WHOI-97-04

Woods Hole Oceanographic Institution

Acoustic Doppler Current Profiling in the Western Pacific during the WOCE P10 Cruise, November/December 1993

by

Frank Bahr and Terrence M. Joyce

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Technical Report

Funding was provided by the National Science Foundation
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Approved for public release; distribution unlimited.

Approved for Distribution:

Philip L. Richardson

Philip L. Richardson, Chair
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Abstract

The objective of this cruise was to occupy a hydrographic section nominally along 149E from Papua New Guinea to the shelf off the coast of Japan near Yokohama as part of the one-time WOCE Hydrographic Programme survey of the Pacific Ocean, line P10. This report describes the processing of shipboard acoustic Doppler current profiler (ADCP) data that were collected during this cruise. New GPS-based heading measurements ("Ashtech heading"), which increase the accuracy of the ADCP, are covered in detail. A subset of the processed data from the New Guinea Coastal Undercurrent and from the Kuroshio is presented.

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1 Introduction

The objective of this cruise was to occupy a hydrographic section nominally along 149E from Papua New Guinea to the shelf off the coast of Japan near Yokohama as part of the one-time WOCE Hydrographic Programme survey of the Pacific Ocean, line P10 (Fig. 1). The sensor suite included a CTD with a 36-place rosette, Gerard Barrels for large-volume water samples, ALACE floats, a lowered acoustic Doppler current profiler (L-ADCP), as well as a shipboard acoustic Doppler current profiler (ADCP).

The purpose of this report is to describe the processing of the shipboard ADCP data and to show some initial results. In the following, the instrument system and the data processing software are introduced in section 2. Section 3 contains the general cruise log as well as notes on the ADCP data collection. Specifics on data processing issues such as calibration, etc., are given in section 4, with special emphasis on the Ashtech heading data that had recently become available on the R/V *Thomas G. Thompson*. Some initial figures from the New Guinea Coastal Undercurrent and from the Kuroshio are shown in section 5, though scientific description of the measurements will be reserved for other publications.

P10

October, 1993

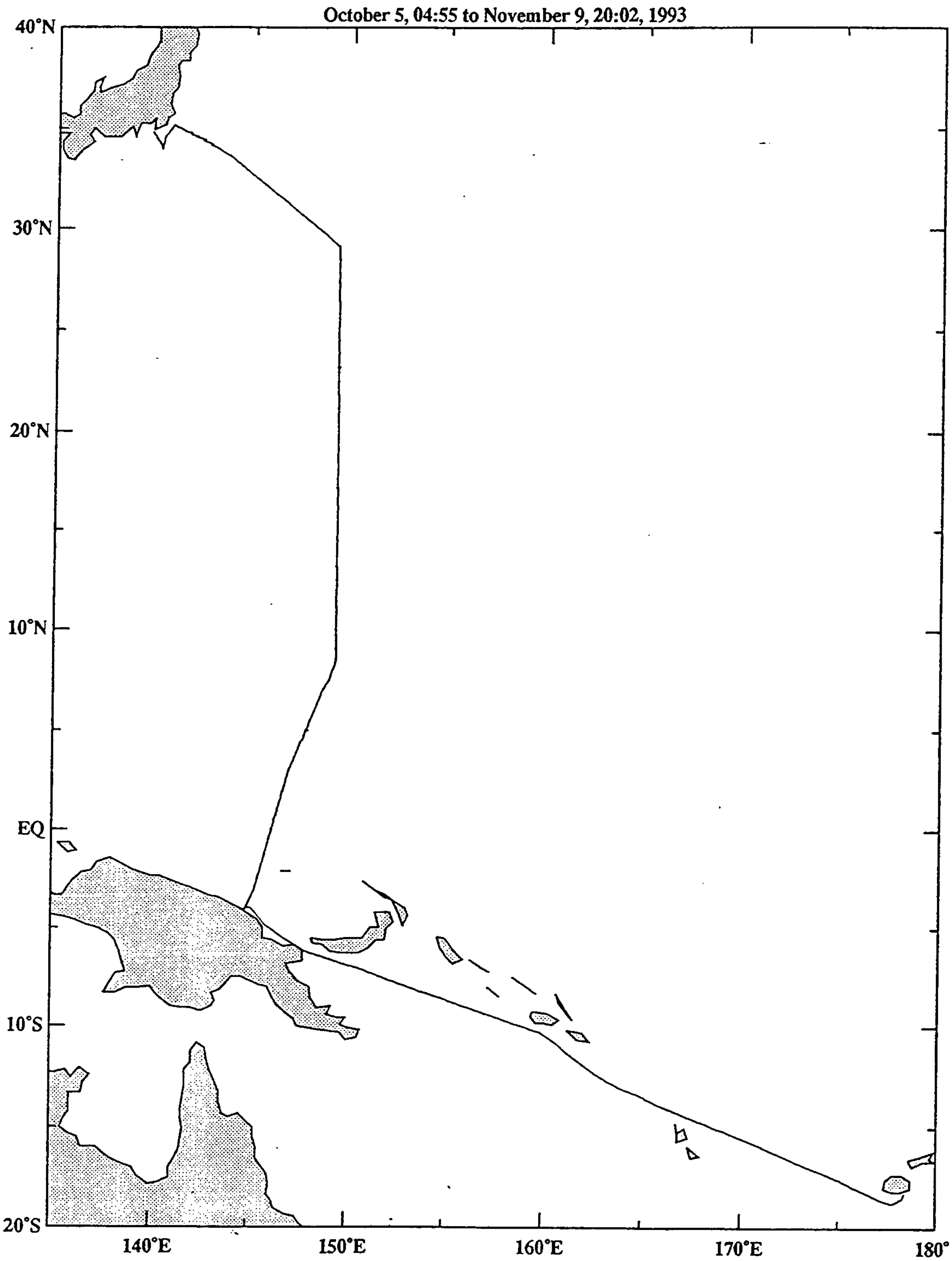


Figure 1: P10 Cruise track, using 15-minute averages.

2 The ADCP System

The ADCP system on the R/V *Thompson* can be divided into several components: the ADCP transducer and its installation, the data acquisition system computers and software, and the navigation instruments.

2.1 ADCP Hardware and Transducer Installation

The ADCP transducer is a standard (narrow band) 150 kHz vessel-mounted transducer from RD Instruments (RDI), Inc. It is mounted in the Janus configuration (i.e., rotated by 45 degrees) in a faired transducer pod that protrudes below the hull by approximately two feet. The pod is expected to eliminate, or at least to reduce, the impact of bubble sweep-down on the ADCP. The transducer depth is nominally 5.9 meters; it is exposed directly to the sea (Flagg and Shi, 1995).

2.2 Navigation

Several instruments provide additional data to the ADCP that are incorporated either in real-time or during post-processing. These are:

- Heading: provided by either of the ship's two Sperry MK-37 gyro compasses. Each ADCP ping is rotated from transducer or ship's coordinates into geographic coordinates using the ship's heading before the pings are combined into the ensemble average (usually about 300 pings for a 5-minute average).

- Position fixes: provided by an MX4200 GPS receiver via RS232 serial connection. The ADCP data processing indicates that selective availability (SA), the U. S. Government's dithering of the GPS signal for non-military users, was in effect during this cruise, degrading the GPS fix accuracy to approximately 100 meters. Two GPS fixes were stored with each profile for post-processing.

- Second heading: in May of 1993, the R/V *Thompson* was equipped with an Ashtech heading system. It calculates the ship's heading using GPS differential carrier phase measurements between a reference antenna and three other antennas. Ashtech data were recorded separately for post-processing.

2.3 The Data Acquisition System

The primary data acquisition was performed by a PC running RDI's Data Acquisition Software (DAS) version 2.48. This software produces the familiar pingdata files ("pingdata.###"), usually one file per day, which were recorded on hard disk. Because the DAS has problems running on faster PCs, the acquisition PC often is a 286 machine, as was the case on the *Thompson*. It is also possible to use 386 machines that are slowed down with software.

For the P10 cruise, DAS configuration parameters included 4 m blanking, 8 m vertical bins and a 16 m pulse. Profiles were usually collected at a rate of approximately once per second and vector-averaged in 5-minute ensembles. To reduce spurious shear from simultaneous variations in depth range and ship's speed during an ensemble, the vector-averaging was done in the usual way as follows (using an option in the DAS). For each velocity profile, the mean over a reference layer (here: bins 4 through 15) was calculated and subtracted from the profile. The reference layer and the reduced profile were then averaged separately over the ensemble, and recombined at the end of the ensemble. The DAS option for screening based on error velocity was used with a threshold of 100 cm/s. Routine data collection included horizontal and vertical velocity components, backscatter amplitude [as measured by the automatic gain control (AGC) level], percent good pings (at each depth bin, the percentage of pings within an ensemble for which data from all four beams were judged acceptable), error velocity, spectral width, and percent 3-beam solution (at each depth, the percentage of acceptable pings that were calculated from three instead of four sound beams). The following direct commands were set:

- FH00002: in bottom track mode, use every other ping for bottom tracking.
- E0004020099: controls positioning of the first bin in ping-to-ping tracking. The average from four bins starting at bin two from only the last ping is used to position the tracking filter.
- B008001: set point where the ADCP narrows the processing filter bandwidth. Here, the switch occurs once the beam with the lowest AGC goes below 80 counts.
- CF63: turns off a modified fish detection algorithm that has caused problems in the past (E. Firing, pers. comm.).

With the present RDI DAS, integrating navigation into the ADCP system requires a "user exit" program that effectively becomes part of the DAS. The *Thompson* used Eric Firing's program, version "ue3.exe". Its main functions were:

- At each ping (about once per second), calculate the velocity of the ship relative to the reference layer. This will be called the ship-reference velocity. It is in geographic coordinates.

- At each ping, filter this ship-reference velocity with a mild exponential filter and display it. Optionally transmit this information and the heading in a "speed log" message, Magnavox 1100 series format, via a serial port.

- At the beginning (ping 2) and the end (just before writing the ensemble out to disk), grab the latest position fix, parse it, and store it in the "user buffer" of the ensemble. Positions are obtained via serial port from an NMEA GGA message source. This velocity and the end-of-ensemble position are stored in the pingdata "loran" structure and are used for displaying the velocity profile relative to the "nav device", if that option is selected in the DAS.

- Optionally transmit the full ensemble data structure out through a serial port.

Using the last option of ue3.exe, each profile was sent serially to a SUN work station where a second copy of the raw data was collected by a program (*monserv*) written at the University of Hawaii. It generated approximately daily files very similar to the "pingdata" files written by the PC's DAS. With the multi-tasking capabilities of the Unix machine, it was possible to generate preliminary ADCP results in close to real time without interrupting the data acquisition.

Ashtech heading data were collected once a second by a PC that had one of the ship's network disks mounted as a local DOS disk. Once per second, the PC recorded:

- The Ashtech's ATT message, which contains heading, pitch, roll, and the quality parameters mrms and brms. The mrms is defined as "the average double differenced carrier phase residual" (Ashtech manual). This value is zero if fewer than five satellites are used in the attitude computation. Typical values are around 2-3 mm. The brms error is defined as "the rms error between the baseline magnitudes determined in the initial survey (i.e., the body reference frame vectors between antennae 1-2, 1-3, and 1-4) and the computed baseline magnitude obtained at the current time. Typical values are 1-3 cm for PDOP<4."

- NMEA GPS position as given by the GGA sentence, which includes time (no date), longitude, latitude, HDOP, number of satellites, and antenna height in meters.

- The speed log message provided by ue3.exe, which contains the ship's heading.

During the cruise, another program (*decash*) was run on a SUN once a day to interpolate any missing gyro heading (only for gaps smaller than 4 seconds), edit out bad data based on thresholds for mrms and brms, and then average the remaining data into one-minute intervals. The results were stored in matlab format (.mat) files and saved for post-processing. As of 1994, a new version of the user-exit program (*ue4.exe*) is available that stores Ashtech heading information in the profile user buffer, simplifying data storage and processing.

2.4 The Data Processing Software (CODAS)

The ADCP processing software used here was developed by a group from the University of Hawaii led by Eric Firing. It is outlined in the following; a more detailed description of the software is given in Appendix A taken from Firing (1991). The specific processing steps for the P10 data set are described in section 4.

CODAS (short for Common Oceanographic Data Access System) consists of a database system for ADCP and other oceanographic data, and a set of programs for ADCP data processing. The programs are written in C and matlab. To obtain the source code and executables for several platforms including PCs, SUN and SGI work stations, contact efiring@soest.hawaii.edu.

The basic data processing steps consist of:

- **Scan** the raw data files to ensure they are readable, to identify gaps or other problems, and to extract information needed to correct the recorded profile times in case the PC clock was in error compared to GPS time.

- **Load** the data into a database suitable for processing and analysis. Profile time corrections are usually performed at this stage.

- **Evaluate** the quality of the data set as a whole by calculating and plotting diagnostic statistics. Signal strength (as measured by the Automatic Gain Control: AGC), percent good pings, error velocity, vertical velocity, and the vertical derivative of the horizontal velocity components are informative. It is useful to compare these variables between on-station and underway periods.

- **Edit** the profiles to eliminate bottom interference, velocity glitches due to interference from the CTD package, etc.

- **Ashtech correction:** Rotate each profile according to the difference *dh* between Ashtech and gyro heading. In addition to temporal changes of the gyro, *dh* may contain a constant heading offset of the Ashtech antenna array. It is, therefore, necessary to perform the ADCP calibration after the Ashtech rotation has been applied in order to determine the angular offset of the Ashtech antennae relative to the ADCP transducer.

- **Calibrate** the profiler-heading device (i.e., gyro compass or other) combination. Scale factor and rotation calibrations must be determined from all available data as a function of time during the cruise and then used to correct the velocity data.

- **Reference** the relative velocity profiles by calculating the ship's position at the end of each profile and the average velocity of the ship during the profile.

- **Adjust depth** for the difference between the actual vertically averaged sound speed (calculated from hydrographic data) and 1470 m/s, the nominal sound speed assumed by RDI in converting pulse travel times to ranges.

3 Cruise Narrative

The following is taken from the P10 cruise report.

3.1 Highlights

WOCE Designation:	P10
EXPOCODE:	3250TN026/1
Chief Scientist:	Melinda Hall Phone: 508-289-2599 e-mail: mindy@latour.whoi.edu
Co-Chief Scientist:	Terrence Joyce Phone: 508-289-2530 e-mail: tjoyce@whoi.edu
Ship:	R/V *Thomas G. Thompson*
Ports of Call:	Fiji, Papua New Guinea to Yokohama, Japan
Dates:	5 October 1993 - 10 November 1993

3.2 General Cruise Log

The P10 cruise was the third in a series of three WHP one-time cruises aboard the R/V *Thompson* in 1993 following P17N and P14N. The ship departed Suva, Fiji, on September 29 and steamed westward toward the northern coastline of Papua New Guinea, where the section began at the 200 m isobath. During the seven-day deadhead, we carried out three test stations (not included in the station numbering scheme) to shake down equipment and water sampling methodology. The station track, designed in early planning documents for 145E, was shifted eastward in an effort to depart the New Guinea coastline perpendicular to the bathymetry, then skirt the Mariana Ridge and Trough to the east, thus making the whole section in the East Mariana Basin, rather than in both that basin and the Philippine Basin farther west. Where bottom depths changed rapidly (near the coast and passing the Caroline Seamounts around 6-8 N), station spacing was dictated by topographic changes. Within 3 degrees of the equator, spacing was every 15 minutes of latitude along the ship track (nominally 15 nm, but slightly more due to the track angle), stretching to 30 nm up to 10.5N, then 40 nm from there to station 73 at 28.5N. At that point we began our dogleg towards the Japan coast in an effort to cross the Kuroshio at approximately a right angle. Over the northern dogleg, station spacing gradually decreased to resolve the strong front of the Kuroshio and ultimately, to accommodate rapid topographic changes near the coast. Stations generally went to within 10 m of the bottom except over the Japan Trench and a few other stations where bottom depths exceed 6000 dbar. No stations were lost due to weather and the ship arrived on schedule in Yokohama on 10 November after a total of 94 small-volume CTD stations, 53 of which with the LADCP attached to the rosette, and seven additional large volume casts.

3.3 Major Problems or Goals Not Achieved

On station 65, on 31 October, we were retrieving the intermediate Large Volume (LV) cast and had taken two Gerard barrels off the wire when the winch failed to stop and the third bottle was 2-blocked, breaking the wire and causing the remaining seven bottles to be lost. Fortunately, no one was injured, but the loss reduced the ability to carry out LV sampling, and the final LV stations were designed to use small volume radiocarbon measurements for the intermediate cast. Another problem was encountered with the salinity measurements causing unacceptably large sample-to-sample "'noise". Various causes were examined including changing Autosals, changing Autosal location until the problem was finally isolated--the 120 ml flint glass WHOI sample bottles were replaced with 200 ml Scripps Kimax bottles commencing with station 59, and a dramatic improvement was seen. The WHOI bottles, which were over five years old, were found to have flakes of an insoluble substance that appeared to come from the inside surface.

3.4 ADCP Data Collection

The following is compiled from the cruise notes of Peter Hacker, University of Hawaii. A more complete version of these notes is contained in Appendix B.

The general ADCP data collection worked without major problems. There were several short gaps on the order of 3 minutes that were associated with changes of the DAS parameters. Bottom tracking was toggled on and off several times to collect bottom track calibration data, and the ensemble length (SI) was changed to one-minute sampling for several short periods. A 30-minute and a second 21-minute gap were due to SUN work station crashes. Though these data would have been available on the PC raw data files, we decided that it was not necessary to obtain the PC files just for that reason since both gaps occurred during stations. Finally, one larger 5-hour gap occurred on November 11. Presumably the acquisition PC's keyboard was hit accidentally sometime at night, causing the DAS to pause until the error was observed several hours later.

There were more problems with the Ashtech heading system, however. The data were unavailable for the first 9 days of the cruise because of instrument problems. Several larger gaps occurred throughout the cruise when the Ashtech deck unit either displayed an error message or had frozen up completely. In either case a hard reboot, sometimes with additional memory reset, was used to bring the data stream back on line. In total, the Ashtech gaps summed up to 12.7 days, or about one third of the cruise time. To better understand the gyro compass behavior, four "Ashtech surveys" were run at different times during the cruise. During such a survey, the ship would steam along a rectangular, or later octagonal, pattern with typically six 1-minute ensembles per side. The data indicated the possibility of identifying gyro errors as function of heading, and they were subsequently used to define a model that could fill the Ashtech gaps.

4 Data Processing

In this section, the specific processing steps under the CODAS software package are described, and some reference to the relevant programs is given. For more details on ADCP data processing with CODAS, the reader is referred to the example database that comes as part of the CODAS software package. It contains the complete directory structure, control files, matlab settings, and other parameters that were used to process a small set of ADCP data, and is accompanied by the document *process.doc* which contains a detailed history of the processing.

4.1 Scan and Load

As the first step, the raw data files were scanned for readability, gaps, and clock drift (program *scanping*). We worked with the SUN version of the raw data rather than the PC version, which, due to the way in which they are collected, produce a new "header" for each profile. Aside from the fact that ADCP gaps were less obvious (since gaps produce a new header as well), this was of little consequence. Several gaps of a few minutes' duration were found, presumably associated with changes in the DAS configuration. Two longer gaps (30 and 21 minutes long, respectively) were due to reboots of the SUN, and could thus have been closed with the PC raw data. Since they occurred during on-station time, however, we decided that this was not reason enough to obtain the PC data. A long gap of nearly 300 minutes that occurred close to the Kuroshio crossing could not be filled because it was due to an interruption of the acquisition PC.

The PC clock is used for time-stamping the ADCP profiles. It can be checked by comparing profile times with GPS fix times, which is routinely done as part of the scanning. The clock offset was found to be zero, and the clock drift was one plus 4.162exp(-8), corresponding to 4 seconds in 3.17 years. The data were, therefore, loaded into the newly created P10 database without time correction (program *loadping)*.

4.2 Editing

The general concepts behind the profile editing steps are described in Appendix A, section 4. However, this data set was one of the first processed with the new set of editing programs that was not yet in place when the document in Appendix A was written. The major changes include a new set of matlab tools that make use of new matlab features available under version 4. As part of that, the tasks of the program *flag* have been included in the matlab routines. An extensive description of the individual steps can be found in the document *process.doc* included in the CODAS example database.

In summary, there are three steps. First, threshold values for a set of database variables are calculated from general statistics (program *profstat*). Next, the complete database is examined in matlab using stagger plots of a suite of variables that may include the three velocity components, amplitude (AGC), percent good, error velocity, and position. The profiles or bins that exceeded the specified thresholds are automatically marked, with differently colored symbols indicating which criterion was exceeded. Profiles that require editing are selected based on these plots. Editing may include specifying the first or last bin for which the velocity data are considered valid (e.g., in cases of inadequate surface blanking or bottom interference, respectively), marking individual vertical bins by setting the corresponding bits in a quality array (e.g., when a few bins show glitches due to CTD wire interference), or in extreme cases marking a complete profile as bad (e.g., for very shallow bottoms in port). The final product of the matlab examination is two ascii lists that identify the "bad" profiles or bin ranges, respectively. They are used as input to a set of programs that then actually implement the editing changes in the database. Optionally, profiles for which bottom interference has been found may be shortened by an additional 15% (program *last_85*).

Criterion	Threshold calculated	Threshold used
Amplitude (AGC)	N/A	10 counts
error velocity	N/A	70
2nd difference of u,v	88.5	90
2nd difference of w	37.2	60
w variance	531 mm^2/s^2	1200 mm^2/s^2

Table 1: Editing criteria. The central column shows the calculated thresholds; the right column shows the thresholds that were eventually used. Units are in mm/s unless indicated otherwise.

For the P10 cruise, the specific threshold variables and their values used are listed in Table 1. Standard values were used for the first two variables. The others were calculated as follows:

- Second difference of horizontal velocities, *d2uv*: mean and standard deviation were calculated from time series of the vertical second difference of *u* and *v* for each vertical bin. The standard deviations for *u* and *v* were vertically averaged over bins 5 through 20, and the two were added. Here and in the following, the time series were taken from the whole database excluding the times for which the ensemble length was set to one minute.
- Second difference for vertical velocity, *d2w*: as for *d2uv*, but in addition the vertical average was multiplied by 4.
- Variance of vertical velocity, *w_var*: standard deviations were calculated from time series of *w* at each depth bin, and averaged over bins 5 through 20. The result was multiplied by three, and then squared to convert to variance.

The calculated threshold values proved to flag too many good profiles, and were, therefore, increased (Table 1, third column).

Aside from several real bottom interference cases throughout the cruise, the usual cases of falsely flagged subsurface amplitude maxima due to scattering layers were found but were easily sorted out (Fig. 2.1, top). CTD wire interference, identified by large values of error velocity and sometimes *d2uv*, occurred quite frequently, and the affected bins were edited out (Fig. 2.1, bottom). There were several short periods of 1-minute ensembles that were extensively flagged by the error velocity criterion. They were in general more noisy than the 5-minute profiles, though not excessively so. Since their noisiness was due to the shorter ensemble length and not necessarily due to glitches, these profiles were not edited with the same rigor.

After the editing changes were implemented in the database (programs *badbin, dbupdate, botmpas3*), the profiles were again checked with the matlab plotting routines, and it was decided that the 15% shortening of profiles with bottom interference (program *last_85*) was not required.

4.3 Temperature and Salinity Correction

For non-obvious reasons, the constant of proportionality between Doppler shift and water speed involves the speed of sound at the transducer only. It is calculated by the DAS based on the temperature measured by a thermistor embedded in the transducer head, and based on the constant salinity specified in the DAS configuration file (start.cnf). Sound speed depends most strongly on temperature, changing by 0.3% per °C at 0°C, and 0.13% per °C at 30°C; its salinity dependence is about 0.1% change per psu (Firing, 1991).

Transducer temperature (Fig. 2.2, top) was checked against surface temperature as recorded by the underway surface measurements of the *Thompson.* Aside from a period of a day or so around October 5th when the underway measurements appeared anomalously large, ADCP and underway temperatures were very similar. Their mean difference was 0.18°C (ADCP > intake), with a standard deviation of 0.053°. Surface salinity was obtained from the underway system as well. It was visually checked against surface bottle samples (Fig. 2.2, bottom) and found to be acceptable. A temperature and salinity correction was implemented in the database that adjusted the transducer temperature by a constant -0.18°C, and by exchanging the constant salinity with the time series of underway salinity (program *fix_temp*).

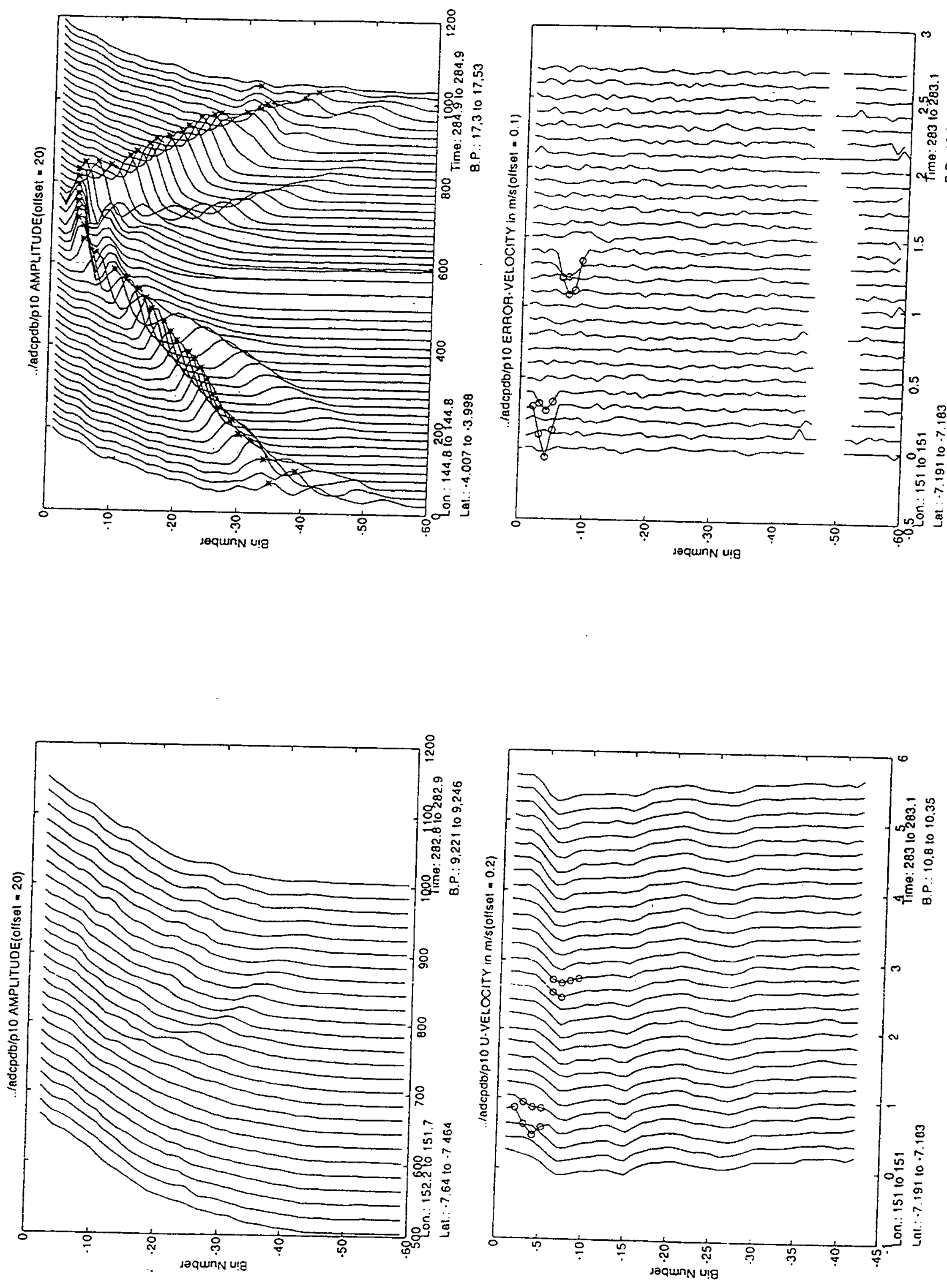


Figure 2.1: Editing examples. To left: scattering layer falsely identified as bottom; top right: true bottom. Bottom: CTD interference as seen by the error velocity (right) and the zonal velocity component (left).

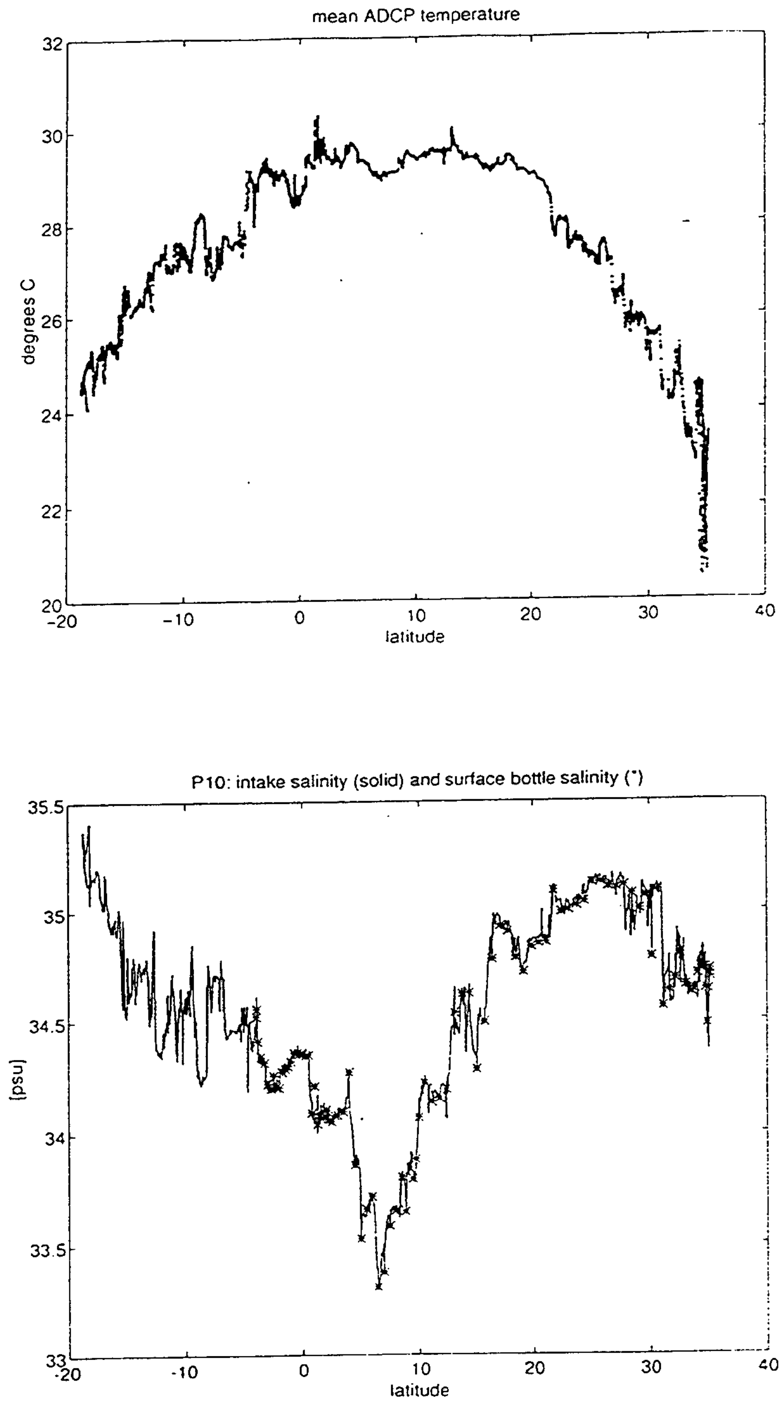


Figure 2.2: Top: Temperature at the ADCP transducer, averaged over an ensemble. Bottom: salinity from the *Thompson*'s underway data acquisition system (solid line), and surface bottle samples (stars).

4.4 Ashtech Heading Correction

4.4.1 Background

Gyro compasses on ships are known to have errors that can reach two to three degrees or more (Bowditch 1977). One portion of the errors can be described as

$$\Delta = 0.0635\ S\ \cos(\theta)\ \sec(L)$$

with ship speed S in knots, and heading θ and latitude L in degrees (Griffith, 1994; Bowditch, 1977). The gyro compass has dials with which speed and latitude can be adjusted by the ship's crew to reduce such errors. During this cruise, the latitude adjustment setting was made in regular intervals, but the speed setting was left at a constant value of ten knots. In recent years, heading devices based on GPS differential phase measurements between a reference antenna and three other antennae have become available (King and Cooper, 1993). The R/V *Thompson* was outfitted in May 1993 by Eric Firing's group with a system made by Ashtech. Prior to P10, the system was in use during P17N (Chereskin) and two legs of P14 (Hacker, Firing).

The Ashtech correction ultimately produces a list (file) specifying a rotation angle for each ADCP profile based on the difference *dh* between Ashtech and gyro heading. In the following, the general Ashtech data processing is described first, followed by a description of the model that was used to fill the substantial gaps in Ashtech data coverage, and how the two datasets were merged.

4.4.2 Ashtech Processing

The programs and procedures described in the following were developed by Eric Firing's group from the University of Hawaii. They represent an early version of the Ashtech processing and have since been modified and simplified substantially.

The one-second Ashtech and gyro heading data were reduced to hourly files of one-minute averages during the cruise (section 2.3). As a first step, these data were loaded into matlab and plotted for inspection, excluding averages with fewer than 40 points or mean mrms of more than 0.004 (programs *loadem.m* and *plotem.m*). A typical time series of the differences between Ashtech and gyro headings (*dh*) include Schuler oscillations around the times of arrival and departure from CTD stations (hours 4, 7, 12, and 15.5), changes associated with re-orientation of the ship while on station (hour 10), and periods of relatively constant *dh* (hours 18 through 22) (Fig. 3a). Time series of pitch and roll (Fig.3b) were not used in the following, but are included here for curiosity. A gap in Ashtech coverage around 1.5 hours is preceded by a sharp increase in brms and a smaller increase in mrms, as well as a drop in the number of satellites available (note that the bottom two panels of Figure 3b are plotted with less stringent editing). Standard deviations from the 1-minute averages for *dh*, gyro heading, pitch, and roll are given in Figure 3c.

Next the one-minute *dh* averages needed to be synchronized with the ADCP profile times. To that end, the hourly files were combined into one-time series and edited, excluding points with mrms > 0.004 m, brms > 0.03 m, and 1-minute averages with fewer than 40 points (program *plot_dh.m*). Contiguous stretches of *dh* were identified, and a five-point median filter was applied, excluding points 0.3 degrees beyond the median. While the threshold of 0.3 sounds rather harsh, relatively few points were actually eliminated by it (Fig. 4). With the input of ADCP profile times (generated here with a time series of gyro headings as stored in the ADCP database, using *lst_hdg*), the 1-minute *dh* averages were then averaged over the ADCP ensemble times (program *step2.m*).

4.4.3 Ashtech Model

During the cruise, Terry Joyce tried to quantify the gyro compass errors. To that end, four surveys were conducted where the ship steamed first on rectangular (or later on octagonal) course patterns with typically six 1-minute ADCP ensembles per side (see Appendix A for details). Plotting the measured difference of Ashtech and gyro heading (*dh)* as a function of heading, he found a distinct pattern that could be fitted by a combination of first and second harmonics of the form

$$dh = a1 + a2*\cos(\Theta) + a3*\sin(\Theta) + a4*\cos(2\Theta) + a5*\sin(2\Theta) \qquad (1)$$

(Fig. 5). The surveys were conducted with constant, relatively low speed, while the speed dial on the gyro compass was left at the high cruising speed setting.A model using data from the whole cruise (Fig. 6) was calculated by binning *dh* over 30 degrees of heading, and fitting the same type of function. This produced a correction that was smaller for most headings while being larger for headings between 250 and 360 degrees (Fig. 7; Table 2). The second model was used subsequently to fill the larger gaps in Ashtech coverage.

coefficients:	a1	a2	a3	a4	a5
surveys 1,2,4	1.154	-0.8291	0.4559	-0.1018	-0.1323
all data	1.041	-0.5087	0.3612	-0.2017	-0.1666

Table 2: Model coefficients using Ashtech minus gyro data from the surveys alone (top), and from using data from the whole cruise (bottom).

A time series of modeled *dh* was produced by applying the time series of heading averaged over each ADCP ensemble to (1). A general comparison of the model to the original Ashtech minus gyro data shows a mean difference between *dh* and model of approximately zero (Fig. 8). Examples from individual time periods throughout the cruise (Figs. 9a-c) show, not surprisingly, that the model does best when the ship's course and speed are relatively constant (295.6 to 296.2 on station, or 294.5, 295.55 for underway), while it fails to reproduce the short-term Schuler oscillations (e.g., 294.55). Occasionally, Schuler-type oscillations appear to last longer than the usual couple of cycles (e.g., following 294.75), though these may be a series of individual events triggered by small velocity changes.

4.4.4 Merging Ashtech and Model

Initially all Ashtech data gaps were filled using the model. It became clear, however, that this was not a good approach for smaller gaps of a few profiles that might occur in the middle of a Schuler oscillation. Here *dh* would vary rapidly while heading itself and, therefore, the model did not. Since the small gaps were usually short compared to the Schuler period, linear interpolation appeared to be a reasonable tool. The choice between using interpolation or the model, which was done through visual inspection by Joyce and Bahr, was generally straightforward. The few more "interesting" cases occurred towards the end of the cruise (e.g., day 312, Fig. 10). The complete record of the final heading correction is shown in Appendix C.

Before rotating the full database, only the reference files used for bottom and water track calibrations were rotated. When comparing the calibration results with those calculated prior to the Ashtech rotation, calibration residuals were found not to have decreased as expected. Eventually (and with Eric Firing's help) the problem was traced to an incorrect sign. The Ashtech correction as shown in Appendix C was, therefore, multiplied by -1 before it was used to rotate the database (program *rotate)*.

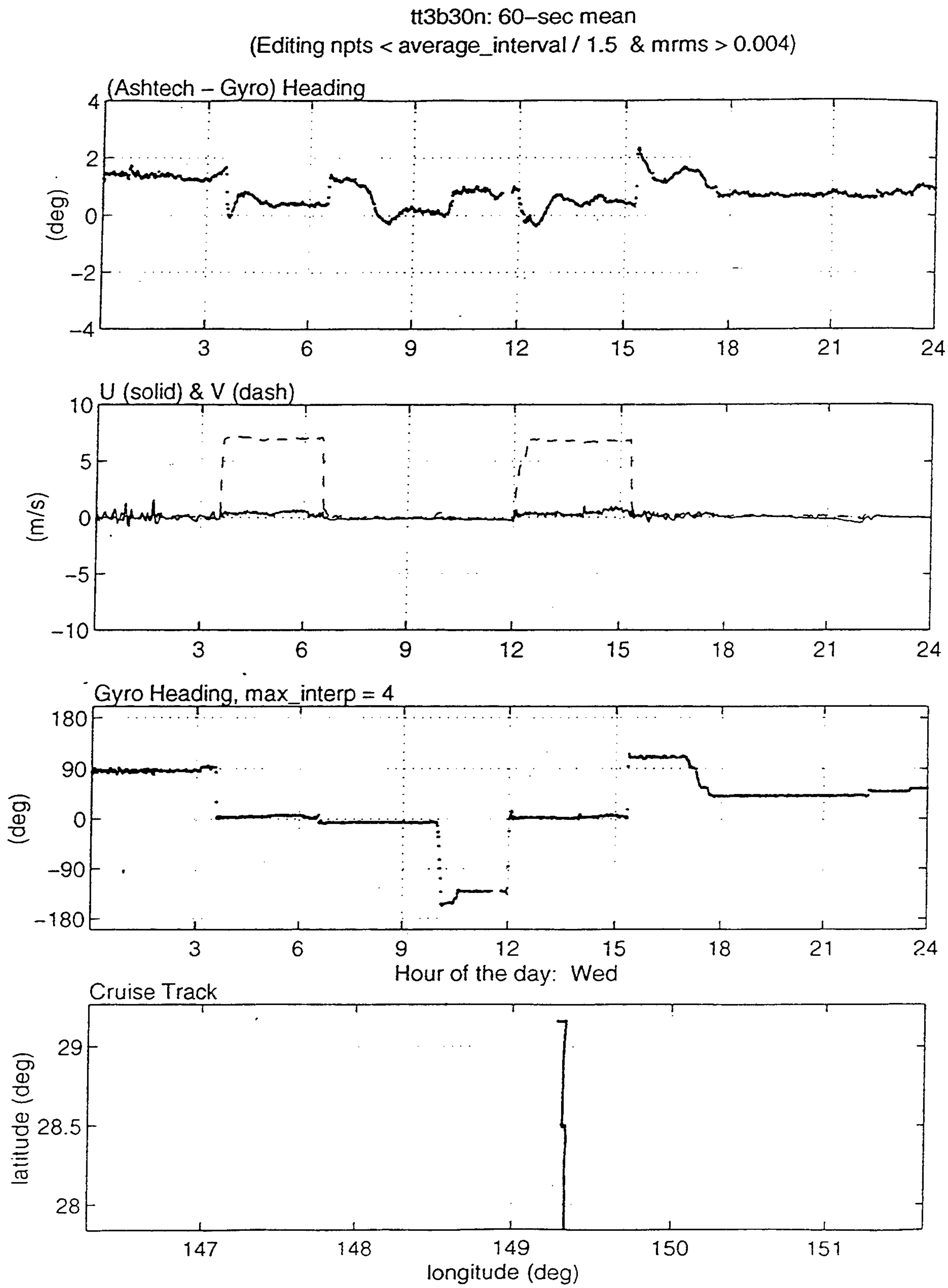


Figure 3a: One-minute averages of 1-second Ashtech data: Ashtech minus gyro heading; ship's speed; gyro heading; position.

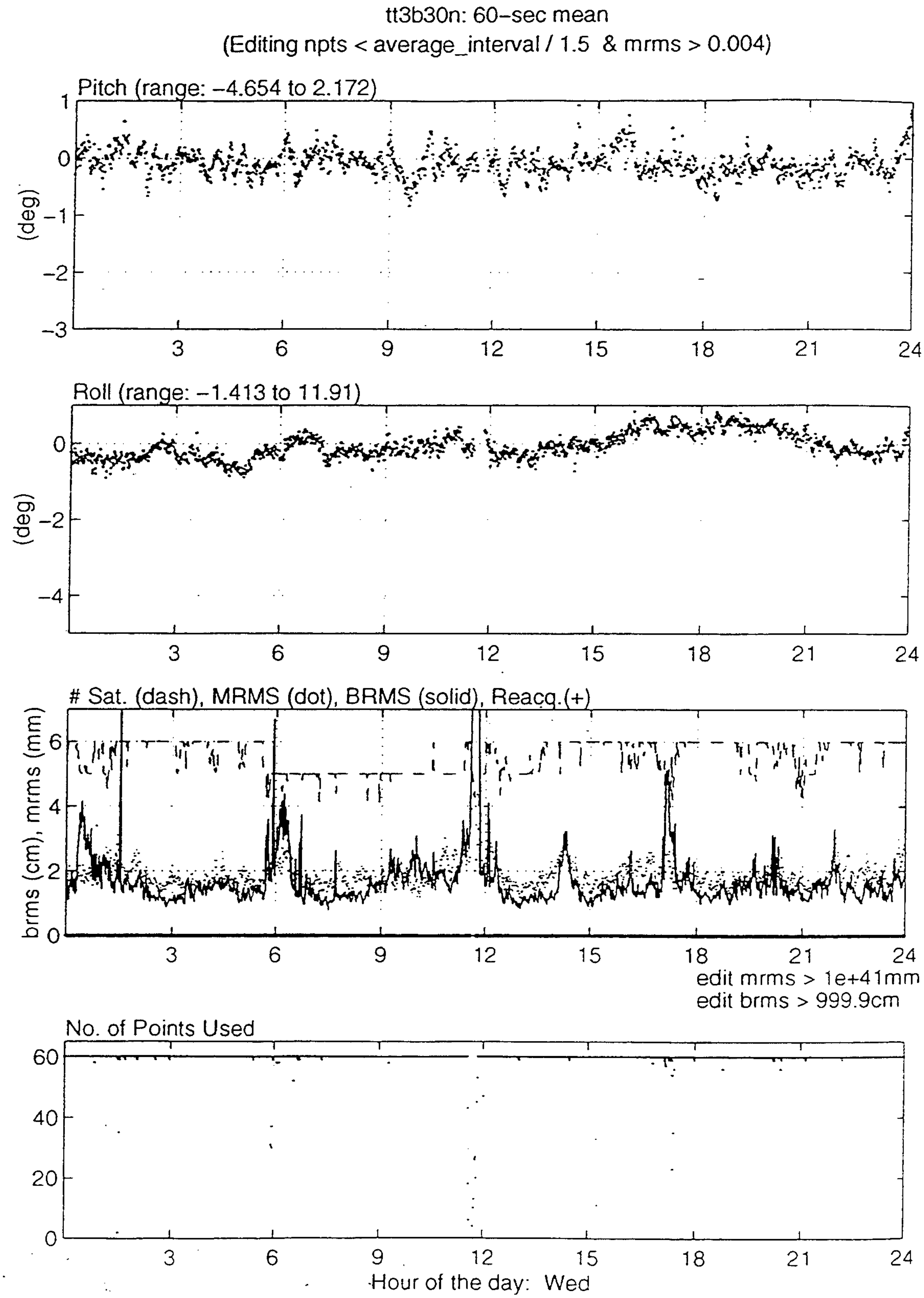


Figure 3b: One-minute averages of 1-second Ashtech data: pitch; roll; number of satellites, mrms, brms; number of samples in 1-minute averages.

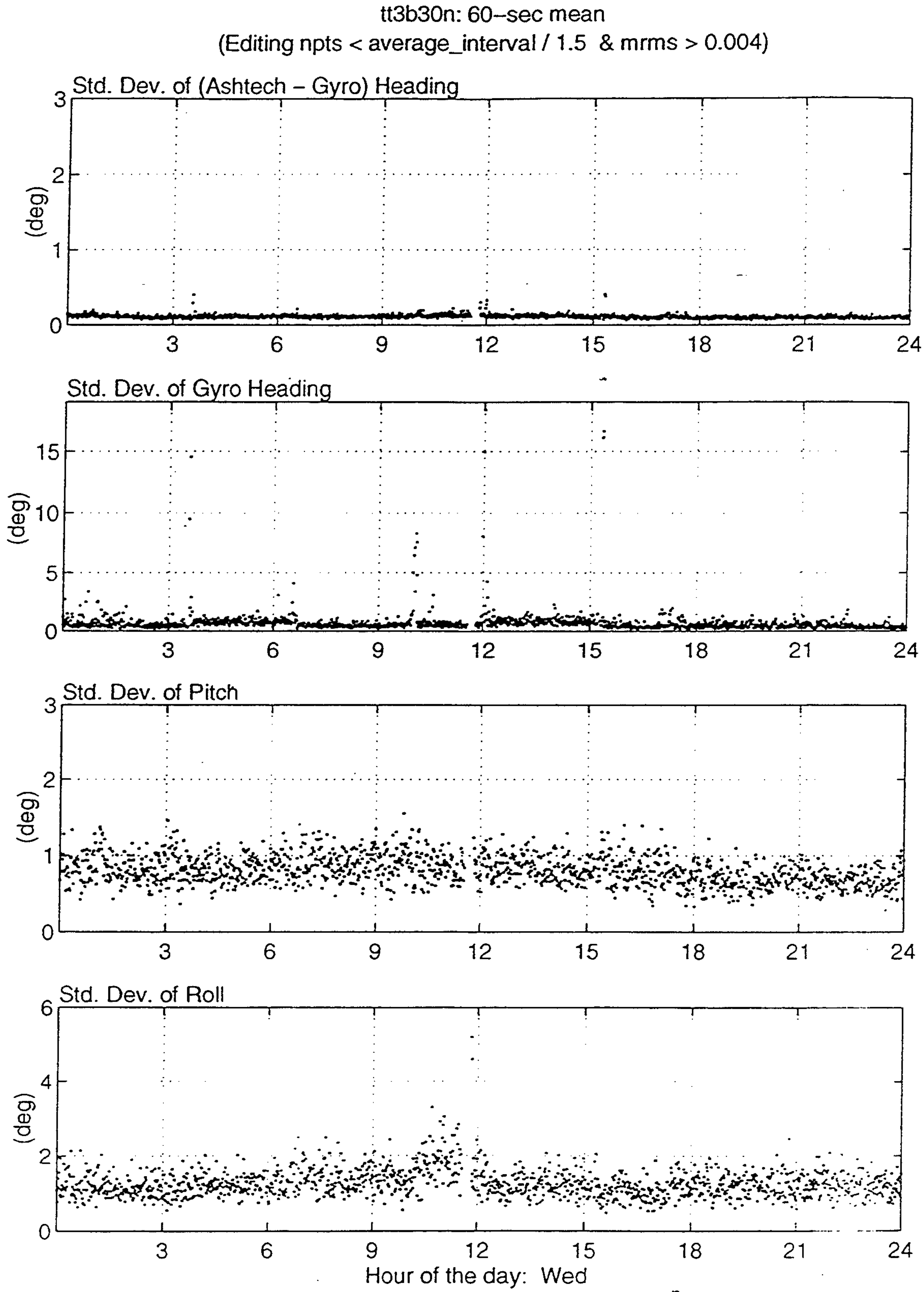


Figure 3c: One-minute averages of 1-second Ashtech data: standard deviation of: Ashtech minus gyro, gyro heading, pitch, roll.

