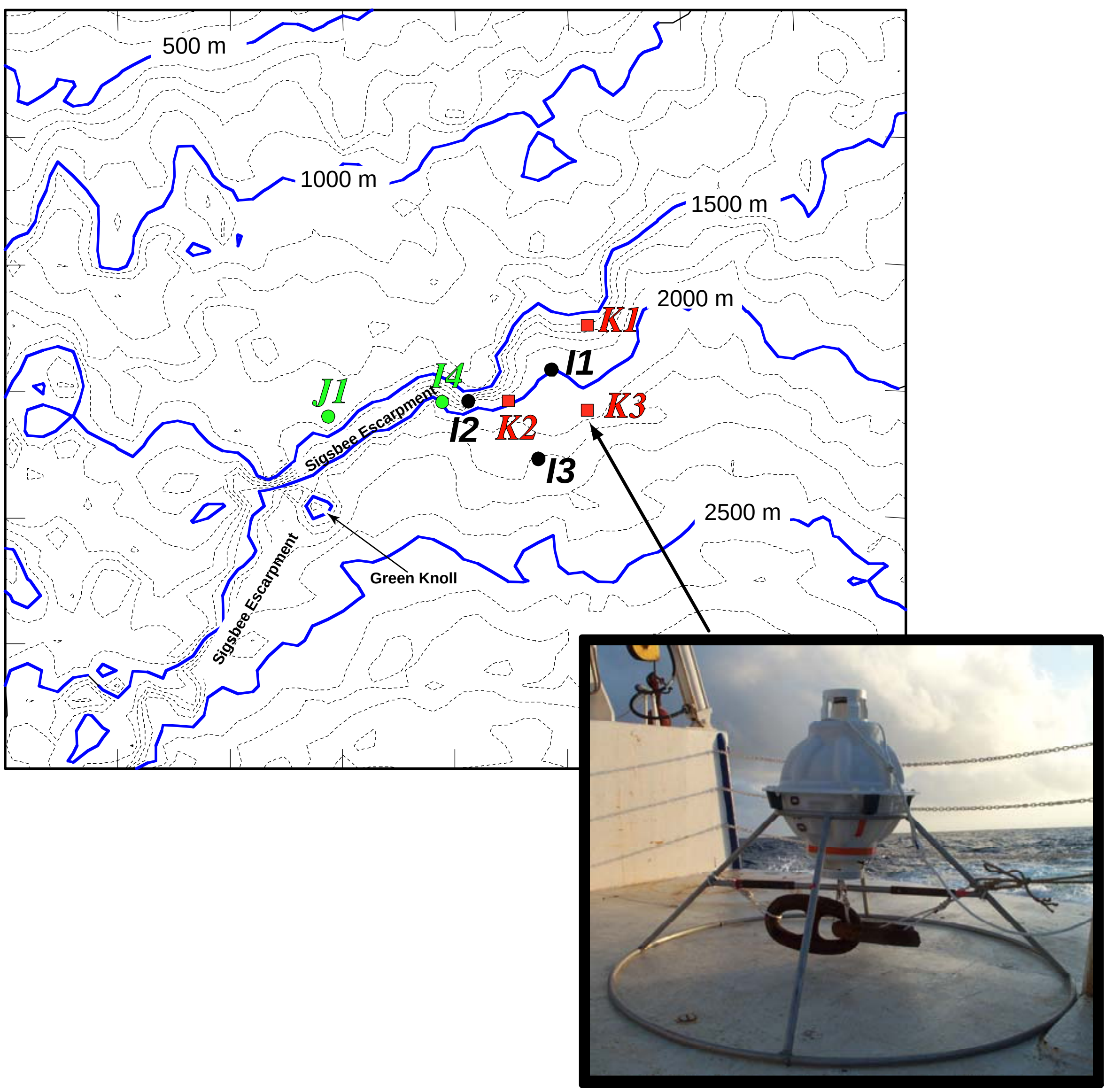
OCS Study
MMS 2003-048

Deepwater Observations in the Northern Gulf of Mexico from In-Situ Current Meters and PIES

Volume I: Executive Summary



MMS
U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Deepwater Observations in the Northern Gulf of Mexico from In-Situ Current Meters and PIES

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ABOUT THE COVER

The map shows the Sigsbee Escarpment south of New Orleans that was the primary focus of measurements from instruments on the indicated moorings. Moorings I1-4 and J1 were normal tautline moorings. Moorings K1-K3 were Inverted Echo Sounders with Pressure (PIES). The picture is of a PIES on the back deck of the mooring deployment vessel. The “orb” contains all the instrumentation associated with operations and recovery of the instrument. The stand is used in regions where strong bottom currents are expected, such as the present study area.

ACKNOWLEDGMENT

The insight of Dr. Willis Pequegnat was verified with this project. One of the authors remembers well listening to Willis many years ago describe how his biological sampling gear lowered near the present study area could not reach the bottom due to very strong bottom currents.

Both the MMS and BP provided support to this measurement program. This cooperative funding was essential to acquisition of the resulting horizontal and vertical coverage as well as the measurement duration. Dr. Alexis Lugo-Fernandez, the MMS COTR, and Mr. David Driver, the BP representative, worked cooperatively to define a program that accomplished both industry and government objectives.

TABLE OF CONTENTS

<u>Page</u>

LIST OF FIGURES

EXECUTIVE SUMMARY

1.0 Introduction

As an extension of the MMS-Funded DeSoto Canyon Eddy Intrusion Study (Hamilton et al., 2000) additional current/temperature measurements were made at the base of the Sigsbee Escarpment in water depths of approximately 2,000m. Deepwater and near-bottom current measurements in this specific area, supported by BP, indicated that periodic higher speed events occurred that could be of considerable importance to expected oil/gas exploration and development in this deepwater area. In order to have representative and pertinent knowledge of conditions in these development areas, the MMS funded a series of fairly site-specific, deepwater current measurements. In conjunction with MMS support, BP provided support to expand the depth and areal coverage of these measurements in what was essentially a cooperatively funded government-industry measurement program.

