Fitting Normal Modes to HF Radial and Total Surface Current Vector Data

Over the Corpus Christi Bay Area

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TABLE OF CONTENTS

Chapter

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

1

1.0 Introduction

The analysis of oceanic surface currents has been an important area of research for the past three decades, with applications in navigation, oceanic biology, and oceanography. Various methods have been used by oceanographers in an attempt to map out and understand the dynamics of the coastal surface currents, from Langrangian drifters to huge phased radar antenna arrays, to compact High Frequency (HF) antenna units referred to as CODARs (Coastal Ocean Dynamics Acquisition Radar); each method displaying a unique set of difficulties and advantages. This research will use the data given by the CODAR units set up at Corpus Christi bay and owned by the Conrad Blucher Institute of Oceanographic Studies. This research will show how by using Normal Mode Analysis (NMA) (*Eremeev* [1996], *Lipphardt* [2000]) one is able to construct complete and accurate two-dimensional maps of the bay's surface currents using either just one or more CODAR units thus allowing for a better understanding of coastal surface currents in open and closed bay areas. Also, the cost saving potential of this approach will allow more research facilities to use radar to map surface currents.

1.1 Overview of the studies at Corpus Christi

The Conrad Blucher Institute for Surveying and Science was established in 1987 as part of the Corpus Christi Campus of the Texas A and M university system. The Institute's mission to conduct private, state, federal research is accomplished in four divisions, however, my research was done in collaboration with the Nearshore Research Division. Under the current administration of Dr. James S. Bonner, in an effort to seek and pioneer new technologies for the benefit of coastal communities the Conrad Blucher institute began the development of a mobile HF Radar unit. The HF radar system that chosen for this project is the state-of-the-art SeaSonde ™ from CODAR Ocean Sensors. The Nearshore Division began its study into a mobile HF Radar unit by purchasing two SeaSondes. These two CODAR units have proven to be invaluable means for the collection of real-time measurements of surface circulation patterns, wind direction, and wave height/direction/period within targeted water bodies. An important feature that these CODAR units bring to the analysis of the bay area is their ability to provide real time measurements over a large area. Until now this technology had only be used in the open oceanic bays such as Monterey Bay in California but had not been tried in the closed shallow bays such as Corpus Christi Bay.

1.2 Basics on HF radar

The part of the electromagnetic spectrum known as High Frequency or HF spans the 3-30 MHz band with wavelengths between 10 meters at the upper end and 100 meters at the lower end. The CODAR itself can go as far as 50 MHz. When a HF Radar signal is directed toward the ocean surface containing waves that are 3-50 meters long it scatters in many different directions. The radar signal that the CODAR looks for is of course the one that is scattered directly back towards its source. The only radar signals that do this are those that scatter off a water wave that is exactly one half the transmitted signal wavelength. The scattered radar EM waves add coherently resulting in a strong energy return at a very precise wavelength. This is known as Bragg Scattering. This is what makes the use of HF so convenient for the mapping of ocean waves, the waves that are associated with the HF wavelengths are always present (Barrick [1977]). CODAR Ocean Sensors provides us with a simple table detailing the relationship of ocean wave height:

Transmission Frequency	**Transmission Wavelength**	**Ocean Wave Height**
25 MHz transmission	12 meter EM wave	6 meter ocean wave
12 MHz transmission	25 meter EM wave	12.5 m ocean wave
5 MHz transmission	60 meter EM wave	30 meter ocean wave

Table 1.

In the case of Corpus Christi Bay the SeaSondes are set to transmit at 25 MHz.

1.3 Data gathering and Mapping with CODAR

The SeaSonde HF radars that are being implemented in Corpus Christi Bay consist of two antenna units and control hardware. A single omni-directional antenna is used for transmitting the HF signal in all directions. The receive antenna unit utilizes three collocated antennas, two loop antennas pointing in the x and y directions, and a monopole antenna pointing in the z direction. This allows the receive unit to gather and separate incoming signals in all 360 degrees.

In order to map out surface currents, the SeaSonde determines three pieces of information: the bearing of the scattering source (referred to as the 'Target'), the range of the target, and finally the speed of the target. The distance to the scattering source in any radar depends on the time delay of the scattered signal after transmission. CODAR Ocean Sensors has developed a patented method of determining the range from this time delay which they have employed in the SeaSonde. In this method, the time delay is converted into a large-scale frequency shift in the scattered signal by modulating the transmitted signal with a swept-frequency signal and demodulating it properly in the receiver. The distance to the scattering sources on the surface of the sea commonly known as the range is extracted from the first digital analysis of the incoming signal and is typically sorted into range 'bins' which are set between 1 and 12 kilometers in width. The SeaSondes at Corpus Christi are set to sort at one-kilometer bins. The next piece of information needed is the speed of the target.

By analyzing the Doppler-frequency shifts due to current and wave motions via a second spectral processing of the signals from each bin, the information about the velocity of the scattering ocean waves is obtained. The length of the time-series used to sample from the range bins determines the resolution of the velocity. For a standard configuration SeaSonde the time-series is collected across 2.5 minutes, constituting 512 sweep modulation cycles with each sweep lasting half a second. The SeaSonde, like any other radar can only measure the velocity component pointing toward or away from the radar, therefore the velocity measurements are the Doppler 'Radial' to the radar from the target on the ocean so the measured velocities outputted by a single radar are known as Radial Velocities or Radials. Finally the last piece of information needed in making current maps is the bearing of the target.

Now that the range and speed of the scatterers has been determined the last step in is to find the bearing angle of the scattering source with regards to the radar. This is done for each set of range and speed or spectral point by using the simultaneous data collected from the three collocated directional receive antennas. Using a complex patented 'direction-finding' algorithm known as MUSIC, SeaSonde will output a file per user determined time period that specifies the radial speeds on the ocean versus the range and bearing about the radar site. For the case of the Corpus Christi SeaSondes the time period is one hour. This map cannot depict completely the surface current flow, however, use of two or more SeaSondes is necessary to construct total vector maps. This is accomplished at the central data combining station that comes with the SeaSondes.

1.4 Current Mapping in Corpus Christi Bay

The Conrad Blucher Institute began mapping the surface currents of Corpus Christi Bay with two SeaSondes measuring nearly 280 points in the bay on an hourly basis. One SeaSonde was placed in the Northwest corner of the bay directly opposite to the Gulf of Mexico with no direct view of the bay's primary ocean inlet near the Aransas Pass; this SeaSonde is referred to as Radar 1. The other SeaSonde was placed on the beach area just in front of the Corpus Christi A & M campus to the South of the bay area with a good view of the inlet, this SeaSonde is referred to as Radar 2 (See Fig. 1). At any given hour both CODAR units produced total vector maps that covered approximately two-thirds of the bay (See Fig 2). The main causes for the gaps in coverage can be attributed to environmental conditions such as terrain features, the heights of the scattering ocean waves, and zones along the baseline between two SeaSondes where total vectors cannot be produced because both SeaSondes see the same radial velocity component.

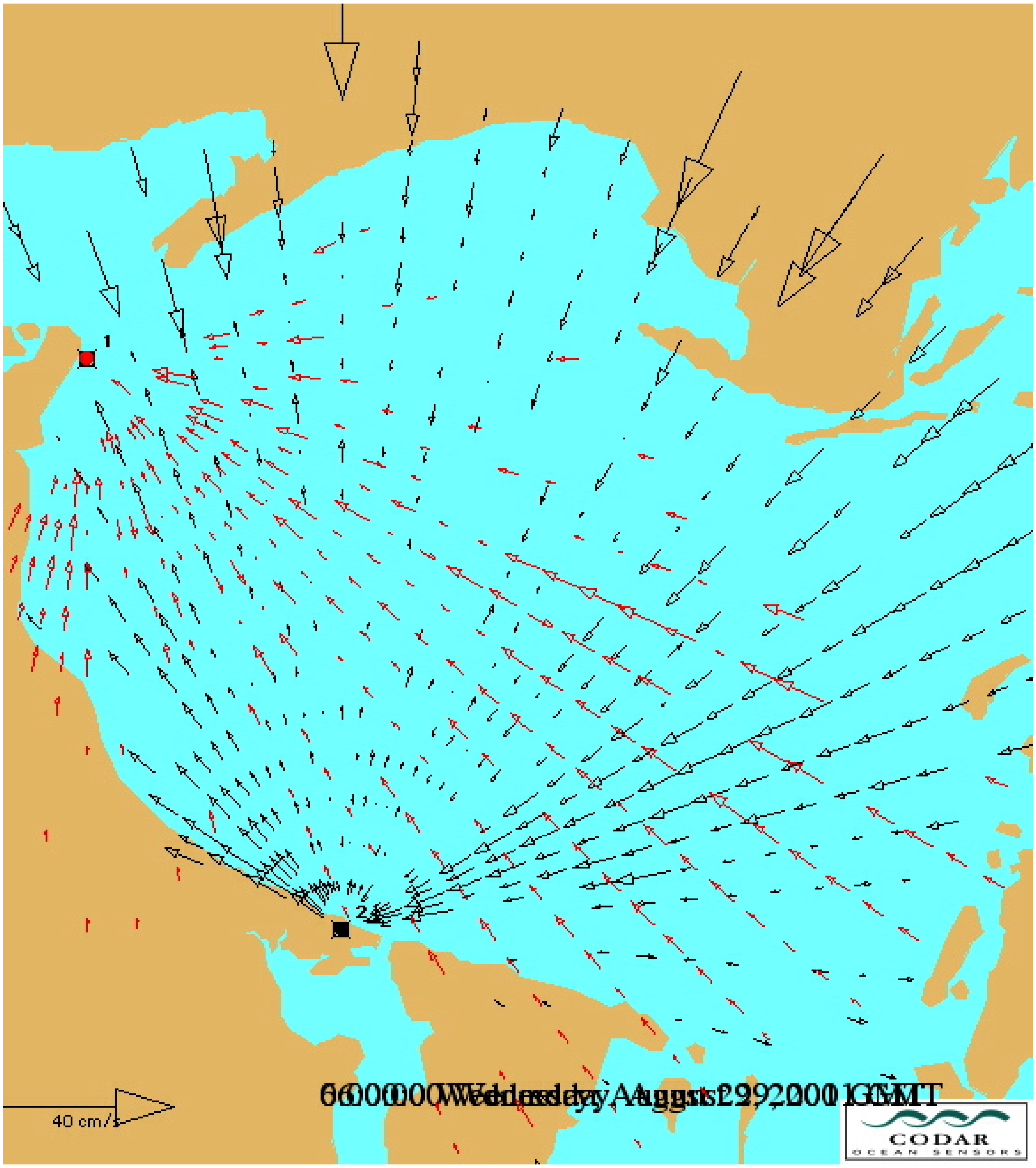


Figure 1. Coverage of the SeaSondes in Corpus Christi Bay

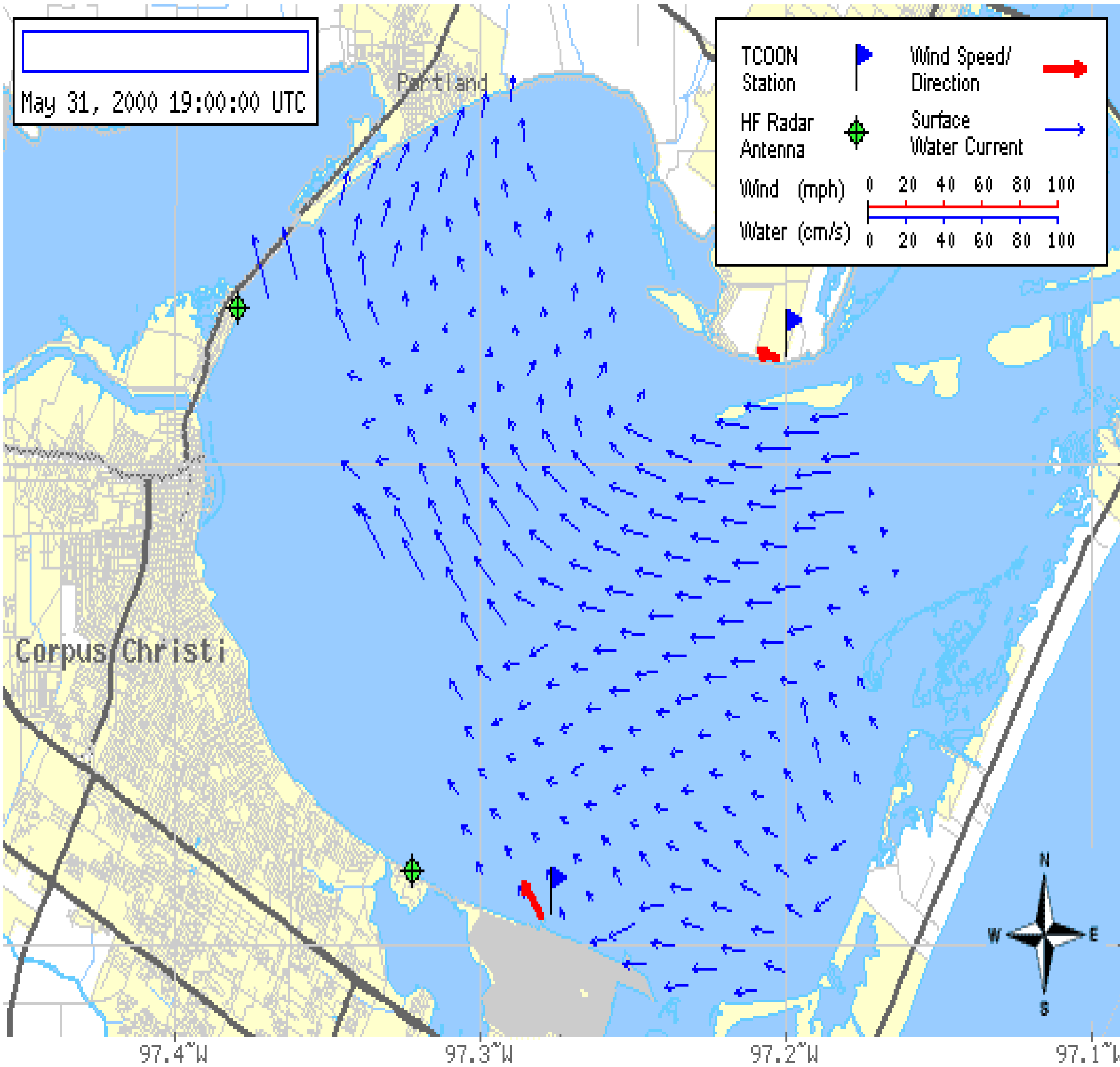


Figure 2. Total Vector Map Produced from HF Radar in Corpus Christi Bay

2

2.0 Background

In order to overcome these disadvantages a numerical approach to modeling surface currents in a bay has been developed and tested. The concept of numerically modeling surface currents in coastal areas is well known and has been developed in the last three decades since the use of Langrangian drifters and from other methods measuring the direction and speed of ocean currents. The method we employed to analyze Corpus Christi Bay begins with a powerful finite-element numerical software package called PDE2D, which will be discussed later. First, the fundamentals will be discussed.

2.1 Theoretical Background

The approach that I am applying was first developed by *Zel'dovich et al.* [1985] where a three-dimensional incompressible velocity field can be represented in terms of two scalar potentials. This involves solving standard elliptical boundary value problems involving

Dirichlet and Neumann boundary conditions. The expression for a three dimensional, incompressible velocity field in terms of two scalar potentials is:

$$\nu = \nabla \times \left[\hat{k}(\Psi) + \nabla \times \left(\hat{k}\Phi \right) \right]$$

where k is the unit vector representing the vertical direction, that is the direction orthogonal to the surface of the coastal zone. In my study, Ψ and Φ represent the set of Dirichlet and Neumann functions to be used as basis functions to describe the velocity field. The velocity field within the given boundaries is then represented as an expansion of eigenfunctions. The surface velocity field is partitioned into two parts which include a homogeneous solution where the normal velocity is held to be zero at the boundaries determined in the model by the shape of the bay, in general, with the assumption that there are no inlets, and an inhomogeneous solution where the surface velocity is dependent on the specified normal flow through the bay inlets located in the bay area being considered.

As shown in *Eremeev, et al* [1992] the calculation of the solutions of the Dirichlet (Ψ) functions (containing the vorticity) on a Cartesian system has a Helmholtz form with the evaluation at the boundary set equal to zero.

$$\nabla^2 \psi_n + \lambda_n \psi_n = 0, \qquad \psi_n\big]_{\text{boundary}} = 0$$

By taking the gradients of the ψ functions with respect to the plane that is being considered the velocity components of the Dirichlet functions can be established:

$$\left(u_n^D, v_n^D\right) = \left(\frac{-\partial \psi_n}{\partial y}, \frac{\partial \psi_n}{\partial x}\right)$$

The solution that satisfies the Neumann boundary conditions for the velocity field equation also give a Helmholtz form for Φ *Eremeev et al.* [1992].

$$\nabla^2 \phi_n + \mu_n \phi_m = 0, \qquad \left.\left(\hat{k} \cdot \nabla \phi_m\right)\right]_{\text{boundary}} = 0$$

The velocity components for the Neumann functions are thus:

$$\left(u_m^N, v_m^N\right) = \left(\frac{-\partial \phi_n}{\partial y}, \frac{\partial \phi_n}{\partial x}\right)$$

Subsequently the case of open boundary is considered with water inlets.

For Corpus Christi bay there is only one main inlet from the Gulf of Mexico, located to the Northeast near Aransas Pass. For this case normal flow, as well as tangential flow is found to exist at the inlet. An inhomogeneous solution can be considered for either the tangential flow or the normal flow, but not both simultaneously as this can lead to an overspecification of the problem.

The normal component of the flow through the open boundary at the main inlet into the Corpus Christi is obtained (*Lipphardt et al.* [2000]):

$$\nabla^2\Theta(x,y,0,t) = S_\Theta(t), \qquad \left.\left(\hat{n}\cdot\nabla\Theta\right)\right]_{\text{boundary}} = \left.\left(\hat{n}\cdot\vec{u}_{\text{model}}\right)\right]_{\text{boundary}}$$

This is the inhomogeneous equation in which **n** is the unit vector pointing out from the normal of the open boundary and **u** is the surface velocity, S being the source term that accounts for the net flow into the domain through its open boundaries, and obtained as:

$$S_\Theta(t) = \frac{\oint \hat{n}\cdot\vec{u}_{model}\,dl}{\iint dxdy}$$

For the case of the tangential component of the flow at the inlet a boundary stream function **Y** can be calculated to the solution (*Lipphardt et al.* [2000]):

$$\nabla^2\Theta(x,y,0,t) = S_\Theta(t),$$
$$\left(\hat{n}\cdot\nabla\Theta\right)\Big|_{boundary} = \left(\hat{n}\cdot\vec{u}_{\mathrm{mod\,el}}\right)\Big|_{boundar}$$

Here t is the unit tangent vector on the boundary and S is the source term that accounts for the net circulation on the domain boundary, S being defined as:

$$\mathrm{S}_\Upsilon(t) = \frac{\oint \hat{t}\cdot\vec{u}_{\mathrm{model}}dl}{\iint dxdy}$$

However the solutions of these equations were obtained using the PDE2D software, which uses a Finite Element Method (Sewell [1993]).

2.2 PDE2D Overview

PDE2D is a software package that was developed by Granville Sewell to assist in the solving of two-dimensional partial differential equations. It primarily uses the “Galerkin” finite element method to solve systems of partial differential equations.

<u>3</u>

3.0 Fitting the Normal Modes to Corpus Christi Bay

Normally most of the radial data is discarded when creating total vector maps of a bay since the total vectors of surface currents are created in areas of a bay where the scans of two or more SeaSondes overlap. We propose to use all the recorded data from one or more SeaSondes to fit Normal Modes Analysis (NMA) functions calculated for the bay to fill in the gaps in the SeaSonde total vector maps for the surface currents. Using the PDE2D software we were able to determine the lowest modes for Corpus Christi Bay, a total of 16 normal modes, 8 modes obeying Dirichlet boundary conditions, 8 modes obeying Neumann boundary conditions were used. From the two SeaSondes we have the radial data files giving radial velocity, range, and bearing from Corpus Christi Bay out to 31 kilometers in range. We now have all the information necessary to fit the NMA functions to the experimental data from the CODAR units. The fitting was accomplished in the following five steps:

1) Convert Each Normal Mode Pattern for Potentials into Velocity Patterns

2) Calculate the Radial Velocity Patterns for the Above Normal Mode Velocities

3) Create a Grid Index File of Nearest Radial Grid Points

4) Find Radial Data Sets to Be Fitted to Normal Modes

5) The Least-Squares Fitting Process to Normal Modes

3.1 Converting Each Normal Mode Pattern for Potentials into Velocity Patterns

Using PDE2D we solve the lowest modes for Corpus Christi Bay, both $\mathbf{\Phi}$ and $\mathbf{\Psi}$ (the stream function and the velocity potential and for the velocities. The maps produced from the PDE2D software of each mode contain the **x** and **y** Cartesian points and the velocities in those directions **u** and **v.** A total of 16 modes, 8 $\mathbf{\Phi}$ and 8 $\mathbf{\Psi}$ maps respectively were implemented (see Appendix 1).

3.2 Calculating the Radial Velocity Patterns for the Normal Mode Velocities

The fitting of Normal Modes to radar data is not a new concept when using the total vector data produced from radar stations. We, however, are looking at fitting NMA functions using only the radial data from one and multiple CODAR units. This means that we seek good total vector normal mode fits where only radial data is available such as using only one radar. Or it can mean that gaps in total vector coverage created because one site may not see a certain point in the bay can be filled by radial data of a site covering that area but whose radial data would normally be discarded.

This step involves first the determining the location of the radar sites on Corpus Christi Bay with respect to the Cartesian grid used by the normal mode maps produced with PDE2D. The way this was accomplished was by overlaying the Cartesian grid used by PDE2D to determine the normal modes of Corpus Christi Bay and finding the coordinates for the SeaSondes. Next, we calculated the unit vector from the radar at each Cartesian grid point and dotted it into the total velocity vector for that mode at that grid point x_i, y_j, this is accomplished with the following relation:

$$v_{i,j}^{r,n} \equiv \hat{r}_{i,j} \cdot \left(u_{i.j}^{n} \hat{x} + v_{i,j}^{n} \hat{y} \right)$$

Here, $v_{i,j}^{r,n}$ is the radial velocity at point x_i, y_j, from mode n and radar r. Unit vector $r_{i,j}$ is the unit vector from the chosen radar position to coordinate x_i, y_j, $u_{i,j}^{n}$ and $v_{i,j}^{r,n}$ are the u and v velocities for mode n, radar r, and coordinate x_i, y_j. This is done for each site and each normal mode (See unitvector.f App. 2). We have now prepared the modal data for comparison with the radial data; the next step is to prepare the radial data that we get from the SeaSondes.

3.3 Creating a Grid Index File of Nearest Radial Grid Points

With the radar site locations now known we now find the four nearest bracketing radial velocity vectors around each grid point x_i, y_j. As aforementioned, SeaSonde finds the range, radial velocity, and polar bearing of surface currents scattering the HF signal in the bay area creating a radial velocity map (see Fig. 1). If overlaid over the radial map produced in the Cartesian grid used by PDE2D from the above step 2, the result is an incompatible comparison between the radial velocity sets. To solve this problem we created several algorithms. First an algorithm that would find all the necessary polar coordinates for each radar site (see cellfind.f App. 2), then an algorithm to find the four nearest polar points to each Cartesian coordinate x_i, y_j (see near4.f App. 2). This program outputs a grid index file that only has to be made once as long as the SeaSondes are not moved from their original sites.

3.4 Finding the Radial Data Sets to be fitted to Normal Modes

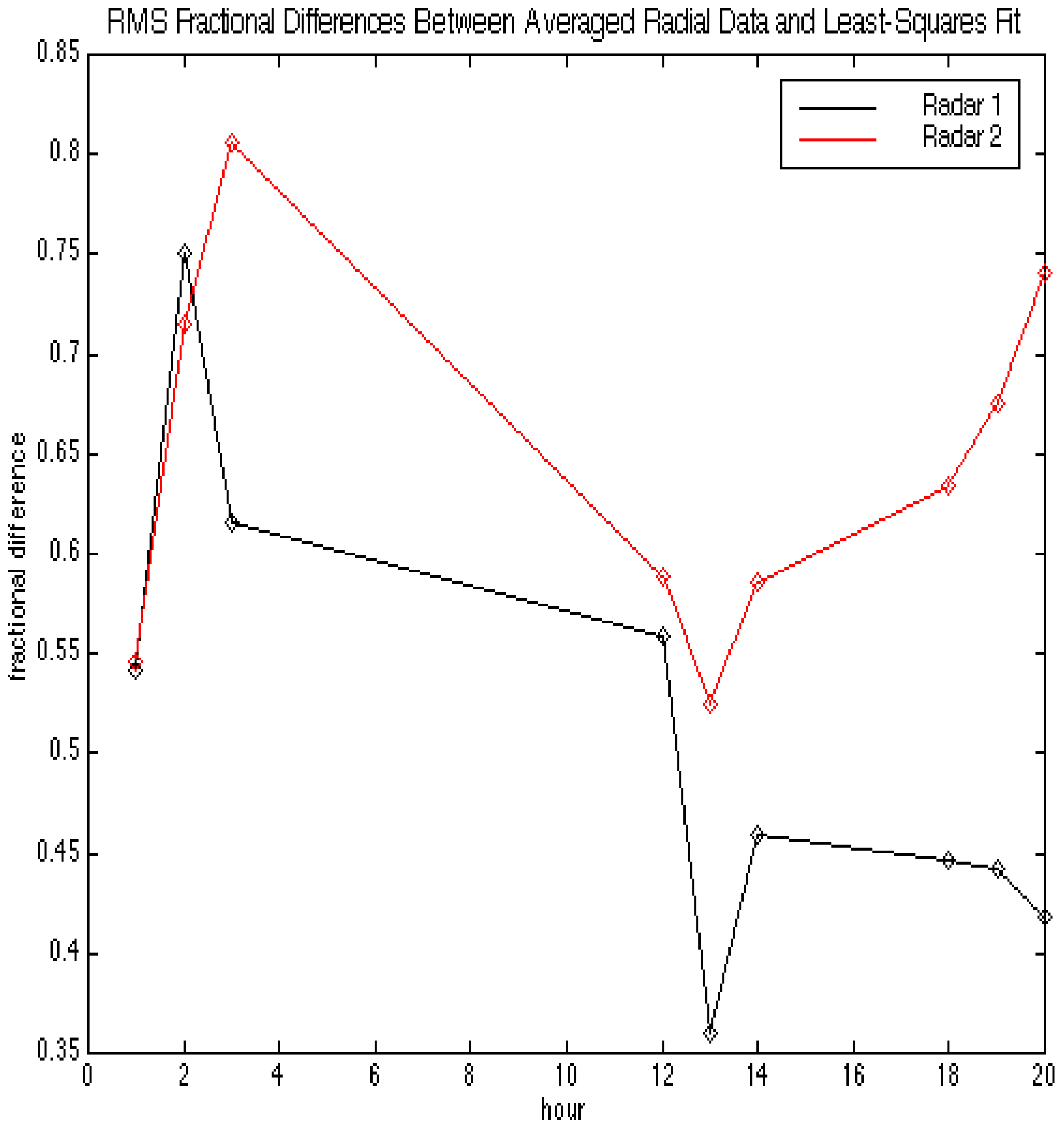
Next, an algorithm was made to turn the range and bearing of the SeaSonde files into Cartesian coordinates (see rsort.f App. 2), the SeaSonde radials can now be sorted with the grid index file and averaged using another algorithm (see velavg.f App. 2) to see if any of the four nearest polar points produces a radial data point. If between one and four of them has a radial velocity at that grid point, then these are averaged to get a radial estimate for that point. If none of the four has data there, then a gap is left at that point x_i, y_j, and it is not used in the fitting process. For the case of Corpus Christi Bay, PDE2D produces 728 points where it calculates **u** and **v** velocities for each mode. Out of all of those possible points approximately 200 to 500 will produce a radial data point from the SeaSonde radial velocity files using the aforementioned method.

