Pol-InSAR-Island – A Multi-frequency Pol-InSAR Benchmark Dataset for Land Cover Segmentation

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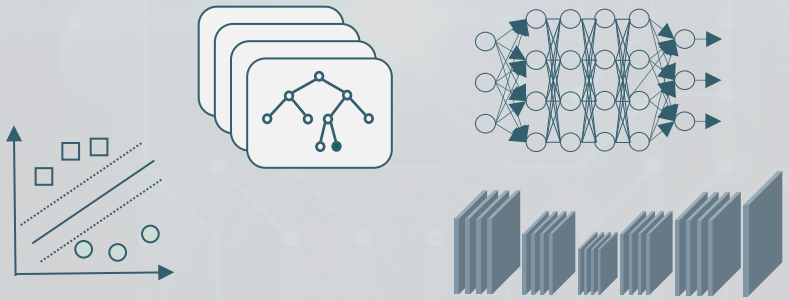
DLR

NLWKN

The era of machine learning

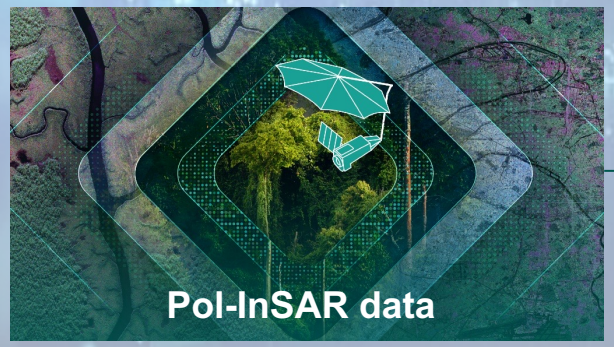
Machine learning models



„A teacher gives a lecture to students “

Training

The era of machine learning



Machine learning models

Land cover classification

Tree height estimation

Ground deformation

Training

Labeled dataset?

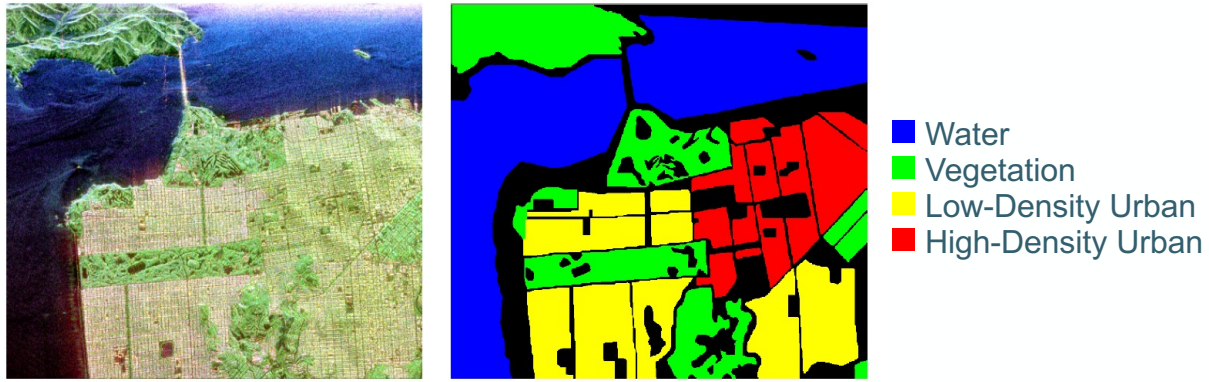
Agenda

Pol-InSAR-Island dataset

1. Benchmark datasets
2. Pol-InSAR data
3. Reference data
4. Baseline classifier
5. Summary

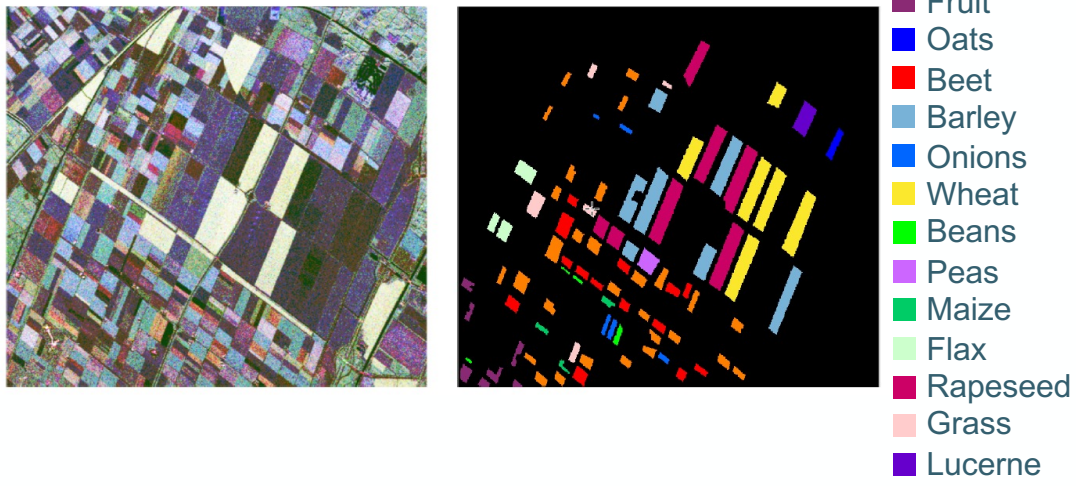
Benchmark datasets – Existing PolSAR datasets

PolSF – Multi-Sensor, San Francisco



E-SAR, Oberpfaffenhofen

AIRSAR, Flevoland



Datasets enable training and testing of deep learning models for PolSAR image segmentation

Training and test areas are not defined

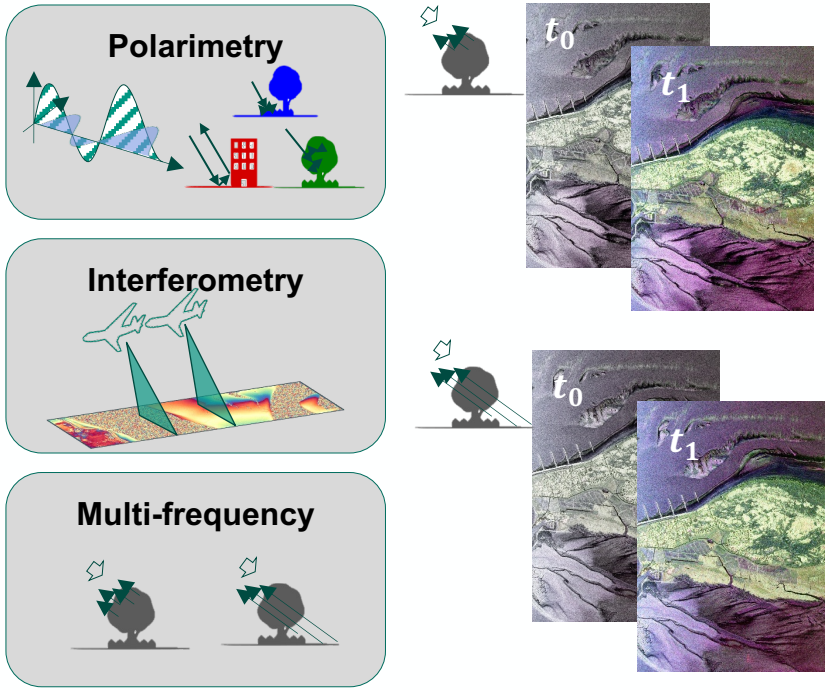
→ Lacking comparability of reported results

Limited challenge: only few classes or low scene complexity

→ Achieving high accuracies even with simple methods

Benchmark datasets – Pol-InSAR-Island

- Expansion of the observation space through multi-frequency and interferometry
  → Improvement of land cover classification
- Limited open access availability of multi-frequency Pol-InSAR data
  → Deep learning approaches for multi-frequency Pol-InSAR classification are less studied



