Land Surface Temperature Estimation Using SSM/I Microwave Data over Saudi Arabia

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ABSTRACT

In this study, the air temperature at ground level or the land surface temperature (LST) over Saudi Arabia was estimated using the Special Sensor Microwave/Imager (SSM/I) microwave brightness temperatures data. A linear regression analysis was used to correlate the SSM/I brightness temperature or combinations of brightness temperatures with temperature obtained from Presidency of Meteorology & Environment (PME) of Saudi Arabia. The statistical correlations were found over the two years 1995 and 1996. It was found that good correlation coefficients ($R \geq 0.9$) occurred between the SSM/I brightness temperatures and LST.

Keywords: Land surface temperature, Passive Microwave, SSM/I, Saudi Arabia.

Introduction

Land surface temperature (LST) information over large areas is an important physical variable for many applications. It is needed for providing boundary condition variable for several models, as an input in numerical weather prediction models, as input in flood forecasting, growth and crop yield models, crop stress detection, and soil moisture models. Improved LST estimation could improve the accuracy of these models.

Accurate estimations of LST for large areas are helpful when obtained within short periods. However, direct measurements of LST over large areas are difficult because of the cost of installation and operation of instruments. On the other hand, remote sensing from earth satellites offers a possible way for determination of the spatial distribution of LST over large areas within a short time.

Several researches have been completed to apply remote sensing of passive microwave to estimate LST over large area. First research, correlating passive microwave brightness temperatures to LST, was accomplished by Lambert (1987), and Lambert and McFarland (1987). They found that there are correlations between the passive microwave brightness temperatures from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) in the 18 and 37 GHz vertical and horizontal channels, and air temperature for dry range and prairie areas in the Northern Great Plains. Furthermore, McFarland et al.(1990) determined LST over the Central Plains of the United States using the Special Sensor Microwave/Imager (SSM/I) brightness temperatures. They found that a regression analysis between all of the SSM/I channels and minimum screen air temperatures (representing the surface temperature) showed good correlations, with root mean-square errors of 2° - 3°C. Mashat and Alamodi (1997) used simple and multiple linear regressions to test the statistical validity of the correlation between SSM/I brightness temperatures and LST over Saudi Arabia. They found that poor correlation coefficients occurred between the SSM/I brightness temperatures and LST at about 6:00 a.m. local solar time, and they found good correlation coefficient occurred between the SSM/I brightness temperatures and LST at about 6:00 p.m. local solar time. Jones and Vonder Haar (1997) found that in order to derive LST it is necessary to adjust for surface emissivity. Basist et al. (1998) developed a method to calculate near-surface temperature from SSM/I over United States. Fily et al. (2003) found a strong linear relationship between microwave (19 and 37 GHz) surface emissivities at horizontal and vertical polarizations over snow- and ice-free areas. They found that it is possible to retrieve LST from microwave brightness temperatures obtained by satellite sensors after atmospheric corrections.

The goal of this research is to use the observed microwave brightness temperatures from the SSM/I to estimate LST over Saudi Arabia.

Data Collection

1) Meteorological Data

Unfortunately hourly LST data over Saudi Arabia could not be obtained either from Presidency of Meteorology & Environment (PME), Ministry of Defense and Aviation, Kingdom of Saudi Arabia or from the Hydrological Division, Ministry of Agriculture, Kingdom of Saudi

