Monitoring Saltmarsh Erosion Using Cumulative Sums of Sentinel-1 Timeseries

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Background and Motivation

Saltmarshes: Importance

- Coastal wetlands that flood and drain with the tide
- They provide many important ecosystem services:
  - coastal flood defence
  - habitat for bird species
  - nursery grounds for fish and crustaceans
  - carbon storage
- European saltmarsh resources are covered by multiple international and national nature conservation designations

Saltmarshes: Conservation Issues

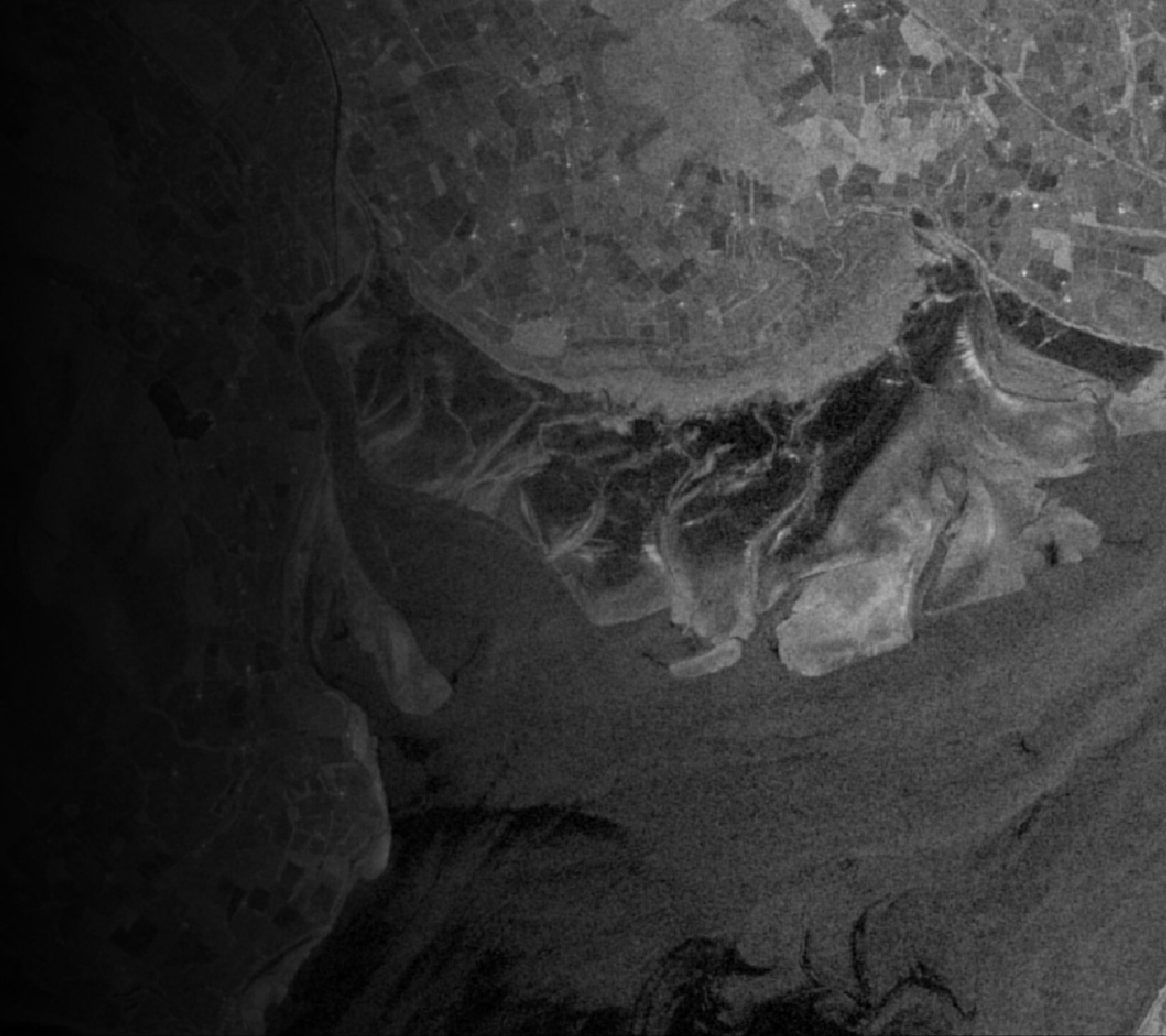
- Saltmarsh area in Europe is considered to be generally declining
- The conservation status of saltmarshes in Europe is generally rated unfavourable
- Increasing saltmarsh erosion is caused by:
  - Agricultural, industrial and urban development (‘coastal squeeze’)
  - Rising sea levels
- Saltmarsh erosion may lead to:
  - Loss of biodiversity
  - Increased flood risk
  - Release of carbon stores

Saltmarshes: Monitoring Erosion

- Clearly important!
- Typical methods include:
  - Field surveys
  - By-eye analysis of aerial photographs
- These methods are time consuming and less effective for continuous monitoring

Synthetic Aperture Radar (SAR)

- Measures the return intensity of a transmitted radar signal from space
- Generally not hindered by cloud cover or low-light levels
- Changes in the roughness, geometry or moisture content of a target can be detected
- Useful for monitoring vegetated areas such as saltmarsh!
- Has been used for wetlands monitoring, but mainly for mapping and studying water dynamics



CUSUM Algorithm

CUSUM Algorithm

$$\Sigma_d = \sum_{i=0}^{N} I_i - E[I]$$

CUSUM at timestep N

Image i

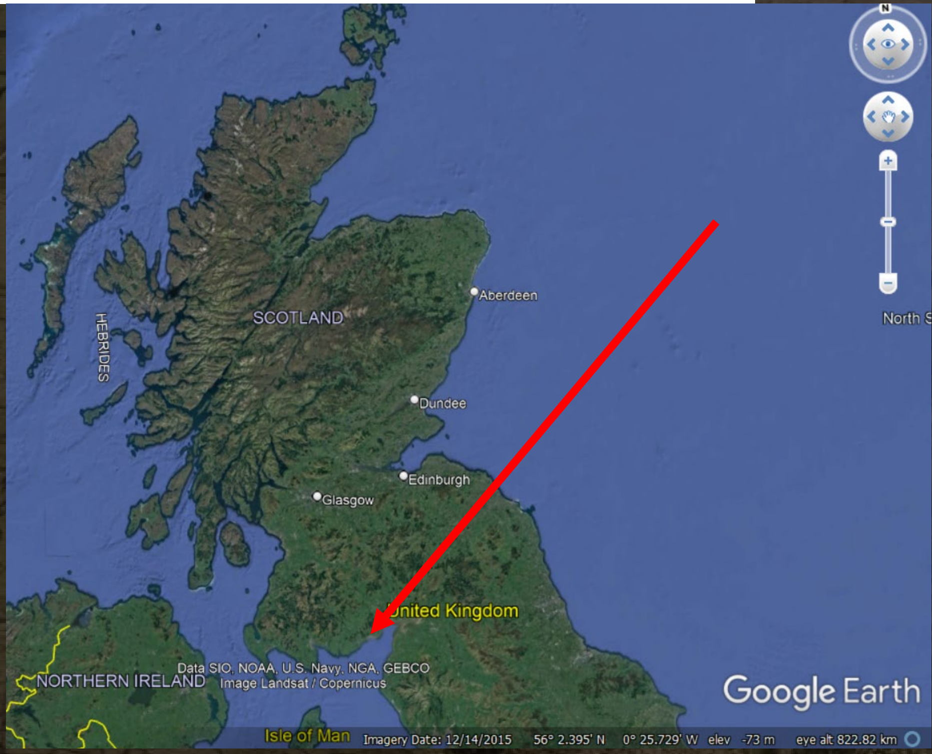
Reference Mean (clutter)

