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# Multitemporal RADARSAT-2 Fine-Beam Polarimetric SAR for Urban Land Cover Mapping

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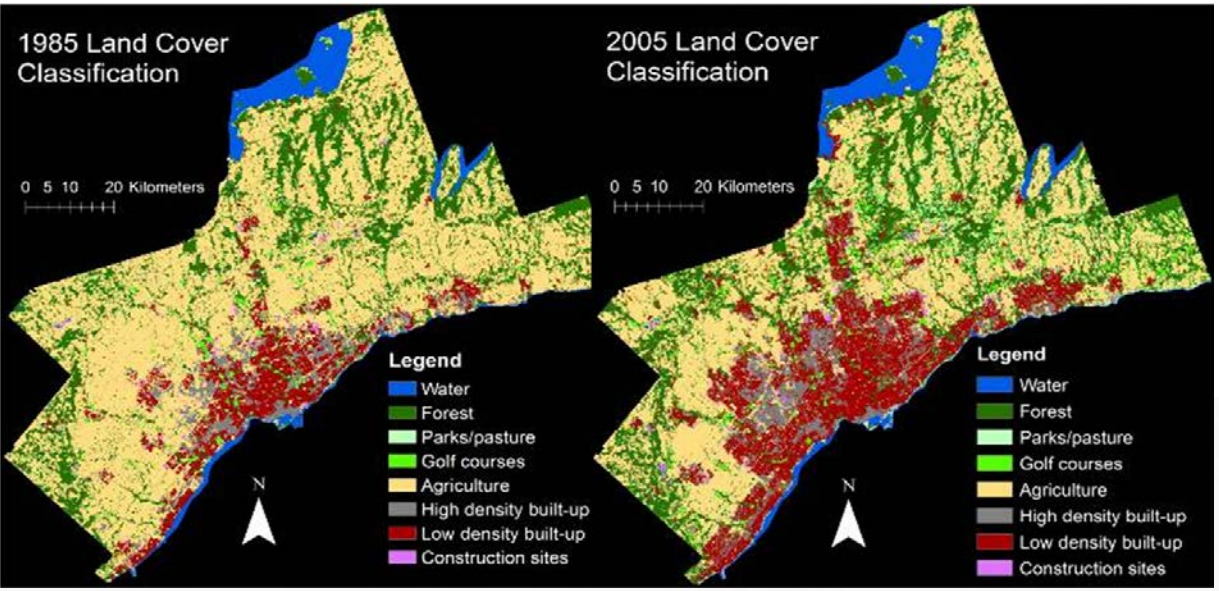
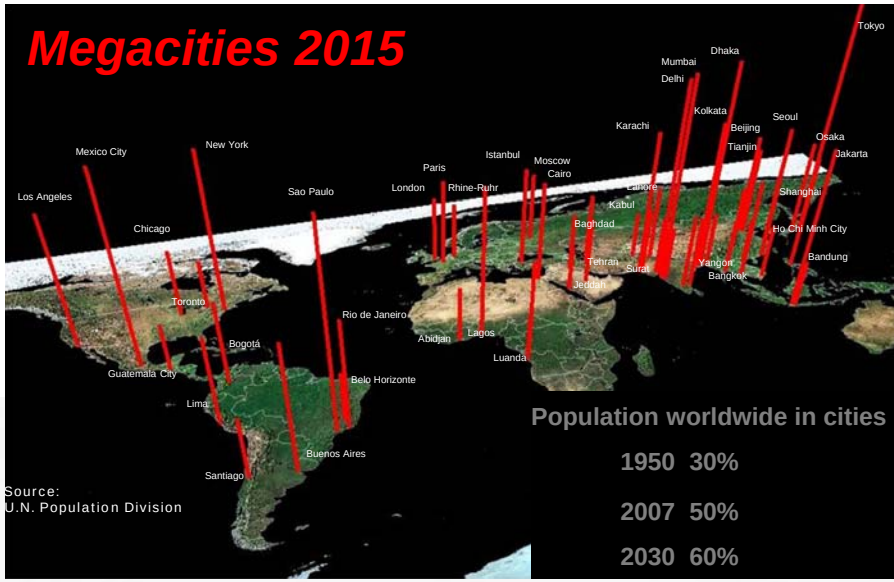
European Space Agency

# Introduction

- Urban represents one of the most dynamic areas due to rapid global urbanization
- Remote sensing can provide timely and reliable LULC information required for sustainable planning
- Spaceborne high resolution polarimetric SAR data has become an attractive data source for urban land cover mapping.



# Background

- Most of the urban analysis using SAR data often only mapped urban extents or very few urban classes.
- Efficiencies of various PolSAR features and multitemporal data combinations have not been fully investigated for urban mapping.
- Ideal segmentation is usually difficult to obtain on SAR data for object-based approach. Pixel-based approaches without contextual analysis generally lead to “Pepper and salt” results. Traditional contextual analysis often produce over averaged results.

# Research Objectives

- Assess various PolSAR features and multitemporal data combinations.
- Evaluate pixel-based contextual classification, object-based classification and hybrid approach.
- Compare different PolSAR distribution models, and integrate multi-models for further improvement.
- Investigate SAR for urban land cover classification: PolSAR or very high resolution single polarization SAR?

# Related Papers

I. Xin Niu, Yifang Ban, 2013, Multitemporal RADARSAT-2 Polarimetric SAR Data for Urban Land Cover Classification using an Object-based Support Vector Machine and a Rule-based Approach. *International Journal of Remote Sensing*, Vol. 34, pp.1-26.

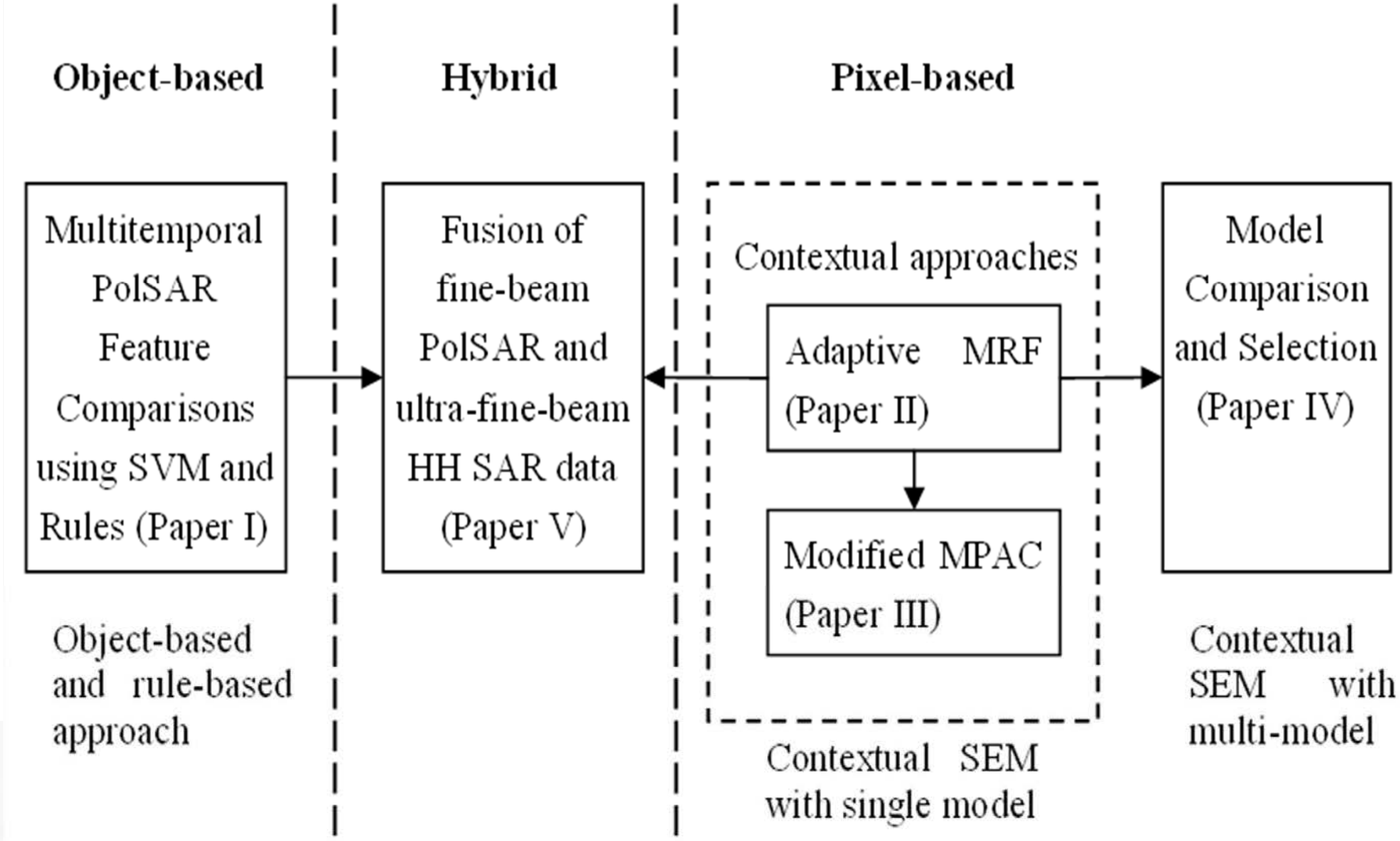
II. Xin Niu, Yifang Ban, 2012, An Adaptive Contextual SEM Algorithm for Urban Land Cover Mapping using Multitemporal High-resolution Polarimetric SAR Data. *IEEE Journal of Selected Topics In Applied Earth Observations And Remote Sensing*, Vol. 5, pp. 1129-1139.

III. Xin Niu, Yifang Ban, 2012, A Novel Contextual Classification Algorithm for Multitemporal Polarimetric SAR Data, Submitted to *IEEE Geoscience and Remote Sensing Letters*.

IV. Xin Niu, Yifang Ban, 2012, Multitemporal Polarimetric RADARSAT-2 SAR Data for Urban Land Cover Mapping Through a Dictionary-based and a Rule-based Model Selection in a Contextual SEM Algorithm. *Canadian Journal of Remote Sensing* (Conditionally accepted).

V. Xin Niu, Yifang Ban, 2012, RADARSAT-2 fine-beam polarimetric and ultra-fine beam SAR data for urban land cover mapping: Comparison and Synergy. Submitted to *IEEE Transaction on Geoscience and Remote Sensing*.

