A Framework to Combine Three Remotely Sensed Data Sources for Vegetation Mapping in the Central Florida Everglades

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Abstract

A framework was designed to integrate three complimentary remotely sensed data sources (aerial photography, hyperspectral imagery, and Light Detection and Ranging (LiDAR)) for mapping vegetation in the Florida Everglades. An object-based pixel/feature-level fusion scheme was developed to combine the three data sources, and a decision-level fusion strategy was applied to produce the final vegetation map by ensemble analysis of three classifiers k-Nearest Neighbor (k-NN), Support Vector Machine (SVM), and Random Forest (RF). The framework was tested to map 11 land-use/land-cover level vegetation types in a portion of the central Florida Everglades. An informative and accurate vegetation map was produced with an overall accuracy of 91.1 % and Kappa value of 0.89. A combination of the three data sources achieved the best result compared with applying aerial photography alone, or a synergy of two data sources. Ensemble analysis of three classifiers not only increased the classification accuracy, but also generated a complementary uncertainty map for the final classified vegetation map. This uncertainty map was able to identify regions with a high robust classification, as well as areas where classification errors were most likely to occur.

Introduction

Many on-going and completed projects in the Comprehensive Everglades Restoration Plan (CERP) require accurate and informative vegetation maps because restoration will cause dramatic modification of plant communities (Doren et al. 1999). Vegetation maps derived from remotely sensed data serve as valuable tools for assessing CERP restoration efforts. With the increasing availability of multi-sensor, multi-temporal, and multi-resolution images, data fusion (the integration of multi-source data) has become a valuable tool for updating wetland inventory (Kloiber et al. 2015). **The primary objective of this study is to explore the potential of fusing aerial photography, hyperspectral imagery, and LiDAR for vegetation mapping in the Florida Everglades.**

Study Area and Data

The study site is a portion of Caloosahatchee River watershed in the central Florida Everglades (Figure 1), with a total of eleven land-use/land-cover level vegetation communities (Table 1). Data sources include: 1) 1 m spatial resolution aerial photographs collected on 11/04 by National Aerial Photography Program (NAPP), 2) 30 m hyperspectral imagery collected 10/05 by Hyperion Imaging Spectrometer onboard EO-1 spacecraft, 3) LiDAR (1.2 pts/m2) collected using Leica ALS-50 system on 12/07 to support Florida Division of Emergency Management, and 4) South Florida Water Management District (SFWMD) digital vegetation map used as reference data.

