AquiferEx Optical and Radar Campaign - Objectives and First Results

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Abstract

In November 2005 an ESA funded airborne campaign was conducted in Southern Tunisia to generate a data base of high resolution optical and radar data in support of science product development with respect to water management applications in semi-arid areas. Both the optical sensor (AVIS of LMU Munich) and the E-SAR sensor of DLR were operated quasi-simultaneously from the same aircraft. In parallel a ground measurement campaign was conducted with the support of Tunisian organisations. This paper describes the acquired optical, radar, and ground reference data, the adopted processing methodologies as well as first results.

1 Introduction

At present a huge variety of space-borne optical and radar sensors are operated by ESA and also by other space agencies delivering remote sensing data at regular intervals to service providers as well as to the scientific community. Commonly, space-borne missions are designed according to specific user and/or scientific needs, but there is a continuous effort to promote and facilitate the use of remote sensing data in support of challenging problems on Earth. In this respect ESA has initiated several projects in the frame of the TIGER initiative of UNESCO supposed to help African countries to better manage their water resources [1]. The *Aquifer* project is one of them and focuses on trans-boundary water resources management [2]. Based on remote sensing data of actual satellites, *Aquifer* has now defined a consolidated list of required products and services as a result of several meetings and intense discussions with the *Aquifer* users on requirements and expectations and generated first prototypes products. In addition a number of science products were defined, which take into account the characteristics of future remote sensing satellites and which are considered to deliver additional support to user needs, especially related to trans-boundary water management problems. In support of this science product development within *Aquifer*, the *AquiferEx* airborne campaign has been conducted in Tunisia in November 2005. It is the first campaign financed by the Data User Element of ESA (DUE) [3]. During *AquiferEx* two sensors were operated in parallel from the same aircraft (a Do-228 owned and operated by the DLR flight department), namely the E-SAR sensor of DLR [4] and the AVIS hyperspectral camera of the University of Munich (LMU) [5].

The primary objective of the campaign is to provide a data base of high resolution radar and optical data to serve for product development, specifically for the refined land use maps within the Aquifer project. In addition, scientific investigations based on polarimetric SAR data are related to land use/land cover classification and soil moisture retrieval. For the *AquiferEx* campaign two test-sites were selected (see **Figure 1**), typical for the southern Tunisian Djeffara, i.e. a sub-aquifer of SASS (Systeme d'Aquifer du Sahara Septentrional), which extends across the borders of Algeria, Libya, and Tunisia.

The paper starts with a description of the test-sites and the sensor parameters in section 2. In section 3

Figure 1 Location of AquiferEx test-sites in Tunisia

the acquired radar, optical and ground data are presented, whereas section 4 is dedicated to first results.

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

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.	3000m		
Swath Width	3.2km		
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-3 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 test 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.

3.1.1 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. 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 geocoded image generation in UTM projection, based on the DEM computed from single-pass interferometry. The C-band image for the southern part of Ben Gardane is shown in **Figure 2** (left, combining two strips with complementary polarisations).

3.2.2 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). The resulting data are spectral reflectances 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. **Figure 2** (right) shows an example for AVIS data gathered at Ben Gardane in a real colour composite.

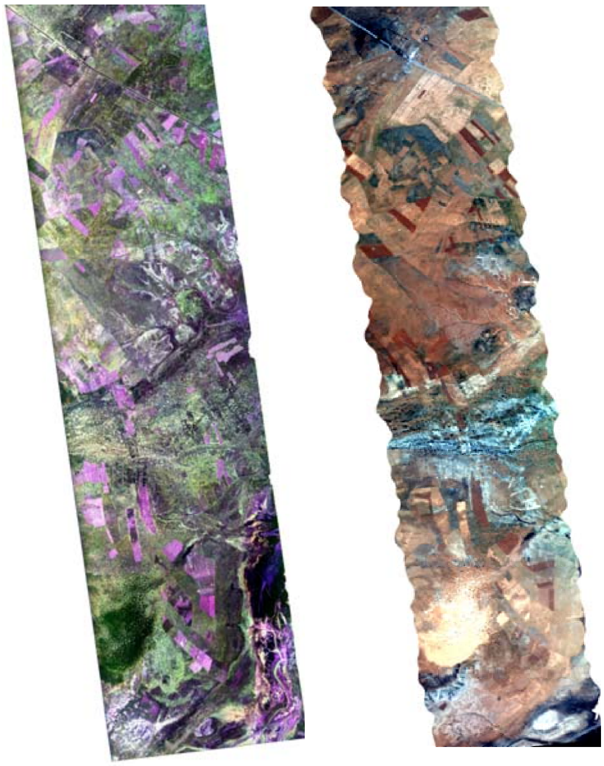

Figure 2: Ben Gardane data sets (south part): E-SAR eastern strip (left, C-band, RGB=HH,HV,VV) and AVIS central strip (right, RGB = 659, 550, 477 nm).

