



White Paper

Change Detection using SAR Data

**John Wessels: Senior Scientist
PCI Geomatics**

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The ability to identify and measure significant changes in target scattering and/or polarimetric parameters at known and co-located image locations provides a very powerful tool for large area military and/or environmental monitoring applications. This paper describes the techniques developed by PCI to calculate a “change measurement” derived from co-registered polarimetric parameters. The detected changes are normalized to a percentile change map making it possible for trained operators to easily identify the areas of change. The following sections describe the developed procedure.

Image-to-image registration

The module AUTOSHIFT was developed by PCI to automatically co-register complex valued coherent SAR image data. AUTOSHIFT computes the optimum sub-pixel shift to apply based upon image to image correlation. Subsequent development focused on combining both coherent and non-coherent registration for detected and complex valued inputs. The extended image to image registration module AUTOGCPFFT is based upon a technique developed internally by PCI. The method extracts the metadata and the known sensor viewing model to provide an initial coarse registration. Once the coarse registration has been determined, sub pixel registration is initiated. The sub-pixel registration is based upon correlation in the spectral domain. The image data is transformed to spectral components using the Fourier transform. The registration is based upon a phase matching technique. This technique avoids biasing the results due to bright returns. In the Fourier domain, the low-frequency (i.e. systematic) and high-frequency (i.e. noise) components are dampened to further reduce registration errors.

Resampling tests have been conducted using coherent and non-coherent image pairs. For the coherent image pair the root mean square (RMS) accuracy was found to be better than 0.1 pixels for a third order polynomial fit. For the non-coherent data, the RMS accuracy for a third order polynomial fit is approximately 0.25 pixels.

Change detection algorithms

A number of change detection algorithms are available to provide fully automated detection. The change calculations do not require the user to specify a threshold to differentiate “change” from “no change” since these are measured in a continuous and normalized manner.

Because the range of the change metrics may be very large (or small) and cannot be known *á priori*, it is difficult to find an optimal look up table to display subtle changes. In an effort to make the change analysis more intuitive, the output is written as a percentile with the changes ranked from zero; representing the minimum change, to one hundred representing the maximum change for the specified metric.

Three change detection metrics were developed. The first metric (CCDINTEN) is based upon changes in total backscattering. The second metric (CCDPHASE) is based upon changes in coherence; and the third is based upon changes in the Wishart distribution (CCDWISH).

CCDPHASE and CCDWISH require complex valued input while CCDINTEN can work with either real or complex valued input.

Full quad RADARSAT-2 data was acquired over the Flevoland test site. The reference image (left) is acquired on May 7th 2010. The test image was acquired on May 31st, 2010 and is shown on the right in Figure 1.

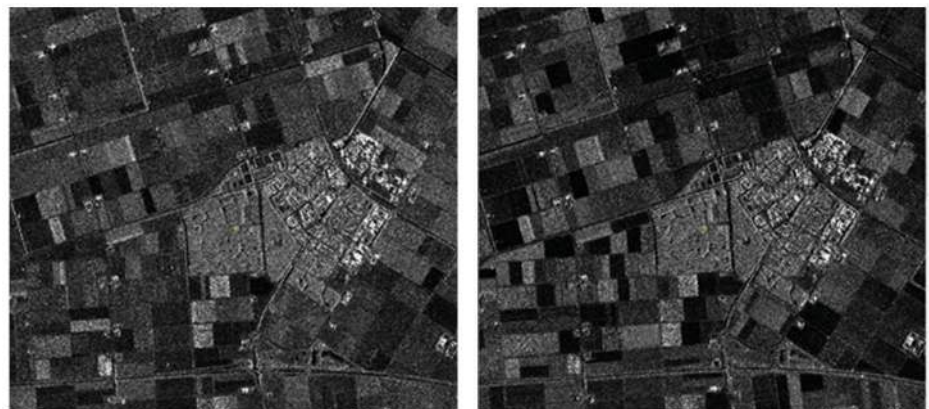


Figure 1: Full Quad RADARSAT-2 Reference (May 7) and Test (May 31) images

CCDINTEN – Intensity-based change detection

This module measures the change in ratio of the total radar backscattering of the test and reference image. CCDINTEN compares the sum of the intensities as indicated by the user selected channel list. This module also supports detected (i.e. positive integers or reals) in addition to complex data input.

The top 2% of the changes detected by CCDINTEN are shown in by the pixels highlighted in yellow in Figure 2.



Figure 2: Top 2% of changes detected by CCDINTEN

CCDPHASE - Coherence (phase)-based change detection

CCDPHASE measures the average coherence (over the user specified window size) between the co-registered areas of the test and reference image. Coherence values will range between zero and one. Areas of change will have coherence values close to zero (i.e. they are no longer coherent) while areas of no change will have higher values. The output consists of the ranked change where the minimum coherence change is mapped to zero and the maximum to one hundred.

