Land-Surface Temperature Retrieval from MSG/SEVIRI over Brazil Using Emissivity Maps Derived from MODIS Data

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Abstract – In the present work a split-window (SW) algorithm is developed in the framework of Brazilian National Institute for Space Research (INPE)/Center for Weather Forecast and Climatic Studies (CPTEC) in order to derive land-surface temperature from Meteosat Second Generation (MSG)/Spinning Enhanced Visible and Infrared Imager (SEVIRI) data over Brazil. In addition, we have computed different regression models relating land-surface emissivity (LSE) in the SEVIRI thermal infrared (TIR) bands to LSE in MODIS bands. The obtained equations allow deriving LSE in SEVIRI TIR bands as a linear combination of emissivities retrieved from 5-km MODIS LSE product in order to be used as input to the developed SW algorithm.

Keywords: land-surface temperature, land-surface emissivity, MSG/SEVIRI, split-window.

1. INTRODUCTION

The purpose of this paper is to derive land-surface temperature (LST) from Meteosat Second Generation (MSG)/Spinning Enhanced Visible and Infrared Imager (SEVIRI) data over Brazil. Accordingly, we have developed a split-window (SW) algorithm in the framework of Brazilian National Institute for Space Research (INPE)/Center for Weather Forecast and Climatic Studies (CPTEC) that is particularly useful to estimate LST under tropical atmospheric conditions. The SW coefficients were estimated by means of regression analysis of simulated observed radiances as obtained from MODTRAN4 (Berk et al., 2000). The simulated database includes different geophysical conditions and relies upon atmospheric temperature and humidity profiles available in TIGR3 database.

It is worth noting that a priori knowledge of land-surface emissivity (LSE) is crucial to derive the LST when its retrieval is based on SW technique. SW algorithms have proven to be computationally efficient and therefore they are especially useful to be used with satellite data possessing high temporal resolution (e.g., 15 minutes for MSG/SEVIRI). However, the SW ability to retrieve accurately LST values depends on an adequate a priori knowledge of LSE. Accordingly information on LSE over regions where LSE is highly variable has to rely on methods that do not strictly assume an a priori knowledge of LSE. In this respect, validation of LSE retrievals from Moderate Resolution Imaging Spectroradiometer (MODIS) (Wan et al., 2002) have shown that the 5-km MODIS LSE product retrieved by the day/night method (Wan and Li, 1997) provide accurate results because the method allows a simultaneous retrieval of LSE and LST. Accordingly, we have also developed different regression models relating LSE in the SEVIRI thermal infrared (TIR) bands to LSE in MODIS bands. The above-mentioned models allow deriving LSE in SEVIRI TIR bands as a linear combination of emissivities retrieved from 5-km MODIS LSE product. The derived LSE maps are then used as input to the developed SW algorithm.

2. METHOD AND DATA

2.1 Land-Surface Emissivity

MODIS instrument on-board the Earth Observing System (EOS) is particularly useful for LSE and LST retrievals due to the global coverage, the radiometric resolution and the multiple TIR bands. The use of MODIS day/night LST algorithm allows estimating values of LSE in seven MODIS bands (20, 22, 23, 29, and 31-33).

As pointed out in Section 1, we will assume that the LSE in SEVIRI TIR channel c, $\varepsilon_{\mathrm{SEVIRI}\_c}$, may be expressed by means of linear combinations of MODIS channel emissivities

$$\varepsilon_{\mathrm{SEVIRI}\_c} = \sum_{\mathrm{MODIS}\_c=1}^{N} a_{\mathrm{MODIS}\_c}\,\varepsilon_{\mathrm{MODIS}\_c} + b_{\mathrm{MODIS}} \qquad (1)$$

where the predictors $\varepsilon_{\mathrm{MODIS}\_c}$ are the MODIS channel emissivities and a_{MODIS_c} and b_{MODIS} are the unknown model coefficients, which are obtained by means of linear regression analyses.