Arabia. Therefore, the data used for this comparative study for testing the validation of the satellite data "the objective of this study", is the hourly surface air temperature at ground level for the years 1995, 1996 and 1997 which was obtained from MPE in the form of routine meteorological observations. This surface air temperature is the temperature of free air at height between 1.25 - 2.00 meters above ground which is standard of the World Meteorological Organization (WMO) level of the screen that shelters the thermometers. This temperature differs to some extent from the ground temperature below known as LST. This data comprises of twenty-nine stations (Table 1), distributed throughout the Kingdom of Saudi Arabia. Data of SULAYEL station (41062) was not available during the time of the study. In addition, it was found that some surface temperature data at 15:00 GMT were missing. The missing data were esimated using the maximum and minimum temperatures by the following formula:

$$(T_{15})_i = (T_{max})_i - \frac{3}{15}\left[(T_{max})_i - (T_{min})_{i+1}\right]$$

where $(T_{15})_i$ is surface temperature (°C) at 15:00 GMT, $(T_{max})_i$ is the maximum temperature (°C), and $(T_{min})_{i+1}$ is the minimum temperature (°C) for the next day.

Table 1. Surface meteorological stations in Saudi Arabia.

Station Name	Station Indicator	Latitude			Longitude			Elevation (meter)
		Deg.	Min.	Sec.	Deg.	Min.	Sec.	
ABHA	41112	18	13	59	42	39	39	2093.35
AL-AHSA	40420	25	17	53	49	29	11	178.17
AL-BAHA	41055	20	17	41	41	38	35	1651.88
AL-JOUF	40361	29	47	19	40	05	55	668.74
ARAR	40357	30	54	08	41	08	26	548.88
BISHA	41084	19	59	28	42	37	09	1161.97
DHAHRAN	40416	26	15	34	50	09	39	16.77
GASSIM	40405	26	18	28	43	46	03	646.71
GIZAN	41140	16	53	49	42	35	05	7.24
GURAIT	40360	31	24	27	37	16	56	503.90
HAFR-AL-BATIN	40377	27	54	--	45	32	--	413.00
HAIL	40394	27	26	04	41	41	28	1001.52
JEDDAH	41024	21	40	42	39	08	54	3.58
K. MUSHAIT	41114	18	17	58	42	48	23	2055.93
MADINAH	40430	24	32	53	39	41	55	635.6
MAKKAH	41030	21	26	16	39	46	08	240.35
NEJRAN	41128	17	36	41	44	24	49	1212.33
QAISUMAH	40373	28	19	08	46	07	49	357.6
RAFHA	40362	29	37	17	43	29	49	444.1

Station Name	Station Indicator	Latitude			Longitude			Elevation (meter)
		Deg.	Min.	Sec.	Deg.	Min.	Sec.	
RIYADH OLD	40438	24	42	40	46	44	18	619.63
RIYADH NEW	40437	24	55	31	46	43	19	613.55
SHARURAH	41136	17	28	04	47	06	29	724.65
SULAYEL	41062	20	27	45	45	36	55	614.39
TABOUK	40375	28	22	35	36	36	25	768.11
AL-TAIF	41036	21	28	44	40	32	56	1452.75
WADI DAWASIR	41061	20	26	30	44	40	49	701.02
TURAIF	40356	31	41	16	38	44	22	852.44
WEJH	40400	26	12	19	36	28	37	23.73
YENBO	40439	24	08	24	38	03	50	10.40

2) SSM/I Data

The data used in this investigation contained passive microwave data from the SSM/I, which is a seven-channel, four-frequency, linearly polarized passive microwave radiometer. The channels are horizontal and vertical polarization at 19.35, 37.0, and 85.5 GHz and only vertical polarization at 22.235 GHz. The radiometer was deployed on the Defense Meteorological Satellite Program (DMSP). The satellite is at an altitude of about 833 km with an orbit period of 102 min. The orbit produces 14 revolutions a day. The SSM/I covers the globe twice a day, so it is possible to get two passes over Saudi Arabia per day. Further details of the SSM/I are given in the *Special Sensor Microwave/Imager User Guide* (Hollinger et al., 1987).

Gridded passive microwave brightness temperature data of SSM/I provided in Kelvins for the years 1995, 1996 and 1997 were obtained from the National Snow and Ice Data Center (NSIDC), in Boulder, Colorado, USA. The data produced at NSIDC are in EASE-Grid (Equal-Area Scalable Earth Grid) format.

