Polarimetric SAR Characterization of Mangrove Forest Environment in the United Arab Emirates (UAE)

SoumayaFatnassi[1], Mohamed Yahia[2], Tarig Ali[3], Maruf Mortula[4]
MACS Laboratory-National Engineering School of Gabes, University of Gabes, Gabes, Tunisia[1, 2]
GIS and Mapping Laboratory, American University of Sharjah, Sharjah, UAE[3]
Civil Engineering Department, American University of Sharjah, Sharjah, UAE[4]

***Abstract*—This Mangrove forests in the United Arab Emirates (UAE) provide valuable ecosystem services such as coastal erosion protection, water purification and refuge for a wide variety of plants and animals. Therefore, the first step toward understanding the mangrove forests is the monitoring of this important ecological system. This paper proposes an original study to characterize the mangrove forest environment in the UAE by using polarimetric synthetic aperture radar (PolSAR) remote sensing. Free access C-band dual- PolSAR Sentinel 1 data have been exploited. The elements as of the covariance matrix as well as the entropy/alpha decomposition parameters have been studied. Results show that the VH intensity, the coherence between VV and VH polarimetric channels, the entropy and alpha angle provide the most pronounced signatures that discern mangrove forests. Thus, these parameters could be exploited to improve the accuracy of the remote sensing monitoring and mapping techniques of mangrove forests in the UAE.**

Keywords—Mangrove forests; dual-PolSAR; sentinel 1; United Arab Emirates; entropy/alpha decomposition

I. INTRODUCTION

Mangrove forests, which appear in the transitional zones between land and sea in most tropical and subtropical coastlines, play a major role in the coastal ecosystem. In the UAE, mangrove forests are mainly located in tidal lagoons with a total extent estimated to be $38km^2$ [2]. They are dominated by gray mangroves (i. e. Avicennia Marina) which tolerate water with high salinity and dry weather conditions (see Fig. 1(c) and Fig. 1(d)). To preserve this important ecosystem, a number of approaches have been proposed to monitor and analyze mangrove forests. Studying mangroves using field methods is time consuming, expensive and difficult because of the harsh environment in mangrove ecosystems. Hence, remote sensing has served as a sustainable tool in studies of mangrove forests. A number of methods have been proposed to monitor and analyze mangrove forests using remote sensing data [17], [10], [11]. Regarding the remote sensing data sources, most previous studies can be grouped into two main groups, those employing optical data and those using Synthetic Aperture Radar (SAR) data.

Optical remote sensing data have been widely used for mangrove monitoring due to the availability of very high temporal and spatial resolution imagery [17], [10], [11]. Nevertheless, such systems are limited in utility by the cloud at mangrove sites and by narrow spatial coverage. Few studies have been conducted to map the mangrove forests in the UAE using optical remote sensing data [6], [7], [8].

Synthetic aperture radar (SAR) data have been explored for mangrove forest mapping. SAR offers benefits that include no sensitivity to cloud or precipitation, wide spatial coverage and sensitivity to the geometrical structure of forests (Zhang et al., 2018). In the literature, several studies have been proposed to study the mangrove forests including bio-mass estimation [16], mapping [5], discrimination of species [15], etc. However, there is no study exploiting SAR data in UAE mangrove forest monitoring. The objective of this paper is to fill this gap.

Full polarimetric SAR (PolSAR) data provide much more backscattering information of mangrove forests than single polarization data [9]. Nevertheless, the majority of currently-available SAR data, such as the free-access Sentinel-1 (VV and VH polarizations) and ALOS (HH and HV polarizations) data, are dual (not full) PolSAR. In comparison to full-pol, dual-pol mode is widely used in the radar remote sensing applications due to its high spatio-temporal coverage.

