Geoprocessing of the Trends of the ENSO Phenomenon, from Peru to the Atlantic Ocean in Brazil.

Newton Silva de Lima*, Eriberto Façanha*, Robson Matos Calazães*, Ricardo Figueiredo*, William Dennis Quispe*, Aldemir Malveira†, Roseilson Souza do Vale‡

*Lutheran University Center of Manaus (Geosciences - Mathematics) / †Federal University of Amazonas (Mathematics)/
‡Federal University of Western Pará (Geosciences)
* †Manaus/ ‡Santarém (Brazil)
(newtonulbra@gmail.com, eribertofacanha@seduc.net, matoscalazaes@gmail.com, rics.fig@gmail.com, William.exner@bol.com.br, amoliveira@gmail.com, roseilsondovale@gmail.com)

***Abstract* — This research investigated 39 cities in the Amazônia, with the purpose of showing the high temperatures of the waters of the Amazon River, using remote sensors (Global Positioning System - GPS and Globalnaya Navigatsionnaya Sputnikovaya System - GLONASS), besides digital weather station and ship navigation, as a contribution to the trends of the El Niño phenomenon in the Amazon. It collected information on water quality, weather and climate, georeferencing of the route and localities during a drought period on the Amazon River, from Iquitos in Peru, to the city of Macapá in Brazil (Atlantic Ocean) in 2016, all data are presented in tables and thematic maps. The results obtained with temporal temperature series, compared to satellite images of temperature gradients, georeferenced map and water quality analysis showed high water temperatures along the river during the entire observation period, probably due to the prolonged El Niño event in 2014, 15 and 16.**

Keywords - GPS; satellite images; Amazon River; warming.

I. INTRODUCTION

Changes in atmospheric circulation in the tropical zone (Walker cell) induce changes in rainfall patterns, devastating floods, and severe droughts that can drastically affect the lives of millions of people [1]. 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 [2]. In 2016 the Amazon River Expedition from Peru to Brazil observed tendencies in which a prolonged El Niño Southern Oscillation (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 [3], and caused strong rains in the Southern region of Brazil [4]. According to the authors of [5] [6] [7], 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 [5], 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. In this paper the causes of these changes are analyzed over the last two decades, and these include the average Sea Surface Temperature (SST) anomalies that are weakened towards the west in direction of the central Pacific; this represents an indicator that needs more observation [8].

Traveling in the Amazon region on the great river that crosses the entire northern portion of South America without the aid of a GPS or GLONASS would be, without a doubt, a difficult task, and could only be possible with the use of paper maps and a good, native navigator. The scenario since its beginning in the Peruvian Amazon up to the mouth of the great river in the Brazilian Amazon is very similar in terms of water, climatic variation, vegetation, fish, human presence, and atmospheric characteristics. This South American mosaic is singular, and these qualities make the use of navigation by satellite technology highly recommended. The most interesting example from this study was the enormous gap in internet access (approximately 90%), but Google Map, the smartphones and the GPS / GLONASS receivers continued to inform the ship's position and route in real time. This facilitated the labeling of samples, and the recording of meteorological data and georeferenced images taken by the camera at the visited sites.

This paper is structured as follows. In Section II, we present the research site, the path taken in the North of South America, the instrumentation and the steps followed in the data collection. Section III presents the results, through maps, graphs, tables of data, comments and finally

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Section IV, we conclude this paper in the form of contribution of the Present State of the Amazon River to the regional warming.

II. MATERIAL AND METHODS

The northern mosaic of South America (Fig. 1) was examined in this research expedition. The average depth of the channel of the Amazon River was described in 2014 [9], (Fig. 2), maintaining or decreasing this condition between 2014-2017 [10]. In the upper deck of the boat, a digital weather station was installed for climate monitoring.