# Structure of the Research



# Study Area


Greater Toronto Area (GTA), Ontario, Canada

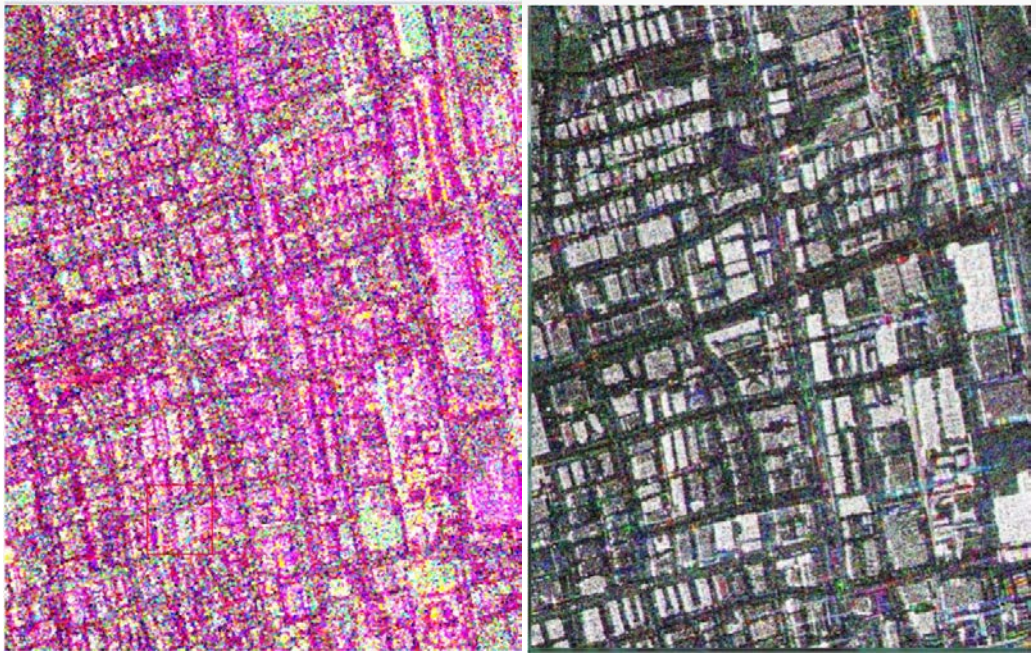
The major landuse/landcover classes:

- Built-up: high-density built-up areas, low-density built-up areas, Industrial and comercial areas, construction sites, wide roads, streets.
- Vegetation: forests, pastures, parks, golf courses and two types of agricultural crops.
- Water

# Data Description

RADARSAT-2 C-band data:

- Six-date fine-beam Quad-Pol single look complex products.
  - Pixel-spacing: range 4.7m; azimuth 5.1m
- Three-date ultra-fine-beam HH SAR data.
  - Pixel-spacing: range 1.6 m; azimuth 1.6 m

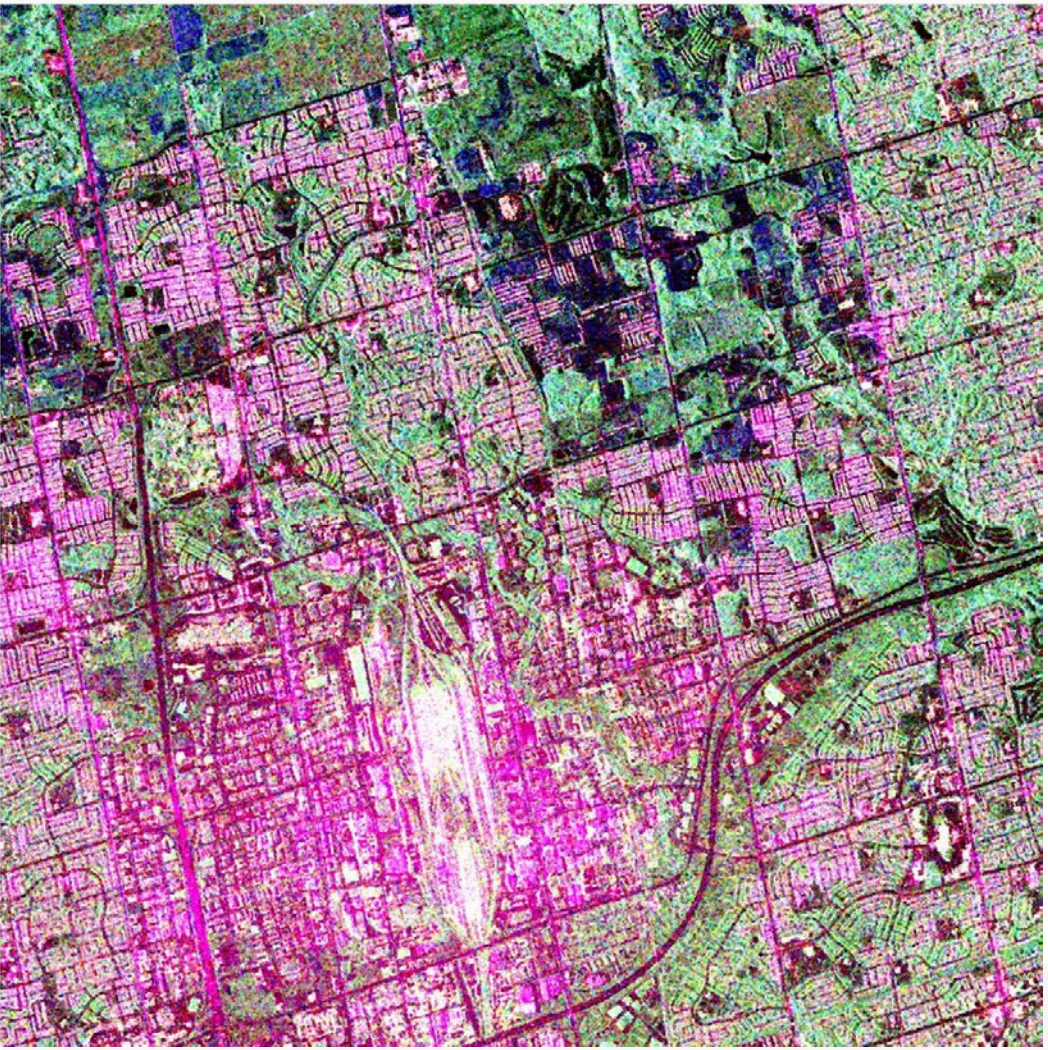


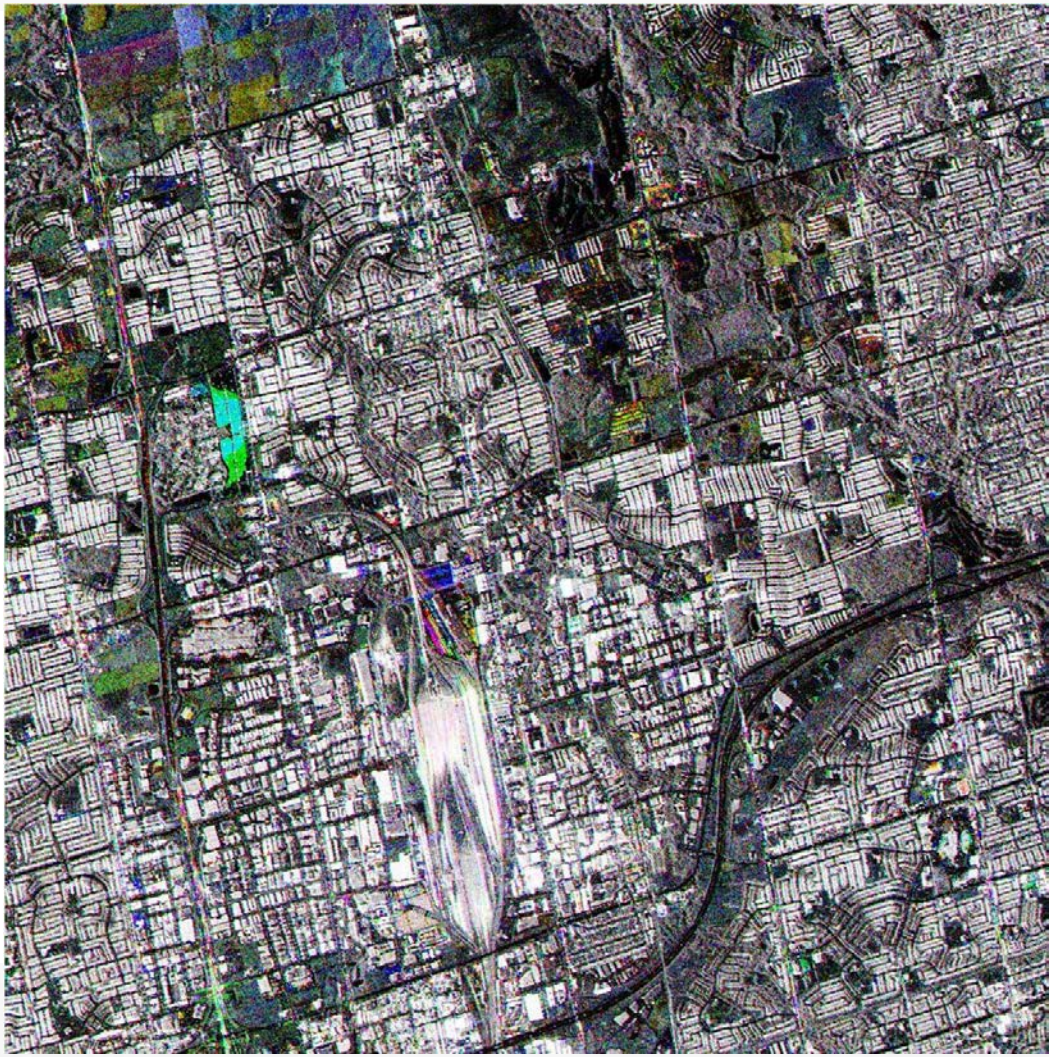
Fine-beam PolSAR Data  Ultra-fine beam HH SAR Data

| Fine-beam PolSAR Data | Orbit | Incidence angle range (degree) | Code |
|---|---|---|---|
| June 11 2008 | Ascending | 40.179~ 41.594 | A1 |
| June 19 2008 | Descending | 40.215~ 41.619 | D1 |
| July 05 2008 | Ascending | 40.182~ 41.597 | A2 |
| August 06 2008 | Descending | 40.197~ 41.612 | D2 |
| August 22 2008 | Ascending | 40.174~ 41.590 | A3 |
| September 15 2008 | Ascending | 40.173~ 41.588 | A4 |

| Ultra-fine beam HH SAR Data | Orbit | Incidence angle range (degree) |
|---|---|---|
| June 25 2008 | Ascending | 30.622~ 32.038 |
| August 12 2008 | Ascending | 30.611~ 32.043 |
| September 05 2008 | Ascending | 30.606~ 32.023 |

