
NOTA TÉCNICA:**SOFTWARE TO ESTIMATE AIR TEMPERATURE IN THE BRAZILIAN NORTHEASTERN REGION USING ARTIFICIAL NEURAL NETWORKS**Michel Castro Moreira¹, Roberto Avelino Cecílio²**ABSTRACT**

Air temperature is one of the most important factors affecting vegetation and controlling key ecological processes. The objective of this study was to develop software using artificial neural networks (ANNs) for the estimation of air temperature in the Northeastern region in Brazil. The architectures, the activation functions of the artificial neurons and the free parameters of the ANNs were defined to build a mathematical function to represent the ANN. The mathematical function was implemented by using Borland Delphi[®] 7 with a graphic interface to facilitate the use of the software. The software developed was denominated *netTemperatura NE*. It allows making a quick and easy estimation of the minimum, mean and maximum air temperatures (monthly or annual) in the Northeastern region of Brazil as a function of geographical coordinates and surface elevation. It is also available for free downloading at <http://nedtec-softwares.webnode.com.br>.

Keywords: artificial intelligence, interpolation, GIS, GTOPO30, climate modeling.

RESUMO**PROGRAMA COMPUTACIONAL PARA ESTIMATIVA DAS TEMPERATURAS DO AR NO NORDESTE BRASILEIRO UTILIZANDO REDES NEURAS ARTIFICIAIS**

A temperatura do ar é um dos fatores mais importantes que afetam a vegetação e controla os processos ecológicos. O objetivo deste trabalho foi desenvolver um programa computacional utilizando redes neurais artificiais para a estimativa da temperatura do ar no Nordeste do Brasil. As arquiteturas, funções de ativação das redes neurais e os parâmetros livres das redes foram definidos para a construção das funções matemáticas que representassem as redes neurais. As funções matemáticas foram implementadas no programa computacional Borland Delphi[®] 7 com uma interface gráfica para facilitar o uso das redes. O programa computacional desenvolvido foi intitulado *netTemperatura NE* e permite de forma fácil e rápida estimar as temperaturas mínima, média e máxima do ar (mensal ou anual) para qualquer localidade do Nordeste do Brasil a partir das coordenadas geográficas e altitude do local de interesse. O *netTemperatura NE* pode ser copiado, gratuitamente, a partir do endereço eletrônico <http://nedtec-softwares.webnode.com.br>.

Palavras-chave: inteligência artificial, interpolação, SIG, GTOPO30, modelagem climática.

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INTRODUCTION

Air temperature is an important characteristic used to determine site suitability for agricultural and forest crops, providing parameters for the habitat of plant, insect, and pathogen species as well as for vegetation zoning patterns. Air temperature is also related with plant productivity, as it is connected with the length of the vegetative period and evapotranspiration (BENAVIDES *et al.*, 2007; CARDOSO *et al.*, 2012).

Spatial modeling of climate variables, such as minimum, medium and maximum air temperature, is of interest for agricultural science. However, such variables are not easy to obtain because they appear as measurements at discrete points (meteorological stations) that are often few and sparsely spread (ROLLAND, 2002), as observed in the Northeastern region in Brazil.

Many different methods have been developed to generate regional maps from point data, based on the continuity of temperature and its strong dependence on elevation. These methods are based on the adjustment of regression equations where the independent variables are latitude, longitude and surface elevation and the dependent variables are the temperature values (ASHCROFT, 2006; BJORNSSON *et al.*, 2007; CHUANYAN *et al.*, 2005; WANG and HOU, 2009). However, many times these equations do not represent air temperature values correctly, mainly mountainous regions (LI *et al.*, 2005), places with complex topography or where geographical coordinates are near extreme values (MEDEIROS *et al.*, 2005).

Different interpolation methods have been used by researchers to model the spatial distribution of air temperature, such as inverse distance weighting interpolation and geo-statistical methods. Thus, there is little evidence that any one method would be optimum across a range of climatic conditions (LI *et al.*, 2000). Attempts to compare interpolation methods to predict air temperatures have only been made in the last years (BENAVIDES *et al.*, 2007; DEGAETANO and BELCHER, 2007; HANCOCK and HUTCHINSON, 2006; MAHDIAN *et al.*, 2009).

