ISSN: 0973-4929, Vol. 12, No. (3) 2017, Pg. 547-552

Current World Environment

Journal Website: www.cwejournal.org

Statistical Models in Estimating Air Temperature in a Mountainous Region of Greece

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Abstract

The current work focuses on the estimation of air temperature (T) conditions in two high altitude (alt) sites (1580 m), each one at different orientation (southeast and northwest) in the mountain (Mt) Aenos in the island of Cephalonia, Greece, by using two well-known statistical models, simple linear regression (SLR) and multi-layer perceptron (MLP), one of the most commonly used artificial neural networks. More specifically, the estimation of mean, maximum and minimum T in high alt sites was based on the respective T data of two lower alt sites (1100 m), the first at southeast and the second at northwest orientations, and was carried out separately for each orientation. The performance of both SLR and MLP models was evaluated by the coefficient of determination (R^2) and the Mean Absolute Error (MAE). Results showed that the examined models (SLR and MLP) provided very satisfactory results with regard to the estimation of mean, maximum and minimum T, regarding southeast orientation (R^2 ranging from 0.96 to 0.98), with mean T estimation being relatively better, as confirmed by the lowest MAE (0.83). Regarding northwest orientation, T estimation was less accurate (lower R^2 and higher MAE), compared to the respective estimation of southeast orientation, but, the results were considered adequate (R^2 and MAE ranging from 0.88 to 0.92 and 1.00 to 1.40, respectively). In general, the estimations of the mean T were better than those of the extreme ones (minimum and maximum T). In addition, better results (higher R^2 and lower, in general, MAE) were obtained when T estimations were based on T data derived from sites located at areas with similar surroundings, as in the case of dense and tall vegetation of the sites at southeast orientation, irrespective of applied method.

Article History

Received: 29 November 2017
Accepted: 23 December 17

Keywords

Aenos mountain, Air temperature, Artificial neural network models, Cephalonia island, Estimation, Greece, Linear regression.

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To link to this article:http://dx.doi.org/10.12944/CWE.12.3.07

Introduction

Mountainous areas (MAs) provide major gathering grounds of water supplies for human and animal consumption as well as for hydroelectric power production and may also contain valuable mineral resources[1]. These areas may be considered as optimum recreation ones, offering visitors a wide variety of activities and being a favorite tourist destination[2]. Despite MAs importance and the fact that they account for 20% of the Earth's land surface, their climatic and weather conditions haven't been adequately explored[1].

Air temperature (T) is the most important determinant of mountain climate[1, 3] but, unfortunately, mountain T data is usually very difficult or impossible to obtain directly because of the small number of the existing meteorological stations (MS) covering MAs and MS insufficient spatial distribution[4], especially in high altitudes (alts). Thus, many times, a necessity arises to estimate T data of high alts based on T data of lower alts.

In order to carry out the aforementioned estimation, a lot of researchers have developed a variety of techniques. Among them, the linear regression analysis has been used in a constructive way to extrapolate T in MAs[5]. Also, in recent years, artificial neural networks (ANNs), a new, relatively, computational method, have been applied to extrapolate T data in MA, contributing promising results[6,7].

Taking the aforementioned issues into account, the objective of our study is to estimate the T at high alt sites of mountain (Mt) Aenos in the island of Cephalonia, Greece based on T data of lower alt sites, by applying linear regression and ANNs models and investigating the hypothesis of their satisfactory performance. To our knowledge, this is

