2 CAMPAIGN SETUP

2.1 Test-Sites description

Two test-sites with different characteristics were defined for data acquisition in agreement with DGRE (Direction Générale des Ressources en Eau) in Tunis. Both were in reach from the same airport of operation.

2.1.1 Ben Gardane

The Ben Gardane test-site is mainly characterized by olive tree plantings and pastures in the centre whereas in the north a salt lake and saline soil prohibits cultivation of crops. In the south shrubs and small trees can be found along an episodic river bed. In case of sufficient rain, some cereals are cultivated in winter. The major problem in this region is that the sea water increasingly invades into the aquifer. During the last decades the pressure within the aquifer was reduced due to massive extraction of ground water for industrial and agricultural purposes. The average content of salt in the ground water is high and can be rated at 5-6 g/l. Therefore no irrigation is performed. Another problem in Ben Gardane is wind erosion. In the last decades a lot of effort was undertaken to cope with that problem: Trees were planted and walls were made up of stone and soil to prevent aeolian soil transport. The heavy wind erosion, the high salinity of the ground water and therefore of the soil in combination with the low precipitation leads to desertification.

2.1.2 Gabès

The Gabès test site is completely different in the sense that in many areas irrigation is performed using water from different levels down to 100m. The Gabès city area is limiting the test-site to the East, in close vicinity to oasis areas characterized by a three layered vegetation (palms, fruit-trees, vegetables & forage crops). The centre part includes small mountains and arid/pasture areas, whereas in the West irrigated crops are cultivated. The two cycles of vegetation per year are from Sept/Oct -> Dec/Jan and from Jan/Feb -> June. The salinity problem is coped with drainage systems. Typical field plots are of size 2m by 15-20m and are irrigated every two weeks.

2.2 Deployed sensors

For both test sites quasi-simultaneous data acquisition was performed by the AVIS hyperspectral sensor in nadir direction and by E-SAR in off-nadir geometry.

2.2.1 Radar Sensor: E-SAR

The E-SAR (experimental SAR) system of the Microwaves and Radar Institute of DLR was extended several times during the last decade. It is a flexible system which serves as a test-bed for developing new applications and testing new techniques [4]. During AquiferEx it was operated in X-, C-, and L-band. The system and processing parameters are given below.

Table 1: E-SAR parameters used for AquiferEx

	X-band	C-band	L-band
Polarisation	VV	VH-VV & HV-HH	HH-HV-VV-VH
Interferometry	sgl-pass	no	repeat-pass
Bandwidth	100 MHz		
PRF/channel	1000 Hz		400 Hz
Resol. slant-range	2 m		
Resol. azimuth	4 m		4.5 m
No. looks	8		
Geocoded product posting	2 m		
Nom. Flight Alt.	3000 m		
Swath Width	3.2 km		
Off-nadir	25-55 deg		
Abs. radiometric accuracy	+/-2 dB	+/- 1 dB	

2.2.2 Optical Sensor: AVIS

AVIS (Airborne Visible Infrared imaging Spectrometer) is a pushbroom imaging spectrometer designed and built in 1998 at the chair for geography and remote sensing of the University Munich (LMU). The concept of AVIS was the development of a cost-effective system for environmental monitoring purposes. Currently the second generation of this system – AVIS-2 – is being operated [5]. The system was developed mainly for the application on small aircrafts such as Do-27 or Piper. AVIS can also be operated on an ultra-light aircraft. Therefore the concept is directed to a manageable size and weight (see Table 2).

Table 2: AVIS-2 Parameters

The specifications of AVIS-2 are as follows:	
Number of bands	64
Spectral range [nm]	400 – 900
Spectral resolution [nm]	9
Radiometric resolution [bit]	14
Spatial resolution [m]	6 (altitude 3000m above ground)
FOV [rad]/ aperture angle [°]	1.1 / 56
IFOV [mrad]	2.2
Spatial sampling [pixel per line]	640
Signal-to-Noise (SNR) [dB]	64 to 65.5
Navigation system	GPS and INS
Weight camera unit (kg)	30
Weight PC unit (kg)	20
Size camera unit [cm]	56 x 44 x 18
Size PC unit [cm]	56 x 44 x 18

3 DATA DESCRIPTION

Both *AquiferEx* test-sites are defined by a 5km by 20km rectangle. Coverage by the E-SAR sensor is ensured by 2 (opposite looking) radar strips of 3km width, with overlay of ca. 1km in far range. AVIS coverage is provided by 3 overlapping strips.

