Prediction of Ionospheric Perturbations Using Artificial Neural Network. Application to ISL Instrument Data- DEMETER Mission

Sid-Ali Ouadfeul, Victor Tourtchine, and Leila Aliouane

LIMOSE, Faculté des Sciences,
Université M'hamad Bougara de Boumerdes,
Avenue de l'indépendance, Boumerdes, Algeria
LABOPHYT, Faculté des Hydrocarbures et de la Chimie,
Université M'hamad Bougara de Boumerdes,
Avenue de l'indépendance, Boumerdes, Algeria
SOuadfeul@ymail.com

Abstract. In this paper, a tentative of prediction of Instrument Langmuir (ISL) installed in the DEMETER satellite is implanted. Prediction is based on the Multilayer Perceptron (MLP) neural network model. The MLP machine is composed of three layers, an input layer with four neurons, a hidden layer with ten neurons and an output layer with the same number of units like the input layer. Parameters to be predicted are electrons and ions density, electrons temperatures and plasma potential. Application to the data of orbit 27447-1 recorded two days before the Laquila earthquake of 06 April 2009 clearly shows the power of the artificial neural network in the prediction of ionospheric perturbations and Plasma analysis.

Keywords: ISL Demter, MLP, Prediction.

1 Introduction

The artificial neural networks (ANNs) have been widely used in physics (Peterson, 1992, Lynch et al, 2001, Ouadfeul and Aliouane, 2013). In plasma physics the ANNs are used by many authors to characterize it. Teng et al (2010) have used a multilayer perceptron algorithm and radial based function algorithm in order to predict the plasma density in a plasma system, the effectiveness of two artificial neural network models is demonstrated. Wei el al (2009) have established an artificial neural network (ANN) model using a back-propagation training algorithm in order to predict the plasma spatial distribution in an electron cyclotron resonance (ECR) — plasma-enhanced chemical vapor deposition (PECVD) plasma system. In this paper we test the efficiency of the Multilayer Perecptron (MLP) for prediction of ionosphere parameters recorded by DEMETER Satellite Langmuir instruments. We start by describing the instrument and the data, after that we describe the neural network MLP machine with detailing its training parameters, the technique is applied to real data

M. Lee et al. (Eds.): ICONIP 2013, Part I, LNCS 8226, pp. 490–497, 2013.

recorded two days before the main shock of L'Aquila earthquake. We finalize the paper by results interpretation and a conclusion.

2 Langmuir Instrument and DEMETER Satellite

DEMETER satellite is designed to study ionospheric disturbances related to earthquake, volcano and human activity, and to detect the electromagnetic environment in global scale (Lebreton , 2012). The satellite has quasisolar-synchronous circular orbit with declination 98.23°, weight 130 kg and height 710 km (which decreased to 660 km in the middle of December, 2005). Its life was supposed to be two years. However, it is still operating now. The Langmuir probe is in principle a simple and very versatile space plasma diagnostic instrument for in situ measurements. A classical Langmuir probe uses a single sensor, which may be of different geometry (cylindrical or spherical). The DEMETER Langmuir Probe (ISL: Instrument Sonde de Langmuir) comprises two Langmuir Probe sensors. It includes a classical cylindrical sensor (5 cm long, dia 6 mm) and a 4-cm diameter spherical Segmented Langmuir Probe (SLP) whose surface is divided in six 1-cm disk sections (Lebreton, 2012, Zhang et al, 2009). A set of instruments were deployed on the satellite, including ICE to detect electric field from DC to 3.5 MHz; IMSC to measure the magnetic field from a few Hz to 20 kHz; IAP to detect ion density and temperature and so on; ISL, Langmuir probe to measure the electron density and temperature. Two kinds of data with different operating modes are provided: survey mode with low sampling rate and burst mode with high sampling rate as the satellite flies over the seismic zones. The mission center of DEMETER provides the data that can be downloaded and Quicklook images (Zhang et al, 2009). Detailed data guide can be referred to the website of DEMETER, http://demeter .cnrs-orleans.fr.

The Langmuir probe is in principle a simple and very versatile space plasma diagnostic instrument for in situ measurements. A classical Langmuir probe uses a single sensor, which may be of different geometry (cylindrical or spherical). The DEMETER Langmuir Probe (ISL: Instrument Sonde de Langmuir) comprises two Langmuir Probe sensors. It includes a classical cylindrical sensor (5 cm long, dia 6 mm) and a 4-cm diameter spherical Segmented Langmuir Probe (SLP) whose surface is divided in six 1-cm disk sections (Lebreton , 2012).