The top 2% of the changes detected by CCDPHASE are shown in by the pixels highlighted in red in Figure 3.

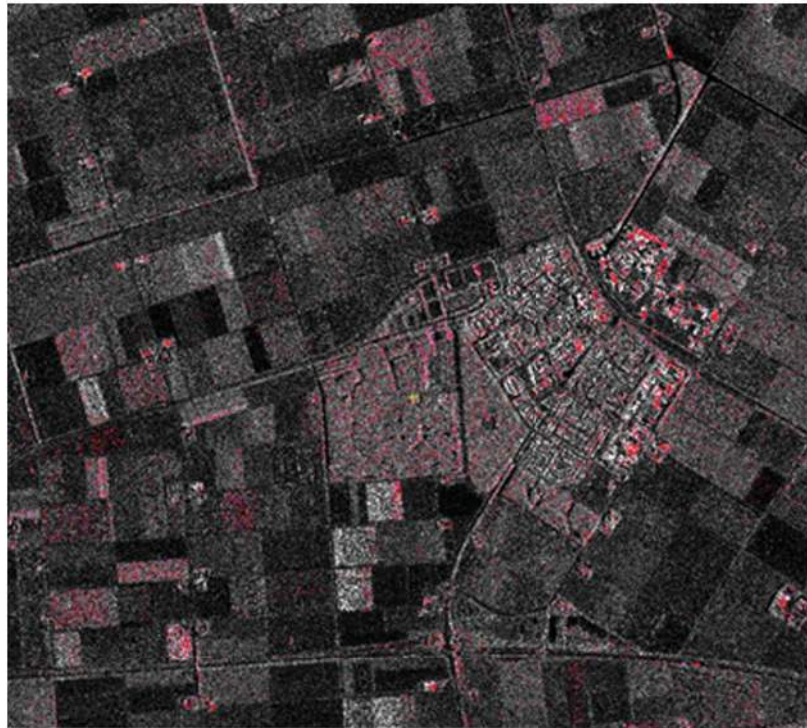


Figure 3: Top 2% of changes detected by CCDPHASE

CCDWISH - Based upon Wishart statistics

This module measures change based upon modified Wishart statistics. For each window, the statistical probability of the area of interest being “the same” is computed. Areas with a high probability are considered to be unchanged, while areas with a low probability are considered to be changed. (i.e. have a low probability of being the same). A channel of ranked changes where 0 represents the minimum change and 100 equals the maximum change is provided.

The top 2% of the changes detected by CCDWISH are shown in by the pixels highlighted in green in Figure 4.



Figure 4: Top 2% of changes detected by CCDWISH

CCDWM - Based upon user-defined weighted metrics

The module CCDWM computes the weighted change value derived from various change detection techniques. Areas which indicate a change for multiple techniques (intensity, coherence, Wishart) are much more likely to indicate real changes and eliminate false positives.

The top 2% of the changes detected by CCDWM where the results from changes in intensity, coherence and Wishart distribution are equally weighted are shown by the pixels highlighted in purple in Figure 5.



Figure 5: Top 2% of changes detected using results from CCDINTEN, CCDPHASE and CCDWISH

Polarimetric change detection

The SAR Polarimetric Workstation (SPW) can be used to generate many polarimetric parameters. Two coherent RADARSAT-2 fine quad (FQ29) data sets acquired over the European Space Agency's (ESA) Flevoland test site are used as input. The test data set was acquired May 31, 2010. The reference data set was acquired on May 7, 2010. Using the SPW software, twenty-seven polarimetric parameters were extracted from each data set. The output polarimetric parameters from each data set are all real valued and are merged into a single file. The two multi-channel data sets are automatically co registered using the technique previously described. An

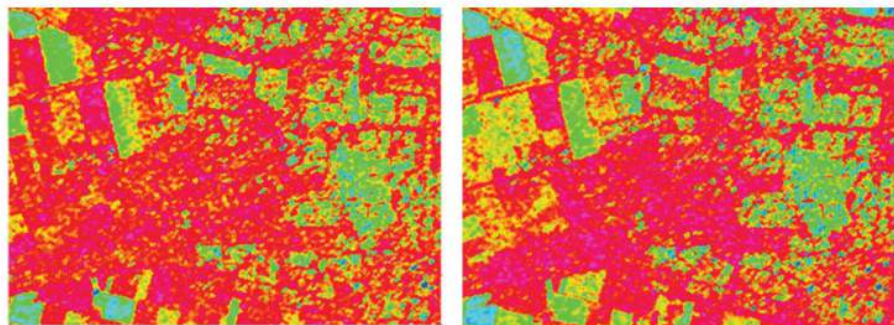


Figure 6: Co-registered entropy layers; May 07 (left) and May 31 (right)

example showing the two co-registered entropy layers is given in Figure 6.

