Emissivity Determination for Land Surface Temperature estimation of Iran using AVHRR Thermal Infrared Data

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ABSTRACT
Land surface temperature (LST) is one of the key parameters in physics of land-surface processes on regional and global scales. Therefore, precise LST is required for a variety of researches including climatic, hydrological, ecological and biogeochemical studies. The main purpose of this paper is to produce LST map of Iran.

The great difference in land cover and type and accordingly presence of different emissivity values makes the LST algorithm or model development complicated. In order to determine surface type and determine relevant emissivity value for each land cover, a combination of different complementary approaches have been applied. For vegetation cover areas, using AVHRR data, a vegetation map has been constructed from ndvi values first and then emissivity values are calculated for pixels located in areas having ndvi values greater than 0.2 and smaller than 0.7. In order to determine emissivity values for non-vegetated areas, geological maps have been used and five types of land surface have been identified. For other land cover types that were not possible to be identified using ndvi and geological maps, land cover classification was performed on AVHRR data. Therefore, emissivity values of around 40% of land have been determined dynamically from ndvi map and classification map. In order to determine the model coefficients, meteorological data at known coordinates in desert regions at the time of satellite overpass have been used. The results have been analyzed using ground truth data provided at known coordinate, however the model coefficients for the whole country are at final calibration stage.

Keywords*: LST, Emissivity, AVHRR.*

1. Introduction

Temperature is such an essential factor in understanding all biological, physical, and chemical systems on Earth and in space that we can safely say that is must be considered in any study involving earth sciences. Thermal infrared remote sensing provides a unique tool for estimating LST in large areas. However, the applicability of remote sensing data in quantitative based studies is limited by the accuracy that can be achieved with such measurements. Atmosphere and the emissivity correction are two basic problems related to the accurate measurements of surface temperature from space. Atmospheric effects can be eliminated using two simultaneous measurements at different wavelengths inside the atmospheric window 10.5-12.5µm. This technique is called Split-Window and has been successfully applied for sea surface measurements with AVHRR channels 4 (i.e. 10.3-11.3µm) and 5 (i.e. 11.5-12.5µm) (McClain et al., 1985). This method can be also applied for LST retrieval provided that emissivity effects are accounted for. Various split-window algorithms have been exhibited that differ in both their form and the calculation of their coefficients. The most common form of split-window algorithms is

$$T_s=T_4+A\,(T_4-T_5)-B \qquad (1)$$

where T_s is land surface temperature, T_4 and T_5 are brightness temperatures in AVHHRR channels 4 and 5, A and B are coefficients in relation to atmospheric effects, viewing angle and ground emissivity. The derivation of many algorithms for SST is based on the assumption that the ground surface acts as a black body with constant ε close to 1. However, the Earth's surface is not a blackbody, which means that its emissivity is less than 1 and is function of the waveband width, vegetation covers, soil moisture, surface roughness, etc.

Iran is a big country with high diversity in land cover. The great difference in land cover and type and accordingly presence of different emissivity values makes the LST algorithm or model development more complicated. An emissivity-box (Cihlar et al., 1997) or a radiometer to determine ground emissivity was not available in this study. Therefore, surface type, NDVI, geological and classification maps have been used and relevant emissivity values for each land cover have been selected from available lists of emissivities in the literature.

2. Data Description

AVHRR images of NOAA-14 of Iran that cover approximately 40.16 to 24.80 latitudes and 43.41 to 63.89 longitudes have been used in this study (Table 1). The daily temperature at 5 cm subsurface measured at ground meteorological stations, by Islamic Republic of Iran Meteorological Organization (IRIMO) corresponding to images have been used as reference data. A plot of distribution of the stations is shown in Figure 1. The images were geometrically corrected using ground control points. Then they were radiometrically enhanced using histogram modifications. Since the time of ground data did not match exactly with the time of images, they have been made simultaneous by linear interpolating.

