

LINEAR FEATURE DETECTION IN SAR IMAGES

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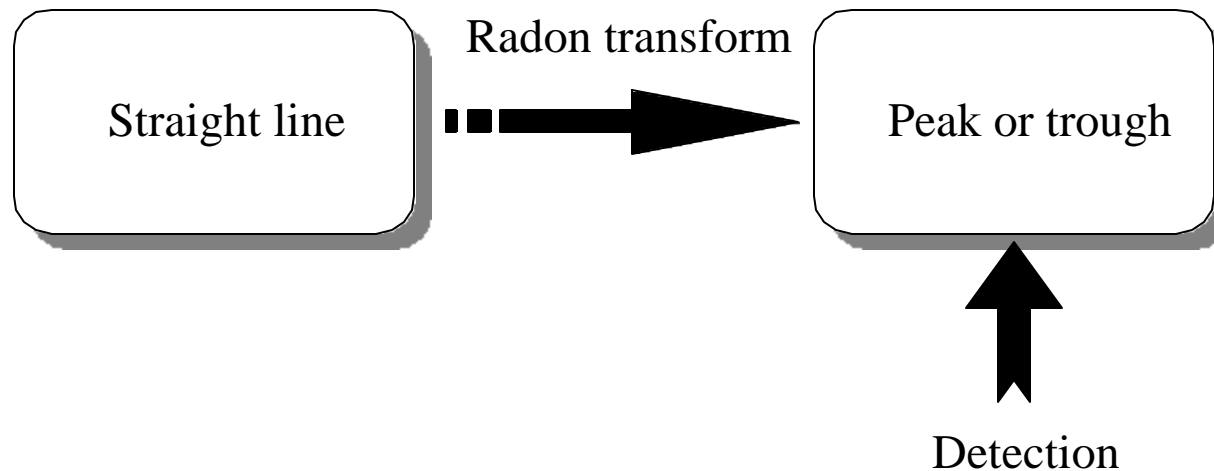
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LINEAR FEATURE DETECTION IN SAR IMAGES

INTRODUCTION

- Ship wakes in Synthetic Aperture Radar (SAR) images
- Detection using Radon transform (DEANS, 1983)



- SAR images affected by speckle
 - ↳ wedding between the Radon transform and a filtering method

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CONTENTS

- Radon transform

 - ↳ discrete form

- Stochastic matched filtering method

- Interpolation-filtering method

 - ↳ theory and subimage processing

- Experimental results on SAR images

 - ↳ comparison with the classical approach

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THE RADON TRANSFORM

○ Consider an image I , with dimensions $M \times M$

The Radon transform \hat{I} of this image is:

$$\hat{I}(x_\theta, \theta) = \sum_{y_\theta=-M/2}^{M/2} I(x_\theta \cos \theta - y_\theta \sin \theta, x_\theta \sin \theta + y_\theta \cos \theta)$$

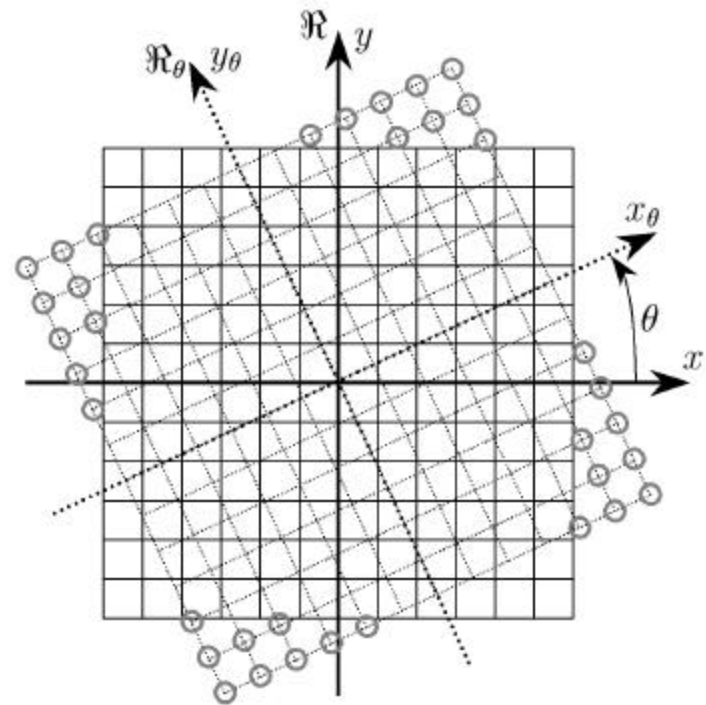
where $(x_\theta, y_\theta) \in \mathbb{Z}$ and $\theta \in [0; \pi]$

○ Problems : - new pixel coordinates in $\mathcal{R} \notin \mathbb{Z}^2$

↳ Computation of the new pixel values

- pixels localized at the edge in $\mathcal{R}_\theta \notin I$ (surrounding points)

↳ Edge effect \Rightarrow size of the image in $\mathcal{R}_\theta : \frac{M}{\sqrt{2}} \times \frac{M}{\sqrt{2}}$



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STOCHASTIC MATCHED FILTERING METHOD

○ Consider the stationary noise-corrupted signal defined over D :

$$Z(x, y) = S(x, y) + B(x, y)$$

where signal $S(x, y)$ and noise $B(x, y)$ are assumed to be independent.