3.5 The Least-Squares fitting Process to Normal Modes

At this point the 16 sets of normal mode radials are combined into a 728X16 matrix (the PDE2D software calculates 728 total vector coordinates for each mode in the Corpus Christi Bay area). From this complete set, all the points that were did not contain and averaged data point from above are removed (see purge.f App. 2). So we are now left with two sets of data, one is the averaged radials derived from SeaSonde radial velocity maps, the other is the radial modal data matrix, each coordinate point in one set corresponding perfectly to the other set. This leaves us with a very overdetermined system of equations where the method of Least Squares can be applied by defining the system of equations as the matrix equation:

$$[b_n] = [a_{n,k}][x_k]$$

Here $[b_n]$ is the averaged radar data at the model point; n, k is the normal mode in question at that point. The matrix $[a_{n,k}]$ represents the radar-directed components of the normal modes for each point corresponding to $[b_n]$ and $[x_k]$ represents the mode coefficient to be determined by least-squares fitting (see leastsolver.f App 2). A detailed explanation of how the method of Least Squares was applied to this case can be found in App. 3. A total of 16 coefficients were found for each set of SeaSonde radials corresponding to each normal mode that was determined using the PDE2D software. These coefficients where then applied to the radial modal data and found the RMS fractional difference (see rms.f App. 2) between averaged radials and modal radials to assess the veracity of our fit for each radar unit (see fig. 3).



RMS Fractional Differences Between Averaged Radial Data and Least-Squares Fit
Radar 1
Radar 2
fractional difference
hour
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0
2
4
6
8
10
12
14
16
18
20

Figure 3.

We used 9 sets of hourly radial data from each SeaSonde, broken up into three thee-hour groups to look at the morning noon and evening, used in Corpus Christi Bay and calculated the fitting coefficients for the individual radar cases and the combined case where the combined data of both radar units and corresponding modal radials were used to calculate the fitting coefficients (see table 2). It was immediately obvious that the data from Radar 2 that is the second SeaSonde located near the A & M campus was producing better fits than that of Radar 1. The next step was to apply the fitting coefficients to the total vectors in the original set of modal data that was outputted from PDE2D.

RADAR 1 MODE COEFFICIENTS

HOUR	0100-0200	0200-0300	1100-1200	1200-1300	1300-1400	1700-1800	1800-1900	1900-2000
phi1	29.94163984	-281.6156582	-129.3393554	-924.1268202	-841.0351646	-909.0132871	-878.5662187	-735.511131
phi2	-353.378119	562.7517038	-1550.578224	260.8434643	-103.8928217	240.6906836	-162.604825	75.05384246
phi3	-153.68794	-102.9600798	-637.6317312	232.9318519	-349.2838958	-182.1321267	-356.43289	305.7057841
phi4	117.0348216	463.4337617	-665.8397178	-196.0077438	-94.16110296	-150.6597042	-246.9074099	-97.36690198
phi5	224.9225358	489.2561058	-367.3223875	-79.350403	-43.57826512	-120.8049009	-125.3210137	-59.58666255
phi6	151.4979811	211.9719949	-242.603761	-88.21517085	-66.14690358	-160.3275325	-192.1742387	-100.3152105
phi7	-152.55033	-219.5543166	10.32090841	45.07614015	-79.13463568	-4.090920139	-51.2970761	-104.1234286
phi8	19.77668576	48.69028837	-108.4467376	-129.6472816	-9.036422048	-56.18790556	-29.45105839	6.736034981
psi1	-169.319817	13.0534881	-366.7310588	14.33512614	-67.56198528	54.78251735	-83.16552875	100.5381025
psi2	108.6519484	152.6653092	189.5020958	10.02110972	52.17959449	124.489854	185.3772095	-100.684178
psi3	24.84178851	48.49086173	-32.92373461	70.93848822	38.93975209	0.487354409	-62.58862773	25.55623721
psi4	31.42587778	24.02929534	-206.6196516	-168.7933229	-124.7592078	-191.1561044	-169.234555	-54.58819181
psi5	10.03862078	-60.0663145	69.49190706	-21.336989	-7.460010051	-31.93123219	-47.40080176	-74.12341994
psi6	10.57542505	3.674201608	24.17972865	-1.67334434	29.76658562	10.74944295	12.41057412	0.189406816
psi7	47.04592079	65.4435901	-30.95592638	-47.43732807	-42.25389867	-73.37413649	-54.55201781	-46.9467815
psi8	-1.70954125	0.680195872	44.74564355	34.20053544	-22.00058066	-7.785371805	-20.67464322	-37.81214936

RADAR 2 MODE COEFFICIENTS

HOUR	0100-0200	0200-0300	1100-1200	1200-1300	1300-1400	1700-1800	1800-1900	1900-2000
phi1	-436.208669	375.6853757	956.234644	-536.594605	-651.6701719	-134.368183	-707.8643472	-550.6656963
phi2	-308.082116	-96.40954048	910.7293417	29.35974379	-124.4202856	-167.3891952	296.5028976	186.1617373
phi3	47.73038607	61.42070379	-466.0189728	40.3723117	54.29007544	202.4125099	372.8749465	347.6396843
phi4	-721.039945	191.0192597	650.7020349	-221.9289738	-271.4824236	97.73486971	-696.0567652	-392.8856474
phi5	371.3611691	52.55623525	162.3929771	116.9574752	97.72576358	271.7718131	201.3014561	178.2365771
phi6	-267.58592	42.4104119	115.0756645	92.11131666	19.57356371	-27.18406448	-39.90417934	-44.21853544
phi7	-244.252117	70.58463815	-209.6185859	-77.68373448	-153.0727035	-18.18128868	-148.1649087	-49.62311511
phi8	-10.2468932	-87.85453777	-304.8944977	79.69319787	147.7808862	-125.7898704	-8.117381436	-36.85316625
psi1	202.6619302	13.59369685	-183.5560107	-275.8886721	-332.2909708	-409.370869	-525.1157439	-334.3646397
psi2	-255.840921	-25.52293209	-271.4367675	-150.2869312	-151.5546672	-74.2884481	-32.86994918	-4.498999831
psi3	433.8087648	-60.75422909	-136.5763699	114.4390606	198.1874511	63.70151504	139.2889791	124.4862707
psi4	279.9502241	-95.13917529	-231.9269287	-28.95629246	14.29079728	-94.16011036	-23.29733904	-32.25291254
psi5	-178.576271	-42.3469709	46.52448253	-134.4162951	-130.6245604	-112.9578724	-52.28380558	-35.54958997
psi6	-315.914789	-21.64452055	-44.97932733	-25.18686038	-29.26487889	-3.075268843	-15.05790011	-5.802345724
psi7	-60.5282014	43.22213806	-23.3331572	-34.1336077	-37.13673055	-32.36690605	-13.15501136	-30.76430339
psi8	5.137700125	-28.65715859	9.737890192	34.25422981	56.75345365	8.970161878	73.8442753	42.44255528

COMBINED RADAR COEFFICIENTS

HOUR	0100-0200	0200-0300	1100-1200	1200-1300	1300-1400	1700-1800	1800-1900	1900-2000
phi1	71.46256023	87.93388754	-600.5371047	-715.3041482	-550.934855	-554.0486634	-635.2090937	-612.4957047
phi2	-213.392192	-103.4067971	-226.0059081	-259.9398341	-285.4965043	-190.1273962	-167.5557183	-160.9768932
phi3	96.22206458	212.7768836	31.41748755	125.3684847	-16.56543985	103.0528934	159.0896303	214.1174926
phi4	47.75330044	13.4264653	85.57280918	38.8392521	71.88531455	1.037011465	-26.35036932	-21.18432453
phi5	69.44920061	94.46842082	75.56391075	136.8973144	66.24099414	80.79047884	65.31322025	51.57925253
phi6	-17.709184	-27.51280791	49.80584626	114.66573	67.84658567	106.8570383	56.63185878	51.51278272
phi7	-90.2666201	7.080852219	-46.42745417	-23.79280326	-68.25503858	-16.08449224	-55.93452507	-23.73897458
phi8	3.795486808	-21.09287427	3.870937253	9.737836897	84.98231229	40.89335913	45.74838477	28.46522954
psi1	-15.1498452	-6.591085175	-321.3632403	-185.3808658	-121.5734131	-143.1373346	-132.3090479	-72.38912854
psi2	-8.59215759	84.14014656	-173.5197543	-97.34611888	-124.3616016	-14.3057268	-67.29392116	-58.64203107
psi3	5.040105635	-23.84607918	72.3853971	88.81876427	92.13035533	47.93848449	37.85028017	60.18682913
psi4	1.026128658	-43.00724768	-63.15798627	-43.09224936	-10.35636475	-17.46019075	-18.31628583	-24.99579084
psi5	-26.4747735	-39.54298489	56.58058823	-59.01219601	-41.26027028	-58.17556371	-39.47114383	-56.39626147
psi6	-22.680797	-38.72530413	-17.71383203	-8.624274078	-4.907207488	0.64986633	3.174205373	5.524583131
psi7	33.66417025	32.97421132	-30.29606883	-29.00104808	-27.54564702	-67.81439341	-52.83095509	-44.66248447
psi8	-8.66400569	4.623050722	32.81509235	13.14304975	-1.485822498	-13.5011528	-1.559681841	-6.286364926

Table 2.

<u>4</u>

4.0 Observations and Analysis

With the fitting coefficients now determined, it was time to normalize the normal mode maps created by PDE2D to acquire complete total vector maps of the Corpus Christi Bay. The SeaSondes already provided total vector maps constructed from the radial data that they were collecting ever hour so we already had the data necessary to compare our total vector maps constructed using normal modes. Before moving to the comparisons, I will discuss the steps taken to make the total vector maps. Then the maps will be presented in three sets. Each set will consist of nine maps for each hour observed, three maps for the case of using only the radial data to fit the modes from Radar 1, three maps utilizing the radial data from Radar 2 to find the fit, and three maps for the combined case where the radial data from both radar units where used to find the fitting coefficients. After each triplet of maps is shown my analysis of the data will follow.

4.1 Construction of Total Vector Maps from Normalized Modes

In order to make a total vector map from the now normalized normal modes the following steps where followed. First two files where constructed both consisting the Cartesian points used by PDE2D . The total vectors where then separated into these files, one file contained 16 columns of **u** velocities while the other file contained 16 columns of **v** velocities. These columns where then multiplied by the corresponding fitting coefficient and then added together to come up with the fitted **u** and **v** vectors for each Cartesian point x_i, y_j . These fitted values where then combined back into two-dimensional vectors in a third file. This process was repeated for each hour of observation and for each individual radar and the combined case.

4.2 Observations for the time of 0100-0300 hrs, Aug. 29, 2001, Corpus Christi Bay

Here we present the first set of total vector maps for the individual radar cases and the combined case for the time of 0000-0100 hrs, 0100-0200 hrs, 0200-0300 hrs universal time, August 29, 2001 for the Corpus Christi Bay. On each map the following features are seen, first there is a set of black vector arrows that seem to occupy about two-thirds of the bay area, these are the total vector maps produced by the SeaSonde combining station. The next feature are the red vector arrows that occupy all of the bay area, these are the fitted values produces from the normal modes. For the individual radar cases a black spot will indicate the location of the SeaSonde from whose radial velocities the fitting coefficients where calculated.

4.3 Observations for the time of 0000-0100 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from midnight to 1:00 AM. The first total surface current map, figure 4, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the SeaSondes. The second map, figure 5, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 6, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

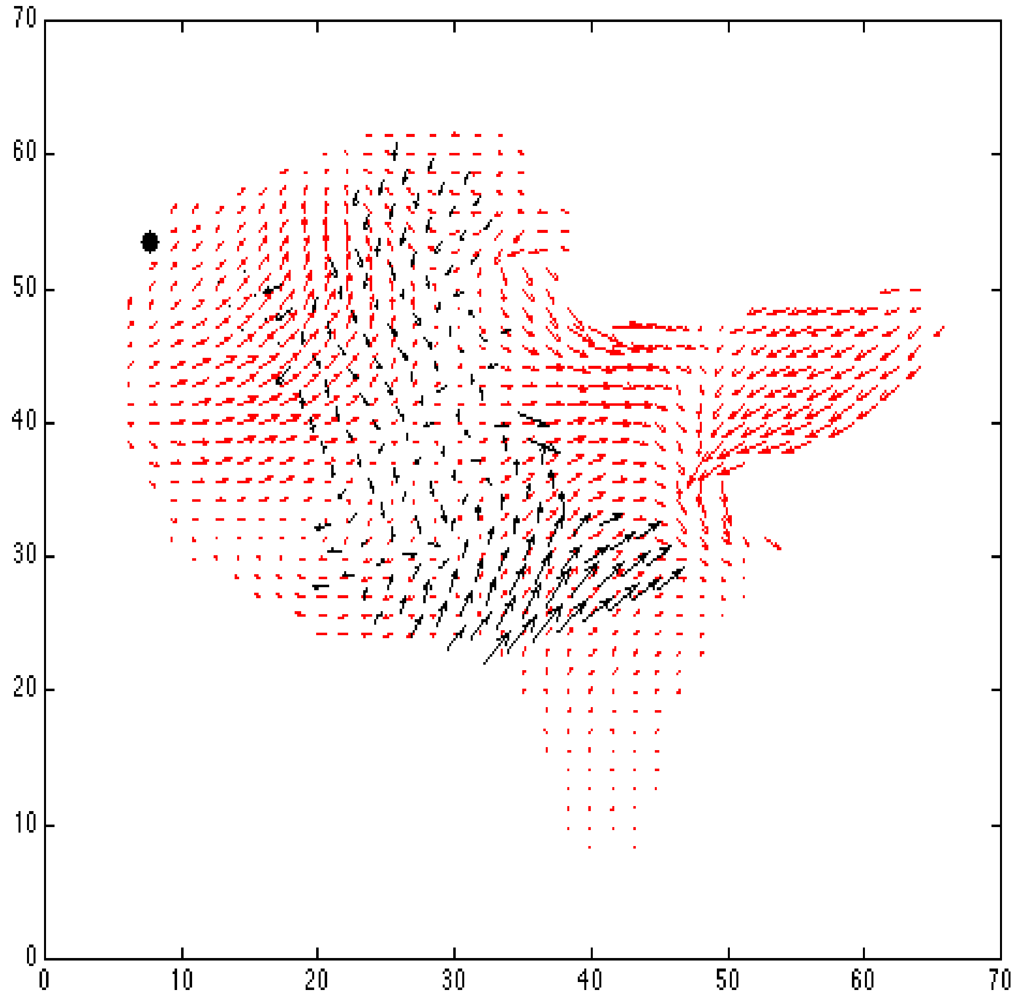


Figure 4. Radar 1 fitted Values vs. SeaSonde Total Vector Map

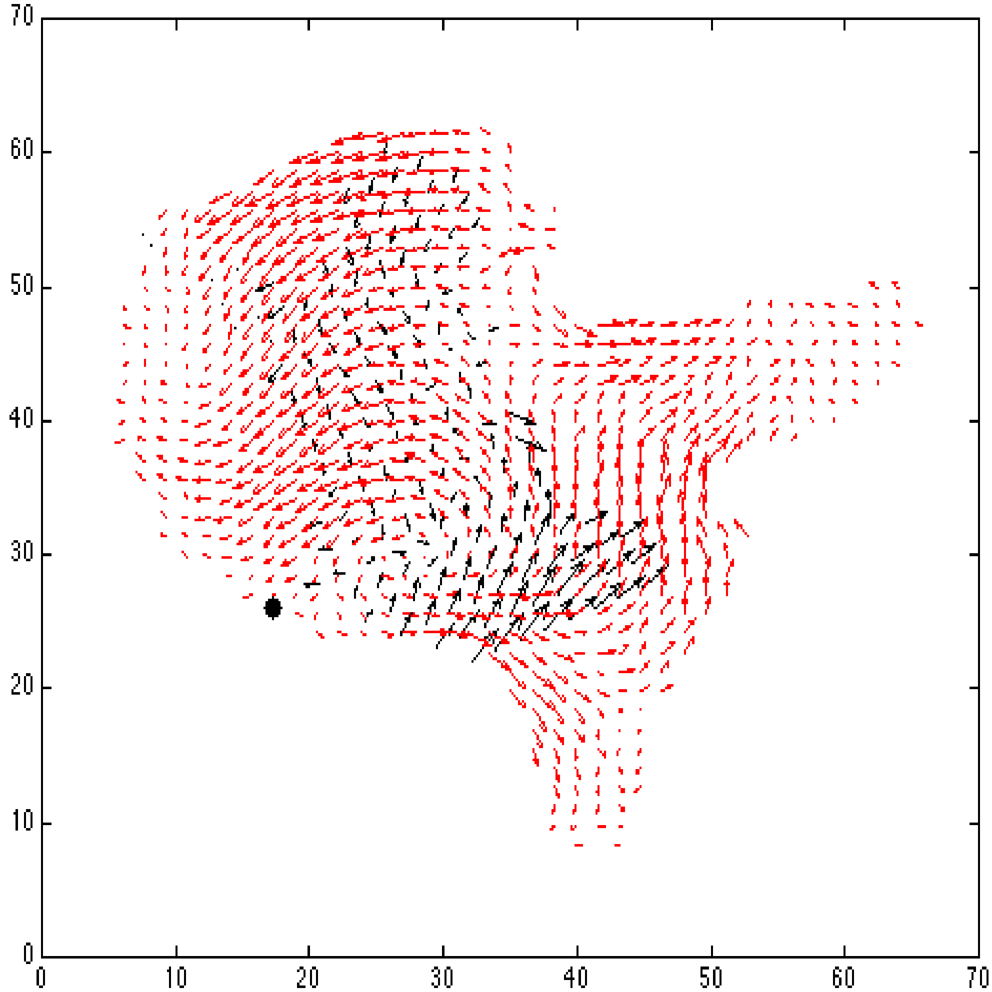


Figure 5. Radar 2 fitted Values vs. SeaSonde Total Vector Map

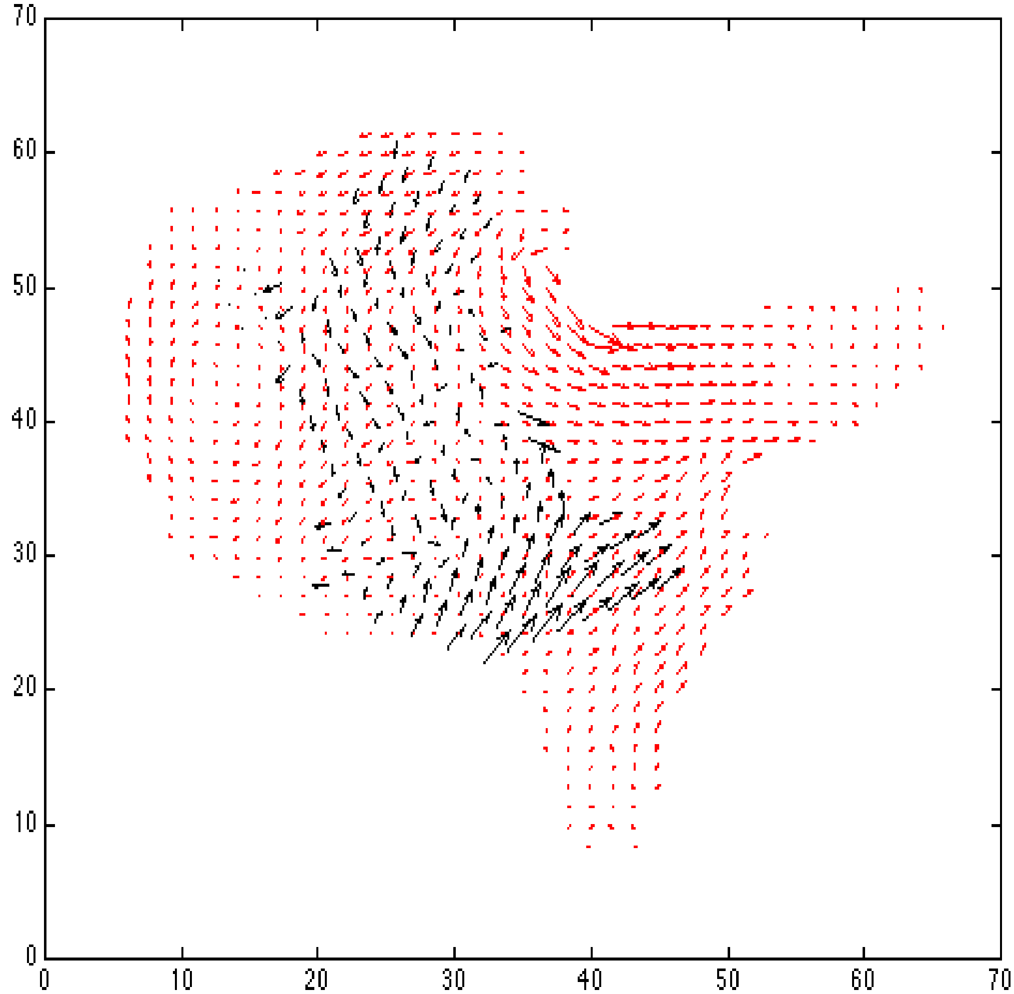


Figure 6. Combined fitted Values vs. SeaSonde Total Vector Map

4.4 Analysis of Time Period 0000-0100 hrs

During this hour, both SeaSondes acquired the least amount of data. Surface waves that the CODAR units are looking for seem to be at a premium at the middle of the night. The result is a very sparse total vector map produced from the SeaSondes. Looking at the first case where the radials of Radar 1 were used to find the fitting coefficients only the large vectors in the Southeastern area of the bay. Comparing the results from figure 5, the total vectors produced from the fitted normal modes give a better agreement to the SeaSonde vector map than that of the Radar 4 case. It seems the position of Radar 2 provides for more radials to be produced and thus providing for a better fit of the normal modes. Analyzing figure 6 we see the combined case produces a better fit than that of the individual radar cases, this is expected and proves that normal modes can be used to fill in the gaps in the SeaSonde vector map.

4.5 Observations for the time of 0100-0200 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 1:00 AM to 2:00 AM. The first total surface current map, figure 7, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the SeaSondes. The second map, figure 8, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 9, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

