Atmospheric Research 144 (2014) 141–150

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Artificial neural networks modeling for forecasting the maximum daily total precipitation at Athens, Greece

P.T. Nastos [a,*], A.G. Paliatsos [b], K.V. Koukouletsos [b], I.K. Larissi [c], K.P. Moustris [d]

[a] Laboratory of Climatology & Atmospheric Environment, Faculty of Geology & Geoenvironment, University of Athens, Greece
[b] Department of Mathematics, Technological & Education Institute of Piraeus, Greece
[c] Laboratory of Environmental Technology, Department of Electronic Computer Systems, Technological & Education Institute of Piraeus, Greece
[d] Department of Mechanical Engineering, Technological & Education Institute of Piraeus, Greece

ARTICLE INFO

Article history:
Received 31 December 2012
Received in revised form 12 November 2013
Accepted 17 November 2013
Available online 27 November 2013

Keywords:
Artificial neural networks
Maximum daily precipitation
Athens

ABSTRACT

Extreme daily precipitation events are involved in significant environmental damages, even in life loss, because of causing adverse impacts, such as flash floods, in urban and sometimes in rural areas. Thus, long-term forecast of such events is of great importance for the preparation of local authorities in order to confront and mitigate the adverse consequences. The objective of this study is to estimate the possibility of forecasting the maximum daily precipitation for the next coming year. For this reason, appropriate prognostic models, such as Artificial Neural Networks (ANNs) were developed and applied. The data used for the analysis concern annual maximum daily precipitation totals, which have been recorded at the National Observatory of Athens (NOA), during the long term period 1891–2009. To evaluate the potential of daily extreme precipitation forecast by the applied ANNs, a different period for validation was considered than the one used for the ANNs training. Thus, the datasets of the period 1891–1980 were used as training datasets, while the datasets of the period 1981–2009 as validation datasets. Appropriate statistical indices, such as the coefficient of determination (R^2), the index of agreement (IA), the Root Mean Square Error (RMSE) and the Mean Bias Error (MBE), were applied to test the reliability of the models. The findings of the analysis showed that, a quite satisfactory relationship ($R^2 = 0.482$, IA = 0.817, RMSE = 16.4 mm and MBE = +5.2 mm) appears between the forecasted and the respective observed maximum daily precipitation totals one year ahead. The developed ANN seems to overestimate the maximum daily precipitation totals appeared in 1988 while underestimate the maximum in 1999, which could be attributed to the relatively low frequency of occurrence of these extreme events within GAA having impact on the optimum training of ANN.

1. Introduction

Extreme precipitation events, which are heavily affected by the local scale, have adverse impacts on ecosystems, agriculture, infrastructure and even loss of life, while these events are involved in land use changes. During the 20th century, floods caused more loss of life and property damage than any other natural disaster in the United States (Easterling et al., 2000). Barlow (2011) found important contributions of hurricane-related activity to extreme precipitation over North America. Min et al. (2011) showed that human-induced increases in greenhouse gases have contributed to the observed intensification of heavy precipitation events found over approximately two-thirds of data-covered parts of Northern Hemisphere land areas. These results are based on a comparison of observed and multi-model simulated changes in extreme precipitation over

* Corresponding author at: Laboratory of Climatology and Atmospheric Environment, Department of Geography and Climatology, Faculty of Geology and Geoenvironment, University of Athens, Panepistimiopolis GR 157 84 Athens, Greece. Tel./fax: +30 210 7274191.
E-mail address: nastos@geol.uoa.gr (P.T. Nastos).

0169-8095/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.atmosres.2013.11.013

the latter half of the twentieth century. Pall et al. (2011) presented a multi-step, physically based 'probabilistic event attribution' framework showing that it is very likely that global anthropogenic greenhouse gas emissions substantially increased the risk of flood occurrence in England and Wales in autumn 2000. The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapor (IPCC, 2007). More specifically, Groisman et al. (2005) found that changes in heavy precipitation frequencies are always higher than changes in precipitation totals and, in some regions, an increase in heavy and/or very heavy precipitation occurred while no change or even a decrease in precipitation totals was observed. Significant positive trend in the frequency of extreme rainfalls (greater than 50 mm per day) was revealed over the last few decades in the USA (Karl et al., 1995; Karl and Knight, 1998). In Australia, Suppiah and Hennessy (1998) found a significant increase in the 90th and 95th percentiles of rainfall, while in Japan, Iwashima and Yamamoto (1993) revealed that, the highest precipitation events were recorded in recent decades. Similar results were presented by Brunetti et al. (2001) and Alpert et al. (2002) for the central and western parts of the Mediterranean basin. Nastos and Zerefos (2008), analyzing the extreme daily precipitation totals in Greece, concluded that positive trends, not statistically significant (95% confidence level.), observed in daily precipitation totals exceeding 30 and 50 mm at the eastern and southeastern regions of the country. The extreme precipitation events appear during winter months in the western and eastern regions, and mainly during autumn in the rest of the country. Similar results have been reported by Kambezidis et al. (2010). Besides, recent studies have concluded that, heavy storms of convective nature in the developed mega-cities could be attributed to the urban heat island (UHI) (Bornstein and Lin, 2000; Cicek and Turkoglu, 2005; Paliatsos et al., 2005; Guo et al., 2006; Nastos and Zerefos, 2007; Philandras et al., 2010; Goswami et al., 2010), resulting in more rapid run off.

