Hydrological Response of the Amazon River to the Droughts of 1996-97 and 2004-2005

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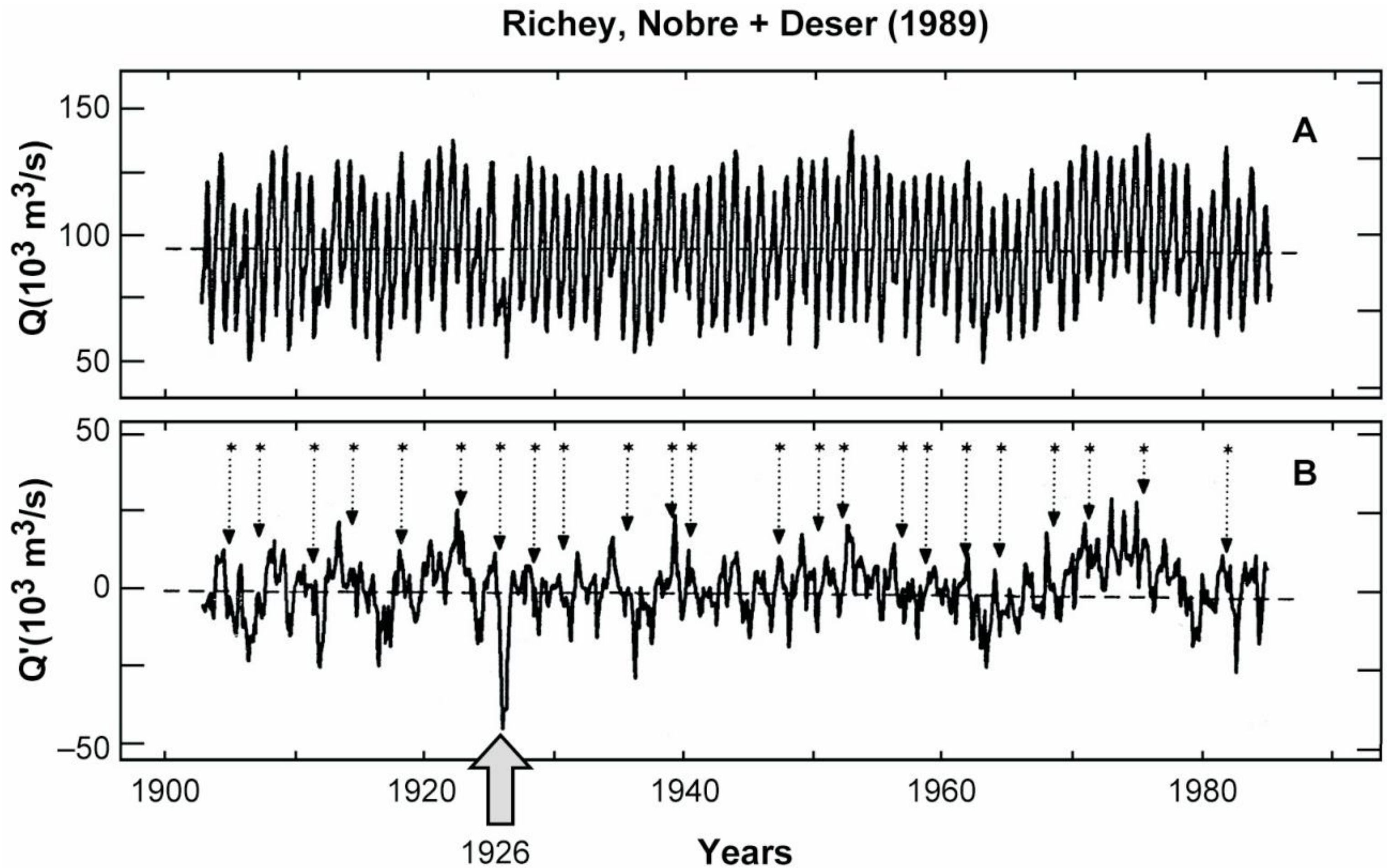
Recent studies suggest that the Amazon is highly vulnerable to:

- global climate change (Cox et al, 2004; Li et al. 2006; Salazar et al. 2007; Cox et al., 2008);
- deforestation and (Sampaio et al., 2007; Costa el al., 2007);
- increased forest fires Brown et al 2006; Cardoso et al. 2003; 2009);
- and has the potential to accelerate those changes by feedback mechanisms (Cox et al 2008; Nobre and Borma 2009).

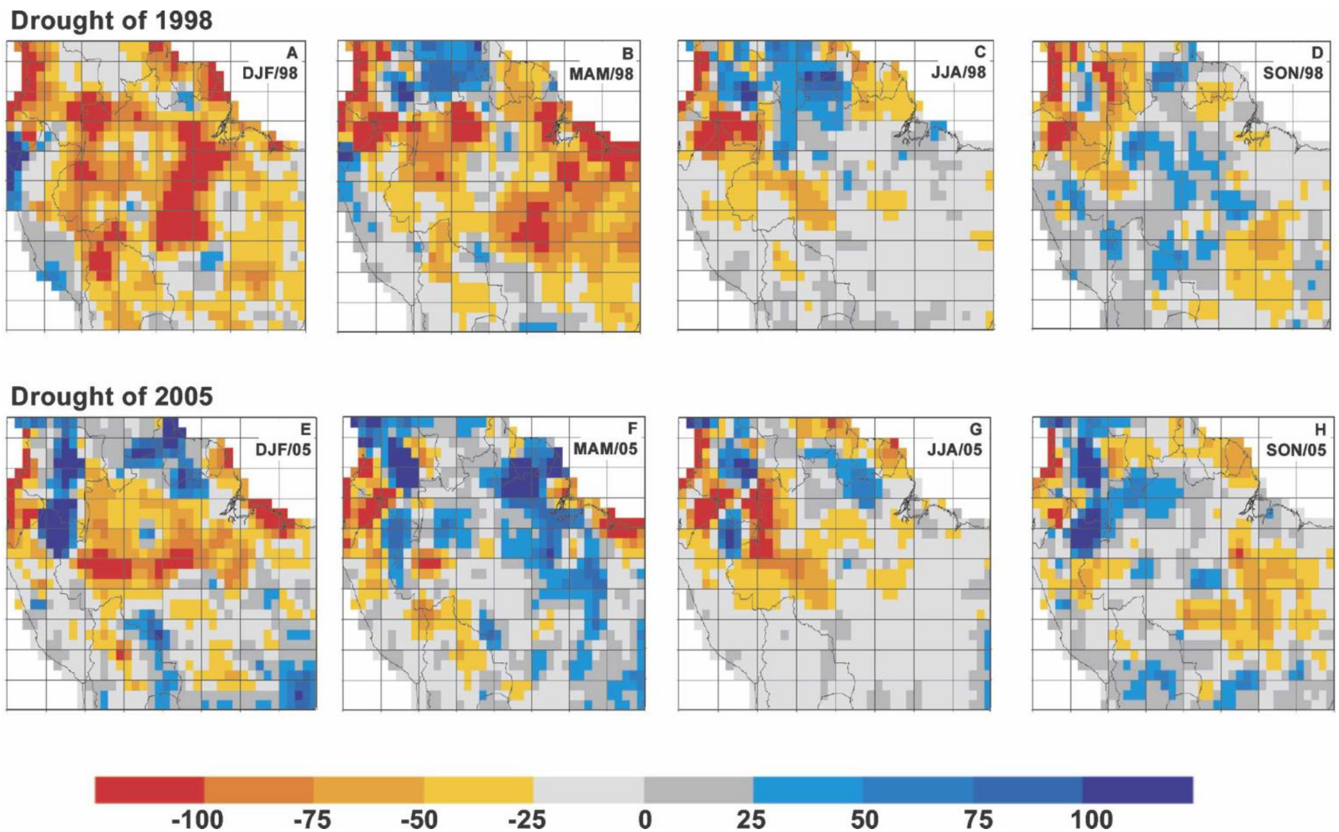
Therefore, a better understanding of how Amazon ecosystems cope with environmental extremes is crucial.

