The influence of solar Lyα and X radiation on the ionospheric D-region: the importance of determination of the quiet ionosphere parameters

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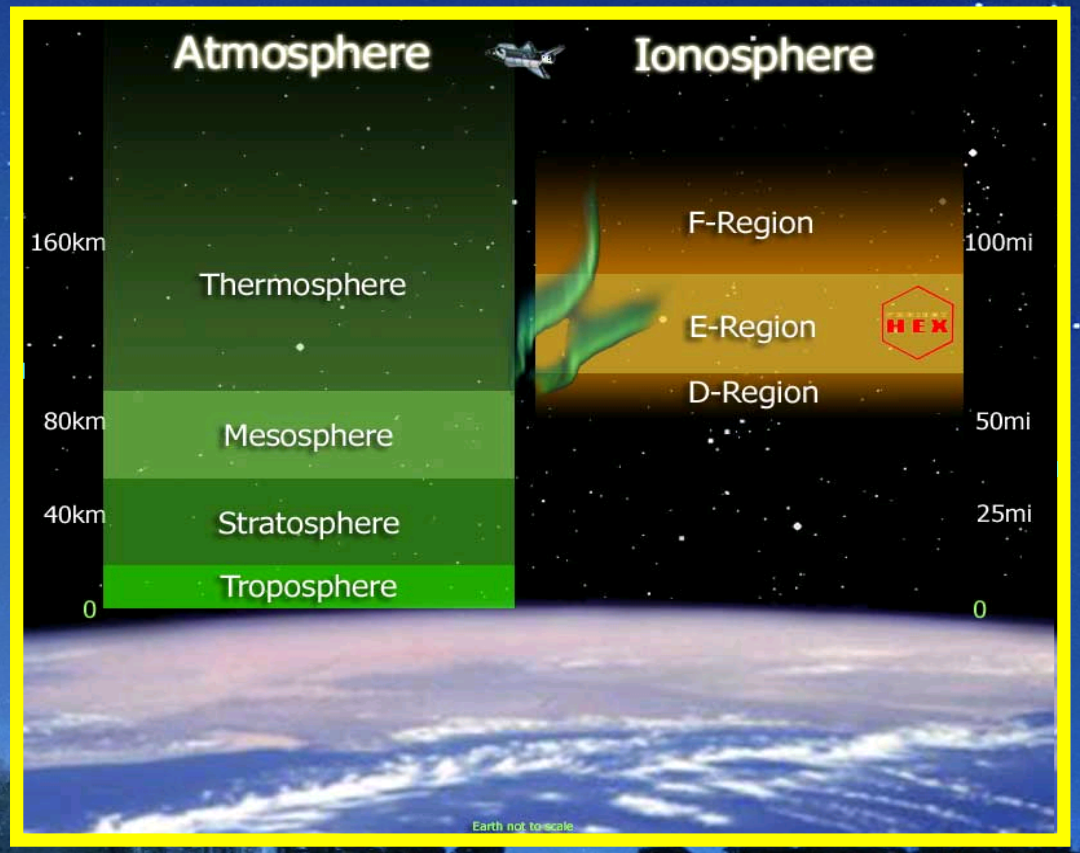
Introduction



Sources of ionization

Quiet D- region
Upper part: solar hydrogen Lyα
Bottom part: cosmic radiation

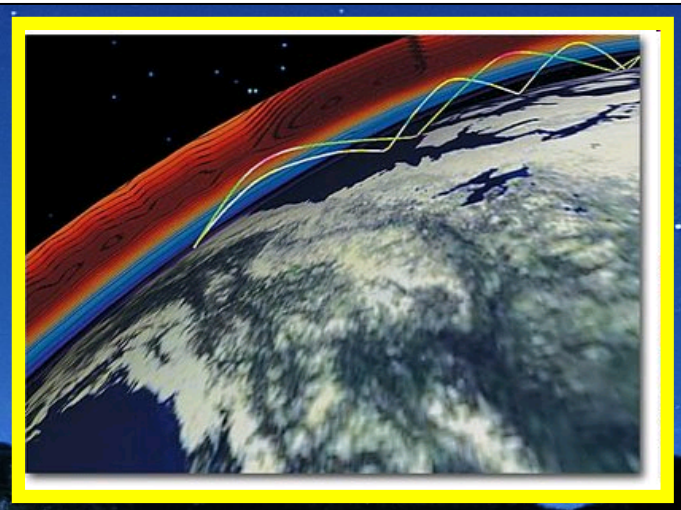
Solar X-ray flare perturbad D-region
X-radiation