The specifics of the various components of measurement program and a characterization of many of the key attributes of the observations are presented in this report.

2.0 Measurements

The specific types and locations of measurements described in this report varied somewhat over the two-year field program. During most of the study, MMS and BP jointly funded field and measurement activities. Although the specific supported measurements varied, the continuity and areal extent of measurements would not have been possible without this joint government-industry support. As shown in Figure 1, Moorings I1, I2 and I3 were deployed over the entire two-year interval. Moorings J1 and I4 were deployed during the first year and the last six months respectively. Moorings K1, K2 and K3 were Inverted Echo Sounders with Pressure (PIES) and were deployed during the final six months in a triangle around the only full-depth mooring (I1).

Moorings J1, I2, I3 and I4 were near bottom or "short" moorings in that they each supported three current meters at 10 m, 100 m and 400 m above the local bottom. This emphasis on near-bottom conditions reflects the focus on documenting and understanding better the higher speed current that were previously measured at a series of BP-funded moorings. Mooring I1 was a full depth mooring with a series of ADCPs, fixed-point current meters, conductivity/temperature instruments, and temperature sensors. This was to provide relatively complete documentation of conditions at depths ranging from 10 m above the bottom to 72 m below the water surface in a water depth of 2100 m. A timeline of resulting observations for the various moorings and instruments in this study are shown in Figure 2. Note, velocity time series resulting from ADCPs are for selected representative depths. Field work occurred on cruises conducted every six months.

A PIES is a bottom-mounted instrument (Figure 3) that transmits an acoustic signal and measures the vertical acoustic travel time (VATT) for the sound signal to travel to the ocean varied ocean locations, University of Rhode Island scientists have developed and implemented data processing methods and algorithms (Gravest Empircal Mode – GEM) which uses extensive

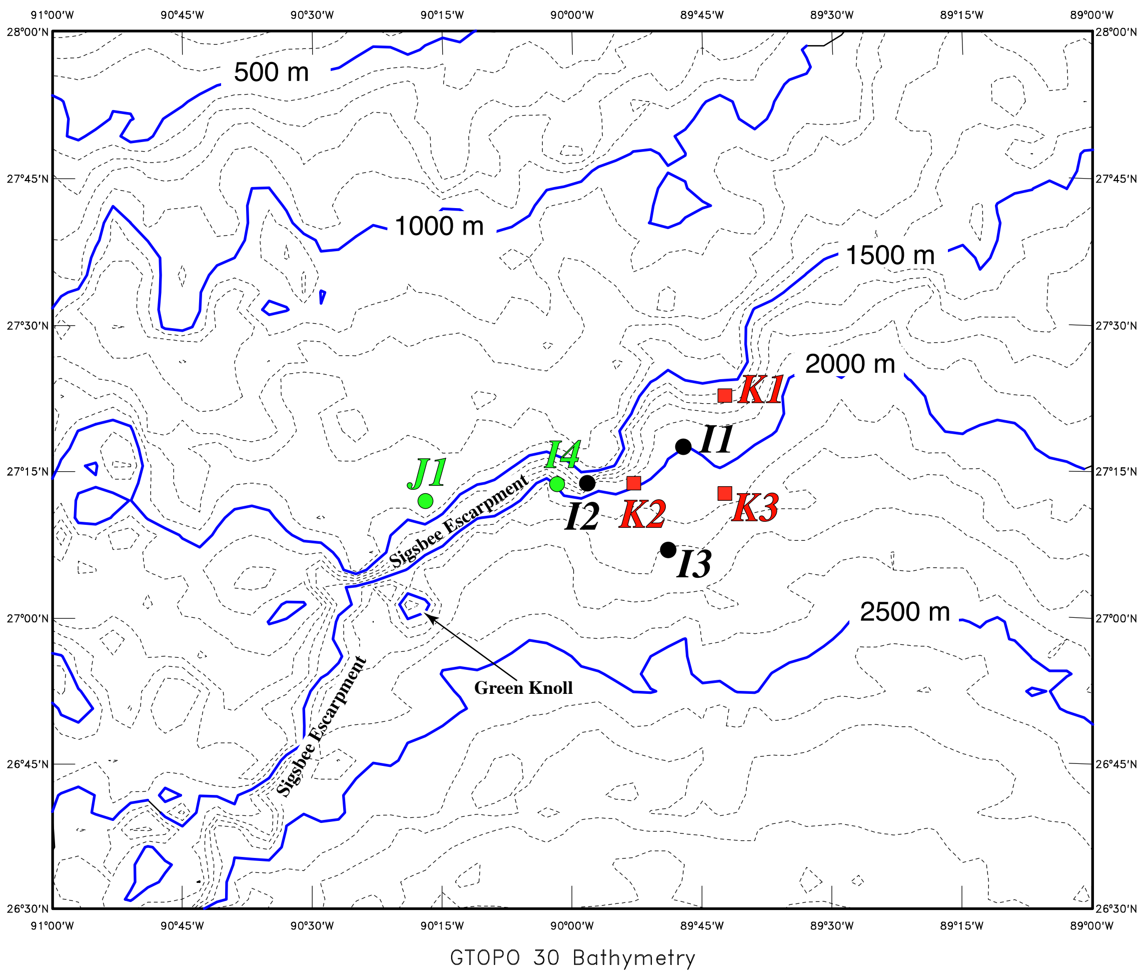


Figure 1. Detailed bathymetric map of the Sigsbee Escarpment in the region south of the Mississippi delta. The positions of the MMS moorings (I1, I2 and I3, black circles) and PIES (K1, K2 and K3, red squares), and the BP moorings (J1 and I4, green circles) are shown.