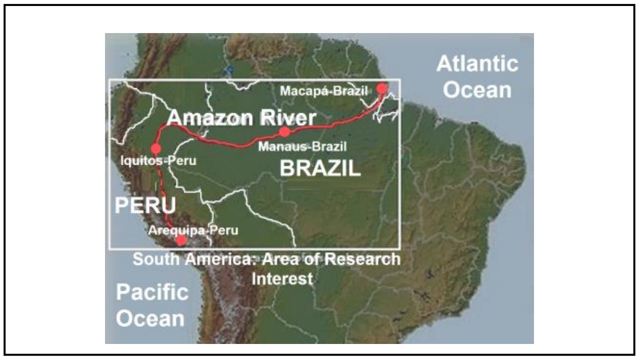

Figure. 1: Image of the mosaic of regions of tropical South America and the 2016 route of the Amazon River Expedition from Peru to Brazil (solidline), and the 2017/18 route (dotted line) (3rd phase, modified route). Source: (Adapted from Google Earth, 2016).

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). The georeferencing was performed with a GPS and satellite images to identify the metadata of the water points and cities along the route (latitude, longitude, altimetry and photography).

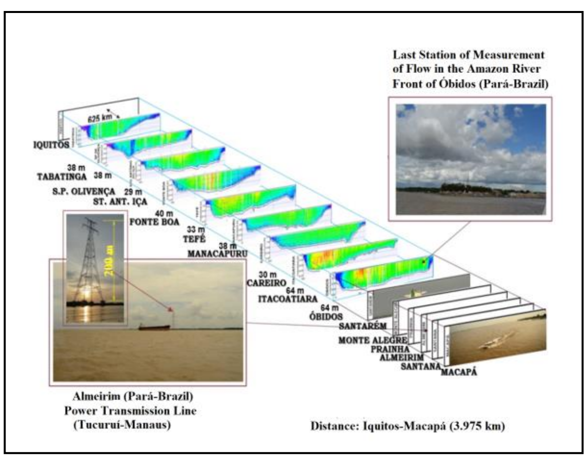

Figure. 2: The main cities of Iquitos (Peru) to Macapá (Brazil). The average depth of the river is shown in the dry season. Source: Adapted from Project Integrated and Sustainable Management of Cross – Border [9].

A. *Sampling and Chronogram*

For monitoring of weather and climate during the period of the research, a FLIR E60 thermal imager, Mira digital thermometer (LASER) and Minipa MT 360 sensors were used. Measurement of ambient air temperature, and the temperature at the edge of the river, middle of the channel, and at 1.0 m below the river´s surface was done using a Digital Weather Station with uninterrupted recording (15 days + 15 days) with data collection (ambient air temperature, humidity, pressure, wind speed and direction, dew point) which 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 (water), and samples were labeled accordingly, using GPS/ GLONASS and satellite images, (Steps 1 and 2 of the Amazon River Expedition protocol).

B. *Applications and Sensors*

We worked with remote sensors (GPS/GLONASS) during the journey (Amazon Peruvian and Brazilian, Atlantic Ocean-Brazil), with Smartphones for localization (Google Map), with or without internet support in the cities we could connect in the Amazon River. We manipulate data from Aqua-Terra (Modis Sensor - Earth Observing System (EOS)) through the Web to understand the current conditions]of land and water use, for reference only.

The instrumentation used was two GPS/GLONASS (with camera and image software with digital georeferencing), to determine the points and locations visited and also to record the route of the entire trip. The data were deposited in the thematic maps; a Digital Weather Station with GPS/GLONASS, to collect the weather conditions of the trip. Camcorder and camera, for documentation purposes. Water collection in all localities for analysis of the Present State of the Amazon River during drought and El Niño prolonged phenomenon, data also deposited in thematic maps. In some cities panoramic drone flights were performed for documentation purposes. Office work was done to createthematic maps (ArcGIS-ESRI) and digital image manipulation. With treatment of field information.

Figure 3 shows the time series of temperature that was taken at three positions (ambient temperature at the ship – 100 m from the edge of the channel – middle of the channel) during the first stage of the expedition (Iquitos/Peru – Manaus/Brazil), using the FLIR E60 thermal imager and weather station. 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) [11].

