Sentinel-1 data of agricultural fields in the Netherlands (Twente)

1. Introduction

Local users (e.g. regional water managers and farmers) would benefit from fine resolution soil moisture products. With Synthetic Aperture Radar (SAR) a fine resolution soil moisture product can be obtained, which would complement the currently available coarse resolution soil moisture products. Sentinel-1 is a new satellite mission that provides images with a high spatiotemporal resolution, a high radiometric accuracy and dual-polarization data. Sensitivity to soil moisture changes is essential to retrieve soil moisture states from the Sentinel-1 data.

Objective: Investigate the sensitivity of Sentinel-1 backscatter to surface soil moisture content and vegetation conditions.

2. Methodology

A. Pre-processing and sensitivity analysis

The Sentinel-1 data characteristics are summarized in Table 1.

Table 1: Characteristics of the Sentinel-1 Interferometric Wide Swath level-1 High resolution mode (Sentinel-1 Team, 2013)

Characteristic	Interferometric Wide Swath (IW) High resolution
Polarizations	VV+VH
Wavelength	C-band (5.405 GHz)
Pixel spacing	10 m × 10 m
Temporal resolution	~3-6 days
Incidence angle range	29.1° - 46°
Maximum Noise Equivalent Sigma Zero (NESZ)	-22 dB
First image for study area	3 Oct 2014
Number of images available	105 (between 3-10-2014 and 31-12-2015)

Figure 1 presents the pre-processing and sensitivity analysis procedure. Backscatter is plotted against soil moisture and vegetation conditions for one hydrological year and one growing season (1-10-2014 – 30-9-2015), because otherwise wet soil moisture conditions and bare/low vegetation conditions would be overrepresented.

B. Study area and ancillary vegetation data

In-situ soil moisture measurements at 5 cm depth collected from the Twente soil moisture monitoring network in the Netherlands (Figure 2) are used as reference. The Twente area is almost flat and has a heterogeneous landscape, including agricultural (mainly grass, cereal and corn), forested and urban land covers. The soil is mainly sand and loamy sand (Dente et al., 2011). Only 5 of the 20 stations could be used, because of major data gaps and inappropriate locations in the period from 1-10-2014 to 30-9-2015. Normalized Difference Vegetation Index (NDVI) data from Groenmonitor (www.groenmonitor.nl) are used as proxy for seasonal vegetation dynamics.

