DEPICTING THE HEADWATERS OF THE AMAZON RIVER THROUGH THE USE OF REMOTE SENSING DATA

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ABSTRACT

Following the concept that the most remote slope is the very birth place of a river a new site for the headwaters of the Amazon is proposed. To depict the site emphasis has been done on the use of LANDSAT Thematic Mapper images. Synoptic viewing and spectral attributes have strongly contributed to follow the mainstream of the Amazon from Iquitos to the vicinities of Cusco and upwards to the headwaters deep in the cliffs of the Western Andean Range of Peru. Spectral attribute helped mostly to trace the Ucayali banks in the lowlands. Dry season images show the Ucayali cutting across longer meanders in the Peruvian Amazonia. Images over this region acquired during the wet season show those meanders enlarged by flooding of Ucayali waters with brigth spectral signatures. To follow the Amazon in the uplands (Apurimac River) images with higher sun elevation angles (wet season) were tried in order to avoid shadowing over the mainstream but lack of cloud free images forced to select winter frames. The Apurimac landscapes use to show very deep slopes and so the low sun angles of winter let some parts of the river meandering in the shadows. The images were printed in 250,000 scale as color composite TM bands 3B4G5R with standard gains in the forest domain and stretched gains for 3B4R5G frames of the rocky and dry uplands. The mainstream of the Amazon River was followed until the Northern cliffs of Nevado Queuhicha. Nevado Queuhicha divides the waters of the Amazon and the Colca River. This mountain with more than 5,000 meters is where the Amazon River start to run. According to system corrected LANDSAT image the coordinates of the Amazon headwaters site are: longitude West 71 degrees 41 minutes 41 seconds and latitude South 15 degrees 31 minutes 52 seconds. From this new birthsite and flowing by the channels of Japura and Tapara the Amazon is the longest river on Earth. Very new aspects of the Amazon fluvial system in the Atlantic coast are presented.

1.INTRODUCTION

To study the Amazon River as a unique fluvial system is the main goal of the Amazing Amazon Project which is one of the many scientific issues about the tropical region going on at the Brazilian Institute of Space Research.

To our understanding the Amazon is a living planetary system where geological parameters are giving us a briefing about the history of South America in terms of the Earth's time and not about the men's time. To our geomorphic model such huge fluvial system is controlled by the Guyana Shield in North, the Brazilian Plateau in the South and the Andes Folding Belt in the West. Sorrounded by these large tectonic features the Amazon System meanders over 7.9 mega square kilometers facing just one geomorphic purpose: to transport the high Andean mountains to the Atlantic. The Amazon subsystems of Guyana and Central Brazil are not weathering any landscape. They are just carrying waters with lack of suspended sediments.

Most of the sediments weathered from the mountains are carried to the Northeastern coastlines of South America. From year to year this silting process born in the Andean waters of the Amazon designs new contourlines in the shores of Guyana, French Guyana, Suriname and Brazil.

The Amazing Amazon Project is studying the huge features of such model through LANDSAT Thematic Mapper images. The sypnotic viewing of LANDSAT together with aerial sampled photos and video are the main support to geological analysis. Starting point of the Project was to map exactly the very headstream of the Amazon in the Andes.

2.BACKGROUNDS

First written reports about the Amazon were those of the Spanish explorers in middle 16th century. Francisco Orellana left Ecuador in 1542 following the Eastern white waters and is indicated in the usual literature as the first explorer to cross South America traveling the Amazon. The Ucayali River, the central feature to this article, was initially traveled by Juan Salinas in the early Spring of 1557. It looks like Orellana followed the waters of Napo River because it is the only big river that leaves Ecuador and enters the Amazon after the mouth of Ucayali.

The headwaters of the Amazon have been adopted as the Marañon River for centuries due to larger channel when compared to Ucayali and Huallaga rivers. The analysis of the last two rivers in terms of their length has shown that they both are longer then the Marañon. In the case of Ucayali we may say hardly longer because to our analysis his very first slope is sited at least 4 and half degrees higher in latitude than the Marañon birthplace.