Severe hydrological droughts in the Amazon have generally been associated to strong El Niño events.

More than 100 years of stage record at Manaus harbor confirm that minimum water levels generally coincide with intense warming in the tropical Pacific sea waters.



During 2005, however, the Amazon experienced a severe drought which was not associated to an El Niño event. Unless what usually occurs during strong El Niño events, when negative rainfall anomalies usually affect central and eastern Amazon drainage basin; **rainfall deficiencies in the drought of 2005 were spatially constrained to the west and southwest of the basin**.

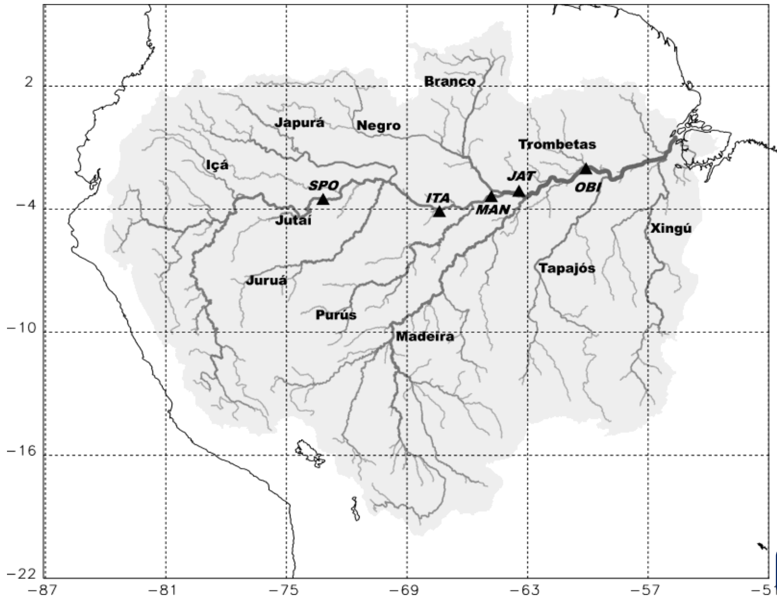


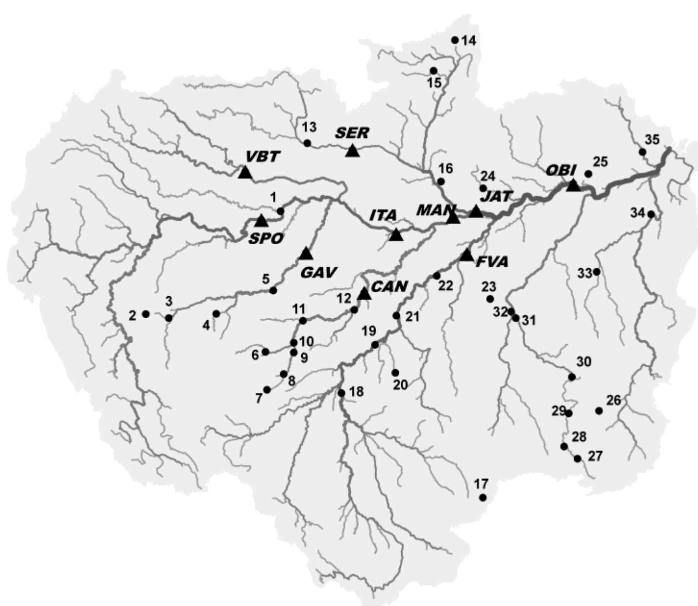
Marengo et al. 2008

In spite of this, discharge stations at the main stem during 2005 recorded minimum water levels as low as those observed during the basin-wide 1996-97 El Niño related drought.

Why an “spatially constrained” drought caused such severe effects on river discharges, equivalent to strong basin-wide EL Niño droughts?

The Amazon Basin

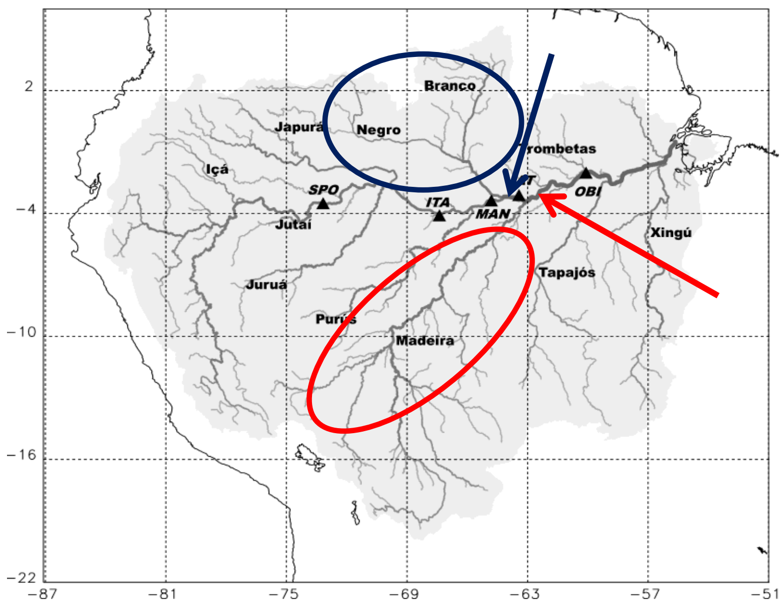




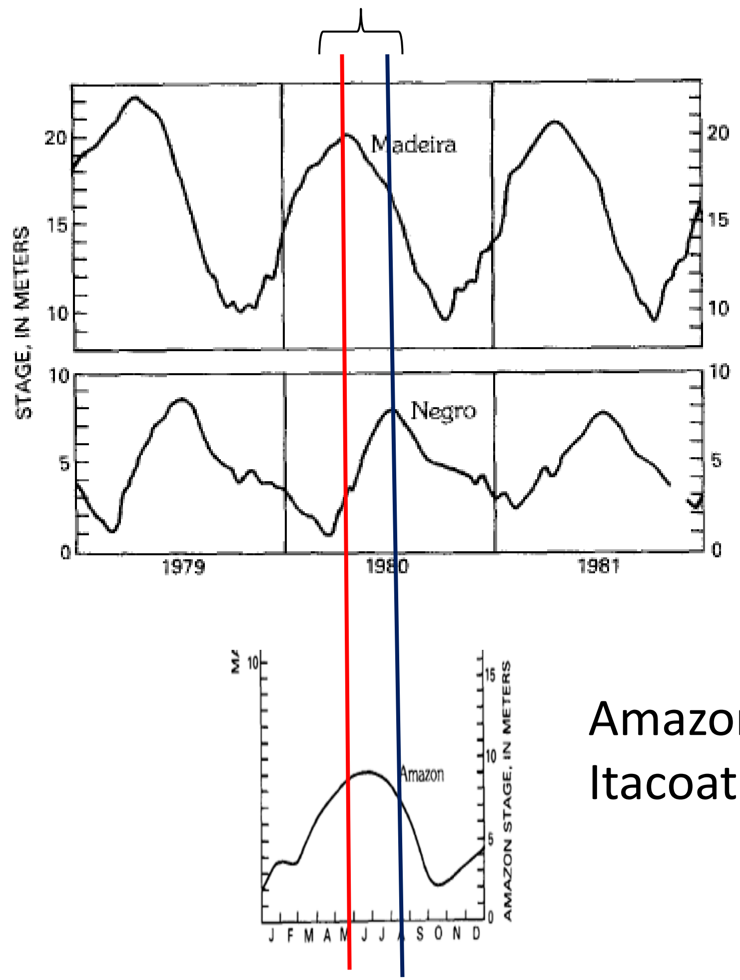
River	Drainage area (km^2)	Rainfall ($mm\ y^{-1}$)	Annual mean discharge ($m^3 s^{-1}$)
Main Stem			
Solimões (São Paulo de Olivença)	990 780	2900	46 500
Solimões (Itapeuá)	1 769 000	n/a	85 485
Solimões (Manacapurú)	2 147 740	2880	103 000
Amazonas (Jatuarana)	2 854 300	2780	131 600
Amazonas (Óbidos)	4 618 750	2520	168 700
Northern tributaries			
Içá	143 760	3160	8800
Japurá	248 000	3000	18 620
Negro	696 810	2566	28 400
Trombetas	128 000	1822	2 555
Southern tributaries			
Jutaí	77 280	2781	3 020
Juruá	185 000	2452	8 440
Purus	370 000	2336	11 000
Madeira	1 420 000	1940	31 200
Tapajós	490 000	2250	13 500
Xingu	504 300	1930	9 700
Whole basin			
Amazon	6 112 000	2460	209 000

