Gazi University Journal of Science
GU J Sci
25(2):327-335 (2012)

ORIGINAL ARTICLE

Forecasting of Air Temperature Based on Remote Sensing

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Received: 30.10.2011 Revised: 19.12.2011 Accepted: 13.01.2012

ABSTRACT

The aim of this research is to forecast air temperature based on remote sensing data. So, land surface temperature and air temperature values which were measured by Republic of Turkey Ministry of Forestry and Water Affairs (Turkish State Meteorological Service) during the period 1995–2001 at seven stations (Adana, Ankara, Balıkesir, İzmir, Samsun, Şanlıurfa, Van) were compared. The monthly land surface temperature and air temperature were used to have correlation coefficients over Turkey. An empirical method was obtained from equation of correlation coefficients. Separately, Price algorithm was used for the estimation of land surface temperature values to get air temperatures. Then as statistical, air temperature values, belongs to meteorological data in Turkey (26–45ºE and 36–42ºN) throughout 2002, were evaluated. The research results showed that accuracy of estimation of the air temperature changes from 2.453ºK to 2.825ºK by root mean square error.

Key Words: *Air temperature, satellite, NOAA-AVHRR.*

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1. INTRODUCTION

Knowledge of air temperature is necessary for many environmental studies and management of the Earth's resources .And it is used in the determination of various heat and radiation fluxes, vapour pressure deficit [1,2,3], water potential [4], urban land use and urban heat island[5,6], public health applications[7], incoming shortwave and longwave radiation, leaf stomatal resistance, ecology, hydrology[8], climatic change[9,10,11,12,13], and atmospheric sciences. Generally, air temperature which is very important is frequently observed and recorded by weather meteorological stations with high accuracy. But the density of the station network is normally not sufficient when air temperature is employed in regional numerical models for climate or evapotranspiration.

So, a new method is necessary to get air temperature over the wide fields by using satellites data. The data of Advanced Very High Resolution Radiometer (AVHRR), Geostationary Operational Environmental Satellite (GOES), Meteosat, TIROS Operational Vertical Sounder (TOVS), LANDSAT/TM and Moderate Resolution Imaging Spectroradiometer (MODIS) have been used in historical term. The air temperatures have been estimated from land surface temperatures retrieved from satellite images with 1km x 1km or 4km x 4km resolution [14, 15, 16] by using thermal infrared radiation emitted from the surface by many researchers [17, 18, 19,20,21,22] . Generally, land surface temperature has been retrieved from two thermal infrared bands (channels 4 and 5 of AVHRR of NOAA) located at 11 µm and 12 µm by using split-window equations. The split-window algorithms are belonged to the difference in the brightness temperatures of thermal infrared bands. Furthermore, land surface temperature depends on the magnitude of the difference between ground emissivity in the bands [23].

Kawamura and Edamatsu used AVHRR thermal infrared data and estimated the air-temperature (T_a) in Japan with 566 coupled data sets of T_a at 1.5 m .The truth data were classified into three groups (forest, fields, and city) according to the ground component and the relation between the AVHRR temperature and the truth temperature was examined. Regression relations using multiple channels were derived to estimate T_a. The rms error was found 2.5-2.8 ºK for each of the categories [24].

Lara Prihodko and Samuel N. Goward explored a methodology for estimating air temperature directly from remotely sensed observations using the correlation between a spectral vegetation index and surface temperature (temperature- vegetation index). Inference of air temperature was based on the hypothesis that the bulk temperature of an infinitely thick vegetation canopy is close to ambient air temperature. They used Advanced Very High Resolution Radiometer observations for the five sites in northeastern Kansas to estimate air temperatures throughout 31 days during 1987 growing season. The air temperature estimates were compared to coincident ground-measured air temperatures recorded at standard meteorological stations. A strong correlation (r=0.93) was found between the satellite estimates and measured air temperatures with a mean error of 2.92 ºC [15].

The correlation between surface temperature and spectral vegetation index has been obtained to estimate air temperature from satellite images that was called the Surface Temperature/Spectral Vegetation Index (TVX) by Czajkowski et al., Prihodko and Goward[14,15]. A linear relationship between surface temperature and vegetation index, where the vegetation index indicates the denseness of the vegetation canopy, was used to determine the air temperature. Another approach was the use of an empirical equation derived from statistical results for estimating air temperature. The TVX concept and the empirical method have provided estimated air temperatures with an rms error of 3ºC [16].