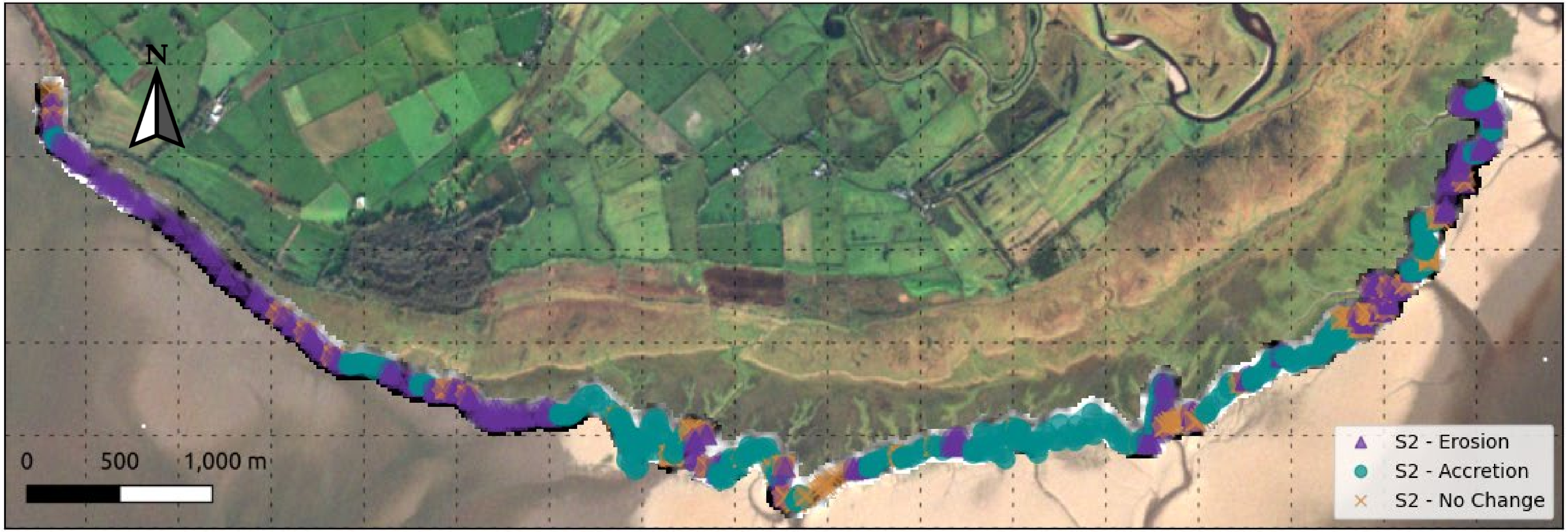
- Previously used for forest monitoring (Ruiz-Ramos et al. 2020):
  - A reference mean (clutter) image is subtracted from each image in the timeseries
  - The resulting difference images are cumulatively summed
  - This amplifies persistent changes

Study Site and Data

Solway Firth Marsh, Scotland

- Site of Special Scientific Interest
- Special Protection Area
- Special Area of Conservation
- Highly dynamic environment with both **erosion** and **accretion** occurring in different areas



