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REPORT
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Recommended practices for Acoustic Doppler Current Profiler (ADCP) deployment

Acknowledgements

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About

This Recommended Practice Guide for Acoustic Doppler Current Profiler (ADCP) deployments is designed to provide sufficient information to identify the most appropriate deployment method, instrument selection, and setup for a range of applications that utilize stationary deployments. An ADCP is a commonly used instrument in the offshore oil and gas industry to measure and monitor the current profiles, i.e., how fast water is moving across an entire water column.

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Revision history

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1.0	March 2022	First release

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Introduction

This Recommended Practice Guide for Acoustic Doppler Current Profiler (ADCP) deployments is designed to provide sufficient information to identify the most appropriate deployment method, instrument selection, and setup for a range of applications that utilize stationary deployments. An ADCP is a commonly used instrument in the offshore oil and gas industry to measure and monitor the current profiles, i.e., how fast water is moving across an entire water column, an important environmental parameter affecting offshore structure design and operations. The guide covers the following aspects of ADCP deployments:

- Principles of operation
- General guidance with respect to instrument characteristics
- Deployment types
- Instrument setup
- Decision trees to support ADCP planning
- A number of example deployment setups

It should be recognized that a clear data requirements specification is required to inform recommended practice approaches. Therefore, guidance is given on the information required to determine the measurement approach. This information is provided to illustrate the exemplar deployments. Vessel Mount ADCP data collection is not considered.

ADCP models considered

Many ADCP manufacturers exist and the principles of good practice are applicable to all ADCP deployments. To help illustrate some of the differences between manufacturers, and the thought process for instrument setup, it was agreed to illustrate the guide utilizing the following ADCP manufacturers:

- Aanderaa
- Nortek
- Teledyne RDI

All three manufacturers offer extensive technical documentation on the technologies they offer, and it is recommended that readers should familiarize themselves with the appropriate technology. A References section, on page 69 of this document, contains information on manufacturers' documentation.

The following table outlines the product lines offered by the different manufacturers; within each product line, a number of different frequency instruments are available that offer different range and resolution characteristics. The range characteristics are provided in Figure 7. All manufacturers provide planning software to support optimization of ADCP configuration for different applications. The software differs in its sophistication, and expert consideration is needed to fully understand the implications of the selections made.

Table 1: Manufacturer ADCP models considered

Aanderaa	**Teledyne RDI**	**Nortek**
Seaguard DCP 600kHz	Ocean Observer ADCP 30kHz 75kHz 150kHz	Aquadopp Z-cell 1Mhz 600kHz
Seaguard DCP Dual head 600kHz	Ocean Observer III 38kHz 75kHz (discontinued Nov 2019)	Signature 10000 500 250 100 55
	Workhorse Sentinel ADCP 300kHz 600kHz 1200kHz	Aquadopp Profiler 2Mhz 1Mhz 600kHz 400Khz
	Sentinel V ADCP 300kHz 600kHz 1200kHz	
	Workhorse horizontal ADCP	
	Workhorse Long Ranger ADCP 75kHz	
	Workhorse Quartermaster 150kHz	
	Pinnacle ADCP 45kHz	

1. Principle of operation

ADCPs comprise a number of transducer heads which may be oriented as three, four or five beam instruments. The measurement is made using the Doppler effect and detailed explanations and descriptions may be found in the documents in the References section on page 69. The Doppler effect is the change in frequency of a wave produced by a moving source with respect to an observer. Waves emitted by an object travelling towards an observer are compressed, resulting in a higher frequency; in contrast, waves emitted by a source travelling away from an observer are stretched out, resulting in a lower frequency. The ADCP transmits an acoustic signal and listens for the return signal. The return signal is time-gated to allow the velocity in multiple cells within the water column to be measured. The velocity is measured along the beam and resolved into horizontal and vertical velocities, calculated via a so-called 'beam-to-earth' transformation.

Transmitting a pair of pulses allows the instrument to utilize the phase difference of the return signal to quantify the currents using the Doppler effect. If a scatterer is stationary in the water, the echo from the pair of pulses will be in phase. However, if the scatterer is moving, the echo from the second pulse will take longer/shorter to return if the scatterer has moved away or closer respectively. This will result in a phase difference. Figure 1 illustrates this concept. The transmit signal is represented by the dashed black line, offset slightly in the vertical to provide clarity. The phase change of 0° (blue line) illustrates the return signal from stationary particles (amplitude slightly increased for clarity). There is no propagation delay, such that the echoes have the same relative phase, which means zero phase change. If the scatterer has moved away, the return signal has a delay, in this example a phase delay of 40° (orange line). If the scatterer has moved 10 ten times the distance, the longer propagation delay is 400° (grey line), as the phase difference is exactly proportional to the particle displacement.

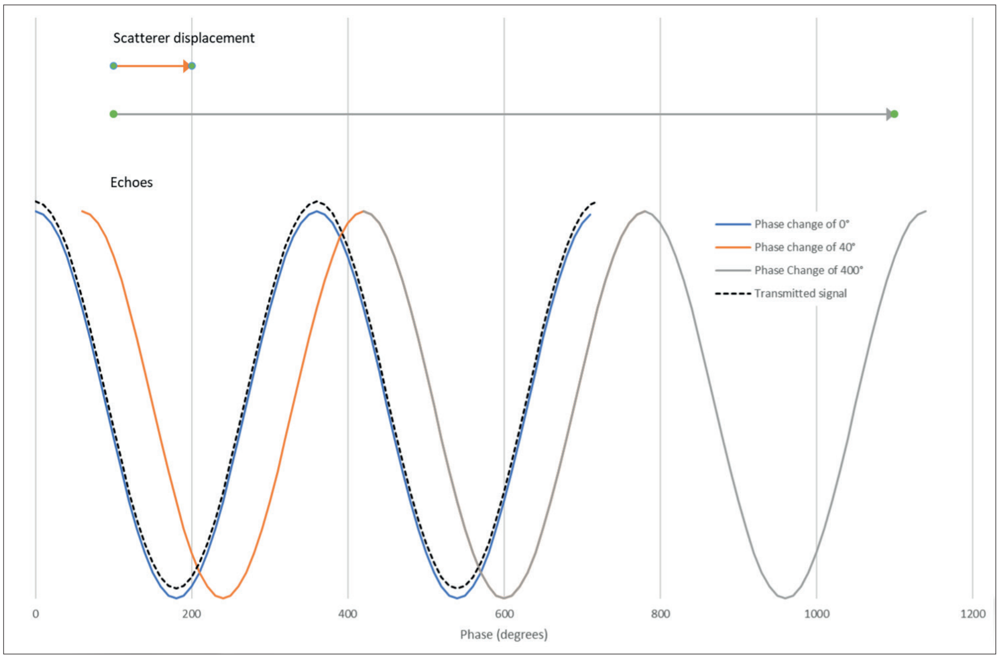

Figure 1: Time dilation. Image © Blue Ocean Consulting, Ltd.

The maximum velocity that an ADCP can measure is effectively the velocity beyond which it cannot resolve the phase wrapping of the return signal. To measure higher velocities requires shorter code packets in the transmitted signal, which impacts on the quality of the data. Therefore, the ambiguity velocity should be set to the maximum expected current speed at the deployment location. The ambiguity velocity, also termed velocity range, is entered into the instruments as the along beam velocity, equivalent to the maximum horizontal velocity multiplied by the sine of the beam angle (measured from the vertical).

Doppler instruments utilize coded-pulse broadband technology. The transducer generates a pulse pair, with each pulse comprising one or more cycles of the transmitted wave form in a number of coded elements. The number of elements is normally matched to the cell size, hence the impact of cell size on data quality. The information that can be contained in the wave form is dependent on the bandwidth. More information may be contained in a wide band, but the Signal to Noise Ratio increases, meaning the wider the band, the shorter the range of the instrument. Wide band is generally referred to as broadband by the manufacturers whereas low bandwidth is referred to as narrowband.

The ADCP is restricted in terms of the area of the water column it can measure both close to the transducer and near boundaries (seabed, water surface) due to transducer ringing and side lobe reflection. These are further described in Sections 1.3 and 1.4.

1.1 ADCP verification

Unlike many single point current meters, it is not easy to 'calibrate' an ADCP as the instrument range does not allow for flume validation. Manufacturers typically utilize a "gold standard" instrument to confirm the ADCP is correctly functioning prior to sale. However, a number of data sets have indicated instruments not providing consistent data.