Discharge stations used to characterize the drought

The Amazon Basin



The Madeira river peaks 2-3 months earlier than the Negro, although it encounters the Amazon downstream

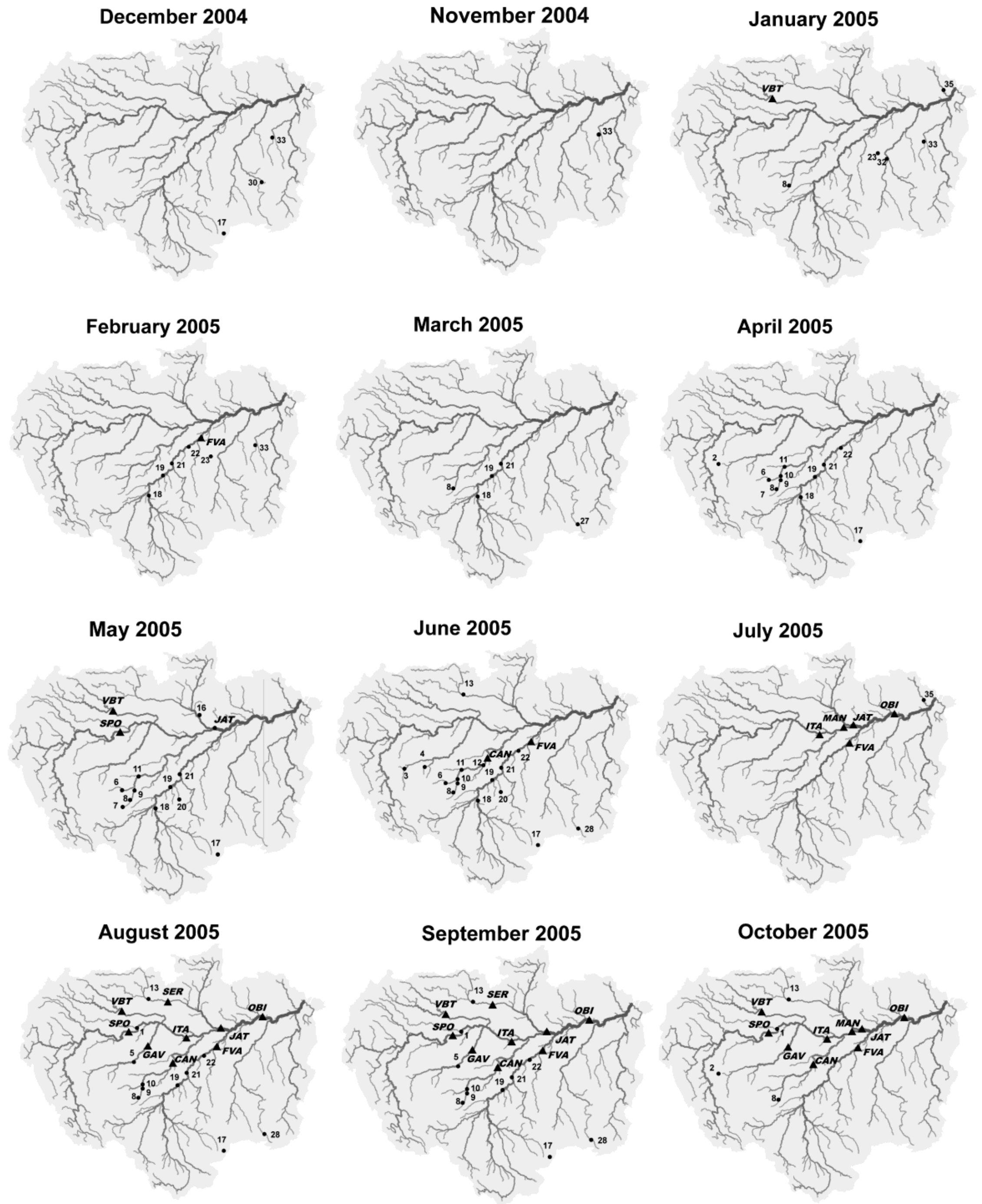


Amazon at Itacoatiara

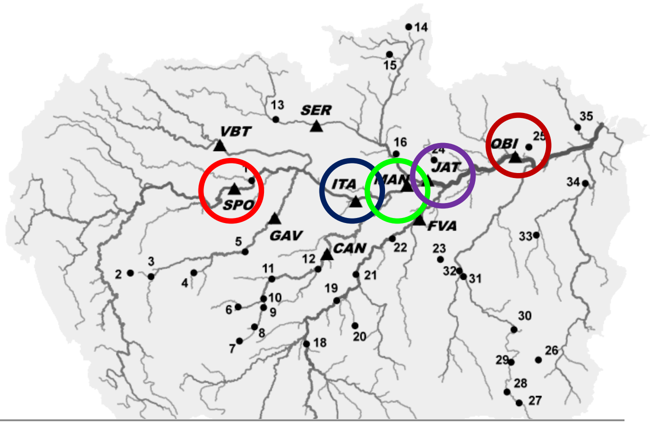
This "peculiar" contribution time of the main tributaries causes strong backwater effects (Meade et al. 1991)