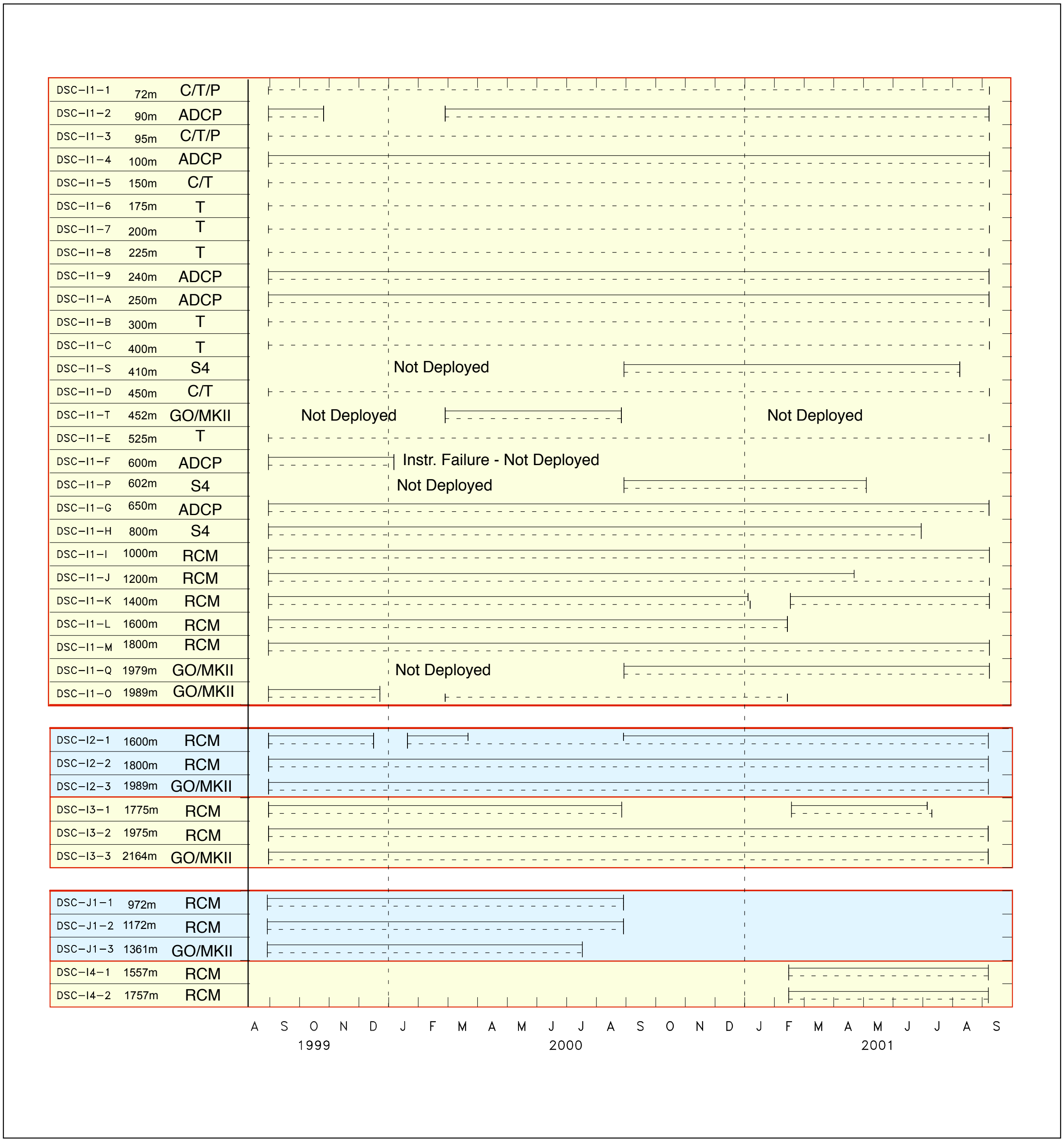


Figure 2. Time lines of data return for the current meter moorings. Solid and dashed lines represent velocity and scaler (e.g. Temperature and Salinity), respectively. On Mooring I1, a 150 kHz, up-directed ADCP failed near the end of the first six months and was replaced by various in-situ current meters for the remainder of the mooring deployments.

