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Validation of Diverse Evapotranspiration Estimation Methods using the Long-term Water Balance in the Amazon River Basin

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1. INTRODUCTION

Evapotranspiration is an important component of the Amazon hydrological balance. Understanding the spatial variability of evapotranspiration in the Amazon is essential to understand climatic dynamics at regional, continental and even global scales (Werth and Avissar, 2004). Furthermore, regional estimates of actual and potential evapotranspiration are needed for tasks of water resources engineering planning and management. The long-term water balance equation, Q=P-EVT, allows to estimate the long-term mean average annual runoff (Q) of any river basin, as a function of the long-term mean annual precipitation (P) and the long-term mean actual evapotranspiration (EVT).

Distributed fields of long-term actual and potential evapotranspiration are estimated in this work, using the methods introduced by Coutagne (1954), Thornthwaite (1948), Turc (1955, 1962), Penman (1948) with Priestley and Taylor approximation (1972), Morton (1983), Choudhury (1999), and Zhang et al. (2001). All these methods are well detailed in the literature and therefore will no be reviewed here. For the Penman method which solely provide estimate of potential evapotranspiration, estimates of actual evapotranspiration were obtained using the formulation proposed by Budyko (1974). Table 1 contains details of required parameters and references used to estimate the different evapotranspiration methods used in this work.

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2. DATA AND METHODOLOGY

The long-term water balance equation for river basins can be used to estimate long-term average flows throughout the entire river network (Eagleson, 1994). For validation purposes, river discharge data from 76 gauged sites throughout the Amazon River basin were compared with the long-term river discharges estimated through the long-term water balance equation, using the different EVT methods. Long term climatic data from the Climate Research Unit (CRU) are used. This is a global, monthly mean data set of temperature, precipitation, diurnal temperature range, relative humidity, wind speed, at 10'x10' Latitude/Longitude resolution, for the period 1961- 1990 (New et al., 1999; 2000; 2002, Mitchell et al., 2002) and it may be found at http://www.cru.uea.ac.uk/cru/data/tmc.htm. The net radiation data from the Surface Radiation Budget (SRB) project, for the period 1986-1995 and 1° x 1° grid resolution (Stackhouse et al., 2000), is used to estimate evaporation in different methods. The monthly historical river discharge records for the Amazon basin at 76 locations and the channel network of the Amazon River (Costa et al., 2002) are used to validate the actual evapotranspiration methods through the long-term water balance.

3. RESULTS

Figure 1 shows diverse estimates of long-term average annual potential evapotranspiration, using the methods by (a) Morton, (b) Modified Penman (with Priestley and Taylor approximation), (c) Thornthwaite and (d) Turc. Figure 2 shows maps of the long-term average annual actual evapotranspiration estimated using the methods by (a) Coutagne, (b) Choudhury, (c) Morton, (d) Budyko (Penman with Priestley and Taylor approximation), (e) Zhang et al., and (f) Turc. Figure 3 illustrate the verification of diverse EVT methods, by comparing observed and estimated long-term average river flows at 76 river gauging stations in the Amazon River basin, in which r.m.s. refers to root mean square estimation error.

Table 1. Methods used to estimate Evapotranspiration.

Method	Type	Input Parameter	Sources*
Coutagne	Actual	Annual Precipitation Mean Annual Temperature	*1* *1*
Thornthwaite	Potential	Monthly mean temperature Mean Annual Temperature	*1* *1*
Turc	Actual and Potential	Annual Precipitation Mean annual temperature	*1* *1*
Penman with Priestley and Taylor approximation	Potential	Monthly mean temperature Monthly Mean Diurnal temperature range Altitude Monthly Net radiation	*1* *1* *1* *2*
Morton	Actual and Potential	Monthly mean temperature Monthly Mean Diurnal temperature range Altitude Monthly Net radiation	*1* *1* *1* *2*
Budyko	Actual	Potential evaporation (Penman method with Priestley and Taylor approximation) Precipitation	*3, 4* *1*
Choudhury	Actual	Annual precipitation Mean Annual net radiation monthly historical streamflow records	*1* *2* *4*
Zhang	Actual	Annual Potential evaporation (Penman method with Priestley and Taylor approximation) Annual Precipitation	*3, 4* *1*

***Sources:** 1: *New et al.* (2002); 2*: Stackhouse et al.* (2000); 3: *Penman* (1948), 4*: Priestley and Taylor* (1972); 5: *Costa et al.* (2002)

