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Anderson Ruhoff
Universidade Federal do Rio Grande do Sul

Walter Collischonn
Universidade Federal do Rio Grande do Sul

Adriano Rolim da Paz
Universidade Federal da Paraíba

Humberto Rocha
University of São Paulo

Validation of the newly improved global evapotranspiration algorithm (MOD16) in two contrasting tropical land cover types

ANDERSON L. RUHOFF[1,2], WALTER COLLISCHONN[2], ADRIANO R. PAZ[3], HUMBERTO R. ROCHA[4], LUIZ E. O. C. ARAGAO[5], YADVINDER S. MALHI[6], QIAOZHEN MU[7] & STEVE RUNNING[7]

1 *Instituto de Ciências Humanas e da Informação, Universidade Federal do Rio Grande, Rio Grande, Brasil. Email: anderson.ruhoff@ufrgs.br*

2 *Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil*

3 *Embrapa Monitoramento por Satélite, Campinas, Brasil*

4 *Instituto de Astronomia, Geofísica e Ciências Atmosféricas da Universidade de São Paulo, São Paulo, Brasil*

5 *School of Geography, University of Exeter, Exeter, UK*

6 *Environmental Change Institute, University of Oxford, Oxford, UK*

7 *School of Forestry, University of Montana, Missoula, USA*

Abstract This article present results from the NASA's EOS MOD16 Project, which aims to estimate global evapotranspiration (ET) using remote sensing and meteorological data. Our specific objective in this study was to evaluate the accuracy of the newly improved MOD16 algorithm at the Rio Grande basin, southern Brazil, using (i) ET observations at two eddy covariance (EC) flux tower sites in different land covers (savanna and sugar-cane plantations) and (ii) ET estimations from hydrological model during the year 2001. Our results show that MOD16 8-days average, monthly ET and annual ET values are consistent with observations of the two EC sites and the hydrological model. The RMSE and bias analyses indicate that the model overestimates ET values for savannas and underestimates these values for the sugar-cane and the whole basin average. Estimates are very consistent in the dry season, while the larger prediction errors occur in the wet season.

Key words eddy covariance, evapotranspiration, hydrological model, LBA, MGB, MOD16, MODIS, remote sensing

INTRODUCTION

Evapotranspiration (ET) plays an important role in global climate dynamics and primary production processes of terrestrial ecosystems. The monitoring of ET in both spatial and temporal scale is a challenge for understanding the hydrology and energy partitioning between the surface and the atmosphere in different biomes, such as tropical biomes, which represent major sources of ET and control of global atmospheric circulation. Many efforts have been made to improve the spatial and temporal estimates of ET based on remote sensing data, at regional, continental and global scales. However, data from optical and thermal remote sensing have some limitations, mainly caused by cloud contamination, scale factors and low frequency of data collection, when compared with meteorological models or radiative transfer models.

Developing a robust algorithm to estimate global ET is a significant challenge because traditionally ET models require explicit characterization of numerous surface and atmospheric parameters which are difficult to determine globally. The MOD16 algorithm, improved from beta version (Mu et al., 2007), combines remote sensing data and meteorological data to estimate global ET. Our objective therefore, is to evaluate the spatial (site and basin) and temporal (8 days, monthly and annual) accuracy of the MOD16 algorithm in two contrasting land covers in Brazil: a tropical savanna biome and a sugar-cane plantation. Specifically, we aimed to compare MOD16 estimates with ET observations from (i) two eddy covariance (EC) flux tower sites in the different land covers and (ii) MGB hydrological model during the year 2001.

MATHERIAL AND METHODS

Study area

The Rio Grande river is the main tributary of the Paraná river in its upper basin and drains an area of about 145,000 km^2. Mean annual rainfall over the basin is approximately 1400 mm and is highly concentrated during summer. Average annual ET is 900 mm yr^{-1}. Seasonally, ET ranges from 1 mm day^{-1} (during dry season, from June to August) to 6 mm day^{-1} (during wet season, from December to February). The EC study sites, which are part of the Large-Scale Biosphere Atmosphere Experiment in Amazonia (LBA), have been described extensively (Rocha et al., 2002; Cabral et al., 2003). These flux towers cover two different land cover types: (i) PDG site, which is characterized by a mixture of natural savanna grasslands and savanna woodlands and (ii) USE site, which is characterized by large sugar-cane plantations.

