THE USE OF OXYGEN ISOTOPIC COMPOSITION TO STUDY WATER DYNAMICS IN AMAZON FLOODPLAIN LAKES


*Centro de Energia Nuclear na Agricultura, Piracicaba, Brazil
**Department of Physical and Meteorology, Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, Brazil
***Comissao Nacional de Energia Nuclear, Rio de Janeiro, Brazil
*School of Oceanography and Quaternary Research Center, Seattle, Washington, United States of America

Abstract/Resumen

THE USE OF OXYGEN ISOTOPIC COMPOSITION TO STUDY WATER DYNAMICS IN AMAZON FLOODPLAIN LAKES.

The lakes formed in the Amazon floodplain play a key role in sustain the high primary productivity in the Amazon Basin because of its high primary productivity. The water volume in these lakes greatly during the year and possible water sources are the feeding river during high water stage of the hydrographs and local inputs from its drainage basin. As these sources are chemically distinct, to understand the nutrient dynamics in these lakes, it is very important to know the relative water contribution of different water sources. In this paper we use a conservative tracer to know the water sources for the lakes and we hypothesis that: 1) In the high water stage lake water is derived predominately from its feeding river. Therefore their δ18O should be similar. 2) In the low water stage lake water is a mixture of watershed and last flood event waters. In this case, lake δ18O should be indicative of the relative contribution of each source. To test this hypothesis we assume a two end member mixing model. If the 18O isotopic composition of these two sources is known the relative contribution of each source may be calculated by isotopic dilution equation. The first step in this work it was to know the 18O isotopic composition of the lakes and feeding rivers and its spatial and temporal variability. Clearly the 18O signal in the lakes of Amazon varia is controlled by the 18O content of the feeding river. But there is a consistente pattern in the 18O enrichment of the lakes versus the feeding rivers, which is more profound in low water period. Our initial hypothesis requires that this varia be of local drainage basin origin. Although it was not possible to measure the isotopic composition of local drainage water, indirect measurement suggest that it could be the case.

UTILIZACION DE LA COMPOSICION ISOTOPICA DEL OXIGENO PARA EL ESTUDIO DE LA DINAMICA DEL AGUA EN LOS LAGOS DE LAS ZONAS INUNDADAS POR EL RIO AMAZONAS.

Los lagos formados en la llanura de inundación amazónica juegan un papel vital en el sustento de alta densidad poblacional en la cuenca amazónica a causa de su alta productividad primaria. El volumen de agua en estos lagos varía ampliamente durante el año y fuentes posibles de agua son los ríos que los alimentan.
durante el periodo de aguas altas así como entradas locales provenientes de sus cuencas de drenaje. Debido a que estas fuentes son claramente diferentes, para comprender la dinámica de nutrientes en estos lagos es importante conocer la contribución relativa de estos aportes. En este trabajo se utiliza 18O como parámetro conservativo para determinar los fuentes de los lagos y se exponen las siguientes hipótesis: 1) En la época de aguas altas, el agua del lago proviene fundamentalmente del río que lo alimenta. Por tanto su contenido en 18O debería ser similar. 2) En la época de aguas bajas el agua del lago es una mezcla de aguas drenadas de la cuenca y de las aguas de las ríos tributarios. En este caso, el 18O del lago debería reflejar la contribución relativa de cada aporte. Para verificar esta hipótesis asumimos un modelo de mezcla con dos miembros puros. Si el contenido isotópico de estas dos fuentes es conocido, la contribución relativa de cada fuente puede ser determinada a través de la ecuación de dilución isotópica. El primer paso en este trabajo fue la determinación de la composición isotópica de los lagos y los ríos tributarios. El contenido de 18O de los lagos amazónicos es controlado claramente por el contenido del río tributario. Pero se produce enriquecimiento en 18O de los lagos en relación con los ríos tributarios, el cual es más pronunciado durante los períodos de aguas bajas. Nuestra hipótesis inicial requiere que este agua provenga del drenaje local de la cuenca. Aunque no fue posible medir la composición isotópica del agua de este drenaje local, medidas indirectas sugieren que esto podría ser el caso.