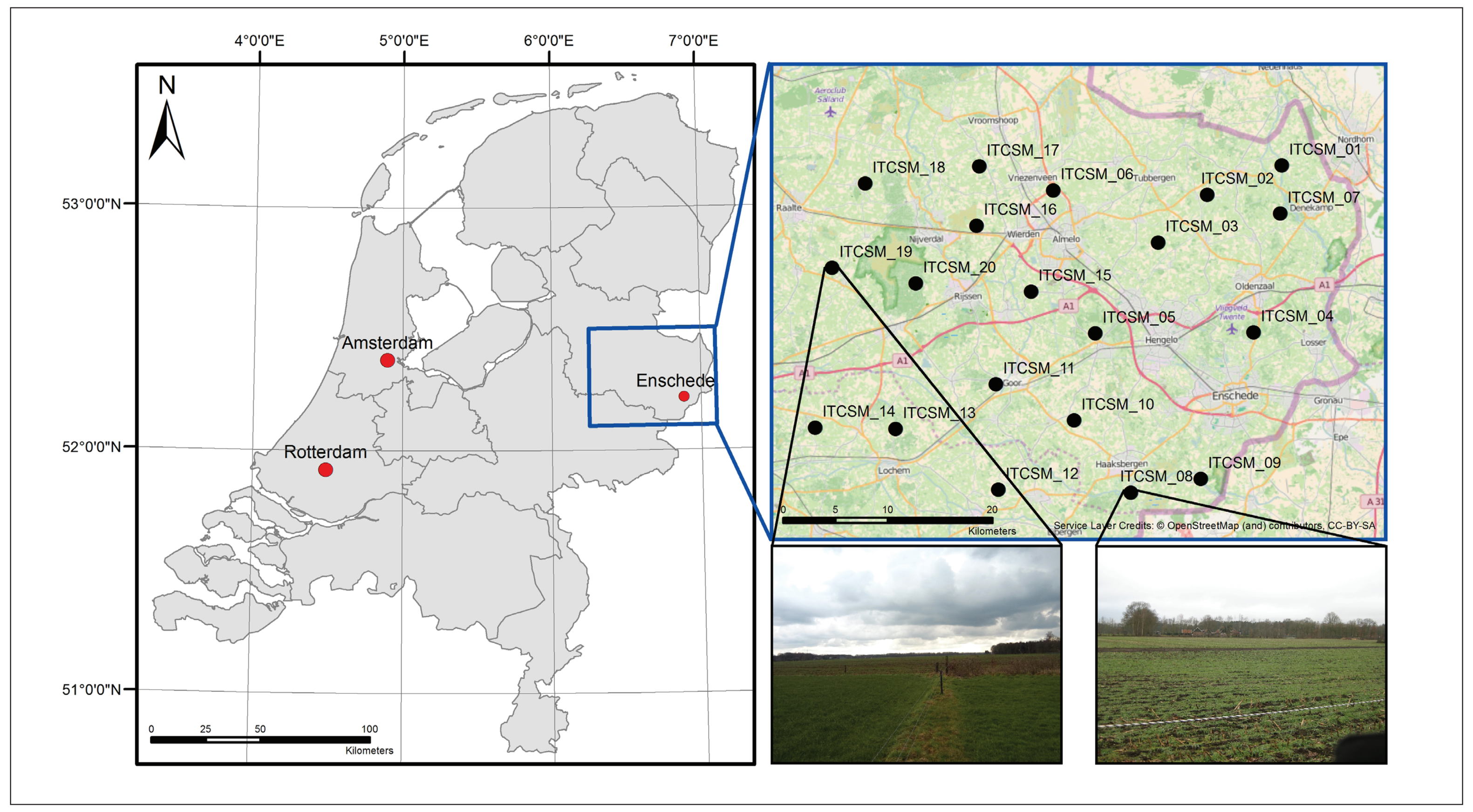

Figure 2: Locations of the soil moisture monitoring stations in the Twente area and photographs of typical pastures (19: 2 fields with grass and 1 field with corn (in winter) and 8: field with corn in winter)

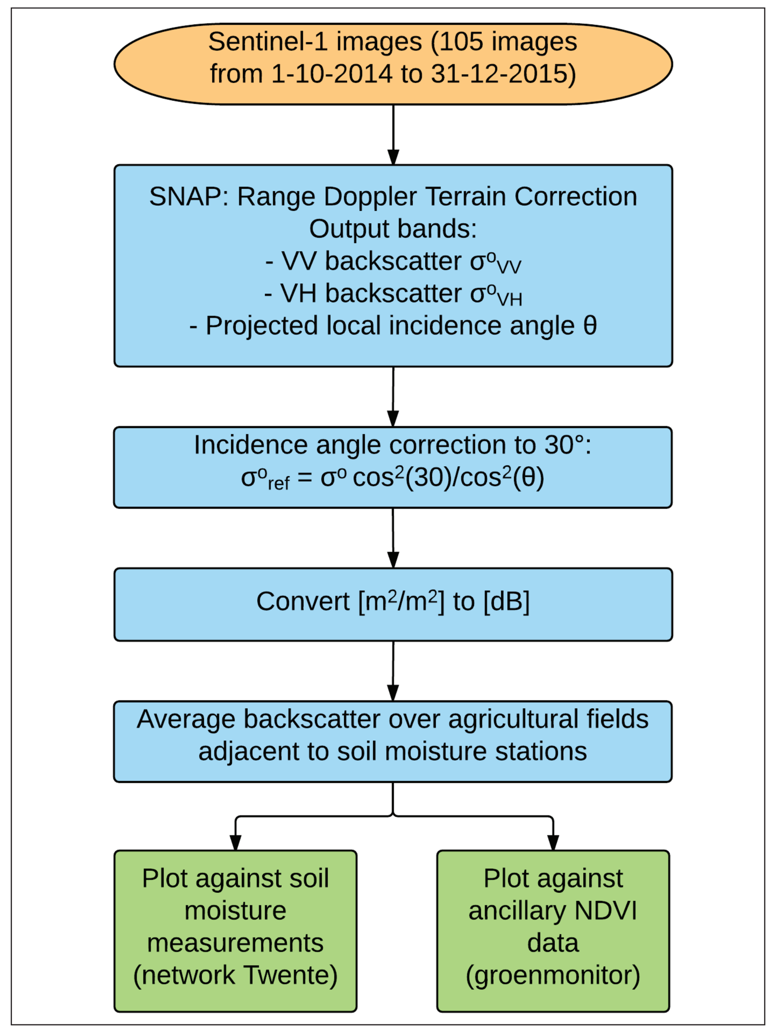

Figure 1: Pre-processing and sensitivity analysis procedure

3. Results

Figure 3: Development of backscatter and soil moisture (wheat field)

- VV backscatter: sensitive to soil moisture.
- VH backscatter: less sensitive to soil moisture. More determined by other effects?
- What is the reason for the peaks?