However, little attention has been given in the literature to entropy-alpha-anisotropy polarimetric target decomposition for mangrove forest analyses despite its wide application for the analysis of vegetation polarimetric responses [3]Using L-band ALOS PALSAR full-pol data, it has been demonstrated that Entropy-alpha-anisotropy target decomposition provided valuable measures of scattering mechanisms of the mangrove forest structure [3]. It has been demonstrated that ALOS PALSAR dual-pol entropy-alpha-anisotropy parameters improved the classification accuracies of mangrove species [20].

In this paper, an extended analysis of the dual-pol response of mangrove forest in the UAE is proposed. The dual-pol parameters including the elements of the covariance matrix as well as the entropy/alpha decomposition parameters are studied to derive strong signatures of the mangrove forests. Single look complex VV and VH Sentinel 1 dual-pol data are tested in this study.

This paper is organized as follows: Section II introduces the study area and the experimental data. Section III introduces dual SAR polarimetry. In Section IV, the polarimetric response of mangrove forests is studied. Finally, Section V gives the conclusions of this paper.

II. Study Area and Data

The study area (see Fig. 1(a) and Fig. 1(b)) is located in Ras Al-Khaimah (RAK) in the eastern coastal areas of the United Arab Emirates facing the Arabian Gulf (see zone A Fig. 1(d)). It consists of a coastal forest of Avicennia Marina mangrove trees with high density (zone B Fig. 1(b)) and low density (zone C Fig. 1(b)) with height ranges from a few centimeters to 3–8 m [1], [14] traversed by inundated (zone D Fig. 1(b) and non inundated (zone E Fig. 1(b)) flat saline loamy clay bare surfaces and surrounded by Ras Al-Khaimah city (zone F Fig. 1(b)). This ecosystem is common in mangrove forest sites of the UAE. Hence, the objective of this paper is to characterize the mangrove forests using the studied dual-pol data and to derive the most significant polarimetric descriptors that emphasize the zones B and C (i. e. mangrove forest) from zones A, D, E and F.

For the experimental data, C-band Sentinel-1 images in the interferometric wide Swath (IW) mode have been employed. The data were acquired on 07 October 2021. The VV and VH single look complex (SLC) products with a spatial resolution of approximately 3×20 m (range×azimut) have been considered in order to characterize the mangrove signatures. The data have preprocessed according to [13]. For better speckle filtering while preserving the polarimetric information, the speckle filtering has been performed using the iterative minimum square error (IMMSE) filter [18]with the input parameters (Initial filter: 11×11 Lee sigma filter [12], number of iterations: 7).

III. Dual Polarimetric SAR Descriptors

In dual polarization SAR, one polarization H (horizontal) or V (vertical) is transmitted. Both polarization H and V are received simultaneously. Hence, the number of parameters is lower compared to fully polarimetric data (i.e. transmitting and receiving both H and V polarization simultaneously). The dual-pol data can be represented by 2×2 covariance matrix:

$$C_2 = \begin{bmatrix} \left\langle |S_{VV}|^2 \right\rangle & \left\langle S_{VV} S_{VH}^* \right\rangle \\ \left\langle S_{VH} S_{VV}^* \right\rangle & \left\langle |S_{VH}|^2 \right\rangle \end{bmatrix} \tag{1}$$

Where $\langle \ \rangle$ is the averaging operator and * is the complex conjugate. S_{VV} and S_{VH} are the dual polarization complex SAR parameters.

The dual-pol descriptors can be obtained directly from the covariance matrix or derived by applying a decomposition. The most important dual-pol descriptors are the intensity channels which are the diagonal elements of the covariance matrix i.e. $\left\langle |S_{VV}|^2 \right\rangle$ and $\left\langle |S_{VH}|^2 \right\rangle$. From the off-diagonal element, the complex coherence between the VV and VH polarimetric channels can be estimated

$$\rho = \frac{\left\langle S_{VH} S_{VV}^* \right\rangle}{\sqrt{\left\langle |S_{VV}|^2 \right\rangle \left\langle |S_{VH}|^2 \right\rangle}} = |\rho| e^{j\varphi} \tag{2}$$

Hence two additional dual-pol descriptors which are the coherence $|\rho|$ and the phase difference φ between VV and VH polarimetric channels respectively are considered in this study. The eigen-decomposition of C_2 gives [4]

$$\mathbf{C}_2 = [\mathbf{U}_2] \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} [\mathbf{U}_2]^{*\mathbf{T}} \tag{3}$$

Where λ_1 and λ_2 are the eigen-values, U_2 contains the eigenvectors and ^{T} denotes the transpose operator.

