AN EVALUATION OF IMAGE FUSION APPLIED TO INLAND AND COASTAL WATERS

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ABSTRACT

Image fusion algorithms can be used to increase the spatial resolution of images. Therefore, evaluate the performance of fusion methods in particular environments such as inland and coastal waters is necessary to ensure a better estimation of optically active components in waters with great spatial variation. Hence, our objective is to assess the performance of HSI, Wisper, and LMVM fusion methods in different water bodies. Our results showed the gradient of watercolor was the principal reason for uncertainties and all analyzed bands resulted in similar performances. Furthermore, HSI and Wisper failed to preserve the spectral and spatial resolution, respectively; and LMVM had better results in preserving spectral resolution and enhancing spatial details. Our results indicate that LMVM method has more potential application for image fusion in inland and coastal waters imagery.

Keywords — pansharpening, spatial resolution, spectral resolution, Landsat-8 OLI.

1. INTRODUCTION

Spatial resolution is a limiting factor of remote sensing in inland and coastal waters. Aquatic systems such as rivers, lakes, lagoons, estuaries, and bays have small areas, which requires high spatial resolution for monitoring their quality and dynamic. For example, tidal currents, resuspension events, algae blooms, point-source delivery of suspended sediments, nutrients, and colored dissolved organic matter (CDOM). These water characteristics create very high variability on much smaller spatial scales than for most open ocean waters.

Image fusion methods - or pansharpening - have been used to improve the spatial resolution of images, combining high-spatial-resolution panchromatic imagery with low-spatial-resolution, often a multispectral image. Several authors access their quality performances; for example, Castro [1] evaluated methods applied in different cities, using CBERS-2B, SPOT-5, IKONOS, and QUICKBIRD. Wald et al. [2] assessed the SFIM method over the south-east of Spain. Nünez et al. [3] evaluated an Additive Wavelet Decomposition in urban and agricultural areas, using SPOT and Landsat-TM images. In summary, these studies evaluated the fusion methods through image or sensor, and not analysing a specific target.

Quality assessment of fusion techniques should specifically address inland and coastal waters, since their characteristics such as low reflectance lead to higher errors. The uncertainties induced by the fusion techniques should be higher in water bodies, because of its watercolor variety caused by suspended sediments, algae blooms, and CDOM. Moreover, the sun glint and the low reflectance should also contribute to those uncertainties. Hence, before applying fusion techniques in water bodies, the impact of these methods explicitly in waters should be assessed.

For all reasons listed above, our objective was to assess the uncertainties caused by image fusion methods in inland and coastal waters. First, the qualitative aspect of fused images was evaluated. Last, the uncertainties in reflectance of the top of the atmosphere (RTOA) were assessed.

2. METHODS

We used the Landsat-8 OLI bands B2 (0.45 - 0.51 µm) B3 (0.53 - 0.59 µm), B4 (0.64 - 0.67 µm) and B8 (0.52 - 0.90 µm), last, the panchromatic band. All bands have 12 bits of radiometric resolution, which makes them suitable for remote sensing in waters. We accessed the data from the United States Geological Survey (USGS) Landsat-8 Collection 1 Tier 1 Raw Scenes, in digital numbers and its original spatial resolution, 30 m and 15 m for multispectral and panchromatic bands, respectively. All dataset was available and were accessed in the Google Earth Engine Platform (https://code.earthengine.google.com/).

We analyzed three methods of image fusion, the HSI (Hue, Intensity, and Saturation), the Wisper, and the LMVM (Local Mean and Variance Matching). Wisper and LMVM are appropriate for preserving the radiometric information [1][4], while the HSI enhances the spatial data and degrades the spectral data [1]. Before fusion, we resampled the multispectral band to 15 m of spatial resolution, using the nearest neighbors and matching cells. For Wisper parameters, we used the Spline filter and any level of decompositions; for LMVM parameters, we used a 3x3 window. We used the software TerraView 5.3 and Orfeo Toolbox 6.6 for fusing the images, where the methods are available.

Our goal was to determine the quality of image fusion methods in high gradients of watercolor. For this reason, we created profiles for each study area (Figure 1) where high gradients were found. Thus, we did not statistically evaluate in all water body, because fused images in homogeneous regions would be redundant. We chose images which show a high gradient between suspended sediment from rivers and oceanic waters in the Estuarine Complex of Paranaguá (ECP), a high gradient of green algae bloom in the Billings Reservoir, and a high gradient of CDOM and suspended matter in the Curuai Lake.

