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***Abstract*—Land surface window (8-12 µm) emissivity is an important parameter for estimating the longwave radiation budget in the study of earth-atmosphere system. This paper focuses on estimation and validation of the window emissivity using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. Using this sensor, it is possible to estimate surface spectral emissivity for five channels in thermal infrared region. An example is presented for a desert region in North Africa. In this paper, a multiple regression was used to relate the five ASTER emissivities to the window emissivity. This regression was developed using laboratory spectral measurement data. We validated this approach using a field radiometer that has a window channel and five spectral channels similar to ASTER's wavelengths. The predicted window emissivities agreed within 0.01 RMSE of measured window emissivity. We applied this regression to emissivities extracted from ASTER data acquired in 2001 and 2002 over a 400 km by 1200 km area in the Sahara Desert. The derived emissivity map showed that the value widely ranges between 0.82 and 0.96 in desert region. These results show that ASTER data is useful for mapping the spatial variations of surface window emissivity over large area in the deserts of the world.**

Keywords-component; thermal infrared, emissivity, radiation budget, Sahara Desert, surface energy balance

I. INTRODUCTION

Land surface emissivity is an important parameter in the longwave earth radiation budget studies. Thermal infrared window (8-12 µm) emissivity is especially important, because a large part of energy emitted at the surface will escape to space under clear sky condition in this wavelength region. Moreover the range of emissivity is large for rocks and soils in the 8-10 µm region, because of absorption features in the reststrahlen bands [1]. ASTER [2] is a sensor onboard the NASA Earth Observing System (EOS) Terra satellite launched in 1999. It has five channels in the 8 to 12 µm band with 90-meter resolution (Table I). Its data can be used to estimate the temperature and surface emissivities of five channels when used with the Temperature Emissivity Separation (TES) algorithm [3], therefore it is useful for mapping window emissivity.

In a previous paper [4], we developed a regression to relate ASTER five channel emissivities to window emissivity for mapping window emissivities. This paper focuses on validation of this linear regression approach and on interpretation of the resulting emissivity map for mapping the window emissivity in larger regions.

II. ESTIMATION AND VALIDATION OF WINDOW EMISSIVITY

As described in the [4], window emissivity, ε_{8-12}, can be predicted using linear combination of emissivities derived from ASTER thermal infrared channels ε_{ch},

$$\varepsilon_{8-12} = \sum_{ch=10}^{14} a_{ch}\varepsilon_{ch} + c \quad (1).$$

where a_{ch} and c are coefficients of the regression. The ε_{8-12} is defined as follows:

$$\varepsilon_{8-12} \equiv \int_{\lambda=8}^{\lambda=12} \varepsilon(\lambda)\,\mathrm{B}(\lambda,T)\,d\lambda \div \int_{\lambda=8_1}^{\lambda=12} \mathrm{B}(\lambda,T)\,d\lambda \quad (2).$$

where T is the surface temperature, $\mathrm{B}(\lambda,T)$ is the Planck function, and λ is the wavelength.

We computed the regression of Eq. (1) using the ε_{8-12} and ε_{ch} calculated from 312 emissivity spectra. These spectra are of the ASTER Spectral Library, the University of California Santa Barbara's MODIS Emissivity Library [5], and our soil samples. TES and the sensor noise were considered in the calculation of ε_{ch}[1]. As a result, the RMSE of predicted ε_{8-12} by the regression was 0.013. The errors were larger in mafic rock samples and maximum error was 0.045. The calculated coefficients are shown in Table II with those in the [4], which didn't considered the effect of TES and sensor noise. These two regressions are quite similar[2]. The errors caused by TES and sensor noise didn't significantly affect the regression analysis.

[1] The RMSE for derived ASTER five channel emissivities caused by TES and sensor noise were between 0.012 and 0.017 depending on channels.

[2] The average absolute difference of predicted window emissivities from these two regressions is only 0.005.

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We validated the approach with measurements using a field radiometer, CIMEL CE312 [6]. This radiometer has a broadband window channel (8.0-13.6 μm) and five channels approximately the same as ASTER (shown in Table II). Measurements were done on bare soils in the Jornada Experimental Range, and on gypsum sands in White Sands National Monument, New Mexico, USA.