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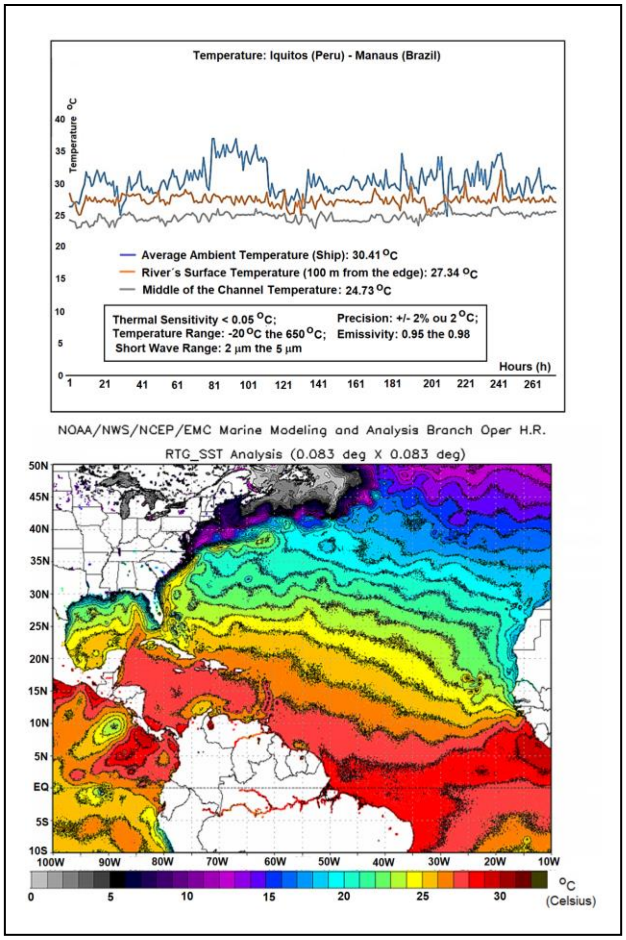

Figure. 3: Time series of temperature along the Amazon River during the first stage of the Expedition (Iquitos/Peru – Manaus/Brazil), and compared to data from the *Marine Modeling and Analysis Branch Oper. H. R.* (Verification Ensembles) of NOAA/NWS/NCEP/EMC. Source: Amazon River Expedition and NOAA, 2016.

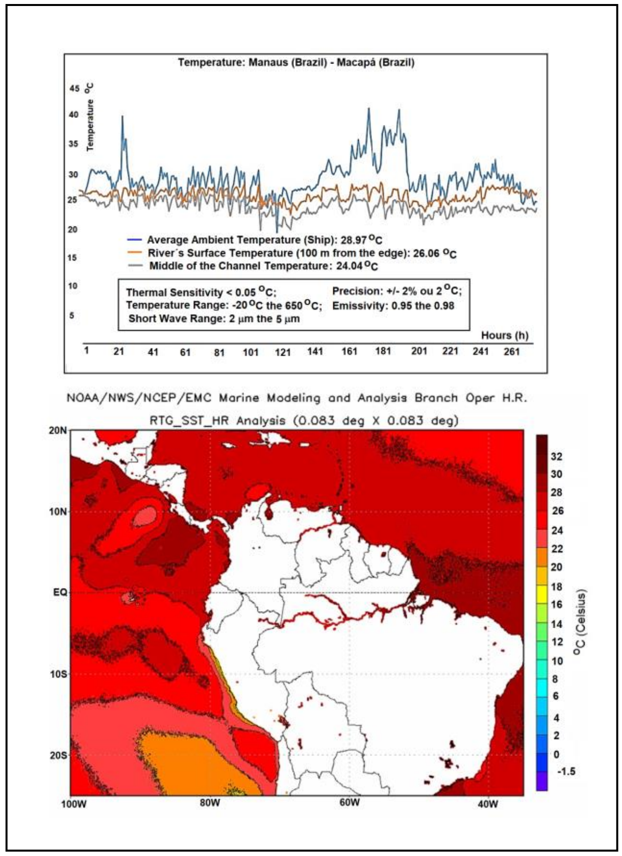

Figure. 4: Time series of temperature along the Amazon River during the 2nd stage of the Expedition (Manaus/Brazil – Macapá/Brazil) and compared to data from the *Marine Modeling and Analysis Branch Oper. H. R.* (Verification Ensembles) of NOAA/NWS/NCEP/EMC. Source: Amazon River Expedition and NOAA, 2016

