Analysis of the Effects of Pansharpening in Change Detection on VHR Images

Francesca Bovolo, *Member, IEEE*, Lorenzo Bruzzone, *Senior Member, IEEE*, Luca Capobianco, *Student Member, IEEE*, Andrea Garzelli, *Senior Member, IEEE*, Silvia Marchesi, *Student Member, IEEE*, and Filippo Nencini

***Abstract*—In this letter, we investigate the effects of pansharpening (PS) applied to multispectral (MS) multitemporal images in change-detection (CD) applications. Although CD maps computed from pansharpened data show an enhanced spatial resolution, they can suffer from errors due to artifacts induced by the fusion process. The rationale of our analysis consists in understanding to which extent such artifacts can affect spatially enhanced CD maps. To this end, a quantitative analysis is performed which is based on a novel strategy that exploits similarity measures to rank PS methods according to their impact on CD performance. Many multiresolution fusion algorithms are considered, and CD results obtained from original MS and from spatially enhanced data are compared.**

***Index Terms*—Change detection (CD), pansharpening (PS), similarity measure, very high geometrical resolution (VHR) images.**

I. Introduction

THE ever-increasing availability of multitemporal very high geometrical resolution (VHR) remote sensing images results in new potentially relevant applications related to environmental monitoring and land cover management. Most of these applications are associated with the analysis of dynamic phenomena that result in changes on the Earth surface. The effects of these phenomena can be detected developing change-detection (CD) techniques capable to automatically identify changes occurred between two VHR images acquired at different times on the same geographical area. The last generation of VHR multispectral (MS) sensors (e.g., the ones mounted onboard of Quickbird (QB), Ikonos, and SPOT-5 satellites) can acquire a panchromatic (PAN) image characterized by very high geometrical resolution (0.7, 1, and 2.5 m, respectively) and low spectral resolution (no spectral diversity and low capacity in distinguishing different kind of changes); and a set of MS images with lower spatial resolution (i.e., 2.8, 4, and 10 m), and higher spectral resolution. In order to take advantage of both high geometrical and spectral resolutions in CD, it is common practice to apply a proper preprocessing, namely, pansharpening (PS). PS merges the properties of PAN and MS data for spatial detail injection from PAN to MS, resulting in a set of images with both high spectral resolution and enhanced geometrical resolution. However, PS can introduce in the images spatial artifacts and spectral distortions that can affect the accuracy of CD maps. Although several quality indexes have been proposed for evaluating PS methods [1], [2], they are not specifically conceived for CD applications. Only in [3], an analysis that quantifies the impact of PS artifacts on CD in a supervised way is presented.

The aim of this letter is to analyze the impact of PS on the accuracy of CD investigating whether the improvement in geometrical resolution of CD maps given by PS is significantly affected or not by artifacts introduced by the PS process in an unsupervised way. To this end, five different multiresolution approaches are considered [4]–[8]. A ranking of PS techniques from the most to the less effective for CD is obtained by defining a novel unsupervised objective strategy based on similarity measures for comparing CD maps. In order to avoid the introduction of any bias in the analysis and to better understand the impact of PS on CD, the CD step is performed according to the standard change vector analysis (CVA) technique [9]–[11].

This letter is organized into six sections. Sections II and III describe the adopted PS and CD techniques, respectively. The unsupervised approaches based on similarity measures for ranking PS techniques are presented in Section IV. Section V illustrates the data set used for the experiments and reports experimental results. Section VI draws the conclusion of this letter.

II. Pansharpening Techniques

PS techniques exploit the complementary spatial/spectral resolution properties of PAN and MS images for producing spatially enhanced (or pansharpened) MS observations. Two main methodological approaches can be considered: 1) methods based on spatial details injection from the PAN image into the MS image driven by local filtering operations (which are classified as multiresolution analysis (MRA) fusion methods) and 2) methods that perform fusion after applying an multispectral transformation to the original data without any filtering operation of the PAN image (component substitution (CS) algorithms).

In our analysis, we considered five techniques for evaluating the impact of PS on CD, which well represent the two main mentioned categories: The first three can be classified as CS algorithms, whereas the last two are based on MRA.

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F. Bovolo, L. Bruzzone, and S. Marchesi are with the Department of Information Engineering and Computer Science, University of Trento, 38123 Trento, Italy (e-mail: francesca.bovolo@disi.unitn.it; lorenzo.bruzzone@ing.unitn.it; silvia.marchesi@disi.unitn.it).

