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Observing behaviour of over-wintering Herring (*Clupea harrengus* L.*)* in Ofoten with Acoustic Current profiler.

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In this paper we present results and interpretation of velocity and signal strength data collected with a 'Continental' Current Profiler on over-wintering herring in the Ofoten in the North of Norway. The instrument was lowered to a depth of 150 m and kept stationary with the transducer upward looking during a period of two months. In the same area and period we had two bottom-mounted echo sounder of the type EK60 at 500m and 400m depths. Data from the echo sounders were used to demonstrate that the Continental signal strength could clearly measure the backscattering of herring. First, we used threshold and contour extraction on the EK60 data. The extracted contours were then overlaid the backscattered data from the Continental. The distribution and density dynamics of the two data sets matched very well. By using the extracted contours for analyzing the speed and direction, we concluded that herring behaviour could efficiently be observed from the Continental. We could not observe the diurnal vertical migration due to the lack of depth coverage of the migration range of herring. Exchange between fish layers was well reflected in the data from the Continental. The horizontal speed and direction showed that the herring aggregations mainly floated on the tidal current during the over-wintering. These observation contrasts the expected rheotaxis, but fits well with the fact that herring is in a state of energy saving and thus would avoid unnecessary swimming.

Keywords: Current Profiler, tidal current, over-wintering Herring, Ofoten, echo sounder.

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Introduction

Traditionally Current profiler is used for measuring water current and vessel speed by measuring the Doppler shift from the sea bottom or particles in the water. Fish and other autonomous life are regarded as noise and biases the measurements.

In (Freitag *et al*.,1992) data from an Acoustic Doppler Current Profiler (ADCP) is compared to data from several Vector Averaging Current Meters (VACM) and Vector Measuring Current Meters (VMCM). The comparison shows that the ADCP is biased towards low velocities. This is proved to be due to contamination of fish echo in the ADCP signal. They use the beam-to-beam difference to implement a fish-bias rejection algorithm. The algorithm reduces the bias induced bye near by fish, an improvement of the rejection algorithm is reported in (Feritage et al.,1993). Mechanical Current Meters can be used to correct the bias in ADCP velocities, this is reported in (Plimton *et al*., 2000).

The occurrence of bias correlating with a diurnal rhythm is reported in (Wilson and Firing, 1991). This is explained by species of micronektion in dense sound scattering layers swimming coherently at sunrise. Kaneda *et al*.(2001) observed strong diurnal signal from the ADCP after a cold-water intrusion from the shelf slope region south of the Bungo Channel. They explain this by an immigration of zooplankton from outside the bay.

From these studies it is clear that the ADCP instrumentation record information of marine life. Current Profilers (CP) has never been used as a standard tool for biomass surveillance al tough some experiments and attempts are reported.

An concurrent ADCP and SeaSoar survey (Roe *et al*.,1996) calculates the volume backscattering (S_v) using an real-time measurement of the absorption coefficient. The study states that ADCP can be used to map quantitative biology on the same scale as hydrography, but never replace well-calibrated echo sounders.

Roe and Griffiths (1993) demonstrate that different biological information can be obtained from routine ADCP operation. This includes horizontal and vertical Log Intensity Anomaly data and horizontal speed data. They conclude that ADCP can give additional valuable information about marine life.

One of the difficulties using a CP for biomass measurements is the uncertainty around ADCP calibration. Brierley *et al*. (1997) suggest that one should avoid using these instruments for abundance measurements despite the positive correlation with EK500 echo sounder. The calibration comparison of an ADCP and EK500 echo sunder by (Griffiths and Diaz, 1996) shows a difference between the two instruments of less then 1 dB. They have a more positive attitude and see this accuracy as sufficient for many qualitative studies.

Several studies using ADCP and a Multiple Opening-Closing Net Environmental Sensing System (MOCNESS) (Ressler, 2002) show that net samples of Crustaceans, small fish and fragments of non-gas-bearing siphonophores had significant positive correlation with the acoustic backscattering, in contrast net samples of other gelationous zooplankton, pteropoid and atlantid molluscs, and gas-filled siphonophore had no significant correlation with volume backscattering. An intercalibration study with MOCNESS and a 307 kHz RD Instrument ADCP was done by (Flagg and Smith, 1988). They showed that it is possible to predict zooplankton biomass with ADCP to approximately ±15 mg m^{-3}. Good results are only possible after carefully calibration of the current profiler. Ressler *et al.*(1998) demonstrates a positive empirical relationship between s_v and MOCNESS catches of zooplankton and micronecton, and indicate that ADCP measurements may be a useful index of zooplankton and micronecton biomass.

One of the earlier works (Hollyday,1974) studied echo frequency distributions from tree schools. Here observed the Doppler shift is related to the schools swimming direction, fish length, tail-beat amplitude and frequency.

Demer *et al*.(2000) use an RD Instrument ADCP. They state that all the beams of the ADCP have to simultaneous ensonify coherent moving aggregations to be able to extract the three-dimensional velocity vector form the school. A fish velocity detection algorithm is also proposed. This is used to separate fish velocity from water current velocity. By using these methods and instrumentation they are able to observe fish swimming in the opposite direction to the prevailing current.

Zedel *et al*. (2003) uses an moored downward looking RD Instrument ADCP to observe over wintering and migrating herring in the in the Vest fjord and deep inside the Ofot fjord in the North of Norway. They observe horizontal and vertical movement of the fish schools. Horizontal movement was form 0 to 50 cm s^{-1}. Highest speeds were observed during daylight.

