TWENTE

SOIL MOISTURE AND SOIL TEMPERATURE

MONITORING NETWORK

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Twente soil moisture and soil temperature monitoring network

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1 INTRODUCTION

Soil moisture is a key variable in land surface processes playing a crucial role in the water cycle. A good description of the temporal and spatial variability of soil moisture allows to better understand all these processes at regional and sub-continental scale. So far it has been demonstrated that passive and active microwave sensors on satellite platform have relevant capabilities to monitor soil moisture. Recently the first attempts were made to obtain global soil moisture maps from radiometer and scatterometer data and to operationally use these products, for example AMSR-E, ASCAT and SMOS soil moisture products. Satellite data with a coarse resolution are more suitable for large scale soil moisture monitoring because they are characterised by a larger swath and a higher revisit time (i.e. 30-50 km resolution and 2-3 days revisit time) than the fine resolution data (i.e. resolution lower than 150 m and revisit time longer than 35 days). However, the validation of the soil moisture products retrieved from the coarse resolution sensors is a critical issue because of the large scale gap between in-situ soil moisture measurements and soil moisture estimates at 30-50 km spatial resolution and due to the typically high spatial variability of soil moisture.

For this reason, extensive soil moisture monitoring networks and techniques to upscale in situ data to the resolution cell of the satellite sensors are required to obtain ground information which can be compared to the retrieved soil moisture products and to evaluate their consistency.

To tackle this validation problem, a soil moisture monitoring network has been installed in the Twente region of The Netherlands, consisting of 20 stations continuously measuring soil moisture and soil temperature over an area of approximately 50 km * 40 km.

The main objective of Twente monitoring network are:

- to obtain a representative value of soil moisture in an area covering a typical resolution cell of satellite observations;
- to investigate the sensitivity of active and passive microwave data to surface parameters, such as soil moisture, soil temperature and vegetation cover;
- to run, calibrate and validate new soil moisture retrieval algorithms;
- to study new approaches to upscale soil moisture information from point to large scale;
- to validate SMOS (ESA), ASCAT (TU Wien), AMSR-E (VUA-NASA) and SMAP soil moisture products.

2 DESCRIPTION OF TWENTE SITE

The Twente soil moisture monitoring network is located in the east part of the Overijssel province in The Netherlands, covering the region called Twente, but also part of the Salland region and Gelderland province. A map of The Netherlands with Overijssel province and Twente region is shown in Figure 1, as well as a Google Earth image of the area covered by the network, where all the monitored sites are highlighted with blue circles and the main cities with red circles.

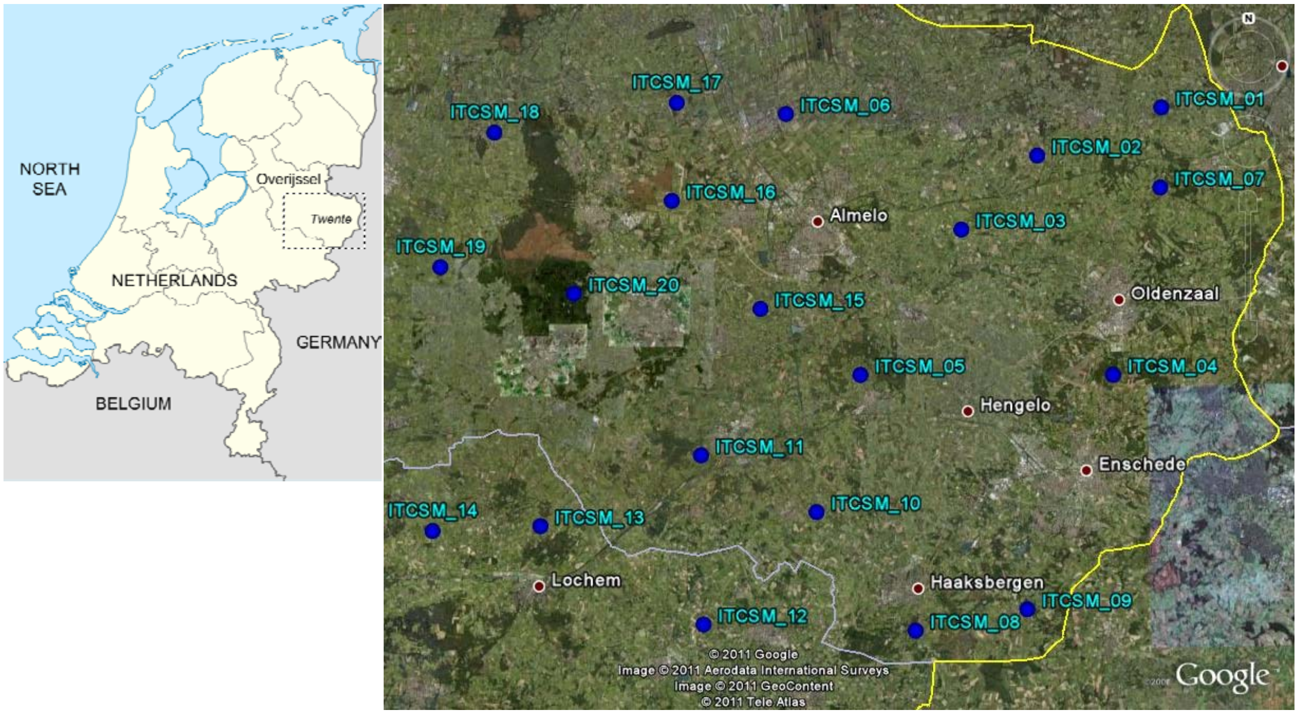

Figure 1 On the left: map of The Netherlands, where the location of Overijssel province, Twente region and soil moisture monitoring network (dashed rectangle) are highlighted. On the right: Google Earth image of the area covered by the network and monitored sites highlighted with blue circles.

20 soil moisture and soil temperature stations have been installed in approximately 50 km * 40 km large area (52°05' – 52°27'N, 6°05' – 7°00'E). The area is quite flat with an elevation ranging between -3 m to 50 m a.s.l. The most diffuse land cover is grassland for pasture which is harvested and fertilized several times in the year. However, the land use of this area includes a mosaic of agricultural fields, forest patches and several urban areas. As it is possible to see in the land use map (Figure 2) provided by the Province of Overijssel, at the website http://gisopenbaar.overijssel.nl/website/bodematlas/bodematlas.html, the main cultivation is corn, which is planted in April and harvested in September, but there are also fields of other cereals and potato.

According to the Koeppen Classification System, the climate in The Netherlands is temperate. Monthly average air temperature and monthly accumulated precipitation, averaged from 1974 to 2009, are shown in Figure 3. The data are provided by the Royal Netherlands Meteorological Institute (KNMI, http://www.knmi.nl/klimatologie/) and were collected at one station (named Twente) located in the Twente region near Enschede. The precipitation is spread all over the year with an average of approximately 760 mm per year. The monthly average air temperature ranges between 3°C in January to approximately 17°C in July.

