INCREASING RESOLUTION OF TEMPERATURE MAPS BY USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND TOPOGRAPHY INFORMATION

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ABSTRACT: A GIS-based method for deriving high-resolution (in space) maps of mean temperature (Base Period; 1971-2000) is developed for Turkey. Heights (one of terrain variables) and lapse rate value (changing rate of temperature with height) are used as predictors of temperatures on 1km resolution of grid points, using a lapse rate-based approach. In this study**,** mean annual temperature values measured at 228 meteorological stations of Turkish State Meteorological Service over Turkey are used for visualization and interpolation to reveal spatial distribution of mean annual temperature values. Mean annual temperatures have been obtained from period of 1971-2000 long term temperature data sets. Elevation data have been obtained from digital elevation models (DEM) with the help of GIS. There have been studied with temperature data of in and around Uludağ stations to determine value of lapse rate. Lapse rate have been found average 5°CKm^{-1} with regression coefficient (R^2) 0.97. Temperature data from 78 stations for first group and 103 stations for second group have been selected from 228 meteorological stations and used during the study. 150 stations for first group and 125 stations for second group were retained for validation. For observations and predicted temperature values of first group (150 stations); maximum, minimum and mean errors are respectively, 2.89, -3.20 and -0.14°C and root-mean-square-error (RMSE) is 1,025 and regression coefficient (R^2) is 0.93. For observations and predicted temperature values of second group (125 stations); maximum, minimum and mean errors are respectively, 2.64, -3.17 and -0.18°C and root-mean-square-error (RMSE) is 0,868 and regression coefficient (R^2) is 0.94. In addition, the method was applied to ERA40 re-analysis data set of the European Center for Medium-Term Weather Forecasts (ECMWF) for method validation. For observations and extracted temperature values of stations; maximum, minimum and mean errors are respectively, 3.1, -3.8 and -0.3°C and root-mean-square-error (RMSE) is 1.114 and regression coefficient (R^2) is 0.94. Predicted temperature values in study, were compared with mean temperature data from the World Climate Data (WorldClim) which were produced by ANUSPLIN model for data verification. For predicted and WorldClim temperature values; maximum, minimum and mean errors are respectively, 2.5, -1.9 and 0.5°C and root-mean-square-error (RMSE) is 0.793 and regression coefficient (R^2) is 0.97.

KEY WORDS: Temperature, Climate, Lapse Rate, Height, Geographical Information Systems (GIS)

1. INTRODUCTION

Meteorological measurements cannot be done in every part of country both due to lack of appropriate topographical condition and high costs of measurement. In countries, with a large and mountainous geography, observation stations often cannot be covered all country. For this reason, different models can be used to detection of changes in temperatures depending on the topography and to derive temperature data. Geographical Information Systems (GIS) used to increase the resolution of the climate model output and meteorological measurements maps, particularly has been a tool since the 2000's. There are some model studies which are made by Geo-statistical and Geographical Weighted Regression (GWR) tools of GIS programs, and using temperature, height, slope and aspect data and the maps were produced. However, these models, although statistically correct, does not reflect the distribution of the temperature depending on topography as climatological perspective.

In this study, it is intended to predict temperature data for the areas which has not got temperature measurement and for this purpose relationship between temperature and elevation data are used. Lapse Rate is defined as the change of temperature with height. Lapse Rate has been changed according to the amount of moisture in air with a rate between 0.5°C to 1.0°C. It is expected to this predicted data can be meet demands of sectors for their analysis and planning.

Temperature changes depending on some factors such as latitude, altitude, sunshine, distance to water sources, vegetation, aspect and so on however, it is a climate parameter which has continuity over topography. Temperature variation shows slowly changing depending on latitude and geographical factors, and does not make sudden jumps or interruptions. In particularly, mean temperatures carry effect of place properties which they occurs in, within their values. It appears that the most important factors in mean temperature variation are altitude and latitude.

