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Predicted Subsurface Temperature Distribution Maps for Turkey

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ABSTRACT

Istanbul Technical University is conducting a study on assessment of the moderate and high temperature geothermal resources of Turkey. One of the phases in this study is to construct subsurface temperature distribution maps at various depths. The constructed maps will be a guide to show the favorable promising hot regions.

Computed temperature distributions based on gradient values are used to obtain the subsurface temperature maps for 500 m and 1000 m depths. The maps are built using Arc GIS software and geostatistical methods.

Two data sets were used to obtain the maps. Data Set 1: 420 data points obtained from the wells with at least a depth of 1 km and Data Set 2: 555 data points obtained from 100/150 m relatively shallow wells.

Variogram models by using computed subsurface temperature values are established, and then predictions are made using some geostatistical (IDW, kriging) methods.

Finally, the maps were illustrated both for regional base and whole country, and the maps were compared with each other by using different geostatistical techniques. All maps were made by using the Geostatistical Analyst extension to ESRI ArcGIS software.

1. INTRODUCTION

One of the most important parameters in assessment of geothermal systems is temperature. There are possibilities to make use of data gained by the investigations on heat flow, geothermal gradient and temperature distribution at certain depths. The true (appropriate) prediction of subsurface temperature and gradient distributions plays an important role in the country's both geothermal energy and future energy politics. Determining temperature distribution along a region gives important hints about geological aspect. These kinds of maps for Turkey may provide important information for the subsurface feedstock, energy resource evaluation studies and studies in geology and geophysics.

The heat flow map which became the basis of the following studies was firstly prepared by Cermak et al. in 1977. And subsequent heat flow maps were prepared by Tezcan (based on gradient data) in 1979 and Ilkisik (based on silica geothermometer data) in 1992. Turkey's gradient distribution map was prepared by Mihcakan and Ocal (1998). Some regional gradient maps were also established by Unalan and Ongur (1979).

For the calculation of the temperature distributions in this study, the deep wells with more than 1 km depth and also 100/150 m shallow wells are selected (used) and the gradient values are both interpolated and extrapolated to calculate the temperature. In the calculations surface temperature is taken to be 15^{o}C.

In this study, Turkey's subsurface temperature distribution maps were generated regionally (north-west and south-east) and as a whole using geostatistical techniques like Inverse Distance Weighting (IDW) and Kriging. In the geneation of both distributions and maps the available data are evaluated by variogram analysis and kriging techniques of geostetistics, so that the error is reduced to possible lowest level in both distributions. Not only the distribution of data but also their positioning in space is taken into consideration in the generation of maps.

2. GENERATION OF SUBSURFACE MAPS USING ARCGIS SOFTWARE

2.1 Data Sets and Analysis

Two data sets were used to obtain the temperature maps. The data set which has 420 data points obtained mostly from the petroleum & natural gas wells with at least a depth of 1 km is called as Data Set 1 (Figure 1). This data set is constructed not only by processing Mihcakan at. al. (2006) gradient values but also using the new informations of geothermal wells.

Figure 1: Location points of Data Set 1

The second set which has 555 data points called Data Set 2 is constructed by processing Ilkısık's (2008), data which is obtained from 100/150 m shallow wells (Figure 2).

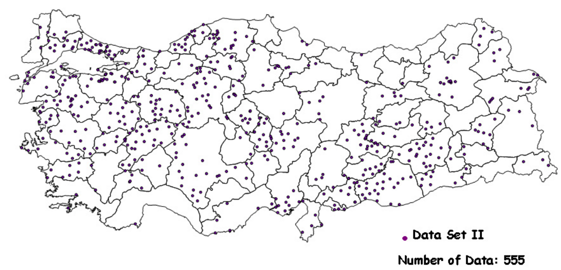

Figure 2: Location points of Data Set 2

The statistical informations of data sets are shown in Figure 3 and 4 respectively. In the figures the vertical axis shows the frequency and the horizontal axis shows the temperature ranges.