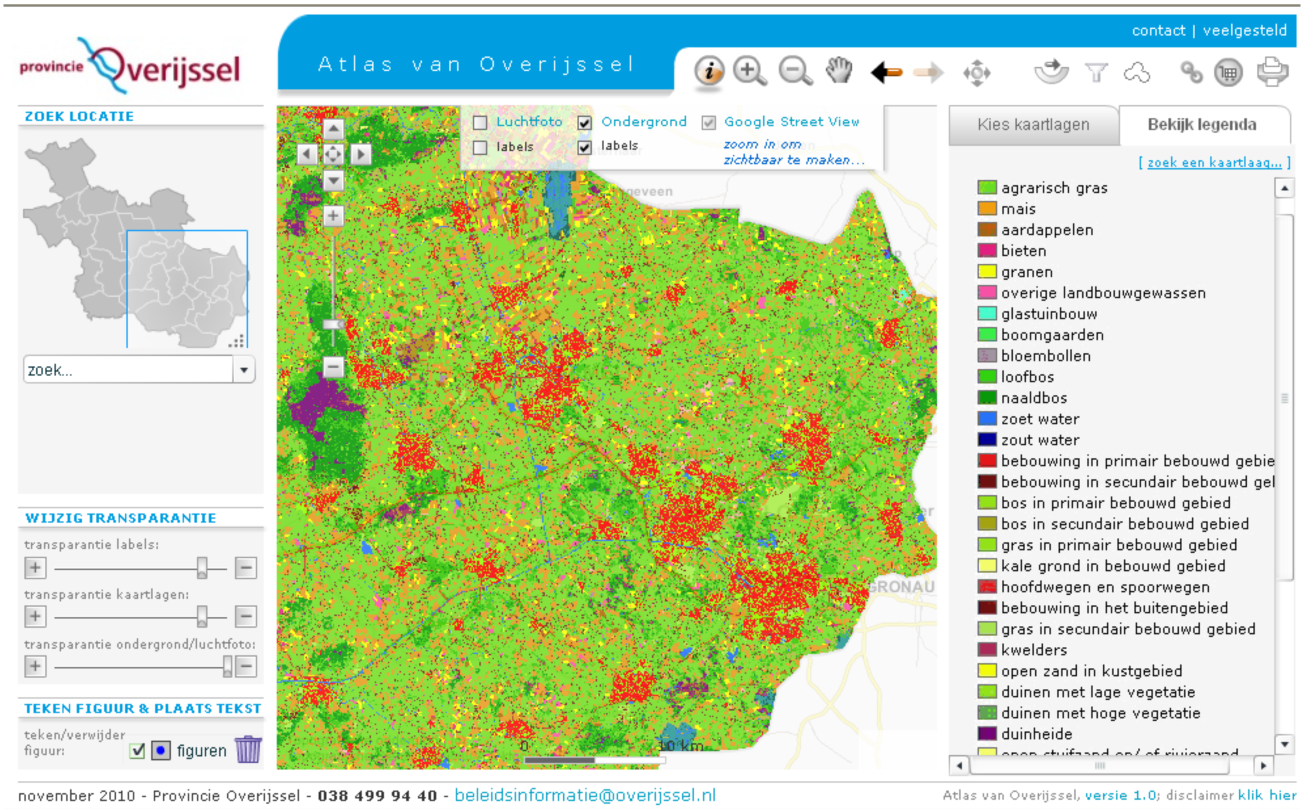

Figure 2 Land use map of Twente area available on the website of the Atlas of Overijssel by the Province of Overijssel http://gisopenbaar.overijssel.nl/website/bodematlas/bodematlas.html.

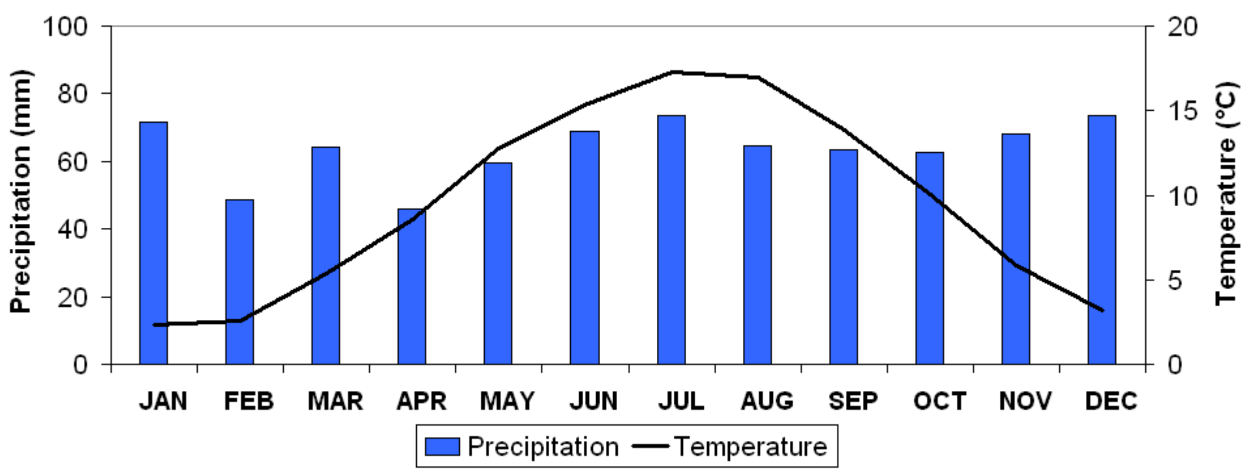

Figure 3 Monthly precipitation and air temperature at Twente site averaged over 35 years (from 1974 to 2009).

There are four main soil types in Twente: sandy soils rich or poor of loam, loamy soils rich or poor of sand, man-made sandy thick earth soils and peat soils covered by a layer of peat or sand. This information has been retrieved from the soil maps (Bodemkaart van Nederland) by Stichting voor Bodemkartering (Wageningen) with a 1:50000 scale and by Alterra, Wageningen WU, website www.bodemdata.nl. Figure 4 shows the soil map 1:50000 by Alterra of the area covered by the network. However, these different soil textures characterise the deeper layers of the soil and not the layer where the sensors are installed. At the soil layer near to the surface, i.e. from 0 to 40 cm depth, the soil is mainly sand and loamy sand (this information is based on the results of the soil particle distribution analyses carried out on soil samples collected at each site, as it will be explained later).

