Evaluating Sentinel-2 imagery for mapping human settlements

Time series information for regression-based unmixing in urban surface fraction mapping

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Background and Objectives

Sentinel-2 for global urban mapping

- Existing **ready-to-use products** provide information on urban extent or features
- Recent optical **Sentinel-2** satellite imagery offers a spatial, temporal and spectral resolution promising for land cover mapping
- How can Sentinel-2 **contribute valuable information** to existing urban mapping approaches?

1) Compare regression-based unmixing to existing products!

2) How can S2 regression modeling contribute to the products by intra-annual metrics?
Study area, data and methods

Study area and methods

Regression-based unmixing with synthetically mixed endmember spectra (Okujeni et al. 2013, 2017)
Study area, data and methods

Method workflow – single image

2018

Spring
2018/04/09

Winter
2018/02/08

Fall
2017/10/16

Summer
2017/08/30

Image
Data

Spectral
library

Synthetic
mixing and
model training

Model
prediction

Map
Study area, data and methods

Method workflow – time series metrics
Study area, data and methods

Validation areas

<table>
<thead>
<tr>
<th>Neighborhood</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport</td>
<td>1</td>
</tr>
<tr>
<td>Residential medium density</td>
<td>2</td>
</tr>
<tr>
<td>Mixed medium density</td>
<td>3</td>
</tr>
<tr>
<td>Residential dense</td>
<td>4</td>
</tr>
<tr>
<td>Mixed dense</td>
<td>5</td>
</tr>
<tr>
<td>Industrial</td>
<td>6</td>
</tr>
<tr>
<td>Residential low density</td>
<td>7</td>
</tr>
<tr>
<td>Rail and Port</td>
<td>8</td>
</tr>
<tr>
<td>Stadium and surroundings</td>
<td>9</td>
</tr>
<tr>
<td>Industrial</td>
<td>10</td>
</tr>
<tr>
<td>Agric. and mixed low dens.</td>
<td>11</td>
</tr>
<tr>
<td>Forest</td>
<td>12</td>
</tr>
<tr>
<td>Residential dense</td>
<td>13</td>
</tr>
<tr>
<td>Residential village</td>
<td>14</td>
</tr>
</tbody>
</table>
Study area, data and methods

Reference data

- Senate Berlin – Vegetation polygons
- Senate Berlin – Imperviousness reference

1. Rasterize
2. Spatial resampling
3. Spatial resampling
4. Sum
5. Normalize (from 0 – 1)
6. Threshold application

Normalized reference for validation
Results - Urban mapping product evaluation

<table>
<thead>
<tr>
<th>Product</th>
<th>GUF</th>
<th>GHSL</th>
<th>ESM</th>
<th>S2 fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>![Reference Image]</td>
<td>![Reference Image]</td>
<td>![Reference Image]</td>
<td>![Reference Image]</td>
</tr>
<tr>
<td>Validation</td>
<td>![Validation Image]</td>
<td>![Validation Image]</td>
<td>![Validation Image]</td>
<td>![Validation Image]</td>
</tr>
</tbody>
</table>

Threshold: 0.2

14 areas, urban & non-urban:
- Overall acc. 0.62
- Producer’s 0.74
- User’s 0.53

14 areas, urban & non-urban:
- Overall acc. 0.86
- Producer’s 0.91
- User’s 0.91

14 areas, urban & non-urban:
- Overall acc. 0.86
- Producer’s 0.84
- User’s 0.97

14 areas, urban & non-urban:
- Overall acc. 0.85
- Producer’s 0.86
- User’s 0.94
Results - Urban mapping product evaluation

<table>
<thead>
<tr>
<th>Product</th>
<th>GUF</th>
<th>GHSL</th>
<th>ESM</th>
<th>S2 fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban &amp; Non-Urban:</td>
<td>Overall acc.</td>
<td>0.60</td>
<td>Overall acc.</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>Producer’s</td>
<td>0.82</td>
<td>Producer’s</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>User’s</td>
<td>0.37</td>
<td>User’s</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Threshold: 0.5
Results - Regression-based unmixing of Sentinel-2

