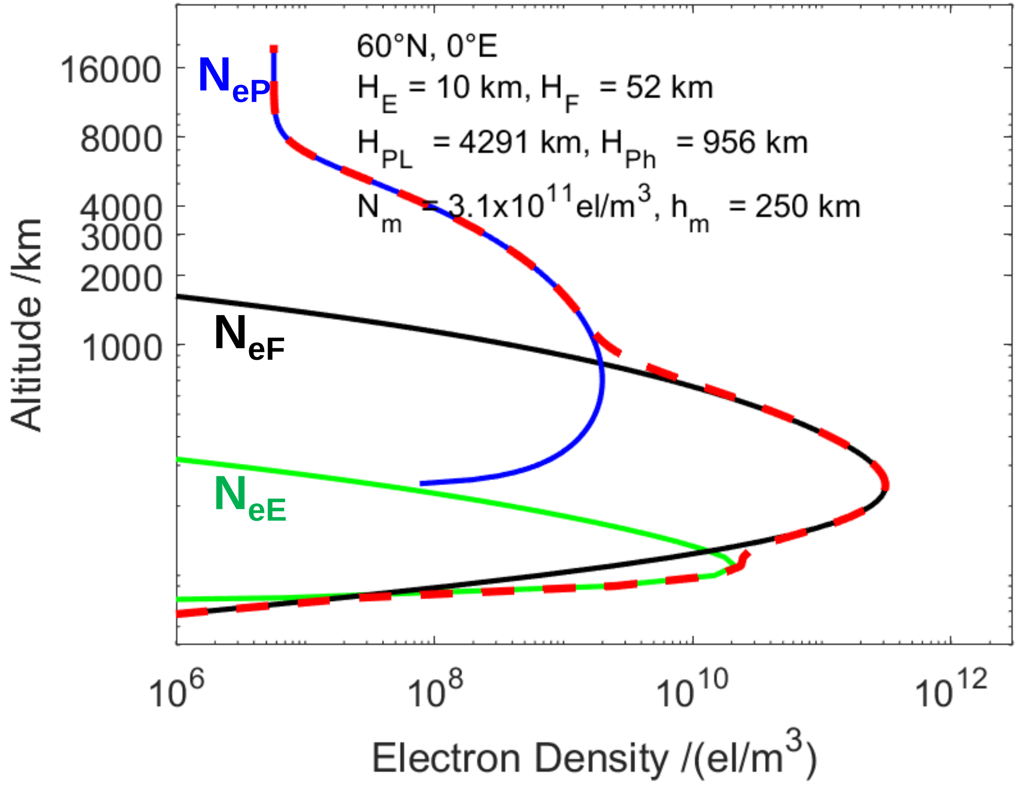


where parameters $Np0_{tp}$ and $Np0_{lp}$ are the basic electron density for the high and lower altitude part, respectively, and Hp_{tp} and Hp_{lp} are corresponding scale heights. The quantity R_E is the earth's radius, L is the McIllwain parameter, F_{PP} defines plasma pause location and its slope and N_{ms} defines the electron density outside the plasmapause.

NEDM2020 formulations

Electron density, $N_e(h) = N_{eE} + N_{eF} + N_{eP}$

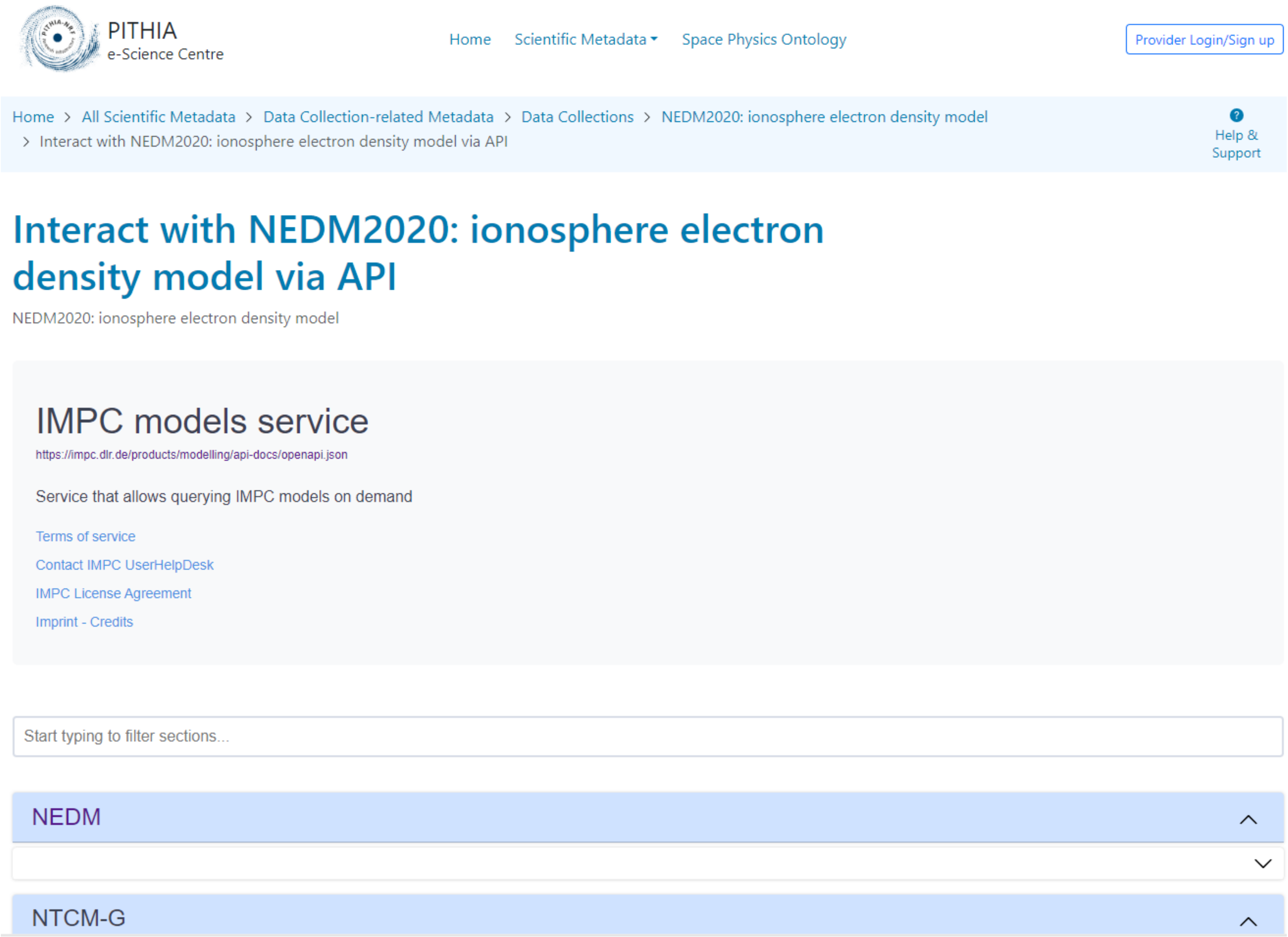
Plasmasphere (> 1000 km)	$N_{eP} = N_{ePL} + N_{ePh}$ $N_{ePL} = N_{ePL1} \cdot exp\left(\frac{R_E(1-L)}{H_{PL}}\right)$ $N_{ePh} = N_{ePh0} \cdot exp\left(-\frac{h}{H_{Ph}}\right)$
F-layer (140 – 1000 km)	$N_{eF} = Nm \cdot exp\left(0.5(1 - z - exp(-z))\right)$
E-layer (90 – 140 km)	$N_{eE} = 1.36 \cdot Z_E \sqrt{1 + 1.15R^*} \cdot D_E \cdot W_E$ $Z_E = exp\{0.5[1 - z_E - exp(-z_E)]\}$ Ching & Chiu (1973)