Multi-frequency Pol-InSAR data

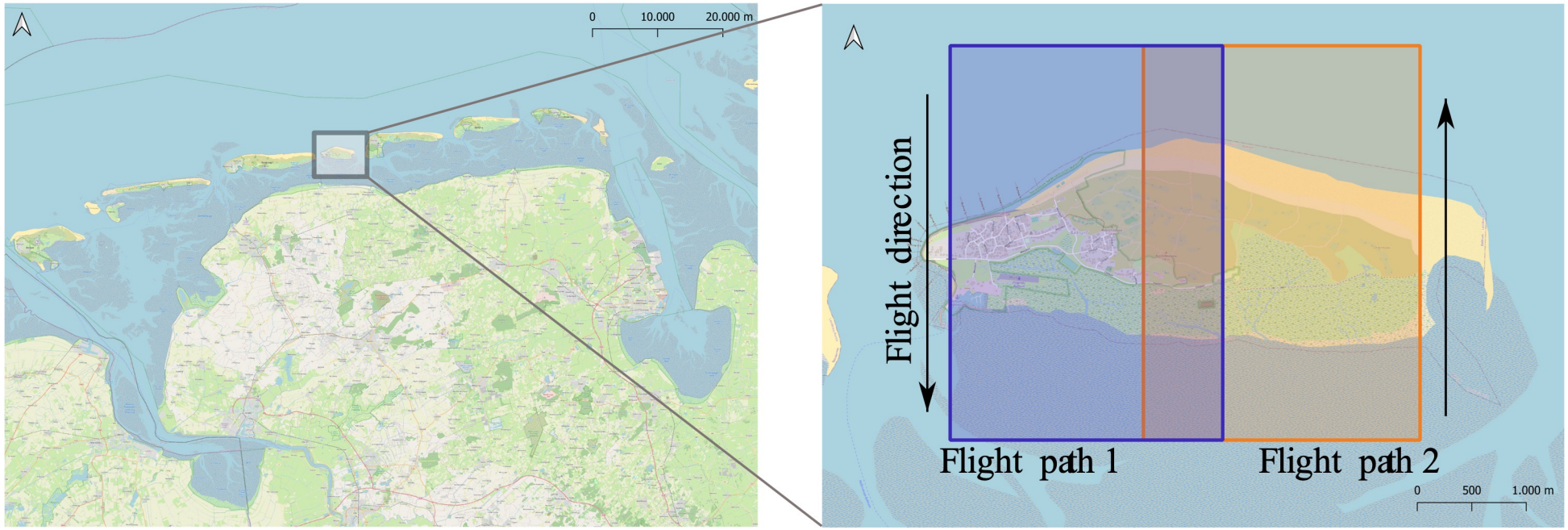
Land cover label

1. Open provision of labeled multi-frequency Pol-InSAR data in high resolution
2. Challenging classification task due to high scene complexity
3. Controlled training and test setting

Agenda


Pol-InSAR-Island dataset
Benchmark datasets
Multi-frequency Pol-InSAR data
Reference data
Baseline classifier
Summary

Multi-frequency Pol-InSAR data – study area



- Study area **Baltrum**: East Frisian Island in the German Wadden Sea
- Area is captured by the **airborne F-SAR** system (DLR) within a measurement campaign in **April 2022**
- Selected image sections originate from two overlapping flight paths

Multi-frequency Pol-InSAR data – F-SAR

Fully polarimetric data: $(s_{hh},\ s_{hv},\ s_{vh},\ s_{vv})$

Used frequency bands: S (3.25GHz)

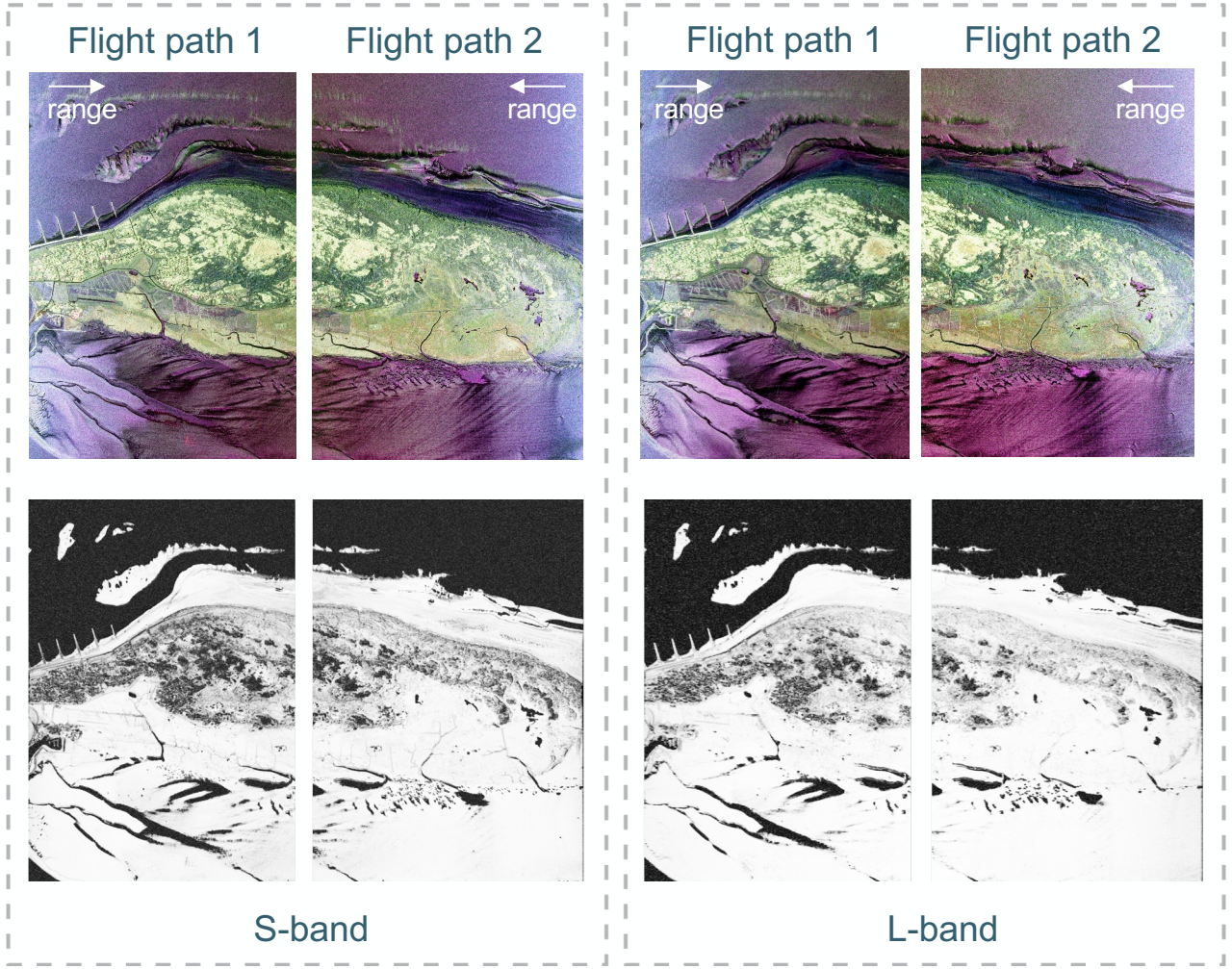
L (1.325GHz)

Incidence angle: 26° to 58°

Interferometry:

- Repeat-pass
- 12 minutes time offset
- 40m vertical baseline

DLR's F-SAR (Source: www.dlr.de)



Multi-frequency Pol-InSAR data – provided data

- Data provided as $\mathbf{T}_6$ coherency matrix for each image pixel:

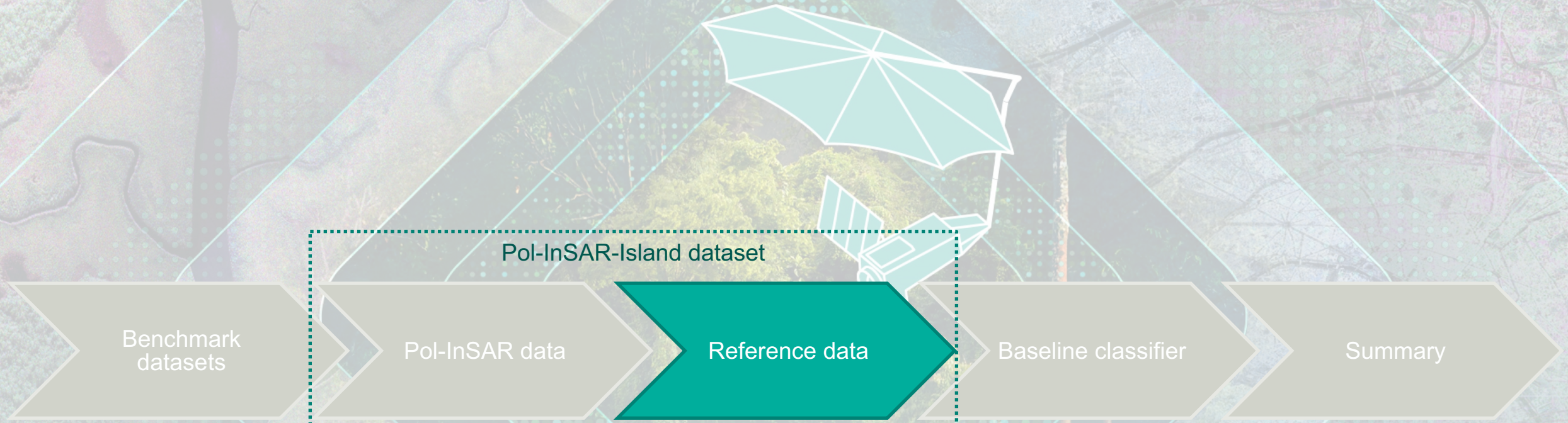
$$\mathbf{T}_6 = \begin{bmatrix} \mathrm{k}_1 \\ \mathrm{k}_2 \end{bmatrix} \begin{bmatrix} \mathrm{k}_1^{*T} & \mathrm{k}_2^{*T} \end{bmatrix} = \begin{bmatrix} \mathbf{T}_{11} & \boldsymbol{\Omega}_{12} \\ \boldsymbol{\Omega}_{21} & \mathbf{T}_{22} \end{bmatrix} \quad \text{with} \quad \mathrm{k_i} = \frac{1}{\sqrt{2}} [s_{hh} + s_{vv}, \quad s_{vv} - s_{hh}, \quad 2s_{hv}]^{\mathrm{T}}$$

