Reduction in water levels and regional warming of the Amazon River from Peru to the Atlantic Ocean in Brazil due to the effects of the 2016 ENSO.

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Abstract

In situ observations of the tendencies of the prolonged ENSO (El Niño Southern Oscillation) phenomenon combined with a trend of regional warming in both western and eastern Amazonia were registered by the Amazon River Peru-Brazil Expedition on the Amazon River. Temperatures were taken at four positions on the river (edge, middle of the canal, 1 m deep below the surface, and ambient air temperature), air pressure and humidity, and the velocity and direction of the wind were the parameters that were sampled from the Peruvian city of Iquitos beginning in July 2016, to the Brazilian city of Macapá at the mouth of the Amazon River in December 2016. The results suggest that there was a decline in water levels along the river during the entire observation period due to the prolonged El Niño event that occurred in 2014, 15 and 16.

Introduction

Changes in atmospheric circulation in the tropical zone (Walker cell) induce change in rainfall patterns, devastating floods, and severe droughts that can drastically affect the lives of millions of people (MOHTADI *et al,* 2017). In the mosaic of landscapes that is tropical South America the tendencies for rainfall, in the Amazon in eastern Brazil, to the northwest of Peru are well-defined by long-term hydrological data for the Amazon basin that were recorded during the 20th century. During this period the tendency for rainfall during the three most humid months and for the subsequent superficial runoff rate during the three months with the greatest runoff for the northeastern region of Brazil demonstrated a slow increase over long periods (MAREGO, TOMASELLA, UVO, 1998). In 2016 the Amazon River Expedition from Peru to Brazil observed tendencies in which a prolonged ENSO event combined with a trend of regional warming increased the demand for water from the reservoirs of Brazilian hydroelectric plants in the Northeast, Central-West, and Southeastern regions of Brazil (CCEE, 2017), and caused strong rains in the Southern region of Brazil (CPTEC, 2016). According to Jiménez-Muñoz *et al* (2016), this event was associated with warming that was without precedent and an extreme drought in the Amazon, compared to other strong ENSO events in 1982/83 and 1997/98. The typical conditions of drought caused by the ENSO were observed and described by Jiménez-Muñuz *et al,* (2016), as occurring only in the eastern Amazon, while in the western region of the Amazon there prevailed an uncommon level of humidity. For researchers this situation can be attributed to the humid-dry dipole at the location of maximum warming of the surface of the equatorial central Pacific Ocean. This humid-dry dipole was also confirmed in the current study through a time series of temperature readings at 4 distinct points (edge, middle of the canal, 1 m deep below the surface, and ambient air temperature) along the Amazon River from the west in Iquitos, Peru, to the east in Macapá, Brazil by the research team of the Amazon River Expedition from Peru to Brazil in 2016. According to Erfanian, Wang and Fomenko (2016), the empirical relationships between rainfall and sea surface temperatures (SST) in the Pacific and Atlantic Oceans represent the factors of tropical ocean variability responsible for the observed precipitation anomalies. These results indicate that the warmer than normal SST for the tropical Pacific and Atlantic Oceans (including El Niño events) were the principal causes of extreme droughts in South America, however, researchers are still unable to explain the severity of the precipitation deficits observed in 2016 in a substantial portion of the Amazon region. Therefore, hydroclimatic variability in South America is strongly coupled, on a large scale, to oceanic and atmospheric phenomena. Specifically, the El Niño Southern Oscillation (ENSO) that affects climatological and hydrological conditions has a “terrestrial – atmospheric” mechanism that forms a bridge

between these two domains and connects the anomalies of SST of the Pacific and Atlantic Oceans (Paveda and Mesa, 1997).

Material and Methods

Map of the Expedition (Arequipa-Peru; Iquitos-Peru; Macapá-Brazil)

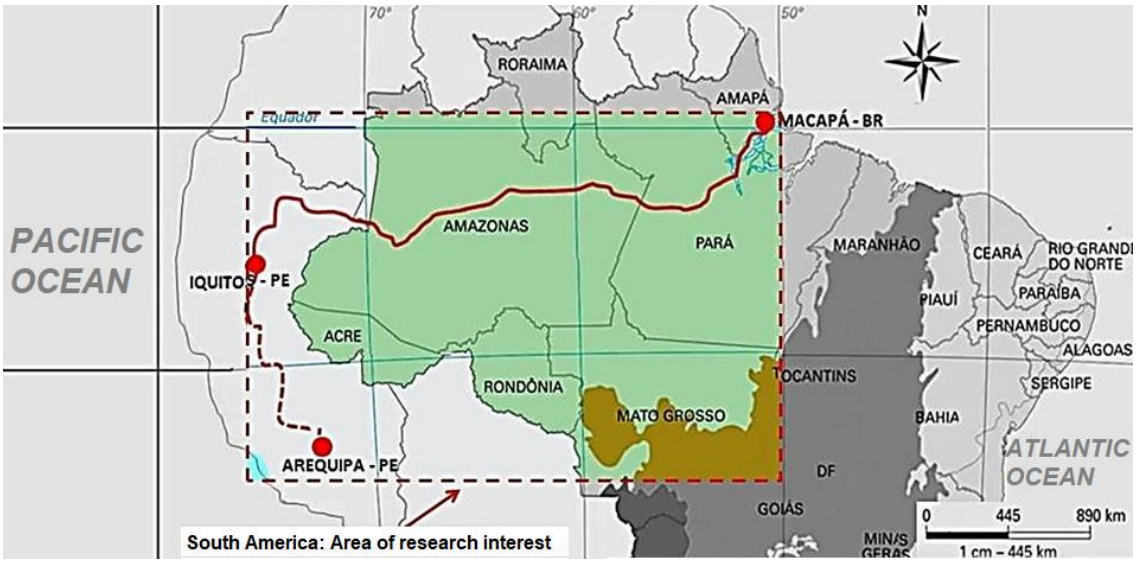

Fig. 1: Image of the mosaic of regions of tropical South America and the 2016 route of the Amazon River Expedition from Peru to Brazil (solid line), and the 2017/18 route (dotted line) (3rd phase, modified route).

