ISOTOPE TRACING OF THE HYDROLOGICAL DYNAMICS OF AN AMAZONIAN FLOODPLAIN

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INTRODUCTION

AMAZON BASIN HYDROLOGY

The Amazon Basin (79.7°W to 50.0°W; 5.4°N to 20.5°S) extends over 6,112,000 km² in both equatorial and subtropical regions. Atmospheric water vapour enters the Basin from the Atlantic Ocean, and moves westward to the Andean Cordillera. The mean annual precipitation over the basin is 2322 mm.y^{-1} (Costa and Foley, 1998). Mean annual water discharge back to the ocean is 209 000 m^3/s (Molinier et al., 1997), which corresponds to about 20% of the total freshwater input from the continents to the oceans. Average discharge (~1079 mm.y^{-1}) corresponds to 50% of the annual rainfall, as a result of an internal recycling precipitation/ evapotranspiration (1243 mm/y/ precipitation).

Due to the size of the Amazon drainage basin, large scale deforestation and land use changes can affect both regional and global climate, while regional climate changes can modify the hydrological dynamics of its rivers (Shukla et al., 1990; Costa and Foley, 1998). All the hydrological models participating in Global Soil Wetness Project showed a strong underestimation and a significant lag in the annual runoff cycle of the Amazon basin (Chapelon et al., 2002). Therefore, a better understanding of the processes that control the Amazon Basin hydrology and climatology is of major interest.

Two of the major research Projects currently in development in the Amazon basin (LBA and HyBAm) are dedicated to improve the understanding of the Amazon hydrology, climatology and biogeochemistry.

AMAZON FLOODPLAINS HYDROLOGY

Floodplains play a major role in the Amazon River hydrology. They store water during the river rising phase and release it when the river level is decreasing. The main consequence on the river annual hydrograph is the smoothing of the river discharge variation: this explains why the maximum discharge at Obidos (280 000 m^3/s) is only 4 times the minimum value (70 000 m^3/s). Floodplains also play an important paper in the sediment dynamics and in the geochemical cycles.

Overall extension of Amazon basin flooded areas (300 000 km², Junk, 1997) is still under investigation. Different remote sensing methods are tested (visible, active radar, passive radar). Sippel et al. (1998) analyzed the SMMR 37GHz polarization difference and estimated a mean annual flooded area of 47 000 km² along the Amazon mainstream (from 70°W to 55.5°W), with a maximum value of 90 000 km² (1953). Radar imagery mosaics (JERS) allowed a finer resolution and gave a 450 000 km² (low river stage) to 750 000 km² (high river stage) estimation for the overall basin (Seyler et al., 2003). The annual volume of river water that passes through floodplains and the contribution of floodplains to the overall river discharge at different phases of the hydrological cycle are still largely unknown.

Few studies are dedicated to detailed hydrological monitoring of specific Amazonian floodplains. Since 1999, the HYBAM Project, has been studying the role of the floodplain lakes ("várzeas") in the hydrological and sedimentological dynamics of the Amazon river, with a particular focus on the Curuai floodplain (Kosuth, 2002; Martinez at al., 2003).

ISOTOPIC GEOCHEMISTRY OF THE AMAZON BASIN WATERS

The isotopic composition of natural waters provides information on both their origin and the processes affecting their cycle, like evaporation, transpiration, condensation, or even mixing (Fritz and Fontes, 1980). Measuring the spatial and temporal isotopic variability of different water bodies (like precipitations, water vapour, surface waters and groundwaters) completes traditional hydrological measurements (rainfalls, discharges, water levels, water conductivity).

Various studies on the isotopic composition of precipitation on the Amazon basin have been published (Gatt and Matsui, 1991; Chaffaut, 1998); some information on the Amazon surface waters is available (Moura dos Reis et al., 1975; Martinelli et al., 1996), explaining their implications on the dynamics of atmospheric circulation and vapour recharge processes. Isotopic composition of Amazonian precipitations and river waters varies along the hydrologic cycle. Precipitations are impoverished during the rainy season due to the mass effect. Surface waters of the Amazon River show an isotopic enrichment during the low river stage (from September to December) and a maximum impoverishment during the high river stage (from April to July), later than the maximum impoverishment observed in the rainfall.