Mean annual temperature values measured at 228 meteorological stations of Turkish State Meteorological Service over Turkey are used for visualization and interpolation to reveal spatial distribution of mean annual temperature values. Mean annual temperatures have been obtained from period of 1971-2000 long term temperature data sets. Elevation data have been obtained from digital elevation models (DEM) with the help of GIS (Figure 1).

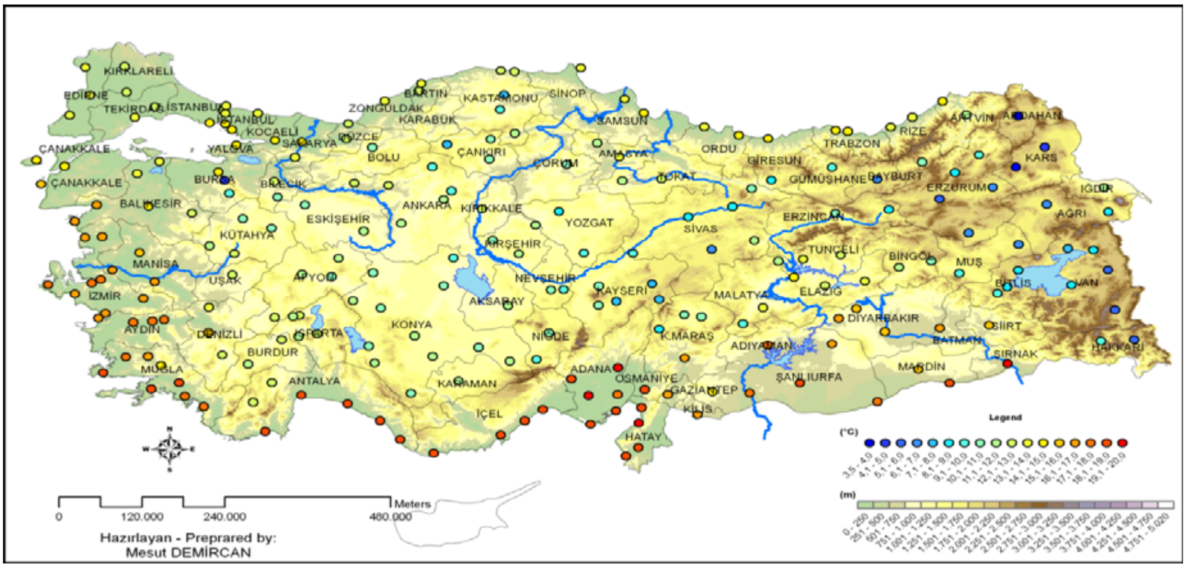

Figure 1 Observed mean temperature values (1971-2000, 228 stations) and Turkey's Digital Elevation Map (DEM)

2. METHOD

Lapse Rate : The rates of adiabatic heating and cooling in the atmosphere are described as lapse rates and are expressed as the change of temperature with height. The adiabatic lapse rate for dry air is very nearly 1°C per 100 m. If condensation occurs in the air parcel, latent heat is released, thereby modifying the rate of temperature change. This retarded rate is called the pseudo-adiabatic lapse rate; it is not a constant for its value depends on the temperature at which the process takes place and the amount of water vapor in the air mass. However, for general descriptive purposes it is assumed as 0.5°C per 100 m (Oliver and Fairbridge, Encyclopedia of World Climatology, 2005).

