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# Monitoring prairie wet area with an integrated LANDSAT ETM+, RADARSAT-1 SAR and ancillary data from LIDAR

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ABSTRACT

The provincial wetland ("status quo") maps of the Prairie Pothole Region, Central Canada, do not adequately depict wetland resources and properties. Using satellite remote sensing data from both LANDSAT Enhanced Thematic Mapper Plus (ETM+) and RADARSAT-1 Synthetic Aperture Radar (SAR) results in a more complete picture, although using both sources together is better than when either source is used alone. This study integrates LANDSAT ETM+, RADARSAT-1 SAR, and LIght Detection And Ranging (LIDAR) data, taking advantage of the synergy in their integration. A simple density slicing of the ETM-5 band was used to map inundated areas from LANDSAT ETM+. A fuzzy thresholding technique was used to map wet areas using RADARSAT-1 SAR data after information from LIDAR-DEMs had been used to correct confusing radar backscatter overlaps between open water and dry, flat, smooth surfaces. Compared to the "status quo", the integrated approach mapped 113% to 600% and 217% to 467% increases in the size of wet areas and pond densities, respectively. Maps based on the ETM-5 band alone detected 133% to 333% and 50% to 350% increases in the size of wet areas and pond densities, respectively over the "status quo" map, while maps based on the RADARSAT-1 SAR data detected 63% to 450% and 100% to 333% increases. The improved mapping capability is attributed to a combinatory power of the integrated approach in detecting small, transient and saturated wet areas.



## 1. Introduction

Wetland mapping activities are motivated by the need to conserve and restore wetlands for their socioeconomic and hydro-ecological functions and services. They are traditionally mapped using indicators such as hydrology, vegetation, or aquatic life and soil that are measured in situ, guided by topographic maps and aerial photographs used as base maps (USACE, 1987; MDEQ, 2001). This technique can produce accurate boundaries, particularly when high-resolution (1:2000–1:20,000) base maps are used, because indicators are measured in situ. However, since the base maps are often snapshots and have coarse resolutions (1:50,000 or 1:250,000; such as the provincial wetland maps of the Prairie Provinces of Central Canada, Saskatchewan), small wetlands (<0.1 ha) and seasonal hydrodynamics are not detected (Brown and Young, 2006). In the Prairie Pothole Region (PPR), small wetlands are the most abundant and impacted wetland type, and most prairie wetlands are rarely stable (Johnson et al., 2005). The water level of prairie wetlands show intra or inter-annual fluctuations in response to atmospheric water balance (i.e., Precipitation (P) – Evapotranspiration (ET)) (Hayashi et al., 1998). Therefore, provincial wetland ("status quo") maps that omit the small wetlands and their hydrodynamics neglect a significant portion of prairie wetland resources and properties.

Alternatively, both optical (e.g., LANDSAT ETM+) and radar (e.g., RADARSAT-1 Synthetic Aperture Radar (SAR)) satellite remote sensing data is available at spatial resolutions that can map small-sized wetlands (Brown and Young, 2006). Because of their multi-temporal observations, satellite sensors can also capture the intra- and inter-annual dynamics of wetland boundaries. Several methods have been used to map wetlands using RADARSAT-1 SAR and LANDSAT ETM+ data. Techniques that have been used with the RADARSAT-1 SAR data include a threshold detection technique (Brun et al., 1990), Saturation Potential Index (SPI) (Gineste et al., 1998; Troch et al., 2001), Principal Component Analysis (PCA) (; Troch et al., 2001; Bourgeau-Chavez et al., 2005), and a fuzzy threshold technique (Sass and Creed, 2008; Clark et al., 2009). Unsupervised classifications (Macleod and Congalton, 1998) and supervised classifications (de Roeck et al., 2008) have been used with LANDSAT data, as well as a Normalized Difference Vegetation Index (NDVI), Infrared-Visible Ratio (IVR), Infrared Ratio (IR), and a Simple Density Slicing of ETM-5 band data as discussed by Ozesmi and Bauer (2002).

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Although each method works well under specific conditions, their broader applications have been scrutinized. For example, the absolute threshold value (−7 dB) proposed by Brun et al. (1990) for use with RADARSAT-1 SAR data, was not as effective when applied to landscapes other than low vegetation such as meadow or pasture (Gineste et al., 1998; Troch et al., 2001). Similarly, though PCA mapped saturated areas on the heterogeneous landscapes of the Zwalm catchment in Belgium (Troch et al., 2001), relating a particular PCA component to surface hydrology was challenging when used to monitor patterns of wetlands in the greater Everglades of South Florida (Bourgeau-Chavez et al., 2005). Recently, the fuzzy threshold technique, which implements adaptive thresholds that account for uncertainties from confounding noise in radar backscatter (the effects of terrain and surface roughness), has shown some success (Sass and Creed, 2008; Clark et al., 2009). With respect to the LANDSAT TM data, NDVI, when applied to LANDSAT TM data did not detect forested wetlands in the lower Roanoke River floodplain of North Carolina (Townsend and Walsh, 1998), but later successfully identified wetlands in open forest and agricultural lands of eastern Canada near Ottawa, Ontario; Montreal, Quebec; and eastern Labrador, Newfoundland (Li and Chen, 2005).

