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Comparison of Some Split-window Algorithms to Estimate Land Surface Temperature from AVHRR Data in Southeastern Tehran, Iran

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Abstract

Land surface temperature (LST) is a significant parameter for many applications. Many studies have proposed various algorithms, such as the split-window method, for retrieving surface temperatures from two spectrally adjacent thermal infrared bands of satellite data. Each algorithm is developed for a limited study area and application. In this paper, as part of developing an optimal split-window method in the southeast of Tehran province, Iran, four commonly applied algorithms to retrieve the LST from AVHRR were compared. This study was carried out in a wheat farm site located in the Pakdasht Agricultural Region. Measurements of LST over the farm were made with a manual infrared radiometer at the time of NOAA overpass for 18 days of May to June 2004. These days were cloud free over the study area. A total of 18 NOAA images were acquired for the days that LST measurements were made. The temperatures derived by the different split-window algorithms were compared to ground truth measurements. The performance of the split window algorithms was checked with three statistical indices: root mean square error (RMSE), mean bias error (MBE) and coefficient of determination (R^2). The results showed that the Ulivieri split-window algorithm produced the lowest value of RMSE and MBE (2.71 and 0.26 K, respectively) and its highest value of R^2 (0.92) gave more accurate results than the other algorithms.

Keywords: Land surface temperature; NOAA; Split-window; Iran

1. Introduction

Understanding the spatial distribution and temporal evolution of land surface temperature (LST) is of significant importance for many applications including numerical weather prediction, climate and environmental studies and estimating evapotranspiration estimation. Together with air temperature, land surface temperature is a key parameter of the energy and water cycles of the earth–atmosphere system.

Split-window algorithms are commonly used to estimate LST from the Advanced Very High Satellite (GOES) or Meteosat systems (Prabhakara et al., 1974). The thermal infrared

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Resolution Radiometer (AVHRR), Geostationary Operational Environmental radiation emitted from the Earth's surface is measured by satellite sensors in spectral intervals named "atmospheric windows" because the effects of the atmospheric absorption are limited to a few percent of the useful signal; however, even though little, this effect, along with the surface emittance effect, produces an underestimation of the surface temperature. The measured temperature, called "brightness temperature", is lower the land surface temperature. In order to have a better estimate of LST two adjacent thermal infrared channels are used; the different absorption in these two spectrally close channels causes to measure two different brightness temperatures whose suitable combination provides the best estimated LST. This technique, called "split-window algorithm", allows using two channels, centered at 11 and 12 micron of the AVHRR/NOAA instrument, also taking into account the spectral surface emissivity.

The surface emissivity may vary significantly because of differences in soil related to its structure, composition, organic matter, or moisture content. By assuming a constant LST emissivity, Price (1983) used NOAA/AVHRR and defined LST with the split-window equation. Various authors suggested split-window methods including non-uniform emissivity to estimate LST (Price, 1984; Becker and Li, 1990; Prata and Platt, 1991; Kerr et al., 1992; Coll et al., 1994; Ulivieri et al., 1994; Sobrino and Raissouni, 2000). Price (1984) showed a potential error magnitude for LST estimates from satellites of 2-3^{o}C. Kerr et al. (1992) derived an equation combining a split-window method and the fractional vegetation cover obtained from the Normalized Difference Vegetation Index (NDVI) to account for changes in vegetation cover.

The accuracy of LST algorithms can vary with regional environmental conditions, such as climate characteristics, the major land surface type, and the soil water content. Comparative study on different LST estimating techniques has been published by Vazques et al. (1997) for south eastern Spain. The results of this study emphasized the necessity to choose or develop an estimation algorithm optimized for a given region. Yang and Yang (2006) modified Becker split window LST algorithm for NOAA-16/17 AVHRR data. They found the correlation between the retrieved LST and the in-situ LST measurement is greater than 0.90 with the RMSE around 3.40K.

The objective of this study was to compare various split-window algorithms for retrieving surface temperature for a agricultural land located in southeast of Tehran province, Iran and, then, to select the most accurate model.

2. Materials and Methods

2.1. Field data collection

An experimental site suitable for the validation of split window algorithms was set up in a large, flat and homogeneous area in the Pakdasht Agricultural Region, which is one of the most important agricultural areas in the southeast of Tehran province, Iran. Principal crop in this region is wheat and other crops grown in this area include alfalfa, barley and corn. The climate in the study area is semiarid with an average annual rainfall of 230 mm, approximately 80% of which occurs during November through April, and reference evapotranspiration of 1390 mm.