The temperature and emissivities (ε_{ch}) of its five channels are derived using TES. We developed a regression to predict the window emissivity from ε_{ch} using emissivity spectra described above. Then, we applied it to measured ε_{ch} and predicted the window emissivities. On the other hand, "measured" window emissivities were calculated from measured window channel radiances and the TES derived temperatures. These "measured" window emissivities were assumed be true value here, and were compared with the predicted (Fig. 1). The predicted values agree with "measured" in 0.0095 RMSE for 71 measurements at six sites.

III. Mapping emissivity in northern Sahara Desert

The regression was applied to ASTER data acquired over a 400 x 1200 km^2 area in northern Sahara Desert (Fig. 2). We selected this area because of wide variety of land cover. We made a mosaic of the 258 scenes of ASTER derived emissivity data acquired from April 2001 to May 2002 on 11 paths. The result is shown in Fig. 3. The window emissivity is low in the sand dune area in Grand Org Oriental and is higher in the area near Mediterranean Sea where vegetations is present.

Fig. 4 shows the histograms of ASTER window emissivity for each area in a land cover map [7]. The values in desert and semi-desert areas (barren and open shrub) range widely between 0.82 and 0.96. Such a variation of window emissivity can cause significant effects on longwave earth radiation budget. The variation of 0.14 is corresponding to the change of irradiance at top of atmosphere approximately 10 W·m^{-2} for dry atmosphere. Therefore mapping window emissivity based on thermal infrared measurements will be useful for radiation budget study.

IV. Relation between emissivity and reflectance in visible and near infrared (For furture study)

For the purpose of mapping emissivity of the world, ASTER data do not have enough coverage at present. MODIS has almost daily coverage, but it has only one channel in 8-9.5 μm, where the largest range of emissivity is observed.

We assessed the relationship between the window emissivity from ASTER data and reflectance in visible and near infrared region from MODIS data, because, in general, brighter sands or soils have lower emissivities than darker ones. The channel 1 (645 nm) showed the strongest correlation with the window emissivity in the study area (Fig. 5). This relation can be used for mapping the window emissivity.

V. Conclusion

A regression method to estimate window emissivities using ASTER thermal infrared data was analyzed and validated. The analysis using a set of spectral data shows that the residual error including TES and sensor noise is small as 0.013 RMSE. Validation using a field radiometer shows the measured window emissivities of soils agree well with estimated values using regression. We generated the window emissivity map of Northern Sahara Desert from ASTER data. It shows that the large range of emissivity between 0.82 and 0.96 exists in the desert and semi-desert region. Further study to determine the best approach is necessary for mapping the window emissivity in all the desert area of the world.

VI. Acknowledgements

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TABLE I. Center wavelength of ASTER and CIMEL CE312

ASTER	Ch.	10	11	12	13	14	-
	λ (μm)	8.29	8.63	9.08	10.66	11.29	-
CIMEL CE312		8.42	8.68	9.14	10.55	11.27	8.0-13.6

TABLE II. Coefficients derived from regression

	a10	*a11*	*a12*	*a13*	*a14*	*c*
This paper	-	0.058	0.351	0.433	-	0.152
Previous [4]	0.014	0.145	0.241	0.467	0.004	0.128

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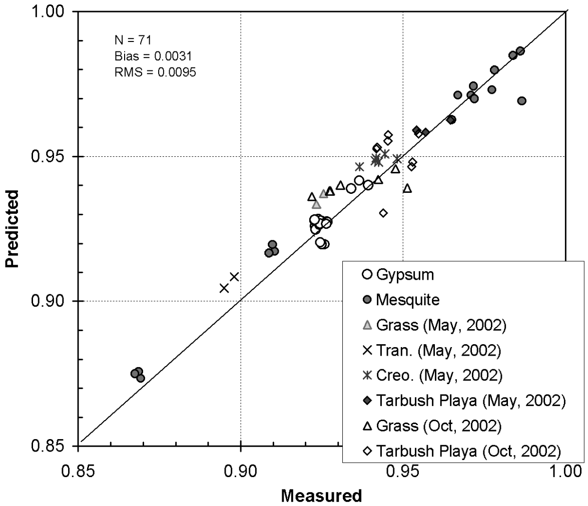

Figure 1. Measured window emissivities by CIMEL CE312 and predicted values using linear regression. Measurements were made in Jornada Experimental Range and in White Sands National Monument, New Mexico, USA.