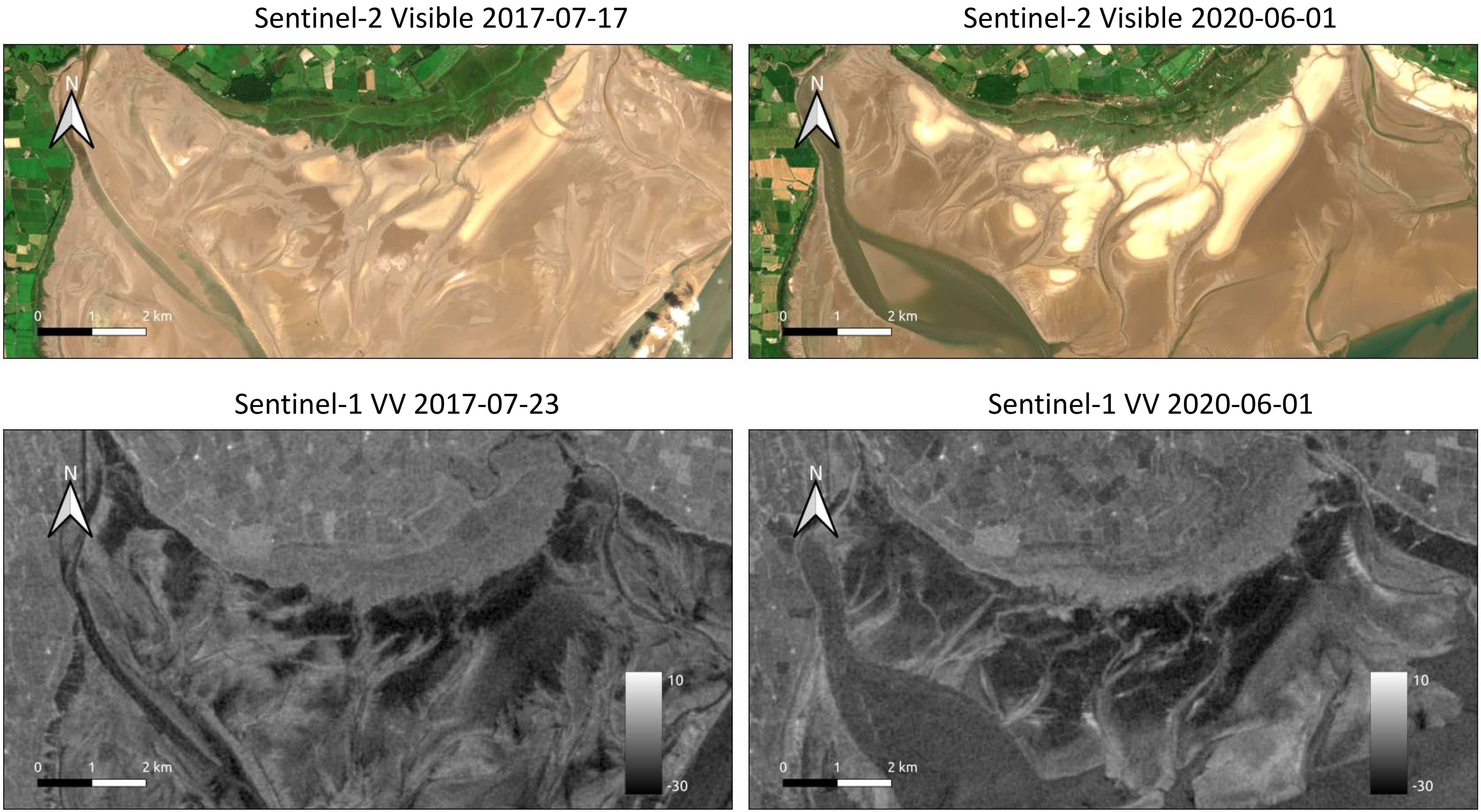


Ground Truth Data

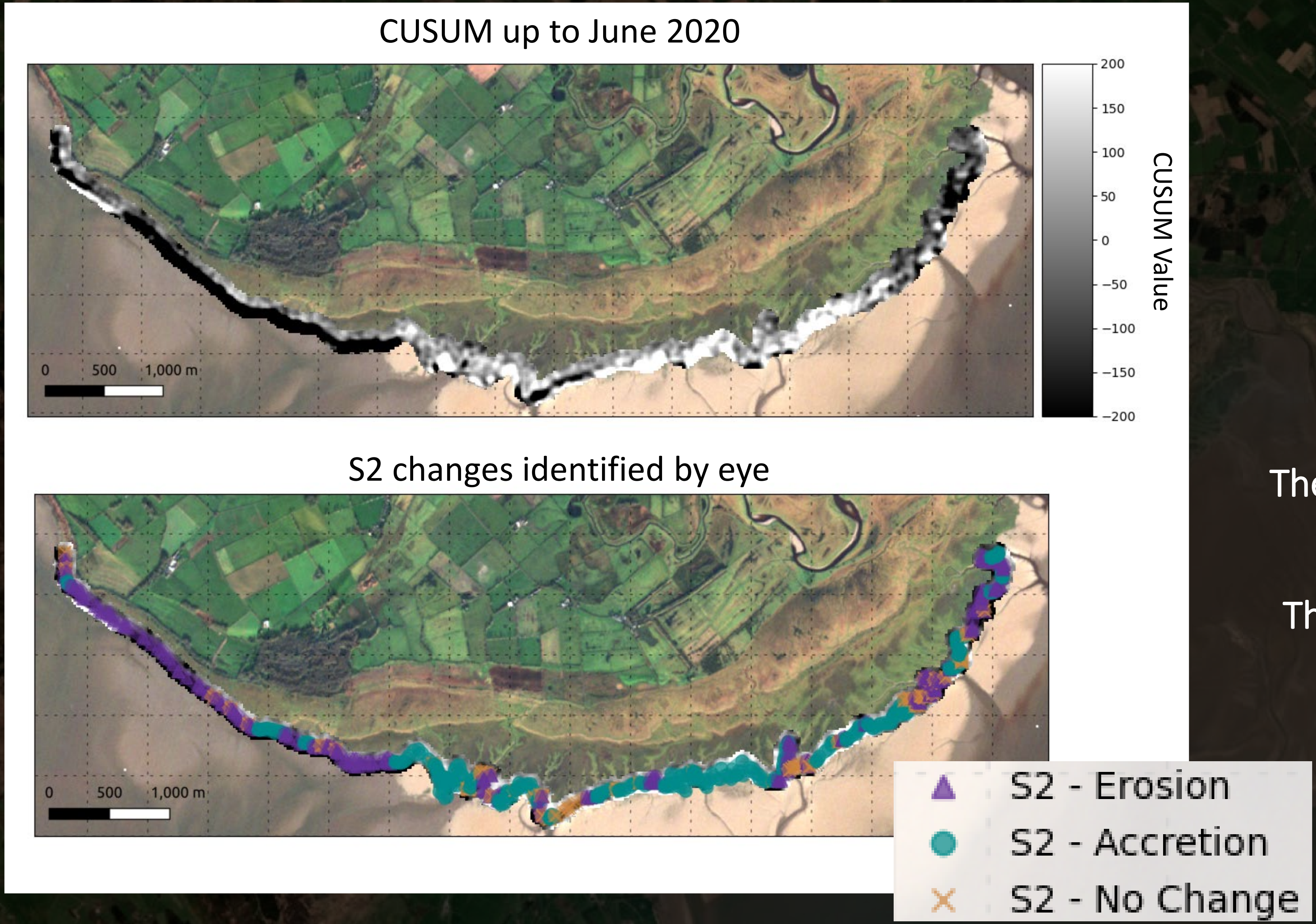
- Sentinel-2 (S2) RGB images (10m resolution)
- Coastal marsh extents drawn by eye for 1 S2 image in summer 2017 and 1 S2 image in summer 2020
- Areas of **erosion**, **accretion** and **no change** identified from this

SAR Data

- Sentinel 1 timeseries, VV
- 6-day revisit time
- 2017 – 2020 (Using 2017 as the reference mean)


Sentinel-2 Visible 2017-07-17
Sentinel-2 Visible 2020-06-01
Sentinel-1 VV 2017-07-23
Sentinel-1 VV 2020-06-01
N
0
1
2 km
10
-30