# PolSAR vs. Ultra-Fine C-HH SAR



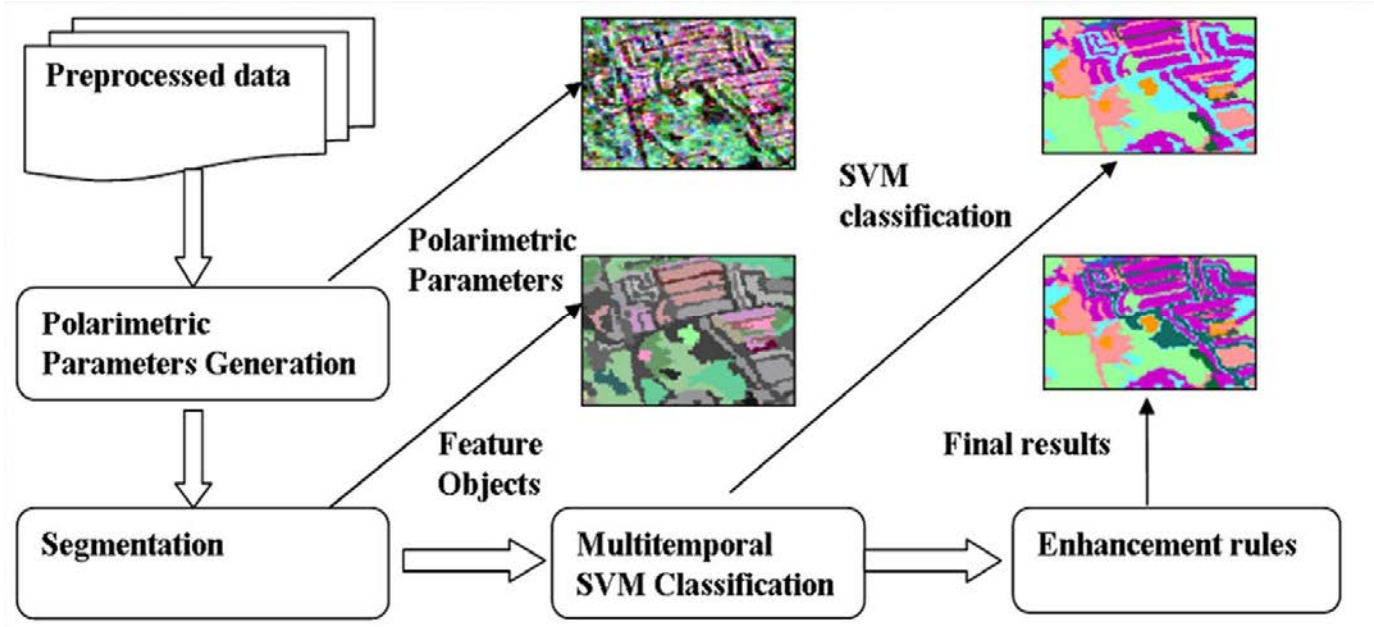


# Object-based Approach

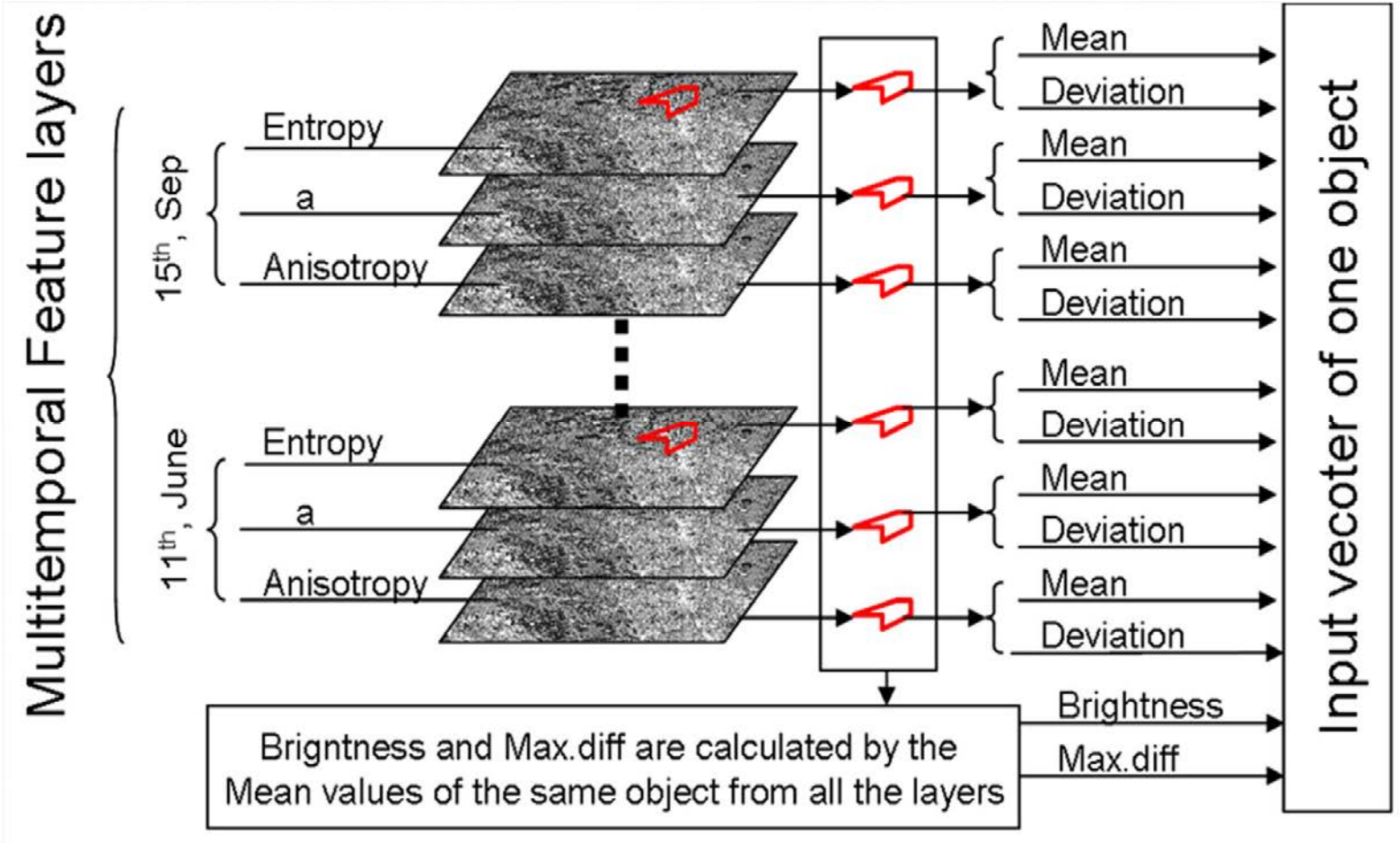
# Object-based SVM and Rule-based Approach

- Method:
  - Object-based SVM
  - Rule-based approach using object features and spatial relationships
  - Comparison of various PolSAR features
  - Comparison of different data combinations

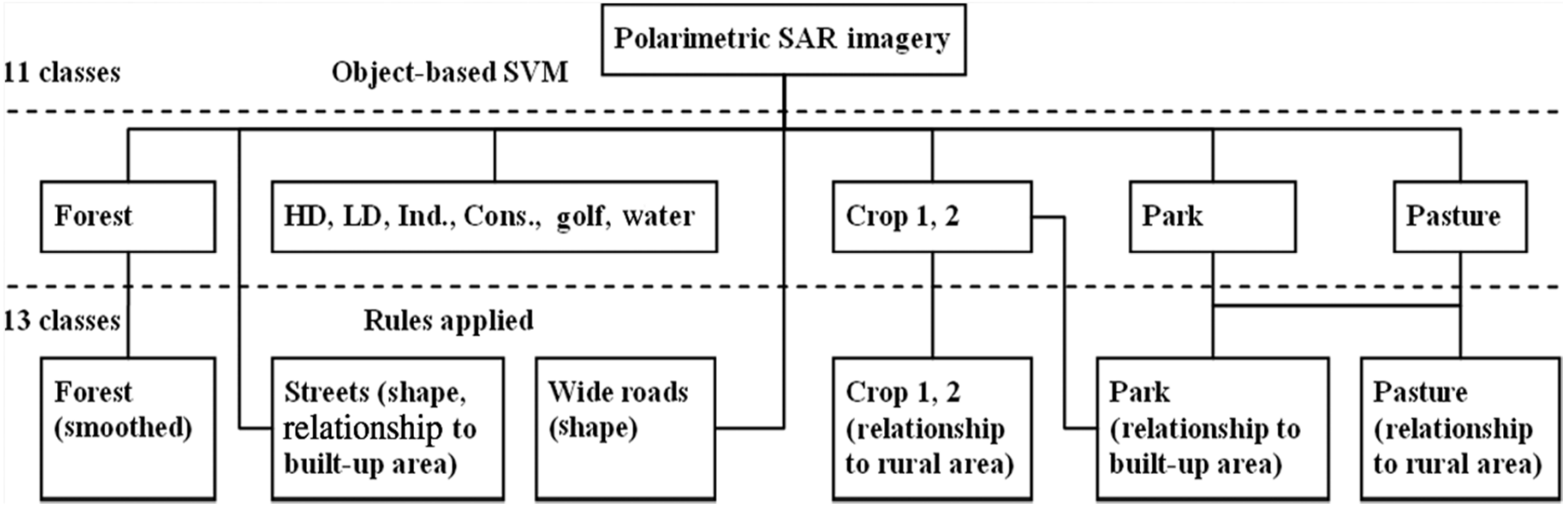
I. Xin Niu, Yifang Ban, 2013, Multitemporal RADARSAT-2 Polarimetric SAR Data for Urban Land Cover Classification using an Object-based Support Vector Machine and a Rule-based Approach. *International Journal of Remote Sensing*, Vol. 34, pp.1-26.