L. Capobianco, A. Garzelli, and F. Nencini are with the Department of Information Engineering, University of Siena, 53100 Siena, Italy (e-mail: capobianco@dii.unisi.it; garzelli@dii.unisi.it; filippo.nencini@gmail.com).

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The generalized intensity hue saturation (GIHS) fusion method [4] computes a generalized intensity (GI) image by a weighted linear combination of the MS bands and subtracts it from the PAN image. Such difference image is added to each MS band. Its main critical point, due to GI generation, is that the fusion products may exhibit significant spectral distortions. However, it normally injects more spatial details from PAN to MS than the other four methods considered.

The Gram–Schmidt (GS) spectral sharpening method [5] considers a simulated PAN image at a lower spatial resolution (obtained, for example, by averaging the original MS bands), and applies to it and to the lower spatial resolution spectral bands the GS transformation, by adopting the simulated PAN image as the first band in the GS transformation. The first transformed band is substituted by the higher spatial resolution PAN image after histogram matching. Finally, the inverse GS transformation is applied to the new set of transformed bands to produce the enhanced spatial resolution MS images.

The minimum mean square error (mmse) PS method [6] applies an optimal GIHS transformation to the MS bands. The weights of the linear combination which provides the GI image and the gains that regulate the spatial detail injection are calculated in a minimum mean squared error sense.

The context-based decision (CBD) method [7] performs selection of spatial details from PAN by thresholding the local correlation coefficient evaluated between the approximation coefficients of PAN and MS obtained from MRA (Laplacian pyramid or undecimated wavelet transform). Space-varying sensors equalization by ratio of local root-mean-squared values of MS and PAN is also applied.

The proportional additive wavelet to the L component (AWLP) PS method [8] combines a PAN image and an MS image by adding the detail planes of the PAN image to the intensity component of the MS image.

III. Adopted Change-Detection Technique

In order to perform CD, we considered the CVA technique, which is a simple and widely used unsupervised CD method. CVA has demonstrated its effectiveness in detecting and characterizing different radiometric changes in multitemporal MS images in several application domains [11]. The simplicity of CVA allows us to properly evaluate PS effects without any significant bias related to the CD technique.[1] CVA is usually applied to MS images acquired by passive sensors and involves multidimensional spectral vectors in order to exploit all the available information on the investigated change.

Let us consider two radiometrically corrected and coregistered pansharpened images $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$ of size $P \times Q$, acquired over the same geographical area at different times t_1 and t_2. Let ω_n and ω_c be the classes of no-changed and changed pixels to be identified. Let B be the number of spectral channels of $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$. The CVA technique emphasizes change information computing an MS difference image $\boldsymbol{X}_D$ by subtracting spectral feature vectors in corresponding spatial position of $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$.

The B-dimensional problem described by $\boldsymbol{X}_D$ is reduced to a 1-D problem by computing the magnitude image as

$$\boldsymbol{X}_D^M = \sqrt{\sum_{i=1}^{B} \boldsymbol{X}_{D_i}^2} \tag{1}$$

where $\boldsymbol{X}_{D_i}$ is the ith spectral component of $\boldsymbol{X}_D$.

According to (1), no-changed pixels present small magnitude values, whereas changed pixels show large values [9], [10]. Let $x_D^M(p,q)$ be a generic pixel in spatial position (p,q) in $\boldsymbol{X}_D^M$. The CD map $\boldsymbol{Y}$ where changed, and no-changed pixels are separated can be computed according to the following decision rule:

$$y(p,q) = \begin{cases} \omega_c, & \text{if } x_D^M(p,q) \geq T \\ \omega_n, & \text{if } x_D^M(p,q) < T \end{cases} \tag{2}$$

where $y(p,q)$ is the label associated to the pixel at spatial position (p,q) in $\boldsymbol{Y}$, and T is the decision threshold. T can be defined either manually or automatically.[2]

IV. Unsupervised Strategy for the Evaluation of the Impact of Pansharpening on Change Detection

As no prior information about the investigated scene is generally available, we propose an unsupervised strategy based on a similarity measure for evaluating the impact of PS techniques on the CD. In order to properly understand the impact of different PS techniques on CD, we perform the analysis at different resolution levels: 1) the one of the PAN image (e.g., 0.7 m for QB images) and 2) the one of the MS image (e.g., 2.8 m for QB images). In the first case, the original MS images are fused with the PAN one, while in the latter the original PAN and MS images are spatially degraded down to a lower resolution before applying PS. This option allows one a comparison between fused products at MS resolution with the original MS set.