○ Observed signal expansion:

$$\hat{Z}(x, y) = \sum_{n=1}^Q z_n \Psi_n(x, y)$$

where: $\left\{ \begin{array}{l} \Psi_n(x, y) : \text{deterministic and linearly independent basis functions} \\ Q : \text{number of basis functions retained for the expansion} \\ \text{uncorrelated random variables defined by } z_n = \iint_D Z(x, y) \Phi_n(x, y) dx dy \end{array} \right.$

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○Determination of functions $\Phi_n(x, y)$

↳ Making sure z_n are uncorrelated

↳ Optimization of the signal to noise ratio K expressed as a Rayleigh quotient

⇒ K will be maximized if $\Phi_n(x, y)$ are solutions of:

$$\iint_D \Gamma_{SS}(x - x', y - y') \Phi_n(x', y') dx' dy' = \lambda_n \iint_D \Gamma_{BB}(x - x', y - y') \Phi_n(x', y') dx' dy'$$

where Γ_{SS} and Γ_{BB} are the covariances of the signal and of the noise

○Determination of functions $\Psi_n(x, y)$

$$\Psi_n(x, y) = \iint_D \Gamma_{BB}(x - x', y - y') \Phi_n(x', y') dx' dy'$$

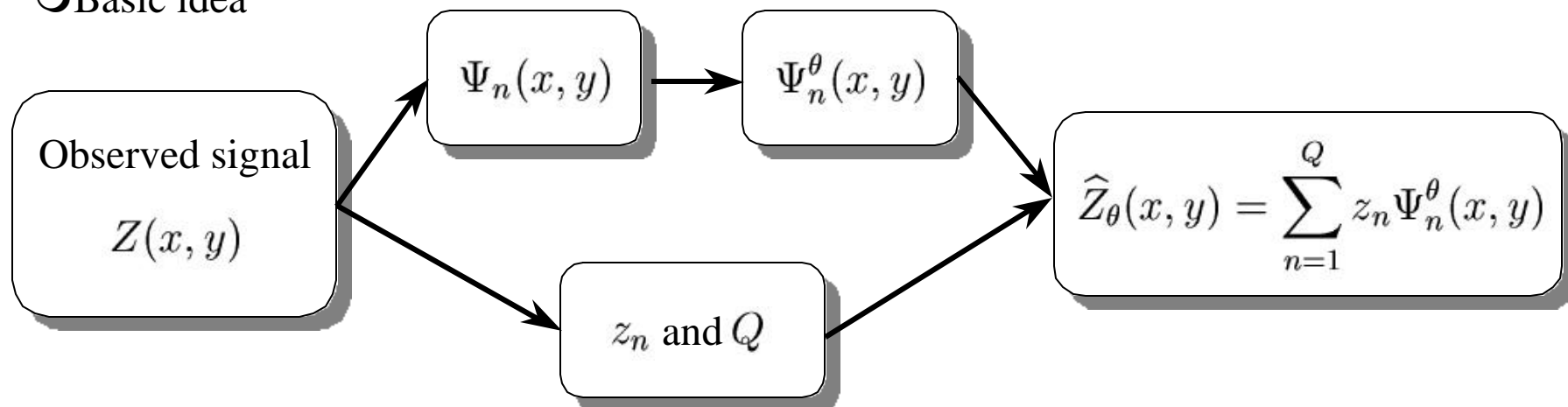
○Signal to noise ratio of the n^{th} component of $Z(x, y)$: $\frac{\sigma_S^2}{\sigma_B^2} \lambda_n$

⇒ number Q of basis functions such as $\lambda_Q \geq 1$

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INTERPOLATION-FILTERING METHOD

○ Basic idea



↳ Observed signal expansion and restoration using interpolated functions $\Psi_n(x, y)$

○ Defaults: heavy CPU budget and memory problems

⇒ new formulation using the discrete cosine transform

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- $Z(x, y)$ interpolation-filtering using DCT, with $D = [-T; T]^2$

Functions	DCT coefficients	
$\Phi_n(x, y)$	$\alpha_{k,l}^n$	$\Phi_n(x, y) \iff \sum_{k=0}^{Nf} \sum_{l=0}^{Nf} \alpha_{k,l}^n \Omega_{k,l,p,q}^{\Gamma_{SS}} = \lambda_n \sum_{k=0}^{Nf} \sum_{l=0}^{Nf} \alpha_{k,l}^n \Omega_{k,l,p,q}^{\Gamma_{BB}}$
$\Psi_n(x, y)$	$\beta_{p,q}^n$	$\Psi_n(x, y) \iff \beta_{p,q}^n = T^2 \sum_{k=0}^{Nf} \sum_{l=0}^{Nf} \alpha_{k,l}^n \Omega_{k,l,p,q}^{\Gamma_{BB}}$
$Z(x, y)$	$\vartheta_{p,q}$	
$\hat{Z}(x, y)$	$\hat{\vartheta}_{k,l}$	$z_n \iff z_n = T^2 \sum_{p=0}^{Nf} \sum_{q=0}^{Nf} \vartheta_{p,q} \alpha_{p,q}^n$
Γ_{SS}	$\Omega_{k,l,p,q}^{\Gamma_{SS}}$	
Γ_{BB}	$\Omega_{k,l,p,q}^{\Gamma_{BB}}$	$\hat{\vartheta}_{k,l} \iff \hat{\vartheta}_{k,l} = \sum_{n=1}^Q z_n \beta_{k,l}^n$

