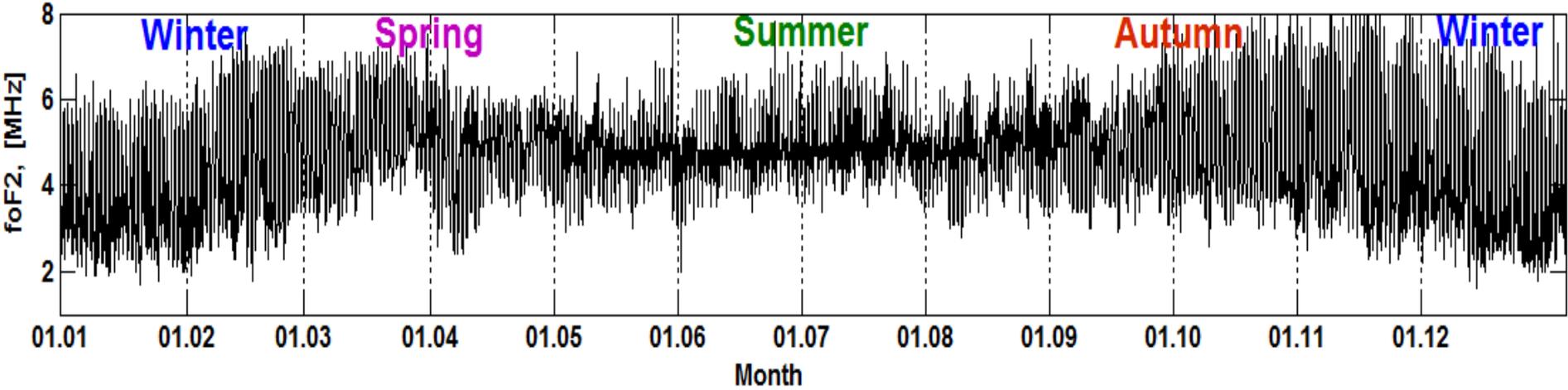Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS

Analysis of ionospheric parameters based on NARX neural networks
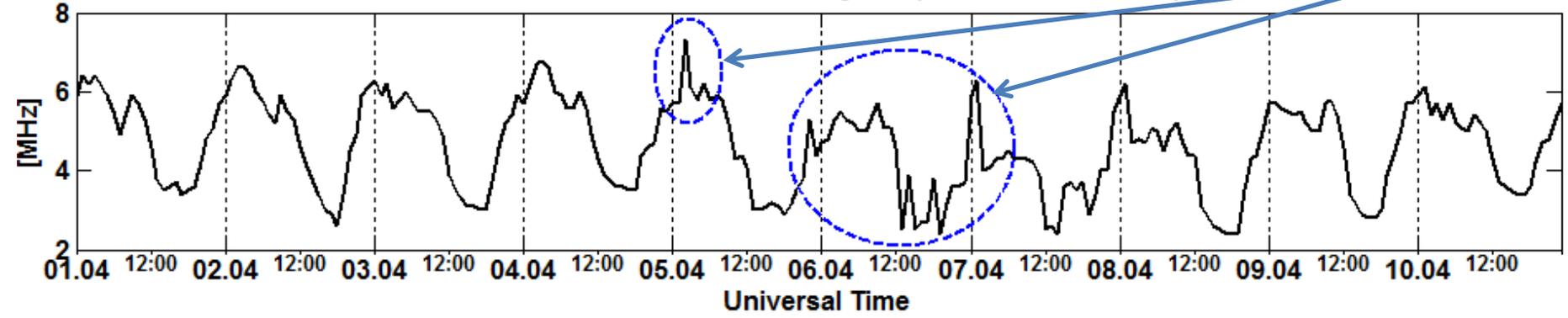
O.V. Mandrikova, Yu.A. Polozov