Figure 4: Development of backscatter and vegetation (wheat field)

- VV backscatter: decreasing with increasing vegetation.
- VH backscatter: increasing with increasing vegetation.

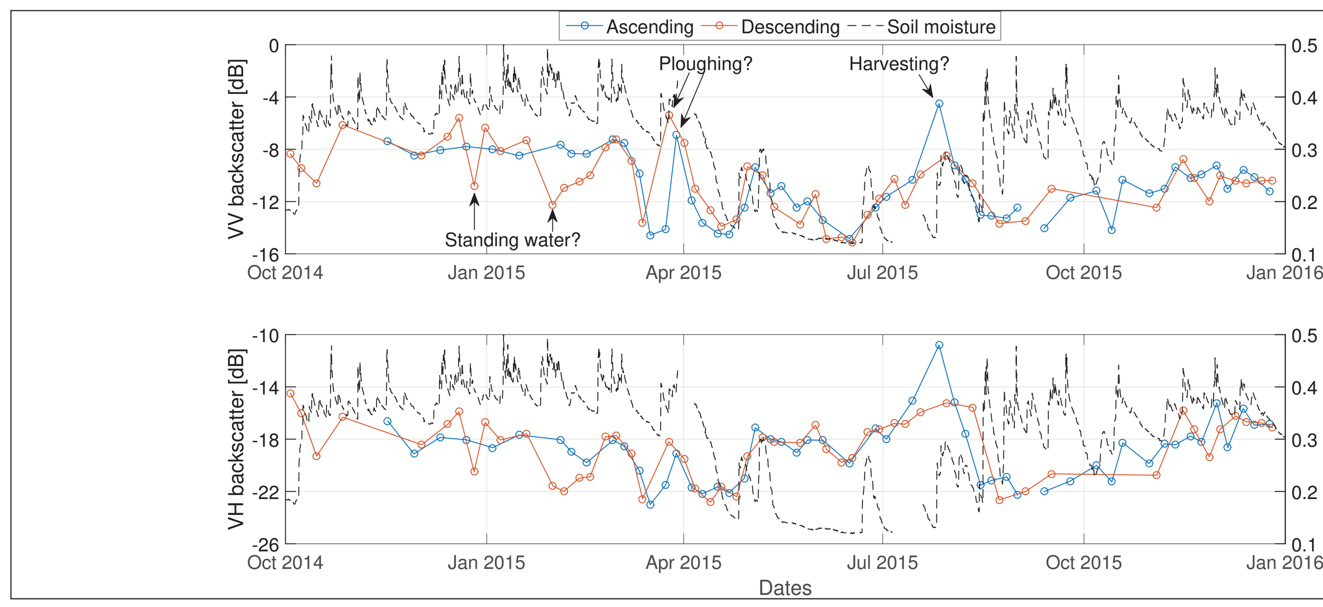

Figure 3: VV and VH backscatter development analogous to soil moisture for the agricultural field adjacent to ITCSM_09 with wheat cover

Figure 5 & Table 2: Sensitivity of backscatter to soil moisture

- VV backscatter
  - o Grass: clearly sensitive to soil moisture, but with large differences among fields.
  - o Wheat: sensitive to soil moisture, but large outliers occur.
- VH backscatter
  - o Generally: less sensitive to soil moisture and lower R^2 than VV.
  - o Wheat: large spread among data points, suggesting that other factors have larger impact than soil moisture.

Figure 6 & Table 3: Sensitivity of backscatter to NDVI

- VV backscatter
  - o Generally: clearly sensitive, decreasing with increasing vegetation.
- VH backscatter
  - o Grass: vegetation effect less well defined.
  - o Wheat: backscatter increases with increasing vegetation.
- Polarization ratio
  - o Generally: decreases with increasing vegetation for all fields, with comparable slopes.

The low R^2 and varying slopes indicate that the relationships contain large uncertainties. This is due to several effects, including roughness changes, response to vegetation/soil moisture dynamics, standing water, speckle, varying angular responses, and uncertainty in backscatter and soil moisture measurements.