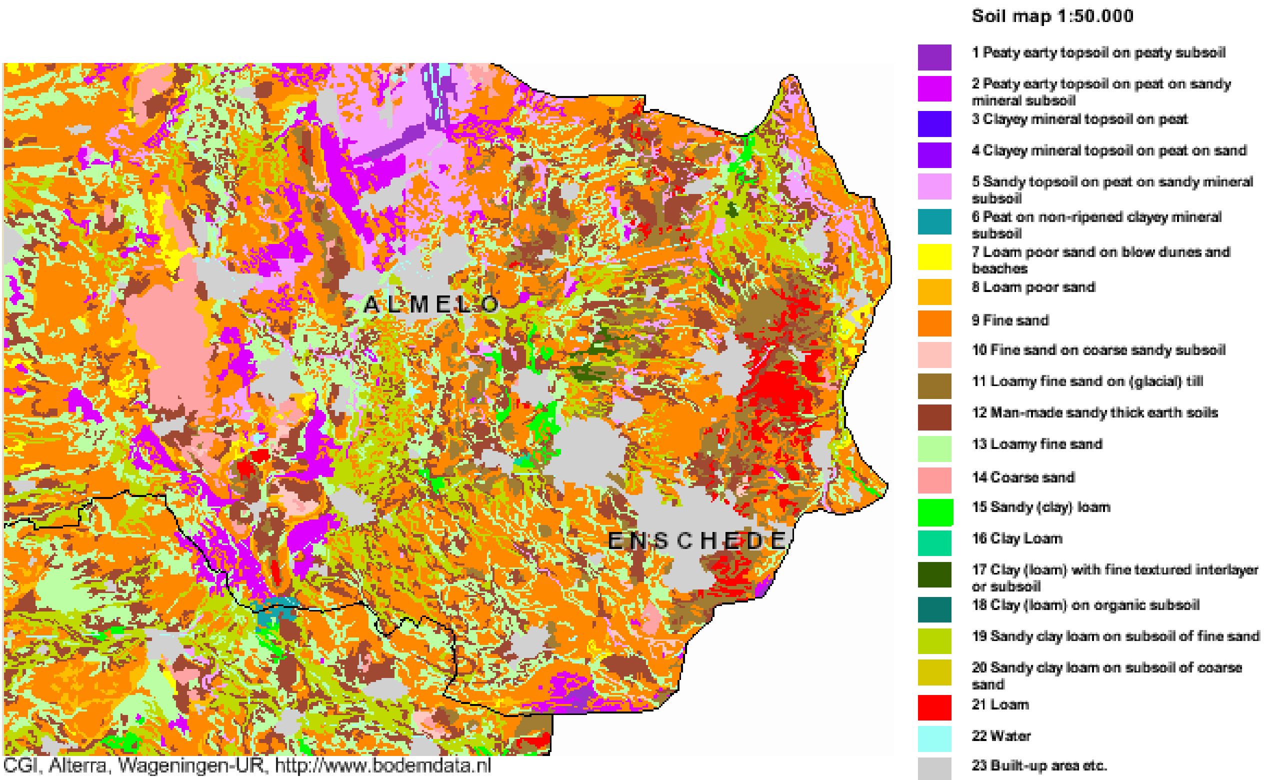

Figure 4 Soil map of Twente area available on Alterra (Wageningen UR) website www.bodemdata.nl

3 DESCRIPTION OF THE MONITORING NETWORK

The installation of the soil moisture and soil temperature monitoring stations started in November 2008 and was concluded in June 2009. Therefore, since July 2009 the complete network is operative. The 20 monitored sites are spread over an area of approximately 50 km * 40 km and they have been selected in order to monitor the area extensively including all the different soil types and all the land covers.

A Landsat 5 TM image acquired on 27 June 2010 over the network area is shown in Figure 2 (with band 7 in red, band 4 in green and band 2 in blue). The locations of all the monitored sites are indicated with white squares. The different colours show a different land use: urban areas in magenta, open water in blue, forest in olive-green, sandy areas in violet, bare soils, sparsely vegetated fields and agricultural fields in pink and bright green (the colour depends on the vegetation development stage).

16 stations have been installed in grassland fields, 3 in corn fields and 1 in a forest. Most of the stations are located at the border of the field (the border between two agricultural fields). The main reason for this choice, which is not optimal, is to put the stations in a safe place, where no land practice is carried out (i.e. ploughing and fertilizing). Only in two sites, ITCSM_02 and ITCSM_17, the measurements are collected at the border of the field near a ditch (NOTE: on 20 April 2011, the station ITCSM_17 has been moved in the same field on the border far from the ditch and renamed ITCSM_17b. At the time this report was written, there was the plan to move also station ITCSM_02). At the sites ITCSM_01, ITCSM_07, ITCSM_14 and ITCSM_16, as well as in the forest, the stations are located in the middle of the field and not at the border (NOTE: the station at site ITCSM_16 was operational until 23 November 2010 and was removed in May 2011). At the time this report was written, there was the plan to re-install the station in a different place of the same field). Figure 6 shows the landscape of all the sites in winter.

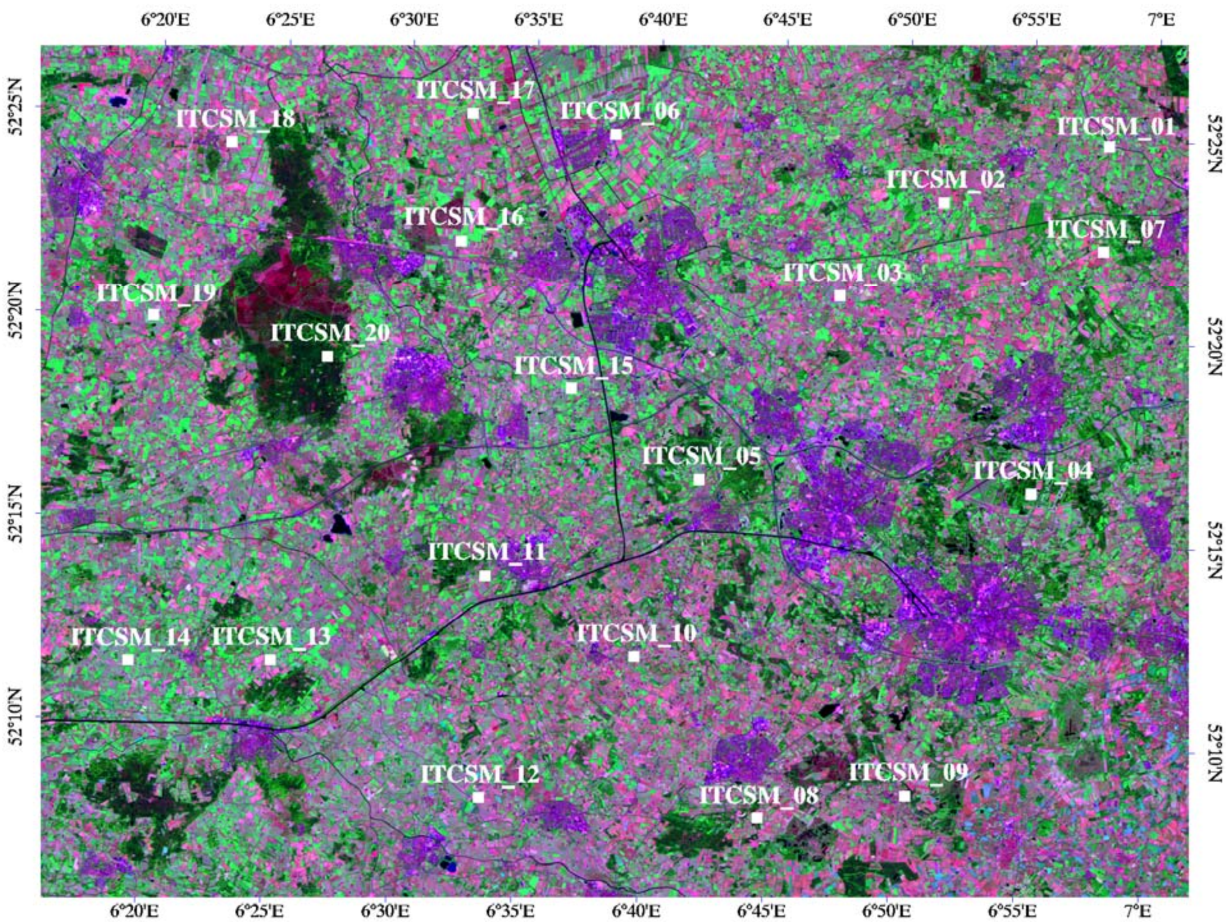

Figure 5 Landsat 5 TM image (RGB: band 7, band 4, band 2) acquired on 27 June 2010 over Twente monitoring network. The locations of the 20 monitored sites are highlighted with white squares.

Figure 6 Landscape at each site in winter.