Ships used in the Amazon River Expedition (2016-18)

Fig. 2: Ships used in the Amazon River Expedition **(A)** Voyager III (Manaus-Tabatinga). **(B)** M. Monteiro II (Tabatinga-Manaus). **(C)** *Flipper* (Santa Rosa-Iquitos-Santa Rosa). **(D)** S. Bartolomeu III and IV, (Manaus–Santarém–Santana—Manuas) July through December, 2016.

An automatic meteorological station was installed on roof of the five passenger transport ships (Fig. 2) used in this research expedition (Fig. 1). The station was free from obstacles that would impede accurate measurement of the variables of interest (temperature, humidity, pressure, wind speed and direction, dew point, and rainfall).

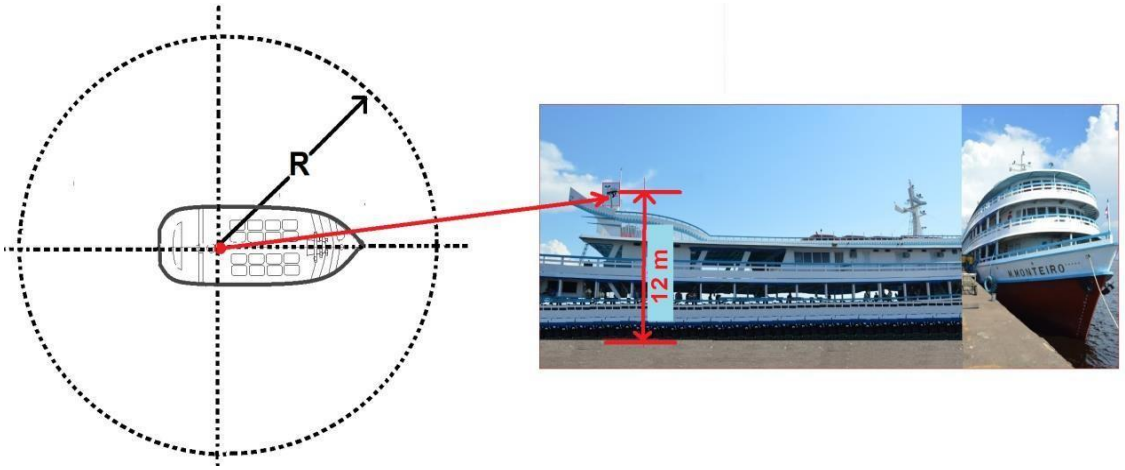

Fig. 3 - ***Footprint* of the boat-mounted meteorological station,** *Lagragian Footprint Model*, *Weather Station* - DAVIS - *Vantage* – *Vue*, ***300 m ≤ R ≤ 500 m,*** on the ship M. Monteiro II, July 2016.

Sampling and chronogram

For monitoring of weather and climate during the period of the research, a I - FLIR-E60 thermal imager, (Tab. 1), and II –Mira digital thermometer– LASER, Minipa MT-360 sensors were used. Measurement of ambient air temperature, and the temperature at the edge of the river, middle of the canal, and at 1.0 m below the river´s surface a Davis meteorological station with uninterrupted recording (15 days + 15 days) with data collection (ambient air temperature, humidity, pressure, wind speed and direction, dew point) were measured every 5 minutes, and *in situ* two liter water samples were taken at each sampling point along the entire river. Temperature values are a composite of 10 *in situ* readings taken at each sampling point. The geographic coordinates of the sampling points were taken along with a description of the weather (climate) and the time at the moment of collection, and samples were labeled accordingly (Steps 1 and 2 of the Amazon River Expedition protocol).

Laboratory analysis of water samples (method used in parentheses)

1-Alkalinity (APHA, 2003; GOLTERMAN, 1970); 2- Calcium (Ca_2^+), hardness, and Magnesium (Mg_2^+) APHA, 1985; GOLTERMAN & CLYMO, 1978); 3 – Chlorides ((FENANTHROLINE – FIA) (MACKERETH, et. al., 1978: GOLTERMAN & CLYMO, 1971); 4- DQO with potassium dichromate (APHA, 2003; MACKERETH, et. al., 1978); 5 – Total and Dissolved iron (FIA) (APHA, 2003); 6 - Phosphate (PO_4) (APHA, 2003; GOLTERMAN, 1970; 7 - Total phosphorus and nitrogen (N and P-TOTAL) (VALDERRAMA, 1980); 8 – Total phosphorus (FIASTAR) (APHA, 2003, ISO 5861, s/d);
9 – Nitrate (FIA) (GOLTERMAN, 1971); 10 –Ammoniacal nitrogen (NH_3) (FIA - *Flow Injection Analysis*) Nessler reagent method; – 11 –Silicates (Silica – Molybdenum blue method) (GOLTERMAN, 1980, MACKERETH, et. al., 1978); 12 – pH (hydrogen ion concentration) (APHA, 2003), 13 – Potassium and sodium by flame emission spectroscopy (MACKERETH, et. al., 1978), 14 – Total suspended solids (STS) (APHA, 2003), 15 – Sulfate (APHA, 2003), 16 – Temperature (FLIR-E60); 17 – Turbidity (turbidity meter); 18 - Color (Spectrophotometer).