Polarimetric information
Interferometric information

- Postprocessing:
  - Flat earth removal
  - Projection to ground range geometry on a $1\mathrm{m} \times 1\mathrm{m}$ grid

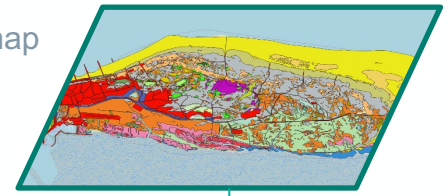
- Content of the final dataset:
  - Two image products (S- and L-band) of flight path 1 of size: $3616\mathrm{m} \times 2502\mathrm{m}$
  - Two image products (S- and L-band) of flight path 2 of size: $3616\mathrm{m} \times 2540\mathrm{m}$

Agenda


Pol-InSAR-Island dataset
Benchmark datasets
Pol-InSAR data
Reference data
Baseline classifier
Summary

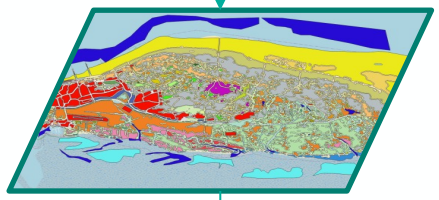
Reference data – workflow

Biotope type map



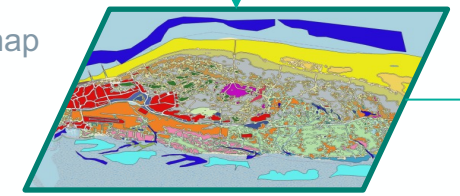
Buffering & Filtering

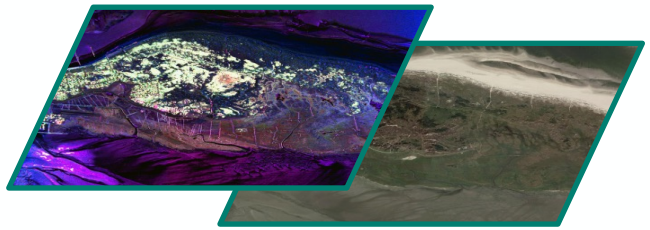
Revised map



Class merging

Target class map





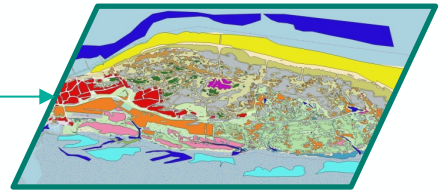
Manual Labeling

Class separability analysis

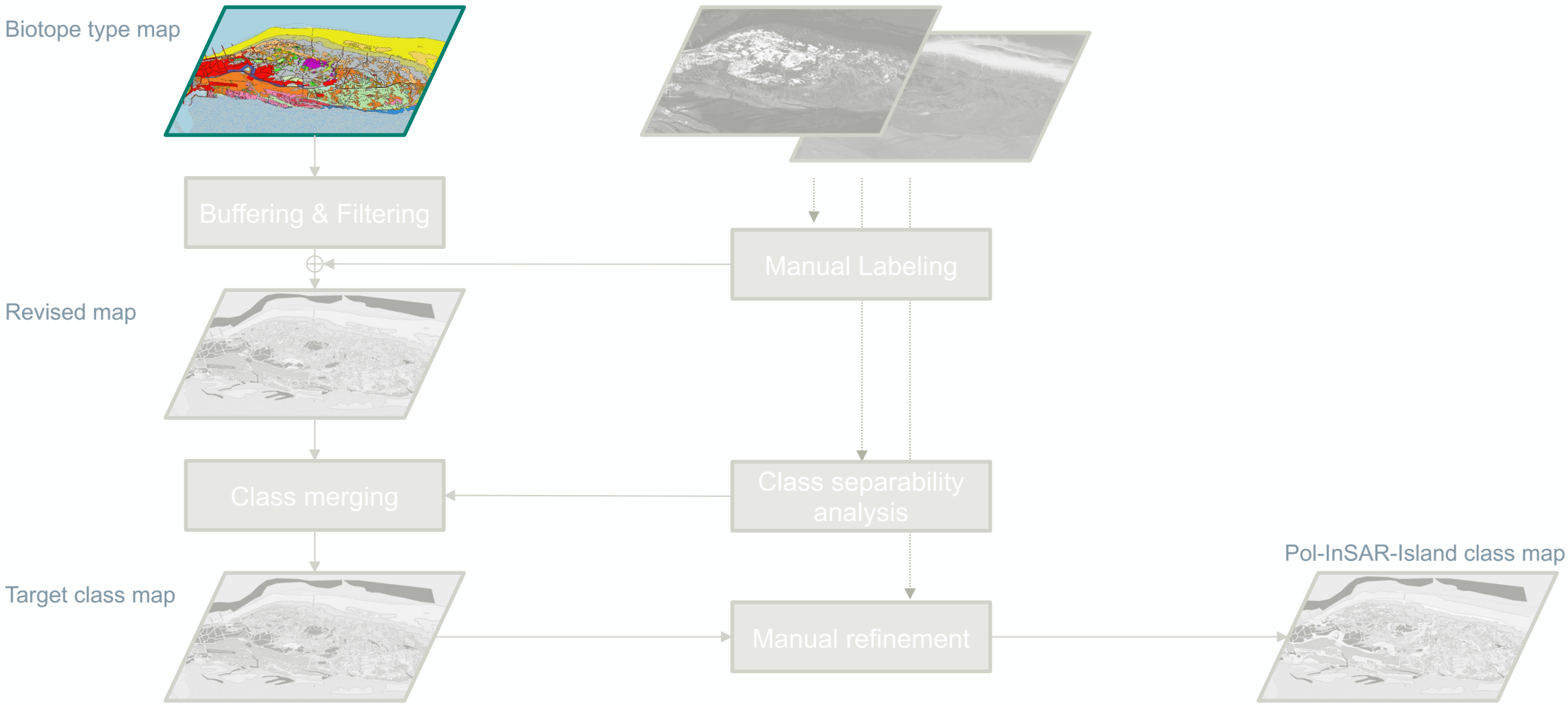
Manual refinement

- Tidal flat
- Water
- Coastal shrub
- Dense, high vegetation
- White dunes beach grass
- Peat bog
- Grey dunes grassland
- Couch grass
- Upper salt marsh
- Lower salt marsh
- Sand
- Settlement