Artificial neural networks (ANNs) have been conceived to mimic the functioning of the human

brain by acquiring knowledge through a learning process and finding optimum weights for the different connections between the individual neurons (PERSSON *et al.*, 2002). The ability to 'train' and 'learn' the output from a given input makes ANNs capable of describing complex large-scale agricultural science issues, such as modeling climate variables. Sárközy (1999) and Biaobrzewski (2008) consider ANNs as an alternative approach to estimate climatic variables, such as predicting air temperature over large surface areas, as applied by Atorre *et al.* (2007); Bryan and Adams (2002); Dahamsheh and Aksoy (2009); Rigol *et al.* (2001); Smith *et al.* (2009) and Wanderley *et al.* (2014).

Moreira and Cecílio (2008) developed ANNs and verified their performance in estimating minimum, medium, and maximum air temperatures, monthly and annually, in the northeastern region in Brazil. In order to apply the ANNs developed, a high cost proprietary computer program is necessary, as well as adequate training. Technicians and extension workers need to master the study tools and to adopt water and soil conservation and improved agricultural productivity practices.

Thus, this paper aimed to develop a computational program that allows the use of the ANNs developed by Moreira and Cecílio (2008) for monthly and annual estimate of the minimum, medium, and maximum air temperatures in the Brazilian Northeastern region.

MATERIAL AND METHODS

The monthly and annual data on the normals of minimum, medium, and maximum air temperatures used in the ANNs developed by Moreira and Cecílio (2008) were collected at thermometric shelters obtained from 74 meteorological stations listed in the climatological normals collected from the northeastern states (Figure 1), and provided by the National Institute of Meteorology (BRASIL, 1992).

The authors developed 13 ANNs to estimate the minimum air temperature, with one referring to each month and one referring to the annual mean. The same procedure was carried out to estimate the medium and maximum air temperatures, totaling 39 ANNs.

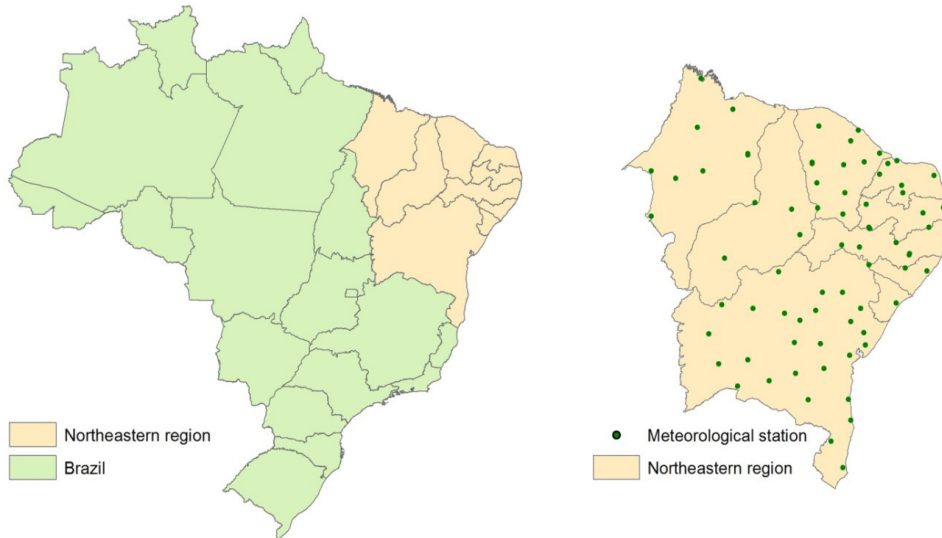


Figure 1. Northeastern region in Brazil and the meteorological stations of the National Institute of Meteorology used to develop the ANNs.