The Cloude-Pottier parameters: entropy H and the mean α angle dual-pol descriptors are [4]:

$$H = -\sum_{i=1}^{2} p_i log_2(p_i) \tag{4}$$

$$p_i = \frac{\lambda_i}{\lambda_1 + \lambda_2} \tag{5}$$

Where

$$\alpha = \sum_{i=1}^{2} p_i \alpha_i \tag{6}$$

The mean amplitude of the mechanism is:

$$\lambda = \sum_{i=1}^{2} p_i \lambda_i \tag{7}$$

Fig. 2 to 5 gave the parameters of the studied zone.

Fig. 1. (a) and (b) Spatial distribution and environment mangrove forests in Ras Al-Khaimah mangrove Greek in the UAE, (c) and (d) The study area (see arrows).

A. VV and VH Intensities

The mangrove forests grow between sea and land areas. They are characterized by a homogeneous crown shape, medium leaf size and arched aerial roots (see Fig. 1(c)). These factors define the roughness, topography, texture, and dielectric constant on which the backscatter, is highly sensitive. Mangrove forests generally are characterized by a volume scattering mechanism (i. e. multiple scattering). Hence, they are highly depolarizing targets. As a result, the VV and VH image exhibit high backscattering intensities (see Fig. 2 zone B). However, in double bounce scattering, one channel does not display high backscattering intensities depending on the orientation of the target. For example for dihedral oriented 45° and dihedral oriented 0°, the VV and VH channels does not exhibit strong backscattering intensity, respectively. These scattering mechanisms occur generally in man-made target such as buildings (see Fig. 2 zone F). Hence, very strong VV and HV intensities (i.e. specular backscattering) are observed in the city zone (see Fig. 2 zone F). In L-band data such those collected from ALOS PALSAR system, high backscattering signal observed in flooded forests originates from double bounce returns between the water surface and forest components can occur [9]. However, in actual C-band Sentinel 1 data, this phenomenon is not pronounced as for L-band since the wave have not the same ability to penetrate inside the mangrove canopy. Hence, this phenomenon is not emphasized as in the city zone where the double bounce is specular. However, double bounce can be noticeable in mangrove trees with low density (see Fig. 2 zone C) and in the boundaries between mangrove forests and flat surfaces (see arrows in Fig. 2).

The surface scattering mechanism does not depolarize the incident wave. The sea and the inundated zone constitute perfect surface reflections. Hence, they show weak backscattering intensities in HH and HV polarizations. The non inundated surface (zone E) is a rough and non-depolarizing target. Thus, it displays strong backscattering intensity in HH polarization only

B. Coherence

The coherence $|\rho|$ measures the degree of linear dependency of VV and VH polarimetric channels. It ranges from 0 to 1. If VV and VH signals are linearly related then $|\rho|=1$. Fig. 3(a) displays the coherence image of the test site. The mangrove forests are characterized by random scattering mechanisms since they are depolarizing targets. As a result, it can be observed that the zone B (i.e. mangrove forest) displays low coherence values. On the other hand, the A, C, D and E and F zones provide more deterministic scattering (i.e. surface scattering for A, D and E zones and double bounce scattering for C and F zones). As a result, the coherence parameter display high values.