The planned procedure encloses three steps; a) preparing the databases; b) calibrating the regression models; and c) applying the developed models. We began by setting up the datasets of channel emissivities for 1) SEVIRI and 2) MODIS using the John Hopkins University (JHU) Spectral Library. Spectral LSE values obtained from JHU were then used to evaluate LSE for a) SEVIRI channels IR3.9, IR8.7, IR10.9, and IR12.0 and b) MODIS channels 20, 22, 23, 29, 31 and 32. The model given by equation (1) was then calibrated by using 182 samples from JHU Library respecting to natural surfaces including vegetation, soils, rocks, water, snow and ice. Finally, we have obtained LSE estimations for SEVIRI channels IR3.9, IR8.7, IR10.8 and IR12.0 within Meteosat-8 disk by applying the calibrated regressions to MODIS11C3 monthly CMG LST product. MODIS11C3 relies on results produced by the day/night algorithm and provides composites of monthly averaged temperature and emissivity values for MODIS bands 20, 22, 23, 29, and 31-33 at 0.05º

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latitude/longitude grids, i.e. to grid cells of 5.6 km by 5.6 km at the Equator. The regression equations were applied to MODIS11C3 for the 12 months of 2005.

2.2 Land-Surface Temperature

In this paper LST is given by the SW algorithm proposed by Sobrino and Raissouni (2000)

$$T_s = a_0 + a_1 T_{b10.8} + a_2 (T_{b10.8} - T_{b12.0}) + a_3 (T_{b10.8} - Tb_{12.0})^2 + a_4 (1-\varepsilon) + a_5 \Delta\varepsilon \tag{2}$$

where $T_{b10.8}$ ($T_{b12.0}$) is the brightness temperature in MSG/SEVIRI channels IR10.8 (IR12.0), $\varepsilon = (\varepsilon_{10.8} + \varepsilon_{12.0})/2$ is the average emissivity in MSG/SEVIRI channels IR10.8 and IR12.0, $\Delta\varepsilon = (\varepsilon_{10.8} - \varepsilon_{12.0})$ is the emissivity difference between the two channels, and a_k ($k = 0$ to 5) are SW coefficients estimated by means of a simulation procedure as described below.

In order to obtain estimates of LST from the SW algorithm (equation (2)), we have estimated the SW coefficients by means of regression analysis of simulated observed radiances as obtained from MODTRAN4. Accordingly, the following cases were considered in the simulation:

1) *Atmospheric Temperature and Humidity Profiles*: The database relies upon atmospheric temperature and humidity profiles from 499 profiles available in TIGR3 database. The air temperature at 2-meter (the profile first level), T_a, is 240 K and the maximum value is 312 K, whereas the water vapor ranges from 0.0 to 6.0 g·cm^{-2};
2) *LST*: We have considered LST as varying around T_a from T_a – 10.0 K to T_a + 15.0 K in steps of 5.0 K;
3) *LSE*: Based on results from Peres and DaCamara (2005) ε was considered as varying from 0.90 to 0.99 in steps of 0.01, and $\Delta\varepsilon$ as varying from –0.01 to 0.01 in steps of 0.01;
4) *Satellite Zenith Angles*: We have selected eight satellite zenith angles (SZA) covering a range of values from nadir to 60.0º.

In order to obtain an operational SW algorithm we have also derived a single algorithm that explicitly takes into account the MSG/SEVIRI SZA. For this purpose we have derived a set of new coefficients (b_{0k}, b_{1k} and b_{2k}) by fitting to a quadratic function of SZA the SW coefficients a_k, as computed for the eight specific SZA (ranging from nadir to 60º)

$$a_k = b_{0k} + b_{1k}\cos(SZA) + b_{2k}\cos(SZA)^2 \tag{3}$$

3. RESULTS

Linear models to convert LSE from MODIS bands are developed for each SEVIRI TIR channel: IR13.9, IR8.7, IR10.8 and IR12.0. It is worth noting that the MODIS bands have a narrower spectral range than SEVIRI bands. Such characteristic allows using different channels of MODIS to represent LSE in SEVIRI band. Accordingly, we have analyzed all possible channels combinations within the SEVIRI bands. Three parameters are used to evaluate the model fit: the root-mean square error (RMSE), the maximum error, and the adjusted coefficient of determination (R^2_{adj}). Results respecting to the best combination are shown in Table1 for SEVIRI channels IR3.9, IR8.7, IR10.8 and IR12.0.

