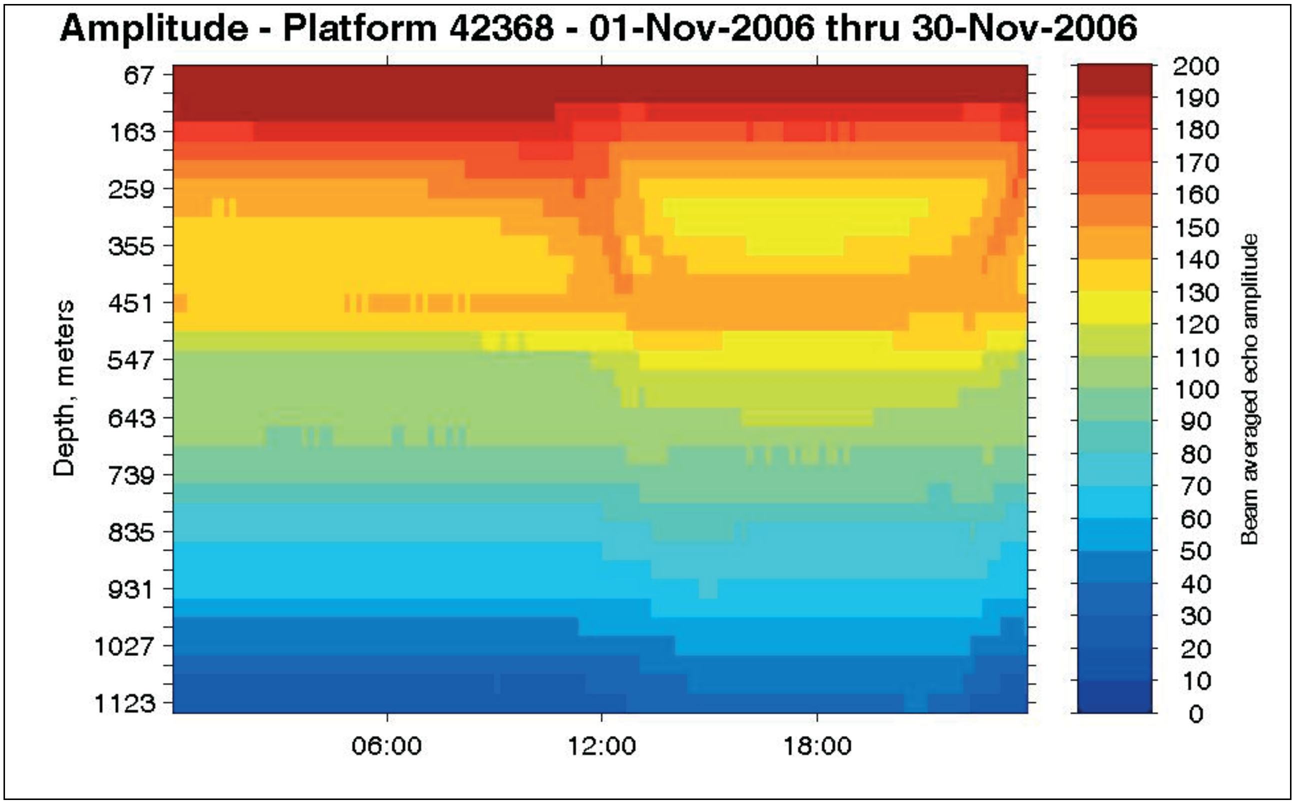
OCS Study
MMS 2009-010

Quality Control Analysis of Acoustic Doppler Current Profiler Data Collected on Offshore Platforms of the Gulf of Mexico



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

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Quality Control and Analysis of Acoustic Doppler Current Profiler Data Collected on Offshore Platforms of the Gulf of Mexico

Authors

L.C. Bender
S.F. DiMarco

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ABOUT THE COVER

The cover art depicts the backscatter amplitude averaged for the four ADCP beams for platform 42368. It shows clear evidence of a vertical diurnal migration, resulting in higher backscatter during the night when organisms ascend to the surface to feed.

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1.0 INTRODUCTION

In 2005 MMS announced Notice to Lessees and Operators (NTL) No. 2005-G05 “Deepwater Ocean Current Monitoring on Floating Facilities” that provides for the submittal of oceanographic data and current monitoring information to MMS via a single publicly available Internet site. The GOMR therefore established that all floating mobile offshore drilling units, and production facilities (with certain exceptions) operating or installed in water depths greater than 400 m must continuously monitor and gather ocean current data in a real-time basis from near the ocean surface (~30 m) to ~1000 m using acoustic Doppler current profiles (ADCP) current monitoring or compatible equipment. The data must be recorded at least once every 12 hours and reported to MMS via the Internet. In water depths greater than ~1100 m, additional equipment, preferably an upward-looking ADCP, is to be installed near ~100 m above bottom. Data from this system should record at least once every 20 minutes. Data are to be reported to MMS via the Internet within 30 days of retrieval. The number of sites required to report data are estimated to be in the range of 30-40. Data will be passed through preliminary (Level 1) processing procedures and reported by the National Data Buoy Center (NDBC).

We proposed to provide to MMS two items regarding industry ADCP data collected and submitted to MMS under NTL No. 2005-G05: 1) an evaluation of the Level 1 QA/QC procedures and 2) provide recommendations for next level quality control of the collected data. We note that we are aware of QARTOD-II (industry workshop) guidelines developed in February 2005 for QA/QC of ADCP data and are keeping close communication with industry and NDBC parties involved with ADCP collected under the NTL No. 2005-G05. After QA/QC evaluation, collected ADCP will be analyzed and synthesized into the CACCL project.

1.1 Evaluation of Level 1 Processing Procedures

We proposed to provide to MMS an evaluation of the ADCP data processing procedures implemented by MMS and the National Data Buoy Center (NDBC). Currently, only quick-look (on-the-fly) processing of the ADCP data is planned. This processing provides a rapid assessment of the incoming data stream in near-real time. The resulting data product is not considered to be of research or archival quality. Level 1 QA/QC include data range checks for pitch/roll, vertical, error, and horizontal velocities, echo (backscatter) intensity, percent good pings and beam solution, beam correlation, and surface (or bottom) reflection. Incoming data that fail one or more Level 1 tests are either flagged or eliminated from the dataset. However, flagging and elimination only pertains to data display (graphical or tabular), NOT to the original data files.

We proposed an independent review of the industry ADCP collected under the NTL No. 2005-G05. This would be executed by an analysis of the incoming (raw) data and a review of the QA’d Level 1 data at up to three selected reporting sites. The raw and Level 1 data would be compared and statistics of percentage of raw data eliminated from the database would be calculated. Physical oceanographic variables (temperature, horizontal current velocity, pressure and salinity, when available) eliminated from the database due to Level 1 failure will be qualitatively examined to verify that elimination from the database is justified. Statistics (mean, variance, maximum and minimum values) of passed and eliminated variables will be compared.

1.2 Recommendation for Level 2 or Delayed Mode (Post-) Processing Procedures

A second element is proposed to provide recommendations for more in-depth processing and archival of the ADCP data. Typically, Level 2 processing entails advanced statistical methods such as variance spectra, empirical orthogonal function (EOF) analysis, and auto- and cross-correlation analysis. Upon completion of the Level 1 Evaluation proposed above, we will provide to MMS recommendations and guidance for additional QA/QC processing of the Level 1 dataset. This includes but not limited to recommendations for additional Level 1 tests (if any), guidance for Level 2 test criteria, formatting and archival. Formatting and archival will be coordinated with national Data Management and Communication (DMAC) initiatives.

1.3 Data Analysis of QA/QC'd ADCP Data

The data will be analyzed using standard oceanographic methodologies and analysis techniques. These include standard visualization techniques, time-series and statistical methods, and numerical analyses. Visualization includes graphical representation of study data (time series representations, vector stick plots, hodographs, vector progressive diagrams, contour plots, property-property plots, and vertical sections) and the production of computer animations of observations and numerical output. Time series and statistical methods include harmonic analyses, complex demodulation, spectral decomposition, wavelet analysis, complex empirical orthogonal function analysis, correlation (coherency) analysis, scales analysis, and objective analysis. Additional analysis and statistical methods may be used as needed.

2.0 METHODS

Our sole source of data for this project was the ADCP binary files publicly available on the NDBC web site at http://www.ndbc.noaa.gov/data/adcp_raw_data/. We wrote specific MATLAB code to sequentially retrieve the files for a specific day, concatenate the day's worth of files together, and extract and convert the binary data into ASCII data files containing the relevant variables. We tested this method of extracting and converting binary data against the Teledyne RD Instruments (RDI) product WINADCP. WINADCP is user directed, not automated as our code was, and is typically used to process the binary data. However because of the nature of the ADCP binary files having only one ensemble per file, using WINADCP for this project would have proven to be laborious and possibly mistake-ridden. In addition WINADCP has no provision for decoding the special MMS header. Consequently we wrote specialized code and tested it on several different binary data files. We found no difference in the data extracted by WINADCP from that of the code we wrote.

It was our intent to conduct an independent review of the industry ADCP data collected under the NTL No. 2005-G05. We relied solely on Appendix 2 of NTL No. 2005-G05 to test how well we could recreate the QC process based on the guidance provided in the appendix. Henceforth we will refer to Appendix 2 of NTL No. 2005-G05 as Appendix 2, even though there are no Appendices in this report. Unfortunately, it was not possible to use Appendix 2 exclusively, as we shall explain in the follow on section, and we had to resort to two other sources of information, the NDBC Web page on Measurement Description and Units, http://www.ndbc.noaa.gov/measdes.shtml, and the article by Crout et al. (2006). Any additional verbal or written guidance that might have been provided by MMS to the operators was unknown to us and would not have been used had it been. We acknowledge extensive discussions with Darryl Simmonds of TRDI that were exceptionally helpful in understanding the internal RDI quality control procedures.

This project was proposed to be a limited study of up to three reporting sites. A complete analysis of every MMS platform was simply not possible, though the mechanisms are now in place to do so. We picked two groups of platforms having a mix of fixed and mobile assets and a range of operators. We thought direct comparison of the measured currents between nearby platforms would help to shed some light on the quality of the data; unfortunately, it did not. Group A consisted of the three platforms 42366, 42368 and 42872 and Group B consisted of the three platforms 42373, 42880 and 42888. Table 1 shows details. The geographic positions were taken from the NDBC Web site as posted on or around November 1, 2006.

Table 1

Platform Details

	42366	**42368**	**42872**	**42372**	**42880**	**42888**
MMS Web Site						
Platform Type	Fixed	Fixed	Mobile	Fixed	Mobile	Mobile
Platform Operator	Anadarko	Conoco	BP Inc.	Chevron	Marathon	Nexen
Platform Name	Red Hawk	Magnolia	Deepwater Horizon	Genesis	Ocean Voyager	Arctic 1
Latitude	27.122	27.204	27.141	27.779	27.718	27.719
Longitude	-91.959	-92.203	-92.119	-90.519	-90.631	-90.798
Nominal water depth, m	1615	1424	1436	789	997	911
MMS Header Info						
Platform Type	Not coded	Not coded	Not coded	Not coded	Not coded	Not coded
Platform Operator	Kerr-McGee	Conoco	BP	Chevron Corporation	Marathon	Nexen
Platform Name	Red Hawk	Magnolia	Horizon	Genesis	Ocean Voyager	Arctic 1
Latitude	27.122	27.200	27.141	27.780	27.718	27.727
Longitude	-91.959	-92.200	-92.119	-90.519	-90.631	-90.793
ADCP Model	RDI 75kHz BB	38kHz OS	38 KHZ	RDI 75kHz BB	75KHZ	75LR
Nominal water depth, m	1615	1400	1434	819	997	911
Transducer depth, m	89	15	32	10	30	25
ADCP Binary Data						
Instrument	WorkHorse LongRanger	Ocean Observer	Ocean Observer	WorkHorse LongRanger	BroadBand	WorkHorse LongRanger
Frequency	75 kHz	38 kHz	75 kHz	75 kHz	75 kHz	75 kHz
Mode	Broadband	Narrowband	Broadband	Narrowband	Broadband	Broadband
Beam pattern	Concave	Concave	Concave	Concave	Concave	Concave
Beam angle, deg	20	30	30	20	20	20
Beam configuration	4-beam Janus	Phased Array	Phased Array	4-beam Janus	4-beam Janus	4-beam Janus
Vertical alignment, deg	42	0	0	21	0	0
Bin mapping used	Y	Y	Y	Y	Y	Y
3-beam solution used	Y	Y	Y	Y	Y	Y
Tilt correction used	Y	Y	Y	Y	Y	Y
Earth coordinates	Y	Y	Y	Y	Y	Y
Correlation Threshold	64	0	120	70	64	64
Error Velocity Threshold, cm/sec	20	10	10	20	99.99	20
False Target Amplitude Threshold	50	255	255	50	255	50

Table 1. Platform Details (continued).

	42366	**42368**	**42872**	**42372**	**42880**	**42888**
Bin length, m	16	32	16	8	16	16
Distance to middle of first bin, m	25.85	51.9	24.73	17.74	32.55	25.66
Blanking length, m	8	20	8	8	16	8
Number of bins	32	34	45	80	35	40
Number of pings per ensemble	400	150	150	295	256	195
Time between pings, sec	3	2	1.5	2	2	3
Averaging interval, min	20	5	3.75	9.83	8.53	9.75
Reporting interval, min	20	10	10	11.92 to 111	10	10
Temperature						
sensor available?	Yes	Yes	Yes	Yes	Yes	Yes
data saved?	Yes	Yes	Yes	Yes	Yes	Yes
Salinity						
sensor available?	No	No	No	No	No	No
data saved?	No, manual input: 35 ppt	No, manual input: 35 ppt	No, manual input: 35 ppt	No, manual input: 35 ppt	No, manual input: 35 ppt	Yes(?)
Transducer depth						
sensor available?	Yes	No	No	Yes	No	Yes
data saved?	No, manual input: 89 m	Manual input: 15 m	Manual input: 32 m	Yes	Yes (?)	Yes
Transducer heading						
sensor available?	Yes	Yes	Yes	Yes	Yes	Yes
data saved?	No, manual input: 120 deg	Yes	Yes	Yes	Yes	Yes
Transducer roll						
sensor available?	Yes	Yes	Yes	Yes	Yes	Yes
data saved?	No, manual input: 0 deg	Yes	Yes	Yes	Yes	Yes
Transducer pitch						
sensor available?	Yes	Yes	Yes	Yes	Yes	Yes
data saved?	No, manual input: 42 deg	Yes	Yes	Yes	Yes	Yes
Speed of sound	Manual input: 1529 m/sec	Manual input: 1539 m/sec	Manual input: 1543 m/sec	Manual input: 1538 m/sec	Calculated from T, S and depth.	Calculated from T, S and depth.

3.0 EVALUATION

The purpose of this report is to evaluate the Level 1 QA/QC procedures and provide recommendations for next level quality control of the collected data. As stated in our proposal, this was to be done in view of the Quality Assurance of Real-Time Oceanographic Data (QARTOD, http://nautilus.baruch.sc.edu/twiki/bin/view) guidelines. As such, it behooves us to understand how the QARTOD guidelines can be traced back to the MMS Level 1 QA/QC flags propounded in Appendix 2 of NTL No. 2005-G05.

The Level 1 QA/QC procedures that are the subject of this report began at RDI. The Level 1 QA/QC procedures that became Appendix 2 were a compromise reached between the lease operators and MMS, with input from RDI and NDBC. The first QARTOD meeting was held on December 3-5, 2003, approximately 16 months before MMS issued NTL No. 2005-G05. The QARTOD-I workshop participants for real-time ocean observations agreed upon a general level of minimum standards for QA/QC, but there were no specific requirements, with actual numbers, for ADCPs or any other instrument. At the QARTOD II meeting held February 28 – March 2, 2005, Don Conlee of NDBC made a plenary presentation, "Initial Automated Quality Checks for Oil Platform Current Data" and provided example thresholds for the QA/QC of ADCP data. These thresholds, in the form of a table, were incorporated directly into the QARTOD-II workshop report as Figure 1, where they apparently remain the QARTOD standard to this day. A comparison of this table to Appendix 2 suggests the table was derived from Appendix 2 and that it was a simplified subset of what was in the appendix. Dr. Matthew Howard, an attendee of the QARTOD-II workshop and a member of the DMAC steering committee, then made a presentation to the DMAC steering committee on April 6, 2005. The table was included in his presentation. It is the stated goal of DMAC to adopt the QARTOD standards. On April 21, 2005, MMS issued NTL No. 2005-G05, "Notice to Lessees and Operators of Federal Oil and Gas Leases and pipeline right-of-way holders on the Outer Continental Shelf, Gulf of Mexico OCS Region, Deepwater Ocean Current Monitoring on Floating Facilities." This included Appendix 2 with specific requirements for QA/QC. QARTOD-III was held on November 2–4, 2005 and continued the work on current measurements, but no final workshop report has been issued. On February 2, 2006 at the 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS), Richard Crout of NDBC made a presentation, "Real-time Oil Platform Ocean Current Data in the Gulf of Mexico: An IOOS industry partnership success story." (Crout et al., 2006). This paper is the most detailed and documented description of the Appendix 2 MMS flags and, for that matter, the most relevant and advanced description of QA/QC. The paper also contains a table of the data quality tests and criteria for MMS ADCP data that is an improvement on the table included in QARTOD-II. In March 2006 NDBC implemented the Level QA/QC procedures into the real time processing stream (Crout and Conlee, 2006). The most recent QARTOD workshop, QARTOD-IV was held June 21-23, 2006. A final workshop report has been issued, but it does not introduce a new version nor modify the table of QARTOD-II.

In summary, the MMS data quality tests of Appendix 2, as documented by Crout et al. (2006), are the basis for the QARTOD and DMAC requirements. Furthermore, they are more comprehensive than any QARTOD requirement suggested to date and are the currently accepted wisdom for the quality assurance of real-time oceanographic data collected from ADCPs. The

MMS flags represent the application of an actual working strategy down at the level of specificity needed to code an automated process. We note that Appendix 2 goes well beyond the ongoing QARTOD discussions of what should be included as QA/QC. Nevertheless, as we will show, there is room for improvement.

Our evaluation of the Level 1 QA/QC procedures could have taken two directions. The first would have been a straightforward comparison of the flags posted on the NDBC site for a particular platform to the flags independently determined by us directly from the ADCP data. Unfortunately, this was not the straightforward task one might think because it entails a level of interpretation of what was intended by the requirements of Appendix 2 and Crout et al. (2006). Our analysis of the Level 1 QA/QC procedures (to be detailed below) showed that there is some level of ambiguity in the implementation of the Appendix 2 requirements. While we could have contacted MMS or NDBC for additional guidance, we chose to take the position of an external scientific review based on just the available data and supporting documentation. There was also some question in our mind as to who was responsible for implementing Appendix 2, each of the individual platform operators or NDBC. There is no provision in the ADCP binary data structure for the operator to transmit the flags so it is our supposition that the QA/QC flags are generated by NDBC. Crout and Conlee (2006) state this to be the case.

It is of extreme importance to understand that the Level 1 QA/QC procedures are not the first and only line of quality control on the ADCP data. By design the RDI instrument carries out a complex set of quality control steps well before the MMS flags are applied. The Level 1 QA/QC procedures are at best a post-processing quality control review. The internal RDI steps and the MMS procedures can and do overlap. Therefore it behooves one to know how RDI internally quality controls the data in order to best evaluate the MMS flags. Hence we took a more detailed approach than a simple comparison of flags and sought to understand and evaluate the Level 1 QA/QC procedures and their efficacy in light of the RDI quality control measures.

This approach is critical because if the MMS flags are less restrictive than the RDI measures, then either the MMS flags are superfluous because they will always show the data is acceptable or too much ADCP data is being internally rejected by a higher than needed standard. On the other hand, if the MMS flags are more restrictive then the RDI standards, then the ADCP data are noisier than they should be and are in danger of being rejected by the MMS QA/QC post-processing. While somewhat counterintuitive, if the RDI standards were more restrictive, in keeping with the intent of the MMS flags, then there is a greater chance of passing on more data that is of higher quality. This will be explained below.

3.1 Quality Control Steps

The order and method in which the RDI software internally quality controls the data is of extreme importance. What follows in a working description, compiled by us, of the sequential steps taken by RDI in the internal quality control of the data. This description is the result of reading RDI technical manuals, speaking with RDI personnel, reading relevant published reports and literature on ADCP quality control and piecing together the details. There is no readily available RDI document that discusses in one place what is presented below.

3.1.1 Step 1

The ADCP determines water mass velocity by measuring the Doppler frequency shift of the backscattered echo. The instrument pulses, or pings, all four transducer faces simultaneously through a single power cable and then processes the returns for each beam with four separate sets of electronics. While the 38 kHz Ocean Observer uses a single phased array transducer to electronically create the four beams, the discussion herein is still applicable. The returns from each transducer are range gated into range cells. Before the next ping is sent, steps 2, 3, 4 and 5 are taken.

3.1.2 Step 2

The radial velocity of each beam is calculated by knowing the transmitted acoustic frequency and the velocity of sound in water at the transducer face. The user can tell the ADCP the speed of sound or the ADCP can compute the speed of sound from temperature, salinity and transducer depth data, if the appropriate sensors are available. If the ADCP is not given a speed of sound, it uses a default value of 1500 m/sec. At this point there is a high level quality control step. According to the RDI technical manuals the radial ambiguity velocity sets the maximum velocity that can be measured when operating in water mode 1. To the best of our knowledge all the platforms operate in water mode 1 (broad bandwidth processing). RDI strongly recommends the default value of 175 cm/s for the Workhorse Long Ranger 75 kHz model and 390 cm/s for the Ocean Observer 38 kHz model. This setting is not recorded in the ADCP binary data per se, but it can be calculated from the lag, the speed of sound (included in the ADCP leader data), and the carrier cycles (the actual formula is available from RDI).

3.1.3 Step 3

Under conditions of severe pitch and roll, radial velocity measurements from each beam at the same range may come from different depths. If high-quality pitch and roll data is available, then this effect can be countered by mapping each beam's range cell to a depth cell, or bin, on the true vertical axis, i.e. aligned with the gravity vector. Bin mapping must be enabled for this to happen and it also requires that the data be collected in earth coordinates. The radial beam velocities, the correlation count, and the echo amplitudes are all bin mapped. If the data is collected in beam coordinates, then bin mapping is not applied and any additional screening is done without accounting for the tilt of the ADCP. For the six cases we examined, bin mapping was enabled and the data was collected in earth coordinates.

3.1.4 Step 4

At this point, internal quality control begins in earnest. The RDI onboard ADCP software performs screening on a ping-by-ping basis of the depth cell mapped, bin data. The purpose of this step is to identify bad data. QA/QC on a ping-by-ping basis maximizes the volume of high quality signal recorded. Velocity data flagged as bad are not used and neither are they averaged into the final ensemble. All correlation count and echo amplitude are included in the ensemble average, even those bins/beams that violate thresholds. The screening tests used to identify bad data are performed in this order: the correlation test, the false target rejection test, and the error velocity test. If data is flagged as bad in an earlier screening, the subsequent screening is skipped. These screening tests can be completely disabled by setting the appropriate threshold values so that the data is accepted. RDI provides recommended values for these thresholds, but in most cases the operators change one or all of the thresholds to meet their requirements (see Table 1).

3.1.4.1 Correlation Test

Correlation magnitude data for a WorkHorse (WH) ADCP or an Ocean Observer (OO) ADCP in broad bandwidth (BB) mode give the magnitude of the normalized echo autocorrelation at the lag used for estimating the Doppler phase shift. The ADCP represents this magnitude by a linear scale between 0 and 255, where 255 is a perfect correlation (i.e., a solid target). As the correlation count decreases, so does the data accuracy. Note that the correlation magnitude for the OO ADCP in narrow bandwidth (NB) mode gives the magnitude of the energy (power) in the low pass filter. A value of 170 to 190 counts for the narrowband correlation represents normal levels whereas lower values mean a reduced signal to noise ratio. The RDI correlation screening test compares the correlation count of each bin of the four beams to the correlation threshold. The correlation threshold is input as part of the ADCP's setup parameters. If the correlation count for any of the four beams is less than the threshold value, then that bin's beam velocity is marked as bad. Correlation decreases with distance from the transducer and establishes the maximum useable range of the ADCP. Correlation screening can affect any beam anywhere in the profile; however, one beam will typically be affected before the other three. Setting the correlation threshold to zero disables this test. RDI recommends a threshold value of 64 for the Workhorse Long Ranger 75 kHz model and 120 for the Ocean Observer 38 kHz model operating in broadband. There is no such threshold, or recommended factory defaults, for the Ocean Observer 38 kHz model operating in narrowband, yet the RDI binary data does contain a value for the threshold. Table 1 shows the values set by the six cases we examined.

3.1.4.2 False Target Rejection Test

Demer et al. (2000) states that bias in water column velocity estimates can result from acoustic backscattering from fish ensonified by one or more beams. Therefore the ADCP firmware includes a false target rejection algorithm that screens the velocity data for the presence of fish or a false target in one or more of the beams. The false target screening process is an iterative process that evaluates the maximum difference between the echo amplitude of the four profiling beams. The design of the test recognizes that a strong return from one beam is not confined to being received by the transducer of just that beam, but radiates sound back to all four transducers and affects the other three beam returns. This crossover contaminates, or biases, the strength of the signal in the other three to be higher than it is. The test also recognizes that a strong return may not necessarily be from a false target. If the maximum difference between the four beams exceeds the threshold, then the first iteration always removes the beam with the weakest amplitude from any further consideration. The screening is then performed on the remaining three beams. If the maximum difference between the echo amplitude of the three remaining beams does not exceed the threshold, then a three-beam solution is still possible at this point. But if the threshold is exceeded, then the second iteration throws out the weakest beam of the remaining three and only two beams are left. Any further use of the bin is invalid and the data from all four beams are discarded for that bin. Setting the false target amplitude threshold to 255 disables the test and admits all four beams, even if one beam is getting a hard return. RDI recommends a threshold value of 50 for the Workhorse Long Ranger 75 kHz model and 50 (while 255 remains the default value) for the Ocean Observer 38 kHz model operating in either broadband or narrowband. Recall that a value of 255 disables the test, which RDI sets for the 38 kHz of the single phased array transducer. Table 1 shows the values set by the six cases we examined.