- Signal of interest restoration in \mathfrak{R}_θ

$$\hat{Z}_\theta(x_\theta, y_\theta) = \sum_{k=0}^{Nf} \sum_{l=0}^{Nf} \hat{\vartheta}_{k,l} \cos\left(\frac{\pi k(x_\theta - T)}{2T}\right) \cos\left(\frac{\pi l(y_\theta - T)}{2T}\right)$$

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Subimage processing

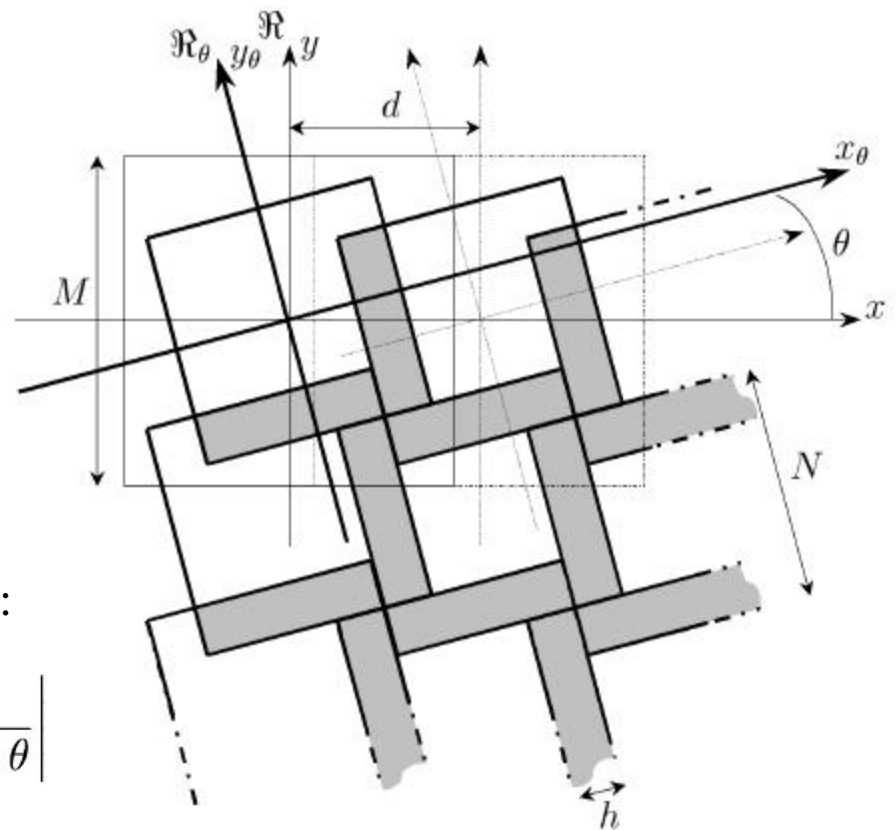
○ Assumption: $Z(x, y)$ is stationary
 ⇒ necessity of a subimage processing

○ Edge effect
 ⇒ overlapping between adjacent subimages:

$$d = \frac{N}{\cos \theta + \sin \theta} \quad \text{and} \quad h = \left| \frac{N \sin \theta}{\sin \theta + \cos \theta} \right|$$

○ Smoothing effect when Q is the same for the whole image
 ⇒ minimization of the mean square error to find Q for each subimage

$$\bar{\epsilon} = \sigma_S^2 + \frac{1}{4} \sum_{n=1}^Q (\sigma_B^2 - \lambda_n \sigma_S^2) \sum_{k=0}^{Nf} \sum_{l=0}^{Nf} (\beta_{k,l}^n)^2$$



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EXPERIMENTAL RESULTS

○ SIR-C/X-SAR image

↳ moving ship

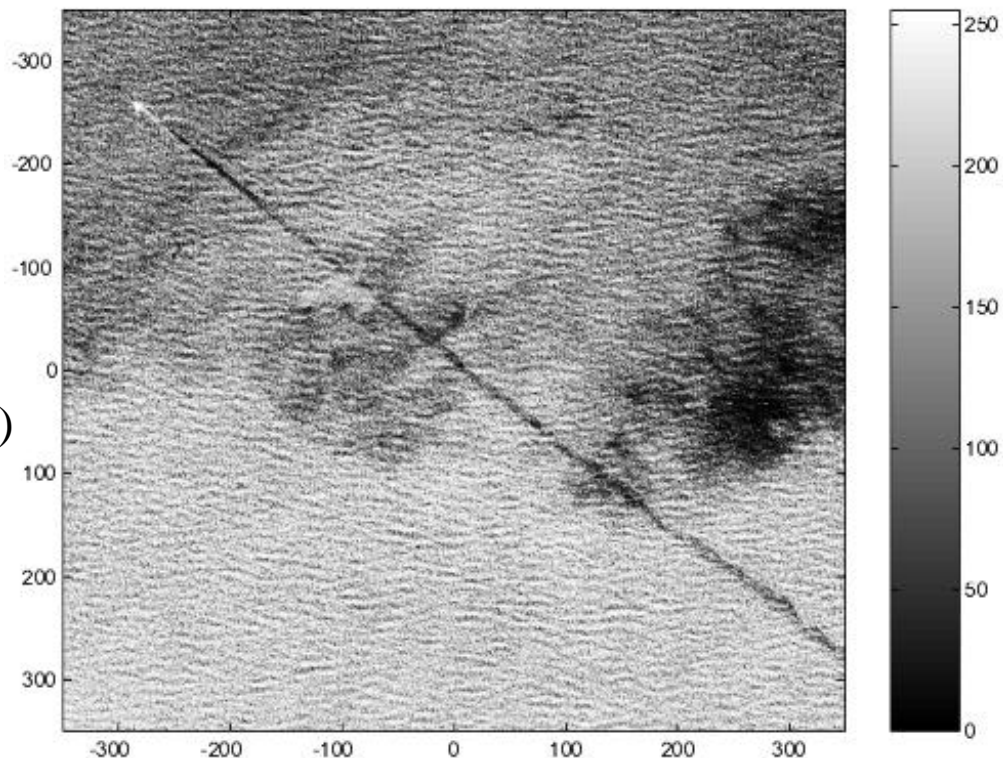
↳ dark turbulent wake (17 miles)

