FORECAST OF RELATIVISTIC ELECTRON FLUXES IN THE OUTER RADIATION BELT AT GEOSYNCHRONOUS ORBIT WITH MACHINE LEARNING METHODS

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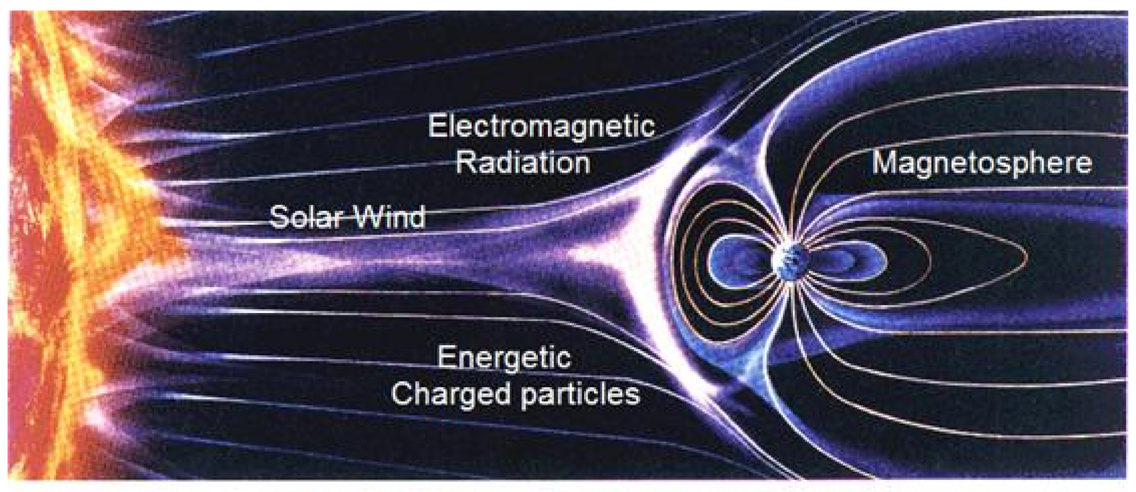
Problem Statement:

Long-term forecast (1-6 day) of the near-Earth radiation environment – namely, forecast of the daily fluence of relativistic (>2 MeV) electrons **of the outer radiation belt of the Earth.**



Magnetosphere Squished by Solar Wind

As it is well known, the intensity of the flux of relativistic electrons in the outer Radiation Belt of the Earth is subject to strong and abrupt changes under the influence of the solar wind.
Relativistic electrons may cause dangerous malfunction of the electronics onboard spacecraft, therefore they are often called killer electrons; so forecast of their flux is necessary.
__Urgency of the study:__ elaboration of an express method working in near-real time, forecast up to 1-6 days ahead.

INPUT DATA

Time series (TS) of daily values of the following physical quantities:

1) *__Solar wind (SW) parameters in L1 point between the Earth and the Sun:__*
SW velocity v (km/s) and **SW protons density nP (cm^{-3}) -** daily max of hourly average (HA) values, and daily average (DA). The data used was from ACE (Advanced Composition Explorer) spacecraft, measured by SWEPAM (Solar Wind Electron Proton Alpha Monitor) device.

2) *__Interplanetary magnetic field (IMF) vector parameters in L1 point (nT) in GSM system:__* **Bz (IMF z-component) -** daily min of HA values and **B magnitude (IMF modulus) -** daily max of HA values, and DA**.** The data used here was also from ACE spacecraft, MAG device.

3) *__Geomagnetic indexes:__*
Equatorial geomagnetic index Dst (nT) (daily min and DA), **planetary indexes Kp** (daily max and DA) **and Ap.** The data used was from WDC for Geomagnetism in Kyoto

4) __**Sunspot number**__ (daily)