Field research work was conducted from May to June 2004 in a 650 ha irrigated wheat farm site (Ghezlagh) located in this region (35°28′N, 51°41′E). During this period the wheat crops are irrigated and attained nearly full cover. In these circumstances, the site shows a high thermal homogeneity and is large enough for making ground measurements of LST comparable to satellite estimates. In addition, the emissivity of green vegetation with full cover is well known (high emissivity with small or null spectral variation between 8 and 13 μm (Rubio et al., 2003; Salisbury and D'Aria, 1992) thus facilitating the measurement of surface temperatures by means of infrared radiometers.

To obtain LST values that are comparable with those obtained using split window algorithms, measurements of surface temperature over the farm were carried out simultaneously over 30 minutes, centered about the time of the satellite overpass. Readings were made with the manual infrared radiometer (measuring between 8-14 μm) every 10 m in the farm. The measurements were generally quite stable, and denoted as the mean soil temperature. The field of view of each measurement was 30 cm on the crop surface.

Radiometric temperatures were corrected for emissivity effects, including the reflection of the downward sky emission. If T_r is the radiometric temperature measured by a thermal infrared radiometer, the equation used to determine the true land surface temperature (T_s) is:

$$B(T_r) = \varepsilon\, B(T_s) + (1-\varepsilon)\, Fd / \pi \qquad (1)$$

Where B is the Planck function weighted for the filter of the radiometer, ε is the surface emissivity and Fd is the downwelling radiance. Because the surface was only covered with vegetation, so the emissivity was assumed as 0.985. The downwelling radiance was measured at an angle of 53^{o} from nadir.

2.2. AVHRR data

The AVHRR sensor onboard NOAA's Polar Operational Environmental Satellite (POES) satellites records radiation reflected and emitted by the land surface at spectral intervals centered at 0.63, 0.91, 3.7, 11 and 12 μm with a spatial resolution of 1.1 km × 1.1 km at nadir. For this study, a total of 18 images of cloud-free NOAA-16 AVHRR level 1b images were collected from the Satellite Active Archive (http://www.saa.noaa.gov/) for period from May to June 2006. This dataset contains daily images, which overpasses Iran between 13:30 and 14:30 local solar time. Table 1 shows the list of the cloud-free midday NOAA-16 AVHRR images used in this study.

The pre-processing of the AVHRR data was carried out at the Geographical Information System and Remote Sensing (GIS and RS) laboratory (Collage of Abureyhan, University of Tehran). The processing was consisted of registering the data to a geographic co-ordinate system and calibrating the AVHRR channels to top-of-atmosphere reflectance (TOA) (channels 1 and 2) and TOA brightness temperature (channels 3, 4 and 5). The reflectances from channels 1 and 2, and the brightness temperature from channels 4 and 5 over 8 pixels enclosing Ghezlagh site were averaged and employed as representative data for the evaluation of split-window algorithms.

2.3. Split-Window algorithms

The emissivity used in split-window algorithms is a critical parameter for the accuracy of LST. The emissivity effect is included in split-window algorithms by using the emissivities of channels 4 and 5, their means, and their difference. Cihlar et al. (1997) derived a log-linear between NDVI and channel 4 emissivity (ε_4) and emissivity difference of channels 4 and 5 (ε_4-ε_5):

$$\varepsilon_4 = 0.9897 + 0.029\ln(\text{NDVI}) \quad (2)$$

$$\varepsilon_4 - \varepsilon_5 = 0.01019 + 0.1344\ln(\text{NDVI}) \quad (3)$$

The split-window algorithms have been developed by many researchers, and four commonly applied algorithms were evaluated in this work and are presented in Table 1.

Table 1. Split-window algorithms in the comparison analysis

Authors (year, Abbreviation)	Split-window algorithms
Price (1984, Price)	$LST = T_4 + 3.33\cdot(T_4 - T_5)\cdot\frac{5.5-\varepsilon_4}{4.5} + 0.75\cdot T_5\cdot\Delta\varepsilon$
Becker and Li (1990, B&L)	$LST = 1.274 + \left(1 + 0.15616\frac{1-\varepsilon}{\varepsilon} - 0.482\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_4+T_5}{2} + \left(6.26 + 3.98\frac{1-\varepsilon}{\varepsilon} + 38.33\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_4-T_5}{2}$
Prata and Platt (1991, P&P)	$LST = 3.45\frac{T_4-T_0}{\varepsilon_4} - 2.45\frac{T_5-T_0}{\varepsilon_5} + 40\frac{1-\varepsilon_4}{\varepsilon_4} + T_0$
Ulivieri et al. (1994, Ulivieri)	$LST = T_4 + 1.8\cdot(T_4 - T_5) + 48\cdot(1-\varepsilon) - 75\cdot\Delta\varepsilon$

T_4 and T_5 are brightness temperature of AVHRR channel 4 and 5, $\varepsilon = (\varepsilon_4 + \varepsilon_5)/2$, T_0=273.15 (K)

3. Results and Discussion

To compare LST estimation algorithms, the most widely used statistical indicators are root mean square error (RMSE), the mean bias error (MBE) and the coefficient of determination (R^2). The RMSE is thought to provide information on the short-term performance of a model by allowing a term by term comparison of the actual difference between the estimated value and the measured value. The smaller the value, the better the model's performance. On the other hand, the MBE is usually thought to provide information on the long-term performance of a model. A positive value gives the average amount of overestimation in the estimated values and vice versa. The smaller the absolute value, the better the model performance.

