Reduced precipitation over large water bodies in the Brazilian Amazon shown from TRMM data

Rodrigo C.D. Paiva¹,³
Diogo C. Buarque¹, Robin T. Clarke¹, Walter Collischonn¹, Daniel G. Allasia²

¹ Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.
² Departamento de Hidráulica e Saneamento, Universidade Federal de Santa Maria, Santa Maria, Brazil.
³ Géosciences Environnement Toulouse, Université Toulouse III Paul Sabatier, Toulouse, France.

Precipitation estimates in the Amazon

• Conventional raingauge stations
  
  • low raingauge density in a region where convective rainfall is spatially highly variable.
  
  • Raingauges are preferentially sited along rivers

• Remote Sensing

  • TRMM – Tropical Rainfall Measurement Mission
  
  • CMORPH - CPC MORPHing technique
  
  • Need for validation
River breezes

- Meso-scale circulations close to large rivers such as river breezes may also affect rainfall distribution locally.

- River breezes result from differences in sensible and latent heat fluxes over land and water, enhancing cloudiness over land (water) during daytime (night time), whilst skies over water (land) remain clear.

- Convergence zones lead to enhanced rainfall over forest and diminished rainfall near rivers.

Local circulation over Tapajós River

GOES visible cloudiness at Tapajós-Amazon confluence

Fitzjarrald et al. (2008)

Silva Dias et al. (2004)
Precipitation monitoring

- Raingauges are often sited near large rivers

- It is possible that raingauge-derived estimates of Amazon rainfall may be biased

- Important implications for:
  - hydrological studies
  - hydrological modeling
  - water resource management
  - calibration and validation of remote-sensed rainfall estimates using raingauge data
  - and others
Objective

Explore rainfall spatial variability in the Brazilian Amazon and the evidence for lower rainfall near its large rivers using TRMM 3B42 data.
Area of study

Brazilian Amazon river basin, river network and test area (rectangle in central Amazon)
Data and Methods

• Remote sensing precipitation estimates:
  • Tropical Rainfall Measurement Mission TRMM 3B42
  • 0.25°×0.25° spatial resolution
  • 3 hour temporal resolution

• Analyses of 3 variables:
  • mean annual rainfall, $P$
  • mean annual number of wet days, $W$ (>2 mm)
  • mean annual rainfall accumulated in each 3-hour time interval, $P_{3hr}$.

• 2 steps:
  • Annual means of $P$ and $W$
  • Diurnal variation of $P$
Methods - Statistical test

• Test area:
  • 68° W to 56° W and from 0° S to 5° S

• Trend Removal:
  • Remove north-south and east-west spatial trends

• Linear regression:
  • \( X^* = a_1 \lambda + a_2 \varphi + a_3 \) where
    \( \lambda = \) latitude, \( \varphi = \) longitude and \( X = P, W \) or \( P_{3hr} \)

• Variable analyzed - regression residual:
  • \( X' = X - X^* \)
Methods - Statistical test

• Water and No Water regions:

  • TRMM 3B42 grid-points were divided into two groups, “Water” and “No Water”

  • Central Amazon wetlands map at 100 m spatial resolution [Hess et al., 2003].

  • Pixels with > 20% inundated area were classified as “Water”

(a) TRMM 3B42 grid-squares constituting the “Water” group;
Methods - Statistical test

- Student t-test:
  
  (i) $t$-test for difference between the “Water” and “No Water” sample means
  
  (ii) $t$-test for difference between grid points values and “No Water” sample means

- 5% significance level

- Correction of sample size for allowing spatial correlation:
  
  - $N' = N (1 - \rho) / (1 + \rho)$  \[Cressie, 1993\]

$N$ = original sample size

$\rho$ = lag-one spatial correlation
(a) Mean annual rainfall from TRMM 3B42 data (1998-2009)

**Reduction of P over main Amazon rivers**
Results

(b) Mean number of wet days from TRMM 3B42 data (1998-2009)

**Reduction of W over main Amazon rivers**
Results – Statistical test

(a) TRMM 3B42 grid-squares constituting the “Water” group;

(b) \( P < P \) from “No Water” group (p<0.05);

(c) \( W < W \) from “No Water” group (p<0.05);
### Results - Summary

#### Table 1. Sample Size, Effective Sample Size, and Mean and Standard Deviation of Residuals After Trend Removal in $P$ and $W$