An increased activity was observed at dawn and dusk. No well-defined velocity was observed during nighttime.

We use contour extraction based on the Radial Sweep algorithm to compare echo intensity of fish between CP and EK60 data. Tidal periods are determined by derivation of the surface height from EK60 with respect to time. This gives us the expected time of maximum and minimum tidal current. A variance filter between the tree beams of the CP is used to remove invalid values. Probability density functions (pdf) are calculated and compared to closer investigate current speeds and swimming speeds.

In this paper we analyze data form a Continental Current Profiler (CP) while observing over wintering herring in the Ofoten fjord in Northern Norway. Our primary goal is to measure the swimming speed and direction of dense herring schools while passing our instrumentation. Traditionally herring observations have been done using a scientific echo sounder the EK500 or EK60 (Røttingen and Tjelmeland, 2003). These instruments have not the ability to measure Doppler shift between received and sent signal. Swimming speed for single fish is calculated using target tracking (Ona and Hansen,1991) and relies on non-over lapping echoes. This clearly has limited the velocity measurements to more disperse fish aggregations. We also use data from bottom mounted EK60 located close to the CP for comparison. Our secondary goal is to gain more insight in the internal dynamics of the herring schools when they are in this hibernating state Vabø (1999) and (Slotte,1999). This is done bye comparing the EK60 and CP data.

Material and Methods

The study took place in the Ofotfjord in the Northern Norway (Figure 1). The study period was from 2002.12.18 to 2002.12.28 this is in the middle of the over wintering period. We use two bottom mounted 38 kHz scientific echo sunders of the type EK60. These are separated by a distance of 415 meters. The one closest to land is at a distance of 1029 meters. The ping rate was set to one ping pr. second. We used a pulse length of 1024 ms. This was done to limit the bandwidth so background noise form the system was filtered away. Transmit power was 1000W. The CP operated on a frequency of 190 kHz and was placed 804 m North East of the two EK60 and 608 m from land. The receiver has a gain scaling accuracy of +/- 1dB over the instrument temperature range (-4 C to +40 C) and a resolution off 0.33 dB. The bin depth was set to 5 m and a 2 min average was sampled every 10 minutes. EK60 data is gathered on land in a Cabin containing the EK60 computer while CP data is collected internal on the instruments hard disk. The geographic configuration of the instruments is shown in Figure 2. The fjord going East-West and we therefore expected the tidal current to be most evident in this direction. Data where extracted and analyzed using ExplorerP, SIMRAD EK60 and MatLab.

The analysis consisted of the following steps:

1. Resample EK60 data to match CP data.
2. Contour extraction from EK60 overlaid CP data.
3. Contour extraction form CP signal strength data.
4. Removing invalid CP data.
5. Analysing pdf's

The first task was to resample the EK60 data to match the CP data in time and depth resolution. This was done by averaging the EK60 data over 10 minutes and in 5 m depth intervals. Next we examined if the CP could see the herring schools by comparing sV values form CP and EK60 did this. We first thresholded the EK60 data to separate between in- and out- school data. The contour was overlaid the CP intensity data for visual inspection, and the threshold for the CP data was adjusted manually to obtain a good contour overlap. The degree of match was then estimated. Since the CP and EK60 operate on different frequencies some differences in the signal strength between the two data sets are expected. To get more accurate segmentation of the in school and out of school data we extracted regions and contours form the CP data and used these in the analysis. The threshold was adjusted so that the schools was separated from the background. The contour from the CP data was then extracted and laid over speed and direction profiles to capture any differences in in- and out- of school data.

The CP uses tree beams to obtain a tree dimensional speed vector. This method anticipates that a homogenous speed field covers all three beams. In our case we have this situation when monitoring large dense schools or water alone. When schools are dispersed one beam may hit fish and one other may hit water voids. We regard such samples to be invalid and use the max min of linearized volume backscattering (sv) between the tree beams to filter invalid data. If the max-min value was below a threshold the data was keep for further analysis.

The abow method enables us to separate our data set in to parts. The in-school data consist of data where the fish school is present. Out- of school data consists mainly of water voids. We construct pdf 's from the in school data and out school data to compare horizontal and vertical speeds. The Kolmogorov-Smirnov test was used to find the differences between in- and out- of school data. Our null hypothesis was that both pdf's came from the same distribution. We rejected the null hypotheses if the test was significant to the 5% level. To be able to extract some features from the pfd's we used the mean, standard deviation, skew ness and kurtosis.

We used the recorded surface height from the EK60 to predict the tidal current. A reasonable assumption is that the surface height is at its minimum or maximum when the tidal is turning and the current is at its weakest. When the tidal current is at its maximum we should be in the middle of maximum and minimum surface height. From this we can se that by derivation of the surface height we get the same phase as the tidal current measured by the CP.

Results

Data from a CP and EK60 was collected during a period of 11 days. The CP was used to give an additional dimension to the EK60 observations so that we could calculate the speed of dens herring schools. The EK60 data was used to validate that the CP could observe herring Schools.

Resampling and EK60 Contour extraction.

The resampled EK60 data is shown in top of Figure 3 together with the extracted contour and the depth of the CP. The contours were extracted by using a threshold of –60dB and –20dB. We then overlaid the contour over the CP data as shown in the lower part of Figure 3. The regions from the CP and EK60 was then matched, this gave a 64% fit. Figure 4 shows the CP signal strength and its corresponding contour. The contour is then overlaid different data sets from the CP to give a visual impression of the correspondence between schools and speed vectors.

