CHANGE DETECTION METHODS FOR THE REVISION OF TOPOGRAPHIC DATABASES

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ABSTRACT:

Database updating and maintenance is becoming a demanding operation in national mapping organisations. Major tasks are the change detection and extraction and its integration in the existing data sets. Change detection is performed between a number of data sets involved in topographic applications. The implementation of more automation coupled with the availability of heterogeneous data requires the investigation, adaptation and evaluation of new approaches and techniques. The demand for rapid mapping operations is continuously increasing. Prior to change detection, extraction of homogeneous features from both the multi-temporal datasets is necessary. Thresholding and texture measures were used to evaluate the potential of rapid extraction of topographic elements from scanned monochrome maps, while the extraction of features from satellite imagery involved initially image and theme enhancement by applying various image fusion and spectral transformations, followed by image classification and thresholding. Interactive and semi-automated change detection methods are proposed and implemented based on non-intersection of old and new features and the generation of buffer zones. These were used for the determination of planimetric changes. The various approaches and methodology developed and implemented along with examples, initial results and limitations are presented and discussed. The tests showed that the approaches were more or less feature/theme dependent, while at the same time they can augment and significantly enhance the conventional topographic methods.

1. INTRODUCTION

Moving from database populating operations to database updating and maintenance is becoming a more and more frequent operation in national mapping organisations. Major tasks are the change detection, change extraction and change integration in the existing datasets. The upcoming plethora of high spatial and spectral resolution satellite imagery along with its high frequency multi-temporal nature will increase the pressure for shorter updating cycles and rapid revision operations. Therefore the increase in automation for change detection, classification and extraction from current data sources, and the integration of changes with the existing geo-spatial databases is quite desirable.

Due to the size of the Canadian territory, current operations at the Centre for Topographic Information, Mapping Services Branch, NRCan, involve the planimetric updating of certain features (such as the road network) in cooperation with the provincial mapping agencies, while other planimetric features would be updated from satellite imagery. Medium/low resolution satellite imagery such as the IRS PAN and LISS has been used (Armenakis and Savopol, 1998; Armenakis, 2000). Due to higher cost and copyright restrictions involved, the image layer of the national framework data will now consist of the 15m and 30m resolutions of Landsat 7 ortho-images (panchromatic and multispectral) for the entire country.

In this paper we will address the change detection methodology and give examples involving different data types such as scanned maps, vectors from existing database, and new imagery. Detected changes will be used to update the national topographic vector database. The various approaches, methodology including the potential of digital image processing techniques and automated procedures as well as the initial results obtained will be presented and discussed.

2. CHANGE DETECTION ANALYSIS

2.1 Definition

Change detection analysis can be defined as the identification and location of differences in the patterns of two temporal datasets at times t_1 and t_2. Specifically change detection involves the comparison of two datasets and consists of four processes, a) detection, that is the discovery of change, b) recognition, that is the thematic classification of the change, c) identification, that is the description of the feature of the thematic change and d) quantification, that is the measure of the magnitude of changes. Since there is a number of types of datasets involved in topographic applications, change detection may be required to be performed for example between image and vector data, between image and image data, between image and map data, between vector and vector data, and between map and map data. Change detection between two multidated images can be digitally performed (Singh, 1989; Hayes and Sader, 2001). However, change detection between other type of data such as current imagery and old topographic data is mostly done visually, while certain level of automation has been achieved (Heipke and Straub, 1999; Ohlhof et al.; 2000; Armenakis, 2000).

