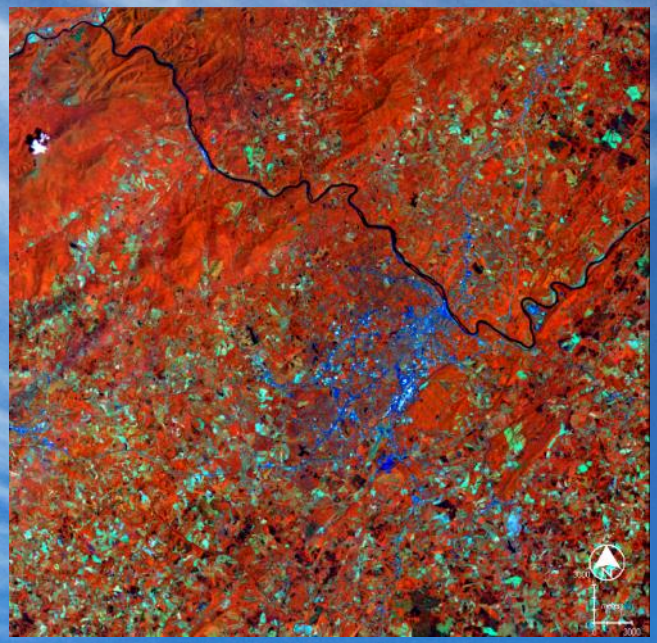
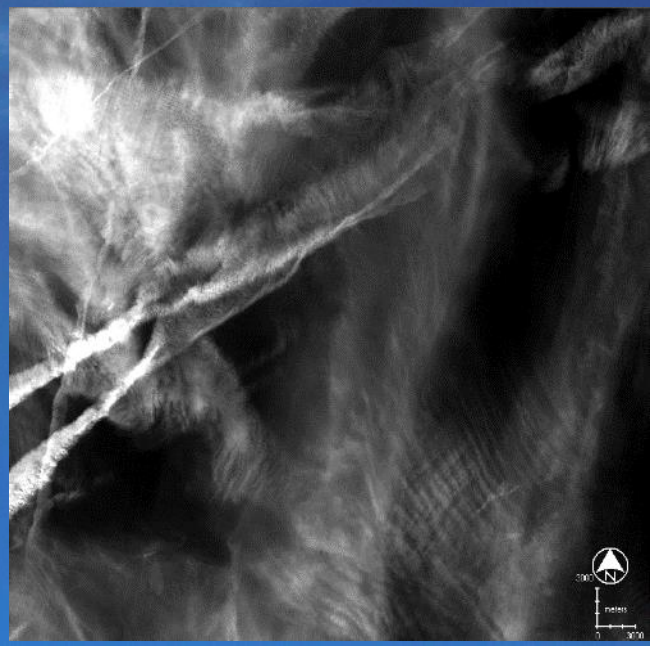
Cirrus Cloud Effects on Land Use Classification of Multi-temporal Landsat 8 Data

A Case Study using Hierarchical/Multilevel Models

Gregory B. Anderson[1] &
Randolph H. Wynne[2]

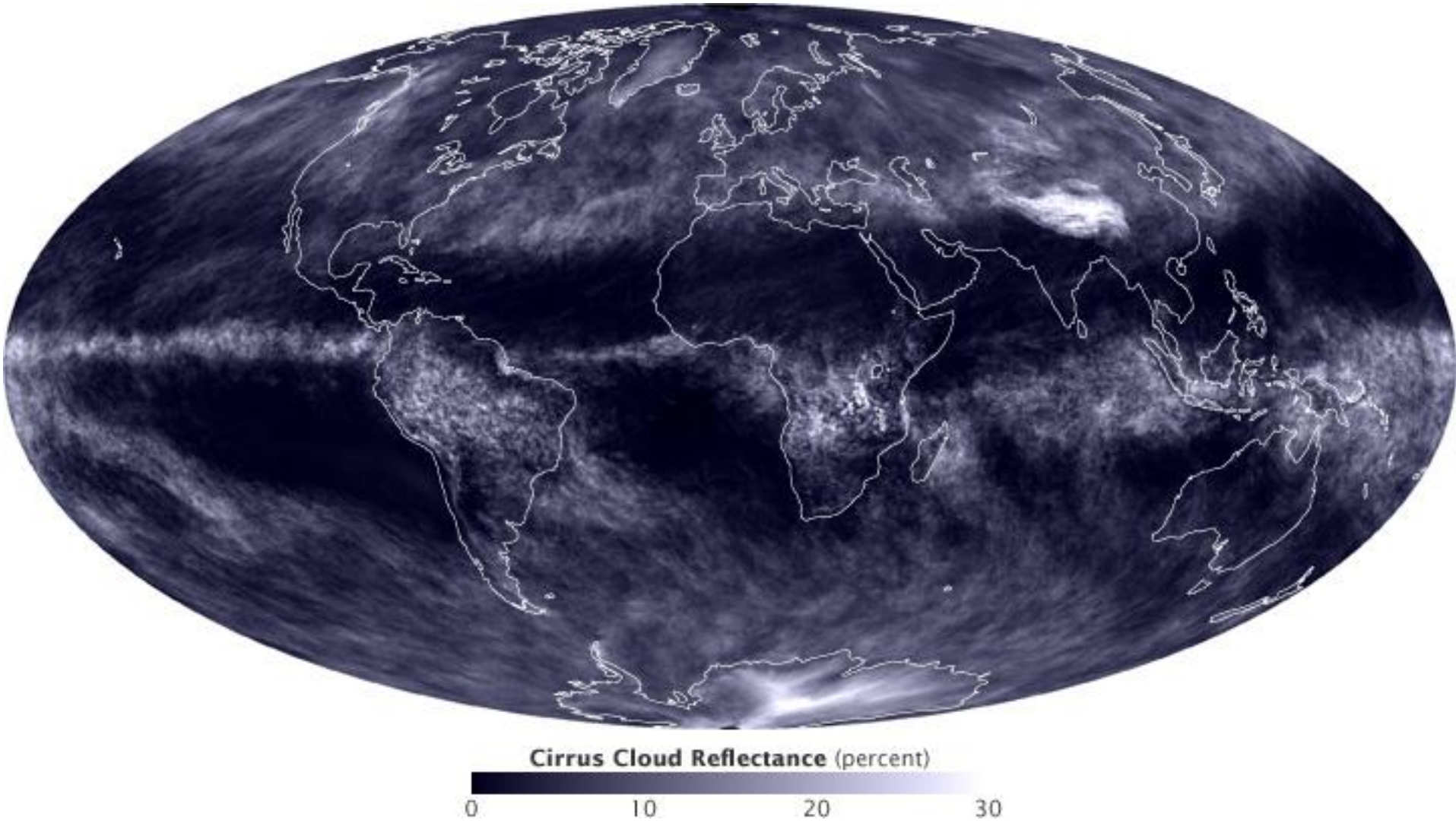
[1] Department of Fish and Wildlife Conservation, Virginia Tech
[2] Department of Forest Resources and Environmental Conservation, Virginia Tech





Cirrus Clouds

Cirrus clouds cover more than 30% of the Earth at any given time!

