Cloud Segmentation for Satellite Imagery

LANGLOIS Henri,
PERNA Luca,
FREDJ Zacharie

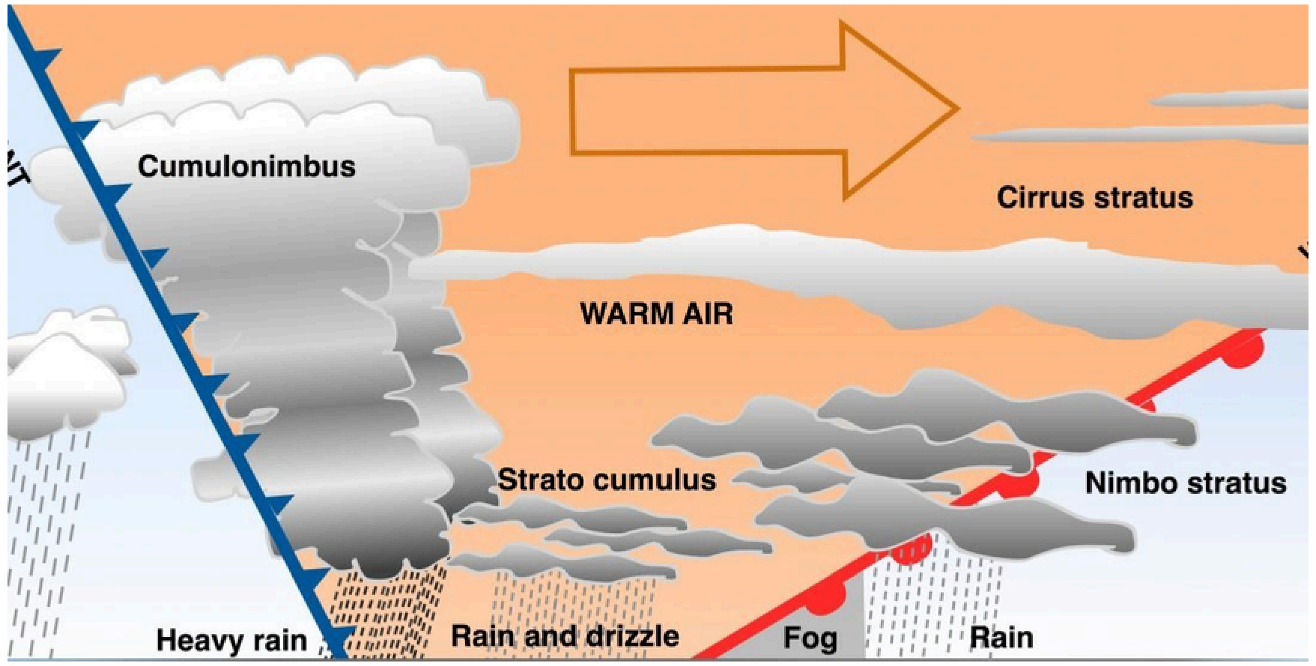
HUDELOT Céline,
Computer Vision

OUTLINE

INTRODUCTION

Clouds play a crucial role :

- producing precipitation
- regulating Earth's temperature by reflecting solar radiation and trapping heat.



PROBLEM DEFINITION

I : multi-spectral satellite image, where I(x, y, b) represents the intensity of the pixel at position (x, y) in spectral band b.

M : binary mask

$$M(x,y) = \begin{cases} 1 & \text{if } I(x,y) \geq \tau \\ 0 & \text{otherwise} \end{cases}$$

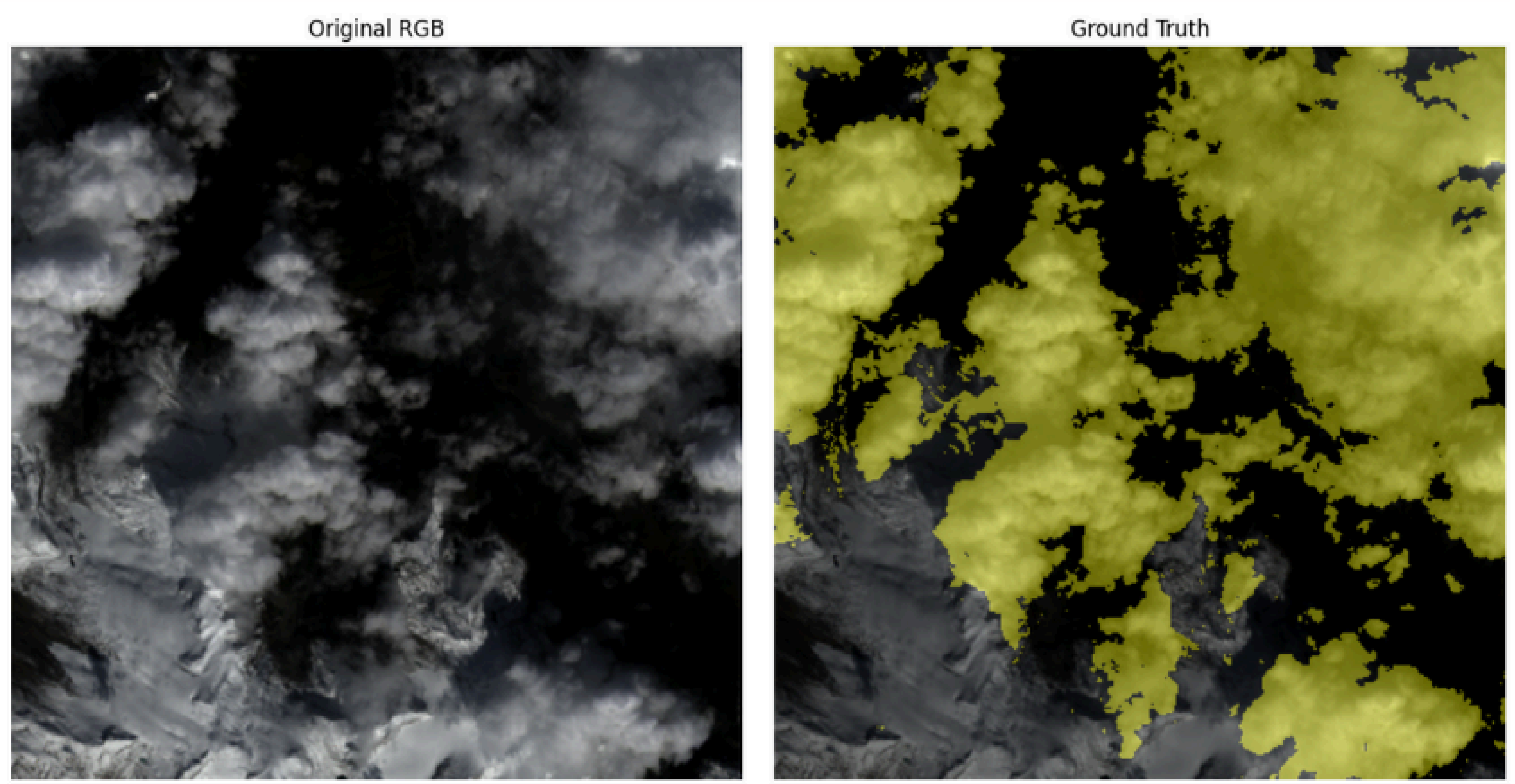
where τ is a threshold chosen to determine whether a pixel is classified as a cloud or not.