During the installation, soil samples were collected in order to analyse bulk density and particle size distribution. Soil sample rings (aluminium cylinders of known volume) were collected at 5 cm depth and oven dried at 105°C to estimate the bulk density (i.e. dry soil mass in a known volume).
The samples for particle size analysis were collected at a depth between 5 and 20 cm. When the soil profile showed a variation at deeper layers, the sample collection and the analyses were repeated for the second horizon as well. The particle size distribution was analysed by means of the standard methods of sieving (by MSc Jiexia Wu at ITC soil laboratory).
Table 1 summarises all the information related to each site of the network and Figure 7 shows the different soils samples collected in situ.

According to the soil analysis carried out on the collected samples, 12 stations are installed in sandy soils and 7 in loamy sand soils (no data available for one site). The soil of this area is therefore characterized by a very low content of clay.

A soil texture map 1:50000 (Bodemkaart van Nederland by Stichting voor Bodemkartering, Wageningen) of the network area is also available, with a detailed description of the characteristics of the soil, at a depth larger than the measuring probes depth, and with an average height of the ground water level. According to this map 7 sites (ITCSM_08, ITCSM_10, ITCSM_13, ITCSM_15, ITCSM_17, ITCSM_19 and ITCSM_20) are characterised by fine sand; 3 sites (ITCSM_03, ITCSM_14, ITCSM_18) by loamy fine sand; 4 sites (ITCSM_02, ITCSM_05, ITCSM_09, ITCSM_11) by man-made sandy thick earth soil; 3 sites (ITCSM_01, ITCSM_07, ITCSM_12) by sandy clay loam on subsoil of fine sand; 2 sites (ITCSM_06 and ITCSM_16) by sandy topsoil on peat on sandy mineral subsoil; and 1 site (ITCSM_04) by loam.

Using the soil samples collected in the field, also the organic matter content has been estimated in ITC soil laboratory (by MSc Jiexia Wu) by means of the method by Walkley-Black. The analysis results are reported in Table 1. However, the results look not reliable (for example the organic matter of the forest should be very high, as the upper layer of the soil consists mainly of leaves and it is poor of soil particles).

Figure 7 Soil samples collected at each site between 5 and 20 cm depth.

Table 1 Network station information (station name, geographical coordinates, elevation a.s.l., date of installation, depth of probes, land cover (LC), soil texture at 5-20 cm depth (ST) from laboratory analyses, soil texture at deep layers from soil map 1:50000 (Bodemkaart van Nederland by Stichting voor Bodemkartering), organic matter content (OM), bulk density at 5 cm depth (BD), ground water table average height (see text for details)). NA stands for Not Available.

Station ID	Coord. (Lat/Lon)	Elev. (m)	Instal. date	Depth (cm)	LC	ST	ST from soil map 1:50000	OM g/kg	BD	GW
ITCSM_01	52°24'53" 6°58'2"	3	Dec 2008	5, 10, 20	Grass bush	NA	Sandy clay loam on subsoil of fine sand	NA	1.49	IV
ITCSM_02	52°23'24" 6°51'26"	28	Nov 2008	5, 10, 20	Grassland	Sand	Man-made sandy thick earth soil	52	1.13	VI
ITCSM_03	52°21'2" 6°47'24"	7	Nov 2008	5, 10	Grassland	Loamy sand	Loamy fine sand	49	1.43	III
ITCSM_04	52°16'18" 6°55'16"	44	Nov 2008	5, 10, 20	Grassland	Loamy sand	Loam	33	1.29	V
ITCSM_05	52°16'24" 6°41'58"	17	May 2009	5, 10, 20, 40	Grassland	Loamy sand	Man-made sandy thick earth soil	74	1.24	VII*
ITCSM_06	52°24'50" 6°38'12"	6	Nov 2008	5, 10	Grassland	Sand	Sandy topsoil on peat on sandy mineral subsoil	58	1.17	III*
ITCSM_07	52°22'18" 6°57'55"	17	Nov 2008	5, 10	Corn	Loamy sand	Sandy clay loam on subsoil of fine sand	24	1.55	III*
ITCSM_08	52°8'9" 6°44'42"	21	Nov 2008	5, 10, 20, 40	Corn	Sand	Fine sand	69	1.13	VI
ITCSM_09	52°8'47" 6°50'35"	29	Dec 2008	5, 10	Corn	Sand	Man-made sandy thick earth soil	46	1.29	VI
ITCSM_10	52°12'0" 6°39'34"	11	Dec 2008	5, 10, 20	Grassland	Sand	Fine sand	41	1.21	III*
ITCSM_11	52°13'52" 6°33'32"	7	Dec 2008	5, 10	Grassland	Loamy sand	Man-made sandy thick earth soil	52	1.47	IV
ITCSM_12	52°8'25" 6°33'35"	8	May 2009	5, 10, 20	Grassland	Sand	Sandy clay loam on subsoil of fine sand	20	1.40	V*
ITCSM_13	52°11'38" 6°25'3"	8	Jun 2009	5, 10	Grassland	Sand	Fine sand	70	0.96	VI
ITCSM_14(*)	52°11'30" 6°19'2"	7	Jun 2009 (- Jun 2010)	5, 10, 20, 30	Grassland	Loamy sand	Loamy fine sand	36	1.42	V
ITCSM_14b	52°11'40" 6°18'50"	7	Apr 2011	5, 10, 20, 30	Grassland	Loamy sand	Loamy fine sand	36	1.42	V
ITCSM_15	52°18'34" 6°36'45"	-3	Nov 2008	5, 10, 20	Grassland	Sand	Fine sand	51	1.25	III*
ITCSM_16	52°22'5" 6°32'8"	5	Apr 2009 (- Nov 2010)	5, 10	Grassland	Sand	Sandy topsoil on peat on sandy mineral subsoil	104	1.18	VI
ITCSM_17(*)	52°25'14" 6°32'26"	3	Apr 2009	5, 10	Grassland	Sand	Fine sand	19	1.36	VII
ITCSM_17b	52°25'13" 6°32'26"	3	Apr 2011	5, 10	Grassland	Sand	Fine sand	19	1.36	VII
ITCSM_18	52°24'19" 6°22'48"	-3	Apr 2009	5, 10, 20	Grassland	Loamy sand	Loamy fine sand	22	1.24	V
ITCSM_19	52°19'60" 6°19'54"	3	Jun 2009	5, 10, 20, 40	Grassland	Sand	Fine sand	43	1.34	V*
ITCSM_20	52°19'8" 6°26'55"	17	Sep 2009	5, 10, 20	Forest	Sand	Sand	44	0.78	VII*

(*) On 20 April 2011 these two stations have been moved to a new location, with the same soil, land cover and ground water characteristics. The stations replacing these two have been renamed as ITCSM_14b and ITCSM_17b. When this report was written there was also the plan to move station ITCSM_02 and ITCSM_16.

As mentioned, the soil texture maps provide also information about the highest and the lowest depth of the ground water table. 8 possible situations are identified in the map and summarized in Table 2. 1 site (ITCSM_03) is located in the ground water table area III; 4 sites (ITCSM_06, ITCSM_07, ITCSM_10 and ITCSM_15) in the area III*; 2 sites (ITCM_01 and ITCSM_11) in the area IV; 3 sites (ITCSM_04, ITCSM_14 and ITCSM_18) in the area V; 2 sites (ITCSM_12 and ITCSM_19) in the area V*; 5 sites (ITCSM_02, ITCSM_08, ITCSM_09, ITCSM_13 and ITCSM_16) in the area VI; 1 site (ITCSM_17) in the area VII; 2 sites (ITCSM_05 and ITCSM_20) in the area VII*.

