VELOCITY ESTIMATION OF MOVING TARGETS BY AZIMUTH DIFFERENTIALS OF SAR IMAGES : PRELIMINARY RESULTS

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ABSTRACT - We present an efficient and robust technique to estimate the velocity of moving targets from a single SAR image. In SAR images, azimuth image shift is a well known phenomenon, which is observed in moving targets having slant-range velocity. Most methods estimated the velocity of moving targets from the distance difference between the road and moving targets or between ship and the ship wake. However, the methods could not be always applied to moving targets because it is difficult to find the road and the ship wake. We adopted a method estimating the velocity of moving targets from azimuth differentials of range-compressed image. This method is based on an assumption that Doppler center frequency shift of moving target causes a phase difference in azimuth differential values. The phase difference is linearly distorted by Doppler rate due to the geometry of SAR image. The linear distortion is eliminated from phase removal procedure, and the constant phase difference is estimated. Finally, range velocity estimates for moving targets are retrieved. This technique is tested using an ENVISAT ASAR image in which several unknown ships are presented. The theoretical accuracy of this technique is discussed by SAR simulation. The advantages and disadvantages of this method over the conventional method are also discussed.

KEY WORDS: Synthetic Aperture Radar, Moving target, Velocity estimation, Ship wake, Azimuth image shift

1. INTRODUCTION

There is a military requirement to extract the moving target velocity vector from a SAR image such as that produced by ENVISAT ASAR. Especially, the estimation of velocity assists the tracking of vessels, which is an important component of ocean surveillance.

A moving ship generates a kind of trace on the water surface, which is called a wake. Conventional methods have been estimated the velocity of ship from the displacement between ship and the wake in azimuth direction. In some circumstances, however, the ship speed can not be estimated from these methods because it is difficult to find the ship wake in SAR images.

The azimuth shift of a moving target from its true position in a SAR image and its relation to the target velocity is well known. Especially, several algorithms for detection and investigation of the moving ship have been developed by Wahl et al. (1993) and Eldhuset (1996). Wakes usually appear in a SAR image as near-linear features that may be brighter or darker than the ocean background. SAR images also tend to exhibit naturally occurring linear features. For a surface ship, these can be usually be eliminated by only accepting lines that pass close to it. The detection of linear wake features can be implemented using the Radon transform (Rees, 1990; Lin and Khoo, 2003).

Nevertheless, its application to velocity extraction must overcome some obstacles. One of these problems is that many ship images are not accompanied by a wake in a SAR image. The appearance of a wake depends on many factors including the ship type, size, and speed. The SAR sensor characteristics including frequency and polarization are important as are the directions of the wind and the ship track relative to the sensor. However, the occurrence of a wake in a SAR image is not fully understood.

In this paper, we propose an efficient and robust method for estimating the velocity of moving targets from azimuth differentials of range-compressed image without further information like ship wake.

The remainder of the paper is organized as follows. Section 2 explains our method using general SAR parameters and geometry in detail. In section 3, the result using ENVISAT ASAR data is presented. Finally, brief discussion about the result and conclusions are provided in Section 4.

2. THEORY

2.1 Velocity retrieval using ship wake

The azimuth displacement, Δ , of the ship image caused by Doppler frequency shift is given by:

$$\Delta = Rv/V , \tag{1}$$

where R is the slant range distance of the radar, V is the platform velocity and v is the target line of sight (LOS) velocity (James, 2003). For example, using values of R=850 km, V=7100 m/s, and v =15 m/s (30 knots), we find Δ=1800 m. All wake lines should lie within about 1800 m of the ship for most practical ship speeds. In the case of the Single Look Complex (SLC) image of ENVISAT ASAR data that has nominal azimuth pixel size of about 4 m, this amount of displacement accounts for about 450 pixels.

2.2 Velocity retrieval using azimuth differential

In the procedure of SAR raw data processing (see figure 1), the range compressed signal at time t is given by:

$$c(t) = a(t;r_s)\cdot \exp\left[-i\frac{4\pi}{\lambda}R(t;r_s)\right], \tag{2}$$

where $a(t;r_s)$ is an arbitrary complex constant and $R(t;r_s)$ is instantaneous slant range at time t.