To overcome this a single point current meter may be placed within the proximal part of the ADCPs range, e.g., 2nd or 3rd bin. This will allow deployment specific systematic errors in the instrument to be highlighted, ground truth the ADCP data at that level, and provide redundancy in case of total ADCP failure. It is mostly due to practicalities that the reference current meter is placed relatively close the instrument – it can be an advantage to keep the mooring short in areas of likely interference from third parties, or where high currents near surface may cause knockdown of a longer mooring. This approach does not mitigate more local issues such as increased noise at the end of the range or reflections from physical objects in certain bins.

The validation of the ADCP data at the reference level can be achieved through simple statistical correlation of the two datasets over the deployment. This will provide an indication of the bias and precision (see following sections compared to the instrument specification and setup software determined precision respectively. Inspection of the time series during stronger current speed events can provide a view of the instrument performance during events which may drive design.

1.2 ADCP errors and uncertainty

ADCP measurement uncertainty comprises two types of error: short-term random error (precision) and long-term bias (accuracy). These concepts are explored in this section along with the consideration of the physical aspects of the velocity itself. Precision is the measure of repeatability of a measurement, whereas accuracy is the closeness to the true value, as illustrated in Figure 2. For ADCP systems, both the precision and accuracy are influenced by the instruments characteristics and the environment. Accuracy is quoted by the manufacturers and addresses the potential long-term bias (inaccuracies) associated with the known characteristics of ADCP technology, but not the influence of external environment factors. The precision is addressed by estimating the standard deviation (measure of precision) for a single ping based on the known characteristics of the technology, but not addressing the external environment factors, and using ensembles (multiple pings) to reduce the standard deviation. As such, the external influences may result in the measurement being farther from true value and less precise.

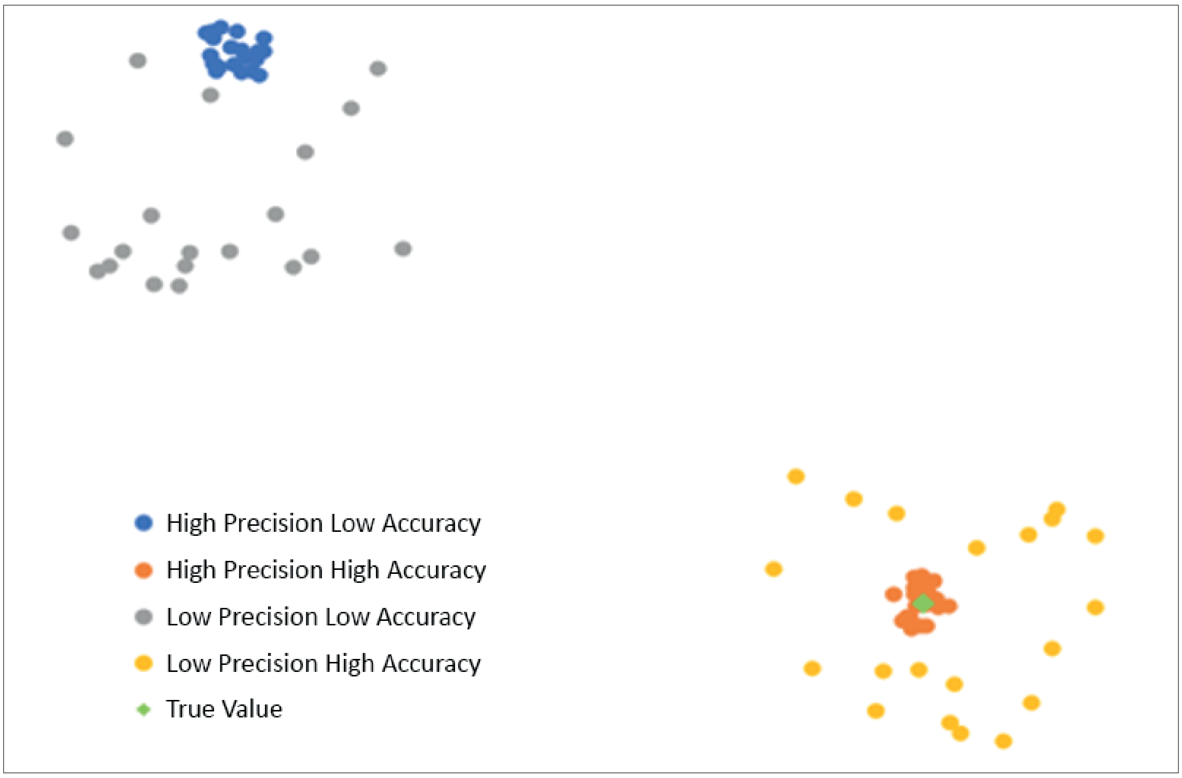

Figure 2: Illustration of accuracy and precision. Image © Blue Ocean Consulting, Ltd.

1.2.1 Current velocity components

When considering ADCP errors and uncertainty it is worth considering the potential components of the total velocity measured by the instrument.

$$u = \bar{u} + \tilde{u} + u'$$

Where u is the total velocity, $\bar{u}$ is the temporal mean, $\tilde{u}$is the wave orbital velocity and u' is the turbulent fluctuation. Generally, ADCPs are utilized to quantify the temporal mean velocity; however. the measurement will include all the above components (unless the measurement is made outside the influence of waves). The contributions of waves and turbulence are an important consideration in the short-term random error and with respect to selecting an appropriate ping interval to minimize their effects. Waves will contribute to the total current measured by the instrument so need careful consideration (see 5.1 for further details). Ocean turbulence occurs at many scales, however microscale turbulence is the critical scale to consider for ADCP measurements. This is likely to be greatest near surface in higher sea states, and within the water column under breaking internal waves. Turbulence may be considered as an external factor that will increase the standard deviation of the measurement.

1.2.2 Short-term random error (precision)

A single Doppler measurement of velocity (ping) is not considered accurate for engineering or operational purposes due to the error associated with short term or random error which partly depends on:

- internal factors such as the size of the transmit pulse, the measurement volume (cell size) and the beam geometry (collectively called Doppler noise)
- external factors such as signal strength of the return echo, wave orbital velocity, turbulence and instrument motion

This error is uncorrelated from ping to ping which permits reduction of the uncertainty through averaging. The standard deviation of the ensemble current measurement is inversely proportional to the square root of the number of pings (N) as shown below.

$$\text{Standard deviation} \propto N^{-\frac{1}{2}}$$

This property allows the effect of the number of pings in a velocity ensemble to predict the standard deviation, knowing the standard deviation of a single ping for the combination of internal factors. However, it should be noted that the frequency of waves and turbulence is relatively high with respect to the mean current component. Therefore, as well as the number of pings, consideration must also be given to the ping interval to prevent aliasing of the mean current. Further details may be found in Section 5.1.

The concept of random error and bias is illustrated in Figure 3, which shows a distribution of N single ping measurements in blue, and a distribution of N/100 ensembles comprising 100 pings in orange. Using an ensemble average reduces the spread of the current speed estimate, and thus makes the measurement more repeatable. The spread may be described as the standard deviation of the noise, which can be estimated for the internal factors, allowing the instrument to be set up to provide acceptable levels of repeatability.