Table 2 Legend of the ground water table information reported in the soil texture maps. Lowest and highest average depth (cm from the surface) of the ground water table for the different areas in Twente.

	Lowest depth	Highest depth
III	80-120	<40
III*	80-120	25-40
IV	80-120	>40
V	>120	<40
V*	>120	25-40
VI	>120	40-80
VII	>160	>80

Soil moisture and soil temperature are monitored at each station at different depths. At all sites the measurements are collected at both 5 and 10 cm depth. In 8 sites out of the 20 (ITCSM_01, ITCSM_02, ITCSM_04, ITCSM_10, ITCSM_12, ITCSM_15, ITCSM_18, ITCSM_20) there is an additional probe measuring at 20 cm depth. In 4 sites (ITCSM_05, ITCSM_08, ITCSM_14, ITCSM_19) a total of four probes have been installed at: 5, 10, 20 and 40 cm depth.

4 DESCRIPTION OF STATION INSTRUMENTATION

Each network station consists of one Em50 ECH_2O datalogger (by Decagon), which is recording the data collected by two to four EC-TM ECH_2O probes (by Decagon) able to measure both soil moisture and soil temperature.

The EC-TM ECH_2O probe consists of 3 flat pins 5.2 cm long. It is a capacitance sensor measuring the dielectric permittivity of the soil surrounding the pins. The dielectric permittivity is then converted in volumetric soil moisture according to a standard calibration equation. The soil temperature is measured using a thermistor located on the same probe.

A specific calibration of the probes was needed for the soil type of Twente area. Therefore soil samples were collected and laboratory calibrations were carried out (see following paragraph).

For the installation, a deep hole in the soil was dug and the probes were installed on one of the hole walls, at different depths and with the pins in horizontal direction. Then probes and datalogger (closed in a box) were completely buried (see Figure 8) (NOTE: at the time this report was written, there was the plan to move the datalogger above the ground in all the sites, except those installed in the middle of the field).


Figure 8 Installation procedure.

The datalogger has been set to store data every 15 minutes (i.e. measurements are carried out every minute and then they are averaged and stored every 15 minutes), which generates a data volume that can be stored by the datalogger memory for a bit longer than one year. The datalogger batteries instead last much longer (depending on the temperature and humidity level in the datalogger).
To ensure complete data continuity, the data are downloaded twice per year: in spring (in April/May) and in autumn (in September/October).

5 PROBE CALIBRATION

EC-TM ECH_2O probes estimate the volumetric water content of the soil by measuring the dielectric constant of the soil. However the dielectric properties of the soils depend on soil texture and salinity. Decagon has determined a generic calibration equation (applied by default by the datalogger), which is valid for all fine textured mineral soils with an accuracy of approximately ± 3%. This accuracy can be increased to 1-2%, performing a soil-specific calibration.
For this reason about 5-6 kg of soil were collected in each location at a depth of about 5-20 cm (as well as at deeper layers, in case the soil profile was different) in order to carry out a laboratory specific calibration, following the instruction guide provided by Decagon.
The following steps were carried out for each sample:

1) The soil was air dried.
2) The soil was packed into the calibration container at approximately the field bulk density.
3) The ECH_2O probe was inserted in the soil.
4) A probe reading was recorded.
5) A soil sample ring was collected from the calibration container.
6) 200 – 300 mL of water were added to the soil.
7) The soil was carefully mixed by hands or a trowel until the mixture was again homogenous.
8) Steps 2 to 7 were repeated until the soil was saturated (collecting in total about 6-7 samples).
9) The soil sample rings were weighed and oven dried at 105°C for 24 hours.
10) Then the dry soil sample rings were weighed again.
11) The volumetric soil moisture was computed [(wet_weight-dry_weight)/dry_weight * bulk density]
12) The volumetric soil moisture measured by rings was plotted against the probe outputs and the best fit was found.

The calibration has been carried out on the following samples:
ITCSM_01 - Sandy clay loam on subsoil of fine sand
ITCSM_02 - Man-made sandy thick earth soil - sand

ITCSM_03 - Loamy fine sand - loamy sand
ITCSM_04 - Loam - loamy sand
ITCSM_06 - Sandy topsoil on peat on sandy mineral subsoil - sand
ITCSM_07 - Sandy clay loam on subsoil of fine sand - loamy sand
ITCSM_08 - Fine sand - sand
ITCSM_11 - Man-made sandy thick - loamy sand
ITCSM_12 - Sandy clay loam on subsoil of fine sand - sand
ITCSM_17 - Fine sand - sand

This selection covers all kinds of soils that characterise Twente area at deep layers according to the soil map by Stichting voor Bodemkartering and all kind of soil textures at the surface layer found with the laboratory analysis.

The plot of the volumetric soil moisture measured by rings against the soil moisture measured by the probes during the calibration process is reported in Figure 9 with the fit lines and the corresponding equations. As a reference the 1:1 line is also included (which corresponds to the default calibration).

Comparing the calibration equations found for each sample, two groups of soils can be found: the first group includes ITCSM_02, ITCSM_04, ITCSM_06, ITCSM_08, ITCSM_11; the second group includes ITCSM_01, ITCSM_07, ITCSM_12, ITCSM_17. The main difference between the fit lines of these two groups is the intercept, whereas the slope is very similar. The fit of the data from ITCSM_03 sample has a completely different slope. The sample ITCSM_03 has the highest content of clay, which could cause the different calibration. The default calibration is clearly not the best option, as it does not fit any group of data.

Applying the default calibration to the probe measurements, the rmse with respect to the gravimetric measurements is 0.054, which can be decreased to 0.023 if the calibration equation obtained fitting all the data in Figure 9 is used. Applying the specific equation found for each group of soils identified in the calibration analysis, the rmse error can be lower than 0.016. However it is not clear which soil characteristic causes the difference in the calibration. The soil texture at the depth of the collected and analysed samples is very similar, as well as the organic matter content. The not-analysed samples have a similar soil texture as well. Therefore, it is not possible to identify a criteria to apply the calibration equation of the first, instead of that of the second group (and vice versa), to the not-calibrated sites. For this reason, it has been chosen to apply the same calibration equation to all the sites, obtained by fitting all the data in Figure 9.