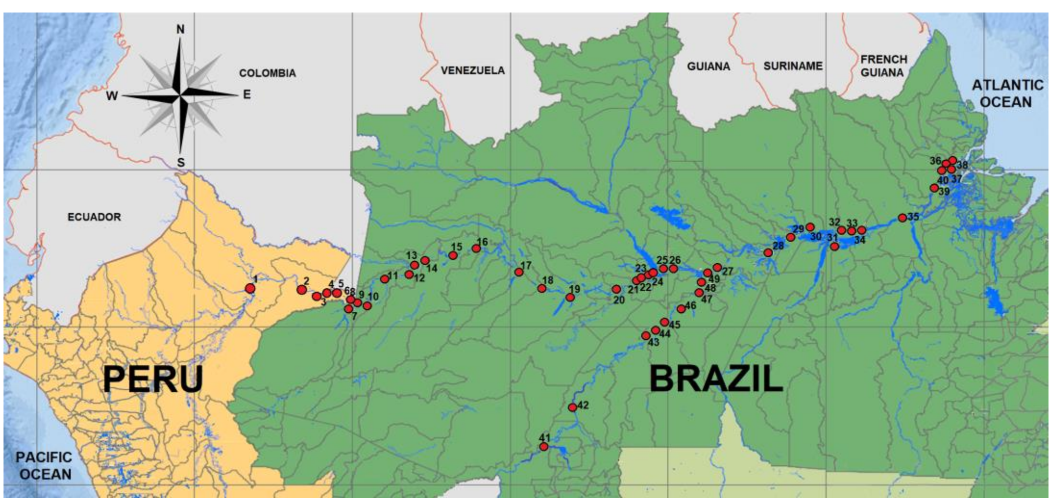

Figure 5. Map of localities in the Amazon River Expedition (PERU-BRAZIL).

TABLE I. WATER SAMPLE ANALYSIS – STAGE ONE OF THE AMAZON RIVER EXPEDITION (PERU-BRAZIL) JULY, 2016

Samples	Geographic Coordinates		Water	Temp.
	Latitude	Longitude	pH	°C
1	S03° 43' 37.6"	W 073° 14' 23.8"	6.61	28.8
2	S03° 48' 18.8"	W 071° 34'25.4"	7.31	26
3	S04° 00' 59.6"	W 071° 06' 07.5"	7.29	26
4	S03° 55' 40.8"	W 070° 47' 10.4"	7.22	25
5	S03° 53' 49"	W 070° 30' 19.1"	7.79	26
6	S04° 06' 39.7"	W 070° 03' 13.8"	6.92	29
7	S04° 13' 04.7"	W 069° 57' 19.1"	6.89	27
8	S04° 13' 44.4"	W 069° 56' 41.0"	7.2	27
9	S04° 22' 19.5"	W 070° 01' 34.3"	7.15	26
10	S04° 18' 31.2"	W 069° 33' 27.5"	6.6	24
11	S03° 27' 42.2"	W 068° 57' 26.4"	7.17	24
12	S03° 21' 14.5"	W 068° 11' 04.2"	7	24
13	S03° 06' 29.1"	W 067° 56' 39.6"	5.81	23
14	S02° 51' 47"	W 067° 46' 13.4"	6.15	26
15	S02° 44' 33.8"	W 066° 46' 19.5"	6.16	25
16	S02 ° 29' 40.6"	W 066° 04' 05.1"	7	25.5
17	S03° 16' 32.1"	W 064° 43' 12.1"	6.87	25.5
18	S03° 47' 18.3"	W 064° 02' 19.8"	6.93	27
19	S04° 03' 17.1"	W 063° 04' 54.0"	6.89	26
20	S03° 47' 17.2"	W 061° 37' 05.8"	6.76	25
21	S03° 33' 34.6"	W 060° 53' 16"	6.75	24.5
22	S03° 28' 34.8"	W 060° 45' 22.9"	6.76	26
23	S03° 19' 17.3"	W 060° 37' 00.6"	6.81	23
24	S03° 19' 17.3"	W 060° 37' 00.6"	6.77	27
25	S03° 08' 11.1"	W 059° 53' 59.1"	5.53	28

III. RESULTS AND DISCUSSION

In this section we show the results that were obtained with the aid of sensors remotely positioned in a network of satellites (GPS, GLONASS and MODIS) that were described using a geographic information system (GIS) map with thematic layers in tables (water and temperature), graphs, and figures, and with correlations with other studies.