Neustrelitz Electron Density Model- NEDM2020

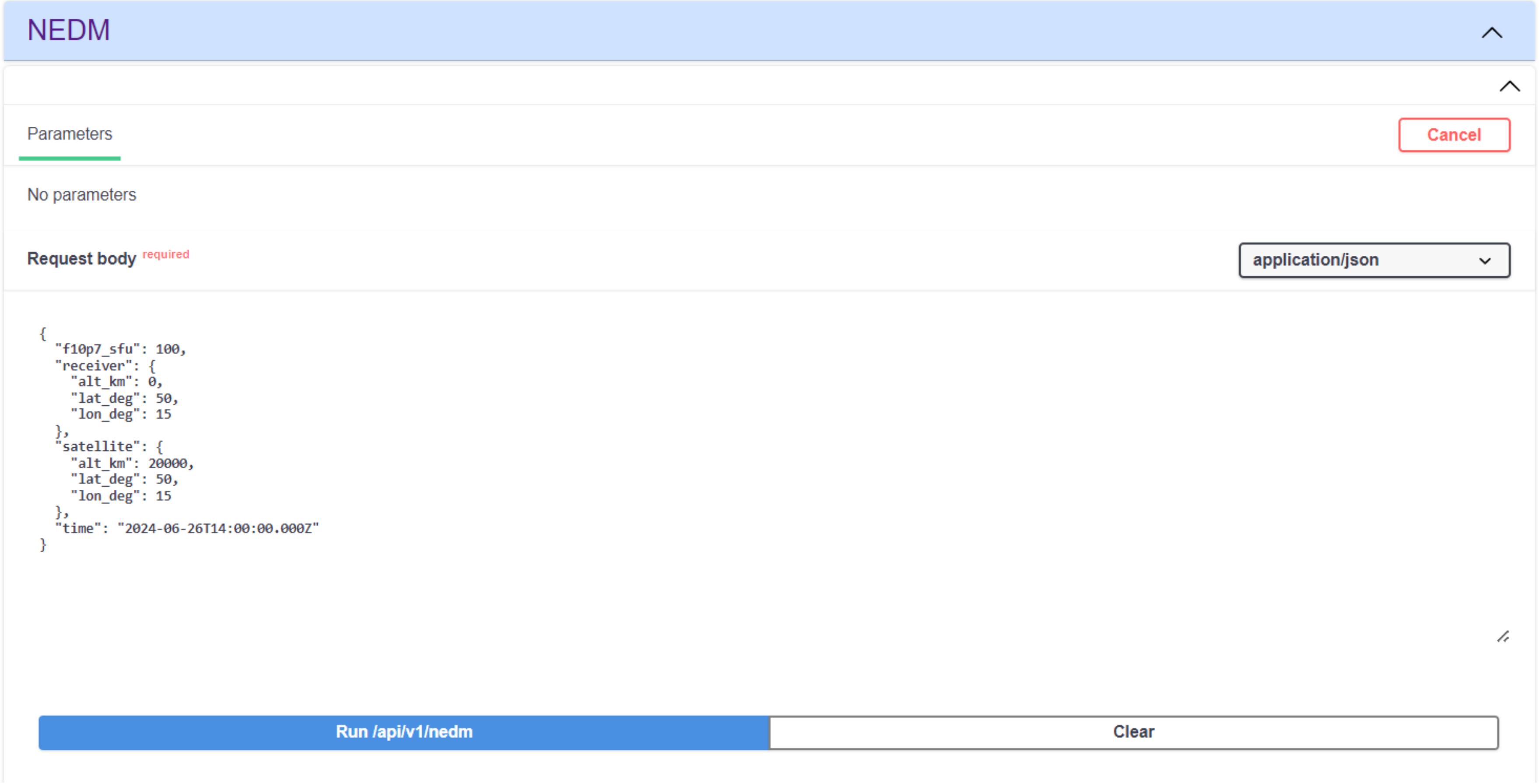
Hoque, MM, N Jakowski, F. Prol (2022) A new climatological electron density model for supporting space weather services, Space Weather Space Climate, swsc200107, doi: 10.1051/swsc/2021044

https://esc.pithia.eu/data-collections/DataCollection_NEDM2020/api/



https://esc.pithia.eu/data-collections/DataCollection_NEDM2020/api/

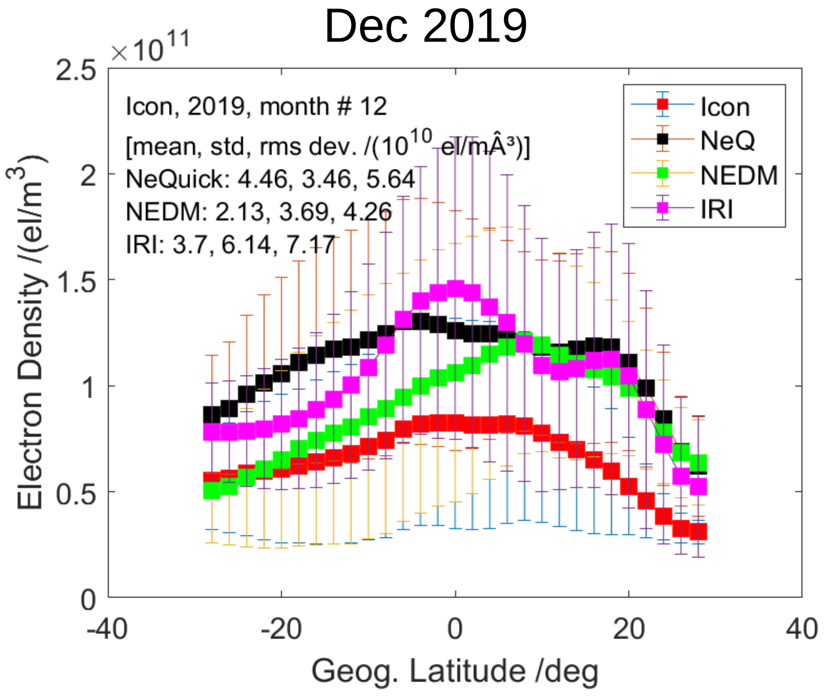
Interact with NEDM2020: ionosphere electron density model via API