(*) Done only between Manaus (Brazil) and Macapá (Brazil).

Additionally, *in situ* analyses of pH, O_2, conductivity, and O_2 saturation were conducted on all water samples.

MATERIAL	SPECIFICATION	TEMP. (°C)	ELECTROMAGNETIC SPECTRUM	EMISSIVITY
WATER	LAYER THICKNESS > 0.1 mm	0 - 100	ALL	0.95 - 0.98

Table 1. Physical characteristics of the FLIR-E60 thermal imager.

Statistical modeling and georeferencing of data.

The time series of temperature reading along the Amazon River were processed and analyzed using the *Marine Modeling and Analysis Branch Oper. H. R.* (Verification ensemble) of NOAA/NWS/NCEP/EMC, (ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gfs/prod). For the characterization of the composition of the El Niño event during this period the temperature gradients of the SST of the equatorial Atlantic and the eastern equatorial Pacific were constructed. All sampling points were georeferenced using a GPS (GARMIN – E60 and the *software TrackMaker*®), and the creation of a thematic map for sampling points was done using *ArqGis*®. Flux measurements (temperature, humidity, pressure, wind speed and direction) were taken using a meteorological station (Vantage-Vue/*DAVIS Instruments Corporation, WeatherLink* 6.0.3), using the static method (Lima, 2017), for covariances (*Eddy Covariance*).

Results and Discussion

Figure 4 below shows systems that were responsible for the atmosphere dynamics on July 26, 2016 between 05:00 LT and 17:0 LT, the first day of the Amazon River Expedition when it left Iquitos, Peru, for Manaus, Brazil. The Intertropical Convergence Zone (ITCZ) is in the north of South America and reaches the Amazon region, and there is a cold front that is developing in the southern Atlantic Ocean and is penetrating the southern region of Brazil.

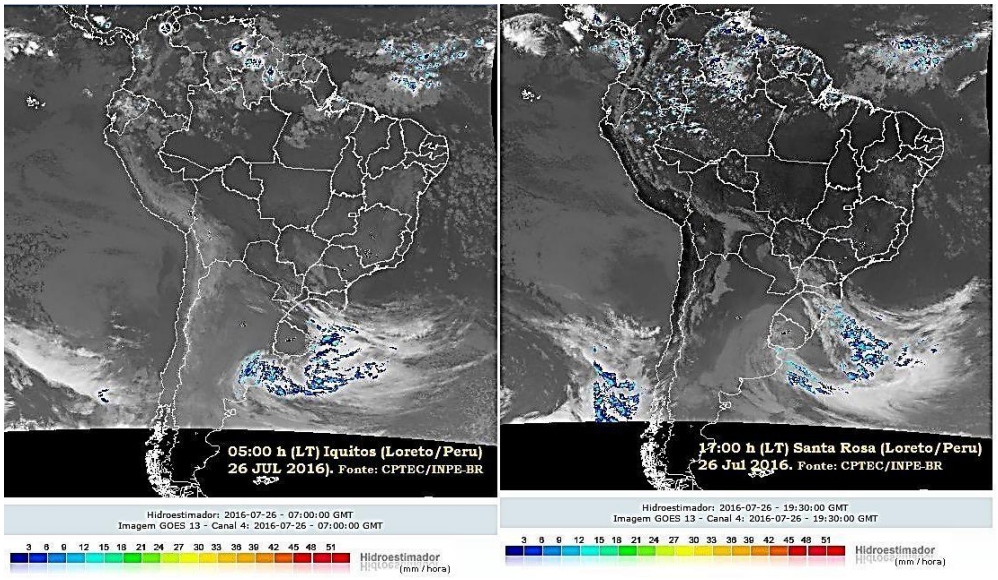

Fig.4: Meteorological conditions on July 26, 2016, between 05:00 LT and 17:00 LT for South America. (Source: CPTEC/INPE, 2016).

Figure 5 shows a graphical rhythmic analysis of weather types between Iquitos (Loreto-Peru), Tabatinga and São Paulo de Oliveira (State of Amazonas-Brazil) on July 26, 2016, between 05:00 LT and 18:00 LT in Peru, and July 27 and 28, 2016 (12:00 h to 03:00 h LT, in Brazil), in which the climatic elements involved in this analysis of atmosphere dynamics are evident (CPTEC/INPE).