3 The Multilayer Perceptron

Multilayer feed-forward networks form an important class of neural networks. Typically the network consists of a set of sensory units or input nodes, that constitute the input layer, one or more hidden layers of neurons or computation nodes, and an output layer. Multi-layer Perceptron (MLP) neural networks with sufficiently many nonlinear units in a single hidden unit layer have been established as universal function approximators. The advantages of the MLP are: Hidden unit outputs (basis functions) change adaptively during training, making it unnecessary for the user to choose them beforehand. The number of free parameters in the MLP can be unambiguously increased in small increments by simply increasing the number of hidden units.

The basic functions are bounded making overflow errors and round-off errors unlikely. The MLP is a feed-forward network consisting of units arranged in layers with only forward connections to units in subsequent layers. The connections have weights associated with them. Each signal traveling along a link is multiplied by its weight.

The input layer, being the first layer, has input units that distribute the inputs to units in subsequent layers. In the following (hidden) layer, each unit sums its inputs and adds a threshold to it and nonlinearly transforms the sum (called the net function) to produce the unit output (called the activation). The output layer units often have linear activations, so that output activations equal net function values.

The layers sandwiched between the input and the output layers are called hidden layers, and the units in the hidden layers are called hidden units (Ouadfeul and Aliouane, 2012, 2013).

4 Application to Real Data

To check the efficiency of the Multilayer perecptron neural network model in the prediction of ionospehric perturbations, data of the 04 April 2009 recorded by the ISL instrument two days before of Italian earthquake of L'Aquila are analyzed. Let us start by giving more details about this huge seismic disaster.

4.1 L' Aquila Earthquake

The 2009 L'Aquila earthquake occurred in the region of Abruzzo, in central Italy (see Fig. 01). The main shock occurred at 03:32 CEST (01:32 UTC) on 6 April 2009, and was rated 5.8 or 5.9 on the Richter scale and 6.3 on the moment magnitude scale; its epicenter was near L'Aquila, the capital of Abruzzo, which together with surrounding villages suffered most damage. There have been several thousand foreshocks and aftershocks since December 2008, more than thirty of which had a Richter magnitude greater than 3.5.

The earthquake was felt throughout central Italy; 297 people are known to have died, making this the deadliest earthquake to hit Italy since the 1980 Irpinia earthquake. In a subsequent inquiry of the handling of the disaster, seven members of the Italian National Commission for the Forecast and Prevention of Major Risks were accused of giving "inexact, incomplete and contradictory" information about the danger of the tremors prior to the main quake. On 22 October 2012, six scientists and one ex-government official were convicted of multiple manslaughter for downplaying the likelihood of a major earthquake six days before it took place. They were each sentenced to six years' imprisonment.