○ 256 gray levels (0: black, 255: white)

○ Image size: 698×698

○ Variation coefficient: 0.277

○ Difficulty: dark patches in the upper right corresponding to smooth area of low wind

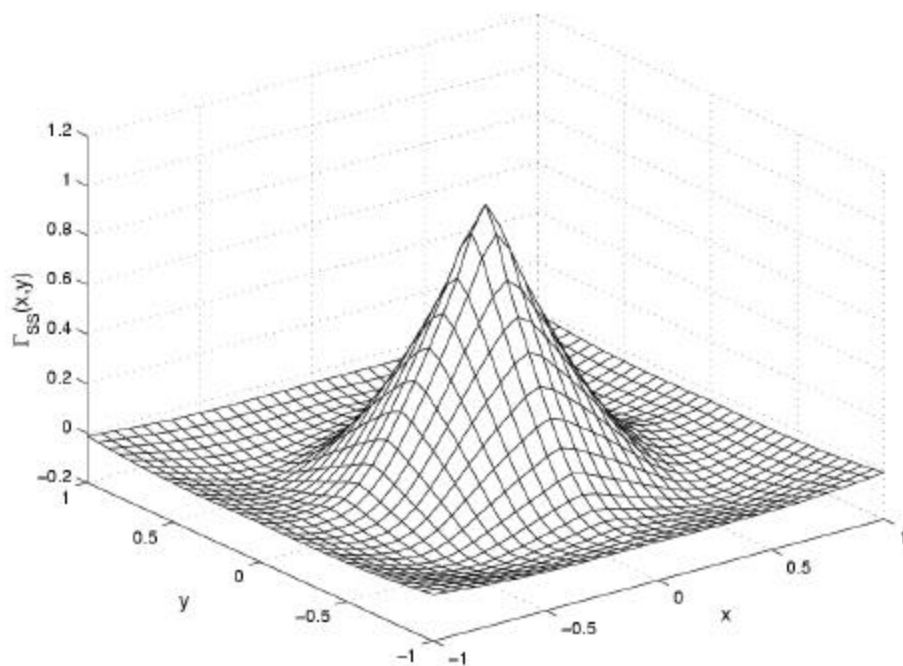


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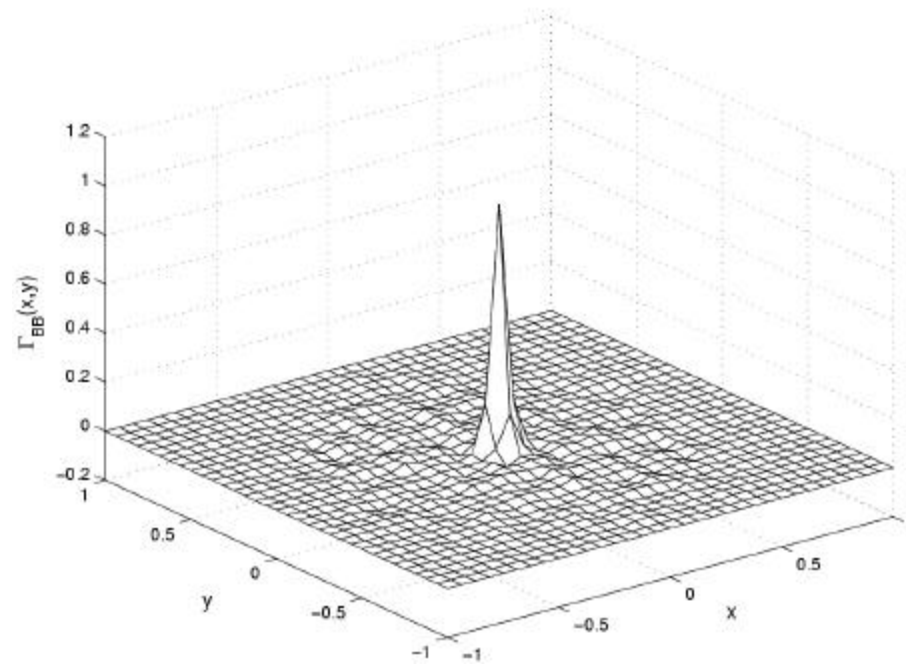
Signal and noise auto-correlation functions