The following formula used for calculating temperature;

$$T_r = T_i \pm (h_i * 0.005) \qquad (1)$$

T_r= Reduced temperature with height;

T_i= Station mean temperature;

h_i= Station height

Inverse distance weighting (IDW) : Weighted moving averaging is a widely used approach to interpolation. A variety of different weighting functions have been used, but inverse distance weighting (IDW) is the most common form in GIS systems. IDW is an exact interpolator, so the data values are honored. The IDW predictor can be given as;

$$\hat{z}(\chi_o) = \frac{\sum_{i=1}^{n} z(\chi_i).d_{i0}^{-r}}{\sum_{i=1}^{n} d_{i0}^{-r}} \tag{2}$$

where the prediction made at the location x_0 is a function of the '***n***' neighboring observations, '***z(x$_i$), i = 1; 2; :::; n, r***' is an exponent which determines the weight assigned to each of the observations, and '***d***' is the distance by which the prediction location **'x$_0$ '** and the observation location **'*x$_i$* '** are separated. As the exponent becomes larger the weight assigned to observations at large distance from the prediction location becomes smaller. That is, as the exponent is increased, the predictions become more similar to the closest observations (Lloyd, Local Models for Spatial Analysis).

3. ANALYSES

There have been studied with different monthly and yearly time period of temperature data of stations which are in and around of Uludag mountain to determine value of lapse rate. Lapse rate have been found average 5°CKm^{-1} with regression coefficient (R^2) 0.97.

It is shown; station names, mean temperatures (°C) (1971-2000) and heights (m) in Table 1, Monthly results of Lapse rate (°CKm^{-1}) and R^2 in Table 2, Lapse rate (°CKm^{-1}) and R^2 results according to station's number and data periods in Table 3, station places in and around of Uludag mountain in Figure 2 and temperature variation with height of stations in and around of Uludag mountain in Figure 3.

Figure 2 Station places in and around of Uludag mountain

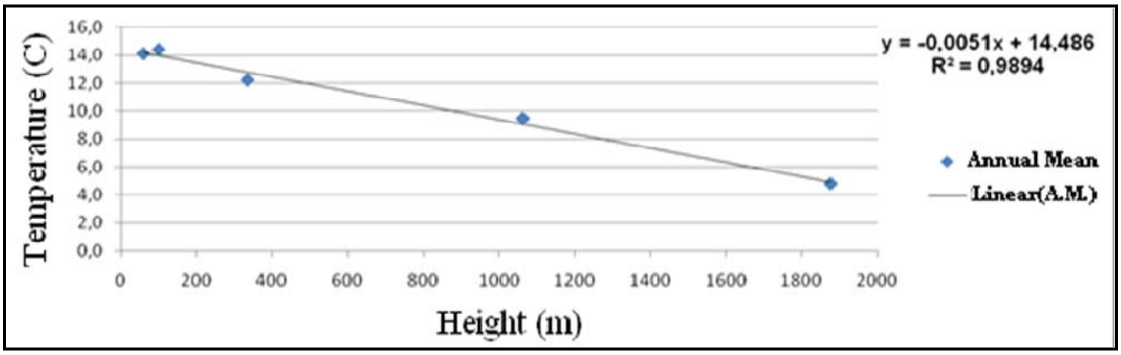

Figure 3 Temperature variation with height of stations in and around of Uludag mountain

Station Name	H(m)	1	2	3	4	5	6	7	8	9	10	11	12	ORT
M.Kemalpaşa	60	5,0	5,8	8,1	13,0	17,3	21,6	23,3	22,9	19,5	15,2	10,3	7,0	14,1
İnegöl	335	2,6	4,0	7,0	11,9	15,8	19,8	21,6	21,1	17,4	13,0	7,9	4,4	12,2
Bursa	100,3	5,2	6,0	8,1	13,0	17,5	22,1	24,3	23,8	20,0	15,3	10,3	7,2	14,4
Uludag Zirve	1877	-3,5	-3,8	-1,2	2,9	7,7	11,4	13,8	13,6	10,5	6,6	1,4	-2,0	4,8
Keleş	1063	0,3	0,7	3,4	8,2	12,8	16,6	18,9	18,6	15,2	10,9	5,8	2,1	9,5
Uludağ Y.konak	1025													
Mudanya	10													
Gemlik	10													

Table 1 Station names, mean temperatures (°C) (1971-2000) and heights (m).