C. Phase Difference

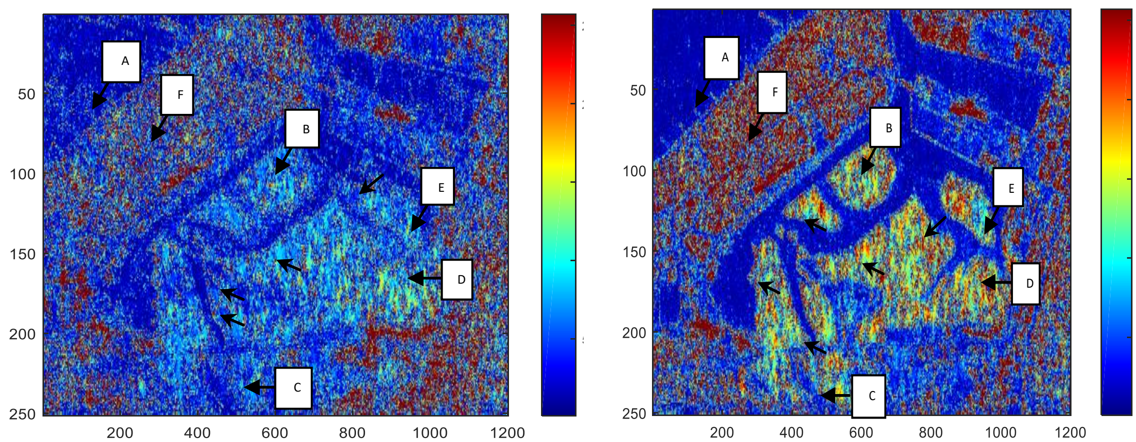
Fig. 4 (a) displays the phase difference image between VV and VH polarimetric channels. It can be observed that this descriptor does not display any particular signature. In fact, this parameter appears noisy and not able to discern the studied zones.

D. H/α

The entropy H is used to characterize the heterogeneity of the media scattering. For deterministic scattering H=0 (e. g. dihedral (i.e. double bounce scattering see Fig. 6) and surface scattering (i.e. simple reflection see Fig. 6) while for random scattering H=1 (e. g. volume scattering see Fig. 6). α angle is an indicator of the type of the scattering mechanism. For surface scattering, α =0°, α =90°for double bounce scattering and α ≈ 50°in dual-pol case (i. e. dihedral scattering such in man-made structures see Fig. 6) for volume scattering such in forests (see Fig. 6).

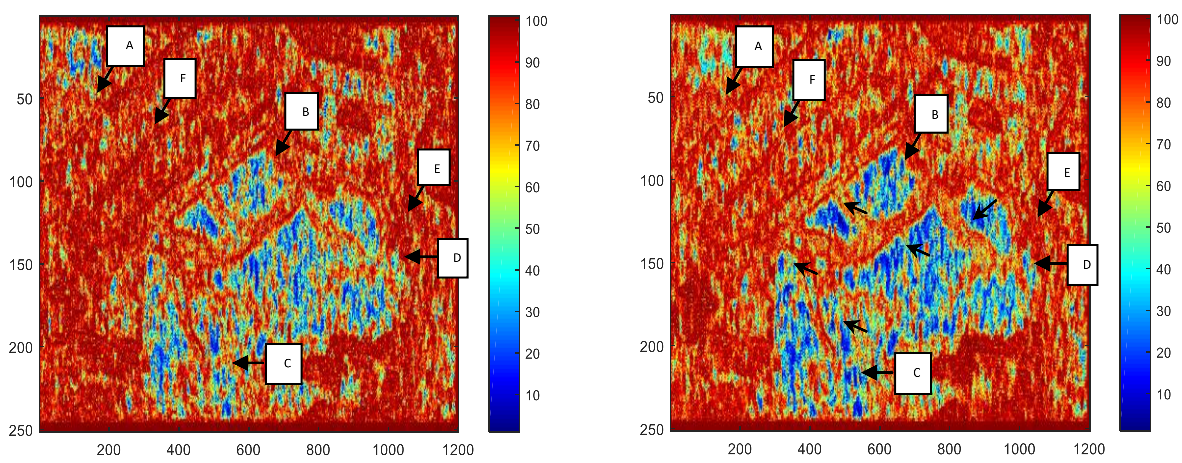
The sea area, the inundated zone and the non inundated zones represent surface scattering. Hence the entropy and alpha angle display relatively low values. The city zone is characterized by double bounce scattering (man-made structures) hence H= 0 and α =90°. Fig. 5 demonstrate that the majority of mangroves zones are characterized by volume scattering (i. e. H=1 and α ≈ 50°). Some isolated points in the mangrove forests are characterized by a double bounce scattering (i. e. H=0 and α=90°) due to the double reflection ground-trunk.

