Polarimetric Change Detection for Wetlands

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Abstract An exciting development in wetland mapping and monitoring is the use of SAR polarimetry which uses both magnitude and phase of the backscattered radar signal for information extraction. This approach allows for the accurate delineation of flooded vegetation due to the double bounce scattering mechanism which the phase helps to identify unambiguously. Repeat pass polarimetric data is then used to monitor the temporal change in flooded vegetation. This information is useful for a variety of applications in wetland mapping and monitoring. This paper will present a novel Curvelet-based technique for the enhancement of polarimetric decomposition channels as well as temporal differences in these channels. Starting with the Freeman-Durden and the Cloude-Pottier polarimetric decomposition of Radarsat-2 data the Curvelet image enhancement and the Curvelet change detection are applied. The results are very promising although a validation by comparison with ground truth data still has to be done.

Key words SAR; polarimetry; image enhancement; change detection; monitoring; water level; flooded vegetation

INTRODUCTION

Synthetic aperture radar (SAR) satellite data, being independent of cloud and smoke cover, able to operate day and night, and not subject to sun-glint, offer a reliable data stream for monitoring water bodies in North America (Brisco et al., 2009). Radar in general is very good at detecting open surface water and has been used operationally for flood monitoring in many countries (Kasischke and Bourgeau-Chavez, 1997). The longer wavelengths employed by SAR also allow for canopy penetration and the subsequent interaction of the radar with the underlying flooded vegetation causes a double bounce scattering mechanism allowing for the identification of flooded vegetation (Pope et al; 1997). These characteristics make SAR an attractive tool for wetland monitoring applications (Brisco et al., 2008).

The recent advance of SAR polarimetry and polarimetric decomposition is proving to be a useful tool for wetland applications (Touzi et al., 2004). Double-bounce scattering is easy to detect with the phase information using the various polarimetric decompositions and provides a mechanism for monitoring annual or seasonal change in flooded vegetation. This is particularly useful for wetland monitoring applications as optical data does not do a very good job at this due to lack of canopy penetration.

Schmitt et al (2009a) recently developed a method for radar image enhancement and change detection using a Curvelet-based approach which has proven promising for man-made objects, i.e. mainly urban applications (Schmitt et al., 2009b). The original application was on magnitude only data, but it was believed to be appropriate for polarimetric data as well. This paper briefly presents the Curvelet-based change detection approach and then demonstrates its utility for change detection in wetlands, especially changes in flooded vegetation, using polarimetric Radarsat-2 data. For the polarimetric decomposition the Freeman-Durden and the Cloude-Pottier algorithms are utilized. The image enhancement on single images as well as on image differences is applied on the individual decomposition channels.

METHODOLOGY

In this section the methodology is described. After briefly presenting the Curvelet-based image enhancement and change detection the polarimetric decompositions used in this paper are described.

Curvelets on SAR images

Curvelets are an alternative image representation. They are characterized by the unique mathematical property that curved singularities can be well approximated with very few coefficients and in a non-adaptive manner (Candès and Donoho, 1999). Like other frequency-based image descriptions the pixel values are calculated as sum of the contributions of all basic elements. This fact implies that for SAR applications the amplitude logarithm has to be used as input because of the multiplicative nature of SAR. These "linear" elements are then transported to a wide range of scales, angles and positions. In order to weight the influence of the single elements on the resulting image a complex coefficient is introduced.

For image enhancement the Curvelet coefficients provide a direct access to the linear features in an image. Increasing the amplitude of a single Curvelet means increasing its influence on the image and hence, amplifying the corresponding structure. As the removal of a certain number of Curvelets causes artifacts, a special continuous weighting function has to be applied. To adapt this weighting function to different image contents, a stochastic approach has been developed taking into account the complex nature and the distribution of the Curvelet coefficients. See Schmitt et al (2009a) for details.

