OBSERVATION OF A BOAT AND ITS WAKE WITH A DUAL-BEAM ALONG-TRACK INTERFEROMETRIC SAR

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1. INTRODUCTION

Ship wakes are often seen in airborne and spaceborne SAR imagery and have attracted considerable interest [1-3]. Conventional optical observations, as well as hydrodynamic analysis suggest that ship wake is comprised of several distinct components of which diverging Kelvin arms and a narrow trailing centerline wake are perhaps the most prominent features [3]. Depending on vessel type and size, its speed, sea state, as well as radar parameters, SAR image may contain signatures of all or just some of these components, and can also have additional peculiar features such as “V-wake” [1]. An extended wake helps trace and find a boat or a ship, and the wake parameters can be used to further infer information about the vessel [4]. At the same time, wake features, their degree of persistence or their absence altogether can help in gauging the sea surface conditions.

Along-track interferometric SAR (AT-InSAR) that senses radial velocity components on the scene offers additional dimension for wake characterization and study [5, 6]. These enhanced capabilities can provide further insights in the hydrodynamics of the wake (by measuring flow and wave speeds) and can certainly contribute to the tasks of estimating ship parameters and sea conditions outlined above. The University of Massachusetts Dual Beam Inteferometer (DBI) combines two C-band AT-InSARs, one pointed forward at a 20^{o} squint and another looking back at about the same angle [7]. Its principal design goal is to retrieve vector surface velocities in one pass [8, 9]. Although a vessel and some components of its wake can shift considerably between the two looks (typically 10 s apart), a retrieval of the surface velocity map of the wake is still an enticing prospect. Also, magnitude images from the fore and aft looks can be used to investigate the visibility of the wake system vs. different viewing angle. While Kelvin arms and their SAR/InSAR imaging mechanisms are understood quite well [2, 3, 6], interferometric signatures for other parts of the wake are not as widely reported. We discuss some of these issues using the DBI images of a small boat as an example.

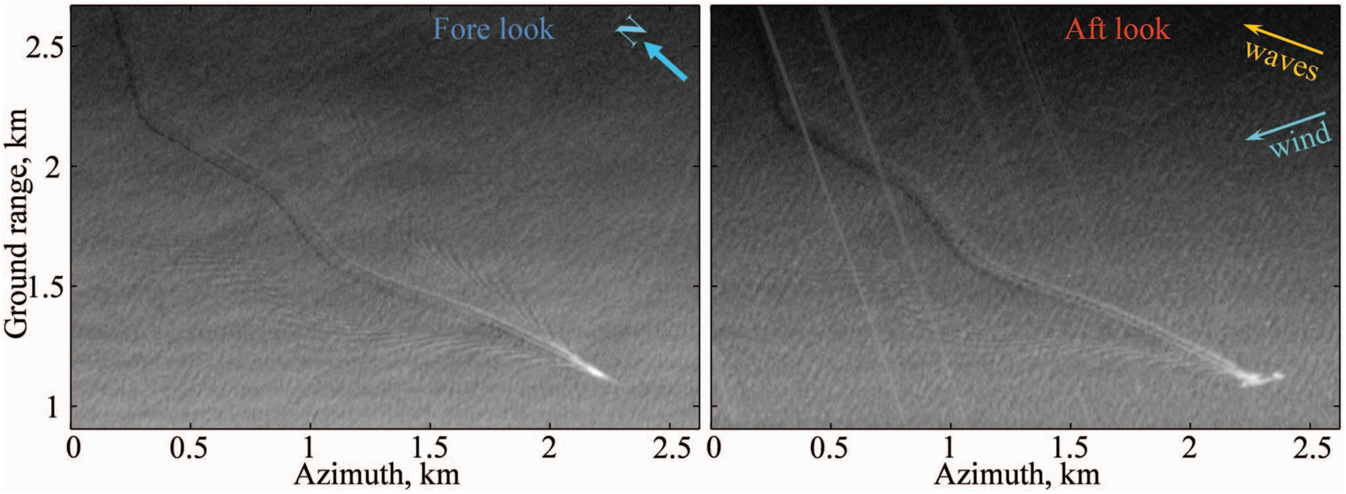

Fig.1 Magnitude SAR images from fore and aft looks (squint angles are 21° and 19°, respectively).

2. DATA DESCRIPTION

The data were collected off the west Florida coast (approximately 80 km SW of Tampa, FL) on August 29, 2003 around 18 hrs 11 min UTC from an airborne platform. The conditions in the area can be approximately assessed based on the available records from the National Data Buoy Center. The coastal station VENF1 (56 km SE from the area) reported a 4 m/s wind coming from ESE (120°), while the buoy 42036 (175 km to the NW) measured a 7.5 m/s ESE (107°) wind. The buoy also reported the dominant wave direction of 158°. As Fig. 1 illustrates, the DBI images (at 6-m resolution) captured a small vessel (presumably a recreational boat) with a fairly pronounced wake pattern. One can readily identify the Kelvin arms, as well as the narrow turbulent wake that trails the boat for kilometers (and is still recognizable at larger ranges not shown in Fig. 1). Since it was a chance encounter, no information about the craft or its motion is available, and neither is any documented visual description.