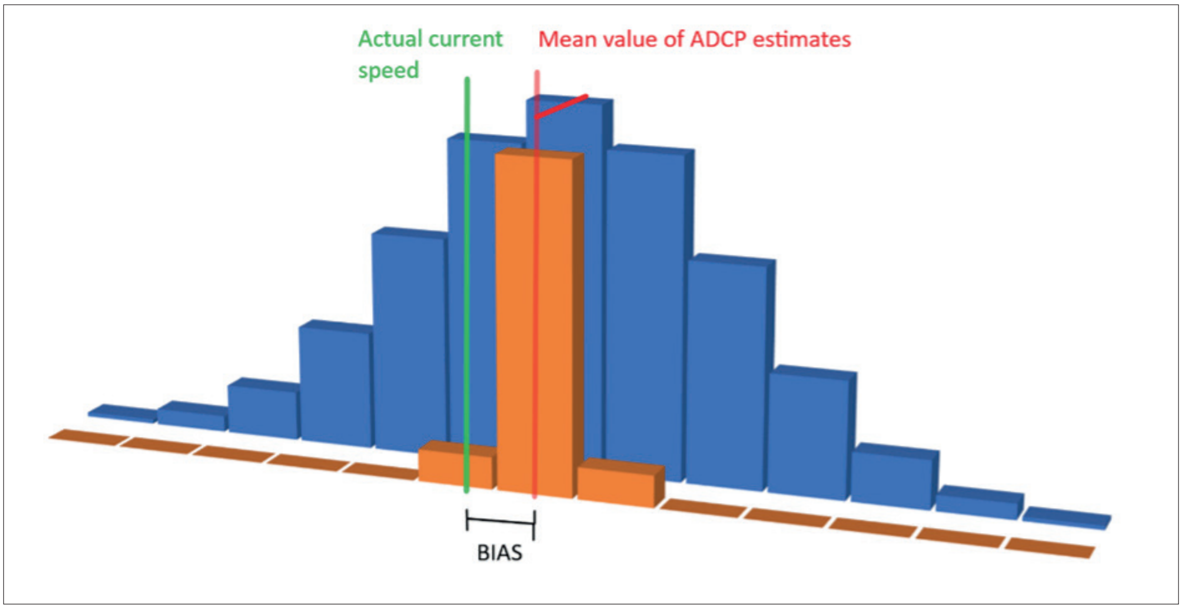

Figure 3: Distribution of ADCP current estimates - blue distribution represents single ping data and the orange distribution represents ensemble averaged data. Image © Blue Ocean Consulting, Ltd.

1.2.3 Bias (accuracy)

Bias is typically estimated by manufacturers and is a function of temperature, mean current speed, signal to noise ratio, beam geometry, etc. It is not possible to measure bias or calibrate/remove it during post processing. It should be noted that the reported bias by manufacturers is small, typically <1% of maximum measured velocity or 0.5cms-1. However, if the application is likely to be sensitive to the bias it may be worth considering including single point measurements within the ADCP range to allow the bias to be estimated. A number of papers suggest the bias in ADCP measurements is much greater than manufacturers claim[1], which is likely a result of the external factors discussed above, and this should be considered in the application of ADCP data. It should also be noted that comparison of point measurements and volumes of water are not expected to yield the same results due to potential spatial aliasing.

1.3 Blanking zone

The blanking zone is the distance from the ADCP transducer face to the edge of the first measurement cell. A blanking zone is required to prevent the vibrations associated with the signal transmission to dissipate. The vibrations are commonly known as transducer ringing. Lower frequency ADCPs require longer blanking zones than higher frequency systems. The influence of the frequency on the blanking zone is important where current measurements are required close to the instrument position in the water column to characterize particular ocean processes. Most manufacturers allow the blanking zone to be specified in the firmware, with recommendations on the minimum blanking zone.

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[1] Bush G and Nolan C. 2018. "Comparison of in-situ current measurement methods, the accuracy in the field and recommendations for engineering design applications." Proceedings of the ASME 2018 37th International Conference on Ocean, Offshore and Arctic Engineering. Madrid, Spain. June 17–22, 2018.

1.4 Side lobe interference

ADCP transducers emit energy in a main beam which is utilized for the current measurement, however they also emit parasitic side lobe beams. The side lobe beams influence how close to a boundary an ADCP can measure the current. The following equation allows the side lobe influence to be calculated. It is generally recognized that one cell length should be added to ensure data are not compromised.

$$D_{SL} = D * (1\text{-}\cos(\theta))$$

D_{SL} is the distance from the boundary affected by side lobe interference.

D is the distance from the ADCP to the boundary.

θ is the beam angle.

Another impact of the side lobe interference is the potential for large objects within the side lobes to influence the current measurement within a cell. This is important when considering deployment of ADCPs adjacent to other bodies within the water such as risers, cables, or imprudently placed mooring components, etc. It is recommended that the ADCP is deployed with a clearance zone 11° greater than the beam angle to avoid biasing of the measurement. 15° clearance provides a good rule of thumb.

1.5 ADCP coordinate system

As stated above, the ADCP measures velocity relative to the individual beams, such that a positive velocity is in the direction of the beam, and the associated horizontal and vertical velocities also point toward the beam, as illustrated in red in Figure 4 for a 4-beam system. The velocities must then be translated into instrument coordinates, i.e., relative to the x, y, z axes. This transformation takes place for the data from each ping.

The different manufacturers utilize different conventions for their beam numbering, and these axes, whereby the z-axis might be pointing up/down. The pitch and roll are measured about the x-axis or y-axis (manufacturer dependent), and the compass is referenced to one of these axes (manufacturer dependent). This information is utilized in converting from the instrument coordinate system to earth coordinate system.

It is possible to select the coordinate system of the output velocity data, for storage onboard the instrument or for transmission to a PC based processing software. If the data are transmitted to a PC, beam coordinate systems should be utilized, and the coordinate transformation undertaken on the PC. This will ensure the rawest form of data is available on the PC if required for trouble shooting. The choice for self-contained instruments depends somewhat on the manufacturer and instrument model. The Nortek and Aanderaa instruments all store raw data, as do the Teledyne RDI V-series and Pinnacle models, so output in earth coordinates is sufficient. Beam coordinates and single ping data may be useful in applications where the flow may not be homogenous to allow post processing.

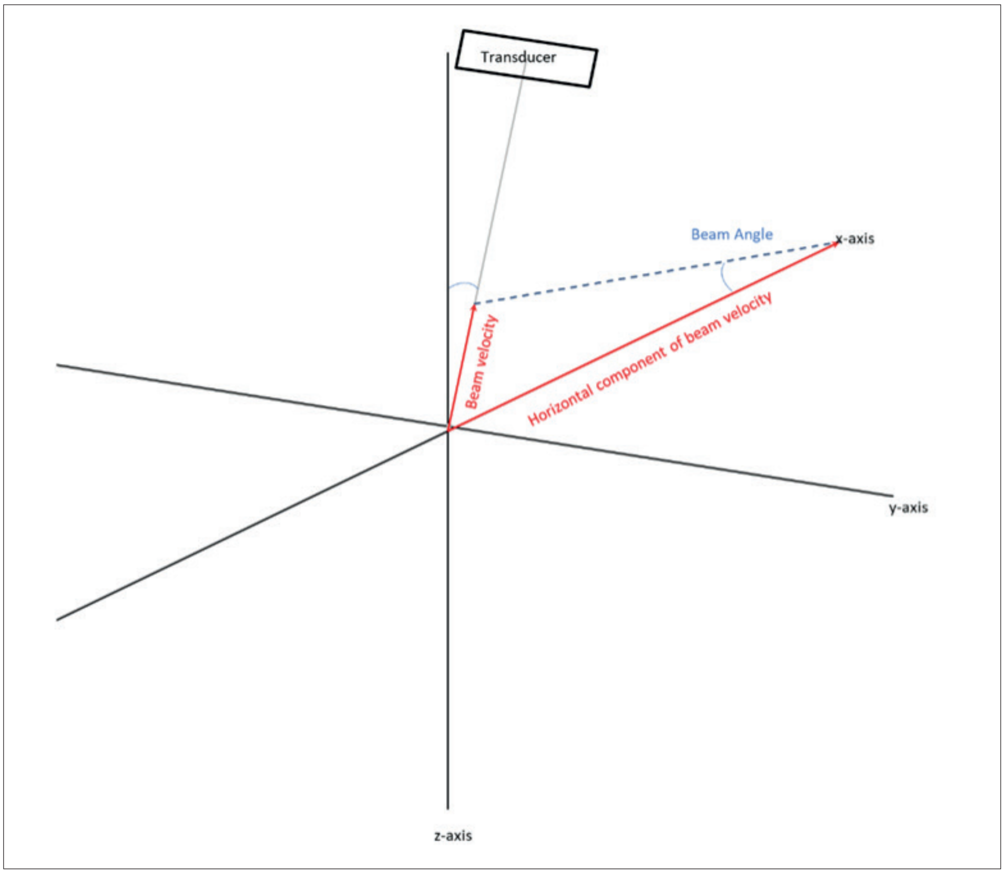

Figure 4: Coordinate system. Image © Blue Ocean Consulting, Ltd.