Khomarudin et al. estimated air temperature using remote sensing data (NOAA/AVHRR and LANDSAT/TM) which were based on thermal diffusivity approach. The steps of this research have included the calibration of land surface temperature, the determination of amplitude and the estimation of air temperature. They obtained best land surface temperature values from NOAA-AVHRR data that were estimated from Ulivieri et al. equation [22]. Physically, they decided that research could estimate air temperature from satellites data, but statistically, this research has not been enough significance to describe the field observation [25].

Riddering and Queen presented a technique for producing estimates of near-surface air temperature (T_a) in complex terrain based on composite data from the NOAA-AVHRR. Results were tested against meteorological data. The correlation coefficient(r) approximately 0.742 and standard errors of the estimate of 2.73ºK were observed in the final model implementation [26].

Stisen et al**.** obtained air temperature belonging to a model that was including satellite data with high temporal resolution that were desired for several modeling applications by exploiting the thermal split-window channels in combination with the red and near infrared channels of the geostationary MSG SEVIRI sensor. The research results showed that accuracy of estimation of the air temperature changes from 2.55 ºK to 2.99 ºK by root mean square error [27].

Vancutsem et al. studied to explore the possibility of retrieving high-resolution near surface air temperature (T_a) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) connected to land surface temperature (T_s) over different ecosystems in Africa. Firstly, comparisons between night MODIS T_s data with minimum T_a showed that MODIS nighttime products have provided a good estimation of minimum T_a (standard deviation = 2.4 ºC). Secondly comparisons intra-day MODIS T_s data with maximum T_a showed that ($\Delta T_s - T_a$) strongly varies according to the seasonality, the ecosystems, the solar radiation and cloud-cover [28].

Lakshmi et al. evaluated the ability of satellites to map air temperature over the large land surface areas. Then, they developed an algorithm that derives surface air temperature by using observations from the TOVS (TIROS Operational Vertical Sounder) suite of instruments and also from the AVHRR (Advanced Very High Resolution Radiometer). In their study, instantaneous estimates from the AVHRR and TOVS were compared to the hourly ground observations collected from 26 meteorological stations in the Red River–Arkansas River basin for a 3-month period from May to July 1987. The result of research showed that the average bias over the 3-month period compared with ground-based observations was approximately 2 ºC or less for the three times of day with TOVS having lower biases than AVHRR [29].

As known, air temperature can be estimated by meteorological stations that use extrapolation techniques. If the distance between stations is large, the estimation error may increase considerably. On the other hand, it has been shown that land surface temperature could be estimated by using satellite data. The procedure was applied to obtain monthly based land surface temperature values over a 12-month period in Turkey. And, land surface temperature was predicted with the Price method. Usage of this method is more suitable for large areas. Land surface temperature data can be used as an important parameter in many applications such as estimation of air temperature. Air temperature is of paramount importance for various applications, for example in the environmental and meteorological research and atmospheric physics. We anticipated that the results of this study would give an idea about the air temperature in Turkey, so seven stations (Adana, Ankara, Balıkesir, İzmir, Samsun, Şanlıurfa, Van) were selected which represented different climatic conditions.

2. METHODOLOGY

2.1. Split-Window Method

The National Oceanic and Atmospheric Administration (NOAA) series of meteorological satellites have played a significant role in various applications of remote sensing for the last two decades. These satellites are in Sun-synchronous orbits at an average altitude of 833 km. They have the advantage of covering the same area twice in each 24-h period with a vast swath width of 2800 km. An area is thus scanned once during the day and once at night. The collected images have advantages because of their field of view of ±55.4° and their spatial resolution of 1.1km at the nadir [30]. The split-window method was used for the determination of monthly global land surface temperatures from the NOAA-AVHRR satellite data, which provide wide coverage together with adequate spatial resolution. The temporal resolutions of NOAA-12-14-15 images at the same location were scanned by the satellite on cloudless days in every month. And satellite images were received in a raw image and zipped data format. They were unzipped and processed with the software 'Quorum to Level-1B' in order to convert this raw image data to Level1B format, so that remote sensing software could be applied for processing. Radiometric and geometric calibrations were first applied to the images to correct the deficiencies and flaws that could result from the imaging sensor in the platform (satellite) [31]. The split-window algorithm for the retrieval of LST from AVHRR data also have been proposed [32]. If T_4 and T_5 are, respectively, the brightness temperatures in channels 4 and 5 of the AVHRR data, the general form of the split-window equation can be written as

$$T_{Price-1984} = T_4 + A(T_4 - T_5) + B \qquad (1)$$

where $T_{Price\text{-}1984}$ represents the land surface temperature, and A and B are the coefficients determined by the impact of atmospheric conditions and other related factors on the thermal spectral radiance and its transmission in channels 4 and 5.