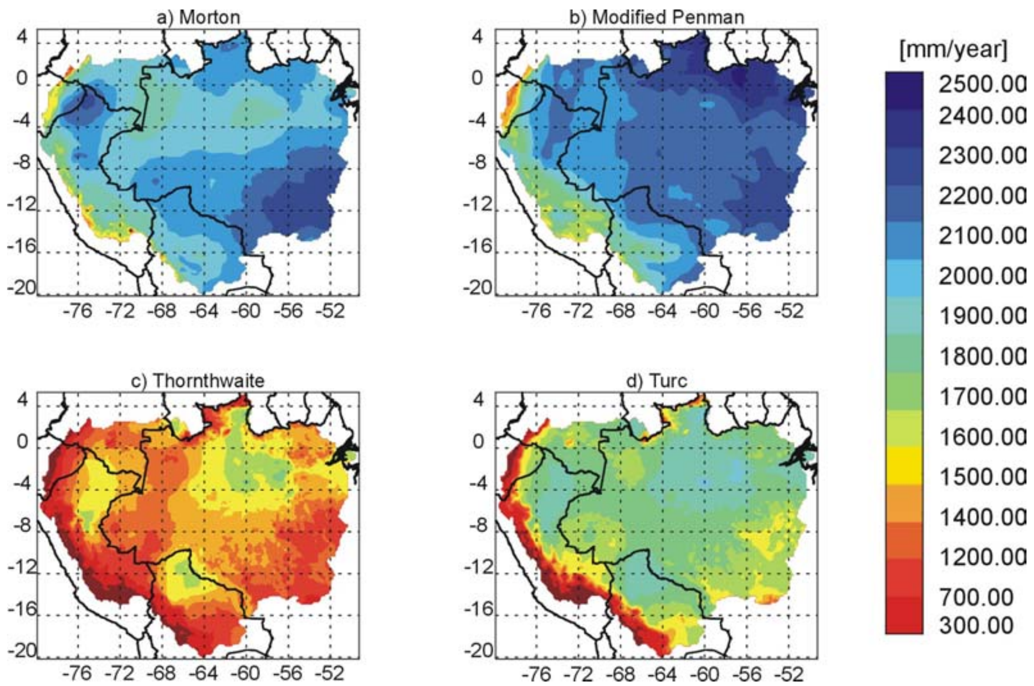

Figure 1. Long-term average annual potential evapotranspiration estimated with the methods by (a) Morton, (b) Modified Penman (with Priestley and Taylor approximation), (c) Thornthwaite and (d) Turc.

