Coastline Detection and Coastal Zone Classification with Spaceborne Synthetic Aperture Radar Imagery

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Outline

Coastline Detection:

- Single-polarization SAR imagery
- Dual-pol SAR data

Coastal Zone Classification:

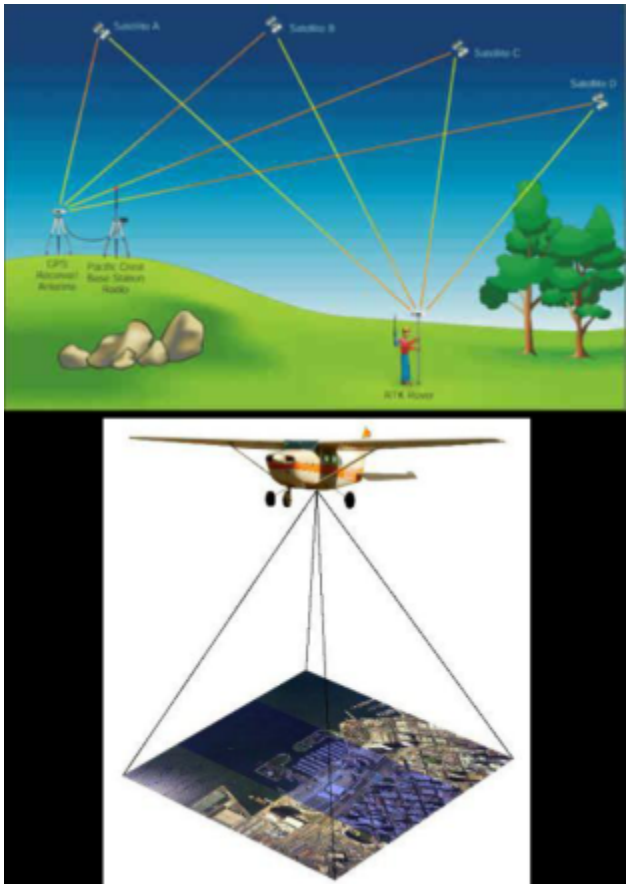
- Full-pol SAR data

Part 1: Coastline Detection

Motivations:

- A continuous update of coastal maps is needed
- Coastal accretion and erosion
- Cartography
- Disasters mapping

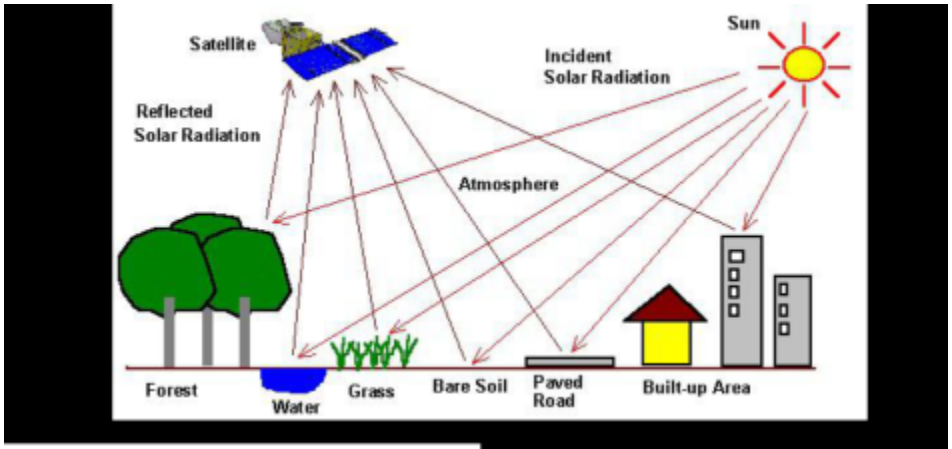
Part 1: Traditional tools

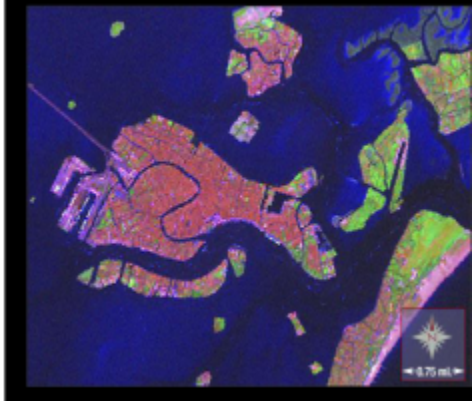


Traditional approaches to coastline mapping are:

- **Geodetic survey and GPS-RTK: high accuracy but limited coverage**
- **Aerial photography: continuous survey but expensive**
- **Airborne videography/video systems: continuous**
- **collection of data but expensive**
- **Conventional techniques are not cost-effective**

Part 1: Modern tools – Optical Sensor

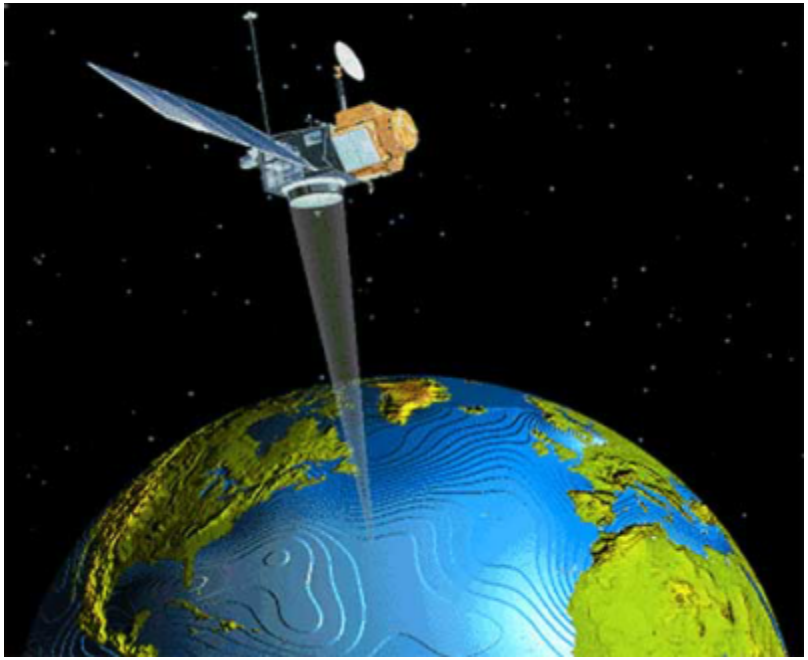




Optical Sensors

- **Cloud cover**
- **Solar illumination**
- **Meteorological conditions**

Part 1: Modern tools - SAR



Advantages:

- **Global coverage**
- **All weather**
- **Day & night**
- **Fine spatial details**
- **Easy image interpretation**

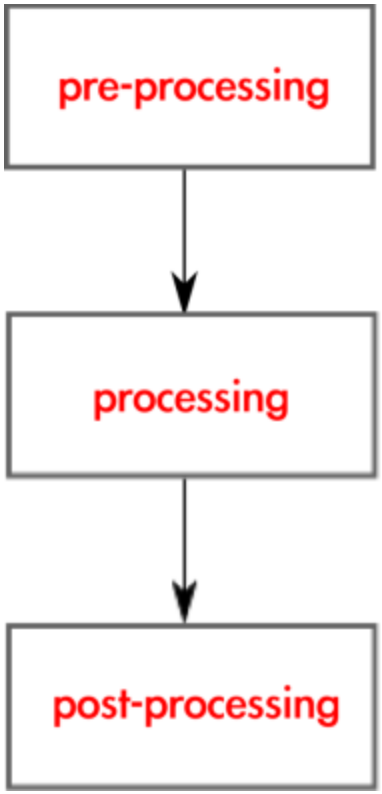
Shortcomings:

- **Revisit time**
- **Not available in some areas**

Main technical issues

- **Speckle**
- **Lack of sea/land contrast**
- **Complexity**

Part 1: Single-Pol SAR coastline detection



-speckle reduction
-geocoding

-land/sea discrimination

-coastline extraction

Land/sea discrimination

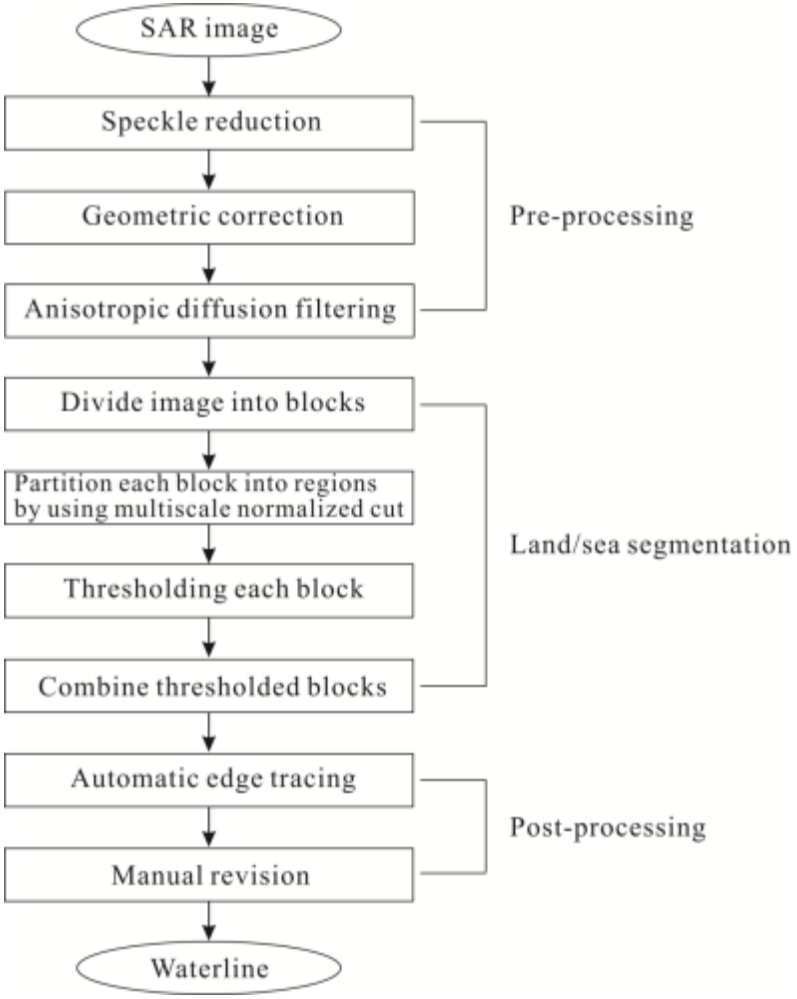
- **Edge detection**
- **Segmentation**

Coastline extraction

- **Edge detection.**
- **Active contour tracing**

Partially unsupervised or supervised

Part 1: Single-Pol SAR coastline detection



Land/sea discrimination

- **Edge detection**
- **Segmentation**

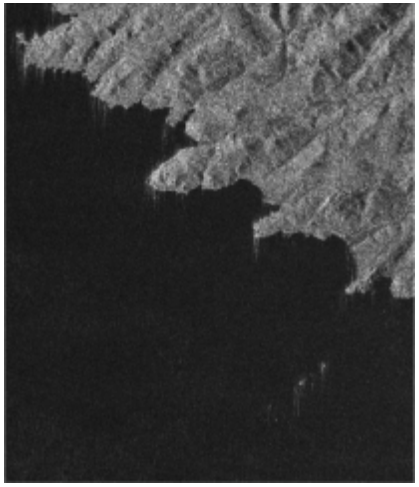
Coastline extraction

- **Edge detection.**
- **Active contour tracing**

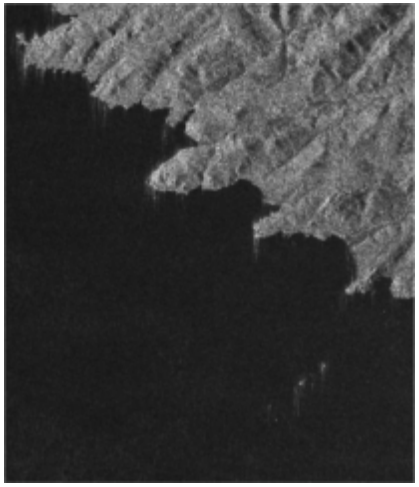
Partially unsupervised or supervised

Diagram of waterline extraction from SAR images

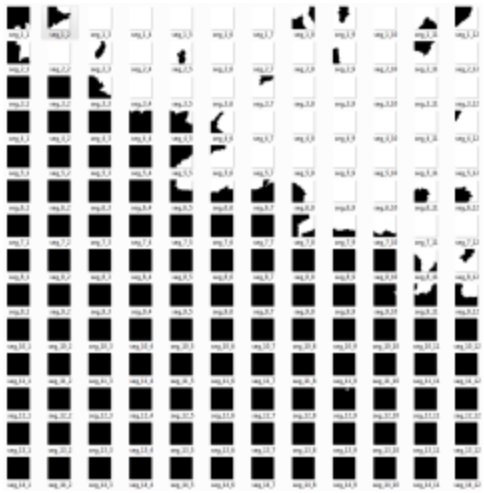
Part 1: Single-Pol SAR coastline detection



CSK VV March 6, 2012 at 05:31

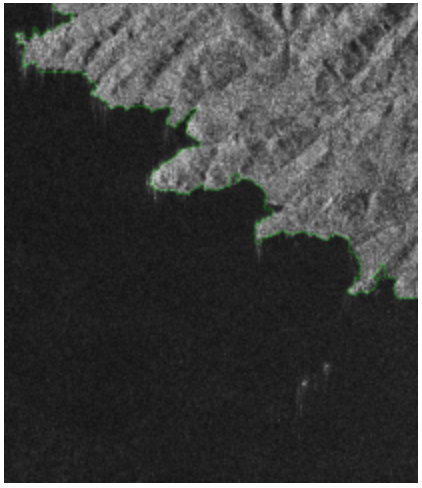


3X3 Lee Filter

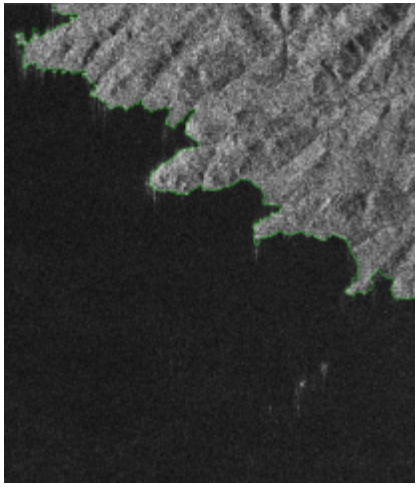


Multi-scale cut, threshold

Automatic edge tracing

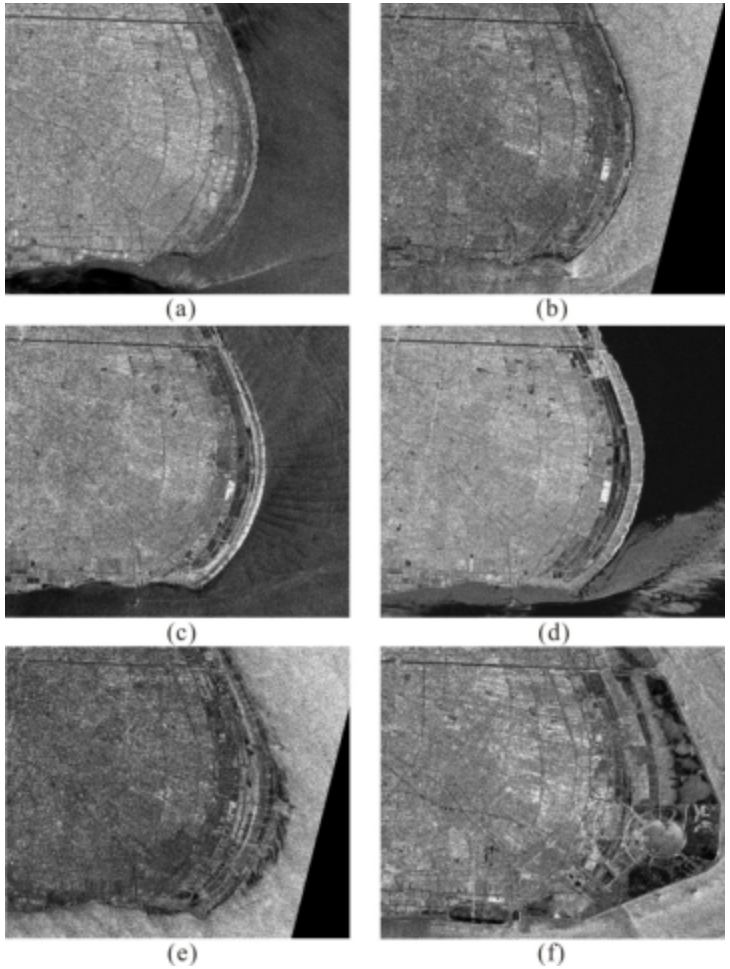


Automatic overlay



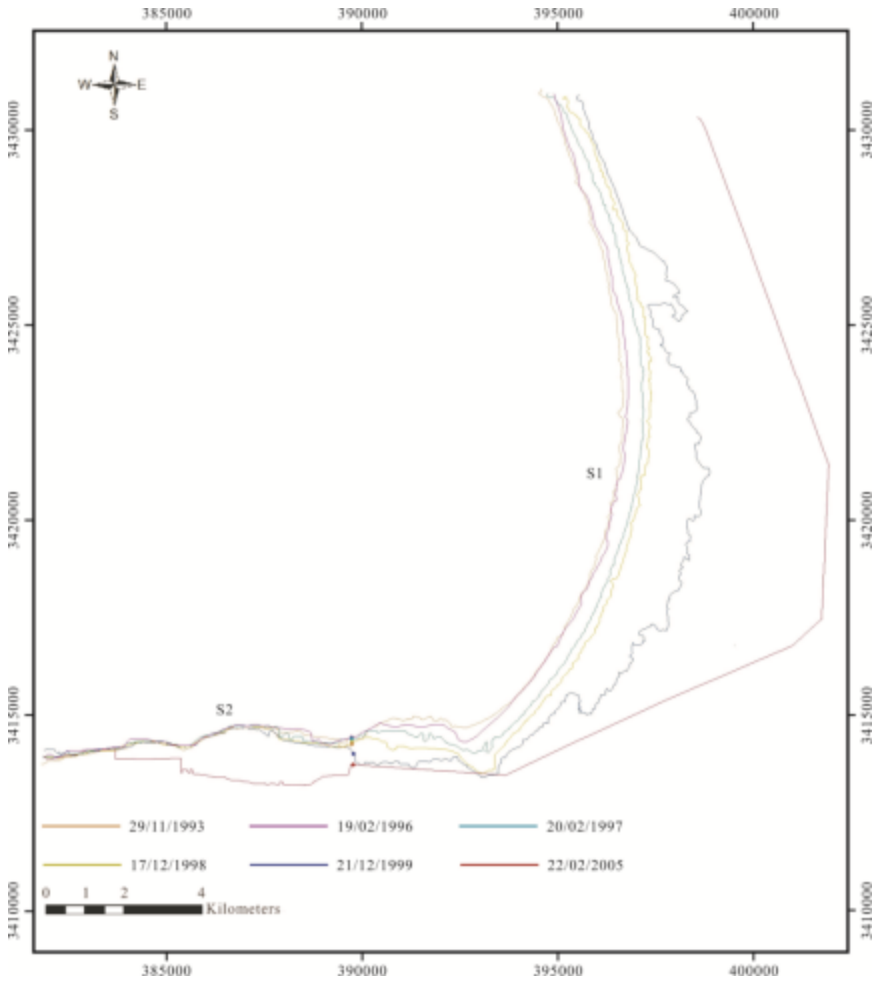
Manually revisit

Part 1: Single-Pol SAR coastline detection



Six SAR images at spring-tide times. The acquisition times of these six SAR images from (a) to (f) are 29 November 1993, 19 February 1996, 20 February 1997, 17 December 1998, 25 May 1999, 16 Nov 1999, 21 December 1999 and 22 February 2005.