Table1. List of AVHRR images used in the study

Orbit	Date/Month	GMT
17481	5/22	10:49
17495	5/23	10:38
17523	5/25	10:16
17608	5/31	10:50
17622	6/1	10:39
17707	6/7	11:13
17749	6/10	10:40
17763	6/11	10:29
17777	6/12	10:18
17848	6/17	11:03
17904	6/21	10:19
17918	6/22	10:09

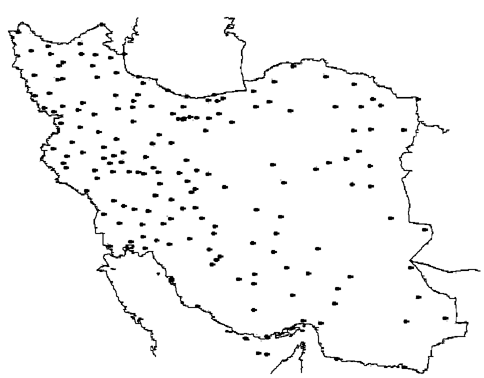

Figure 1: Distribution of meteorological stations

3. Emissivity determination

Lack of knowledge of emissivity introduces an LST error to temperature maps. Most methods for LST estimation assume the emissivity is known and has a constant value. But actually, emissivity in most cases is dynamic and has to be determined in the time of LST calculations. Land Surface Emissivity (LSE) affects satellite measurements in three ways (Prata, 1993):

1. LSE causes a reduction of the surface emitted radiance.
2. Non-black surface reflects radiance.
3. The anisotropy of reflecting and emissivity can reduce or increase the total radiance from the surface.

A number of techniques for estimating emissivity from satellite sensor data have been developed in other studies. Most of them required ground measurements and radiosound data. Since such data were not available in this study, the emissivity values from other studies (Nerry et al. 1990, Wan and Dozier 1989, Label and Stoll 1991, Humes et al. 1994, and others) have been used for different types of land cover where required. However, in order to prepare emissivity database for the whole country, a complementary approach using three types of data have been used. These are:

1. NDVI map; the ndvi for each pixel is calculated using:

$$\text{NDVI}=\frac{r_{NIR}-r_R}{r_{NIR}+r_R} \qquad (2)$$

where r_{NIR} and r_R represent the percentage reflected radiation in the near-infrared and red portion of the spectrum respectively.

2. Geological map at 1:2,500,000 scale shown in Figure 2.
3. Classification map, for which the land-cover classification was performed on AVHRR images.

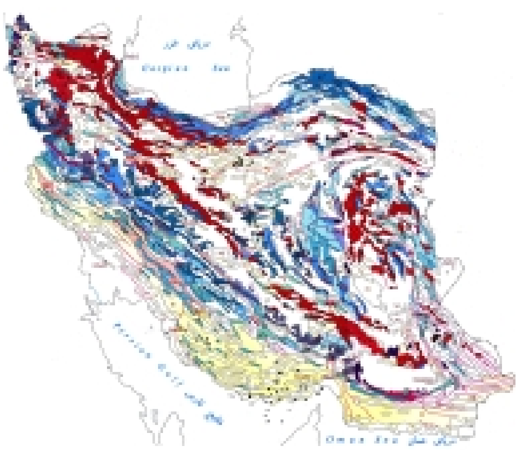

Figure 2: Geological map of Iran

In general, the effective emissivity of a pixel should be estimated by summing up the contributions from its surface type. Van de Griend and Owe (1993) found a high correlation between measured ε and ndvi. The following equation describes the relation between measured ε and ndvi:

$$\varepsilon = a+b*ln\ (ndvi) \qquad (3)$$

where a=1.0094 and b=0.047 were derived from regression analysis for ndvi values from 0.2 to 0.7. Therefore using AVHRR data, for vegetation cover areas in Iran, a vegetation map has been constructed from ndvi values first and then emissivity values are calculated for those pixels containing ndvi values greater than 0.2 and smaller than 0.7. The emissivity values extracted for these areas are around 0.93 and 0.99 respectively.

In order to determine emissivity values for non-vegetated areas, geological maps have been used and five types of land surface have been identified. They are Ultra Basic, Gabbro and Basic Igneous, Diorite and Acid Igneous, Dolomite and Lime, and Sand rock and Conglomerate. The emissivity values for these land types are around 0.856, 0.934, 0.877, 0.958 and 0.912 respectively. The emissivity values have been extracted from tables presented in Nerry et al. (1990), and Wan and Dozier (1989). As an example, a sample of relevant emissivities based on geological map is shown in Figure 3. For each class (surface type) shown in the fingure, an emissivity value has been related from tables presented in other studies.