The change detection concept is now extended to combine the normalized (i.e. ranked) changes detected for multiple layers. For each layer the smallest change is mapped to zero and the largest change to one hundred. The weighting assigned to each polarimetric change layer can be tuned for different target types. Targets meeting all of the following conditions were identified as changes in point targets. The following heuristics were used.

- **Average normalized change for all 27 parameters > 90%**
- **Change in total power ratio > 99.5 %**
- **Change in maximum degree of polarization > 99.5 %**
- **Change in entropy > 99.5 %**



Figure 7: Change detection using point target heuristics

Figure 7 shows the point target changes overlaid on the total power image. For illustrative purposes, the detected points (single pixel) have been circled.

Cross-sensor polarimetric change detection

The change detection capabilities were further tested by automatically registering cross sensor (RADARSAT-2 and TerraSAR-X) data sets. The May 7th, calibrated (to σ°), C-Band RADARSAT-2 data with a sample spacing of 4.7 x 4.7 square

meters and an incident angle range of 46.841 to 48.038 degrees was co-registered to the May 4th, uncalibrated, X-Band, TerraSAR-X data with a sample size of 2.3 x 6.7 square meters and incident angles between 29.727 and 31.309 degrees. Both passes were acquired in descending mode. The area of overlap is delineated by

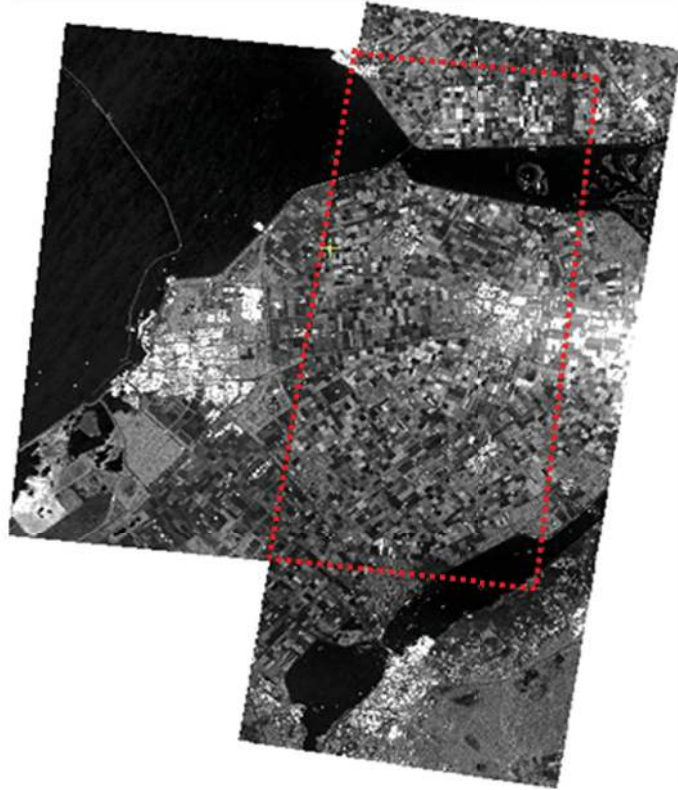


Figure 8: Automatically co-registered RADARSAT-2 (left) and TerraSAR-X (right)

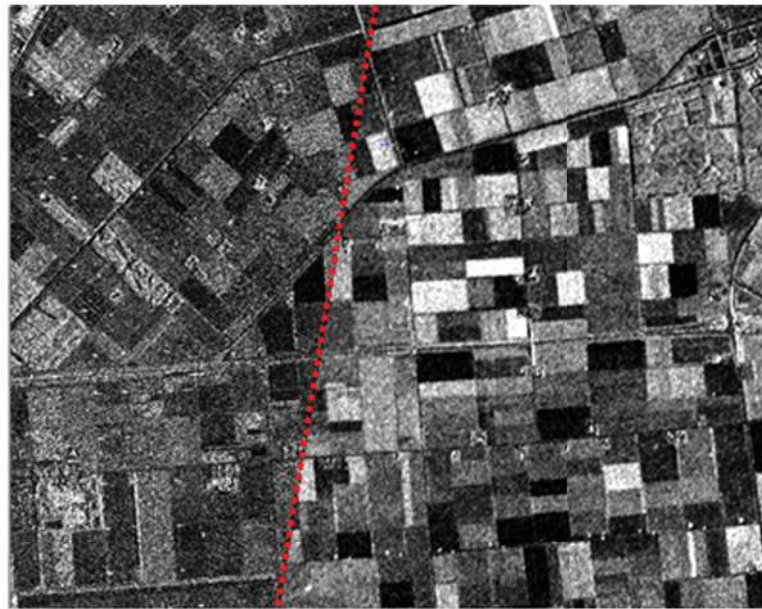


Figure 9: Enlargement showing cross-sensor registration

the red dashes. The RMS error was approximately 0.25 pixels. The registration of the full images is shown in Figure 8. Figure 9 shows the co registration along a portion of the left side of the overlap area.