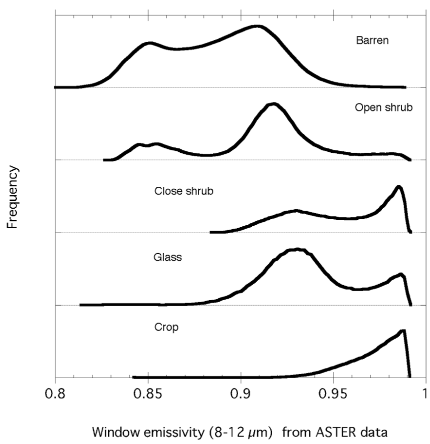

Figure 4. Histograms of window emissivities for each land cover type in the study area. The values of Barren and Open shrub range widely between 0.82 to 0.96.

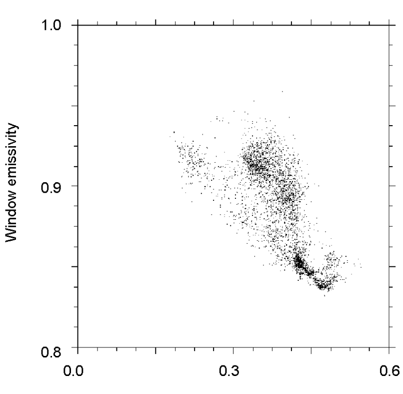

Figure 5. The relationship between reflectance at 645 nm from MODIS and window emissivity (8-12 μm) from ASTER in the study area.

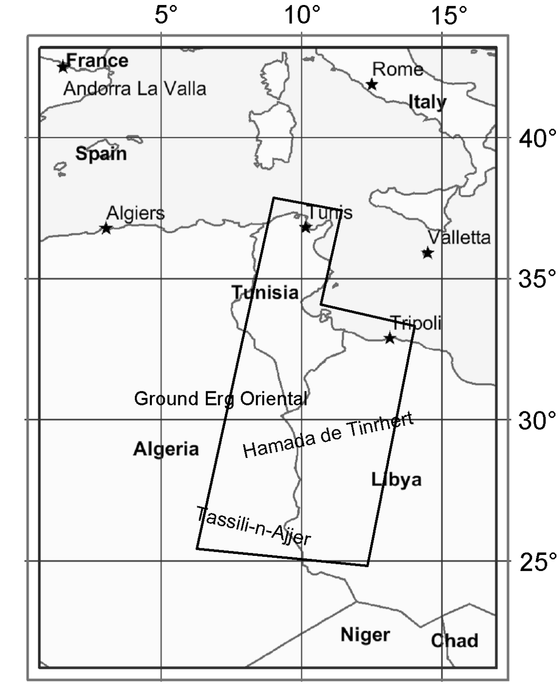

Figure 2. The study area over Tunisia, Algeria, and Libya. 258 scenes of ASTER data are used to cover this area.

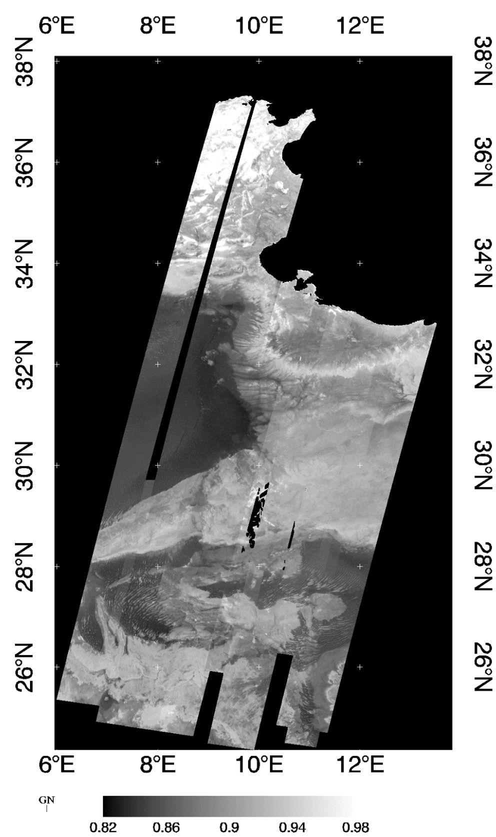

Figure 3. Window emissivity created using ASTER thermal data of 400 x 1200 km region in a part of Sahara Desert.