For SAR image change detection, two images – already transformed into the Curvelet coefficient domain – can easily be compared by differentiating the corresponding Curvelet coefficients. The resulting coefficient differences are subsequently enhanced by the same procedure as for single image enhancement and transformed back to the spatial domain. As for the multiplicative model used for intensities only relative changes can be determined, the increase can be given in percentage or in dB, often used in radar image interpretation.

Polarimetric Decompositions

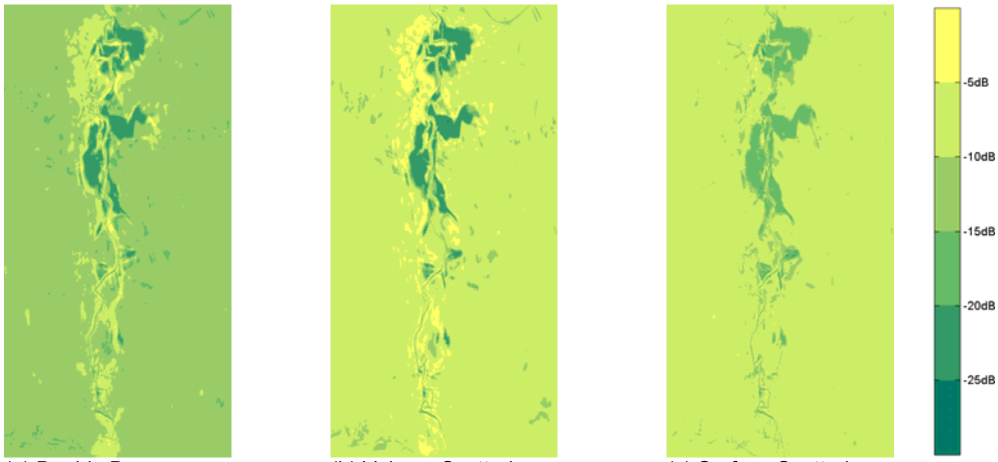
The Freeman-Durden decomposition is based on the decomposition of the total backscattered power into three contributions: the intensities caused by double bounce scattering, by volume scattering, and by surface scattering (Freeman and Durden, 1998). Dividing the single components by the total backscattered power gives the percentage of the single scattering mechanisms. For change detection the intensity of each scattering mechanism is preferred, because the relative contribution is always correlated to the total intensity, which can be highly variable.

In contrast, Cloude-Pottier distinguishes three possible scattering contributions without defining the types of scattering mechanisms in advance. The diversity of these three contributions is represented by the Entropy, a dimensionless value ranging from zero (only one dominant scattering contribution) to one (three equal scattering contributions). The mean values of the Entropy the Anisotropy – again a dimensionless value ranging from zero to one – describes the relation between the second and the third scattering contribution. A high Anistropy denotes (together with mean Entropy) the presence of only two dominant scattering contributions, while low entropy identifies nearly equal intensities of the second and the third contribution. To determine the corresponding scattering mechanism type the Alpha angle is introduced, which can be calculated for all three scattering contributions. To get a single scattering mechanism for each resolution cell, the Alpha angle is averaged over all three contributions weighted by the relative intensity. The lowest value of the Alpha angle is zero, which denotes a pure surface scattering. The highest value of 90 degrees shows pure double bounce scattering. Values around 45 degrees refer to volume scattering (Cloude and Pottier, 1997). Thus, the definition of the scattering mechanism is packed into a single layer.

The Curvelet-based image enhancement and change detection routine can be applied on the layers of the Freeman-Durden decomposition without any modification because these layers share the same statistical properties as like single polarized SAR intensities. For the Cloude-Pottier decomposition the multiplicative approach has to be changed into an additive approach by omitting the logarithm step. The results of the change detection are no longer relative, but absolute change values either dimensionless from Entropy and Anisotropy or in degrees for the averaged Alpha angle.