CHALLENGES

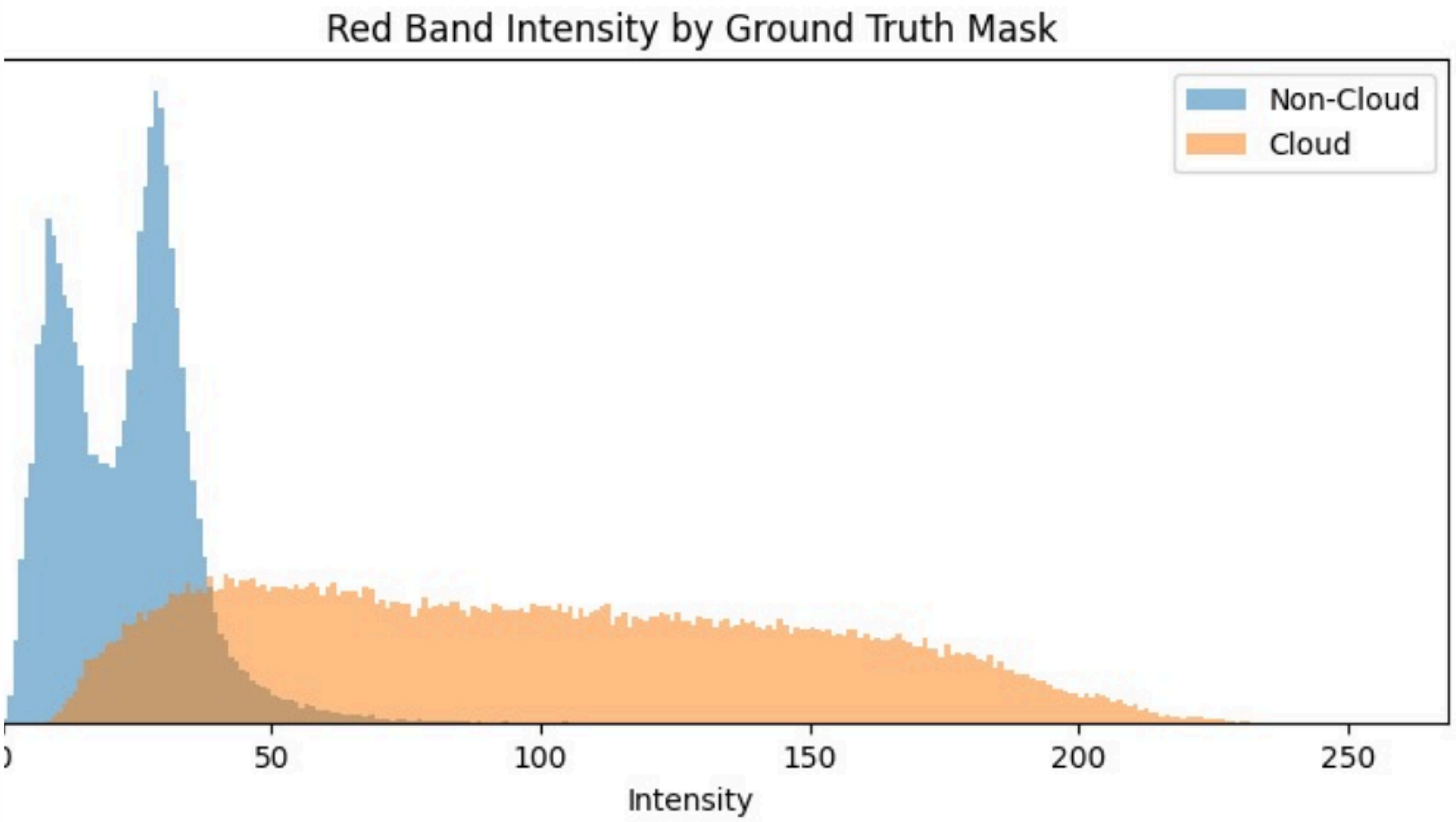
Several challenges :

- High variability in clouds appearances
- Surface features (e.g., snow, ice) can exhibit reflectance properties
- Lighting conditions and atmospheric effects

CHALLENGES



CHALLENGES

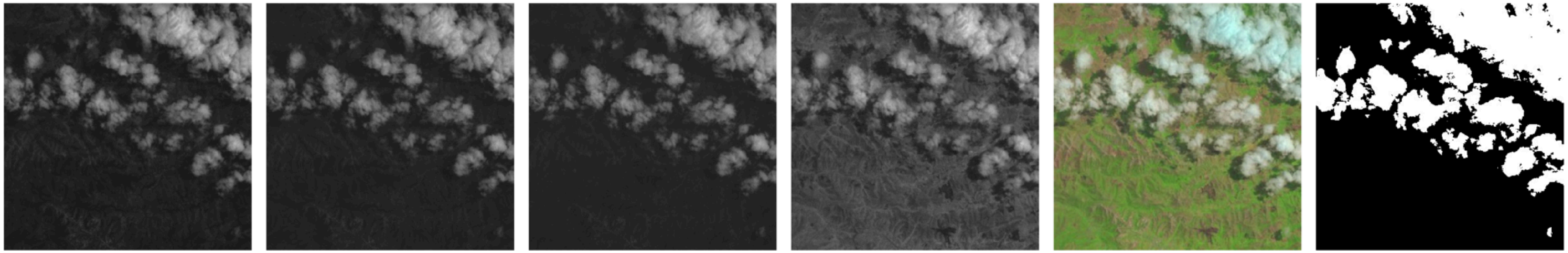


Red Band Intensity by Ground Truth Mask
Non-Cloud
Cloud
0
50
100
150
200
250
Intensity

METHODOLOGY

Data Preprocessing : 38-Cloud" dataset, S. Mohajerani and al.

- 38 Landsat 8 scenes
- Each image contains four spectral bands: red, green, blue, and near-infrared (NIR),
- Ground truth masks



METHODOLOGY

Computer Vision Methods Selection : Otsu

Find the optimal threshold that maximizes the inter-class variance between the background and foreground pixels.

Inter-Class Variance:

$$\sigma_b^2(t) = \omega_0(t)\omega_1(t)\left[\mu_0(t) - \mu_1(t)\right]^2$$

Optimal Threshold:

$$t^* = \arg\max_t \sigma_b^2(t)$$

METHODOLOGY

Computer Vision Methods Selection : Watershed

Morphological technique that treats images as topographic surfaces to delineate regions based on gradient magnitudes.

Distance Transform : Create a ”height map,” where each pixel’s value represents its distance to the nearest background pixel.

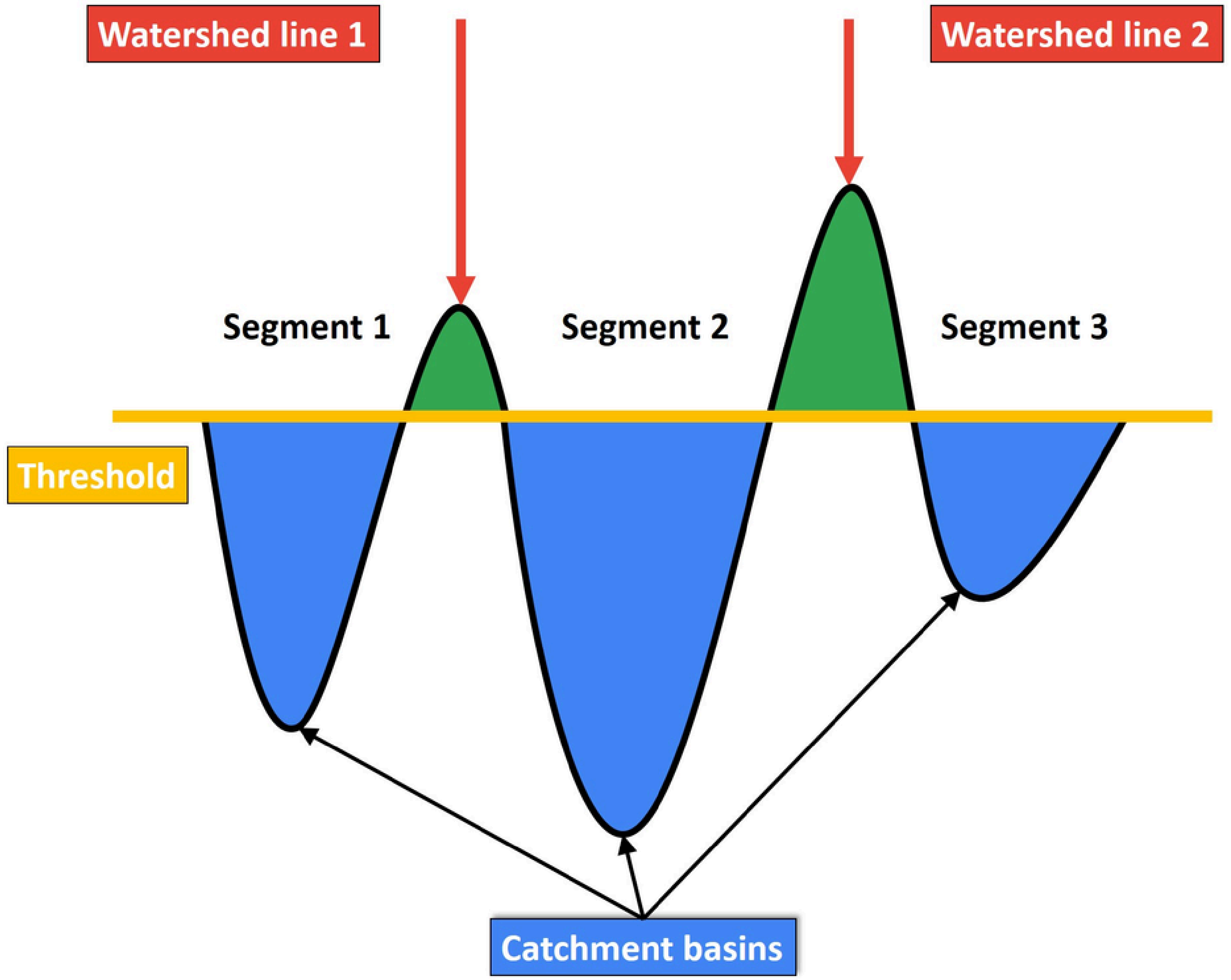
$$D(x, y) = \min \sqrt{(x - x')^2 + (y - y')^2}$$

METHODOLOGY

Computer Vision Methods Selection : Watershed

Watershed Transform : Assigns each pixel to a catchment basin based on the gradient flow

$$W(x, y) = \arg\min_{m \in M} \mathrm{dist}(P, m)$$



METHODOLOGY

Supervised Methods Selection : Gaussian Naives Bayes (GNB)

Probabilistic classifier that applies Bayes' theorem, enabling effective classification of cloud and non-cloud pixels based on spectral features.