Let us consider a set of multitemporal pansharpened pairs obtained applying different PS techniques to two multitemporal images acquired over the same geographical area at different times. Pansharpened multitemporal images obtained with the same PS approach are mostly affected by similar PS artifacts, nevertheless differences in artifacts can occur where multitemporal data show radiometric and geometric differences rising from both different acquisition conditions and the presence of changes on the ground. CD performed according to CVA (but also to more advanced techniques) can only partially compensate for such kind of artifacts. Moreover, images obtained with different PS approaches are affected by different artifacts peculiar of the applied PS technique. As the quality of pansharpened images diminishes (artifacts increases), the CD maps quality decreases together with the capability of the adopted CD technique in compensating artifacts effects. If artifacts induced by different PS techniques are independent, low-quality CD maps obtained from different pansharpened pairs tend to be

[1] More complex techniques would implicitly reduce the impact of PS artifacts on CD maps.

[2] Details on automatic threshold selection can be found in [9] and [11].

significantly different to each other and vice versa. According to this observation, we propose to use a similarity measure computed among CD maps in order to identify PS techniques that less affect CD. Such a measure results unbiased and reliable if the effects of artifacts introduced by PS techniques in the CD maps are uncorrelated.[3]

The proposed strategy considers N CD maps obtained by the CVA on N different pansharpened multitemporal pairs. Let us represent ω_c and ω_n assigned according to (2) with $+1$ and -1, respectively. For each pair of CD maps $\boldsymbol{Y}_i$ and $\boldsymbol{Y}_j$, with $i, j = 1, \ldots, N$ and $i \neq j$, we compute a measure of similarity H_{ij} of the CD maps on the $P \times Q$ pixels of the images as

$$H_{ij} = \frac{1}{PQ} \sum_{p=1}^{P} \sum_{q=1}^{Q} y_i(p,q) \cdot y_j(p,q) \tag{3}$$

where $y_i(p,q)$ and $y_j(p,q)$ are the labels of the pixel in position (p,q) in the CD maps $\boldsymbol{Y}_i$ and $\boldsymbol{Y}_j$, respectively. As $y_i(p,q)$ and $y_j(p,q)$ can assume values in $\{-1,+1\}$, their product is equal to 1 if $y_i(p,q) = y_j(p,q)$ and to -1 otherwise. Accordingly, the value of the similarity measure H_{ij} is equal to 1 if $\boldsymbol{Y}_i$ and $\boldsymbol{Y}_j$ are identical, and is lower than 1 otherwise. In general, H_{ij} belongs to the interval $[-1,+1]$. On the basis of this measure, two different strategies can be implemented: 1) comparison of the similarities among CD maps obtained with different PS techniques and 2) comparison of the similarities of CD maps with a reference map.

1) *Comparison of the similarities among CD maps*: An absolute measure of similarity of each map $\boldsymbol{Y}_i$ to all the others can be defined by computing the average value of H_{ij}, i.e.,

$$H_i = \frac{1}{N-1} \sum_{j=1, j \neq i}^{N} H_{ij} \qquad H_i \in [-1,+1]. \tag{4}$$

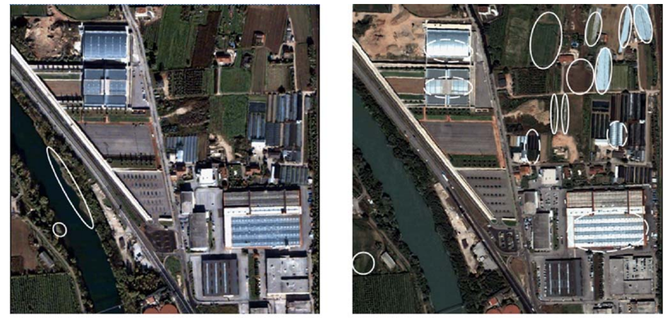
According to the value of H_i, the N considered PS techniques can be ranked from the less affecting CD (high average similarity) to the most affecting it (low average similarity). This strategy can be applied either to full-scale pansharpened images or to reduced-resolution pansharpened images.