Part 1: Single-Pol SAR coastline detection



Waterline movement due to the land reclamation project – one of the largest in the world

Part 1: Single-Pol SAR coastline detection

Case Study Results:

The shoreline moved substantially seaward from 1993 to 2005.

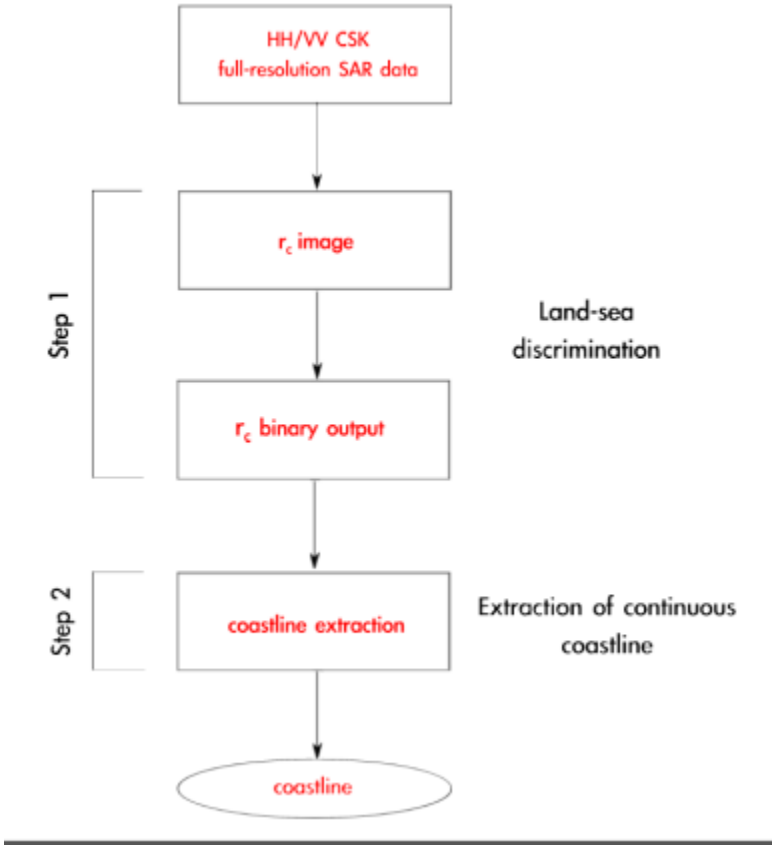
- 1993 to 1996, the shoreline moved slowly < 40 m/year, natural forces
- 1996 and 1999, the shoreline moved fast > 190 m/year, artificial impelling siltation and the silt in the Yangtze River deposition
- After 1999, shoreline movement became faster in both east and west sides, with an average speed of 390 m/y and 160 m/y respectively, tidal flat reclamation project.

Summary:

A new method for waterline extraction from SAR images using divide-and-combine approach and multi-scale normalized cut segmentation was implemented in this study.

Our results indicate the proposed method was effective in waterline extraction from ERS-1/2 and ENVISAT SAR images with accuracy better than 100 m.

Part 1: Dual-Pol SAR coastline detection

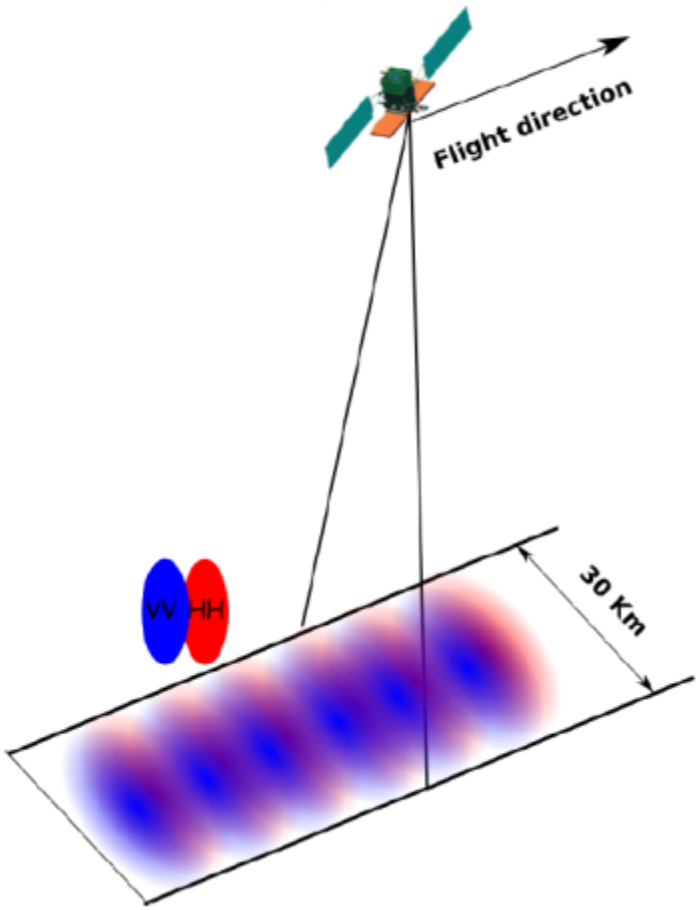


A two-step procedure is proposed to extract coastline by dual-pol SAR data that covers the processing and post-processing steps of conventional techniques

1) **PingPong HH/VV CSK SAR data for land/sea discrimination**

2) **Simple image processing to extract coastline;**

Part 1: Dual-Pol SAR coastline detection



CSK PingPong mode

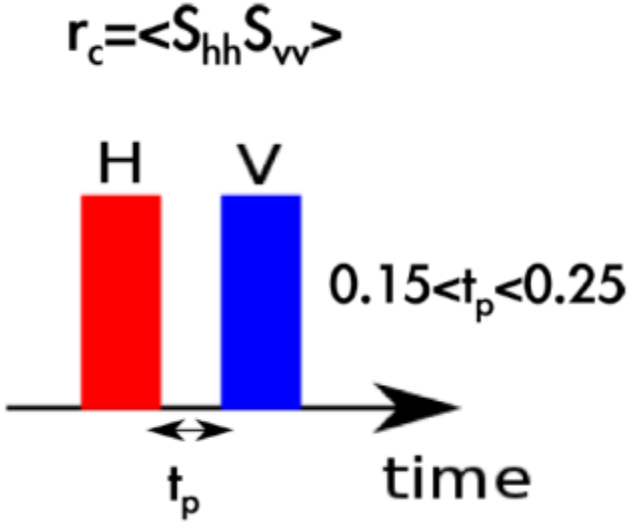
Spatial resolution 15 X 15m.
Swath 30 X30km.

PingPong mode implements a strip acquisition by alternating a pair of TX/RX polarizations across bursts by means of an antenna steering

The signal pol is alternated between two possible ones: VV, HH, HV and VH.

The time offset between two successive bursts, tp, varies, according to the beam type, between 0:15s and 0:25s.

Part 1: Dual-Pol SAR coastline detection



PingPong mode acts like an along-track interferometer

Distinguish land/sea surface

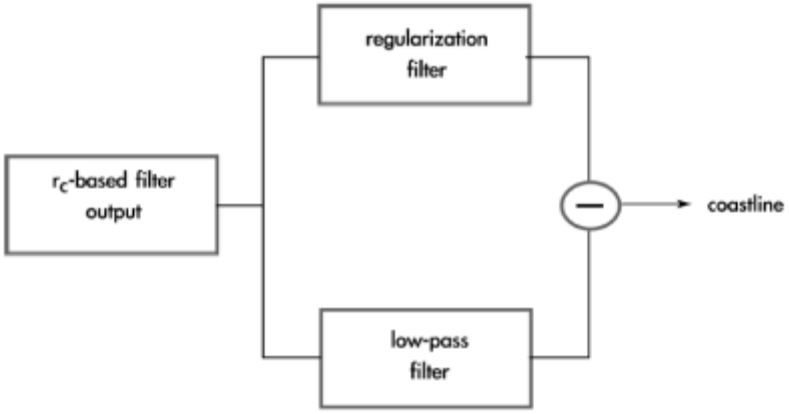
- **Sea surface scattering**

  ts < 0:035s;
  tp >> ts
  rc = 0

- **Land scattering**

  A stronger and more persistent backscattered signal is expected;
  tp < ts;
  Larger rc values are expected;

Part 1: Dual-Pol SAR coastline detection



Step 2:

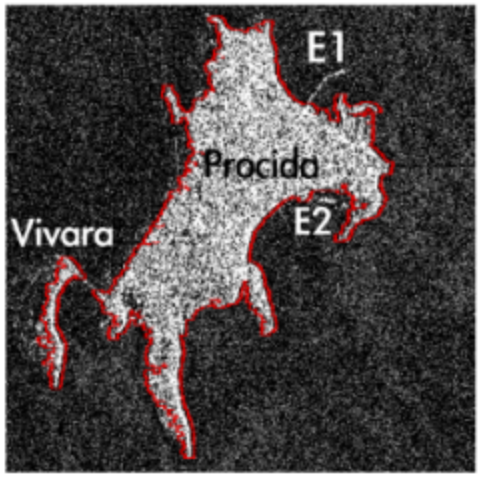
Small isolated targets are filtered out from the rc binary image;

Two Gaussian kernels to extract intermediate frequencies in the spatial domain;

A narrow regularization Filter and a broader LP filter applied.