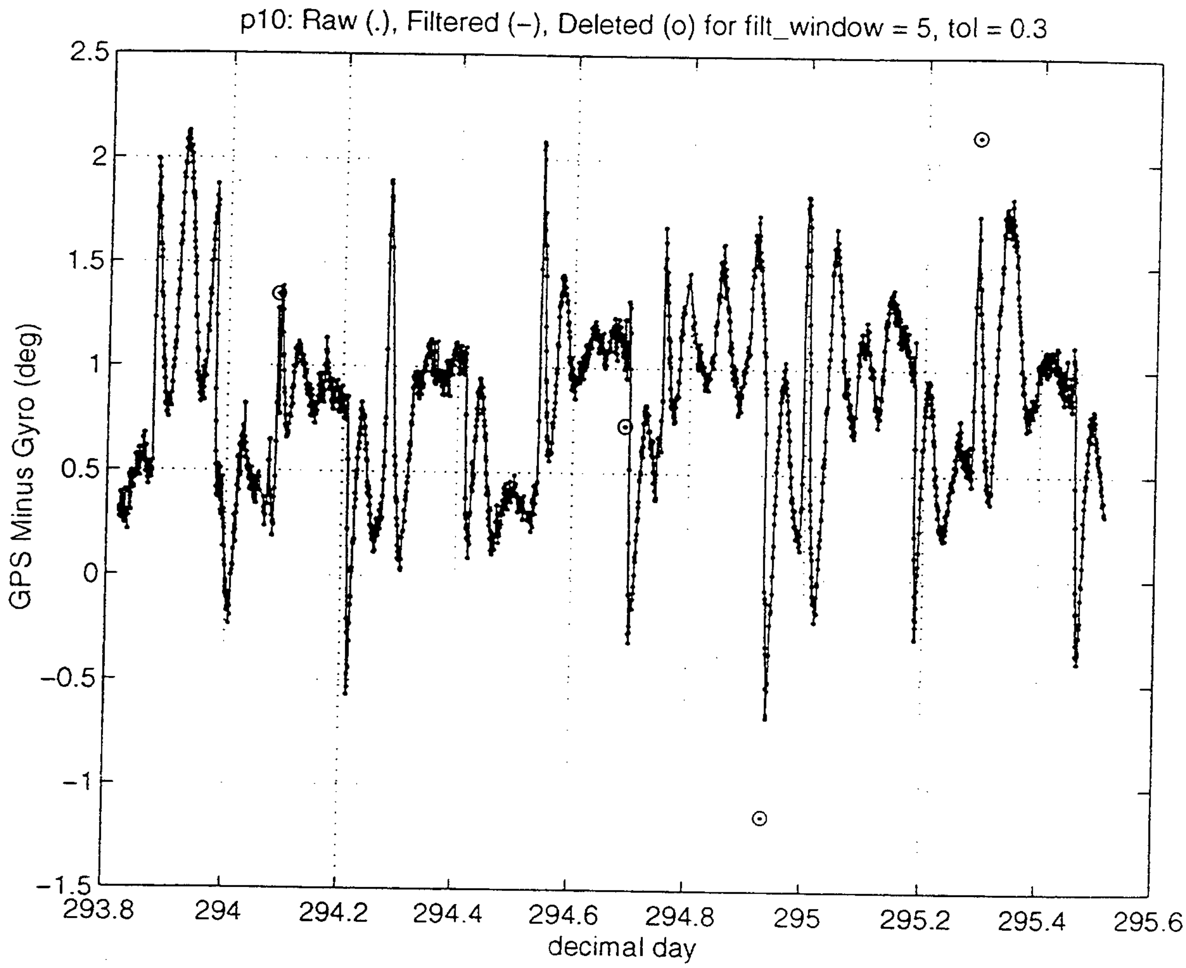


Figure 4: Raw (dots) and median filtered (solid lines) 1-minute averages, and outliers excluded by the filter (circles).

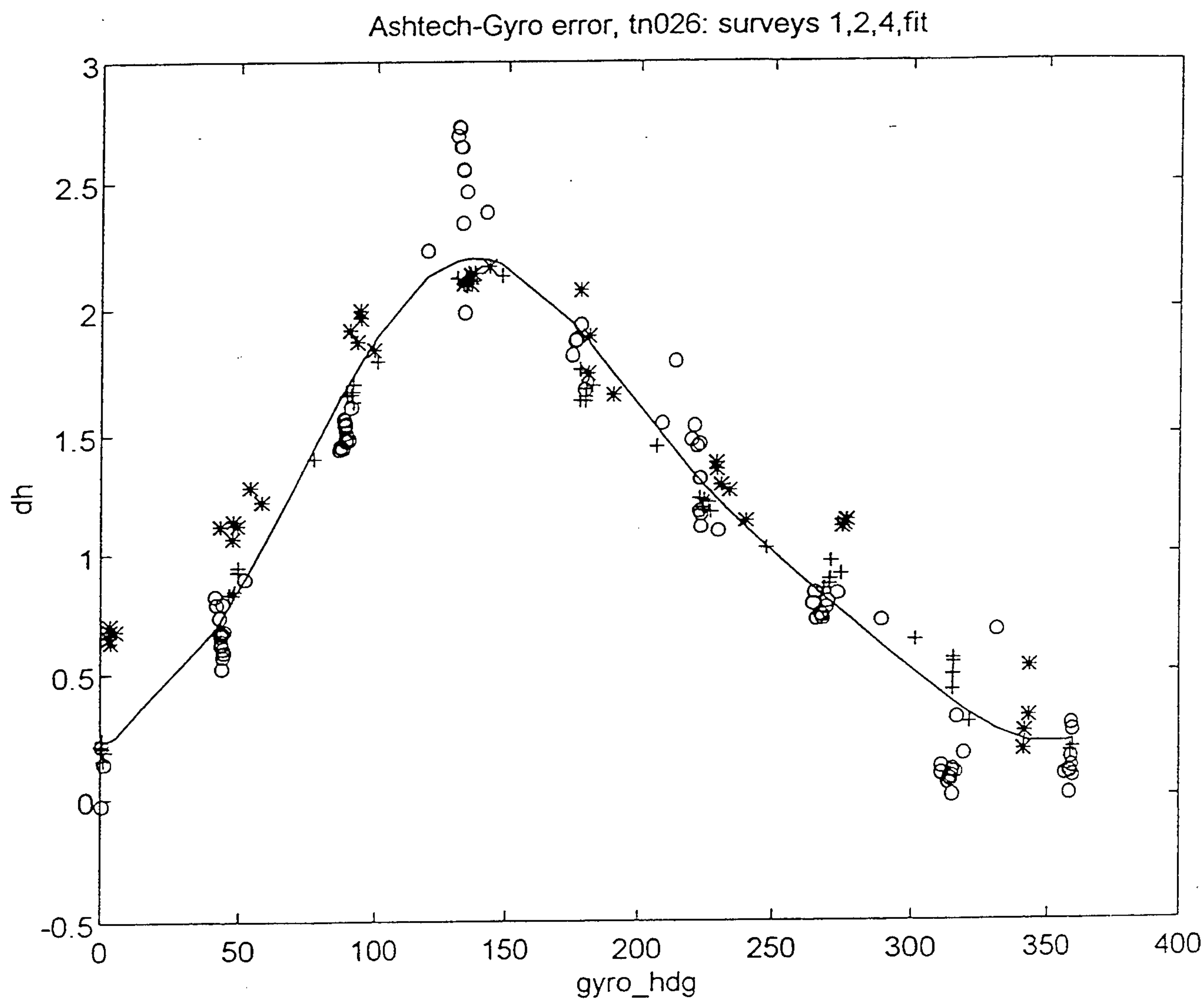


Figure 5: Ashtech-gyro heading during survey 1 (circles); survey 2 (+); and survey 4 (stars).

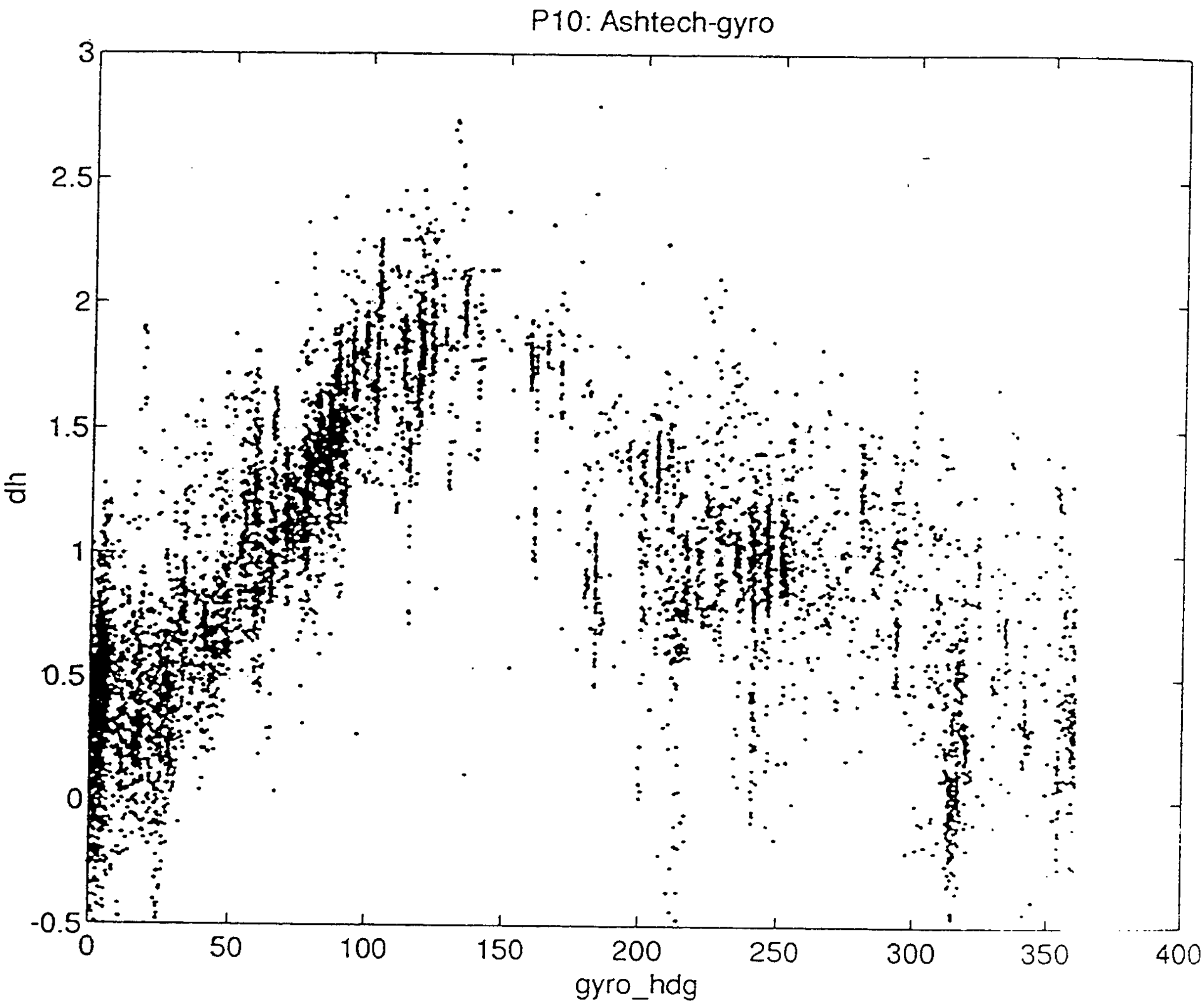


Figure 6: Ashtech-gyro heading, using mean heading from each ADCP profile.

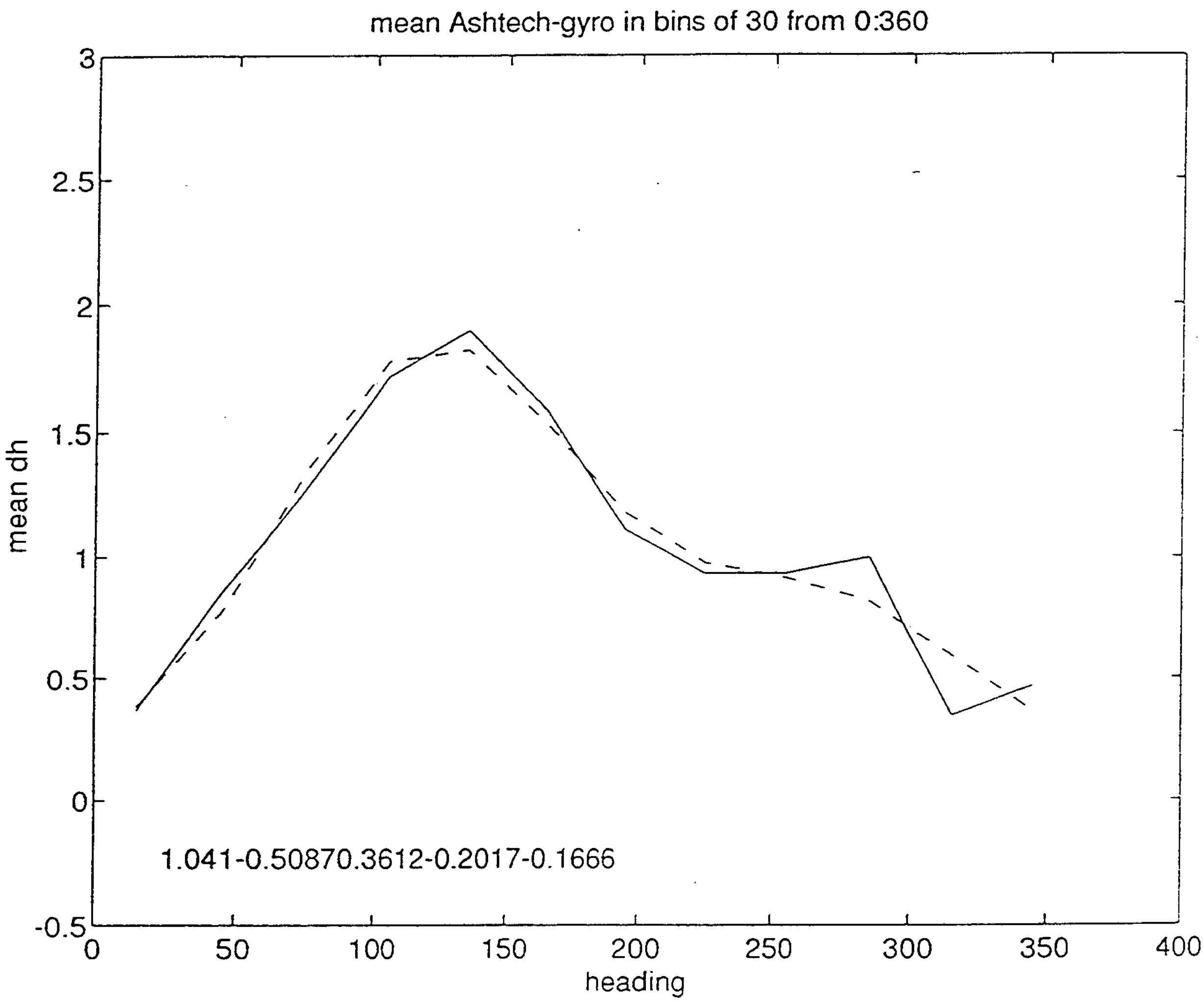


Figure 7: Mean Ashtech-gyro heading over bins of 30 degrees (solid), and fitted model (dashed). The string of numbers lists the model coefficients a1 through a5.

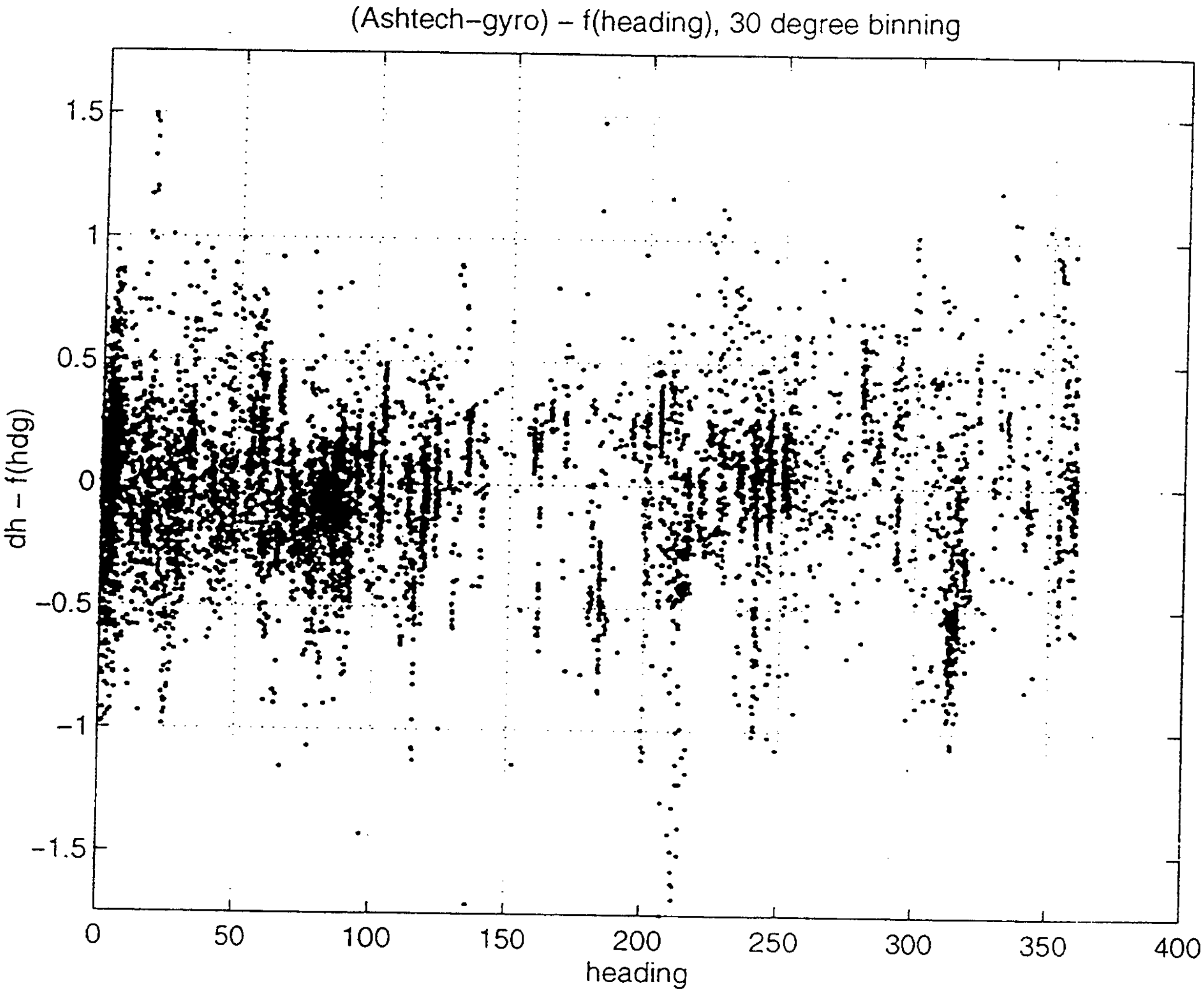


Figure 8: Ashtech-gyro minus model, using mean heading from each ADCP profile.

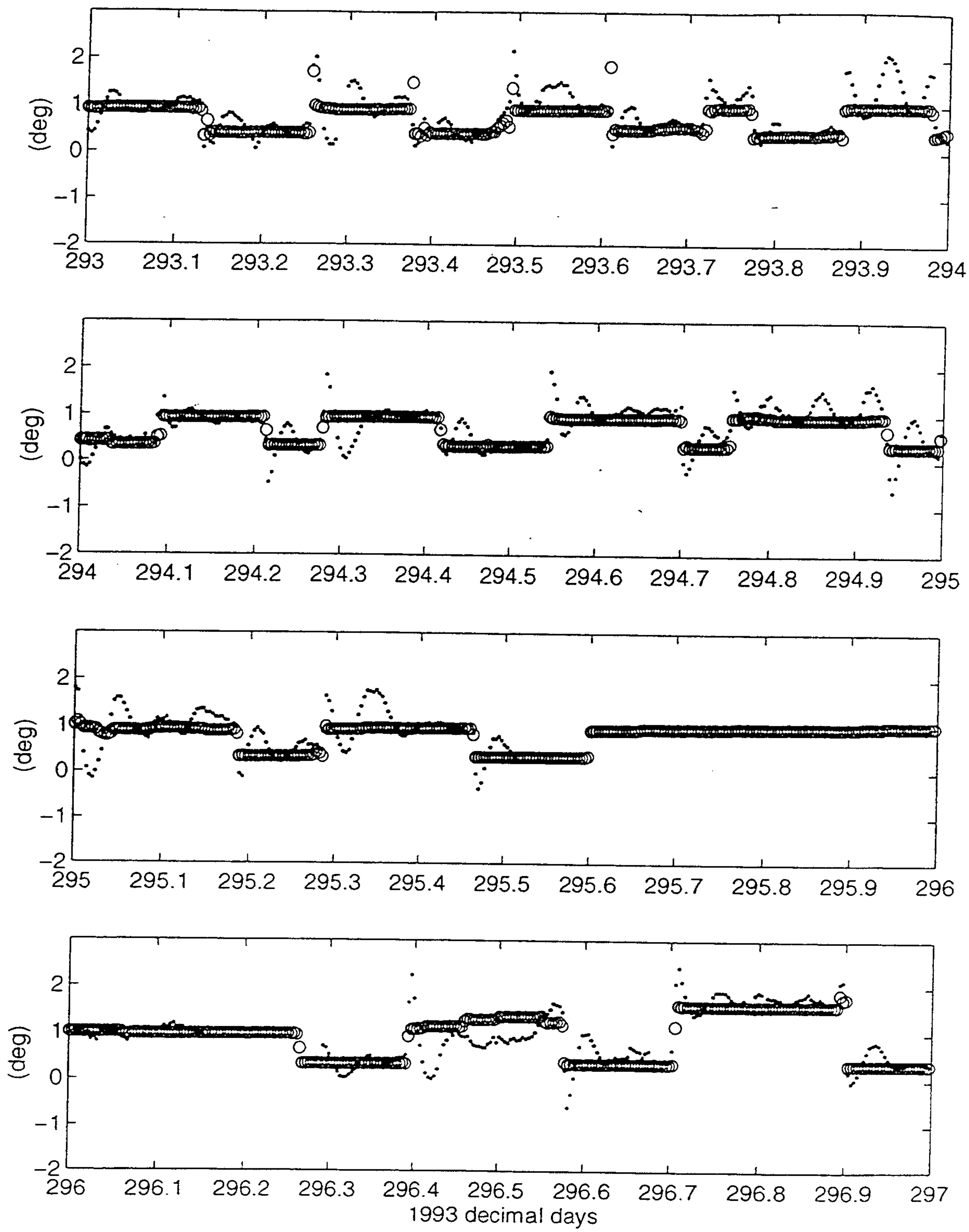


Figure 9a: Time series of Ashtech-gyro (dots) and model (circles).

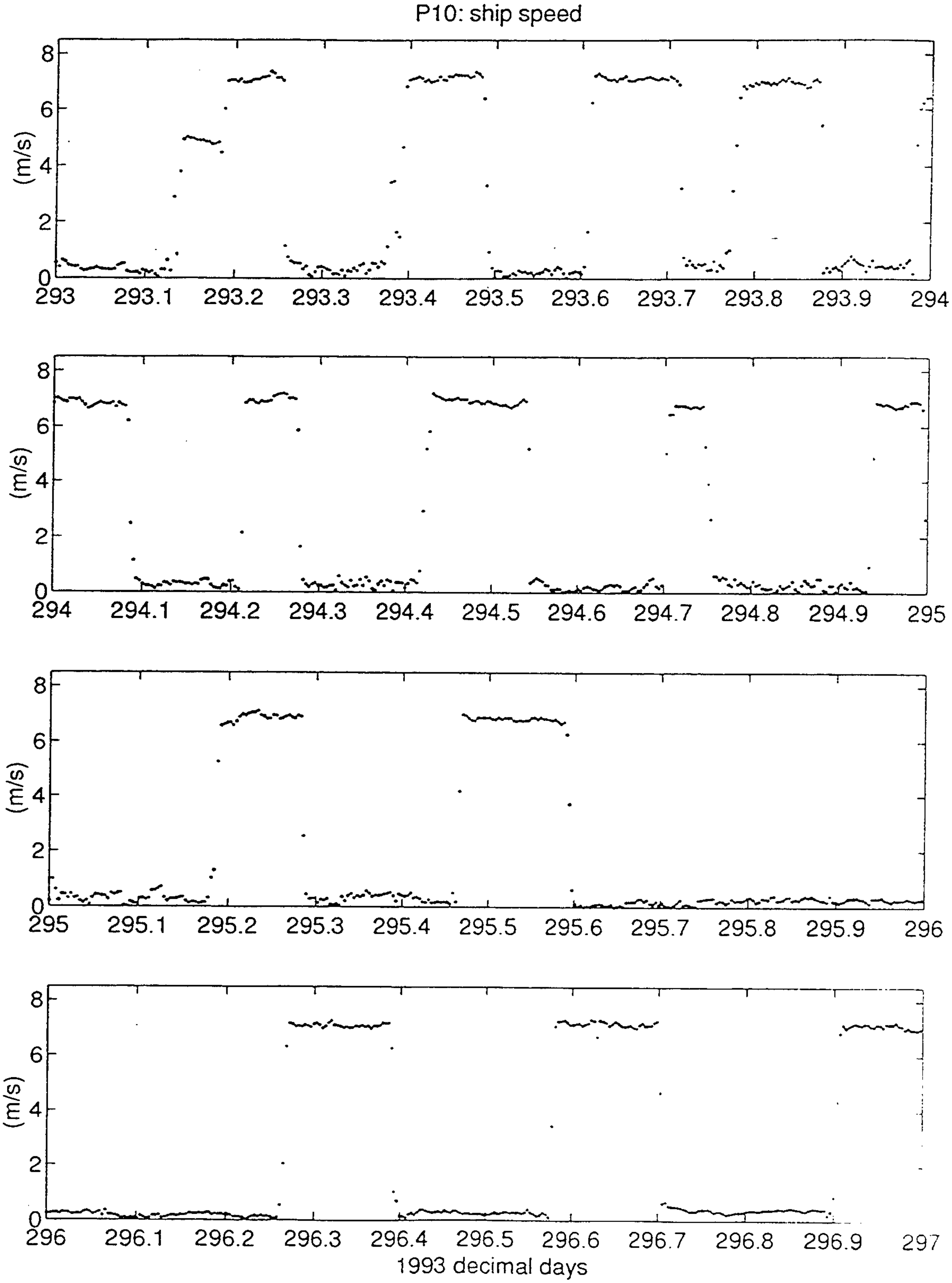


Figure 9b: Time series of ship's speed, same time period as Fig. 9a.

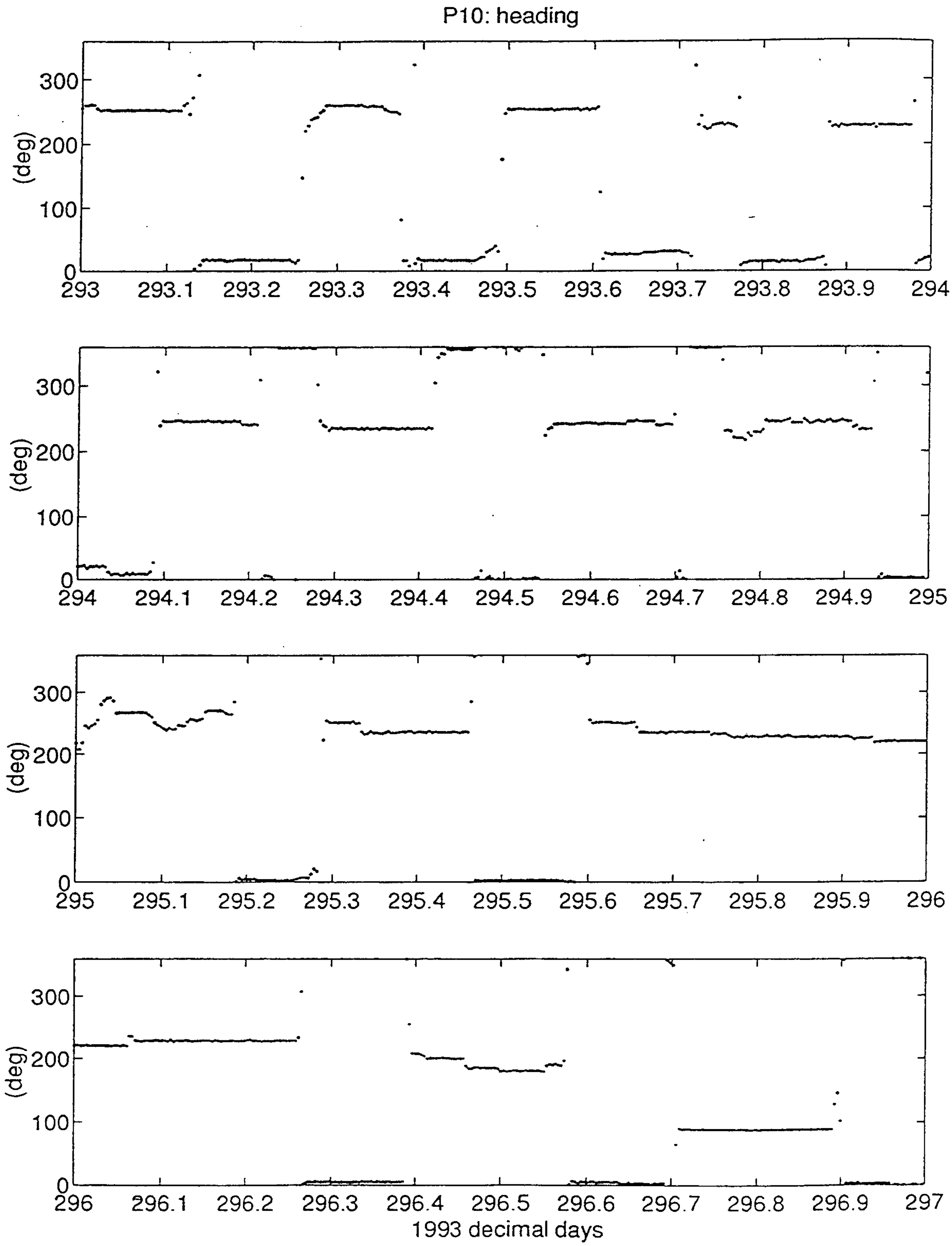


Figure 9c: Time series of ship's heading, same time period as Fig. 9a.

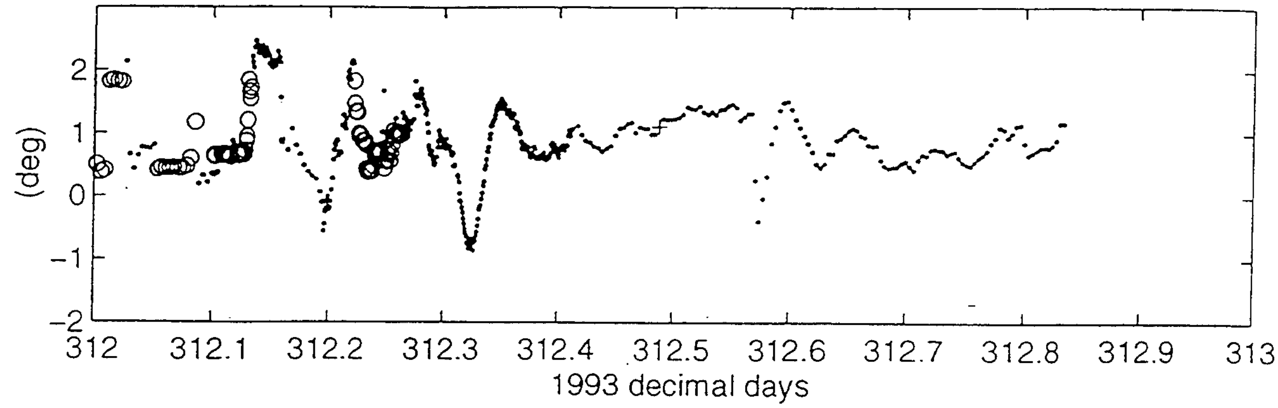


Figure 10: Time series of gyro correction based on Ashtech data (dots), linear interpolation (plus sign, day 312.5), and model (circles).

4.5 Calibration

Basic methods for ADCP calibrations are explained in Joyce (1989) and Pollard and Read (1989). For the P10 dataset, we have used two approaches: bottom tracking and water tracking. These two methods should give identical results for the transducer orientation, but can give scale factor differences of the order of 0.5% (Firing et al., 1995). Bottom tracking, while often yielding less noisy results, should, therefore, be considered a useful supplement to water tracking. In the following, the two methods are discussed individually including how they were affected by the Ashtech correction, followed by a summary of the final calibration used.

4.5.1 Bottom Tracking

In the bottom track method, the ship's displacement over the ground as measured by the ADCP is compared with the ship's displacement measured by navigation fixes. A scale factor A and a phase φ are calculated that, when multiplying the uncorrected bottom track velocity vector $U_u = u + iv$ in the form

$$U_c = A\, e^{I(\varphi\pi/180)}\, U_u \quad (2),$$

minimize the difference between the integrated corrected bottom track velocity U_c and the ship's track as given by the navigation (GPS) fixes. φ is the counterclockwise angle in degrees between the gyro compass forward axis and the transducer forward axis. Obviously the water depth must be such that the ADCP can reach the bottom. Excluding extremely shallow and deep depths where results might be questionable, the bottom tracking range for a 150 kHz transducer reaches from about 40 to 450 meters. Steeply sloping bottoms, such as around mid-oceanic islands, can introduce problems. Calibration runs do not have to be straight, though a long horizontal extent is advantageous. Depending on the quality of GPS fixes, bottom tracking as short as one hour may provide good results, with longer runs preferred. The length of a useful segment is given by the time during which bottom tracking was contiguous.

Excluding a very short piece from the ship's departure from Suva, four contiguous bottom tracking segments were available for P10: two segments taken about one week into the cruise, and two taken on the second-to-last day. As a matter of choice and following the suggested CODAS processing, we decided to calculate all rotation angles prior to actually rotating the database. Thus, the bottom track data were extracted from the ADCP database prior to the Ashtech correction. Instead, the extracted bottom track data themselves were rotated using the Ashtech correction angles (program *navrot*). This effectively moved the transducer into a new reference frame relative to the Ashtech antenna array rather than relative to the gyro compass. The calculated transducer offset may, therefore, contain a constant offset between the gyro and the antenna array.

The first two bottom track segments occurred before the Ashtech came on line, and were, therefore, rotated using only the model (Table 3). Segments three and four were corrected using a mix of model and Ashtech headings. They were analyzed again over the shorter periods with a complete Ashtech record. Aside from segment three (day 312.11), variations of the phase angles φ were within 0.5 degrees, and amplitude variations were within 0.019. Fit residuals were generally of the order of 60 meters (Fig. 11, top). The third segment was anomalous with large fit residuals, and should probably be disregarded. The fourth segment was collected under the most preferential circumstances and should be weighted the most.

segment #, start time	# of ensembles, ensemble length	amplitude	phase (degrees)	heading correction
1, 284.556308	21, 5 min	0.9925 (0.9920)	2.169 (1.180)	model
2, 284.865752	48, 1 min	0.9930 (0.9975)	2.712 (1.800)	model
3, 312.110567	71, 1 min	0.9900 (0.9905)	2.083 (-0.054)	mix
3, 312.133	38, 1 min	0.9931 (0.9927)	2.115 (-0.143)	Ashtech
4, 312.196563	163, 1 min	0.9974 (1.0002)	2.502 (1.528)	mix
4, 312.264	65, 1 min	0.9946 (0.9945)	2.463 (1.355)	Ashtech

Table 3: Bottom track calibration results, with heading correction. Numbers in parentheses come from unrotated bottom track data. Time is in decimal days (= Julian day minus one).

For comparison, the same bottom track calculations were performed using the unrotated bottom track velocities (Table 3, in parentheses). Amplitude variations were actually smaller (0.011), while variations in φ were larger (0.7). Fit residuals (e.g., Fig.11, bottom) were about 10 to 20 percent larger.

4.5.2 Water Tracking

In the water track or acceleration method, ship's accelerations relative to the water measured by the ADCP are compared to accelerations over the ground measured by GPS. Any substantial accelerations of the ship during good GPS coverage can be used. On a normal hydrographic cruise, most calibration points are usually obtained from station arrival and departure. Sharp turns in the cruise track provide calibration points as well.

To derive a time series of water track calibrations, first the ship's velocities relative to the water were computed from each ADCP ensemble by vertically averaging over a suitable layer. The idea is to choose a layer that shows smooth variations in velocity over time. A standard range is bins 5 to 20, which was used here as well (program *adcpsect*, nav option). Like the bottom track data earlier, the reference layer velocities were again rotated using the Ashtech heading correction (program *rotnav*). Next, the reference layer record was searched for accelerations defined by speed changes of more than 3 m/s, or heading changes for more than 60 degrees while the ship's speed was at least 2 m/s (program *timslip*). For each acceleration, the ship's velocity over the bottom (calculated from the five-minute GPS fixes) and relative to the reference layer was averaged over a set of profiles. The set configuration can be varied with the aim of reducing the scatter over a group of calibration points. After some trials, we decided to average over three ensembles, each group separated by one ensemble from the velocity jump (*timslip* options: 9 ensembles, 1:3, 6:8). Finally, a phase φ and a scale factor A were calculated by adjusting the reference layer velocity difference $\Delta U_R = U_{R,after} - U_{R,before}$ (with U=u+iv as before) to the absolute velocity difference $\Delta U_{GPS} = U_{GPS,after} - U_{GPS,before}$ in the form

$$\Delta U_{GPS} = A\, e^{i(\varphi\pi/180)}\, \Delta U_R$$

(before and after refer to the timing relative to the ship's velocity change). Again, φ is the counterclockwise angle between the heading forward axis and the transducer forward axis.

The initial set thus produced contained a total of 211 calibration points. After excluding time periods with large Ashtech gaps, i.e., where the applied Ashtech rotation was based only on the model, 172 points remained. In matlab, these points were further edited to exclude outliers based on thresholds for:

- amplitude (required to be within 0.04 of the median),
- phase (required to be within 3 degrees of the median),
- variance of the reference layer velocity within a set (less than 0.07).

Additional criteria based on time shifting of the GPS fixes and on the size of the velocity jump were disabled by large thresholds. Original and edited points were then plotted for examination (Fig. 12, top), and means, standard deviations, and linear trends were calculated (Table 4).

Description	# of points	mean A	mean φ	std. A	std. φ	slope A	slope φ
all points	187 of 211	0.9924	2.565	0.0118	0.654	0.0	-0.108
no Ash. gaps	155 of 172	0.9922	2.504	0.0117	0.601	0.003	0.111
all, no rotat.	191 of 211	0.994	2.192	0.0121	0.749	0.0	-0.285

Table 4: Water track calibration results. # of points: reduction due to *adcpcal* editing. Slope: linear trend over 30 days.

The water track method is based on the assumption that water velocities averaged over the reference layer remain constant before and after the acceleration. This assumption could be violated by either an actual velocity change, or by a perceived change due to, for example, a time varying gyro error. Schuler oscillations with time periods of about 83 minutes, excited most efficiently by a change in latitudinal ship's speed, are a prime candidate for the latter. To evaluate their effect, the calibration calculations were repeated for the un-rotated reference layer velocities. In general, scatter amongst the calibration points was somewhat larger (Fig. 12, bottom; Table 4). In addition, a mean change of the phase is seen over the last one to two days that was absent in the Ashtech rotated results. It occurred with a period of more rapid course and speed changes, and large Ashtech-gyro differences (Appendix C). The mean amplitude and phase differed less, however, between Ashtech corrected and uncorrected calibrations than it did for the corresponding bottom track results (Table 3).

4.5.3 Final Calibration and Rotation

Averaging φ from the last segment of bottom tracking without Ashtech gaps and from the mean water track value, again excluding times without Ashtech data, the constant offset between ADCP transducer and the Ashtech antenna array was determined to be 2.484 degrees. A constant amplitude scale factor of 0.9922 was selected based on the water track calibration alone. The complete database was rotated using the time series of final Ashtech corrections and the constant amplitude A and phase φ given above (program *rotate*, run twice: once for Ashtech corrections and once for constant A and φ).

As a check, the water track calibration calculations were repeated for the rotated database. When the large Ashtech gaps were excluded, amplitude and phase came out to 0.9997 and -0.012, respectively. Considering the complete record, amplitude and phase were calculated as 0.9999 and +0.02.

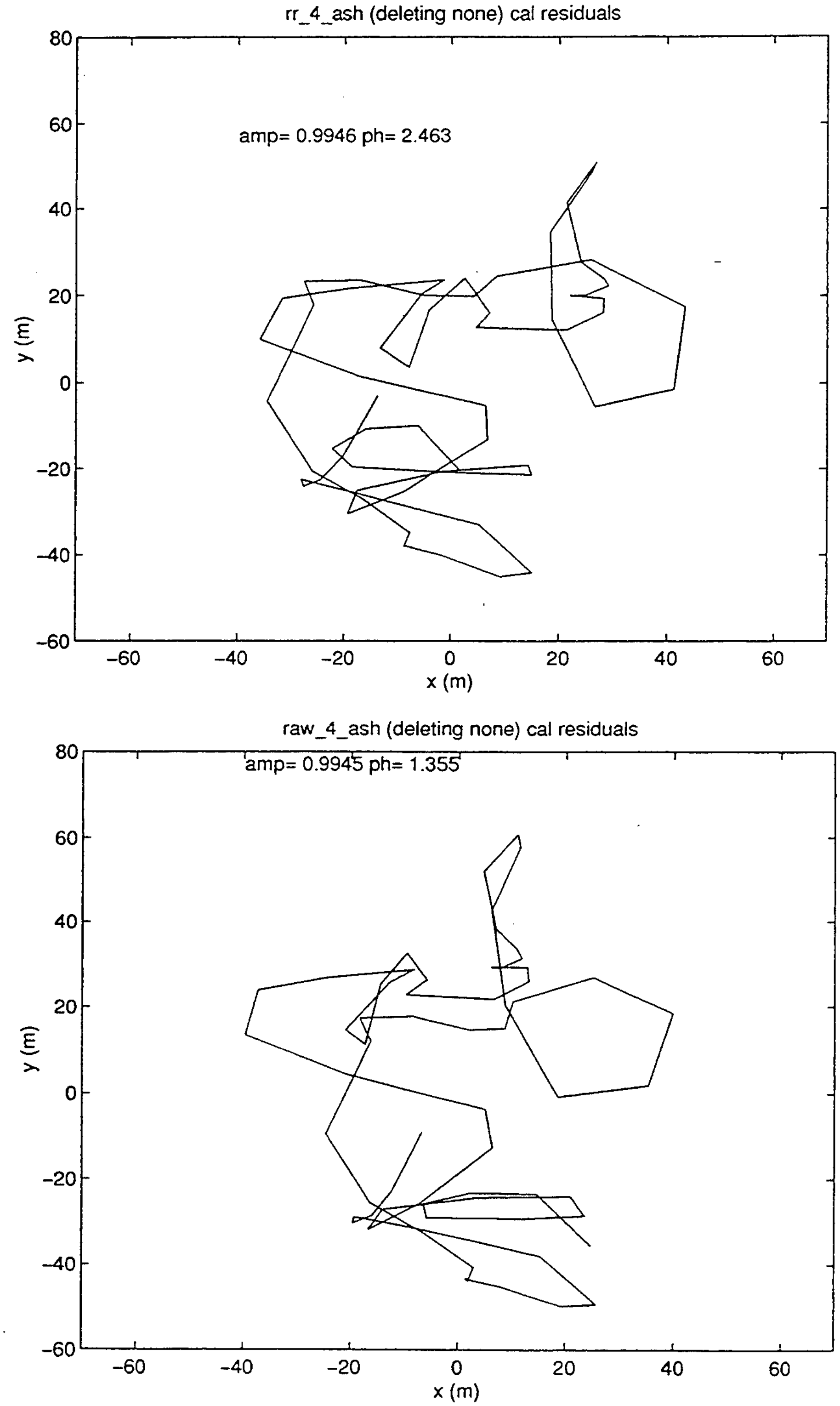


Figure 11: Bottom track residuals. Top: with gyro correction; bottom: without. After the first 15 bottom track points with ship's speed and heading of 0.3 m/s and 50°, respectively. Ship's speed and heading were fairly constant over the remaining 50 points, and values of approximately 6 m/s at 200°. There was one brief period of approximately four bottom track points where the ship's speed dropped to 1 m/s.

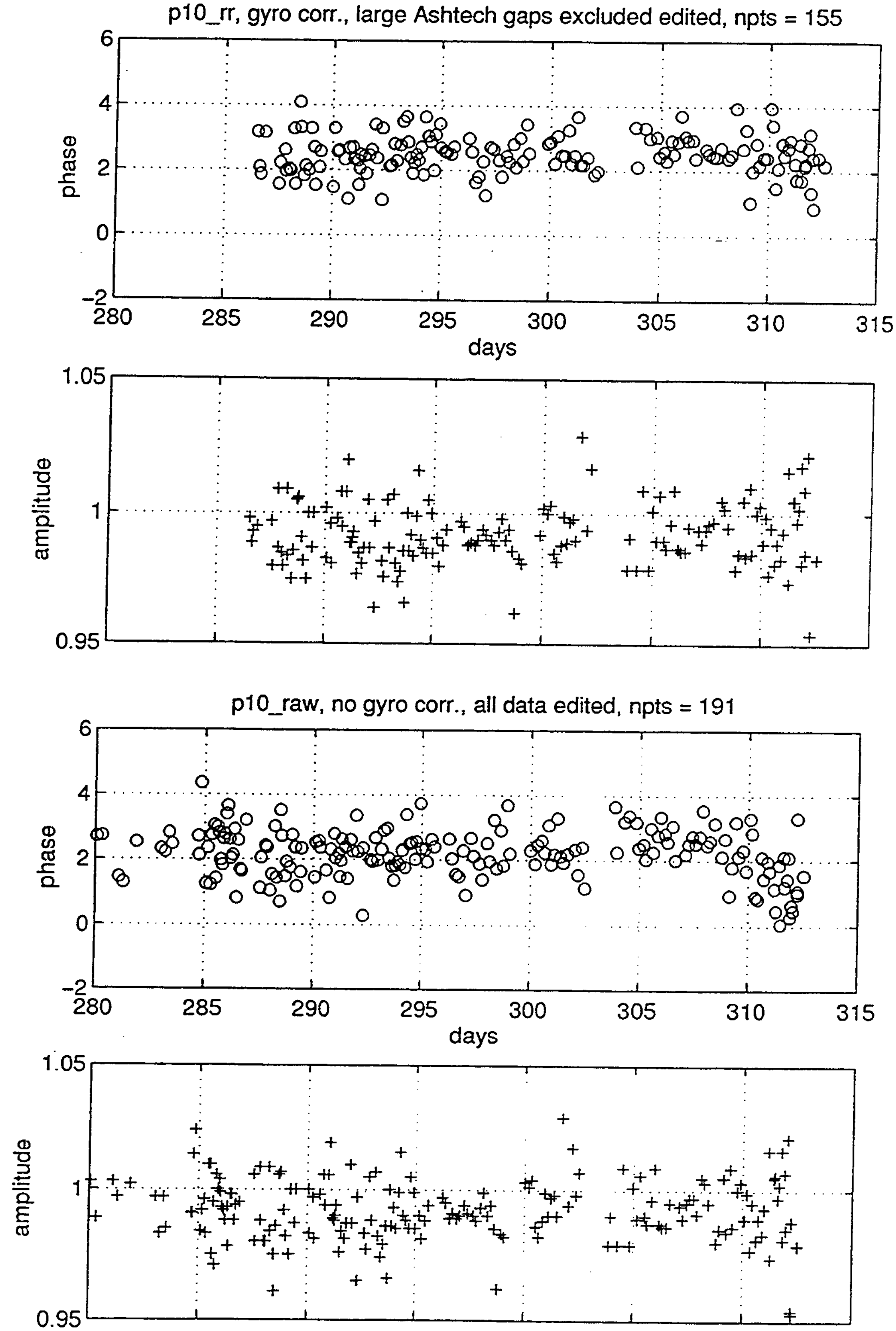


Figure 12: Water track phase φ and amplitude A. Top two panels: after applying gyro correction the first cruise days without Ashtech data were excluded. Bottom two panels: without gyro correction.

4.6 Navigation

In this section the conversion of ADCP velocity profiles relative to the ship to absolute velocity profiles is described. It involves the intermediate calculation of the absolute velocity of a reference layer (e.g., Wilson and Leetmaa, 1988) rather than calculating the absolute ship's speed directly by differencing GPS fixes. It is based on the assumption that the velocity of an oceanic layer will vary more slowly in time than the ship's velocity, and therefore short-term velocity fluctuations can be identified as GPS fix errors.

Conversely, the reference layer should be chosen such that its velocity varies as smoothly as possible along the cruise track. In general, this would be the thickest layer that contains good data, excluding the first few bins for surface effects. Some typical range is bin 5 through 20, which was chosen here as well. Thus, the relative reference layer velocity was computed for each profile as the vertical average over that bin range (program *adcpsect*).

Next, the GPS fixes were extracted from the database. The userexit program used here recorded two GPS fixes in the user buffer of each profile: the first and last fix available during the ensemble acquisition. Since the acquisition PC needs some time at the end of an ensemble to write the data etc., these two fixes are typically a few seconds apart. Under the option used here, the fix retrieval program (*ubprint*) averages these two fixes to calculate a position as close to the end of an ensemble as possible. The extracted fixes were edited with threshold values for Horizontal Dilution of Precision (HDOP, ≤6) and for a maximum time since the last 3-satellite fix (≤6 hours; program *edfix*). However, only one fix was found to exceed under these criteria (day 312.22, with HDOP = 8).

For each profile, the absolute velocity of the reference layer was then computed as the difference between the velocity of the ship over ground, determined from the fixes, and the velocity of the ship relative to the reference layer (which is, of course, given by the reference layer velocity multiplied by -1; Fig. 13 top, step curve). GPS position errors show up as an anomalous current in one direction, immediately followed by a similarly large anomalous current in the opposite direction (e.g., at day 282.63). This initial estimate was smoothed by convolution with a Blackman window function *w(t)* (Blackman and Tuckey, 1959) of width T,

$$w(t) = 0.42 - 0.5\cos(2\pi/T) + 0.08\cos(4\pi t/T).$$

(Fig. 13 top, smooth curve; program *smoothr*). The choice of the filter width depends mostly on the quality of the fixes, and might be as short as 15 minutes with good GPS. Here we have used a filter width of one hour, after deciding that a 40-minute filter width (Fig. 13, bottom) was too much influenced by GPS glitches. See section 6 in Appendix A for further thoughts by Eric Firing about the filtering. The estimates of reference layer velocity were plotted for the whole cruise, along with ship's position (Appendix D). These plots are routinely examined for large outlier fixes, which would then be manually excluded from the record. Here, one fix was marked as bad (day 288.67). It had occurred within a group of three fixes for which the antenna height was calculated as 999, but looked otherwise okay. The plots also serve to document other important aspects of the ADCP data set such as the spatial coverage, the general quality of the GPS fixes, and the degree to which particular current features are resolved in the smoothed reference layer velocity.

The smoothed estimate of the absolute reference layer velocity was added to the velocity of the ship relative to the reference layer to give the final estimate of the ship's velocity. The latter was then integrated over each interval of nearly continuous ADCP data and fit to the ensemble of position fixes within the interval to generate the ship's track. The ship's position and velocity for each profile were written back into the ADCP database (program *putnav*). One could add the ship's velocity to the velocity profile and then store the resulting absolute profile, but instead the CODAS software does this calculation as needed when plotting and analyzing the data.