Following the development of the ANNs, it was necessary to know the respective architectures, neuron activation functions and free parameters w 's and b 's to generate the mathematical functions to represent them, according to the model presented in the equation

$$y^{ij} = f\left(\sum_{i=1}^n y^{i(j-1)}w_i^{ij} + b^{ij}\right) \quad (1)$$

where,

y^{ij} = output value of neuron i of layer j ;
 n = number of neurons of the previous layer;

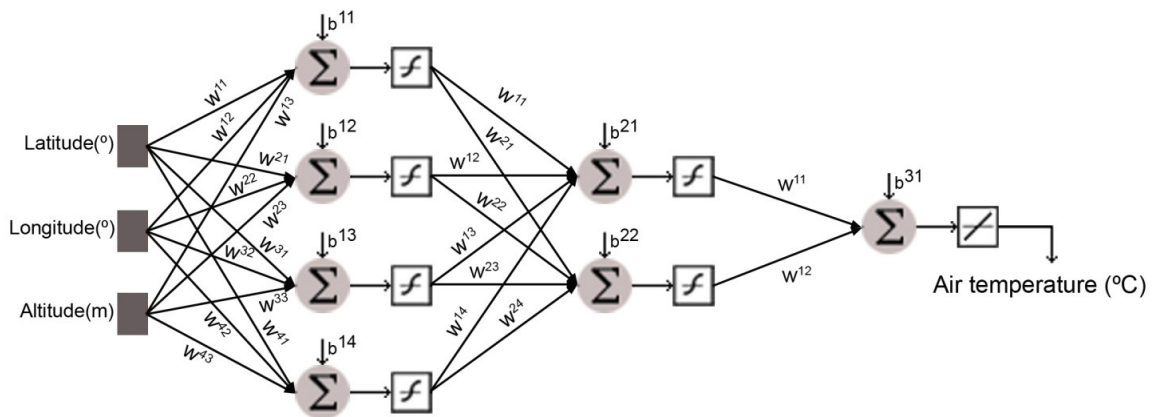
$y^{i(j-1)}$ = output of neuron i ' value from the previous layer;

w_i^{ij} = synaptic weight value of neuron i of layer j , activated by neuron i ' from the previous layer ;

b^{ij} = offset value of neuron i of layer j ; and

f = activation function of neuron i .

The ANNs developed are of the autosynaptic type, displaying a 3- n_1 - n_2 -1 architecture, with these values corresponding to an input vector with three variables, two intermediary layers with n_1 and n_2 artificial neurons and one neuron in the output layer (Figure 2).



Source: Moreira et al. (2008).

Figure 2. Illustration of architecture 3-4-2-1 of an artificial neural net to estimate air temperature.

The input vector of the ANNs developed is composed by the latitude and longitude values, in decimal degrees; as well as by the altitude value, in meters. A linear activation function is found in the output layer neuron that supplies the air temperature value to the place represented by the input vector in °C. The activation functions of the intermediary layer neurons are of the sigmoid hyperbolic tangent type. Equations 2 and 3 illustrate the activation functions of the linear and sigmoid hyperbolic tangent (MATLAB, 2000).

$$\text{lin}(x) = x \quad (2)$$

where,

x = normalized, adimensional value.

$$\text{tanh sig}(x) = \frac{2}{(1 + e^{-2x}) - 1} \quad (3)$$

The free parameters w 's and b 's of the ANNs were exported in text files where data on all the ANNs developed were stored. Thus, based on the architectures, neuron activation functions and the free parameters w 's and b 's, the 39 mathematical equations representative of the ANNs could be structured and be computationally implemented, using the Borland Delphi 7.0 programming environment.

A graphic interface was developed so as to allow the user to visualize the Brazilian northeastern region map to obtain the monthly and annual values of minimum, medium, and maximum air temperatures, by simply clicking the mouse button on the map. The map was geo-referenced so that when clicking on it, latitude, longitude and altitude values of the locality of interest and the air temperature values estimated would be provided by the program.

To obtain information on the geographic coordinates and altitude of the locality of interest, a group box was supplied to manually enter these data and later click the "Calculate button".

A list of the Northeastern region municipalities in Brazil and a map were made available to the users to allow them to obtain the air temperature values by the name of the locality of interest. The names of the municipalities and their respective locations, in geographic coordinates were obtained from the Brazilian Institute of Geography and Statistics (IBGE).