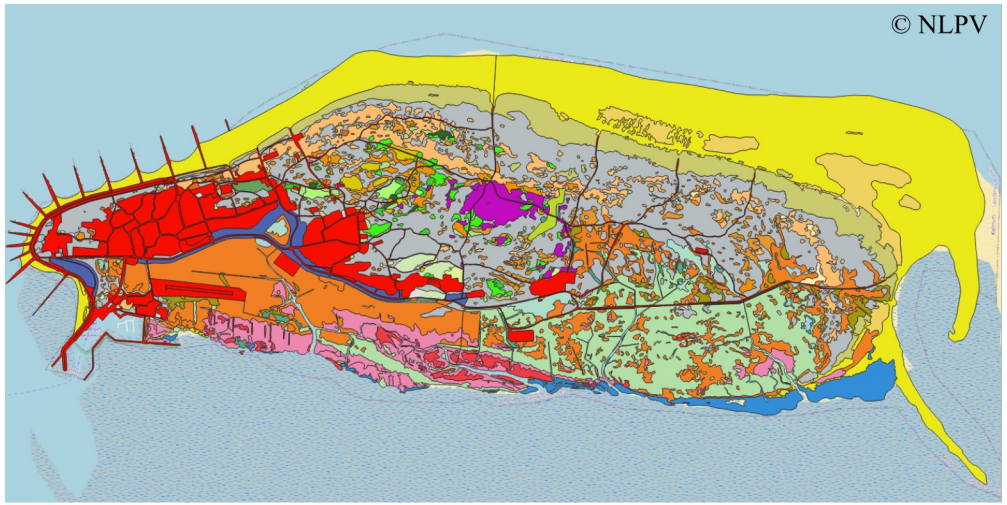
Pol-InSAR-Island class map



Reference data – workflow



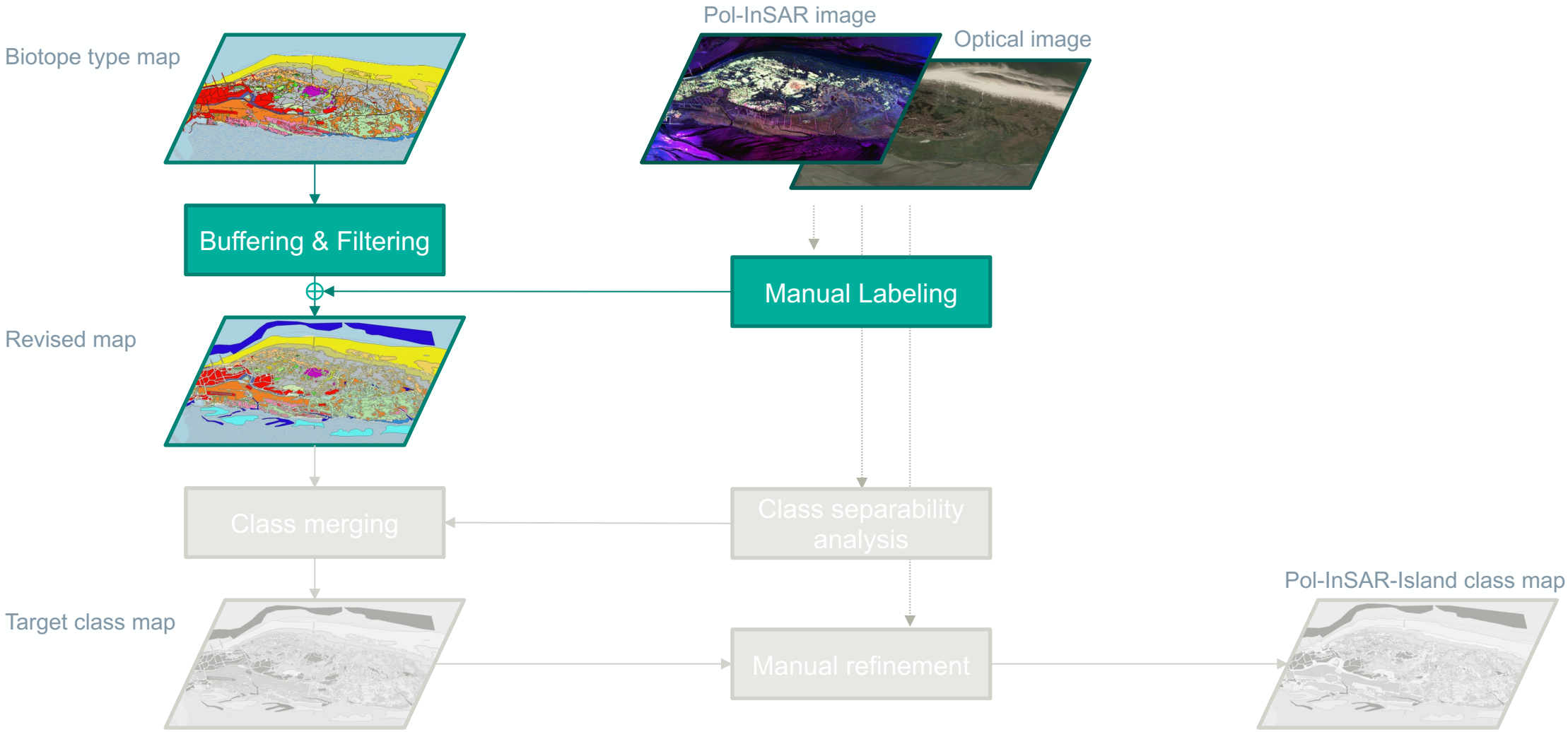
Reference data – biotope type map



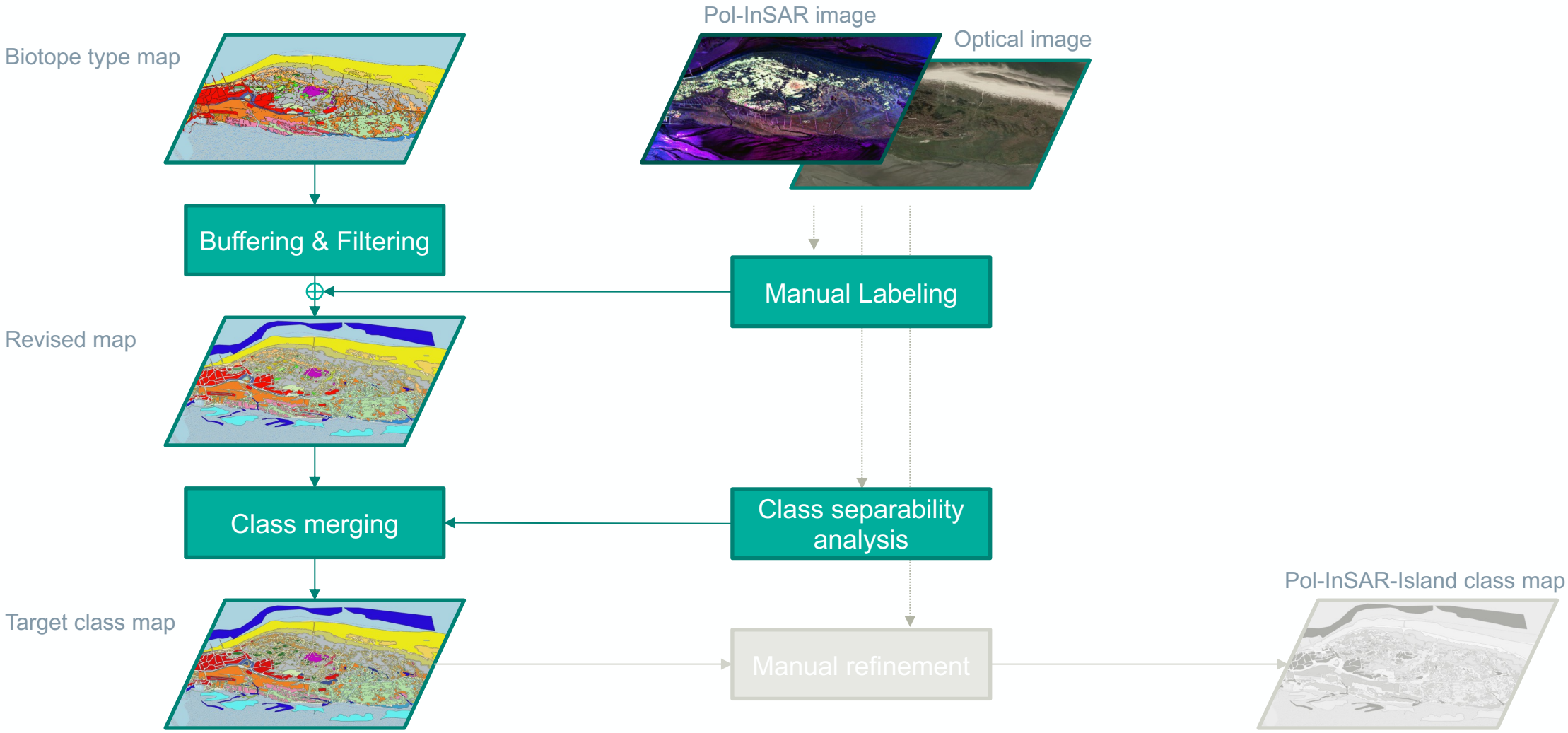
- Settlement
- Dyke
- Salt marsh dune
- White dune
- Salt affected dune area
- Calcareous dune valley
- Reed bed of dune valley
- Eutrophocated dune Valley
- Grey dune
- Lower salt marsh
- Peat bog
- Brakish reed
- Sea clubrush
- Upper salt marsh
- Tall shrubbery of wet dune valleys
- Low-growing coastal dune shrub
- Sea-buckthorn coastal dune shrub
- Potato rose bush
- Sandy beach
- Sand dam
- Sand coach grass
- Couch grass
- Forest
- Alder shrub
- Birch and pine
- Birch and quaking aspen
- Other coniferous forest
- Slit grass
- Pickleweed

- Baltrum is mainly covered by natural coastal area (e.g. saltmarshes and dune landscape)
- Starting point for data labeling: Existing biotope type map
  - Generated in 2013 as part of the Trilateral Monitoring and Assessment Program (TMAP)
  - Published by the Lower Saxon Wadden Sea National Park Authority
  - Classified by 40 biotope types