The polarimetric parameters for each sensor were generated as before. The change detection heuristics (from CCDINTEN) for the cross-sensor demonstration are given by:

- **Average normalized change for 6 defined range parameter >85%**
- **Ratio change percentile (Absolute dBs) in total power >99.5 %**
- **Ratio change in degree of polarization >99.5 %**
- **Ratio change in Entropy >99.5 %**

The original TerraSAR-X image (left) and the detected point targets overlaid on the RADARSAT-2 image is shown Figure 10. In a similar manner, the original RADARSAT-2 image (left) and detected point targets overlaid on the RADARSAT-2 image are shown in Figure 11. The right hand portion of these figures is identical.

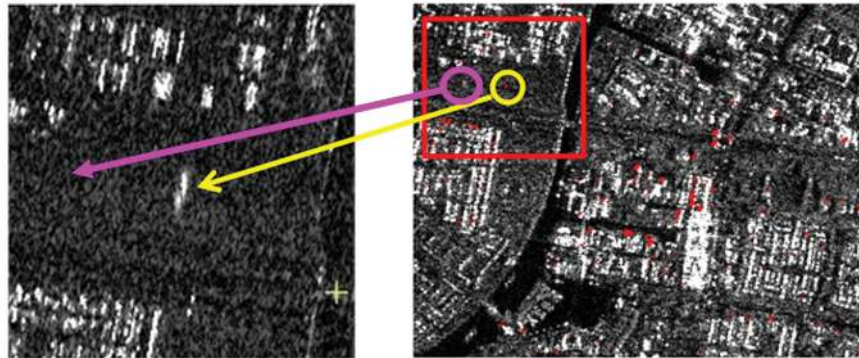


Figure 10: Detected targets (right) with original May 4th TerraSAR-X image (left) showing departing targets in yellow and arriving targets in purple

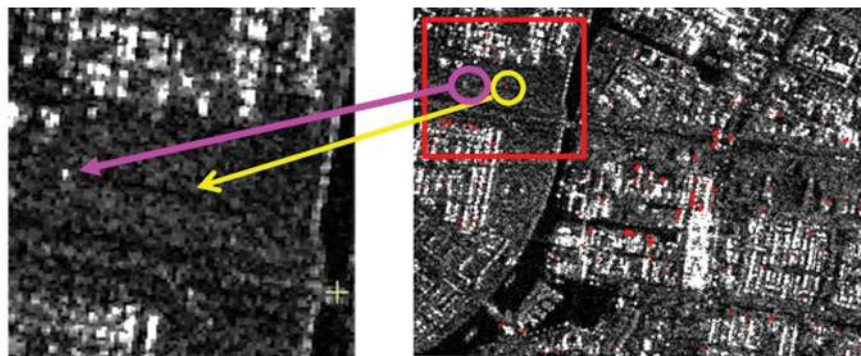


Figure 11: Detected targets (right) with original May 7th RADARSAT-2 image (left) showing departing targets in yellow and arriving targets in purple.

Note the target circled in yellow is found on the May 4th TerraSAR image but not in the May 7th RADARSAT-2 image. The target circled in purple is found in the RADARSAT-2 image but not the TerraSAR-X image.

It should be noted that no ground truth is available for the cross sensor change detection so it is difficult to quantify the results. However; when the locations of the detected changes are compared with the optical data from Bing Maps™, the point target changes are highly correlated to parking lots in industrial areas. Figure 12 shows the optical Bing Map™ image (left) and the detected targets (both appearing and departing) overlaid on the May 7th RADARSAT-2 data (right).



Figure 12: Flevoland optical image (Bing Maps™) and RADARSAT-2/TerraSAR-X point target change map

About the Author

John Wessels joined PCI Geomatics in 2008 as the company's senior remote sensing scientist. He is responsible for the development and implementation of all radar related technologies and applications.

Mr. Wessels has over 30 years of international experience leading the technical development of remote sensing applications using radar and optical satellite data. He has developed applications for coastal surveillance, ship detection, environmental assessment and disaster monitoring. He is currently involved in the development of change detection techniques from polarimetric data for environmental and military applications.



Mr. Wessels received his Bachelor of Science degree in Mathematics and Computer Science from the University of Guelph in 1975.