Estimation of Discharge for the Amazon River Branches with Wavelet Analysis

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Abstract: In this study, we attempted to estimate the discharge of the Amazon River branches from JERS-1/SAR images, which are independent of the weather. We visualized some traces of the Amazon River branches, transformed river shapes into a one-dimensional signal, and calculated the characteristics of the river shapes such as the meandering wavelength and the amplitude with Fourier and wavelet analysis. Then, we related the characteristics of the river shapes with the existing discharge data and derived some regression equations. Finally, we estimated the discharge of the Amazon River branches from the SAR images.

Keywords: SAR, discharge, image processing, Fourier, wavelet, river geomorphology

1. Introduction

Recently, desertification and degradation of water cycle by deforestation in the Amazon, South America, have become an important problem. In this study, we attempted to estimate the discharge of the Amazon River branches from JERS-1/SAR images, which are independent of the weather. According to the river geomorphology, the river shapes such as the amplitude and the meandering are related with its discharges. For example, a small meandering wavelength shows low discharge, while a big one shows high discharge. First, we visualized some traces of the Amazon River branches by filtering, which were not found in the original SAR images. Next, we transformed river shapes into a one-dimensional signal, and calculated the river characteristics with Fourier and wavelet analysis. Then, we related the characteristics of the river shapes with the existing discharge data and derived some regression equations. Finally, we estimated the discharge of the Amazon River branches from the SAR images.

2. Method

1) Study Area

We selected 11 stations in the Amazon Basin, and 12 scenes of JERS-1/SAR, which observed approximately rainy seasons from 1993 to 1997 at a nearby site of the discharge measurement stations. Beside, we used the discharge data of the Amazon River branches, Rio Madeira, Rio Jipanara, Rio Purus, Rio Guapore, Rio Tabajara, and Rio Juruena, which were observed from 1965 to 1997. In the absence of discharge data on the same date of SAR observation, we used the mean discharge during the observation periods.

2) Approach to Estimate River Discharge

First, to remove speckle noises of the original SAR images, we used a SFP filter and an enhanced SFP filter, and integrated two images. Next, we emphasized difference of the surroundings in order to extract a thin river from the bright characteristic spots. We prepared a 5-by-5 window, and calculated the sum of the absolute difference between a center pixel and its surrounding pixel values. Then, we emphasized isolated string scatters, and visualized a thin river from the bright characteristic spots (Fig. 1).

Next, to extract the only river shapes, we applied binalizing and thinning for the images (Fig. 2). First, we obtained the coordinates through the river path at every constant interval, and calculated each angle from the adjacent line segment (Fig. 3). We determined this constant length was 20 pixels (500 m) because the smallest river wavelength was approximately 500 m. By this technique, we transformed the river shapes into a one-dimensional signal (Fig. 4). This signal showed that a small meandering had high frequency and big amplitude, while a large meandering had low frequency and small amplitude.

Next, to analyze that signal's frequency or the characteristics of the river shapes, we applied Fourier and continuous wavelet transform for the one-dimensional signals (Fig. 5-8). In this technique, we could treat the river shapes in the frequency domain. The mother wavelet that we applied was the Gabor wavelet expressed as the equation (1), which showed the best fitting wave for the original wave. The wavelet's scale corresponded to the frequency, and then the bigger scale corresponded to the lower frequency. We showed the space-frequency two-dimensional plane, where, an x axis was spatial scale, a y axis was wavelet's scale, and a z axis was spectral intensity.

$$y(x) = \frac{1}{2\sqrt{ps}} \exp\left(-\frac{x^2}{s^2} \right) \exp(ix) . \qquad (1)$$

Moreover, we applied the multi-resolution analysis with discrete wavelet transform to the original signals. In this technique, we analyzed which level of that frequency was included in which part of the signals. The level corresponded to the frequency, and then the higher level was equivalent to the lower frequency. This mother wavelet that we applied was the Daubechie's wavelet.

Furthermore, we calculated the averages of every Fourier spectrum, wavelet's scale and level. We obtained probability for the characteristics of the river shapes as follows.

$$I = \frac{\sum_{j=1}^{N} j\overline{w^{(j)}}}{\left(\sum_{j=1}^{N} \overline{w^{(j)}} \right)^2} \qquad (2)$$

where j is a wavelet's level or scale, $\overline{w^{(j)}}$ is the average of spectral intensity, and N is the number of the level or scale.

Finally, to compare these characteristics with the existing discharge data, we derived some regression equations between the Fourier power spectrum and the discharge, the wavelet's scale and the discharge, the level and the discharge, and the amplitude of the one-dimensional signal and the discharge.

3. Results

We could obtain a good correlation between the discharge of the Amazon River and the characteristics of the river shapes (Table 1). Derived some regression equations was follows.

$$Q = 1.17 \times 10^6 q^{-2.35} \qquad (R^2 = 0.787)$$
$$Q = 4.95 \times 10^8 FT + 612 \qquad (R^2 = 0.683)$$
$$Q = 1.49 \times 10^6 CWT - 9690 \qquad (R^2 = 0.819)$$
$$Q = 3.65 \times 10^5 DWT - 9210 \qquad (R^2 = 0.817)$$

where Q is the discharge (m^3/s), q is the amplitude of the one-dimensional signal (degree), FT is the Fourier power spectrum, CWT is the continuous wavelet spectrum, and DWT is the discrete wavelet spectrum.

