A NEW LIGHT ON ORIGINS OF POLARIMETRIC MISCLASSIFICATION OF THE SOMA DISTRICT, DUE TO THE DIFFICULTY TO PREDICT ENTROPY

E. Colin Koeniguer, F. Weissgerber, N. Trouvé, and J.M. Nicolas

Onera, France

ABSTRACT

Entropy is often used in polarimetric classification algorithms, for example by unsupervised Wishart classification in alpha entropy feature space. In this framework, entropy is supposed to be low for man-made targets. However, on most examples of classification results on San Francisco images, this parameter fails to well classify the SOMA district, which contains a lot skyscrapers with a particular orientation. Even very recent studies fail to compensate the orientation effect on this area. Moreover, TerraSAR-X images are also difficult to handle because they show a high entropy with poor contrast between natural and deterministic targets. Then, this paper investigates the reason of these issues. Several aspects are investigated: does entropy depends on noise ratio, wavelength, resolution size, orientation effect or complexity of the medium?

Key words: polarimetry, entropy, urban areas, classification.

1. INTRODUCTION

Polarimetric entropy is often considered as a degree of randomness of different polarimetric mechanisms occurring within a resolution cell. It is also considered as an indicator of "determinism" of a target, i.e. as its ability to transform a polarized wave into a partially polarized wave. Therefore, it is often assumed that manufactured targets have low entropy, as well as natural targets have high entropy. Also, in an image of urban area, we might think to use this parameter for the detection of built-up areas. Numerous polarimetric classification methods also use this parameter.

However, the use of this parameter for classification purpose is not so simple. Firstly, entropy requires a statistical estimation, and it is well known that the results depend of how this estimation is performed, and depends on the number of samples. Furthermore, it is known that entropy levels are connected to numerous factors related to the design of the sensor, such as the resolution, the noise level, and the wavelength.

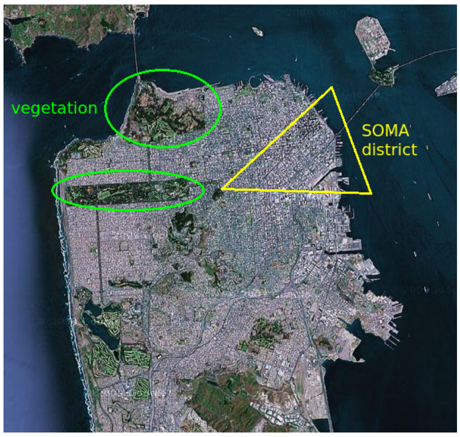


Figure 1. Ground truth and location of the SOMA district

Therefore, if we want to perform an unsupervised classification by using entropy, it is necessary to know the relationship between these sensor parameters and the resulting polarimetric parameters, to determine the appropriate thresholds.

Within the framework of the POLSARAP study that highlights the contribution of polarimetry, performances of polarimetric parameters for the detection of built-up areas have been compared. These performances have been investigated on polarimetric images over San Francisco. This test site is well known in polarimetry because it is representative of the different classes of targets: ocean, built-up areas, and vegetation, as shown in Fig. 1.

For the classification algorithms based on the polarimetric information, two issues have emerged:

- Conventional polarimetric parameters such as entropy or double bounce powers have all failed to provide a correct classification on a specific area in San Francisco, for all the images viewed from different sensors. This area is called the SOMA district. It contains many sky scrapers. Looking more carefully on classification results previously published in the literature, it turned out that all polarimetric classifications fail on this SOMA district.

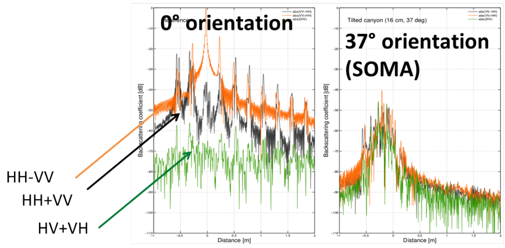


Figure 2. Results of exact modelling for a urban canyon

- Entropy is very high all over the TerraSAR-X image.