2.2 Domain of comparison

When comparing two datasets the domain of comparison has to be defined. For example, vector data provides a classified abstract representation of the landscape, while imagery is an unclassified continuous but resolution-dependent generalized representation of the landscape. If comparing data of the same nature (i.e., two homogeneous satellite images) the change detection can be determined at the *data level* domain (comparison of pre-processed data), while when comparing heterogeneous datasets the change detection is performed at the *decision level* domain (comparison of analysed data), as some data processing (e.g., image classification, vectorization of detected features) needs to be done prior to change detection. For example, the latter level is the one used in this study for the analysis and comparison of topographic data and Landsat 7 ETM+ orthoimage due to their heterogeneity. For the generation of homogeneous features the analysis involves the decomposition of the data to basic feature elements (linear or polygonal) using several image extraction techniques based on the various topographic themes,

2.3 Type of changes

Changes of features occur, when either the spatial and/or the attribute characteristics of an existing feature have changed. A change can therefore be in the form of:
a) *Spatial modification*, when the changes in the geometry of an existing feature and its corresponding new feature exceed the accuracy buffer limits and/or when the topology changes; and
b) *Attribute modification*, when the thematic values of an existing feature change**.**
The changes in the data patterns are then determined based on the following definitions:
Confirmation of the existing data, when neither their spatial nor the attribute elements of an existing feature have changed.
Addition of features, when a new feature is added or an existing feature is modified.
Deletion of feature when a feature or part of it is eliminated.
The information about deletions and additions is kept and time stamped in separate files, thus facilitating the tracking of the changes. For the integration of the new and old datasets, validation and editing including topology are required.

3. CHANGE DETECTION METHODS

We have tested and implemented two ways of detecting changes between existing topographic data and satellite imagery, based on the results of the extraction of homogeneous features: interactive and semi-automated change detection. Planimetric accuracy tolerance is used for the acceptance or rejection of differences as actual changes.

3.1 Interactive change detection

The differentials between old and new data are determined visually by superimposition of the old/new vector data over new/old raster or vector data. The interactive comparison is performed visually and allows the operator to detect patterns of non-matching elements between the two datasets and collect the changes with heads-up digitizing. The procedure has been enhanced with rapid feature extraction to assist the operator.

3.2 Semi-automated change detection

The change is defined as the non-intersection of the old and new vector features between two temporal spatial states (S_1 and S_2). If the output of the non-intersection contains data from S_1, then changes are considered as deletions. If it contains data from S_2, changes are considered as additions. The changes consist of additions and deletions. A deletion is the difference between the old state and the common elements between the two states, while an addition is the difference between the new state and the common elements between the two states. The total changes and the additions and deletions are then expressed as follows:

$$C_{ha} = A_{dd} + D_{el} \qquad (1)$$

$$A_{dd} = S_2 - S_1 \cap S_2 \qquad (2)$$

$$D_{el} = S_1 - S_1 \cap S_2 \qquad (3)$$

where, C_{ha} = total spatial change
A_{dd} = additions
D_{el} = deletions
S_1 = spatial state at time 1
S_2 = spatial state at time 2

A detected change could be caused by differences in positional accuracies between the two datasets. The significance of change can be expressed based on accuracy tolerances and minimum sizes. To account for accuracy tolerances, appropriate spatial buffers are generated around both features during the change detection operation, while the minimum sizes satisfying the specifications are handled using appropriate spatial filters. The buffering and filtering operations are used to keep only the significant changes.

Whatever vector segments are outside the buffer zones are considered as changes: a) if the new features from the S_2 data are outside the buffer applied to S_1 features, changes are considered as the actual additions; and b) if the old features from the S_1 data are outside the buffer of the S_2 features, changes are considered as the actual deletions (Fig. 1). This approach allows for quantification of changes per theme by calculating for example total length and/or area of change.

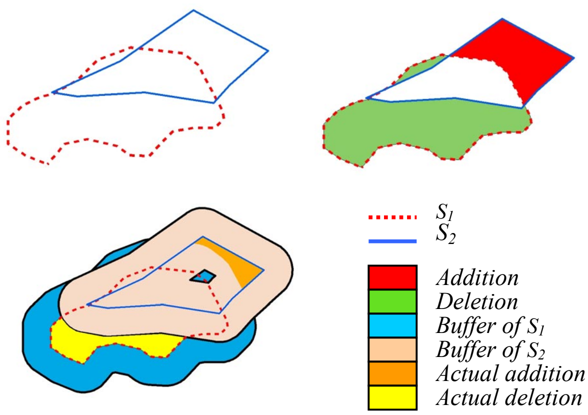

Figure 1: Actual change detection: addition and deletion.