In mangrove forests with low density (Fig. 5 zone C) and the borders between the mangrove forests and the flat surfaces (Fig. 5 arrows), double bounce scattering is also pronounced.



a) b)

Fig. 2. (a) VV intensity image, (b) VH intensity image.



a) b)

Fig. 3. (a) Coherence |ρ| (×100) image (b) 1-H (×100) image.

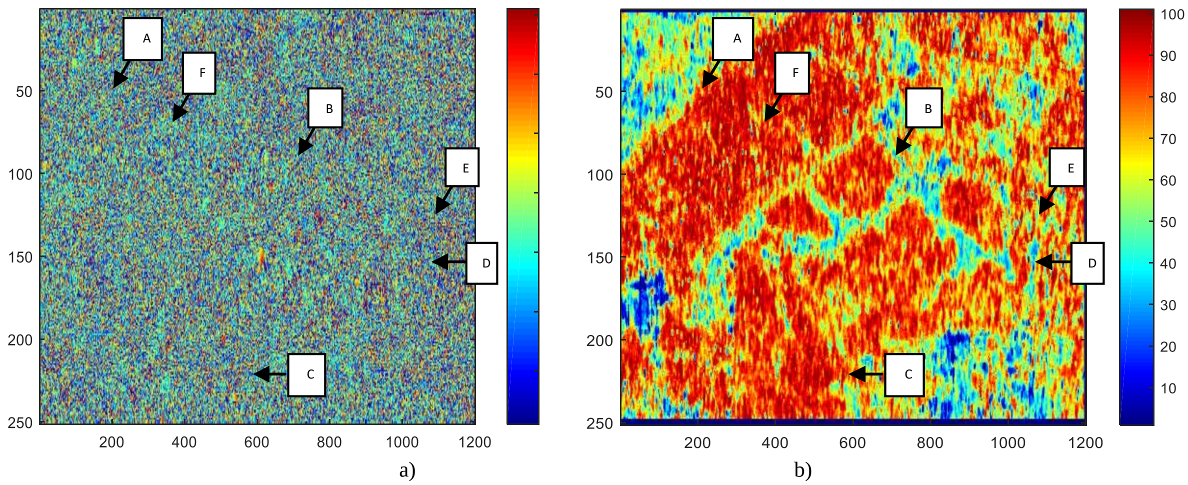


Fig. 4. a) Phase difference φ image, b) Entropy H (×100) image (Lee sigma filter).