1.6 Quality assurance and control

The use of acoustic transmission and return signals within ADCPs means that information on the quality of the signal and echoes is generated. This allows a number of quality control parameters to be collected and utilized in the quality assurance (QA)/quality control (QC) process. Quality Assurance comprises the processes used to ensure high quality data. These processes are, generally, algorithms that can be applied to the data within software, such that QA is readily applied within real time data streams and that data failing the QA procedures are appropriately flagged to allow further consideration, or are not displayed in near real time if the data are invalid. Quality Control examines the quality of assured data, generally with human interaction to ensure the data is fully fit for purpose, and this may include omitting data from the database. Wanis et al (2015) provides a view of QA/QC procedures as applied to Teledyne RD Instruments products, but the process is very similar for other manufacturers. A number of reference documents address QA/QC of ADCP data.[2,3]

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[2] United States Department of Commerce, National Oceanic and Atmospheric Administration. "Integrated Ocean Observing System (IOOS)/Quality Assurance-Quality Control of Real-Time Oceanographic Data (QARTOD). Manual for Real-Time Quality Control of In-Situ Current Observations A Guide to Quality Control and Quality Assurance of Acoustic Doppler Current Profiler Observations Version 2.1." Silver Spring, United States. 2019.

[3] Bender LC and DiMarco SF. "Quality control and analysis of acoustic Doppler current profiler data collected on offshore platforms of the Gulf of Mexico." United States Department of the Interior, Minerals Management Service. New Orleans, Louisiana. 2008.

Quality Assurance practices extend to pre-deployment preparation of the equipment and include:

- Protection against marine growth
- Field calibration of the magnetic compass

These practices are documented in the manufacturer's operational manuals and are not considered here.

Quality assurance parameters derived from the instruments include:

- Instrument motion (heading, pitch, and roll)
- Signal quality (echo intensity, correlation magnitude)
- Velocity data (error velocity if provided)

These are considered in further detail below.

1.6.1 Instrument motion

To function correctly, the ADCP needs to remain relatively stable. If the ADCP is subject to rapid rotation, the signal is likely to deteriorate resulting in poor data quality. Therefore, the instrument heading should be checked to ensure that the ADCP heading remains stable. An important consideration is the rate of heading sampling, as discussed in Section 2.4 to ensure sufficient data are available to inform this activity.

Pitch and roll tilts the instruments which impacts the location of measurement cells. This is illustrated in Figure 5, which shows a beam pattern with zero tilt (blue) and a beam pattern with 15° tilt in orange, with the y-axis showing elevation within the water column and the x-axis the horizontal distance. Based on time gating of the return signal the left-hand tilted cell is one cell above its original elevation and the right beam two cells below the non-tilted cell. Most manufacturers have introduced automated bin mapping algorithms to overcome pitch and roll, but the mapped data may be less reliable than data from an instrument not suffering from pitch/roll. Therefore, care should be taken in application of such algorithms within the instruments, and it may be better to apply such quality assurance in post processing.

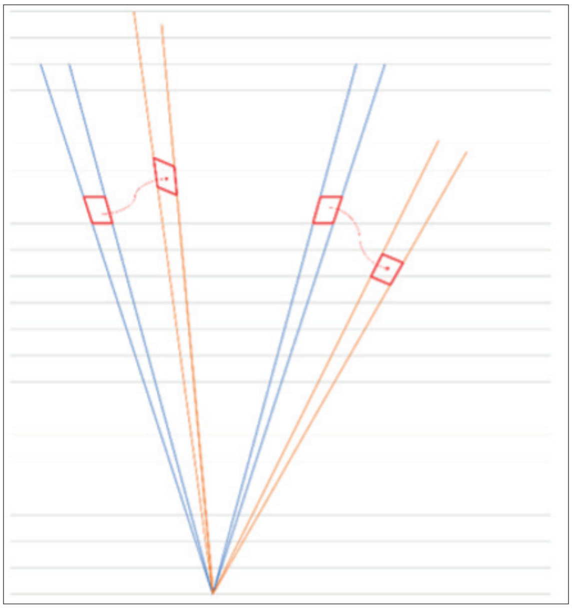

Figure 5: Illustration of cell mapping for tilt. Image © Blue Ocean Consulting, Ltd.

1.6.2 Signal quality

Echo intensity (sometimes referred to as backscatter intensity) is measured within each cell of each beam, and represents the energy received by the ADCP from the scatterers within the water column. It is measured in units proportional to decibels. A low-echo intensity will likely result in a poor signal to noise ratio, whereas a high echo intensity may be indicative of reflection from a boundary (sea-surface or seabed), interference with the beam by the mooring or other subsea assets. Manufacturers provide guidance on acceptable echo intensity, as they each characterise this parameter in slightly different ways.

Another interesting facet of the echo amplitude is the ability to use the echo intensity to observe other ocean processes including plankton migration, suspended sediment load and internal structure of the ocean. Only the internal structure will be considered here as it pertains to observation of internal waves. Extensive literature on application of echo intensity data to the other processes is available, but beyond the scope of this document.

An example of an echogram is provided in Figure 6. This image illustrates the diel migration of plankton (see 1.7.1), along with internal wave structures, schools of fish and unknown reflectors. The diel migration is visible in the vertical velocity show in the middle panel.

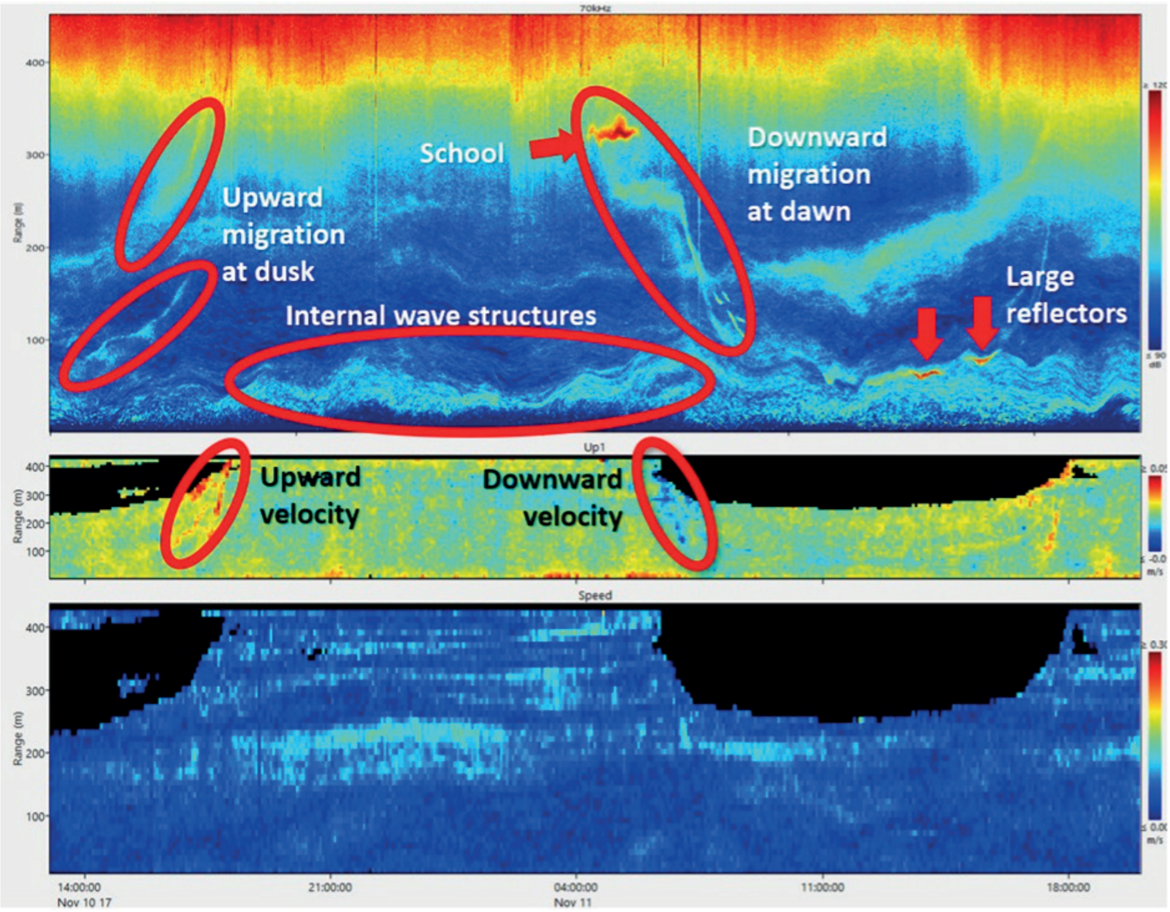

Figure 6: Echogram showing water column features in a Signature 100 dataset (Image courtesy of Nortek, copyright Nortek)

Correlation is utilized to compare echoes from coded pulses within a single ping. High correlation indicates that the return signals are similar, whereas low correlation indicate return signals are dissimilar. If high correlation is achieved the confidence in the computed phase change is greater, thus providing an indication of data quality. Low values may relate to poor signal to noise ratio (for example caused by exceeding range limits) or exceedance of ambiguity velocity.

