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Richard A. Skop

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

Prepared by

Richard A. Skop
Division of Applied Marine Physics
Rosenstiel School of Marine and Atmospheric Science
University of Miami, Miami, FL

January 1998

REMOVAL OF GPS ERRORS FROM CURRENTS DETERMINED

USING VHF RADAR FROM A MOVING SHIP

Final Technical Report for NRL Contract No. N00014-97-1-G903

Introduction

This document represents the Final Technical Report for NRL Contract No. N00014-97-1-G903, "Removal of GPS Errors from Currents Determined Using VHF Radar from a Moving Ship" -- period of performance November 7, 1996 through November 6, 1997.

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 u_r is given by
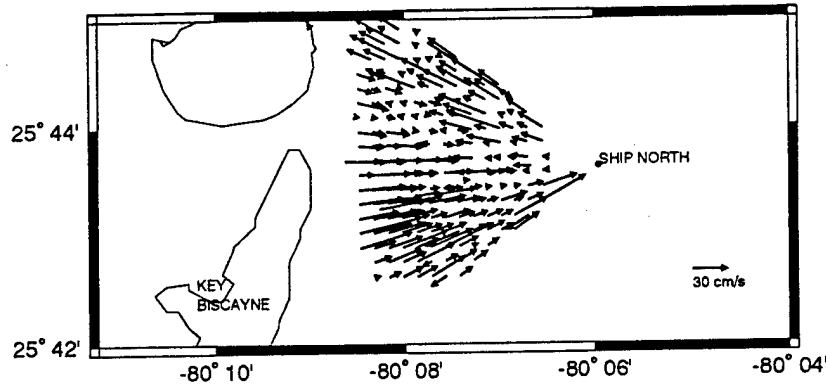
Figure 1. Doppler corrected radial currents showing the perceived circulation due to GPS errors in the ship position measurements.

$$u_r = \frac{\lambda}{2}\left(f_+ + f_-\right) - \left(U\sin\theta + V\cos\theta\right) \ . \tag{1}$$

Here, f_+ and f_- are the frequencies at the locations of the peak spectral pairs in the Doppler return spectra, λ is the wavelength of the Bragg resonant wave (λ = 3 m for the VHF mode of OSCR operation), and θ 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 δU 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

$$u_r = u_{rT} + \left(\delta U\sin\theta + \delta V\cos\theta\right) \ . \tag{2}$$

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The objective of our research was to develop algorithms to best estimate δU and δV and, hence, to minimize GPS errors in the radial currents determined using VHF radar from a moving ship.

Technical Accomplishments

Best estimates of δU and δV are determined, theoretically, by a least-squares procedure. That is, δU and δV are evaluated to minimize the residual between the measured flow field and the representation of the swirl flow field. From equation (2), the residual Γ is defined by

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

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 nth 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, δV cannot be allowed to vary independently of δU Such an independent variation would result in estimating a zero velocity for flow fields having a true velocity directly toward or away from the OSCR array.

We have postulated and examined the influence on the calculated radial currents of several constraints on δV. In the first case, we have taken δV as zero. The value of δU which

minimizes the residual Γ is then found as

$$\delta U = \frac{\sum_{n=1}^{N} u_{rn} \sin\theta_n}{\sum_{n=1}^{N} \left(\sin\theta_n\right)^2} , \qquad (4a)$$

and the "true" radial current is given by

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

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 δU which minimizes the residual is then found as

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

and the "true" radial current is given by

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

The plus or minus sign is taken as that one which provides the smallest value for Γ when δU 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 δV and δU. 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.

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