4. GENERATION OF HOMOGENEOUS FEATURES FOR COMPARISON

Due to the heterogeneity of the multi-temporal data types, the change detection in our tests is performed at the decision level. As the existing data is in vector form, initially homogeneous vector features are extracted from the two datasets prior to change detection.

4.1 Extraction from scanned maps

The extraction process from scanned topographic maps involves the distinction of certain map features belonging to one theme (e.g., water bodies) from other map features and from the map background followed by the extraction of the exact geometrical shape of the feature. Automatic extraction of features from scanned topographic has been studied as a viable alternative to manual digitization and to reduce manual editing from raster to vector operations (Nebiker and Carosio, 1995; Carosio and Stengele, 1993). Fully automated vectorization of the raster map at this phase would be rather difficult as it would require the development and implementation of pattern recognition techniques for symbol identification and extraction of various cartographically represented elements, which presently cannot automatically be distinguished without human intervention. Semi-automated approach for feature extraction is the computer-assisted vectorization (e.g., on-screen line follower) of the rasterized map elements. Fast vectorization of map elements can also be done by thresholding and texture analysis followed by raster-to-vector conversion without any topology.

Considering the raster map as a grayscale image, it is possible to apply the thresholding technique using the map histogram. This method uses the fact that the map lines, which delineate or represent most of the cartographic information (including symbols and toponymy), appear much darker than contours and grid lines. Therefore, the thresholding permits the distinction, in a raster format, of relevant topographic information such as the lakes, rivers, wetlands, wooded areas, eskers, roads, etc., from contours and grid lines. The most appropriate threshold value (value delineating these two general classes) has to be determined by the operator since this value may vary according to the printing and scanning specifics.

Texture measures (Haralick and Shapiro, 1992) are used to examine the spatial patterns and variations of the gray values in a pixel's neighbourhood in an image. It can be used to define fineness, coarseness, roughness, contrast, regularity, directionality and periodicity in image patterns. Texture measures can be expressed in terms of variance, mean, entropy, energy and homogeneity of the kernel image window. The mean and variance provide a simple description of the statistics of the gray values, while the entropy provides spatial information of the gray values related to their directionality and frequency of occurrence (Sonka et al., 1993). As such, the entropy parameter is the most promising for our experiments.

4.2 Extraction from imagery

To improve the capacity for feature distinction and interpretation from satellite multi-spectral imagery, various image enhancement techniques (radiometric, spatial and spectral) are performed prior to any feature extraction. Specifically for feature recognition, image fusion (e.g., IHS, PCA, IMG-FUSE), and image transformations (e.g., Tasseled Cap, NDVI) are applied. Image fusion allows for meeting the geometric requirements due to the use of the higher resolution band, while it increases the interpretability of the features due to lower resolution spectral bands. Image transformations can enhance specific characteristics of the surface cover (e.g., vegetation variations, wetness, brightness).
Feature extraction is then performed either by image classification (unsupervised, supervised) or by band-based thresholding. Spatial filtering is applied to satisfy the minimum size specifications for the extracted areal features. An automatic vectorization of the extracted polygonal boundaries follows.

5. CHANGE DETECTION APPLICATIONS

The decisions concerning the domain of comparison of the datasets and the selection of the most appropriate methods in data processing, data extraction and change detection procedures depending on a number of factors. Factors such as the type and time of acquisition of the two datasets, the topographic themes to analyse and the applicable level of automation, are influencing the decisions taken for the whole process of change detection. The following two examples of change detection demonstrate the required flexibility of the process for data extraction and change detection as well as the applicability of the proposed methodology.