3.1.4.3 Error Velocity Test

The error velocity is the difference between the vertical velocities computed using beam pairs 1 and 2 to beam pairs 3 and 4. The error velocity is thus a measure of the variability in the velocity data. If the current field being measured is horizontally isotropic, then theoretically all four radial velocities should be the same and the error velocity would be zero. The error velocity test screens each ping for unacceptable noise and anisotropy in the data. It can detect consistent obstructions from solid scatterers, such as the presence of a drill string, that cause bias in the data. The test compares the error velocity to a threshold. If the error velocity is greater than the threshold, then the ADCP flags all four beams of the affected bin as bad and replaces the error velocity with -32768. Setting the error velocity threshold to a very high setting effectively disables the test and admits all four beams. RDI's internal error velocity default screening values are set purposely high and disable this screening inside the system. RDI recommends a lower threshold value during post processing of ADCP data. Table 1 shows the values set by the six cases we examined.

Each of these three screening tests has a direct counterpart in the MMS flags. There is a relationship between the RDI screening test and the MMS QC flags that should be understood, but one operates on the individual ping data and the other on the ensemble average. For example, the MMS QC flags do not change the value of the water-mass velocity that has already been calculated. They can't fully replace the RDI quality control, particularly if four beam solutions have already been used when a three-beam solution should have been used. If the RDI thresholds are set correctly, then the MMS flags can act as an additional quality assurance and provide a higher level of quality.

3.1.5 Step 5

If after the first three screening tests, only one beam velocity in a particular depth cell is marked bad, then a three-beam solution is still possible, but only if such a solution is enabled. For the six cases we examined this was the case (see Table 1). Water-mass velocities can only be calculated for those pings having three- and four-beam data. In all other cases of bad data, none of the radial velocities can be used and that bin cell is rejected.

The bins having four individual radial beam velocities are then transformed, knowing the beam angle of the instrument, from beam coordinates to instrument coordinates. This step results in two horizontal velocity components based on beams 1 and 2 and on beams 3 and 4 respectively, the vertical velocity based on the average of the four beam velocities, and the error velocity based on the difference in vertical velocity measured by beam pairs 1 and 2 to the beam pairs 3 and 4. The RDI firmware applies the error velocity test for the second time, but this time applied to the coordinate transformed error velocity. The potential is that what were four-beam solutions are now rejected.

The only difference between a three-beam and four-beam solution is that an error velocity in the transformed coordinate system is no longer possible. When the ADCP does a 3-beam solution it stops calculating the error velocity because it needs four beams to do so. But there is still an error velocity determined at the radial beam stage (step 4) before the screening tests were applied.

3.1.6 Step 6

At this point the next ping is sent. If the user selects multiple pings per ensemble, then each of the ping to ping returns are saved and formed into an ensemble-average. For example, if there are ten pings per ensemble, the ensemble-average is the average of the ten pings. Velocity data flagged as bad are not averaged into the final ensemble. All correlation count and echo amplitude are included in the ensemble average, even those bins/beams that violated thresholds. The ensemble-averaged beam velocity, echo amplitude, and correlation count for each beam and each range cell are then sent on to the next step for processing.

3.1.7 Step 7

By this point internal quality control is complete.

3.2 Quality Control Flags

In this section the flags are specifically examined.

Finding #1: Before examining each of the tests we note that the connection between Appendix 2 and the flag designations listed on the NDBC Web site can only be found on the NDBC Web site or Crout et al. (2006).

Recommendation #1: Appendix 2 should specifically list the flag numbering scheme. The NDBC Web site explanation should be far more detailed as to how the flags are determined.

3.2.1 Flag 1 - Profile Test

Finding #2: As stated in Appendix 2 paragraph 3.2.6.6, this test is a Q/C measure of the overall profile status based on a compilation of the QA/QC values for each bin. What is not clear is how flag 1 is to be calculated for each bin because there is guidance in two different sections of Appendix 2. Paragraph 3.2.6.8 states that the flag depends on the percentage of QA/QC values for each bin flagged as suspect or failed. In addition to paragraph 3.2.6.8, Section 1.1.1 contains language stating that the bin and profile shall be flagged with the most severe of the flags discovered in the QC process. Faced with what we viewed as an inconsistency, we applied the guidance under Section 1.1.1 on Quality Control to determine the most severe flag of flags 2 through 8 and assigned that value to flag 1 for each bin. The overall profile flag was then determined by the requirements in paragraph 3.2.6.8.

Recommendation #2: Clarify this discrepancy.

3.2.2 Flag 2 - BIT Result Test

Finding #3: As stated in Appendix 2, Section 1.1.1.1, the BIT result provides a measure of the general health of the system and is an *ensemble based product*. It contains no information about individual bins and applying flag 2 to each bin, as done by NDBC, simply ensures that all bins contain the flag but does not provide any additional information. Appendix 2 states that the BIT result is "only available for Workhorse LongRanger," but it does not provide any guidance regarding what to code for an Ocean Observer. We choose to use a 9, consistent with what is stated on the Web site and recommended by QARTOD.

Recommendation #3: The amount of storage space needed to store the results of this test could be greatly reduced by using a single flag for each ensemble.

3.2.3 Flag 3 - Error Velocity Test

Finding #4: It is not clear as to how MMS intended this test to be coded. Error velocity can be both positive and negative. The stated requirements would flag all negative velocities as good, no matter how large. We reasonably chose to apply the test to the absolute value of the error velocity.

Recommendation #4: Modify the requirement to specifically state the absolute value.

3.2.4 Flag 4 - Percent Good Test

Finding #5: As stated in Appendix 2, Section 1.1.1.3, the percent good thresholds were based on agreed upon requirements regarding the profiling mode, the bin size, the time between pings, the minimum averaging interval, etc. As seen from Table 1, in none of the six cases we examined were these requirements met. There are no provisions in the QC flag structure to indicate if the operator met the agreed upon requirements.

Recommendation #5: Specify the ADCP setup parameters as a requirement, provide the exact setup parameters in the Appendix and add a new flag that indicates if the actual setup parameters are to specification. If not, provide space in the meta data to explain why the deviation is acceptable.

3.2.5 Flag 5 - Correlation Magnitude Test

Finding #6: Correlation magnitude data for broadband give the magnitude of the normalized echo autocorrelation at the lag used for estimating Doppler phase change. The ADCP represents this magnitude by a linear scale between 0 and 255, where 255 is perfect correlation (i.e., a solid target). Correlation magnitude for OO narrow bandwidth (NB) processing gives the magnitude of the energy (power) in the low pass filter. Values of 170 to 190 counts represents normal levels whereas lower values mean a reduced signal to noise ratio.

Recommendation #6: None.

3.2.6 Flag 6 - Vertical Velocity Test

Finding #7: The guidance for this test, Section 1.1.1.5 of Appendix 2, is unclear as to what constitutes the “difference” that the bin’s vertical velocity should be compared to. The QARTOD guidance states it is to be applied to departures from the mean. However we note that this implies that a range check has first been applied, for if every vertical velocity was 100 cm/sec then this test, without the range check, would be passed.

Recommendation #7: Mirror the language of the error velocity test, as modified by the recommendation for that test. An ensemble-averaged vertical velocity of more than 30 cm sec is unlikely and improbable. Use the absolute value as the standard.

3.2.7 Flags 7 & 8 - Horizontal Velocity Test

Finding #8: While the guidance provided in this paragraph, Section 3.2.6.6 of Appendix 2, clearly states this test is based on the velocity magnitude computed from the east and north components, the application used by NDBC and defined in the web site bases the test on each of the horizontal velocity components. Note that Web site states that Flag 7 represents the North Horizontal Velocity test status and Flag 8 represents the East Horizontal Velocity test status.

Recommendation #8: Clarify that the flag has no meaning when individually applied to each vector component.

3.2.8 Flag 9 - Echo Intensity Test

Finding #9: The echo intensity test is applied by comparing the ensemble-averaged echo intensity at a particular bin to the echo intensity of the previous bin. If the echo intensity is high in two or more beams it may indicate a solid boundary such as the bottom or an obstruction. Therefore if the rise on two or more beams exceeds 30 counts, then a failed flag is assigned to all four beams of that bin. This test was intended to check for surface or bottom reflections as well as risers, but was not intended for fish. This means there are two verifications done using echo intensity, one for fish on a bin-to-bin ping-by-ping basis and this test on a bin-to-bin difference on the ensemble average, which may only be a single ping.

Recommendation #9: None

3.3 Individual Platform Evaluation

We evaluated a month’s worth of data (November 2006) for six platforms. In the interests of limiting the number of figures and discussion to a reasonable subset, we focused our discussion specifically to the data from November 1, 2006. This provided an adequate sample for discussing quality control issues. Our tool of choice for this individual platform evaluation was the colorized contour. It graphically presents the magnitude of a variable, such as velocity or echo intensity as a function of depth and time. Essentially a color scale is assigned to the variable range and every bin is plotted as a color. The result is a graphical and readily assessed view of a day’s worth of data. The contour was made for the horizontal speed and direction of the currents, the vertical velocity, the error velocity, the correlation count, the echo amplitude, and the percent of good beams. The more pedestrian time series plots are used to show the heading, pitch and roll and the salinity, transducer depth, water temperature, and speed of sound.

Finding #10: Each ADCP binary set of data is coded with some level of meta data. Table 1 shows a subset of that data that we reviewed. There is no consistency in the ADCP setup parameters, of which Table 1 shows a limited subset of the total. Among the six platforms the correlation threshold varies from 0 to 120, the error velocity threshold varies from 10 to 99.99 cm/sec, and the false target amplitude threshold varies from 50 to 255. The bin length, the blanking length, the number of pings per ensemble, and the time between pings are all different. There is language in paragraph 1.1.1.3 of Appendix 2 regarding an agreed upon requirement for the bin size, minimum time between pings, and minimum averaging interval, but none of the platforms we examined met those requirements.

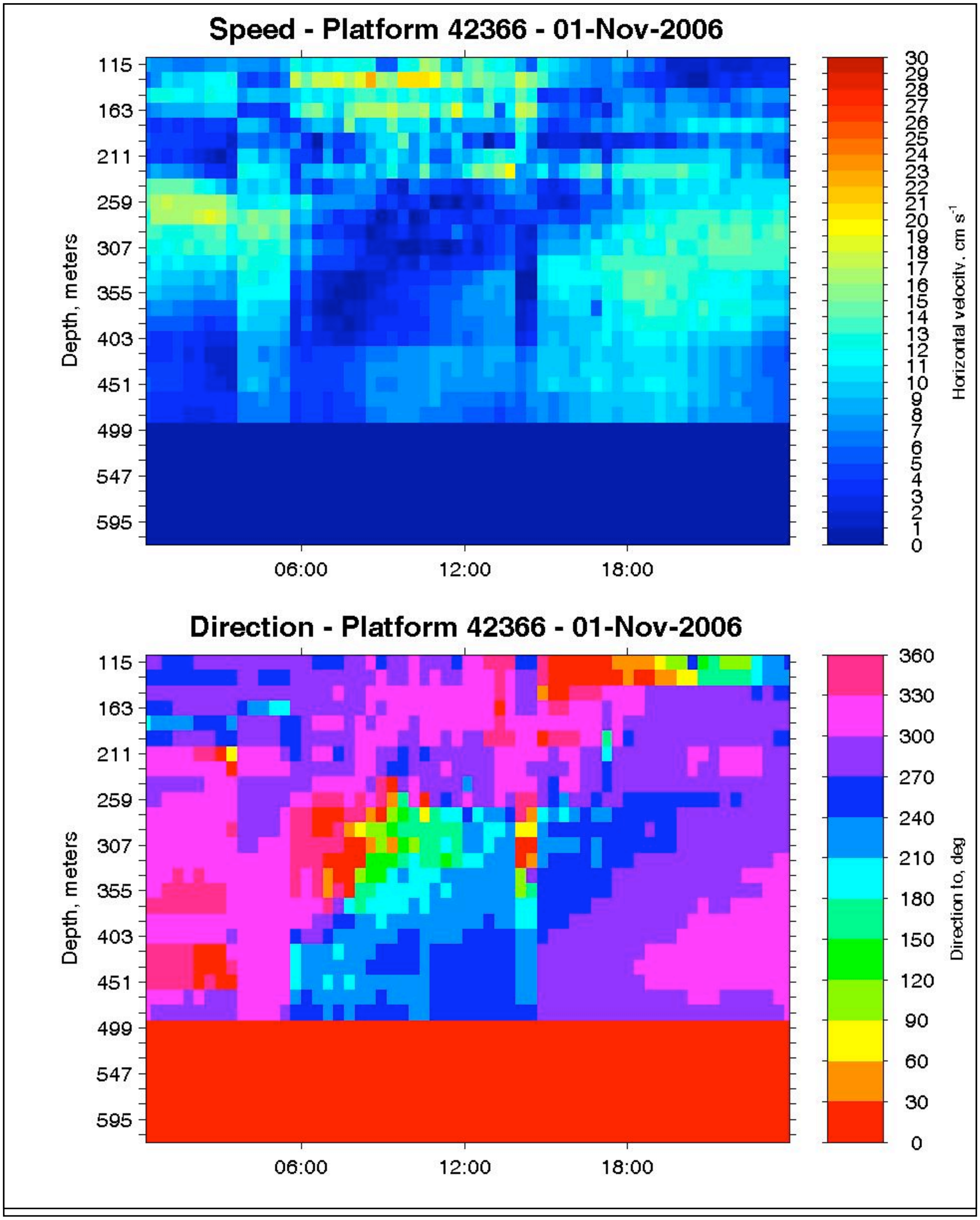
Recommendation #10: To ensure a consistent and universal level of quality across all operators and platforms, the ADCP setup parameters should be specified and required. A quality control flag should be included that evaluates whether the setup parameters are met. The meta data should contain provisions to explain deviations from the required/recommended setup parameters. In lieu of this recommendation a requirement that the standard deviation of the velocity be less than a specified value is recommended.

3.3.1 Platform 42366

The ADCP at platform 42366 is a 75 kHz WorkHorse LongRanger ADCP with a 20 degree beam angle mounted at nominal depth of 89 m. The ADCP is not pointed vertically (0^{o} tilt), but is aligned at a 42^{o} angle. The platform is fixed. The ADCP is operating in broadband mode, which improves the standard deviation (short term precision) of the velocity estimates, but at the expense of range. Table 1 lists the various particulars concerning this ADCP. Given the setup parameters for bin length and number of pings per ensemble, the best possible standard deviation for the velocity is 0.2 cm/sec. The minimum expected standard deviation, based on requiring at least 5% of the total pings per ensemble for a three- or four-beam solution is 0.9 cm/sec. Figure 1 shows the horizontal speed and direction; Figure 2, the vertical velocity and the error velocity; Figure 3, the correlation count; Figure 4, the amplitude, or echo intensity; Figure 5, details about the percentage of good pings; and Figure 6, the orientation of the ADCP and specific environmental data.

There is no issue with the data itself (speed, direction, velocity, percent good, correlation count and echo intensity) as there are no discrepancies between what is posted on the NDBC Web site and what we independently extracted from the binary data as part of this project.

Finding #11: We begin our analysis of this platform by examining the upper panel of Figure 6 which shows the recorded heading, pitch and roll of the ADCP. With every ensemble collected, the ADCP records the sensors that are available. It checks for temperature, salinity, transducer depth, heading, pitch and roll. It next checks to see which of the six sensors the user wants to use or whether the sensor is being manually overridden. If the sensor is not available or is over-ridden, then the user input value for that sensor is substituted or, if there is no user value, the system default is used. In the case of 42366 we see from Table 1 that the heading, roll and pitch sensors are available, but the user chose to manually input values of 120 degrees for the heading, zero degrees for the roll, and 42 degrees for the pitch. Whether this is the actual orientation of the ADCP can't be substantiated from the 'data' alone. What it means is that when the ADCP processes the beam data it 'thinks' beams 1 and 2 are tilted 42 degrees up from the vertical, that beam 3 is pointed at 62 degrees up from the vertical (almost horizontal), and that beam 4 is pointed at 22 degrees past the vertical and 'underneath' beam 4. The water column that is being sampled is not underneath the ADCP, but well out to the side. The RDI specifications for this instrument state that the tilt range is $\pm 50^{o}$. Even though bin mapping and tilt compensation have been enabled (see Table 1), a 42 degree tilt is at the extreme. Examining Figures 1 and 2 it is obvious that the vertical penetration of the instrument is limited to a depth of no more than 600 m. This is a simple mathematical consequence of tilting the instrument at 42 degrees; the vertical penetration of beam 3 is limited. The other consequence is that the correlation count for beam 3 fails the threshold of 64 counts for every profile (see Figure 3). As a result, three beam solutions are needed. There is no independent check on the error velocity.


Speed - Platform 42366 - 01-Nov-2006

Direction - Platform 42366 - 01-Nov-2006

Figure 1. Colorized contours of horizontal velocity (top panel) and current direction (bottom panel) at platform 42366 for November 1, 2006.

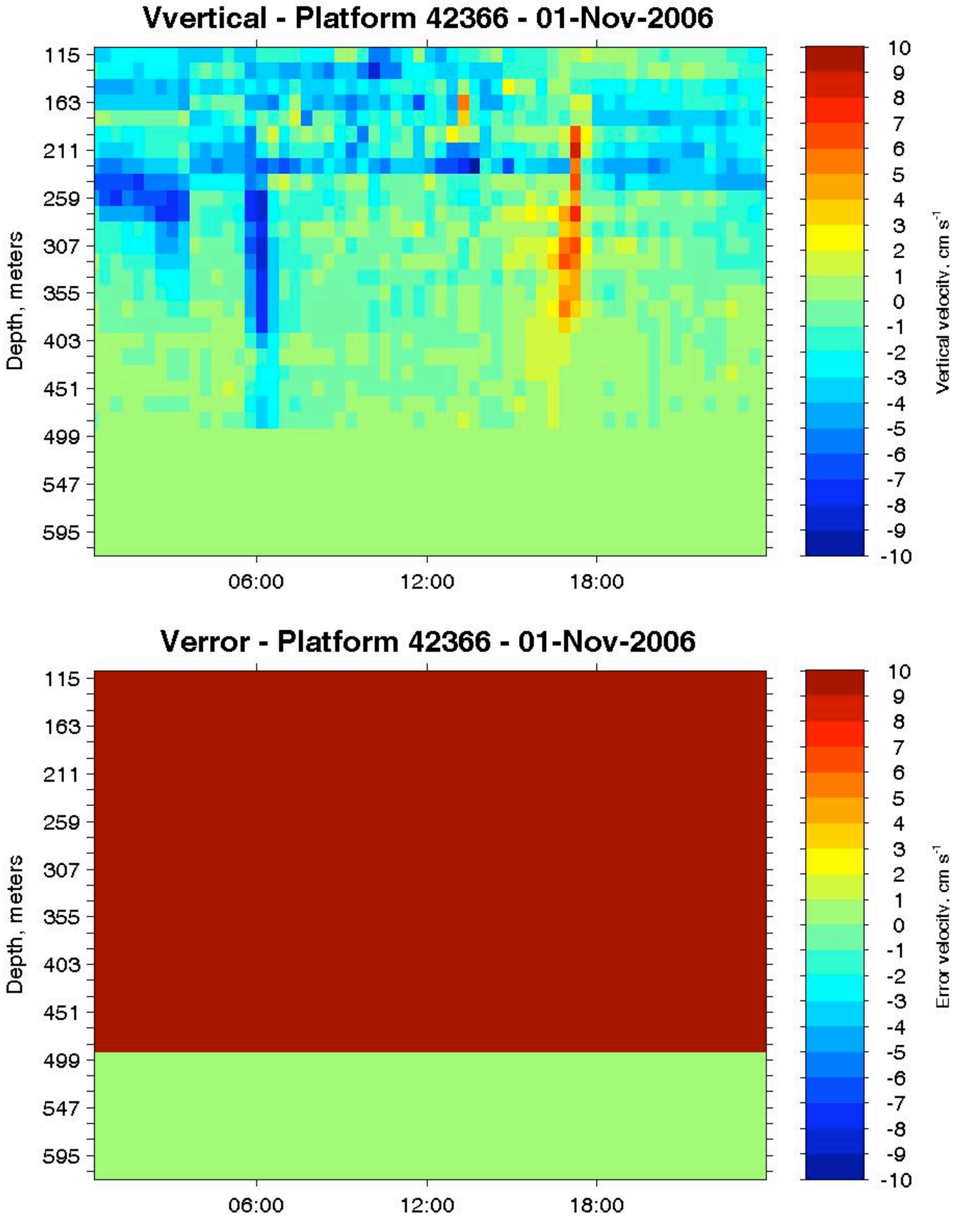


Figure 2. Colorized contour of vertical velocity (top panel) and error velocity (bottom panel) at platform 42366 for November 1, 2006.

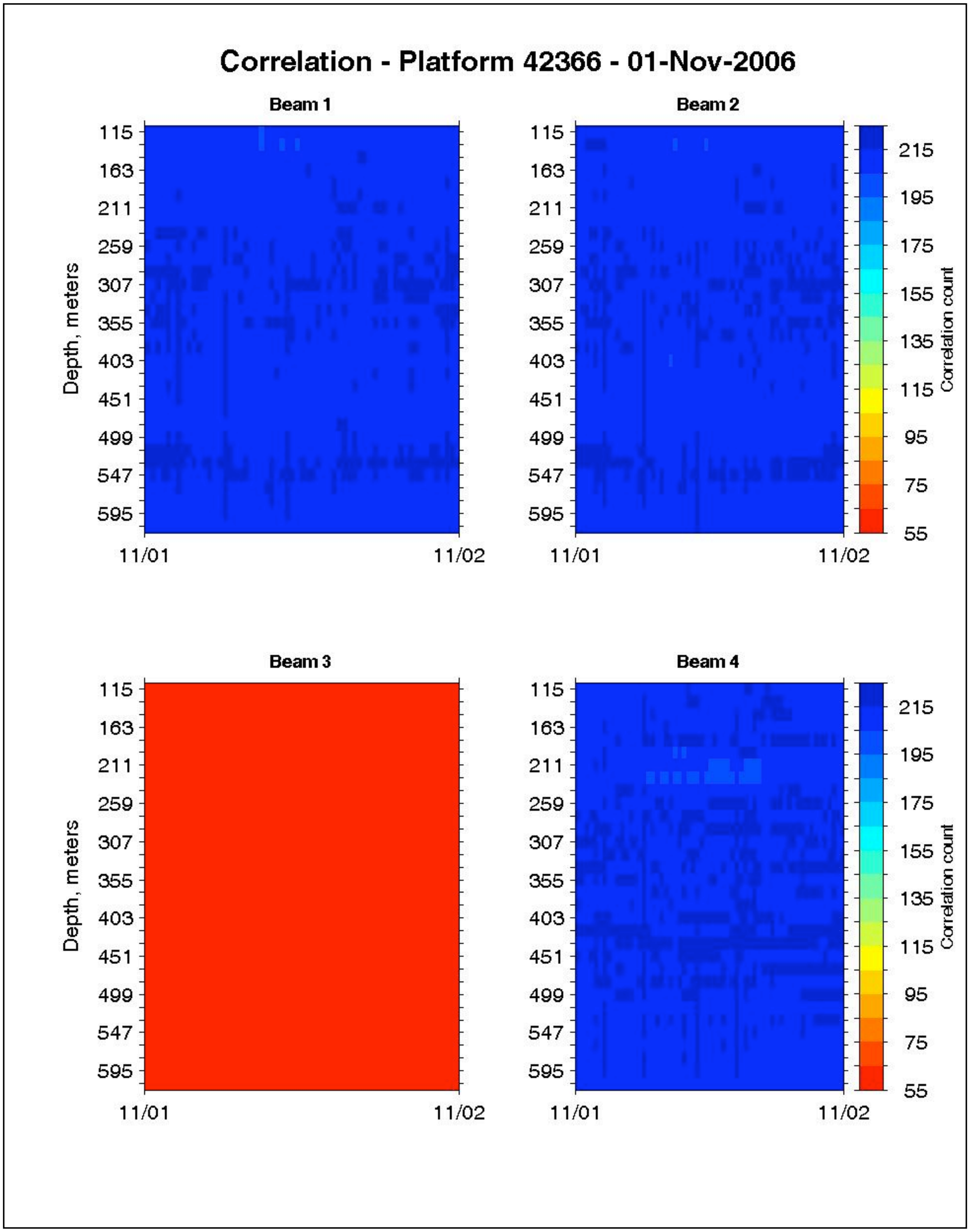


Figure 3. Colorized contour of correlation count for the four ADCP beams at platform 42366 for November 1, 2006.