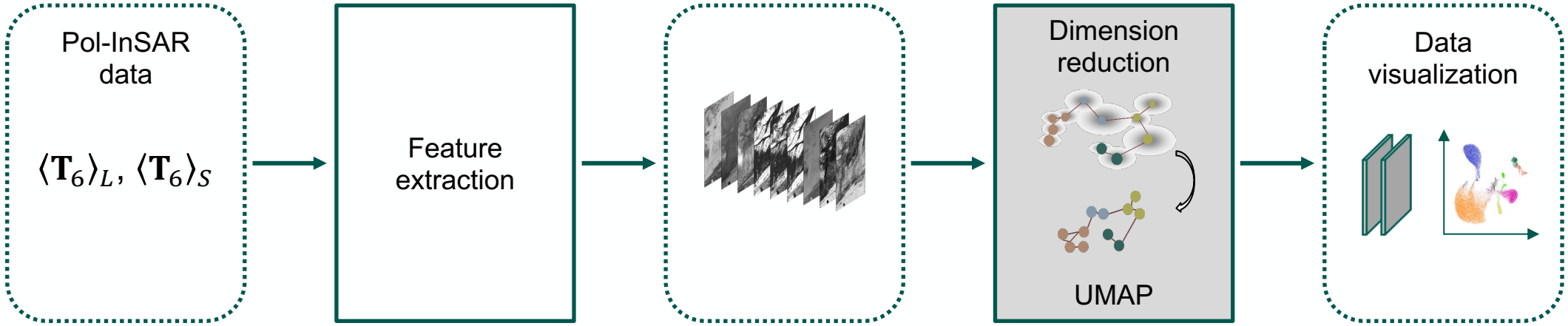
Reference data – workflow



Reference data – workflow



Reference data – class separability analysis

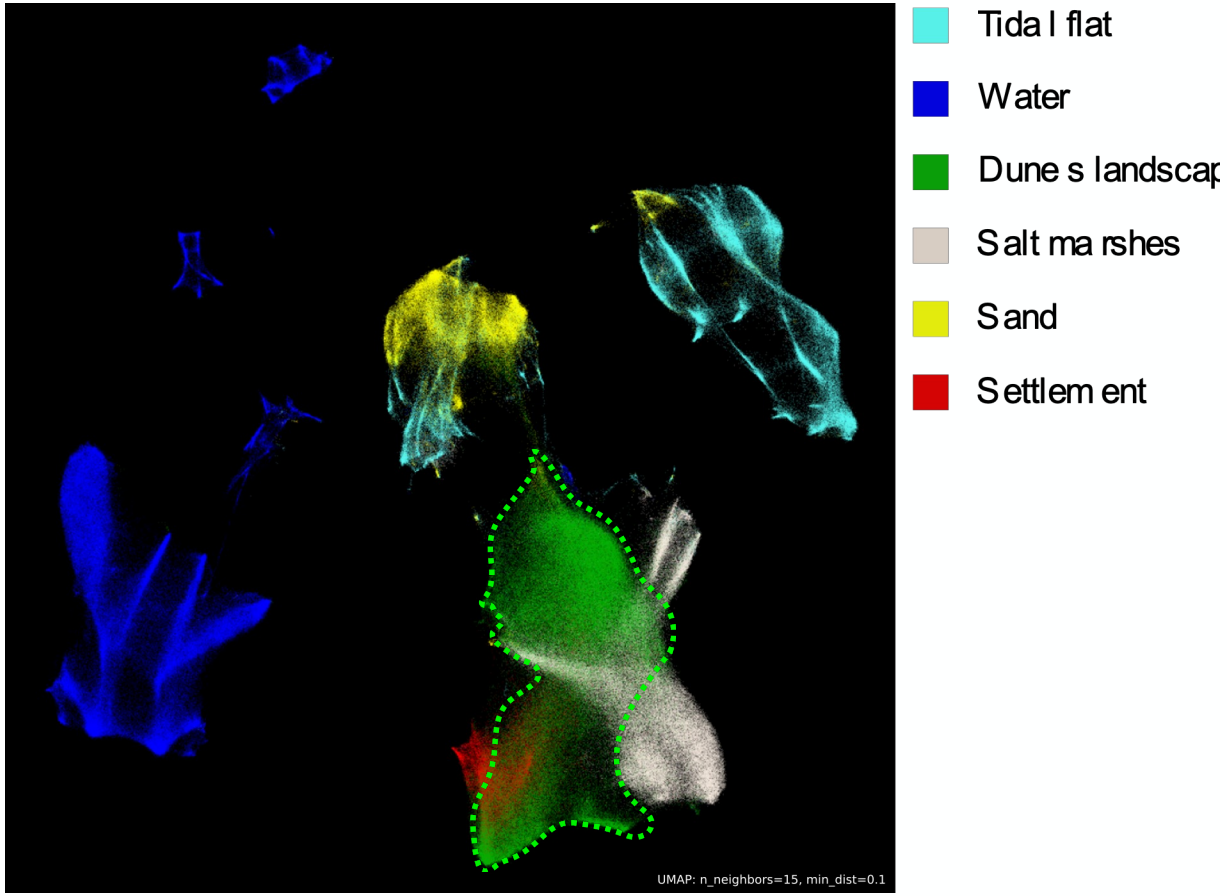


Visualization of data structure based on feature similarity

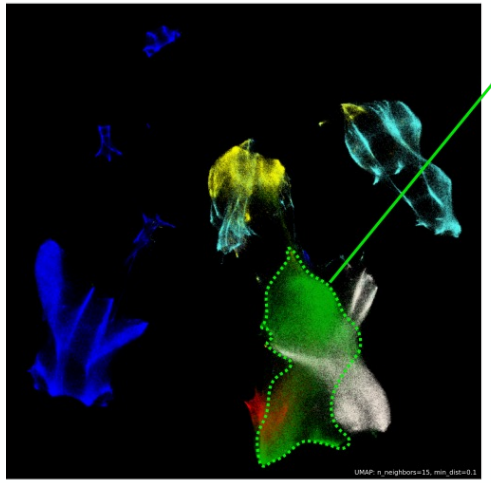
Extracting multi-dimensional feature vector of L- and S-band data:

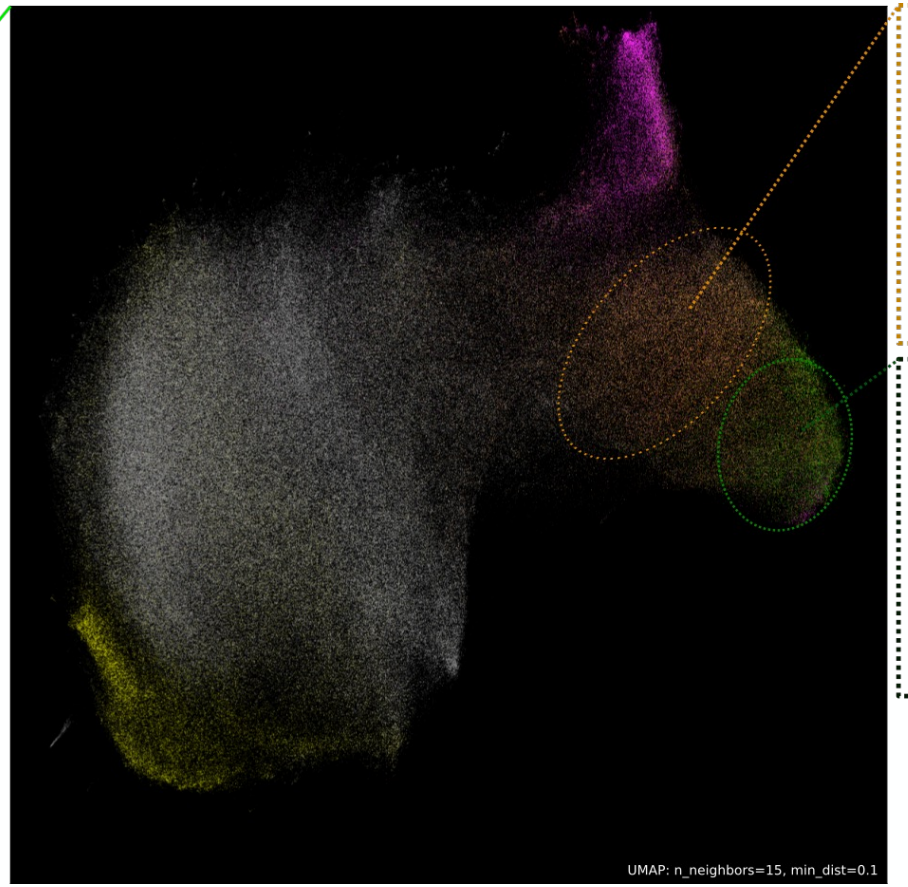
- Intensities and polarimetric phase
- Elementary scattering mechanisms and polarimetric features based on target decomposition
- Interferometric coherence