1.6.3 Velocity data

A significant advantage of 4-beam array ADCPs is that they allow the error velocities to be calculated for pairs of beams/cells. The error velocity is the sum of the vertical velocity components from opposite pairs of beams. In a homogeneous flow, error velocity will be zero. In many ocean current processes, this would be expected, and if a large error velocity is evident it would suggest that one of the beams may be problematic. In current processes, such as passage of internal waves, where the flow in opposite beams is likely to be significantly different, careful consideration must be given to how the error velocity is utilized to avoid removal of good data. This is explored in Section 8.4 which considers recommended practice for internal wave measurement.

1.7 External factors

1.7.1 Reflectors

ADCPs require small particles or plankton to be present in the water column to reflect the transmitted acoustic signal. It is assumed that the reflectors are carried at the ambient speed of the water. One key point of consideration is the vertical migration of plankton, zooplankton move upwards through the water column to feed on phytoplankton during day light hours and return to depth during darkness. This can impact the signal return strength within the water column and influence the vertical velocity measurements. Some plankton swim horizontally and may contribute erroneously to the measured current, but typically they have low velocities. Low number of reflectors reduced the Signal to Noise Ratio (SNR), resulting in lower range.

Low reflector counts occur frequently in tropical regions. In the low- and mid-latitude ocean, warm and sunlit surface water is separated from the cold, nutrient-rich deep water by a strong pycnocline that constrains vertical mixing of water resulting in reduced nutrient supply, which becomes the limiting factor for productivity. The Gulf of Mexico is one such area, although this may be modulated by hurricane passage. These regions of low productivity are dissected by areas, close to the equator and along the eastern boundaries of basins, which are subject to wind induced upwelling which releases the deep nutrients into the surface layer. In high latitudes the vertical density gradient is generally weak and nutrient supply does not limit productivity. Seasonality is greatest at high latitudes and is driven by the availability of light, i.e., concentrations are lower during winter periods. This has been evident in ADCP data collected in the deep Arctic water mass offshore Norway.

1.7.2 Speed of sound

The speed of sound at the transducer head is an important consideration in the operation of ADCPs. The velocity component is proportional to the speed of sound at the transducer therefore accurate definition of the speed of sound is required. Most ADCP systems utilize thermistors to measure the temperature, and the entry of a single value of salinity. These are then used to calculate the speed of sound. If there is likely to be significant variation in the salinity at the transducer head, it is recommended that salinity is also measured and a correction to the measured current velocities made during post processing.

The speed of sound over the measurement profile has no impact on the horizontal current measurement, due to the horizontal wave number being conserved, according to Snell's law. However, the vertical velocity component is proportional to variations in speed of sound, so if this is utilized to understand current processes with a strong vertical component, careful consideration of the variability in speed of sound over the profile is required.

The speed of sound is utilized to time gate return signals, so it also has a direct impact on where the instrument records the velocity in the water column.

Speed of sound varies with temperature, salinity and depth. The effects of temperature are more important than salinity with a nominal 5°C change in temperature having a similar impact to a 10PSU change in salinity. The influence of depth on speed of sound can be included in the instrument firmware. This illustrates that temperature is more important than salinity with a nominal 5°C change in temperature having a similar impact to a 10PSU change in salinity. Given the greater dependency of speed of sound on temperature it is common to utilize the instrument thermistor to measure temperature at the transducer head and enter a single salinity value into the firmware to utilize in the instrument speed of sound calculation. Given the dependency of speed of sound on temperature, it is important to periodically check the ADCP thermistor for accuracy.

1.7.3 Ambient noise

Ambient noise in the ocean is generally low with respect to the frequencies utilized in ADCP technology. The major exception to this is communication hardware utilized in drilling and operational activities, and azimuth thrusters in some instances. If a noise assessment has been undertaken of an asset this knowledge may help to optimize the ADCP deployment. If no assessment has been made, then information on subsea acoustics in operation should be made available, including other ADCP systems, sonars, etc.

1.7.4 Temperature

Temperature impacts ADCP operations in two ways, beyond its impact on speed of sound; battery capacity is effectively reduced with lower temperatures, whereas range increases. Therefore, temperature requires attention - the optimal setup for tropical waters may be very different to cold waters.

1.7.5 Marine growth

Although marine growth has less impact on ADCP operation than impeller current meters, consideration is still required to ensure data quality is maintained, and mooring drag is minimized. If marine growth is likely to be significant, consideration should be given to application of anti-fouling substances. Methods such as anti-fouling paints need to be considered in the context of:

- Impact on the marine environment
- Potential impact on instrument operation as some paints contain copper flakes which affect signal pattern
- Impact on the transducer as some are acidic and damage the transducer surface

More basic methods include application of zinc oxide or mixtures of Vaseline and chilli powder. There are also products in the marketplace that apply coatings to the transducer or entire instrument, and others which utilize adhesive anti-fouling stickers applied to the transducers. These solutions appear to be environmentally friendly.

2. General guidance

This section provides information on physical characteristics of ADCP technology, and how they influence instrument choice and setup.

2.1 Instrument frequency

The instrument frequency controls the range capability of the ADCP, the blanking zone (see Section 1.3 for further details) and the minimum cell size. The range capability is illustrated in Figure 7.

Figure 7: Nominal Range of Instruments by frequency (note Sentinel V and z-cell labels are removed for clarity, these instruments have a similar range for their frequencies to the Sentinel and Aquadopp profilers respectively). Image © Blue Ocean Consulting, Ltd.

The different frequencies lend themselves to characterization of different ocean processes as detailed in Table 2.

Table 2: ADCP frequencies, range, resolution for ocean process characterization

Frequency (kHz)	Range (m)	Resolution (m)	Processes
2000	2-4	0,1	Turbulence
1000-1200	10-15m	0,2	Boundary layers
600	40-80	0.5	Tides, internal waves, sub-meso scale near surface / bottom currents
300	80-120	1	Meso-scale Near-Surface and Bottom currents
75	400-800	5-10	Large-Scale Upper Ocean Currents, MLD, Shelf-Slope Dynamics
<55	1000+	10+	Large-scale Upper and Interior Ocean current

2.2 Transducer configuration

There are four main types of transducer:

- 3-beam array
- 4-beam array
- 5-beam array
- Phased array

Nortek is the only manufacturer to use a three-beam array, and these are used on its AquaDopp Profiler series and Signature 55. Typically, the transducer heads are oriented in a convex configuration, except for dedicated vessel mounted systems, which utilize a concave configuration.

Four-beam arrays utilize a Janus configuration that prevents cross beam interference. The four-beam solution allows comparison of the vertical velocity component of opposite beams as outlined in 1.6.3.

Five-beam arrays were initially introduced to support wave measurements through the use of an echosounder to track the water surface. However, the fifth beam has been extended to applications such as observations of ice, biomass, and vertical structure (for example internal waves where the conditions permit). The fifth beam is oriented vertically and may be at the same frequency as the Janus configured beams or be at a different frequency.

Phased array instruments are manufactured by Teledyne RDI and offer a number of advantages over the traditional 4 beam systems. These include:

- a smaller form function and hence less weight
- horizontal velocity is independent of speed of sound due to the phased array design
- reduced side lobe reflection zone

However, the vertical velocity is less precise, so this must be considered when attempting to measure oceanographic processes such as upwelling/downwelling and internal waves.

ADCPs collect velocity data in beam coordinates (i.e., along the beam azimuths) and typically translate to earth coordinates (relative to magnetic north) using either onboard processing or computer-based processing. It is important to consider that the manufacturing process will not achieve perfect orientation of exactly 90° separation for 4 beam systems and 120°for 3 beam systems. Therefore, a correction is also required for the misalignment of the transducers. Manufacturing tolerances vary between manufacturers and product lines. It is important to understand potential errors in directionality, particularly for direction sensitive applications. The manufacturers include a correction in their firmware, but if data are collected in beam coordinates and later translated to earth coordinates in other software, it is essential that the transducer misalignment is considered.