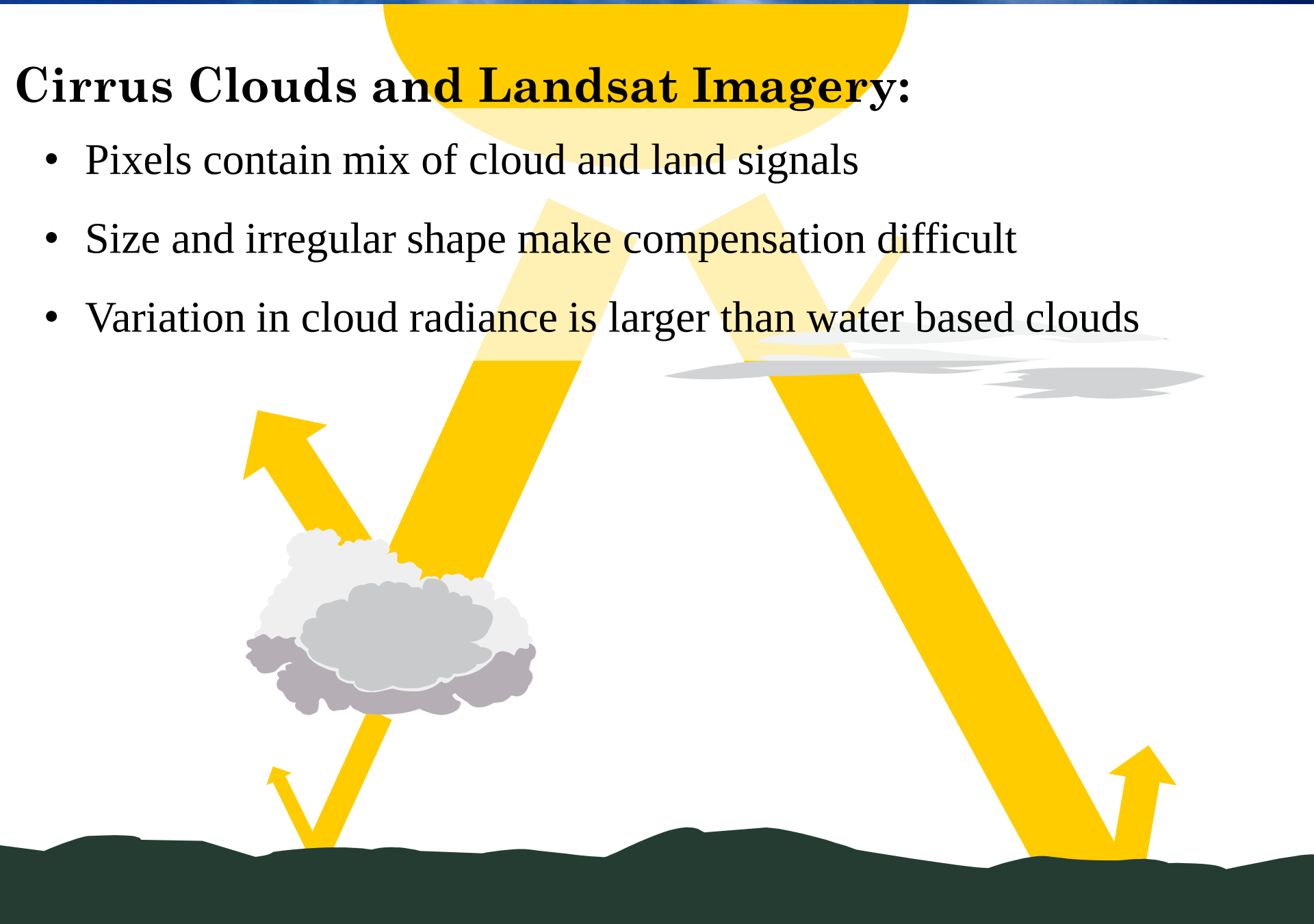


Source: http://earthobservatory.nasa.gov

The Problem with Cirrus Clouds

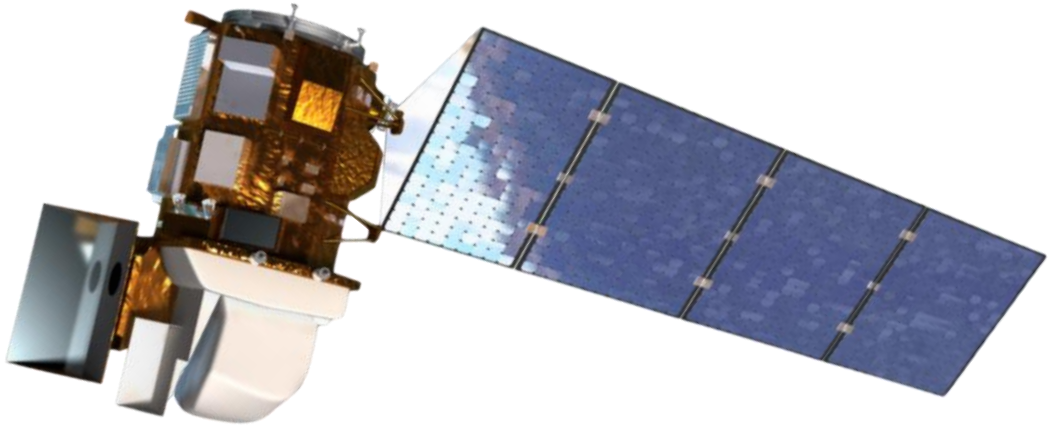
Cirrus Clouds and Landsat Imagery:

- Pixels contain mix of cloud and land signals
- Size and irregular shape make compensation difficult
- Variation in cloud radiance is larger than water based clouds

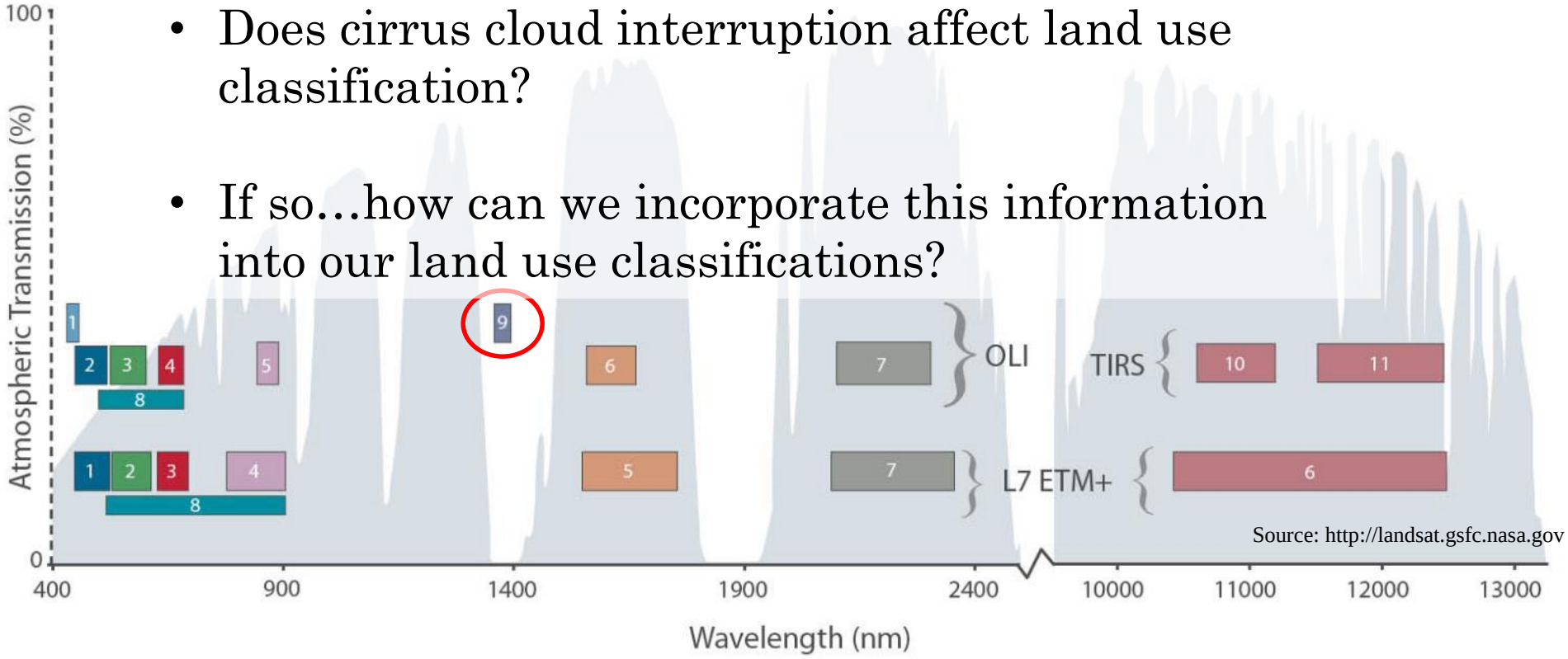


Landsat 8 Cirrus Band

Landsat 8 OLI



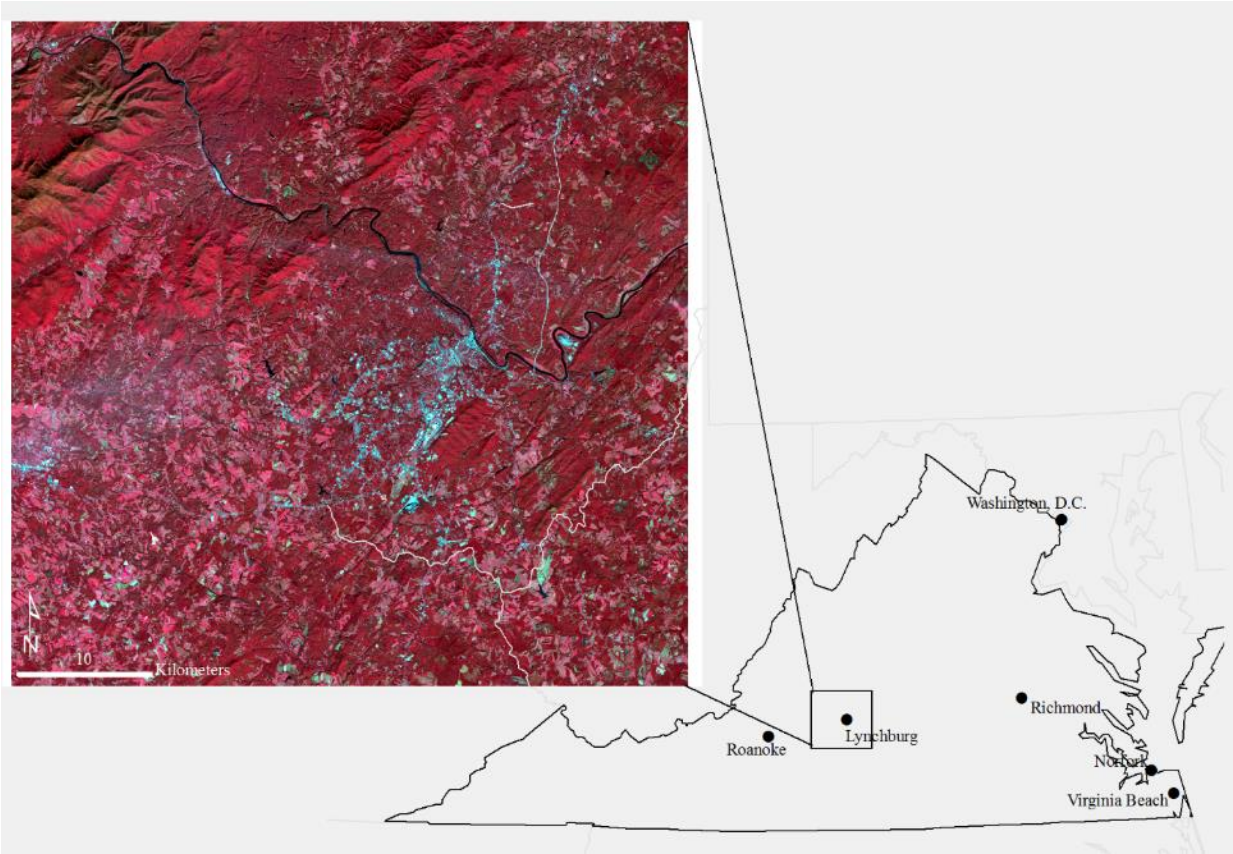
- Does cirrus cloud interruption affect land use classification?
- If so…how can we incorporate this information into our land use classifications?