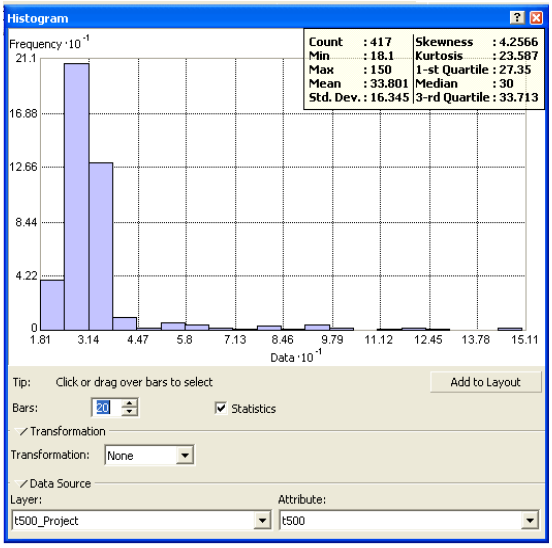

Figure 3: Statistics of Data Set 1 for 500 m depth

In Data Set 1, a clustered distribution is dominant in the north western and south eastern parts of Turkey. But, although Data Set 2 is distributed more homogeneously than Data Set 1, Data Set 1 is more reliable because the values are coming from deeper sources, so that they can not affected by the surface near surface effects.

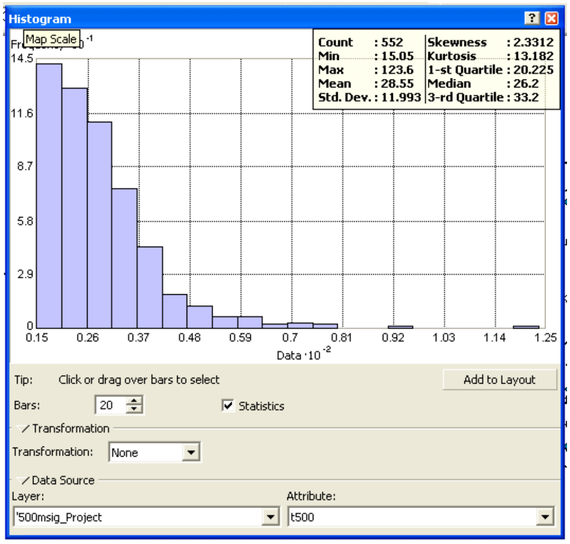

Figure 4: Statistics of Data Set 2 for 500 m depth

2.2 Methods

There are two main groupings of interpolation techniques: deterministic and geostatistical. All methods rely on the similarity of nearby sample points to create the surface. Deterministic techniques use mathematical functions for interpolation. Geostatistics rely on both statistical and mathematical methods which can be used to create surfaces and assess the uncertainty of the predictions. In this study Inverse Distance Weighting and (ordinary) Kriging are used to generate subsurface temperature distribution maps.

2.2.1 Inverse Distance Weighting Method (IDW)

IDW, is one of the deterministic techniques because they are directly based on the surrounding measured values or on specified mathematical formulas that determine the smoothness of the resulting surface. To account for the distance relationship, the values of closer points are weighted more heavily than those farther away. The weight of a value decreases as the distance increases from the prediction location (ESRI, 2004).

2.2.2 Kriging Method

Kriging is based on geostatistical techniques that are based on statistical models that include autocorrelation (statistical relationships among the measured points). Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for each location. However, the weights are based not only on the distance between the measured points and the prediction location, but also on the overall spatial arrangement among the measured points. It uses models of spatial correlation, which can be formulated in terms of covariance or semivariogram functions. Prediction maps are created by contouring many interpolated values, systematically obtained throughout the region (ESRI, 2004).

In this study, in the generations of maps, ordinary prediction method is used. Simple, ordinary and universal kriging predictors are all linear predictors meaning that prediction at any location is obtained as a weighted average of neighboring data. These three models make different assumptions about the mean value of the variable under study: simple kriging requires a known mean value as input to the model, while ordinary kriging assumes a constant, but unknown mean, and estimates the mean value as a constant in the searching neighborhood.

3. REGIONAL INVESTIGATOIN

In order to investigate maps are generated regionally. This will help to construct regional temperature maps in more detail and compare with the whole picture. In regional maps, Data Set 1 representing deeper wells is used. Data Set 1 obtained coming from the deeper parts is believed to reflect more realistic values than Data Set 2. Two regional maps for Northwest (Thrace) and Southeast (Southeast Anatolia) are generated.