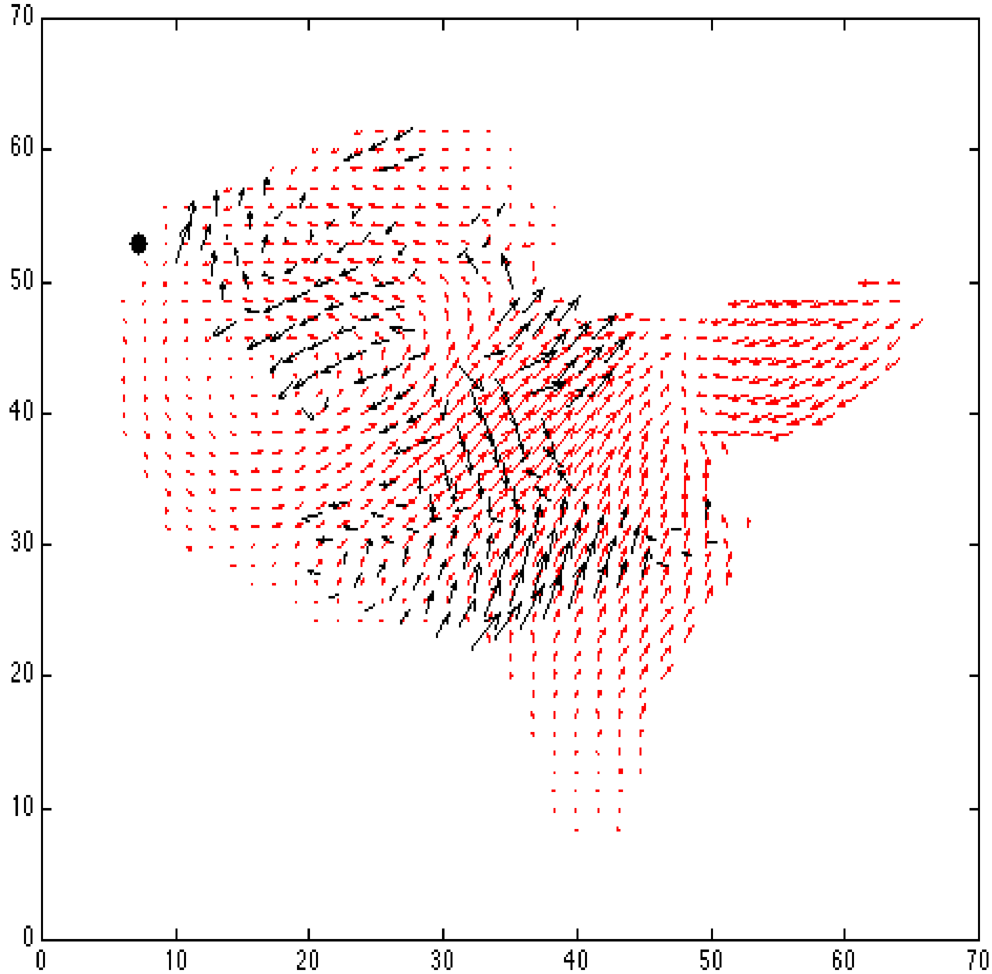


Figure 7. Radar 1 fitted Values vs. SeaSonde Total Vector Map

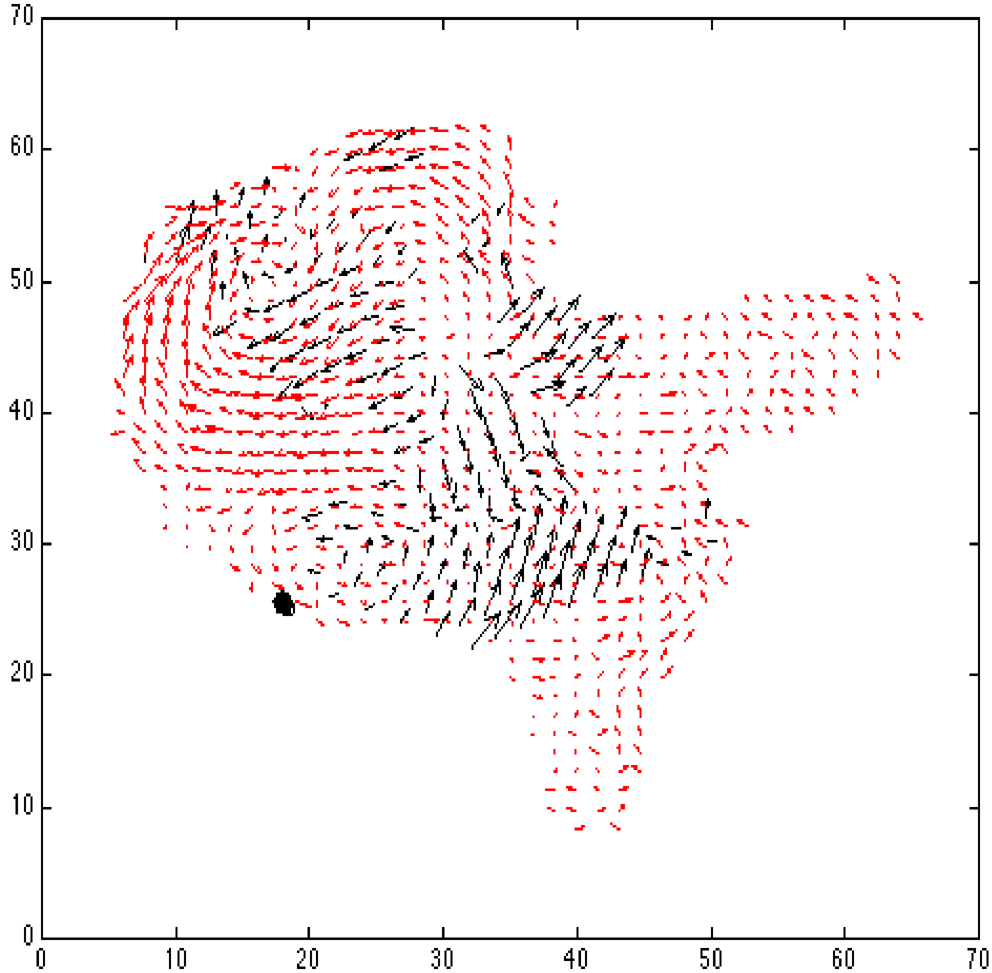


Figure 8. Radar 2 fitted Values vs. SeaSonde Total Vector Map

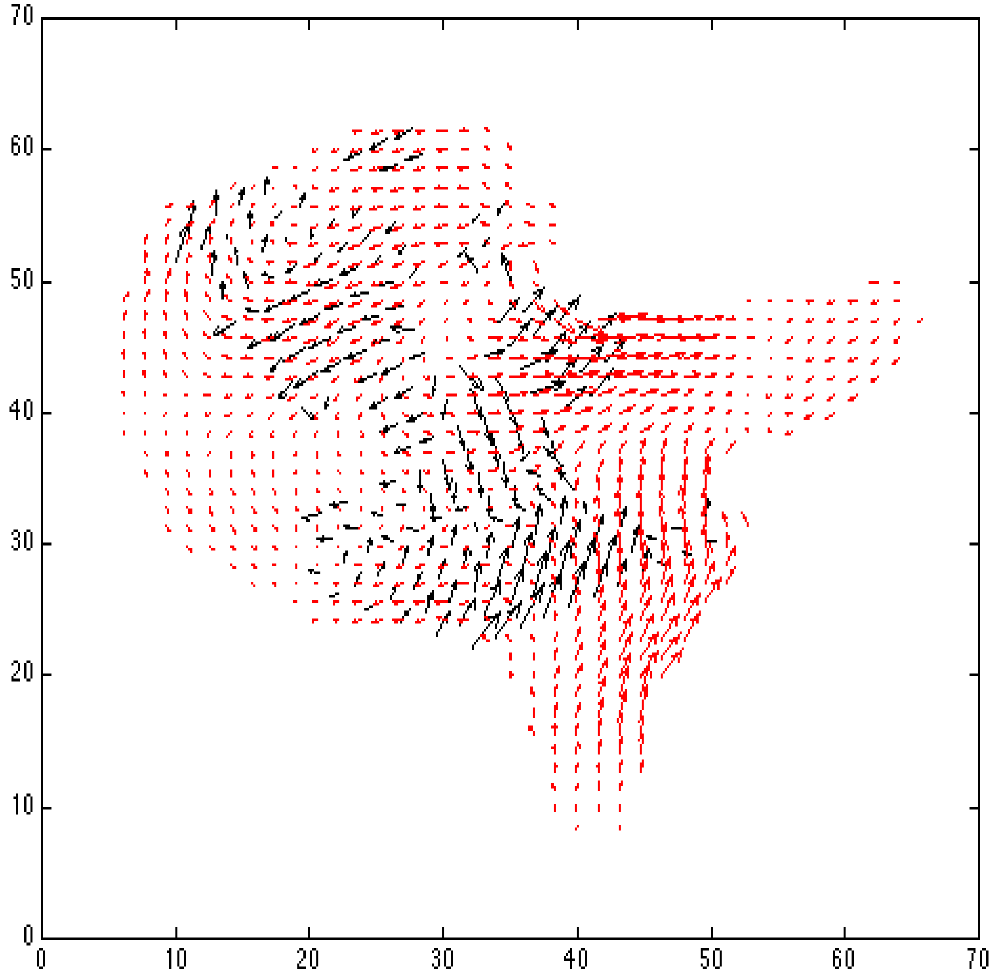


Figure 9. Combined fitted Values vs. SeaSonde Total Vector Map

4.6 Analysis of Time Period 0100-0200 hrs

Beginning with figure 7, we see that the fitted data compares only marginally with that of the total vector map produced by the CODAR units. The vectors at the center of the bay do not compare that well and good correlations can only be found near the radar site and to the Southwest where strong currents dominate. Looking carefully at the total vector map from the SeaSondes we see that the surface currents are very erratic and the NMA functions struggle to model the currents accurately with the radials from Radar 1. Looking at figure 8 we see a much better agreement with the SeaSonde total vector data than with figure 7, Radar 2 with its better position and wider scanning area makes more radial data available for the fitting process and thus a better fit. So it seems to me that the position of Radar 2 is an important factor in the accuracy of the fitted total vector map. When we consider the combined case, figure 9, we see the best agreement from all three cases. Here we see the magnitudes and directions of the vectors of the fitted values matching closely to the SeaSonde values in all areas.

4.7 Observations for the time of 0200-0300 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 2:00 AM to 3:00 AM. The first total surface current map, figure 10, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the SeaSondes. The second map, figure 11, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour.

The third map, figure 12, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

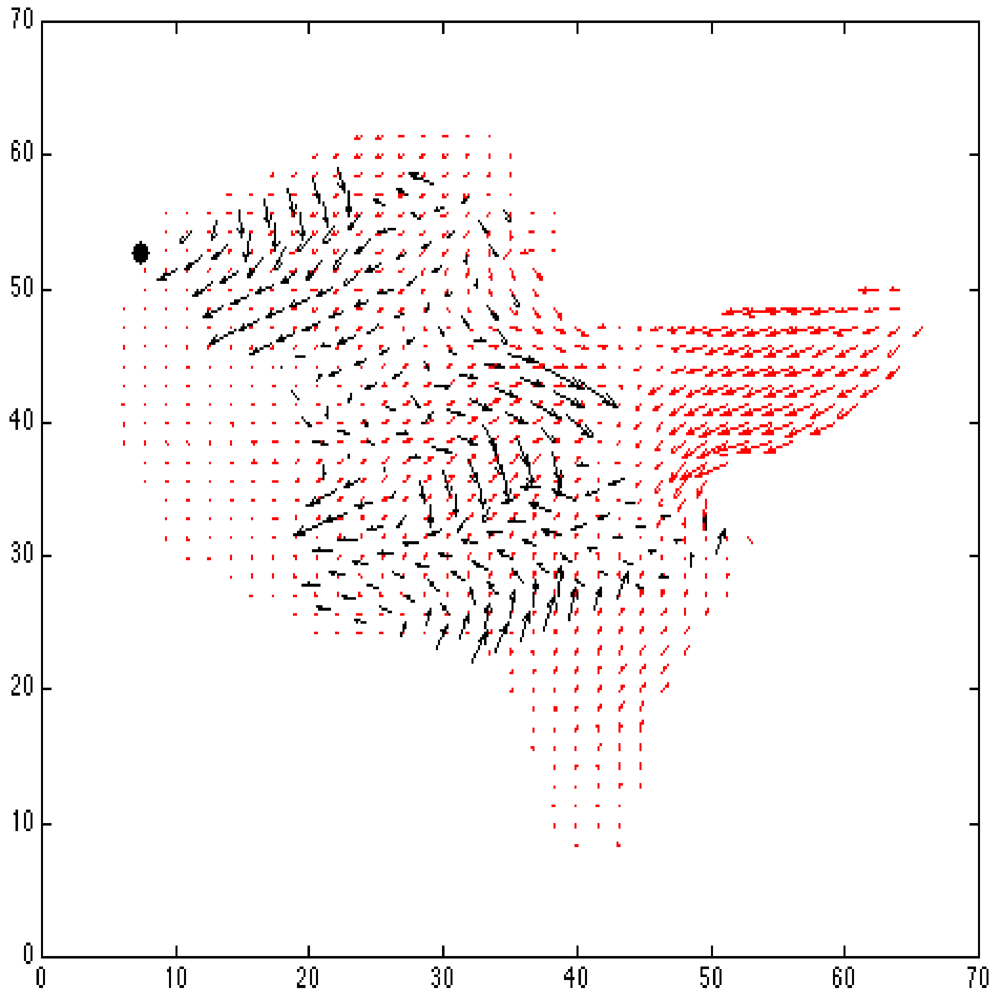


Figure 10. Radar 1 fitted Values vs. SeaSonde Total Vector Map

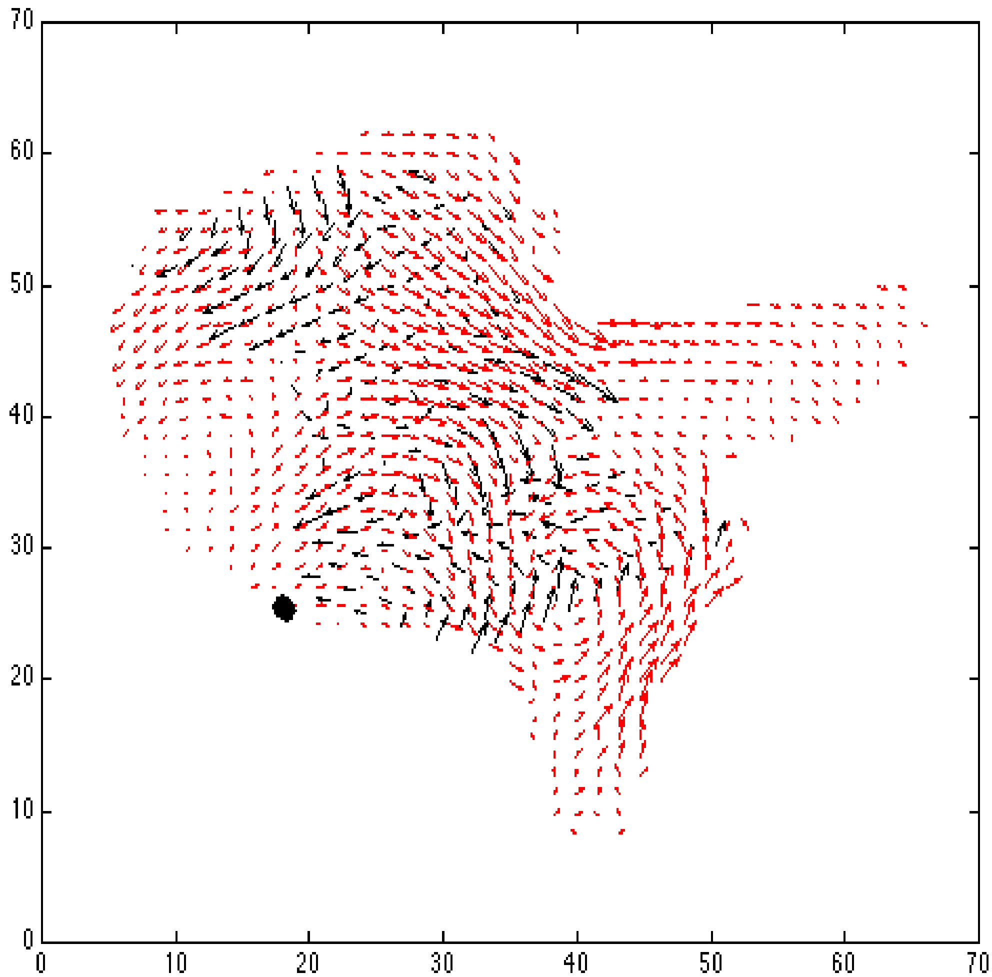


Figure 11. Radar 2 fitted Values vs. SeaSonde Total Vector Map

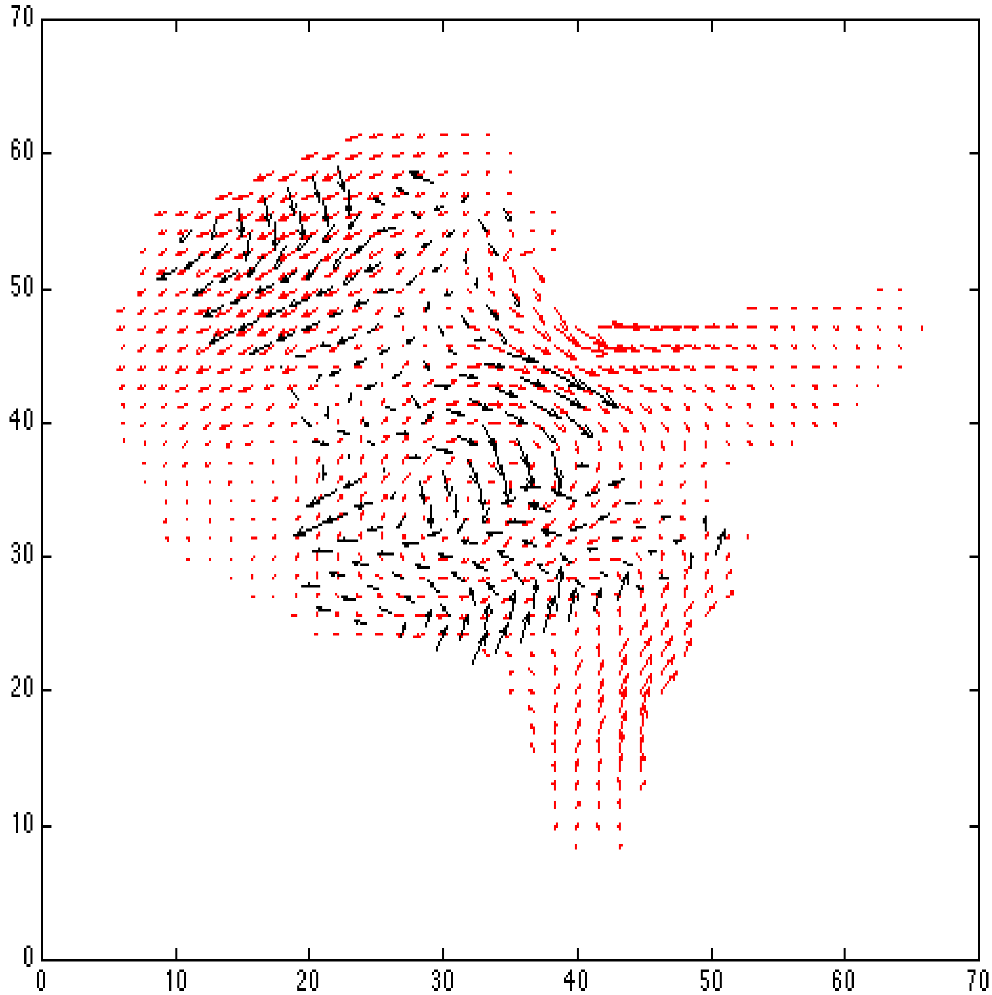


Figure 12. Combined fitted Values vs. SeaSonde Total Vector Map

4.8 Analysis of Time Period 0200-0300 hrs

Looking at the Radar 1 comparison, figure 10, we see that the fitted vector magnitudes are all smaller when compared with the total vector map produced by the SeaSondes except for those vectors near the inlet. Most vectors agree marginally at the most with the experimental data except for those near the radar site. The Radar 2 case, figure 11, is in far better agreement. Even though the total vector field indicated by the SeaSondes shows the currents still erratic with no definite flow, the fitted values agree very well with the experimental data in direction and magnitude. Once again, it seems the superior position of the second SeaSonde makes all the difference when it comes to fitting normal modes to the radials. If we look at figure 12, the combined case further refines the fitted values, matching up with the experimental data very well and providing a trustworthy fill in the data gaps that the two SeaSondes could not provide. We can see that using normal modes normalized by using radial data from one radar has so far been a viable method for the creation of total surface current maps when the surface currents are erratic.

4.9 Observations for the time of 1100-1400 hrs, Aug. 29, 2001, Corpus Christi Bay

Here we present the second set of total vector maps for the individual radar cases and the combined case for the time of 1100-1200 hrs, 1200-1300 hrs, 1300-1400 hrs universal time, August 29, 2001 for the Corpus Christi Bay. On each map the following features are seen, first there is a set of black vector arrows that seem to occupy about two-thirds of the bay area, these are the total vector maps produced by the SeaSonde combining station. The next feature are the red vector arrows that occupy all of the bay area, these are the fitted values produces from the normal modes. For the individual radar cases a black spot will indicate the location of the SeaSonde from whose radial velocities the fitting coefficients where calculated.

4.10 Observations for the time of 1100-1200 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 11:00 AM to 12:00 PM. The first total surface current map, figure 13, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the SeaSondes. The second map, figure 14, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 15, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

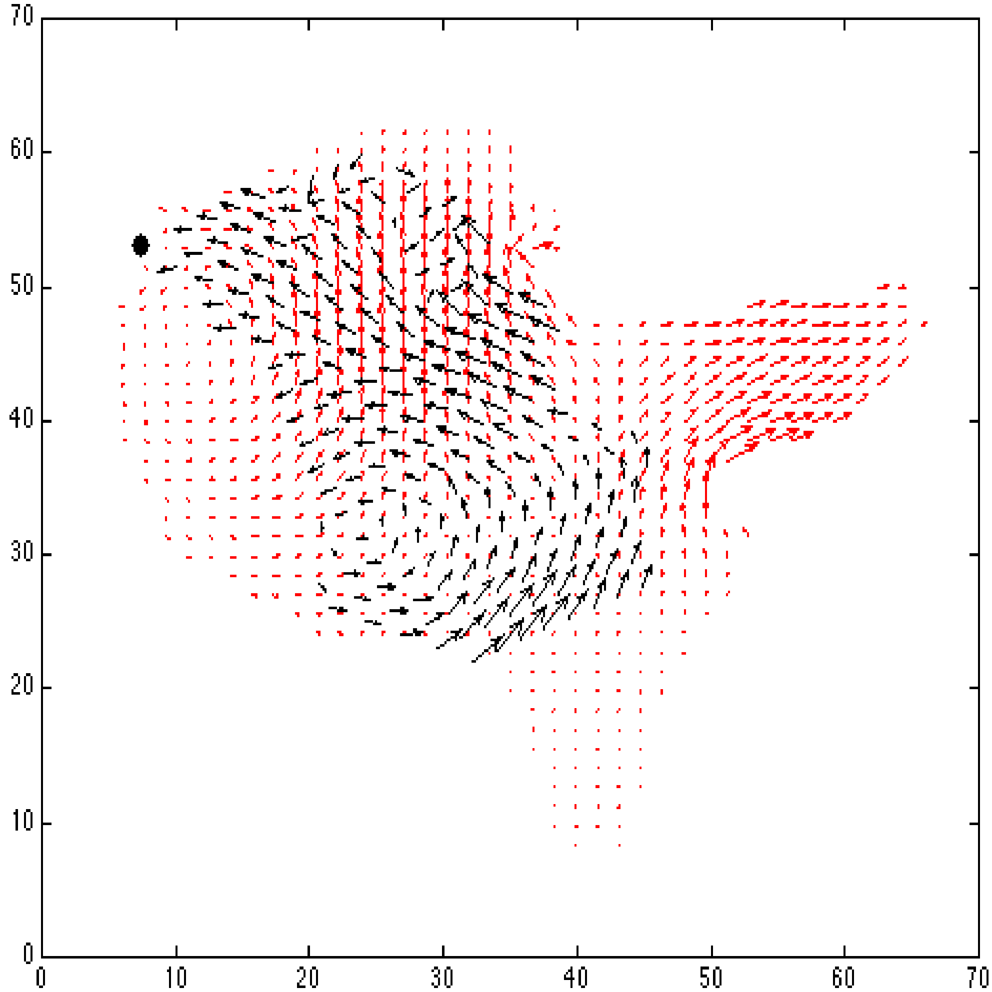


Figure 13. Radar1 fitted Values vs. SeaSonde Total Vector Map

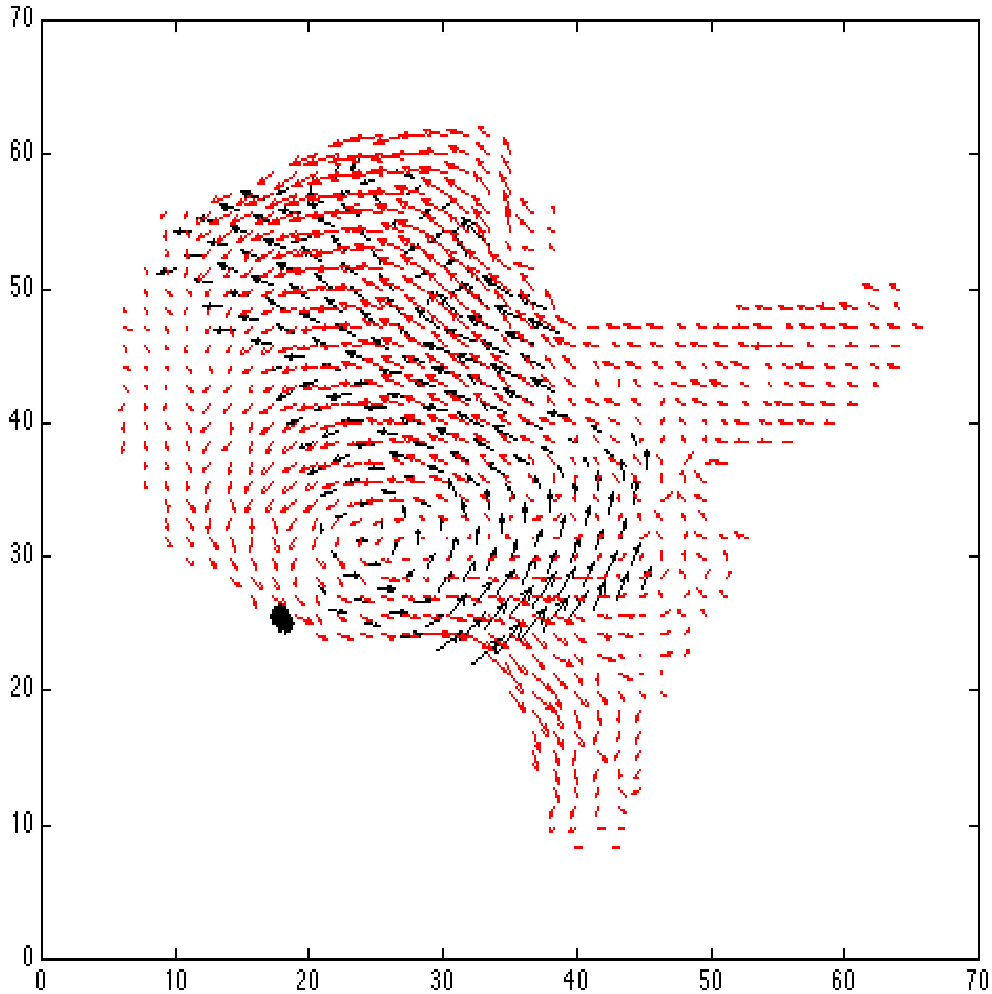


Figure 14. Radar 2 fitted Values vs. SeaSonde Total Vector Map

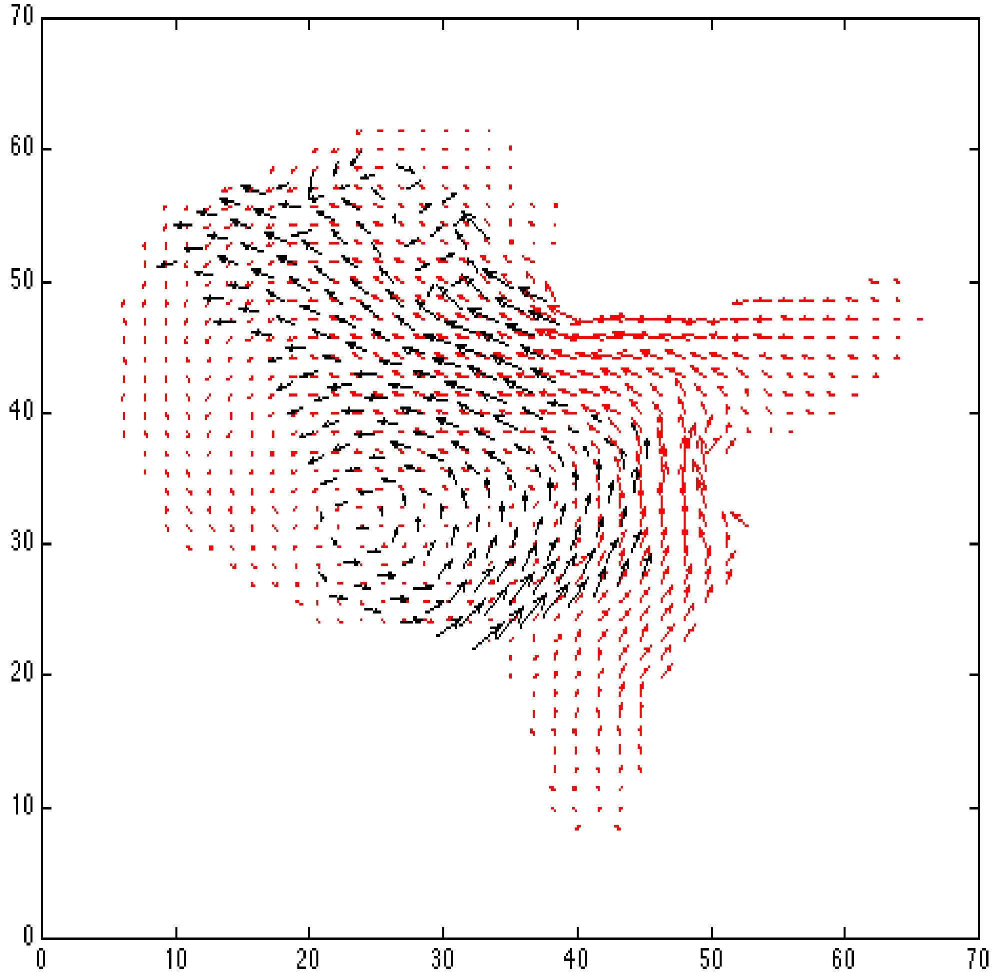


Figure 15. Combined fitted Values vs. SeaSonde Total Vector Map

4.11 Analysis of Time Period 1100-1200 hrs

During the middle of the day the surface currents in Corpus Christi Bay acquire a more uniform flow and the formation of a vorticity near the second SeaSonde site. The bay has now acquired a totally different characteristic than in the early morning. Beginning with figure 13 we see that the fitted values agree only marginally with those of the SeaSonde total vector map, the best agreements being those points nearest to the Radar 1 site. Once again the position of Radar 1 handicaps the fit of the normal modes, in figure 14 however, we see a much better fit as Radar 2's better view of the bay area allows for more radials to be produced. This fitted total current map is in very good agreement with the experimental data. Figure 15 once again refines on the Radar 2 case as we expect it to, this fit using both sets of radials to normalize the NMA functions produced from PDE2D. Even though the surface currents in the bay area are completely different when compared to the early morning observations, we can still use one radar to produce a good complete total surface current map. Once again the position of the SeaSonde when using only one radar unit to find the normalization coefficients of the normal modes is key to how well a fit is obtained.