2) *Comparison of the similarities of CD maps with a reference map*: Instead of considering relative reference CD maps, an absolute reference $\boldsymbol{Y}_{\text{ref}}$ can be defined. To this end, two procedures can be considered. The first one is based on a supervised method. Thus, $\boldsymbol{Y}_{\text{ref}}$ can be a map built according to available prior information about changes occurred on the ground, or, in the case of the spatially degraded data set, it can be the CD map computed applying the CVA to the original multitemporal MS images (MSmap) which represents an upperbound of CD performance at this resolution as computed from artifacts-free multitemporal data. The second procedure computes $\boldsymbol{Y}_{\text{ref}}$ by applying a majority voting rule to the set of N CD maps $\boldsymbol{Y}_i$ $(i = 1, \ldots, N)$ as

$$y_{\text{ref}}(p,q) = \begin{cases} \omega_c, & \text{if } \sum_{i=1}^{N} y_i(p,q) > 0 \\ \omega_n, & \text{if } \sum_{i=1}^{N} y_i(p,q) \leq 0. \end{cases} \tag{5}$$

In this case, the similarity can be computed by applying (3) with $\boldsymbol{Y}_j = \boldsymbol{Y}_{\text{ref}}$. The rationale of this procedure is to assume that the CD map obtained according to majority voting (MVmap) represents a reliable CD result where the main artifacts are filtered out. This assumption holds when considering PS methods that result in uncorrelated artifacts. It is worth noting that the statistical significance of the proposed measures increases with the number and the diversity of the considered PS methods.

[3]This is true when considering a comprehensive set of PS methods including high-performance (mmse, CBD, AWLP), and state-of-the-art (GS, GIHS) fusion algorithms which are based on different spatial injection strategies.



(a) (b)

Fig. 1. True-color composition of the pansharpened images of the Trento city (Italy) acquired by the QB VHR MS sensor in (a) October 2005 and (b) July 2006 (occurred changes appear in white circles).

V. Experimental Results

A multitemporal data set made up of two MS and PAN QB images acquired on the Trento city (Italy) in October 2005 and July 2006 was considered to evaluate the impact of the different investigated PS techniques on the CD process. In the preprocessing phase, images were: 1) radiometrically corrected and 2) coregistered by means of 12 ground control points. Final MS images are made up of 380×376 pixels while PAN images consist of 1520×1504 pixels. Between the acquisition dates, some changes related to urban and rural areas occurred on the ground (white circles in Fig. 1).

In the first experiment, we expanded the original images through standard interpolation (upsampling by four followed by low-pass filtering at 1/4 cutoff). As expected, the obtained multitemporal images show a low geometrical details content (see EXP column, Fig. 2). The corresponding CD map (see Fig. 2) is unreliable and geometrical details are mostly blurred or lost. According to this observations expanded multitemporal pairs were not further considered.

In the second experiment, we applied the five PS methods $(N = 5)$ described in Section II to the considered data set and to a degraded version of it in order to obtain two sets of five pairs of spatially enhanced multitemporal MS images: 1) one at