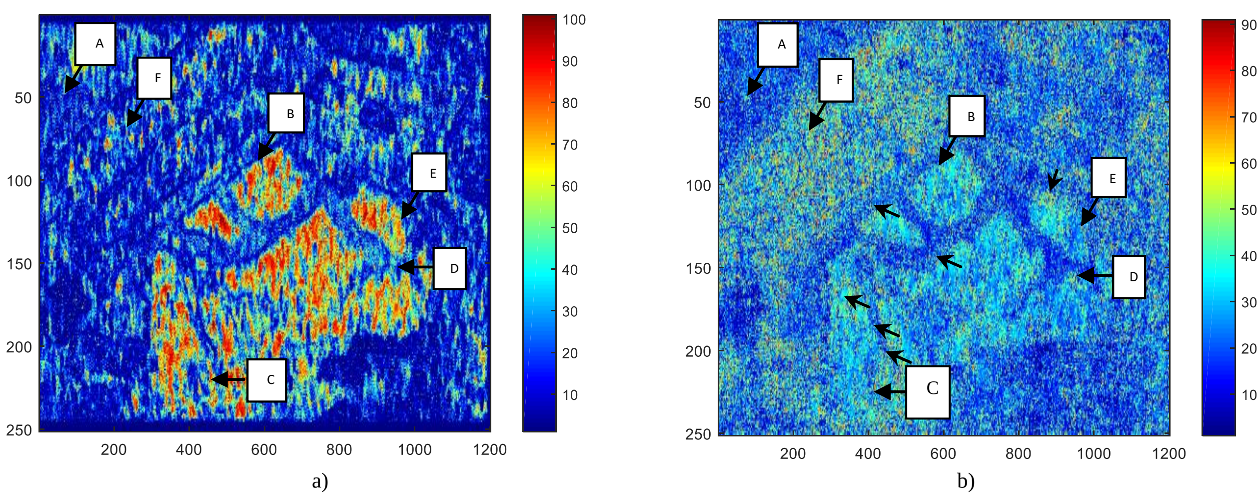


Fig. 5. a) Considered entropy H (×100) image, b) α image.

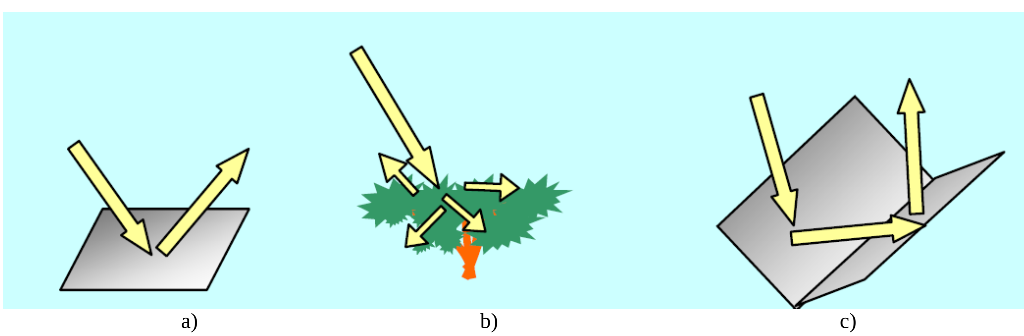


Fig. 6. a) Surface scattering (e.g. plate surface) H=0 and α =0°, b) volume scattering (e. g. random scattering in forests) H=1 and α =45°(in PolSAR case), c) double bounce scattering (e. g. dihedral) H=0 and α =90°.

E. Mean of Eigenvalues λ

The mean of eigen-values λ is an intensity parameter as VV and VH intensities. Fig. 7 displays the λ image. It can be observed that zone A and D zones display low values. The city zone d display very high values. B zone and D zone show high λ values.

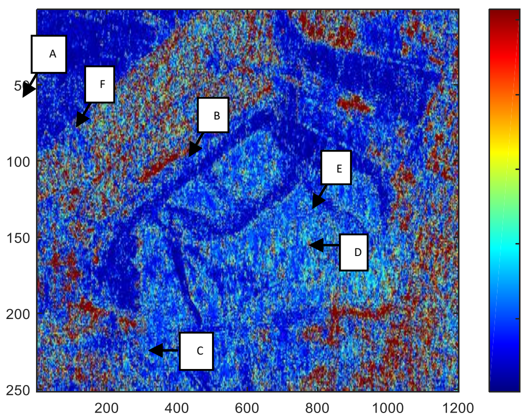


Fig. 7. λ image.