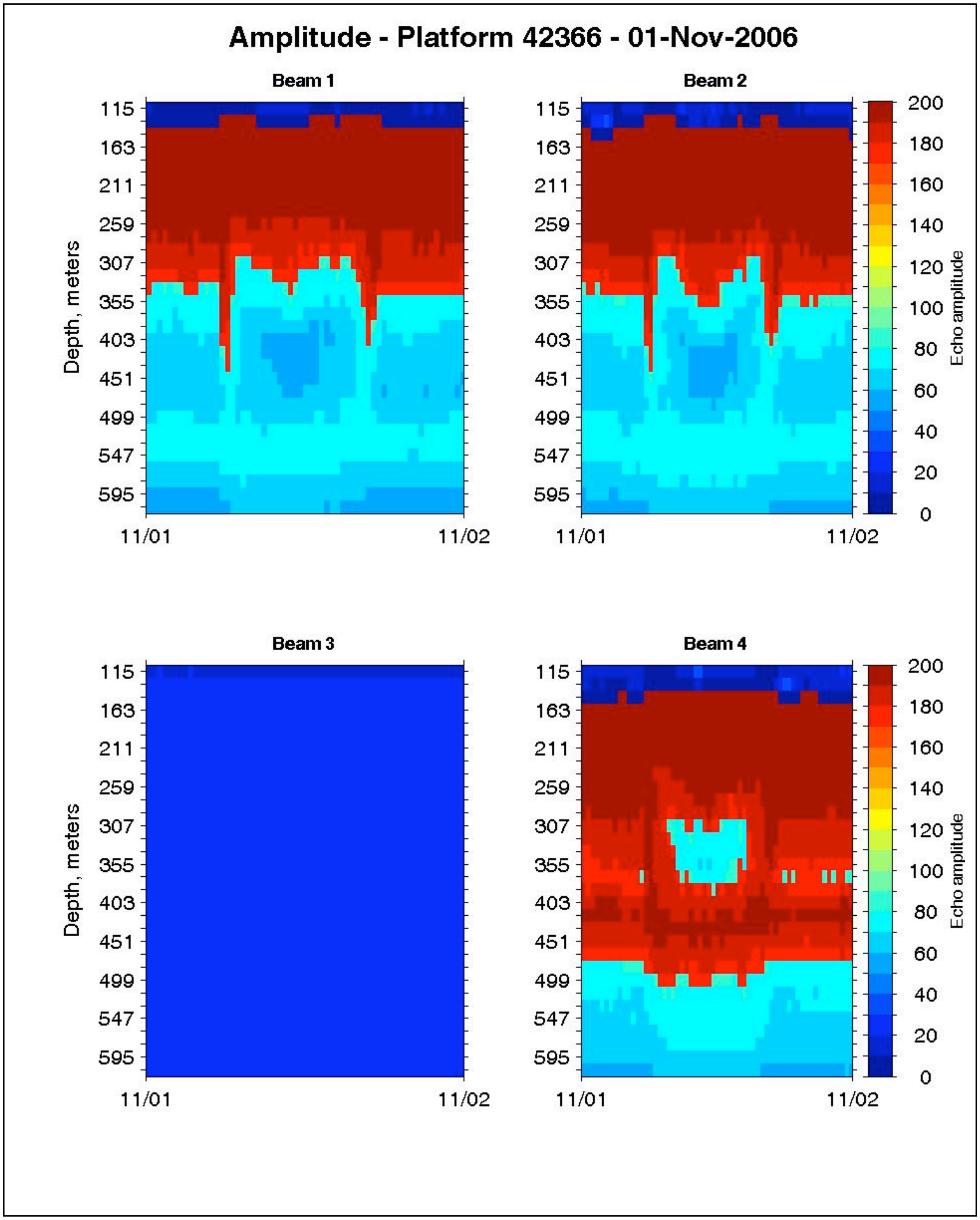


Figure 4. Colorized contour of amplitude (echo intensity) for the four ADCP beams at platform 42366 for November 1, 2006.

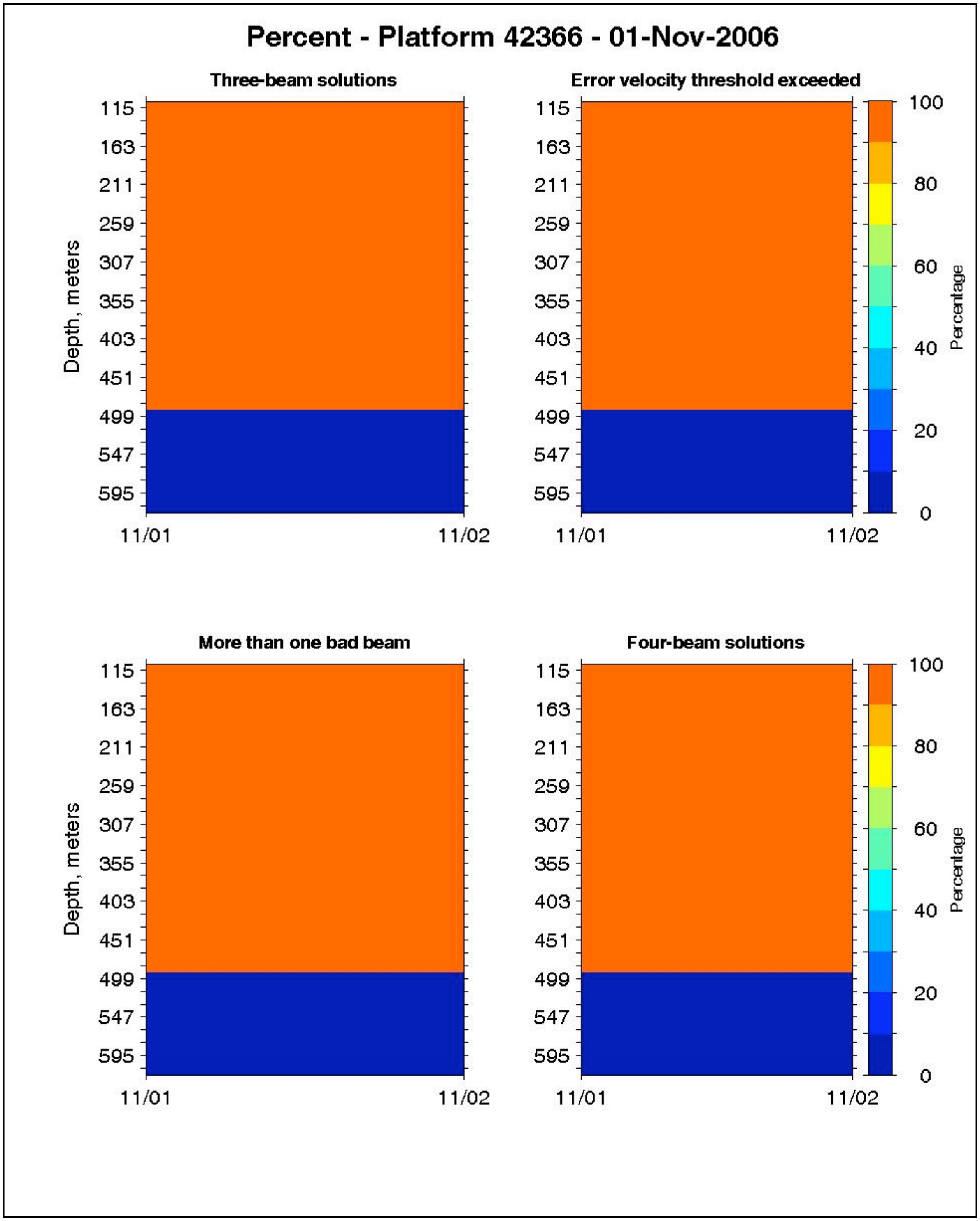


Figure 5. Colorized contours of the percentage of solutions at platform 42366 for November 1, 2006.

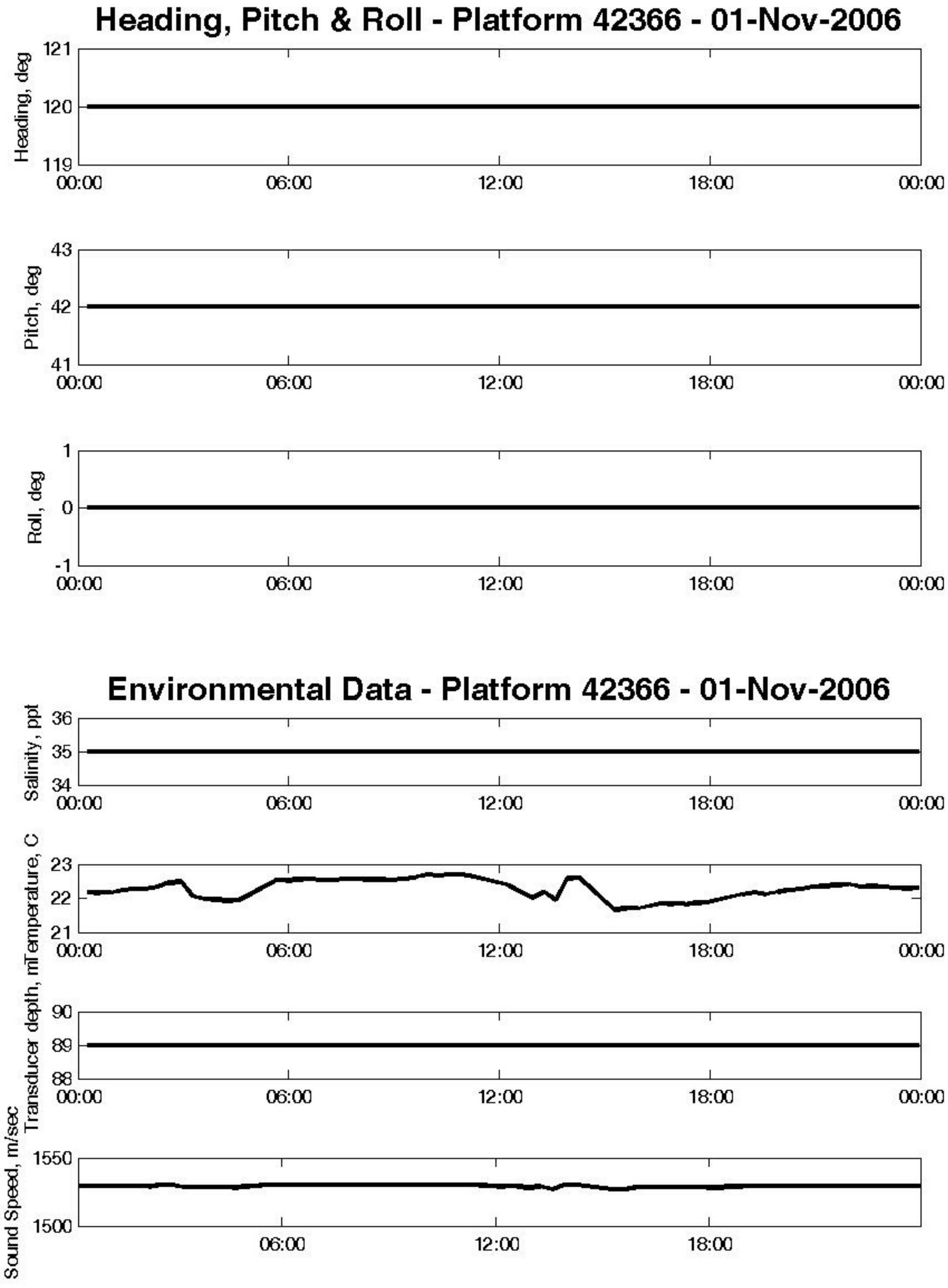


Figure 6. Time series of recorded heading, pitch and roll (top panel) and environmental data (bottom panel) at platform 42366 for November 1, 2006.

Recommendation #11: In some cases, the physical constraints on mounting an ADCP to a platform will require an unusual set up. In this case we encounter a platform that more than likely had to tilt the ADCP out at an extreme angle in order to either avoid the drill string or the platform legs. This orientation is not without consequences. Tilting the instrument at 42 degrees disables the accuracy of the magnetic flux compass, which is only accurate to a tilt of 15 degrees. In order to avoid seriously biasing the data, it appears as if the compass heading was manually set, along with the pitch and roll. From an independent reviewer's perspective, we are left to wonder why the instrument was set up in this manner and question whether it actually was oriented in the water as stated. This information should be required in the meta data; otherwise from a strict quality control sense this data set is questionable.

Finding #12: The percentage of good and bad pings, Figure 5, shows some puzzling results. Beam 3 consistently failed both the correlation threshold test and the false target test, thus invoking a three-beam solution for most of the bins. The four individual panels in Figure 5 are not self consistent. We observe that 98–100% of the bins had good 3-beam solutions. Consequently one would expect that the percentage of good four-beam solutions to be no more than 2%, but the actual data looks like a copy of the percentage of good 3-beam solutions. The validity of this data field is highly questionable and the efficacy of the percent good test, flag 4, is in some doubt. Furthermore, if there are only 3-beam solutions, then the error velocity can not be calculated.

Recommendation #12: The sum of the percentage of good 3- and 4-beam solutions can not exceed 100%. If it does, then this is an indication of an error that should be flagged and investigated.

Finding #13: The vertical velocity (top panel of Figure 2) shows a consistent pattern seen in every vertical velocity across most platforms and dates, evidence of a distinct diurnal vertical migration of plankton and grazers, which is characterized by a high vertical velocity at dawn and dusk. The ascent of plankton to their feeding level at dusk and their return to depth at dawn has been well documented. This can be seen in Figure 8 for platform 42368, Figure 26 for 42880, and Figure 32 for 42888. The difference in Figure 2 for platform 42366 is that the times of descent and ascent are not the same as the other platforms. Instead of the descent occurring at 1200 GMT and the ascent at 2400 GMT, it occurs at 0600 and 1800. This clearly suggests that the data for this platform are being time stamped in local time, six hours different from GMT, and not GMT as required by Appendix 2 ("All time references within the file should be GMT.").

Recommendation #13: In the absence of any other identified method, the vertical velocity contours could be used to ensure that the data are being time stamped properly.

Finding #14: Moore and Stewart (2003) report that FugroGEOS has collected current velocity data in a number of geographical areas where the scatterers appear to move not only vertically, but also horizontally. The authors found a reduction of the near-surface horizontal current speed at night, commensurate with elevated states of the echo amplitude. They attributed this reduction to the presence of grazing organisms that are capable of maintaining their position relative to the ground. Moore and Stewart found that the organisms were capable of sustained horizontal speeds of at least 20 cm/sec. For a 38 kHz with a wavelength of 39 mm, the size of the main scatterers would range from 3.9 to 39 mm. For a 75 kHz, the size range is 2 to 20 mm. This finding is different from that of Plimpton et al. (1996). They found that the times of high horizontal speeds were highly coincidental with time of large differences in beam-to-beam echo intensity, attributed to the presence of large pelagic fish ensonified in a single beam. In this case there are no such large beam-to-beam differences; each of the beams shows a highly consistent echo amplitude pattern. A diel reduction in the horizontal current speed is clearly seen in this platform's record, not only at the surface but also at depth. When the grazers are near the surface feeding during the night, Figure 1 shows a reduction in the horizontal speed (see the bin associated with a depth of 131 m) to nearly zero. After the organisms descend, the near-surface horizontal current speeds increase to approximately 20 cm/sec. Conversely at depth (see the bins associated with the depth range from 259 to 403 m) the speeds are higher when the organisms are at the surface then when they descend to depth during the day.

Recommendation #14: Users of this data should be aware that there may be small biases in the horizontal speed due to the presence of widely distributed, relatively fast swimming organisms.

3.3.2 Platform 42368

The ADCP at platform 42368 is a 38 kHz Ocean Observer ADCP with a 30 degree beam angle mounted at nominal depth of 15 m. The ADCP is pointed vertically (~0^o tilt). The platform is fixed. The ADCP is operating in narrowband mode, which improves the range, but at the expense of standard deviation. Table 1 lists the various particulars concerning this ADCP. The two-second time between pings is smaller than the RDI recommended three seconds. Given the setup parameters for bin length and number of pings per ensemble, the best possible standard deviation for the velocity is 1.2 cm/sec. The minimum expected standard deviation, based on requiring at least 22% of the total pings per ensemble for a three- or four-beam solution is 3.5 cm/sec. Figure 7 shows the horizontal speed and direction; Figure 8, the vertical velocity and the error velocity; Figure 9, the correlation count; Figure 10, the amplitude, or echo intensity; Figure 11, details about the percentage of good pings; and Figure 12, the orientation of the ADCP and specific environmental data.

There is no issue with the data itself (speed, direction, velocity, percent good, correlation count and echo intensity) as there are no discrepancies between what is posted on the NDBC Web site and what we independently extracted from the binary data as part of this project. However, there is an error velocity of 15.1 cm/sec that is flagged incorrectly (see highlighted value in Table 2).

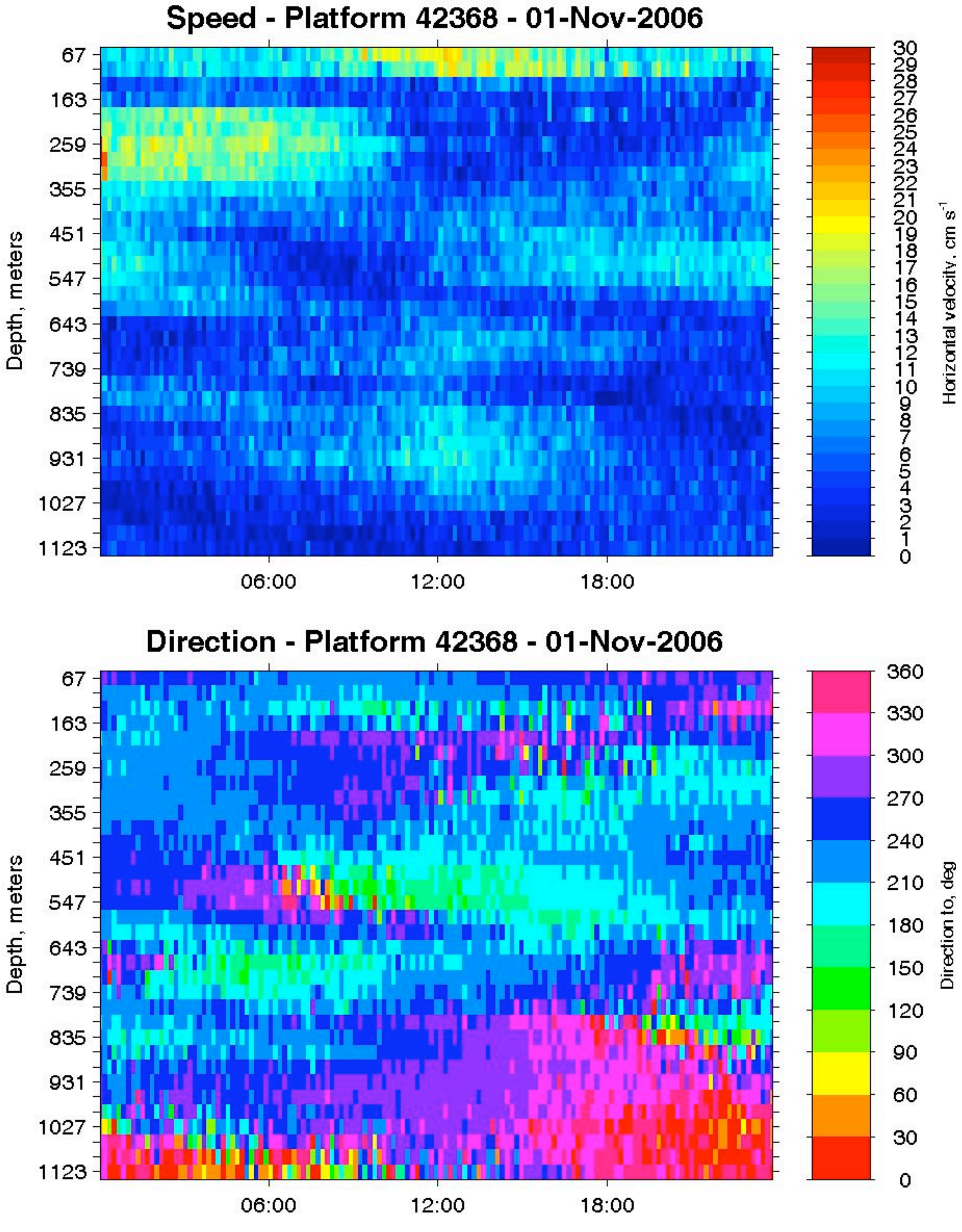
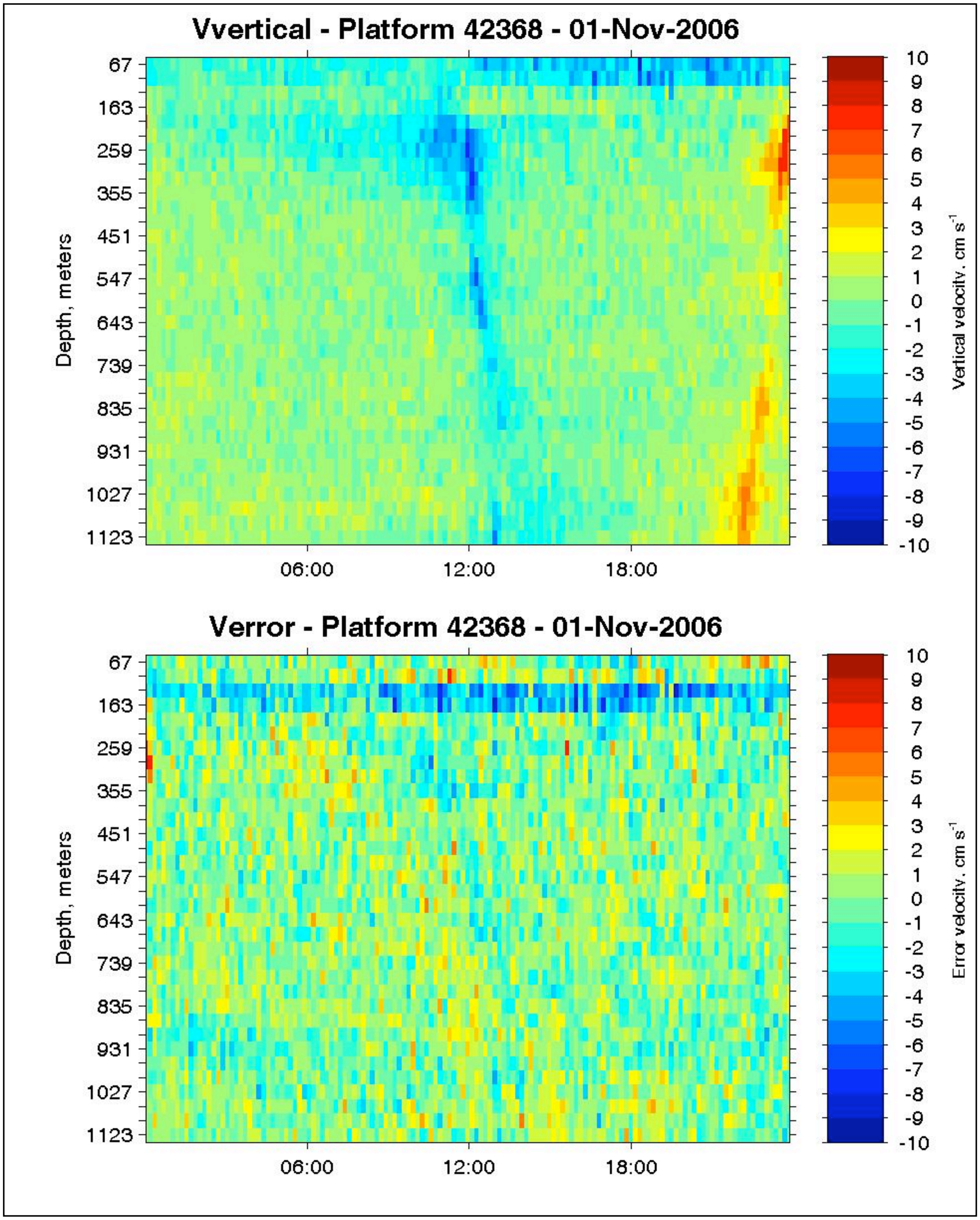


Figure 7. Colorized contours of horizontal current speed (top panel) and current direction (bottom panel) at platform 42368 for November 1, 2006.



Vvertical - Platform 42368 - 01-Nov-2006

Verror - Platform 42368 - 01-Nov-2006

Figure 8. Colorized contours of vertical velocity (top panel) and error velocity (bottom panel) at platform 42368 for November 1, 2006.

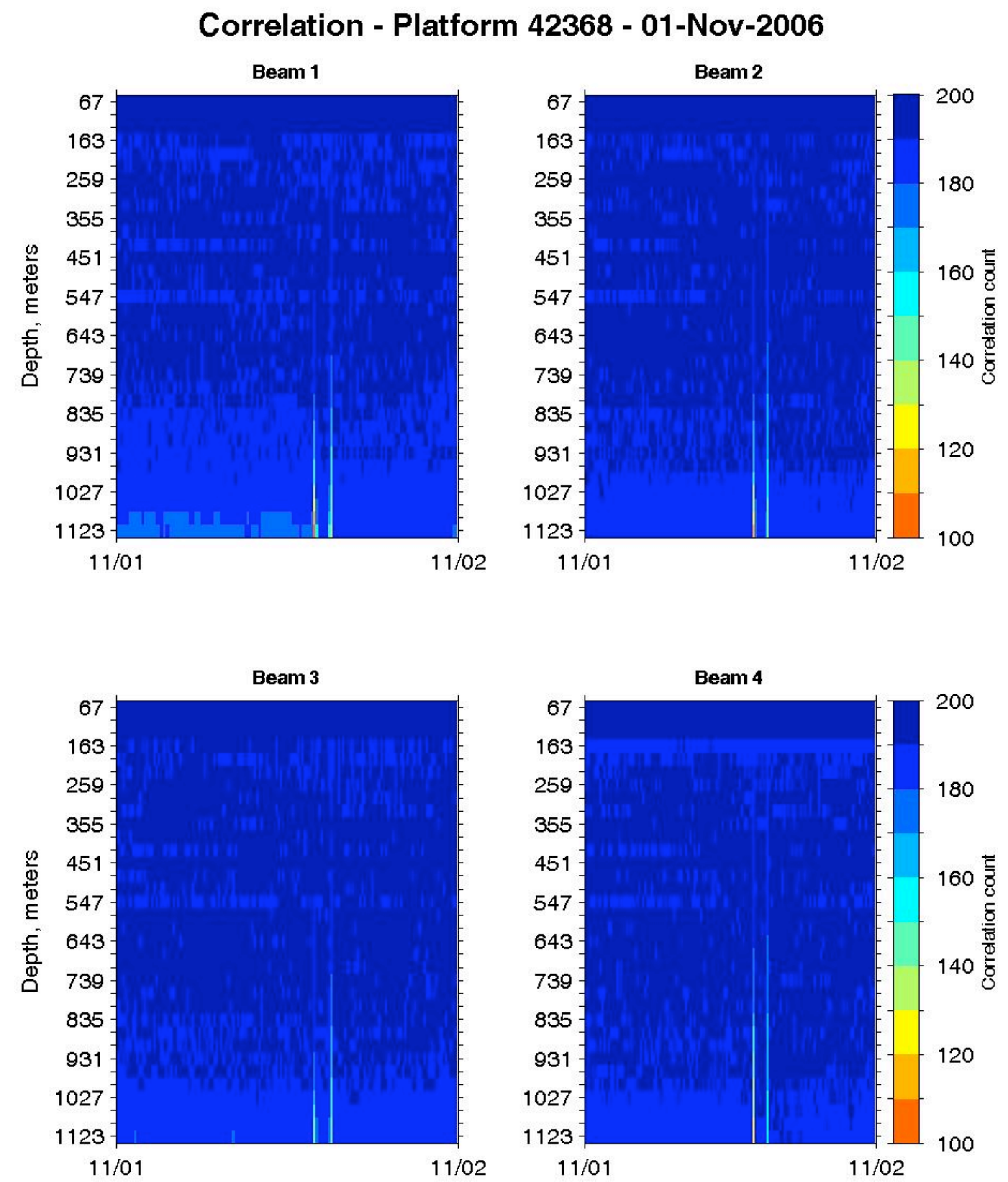


Figure 9. Colorized contour of the correlation count for the four ADCP beams at platform 42368 for November 1, 2006.