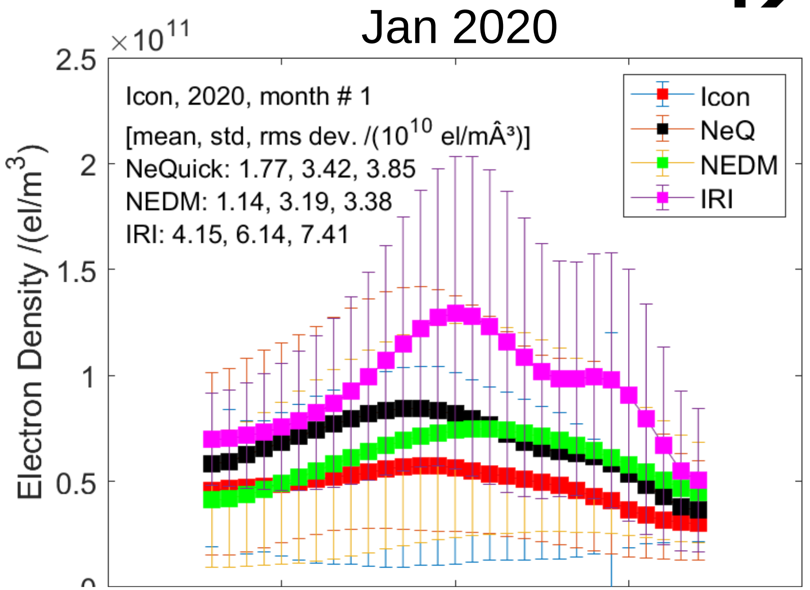


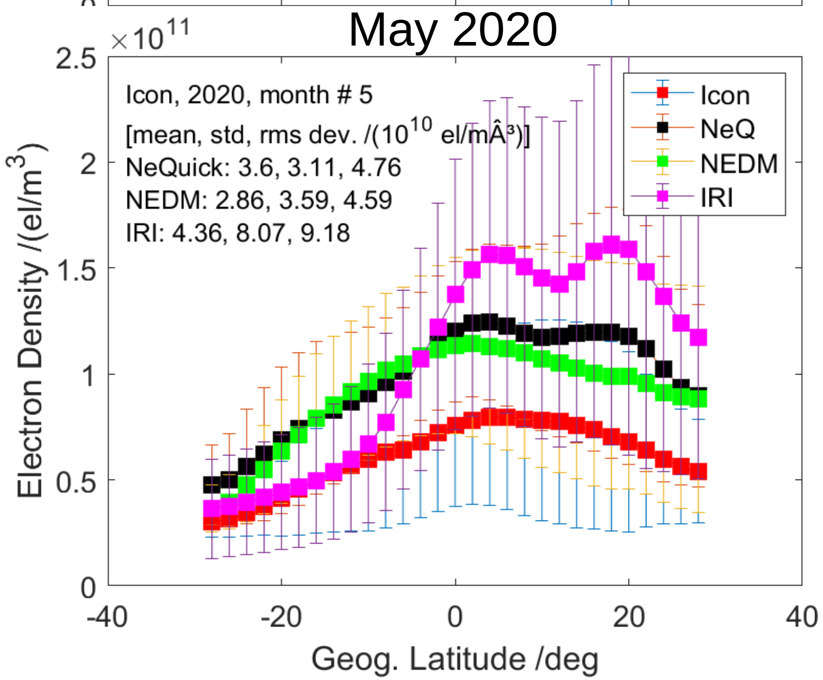
Model validation against in-situ data from ICON missions

Comparison at ~575 km height

NEDM2020, **NeQuick2** and **IRI-2016** electron density mean variations with geographic latitude in comparison with **ICON's plasma density from the ion velocity meter (IVM) instrument** [Hoque et al. 2022, SWSC].