Results

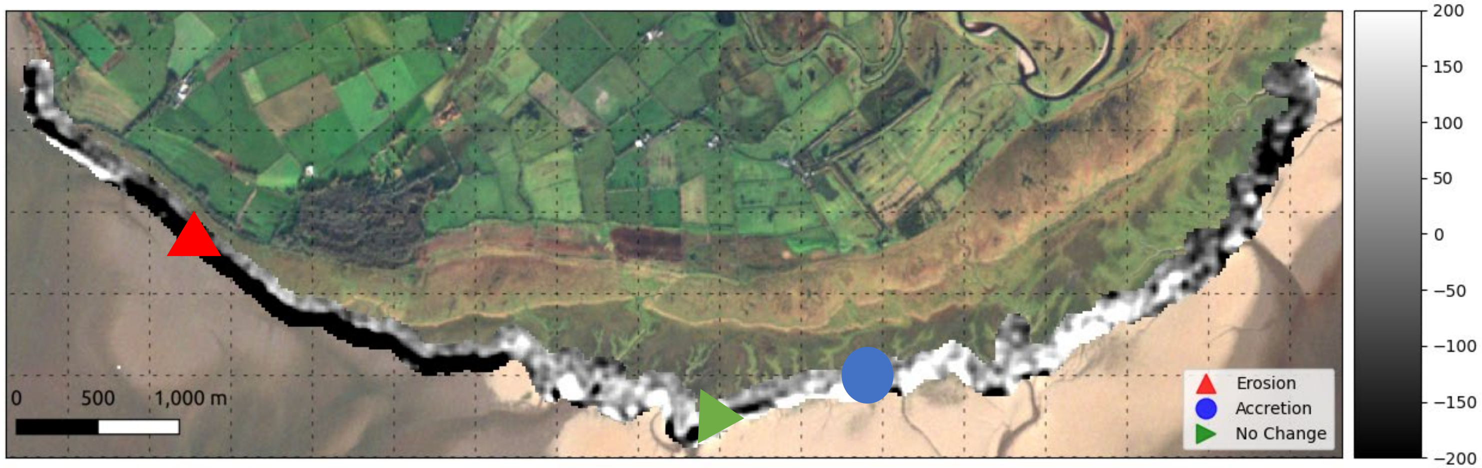


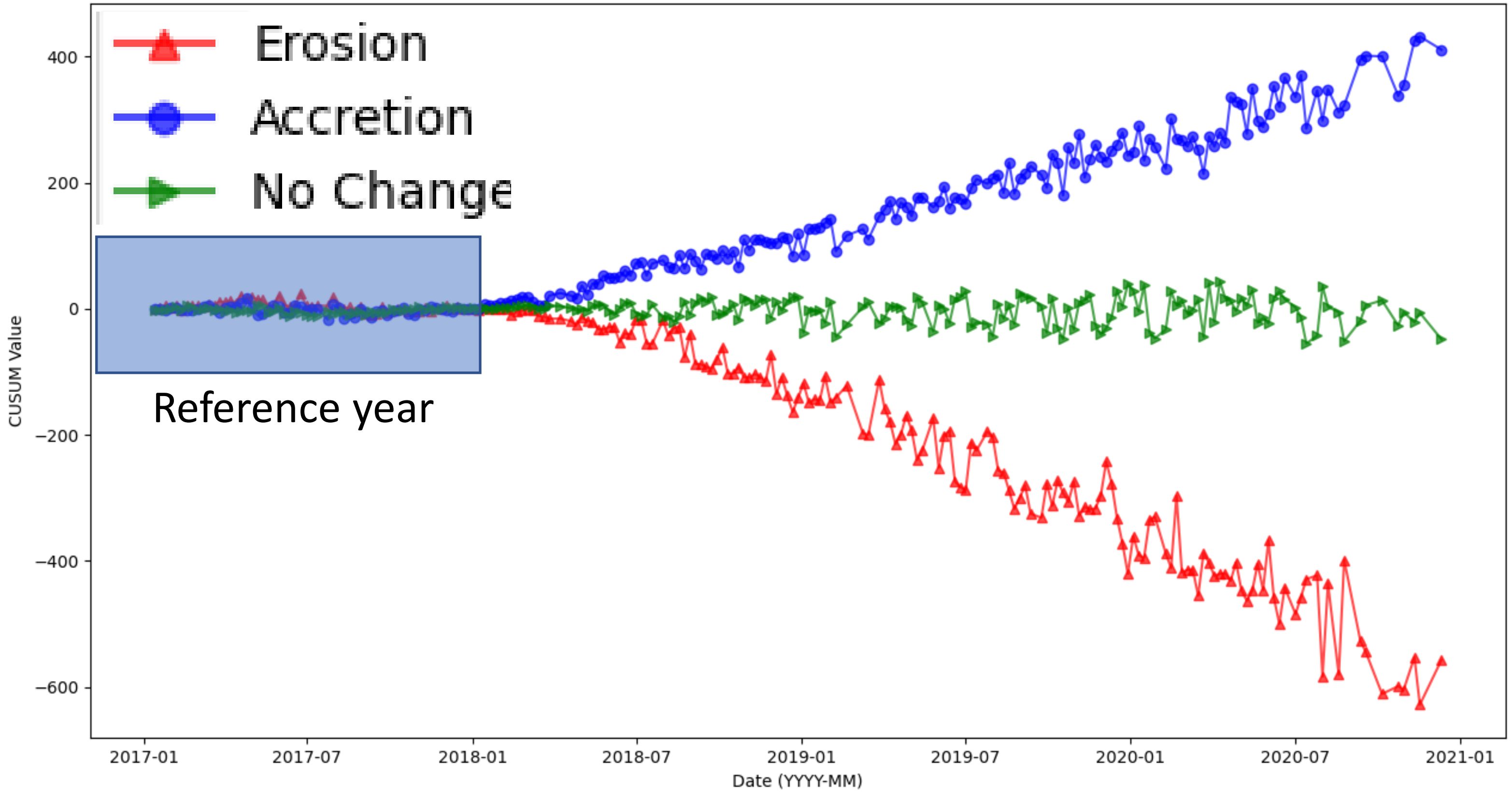
Visual Inspection

The areas of erosion appear as dark in the CUSUM

The areas of accretion appear as bright in the CUSUM

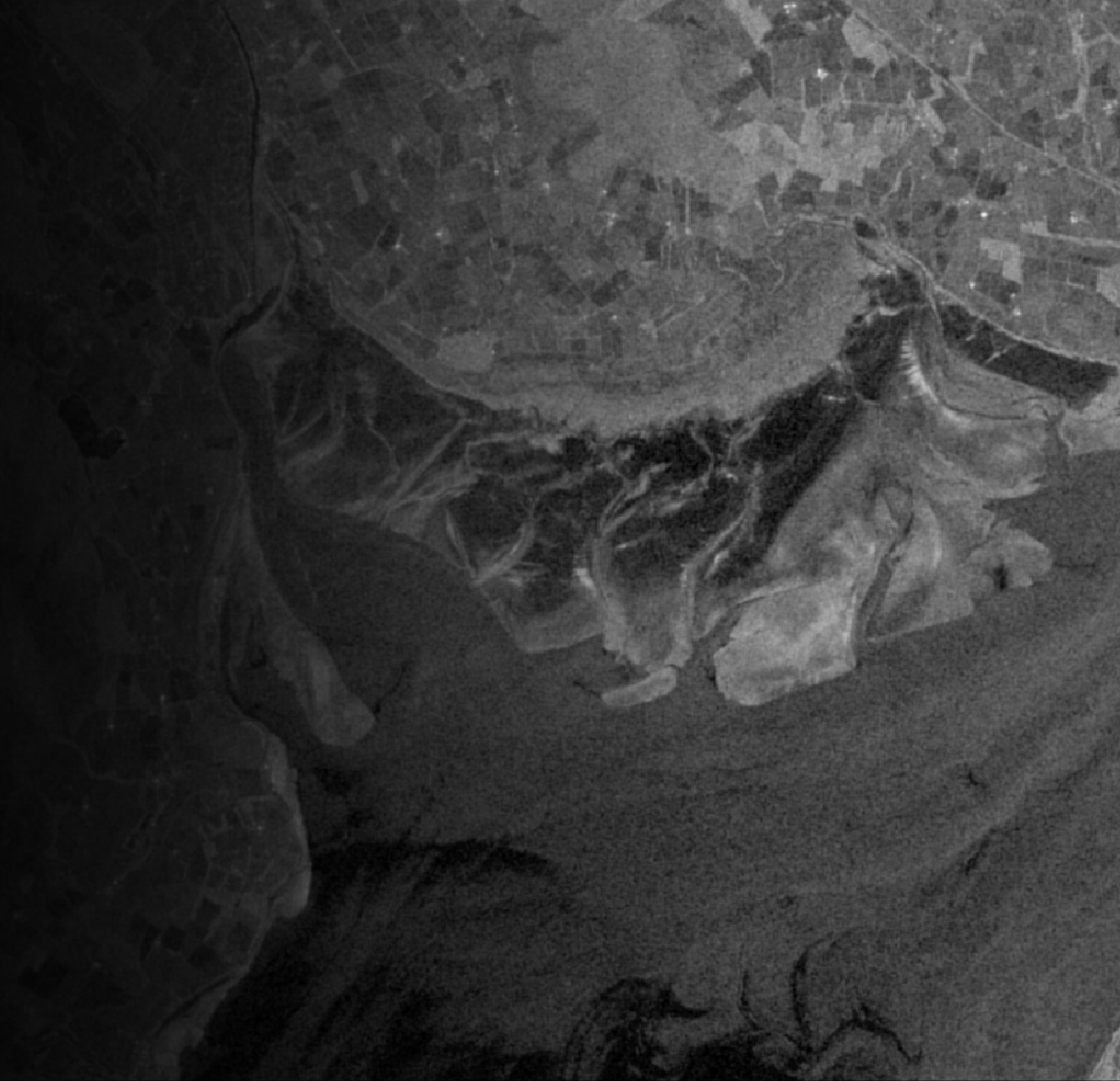
Inspecting the CUSUM timeseries



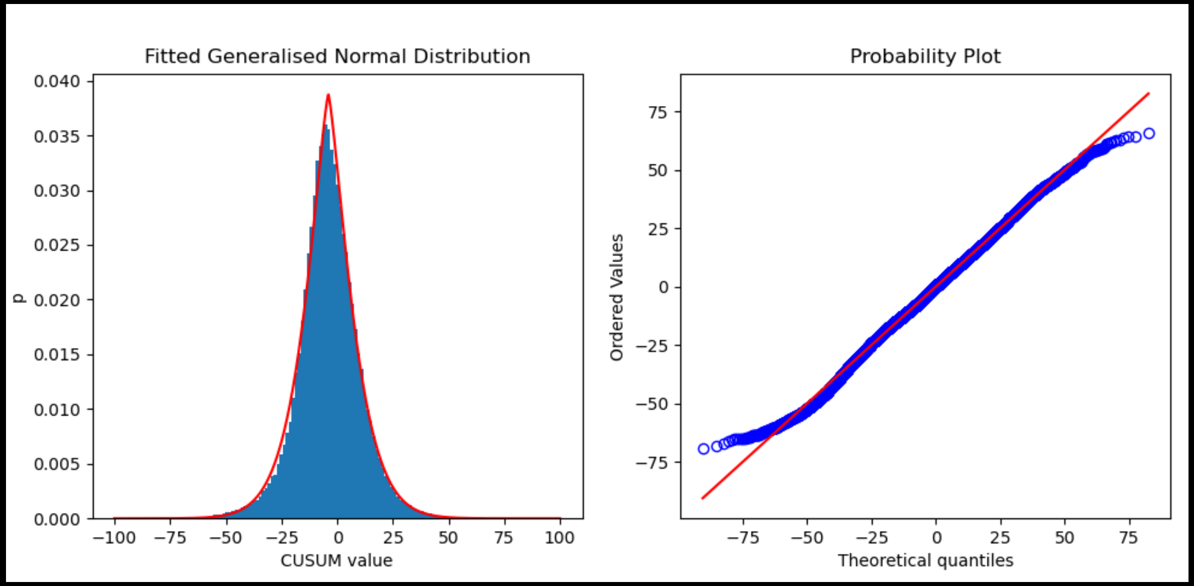