	1	2	3	4	5	6	7	8	9	10	11	12
Lapse Rate	5	5	5	6	5	6	5	5	5	5	5	5
R^2	0.977	0.996	0.998	0.994	0.991	0.990	0.979	0.976	0.977	0.980	0.978	0.973

Table 2 Monthly results of Lapse rate (°CKm^{-1}) and R^2.

Station Number	Period	Lapse Rate	R^2
7	1966-1967	5	0.9714
8	1972-1975	5	0,9695
5	1971-2000	5	0,9894
8	1982-1985	5	0,9693
7	1985-1991	5	0,9615

Table 3 Lapse rate (°CKm^{-1}) and R^2 results according to station's number and data periods

Three groups were formed from data. In first group 78 stations, in second group 103 stations and in third group 228 stations have been used during the study. In first group 150 stations and in second group 125 stations were retained for validation. Annual mean temperatures have been obtained from period of 1971-2000 long term temperature data sets in Figure 4 and reduced to sea level by using height of station and formula 1 in Figure 5. This values mapped by using IDW method of ArcGIS. Grid points with dimension of 1x1Km, have been formed by HAWHTS TOOL in GIS which are covered Turkey. Elevation data have been obtained from digital elevation models (DEM) with the help of ArcGIS. Reduced temperature have been extracted to grid point and calculated for their height by using formula 1 and mapped with IDW method of ArcGIS in Figure 6. Root-mean-square-error (RMSE) and regression coefficient (R^2) have been calculated from differences between observations and predicted temperature values of 150 stations in first group and 125 stations in second group in Table 4, Figure 7 and 8.