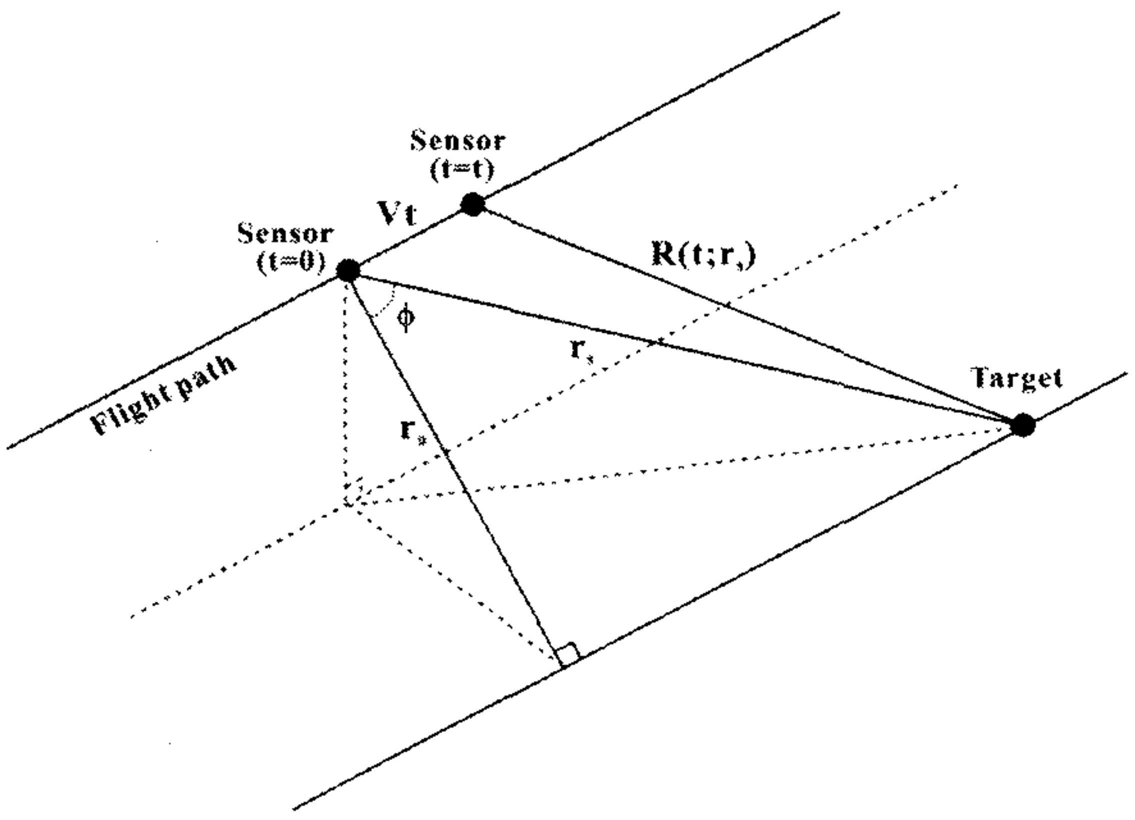

Figure 1. SAR geometry.

If the target is a moving object, eq. (2) can be approximately rewritten as given by:

$$c(t) \approx a(t;r_s)\cdot \exp\left[-i\frac{4\pi}{\lambda}r_s(0)\right] \cdot \exp\left\{i\cdot 2\pi\cdot\left[(f_{DC}+\frac{2}{\lambda}\dot{r}_s)\cdot t+\frac{1}{2}(f_R+\frac{2}{\lambda}\ddot{r}_s)\cdot t^2\right]\right\}, \tag{3}$$

where f_{DC} is a Doppler center frequency, f_R is a Doppler rate, and $\dot{r}_s$ and $\ddot{r}_s$ are LOS velocity and acceleration for moving target. Similarly, the signal at after time of t_c is the followings:

$$c(t+t_c) \approx a(t+t_c;r_s)\cdot \exp\left[-i\frac{4\pi}{\lambda}r_s(0)\right] \cdot \exp\left\{i\cdot 2\pi\cdot\left[(f_{DC}+\frac{2}{\lambda}\dot{r}_s)\cdot (t+t_c)+\frac{1}{2}(f_R+\frac{2}{\lambda}\ddot{r}_s)\cdot (t+t_c)^2\right]\right\}\cdot \tag{4}$$

If the target velocity is consistent, the target acceleration, $\ddot{r}_s$, can be assumed to be zero due to the very short illumination time of the satellite SAR system. The azimuth differential signal between t and $t+t_c$ times is given by:

$$c_{diff}(t_c) = c(t+t_c)\cdot c^*(t)$$

$$= a(t+t_c;r_s)a(t;r_s)\cdot \exp\left[i2\pi\left(f_{DC}t_c+\frac{1}{2}f_R t_c{}^2\right)\right] \cdot \exp\left[i2\pi\frac{2\dot{r}_s t_c}{\lambda}\right]\cdot \exp[i2\pi f_R t_c t], \tag{5}$$

where * means complex conjugate.