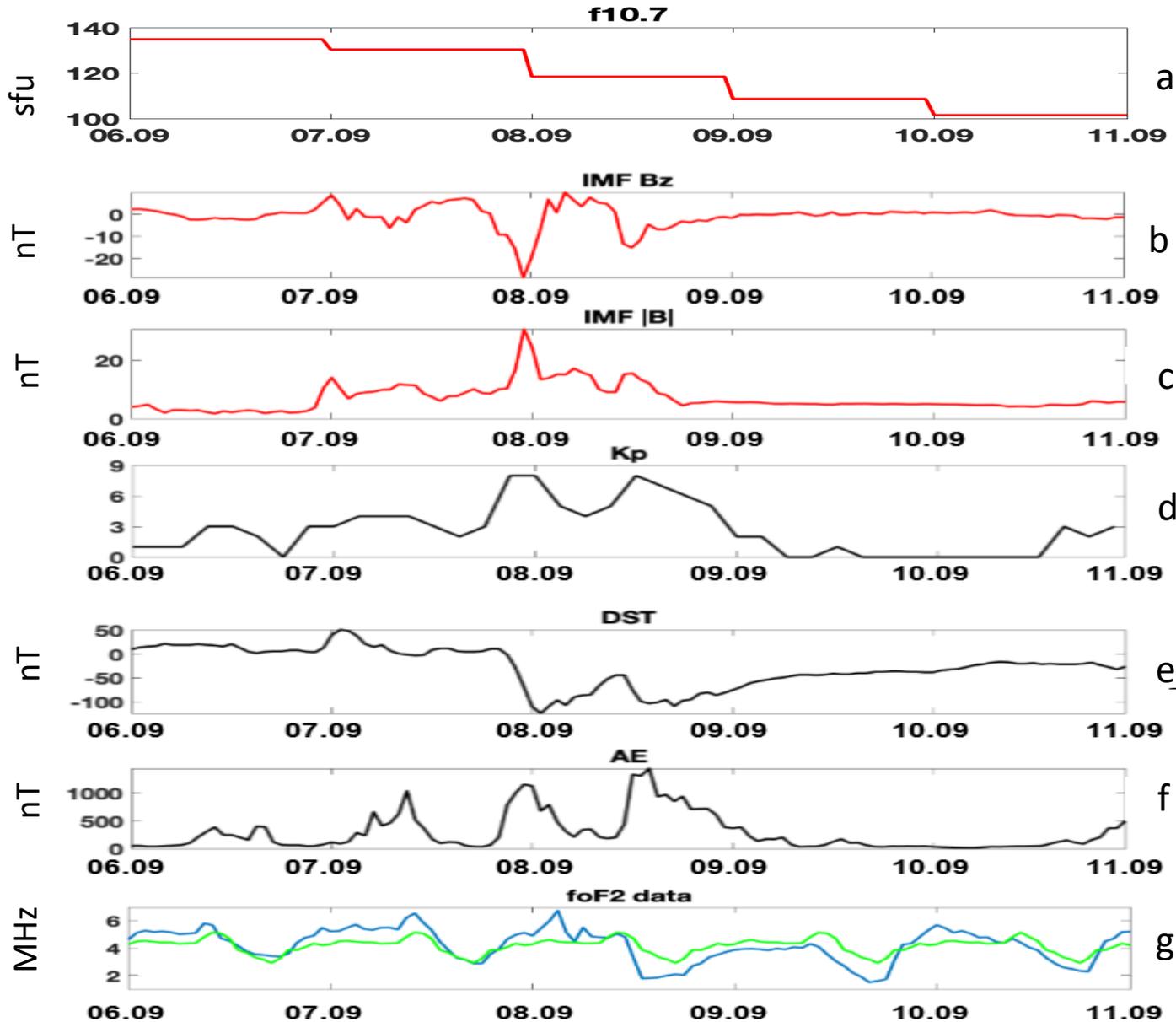# *Time series structure of the critical frequency of the ionosphere*

Ionospheric critical frequency time series for 2011 year (Paratunka station, Kamchatka, Russia)

Winter   Spring   Summer   Autumn   Winter

Anomalies

foF2 time series for 2010 year (Paratunka station)