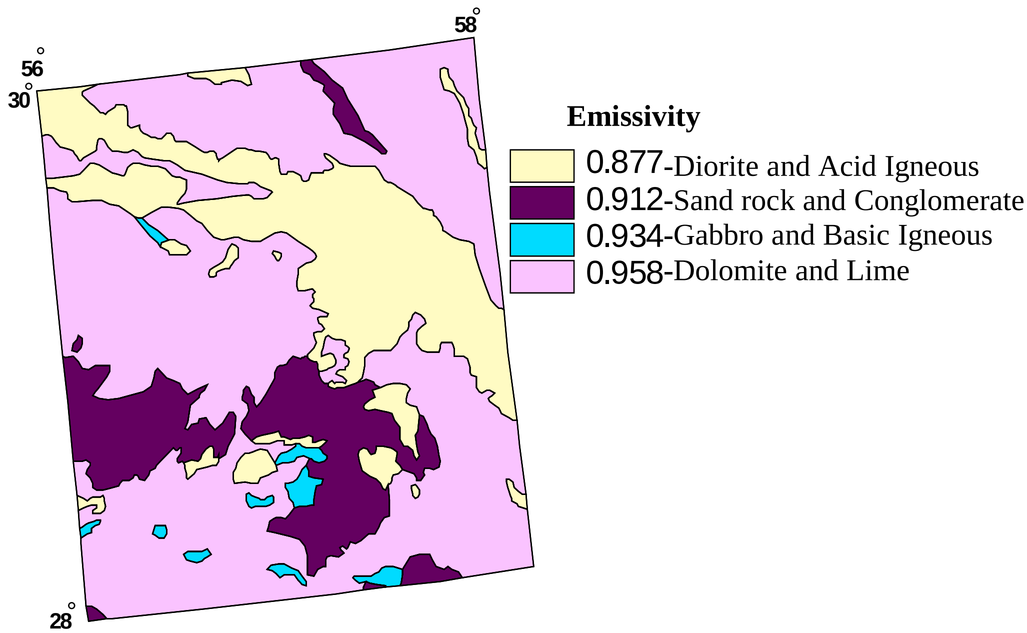

Figure 3: Emissivity map has been extracted from geological map

There are other land cover types that were not possible to be identified using ndvi and geological maps. These include areas having ndvi values greater than 0.7, seasonal lakes, bedrocks, sandy bare soils and loamy bare soils. In order to find these classes, land cover classification was performed on AVHRR data. The emissivity values for ndvi (greater than 0.7), seasonal lakes, bed rocks, sandy bare soils and loamy bare soils are 0.989, 0.97, 0.959, 0.93 and 0.914 respectively. The emissivity values have been extracted from tables presented in Label and Stoll (1991), and Humes et al. (1994) .The extend of each one of the five classes have not been considered constant, as they are extracted dynamically, and the emissivity values are assigned for each type when the LST map is being produced. Therefore, emissivity values of around 40% of land have been determined dynamically from ndvi and classification maps.

4. Modeling

Various climate conditions are present at the same time in one season in different places in Iran. Therefore, determination of exact coefficient for LST algorithm for the whole country requires more ground observations in different seasons. These observations were collected. Since deserts in Iran have almost similar climate conditions, they have been selected to deal with separately. Boundaries of deserts are shown in Figure 4.

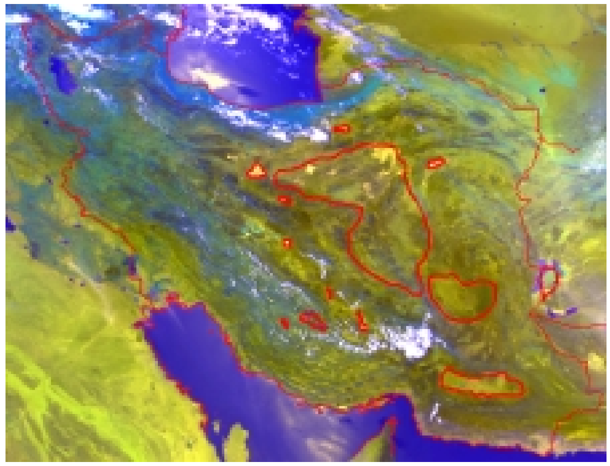

Figure 4: Boundaries of Iran's deserts

As mentioned, the brightness temperature measured by a satellite sensor differs from the ground surface temperature because of effects of surface emissivity and the attenuation due to the intervening atmosphere. In order to account surface emissivity effect in LST model, emissivity value has been applied on brightness temperature using Stephan-Boltzmann law (Equation 4).