IV. Discussion

The polarimetric characterization of the mangrove forest environment of the UAE shows that the HV intensity image is more able to discern the mangrove forest than the VV intensity image. Since the mangrove forests are highly depolarizing targets, the VH image better discern their extent. Hence, since the inundated zones between the mangrove regions are no-polarizing zones, they are better described. The open area (E) is also a non-polarizing target. Hence, it is better emphasized from the mangrove trees. The coherence image emphasizes also the mangrove forest zones since all the behavior displayed low coherence values except the mangrove zones which are characterized by random scattering. The environment of the mangrove forest is non-depolarizing (H=0) whereas dense mangrove trees are highly depolarizing. Hence, the entropy parameter is a powerful indicator to discern dense mangrove trees. However, the entropy parameter cannot emphasize double bounce generated by ground-trunk scattering and surface scattering generated by the inundated and non inundated zones since H=0. It is interesting to observe that the entropy H and the coherence |ρ| are highly correlated since 1-|ρ| image provided practically the same information as H image (see Fig. 3). Hence, only the entropy can be kept to characterize the mangrove forest environment.

In the environment of mangrove forests in the UAE, only dense mangrove zones are characterized by a volume scattering. Hence, alpha angle is able to emphasize this area. However, in high entropy zones, the alpha angle cannot provide additional information. Alpha angle is generally significant in medium and low entropy values. In fact, contrary to the entropy parameter, alpha angle is able to discern double reflection from simple reflection (i. e. H=0 for both reflections whereas alpha =0 for simple reflection and alpha =90° for double reflection see Fig. 6). This phenomenon is observable mainly at the borders between mangroves and flat surfaces which present double bounce reflections (see arrows in Fig. 5 (b)). It is also interesting to observe that in low density mangrove forests double bounce reflection is dominant (see zone C in Fig. 5(b)). Concerning λ image, it can be observed that this descriptor does not introduce additional information to VV and VH intensity image.

In conclusion, the combination of polarimetric descriptors HV intensity, entropy (or coherence) and alpha angle is able to emphasize the mangrove forests of the UAE (with high and low density) from their environment. It is important to notice that the choice of the polarimetric filter it crucial. In fact, Fig. 4 (b) displays the entropy image of the test site after applying the 7×7 Lee sigma filter (using PolSAR-pro software). It can be observed that the filter is not able to preserve the polarimetric information in the city zone which displays high entropy. This phenomenon is due mixing of different scattering media [19]. As a future research direction, we propose to use the entropy and alpha angle parameters in segmentation and classification algorithms of mangrove forests in UAE. We could also use other types of decomposition for the characterization of polarimetric images in the mangrove forest environment in the UAE.

V. Conclusion

In this paper, the environment of mangrove forests in the UAE has been studied using free access C-band dual- PolSAR Sentinel 1 data. Among the studied polarimetric descriptors, results show that the VH intensity, the coherence between VV and VH polarimetric channels, the entropy and alpha angle provide the most pronounced signatures that discern mangrove forests. Thus, these parameters could be exploited for further applications related to mangrove forests in the UAE.

Acknowledgment

The authors would like to thank the Smart City Research grant from American University of Sharjah, UAE, Grant, FRG21-M-E77 and ESA for providing PolSAR data.

References

[1] Alsumaiti T S (2014) An assessment of avicennia marina forest structure and above ground biomass in eastern mangrove lagoon national park, AbuDhabi. Arab WorldGeogr 17:166–185.

[2] Blasco F, Carayon J L, Aizpuru M (2001) World mangrove resources. Glomis Electronic Journal 1:1-3.

[3] Brown I, Mwansasu S, Westerberg L O (2016) L-band polarimetric target decomposition of mangroves of the Rufiji Delta, Tanzania. Remote Sensing 8:, 140–. doi:10.3390/rs8020140 .

[4] Cloude S, Pottier E (1996) A review of target decomposition theorems in radar polarimetry. IEEE Trans. Geosci Remote Sens 34: 498–518. DOI: 10.1109/36.485127.

[5] de Souza Pereira F R, Kampel M, Cunha-Lignon M (2012) Mapping of mangrove forests on the southern coast of São Paulo, Brazil, using synthetic aperture radar data from ALOS/PALSAR. Remote Sens Lett 3 : 567–576.DOI:10.1080/01431161.2011.641511.