We chose two methods to evaluate the performance of the algorithms, by its quality and accuracy. First, we considered the highlight of watercolor fronts and the mean brightness of the image. Last, we resampled the fused images to the original spatial resolution (30m), calculated the RTOA in the fused and original images by the method from USGS [5]. Then, we analyzed the fused images calculating the Bias in the profiles.

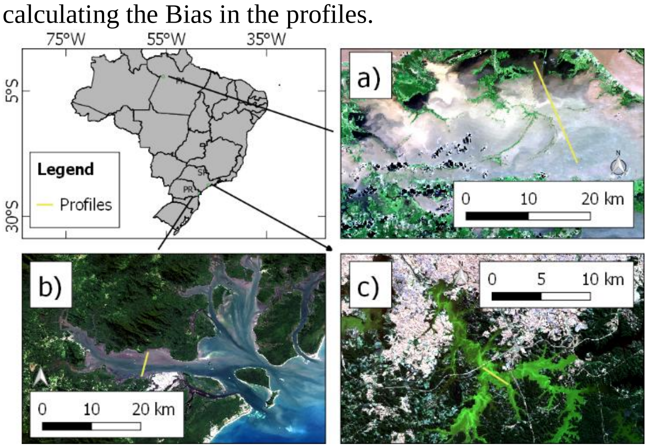

Figure 1. Location of the study areas, (a) Curuai Lake, (b) Estuarine Complex of Paranaguá, and (c) Billings Reservoir.

The evaluating methods have two tendencies. The aspect analysis depends on the author's interpretation, and it can differ for the readers despite the arguments presented. Moreover, the statistical results overestimate the favorable agreement in Bias, because resampling using the mean values (15m to 30 m), a variety of combinations of 4 pixels (15 m) can result in the same mean for 1 pixel (30 m). Thus, the statistical result should be interpreted as the minimum uncertainty.

3. RESULTS

3.1. Estuarine Complex of Paranaguá

Analyzing the fusion methods in the inner estuary and comparing all images in the same contrast, LMVM method showed improvements in the qualitative aspect, while the Wisper and HSI methods failed to enhance the visible perspective (Figure 2). For LMVM, the borderline was less pixeled than the original image in the RGB image, preserving spectral data, shown by the same brightness and color compared to the original image. For HSI, the image was brighter than the original. Additionally, the Wisper showed pixeled characteristics from the 30 m images, preserving the lower spatial resolution characteristics. Hence, the LMVM were better than Wisper in enhancing gradient aspects of the ECP, improving the linearity of waterfronts caused by suspended sediments.

For uncertainties caused by the fusion methods (Figure 3), the HSI method showed higher Bias than Wisper and LMVM for all bands. HSI tended to overestimate RTOA approximately 10 % percent in all bands; while the other methods underestimated and overestimated from -5 to 5 % through all profile, resembling to have the same bias.

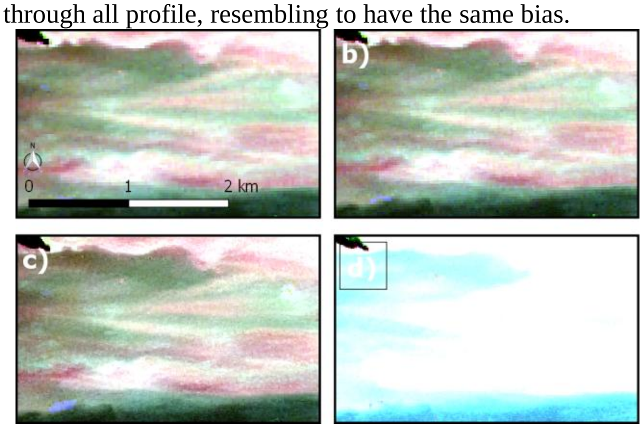

Figure 2. The inner region of ECP, showing the (a) Original image, (b) Wisper, (c) LMVM, and (d) HSI.

3.2. Curuai Lake

The Curuai Lake showed a high gradient of watercolor, caused by the high sediment load from the Amazon River, pronounced by the brightest plume which is according to the river sediment current. CDOM is noticeable by the dark color, occurring in the borders where there is no influence by the sediment flow.

In the qualitative analysis, the HSI and LMVM fusion methods improved the spatial resolution, enhancing the details of watercolor fronts, while the Wisper method does change the qualitative aspect (Figure 3). However, the HSI increased brightness too much, not preserving the color of the image.

Regarding the statistical result, the HSI had a significant error, overestimating all image with a Bias from 40 to 45 %, evidenced by the brighter image. Mostly, the Bias of Wisper and LMVM were similar to the ECP results, varying from -5 to 5 %.