Reference data – analysis of class separability



Reference data – analysis of class separability



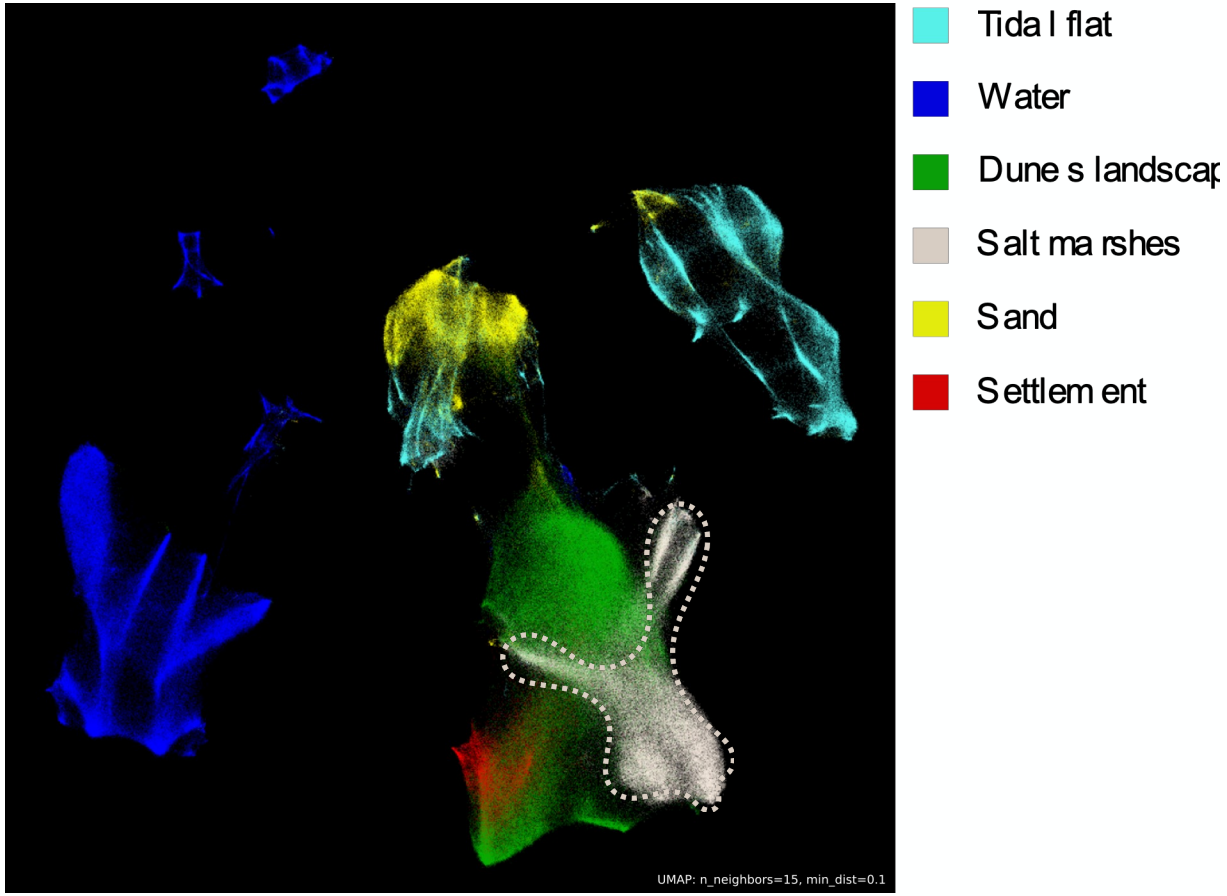


Coastal Shrub
- Low-growing coastal dune shrub
- Sea-buckthorn coastal dune shrub
- Potato rose bush of the coastal dunes
- Other coastal dune shrub

Dense, high vegetation
- Single tree
- Forest
- Alder shrub
- Birch and pine
- Birch and quaking aspen
- Other coniferous forest
- Tall shrubbery of wet dune valleys

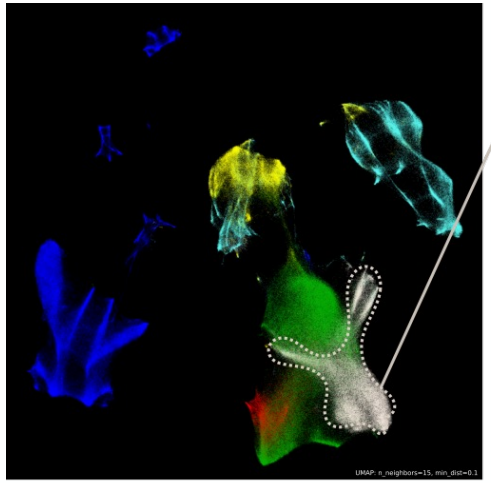
- White dunes beach grass
- Peat bog
- Grey dunes grassland

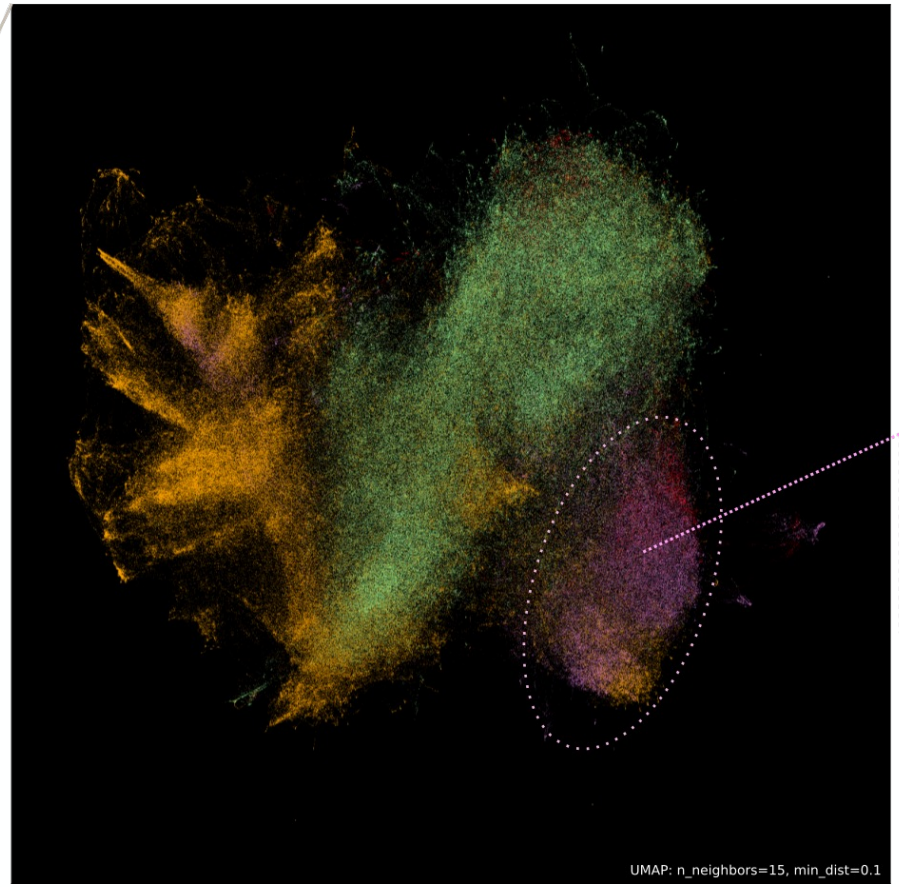
Reference data – analysis of class separability