The LST values estimated by the four split-window algorithms were compared with measured values. This comparison is shown in Figure 1, while the summary of statistic results is presented in Table 2. All the algorithms have similar coefficients of determination. The largest difference between coefficients of determination of the best model and the worst is only 0.03. The high values of coefficient of determination (R^2>0.89) for all algorithms showed that there was good linear regression between these algorithms and measured data. However, three algorithms significantly overestimated LST (between 1.5 and 5.23 k) and the Ulivieri split window algorithm provided lowest MBE value (MBE=0.26).

Considering the RMSE, the results for Price, Becker and Li, Prata and Platt algorithms have poor results, but the Ulivieri algorithm has the lowest value of RMSE (2.71 K).

The results in Figure 1 and Table 2 show that the highest errors are associated respectively with becker and Li, Prata and Platt, and Price algorithms and the lowest error is associated with the Ulivieri algorithm. Since these four algorithms have different formulations, there are large differences between some of them for retrieving LST. Thus the algorithms need to be tested for understanding the differences. The atmosphere is a key factor to modify the radiance from the Earth surface by water vapour or aerosol. In next step, the four algorithms were investigated for atmospheric effects.

Each algorithm was further tested for relative sensitivity by analyzing the variation of the deviation between the LST and brightness temperature of Channel 4 (T4). Channel 4 was chosen instead of Channel 5, because there is more atmospheric effect (absorption by water vapour) in Channel 5 than in Channel 4. Figure 2 shows a plot of deviation between the LST and T4 versus T4 for data used in this study. As seen in Fig. 2, Becker and Li, Prata and Platt, and Price algorithms (lines B, C and A) produced the largest deviation from T4, while the Ulivieri algorithm (line D) has smaller deviations but similar trend each other. The deviation of temperatures estimated by ulivieri was much less sensitive to the variation of Channel 4 (T4) than those of other algorithms, so the Ulivieri algorithm may exhibit a lesser atmospheric effect on the accuracy. As a result, The Ulivieri algorithm may be proposed as a split-window algorithm for estimating LST in southeast of Tehran with better accuracy.

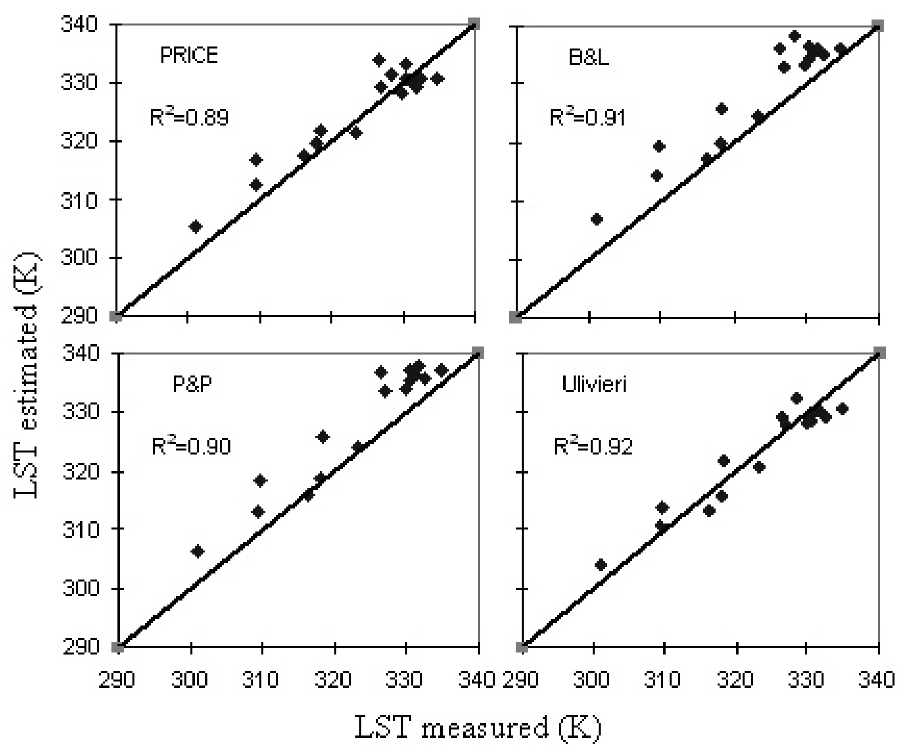

Fig. 1. Comparision of measured LST vs. estimated LST using four different split window algorithms