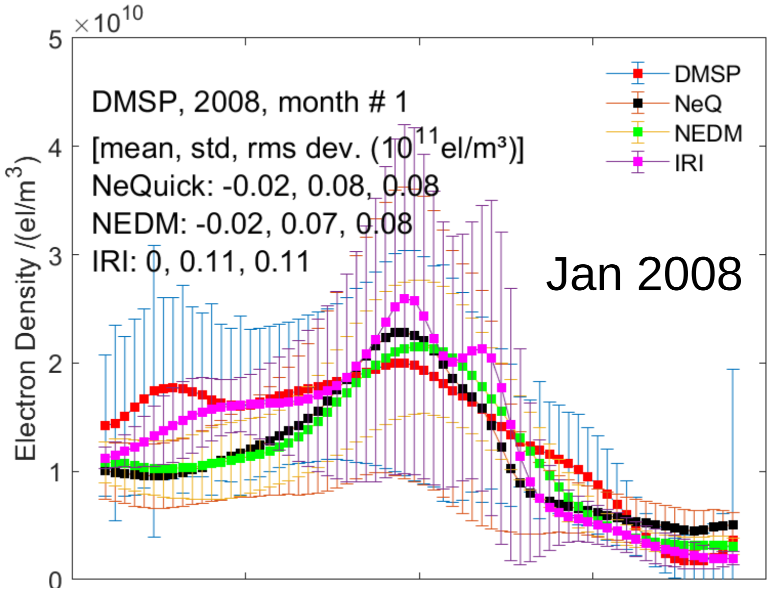


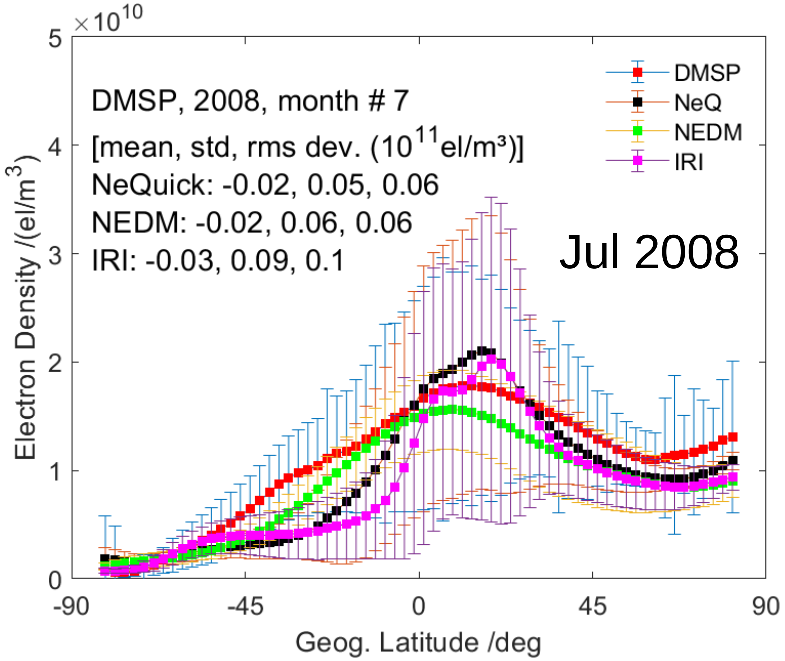




ICON has a low inclination of about 27°

Model validation against in-situ data from DMSP missions

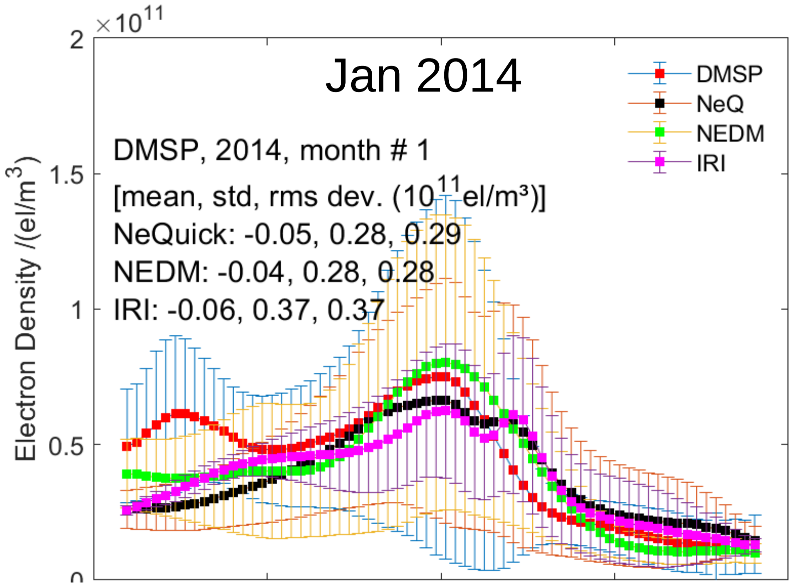


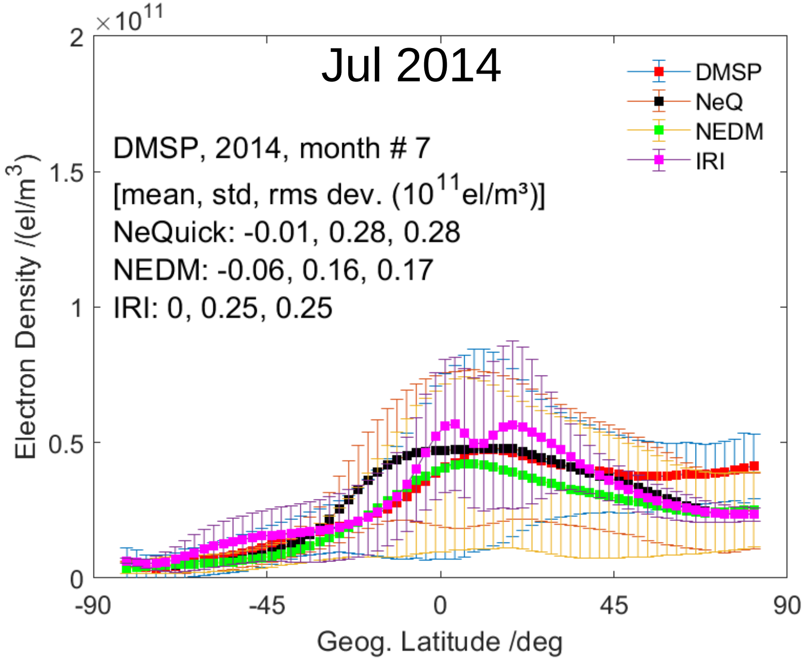


Comparison at ~800 km height

NEDM2020, **NeQuick2** and **IRI-2016** electron density mean variations with geographic latitude in comparison with **DMSP satellite in situ** data from the scintillation cup instrument [Hoque et al. 2022, SWSC]

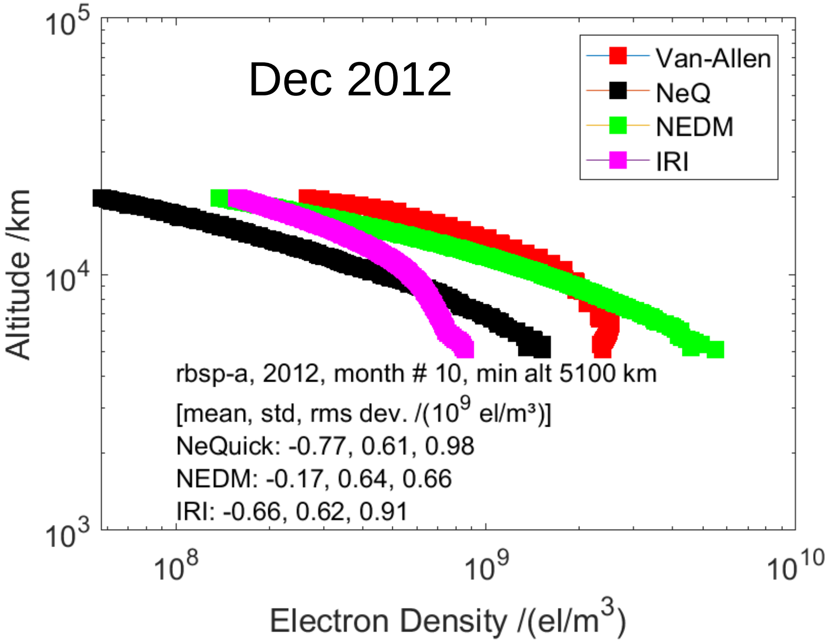
DMSP has sun-synchronous near-polar orbit.