Reference data – analysis of class separability

Salt marsh

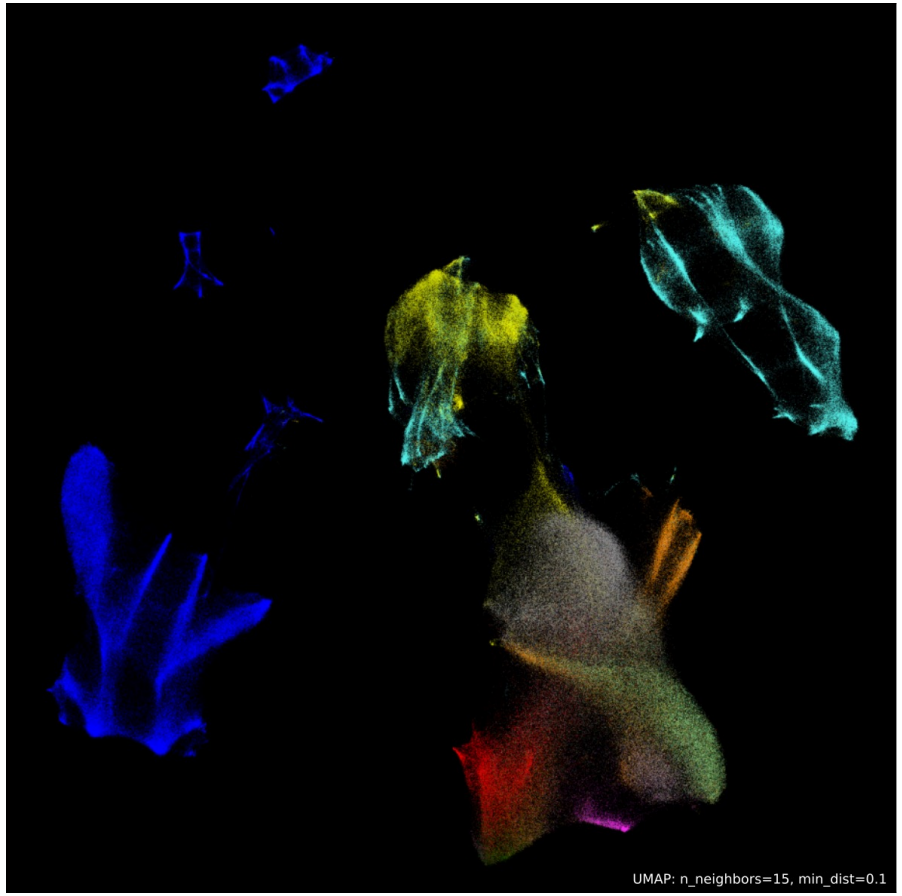




- Couch grass
- Upper salt marsh

Lower salt marsh
- Slit grass
- Lower salt marsh

Reference data – analysis of class separability

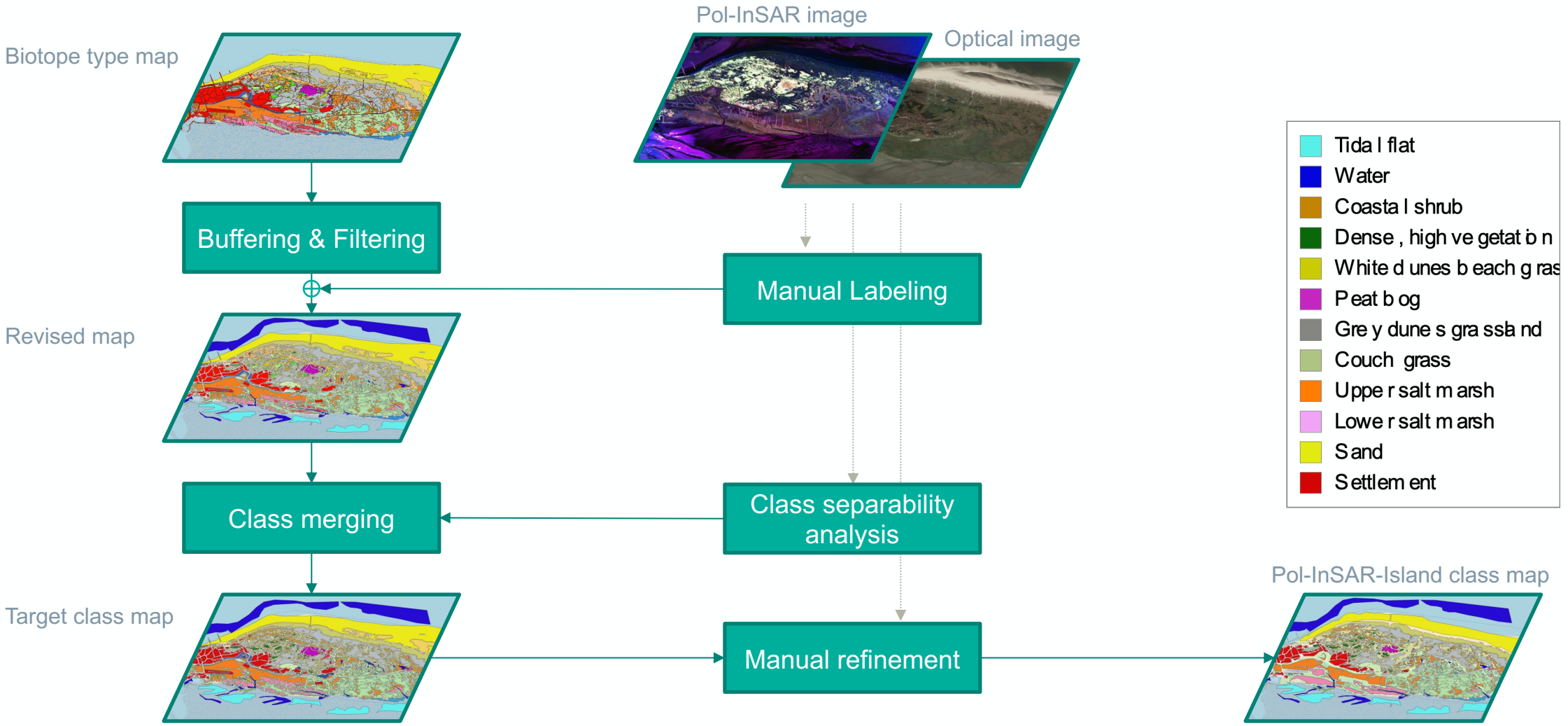


- Tidal flat
- Water
- Coastal shrub
- Dense, high vegetation
- White dunes beach grass
- Peat bog
- Grey dunes grassland
- Couch grass
- Upper salt marsh
- Lower salt marsh
- Sand
- Settlement

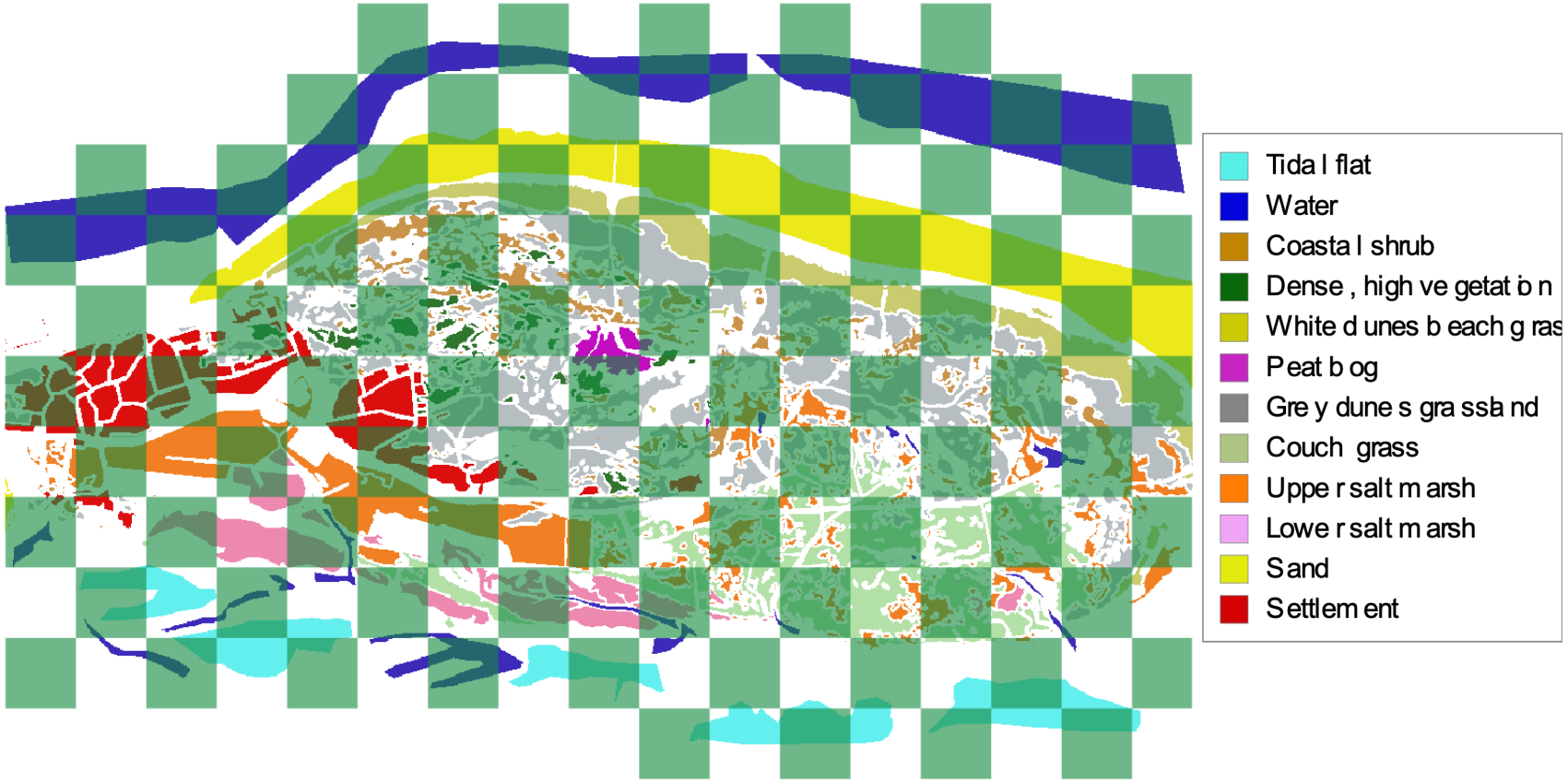
Dunes landscape

Salt marshes

Reference data – workflow



Reference data – Training and test data



Test data

~ 5 million labeled pixels

Using chessboard grid for data splitting:

- Patch size: 512×512
- Covering all classes in training and test set
- Covering entire incidence angle interval in training and test set

Imbalanced class distribution:

Agenda

Benchmark datasets

Pol-InSAR data

Reference data

Baseline classifier

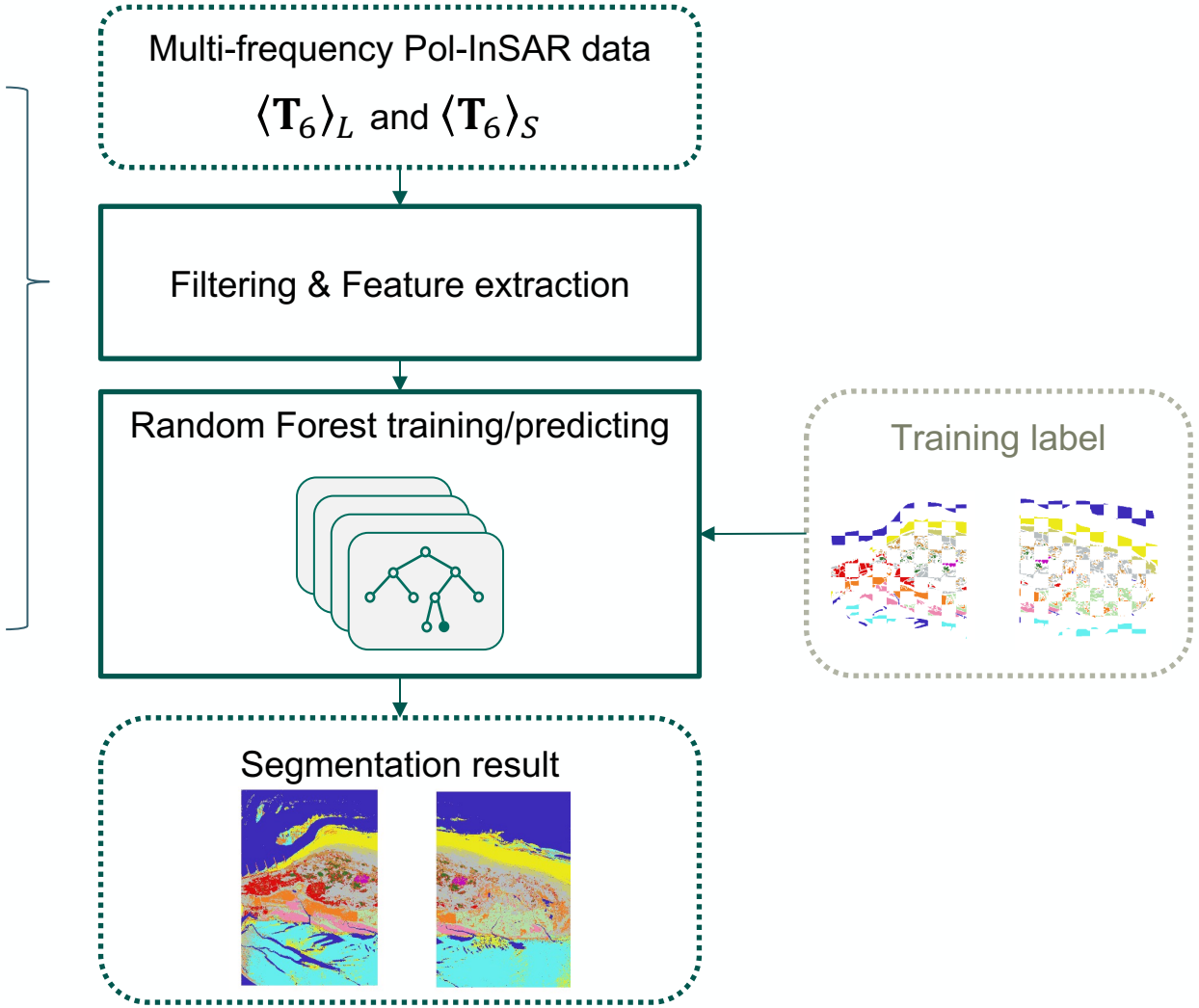
Summary

Baseline classifier – Random Forest

Refined Lee filter

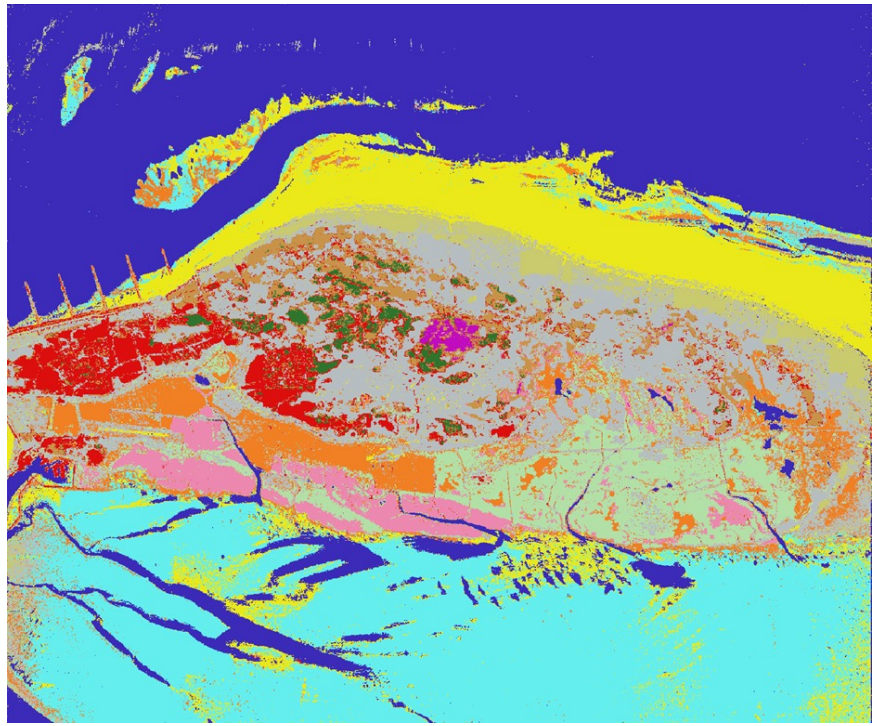
Features:

- $|T_{ij}|\ [dB], i,j \in (1,2,3)$
- $\arg(T_{ij})$
- $H, A, \bar{\alpha}, \overline{\lambda}, p_1, p_2, p_3$
- $f_{odd}, f_{dbl}, f_{vol}$ (Yamaguchi decomposition)
- Interferometric coherences $|\gamma_{XX}|$

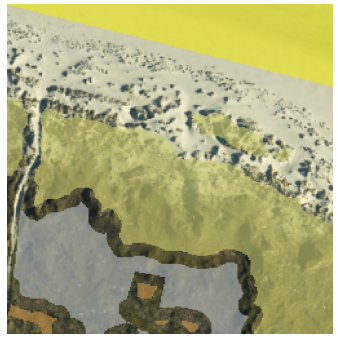


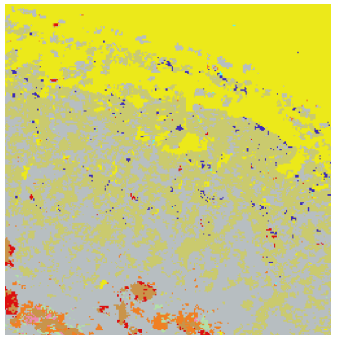
Baseline classifier – result

Random Forest classifier – segmentation result

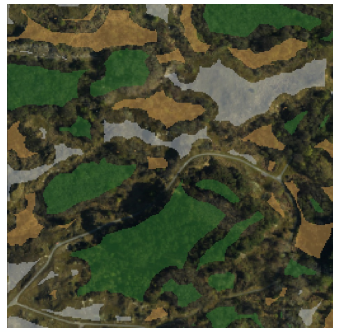


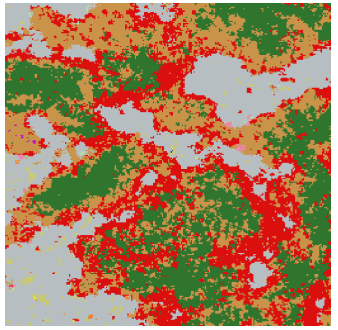
Challenges





White dune





False prediction of **Settlement**

	Tidal flat	Water	Coastal shrub	Dense vegetation	White dune	Peat bog	Grey dune	Couch grass	Upper saltmarsh	Lower saltmarsh	Sand	Settle-ment	mean
Random Forest (recall [%])	93.48	99.58	64.14	56.81	50.59	72.19	83.01	82.92	66.94	90.77	96.95	71.15	**77.38**

Agenda

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Summary

Labeled multi-frequency Pol-InSAR dataset

F-SAR data acquired over Baltrum in the German Wadden Sea

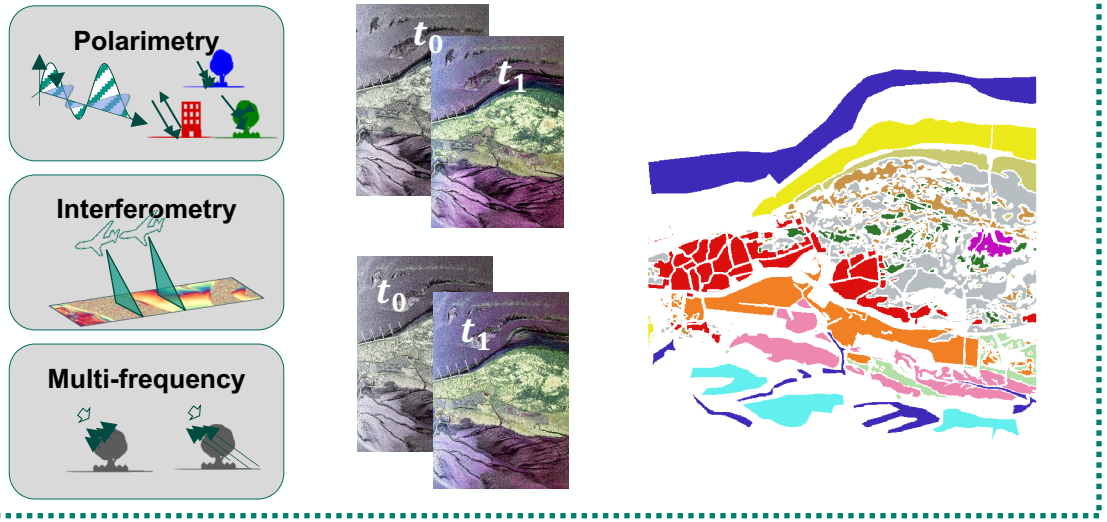
Advantages:

- Open accessibility to accelerate learning-based PolInSAR classification
- Challenging land cover classification task
- Controlled training and test setting

Limitations:

- Label gaps
- Single sensor and single location

  → Transferability is questionable



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Pol-InSAR-Island

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