4.12 Observations for the time of 1200-1300 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 12:00 PM to 1:00 PM. The first total surface current map, figure 16, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the

SeaSondes. The second map, figure 17, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 18, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

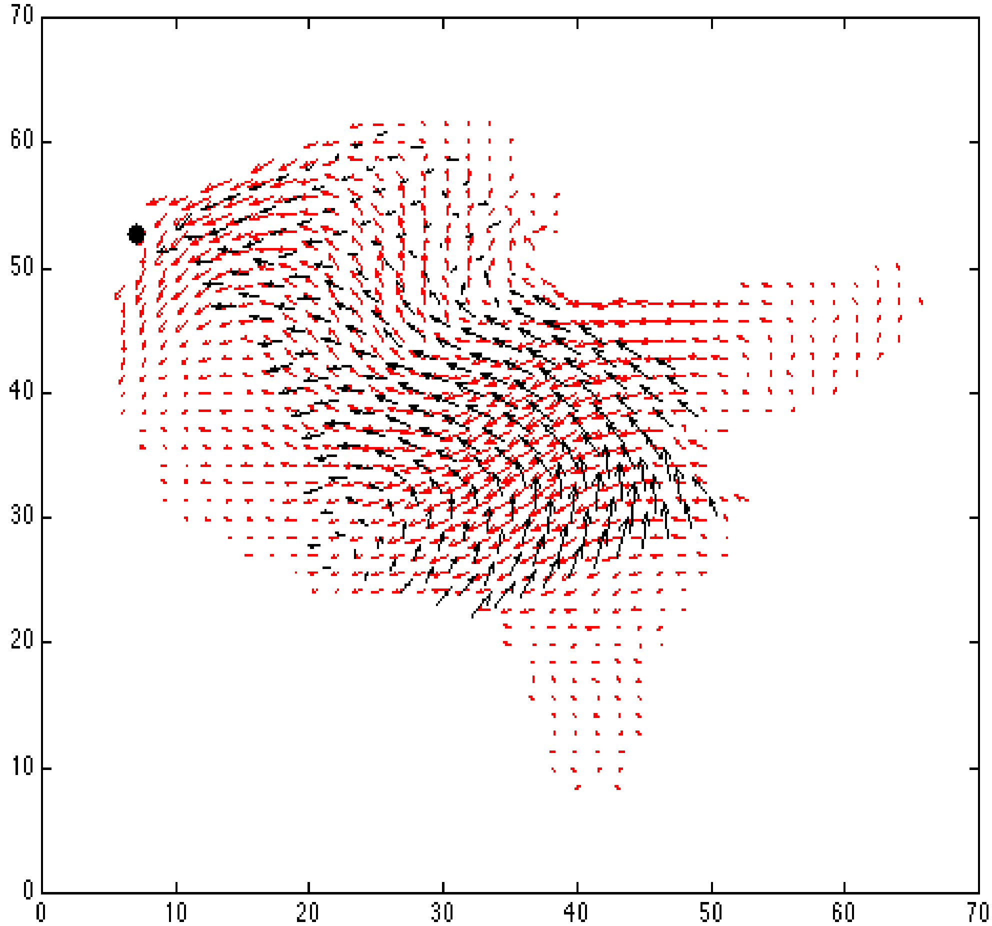


Figure 16. Radar 1 fitted Values vs. SeaSonde Total Vector Maps

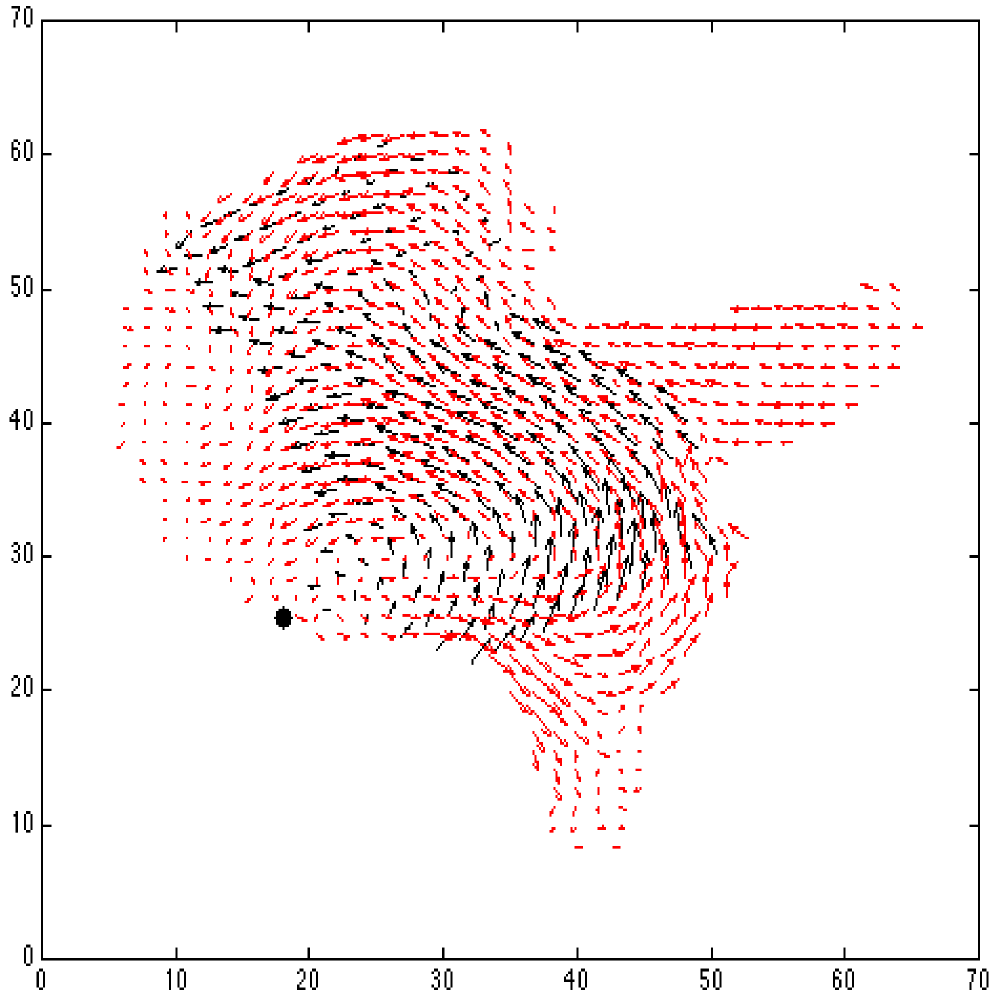


Figure 17. Radar 2 fitted Values vs. SeaSonde Total Vector Map

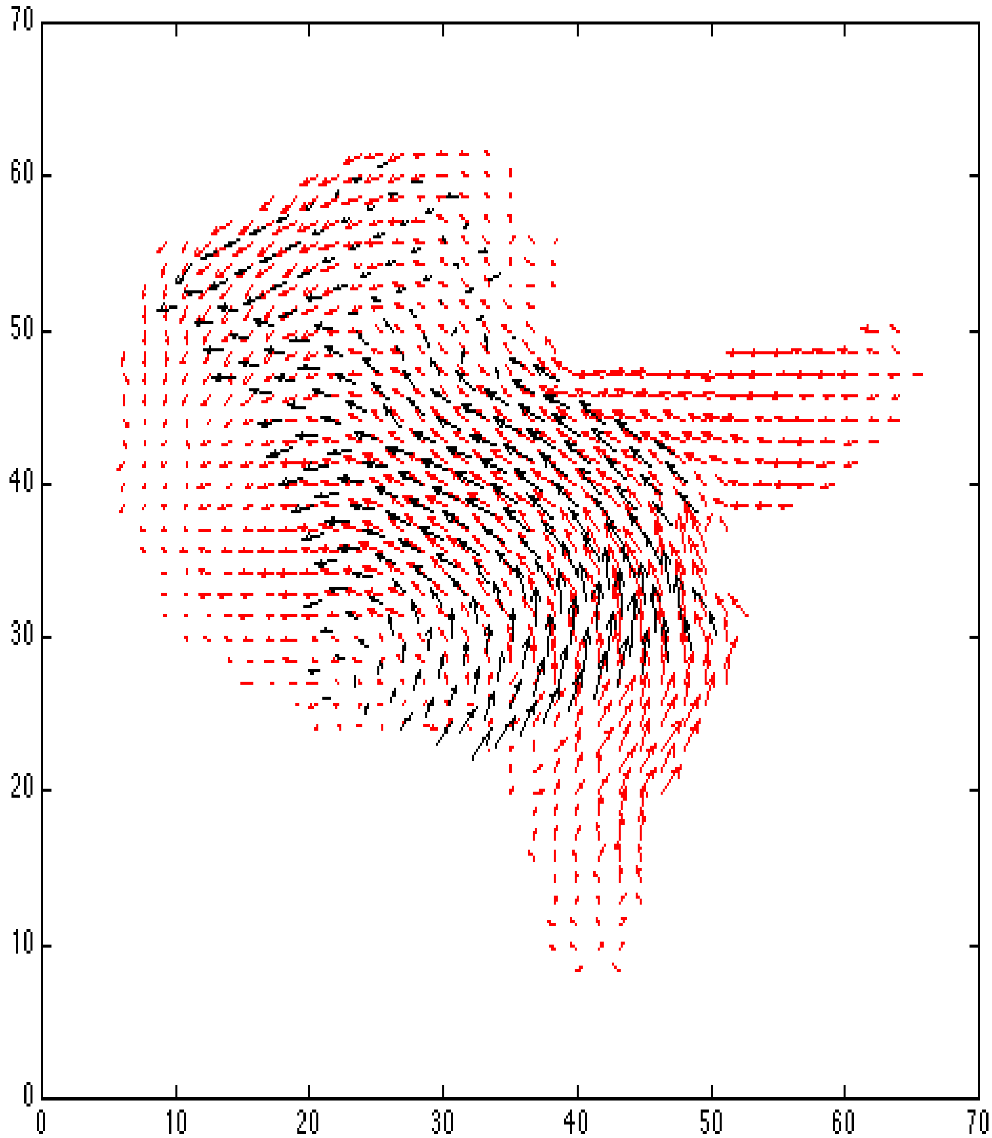


Figure 18. Combined fitted Values vs. SeaSonde Total Vector Map

4.13 Analysis of Time Period 1200-1300 hrs

During this hour we see that the surface currents are flowing in a more uniform direction than any other time so far observed. The vorticity in the southern bay area is beginning to decay and the currents are generally flowing from the Southeast to the Northwest with a pocket of chaotic current up to the north. Looking at figure 16 we see that the fitted vectors agree with the experimental data better than at any time so far observed for the Radar 1 case. Even though the fit is not perfect we see the general trend of the fitted total vectors follows that of the experimental total vectors. When we consider the Radar 2 case in figure 17, we find the fitted values modeling the SeaSonde total vectors nearly perfectly. Now with the current moving in a more uniform direction and the radar unit's excellent view of Corpus Christi Bay's primary inlet, the normalized modes have little trouble in producing an excellent total surface current map. The combined case makes further refinements to the fitted total surface current map in figure 18. We see once again the importance of position of the radar sites, although Radar 1 gives a fair agreement in the trend of the direction of the surface currents, it cannot compare to the accuracy of Radar 2's fitted total vector map.

4.14 Observations for the time of 1300-1400 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 1:00 PM to 2:00 PM. The first total surface current map, figure 19, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the

SeaSondes. The second map, figure 20, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 21, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

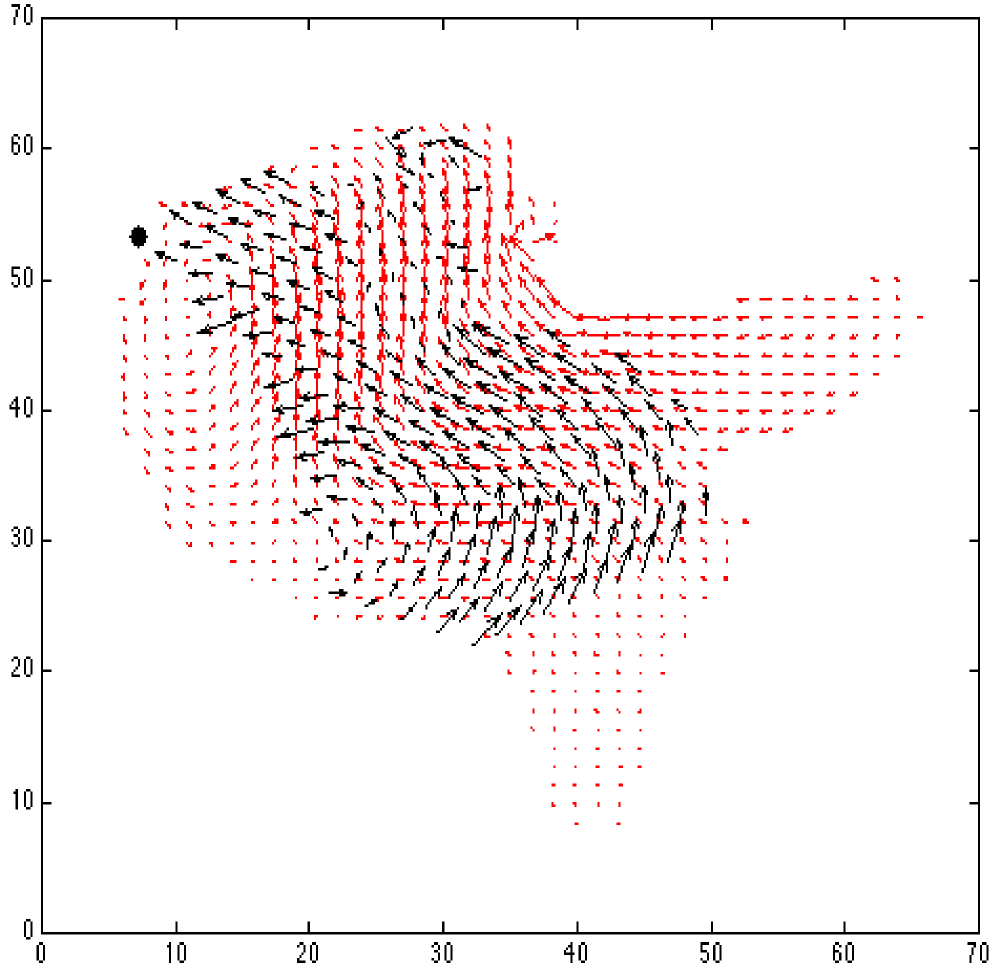


Figure 19. Radar 1 fitted Values vs. SeaSonde Total Vector Map

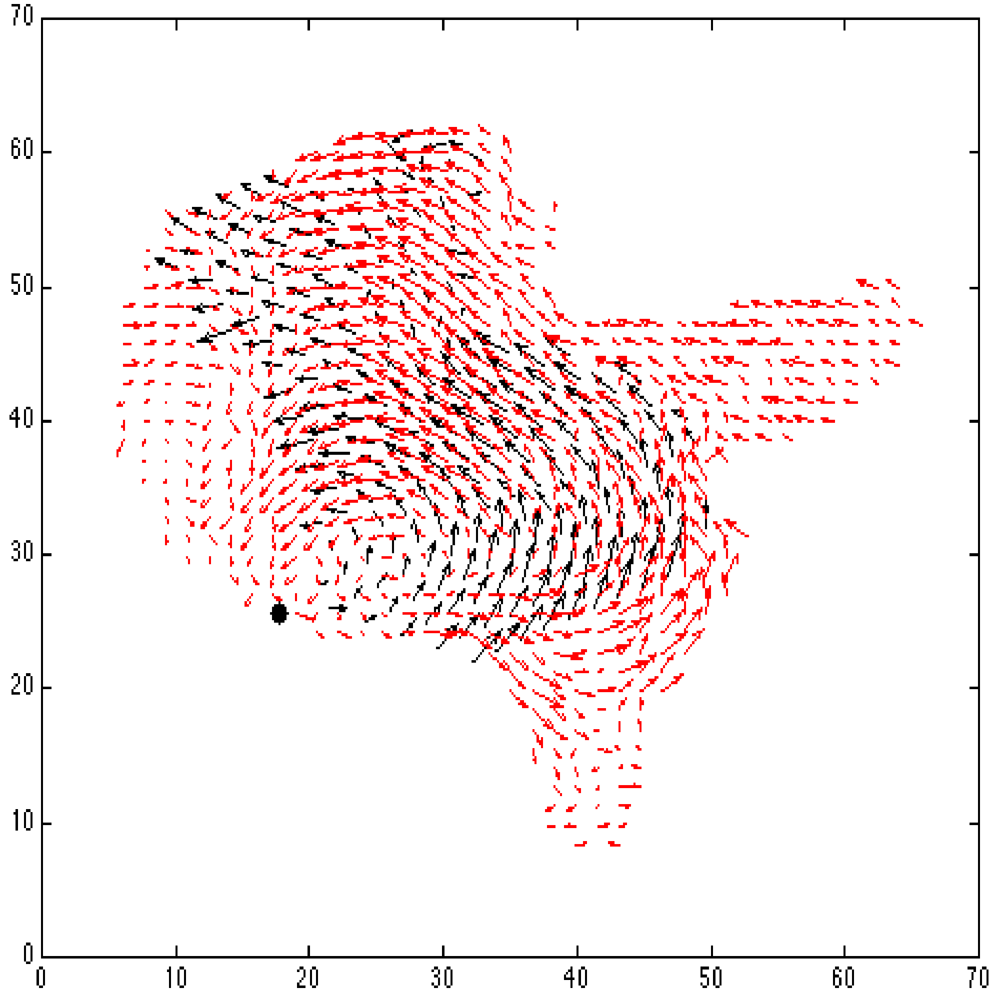


Figure 20. Radar 2 fitted values vs. SeaSonde Total Vector Map

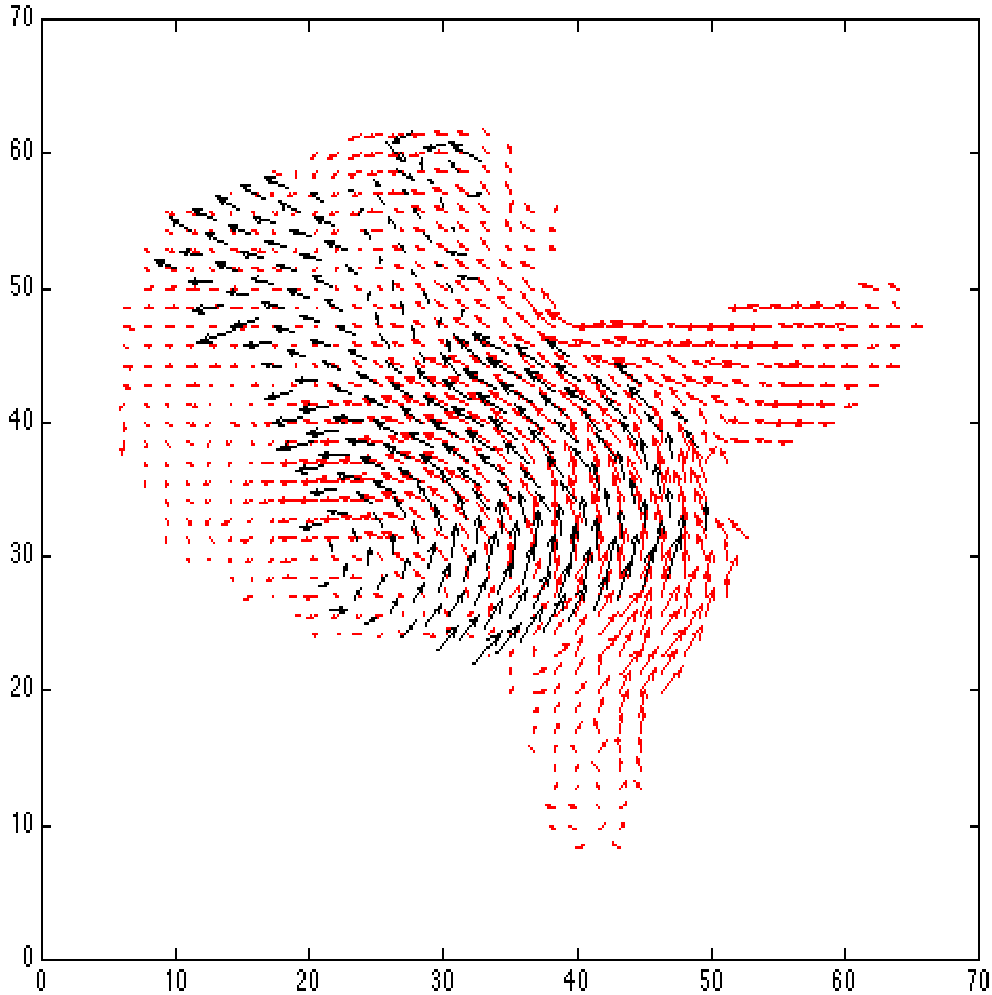


Figure 21. Combined fitted Values vs. SeaSonde Total Vector Map

4.15 Analysis of Time Period 1300-1400 hrs

This is the last hour observed in the midday group. Observing the SeaSonde total vector map we see a continuation of the current flow from Southeast to Northwest but with greater speed as the magnitudes of the total vectors have increase somewhat. Looking at figure 19, we see that the radials produced by Radar 1 simply do not give us enough information for the creation of an accurate total vector map. The patch of chaotic flow near the radar seems to dominate and thus gives us a poor agreement with the experimental data throughout the rest of the bay. Figure 20 presents us with the opposite case. Once again Radar 2's superior position allows for a better fit and produces a total vector map that is in better agreement with the experimental data. Although the total vectors produced by Radar 2's radials gloss over the chaotic patch up in the Northwest of the bay, the rest of the total vectors agree very well with the total surface current data from the SeaSondes. By combining both radar data sets, figure 21 presents a very accurate total vector map, agreeing well with the experimental data throughout the whole of Corpus Christi Bay.

4.16 Observations for the time of 1700-2000 hrs, Aug. 29, 2001, Corpus Christi Bay

Here we present the final set of total vector maps for the individual radar cases and the combined case for the time of 1700-1800 hrs, 1800-1900 hrs, 1900-2000 hrs universal time, August 29, 2001 for the Corpus Christi Bay. On each map the following features are seen, first there is a set of black vector arrows that seem to occupy about two-thirds of the bay area, these are the total vector maps produced by the SeaSonde combining station. The next feature are the red vector arrows that occupy all of the bay area, these are the fitted values produces from the normal modes. For the individual radar cases a black spot will indicate the location of the SeaSonde from whose radial velocities the fitting coefficients where calculated.

4.17 Observations for the time of 1700-1800 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 5:00 PM to 6:00 PM. The first total surface current map, figure 22, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the SeaSondes. The second map, figure 23, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 24, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