Removing invalid CP data

A max-min filter was used to remove invalid data. We set as a demand that not more then 10% of the data in the analysis should contain invalid data. A threshold of 0.05 gave us 7.9% invalid data in our dataset. Probability density functions for in school, out school and invalid data are shown in Figure 5 together with the max-min filtered data.

Tidal current

A strong periodic signal in the CP data indicates the tidal current. We used the surface height to prove that this periodic signal was in fact the tidal current. Figure 6 shows the comparison of water phase height and tidal current phase. By deriving the surface height we get the same phase.

Probability density functions

Figure 7 shows the pdf for speed and direction. Statistic features from the pdf's can be viewed in Table 1. The vertical (velZ), east west (velEW) and north south speed (velNS) have a more symmetric distribution while the horizontal speed is non symmetric with a strong tail. The horizontal direction pdf is bimodal with peaks at 98 and 266 degrees for in-school and out- of school data. The Kolmogorov-Smirnov test shows us that the in-school and out-school data has a significant difference to the 5% level.

For velZ we see that in-school data have a somewhat higher downward vertical velocity compared to the out-school data. The speed distribution is also broader then the out-school distribution. The in-school data have a tail for upward speeds. Out- of school data is more focused around the mean velocity than the in-school data. The mean speed for in-school data was 2 cm/s in the downward direction, and a maximum at around 21 cm/s for both directions.

In the velEW data set the overall speed is to the east for both in-school and out-school data. The out- of school data has a lower speed. The in-school data have a broader specter of speeds and is less skewed than the out- of school data which has a longer tail for speeds in the west direction. The in-school data are more focused around the mean velocity at 4.4 cm/s. The maximum-recorded velocity was 60 cm/s for the east direction and 50 cm/s for the west direction.

The velNS data set has the same mean velocity and little differences in standard deviation. Both are skewed slightly to the south speed directions and have the same focus around the mean velocity direction at 2.7 cm/s. The maximum-recorded velocity was 28 cm/s for the north direction and 37 cm/s for the west direction.

Horizontal velocity is derived from the east-west and north south velocity. The in-school data have on average a higher speed then the out of school data. The standard deviation and skewness is very similar for the two data sets. We se that the out- of school data are more focused around the mean than the in-school data. The mean velocity for in-school data was 13 cm/s with a maximum at 64 cm/s.

Discussion

In this paper we have studied the ability of a CP to observe behavioral characteristics of schools of herring. We split the data into in-school data and out- of school data and calculated the pdf's. The Kolmogorov-Smirnov test showed significant difference between in-school data and out- of school data in all of the datasets. This indicates some differences between flow of water and movements of schools of fish and, thus agrees with observations in earlier works.

From this analysis we observe that the herring descents in the deeper parts of the fjord at an average speed of around 2 cm/s we also observe an average south speed component of 2.7 cm/s. The water current has a similar direction but lower average speed in the down direction. The east-west component is higher and has on average a west component of 4.4 cm/s.

The downward fish movement supports the hypothesis that the herring uses a swim and glide behaviour for energy minimization. The southward movement combined with the downward movement support the hypothesis that the schools has a dynamic where the main descent is located at some distance from land and the ascent is done by following the bottom to the shore. For the fish to get out from the shore a south naval component is needed. The higher in- school in contrast to the lower out- of school speed in the east-west direction indicate that the schools swim with the tidal current in the east direction.

The swim and glide phenomena is reported in (Huse and Ona,1996). When the herring swims upward the target strength is less then when it glides downwards. We also know that the CP process data in a manner that make objects with large target strength count more than objects with less target strength. The swim and glide behaviour will therefore give a downward contribution to the vertical velocity even if the herring maintains a mean constant depth.

The phase correlation between the velEW and the time derivative of the surface height demonstrates the dominating tidal forces. The horizontal directions peaks at 98 and 266 degrees which is close to the east (90 degrees) and west (270 degrees) direction. This also agree with the along direction of the fjord. This reduces the energy usage and is sensible due to the hibernating state the herring is in.

The average swimming speed of herring is low 2-12 cm/s. The much higher speeds around 50-60 cm/s might be due to burst swimming triggered by avoidance reactions and swimming with the tidal current. Figure 4c shows the velZ data profiler and demonstrates regions of high swimming speed inside the school. These can distinctly bee seen as yellow and read aeries inside the school contour.

The small differences in values between in- school data and out of school data gives us the impression that the tidal current dominates the herring movement. To make a more detailed analysis of the data we need to filter the tidal current, this will be done using the surface height as sampled from the EK60. The data has to be segmented into up migration, nighttime and down migration datasets. This can give some more detailed information about the dynamics in the herring schools.