- *Ben Gardane:* All Ben Gardane data were acquired on November, 9, 2005 at dry weather conditions (no clouds) in the time period 10:10-13:25 UTC.
- *Gabès:* Data acquisition for Gabès test-site was performed on two days (November 11 and 12, 2005, from 10:30 to 12:30 UTC and 13:30 to 14:45 UTC, respectively). Due to high dynamic backscatter and non-optimum weather conditions (clouds below flight level) successful completion of the measurement program could not be achieved on the first day. However, strong rain falls during night and morning hours on the second day offer the possibility for change detection in the eastern part of the test-site, especially related to soil moisture.

For processing and ease of handling during evaluation, each E-SAR strip was split into two segments.

3.1. E-SAR data summary

For both test sites the acquired E-SAR data can be summarised as follows: 2 passes of interferometric X-band for computation of a digital elevation model (DEM), 4 passes of C-band to obtain all polarisations, and 4 passes of L-band to include the possibility of repeat-pass interferometric evaluations at different baselines. For Ben Gardane the nominal baseline was selected to 0m, whereas for the Gabès test-sites baselines of nominal 15m and 60m were used to allow (via Pol-InSAR based model inversion) studies of vegetation height for trees and agricultural crops, respectively.

The processing of the data includes full motion compensation, radiometric calibration, and geo-coded image generation in UTM projection, based on the DEM computed from single-pass interferometry.

Radiometry profiles in terms of $\gamma=\sigma^0/cos(\theta)$ of the semi-arid Ben Gardane test-site are shown in **Fig 2.** Despite of the very low reflectivity, especially in the cross-polarisation, the receiver gain settings could be adjusted to acquire data with sufficient SNR. For Gabès test site these settings needed adjustment several times during one overflight.

In **Fig** 3 we depict the interferometric baselines as flown for the Gabès test-site. Unfortunately, it was not possible to keep the same flight altitude for both days due to air traffic control restrictions (75m vertical offset). Note also the turbulences on the 0307 flight line (yellow), which relate to strong cumulus clouds appearing over the test site. On the right we display the estimates of residual motion errors in the order of centimetres, which were computed from the interferometric combination of the data itself and were used to obtain refined interferometric outputs.

Images for the southern part of Ben Gardane are shown in **Fig 4** (C-band combining two strips with complementary polarisations - left and L-band - middle).

3.2. AVIS data summary

Three flight stripes of AVIS data were acquired at Ben Gardane on November 9. Another three flight stripes were acquired at Gabès on November 11 and one on November 12. AVIS data were radiometric pre-processed, atmospheric corrected and reflection calibrated using a model based on MODTRAN. The geometric correction was conducted using GPS data and recordings of the inertial navigation system (INS see also Table 2).