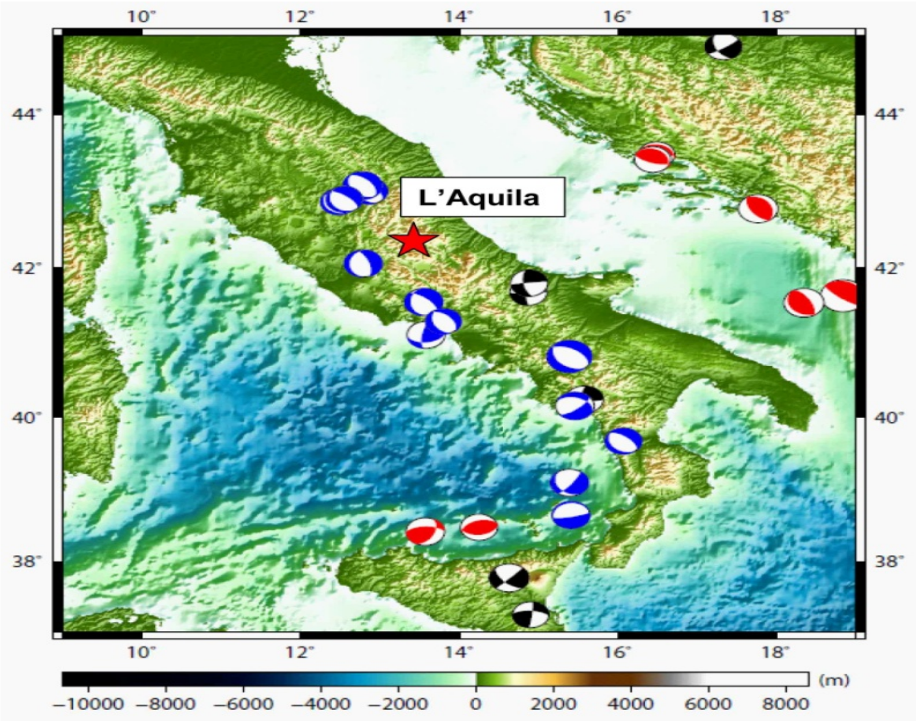

Fig. 1. Map of Italy centered around the L'Aquila region

4.2 Data Analysis

Data of ISL Langmuir DEMETER satellite recorded two days before then main shock of L'Aquila earthquake are analyzed by the multilayer perceptron, the goal is check the efficiency of the MLP neural network to predict future time series. Parameters to be predicted are: Electron Density, Ion Density, Electron temperature and Plasma potential. A neural network machine of three layers is implanted, the input layer is constituted of four neurons, and the hidden layer is composed of 10 neurons and an output layer of four neurons. The first 640 samples recorded by the ISL instrument are used as input (see Fig. 2); the second 640 samples are used as a desired output of the MLP machine (see Fig. 3).

In the training stage weights of connection are optimized to minimize the root mean square error between the desired output and the calculated output by the MLP machine. To check the power of the MLP machine for prediction of these parameters, a generalization of this implanted machine is done. At this step the second 640 samples are now used as an input of the MLP machine, the goal is to predict a future time series of 300 samples.