Measurements of the Amazon length following the Ucayali River instead of Marañon River were carried out by many cartographers and geographers. Most of the measurements released in the last 50 years are summarized in table 1.

1. O.H. Walkey	UK	1949	6.517 km
2. E.J. Devroey	USA	1950	6.595 km
3. David Cook	USA	????	6.750 km (South.ch.)
4. David Cook	USA	????	6.448 km (North.ch.)
5. IIAP-Peru	Peru	????	6.885 km
6. SGN-Peru	Peru	????	6.762 km
7. J.Cousteau	France	1984	7.025 km
8. J.C.P.Grande	Brazil	1955	6.571 km

Table 1. Measurements of Amazon Length.

Several Missions to/from Ucayali and Apurimac rivers are described in books and magazines. The more important was that of Loren McIntyre in 1971 when he traced the Amazon on the slopes of Mount Mismi in Southern Peru. Another very important task was accomplished by Brazilian newswoman Paula Saldanha and videomaker Roberto Werneck in late 1994. They led a TV team to Mount Mismi and are the first Brazilians to reach that slope of the Amazon.

Those measurements and the missions were based in different maps and scales. Most of the cartographic information were drawn from pachromatic air photos with lack of synoptic, temporal and spectral attributes that we think to be hardly important to study the Amazon waters. These attributes are largely found in Thematic Mapper frames and so emphasis has been made in the use of LANDSAT data.

3.REMOTE SENSING AND CARTOGRAPHIC DATA

A good collection of TM prints ready to be analysed is available at INPE Customer Service in São José dos Campos. Almost 600 color 250.000 prints covering Brazil and part of South America are archived in the office and were largely used to study the Amazon stream until Iquitos. Table 2 shows the list of TM images, the Shuttle frame and additional cartographic information.

4.SOME METHODOLOGICAL ASPECTS

To study the Ucayali-Apurimac waterscape is not such easy issue since the first stream lays around 5,000 meters height and falls to last than 70 meters in the Peruvian Amazonia. The very deep slopes in the highlands causes the Apurimac to flow in the shadows mostly of the low sun elevation angles of the winter days. Images of winter are easier to find due to the lack of clouds but they were collected at low elevation angles of sun illumination (range 37-43). In some cases as downwards of Quehue and Acobamba Abyss is hardly difficult to outline the Apurimac bounds because of the shadowing due to the 300 meters steep slopes. The interpretative pro-

Path/Row	Passday	Sun Angle
003/71	May 4th-90	40
003/70	Jul 12th-86	37
003/70	Aug 8th-90	40
004/70	May 30th-91	38
004/69	Oct 2nd-90	53
004/69	Jun 22nd-90	39
005/68	Jul 26th-86	40
005/69	Aug 6th-90	40
006/67	Aug 13th-90	43
006/68	Aug 13th-90	43
006/66	May 25th-90	43
006/66	Aug 16th-91	46
006/65	Jun 13th-91	42
006/64	Aug 7th-88	48
006/63	Aug 26th-89	51
007/65	Jul 19th-90	42
007/64	Sep 18th-89	54
STS/26	frame 40-055	p.m.(Shuttle Hasselblad color print)

*Thematic Mapper band 3 Mosaic of Brazilian Amazon (1:2,500,000) - (Figure 1)
*DMA Navigation Chart ONC N-25 (1:1,000,000)
*LANDSAT-MSS Planimetric Chart of Peru (1:1,000,000)

Table 2.Images and Maps.

TM frames listed above are all system corrected. The accuracy for internal measurement in those frames is 1 pixel (30 meters) and the accuracy of absolute positioning falls within 1 kilometer in latitude and 400 meters in longitude.

cedure in such cases was:

-To select summer images with higher sun angles or;

-To outline the river following the linemaps available or;

-To trace the shadow of the slope in the winter image.

The images of Peruvian Amazon are much more simple to be selected because the dry season of the river comes very close to the dry season of the weather (cloud free) and so the main stream is easily draftet. However one image of the end of the rainy days (May) shows the Ucayali low waters flowing in the longer meanders. Cloud free images of the wet season would show a longer Ucayli. This is not the case for lower Amazon waters in Brazil.