5.1 Case 1: Interactive change detection for water bodies between scanned maps and Landsat 7 imagery

Datasets
Both S_1 and S_2 datasets cover a taiga zone located in the North West Territories, Canada, where S_1 (data at time t_1) is monochrome paper maps (1:50 000 scale) edited in 1979 and scanned at 600 dpi resolution; and S_2 (data at time t_2) is Landsat-7 ETM+ image acquired on June 14, 2000 and consists of 7 bands (one panchromatic at 15m-resolution and six multispectral at 30m-resolution).

Vector extraction from scanned map
The direct superimposition of the two raster data (map and imagery) is not the easiest way for detecting interactively cartographic changes. To facilitate this visual process, vectors were extracted automatically from the map representing certain topographic features. Two methods are used to extract the different vector features from the scanned map: thresholding and the entropy measure of texture (Armenakis et al., 2001).

The thresholding method is used to extract most of the cartographic information (including symbols and toponymy) in a single layer (no distinction in the extracted features). The most appropriate threshold value is determined using the histogram by evaluating the natural spectral break between two general classes: (1) feature boundary lines including toponymy and (2) contours lines including the map grid. The results of the map thresholding are then filtered using median and sieve filters to remove noise and all polygons that are smaller than a given minimum size, measured in pixels area. The level of filtering must be chosen adequately to both keep small or isolated feature map lines and remove enough grid lines and contours that may reduce the feature visibility. Vector features are obtained through an R=>V conversion (interactive or automatic) of the thresholded results. From this automatic fast vectorization, vectors of raster elements that represent the old information or our prior knowledge of the topographic features are obtained. This output vectors could be used either in an interactive change detection process with the imagery as the background layer or in a feature extraction process from the imagery by selecting appropriate training sites prior to the image classification. There is a limited use of these output vectors because of the fact that they are not topologically structured and include map elements such as symbols and text. An example of these vectors superimposed with a Landsat 7 band is presented in Figure 2a.

Considering that water bodies are represented differently in the 1:50 000 scale monochrome maps (polygonal screened gray patterns) than the rest of the map (linear patterns), a method using the entropy measure has been implemented to automate the extraction of lakes from the scanned maps. In the entropy calculation, a distance of 1 was used between two neighbouring pixels and a directional invariant outcome. The degree of detection of small objects depends on the kernel size of co-occurrence matrix of the entropy measure (11x11 pixels kernel was used). Larger size kernel allows for more data to compute a significant entropy measure but reduces the ability to detect small objects. To extract automatically the lakes boundaries, the entropy filter was applied to the raster map, followed by thresholding of the resulting image between lakes and no lakes, then by a median filter to eliminate noise, then a filtering to remove lakes that do not respect the minimum size requirement, and finally by vectorizing the resulted binary image. This automated vector extraction is limited to this specific feature. An example of these vectors superimposed with a Landsat 7 band is also presented in Figure 2b.

Vector extraction from imagery

Considering the latitude (around 64°N, taiga zone in Northern Canada) and time of the year in the Landsat-7 acquisition, most of the large lakes (predominant cartographic feature) are still frozen. Within the smaller lakes, most of the covering ice was melted. The spectral difference between frozen and non-frozen lakes with spectral bands ETM1 to ETM4 and even with ETM8 (panchromatic) was clearly visible. Spectral bands ETM5 and ETM7 did not show this distinction. Since we are not interested in this spectral difference, the latter bands were selected for the extraction of waterbodies from Landsat 7. A simple region thresholding of band ETM5, considering values (gray levels) from 0 to 25, allowed for the extraction of the lakes (Figure 2c). In all the fusion experiments, few feature enhancements were obtained because of the nature of each spectral band and the time of acquisition of the image (frozen water, wet soils, few vegetation, etc.). In this particular case, only lakes could be extracted by a simple thresholding (no fusion and supervised classification were necessary).