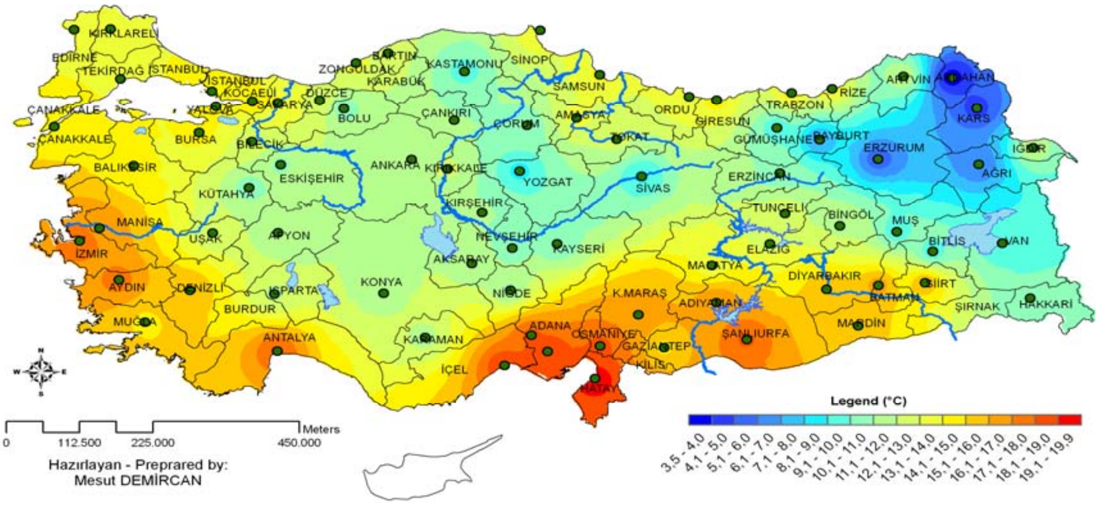

Figure 4 Annual mean temperatures of 78 stations (1971-2000**).**

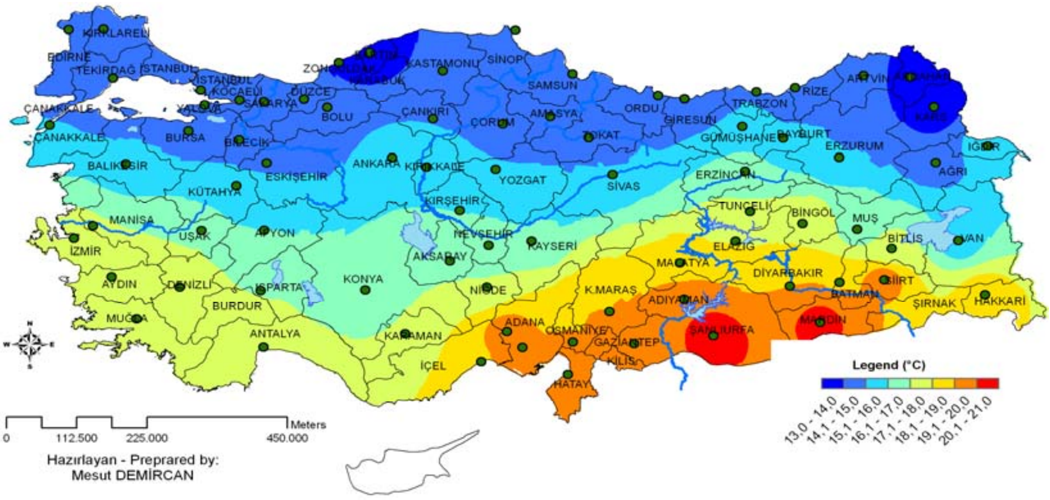

Figure 5 Temperature, reduced to sea level.

Figure 6 Gridded baseline predicted temperature surfaces, resolution 1X1 km (from 78 Stations, 1971-2000).

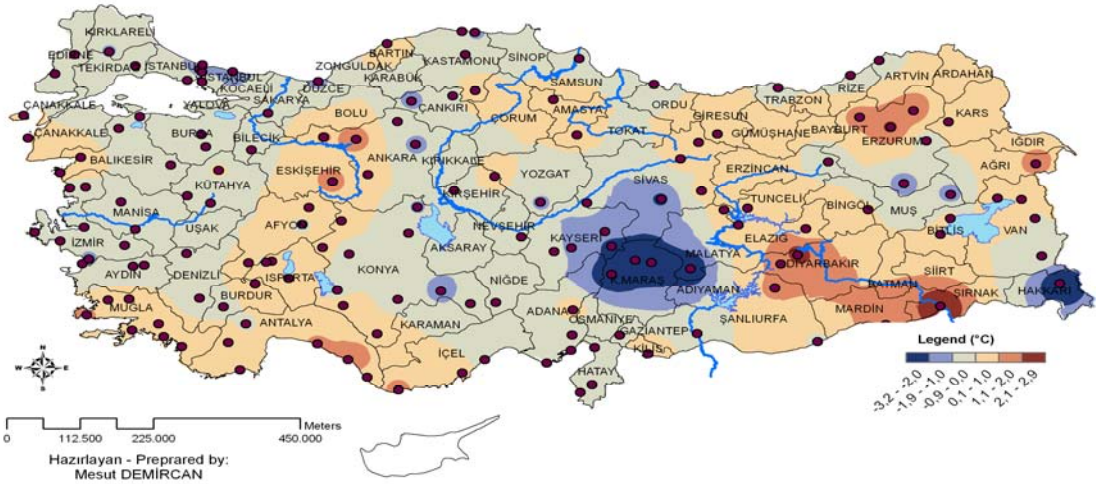

Figure 7 Differences between observed and predicted temperature (for 150 stations).