Lower ionosphere observation

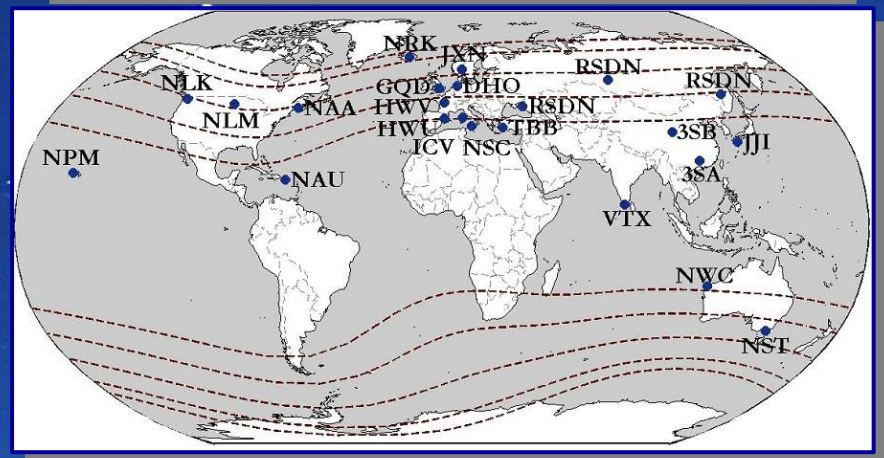
- Very low/low frequency (VLF/LF) radio waves
- Radars
- Rockets

3 kHz – 30 kHz VLF
30 kHz – 300 kHz LF

Earth-ionosphere waveguide



Global setup
Numerous worldwide located transmitters and receivers

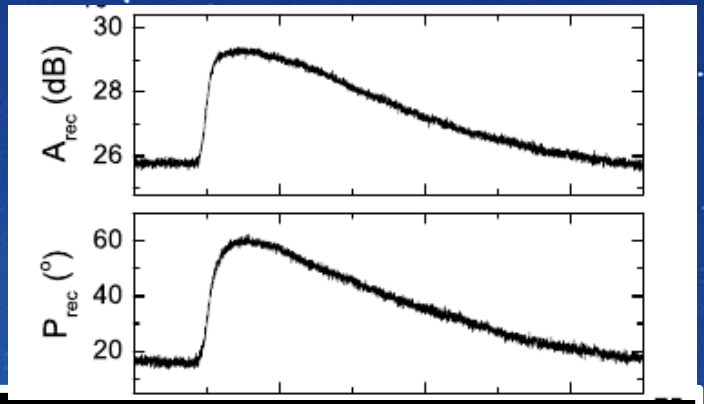


Time resolution of data
0.001 s – 1 s

- **Continuous receiving**
  Detection of unpredictable events

Modelling based on VLF/LF remote sensing

$$\Delta A_{\mathrm{sim}}(\beta, H') \approx \Delta A_{\mathrm{rec}}(t),$$
$$\Delta P_{\mathrm{sim}}(\beta, H') \approx \Delta P_{\mathrm{rec}}(t).$$



Numerical model for VLF/LF signal propagation: the Long-Wave Propagation Capability (LWPC) program

(Ferguson, J.A. Computer Programs for Assessment of Long-Wavelength Radio Communications, Version 2.0; Space and Naval Warfare Systems Center: San Diego, CA, USA, 1998.)

Input parameters in LWPC:
signal properties, receiver position and Wait's parameters ("sharpness" β and signal reflection height H') - ionospheric parameters which are used for calculation of the D-region electron density *(Wait, J.R.; Spies, K.P. Characteristics of the Earth-Ionosphere Waveguide for VLF Radio Waves; NBS Technical Note: Boulder, CO, USA, 1964.)*.