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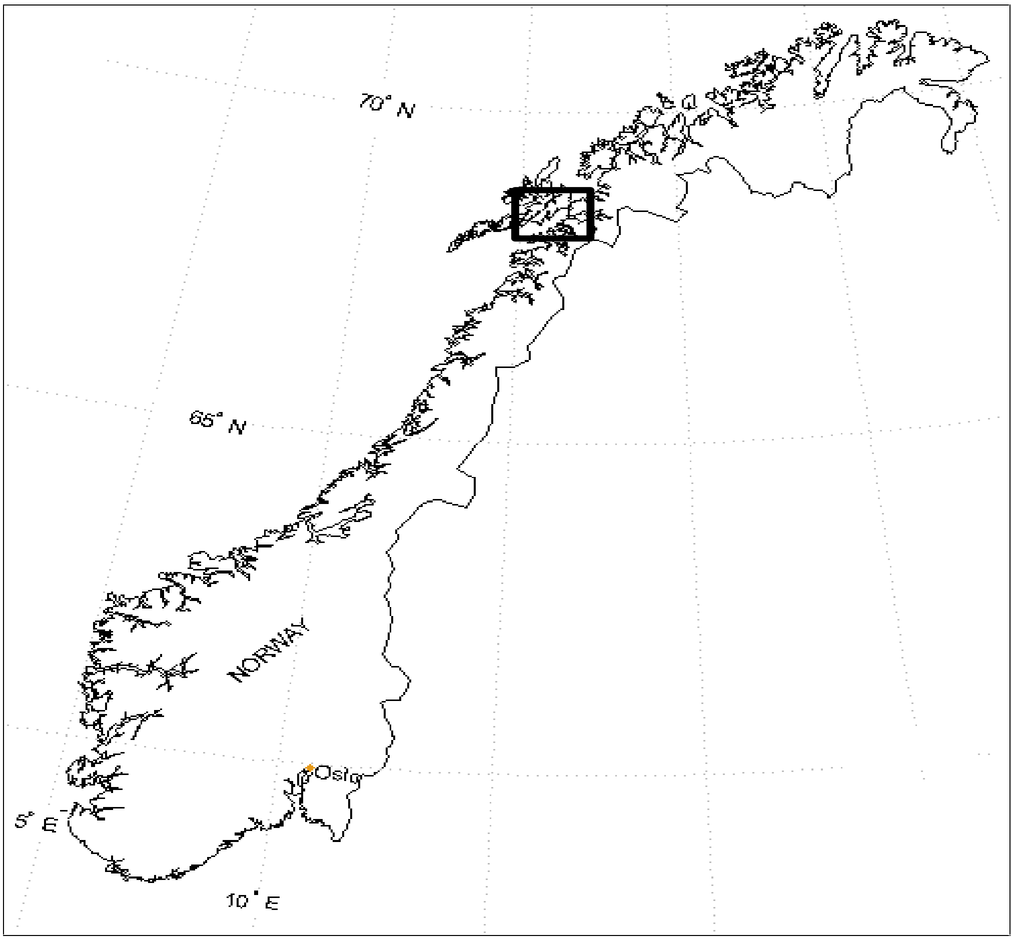

Figure 1.Place of study is marked by a square.