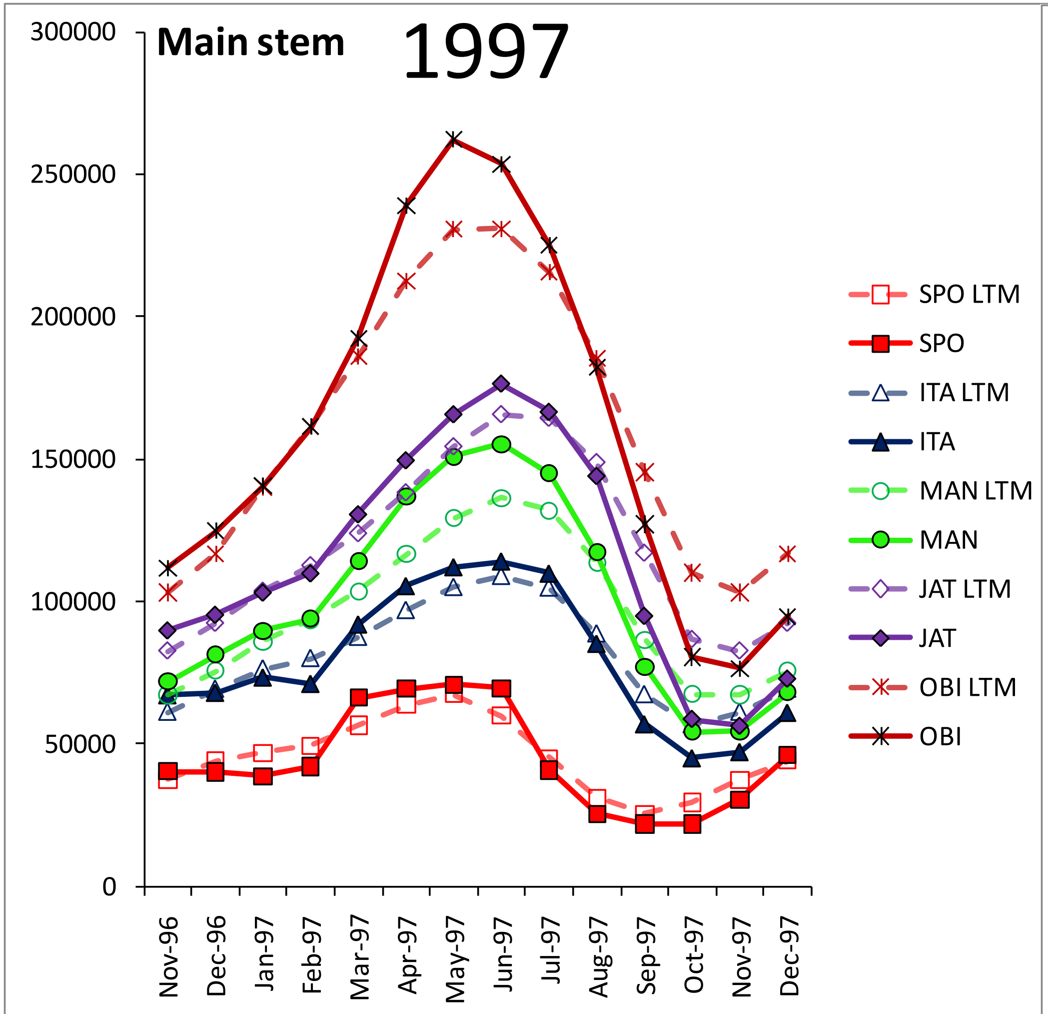
The drought of 2005: Geographical context:

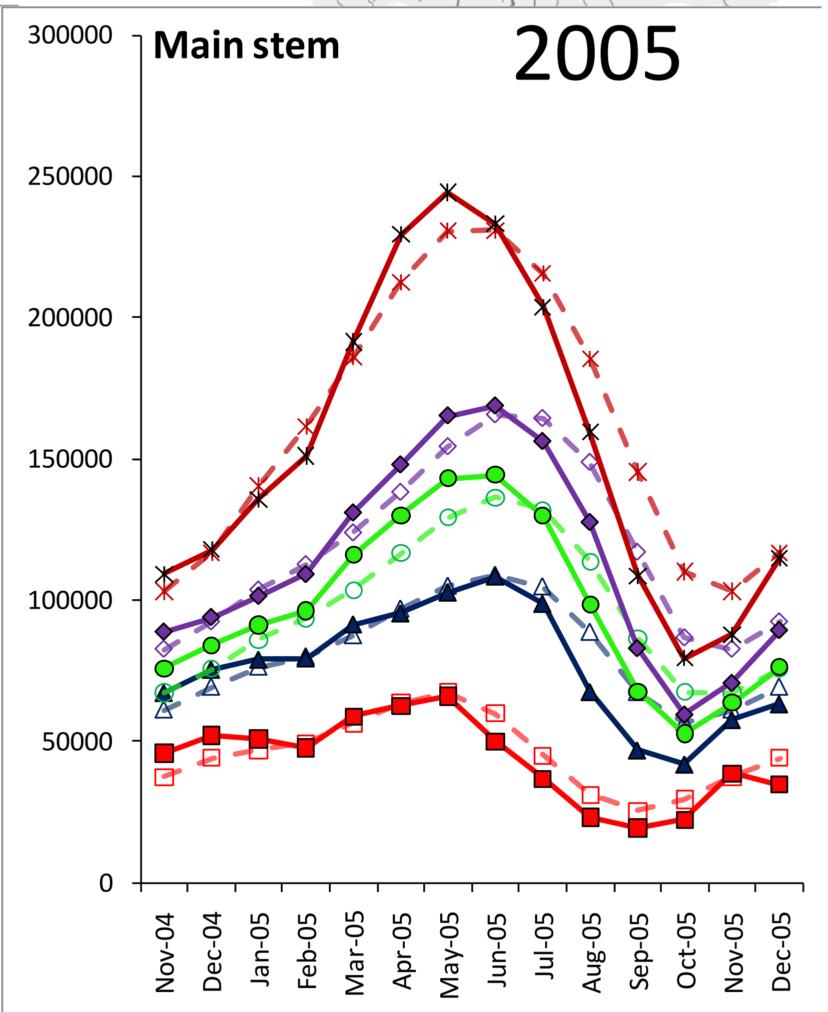
Discharge stations with flow values lower than -1σ