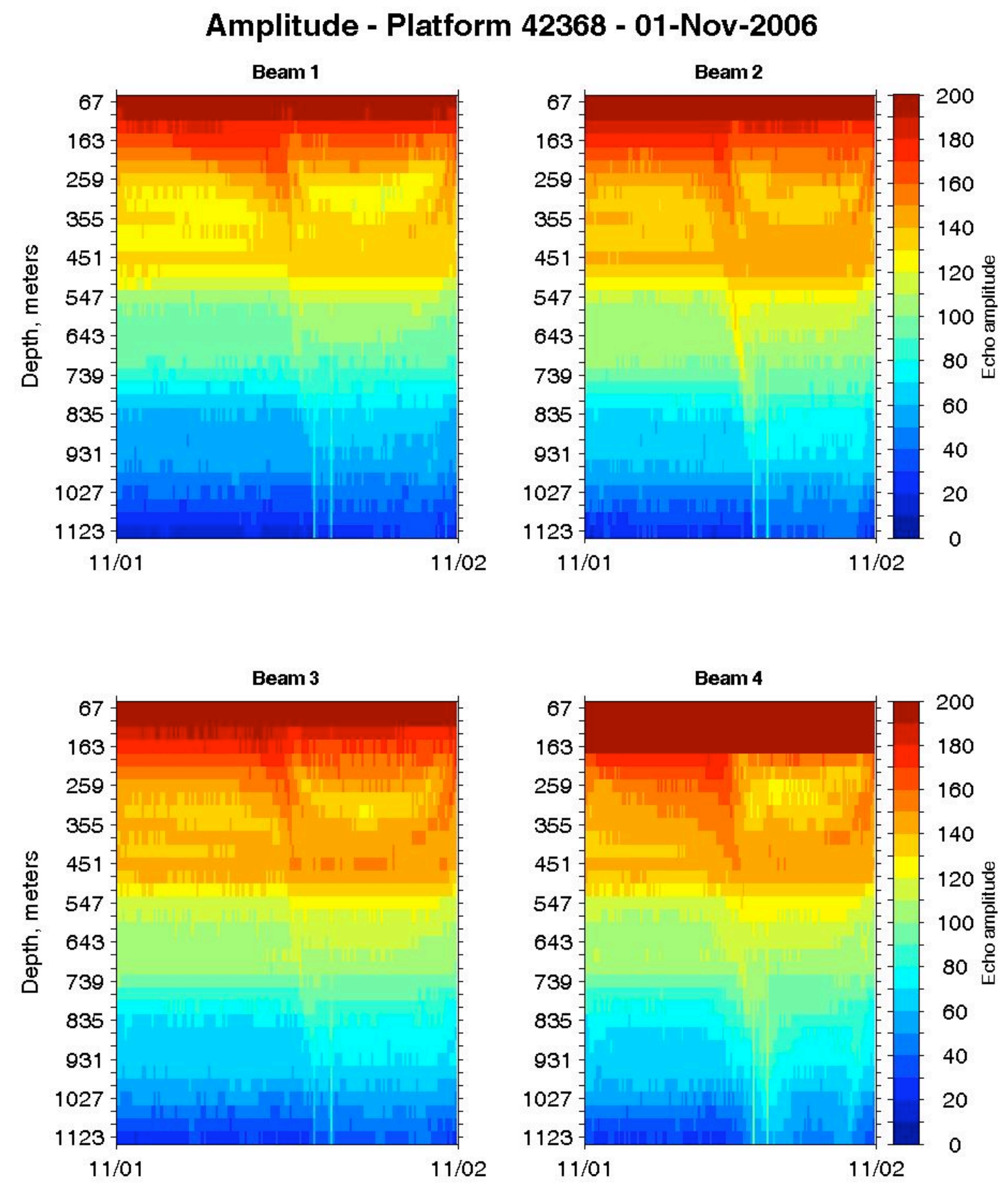


Figure 10. Colorized contour of the amplitude (echo intensity) for the four ADCP beams at platform 42368 for November 1, 2006.

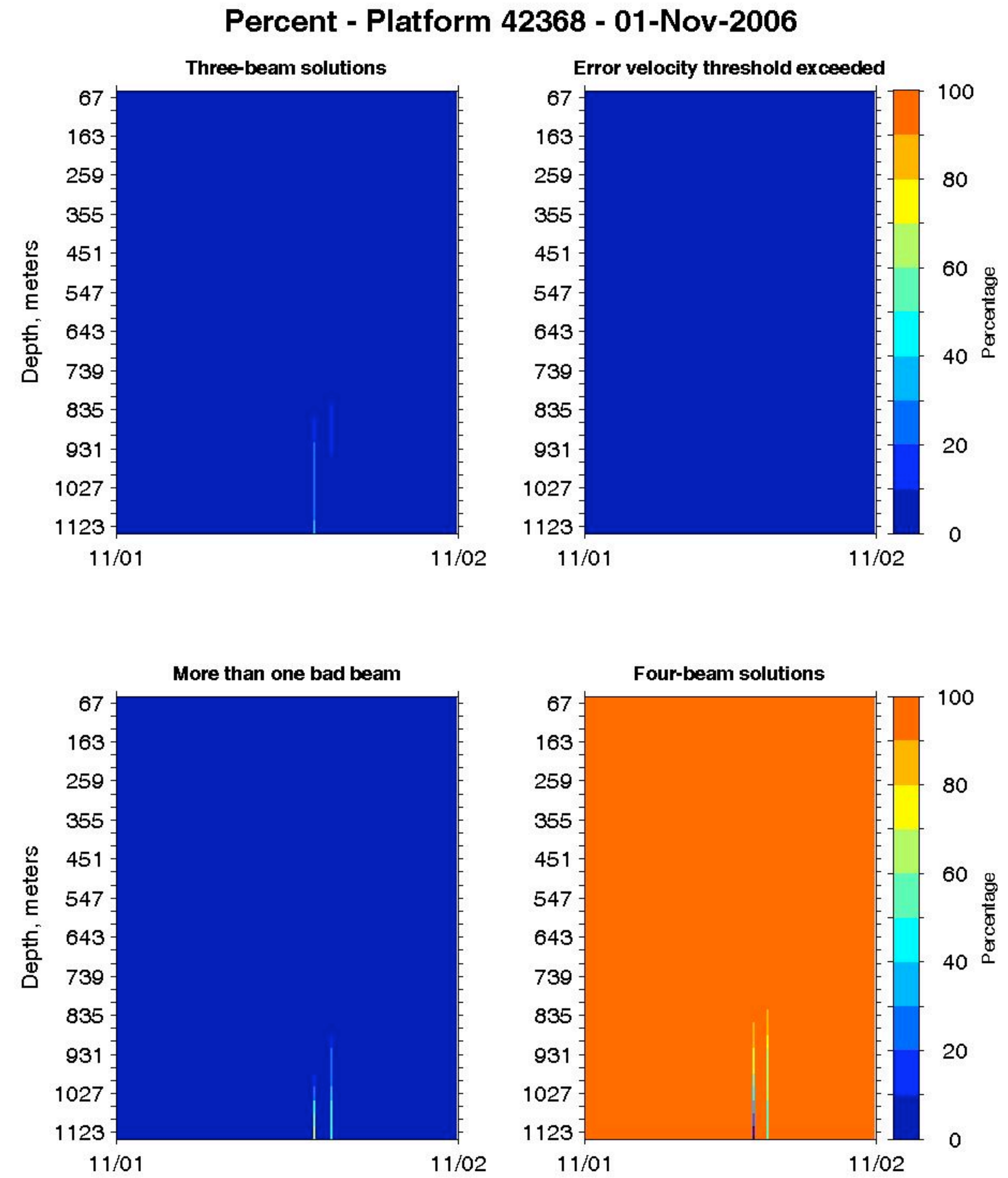


Figure 11. Colorized contour of the percentage at solutions at platform 42368 for November 1, 2006.

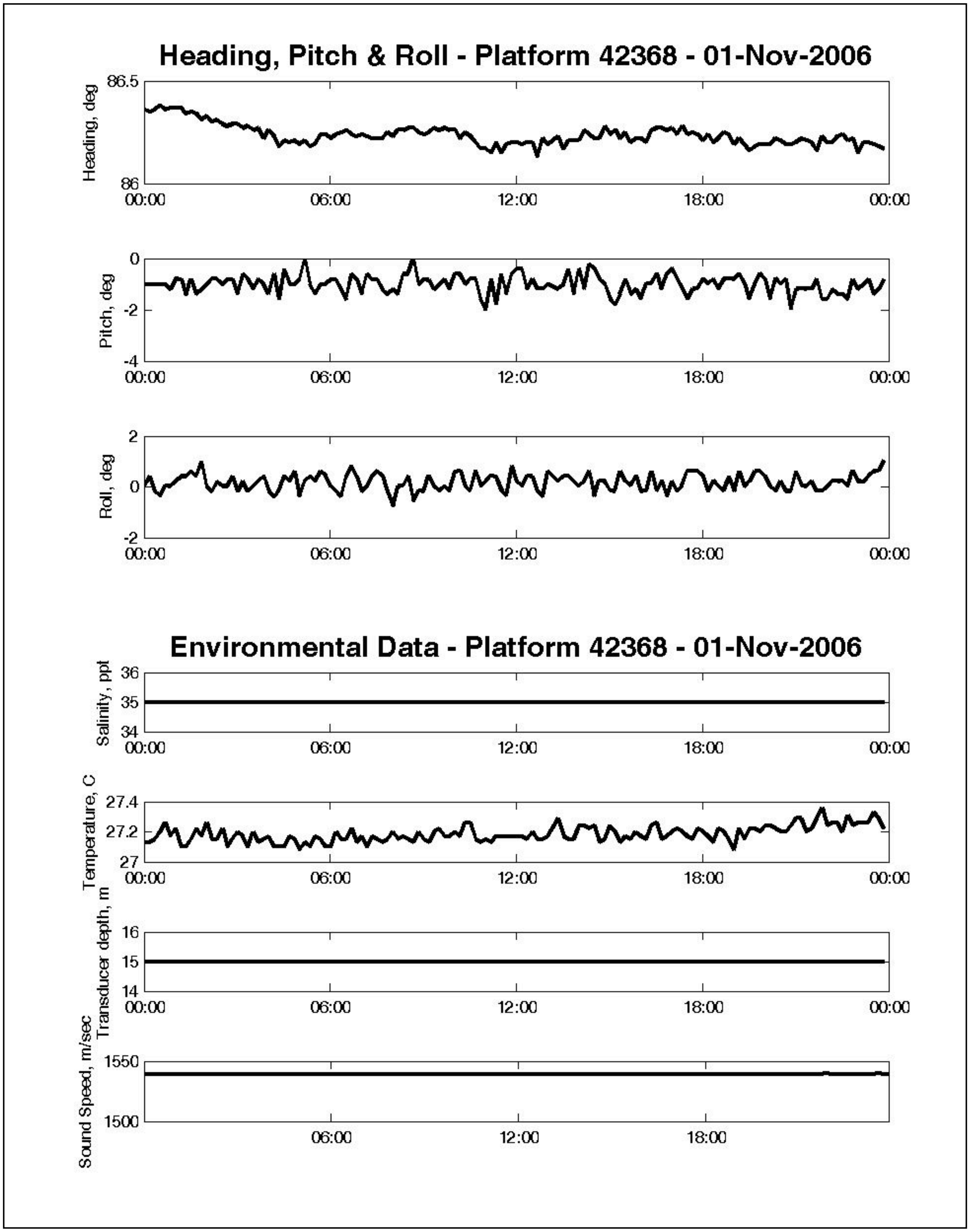


Figure 12. Time series of recorded heading, pitch and roll (top panel) and environmental data (bottom panel) at platform 42368 for November 1, 2006.

Table 2

Quality Control Data for Platform 42368

42368 NDBC LATITUDE: 27.20 LONGITUDE: -92.20 PROFILE_STATUS: 3

Bin	Depth, m	Dir, deg. to	Speed, cm s^{-1}	ErrVl, cm s^{-1}	VerVl, cm s^{-1}	%Good3	%Good4	%GoodE	EI1	EI2	EI3	EI4	CM1	CM2	CM3	CM4	Flags
1	66.9	267	10.2	0.5	-1.6	0	100	0	206	212	219	215	191	191	191	191	393333330
2	98.9	243	6.8	-0.4	-2.8	0	100	0	189	195	200	198	191	191	191	191	393333330
3	130.9	249	5.6	-4	0.5	0	100	0	174	176	180	208	191	191	191	192	393333330
4	162.9	258	9	4.8	2.6	0	100	0	168	171	177	194	190	190	190	189	393333330
5	194.9	205	12.4	0	5.2	0	100	0	162	165	171	168	190	190	190	190	393333330
6	226.9	224	13.2	3.9	3	0	100	0	153	159	161	162	190	190	190	189	393333330
7	258.9	243	31.4	15.1	-1.9	0	100	0	144	149	153	179	190	189	190	191	393333330
8	290.9	241	32.7	11.6	-1.5	0	100	0	137	142	148	167	190	190	190	188	393333330
9	322.9	229	15.7	1.1	1	0	100	0	131	139	142	142	190	190	190	189	393333330
10	354.9	228	9.4	-1.7	1.5	0	100	0	132	141	146	144	190	190	190	190	393333330
11	386.9	230	10.3	-0.7	1	0	100	0	127	138	140	141	189	190	190	190	393333330
12	418.9	254	12.1	1.7	0.5	0	100	0	126	137	139	138	189	190	190	190	393333330
13	450.9	259	10.7	0.3	0.2	0	100	0	133	141	145	143	190	190	190	190	393333330
14	482.9	257	15.2	-1.8	0.2	0	100	0	130	136	140	140	190	190	190	190	393333330
15	514.9	257	14.8	-0.4	1.1	0	100	0	121	129	128	130	190	190	190	190	393333330
16	546.9	250	12.1	-0.2	1.3	0	100	0	105	112	115	114	190	189	189	189	393333333
17	578.9	219	9.1	-1	1.2	0	100	0	98	107	110	108	190	190	190	190	393333333
18	610.9	219	6	-3.2	0	0	100	0	96	104	106	107	190	190	190	190	393333333
19	642.9	252	2.8	0.9	0.9	0	100	0	95	103	107	106	190	190	190	190	393333333
20	674.9	271	4.5	-0.3	-0.2	0	100	0	96	104	106	109	190	190	190	190	393333333
21	706.9	224	3.5	-1.1	0	0	100	0	91	99	105	103	190	190	190	190	393333333
22	738.9	214	3.4	-1.6	0.9	0	100	0	84	95	96	96	190	190	190	190	393333333
23	770.9	237	5.3	-0.5	0.9	0	100	0	73	84	85	91	190	190	190	190	393333333
24	802.9	184	5.6	0.2	0.4	0	100	0	68	75	76	82	190	190	190	190	393333333
25	834.9	232	3.3	0.2	0.9	0	100	0	58	68	69	73	189	189	190	189	393333333
26	866.9	245	3.5	0.1	1.2	0	100	0	56	67	66	69	189	190	189	190	393333333
27	898.9	245	5.4	-0.1	0.9	0	100	0	53	65	67	69	189	189	190	190	393333333
28	930.9	284	5.6	-0.6	0.7	0	100	0	54	61	66	66	189	189	189	190	393333333
29	962.9	276	2.7	0.1	0.4	0	100	0	51	58	61	64	189	189	189	189	393333333
30	994.9	299	1	0	0.2	0	100	0	42	55	57	61	188	190	190	189	393333333
31	1026.9	45	1.1	1.4	0.4	0	100	0	43	48	51	56	188	189	189	189	393333333
32	1058.9	325	3.2	0.8	1.1	0	100	0	34	39	42	44	185	188	188	188	393333333
33	1090.9	331	1.3	1.2	0.9	0	100	0	26	29	35	38	180	184	185	188	393333333
34	1122.9	328	3.6	1.2	0.5	0	100	0	17	24	27	34	176	184	184	187	393333333

Finding #15: The vertical velocity (see top panel of Figure 8) shows evidence of a distinct diurnal vertical migration of plankton and grazers, i.e., a high vertical velocity at dawn and dusk. This vertical migration is seen to at least a depth of 1123 m. A reduction in the horizontal current speed (see top panel of Figure 7) is clearly seen at the surface and at depth. When the grazers are near the surface feeding during the night, the horizontal speed (see the top two bins) is nearly zero. After the organisms descend, the near-surface horizontal current speeds increase to approximately 20 cm/sec. Conversely at depth (see the bins associated with the depth range from 195 to 323 m) the speeds are higher when the organisms are at the surface (0000 to 1200 GMT) than when they descend to depth during the day (1200 to 2400 GMT).

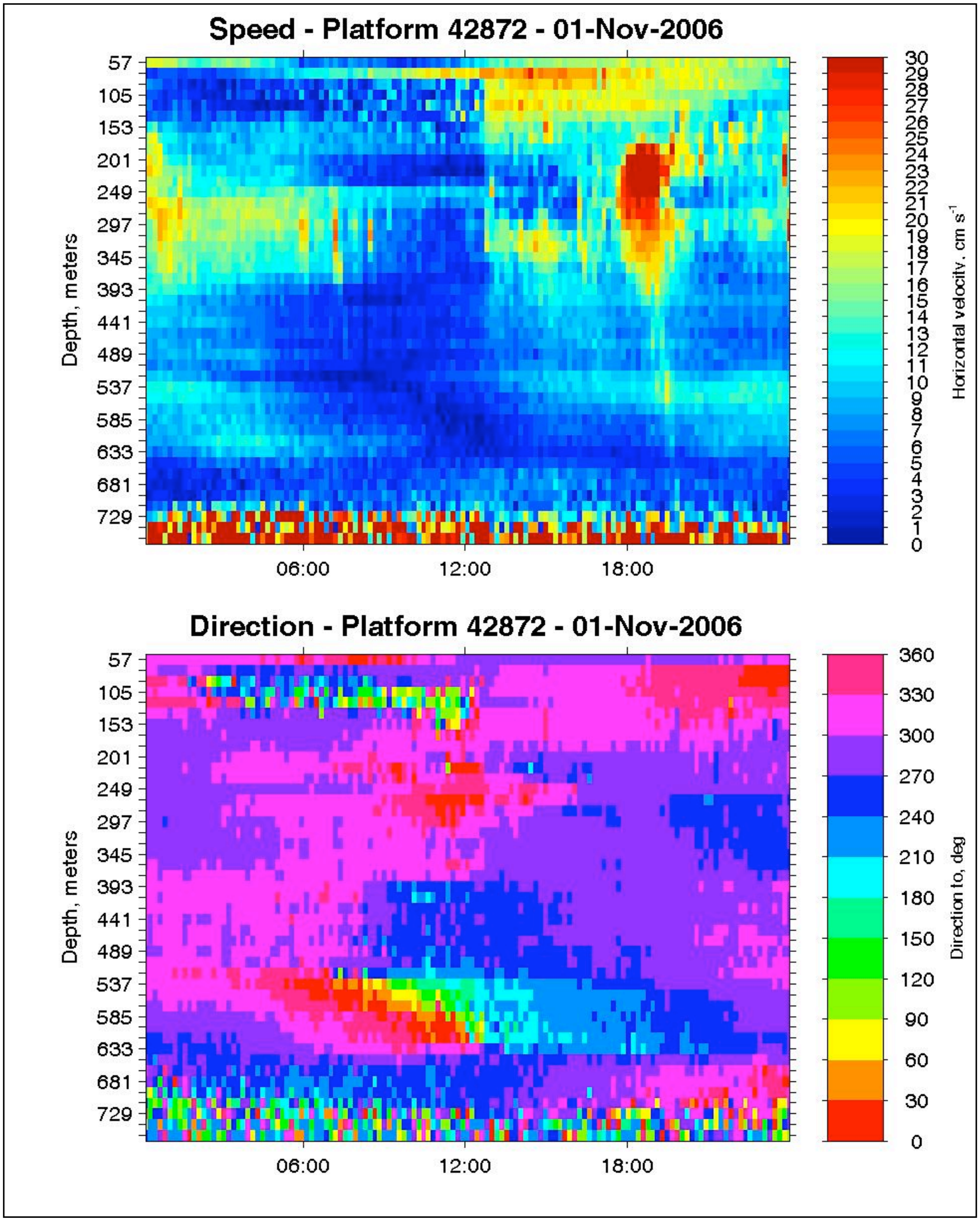
Recommendation #15: Users of this data should be aware that there may be small biases in the horizontal speed due to the presence of widely distributed, relatively fast swimming organisms.

3.3.3 Platform 42872

The ADCP at platform 42872 is a 75 kHz Ocean Observer ADCP with a 30 degree beam angle mounted at nominal depth of 32 m. This instrument is in fact a 75 kHz, not a 38 kHz as manually input in the MMS header. The instrument frequency is encoded in the system configuration byte and according to RDI the frequency was set correctly. RDI has confirmed that one 75 kHz Ocean Observer was sold to an oil company over ten years ago. The ADCP is pointed vertically ($\sim 0^{o}$ tilt). The platform is mobile, but the position is manually input. The ADCP is operating in broadband mode, which improves the standard deviation of the velocity estimates, but at the expense of range. Table 1 lists the various particulars concerning this ADCP. The 1.5 second time between pings is smaller than the RDI recommended two seconds. Given the setup parameters for bin length and number of pings per ensemble, the best possible standard deviation for the velocity is 0.6 cm/sec. The minimum expected standard deviation, based on requiring at least 5% of the total pings per ensemble for a three- or four-beam solution is 1.2 cm/sec. Figure 13 shows the horizontal speed and direction; Figure 14, the vertical velocity and the error velocity; Figure 15, the correlation count; Figure 16, the amplitude, or echo intensity; Figure 17, details about the percentage of good pings; and Figure 18, the orientation of the ADCP and specific environmental data.

Finding #16: There is no issue with the data itself (speed, direction, velocity, percent good, correlation count and echo intensity) as there are no discrepancies between what is posted on the NDBC Web site and what we independently extracted from the binary data as part of this project. There is of course an issue with the QC flags; should they be based on the fact that the instrument is an Ocean Observer or that it is a 75 kHz? A 75 kHz is encoded in the binary ADCP fixed leader data. A “38 KHZ” is input in the MMS header. Analysis of the QC data flags suggests the flags were calculated assuming an OO 38 kHz. As a result, data from deep in the water column that could have been acceptable were rejected by the RDI internal quality control steps on the basis of failing the correlation test.

Recommendation #16: Use the ADCP binary data to determine the frequency and calculate the QC flags based on this, not the encoded MMS header frequency.



Speed - Platform 42872 - 01-Nov-2006

Direction - Platform 42872 - 01-Nov-2006

Figure 13. Colorized contours of horizontal velocity (top panel) and current direction (bottom panel) at platform 42872 for November 1, 2006.

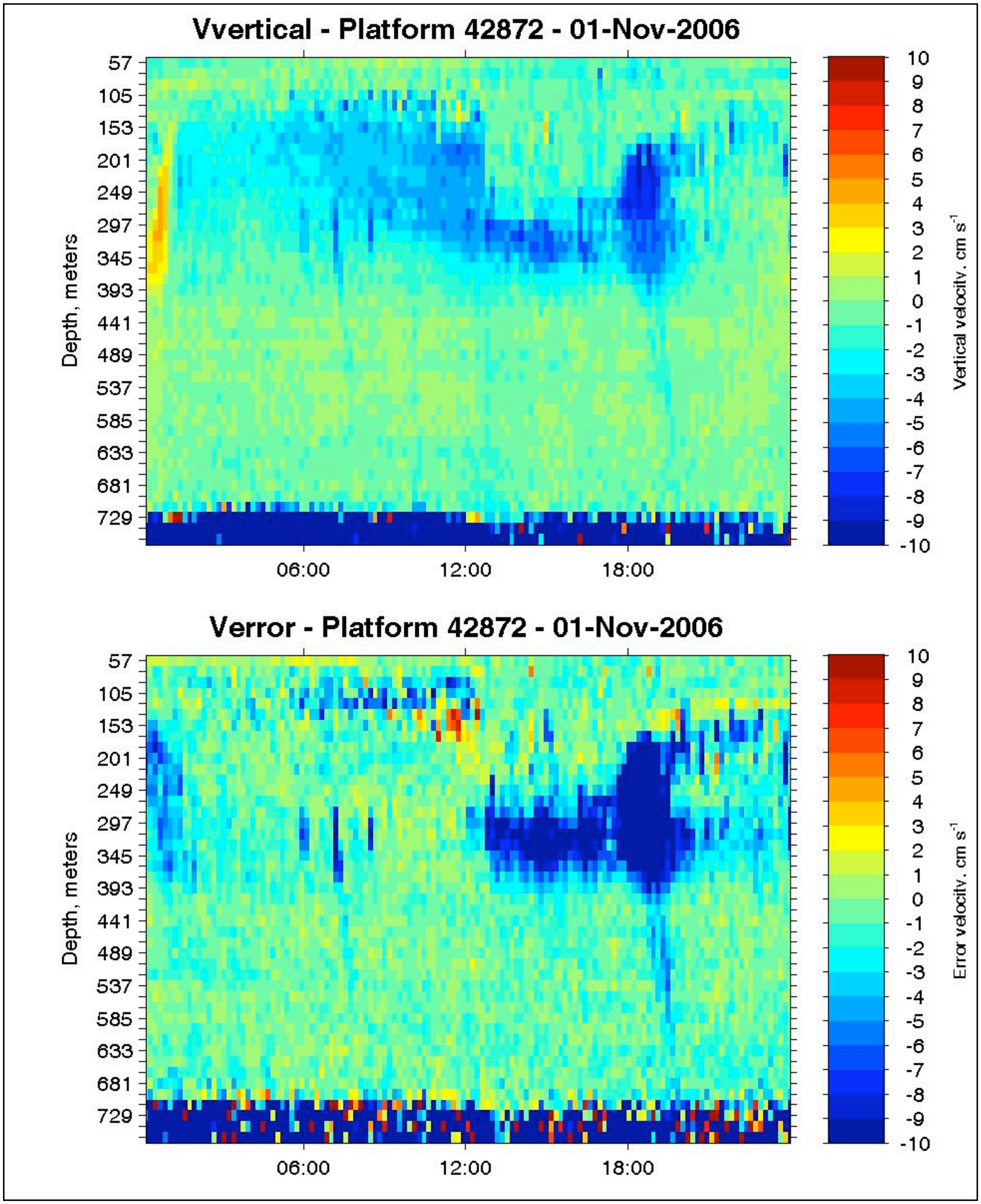


Figure 14. Colorized contours of vertical velocity (top panel) and error velocity (bottom panel) at platform 42872 for November 1, 2006.

