### Title and Subtitle
Removal of GPS Errors from Currents Determined Using VHF Radar from a Moving Ship

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### Abstract
REMOVAL OF GPS ERRORS FROM CURRENTS DETERMINED USING VHF RADAR FROM A MOVING SHIP


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Introduction


Technical Objectives and Issues

During the Ocean Surface Current Radar (OSCR) Shipboard Experiments, sponsored under NRL-SSC Grants N00014-93-1-G900 and N00014-95-1-G905, several sets of radial currents were obtained with the platform moving over ground at a speed of approximately 1 m/s during the OSCR transmit-receive cycle. The initial analysis of the moving ship OSCR experiments was completed by us (Peters and Skop, 1995; Peters and Skop, 1997) under NRL-SSC Grant N00014-95-1-G905. The radial currents extracted from the ship-based OSCR data showed a noticeable circulation or swirl, on the order of 30 cm/s. An example is shown in Figure 1. This perceived circulation is due primarily to GPS errors in the ship position measurements. These errors lead to errors in the calculated values of the ship ahead and athwartship velocities, U and V, and to corresponding errors in the Doppler correction to the measured radial current. The Doppler corrected radial current ur is given by
Figure 1. Doppler corrected radial currents showing the perceived circulation due to GPS errors in the ship position measurements.

\[ u_x = \frac{\lambda}{2} (f_+ + f_-) - (U \sin \theta + V \cos \theta) . \]  \hspace{1cm} (1)

Here, \(f_+\) and \(f_-\) are the frequencies at the locations of the peak spectral pairs in the Doppler return spectra, \(\lambda\) is the wavelength of the Bragg resonant wave (\(\lambda = 3\) m for the VHF mode of OSCR operation), and \(\theta\) in the angle made between an OSCR cell and the boresite of the OSCR array.

Suppose that the true mean ahead velocity \(U_T\) is given by \(U_T = U + \delta U\), where the velocity error \(\delta U\) is caused by GPS errors. Similarly, suppose that the true athwartship velocity \(V_T\) is given by \(V_T = V + \delta V\). Substituting these relations for \(U_T\) and \(V_T\) into equation (1), the relationship between the extracted radial current and the true radial current \(u_{rT}\) is found as

\[ u_x = u_{rT} + (\delta U \sin \theta + \delta V \cos \theta) . \]  \hspace{1cm} (2)
The objective of our research was to develop algorithms to best estimate $\delta U$ and $\delta V$ and, hence, to minimize GPS errors in the radial currents determined using VHF radar from a moving ship.

**Technical Accomplishments**

Best estimates of $\delta U$ and $\delta V$ are determined, theoretically, by a least-squares procedure. That is, $\delta U$ and $\delta V$ are evaluated to minimize the residual between the measured flow field and the representation of the swirl flow field. From equation (2), the residual $\Gamma$ is defined by

$$\Gamma = \sum_{n=1}^{N} \left[ u_{rn} - (\delta U \sin \theta_n + \delta V \cos \theta_n) \right]^2 ,$$  \hspace{1cm} (3)

where $n$ designates a particular cell in the OSCR domain and where $N$ is the total number of cells used in forming the residual.

Several constraints are necessary in forming and minimizing the summation given in equation (3). Let $R_n$ denote the distance of the $n$th cell from the OSCR array. Then, for each $\{R_n, \theta_n\}$ pair in the summation, there must be a corresponding $\{R_n, -\theta_n\}$ to avoid left-right bias. Also, $\delta V$ cannot be allowed to vary independently of $\delta U$. Such an independent variation would result in estimating a zero velocity for flow fields having a true velocity directly towards or away from the OSCR array.

We have postulated and examined the influence on the calculated radial currents of several constraints on $\delta V$. In the first case, we have taken $\delta V$ as zero. The value of $\delta U$ which
minimizes the residual $\Gamma$ is then found as

$$\delta U = \frac{\sum_{n=1}^{N} u_{rn} \sin \theta_n}{\sum_{n=1}^{N} (\sin \theta_n)^2}.$$  \hfill (4a)

and the "true" radial current is given by

$$u_{rT} = u_r - \delta U \sin \theta.$$  \hfill (4b)

In the second case, we have taken the ratio of the velocity errors as equal to the ratio of the measured velocities; that is, $\delta V/\delta U = \pm |V|/U$. The value of $\delta U$ which minimizes the residual is then found as

$$\delta U = \frac{\sum_{n=1}^{N} u_{rn} (\sin \theta_n \pm |V|/U \cos \theta_n)}{\sum_{n=1}^{N} (\sin \theta_n \pm |V|/U \cos \theta_n)^2},$$  \hfill (5a)

and the "true" radial current is given by

$$u_{rT} = u_r - \delta U \left( \sin \theta \pm \frac{|V|}{U} \cos \theta \right).$$  \hfill (5b)

The plus or minus sign is taken as that one which provides the smallest value for $\Gamma$ when $\delta U$ is back-substituted in equation (3).

Equations (4) and (5) have been applied to each set of radial current data obtained during the OSCR shipboard experiment. We have found that the reduction in the perceived circulation due to
GPS errors in the ship position measurements is less than 20% for each case. One possible reason for this failure to reduce the extraneous swirl is the nature of the constraints employed between $\delta V$ and $\delta U$. A second possible reason is the inherent noisiness of the OSCR radial current data in low current situations.

**Significance of Accomplishments**

We have shown that it is not possible to reduce the perceived circulation in radial currents due to GPS errors in the ship position measurements by simple least-squares algorithms. The utility of a shipboard based OSCR for measuring ocean surface currents depends, hence, on more accurate techniques for measuring the ship's position. Such improved accuracy can be accomplished by using military or differential GPS systems as opposed to the civilian system employed in our experiments.

**References**