A previous study in [1] as analyzed why the level of entropy is high on this particular SOMA district. On our previous images, the high level of entropy was not the only particularity of the SOMA district. Orientation effects related to this area on the polarimetric response have been identified: as this area has an orientation far from the axis of the sensor, it was subsequently shown that the level of HV return is high, as shown in Fig.2 . In classical decompositions, the volume contribution is overestimated. We know that it is necessary to perform a disorientation in an attempt to reassess these canonical mechanisms in a way that remove the orientation effect. However, this operation is often ineffective in presence of strong orientation effects.

In this paper, we propose to analyze first in the next section the deterministic parameters and effects related to the orientation effects. Then, in section 3 we try to answer the question: why the level of entropy is high on the whole TerraSAR-X image? Finally in section 4 we see how temporal estimation of entropy seems to be a promising tool to obtain a first discrimination between deterministic and non deterministic targets, and to be able after that to propose the adapted kinds of decomposition. In the conclusion we summarize our recommendation over the use of polarimetry in high resolution images.

2. ANALYSIS OF THE FIRST ORDER PARAMETERS: DOUBLE BOUNCE MECHANISM, CROSS POLARIZATION EFFECTS AND ORIENTATION EFFECTS

Classical deorientation algorithms aim at

- estimating the orientation angle of the target under study,
- applying a rotation of the polarimetric basis to align the axis of the target on the horizontal axis, and therefore obtaing zero cross polarization returns.

However, in the case of a pure dihedral mechanism, this operation is not so simple, for many reasons:

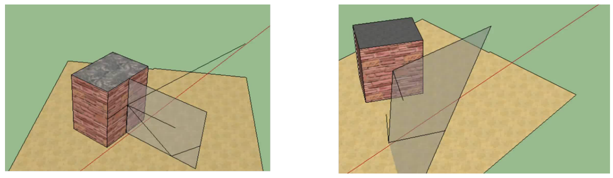


Figure 3. The classical double-bounce effect on the left, and one type of interaction for an oriented building

- First, we are not faced to metallic canonical effects but to dielectric ones. The Fresnel coefficients on dielectric materials are not equal for the HH and the VV polarization, and so the corresponding scattering matrix is not strictly equal to the second Pauli matrix.
- Second, the rotation is applied in the wave plane. As a consequence, a dihedral effect whose corner is horizontal with a given orientation has not necessary a polarimetric orientation angle (POA) equal to this orientation.
- Finally, the double bounce mechanism related to a vertical wall with a given orientation angle cannot involve two successive specular scattering. Generally, it is assumed that the vertical wall implies a specular one, whereas the ground do not, as illustrated in Fig. 3. Therefor, this real double bounce effects has a very smaller return that the classical ones. Small elements of the facade can now also contribute to the polarimetric return, and can have comparable amplitudes. In this case the double bounce effect is not more dominant.

Previous electromagnetic simulations performed with a 3D commercial tool (FEKO) on a urban canyon confirm this last point. The analysis has shown that as soon that the buildings are no more aligned with the trajectory direction, all mechanisms have comparable amplitudes, and double-bounce effects become very low.

Most of the time, the mixture of different mechanisms is not stable from a pixel to a close one. That is why a very high entropy can be observed for this particular SOMA district for all images where it has a strong orientation related to the azimuth direction, as shown on Fig. 4.

But there is still another question to answer about the very high levels of entropy measured on the TerraSAR-X image. That is what we try to answer in the next section.

3. WHY A HIGH ENTROPY OVER TERRASAR-X IMAGES OVER URBAN?

Entropy on TerraSAR-X image is high on the whole image as it can be seen in Fig. 3. Several assumptions have been proposed to explain this behavior.