MOD16 algorithm

The MOD16 algorithm is based on the Penman-Monteith equation and calculates both canopy conductance and soil evaporation using a combination of remote sensing and global meteorological data. The Global Meteorological Assimilation Office data (GMAO) at 1.00° x 1.25° resolution were used as meteorological inputs. This product includes: daily total downward radiation, air temperature and vapor pressure. Remote sensing inputs are derived from MODIS data and include MOD12Q1 land cover (Friedl et al., 2002), MOD13A2 EVI (Huete et al., 2002), MOD15 LAI/FPAR (Myneni et al., 2002) and MOD43C1 albedo (Schaaf et al., 2002). According to Mu et al. (in preparation), improvements to the MOD16 over the previous version (Mu et al., 2007) included: (i) separation of canopy into wet and dry surface, which provides water lost estimates of canopy evaporation from the wet canopy surface and the canopy transpiration from dry surface; (ii) consideration of saturate wet surface and soil moisture, in which the ground surface evaporation includes potential evaporation from the saturate wet surface and actual evaporation from the soil moisture ; (iii) inclusion of daytime and night-time ET estimates; (iv) the amount of soil heat flux is estimated and now only occurs to the radiation partitioned on the ground surface; (v) improvement of methods for estimating stomatal conductance, aerodynamic resistance and vegetation cover fraction.

MGB hydrological model

The MGB is a large scale model, which is composed of modules for calculating the soil water budget, evapotranspiration, runoff and streamflow (Collischonn et al, 2007). The Grouped Response Unit (GRU) (Kouwen et al., 1993) approach is used for hydrological classification of all areas with a similar combination of soil and land cover without consideration of their exact locality within the grid cell. A grid contains a limited number of distinct GRUs. ET is computed for each GRU using Penman-Monteith equation (Shuttleworth, 1993).

RESULTS AND DISCUSSION

Validation of ET estimates from the MGB hydrological model

The root mean square error (RMSE) and BIAS analyses indicate that MGB overestimates daily ET in 0.06 mm day^{-1} at PDG site and underestimates in 0.13 mm day^{-1} at USE site when compared with EC flux tower sites. At PDG site, the correlation coefficient was R^2=0.80 and RMSE was ±0.72 mm day^{-1}, while at USE site, the correlation coefficient was R^2=0.82 and RMSE was ±0.51 mm day^{-1}. The estimation of ET using the MGB showed better results at monthly and annual time scales. Considering the monthly ET at PDG site, the correlation coefficient was 0.91. The differences between estimated and observed ET ranged from 1 to 29 mm m^{-1}, with RMSE of ±11 mm m^{-1} (15% of the average monthly ET). For annual ET, the difference was less than 30 mm yr^{-1}, representing 3.5% of annual ET checked at PDG site. At USE site, the correlation coefficient was 0.98 and the differences between estimated and observed ET ranged from 0 to 10mm m^{-1} , with RMSE of ±4.0 mm m^{-1} (5% of the average monthly ET). For annual ET, the difference was less than 15 mm yr^{-1}, representing 1.2% of annual ET checked at USE site.

MOD16 ET validation

The ET average based on a 3 x 3 window over the 1km resolution MODIS pixels surrounding each site was compared with the EC flux tower observations.

At the PDG site (Fig. 1a), the correlation coefficients between the ET observations and MOD16 algorithm estimates for the 8-days average was R^2=0.79 (p<0.00001), RMSE was ±0.78 mm day^{-1} and mean bias was +0.54 mm day^{-1}. Considering monthly ET, the correlation coefficient was R^2=0.89, RMSE was 19 mm m^{-1} (32% of the average monthly ET) and mean bias was 15 mm m^{-1}. The annual ET observed during the year 2001 was 993 mm yr^{-1} and annual ET estimated was 1183 mm yr^{-1}, 19% higher than observed ET. It is important to note however that the PDG site, which is located in the savanna area, is misclassified as an evergreen broadleaf forest at MOD12Q1 Land Cover data. Misclassification of the land cover may explain the ET overestimation. Misclassification leads to the selection of wrong parameters for vapor pressure deficit (VPD) and minimum air temperature for stomatal conductance constraints, resulting in less accurate ET estimates. Daily total downward radiation was the most important single variable, explaining 70% of the variance in ET. LAI was also important, explaining 62% of the variance in ET.