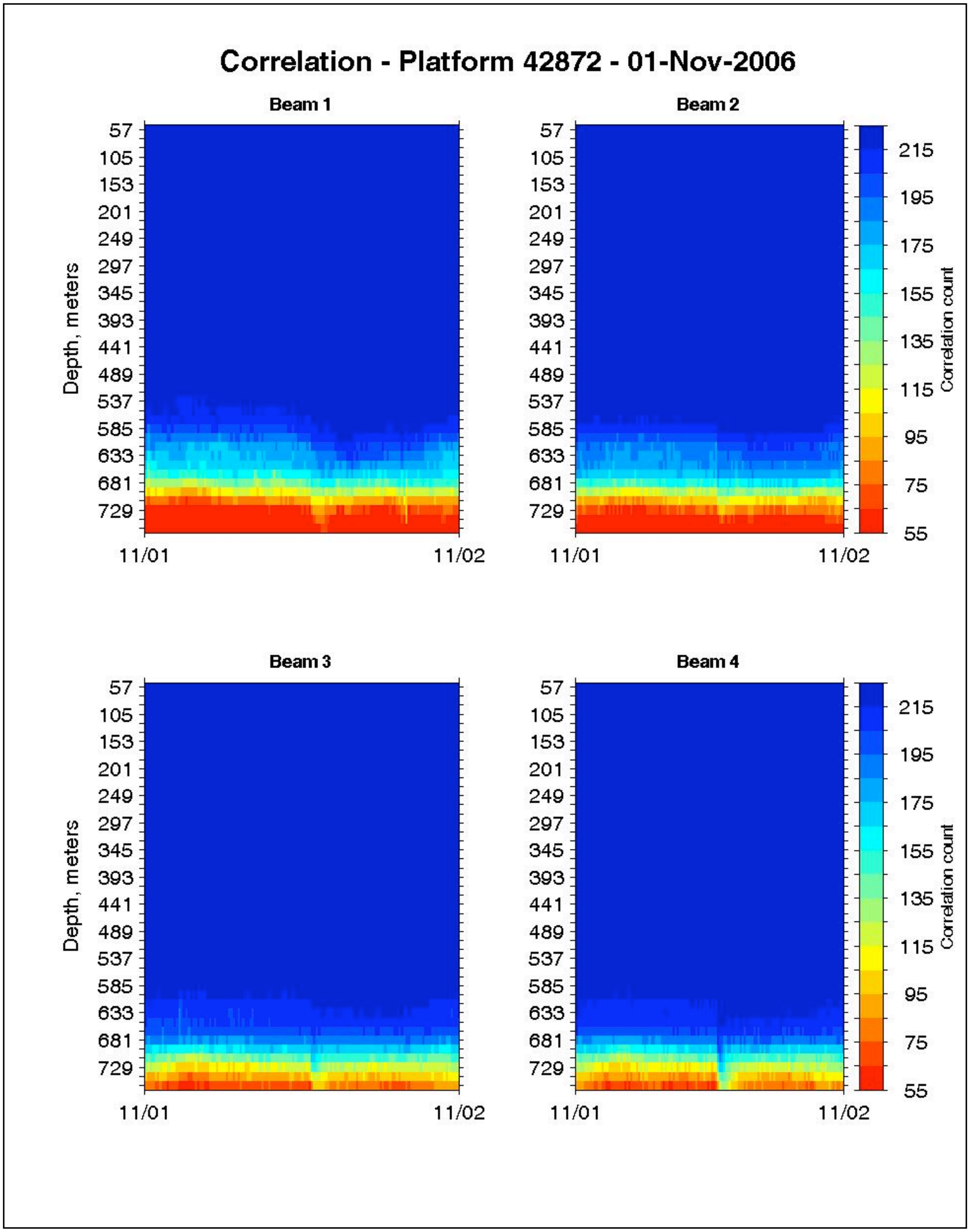


Figure 15. Colorized contour of the correlation count for the four ADCP beams at platform 42872 for November 1, 2006.

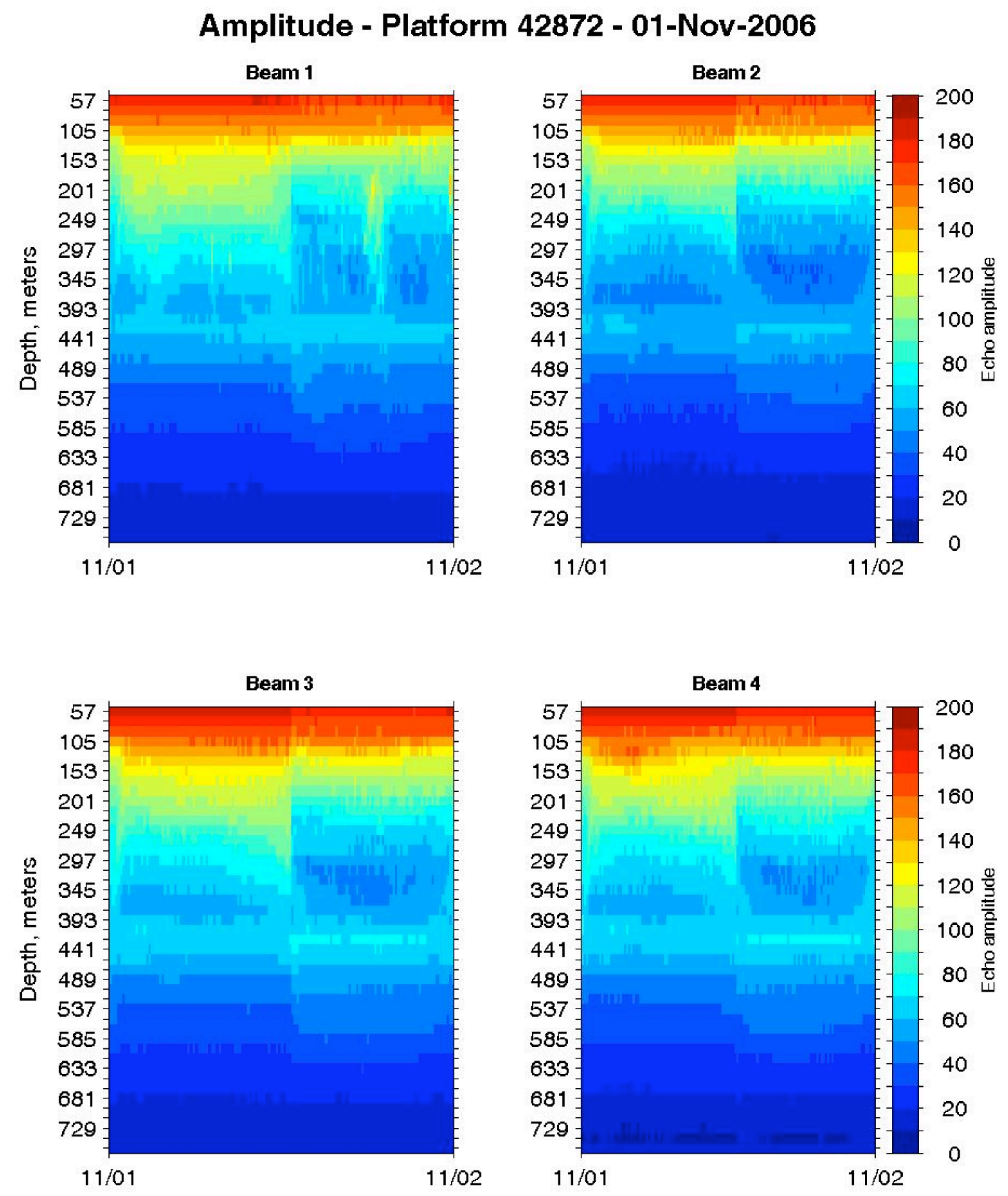


Figure 16. Colorized contour of amplitude (echo intensity) for the four ADCP beams at platform 42872 for November 1, 2006.

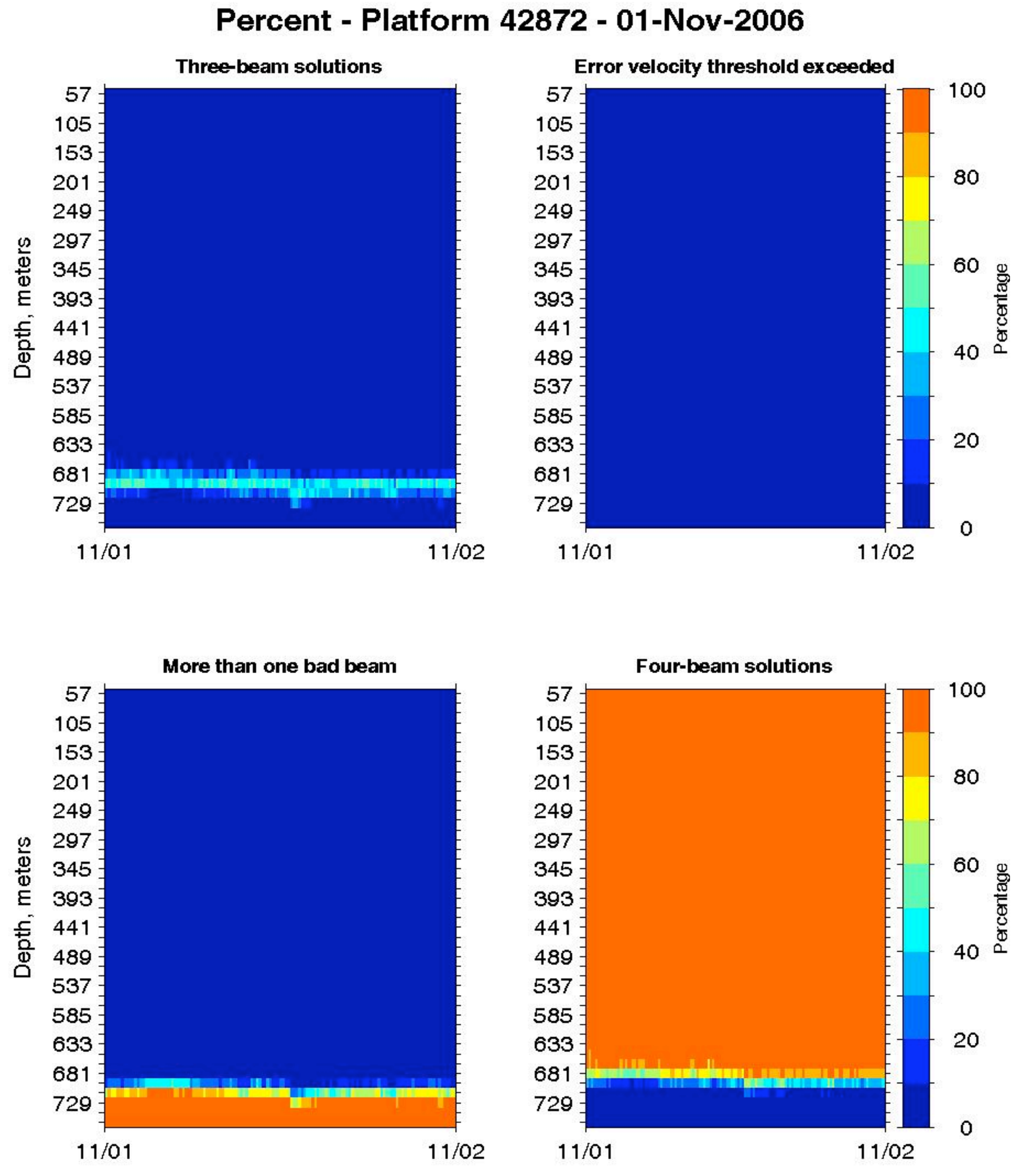


Figure 17. Colorized contours of the percentage of solutions at platform 42872 for November 1, 2006.

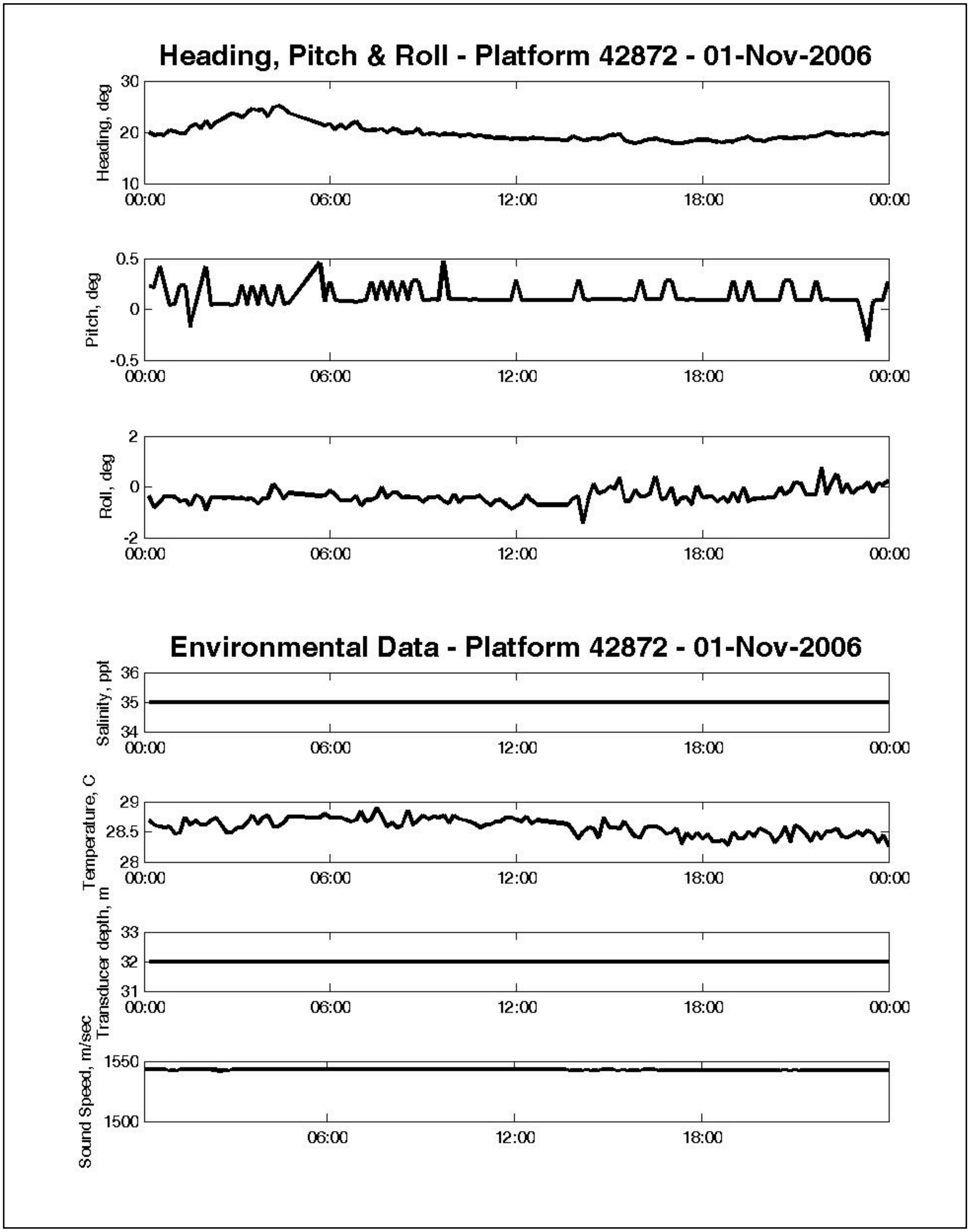


Figure 18. Time series of recorded heading, pitch and roll (top panel) and environmental data (bottom panel) at platform 42872 for November 1, 2006.

Finding #17: The vertical velocity (see top panel of Figure 14) shows evidence of a distinct diurnal vertical migration of plankton and grazers, i.e., a high vertical velocity at dawn, though less distinct at dusk. A reduction in the horizontal current speed (see top panel of Figure 13) is clearly seen at the surface and at depth. When the grazers are near the surface feeding during the night, the horizontal speed (see the bins associated with the depth range from 73 to 137 m) is nearly zero. We also note a somewhat random variation range in the current direction over this time and depth that suggests the presence of grazing organisms. Quite abruptly at about 1300 GMT there is a marked increase in the horizontal current speed. After the organisms descend, the near-surface horizontal current speeds increase to nearly 30 cm/sec. Conversely at depth (see the bins associated with the depth range from 249 to 345 m) the speeds are higher when the organisms are at the surface (0000 to 1200 GMT).

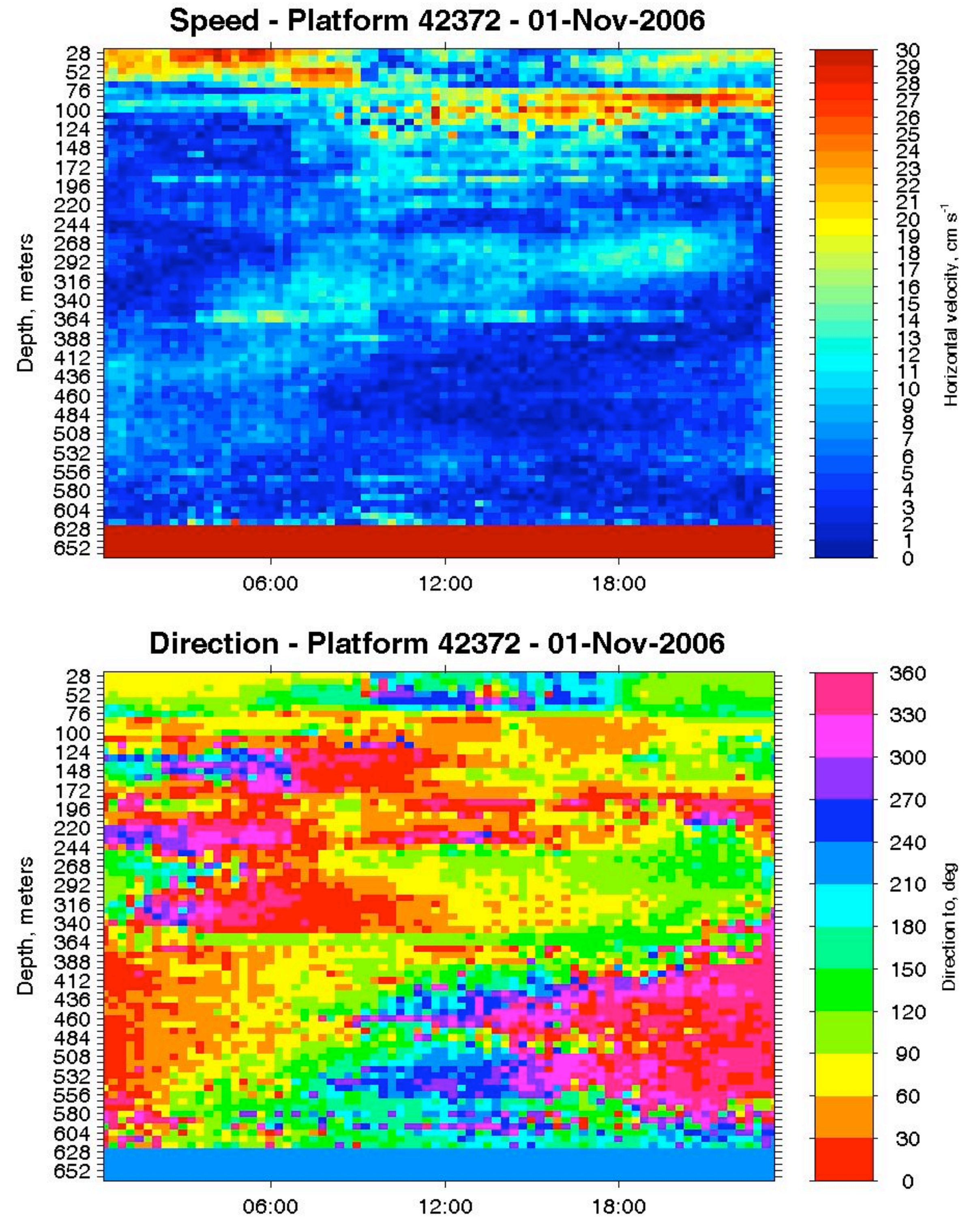
Recommendation #17: Users of this data should be aware that there may be small biases in the horizontal speed due to the presence of widely distributed, relatively fast swimming organisms.

Finding #18:
At approximately 1100 GMT on 28 November 2006 the ADCP setup parameter file was modified so that the number of pings per ensemble was changed from 150 to only 1. This had a dramatic effect on the resulting data as can be seen in Figure 19 for a graphical view of the randomization in speed and direction. This setup change continued until approximately 0800 GMT on 1 December 2006. It may well be that the platform was being moved at this time, but we have no way of knowing since the position information is manually input. The requirements for an existing platform give the option of using a GPS stream or manually inputting the position. Appendix 2 implies that the nominal location is acceptable.

Recommendation #18: The requirements for an existing platform give the option of using a GPS stream or manually inputting the position. Appendix 2 implies that the nominal location is acceptable. This option should be eliminated and GPS input required for all platforms, even fixed. Modify the archival ADCP binary data files with the best approximation of the geographic position. Provide a QC flag that indicates the reliability of the position data.

3.3.4 Platform 42372

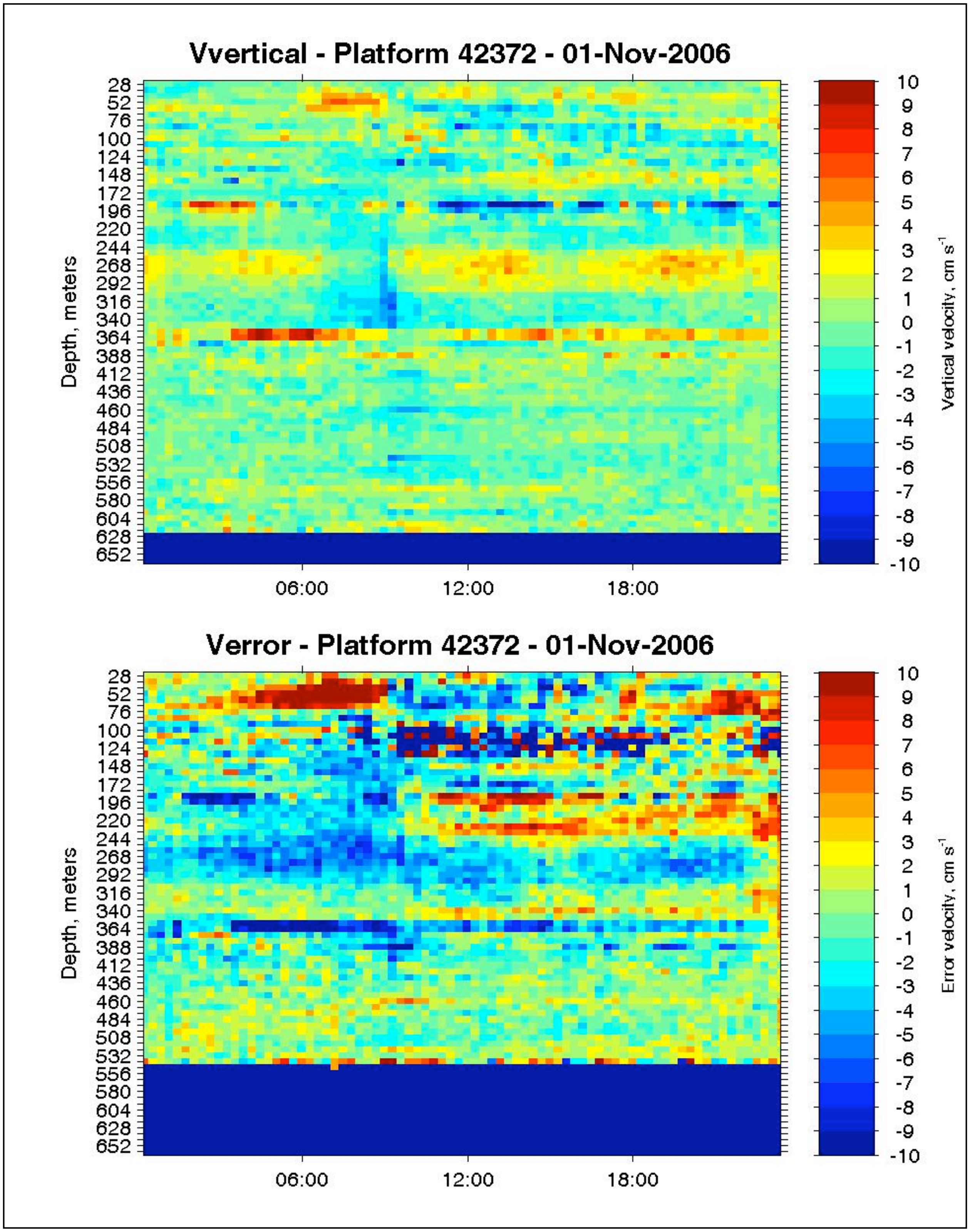
The ADCP at platform 42372 is a 75 kHz WorkHorse LongRanger ADCP with a 20 degree beam angle mounted at nominal depth of 10 m. The ADCP is not oriented vertically (0^o tilt), but is aligned at a 21^o angle, implying that beam #4 is pointed straight down. The platform is fixed. The ADCP is operating in the narrowest broad bandwidth processing mode (WB1), which improves the range, but at the expense of standard deviation (but not as much as true narrow bandwidth processing). Table 1 lists the various particulars concerning this ADCP. Given the setup parameters for bin length and number of pings per ensemble, the best possible standard deviation for the velocity is 0.9 cm/sec. The minimum expected standard deviation, based on requiring at least 5% of the total pings per ensemble for a three- or four-beam solution is 2.1 cm/sec. Figure 19 shows the horizontal speed and direction; Figure 20, the vertical velocity and the error velocity; Figure 21, the correlation count; Figure 22, the amplitude, or echo intensity; Figure 23, details about the percentage of good pings; and Figure 24, the orientation of the ADCP and specific environmental data.



Speed - Platform 42372 - 01-Nov-2006

Direction - Platform 42372 - 01-Nov-2006

Figure 19. Colorized contours of horizontal velocity (top panel) and current direction (bottom panel) at platform 42372 for November 1, 2006.