Figure 4. Entropy on several polarimetric image of San Francisco: AIRSAR, RADARSAT-2, ALOS

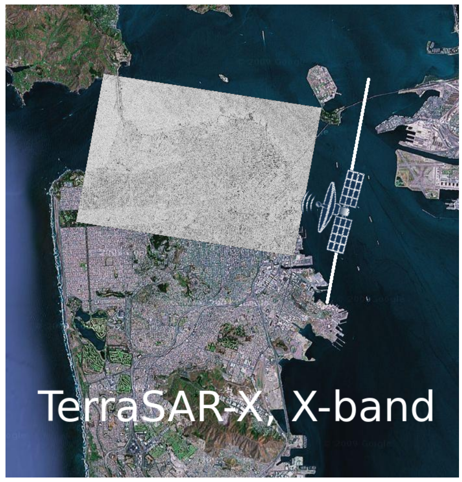


Figure 5. Entropy on TerraSAR-X image

For the first one:

- High entropy in TerraSAR-X is due to the relative noise of the sensor. We know that noise is particularly high on the experimentally HV channel.
- High entropy in TerraSAR-X relates to the wavelength.
- High entropy in TerraSAR-X relates to the degree of complexity of the scene, and the resolution-cell size.

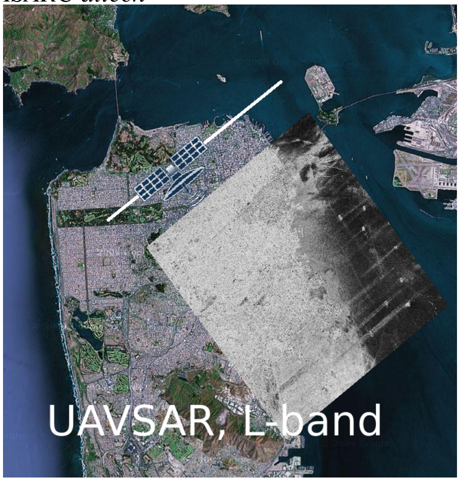
To invalidate the initial assumptions and to confirm the last one, we have adopted a multi-layered approach by using both EM simulations, statistics simulations, and analysis of available images. To this aim we got a set of polarimetric images available on the same area, and we analyzed the levels of entropy results in light of parameters of the different sensors: AIRSAR, SIR-C, ALOS, RADARSAT-2, TerraSAR-X, UAVSAR. Thus we can discuss the comparison of mean levels of entropy for various resolutions, various pixel size, and various wavelengths.

In the recent POLSAR image of UAVSAR, the SOMA district is oriented parallel to the trajectory axis. Entropy of SOMA is lower than for the other districts, as can be seen in Fig. 3.

In addition, all other districts have very high entropy, although it is L-band data. This allows us to invalidate some of our initial assumtions: a high entropy is not only linked to high frequency used by TerraSAR-X, neither to bad Signal to Noise Ratio.

As UAVSAR and TerraSAR-X resolutions are better than in other satellite sensors, we believe that high entropy is linked to the combination of two factors:

Figure 6. Entropy on UAVSAR image, courtesy of JPL/NASARC altech



- When orientation of the streets are not strictly the same than the sensor trajectory, all mechanisms have comparable amplitudes
- When resolution dimensions lie around one meter, the different mechanisms are mixed together in the estimation of the coherence matrix, and then the estimated entropy is very high.

4. TOWARDS TEMPORAL ESTIMATION

We have seen that for oriented districts, and for some resolution ranges, entropy is high when estimated spatially and therefore, it cannot be used efficiently for built-up detection or land classification.

Two solutions are possible to improve results in this resolution range:

- The use of spatial filtering algorithms really adapted to the structural complexity of the environment, such as NL-SAR filter.
- The use of a temporal estimation. If a few years ago, access to polarimetric SAR data on the same site were rare, today the number of revisits over the same site increases, and can be used for a statistics estimation of second order parameters.

In order to demonstrate the potential of a temporal estimation, we calculated the entropy of parts of image for three types of estimation:

- A spatial average over 3 pixels
- A spatial average using a classical 5x5 pixels.