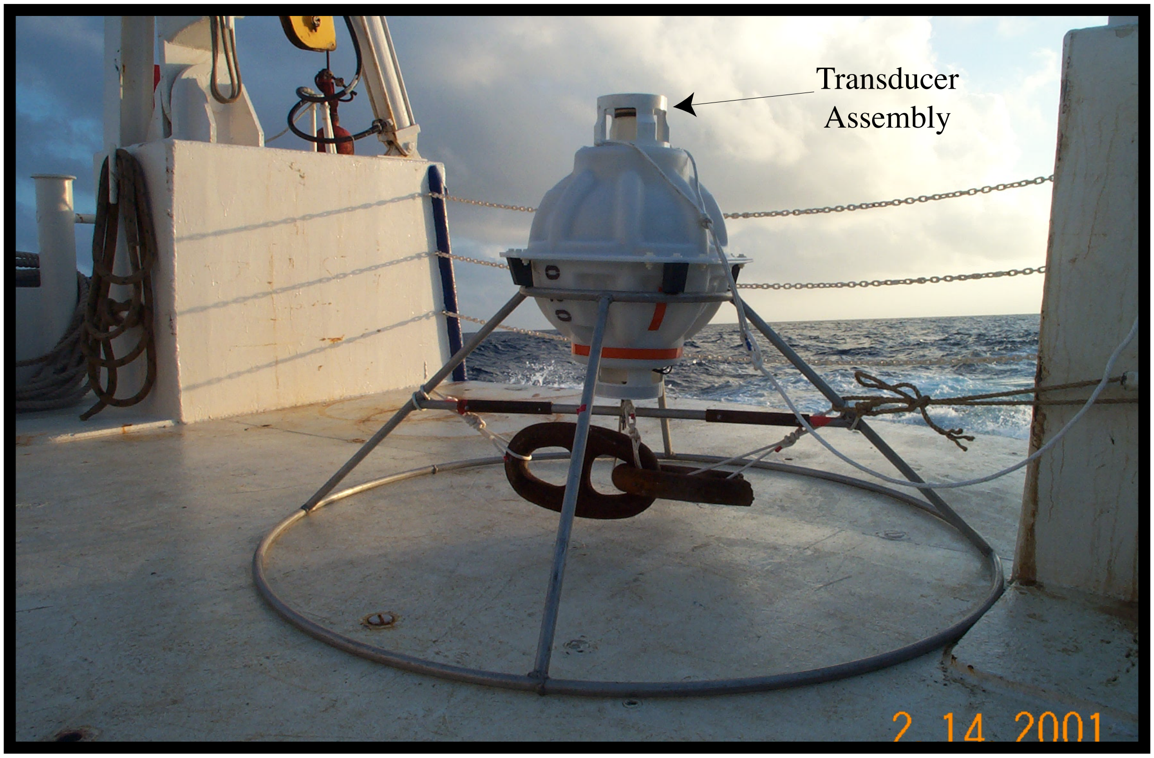


Figure 3. PIES on the back deck of the deployment vessel in a cradle used in regions of expected strong bottom currents. Prior to deployment, the ropes to the weights (chain links) were removed, as were the rubber "stoppers" around the equatorial rib. This configuration orients vertically on a sloping bottom since the weights tend to orient the instrument toward the vertical. The transducer is at the top of the orb, and the release, radio and light are at the bottom. When the acoustic release is activated, the unit separates from the chain links and the orb rises to the surface with the transducer pointing downward. This causes the light and radio to be at the water surface.

basin and regional hydrographic measurements to estimate the depths of various isotherms, isopycnals, and isobars (e.g. Watts et al., 2001). Essentially, it produces a time series of profiles of these variables. In turn, knowledge of the density field at two locations allows estimation of a geostropic velocity profile. Having pressure information at three known and proximate locations, allows estimation of a profile of the relative velocity vector (i.e. a velocity shear profile). Using an appropriate reference velocity measurement, a shear profile can be converted to an absolute velocity profile. In conjunction with bottom-pressure measurements, the relative contribution of the barotropic and baroclinic components of the total geostrophic pressure field can be estimated. Using historical C/T/D profiles to develop an appropriate GEM and three PIES in a triangle about Mooring I1 provided information needed to estimate absolute velocity profiles. Because I1 was a full depth mooring, additional measured current, temperature and salinity time series were available against which the PIES-based velocities were be compared.

3.0 Results

The two years of data, from the three main moorings in the region of the Sigsbee Escarpment on the lower slope south of the Mississippi Delta, have shown unusually strong deep current flows, in particular near the base of the Escarpment (Figure 4). The bottom intensified, nearly depth-independent motions are typical of topographic Rossby waves (TRW) observed in this and other regions of the deep Gulf. However, energy levels at these sites are exceptional and the dominant periods of the motions are approximately 10 to 14 days which is short compared to other regions of the eastern and western Gulf (Hamilton, 1990). Maximum currents at the I2 mooring were of order 85 to 95 cm/s for an event early in the record (Figure 4). This energy seems to spill over the escarpment to the J1 site at the top of the Escarpment on some occasions when very-high energy events occurred at I2. Otherwise, the velocities at J1 were much less energetic than at the moorings south of the Escarpment. Similarly, bottom velocities at another site (I4) just west of I2, on the Escarpment, were also much weaker than measured at the base of the escarpment and in deeper water depths.

The records show a number of distinct wave trains passing through the site (Figure 5). The first, between September 1999 and January 2000, showed the highest current speeds and at the beginning of the record there were indications that upper-layer disturbances, caused by cyclonic frontal eddies on the LC front, were coherent with the lower layer flows. In this first period, upper-layer currents were vigorous due to the presence of the LC and later the presence of Eddy J. The second period began in April 2000 and lasted to the end of August 2000. These TRW's were also energetic though with slightly longer characteristic periods, stronger bottom trapping, and larger westward amplification between I1 and I2, than observed in the first period. The upper-layer currents were quiescent during this second interval as Eddy J had moved off into the western Gulf. Thus, there was no evident connection with the initiation of the April TRW's with