Flow chart of multitemporal data fusion combining SVM and rule-based method




SVM input vector formed by multitemporal features




SVM and rule-based classification scheme.

# Pixel-based Approach

# Contextual SEM Algorithm

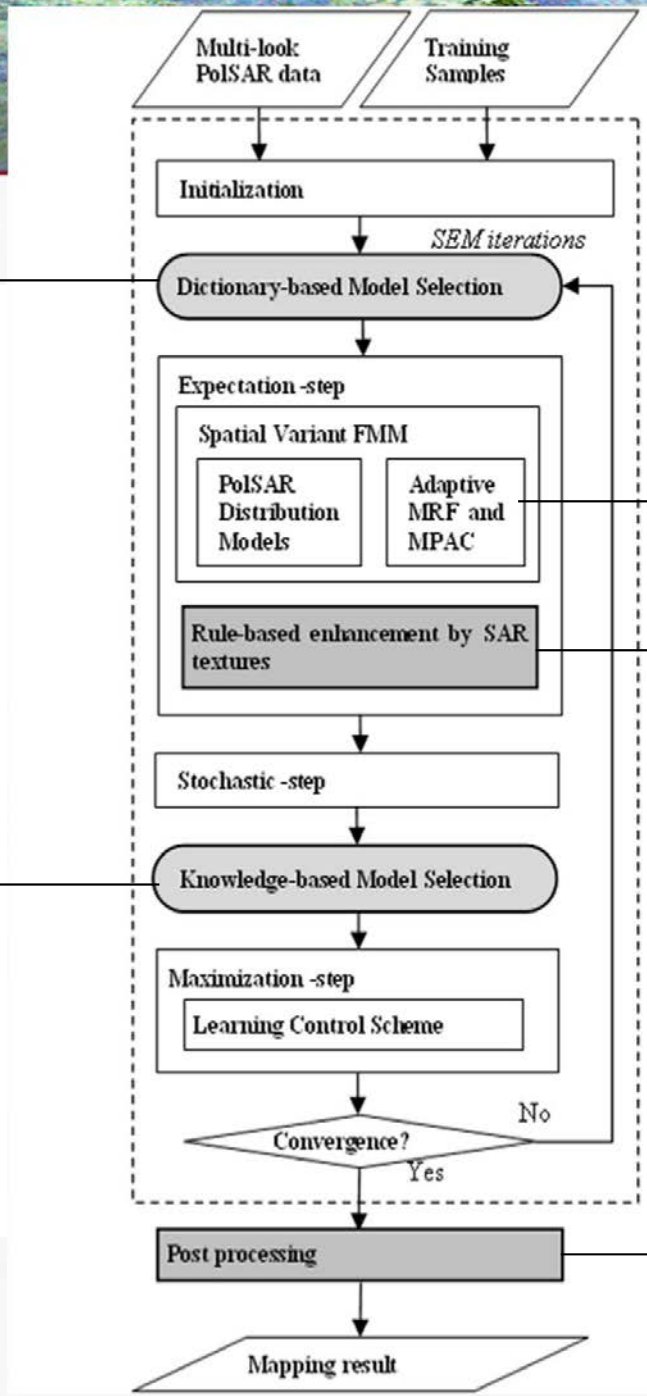
- Method:
  - Adaptive markov random field (MRF)
  - Spatially variant Finite Mixture Models (FMM)
  - Stochastic expectation maximum (SEM) algorithm
  - Comparison of the contextual SEM with various PolSAR models and contextual SVM
  - Learning control

II. Xin Niu, Yifang Ban, 2012, An Adaptive Contextual SEM Algorithm for Urban Land Cover Mapping using Multitemporal High-resolution Polarimetric SAR Data. *IEEE Journal of Selected Topics In Applied Earth Observations And Remote Sensing*, Vol. 5, pp. 1129-1139.

# Contextual SEM Algorithm

- Method:
  - Modified multiscale pappas adaptive clustering (MPAC)
  - SEM algorithm
  - Combination of adaptive MRF and modified MPAC
  - Comparison of the contextual approaches with SVM

III. Xin Niu, Yifang Ban, 2012, A Novel Contextual Classification Algorithm for Multitemporal Polarimetric SAR Data, Submitted to *IEEE Geoscience and Remote Sensing Letters*.




Model selection
(Paper IV)

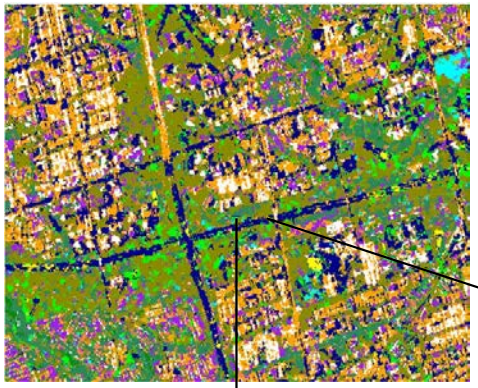
Contextual analysis
(Paper II)
(Paper III)

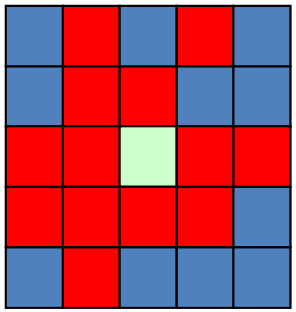
Texture enhancement and rule-based extraction for hybrid approach
(Paper V)

The structure of the proposed contextual SEM algorithm

# MRF

Labeling map

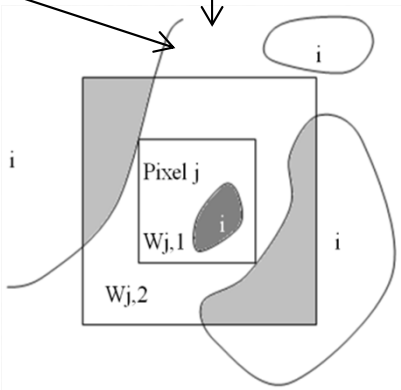




MRF gives the prior probability

# MPAC

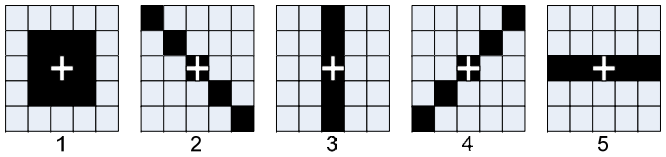
PolSAR image




MPAC estimates the varying class features for the observation probability

# Adaptive MRF

(1) Adaptive neighborhood




(2) Adaptive energy function

$$p(L_s \mid L_r, r \in \eta_s) = \frac{1}{Z_s} \exp\{(\beta(1-b_s)\sum_{r \in \eta_s} \delta(L_s - L_r))\}.$$

# Modified MPAC

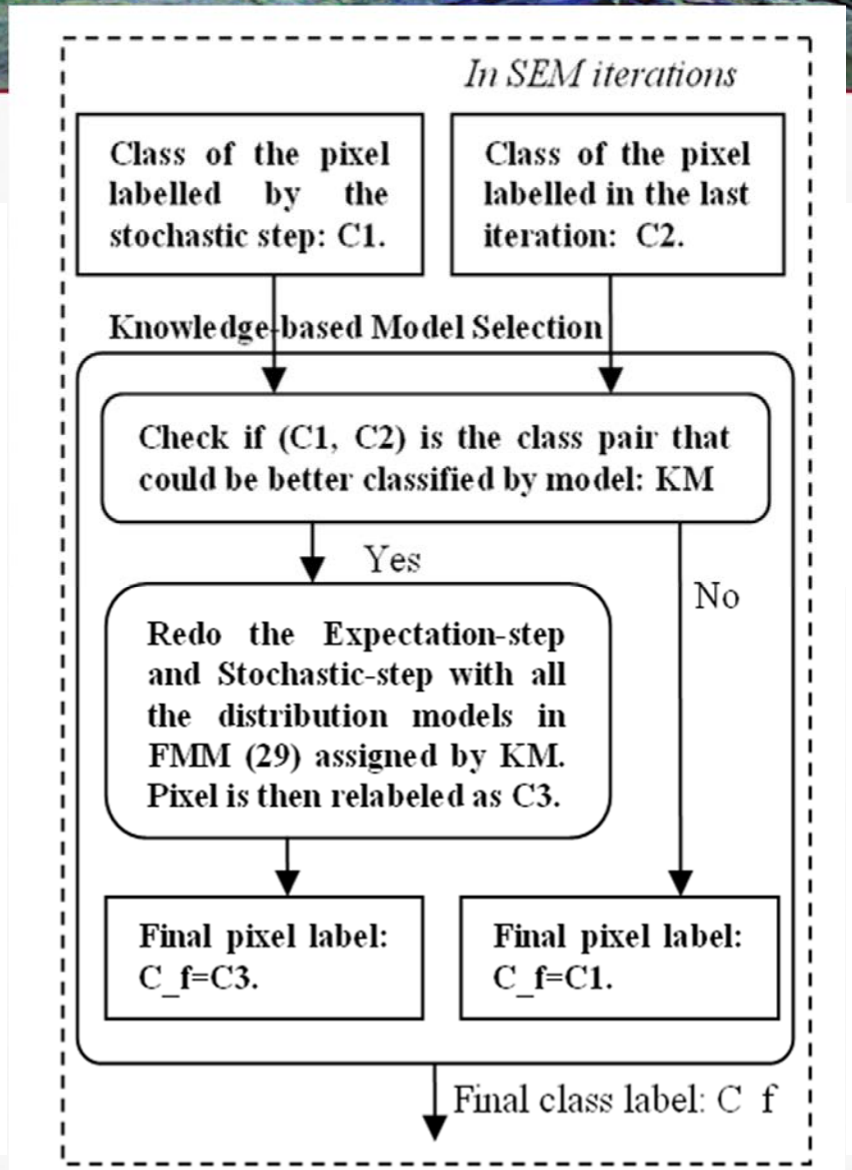
$$\begin{cases} p(C_j \mid l_j) = \max\{ f_{l_j}(C_j \mid \Theta, \hat{\mu}_{W\,j1}(l_j)), \ldots, \\ \quad f_{l_j}(C_j \mid \Theta, \hat{\mu}_{W\,jS}(l_j)), f_{l_j}(C_j \mid \Theta, \hat{\mu}_{W}\ (l_j))\}, \\ \text{if local statistic } \hat{\mu}_{W\,jst}(l_j) \text{ exists and} \\ \quad \text{is considered reliable, } \forall s \in \{1, \ldots, S\} \\ \\ p(C_j \mid l_j) = f_{l_j}(C_j \mid \Theta, \hat{\mu}_{W\,t}(l_j)) \\ \text{if local statistic } \hat{\mu}_{W\,jst}(l_j) \text{ does not exists or} \\ \quad \text{is not considered reliable, } \forall s \in \{1, \ldots, S\} \end{cases}$$

MPAC gives the multitiemporal observation probability using the estimated class features from the multiscale adaptive windows and also the global range.