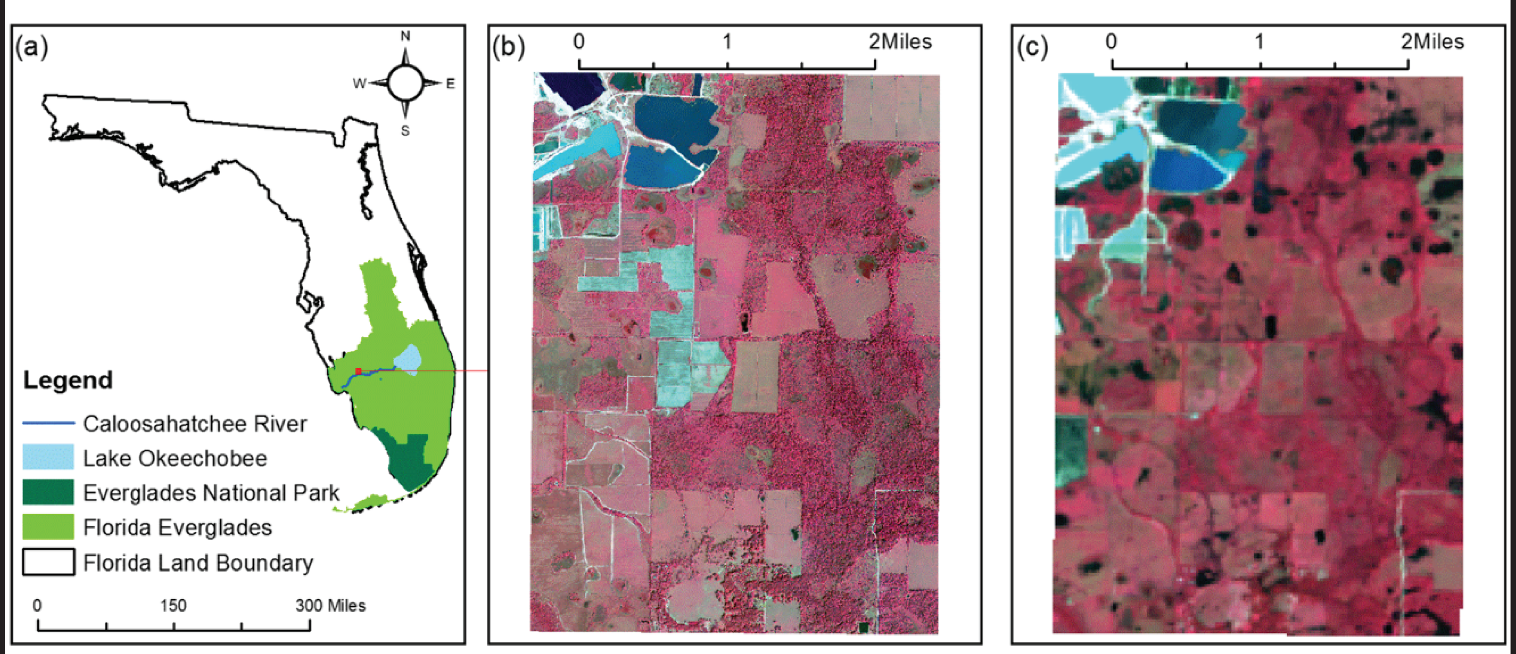

Figure 1 Map of the Florida Everglades (**a**), study site shown as a color infrared (CIR) 1-meter aerial photography (**b**), and a color composite from the 30-meter EO-1/Hyperion imagery (Bands 40, 30, and 20 as red, green and blue) (**c**).

Table 1 Vegetation communities and the number of reference image objects for each.

Vegetation types	Reference objects	Dominant species
1. Improved pastures	92	Single grass
2. Unimproved pastures	32	Variety of native grasses
3. Woodland pastures	56	Variety of native tree and shrub
4. Field crops	110	Hay, grasses, sugar cane
5. Citrus groves	14	Oranges, grapefruits and tangerines
6. Upland shrub and brushland	28	Various types of herbs and grasses
7. Palmetto prairies	20	Saw palmetto
8. Mixed rangeland	22	Mixture of herbaceous species and shrubs
9. Pine flatwoods	252	Slash pine, saw palmetto, gall berry, grasses
10. Mixed wetland shrubs	18	Various shrubs
11. Freshwater marshes and wet prairies	94	Herbaceous vegetation

Methodology

For this study a framework was designed to fuse three remotely sensed data to effectively map vegetation in the Everglades, as shown in Figure 2.