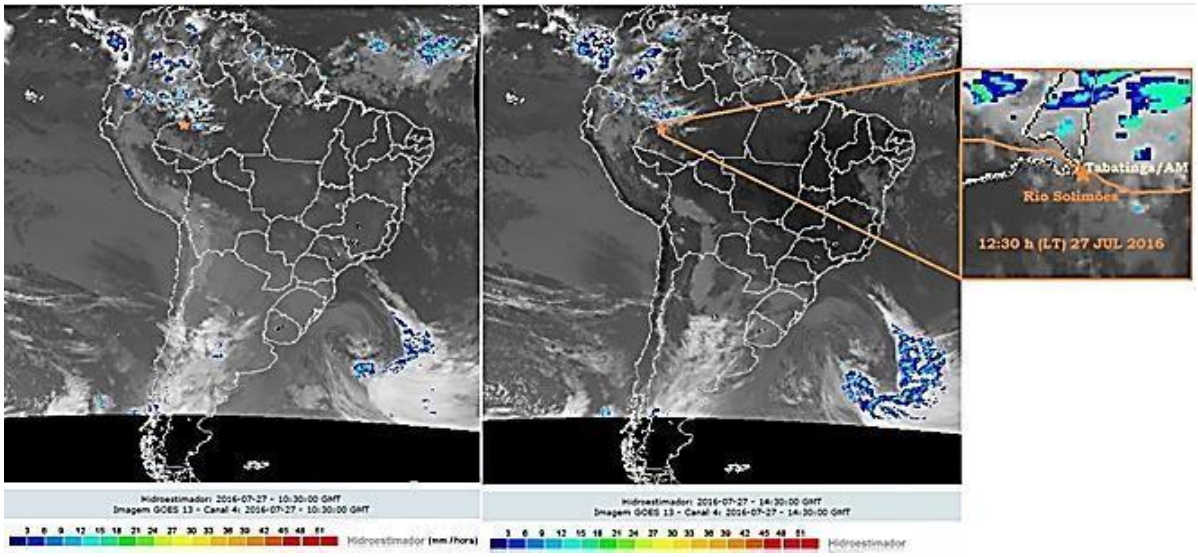

Fig.5: Meteorological conditions on July 27, 2016, between 10:30 and 14:30 GMT, for South America. (Source: CPTEC/INPE, 2016).

Figure 6 shows the time series of temperature that was taken at three positions (ambient temperature at the ship – 100 m from the edge of the canal – middle of the canal) during the first stage of the expedition (Iquitos/Peru – Manaus/Brazil), using the FLIR E60 thermal imager. The image next to the time series shows SST in Real Time Global (RTG), High Resolution (HR) and was obtained by NOAA/NCEP/NWS by analyzing satellite images, ocean floats, sea ice cover, salinity, and conducting mathematical modeling in a second degree polynomial series (Branch analysis method), (ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/gfs/prod), and indicates correlation with the results obtained by the Amazon River Expedition.

The observations from this study suggest regional warming of temperature gradients in the stretch between Iquitos-Peru to Manaus-Brazil) in July, 2016, (dry season), with average ambient temperature at the ship (in the shade) of 30.41^{0}C, at the river´s surface (100 m from the edge) of 27.34^{0}C, and at the middle of the canal of 24.73^{0}C, (Fig.6). During the 2nd stage of the Expedition (Manaus-Brazil to Macapá-Brazil) in December 2016, the rainy season had already begun and average temperatures were slightly reduced, with average ambient temperature at the ship of 28.97^{0}C, at the river´s surface (100 m from the edge) of 26.06^{0}C, and at the middle of the canal of 24.04^{0}C. The interval between the first and second stages was taken in order to be able to verify the effect of drought on the river due to the time necessary for water to flow across the large distance from Iquitos-Peru to Macapá-Brazil (Fig.7). The margin of error is shown in Figures 6 and 7 and in Table 1.

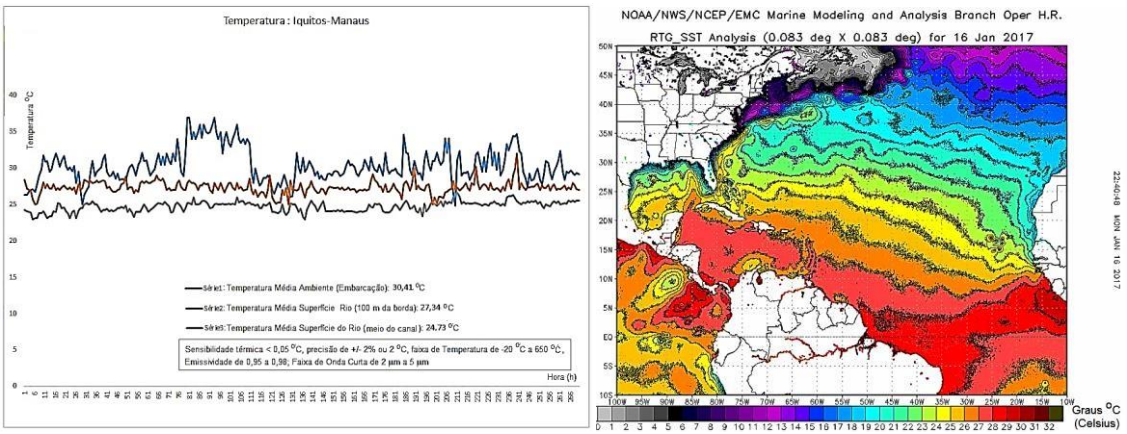

Fig. 6: Time series of temperature along the Amazon River during the first stage of the Expedition (Iquitos/Peru – Manaus/Brazil), and compared to data from the *Marine Modeling and Analysis Branch Oper. H. R.* (Verification Ensembles) of NOAA/NWS/NCEP/EMC. Source: Amazon River Expedition and NOAA, 2016.

The time series of temperature was taken at three positions (ambient temperature at the ship – 100 m from the edge of the canal – middle of the canal) during the 2nd stage of the Expedition (Manaus-Brazil to Macapá-Brazil) in December 2016 using the FLIR E60 thermal imager. The image next to the time series shows SST in Real Time Global (RTG), High Resolution (HR) and was obtained by NOAA/NCEP/NWS and indicates correlation with the results obtained by the Amazon River Expedition (Fig 7).