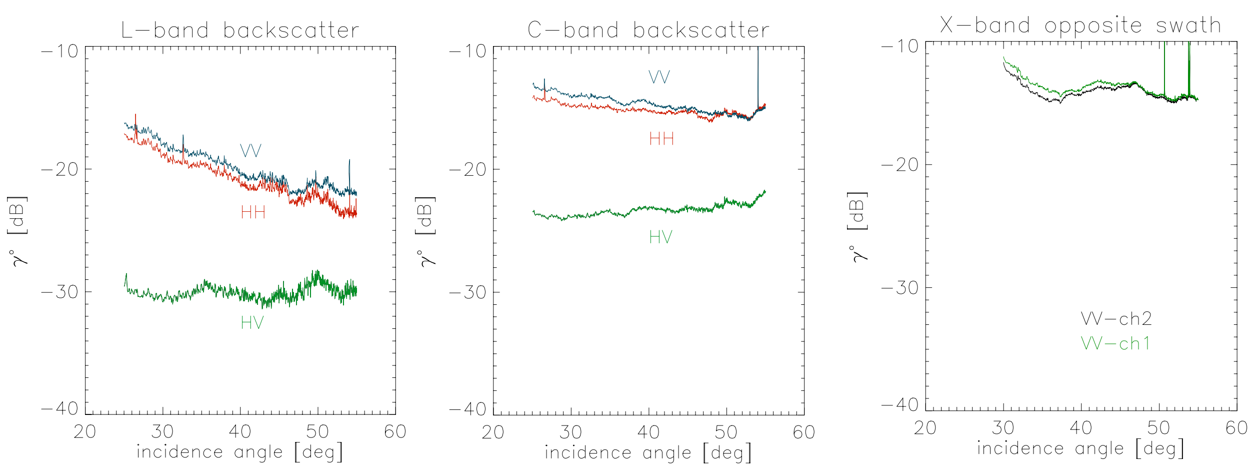

Fig. 2: Radiometric profiles for Ben Gardane data sets (south part). Note the increasing backscatter with wavelength and the low backscatter intensities, especially for the cross-polarised channels.

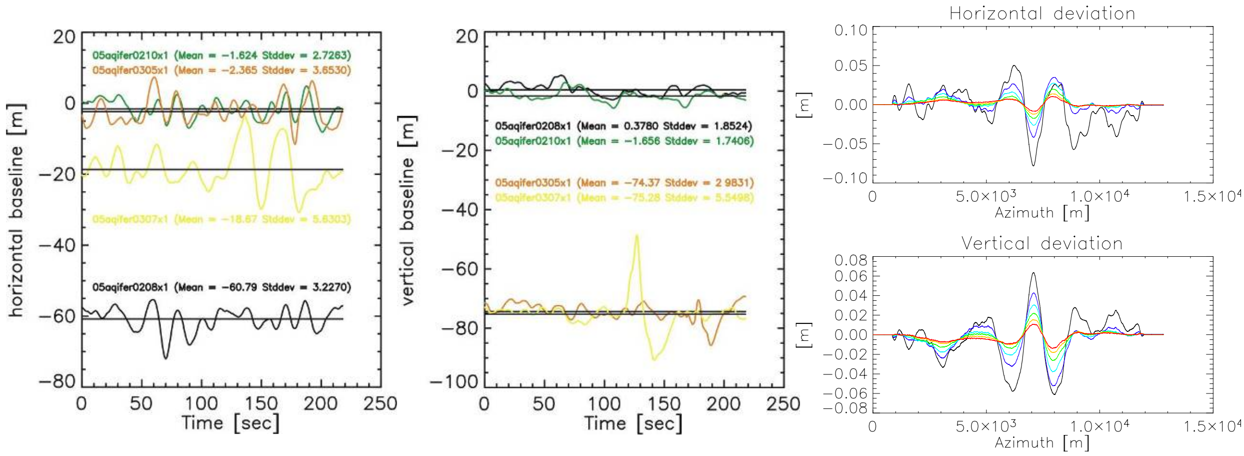

Fig. 3 Interferometric baselines flown for Gabès test site, southern strip. Residual motion errors iteratively estimated from the interferometric data are displayed on the right for the 60m baseline slave.