Designing a statistical test: Defining ‘Clutter’

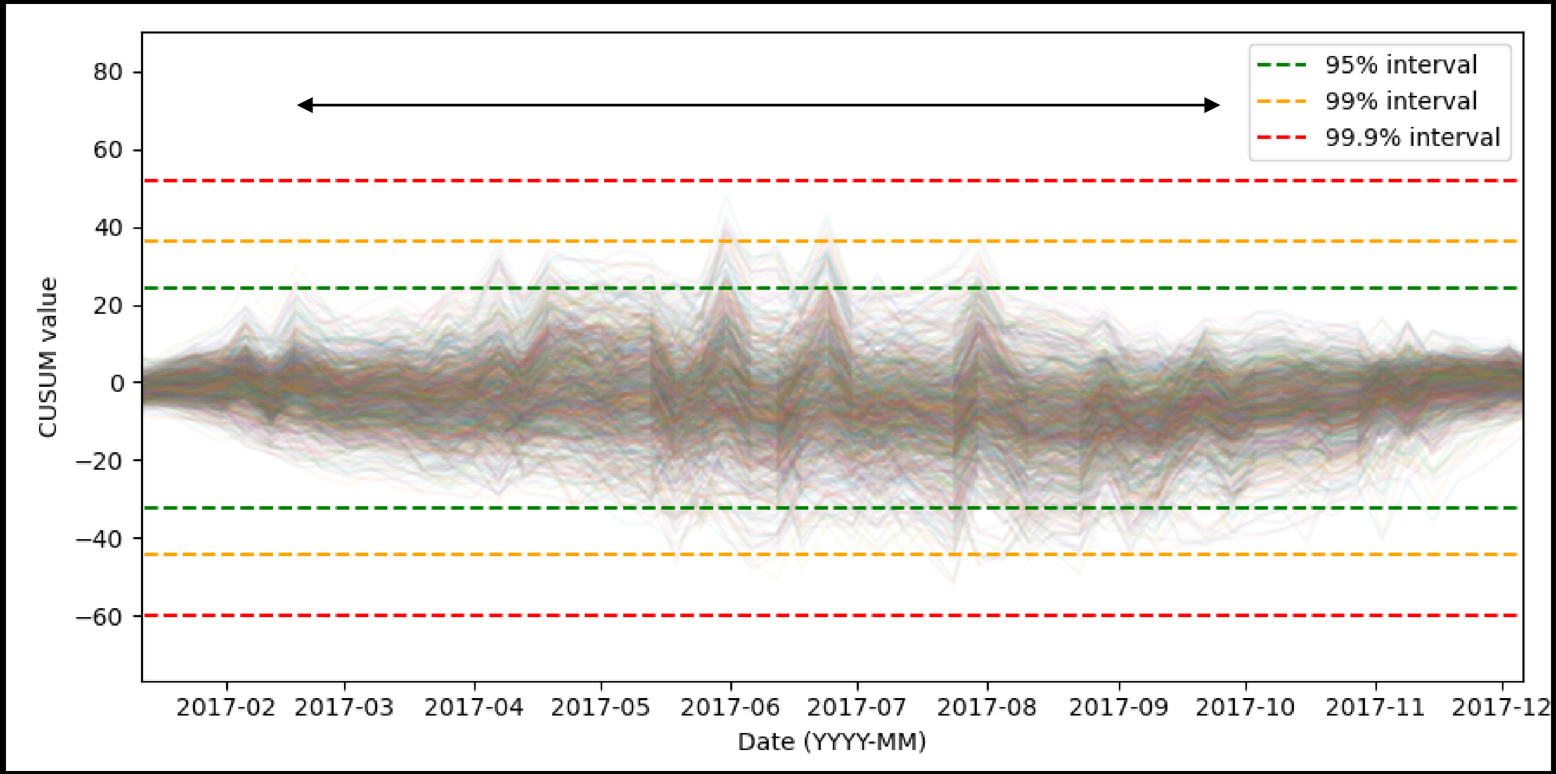
- We want to model the CUSUM signal when no (significant) changes to shoreline are occurring
- We use March to September 2017 (spring and summer)
- It is less likely to include changes consequence of storms
- Avoids using the start/end of 2017 which are forced to be zero