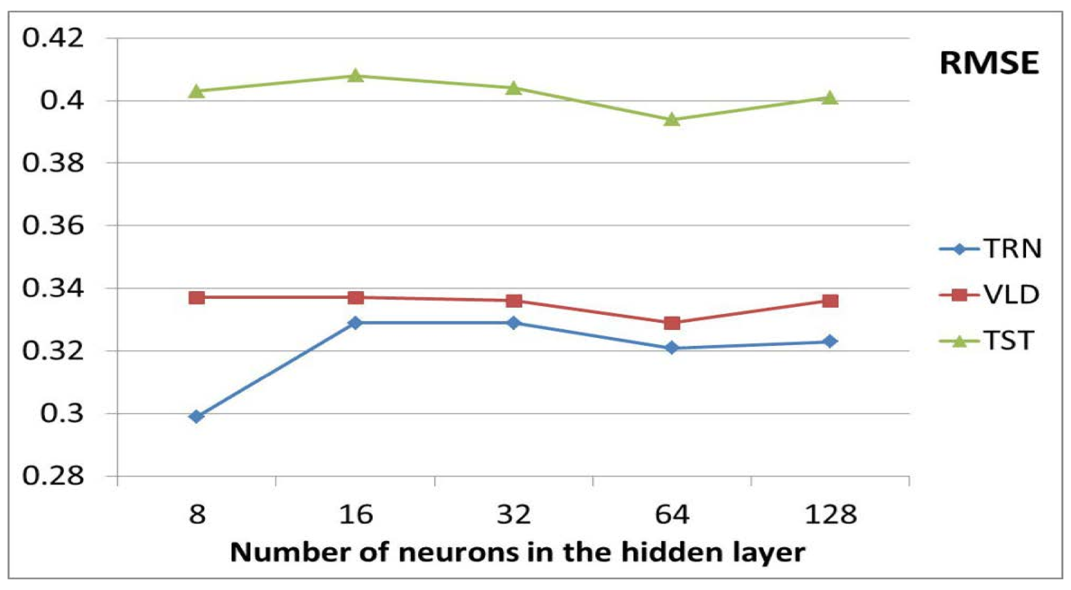
5) __**Relativistic electrons (>2 MeV) flux**__ (DA) measured at geostationary orbit by GOES satellite.

Time series of sine and cosine values with yearly period

__Data period: from May 2010 to Feb 2017__

ANN ARCHITECTURE AND PARAMETERS

__The purpose of the modeling:__ to perform daily ANN prediction of the decimal logarithm of the daily fluence, with the horizon from 1 to 6 days ahead, from the same point in time, i.e. having the same input values for the ANN.
This problem is solved by building __6 separate single-output ANNs, each with its own prediction horizon__.
When choosing the optimal architecture, multi-layer perceptrons with various numbers of neurons in the single hidden layer were investigated. The optimal architecture found was with 64 neurons.

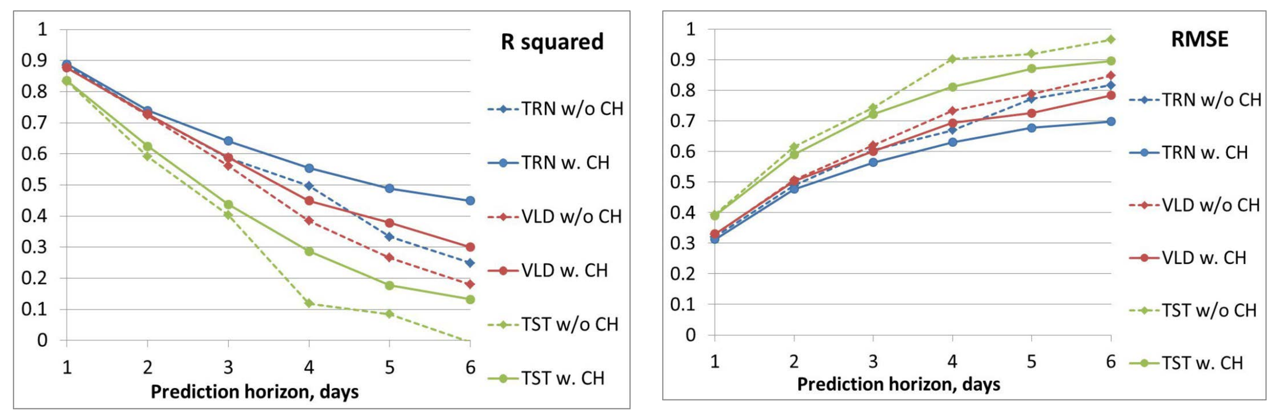


ANN architecture: MLP with 64 neurons in the single hidden layer; *tanh* activation function in the hidden layer; linear activation function in the output layer; trained by standard error backpropagation with learning rate 0.01 and moment 0.5, with random presentation of patterns during training.