Bayes' Theorem for Classification: The posterior probability of class k given a feature vector x is:

$$P(k|x) = \frac{P(x|k) \cdot P(k)}{P(x)}$$

METHODOLOGY

Supervised Methods Selection : Histogram-based

Uses the distribution of pixel intensities across spectral bands to distinguish between cloud and non-cloud pixels.

Histogram Computation and Probability Conversion: computes histograms for each class and converts them into probabilities using Laplace smoothing

$$P(x|k) = \frac{\text{counts}_k(x) + 1}{\sum(\text{counts}_k + 1)}$$

Log-Likelihood Calculation for Classification :

$$\log P(k|x) = \sum_{i=1}^{n} \log P(x_i|k) + \log P(k)$$

METHODOLOGY

Supervised Methods Selection : Decision Tree

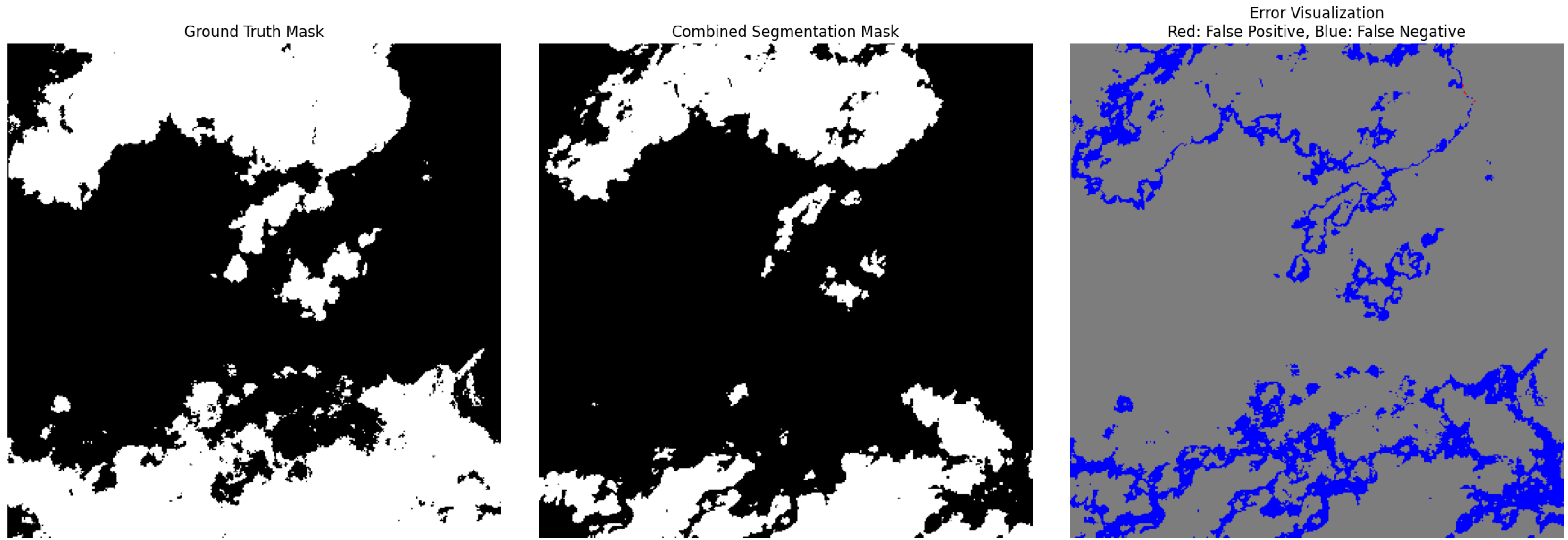
Trained per pixel to learn the most efficient decision boundaries between cloud and non-cloud pixels.

Gini Impurity Minimization: Every new split aims to minimize the impurity of the two leaves it generates.