For more information contact nsidc@kryos.colorado.edu.

Data Analysis Methods

The SSM/I grid cells that contain surface meteorological station which operates by PME were selected, and each grid cell will be called by the name of the station. The stations in close (about 25 km) to the Red Sea (YENBO, WEJH, JEDDAH, and GIZAN) and the Arabian Gulf (DHAHRAN) were eliminated from this study. A computer program (FORTRAN) was written to read daily files of SSM/I data to extract brightness temperature values for each grid cell selected. A new data file for each grid cell was created containing the julain day, the year, the seven channels of the SSM/I brightness temperatures (V19, H19, V22, V37, H37, V85, and H85, where V is vertical polarization, H is horizontal polarization, and 19, 22, 37, and 85 are frequencies 19.35, 22.235, 37.0, and 85.5 GHz, respectively), and the consistent "ground truth" land surface temperature in Kelvins. It was found that for each grid cell the brightness temperatures data were not available for several julain days due to the swath (1400 km) of the SSM/I. Moreover, BISHA grid cell had no brightness temperatures data for all days.

A simple linear regression method was used to determine the degree of correlation of LST and the seven channels of SSM/I brightness temperatures for the years 1995 and 1996. The data sets (8100 measurements available for each variable for all the twenty two grid cells) were analyzed using SPSS statistical software. The data set for the year 1997 will be used to test the results.

Results and Discussion

Statistical correlation analyses for the data sets were performed. A simple linear regression was used to determine the degree of correlation between the SSM/I brightness temperatures (V19, H19, V22, V37, H37, V85, and H85) and LST at 15:00 GMT for the years 1995 and 1996 over Saudi Arabia. The results of the analyses are summarized in Table 2. The correlation cofficient values ranged from high correlation (R=0.976) with V37, for QAISUMAH grid cell, to low correlation (R=0.360) with H85, for MAKKAH grid cell.

Table 2. Correlation cofficients (R) between SSM/I brightness temperatures and LST for each grid cell, and all grid cells together at 15:00 GMT, for 1995 and 1996.

Grid Cell	Number of observations	Correlation coefficients (R)						
		V19	H19	V22	V37	H37	V85	H85
ABHA	277	0.871	0.799	0.862	0.854	0.727	0.668	0.571
AL-AHSA	367	0.966	0.879	0.961	0.969	0.886	0.950	0.849
AL-BAHA	333	0.930	0.886	0.915	0.882	0.826	0.626	0.595
AL-JOUF	395	0.971	0.951	0.964	0.963	0.933	0.952	0.887
ARAR	405	0.968	0.911	0.971	0.966	0.847	0.938	0.797
GASSIM	375	0.968	0.924	0.967	0.964	0.910	0.914	0.821
GURAIT	405	0.972	0.960	0.970	0.963	0.949	0.939	0.884
HAFR-AL-BATIN	389	0.966	0.883	0.971	0.975	0.877	0.948	0.837
HAIL	385	0.968	0.942	0.970	0.964	0.936	0.890	0.853
K. MUSHAIT	279	0.890	0.822	0.875	0.865	0.753	0.679	0.602
MADINAH	386	0.966	0.960	0.963	0.964	0.953	0.904	0.863

Grid Cell	Number of observations	Correlation coefficients (R)						
		V19	H19	V22	V37	H37	V85	H85
MAKKAH	356	0.900	0.842	0.861	0.798	0.746	0.423	0.360
NEJRAN	355	0.878	0.837	0.868	0.863	0.844	0.808	0.765
QAISUMAH	389	0.974	0.906	0.975	0.976	0.895	0.901	0.807
RAFHA	393	0.959	0.899	0.969	0.964	0.894	0.936	0.856
RIYADH OLD	371	0.947	0.858	0.953	0.922	0.829	0.903	0.714
RIYADH NEW	373	0.949	0.860	0.954	0.924	0.835	0.907	0.732
SHARURAH	351	0.947	0.876	0.914	0.937	0.889	0.762	0.738
TABOUK	387	0.965	0.947	0.968	0.966	0.926	0.950	0.878
AL-TAIF	358	0.917	0.853	0.900	0.865	0.830	0.765	0.659
WADI DAWASIR	365	0.966	0.884	0.951	0.957	0.913	0.869	0.819
TURAIF	406	0.971	0.953	0.969	0.968	0.943	0.960	0.909
All grid cells together	8100	0.897	0.635	0.913	0.879	0.665	0.851	0.708