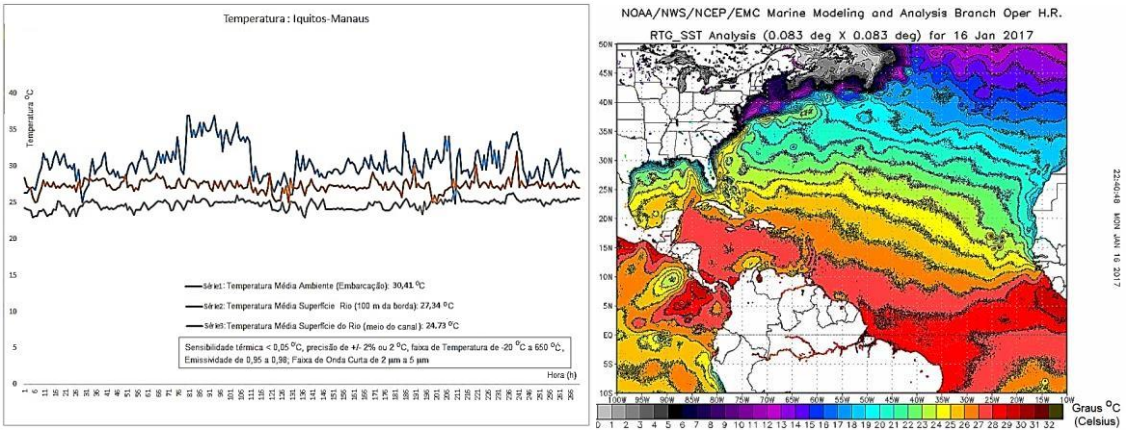

Fig. 7: Time series of temperature along the Amazon River during the second stage of the Expedition (Manaus/Brasil – Macapá/Brasil), and compared to data from the *Marine Modeling and Analysis Branch Oper. H. R.* (Verification Ensembles) of NOAA/NWS/NCEP/EMC. Source: Amazon River Expedition and NOAA, 2016.

The analyses of the water samples from both stages of the expedition are list in Tables 2 (1st stage) and 3 (2nd stage), and these data describe the "actual state" of the Amazon River in 2016 during the dry season in the Amazon. In Tabatinga at the entry of the Amazon River into Brazil, during the month of July 2016, the level of the Solimões River (the name given to the river from this point to Manaus, Brazil) was 5.54 m (at the end of the rainy season it was 11.62 m at this sampling point in May 2016), and the highest level recorded here was in May 1999 when the depth was 13.38 m with respect to sea level (ANA/CPRM/SIPAM, 2017). During this period of the expedition the El Niño climate phenomenon was already firmly established in the region since it had begun in 2014, lasted for all of 2015, and was still strong in 2016. The effects of this drought were clearly visible during the entire voyage along the river from Peru to the Atlantic, principally due to the marks left on trees in the *várzea* areas at the river's edge by the previous high-water season. However, the quality of the water from the Amazon River at the 39 georeferenced sample points was satisfactory and within the standard for potable water for human consumption by communities adjacent to the river's edge from the western portion of the basin to the Atlantic, although basic sanitation services are a preoccupation for all the communities located at these 39 sampling points, including for Iquitos (Peru), Manaus, Santarém and Macapá (Brazil).

At the end of December 2016, the Tapajós River in Santarém, Pará, Brazil, located in the lower Amazon region, was more than 6 m below the base of the contention dike that serves as a waterfront walkway for urban dwellers along the Tapajós' edge in front of the city. A vertical line near the pier in front of the church of *Nossa Senhora da Conceição* approximately 5m above the base of this dike represented the maximum extent of the previous high-water mark, and this mark extended for more than 60 m horizontally to near the municipal fish market. Rainfall is still sporadic during this period of the year in Santarém and almost always occurs early in the first hours of the morning before sunrise or at the end of the afternoon, but is always brief in duration.

Nearing the mouth of the Amazon River, the weather was constantly cloudy with grey and dark, low nimbostratus (Ns) clouds at about 2,000 to 3,000 m, with a constant fine rain near Prainha (Pará/Brazil) and Almeirim (Pará/Brazil), (08:20 LT), and the air temperature and the dew point temperature at the level of the river's surface were very similar, indicating a condition of saturation. There was fog on the horizon, and this fog goes by the name of hot fog because the drops are well above the freezing temperature. It was most likely an advective fog in function of the horizontal dynamic of atmospheric migration that was in a situation

that was more adequate for saturation, since, being nearer to the Atlantic Ocean (approximately 300 km), the ocean breeze that penetrates the coast of Amapá at Macapá (Brazilian Atlantic coast), in this period of the year has favorable conditions for the trade winds, including for the ITCZ, that can stimulate the development of climatic variation in this region of the Amazon River.

Recommendation

At the site (https://sites.google.com/view/amazonriverexpedition) there is more information about the "actual state" of the Amazon River in 2016, not only with respect to climatology, but also with respect to the life of people in the communities in this region.

Conclusion

The Amazon River, during the dry season of 2016, was influenced by a prolonged El Niño climatic tendency (2014, 2015 and 2016). The results show that there was a reduction in water levels along the entire sampling trip on the river, from the city of Iquitos in Peru to the Brazilian city of Macapá near the interface of Brazil and the Atlantic Ocean. The sea surface temperature stimulated the establishment of an increasing temperature gradient in the equatorial region along the river, up to its mouth at the Atlantic Ocean, where the river accompanied the same temperature regime as the ocean during this period. This gradient established the climatic phenomenon called the wet-dry dipole, combined with a tendency for regional warming during the El Niño event of 2016.

