Estimation of Evapotranspiration in the Amazon River Basin Using the Atmospheric Water Balance Method

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Abstract

This study investigates the seasonal changes of evapotranspiration in the Amazon river basin during the FGGE period. The relationship between basin storage and evapotranspiration is also investigated. The atmospheric water balance method and that of the basin are used for the analysis, using the global objective analyzed data set, precipitation data and discharge data. Since the seasonal change pattern of precipitation shows good correspondence to that of water vapor flux convergence, monthly evapotranspiration remains almost constant within a year. On the other hand, the seasonal changes of basin storage are very great and it is concluded that evapotranspiration in the entire Amazon river basin is not affected by the seasonal changes of basin storage even in the dry season. It is also found that the role of evapotranspiration in the water cycle in the basin is relatively more important in the dry season than in the rainy season.

Key words: seasonal change, evapotranspiration, global objective analyzed data set, water vapor flux convergence, water cycle

1. Introduction

It is very important to estimate the accurate value of evapotranspiration in order to investigate the water budget and water circulation in the basin. In the Amazon river basin, it is known that the annual evapotranspiration is about one half of the annual precipitation (e.g. Salati, 1987) and evapotranspiration contributes considerably to the local water circulation in the basin (Salati et al., 1979). However, the seasonal changes in the role of evapotranspiration on the water cycle in the basin and the relationship between evapotranspiration and basin storage have not been clarified yet. In this study, both of these problems are investigated in the case of the FGGE period (the First GARP Global Experiment, from December 1978 to November 1979), when special atmospheric observation was carried out on a global scale.

2. Water Balance Equation

The atmospheric water balance equation and that of the basin are connected with the term \(E - P\) and can be written as

\[
\frac{dS}{dt} + R_o = -(E - P) = -\nabla \cdot \vec{Q} - \frac{dW}{dt}.
\]

Where, \(S\), \(R_o\), \(E\), and \(P\) are basin storage, runoff near the river mouth, evapotranspiration, precipitation, respectively. \(\nabla\) is the horizontal differential operator. \(\vec{Q}\) and \(W\) are the vertically integrated water vapor flux vector and precipitable water, respectively. Averaged over one year, both the interannual variability of basin storage and precipitable water are negligible. Therefore the annual runoff should be equal to the annual water vapor flux convergence.

In equation (1), the seasonal changes of basin storage are difficult to measure directly. However, the residence time of water vapor is only about 5.5 days in the Amazon river basin (Marques et al., 1979), monthly evapotranspiration may be estimated as a difference between monthly precipitation and monthly water vapor flux convergence. After estimating monthly evapotranspiration, monthly change of basin storage can be estimated by the equation (1).
3. Data

The areal precipitation is estimated using the Monthly Climatic Data for the World published by the National Oceanic and Atmospheric Administration (NOAA). The Thiessen method (Thiessen, 1911) is adopted and its annual value is estimated to be 2,152.6 mm/year.

Precipitable water and water vapor flux convergence are calculated using one of the FGGE "main" III-b data sets (Hereafter called FGGE III-b data) analyzed at the European Center for Medium-Range Weather Forecasts (ECMWF).

Runoff near the river mouth is estimated using discharge data prepared by the Global Runoff Data Centre. The summation of monthly runoff at Altamira and Obidos is regarded as the total runoff of the Amazon river basin (Fig. 1). The discharge data from the FGGE period are available in the case of Altamira, but as for Obidos, they are missing from 1979. Therefore the average runoff when discharge data are available (from 1928 to 1947, 1969, from 1971 to 1978, and from 1980 to 1983) is assumed to be the runoff at Obidos during the FGGE period.