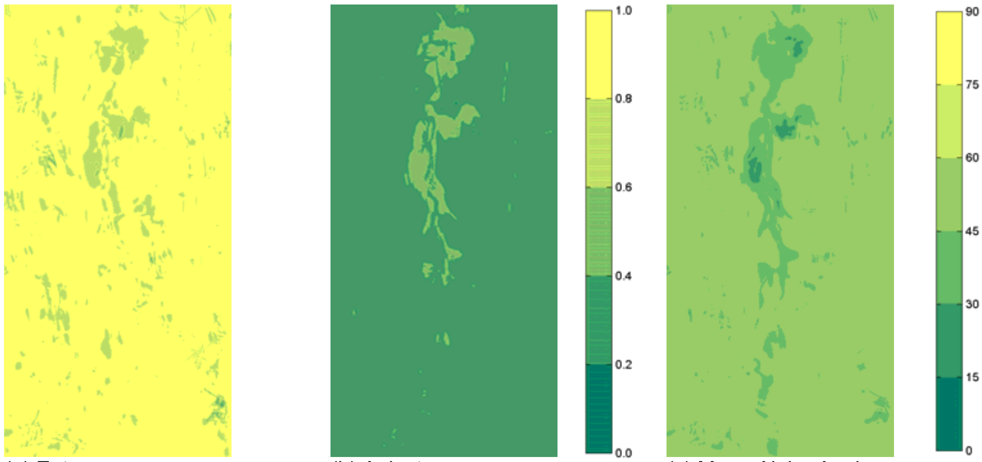
RESULTS

In this section the results of the Curvelet-based image enhancement and the Curvelet-based change detection using RADARSAT-2 polarimetric images of a wetland near Gagetown (NB) are presented. Five images have been acquired so far in 2010: (I) 04/27, (II) 05/21, (III) 06/14, (IV) 07/08 and (V) 08/01. Fig. 1 shows the three layers of Freeman-Durden in a logarithmic scaling. Open water surfaces clearly stick out as dark regions. In Fig. 1a&b some brighter regions around the open water are visible. As they appear both in the double bounce and the volume scattering layer these higher values might indicate flooded vegetation. The parameters of the Cloude-Pottier decomposition are shown in Fig. 2. While the Entropy image (Fig. 2a) contains nearly no structures, the Anisotropy and the Alpha angle in Fig. 2b&c show structures similar to the open water surfaces that can be found in Fig. 1. Thanks to the Curvelet-based image enhancement the images are very smooth but still very detailed so that they can act as an ideal basis for land cover classification.



(a) Double Bounce (b) Volume Scattering (c) Surface Scattering

Figure 1: Freeman-Durden decomposition after Curvelet-based image enhancement (I)



(a) Entropy (b) Anisotropy (c) Mean Alpha Angle

Figure 2: Cloude-Pottier decomposition after Curvelet-based image enhancement (I)

For change detection purposes we will focus on the double bounce layer of the Freeman-Durden and the Alpha angle of the Cloude-Pottier decomposition. As both layers provide the highest contrast in single images they are expected to be affected by the biggest changes. These two layers are capable of identifying double bounce scattering, which is related to flooded vegetation. The Freeman-Durden double bounce layer (Fig. 3) depicts high changes along the open water surfaces, but also slight changes in the forested areas. The Cloude-Pottier Alpha angle shows fewer changes. Almost all changes are related to the surrounding areas of the open water. The changes in the forested areas disappear completely. But, it seems to be less sensitive in comparison to the Freeman-Durden decomposition. For this reason it is recommended to use the dominant Alpha angle instead of the averaged one, if a very sensitive parameter is desired.

CONCLUSION

The Curvelet-based image enhancement and change detection method shows high potential for wetland mapping and change detection using polarimetric decompositions. Very clear and nearly noise-free classifications out of a single image acquisition can be produced. In time series, changes in the scattering mechanisms can easily be identified. Work is still needed on the correlation of the changes in the scattering mechanisms and the water level changes to target conditions in the wetland. Therefore, there is a need for validation of the results which is currently underway.