Vvertical - Platform 42372 - 01-Nov-2006

Verror - Platform 42372 - 01-Nov-2006

Figure 20. Colorized contours of vertical velocity (top panel) and current direction (bottom panel) at platform 42372 for November 1, 2006.

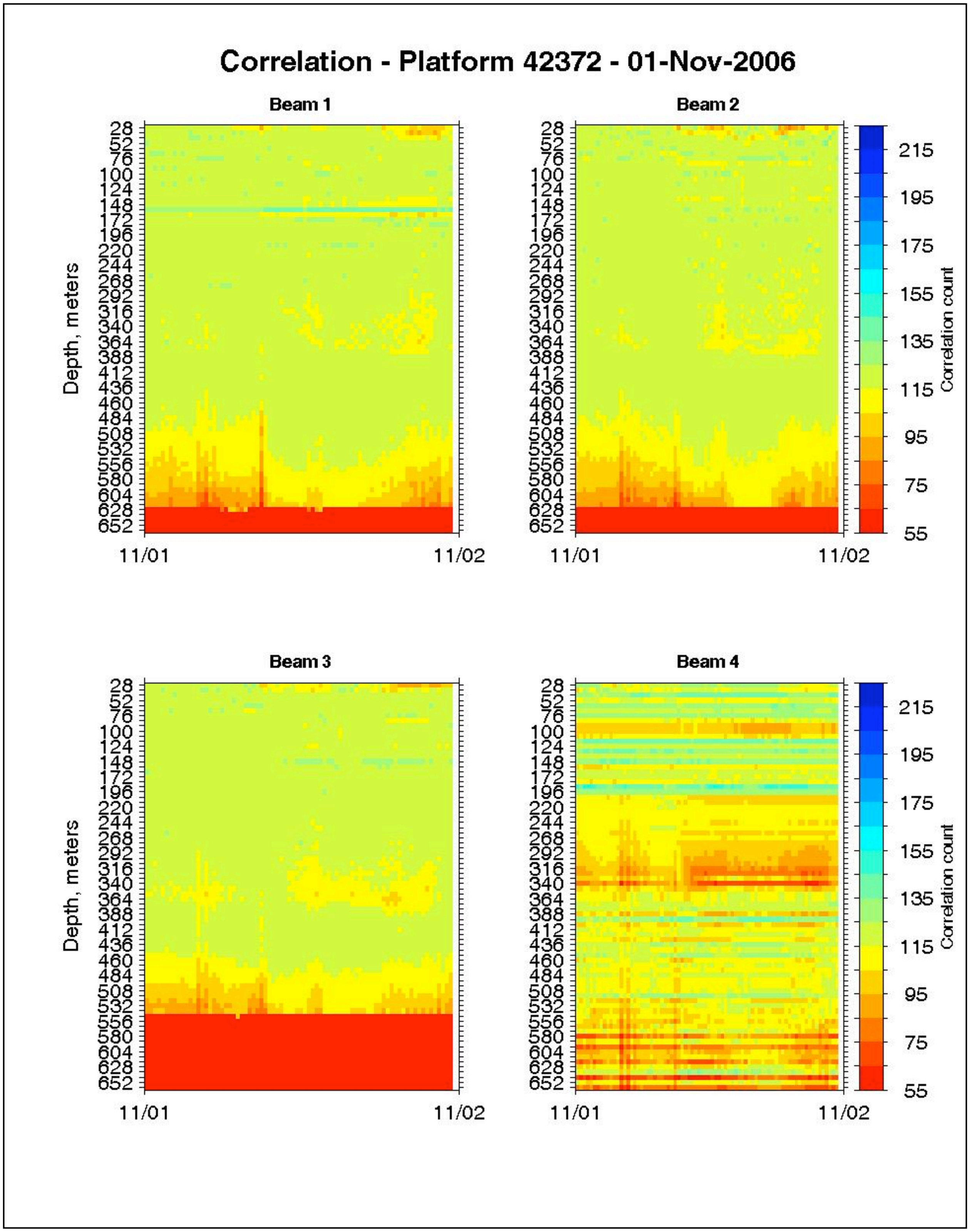


Figure 21. Colorized contour of the correlation count for the four ADCP beams at platform 42372 for November 1, 2006.

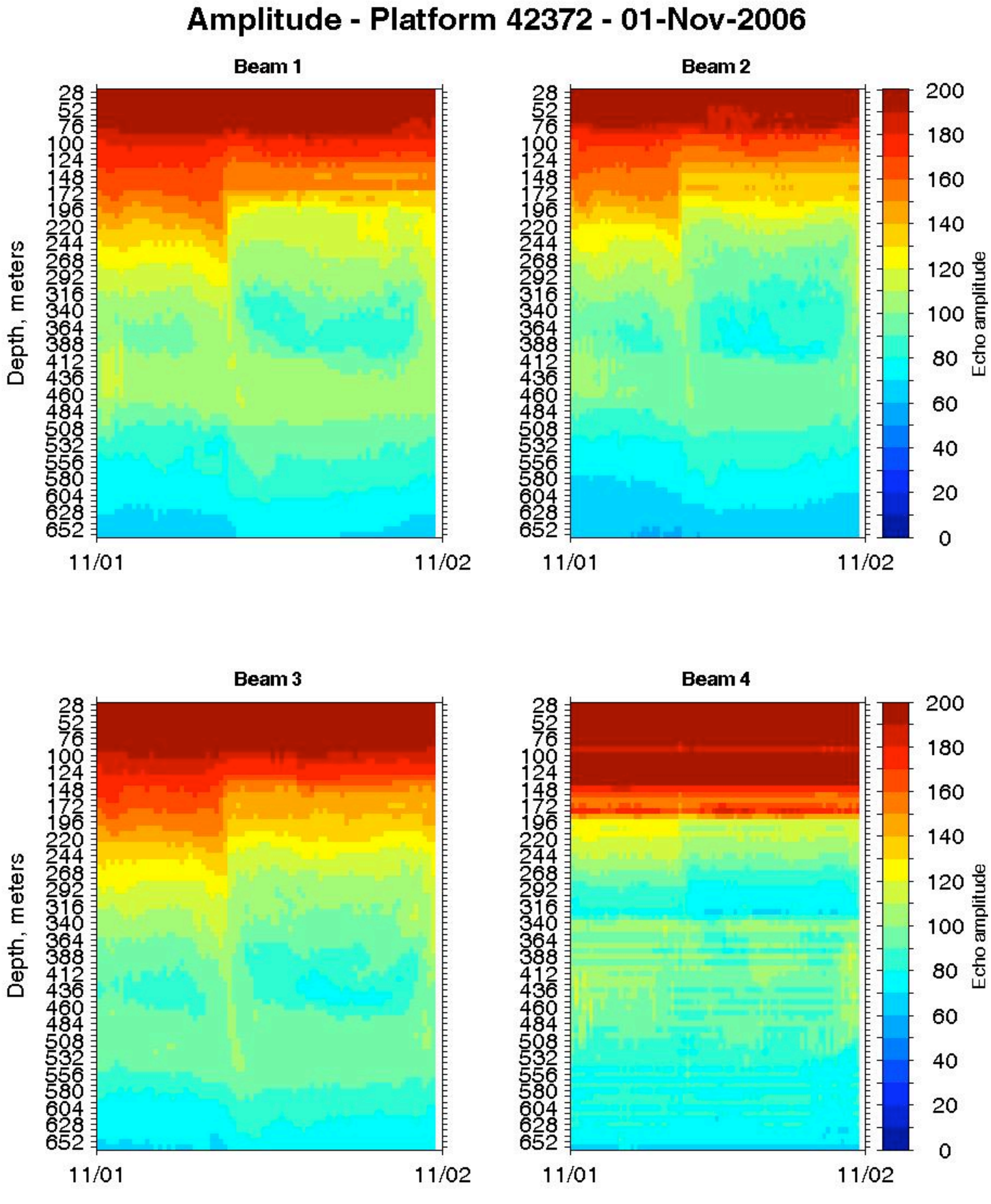


Figure 22. Colorized contour of amplitude (echo intensity) for the four ADCP beams at platform 42372 for November 1, 2006.

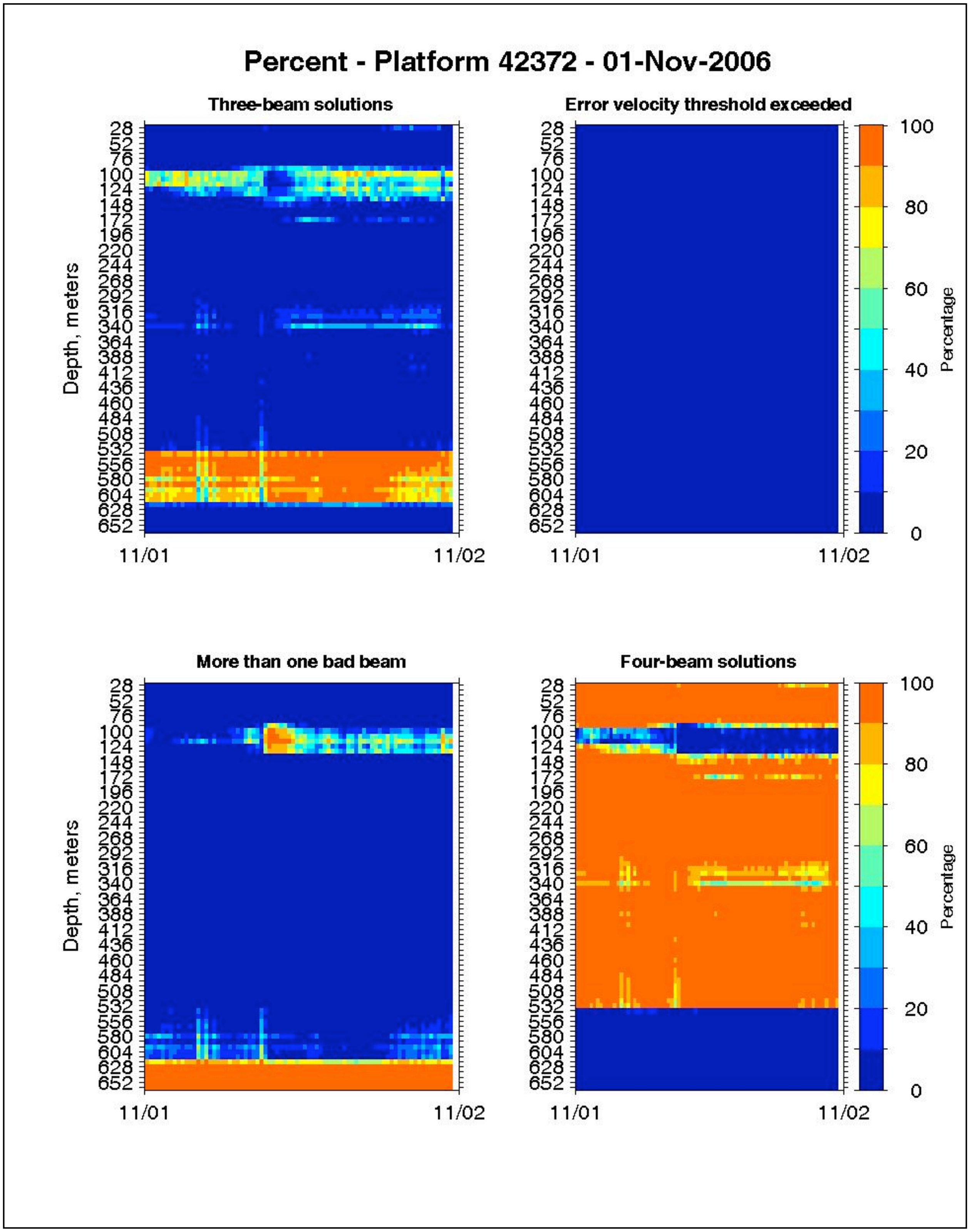


Figure 23. Colorized contour of the percentage of solutions at platform 42372 for November 1, 2006.

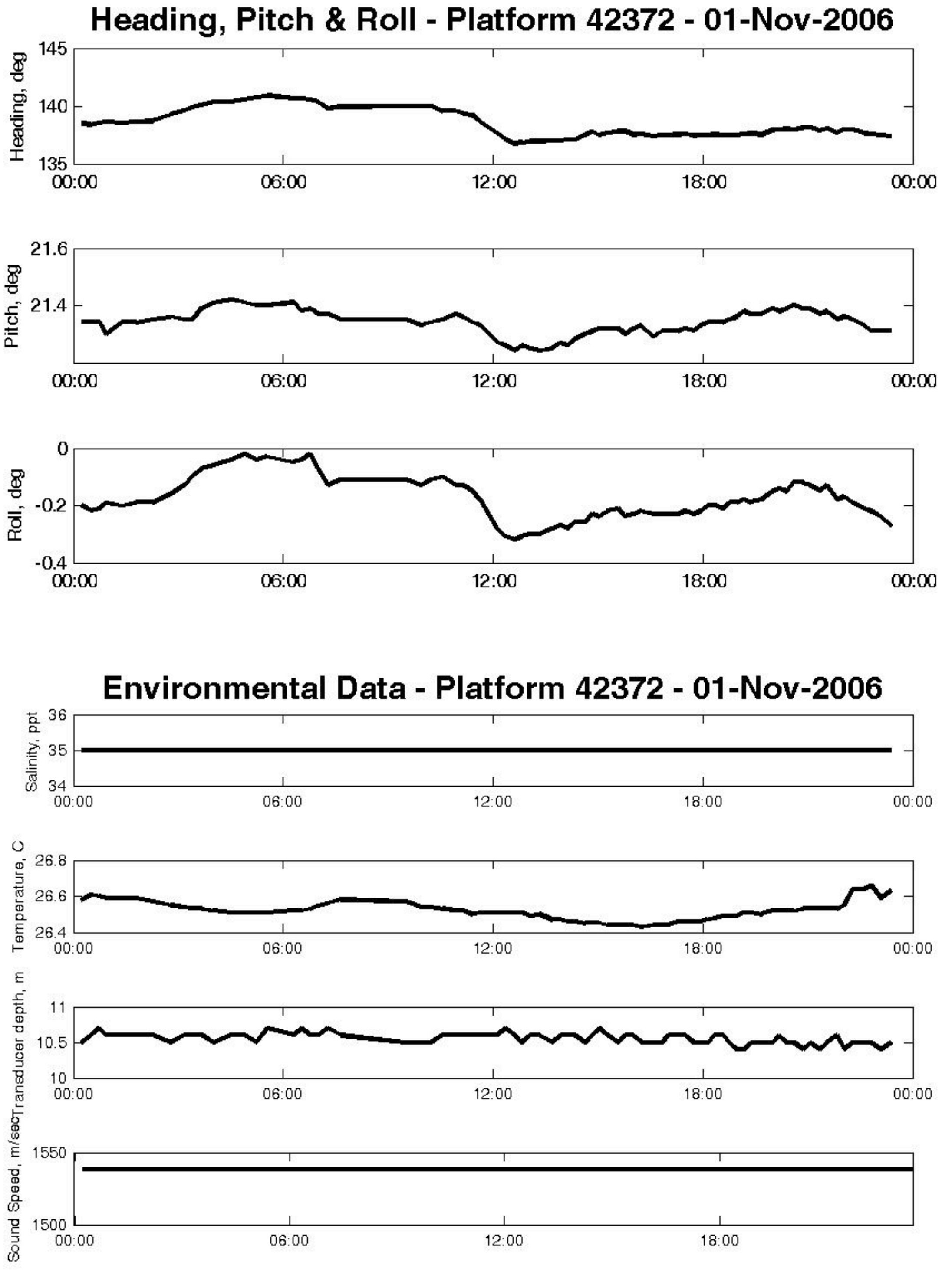


Figure 24. Time series of recorded heading, pitch and roll (top panel) and environmental data (bottom panel) at platform 42372 for November 1, 2006.

There is no issue with the data itself (speed, direction, velocity, percent good, correlation count and echo intensity) and no discrepancies between what is posted on the NDBC Web site and what we independently extracted from the binary data as part of this project.

Finding #19: A reduction in the horizontal current speed (see top panel of Figure 19) is clearly seen at the surface and at depth. When the grazers are near the surface feeding during the night, 1200 to 1800 GMT, the horizontal speed (see the bins associated with the depth range from 28 to 52 m) is nearly zero. We also note a somewhat random variation in the current direction over the same time and depth range that suggests the presence of grazing organisms. After the organisms descend, the near-surface horizontal current speeds increase to nearly 30 cm/sec. Conversely at depth (see the bins associated with the depth range from 76 to 100 m) the speeds are 25 – 30 cm/sec when the organisms are at the surface (0000 to 1200 GMT) and nearly zero during the day. We also note a distinct correlation over the entire water column between current direction and current speed. Where the speeds are low, the current directions are random and where the speeds are high the directions are towards the north to northeast.

Recommendation #19: Users of this data should be aware that there may be small biases in the horizontal speed due to the presence of widely distributed, relatively fast swimming organisms.

Finding #20: The vertical velocity, top panel of Figure 20, is quite different from any of the other platforms examined. There is no evidence of a distinct diurnal vertical migration of plankton and grazers, though the speed and direction suggest they are present. The correlation and echo amplitude for Beam #4 (see Figures 21 and 22, respectively) show a unique lineal pattern that may be due to the fact that the beam is pointed straight down and aligned along a column leg (this should be noted in the meta data) or it may be due to deterioration in the set of electronics for this beam. Figures 25 and 26 show that by November 25, 2006, the correlation and amplitude have degraded noticeably. This could be the result of changes in the environment or changes in the ADCP. While it is true that a lowering of the echo amplitude suggests a beam issue, it is not always the case. A slight pitch, roll or heading change could result in a beam now striking the riser and causing a dramatic change in the echo amplitudes.

Recommendation #20: Whether the beam 4 response is due to environmental or system changes, it illustrates that a machine-based automated quality control procedure is limited to problems that have been encountered in the past. The benefit of an experienced person reviewing the data can be invaluable.

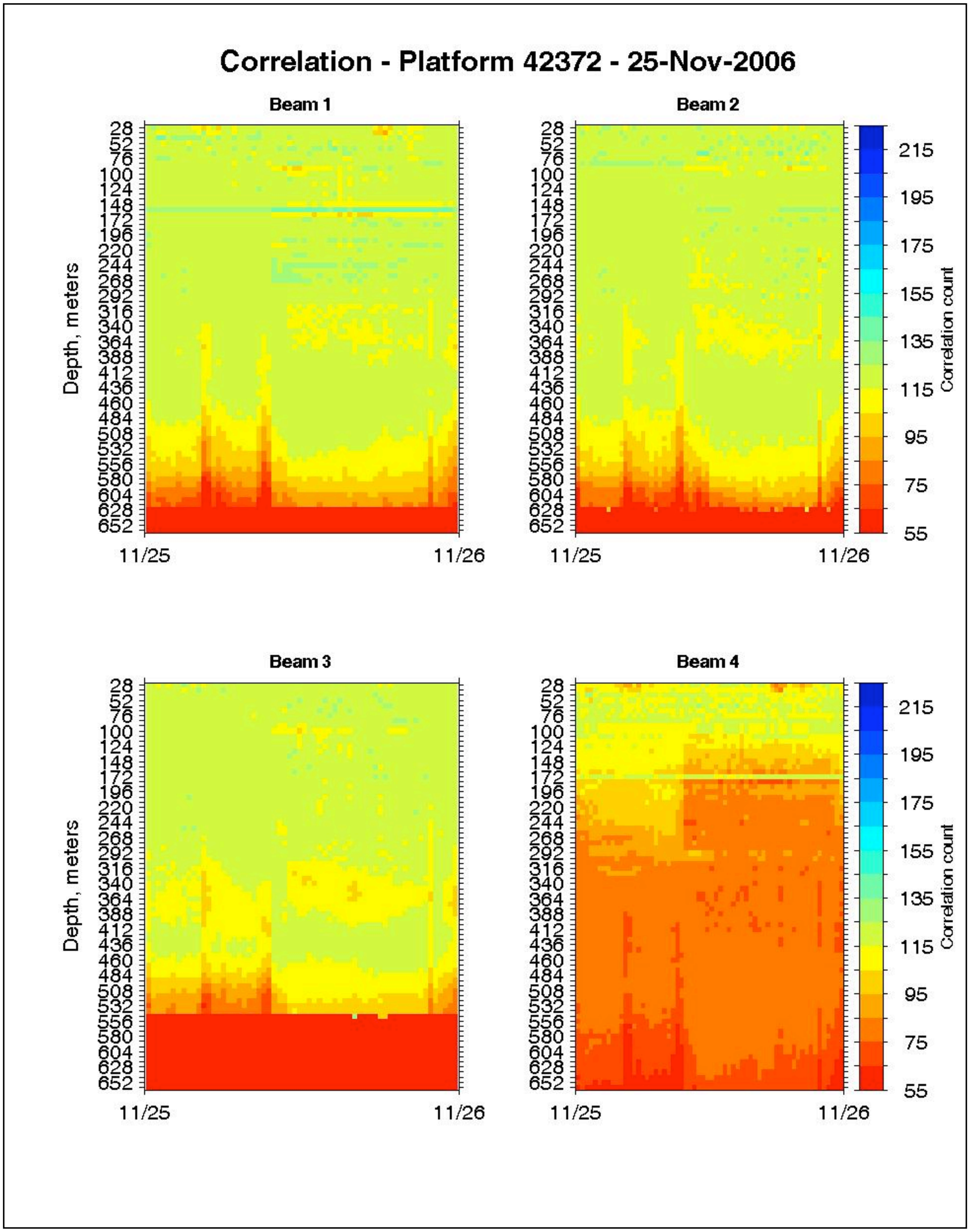


Figure 25. Colorized contour of the correlation count for the four ADCP beams at platform 42372 for November 25, 2006.

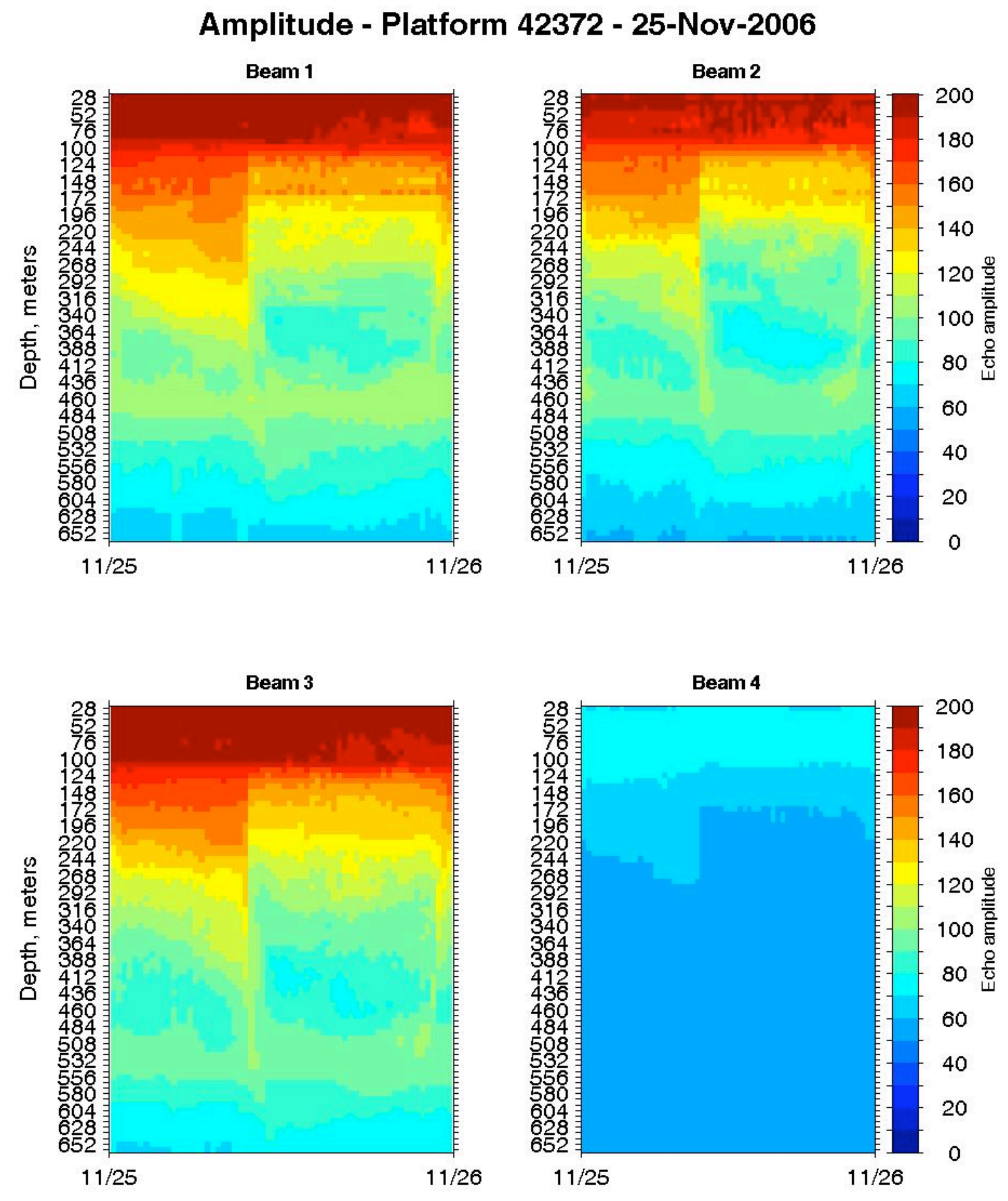


Figure 26. Colorized contour of amplitude (echo intensity) for the four ADCP beams at platform 42372 for November 25, 2006.

3.3.5 Platform 42880

The ADCP at platform 42880 is a 75 kHz BroadBand ADCP with a 20 degree beam angle mounted at nominal depth of 30 m. The ADCP is pointed vertically (~0^o tilt). The platform is mobile, but the position is manually input. The ADCP is operating in broadband mode, which improves the standard deviation of the velocity estimates, but at the expense of range. Table 1 lists the various particulars concerning this ADCP. Given the setup parameters for bin length and number of pings per ensemble, the best possible standard deviation for the velocity is 0.3 cm/sec. The minimum expected standard deviation, based on requiring at least 5% of the total pings per ensemble for a three- or four-beam solution is 1.1 cm/sec. Figure 27 shows the horizontal speed and direction; Figure 28, the vertical velocity and the error velocity; Figure 29, the correlation count; Figure 30, the amplitude, or echo intensity; Figure 31, details about the percentage of good pings; and Figure 32, the orientation of the ADCP and specific environmental data.