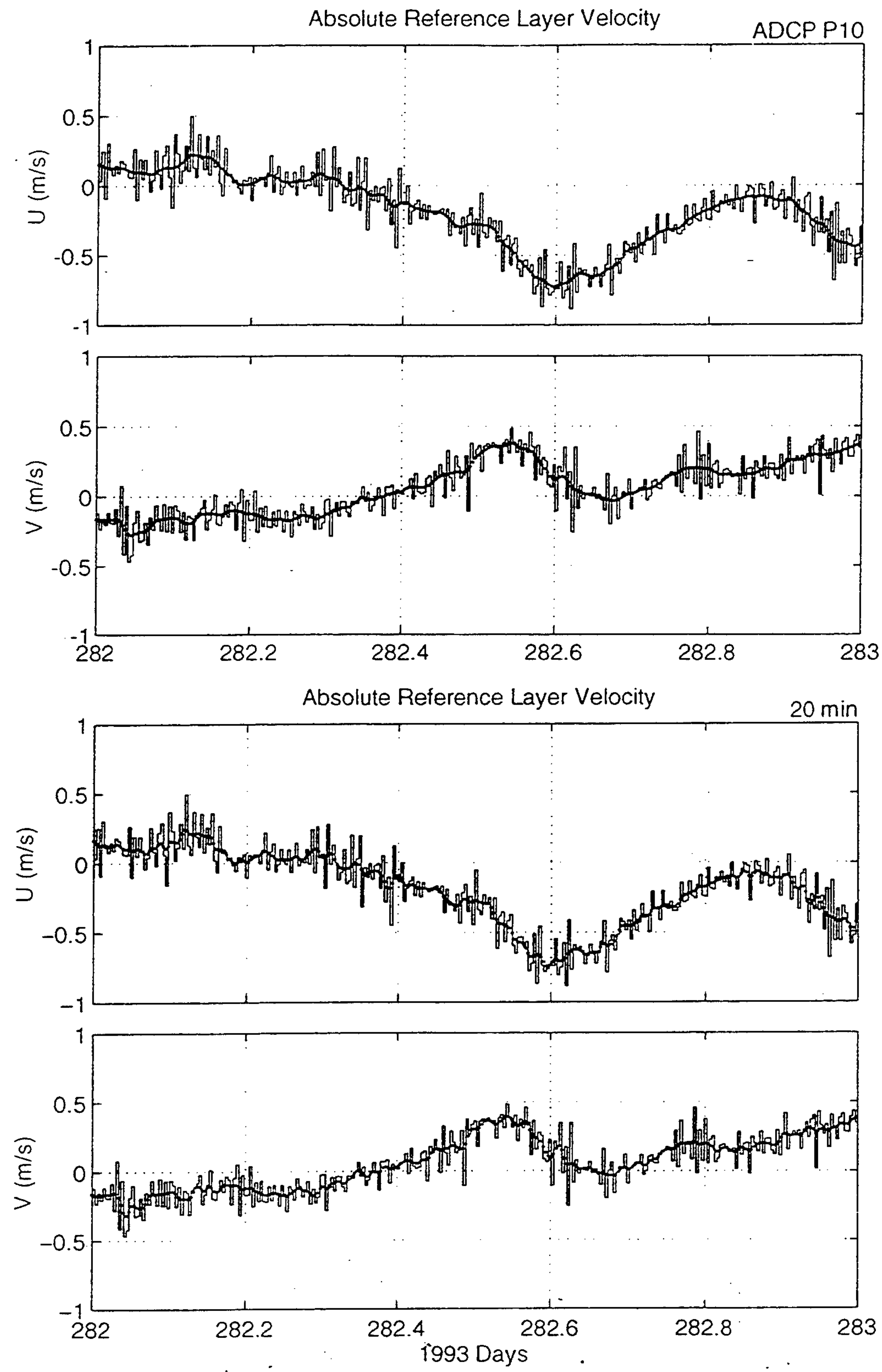


Figure 13: Absolute reference layer velocity, averaged between fixes (piecewise constant), and smoothed (dots). Top two panels: with smoothing filter width of one hour. Bottom two panels: smoothing filter width of 40 minutes (20 minutes half width).

4.7 Profile Quality

ADCP profile quality is routinely checked with several statistics, calculated separately for underway and on-station data. A cruise may be broken into several segments and analyzed separately; for the plots shown here, data from the whole cruise excluding the more noisy segments with 1-minute ensembles were used.

To identify time ranges of underway and on-station data, the relative reference layer velocity (ADCP velocity averaged over bins 5 through 20, relative to the ship) were searched for speeds larger or smaller than 1.5 m/s, or about 3 knots (program *arrdep*). Time periods of 1-minute ensembles were manually edited out. With the resulting time ranges as input, profile statistics for vertical shear of horizontal velocities, for vertical velocity, error velocity, amplitude, spectral width, percent good, and percent 3-beam solution were calculated (Fig. 14a-d, program *profstat*).

4.7.1 Vertical Shear of u, v (Fig. 14a)

Mean and standard deviation of the vertical shear as measured by the first vertical difference can be used to identify problems in the shallowest bins due to insufficient surface blanking or DAS processing filter problems. The relatively small shear seen here suggests that the selected surface blanking (4 meters) and direct commands for filter control (B008001) and for ping-to-ping filter tracking (E0004020099) worked well for the *Thompson*. A detailed description of the DAS direct commands can be found in the RDI manual (RDI, 1991), and more information on processing filter issues are given in Chereskin et al., 1989. Aside from the first bin of v, the horizontal shear was remarkably similar for underway and on station data.

4.7.2 Vertical and Error Velocity (Fig. 14b)

The 4-beam Janus configuration used by RD Instruments provides two independent estimates of vertical velocity, w. The average of these is recorded as vertical velocity, and cos(30°)/2 (=0.433) times the difference between the two estimates is recorded as error velocity, E. Since the true vertical velocity in the ocean is usually very small, particularly when temporarily and spatially averaged, both w and E often indicate measurement error or flow disturbances.

Below the top few bins, the depth-averaged vertical velocity when the ship is underway is essentially a measure of the fore-aft tilt of the "vertical" axis of the transducer. This tilt can arise through misalignment of the transducer installation, changes in trim of the ship as water and fuel are consumed, and, over the very short term, pitch. Similar to horizontal misalignments, vertical velocity errors are proportional to ship's speed, with a one degree tilt producing a signal of about 1.7% of the ship's speed. For the *Thompson*'s cruising speed of about 7 m/s, the average vertical velocity of 5 cm/s would indicate a tilt aft (the bow was high) of 0.4 degrees.

Near the surface, the underway vertical velocity *w* is large and negative, decreasing exponentially over the top 50 meters. On station, *w* is small and negative. A *w* profile of this shape is typically observed for ship-mounted ADCPs, and though the cause has not definitely been determined, it is suspected to be related to flow disturbances around the ship's hull. The magnitude of -10 cm/s near the surface was also seen on a more recent set of cruises on the R/V *Thompson* (Flagg and Shi, 1995).

Depth-averaged error velocity when the ship is underway may indicate misalignment of the transducer elements relative to each other. Short-term increases in error velocity from on-station periods could be caused by a combination of vertical shear of horizontal velocities and ship's tilt (Bahr, 1990). For the P10 cruise, both underway and on-station error velocities were small.

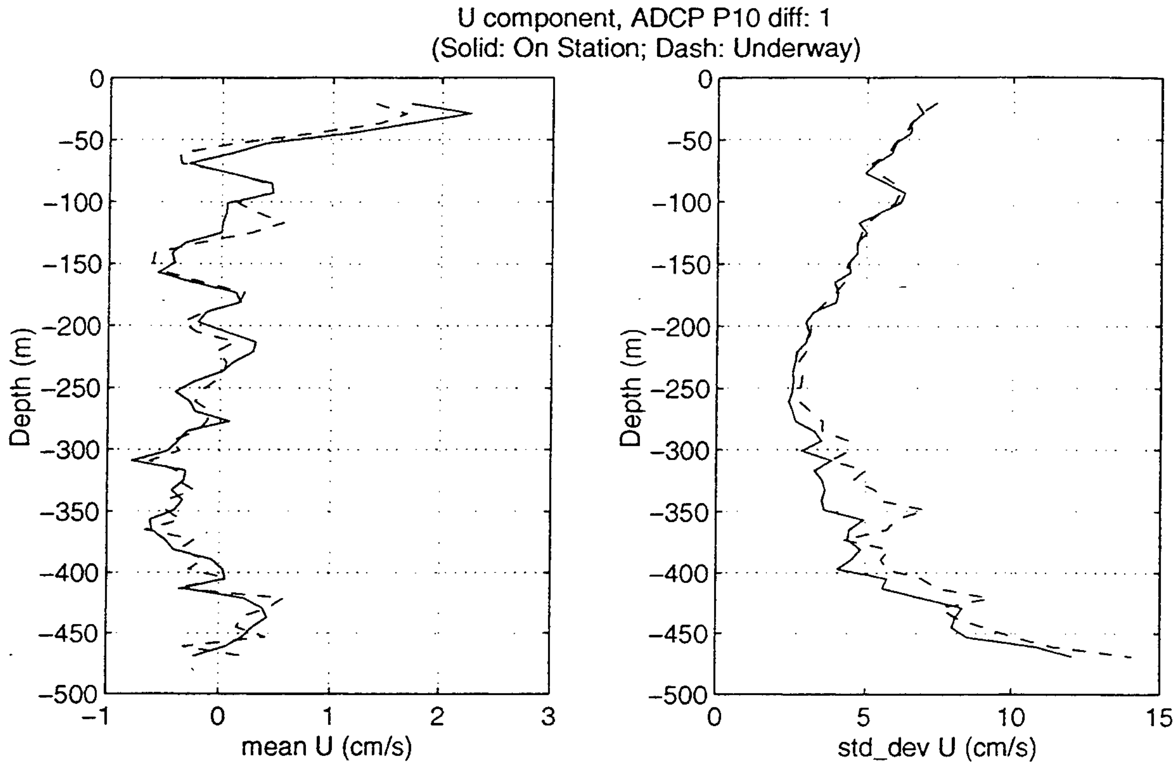
4.7.3 Amplitude (AGC) and Spectral Width (Fig. 14c)

Amplitude gain control (AGC) corresponds to the depth-varying amplification used by the ADCP profiler to maintain a constant signal level for all vertical bins. It is generally used as a measure of signal strength. Underway AGC levels are typically elevated for the bottom-most bins, indicating a higher noise floor due to ship's propeller noise, etc. This is often accompanied by a decrease in shallow AGC, suggesting that the effective signal strength is reduced simultaneously. While these effects were also found in the AGC profiles shown here, the magnitude of the reductions was small (compare with, e.g., Bahr et al., 1990). Spectral width will not be discussed, but is shown here for completeness only.

4.7.4 Percent Good, and 3-Beam Solution (Fig. 14d)

Percent good indicates what percentage of pings in an ensemble were considered good pings and were used for the ensemble average. It is used by many of the CODAS data access routines as a quality criterion, with 30% being a typical threshold for accepting data. As expected, percent good was highest near the surface and was reduced toward the bottom end of the profile. The highest profile quality (as indicated by percent good) was present in the upper 250 meters, though acceptable data could on average be found to below 400 meters depth. In general, underway data frequently show reduced percent good returns due to ship's noise etc., but underway and on-station percentages were remarkably similar here. This again indicates the good characteristics of the R/V *Thompson* as an ADCP platform. The main effect of ship's speed on profile quality was an increase in percent good variability at deeper depths.

Only three of the four beams of the ADCP are necessary to compute the three velocity components. All four are normally used when available. When data from only three beams are available or acceptable (on any given ping or bin), the DAS will optionally use the three-beam solution if it is "turned on" in the DAS's *start.cnf*. For each depth bin, percent-3-beam is then the percentage of pings in an ensemble for which the 3-beam solution was used. As expected, the percentage was vanishing at shallow to mid depths (aside from a small maximum at the very first bins), and then increased with depth since all four beams did not drop out at the same depth. Again, underway and on-station data were very similar.



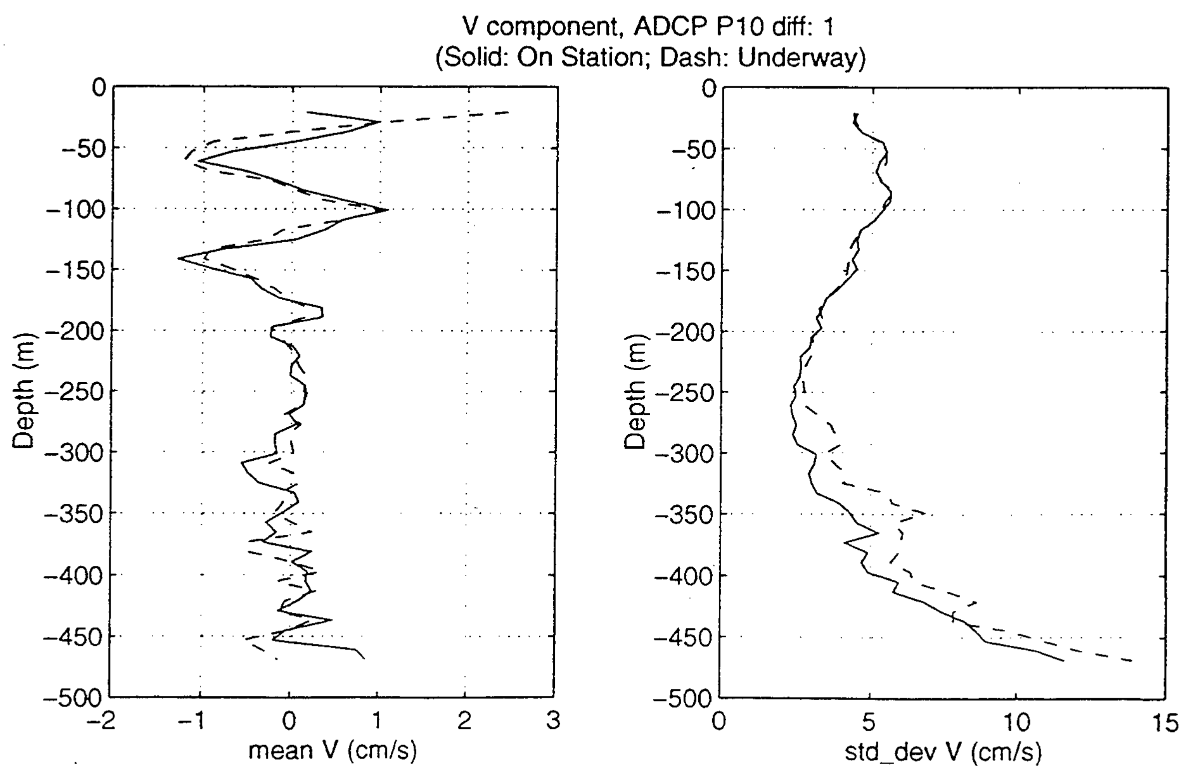


Figure 14a: Mean standard deviation of vertical shear of *u* (top) and *v* (bottom).

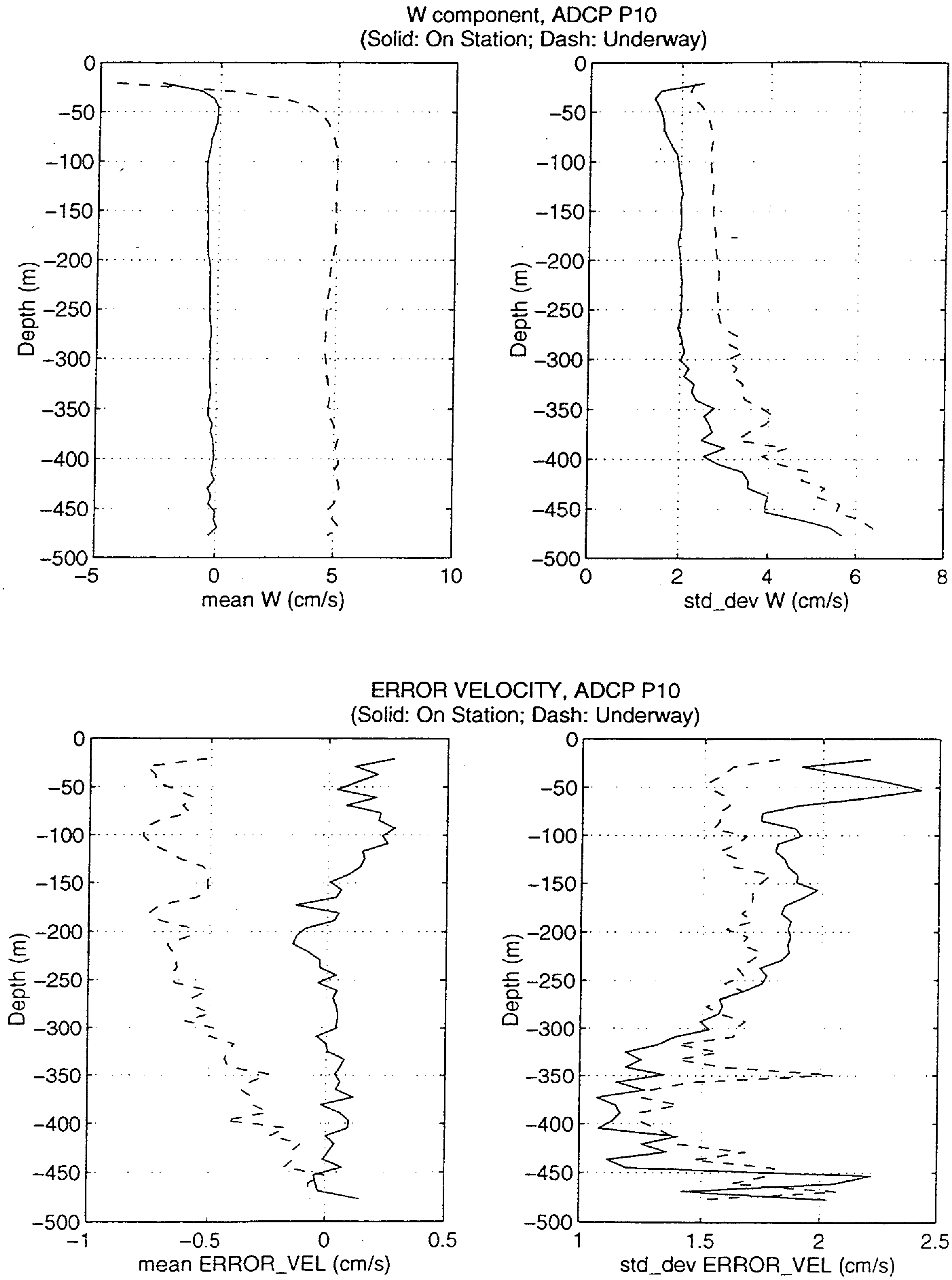


Figure 14b: Mean and standard deviation of w (top) and E (bottom).

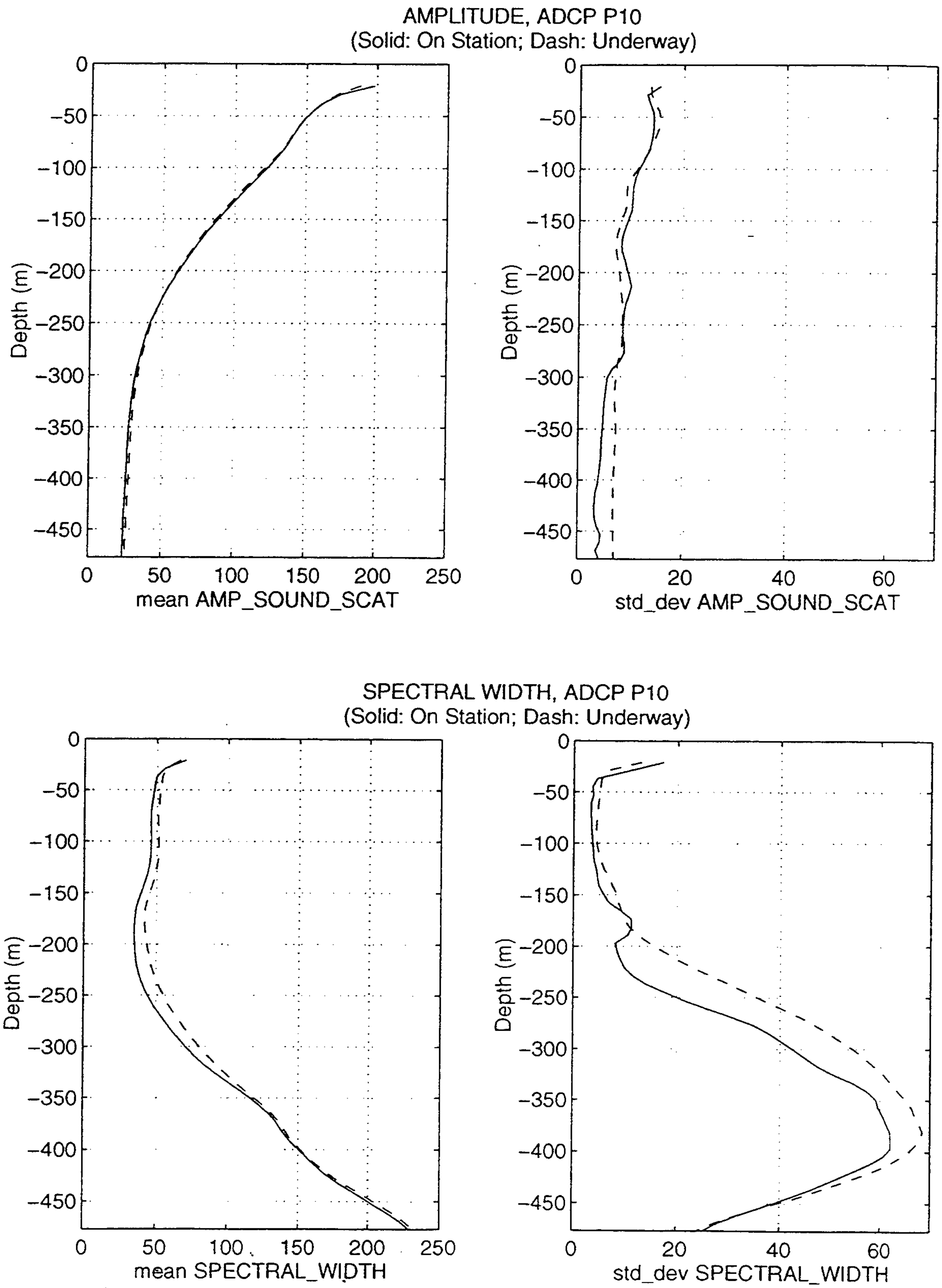
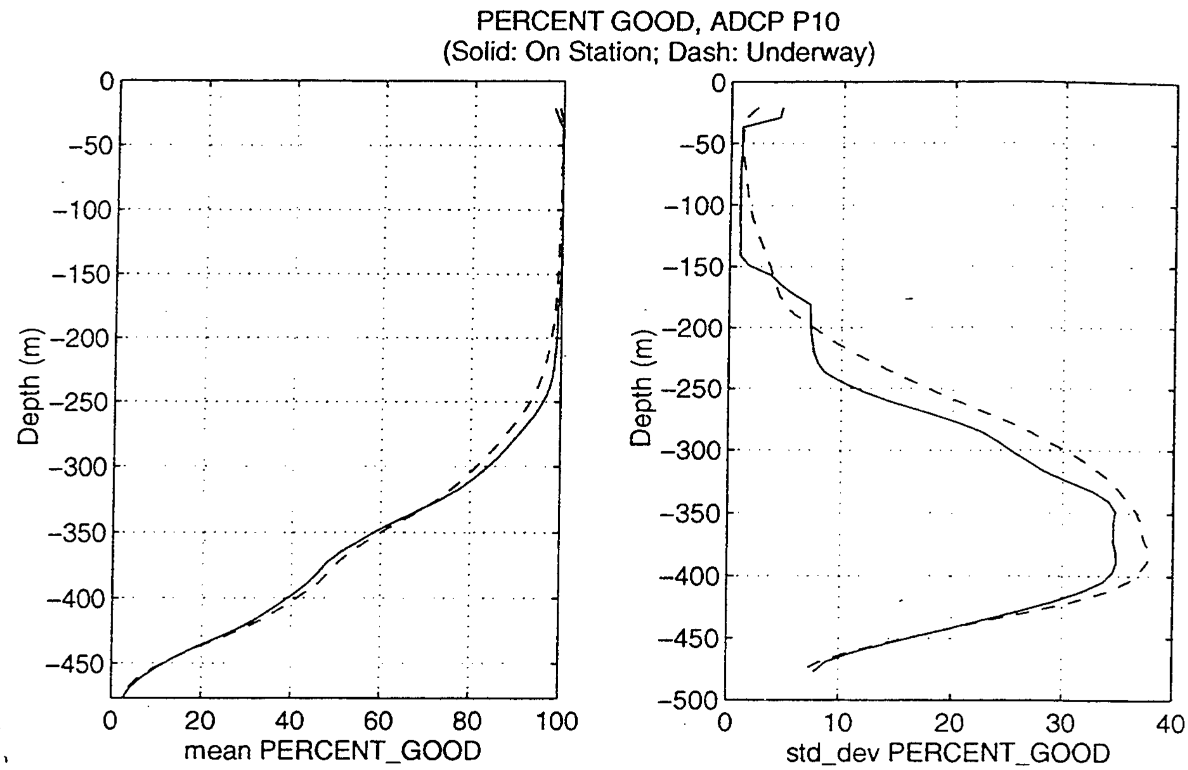


Figure 14c: Mean and standard deviation of AGC (top) and spectral width (bottom).



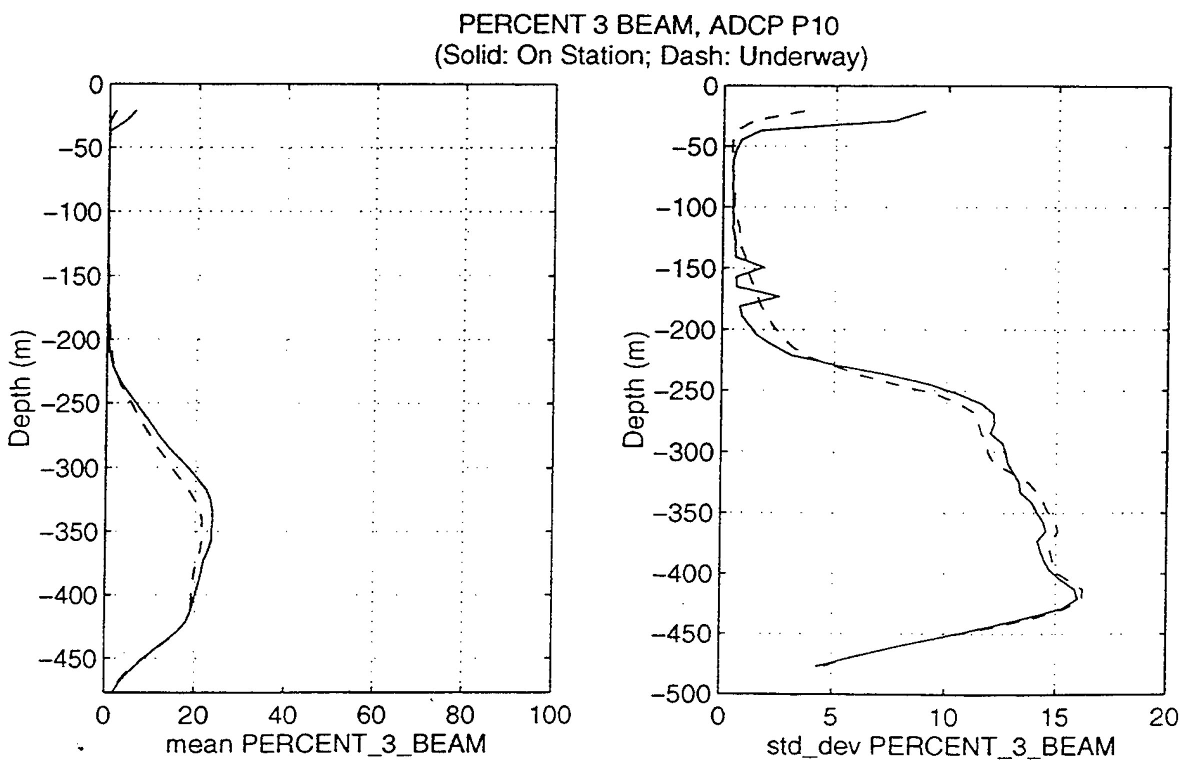


Figure 14d: Mean and standard deviation of percent good (top) and percent 3-beam (bottom).

5. Velocity Contours and Maps

Contour and vector plots are shown for the New Guinea approach with the New Guinea Coastal Undercurrent and for the crossing of the Kuroshio (Figs. 15 to 20). In the following, the generation of these figures is described.

5.1 Contours

In the CODAS database, velocity profiles are accessed by time. Therefore, a list of time ranges was produced first that corresponds to a geographical grid along the cruise track (program *llgrid*). The grid step size was 0.2 degrees in latitude for the New Guinea section and 0.1 degrees in longitude for the Kuroshio section; longitude (for New Guinea) and latitude (for the Kuroshio) gridding was disabled by large grid steps. It was possible to use a smaller grid step for the Kuroshio without making the resulting time ranges too small because of the slanted, northwesterly cruise track there. The ADCP profiles falling within the same time range were averaged in time and regridded in the vertical onto a ten-meter grid, selecting only depth bins with percent_good greater than 30 (program *adcpsect*, contour option). The ascii output file was then plotted with a contour program from the University of Hawaii, called *contour*, that is routinely used together with the CODAS programs.

Contour interpolates the input data onto a uniform grid (set to10 decibars and 0.2 degrees for both sections) using a combination of Laplacian and spline interpolation as selected by the user with the parameter *cay*. Here, *cay* was set to 0.5, selecting both methods with equal weight. The parameter *del*, which controls the amount of anisotropy in the interpolation, was set to 0.2, giving more weight to horizontal gradients. These are routine settings for ADCP contour sections. For the one example checked out of curiosity, the v component of the New Guinea section, settings of $del = 1$ (no anisotropy) and $cay = 5$ (mostly spline interpolation) did not noticeably change the graph.

In the New Guinea section (Fig. 15 a,b), the southern end is given by the rising bottom off New Guinea as measured by ADCP bottom tracking (solid line rising to 0 meters depth). Two versions of the Kuroshio sections are provided: one in geophysical coordinates (Fig. 16 a,b), the other in rotated coordinates that align with the ship's track (Fig. 17 a,b). The ship's course was taken to be a constant 300 degrees, which corresponded closely to the ship's heading from that time as stored in the database. The rotation was implemented by multiplying ADCP velocity $U=u+i*v$ by $exp(i*\varphi)$ with $\varphi = 30$ degrees. Along-track velocity is positive toward the southeast, across-track velocity is positive toward the northeast.

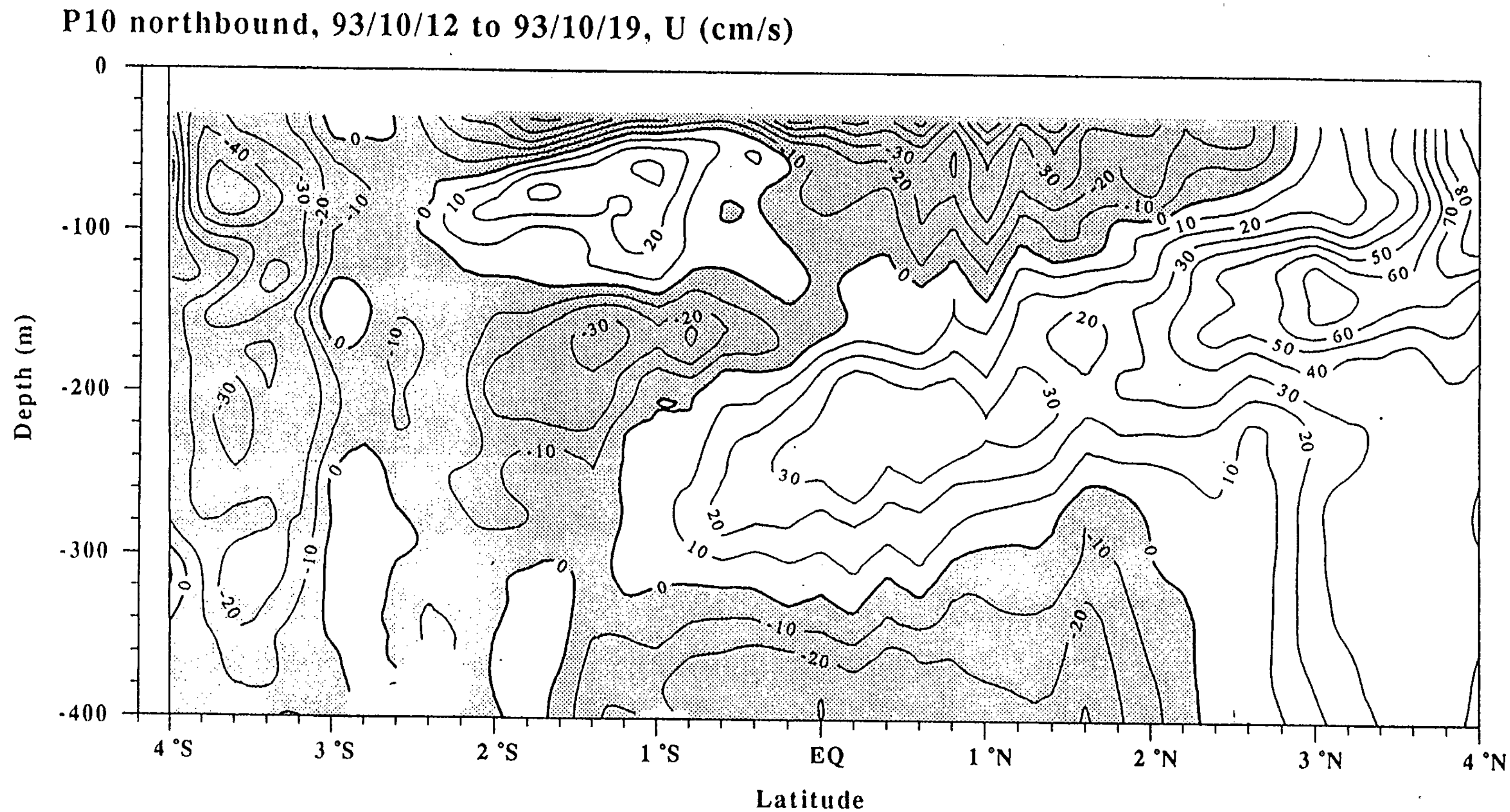


Figure 15a: Zonal velocity (u) across the equator; New Guinea's coast is indicated on the left.

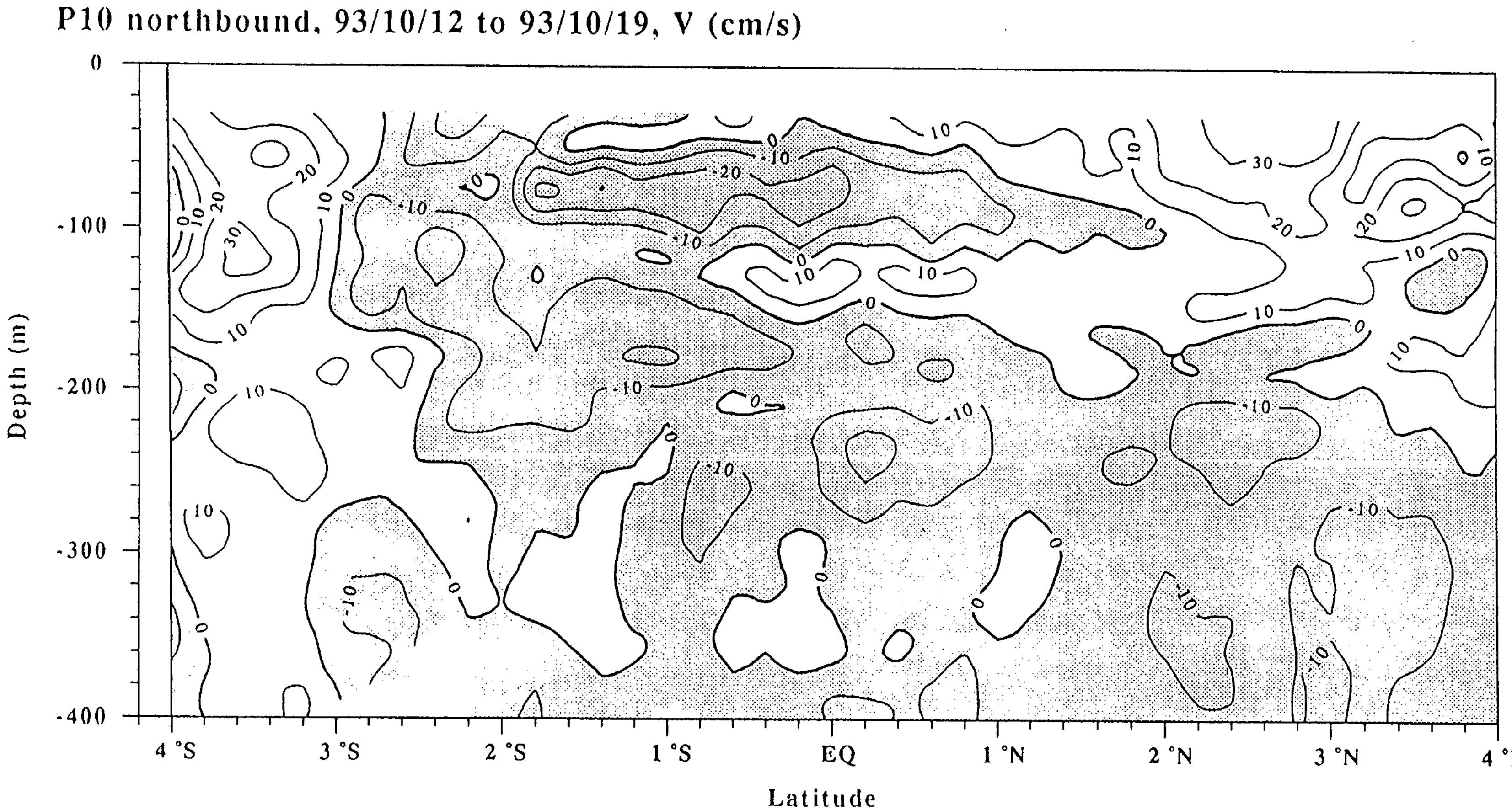


Figure 15b: Meridional velocity (v) across the equator; New Guinea's coast is indicated on the left.

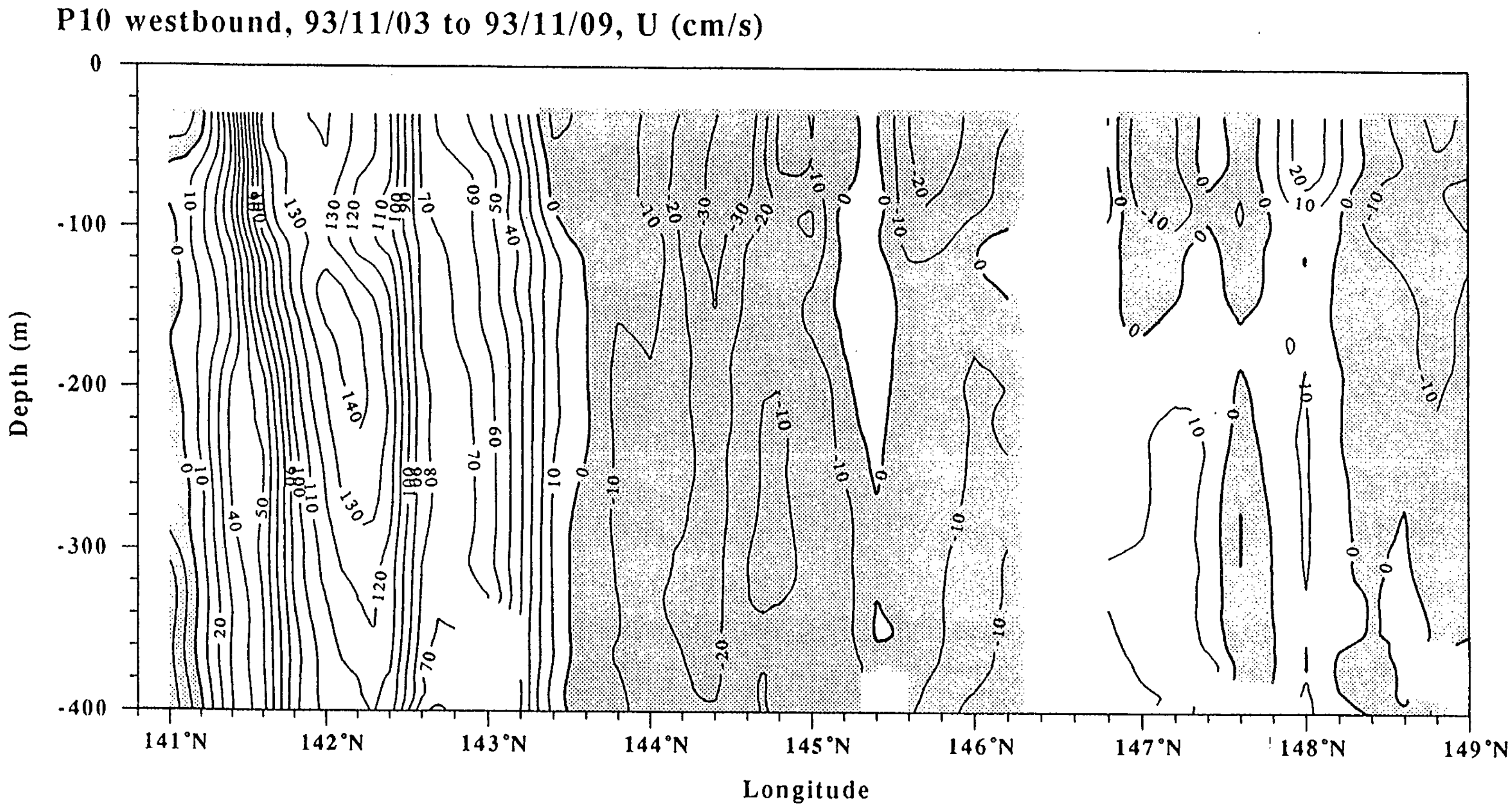


Figure 16a: Zonal velocity (*u*) across Kuroshio.

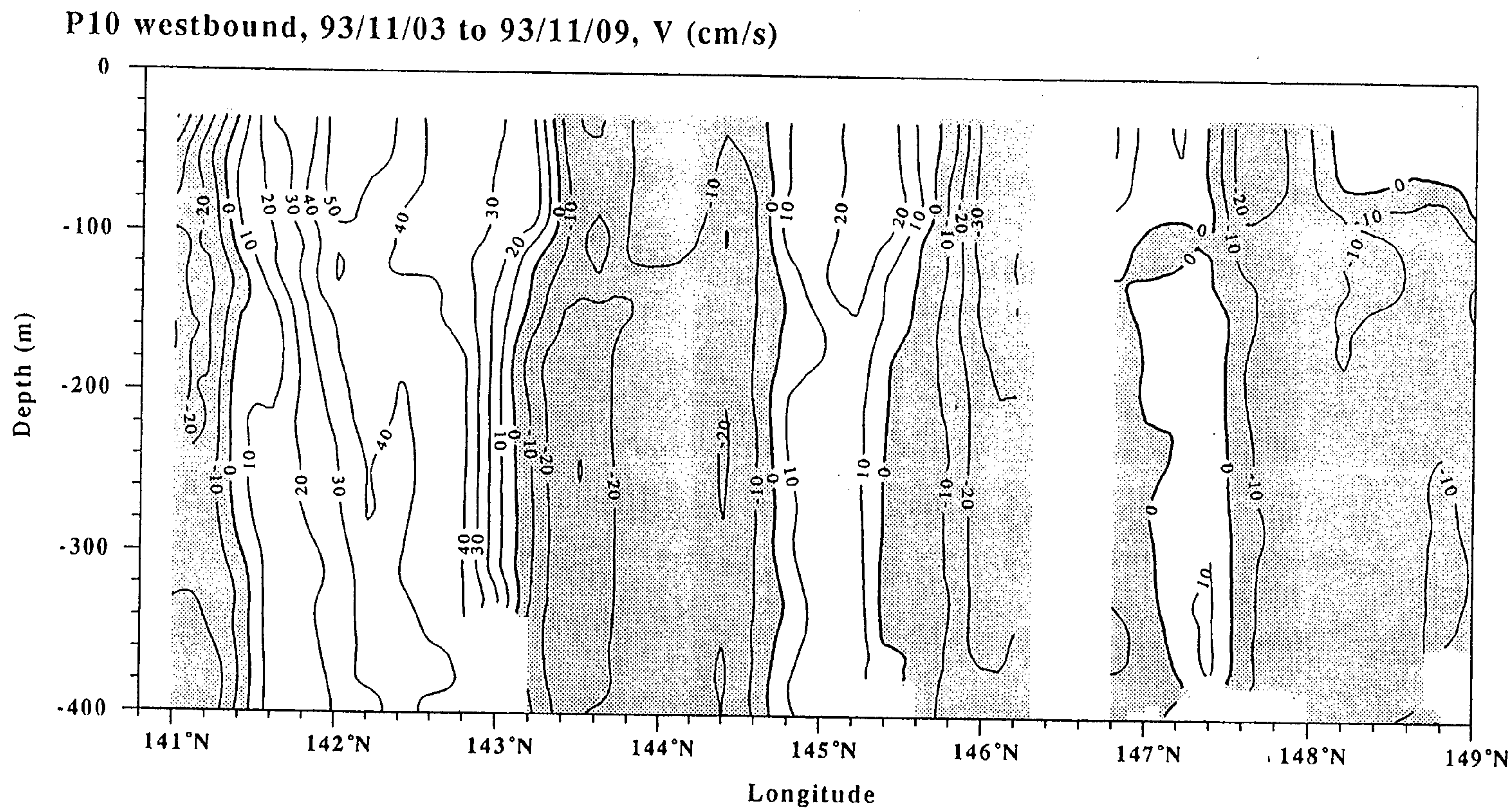


Figure 16b: Meridional velocity (v) across the Kuroshio.

P10 westbound, 93/11/03 to 93/11/09, along section (cm/s)

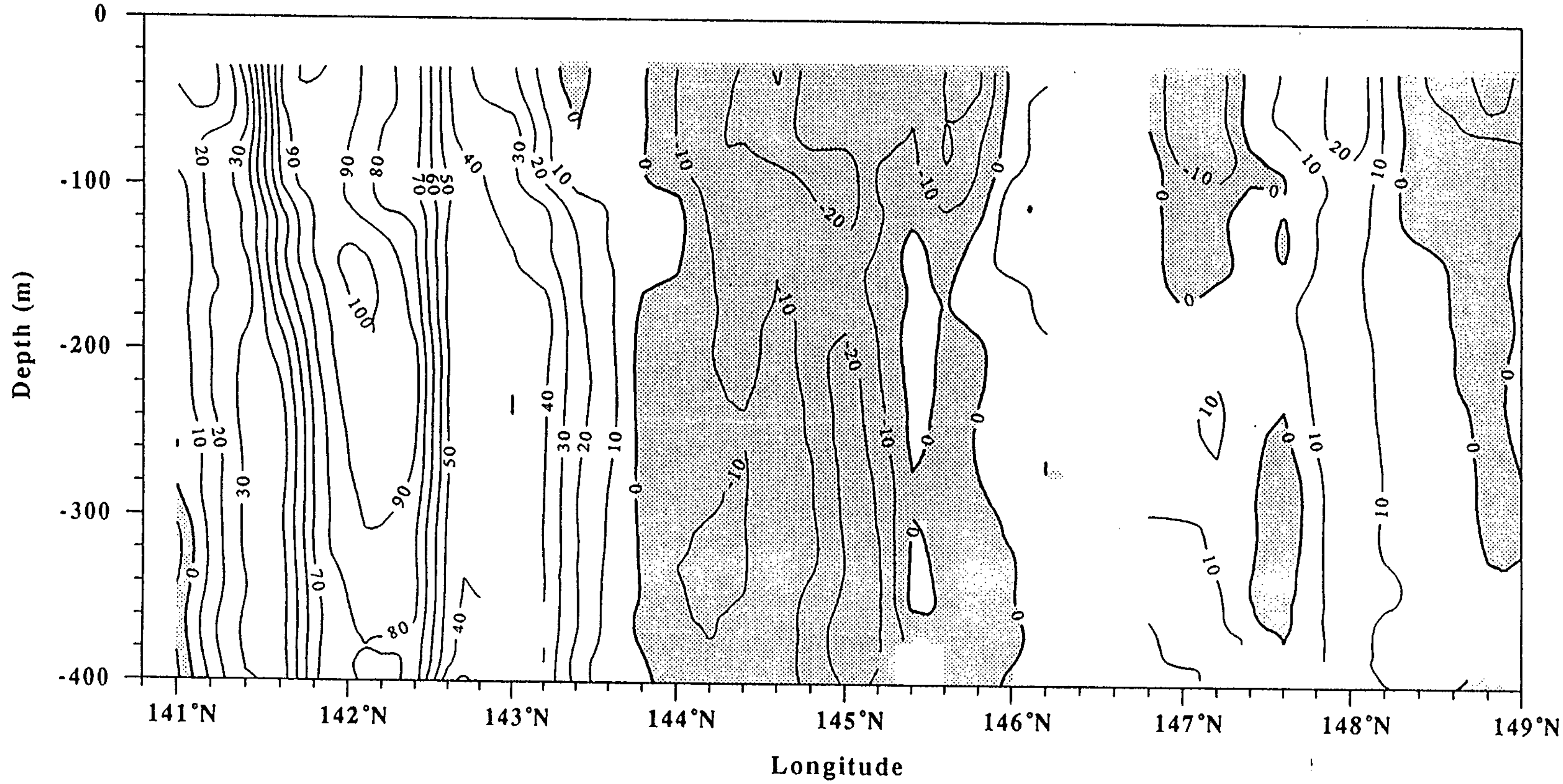


Figure 17a: Velocity along the cruise track crossing the Kuroshio, positive towards the SE.