Part 1: Dual-Pol SAR coastline detection

a)

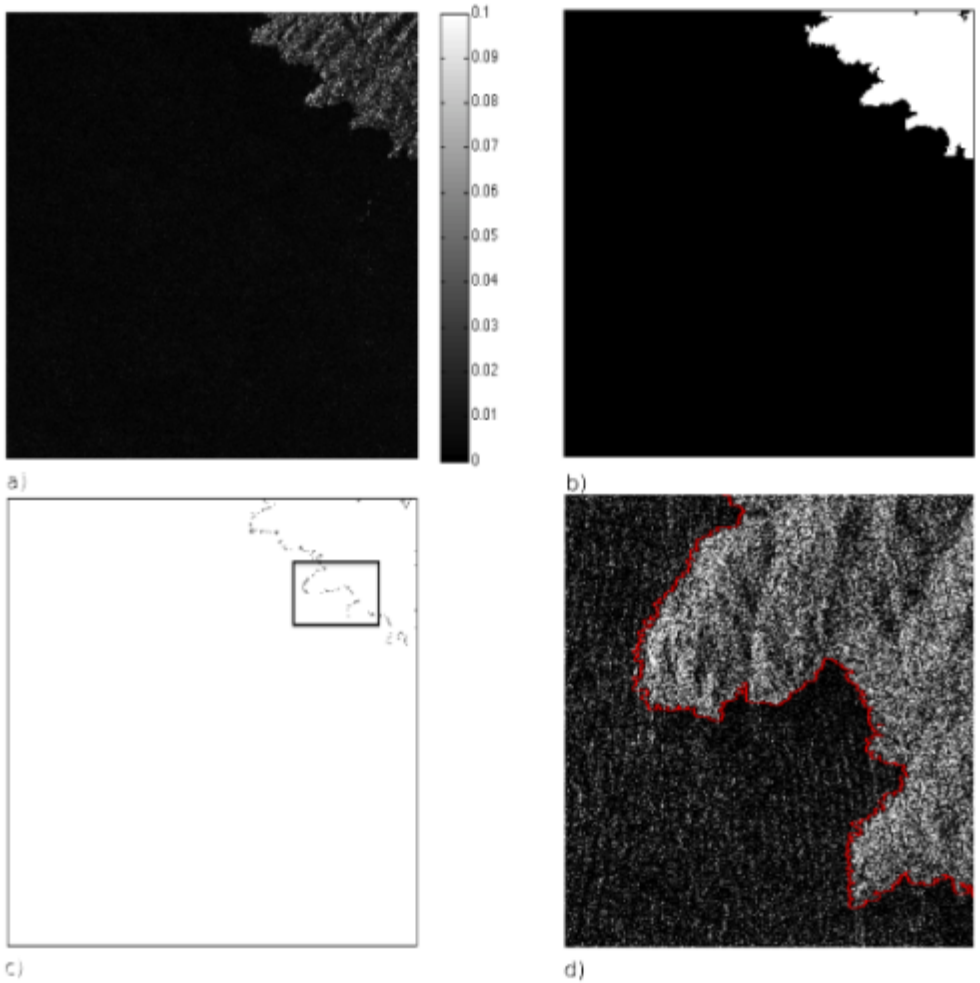


b)

c)

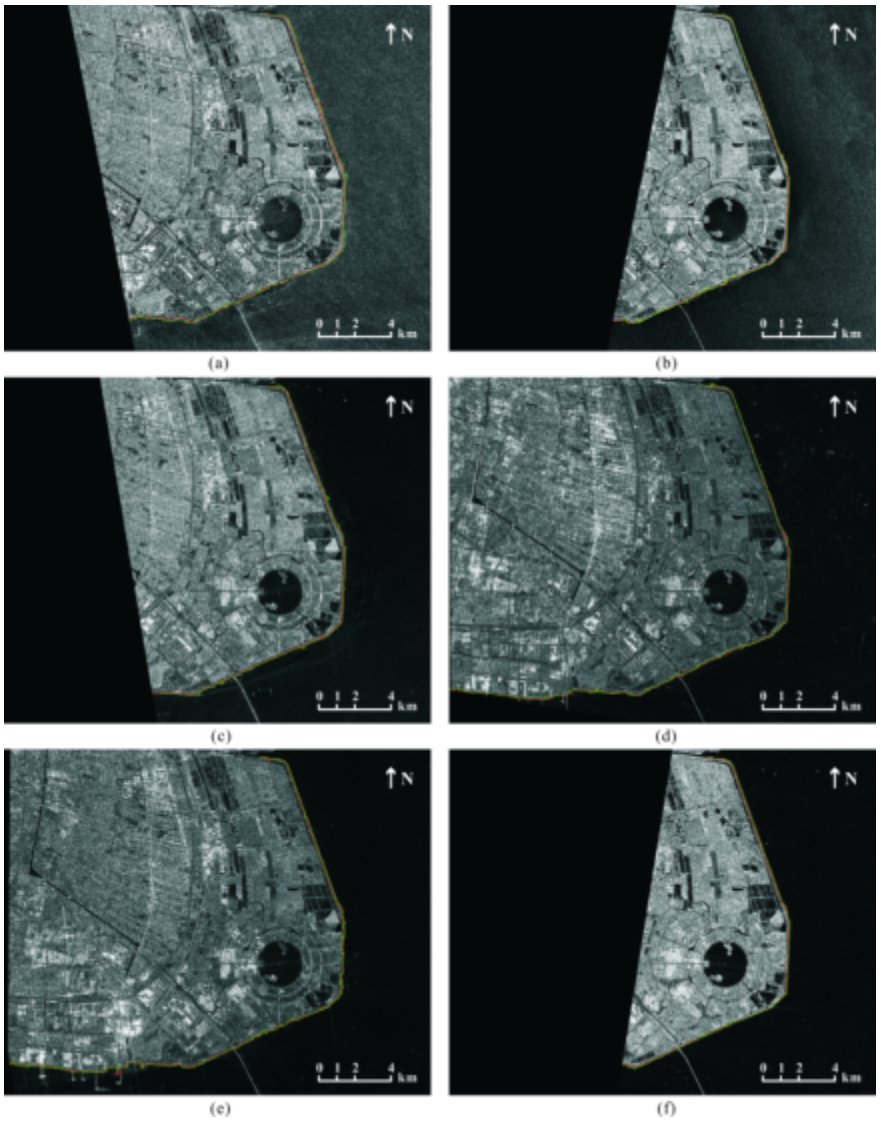
d)