$$G = 1 - \sum_{i=1}^{K} p_i^2$$

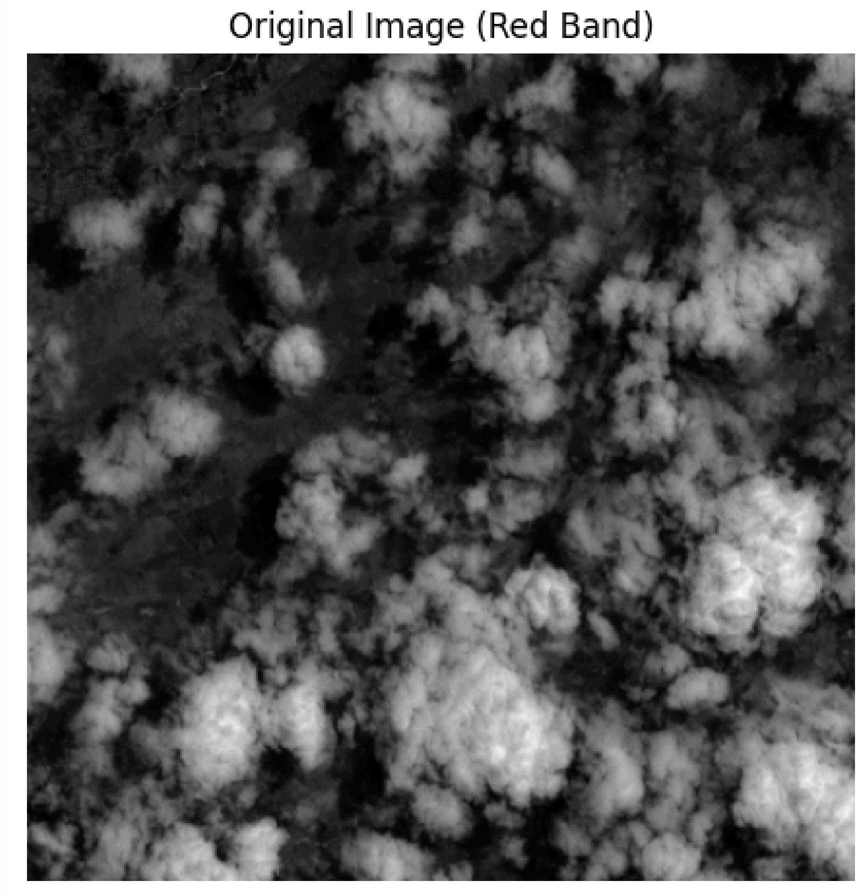
RESULTS

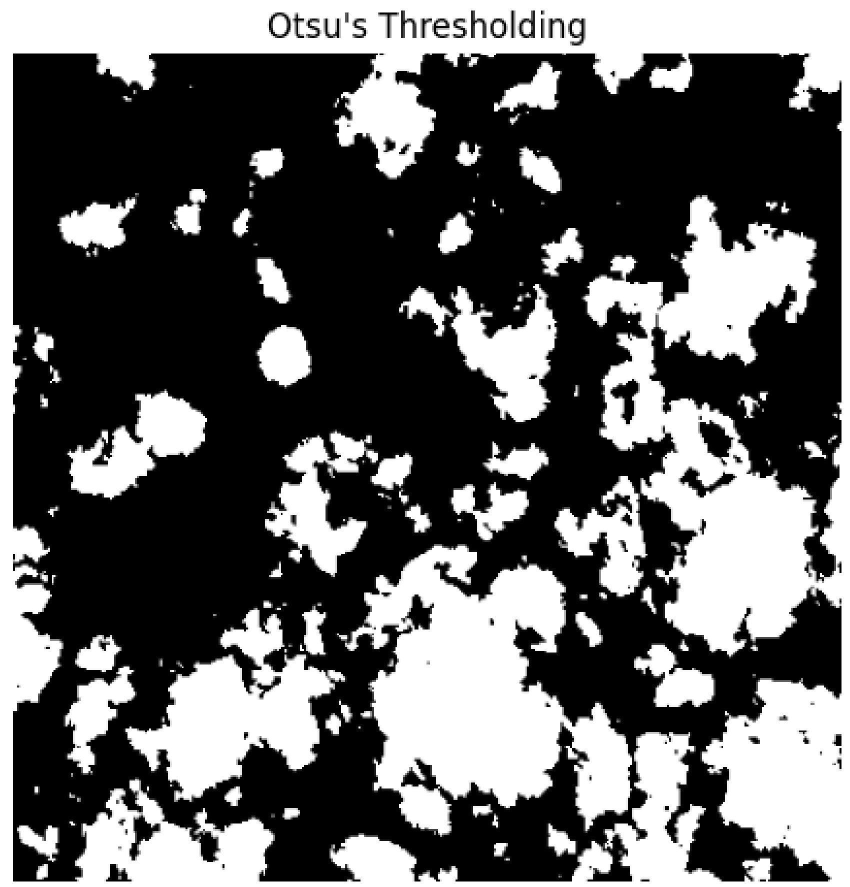
Otsu

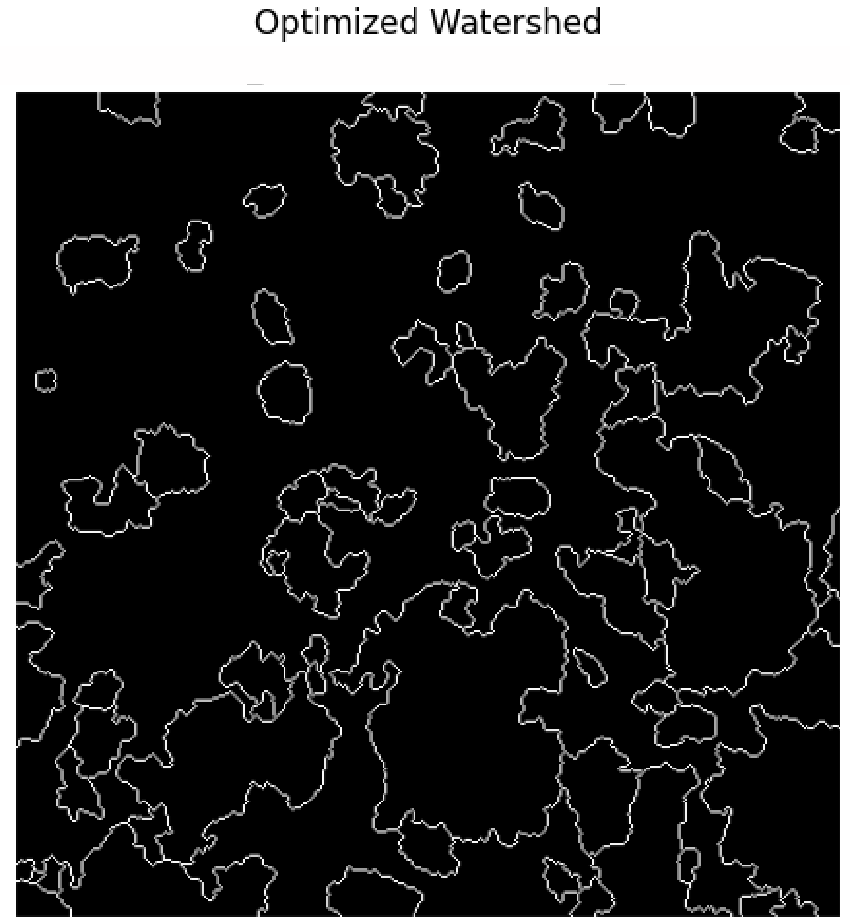


RESULTS

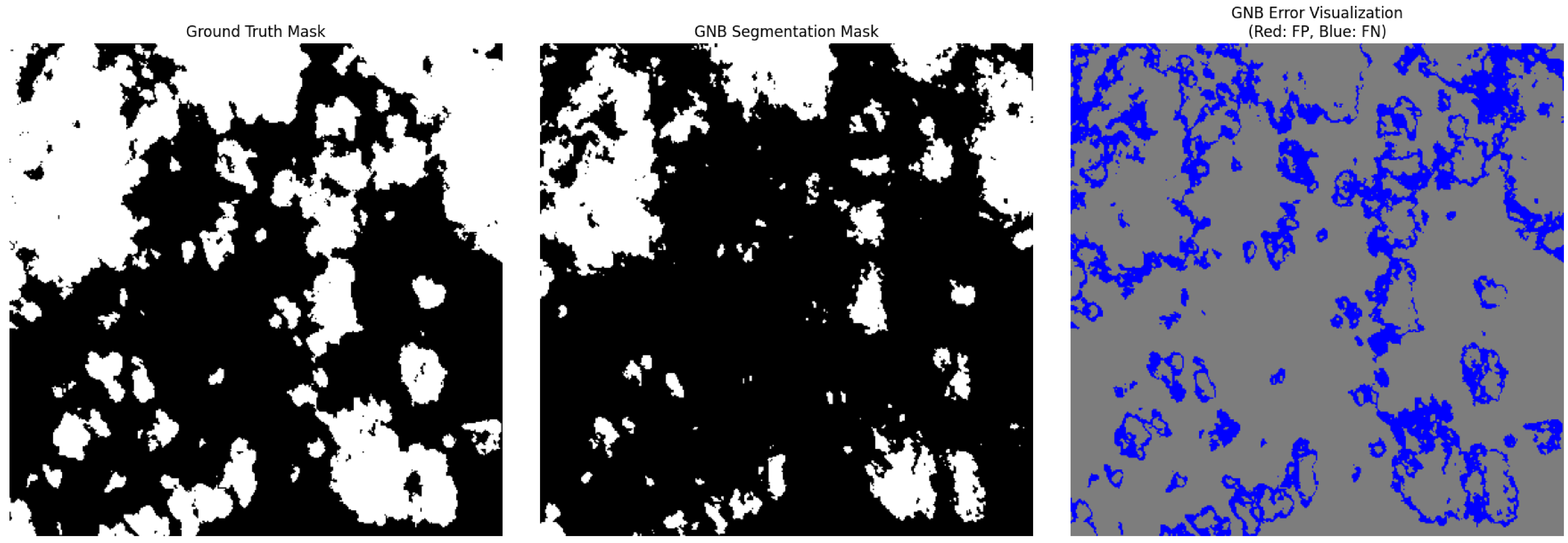
Otsu VS Watershed





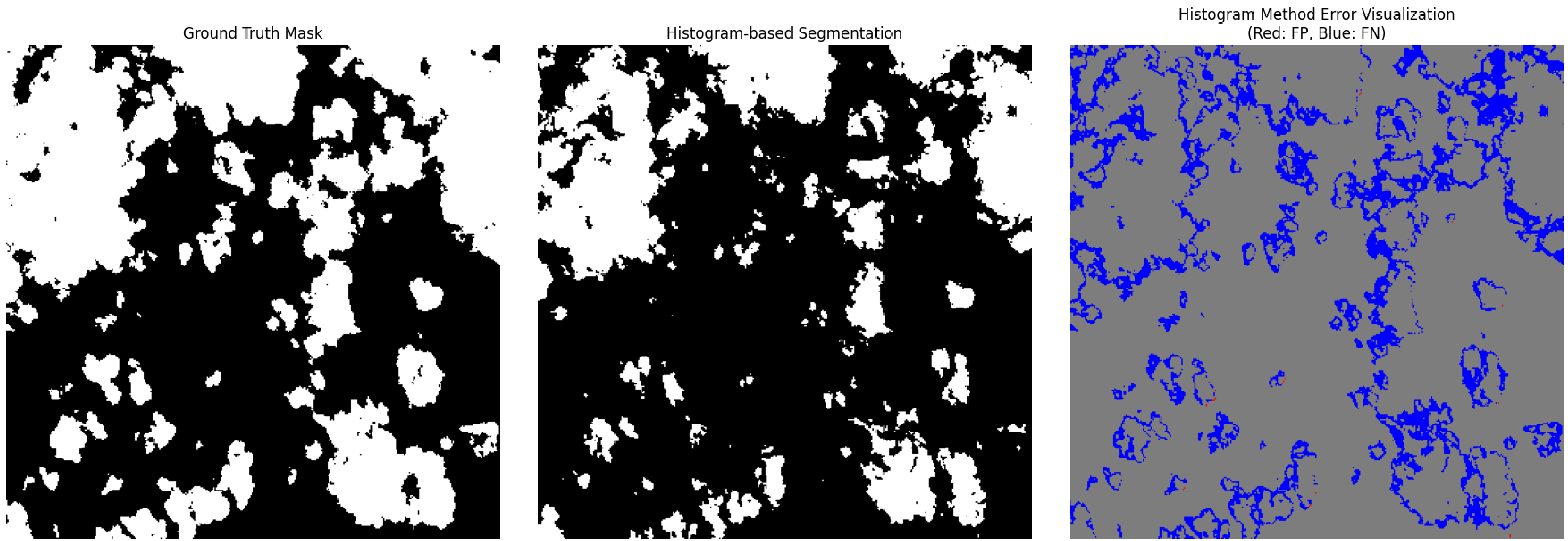