CURUAI FLOODPLAIN : DATA ACQUISITION AND HYDROLOGICAL MODELING

The Lago Grande de Curuai floodplain (Fig. 1) is located on the right margin of the Amazon river, in front of Obidos city (1.9°S, 55.5°W), 900 km upstream from the Ocean. This floodplain is a complex system of more than 30 interconnected lakes, linked to the Amazon river by 8 channels, 2 of them with a permanent flow. Floodplain extension varies from 700 km² to 2300 km² (Martinez et al., 2003). Maximum flood amplitude is 7.0 m at Obidos station (1990-2002).

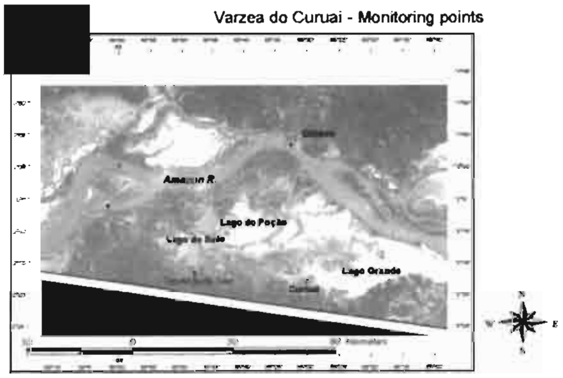

Figure 1. Monitoring points on the Lago Grande de Curuai floodplain.

Floodplain hydrology is controlled by the main river regime depending on the floodplain geometry (lakes, channels), the local climate regime (rainfall and radiations), the watershed hydrology (runoff to the floodplain) and all other related processes (infiltration, runoff, evaporation, channel flow, lake storage, etc...). The hydrology of the Curuai floodplain has been monitored since March, 1999 through daily records of rainfall, and water levels in the main river, in the major lakes and in an evaporation tank. Water samples have been collected every ten days in 10 stations for geochemical and sedimentological analysis. Fifteen field measurement campaigns have been organized at various stages of the hydrological cycle to measure liquid and solid discharges in the channels and to study the spatial heterogeneity of waters geochemical characteristics.

An hydrological-hydrodynamical model of the Amazonian floodplains has been developed and validated on the Curuai floodplain (Kosuth, 2002). Calibration was realised on measured channel discharges and lakes water levels. The model was run over the 1998-2002 period and provided time series of simulated lakes water levels and water flux (channel discharges, watershed runoffs, rainfall and evapotranspiration). Field measurements and hydrological modelling allowed us to estimate and quantify the various water fluxes and the volume of river water entering the floodplain during an hydrological cycle. Anyhow some water fluxes cannot be directly measured (evapotranspiration, watershed runoff, river bank overflow) and indirect methods, such as isotopic geochemistry, are needed to confirm or infirm these first hydrological hypothesis and results.

ISOTOPIC GEOCHEMISTRY OF THE CURUAI FLOODPLAIN WATERS

Temporal changes in the isotopic ratios of lakes waters may provide a sensitive record of water inflows origin and intensity of evaporation, related to water residence time in the lake. The present study has been realized in the framework of the "Isotope tracing of hydrological processes in large river basins" IAEA Programme.

Isotopic monitoring started by August 2001 with systematic sampling of water every ten days at 12 locations. First results for 2001-2002 hydrological cycle are presented in Table 1.

Table 1. Isotopic composition of floodplain main water bodies along the (2001-2002) hydrologic cycle (the river water values are estimated from Moura dos Reis et al, 1975).