Part 1: Dual-Pol SAR coastline detection



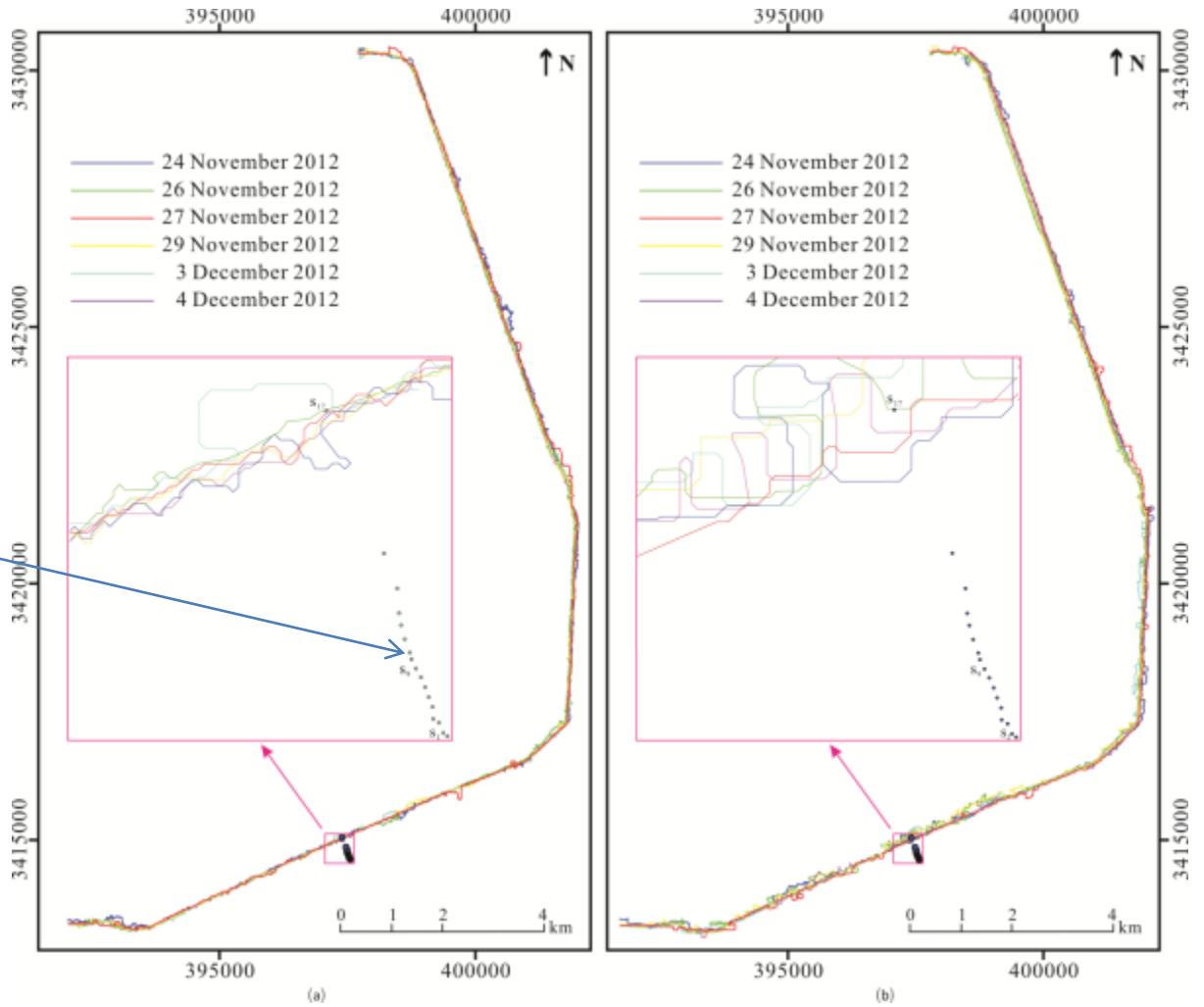
Italy

Part 1: Dual-Pol SAR coastline detection



Part 1: Dual-Pol SAR coastline detection

GPS stations



Single-Pol:
Bias:13.8 m; STD=20.8m

Dual-Pol:
Bias:26.0 m; STD=66.8m

Part 1: Summary

1) Both methods work well in shoreline extraction from SAR images in the intertidal flat under light to moderate wind conditions. The reason is that when the tide level is high and the wind is not strong, the boundary between water and land is clear in SAR images.
2) The accuracy of the waterline extracted from CSK SAR images by both methods decreases where there was water in the intertidal flat. The reason is that the boundary between water and wet intertidal flat is not clear in SAR images.
3) The single-polarization method has slightly higher accuracy in waterline extraction from SAR images than the dual-polarization method due to a supervised post-processing. The dual-polarization method has higher efficiency in waterline extraction from SAR images due to automatic processing.

Part 2: Coastal Zone Classification

mud flats

aquiculture grids

mussel beds

mangroves

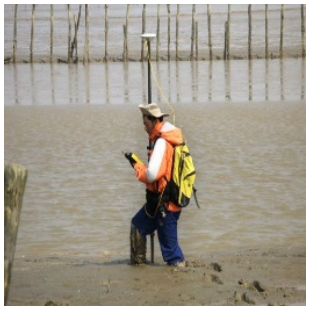
sand flats

vegetated dune

Coastal zones

- **are intermediate areas between the land and sea with high accessibility;**
- **host interactions between land and ocean systems;**
- **play critical roles in regulating global hydrology and climate, and chemical modifications;**
- **provide remarkable productivity and biodiversity.**

Part 2: Traditional Tools





Natural factors

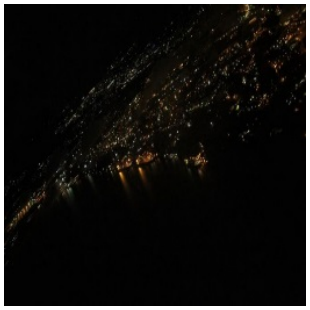
- large span, weather and tidal conditions ;
- repetitive flooding that cause dangerous;
- somewhere hard to access neither by boat nor on foot.

Economic factors

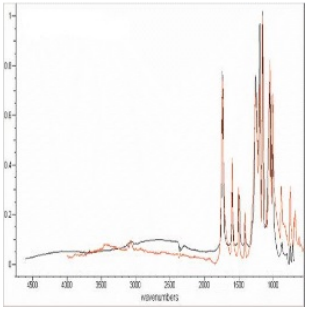
- time consuming;
- manpower consuming;
- material resources consuming.

Part 2: Modern Tools – Optical Sensor

cloud



daylight



similar spectrum

Optical sensors

- **strong dependence on cloud conditions and daylight;**
- **short time window around low tide (approx. 3h);**
- **similar spectral characteristics;**
- **omission or underestimation of wetland areas covered by forest, scrub, and grasses.**

Part 2: Modern Tools – SAR

Synthetic Aperture Radar (SAR)

- **all-weather capabilities;**
- **independence of daylight;**
- **penetrating capacity;**
- **obtainment of dynamic information in the upper ocean;**
- **acquisition of structural and electromagnetic information;**
- **multi-temporal, multi-polarization, and multi-frequency;**
- **routine and accurate monitoring of intertidal flats.**

ALOS-1

ALOS-2

Radarsat-1

Radarsat-2

TerraSAR

EnviSAT

Cosmo-Skymed

SeaSAT

Part 2: Land Cover types in coastal zone

Sediments

- **sand flats: sandy tidal shoals with abundant linguoid ripples, sinuous and linear megaripples, and exposed at low tide;**
- **mud flats: coastal sand dunes formed by sandy quartz sediments after being reworked by wind;**

Habitats

- **mangroves: dense mangrove forests over tidal mud flats between high spring and mean tide levels;**
- **mussel beds: bivalves that stick out of sediments, increasing local surface roughness;**
- **wetland: coastal coverage without many sedges or rushes, but dominated by grasses;**
- **transition zones: supratidal mangroves and marshes that are topographically higher, always with smaller mangroves and widely spaced grasses.**


sand flats


mud flats

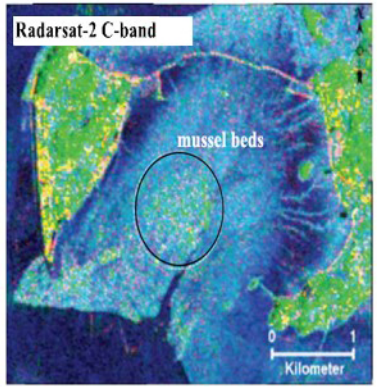

mangroves

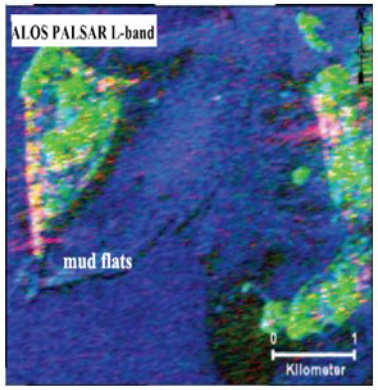

mussel beds

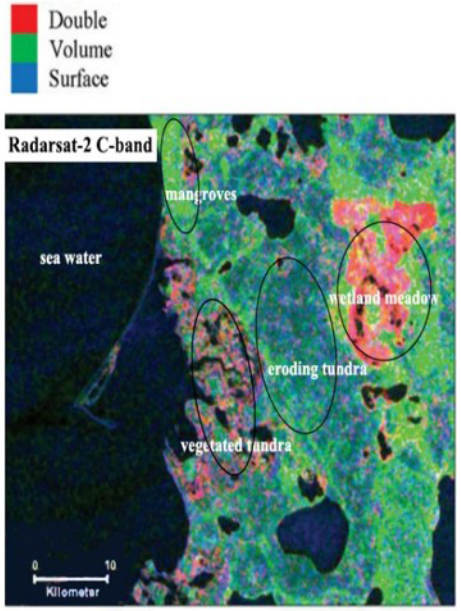

wetland


transition zones

Part 2: Scattering Behavior of Sediments and Habitats







Surface scattering dominant

- mud flats;
- sand flats;
- rocky outcrops;
- peat;
- woody debris;…

Volume scattering dominant

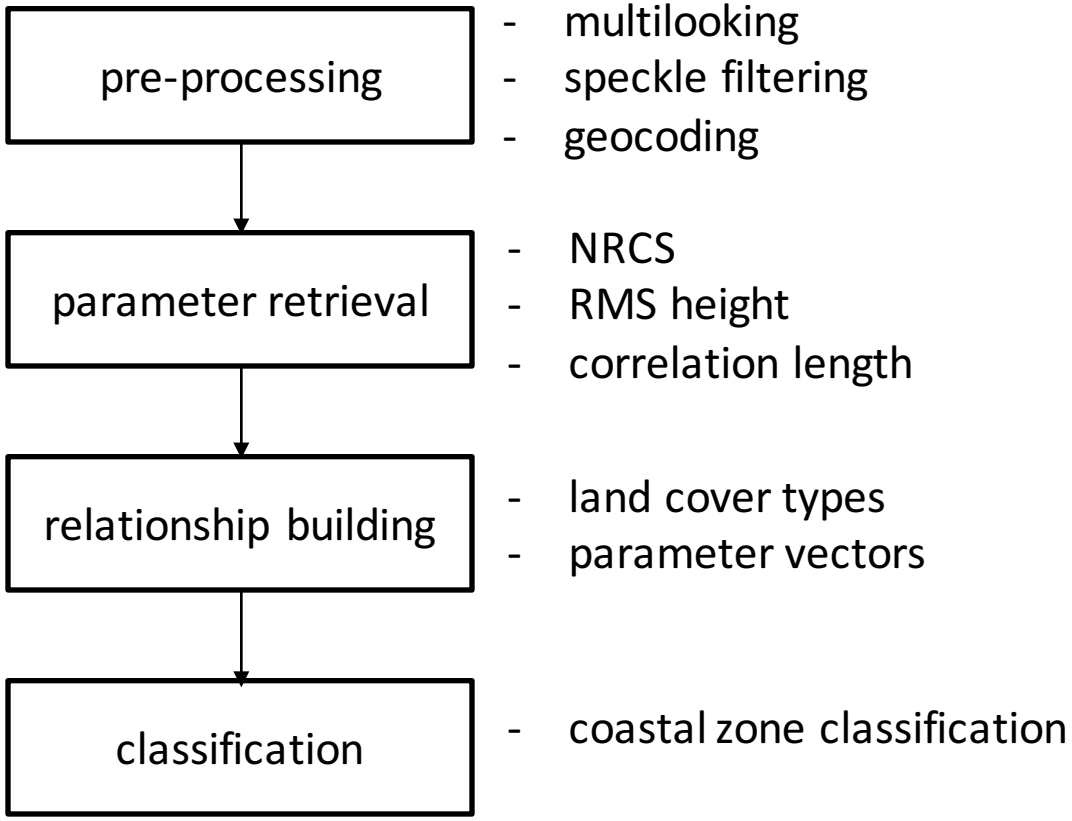
- mussel beds;
- human made materials;
- eroding tundra;
- mangroves;…