Figure 3 shows the time series of temperature that was taken at three positions (ambient temperature at the ship – 100 m from the edge of the channel – middle of the channel) during the first stage of the expedition (Iquitos/Peru – Manaus/Brazil), using the FLIR E60 thermal imager and weather station. 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) [11]. These results indicate correlation with those 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°C, at the river´s surface (100 m from the edge) of 27.34°C, and at the middle of the channel of 24.73°C (Fig.3). 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°C, at the river´s surface (100 m from the edge) of 26.06°C, and at the middle of the channel of 24.04°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 (Figs. 3 and 4).

The analyses of the water samples from both stages of the expedition are listed in Tables I (1st stage) and II (2nd stage), and these data describe the "actual state" of the Amazon River in 2016 during the dry season in the Amazon. 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 (Fig. 5, Tables III and IV) 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).

Figure 5 shows the georeferenced map of the 39 cities of the Amazon river expedition from Iquitos in Peru to Macapá in Brazil (Table III). The cities from points 41 to 49 are the main tributary (Madeira river) on the right downstream of the river Amazonas, but it is not the focus of this work.

Table IV indicates the water quality of the Amazon River during the prolonged heating of El Niño in the Amazon region in 2016.

TABLE II. WATER SAMPLE ANALYSIS – STAGE TWO OF THE AMAZON RIVER EXPEDITION (PERU-BRAZIL) DEC., 2016.

Samples	Geographic Coordinates		Water	Temp.
	Latitude	Longitude	pH	°C
26	S03° 08' 21.3"	W 60° 01' 35.1"	5.14	27.6
27	S03° 08' 54.3"	W 58° 26' 54.1"	6.56	27
28	S02° 38' 01.6"	W 56° 45' 21.7"	6.7	27
29	S02° 09' 05.9"	W 56° 05' 43.1"	6.54	27
30	S01° 55' 22.2"	W 55° 30' 55.3"	6.75	27
31	S02° 24' 52.1"	W 054° 44' 13.8"	6.16	27
32	S02° 25' 00"	W 054° 43' 22.2"	6.07	27
33	S02° 00' 35.1"	W 054° 04' 10.0"	6.54	27
34	S02° 00' 35.3"	W 054° 04' 11.8"	6.41	26.6
35	S01° 31' 58.7"	W 052° 34' 34.5"	6.45	28
36	S00° 03' 27.4"	W 051° 10' 42.1"	6.5	27
37	N00° 01' 37.4"	W 051° 02' 55.1"	6.6	26.3
38	N00° 02' 00.2"	W 051° 02' 43.1"	6.44	27
39	S00° 31' 20"	W 051° 29' 59.7"	6.81	26.6

TABLE III. THE 39 CITIES OF THE AMAZON RIVER (PERU-BRAZIL) DECEMBER, 2016.