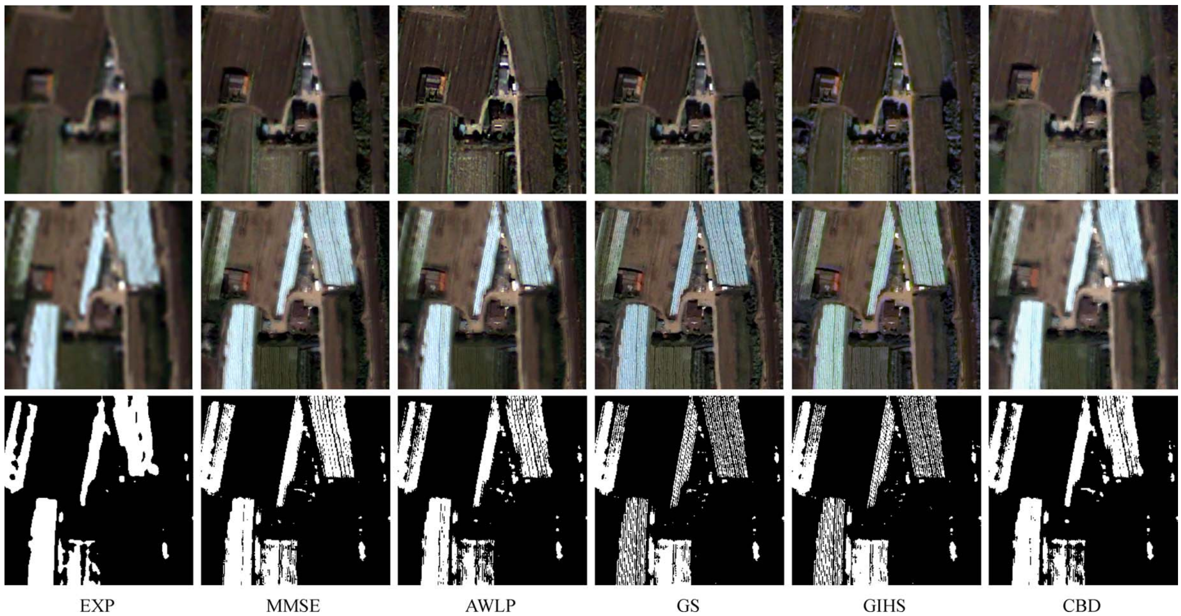


Fig. 2. True-color composite of 256 × 256 details of 0.7-m QB data acquired on October 2005 (first row) and July 2006 (second row) for the upscaled and five pansharpened images. CD maps obtained for the upscaled and the five pansharpened multitemporal pairs at 0.7 m of resolution (third row).

TABLE I
ESTIMATED SIMILARITY MEASURES WITH RESPECT TO THE MSMAP AT 2.8 m AND TO THE MVMAP AT 2.8 AND 0.7 m; AVERAGE SIMILARITY MEASURE H_i AT 2.8 AND 0.7 m. HIGHEST SCORES APPEAR IN BOLD TYPE

	Geometrical Resolution $2.8m$			**Geometrical Resolution** $0.7m$	
PS method	$\boldsymbol{Y}_{\mathrm{ref}} = \mathrm{MSmap}$	$\boldsymbol{Y}_{\mathrm{ref}} = \mathrm{MVmap}$	H_i	$\boldsymbol{Y}_{\mathrm{ref}} = \mathrm{MVmap}$	H_i
MMSE	**0.963**	**0.996**	**0.979**	**0.995**	**0.978**
AWLP	0.961	0.986	0.976	0.982	0.973
GIHS	0.961	0.980	0.975	0.982	0.974
GS	0.960	0.980	0.976	0.981	0.973
CBD	0.960	0.983	0.974	0.979	0.971

the geometrical resolution of the PAN image (0.7 m) and 2) one at the geometrical resolution of the MS image (2.8 m).[4]

In order to estimate which pansharpenend pair resulted in the CD map with the best tradeoff between geometrical details content and differences induced by PS artifacts, we exploited the proposed unsupervised strategy. First, we applied the CVA technique to multitemporal pairs of fused images at both resolutions and to the original MS images. The 11 magnitude images were thresholded according to (2). For the considered data set, we found that $T = 500$ was a reasonable value. This value was used for each magnitude image because small spectral differences due to the adopted PS technique do not significantly alter the statistics of the classes of interest. Fixing the value of T avoids possible bias due to the use of automatic thresholding techniques.[5] In Table I, the similarity measures (3) obtained using as reference both the MVmap computed according to (5), and the average similarity measure in (4) are reported for all pansharpened pairs at both resolutions. For the 2.8-m-resolution data, the similarity measure obtained using as reference the CD map computed on the original MS data (MSmap) is also reported (see first column, Table I). If we evaluate the similarity between MVmap and MSmap according to (3), we obtain a value equal to 0.965. This value is higher than all the similarities computed by considering the CD maps produced from the different PS pairs, thus confirming the effectiveness of MVmap as reference.

Although CD results are scale dependent, from Table I, one can see that the impact of PS is very similar for the two scales. In particular, the mmse method always attained the best global score, followed by AWLP, whereas GIHS, GS, and CBD provided, on average, poorer results. In few cases, PS methods can perform differently at different resolutions, e.g., CBD which provides better results at 2.8 m (third in ranking) than at 0.7 m (fifth in ranking). An opposite situation occurs for GIHS: second in ranking at 0.7 m and fourth at 2.8 m.

Results summarized in Table I and aforementioned comments are confirmed by the qualitative analysis of the CD maps at 0.7-m resolution (Fig. 2, third row). As one can observe, the CD map obtained with mmse pansharpened images shows a better visual quality. In particular, border regions and geometrical details are better modeled. This map, but also the other ones, shows a higher quality than the one obtained from MS images simply interpolated by a factor of four (see EXP column, Fig. 2), thus confirming that PS improves CD performance.