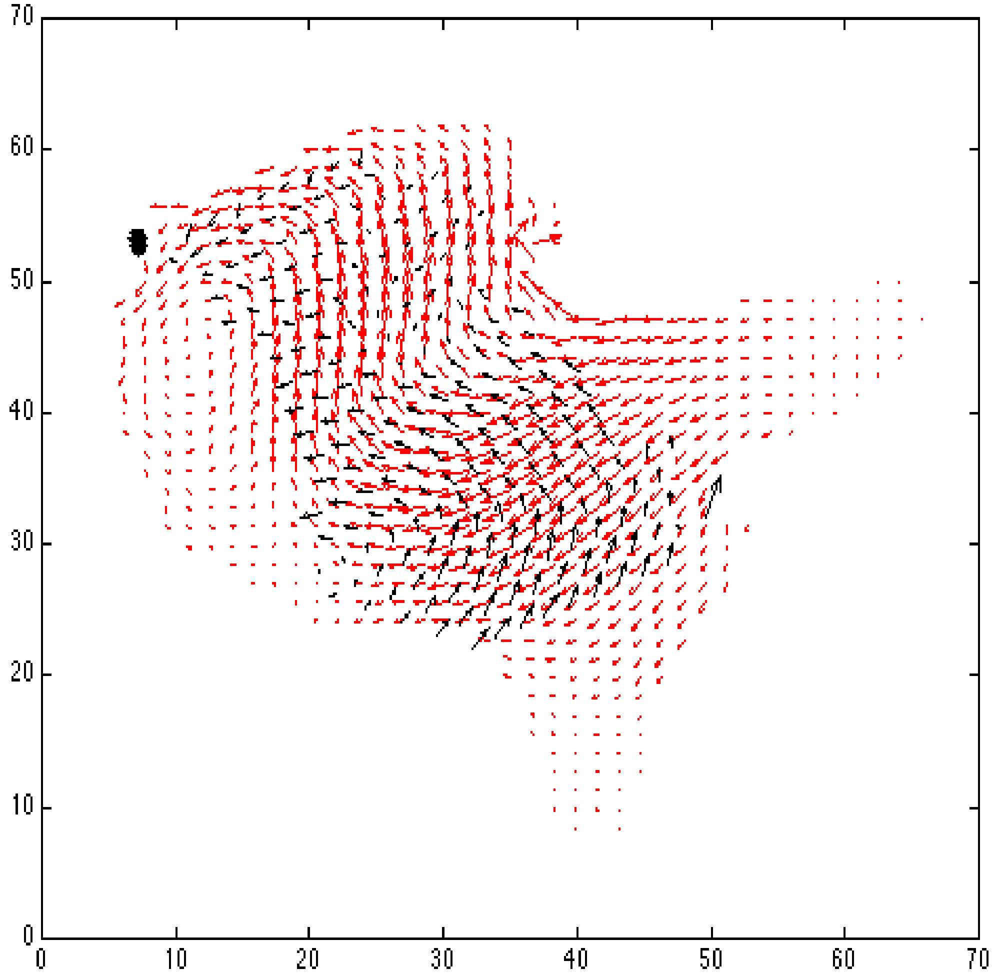


Figure 22. Radar 1 fitted Values vs. SeaSonde Total Vector Map

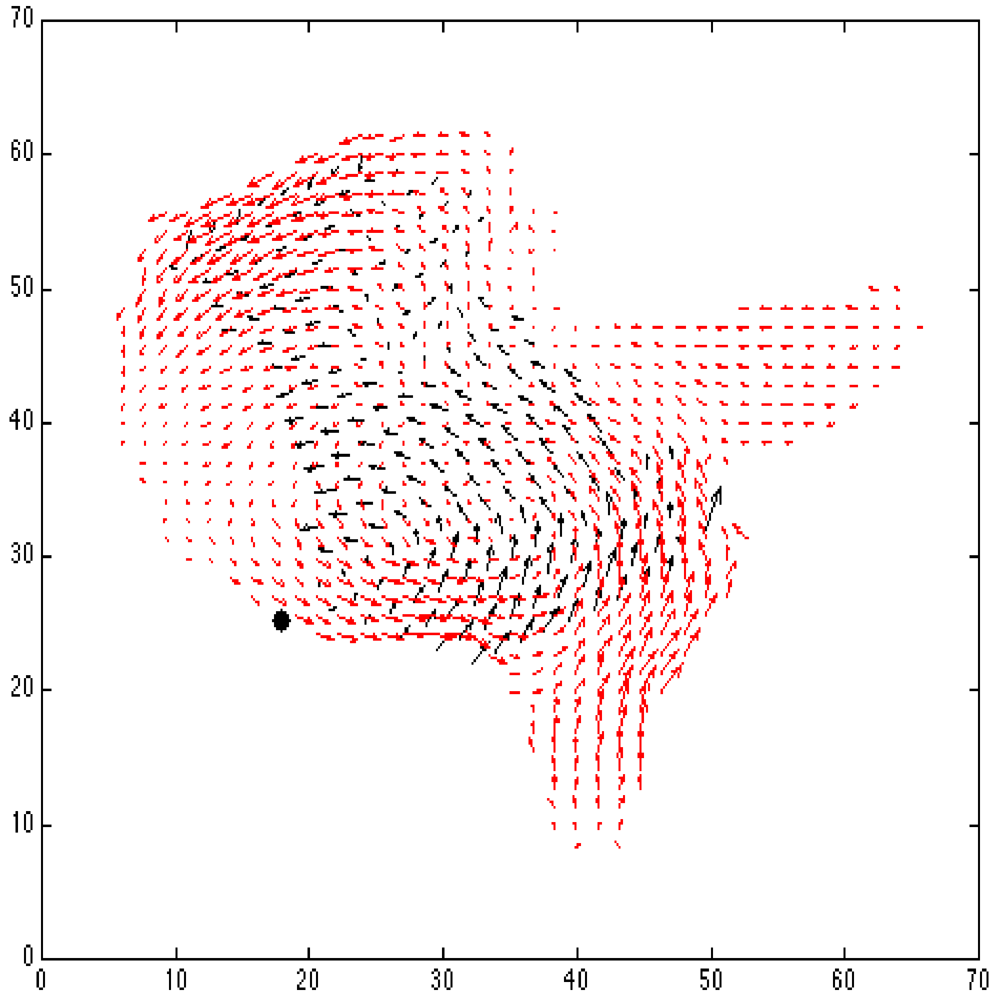


Figure 23. Radar 2 fitted Values vs. SeaSonde Total Vector Map

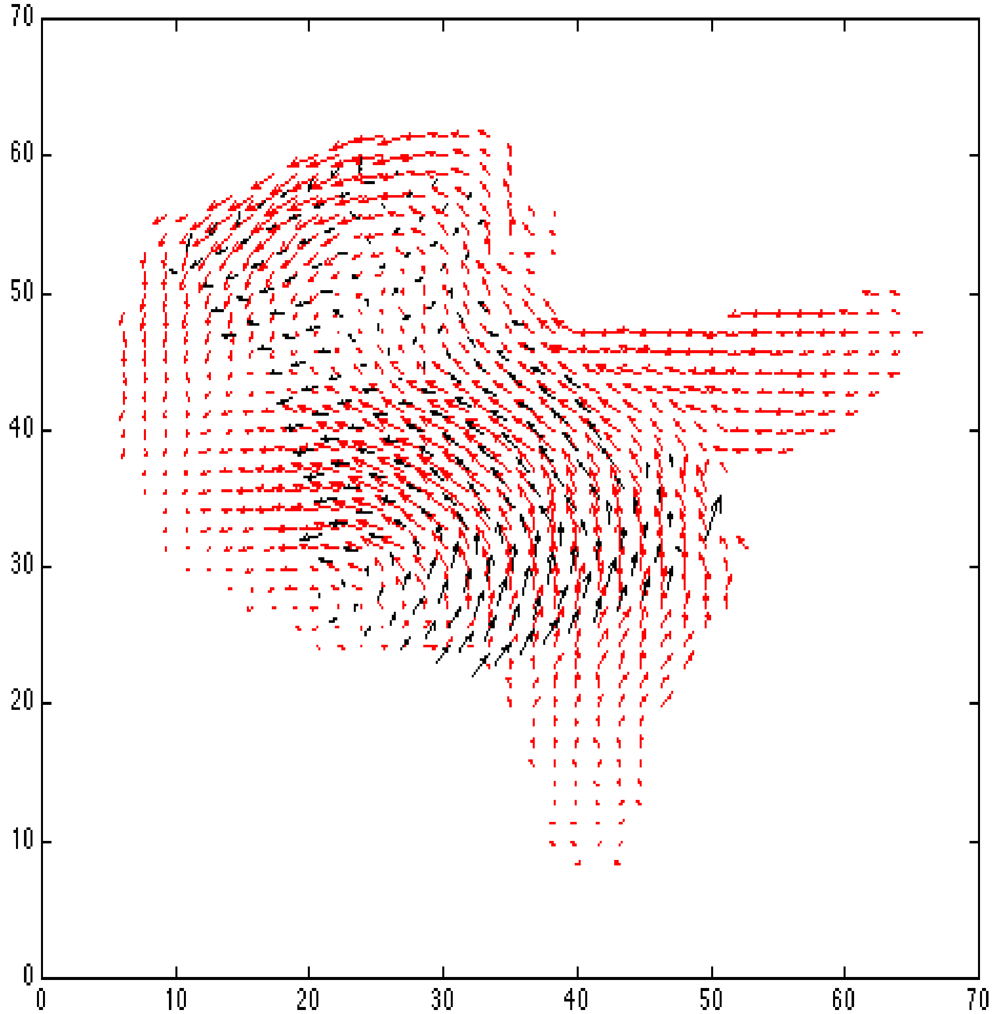


Figure 24. Combined fitted Values vs. SeaSonde Total Vector Map

4.18 Analysis of Time Period 1700-1800 hrs

During this period the SeaSondes measure a weakening of the surface currents though the direction of propagation remains close to that of the midday readings. Figure 22 shows that the Radar 1 radials provide for a mediocre at best total vector map from the normal modes, although the trend is fairly in the right direction there are many in discrepancies that cannot be reconciled in the center area of the bay. Figure 23 shows us a better fit from the normal modes fit using the radials of Radar 2. The combined values are once again the best case as the combined radials produce a fitted total vector map that is in excellent agreement with the total vector map created by the SeaSonde combining station.

4.19 Observations for the time of 1800-1900 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 6:00 PM to 7:00 PM. The first total surface current map, figure 25, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the SeaSondes. The second map, figure 26, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 27, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

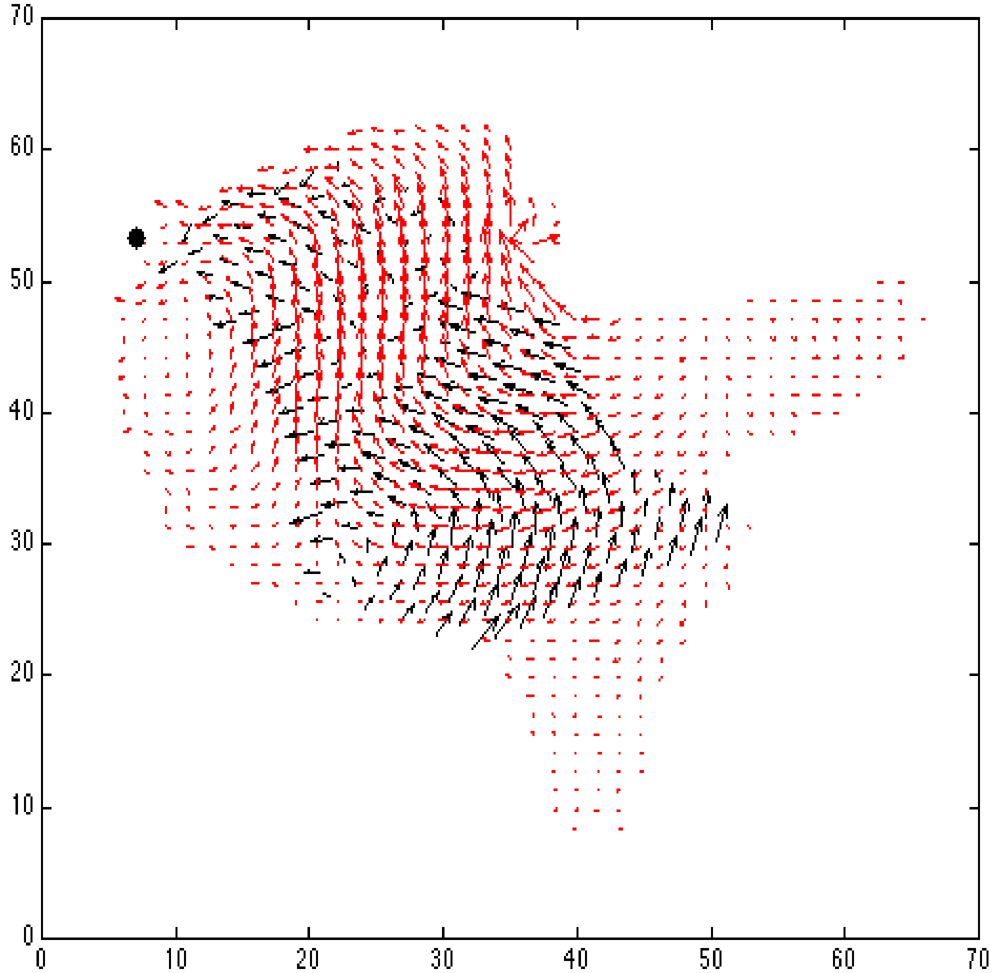


Figure 25. Radar 1 fitted Values vs. SeaSonde Total Vector Map

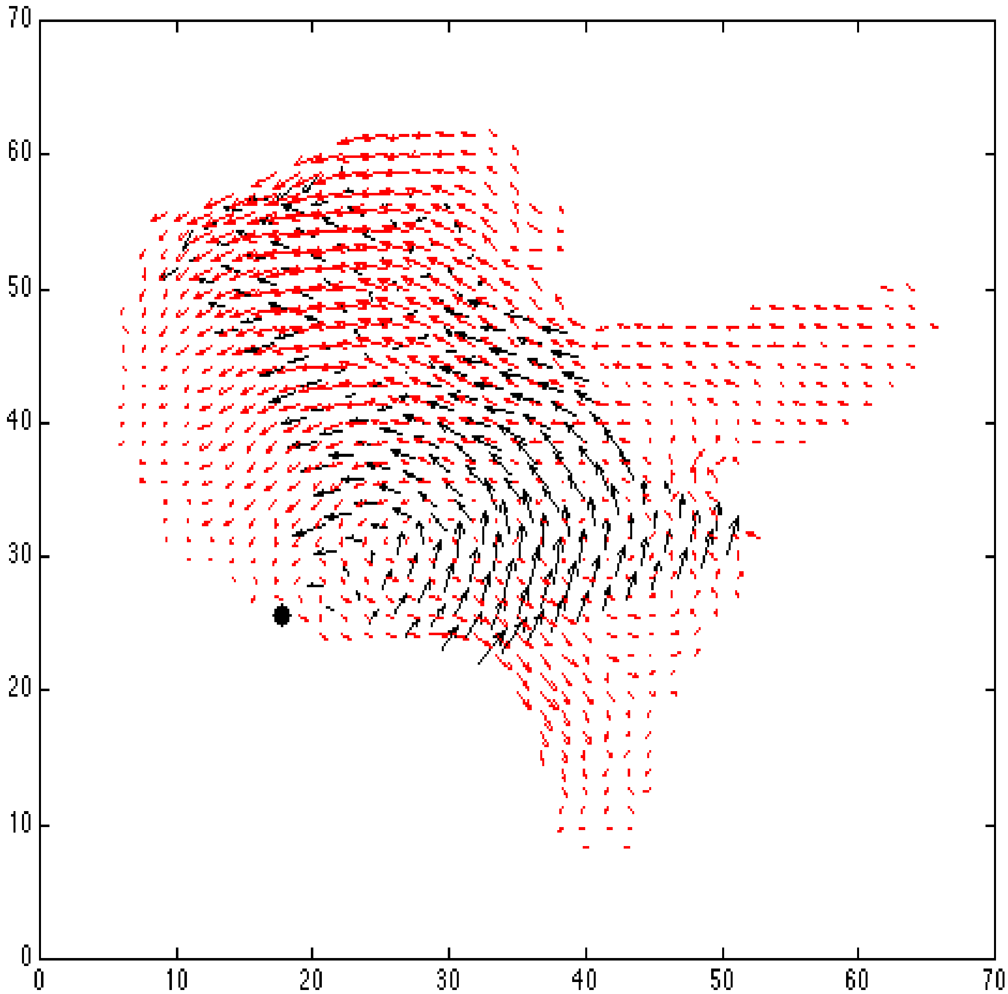


Figure 26. Radar 2 fitted Values vs. SeaSonde Total Vector Map

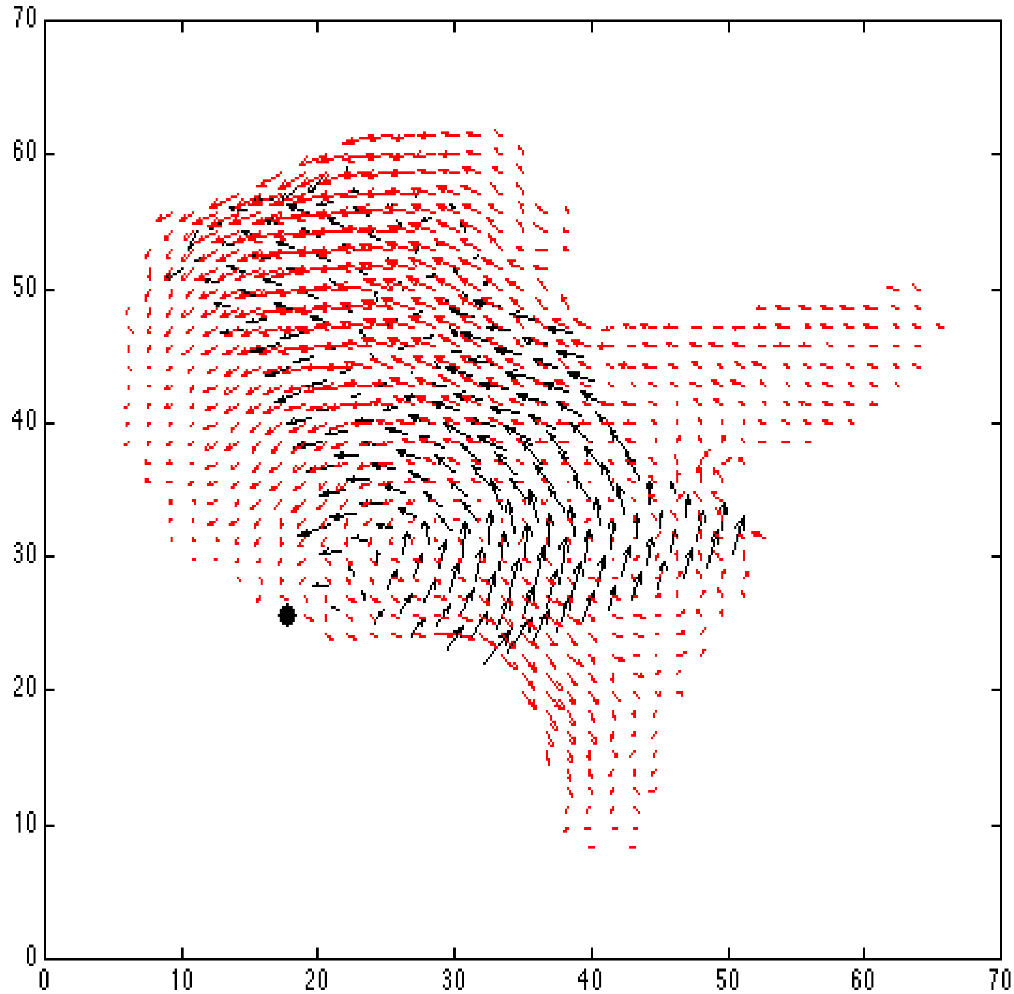


Figure 27. Combined fitted Values vs. SeaSonde Total Vector Map

4.20 Analysis of Time Period 1800-1900 hrs

As the evening draws on, the SeaSonde total vector map indicates the uniform flow of the bay's surface currents slowly beginning break up. The mostly random patch of currents up in the Northwest area has begun to spread further south. Looking at figure 25, the normalized modes attempt to compromise for the random currents in the Northwest corner and do a fair job of agreeing with the SeaSonde total vectors near the Radar 1 site. In figure 26 we see that Radar 2's better positioning affords for a better overall fitted vector map, though the random area of surface currents is mostly not visible in the fitted modes vector map. When both sets of radials are used to determine the normalization coefficients as shown in figure 27 even this increasing area of erratic surface currents is modeled fairly well giving more evidence of the viability of this method of filling data gaps using only radial data.

4.21 Observations for the time of 1900-2000 hrs, Aug. 29, 2001, Corpus Christi Bay

The following three maps will be for the surface currents measured from 7:00 PM to 8:00 PM. The first total surface current map, figure 28, was constructed from the radial velocity data of Radar 1 and compared with the total vector map produced by both the SeaSondes. The second map, figure 29, compares the fitted values produced from Radar 2 radial velocity data to the total vector map produced by both SeaSondes for the given hour. The third map, figure 30, compares the fitted values produced from the radials of both radar units for the given hour with the total vector map produced from the SeaSondes.

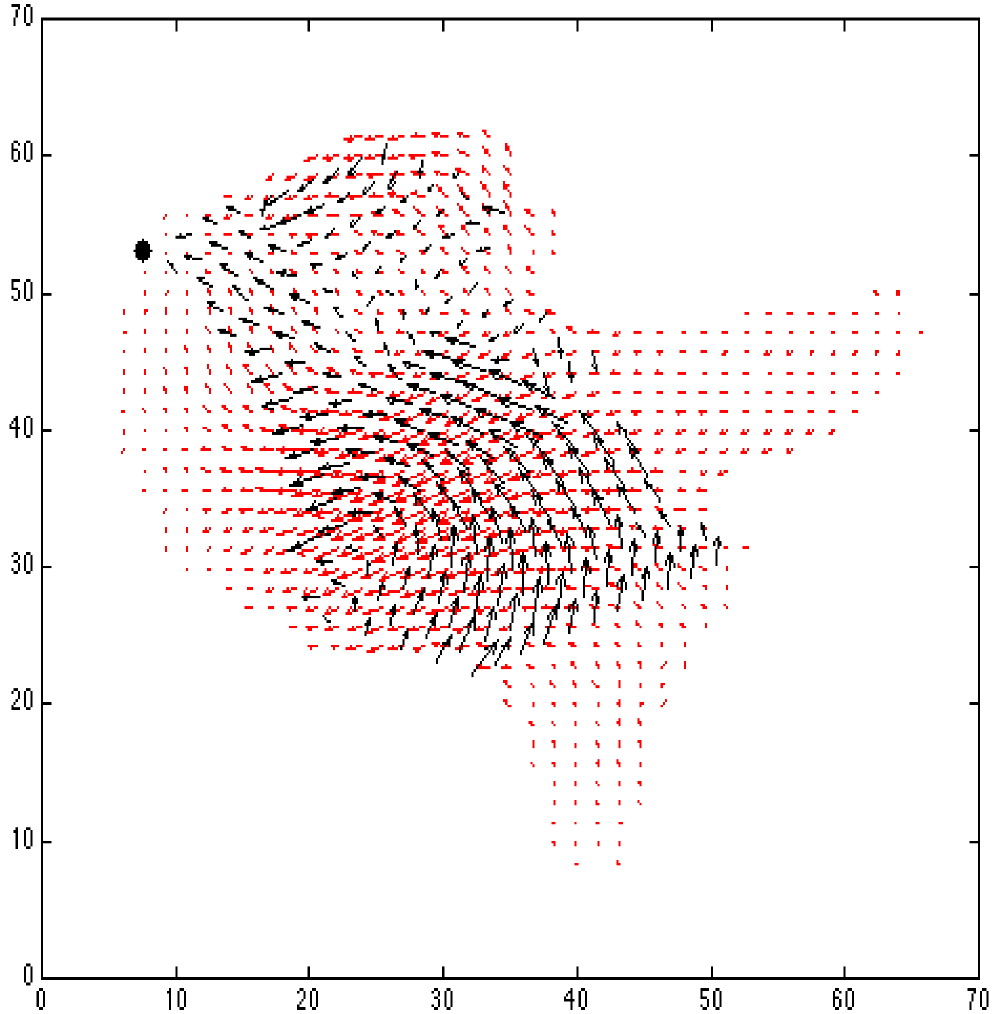


Figure 28. Radar 1 fitted Values vs. SeaSonde Total Vector Map

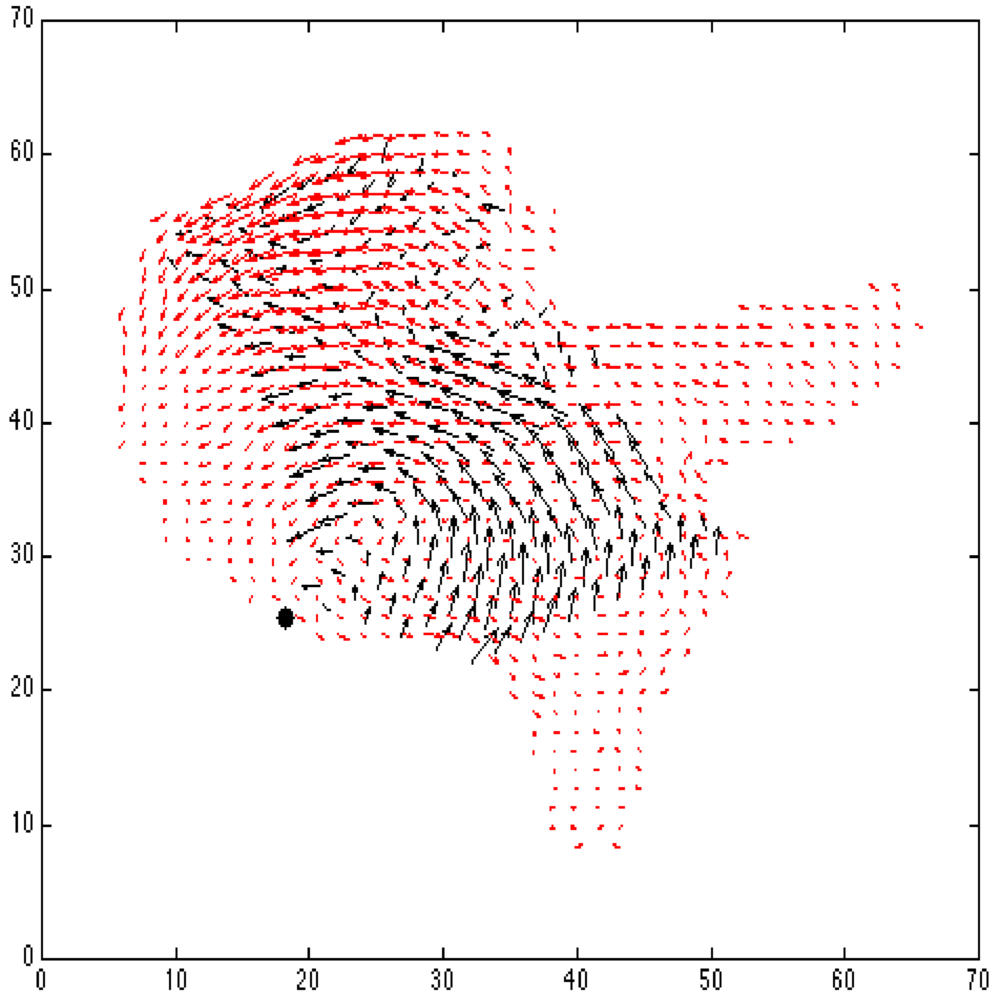


Figure 29. Radar 2 fitted Values vs. SeaSonde Total Vector Map

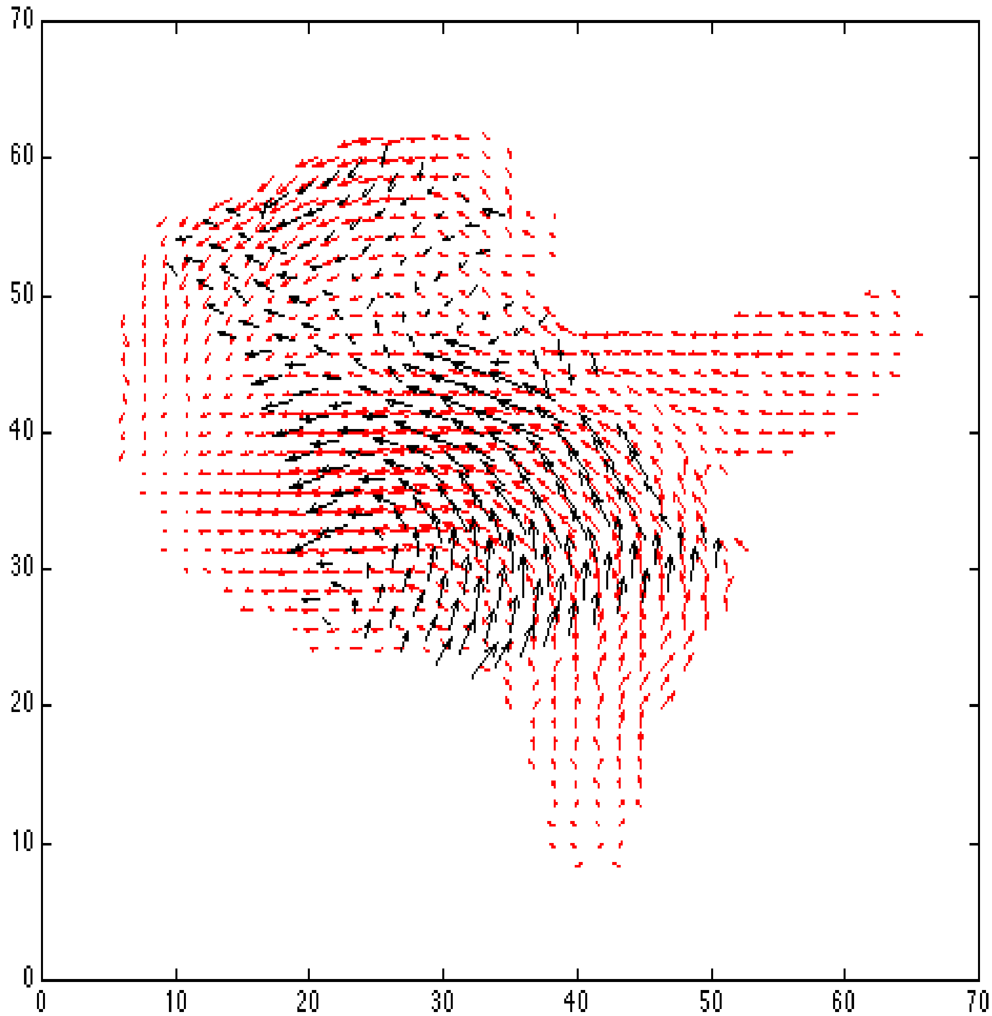


Figure 30. Combined fitted Values vs. SeaSonde total Vector Map

4.22 Analysis of Time Period 1900-2000 hrs

During this hour of observation, we see a further degeneration of the uniform flow pattern that had dominated during most of the day in the Corpus Christi Bay. Indeed we are beginning to see the surface currents beginning to revert to the erratic patterns indicated in the early morning hours of observation. It seems that the waves that scatter back towards the radar positions are beginning to thin out thus we see less and less radials generated by the SeaSondes although the flow in the center of the bay is still generally strong. It is this area of the bay that will now dictate the way the normal modes will fit to the data given by the SeaSondes. In figure 28, most of the strong radar returns will be at the farthest range bins of Radar 1. That being the case most of the vectors with strong magnitudes will in the fitted vector map will appear in the center of the bay. The direction of the vectors fit marginally at best. Looking at figure 29, Radar 2's radials are beginning to also show less accuracy as more and more of the surface currents begin to move in a more erratic motion although the fitted total vectors in the center of the bay are still in good agreement with the total vector map produced by the SeaSondes. Finally figure 30 indicates to us that even though the individual cases produce mediocre results the use of both sets of velocity radials for the purpose of finding the normalization coefficients is still viable.

5

5.0 Conclusions

Although the use of NMA functions to model surface currents is not a new concept, it was only accomplished by using the total vectors produced by multiple radars to normalize the normal modes so that total surface current maps could be produced. Our idea was to use only the radial data from one or more radar units to accomplish the same result. As we have seen it has been demonstrated that by using the radial data from a single radar it is very possible to model a bay's surface currents. We have also shown that these surface currents maps do a good job of filling in the gaps of data that are missing from the total vector maps produced by the SeaSondes. During our study we have also noted that the positioning of a radar unit is very important to the fitting process. Because of its better positioning, Radar 2 was able to create superior fitted total surface current maps alone than Radar 1 could. This was shown time and again in all three observational periods of the day. Finally, when both sets of radial data were applied to the fitting process, we were able to construct fairly good total surface current maps that consistently matched and augmented the experimental surface current maps.

5.1 Future Study

Although it is possible to create good normal mode fitted total vector maps from the radial data gathered by one or multiple radar units I believe that the results would be better if we had a better understanding of the wind-sea interaction at the surface of the Corpus Christi Bay. Future work should be to find a way to add in the information of how the wind interacts with ocean waves so that an even better surface current map can be produced as well as a finer understanding of the dynamic that is at play here. Also since the writing of this thesis, the Conrad Blucher Institute has purchased three more SeaSondes for their research into surface currents. Application of this modeling method using the other new radar units would further increase the accuracy of the fitted total vector maps created using Normal Mode Analysis.