# Model Comparison and Selection

- Method:
  - Contextual SEM
  - Comparison of Various PolSAR models
  - Dictionary-based model selection
  - Rule-based model selection

IV. Xin Niu, Yifang Ban, 2012, Multitemporal Polarimetric RADARSAT-2 SAR Data for Urban Land Cover Mapping Through a Dictionary-based and a Rule-based Model Selection in a Contextual SEM Algorithm. *Canadian Journal of Remote Sensing* (Conditionally accepted).



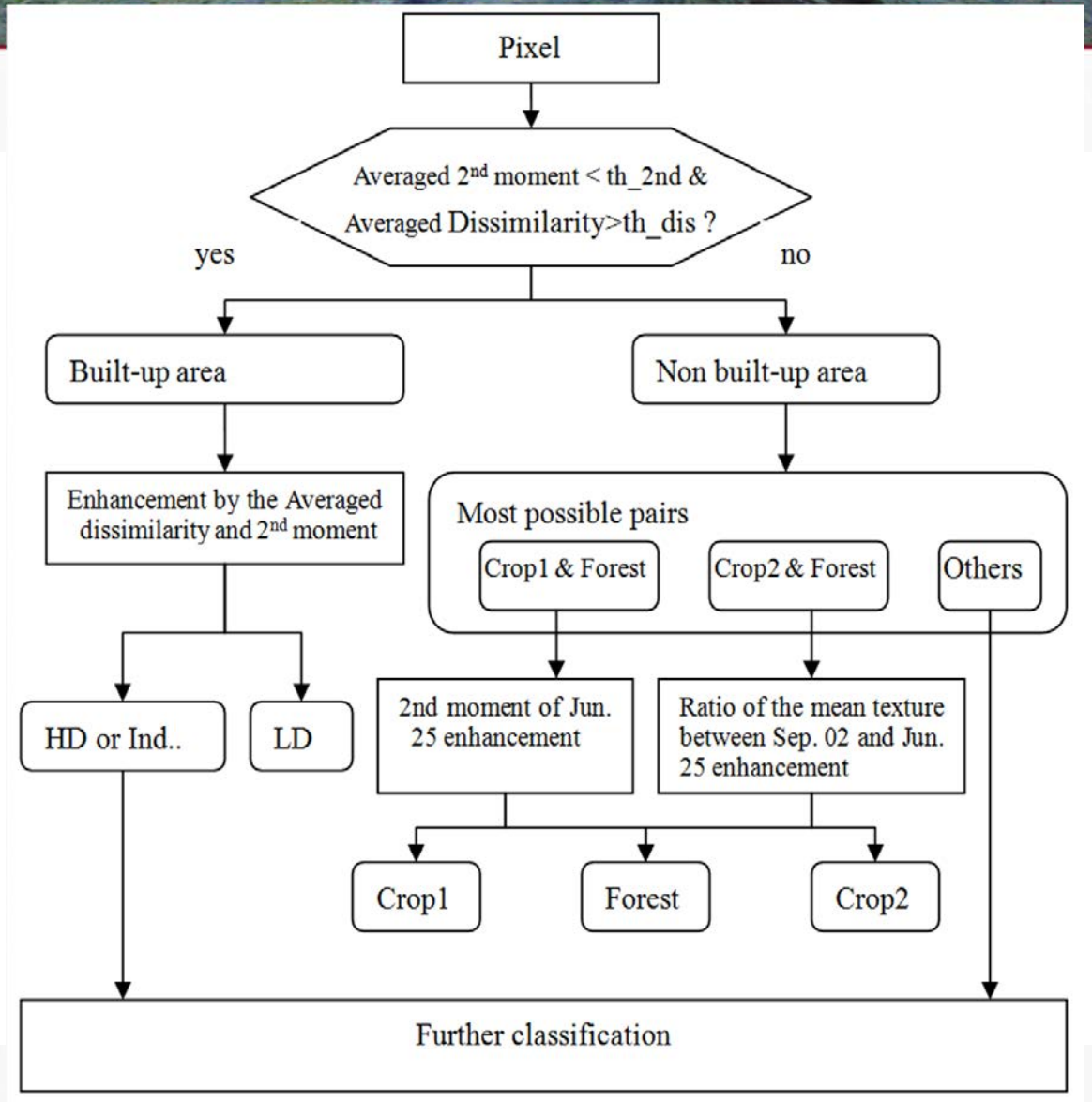

Scheme of the proposed rule-based model selection

# Hybrid Approach

# Texture Enhancement and Rule-based Feature Extraction

- Method:
  - Contextual SEM
  - Texture enhancement scheme
  - Pixel- and object-based fusion approach
  - Comparison of the Fine-beam Polarimetric and Ultra-fine Beam HH SAR Data

V. Xin Niu, Yifang Ban, 2012, RADARSAT-2 Fine-beam Polarimetric and Ultra-fine Beam SAR Data for Urban Land Cover Mapping: Comparison and Synergy. Submitted to *IEEE Transaction on Geoscience and Remote Sensing*.

