

The importance of SAR frequency, polarization, and incident angle for mapping arid regions, the Jabali test site, Yemen

Jean-Paul Deroin⁽¹⁾, Ismail Al-Ganad⁽²⁾, Mohammed Al-Thari⁽³⁾

⁽¹⁾ Université Paris -Est, 5 boulevard Descartes 77454 Marne la Vallée cedex France, jean-paul.deroin@univ-mlv.fr

⁽²⁾ Yemen Geological Survey and Mineral Resources Board, Sana'a, Republic of Yemen

⁽³⁾ ZincOx Resources plc, Sana'a, Republic of Yemen

Abstract

The Jabali test site, Yemen, has been chosen for evaluating the interest of quad-polarized ALOS PALSAR data for geological purposes. Although the SAR data suffer considerable layover effects due to the very low incident angle, the signal in each polarization could be successfully analysed in the flat areas. ENVISAT ASAR data are used for comparison.

Keywords: Radar, Rayleigh criterion, Surface roughness, Desert pavement.

1. INTRODUCTION

Multifrequency and polarimetric SAR studies have demonstrated the ability to retrieve slope, moisture, and particularly specific surface roughness parameters. But as volume scattering is more frequently associated with vegetation, polarimetric techniques have been mainly applied in the field of forestry and agriculture. A higher degree of small-scale surface roughness conducts to greater depolarization. Basically, HH like-polarized data are interesting for the mapping of ice types, whereas HV reveals ice edges (using C band). VV-like polarized data are more interesting for oil spills detection. HV or VH polarizations have demonstrated their potential for vegetation, clear cuts, ships, fire scars, or building height detection. HV is also interesting to detect slopes. However, most authors consider quad-polarization of minor or moderate benefit in the field of geology.

Whereas polarization is obviously relevant for applications such as agriculture (crop discrimination) or glaciology, geological examples of the interest of cross or full polarimetry are relatively rare in the literature. Nevertheless, polarimetry has been demonstrated as a key parameter in radar geologic studies since the seminal works by Schaber [1]. To avoid or minimize the confusion between moisture, slope, and roughness effects, arid flat areas are generally used for methodological approaches [2].

Synthetic Aperture Radar (SARs) were first like-polarized, then dual-, cross- or alternating polarized (Table I). The *Phased Array type L-band Synthetic Aperture Radar* (PALSAR) onboard the *Advanced Land Observing*

