THE PHASE INFORMATION CONTENT OF COMPLEX MULTIFREQUENCY MULTIPOLARIZATION SAR IMAGES[1]

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ABSTRACT:

Complex multichannel SAR images carry two types of meaningful information: the channel amplitude or intensity (relative energy information) and phase differences among pairs of channels. In this work we are mainly concerned with the second case. Phase information is considered present when a preferential phase (the mode) can be detected. This phase information is discriminatory if it is possible to relate different phases differences to distinct objects. A multivariate gaussian assumption for the complex scattering amplitudes leads to phase differences distribution in which the mode of the distribution is equal to the phase of the complex covariance between channels (when the modulus of the distribution is adequately large to ensure significance). Tests were carried out on data gathered over an agricultural area in Britain by the Maestro 1989 campaign and it was found that different HH-VV phases differences can be assigned to distinct agricultural fields, being the mode of phase distribution compatible with the phase of complex covariance between these two channels.

KEY WORDS: SAR, Radar image processing, polarimetry, phase information.

1.INTRODUCTION

Polarimetric multifrequency SAR images provide five potential information per pixel and per frequency. These are three amplitudes and two phases differences in the scattering matrix[1]:

$$S_f = \begin{pmatrix} S_{f11} & S_{f12} \\ S_{f12} & S_{f22} \end{pmatrix} \quad (1)$$

where f is frequency and reprocity is assumed. Phase difference is a distinctive feature of polarimetric data and will be the focus of this work. It will be investigated how one can define and measure phase information and its quality. Can this phase difference be used as a feature for object classification?

In a earlier work [2], during the construction of MSAR covariance model, under the image formation point of view, it was supposed that phase differences between two channels are fixed and this value, object dependent. This constant phase difference appears as the argument of the covariance between two channels, when normality and extended target assumptions are assumed . How much is the case for real data? Practical experiments show however that this phase difference is not unique, but spread around a most likely value: the mode.

At this point some definition is convenient. Phase information is present when there is a narrow distribution for phase differences, which means that for a particular pair of channels (and a certain object) is possible to find a preferential value of phase. This is the mode of the distribution. This phase information is discriminatory if a set of objects in a scene show different phase differences, which can be used as features to separate them.

A working hypothesis for distributed targets in quadpolarized data[3] is that the scattering matrix elements obey a zero-mean multivariate complex gaussian distribution.:

$$p(S) = \frac{1}{\pi^3|C_S|}\exp\left(-S^T C_S^{-1} S\right) \quad (2)$$

where $S = (S_1, S_2, S_3, ..)^T = (S_{111}, S_{112}, S_{122}, S_{211}, ...)^T$. The covariance matrix of the complex scattering amplitudes is given by $C_S(i,j) = E[S_i S_j]$ and E[] denotes expectation. On the basis of scattering models, we expect $E[S_1 S^*_2] = E[S_2 S^*_3] = 0$, and $E[S_i S^*_j]=0$, when different frequencies are involved. For one frequency, C_S has the form:

$$C_S = \begin{pmatrix} \sigma_{11}^2 & 0 & \rho \\ 0 & \sigma_{12}^2 & 0 \\ \rho^* & 0 & \sigma_{22}^2 \end{pmatrix} \quad (3)$$

For this distribution, the phase difference distribution between two channels i and j has PDF[3]:

$$p(\theta) = \frac{1}{2\pi}\left(\frac{1-X^2}{1-Y^2}\right)\left(1+\frac{Y}{\sqrt{1-Y^2}}\left[\frac{\pi}{2}+\sin^{-1}Y\right]\right) \quad (4)$$

for θ in the range $-\pi < \theta \leq \pi$, where

$$X = \frac{C_{ij}}{\sqrt{C_{ii}C_{jj}}}$$

is the correlation coeficient of channels i and j and

$$Y = |X| \cos(\theta - Arg(X))$$

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This distribution is uni-modal, with mode = Arg(X), and shape controlled by |X|.Low |X| means flat distribution, high |X| means peaked distribution.

Data from 1989 Maestro campaign provided an opportunity to investigate phase properties and hypothesis used for the model construction, which are in brief: once there exists a fixed phase difference between two polarizations, this will appear as the argument of the covariance between these two channels and this will also be the mode of this phase difference, provided |X| is large enough. In this paper uncalibrated data will be used for investigating the properties of phase prior to any radiometric correction. In a subsequent paper it will be investigated how the calibration procedures can modify phase definition quality and discriminatory power.

2. CHECKING PHASE PROPERTIES

Observing the histogram of phases differences one can see what is the mode (within certain precision), and compare if this mode agree with the argument of the covariance or how the spread of the distribution depends on the correlation coeficient.

However, when dealing with MSAR images, the number of channels combinations is high and visual inspection of histograms is not practical, besides the uncertainty of the method. An automatic method was chosen to find the mode for each calculated phase difference, by estimating the rate of an inhomogenous Poisson process by J<u>th</u> waiting times[4].