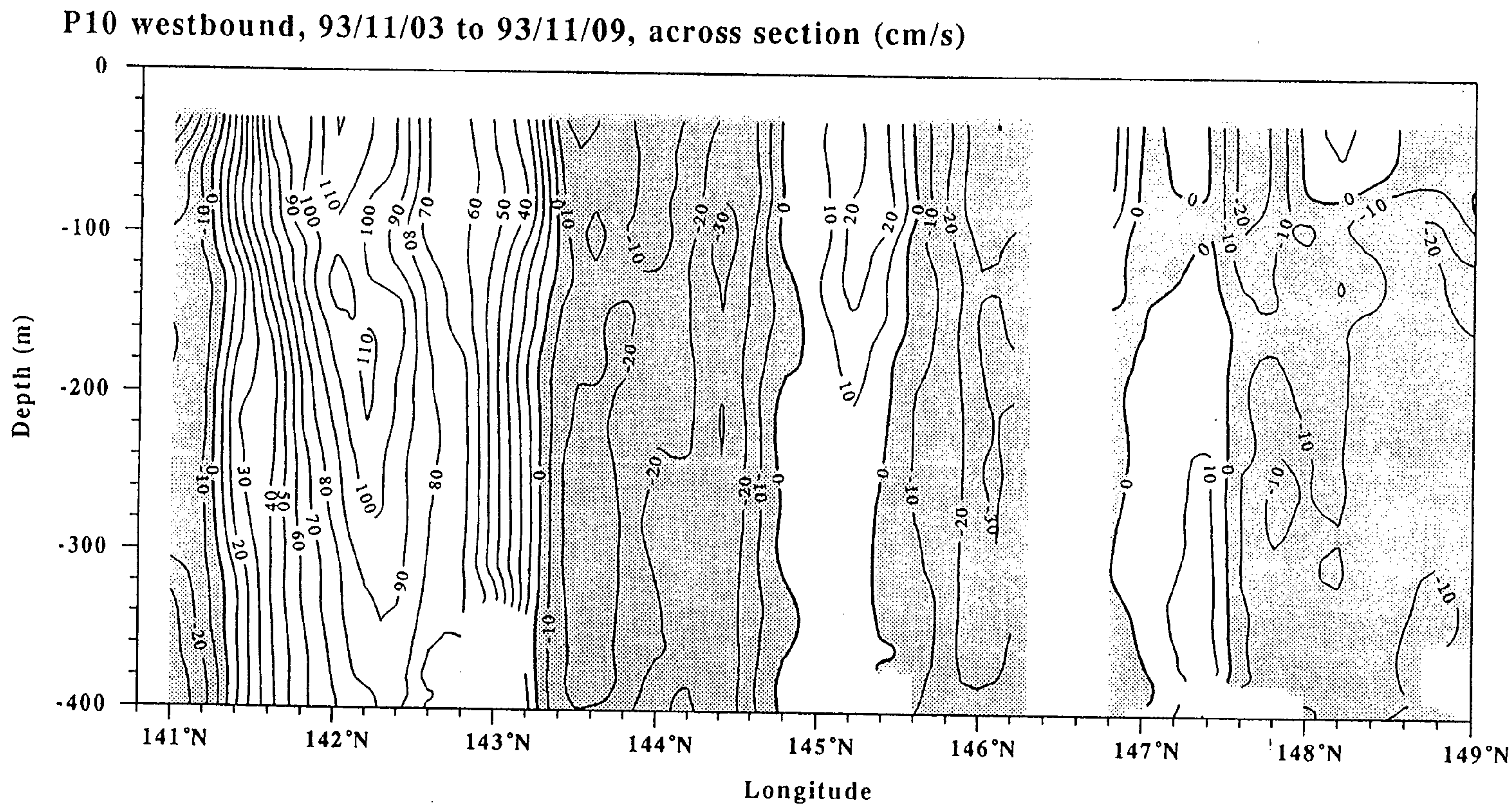


Figure 17b: Velocity across the cruise track crossing the Kuroshio, positive towards the SW.

5.2 Vector Maps

As for the contour plots, ADCP time ranges need to be generated as the first step. One may produce a list of time ranges that correspond to a geographical grid superimposed onto the cruise track. Here, we have chosen to use half-hour time averages. This has the advantage of indicating when the ship was on station, and what the temporal variability--or lack thereof--was. In addition to the time averaging, velocity profiles were averaged in the vertical over depth ranges of 140 to 160 meters for the Kuroshio, and 70 to 90 meters for the New Guinea approach, (program *adcpsect*, vector option). When plotting the resulting ascii files of u and v, the longitudinal axis for the Kuroshio plot was scaled by $1/\cos(33°)=1.192$ (Fig. 18, program *vector*). The New Guinea Coastal Undercurrent is depicted on two maps: the first one includes the approach along the New Guinea coast (Fig. 19), while the second one shows just the transect across the current in an enlarged scale (Fig. 20).

P10

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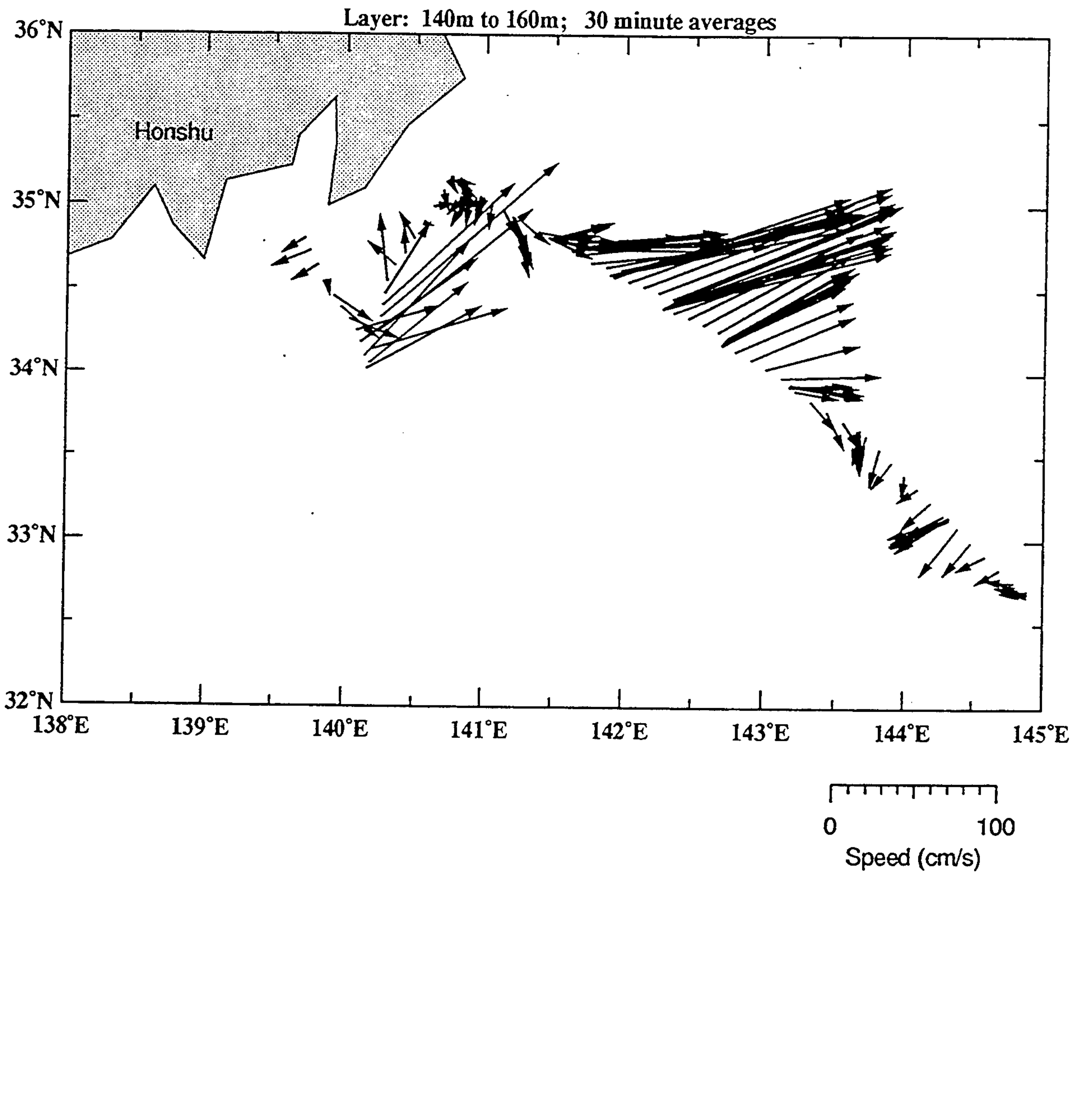

Figure 18: Velocity vectors from half-hour averages over the depths from 140 to 160 meters.

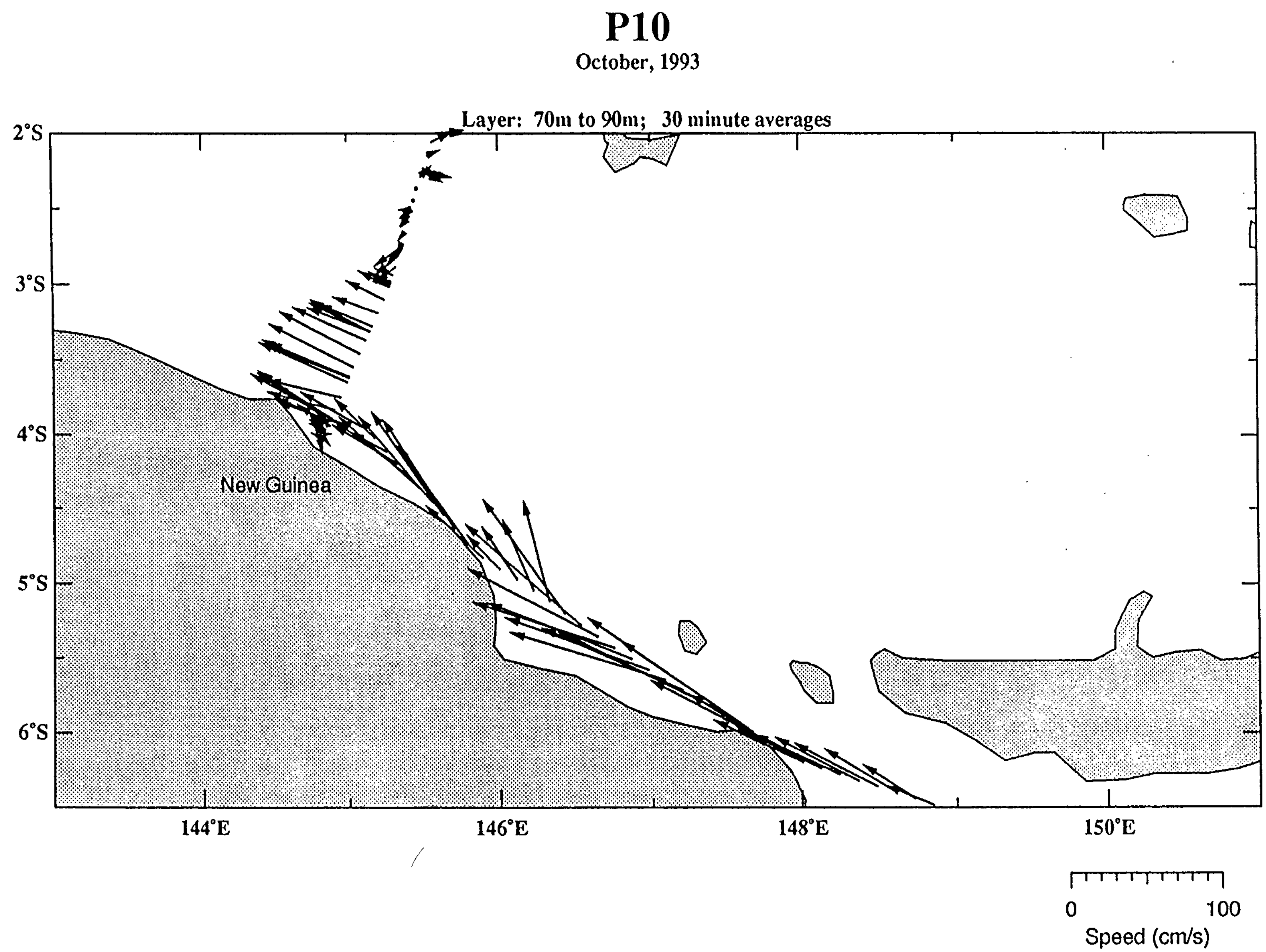

Figure 19: Velocity vectors from half-hour averages over the depths from 70 to 90 meters.

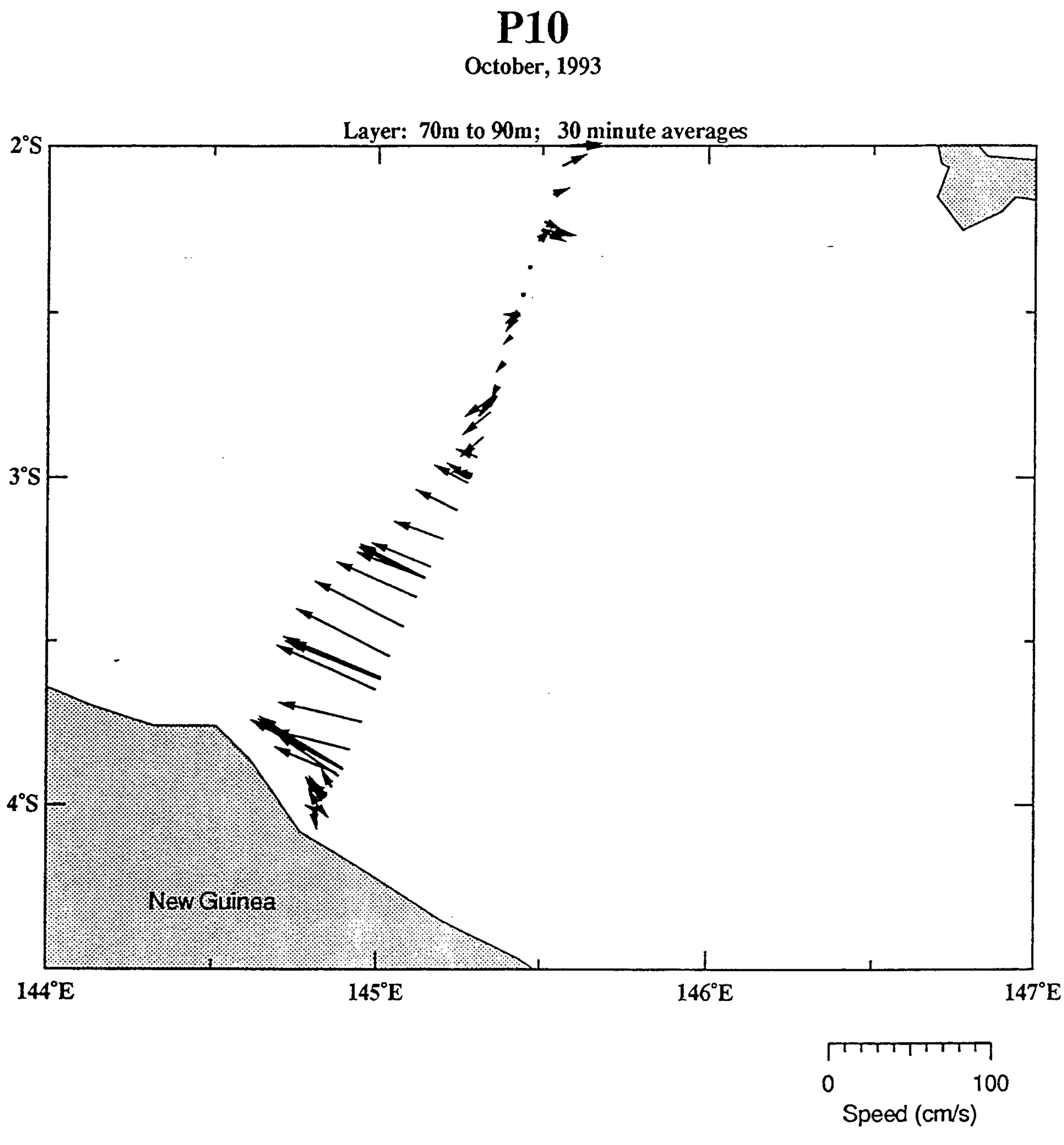

Figure 20: As Figure 19, but plotted with half the map scale.

6. Acknowledgments

Special thanks go to Eric Firing and Julie Ranada from the University of Hawaii for support with the Ashtech heading data and all other phases of the data processing. Peter Hacker provided detailed notes and helpful comments about the cruise. Thanks to Pat Caldell (U. Hawaii) and Charlie Flagg (Brookhaven National Laboratory, New York) for valuable input, and to June Firing (U. Hawaii) for locating and supplying the ADCP configuration file. This work was supported by the NSF Grant OCE93-06689.

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Appendix A: The UH ADCP Data Processing System

[Reproduced from Appendix B from "*WOCE Hydrographic Operations and Methods:* Acoustic Doppler Current Profiling Measurements and Navigation." by E. Firing, 1991. The full document is available via anonymous ftp from noio.soest.hawaii.edu, directory pub/codas3, file opmeth.ps.]

The University of Hawaii ADCP data processing system has been developed and used over several years. It has been used by several groups in addition to mine to process more than two ship-years of ADCP data. Some of this processing has been done at sea in near real time by people with no more than a few hours of training by my group. However, this required considerable time and effort by the new users; the system is large and its use involves many steps. A description of the system and an example of its use are given by Bahr et al. (1990).

The software may be obtained from me by request: telemail to e.firing/OMNET or Internet email to efiring@soest.hawaii.edu. The standard distribution package includes all source code, documentation, and a sample data set illustrating all stages of processing. The source code is internally documented and external documents have been written for many of the major operations. These are now being assembled into a users' manual that will describe all data processing procedures.

A.1 Hardware

The UH system is designed to run on a variety of machines starting with a simple PC-compatible and including VAX-VMS and most UNIX machines. The reasons for specifying this degree of machine independence are:

- Hardware is changing rapidly, and one wants to be able to take advantage of improvements as they occur, with minimal cost in software modification and maintenance.

- Portable software can be used by more members of the community than can machine-specific software; it can contribute to a pool of common software.

- PC-compatibles are so cheap, ubiquitous, and physically portable that they can always be taken along when travelling or going to sea. With software that runs on a PC, one can always process data in near real time at sea.

The minimal configuration for the UH system is a PC with 640K of RAM, a math coprocessor, and a 40-Mbyte hard disk. The system has been used extensively with such machines and also with Sun-3 and Sun-4 machines. A Postscript-compatible laser printer is recommended for plot output, although an HPGL plotter (laser is preferred, pen is usable) can also be used.

A.2 User Interface

Most routines in the UH system are governed by ASCII control files that are designed for readability and therefore help document the processing of each data set. All control files can contain unlimited comments; standard sample control files start with a comment block that explains the parameters in the file and gives examples. Each parameter (or list) in a control file is preceded by a descriptive key word, which identifies the parameter to both the machine and the operator. Control files for complicated routines have optional parameters; when not needed for a particular operation they can be omitted, shortening and simplifying the file.

Many routines also use intermediate ASCII data files that are also designed to be human-readable, with headers and comments. For example, files listing satellite fixes are edited, both mechanically and by hand, by prefixing the character "%" as a comment indicator to lines with bad fixes that are to be ignored in future steps. Additional comments can be used to explain why a fix was deemed bad.

One commercial program is used as part of the UH system. Matlab (by the MathWorks, Inc. It is available for the PC, 386-PC, Sun, Vax, and several others) and provides easy plotting and interactive calculations.

The first step in processing a new data set with the UH system is to run a batch file (or UNIX script) that builds a directory tree for the new data set with subdirectories for each of the processing steps. These subdirectories are then filled automatically with example control files and Matlab program files ("m-files"). The operator need only copy his raw data files into the appropriate subdirectory, modify the sample control files as needed, and run the processing programs.

A.3 Database

A typical one-month cruise generates about 10 Mbytes of binary ADCP data which include many variables, both scalars and arrays. The variables included in a data set can change from one cruise to another. The size and complexity of ADCP data sets therefore warrant the use of a database system rather than a simple fixed file format. To fill this need, Ramon Cabrera, Julie Ranada, and I have developed CODAS (Common Oceanographic Data Access System): a set of machine-independent subroutines for the storage and retrieval of oceanographic and other scientific data. It is designed for maximum storage efficiency combined with fast random or sequential access. It is flexible enough to comfortably accommodate data from a wide variety of instruments, such as the Acoustic Doppler Current Profiler (ADCP), the CTD, current meter moorings, and pressure gauges, together with auxiliary observations and instrument configuration parameters.

CODAS is hierarchical. Data are organized into profiles, each of which may consist of several arrays (for example, one for each of three velocity components) and other data (flags, data collection parameters, notes, etc.) Profiles are collected together in blocks, each of which is an independent, self-describing unit of data. The internal description of each variable in a block includes the name, units, and scale factors. A profile is located within a block via a profile directory that is part of the block. Blocks are catalogued in a block directory.

A CODAS database contains only two kinds of files: a set of data block files, and a single block directory file. The data block files are independent units and contain all the information required to make a block directory file. Hence, data blocks from different sources can be combined into a working database by running a utility program that generates a new block directory file.

CODAS was written in C with care taken to make it portable among modern machines. It has been used on IBM PC-compatibles, a VAX 750, an Alliant, and Sun workstations. Data blocks are normally stored in the binary format of the machine on which they were created or are actively being used. When moved to another machine and assembled into a new database, they are automatically translated to the new binary format if necessary (as in going from a PC to a Sun, for example).

Storage space is minimized. The user is free to use 1, 2, or 4 byte integers, floating point, double precision, or ASCII. However, use of the most compact format for each variable is encouraged, because the system (optionally) automatically converts and scales array data from any number format to floating point when reading, and the reverse when writing. Storage space is allocated as needed when the data are stored; there is no need to waste space by specifying fixed array lengths, for example. The extensive directory structure adds only a few percent of storage overhead.

A.4 Editing

The premises behind the UH editing system are:

- Because of the volume of ADCP data, automated scanning for possible problems is essential.
- We do not yet know enough to design a purely automated editing system; an operator must be able to review the results of the scanning and decide exactly how the editing should proceed.
- Because editing is sometimes done iteratively, and one might sometimes want to undo a step, the eventual changes to the database should be kept to a minimum and should be reversible where possible.
- The editing process should be self-documenting.

The main problems to be removed by editing are usually limited to interference from the bottom reflection in shallow water, interference from the hydrographic wire during CTD stations, and diminishing accuracy at the bottom of the profile. With a poor installation or a poor choice of setup parameters, it may also be necessary to reject data from the top depth bin(s).

In the UH system, suspect profiles or bin ranges are identified primarily by running a program ("FLAG") that tests each profile in a given time range for several conditions and writes an ASCII file listing cases in which user-specified thresholds are exceeded. The variables being checked include error velocity, the variance in the vertical of the vertical velocity component, the signal strength, and the second vertical difference of each of the velocity components. Large values of the error velocity coinciding with large second differences in the vertical velocity component and in at least one of the horizontal velocity components indicate interference by something like a hydrographic wire. On the *Moana Wave*, for example, this occurs occasionally during CTD stations, is usually confined to a few depth bins among the top ten, and is usually quite subtle--the horizontal velocity component glitches are typically only 5-10 cm/s. A local maximum of the signal amplitude indicates either a scattering layer or the bottom, when the bottom is deeper than about 30 m. When the bottom is very shallow it does not cause an amplitude maximum, but it usually leads to high variance in the vertical velocity profile, hence our use of this statistic.

After running the FLAG program, one normally uses Matlab to look at sequences of profiles ("stagger plots") that are suspect, to make a final decision about what to edit. In many cases the output of the FLAG program can be used with little modification to control the programs that modify the database; in other cases a difficult judgement must be made.

Once the decisions have been made, editing is done on the database. In the case of bottom interference, the appropriate portions of the FLAG output file are used to specify the last bin of each profile for which velocity data will be considered valid, and this bin number is recorded in the database with each profile. If there is a problem in the top depth bins, caused, for example, by inadequate blanking interval or by ringing of the transducer installation, then the first bin of the profile for which the data are acceptable may be recorded with each profile. Otherwise, by default this is bin 1. When the velocity in individual bins is judged bad, a file listing these bad bins is used to control a program that sets the appropriate bits in an array of flag bytes. (This is a recent improvement in the system. Previously we set the actual velocity values themselves to a bad flag value.)

Additional editing is normally done when the data are accessed. Typically one specifies a percent-good criterion, and the access program flags as bad any velocities for which the recorded percent-good is below the threshold. We usually use 30%.

Although our editing system is quite thorough, flexible, and effective, it can also be confusing and difficult to use; we plan major improvements.

A.5 Calibration

Routines are available for both the bottom-track and the acceleration method of determining the calibration factors. For the bottom track method the user must select the time ranges with continuous bottom track and navigation data. An interactive Matlab routine is then used to edit the navigation data and write the least-squares, best-fit calibration factors to a file. For the acceleration calibration method, a program automatically selects the accelerations for which GPS data are available and calculates the calibration factor for each acceleration. This is written to a file along with quality statistics. This file is input to a Matlab routine which edits, plots, and writes out a statistical summary.

A.6 Navigation

Position fixes, GPS or Transit, are automatically screened and merged by an editing program. Rejected fixes are simply commented in the file, so that they can be manually reinserted if desired. Additional manual editing is also done, in an iterative fashion, by commenting out questionable fixes.

Calculation of absolute velocity profiles involves the intermediate calculation of the absolute velocity of a reference layer (we use bins 5 to 20, about 50--170 m) in the usual way (e.g., Kosro, 1985; Wilson and Leetmaa, 1988). Averaged between fixes, the velocity of the reference layer is just the difference between the velocity of the ship over the ground, determined from the fixes, and the velocity of the ship relative to the reference layer, from the ADCP profiles. This initial estimate of the reference layer velocity, which is constant between fixes, is then smoothed by convolution with a Blackman window function $w(t)$ (Blackman and Tukey, 1958) of width T,

$$w(t) = 0.42 - 0.5\cos(2\pi t/T) + 0.08\cos(4\pi t/T).$$

Since the function being filtered is piecewise constant, the convolution can be evaluated efficiently by analytic integration over each constant piece. The choice of filter width depends on the characteristics of the data: the quality of the fixes and the expected amplitude and time scales of the currents being surveyed. When GPS is good and there are small-scale current features of interest, T might be as short as 15 minutes. In the worst case of poor Transit quality and no GPS, T can be up to 12 hours.

Our method of smoothing the reference layer velocity is probably not optimal in many cases; its main virtue is simplicity. The biggest problem is that it does not take into account nonuniform motion of the ship; smoothing is done in the time domain only. In a region of large spatial current gradients, this guarantees errors when the ship changes course or stops for a station. Usually this error has little effect on the outcome of data analysis. The problem is likely to be worst, and hardest to fix with a simple algorithm, when the ship reverses course in a region of large along-track gradient of the cross-track current--for example, when approaching a coast along which flows a western boundary current. Time-domain smoothing of the reference layer velocity then causes a systematic underestimate of the maximum speed of the current.

Estimates of reference layer velocity as a function of time are plotted routinely (using Matlab) in 2-day intervals along with the ship's position. This reveals outlying fixes or intervals of bad GPS that have to be edited out, and also helps one choose a smoothing filter width. The plots resulting from the final iteration of this process serve to document some important aspects of the ADCP data set: the spatial coverage, the quantity and quality of position fixes, and the degree to which major current features have been resolved by the smoothed reference layer estimate.

The smoothed estimate of the reference layer velocity over the ground is added to the velocity of the ship relative to the reference layer to give the final estimate of the ship's velocity, which is then integrated over each interval of nearly continuous ADCP data and fit to the ensemble of position fixes within the interval to generate the ship's track. The ship's position and velocity for each profile are written back to the ADCP database. We could add the ship's velocity to the velocity profile and store the resulting estimated absolute profile, but for the present we choose instead to do this calculation as needed when plotting and analyzing the data.

A.7 Gridding and Plotting

ADCP profiles typically give velocity estimates at nominal 8-m intervals in the vertical. We use nearby CTD profiles, when available, to correct these depths for the difference between nominal and true sound speed. Additionally, the profiles are interpolated to any user-specified grid in depth or density coordinates. The interpolation can be done using integration to reduce aliasing and to give an average velocity over a given layer. The integrated velocity is also available for use in transport calculations.

In the horizontal, one typically wants to average profiles in latitude or longitude bins. The approach taken by the UH system involves two steps. First, a program searches the database to find the time ranges corresponding to user-specified latitude-longitude grid. Second, these time ranges (edited or modified if necessary) are used to control the data access and averaging process. Additionally one may specify the use of only underway data or only on-station data. Another option is to calculate transport by integrating horizontally.

Standard plots for viewing the data are of two types: vector maps and contoured sections. For the former we use Matlab or a custom vector mapping program. For contouring we use a dedicated contour program. The vector and contour programs, unlike the rest of the processing system, have not yet been adapted and compiled on a PC; we usually run them on a Sun workstation with hardcopy from a Postscript printer.

Appendix B: ADCP Cruise Log

A synopsis of hand-written cruise notes by Dr. Peter Hacker, taken during the cruise. References to data backups and data processing done during the cruise are not repeated here.

10/5/93
- backed up TO25 ADCP ping files to 8 big floppies, first has .cnf
- deleted pingfiles from ADCP acquisition PC
- modified start.cnt for TN026 and copied file to TN026.cnf
- 04:30Z: underway from Suva, 6-7 day transit to PNG and start of P10 line
- 04:50Z: bottom tracking, every third ping. Turned off bottom tracking after about 1/2 hour

10/6/93
- noticed no Ashtech data stream; error message on screen. Turn system off and back on again, system comes up.

10/9/93
- reboot ADCP PC at slow speed. (It has been on fast for last couple of days at least.) After rebooting U and V between 200-400m about -10cm/s. Before reboot (with fast PC) U and V about -25cm/s. Significant?

10/11/93
- worked on Ashtech all day. Antennae, settings.... to Eric.

10/12/93
- 19:39Z: set ADCP SI to 60 sec for survey to coast and back
- 20:45Z: enable bottom tracking at 500m depth
- 21:38Z: turn off bottom tracking at 500m

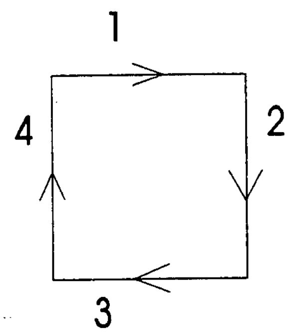
10/13/93
- 00:15Z: changed ADCP SI from 60 to 300 seconds

10/14/95
- 06:12Z: Error: Sun full

10/16/93
- ADCP Ashtech survey at equator, ADCP file pingdata.010.

time	speed	course	ensemble #
0010Z	6.0	89.8	9
0021:30Z	5.5	179.0	21 *)
0033:42Z	5.6	271.2	32
0044:25Z	4.5	00.1	43

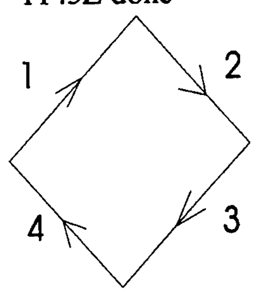
*) lost Ashtech for a few minutes



- ADCP Ashtech survey at 0 degrees 30' N
  1044Z: changed to 1-minute ensembles

time	speed	course	ensemble #
1059	5.8	43.5	15
1110Z	4.2	135	26
1121Z	5.6	223.5	37
1132.30Z	5.5	315	48

1143Z done



10/18/95

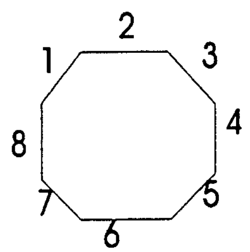
- 01:00Z (approx): Gyro latitude adjustment made on bridge
- 06:45Z: ADCP survey

time	speed	course	ensemble #
115059Z	2.0	48.5	577
120230Z	2.4	48.5	1 *)
120930Z	1.8	92.2	7
121625Z	1.5	138.7	14
1223Z	1.2	181.7	21
1230Z	1.4	226.5	28
123640Z	1.4	272.0	35

124230Z	2.0	315.0	41
124910Z	2.0	02.0	48

*) reset ADCP to 1 min ensembles

- 1305Z: ADCP reset to 5 min @



10/19/93 - set latitude adjustment on ship's gyro

10/20/93 - 20:05Z: Sun was full. Power off for automatic reboot
- 20:10Z: power on
- 20:15Z: restart

10/21/93 - 01:49Z: bridge adjust gyros to 6 degrees latitude

10/22/93 - 00:02Z: bridge adjust gyros to 8 degrees latitude
- 23:40Z: bridge adjust gyros to 10 degrees latitude

10/23/93 - 21:26Z: Ashtech: "Illegal Instruction" on screen. No data stream. Turned unit off and on again. Problem seems cleaned up.

10/24/93 - 02:25Z: Ashtech: same problem as earlier. turned unit off and on again.
- 06:50Z: Ashtech: hung up again: no update on screen. Turned unit off and on again.

10/25/93 - 00:08Z: gyro adjustment for latitude

10/27/95 - 00:05Z: gyro adjustment for latitude

10/28/93 - 12:35Z: gyro adjustment for latitude

10/29/93 - 10:30Z: gyro adjustment for latitude

10/30/93 - 10:50Z: gyros boosted to 23 degrees N

10/31/93 - 14:00LOCAL(!): tube locked Gerard cast, station 65 (23 10.0N, 149

20.0E). Draggin operation for next 15 hours or so

11/01/93 - 12:30Z: update latitude adjustment on gyros

11/03/93 - 12:43Z: adjust gyros for latitude

11/04/93 - 12:30Z: adjust gyros to 30 degrees N
- 23:25Z calibration procedure; file t9310

11/05/93 - 00:52Z: Ashtech not reporting heading - turned off
- 03:20Z: cold restart; reset memory of Ashtech. System back up and working - not recording data since about 22:00Z yesterday.
- 18:20Z: Sun control space getting too small. Power down.
- 18:31Z: Power up
- 18:40Z: all ok.

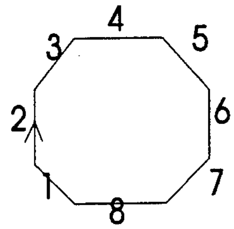
11/06/93 - [during processing, found:] gap 11:44:33 - 16:27:49: ADCP PC space bar must have been hit. Dan and Susan restart in the middle of the night; second gap 18:19:33 - 18:49:33 - Sun reboot
- 23:37Z: advance gyros to 33 N

11/07/93 - 12:43Z: bumped latitude adjustment for gyros.

11/09/93 - 0215Z (about): heading along track towards coast for ADCP run
- 0224Z: change SI to 60 seconds from 300 seconds. Heading 310 at SOG 10 knots.
- 0233Z: 35 7.5N, 140 49.9E, 520m for station 93
- 0304Z: starting turn of 180 degrees to back track. Shallowest depth about 180 m.
- 0348Z: on station after transit away from coast
- 0439Z: BT enabled, SI=60 seconds for run up shelf again.

time	speed	course
0453Z	2.0	315
0459Z	1.6*)	000
0505Z	2.0	045
0511Z	2.8	090
0516Z	2.5	135
0521Z	2.5	180
0525Z	3.5	225
0530Z	2.9	270

*) into the wind; wind 038 degrees @ 20 knots

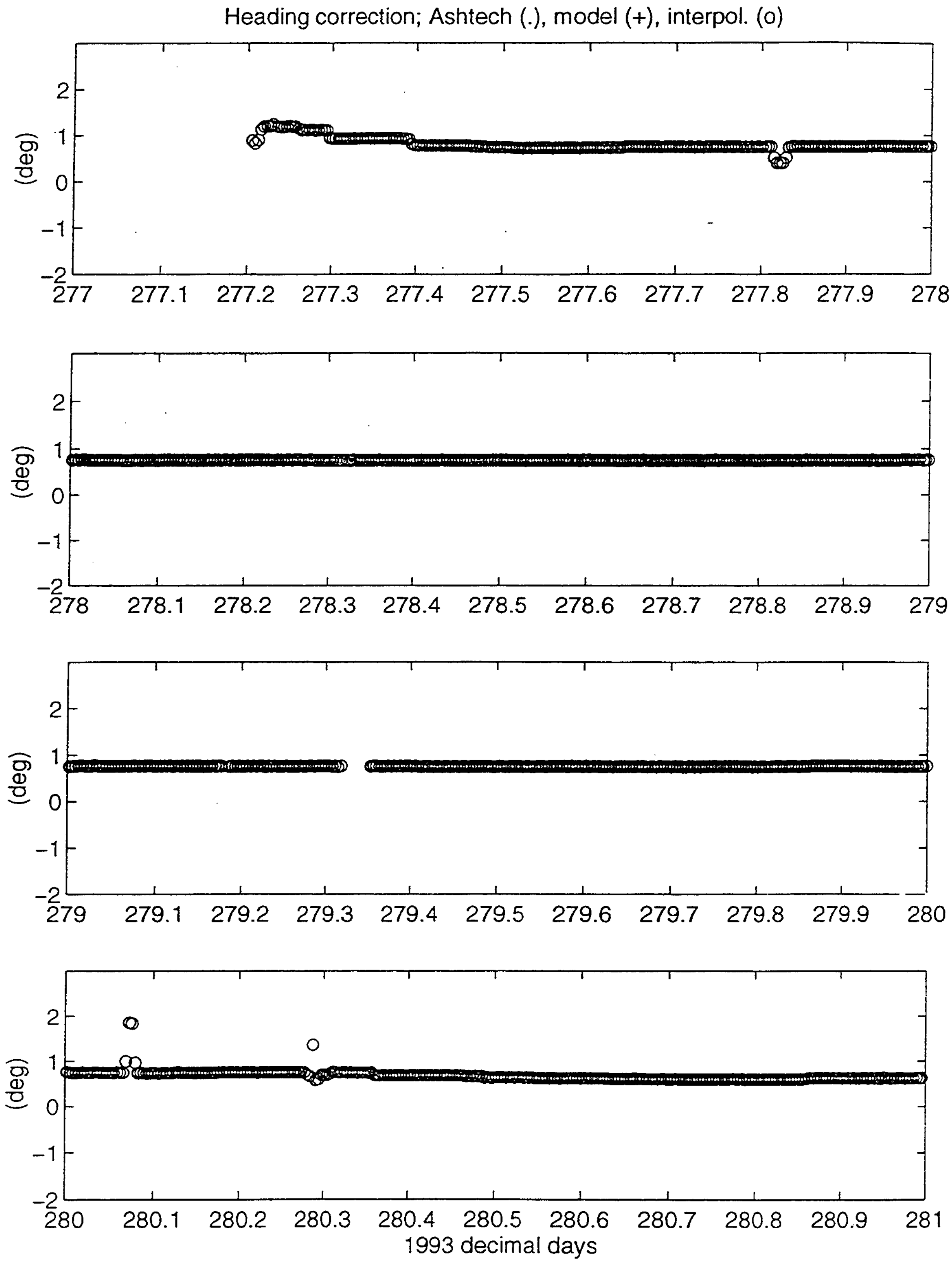


- 0640Z: left station CTD094 for ADCP survey of Kuroshio. Heading 210 at full speed.
- 0815Z: went over ridge at 400m depth. Edit!!

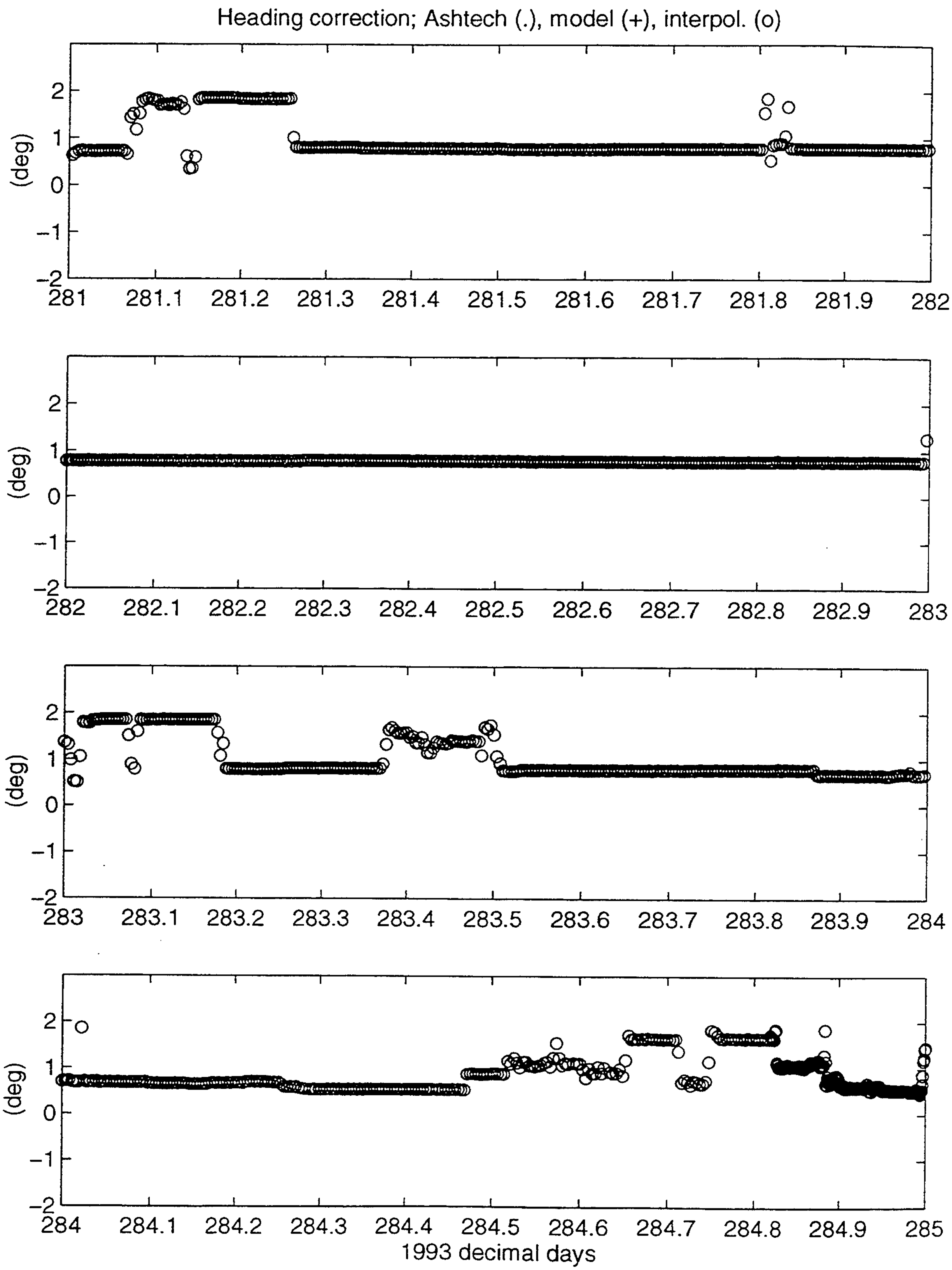
11/09/93 - turned off ADCP PC

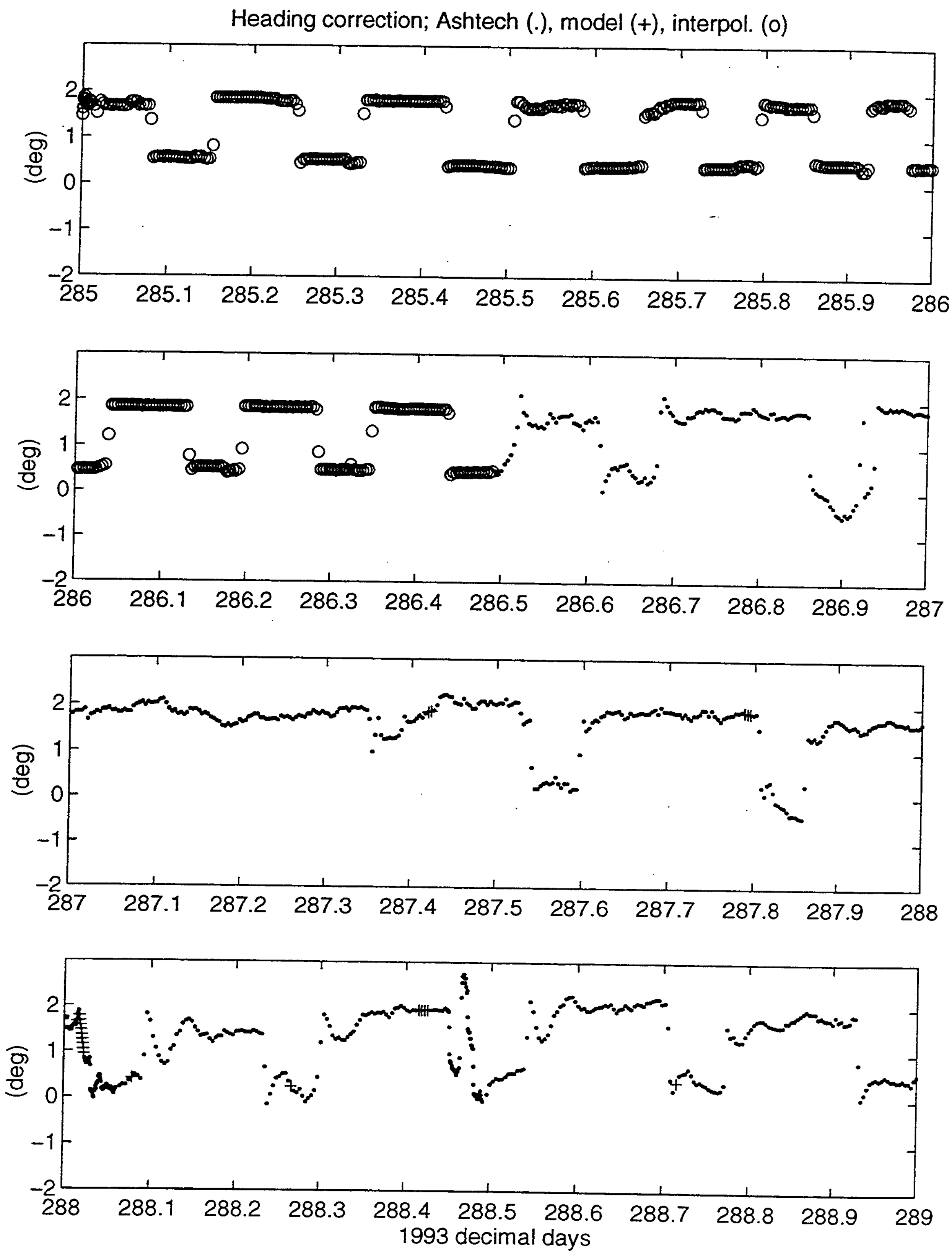
Appendix C: Ashtech Heading Corrections

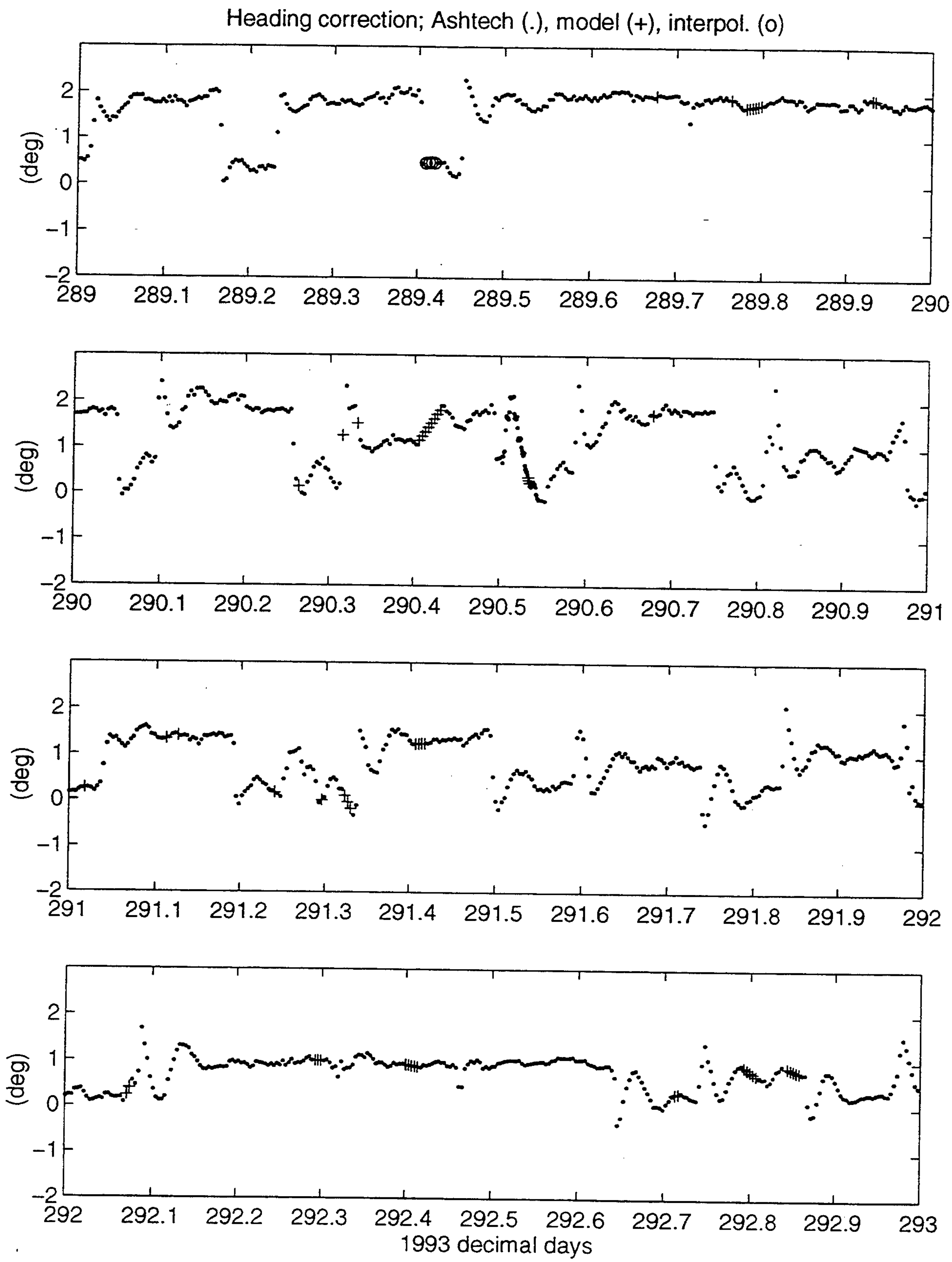
The complete time series of Ashtech heading corrections *dh* as determined by the Ashtech array (indicated by dots), by the model giving *dh* as function of heading indicated by plus signs, or by linear interpolation over small gaps in the original Ashtech record indicated by circles.



