A VARIATIONAL APPROACH FOR THE DESTRIPING OF MODIS DATA

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1. INTRODUCTION

The Moderate Resolution Imaging Spectrometer (MODIS) monitors the earth in 36 spectral bands using a cross-track double-sided continuously rotating scan mirror. The imperfect calibration of the linear arrays of detectors and additional random noise in the internal calibration system induce detector-to-detector stripes, mirror side stripes and noisy stripes visible in most emissive bands. This artifact affects seriously the visual quality and radiometric integrity of measured data. Several approaches including FFT filtering([1, 2]), wavelet analysis ([3, 4]) and statistical techniques such as moment matching or histogram matching have been used to reduce striping on MODIS Data([5, 6, 7]). Despite an extensive and diverse destriping litterature, most techniques display residual stripes if not strong distortion from the original image. In this paper, we introduce a robust destriping methodology based on a variational approach.

2. PROBLEM MODELISATION

Let us denote by I the signal associated with the destriped image. Assuming that the stripe s is an additive noise, the observed striped image I_s can be written as:

$$I_s = I + s \tag{1}$$

Analysis of MODIS images shows that the stripe s can be considered as a structured noise that varies slowly along a line but drastically along the y axis of the image, which translates as:

$$\left\| \frac{\partial s}{\partial x} \right\| \ll \left\| \frac{\partial s}{\partial y} \right\| \tag{2}$$

Where $||.||$ stands for the L^2 norm of a scalar function. This simple and yet realistic consideration on the stripe spatial gradient justifies the variational approach and provides a much reliable solution to remove most of the striping noise without introducing any blurring effects. Figure 1(a) shows a striped image for which the left side of the previous equation is roughly 100 times smaller that the right side.

3. PROPOSED METHOD

We propose to tackle the problem by means of variational approach. As pointed out in the previous section the main characteristic of striping effect is that its variation is mainly concentrated in the vertical direction. Most variational approaches (like [8]) are designed to remove a less structured noise (mostly gaussian white uniform noise) and will surely fail in our case because the amount of noise to be removed is not uniform over an image. Therefore, we aim at decomposing the signal I_s so that the striping effect can be isolated from the image natural content. More precisely, we impose that the noisy component of I_s minimizes an energy that is compatible with its characteristical horizontal low variance. Similarly, the original signal contained in I_s shall minimize an energy that differentiates it from the stripe noise (an example of such approach can be found in [9]). Hence, the variational problem can be formulated as:

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$$\tilde{I} = \text{Argmin}_u(\|D_x(I_s - u)\|^2 + \lambda\|D_y(u - K * I_s)\|^2) \text{ such that mean}(I_s - u) = 0. \quad (3)$$

Where $\tilde{I}$ represents the restored image, D_x is the horizontal differentiator (x-component of the gradient), D_y the vertical differentiator and K a low-pass filter (an average filter in our case) used here only to constraint the mean value of the restored image lines. Without it, and due to the fact that quadratic energies are sensitive to outliers, the resulting image would have equal mean value over every one of its lines. As shown in figure 1(c), the quadratic restoration scheme of equation (3) provides good results but induces blurring artifacts around ocean-continent interfaces. This is due to quadratic functionals requiring homogeneous images without strong discontinuities. Since the seminal work of Rudin, Osher and Fatemi ([8]), use of total variation has been proposed as a very effective alternative to quadratic restoration in that it allows the restoration of non continuous images. The total variation can be included in the natural optimization problem as follows:

$$\tilde{I} = \text{Argmin}_u(TV_x(I_s - u) + \lambda TV_y(u)) \text{ such that mean}(I_s - u) = 0. \quad (4)$$

Where $TV_x(u)$ (resp. $TV_y(u)$) is the integral over the image of the absolute value of the x-derivative (resp. y-derivative). Because of its robustness against outliers, the total variation method offers the advantage of leaving aside the low-pass filter K used in the quadratic restoration scheme. In both methods, the parameter λ can be chosen to maximize noise reduction and minimize image distortion (Fig 3). The full version of this paper will detail the algorithms for solving the optimization problems (3) and (4).

4. EXPERIMENTAL RESULTS

A scene acquired by MODIS Terra in the Mediterranean Sea on the 2nd of August 2008 was selected to illustrate this study. The results obtained with our destriping algorithms are shown on an image derived from band 30 (9.580-9.880 μm) heavily affected with detector-to-detector stripes, mirror banding and random stripes (Fig 1). Besides the visual quality improvement, mean cross-track profiles and ensemble averaged power spectrums show excellent qualitative and quantitative results when compared with the histogram matching technique.

