Texture methods for sea waves' classification with the use of SAR images

Research Team
V. Karathanassi, Lecturer
K. Topouzelis, D. Sarantopoulos, C. Iossifidis
Laboratory of Remote Sensing, National Technical University of Athens,

INTRODUCTION

Low spatial and temporal resolution of sea wave height and direction data derived from relevant numerical models, lead to the SAR image processing investigation. In this direction, different phenomena which affect the radar imaging mechanism were studied. Among them, the following are considered to be most significant (1): velocity bunching, tilt modulation, hydrodynamic modulation, and range dependence.

Although the previous phenomena have been significantly investigated, the effect of surface wave motion on the SAR imaging mechanism still remains unclear. Most of the studies of SAR imaging water surface waves use the image spectrum approach (2,3,4,5). Another approach for extracting wave characteristics through SAR images is texture analysis. Significant wave height was estimated with relatively high accuracy, using X band radar sea surface images and texture analysis (6). Accuracy was found to be low in case of heavy precipitations.

In this study the authors investigated the potential of texture analysis to detect wind direction (7), wind intensity, significant height of waves and waves' direction. It was clearly shown that texture indices were strongly associated to wave direction. Thus an attempt to extract information on sea wave direction was made. Texture theory and algorithms were applied so as to develop the most appropriate methodology in order to extract wave direction accurately. The methodology was evaluated over light wind conditions. Through this methodology, phenomena which affect the radar imaging mechanism were revealed and an attempt to measure and eliminate their effects was made. Moreover, the texture parameters most associated to wave direction were indicated, thus providing an application of texture analysis in sea wave direction extraction.

METHODOLOGY

In this study, second order statistical information based on Haralick's cooccurrence matrix method was selected and applied on SAR images. Cooccurrence matrices count how often pairs of gray levels of pixels, which are separated by a certain distance and lie along a certain direction, occur in a digital image. Usually, they are not used directly but features based on them are computed. These features describe some characteristics of texture, such as homogeneity, coarseness and periodicity. Haralick et al. (8) suggested the use of 14 textural features. The ideal option regarding the extraction of wave direction would be the calculation of cooccurrence matrices for the entire 0^o to 180^o range, with $10\ ^o$ angular span. But given current computational storage and speed capacity, this is hardly handled, since the size of a single image after geometric THALES Project No. 65/1173correction is approximately 160Mb and each direction produces eight image files, each one much larger in size because it contains float numbers. Therefore, as tilt modulation and velocity bunching are more pronounced for range and azimuth wave components respectively, the range and azimuth direction of the SAR image defined the main directions for which texture measurements were implemented. In this way, the study of these phenomena through texture analysis can also be carried out. The next figure shows the directions proposed.

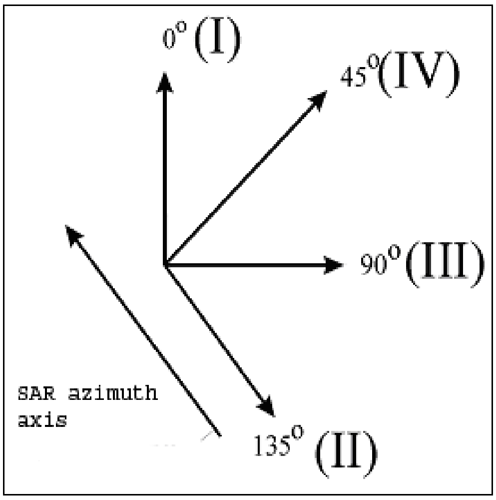


Figure 1. The directions for which cooccurence matrices were calculated

An a priori evaluation of the textural features which are most associated with sea wave characteristics was implemented. Its results provided eight features to be calculated through cooccurence matrices and further examined. These are: mean, variance, homogeneity, contrast dissimilarity, entropy, angular second moment and correlation. Each feature provided a textural image. Further analysis of the textural images is within the main objectives of this work.