- Spring 2018/04/09
- Fall 2017/10/16
- Winter 2018/02/08
- Median Image 2017/2018
- Median Image + NDVI – 95th percentile

Input:
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue

Prediction:
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue

Reference:
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue
- RGB Red/Green/Blue
# Results - Regression-based unmixing of Sentinel-2

## Overall quality metrics

<table>
<thead>
<tr>
<th>Input</th>
<th>Prediction</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2018/04/09</td>
<td>Fall 2017/10/16</td>
<td>Winter 2018/02/08</td>
</tr>
<tr>
<td>Overall quality metrics</td>
<td>Overall quality metrics</td>
<td>Overall quality metrics</td>
</tr>
<tr>
<td>Werte</td>
<td>Werte</td>
<td>Werte</td>
</tr>
<tr>
<td>Spring</td>
<td>Fall</td>
<td>Winter</td>
</tr>
<tr>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**Overall quality metrics**

- **MAE**
- **Intercept**
- **Slope**
**Results** - Resolving soil/imperviousness confusion

<table>
<thead>
<tr>
<th>Season</th>
<th>Date</th>
<th>Input</th>
<th>Prediction</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>2018/04/09</td>
<td>RGB Red/Green/Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>2017/10/16</td>
<td>RGB Red/Green/Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>2018/02/08</td>
<td>RGB Red/Green/Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median Image</td>
<td>2017/2018</td>
<td>RGB Red/Green/Blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median Image</td>
<td></td>
<td>RGB Red/Green/Blue</td>
<td>+ NDVI – 95th percentile</td>
<td></td>
</tr>
</tbody>
</table>
Results - Resolving soil/imperviousness confusion

Area-specific quality metrics / area 14

- Input
  - Spring
    - 2018/04/09
  - Fall
    - 2017/10/16
  - Winter
    - 2018/02/08
  - Median Image
    - 2017/2018
  - Median Image + NDVI – 95th percentile

- Prediction
  - zonal_MAE
  - Intercept
  - Slope

- Reference

Median Image

RGB Red/Green/Blue

Results – Large area mapping  Surface model: Amsterdam-Berlin trajectory
Results – Large area mapping  Surface model: Amsterdam-Berlin trajectory
Results

Model training - Berlin trajectory

Mean Absolute Error
Results – Large area mapping  Rural area – settlements
Results — Large area mapping  Rural area — woody vegetation
Results – Large area mapping  Rural area – non-woody vegetation
Discussion and Conclusion

- **Sentinel-2** can add valuable information to urban mapping due to its temporal density.
- Using regression-based unmixing contributes a **gradual perspective** on urban areas by providing accurate **fraction images**. **Quality measures** depend on **reference definition**.
- Optical imagery is affected by vegetation **phenology**. Intra-annual **time series metrics** help to encounter the problem of finding best images.
- The applied method is based on **free data**.
- **Surface fractions** can be a proxy for other urban parameters.
Thank you for your attention!

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Evaluating Sentinel-2 imagery for mapping human settlements

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@HumboldtRemSens
Composition – Spectral median + NDVI
State-of-the-art remote sensing in urban mapping

Optical RS - Urban surface classification and fractions

Most urban areas are composed of objects that are smaller than pixel size: mixed pixel problem.
State-of-the-art remote sensing in urban mapping

Optical RS - Urban surface classification and fractions

Okujeni et al. 2017 used a Support Vector Regression approach with synthetic spectral mixing to derive **surface fractions** for gradual urban mapping and thematic enhancement.
State-of-the-art remote sensing in urban mapping

Optical RS - Urban surface classification and fractions

... This helps to quantify land cover and counteract the mixed pixel problem.

HyMap (9 m)  
Landsat (30 m)
Study area, data and methods

Study area and methods

Regression-based unmixing with synthetically mixed endmember spectra (Okujeni et al. 2013, 2017)

Berlin, Germany