○ *a priori* knowledge of the signal and the noise auto-correlation functions

⇒ determination of normalized auto-correlation models



Signal auto-correlation function

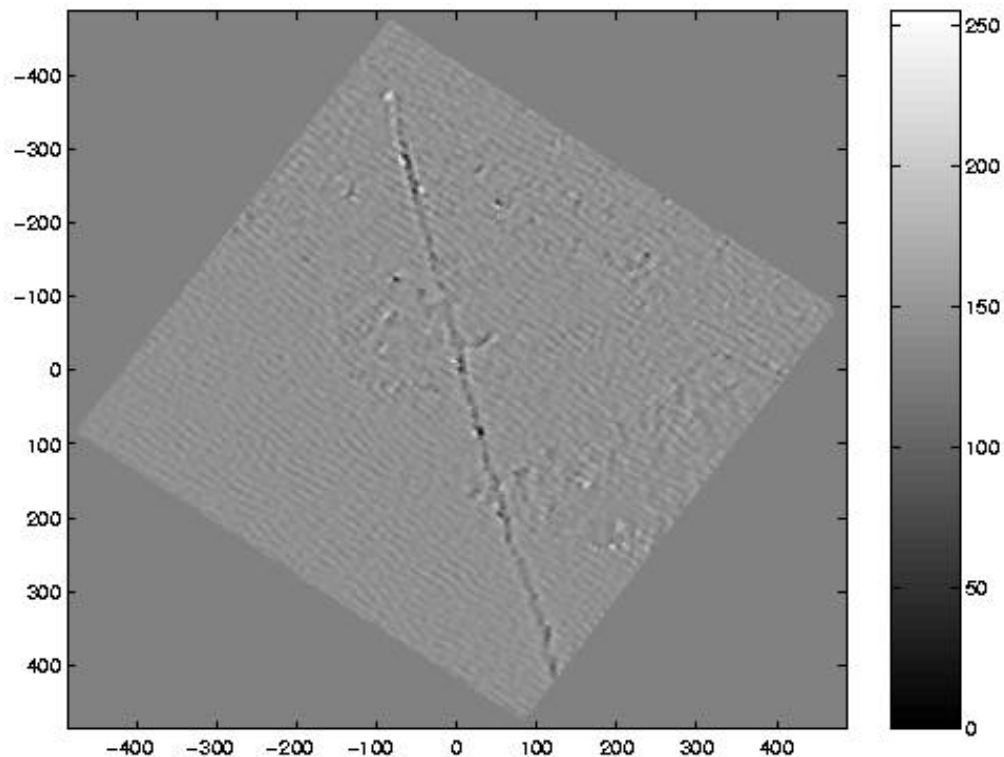


Noise auto-correlation function

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Interpolation-filtering of the SIR-C/X-SAR image

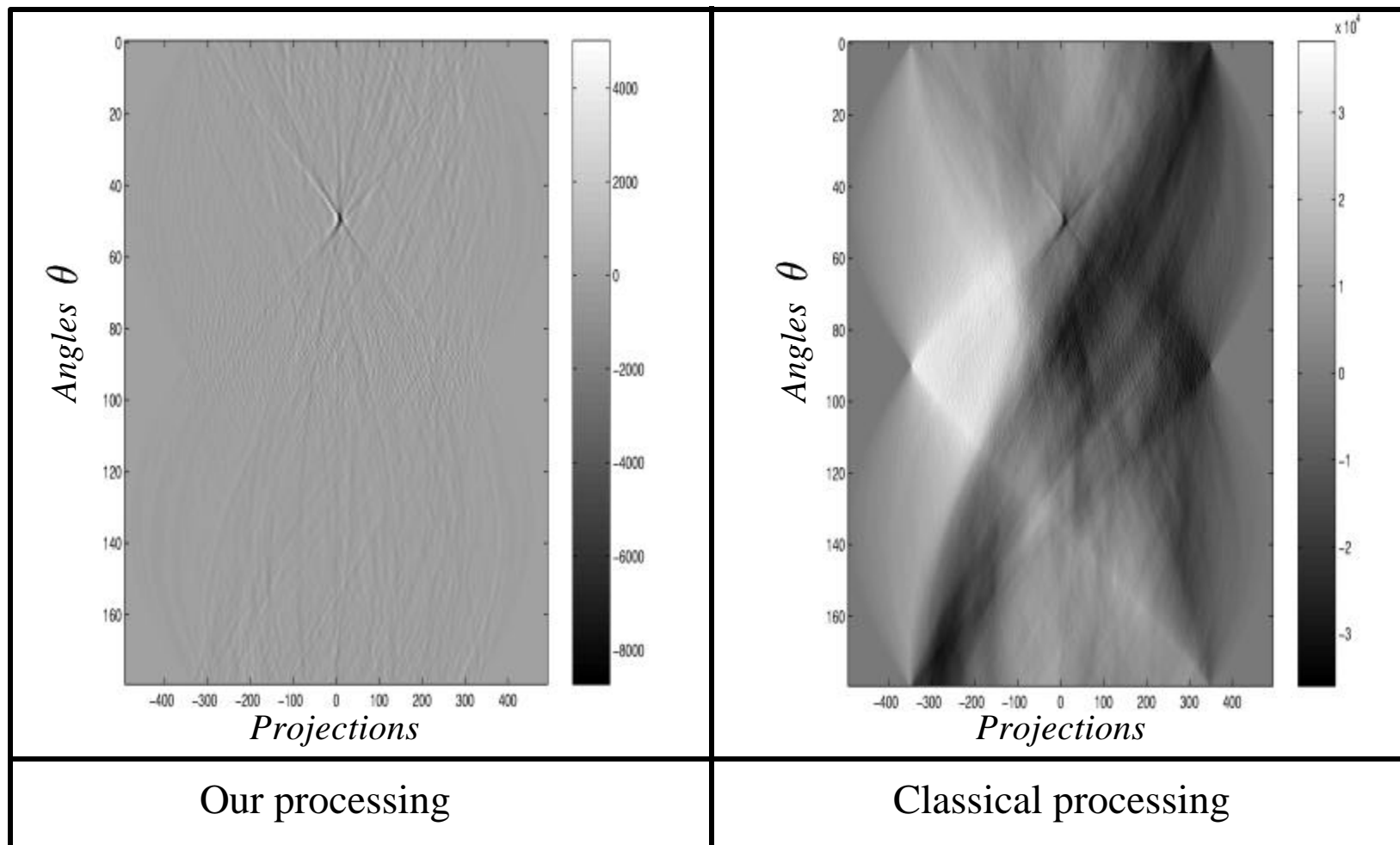
- Rotation angle: 35°
- Number Q of basis functions:
 - ↳ approximately 13 for the wake
 - ↳ near 1 for the rest of the image
- Image size: 973×973
- Variation coefficient: 0.016