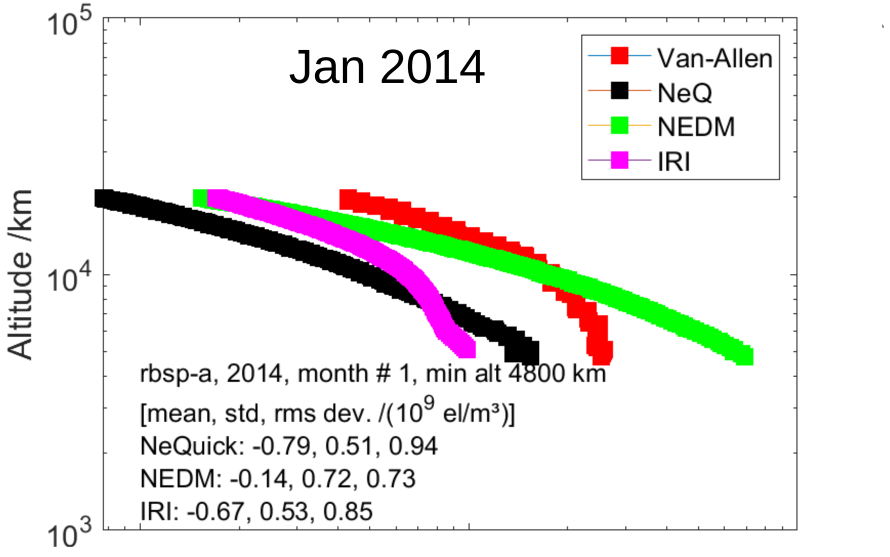


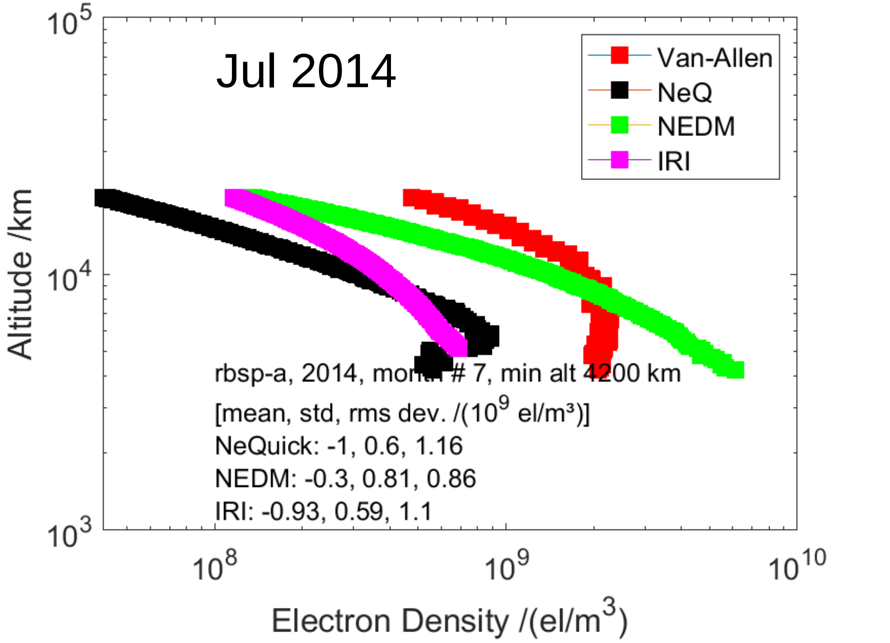


Model validation against in-situ data from Van Allen probes

Figures compare the performance of the **NEDM2020** with the **NeQuick2**, **IRI-Plas** with respect to the reference in-situ data from RBSP-A (Radiation Belt Storm Probes) instrument of **Van Allen Probes** [Hoque et al. 2022].



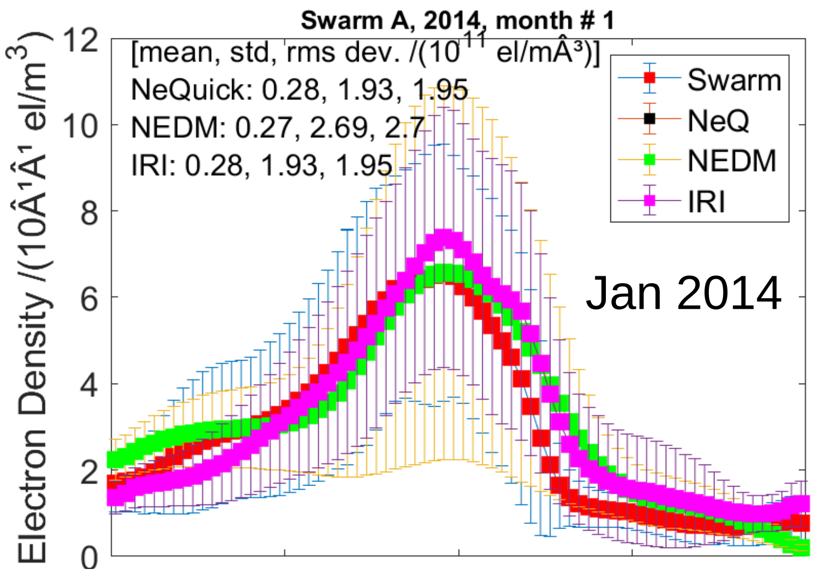


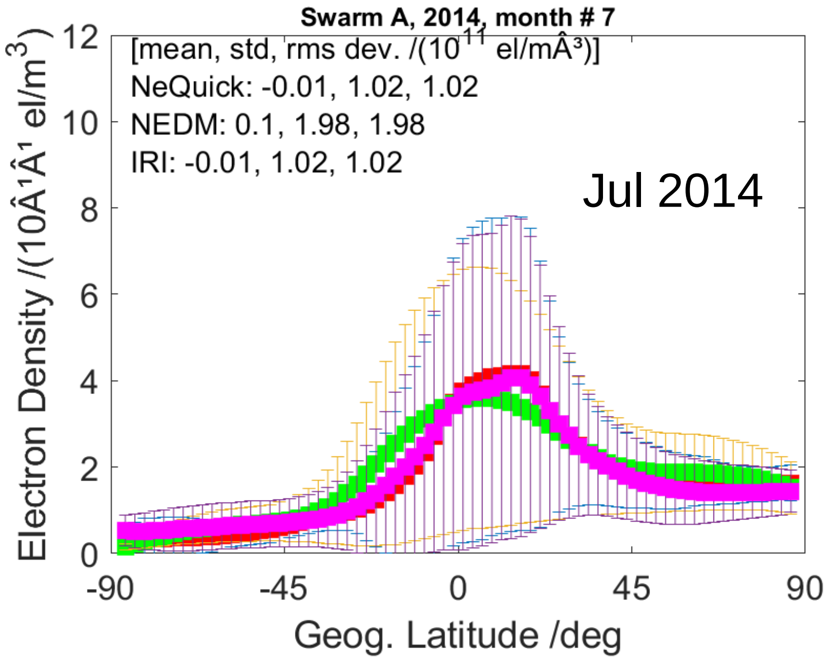


Due to flying at a very low inclination orbit of about 10° the Van Allen data only covers low latitude regions on both side of the equator. The data covers a large altitude range approximately 600 – 30,500 km for electron density.

IRI-Plas source: http://www.ionolab.org/

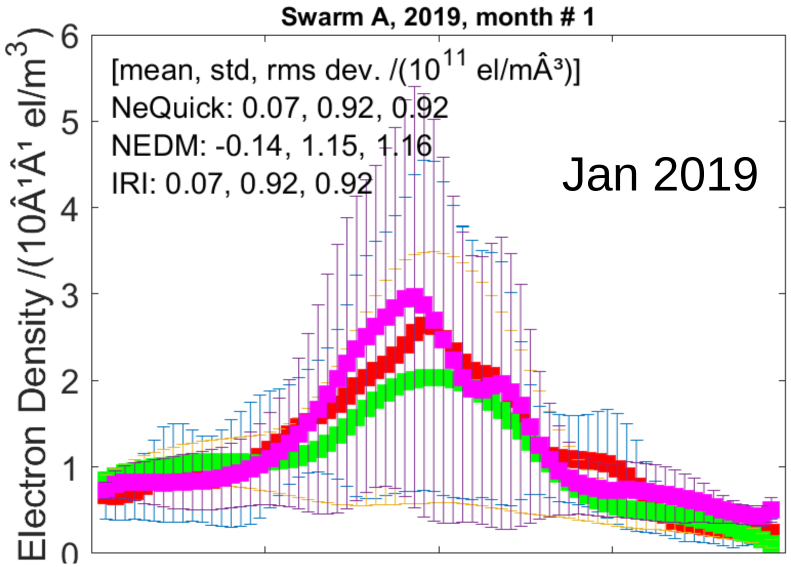
Model comparison against Swarm-A in-situ data