	Amazon river Obidos (sim.)		Curuai Rain		Watershed runoff (Tabatinga)		Groundwaters (Curuai Well)		L. Sale (São Nicolau)		L. Poção		L. Grande (Curuai)		L. Grande (downstr. channel)	
	O18 (‰)	D (‰)	O18 (‰)	D (‰)	O18 (‰)	D (‰)	O18 (‰)	D (‰)	O18 (‰)	D (‰)	O18 (‰)	D (‰)	O18 (‰)	D (‰)	O18 (‰)	D (‰)
20/08/2001	-6.2	-39.2			-5.6	-34.7	-6.5	-42.6	-4.4	-30.1		-31.3		-30.3		
30/08/2001	-6.0	-37.8			-5.7	-34.8	-5.6	-42.3	-4.0	-27.7		-29.3		-28.7		
10/09/2001	-5.8	-36.2	-2.3	-11.4	-5.3	-33.5	-1.1	-41.9	-3.9	-26.8		-27.0		-27.8		
20/09/2001	-5.6	-35.0	-0.2	5.7	-5.4	-34.7	-6.8	-42.5	-3.3	-22.8		-24.7		-26.5		
30/09/2001	-5.5	-33.7			-5.6	-36.1	-6.7	-43.0	-2.9	-21.3		-20.5		-24.6		
10/10/2001	-5.3	-32.6			-5.4	-36.4	-6.6	-42.7	-2.1	-17.5		-16.6		-29.2		
20/10/2001	-5.2	-31.7			-5.5	-35.5		-42.0	-2.0	-14.9		-10.3		-27.1		
30/10/2001	-5.0	-30.9	6.8	37.1	-5.6	-35.5		-43.6	-1.0	-8.8		-4.9		-31.7		
10/11/2001	-5.0	-30.4	-11.8	-85.4	-5.5	-35.0		-43.4	-0.4	-6.7		4.7		-32.7		
20/11/2001	-4.9	-30.3			-5.7	-35.5		-43.1	-3.5			11.1		-32.4		
30/11/2001	-4.8	-30.4			-5.8	-35.1		-43.2	0.4	-2.6		16.5		-31.9		
10/12/2001	-4.8	-30.8	-1.6	-3.8	-5.6	-35.5		-41.7	0.4	-2.7		12.7		-17.3		-21.6
20/12/2001	-4.8	-31.1			-5.7	-35.5		-42.8	-1.6	-11.3		-0.5		[illegible]		-28.7
30/12/2001	[illegible]	-31.6	-2.0	-7.5	-4.9	-30.9		-43.1	-1.5	-10.9		-17.0		-19.1		-28.7
10/01/2002	-5.0	-32.2	-1.9	-11.6	-5.7	-35.1	-6.7	-43.0	-3.6	-22.1		-22.3		-20.3		-29.1
20/01/2002	-5.1	-32.7	2.2	17.4	-7.8	-32.7		-43.7	-3.5	-22.7		-28.0		-35.6		-29.4
30/01/2002	-5.1	-33.3	-1.3	-1.2				-43.5	-3.3	-22.4		-27.4		-31.6		-34.3
10/02/2002	-5.3	-34.0	-3.0	-18.8	-7.8	-37.1		-43.9	-4.2	-26.5		-23.4		-28.9		-26.1
20/02/2002	-5.4	-34.4	-4.6	-30.4	-6.0	-36.0		-43.8	-4.1	-27.1		-24.1		-25.0		-28.8
28/02/2002	-5.5	-35.0	-3.1	-13.9	-5.1	-30.5		-44.2	-3.7	-25.8		-22.5				-30.5
10/03/2002	-5.6	-35.5			-5.8	-36.7		-43.7	-4.2	-26.6		-2.9		-25.5		-30.8
20/03/2002	-5.8	-36.3	-7.0	-46.8	-5.7	-34.5		-43.3				[illegible]0.7		-31.2		
30/03/2002	-5.9	-37.1	-8.1	-52.3	-6.3	-39.6										
10/04/2002	-6.1	-38.0	-9.7	-69.4		-41.7		-43.3				-23.7		-34.4		-34.8
20/04/2002	-6.2	-38.7	-14.2	-106.9	-6.6	-41.2										
30/04/2002	-6.4	-39.3	-6.6	-40.1	-5.7	-38.8										
10/05/2002	-6.5	-40.0	-6.0	-36.8	-5.4	-36.7		-43.3				-37.4		-32.3		-29.7
20/05/2002	-6.6	-40.8	-4.1	-22.3	-5.9	-37.7										
30/05/2002	-6.6	-42.1	-2.9	-11.4	-5.4	-35.4										
10/06/2002	-6.7	-43.3	-4.2	-22.1	-5.3	-35.0		-42.7				-41.9		-36.1		-29.1
20/06/2002	-6.7	-43.6	[illegible]	-29.3	-6.9	-33.7										
30/06/2002	-6.7	-43.0			-5.0	-34.7										
10/07/2002	-6.7	-42.3														
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10/08/2002	-6.3	-40.1														
20/08/2002	-6.2	-39.1	-1.2	-4.3												
average	-5.8	-36.3	-4.0	-24.6	-5.8	-35.7	-5.7	-43.1	-2.7	-18.9		-16.5		-28.3		-29.4
st. Dev.	0.7	4.3	4.5	32.4	0.7	2.4	2.1	0.6	1.5	8.8		15.7		5.3		3.3