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APPENDIX 1

Here the modal vector maps created by PDE2D are showcased. These are the same maps that where used to fit to the total vector maps created by the two SeaSondes in Corpus Christi Bay. There are a total of 16 maps, 8 for the lowest modes (**Φ**) that satisfy the Dirichlet conditions, 8 for the lowest modes (**Ψ**) that satisfy the Neumann boundary conditions.

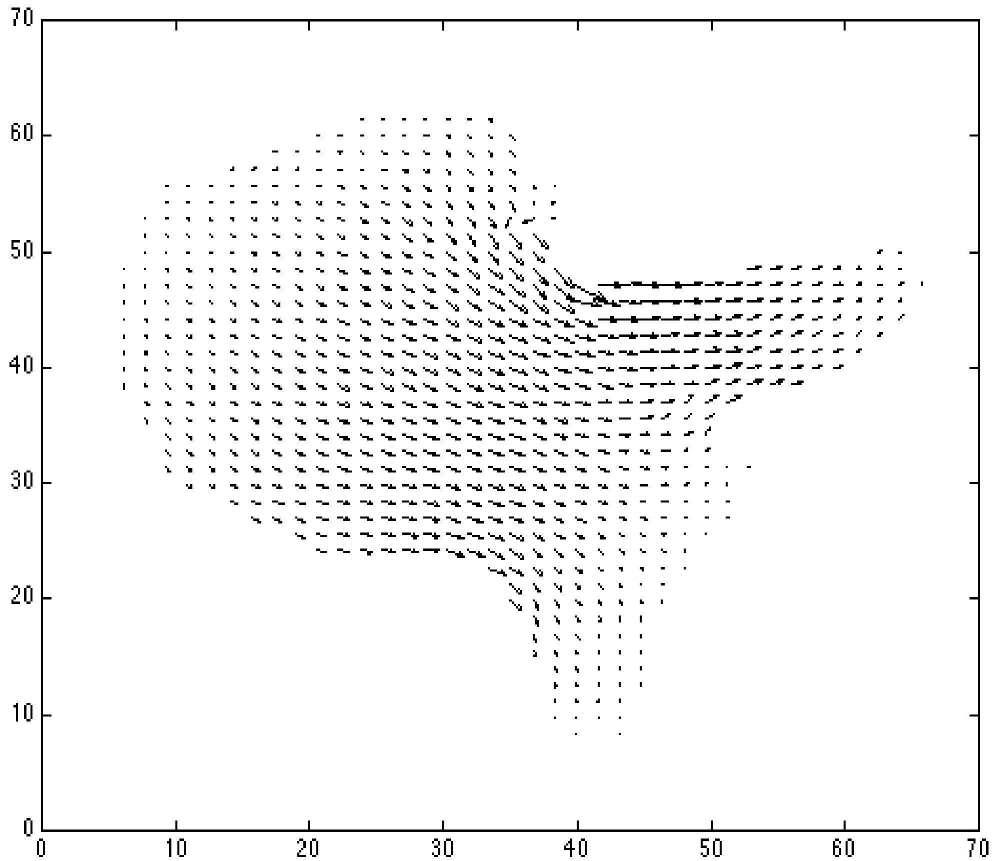

Figure 31. Φ_1

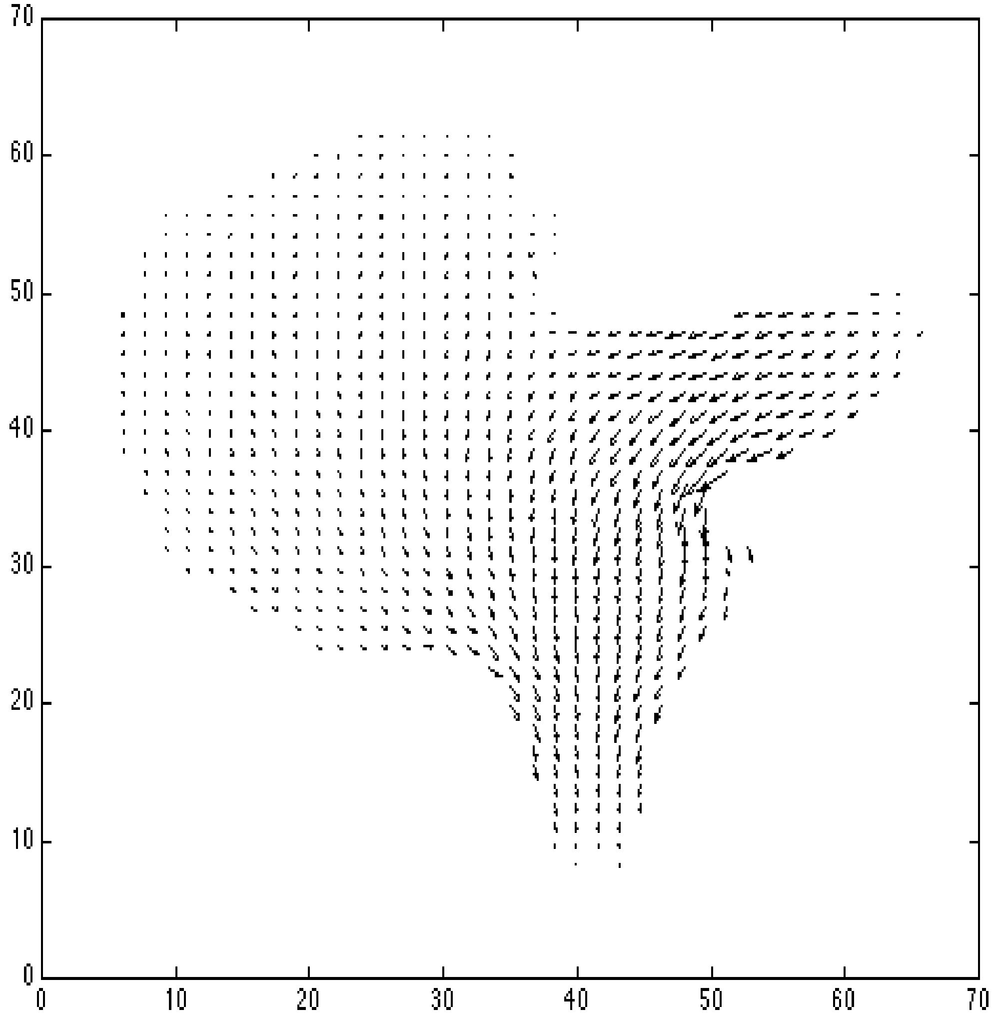

Figure 32. Φ_2

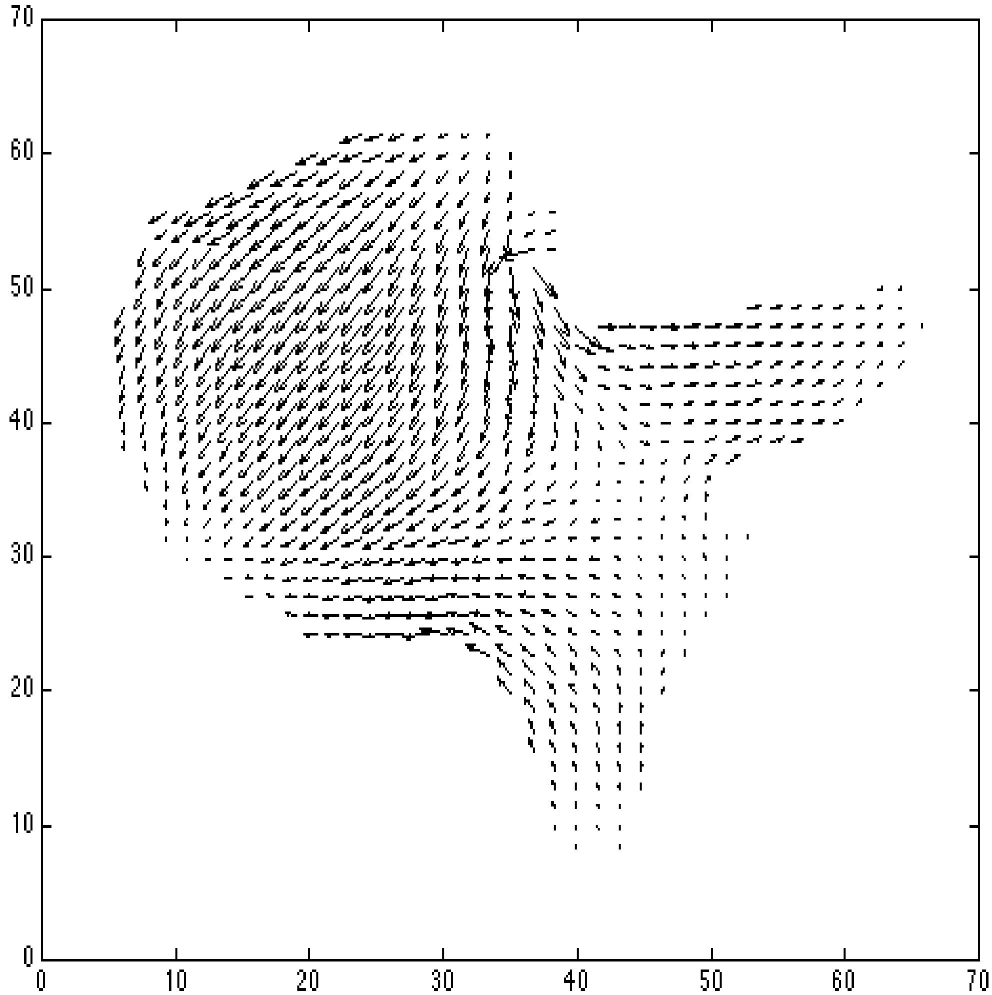

Figure 33. Φ_3

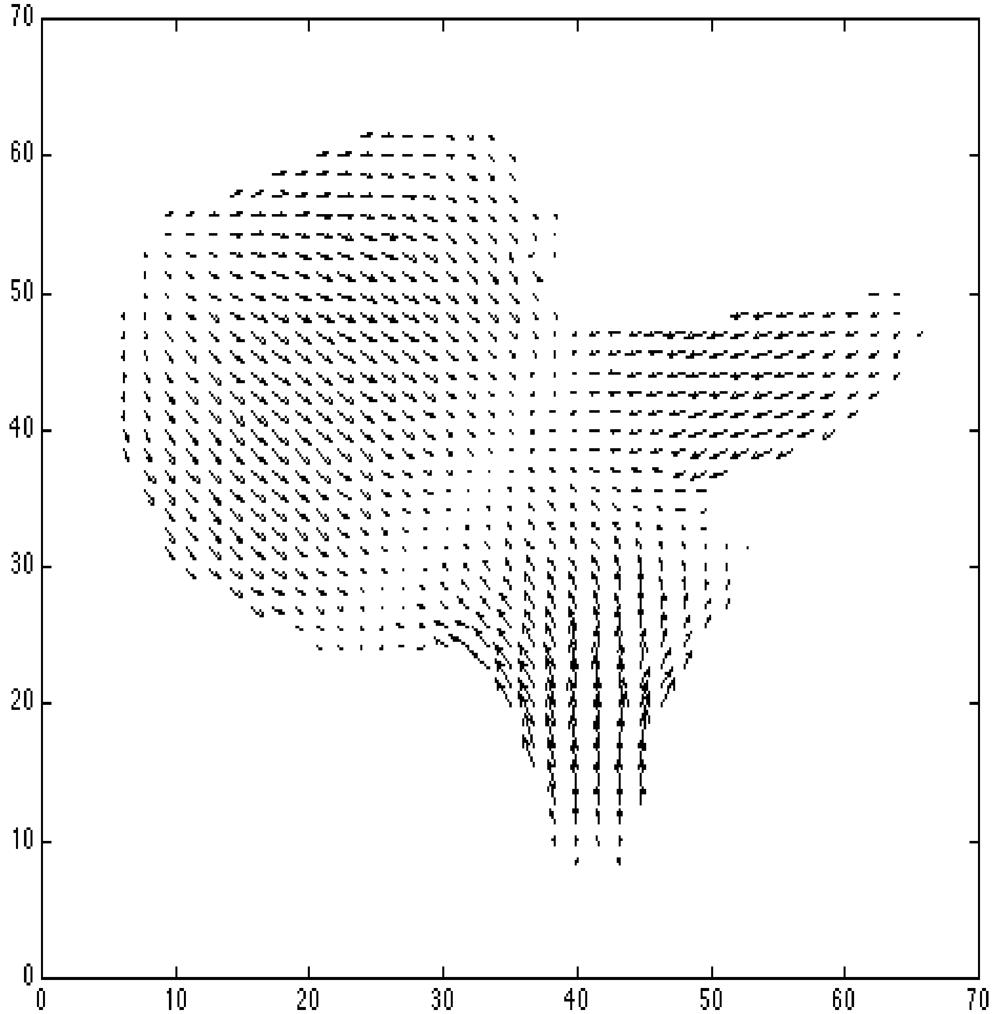

Figure 34. Φ_4

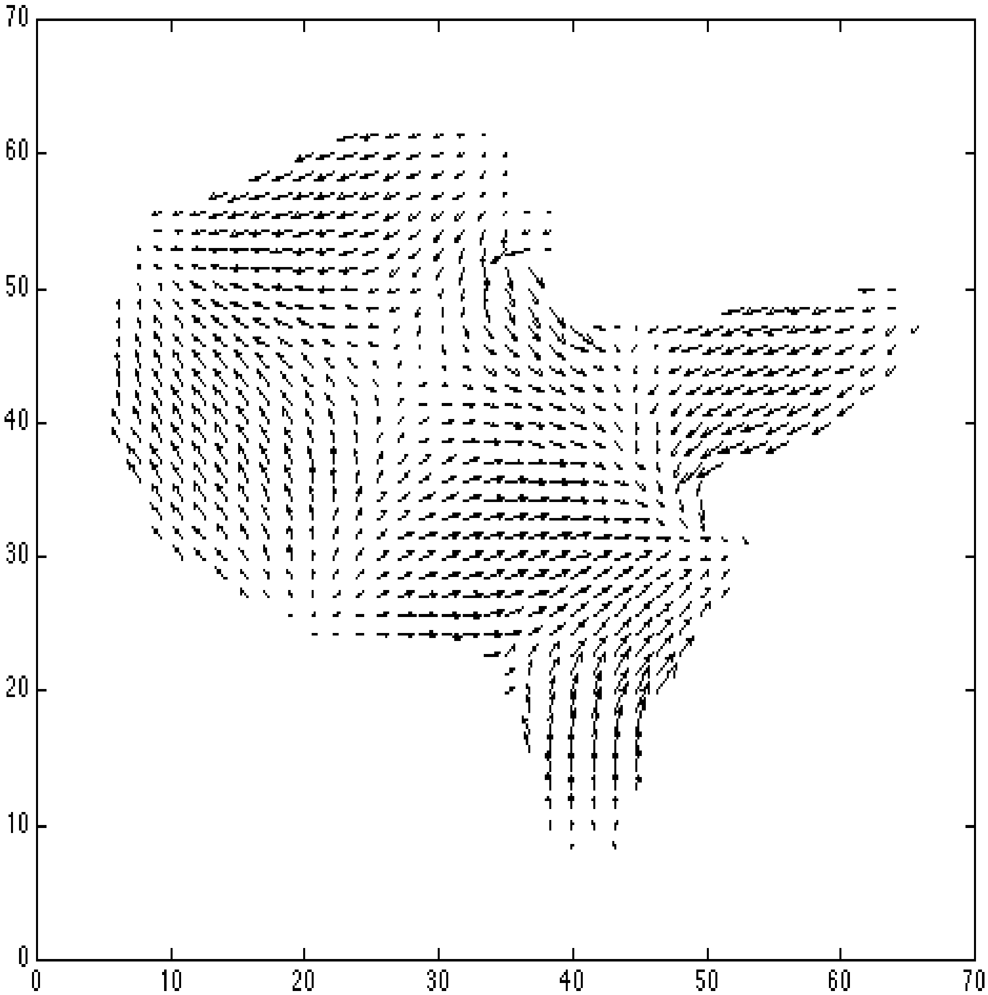

Figure 35. Φ_5

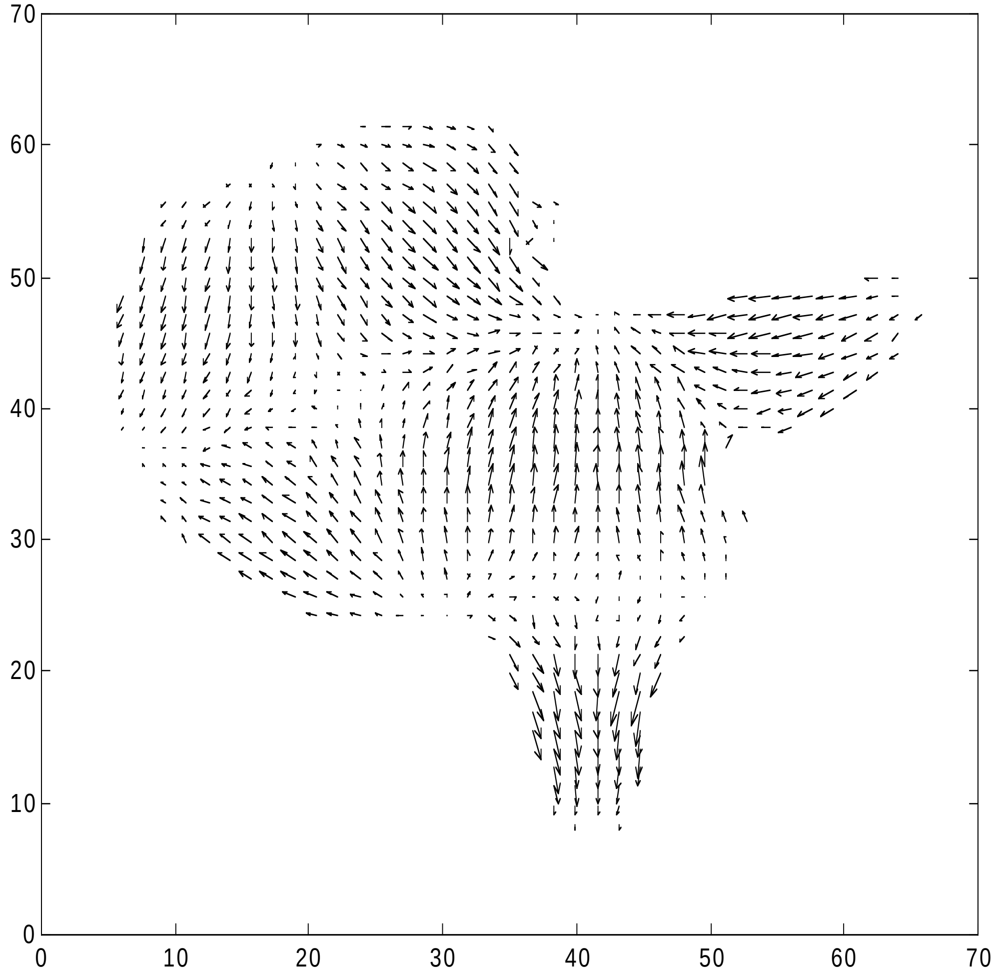

Figure 36. Φ_6

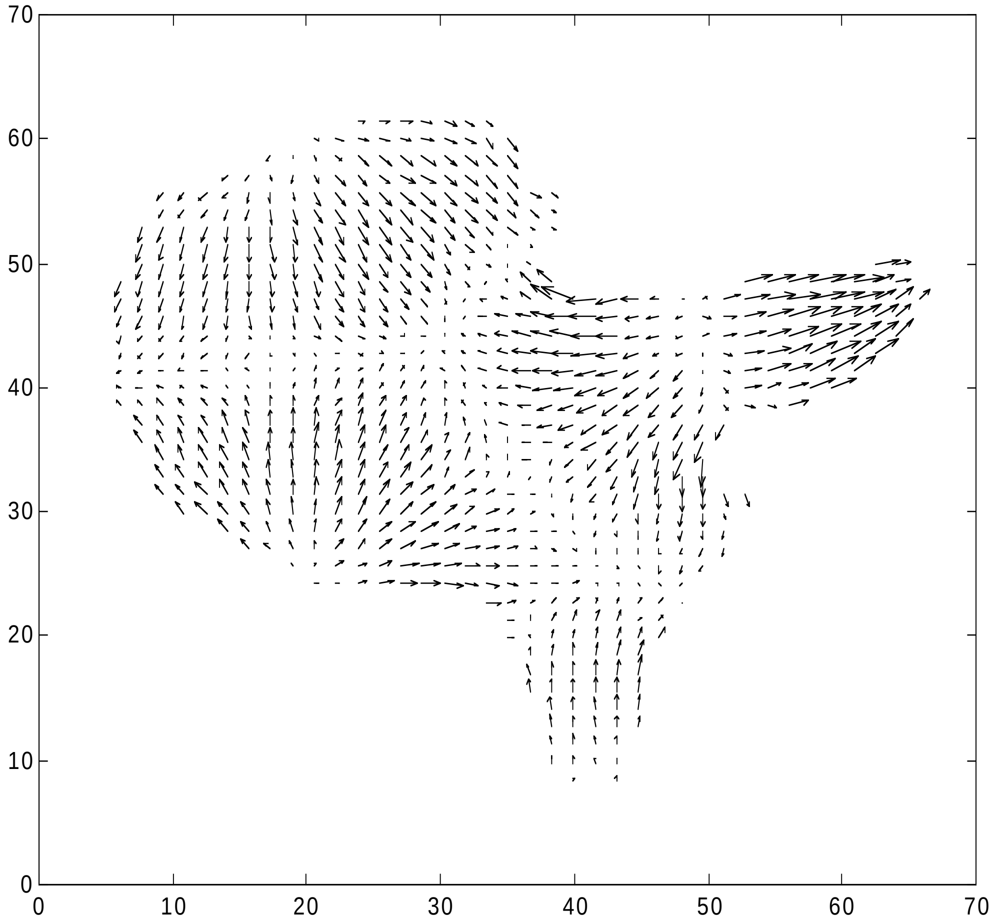

Figure 37. Φ_7

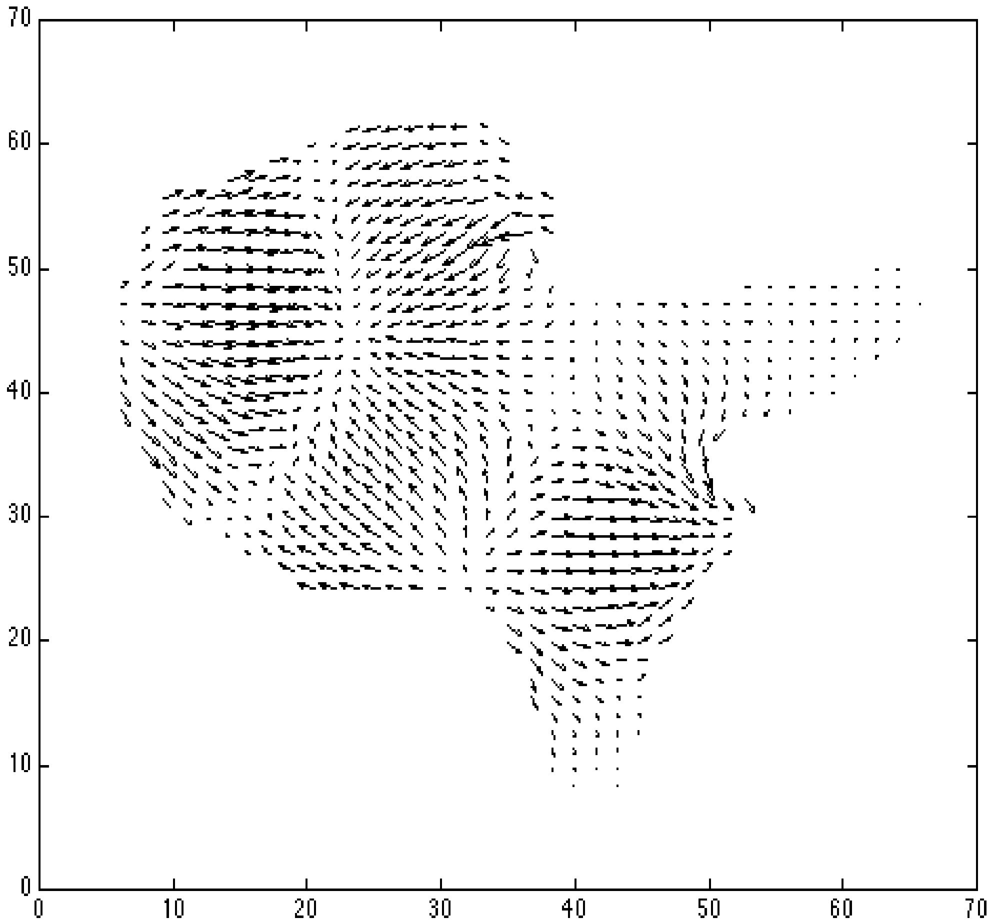

Figure 38. Φ_8

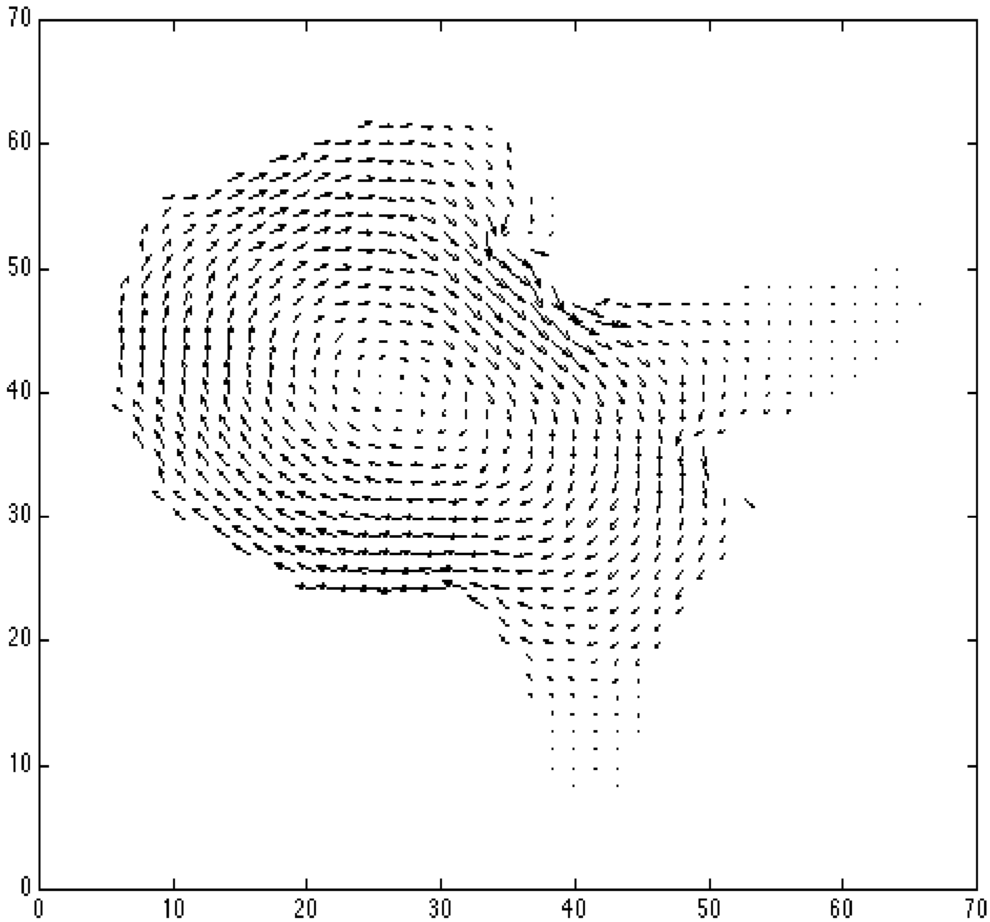

Figure 39. Ψ_1

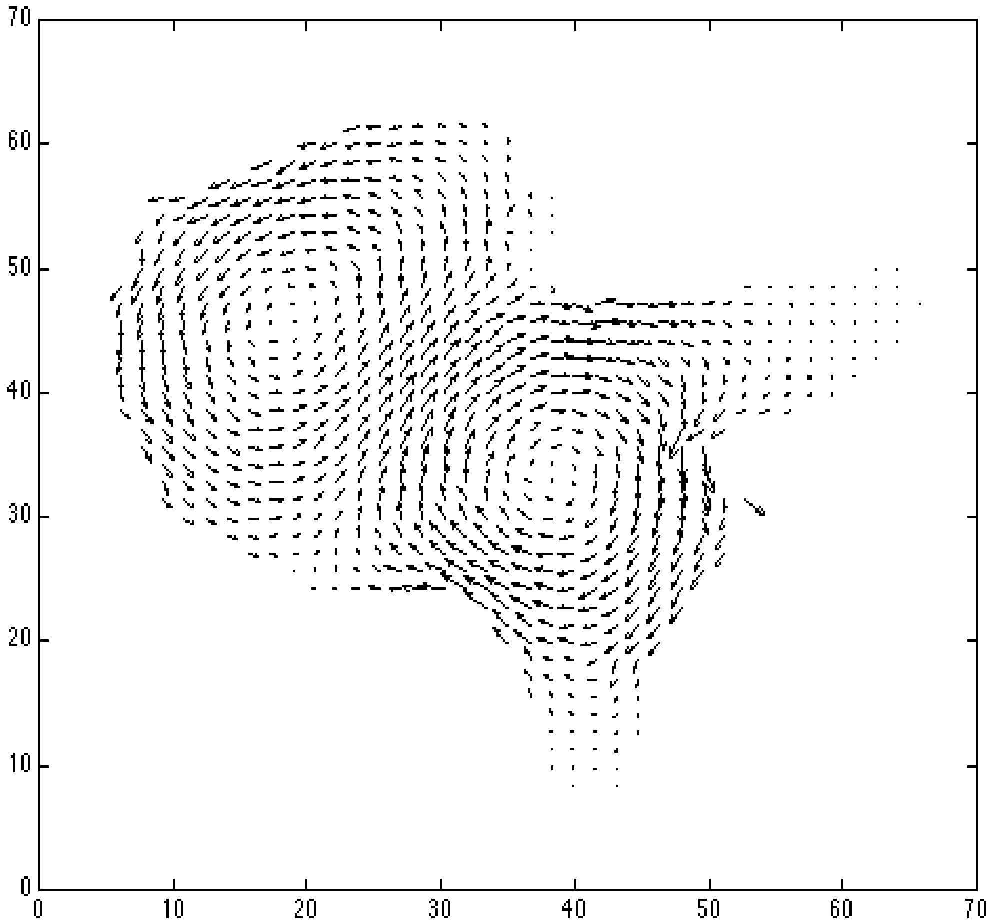

Figure 40. Ψ_2

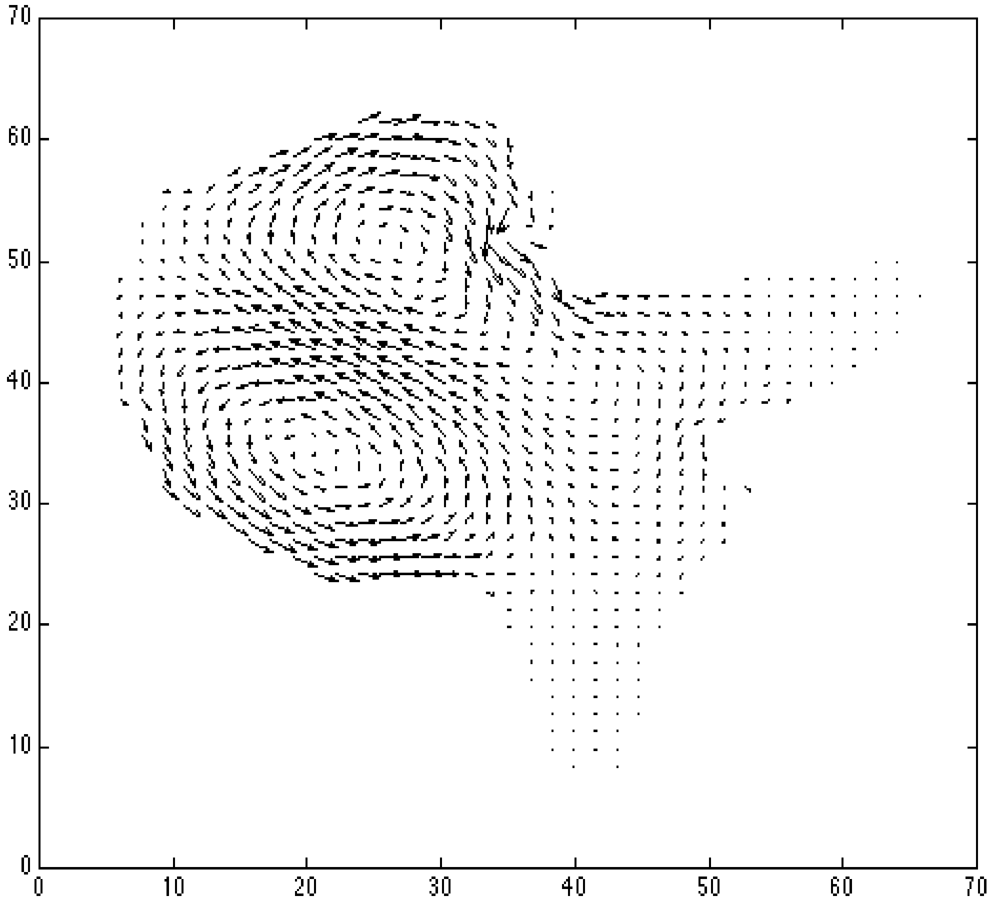

Figure 41. Ψ_3

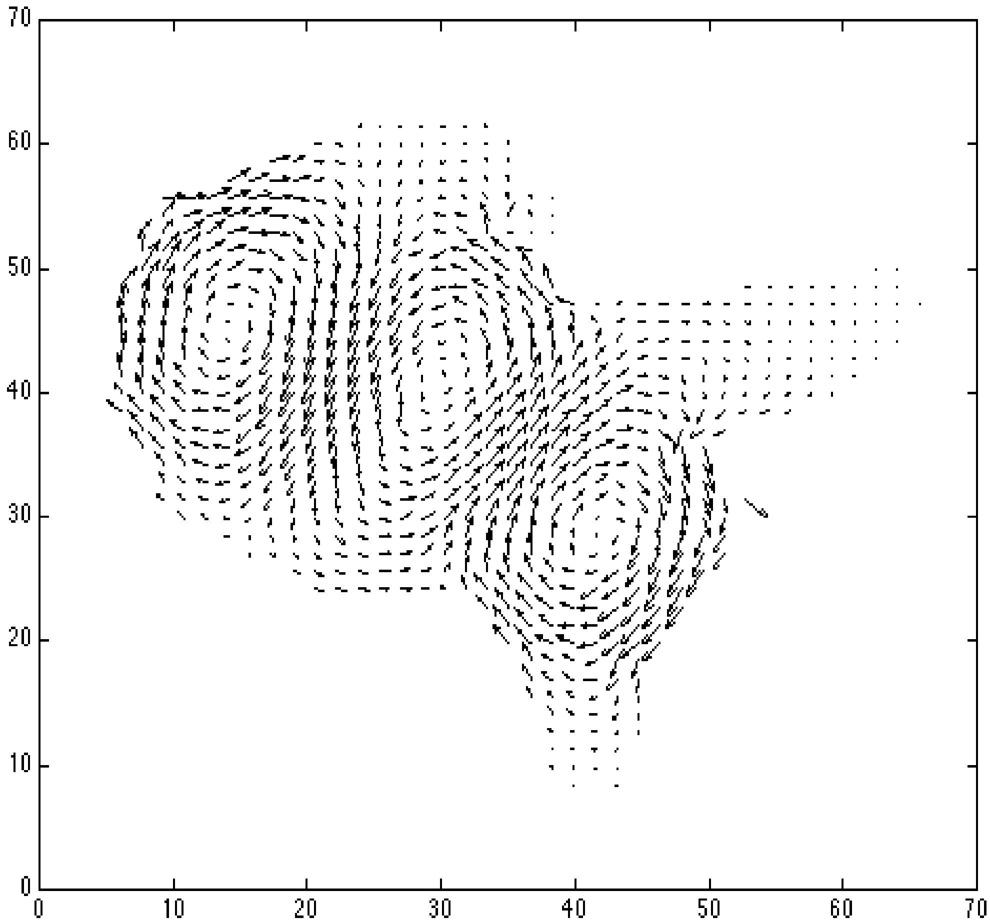

Figure 42. Ψ_4

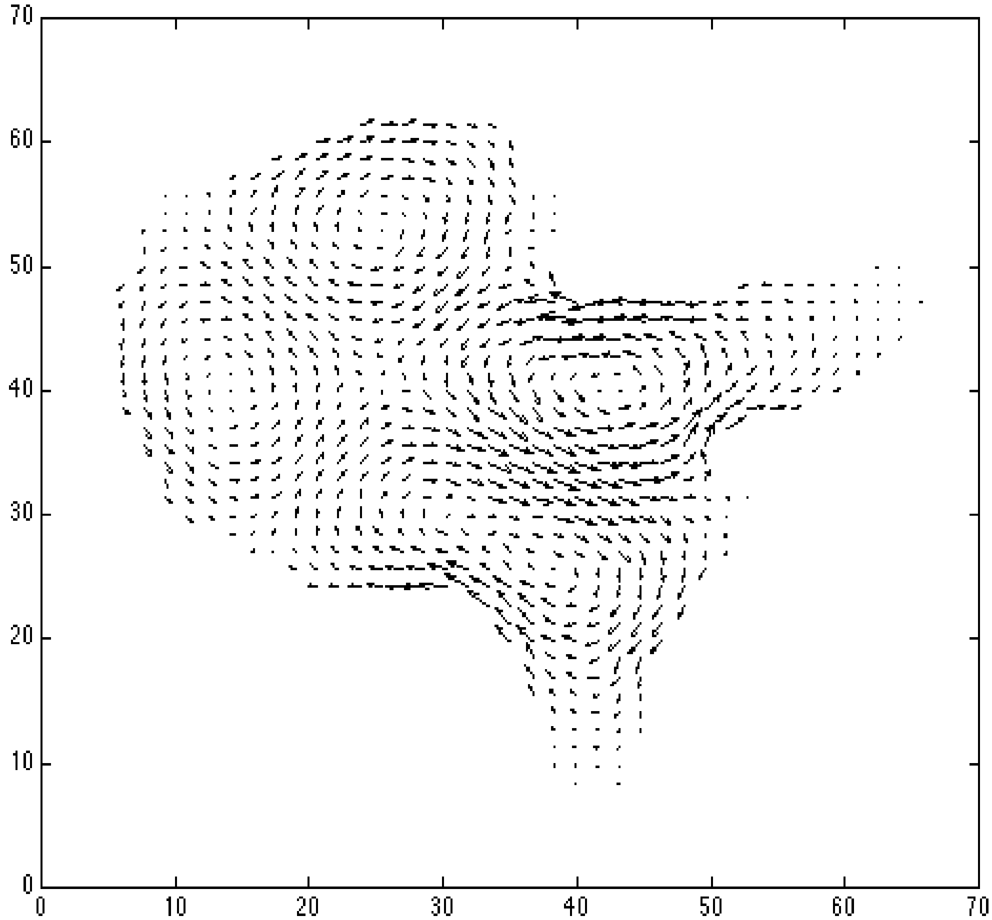

Figure 43. Ψ_5

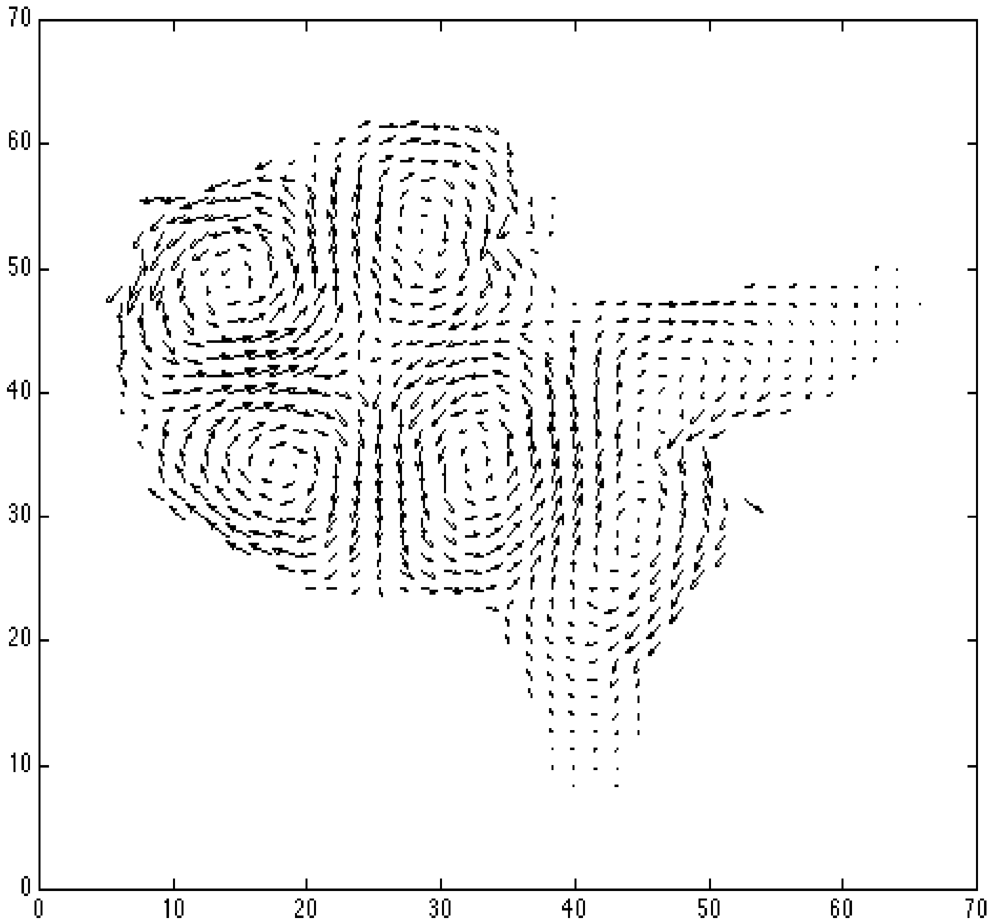

Figure 44. Ψ_6

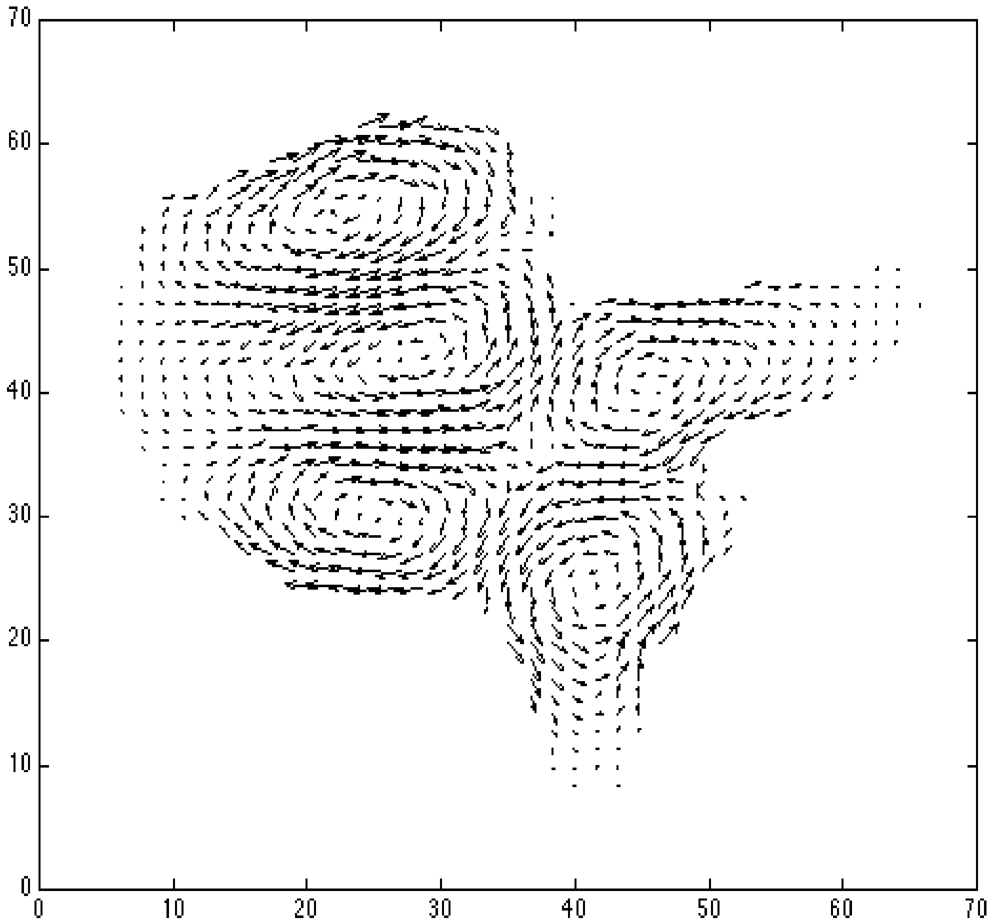

Figure 45. Ψ_7

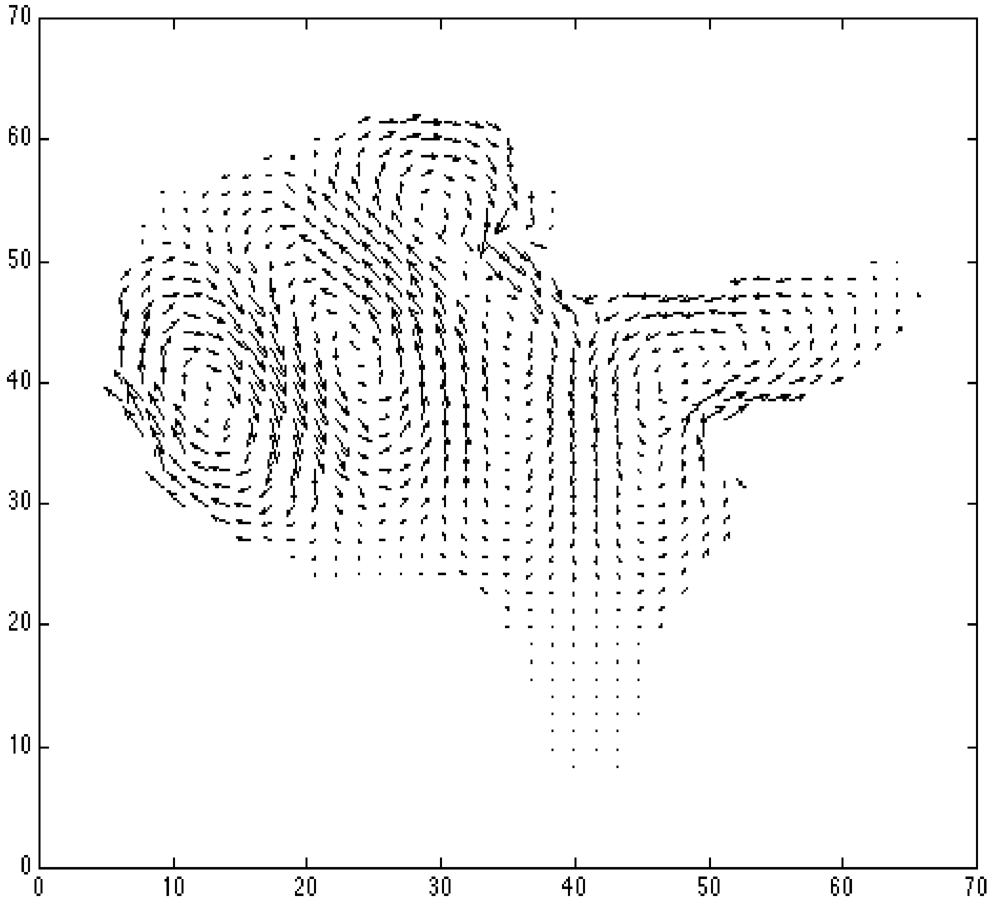

Figure 46. Ψ_8

APPENDIX 2

This appendix presents the various algorithms used in this research. Each program is written in FORTRAN 77 and is commented. References to where these programs apply in the research are in Section 3.

```
      PROGRAM CELLFND

       REAL*4 THETA, RNG(10)
       REAL*4 CRTX(400), CRTY(400), RADX(400), RADY(400)
       REAL*4 ANG,STRTX,STRTY,XCOOR,YCOOR
 C ****declaration of variables****
       INTEGER*2 CTR,CNT,CT
       INTEGER*2 MIN,MAX,RANGE
C  ****entering parameters over which the radial field is to be found*****
       WRITE(*,*) "Input min and max angle."
       READ(*,*) MIN, MAX
       WRITE(*,*) "Input angle intervel."
       READ(*,*) ANG
       WRITE(*,*) "Input Range Cell size in kilometers."
       READ(*,*) RANGE

       WRITE(*,*) "Enter in radar x and y coordinate."
       READ(*,*) STRTX,STRTY

       OPEN(6,FILE='angle_pts.tst')

       CNT=0

   10 CONTINUE
C****making the polar points for the information given
       DO 30 CTR=MIN,MAX,ANG

       THETA= CTR*3.141593/180.0
       XCOOR= 2*RANGE*COS(THETA)+STRTX
       YCOOR= 2*RANGE*SIN(THETA)+STRTY

       WRITE(6,*) XCOOR,YCOOR
       CNT=CNT+1
! 345678
   30 CONTINUE
       IF(RANGE<32) THEN
       RANGE=RANGE+1
       WRITE(*,*) "MAKING CELL NUMBER -->",RANGE
       GOTO 10
       ELSE
       WRITE(*,*) "ALL NUMBERS ACOUNTED FOR",CNT
       ENDIF


       STOP
       END
```

```
! 345678
      PROGRAM ANGLR
!     The purpose of this program is to find the angles from the cartesian
!     grid points given in the pde2d calculation to the given radar position
!     in the same grid. Note xo and yo for rad1 is 7.6 and 52.0
!     20.1034, 24.9765
      PARAMETER(xo=7.6, yo=52.0,rad1=464,rad2=288)
      REAL xn,yn,theta,vel,an,bn,u,v,phi
      INTEGER CTR
!
!
      OPEN(5,FILE='sums_rad1.txt')
      OPEN(6,FILE='angles.txt')
      OPEN(7,FILE='sums_uv_r1_7.txt')
!
      DO 10 CTR=1,rad1
      READ(5,*) xn,yn,vel
!   15 FORMAT(F8.5,1X,F8.5,1X,F8.5)
!      WRITE(*,*) vel
      an=xn-xo
      bn=yn-yo
      theta=ATAN(bn/an)
      phi=theta*3.141593/180
      u=vel*COS(theta)
      v=vel*SIN(theta)
!
      WRITE(6,17) xn,yn,theta
   17 FORMAT(F8.5,1X,F8.5,1X,F8.5)
      WRITE(7,18) xn,yn,u,v
   18 FORMAT(F8.5,1X,F8.5,1X,F9.5,1X,F9.5)
   10 CONTINUE
! 345678
      STOP
      END
```

```
      PROGRAM LEASTSOLVER
      IMPLICIT DOUBLE PRECISION (a-h,o-z)
      PARAMETER (m=635,n=16)
!     M=288 FOR RAD 2
      DIMENSION a(m,n),x(n),b(m),wk(2*m)
      INTEGER CTR
      DOUBLE PRECISION AA,BB,CC,DD,EE,FF,GG,HH,II,JJ,KK,LL,MM,NN,OO,PP
      REAL XCOOR,YCOOR

!
!
      OPEN(7,FILE='pmodes_hr1.txt')
      DO 61 CTR=1,m,1
      READ(7,*) AA,BB,CC,DD,EE,FF,GG,HH,II,JJ,KK,LL,MM,NN,OO,PP
!      READ(7,*) AA,BB,CC,DD
      a(CTR,1)=AA
      a(CTR,2)=BB
      a(CTR,3)=CC
      a(CTR,4)=DD
      a(CTR,5)=EE
      a(CTR,6)=FF
      a(CTR,7)=GG
      a(CTR,8)=HH
      a(CTR,9)=II
      a(CTR,10)=JJ
      a(CTR,11)=KK
      a(CTR,12)=LL
      a(CTR,13)=MM
      a(CTR,14)=NN
      a(CTR,15)=OO
      a(CTR,16)=PP
!      WRITE(*,*) AA,BB,CC,DD,EE,FF,GG,HH,II,JJ,KK,LL,MM,NN
   61 CONTINUE
!      pause
!
      OPEN(8,FILE='purge_hr1.txt')
      OPEN(6,FILE='a_hr1n.txt')
      DO 62 CTR=1,m,1
      READ(8,*) XCOOR,YCOOR,b(CTR)
!      READ(8,60) XCOOR,YCOOR,b(CTR)
!   60 FORMAT(F7.4,1X,F7.4,1X,F7.4)
!      WRITE(*,*) XCOOR,YCOOR,b(CTR)
   62 CONTINUE
!
! **************************************************!
```

```
      CALL DLLSQR(a,m,m,n,x,b,wk)
      print *,'these are the elements of vector x:'
      DO 63 CTR=1,16,1
      WRITE(*,*) x(CTR), CTR
      WRITE(6,*) x(CTR), CTR
   63 CONTINUE
      STOP
      END

      SUBROUTINE DLLSQR(A,IA,M,N,X,B,WK)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
!                      DECLARATIONS FOR ARGUMENTS
      DOUBLE PRECISION A(IA,N),X(N),B(M),WK(2*M)
      INTEGER IA,M,N
!
!  SUBROUTINE DLLSQR SOLVES THE LINEAR LEAST SQUARES PROBLEM
!
!       MINIMIZE  2-NORM OF (A*X-B)
!
!
!  ARGUMENTS
!
!         ON INPUT                        ON OUTPUT
!         --------                        ---------
!
!   A     - THE M BY N MATRIX.            DESTROYED.
!
!   IA    - THE FIRST DIMENSION OF MATRIX A,
!         AS ACTUALLY DIMENSIONED IN THE
!         CALLING PROGRAM (IA.GE.M).
!
!   M     - THE NUMBER OF ROWS IN A.
!
!   N     - THE NUMBER OF COLUMNS IN A.
!
!   X     -                               AN N-VECTOR CONTAINING
!                                         THE LEAST SQUARES
!                                         SOLUTION.
!
!   B     - THE RIGHT HAND SIDE M-VECTOR. DESTROYED.
!
!   WK    - WORK VECTOR OF LENGTH 2*M
!
! ----------------------------------------------------------------
!                      EPS = MACHINE FLOATING POINT RELATIVE
!                            PRECISION
```

```
! ***************************
      DATA EPS/2.D-16/
! ***************************
!                       AMAX = MAXIMUM ELEMENT OF A
      AMAX = 0.0
      DO 5 I=1,M
      DO 5 J=1,N
    5 AMAX = MAX(AMAX,ABS(A(I,J)))
      ERRLIM = 1000*EPS*AMAX
!                       REDUCTION TO ROW ECHELON FORM
      CALL REDQ(A,IA,M,N,B,WK,NPIVOT,ERRLIM,WK(M+1))
!                       CAUTION USER IF SOLUTION NOT UNIQUE.
      IF (NPIVOT.NE.N) THEN
        PRINT 10
   10   FORMAT (' NOTE: SOLUTION IS NOT UNIQUE ')
      ENDIF
!                       ASSIGN VALUE OF ZERO TO NON-PIVOT
!                       VARIABLES.
      DO 15 K=1,N
        X(K) = 0.0
   15 CONTINUE
!                       SOLVE FOR PIVOT VARIABLES USING BACK
!                       SUBSTITUTION.
      DO 25 I=NPIVOT,1,-1
        L = WK(I)
        SUM = 0.0
        IF (L+1.LE.N) THEN
          DO 20 K=L+1,N
            SUM = SUM + A(I,K)*X(K)
   20     CONTINUE
        ENDIF
        X(L) = (B(I)-SUM)/A(I,L)
   25 CONTINUE
      RETURN
      END

      SUBROUTINE REDQ(A,IA,M,N,B,PIVOT,NPIVOT,ERRLIM,WK)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
!                       DECLARATIONS FOR ARGUMENTS
      DOUBLE PRECISION A(IA,N),B(M),PIVOT(M),ERRLIM,WK(M)
      INTEGER IA,M,N,NPIVOT
!                       USE GIVENS ROTATIONS TO REDUCE A
!                       TO ROW ECHELON FORM
      I = 1
      DO 15 L=1,N
!                       USE PIVOT A(I,L) TO KNOCK OUT ELEMENTS
```

```
!                       I+1 TO M IN COLUMN L.
      IF (I+1.LE.M) THEN
        DO 10 J=I+1,M
          IF (A(J,L).EQ.0.0) GO TO 10
          DEN = SQRT(A(I,L)**2+A(J,L)**2)
          C = A(I,L)/DEN
          S = A(J,L)/DEN
!                       PREMULTIPLY A BY QIJ**T
          DO 5 K=L,N
            BIK = C*A(I,K) + S*A(J,K)
            BJK =-S*A(I,K) + C*A(J,K)
            A(I,K) = BIK
            A(J,K) = BJK
   5      CONTINUE
!                       PREMULTIPLY B BY QIJ**T
          BI = C*B(I) + S*B(J)
          BJ =-S*B(I) + C*B(J)
          B(I) = BI
          B(J) = BJ
  10    CONTINUE
      ENDIF
!                       PIVOT A(I,L) IS NONZERO AFTER PROCESSING
!                       COLUMN L--MOVE DOWN TO NEXT ROW, I+1
      IF (ABS(A(I,L)).GT.ERRLIM) THEN
        NPIVOT = I
        PIVOT(NPIVOT) = L
        I = I+1
        IF (I.GT.M) RETURN
      ENDIF
  15 CONTINUE
    RETURN
    END
```

```
      PROGRAM NEAR4
!     This program is designed to find the four nearest neighbor points
!     of a cartesian point when compared to a given set of overlapping
!     polar points