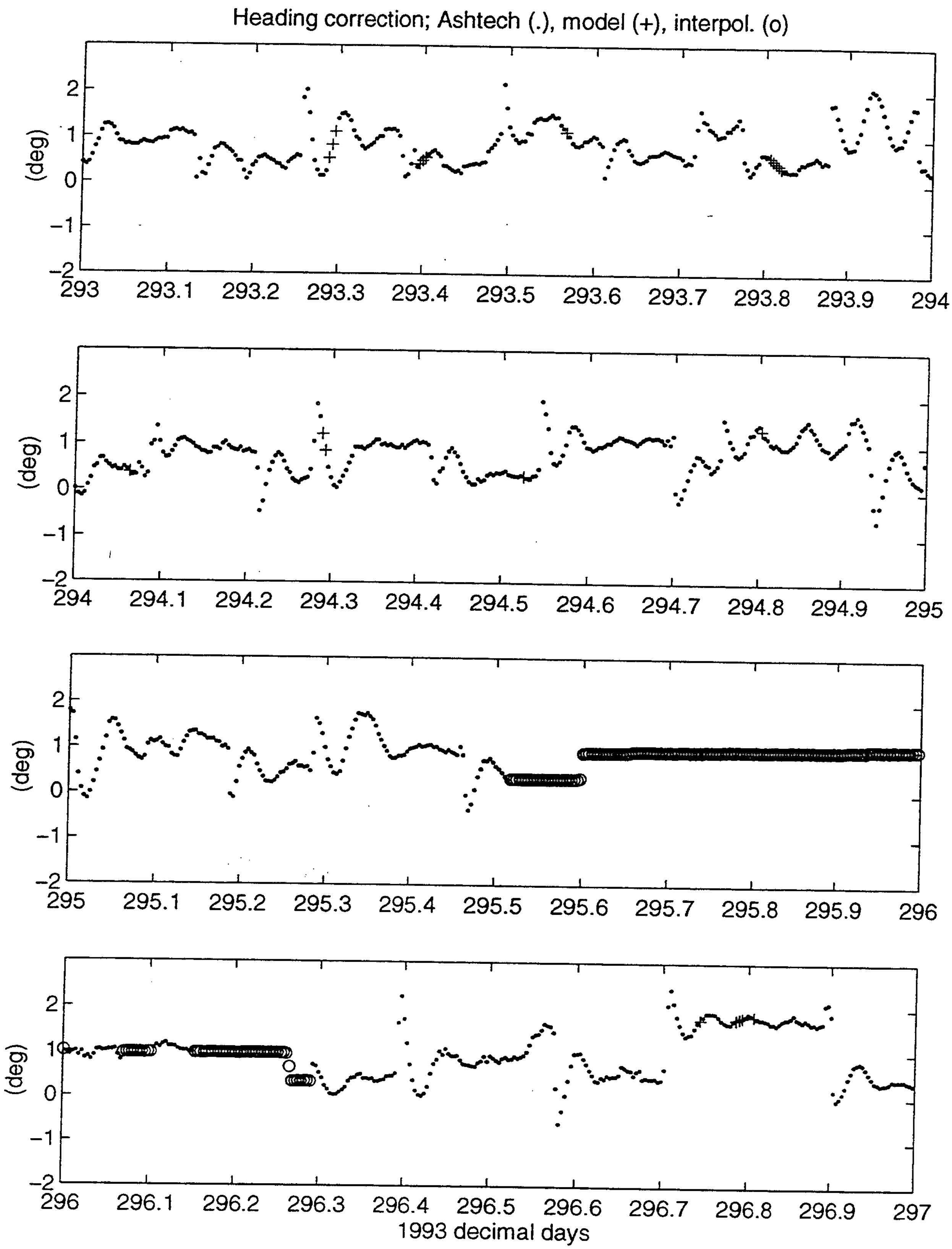
Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
2
1
0
−1
−2
277
277.1
277.2
277.3
277.4
277.5
277.6
277.7
277.8
277.9
278
278.1
278.2
278.3
278.4
278.5
278.6
278.7
278.8
278.9
279
279.1
279.2
279.3
279.4
279.5
279.6
279.7
279.8
279.9
280
280.1
280.2
280.3
280.4
280.5
280.6
280.7
280.8
280.9
281
1993 decimal days


Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
2
1
0
−1
−2
281
281.1
281.2
281.3
281.4
281.5
281.6
281.7
281.8
281.9
282
282.1
282.2
282.3
282.4
282.5
282.6
282.7
282.8
282.9
283
283.1
283.2
283.3
283.4
283.5
283.6
283.7
283.8
283.9
284
284.1
284.2
284.3
284.4
284.5
284.6
284.7
284.8
284.9
285
1993 decimal days


Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
285
285.1
285.2
285.3
285.4
285.5
285.6
285.7
285.8
285.9
286
287
288
289
1993 decimal days

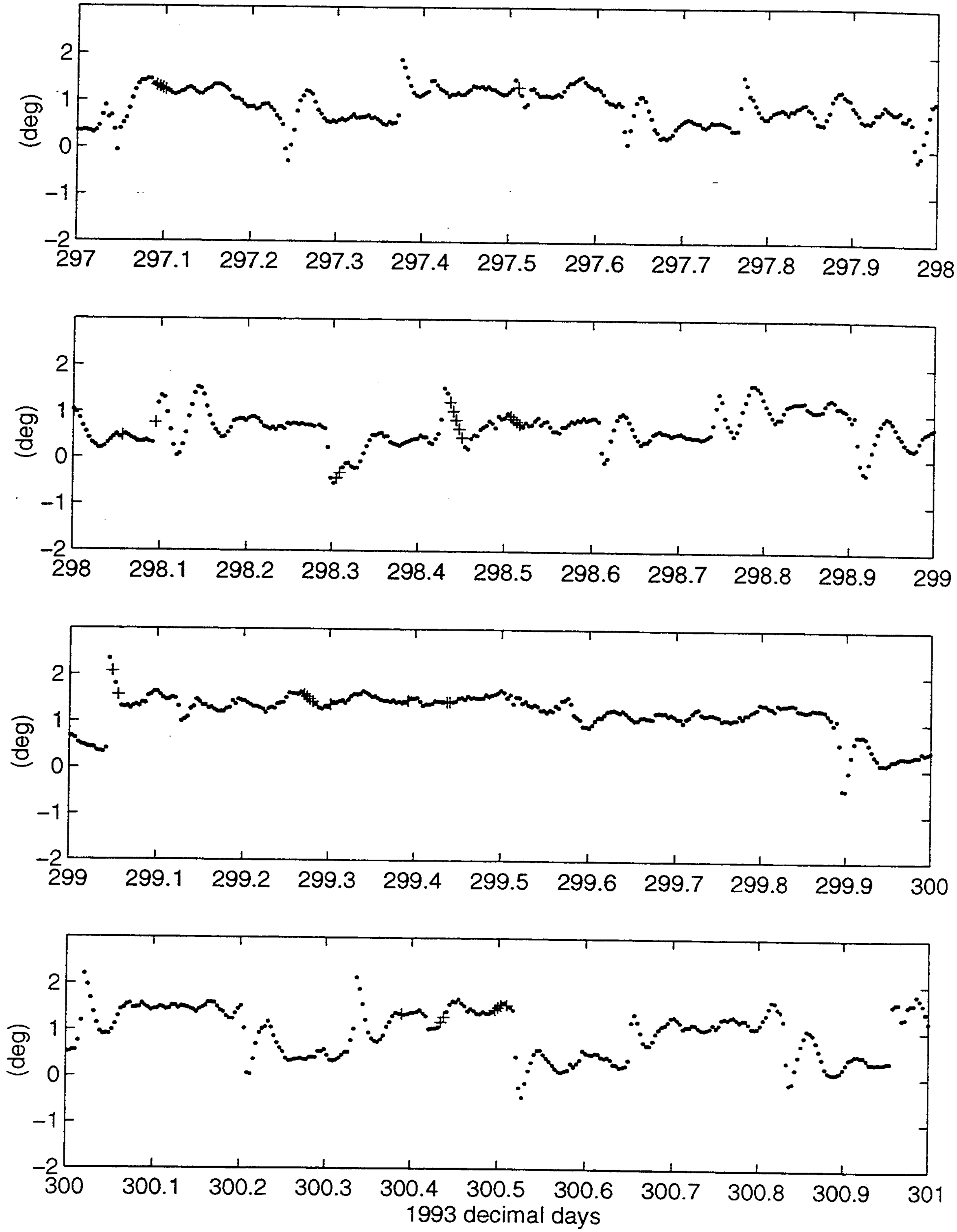


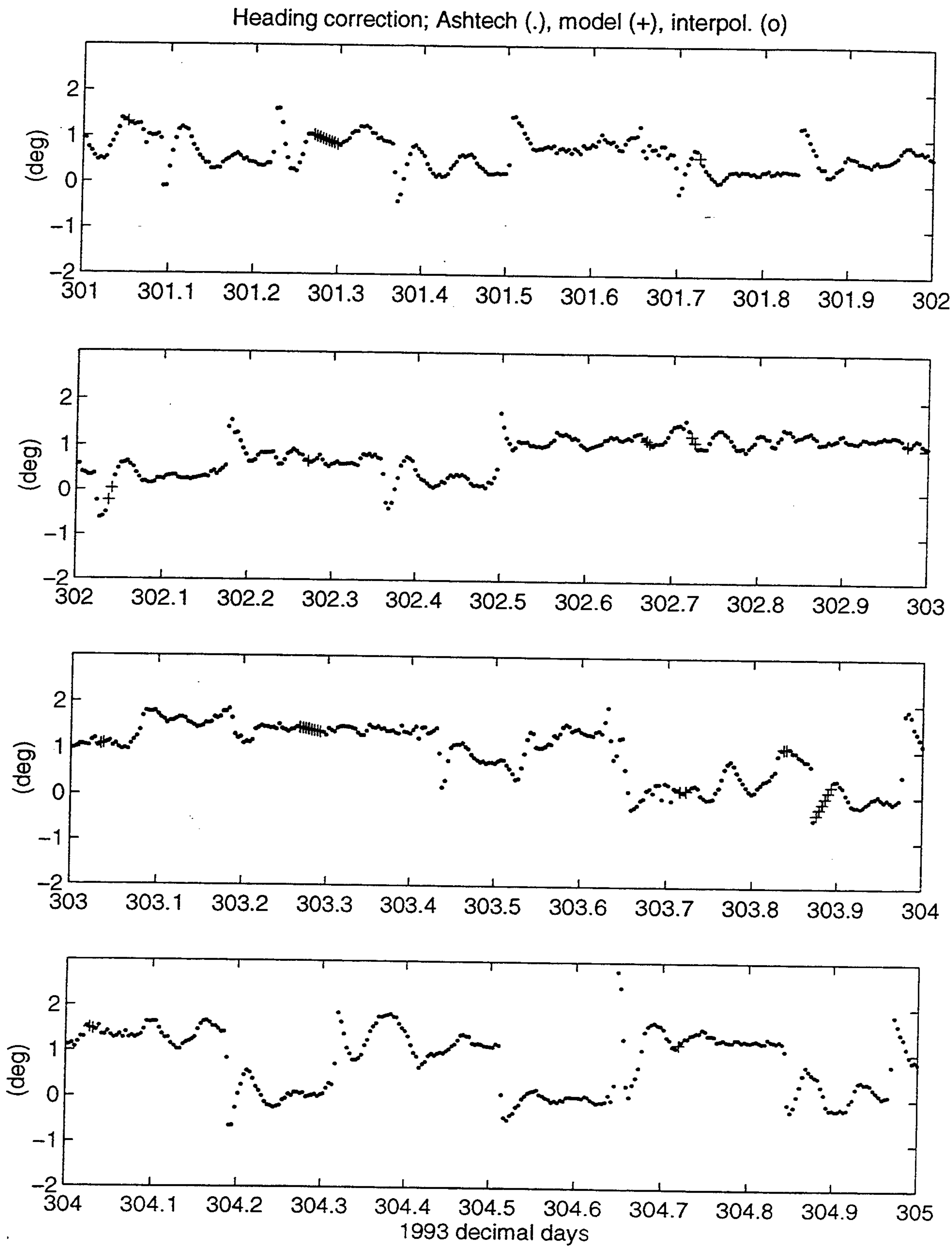
Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
2
1
0
-1
-2
289
289.1
289.2
289.3
289.4
289.5
289.6
289.7
289.8
289.9
290
290.1
290.2
290.3
290.4
290.5
290.6
290.7
290.8
290.9
291
291.1
291.2
291.3
291.4
291.5
291.6
291.7
291.8
291.9
292
292.1
292.2
292.3
292.4
292.5
292.6
292.7
292.8
292.9
293
1993 decimal days

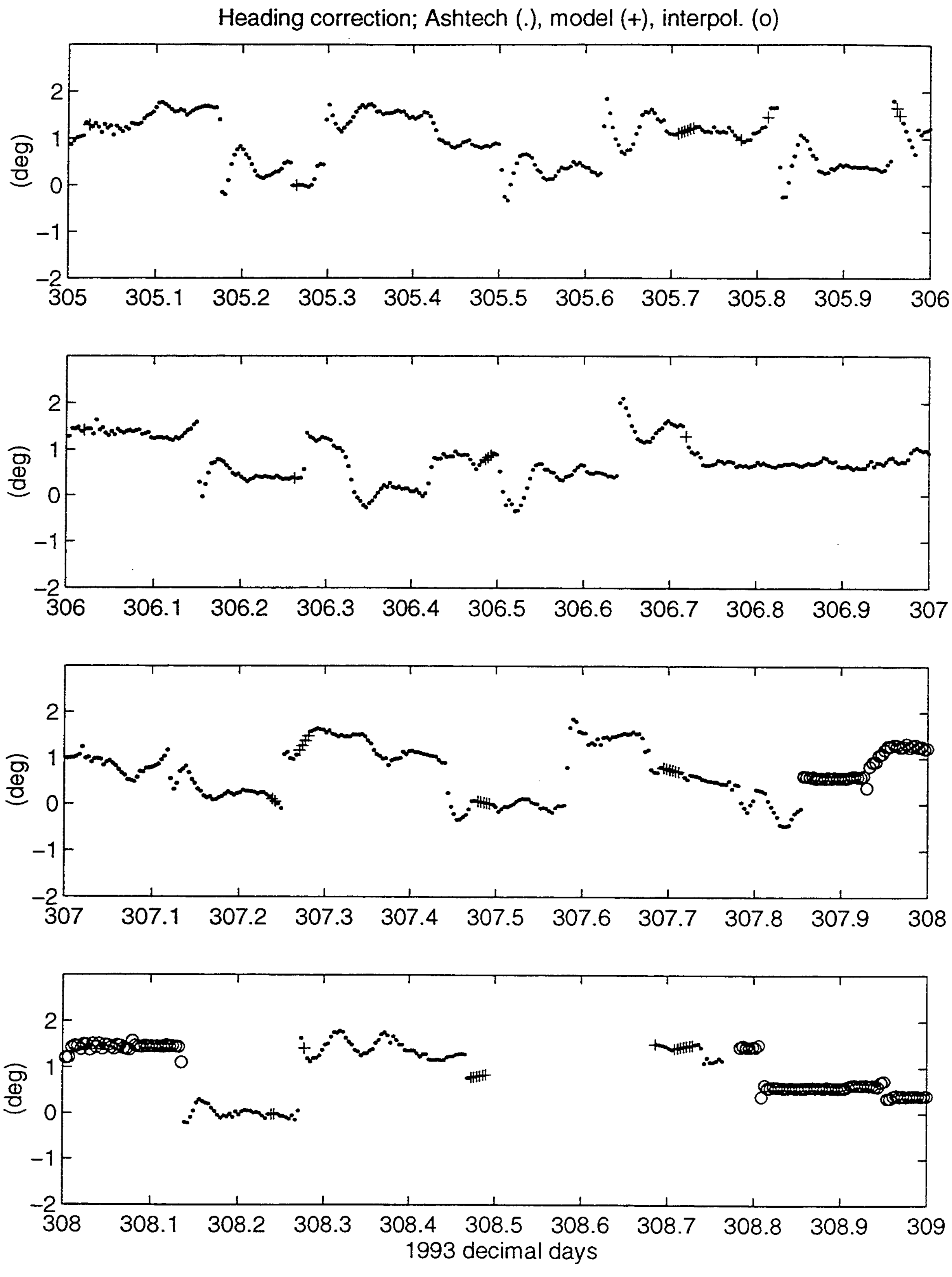


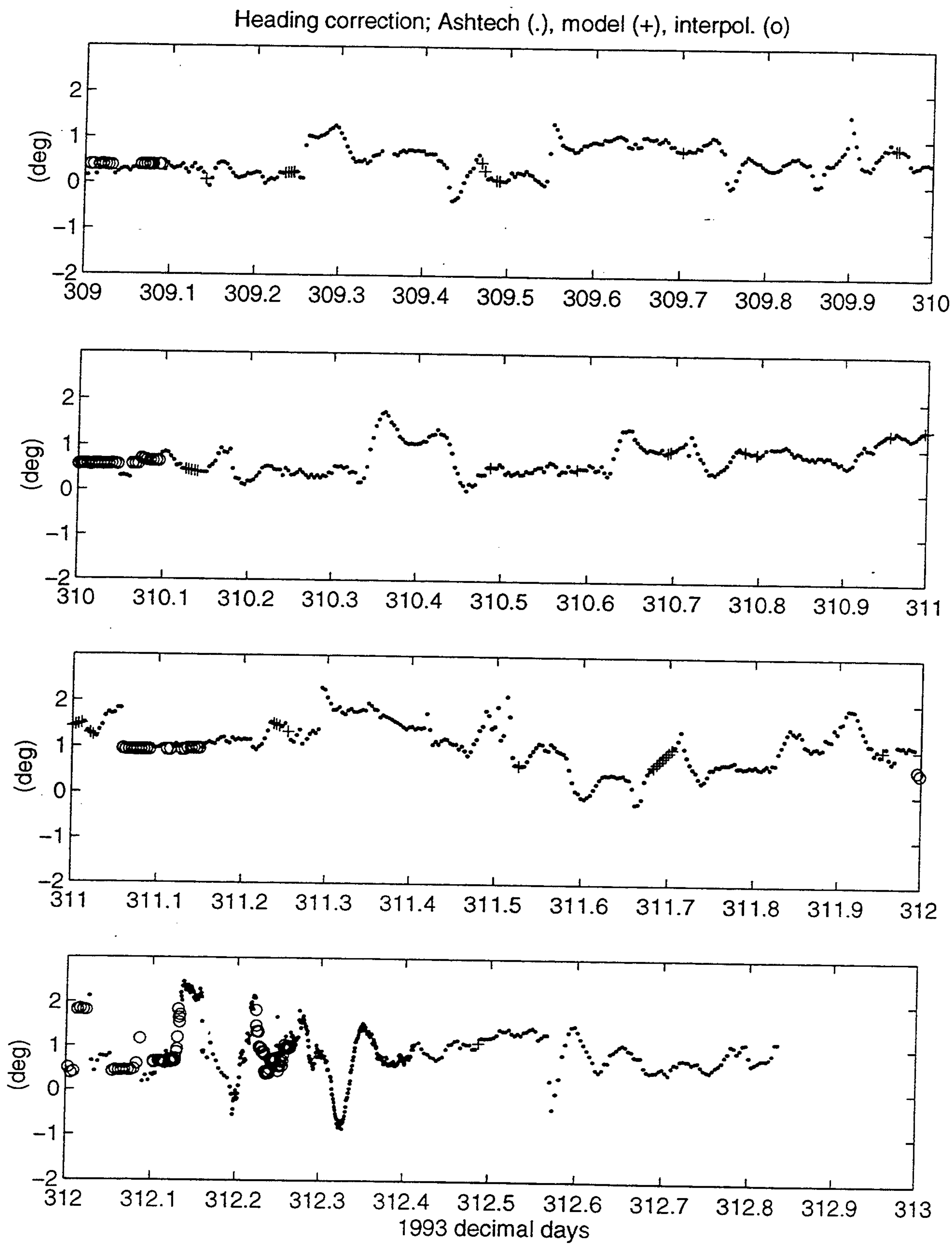
Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
1993 decimal days

Heading correction; Ashtech (.), model (+), interpol. (o)



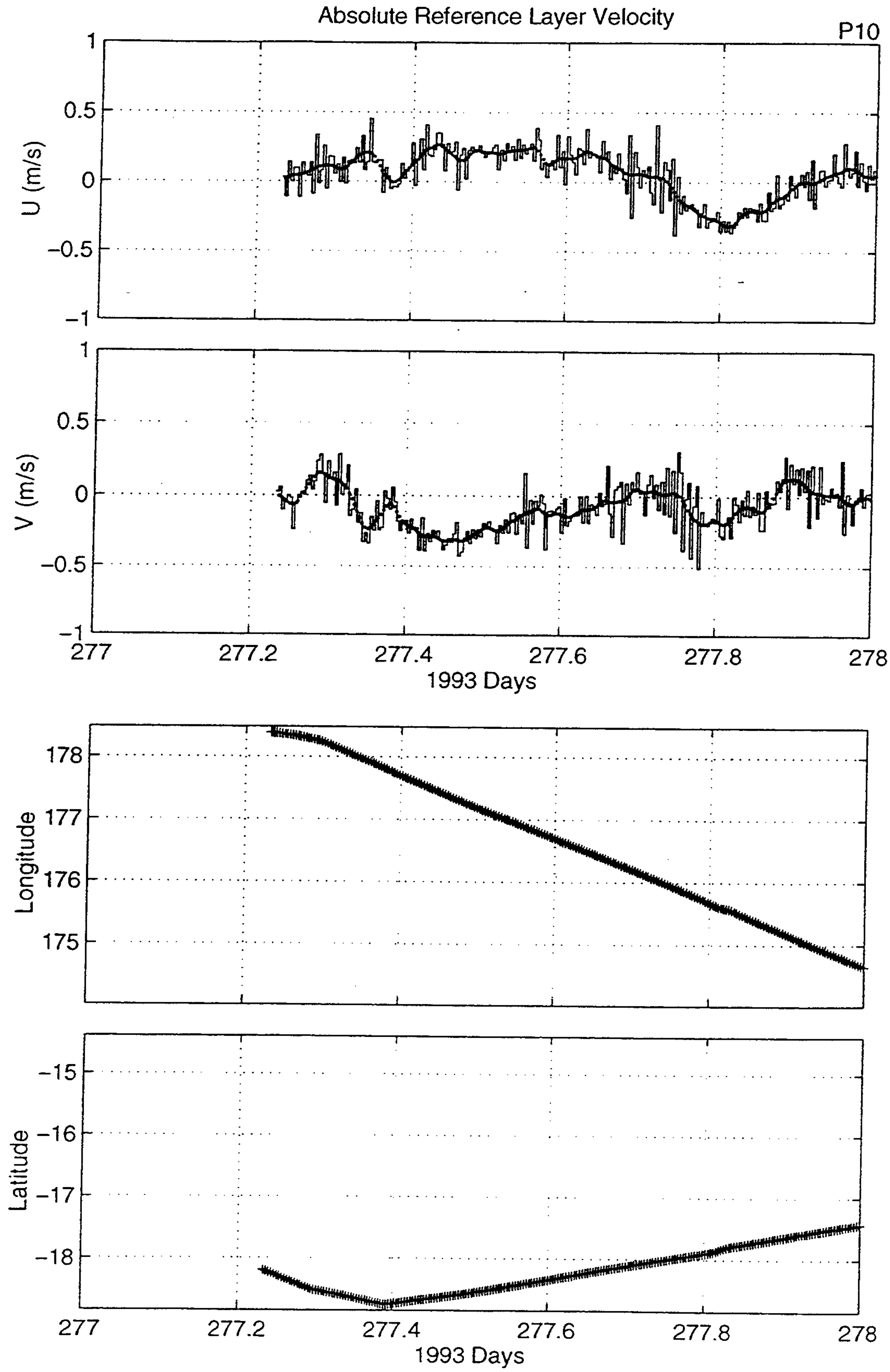

Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
2
1
0
−1
−2
301
301.1
301.2
301.3
301.4
301.5
301.6
301.7
301.8
301.9
302
302.1
302.2
302.3
302.4
302.5
302.6
302.7
302.8
302.9
303
303.1
303.2
303.3
303.4
303.5
303.6
303.7
303.8
303.9
304
304.1
304.2
304.3
304.4
304.5
304.6
304.7
304.8
304.9
305
1993 decimal days

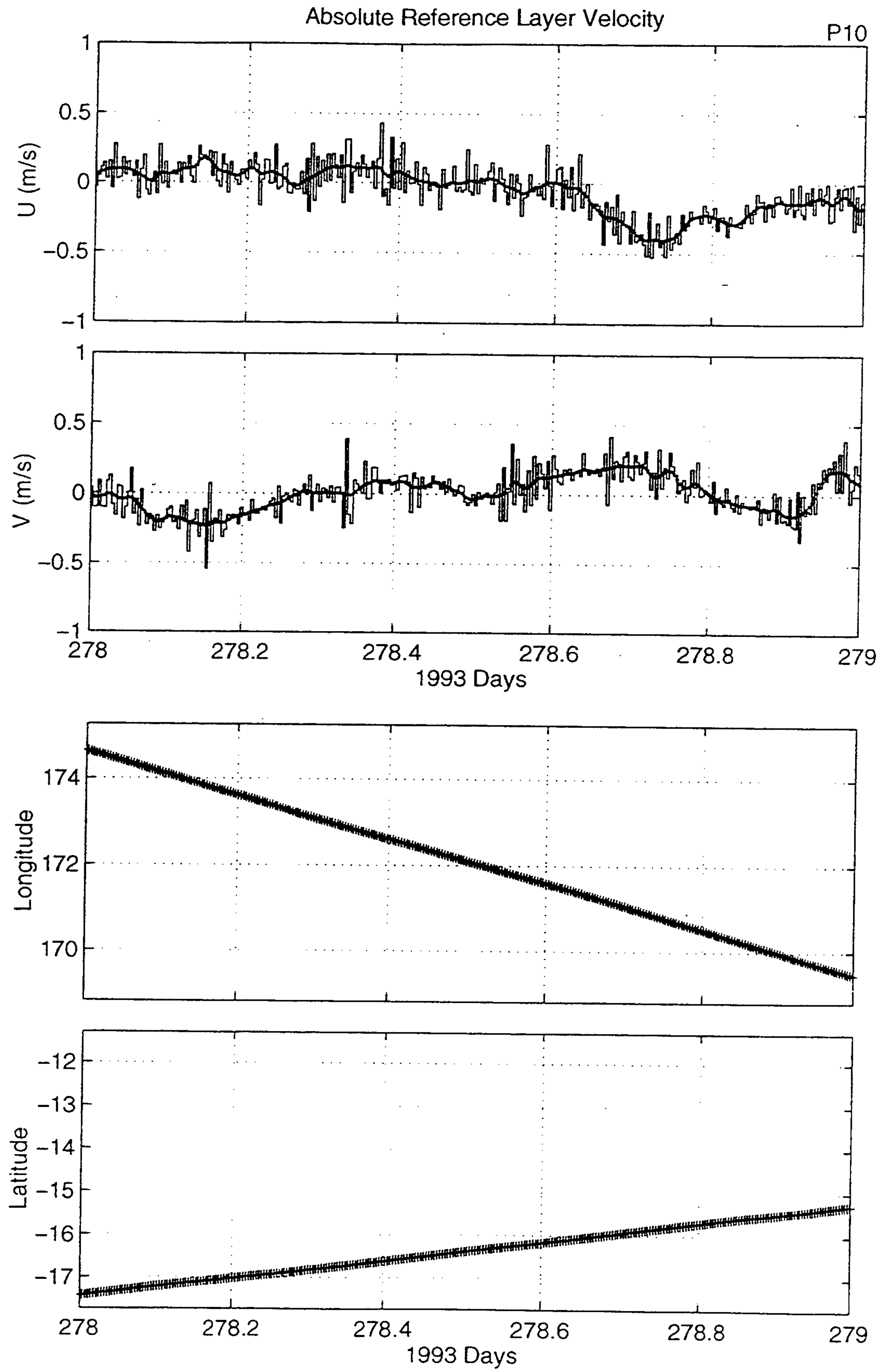

Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
2
1
0
−1
−2
305
305.1
305.2
305.3
305.4
305.5
305.6
305.7
305.8
305.9
306
306.1
306.2
306.3
306.4
306.5
306.6
306.7
306.8
306.9
307
307.1
307.2
307.3
307.4
307.5
307.6
307.7
307.8
307.9
308
308.1
308.2
308.3
308.4
308.5
308.6
308.7
308.8
308.9
309
1993 decimal days

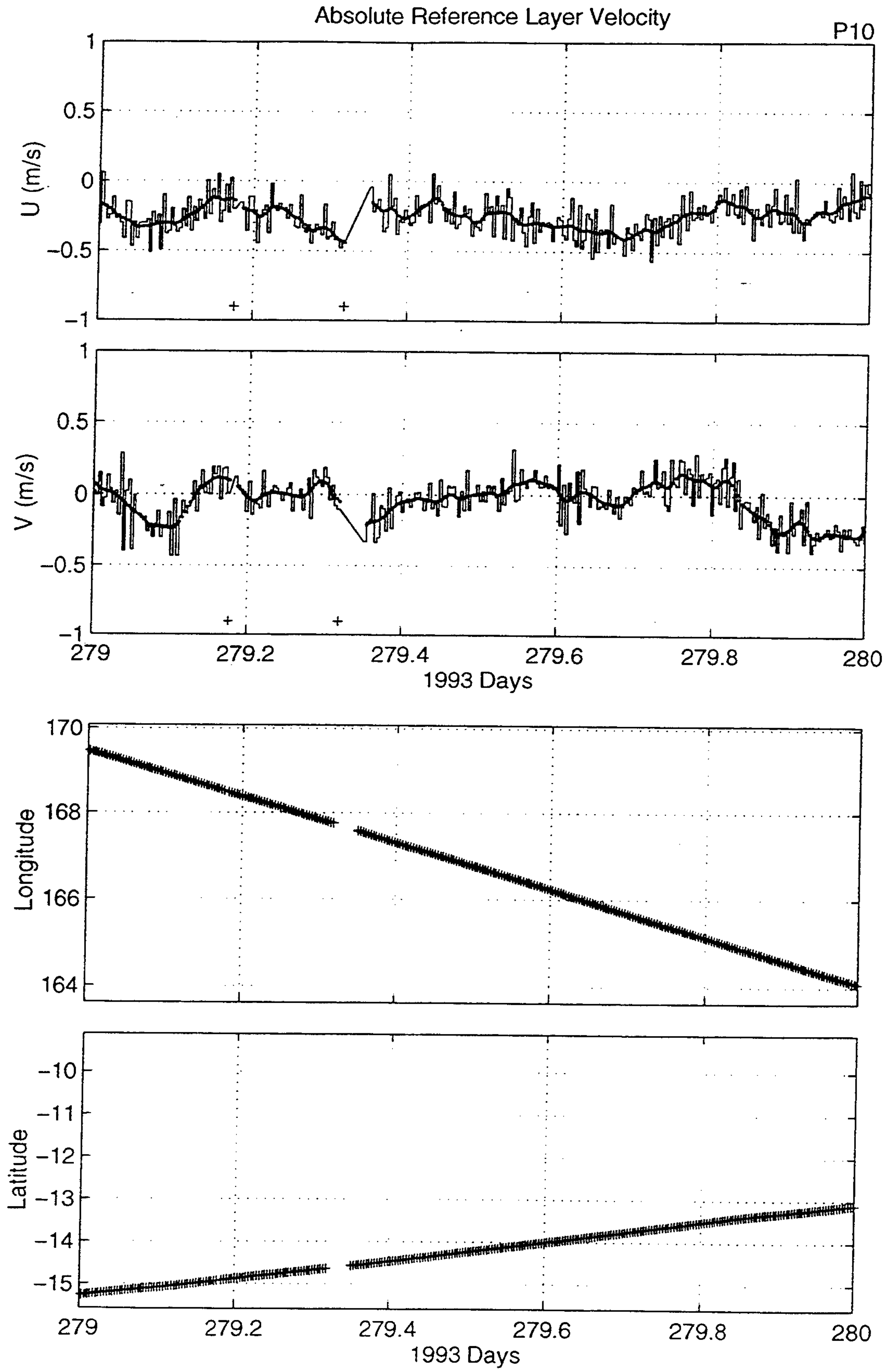

Heading correction; Ashtech (.), model (+), interpol. (o)
(deg)
2
1
0
−1
−2
309
309.1
309.2
309.3
309.4
309.5
309.6
309.7
309.8
309.9
310
310.1
310.2
310.3
310.4
310.5
310.6
310.7
310.8
310.9
311
311.1
311.2
311.3
311.4
311.5
311.6
311.7
311.8
311.9
312
312.1
312.2
312.3
312.4
312.5
312.6
312.7
312.8
312.9
313
1993 decimal days

Appendix D: Absolute Reference Layer Velocity

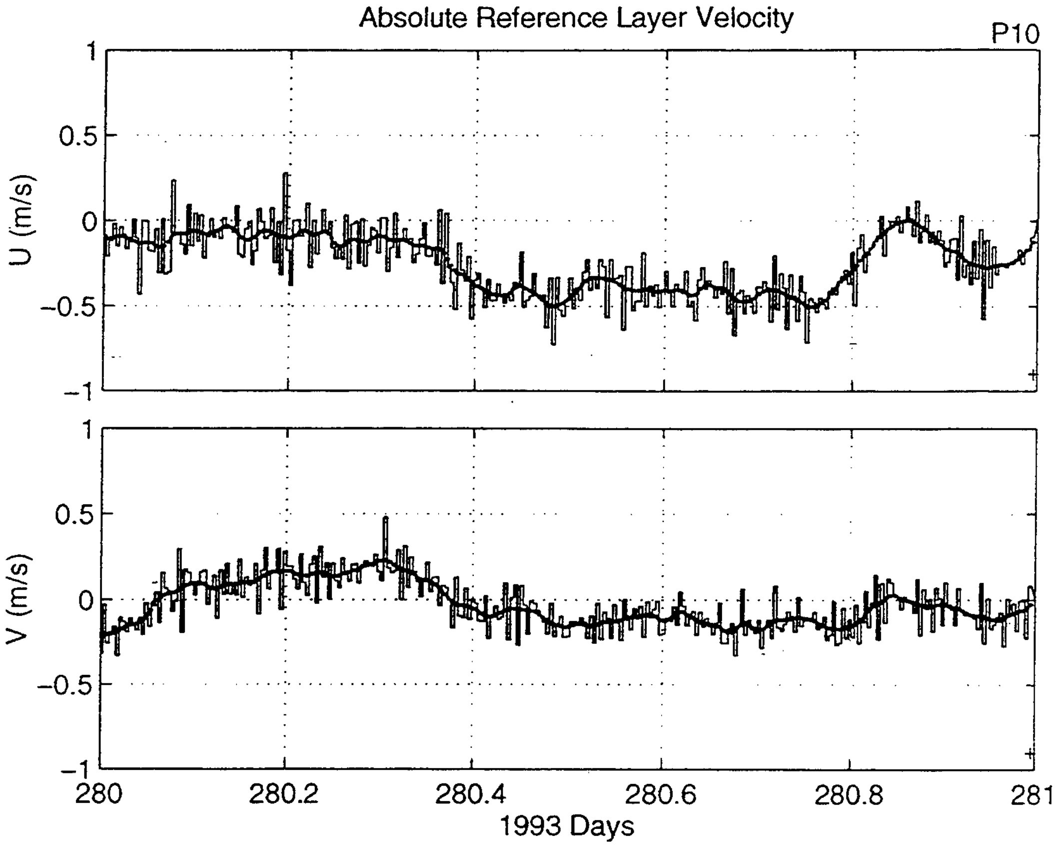
For each day of the cruise, the top halves of following pages show the absolute reference layer velocity averaged between fixes (piecewise constant) and smoothed (series of dots). A velocity scale of ±1m/s was sufficient for most of the cruise, but days 310 and 311 from the Kuroshio crossing had to be plotted with a scale of ±1.75 m/s as well. The bottom halves show longitude and latitude as function of time.


Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days

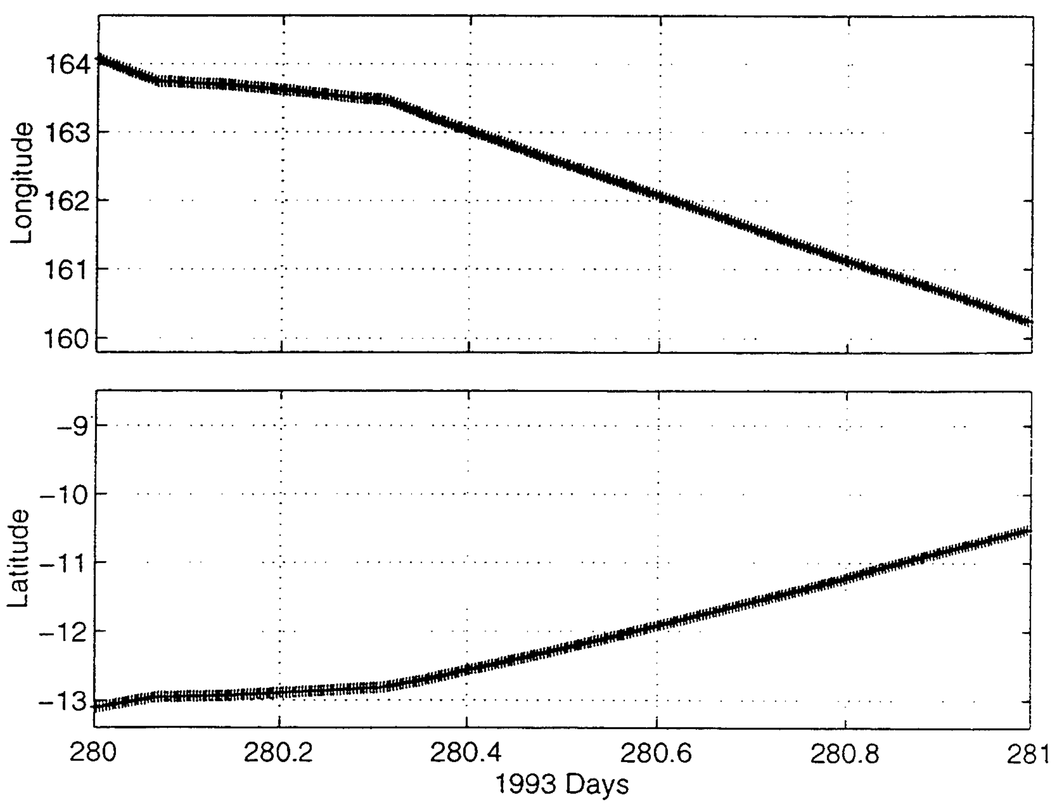

Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days



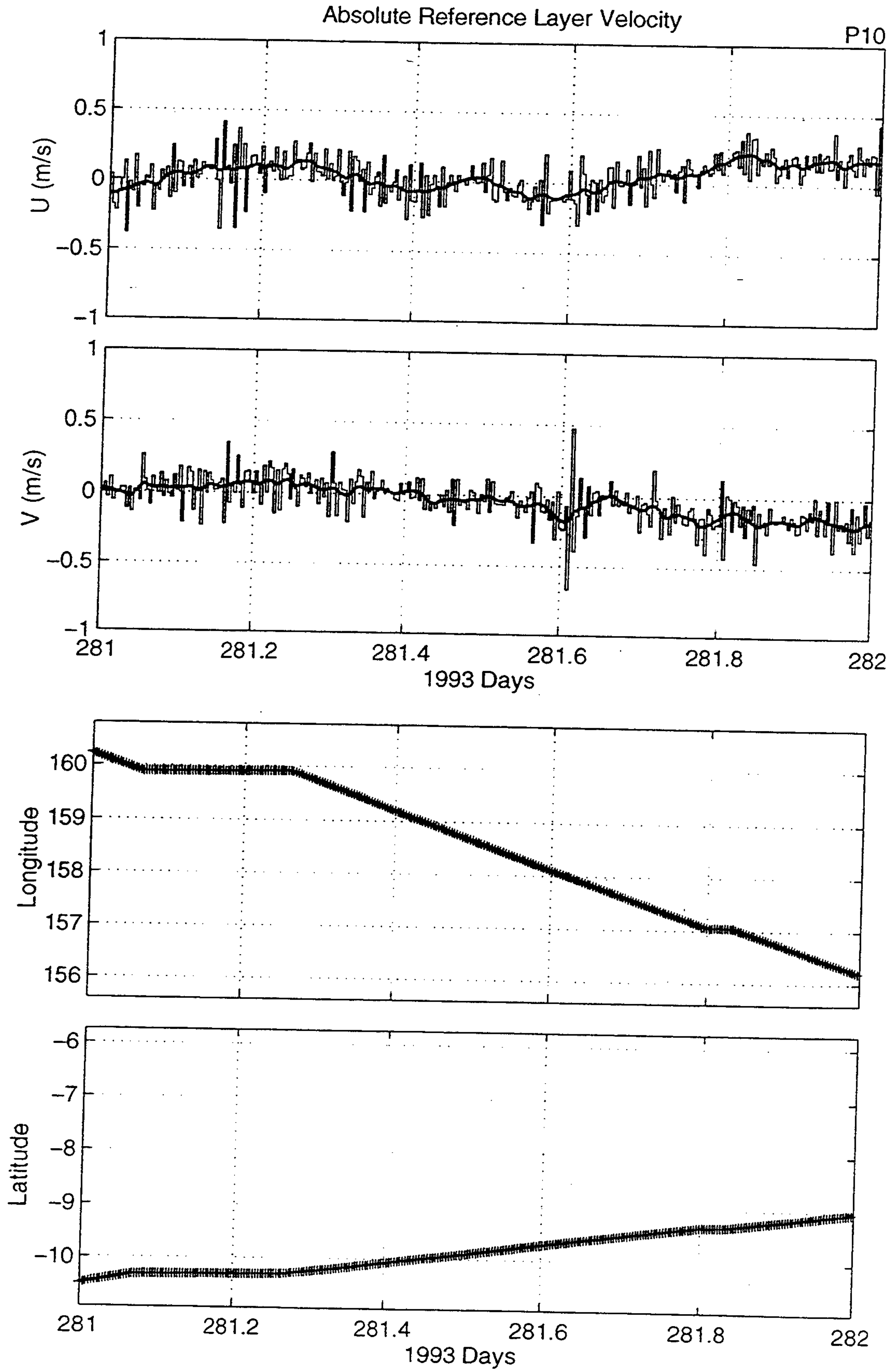
Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
279
279.2
279.4
279.6
279.8
280

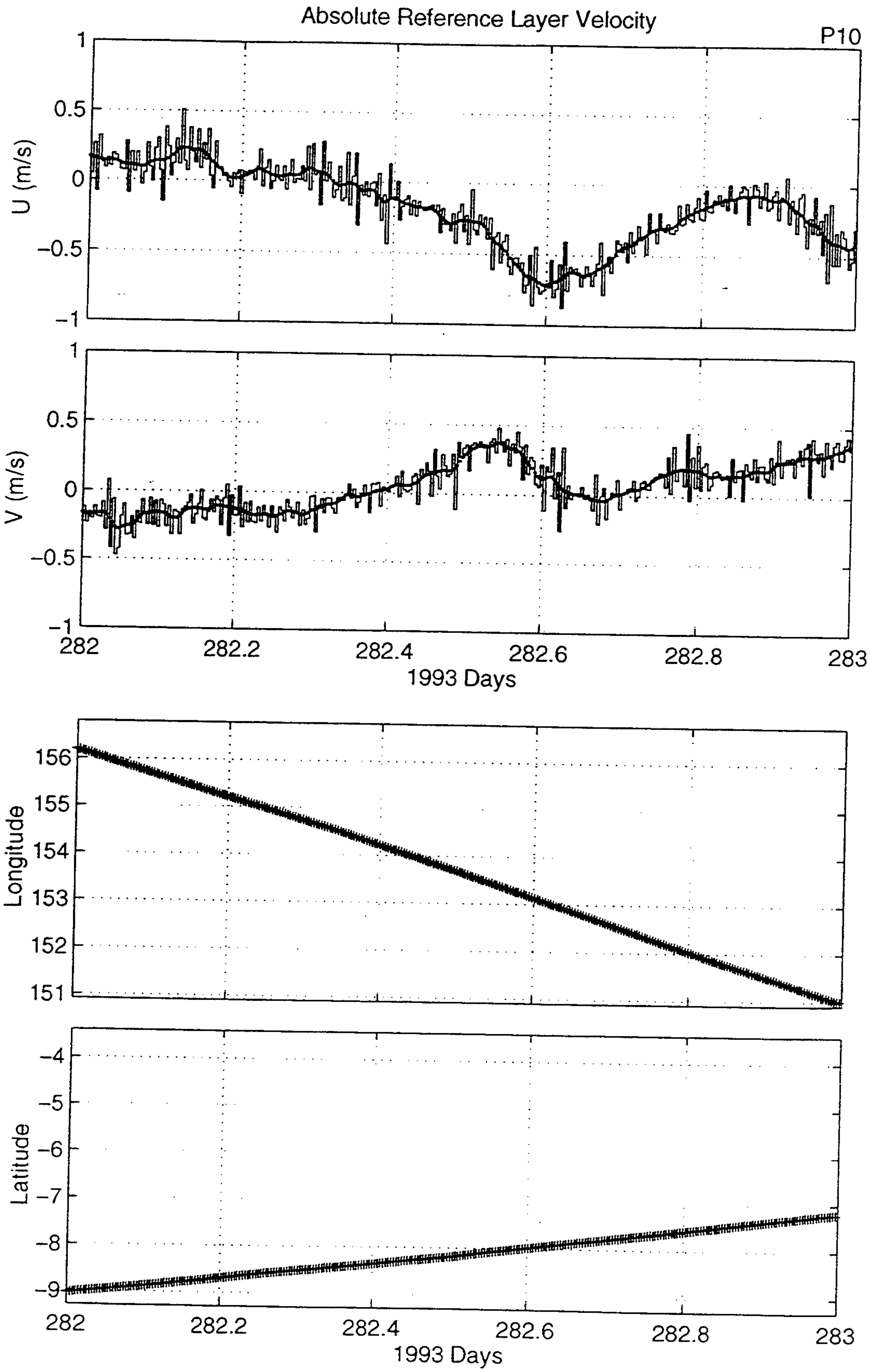


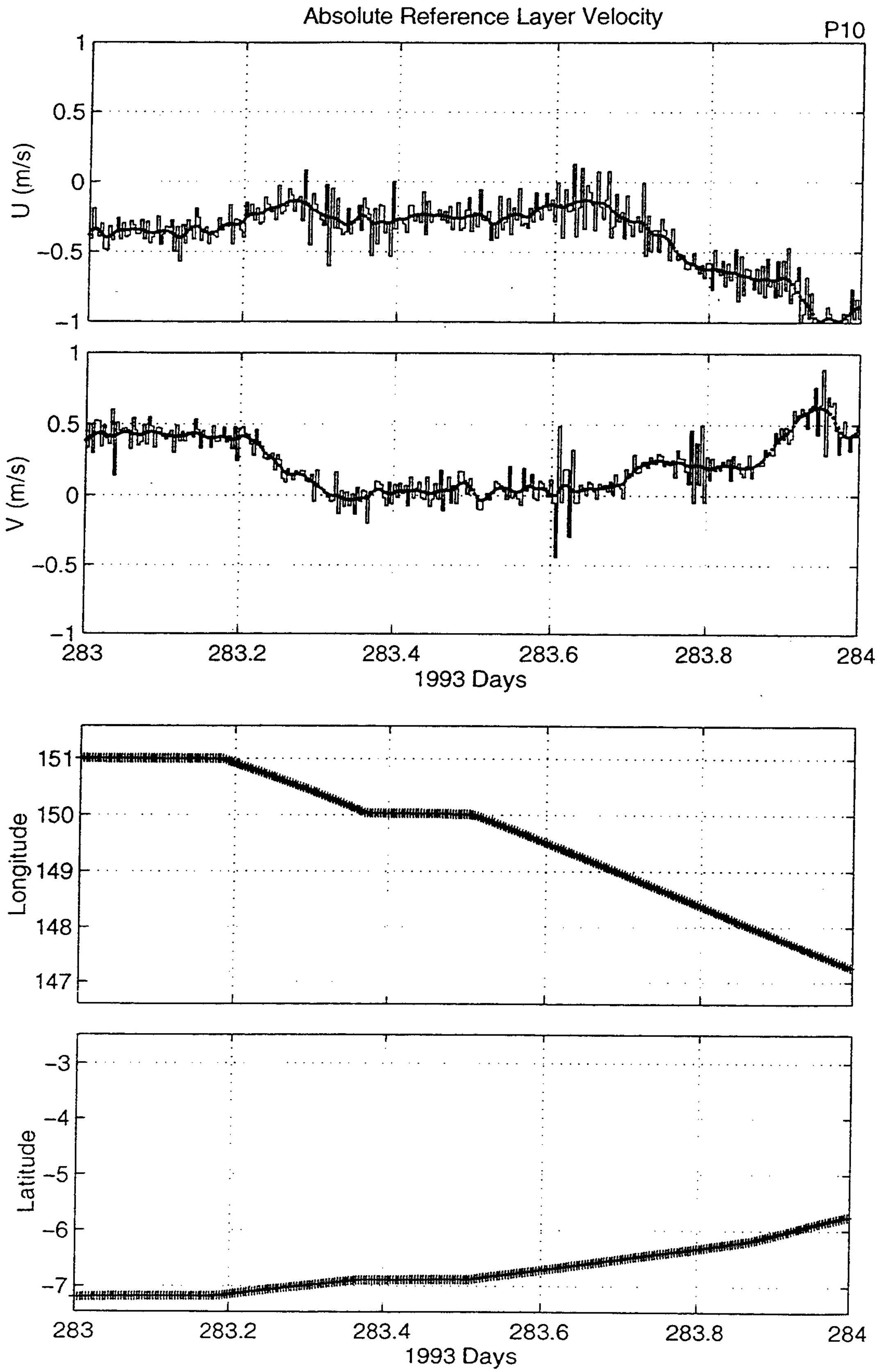
Absolute Reference Layer Velocity
P10
U (m/s)
1
0.5
0
−0.5
−1
V (m/s)
1
0.5
0
−0.5
−1
280
280.2
280.4
280.6
280.8
281
1993 Days



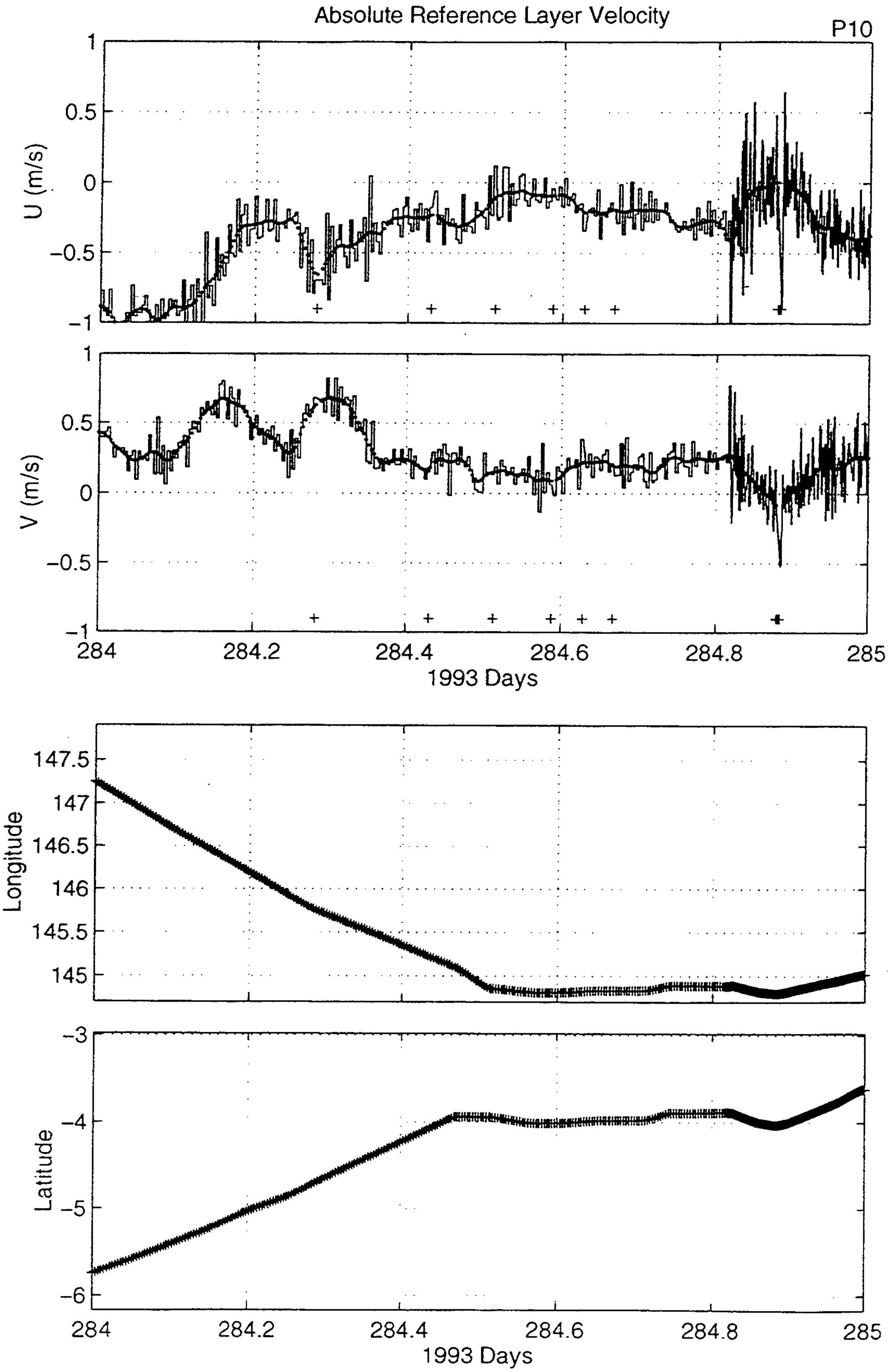
Longitude
164
163
162
161
160
Latitude
−9
−10
−11
−12
−13
280
280.2
280.4
280.6
280.8
281
1993 Days