1. INTRODUCTION

During its annual hydrological cycle, the level of the Amazon River changes by 10m, inundating an extensive floodplain ("varzea") of 60,000km² [1]. This flood regime forms multiple lakes ("lagos") in the depressions of the varzea. These lakes are characterized by highly dynamic water and nutrient cycles and are capable of sustaining high primary productivity rates [2,3]. They are a very important food source for the local population [4], and are the most populated region in the Amazon basin [5].

Water volume in a floodplain lake may change greatly during the year, even disappearing totally in extreme cases, during the dry season [6,7]. Possible water sources for the lakes are: the feeding river during the high water stage of the hydrograph, and local inputs from its drainage basin. Those two sources are chemically distinct, and the relative contribution of each is determined by the balance of chemical and biological processes in the lake. Therefore, the chemical composition, the relative contribution of different water sources is very important for the study of the lake dynamics.

It is the objective of this paper to determine the relative contribution of these two sources to the water body in the lake. These two sources are: (1) The high water stage lake water is derived predominantly from its feeding river. Therefore their 18O should be similar. (2) In the low water stage lake water is a mixture of watershed and last flood event waters (onset of precipitation and lake flooding events are two months out of phase). In this case, lake 18O should be indicative of the relative contribution of each source.

We will test this hypothesis with a two end-member mixing model analyzing field samples collected in the lakes at different hydrological stages. The hypothesis will then be tested, taking into account the spatial and temporal variations occurring in a system as large as the Amazon basin.

2. STUDY AREA

The Amazon basin is bounded to the north by the Guiana Shield, to the south by the Brazilian Shield, to the west by the Andes Cordillera, and to the east by the Atlantic Ocean; the total basin area is approximately 6,000,000km² [8]. Mean precipitation in the basin is 2,000mm per year [9] and the mean minimum and maximum river discharge at Óbidos, 6,000m³ from the mouth, is 110,000m³/s, and 220,000m³/s, respectively [10].

The annual fluctuation in river level is the main recharge mechanism for the lakes. Maximum and minimum water levels occur at different times among the different tributaries and even along the main channel. Up river, approximately at 20oS (Figure 1), maximum water level occurs during December–January, while near Manaus it occurs during May–June, and at Óbidos, due to the Madeira river with its maximum water level occurring two months before the Amazon, during April. In general, maximum water levels in the rivers are associated with the end of the raining season, maximum discharges generally occurring 2 months after the maximum precipitation [11].

3. METHODS

3.1. Working Model

To analyze the relative water sources for the floodplain lakes, we assume a two end-member mixing model, with water sources for the lakes being a mixture of the feeding river and local drainage. We assume that isotopic enrichment through evaporation is low, relative to the two primary end members (G. C. Cat., pers. comm.).

If the 18O isotopic composition of these two sources and of the lake water are known, the relative contribution of each source may be calculated by the following equation:

\[ \frac{\delta^{18}O_{w} - \delta^{18}O_{rv}}{\delta^{18}O_{rv} - \delta^{18}O_{rv}} = \frac{\delta^{18}O_{w}}{\delta^{18}O_{rv}} = \text{relative basin water contribution} \]

where

\[ \delta^{18}O_{w} = \text{lake water isotopic composition} \]
\[ \delta^{18}O_{rv} = \text{river water isotopic composition} \]
\[ \delta^{18}O_{rv} = \text{basin water isotopic composition} \]

Two main assumptions were made for this model:

1. End-member isotopic composition should be known and differ significantly between each other and during the hydrological cycle.
(2) Lake isotopic composition should be known and any alteration due to
physico-chemical processes should be predictable.

3.2. Sampling Regime

Lake samples were collected primarily near the Solimões/Amazonas river,
near the Japurá river (left margin tributary) and near the Anái-Parana
(channel linkage between the Solimões and Japurá rivers). Samples were
collected in a reach about 1800km, extending approximately from 68°W to
55°W (Figure 1, Table 1).

![Map of the study area showing sampling sites.](image)

Figure 1. Study area, central floodplain of the Solimões/Amazon river showing lakes sampling sites.