Output parameters in LWPC:
amplitude and phase → Wait's parameters

Motivation

- The parameters in quiet conditions can significantly affect the modeling in both quiet and disturbed state
- However, they are soon considered as known quantities which are determined in previous statistical studies that, generally, do not represent the considered periods and areas.

QIonDR model

- We developed a numerical tool to model the daytime ionospheric parameters over the middle and low latitudes,
- We provided an analytical expression valid over a part of Europe for midday parameters.

remote sensing

MDPI

Article

Quiet Ionospheric D-Region (QIonDR) Model Based on VLF/LF Observations

Aleksandra Nina [1,*], Giovanni Nico [2,3], Srđan T. Mitrović [4], Vladimir M. Čadež [5], Ivana R. Milošević [1], Milan Radovanović [6,7] and Luka Č. Popović [5,8,9]

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QionDR model description and application

It is divided in two parts related to

- Midday period – provides equations for estimation ionospheric parameters with respect to day of year and sunspot number
- Daytime period – provides time evolutions of ionospheric parameters between sunrise and sunset

The proposed methodology is applied to areas monitored by two VLF/LF radio signals emitted and recorded by relatively closely located transmitters
and one receivers.

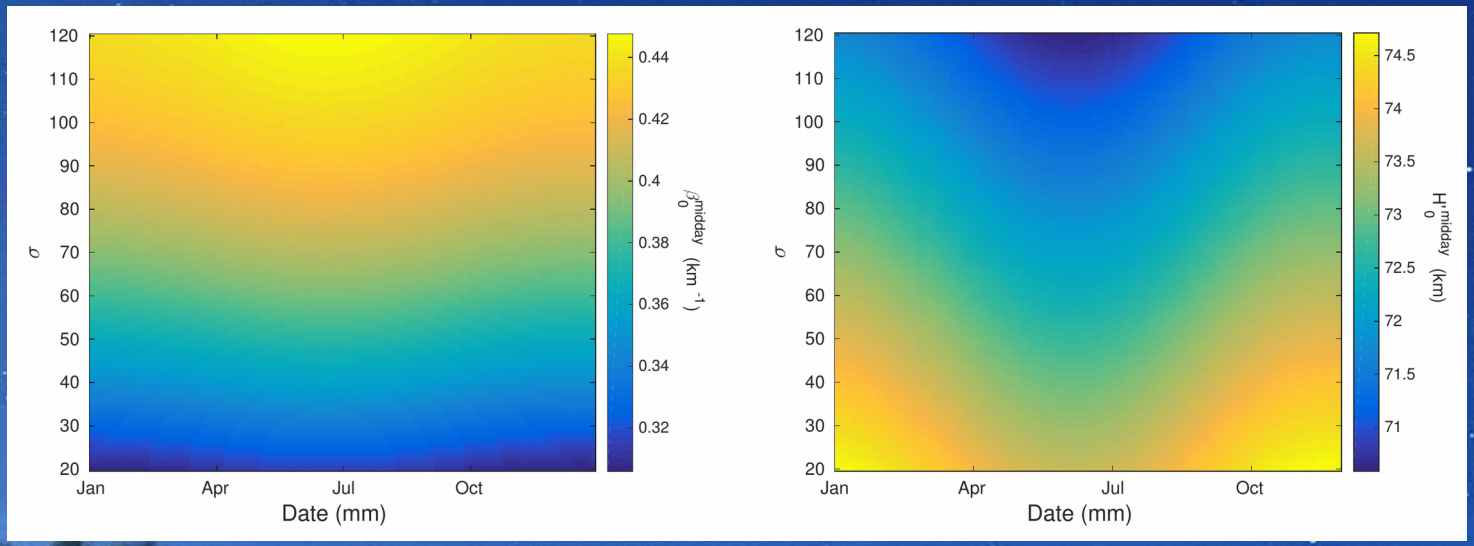
Model is applied on VLF signals emitted by DHO and ICV transmitters located in Germany and Italy, respectively and received in Belgrade, Serbia.