SIR-C/X-SAR image in reference system \mathcal{R}_{35}

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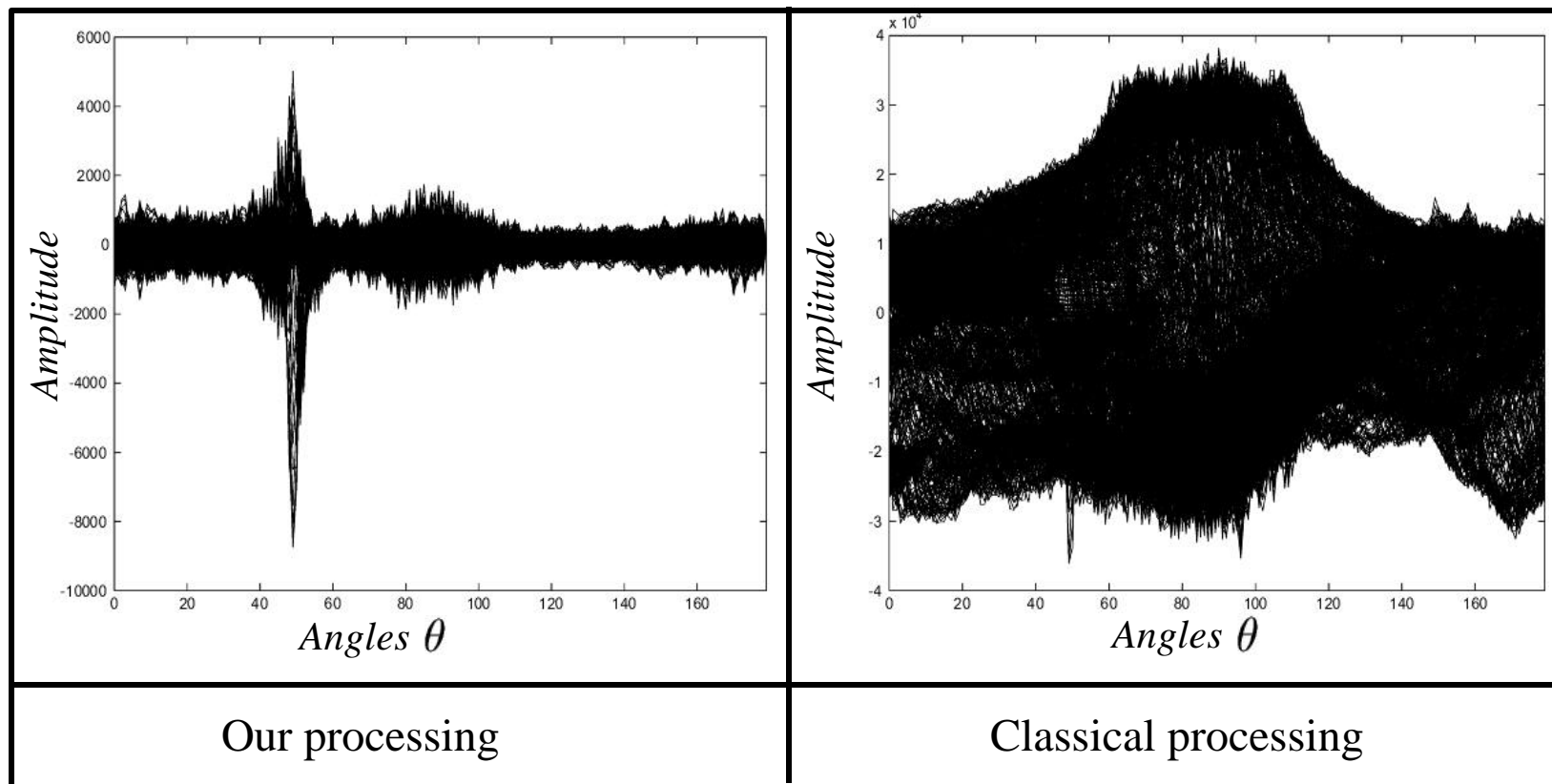
Radon domain displayed as image



↪ Trough corresponding to the wake localized near 51°

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Radon domain displayed as graph



