Mapping soil moisture content using Sentinel-1 and Sentinel-2: case study from Kenya

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Introduction

Project title: Synergy of multi-temporal Sentinel-1 and 2 images for soil water resources monitoring in Africa

Aim of the project:
- Assess the potential a combination of data from the Sentinel satellites for the high resolution mapping of soil moisture in Kenya
- Capacity building: 2 trainings (Italy and Kenya), joint field campaign

The importance of soil moisture – it is a key parameter in the hydrologic cycle, it is related to natural hazards, in case of agriculture, it can be related to drought and yield. The sentinel family of satellites provides the tools for the spatially and temporally continuous monitoring.
Test-Sites

- 5 test-sites in Kenya:
  - Uasin Gishu
  - Elgeyo-Marakwet
  - Narok
  - Machakos
  - Kajiado

- Focus on agricultural areas but pastoralism and livestock farming are present
- Very different climatic conditions
- Test-sites were selected based on an evaluation of stakeholder interests and focus of the study
Field campaigns

- 6 field campaigns
- Uasin Gishu and Elgeyo Marakwet were visited twice – all other sites once
- Field campaign dates (2016):
  - April 18th, 2016
  - May 31st, 2016
  - August 16th, 2016
  - September 4th-5th, 2016
  - October 3rd, 2016
- 172 samples (with 2-4 replicated each) collected
- Gravimetric samples
 Sentinel-1
- C-Band Synthetic Aperture Radar
- Product used: IW GRDH
  - Spatial resolution: 5x20 m
  - Swath width: 250 km
  - Polarization: VV+VH
  - Revisit time: 6 days (2 satellites) - potentially

 Sentinel-2
- MSI (Multispectral Imager)
- Product used: L1C (TOA)
  - Spatial resolution: 10 m, 20 m and 60 m
  - 12 spectral bands
  - Revisit time: 5 days (2 satellites)
- Sentinel-2A operational; Sentinel-2B in orbit
Sentinel-1

**Sentinel-1 Constellation Observation Scenario:**
**Revisit & Coverage Frequency**

<table>
<thead>
<tr>
<th>PASS</th>
<th>REVISIT</th>
<th>FREQUENCY *</th>
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<tbody>
<tr>
<td>ASCENDING</td>
<td>6 days</td>
<td>12 days</td>
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<table>
<thead>
<tr>
<th>COVERAGE</th>
<th>FREQUENCY **</th>
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<tbody>
<tr>
<td>1-2 days</td>
<td>Highly active volcanoes</td>
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<tr>
<td>3 days</td>
<td>Fast subsidence</td>
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<tr>
<td>6 days</td>
<td>Short growth cycle, intensive agriculture</td>
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<td>12 days</td>
<td>Fast changing wetlands</td>
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<td>Fast moving outlet glaciers</td>
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<td>Permafrost &amp; glaciers</td>
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**REFERENCE DATA SITES (6th repeat)**

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**Sentinel-1 Constellation Observation Scenario:**
**Mode - Polarisation - Observation Geometry**

**Polarisation Schema**

- VH or H-HV
- HH or H-HV

**Mode / Polarisation**

- SM mode / dual-polarisation
- SM mode / single-polarisation
- EW mode / dual-polarisation
- EW mode / single-polarisation
- Calibration Site (locally different modes or polarisations possible)

**PASS**

- ASCENDING
- DESCENDING
Sentinel-1 Soil Moisture: Model Building

Machine Learning (Support Vector Regression) for soil moisture retrieval

Datasets

- SAR Backscatter
- Sentinel-1 single-pol 20 m
- Optical imagery
- Sentinel-2 MSI 10-20 m
- Ancillary Dataset
- S2 based land-cover classification 20 m
- In-situ TDR measurements
Method – Model Training

Building a data driven estimation model based on a Support Vector Regression Method

- \( \sigma_0 \)
- Local Incidence Angle
- Visible bands (2,3,4)
- Red-edge bands (5,6,7)
- NIR band (8)

- Modelling non-linear, multi-dimensional problems:
- Minimize: \( \frac{1}{2} w^2 + C \sum_{i=1}^{N} (\xi_i + \xi_i^*) \)
- Optimization of the free parameters

Method – Model Training

With the trained model soil moisture can be estimated for unseen samples

Model Validation

- S1
  - RMSE: 7.68
  - R: 0.698

- S1+LIA
  - RMSE: 7.46
  - R: 0.706

- S1+LIA+LC
  - RMSE: 5.18
  - R: 0.881

- S1+LIA+S2
  - RMSE: 5.06
  - R: 0.884

- S2 cloud-free composite

- S2
  - RMSE: 3.48
  - R: 0.94

- S1+LIA+S2
  - RMSE: 3.07
  - R: 0.955

- S1+LIA+S2+LC
  - RMSE: 3.32
  - R: 0.948
Model Validation: Mapping

Soil Moisture map of Kajiado – August 16, 2016

S1 + S2 (cloud-free composite)
Soil Moisture Estimation

Soil moisture time-series 1

Soil moisture time-series 2

Soil Moisture: Uasin Gishu/Elgeyo Marakwet
October 3, 2016
Soil Moisture Estimation

Soil moisture time-series 1

Soil moisture time-series 2
Conclusions

- Support Vector Regression allows to establish an accurate retrieval model
- The quality of training data is of high importance
- It is not possible to estimate the surface soil moisture content based on single-pol backscatter measurements alone
- We were able to show that Sentinel-2 leads to an improvement, mainly due to its relationship with land cover
- We can use a cloud-free Sentinel-2 composite
- The Sentinel-1 acquisition scheme presents a major limitation for the application over Kenya and Africa in general
Next steps ...

- Upscale both temporally and spatially (from local test sites to a national or regional scale)
- Link the soil moisture content to other phenomena like droughts, agricultural yield or natural hazards
- Work towards the robust detection of anomalies
- The combination with other soil moisture products
Thank you for your attention!