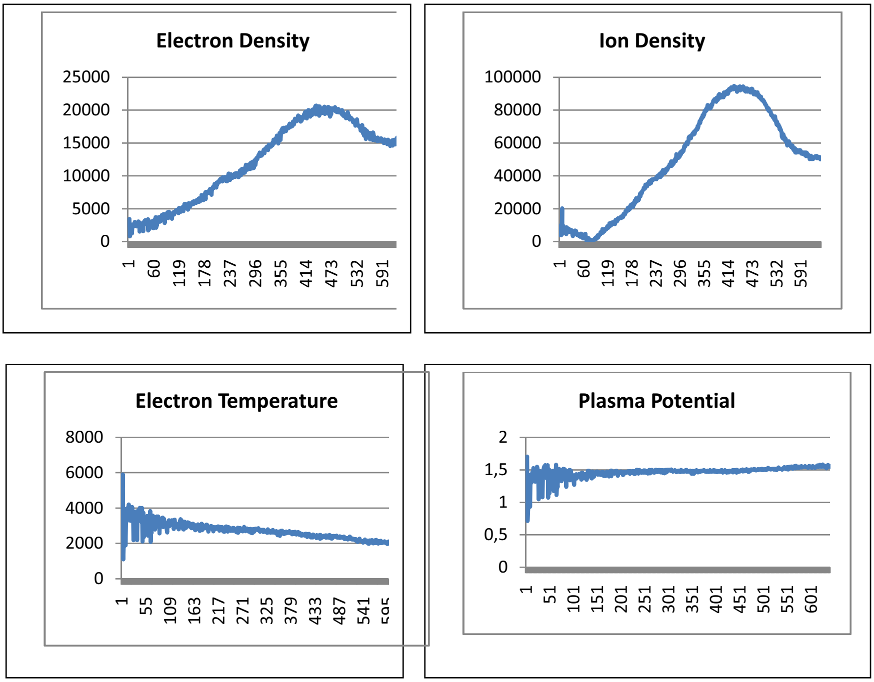

Fig. 2. Input of the Multilayer Perceptron neural network machine

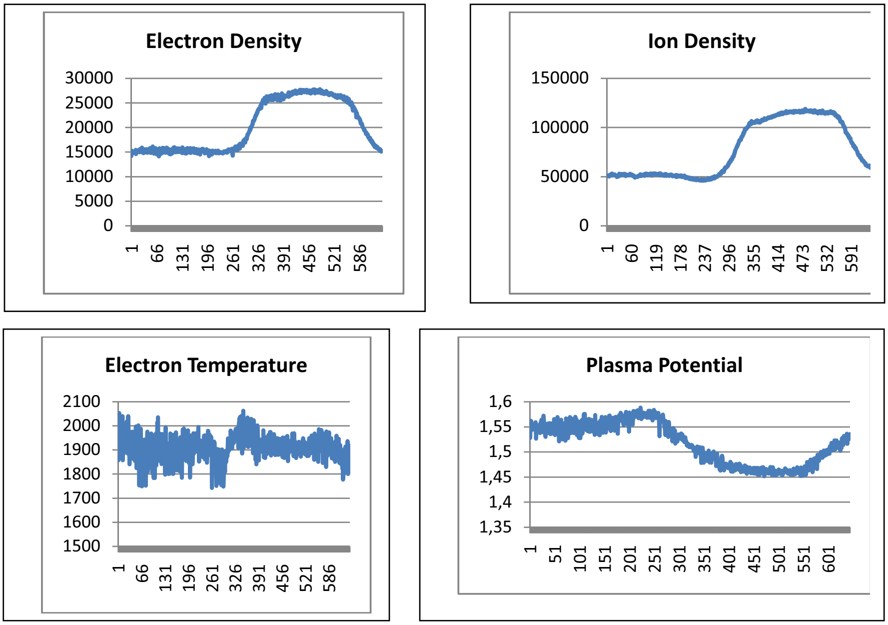

Fig.3. Desired output of the MLP machine

5 Results, Interpretation and Conclusion

Graphs of predicted plasma parameters are presented in black color in Fig. 4, Red graphs are the recorded parameters by the ISL Demeter satellite. Comparison between the two graphs clearly shows that the implanted neural network machine has the capacity and the memory to provide future ionosphere parameters. We can see that the ANN machine has a good memory for the most of each time series, however the machine start to lose slightly the memory at the end of each series.

The implanted machine can greatly be used for prediction of ionosphereic perturbations, which have a big relation with seismic activity; the artificial neural network method plays an important role in the seismic hazard prevention. We suggest testing other neural network models like the Radial Basis Function (RBF) to decide about which kind of neural network can be used for prediction of ISL Langmuir satellite data.

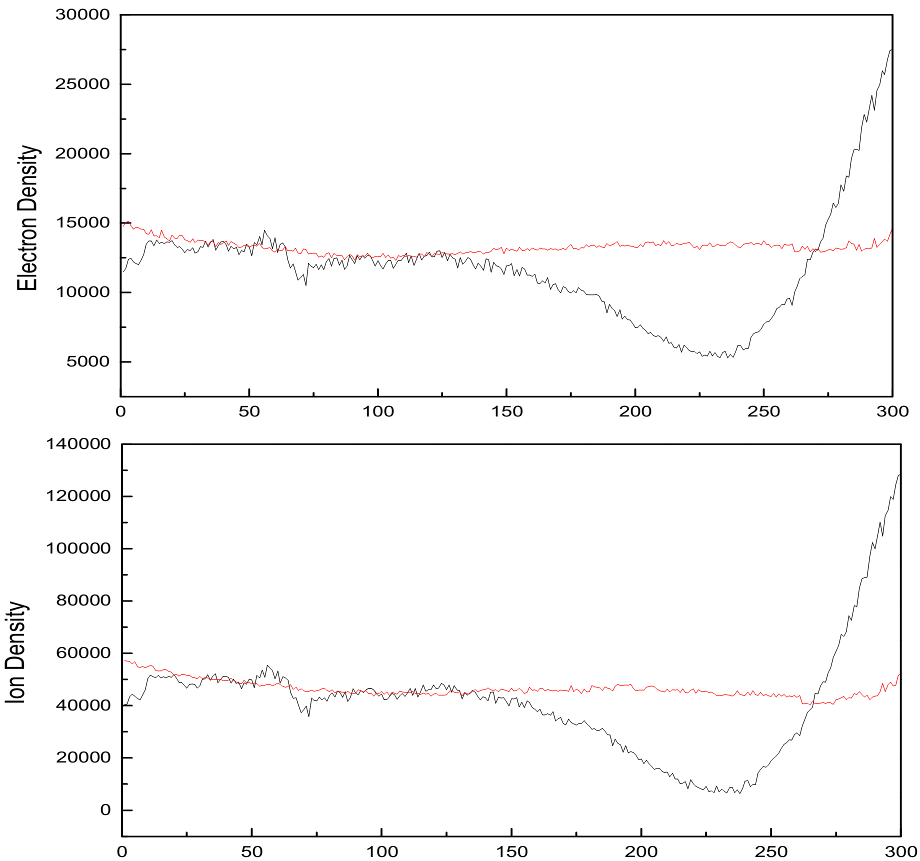

Fig. 4. Predicted plasma ionospheric parameters (black color) compared to recorded parameters by DEMETER satellite (red color)