Four sampling periods, corresponding to two different stages of the
hydrograph were used (Figure 2). First sampling was performed during
January/February 1984. During this period, although coincident with the
onset of the water rising stage of the river hydrograph (Figure 2), water
was flowing from the lakes to the river, and it was considered therefore to
be low water sampling. The other three sampling were performed during high
water stages or beginning of water falling stage (June/July 1984,
July/August 1985, and April/May 1987). During those sampling periods water
flow was always from the river to the lake. Sampling periods were coincident
with cruises 7, 8, 9 and 10 of the CARBEX project (Carbon in the Amazon River
Experiment), and will be so designated henceon.

![Graph showing hydrograph stages.](image)

Figure 2. Hydrograph of the Solimões/Amazon river at Santo Antonio do Ica
(lower river), Tapajos and Uatumã (dowriver). The bars shows the
timing of the sampling. Full lines indicate real time and dashed
lines indicate only the hydrograph stage.

Table 1. $\Delta$D/$\delta^{18}O$ values of the lakes in the four sampling periods and the
respectively feeding tributaries. All is Anái, S Solimões, J Japurá
and AM Amazonas.

<table>
<thead>
<tr>
<th>#</th>
<th>Feeding River and Lakes</th>
<th>Trib.</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solimões</td>
<td></td>
<td>-6.4</td>
<td>-7.2</td>
<td>-5.8</td>
<td>-5.6</td>
</tr>
<tr>
<td>2</td>
<td>Japurá</td>
<td></td>
<td>-5.3</td>
<td>-6.5</td>
<td>-5.9</td>
<td>-5.1</td>
</tr>
<tr>
<td>3</td>
<td>Anái</td>
<td></td>
<td>-6.4</td>
<td>-7.9</td>
<td>-6.0</td>
<td>-5.6</td>
</tr>
<tr>
<td>4</td>
<td>Amazonas</td>
<td></td>
<td>-5.6</td>
<td>-5.8</td>
<td>-5.0</td>
<td>-5.3</td>
</tr>
<tr>
<td>5</td>
<td>Açu</td>
<td>AM</td>
<td>-3.1</td>
<td>-7.9</td>
<td>-5.6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Aramaçu</td>
<td>AM</td>
<td>-7.7</td>
<td>-3.7</td>
<td>-5.8</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Tucuruí</td>
<td>AM</td>
<td>-8.4</td>
<td>-4.5</td>
<td>-6.1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Mata</td>
<td>AM</td>
<td>-5.1</td>
<td>-5.1</td>
<td>-5.1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Maraá</td>
<td>J</td>
<td>-5.5</td>
<td>-6.1</td>
<td>-4.6</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Jaraqui</td>
<td>J</td>
<td>-5.7</td>
<td>-5.6</td>
<td>-4.4</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Mari</td>
<td>S</td>
<td>-6.1</td>
<td>-5.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Pedrinho</td>
<td>S</td>
<td>-5.7</td>
<td>-5.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Araçá</td>
<td>J</td>
<td>-8.1</td>
<td>-5.7</td>
<td>-5.2</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Uarã</td>
<td>S</td>
<td>-6.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Conrado</td>
<td>S</td>
<td>-5.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Caxiú</td>
<td>J</td>
<td>-5.9</td>
<td>-5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Açu</td>
<td>S</td>
<td>-6.0</td>
<td>-5.0</td>
<td>-2.0</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Aramaçu</td>
<td>AM</td>
<td>-5.6</td>
<td>-5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Tucuruí</td>
<td>AM</td>
<td>-5.9</td>
<td>-4.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Mata</td>
<td>AM</td>
<td>-5.8</td>
<td>-5.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Maraá</td>
<td>J</td>
<td>-5.8</td>
<td>-5.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Jaraqui</td>
<td>J</td>
<td>-7.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Mari</td>
<td>S</td>
<td>-5.2</td>
<td>-5.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Pedrinho</td>
<td>S</td>
<td>-6.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Araçá</td>
<td>S</td>
<td>-6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Uarã</td>
<td>S</td>
<td>-5.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Conrado</td>
<td>S</td>
<td>-6.3</td>
<td>-4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Caxiú</td>
<td>S</td>
<td>-4.5</td>
<td>-4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Aramaçu</td>
<td>J</td>
<td>-6.3</td>
<td>-5.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Tucuruí</td>
<td>J</td>
<td>-5.6</td>
<td>-4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Mata</td>
<td>AM</td>
<td>-5.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Maraá</td>
<td>AM</td>
<td>-4.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Jaraqui</td>
<td>AM</td>
<td>-6.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Mari</td>
<td>AM</td>
<td>-4.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Pedrinho</td>
<td>AM</td>
<td>-6.4</td>
<td>-3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Araçá</td>
<td>AM</td>
<td>-4.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Uarã</td>
<td>AM</td>
<td>-5.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Conrado</td>
<td>AM</td>
<td>-6.4</td>
<td>-4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Caxiú</td>
<td>AM</td>
<td>-5.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Aramaçu</td>
<td>AM</td>
<td>-5.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$#$ Indicates lakes local in Figure 1.
About 40 lakes were sampled in total, although it was not possible, in
many cases, to sample the same lake in all cruises (Table 1). During
Cruise 7, twelve lakes were sampled, 5 in the Solimões river, 3 in the Jacupa
river, and 2 in the Aupi-Parana. In cruise 8, the number of sampled lakes
was also 12 (3 in the Solimões, 4 in the Jacupa, and 3 in the Aupi-Parana).
For cruise 9 the number of sampled lakes was expanded to 21 (14 in the
Solimões/Amazonas, 5 in the Jacupa, and 2 in the Aupi-Parana). Finally,
during cruise 10, 25 lakes were sampled (16 in the Solimões/Amazonas, 5 in the
Jacupa, and 4 in the Aupi-Parana). Therefore, only for cruises 9 and 10 the
sampling reached extended for 1800km. For cruises 7 and 8 sampling was restricted
to the west part of the basin. The Aupi-Parana contains water from either
the Rio Solimões or Rio Jacupa, mixed with local drainage waters, depending
on the relative stage of the different rivers.