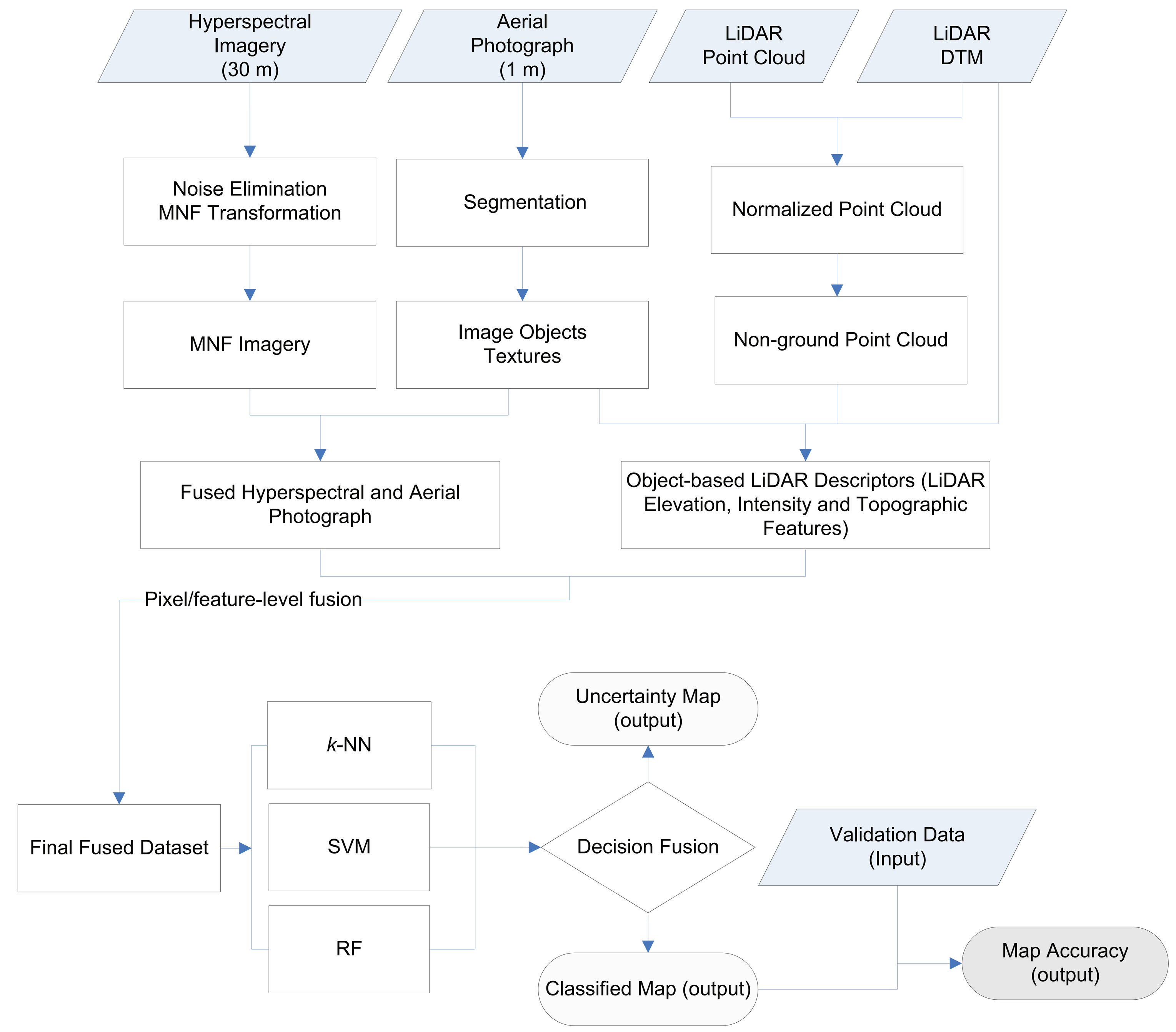

Figure 2 The designed framework to combine three remotely sensed data sources for wetland vegetation mapping.

Results

The best result was achieved by fusing three data sources, and the ensemble analysis result displayed as Experiment 13 in Table 2 increased the classification. An object-based vegetation map was thus produced using the fused dataset of the three data sources and ensemble analysis of three classifiers, as shown in Figure 3(a). The corresponding uncertainty map is shown as Figure 3(b).

Table 2 Classification accuracies and statistical tests from different datasets and classifiers.

Experiment	Overall Accuracy (%)	Kappa Value	z-Score (Kappa)	z-Score (McNemar)
Aerial Photograph				
1. *k*-NN	71.3	0.65	23.9	4.91*; 4.64 (1/4; 1/7)
2. SVM	69.6	0.63	22.2	6.44*; 6.04 (2/5; 2/8)
3. RF	72.9	0.67	24.5	4.81*; 4.65 (3/6; 3/9)
Aerial Photograph and Hyperspectral Imagery				
4. *k*-NN	83.2	0.80	35.1	4.42* (4/13)
5. SVM	84.6	0.81	36.3	3.62* (5/13)
6. RF	82.7	0.79	33.4	4.62* (6/13)
Aerial Photograph and LiDAR				
7. *k*-NN	82.7	0.79	33.5	4.73* (7/13)
8. SVM	85.1	0.82	37.2	3.89* (8/13)
9. RF	82.7	0.79	33.5	4.73* (9/13)
Aerial Photograph, Hyperspectral Imagery, and LiDAR				
10. *k*-NN	88.1	0.86	42.9	2.52* (10/13)
11. SVM	90.5	0.88	48.6	0.63 (11/13)
12. RF	87.5	0.85	41.5	2.71* (12/13)
13. EA	91.1	0.89	48.9	NA

k-NN: *k*-Nearest Neighbor; SVM: Support Vector Machine; RF: Random Forest; EA: Ensemble Analysis of *k*-NN, SVM, and RF; *: significant with 95 percent confidence; For the McNemar tests 1/4, 1/7, 2/5,…12/13 refer to the test between Experiments 1 and 4, 1 and 7, 2 and 5,… 12 and 13, respectively.