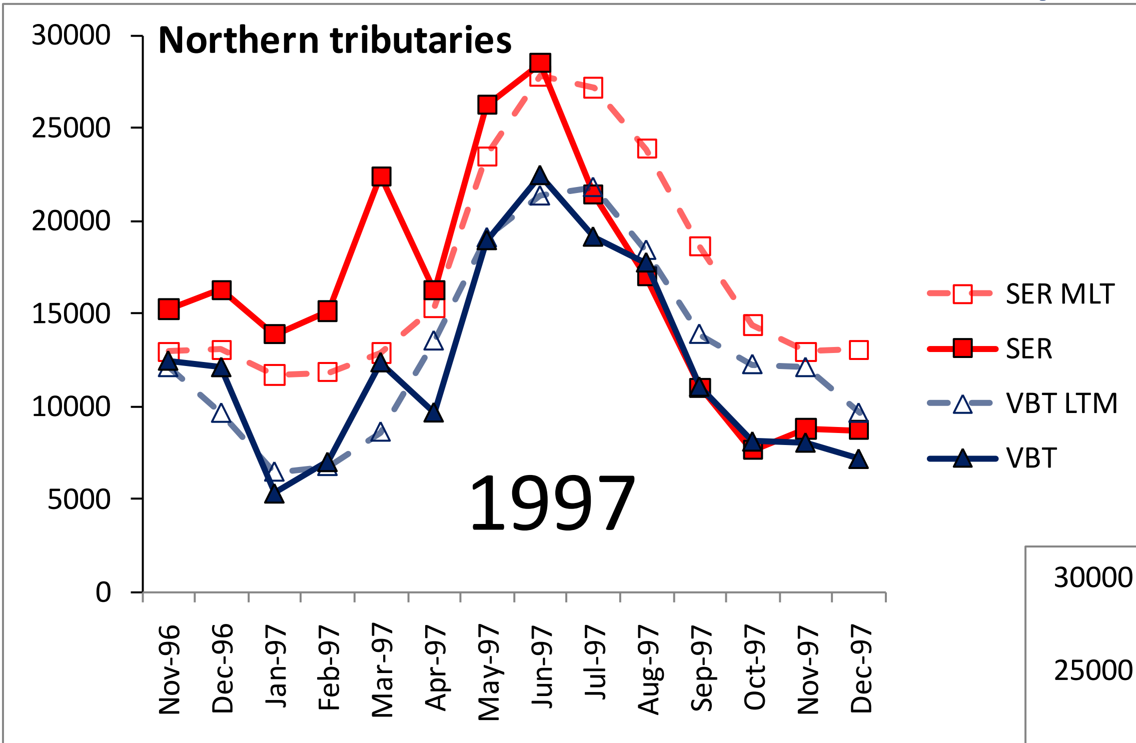


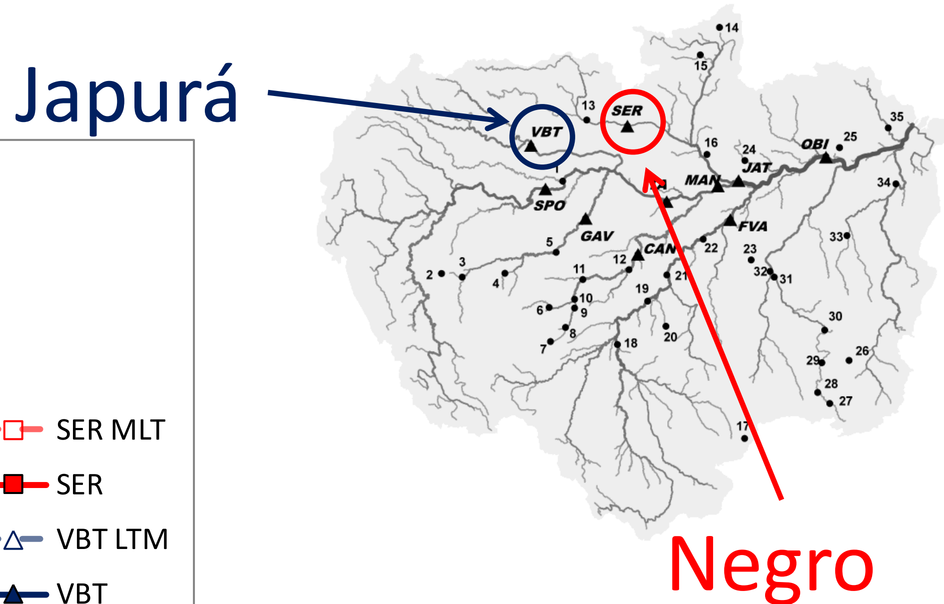
Discharges variations during 1997 and 2005 droughts along the main stem