At the USE site (Fig. 1b), the correlation coefficients between the ET observations and MOD16 algorithm estimates for the 8-days average was R^2=0.82 (p<0.00001) and RMSE was ±0.46 mm day^{-1}. Considering monthly ET, the correlation coefficient was R^2=0.86, RMSE was 15 mm m^{-1} (20% % of the average monthly ET) and mean bias was –10 mm m^{-1}. Annual ET observed was 1025 mm yr^{-1} and annual ET estimated was 893 mm yr^{-1}, 13% lower than observed ET. The variance in ET was explained by FPAR (84%), LAI (82%) and vapor pressure deficit (75%). Despite the differences in absolute values, both ET profiles well represented the seasonal dynamics of natural savannas (PDG) and agricultural (USE) systems.

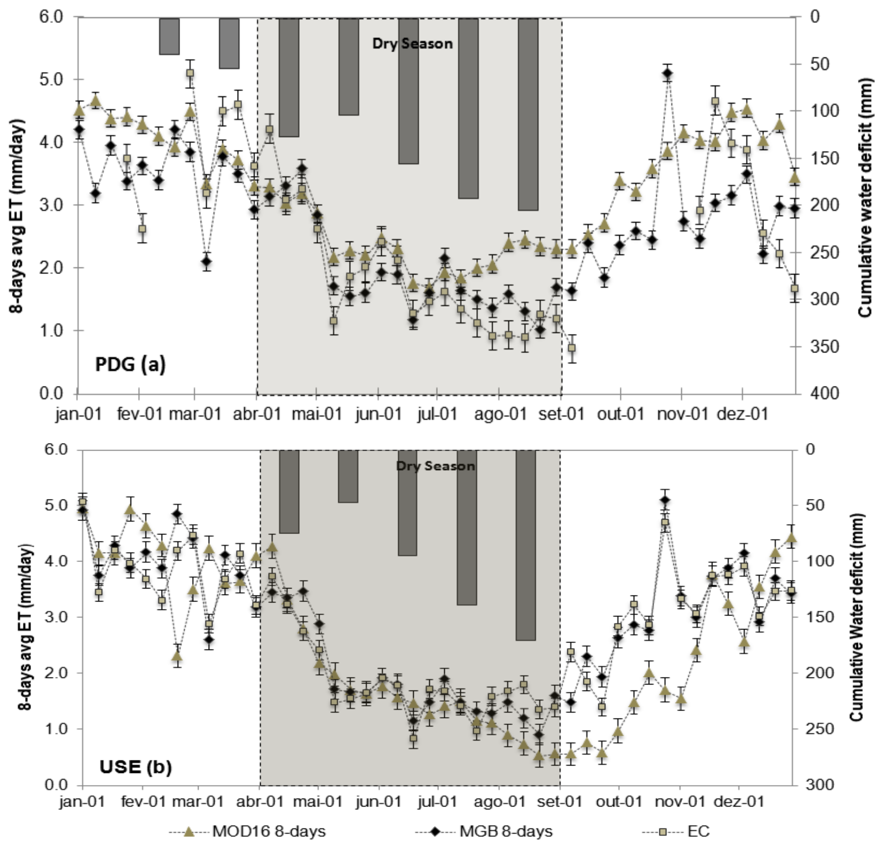

Fig. 1 Time series of tower measurement (EC) and model predictions (MGB and MOD16) at PDG site (a) and USE site (b). Climatological dry season is shaded, left *y*-axis is ET (mm day^{-1}), right *y*-axis is the cumulative water deficit (mm) and *x*-axis is year (2001).

The correlation coefficient calculated between ET estimates from MOD16 and MGB at the basin scale varied between R^2=0.31 and R^2=0.94, with an average of R^2=0.80. We observed a low RMSE in the dry season (less than 0.5 mm day^{-1}) and high in the wet season (more than 1.0 mm day^{-1}). MGB annual ET estimated was 934 mm yr^{-1} and MOD16 annual ET estimated was 733 mm yr^{-1}, 21% lower MGB ET (Fig. 2). The ET estimations from MOD16 are much lower in the wet season than the ET predicted from MGB, probably because LAI is underestimated and seasonality is very small.