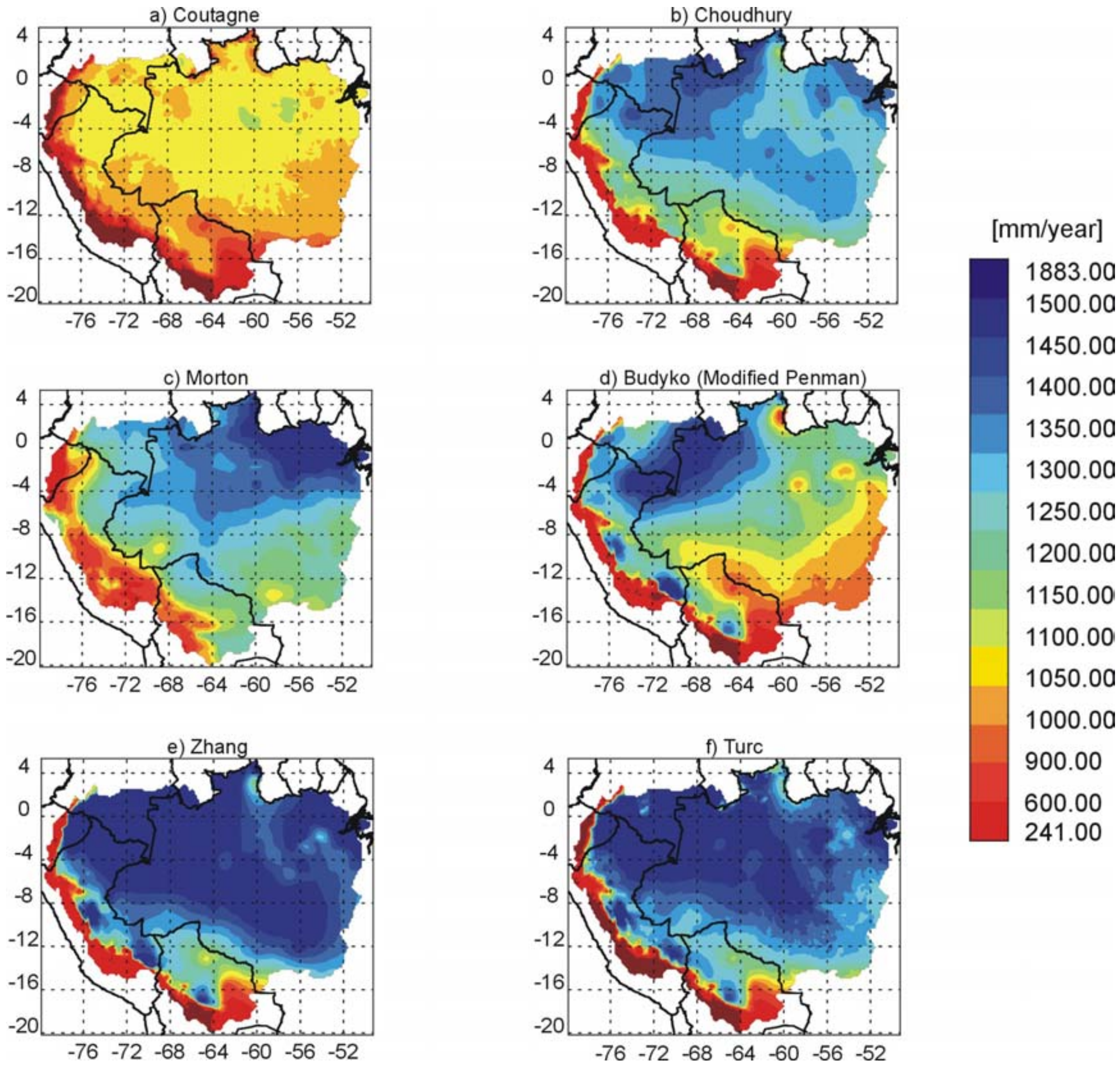

Figure 2. Long-term average annual actual evapotranspiration estimated using the methods by (a) Coutagne, (b) Choudhury, (c) Morton, (d) Budyko (Penman with Priestley and Taylor approximation), (e) Zhang and (f) Turc.

The performance of the different methods used to estimate actual evaporation were compared with estimates from long-term water balance equation in gauged basins. Estimation of average river flows is performed through integration of precipitation and evapotranspiration over the river basins draining through the 76 gauged stations. Results indicate that the methods of Turc and Thornthwaite, which are based on temperature, tended to underestimate potential evapotranspiration, when compared with those of Morton and Penman (with Priestley and Taylor approximation) (Figure 1). The Coutagne method shows the lowest values of actual evapotranspiration, and the Zhang and Turc methods produce the higher estimates. The methods by Choudhury, Morton and Budyko (obtained using potential evaporation from Penman with Priestley and Taylor approximation), show quite similar estimates (Figure 2). The method of Choudhury (1999) uses the long-term water balance equation to fit an optimal parameter (α) to estimate the long-term annual actual evapotranspiration. Choudhury found a this parameter to be α=1.8, for large river basins and α=2.6 for field plots, and therefore the parameter α depends on the spatial scale. We found a mean optimal value of α=2.1 for all sub-basins of the Amazon River basin, which minimizes the error in the long-term balance equation compared with historical streamflow data.

Figure 3 shows observed and estimated long-term river flows, using the different evapotranspiration methods. Our result indicate that the methods of Choudhury (18.7), Turc (20.9%), Zhang (21.6%), Budyko (22.3%) exhibitthe lowest errors in closing the long-term water balance equation.