Thrace Region: 80 temperature data values are selected for the analysis of Thrace region both for 500 m and 1000 m depths. These data are mostly collected from natural gas wells with a few geothermal wells. In Figure 5, the distribution of data is shown.

In this data set (for 500 m depth), there is only one high temperature value, Tuzla that is located in South-western edge of the map. This data is the only data that can be characterized as outlier. Rest of the data is normally distributed. The statistical properties of Thrace Region data both for 500 m and 1000 m depths are shown in Figure 6 and 7 respectively.

Figure 5: Location points of Thrace region

In this data set (for 500 m depth), minimum, maximum, mean temperature, and standard deviation are as follows: 26°C, 95°C, 33°C, 7°C. The median is found to be 32°C that shows the outlier does not statistically affect distribution.

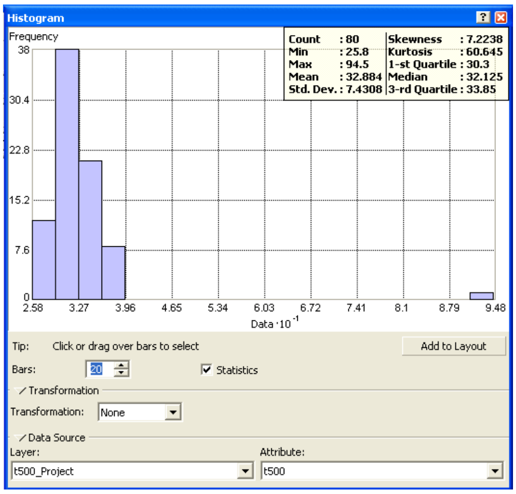

Figure 6: Statistics of Thrace region for 500 m depth

For the data set (for 1000 m depth) minimum, maximum, mean temperatures and standard deviation are as follows: 37°C, 174°C, 51°C and 15°C. The median is found to be 49°C, again showing that the outlier does not statistically affect distribution.

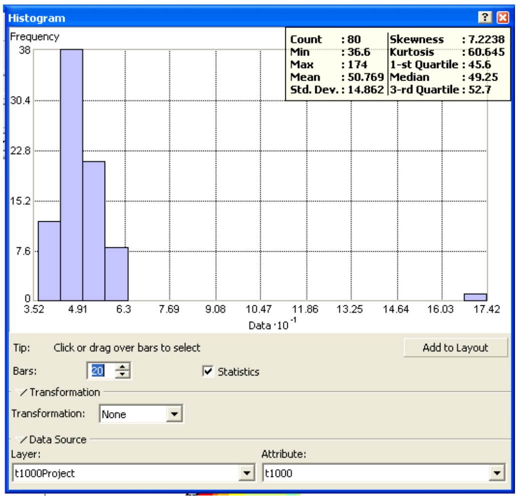

Figure 7: Statistics of Thrace region for 1000 m depth

Southeast Region: 255 temperature data values are selected for the analysis of Southeast region both for 500 m and 1000 m depths. These data are mostly collected from oil and natural gas wells with a few geothermal wells. In Figure 8, the distribution of data is shown.

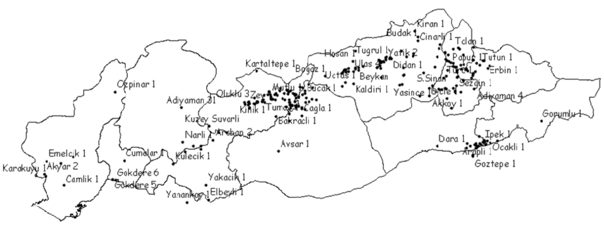

Figure 8: Location points of Southeast Anatolia

As can be seen from the locations of data, they are not distributed homogeneously. Most of them are gathered in the north and north-eastern parts.

The statistical properties of Southeastern Anatolia data both for 500 m and 1000 m depths are shown in Figure 9 and 10 respectively.

For Southeastern Anatolia (for 500 m depth), nearly normal distribution is dominant. Minimum, maximum, mean temperature and standard deviation are as follows: 19°C, 47°C, 30°C, 4°C.