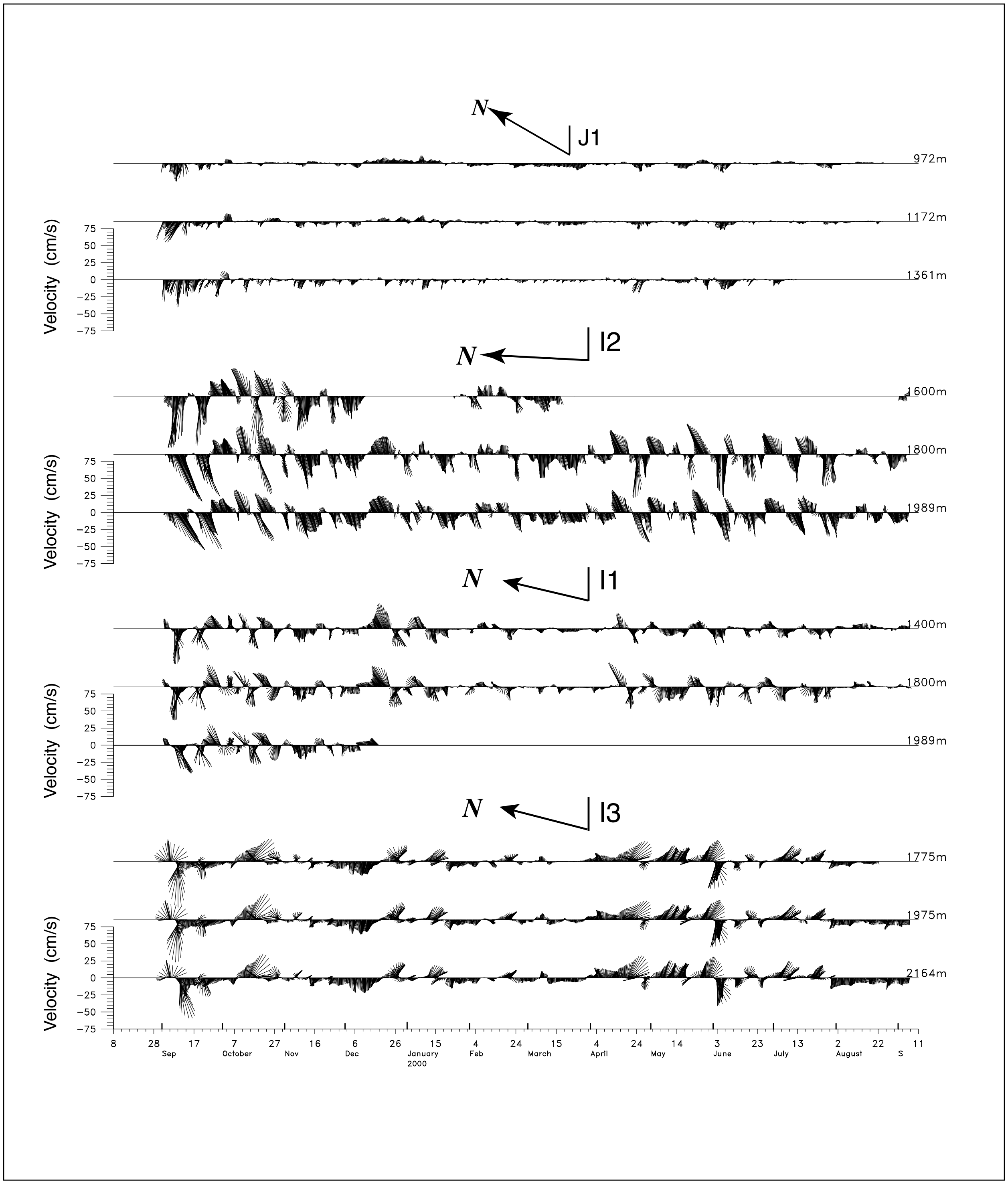
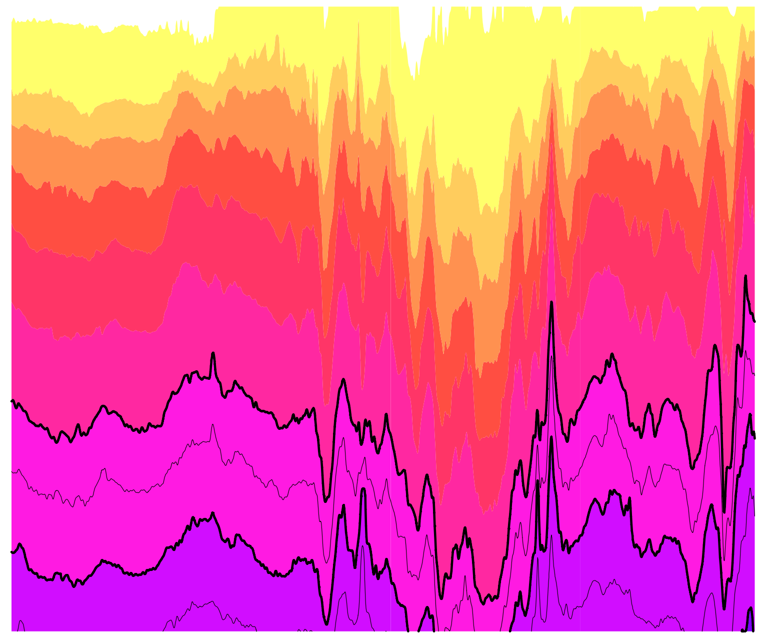


Figure 4. The first year of 40-HLP velocity vectors from below 1000 m at I1, I2, I3 and J1. The direction of the y (V-component) axis with respect to North for each mooring is indicated.



simultaneous fluctuations of the upper-layer currents. A third interval of energetic TRW's which began in February 2001 and was associated with the shedding of Eddy M and associated cyclonic circulations. In all, five wave trains, with differing periods and wavelengths were identified in the bottom records. Ray-tracing suggests that (1) the west side of the LC is the most likely source region for these waves and (2) it is difficult for such short period waves to penetrate into the western Gulf basin. This is an accord with earlier measurements (Hamilton 1990) that showed 20- to 30-day TRW's dominating in the central and western Gulf. If the mechanism for coupling of surface propagating eddies or meanders with deep TRW motions that has been put forward for TRW generation by the Gulf Stream in the North Atlantic (Pickart, 1995) applies in this portion of the Gulf of Mexico, then small cyclonic frontal eddies on the LC and LCE fronts could be candidates for generating deep, short-period TRW's in the eastern Gulf.

It is apparent from these measurements and the previous one-year of current data obtained by BP at a site close to I1 (Hamilton, 1998), that TRW activity is fairly continuous at the base of the Escarpment in this region(Figure 4). The distribution of energy across the array was quite inhomogeneous, and varied with the different observed wave trains. The rotation of the principal axes of the motions from partly across-isobath at I3 to along-isobath at I1 and I2 suggests that the relatively steep slope of the Escarpment may be influencing the propagation of the TRW's, possibly by reflecting the energy back into deep water. The weak currents at J1 and I4 suggest that the Escarpment in this region was an effective barrier to TRW motions propagating into shallower water.