Designing a statistical test: clutter pdf

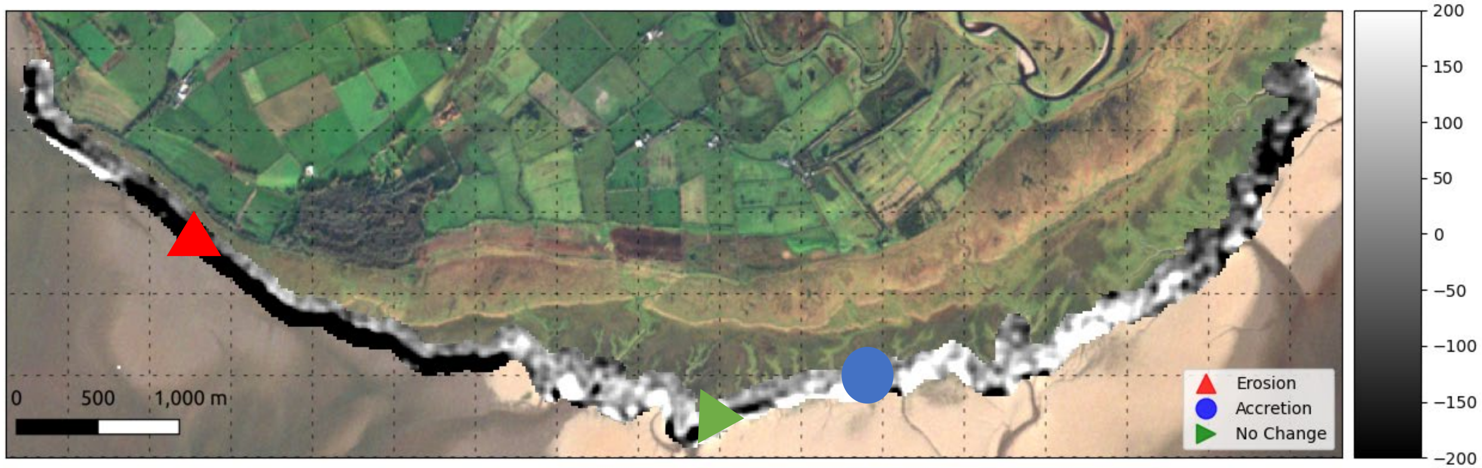


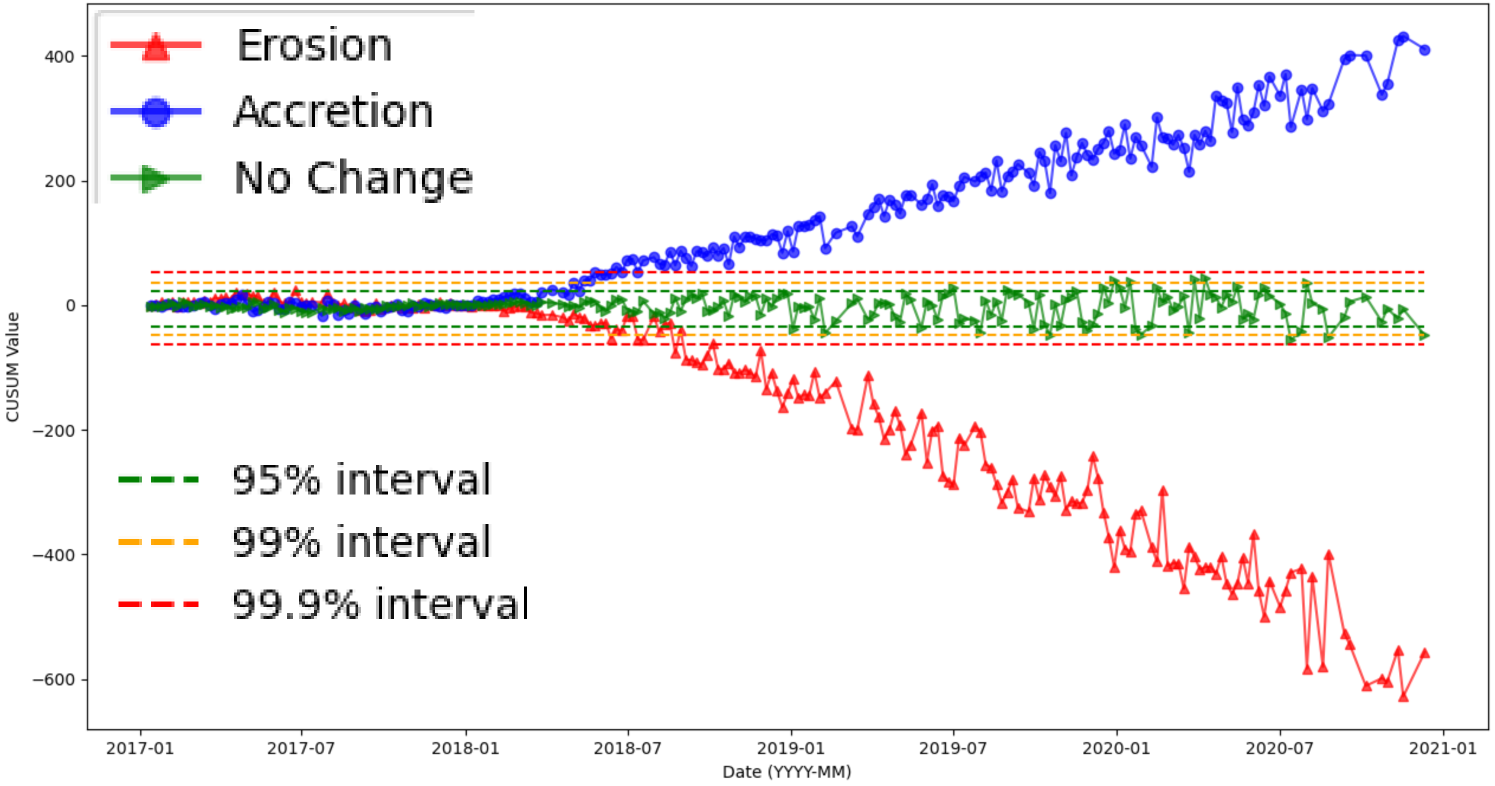
Clutter (mar-sept 2017)



- We fitted a Generalized Normal Distribution to the clutter data
- Issues with the tails – some improvement needed here
- We defined the detection thresholds using Constant False Alarm Rates)

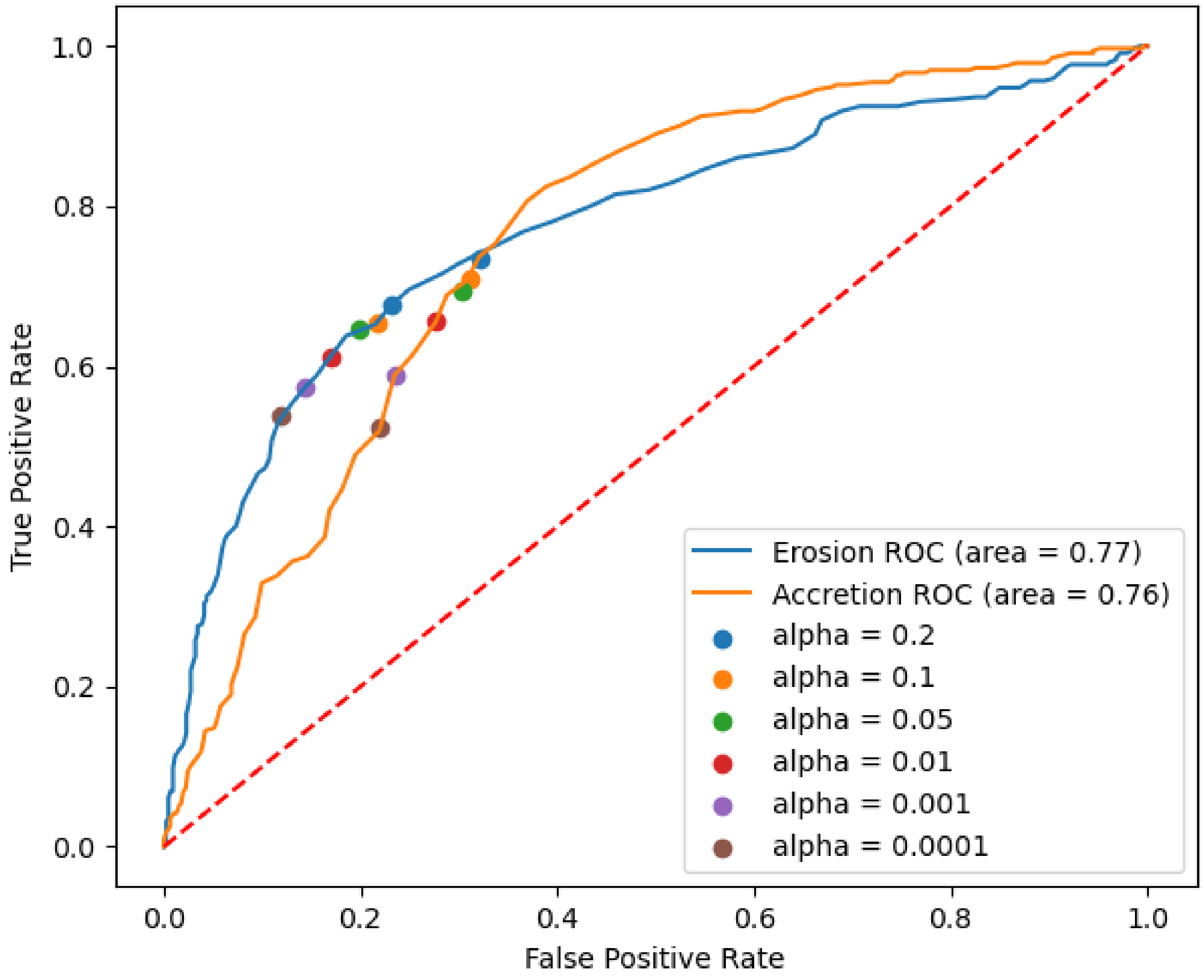
Inspecting the CUSUM timeseries – with detection thresholds