Double bounce scattering dominant

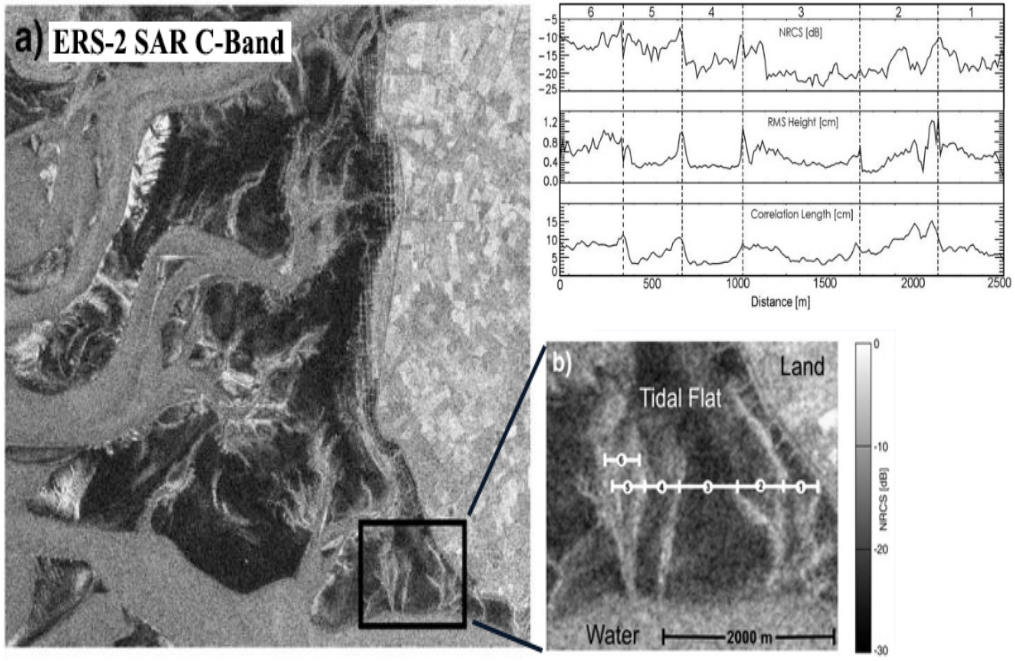
- laterite blocks;
- wetland meadow;…

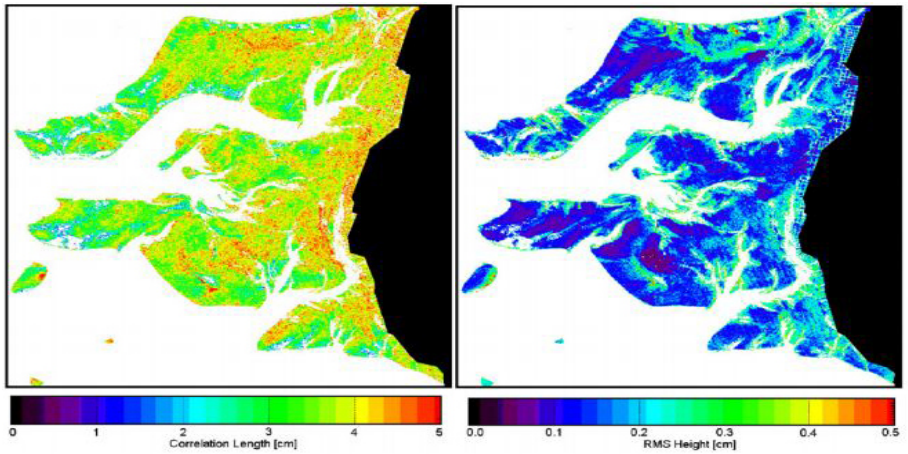
Part 2: Classification Methods

1 Based on backscattering models



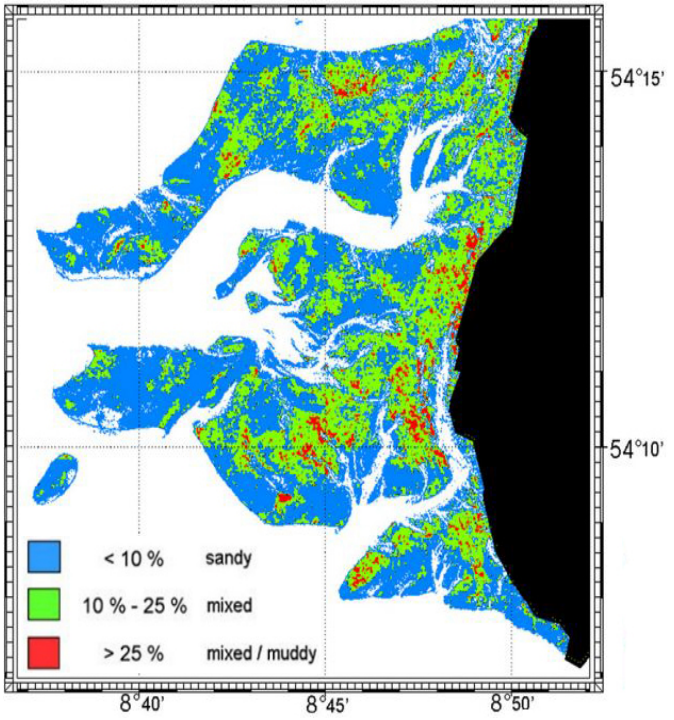
Part 2: Classification Methods





Feasibility

- **from 1 to 6, different cover types locates between each starting and ending nodes;**
- **different cover types give different parameter patterns;**



Part 2: Classification Methods

——based on backscattering models

Advantages

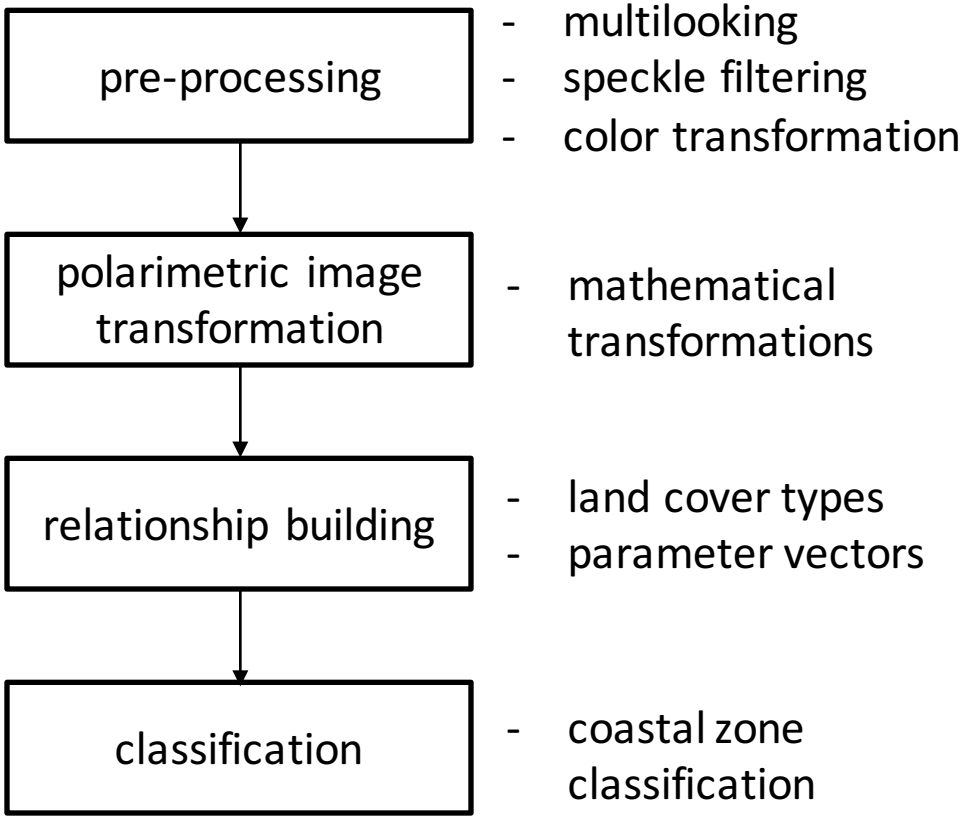
- **the retrieved parameters can be considered as proxies for sediment type;**
- **relatively high applicability;**
- **connection with scattering mechanisms.**

Limitations

- **correlation lengths always contain errors mainly because of the partial form of the autocorrelation function used in calculations;**
- **the surface roughness are always underestimated because of the remained water in the ripple troughs on the flats;**
- **the total NRCS are sensitive to the wind speed and local weather conditions;**
- **different model gives different results under different environmental condition;**
- **mainly suitable for natural media on intertidal flats.**