Because the altitude value is needed by the ANNs in order to calculate the air temperature of a particular locality, an elevation data base was incorporated to the computational program, with its access being automatically made based on the identification of that particular locality. Altitude data were obtained from the GTOPO30 Project, which consists of a source of altimetry data with a horizontal resolution of approximately 1 km, developed at a global scale by the United States Geological Survey's Center for Earth Resources Observation and Science (EROS).

RESULTS AND DISCUSSION

The computer program developed to estimate the monthly and annual values of the minimum, medium, and maximum air temperature values for the Northeastern region in Brazil was denominated *netTemperatura NE* and can be obtained free of charge at the electronic address <http://nedtec-sofwares.webnode.com.br>. Figure 3 illustrates its presentation screen, listing names, purpose, and the institutions responsible for its development.

Figure 4 presents the main screen of *netTemperatura NE*, in which the user can identify the place of interest in three different ways: 1-by clicking the mouse on the Northeastern region map (field 1); 2- by selecting the name of the place (field 2); or 3-by supplying the latitude, longitude and altitude values of the place of interest (field 3).

When selecting a particular place, two lines (horizontal and vertical) are displayed on the map, indicating the place selected in their intersection. The air temperature values estimated

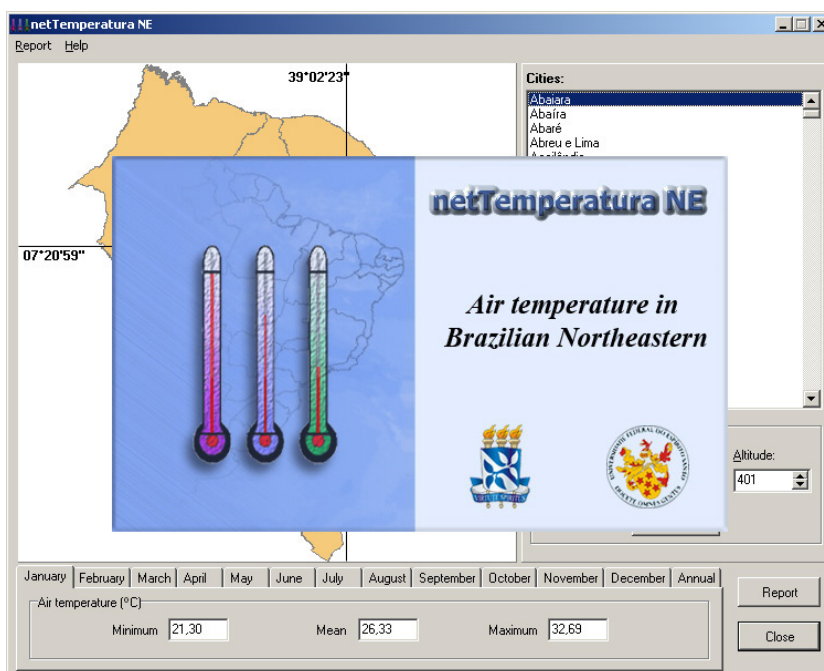


Figure 3. Presentation screen of *netTemperatura NE*.