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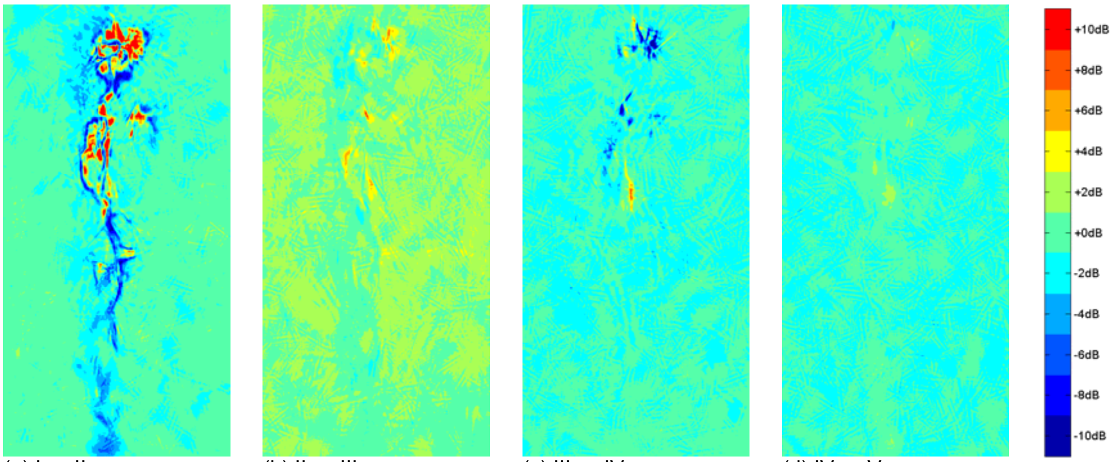
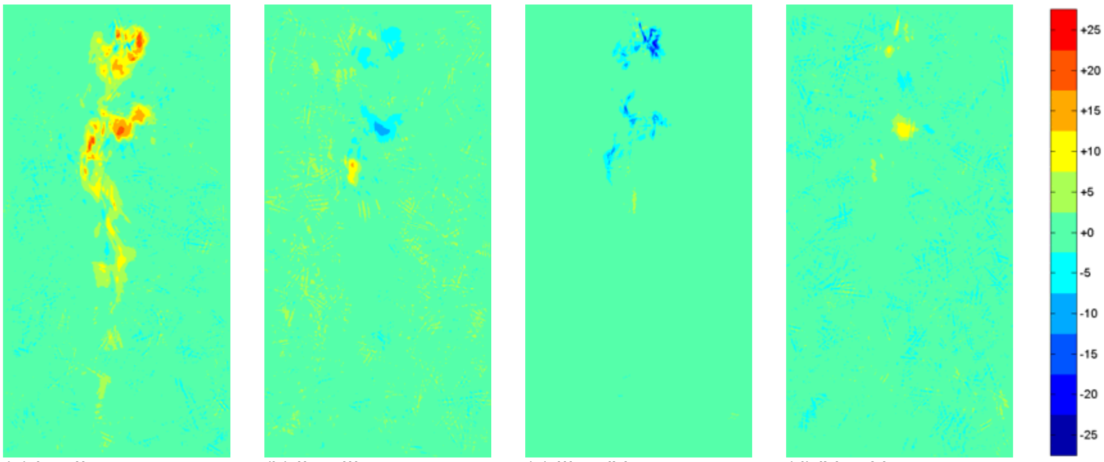


(a) I → II (b) II → III (c) III → IV (d) IV → V

Figure 3: Curvelet-enhanced changes in Freeman-Durden Double Bounce Scattering intensity



(a) I → II (b) II → III (c) III → IV (d) IV → V

Figure 4: Curvelet-enhanced changes in Cloude-Pottier averaged Alpha angle

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