WATER INPUTS TO THE FLOODPLAIN

The different classes of water inputs to the floodplain are (1) the Amazon river, (2) direct rainfalls, (3) surface runoff from the watershed, and (4) groundwater flow. Fig. 2 illustrates the isotopic composition (in Deuterium) of each of these sources for the 2001-2002 period (measurement errors have been filtered).

Isotopic composition of the Amazon River at Obidos is not yet analysed for this period but values have been derived from measurements at the Amazon mouth (Moura dos Reis et al, 1975). Comparison with measured values for the 2001-2002 period is satisfactory. River waters isotopic composition presents limited variations: -5.8 +/- 0.7‰ (^{18}O); -36.3 +/-4.3‰ (D). The river isotopic signature becomes impoverished in phase with increasing discharge.

Local rainfalls show large annual variations (D from +30‰ to –90‰). Weighted averages are –4.5‰ (O^{18}) and –26.8‰ (D). The rainfall isotopic signature is out of phase with the pluviograph (enriched during the dry season, and impoverished during the rainy season).

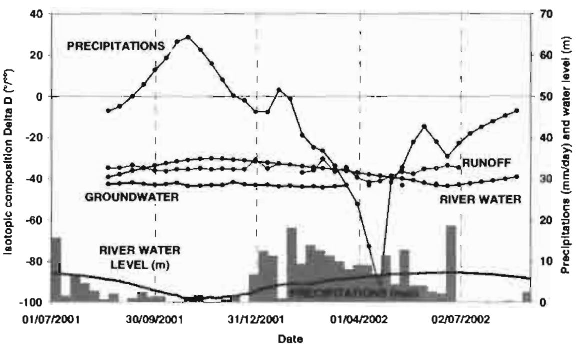

Figure 2. Isotopic composition (deuterium) along the hydrological cycle (2001-2002) of the different main water inputs to the floodplain system.

Groundwater presents a steady isotopic composition of -43.1 +/-0.6‰(D), averaging large rainfalls signature.

Surface runoff from the watershed (stream at Tabatinga do Sale) presents a uniform composition throughout the year (-35.7 +/- 2.4‰), probably due to a dominant contribution by groundwater and the runoff on the forested drainage basin.

FLOODPLAIN LAKES

Figure 3 illustrates the evolution of the isotopic composition (Deuterium) in the main lakes of the várzea along the hydrological cycle.

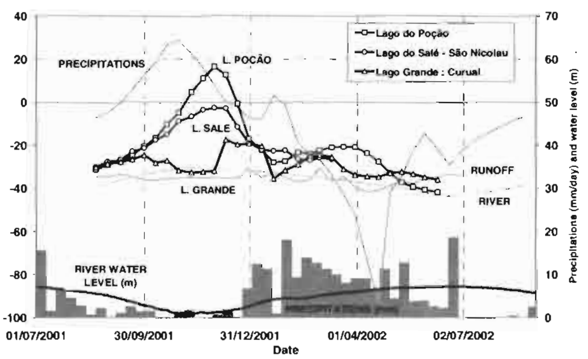

Figure 3. Isotopic composition of the surface waters of the main floodplain lakes of the Curuai várzea (deuterium) during one hydrologic cycle (2001-2002).