Generally, the existence of these many techniques implies that there is no single best technique for mapping and monitoring wetlands. Additionally, both LANDSAT ETM+ and RADARSAT-1 SAR data have their own limitations. The LANDSAT TM sensors cannot penetrate clouds and vegetation to detect wetlands underneath (Townsend and Walsh, 1998). While radar signals can penetrate clouds, topography (terrain effects) and surface roughness can adversely impact accuracy (Dobson and Ulaby, 1998).

The objectives of this study were therefore to: a) develop a prairie wetland mapping tool that integrates LANDSAT ETM+/RADARSAT-1 SAR data and ancillary terrain information from LIDAR (LIght Detection And Ranging); and b) examine prairie wet areas and characterize the regional and temporal dynamics of wet area hydrology during the snow-free period. It was hypothesized that a synergy in the integrated approach could overcome the limitations in either data source and produces more accurate wetland maps. In this study, the term "wetland" is used interchangeably with "wet area." Both wet areas and wetlands consist of inundated (open-water) and saturated areas. To meet the definition of wetland in terms of hydrologic permanencies, however, areas must be wet during two consecutive cycles of observation (21 days). However, the term "wet area" instead of "wetland" is used to avoid arguments that may rise from unaccounted soils' morphological properties that often used in wetland definition.

## 2. Methods

### 2.1. Study area

Three study sites (Fig. 1) were selected: Old Wives, about 80 km southwest of Moose Jaw, Saskatchewan; Allan Hills, about 50 km southeast of Saskatoon, Saskatchewan; and Hartt, about 40 km northeast of Melfort, Saskatchewan. The sites, which are situated along the north–south prairie climatic gradient, were picked to: a) test the developed mapping and monitoring tools across prairie regions; and b) examine the hydrologic responses of prairie wetlands along a north-to-south climatic gradient. The 30-year (1975–2005) annual mean temperature and total precipitation of the study areas indicate that Hartt, the northernmost site, has a lower temperature and higher precipitation (1 °C and 453 mm, respectively) than Old Wives (3.4 °C and 352 mm, respectively), the southernmost site (Agriculture and Agri-food Canada, 1997). Similarly, the average temperature and cumulative precipitation and potential ET were 11.9 °C, 506 mm and 507 mm at Hartt and 13.7 °C, 509 mm and −257 mm at Old Wives during the study period of 2005. The topography, soils, and vegetation of the study sites are similar and typical of the broader PPR. They have a rolling, hummocky topography with 5% to 10% average slope gradients. The soils are clay-loam in texture and fall under the Canadian soil order known as "Chernozem," while the vegetation of the study areas is homogeneously native prairie grassland.

### 2.2. Data description and pre-processing

Multi-temporal LANDSAT ETM+ and RADARSAT-1 SAR data, provincial wetland maps and terrain data from LIDAR were used in this study. A sensor carried aboard the LANDSAT 7 satellite collected LANDSAT ETM+ images. The images have 30 m × 30 m spatial resolution, 180 km × 180 km swath width, and consist of eight spectral bands: three visible, three infrared, one thermal infrared, and one panchromatic band. They were provided by the U.S. Geological Survey – Earth Resources and Observation Science (USGS-EROS). The images were pre-processed by the USGS-EROS to remove systemic and terrain-induced distortions, then projected and referenced to Universal Transverse Mercator (UTM) and World Reference System (WRS), respectively. The images were cloud-free but had gaps from defects due to a LANDSAT 7 instrumental malfunction. After the images were cropped to the size of the study sites the gaps were filled following a procedure obtained from the USGS-EROS using data from the closest anniversary images taken prior to 2003 (Scaramuzza et al.,

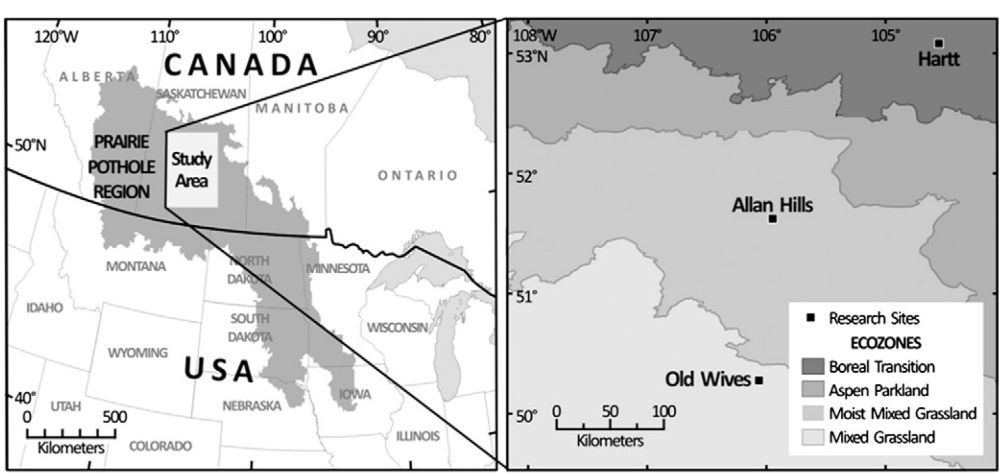


**Fig. 1.** Map showing study site locations.