Nonlinear Predictive Model Identification for Kp Index Forecasting

Yuanlin Gu, Hua-Liang Wei, Richard J. Boynton, Simon N. Walker, Michael A. Balikhin

Department of Automatic Control and Systems Engineering, University of Sheffield, Sheffield, UK

Abstract

Forecasting of Kp index is important for understanding the dynamic relationship between the magnetosphere and solar wind. This study presents 3-hours ahead prediction for Kp index using NARMAX models. Numerical results show that the models can produce very good Kp forecast performance and provide transparent and compact representations of the relationship between Kp index and solar wind parameters.

Backgrounds

Many advanced systems and equipment on or nearby earth, for example, navigation systems, communication systems, satellites, and power grid, are sensitive to space weather changes. In order to understand and forecast the geomagnetic activity, the Kp (planetarische Kennziffer) index was first introduced by Bartels in 1949. The values of Kp index range from 0 (very quiet) to 9. The correlation between Kp index and solar wind has been confirmed. This study aims to build models to represent the relationship between Kp index and solar wind parameters.

Data

A brief description of Kp index (output variable) and solar wind parameters (input variables) are shown in **Table 1**. In this study, the Kp data of year 2000 is used (first half for training and second half for testing). As shown in **Fig. 1** (upper panel), there are much more data points of quite Kp times than active Kp times. In order to overcome the data imbalance issue and improve the prediction performance for high Kp values, a data balancing method is introduced to resample the training data, so that the model can well predict both low and high Kp values. A comparison of the raw data and balanced data is shown in **Fig. 1**.

TABLE 1 KP INDEX AND SOLAR WIND VARIABLES

Name	Description
Kp	Kp index
Bs	Magnitude of the interplanetary magnetic field
n	Solar wind density (proton density) $[n/cc]$
p	Solar wind pressure (flow pressure) $[nPa]$
V	Solar wind speed (flow speed) $[km/s]$
VBs	Solar wind rectified electric field (defined as $V \times Bs/1000$)