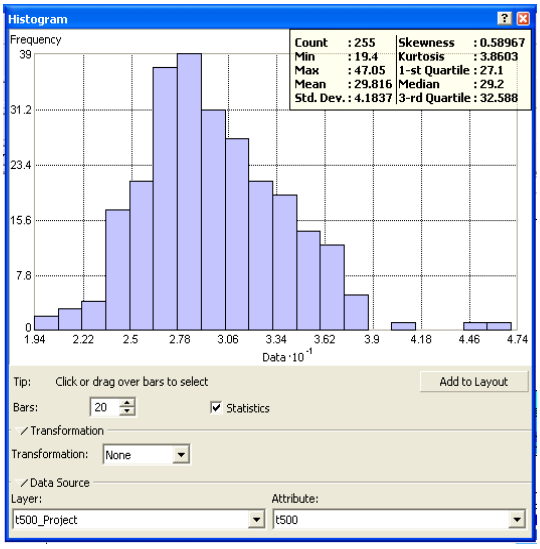

Figure 9: Statistics of Southeastern Anatolia region for 500 m depth

For Southeastern Anatolia (for 1000 m depth), minimum, maximum, mean temperature, and standart deviation are as follows: 24°C, 79°C, 45°C, 8°C.

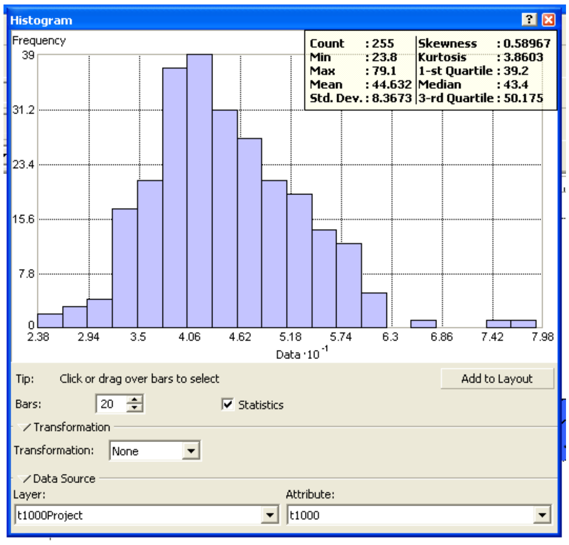

Figure 10: Statistics of Southeastern Anatolia region for 1000 m depth

The chosen parameters in the generation of IDW maps are shown in Table 1.

Table 1: Chosen Parameters for Trace and Southeast Anatolian Region in IDW Temperature Distribution Maps.

Parameters	Trace Region 500 m	Trace Region 1000	Southeastern Anatolia Region 500	Southeastern Anatolia Region 1000
Optimize Power	1	1	1.95	1.95
Neighbors to include	16	16	16	16
Include at least	10	13	10	13
Sector Type	8 slice	8 slice	4 slice	4 slice
Major Semiaxis	66214	66214	173881	173881
Minor Semiaxis	66214	66214	173881	173881
Anizotropy Factor	1	1	1	1
RMS	7.466	14.88	3.37	6.73

The explanations of the chosen parameters used in Table 1 are as given below.

Optimized power value is determined by minimizing the root-mean-square prediction error (RMSPE). The RMSPE is a summary statistic quantifying the error of the prediction surface. **Neighbors to include** are the neighbors that will be used to estimate the value at the unknown location. **Include at least** is the minimum number of points to be used (in each sector) to estimate the value at the unknown location. **Sector type** is the number and geometry of sectors used in the search. **Major/minor semi axis** is the radius of the circle or ellipse. **Anisotropy factor** is the ratio of the major to minor axis. **RMS (Root mean squared)** is an indication of how good (closely) the predictions are.

The generated temperature distribution maps (IDW method and kriging method) for Thrace region are shown in Figures 11, 12, 13 and 14 respectively. The maps for the Southeastern Anatolia region are shown in Figures 15-18.

The chosen parameters in the generation of kriging maps are shown is Table 2. The explanations of chosen parameters used in Table 2 are given below.