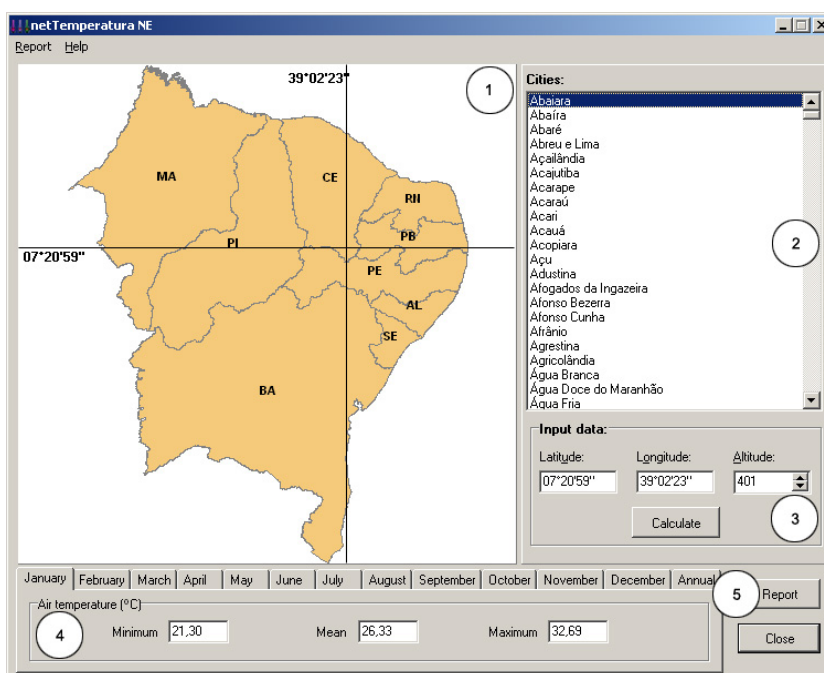


Figure 4. Main screen of *netTemperatura NE*.

are displayed in field 4 of Figure 4, where the options for month visualization are shown, and the last one (annual), representing the annual mean temperature.

The *netTemperatura NE* software allows printing reports containing information on location (name, latitude, longitude and altitude) of the

Northeastern region map illustrating the place of interest and the monthly and annual values of the minimum, medium, and maximum temperatures. The user must only press the button “Report” (field 5), or select the option “Report” in the main menu of the program. Figure 5 shows a report provided by *netTemperatura NE* for Abaiara, Ceará (CE).

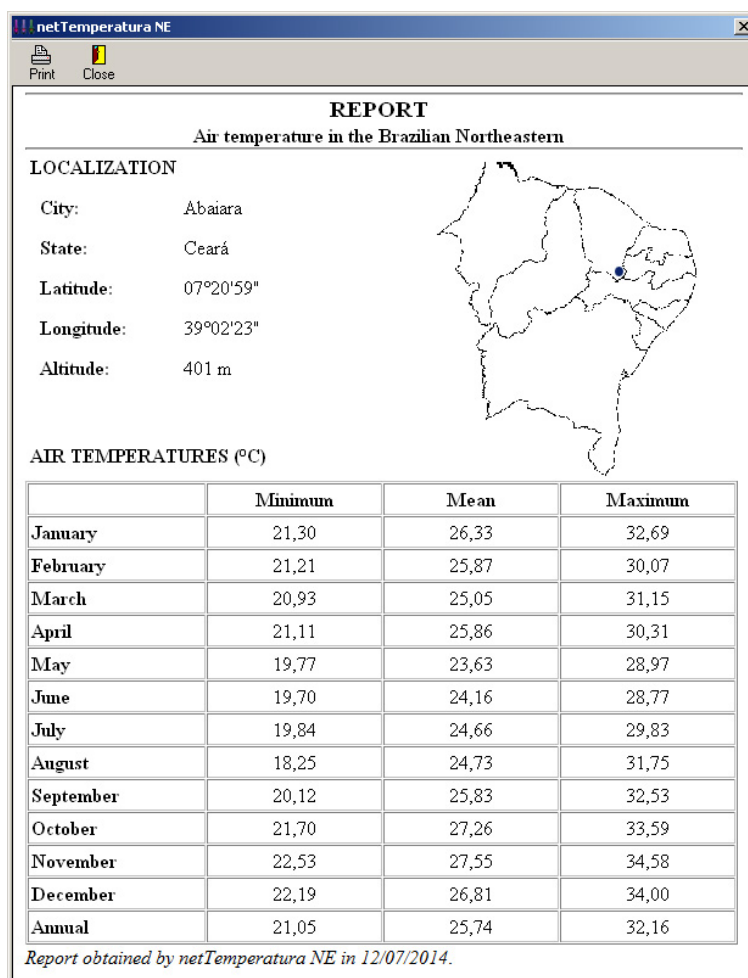


Figure 5. Report generated by the *netTemperatura NE* for the locality of Abaiara (CE).

CONCLUSION

- *NetTemperatura NE* software allows quick and easy monthly and annual estimation of the minimum, medium, and maximum values of air temperature for any place in the Northeastern region in Brazil.

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