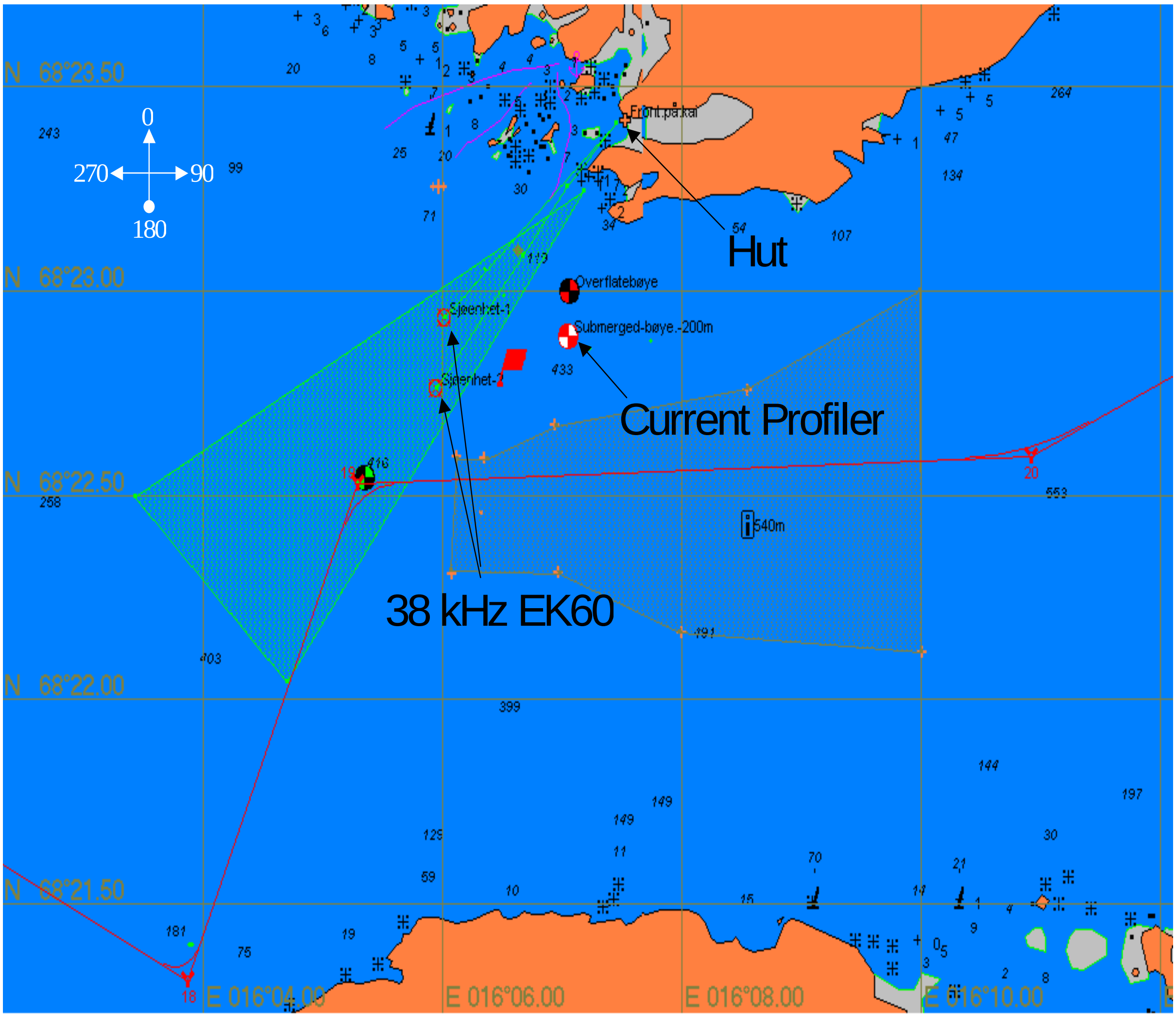

Figure 2.Geographic location of the instrumentation. Arrows on the map show the different instruments.

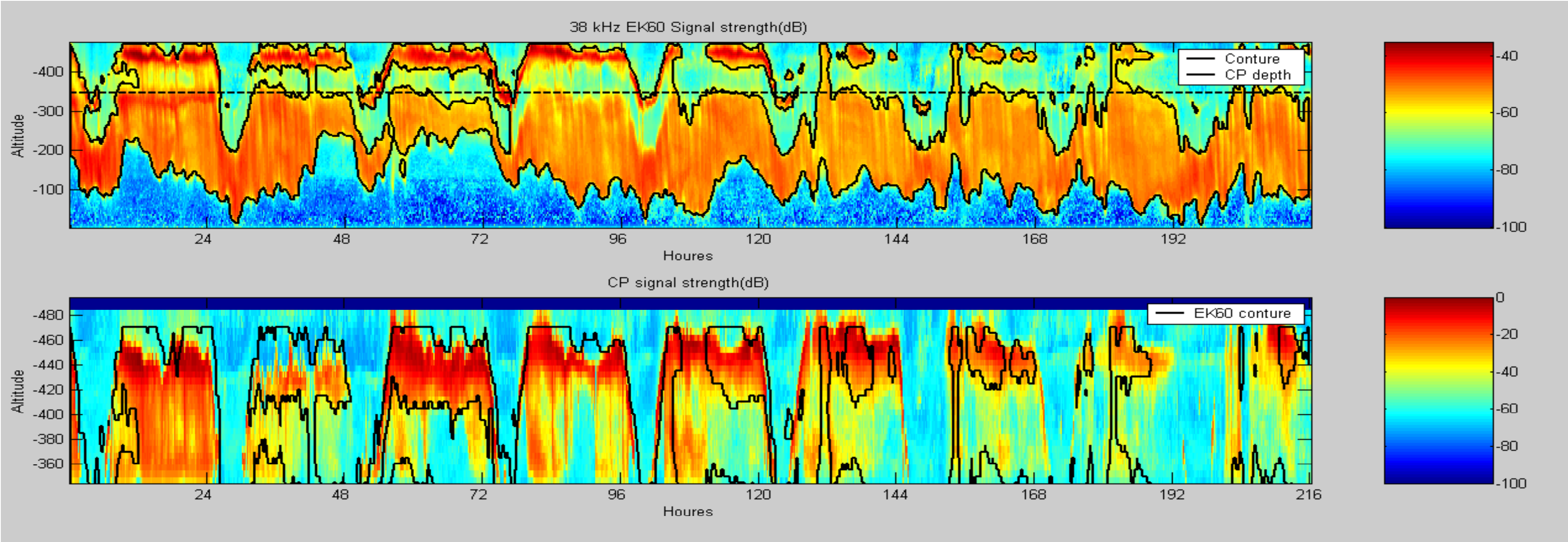

Figure 3. Top: EK60 Echogram, solid black line shows the extracted contour and draws the border between in school and out school data. Hatched line shows the depth of the CP. Bottom image shows the CP data. Black solid line is the contour extracted from the EK60 data.