[6] Elmahdy S, Ali T, Mohamed M, Howari F M, Abouleish M, and Simonet D (2020) Spatiotemporal mapping and monitoring of mangrove forests changes from 1990 to 2019 in the northern Emirates, UAE using random forest, kernel logistic regression and naive Bayes tree models. Front. Environ. Sci 8: 102. DOI:10.3389/fenvs.2020.00102.

[7] Elmahdy S, Mohamed M M (2018) Monitoring and analysing the Emirate of Dubai's land use/land cover changes: an integrated, low-cost

remote sensing approach. Int. J. Digital Earth 11: 1132–1150. DOI:10.1080/17538947.2017.1379563.

[8] Elmahdy S, Mohamed M M (2013) Change detection and mapping of mangrove using multi-temporal remote sensing data: a case study of Abu Dhabi, UAE. J. Geomatics 7: 41–45.

[9] Ferrentino E, Nunziata F, Zhang H, Migliacci M (2020) On the ability of PolSAR measurements to discriminate among mangrove species. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 13: 2729 – 2737. DOI:10.3390/rs11080921.

[10] Heumann B W (2011) Satellite remote sensing of mangrove forests: Recent advances and future opportunities. Prog Phys Geogr 35: 87–108.DOI:10.1177/0309133310385371.

[11] Kuenzer C, Bluemel A, Gebhardt S, Quoc T V, Dech S (2011) Remote sensing of mangrove ecosystems: A review. Remote Sens 3: 878–928. DOI:10.3390/rs3050878.

[12] Lee J S, Ainsworth T, Wang L Y, Chen K S (2015) Polarimetric SAR speckle filtering and the extended sigma filter. IEEE Trans Geosci Remote Sens 53: pp. 1150–1160. DOI: 10.1109/TGRS.2014.2335114.

[13] Mandal D, Vaka D S, Bhogapurapu N R, Vanama V S K, Kumar V, Rao Y S, Bhattacharya (2019) A. Sentinel-1 SLC preprocessing workflow for polarimetric applications: A generic practice for generating dual-pol covariance matrix elements in SNAP S-1 toolbox. Preprints, 2019110393. DOI: 10.20944/preprints201911.0393.v1.

[14] Moore G E, Grizzle R E, Ward K M (2013) Mangrove resources of the United Arab Emirates: mapping and site survey 2011–2013,"in Final Report to the United Arab Emirates Ministry of Environment and Water, University of New Hampshire, (Durham, NC: Jackson Estuarine Laboratory).

[15] Pham T D, Bui D T, Yoshino K, and Le N N (2018) Optimized rule-based logistic model tree algorithm for mapping mangrove species using ALOS PALSAR imagery and GIS in the tropical region. Environ. Earth Sci 7.DOI:10.1007/s12665-018-7373-y.

[16] Rauste Y, Hame T, Pullianen J, Heiska K,Hallikainen M (1994) Radar-based forest biomass estimation. Int J Remote Sens 15: 2797–2808.

[17] Wang L, Jia M, Yin D, Tian J (2019) A review of remote sensing for mangrove forests: 1956–2018. Remote Sens Environ 231 : 111223.

[18] Yahia M, Ali T, Mortula M M, Abdelfattah R, Elmahdy S (2020) Polarimetric SAR speckle reduction by hybrid iterative filtering. IEEE Access 8.DOI:10.1016/j.rse.2019.111223.

[19] Yahia,M; Aguili,T. Characterization and correction of multilook effects on eigendecomposition parameters in PolSAR images IEEE Trans Geosci Remote Sens 2015 53:5237-5246.DOI:10.1109/TGRS.2015.2419717.

[20] Zhang,H;Wang,T; Liu,M; Lin,H; Chu,LM; Devlin,AT. Potential of combining optical and dual polarimetric SAR data for improving mangrove species discrimination using rotation forest. Remote sensing 2018 10:467. DOI:10.3390/rs10030467.