5. CONCLUSION

Destriping techniques based on statistical assumptions or detectors equalization ([4, 5]) cannot take into account the non-linearity of detectors input/output transfer function. On MODIS emissive bands, a considerable percentage of the striping effect is due to random stripes which compromises seriously the radiometric accuracy of high level products. The variational approach introduced in this paper and the results obtained on MODIS data offer a new perspective for the destriping of imaging spectrometer data.

6. REFERENCES

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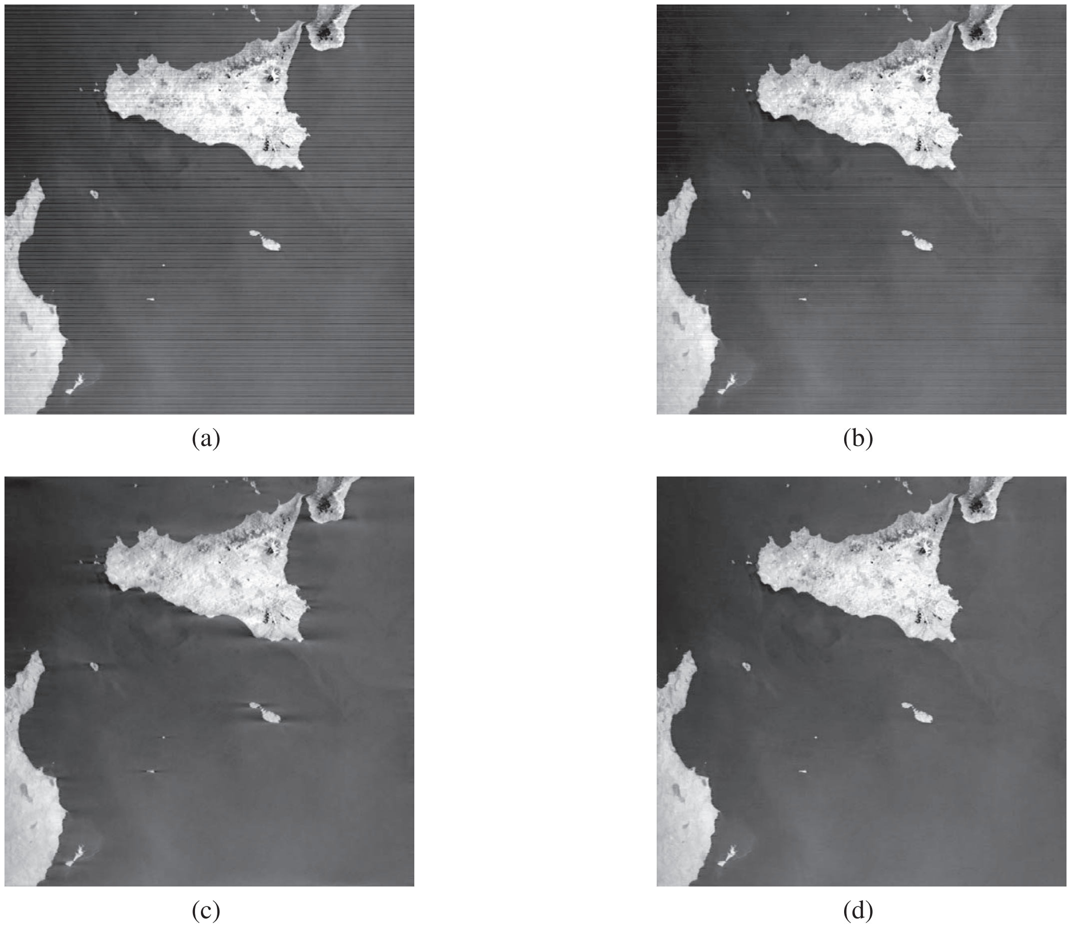

Fig. 1. (a) Original Image (b) Histogram Matching (c) Quadratic restoration (eq. 3) (d) Total Variation restoration (eq. 4). Although the total variation method shows better results, the quadratic restoration can be used on homogenous images with the benefit of a faster computational time.