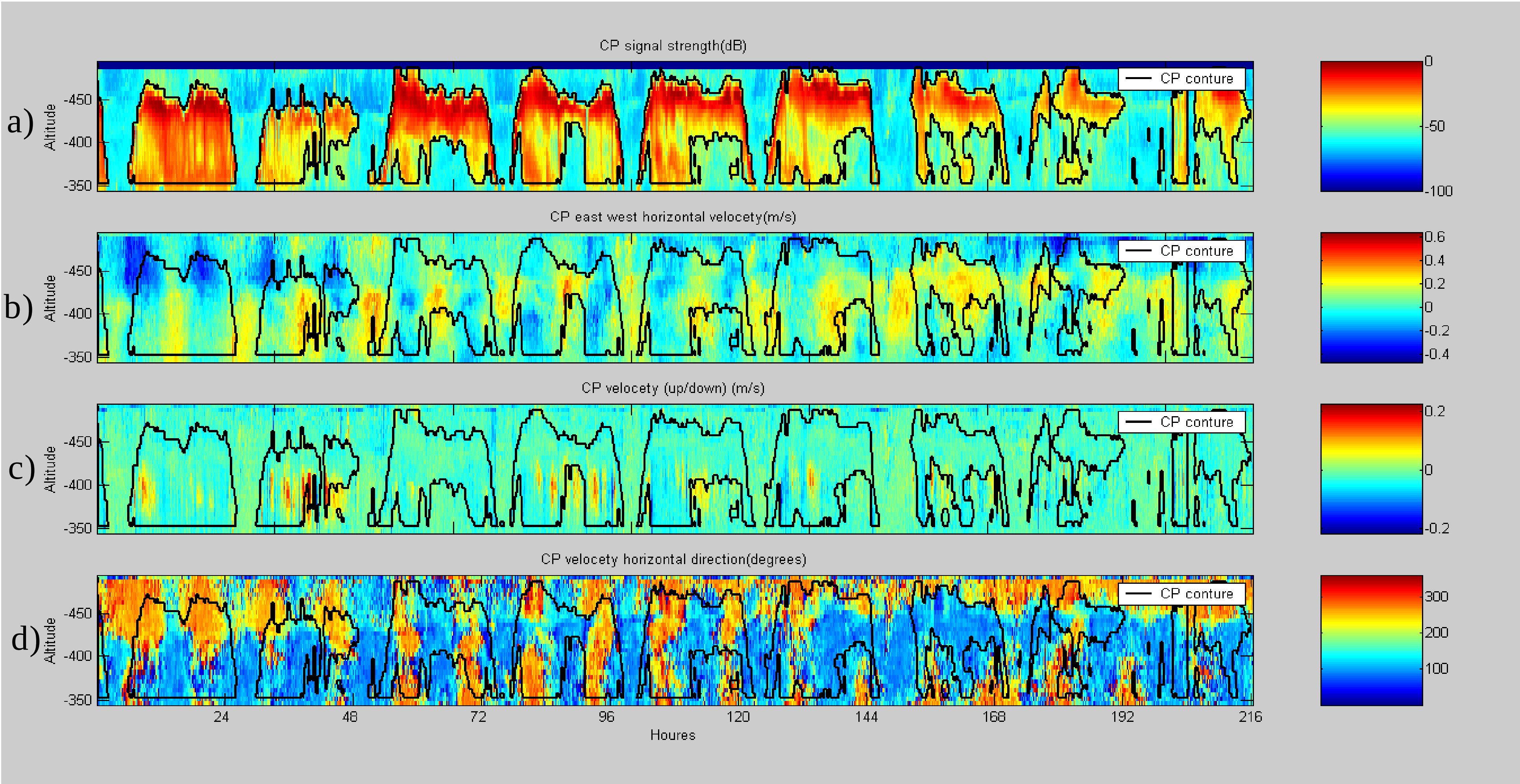

Figure 4 Shows the contour extracted from the CP signal strength overlaid the other data sets. a) CP signal strength. b) Horizontal east west speed. Negative values are in the east direction. c) Vertical speeds, positive speed is toward the surface. d) Direction of speed vectors in horizontal plane. The degrees corresponds to geographical degrees where north=0, south=180, west=270 and east=90.