Evaluating Performance

- We tested a range of different Constant False Alarm Rates (alpha) against the ground truth data
- Evaluation using Receiver Operating Characteristic (ROC) curves for both **erosion** and **accretion** classification



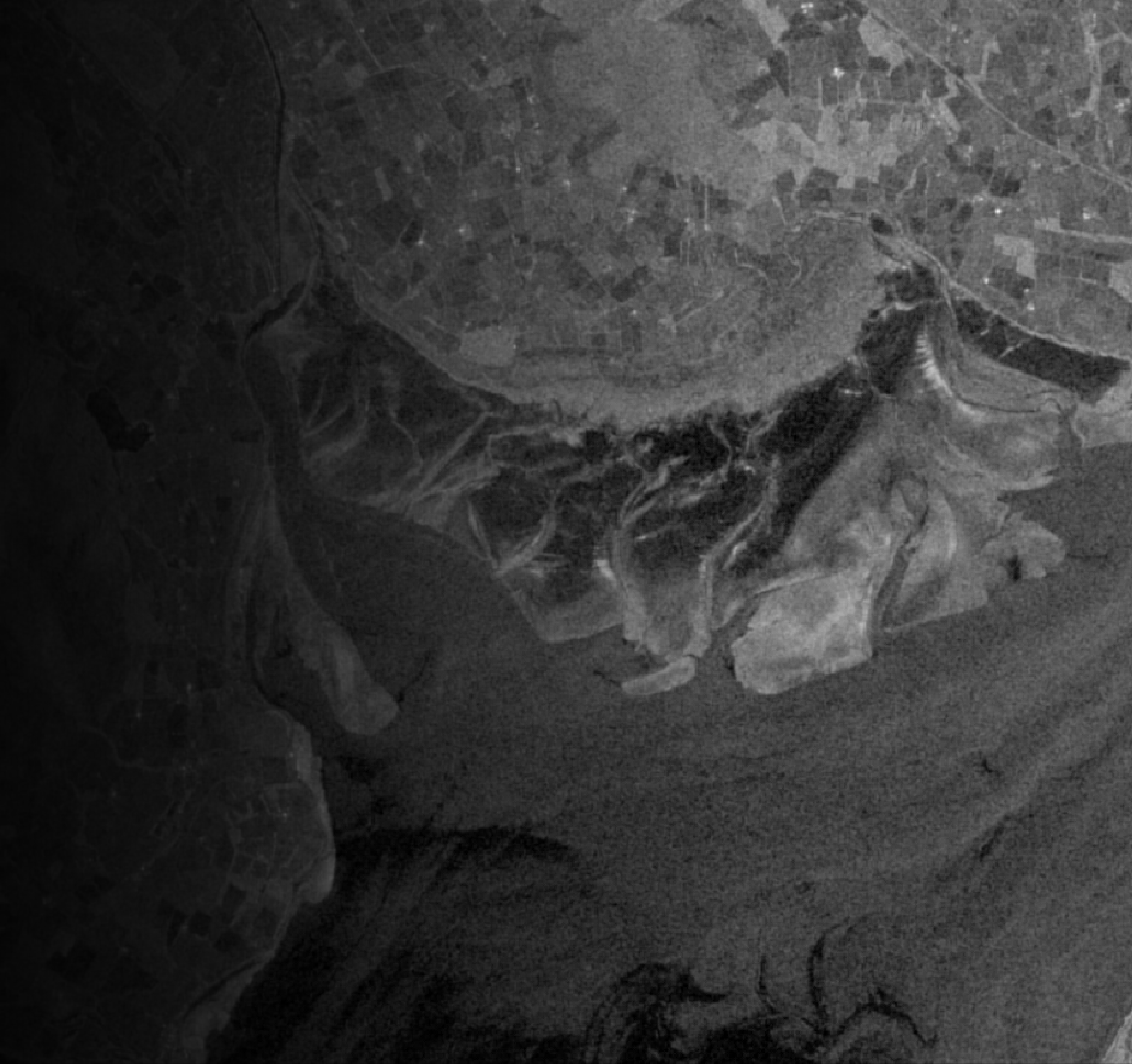
Evaluating Performance

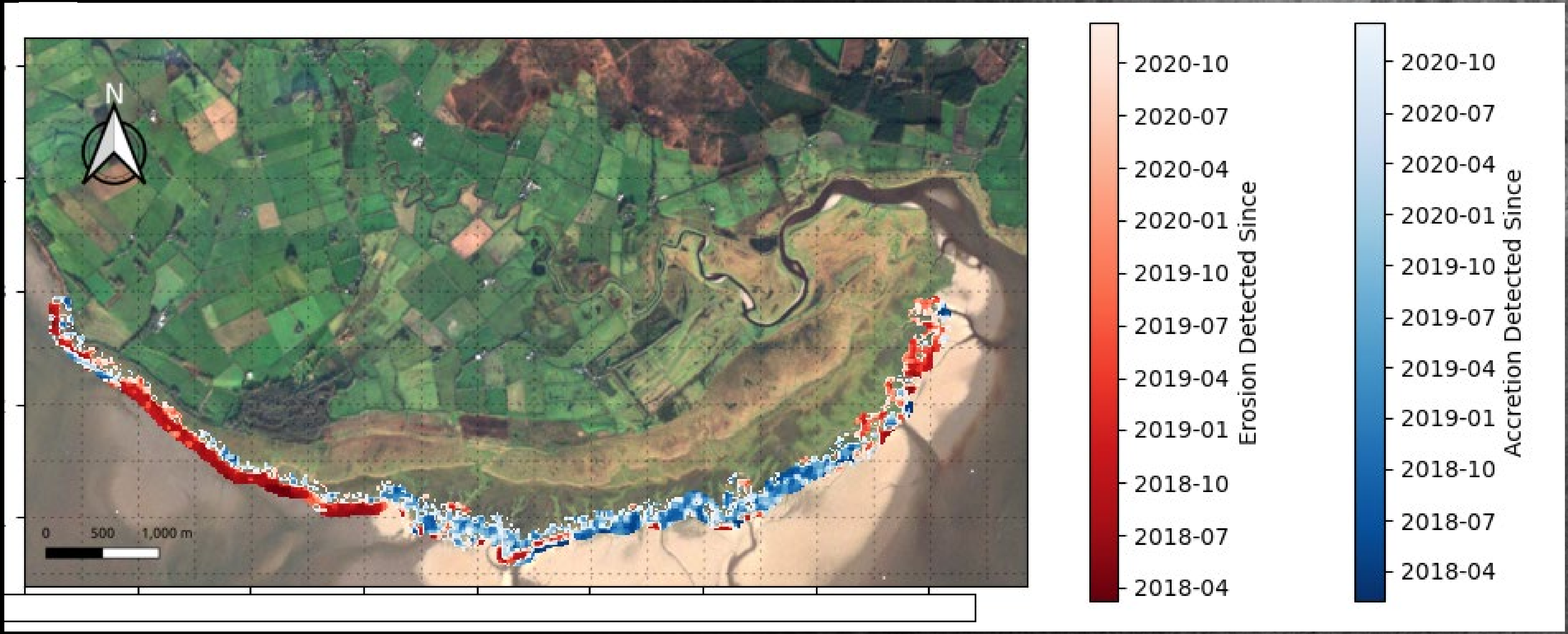
- We evaluation F1 score, Cohen Kappa Score, Overall Accuracy
- The value of alpha=0.2 is best for erosion and accretion classification
- The lower alpha is best for no-change classification