Part 2: Classification Methods

2 Based on image transformation of multi-polarized SAR data



Data preparation

- **change color space;**
- **polarimetric intensity channels HH/HV/VH/VV;**

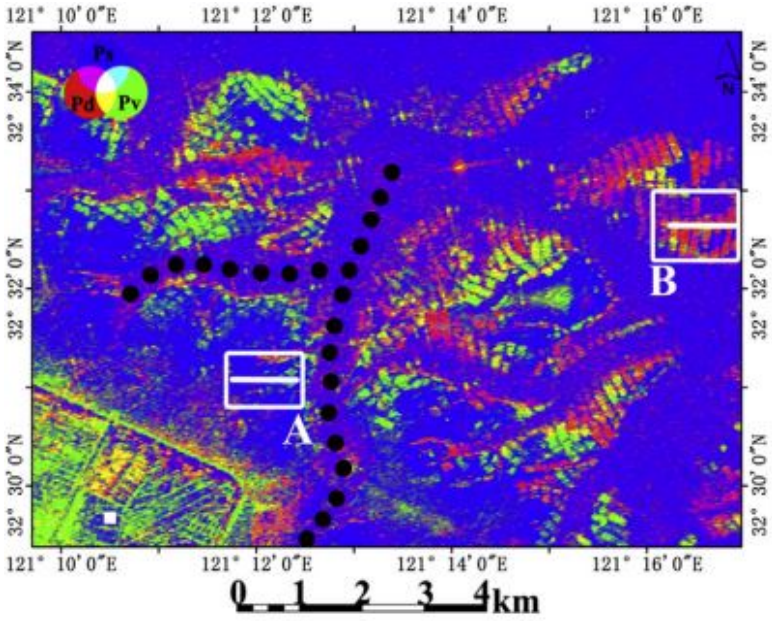
Mathematical transformation

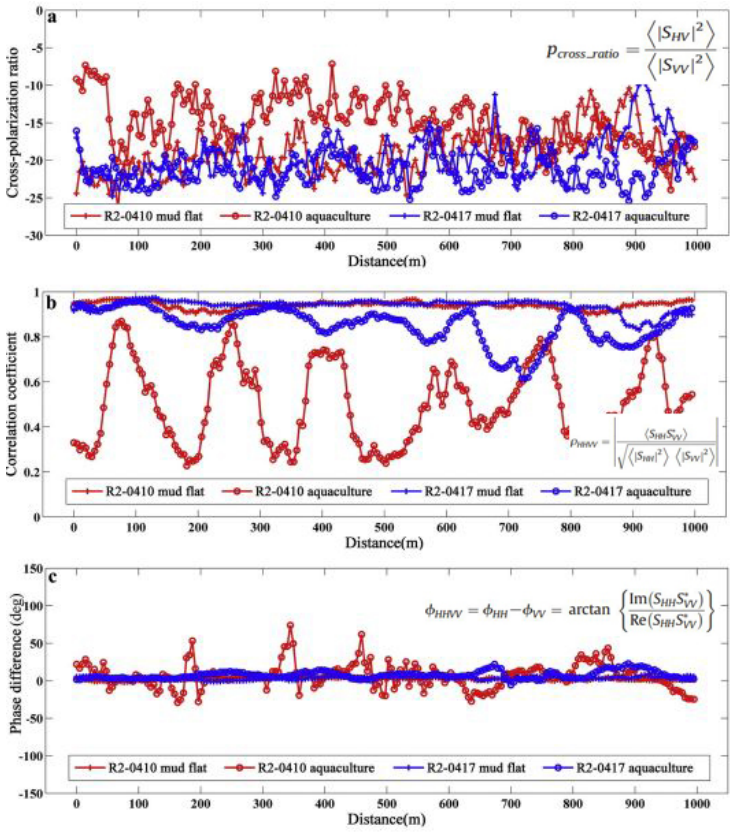
- **make targets of interest visible;**
- **highlight scattering differences between intensity channels;**
- **connect numeral parameters with land cover classes;**

Classifiers

- **Minimize disparities within classes;**
- **Maximize disparities between classes.**

Part 2: Classification Methods

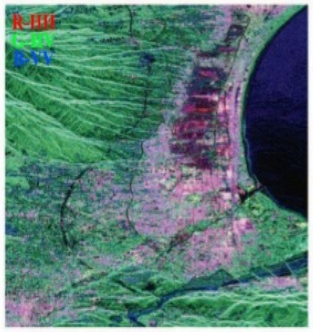


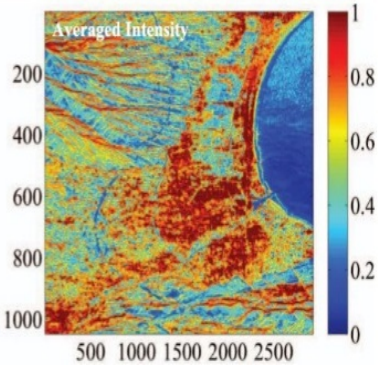


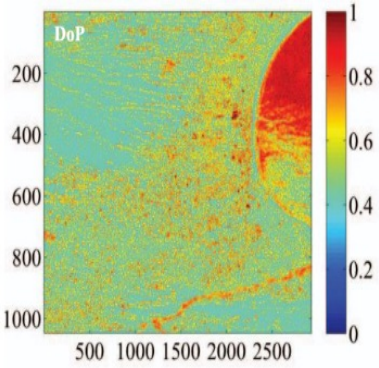
Feasibility

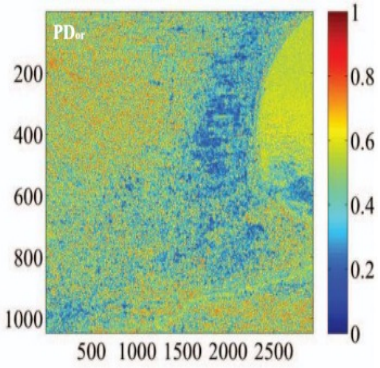
- **color composite (R-HH,G-HV,B-VV);**
- **mathematical transformation (ρcross，ρHHVV，ΦHHVV,…);**
- **different cover types behave differently in mathematical indicators based on original channels.**

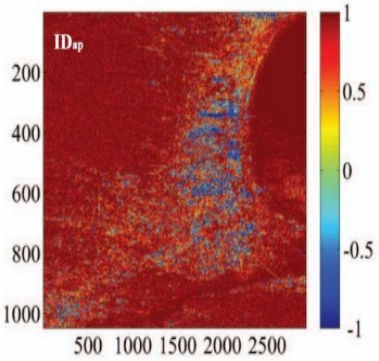
Part 2: Classification Methods

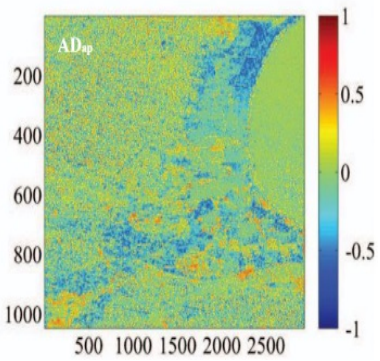








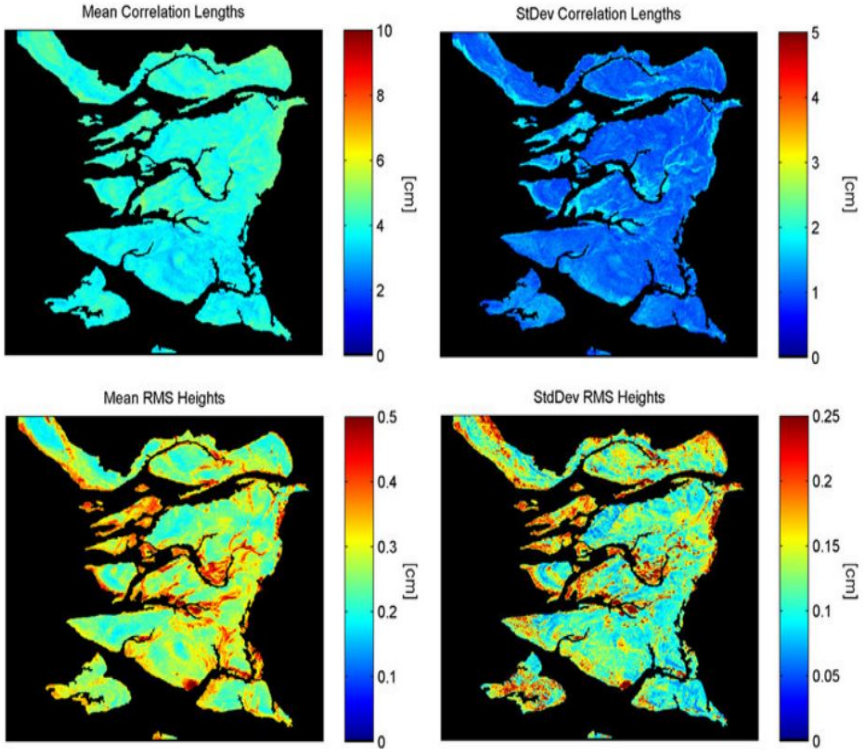


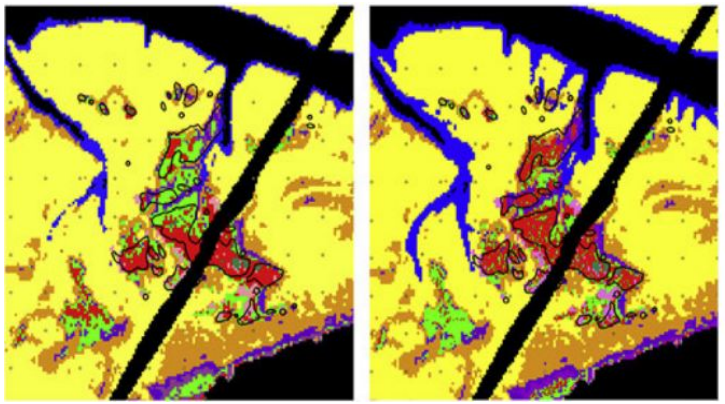


Other indicators

- **intensity ratio (DoP, mean intensity);**
- **POINCARE sphere (PD_{or}, ID_{ap}, AD_{ap},…);**
- **polarization ratio (ρ_{cross}， ρ_{HHVV}， Φ_{HHVV},…);**

Part 2: Classification Methods





Each indicator gives unique characteristics that can highlight certain targets with unique scattering patterns. Focusing on different objectives in classification, many classes can be extracted.