Since the phase of eq.(5) is a linear function of azimuth time t, it appears with a slope of $2\pi f_R t_c$. Accordingly, f_R can be estimated by measuring this slope. After eliminating the first and third phase terms of the eq.(5), remaining phase shows an information about LOS velocity for moving target, $\dot{r}_s$.

3. RESULT

An ENVISAT ASAR image over the west sea of the Korea which acquired on Jan 13, 2006 was used for this study. This scene contains numerous unidentified vessels of various sizes.

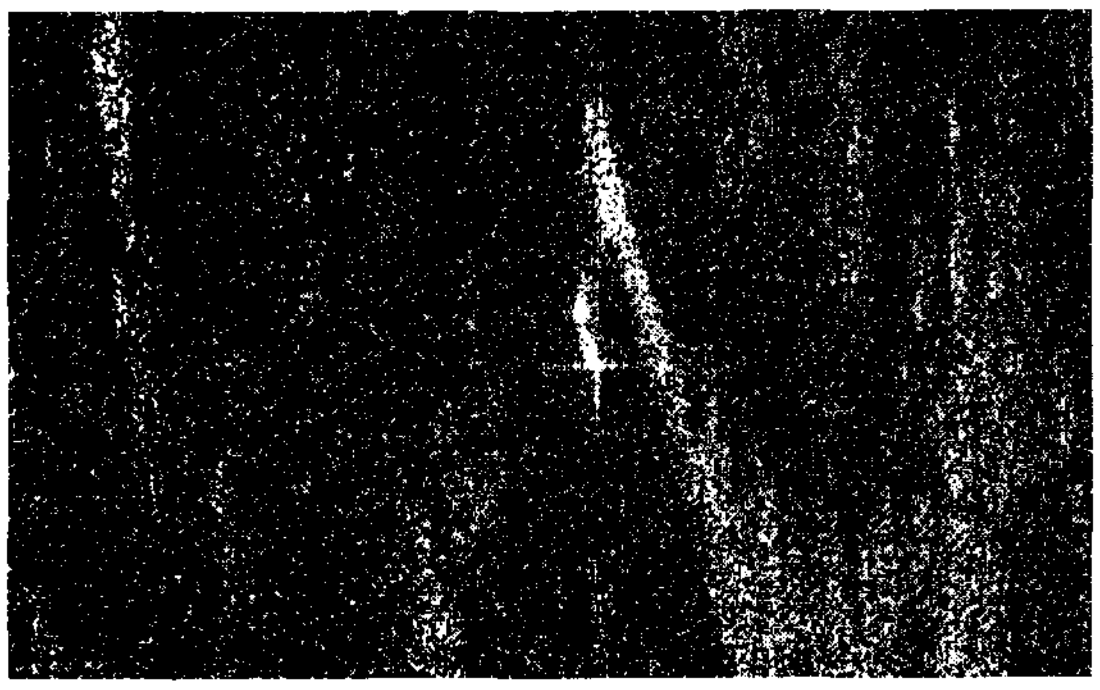

Figure 2. Target ship and its wake in SLC image.

