Delineating Surface Water Features in the Prairie Pothole Wetlands with MODIS Data

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Abstract

Observation and investigation of the surface water dynamics in the Prairie Pothole Region (PPR) are important for understanding the hydrological characteristics of the wetland ecosystem. In this study, we developed a water delineation model using the 500-meter resolution Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance data. The Landsat TM and ETM+ imagery was used to calibrate and validate the model. We have produced a prototype of the MODIS water feature maps for the U.S. portion of the PPR at 32-day intervals for the growing seasons from 2000 to 2006.

I. Introduction

The Prairie Pothole Region, covered with thousands of shallow ponds known as potholes formed when continental glaciers retreated more than 10,000 years ago, is a large wetland area in central North America (fig. 1). The PPR wetlands are valuable because of the ecosystem services they provide, including water balance, flood mediation, habitat for migratory birds, waterfowl production, and carbon sequestration. During the last century, impacts of intense land use and climate change have caused drastic reductions of surface water area and wetland habitat in most areas of PPR. An estimated 40 – 50 percent of the original prairie pothole wetlands remain undrained today.

Spatial and temporal observations of the surface water dynamics are important for understanding the hydrological and ecological characteristics in PPR wetlands. Remote sensing techniques serve a critical role in monitoring surface water variations. Of the current sensors, MODIS has the advantages of large coverage (a swath of 2,330 km), frequent observations (daily), multiple bands, and free accessibility. Therefore, MODIS surface reflectance data may provide a tool for detecting water features and monitoring the surface water area dynamics within wetlands.

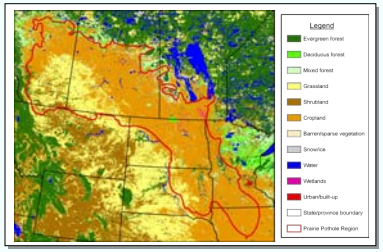

Fig. 1. Land cover map of the Prairie Pothole Region (PPR) in North America. The study area is the wetlands of the U.S. portion of the PPR. The land covers were simplified from the GLC2000 map.

II. Objective

The objective of this study was to investigate the practicality of monitoring the surface water dynamics of PPR wetlands using the coarse resolution MODIS reflectance data.

III. Data

We used the MODIS surface reflectance data (MOD09A1, Version 4) processed as 8-day composites at 500-meter resolution from 26 February 2000 to 31 December 2006. Quality Assurance (QA) layer was used to mask the cloud and shadow contaminated pixels.

Additionally, we acquired 26 Landsat TM and ETM+ scenes (in nine path/rows). All Landsat images were clipped to 100×100 km subsets (fig. 2). Among the 26 Landsat image subsets, 14 were used to calibrate the MODIS water delineation models and 12 were used to independently validate the MODIS water feature products.

Fig. 2. A total of 26 Landsat TM and ETM+ scenes in nine path/rows were used to calibrate the water delineation models and validate the MODIS surface water maps.

IV. Methods and Results

The normalized difference water index (NDWI, defined as NDWI = (green – NIR)/(green + NIR), or (green – MIR)/(green + MIR), was used to delineate the surface water features (McFeeters, 1996; Xu, 2006). Landsat images provide adjustments to the NDWI thresholds so that three levels of percent-water from the MODIS data can be obtained: land (water < 25%), land/water mixture (water = 25 – 75%), and water (water >75%).

The procedure for developing the MODIS water delineation model included the following steps: (1) selected 14 samples of cloud-free Landsat scenes and samples of MODIS images that match the dates and areas of the Landsat scenes, (2) created water/nonwater maps for the Landsat scenes, then converted them into percent-water area for 500-m grids that match the pixel sizes of the MODIS data (fig. 3), (3) used the percent-water images to adjust the NDWI thresholds in order to generate three levels of percent-water for the MODIS images (fig. 4), and (4) used 12 independent Landsat percent-water area maps to assess the accuracy of the MODIS water maps.