Poção and Salé lakes, located in the inner part of the floodplain lakes system, clearly show an isotope enrichment during the river decreasing stage (dry season). This is due to the active evaporation process and the absence of external water inputs (either rainfall or river inflow). Although river starts rising on Nov./10/2002, isotope impoverishment of lakes waters only starts by the first weeks of December 2001, when the river inflow reaches a certain threshold.

Lake Grande isotopic composition shows a more erratic dynamics without dry season enrichment and with relatively high values from Dec., 10th to Jan., 10th. This can be explained by the sampling site (Curuai) location, situated on the southern limit of the lake, under the influence of groundwater and watershed runoff. During the low water stage, groundwater with constant isotope composition flows to the lake. When the river starts rising (in early December), the water inflow coming from the Amazon pushes isotopically enriched lake waters (submitted to high evaporation during the dry season) from the eastern part of the lake towards Curuai. By January, 20th of 2002, low rainfalls and stabilised river level induce renewed groundwater contribution at Curuai.

During the dry season, the maximum enrichment of lakes waters decreases from the Lake Poção (max. +16‰) to the Lake Salé (max. -3‰) and Lake Grande (max. -15‰). During the river rising stage (rainy season), lakes waters show a decreased isotopic composition, tending to the river waters isotopic values. Local temporary enrichments can be observed (Lake Poção, February – March 2002) probably due to the evaporation process when new inputs of water are limited.

WATER OUTPUTS BACK TO THE RIVER

Isotopic composition of waters from the eastern (downstream) channel connecting the floodplain to the river (Boca do Lago from 20/04/2002) show that permanent channel water is in phase with the river water during the rainy season (Fig. 4), but is enriched at the end of the rising stage when water flows back to the mainstream (-30‰ against -40‰).

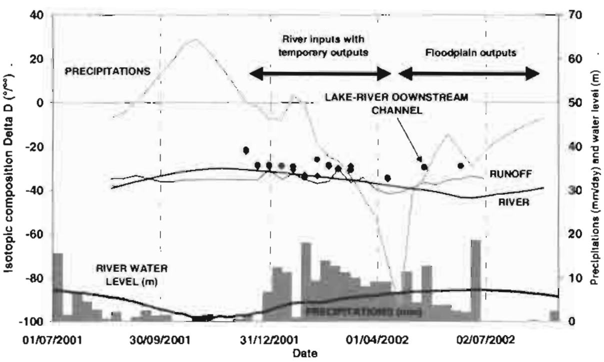

Figure 4. Isotopic composition of waters on downstream connexion canal between lake and floodplain.

ISOTOPIC GEOCHEMISTRY CONTRIBUTION TO THE UNDERSTANDING OF FLOODPLAIN HYDROLOGY

As mentioned above, most part of the floodplain flows cannot be regularly measured (river inflow to the floodplain, bank overflow, watershed runoff to the lakes, intensity of the evaporation process) and related hypothesis on the floodplain hydrological dynamics can hardly be verified. Thanks to the conservativity of the water stable isotopes, isotopic geochemistry can help in evaluating the validity of current assumptions concerning the hydrological dynamics of the system.

ISOTOPIC MODELING OF FLOODPLAIN

We developed a model of isotopic geochemistry dynamics, simulating mixing and fractioning processes, and we coupled it to the hydrological model. Model inputs are time-varying isotopic composition of rainfall, runoff and river waters, and lakes water temperatures that influence equilibrium fractioning during evaporation. Model outputs are the time-varying isotopic compositions of lakes and water fluxes between the lakes and the river. Although the general dynamics of isotopic composition is retrieved, some model discrepancies can be identified:

(1) observed isotopic impoverishment of lakes starts on the first week of December while simulated impoverishment starts one month later. This indicates an overestimation of the channel bottom topography that delays the inflow from the river to the floodplain.

(2) calculated maximum enrichments are underestimated for the Poção and Salé lakes and overestimated for the Grande lake; the isotopic impoverishment during the river rising stage (and rainy season) is slower than observed (Poção, Sale).

This indicates that respective contributions by rainfall, river inflow and lake evaporation are not fully satisfactorily retrieved in the model.

