



Improved soil moisture estimation with Sentinel-1 for arable land at the field scale

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Summary

This presentation describes an approach to retrieve a useful field-scale soil moisture estimate from Sentinel-1 C-band SAR at times when the vegetation in the field is growing so rapidly that the radar does not directly measure soil moisture as it cannot penetrate the canopy. The approach is a two-dimensional interpolation solution, building on the change detection method, which gives good results. This plugs a significant gap in the capability for remote sensing of soil moisture in the main growing season, for the benefit of farmers and agronomists.

If you have any suggestions or further questions then please contact me via email at john.e.beale@cranfield.ac.uk.



Outline

- 1 Introduction
- 2 Materials and Methods
- 3 Results
- 4 Conclusions
- 5 Recommendations
- 6 Acknowledgements and References

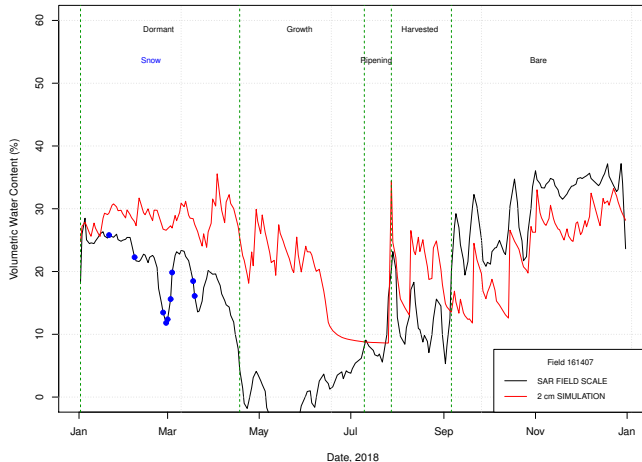


Introduction

- SAR data from satellites, such as ESA's Sentinel-1, are being exploited to estimate surface soil moisture (SM) at scale
- Change detection (CD) algorithms [1, 2, 3, 4], do not need model training or *a priori* information
- CD assumptions are not valid for arable fields [5, 6, 7]; typical errors in volumetric water content (VWC) are [8, 9]:
 - ▶ Up to 20 vol.% during the crop main growth period
 - ▶ 4 to 10 vol.% when the soil is bare
- Limited benefit to agriculture (5 vol.% desired)
- A new method of Inverse Distance and Confidence Weighting (IDCW) is proposed for implementing CD at field-scale that is effective for arable crops at all times of year

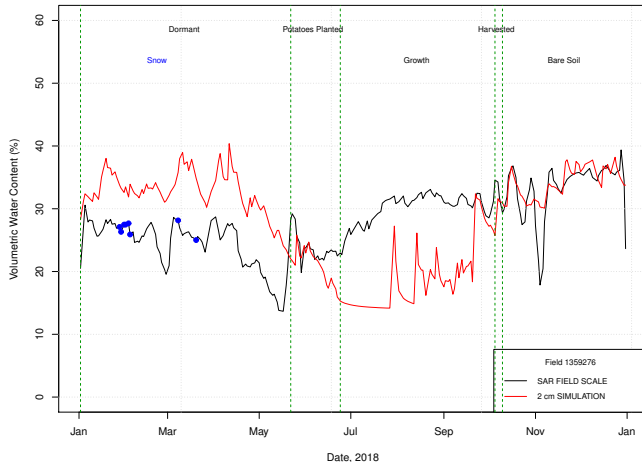
Arable Field Performance of CD Algorithm - Example 1

- Winter wheat field time series plot 2018 (#161407 at Fincham)
 - ▶ Field Scale SM estimate by CD (black)
 - ▶ 2 cm SM (red)
 - ▶ Crop and tillage activities - vertical, dotted, green lines
 - ▶ Blue dots - days of snow or ice
- CD estimate very low in spring/early summer
- Good match after ploughing (bare soil)