Table 1. Results of SEVIRI/MODIS regression for SEVIRI channels

SEVIRI Channel	Used MODIS Channels	RMSE	Maximum Error	R^2_{adj}
IR3.9	20 and 23	0.003	0.014	0.999
IR8.7	29	0.009	0.040	0.984
IR10.8	31	0.007	0.020	0.964
IR12.0	31 and 32	0.002	0.008	0.992

The obtained linear models were finally applied to emissivities in MODIS channels 20, 22, 23, 29, 31 and 32 computed from MOD11C3 Monthly GMC LST Product for each month of 2005 over a region from 80 S to 80 N and 80 W to 80 E. Figures 1-6 display the above mentioned product in bands 20, 22, 23, 29, 31 and 32 for November 2005. Results for LSE in SEVIRI channels IR3.9, IR8.7, IR10.8 and IR12.0 are shown in Figures 7-10 for the South America window within Meteosat-8 disk. The original MOD11C3 Monthly GMC LST Product (geographical projection with 0.05° × 0.05°) was re-projected to the SEVIRI instrument resolution and to the normalized geostationary projection by averaging all pixels within each grid box.

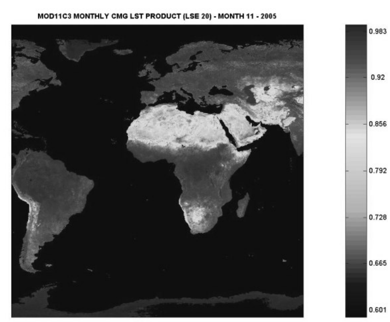

Figure 1. LSE in band 20 from MOD11C3 Product for November 2005.

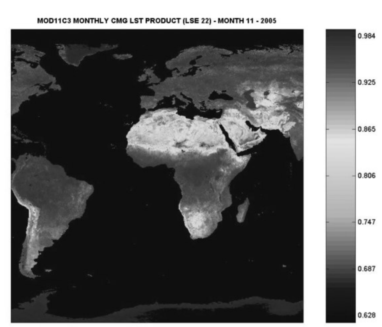

Figure 2. As in Figure 1, but respecting to band 22.

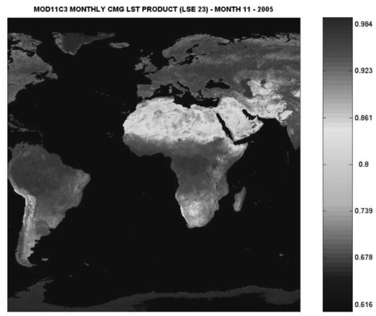

Figure 3. As in Figure 1, but respecting to band 23.

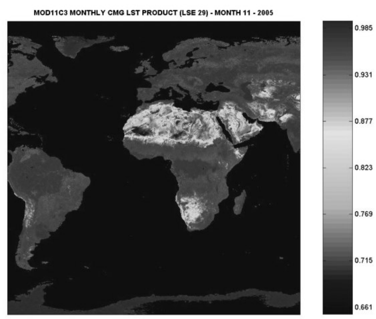

Figure 4. As in Figure 1, but respecting to band 29.

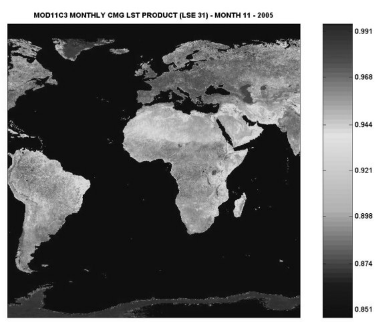

Figure 5. As in Figure 1, but respecting to band 31.

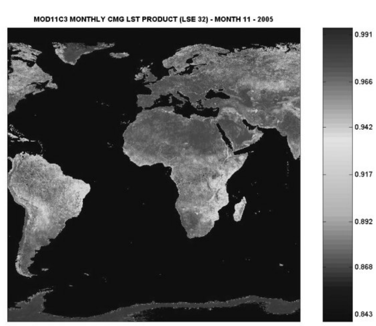

Figure 6. As in Figure 1, but respecting to band 32.

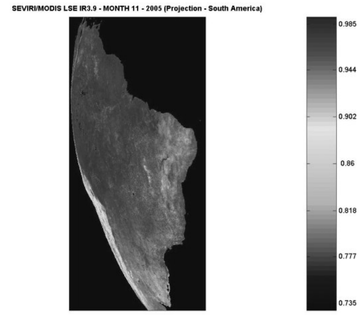

Figure 7. LSE for SEVIRI channels IR3.9 respecting to South America window within Meteosat-8 disk for November 2005 computed from MODIS Product shown in Figures 1-6.