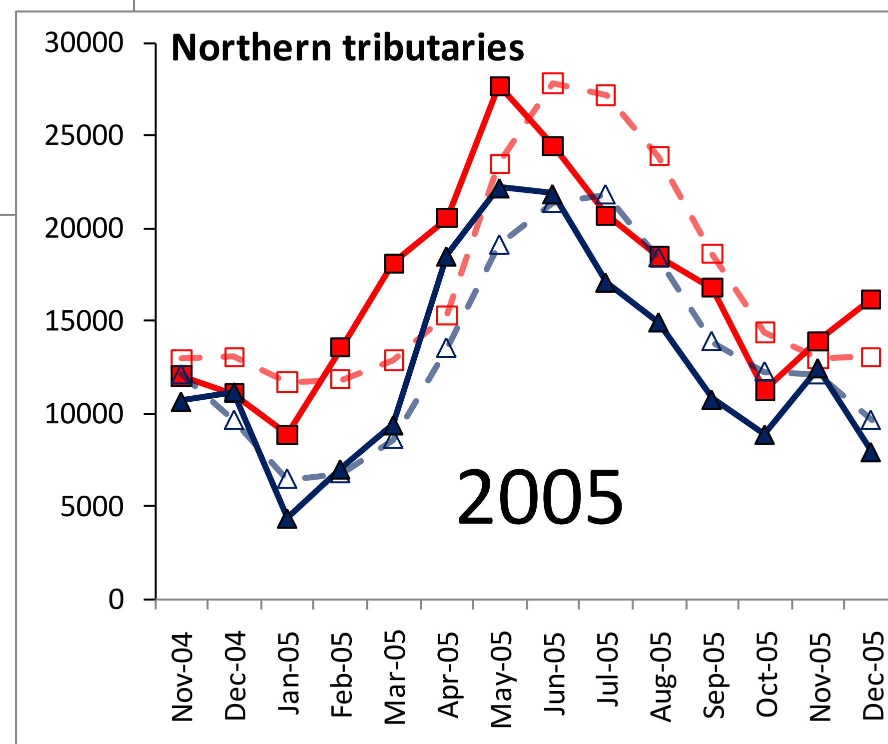




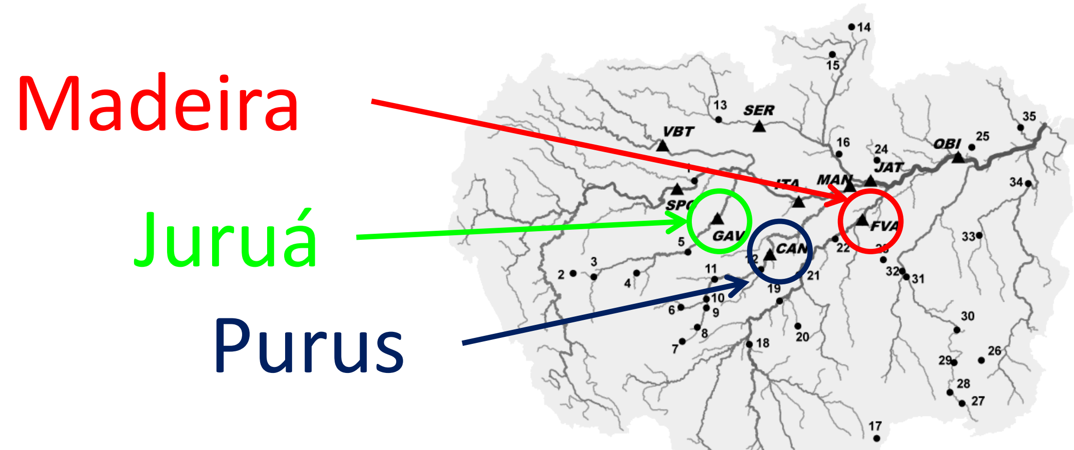


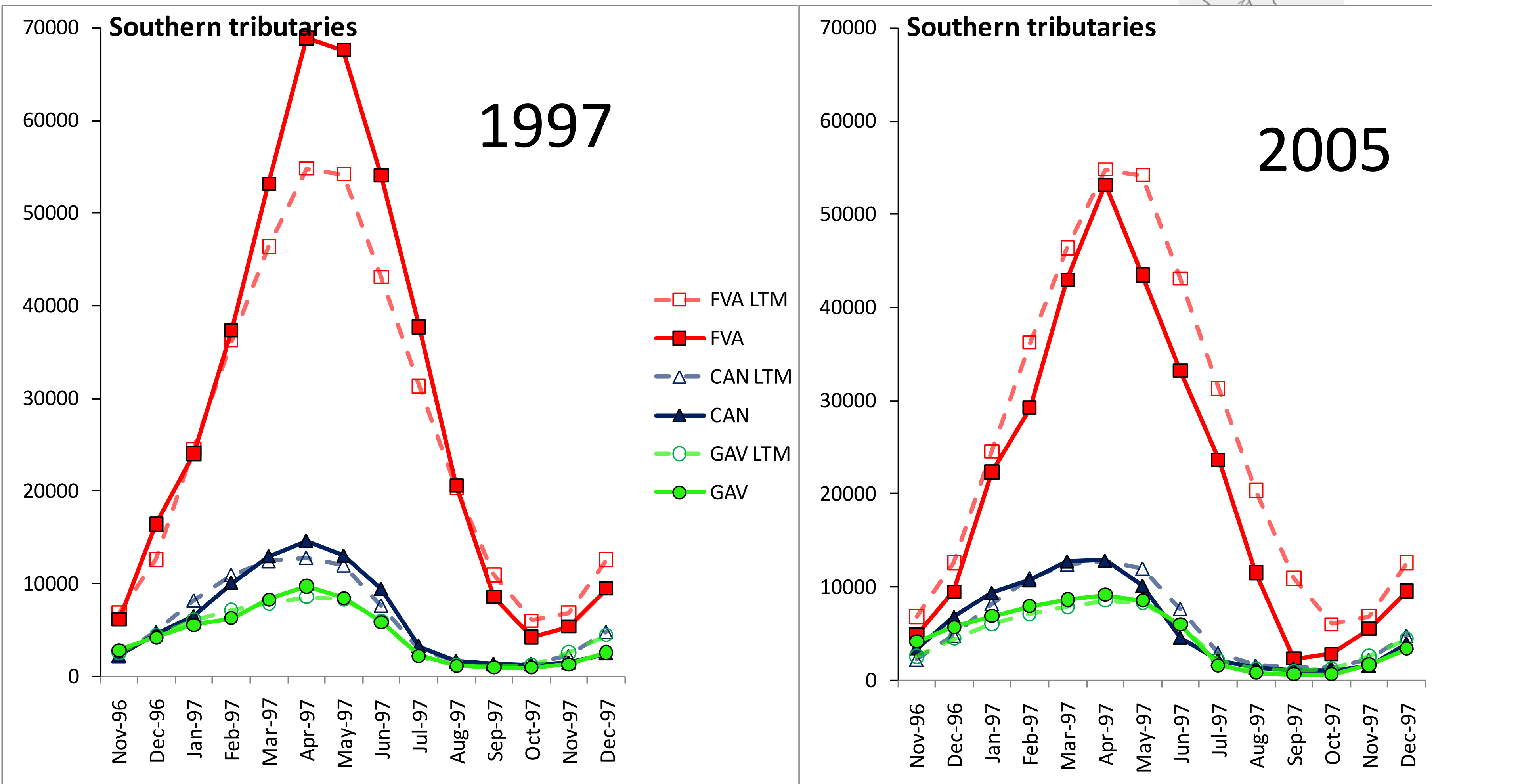


Discharges variations during 1997 and 2005 droughts in northern tributaries



Discharges variations during 1997 and 2005 droughts in southern tributaries





Annual minimum monthly discharge and the percentage of the minimum relative to the long term mean (% LTM).

Code	Station	1997			2005		
		Annual monthly minimum discharge	Month	% LTM	Annual monthly minimum discharge	Month	% LTM
Main Stem							
SPO	São Paulo de Olivença	21755	Sep	86.0	19327.2	Sep	76.4
ITA	Itapeuã	45051.3	Oct	79.4	41973.5	Oct	73.9
MAN	Manacapuru	54124.0	Oct	80.4	52780.4	Oct	78.4
JAT	Jatuarana	67226.1	Nov	68.2	59543.9	Oct	72.1
OBI	Óbidos	76394.0	Nov	74.1	79477.1	Oct	77.1
Main Tributaries							
GAV	Gavião	877.3	Sep	91.9	574.2	Sep	60.1
VBT	Vila Bittencourt	7179.0	Dec	74.7	7964.9	Dec	82.8
CAN	Canutama	1205.5	Oct	87.6	1034.3	Oct	75.1
SER	Serrinha	7626.5	Oct	53.0	11258.2	Oct	78.3
FVA	Fazenda Vista Alegre	4182.3	Oct	69.7	2247.6	Sep	37.4

During the 1996-97 drought, discharges deficits along the main-stem were controlled most of the time by northern tributaries.

In 2004-05, on the other hand, the discharge in northern tributaries peaked earlier and initiated a rapid recession, accelerating the falling of river stages in the main-stem.

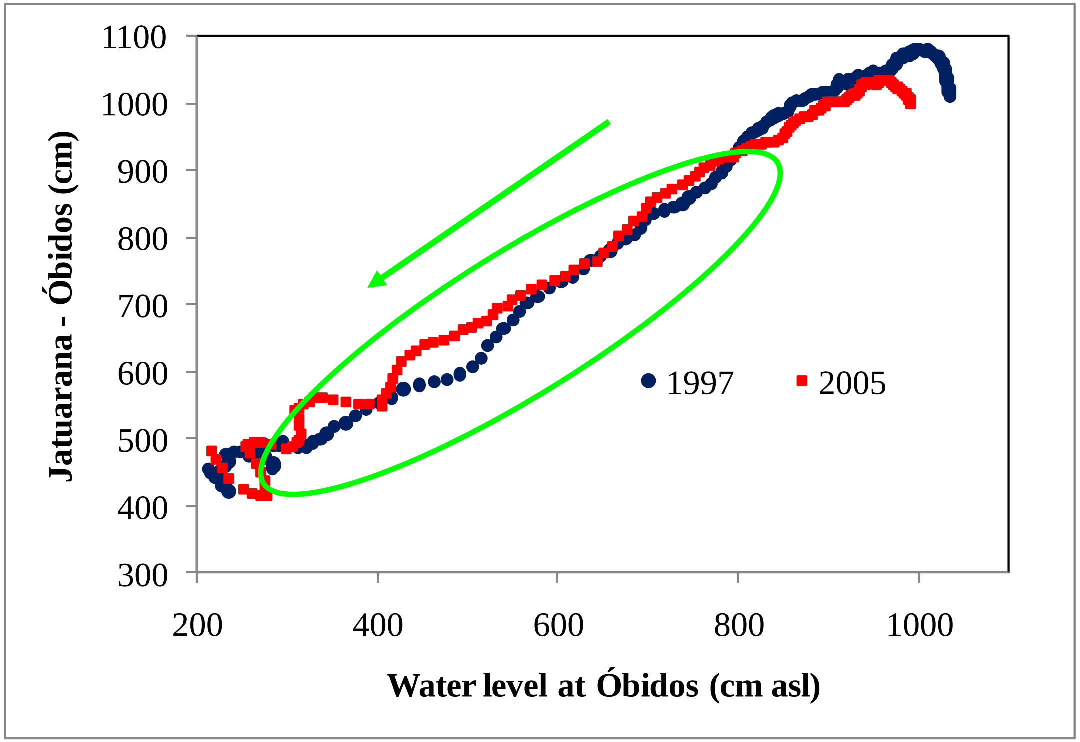
During the 2004-05 drought, the signal observed in the main-stem was controlled mostly by the southern tributaries.

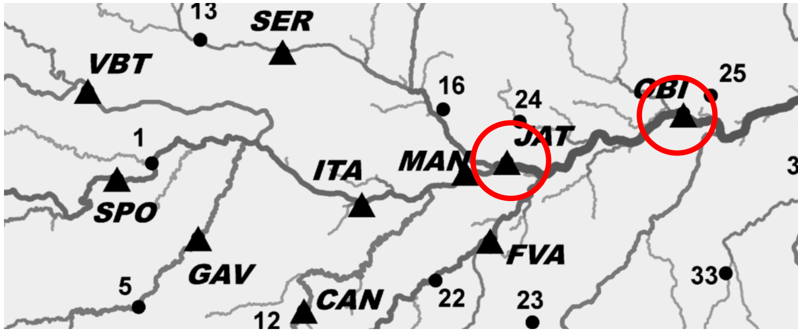
In normal years, the highest stages in the Madeira river occur two to three months prior to those in the Negro river, and the time displacement between the peaks is fundamental for damping the extremes along the main-stem (Meade et al. 1991).

Comparison between both drought revealed that during 1996-97, the Madeira river at Fazenda Vista Alegre station peaked two months earlier than the Negro river at Serrinha station.

During 2004-05, on the other hand, peak time difference was reduced to a month because the Negro river peaked earlier than normal, and the recession in all tributaries began almost simultaneously

An almost coincident recession of northern and southern tributaries during 2004-05, combined with lower than normal river discharges of southern tributaries affected the gradients along the main-stem





Daily water level at Óbidos station minus water levels at Jatuarana station; plotted against the water levels at Óbidos, for the whole recession of 1997 and 2005

Water level data suggests that water gradients were higher during 2005 compared to 1997, as a consequence of lower than normal river discharges in the Madeira river

Conclusions:

The analysis of the hydrographs along the main stem and in individual tributaries indicate that the drought of 1996-97 was mostly controlled by tributaries draining the northern part of the basin, while the 2004-05 event were controlled by southwestern tributaries.

In the drought of 1996-97 discharges were close to the mean during early 1997, became well above the mean during the high water; and drastically dropped after July 1997, producing very low discharges during November 1997. Lower than normal discharges continue well beyond 1997.