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Table 2 – Water sample analysis – Stage one of the Amazon River Expedition (Peru-Brazil) July, 2016

Sample Collection point	Geographical Coordinates	Hour Date Weather	Temp.	pH	Conductiviity	O_2 Dissolved	Alkalinity	Turbidity	Suspended solids	DQO	Chloride (Cl)	Color	Iron Dissolved	Total Iron	Ammonia (NH_4)	Potassium (K)	Sodium (Na)

Nitrate (NO2) **Nitrogênio Total** **Fósforo Total** **Fosfato (PO4)**

Longitude (S) **Latitude (W)** **°C** **(µS/cm)** **(mgHCO3/L)**

% **mg/L** **(NTU)** **(mg/L)** **(mg/L)** **(mg/L)** **(mg/L)** **(mg/L)** **(mg/L)** **(mg/L)** **(mg/L)** **(mg/L)** **(mg/L)**

(mg/L) **(mg/L)** **(mg/L)**

1	PUERTO IQUITOS - PE	S 03° 43' 37.6''	W 073° 14' 23.8''	05h20	26/7/2016	Overcast	6,61	28,8	48,3	22,57	113,50				
9,50	15,60	0,02	48,21	82,59	2,48	0,184	1,786	0,450	0,85	3,41	0,464	0,760	0,028	< 0,002	*
2	SAN ANTONIO - PE	S 03° 48' 18.8''	W 071° 34'25.4''	11h25	26/7/2016	Sunny	7,31	26	112,0	51,24	117,60				
10,02	104,00	0,21	26,71	48,628	5,17	0,158	5,269	0,161	1,00	6,58	0,197	0,486	0,289	< 0,002	*
3	SAN PABLO - PE	S 04° 00' 59.6''	W 071° 06' 07.5''	12h45	26/7/2016	Sunny	7,22	25	119,9	46,36	103,70				
8,27	53,56	0,08	21,50	49,449	11,47	0,201	2,866	0,167	1,00	6,28	0,189	0,422	0,149	< 0,002	*
4	CHIMBOTE - PE	S 03° 55' 40.8''	W 070° 47' 10.4''	13h34	26/7/2016	Sunny	7,79	26	117,4	47,58	111,80				
8,81	50,18	0,07	22,80	46,985	5,14	0,107	2,678	0,174	1,00	6,13	0,384	0,400	0,141	< 0,002	*
5	CABALLO COCHA - PE	S 03° 53' 49''	W 070° 30' 19.1''	14h29	26/7/2016	Sunny	6,92	29	78,1	36,60	108,10				
9,31	8,84	0,01	28,02	38,769	2,32	0,124	1,675	0,181	1,00	3,71	0,010	0,434	0,013	< 0,002	*
6	PUERTO ALEGRIA - PE	S 04° 06' 39.7''	W 070° 03' 13.8''	16h15	26/7/2016	Overcast	6,89	27	106,5	48,19	108,00				
8,56	79,56	0,14	37,79	65,880	3,72	0,184	5,440	0,250	1,16	5,37	0,226	0,559	0,204	< 0,002	*
7	PUERTO SANTA ROSA - PE	S 04° 13' 04.7''	W 069° 57' 19.1''	16h41	26/7/2016	Overcast	7,20	27	103,7	44,53	109,20				
9,44	75,40	0,12	26,06	58,486	4,70	0,124	3,898	0,167	1,00	5,67	0,198	0,439	0,174	< 0,002	*
8	PORTO TABATINGA - BR	S 04° 13' 44.4''	W 069° 56' 41.0''	17h25	26/7/2016	Overcast	7,15	26	104,3	47,58	110,20				
8,36	73,06	0,12	27,36	45,342	4,78	0,176	4,412	0,167	1,16	5,52	0,305	0,511	0,199	0,003	
9	BENJAMIN CONSTANT -BR	S 04° 22' 19.5''	W 070° 01' 34.3''	13h30	27/7/2016	Overcast	6,60	24	28,3	13,42	115,80				
9,29	41,08	0,05	29,32	96,55	0,95	0,218	n.t	0,457	0,69	2,51	0,253	0,553	0,091	< 0,002	*
10	FEIJOAL - BR	S 04° 18' 31.2''	W 069° 33' 27.5''	17h37	27/7/2016	Overcast	7,17	24	100,3	42,09	124,00				
9,85	83,98	0,16	28,02	43,698	4,16	0,176	5,269	0,181	1,00	5,52	0,206	0,456	0,214	< 0,002	*
11	SÃO PAULO DE OLIVENÇA - BR	S 03° 27' 42.2''	W 068° 57' 26.4''	3h00	28/7/2016	Overcast	7,00	24	98,1	43,31	113,20				
9,75	82,42	0,14	29,32	65,880	4,35	0,193	4,240	0,195	1,00	5,52	0,194	0,480	0,204	< 0,002	*
12	AMATURÁ - BR	S 03° 21' 14.5''	W 068° 11' 04.2''	06h10	28/7/2016	Overcast	5,81	23	9,51	4,27	99,80				
9,71	6,24	0,01	23,46	47,806	0,95	0,176	1,007	0,181	0,37	1,45	0,040	0,296	-0,002	< 0,002	*
13	SANTO ANTONIO DO IÇA - BR	S 03° 06' 29.1''	W 067° 56' 39.6''	9h42	28/7/2016	Overcast	6,15	26	17,45	9,15	117,50				
9,61	21,06	0,04	28,67	58,486	0,79	0,201	2,455	0,209	0,85	1,75	0,061	0,406	0,041	< 0,002	*
14	TONANTINS - BR	S 02° 51' 47''	W 067° 46' 13.4''	13h07	28/7/2016	Rainy	6,16	25	17,92	9,76	109,00				
8,99	10,92	0,01	25,41	56,022	0,70	0,176	1,641	0,195	0,37	1,60	0,050	0,348	0,018	< 0,002	*
15	JUTAÍ -BR	S 02° 44' 33.8''	W 066° 46' 19.5''	20h29	28/7/2016	Overcast	7,00	25,5	75,0	32,33	119,50				
9,48	54,60	0,09	28,02	51,914	3,72	0,201	3,383	0,167	0,85	4,32	0,094	0,347	0,141	< 0,002	*
16	FONTE BOA - BR	S 02 ° 29' 40.6''	W 066° 04' 05.1''	02h26	29/7/2016	Overcast	6,87	25,5	68,5	29,89	118,90				
9,92	63,44	0,13	31,27	63,415	3,36	0,210	3,898	0,195	0,85	4,17	0,160	0,434	0,144	< 0,002	*
17	TEFÉ (LAGO) - BR	S 03° 16' 32.1''	W 064° 43' 12.1''	13h11	29/7/2016	Sunny	6,93	27	69,3	31,72	108,30				
9,07	42,12	0,07	28,02	55,200	3,39	0,201	3,126	0,229	1,00	4,32	0,155	0,408	0,111	< 0,002	*
18	ILHA DO CATUÁ GRANDE - BR	S 03° 47' 18.3''	W 064° 02' 19.8''	17h30	29/7/2016	Overcast	6,89	26	64,2	30,50	110,00				
9,42	44,20	0,07	29,97	60,129	2,84	0,193	3,383	0,229	0,85	4,01	0,127	0,391	0,088	< 0,002	*
19	COARI - BR	S 04° 03' 17.1''	W 063° 04' 54.0''	21h20	29/7/2016	Overcast	6,76	25	54,4	25,01	100,70				
8,34	29,38	0,04	28,02	63,415	2,51	0,201	2,463	0,195	0,85	3,26	0,126	0,357	0,073	< 0,002	*