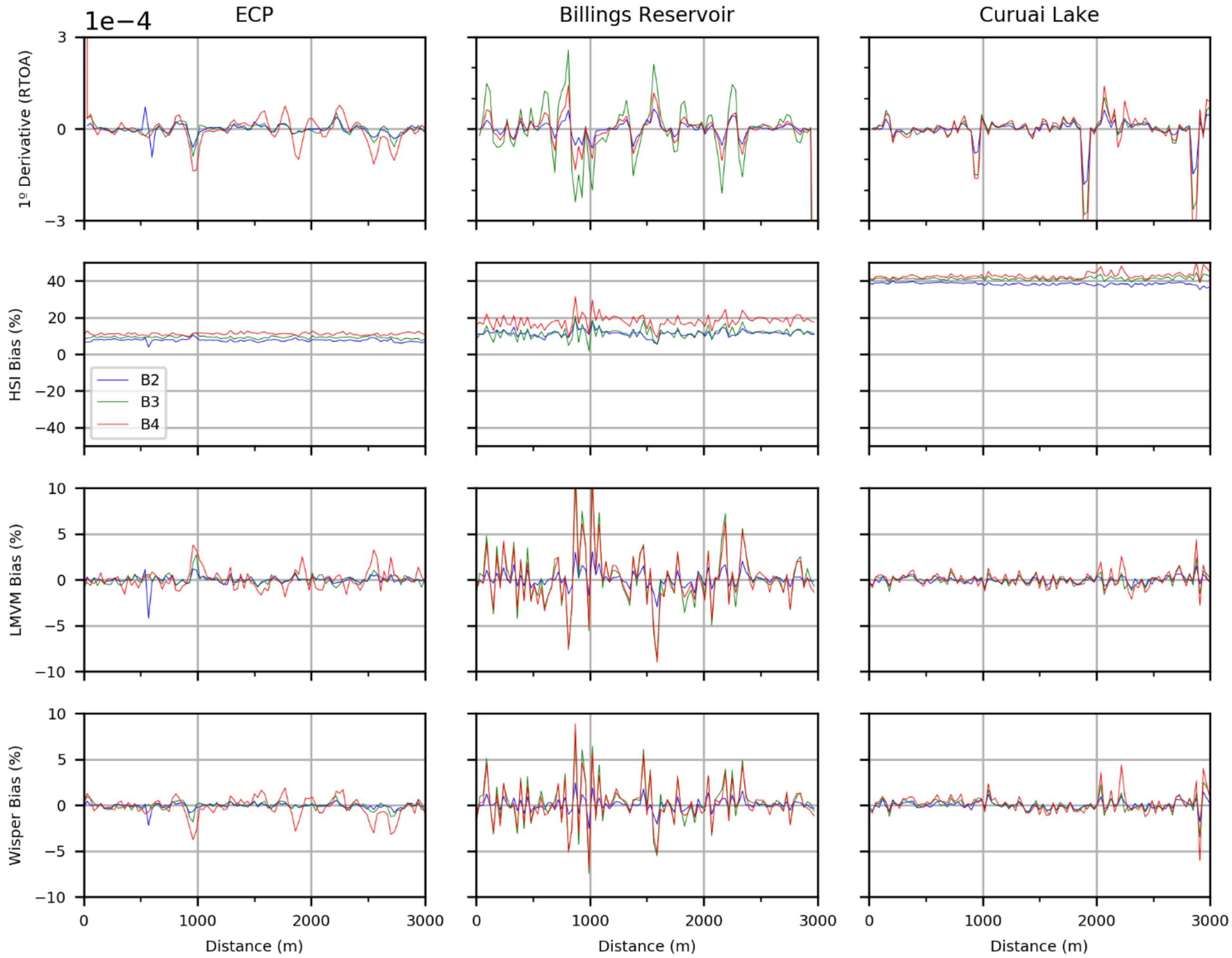

Figure 3. Comparison of waterfronts (1º Derivative) and the Bias of IHS, LMVM, and Wisper, for each area of study and band.

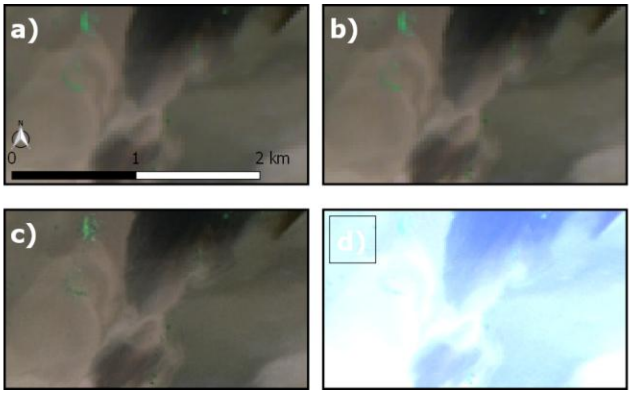

Figure 4. North region of Curuai Lake, showing the (a) Original image, (b) Wisper, (c) LMVM, and (d) HSI.