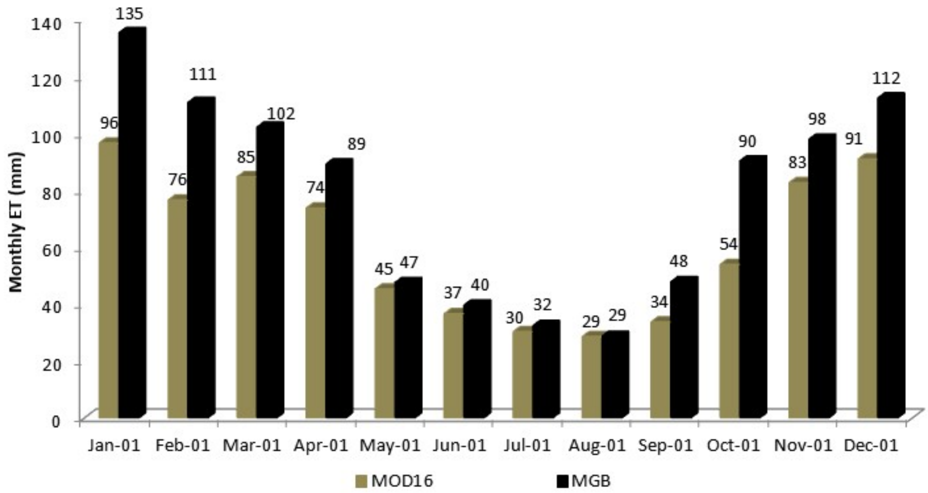

Fig. 2 Comparison of the monthly ET estimated using MOD16 algorithm and MGB hydrological model at basin scale. The *y*-axis is ET (mm) and *x*-axis is the year (2001).

CONCLUSIONS

The existing biases between MOD16 ET and EC observations and hydrological models may be influenced by algorithm input data, such as LAI (MOD15), land cover (MOD12) and GMAO data. Underestimations of LAI may results in underestimates of ET even if other input data are relatively accurate. MOD16 ET estimates are very consistent in the dry season, while the larger prediction errors occur in the wet season.

REFERENCES

Cabral, O.M.R.; Rocha, H.R.; Ligo, M.A.; Brunini, O.; Dias, M.A.F.S. (2003) Fluxos turbulentos de calor sensível, vapor d'água e CO2 sobre plantação de cana-de-açúcar (Saccharum sp) em Sertãozinho, SP. *Revista Brasileira de Meteorologia* **18**(1), 61-70.

Collischonn. W.; Allasia, D.; Silva, B.C.; Tucci, C.E.M.. (2007) The MGB-IPH model for large scale rainfall runoff modeling. *Hydrological Sciences Journal* **52**(5), 878–895, DOI: 10.1623/hysj.52.5.878.

Friedl, M.A.; McIver, D.K.; Hodges, J.C.F.; Zhang, X.Y.; Muchoney, D.; Strahler, A.H. et al. 2002 Global land cover mapping from MODIS: Algorithms and early results. *Remote Sensing of Environment* **83**(1–2), 287−302.

Huete, A.; Didan, K.; Miura, T.; Rodriguez, E.P.; Gao, X.; Ferreira, L.G. 2002 Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* **83**, 195−213.

Kouwen, N.; Soulis, E.; Pietroniro, A.; Donald, J.; Harrington, R. (1993) Grouped response units for distributed hydrologic modeling. *Journal of Water Resources Planning and Management* **119**(3), 289–305.

Mu, Q.; Heinsch, F.A.; Zhao, M.; Running, S.W. (2007) Development of a global evapotranspiration algorithm based on MODIS and global meteorology data. *Remote Sensing of Environment* **111**(4), 519–536.

Mu, Q.; Zhao, M.; Running, S.W. Improvements of the MODIS Terrestrial Evapotranspiration Algorithm. (*in preparation*).

Myneni, R.B.; Hoffman, S.; Knyazikhin, Y.; Privette, J.L.; Glassy, J.; Tian, Y. et al. (2002) Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data. *Remote Sensing of Environment* **83**(1–2), 214−231.

Rocha, H.R.; Freitas, H.C.; Dias, M.A.F.S.; Ligo, M.A.; Cabral, O.M.R.; Tannus, R.N. Rosolem, R. (2002) Measurements of CO2 exchange over a woodland savanna (Cerrado Sensu stricto) in southeast Brasil. *Biota Neotropica* **2**(1), 1–11.

Schaaf, C.B.; Gao, F.; Strahler, A.H.; Lucht,W.; Li, X.; Tsang, T.; et al. (2002) First operational BRDF, Albedo and Nadir Reflectance Products from MODIS. *Remote Sensing of Environment* **83**, 135−148.

Shuttleworth, W.J. (1993). Evaporation. In: Maidment, D.R. *Handbook of Hydrology*. Mc GRaw Hill, New York, USA.