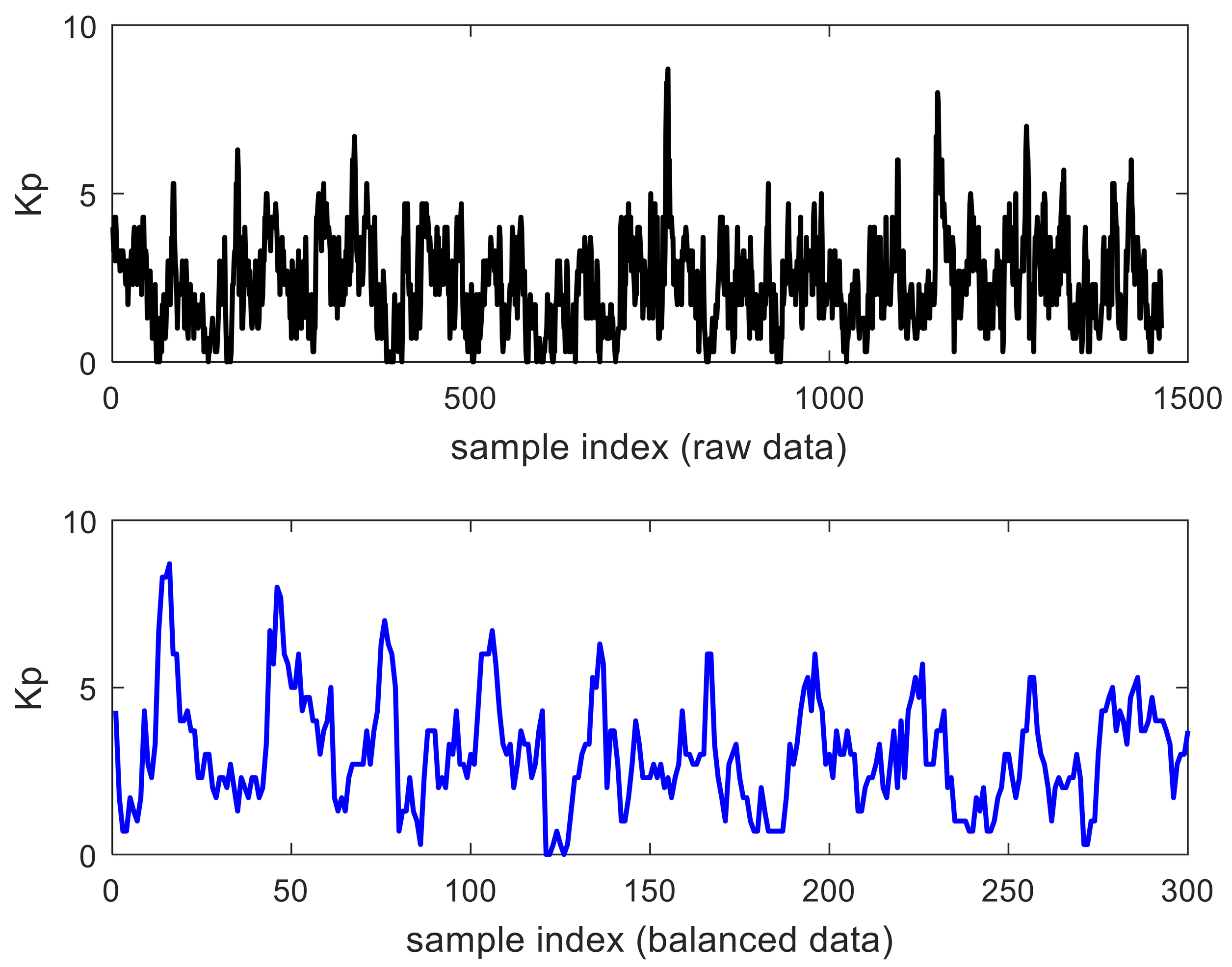

Fig. 1 A comparison of raw data and balanced data for training

NARMAX Model

The input-output relationship of a nonlinear dynamic system can be represented using nonlinear autoregressive moving average with exogenous inputs (NARMAX) model as:

$$y(t) = f(y(t-1), \dots, y(t-n_y), u(t-1), \dots, u(t-n_u), e(t-1), \dots, e(t-n_e))$$

where $y(t)$, $u(t)$ and $e(t)$ are the output, input and prediction error, respectively; n_y, n_u, and n_e are the associated maximum lags, and $f(\cdot)$ is some nonlinear function which is unknown in advance and can be identified from experimental data by using some model structure detection algorithm

Results

Two types of models, one using autoregressive variables and another without using autoregressive variables, are built for 3 hour ahead Kp forecast. The correlation of predicted and observed Kp index of the two models is 0.82 and 0.69, respectively. As shown in **Fig. 2** and **Fig. 3,** both models can give excellent 3 hours ahead prediction.