$$T_{rad} = \varepsilon^{1/4} T_{kin} \qquad (4)$$

where T_{rad} is kinetic temperature, T_{kin} is radiation temperature and ε is emissivity. Split window algorithm has been applied to reduce atmospheric effect (Equation5). The angular characteristics of surface emissivity has not been considered at the determination of split-window equation, but taking into account zenith angle, the effect of the longer atmospheric path length has been minimized.

$$T_S = a\, T_4 + b\, (T_4 - T_5) + c\, (T_4 - T_5)\, (Sec\theta - 1) + d \qquad (5)$$

where T4 and T5 are brightness temperatures in channel 4 and 5 respectively, and θ is satellite zenith angle.

In order to determine model coefficients, 25 meteorological observations in desert regions were selected from which 7 observations were omitted based on statistical analysis. The correlation coefficients of meteorological data and satellite data have been shown in Table 2.

Table2. Correlation of satellite data and meteorological data

Parameters	Correlation coefficients
Tb_4 and meteorological observations	0.89361
Tb_5 and meteorological observations	0.84015

The model coefficient values (i.e. a, b, c and d) have been computed using a least-square linear regression for deserts of Iran (Table 3). The RMSE for the coefficients is 1.13.

Table3. Coefficients of LST algorithm

Model coefficient	Model coefficient value
a	1.0114
b	0.60912
c	0.7006
d	5.008

Plots for brightness temperatures in channel 4 and 5, meteorological observations, and calculated temperature (LST) using the model constructed for desert regions have been shown in figures 5. Also a comparison made on the calculated LST at each point with relevant observation have been shown in Figure 6.