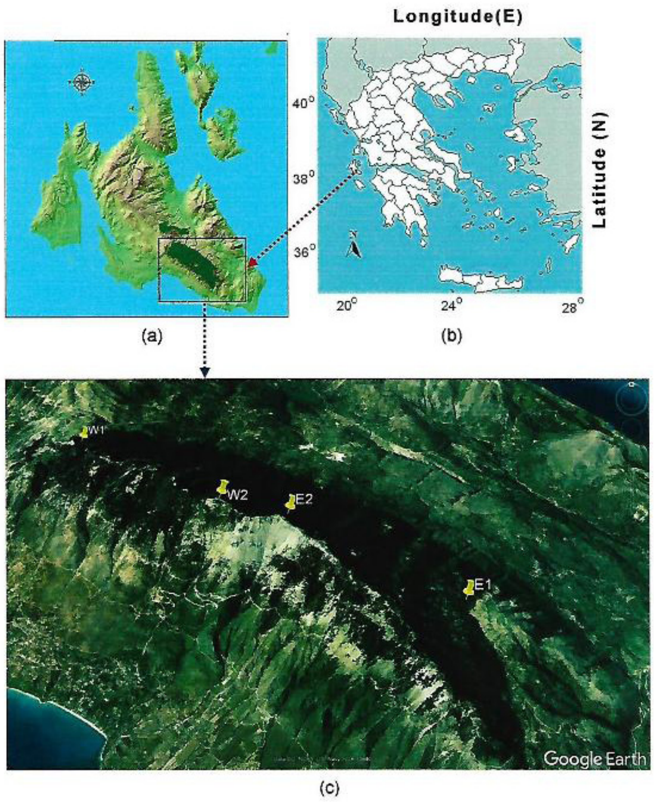

Fig. 1: Study region (inside the square) in Cephalonia island (a), Greece (b) and measurement sites (W1, W2, E1, E2) at mountain Aenos (c), modified from Google Earth[9].

the first time such a type of study takes place at this MA which is of utmost ecological importance.

Materials and Methods

The study was conducted in the National Park of Mt Aenos located in the southeastern part of the