Space weather impact , 2017

a — https://omniweb.gsfc.nasa.gov

b — https://cdaweb.gsfc.nasa.gov

c

d — http://isgi.unistra.fr

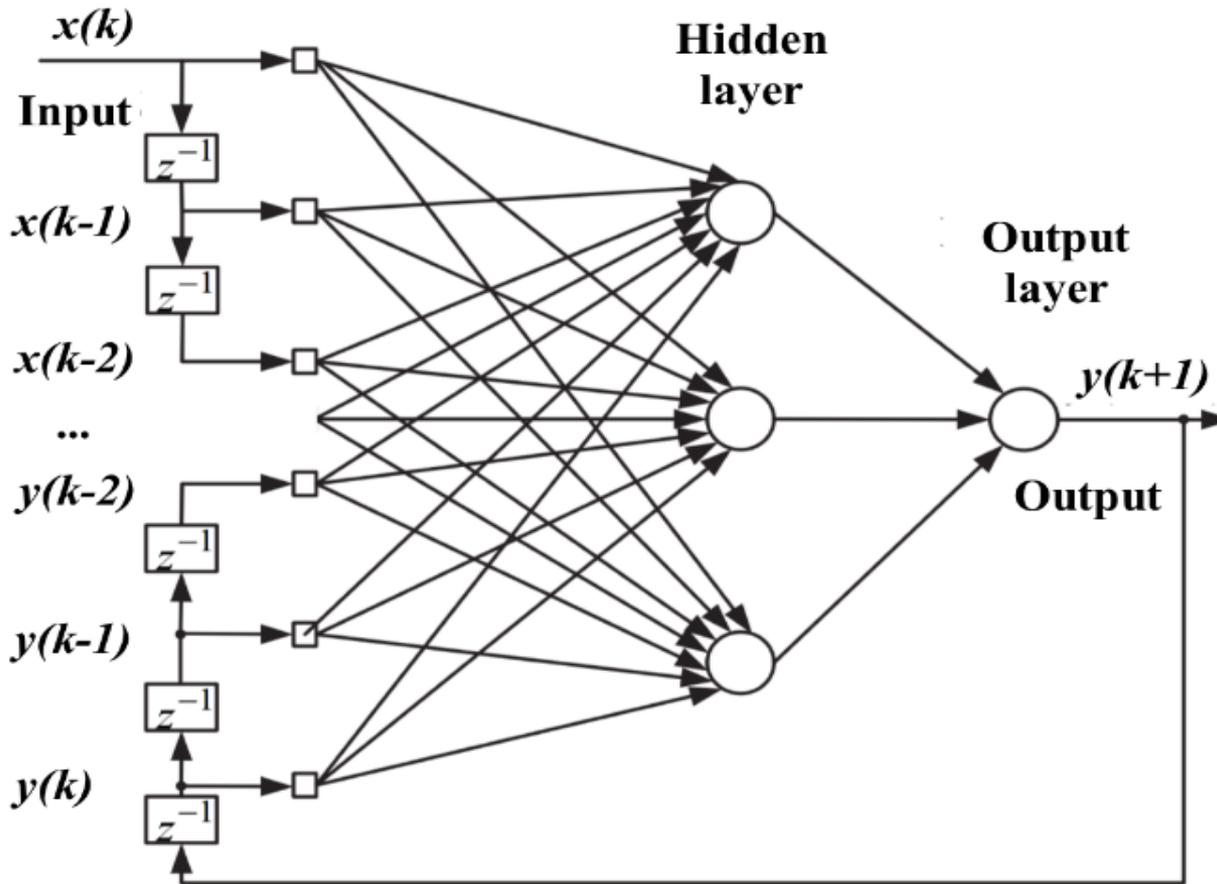e — https://cdaweb.gsfc.nasa.gov

f

g — https://csu.ikir.ru/home

Generalized recurrent network architecture

Input to hidden layer: $x(k), x(k-1), ..., x(k-l_x), y(k), y(k-1), ..., y(k-l_y)$