<table>
<thead>
<tr>
<th>Region</th>
<th>N</th>
<th>N'</th>
<th>$P$ [mm]</th>
<th></th>
<th>$W$ [days]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Water</td>
<td>320</td>
<td>28</td>
<td>-82.5</td>
<td>147.2</td>
<td>-7.3</td>
<td>10.9</td>
</tr>
<tr>
<td>No Water</td>
<td>640</td>
<td>57</td>
<td>41.2</td>
<td>129.1</td>
<td>3.7</td>
<td>7.7</td>
</tr>
<tr>
<td>All grid points$^b$</td>
<td>960</td>
<td>84</td>
<td>2486</td>
<td>211.7</td>
<td>169.8</td>
<td>18.4</td>
</tr>
</tbody>
</table>

$^a$N, number of TRMM 3B42 grid-points; N', effective sample size; SD, standard deviation. Values from grid-squares denoted by “Water”, “No Water”.

$^b$Statistics computed using original $P$ and $W$ values.

- $P$ over “Water” pixels is reduced in 5%
- $W$ over “Water” pixels is reduced in 6.5%
- $P$ and $W$ were significantly smaller at “Water” than at “No Water” grid-points ($p<0.05$)
Results – diurnal variation of $P_{3hr}$

$P$ occurring during **afternoon-night** (A-N) period
(15 to 06 UTC, or approximately 11 to 02 h in local time)

**Larger reduction of $P$ over main Amazon rivers**
Results – diurnal variation of $P_{3hr}$

$P$ occurring during **night-morning** (N-M) period
(06 to 15 UTC or approximately 02 to 11 h in local time)

**Opposite behavior:** Increase of $P$ over main Amazon rivers, but less pronounced
Results – diurnal variation of $P_{3hr}$

Diurnal variation of $P'_{3hr}$ averaged over grid-points denoted by “Water” (line with stars) and by “No Water” (line with circles) and its relative difference (bold line)
**Results – diurnal variation of** $P_{3hr}$

**Table 2. Summary of Diurnal Variation in Rainfall**

<table>
<thead>
<tr>
<th>Time Interval (UTC)</th>
<th>Total $P_{3hr}$ (%)</th>
<th>$P'_{3hr}$ Mean</th>
<th>$P'_{3hr}$ SD</th>
<th>$p^b$</th>
<th>Rel. Dif.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water</td>
<td>No Water</td>
<td>Water</td>
<td>No Water</td>
</tr>
<tr>
<td>00–03</td>
<td>10</td>
<td>-18.9</td>
<td>9.5</td>
<td>50.1</td>
<td>71.1</td>
</tr>
<tr>
<td>03–06</td>
<td>10</td>
<td>-9.8</td>
<td>4.9</td>
<td>64.1</td>
<td>84.4</td>
</tr>
<tr>
<td>06–09</td>
<td>11</td>
<td>6.0</td>
<td>-3.0</td>
<td>57.1</td>
<td>64.3</td>
</tr>
<tr>
<td>09–12</td>
<td>10</td>
<td>13.9</td>
<td>-6.9</td>
<td>44.6</td>
<td>49.4</td>
</tr>
<tr>
<td>12–15</td>
<td>9</td>
<td>18.7</td>
<td>-9.4</td>
<td>44.2</td>
<td>45.2</td>
</tr>
<tr>
<td>15–18</td>
<td>17</td>
<td>-7.6</td>
<td>3.8</td>
<td>83.3</td>
<td>94.2</td>
</tr>
<tr>
<td>18–21</td>
<td>20</td>
<td>-53.5</td>
<td>26.8</td>
<td>99.2</td>
<td>103.5</td>
</tr>
<tr>
<td>21–00</td>
<td>13</td>
<td>-30.7</td>
<td>15.4</td>
<td>54.1</td>
<td>63.1</td>
</tr>
</tbody>
</table>

*a*Fraction of $P$ (1998–2009); mean and standard deviation (SD) of $P'_{3hr}$ from grid-points denoted by “Water” and “No Water”; probability ($p$) of observed difference between $P'_{3hr,N}$ and $P'_{3hr,W}$, on the null hypothesis of no difference in rainfall between “Water” and “No Water”; and relative difference between $P'_{3hr,W}$ and $P'_{3hr,N}$.

*b*Significant values are marked in bold.
Results

Observed precipitation spatial variability in TRMM data results from:

A physical phenomena such as river breezes?

Errors in remote sensing estimates?