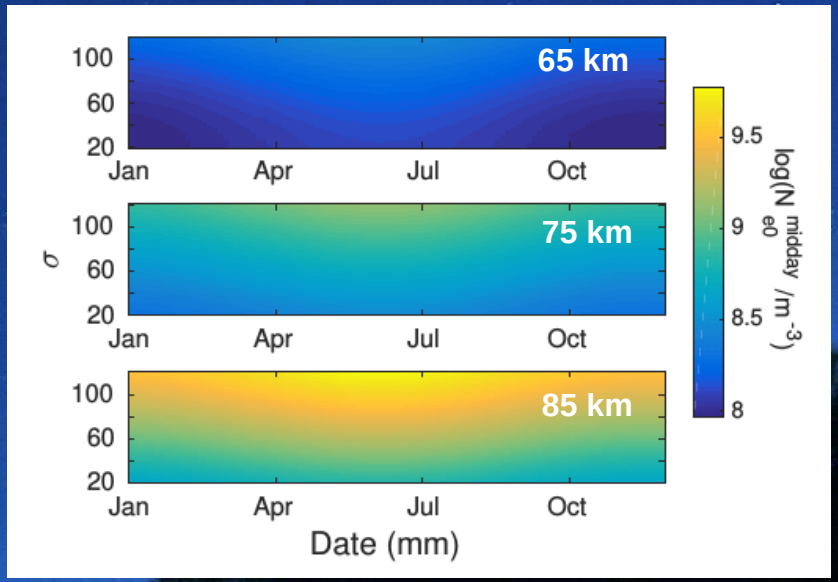
Results - Midday periods

D-region over Central Europe

σ- daily smoothed sunspot number
χ - day of year

We consider:
- Two signals
- Periods before and during influence of a solar X-ray flare
- Variations of the amplitude and phase from their values before perturbation induced by a solar X-ray flare





$$\beta_0^{\text{midday}} = 0.2635 + 0.002573 \cdot \sigma - 9.024 \cdot 10^{-6}\sigma^2 + 0.005351 \cdot \cos(2\pi(\chi - 0.4712))$$

$$H_0'^{\text{midday}} = 74.74 - 0.02984 \cdot \sigma + 0.5705 \cdot \cos(2\pi(\chi - 0.4712) + \pi)$$

$$N_{e0}^{\text{midday}}(\sigma, \chi, h) = 1.43 \cdot 10^{13} e^{-\beta^{\text{midday}}(\sigma,\chi)H'^{\text{midday}}(\sigma,\chi)} e^{[\beta^{\text{midday}}(\sigma,\chi)-0.15]h}$$

Thomson, N.R. Experimental daytime VLF ionospheric parameters. J. Atmos. Solar Terr. Phys. 1993, 55, 173.

Results - Daytime periods

We consider:
- One signal
- The daytime period far from the sunrise and sunset due to approximation of horizontally uniform ionosphere
- Variations of the amplitude and phase from their values at the midday