Table 2. Statistical results between measured LST and estimated LST using split window algorithms

Algorithm	RMSE (K)	MBE (K)	R^2
Price	3.56	1.5	0.89
B&L	5.66	4.88	0.90
P&P	6.14	5.23	0.90
Ulivieri	2.71	0.26	0.92

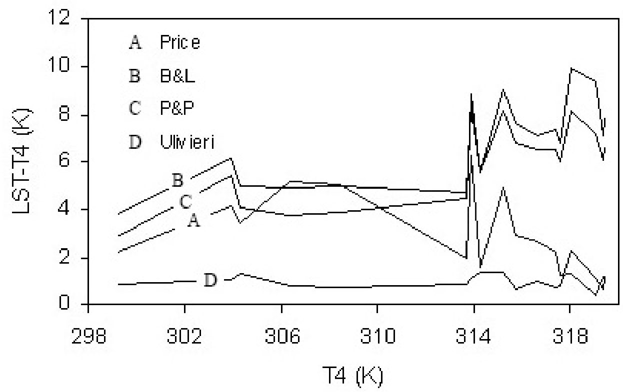

Fig. 2. Variations of the deviations of surface temperature (LST) from brightness temperature of AVHRR Channel 4

4. Conclusions

This study has evaluated four algorithms for retrieving surface temperature from AVHRR images in southeast of Tehran, Iran. The algorithms of becker and Li, Prata and Platt, and Price have the tendency to overestimate the observed land surface temperature. The algorithm developed by Ulivieri has shown to be a reasonably accurate method for estimating LST. In testing sensitivity to atmospheric effects, the LST of the Ulivieri algorithm is much less influenced by water vapour absorption. Therefore, the Ulivieri algorithm may be used as a split-window method for retrieving LST in southeast of Tehran with better accuracy because it takes better account of atmospheric effects.

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References

Becker, F. and Z.L. Li, 2001. Towards a local split window method over land surfaces. Int. J. Remote Sens, 11: 369-393.

Cihlar, J., H. Ly, Z. Li, J. Chen, J. Pokrant and F. Huang, 1997. Multitemporal, multichannel AVHRR data sets for land biosphere studies-artifacts and corrections. Remote Sens. Environ, 60: 35-57.

Coll, C., V. Casselles, J.A. Sobrino and E. Valor, 1994. On the atmospheric dependence of the split-window equation for land surface temperature. Int. J. Remote Sens, 15: 105-122.

Kerr, Y.H., J.P. Lagouarde and J. Imbernon, 1992. Accurate land surface temperature retrieval from AVHRR data with use of an improved split window algorithm. Remote Sens. Environ, 41: 197-209.

Prabhakara, C., G. Dalu and V.G. Kunde, 1974. Estimation of sea surface temperature from remote sensing in the 11- to 13-μm window region. J. Geophys. Res., 79: 5039-5044.

Prata, A.J. and C.M.R. Platt, 1991. Land surface temperature measurements from the AVHRR. Proceeding of The 5th AVHRR Data Users' Meeting, Tromso, Norwa, 433-438.

Price, J.C 1983. Estimation surface temperature from satellite thermal infrared data- A simple formulation for the atmospheric effect. Remote Sens. Environ., 13: 353-361.

Price, J.C. 1984. Land surface temperature measurements from the split window channels of the NOAA7 Advanced Very High Resolution Radiometer. J. Geophys. Res, 89: 7231-7237.

Rubio, E., V. Caselles, V. Coll, V. Valor and F. Sospedra, 2003. Thermal infrared emissivities of natural surfaces: Improvements on the experimental set-up and new measurements. Int. J. Remote Sens, 24(24): 5379– 5390.

Salisbury, J.W. and D.M. D'Aria, 1992. Emissivity of terrestrial materials in the 8 –14 Am atmospheric window. Remote Sens. Environ, , 42: 83–106.

Sobrino, J.A. and N. Raissouni, 2000. Toward remote sensing methods for land cover dynamic monitoring: Application to Marocco. Int. J. Remote Sens, 21, 353–363.

Ulivieri, C., M.M. Castronouvo, R. Francioni and A. Cardillo, 1994. A split-window algorithm for estimating land surface temperature from satellites. Adv. Space Res, 14(3): 59-65.

Yang, H. and Z. Yang, 2006. A modified land surface temperature split window retrieval algorithm and its applications over China. Global and Planetary Change 52, 207–215.

Vázquez, D.P., F.J.O. Reyes and L.A. Arboledas, 1997. A comparative study of algorithms for estimating land surface temperature from AVHRR Data. Remote Sens. Environ, 62(3): 215-222.