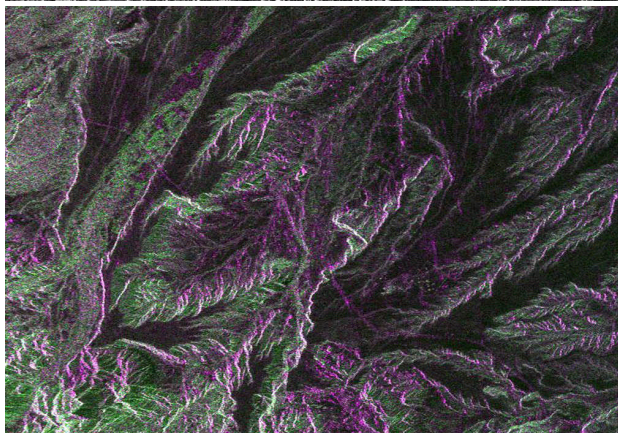
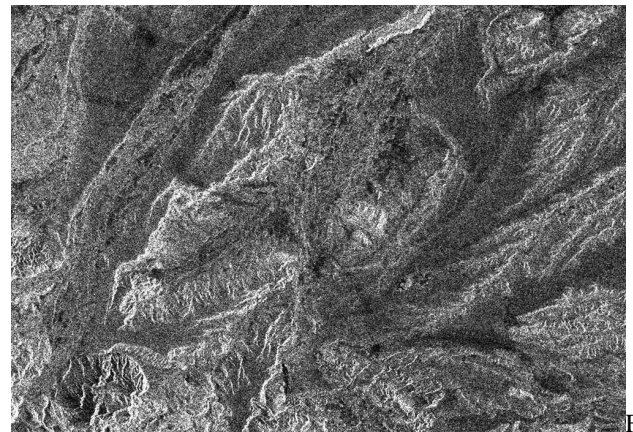
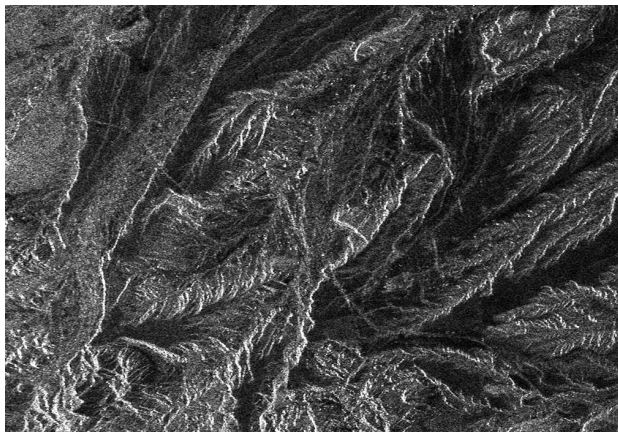
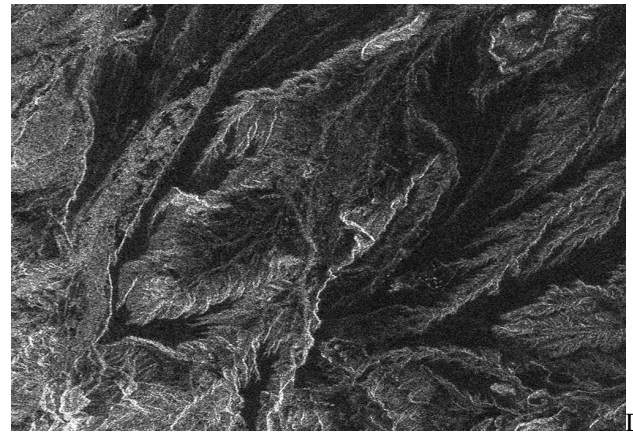
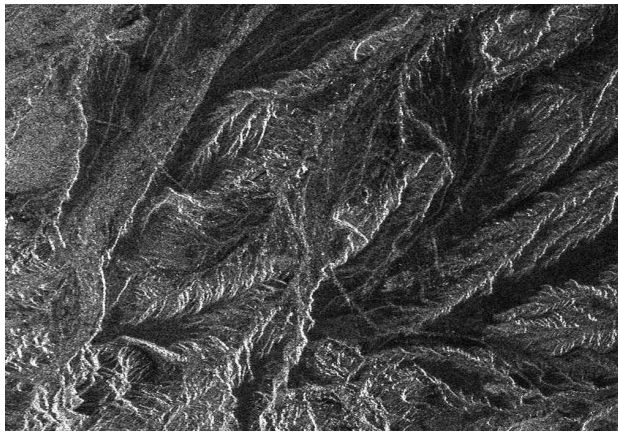
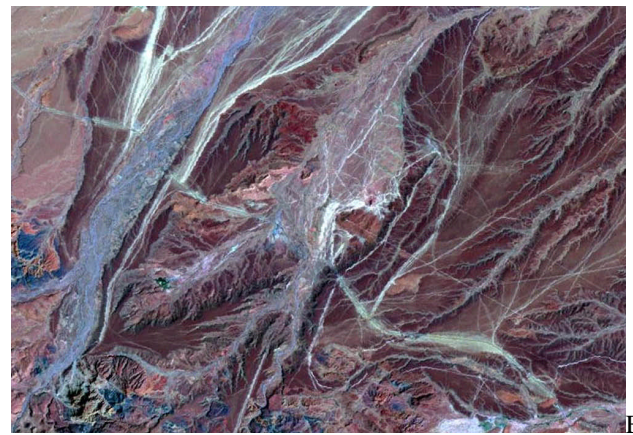
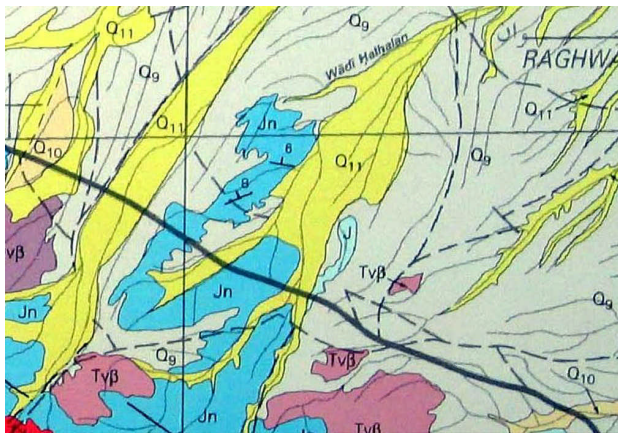
Satellite (ALOS) launched on 24 January 2006 is the first spaceborne system allowing regular quad-polarized SAR acquisition (PSR_P product). Even if single polarization (FBS) or dual polarization (FBD) present better ground pixel size, it appears particularly relevant to evaluate the potential of these first full-polarimetric data. The present paper emphasizes the interest of polarimetric data in flat desertic areas.