CONTRIBUTION OF FLOODPLAIN OUTPUTS TO THE RIVER DISCHARGE

As shown earlier through measured values (Fig. 4) and simulation results, isotopic composition of floodplain waters flowing back to the river is richer than that of the Amazon River water. At the annual scale, the floodplain dynamics contributes to smoothen the isotopic composition of the water of the Amazon River downstream.

Although further studies are clearly needed, these first results allow estimating the contribution of the floodplain lakes to the isotopic enrichment of the Amazon River during an hydrological cycle.

CONCLUSION

Tracing of stable isotopes in Curuai floodplain proved to be useful to characterize the spatial and temporal variability of floodplain hydrological dynamics.

Measured isotopic compositions of floodplain waters were compared to values calculated by a coupled hydrological-isotopical simulation model. The method allowed to constraint contributions by different water sources (river, rainfall, watershed runoff, groundwater) and control by various physical processes (mixing, fractioning). Above all, isotopic geochemistry provides an indirect method to validate the estimation of some water flux that cannot be directly measured like watershed runoff, river bank overflow, or lake evaporation.

Floodplain waters flowing back to the river are generally enriched in stable isotopes, due to the evaporation of the lakes during the dry season. This suggests a method to quantify floodplains contribution to river discharge and chemical composition along the hydrological cycle.

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REFERENCES

Chaffaut I., 1998. Précipitations d'altitude, eaux souterraines et changements climatiques de l'Altiplano nord-chilien. PhD dissertation, Université Paris XI Orsay, France.

Chapelon N., Douville H., Kosuth P., Oki T., 2002. Off-line simulation of the Amazon water balance. in Climate Dynamics vol. 19 , pp 141-154.

Costa M. H., Foley J.A., 1998. Trends in the hydrologic cycle of the Amazon basin. Journal of Geophysical Research, vol. 104, NO.D12, pp 14189-14198.

Fritz P., Fontes Ch., 1980. Handbook of Environmental Isotope Geochemistry, The Terrestrial Environment-A, Elsevier.

Gat, J.R. Matsui, E. 1991. Atmospheric water balance in the amazon basin : an isotopic evapotranspiration model. In : J. Geophys. Res., vol. 96, n° D7, p. 13179-13188.

Junk W.J., 1997. General aspects of the floodplain ecology with special reference to amazonian floodplains, 3-20. In The central Amazon floodplain, Ecology of a pulsing system. Junk W.J. (ed.), Ecological Studies 126, Springer.

Kosuth P., 2002. Hydrological dynamics of the varzea of Lago Grande de Curuai. In 2nd LBA (Large Scale Biosphere Atmosphere) Scientific Conference, Manaus, Brazil.

Martinelli, L.A., Victoria R.L., Sternberg L.S.L., Ribeiro A. and Moreira M.Z., 1996. Using stables isotopes to determine sources of evaporated water to the atmosphere in the Amazon basin. In : Journal of Hydrology 183, pp 191-204.

Martinez J.M., Kosuth P., Cochonneau G., Maurice-Bourgoin L., Seyler F., Bourrel L. and Guyot J.L., 2003. Application of remote sensing data for the quantification of an Amazon floodplain extension, dynamics and water storage. EGS-AGU-EUG Joint Assembly, Nice, April, 2003, France.

Molinier M., Guyot J.L., Callède J., Guimarães V., Oliveira E., Filizola N., 1997. Hydrologie du bassin amazonien, 24-41. In Environnement et développement en Amazonie brésilienne, Théry H. (ed.), Publ. Belin, Paris.

Moura dos Reis C., Tancredi A. C. F. N. S., Matsui E., Salati E., 1975. Caracterização das águas da região de Marajo através de concentrações de O 18 e D. In : A.Amazônica vol.7 n2, 209-222

Seyler F., Martinez J.M., Prigent C., Kosuth P., 2003. Apports de la télédétection à la quantification de la dynamique des zones inondées du bassin amazonien. In Revue de la SFPT (subm.)

Sippel S.J., Hamilton S.K., Melack J.M., Novo E.M.M., 1998. Passive microwave observations of inundation area and the area/stage relation in the Amazon River floodplain. In Int. Journal of Remote Sensing, vol 19, NO 16, pp 3055-3074.