RESULTS

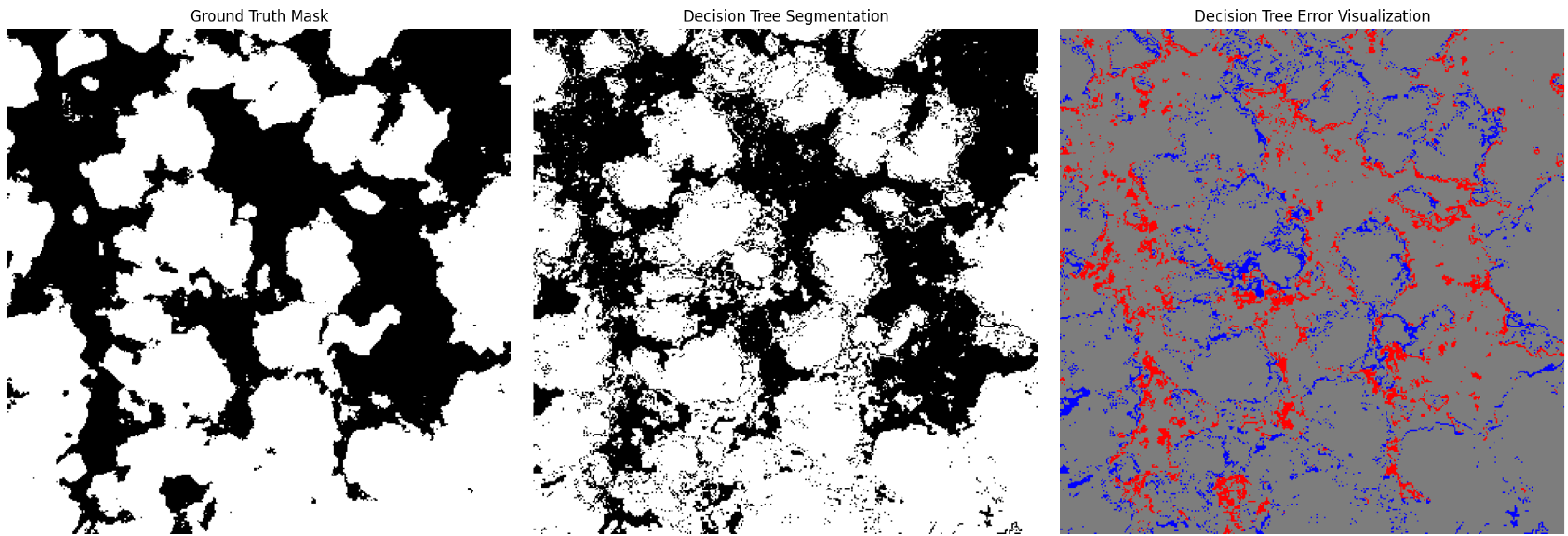


Ground Truth Mask
GNB Segmentation Mask
GNB Error Visualization
(Red: FP, Blue: FN)

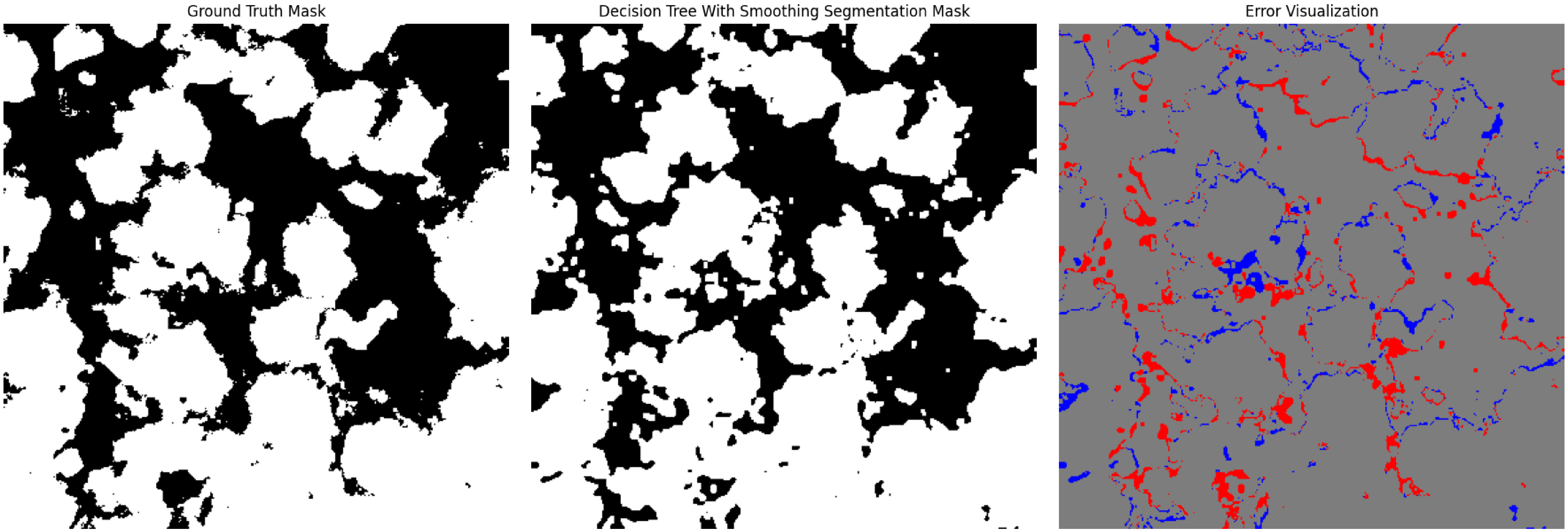
RESULTS


Ground Truth Mask
Histogram-based Segmentation
Histogram Method Error Visualization
(Red: FP, Blue: FN)