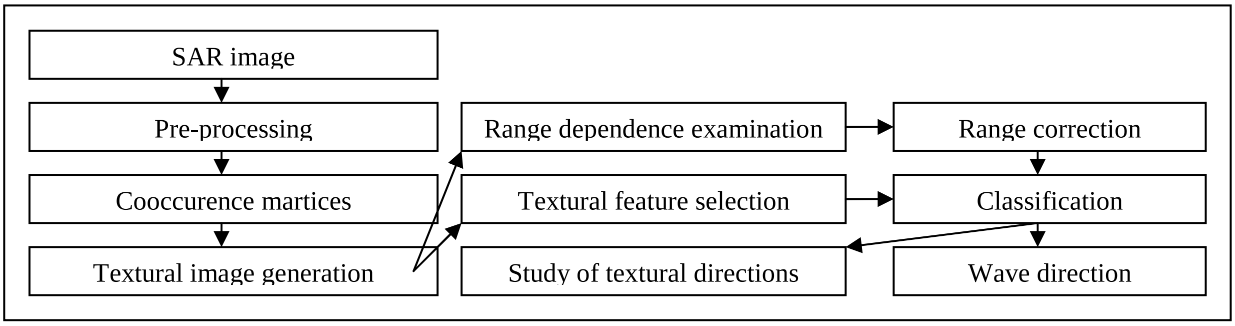


Figure 2. The methodology proposed

Apart from resolution reduction, preprocessing procedure included speckle filtering, as well as geocoding. The former reveals the variability hidden in the backscatter cross-section, caused by superimpositions of coherent contributions from several discrete scattering elements on the sea surface. The latter was required for the comparison of method results with those derived by the hydrodynamic model.

METHOD IMPLEMENTATION

SAR and ancillary data

The south-east Aegean sea area was chosen as a study area. The ERS II image captured on September 10, 2000 was selected. According to the National Meteorological Service of Greece, at the time when image was captured, wind speed was 8 nautical knots. Data on sea wave direction were provided by the TOPEX /POSEIDON hydrodynamic model developed by the Greek National Centre for Marine Research. These have a spatial resolution equal to 0.05 ^{o}, which in the Hellenic Geographic Coordinate System (EGSA 87) corresponds to 4500m and 5548m in the x and ψ axis, respectively. Figure 3 shows the study area, as well as wave direction as derived from the TOPEX /POSEIDON hydrodynamic model. Points in figure 3 are coloured according to wave direction. Wave directions for the study area range from 101 ^{o} to 159 ^{o}.

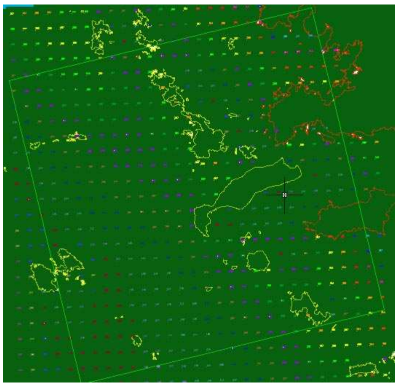


Figure 3. The TOPEX /POSEIDON data for the study area in CAD environment

After further processing, the data of the model were presented as a raster image. In the raster image, wave directions were classified into 18 categories using a 3 ^{o} step.

Application of the cooccurrence matrix method. Range correction

Cooccurrence matrices were calculated with one pixel distance for the directions defined in figure one. In test areas ,several window sizes were examined (7x7, 11x11, 15x15, 19x19, 23x23, 27x27 and 29x29). By visual inspection, the 29x29 window size was selected as the most appropriate for the calculation of the cooccurrence matrices, because it shows texture most consistently. Each direction implies a cooccurrence matrix. Based on elements p(i,j) of the cooccurrence matrix, the following textural features were calculated for each direction: mean, variance, homogeneity, contrast dissimilarity, entropy, angular second moment and correlation. Each feature generates a textural image, hence 36 images were totally generated for the four directions. Variations on the textural images were examined and the images presenting the features of angular second moment and correlation were excluded from further analysis because they did not contain any useful information.

In the rest of the textural images, it was observed that sea areas with the same wave direction were shown with different textural values if they were on different positions along lines with a direction similar to that defined by the ground range of the SAR image, i.e. on different columns of the original SAR image. For example, sea areas with wave direction 128°-130° were presented with different textural values when they were in the far, middle or near ground range of the SAR image. According to the decay law of the electromagnetic energy with distance, lower radar image intensities are registered for larger distances. This affects textural features. For example, contrast will be higher for pixels found in the near range than for those found in the far range. Homogeneity has the opposite behavior. Dissimilarity follows the contrast behavior, etc.

Special consideration was given to deriving mathematical expressions of texture variation along range direction. For each textural image, a function was established as follows:

$$\Delta(t) = f(r) \quad (1)$$

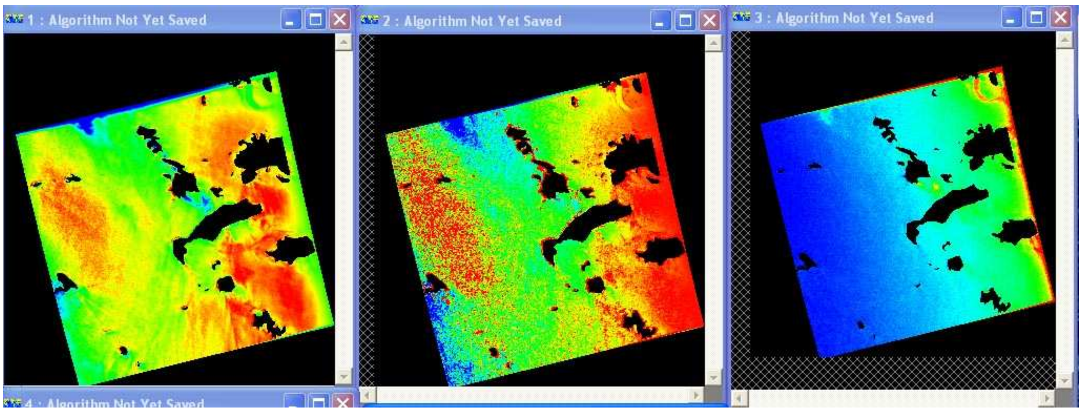
where t is the textural value, $\Delta(t)$ is its variation along range, and r is the range value, i.e. the number of the column in the original SAR image.

Then linear and non linear regression models, such as exponential and logarithmic models, were applied in order to reveal relationships between range and variation of the textural value and to calculate their correlation. For this, it was necessary to transform textural images, as well as raster data resulting from TOPEX / POSEIDON, to SAR image geometry. Samples with the same wave direction allocated along the range direction of the SAR image were selected in order to provide values to the models. Linear functions rendered relationships between range and variations of the textural values quite satisfactorily. The relationship established i.e. for the mean textural feature is $dt = 0.000888926\, r - 2.2114$.

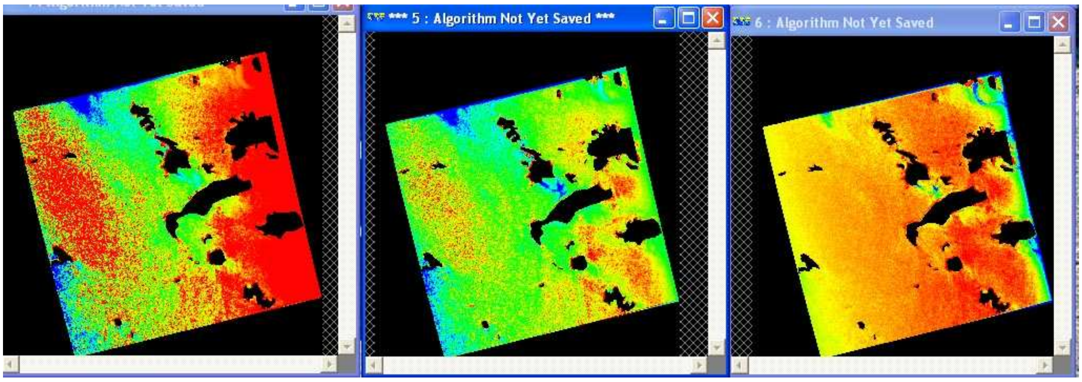
Once the functions were established, the transformed texture images were corrected by the dt value. The corrected texture values were derived by the relationship:

$$t_n = t_o \pm dt \quad (2)$$

After that, geometric correction of the range corrected images was implemented. Texture images, for the direction IV, following range correction, are given in figure 4.



(a) (b) (c)



(d) (e) (f)

Figure 4. Texture images of a) Mean, b) Variance, c) Homogeneity, d) Contrast, e) Dissimilarity, and f) Entropy, after range correction.

Classification. Evaluation of the results.

For each direction, supervised classification was performed using the maximum likelihood algorithm and the six corrected texture images from range dependence. Sea surface was classified into 18 wave direction classes. Results were compared with the respective reference image of the study area produced by the classification of the TOPEX/POSEIDON model data. Training and test sites for every category were selected from the TOPEX/POSEIDON raster images. Classification results are presented in table 1. In order to estimate range dependence on sea wave direction, supervised classification was also implemented on the original texture images for every direction. The overall accuracy of these classifications is given in table 2.

	Dir. I		Dir. II		Dir. III		Dir. IV	
	Error	Correct	Error	Correct	Error	Correct	Error	Correct
157-159	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%
153-156	5.3%	94.7%	5.3%	94.7%	0.7%	99.3%	12.9%	87.1%
149-152	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%
146-148	31.0%	69.0%	31.0%	69.0%	13.8%	86.2%	0.0%	100.0%
143-145	77.7%	22.3%	77.7%	22.3%	92.8%	7.2%	0.0%	100.0%
140-142	84.7%	15.3%	84.7%	15.3%	4.6%	95.4%	30.9%	69.1%
137-139	85.6%	14.4%	85.6%	14.4%	72.9%	27.1%	28.4%	71.6%
134-136	89.0%	11.0%	89.0%	11.0%	50.1%	49.9%	0.0%	100.0%
131-133	100.0%	0.0%	100.0%	0.0%	50.3%	49.7%	50.3%	49.7%
128-130	7.9%	92.1%	7.9%	92.1%	4.1%	95.9%	0.9%	99.1%
125-127	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%	0.4%	99.6%
122-124	60.5%	39.5%	60.5%	39.5%	0.1%	99.9%	27.1%	72.9%
119-121	18.0%	82.0%	18.0%	82.0%	100.0%	0.0%	53.5%	46.5%
116-118	0.0%	100.0%	0.0%	100.0%	1.3%	98.7%	0.0%	100.0%
113-115	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%	4.9%	95.1%
110-112	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%
107-109	33.5%	66.5%	33.5%	66.5%	0.0%	100.0%	0.0%	100.0%
104-106	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%
Overall Accuracy		74.9%		74.9%		86.6%		88.6%