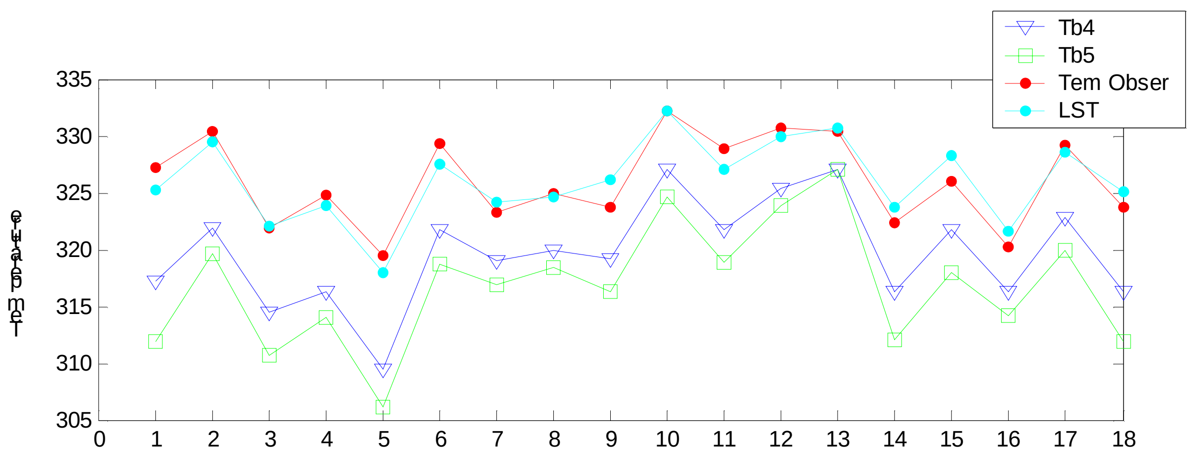

Figure 5. Plot of Brightness Temperature, Meteorological data and LST

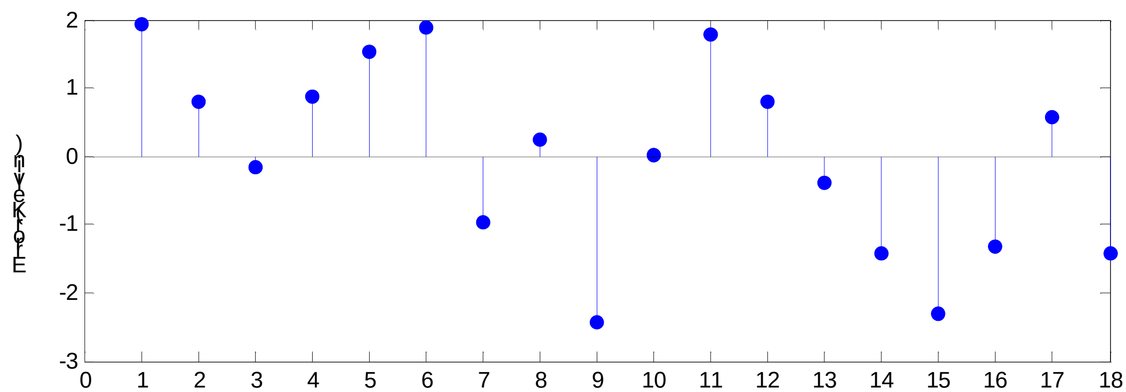

Figure 6. Comparison of Observations and LST

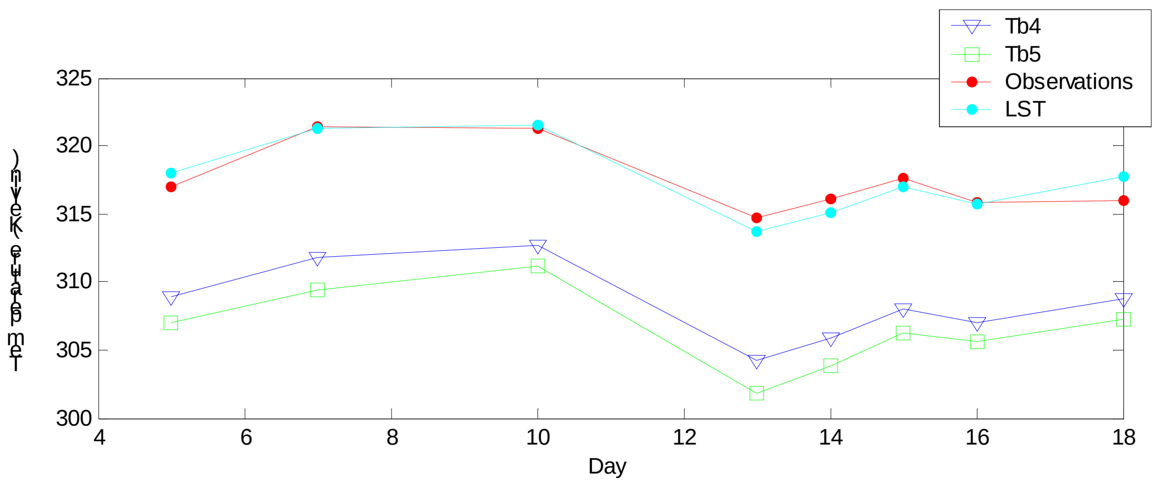

Figure 7. Plot of Brightness Temperature, Ground data and LST

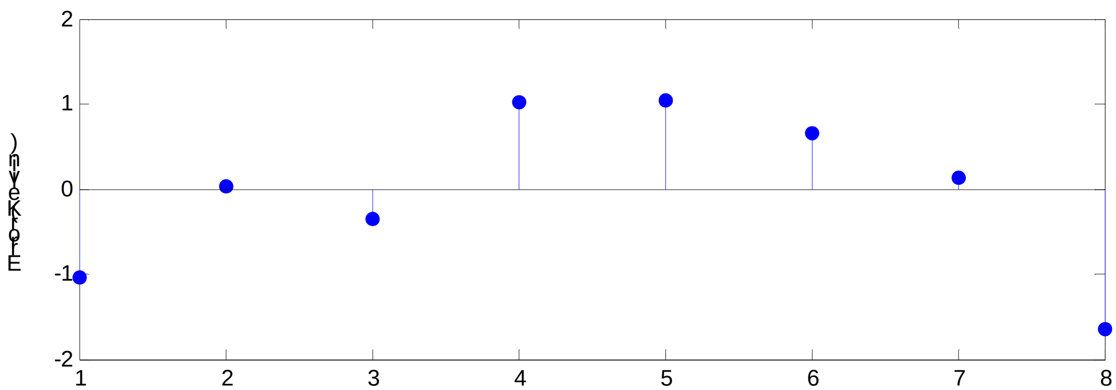

Figure 8. Comparison of ground data and LST

In order to check accuracy of computed coefficients, 8 ground observations data have been used. The correlation coefficient for ground observations and satellite data is 0.92 and corresponding RMSE obtained using desert model is 1.1398.

Plots for ground observations, corresponding Tb_4 and Tb_5, and LST using the desert model have been shown in figures 7. Also a comparison made on the LST at each point with relevant observation have been shown in Figure 8.

As mentioned, Iran is a big country with high diversity in land cover. The great difference in land cover and type and accordingly presence of different emissivity values makes the LST algorithm or model development more complicated. Therefore, determination of exact coefficients for LST algorithm for the whole country requires more ground observations and analysis, hence, the model coefficients is at final calibration stage in this study.

Conclusion

Accurate LST maps are strongly required for many applications, notably agrometeorology climate and environmental studies. Satellite remote sensing in the infrared provides an interesting alternative for the global and continuous measurements of this parameter. One of the problems in LST estimation using remote sensing data is the emissivity effect. The emissivity mainly depends on land surface type, condition, and the wavelength considered, and hence rather difficult to apply. Neglecting these variations could introduce large errors in LST estimation. In order to construct LST model, emissivity effect has been accounted in this study. The emissivity values for different land covers have been determined using three complementary NDVI, geological and classification maps using AVHRR images. The coefficient