2.3 Beam angle

The beam angle has a number of consequences:

- It influences the region of side lobe reflection as already discussed.
- It impacts the distance between current measurement in the beams. This can be important when the flow is not horizontally homogeneous. This is illustrated in Figure 8 for a 4-beam system for two opposite beams with a 180° azimuth separation.

It should be noted that in addition to the beam angle, consideration must be given to the beam width and beam spreading. Generally, a clearance zone of 15° around the beam must be maintained to avoid interference from structures, as outlined in Section 1.4.

2.4 Compass

All ADCP manufacturers utilize fluxgate magnetometers as the standard compass technology. As such, they are susceptible to interference from ferrous materials that influence the earth's magnetic field. This means greater attention needs to be paid to the hardware supporting the ADCP and the proximity of ferrous structures such as rigs. The manufacturers offer some degree of in-situ calibration for real time systems; however, this relies on the azimuth angle between the instrument and ferrous object remaining constant, which is generally not the case for rigs, drill ships, etc. Therefore, it is recommended to move the instrument out of the influence of magnetic materials. In addition to QA procedures of pre-deployment magnetic calibration, it may also be useful to calibrate the directionality of an ADCP by using a temporary current meter to provide current direction in the lower part of the profile. This approach is only valid if the asset from which the ADCP is suspended maintains its heading through the measurement campaign.

It should also be noted that tilt data derived from an accelerometer will be disturbed by the accelerations due to motion, and that this will affect the performance of the heading measurement. To overcome this, consideration should be given to using heading reference systems on instruments that may move rapidly, such as surface buoys and potential rig deployments.

2.5 Depth rating

Instruments are manufactured to withstand subsea pressure. As such, appropriate depth rated instruments should be selected for their depth of deployment. All ancillary sensors should also be appropriately depth rated to prevent water ingress.

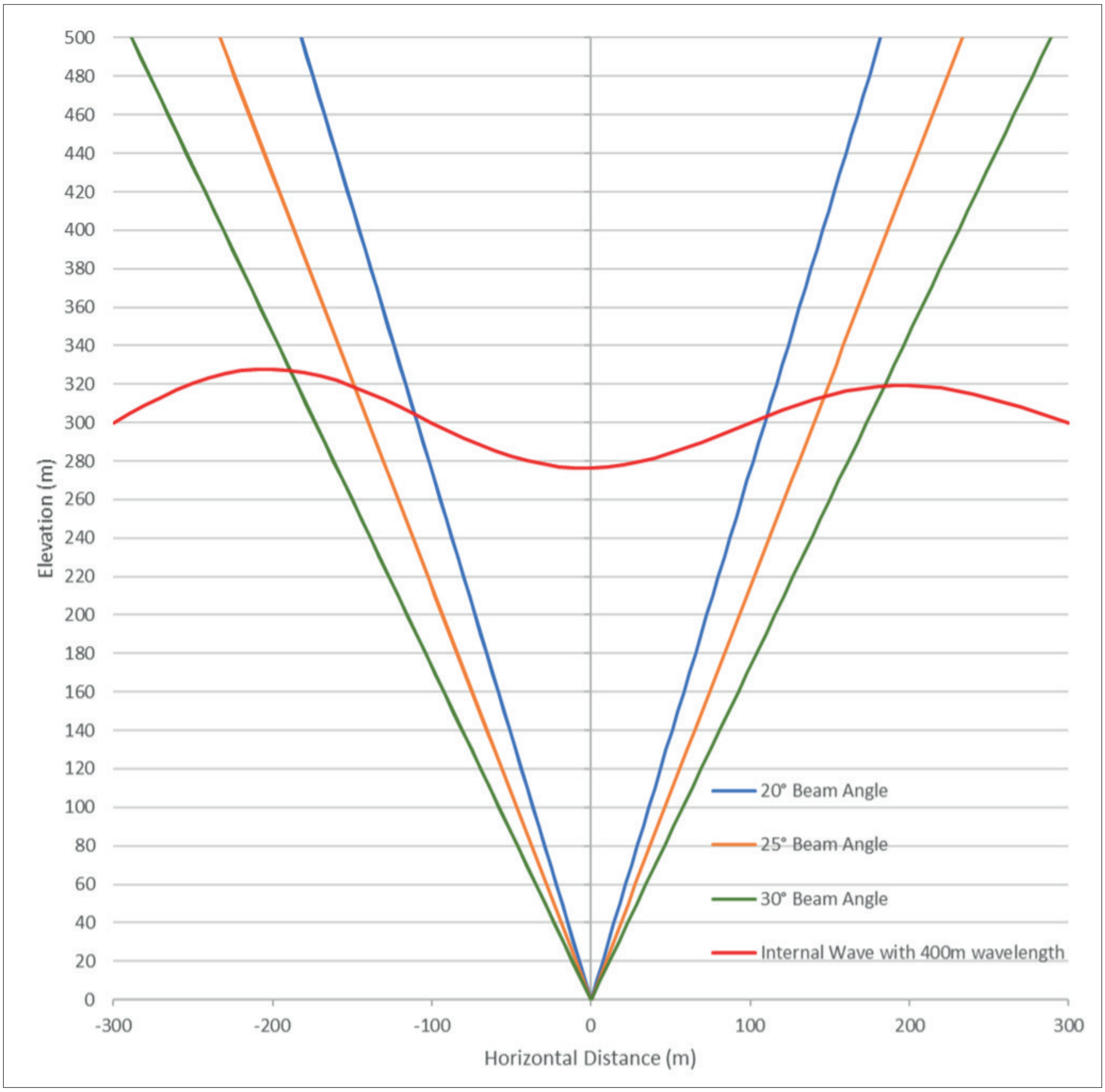

Figure 8: Horizontal measurement separation as function of beam angle and depth. A 400m internal wave form is illustrated to show the potential influence of a non-homogeneous flow.
Image © Blue Ocean Consulting, Ltd.

3. Deployment types

ADCPs can be deployed in a number of ways depending on the application. The choice of deployment method is initially determined by the depth profile of interest. Often this extends to the full water column, but consideration of the three generic areas of the water column allows ready consideration of the pros/cons of each method as detailed in Table 3. All deployment activities should be undertaken in compliance with IOGP Report 447 - *HSE guidelines for metocean surveys including Arctic areas.*

Table 3: Deployment solutions for various generic depth profiles

Depth profile of interest	**Deployment Type**	**Pros**	**Cons**
Upper Water column	Rig ADCP	Relatively low-cost platform Provides data to inform operations and engineering design Permits remote monitoring of data quality	Requires additional horizontal ADCP to capture near surface Needs care to avoid risers/other infrastructure Duration limited to drilling programme, which is likely insufficient for design Requires additional measurement system deployed at depth if water depth greater than 900-1000m
	Surface buoy	Permits real time data transmission to support operations and/or provide data security Allows meteorological and wave data to be collected	Quality of data can be compromised by buoy motion Need to avoid broadband solutions Increased risk of 3rd party interference/collision
	Subsea buoy	Relatively stable platform No surface expression can be advantageous in areas of 3rd party interference	Data security is unknown until recovery without data transmission Does not provide operational support unless coupled using acoustic modems and a surface data gateway Needs good mooring design to mitigate knockdown Limited near surface data due to side lobe zone Particularly limited in large sea-states, due to wave trough influence and aeration of the upper water column
Mid-water Column	In-line buoy	No surface expression, which can reduce interference Relatively stable platform Can be deployed upward/ downward looking to avoid potential interference with other instruments	Needs good mooring design to avoid knockdown Data security is unknown until recovery
Lower water column	Short mooring	Relatively stable platform Simple deployment Acoustic beacons permit location if dragged Satellite beacons may provide alerts if trawled to surface	First measurement generally well above bed / pipeline height if upward looking Unless data is transmitted to surface buoy, interference is unknown

Depth profile of interest	Deployment Type	Pros	Cons
	Seabed frame	Stable platform	Can be turned upside down by fishing activity, which makes tracking and recovery difficult Unless data is transmitted to surface, mooring interference is unknown Potential for tilt unless gimballed Deployment in deepwater may require additional lifting capability

The considerations for each type of deployment are outlined below. Section 4 is also provided on mooring design as this is an important consideration.