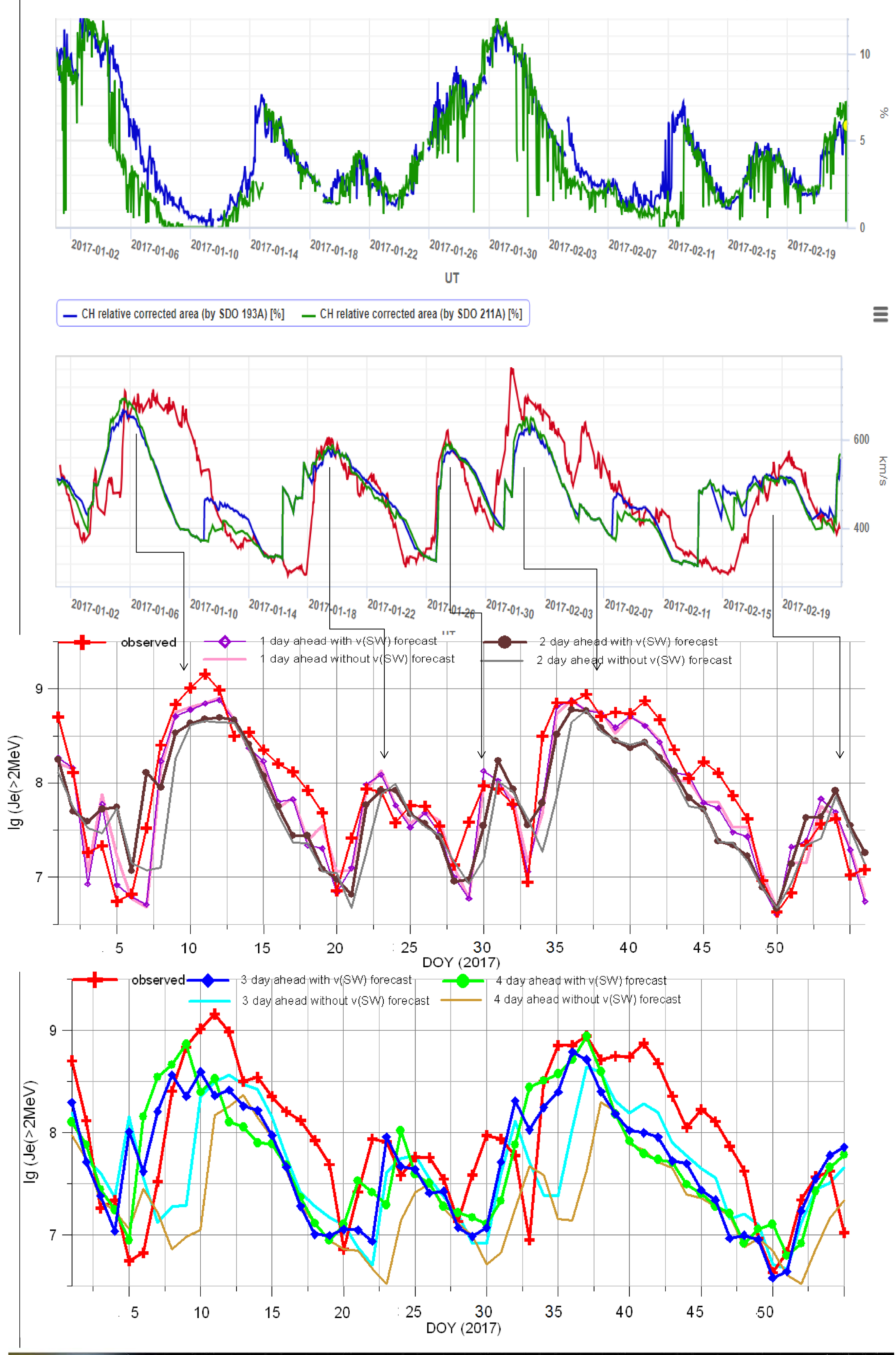
SOLAR WIND VELOCITY FORECAST AS INPUT PARAMETER