Samples were always collected at the surface with a Niskin bottle, at
the middle of the lake, or near the channel linkage with the river, in the
case of big lakes. Samples were immediately stored in tightly capped plastic
bottles, where they were kept until analysis. Analysis was performed at the
Centro de Energia Nuclear na Agricultura, using a Micromass 600E mass
spectrometer equipped with double inlet and double collector systems. All
samples were analyzed in replicates with a maximum deviation of 0.5%/oo
permitted between them. All results are reported in 618O/oo in relation to
the VSMOW standard.

4. RESULTS

During the low water, rising limb period (C7), 618O in the lakes varied
between -6.8%/oo and -1.5%/oo (Table 1). The mean 618O for the Solimões
main channel was -6.7%/oo and the mean for the lakes fed by the Solimões was
-5.2%/oo. The 618O values for the Rio Jacupa and the lakes fed by the Jacupa
were -5.1%/oo and -4.2%/oo, and for the Aupi-Parana and its lakes -6.4%/oo
and -3.5%/oo, respectively (Figure 1).

For C8, about three months after C7, the increase in river water level
drove the flow of water to be from the river to the lake. Between C7 and C8
there was a marked variation in the river isotopic composition. Mean 618O for
the Solimões, Jacupa, and Aupi all decreased, to -7.2%/oo, -6.6%/oo, and
-7.9%/oo respectively. This decrease in 618O was in part reflected on the lake
isotopic composition that, in general, also shows a decrease in 618O.
The main channel to the lakes decreased in -6.5%/oo, to -7.9%/oo and
-6.7%/oo for the lakes fed by the Aupi-Parana and Jacupa, respectively (Figure 3).

C9 was at approximately the same stage of the falling limb of the
hydrograph as C8, but one year later. However, the values of 618O in C9
differed considerably from C7 and from C8. The main channel to the Solimões
was isotopically enriched relative to C7 and C8, at -5.5%/oo, which was
comparable to the downriver Amazonas value of -5.4%/oo. The value of the
Rio Jacupa was -5.9%/oo, and of the Aupi-Parana -6.0%/oo. Though the 618O
values differed, the same pattern of the lakes being enriched relative to
the feeding waters held, with -5.8%/oo, -4.9%/oo, -5.6%/oo, and -6.1%/oo
for the lakes of the Solimões, Amazonas, Jacupa, and Aupi, respectively.