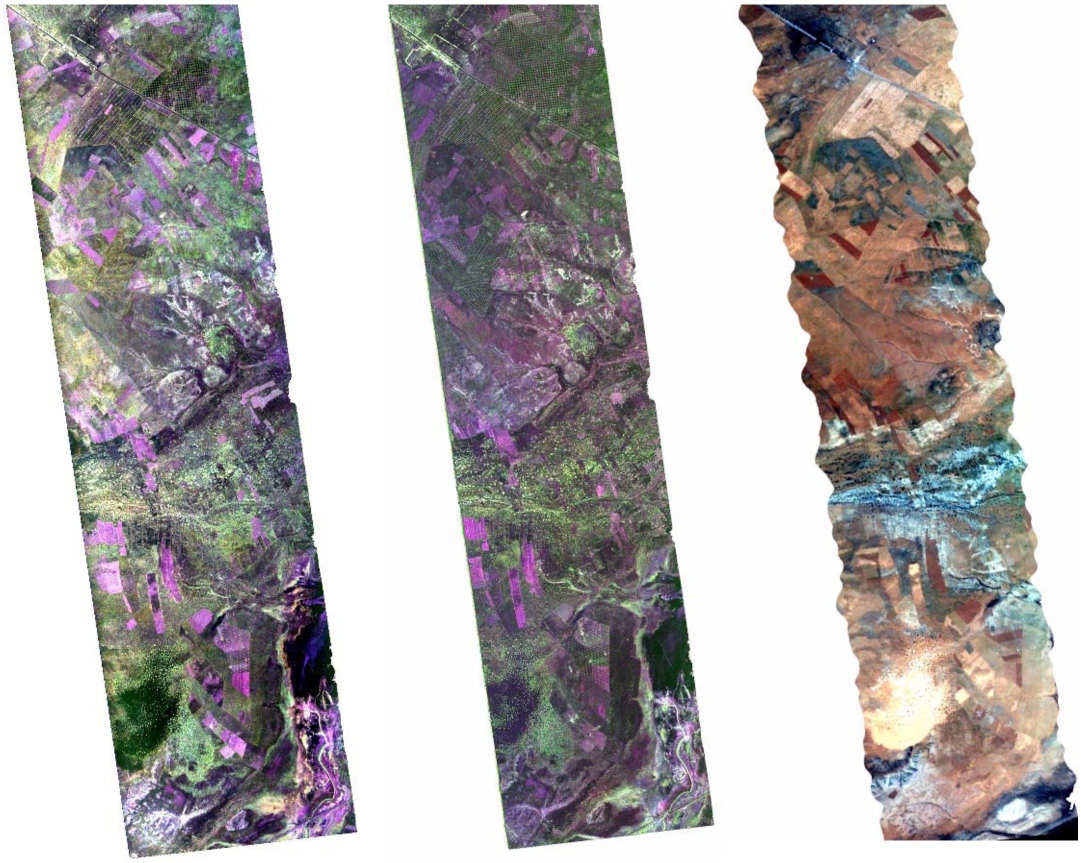

Fig. 4: Ben Gardane data sets (south part): E-SAR eastern strip (left, C-band, middle, L-band, RGB=HH,HV,VV) and AVIS central strip (right, RGB = 659, 550, 477 nm).

The resulting data are spectral reflectance matching UTM projection. At a flight altitude of approx. 3000 m above ground, the resulting spatial resolution along track and across track was 6 m and 4.7 m respectively. To obtain square pixels the data were resampled to 6m. **Fig 4** (right) shows an example for AVIS data gathered at Ben Gardane in a real colour composite.

3.3. Ground measurements

Different types of ground measurements were conducted to attain an overview of the area and to secure validation and calibration data for the aerial imagery. The measurements were concentrated in several sampling areas, where the local authorities granted a permit for access into the fields.

The following measurements were carried out and subsequently integrated into a GIS:

- Soil roughness as validation data for roughness retrieval using SAR data.
- Volumetric and gravimetric soil moisture measurements as validation basis for the soil moisture retrieval using SAR data.
- Land cover mapping to obtain a validation basis for an advanced land cover classification to be performed with the remote sensing data.
- Field spectrometer measurements as validation basis for the atmospheric correction and reflectance calibration of the AVIS data.
- Vegetation sampling including wet/dry biomass, plant height, phenological stage and photographic documentation.
- Leaf Area measurements as key parameter for different land cover types and vegetation modelling.

Additional measurements were performed by a team of ITC and TU Delft to provide reference data for scientific investigations outside the *AquiferEx* framework. These additional measurements include further soil moisture samplings, 24h soil moisture data logger, sap flow measurements on olive trees, and ground penetrating radar.

4 Radar data evaluations

Scientific products to be assessed from polarimetric radar data of AquiferEx campaign include land use classification and soil moisture retrieval. In the frame of *AquiferEx* radar data evaluation has been restricted to Gabès test site.

4.1 Soil moisture

In this section the retrieval of soil moisture from bare surfaces using the X-Bragg model [6] is discussed. **Fig 5** depicts the entropy-alpha diagram obtained for the Gabès test-site in L- and C-band. Comparing the two diagrams it becomes clear that L-band is better suited to be adopted for the model as the percentage of surface scattering contributions (low entropy and alpha angle) is much higher than in C-band. Therefore estimates of soil moisture are only performed from L-band data. **Fig 6** presents the estimates of volumetric moisture content ranging from 3% (blue) to 30% (red). Different irrigated fields can be distinguished as well as large areas of non-cultivated land. A white mask has been used to mask out areas where the validity of the model is not assured.