Interactive change detection

After extracting vectors from the old 1:50 000 scale monochrome map and choosing the most appropriate Landsat 7 image band(s) as background, the change detection process between these two datasets could be done quickly by the interactive superimposition method. Figure 2 gives a visual comparison between lakes vectors from map thresholding (2a) or texture analysis (2b) and from band ETM5 of Landsat-7 imagery (2c). By using the extracted lake vectors from the imagery, the interactive change detection could also be done with the raster map as background (Fig. 2c).

Regarding the type of changes based on the contextual information from the Landsat-7 imagery, confirmations and geometric modifications (additions or deletions) could be done with higher confidence than complete feature additions or deletions (that imply a certain level of feature identification that is difficult to get from Landsat-7 only). These two types of changes have to be determined with caution in Landat-7 image due to its resolution. For example, a map feature will not have necessarily to be removed or added if it is not visible and properly identifiable in the image.

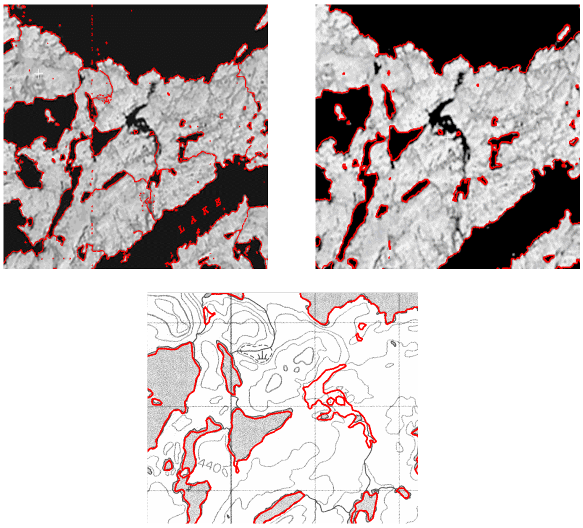

Figure 2 – Interactive change detection with Landsat-7 band ETM5 as background a) map lake vectors obtained by thresholding; b) map lake vectors obtained by texture analysis; c) lake vectors from Landsat-7 band ETM5 with the raster map as background.

5.2 Case 2: Semi-automated change detection for vegetation, wetlands and water bodies

Datasets

Both S_1 and S_2 cover a zone located in mixed boreal forest of Northern Alberta, Canada, where S_1 (data at time t_1): Vectors obtained from the National Topographic Database (NTDB, 1:50 000 scale) dated 1979 with 30m of planimetric accuracy. The data is ready for use as they are in vector form, structured and organized by themes; and S_2 (data at time t_2): Landsat-7 ETM+ image acquired on May 29, 2000 consisting of 7 bands as before.

Theme enhancement by image transformation

The ground resolution of Landsat-7 imagery limits its capacity for detection and extraction of all 1:50 000 scale map features. Some vector features from S_1 are not visible or not distinguishable in the image. The time of the year for the image acquisition represents also an important limiting factor with respect to the geographic location, the topography of the terrain, and the type and number of topographic features to consider. To improve the capacity of feature distinction and interpretation from the Landsat-7, various image enhancement techniques (radiometric, spatial and spectral) are applied prior to any feature extraction. Specifically for the enhancement of feature recognition various image fusion and transformations have been tested.

To fuse Landsat-7 ETM+ bands (panchromatic and multispectral), the IMGFUSE routine of PCI package that is based on cross-correlation between high and low-resolution bands (computed band by band) was used. The advantage of this fusion method is that it preserves the radiometric properties of the original multispectral channels (Cheng et al., 2000), while common fusion methods such as IHS and PCA usually distort them (Chavez et al., 1991).

As the vegetation cover seems to be an important factor in modulating the information content of the various Landsat-7 bands, a spectral band transformation expressly designed for the enhancement of the vegetation cover density and condition, called the “Tasselled Cap” (Mather, 1987), was applied. The six multispectral bands of Landsat-7, except the thermal ones, are used in order to compute three parameters called brightness, greenness and wetness. Brightness is a weighted sum of all six ETM channels and expresses the total reflection capacity of a surface cover. Small areas dominated by dispersed vegetation appear brighter (high total reflection). Greenness expresses the difference between the total reflectance in the near infrared bands and in the visible bands and has been shown to be moderately well correlated to the density of the vegetation cover. Wetness expresses the difference between the total reflection capacity between the visible-near infrared channels and the SWIR channels, more sensitive to moisture surface content.