20	ANAMÃ - BR	S 03° 47' 17.2''	W 061° 37' 05.8''	05h28	30/7/2016	Overcast	6,75	24,5	50,7	23,79	103,80				
7,79	44,46	0,08	26,06	66,702	2,38	0,176	3,469	0,195	0,69	2,96	0,129	0,408	0,101	< 0,002	*
21	RIO MANACAPURU - BR	S 03° 33' 34.6''	W 060° 53' 16''	08h47	30/7/2016	Sunny	6,76	26	48,1	22,57	119,10				
9,00	20,80	0,03	29,32	65,880	2,35	0,158	1,984	0,216	0,69	2,96	0,117	0,371	0,048	< 0,002	*
22	LAGO MANAQUIRI - BR	S 03° 28' 34.8''	W 060° 45' 22.9''	09h25	30/7/2016	Sunny	6,81	23	48,5	22,57	129,70				
10,45	29,38	0,05	29,32	52,735	2,02	0,167	2,086	0,195	0,69	3,11	0,120	0,374	0,076	< 0,002	*
23	IRANDUBA - BR	S 03° 17' 31''	W 060° 11' 22.9''	11h03	30/7/2016	Sunny	6,77	27	48,6	22,57	108,50				
9,11	24,44	0,04	29,32	59,308	2,29	0,176	0,313	0,202	0,85	3,11	0,105	0,381	0,061	< 0,002	*
24	MANAUS (RIO NEGRO) - BR	S 03° 08' 11.1''	W 059° 53' 59.1''	13h44	30/7/2016	Sunny	5,53	28	9,0	3,66	114,80				
9,61	3,64	0,00	60,59	148,525	1,09	0,236	1,281	0,484	0,37	1,75	0,051	0,415	0,078	< 0,002	*

Table 3 – Water sample analysis – Stage two of the Amazon River Expedition (Peru-Brazil) December, 2016

Sample	Geographical Coordinates Longitude	Location	Hour	Date	Weather	pH	pH	Temp.	Alkalinity	Conductivity	DQO	Color	Chlorides (Cl^-)	Turbidity	Dissolved Fe	Total Fe	Ammonia (NH_4)	Potassium (K)	Sodium (Na)

Collection poi

y Oxygen Oxygen Satur

Suspended Solids

Hardness Calcium (Ca) Magnesiumo (Mg) Si N Total (N) Nitrate (NO_3) Nitrite ate Phosph (PO 4) Total P (P)

(S) Latitude (W) °C (μS/cm) mg/L %

(mgHCO3/L) (NTU) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L)

(mgHCO3/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L) (mg/L)

1 Manaus - AM Rio Negro S 03° 08' 21.3'' W 60° 01' 35.1''

08h13 20/12/2016 Overcast 5.14 27.6
7.92 5.76 77 2.44
3,9 0.00 50,17 7.551 0.76
0.162 0.473 0.433 0.50 1.20
3.78 0.00 0.83 2.221 0.347
0.243 0.012 0.006 0.013