values for LST algorithm in desert regions in Iran have been computed using a least-square linear regression and obtained RMSE is around 1.13. However, determination of exact coefficients for LST algorithm for the whole country requires more ground observations and analysis, hence, the model coefficients is at final calibration stage.

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References

Csiszár .I and Kerényi .J, 1995, The effect of the vegetation index on the daily variation of the active surface temperature*, Adv.Space Res. Vol.16, No.10, (10)177-(10)180.*

Dash .P, Göttsche .M.F, Olesen F.S, and Fischer .H, 2002, Land surface temperature and emissivity estimation from passive sensor data: theory and practice-current trends, *Int.J.Remote Sensing, Vol. 23, No.13, 2563-2594.*

Göita .K, Royer .A, and Bussieres .N, 1997, Crseharactarization of land surface thermal structure from NOAA-AVHRR data over a Northern Ecosystem, *Remote Sens Environ .60:282-298.*

Kerenyi .J,1998,Angular dependent split-window method for the determination of land surface temperature *, Adv.Space Res. Vol.22,No.5,637-640.*

Qin .Z ,and Karnieli .A ,1999,Progress in remote sensing of land surface temperature and ground emissivity using NOAA-AVHRR data *, Int.J.Remote Sensing , Vol. 20, No.12,2367-2393.*

Sabins Floyd F, 2002, Remote sensing: principles and interpretation, 3d *ed.*

Van De Griend .A.A and Owe .M,1993,On the relationship between thermal emissivity and the normalized difference vegetation index for natural surfaces , *Int.J.Remote Sensing , Vol. 14, No.6,1119-1131.*

Vázquez .D.P, Olmo Reyes .F.J, and Arboledas A.L ,1997, A comparative study of algorithms for estimating land surface temperature from AVHRR data ,*Remote Sens Environ .62:215-222.*

Wan.Z and Dozier.J, 1989, Land surface temperature measurement from space: physical principles and inverse modeling, *IEEE Trans. Geosci Remote Sensing, Vol 27,268-278.*

Wan.Z and Dozier.J, 1996, A generalized split-window algorithm for retrieving land surface temperature from space, *IEEE Trans. Geosci Remote Sensing, Vol 34, No.4, 892-905.*