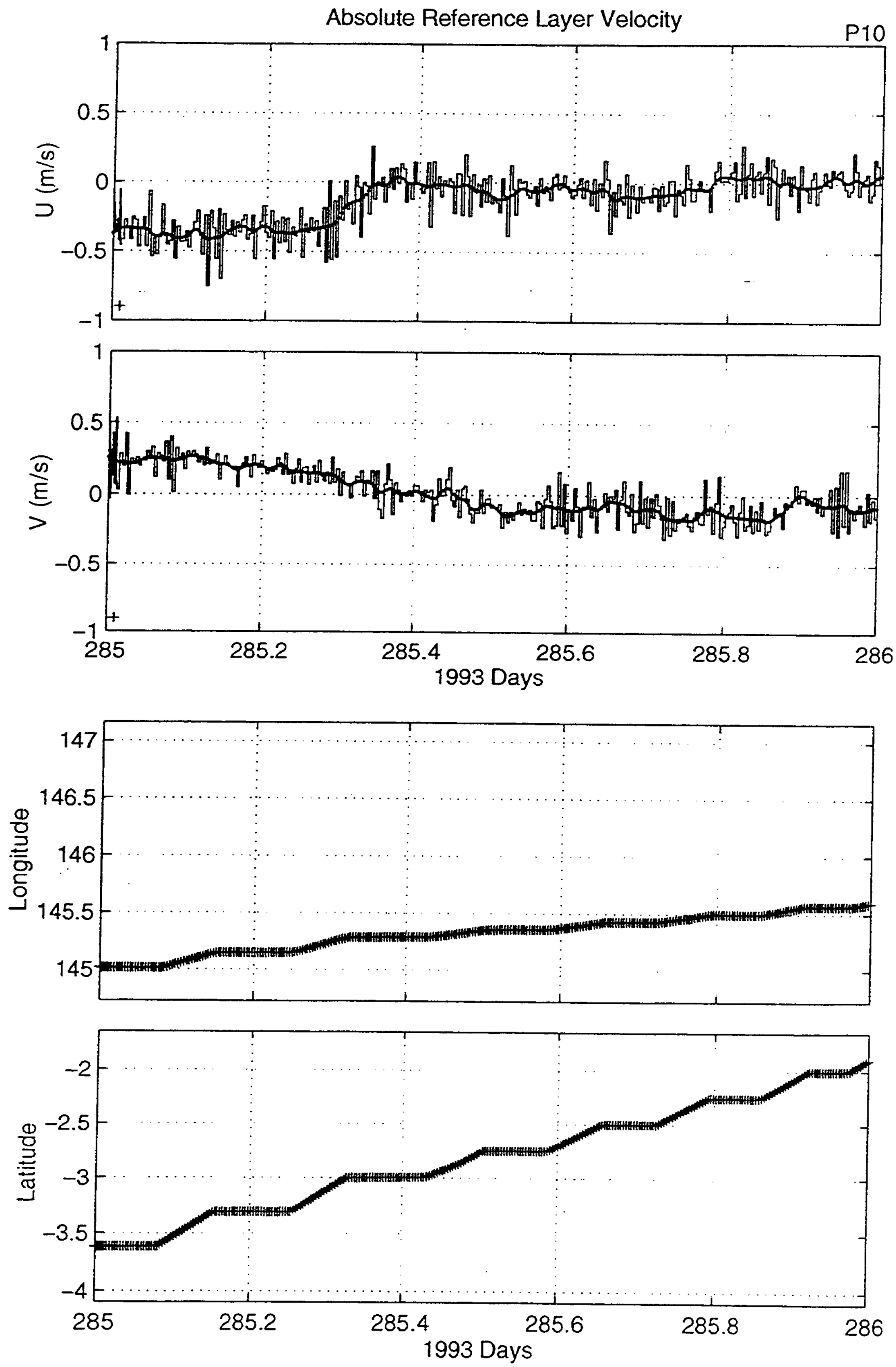

Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days

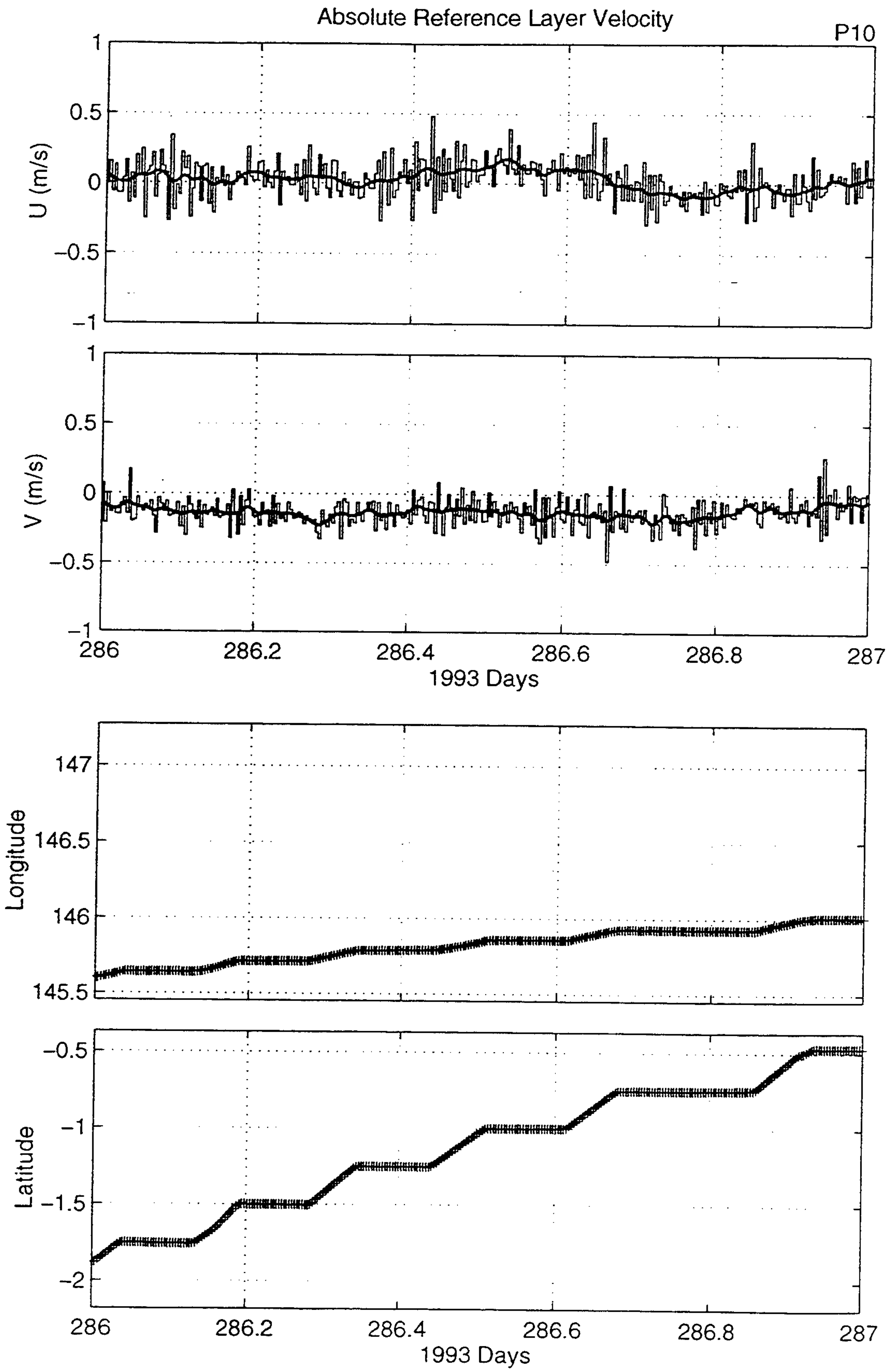

Absolute Reference Layer Velocity
P10
U (m/s)
1
0.5
0
−0.5
−1
V (m/s)
1
0.5
0
−0.5
−1
282
282.2
282.4
282.6
282.8
283
1993 Days
Longitude
156
155
154
153
152
151
Latitude
−4
−5
−6
−7
−8
−9
282
282.2
282.4
282.6
282.8
283
1993 Days



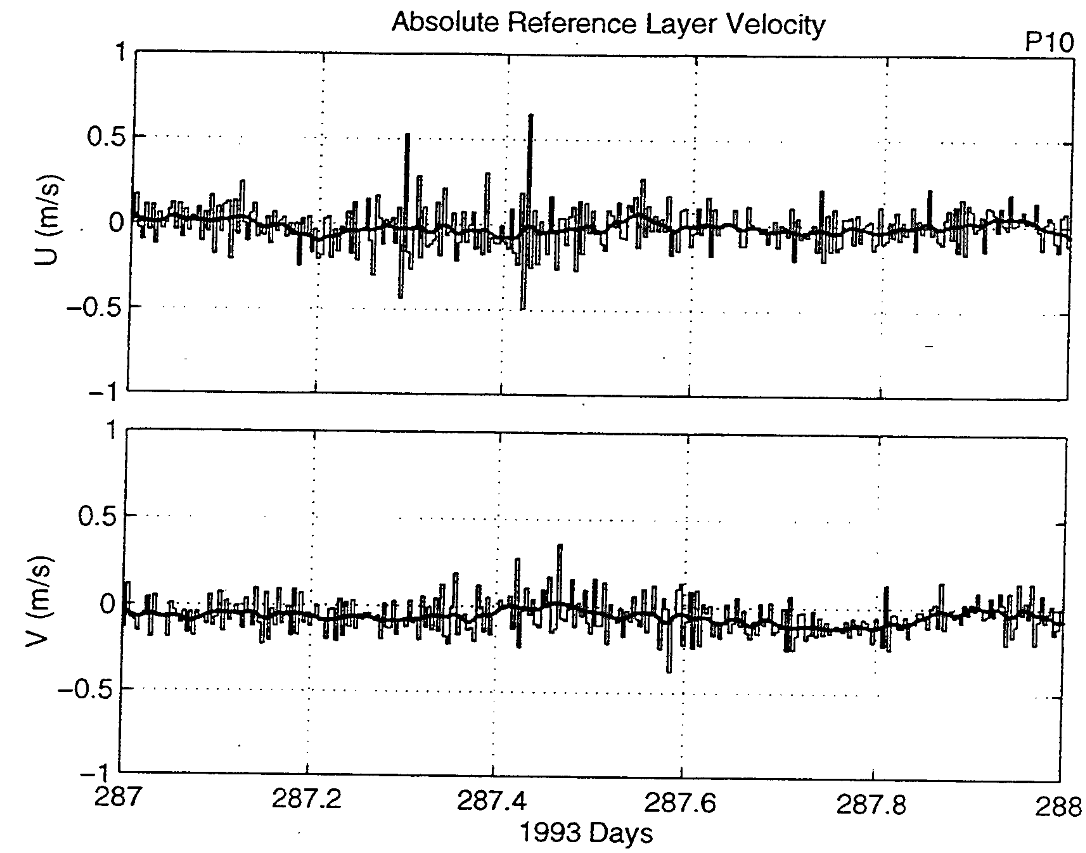
Absolute Reference Layer Velocity
P10
U (m/s)
1
0.5
0
−0.5
−1
V (m/s)
1
0.5
0
−0.5
−1
283
283.2
283.4
283.6
283.8
284
1993 Days
Longitude
151
150
149
148
147
Latitude
−3
−4
−5
−6
−7
283
283.2
283.4
283.6
283.8
284
1993 Days

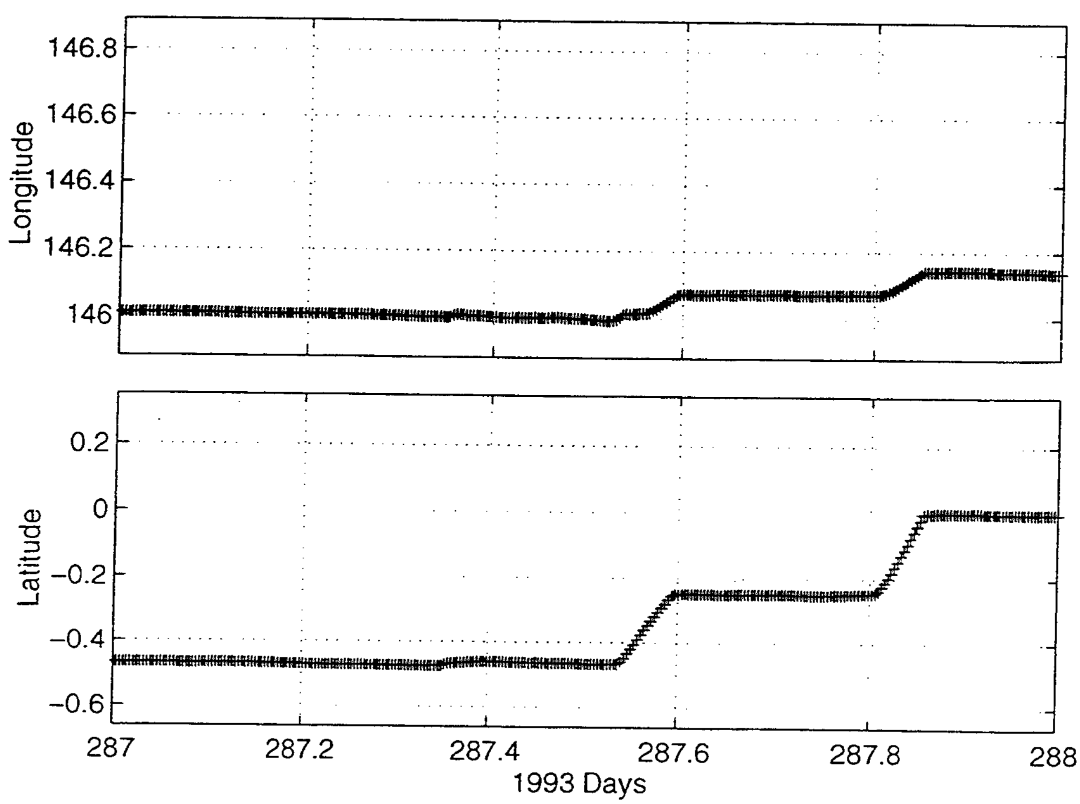

Absolute Reference Layer Velocity
P10
U (m/s)
1
0.5
0
−0.5
−1
V (m/s)
1
0.5
0
−0.5
−1
284
284.2
284.4
284.6
284.8
285
1993 Days
Longitude
147.5
147
146.5
146
145.5
145
Latitude
−3
−4
−5
−6
284
284.2
284.4
284.6
284.8
285
1993 Days

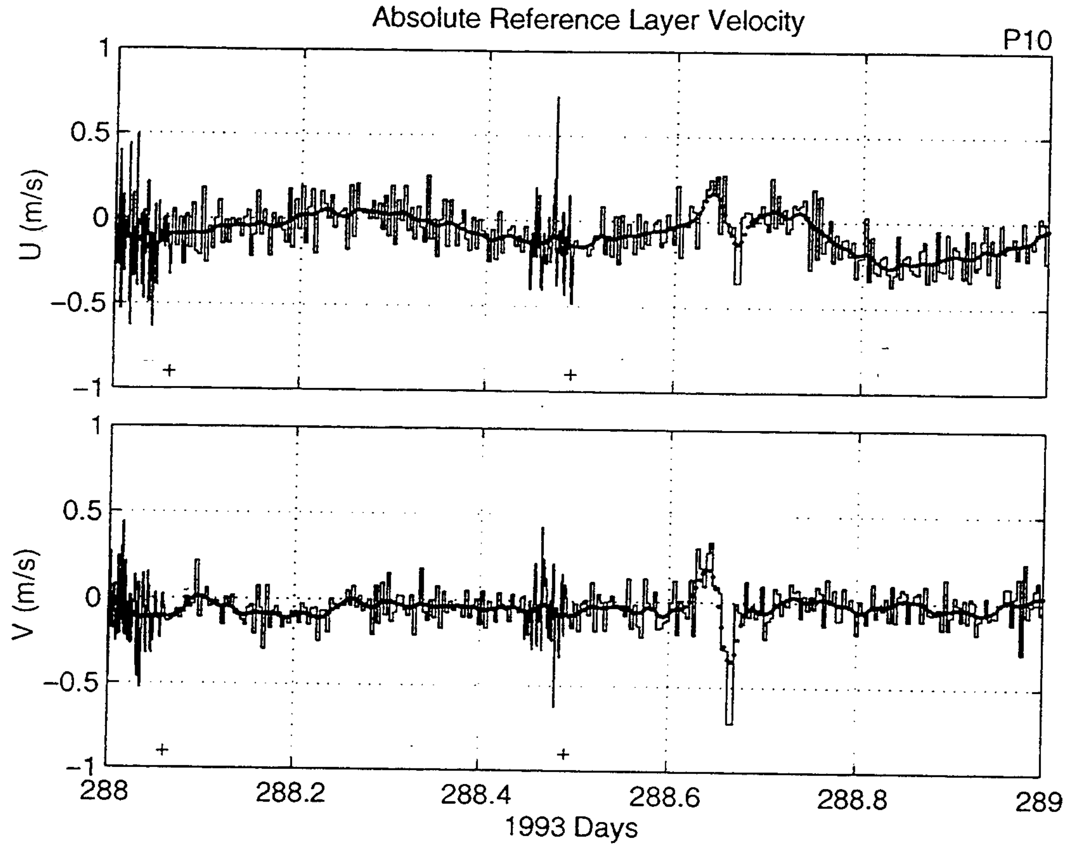

Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days
285
285.2
285.4
285.6
285.8
286

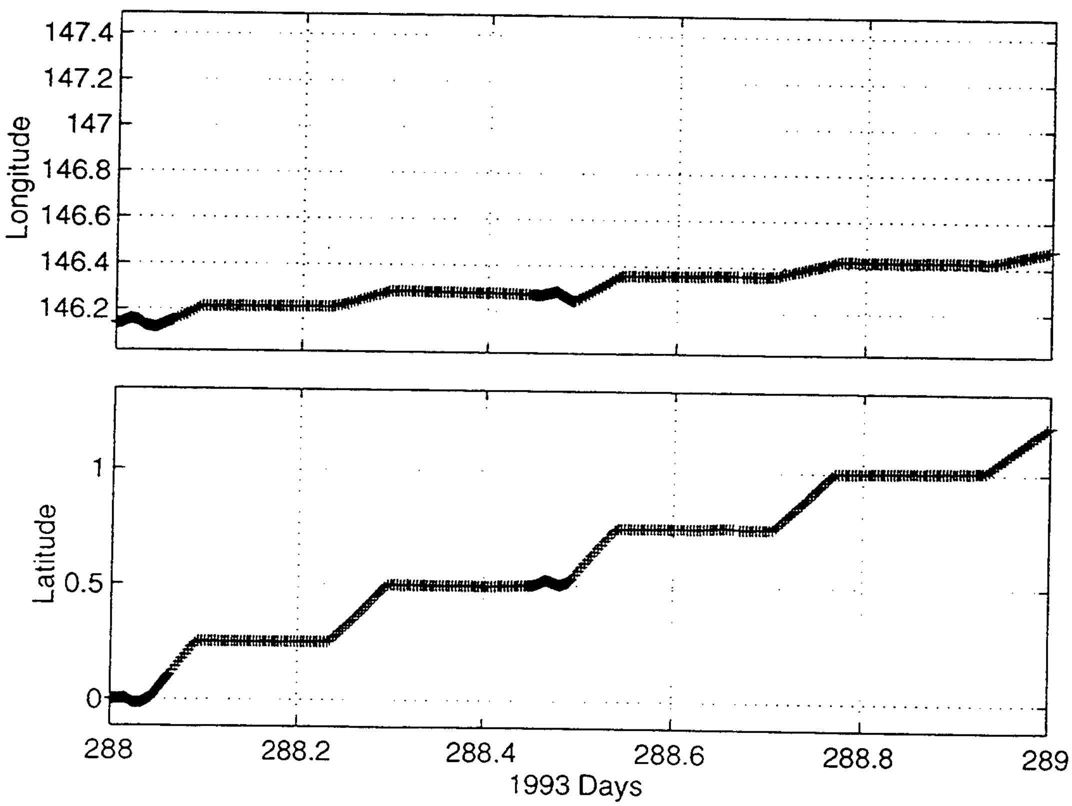


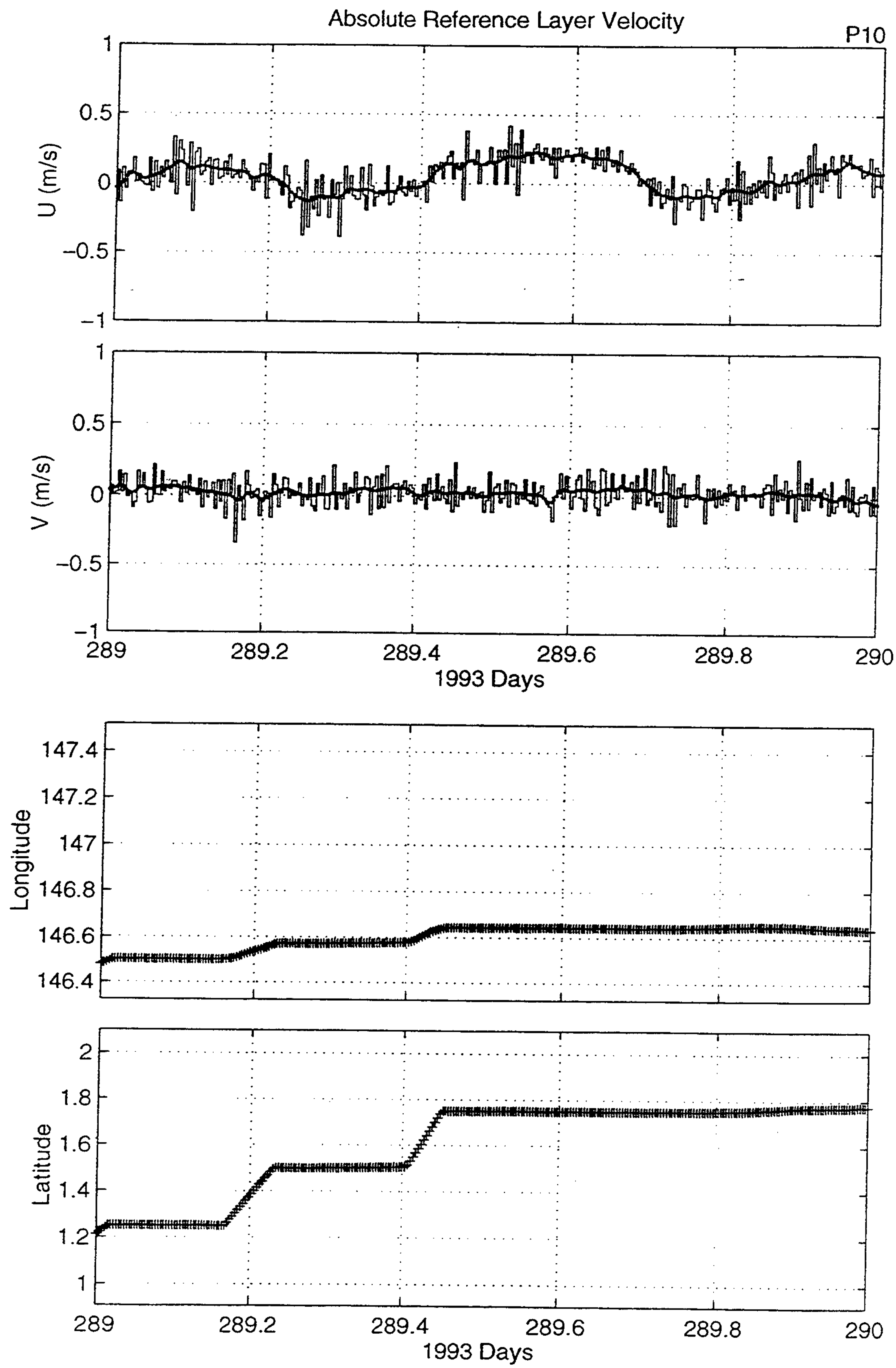
Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days

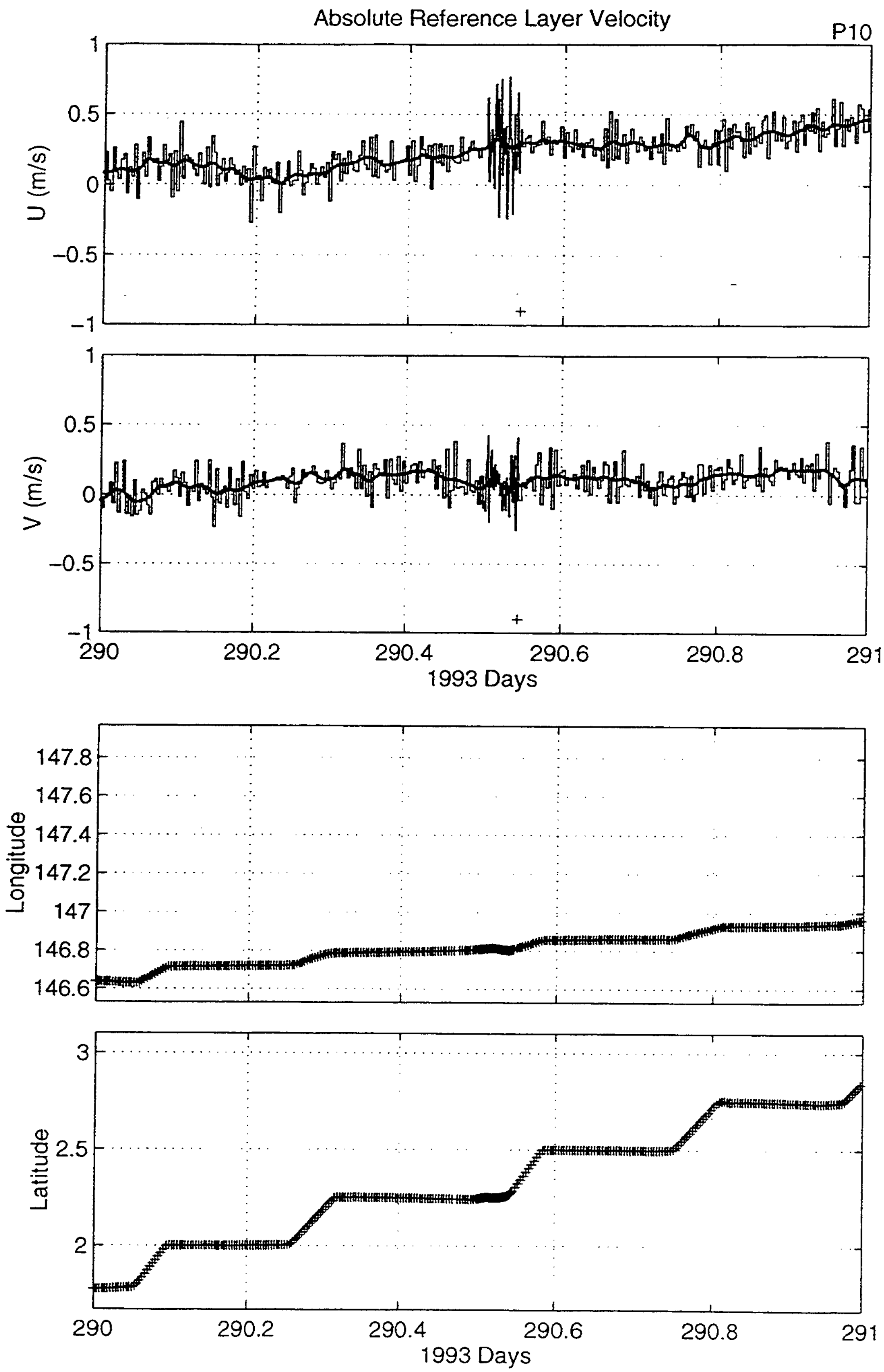

Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1
0.5
0
−0.5
−1
287
287.2
287.4
287.6
287.8
288
1993 Days


Longitude
146.8
146.6
146.4
146.2
146
Latitude
0.2
0
−0.2
−0.4
−0.6
287
287.2
287.4
287.6
287.8
288
1993 Days

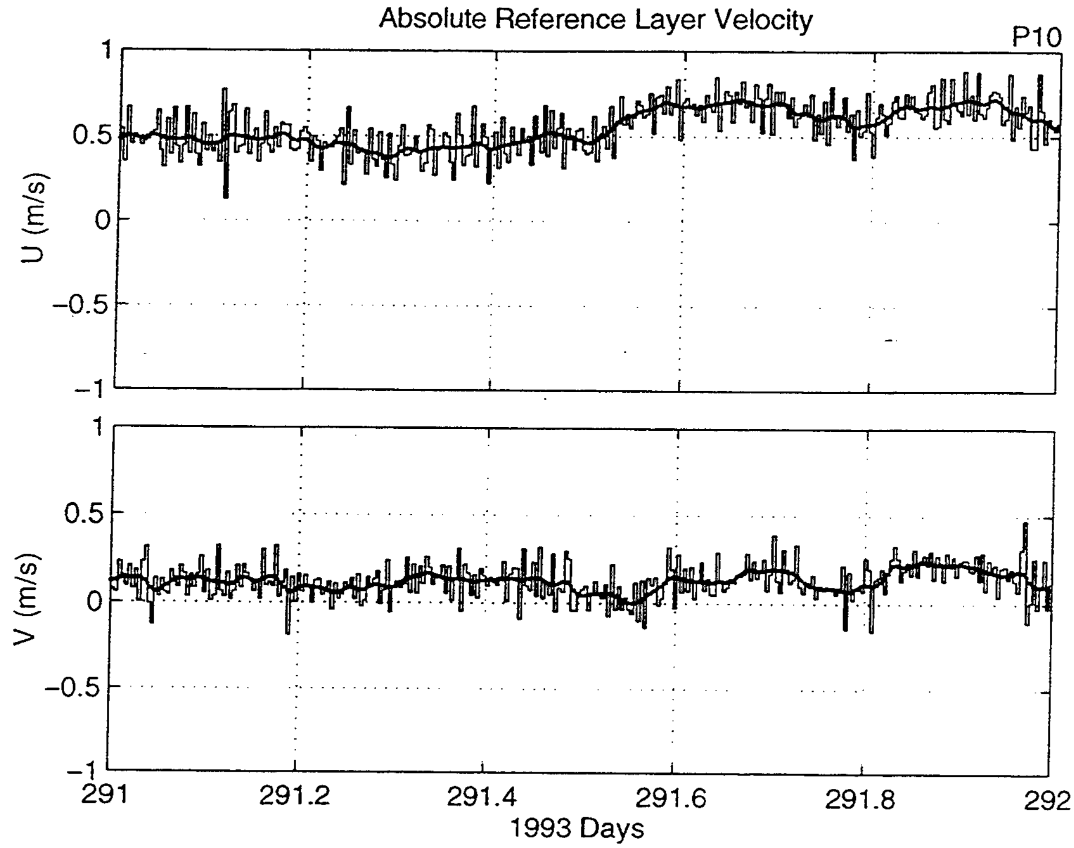

Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days

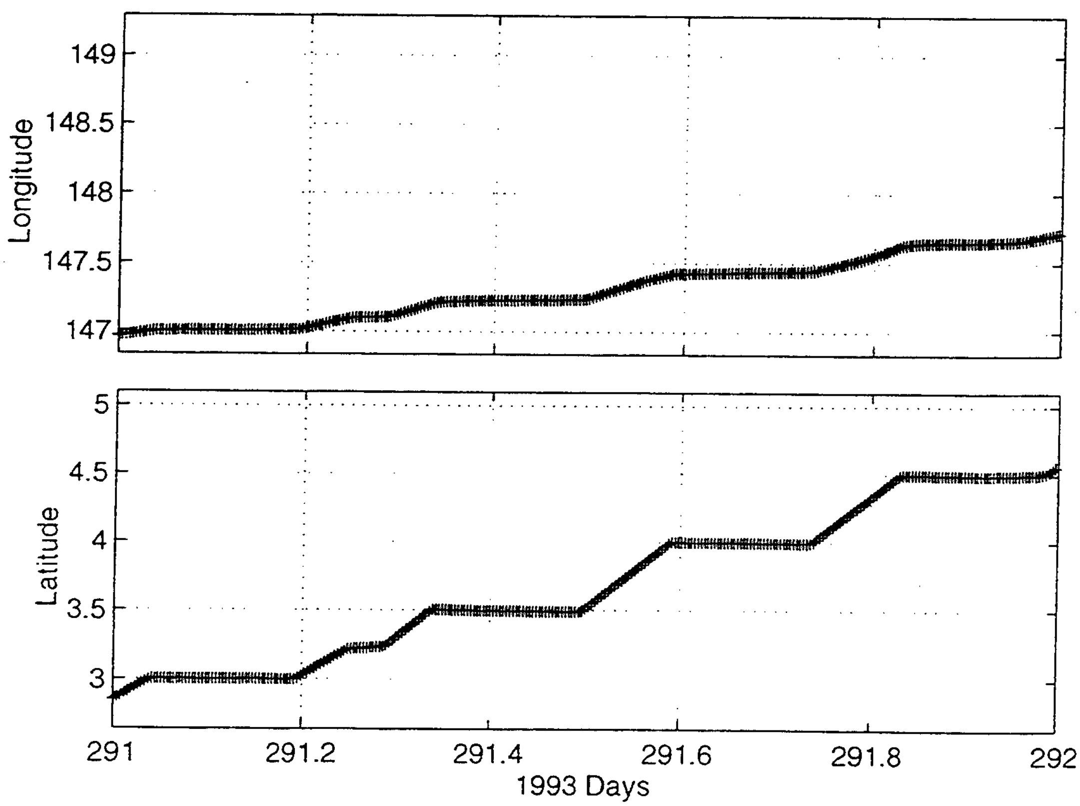

Longitude
Latitude
1993 Days

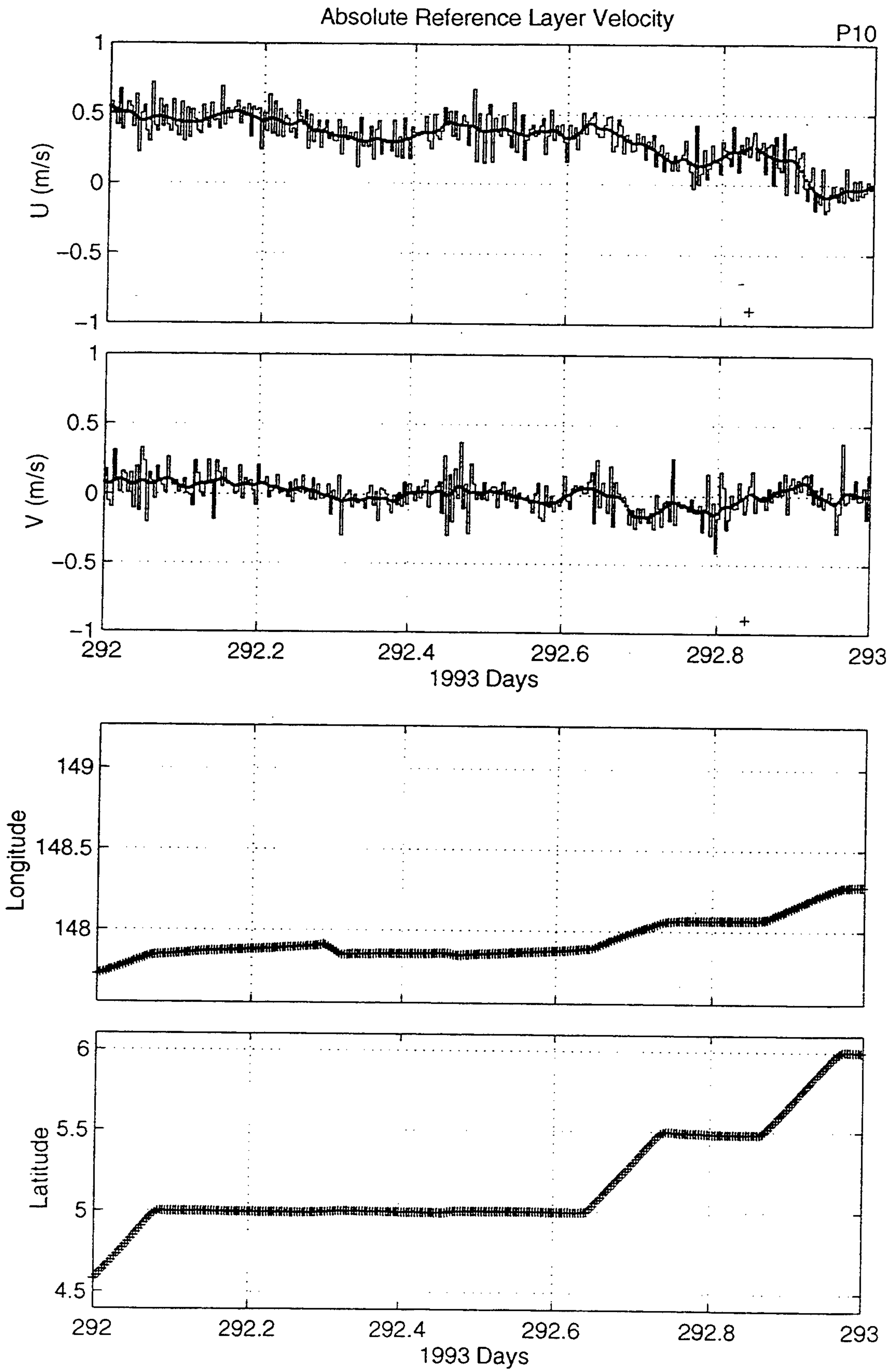

Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days



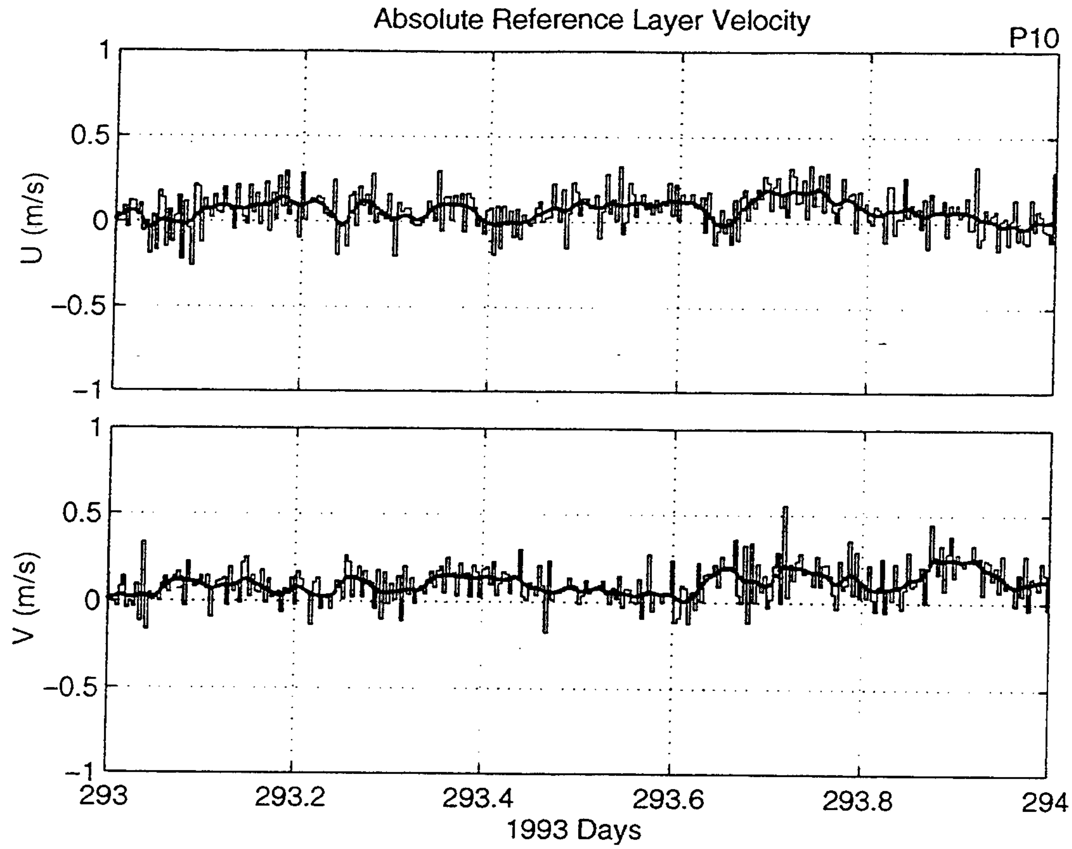
Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days

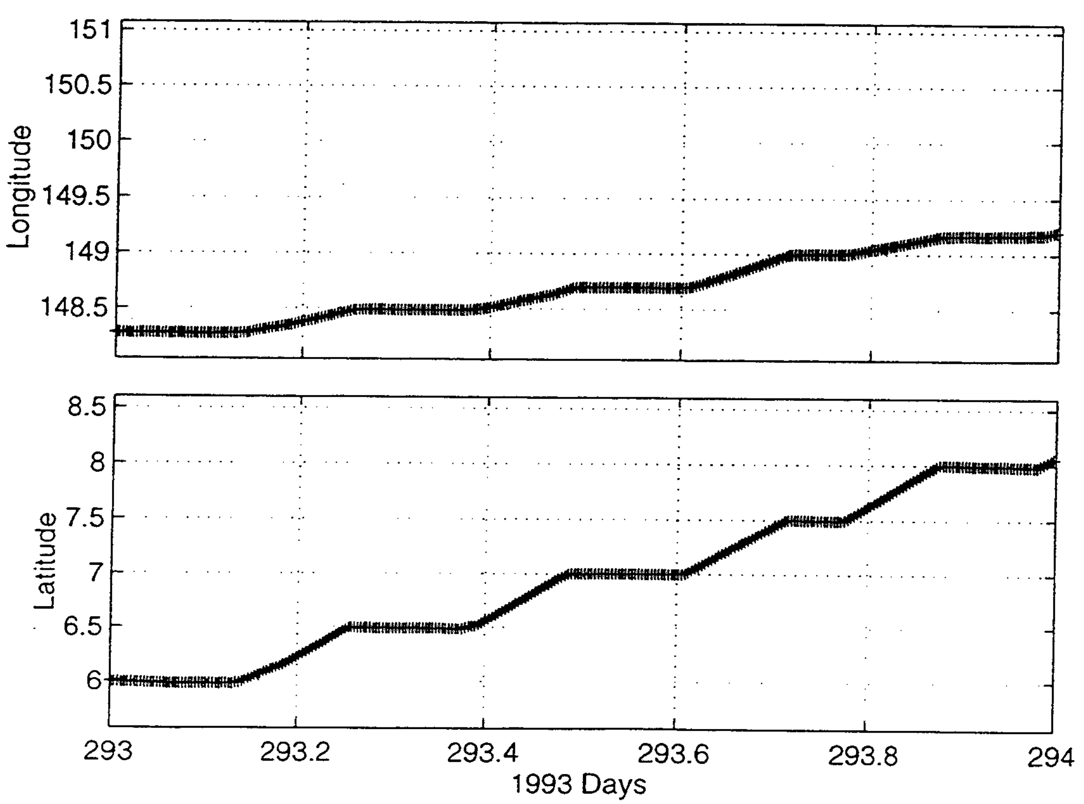

Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1
0.5
0
−0.5
−1
291
291.2
291.4
291.6
291.8
292
1993 Days

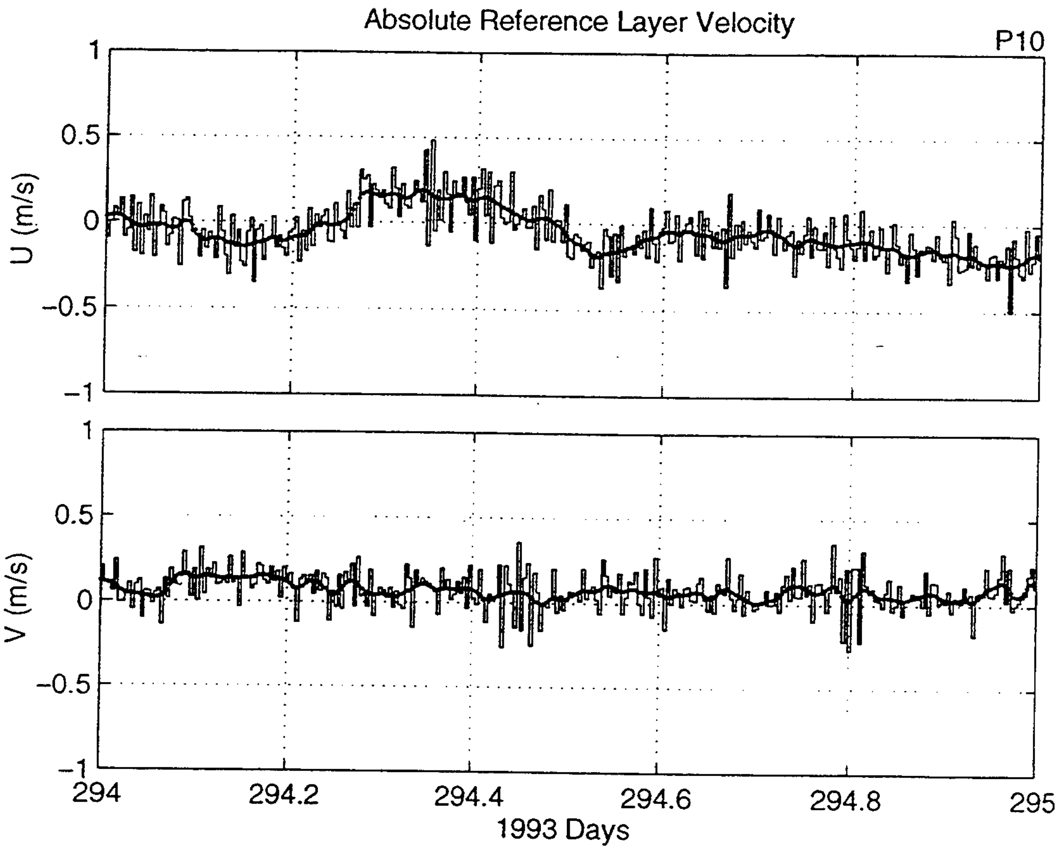

Longitude
149
148.5
148
147.5
147
Latitude
5
4.5
4
3.5
3
291
291.2
291.4
291.6
291.8
292
1993 Days