The maturing autonomous vessel technology market provides opportunities to deploy low cost vessels to harvest ADCP data via acoustic modem. Similarly, if traditional vessels are on site, autonomous underwater vehicles may also offer a data harvesting capability, without mooring recovery. This may offer data security without a permanent surface expression on the mooring, and reduce HSE exposure hours. Reliable subsurface navigation would be critical for reliable current measurement.

3.1 Rig mounted

Rig mounted ADCPs are commonly utilized to support safe and efficient drilling operations, and therefore require real time data transmission and display. As well as providing the operational data, the current data are often used for infrastructure design and operational planning purposes which increases the value of the measurement. The instrument setup must ensure that all the data applications are addressed to realize the value. The measurement range from a Rig Mounted ADCP system is nominally 900-1000m. If the water depth is greater than this then a subsea mooring will be required to measure currents over the profile in deeper water, if required. Data can be transmitted via acoustic modem in real time directly to the rig or through a data gateway buoy.

Typically rig systems are temporary installations to address current regimes that provide challenging conditions, to provide currents in frontier regions, or to satisfy regulatory conditions. Due to the real time nature of the systems, the ADCPs are deployed in direct reading mode via a cable, which allows the instruments to receive power from the rig and provide instrument control to the ADCP and data communications to the rig. Having power supplied from the rig is an advantage as the instrument can be set up to optimize the data collection with no compromises required with respect to the energy utilized in transmission or data stored on the instrument. The planned deployment configuration can also be tested to ensure it is providing high quality data, and if necessary, refinements to the configuration can be made.

A deployment frame is required to support the ADCP, and this generally has one or two tugger winches which control the support wires that allow the ADCP to be lowered to the required depth. Most contractors offer single and/or dual wire installations. The latter has a number of advantages in terms of redundancy of support and perhaps more importantly a greater ability to control the orientation of the transducer heads to avoid contamination of the return signal by the drilling riser or other subsea assets. The dual wire systems are inherently more expensive due to the additional tugger winch and have a slightly larger footprint, however they are likely to offer more reliable data acquisition and thus represent recommended practice. The deployment frame and all lifting components should be certified according to the local HSE/company regulations.

Due to the congested nature of many rigs/drill ships the location of the deployment is confined to an open space and may not represent the optimal location from a current measurement perspective. For example, many drill ships place the ADCP system on the stern of the vessel where the heave motions are greater. Although no control of placement may be available it is important to document the location of the ADCP, and if motion measurements are available to potentially translate these to the transducer head to better understand their influence on the current measurements.

The ADCP is normally deployed in a stainless-steel collar or housing (depending on instrument type). Marine grade stainless steel (316) is austenitic (i.e., non-magnetic); however, welding can change the crystal structure to a magnetic form so the influence of any supporting components on the instrument compass should be considered.

When deciding on the depth of deployment, consider the following:

- Potential interference to the flow from pontoons or ship hull
- Potential magnetic influence of the rig: as the ADCP may twist or turn on its support system, it is critical that the compass sampling is configured to record ADCP heading at each current measurement (ping).
- The ambient noise conditions created by the rig. The ambient noise is primarily from thrusters and acoustic devices that may be operating at a frequency close to the ADCP. Contractors generally have significant experience of the level of ambient noise of a particular rig and are best placed to decide the depth of deployment. If the rig is commonly utilized by the operator the historic performance of the ADCP system can also be considered.

It should be noted that because the main profiling instrument needs to be deployed below the main infrastructure of the rig (pontoons / hull), it is often much deeper than the surface currents. Given the need for current information in the upper 30m of the water column, it is generally desirable to also deploy a horizontal ADCP that measures currents away from the rig. Angling the horizontal ADCP allows the current to be measured relatively near surface.

It is recommended to utilize the manufacturer's proprietary software for control of the instrument and to process and store the data, including the Teledyne RD Instruments VMDAS and Nortek Signature Deployment software. Aanderaa also offer real time software (AADI Real-time collector) but the range of the instrument (60-80m) is generally insufficient for rig systems. Use of the manufacturer software will allow the offshore engineer to readily deploy the planned setup and check its efficacy in delivering high quality data. If poor data are returned the instrument setup can modified in an iterative manner if required. Using these software packages also allows the rawest form of the data, single ping data, to be stored. Raw data allows diagnostic analysis of the data to be undertaken, this may help to optimize future averaging plans or potentially help overcome issues such as riser interference should this occur.

Systems providing real time data should be subject to quality assurance. It is recommended that QARTOD standards are utilized to inform the quality assurance. All data should be recorded, and quality control flags utilized to determine whether data are of sufficient quality to display.

Some rigs have permanent installations with ADCPs attached to the structures in a fixed orientation. These are not considered in this document as they require bespoke solutions depending on the deployment location.

3.2 Surface buoy mounted

Surface buoys are generally utilized when multi-parameter data collection programmes are required, or when current profile data is required in real time to support operations. The ability to transmit data in real time offers opportunities to use the data for operational support and provides greater data security. It should be recognized that to properly inform data quality assurance for operational support and to inform data quality control for other applications, relevant ADCP quality parameters should be transmitted.

It is important to consider whether a surface buoy mounted ADCP is the most appropriate solution, and this should include consideration of:

- Vessel traffic – in areas of high vessel traffic potential for buoy strike may pose a risk to successful data collection
- Nature of third-party interference (vessels tying up, vandalism) – vessels tying up will change the motion characteristics of the buoy which may have a negative impact on data quality, vandalism may result in loss of transmission capability, rechargeable power sources, etc.
- Fishing activity – fishing interference may be managed through fishing liaison or notice to mariners in some countries, in other areas fishing vessels may be less considerate in their interaction with buoys
- Quality of data – see following paragraphs

Surface mounted buoys are generally not stable platforms, particularly with respect to heave characteristics. As such this represents a challenge to Doppler technology. When selecting/configuring an ADCP for surface buoy deployment it should be noted that broadband technology is more susceptible to buoy motions than narrowband technology. The whole premise of broadband technology is to measure the difference in arrival time from successive pulses. However, the buoy motion will directly impact the time difference as the buoy moves towards or away from the reflector. Thus, the use of narrowband technology is likely to give more reliable measurements from a surface buoy. It should be noted that with both technologies the time gating of signals from within a cell is affected. This is likely to have minimal impact as the buoy motion during the transmit/receipt duration will likely be small.

Mooring analysis (see Section 4.6), including the impact of current and waves, should be undertaken to inform the likely motions of the surface buoy. If significant motions are likely, it may be appropriate to utilize an upward looking ADCP deployed at a depth to capture the upper water column. The potential inclination of the buoy should be considered. If inclination is likely to be high, then correction with respect to cell (bin) mapping is required.[4]

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[4] Velasco DW et al. "Enhancing the Accuracy of Current Profiles from Surface Buoy-Mounted Systems," 2018 OCEANS - MTS/IEEE Kobe Techno-Oceans (OTO). Kobe Japan. May 28-31, 2018.

A number of ADCP models permit this to be undertaken within the instrument firmware, but it is recommended to collect the rawest form of data.

The inclination will also impact the performance of the compass. Therefore, an attitude and heading reference system (AHRS) should be utilized to minimize the impact. This might be within the ADCP or already be available on the buoy. Such systems are cheap and low power so can be readily fitted to a buoy. A key consideration is to ensure the motions derived from a buoy based AHRS unit are translated to the position of the ADCP compass/transducer, and that appropriate processing is implemented.

ADCPs mounted in buoys may be deployed in self-contained mode or integrated into the buoy system. The latter approach is preferable as it allows provision of power from the buoy and allows data transmission and the ability to interface to the ADCP via satellite or local communications depending on the buoy system capability.

In addition to the vertical motions, ADCPs mounted in buoys can suffer from poor performance due to bubbles adjacent to the transducer face. The bubbles generally reduce the profiling range of the instrument so this should be borne in mind. To alleviate this problem, the ADCP is sometimes suspended just below the surface buoy as an in-line downward looking instrument. It should be noted that this does not overcome the issues associated with heave impacting broadband processing.