Table 1. Frequency and Polarization of SARs

S/C	Band	Polarization	Launch
SEASAT	L	HH	1978
SIR-A	L	HH	1981
SIR-B	L	HH	1984
COSMOS-1870	S	HH	1987
ALMAZ-1	S	HH	1991
ERS1 EMI	C	VV	1991
JERS SAR	L	HH	1992
SIR-C	C and L	quad	1994
X-SAR	X	VV	1994
ERS2 EMI	C	VV	1995
RADARSAT 1	C	HH	1995
ENVISAT ASAR	C	HH or VV	2002
ALOS-PALSAR	L	quad	2006
TERRASAR X	X	HH-VV/HV-VH	2007
RADARSAT 2	L	quad	12/2007

2. THE TEST SITE

The Jabali area is located about 70km as the crow flies north-east from Sana'a, the capital city of the Republic of Yemen. Landscapes are characterized by a mountainous basement, volcanic trapps, isolated magmatic bodies, karstic plateaus separated by wadis, endoreic basins, and some sand streaks to the north, close to the Rub Al-Khali. Since 2006, a joint project is carrying out including geologists and archaeologists for the study of Jabali, a famous medieval silver mine [3, 4]. Mineral rights are held through an exploration licence which is led by ZincOx. Mining will be from an open pit. The production of zinc (and lead) is expected to commence during the second half of 2008.



*Figure 1. The Jabali test site (about 18 km x 12 km)
Wadi Al-Khaniq appears in the left (west) part
of each datum.*

A. Geological map at 1:250,000 (extract), Q (yellow and grey) Quaternary modern deposits, J (blue): Jurassic carbonates, T (violet): Tertiary magmatism. B. Landsat Thematic Mapper (color composite RGB=TM₇-TM₃-TM₁). C. ALOS PALSAR L-HH. D. ALOS PALSAR L-HV. E. ALOS PALSAR L-VV. F. ENVISAT ASAR C-VV. G. Color composite ALOS PALSAR RGB=L-HH/L-HV/L-VV.

Desert pavements, also named *regs*, are surfaces of closely packed rounded or angular rock debris, that form a mosaic in a matrix of fine sediment. Coarse fragments are alluvial pebbles, gravels, or boulders weathered from bedrock. Desert pavements occur mostly in sand-poor regions, such as desert plains near bedrock outcrops, on plateaus, in alluvial fans or wadis, all these types of environment being represented in the region of Jabali. The mechanics of the formation of such surfaces is still controversial, but different actions could be invoked, deflation, water sorting, and upward migration of coarse particles by wetting-drying or by freezing-thawing cycles.

Our test site is covered by a large number of remote sensing data. The main data used are summarized in table 2.

Table 2. Main data used for the study of the Jabali test site.