3.3. Billings Reservoir

The HSI and LMVM algorithm showed the best qualitative result, by its edge highlighting and less pixeled appearance, improving the spatial resolution on the reservoir's borders and bloom fronts. Last, the Wisper model had an unsatisfactory result, the worst visual sharpening, and pixeled appearance resembling the original image (Figure 4).

Examining the Bias profiles, it showed a similar pattern for every algorithm, which related its highest Bias with the highest reflectance shifts on the profile, showed by the 1º derivative of RTOA. Concerning the methods, the HSI model showed the worst results for the bias, varying from 0 to 30 % approximately, indicating RTOA was always higher than the original data. For the LMVM algorithm, it had lower values varying from -10 to 10% approximately. Last, the Wisper algorithm had a Bias from -8 to 10%, which was the best statistical result.

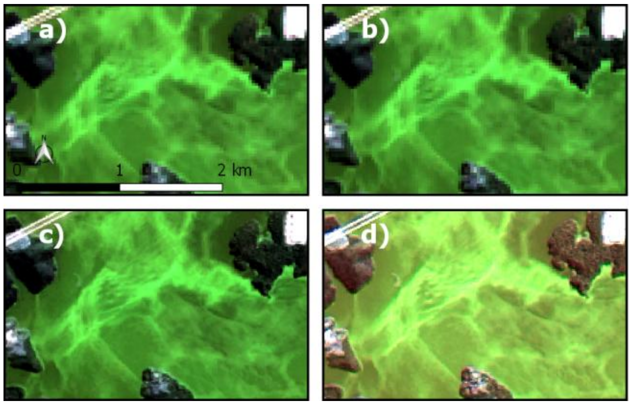

Figure 5. The central area of Billings Reservoir, showing the (a) Original image, (b) Wisper, (c) LMVM, and (d) HSI.

4. DISCUSSION

The HSI had brighter pixels for all regions, especially for the Curuai Lake, which can be explained by the difference of intensity from the multispectral and panchromatic bands [6]. Thus, the HSI method was not suitable for preserving spectral details, as expected. On the other hand, LMVM enhanced the spatial analysis with enrichment in waterfront details and preserving the spectral values for all images and bands. The improvement occurred because LMVM conserves the spectral information in the fused product, by controlling window size. Small windows produce the least distortion [4], which in our case was 3x3.

The gradient Bias of LMVM were higher in band B3 than B2 and B4, in the Billings reservoir. Oppositely, for Curuai Lake and ECP, B4 had higher Bias than other bands. Analyzing the 1º derivative of RTOA, Billings Reservoir had higher gradients in band B3; and Curuai Lake and ECP had a higher gradient of RTOA in band B4. Furthermore, spikes of Bias occurred at the same position of spikes of the 1º derivative. Thus, the Bias tends to be higher where higher gradients occur.

Moreover, band B2 had the lowest Bias in the profile. This result was not expected because B2 is less integrated into the panchromatic band, and it should have a lower quality in the fusion technique. Although, band B2 gradient had low values in all profiles. Consequently, if higher gradients caused the uncertainties, a smoother gradient such as B2 was susceptible to lower Bias.

5. CONCLUSION

We performed the HSI, Wisper, and LMVM fusion methods in different images in inland and coastal waters. For different watercolor fronts, such as green algae bloom, suspended sediments load from rivers in estuaries, and black waters caused by CDOM. LMVM method was most suitable considering the qualitative analysis and the uncertainties in the RTOA. On the other hand, the Wisper failed to enhance the spatial information, and HSI method produced results with less accuracy in RTOA.

The primary influence in uncertainties was the gradient of watercolor fronts. In regions with a high slope gradient, the uncertainties increased, and vice versa. Furthermore, the Landsat-8 OLI bands 2, 3 and 4 had a good agreement using the LMVM algorithm.

In conclusion, our study opens new questions to fusion methods in water bodies. First, could uncertainties caused by the methods in RTOA have a more significant impact on the surface reflectance after atmospheric correction? Second, how much is the impact of fusion algorithms in different spatial resolution ratios?

6. ACKNOWLEDGMENTS

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7. REFERENCES

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