In order to better understand the CD results, we compared them with the quality of multitemporal pansharpened images measured according to quality indexes such as relative

[4]The latter one has been obtained by applying PS to original data spatially degraded by four according to the protocol proposed in [1].

[5]The value of T strictly depends on the considered CD problem and different automatic thresholding techniques can be adopted [9], [11].

TABLE II
QUALITY INDEXES OF PANSHARPENED IMAGES AT 2.8 m: FIRST (SECOND) DATE ON THE LEFT (RIGHT). BEST SCORES APPEAR IN BOLD TYPE

	ERGAS		Q4		SAM	
MMSE	3.65	**2.80**	0.840	**0.899**	3.85	**3.15**
CBD	**3.52**	2.85	**0.851**	0.896	**3.65**	3.24
AWLP	3.94	2.97	0.843	0.890	4.46	3.47
GS	4.31	3.75	0.773	0.800	4.19	4.04
GIHS	4.46	3.65	0.718	0.787	4.52	3.75

dimensionless global error in synthesis (ERGAS), Q4, and spectral angle mapper (SAM). ERGAS [12] is given by

$$\mathrm{ERGAS} = 100\frac{d_h}{d_l}\sqrt{\frac{1}{B}\sum_{i=0}^{B-1}\left(\frac{\mathrm{RMSE}(i)}{\mu(i)}\right)^2} \tag{6}$$

where d_h/d_l is the ratio between the pixel sizes of the PAN and MS images (e.g., 1/4 for QB and Ikonos data), and $\mu(i)$ is the mean of the ith band. ERGAS measures a distortion and thus must be as small as possible. Q4 is the unique image quality index based on quaternion theory for MS images having four spectral bands [2]. The highest value of Q4, attained if and only if the test MS image is equal to the reference, is one. SAM denotes the absolute value of the angle between two spectral vectors; hence SAM equal to zero indicates absence of spectral distortion. SAM is averaged over the whole image to yield a global distortion index.

To evaluate all mentioned indexes, reference original bands are required. Therefore, PS quality assessment was carried out only on data at the geometrical resolution of the MS image (i.e., numerical values are calculated considering fused and original data at 2.8-m resolution).

A qualitative analysis of Fig. 2 points out that the mmse and AWLP effectively preserve spectral properties. Fused images obtained by GS and GIHS clearly show overenhancement in the vegetated regions, which affects CD. The mmse method and, to a lesser extent, AWLP guarantee a more accurate texture injection, particularly in the green wavelength. Quality index values reported in Table II are in accordance with these observations. Best spatially averaged results at 2.8 m are provided by the CBD and mmse methods, followed by AWLP, whereas GIHS and GS show a significantly lower performance. It is worth noting that despite CBD is characterized by high-quality indexes (high global quality of the fused image), it may locally introduce fusion artifacts, i.e., no spatial injection, due to statistical instabilities. When such local inaccuracies appear on image regions where changes occurred, CD performance degrades (see Table I).

Comparing numerical values reported in Tables I and II, it appears that pansharpened image pairs characterized by better quality indexes not always result in CD maps with higher similarity measures, as in the case of CDB. Therefore, the proposed quality index for CD maps obtained from spatially enhanced images at 0.7 m without any reference data becomes relevant. It is worth noting that the validity of the proposed measure is confirmed by the agreement between similarities computed at full and degraded resolution, where information about original bands can be exploited.

VI. CONCLUSION

Although it has been proven that the pansharpened images result in higher quality CD maps wrt images interpolated by a factor of four, PS artifacts can significantly impact on the CD process. In this letter, a quantitative and qualitative analysis of the effects of different PS methods on CD is presented. The impact of PS on CD was analyzed both at degraded and full scale, according to a novel strategy based on similarity measures. At degraded scale, the available reference CD maps have been compared to the maps obtained from pairs of pansharpened spatially degraded MS images. At full resolution, which is the most relevant in practical CD applications, spatially enhanced images have been considered. The two analysis resulted in similar ranking of PS methods from the one that less affects CD to the one that most affects it, confirming that the proposed technique can be effectively employed for adaptively selecting in an unsupervised way the most reliable PS technique for different data sets and CD problems. Finally, it has been shown that pansharpened image pairs with higher quality indexes nonnecessarily result in more accurate CD maps, thus proving the usefulness of the proposed approach. Specifically, extreme care should be taken on the choice of the PS algorithm for CD with a particular attention to PS techniques based on local statistics estimation.

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