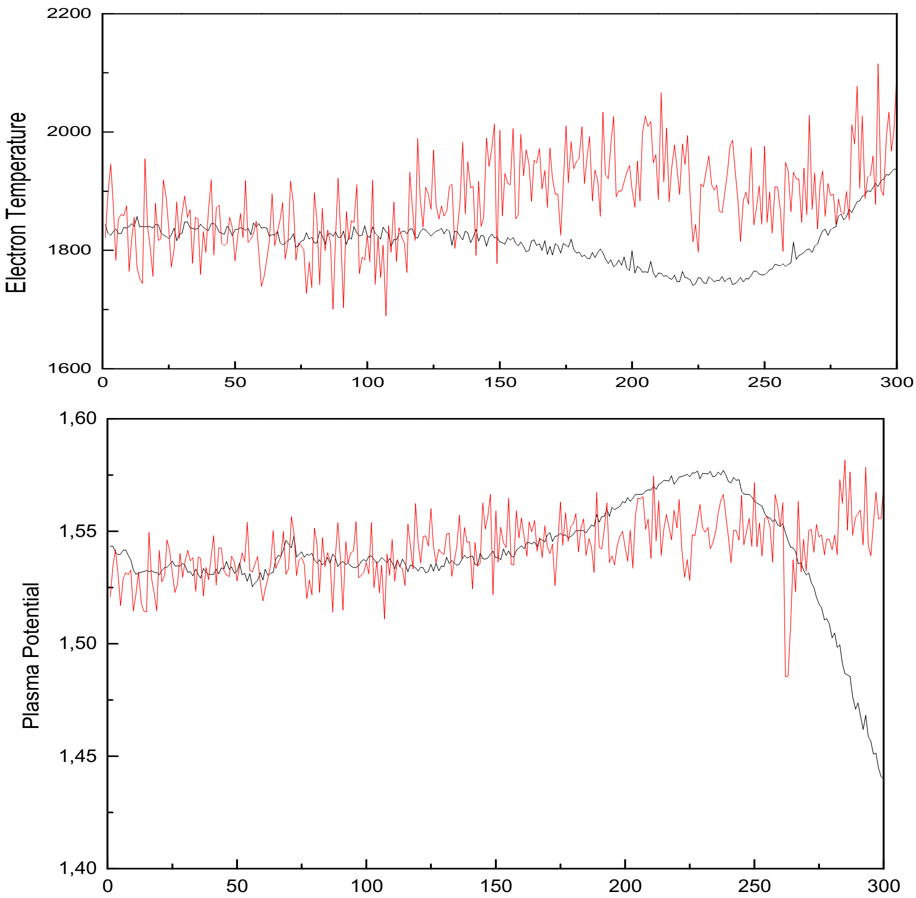

Fig. 4. (*Continued.*)

References

1. Peterson, C.: Neural Networks in High Energy Physics. In: Plenary talk presented at the "Computing in High Energy Physics", Annecy, France, September 21-25, 1991 (1992)
2. Lynch, M., Patel, H., Abrahamse, A., Rupa Rajendran, A., Medsker, L.: Neural network applications in physics. In: Proceedings of the International Joint Conference on Neural Networks, IJCNN 2001, vol. 3, pp. 2054–2058 (2001), doi:10.1109/IJCNN.2001.938482
3. Leberton, J.-P.: On the issue of surface contamination of a Langmuir Probe sesor: Demter IS results. Geophysical Research Abstrcats 14, EGU2012-13806
4. Ouadfeul, S.-A., Aliouane, L.: Lithofacies prediction from well log data using a multilayer perceptron (MLP) and Kohonen's self-organizing map (SOM) – a case study from the Algerian Sahara. Pattern Recogn. Phys. 1, 59–62 (2013), doi:10.5194/prp-1-59-2013
5. Ouadfeul, S.-A., Aliouane, L.: Lithofacies Classification Using the Multilayer Perceptron and the Self-organizing Neural Networks. In: Huang, T., Zeng, Z., Li, C., Leung, C.S. (eds.) ICONIP 2012, Part V. LNCS, vol. 7667, pp. 737–744. Springer, Heidelberg (2012)

6. Teng, W., Xiang-Dong, G., Wei, L.: Characterisation of the plasma density with two artificial neural network models. Chinese Phys. B 19, 070505 (2010), doi:10.1088/1674-1056/19/7/070505
7. Wei, L., Jun-Fang, C., Teng, W.: Prediction of the plasma distribution using an artificial neural network. Chinese Phys. B 18 2441 (2009), doi:10.1088/1674-1056/18/6/053
8. Zhang, X., Qian, J., Ouyang, X., Shen, X., Cai, J., Zhao, S.: Ionospheric electromagnetic perturbations observed on DEMETER satellite before Chile M7.9 earthquake. Earthquake Science 22(3), 251–255 (2009)