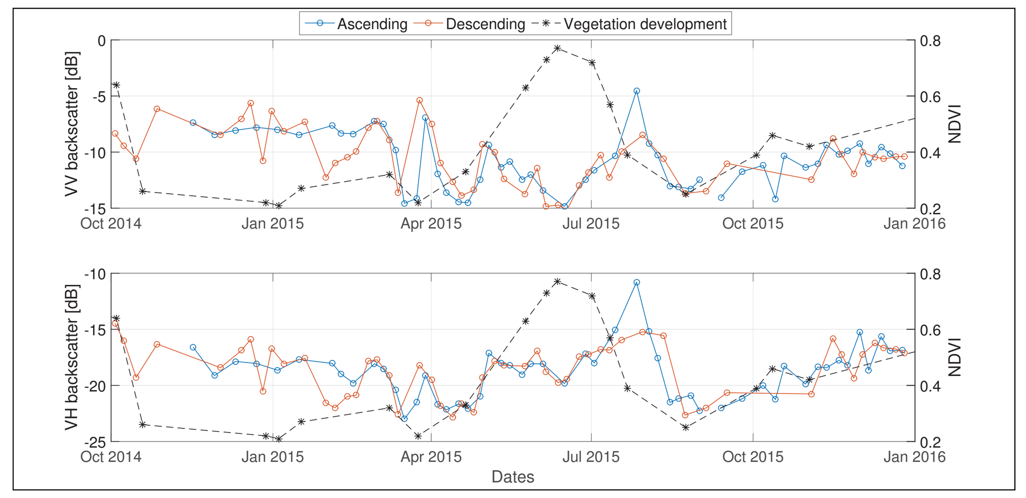

Figure 4: VV and VH backscatter development analogous to NDVI for the agricultural field adjacent to ITCSM_09 with wheat cover

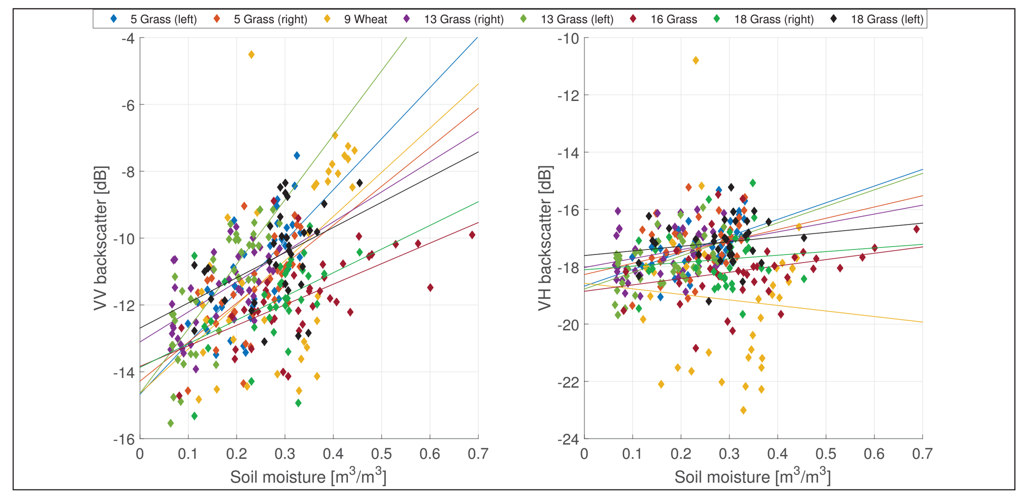

Figure 5: Sensitivity of backscatter (ascending orbit images) to soil moisture measurements. The slopes and coefficients of determination of the regression lines are presented in Table 2.