The split-window algorithm developed by Price-1984 for NOAA-7 has been extensively quoted for LST study. After making several simplifications to the atmospheric effects on the radiation transmission from the ground to the sensor, Price-1984 obtained his split-window algorithm, having the general form of equation (1). Coefficient B in the algorithm of Price-1984 is given as B=0 and coefficient A is

$$A = \frac{1}{A_r - 1} \qquad (2)$$

where $A_r=A_5/A_4$ is the function of atmospheric conditions, especially the contributions of atmospheric radiation emission and absorption in the thermal region. The successful use of the split-window algorithm relies on the accuracy of determination of the ratio A_r as a result of atmospheric effects. However, due to lack of detailed data on the atmospheric profile during the satellite pass, it is difficult to directly compute the ratio.

It is assumed that surface temperature is uniform over a small area with uniform surface features. Thus, the observed variation of brightness temperature is due to atmospheric nonuniformity. Based on this assumption, Price-1984 estimated A_r as the ratio of the observed variation of brightness temperature of a small area on the studied image with relatively uniform surface features under the pixel scale. Considering the possible impacts of instrument noise of the sensor and the nonuniformity of surface brightness temperature of the small area, it is preferable to compute the ratio A_r from averaged quantities. Thus, $A_r=\Delta T_5/\Delta T_4$, where ΔT_5 and ΔT_4 are the average variation of brightness temperature of the small area in channels 4 and 5, respectively. Price found that the value A_r =1.30 is reasonable for most ground surfaces. Thus, equation (1) becomes

$$T_{Price-1984} = T_4 + 3.33(T_4 - T_5) \qquad (3)$$

Obviously, when applied to other regions, this formula may be subject to possible errors due to the difference from the small area used to compute A_r and many unknown atmospheric effects. The surfaces in agricultural areas have an average emissivity of ε =0.97 in the thermal spectral interval 10.8 ± 11.9 mm and a value of 0.96 may be assumed for most of the land surface and vegetation cover. According to the relationship between emissivity and temperature, after accounting for the effect of surface emissivity variation, Price calibrated his algorithm as follows [17],

$$T_{Price-1984} = \left[T_4 + A(T_4 - T_5)\right]\left(\frac{5.5-\varepsilon_4}{4.5}\right) - 0.75T_5\Delta\varepsilon \quad (4)$$

The algorithm requires

- Brightness temperatures in channels 4 (T_4) and 5 (T_5)

- For NOAA-AVHRR data, coefficient A=3.33

- The mean emissivity in these channels,

$\varepsilon=(\varepsilon_4+\varepsilon_5)/2=0.975$

- The spectral emissivity difference, $\Delta\varepsilon=\varepsilon_4-\varepsilon_5=-0.005$ [33, 34].

2.2. Empirical Method

Meteorological data (land surface temperature and air temperature) in Turkey which were measured by Republic of Turkey Ministry of Forestry and Water Affairs (Turkish State Meteorological Service) during the period **of** 1995–2001 from seven stations were compared. The monthly global land surface temperature and air temperature over Turkey were determined to have correlation coefficients of 96.98 % and y=0.9155x+23.209 (Figure 1). Since correlation coefficients were good enough for relationships between land surface temperature and air temperature (ground data) have been used in developing method.