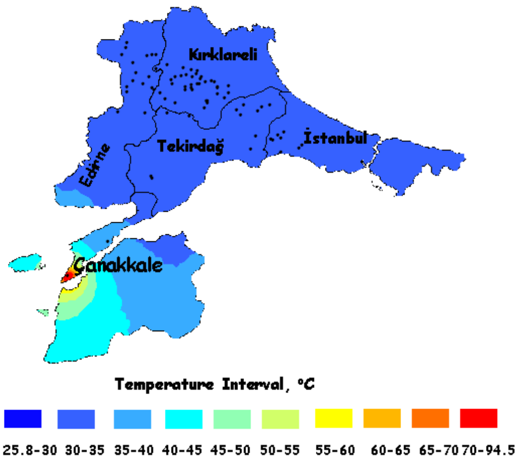

Figure 11: 500 m depth temperature distribution map IDW Data Set 1

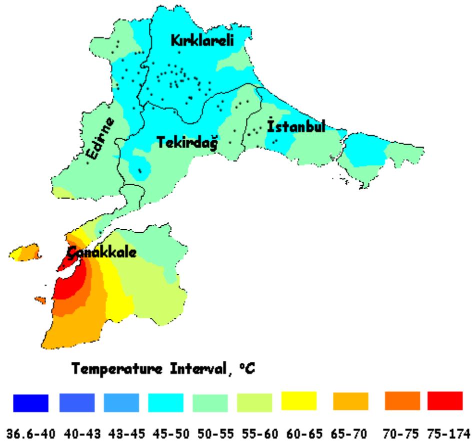

Figure 12: 1000 m depth temperature distribution map IDW Data Set 1

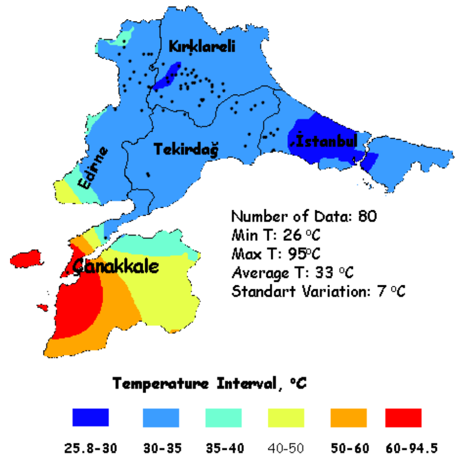

Figure 13: 500 m depth temperature distribution map Kriging Data Set 1

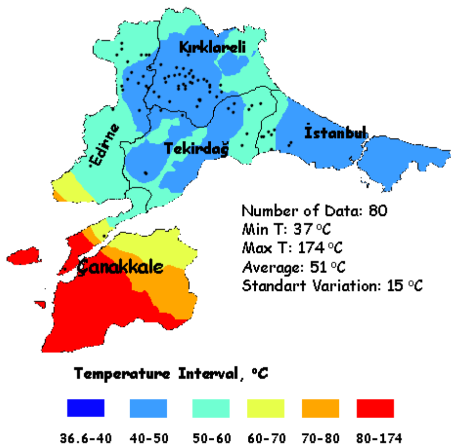

Figure 14: 1000 m depth temperature distribution map kriging Data Set 1

Lag size (binning) is the size of a distance class into which pairs of locations are grouped in order to reduce the large number of possible combinations. **Nugget** is a parameter of covariance or semivariogram model that represents independent error and measurement error that is too fine to detect. **Range** is the distance where the model first flattens out. **Sill** is the value that the semivariogram model attains at the range (the value on the y axis). Partial sill is the sill minus nugget. **ASE (average standard error)** and **RMSS (root mean square standardized)** are indications of how good (closely) the predictions are.

Table 2. Chosen Parameters for Trace and Southeast Anatolian Region in Kriging Temperature Distribution Map.