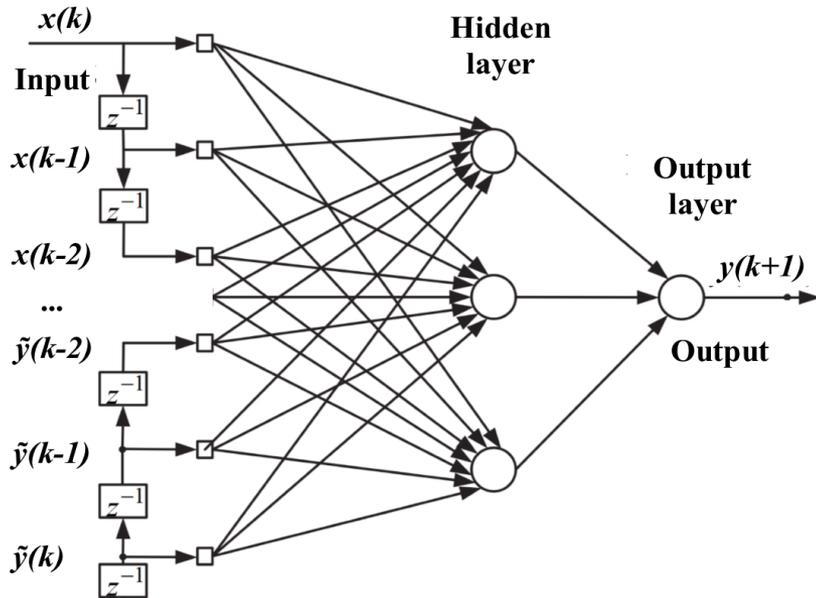Delays relative to neural network output: $l_x = l_y$

Used time line delays:
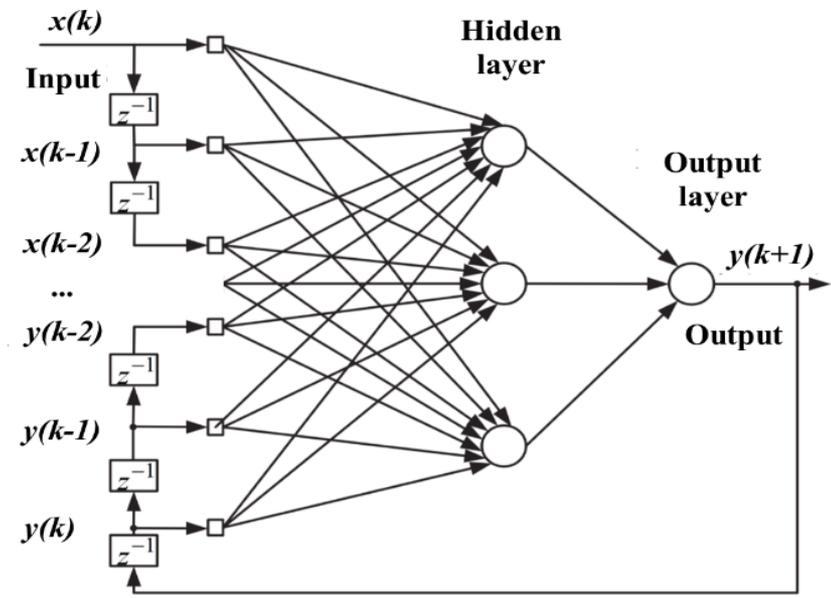$$l_x = l_y = 2$$
$$l_x = l_y = 5$$
$$l_x = l_y = 24$$

NARX SPA and NARX PA architectures

NARX SPA

NARX PA

$$y(k+1) = F[x(k), x(k-1), \dots,$$
$$x(k-l_x), \hat{y}(k),$$
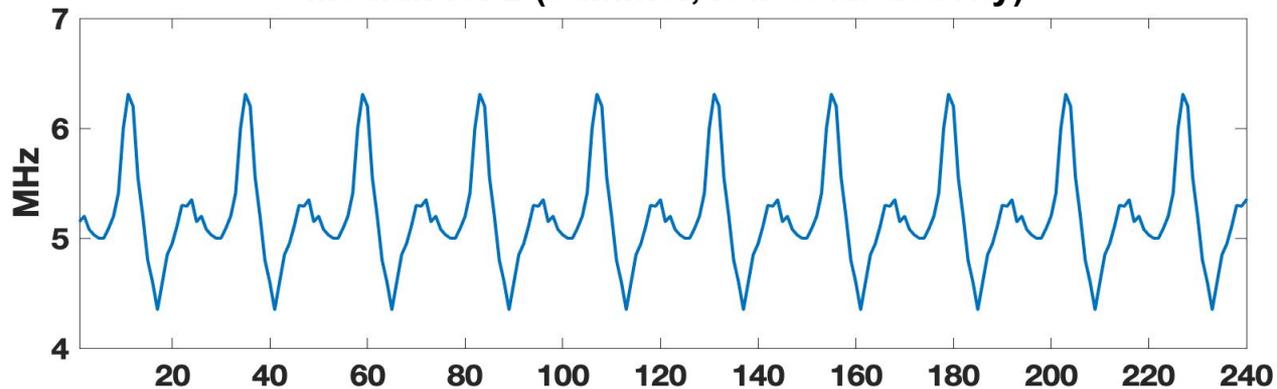$$\hat{y}(k-1), \dots, \hat{y}(k-l_y)].$$