4. Conclusions

We analyzed the JERS-1/SAR images about 12 scenes from 1993 to 1997, and found out that characteristics of the river geomorphology correlated the discharge of the Amazon River well. In particular, we found that the continuous wavelet analysis was the best method to estimate the river discharge. However, we could obtain the difference between some rivers, but a very small change such as a seasonal change was hard to be derived. In the future, we will analyze the precipitation data, branch length, the number of branches, and brightness of the river, and estimate the seasonal change of its discharge.

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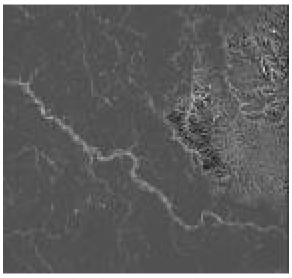

Fig. 1. Filtered SAR image (Path = 416, Row = 315, Tabajara)

Fig. 2. Binalized image (Path = 416, Row = 315)

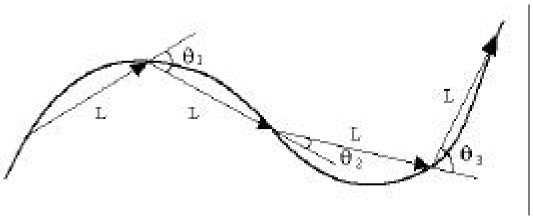

Fig.3. One-dimensional transform model

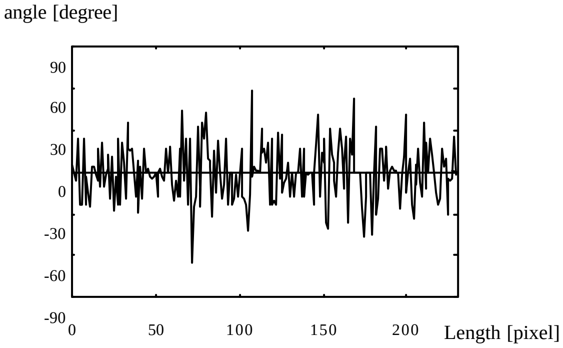

Fig.4. One-dimensional signal (Path = 416, Row = 315)

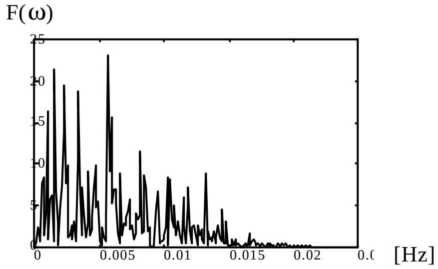

Fig. 5. Fourier spectrum (Path = 415, Row = 318, Tabajara)

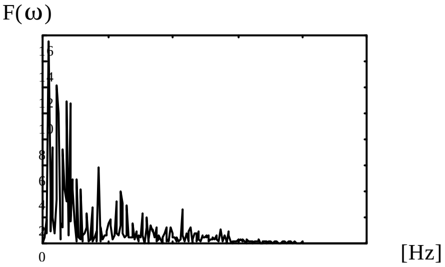

Fig.6. Fourier spectrum (Path =419, Row = 315, Porto Velho)

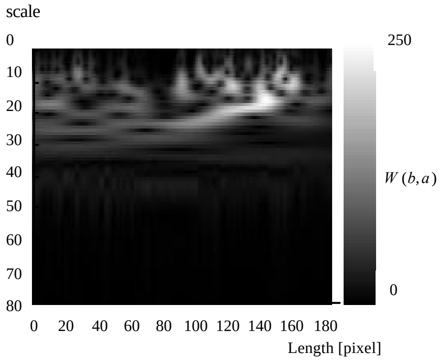

Fig.7. Continuous wavelet transform (Jipanara)

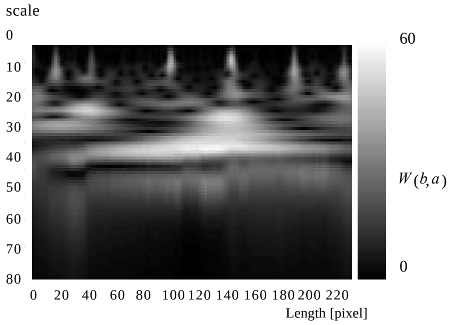

Fig.8. Continuous wavelet transform (Manaus)

Table.1. One-dimensional signal' s amplitude, Characteristics of Fourier and wavelet transform, and Discharg

Station Name	River Name	One-dimensional Signal*	Fourier Transform**	Continuous Wavelet Transform***	Discrete Wavelet Transform***	Average Discharge (m3/s)
Pimenteiras	Rio Guapore	22.058	2.77E-06	0.00610	0.0228	528.6
Jiparana	Rio Jiparana	15.795	7.67E-06	0.00938	0.0353	713.1
Pedras Negras	Rio Guapore	19.548	3.23E-06	0.00755	0.0282	918.8
Seringal Da Caridade	Rio Purus	30.259	1.88E-06	0.00473	0.0185	1279.0
Tabajara	Rio Jiparana	13.389	1.23E-05	0.01030	0.0406	1348.4
Fontanilhas	Rio Juruena	14.549	7.94E-06	0.00947	0.0381	1425.5
Labrea	Rio Purus	12.460	3.93E-06	0.00959	0.0364	5569.6
Aruma	Rio Purus	7.902	8.23E-06	0.01355	0.0618	10434.6
Porto Velho	Rio Madeira	7.083	1.95E-05	0.01480	0.0602	18849.3
Fortaleza	Rio Tapajos	5.825	4.55E-05	0.02114	0.0808	20990.7
Manaus	Amazonas	3.410	1.15E-04	0.03210	0.1484	128508.2

* average amplitude of the one-dimensional signal

** probability density of spectrum intensity in Fourier transform

*** probability density of spectrum intensity in continuous and discrete wavelet transform