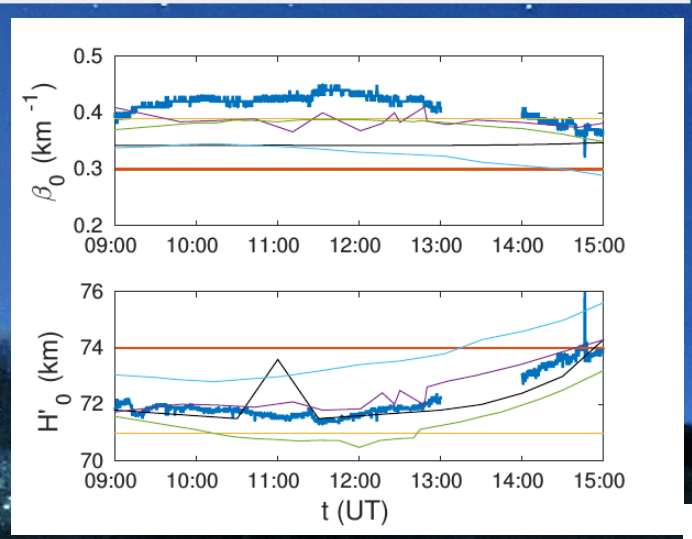
Recorded values

$$A - A^{\text{midday}} = A_{\text{mod}} - A_{\text{mod}}^{\text{midday}}$$

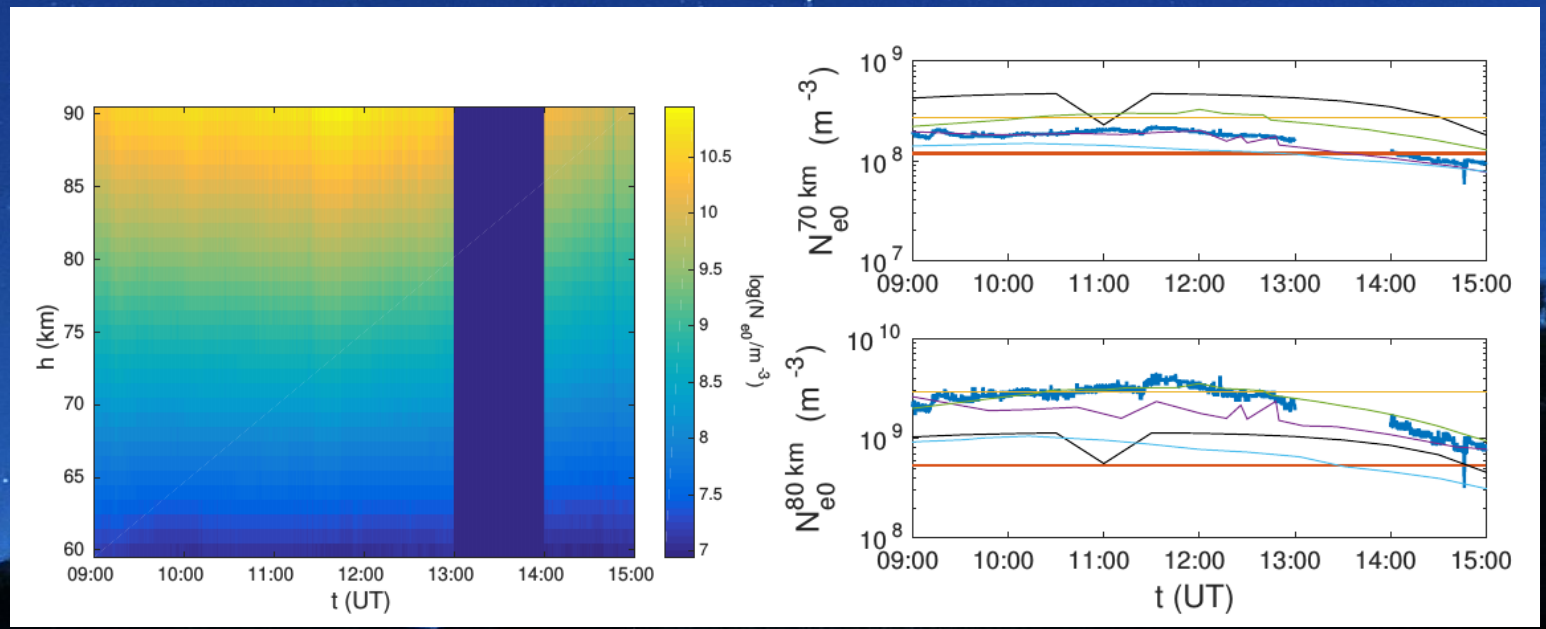
$$P - P^{\text{midday}} = P_{\text{mod}} - P_{\text{mod}}^{\text{midday}}.$$