However, extreme precipitation events address not only increased precipitation totals but prolonged droughts over many regions (Kundzewicz et al., 2006; Lehner et al., 2006; Sheffield and Wood, 2007; Beniston et al., 2007; Diodato and Bellocchi, 2008; Kostopoulou and Jones, 2005; Nastos and Zerefos, 2009).

The simulation of extreme precipitation events was carried out by using either stochastic weather generators (i.e., a hybrid technique with a gamma distribution for low to moderate intensities and a generalized Pareto distribution for high intensities) (Furrer and Katz, 2008) or appropriate distributions such as the extreme value distribution of type II (EV2) for modeling annual maximum rainfall series (Koutsoyiannis, 2004).

During the last decade, Artificial Neuron Networks (ANNs) have been applied to rainfall forecasting (Bodri and Cermak, 2000; Luck et al., 2000; Silverman and Dracup, 2000; Sakellariou and Kambezidis, 2004; Cigizoglou and Alp, 2004; Moustris et al., 2011). Additionally, ANNs have been used in forecasting extreme precipitation events. Sahai et al. (2000) applied ANN models in order to forecast total precipitation during the summer monsoon period across India (Root Mean Square Error (RMSE) equals 54.2 mm), using as input data the rainfall during June–July–August and September months for the period 1871–1994. Freiwan and Cigizoglu (2005) developed a number of different multilayer perceptron ANN models in order to forecast precipitation for the next month resulting in RMSE between 25.8 and 33.6 mm, depending on the used ANN model type. Marzano et al. (2006) used neural-network approach in order to estimate precipitation intensity and extinction from ground. They found that the ANN retrieval algorithm tends to provide a better accuracy and a reduced error bias, especially for low-to-moderate rain rates. Manzato (2007) developed ANNs for the prediction of both the likelihood of occurrence, and intensity of storms over the region of Friuli Venezia Giulia in Italy, with satisfactory results. Wardah et al. (2008) used meteorological satellite data and developed back-propagation ANNs for the estimation of rainfalls caused massive damages and flooding in the Klang river basin in Malaysia. Mar and Naing (2008) used ANN models for the prediction of the monthly rainfall amount in Yangon (Myanmar–South East Asia). The major aim was to evaluate a suitable neural network model for monthly precipitation mapping of Myanmar. In measuring network performance using RMSE, experimental results significantly show that 3 inputs-10 hiddens-1 output architecture model gives the best prediction result for monthly precipitation in Myanmar.

Extreme precipitation is difficult to reproduce, especially for the intensities and patterns of extreme events, which are heavily affected by the local scale. For this reason, it is necessary to study these events by analyzing long time series of observations (IPCC, 2001). The goal of this study is to estimate the capacity of ANNs in forecasting the maximum daily precipitation for the next coming year, using historical daily precipitation totals, recorded at the National Observatory of Athens (NOA), during the period 1891–2009.

2. Data and methodology

The dataset used for ANN's training and evaluation concerns the observed annual daily maximum precipitation recorded at the National Observatory of Athens (NOA), during the time period 1891–2009, the longest reliable precipitation time series for Greece available, due to unchanged position of the meteorological station. NOA (longitude: 23° 43′E, latitude: 37° 58′N, h = 107 m above sea level) is located on the Hill of Nymphs near the center of Athens within the greater Athens area (GAA).

ANNs modeling is a branch of artificial intelligence developed in 1950s aiming at imitating the biological brain architecture. ANNs are parallel-distributed systems made of many interconnected nonlinear processing elements (PEs), called neurons (Hect-Nielsen, 1990). A renewal of interest has been grown exponentially in the last decade, mainly concerning the availability of suitable hardware that has made them convenient for fast data analysis and information processing. MultiLayer Perceptron model (MLP) is the most commonly used type of ANNs. Its structure consists of PEs and connections. The PEs called neurons are arranged in layers: the input layer, one or more hidden layers, and the output layer. An input layer serves a buffer that distributes input signals to the next layer, which is a hidden layer. Each unit in the hidden layer sums its input, processes it with a transfer function, and distributes the result to the output layer. Also, several hidden