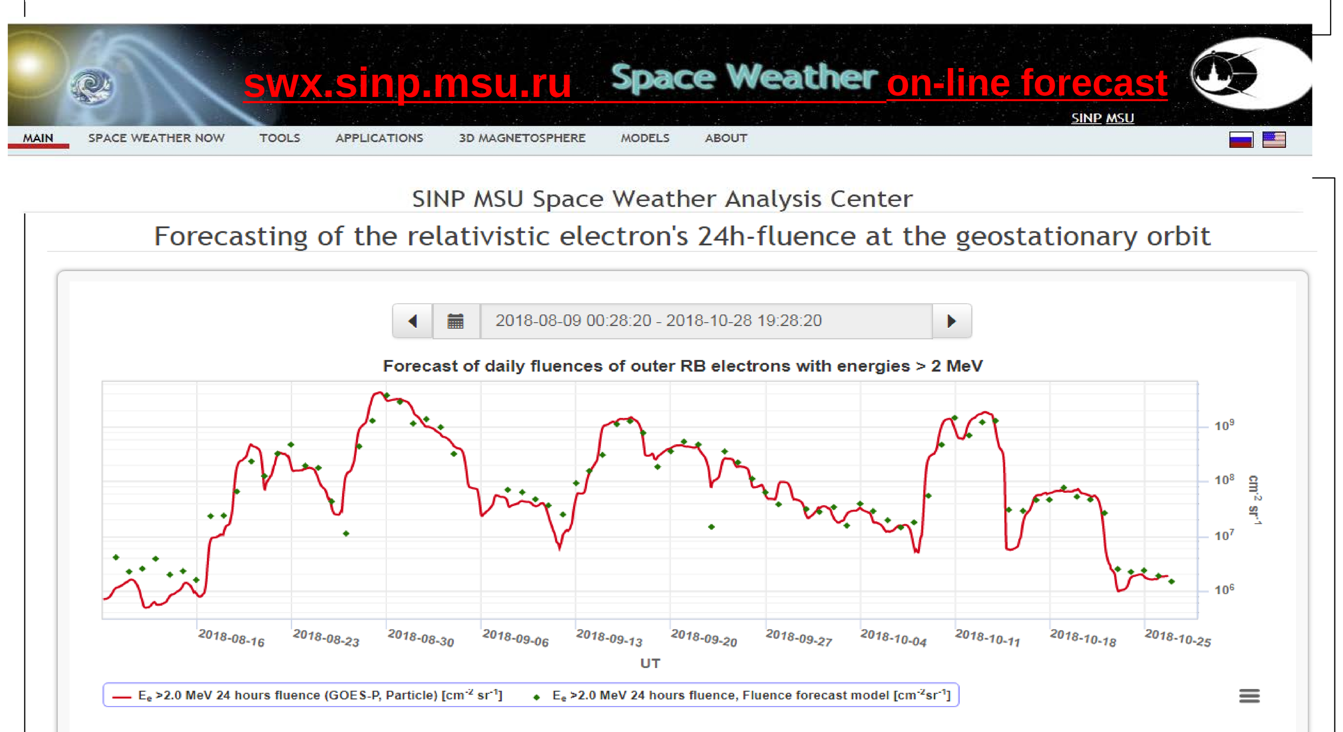
To improve the forecast with a horizon of more than a day, **the results of the high-speed SW streams velocity forecast** carried out by the data on the size of coronal holes obtained from the images of the Sun (e.g Yu. Shugay et al. J. Space Weather Space Clim., 8 (2018) A28), taken for 1 to 4 days ahead, **were used as additional input parameters.**
To predict the arrival time and velocity of SW streams at 1 AU, we used the EUV images in 19.3 nm band from the SDO/AIA as the initial data. The SW velocity was calculated from the relative areas of coronal holes at the central part of the disk based on the images. The root mean square error between the predicted and the observed SW velocity values was equal to 91 km/s. and the correlation coefficient was 0.55 for the 2017 year.

STATISTICS



R2 - coefficient of determination RMSE - Root Mean Squared Error





Gradient Boosted Regression Trees (GBRT) used for online prediction are a generalization of boosting to arbitrary differentiable loss functions. GBRT is an accurate and effective off-the-shelf procedure that can be used for both regression and classification problems.
The advantages of GBRT are: natural handling of data of mixed type (i.e. heterogeneous features); high predictive power; robustness to outliers in the output space (via robust loss functions).

SUMMARY

It was found that using the forecast of the solar wind velocity carried out on the basis of solar images in the UV range can significantly improve the forecast of average daily fluences for forecast horizons of 2 or more days.

This study was supported by the Russian Science Foundation, grant no.16-17-00098