Vector extraction from imagery

Feature extraction is performed by either thresholding as discussed before or image classification followed by automatic vectorization if required. For certain features such as vegetation and wetlands better results obtained by classification. The three bands of the fused image (PCI-IMGFUSE routine) corresponding to ETM3, ETM4 and ETM5, the three Tasseled Cap parameters (brightness, greenness and wetness) and the NDVI result were used as input data. Noting that field ground truth and verification are not available, the existing topographic vectors were used as 'prior knowledge' to provide cues and guidance in the classification process from imagery. This knowledge is used as contextual information for selecting training sites for pixel-based classification. The training sites were selected considering our prior knowledge of the topographic features: vectors from 1:50 000 scale scanned map and from 1981 fire polygons of the Alberta Sustainable Resource Development, Forest Protection. For features like vegetation and wetlands, the selection of training sites is somehow difficult due to the variation in spectral signatures. These variations could reflect the presence of sub-classes in the defined topographic feature (e.g., cleared cuts, burned areas and regenerated forests are included in wooded areas, while all types and conditions of swamps/marshes are included in wetlands). To take into account these spectral variations even though there are not reflected in the map content, different training sites have to be selected to create several sub-classes for the same feature. After the classification process (by maximum likelihood) the sub-classes were aggregated to adapt the detected classes to general categories of map elements (vegetation, wetlands, water bodies). In this case, six sub-classes were extracted (water bodies, marshes, swamps, recent cuts, burned areas, wooded areas) and aggregated to obtain three final classes (water bodies, wetlands and vegetation). Based on our training sites, the Kappa coefficient was 0.95. In comparison, without image fusion, the classification leads to Kappa coefficient of 0.87. Following supervised image classification, classes detected and properly identified are extracted and then filtered to consider the minimal size requirements of the map. Then, the boundaries of the classified regions were subsequently vectorized. Feature extraction from imagery was limited to polygonal features.

For certain features such as water bodies better results were obtained by a simple region thresholding of the panchromatic band ETM8, considering values (gray levels) from 0 to 25. In all the fusion experiments, few feature improvements were obtained. The use of the single higher-resolution band permits the extraction of better-defined boundaries for the water bodies.

Semi-automated change detection

Figure 3 presents the steps for the semi-automated change detection process between old lake vectors and new lake vectors extracted from band ETM8 of Landsat-7. The non-intersection method is applied directly on the original vectors (3a) to obtain addition and deletion zones representing the change (3b). Then a 30m-buffer is generated around both original vectors to consider the planimetric accuracy tolerance (3c). The non-intersection method between the deletions and the new-buffered vectors determine the actual deletions while the non-intersection method between the additions and the old buffered vectors determine the actual additions (3d).

6. CONCLUDING REMARKS

Rapid change detection and data updating is becoming a significant requirement for mapping organizations and for detecting and monitoring changes of the landscape. The requirements for implementing automated procedures coupled with the availability of heterogeneous data are pushing towards the investigation, adaptation and evaluation of new approaches and techniques for detection and integration of change. The data sets to be compared at two or more time periods are usually in various forms. The domain of comparison is determined based on the level of data semantics and processing. This implies that generation of homogeneous features is required for each temporal datasets.

In this study emphasis was placed in automating the various tasks involved in feature extraction and change detection. The initial datasets at time 1 consisted of monochrome topographic raster maps and database vectors, while the new data set was Landsat 7 ETM+ imagery. The detection of planimetric changes was performed on vector data extracted from both data sets. The entropy measure of the image texture and image thresholding were used for the extraction of certain features from the raster maps. For the image data, image and theme enhancements were performed by applying various image fusion (e.g., PCI-IMGFUSE) and spectral enhancement (e.g., Tasselled cap, NDVI). Image thresholding and image classification were applied for the extraction of features from the imagery.