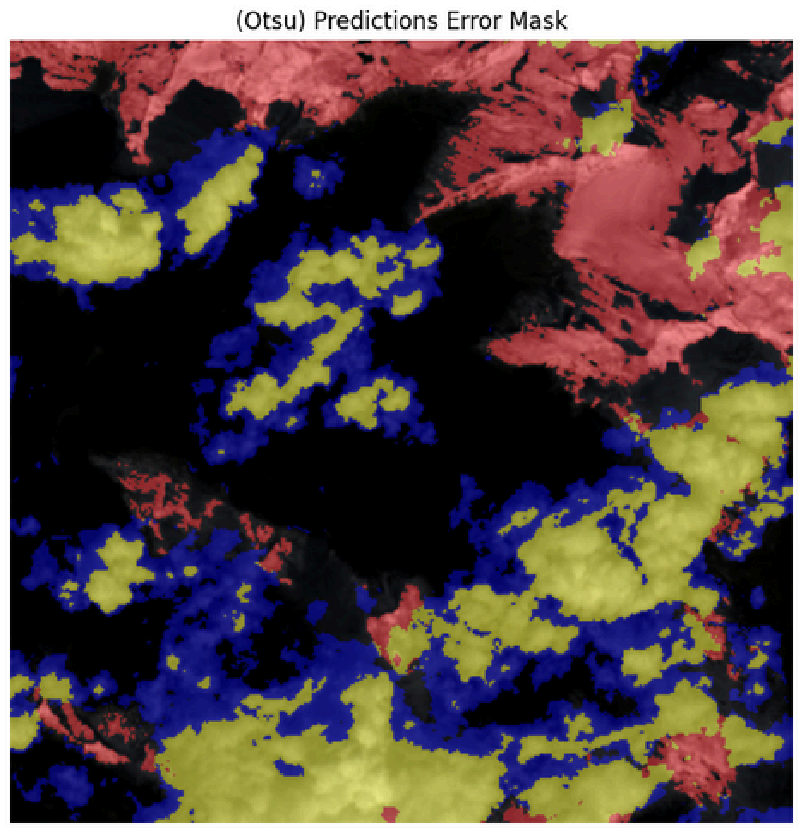
RESULTS

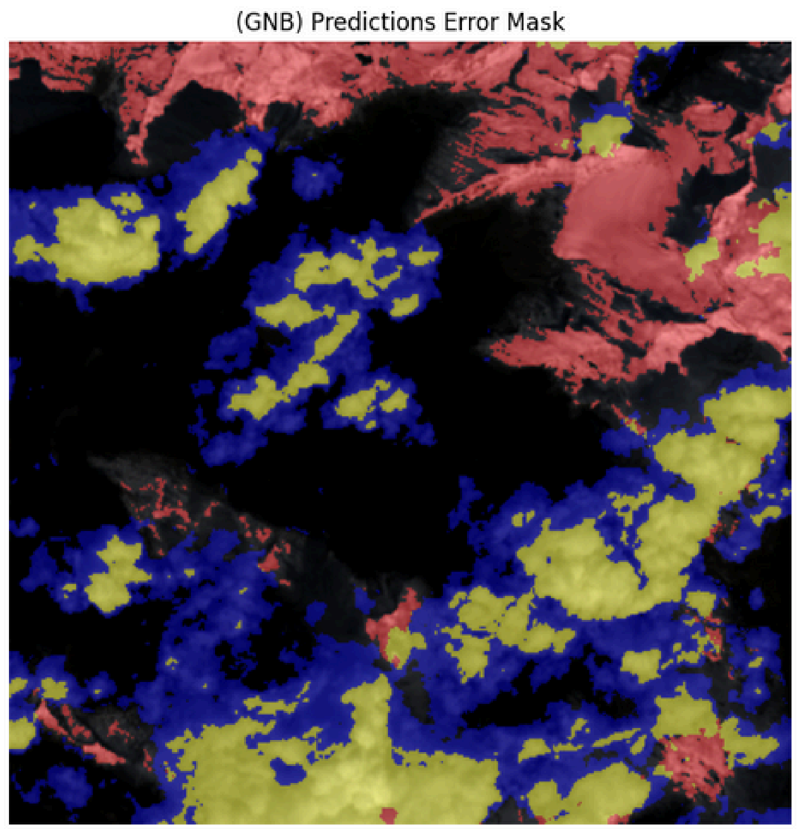

Ground Truth Mask
Decision Tree Segmentation
Decision Tree Error Visualization

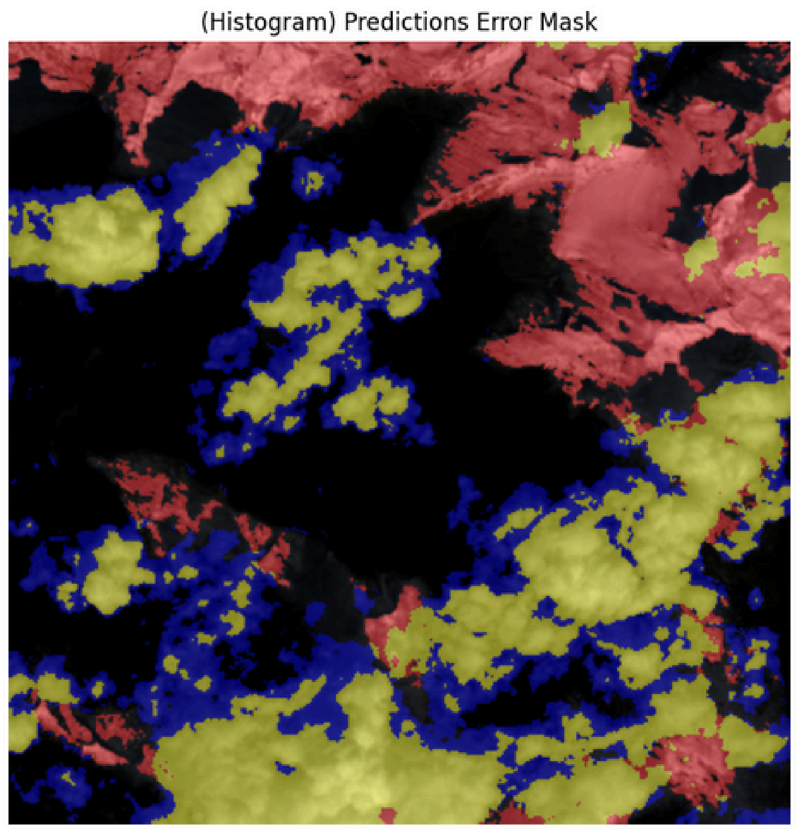
RESULTS

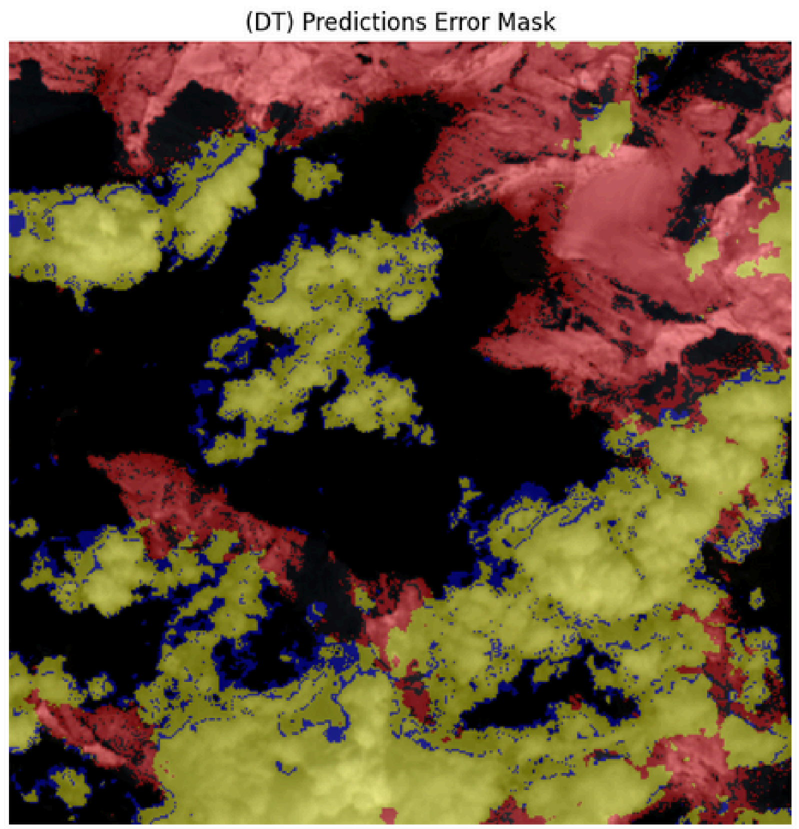

Ground Truth Mask
Decision Tree With Smoothing Segmentation Mask
Error Visualization

RESULTS


(Otsu) Predictions Error Mask


(GNB) Predictions Error Mask


(Histogram) Predictions Error Mask


(DT) Predictions Error Mask

RESULTS

$$\text{Precision} = \frac{TP}{TP + FP}$$

$$\text{Recall} = \frac{TP}{TP + FN}$$

$$\text{F1 Score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

$$\text{Jaccard Index} = \frac{TP}{TP + FP + FN}$$

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

Method	Precision	Recall	F1 Score	Jaccard	Accuracy
GNB	0.7234	0.6199	0.6050	0.5203	0.7594
Histogram-based	0.7089	0.6899	0.6406	0.5657	0.7697
Otsu's Method	0.7148	0.5489	0.5558	0.4484	0.6926
Watershed	0.5523	0.0424	0.0662	0.0349	0.5483
Decision Tree	0.6812	0.7765	0.6775	0.6232	0.7935

Table 1: Average metrics over 1000 images for different segmentation methods.

CONCLUSION

- Investigated classical computer vision techniques and supervised learning for cloud segmentation in satellite imagery.
- Observed differences in performance metrics across methods, with trade-offs between precision and recall.
- Explore hybrid techniques combining classical segmentation with lightweight learning-based refinements.

THANK YOU FOR YOUR ATTENTION !