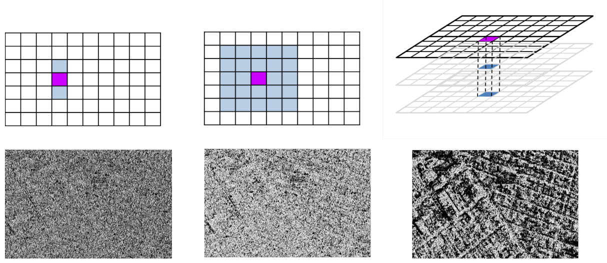


Figure 7. Entropy maps computed using different methods

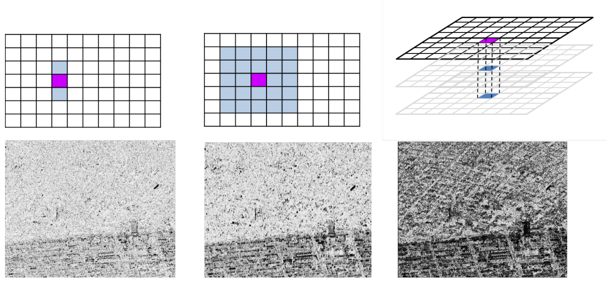


Figure 8. Entropy maps computed using different methods

- A temporel average using 3 passes

over an extract of a TerraSA-X image, and over an extract of a UAVSAR image.

Results on the TerraSAR-X image presented in Fig. 7 show that a spatial estimation gives poor results, whereas a contrast seems to appear between deterministic and non deterministic targets using a temporal estimation over only 3 pixels.

On the UAVSAR image, when we increase the number of pixels used in the spatial estimation, the contrast between districts with different orientations increases. When we use the temporal estimation, then the contrast between these different districts decreases, while the contrast between deterministic and non deterministic targets increases, as shown in Fig. 8.

These results need to be confirmed on larger temporal image stacks, but they are very promising for the benefit of temporal estimates in urban polarimetric images.

5. CONCLUSION

This comprehensive study allows us to make the following conclusions:

- Entropy is obviously affected by the thermal noise of the sensor. However, this influence is less com-

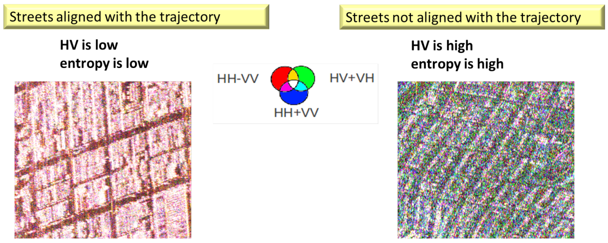


Figure 9. Introduction to the two types of district configurations

pared to the following two influences: building orientation, and resolution-cell size.

- Disorientation in urban areas is not only followed by an increase of the cross pol signal, but also an increase of entropy. Disorientation leads to mix randomly the mechanisms and makes it impossible or at least very difficult to correct the effect of deorientation on the double-bounce mechanism: even if we are able to highlight the presence of this effect, other mechanisms involved remain mixed in the resolution cell. This leads to the common misclassification results, even with deorientation effects.

- High entropy in urban areas is strongly linked to resolution-cell size. For a given wavelength, at L-band, entropy remains low when resolution is poor. Entropy increases with improved resolutions, probably because the spatial variability of polarimetric behavior is more important. For large resolution cells on the contrary, the behavior is more stable in a cell to another one.

To summarize, there are thus two major types of configurations we can face in a polarimetric image as depicted on Fig. **??**: that of a well oriented district whose entropy and HV backscattering is low and that of a deoriented district with high HV signal, and high entropy also, especially when estimated spatially.

REFERENCES

[1] Thirion-Lefevre, Laetitia and Guinvarc'h, Regis and Colin-Koeniguer, Elise and Mokadem, Azza, Propagation mechanisms in urban canyons. Distorsions and entropy, EUSAR, 2014

[2] Weissgerber, F and Colin-Koeniguer, E. and Trouvé, N. and Nicolas, J-M. , 2014, Statistics for complex correlation coefficients applied to advanced SAR modes: Interferometry and Polarimetry, International Radar Conference, 2014