Source: http://landsat.gsfc.nasa.gov

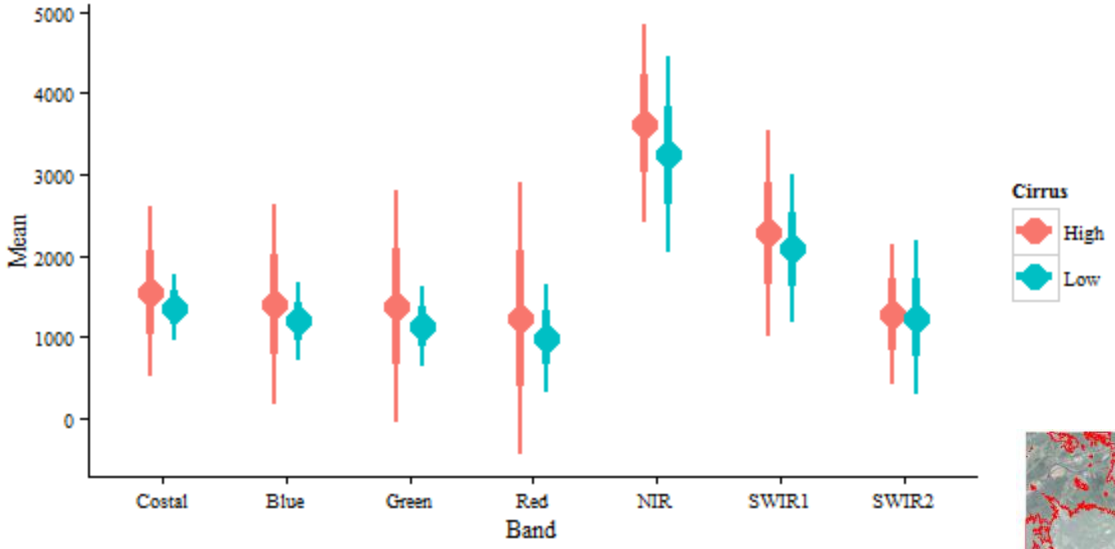
Objectives

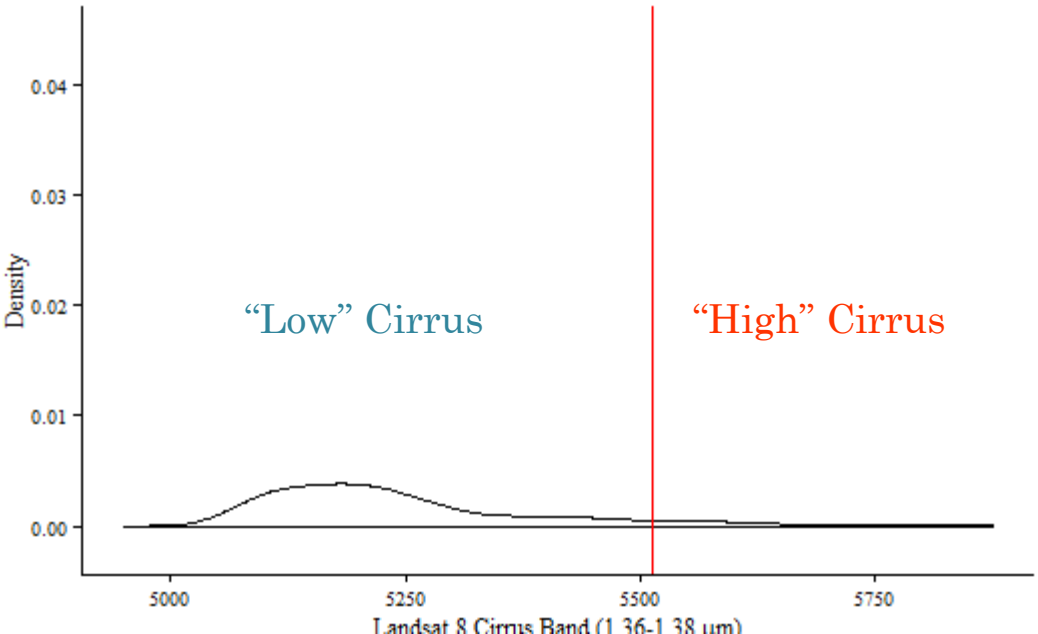
- Investigate the relationship between cirrus cloud presence and reflectance of Landsat 8 bands
- Attempt to improve image classification using:
  - MCMC Hierarchical Model



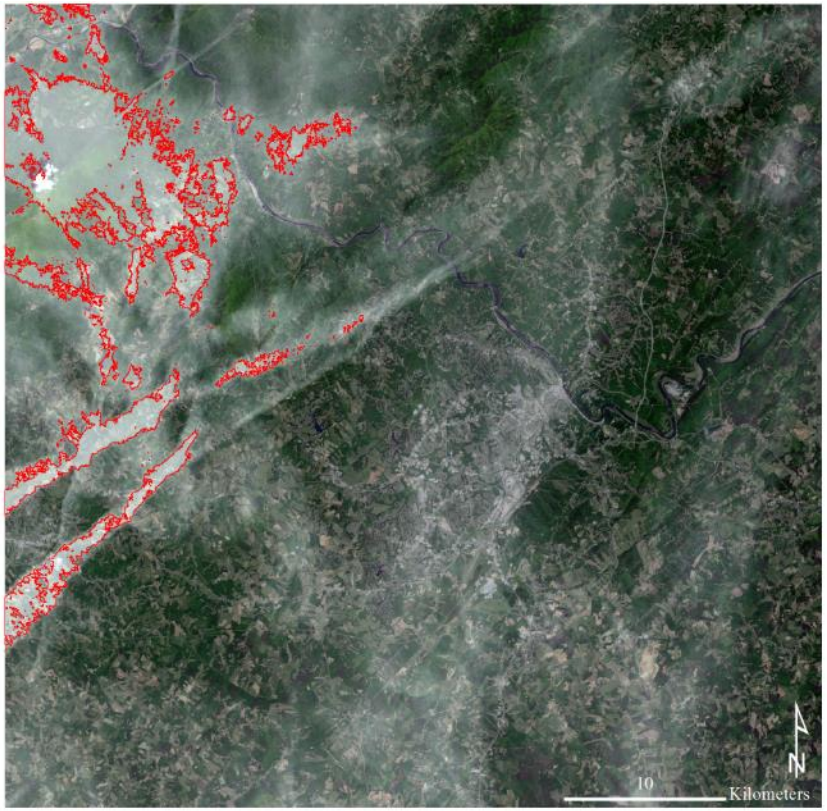
Prevalence of Cirrus Clouds in Sample Data

Urban Signature



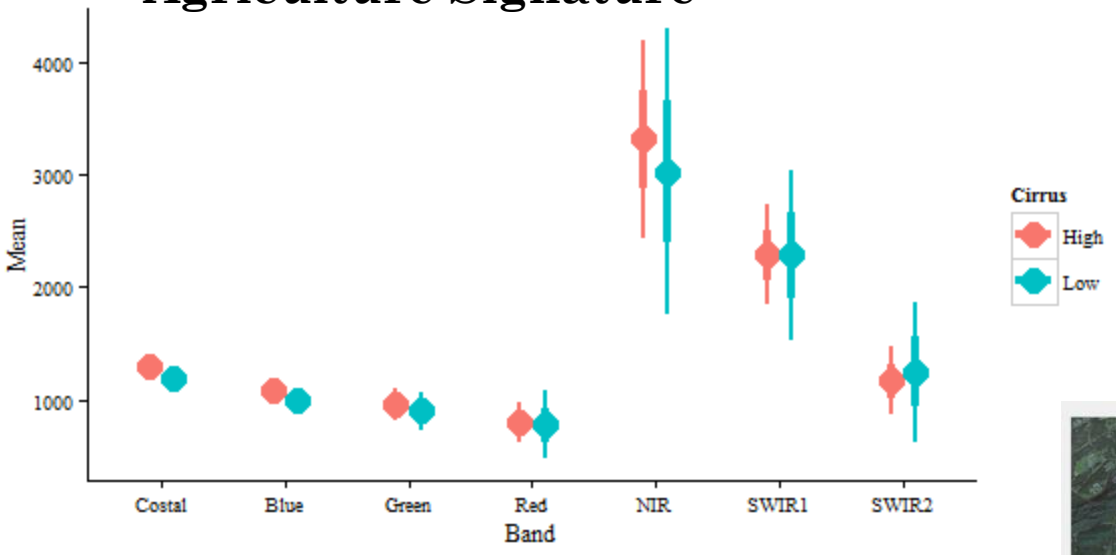


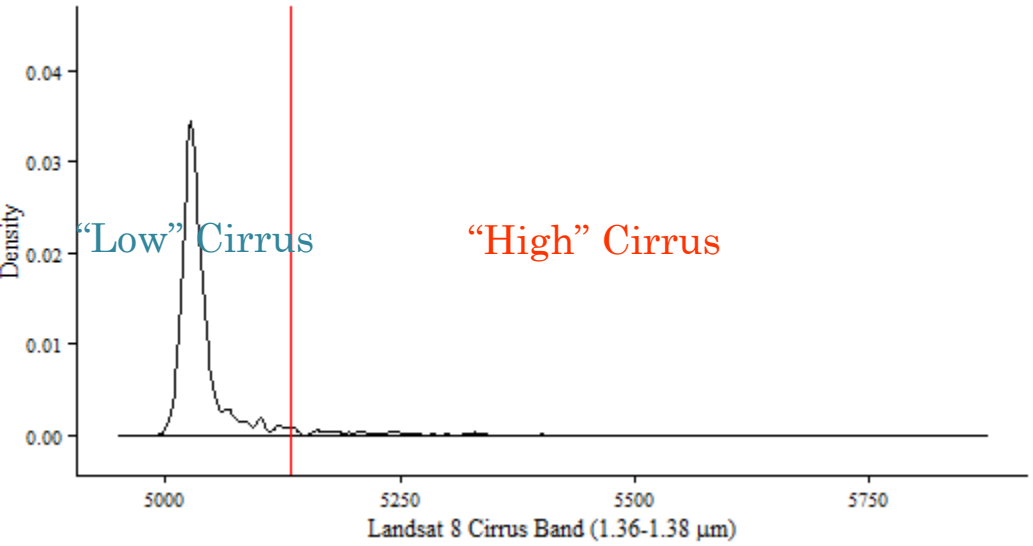
May 30, 2013



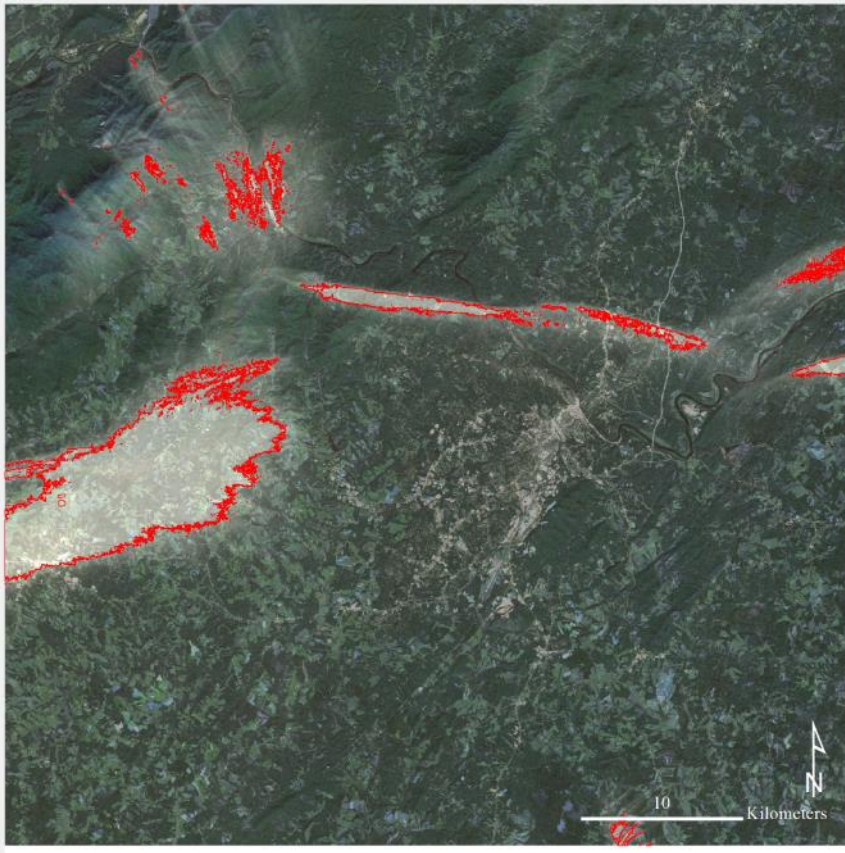
Prevalence of Cirrus Clouds in Sample Data