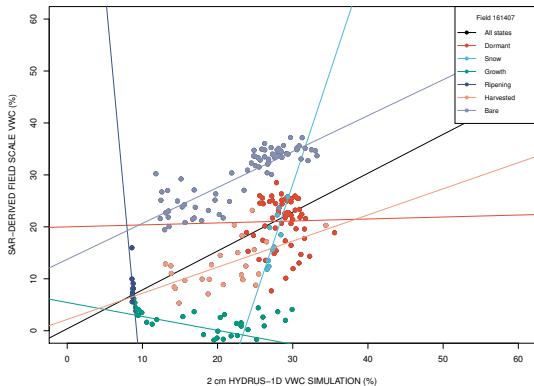
Arable Field Performance of CD Algorithm - Example 2

- Potato field time series plot 2018 (#1359276 at Spen Farm)
 - ▶ Field Scale SM estimate by CD (black)
 - ▶ 2 cm SM (red)
 - ▶ Crop and tillage activities - vertical, dotted, green lines
 - ▶ Blue dots - days of snow or ice
- CD estimate very high in summer
- Good match after harvesting (bare soil)

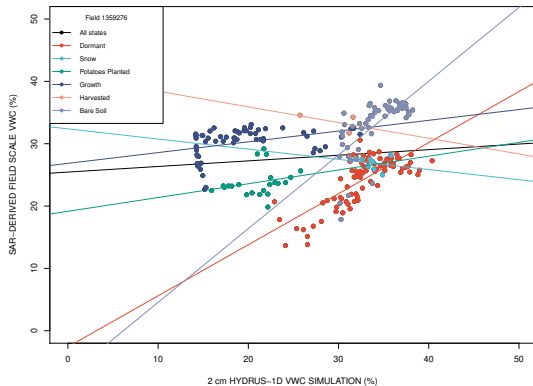


Arable Field Performance of CD Algorithm - Regression

Winter Wheat



Potatoes



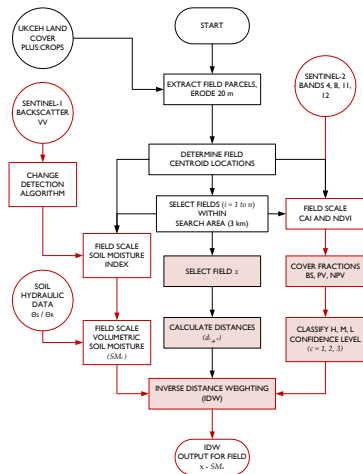
Arable Fields Summary of Performance

Crop Type	Year Round	Winter Dormancy	Growth Phase	Ripening	Post-harvest/Cut	Bare Soil
Winter Wheat (Trad. Till)	LOW	LOW	NONE	LOW	MEDIUM	HIGH
Winter Wheat (Min. Till)	MEDIUM	MEDIUM	LOW	MEDIUM	MEDIUM	HIGH
Oil-seed Rape	MEDIUM	LOW	NONE	NONE	MEDIUM	MEDIUM
Grass (Pasture)	HIGH					
Grass (Ley)	LOW	HIGH	LOW		HIGH	
Potatoes	LOW	HIGH	LOW		LOW	

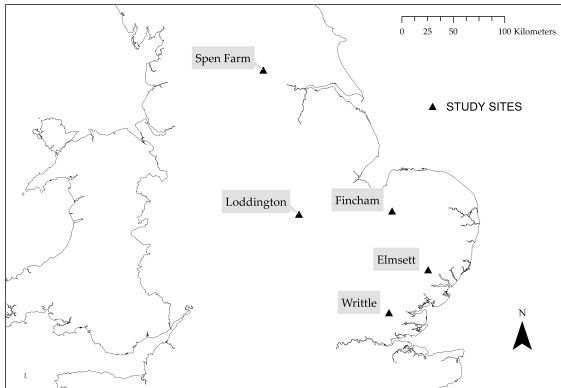
- Using C-band Sentinel-1 SAR data, CD has no capability to estimate SM in most arable crops at a crucial time of crop development
- An alternative strategy must be found to provide a soil moisture capability during these periods.