$$y(k+1) = F[x(k), x(k-1), \dots,$$
$$x(k-l_x), y(k),$$
$$y(k-1), \dots, y(k-l_y)],$$

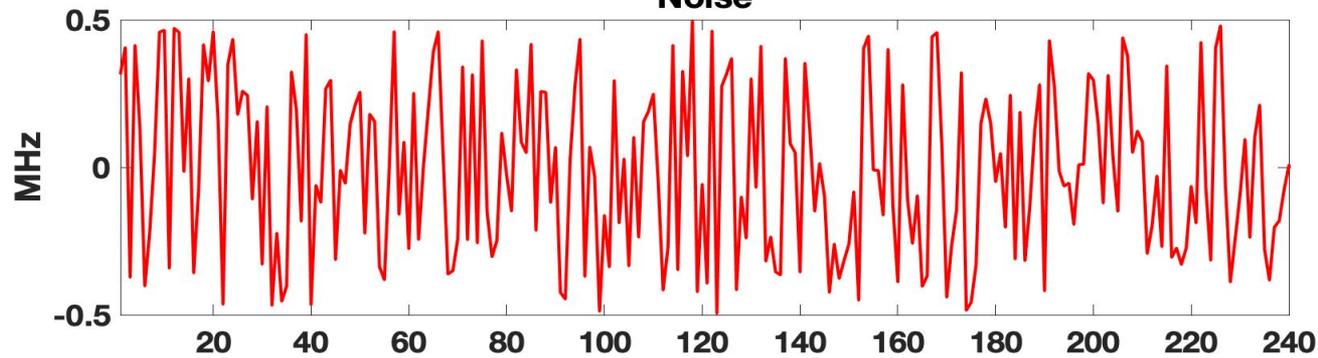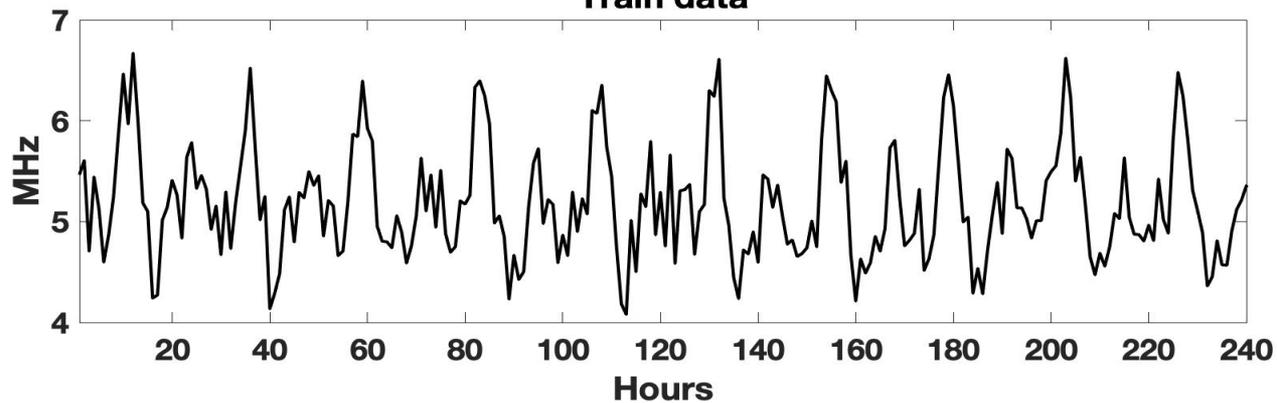$F(\cdot)$ - neural network mapping function