The best correlation cofficient (R) between SSM/I brightness temperatures and LST for each grid cell and all grid cells together at 15:00 GMT, for 1995 and 1996 are presented in Table 3. The values of the best correlation cofficient (R) were greater than or equal to 0.9 for each grid cell, except ABHA grid cell (R=0.871) and K. MUSHAIT grid cell (R=0.89) due to the rainfall over the area. It was found that the V19 was the best channel to estimate LST over the following grid cells: ABHA, AL-BAHA, AL-JOUF, GASSIM, GURAIT, K. MUSHAIT, MADINAH, MAKKAH, NEJRAN, SHARURAH, AL-TAIF, WADI DAWASIR, and TURAIF. On the other hand, the V22 was the best channel to estimate LST over the following grid cells: ARAR, HAIL, RAFHA, RIYADH OLD, RIYADH NEW, TABOUK, and over all grid cells together. While, the V37 was the best channel to estimate LST over HAFR-AL-BATIN and QAISUMAH grid cells.

Table 3. The best correlation cofficient (R) between SSM/I brightness temperatures and LST for each grid cell, and all grid cells together at 15:00 GMT, for 1995 and 1996.

Grid Cell	Number of observations	Correlation coefficients (R)	Variable used	Equation
ABHA	277	0.871	V19	$(T)_{15}$=0.965×V19+19.395
AL-AHSA	367	0.969	V37	$(T)_{15}$=0.970×V37+22.086
AL-BAHA	333	0.930	V19	$(T)_{15}$=0.958×V19+26.931
AL-JOUF	395	0.971	V19	$(T)_{15}$=0.975×V19+15.985
ARAR	405	0.971	V22	$(T)_{15}$=1.014×V22+11.724
GASSIM	375	0.968	V19	$(T)_{15}$=0.904×V19+38.636
GURAIT	405	0.972	V19	$(T)_{15}$=0.883×V19+46.415
HAFR-AL-BATIN	389	0.975	V37	$(T)_{15}$=0.961×V37+29.243
HAIL	385	0.970	V22	$(T)_{15}$=0.955×V22+25.940

K. MUSHAIT	279	0.890	V19	$(T)_{15}$=0.993×V19+12.477
MADINAH	386	0.966	V19	$(T)_{15}$=0.853×V19+58.869
MAKKAH	356	0.900	V19	$(T)_{15}$=0.816×V19+68.523
NEJRAN	355	0.878	V19	$(T)_{15}$=0.812×V19+62.171
QAISUMAH	389	0.976	V37	$(T)_{15}$=0.920×V37+37.631
RAFHA	393	0.969	V22	$(T)_{15}$=0.948×V22+30.357
RIYADH OLD	371	0.953	V22	$(T)_{15}$=1.045×V22+1.045
RIYADH NEW	373	0.954	V22	$(T)_{15}$=1.061×V22+1.330
SHARURAH	351	0.947	V19	$(T)_{15}$=0.914×V19+29.19
TABOUK	387	0.968	V22	$(T)_{15}$=0.872×V22+49.703
AL-TAIF	358	0.917	V19	$(T)_{15}$=0.841×V19+56.786
WADI DAWASIR	365	0.966	V19	$(T)_{15}$=0.914×V19+32.861
TURAIF	406	0.971	V19	$(T)_{15}$=0.861×V19+51.240
All grid cells together	8100	0.913	V22	$(T)_{15}$=0.877×V22+48.836