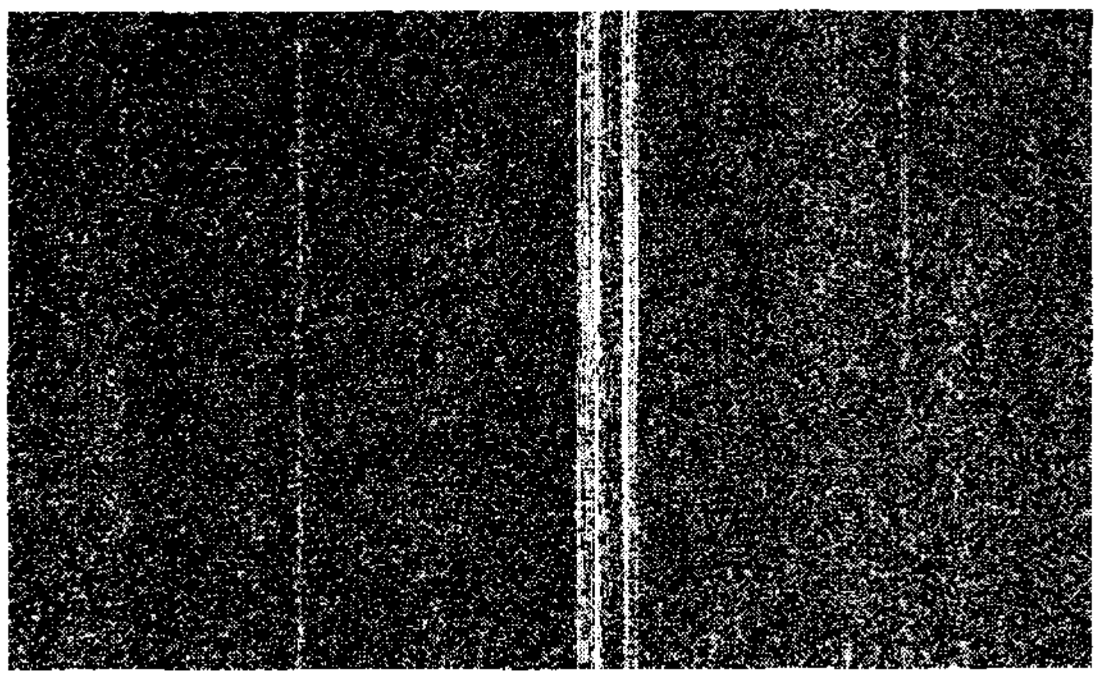

Figure 3. Target ship and its wake in SLC image in Range compressed image.

Figure 2 shows an azimuth shift phenomenon of the moving target. The moving ship is appeared in the middle of the figure, and its ship wake is presented above the target as a bright slant line in azimuth distance of about 119 pixels.

Figure 3 shows a range compressed image of the areas over figure 2. Because the azimuth compression is not performed yet, the signal of the target is distributed along the azimuth line. According to the eq. (5), The phase of the azimuth differential signal in the target line have a part related to the variation of Doppler frequency, $-2\dot{r}_s/\lambda$. In theoretical viewpoint, the Doppler frequency variation due to the motion of the moving target should be

$$\Delta f_{Dop} = \frac{n_{az}}{PRF} \cdot f_R, \tag{6}$$

where n_{az} is the number of pixels between moving target and its true position.

Figure 4 shows the slope of the phase in the azimuth differential signal at the line of target in figure 3 (vertical bright line in the middle of the image). Phase unwrapping is desirable for the step of measuring the slope from the data, because the sloped phase is usually distributed in wrapped form over more than one cycle. The time interval of the two azimuth signal, t_c, is the multiple of $1/PRF$. If we assume the signal is only concerned about the isolated target, for example a moving ship in open sea, the central position of the linearly sloped phase indicates the location of moving target.