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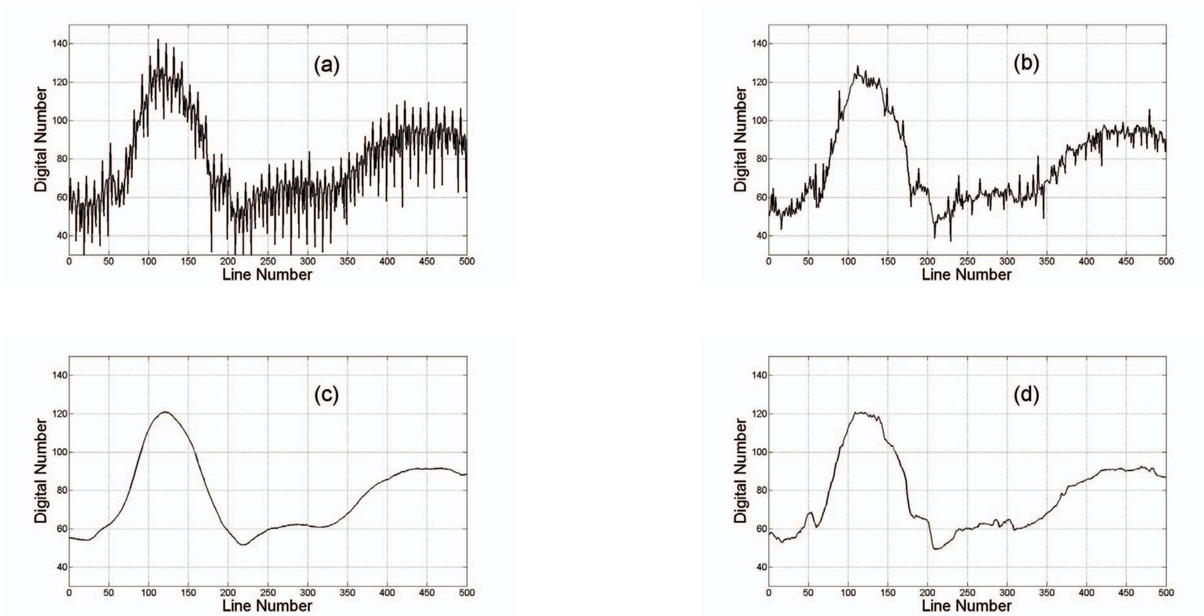

Fig. 2. Mean cross-track profiles (i.e. mean over a line) of (a) Original Image (b) Histogram Matching (c) Quadratic (d) Total Variation. The figure clearly shows that histogram matching only deals with the periodic behavior of striping noise. The assumptions used in our variational approaches allow a much better restoration. Notice also how, unlike the quadratic method, the total variation restoration preserves all the natural discontinuities of the image.

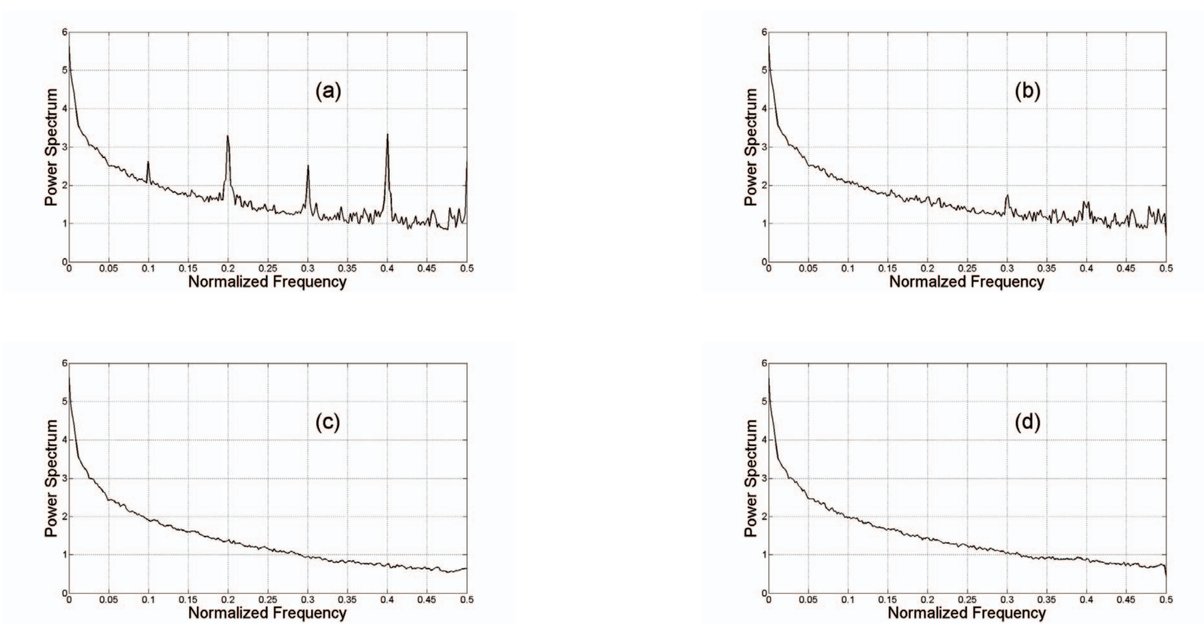

Fig. 3. Mean column power spectrum (logarithmic scale) of (a) Original Image (b) Histogram Matching (c) Quadratic (d) Total Variation. The peaks in image (a) illustrate the periodic nature of the striping effect. The remaining strong variations observed in the power spectrum (b) correspond to random stripes and emphasize the limitations of statistical techniques such histogram matching.