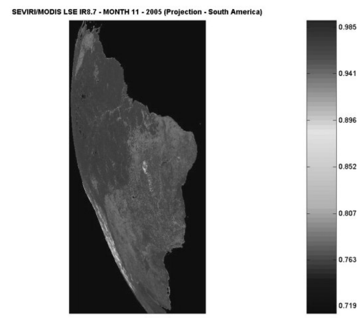

Figure 8. As in Figure 7, but respecting to channel IR8.7.

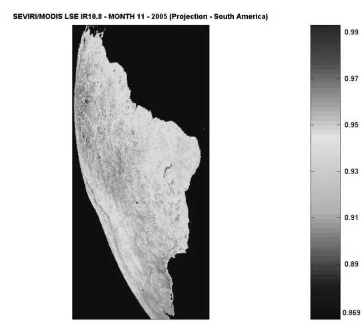

Figure 9. As in Figure 7, but respecting to channel IR10.8.

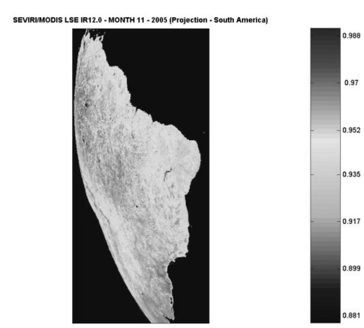

Figure 10. As in Figure 7, but respecting to channel IR12.0.

Results respecting to the usage of the SW algorithm (equation (2)) over the South America window are shown in Figures 11-14 for November 23 at 15:30, 17:00, 18:30 and 20:30 UTC, respectively.

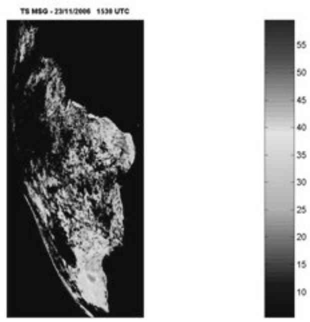

Figure 11. LST retrieval using the developed SW algorithm and the LSE maps for November 23 at 15:30 UTC.

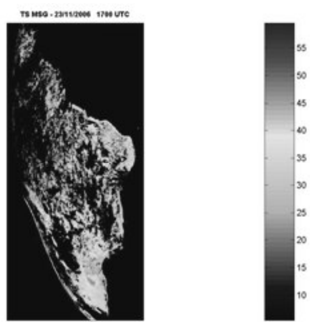

Figure 12. As in Figure 11, but respecting to 17:00 UTC.

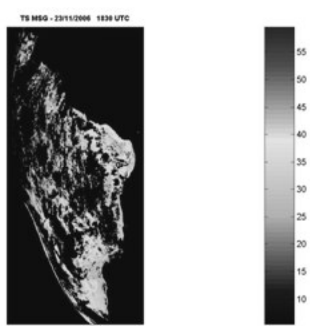

Figure 13. As in Figure 11, but respecting to 18:30 UTC.

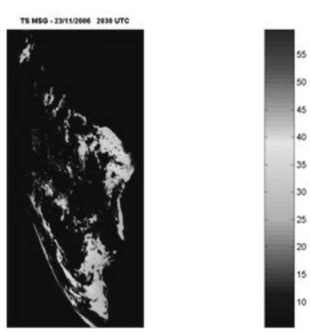

Figure 14. As in Figure 11, but respecting to 20:30 UTC.

4. CONCLUSIONS

We have developed in this work different regression models relating LSE in the SEVIRI TIR bands to LSE in MODIS bands. The obtained equations allow expressing LSE in SEVIRI channels IR3.9, IR18.7, IR10.8 and IR12.0 as a linear combination of emissivities retrieved from 5-km MODIS LSE product. The usefulness of the developed linear equations is supported by the obtained results from calibration, which present RMSE values less than 0.01 for all selected equations.

The calibrated regressions were also applied to real data from MODIS11C3 monthly CMG LST products with the purpose of producing LSE estimations in SEVIRI channels IR3.9, IR8.7, IR10.8 and IR12.0 within Meteosat-8 disk.

The derived LSE maps for Meteosat-8 were then used as input to a SW algorithm developed in the framework of INPE/CPTEC. The developed approach allows retrieving LST with unprecedented temporal resolution over the South American continent and therefore it is expected to improve our knowledge of surface processes and to bring new insights into the properties of the land surface.

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