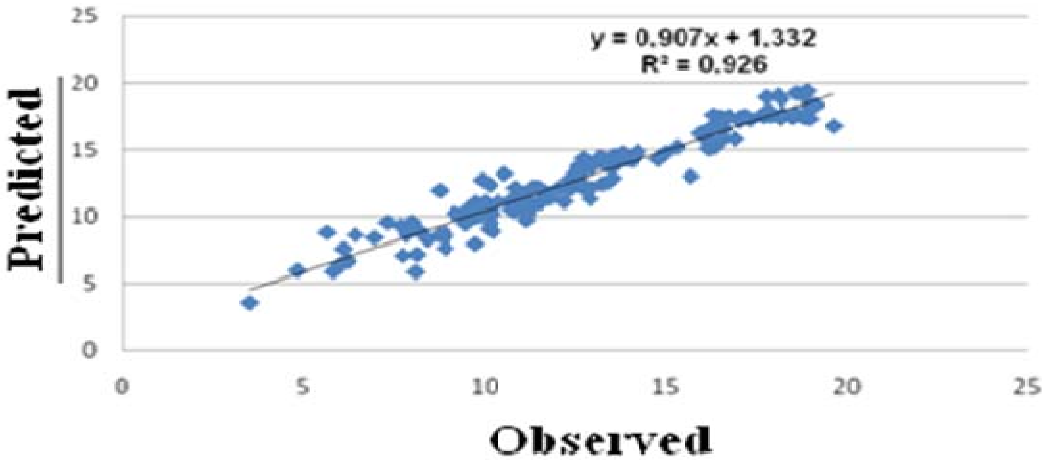

Figure 8 Relation between observed and predicted.

St. Number for modelling St. number for verification	78 150	108 125	228 0
RMSE	1,025	0,868	0,380
R^2	0,926	0,944	0,989
Mean Error	-0,14	-0,18	0,04
Maximum Error	2,89	2,64	2,48
Minimum Error	-3,20	-3,17	-0,99

Table 4. RMSE, R^2 and error values.

4. VERIFICATION OF METHOD AND RESULTS

A. Verification of Method

For verification of Method, temperature values of ERA40 re-analysis data set (which have 1,125° (~125km) resolution and height between about 50m and 2500m) have been downloaded from The European Centre for Medium-Range Weather Forecasts (ECMWF) and downscaled with mentioned method. Mean, maximum and minimum errors between mean temperature of stations and mean temperature of ERA40 are, respectively, -0.3, 3.1 and -3.8°C and it is calculated for RMSE 1.114 °C and for R^2 0.9239°C in Figure 9,10,11.

Figure 9 ERA40's temperature distribution (1971-2000).

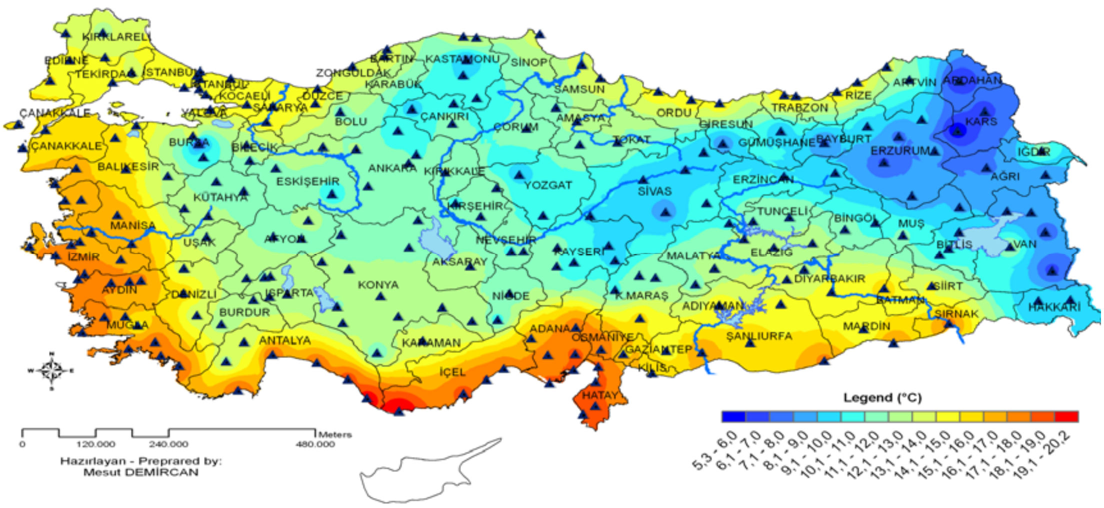

Figure 10 Distribution of extracted ERA40's values to Stations.