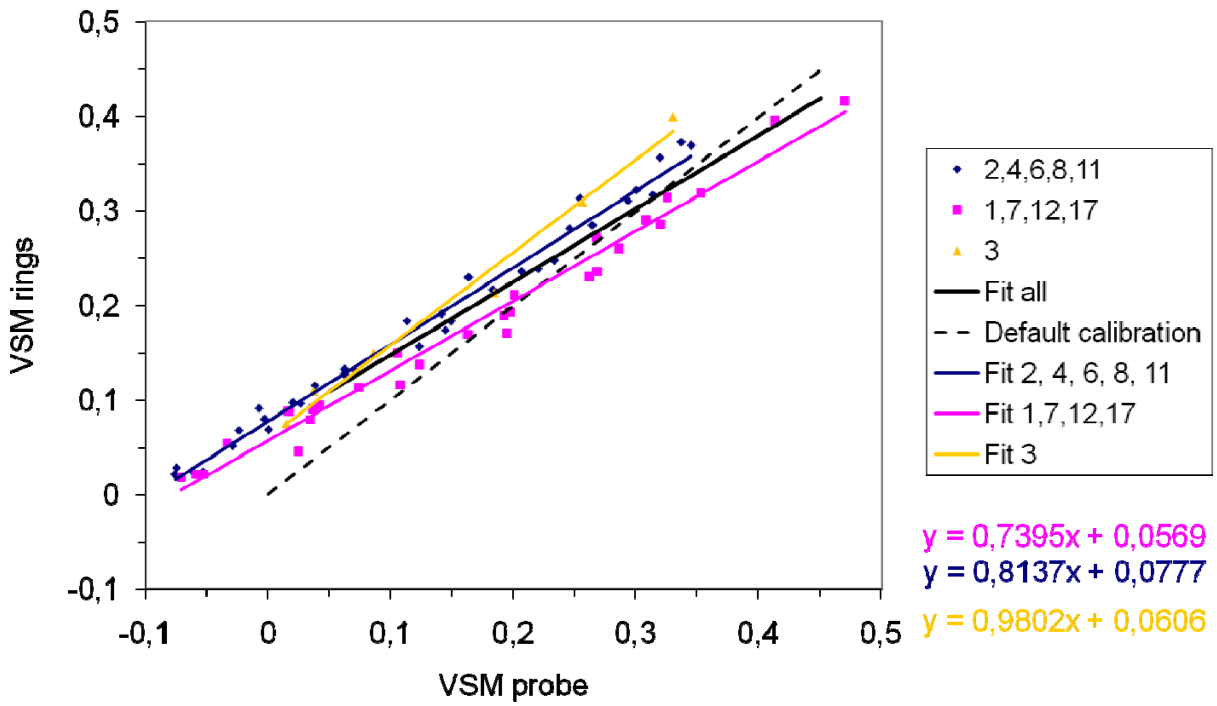

Figure 9 Volumetric soil moisture measured by the ECH2O probes vs. volumetric soil moisture measured by the rings in the soil samples used for the probe calibration.

The general calibration equation is:
$VSM_{calibrated} = 0.7751*VSM_{ECH2O} + 0.0706$
However, this calibration equation is not valid for the site located in the forest. The soil in the forest has completely different characteristics than the other sites, as it is very rich of organic matter. Unfortunately, a specific laboratory calibration has not been carried out yet. It has been decided not to apply a calibration to the soil moisture measurements in the forest.
In conclusion, the calibration has led to a decrease of the rmse between the volumetric soil moisture measured by the rings and that measured by the probes from 0.054 to 0.023 m^3/m^3.

6 DATA DESCRIPTION AND QUALITY CONTROL

Continuous 15-min volumetric soil moisture and soil temperature data have been collected in 20 sites starting from September 2009 (approximately half of the network was installed in November-December 2008, the other half in May-June 2009 and the forest site in September 2009).
Most of the probes and dataloggers have been working properly. Only few data are missing and the main reasons are: malfunctioning probes due to not perfect connection to the datalogger or malfunctioning dataloggers due to water infiltrated in the datalogger.
The quality of the data has been checked observing the consistency of the soil moisture behaviour in time and space for all the sites, analysing the time series and comparing the behaviour of each site variable with the other sites and with precipitation data.
The precipitation data have been provided by the Royal Netherlands Meteorological Institute (KNMI). There are 15 KNMI stations measuring the precipitation in the area of the network since 1950 and the daily accumulated precipitation is available at http://www.knmi.nl/klimatologie/

As an example of the collected data in one of the sites of the network, Figure 10 shows the volumetric soil moisture and soil temperature measured at different depths at ITCSM_05 site from the time of installation (end of May 2009) to November 2010. The daily precipitation recorded at nearest KNMI station (Hengelo-O-668) has been included as reference in the plot.

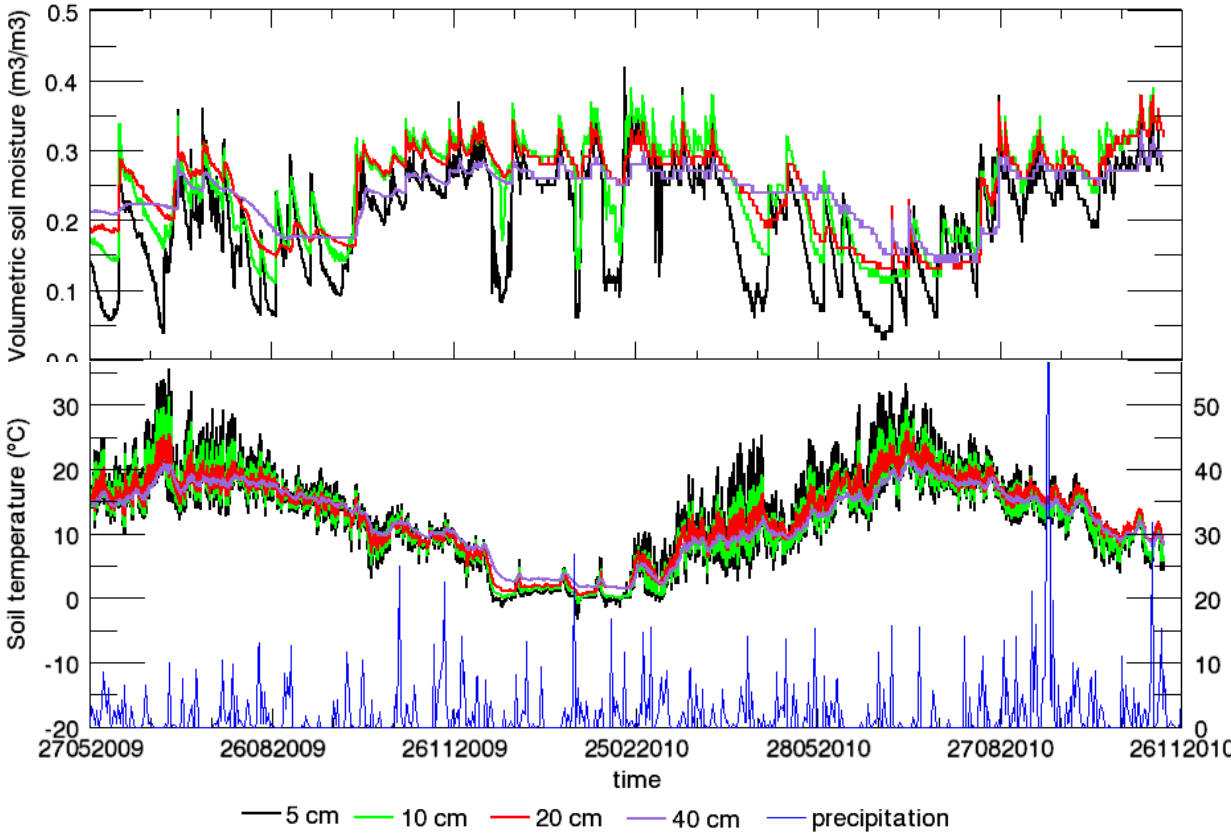

Figure 10 Volumetric soil moisture and soil temperature measured at different depths at ITCSM_05 site and daily precipitation recorded at KNMI station Hengelo-O-668

There is a good agreement between 5 cm soil moisture trend and precipitation, showing a good response of the ECH_2O probes to soil wetting and drying. The soil layers at 10, 20 and 40 cm depth show in average a similar soil water content than at 5 cm depth in all the seasons, but with a smoother behaviour than the surface layer, as well as in agreement with it. The soil temperature, especially at 5 and 10 cm depth, shows a reasonable decrease in correspondence to rainfall events.
From October to March the soil is wet and in the rest of the year the soil can become dry due to the higher temperature and evaporation. The probes at 5 and 10 cm depth measure low values of soil moisture in winter, as well. However, this happens when the soil temperature drops below zero. This is very likely due to the measurement technique of the probe itself and not to the weather conditions (i.e. the winter season in Twente is not drier than other seasons to justify drier soils). As soon as the soil temperature drops below 0°C, the water content freezes, therefore the water molecules are not able to move freely anymore. Then the soil permittivity decreases and the probes measure a lower value of soil moisture. This implies that when the soil temperature is below 0°C, the probes measure a different and lower soil moisture (i.e. only liquid water content), though the total soil water content is unchanged.
The calibrated volumetric soil moisture and the soil temperature measured at 5 cm depth in all the stations from November 2008 to November 2010 are shown in Figure 11.

