Evaluation of the Utility of MODIS and ASTER Derived Soil Emissivity for Climate and Energy Balance Simulations

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Objective

▪ To perform a sensitivity study of climates and energy balance simulations with more realistic soil emissivities from MODIS and ASTER over Northern Africa and the Arabian Peninsula.

▪ To analyze relationships between MODIS albedo and ASTER emissivity over Sahara and to provide guidance for the possible inclusion of such relationships to represent the land surface soil emissivity in climate models.

Introduction

▪ Current climate models generally represent the land surface soil emissivity by a constant value due to limited observations. For example, a constant soil emissivity of 0.96 is used in the recently developed Community Land Model (CLM2) [*Bonan et al.*, 2002].

▪ Satellite observations from the ASTER and MODIS show significant spatial variability of surface emissivity, ranging from 0.83 to 0.96, over deserts and semi-deserts [*Ogawa et al.*, 2004]. Such variability suggests that climate models may need to better represent the spatial and spectral variations of emissivity based on satellite observations.

▪ Would a more realistic emissivity representation improve climate and energy balance simulations over arid and semiarid regions in CLM2? If so, how to characterize the soil emissivity in the model? Here we first performed a sensitivity test of climate and energy balance simulations using MODIS/ASTER emissivities and then proposed a simple method to represent soil emissiviy in climate models.

Data and Method

▪ We focus our study region in the Sahara desert and Arabian Peninsula (10°N-30°N, 20°W-50°E) and use the 8-13.5 μm emissivity data generated from ASTER and MODIS data [*Ogawa et al.*, 2004].

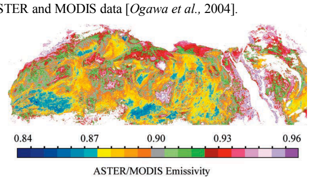

Figure 1. Spatial distributions of emissivity (8-13.5 μm) over the Sahara desert and Arabian Peninsula at 0.05° resolution [*Ogawa et al.*, 2004].

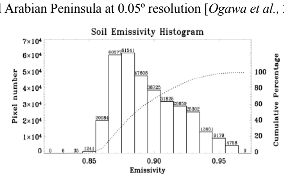

Figure 2. Emissivity histograms over bare soil pixels in Figure 1.

▪ We designed four experiments by replacing the CLM2 soil emissivity of 0.96 in our study region by 0.92, 0.90, 0.88, and 0.84, respectively, and one control run to test the sensitivity of climate and energy balances. In total, five 20-year simulations are executed from CLM2 coupled with Community Atmosphere Model (CAM2) using observed sea surface temperature and sea ice from 1979 to 1998.

▪ Both spatial distributions and regional averages of model outputs are analyzed mainly over non-vegetated grid cells. The regional averages are performed over a smaller area (17°N-30°N, 0°E-30°E), located in the center of our study region, to reduce possible impacts from vegetation and surrounding water.

▪ Five model variables, ground and air temperature, net and upward longwave radiation, and sensible heat flux, were examined here.

Sensitivity of Simulated Climates and Energy Balance to Soil Emissivity

▪ Analysis of satellite observations suggests that the soil emissivity in current models is too high over our study region.

▪ There is a linear relationship between changes in emissivity and changes in climate and energy balance variables. On average for the study region, a decrease of soil emissivity by 0.1 will increase ground and air temperature by about 1.1°C and 0.8°C and decrease net and upward longwave radiation by about 6.6 Wm^{-2} and 8.1 Wm^{-2}, respectively, at the ground surface. The decreased net longwave radiation (less emission) is mainly balanced by an increase of sensible heat flux of about 5.9 Wm^{-2}.

▪ These relations vary seasonally and diurnally. The temperature increases are slightly higher in winter than in summer and twice as large during nighttime as during daytime, while the sensible heat flux and longwave radiation show more change in summer/daytime than in winter/nighttime.

▪ When a more realistic emissivity value is used, the model cold bias over the Sahara in comparison with land surface air temperature observations could be partially reduced.

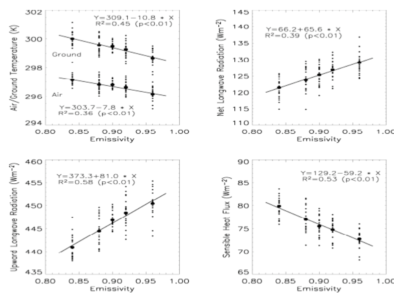

Figure 3. Changes in annual mean ground and air temperature, net longwave radiation, upward longwave radiation, and sensible heat flux as a function of the soil emissivity of 0.96, 0.92, 0.90, 0.88, and 0.84. The smaller dot represents annual means and the larger dot represents the 20-year average. A linear regression was fit to each variable for the annual means and its slope is estimated to assess how much the variable will change for a unit change of emissivity. The significance of each regression is also shown..