Conclusions:

In the drought of 2004-05, on the other hand, tributaries which drain the northern part of the basin peaked earlier than “normal”, and then initiated a rapid recession, almost simultaneously than the southern tributaries.

This combination heavily impacted the main stem because it increased water level slopes in the main-stem, causing a rapid decline of river stages reaching minimum levels in October 2005.

Conclusions:

The analysis of both droughts revealed that, in the Amazon River, regionally restricted negative rainfall anomalies can have a stronger impact downstream than more geographically extensive droughts, providing that rainfall deficiencies occur on critical time during the main stem recession.

Obrigado!

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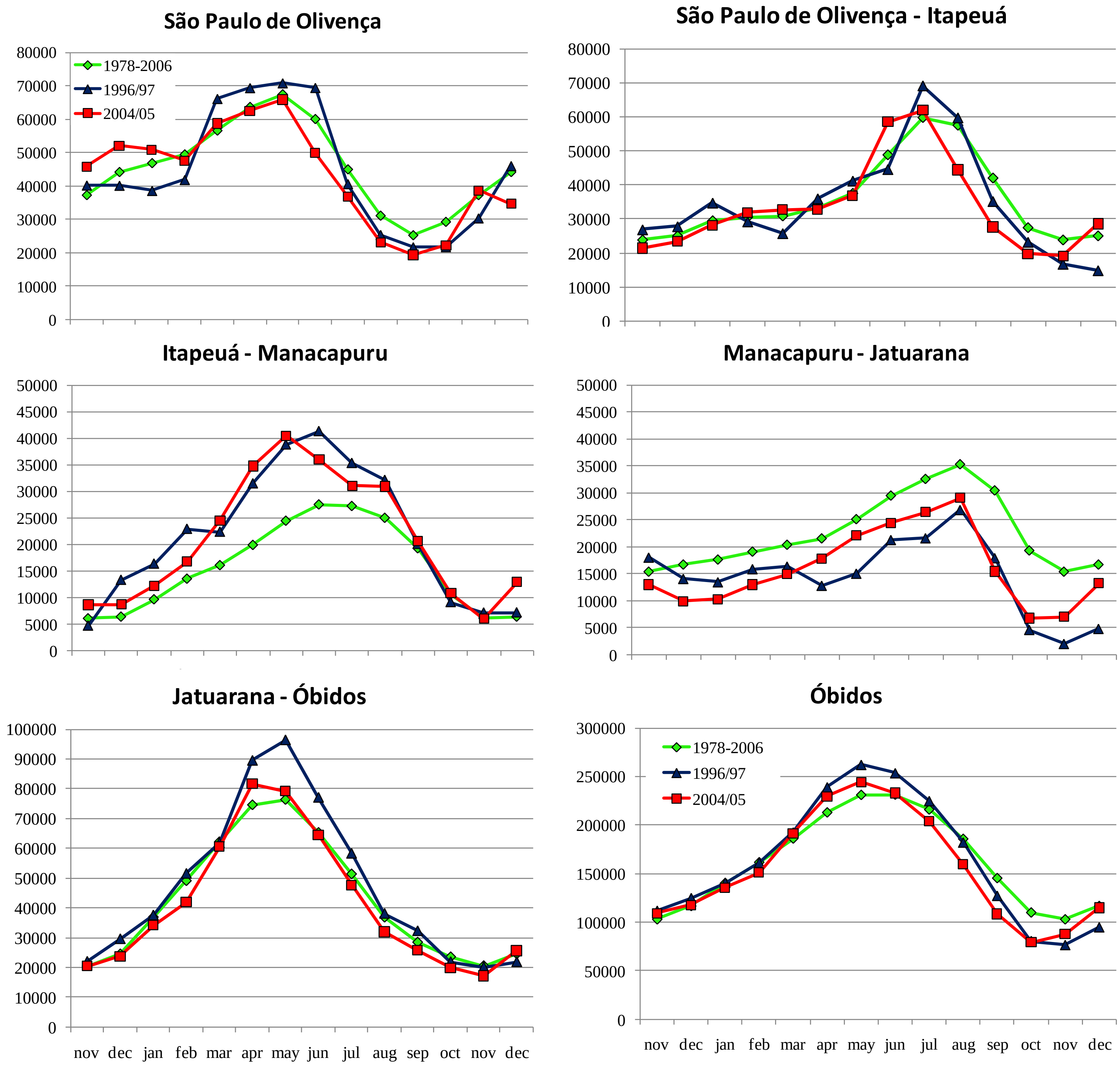
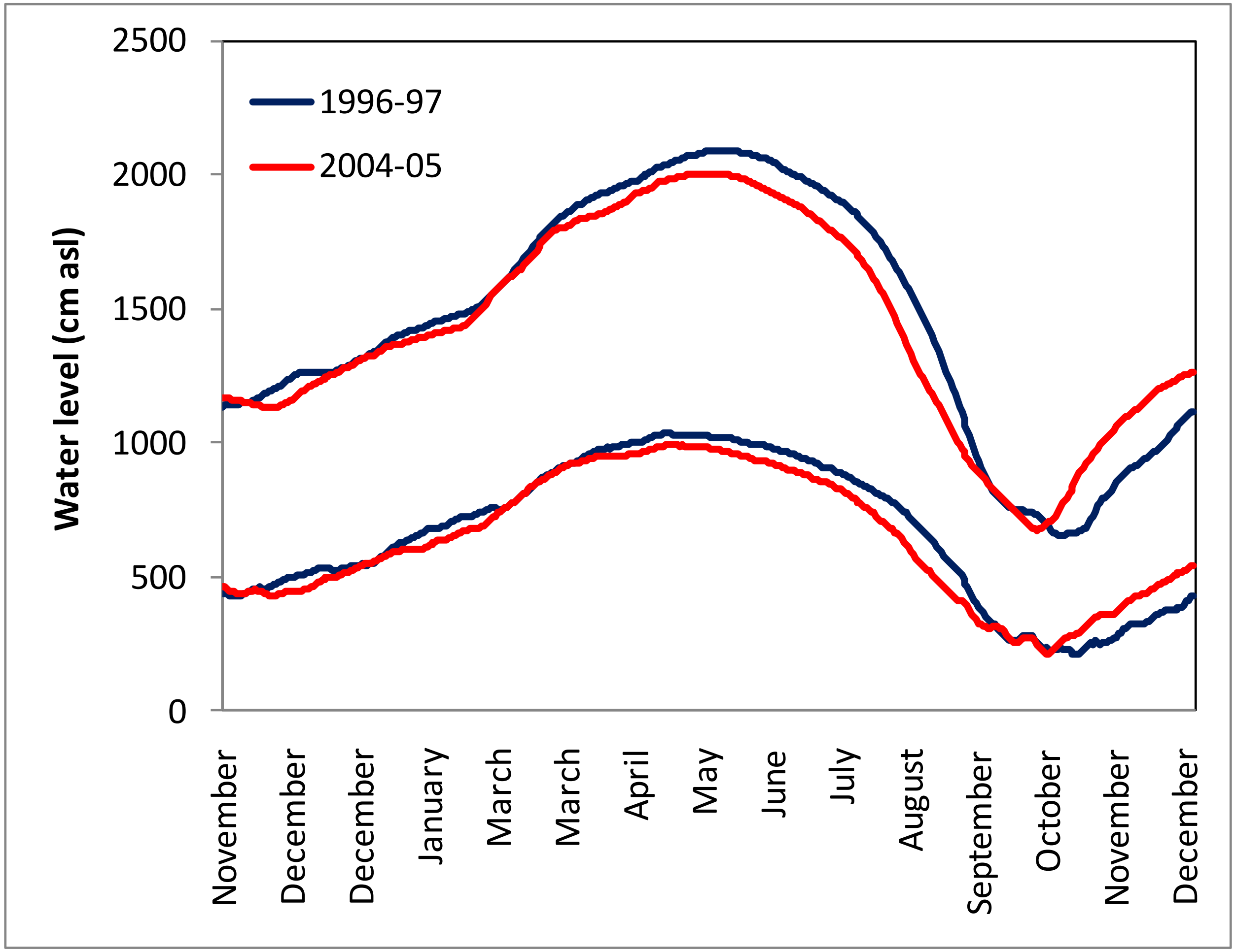
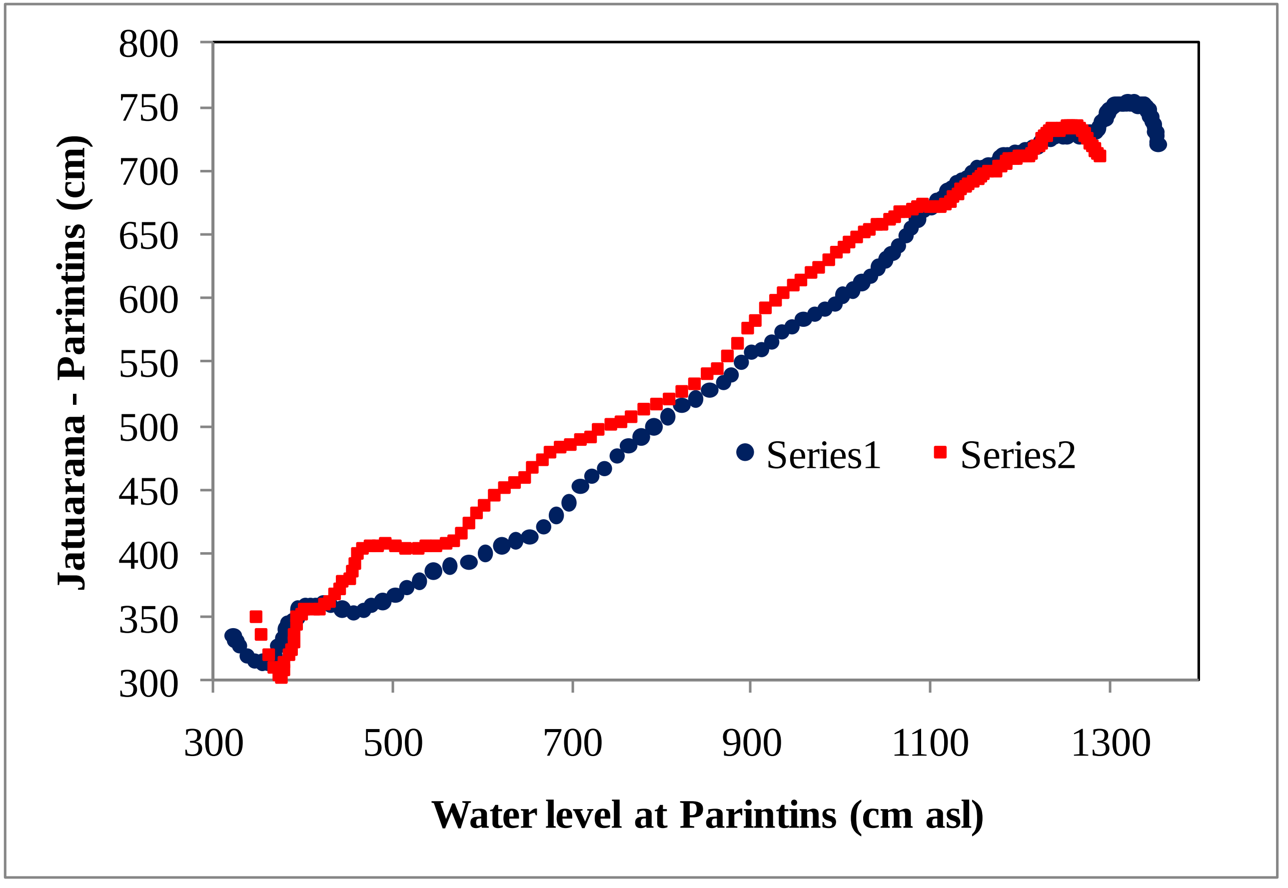
Analysis of incremental discharges along the main-stem