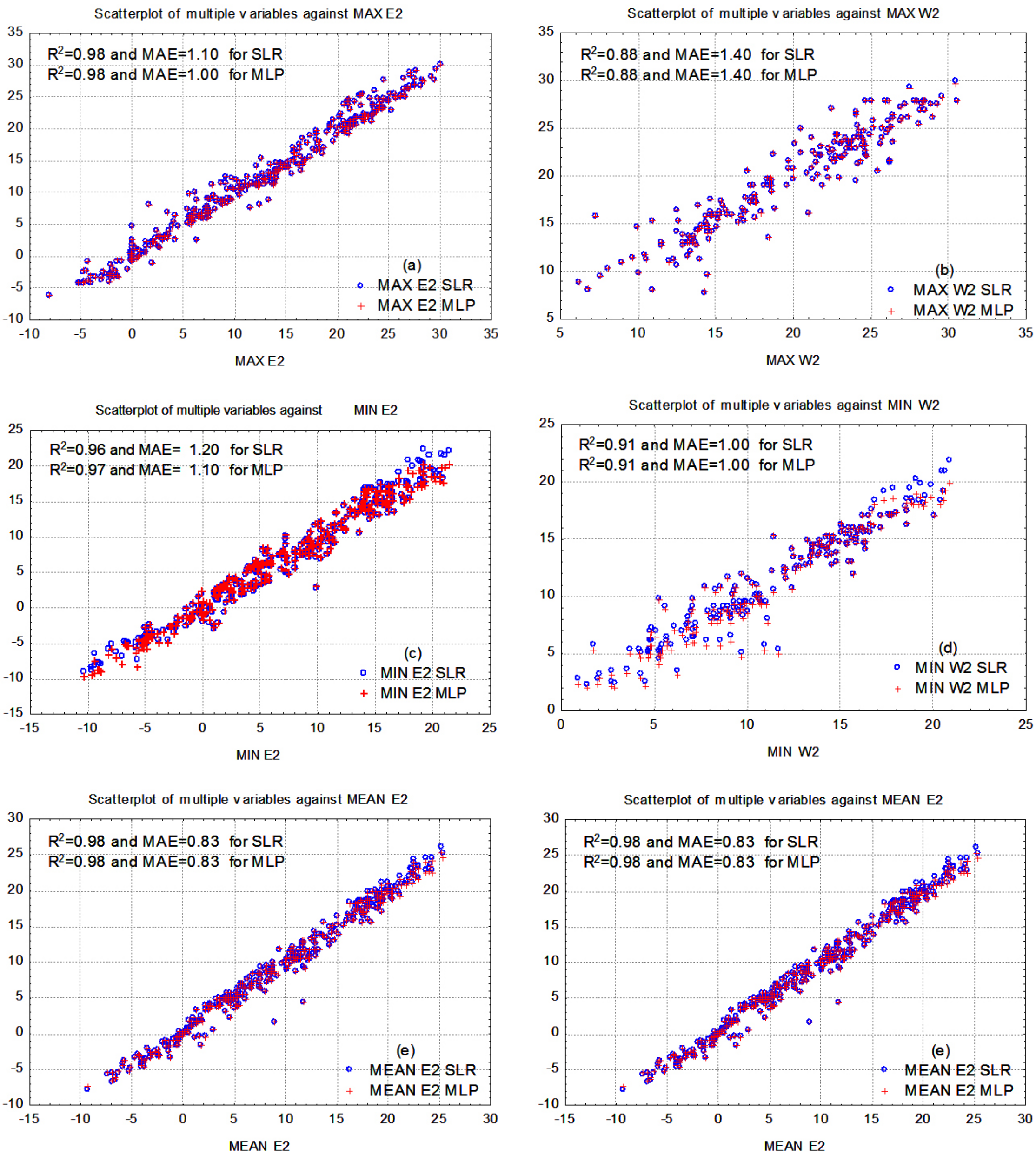

Fig. 2: Scatterplots of observed versus estimated air temperature (°) values for maximum (MAX) (a), minimum (MIN) (c) and mean (e) air temperatures of site E2 (reference site E1) and MAX (b),MIN (d) and mean (f) air temperatures of site W2 (reference site W1). R^2: determination coefficient, MAE: mean absolute error, SLR: simple linear regression, MLP: multi-layer perceptron

Cephalonia island (Figure 1a), Greece (Figure 1b). Aenos is one of the most important ecological locations of the Ionian Islands in Western Greece with a maximum alt of about 1620 m. It hosts a wealthy flora, e.g. the well-known endemic plant species cephalonian fir (Abies cephalonica L.)[8]. It is also an attractive tourist destination because of the great variety of activities that offers, such as mountaineering, trekking and bird watching.

Four sites were selected in the study region (Figure 1c). Their selection was based mainly on alt and orientation of the respective locations. Thus, there were two different orientations (northwest and southeast) with each of them to comprise two different alts (1100 and 1580 m). Specifically, the first site, W1 (38°09´38.3´´N, 020°37´25.0´´E, alt of 1100 m), was located in the northwestern side, characterized by dense and tall vegetation. The second site, E1 (38°07´30.3´´N, 020°42´14.6´´E, alt of 1100 m) was located in the southeastern side, characterized by the aforementioned vegetation. The third site, W2 (38°08´27.7´´N, 020°39´36.0´´E, alt of 1580 m) was located in the northwestern side, characterized by the existence of an open area which was much less forested. The fourth site, E2 (38°08´16.2´´N, 020°40´21.6´´E, alt of 1580 m), was located in the southeastern side, characterized by dense and tall vegetation. The orientation, alt., latitude and longitude of each site were evaluated using a mobile Global Positioning System (Garmin eTrex Vista) and cross-checked against 1:65000 topographic maps.

Air temperature was monitored simultaneously every 10 min by sensors with the help of data microloggers (Hobo Pro v2 U23-001, Onset Computer Corporation, USA, accuracy ±2.0° for T over 0° to 50°) for the time period of one year (2012). These instruments were enclosed in appropriate shelters to protect them from direct radiation and precipitation and mounted under trees 1.5 m above the ground surface. The shape of the shelters allowed acceptable air ventilation. The above instruments were tested in the laboratory and in situ without appearing any problem. Data were collected every 3 months and mean, maximum and minimum T were calculated for each site on hourly basis and then on daily basis[5].