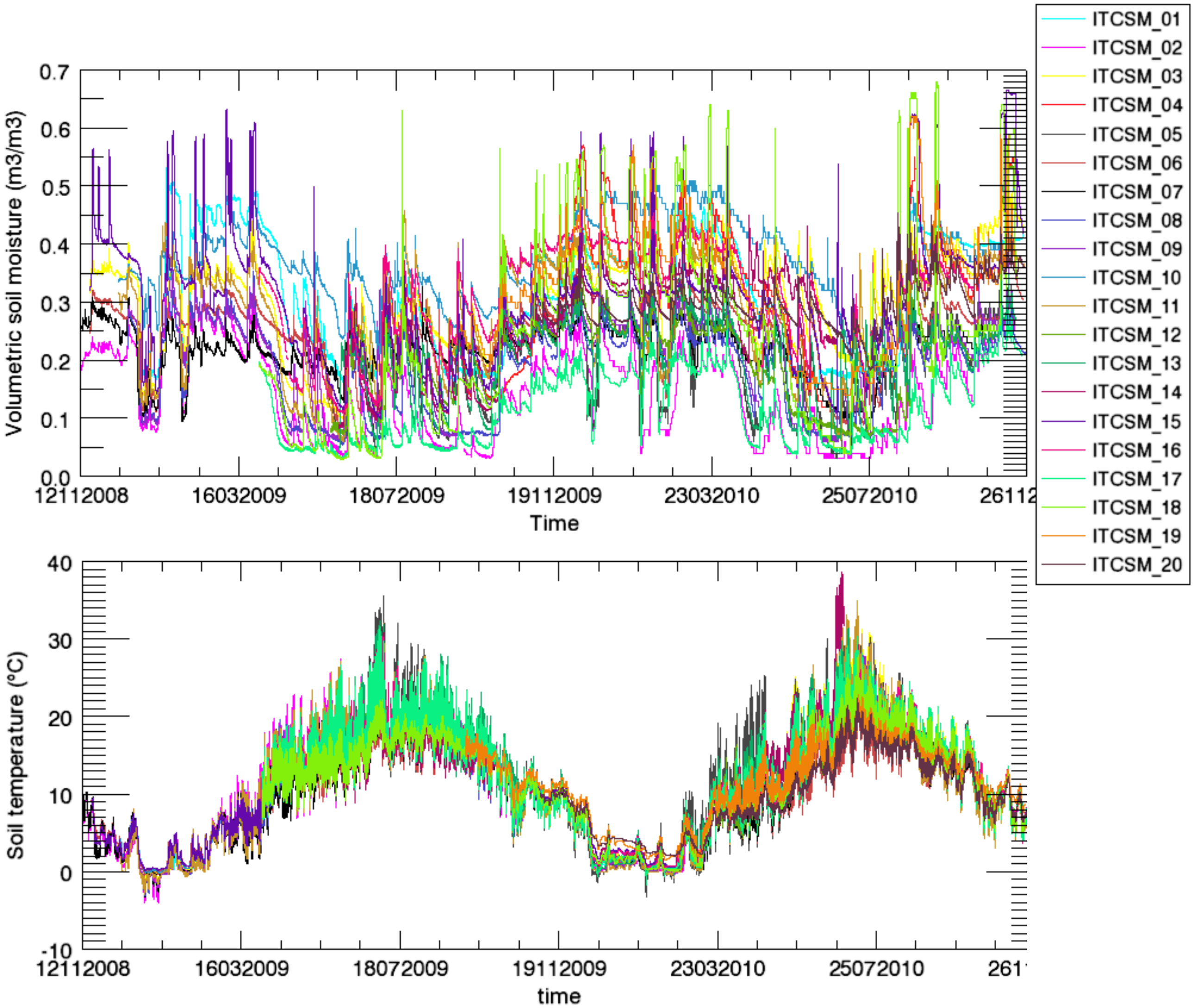

Figure 11 Volumetric soil moisture and soil temperature measured at 5 cm depth at each site of Twente network.

The plot shows an interesting spatial variability of surface soil moisture in the area, within a range of approximately 0.25 m^3/m^3 from the driest to the wettest site, but a very little spatial variability of surface soil temperature. The spatial variability does not depend on the season. The main factors which can cause this spatial variability are the land cover and the ground water table height, whereas, the soil texture in the area is quite homogeneous, varying from loam sand to sand at surface layer. Indeed it was not found a specific dependence on the soil texture. Whereas, it has been observed that the sites characterised by a high ground water table are generally wetter than the sites with a low ground water table.

Figure 12 shows one example of wet site, i.e. ITCSM_10, where the ground water table level is ranging between less than 40 cm to 120 cm below the surface and one example of dry field, i.e. ITCSM_05, where the ground water table level varies from more that 80 cm to less than 160 cm.

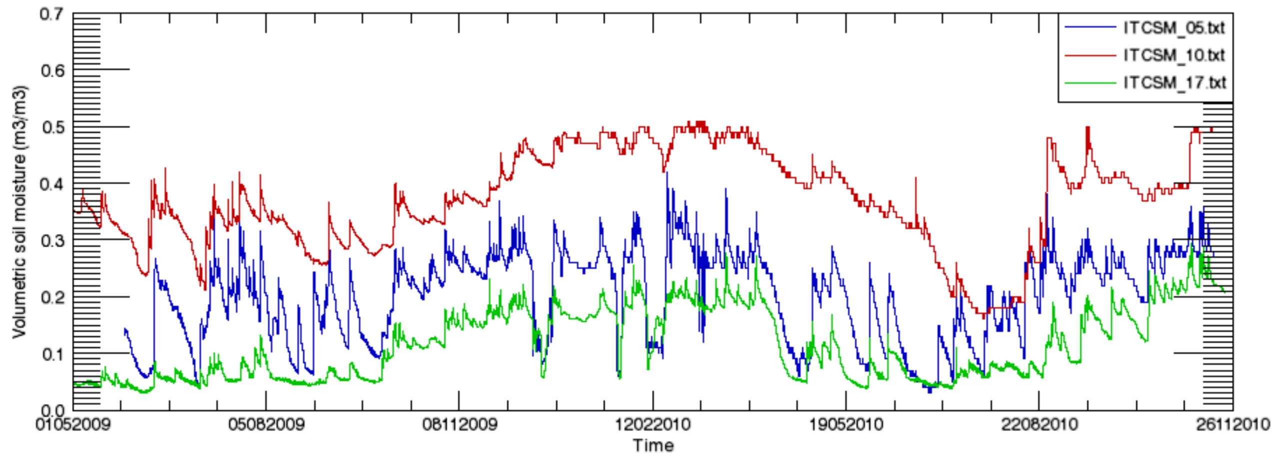

Figure 12 Time series of volumetric soil moisture measured at 5 cm depth at site ITCSM_10 (wettest), ITCSM_05 (driest) and ITCSM_17 (near ditch).