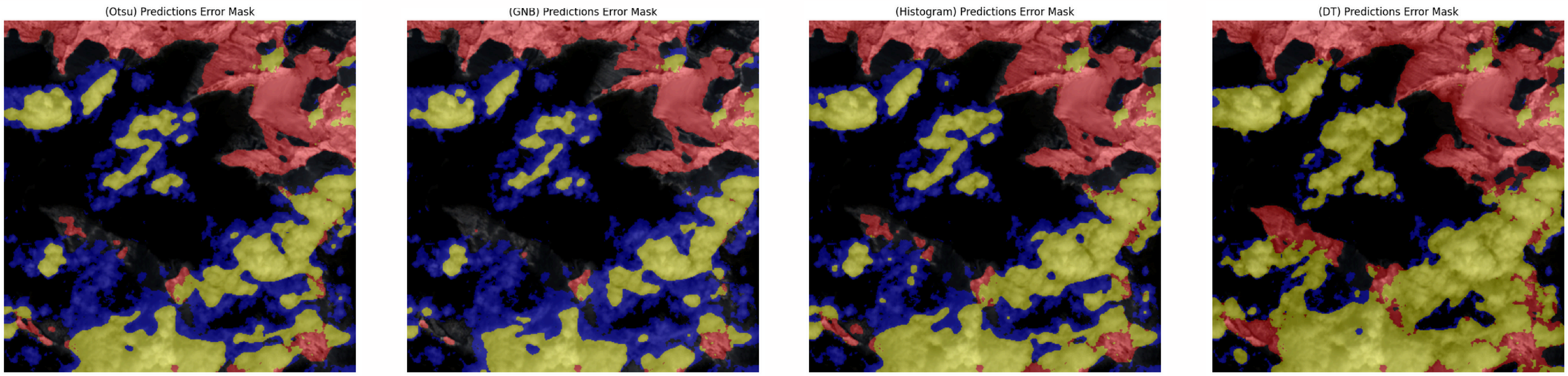
Any questions

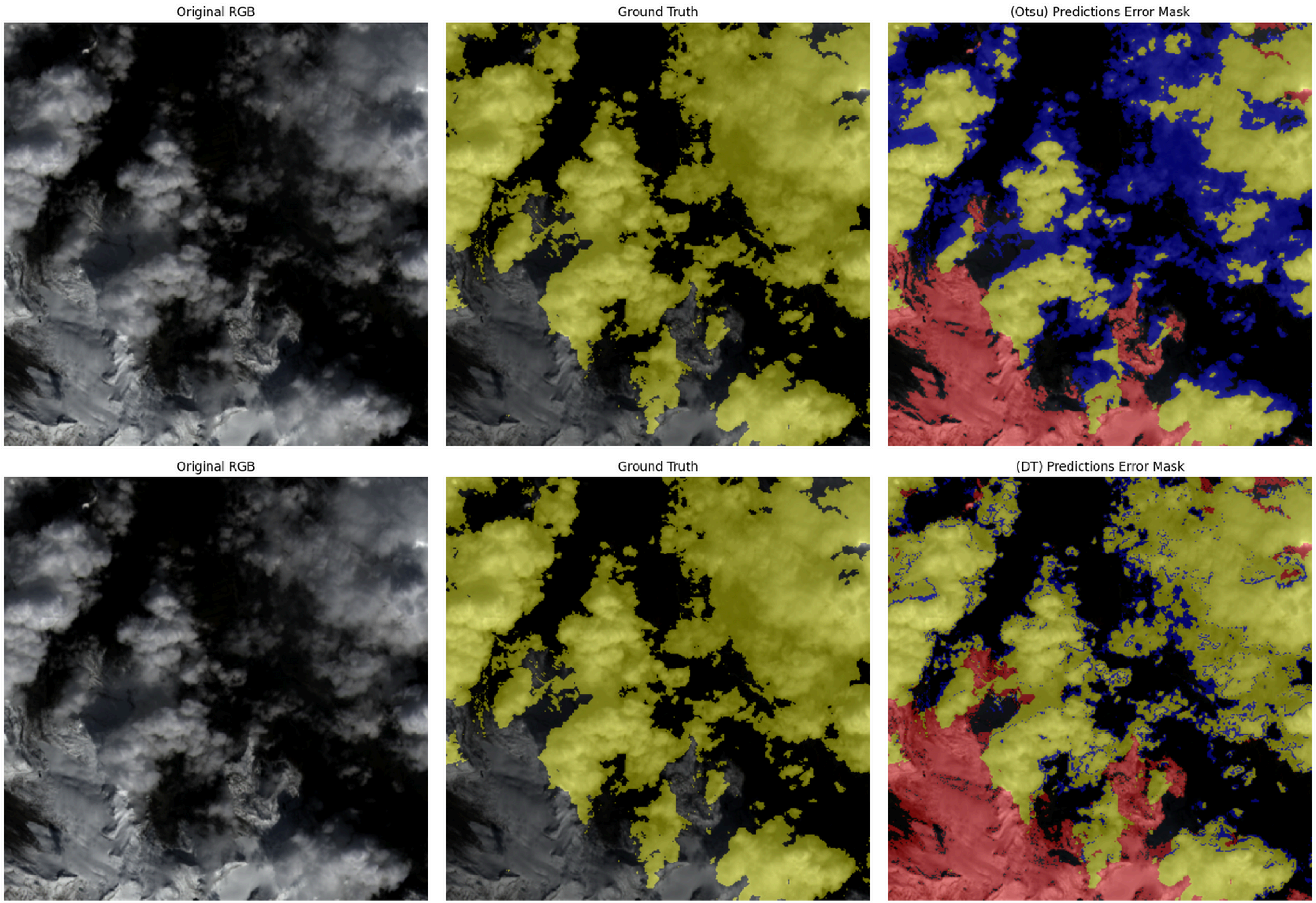
Appendix

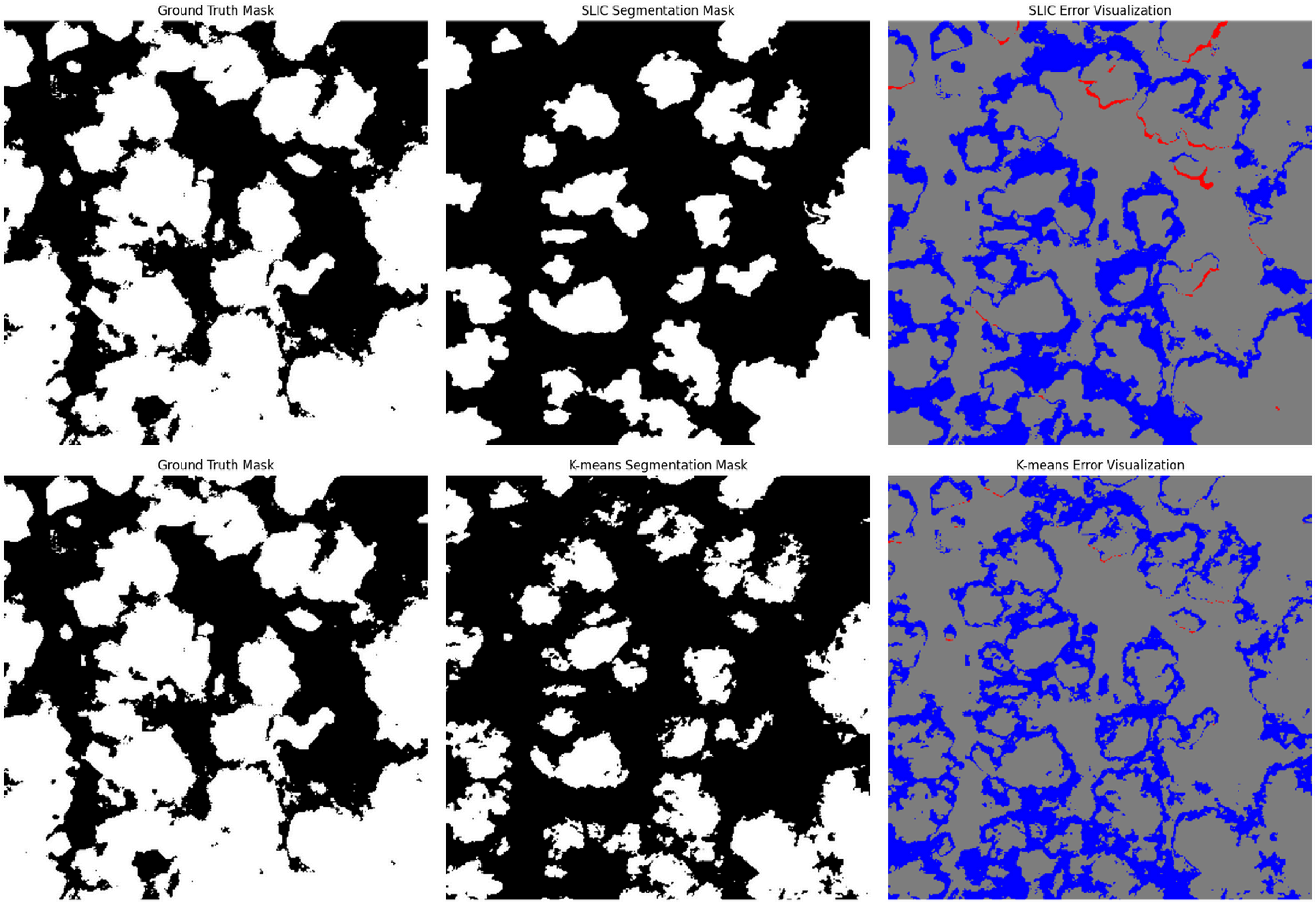
RESULTS

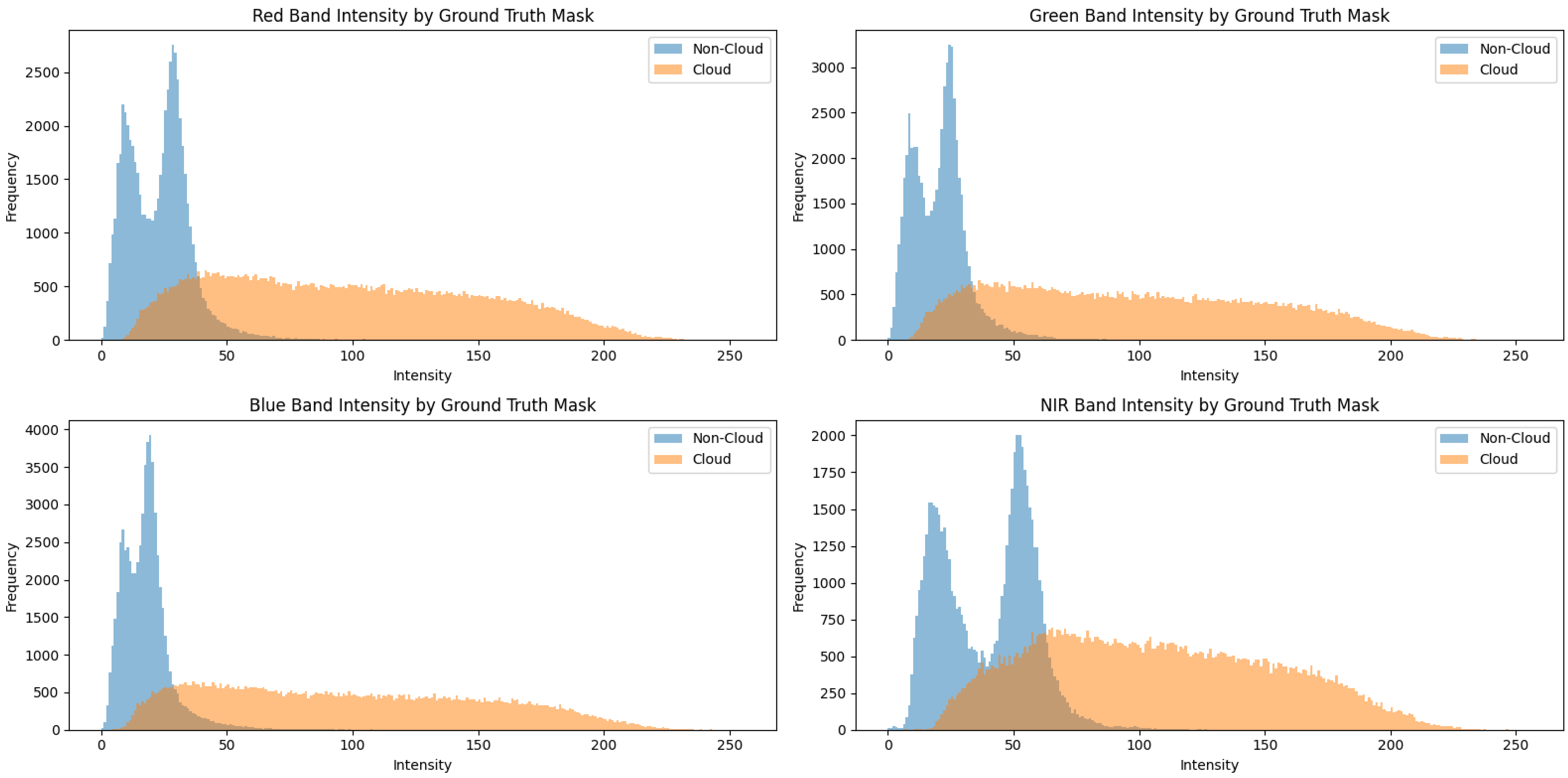
Method (denoised)	Precision	Recall	F1	Jaccard	Accuracy
GNB	0.7258	0.6374	0.6219	0.5435	0.7656
Histogram-based	0.6906	0.7425	0.6587	0.5962	0.7682
Otsu's Method	0.7142	0.5420	0.5477	0.4458	0.6796
Decision Tree	0.6909	0.7812	0.6839	0.6328	0.7961