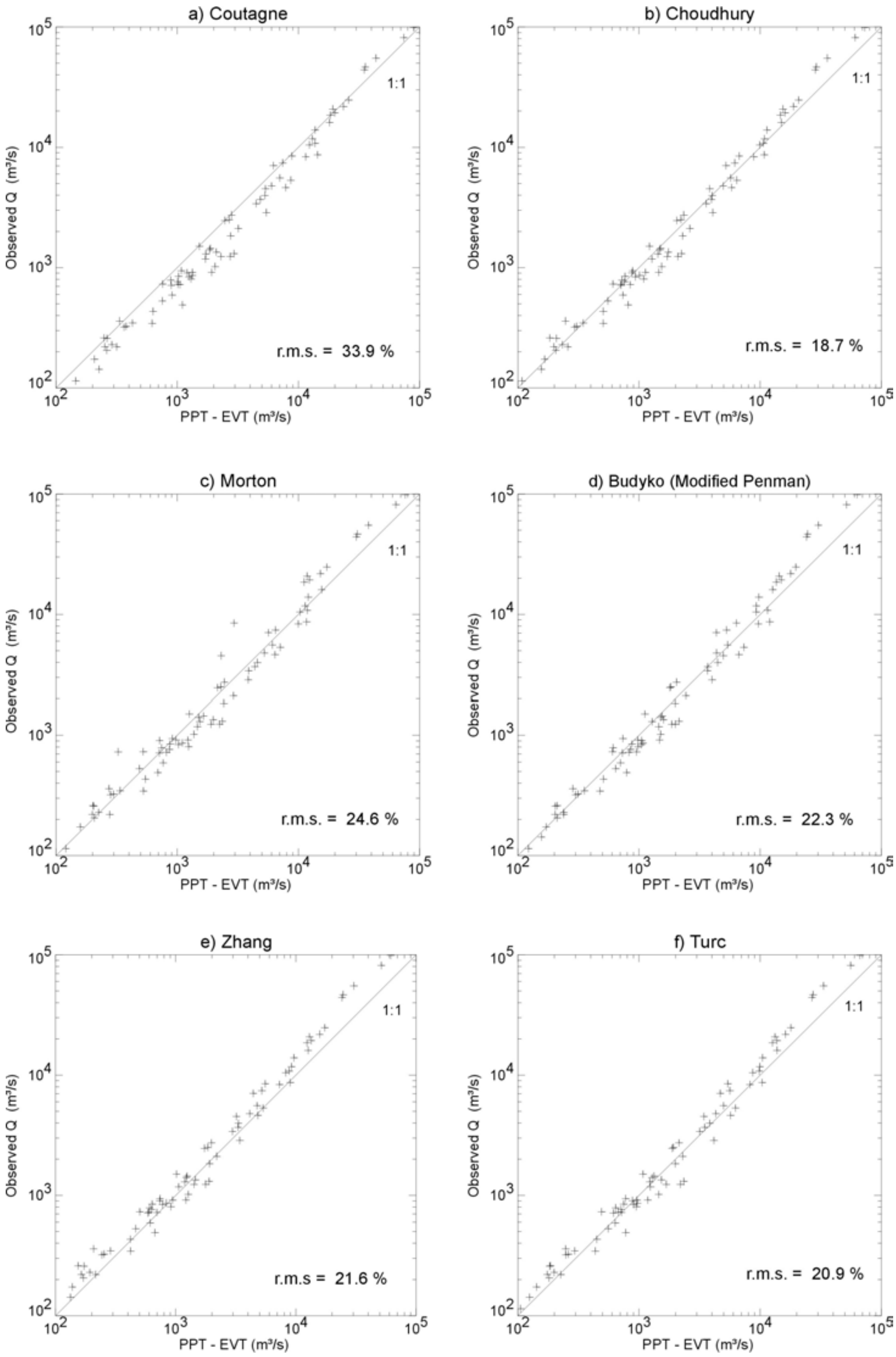

Figure 3. Comparison of observed and estimated long-term average river flows at 76 river gauging stations in Amazon basin, using diverse evapotranspiration methods. r.m.s. refers to root mean square error estimation.

Few accurate multi-year measurements are available to test the Choudhury evapotranspiration method. At Santarem (3.05°S, 54.54°W), Manaus (2.45°S, 60.11°W), and Ji-Parana (10.6°S, 61.5°W) mean actual evaporation values are estimated as 3.75, 3.52, and 3.7 mm/day^{-1} respectively, in good agreement with observations: 3.07 (Hutyra et al., 2005) and 3.51 (da Rocha et al., 2004) in Santarem; 3.05 (Malhi et al, 2002) and 3.45 (Shuttleworth et al., 1984) in Manaus; and 3.69 (wet season) and 3.83 (dry season) (Von Randow et al., 2004) in Ji-Parana.

4. CONCLUSIONS

Diverse methods have been applied to estimate the long-term annual average fields of actual and potential evapotranspiration over the

Amazon River basin, including those by Morton, Penman (Priestley and Taylor), Thornthwaite and Turc, for potential evapotranspiration, and those by Coutagne, Choudhury, Morton, Budyko, Zhang and Turc, for actual evapotranspiration.

The four methods of estimating potential evaporation evaluated here exhibit wide differences in range and spatial variation. The higher estimated values are the ones obtained using the Morton and Penman methods and the lowest in the Thornthwaite and Turc methods.

Validation of diverse estimates of long-term actual evapotranspiration is performed via the long-term water balance equation at 76 river gauging stations. Our results show that the Choudhury and Turc methods of actual evapotranspiration exhibit the lowest errors, with values of 18.7% and 20.9%, respectively. It is worth noting that these two methods require solely precipitation and temperature input data. Even though there are not many observations to validate the results, the Choudhury method show good agreement with the few accurate multi-year measurements existent.

Improvement of these results can be obtained through better estimates of the long-term mean annual precipitation field, but also using a larger data set of observed river stream flows over the Amazon, especially for smaller drainage areas. Our results shed light towards understanding the hydrologic cycle of the Amazon River basin, of fundamental importance at global scale.

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