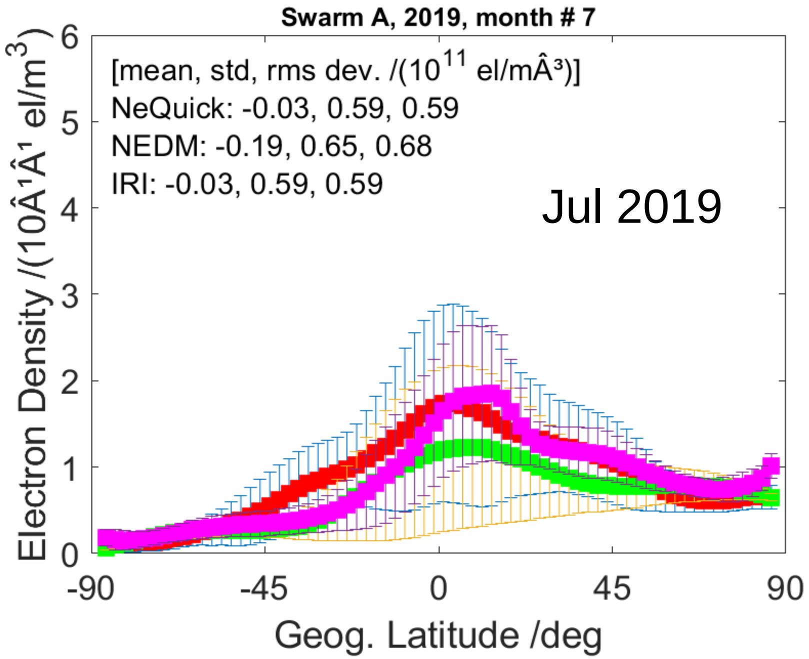




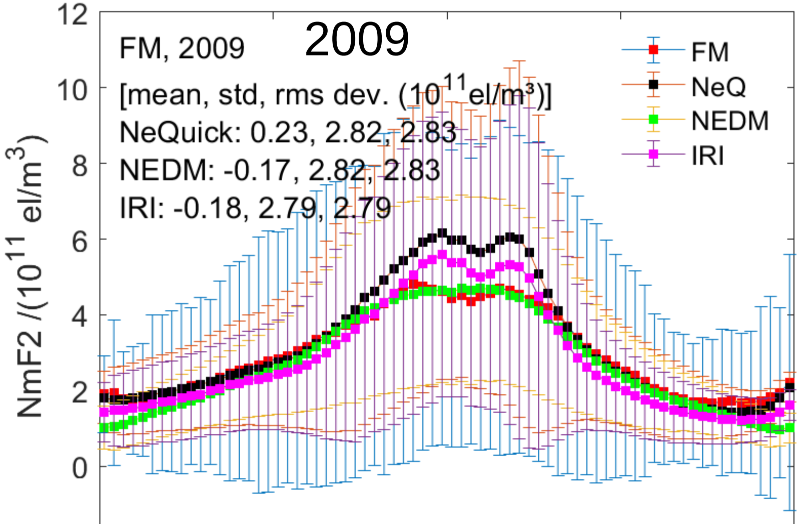
Comparison at ~460 km height

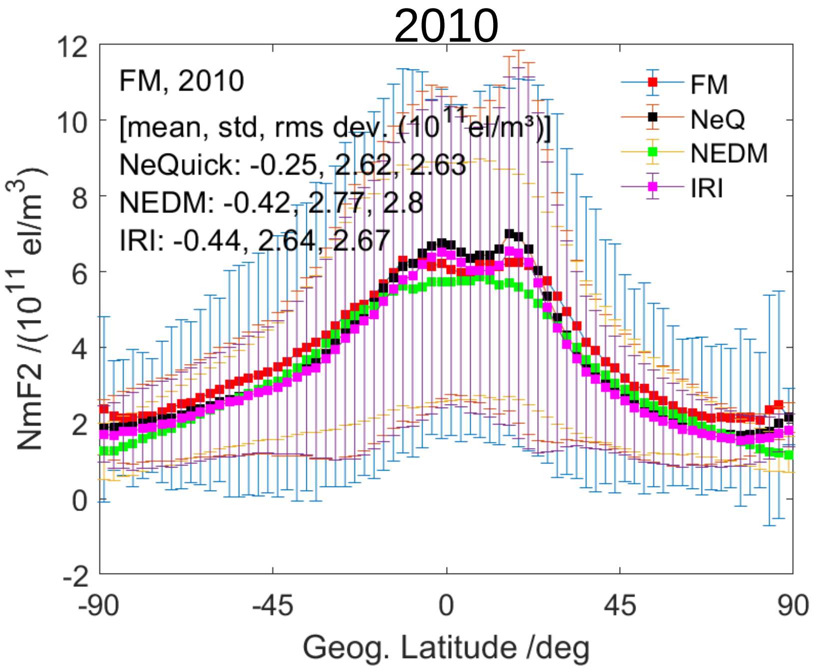
NEDM2020, **NeQuick2** and **IRI-2016** electron density mean variations with geographic latitude in comparison with **Swarm-A Langmuir Probe (LP) in situ** data [Hoque et al. 2022, SWSC]



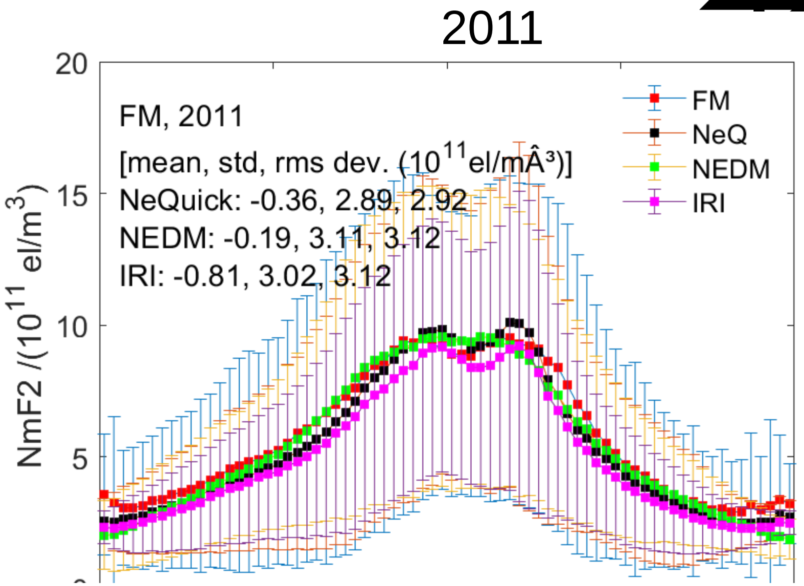


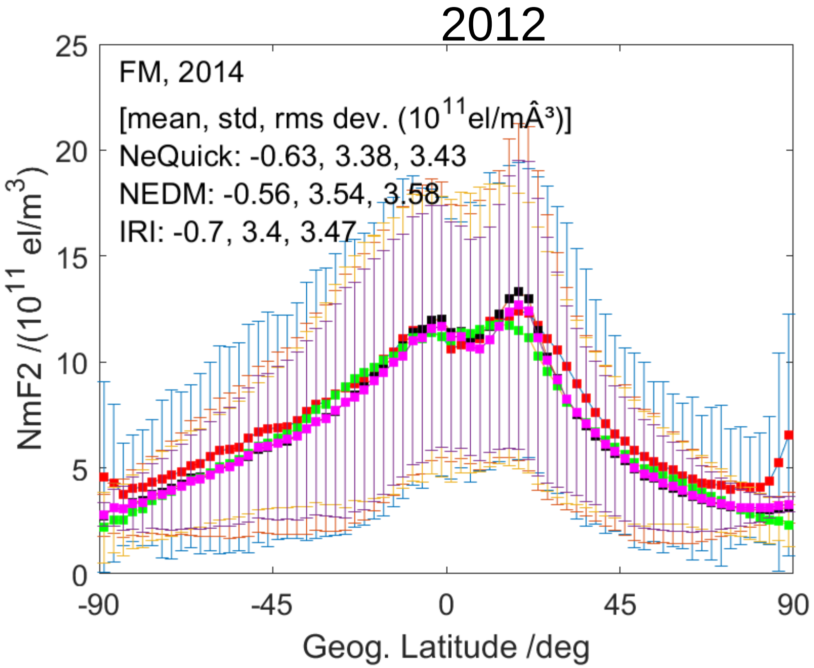
Model comparison against COSMIC-1 NmF2 data