Upper-layer currents were dominated by the passage of the two major LC anticyclones and associated processes (Figure 5). The periphery of these eddies seem to have produced the most energetic temperature and velocity fluctuations that were often associated with rapidly translating cold cyclones. The passage of Eddy M into the western Gulf, between February and June 2001, allowed partial analysis of radial and azimuthal flows from mooring I1. The path and characteristics of Eddy M were analyzed using drifter trajectories acquired from Horizon Marine, Inc. These data in conjunction with satellite altimetry showed this eddy moved further north than the previous Eddy J, and the center of the Eddy M passed within 60 km of the I1 mooring, so that a substantial portion of the eddy interior was measured. Eddy M was probably forced northwards and towards the slope by a large cyclone on its western side that formed while the eddy was still attached to the LC. This cyclone eventually moved up onto the slope and blocked further westward passage of Eddy M, which moved rapidly southwards during May 2001, and then resumed a more commonly seen southwestward path into the western deep Gulf. The azimuthal velocity and temperature profiles behaved roughly as expected for an elliptical eddy in solid body rotation with a period of 8 to 10 days. However, there were significant anomalies that were associated with either attachment to the Loop Current or interactions with the cyclone and slope. The passage of the eddy allowed estimation of the distances from the center to the maximum velocity, along the semi-major axis, and the width of the cyclonic shear zone outside the maximum velocity position. These were 150 and 50 km, respectively. The narrow cyclonic shear zone implies a large positive vorticity anomaly and thus a generation region for non-linear instabilities.

Analysis of upper-layer inertial currents show that they were present and varied in amplitude with time and depth. In the January – February, 2001 interval, before the arrival of Eddy M, when the upper-layer velocities were dominated by vigorous interacting cyclones, strong inertial currents were generated in the surface layer (Figure 6). These were more vigorous than in the fall and winter of 2000, when background currents were small and wind forcing was stronger. It was speculated that the interacting eddies were partially responsible for the increased amplitudes of the inertial oscillations. The January – February inertial waves did not propagate to deeper depths until Eddy M arrived. In Eddy M, the region just above the main thermocline had greater inertial energy than the surface indicating the propagating inertial internal waves were being trapped by the negative vorticity anomaly in the center of the eddy. Below 800 to 1000 m, inertial oscillations had negligible amplitudes.

Three bottom-mounted PIES were deployed in a triangle around mooring I1 to test the viability of using the GEM methodology to generate low-frequency temperature, salinity and geostrophic velocity depth profiles. Deployment of an array of PIES and bottom current meter moorings is much more cost effective for large-scale measurement programs in deep water, than deploying arrays of full-depth moorings like I1. A preliminary GEM was constructed from historical CTD data for the Gulf and applied to the bottom pressure and travel time records from the three PIES deployed in the last 6-months of the study. The results derived profiles of temperature, salinity and geostrophic currents were compared with appropriate direct measurements of these quantities from mooring I1(Figures 7, 8 and 9). The time series comparisons were good for all depths with high statistical significance and confidence. The last six months of the deployment included part of the passage of Eddy M. This tests point to the confident use of PIES in future deep Gulf physical oceanographic measurement programs.

