Hyper-temporal Water Body Dynamics Mapping using Sentinel-1 Time Series Clustering

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ESA Mapping Water Bodies from Space
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• Thematic:
  • capture full water dynamics of as many wetlands as possible
  • produce high temporal and spatial resolution surface water
    dynamics (SWD) maps
  • no global application, but rather the maximum detail for specific
    areas

• Technical:
  • be as automatic as possible („press play approach“)
  • Approach must be applicable to whole variety of natural
    conditions
  • Integrate all data available from Sentinel-1 VV GRD mode (both
    satellites and orbits)
  • Easy computation scalability
The problem with sea state

Backscatter characteristics of water surfaces under different environmental conditions. Camargue, Southern France, Sentinel-1 IW VV, acquired on Jan. 01 2015 and Feb. 02 2015 respectively (approx. 50x42 km²).
3 Analysis of temporal backscatter dynamics

Visualization of backscatter variability

time series clustering methodology

- Compute moving window average smoothed time series
- Build clustering image space with original and smoothed time series
- Perform clustering
- Reorder clustering result into original sequence
Cluster Separability: Sum of Squares Ratio

- Variance explained by clustering as an indicator for class separability
- Between sum of squares / total sum of squares ratio
Mapping of maximum water extent

- Minimum backscatter thresholding

- Speckle is filtered almost completely

- Bimodal histogram with very good separability

- Rare flood events are easily missed

- Does not work in arid regions
Mapping of minimum water extent

• Maximum backscatter thresholding?
Mapping of minimum water extent

- Supervised classification of Min, Median and Max
- Rare land occurrences are easily missed
- Does not work in areas without permanent water bodies
Download and processing of ~16000 Sentinel-1 GRD products (approx. 14 TB)

5 x 24 CPUs @ 500 GB RAM

Development of own Python software “pyroSAR” for image organization and processing:
https://github.com/johntruckenbrodt/pyroSAR.git
- Interfaces to SNAP and GAMMA
- Own implementation of border noise artifact removal

Development of an R package “tsar” for scalable time series computations:
https://github.com/johntruckenbrodt/tsar.git
- Automatic INSPIRE metadata creation and uplink to project server
## Test sites

<table>
<thead>
<tr>
<th>Country</th>
<th>Site Name</th>
<th>Total Area (km²)</th>
<th>Site Type</th>
<th>EcoRegion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egypt</td>
<td>Lake Burullus</td>
<td>1489.6</td>
<td>Coastal</td>
<td>Flooded Grasslands and Savannas</td>
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<tr>
<td>Estonia</td>
<td>Matsalu Nature Reserve</td>
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<td>Temperate Broadleaf and Mixed Forests</td>
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<td>Mediterranean Forests, Woodlands and Scrub</td>
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<td>Greece</td>
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<td>Mediterranean Forests, Woodlands and Scrub</td>
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<td>Italy</td>
<td>Fucecchio wetland</td>
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<td>Jordan</td>
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<td>Deserts and Xeric Shrublands</td>
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<td>Lithuania</td>
<td>Nemunas delta regional Park</td>
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<td>Temperate Broadleaf and Mixed Forests</td>
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<tr>
<td>Spain</td>
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<td>Mediterranean Forests, Woodlands and Scrub</td>
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<td>Store Mosse</td>
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<td>Temperate Broadleaf and Mixed Forests</td>
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<tr>
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<td>Kristianstad Vattenrike</td>
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<td>Temperate Broadleaf and Mixed Forests</td>
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<td>Inland</td>
<td>Peatbogs, wet forests, inland marshes</td>
</tr>
<tr>
<td>Tanzania</td>
<td>Kilombero floodplain</td>
<td>40154.71</td>
<td>Inland</td>
<td>Flooded Grasslands and Savannas</td>
</tr>
</tbody>
</table>
Nemunas, Lithuania
Kilombero Floodplain, Tanzania
Lake Burullus, Egypt
Camargue, France
http://portal.swos-service.eu
Conclusions

• Time-series analysis has proven much more successful than per-image classification for S1 SWD mapping

• K-means was chosen as a simple way of time-series clustering and classification

• K-means separability (between SS/total SS) can be used as a measure of detecting permanent water bodies

• Approach still needs supervision and does not work for all situations and thus must be used with care
  
  • E.g. in areas with no clear separation of land and water like swamps/mires

• Other alternative approaches have been developed for situations where clustering does not work well or is just not necessary
  
  • Reduction of backscatter variability by Savitzky-Golay filtering and subsequent per-image thresholding
  
  • Backscatter distribution estimation suing Gaussian mixture modeling for time series threshold estimation
Current and future work

• Incorporation of other data sources to assess e.g. flooded vegetation and discrimination of sand and water (sensor fusion)
• Validation campaign, comparison with other SWD products
• Improvement of clustering reliability
  • E.g. Gaussian processes regression and Gaussian mixing
• Automation of minimum/maximum water extent mapping or completely remove the need for it
• Expand to a more hydrologically comprehensive approach incorporating soil moisture
• In general, have more fun with SAR time series, there is much more to explore
Thank You!

For more information, contact

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