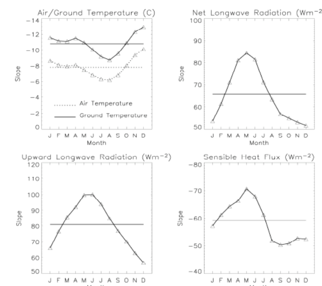

Figure 4. Seasonal variations of the estimated slopes for ground and air temperature, net longwave radiation, upward longwave radiation, and sensible heat flux. The slopes are estimated as Figure 3. The symbol "•" denotes the slopes that are statistically significant at the 5% level. The constant line denotes the estimated slope for the annual mean.

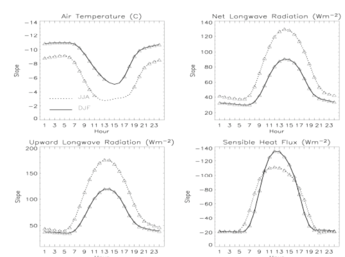

Figure 5. Diurnal variations in universal time of the estimated slopes for air temperature, net longwave radiation, upward longwave radiation, and sensible heat flux in winter (DJF) and summer (JJA). The slopes are estimated as Figure 3. The symbol "•" denotes the slopes that are statistically significant at the 5% level.

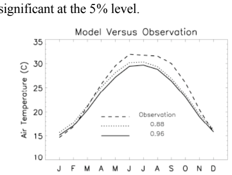

Figure 6. Seasonal variations in surface air temperature between observations and model simulations from the control run and the experiment with the soil emissivity of 0.88 averaged over 17°N-30°N, 0°E-30°E from 1979 to 1998.

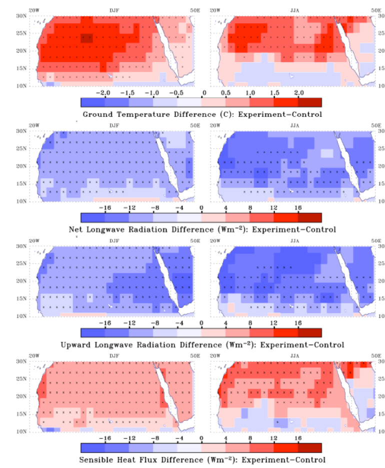

Figure 7. Spatial distributions of differences in ground temperature, net longwave radiation, upward longwave radiation, and sensible heat flux between the control run and the experiment with the soil emissivity of 0.84 averaged from 1979 to 1998 in winter (DJF) and summer (JJA). The symbol "x" denotes grid cells with a significant difference at the 5% level.

Soil Albedo versus Emissivity Relationship

▪ Considerable spatial variability in albedo and emissivity over deserts and semi-deserts has been observed from satellite observations.

▪ Emissivity over bare soils exhibits statistically significant correlations with albedo at both broadbands and most of spectral bands. It decreases linearly with albedo.

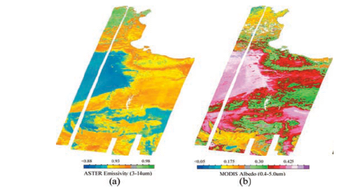

Figure 8. Spatial patterns of (a) ASTER emissivity and (b) MODIS broadband albedo (0.4-5.0 μm). The spatial correlation coefficient is R=-0.76 (p<0.01).

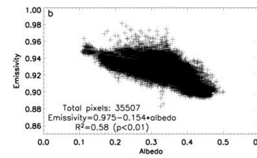

Figure 9. Scatter plot of relationships between ASTER emissivity and MODIS albedo (0.4-5.0 μm) in Figure 8.

Table 1. Correlations between MODIS spectral band albedos and ASTER emissivity.

MODIS bands	1	2	3	4	5	6	7
Correlation (R)	-.76	-.74	-.16	-.52	-.77	-.77	-.85

Conclusions

▪ There is a linear relationship between changes in emissivity and changes in climate and energy balance variables. On average for the study region, a decrease of soil emissivity by 0.1 will increase ground and air temperature by about 1.1°C and 0.8°C and decrease net and upward longwave radiation by about 6.6 Wm^{-2} and 8.1 Wm^{-2}, respectively, at the ground surface. The decreased net longwave radiation (less emission) is mainly balanced by an increase of sensible heat flux of about 5.9 Wm^{-2}.

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▪ Satellite observations suggests that the soil emissivity in current models is too high over the Sahara. When a more realistic emissivity value is used, the CLM2 cold bias in comparison with land surface air temperature observations could be partially reduced.

▪ Both bare soil albedo and emissivity show similar considerable spatial variability, larger than assumed by most climate models. Soil emissivity exhibits statistically significant correlations with albedos at both broadbands and most of spectral bands and decreases linearly with albedos. These results provides guidance for the possible inclusion of such correlation to specify albedo and emissivity in climate models.

Reference

Bonan et al., *Global Biogeochem. Cycles*, *16*, 2002.

Ogawa et al., *Earth Interaction*, *8*, 2004.

Zhou et al., *Geophy. Res. Lett.*, *31*, 2003.

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