C10 was in the following hydrological year from C9, at the highest
stage of the cruises reported here and on the rising limb of the hydrograph.
Feeding river 618O values were comparable to C9, with -5.6%/oo, -5.3%/oo,
-5.1%/oo, and -5.6%/oo, for the Solimões, Amazonas, Jacupa, and Aupi,
respectively. There was less difference between the feeding river and
lakes than previously, with relative 618O values of -5.8%/oo, -4.8%/oo,
-5.0%/oo, and -5.7%/oo.

5. DISCUSSION

5.1. Trends in Isotopic Composition

The overall variability in the 618O signal in the lakes of the Amazon
basin is clearly controlled by the 618O content of the feeding river. Richey
et al. [10] related the isotopic content of the mainstem and its major
tributaries to the overall climate regime in the basin.

Within the overall control exerted by the feeding water, there were clear
patterns of difference between the feeding water and lakes, though the
statistics are not strong, due to the low number of samples. The differences
were not as pronounced on C7, when waters were draining from the lakes into
the rivers. The rapid change in lake isotopic composition between contiguous
lakes 7 and 8 indicates that they are sensitive to alterations in the isotopic
composition of its water sources. Though C9 is considered a high water cruise,
the level of the rivers was falling and the floodplain had been inundated for
some time; hence there were differences. Least difference was on C10, the
period of greatest flooding.

5.2. Relative Contributions of River and Drainage Basin Water

The fact that there appears to be a consistent pattern in the 18O
enrichment of the lakes versus the feeding river requires that there be a source
of 18O-enriched water. Our initial hypothesis requires that this water be of
local drainage basin origin.

Although it was not possible to measure the isotopic composition of local
drainage waters, the isotopic composition of the rainwater in the region could
be considered as a first approach. The median for rainwater 618O (1965 to 1987 data)
was -3.5%/oo [11,13]. Moreover, rivers with drainage basins
entirely contained in the Amazon depression do show systematic δ⁰¹⁸O enrichment when compared to rivers with head waters in the Andes region [10]. Forsberg et al. [3], using alkalinity as a conservative tracer, estimated basin water contribution to several lakes for δ⁰¹⁸O through the following equation:

\[
\text{BU} = \frac{(\text{Alk}_L - \text{Alk}_{rw})}{(\text{Alk}_bw - \text{Alk}_{rw})} \quad (2)
\]

where

\[
\text{BU} = \text{relative basin water contribution}
\]

\[
\text{Alk}_L = \text{lake water alkalinity}
\]

\[
\text{Alk}_{rw} = \text{river water alkalinity}
\]

\[
\text{Alk}_{bw} = \text{basin water alkalinity}
\]

Combining equations 1 and 2 the δ⁰¹⁸O of local drainage water could be estimated by the following equation:

\[
\delta_{bu} = \frac{(\delta_{18O}_L - \delta_{18O}_{rw} \cdot (\text{BU}))}{\text{BU}} \quad (3)
\]

where BU is the relative river water contribution.

Estimated values for some lakes during the low water sampling period are presented in Table 2. With the exception of Purado lake, estimated values ranged from -3.2‰ to -6.8‰, with less negative values for the lakes fed by the Japura river. The estimated results are reasonably consistent, with values always higher than the correspondent feeding river, with the exception of the Justa lake. Maximum difference for the Solimões/Amazonas lakes was 1.9‰, while for the Japura was 0.9‰.

Table 2. δ⁰¹⁸O‰ basin water of some lakes estimated by equation 3. For more details see text, item 5.