Shukla J, Nobre C, and Sellers P., 1989. Amazon deforestation and climate change. Science 247, 1322-1325.

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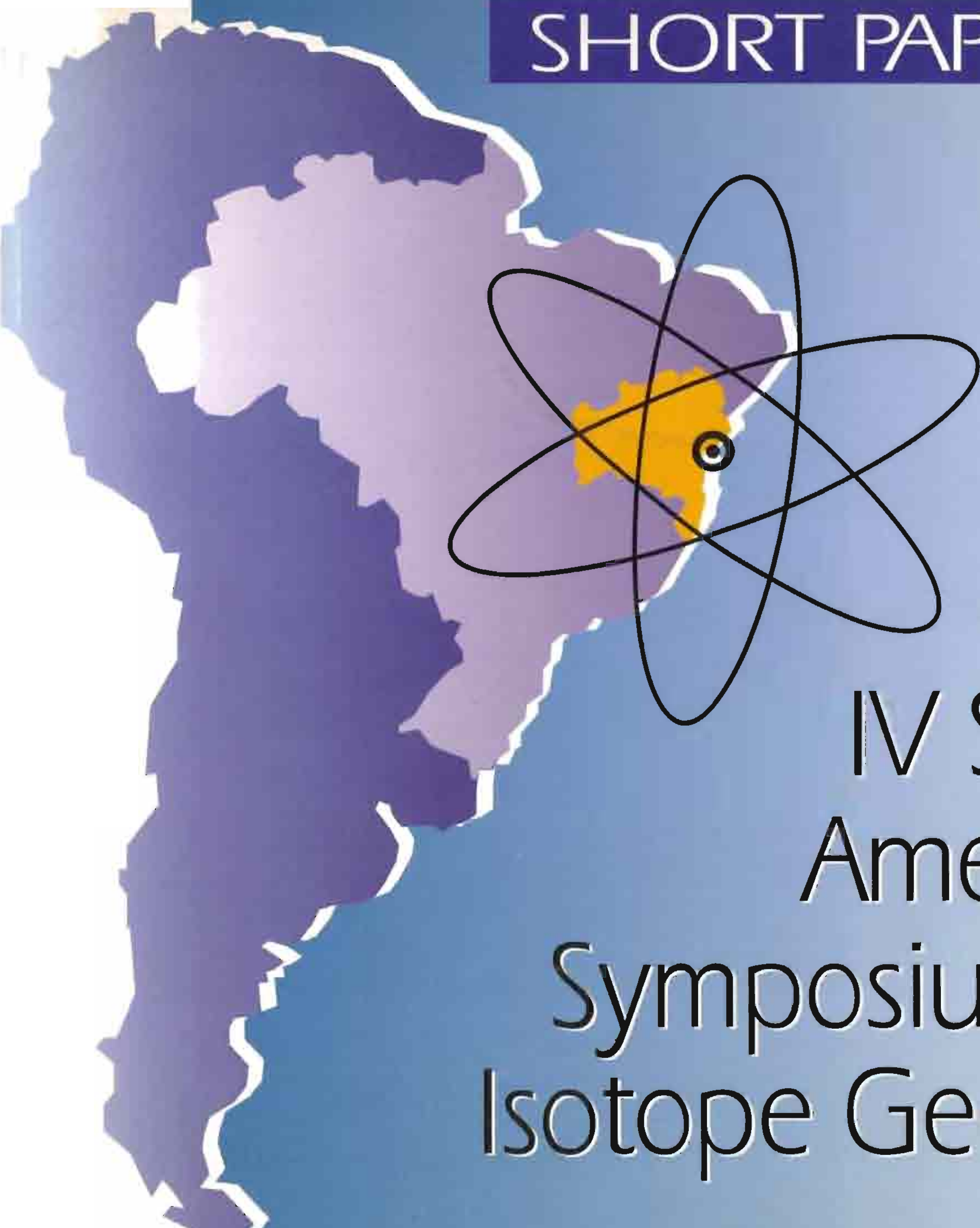

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Reference.

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