RADAR			
S/C	Frequency	Polarization	Date
ALOS PALSAR	L	HH-VV-HV-VH	20061115
ENVISAT ASAR	C	VV	20040216
SRTM DEM	X, C		20000200
SIR-C/X-SAR	X, C, L	VV(X),HH(C,L)	19941002
OPTICAL			
S/C	Range	Resolution	Date
ALOS AVNIR-2	V-PIR	10 m	20061018
TERRA ASTER	V to SWIR	15 – 30 m	20041008
SPOT 5	Panchro	2.5 m	20021020
Quick-Bird	V	0.67 m	20020330
LANDSAT ETM+	V to SWIR	15 - 30 m	20000319
LANDSAT TM	V to SWIR	30 m	19870204
LANDSAT MSS	V to PIR	80 m	19751006

3 SURFACE ROUGHNESS ANALYSES

The quad-polarized data have been analyzed using some optical data as well (Figure 1). Regions of interest within the Jabali test site have been selected in the desert pavement areas, corresponding to more or less rough media. The flatness of each region has been checked using the SRTM DEM. Slopes higher than 1.5° have been systematically rejected. These reg surfaces could be developed on different substrates (limestones, volcanics, alluvials...) and consequently present very different characteristics in term of nature, geometry, spatial distribution, and rms of the boulders. Some regions of interest do not correspond to desert pavement surfaces, but to outcropping lithologies, limestone, dolomite, basalt, etc.

The correlation between the different polarizations is always high (Table 3). It should be mentioned the relatively similar values obtained in HH and VV. The values in cross polarization (HV or VH) are particularly low, probably because of the very low incident angle.

Table 3. Correlation between the 4 PALSAR polarizations for the 26 regions of interest.

	HH	HV	VH	VV
HH	1.000	0.925	0.932	0.998
HV		1.000	0.999	0.931
VH			1.000	0.936
VV				1.000

In spite of a high correlation between the different polarizations, some trends appear. First, most of the reg surfaces present similar backscattering characteristics in both HH and VV mode. This is the case for all desert pavement surfaces developed on bedrock outcrops, plateaus and alluvial fans. Depolarization (HV or VH) is clearly linked to slope (Figure 1, G).

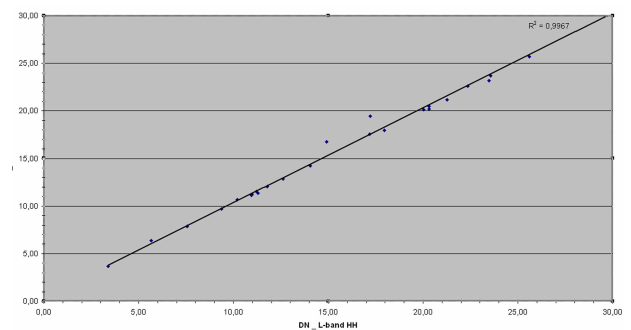


Figure 2. Relation between HH and VV polarization for 26 regions of interest

Three regions of interest present a significantly higher response in VV mode than in HH mode (+ 2 DN or more). They correspond to a deeply-karstified carbonate surface, a Quaternary basalt flow, and elongated sand dunes, respectively. These landscape units are elevated surfaces with a 2nd order roughness particularly well perceived by the L-band.

Only three regions of interest show a higher response in HH mode than in VV mode. They are all localized in the wadi Al-Khaniq, downstream the area of Jabali. In the field, the areas are characterized by flat modern alluvial deposits, some boulders and numerous shrubs. These trees offer large flat canopy sensitive to the horizontal component of the polarization (Figure 3).

A comparison with the ENVISAT ASAR data has been initiated. First results indicate the higher sensitivity of the C-band to the reg surfaces, particularly along the main track from Jabali to the road Sana'a-Ma'rib. The surfaces within the wadi Al-Khaniq (with a high response in L-HH of ALOS PALSAR) are characterized by low values in the ASAR data.

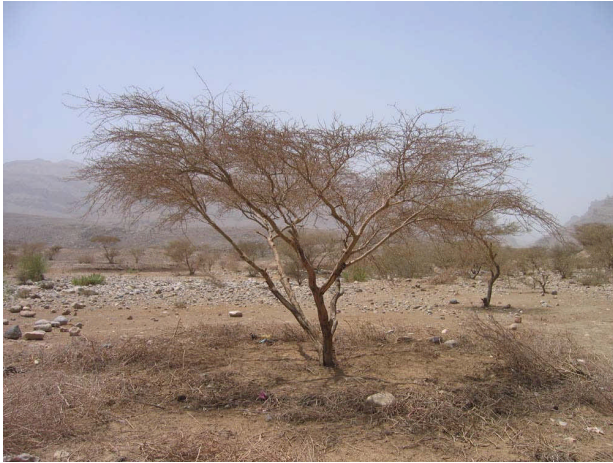


Figure 3. Typical tree in the wadi Al-Khaniq.
Note the flat canopy.