There is no issue with the data itself (speed, direction, velocity, percent good, correlation count and echo intensity) and no discrepancies between what is posted on the NDBC Web site and what we independently extracted from the binary data as part of this project. But there is a discrepancy in the depth of the bins. Apparently NDBC is calculating the depth of the bins based on depth of the transducer entered into the MMS header data, 30 m. There is no active pressure sensor on this ADCP, but the manually input depth is 27 m. All the figures for this section use the 27 m depth.

Finding #21: Evidence of grazing organisms is not readily seen in the horizontal current speed and direction (Figure 27), but it is seen in the vertical velocity. The vertical velocity (see top panel of Figure 28) shows evidence of a distinct diurnal vertical migration of plankton and grazers, i.e., a high vertical velocity at dawn and dusk. The echo intensity (Figure 30) shows a distinct increase in the amplitude at about 1200 GMT, when the grazing organisms are descending to a depth of approximately 300 m.

Recommendation #21: Users of this data should be aware that there may be small biases in the horizontal speed due to the presence of relatively fast swimming organisms.

Finding #22: The amplitude of beam 3 (Figure 30) shows an unusually high return in the depth range from 90–108 m. If the false target detection test had been enabled for this instrument – it wasn't, see Table 1 – then a three beam solution may have been possible. The false target screening process is an iterative process that evaluates the maximum difference between the echo amplitude of the profiling beams. If the maximum difference exceeds the threshold, then the first iteration always removes the beam with the weakest amplitude from any further consideration. The screening is then performed on the remaining three beams. If the maximum difference between the echo amplitude of the three profiling beams does not exceed the threshold, then a three-beam solution is possible. We also see from the correlation count, Figure 29, that beam 3 shows much lower count than the other three beams, particularly in the depth range of 250–400 m. This corresponds to the increased number of three beam solutions in this region, as seen in Figure 31.

Recommendation #22: None.

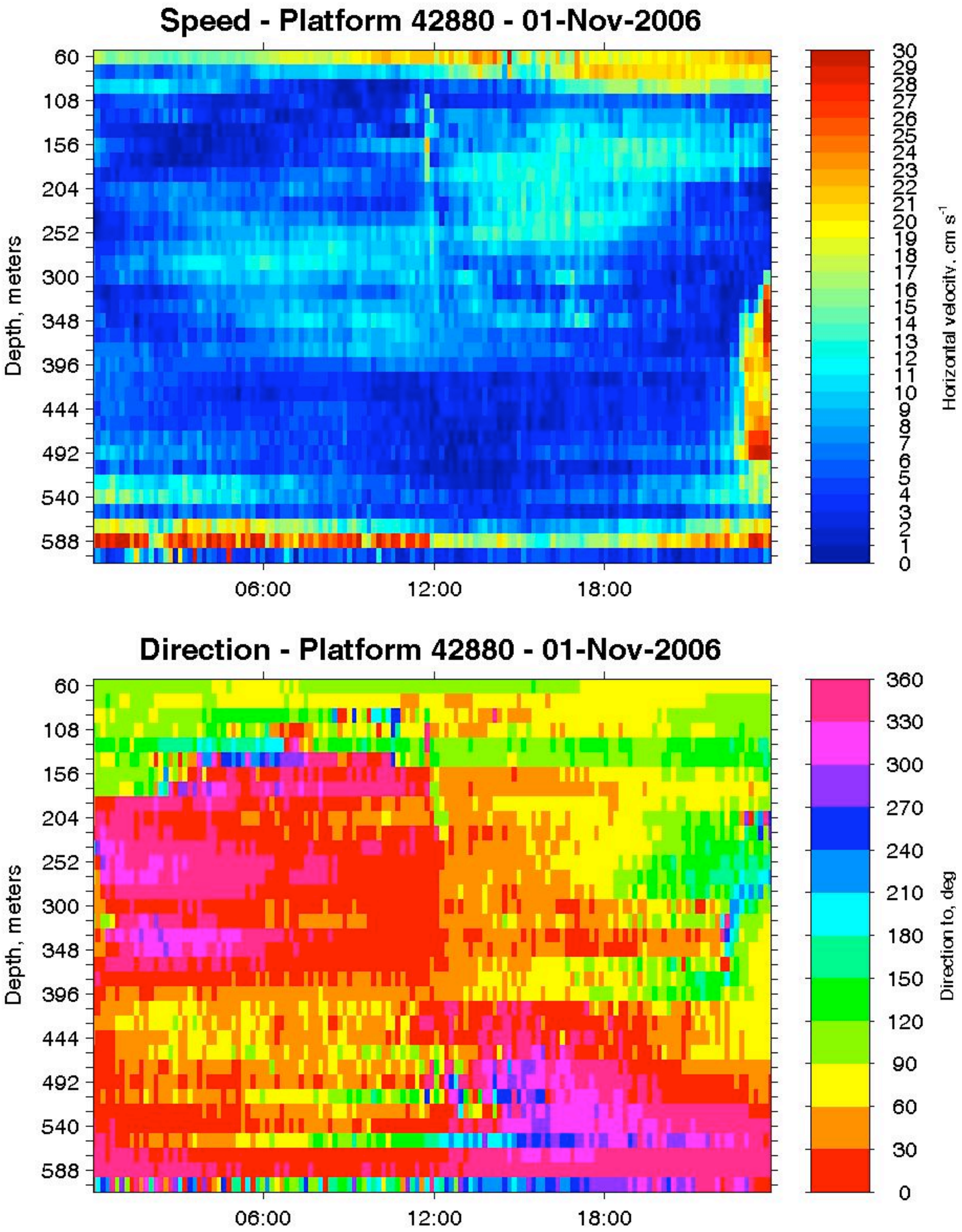


Figure 27. Colorized contours of horizontal velocity (top panel) and current direction (bottom panel) at platform 42880 for November 1, 2006.

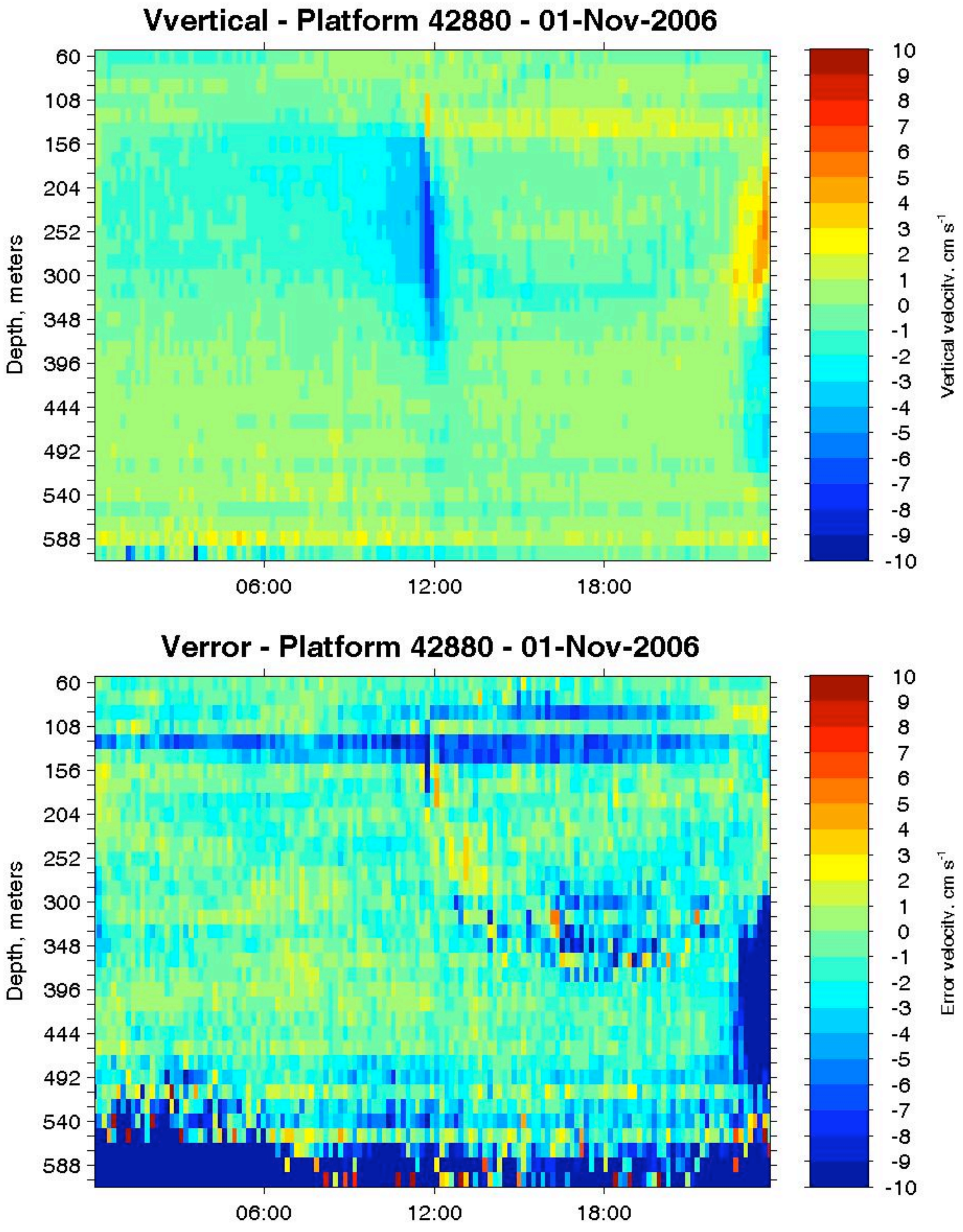


Figure 28. Colorized contours of vertical velocity (top panel) and error velocity (bottom panel) at platform 42880 for November 1, 2006.

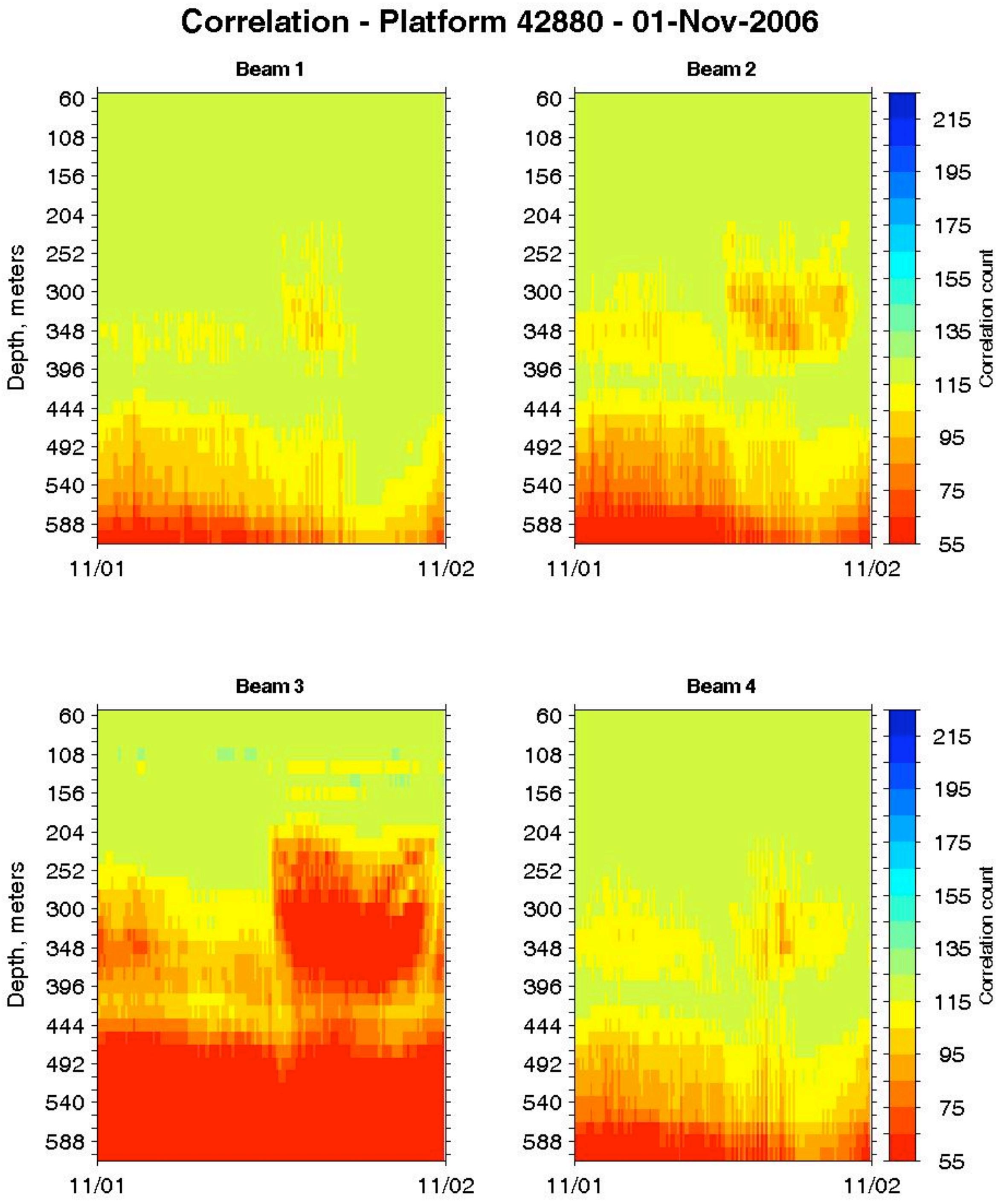


Figure 29. Colorized contour of correlation count for the four ADCP beams at platform 42880 for November 1, 2006.

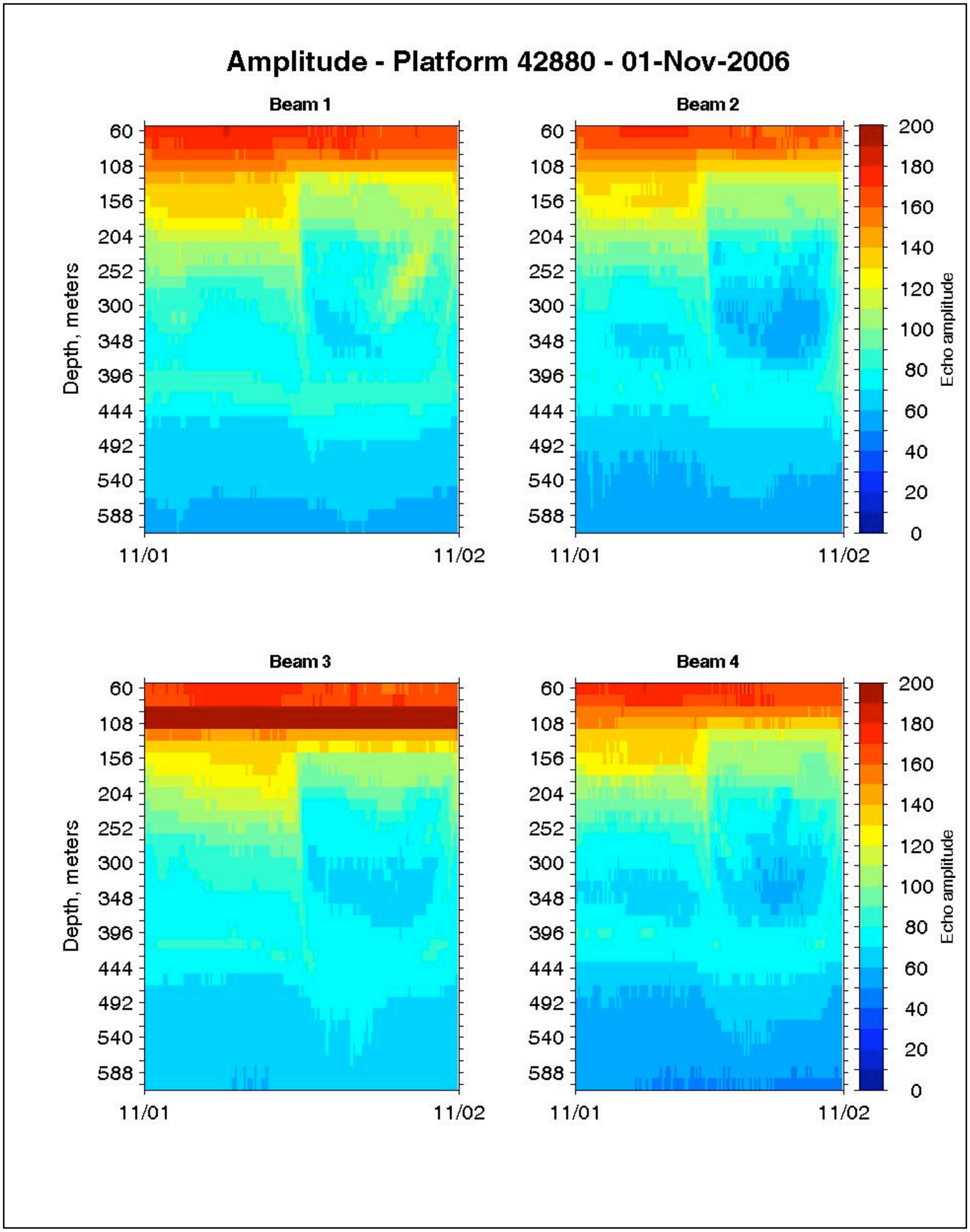


Figure 30. Colorized contour of amplitude (echo intensity) for the four ADCP beams at platform 42880 for November 1, 2006.

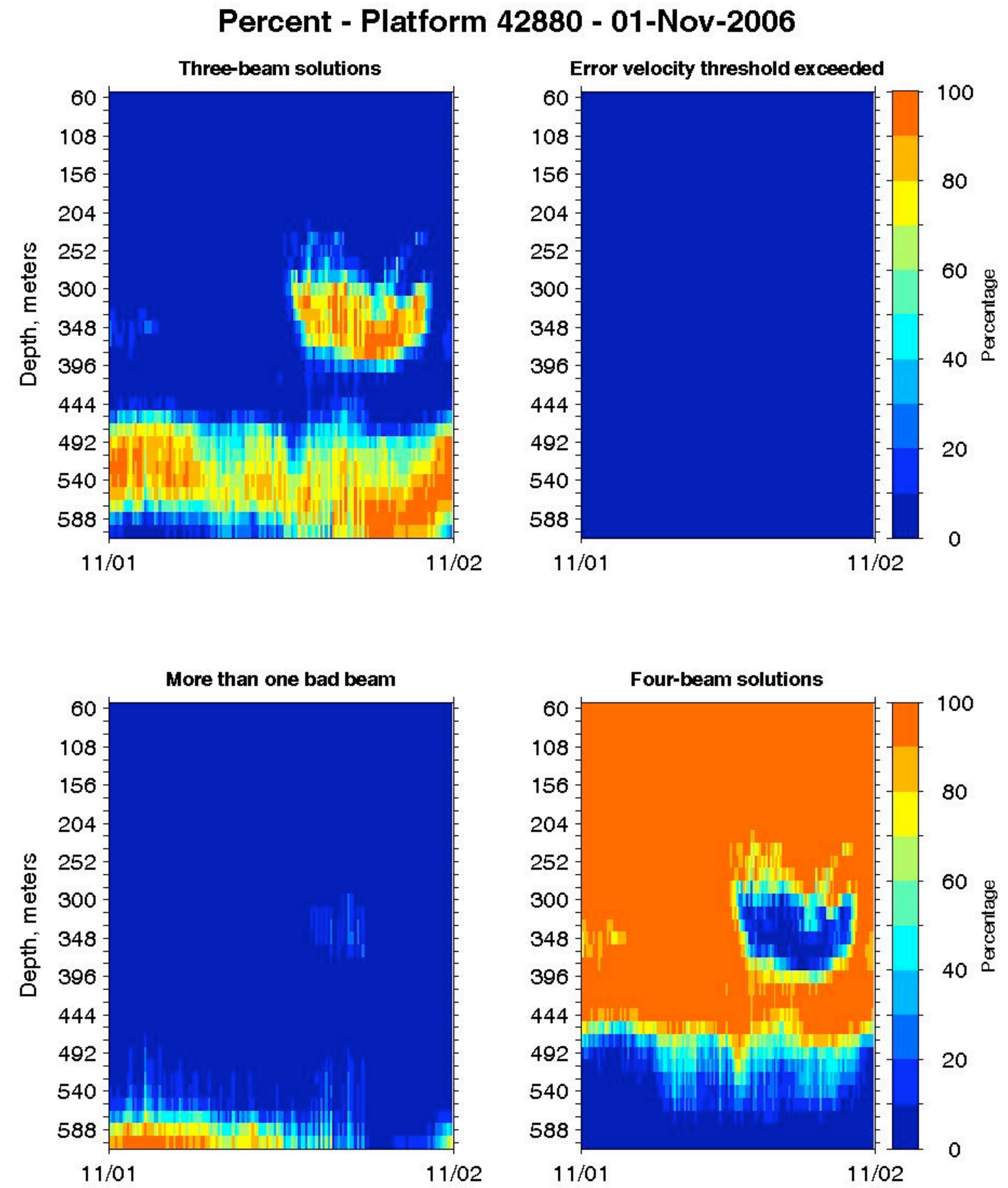
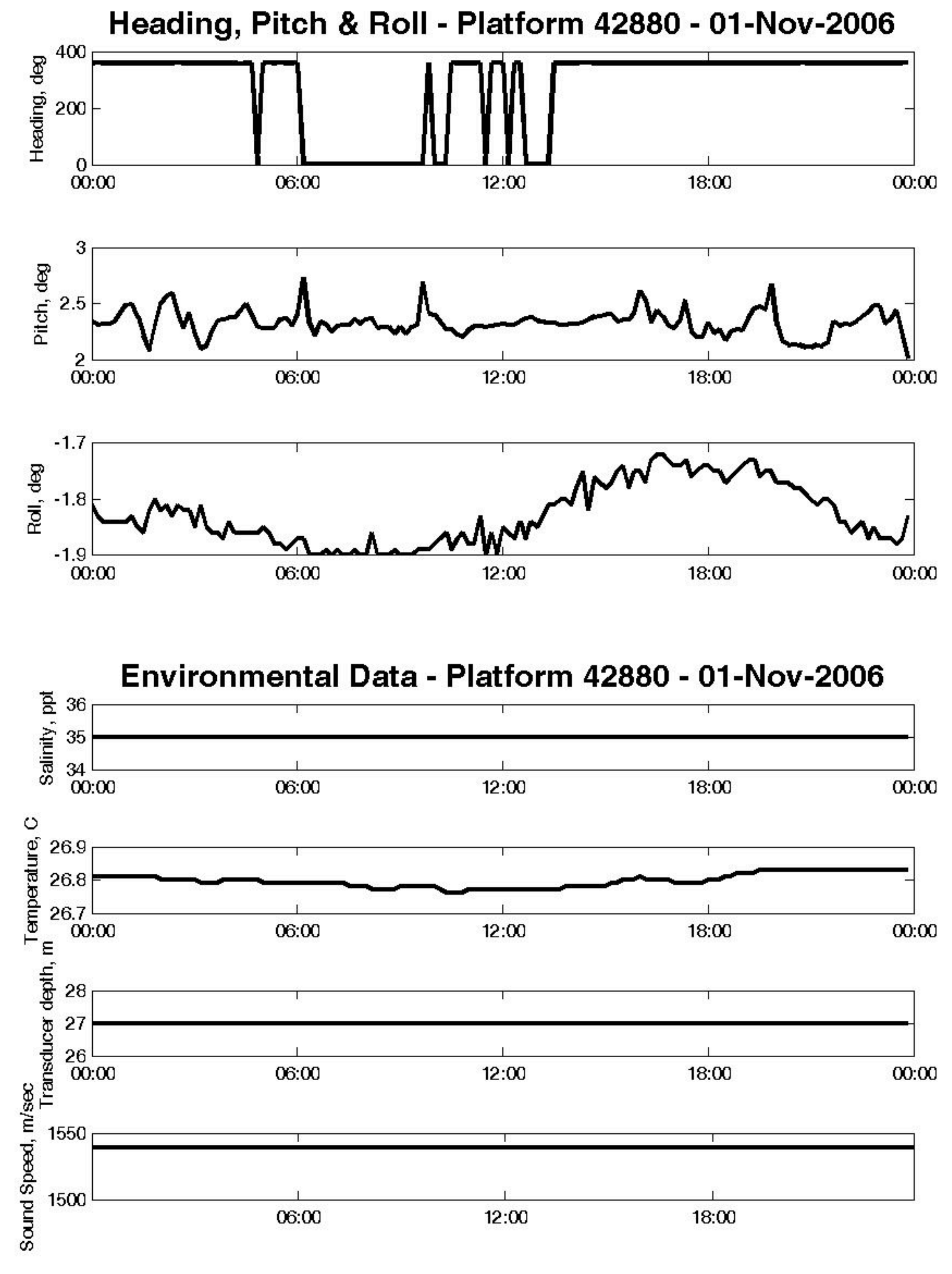


Figure 31. Colorized contours of the percentage of solutions at platform 42880 for November 1, 2006.


Heading, Pitch & Roll - Platform 42880 - 01-Nov-2006

Environmental Data - Platform 42880 - 01-Nov-2006

Figure 32. Time series of recorded heading, pitch and roll (top panel) and environmental data (bottom panel) at platform 42880 for November 1, 2006.

3.3.6 Platform 42888

The ADCP at platform 42888 is a 75 kHz WorkHorse LongRanger ADCP with a 20 degree beam angle mounted at nominal depth of 32 m. The ADCP is pointed vertically (~0^{o} tilt). The platform is mobile, but the position is manually input. The ADCP is operating in broadband mode, which improves the standard deviation of the velocity estimates, but at the expense of range. Table 1 lists the various particulars concerning this ADCP. Given the setup parameters for bin length and number of pings per ensemble, the best possible standard deviation for the velocity is 0.3 cm/sec. The minimum expected standard deviation, based on requiring at least 5% of the total pings per ensemble for a three- or four-beam solution is 1.3 cm/sec. Figure 33 shows the horizontal speed and direction; Figure 34, the vertical velocity and the error velocity; Figure 35, the correlation count; Figure 36, the amplitude, or echo intensity; Figure 37, details about the percentage of good pings; and Figure 38, the orientation of the ADCP and specific environmental data.