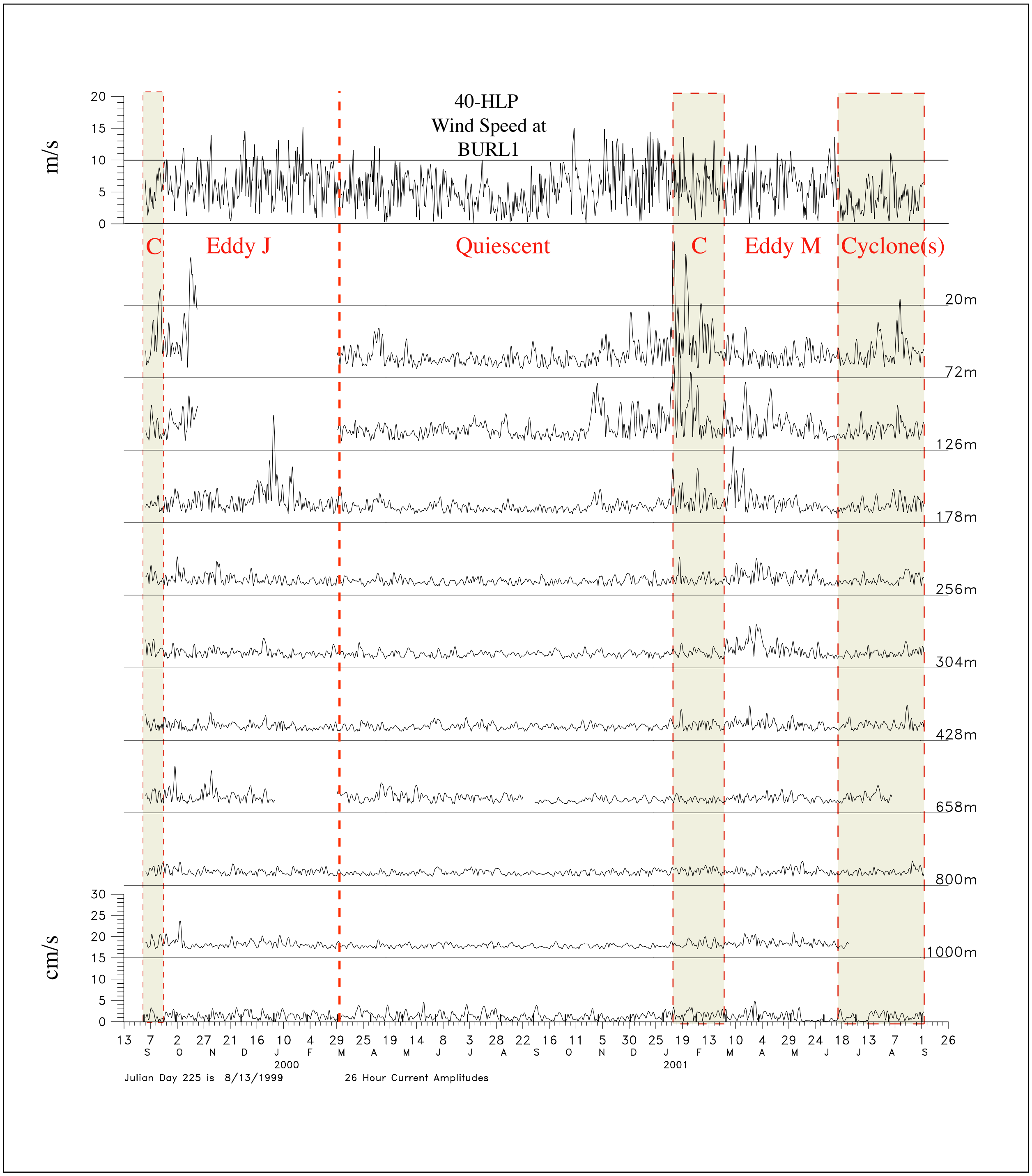


Figure 6. Amplitudes of inertial (26 hour) current oscillations at the indicated depths of mooring I1. Top panel shows the 40-HLP wind speed at the BURL1 C-MAN Station. The vertical axes show the amplitudes (in cm/s) of inertial current oscillation. The dashed vertical lines help identify intervals when LC eddies and their peripheral cyclones (C) dominated the upper layer at Mooring I1.

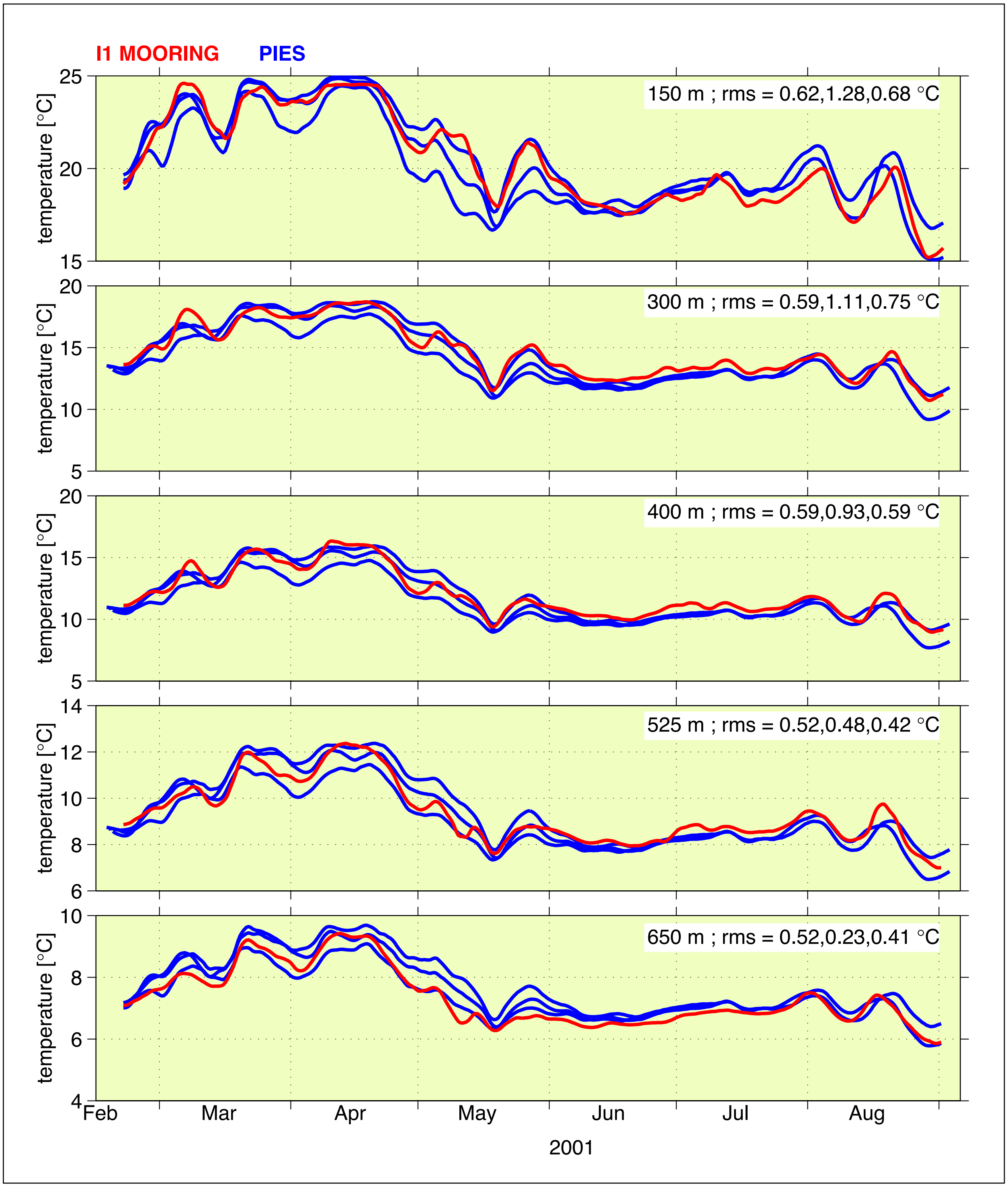


Figure 7. Comparison of temperature time series measured by the I1 mooring (red) and temperatures estimated at the same set of depths by the 3 nearby PIES (blue) using the GEM interpretation of the tau (τ = RT travel time) measurements.