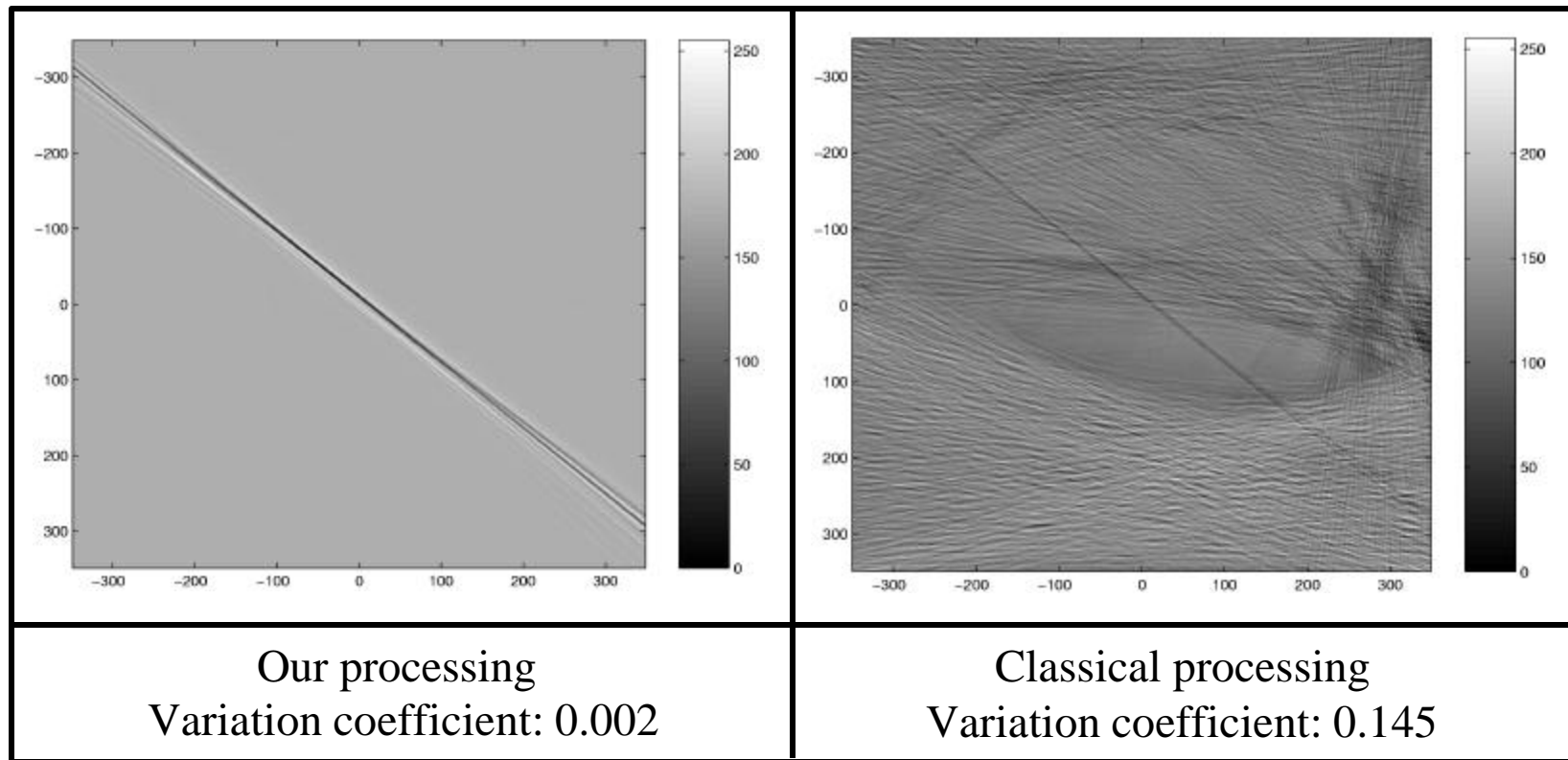
⇒ No ambiguity about the presence of a ship wake with our processing

⇒ detection by simply using a threshold contrarily to classical approach

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Reconstructed image using the transform domain

↳ Inverse Radon transform applied to the transform domain raised to the power of 3