Finding #23: There is no issue with the data itself (speed, direction, velocity, percent good, correlation count and echo intensity) and no discrepancies between what is posted on the NDBC Web site and what we independently extracted from the binary data as part of this project. But there is a discrepancy in the depth of the bins. Apparently NDBC is calculating the depth of the bins based on depth of the transducer entered into the MMS header data. However, there is an active pressure sensor on this ADCP and it is reporting a depth of 43 m, not the nominal depth of 25 m. All the figures for this section use 43 m.

Recommendation #23: The active pressure sensor, if available, should be used to determine the depth of the bins.

Finding #24: The vertical velocity (see top panel of Figure 34) shows evidence of a distinct diurnal vertical migration of plankton and grazers, i.e., a high vertical velocity at dawn and at dusk. A reduction in the horizontal current speed (see top panel of Figure 33) is seen at the surface. When the grazers are near the surface feeding during the night (0000 to 1200 GMT), the horizontal speed (see the top two bins) is nearly zero. After the organisms descend, the horizontal current speeds increase to 20 cm/sec. We also note a somewhat random variation range in the current direction over time and depth that suggests the presence of grazing organisms.

Recommendation #24: Users of this data should be aware that there may be small biases in the horizontal speed due to the presence of widely distributed, relatively fast swimming organisms.

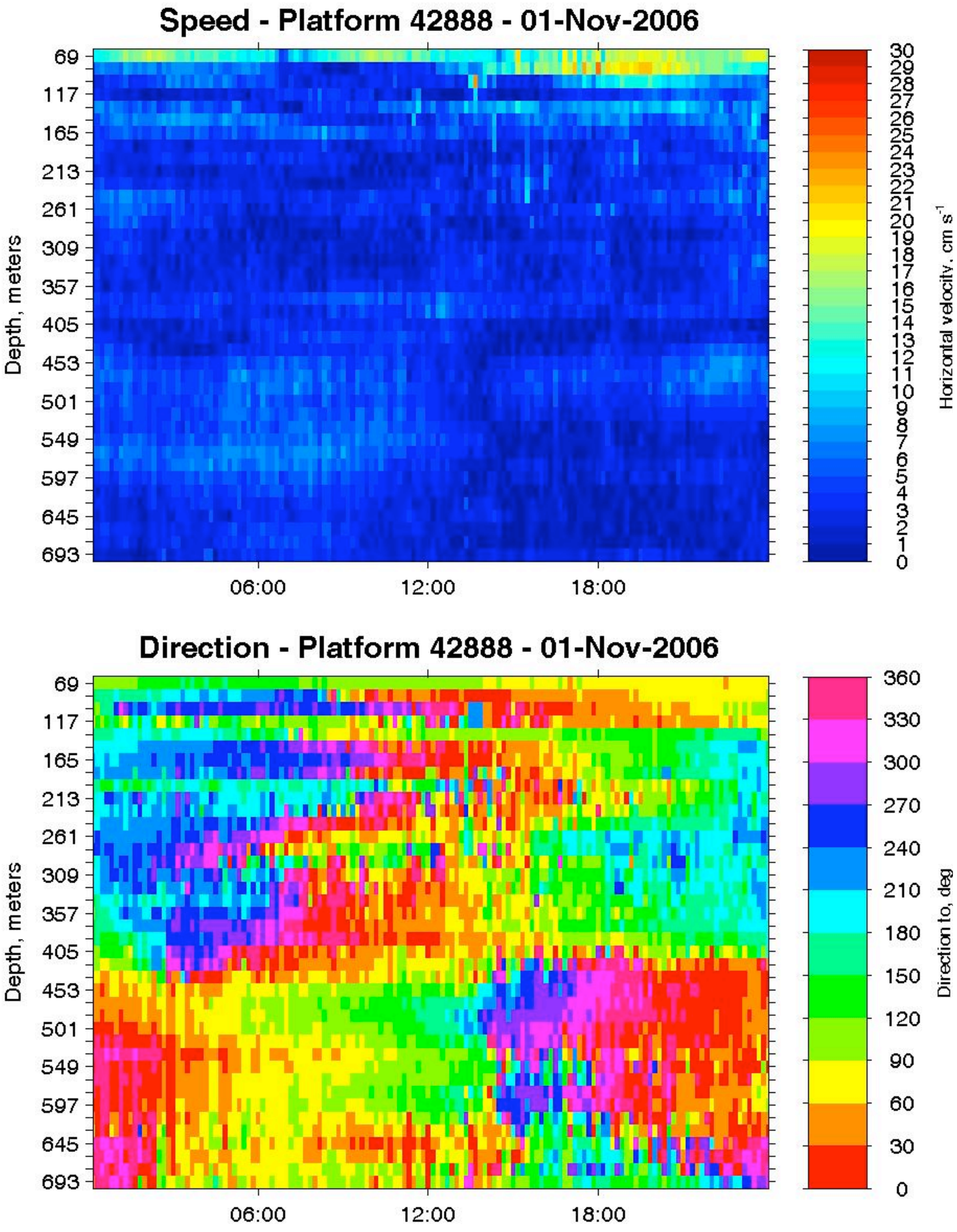


Figure 33. Colorized contours of horizontal velocity (top panel) and current direction (bottom panel) at platform 42888 for November 1, 2006.

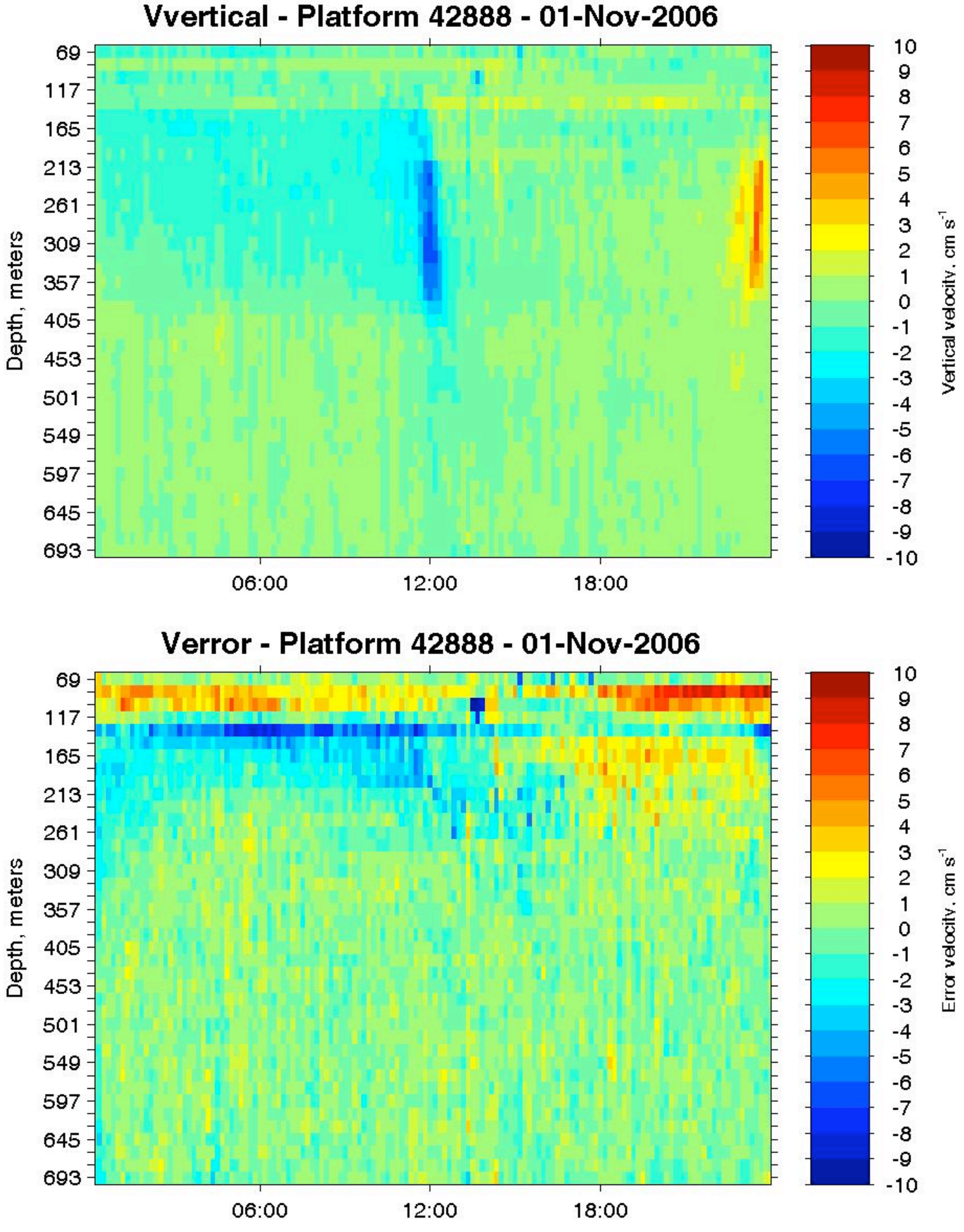


Figure 34. Colorized contours of vertical velocity (top panel) and error velocity (bottom panel) at platform 42888 for November 1, 2006.

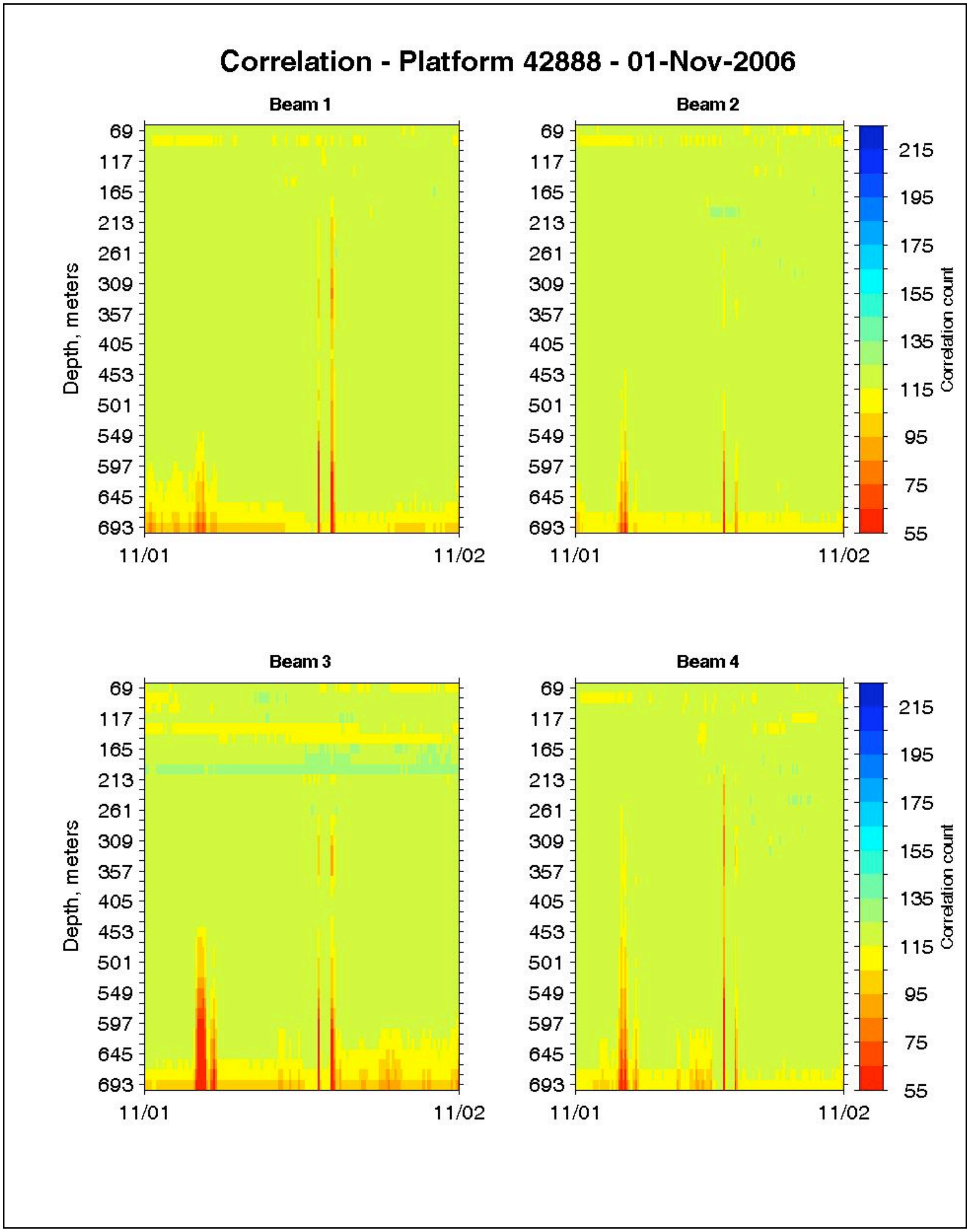


Figure 35. Colorized contour of correlation count for the four ADCP beams at platform 42888 for November 1, 2006.

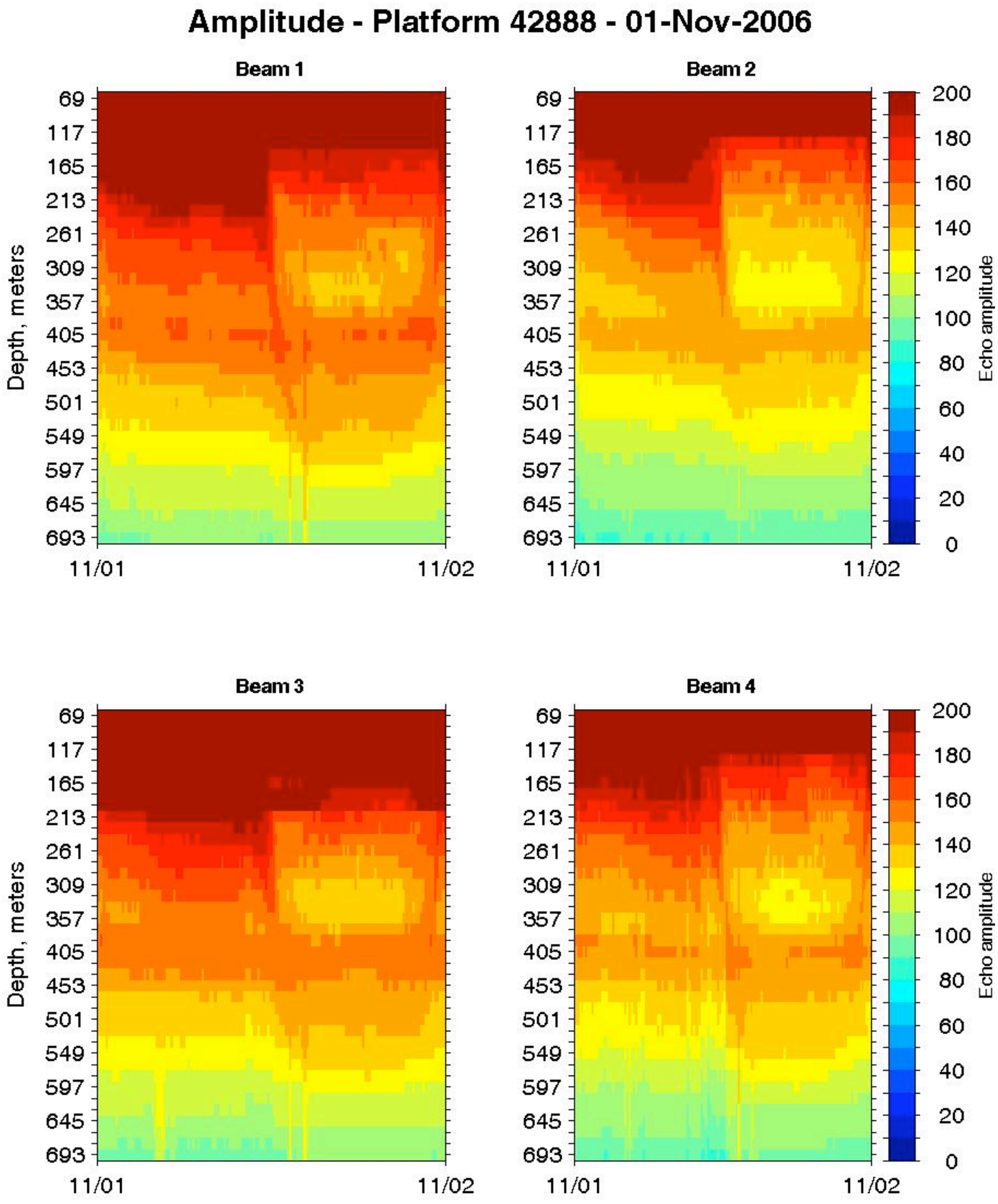


Figure 36. Colorized contour of amplitude (echo intensity) for the four ADCP beams at platform 42888 for November 1, 2006.

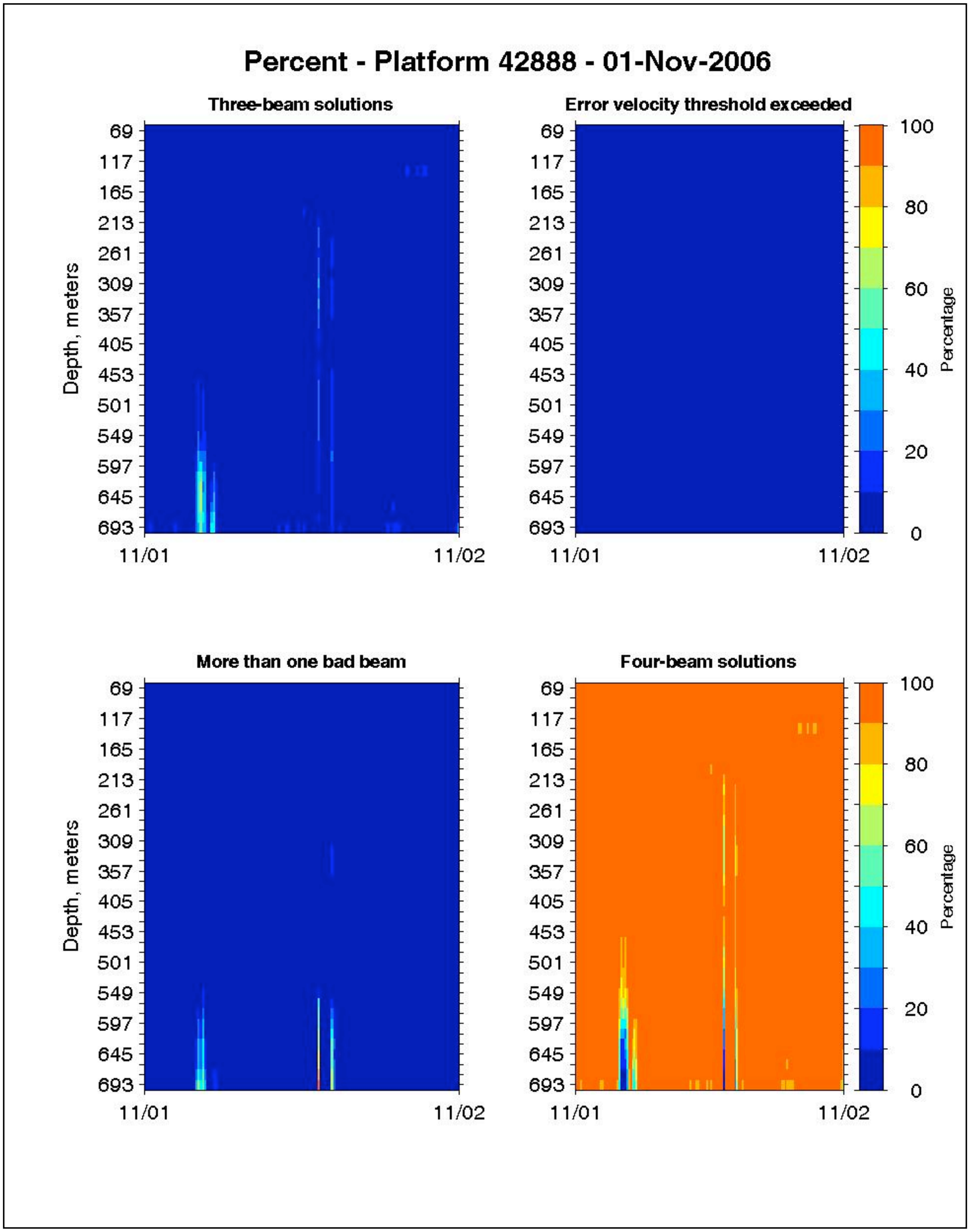


Figure 37. Colorized contours of the percentage of solutions at platform 42880 for November 1, 2006.

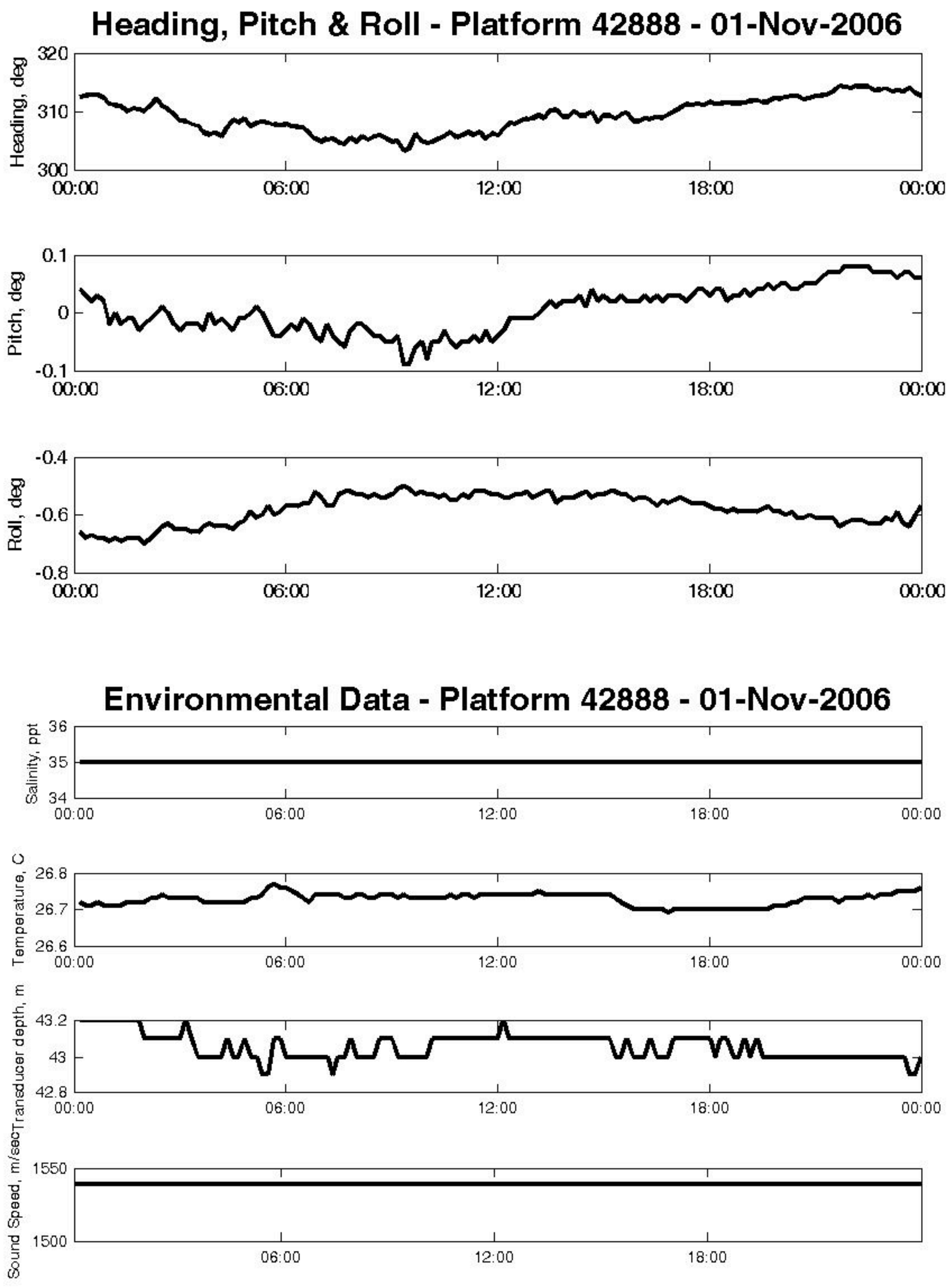


Figure 38. Time series of recorded heading, pitch and roll (top panel) and environmental data (bottom panel) at platform 42888 for November 1, 2006.

4.0 RECOMMENDATIONS

1. We recommend a workshop involving RDI, MMS, NDBC, and the operators to discuss the results of this report and to discuss how quality control can reasonably be achieved across different instrument, different platforms, and different operators. For example, is the goal a reasonable level of assurance that the standard deviation in the good velocity data does not exceed a critical value, no matter where and how it was collected? Given the level of what appears to be contamination by grazing organisms that appear to hold position in currents of up to 25 cm/sec, what is the strength of the current that is of most interest?
2. The ideal quality control environment would be achieved by saving the ping-by-ping data. In this way the setup parameters would be irrelevant and all the QC could be performed as post processing and strictly controlled. The next best quality control environment would be to forego the ping-by-ping data and accept ensemble averaged data, but require a consistent set of parameters that are designed specifically for each of the two instrument types and should not be altered by the operators. The most likely level of quality control would be ensemble-averaged data collected under a wide and essentially uncontrolled range of setup parameters. But the quality control parameters would be tailored to the setup parameters, such as bin length, number of pings per ensemble, and minimum acceptable averaging period.
3. The potential effect of grazing organisms on the validity of the velocity data could be large. A plan to study how prevalent and how influential this may be is recommended if velocity accuracies of better than 20 cm/sec are desired.

5.0 CONCLUSIONS

This is a report about quality assurance, but it is not just merely an evaluation of the Level I QA/QC procedures, it is an evaluation of the quality measures that are part of the RDI software and it is a report on how the MMS procedures complement, overlap, extend and in some cases are superfluous to the RDI internal measures. This evaluation could not be carried out without examining in great detail how an RDI ADCP performs quality control. We have asked numerous questions about the RDI QA/QC procedures that may not have been asked before in this context. It is our opinion that this report provides one of, if not the first opportunities, to examine ADCP quality control issues across a wide range of operators, platforms and physical setup. The vast majority of quality control to date has been done by individual operators.

6.0 REFERENCES

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

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

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

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.