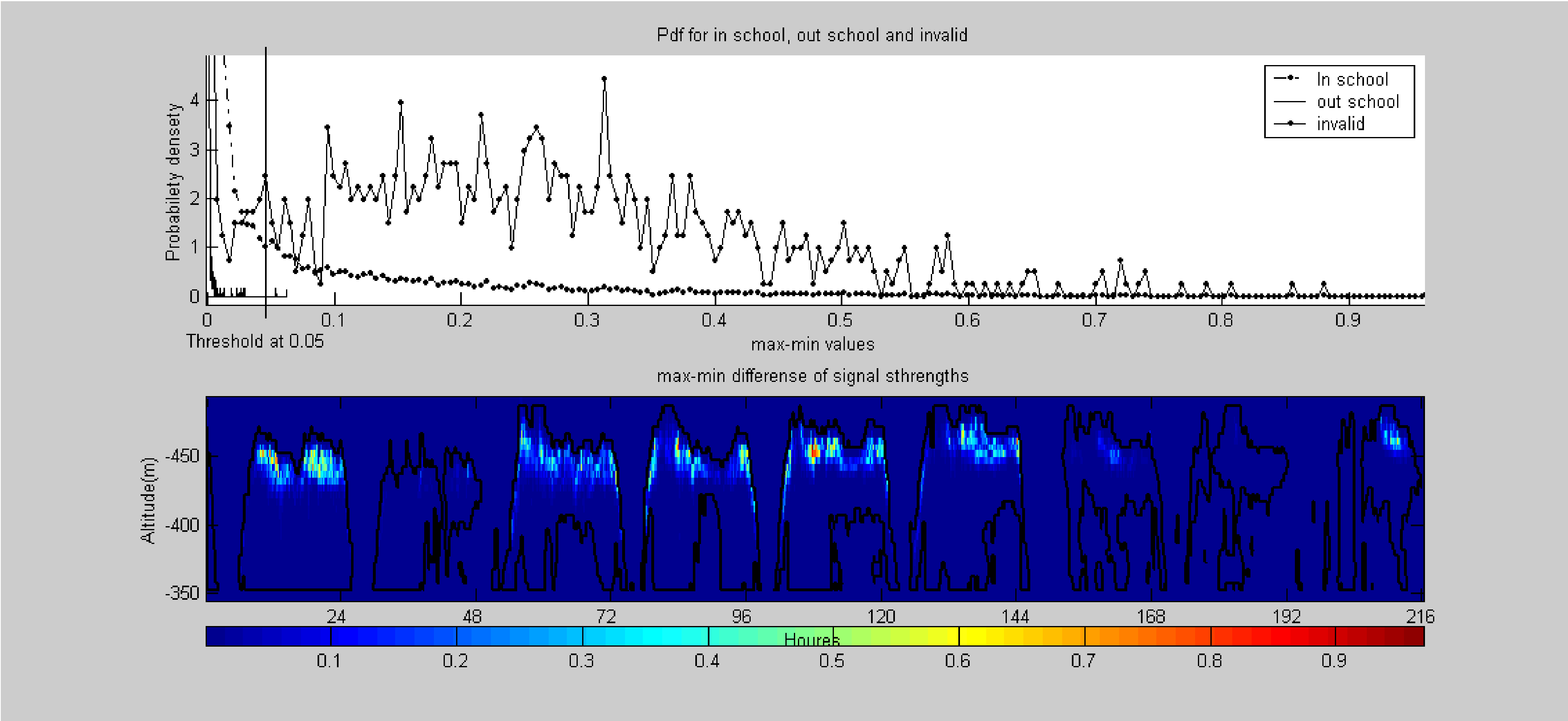

Figure 5 Top shows pdf's for in school, out school and invalid data. The pdf for invalid is used to calculate the probability that data contains invalid values for a specific threshold on the max-min values calculated from the tree beam intensities. Threshold used is in indicated with a vertical line. Bottom figure shows the result from the max-min filter. Black solid lines are the contours of the schools.

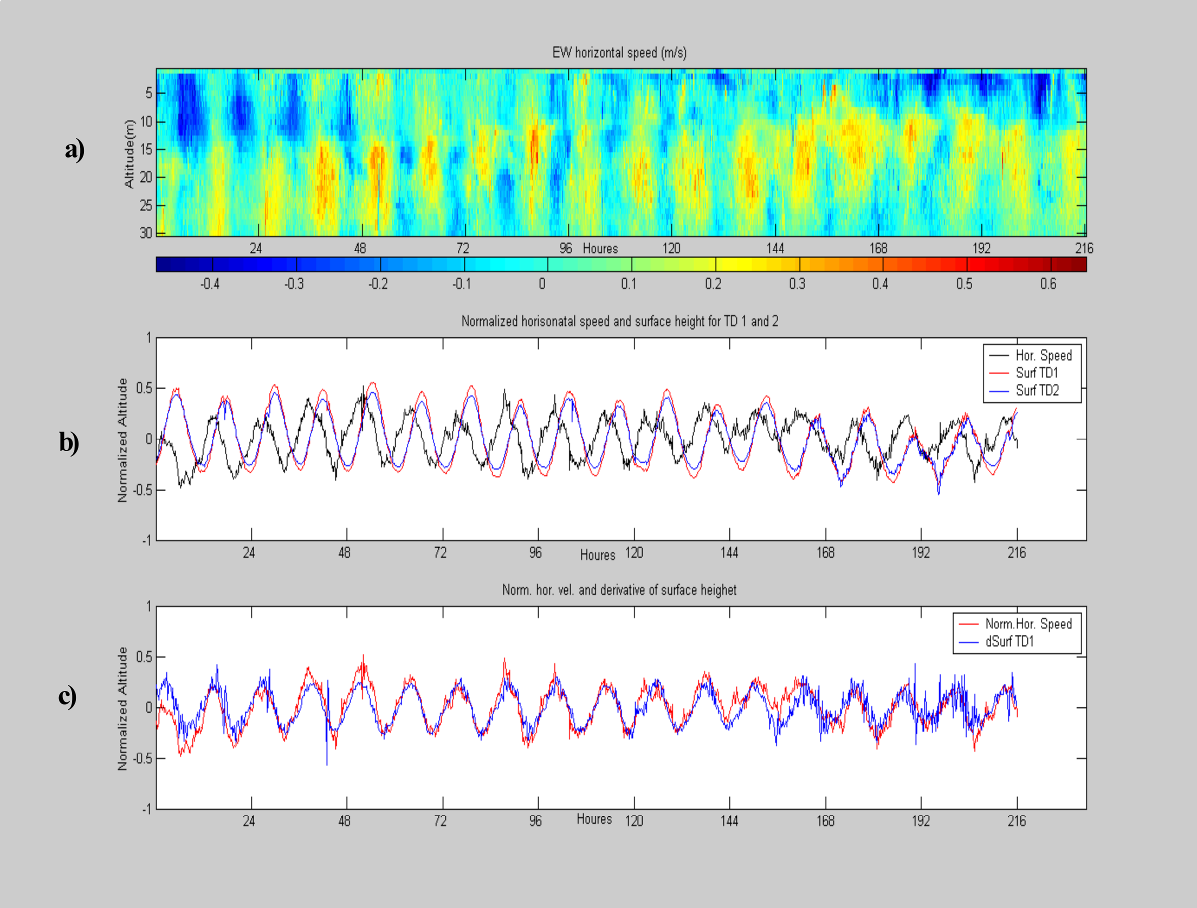

Figure 6 Tidal current and surface height. a) Horizontal East West speed. b) Black line is column-averaged speed. Red and blue line is surface height from the two EK60's. c) Red line is column-averaged speed. Blue line is derived surface height. The time series is normalized.