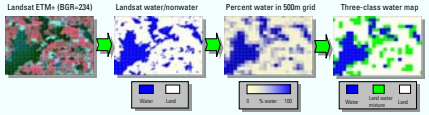

Fig. 3. Illustration of converting a Landsat ETM+ image (p29r29, 4 Aug 2001) to percent-water map and three-class of MODIS grid water map.

IV. Methods and Results (cont'd)

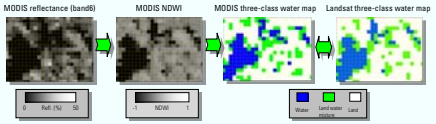

Fig. 4. Illustration of converting a 8-day MODIS reflectance image (8-day composite, 28 July - 4 Aug 2001) to NDWI map and three-class MODIS water map. Note the agreement between MODIS and Landsat water maps.

To validate the MODIS three-class water map, we compared the MODIS-derived water area with the Landsat-derived water area at 5-km grid level (fig. 5). In the comparison, total surface water area within each 5-km grid was calculated for both MODIS- and Landsat-derived maps. We estimated the MODIS water area according to the assumption:

1 water pixel = 0.25 km^2 of water area

1 land/water mixture pixel = 0.5 water pixel = 0.125 km^2 of water area

Agreement analysis was performed for the MODIS- and Landsat-estimated water areas. For 12 Landsat scenes (100 × 100 km subsets), there are 400 grids × 12 scenes = 4,800 grids. The regression for the 4,800 grids shows a high correlation between the two estimates (fig. 6), implying the water estimation with MODIS is satisfactorily accurate.

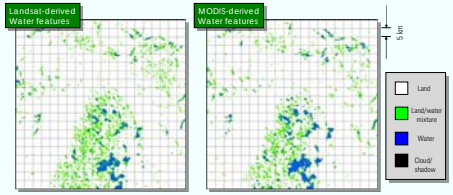

Fig. 5. Agreement between the MODIS- and Landsat-derived three-class water maps for a subset of Landsat scene. The percent water areas in MODIS- and Landsat-derived maps were compared at a 5-km grid level.

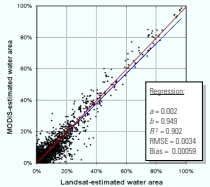

Fig. 6. Linear regression of Landsat-estimated and MODIS-estimated surface water areas. Coefficients *a* and *b* are the intercept and slope.

By applying the MODIS water delineation model, we were able to produce 500-m surface water maps. After the cloud and shadow pixels were masked, the original MODIS 8-day composites were aggregated to 32-day composites. The prototype of the MODIS water map is a 32-day composite for the growing season of 2002 – 2006 from PPR wetlands. Fig. 7 shows the MODIS surface water maps showing the interannual water dynamics in the summer season.

IV. Methods and Results (cont'd)

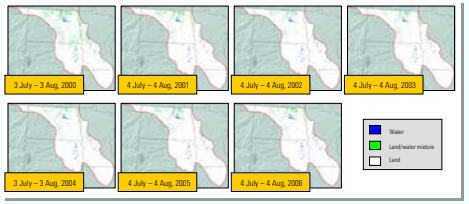

Fig. 7. Surface water maps based on the 32-day composite 500-m MODIS NDWI data. The selected maps show the interannual water variations during the summer from 2000 to 2006.

V. Summary

We have produced and illustrated a prototype of the MODIS water feature maps for the U.S. portion of the PPR at 32-day intervals for the growing seasons from 2000 to 2006. The time series of MODIS-derived water feature maps will be useful for delineating water features and monitoring water area dynamics in this area, and these products provide coarse resolution information to support conservation and management across large regions of the PPR wetlands. The development of the technique is also valuable for analysis of water dynamics for different wetland areas, such as the Yukon River Basin in Alaska. Further investigation will include analyses of relationship between surface water area and climate, and temporal and spatial correlation of bird abundance and surface water.

Literature Cited

McFeeters, S. K., 1996. The use of Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, 17(7): 1425-1432.

Xu, H., 2006. Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, 27(14): 3025-3033.

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