3. INITIAL ANALYSIS AND DISCUSSION

Judging from its extensive turbulent wake, the craft had been changing course several times prior to the encounter. However, during its last leg it appears to move along a rather straight trajectory, at 26° to the plane path. The aft look apparently shows the "boat off the wake" effect due to significant range velocity component. Another noticeable feature in the aft image is the absence of the port-side Kelvin arm, most likely because of the predominantly cross-range wave propagation direction. The signal within the turbulent wake is sufficiently strong and reveals some internal structure like the presence of bright line in the middle.

3.1. Estimation of the boat velocity from SAR magnitude images

In AT-InSAR systems (such as DBI) the interferometric phase that forms the basis for velocity retrievals can have an arbitrary bias. One of the major reasons appears to be imperfect attitude measurements that could allow

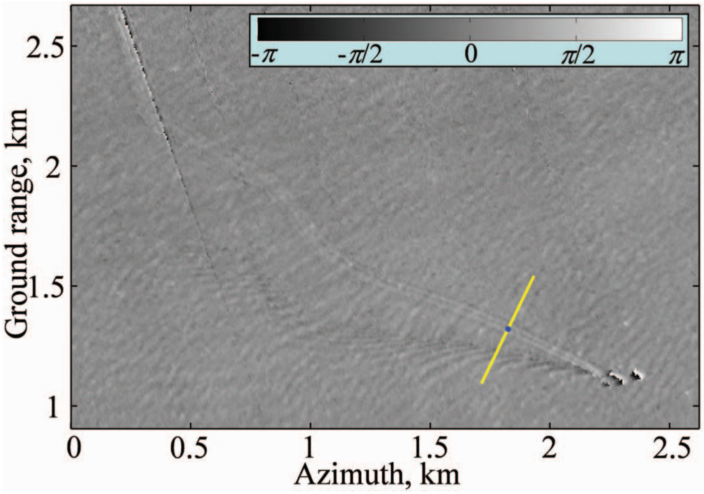

Fig. 2. Interferometric phase for aft look.

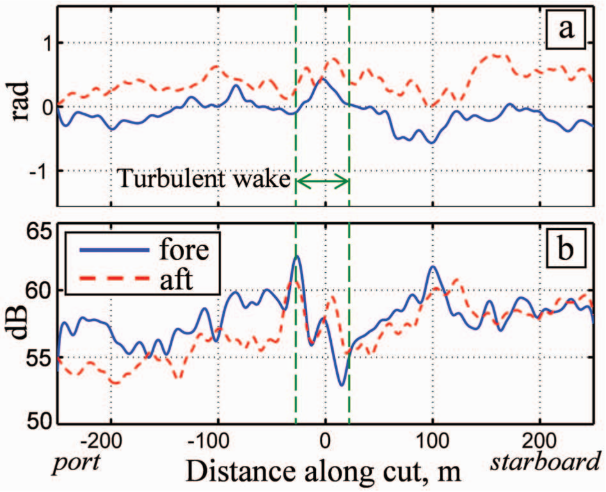

Fig. 3. a) Interferometric phase and b) image intensity along the cut shown in Fig. 2

significant cross-track antenna displacement to creep in. With the land in image, the phase calibration is straightforward. In the open ocean one can use targets with known motion as a reference. In our case, we attempt to estimate the vector boat velocity and use it to calibrate the phase. The "boat off the wake" effect is an obvious candidate [8] and yields the craft speed v=10.6 m/s. The velocity direction is assumed consistent with the centerline wake. This estimate helps gain additional information about the vessel. Since virtually no transverse waves are visible in the Kelvin wake, the Froude number, $\mathrm{Fr} = v/\sqrt{gL}$ (L is the ship length and g is the gravity acceleration) appears to exceed 1. This puts the upper limit on the craft length at approximately 10 m and supports its presumed classification as a recreational or a fishing boat.

3.2. Interferometric phase data

The phase image from the aft channel is shown in Fig. 2. It was calibrated using the boat velocity estimate discussed above. A tilted line around 0.5-km azimuth is an obvious data anomaly and should be disregarded. As with the magnitude image in Fig 1, only one side of the Kelvin wake is visible. (The fore phase map not shown here because of space considerations does contain both Kelvin arms). Just as with the magnitude images, the turbulent wake is well-defined for the whole range extent and shows internal structure.

The wake image pattern can be examined in detail by taking a cut perpendicular to the centerline direction, as the line in Fig. 2 illustrates. The cut is located 500 m behind the boat's position in the aft snapshot. In the fore image occurring 10 s earlier, the same location would be about 400 m behind the boat. The phase values across this 500 m-long cut are plotted in Fig. 3a. For reference, Fig. 3b displays intensities in SAR images along the same cut. The vertical dashed lines delineate the extent of the turbulent wake inferred from a visual examination of the magnitude SAR images. One can argue that the behavior of the calibrated phase is fairly reasonable. For example, around -80 m the fore phase exhibits a positive peak as the receding port-side Kelvin arm is encountered (the phase is positive for velocities away from the radar [9]). For the same fore-looking geometry the Kelvin waves on the other side of the cut are approaching the radar, and the fore phase in Fig. 3a becomes negative around 80 m. The general positive sign of the aft phase seems consistent with the overall wind and wave direction away from the radar in the aft-looking geometry. Again, Fig. 3 illustrates the internal structure within the turbulent wake in both phase and intensity plots.

The next step in this effort will be to combine the two phase measurements to retrieve the vector velocity field of the scene, including the wake. This task, however, will depend on how well the phase calibration procedure based on the boat velocity estimate worked, and additional calibration considerations and approaches may be required.

4. REFERENCES

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