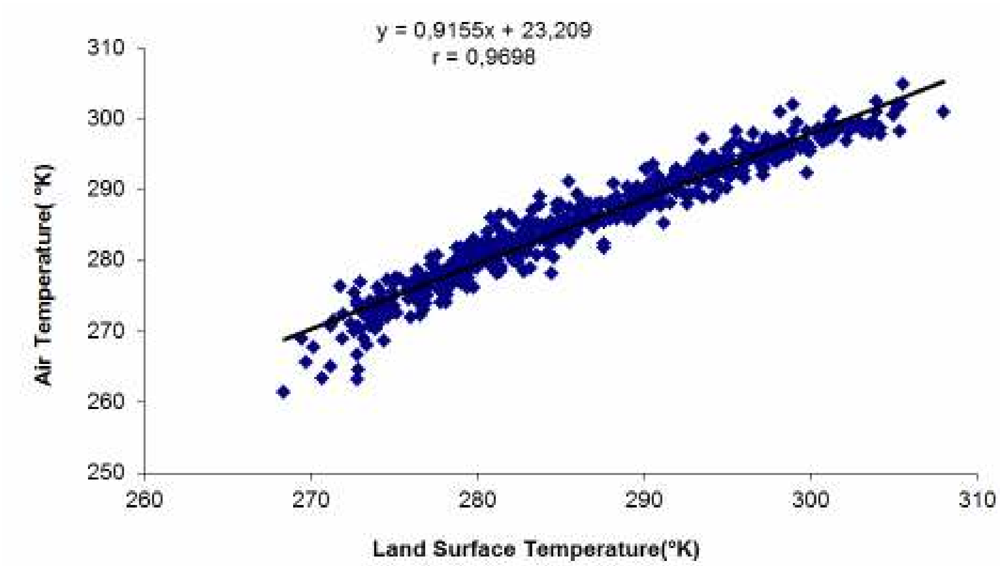

Figure 1. Comparison of land surface temperature and air temperature values measured by Republic of Turkey Ministry of Forestry and Water Affairs (Turkish State Meteorological Service) during the period of 1995–2001 from the seven stations in Turkey.

2.3. Evaluation of the Estimation Results

The choice of the relevant criteria allowing performance evaluation of the estimation methods is an important issue. Various statistical parameters can be used to measure the strength of the statistical relationship between the estimated values and the reference values. We assume that v_i , (i =1, n) is the set of n reference values and e_i, (i =1, n) is the set of the estimates. $\overline{v}$ and $\overline{e}$ are mean of reference and estimates values respectively. The bias, linear correlation coefficient (*r*), Root Mean Squared Error(RMSE) can be calculated by using standard deviations of reference (σ_v) and estimate (σ_e) values, mean of reference and estimates values, estimated values and the reference values. The bias which is the difference between the mean estimate $\overline{e}$ and the mean reference value $\overline{v}$. The statistical criteria formula of the linear correlation coefficient *r* is the following,

$$r = \frac{\sum_{i=1}^{n}(v_i-\overline{v})(e_i-\overline{e})}{n\sigma_v\sigma_e} \quad (5)$$

where *r* measures the proximity between estimate and reference. It is not sensitive to a bias [35]. The formula of the RMSE is;

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(e_i-v_i)^2\right]^{\frac{1}{2}} \quad (6)$$

In statistics, RMSE is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated [36].

3. RESULTS AND DISCUSSION

In the first step of this study, as a result of the comparison of the data which is Empirical method, obtained from the meteorology stations, in order to define the correlation between the monthly air temperature and monthly land surface temperature. And statistical comparison has been applied with the usage of equation 5. A strong, linear correlation between them has been seen(r = 0.9698). Besides, as a result of comparison, regarding y air temperature and x land surface temperature, y=0.9698x+23.209 equation has been achieved.

In the second step, equation-4 has been used to estimate the land surface temperature(x) at y=0.9155x+23.209 equation. Land surface temperature values obtained depending on Price-1984 algorithm and have reached the air temperature values being used in the equation.

January-December 2002 has been decided on studying period for the air temperature values depending on the satellite data of Adana, Ankara, Balıkesir, İzmir, Samsun, Şanlıurfa and Van provinces (see Appendix-1).

With the usage of equation-6, air temperature values obtained depending on Price-1984 algorithm has been evaluated with the air temperature values taken from Republic of Turkey Ministry of Forestry and Water Affairs (Turkish State Meteorological Service). As a result of evaluation, for Adana, Ankara, Balıkesir, İzmir, Samsun, Şanlıurfa, Van provinces; RMSE values 2.453 ºK, 2.821 ºK, 2.673 ºK, 2.518 ºK, 2.697 ºK, 2.804ºK and 2.825 ºK have respectively been calculated. The smallest RMSE value for Adana city by 2.453ºK, the biggest RMSE value for Van city by 2.825 ºK have been found out.