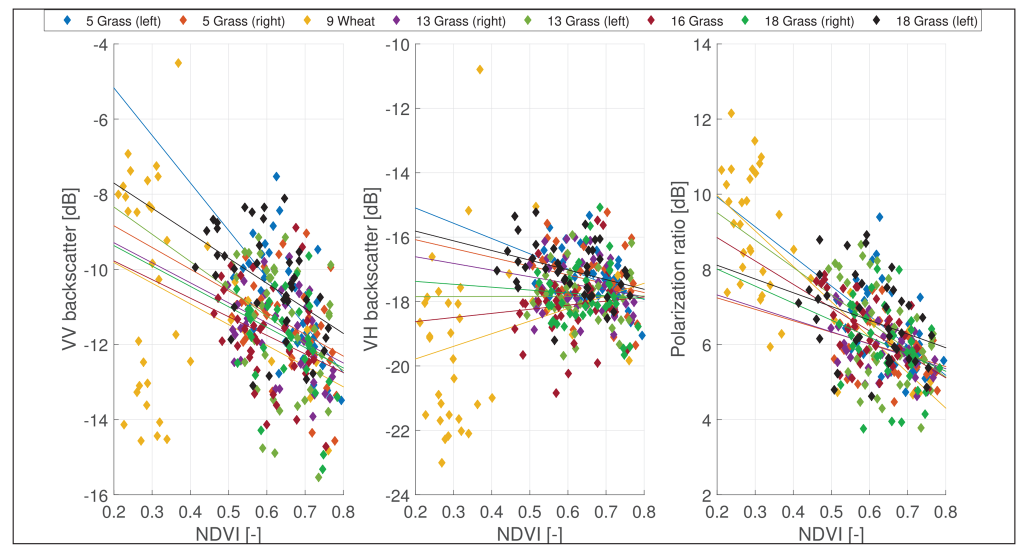

Figure 6: Sensitivity of backscatter (ascending orbit images) to ancillary NDVI information. The slopes and coefficients of determination of the regression lines are presented in Table 3.

Table 2: Slope and coefficients of determination (R^2) of the regression lines in Figure 5

		VV ascending		VV descending		VH ascending		VH descending	
		Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
ITCSM_5	Grass (left field)	15.29	0.48	5.12	0.14	5.82	0.25	1.05	0.01
ITCSM_5	Grass (right field)	11.66	0.38	11.42	0.46	3.93	0.08	4.44	0.12
ITCSM_9	Wheat	13.22	0.27	17.20	0.41	-1.93	0.01	-1.43	0.00
ITCSM_13	Grass (right field)	8.98	0.34	6.99	0.34	3.11	0.07	2.56	0.05
ITCSM_13	Grass (left field)	19.31	0.66	13.93	0.64	5.77	0.25	2.94	0.07
ITCSM_16	Grass	6.15	0.37	6.53	0.47	2.21	0.07	2.07	0.12
ITCSM_18	Grass (right field)	7.08	0.19	6.57	0.14	1.27	0.01	3.08	0.05
ITCSM_18	Grass (left field)	7.53	0.19	4.42	0.09	1.62	0.03	-0.15	0.00

Table 3: Slope and coefficients of determination (R^2) of the regression lines in Figure 6

		VV ascending		VV descending		VH ascending		VH descending		PR ascending		PR descending	
		Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
ITCSM_5	Grass (left field)	-12.64	0.39	-4.70	0.13	-4.74	0.20	-1.01	0.01	-7.90	0.28	-3.69	0.16
ITCSM_5	Grass (right field)	-5.78	0.16	-5.42	0.15	-2.73	0.06	-2.19	0.04	-3.05	0.13	-3.23	0.11
ITCSM_9	Wheat	-5.52	0.11	-7.88	0.28	3.92	0.07	3.66	0.08	-9.43	0.56	-11.54	0.73
ITCSM_12	Corn	6.62	0.25	2.00	0.02	10.99	0.55	10.33	0.50	-4.36	0.24	-8.33	0.37
ITCSM_13	Grass (right field)	-5.34	0.15	-3.57	0.11	-2.06	0.04	-0.64	0.00	-3.27	0.17	-2.92	0.10
ITCSM_13	Grass (left field)	-7.26	0.11	-6.46	0.14	0.03	0.00	1.30	0.01	-7.29	0.21	-7.75	0.29
ITCSM_16	Grass	-4.95	0.10	-7.07	0.18	1.27	0.01	-0.60	0.00	-6.22	0.33	-6.47	0.22
ITCSM_18	Grass (right field)	-5.43	0.10	-4.37	0.06	-0.90	0.00	-1.28	0.01	-4.53	0.10	-3.08	0.05
ITCSM_18	Grass (left field)	-6.67	0.22	-5.04	0.21	-3.01	0.12	-1.49	0.03	-3.66	0.09	-3.55	0.14

4. Conclusions and outlook

The results provide insight into the potential of Sentinel-1 data to quantify vegetation and soil moisture states. The sensitivity of backscatter to soil moisture is noticeable but weak, because the effects of vegetation dynamics, surface roughness and standing water are not considered yet. The research should be extended to other crop types, especially corn and potatoes. The research is continued with the testing of three promising methods, namely a data-driven algorithm, a radiative transfer model and a downscaling algorithm.

The objective of the research is to develop an operationally applicable method to estimate surface soil moisture from Sentinel-1 data over the dominant agricultural crop types in the Netherlands.

The research is part of the OWAS1S project (Optimizing Water Availability with Sentinel 1 Satellites). The OWAS1S project stands for integration of the freely available global Sentinel-1 data and local knowledge on soil physical processes to optimize water management of regional water systems and to develop value-added products for agriculture.

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