	Accretion			Erosion			No Change			Summary		
Alpha	**F1 Score**	**TPR**	**FPR**	**F1 Score**	**TPR**	**FPR**	**F1 Score**	**TPR**	**FPR**	**Weighted F1 Score**	**Cohen Kappa Score**	**Overall Accuracy**
0.2	**0.68**	**0.73**	0.32	**0.69**	**0.68**	0.23	0.11	0.08	**0.08**	**0.60**	**0.36**	**0.62**
0.1	0.66	0.71	0.31	0.68	0.66	0.22	0.13	0.12	0.11	0.60	0.34	0.61
0.05	0.66	0.69	0.30	0.68	0.65	0.20	0.18	0.18	0.13	0.60	0.35	0.60
0.01	0.64	0.66	0.28	0.67	0.61	0.17	0.21	0.25	0.19	0.60	0.33	0.58
0.001	0.62	0.59	0.23	0.65	0.57	0.14	0.23	0.36	0.27	0.58	0.31	0.55
0.0001	0.57	0.52	**0.22**	0.64	0.54	**0.12**	**0.24**	**0.42**	0.34	0.56	0.28	0.52

Detecting areas of concern

- We can look at entire CUSUM timeseries
- We use constant false alarm rate of 1%
- Identify when the erosion and accretion first occurred (recent changes coloured lighter, long-term changes darker)




N
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2020-10
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2019-07
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2019-01
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2018-07
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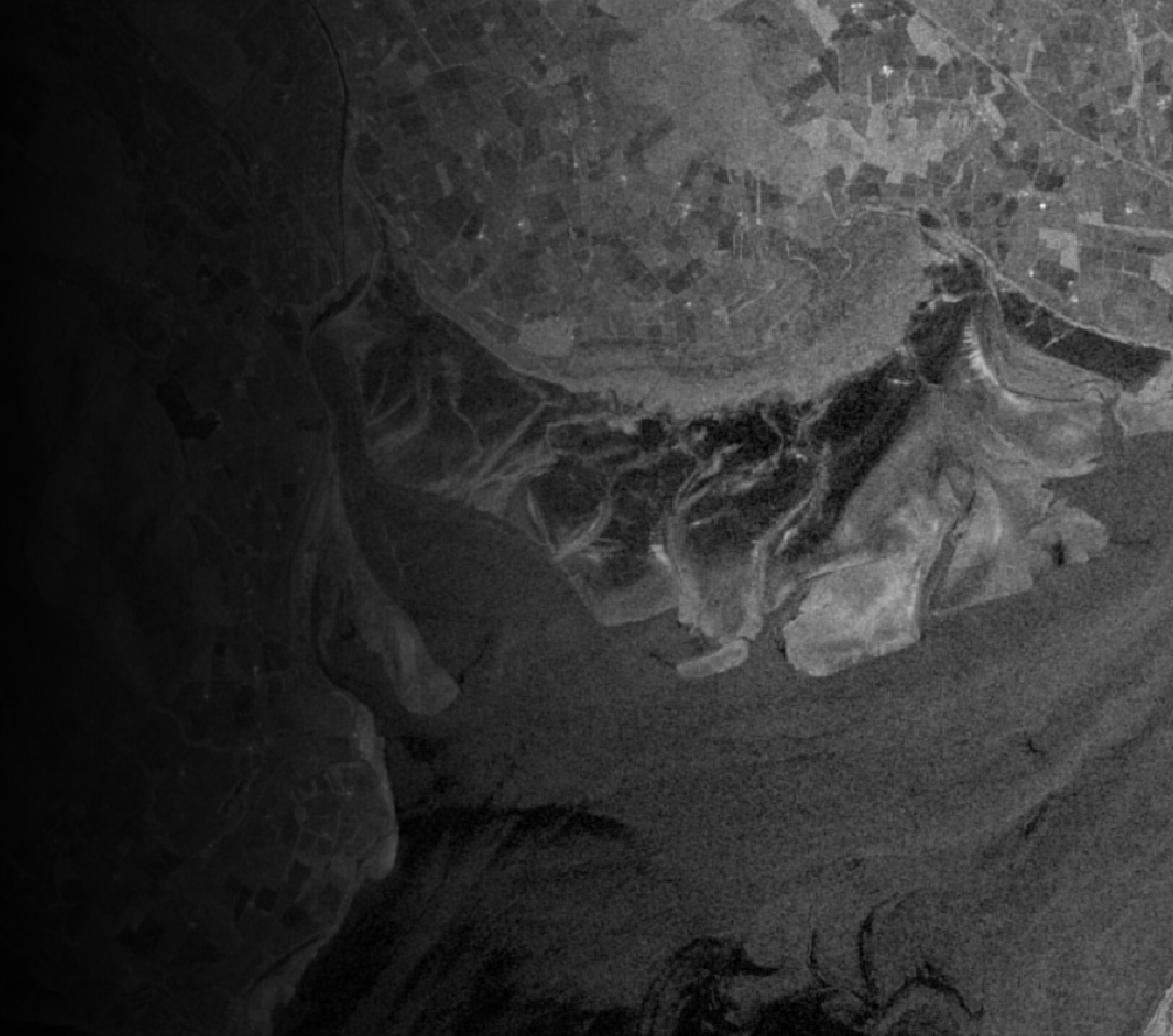
Erosion Detected Since
2020-10
2020-07
2020-04
2020-01
2019-10
2019-07
2019-04
2019-01
2018-10
2018-07
2018-04
Accretion Detected Since

Conclusions

- SAR CUSUM algorithm can be used to identify erosion and accretion in a saltmarsh environment
- This allows for detection of both short and long-term changes
- Further work required to:
  - Evaluate with improved ground truth dataset (drone imagery?)
  - Improve clutter definition and distribution fit
  - Evaluate for other saltmarsh systems



Thanks you for your attention