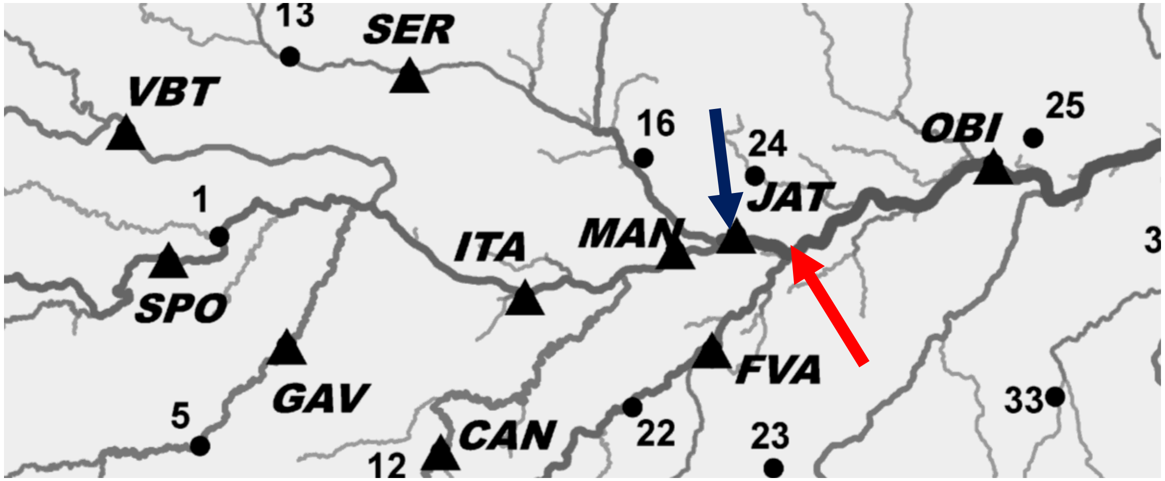


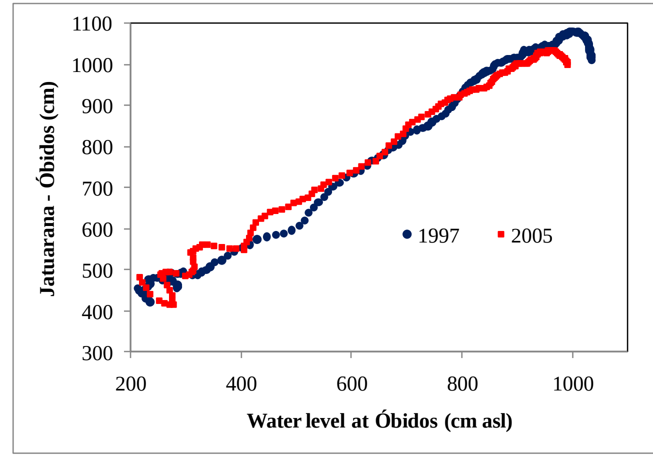
2500
2000
1500
1000
500
0
Water level (cm asl)
1996-97
2004-05
November
December
December
January
March
March
April
May
June
July
August
September
October
November
December

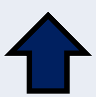
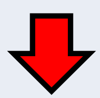
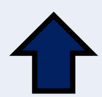
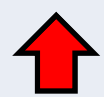


Jatuarana - Parintins (cm)
800
750
700
650
600
550
500
450
400
350
300
300
500
700
900
1100
1300
Water level at Parintins (cm asl)
Series1
Series2

In other words





	1996-97		2004-05	
	Negro	Madeira	Negro	Madeira
High water				
Falling stage