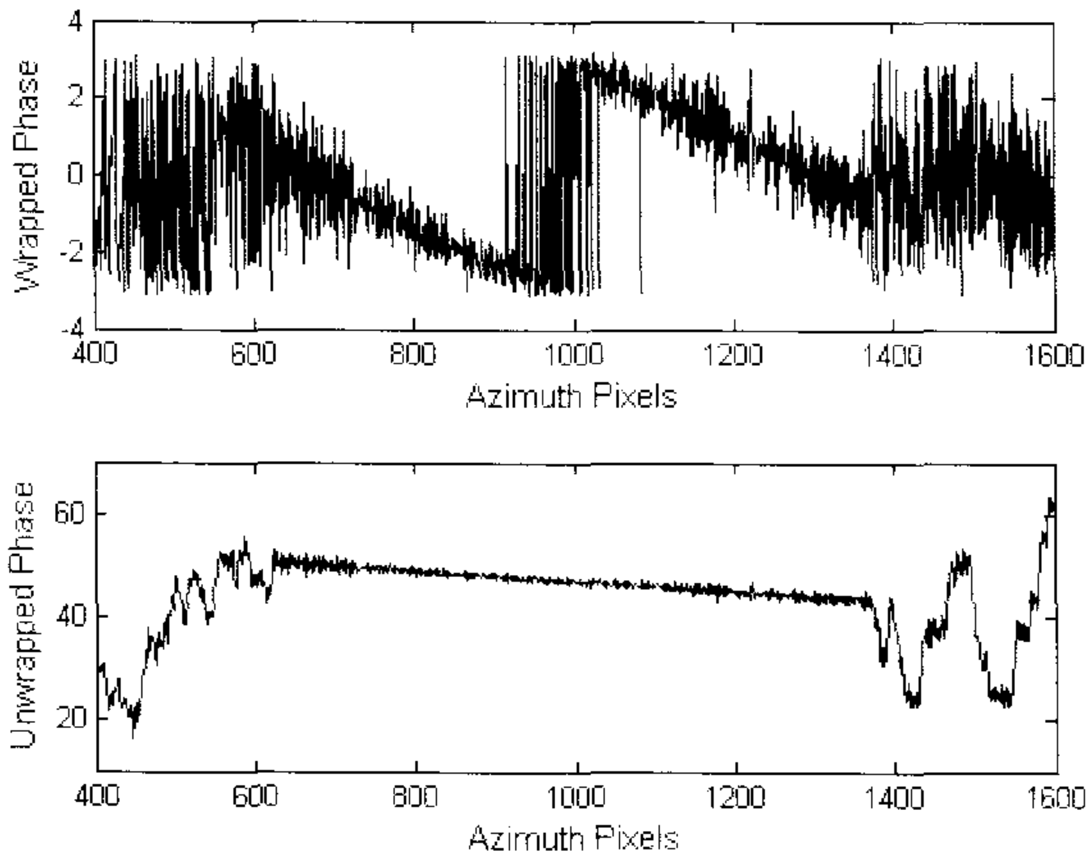

Figure 4. Sloped phase in azimuth differential data

Since this algorithm is highly dependent on the value of the reference Doppler frequency, it is crucial to estimate it carefully. The image used for this study covers land and sea together. This means that the reference Doppler frequency should be estimated at stationary target, for example, lands. Figure 5 shows the image used for this estimation and the estimated Doppler frequency by using the line to line correlation method developed by Soren Madsen (1989). Since the right side of the scene contains broad sea, it affects the value of the Doppler frequency. To compensate this effect, we fit the first 1360 samples in linear polynomial and then calculated the value of Doppler frequency at target region using the slope of fitting polynomial. The value from the line to line correlation method was 90.2 Hz, but it from the fitting method was 246.5 Hz.

After removing first and third phase terms of eq. (5) from the azimuth differential data, the remaining phase is directly concerned to the velocity of the moving target in line of sight direction. In this study, the estimated velocity of the ship in Fig. 2 was -4.026 m/s, while it was -3.979 m/s by conventional ship wake shifting distance method. The sign of the value means heading direction of the target. Negative sign accounts for the direction toward the sensor. We tested our algorithm to another moving ship which is located near the land. The result was +3.542 m/s, while it was +2.47 m/s by ship wake shifting distance method. This difference is mainly due to the bad estimation of the center position of the target in the azimuth differential signal and this effect will be discussed in the next section.