4. DISCUSSION AND CONCLUSIONS

Whereas the retrieval of the surface parameters (moisture and roughness) has been successfully obtained in radar remote sensing [e.g. 5], the roughness of geological surfaces has been poorly illustrated, principally because of the lack of valuable indication concerning the correlation length to be used in theoretical models. Therefore, the empirical Rayleigh criterion provides a relatively good estimation of the range to be considered to interpret the surface roughness influence (Table 4). The numbers should be compared to the rms values (by reference to the height of the rock fragments). Measurements in the Adrar region, Mauritania, have shown a distribution of the rms between 0.07cm for the smoothest reg and 2.10cm for the roughest reg. In the case of Jabali, the values are probably comparable (field data analysis in progress). This clearly illustrates the relative inadequacy of the L-band for studying the desert pavement.

Table 4. The Rayleigh criterion.

			S U R F A C E S (values in cm)		
			Smooth	Intermediate	Rough
SAR	cm.	loc. inc.			
PALSAR	23.5	9.3°	0.95	2.97	5.40
ASAR	5.6	23.4°	0.24	0.75	1.36

The Jabali test site illustrates the interest of quad-polarized ALOS PALSAR data for the geological study of desert pavement surfaces. Nevertheless, our preliminary comparison with the ASAR sensor is rendered difficult by difference in frequency, incident angle, and even in orbitography. Indeed, the PALSAR data have been acquired on an ascending orbit whereas the ASAR data have been acquired on a descending orbit. Although the PALSAR data suffer a considerable layover effect due to

the very low incident angle, the signal in each polarization could be analysed in the flat areas, the slope of which is lower than 1.5°.

Theoretically, VV polarization is more associated to vegetation and HH polarization to mineral surface. In our case study, it has been shown the interest of the VV polarization for discriminating some lithologies. On the contrary, HH polarization allows to detect the influence of specific trees in wadis.

The large band of PALSAR (L-band) is not totally suitable for the detailed study of reg surfaces. Nevertheless, this band when associated to the quad-polarization and a very low incident angle (study of the flat areas only) appears relevant for detecting some particular lithological or vegetation features.

More detailed studies on the backscattering coefficient of desert pavement surfaces will be carried out with the use of other SAR systems, particularly SIR-C/X-SAR data acquired in 1994.

Acknowledgement

This research is conducted under the agreement of ALOS ADEN AO 3643. The field mission has been facilitated by Mr Brett Grist, ZincOx, Sana'a Office. We are also indebted to Major Khaled Al Naphani and the National Guard of Yemen for assistance with field work.

References

- [1] G.G. SCHABER et al., "The use of multifrequency and polarization SIR-C/X-SAR data in geologic studies of Bir Safsaf, Egypt," *Remote Sensing of Environment*, Vol.59, 1997, pp.337-363.
- [2] J.P. DEROIN et al., "An empirical model for interpreting the relationship between backscattering and arid land surface roughness as seen with the SAR," *IEEE Transactions on Geosciences*, Vol.35, No.1, 1997, pp.86-91.
- [3] J.P. DEROIN et al., "Cartographie géologique télé-analytique. Influence de la résolution spatiale. Application à la région de Kawkaban-Sana'a-Ma'rib (République du Yémen)," *Photo-Interprétation*, Vol.42, No.3, 2006, pp.3-18 and 59-62.
- [4] J.P. DEROIN et al., "Archaeological remote sensing in Yemen, the Jabali test site. From large-scale survey to field investigation," *Proceedings of the 2nd International Workshop*, edited by S. Campana et M. Forte, p.7-12, 4 fig., 2 tabl., *British Archaeological Reports, BAR International Series*, 1568, 2006, 579 p.
- [5] I. HAJNSEK et al., "Inversion of surface parameter from polarimetric SAR," *IEEE Transactions on Geosciences*, Vol.41, No.4, 2003, pp.727-744.