The mouth of Negro River reaches the flooding peak in June wich is the center of the dry season (Soares, 1958). Cloud free images of the middle Amazon are oftenly from June, July and August wich means dry weather and flooding season. The Amazon in the flooding season meanders harder imbricately with larger margins around islands. In these cases we have followed the longer and the larger stream. To our understanding in some sections of the Amazon as in the Japura River domain and Matapa Island near the city of Santarem the main stream of the wet season may be not the main stream of the dry season.

Availability of cloud free images made just possible to analyse a dry Ucayali and a flood Amazon.

The focal point to our model and the main attribute of the Amazon in multispectral data is the white signature of the turbid waters in the visible bands of TM frames. The spectral attribute of the Amazon waters is the key parameter to analyse and to measure the length of this amazing fluvial system.

5.DEPICTING THE HEADSTREAMS

The Ucayali Basin has two main branches in the Andean landscapes: Apurimac and Urubamba rivers. The upper basins of these rivers form a very complex network of streams with Colca River that runs to the Pacific and the Titicaca Lake tributaries.

The Urubamba River has a well designed valley and begins to run from the all weather-snow peaks (nevados) that divide waters from the Titicaca shed. These perennial snowed peaks are clearly defined as greenish blue in TM 3B4G5R color composite.

The Apurimac River from Atalaya to upwards is refered as Tambo, Ene, Hornillos and Manigote until to reach the first slope of the Amazon in the Chila Mountains as part of the Western Andean Ridge of Southern Peru. The several names applied to Apurimac just reflect how much imbricated is the flowing of the river along the steep valleys controlled by the geological structure. The Mount Quehuicha is the ultimate bound between the slopes of Colca and Apurimac rivers (figure 2). This mount was refered as the probable source of the Amazon by Strain and Engle (1992). Quehuicha is a mount with lack of perennial snows in the images (TM 003/71 of May 4th 1990 and Shuttle 40.055 of November 1988). The landscapes of Quehuicha have aridland brightness dominated by salt, rolled stones and sand without lakes at all. Quehuicha is higher then 5,000 meters and rises in latitude South 15 degrees 31 minutes 52 seconds and longitude West 71 degrees 41 minutes 41 seconds. These coordinates were measured from TM-LANDSAT system-corrected images together with ground control points and contourlines from DMA map (table 2). There are two nevados in the vicinities of Queuhicha one to the Northeast (5,564 meters) and other to Northwest (5,529 meters). These three mounts are dividing the upper waters of the Apurimac and the Colca River.

The Ridge that lies Northwestern from Chila Mountains to Huanzo Range shows at least two sites where the waters that run to the Pacific and to the Atlantic may have a seasonal connection. The connections are due mainly to the amount of water in the glacial lakes that are spread over the suspended valleys along the ridge. One site is around the lakes in the upper Velille River the first large tributary of the left margin of the Apurimac (latitude 15 degrees 5 minutes and longitude 71 degrees 56 minutes). The other site is the very upper valley of OcoÒa River (Pacific border) in Huanzo Lake (latitude 14 degrees 40 minutes and longitude 72 degrees and 44 minutes). The margins of these lakes show scars of sazonal streams that live the tarns and run to the North (Atlantic Border) and to the South (Pacific Border).

6. FIRST RESULTS: MEASUREMENTS

Up to now we have been studying the main stream of the Amazon and the alternative large and longer channels that are the opposite margin of the River around the islands. Examples of channels are the following:

-Japura Channel: lives the main stream meets the Japura River and returns to the Amazon downwards near the city of Tefe.