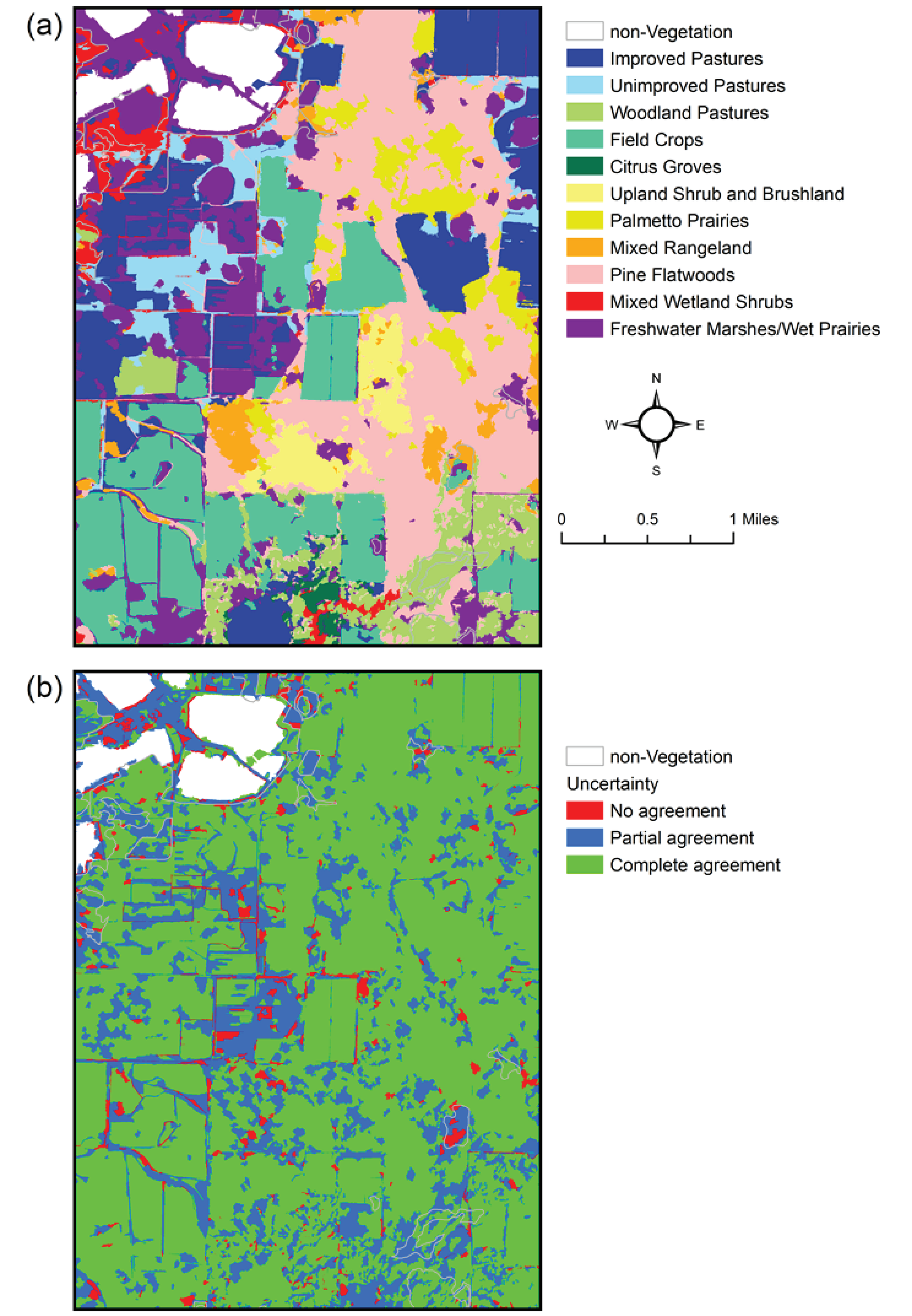

Figure 3. (**a**) Classified vegetation map from the fused dataset and ensemble analysis of the outputs of three classifiers; and (**b**) the uncertainty map generated from ensemble analysis of three classifiers.

Discussion

The developed object-based pixel/ feature-level fusion scheme successfully combines the spatial features of aerial photography, rich spectral contents of hyperspectral imagery, and elevation, intensity, and low posting-density LiDAR features. It complements the shortages and takes advantage of the benefit of each individual data source.

Conclusions

- A fusion of three data sources shows the promise to map diverse vegetation communities in complex wetlands. An integration of three data sources significantly improves the classification compared with the application of two data sources.
- The designed framework can be used as an alternative to the current manual procedure for updating and building vegetation databases in the Everglades. CERP largely collects aerial photographs; the EO-1/Hyperion is still on orbit and acquiring hyperspectral imagery; low-posting density LiDAR is available for many regions in the Everglades. Fusing three data sources has a potential to map broad areas in the Everglades with a reduced cost. With the increasing availability of three types of data it is anticipated this study can benefit the global wetland mapping in general, and the Florida Everglades in particular.

References

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