Detection of water bodies with multi-temporal Sentinel-1 SAR observations: examples from West Africa and Greenland

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The legacy of water body mapping with ASAR

- Detection of open water bodies with C-band SAR backscatter globally has been demonstrated (Santoro et al., 2015; Lamarche et al., 2017)

- However, a purely backscatter-driven detection often misclassifies land surfaces as water:
  - *Arid terrain* (smooth soil $\rightarrow$ low backscatter)
  - *Glaciers and snow fields* (wet snow $\rightarrow$ low backscatter)
Scope of this study

• With Envisat ASAR data, systematic analysis of signatures of the SAR backscatter over water and land was possible thanks to the availability of multiple observations.

• Sentinel-1A and -1B are set to observe repeatedly land masses, with additional or other features with respect to ASAR (higher spatial resolution, dual-polarization, fixed viewing geometry).

• Question: can Sentinel-1 SAR datasets improve characterization of water surfaces in areas identified with ASAR to be prone to classification errors when using C-band?
Experimental setup

1. Northern Europe: first attempts to understand metrics of Sentinel-1 SAR data and develop water classification approaches as part of the CCI Land Cover project activities on the new Sentinel datasets (2015-2016)

2. West Africa: application of the initial development to prototype water body mapping in large areas with Sentinel-1 as contribution to the Africa mapping of the CCI Land Cover project with Sentinel-2 data (2017)

3. Greenland: application of Sentinel-1 water body detection approach to identify lakes in Greenland and track their dynamics to support mapping and monitoring of ice-marginal lakes with multiple observations as part of the CCI Glaciers project (2018)
1. Northern Europe

2. West Africa

3. Greenland
Site: Southwest Sweden

Reference: data mask of Global Forest Change product (GFC) (Hansen et al., 2013)

Histograms represent the mean and the 10th-90th percentiles (based on ~ 15,000 pixels)
Site: Southwest Sweden

Reference: data mask of Global Forest Change product (GFC) (Hansen et al., 2013)

Monthly average based on 1-5 observations

Histograms represent the mean and the 10th-90th percentile (based on ~15,000 pixels)
Sentinel-1 water detection for northern latitudes

**Water detection based on Support Vector Machine, trained with GFC data mask pixels**

**Overall accuracy based on ~ 46,000 test samples from GFC data mask**
GFC water mask layer
Sentinel-1 water body map of Southern Sweden

Sentinel-1 classification based on average VH-pol backscatter of August 2015 (3 images)
• Monthly Sentinel-1 average backscatter images (co- and cross-pol, at unfrozen season) are sufficient to obtain a water detection with > 90% overall accuracy

• Major water commission error: commission of water in cropland (0.6% of area)

• Major water omission error: omission of water along shorelines (0.7% of area)

• Note: this was an “easy” setting for demonstrating the capabilities of Sentinel-1 to detect water bodies
1. Northern Europe

2. West Africa

3. Greenland
Sentinel-1 dataset and processing for West Africa

- Demonstrator for large-area processing and classification with 6,700 S1 GRDs covering western Africa (January 2015 – May 2017)
- Processing on AWS: recipes provided by user (GAMMA) and scaled up by EBD
- Output: co-registered stacks of radiometric terrain corrected and multi-temporally filtered backscatter products @20 m resolution
Sentinel-1 water body indicator

- To avoid water commission errors in arid terrain, seasonal averages (3 months) were used → 8 backscatter predictors + local incidence angle → detecting potential water bodies
- Machine learning algorithms tested: best performance with bagged trees
- Training samples selected by visual interpretation of Google Earth high-res. imagery

Water commission (desert, very arid terrain)

Water omission (ocean behaves differently than inland water)
Sentinel-1 water body product

- A pure “radar”-based solution required additional cleaning to overcome systematic errors
- Existing optical water products were affected locally by cloud cover (water omission)
- Cleaning was supported by the CCI Water Body Product because of its overall reliability
Details of the Sentinel-1 water body product

Delta river system in Guinea Bissau

Detail of Lake Volta, Ghana
Comparing optical and radar water detection

**Barrage de Selengue**

[Sentinel-1 water product (epoch 2015)]
Binary water/land classification

[JRC water occurrence 2014-2015]
Occurrence in months (light to dark blue: 1 to 12 months)
Comparing optical and radar water detection

Port Loko, Sierra Leone

Sentinel-1 water product (epoch 2015)
Binary water/land classification

JRC water occurrence 2014-2015
Occurrence in months (light to dark blue: 1 to 12 months)
• Seasonal averages were able to overcome classification errors in arid terrain. Some features still required auxiliary datasets to avoid water commission errors.
• Water omissions mostly occurred in correspondence of shorelines (mixed pixels).
• Small or narrow water bodies (less than twice the 20 m pixel size) remained often undetected.
• 3 years of Sentinel-1 data were necessary to obtain a spatially consistent average backscatter in each season (note: Sentinel-1 was still in its infancy).
• A radar-based solution to map water bodies achieved detailed detection but sub-optimal delineation → radar-optical combination appears to be a win-win solution.
1. Northern Europe
2. West Africa
3. Greenland
Setup of study

- Lakes appearing at glaciers’ margins are highly dynamic and currently shrink globally
- Inventory of ice-marginal lakes targeted locally so far → looking for a continental perspective with currently orbiting satellites
- One year of Sentinel-1A / -1B data (2017) under investigation at Disko Bay (red outline) to assess the capability to detect water in a polar environment (300 images)
- Spatial resolution: 10 m
Signatures of monthly backscatter averages

- Land, x Water
To avoid water commission errors due to wet snow conditions, monthly averages were used → 24 backscatter predictors → detecting potential water bodies with bagged trees

- Training samples selected from an independent dataset of lakes obtained from SPOT data acquired in 2016

- Cross-validation of bagged trees: 98.9% overall accuracy, based on 56,000 samples
Comparing water body maps

- Major lakes well detected but not well delineated
- Smaller / narrow lakes (< 1 hectare) often undetected with current classification settings
• Using the backscatter trajectories of water and other land surface types avoided the erroneous detection of water over land (snow and ice features)
• Current setting with 24 predictors might have overfitted the classification algorithm causing under-representation of water
• Under-representation might also be due to having averaged both ascending and descending data takes
• Repeated observations every 6 days greatly supported the mapping
• Co- and cross-polarized backscatter were found to be complementary
• Future: algorithm development with integration of radar-, optical- and DEM-based lake detections

First indications from the Disko Bay study