Being compared to the studies in literature; Kawamura and Edamatsu, in their studies, have estimated air temperature with 2.5-2.8 ºK RMS error [24]. Prihodko and Goward 2.92 ºK RMS error [15], Cresswell et al. 3 ºK RMS error [16], Lakshmi et al. 2 ºK RMS error [4], Riddering and Queen 2.73 ºK RMS error [26], Stisen et al 2.55-2.99 ºK RMS error [27], Vancutsem et al 2.4 ºK RMS error [28] have calculated air temperature. When the studies in the literature have been analyzed, RMSE values vary from 2.5 ºK to 3 ºK. The RMSE values in the study vary between 2.453 ºK-2.825 ºK. As a result, it is seen that air temperature has been estimated with high accuracy and its result is very compatible with litterateur.

4. CONCLUSIONS

Studies have shown that use of method for calculation of air temperature is cheap and effective. The results from the seven locations chosen show a relatively good agreement between the measured and predicted values during the studying period. It has been shown that using satellite-estimated data may help to increase the accuracy of the estimation. Method can be applied to areas where no reliable station data exist or the distances between the stations are very large. Estimation of air temperature on construction of air temperature database is very useful for environmental, meteorological and other applications.

ACKNOWLEDGMENTS

We would like to express our gratitude to Republic of Turkey Ministry of Forestry and Water Affairs (Turkish State Meteorological Service) personnel, providing us every kind of facilities on getting the meteorological data and to Scientific and Technological Research Council of Turkey- Bilten personnel, providing every kind of facilities on getting the satellite data.

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Appendix- 1. Air temperature values depends on meteorological and satellite data

City	Month(2002)	Meteorological air temperature(ºK)	Satellite air temperature(ºK)
Adana	January	279.30	280.82
	February	290.00	293.60
	March	283.90	286.55
	April	286.50	289.00
	May	292.20	294.70
	June	301.50	302.20
	July	300.00	298.70
	August	300.30	304.30
	September	293.27	295.17
	October	289.80	292.70
	November	283.00	284.04
	December	273.10	275.58
Ankara	January	271.40	274.13
	February	280.80	284.54
	March	274.00	273.42
	April	280.50	283.81
	May	284.10	286.83
	June	294.00	297.96
	July	295.20	298.53
	August	294.60	296.09
	September	284.50	282.31
	October	282.00	284.27
	November	272.00	274.34
	December	258.70	262.00
Balıkesir	January	272.20	273.86
	February	284.80	287.50
	March	277.80	276.41
	April	276.00	274.51
	May	286.20	288.28
	June	293.00	297.08
	July	294.80	297.67
	August	297.00	294.36
	September	287.47	290.47
	October	283.20	285.63

	November	274.00	277.10
	December	265.90	269.19
İzmir	January	282.60	284.70
	February	289.10	292.42
	March	285.80	282.37
	April	286.20	289.18
	May	290.10	291.80
	June	300.50	298.60
	July	298.90	295.69
	August	304.60	302.25
	September	291.13	294.16
	October	287.50	289.30
	November	282.60	284.20
	December	277.60	275.96
Samsun	January	282.80	284.50
	February	280.80	283.61
	March	281.50	278.97
	April	278.80	281.60
	May	287.90	290.00
	June	293.50	295.40
	July	296.00	299.60
	August	296.50	294.62
	September	289.07	291.92
	October	288.00	292.80
	November	283.20	281.14
	December	270.65	272.18
Şanlıurfa	January	279.00	276.15
	February	286.10	284.67
	March	282.60	284.88
	April	286.70	289.88
	May	292.80	294.98
	June	298.40	303.00
	July	302.00	306.00
	August	301.55	304.54
	September	296.00	293.63
	October	287.60	289.86
	November	279.90	277.34
	December	269.50	270.36
	September	290.80	292.34
	October	282.80	284.20

	November	272.00	274.78
	December	263.05	265.17
Van	January	267.20	266.40
	February	271.20	272.50
	March	269.20	276.10
	April	276.50	278.83
	May	289.00	291.20
	June	290.00	292.80
	July	292.30	295.40
	August	296.55	295.30
	September	290.80	292.34
	October	282.80	284.20
	November	272.00	274.78
	December	263.05	265.17