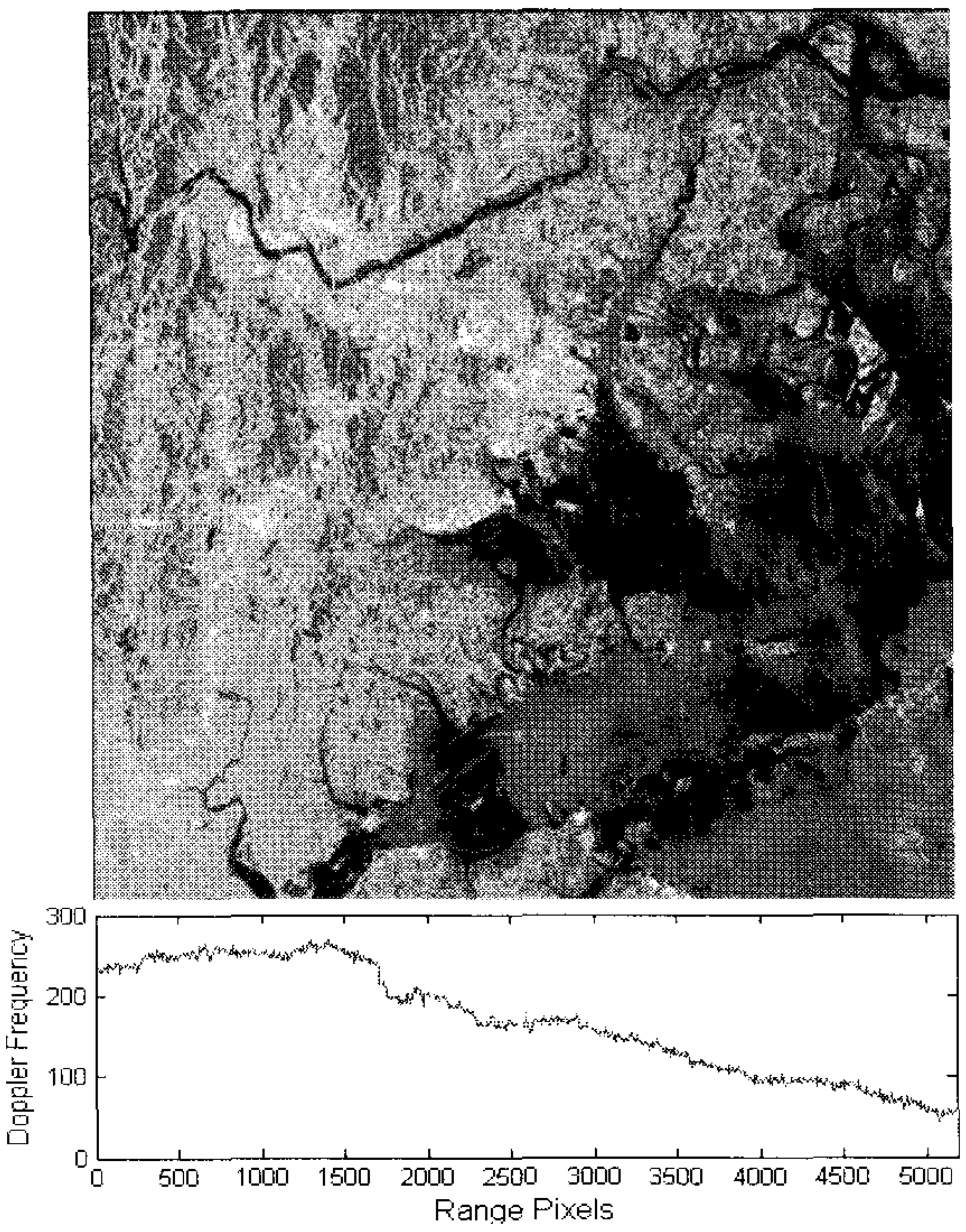

Figure 5. Test image and estimated Doppler frequency

4. DISCUSSION AND CONCLUSION

In this paper, we proposed an efficient and robust approach for estimating the velocity of the moving target on SAR image. To retrieve the LOS velocity for a target, we used the range compressed image, which is a by-product of SAR raw data processing. Additional information which indicates the motion of the target, like ship wake, is not required, because the proposed method uses the phase difference in azimuth differential values,

The presented result, achieved on an ENVISAT ASAR data, is nearly coincident with the result from ship wake distance method. One important requirement in our algorithm is that the target should be isolated from its surrounding materials. If the some bright targets exist near the target, the moving target signal is corrupted by them. This effect results in the difficulty in determining the center position of the moving target signal. Since the extra materials nearby the target also generates coherent signal in azimuth line of range compressed data, the linearly sloped section of the azimuth differential data is extended and this effect results in bad estimation of the center position.

Based on this preliminary result, it was possible to estimate the velocity of a bright moving single target. To estimate the velocity of targets, an additional process for separating the moving target signal from the background signal may be required.

References

Eldhuset K., 1996, *An automatic ship and ship wake detection system for spaceborne SAR images in coastal regions*, IEEE Transactions on Geoscience and Remote Sensing, vol. 34, no.4, July 1996, pp. 1010-1019.

Lin I-I. and V. Khoo, 2003, *Computer-based algorithm for ship detection from SAR imagery*, http://earth.esa.int/symposia/papers/lini/, April 2003.

James K.E., 2003, *The estimation of Ship Velocity From SAR Imagery*, Geoscience and Remote Sensing Symposium, IGARSS '03. Proceedings.

Rees W.G., 1990, *Physical principle of remote sensing*, Cambridge University Press, Cambridge, UK.

Madsen. S. N., 1989, *Estimating the Doppler Centroid of SAR Data*, IEEE Trans. Aerospace and Electronic Systems, vol. AES-25, pp. 134 –140, Mar.

Wahl T., Eldhuset K., and Skoelv A., 1993, *Ship traffic monitoring using the ERS-1 SAR, Proceedings of the First ERS-1 Symposium-Space at the Service of our Environment*, Cannes, France, 4-6 November 1992, ESA SP-359 (March 1993), pp. 823-828.