Parameters	Trace Region 500 m kriging	Trace Region 1000 m kriging	Southeast Anatolia Region 500 m kriging	Southeast Anatolia Region 1000 m kriging
Type of Kriging	ordinary	ordinary	ordinary	ordinary
Direction	80.0	180.0	70.0	83
Partial Sill	100	180	7.7631	29.62
Nugget	10	79	10.038	42.47
Lag Size	16000	16000	16000	16000
Number of Lags	10	10	10	10
Neighbors to include	5	5	5	5
Include at least	2	2	2	2
Sector Type	4 slice	4 slice	4 slice	4 slice
Major Semiaxis	152360	152360	158795	152169
Minor Semiaxis	158795	158795	46695.8	72496.4
Anizotropy Factor	0.96	0.96	3.4	2.099
RMS	8.128	15.83	3.62	7.172
Average Standard Error	5.258	11.04	3.622	7.302
RMSS	0.9211	1.038	0.9975	0.9816

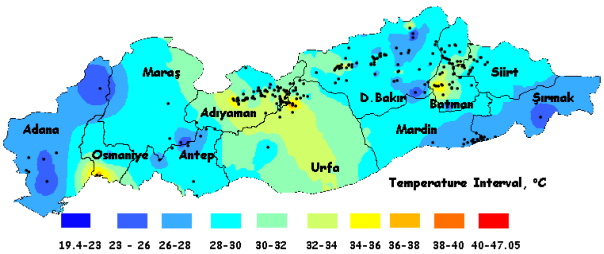

Figure 15: 500 m depth temperature distribution map IDW Data Set 1

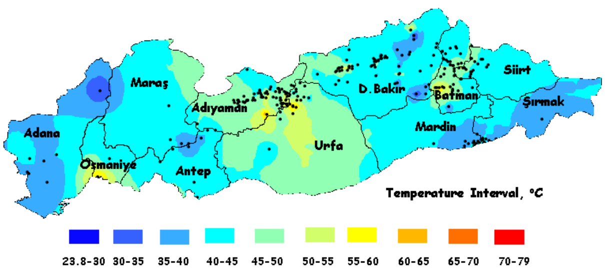

Figure 16: 1000 m depth temperature distribution map IDW Data Set 1

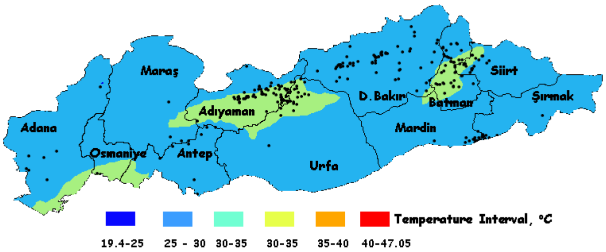

Figure 17: 500 m depth temperature distribution map with kriging Data Set 1

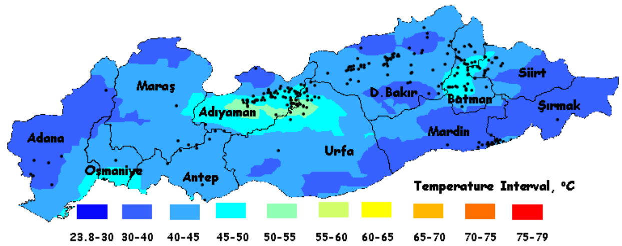

Figure 18: 1000 m depth temperature distribution map with kriging Data Set 1

4. GENERAL ASSESSMENT

In order to make a general assessment for the whole country, two data sets (deep and shallow well information, a total of 968 values) are combined and used as a one data set. Ordinary kriging prediction (Figure 20) and standard error (uncertainty) temperature (Figure 21) maps are generated using this data set.

The statistical summary of 968 data points is given in Figure 19.

For combined data set (for 500 m depth), nearly log normal distribution is dominant. In the generation of temperature distribution for whole country, we did not want to disturb the data set so in this case no transformation is implemented. Minimum, maximum, mean temperatures and standard deviation are as follows: 15°C, 150°C, 31°C, 14°C.