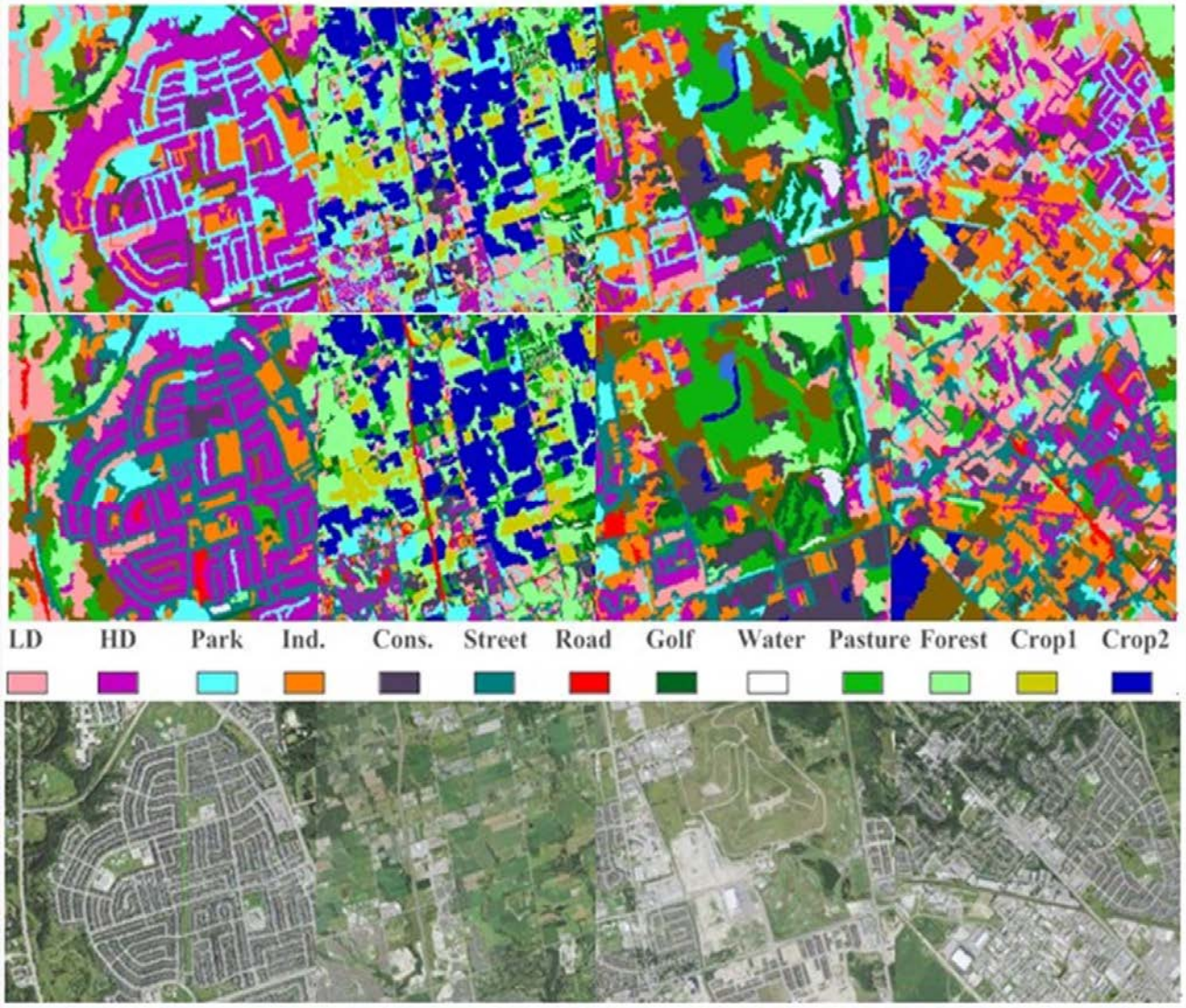



Texture enhancement scheme

# Results & Discussion

# Object-based Approach

# Object-based Classification

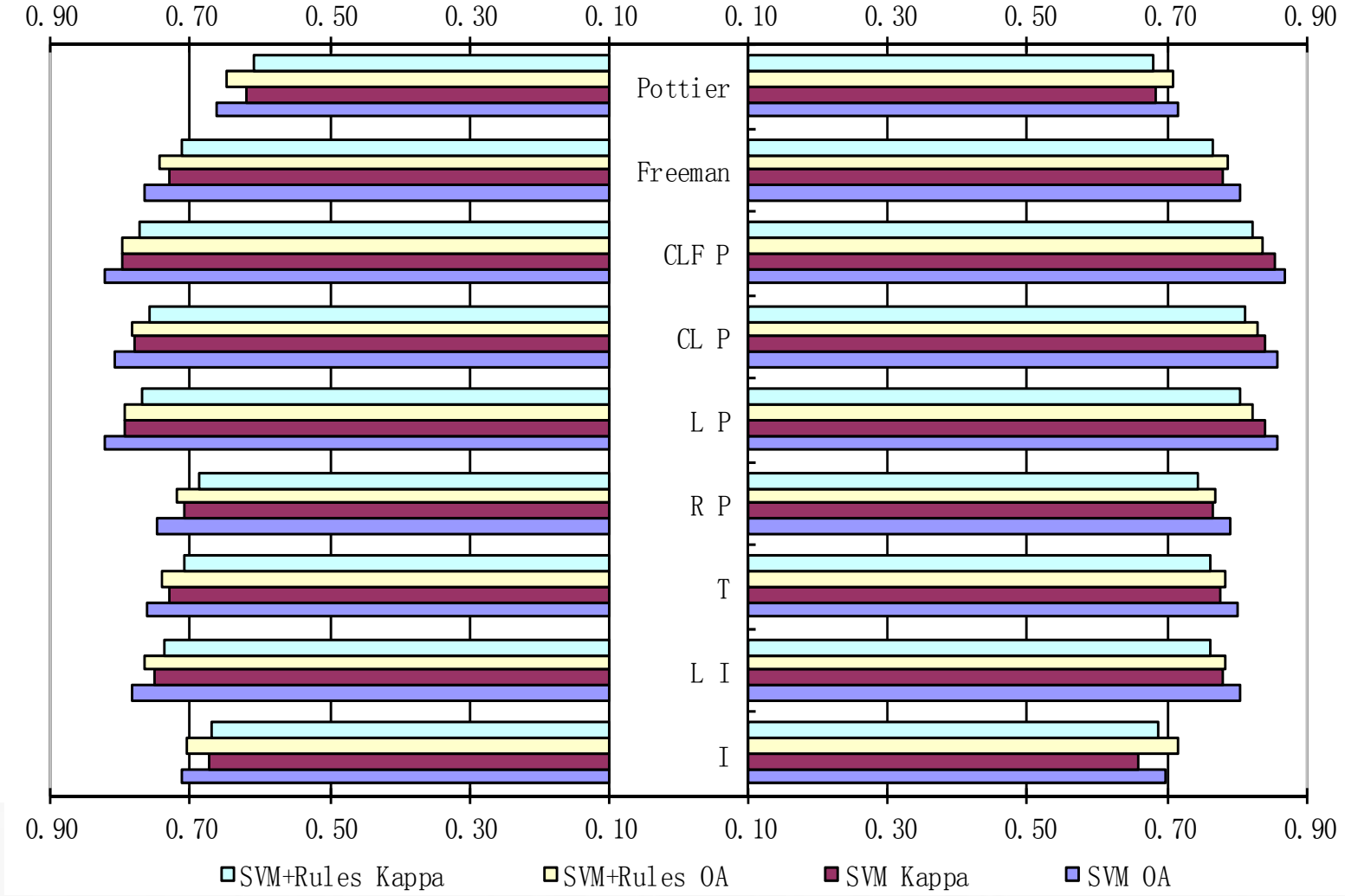



SVM

SVM with Rules

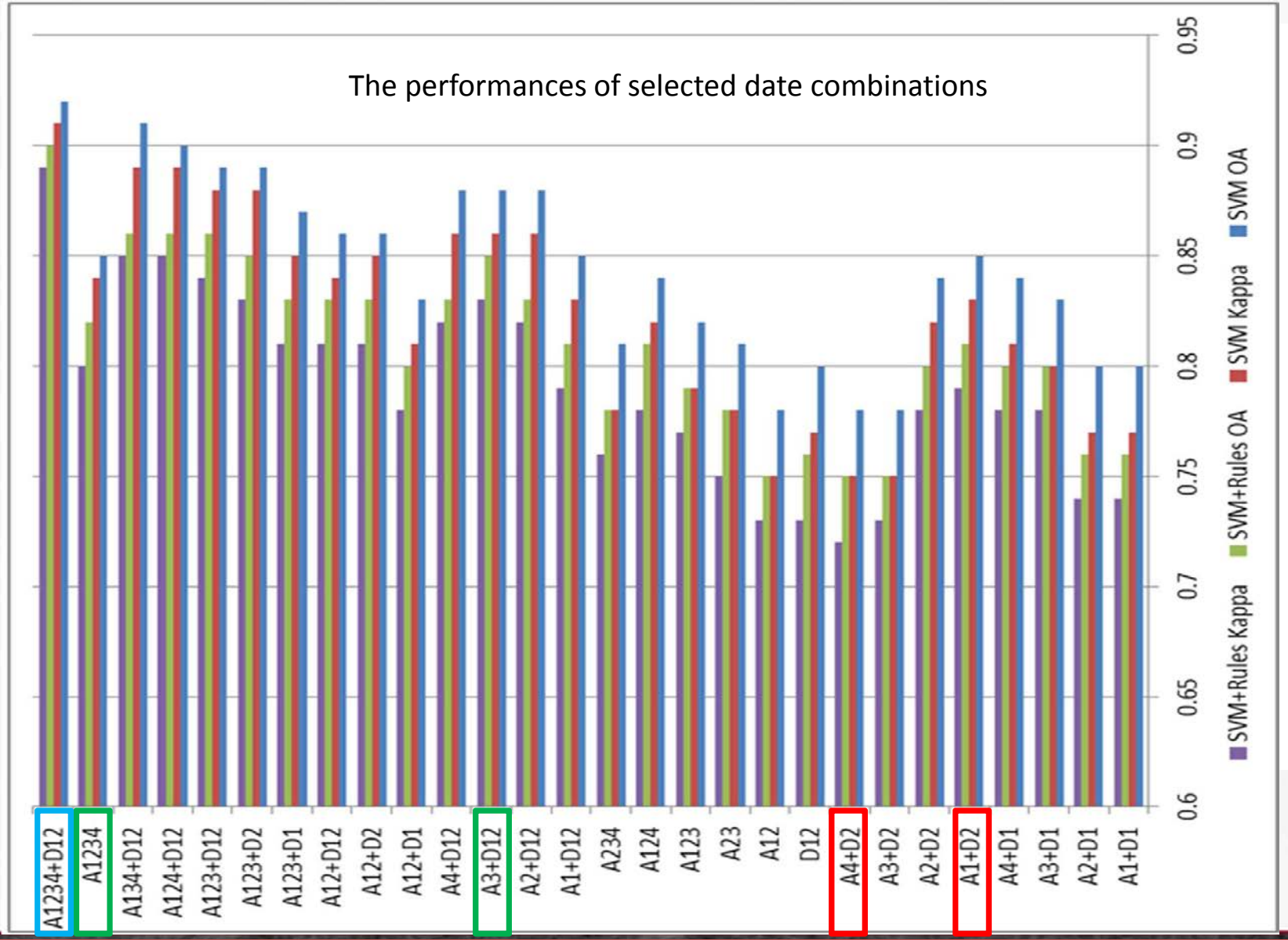
Selected samples of the classification results by Compressed Logarithmic Pauli parameters. Up: SVM results. Middle: SVM combined rules. Bottom: corresponding ground truths

# PolSAR feature comparisons




Comparison of various polarimetric SAR parameters on the ascending (right) and the descending (left) data stack

# Multitemporal Combination Comparisons



# Pixel-based Approach

# Comparison of the Contextual Approaches and SVM

Google earth image

PolSAR Pauli image

adaptive MRF

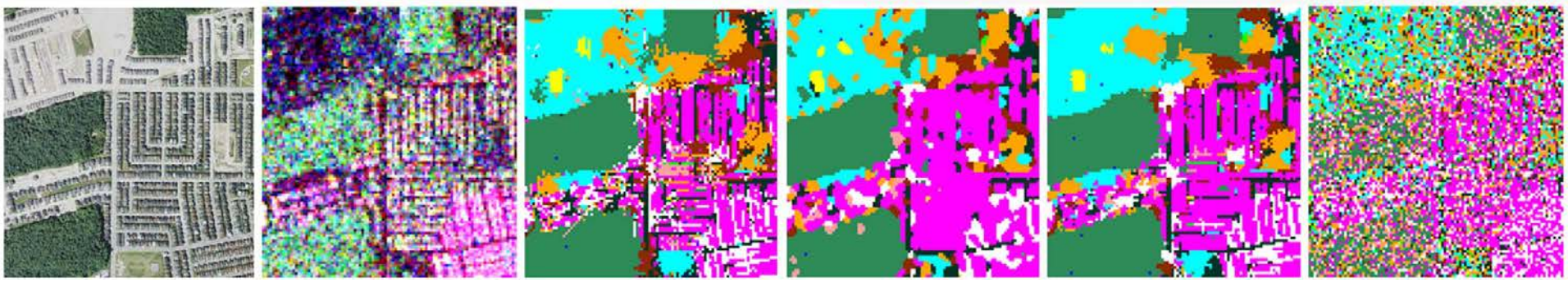
original MPAC

MPAC+adaptive MRF

SVM

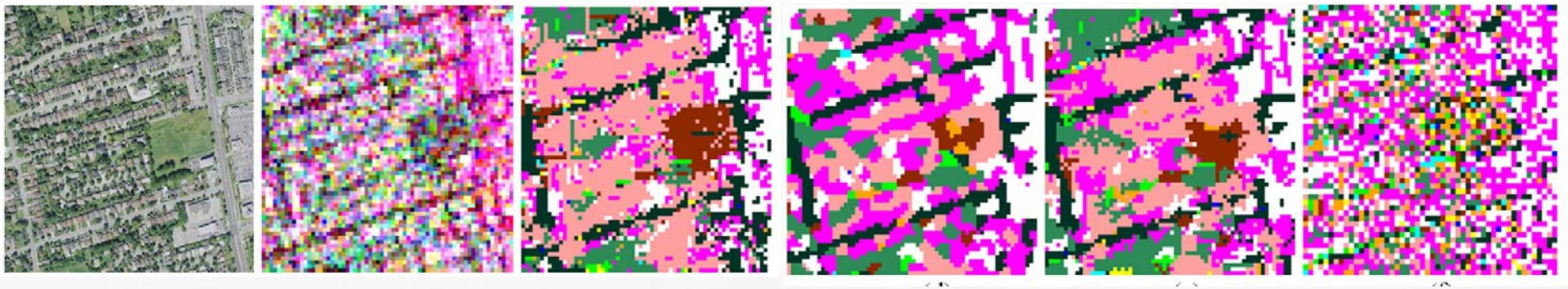
Pasture Water Forest Crop 1 Crop 2 Golf Cons Ind HD LD Road