![Fig. 1](image1.jpg) Fig. 1 The area, drainage map and discharge stations of the Amazon river basin. (A: Altamira, O: Obidos, P: Porto Velho)

![Fig. 2](image2.jpg) Fig. 2 The seasonal changes of precipitation, modified water vapor flux convergence and evapotranspiration in the basin.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Drainage Area, The Annual Discharge and Runoff of the Amazon River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
<td>Site</td>
</tr>
<tr>
<td>Leopold (1962)</td>
<td>(M)</td>
</tr>
<tr>
<td>Henning (1970)</td>
<td>(E+T)</td>
</tr>
<tr>
<td>Unesco (1971)</td>
<td>(O)</td>
</tr>
<tr>
<td>(M)</td>
<td>6,300</td>
</tr>
<tr>
<td>Nace (1972)</td>
<td>(O)</td>
</tr>
<tr>
<td>Unesco (1974)</td>
<td>(M)</td>
</tr>
<tr>
<td>Bargwartner and Reichel (1975)</td>
<td>(O)</td>
</tr>
<tr>
<td>Villa Nova et al. (1976) (^1)</td>
<td>(O)</td>
</tr>
<tr>
<td>(M)</td>
<td>6,000</td>
</tr>
<tr>
<td>Milliman and Meade (1983)</td>
<td>(M)</td>
</tr>
<tr>
<td>Nishizawa and Koike (1992)</td>
<td>(O)</td>
</tr>
<tr>
<td>(M)</td>
<td>6,500</td>
</tr>
</tbody>
</table>

For this study:
- **Xingu river** \( (A) \) 450 8,400 591 1978.12–1979.11
- **Total** \( (O+A) \) 5,090 163,500 1,014

(M): River mouth of the Amazon river basin, (E+T): Entire Amazon and Tocantins river basin

(These sites, Discharge is not a direct observation but an extrapolated value)


Blank of the period shows that it is not noted in each research.

\(^1\): Cited from Oltman (1967)
4. Results

The annual water vapor flux convergence and the annual runoff are estimated to be 737.3 mm/year and 1,013.5 mm/year, respectively. For comparison, the annual runoff values obtained by previous studies are shown in Table 1. Except for Leopold (1962), all the annual runoffs are more than 800 mm/year and their average is 977 mm/year. The underestimation of the annual water vapor flux convergence is due to the characteristics of the FGGE III-b data analyzed at the ECMWF, as suggested by Masuda (1988). The annual runoff obtained by this study is similar to that of previous ones and it seems to be more precise and reliable than the annual water vapor flux convergence. Therefore the annual water vapor flux convergence should be modified to meet the annual runoff, and hereafter the water vapor flux convergence multiplied the factor 1.37 (Abbreviated to modified water vapor flux convergence in the following) is treated in the following analysis.

The seasonal change pattern of precipitation is in good agreement with that of modified water vapor flux convergence and monthly evapotranspiration is found to remain almost constant during the FGGE period (Fig. 2). This result does not contradict previous studies based on direct evapotranspiration measurements (e.g. Jordan and Heuveldop, 1981, Shuttleworth, 1988) and indicates that the function of evapotranspiration in the tropical forests is very active regardless of season. On the other hand, the seasonal changes in basin storage is very great within a year (Fig. 3) and it is concluded that evapotranspiration in the Amazon river basin is not affected by the seasonal changes in basin storage even in the dry season.

The annual evapotranspiration ratio obtained by this study is about 53 percent and does not contradict the results of previous studies (See Table 3 of Salati, 1987). However, the seasonal changes of the evapotranspiration ratio are very great within a year (Fig. 4). In the rainy season, the monthly evapotranspiration ratio is estimated to be about 30 to 40 percent, though in the dry season it is estimated to be much larger. Since water vapor flux convergence becomes near zero in the dry season (Fig. 2), evapotranspiration is almost equal to precipitation during this period. Therefore the role of evapotranspiration in the water cycle in the Amazon river basin is found to be relatively more important in the dry season than in the rainy season.

5. Conclusion

The following results are obtained by this study.

1. Monthly evapotranspiration in the Amazon river basin remains almost constant over one year during the FGGE period.
2. The seasonal changes of the relative value of basin storage are very great and evapotranspiration in the entire basin is not affected by the seasonal changes of basin storage even in the dry season.

3. The role of evapotranspiration in the water cycle in the Amazon river basin is relatively more important in the dry season than in the rainy season.

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