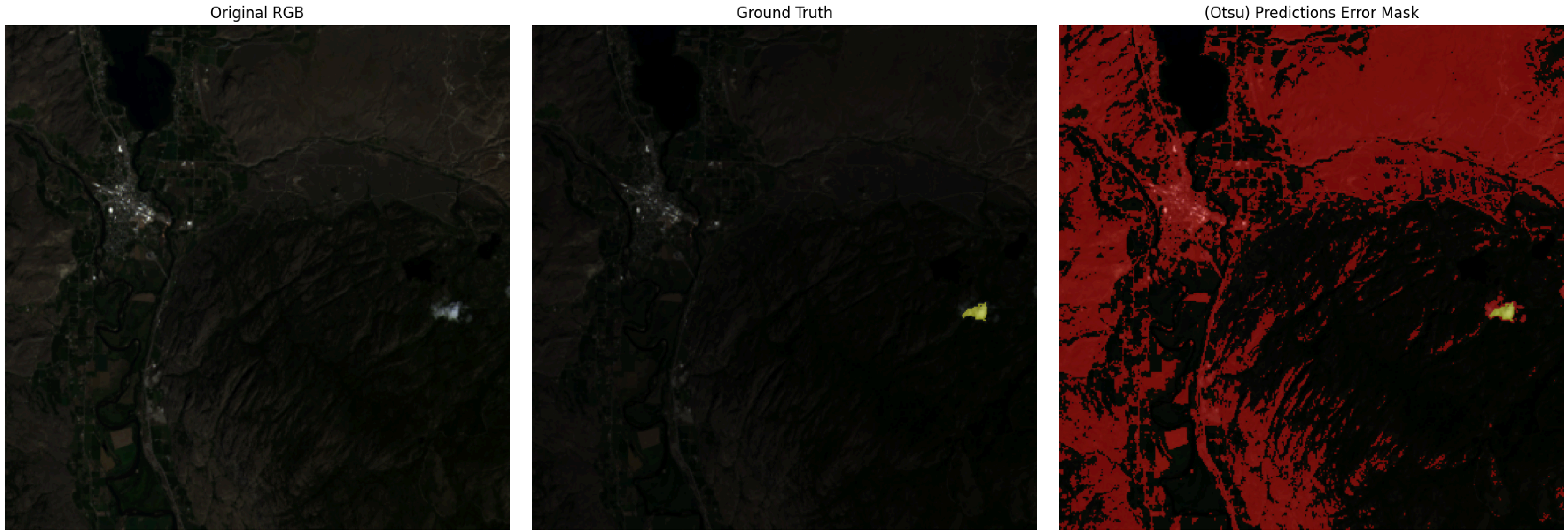
Table 2: Average Metrics with Denoising over 1000 images


(Otsu) Predictions Error Mask
(GNB) Predictions Error Mask
(Histogram) Predictions Error Mask
(DT) Predictions Error Mask

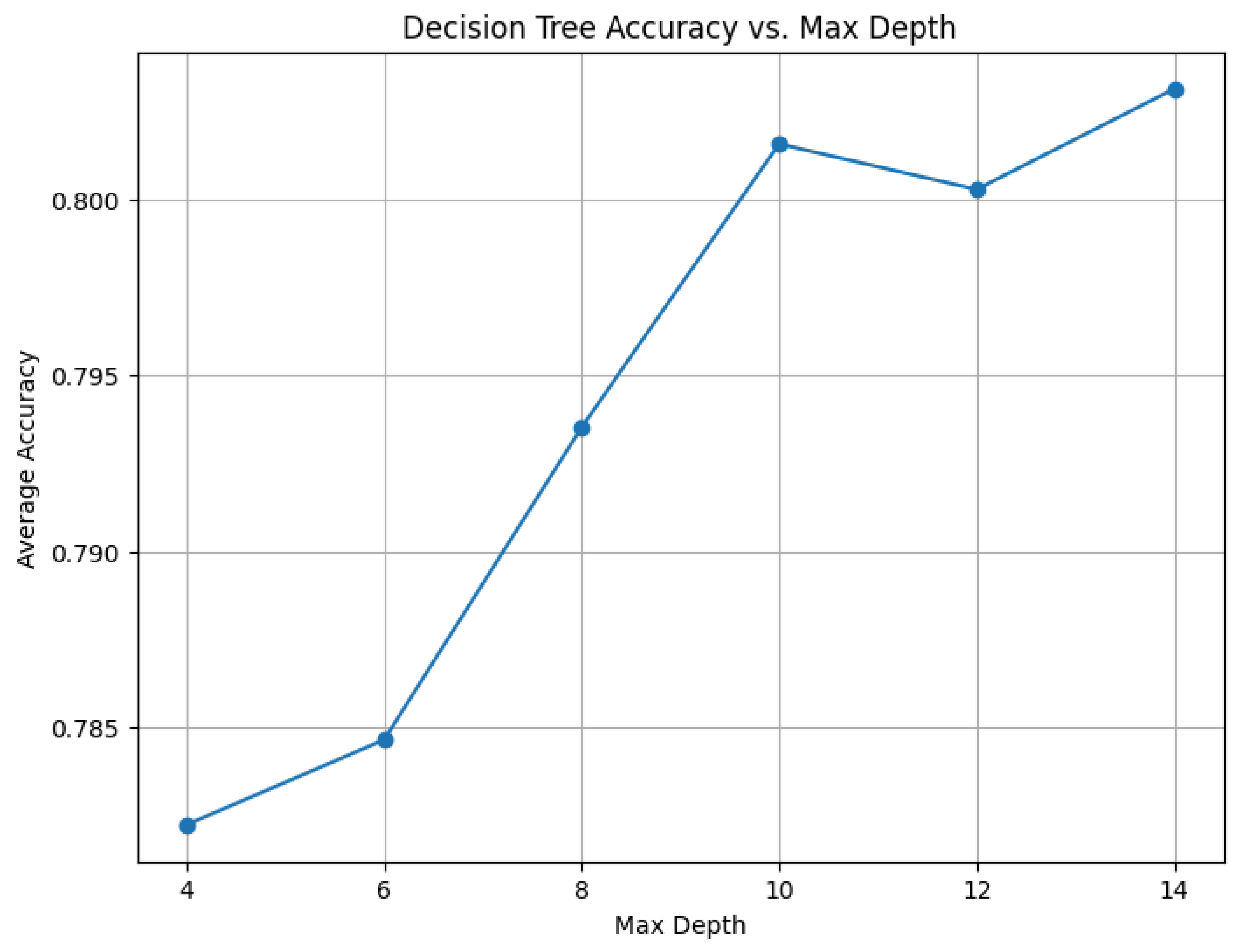

Original RGB
Ground Truth
(Otsu) Predictions Error Mask
Original RGB
Ground Truth
(DT) Predictions Error Mask


Ground Truth Mask
SLIC Segmentation Mask
SLIC Error Visualization
Ground Truth Mask
K-means Segmentation Mask
K-means Error Visualization


Red Band Intensity by Ground Truth Mask
Green Band Intensity by Ground Truth Mask
Blue Band Intensity by Ground Truth Mask
NIR Band Intensity by Ground Truth Mask
Non-Cloud
Cloud
Frequency
Intensity


Original RGB
Ground Truth
(Otsu) Predictions Error Mask

RESULTS



Decision Tree Accuracy vs. Max Depth
Average Accuracy
0.800
0.795
0.790
0.785
4
6
8
10
12
14
Max Depth