# Comparison of the contextual approaches and SVM



Google Map | Pauli image | adaptive MRF | original MPAC | MPAC+adaptive MRF | SVM

Zooming examples in a LD area



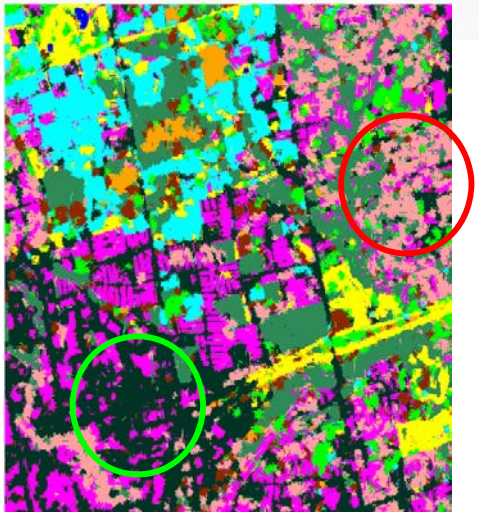
Google Map | Pauli image | adaptive MRF | original MPAC | MPAC+adaptive MRF | SVM

Pasture | Water | Forest | Crop 1 | Crop 2 | Golf | Cons | Ind | HD | LD | Road

# Comparison of Various PolSAR Models

Google Map

Pauli image



G0p

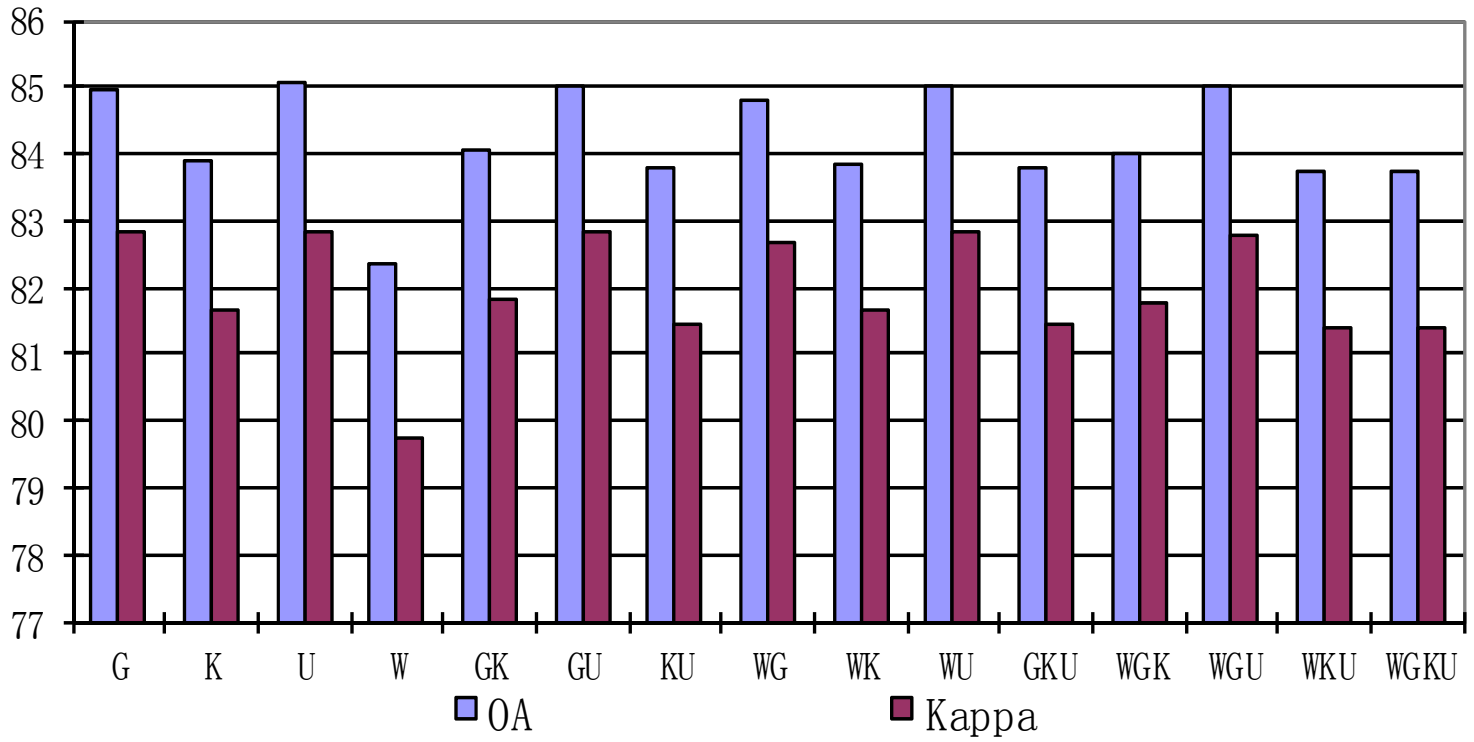
Kp

KummerU

Wishart

LD HD Road Cons. Golf Pasture Water Forest Crop1 Crop2

# Effects of the dictionary-based model selection




Overall Accuracy and Kappa for the different dictionaries. G=G0p, K=Kp, U=KummerU, W=Wishart. Unit is in percent.