Generating model data

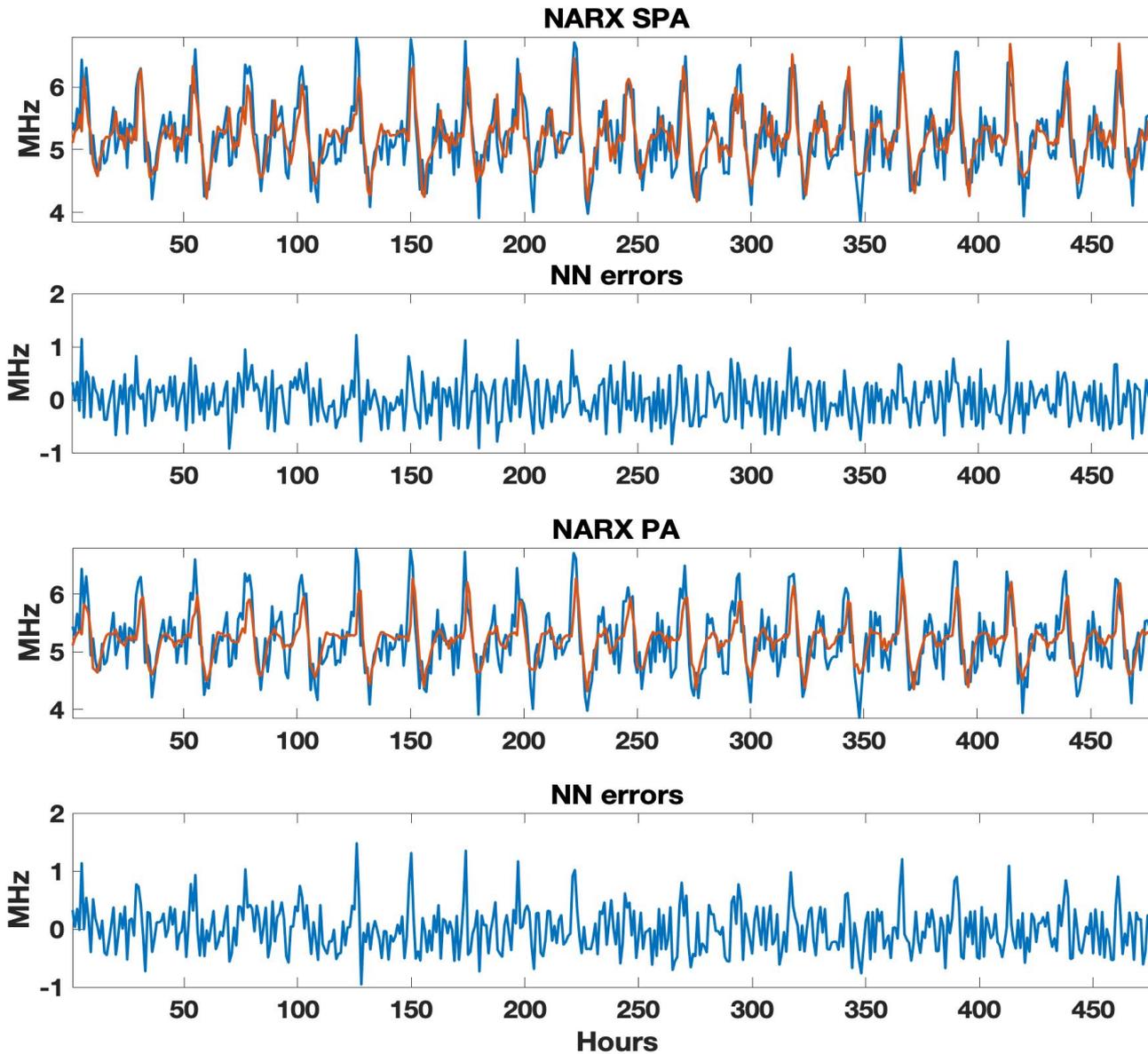**Median foF2 (summer, low solar activity)**
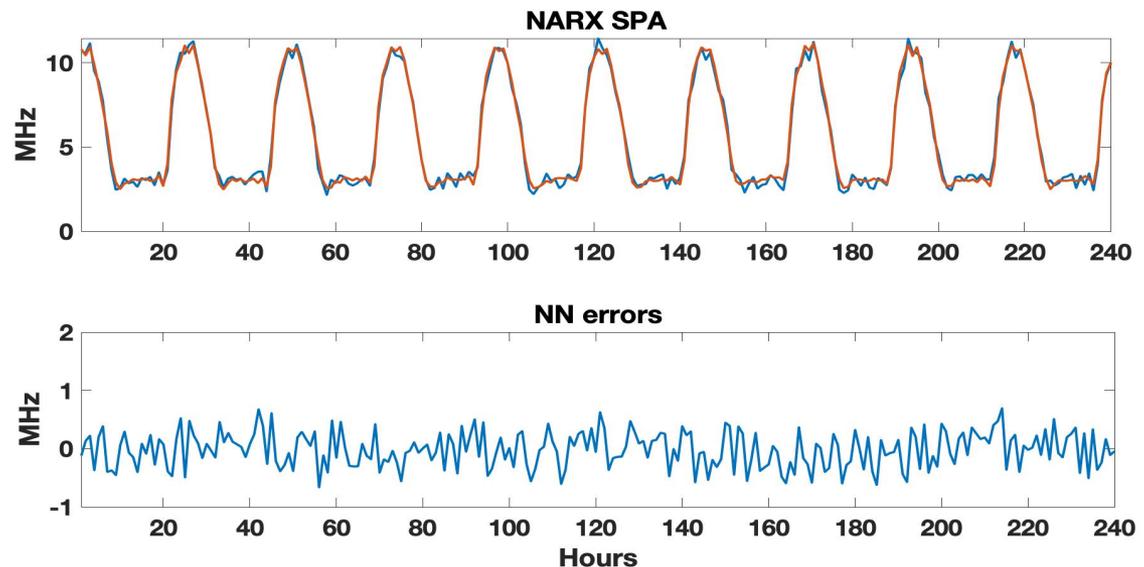
Noise