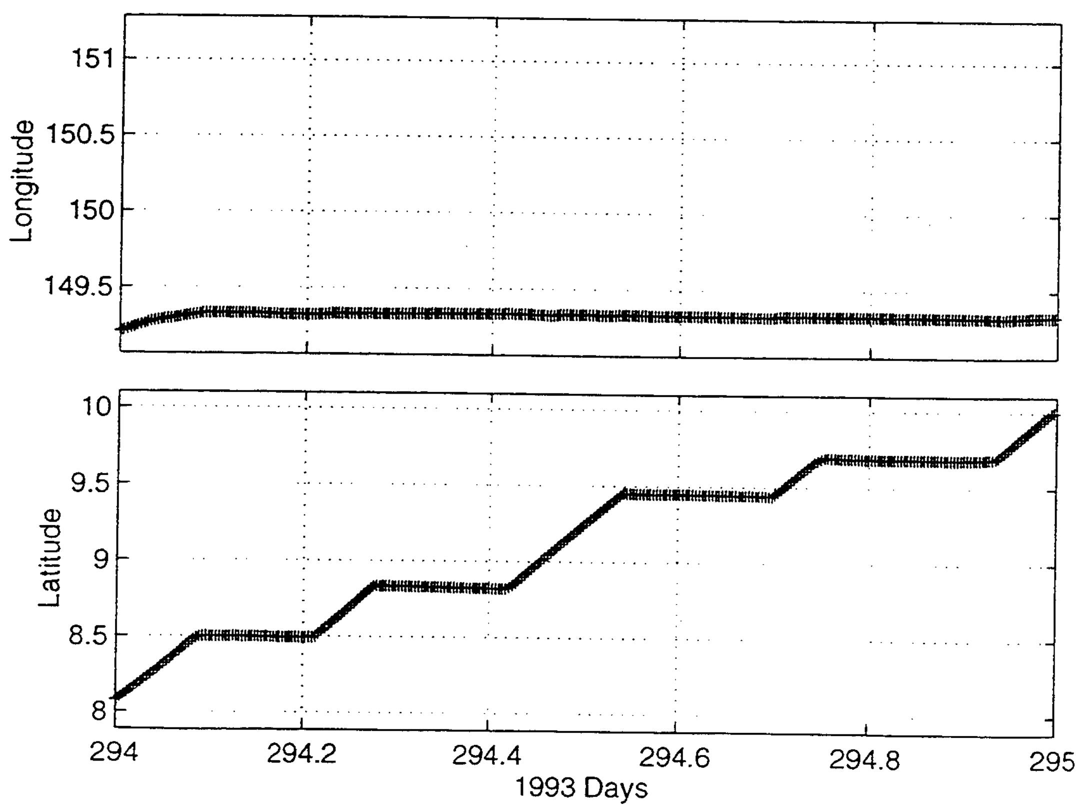


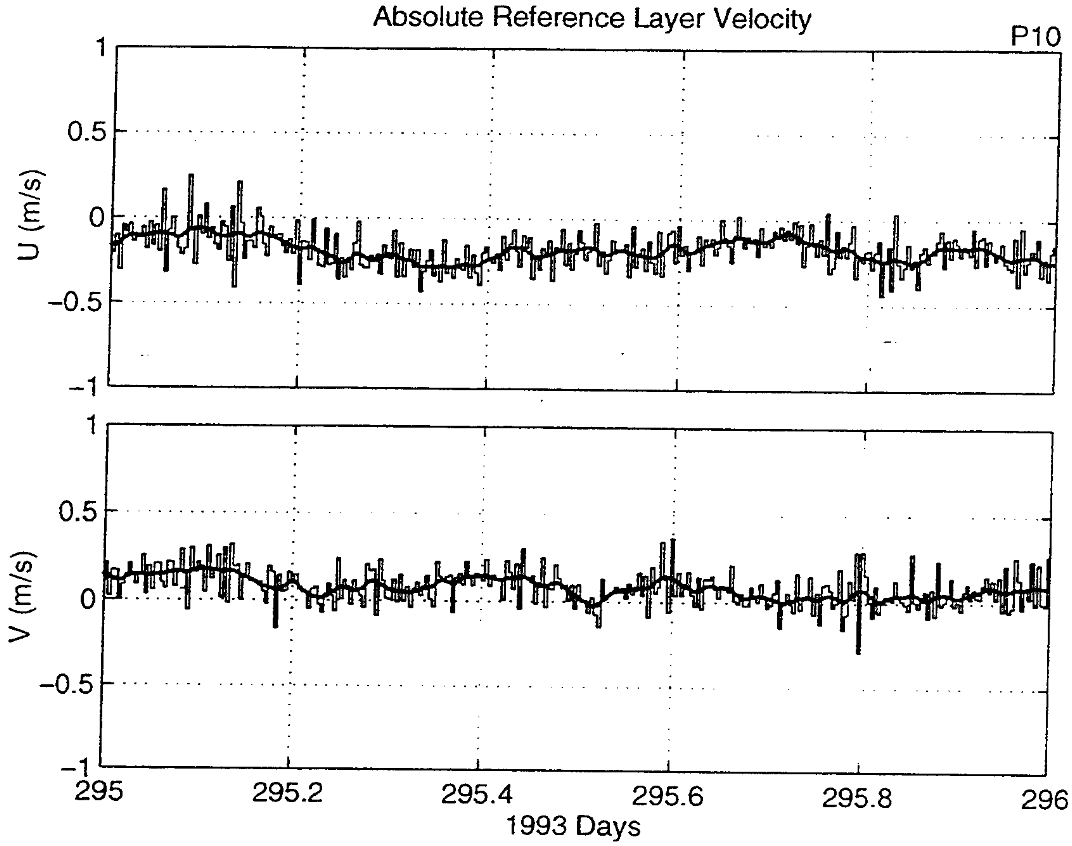
Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days


Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days

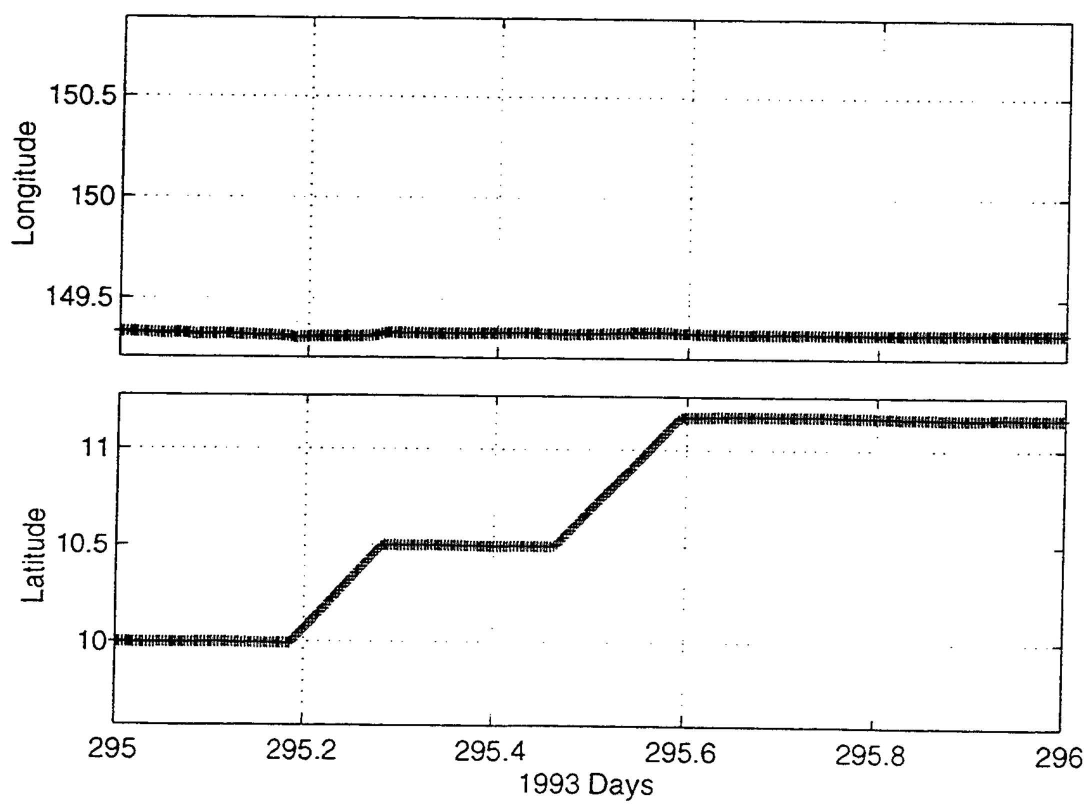

Longitude
Latitude
1993 Days


Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days

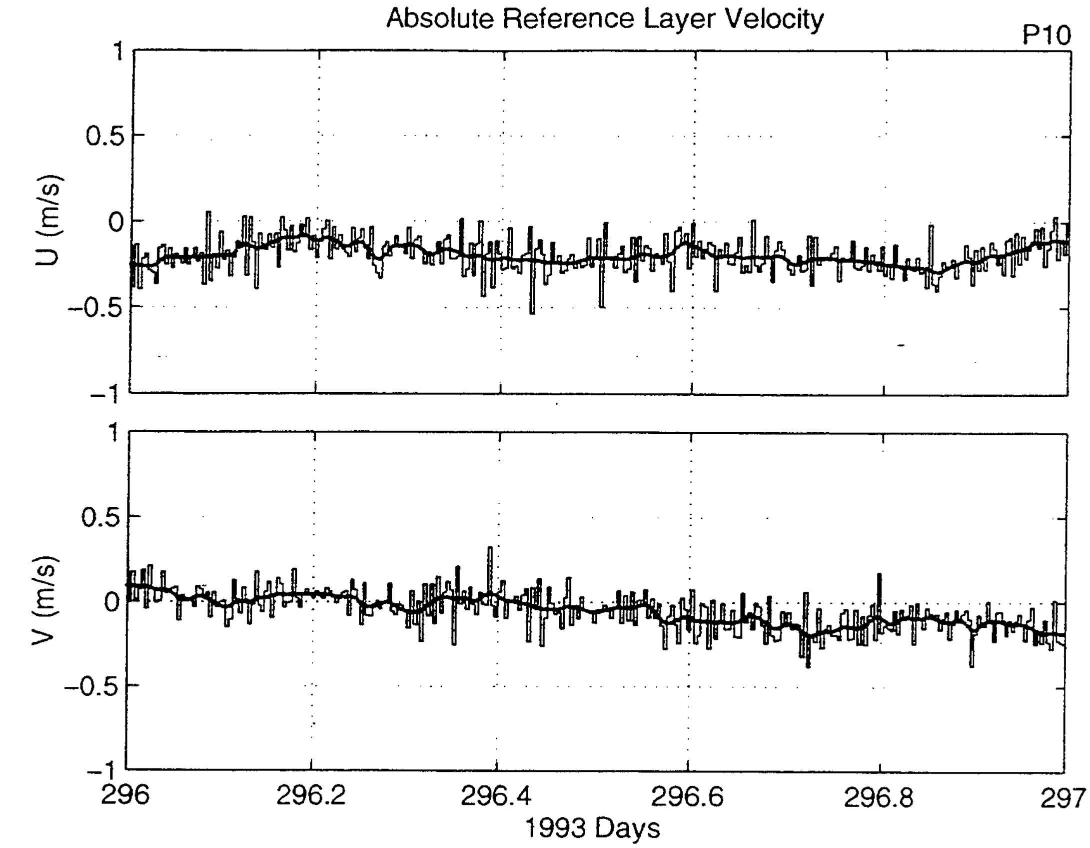

Longitude
Latitude
1993 Days

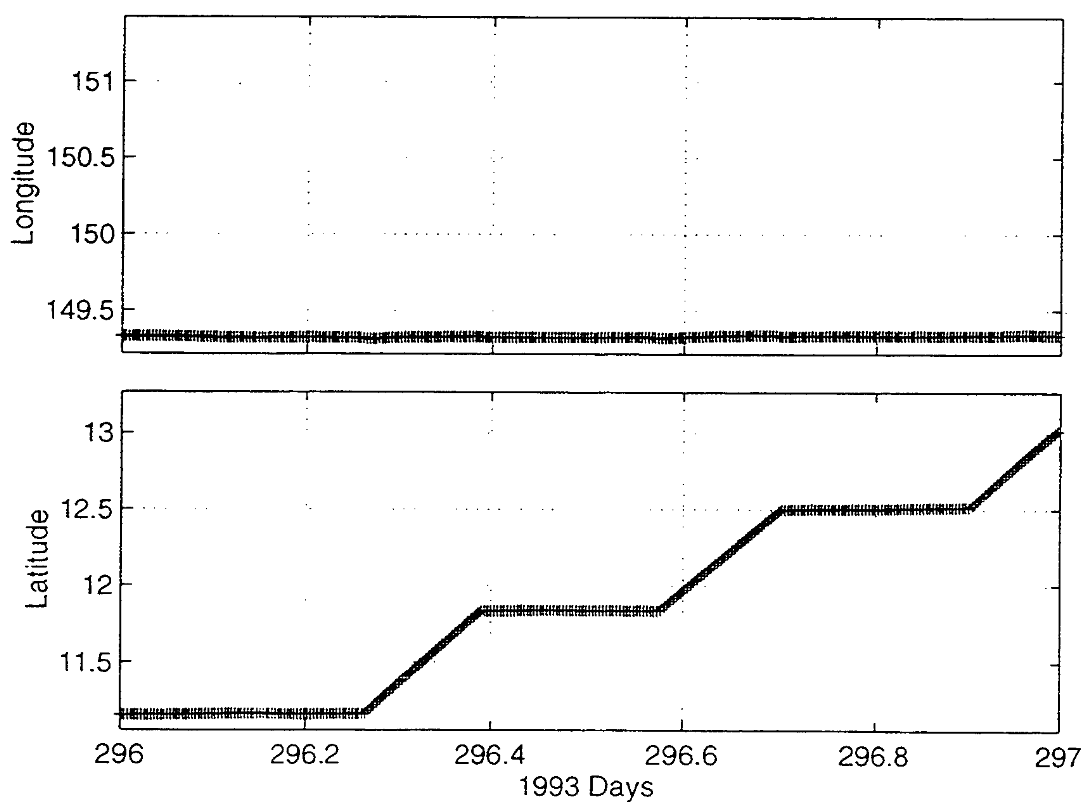


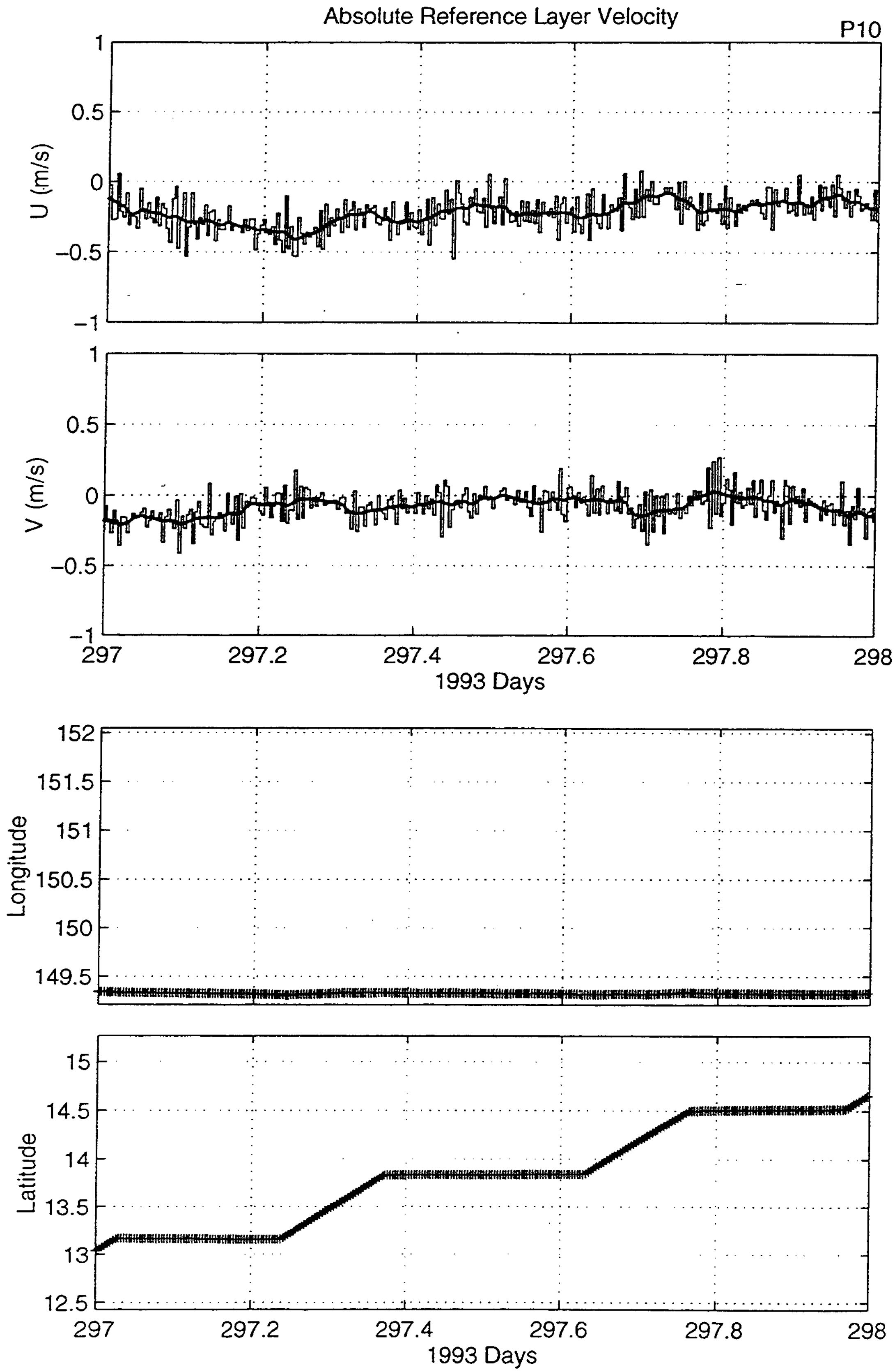
Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1
0.5
0
-0.5
-1
295
295.2
295.4
295.6
295.8
296
1993 Days



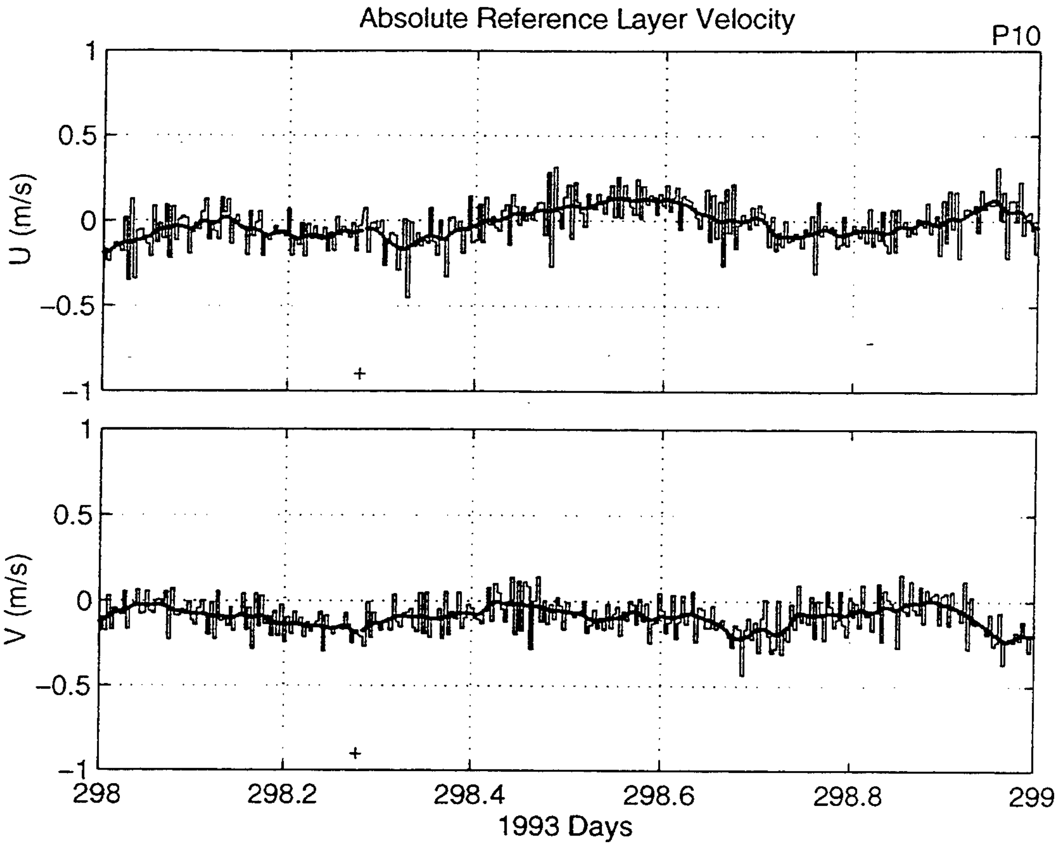
Longitude
150.5
150
149.5
Latitude
11
10.5
10
295
295.2
295.4
295.6
295.8
296
1993 Days

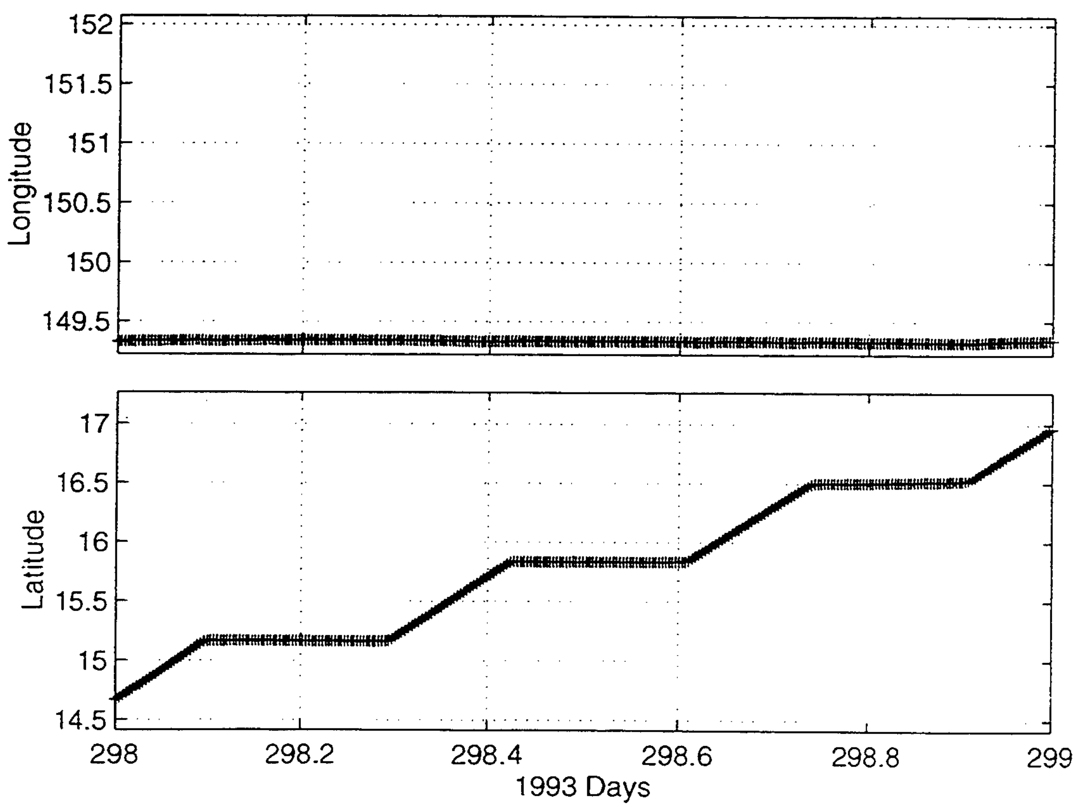

Absolute Reference Layer Velocity
P10
1
0.5
0
−0.5
−1
U (m/s)
1
0.5
0
−0.5
−1
V (m/s)
296
296.2
296.4
296.6
296.8
297
1993 Days

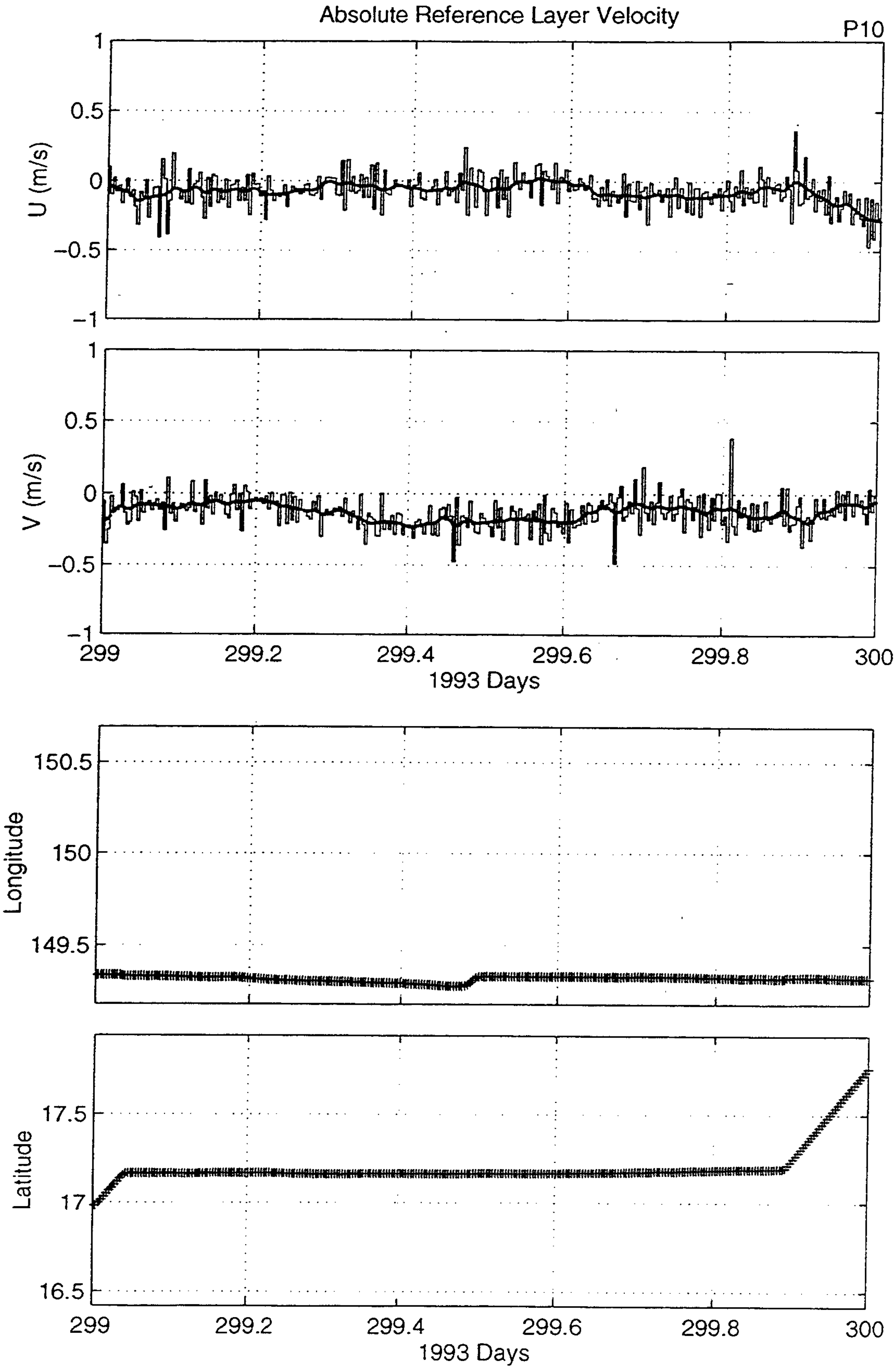

151
150.5
150
149.5
Longitude
13
12.5
12
11.5
Latitude
296
296.2
296.4
296.6
296.8
297
1993 Days

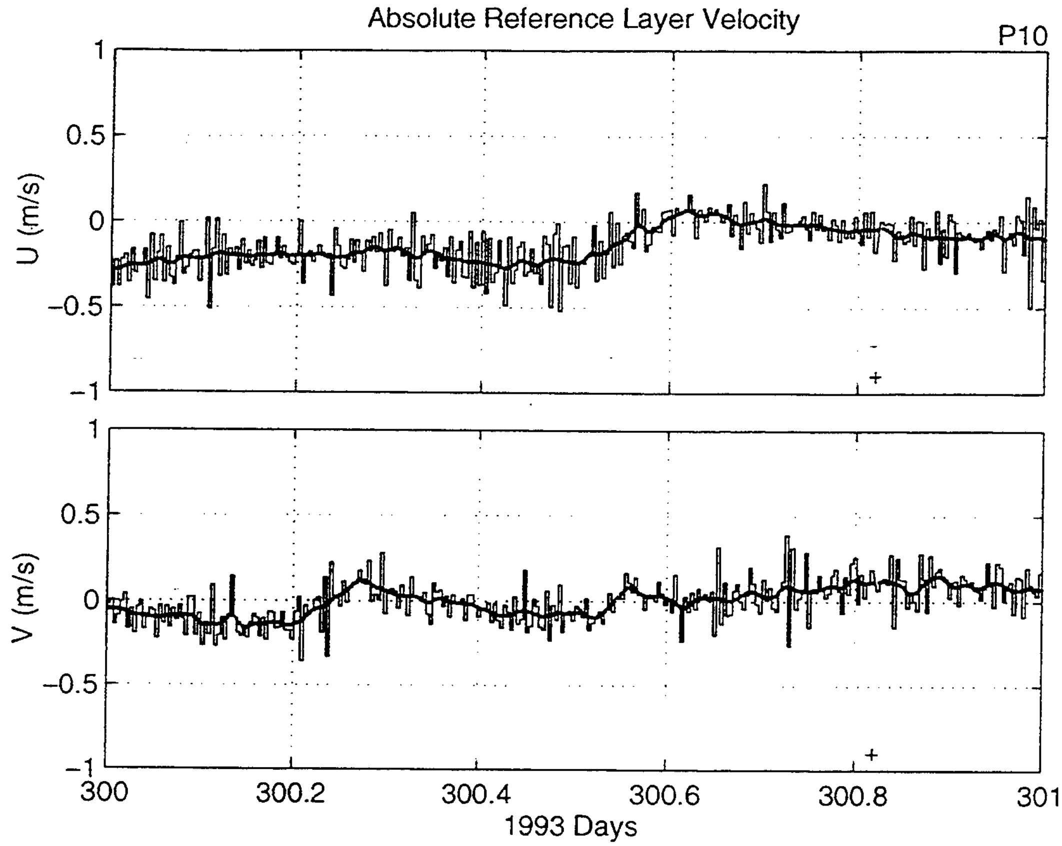


Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days


Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
298
298.2
298.4
298.6
298.8
299


Longitude
Latitude
1993 Days
298
298.2
298.4
298.6
298.8
299


Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1
0.5
0
-0.5
-1
299
299.2
299.4
299.6
299.8
300
1993 Days
Longitude
150.5
150
149.5
Latitude
17.5
17
16.5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U (m/s)
V (m/s)
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300
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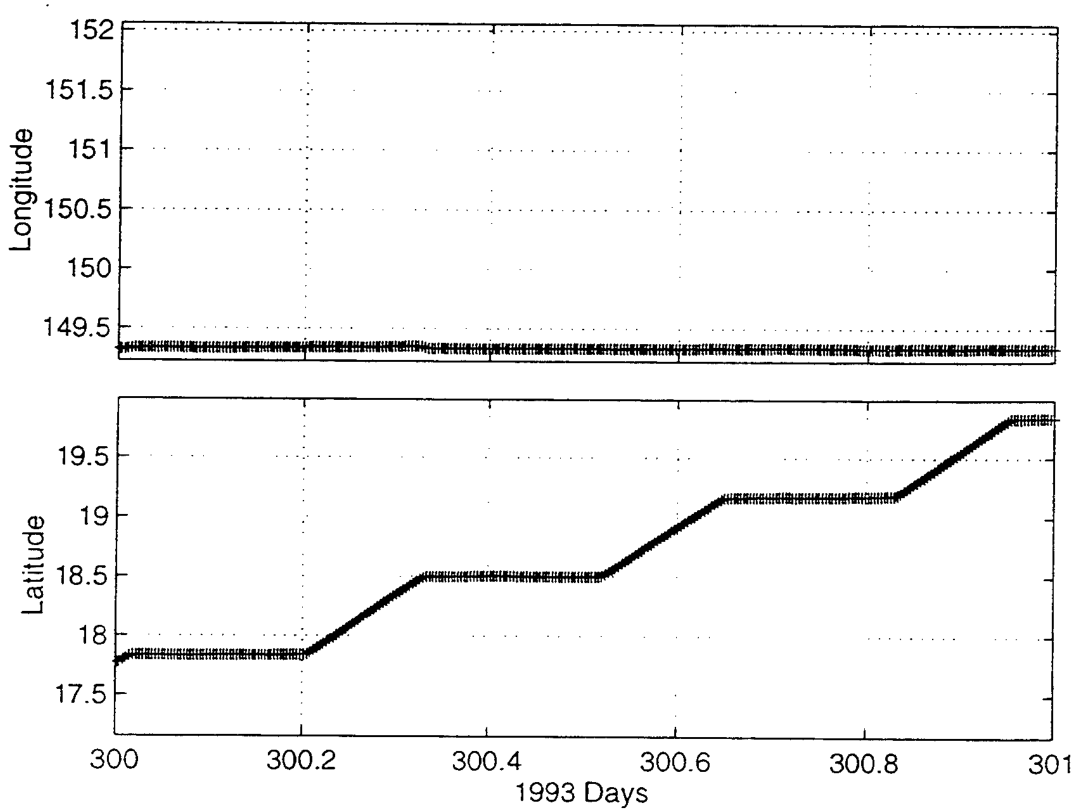
300.6
300.8
301
1993 Days


Longitude
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151
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150
149.5
Latitude
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19
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18
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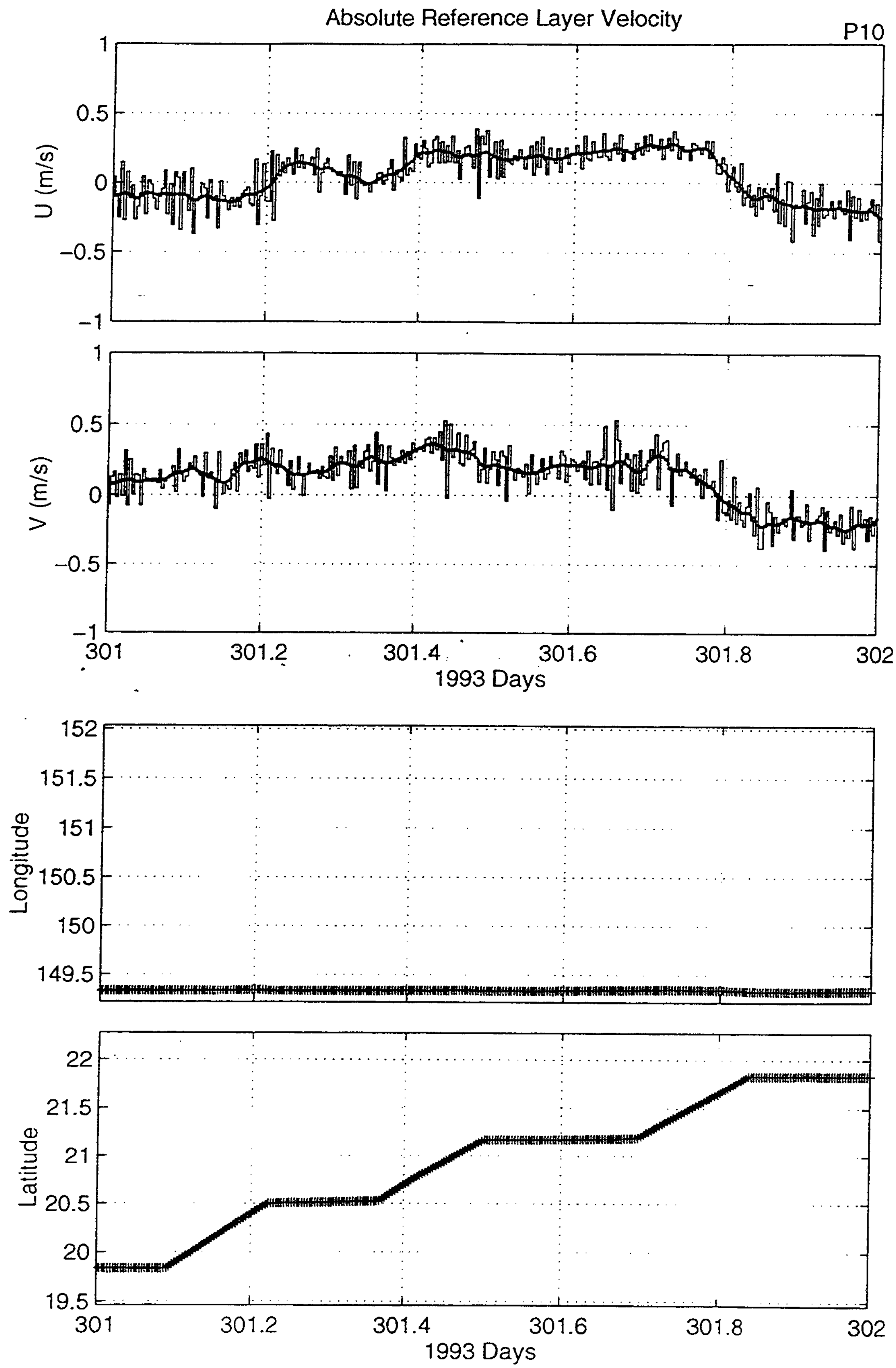
300.4
300.6
300.8
301
1993 Days



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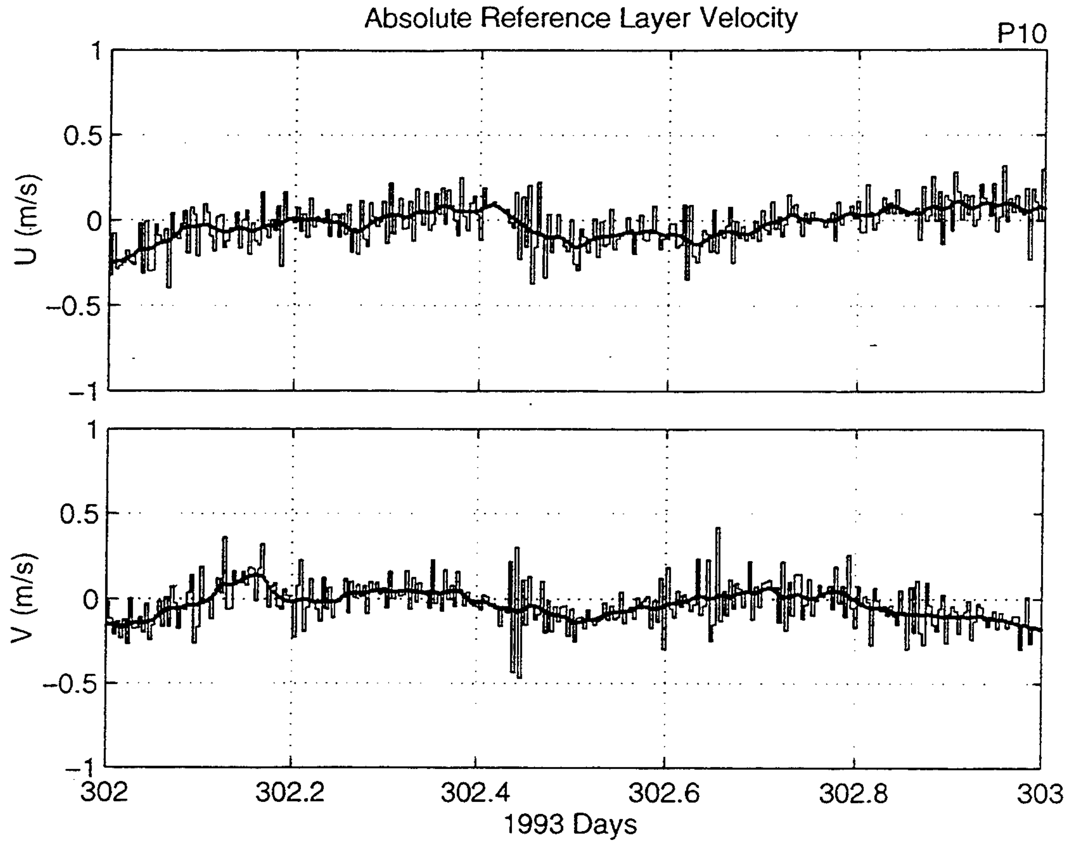
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days



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P10
U (m/s)
V (m/s)
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-0.5
-1
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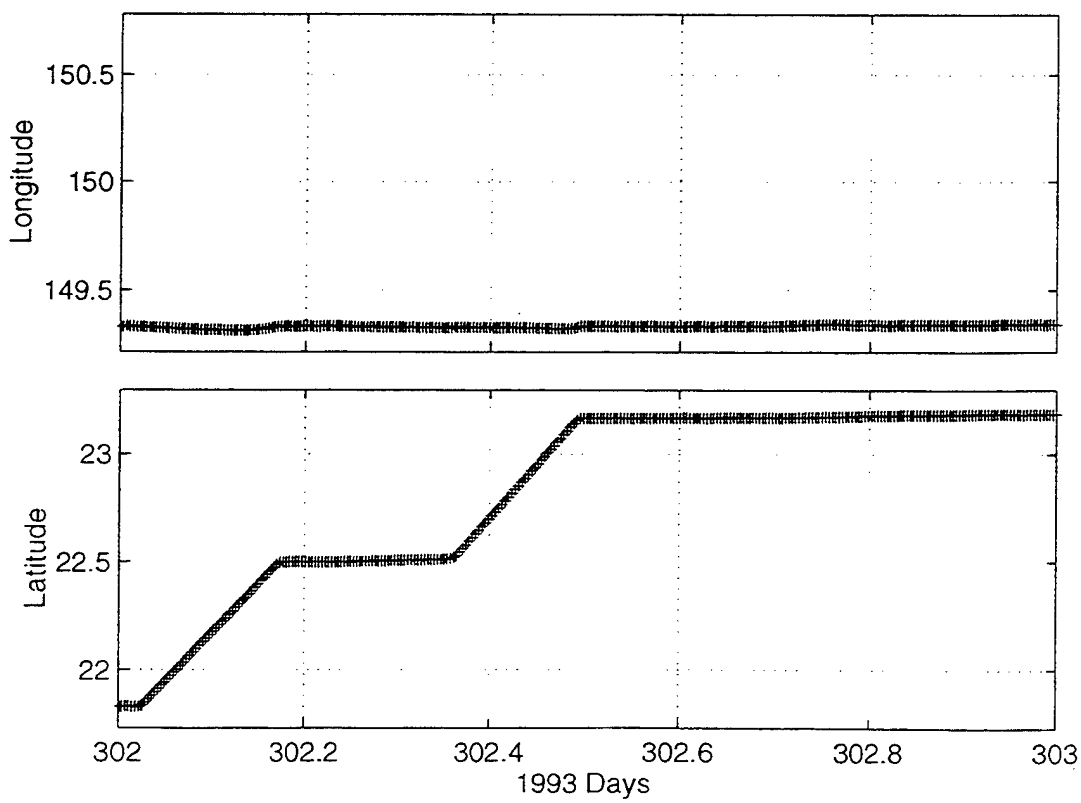
302.6
302.8
303
1993 Days



Longitude
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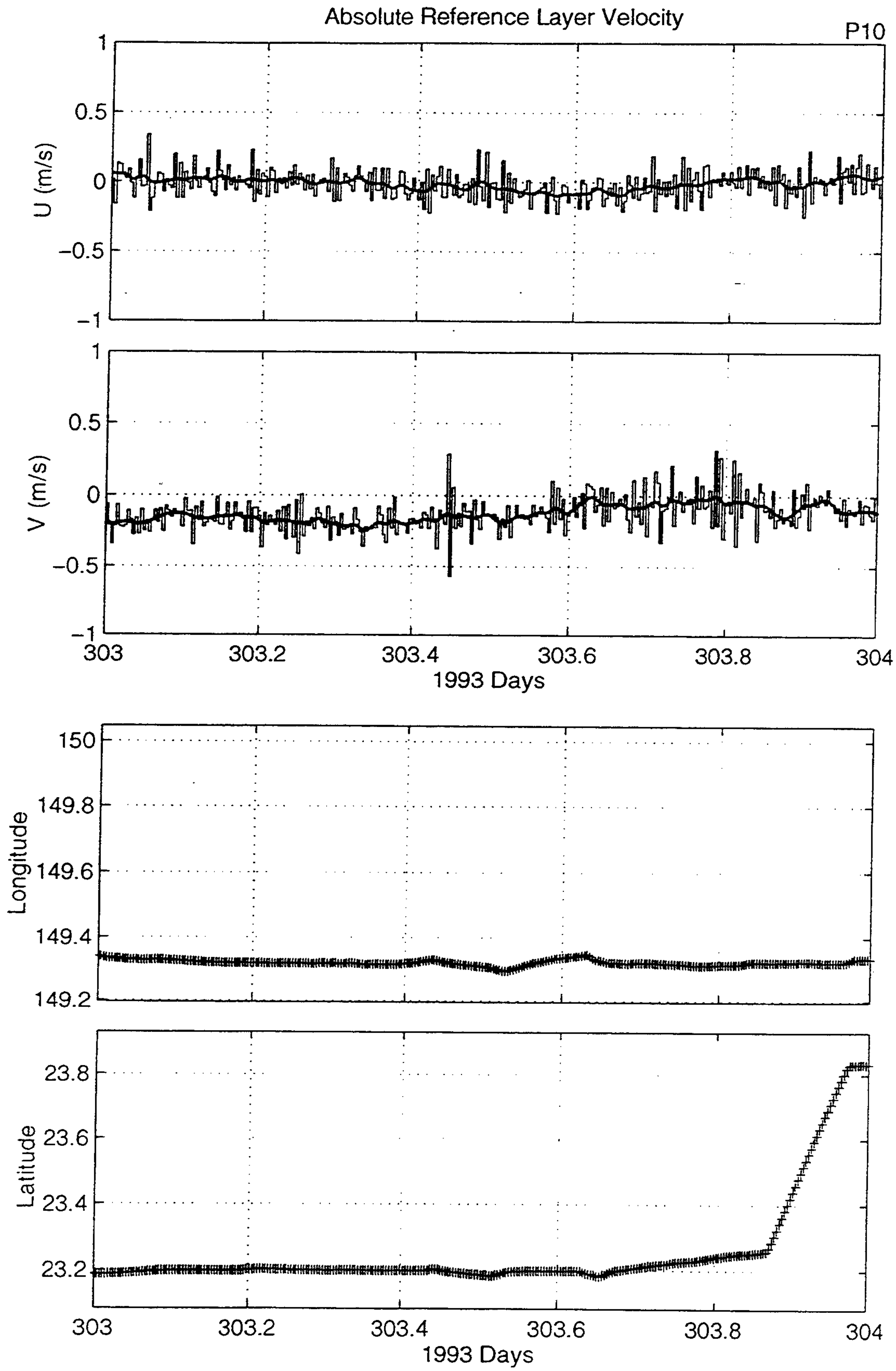
150
149.5
Latitude
23
22.5
22
302
302.2
302.4
302.6
302.8
303
1993 Days



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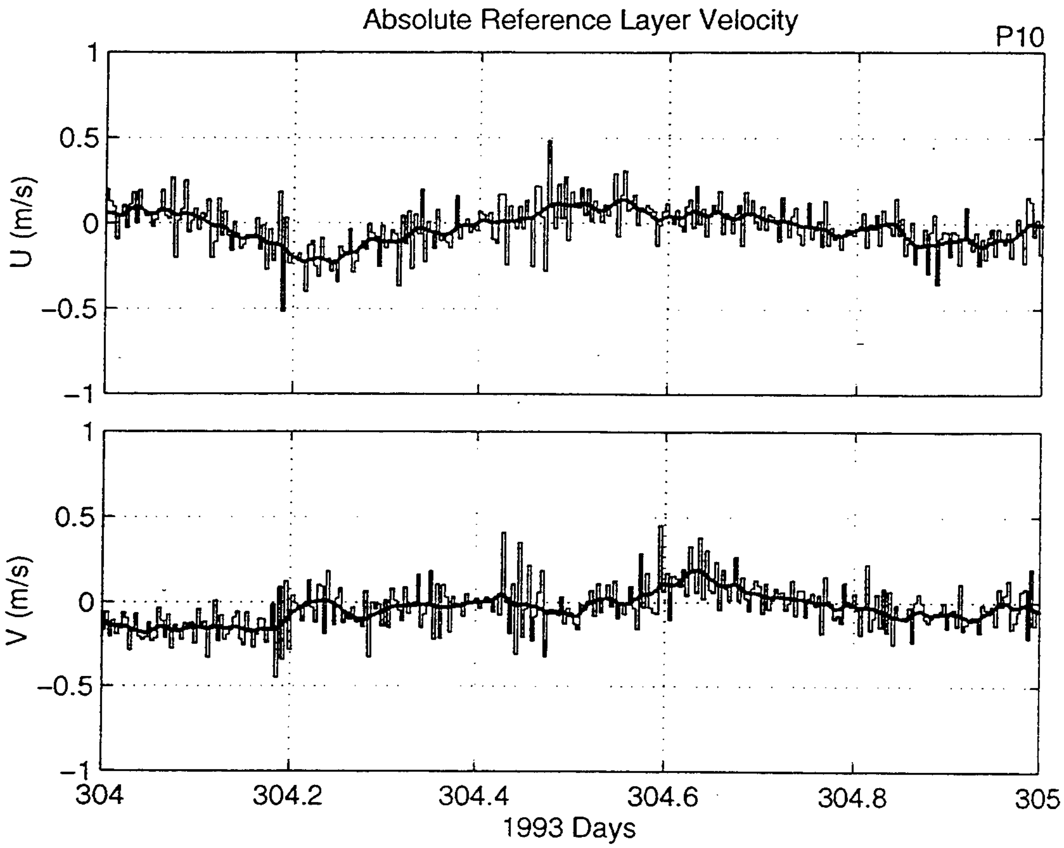
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days



Absolute Reference Layer Velocity
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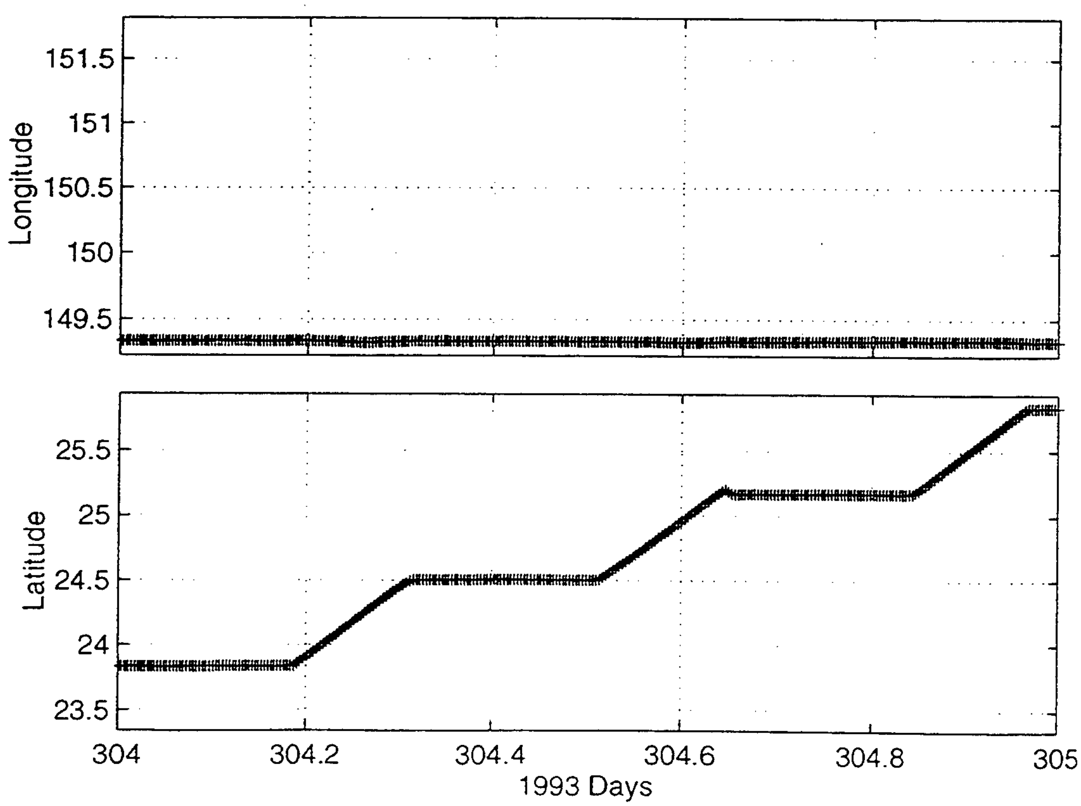
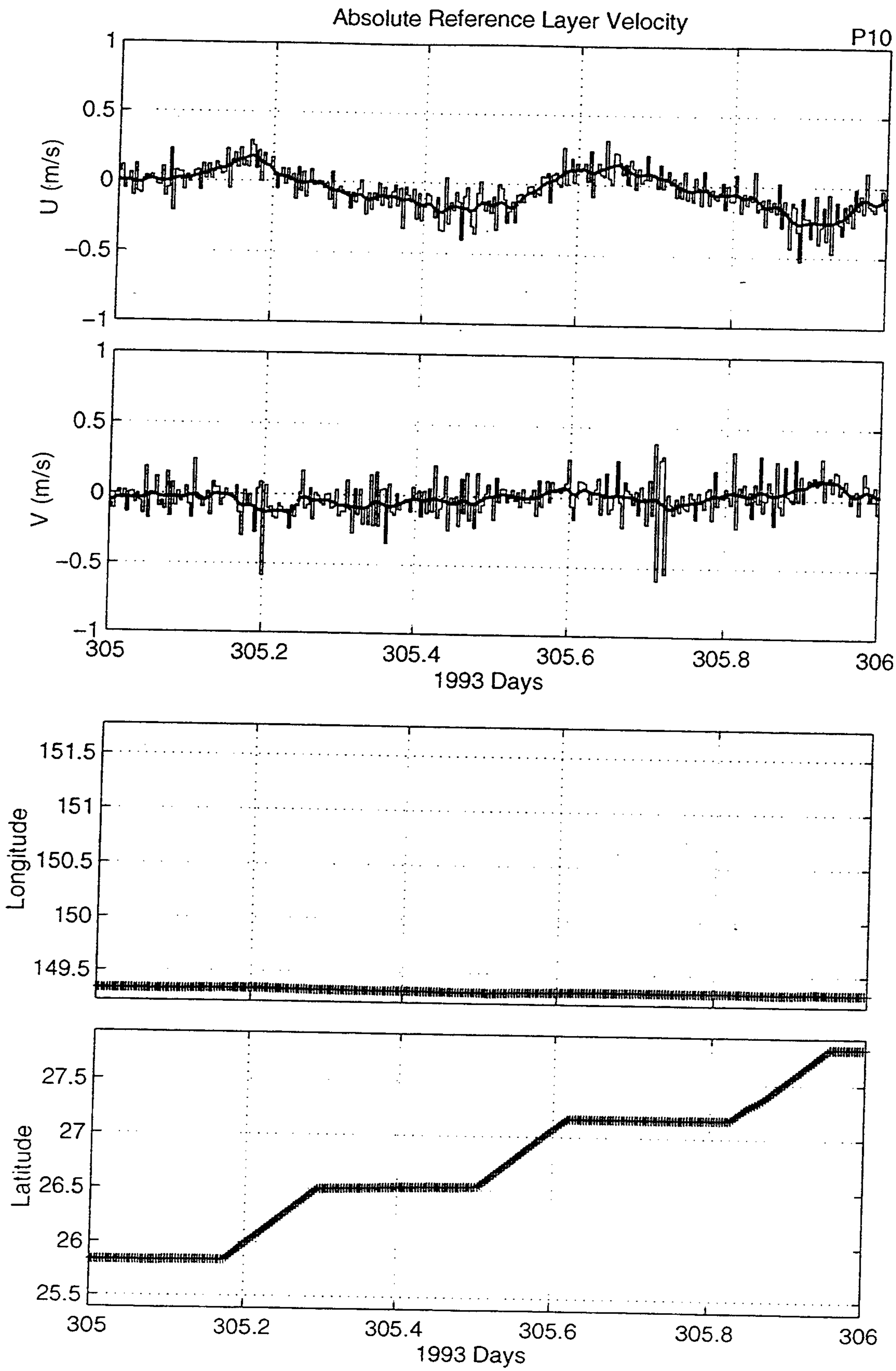
U (m/s)
V (m/s)
1993 Days