      REAL XCRD,YCRD
      COMMON NDX(4),CR(4000,2),Y(4,2)
      REAL NDX,CR,Y
      INTEGER HUM
!     pdeptsfile contains the models x y positions
!     nearptsfile will have the total nearest neighbors coordinates
      OPEN(6,FILE='pdeptsfile.txt')
      OPEN(8,FILE='nearptsfile.txt')
!
      DO 10 HUM=1,729,1
      READ(6,*,END=30) XCRD,YCRD
      CALL NRST4(XCRD,YCRD)
   10 CONTINUE
   30 CONTINUE
!
      STOP
      END
! The subroutine NRST4 compares the inputed cartesian coordinate from
! the main program to the entire polar coordinate system defined from
! the CELLFIND program given in the angle_ptsfile.txt
      SUBROUTINE NRST4(XCOOR,YCOOR)
      INTEGER CNT,NUM,CN,BS,I,MRK
      INTEGER CTR,MAX,CT,p1,p2,p3,p4
      REAL XRAD,YRAD,DIS1,DIS2
      REAL NEAR(4),N,SEGX,SEGY,MAG(4000)
      COMMON NDEX(4),COORD(4000,2),ARY(4,2)
      REAL NDEX,COORD,ARY
      MAX=0
      CNT=1
      OPEN(7,FILE='angle_ptsfile.txt')
      OPEN(5,FILE='seglength.txt')
      OPEN(4,FILE='segorder.txt')
      OPEN(3,FILE='TEST.TST')
!   angle_ptsfile contains the radial postions out to 31 km it has 2336 pts
!   this encompasses 360 degrees around the radar position at 5 degree
!   intervals at 2 kilometer range cells

!   Loop 100 reads in the polar point coordinates into the COORD array
!   and calculates the distance from the given cartesian coordinate XCOOR
!   YCOOR to each polar point
      DO 100 CTR=1,1184,1
```

```
      READ(7,*,END=100) XRAD,YRAD
      COORD(CTR,1)=XRAD
      COORD(CTR,2)=YRAD
      SEGX=XRAD-XCOOR
      SEGY=YRAD-YCOOR
      MAG(CTR)=SQRT(SEGX**2+SEGY**2)
      MAX=CTR
      WRITE(5,*) MAX,XRAD,YRAD,XCOOR,YCOOR,MAG(CTR)
  100 CONTINUE
  150 DIS1=MAG(1)
      DIS2=999.
      WRITE(3,*) DIS1,DIS2
!     loop 200 compares each distance calculated to each other until
!     only the for smallest distances remain, thus the 4 nearest
!     neighbors are found.
!     This process is done for each cartesian point and places into the
!     file called nearptsfile.txt
      NUM=1
      CN=0
      QST=1
      DO 200 CT=1,MAX,1
      IF(DIS1.LT.DIS2) THEN
      NEAR(CNT)=DIS1
      NUM=NUM+1
      DIS2=MAG(NUM)
      ELSE
      QST=0
      DIS1=DIS2
      MRK=CT
      NUM=NUM+1
      DIS2=MAG(NUM)
      ENDIF
      IF(NUM-1.GE.MAX) GOTO 400
  200 CONTINUE
!  400 WRITE(*,*) "END DOLOOP 200",NUM,NEAR(CNT),CNT
  400 CONTINUE
      IF(QST.EQ.1) THEN
      MRK=1
      ENDIF
      DO 500 CT=1,MAX,1
      IF(MRK.EQ.CT) THEN
      NDEX(CNT)=CT
      MAG(CT)=999.
      GOTO 500
      ELSE
      CONTINUE
```

```
      ENDIF
!      PAUSE
  500 CONTINUE
      N=NEAR(1)
      DO 600 CT=1,MAX,1
  600 CONTINUE
      NEAR(1)=N
      IF(CNT.EQ.4) THEN
      WRITE(4,*) NEAR(1),NEAR(2),NEAR(3),NEAR(4)
      BS=1
      WRITE(4,*) NDEX(1),NDEX(2),NDEX(3),NDEX(4)
      NUM=NDEX(4)
      p1=NDEX(1)
      p2=NDEX(2)
      p3=NDEX(3)
      p4=NDEX(4)
      ARY(1,1)=COORD(p1,1)
      ARY(1,2)=COORD(p1,2)
      ARY(2,1)=COORD(p2,1)
      ARY(2,2)=COORD(p2,2)
      ARY(3,1)=COORD(p3,1)
      ARY(3,2)=COORD(p3,2)
      ARY(4,1)=COORD(p4,1)
      ARY(4,2)=COORD(p4,2)
      WRITE(8,*) XCOOR,YCOOR,(ARY(I,1),ARY(I,2),I=1,4)
      ELSE
      CNT=CNT+1
      GOTO 150
      ENDIF
      REWIND 7
      RETURN
      END
```

```
      PROGRAM PURGE
!     This program will select the coordinates with
!     velocities for the least squares fit
      REAL XCOOR,YCOOR,VEL
      REAL m1,m2,m3,m4,m5,m6,m7,m8,m9,m10,m11,m12,m13,m14,m15,m16

      INTEGER CTR

      OPEN(5,FILE='radial_modes_rad1.txt')
      OPEN(6,FILE='averaged_vel_rad1.txt')
      OPEN(7,FILE='purge_rad1.txt')
      OPEN(8,FILE='purge_modes_rad1.txt')

!     AVGVEL has 729 rows totalmodes has 728

      DO 10 CTR=1,727
      READ(6,*) XCOOR,YCOOR,VEL
      READ(5,*) m1,m2,m3,m4,m5,m6,m7,m8,m9,m10,m11,m12,m13,m14,m15,m16
!      READ(5,*) m1
      IF (VEL.EQ.999) THEN
      CONTINUE
      ELSE
      WRITE(7,20) XCOOR,YCOOR,VEL
   20 FORMAT (F7.4,1X,F7.4,1X,F9.5)
      WRITE(8,25) m1,m2,m3,m4,m5,m6,m7,m8,m9,m10,m11,m12,m13,m14,m15,m16
   25 FORMAT (16(F8.5,1X))
      ENDIF
   10 CONTINUE
      STOP
      END
```

```
PROGRAM RSORT
!    This program is designed to move radial velocities and
!    directions from a given SeaSonde output into the coordinate
!    system used by the PDE2D model for comparison with modes
! 345678
     INTEGER MAX,CT,CTR,CNT,CN,NUM
     INTEGER CELL,AMT,CNDEX(35),CHSER(35)
     DIMENSION INDEX(100),THETA(100,100),VEL(100,100),ERROR(100,100)
     INTEGER INDEX
     REAL THETA,VEL,ERROR
     REAL NUM2
!
     OPEN(6,FILE='hr0000-0100')
     OPEN(7,FILE='angle.txt')
     OPEN(8,FILE='converted_pts.txt')
     OPEN(9,FILE='converted_pts_uv.txt')
!
!
     READ(6,*) MAX
     WRITE(*,*) "READING TOTAL CELLS--> ",MAX
!
!
     DO 20 CT=1,MAX,1
     READ(6,*) AMT,CELL
     CNDEX(CT)=CELL
!   CNDEX holds the range cell
!   CHSER will allow to choose the number in INDEX
!   INDEX holds the number of angles per range cell
!    WRITE(*,*) CELL
     IF(AMT.EQ.0) THEN
     CHSER(CT)=0
     GOTO 20
     ELSE
     CHSER(CT)=1
     INDEX(CT)=AMT
     NUM=INDEX(CT)
!   THETA holds the angles per range cell
!   VEL holds the velocity at the angle and range cell
!   ERROR holds the error in velocity per angle and range cell
!     WRITE(*,*) "PROCESSING CELL ",CELL
     READ(6,*) ((THETA(CTR,CNT),CTR=CELL,CELL),CNT=1,NUM)
     READ(6,*) ((VEL(CTR,CNT),CTR=CELL,CELL),CNT=1,NUM)
     READ(6,*) ((ERROR(CTR,CNT),CTR=CELL,CELL),CNT=1,NUM)
     WRITE(7,*) CELL,AMT,((THETA(CTR,CNT)+90,CTR=CELL,CELL),CNT=1,NUM)
     ENDIF
```

```
   20 CONTINUE
!
!     WRITE(*,*) "CNDEX(",CT-1,")->",CNDEX(CT-1)
!     PAUSE
      DO 30 CT=1,MAX,1
      NUM=INDEX(CT)
      CN=CHSER(CT)
      IF(CN.EQ.1) THEN
      WRITE(*,*) "DATA IN -->", CT
      CELL=CNDEX(CT)
      DO 40 CTR=CELL,CELL,1
      DO 50 CNT=1,NUM,1
      IF((THETA(CTR,CNT)+90).GE.360) THEN
      THETA(CTR,CNT)=THETA(CTR,CNT)+90-360
      NUM2=THETA(CTR,CNT)
      CALL TRANS(CNDEX(CT),NUM2,VEL(CTR,CNT),ERROR(CTR,CNT))
!     WRITE(*,*) CELL, NUM2
      ELSE
      THETA(CTR,CNT)=THETA(CTR,CNT)+90
      NUM2=THETA(CTR,CNT)
      CALL TRANS(CNDEX(CT),NUM2,VEL(CTR,CNT),ERROR(CTR,CNT))
!     WRITE(*,*) CELL, NUM2
      ENDIF
   50 CONTINUE
   40 CONTINUE
      ELSE
      WRITE(*,*) "NO DATA IN -->",CN
      ENDIF
   30 CONTINUE
  100 CONTINUE
!
      STOP
      END
!     This subroutine will make the coordinate transform to be
!     aligned up with the model data
      SUBROUTINE TRANS(LN,ETA,V,ER)
!
      REAL YPRM,UVEL
      REAL XPRM,VVEL
!
      REAL XZERO,YZERO,PHI
!
      INTEGER RNG
!
      RNG=LN
      XZERO=7.6
```

```
      YZERO=52.0
      PHI=ETA*3.141593/180
      WRITE(*,*) RNG,PHI,ETA
      XPRM=(2*RNG*COS(PHI)+XZERO)
      YPRM=(2*RNG*SIN(PHI)+YZERO)
      UVEL=-V*COS(PHI)
      VVEL=-V*SIN(PHI)
!      WRITE(*,*) XPRM,YPRM,V,ER,LN,RNG
      WRITE(8,*) XPRM,YPRM,-V
      WRITE(9,*) XPRM,YPRM,UVEL,VVEL


      RETURN
      END
```

```
PROGRAM SUM
! This program is used to compare the purged avaeraged velocities
! with the summed modes using the coefficients from the Least Squares
! process
    PARAMETER (r1=499, r2=288)
    REAL m1,m2,m3,m4,m5,m6,m7,m8,m9,m10,m11,m12,m13,m14,m15,m16
    REAL s1,s2,s3,s4,s5,s6,s7,s8,s9,s10,s11,s12,s13,s14,s15,s16,sm
    REAL x(r1),y(r1),v,a(16)
    INTEGER ctr,ct
!
    OPEN(5,FILE='purge_modes_rad1.txt')
    OPEN(6,FILE='afile.txt')
    OPEN(7,FILE='sums_rad1.txt')
    OPEN(8,FILE='purge_rad1.txt')
!
    DO 30 ct=1,r1
    READ(8,*) x(ct),y(ct),v
!    READ(8,35) x(ct),y(ct),v
!  35 FORMAT(F6.3,1X,F7.5,1X,F8.5)
!    WRITE(*,*) y(ct)
  30 CONTINUE
!
    DO 20 ct=1,16
    READ(6,*) a(ct)
!  25 FORMAT (F13.9)
  20 CONTINUE
!
    DO 10 ctr=1,r1
    READ(5,*) m1,m2,m3,m4,m5,m6,m7,m8,m9,m10,m11,m12,m13,m14,m15,m16
!  15 FORMAT (14F8.5)
    s1=m1*a(1)
    s2=m2*a(2)
    s3=m3*a(3)
    s4=m4*a(4)
    s5=m5*a(5)
    s6=m6*a(6)
    s7=m7*a(7)
    s8=m8*a(8)
    s9=m9*a(9)
    s10=m10*a(10)
    s11=m11*a(11)
    s12=m12*a(12)
    s13=m13*a(13)
    s14=m14*a(14)
    s15=m15*a(15)
    s16=m16*a(16)
```

```
  sm=s1+s2+s3+s4+s5+s6+s7+s8+s9+s10+s11+s12+s13+s14+s15+s16
  WRITE(7,17) x(ctr),y(ctr),sm
17 FORMAT(F8.5,1X,F8.5,1X,F9.5)
10 CONTINUE


  STOP
  END
```

```
      PROGRAM UNITVECTOR
      REAL VECX(740),VECY(740),MG(740)
      COMMON VECX,VECY,MG
      INTEGER CTR
      COMMON CTR

      REAL CRDX(740),CRDY(740),RAD1,RAD2
      REAL VELU(740),VELV(740)
      REAL MODE
      INTEGER CHK,CNT

      RAD1=7.6
      RAD2=52.0
      OPEN(5,FILE='phi8_uv.txt')
      OPEN(6,FILE='phi8.txt')
      OPEN(7,FILE='phi8_mag.txt')
      CHK=0
      CNT=1
      CTR=1
      READ(6,*) MODE
      WRITE(*,*) MODE
      PAUSE

   10 READ(6,*,END=20) CHK,CRDX(CNT),CRDY(CNT),VELU(CNT),VELV(CNT)