The validation is performed on the sample points with TDR ground measurements (see **Fig 7**). Apparently, the performance is better if only bare soil points are evaluated, which confirms the present knowledge that soil moisture estimates under the presence of vegetation are more difficult to be obtained. Note also, that volumetric soil moisture estimates of very dry soil (below 10%) from TDR are not reliable due to likely inclusion of air in the vicinity of the probes, which causes an overestimation.

To further investigate the validity of the comparison, the penetration depth of L-band radar has been investigated at the location of one trihedral reflector. Effective scattering height were found to be within 0.3-1.3 m, which indicates that TDR measurements performed at the surface layer only (10-15cm depth) should be treated carefully. For dry areas other validation methods should be considered for the future. For the AquiferEx test sites the GPR measurements will be compared with airborne radar and ground measurements in a future step.

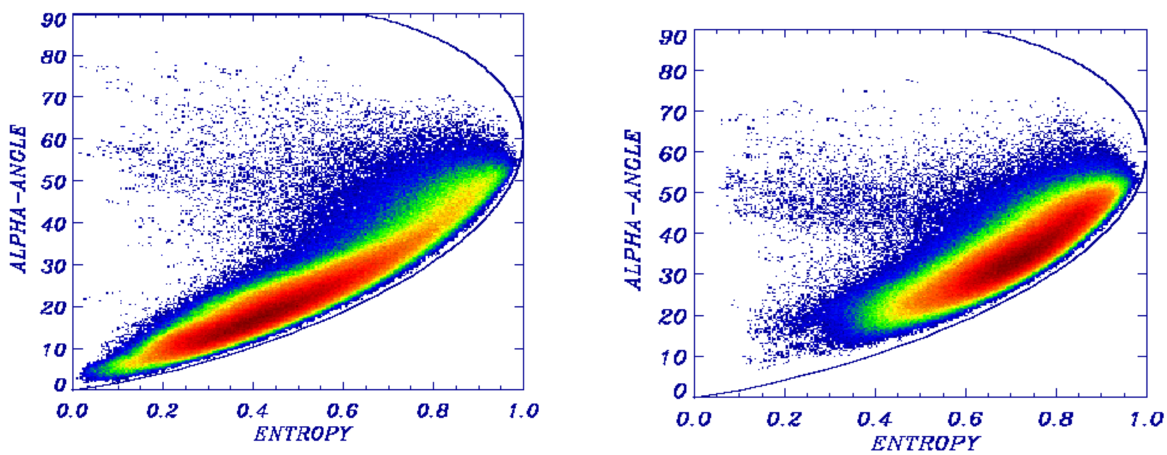

Fig. 5: Entropy alpha diagram for south-west Gabès test-site obtained from polarimetric E-SAR data in L-band (left) and C-band (right).