*Tian and Peters-Lidard [2007]* reported *systematic positive errors* in TRMM 3B42 rainfall estimates for pixels associated with *inland water-bodies* in USA, and speculate that this inconsistency results from deficiencies in the TRMM assumptions about *water-surface emissivity*.

Our *results are not consistent with errors of Tian and Peters-Lidard [2007]* but are *in accordance* with other local scale observational studies and description of *river breeze effects on precipitation.*
Conclusions

• TRMM 3B42 data show a very clear reduction in $P$ and $W$ near large water bodies, specially at Solimões/Amazon Tapajós and Negro Rivers, and near the extensive Balbina reservoir;

• $P$ and $W$ were lower near large water bodies, by 5% and 6.5% respectively;

• The reduction in rainfall near large rivers is greatest during the afternoon (15 to 06 UTC), when most rainfall is convective. An opposite pattern occurring during night-morning (06-15 UTC) is clearly discernible, although not statistically significant using the approximate test-procedure used.
Conclusions

• Our results are not consistent with errors over inland water bodies in TRMM 3B42 data reported by Tian and Peters-Lidard [2007] but are in accordance with other observational studies and description of river breeze effects on precipitation.

• Factors that include the uncertainty in TRMM 3B42 rainfall estimates and the scale of the TRMM 3B42 grid suggest that the quantitative estimates of rainfall reduction close to large rivers reported here should not be regarded as definitive; and reductions in $P$, $W$ and $P_{3hr}$ may well be locally greater than those given.

• It is possible that average rainfall in central Amazon is being systematically underestimated due to the location of the majority of raingauges close to the major rivers.
Reduced precipitation over large water bodies in the Brazilian Amazon shown from TRMM data

Rodrigo Cauduro Dias Paiva, Diogo Costa Buarque, Robin T. Clarke, Walter Collischonn, and Daniel Gustavo Allasia

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Tropical Rainfall Measurement Mission (TRMM) data show lower rainfall over large water bodies in the Brazilian Amazon. Mean annual rainfall \( P \), number of wet days (rainfall > 2 mm) \( W \) and annual rainfall accumulated over 3-hour time intervals \( P_{3hr} \) were computed from TRMM 3B42 data for 1998–2009. Reduced rainfall was marked over the Rio Solimões/Amazon, along most Amazon tributaries and over the Balbina reservoir. In a smaller area, a heuristic argument showed that \( P \) and \( W \) were reduced by 5% and 6.5% respectively. Allowing for TRMM 3B42 spatial resolution, the reduction may be locally greater. Analyses of diurnal rainfall patterns showed that rainfall is lowest over large rivers during the afternoon, when most rainfall is convective, but at night and early morning the opposite occurs, with increased rainfall over rivers, although this pattern is less marked. Rainfall patterns reported from studies of smaller Amazonian regions therefore exist more widely. Citation: Paiva, R. C. D., D. C. Buarque, R. T. Clarke, W. Collischonn, and D. G. Allasia (2011), Reduced precipitation over large water bodies in the Brazilian Amazon shown from TRMM data, Geophys. Res. Lett., 38, L04406, doi:10.1029/2010GL045277.

Information where in situ observations are lacking. However, the use of remote-sensed rainfall estimates is not without problems: Tian and Peters-Lidard (2007), for example, reported systematic positive errors in TRMM 3B42 rainfall estimates for pixels associated within land water-bodies, and speculate that this inconsistency results from deficiencies in the TRMM assumptions about water-surface emissivity.

In the Amazon, raingauges are preferentially sited along rivers where most settlements lie [Oliveira and Fitzjarrald, 1993; de Gonçalves et al., 2006; Fitzjarrald et al., 2008]. However, meso-scale circulations close to large rivers such as river breezes may also affect rainfall distribution locally [Silva Dias et al., 2004; Fitzjarrald et al., 2008] and lead to reduced rainfall [Garstang and Fitzjarrald, 1999].

River breezes result from differences in sensible and latent heat fluxes over land and water, enhancing cloudiness over land during daytime, whilst skies over water remain clear; at nighttime, the opposite occurs. Garstang and Fitzjarrald [1999] stated that away from large Amazonian rivers, convergence zones lead to enhanced rainfall over forest and diminished rainfall near rivers, and that daytime enhancement/diminution has a greater net effect on rainfall near rivers than the reverse night-time situations.
Obrigado
Thank you
Gracias
Merci