      IF(CHK==1) THEN
      CALL UNIT(RAD1,RAD2,CRDX(CNT),CRDY(CNT),VELU(CNT),VELV(CNT))
      WRITE(5,14) VECX(CNT),VECY(CNT)
   14 FORMAT(F8.5,1X,F8.5)
      WRITE(7,15) MG(CNT)
   15 FORMAT (F8.5)
      CNT=CNT+1
      CTR=CNT
      GOTO 10
      ELSE
      WRITE(*,*) CHK
      ENDIF
   20 CONTINUE
      WRITE(*,*) CNT

      STOP
      END

! This program will allow for the reading in of
! the PDE2D data files.

      SUBROUTINE UNIT(RADX,RADY,PNTX,PNTY,UVEL,VVEL)
```

```
      REAL*4 X,Y,I,J
      REAL*4 A,B,C,D,E,F,G,H
      REAL*4 UNITX,UNITY

      REAL*4 M(740),N(740),MAG(740)
      COMMON M,N,MAG

      INTEGER CT
      COMMON CT

! Here we transfer the input coordinates into the subroutine's variables

      X=RADX
      Y=RADY
      I=PNTX
      J=PNTY

! Calculation of the unit vector using the following equation

!   Rhat= R/Rmag   R=rpoint - rradar  Rmag= (rpoint^2 + rradar^2)^1/2
!   rpoint is the vector from origin to a data point
!   rradar is the vector from the origin to the radar
!   R is the vector from the radar to the specific data point

!  First we combine the  vector R's x and Y components

      A=I-X
      B=J-Y
!  Next we square the x and y components from the magnitude

      C=X+Y
      D=I+J
      E=C*C
      F=D*D
      G=E+F
!   Now with take the square root to find the magnitude of R

      H=SQRT(G)

!   Now the unit vector is put together

      UNITX=A/H
      UNITY=B/H

!   Now the unit vector is multiplied into the U and V velocities
```

```
M(CT)=UNITX*UVEL
N(CT)=UNITY*VVEL
MAG(CT)=M(CT)+N(CT)


RETURN
END
```

```
! 345678
      PROGRAM RMS
      PARAMETER(rad1=189,rad2=288,comb=430)
      REAL lsq(740),oval(740),sVBR,iDIF,oDIF,rVBR,riDIF
      REAL frac
      INTEGER ctr

      OPEN(5,FILE='sums_rad1.txt')
      OPEN(6,FILE='rms_hr1rad1.txt')
      OPEN(7,FILE='purge_rad1.txt')
      iDIF=0
      oDIF=0
      sVBR=0
      DO 10 ctr=1,rad1
      READ(5,*) x,y,lsq(ctr)
!     READ(6,*) x,y,bval(ctr)
      READ(7,*) x,y,oval(ctr)
      sVBR=sVBR+(oval(ctr)**2)/rad1
      iDIF=iDIF+(oval(ctr)-lsq(ctr))**2/rad1
!     oDIF=oDIF+(bval(ctr)-lsq(ctr))**2/rad1
   10 CONTINUE
      rVBR=SQRT(sVBR)
      riDIF=SQRT(iDIF)
!     roDIF=SQRT(oDIF)
      frac=riDIF/rVBR
      WRITE(6,*) "rmsRin=     ",rVBR
      WRITE(6,*) "rmsinDiff=  ",riDIF
      WRITE(6,*) "fracRadDiff=",frac
      STOP
      END
```

```
! 345678
      PROGRAM VELAVG
!     THIS program is used to average out the nearest neighbor
!     velocities per unit program
! 6/5 changing out nrst4 and rvel for u and v to avg out a 2d vector
      DIMENSION XCRD(800,2),RCRD(800,2),F(800,4)
      REAL XCRD,RCRD,F
      DIMENSION S(800,2),T(800,2),Q(800,2),CNDEX(800,4)
      REAL S,T,Q,CNDEX,AVG,TOT,CN
      DIMENSION u(800,4),v(800)
      REAL u,v,A,B,C
      INTEGER CTR,CNT,NUM,NUM2,SUM,c
!      NUM=238
!      NUM2=729
! for rad 2 NUM 448 NUM2 is 730
      NUM=0
      NUM2=729

      OPEN(6,FILE='converted_pts.txt')
      OPEN(7,FILE='nearptsfile.txt')
      OPEN(8,FILE='TEST.TST')
  200 READ(6,*,END=250) A,B,C
      NUM=NUM+1
      GOTO 200
  250 CONTINUE
      REWIND 6
      DO 10 CTR=1,NUM,1
      READ(6,*) RCRD(CTR,1),RCRD(CTR,2),v(CTR)
   10 CONTINUE
      DO 11 CTR=1,NUM2,1
      READ(7,*) RX,RY,X1,Y1,X2,Y2,X3,Y3,X4,Y4
      XCRD(CTR,1)=RX
      XCRD(CTR,2)=RY
      F(CTR,1)=X1
      F(CTR,2)=Y1
      S(CTR,1)=X2
      S(CTR,2)=Y2
      T(CTR,1)=X3
      T(CTR,2)=Y3
      Q(CTR,1)=X4
      Q(CTR,2)=Y4
   11 CONTINUE
      CN=0
      DO 13 CNT=1,NUM2,1
      DO 12 CTR=1,NUM,1
      IF (F(CNT,1).EQ.RCRD(CTR,1)) THEN
```

```
      IF (F(CNT,2).EQ.RCRD(CTR,2)) THEN
      u(CN,1)=v(CTR)
!      NRST4(CN,1)=RVEL(CTR)
      CNDEX(CN,1)=1
      GOTO 20
      ENDIF
      ELSE
      u(CN,1)=0.0
!      NRST4(CN,1)=0.0
      CNDEX(CN,1)=0
      ENDIF
   12 CONTINUE
   20 CONTINUE
      CN=CN+1
   13 CONTINUE
      CN=0
      DO 15 CNT=1,NUM2,1
      DO 14 CTR=1,NUM,1
      IF (S(CNT,1).EQ.RCRD(CTR,1)) THEN
      IF (S(CNT,2).EQ.RCRD(CTR,2)) THEN
      u(CN,2)=v(CTR)
!      NRST4(CN,2)=RVEL(CTR)
      CNDEX(CN,2)=1
      GOTO 30
      ENDIF
      ELSE
      u(CN,2)=0.0
!      NRST4(CN,2)=0.0
      CNDEX(CN,2)=0
      ENDIF
   14 CONTINUE
   30 CONTINUE
      CN=CN+1
   15 CONTINUE
      CN=0
      DO 17 CNT=1,NUM2,1
      DO 16 CTR=1,NUM,1
      IF (T(CNT,1).EQ.RCRD(CTR,1)) THEN
      IF (T(CNT,2).EQ.RCRD(CTR,2)) THEN
      u(CN,3)=v(CTR)
!      NRST4(CN,3)=RVEL(CTR)
      CNDEX(CN,3)=1
      GOTO 40
      ENDIF
      ELSE
      u(CN,3)=0.0
```

```
!     NRST4(CN,3)=0.0
      CNDEX(CN,3)=0
      ENDIF
   16 CONTINUE
   40 CONTINUE
      CN=CN+1
   17 CONTINUE
      CN=0
      DO 19 CNT=1,NUM2,1
      DO 18 CTR=1,NUM,1
      IF (Q(CNT,1).EQ.RCRD(CTR,1)) THEN
      IF (Q(CNT,2).EQ.RCRD(CTR,2)) THEN
      u(CN,4)=v(CTR)
!     NRST4(CN,4)=RVEL(CTR)
      CNDEX(CN,4)=1
      GOTO 50
      ENDIF
      ELSE
      u(CN,4)=0.0
!     NRST4(CN,4)=0.0
      CNDEX(CN,4)=0
      ENDIF
   18 CONTINUE
   50 CONTINUE
      CN=CN+1
   19 CONTINUE

      OPEN(9,FILE='averaged_vel_rad1.txt')
      DO 21 c=1,NUM2-1,1
      WRITE(8,*)u(c,1),u(c,2),u(c,3),u(c,4)
!     WRITE(8,*) CNDEX(CTR,1),CNDEX(CTR,2),CNDEX(CTR,3),CNDEX(CTR,4)
      TOT=CNDEX(c,1)+CNDEX(c,2)+CNDEX(c,3)+CNDEX(c,4)
      CN=u(c,1)+u(c,2)+u(c,3)+u(c,4)
      IF (TOT.EQ.0) THEN
      SUM=999
      WRITE(9,350) XCRD(c,1),XCRD(c,2),SUM
  350 FORMAT (F7.4,1X,F7.4,1X,I3)
      ELSE
      AVG=CN/TOT
!     AVGY=CNY/TOT
      WRITE(9,400) XCRD(c,1),XCRD(c,2),AVG
  400 FORMAT (F7.4,1X,F7.4,1X,F8.4)
      ENDIF
   21 CONTINUE
      STOP
      END
```

APPENDIX 3

This appendix details the analytical method by which the Least-Squares method was employed to find the normalizing coefficients for the normal modes being used to produce total vector maps of the Corpus Christi Bay.

Given an overdetermined system of equations, use of the Least Squares minimization leads into a completely determined system with an invertible square matrix. The system of equations comprises the summation of our 16 normal mode functions aforementioned. For Corpus Christi Bay PDE2D uses up to 728 data values (at each grid point where there is data) for each of the 16 modes (whose coefficients are unknown), thus giving us a very overdetermined system. We can define the system of equations as the matrix equation:

$$[b_n] = [a_{n,k}][x_k]$$

Here **b** is the averaged radar data at the model point; n, k indicates the normal mode in question at that point. The matrix, **a** represents the radar-directed components of the normal modes for each point corresponding to **b** and **x** represents the mode coefficient to be determined by least-squares fitting. There are N equations expressed as:

$$B_k \equiv \sum_{n=1}^{N} A_{k,m} x_m \quad 1 \le n \le$$

To minimize the mean-squared differences between the data points, **b** and the fitting function [**a**][**x**] the following expression was employed.

$$L(\vec{x}) = \sum_{n=1}^{N} \left[b_n - \sum_{n=1}^{M} a_{n,k} x_k \right]^2 \Rightarrow \text{Minimun}$$

Here L is referred as the residual fit, which would be zero if the fit were perfect, but can never be zero for more equations than unknowns with noisy data. To find the minimum of the residual fit it must be differentiated with respect to its variables and set to zero. The m-th equation can be expressed as:

$$\sum_{n=1}^{N} b_n a_{n,m} = \sum_{n=1}^{M} \sum_{n=1}^{N} a_{n,k} a_{n,m} x$$

Within this expression there are now M equations with M unknowns, a square system of linear equations. The following expressions can now be defined as:

$$A_{k,m} \equiv \sum_{n=1}^{N} a_{n,k} a_{n,m}; \; B_m \equiv \sum_{n=1}^{N} b_n a_{n,m}$$

The new system of M equations and M unknowns can now be expressed as:

$$B_k \equiv \sum_{n=1}^{N} A_{k,m} x_m$$

CURRICULUM VITAE

Hector Aguilar Jr. was born on April 26, 1973 in El Paso, Texas. The only son of Hector Aguilar and Alicia Gamino, he graduated from Andress High School, El Paso, Texas in the spring of 1991 and entered military service the following summer. He was honorably discharged in 1994 where he entered the El Paso Community College later to transfer to the University of Texas at El Paso. While pursuing his bachelor's degree in physics he worked as a research assistant under various faculty involving molecular dynamics, surface physics, and environmental physics. He presented work at the 1995 American Physical Society conference in San Diego, California on super ionic crystal lattices. He earned his Bachelor's degree in physics in the summer 1999 and went to work at CAS Weapon Systems Analysis Ltd. He entered the Graduate School at the University of Texas at El Paso in 1999.

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