Train data

Model data NN errors

Used delays:

$$l_x = l_y = 5$$

Hidden layer:
20 neurons

Standard deviations of neural network errors

Season	Time delay 2		Time delay 5		Time delay 24	
	NARX SPA	NARX PA	NARX SPA	NARX PA	NARX SPA	NARX PA
Winter (low solar activity)	0.47	0.57	0.42	0.53	0.31	0.3
Summer (low solar activity)	0.42	0.46	0.36	0.39	0.3	0.29
Winter (high solar activity)	0.5	0.78	0.43	0.67	0.3	0.29
Summer (high solar activity)	0.42	0.45	0.36	0.37	0.32	0.3

$$S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(e_i - \overline{e})^2},$$

$$\overline{e} = \frac{1}{N}\sum_{i=1}^{N}e_i$$

$$e_i = \hat{y}(i) - y(i)$$

(a) – data foF2 (black) median foF2 (green);

(b) – errors NARX PA (TLD 2)

(c) - errors NARX SPA (TLD 2)

(d) – errors NARX PA (TLD 5)

(e) – errors NARX SPA (TLD 5)

(f) – errors NARX PA (TLD 24)

(g) – errors NARX SPA (TLD 24)

(h) – IMF Bz

(i) – DST

Results of foF2 data processing for the period August 03 – 08, 2018

(a) – data foF2 (black) median foF2 (green);

(b) – errors NARX PA (TLD 2)

(c) - errors NARX SPA (TLD 2)

(d) – errors NARX PA (TLD 5)

(e) – errors NARX SPA (TLD 5)

(f) – errors NARX PA (TLD 24)

(g) – errors NARX SPA (TLD 24)