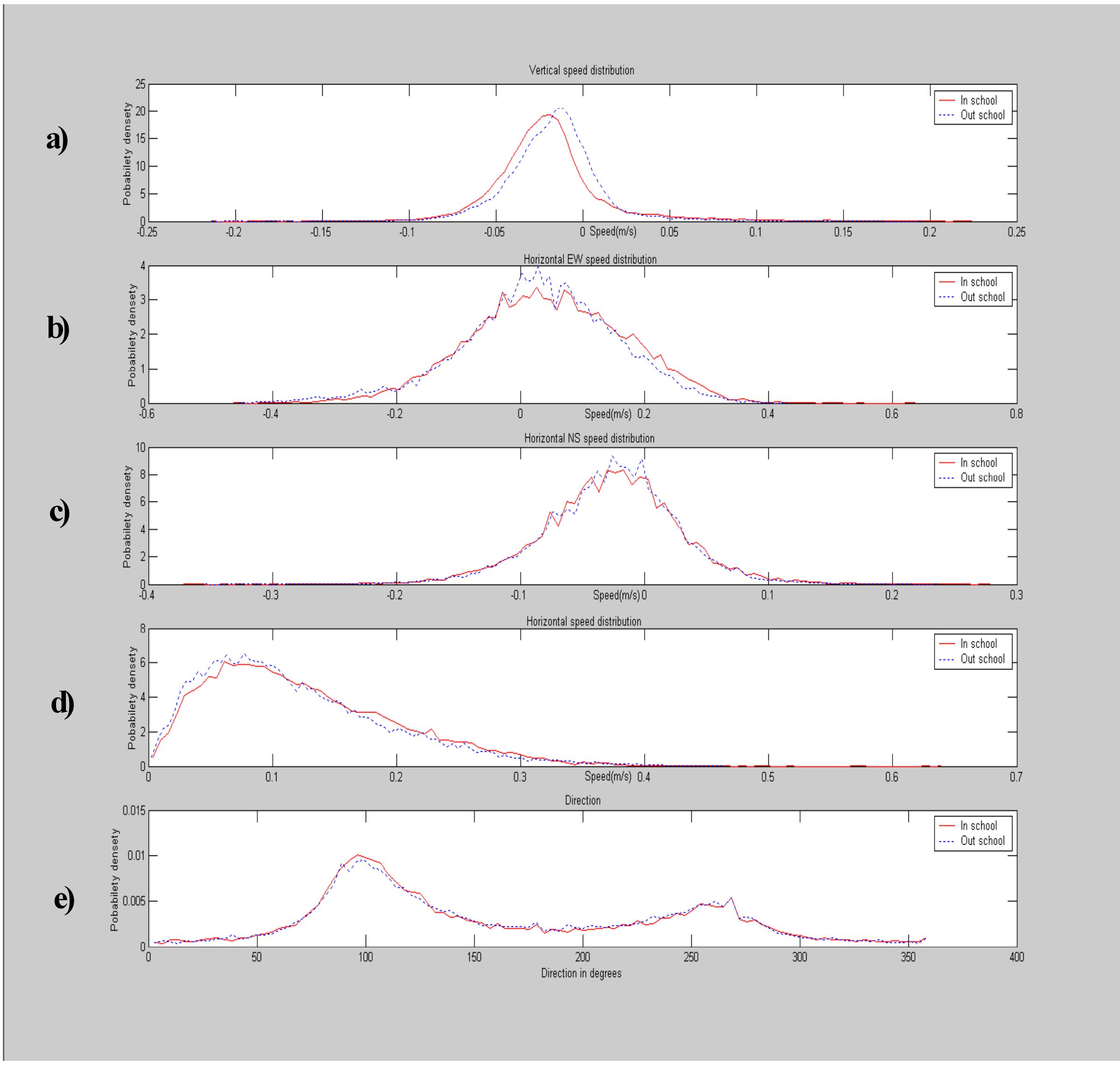

Figure 7 Shows the pdf's from the whole data set. Red line is pdf for in school data and blue-hatched line is pdf from out school data. a) Vertical speed. b) East West Horizontal speed. c) North South horizontal speed d) Absolute horizontal speed. e) Geographical direction of absolute horizontal speed. f) Vertical speed direction.

Table 1 Statistic features from the pdf’s in Figure 7. VelZ is the vertical speed. velEW is the speed in the East west direction where negative values is to the west. VelNS is the speed in the North South direction where negative values are to the south. P denotes the significant level. H =1 of the null hypotheses is rejected. Mean, skew and kurt is the average, standard deviation and kurtosis for the in- and out- school data. These are followed by the differences of the absolute values.

	p	H	mean in	mean out	dmean	std in	std out	dstd	skew in	skew out	dSkew	kurt in	kurt out	dkurt
VelZ	0.000	1	-0.0197	-0.0169	-0.0028	0.0330	0.0276	0.0054	1.4397	0.5288	0.9108	9.9720	8.1817	1.7902
VelEW	0.000	1	0.0444	0.0295	0.0149	0.1251	0.1228	0.0023	-0.0350	-0.3471	0.3121	2.9698	3.4931	-0.5232
VelNS	0.006	1	-0.0270	-0.0273	0.0004	0.0565	0.0533	0.0032	-0.1001	-0.2856	0.1856	4.7320	4.4880	0.2440
horVel	0.000	1	0.1258	0.1183	0.0075	0.0764	0.0750	0.0015	0.9066	0.9982	-0.0915	3.8994	3.9123	-0.0129