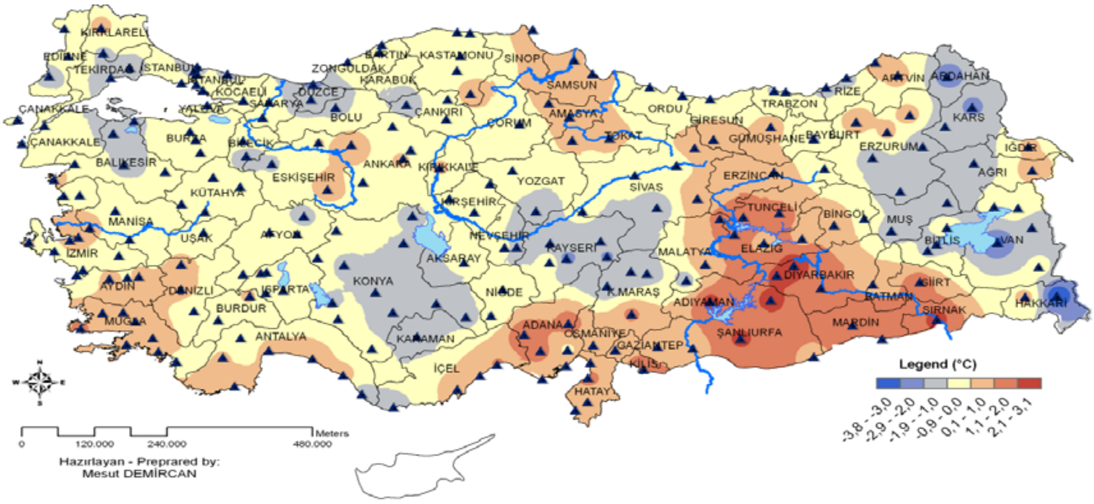

Figure 11 Distribution of errors between mean temperature of stations and mean temperature of ERA40.

B. Verification of Data

Predicted temperature values have been compared with mean temperature map from Global Climate Data (WorldClim) for verification (period 1971-2000). Mean, maximum and minimum errors between mean temperature of stations and mean temperature of WorldClim are, respectively, -0.5, 2.5 and -1.9°C and it is calculated for RMSE 0.793°C and for R^2 0.972°C in Figure 12,13, 14.