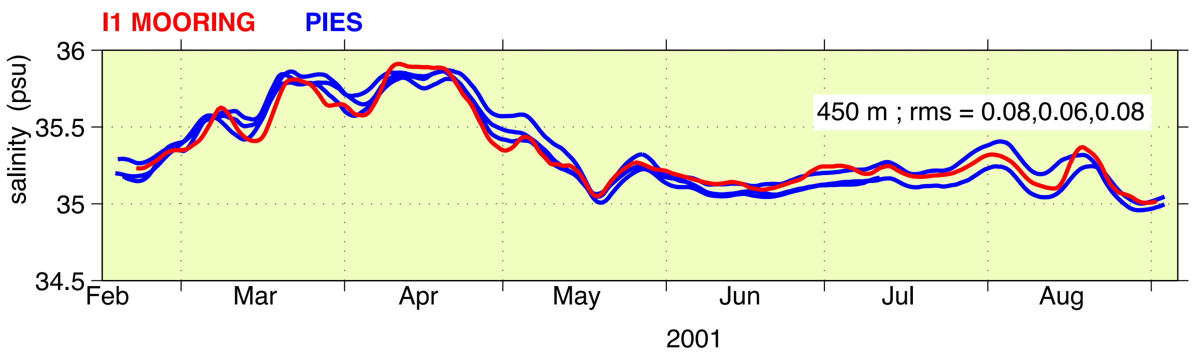


Figure 8. Comparison of salinity time series measured by the I1 mooring (red) and salinity estimated at 450 dbar by the 3 nearby PIES (blue) using the GEM interpretation of the tau (τ) measurements.

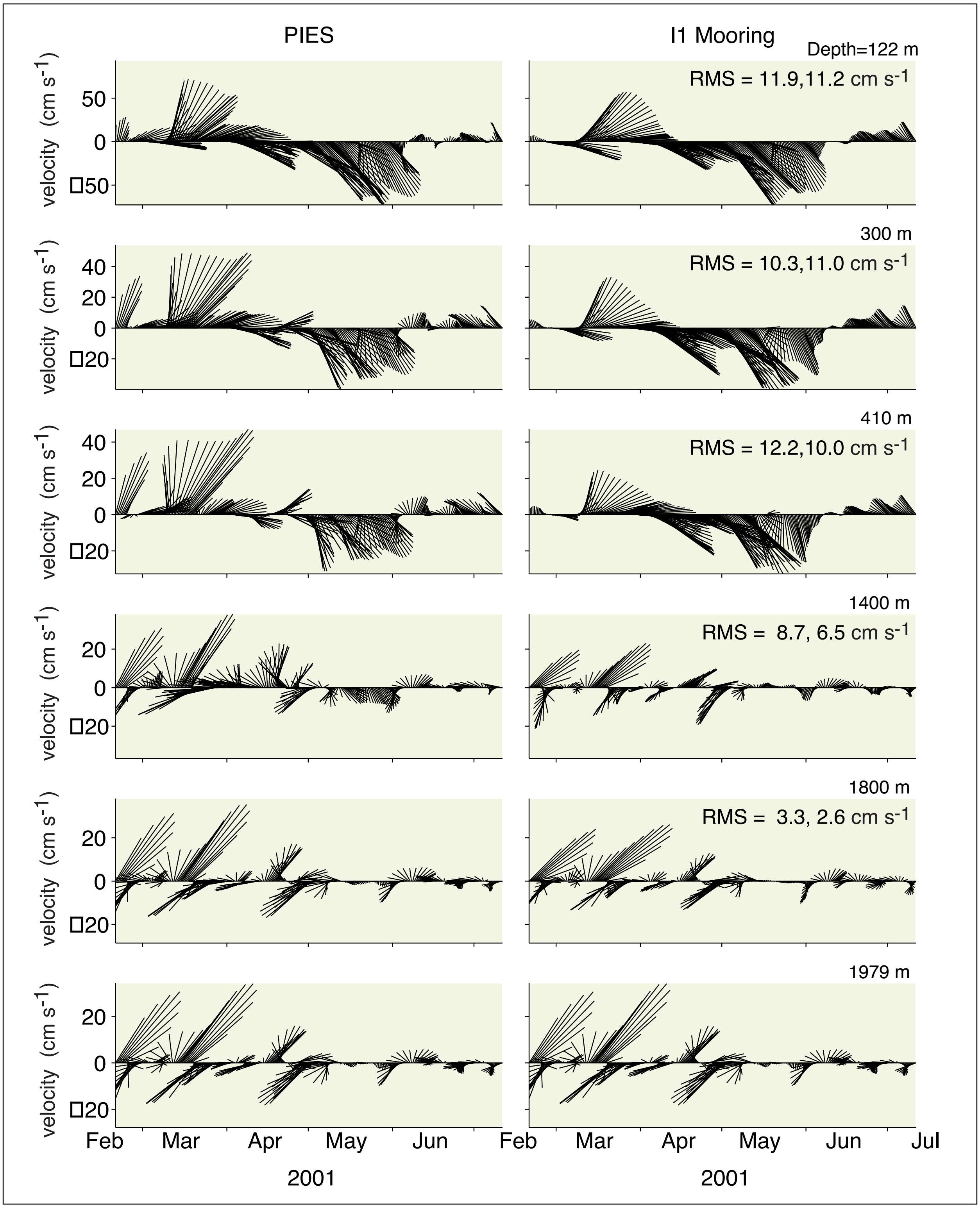


Figure 9. Comparison of velocity measured by the I1 mooring (right) and velocity estimated at the same set of depths by the 3 nearby PIES (left) using the GEM interpretation of the tau (τ) measurements and referencing geostrophic shears to the deep current meter on the I1 mooring.

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The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

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