NEDM2020, **NeQuick2** and **IRI-2016** electron density mean variations with geographic latitude in comparison with **COSMIC-1 RO derived NmF2** data [Hoque et al. 2022, SWSC]





Neustrelitz/ESOC PlasmaPause Model (NEPPM)

DLR

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RESEARCH ARTICLE — OPEN ACCESS

A new model for plasmapause locations derived from IMAGE RPI and Van Allen Probes data

Daniela Banyś[1,*], Joachim Feltens[1,2], Norbert Jakowski[1], Jens Berdermann[1], Mainul M. Hoque[1], René Zandbergen[3], and Werner Enderle[3]

[1] German Aerospace Center (DLR), Institute for Solar-Terrestrial Physics, Kalkhorstweg 53, 17235 Neustrelitz, Germany
[2] Telespazio Germany GmbH c/o European Space Operations Centre (ESA/ESOC), Robert-Bosch-Str. 5, 64293 Darmstadt, Germany (Retired)
[3] European Space Operations Centre (ESA/ESOC), Robert-Bosch-Str. 5, 64293 Darmstadt, Germany

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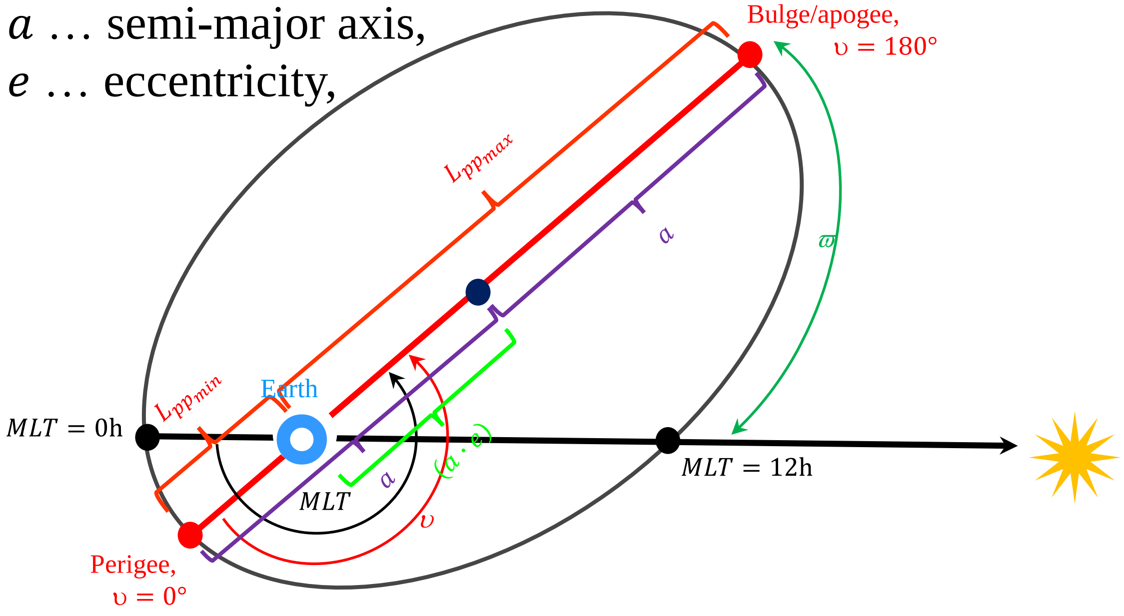
Abstract – The outer boundary of the plasmasphere, the plasmapause, is characterized by a sharp electron density gradient that changes under varying space weather conditions. We developed a new model, called the Neustrelitz/ESOC PlasmaPause Model (NEPPM), for providing plasmapause location in terms of *L*-shell utilizing electron density measurements from the Van Allen Probes from 2012 to 2018 and the IMAGE satellite data from 2001 to 2005. Both datasets were preprocessed, and algorithms were developed for the automatic detection of plasmapause location L_{pp} where L denotes the McIlwain parameter. The suggested model provides a simple ellipse-based approach determined by the semi-major axis, the eccentricity, and the orientation angle of the semi-major axis. The modelled L_{pp} varies as a function of the *Dst* index and magnetic local time *MLT*. The NEPPM results are compared with the Global Core Plasma Model (GCPM). The plasmapause bulge in the evening hours follows the level of geomagnetic activity. The NEPPM will complete the NPSM (Neustrelitz PlasmaSphere Model), which was derived from dual-frequency GPS measurements onboard the CHAMP satellite mission.

ESA-ESOC: European Space Operations Centre

Neustrelitz/ESOC PlasmaPause Model (NEPPM)