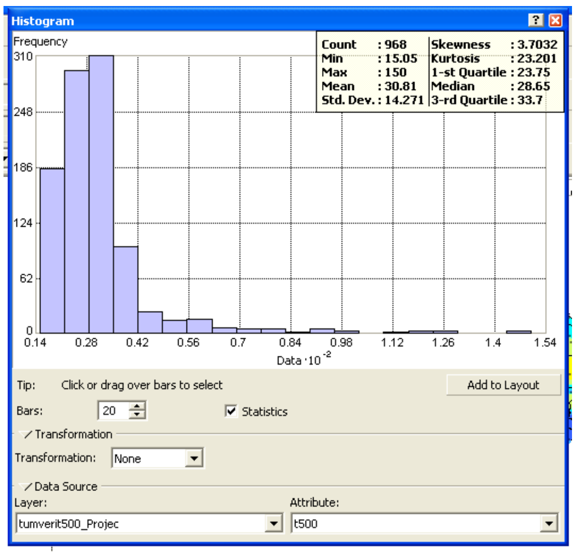

Figure 19: Statistics of Data Set 1 and 2 for 500 m depth

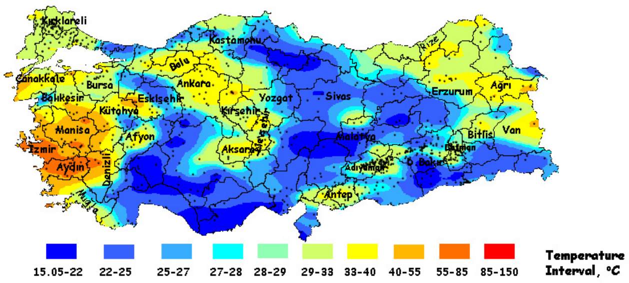

Figure 20: 500 m depth temperature distribution map with kriging Data Set 1 and Data Set 2

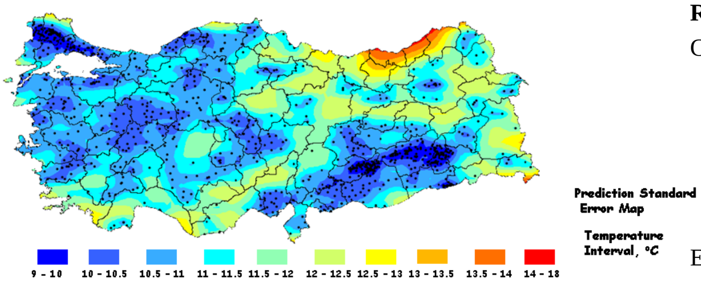

Figure 21: 500 m depth temperature prediction standard error distribution map with kriging Data Set 1 and Data Set

These statistics serve as diagnostics to indicate whether the model and/or its associated parameter values are reasonable for map production. They also serve as diagnostics to evaluate a model and find its optimal parameters (semivariogram/covariance, search neighborhood, trend, and so on).

Geostatistical methods of data interpolation also provide measure of the uncertainty of the prediction (Average Standard, Mean Standardized, and Root-Mean-Square Standardized prediction errors), giving an indication of how good the predictions are.

If the prediction errors are unbiased, the mean prediction error should be near zero. However, this value depends on the scale of the data, so the mean standardized prediction error gives the prediction errors divided by their prediction standard errors. This value should also be as close to zero as possible.

The root-mean-squared prediction error indicates how closely the model predicts the measured values. Smaller the root-mean-squared prediction error is, better the predictions are.

RESULS AND DISCUSSIONS

Temperature maps for Thrace, Southeastern Anatolia and the whole country both for 500 m and 1000 m depths are generated and compared using deterministic (IDW) and geostatistical (kriging) methods.

In the comparison the prediction error (PE) values are taken into consideration.

Temperature distribution of 500 m of Turkey prepared by combining one shallow data set (Data Set 2) and one deep data set (Data Set 1) presents a meaningful map in the sense that it reflects some particular features of Turkey (Figure 12). It shows hot Aegean Region which was indicated by Ilkisik (1992) and Tezcan (1979) studies, and relatively a hot region in central Anatolia. It also illustrates recent volcanic activity areas in central and eastern Anatolia where volcanoes were formed. On the other hand, error distribution map is also meaningful since it represents higher errors where there is scarce data.

As for the regional maps both are sedimentary basins with relatively higher amount of data because of sufficient number of oil and natural gas wells. It is interesting that some relatively hot spots appear in maps of Southeastern Anatolia. They are related to semi thermal areas formed in that basin. On the other hand, no such occurrences can be found in Thrace basin. Hot spot observed in the southeastern part of that basin is related to a hydrothermal resource which can be considered as an outlier.

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