Materials and Methods

- Field geospatial information
 - ▶ Boundaries (erode 20 m)
 - ▶ Centroid locations
- Classify by CD confidence level, c
- Field-scale SM estimate, SM_i , by CD
- Spatial interpolation and confidence weighting
- Alternative field-scale SM estimate SM_x for field x



Test Sites



- Five test sites

- ▶ Arable farming
- ▶ Locations within the COSMOS-UK network [10]
- ▶ Soil hydraulic parameters and 2 cm soil moisture profiles for 2018 were calculated for Beale et al. [9]

- Processing extents (at each site)

- ▶ 3 km for IDCW (> 100 fields at each test site)
- ▶ 5 km for Sentine1-1 and Sentinel-2 analysis
- ▶ 8 to 10 assessment fields selected

- UKCEH Land Cover Plus:Crops 2018 [11] (LCPC) for field boundaries - eroded by 20 m to exclude field margins, hedges and buildings
- Field scale SM derived from C-band SAR (Sentinel-1 GRD Level 1 IW VV) using CD algorithm [3, 4] implemented in Google Earth Engine (GEE), and scaled to volumetric SM [9].
- Sentinel-2 Level 2 MSI data for confidence level assessment
- Reference soil moisture at 2 cm depth [9]

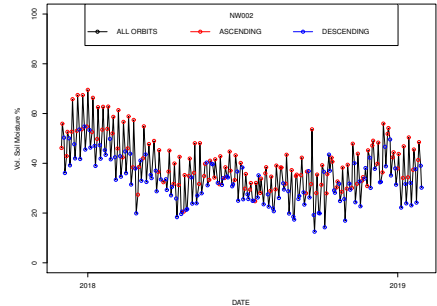
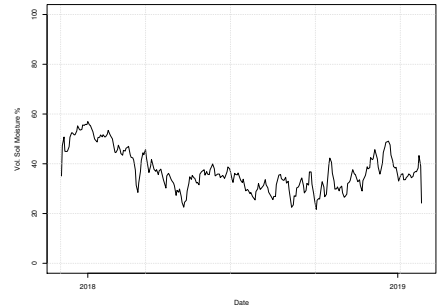


Filtering of field-scale SAR-derived SM

Potential causes

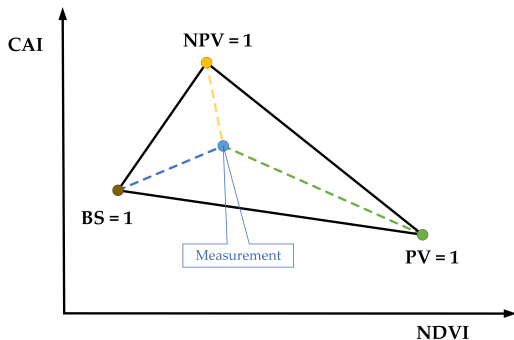
- The presence of scattering centres
- Structured soil surface roughness
- Errors in normalisation of backscatter
- SM differences due to times of day
- Layover affects

After smoothing Savitzky-Golay filtering
(window of 7, 3rd order)



CD confidence level classification (1)

- Based the relative fractional land cover of bare soil (BS), photosynthetically active vegetation (PV) and non-photosynthetically active vegetation (NPV)
- Triangle space method adapted from Yue and Tian [12]



Vegetation indices – Sentinel-2 bands

$$NDVI = \frac{(NIR - red)}{(NIR + red)} = \frac{(B8 - B4)}{(B8 + B4)}$$

Surrogate of Cellulose Absorption Index (CAI) [13]
proposed for Sentinel-2 [14]:

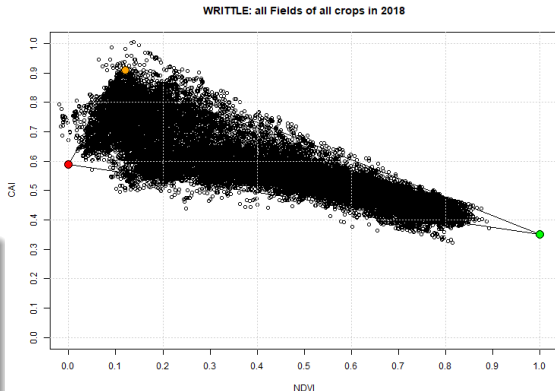
$$CAI^* = \frac{B12}{B11}$$

CD confidence level classification (2)