Having defined and process the data sets for the epoch comparison, change detection was performed both visually and in an automated mode. The proposed and implemented automated technique is based on the non-intersection of old and new features, where a) additions are determined as the difference between the new features and the common elements of the two epochs; and b) deletions are difference between the old features and the common elements of the two epochs. To account for accuracy tolerances spatial buffer zones were incorporated as well. The tests showed that feature extraction operations were more or less feature/theme dependent, while the proposed semi-automated change detection technique can be implemented in the operational environment. They also showed that visual change detection approaches can be improved when enhanced data sets are used, while the incorporation of image processing techniques supports the effort to automate the process. Research work needs to continue to provide improved methods and tools for rapid and flexible extraction of homogeneous features, while further work is required to refine, test and implement the change detection methods. As multitemporal imagery will be coming more available change detection from multi-temporal images has to be investigated for topographic applications.

7. ACKNOWLEDGEMENT

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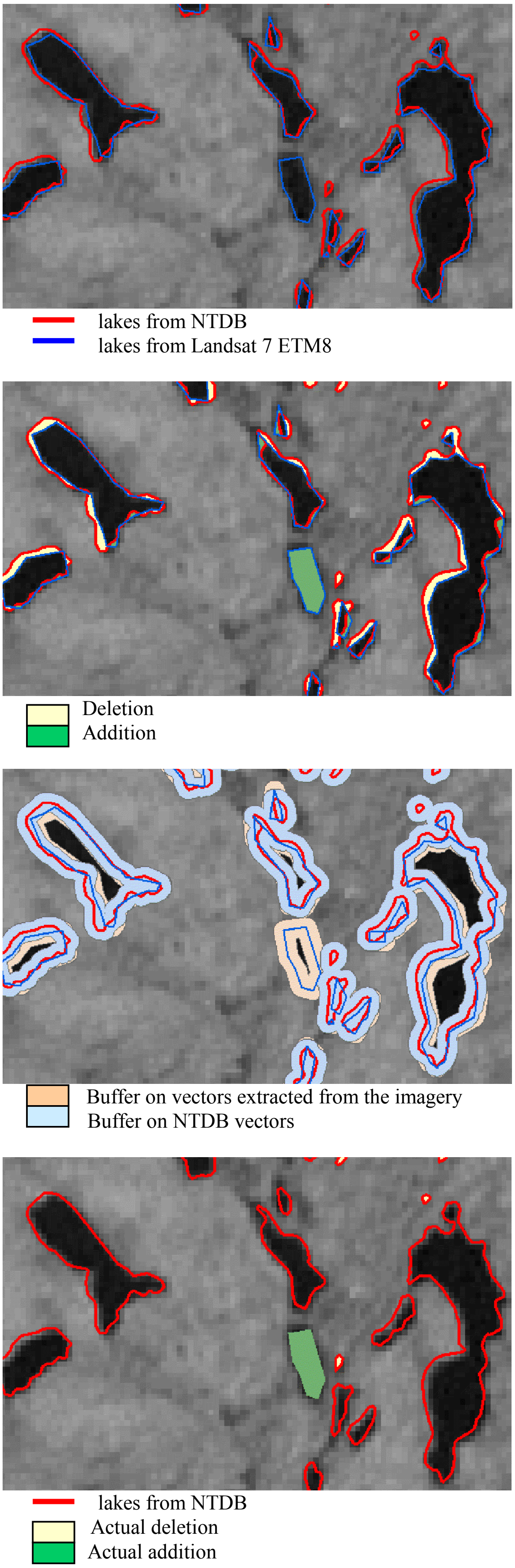

Figure 3: Change detection between old and new lake vectors.

in the developed approaches and their implementation.

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