Test the results

It is useful to examine the results obtained above; therefore, the data for the year 1997 will be tested. Two methods were used to test the results. The first method (Method1) is to use the equation for each single grid cell as showen in Table 2 to estimate LST at 15:00 GMT for each cell using SSM/I data, and the second method (Method2) is to use the single equation for all grid cells to estimate LST at 15:00 GMT using SSM/I data. A simple linear regression was used to test the statistical validity, and determine the degree of correlation of LST using SSM/I data by the two methods and the reference measured temperatures obtained from PME (Figures 1 and 2). The correlation coefficients for the simple linear regression (R) for Method1 and Method2 were found to be 0.942 and 0.906 respectively, while the number of observations (N) was 4386. It is suggested that the SSM/I brightness temperatures data can be used to estimate LST over Saudi Arabia.

Conclusions

In this study a linear relationship is found between LST and SSM/I brightness temperatures (V19, V22, V37) over Saudi Arabia. It is then possible to retrieve LST over Saudi Arabia from SSM/I.

Further research is needed to differentiate the impact of vegetation cover, soil type, soil moisture, and topographic characteristics.

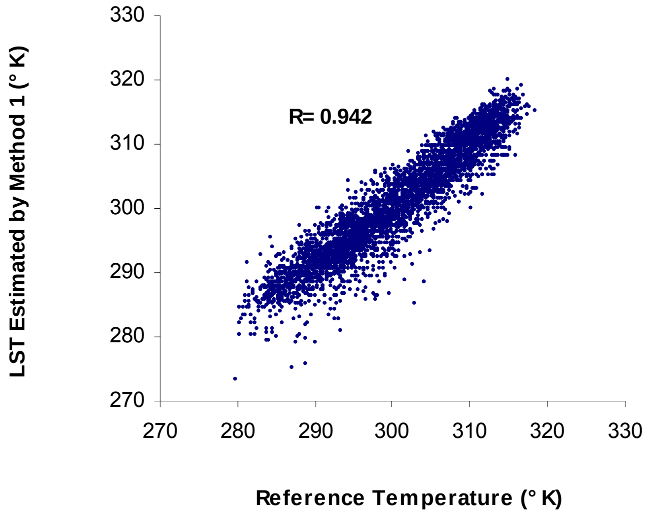

Figure 1. Scatterplot of LST estimated using SSM/I data by Method1 versus reference temperature measured by PME for the year 1997 over Saudi Arabia.

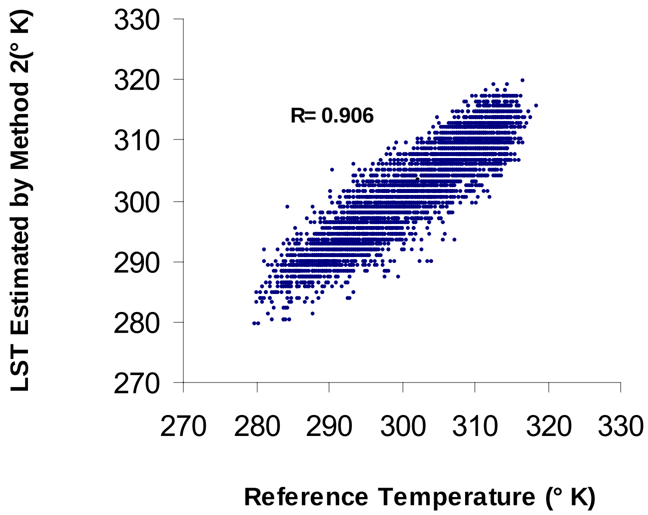

Figure 2. Scatterplot of LST estimated using SSM/I data by Method2 versus reference temperature measured by PME for the year 1997 over Saudi Arabia.

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