Longitude
Latitude
1993 Days



Absolute Reference Layer Velocity
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U (m/s)
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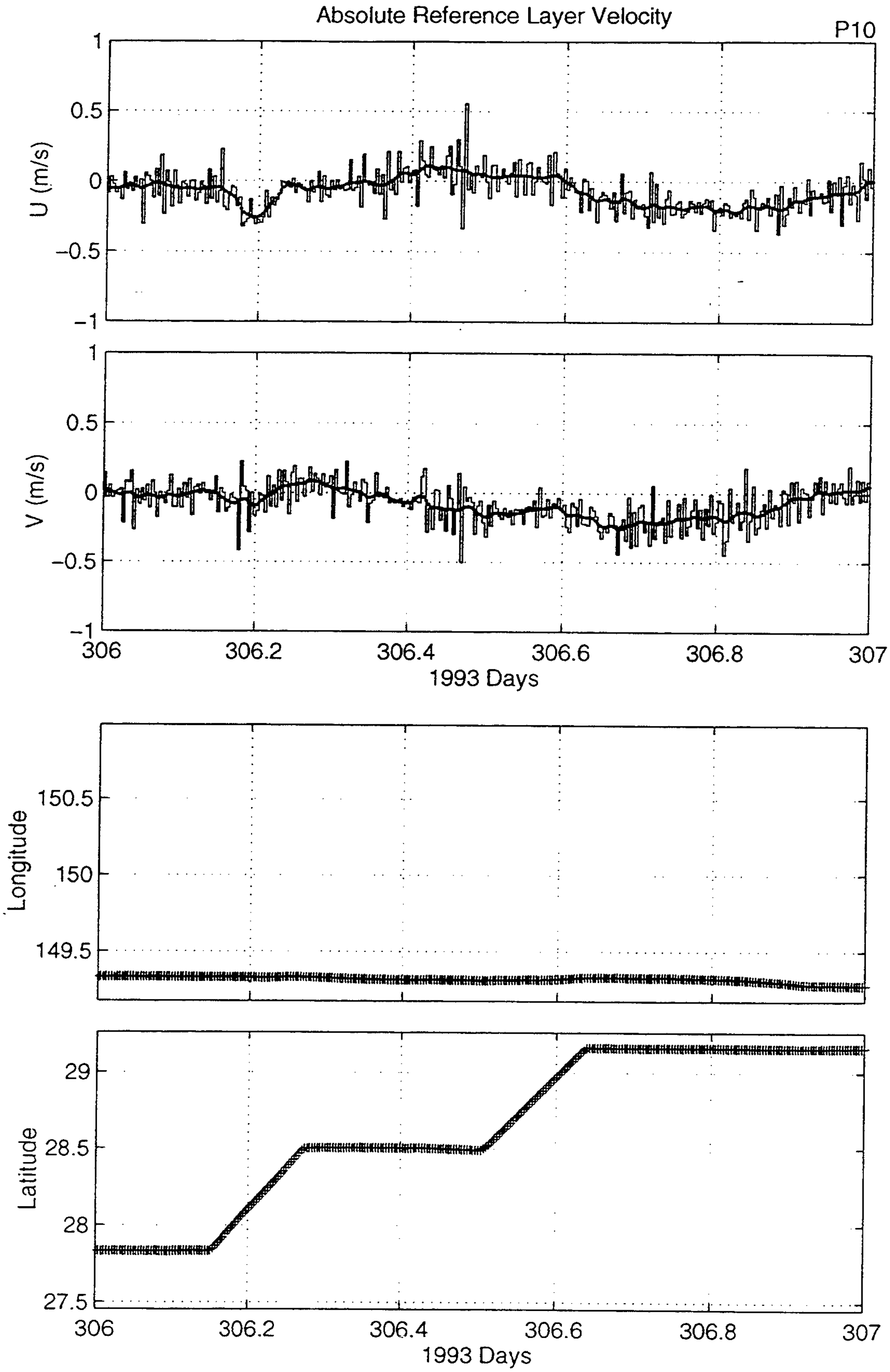
0.5
0
−0.5
−1
V (m/s)
1
0.5
0
−0.5
−1
305
305.2
305.4
305.6
305.8
306
1993 Days
Longitude
151.5
151
150.5
150
149.5
Latitude
27.5
27
26.5
26
25.5
305
305.2
305.4
305.6
305.8
306
1993 Days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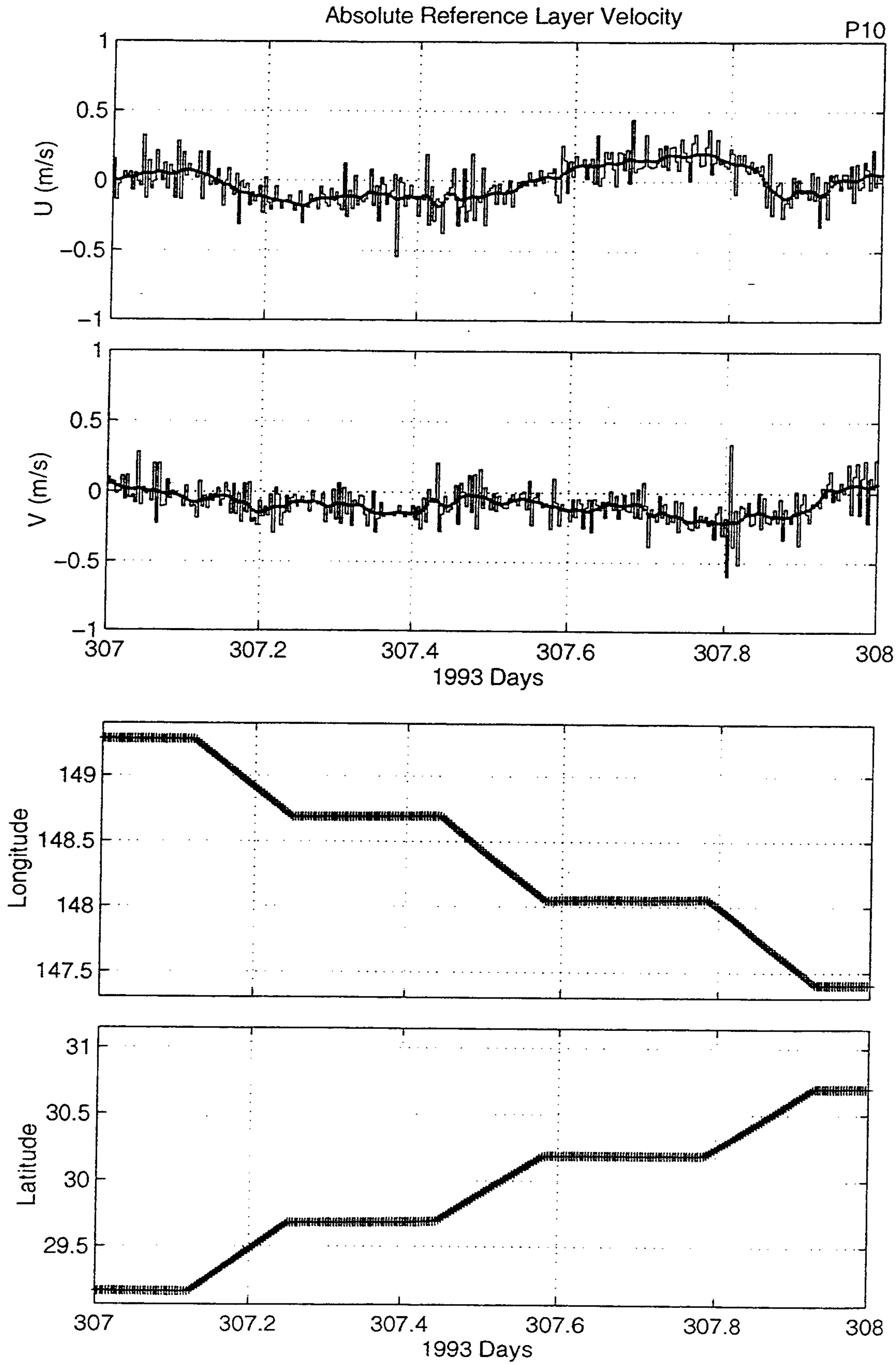
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days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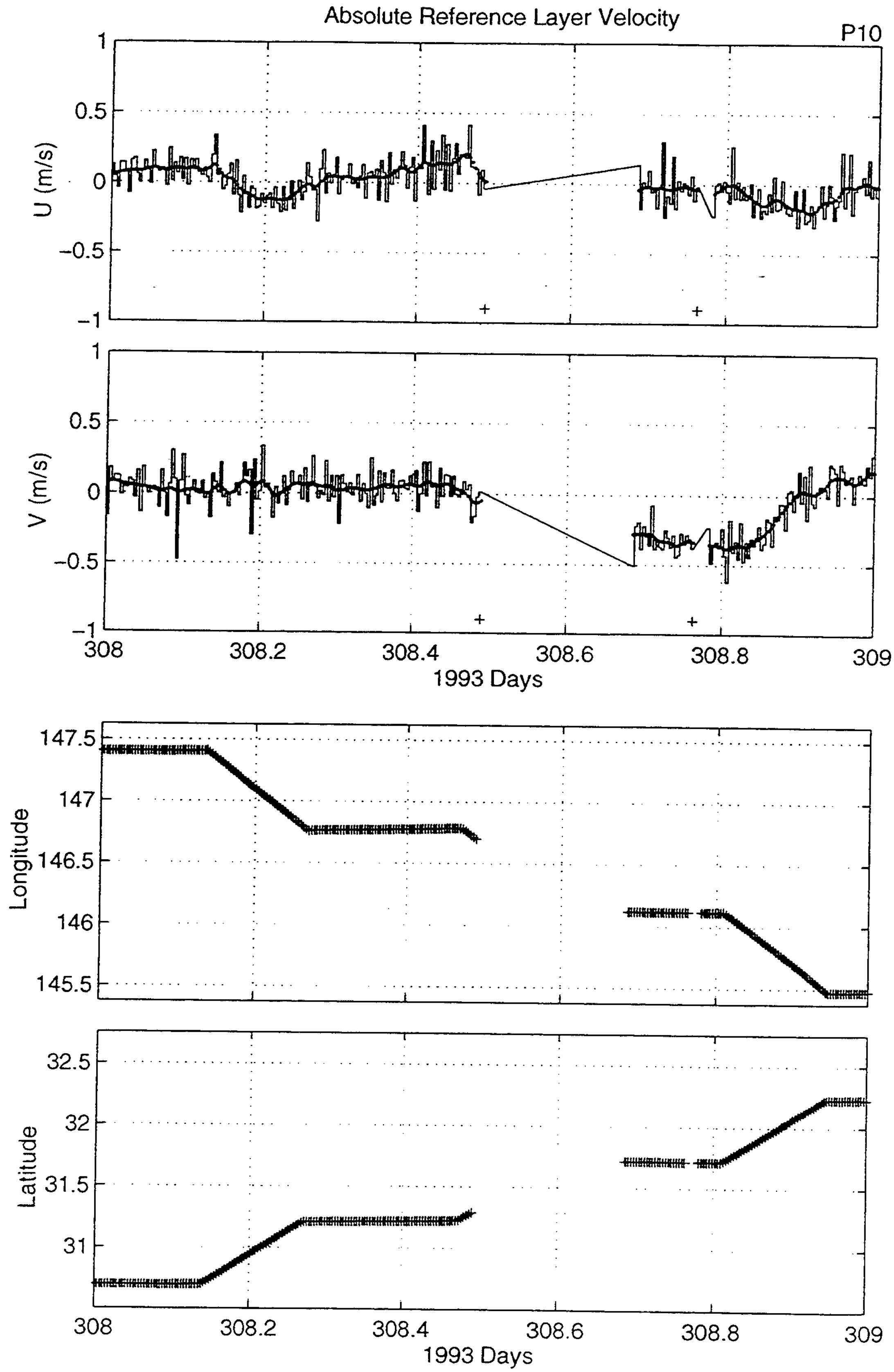
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days


Absolute Reference Layer Velocity
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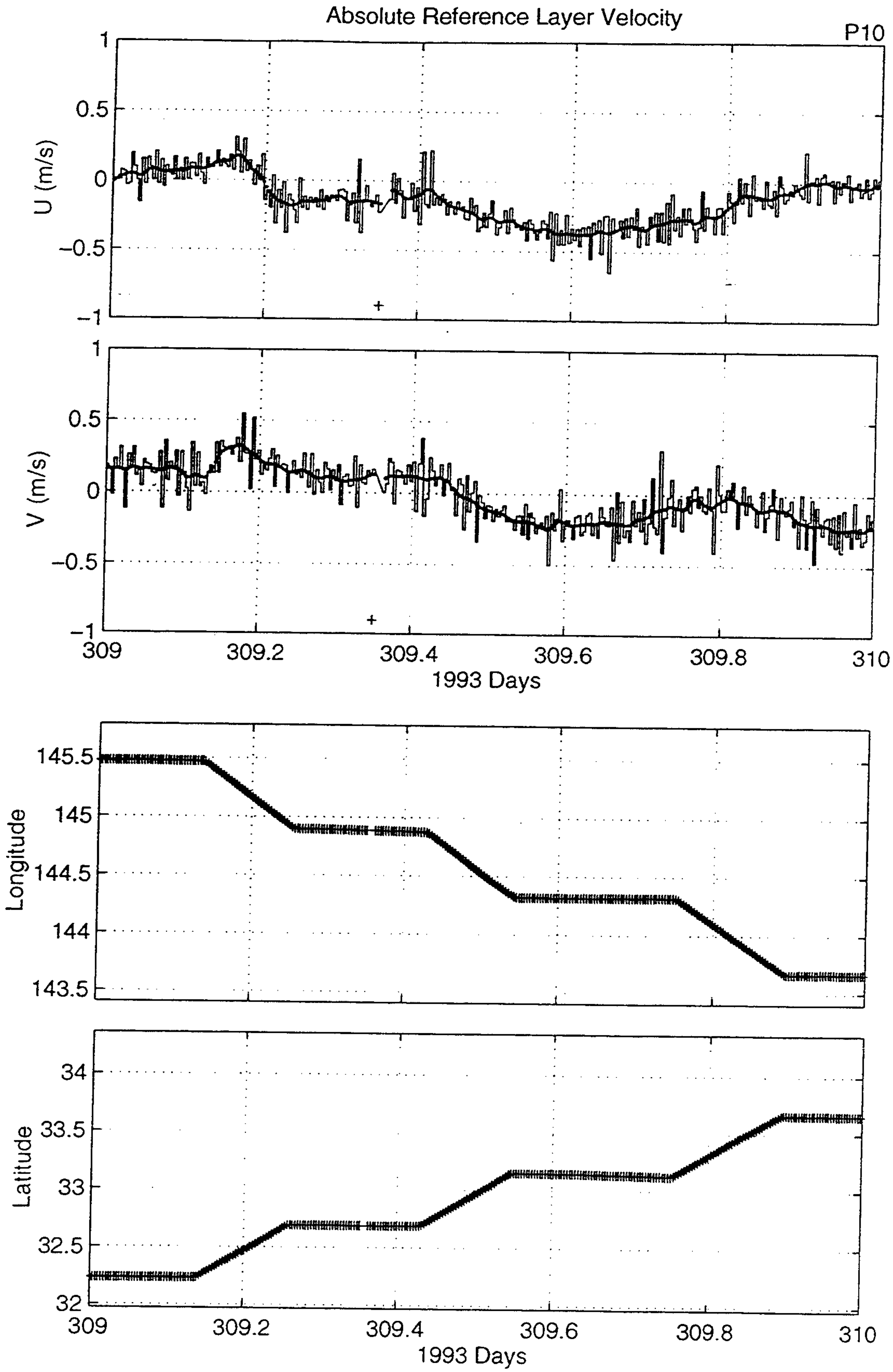
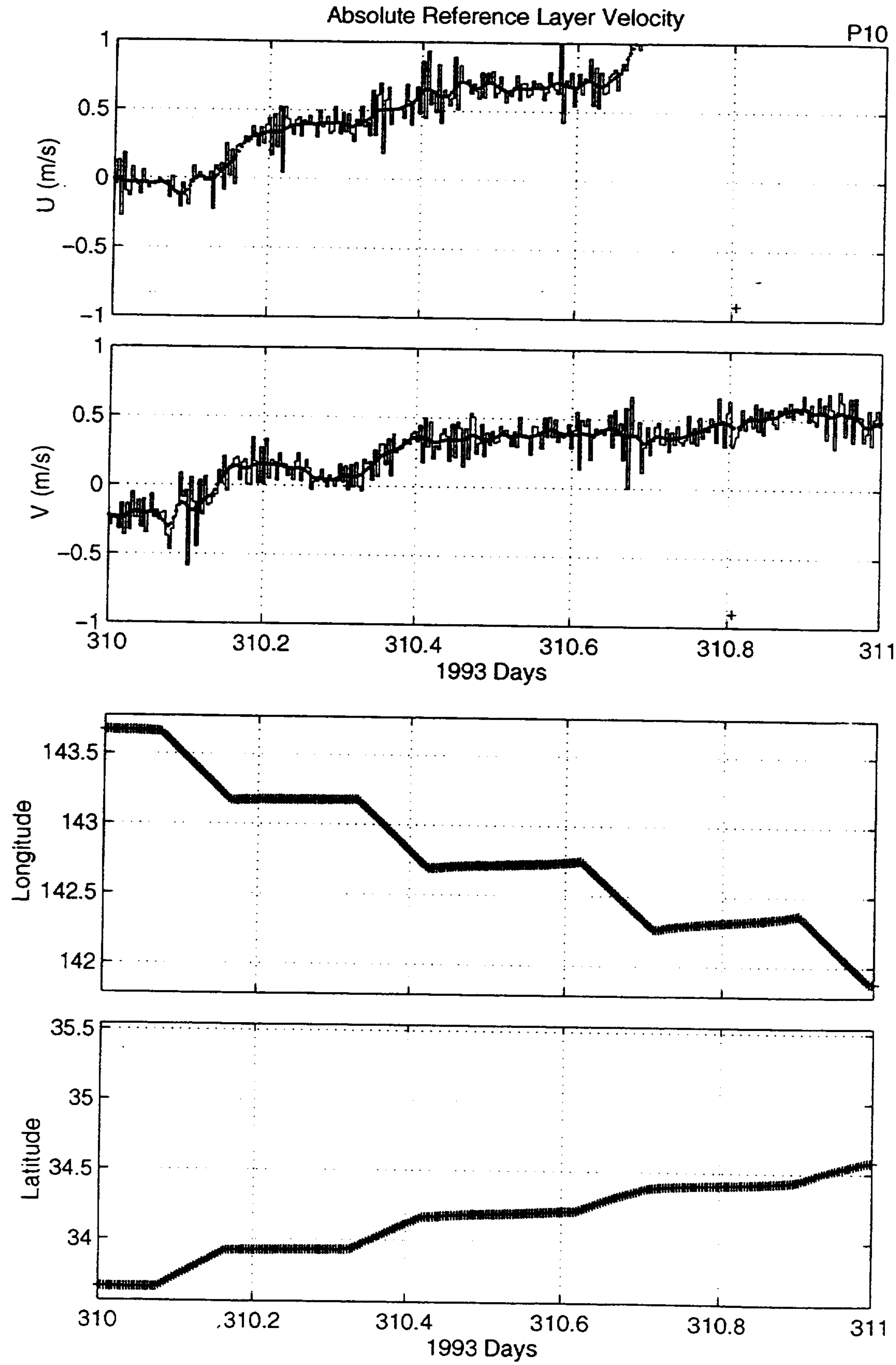
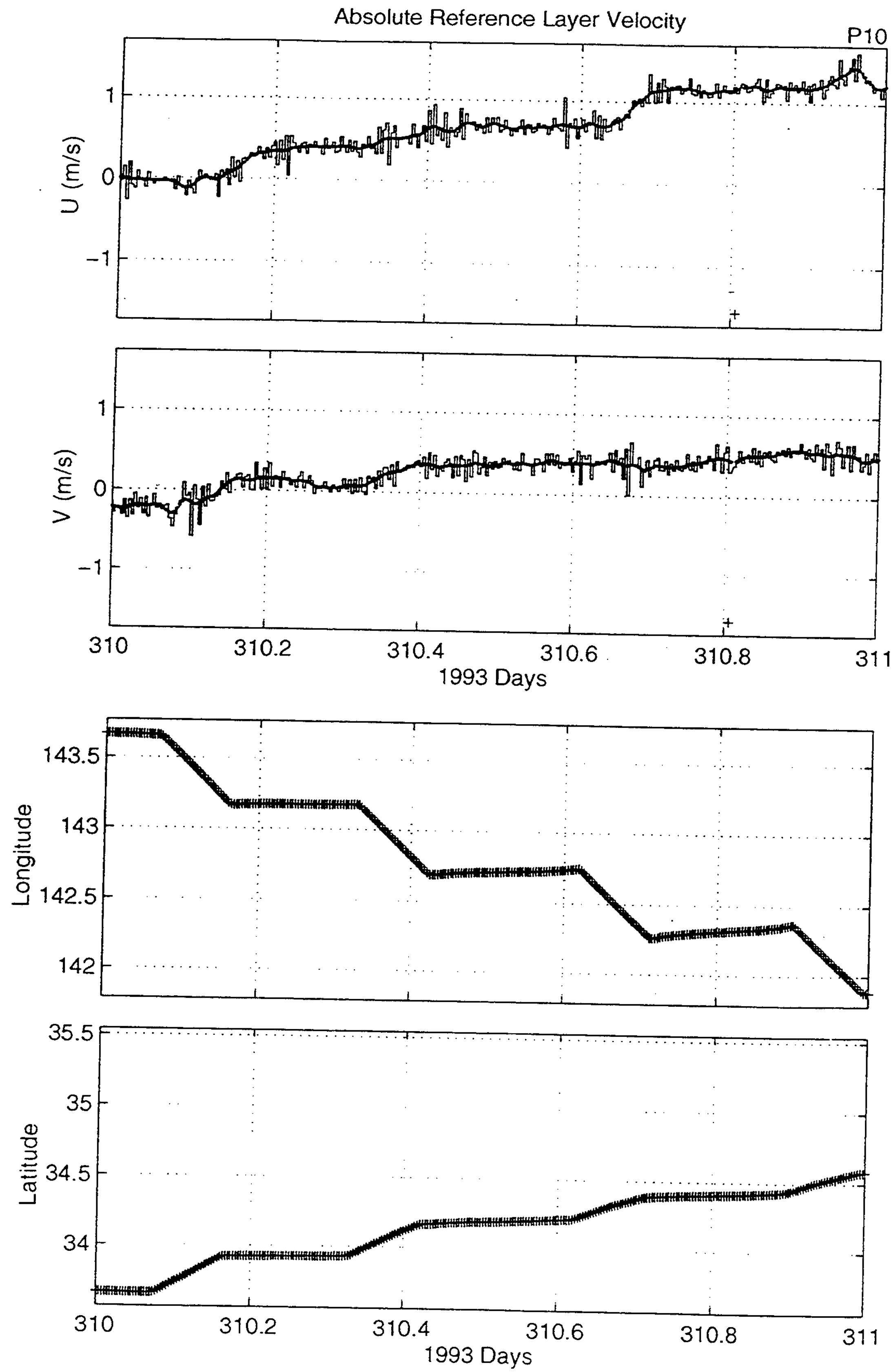
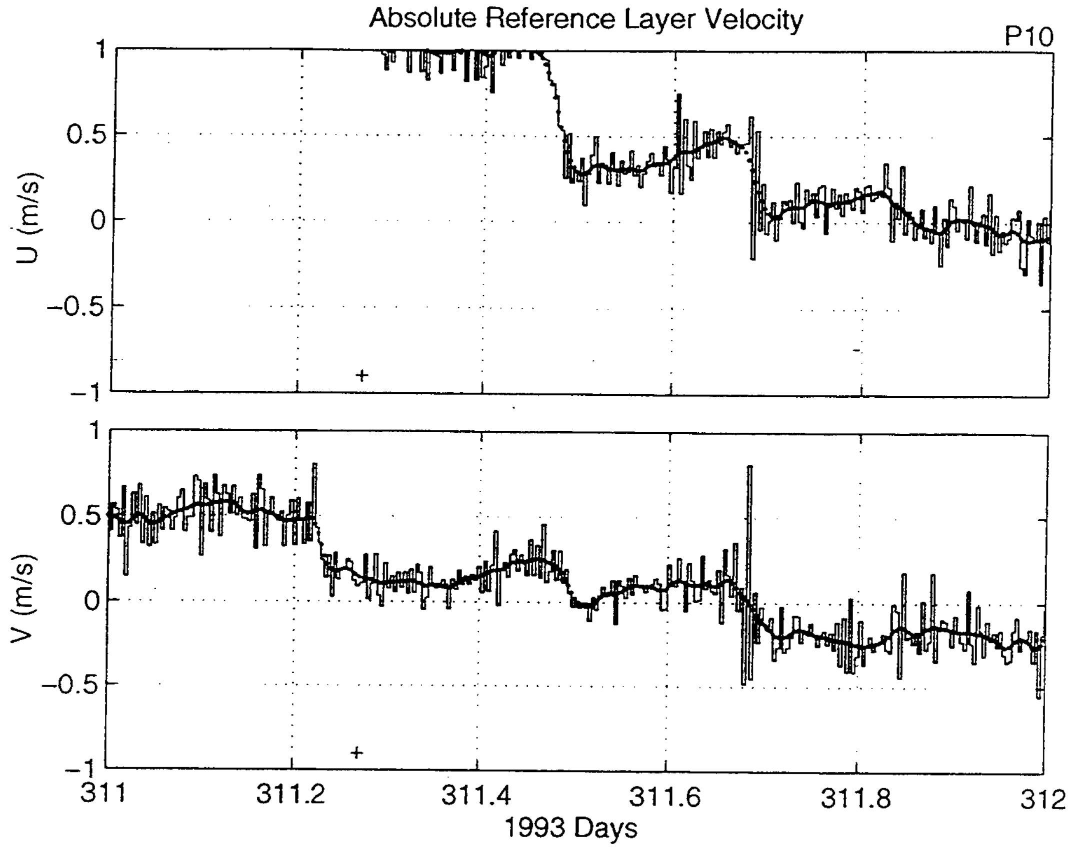
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days



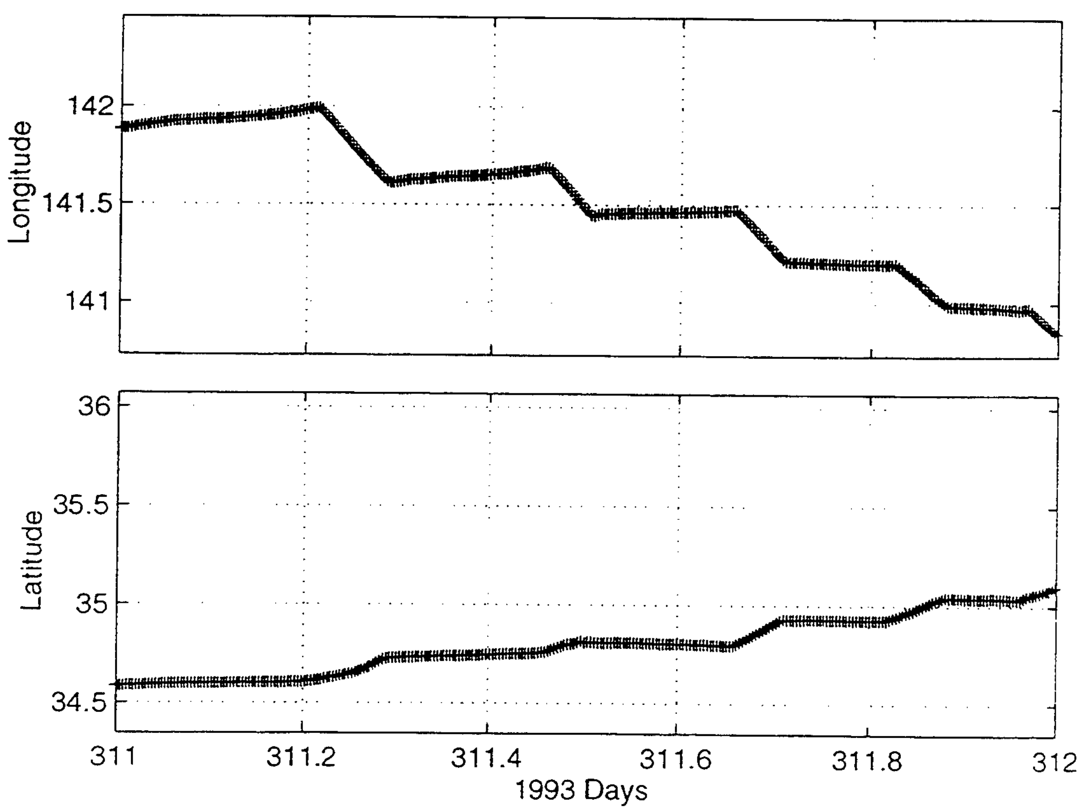
Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days


Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days

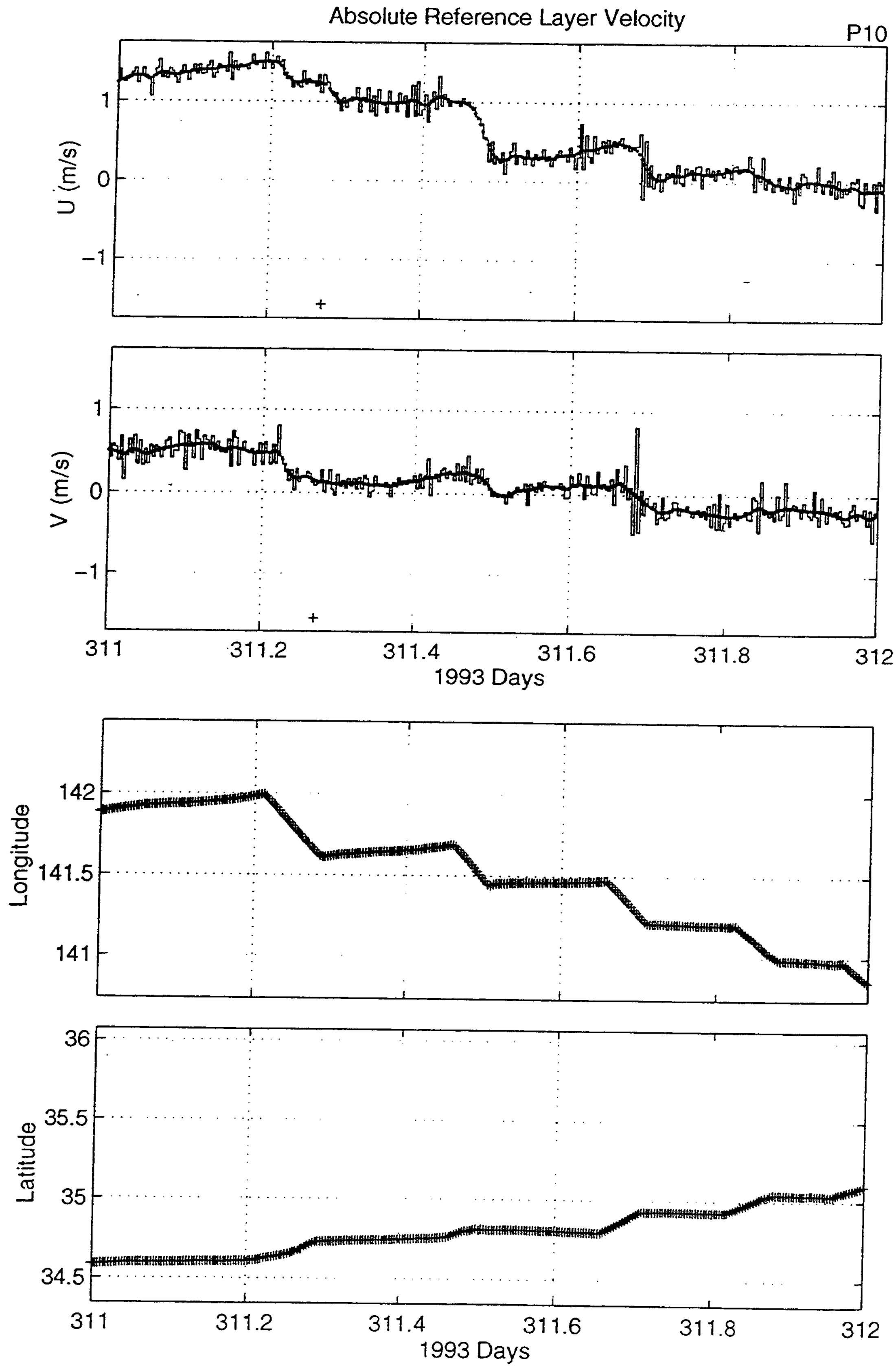

Absolute Reference Layer Velocity
P10
U (m/s)
1
0
−1
V (m/s)
1
0
−1
310
310.2
310.4
310.6
310.8
311
1993 Days
Longitude
143.5
143
142.5
142
Latitude
35.5
35
34.5
34
310
310.2
310.4
310.6
310.8
311
1993 Days



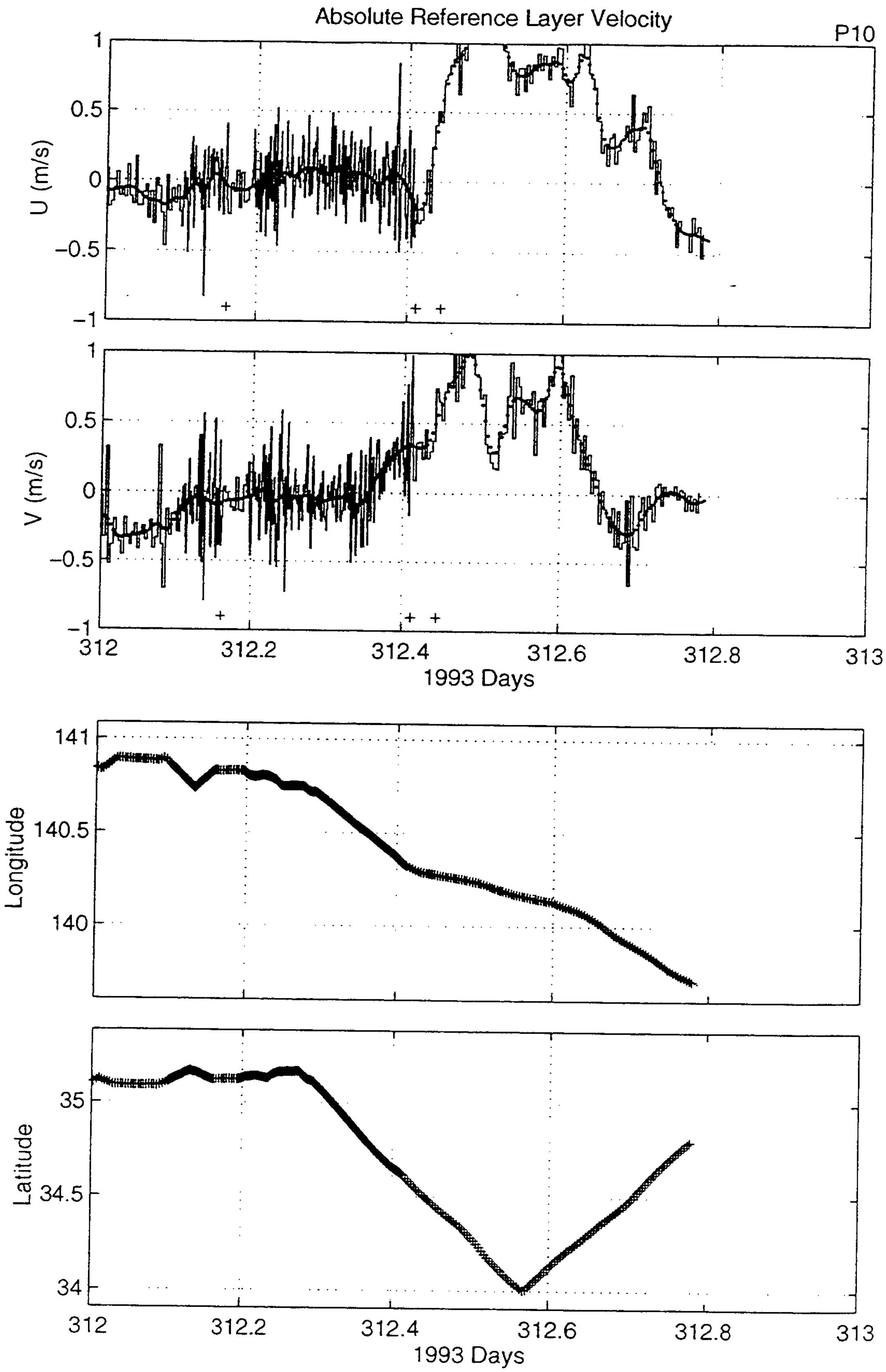
Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days



Longitude
Latitude
1993 Days



Absolute Reference Layer Velocity
P10
U (m/s)
1
0
−1
V (m/s)
1
0
−1
311
311.2
311.4
311.6
311.8
312
1993 Days
Longitude
142
141.5
141
Latitude
36
35.5
35
34.5
311
311.2
311.4
311.6
311.8
312
1993 Days



Absolute Reference Layer Velocity
P10
U (m/s)
V (m/s)
1993 Days
Longitude
Latitude
1993 Days

Appendix E: The ADCP DAS Configuration File

The following is a listing of the startup configuration file start.cnf for RD Instrument's data acquisition software (DAS) that was used during P10.

AD,SI,HUNDREDTHS	300.00 Sampling interval
AD,NB,WHOLE	60 Number of Depth Bins
AD,BL,WHOLE	3 Bin Length
AD,PL,WHOLE	16 Pulse Length
AD,BK,TENTHS	4.0 Blank Beyond Transmit
AD,PE,WHOLE	1 Pings Per Ensemble
AD,PC,HUNDREDTHS	1.00 Pulse Cycle Time
AD,PG,WHOLE	25 Percent Pings Good Threshold
XX,OD2,WHOLE	5 [SYSTEM DEFAULT, OD2]
XX,TE,HUNDREDTHS	0.00 [SYSTEM DEFAULT, TE]
AD,US,BOOLE	YES Use Direct Commands on StartUp
DP,TR,BOOLE	NO Toggle roll compensation
DP,TP,BOOLE	NO Toggle Pitch compensation
DP,TH,BOOLE	YES Toggle Heading compensation
DP,VS,BOOLE	YES Calculate Sound Velocity from TEMP/Salinity
DP,UR,BOOLE	YES Use Reference Layer
DP,FR,WHOLE	4 First Bin for reference Layer
DP,LR,WHOLE	15 Last Bin for reference Layer
DP,BT,BOOLE	NO Use Bottom Track
DP,B3,BOOLE	YES Use 3 Beam Solutions
DP,EV,BOOLE	YES Use Error Velocity as Percent Good Criterion
DP,ME,TENTHS	100.0 Max. Error Velocity for Valid Data (cm/sec)
DR,RD,BOOLE	YES Recording on disk
DR,RX,BOOLE	YES Record N/S (FORE/AFT) Vel.
DR,RY,BOOLE	YES Record E/W (FORT/STBD) Vel.
DR,RZ,BOOLE	YES Record vertical vel.
DR,RE,BOOLE	YES Record error Good
DR,RB,BOOLE	YES Bytes of user prog. buffer
DR,RP,BOOLE	YES Record Percent good
DR,RA,BOOLE	YES Record average AGC/Bin
DR,RN,BOOLE	YES Record Ancillary data
DR,AP,BOOLE	NO Auto-ping on start-up
XX,LDR,TRI	3 [SYSTEM DEFAULT, LDR]
XX,RB2,WHOLE	72 [SYSTEM DEFAULT, RB2]
DR,RC,BOOLE	NO Record CTD data
XX,FB,WHOLE	1 [SYSTEM DEFAULT, FB]

XX,PU,BOOLE	NO [SYSTEM DEFAULT, PU]
GC,TG,TRI	1 DISPLAY (NO/GRAPH/TAB)
GC,ZV,WHOLE	4 ZERO VELOCITY REFERENCE (S/B/M/L)
GC,VL,WHOLE	-100 LOWEST VELOCITY ON GRAPH
CG,VH,WHOLE	100 HIGHEST VELOCITY ON GRAPH
GC,DL,WHOLE	0 LOWEST DEPTHS ON GRAPH
GC,DH,WHOLE	400 HIGHEST DEPTHS ON GRAPH
GC,SW,BOOLE	NO SET DEPTHS WINDOW TO INCLUDE ALL BINS
GC,MP,WHOLE	25 MINIMUM PERCENT GOOD TO PLOT
SG,PNS,BOOLE	YES PLOT NORTH/SOUTH VEL.
SG,PEW,BOOLE	YES PLOT EAST/WEST VEL.
SG,PVT,BOOLE	NO PLOT VERTICAL VEL.
SG,PEV,BOOLE	NO PLOT ERROR VEL.
SG,PPE,BOOLE	NO PLOT PERCENT ERROR
SG,PMD,BOOLE	NO PLOT MAG AND DIR
SG,PSW,BOOLE	NO PLOT AVERAGE SP. W.
SG,PAV,BOOLE	YES PLOT AVERAGE AGC.
SG,PPG,BOOLE	YES PLOT PERCENT GOOD
SG,PD1,BOOLE	NO PLOT DOPPLER 1
SG,PD2,BOOLE	NO PLOT DOPPLER 2
SG,PD3,BOOLE	NO PLOT DOPPLER 3
SG,PD4,BOOLE	NO PLOT DOPPLER 4
SG,PW1,BOOLE	NO PLOT SP. W. 1
SG,PW2,BOOLE	NO PLOT SP. W. 2
SG,PW3,BOOLE	NO PLOT SP. W. 3
SG,PW4,BOOLE	NO PLOT SP. W. 4
SG,PA1,BOOLE	NO PLOT AGC 1
SG,PA2,BOOLE	NO PLOT AGC 2
SG,PA3,BOOLE	NO PLOT AGC 3
SG,PA4,BOOLE	NO PLOT AGC 4
SG,PP3,BOOLE	NO PLOT 3-BEAM SOLUTION
SS,OD,WHOLE	5 OffSet for Depth
SS,OH,TENTHS	45.0 OffSet for Heading
SS,OP,TENTHS	0.0 OffSet for Pitch
SS,ZR,TENTHS	0.0 OffSet for Roll
SS,OT,HUNDREDTHS	45.00 OffSet FOR temp
SS,ST,HUNDREDTHS	50.00 Scale for Temp
SS,SL,HUNDREDTHS	35.00 Salinity (PPT)
SS,UD,BOOLE	YES Toggle UP/DOWN
SS,CV,BOOLE	NO Toggle concave/Convex transducerhead
SS,MA,TENTHS	30.0 Mounting angle for transducers.
SS,SS,HUNDREDTHS	1530.00 Speed of Sound (m/sec)
XX,GP,BOOLE	YES [SYSTEM DEFAULT, GP]

XX,DD,TENTHS	1.0 [SYSTEM DEFAULT, DD]
XX,PT,BOOLE	NO [SYSTEM DEFAULT, PT]
XX,TU,TRI	2 [SYSTEM DEFAULT, TU]
TB,FP,WHOLE	1 FIRST BINS TO PRINT
TB,LP,WHOLE	64 LAST BIN TO PRINT
TB,SK,WHOLE	6 SKIP INTERVAL BETWEEN BINS
TB,DT,BOOLE	YES DIAGNOSTIC TAB MODE
DU,TD,BOOLE	NO TOGGLE USE OF DUMMY DATA
XX,PN,WHOLE	0 [SYSTEM DEFAULT, PN]
DR,SD,WHOLE	3 Second recording drive
DR,PD,WHOLE	3 First recording drive (1=A:,2=B: ...)
DP,PX,BOOLE	NO Profiler does XYZE transform
SS,LC,TENTHS	5.0 Limit of Knots change
SS,NW,TENTHS	0.5 Weight of new knots of value
GC,GM,TRI	2 GRAPHICS CONTROL 0=LO RES, 1=HI RES, 2=ENHANCED
AD,PS,BOOLE	NO YES=SERIAL/NO=PARALLEL Profiler Link
XX,LNN,BOOLE	YES [SYSTEM DEFAULT, LNN]
XX,BM,BOOLE	YES [SYSTEM DEFAULT, BM]
XX,RSD,BOOLE	NO RECORD STANDARD DEVIATION OF VELOCITIES PER BIN
XX,DRV,WHOLE	0 [SYSTEM DEFAULT, DRV]
XX,PBD,WHOLE	3 [SYSTEM DEFAULT, PBD]
TB,RS,BOOLE	NO SHOW RHPT STATISTIC
UX,EE,BOOLE	YES ENABLE EXIT TO EXTERNAL PROGRAM
SS,VSC,TRI	0 Velocity scale adjustment
AD,DM,BOOLE	NO USE DMA
TB,SC,BOOLE	NO SHOW CTD DATA
AD,CW,BOOLE	YES Collect spectral width
DR,RW,BOOLE	YES Record average SP.W./Bin
DR,RRD,BOOLE	NO Record last raw dopplers
DR,RRA,BOOLE	NO Record last raw AGC
DR,RRW,BOOLE	NO Record last SP.W.
DR,R3,BOOLE	YES Record average 3-Beam solutions
DR,RBS,BOOLE	YES Record beam statistic
XX,STD,BOOLE	NO [SYSTEM DEFAULT, STD]
LR,HB,HUNDREDTHS	0.00 Heading Bias
SL,1,ARRAY5	0 1 8 NONE 19200 PROFILER
SL,2,ARRAY5	0 1 8 NONE 1200 LORAN RECEIVER
SL,3,ARRAY5	0 1 8 NONE 1200 REMOTE DISPLAY
SL,4,ARRAY5	0 1 8 NONE 1200 ENSEMBLE OUTPUT
SL,5,ARRAY5	0 1 8 NONE 1200 AUX 1
SL,6,ARRAY5	0 1 8 NONE 1200 AUX 2

DU,1,ARRAY6	100.00	100.00	60.00	0.00	0.00	YES	D1
DU,2,ARRAY6	-100.00	-100.00	60.00	0.00	0.00	YES	D2
DU,3,ARRAY6	200.00	200.00	60.00	0.00	0.00	YES	D3
DU,4,ARRAY6	-200.00	-200.00	60.00	0.00	0.00	YES	D4
DU,5,ARRAY6	200.00	19.00	60.00	0.00	0.00	YES	AGC
DU,6,ARRAY6	0.00	0.00	60.00	0.00	0.00	NO	SP. W.
DU,7,ARRAY6	0.00	0.00	60.00	0.00	0.00	NO	ROLL
DU,8,ARRAY6	0.00	0.00	60.00	0.00	0.00	NO	PITCH
DU,9,ARRAY6	0.00	0.00	60.00	0.00	0.00	NO	HEADING
DU,10,ARRAY6	0.00	0.00	60.00	0.00	0.00	NO	TEMPERATURE

DC,1,SPECIAL "FH00002" MACRO 1
DC,2,SPECIAL "E0004020099" MACRO 2
DC,3,SPECIAL "B008001" MACRO 3
DC,4,SPECIAL "CF63" MACRO 4
CI,1,SPECIAL "TN026" CRUISE ID GOES HERE
LR,1,SPECIAL " " LORAN FILE NAME GOES HERE

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16. Abstract (Limit: 200 words)

The objective of this cruise was to occupy a hydrographic section nominally along 149E from Papua New Guinea to the shelf off the coast of Japan near Yokohama as part of the one-time WOCE Hydrographic Programme survey of the Pacific Ocean, line P10. This report describes the processing of shipboard acoustic Doppler current profiler (ADCP) data that were collected during this cruise. New GPS-based heading measurements ("Ashtech heading"), which increase the accuracy of the ADCP, are covered in detail. A subset of the processed data from the New Guinea Coastal Undercurrent and from the Kuroshio is presented.

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shipboard ADCP
Ashtech heading

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