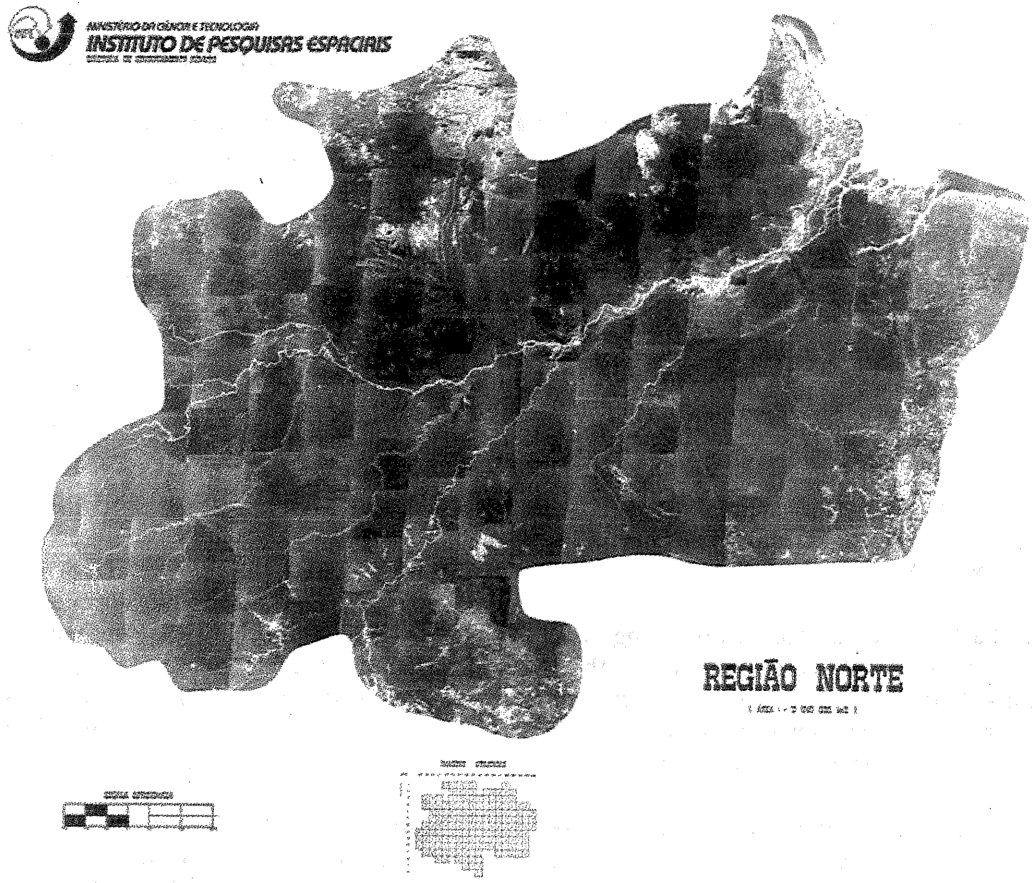
-Tapara Channel: lives the main stream and sorrounds the Matapa Island near Santarem.

-Breves-Gurupa Channel: lives the Amazon and meets the Tocantins River to form the Marajo Island.

These channels are intrinsic part of the Amazon since they help to design the large fluvial islands. Those channels are included in the measurements of the River length. There are however dozens of shorter channels (locally named as furos and paranas) that are not being measured because they are 50-100 meters wide and sharper then the pencil trace in 250.000 scale.

Turbid sazonal meanders that can be drawn as the main stream in the flood season were included in the measurements. These larger meanders are commonly found in the low waters of Ucayali (figure 2).

Figure1 - Brazilian Amazonia Mosaic of TM3-Landsat Frames:
Dark and bright signatures of amazon tributaries



These meanders are 1,2 kilometers wide.

Preliminary measurements applied just for the new segments as Quehuicha sector, sazonal (turbid) meanders of Ucayali and the channels of Japura and Tapara have increased 300 kilometers the length of the River.

Any measurement of table 1 increased by 300 kilometers make the Amazon longer then 6,670 kilometers which is the acceptable length of Nile River everywhere in the literature. The fact that the Amazon would be the longest river on Earth was firstly issued by Schreider and Schreider (1970) and more recently by the Instituto Geografico Nacional of Peru. Our purpose is to come up with more precise figures and procedures about the total length of the River. These figures will arise as the Amazing Amazon Project advances into the knowledge of this huge fluvial system.