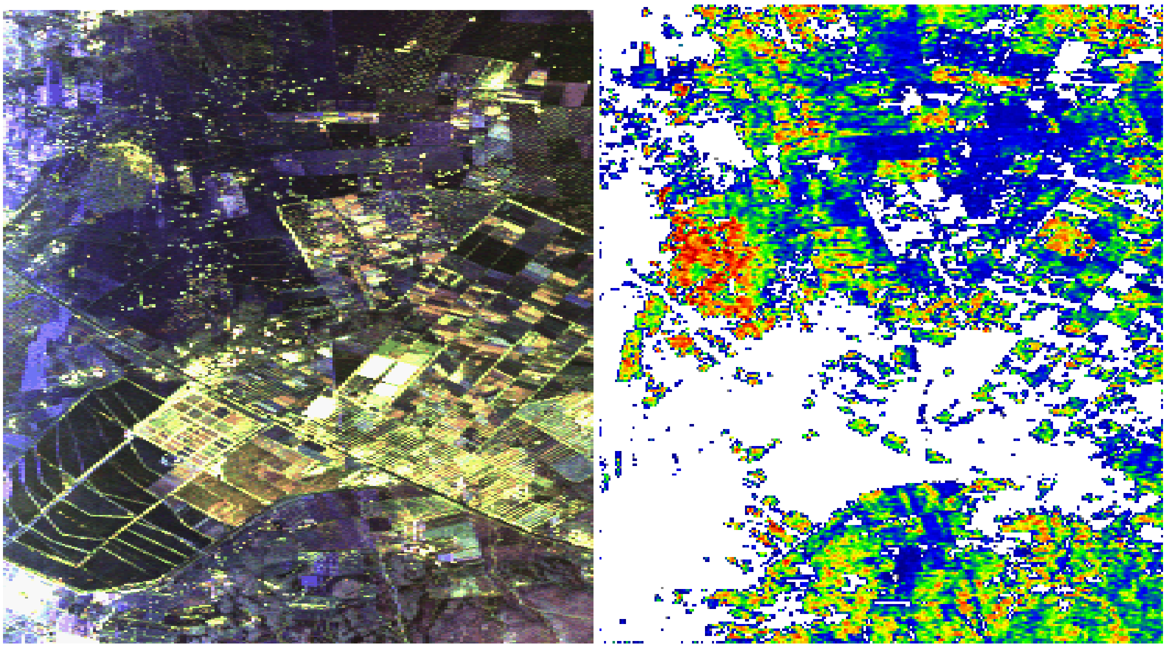

Fig. 6: Polarimetric L-band image (left, RGB=HH+VV, HH-VV, HV).
Soil moisture map derived from polarimetric E-SAR data in L-band acquired at Gabès (right).

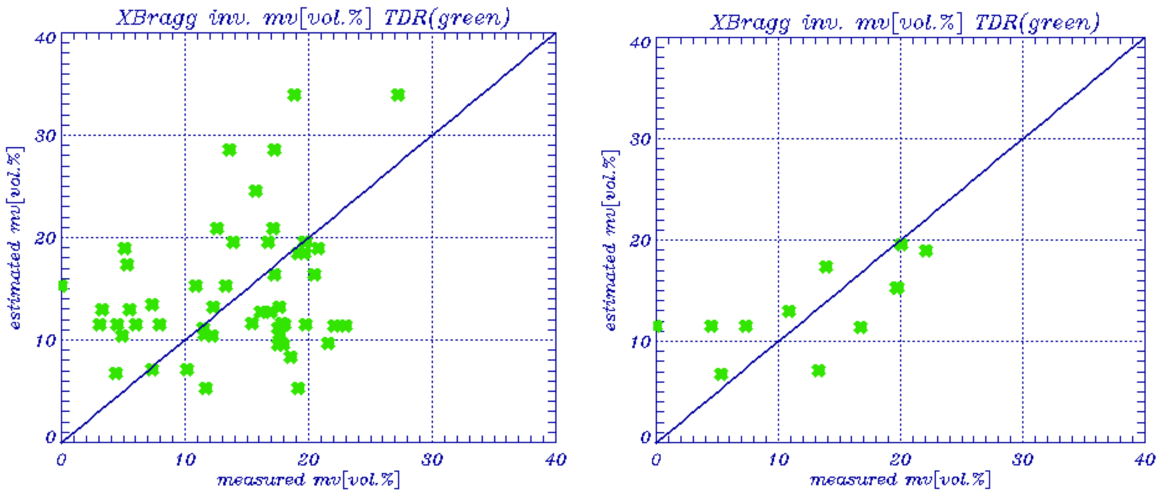

Fig. 7: Validation of volumetric soil moisture estimates with in situ TDR measurements. All samples (left) vs. only bare soil samples (right).

4.2 Polarimetric classification

One of the established tools for classification of polarimetric SAR data is the Wishart classifier based on second order statistics of the coherency matrix, where the polarimetric statistical parameters (Entropy/Alpha/Anisotropy) are used to initialise the maximum likehood classification procedure. The classification procedure is a part of the POLSAR-PRO software that ESA is distributing free of charge to the scientists [7]. This tool has been used to generate the classification result shown in **Fig 8.** In forehand of the classification the polarimetric refined Lee filter has been applied with a window size of 7.