Point	Place of Collections
1	PUERTO IQUITOS (PERU)
2	SAN ANTÔNIO (PERU)
3	SAN PABLO (PERU)
4	CIEN BOTE (PERU)
5	CABALLO COCHA (PERU)
6	PUERTO ALEGRIA (PERU)
7	PUERTO SANTA ROSA (PERU)
8	TABATINGA HARBOUR (BRAZIL)
9	BENJAMIN CONSTANT HARBOUR (BRAZIL)
10	FEIJOAL (BRAZIL)
11	SÃO PAULO DE OLIVENÇA HARBOUR (BRAZIL)
12	AMATURÁ CITY (BRAZIL)
13	SANTO ANTONIO DO IÇA CITY (BRAZIL)
14	TONANTINS HARBOUR (BRAZIL)
15	JUTAÍ HARBOUR (BRAZIL)
16	FONTE BOA HARBOUR (BRAZIL)
17	TEFÉ OF LAKE (BRAZIL)
18	BIG CATUÁ ISLAND (BRAZIL)
19	COARI (BRAZIL)
20	ANAMÃ (BRAZIL)
21	MANACAPURU RIVER (BRAZIL)
22	MANAQUIRI LAKE (BRAZIL)
23	IRANDUBA INPUT
24	IRANDUBA
25	MANAUS (BLACK RIVER) (BRAZIL)
26	MANAUS HARBOUR - AM (BRAZIL)
27	ITACOATIARA - AM (BRAZIL)
28	PARINTINS HARBOUR (BRAZIL)
29	JURITI HARBOUR (BRAZIL)
30	ÓBIDOS HARBOUR (BRAZIL)
31	DOCAS HARBOUR (BRAZIL)
32	TIRADENTES SQUARE HARBOUR
33	MONTE ALEGRE HARBOUR (BRAZIL)
34	PRAINHA HARBOUR (BRAZIL)
35	ALMEIRIM HARBOUR (BRAZIL)
36	SANTANA HARBOUR (BRAZIL)
37	FORT HOTEL (MACAPÁ-BRAZIL)
38	STATION *BONDE* (MACAPÁ-BRAZIL)
39	MARACÁ RIVER (BRAZIL)

TABLE IV. WATER QUALITY OF THE AMAZON RIVER (PERU-BRAZIL) DECEMBER. 2016.

Samples	Conductivity	Alkalinity	Dissolved Oxygen		Turbidity
	µS/cm	(mgHCO3/L)	%	mg/L	(NTU)
1	48.3	22.57	113.5	9.5	15.6
2	112	51.24	117.6	10.02	104
3	123.7	48.19	105.7	8.46	83.72
4	119.9	46.36	103.7	8.27	53.56
5	117.4	47.58	111.8	8.81	50.18
6	78.1	36.6	108.1	9.31	8.84
7	106.5	48.19	108	8.56	79.56
8	103.7	44.53	109.2	9.44	75.4
9	104.3	47.58	110.2	8.36	73.06
10	28.3	13.42	115.8	9.29	41.08
11	100.3	42.09	124	9.85	83.98
12	98.1	43.31	113.2	9.75	82.42
13	9.51	4.27	99.8	9.71	6.24
14	17.45	9.15	117.5	9.61	21.06
15	17.92	9.76	109	8.99	10.92
16	75	32.33	119.5	9.48	54.6
17	68.5	29.89	118.9	9.92	63.44
18	69.3	31.72	108.3	9.07	42.12
19	64.2	30.5	110	9.42	44.2
20	54.4	25.01	100.7	8.34	29.38
21	50.7	23.79	103.8	7.79	44.46
22	48.1	22.57	119.1	9	20.8
23	48.5	22.57	129.7	10.45	29.38
24	48.6	22.57	108.5	9.11	24.44
25	9	3.66	114.8	9.61	3.64
26	7.92	2.44	77	5.76	3.9
27	53.3	17.08	76.6	5.35	35.36
28	51.3	16.47	69.3	5.66	44.46
29	51.2	15.25	70.5	5.63	37.44
30	52.8	18.3	68.8	5.64	38.48
31	13.8	7.32	74.9	5.68	4.68
32	13.92	6.1	82.5	6.36	2.6
33	45.7	16.47	67.2	5.29	57.46
34	50	17.69	64.05	4.98	41.34
35	47.5	21.96	71.2	5.28	33.28
36	53.1	23.18	58.4	4.70	27.56
37	53.3	22.57	71.9	5.96	27.56
38	56.5	25.01	67.7	5.37	27.3
39	45.9	21.35	65.3	4.94	36.92

In [12], 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.

IV. CONCLUSION

The oceans and enormous body of water are the main source of thermal inertia in the climate system [13]. In the current study, we contribute information on temperatures during an El Niño event. With georeferenced sample sites, since the Amazon River is an enormous body of water, and together with the Amazon forest and the equatorial Atlantic and Pacific Oceans models the climate of the South American climate.

The Amazon River, during the dry season of 2016, was influenced by a prolonged El Niño climatic tendency (2014, 2015 and 2016). With the help of georeferencing, it was possible to show the correlation between temperature measurements and satellite images throughout the trip 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, combined with a tendency for regional warming during the El Niño event of 2016.

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