In order to estimate the mean, maximum and minimum T of the high alt (1580 m) based on the respective T data of the lower alt (1100 m), for each orientation, the multi-layer perceptron (MLP) model[10], one of the most commonly used ANNs, with one hidden layer[6] as well as the simple linear regression (SLR) model were developed[11].

The performance of both models (SLR and MLP) was evaluated by two statistical parameters, the coefficient of determination (R^2) and the Mean Absolute Error (MAE). Moreover, the validation of the studied models was confirmed through the graphical analysis of the residuals by means of normal probability plots and scatterplots of residuals versus predictors. In the present study, it was assured that the results were significant at $P \leq 0.05$[11,12].

Results and Discussion

The estimation of T at the sites with the high alt (1580 m) based on T at the sites with the lower alt (1100 m) of Mt Aenos at both examined orientations (northwest and southeast), after the application of SLR and MLP models is shown in Figure 2. Based on the analysis of the scatter plots and the R^2 values regarding E1 and E2 sites which were located in the southeastern side, it was demonstrated that both methods of analysis, SLR and MLP, provided very satisfactory results with regard to the estimation of mean, maximum and minimum T (Figure 2a, c and e).

Comparing the afore mentioned graphs, it was clear that the mean T estimation was relatively better from the respective maximum and minimum T estimations. This finding was confirmed mainly by the appearance of the lowest MAE (0.83) in the case of the mean T estimation, in relation to the maximum and minimum T estimations. The satisfactory estimations which were achieved using the two aforementioned techniques (MLP and SLR) may be attributed to the fact that both E1 and E2 sites were characterized by similar surroundings. In other words, the domination of tall and dense vegetation in these sites impacted their T resulting in similar thermal differences, taking into account the effect of alt.

On the contrary, the sites W1 and W2 in the northwestern side of Mt Aenos were located in areas with different plant cover. The W1 site was located under tall and dense vegetation, while W2 was located in a scarcely plant covered location. This fact resulted in the alteration of T differences between these two sites, in agreement with Ferrez *et al*[13] and Maria Karlsson[14], and this alteration had a serious impact on the different image of the respective scatter plots (Figure 2b, d and f) compared to those of Figure 2a, c and e. Specifically, the coefficients of determination R^2 were lower and the MAE, in general, higher in northwest (Figure 2b, d and f) compared to southeast orientation (Figure 2a, c and e). Nevertheless, R^2 values regarding W1 and W2 sites may be considered satisfactory (0.88-0.92), and, this, in combination with the respected MAE values (1.0-1.4), indicates that both the estimation methods (SLR and MLP) provide adequate results. From an overall point of view, comparing scatter plots, R^2 and the respected MAE of sites E1, E2 and W1, W2 (Figure 2a, b, c, d, e and f), it was demonstrated, in general, that the estimations of the mean T were better than those of the extreme ones (minimum and maximum T). This fact could be attributed, in a high degree, to the fundamental characteristic of the mean T to express average and more normalized thermal conditions, instead of maximum and minimum T which expresses instant thermal conditions[15], leading thus to a more integrated view of the thermal environment.

In conclusion, it was confirmed that better results (higher R^2 and lower, in general, MAE) were obtained when T estimations were based on T data derived from sites located at areas with similar surroundings, as in the case of dense and tall vegetation of E1 and E2 sites, irrespective of applied method (SLR and MLP). On the contrary, when the surroundings of the studied sites were different, as in the case of W1 (dense and tall vegetation) and W2 (sparsely forest covered site), the respective estimations were less accurate.

Conflict of Interest

The authors declare that there is no conflict of interest.

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