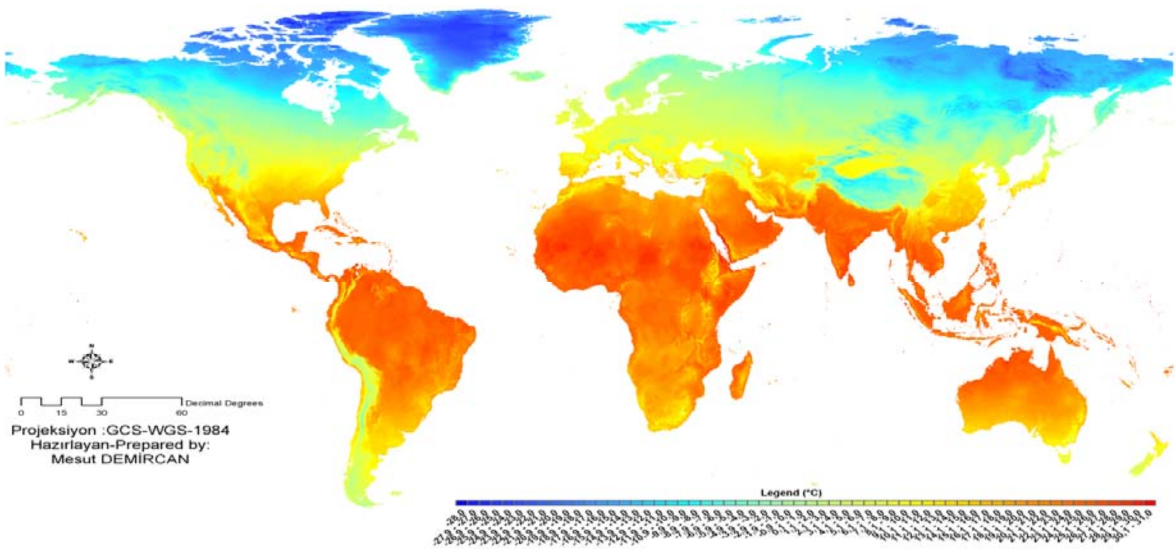

Figure 12 WORLDCLIM's temperature distribution (1971-2000).

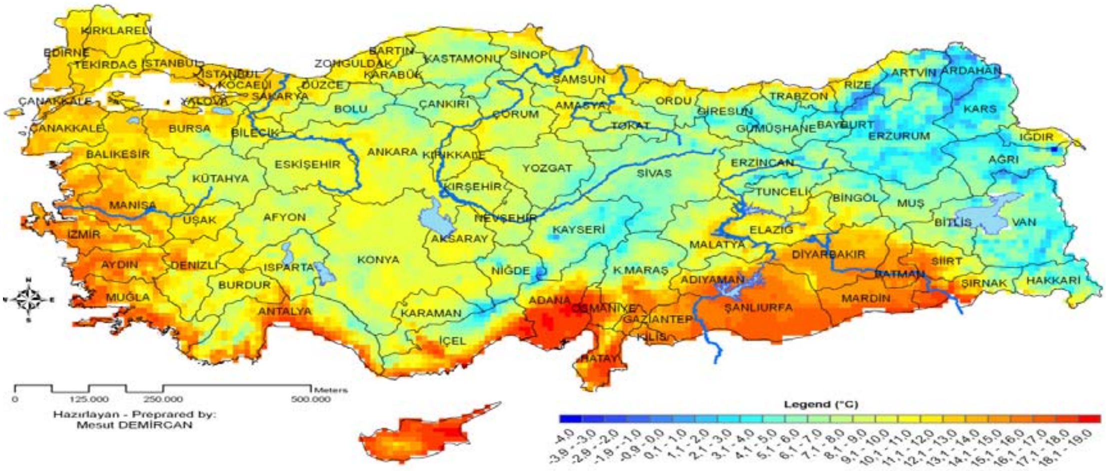

Figure 13 Extracted temperature value to grid point (resolution 1x1Km) from WORLDCLIM

Figure 14 Differences with predicted temperature and WORLDCLIM temperature.

5. CONCLUSION AND REMARKS

1. To determine Lapse rate a pre-study has been made in and around of Uludag. Lapse rate have been found average 5°CKm^{-1} with regression coefficient (R^2) 0.97.
2. Results from First Group; Predicted temperatures are lower than observed values between -2.2 and -3.2°C in Göksun, Yüksekova, Elbistan, Sarız, Afşin and Kangal; and higher than observed values between 2.2 and 2.9°C in Cizre, Ergani and Tortum.
3. Results from Second Group; Predicted temperatures are lower than observed values between -2.2 and -3.2°C in Doğansehir, Göksun and Yüksekova, Elbistan, Sarız, Afşin, Kangal; and higher than observed values between 2.4 and 2.6°C in Cizre, Ergani and Tortum.
4. Digital elevation data is one of the most important components, so the differences of height between station's height and DEM's height and grid structure may be source of errors and increase amount of error value.
5. This model is very easy and practical way to distribute and interpolate data over topography.

6. SOURCE

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