For evaluating the flatness of the distribution, one can use the kurtosis, the normalized fourth moment of a distribution for which one possible estimate is:

$$\mathrm{kurt}(x_1,\ldots,x_N) = \left\{\frac{1}{N}\sum_{j=1}^{N}\left[\frac{x_j-\bar{x}}{\sigma}\right]^4\right\}-3 \qquad (5)$$

Kurtosis is a nondimensional quantity which measures the relative sharpness or flatness of a distribution, being 0 (zero) for the gaussian distribution. Care is needed, because phase is periodic, so a convenient 2π window must be set, to calculate the moments. The mode is the natural choice to center this window. If a phase distribution is very peaked, the mean is expected to be near of the mode and the kurtosis a large positive value. If the distribution is flat, the mode and mean can be very different from the covariance argument (because of the instability of the situation), and the kurtosis will be negative.

3. RESULTS

The model described above was tested using relatively homogeneous areas from the UK test-site. Phase difference properties and quality were tested on a fairly large agricultural area in Reedham (four polarizations - C band)- 1 class only. The availability of ground data over the Feltwell test site allowed the study of phase difference discriminatory power and consistency. Four different crops and ground cover were defined using four polarizations and frequencies C and P: sugar beet (four test-sites), stubble (five test-sites), wheat (three test-sites) and potato (two test-sites).

Table 1 presents the modulus and argument of the correlation coefficient, the mode (31 wait times), the average around this mode, and the kurtosis for three channel combinations: HH-VV (S_{11}-S_{22}), HV-VH and HH-HV - Reedham area. It is possible to observe that, contrary to that one can expect, the correlation coefficient between HV and VH is not ONE, probably due to cross-talk [5].

TABLE 1
PHASE DIFFERENCES PROPERTIES AND QUALITY

channels	$\|\rho\|$	$\angle\rho$	mode	average	kurt
HV-VH	0.945	-73.100	-75.900	-72.800	8.930
HH-VV	0.511	-91.300	-96.400	-93.800	0.020
HH-HV	0.034	-16.100	-139.700	-137.800	-1.220

The mode and average are consistent (similar) with the argument of covariance in the HH-VV and HV-VH cases, although the kurtosis is much higher for the HV-VH case.This is also coherent with the fact that the correlation is higher in the second case. In the HH-HV case, the argument of the correlation does not agree with the mode and average and the kurtosis is lower than -1.2 (-1.2 is the lower theoretical value for kurtosis for non-valley distributions - flat distribution case). So the general behavior is consistent with the model for phase difference distribution.

Table 2 presents some phase differences for Feltwell area, frequencies C and P and Table 3 presents the range of correlation coeficient for each class and channel combination. In general, it is possible to note that, although these test-site were not very large because of reduced field sizes, there is a relative stability of phase difference values within the same class and some divergence when comparing two distinct classes. Sugar beet is distinct from wheat and potato by ~70 degrees in HH-VV_P . Stubble is distinct from other classes by ~20 degrees.

TABLE 2
PHASES DIFFERENCES

classes	HH-VV_C	HH-VV_P	HV-VH_P
sugar beet	-58.000	-36.300	69.500
	-61.300	-29.600	67.500
	-60.900	-33.200	69.700
	-60.900	-33.400	68.500
stubble	-45.000	-64.800	68.100
	-40.700	-118.000	-115.000
	-44.700	-80.100	106.000
	-46.000	-78.600	70.700
	-47.600	-71.500	-88.700
wheat	-55.600	-103.200	-1.200
	-61.000	-104.200	-61.000
	-43.600	-103.000	63.700
potato	-64.900	-104.300	71.700
	-63.100	-102.000	68.800

TABLE 3
CORRELATION COEFICIENT RANGES

classes	$HH\text{-}VV_C$	$HH\text{-}VV_P$	$HV\text{-}VH_P$
sugar beet	~0.66	.56-.61	.38-.61
stubble	.50-.71	.12-.60	.04-.18
wheat	.27-.34	.18-.28	.07-.31
potato	.51-.54	.43-.57	.70-.78

Lower stability is noticeable for the cases when the correlation coefficient is low. For example, the anomalous value -118 degrees for $HH\text{-}VV_P$ (stubble) occurs when the correlation is .12. The greater variability of wheat coincides with low correlations.

Special note has to be given to $HV\text{-}VH_P$: for stubble and wheat classes the correlation is low, in contradiction to that is expected by the theory. This result can be explained due to cross-talk and the influence of noise in low backscatter regions, as discussed in [5]. HV-VH phases differences for C band were ~103 degrees, which goes to zero when calibration is done. No discrimination was observed when using HV-VH. All other remaining correlations were zero and no other phase information was observed.

4. CONCLUSIONS

The overall conclusion is that the phase information can be observed, that is, it is possible to have well peaked phase differences but only HH-VV phases can be discriminatory, and independent from amplitude information. Amplitude information seems to have influence on the level of noise included in the phases statistics and so in the phase information quality. These results reinforce the importance of working with complex data, and suggest that, even without calibration, phases differences can be potentially used for classification.

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