The comparison of the obtained classification map with land use protocols obtained by the ground team during the campaign revealed the classes summarized in Table 3. Land use protocols were taken in the lower middle part of **Fig.8.** Note that due to the high change of incidence angle within an airborne SAR acquisition the same land use may map into different classes/colours in this classification. For example the yellow and green areas on the left of **Fig 8** (steep incidence angle) may not be cultivated land.

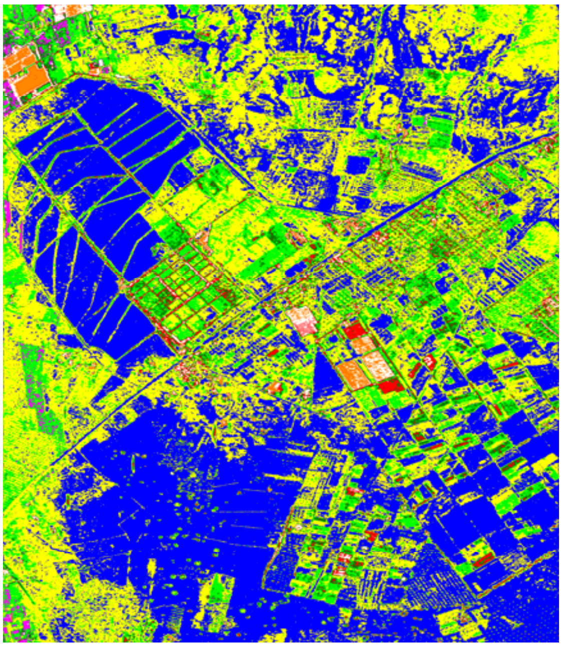

Fig. 8: H/alpha angle Wishart classification of south-west Gabès area based on polarimetric L-band data using POLSARPRO.

Table 3: Land cover /land use classes for Gabès.

Colour	**Land cover / land use**
	non cultivated bare soil
	ploughed or harvested fields & alfalfa
	fresh cultivated fields & alafalfa
	mature crops (carrots & gombo), trees
	high vegetation, trees
	no ground truth
	no ground truth
	ploughed fields

5 Conclusions

5.1 Further work

The acquired E-SAR data have not yet been fully evaluated. The potential of the acquired repeat-pass interferometric data at different baselines should be subject of further research, as is also the linking between the airborne SAR and ground based GPR data. In parallel to the SAR data also analyses of the AVIS airborne data were performed relating the spectral signatures to the in-situ ground based spectrometer data and to data of the CHRIS sensor onboard the Proba satellite. Attempts for estimating the degree of desertification for Ben Gardane test site are presently performed at the University of Munich based on [8]. Further work within the ongoing Aquifer project includes the combination of AVIS and E-SAR data into a refined land use product, which should serve for purposes of model based water abstraction estimates. Comparison with space-borne data acquired in the same time frame is also foreseen. Although not launched at the time of the AquiferEx campaign, the potential of polarimetric PALSAR data of the Japanese ALOS satellite are worthwhile investigating with respect to both, the classification and soil moisture retrieval presented in section 4. Despite the fact that the limited resolution of this space-borne sensor will not allow the discrimination of the properties of individual field structures as has been demonstrated with the airborne data, it offers a possibility for regular data acquisition.

5.2 Project Summary

A brief overview of the performed AquiferEx campaign has been given where the main outcomes can be summarised as:

- A data base of high resolution optical (hyperspectral) and radar (multi-frequency and polarisation) data has been acquired, for areas typical of semi-arid regions covering a huge variety of land use and irrigation practise.
- Soil moisture retrieval from polarimetric SAR data using the X-Bragg model has been demonstrated and validated. Good performance has been achieved for bare surfaces.
- Classification results based on second order statistics polarimetric SAR data demonstrate the information content of this kind of data. The results were generated using POLSARPRO.

Both, soil moisture and classification results demonstrate that high resolution radar sensors are able to provide relevant information for national authorities to help the management of water resources in arid regions, which is one of the most challenging tasks in African countries. The further use of the acquired airborne data and the synergy with satellite data will further be investigated in the frame of *Aquifer* and follow-on projects.

Acknowledgements

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