Agriculture Signature



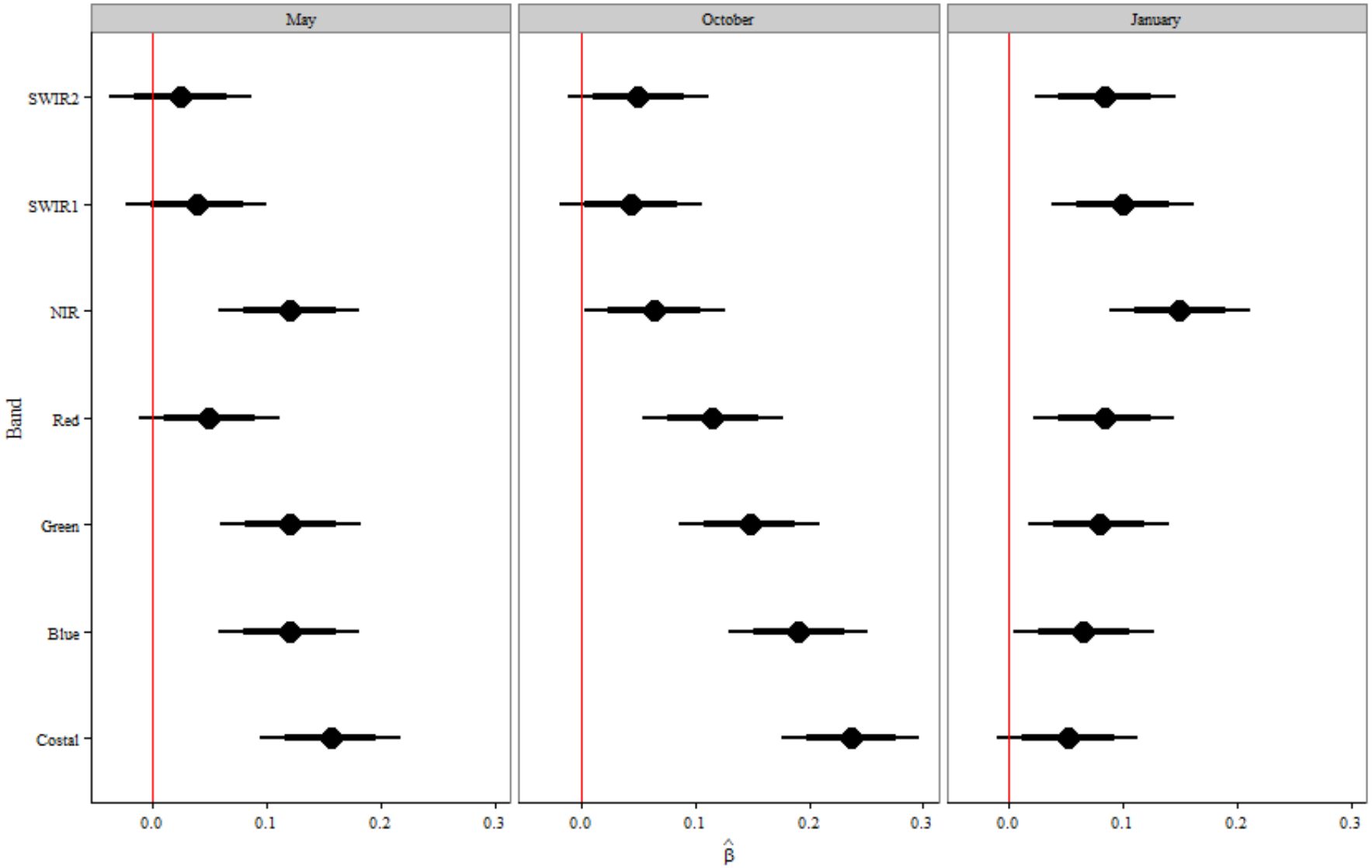


October 21, 2013

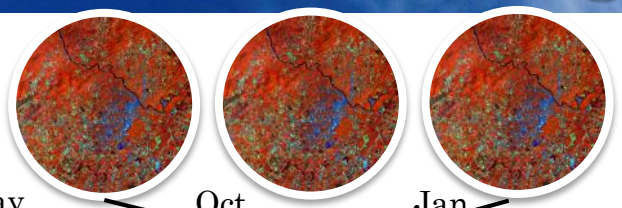


Cirrus Clouds and Band Reflectance

- Regression slopes (circles) for relationship between cirrus and respective bands



Classification Using Multinomial Logistic Regression



Landsat 8 Images (Multitemporal)

May

Oct.

Jan.

Image Preprocessing

$$\rho(x, y, \lambda_i) = \frac{\pi L(x, y, \lambda_i)}{\cos(\theta(x, y))I(\lambda$$

High Resolution Aerial Photography

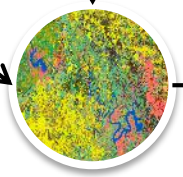
Extract Reflectance Bands at Testing Points

Extract Reflectance Bands at Training Points

Create Training Land Use Data

Create Testing Land Use Data

Perform Multinomial Regression



Classify Points and Landscape

Perform Accuracy Assessment

Classification Using Multinomial Logistic Regression

Prediction

Classification	Water	Urban	Forest	Ag	Totals
Water	8	1	0	0	9
Urban	0	50	4	6	60
Forest	0	6	316	6	328
Ag	0	6	3	94	103
Totals	8	63	323	106	500

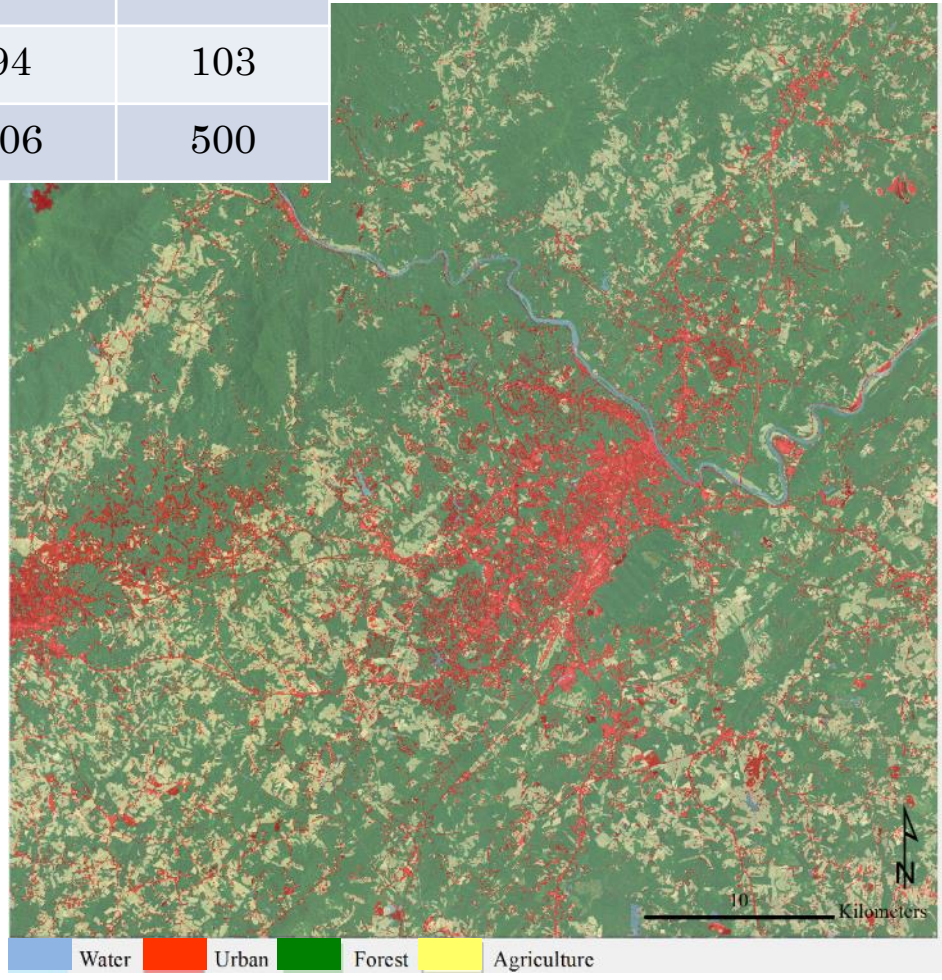
Overall Accuracy:

93.6% (95% CI=0.91, 0.96)

p-value=2.2e-16

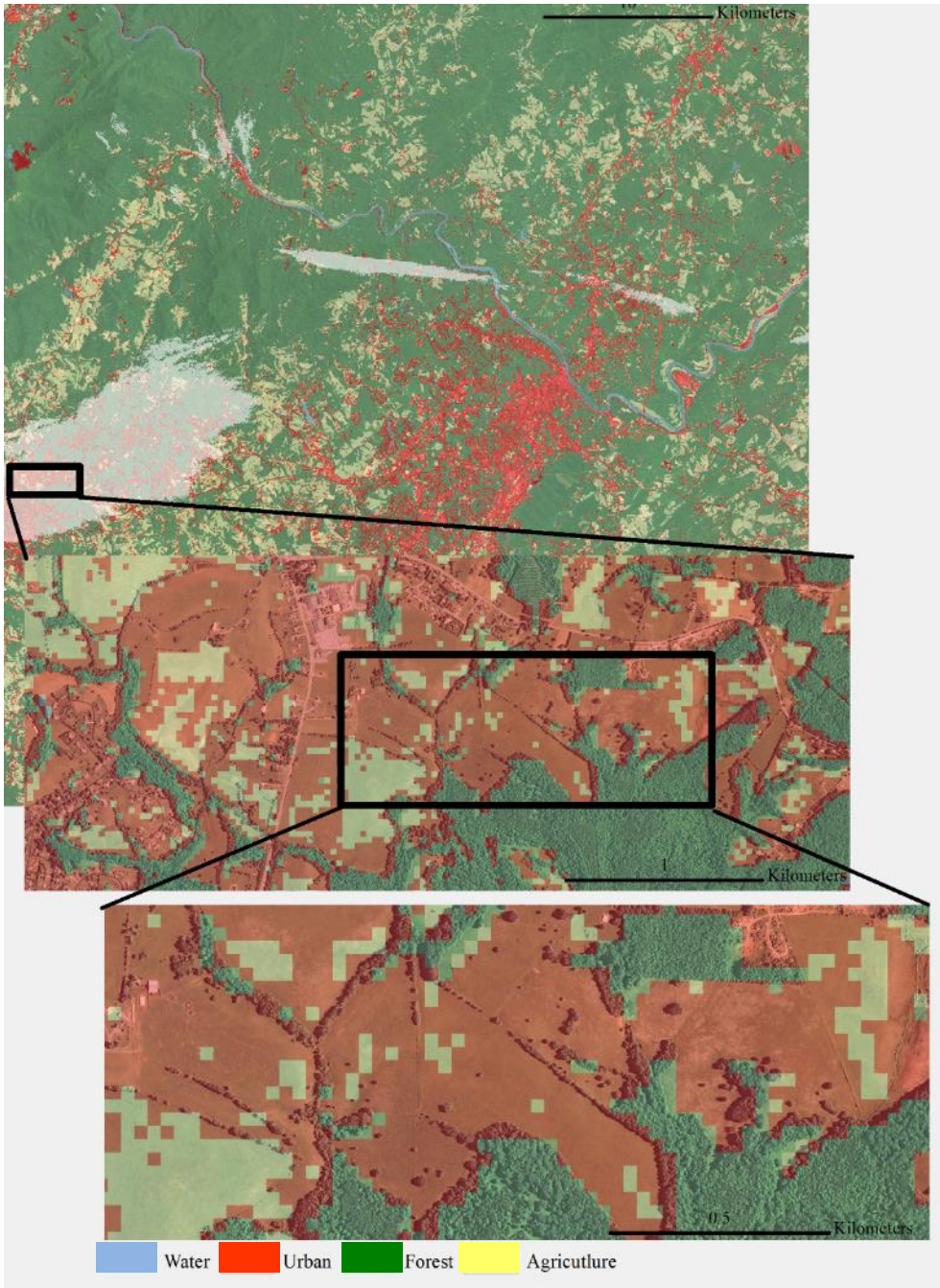
Cohen's Kappa:

0.8762



Classification Using Multinomial Logistic Regression

- 376 km^2 affected by “high” cirrus cloud interruption
  - 14.76% of the area



Classification Using Multinomial Logistic Regression

Prediction

Classification	Water	Urban	Forest	Ag	Totals
Water	3	0	0	0	3
Urban	0	32	0	0	32
Forest	0	17	340	3	360
Ag	0	34	4	75	113
Totals	3	83	344	78	508

Overall Accuracy:

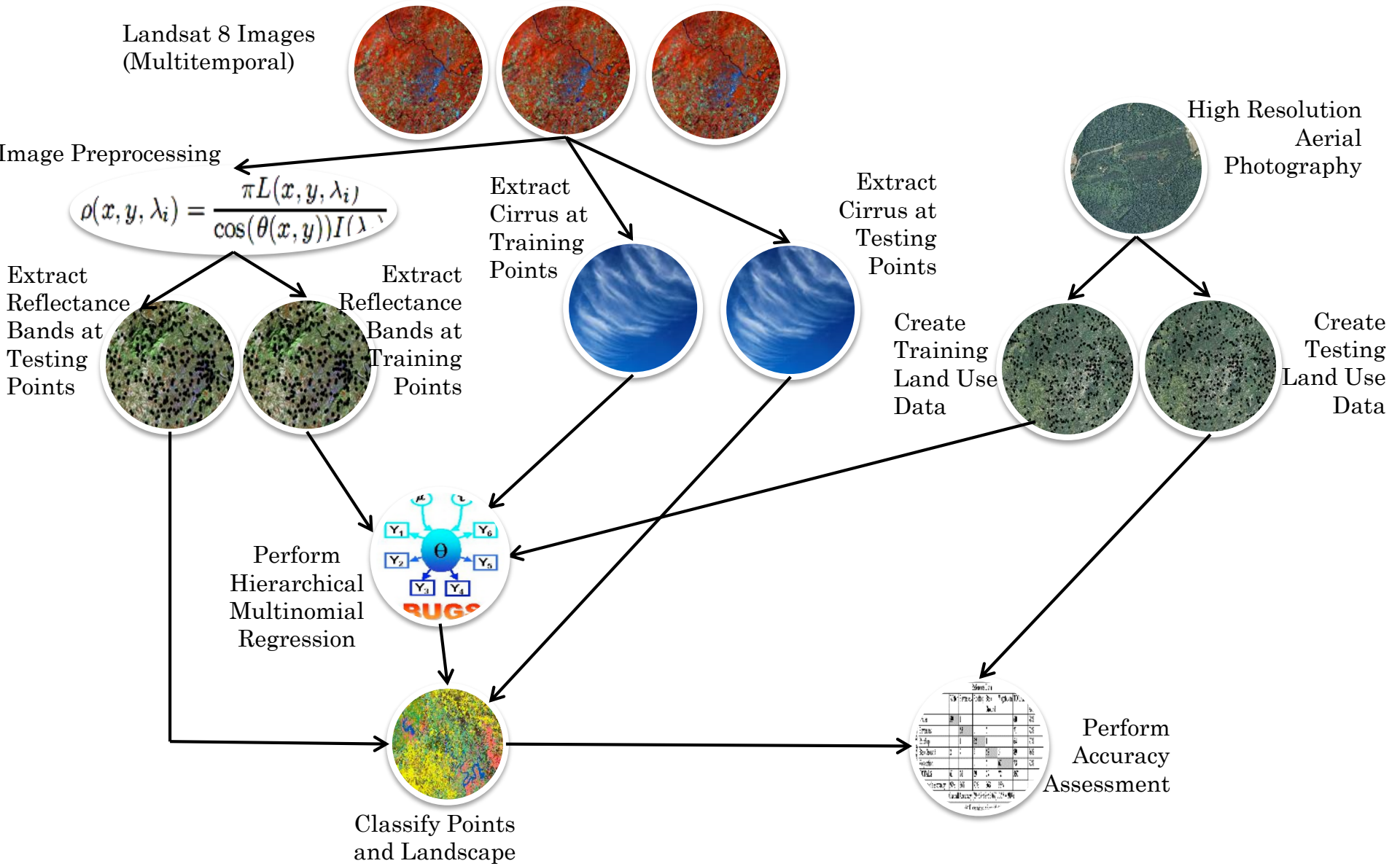
88.6% (95% CI=85, 91)

p-value=2.2e-16

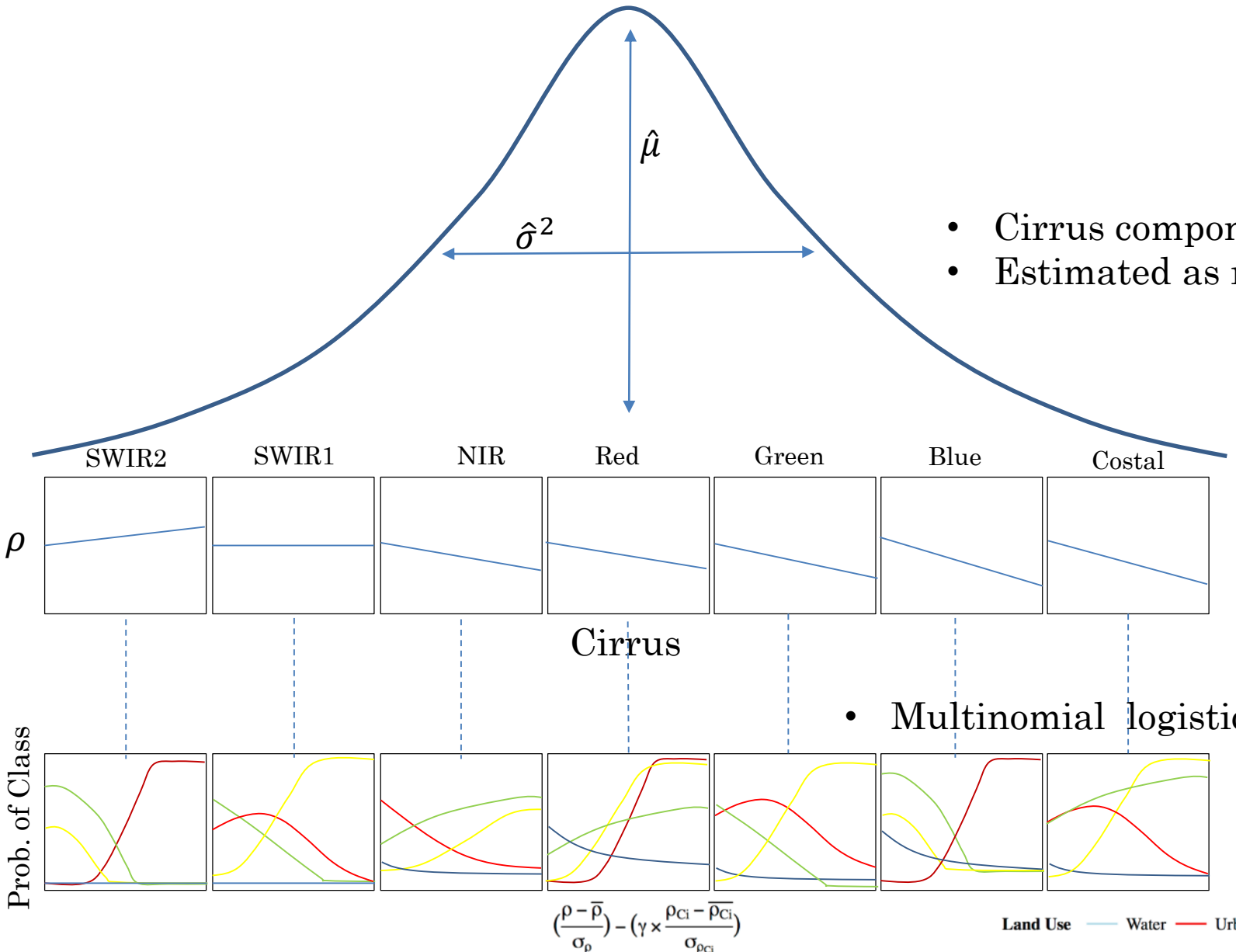
Cohen's Kappa:

0.76

An Hierarchical Approach to Dealing with Cirrus Clouds



An Hierarchical Approach to Dealing with Cirrus Clouds



- Cirrus component of model
- Estimated as random effects

- Multinomial logistic regression

An Hierarchical Approach to Dealing with Cirrus Clouds

Prediction

Classification	Water	Urban	Forest	Ag	Totals
Water	8	0	0	0	8
Urban	0	54	5	2	61
Forest	0	5	314	4	323
Ag	0	4	4	100	108
Totals	8	63	323	106	500