$$L_{pp} = \frac{a \cdot (1 - e^2)}{1 + e \cdot \cos(x + \varpi)}$$

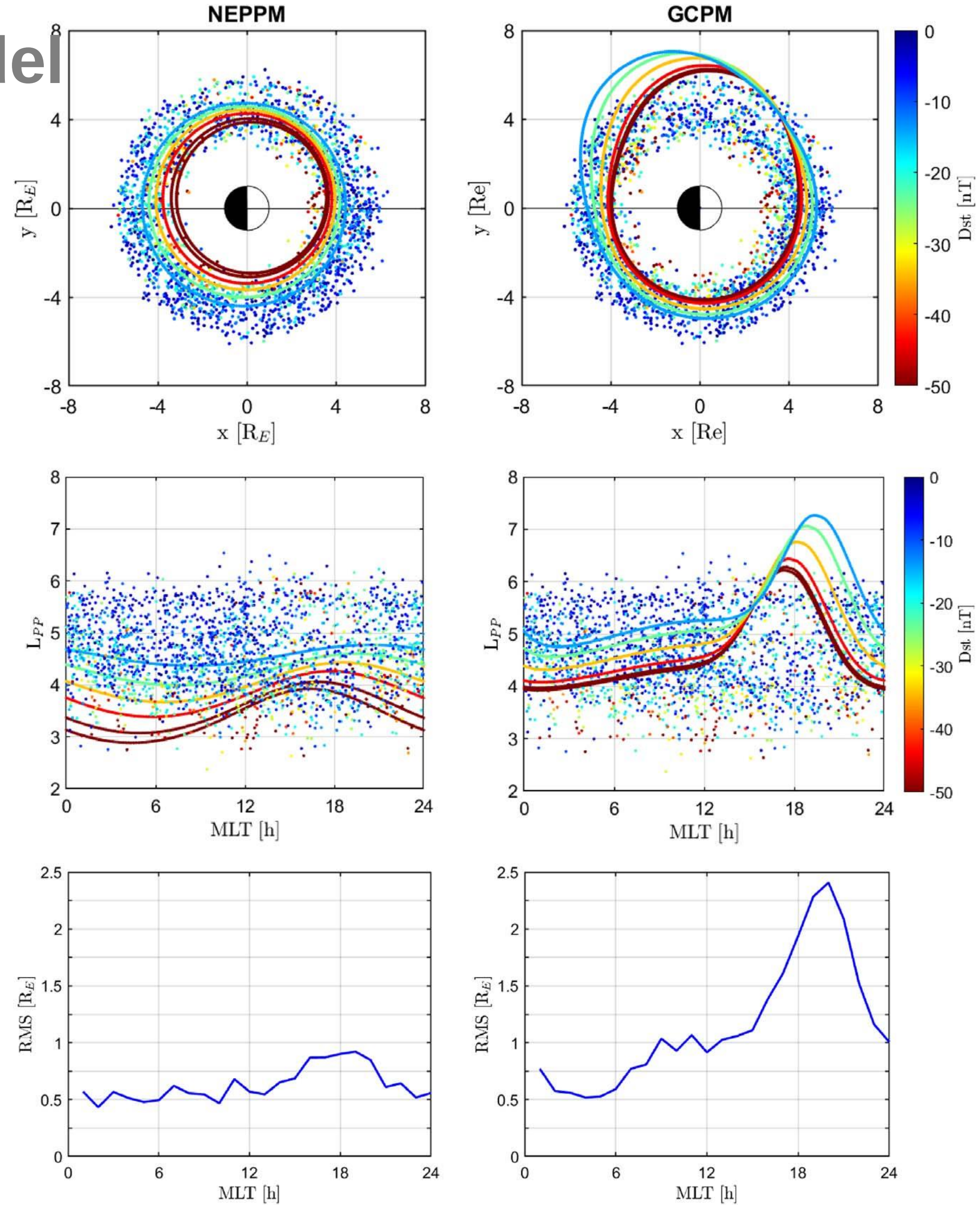
a … semi-major axis,
e … eccentricity,



x … magnetic local time expressed in radians, i.e. $x = \frac{\pi}{12\text{ h}} \cdot MLT$,

ϖ … orientation angle to align the ellipse line of apsides (υ = 0°, 180°) to the bulge direction in the MLT system,

GCPM: Global Core Plasma Model



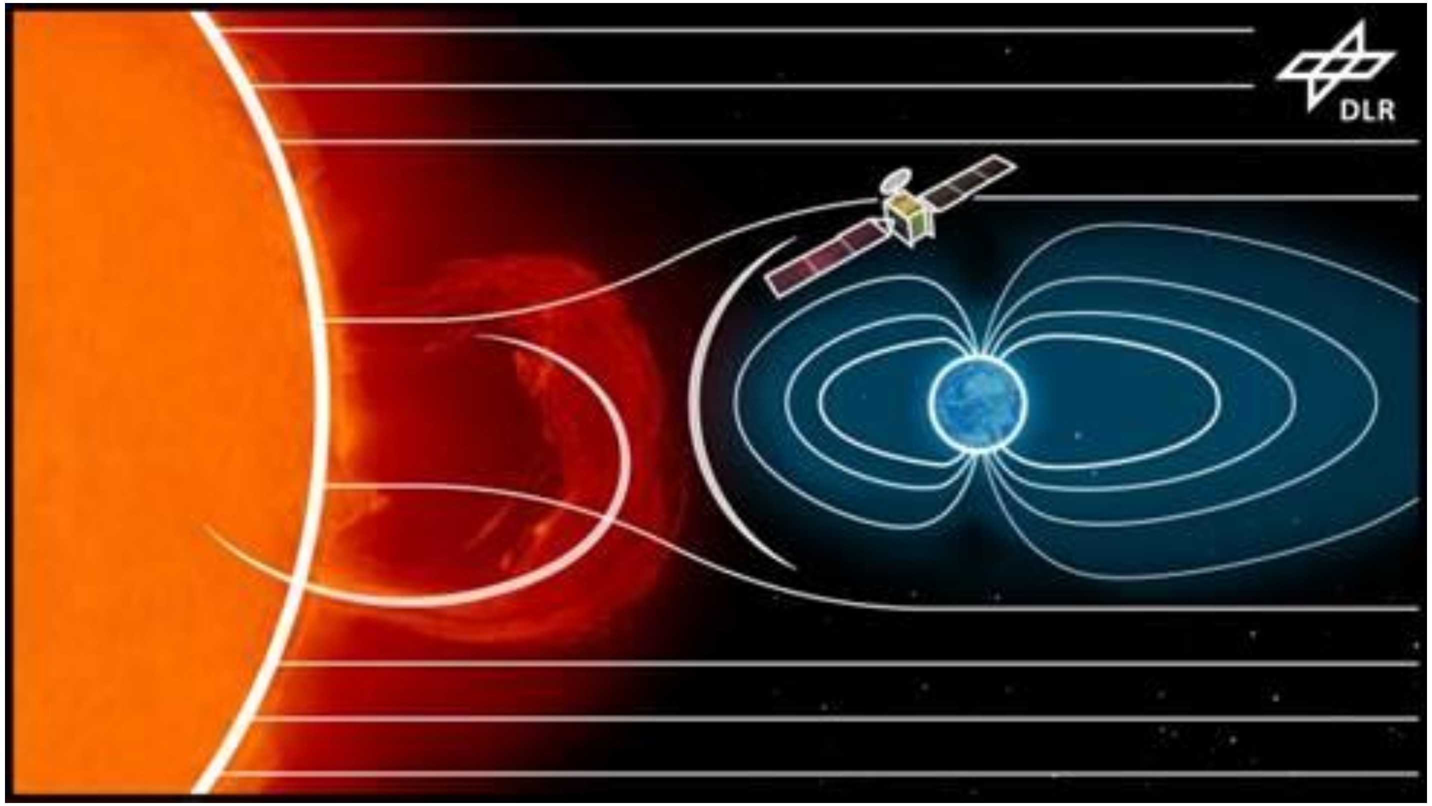
Summary

- Neustrelitz Electron Density Model (NEDM2020) is developed aiming for supporting space weather services and mitigation of propagation errors for trans-ionospheric signals.
- The model can provide electron concentration at any given location and time in the ionosphere for trans-ionospheric applications (altitude range **80 – 20,000 km**).
- NEDM2020 performs better than the NeQuick2, IRI when compared with the in-situ data from Van Allen Probes and ICON satellites. When compared with Swarm-A data NEDM2020, NeQuick2 and IRI perform very similarly.

Comparison with IRI shows that there is a scope of improving IRI topside ionosphere and plasmasphere by applying NEDM or corresponding plasmasphere model to IRI topside!

- Currently we are using NEDM2020 as a background model in data assimilation employing a 3D variational approach
    - Any current users (academic/industry/government)?
        - IMPC (Ionosphere Monitoring and Prediction Center, https://impc.dlr.de),
    - Is the model available for others to use?
        - NEDM2020 is currently available via ESA project PITHIA-NFR

Thank you!



Dr. M Mainul Hoque
email: Mainul.Hoque@dlr.de
Institute for Solar-Terrestrial Physics
German Aerospace Center (DLR)
http://www.DLR.de/so