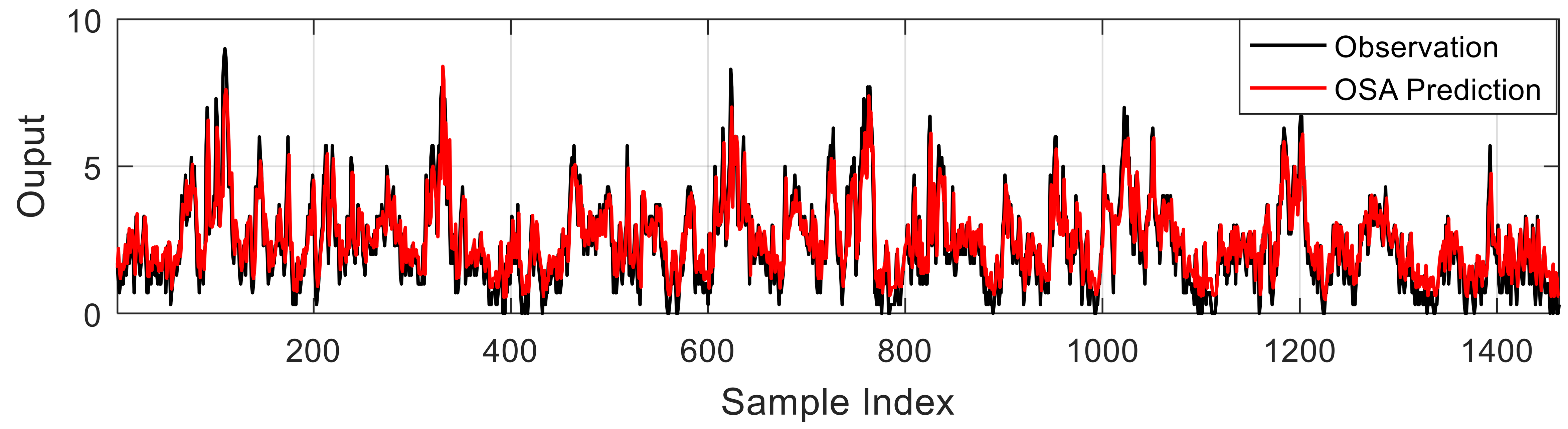

Fig. 2 A comparison of observed and predicted Kp values of second half of 2000 (model with autoregressive terms)

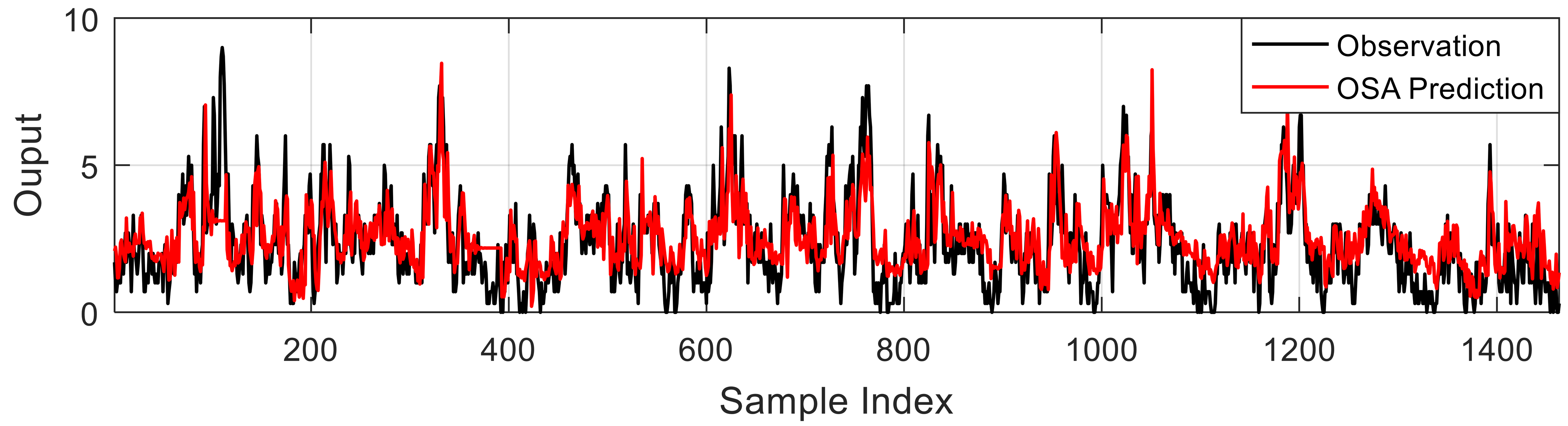

Fig. 3 A comparison of observed and predicted Kp values of second half of 2000 (model without autoregressive terms)

Conclusions

Two types of NARMAX models, one with autoregressive model terms and another without autoregressive terms (the latter is called Volterra series model), were constructed for 3 hours ahead prediction of Kp index. The training data are resampled by using a data balancing method to overcome the imbalance data issue so as to improve the prediction capacity of the model for prediction active Kp times and it turns out that the models can forecast the active times very well Overall, the models cannot only be used for Kp forecast, but also provide a useful transparent and compact representation of the relationship between Kp index and solar wind variables.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 637302.

Contact: Hua-Liang Wei (w.hualiang@sheffield.ac.uk)