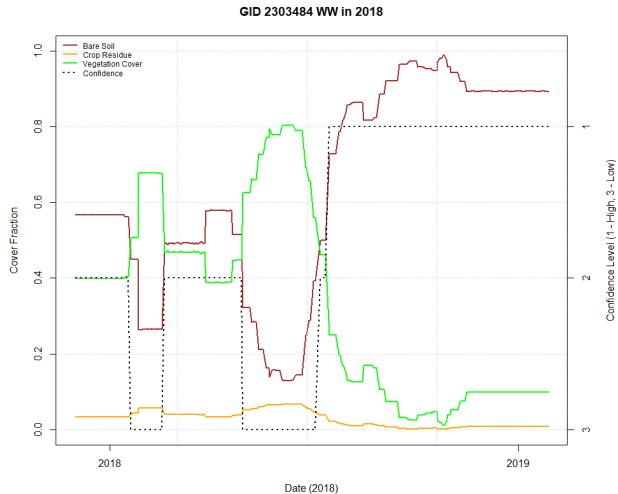
- Cover fractions established by spectral unmixing
- End member determination by scatter plot of all CAI/NDVI pairs at each site
- Confidence level assigned as below

Classification scheme

Class, c	Confidence Level	BS	NPV	PV	Logic
1	HIGH	> 0.6	< 0.2	< 0.3	AND
2	MEDIUM	> 0.4	< 0.2	< 0.5	AND
3	LOW	≤ 0.4	≥ 0.2	≥ 0.5	OR



Example: winter wheat field (2303484) at Fincham in 2018

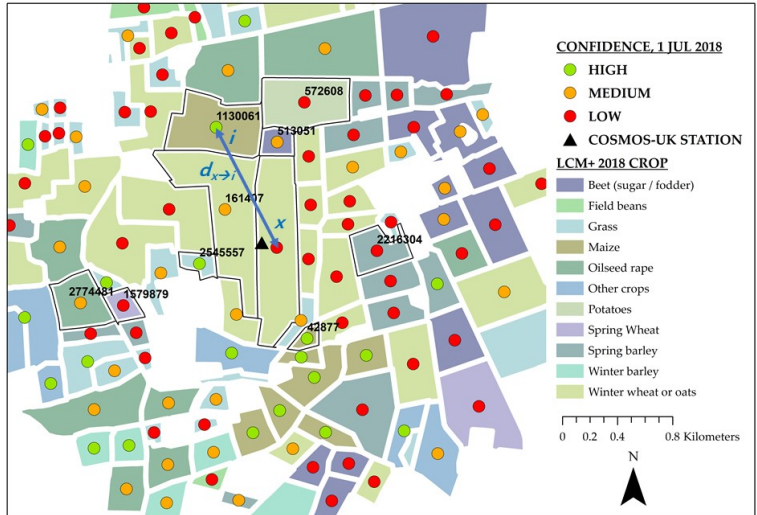


Spatial interpolation algorithm

Inverse distance and confidence weighting (IDCW)

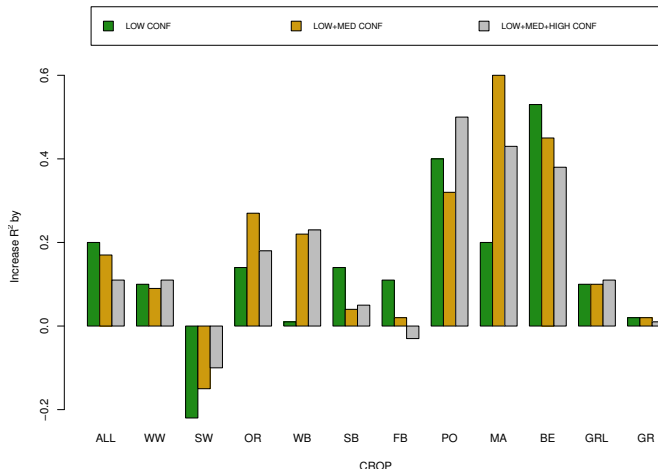
$$SM_x = \frac{\sum_{i=1}^n \frac{SM_i}{|d_{i \rightarrow x}|^{p * c_i^q}}}{\sum_{i=1}^n \frac{1}{|d_{i \rightarrow x}|^{p * c_i^q}}}$$