7.FIRST RESULTS: NEW ASPECTS

Remote Sensing data are showing very new aspects of the Amazon that may never have been refered before Figure1 (Mosaic of Amazon Brazilian Basin). Some of theses aspects are:

i) The key attribute of the Amazon is the bright signature of the waters in the visible bands of Thematic Mapper sensing devices.

ii) To map the turbid waters is to follow all the rivers of the Amazon that are born in the Andean Ridge like: Putumaio-Iça, Japura, Napo, Marañon, Ucayali, Jurua, Purus and Madeira (figure 1).

iii) The turbid waters gather weathered sediments from the Andean Ridge exclusively.

iv) The rivers with clear waters (Tapajos, Xingu and Tocantins/Araguaia) are not bringing to the Amazon any coarsed sediments because there are no more mountains in Brazilian Central Plateau. Some parts of Xingu and Tapajos are turbid due to gold miners (garimpos) (figure 1).

v) The black rivers of the Northern margin (Negro, Uatum,,, Trombetas, Paru and Jari) do not bring any coarsed sediments either. They are full of organic matter washed from the leaves(figure 1).

vi) The main purpose of the Amazon System is to modelate the Andean landscapes and wash the Ridge into the Atlantic.

vii) Part of the sediments are being (and has been for thousands of years) gathered by the River into the Atlantic until to reach the Eastern coast of South America from Northern Amapa to French Guyana and probably Georgetown (figure 2).

viii) Sediments of the River were registered by Remote Sensing devices at least 120 kilometers off Cape Norte in the coast of Amapa.

ix) Muddy banks and silting waters of Amazon origin are the main features depicted in LANDSAT images of Cayenne and Kourou. The muddy banks with shrub cover appeared as green color and silting waters are greenish blue (figure 2).

x) The same features are observed in the images of Paramaribo and New Amsterdam.

xi) The Georgetown swamps and mangroves that were dried and moved to cropfields (sugar cane and rice) can be correlated to the Amazon sedimentation process since the banks and the waters show the same signatures as the features depicted in the images of Paramaribo and Cayenne.

xii) To our model the source of mud and silt that are designing new features in the Northeastern South America coastline is the Eastern landscapes of the Andean Ridge more than 7,000 kilometers away.

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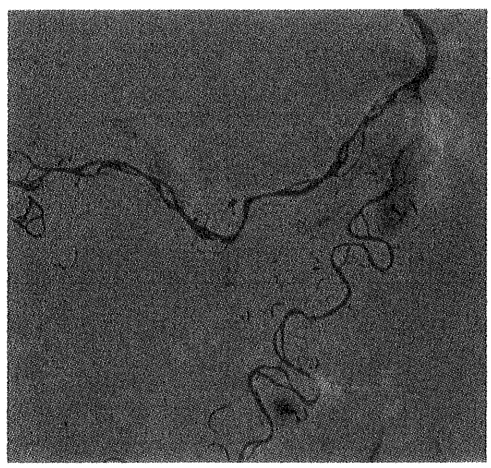
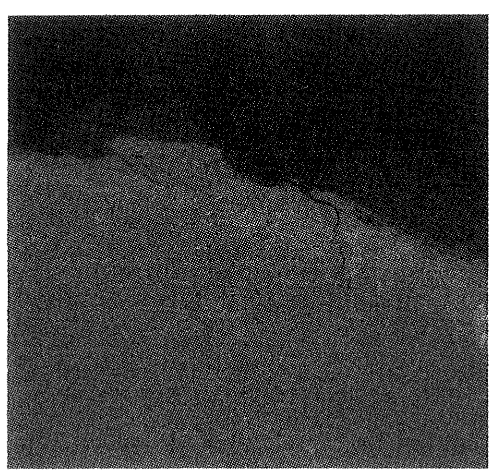
Western Edge of Chila Mountains: Mount is located at the lower right corner.



Mouth of Maranhão in Ucayali river



Cayene Coast

Figure 2