(h) – IMF Bz

(i) – DST
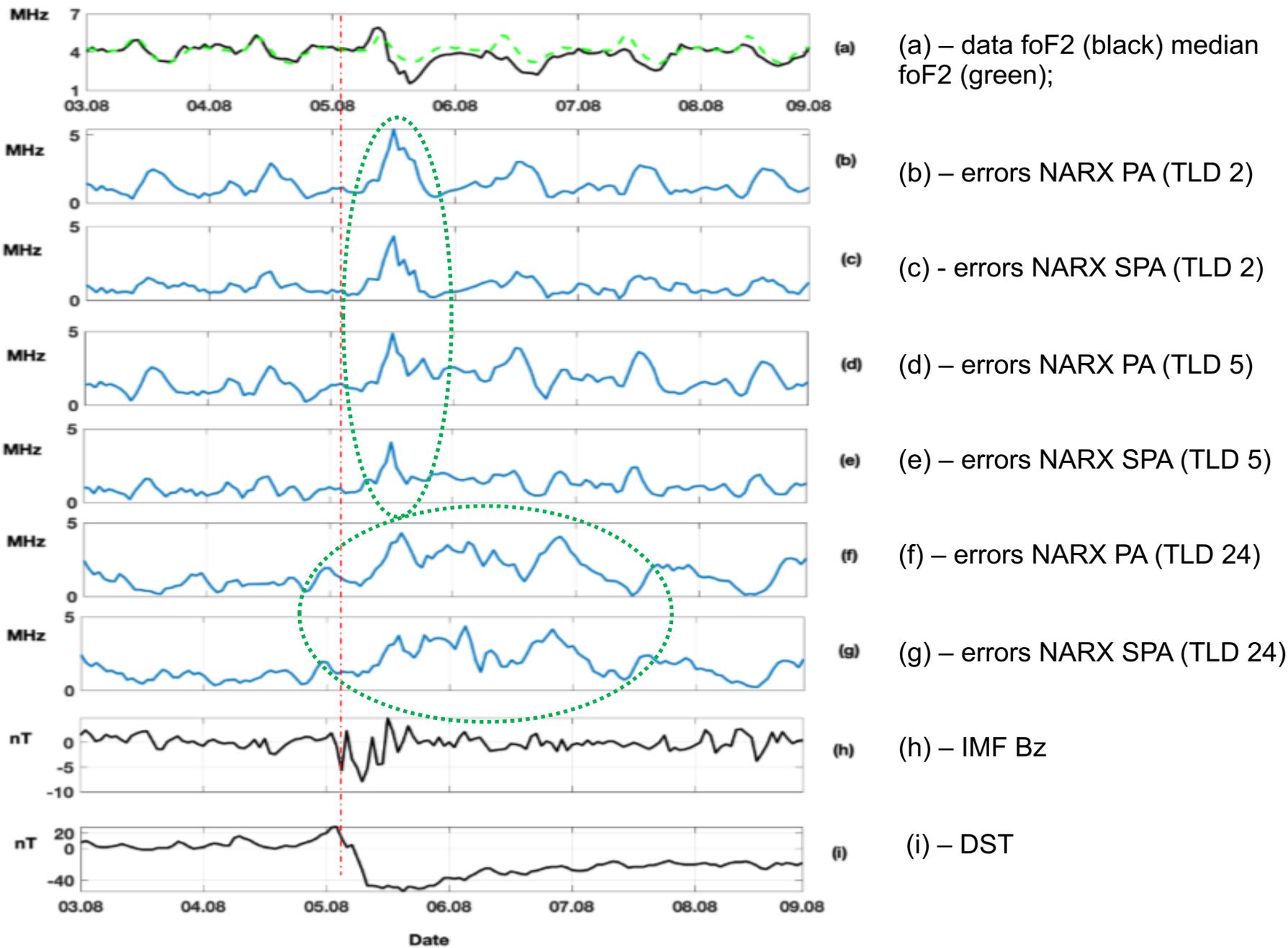
Conclusions

NARX neural networks has shown that it can be used to detect anomalous features in the regular course of the foF2 time series. NN formed for different levels of solar activity and seasons. It demonstrated better approximation abilities for the NARX SPA architecture. With an increase of delay lines number, the ability to simulate a regular foF2 behavior increases. NARX neural networks can be used to detect anomalies in ionospheric parameters during periods of geomagnetic and ionospheric disturbances.

Mandrikova O., Fetisova N., Polozov Y. Hybrid Model for Time Series of Complex Structure with ARIMA Components // Mathematics. - 2021. - V.9. - P. 1122. https://doi.org/10.3390/math9101122.