# Effects of the rule-based model selection

Google Map

G0p

G0p + HD_Road Rule

Google Map

Wishart

Wishart + LD_Forest

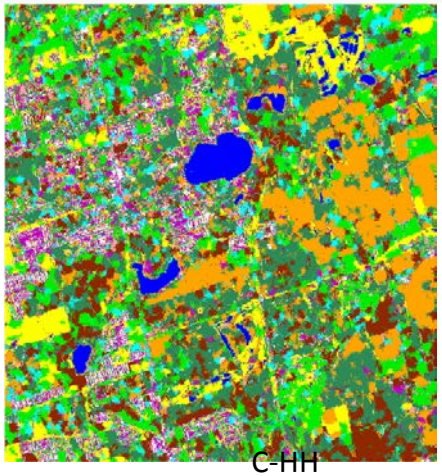
Rule

LD | HD | Road | Cons. | Golf | Pasture | Water | Forest | Crop1 | Crop2

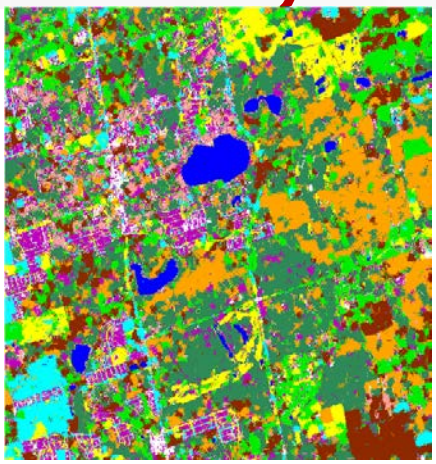
# Hybrid Approach

# PolSAR data and C-HH data with and without texture analysis

Google Map

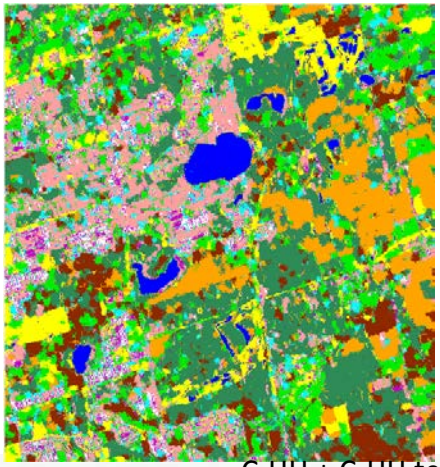


C-HH

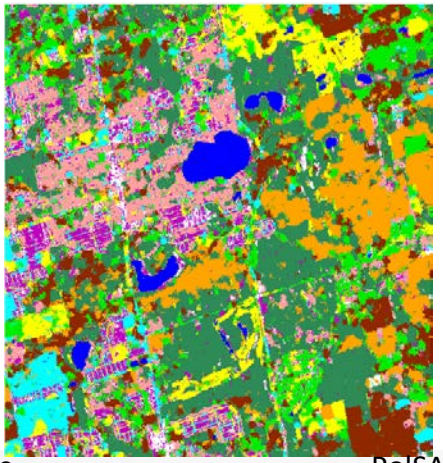


PolSAR

Pauli image



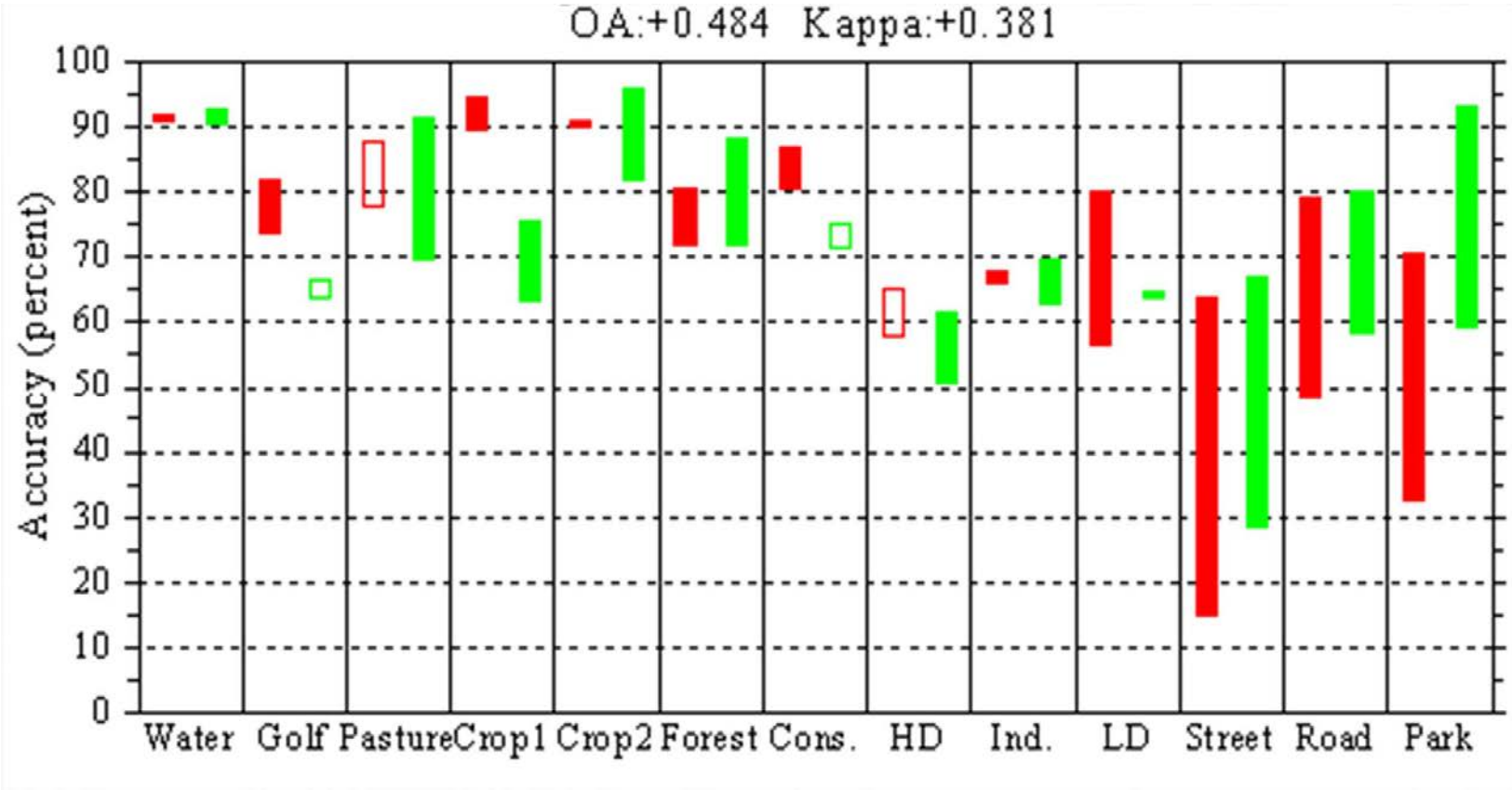
C-HH + C-HH texture



PolSAR + C-HH texture


Google map (a), PolSAR Pauli image (b), and results by the PolSAR (c) and C-HH SAR (d) data without (1) and with (2) texture analysis.

# Improvement by the hybrid approach to the pixel-based classification of PolSAR data




Changes of the Producer accuracies (red) and User accuracies (green) from using only contextual SEM to the hybrid approach (with texture analysis and rule-based approach) on the PolSAR data. The solid bar is for the increase, the hollow one is for the decrease.

# Results: Hybrid Approach

Google Map

Pauli image

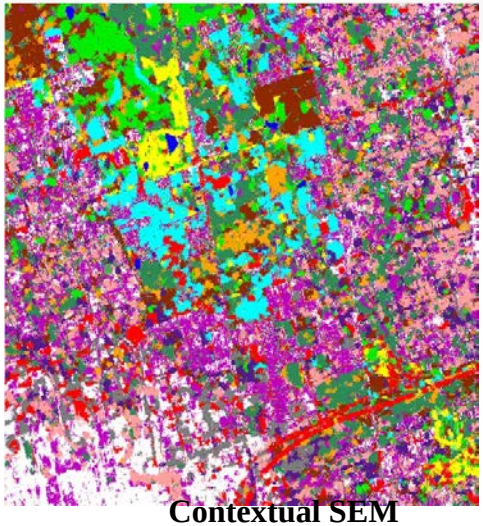
PolSAR using hybrid approach

# Comparison of Pixel-, Object-based & Hybrid Approaches

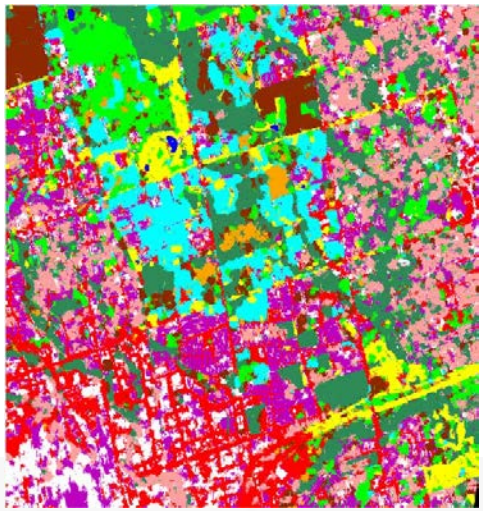
# Comparison of the Mapping Approaches

Google Map

Pauli image

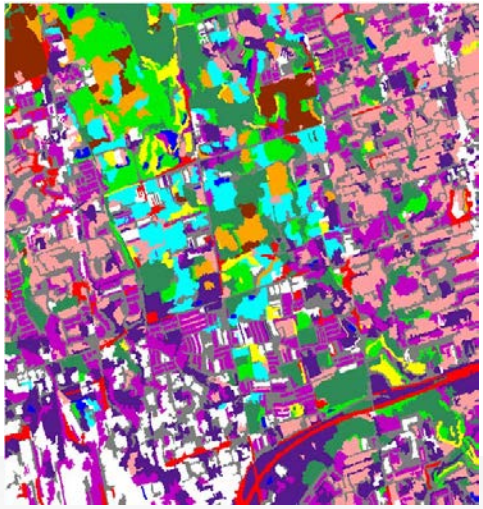


Contextual SEM



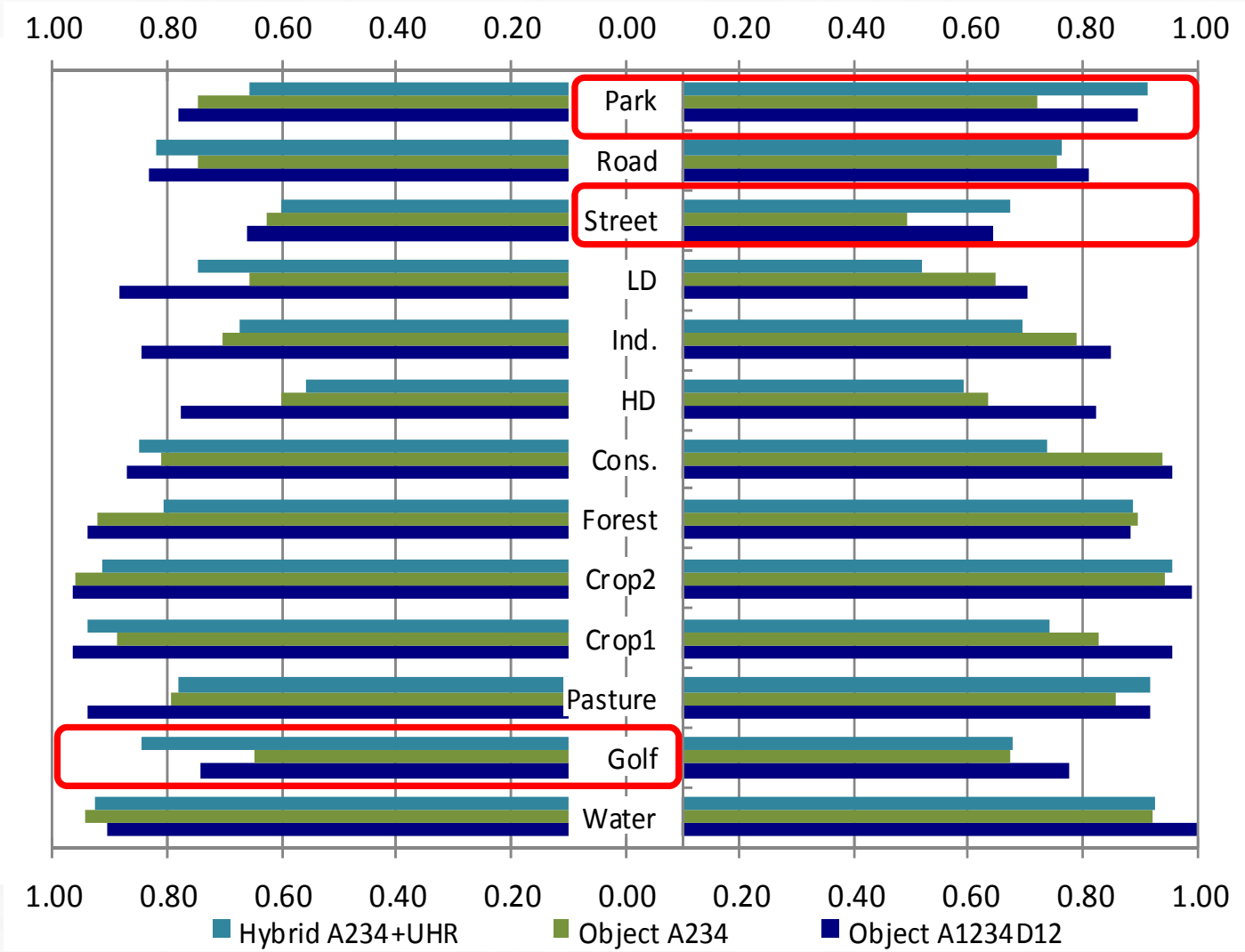
Contextual SEM+ Model Selection

Hybrid approach



Object-based approach

# Comparison of the Mapping Approaches




The producer (left) and user (right) accuracy

**OA: Hybrid (0.76)** **Object A234 (0.78)** **Object A1234D12 (0.86)**

# Conclusions & Future research

# Conclusions

- The processed Pauli parameters were found effective for detailed urban mapping. And the combination of ascending and descending data with proper time span was fond significant in urban land cover mapping using multitemporal PolSAR data.
- The proposed contextual approaches were effective for detailed urban mapping using high resolution PolSAR data. Object-based approaches were found relatively more efficient.
- G0p, Kp and KummerU were generally more effective than Wishart model for detailed urban mapping using high resolution PolSAR data. The proposed rule-based model selection was found more effective than the dictionary-based model selection for urban mapping.
- SAR polarizations have been noticed significance for identifying different urban classes. The proposed hybrid approach could effectively improve the urban mapping results

# Future Research

- POLinSAR!
- Further development of hybrid methods for high resolution PolSAR data.
- Investigating effective multi-frequency, and multi-resolution data fusion.