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ANOTHER SAR IMAGE

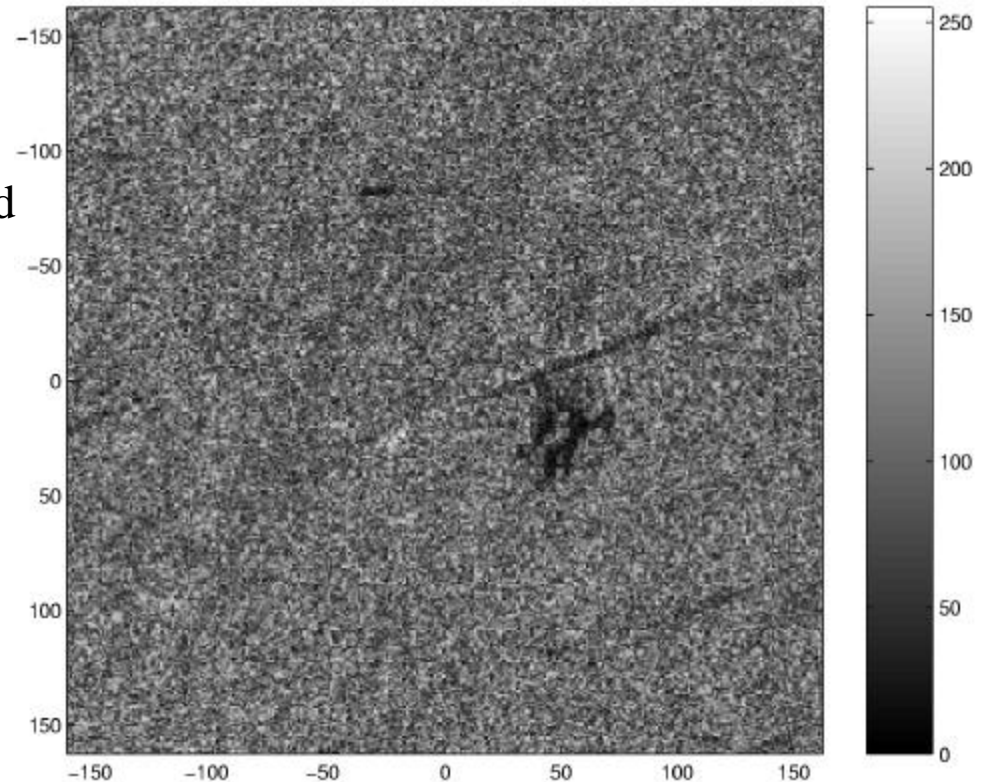
○ ERS SAR image

↳ ship pixels replaced by mean background

↳ dark turbulent wake

○ 256 gray levels (0: black, 255: white)

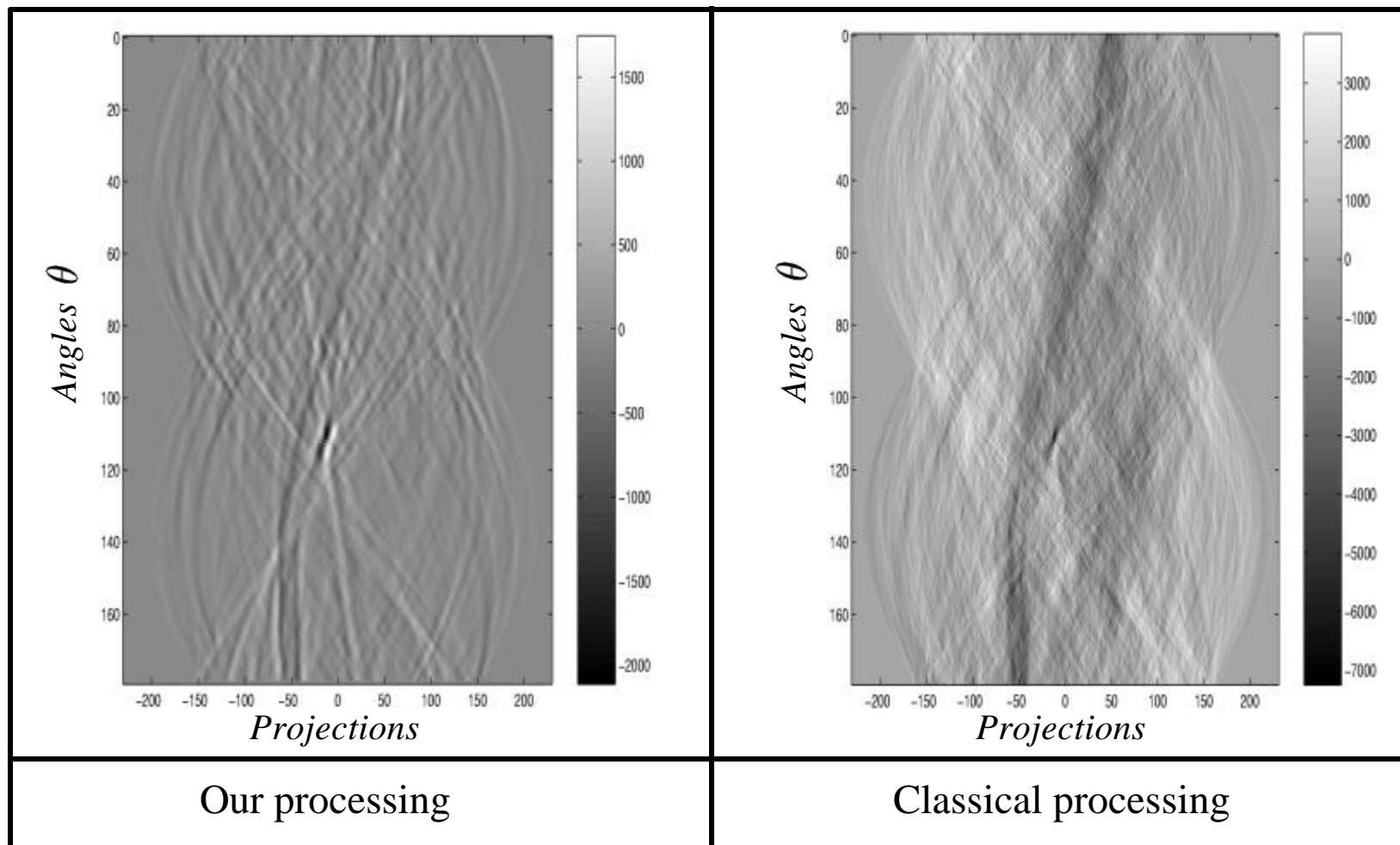
○ Image size: 325×325



○ Difficulty: dark patch near the wake (slick oil)

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Radon domain displayed as image



↪ Trough corresponding to the wake localized near 115°

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CONCLUSION

- New processing for ship wakes detection
 - ↳ SAR image Radon transform
 - ↳ original contribution: taking into account the speckle for image interpolation

- Better detection with lower probability of false alarm or no detection

- Future work: extension of this method to the localized Radon transform