<table>
<thead>
<tr>
<th>#</th>
<th>Lakes</th>
<th>Trib.*</th>
<th>δ⁰¹⁸O</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Purado</td>
<td>All</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>Mara</td>
<td>J</td>
<td>-3.2</td>
</tr>
<tr>
<td>6</td>
<td>Jaruqi</td>
<td>J</td>
<td>-4.0</td>
</tr>
<tr>
<td>12</td>
<td>Colu</td>
<td>J</td>
<td>-4.3</td>
</tr>
<tr>
<td>14</td>
<td>Alvara</td>
<td>S</td>
<td>-4.7</td>
</tr>
<tr>
<td>15</td>
<td>Telê</td>
<td>S</td>
<td>-4.8</td>
</tr>
<tr>
<td>17</td>
<td>Justi</td>
<td>S</td>
<td>-6.8</td>
</tr>
<tr>
<td>19</td>
<td>Catua</td>
<td>S</td>
<td>-5.7</td>
</tr>
<tr>
<td>21</td>
<td>Ipiru</td>
<td>S</td>
<td>-5.1</td>
</tr>
<tr>
<td>23</td>
<td>Panar</td>
<td>S</td>
<td>-6.2</td>
</tr>
</tbody>
</table>

# indicates lakes localization in the Figure 1.
* indicates feeding tributaries.

5.3. Initial Hypothesis and Future Tests

Within the constraints of data availability, results of the observed patterns of δ⁰¹⁸O and the model calculations support the initial hypothesis. They further suggest that it should be possible to calculate with some precision the relative sources of water, with improved data and a more detailed model.

In light of the complexity of individual lakes, testing this model on a finer scale and to explore the potential impact of evaporation for a specific site is a challenge. Lakes frequently have more than one linkage channel to the river, several feeding local "igarapés", and can be tens of kilometers. Moreover, in order to quantify evaporation effects on the lake isotopic composition, a systematic water sampling scheme is imperative.

For the continuation of this study, an intensive systematic monitoring of two lakes near Manaus, will be undertaken. Lakes, feeding rivers, and basin water isotopic compositions will be measured, specially during the dry period where few data are available. If the isotopic composition of the two main sources (river water and basin water) are known, two distinct situations might occur: one in which the isotopic composition of the lake water falls in the world meteoric water line (Figure 4), and the relative contribution of each source could be easily calculated with equation 1. On the other hand, if evaporation does have an effect, lake water isotopic
composition would not fall on the meteorical water line (Figure 2), and the original lake water $^{18}$O could be back calculated through the following equation (13):

$$
\delta = \frac{b(\delta_a - \delta_h) + c \delta_a + (1 - h) \eta}{b(\delta_a - \delta_h) + c \delta_a + (1 - h) \eta} \delta^{18}O - \delta^{18}O
$$

and

$$
\delta_x = \delta^{18}O + 10
$$

where

$\delta = \text{D, }^{18}$O slope

$\delta_a = \text{relative humidity normalized to the temperature of the evaporating surface}$

$\delta_h = \text{delta values of atmospheric moisture}$

$\delta_x = \text{delta values of the lake initial isotopic composition}$

$\eta = \text{equilibrium fractionation factor}$

$\eta = \text{diffusion ratio excess.}$

Combining equations 4 and 5, $\delta^{18}$O could be calculated, and with equation 1 the relative contribution of each source could also be estimated. The critical parameter, however, would be the measurement of $\delta_a$, which varies both temporally and spatially [14,15]. Water vapor sampling in field conditions, specially over the Amazon, is very difficult [16]. $\delta_a$ values could be measured through class A evaporation pans. The pan would have to be installed near the lake, protected from the rain, and daily maintenance would be necessary, which also makes it very difficult. On the other hand, $\delta_a$ values could be estimated through the measurement of leaf water $^{18}$O near the lake [17]. If leaf water is assumed to be in equilibrium with local atmospheric water, the following relationship would hold:

$$
\delta_a = c \delta + \eta(1 - h) + b \delta_a + (1 - h) \delta_{in}
$$

Isolating the value for $\delta_a$,

$$
\delta_a = \frac{\delta - c \delta + \eta(1 - h) - \delta_{in}(1 - h)}{h}
$$

Combining equations 5 and 7, the value of $\delta^{18}$O could then be estimated measuring only the values of $\delta_a$. In this case the value of $\delta_a$ is assumed to be equal to the isotopic composition of rainwater in the region.

This program should be implemented in the near future, 1980-1989, in connection with the CAMREX and IAEA/CERNA B78/041D projects.