Based on IDW [15]



Results (1)

Increase in coefficient of determination, R^2

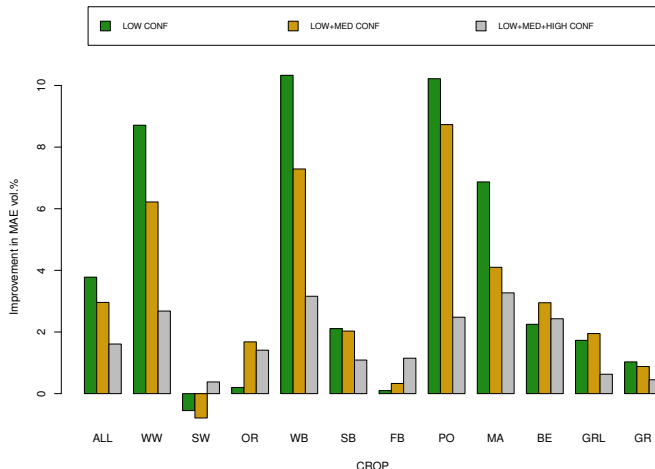


Key to crop types

- ALL all crops
- WW winter wheat
- SW spring wheat
- OR oil-seed rape
- WB winter barley
- SB spring barley
- FB field beans
- PO potatoes
- BE beet
- GRL ley grass
- GR grass (not ley)

Results (2)

Reduction of mean absolute error, *MAE*



Key to crop types

- ALL all crops
- WW winter wheat
- SW spring wheat
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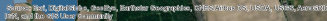
Results (3) - Benefits of IDCW to the accuracy of field-scale, SAR-derived surface SM

Crop	Period of confidence level:			Headline
	All Year	Low	Low/Medium	
All	▲	▲	▲	
Oil-Seed Rape	▲	□	▲	MAE down from 7.42 vol.% to 6.01 vol.% over the whole year
Winter Wheat	▲	▲▲	▲▲	For LOW confidence MAE down from 16.1 vol.% to 7.39 vol.%
Spring Wheat	□	▽	▽	Reduction in R^2
Winter Barley	▲	▲▲	▲▲	MAE down from 20.5 vol.% to 10 vol.% in low conf.
Spring Barley	▲	▲	▲	R^2 up from 0.39 to 0.53 in low conf.
Field Beans	□	□	□	No benefit
Potatoes	▲▲	▲▲	▲▲	MAE down from 15 vol.% to 4.7 vol.% in low conf.
Maize	▲▲	▲▲	▲▲	MAE down from 11.5 vol.% to 4.5 vol.% in low conf.
Beet	▲	▲	▲▲	R^2 up from 0.09 to 0.62 in low conf.
Ley Grass	□	▲	▲	MAE down from 10 vol.% to 8 vol.% in low conf.
Grass	□	□	□	No benefit

▲▲ = Large benefit, ▲ = Small benefit, □ = No benefit, ▽ = Small disbenefit.



SM values derived from
Sentinel-1 C-band SAR by
field-scale CD followed by
IDCW



Conclusions

- Field-scale arable crop performance of CD for SM estimation from Sentinel-1 SAR data is a function of crop canopy development and tillage state
- SM estimation errors of up 20 vol.% were found during the peak growth period
- The proposed automated process based on spectral vegetation indices is effective at identifying these periods of poor performance
- The proposed IDCW is effective for arable crops at all times of year, reducing errors to 5 vol.% as required for agricultural use [16]
- IDCW benefit is greatest for autumn-sown cereal crops
- These methods require no model training or *a-priori* knowledge of land use and crop type

The output from this study is a step towards providing a useful and reliable field-scale soil moisture product that works as well on arable fields as it does for other land uses



Recommendations

The proposed method is capable of further refinement and enhancements

- Extension to consider landscape heterogeneity/topography
- Modify interpolation according to soil maps and rainfall radar
- Use SAR data to identify periods of poor performance
- Find a solution to differentiate between grazed grass fields and ley grass



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