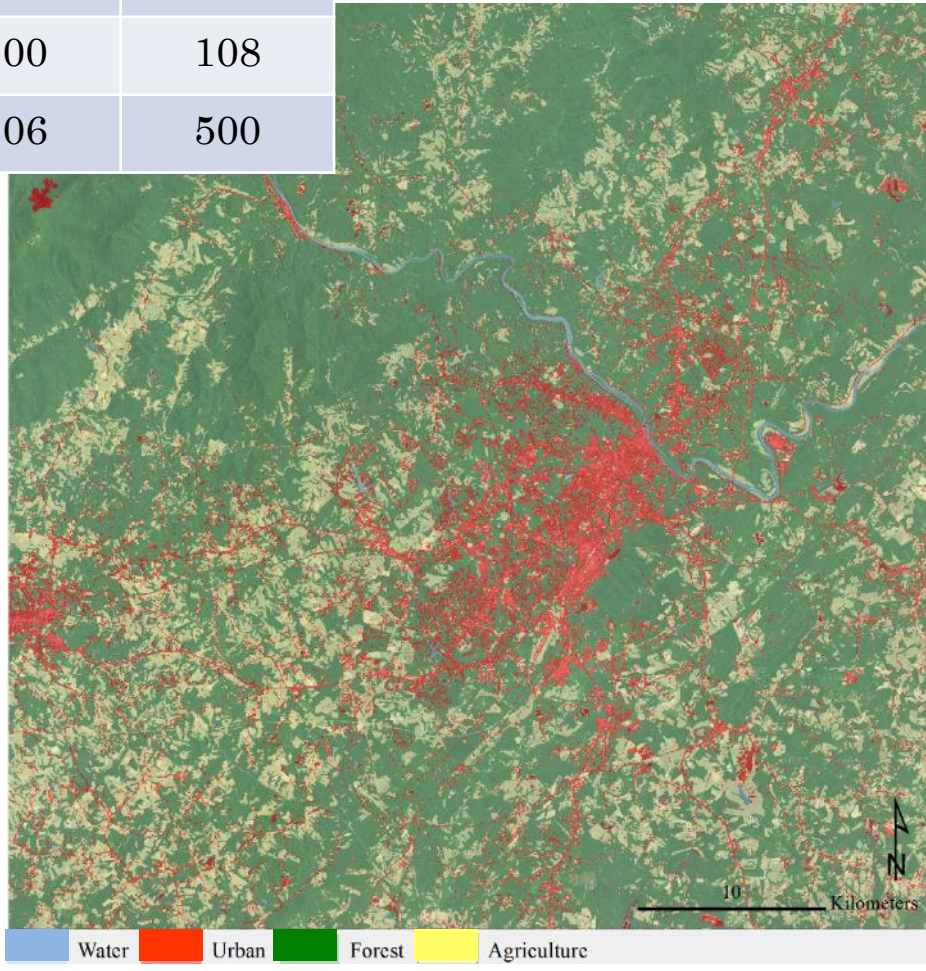
Overall Accuracy:

95.2% (95% CI=0.93, 0.97)

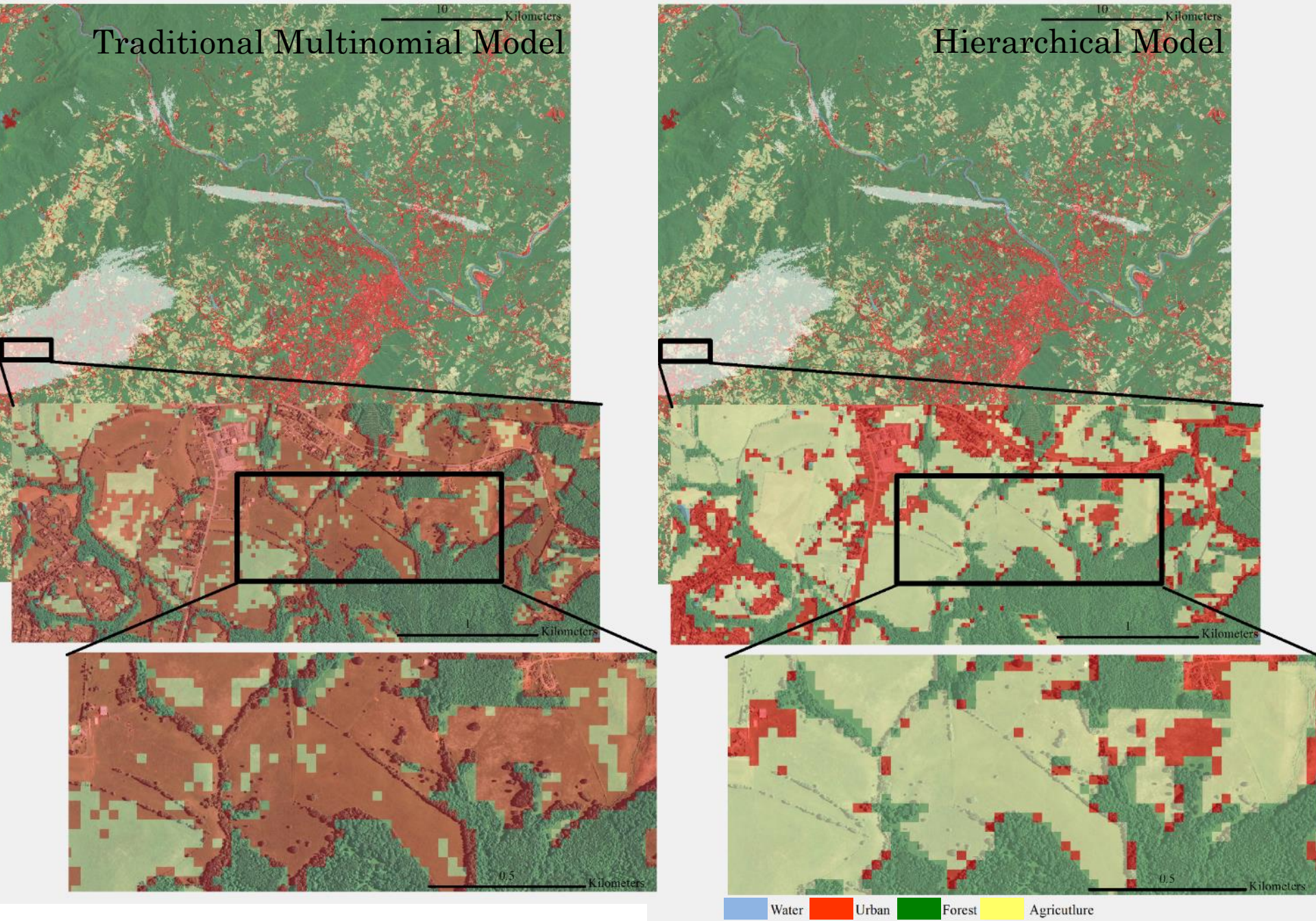
p-value=2.2e-16

Cohen's Kappa:

0.9079



An Hierarchical Approach to Dealing with Cirrus Clouds



An Hierarchical Approach to Dealing with Cirrus Clouds

Prediction

Classification

Class	Water	Urban	Forest	Ag	Totals
Water	3	0	0	0	3
Urban	0	31	1	0	32
Forest	0	2	356	2	360
Ag	0	2	2	109	113
Totals	3	35	359	111	508

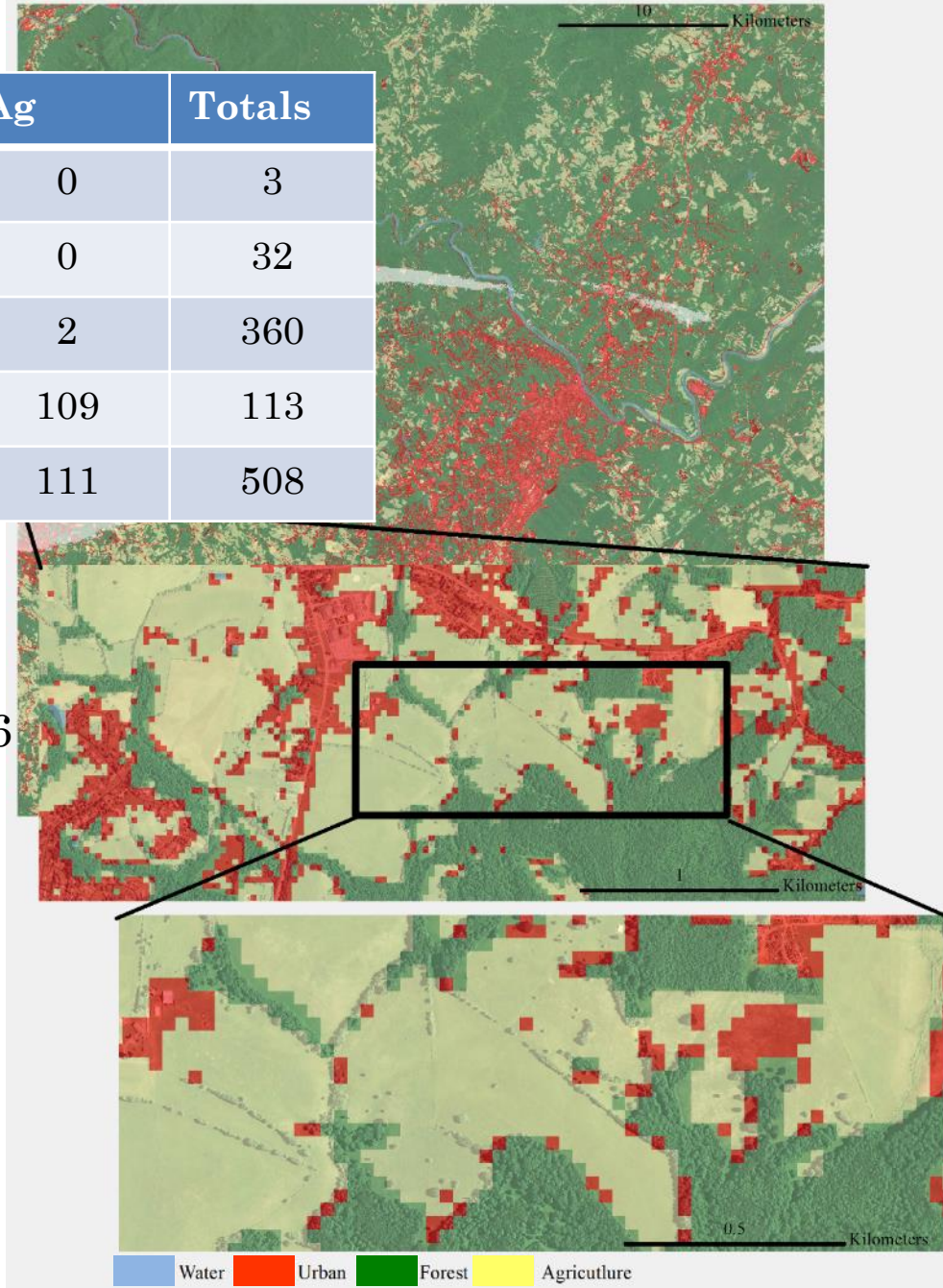
Overall Accuracy:

98.2% (95% CI=0.96, 0.99)

p-value=2.2e-16

Cohen's Kappa:

0.9603



An Hierarchical Approach to Dealing with Cirrus Clouds

Traditional Multinomial Regression

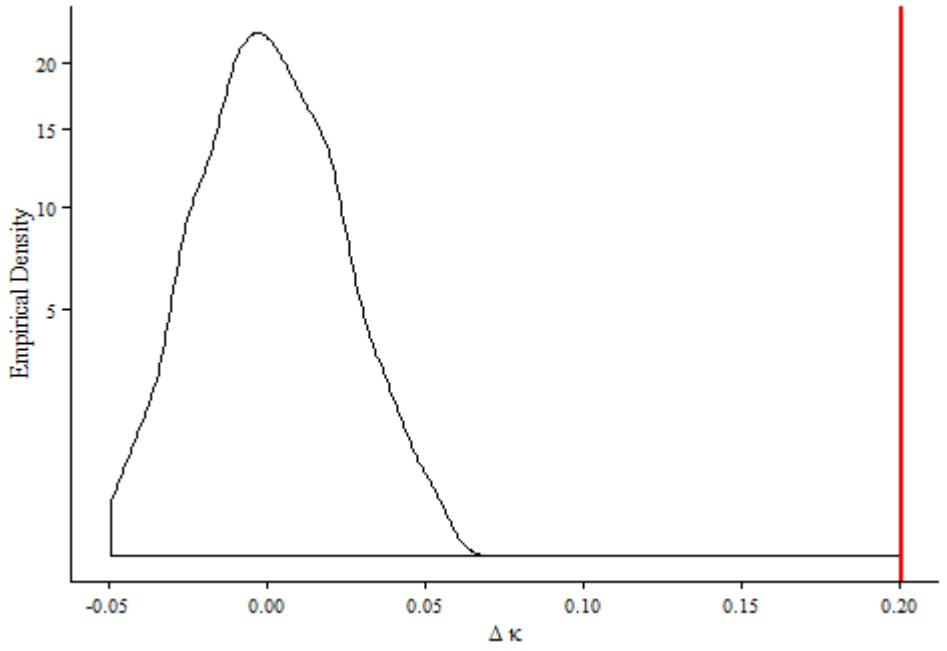
Hierarchical Multinomial Error Model

	Correct	Incorrect
Correct	448	2
Incorrect	51	7

McNemar Test:

p-value=0.009

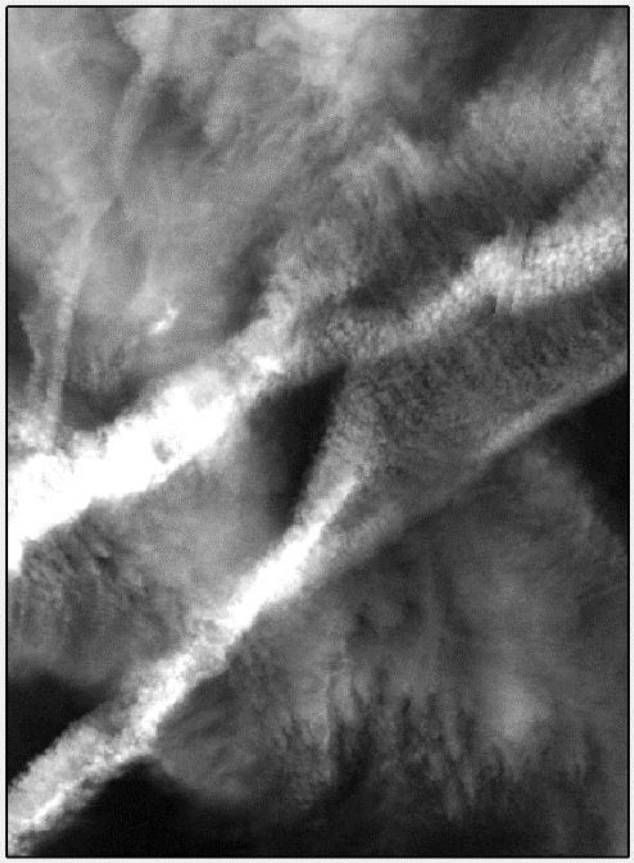
Permutation Based Test



Probability of observing a difference in K this large by chance:

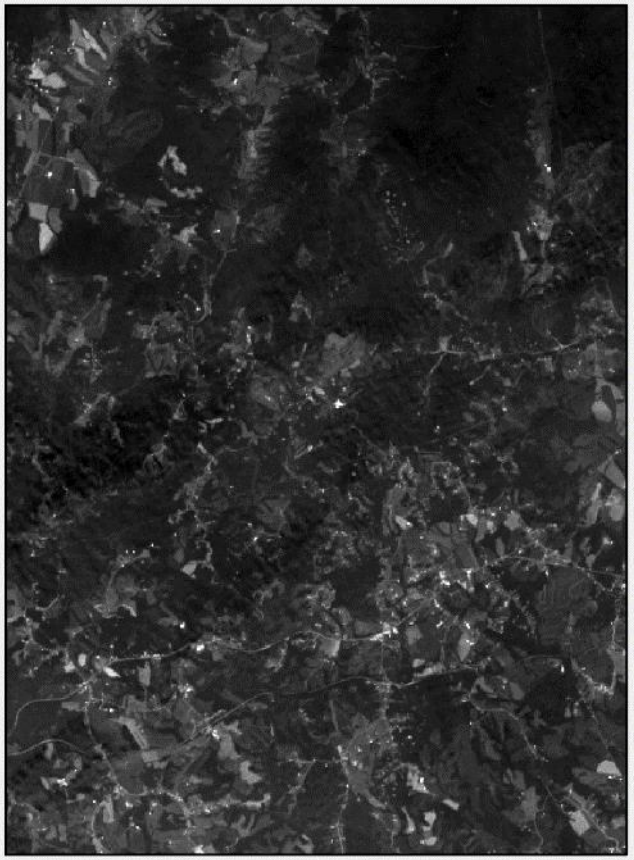
p.value=0.001

An Hierarchical Approach to Dealing with Cirrus Clouds



Cirrus
in May

Costal Aerosol
in May



Predicted Costal Aerosol
in May

Conclusions

- Cirrus clouds have band specific effects on measured reflectance
- The effect can cause misclassification of landsat scenes using traditional approaches
- Cirrus clouds can be combated using a hierarchical model that incorporates cirrus band reflectance into the classification scheme.

Potential Problems with Hierarchical Approach:

- High computational time
- Requires specification of priors
- Implementation is not straightforward
- Model selection with collinear bands is difficult

Future Directions

- Evaluate model with more land classes
- Evaluate model in tropical areas where cirrus is much more present

Thanks!

- All analyses done in R and JAGS (Just Another Gibbs Sampler)
- Code available upon request
  - Contact:

Greg Anderson
quanteco@vt.edu

Questions?

An Hierarchical Approach to Dealing with Cirrus Clouds

The probability that pixel i is land class j:

$$\Pr(y_i = j) = p_{ij} = \Pr\left[\mu_{ij} > \mu_{ik}\right] \; \forall \; k \neq j$$

where

$$p_{ij} = \frac{e^{\alpha_j + \mathbf{X}_i \boldsymbol{\beta}_j}}{\sum_{k=1}^{J} e^{\alpha_j + \mathbf{X}_i \boldsymbol{\beta}_j}}$$

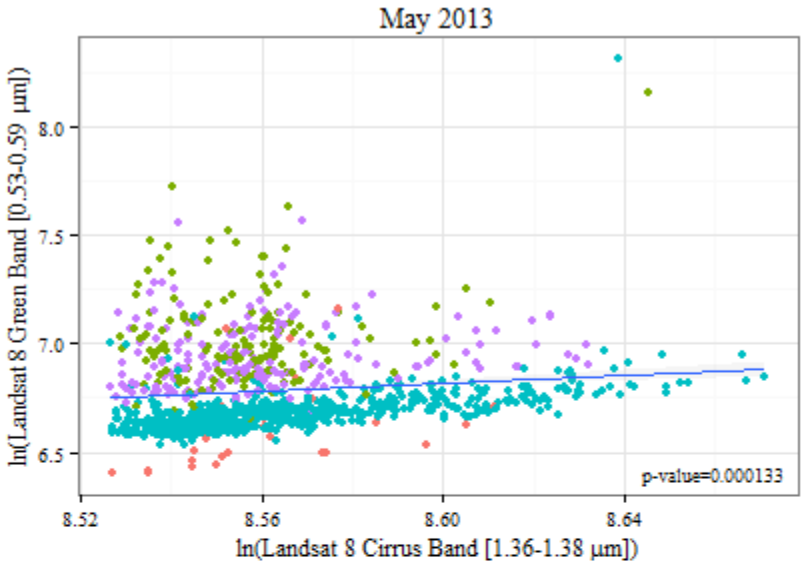
and $\mathbf{X}_i$ is described by:

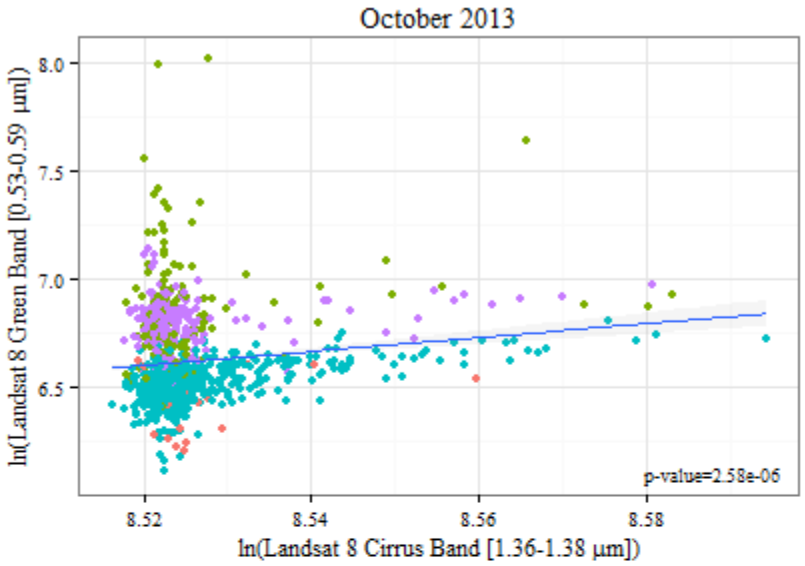
$$\mathbf{W}_i = \mathbf{X}_i + \boldsymbol{\gamma} * Cirrus_i + \boldsymbol{\epsilon}$$