The driest sites are ITCSM_02 and ITCSM_17, but the reason is very probably due to the location of the sensors. In these two sites (only in these two) the monitoring station was installed very near a ditch, which is generally a dry area. The data analysis carried out by Jiexia Wu during her MSc study ("Soil moisture temporal stability and its application in remote sensing products validation" by J.Wu, MSc thesis, ITC) showed that the monitoring stations measure a drier value of soil moisture than what is observed in the rest of the field. This is also the reason why on April 20th, 2011 the station of site ITCSM_17 has been moved in another place of the same field and it has been planned to move also the station of site ITCSM_02 (not done at the moment when this report was written).
The land cover is affecting the spatial and temporal variability of the soil moisture in Twente network as well. Figure 13 shows the time series of volumetric soil moisture measured in one of the corn fields, i.e. ITCSM_09, compared to those measured in the meadow fields. The measurements collected in the other corn fields have a similar behaviour. The corn fields are drier than the meadow fields, as expected. This happens in particular in spring and summer, when the vegetation is high. The forest site measurements show a similar trend to the corn sites in winter, but wetter conditions in spring and summer.

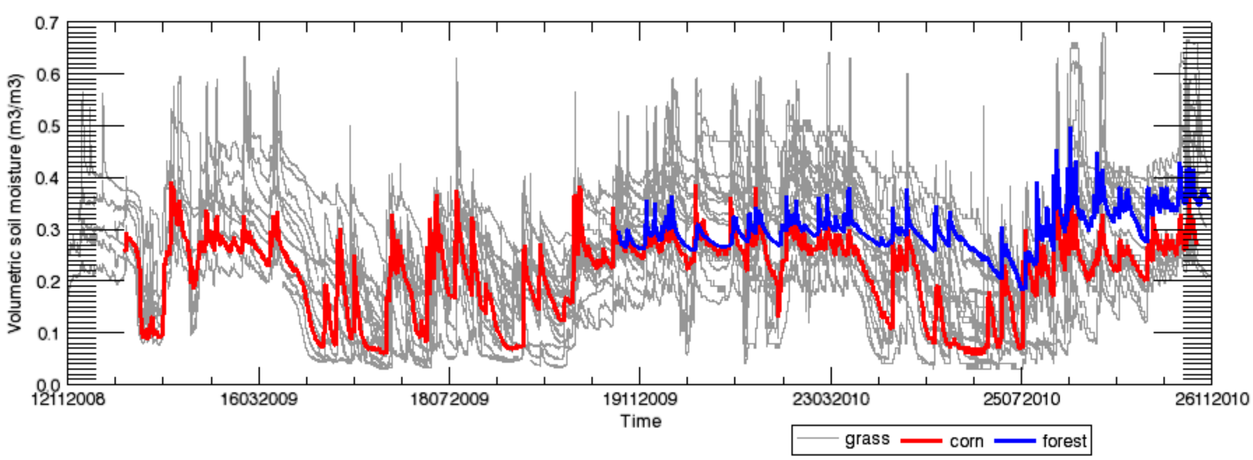

Figure 13 Time series of the volumetric soil moisture measured at 5 cm depth at one of the stations installed in a corn field (ITCSM_09) and at the forest site, compared with the measurements in meadow fields.

The mean volumetric soil moisture and the mean soil temperature obtained by computing a spatial average of the data collected at all the 20 sites of the network, at 5 cm depth, are shown in Figure 14 and compared with the average daily precipitation recorded in the area (average of rainfall data collected at 15 sites). The mean time series show very clearly the seasonality behaviour of both soil moisture and temperature. Between November and March the soil moisture is on average approximately 0.3 m^3/m^3 and the soil temperature is 5°C, dropping many times below 0°C. In April the soil dries out as there is less precipitation and the temperature increases. From May to September the soil moisture is approximately 0.15 m^3/m^3 on average and the soil temperature is 17°C. The effect of frozen soils on the soil moisture measurements is evident in the mean soil moisture as well.

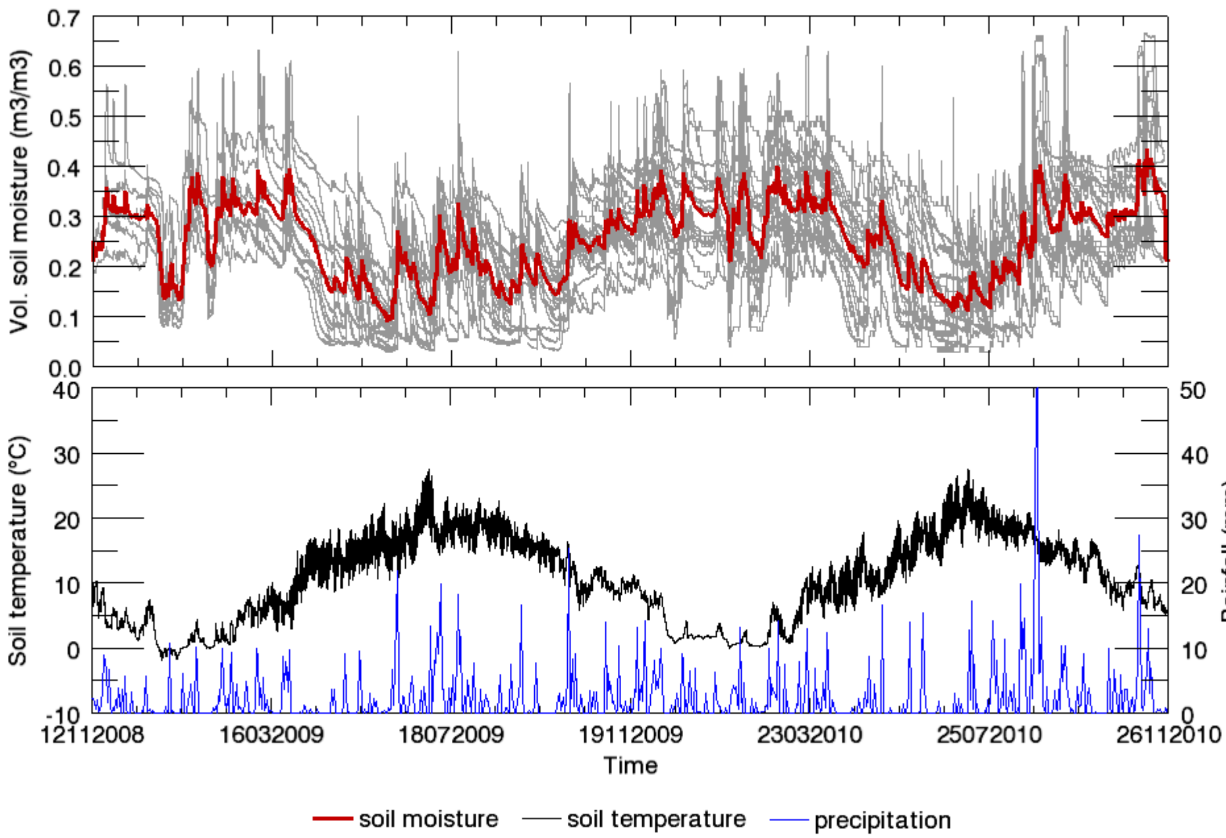

Figure 14 Mean volumetric soil moisture and mean soil temperature obtained by computing a spatial average of the data collected at all the 20 sites of Twente network, at 5 cm depth, compared with the average daily precipitation recorded in the area.