Values obtained in the first part of model

Quiet conditions



6 September 2014

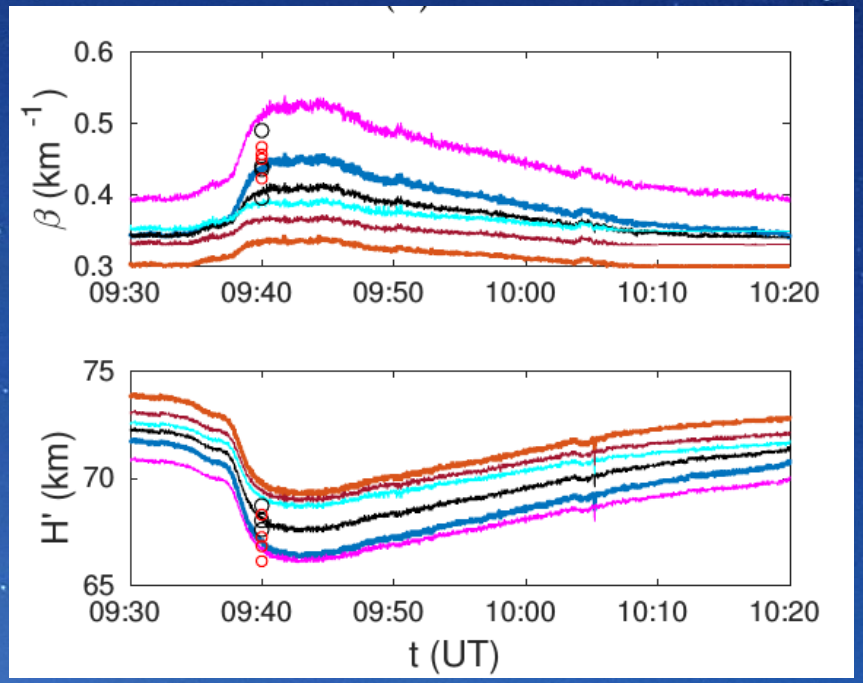


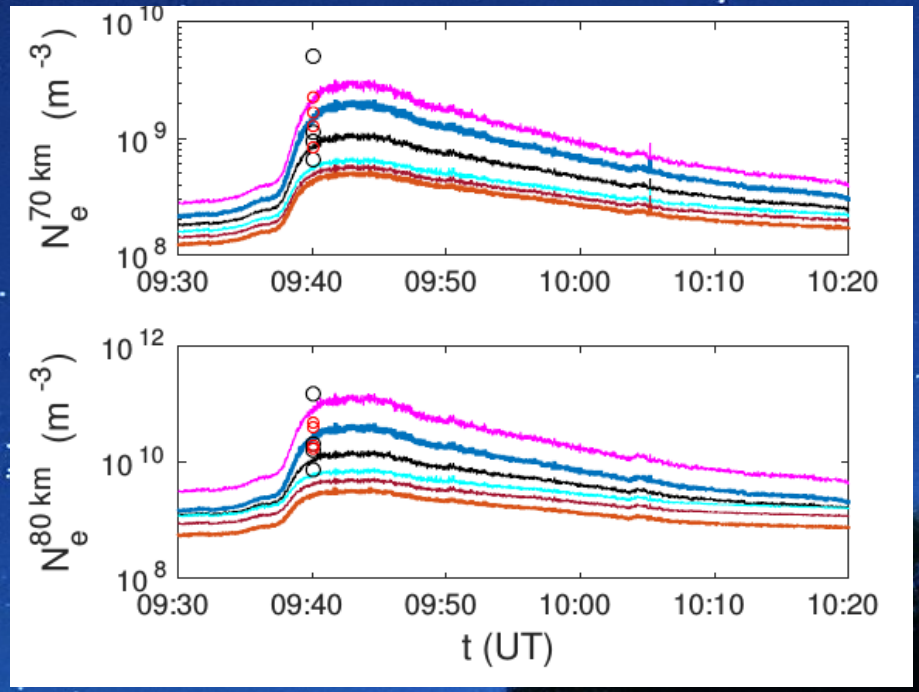
QIonDR; LWPC default [22]; IRI [52]; Thomson et al., 2005 [27]; Han et al., 2011 [33]; McRae and Thomson, 2000 [35]; Thomson et al., 2017 [53]

Results - Daytime periods

Disturbed conditions

solar X-ray flare - 17 September, 2015





Parameters in quiet conditions are determined in:

QIonDR; LWPC default [22]; IRI [52];
Thomson et al., 2005 [27]; McRae and Thomson, 2000 [35]; Thomson et al., 2017 [53]
o Grubor et al., 2008 [29]; o McRae and Thomson, 2004 [26]

Summary

- QionDR model provides a numerical tool for modelling the daytime Wait's parameters over the middle and low latitudes depending on location, sunspot number and day of year.
- Analytical expressions valid over a part of Europe for midday Wait's parameters are developed in this study.
- Determination of Wait's parameters in quiet state is important for modelling the D-region parameters during disturbance.

Thank you for your attention!

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