3.2.3 Ground measurements

Different types of ground measurements were conducted to attain an overview of the area and to obtain 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:

- Estimation of 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 First Results

4.1 Soil moisture

Scientific products to be assessed from polarimetric radar data include land use classification using polarimetric data and soil moisture retrieval. **Figure 3** presents a first result for soil moisture retrieval in the western part of Gabès test-site based on the X-Bragg surface parameter model. Estimates of volumetric moisture content range from 3% (blue) to 30% (red). Irrigated fields can be distinguished. For more details and validation, see [6] in these proceedings.

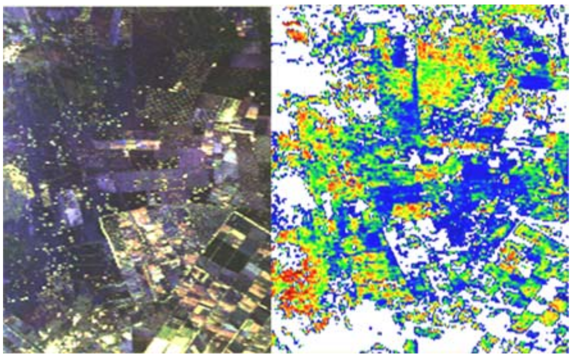

Figure 3: Soil moisture map derived from polarimetric E-SAR data in L-band acquired at Gabès (right). Polarimetric imge (left, RGB=HH+VV, HH-VV, HV)

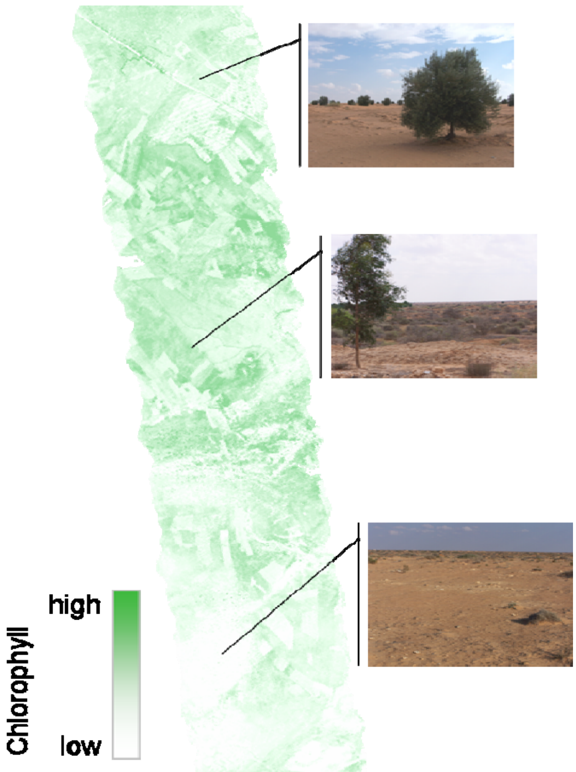

Figure 4: Chlorophyll map derived from AVIS data acquired at Ben Gardane

4.2 Vegetation density

Figure 4 presents a map of the spatial distribution of chlorophyll, i.e. the greener the more chlorophyll or green vegetation is apparent (for methodology see [7]). The olive plantings in the upper part of **Figure 4** can clearly be distinguished from more densely vegetated area in the centre and the nearly bare soil in the lower parts. The area in the centre is mainly used as pasture for goats and sheep. The bottom part is affected by a high soil salinity preventing a dense vegetation cover. This area can only be used as pasture for camels which get along with plants tolerating saline soils.

4.3 Further work

Further work includes the validation using the acquired ground measurements and (within the Aquifer project) 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.

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References

[1] http://www.tiger.esa.int/about.asp

[2] http://www2.gaf.de/aquifer/

[3] http://dup.esrin.esa.it/

[4] Scheiber, R., Reigber, A., Ulbricht, A. Papathanassiou, K.P., Horn, R., Buckreuss, S. and Moreira, A.: *Overview of Interferometric Data Acquisition and Processing Modes of the Experimental Airborne SAR System of DLR*, Proc. IGARSS, Hamburg, 1999

[5] Mauser, W.: *The Airborne Visible/Infrared imaging Spectrometer AVIS-2 – Multiangular and Hyperspectral Data for Environmental Analysis*, Proc. IGARSS 2003, Tolouse (France), 2003.

[6] Hajnsek, I.: *AquiferEx: Quantitative Surface Parameter Estimation using Polarimetric SAR Interferometry.* Proc. of EUSAR, Dresden, 2006

[7] Oppelt, N.: *Derivation of Chlorophyll and Nitrogen of Plants Using the Airborne Imaging Spectrometer AVIS.* PhD thesis, http://edoc.ub.uni-muenchen.de/archive, Munich, 2002