Table 1. Classification results after range correction

Direction	I	II	III	IV
Overall Accuracy	27,10%	27,10%	46,60%	58,60%

Table 2. Overall classification accuracy before the application of range correction

Classification accuracy was significantly increased after range correction. An increase in the order of 30% was achieved for range direction and 48% for azimuth direction.

Texture analysis in the range direction (IV) produced the highest accuracy (88.6%). Indeed, tilt modulation contributes to better sea surface imaging by the SAR mechanism. The return signal tends to be stronger from the slope of those wave components which face towards the radar and weaker from those that face away. Thus alternations in signal intensity are more pronounced towards the range direction; hence texture analysis produces more accurate results towards this direction. On the contrary, towards azimuth direction (II), velocity bunching affects classification results which present 77.8% accuracy. Texture analysis towards this direction gives unreliable results since Doppler shift biases the wave components that are propagating in the azimuth direction. It should be noted that the light wind conditions which domain in the study area produce swells that are mostly affected by velocity bunching.Texture analysis in direction III, i.e. 90^o, produces overall accuracy similar to that produced in the range direction. Thorough examination of the accuracy produced by each class makes clear that this is probably random. Indeed, in direction IV, the classes of wave direction which are close to the azimuth direction (131^o-133^o) systematically present higher error, which means that even if the texture analysis is performed in the range direction, we cannot avoid velocity bunching effects produced by waves propagating in azimuth direction or having strong components in it. On the contrary, in direction III, errors are more randomly distributed among the wave direction classes. On the other hand, accuracy is higher in direction III than in direction II (azimuth) because significant components of waves having the range direction contribute to it. Moreover, accuracy in direction III is higher than in direction I because the azimuth components of the waves which contribute to it have a similar direction to that which prevails in the study area. Azimuth components which contribute to direction I have the negative direction, consequently increasing classification errors. To a degree, the above analysis permits determining the positive or negative propagation of a wave along a direction. Figure 5 shows classification results in the range direction.

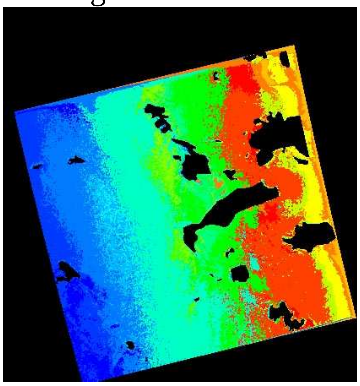


Figure 5. Classification of the wave direction resulting from texture analysis in range direction.

CONCLUSIONS

In this study, 2nd order texture analysis was performed in order to investigate a) the potential of texture to detect wave direction, b) wave range dependence, and c) velocity bunching effects on SAR images. Thorough analysis of background contribution to the textural values, detailed examination of the textural features which are sensible to sea wave detection, systematic investigation of the directions in which texture should be calculated and analysis of the classification results indicated that:

- range dependence is very pronounced in texture images. However, linear models can satisfactorily eliminate the range factor, which in the study case reduces results accuracy up to 48%.
- the mean, variance, homogeneity, contrast, dissimilarity, and entropy features are the most appropriate for the detection of sea wave direction,
- in texture analysis, the range direction of the SAR image is the most appropriate for calculating textural features due to tilt modulation.
- classification satisfactorily detects sea wave direction, producing overall accuracy in the order of 88%. Errors are mainly due to velocity bunching effects. Accuracy of estimations for the wave direction classes showed that velocity bunching seriously affects the detection of wave direction that coincides with the SAR azimuth direction.
- For the study case, overall accuracy produced by texture analysis in the diagonal directions indicated the negative propagation of the sea waves in relation to the SAR azimuth axis. But this needs further investigation.

Unsupervised classifications are the next step to be implemented in order to develop an automated method for sea wave detection and reduce the need for ancillary data. Moreover, further analysis should be performed for different sea state conditions.

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