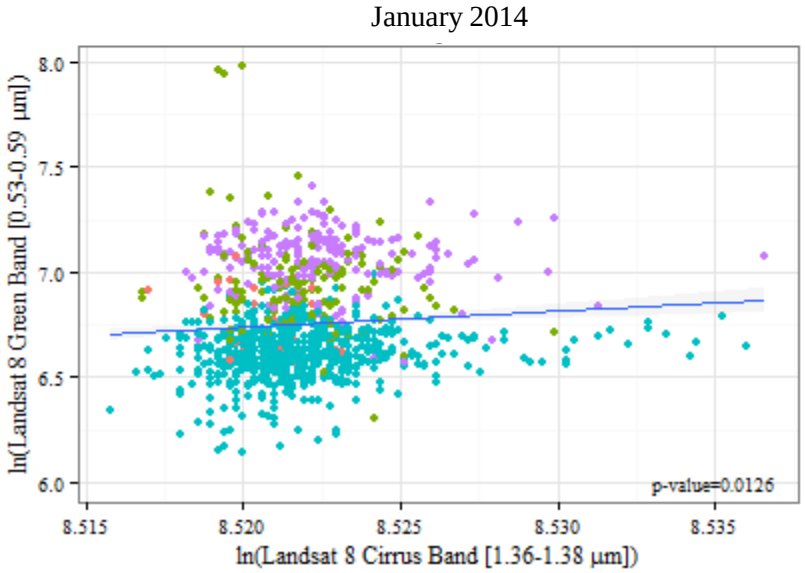
$$\gamma_k \sim N(\mu_\gamma, \sigma_\gamma^2) \qquad \boldsymbol{\epsilon} \sim N(0, {\sigma_\epsilon}^2)$$

Cirrus Clouds and Band Reflectance

- Relationships are strongest in May and with visible bands

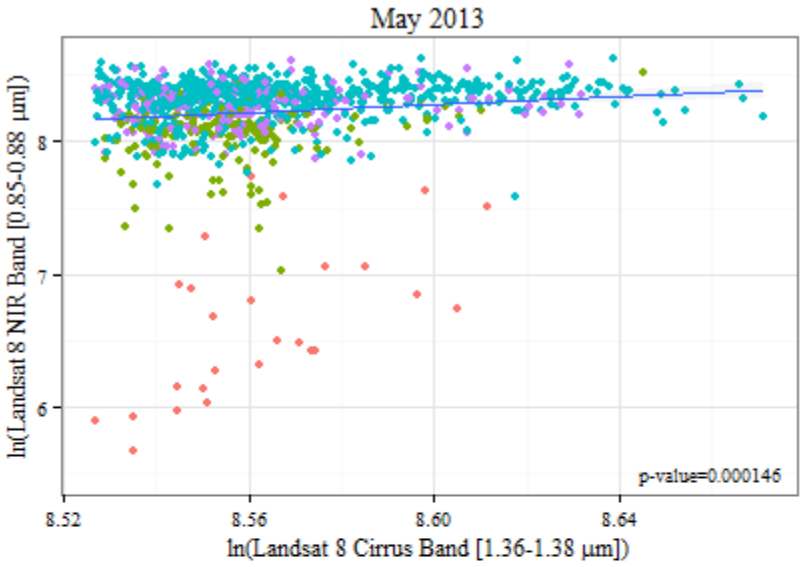


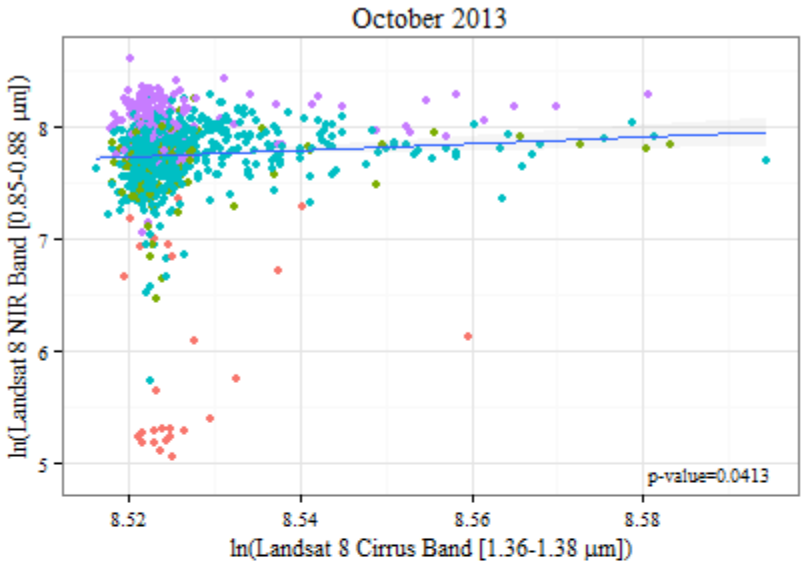


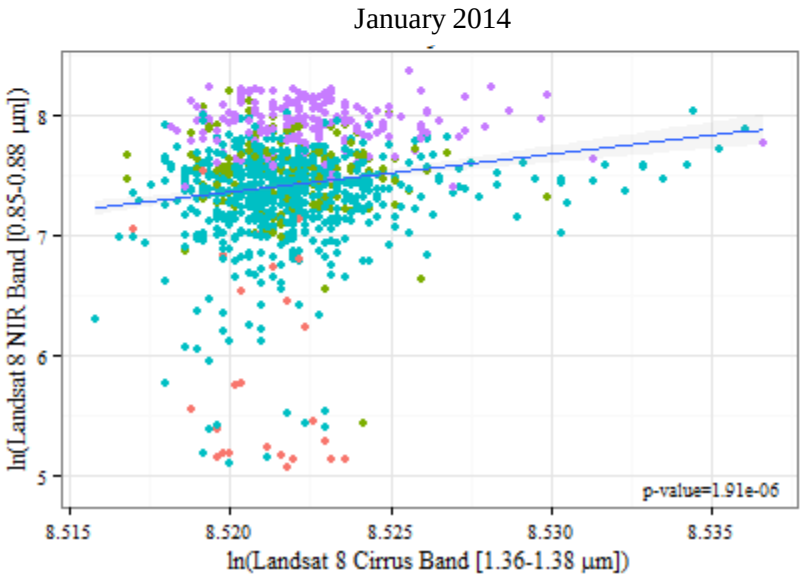


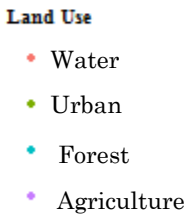
Prevalence of Cirrus Clouds in Sample Data

- Weaker signals in Near Infrared



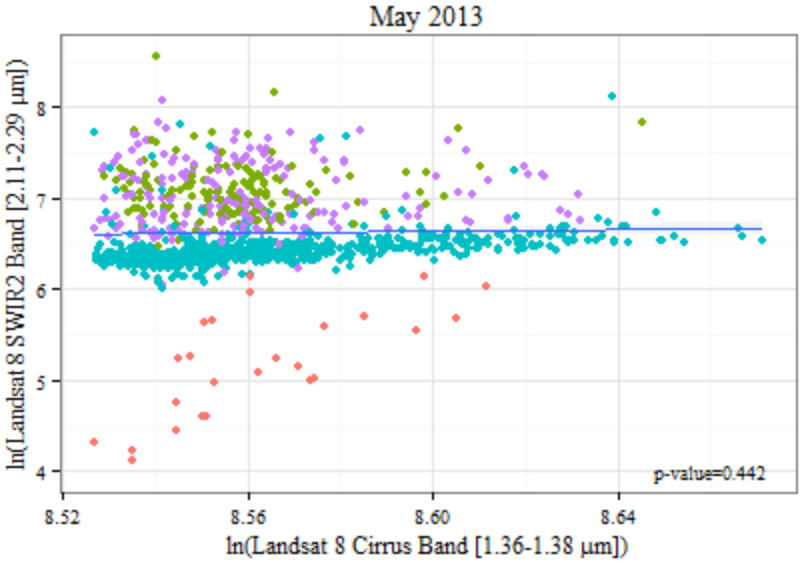


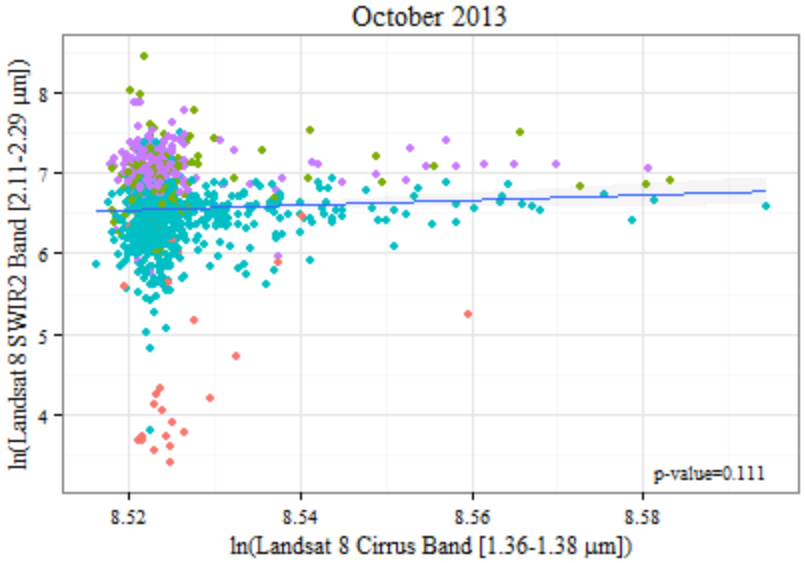


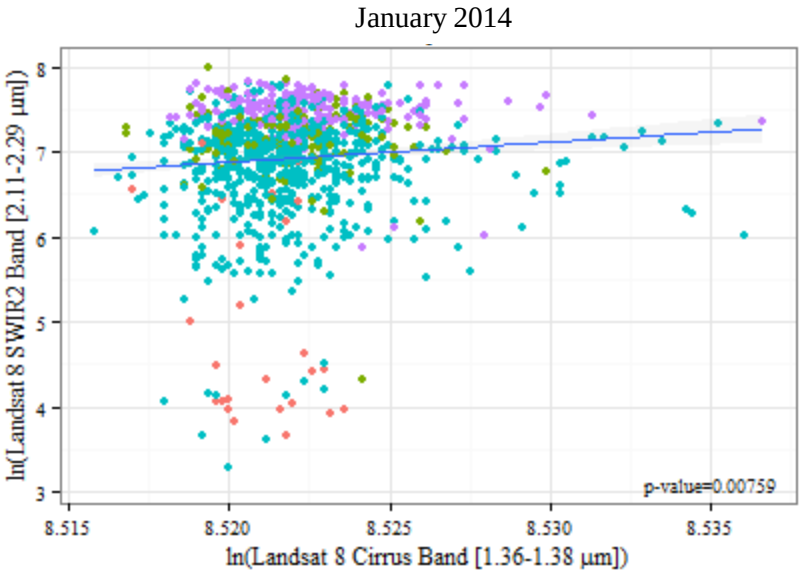


Prevalence of Cirrus Clouds in Sample Data

- Nearly no relationship for SWIR







An Hierarchical Approach to Dealing with Cirrus Clouds

Traditional Multinomial Regression

Hierarchical Multinomial Error Model

	Correct	Incorrect
Correct	463	5
Incorrect	13	19

One-Tailed McNemar Test:

p-value=0.0264

Probability of observing a difference in K this large by chance:

p.value=0.026

Permutation Based Test