Part 2: Classification Methods

——based on image transformation

Advantages

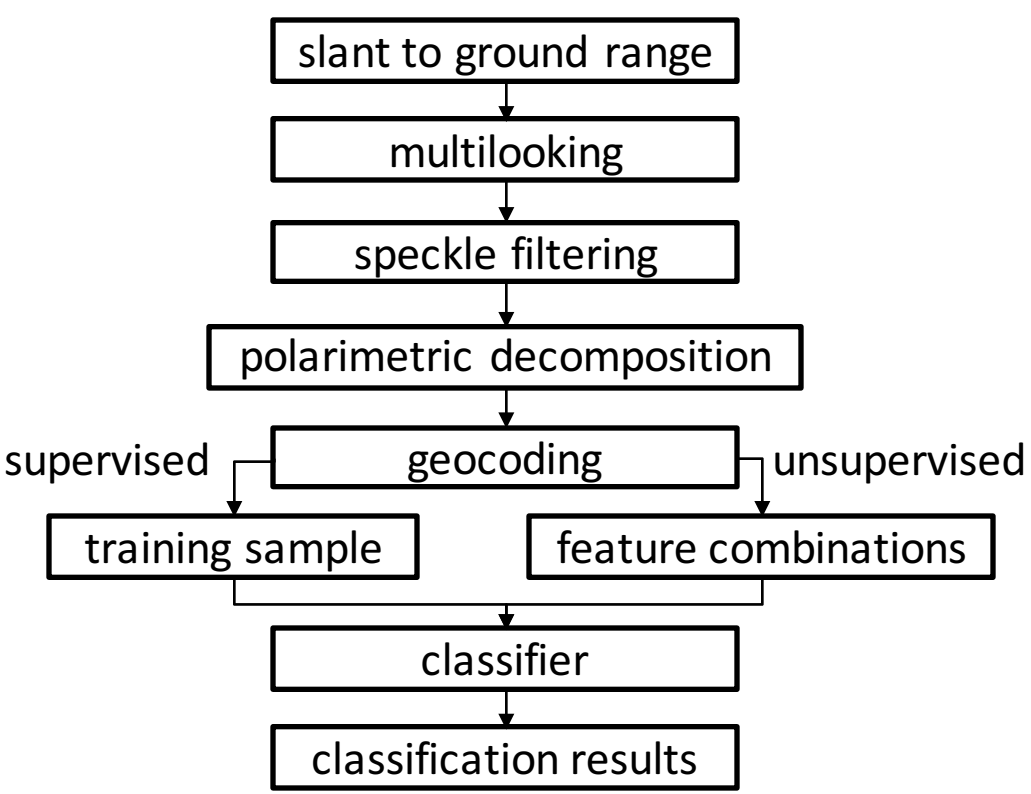
- **object-oriented features as valuable input for existing classification system;**
- **not only focus on scattering mechanisms, but also target structures;**
- **suitable for various land cover types by introducing polarization channels.**

Limitations

- **sensitive to environmental conditions;**
- **limited classification capability for certain land cover type on intertidal flats, such as coastal sediment types subdivision;**
- **not fully exploit polarimetric information.**

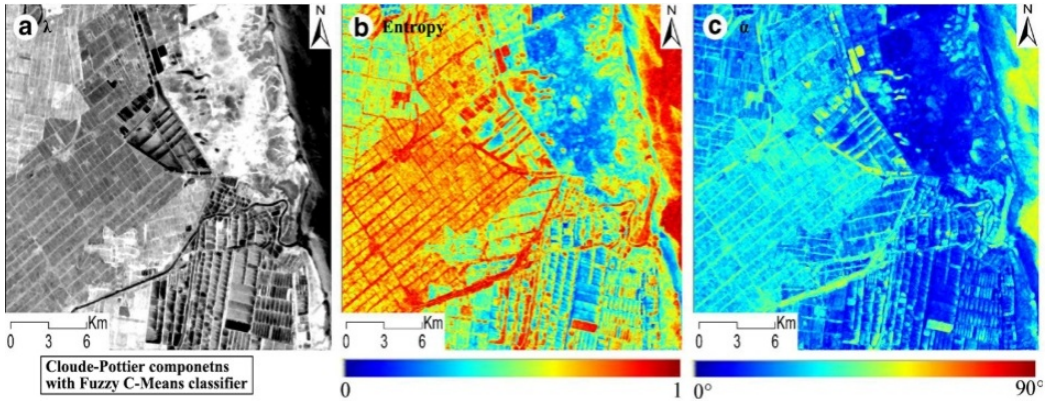
Part 2: Classification Methods

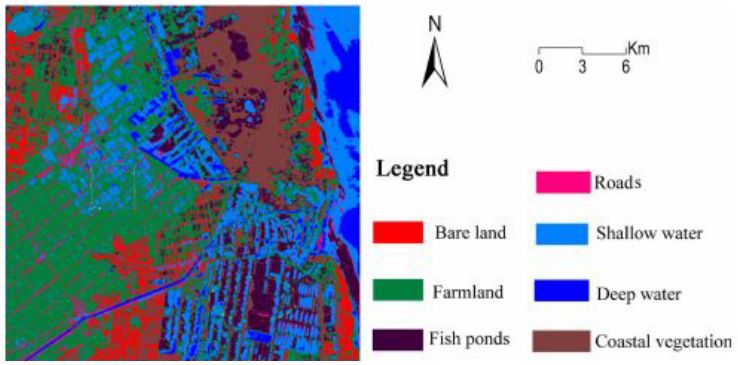
3 Based on incoherent polarimetric decomposition theory



- pre-processing
- decomposition components extraction
- Classification
  - supervised
  - unsupervised

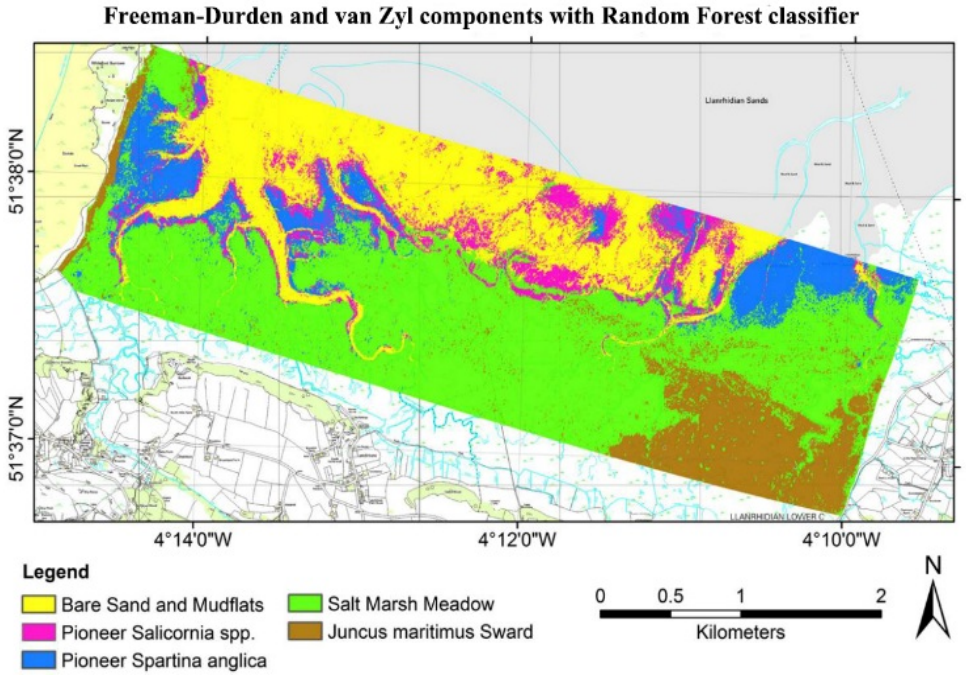
Part 2: Classification Methods





Decomposition theory

- based on wave dichotomy
- based on eigenvalues analysis
- based on physical scattering model



Part 2: Classification Methods

——based on polarimetric decomposition theory

Advantages

- **fully exploit target structure and geophysical information;**
- **increase classification accuracy considerably;**
- **more intuitive to interpret than backscatter intensity channels;**
- **better suited for unsupervised SAR classification of intertidal flats .**

Limitations

- **greater classification capability for land cover types on intertidal flats, such as coastal sediment types subdivision and mussel beds extraction;**
- **require full-polarization SAR data source which are limited available.**

Part 2: Research Expectations

- **SAR acquisitions are promising data source for classification of intertidal flats;**
- **Multi-polarization SAR acquisitions show large potentials for detecting structure and geophysical information that always invisible in other types of SAR data.**
- **For the rapidly changing tidal flats, some land cover types are still difficult to distinguish or extracted with lower accuracies, which needs more SAR information as ancillary.**
- **Multi-temporal and multi-frequency SAR acquisitions are anticipated to develop more information statistically from frequent- and time-series.**

Part 2: Summary

- **Different coastal zone types can be classified from SAR imagery;**
- **Need more validation studies;**
- **Shortcoming is the limited coverage by full-pol imagery (TerraSAR, ALOS-2, Cosmo-Skymed).**