2 Itacoatiara - AM Rio Amazonas S 03° 08' 54.3'' W 58° 26' 54.1''

17H40 20/12/2016
Overcast 6.56 27
53.30 5.35
76.6 17.08
35.36 0.35,84 9.194
3.31 0.081 2.720
0.229 0.90 3.50
27.37 7.45 1.46
3.970 0.325 0.031
0.017 0.004 0.074

3 Parintins - AM Rio Amazonas S 02° 38' 01.6'' W 56° 45' 21.7''

4 Juriti - PA Rio Amazonas S 02° 09' 05.9'' W 56° 05' 43.1''

5 Óbidos - PA Rio Amazonas S 01° 55' 22.2'' W 55° 30' 55.3''

4h26 21/12/2016 Rainy 6.7
27 51.30 5.66
69.3 16.47 44.46
0.06 27.36 11.658 2.55
0.091 3.122 0.248 1.00
3.20 25.14 6.17 1.75
3.930 0.400 0.178 0.019
0.014 0.102

9h47 21/12/2016 Overcast 6.54
27 51.20 5.63
70.5 15.25 374.4
0.04 29.32 14.945 2.65
0.051 2.190 0.322 1.10
3.40 27.81 5.85 2.53
4.010 0.706 0.499 0.026
0.021 0.072

12h36 21/12/2016 Overcast 6.75
27 52.80 5.64
68.8 18.3 38.48
0.05 27.36 60.951 2.52
0.051 2.210 0.254 1.00
3.60 29.15 6.01 2.72
4.207 0.552 0.558 0.011
0.007 0.069

6 Porto das Docas Santarém - PA Rio Tapajós S 02° 24' 52.1'' W 054° 44' 13.8''

7 Pça Tiradentes - Santarém PA Rio Tapajós S 02° 25' 00'' W 054° 43' 22.2''

18h37 21/12/2016 Overcast 6.16
27 13.80 5.68
74.9 7.32 4.68
0.00 23.46 5.908 0.58
0.041 0.593 0.155 1.00
1.10 8.23 0.64 1.41
3.909 0.515 0.253 0.005
0.004 0.035

18h22 22/12/2016 Overcast 6.07
27 13.92 6.36
82.5 6.1 2.6
0.00 22.80 14.945 0.68
0.041 0.372 0.168 1.10
1.20 5.12 0.56 0.78
4.652 0.507 0.276 0.008
0.003 0.016

8 Monte Alegre - PA Rio Amazonas S 02° 00' 35.1'' W 054° 04' 10.0''

0h15 23/12/2016 Rainy
6.54 27 45.70
5.29 67.2
16.47 57.46 0.04
29.32 13.302 3.19
0.041 3.724 0.580
1.80 3.40 20.25
4.33 1.80 4.329
0.453 0.334 0.077
0.054 0.029

9 Prainha - PA Rio Amazonas 10 Almeirim - PA Rio Amazonas 11 Santana - AP Rio Amazonas Rio

S 02° 00' 35.3''
S 01° 31' 58.7''
S 00° 03' 27.4''

W 054° 04' 11.8''
W 052° 34' 34.5''
W 051° 10' 42.1''

4h54 23/12/2016 Rainy 6.41
26.6 50.00 4.98
64.05 17.69 41.34
0.06 30.62 14.123 2.35
0.322 2.720 0.248 1.00
3.30 25.59 6.01 1.95
3.904 0.392 0.234 0.016
0.009 0.127

11h 23/12/2016 Rainy 6.45
28 47.50 5.28
71.2 21.96 33.28
0.04 28.67 12.480 2.28
0.081 2.310 0.254 1.00
3.20 21.58 6.25 0.92
4.051 0.391 0.270 0.014
0.006 0.071

2h10 24/12/2016 Rainy 6.5
27 53.10 4.70
58.4 23.18 27.56
0.04 26.71 16.588 3.58
0.071 1.688 0.254 1.00
4.00 22.92 6.65 0.97
3.919 0.324 0.211 0.009
0.007 0.052

12 Macapá- AP Amazonas (Foz) Hotel Rio Amazonas (Foz) Bonde
N 00° 01' 37.4''
W 051° 02' 55.1''

13h 25/12/2016 Sunny
6.6 26.3 53.30
5.96 71.9
22.57 27.56 0.03
25.41 2.622 3.16
0.061 1.216 0.217
1.10 3.80 21.58
6.57 0.73 3.823
0.571 0.327 0.005
0.004 0.072

13 Macapá- AP
N 00° 02' 00.2''
W 051° 02' 43.1''

11h 26/12/2016 Sunny
6.44 27 56.50
5.37 67.7
25.01 27.3 0.05
27.36 0.978 3.38
0.051 1.868 0.217
1.20 4.00 25.59
6.73 1.51 3.894
0.327 0.166 0.012
0.007 0.030

14 Macapá- AP Rio Maracá - Vazante
S 00° 31' 20''
S 00° 32' 38.9''
W 051° 29' 59.7''
W 051° 31' 47.7''

21h39 26/12/2016 Overcast 6.81
26.6 45.90 4.94
65.3 21.35 36.92
0.05 26.71 4.265 2.13
0.061 2.419 0.217 1.00
3.00 21.36 5.77 1.17
4.218 0.444 0.273 0.008
0.006 0.088

15 Macapá- AP lg. Ajurixi - Vasante

21h58 26/12/2016 Overcast 6.84
27 46.40 4.00
67.3 21.96 36.48
0.05 26.06 0.978 2.23
0.061 2.250 0.242 1.00
3.10 21.58 5.69 1.26
4.440 0.542 0.295 0.009
0.011 0.102