3.3 Mid-water column deployment

Mid-water column deployment allows measurement of most parts of the water column, and typically offers a stable deployment solution, particularly in comparison with surface buoys. The elevation of the buoys, and hence current profile range within the depth, will be impacted by the mooring design and performance with respect to knockdown. Depending on the current conditions it is sometimes possible to locate the ADCP in a region of lower currents, thus minimizing the drag on the mooring. Mooring design is considered in Section 4.

If measuring the upper water column, careful consideration must be given to the elevation of the ADCP to minimize the side lobe reflection zone. In some instances, this may require deployment of a high frequency ADCP relatively near the surface (to measure the current profile over the likely depth of infrastructure for example), plus a lower frequency instrument to capture the full impact of processes such as mesoscale eddies.

In-line measurements are often utilized to ensure full water column coverage and may comprise several upward and downward looking ADCPs. If the system is downward looking and within range of the seabed the impact of side lobe reflections requires consideration. Most riser engineering analyses require estimation of simultaneous currents through the complete water column, so efforts to achieve this can be of value to reduce uncertainty.

3.4 Short mooring

Short moorings or stumpy moorings are often used to measure near-bed currents in a mooring design that utilizes a sinker weight, acoustic release, and an ADCP flotation device. The entire mooring can often be deployed with a basic vessel of opportunity and potentially without the use of lifting equipment. The ADCP may be upward looking or downward looking depending on the required current data. If the ADCP is downward looking, care must be taken to ensure that the mooring components do not enter the transducer clearance zone. This is readily considered in the mooring design. Upward-looking ADCPs generally do not capture the area in which infrastructure such as pipelines sit; therefore empirical equations to reduce currents from several meters above seabed to the pipeline position are used. This may be overcome through the careful design of a downward looking ADCP configuration. A downward looking ADCP suffers from the inability to measure current very close to the seabed due to side lobe reflections; however, placing a high frequency instrument with small cells 5m above seabed would reduce the side lobe reflection zone to 0.3 to 0.67m depending on beam angle, thus enabling the profile close to the seabed to be measured.

In areas of high fishing activity, the short mooring can often offer a good solution, particularly if the region is readily accessed, as the entire mooring is often recovered by fishermen and satellite beacons allow tracking and potential recovery. It should be noted that this requires the beacon to be "visible" during a satellite pass which does not always occur. If the beacon provides a single location, additional evidence to potentially identify a fishing vessel should be considered. The simple deployment of short moorings should allow replacement of the mooring in a reasonably cost-efficient manner.

Figure 9: An ADCP in short mooring flotation collar designed for low current environment (© 2021 Blue Ocean Consulting Ltd)

3.5 Seabed frames

Seabed frames are generally utilized in shallow water with 50m water depth being a common upper depth limit. They may be deployed deeper, but the deployment solution becomes more challenging from ships of opportunity and is not typically offered by commercial companies.

The development of wave measurement capability utilising Doppler technology combined with surface tracking makes such ADCPs a popular choice for shallow water (<30m) measurements of gravity waves and current profiles. Wave measurement is beyond the scope of this document, and as such only current measurement is considered.

The bed frame is often designed to offer trawl protection in areas of high fishing. However, it should be noted that trawl proof frames are difficult to achieve. The trawl proof nature of frames generally prevents them from being caught in the nets, but their resilience is dependent on the bed conditions and fishing gear utilized. Given the potential for a frame to be dragged and inverted, a bed frame is not always the best choice as it is harder to recover - as the acoustic beacon will be oriented towards the seabed, and knowledge of trawling impact will likely only occur during the scheduled servicing or recovery. Examples of bed frames are shown in Figure 10, which shows a trawl proof frame in elevation and plan on the left and a regular frame on the right. If the seabed is not flat, a gimbal will be required to ensure verticality of the instrument.

Figure 10: Example bedframes. Courtesy of DeepWater Buoyancy, Inc.

Bed frame recovery is usually achieved through the use of a pop-up buoy. The buoy is attached to the seabed frame by rope with sufficient strength to safely lift the bed frame. On recovery an acoustic release is interrogated and released allowing the buoy to float to the surface.

4. Mooring design

The mooring should be designed to ensure its integrity over the life of the measurement programme, and to optimize the location of ADCPs with respect to the required measurement profile and impact of drag on the mooring. Various components of mooring design are considered below, along with mooring analysis. The mooring components may comprise a mixture of metals, and where this occurs, isolation of components must be undertaken to prevent corrosion.

4.1 Flotation

Flotation buoys are used to support ADCPs measurements, and may be deployed as in-line flotation or terminal flotation (i.e., at the top of the mooring line). Syntactic foam collars/ buoys are the most common type as the flotation itself has no impact on the instruments compass and provide strong performance with respect to uplift compared to drag. Reducing drag helps to minimize instrument tilt and excursion. The syntactic foam shape is generally spherical, elliptical, or torpedo-shaped to minimize drag. It should be noted that although elliptical buoys offer less drag, if their inclination is significant, they may flip and effectively become a parachute that has the potential to drag a mooring off location. In energetic flow regimes the use of torpedo buoys can both reduce drag, and buoy motions such as yaw, pitch, etc. Torpedo buoys make use of various designs: a number have simple fins, and these offer less drag than those which combine fins and a tail ring. The tail ring offers advantages with respect to motion stability associated with yaw, etc.

Examples of such buoys are illustrated in Figure 11.

Figure 11: Examples of subsurface ADCPs. Courtesy of Deepwater Buoyancy, Inc.

A stainless steel frame passes through the syntactic foam and the ADCP is attached to this frame. The design of the frame precludes beam interference by the frame. The in-line strength of the frame should be consistent with the strain of the mooring design. In-line ADCPs can be deployed in either upward or downward looking mode. Care should be taken to avoid contamination of the signal by other ADCPs in the mooring string.

If additional instrumentation is to be deployed on the buoyancy, it is much better that it is deployed in a suitable well on the buoy. This avoids potential interference with beams and ensures the drag is minimized.

The centre of mass/buoyancy of any flotation should ensure that following surfacing, light and/or satellite beacons do not remain submerged.

4.2 Wire rope/synthetic rope

The size of wire/synthetic rope utilized in the mooring will be driven by the loads applied during towing, freefall and in-situ placement of the mooring. This is obtained from the mooring analysis, so this is generally an iterative process. The relative pros and cons for each type of rope are outlined in Table 4. The selection of rope is beyond the scope of this document, as it will need to address the mooring components, local current regime, etc., which does not allow for generic guidance. It should be noted that torque balanced wire rope should be utilized to reduce rotation and provide a higher elastic limit to improve service life. Additionally, torque balanced wire rope will provide a higher strength to weight ratio which may reduce buoyancy requirements.

Table 4: Rope pros and cons

Rope	Pros	Cons
Bare wire rope	Readily sourced and low cost Cheap terminations	Comparatively high drag coefficient
Plastic coated wire rope	Reduced drag Safer handling	Expensive terminations Difficult to evaluate condition of wire if plastic coating is damaged Environmentally friendly disposal options may be limited Resistant to fishing hooks from deep sea fishing boats
Synthetic rope	Lightweight thus requires less buoyancy	Environmentally unfriendly (although recycling is available in some geographies) Not shark resistant Easily snagged by fishing hooks from deep sea fishing boats Potential for stretching over deployment, leading to changes in measurement elevation.

4.3 Anchor weight

The anchor weight should be designed to maintain mooring on location, considering both the uplift of the mooring buoyancy and the potential for dragging. Typically, dead weight anchors are utilized comprising bundles of scrap chain or railway wheels as they are relatively cheap.

Where the sea floor is soft the anchor may sink into the seabed and mud mats may be required to ensure the anchor stays on the surface of the seabed and the design elevation for the instrumentation is maintained. If a mud mat is not utilized, consideration needs to be given to the likely depth of penetration to ensure acoustic releases remain in the water column.

4.4 Acoustic releases

Acoustic releases are critical to buoy recovery and location of the mooring. Recommended practice is to utilize a pair of acoustic releases to provide redundancy. In addition to the release functionality, the acoustic units should include the ability to communicate the inclination of the release and the range to the release. The former ensures the mooring is vertical and the latter enables "boxing in" of the mooring to ensure an accurate location is achieved. The choice of batteries for the acoustic releases should ensure significant redundancy at the scheduled time of recovery.

4.5 Shackles/chain

Shackles and chain should be selected to provide appropriate safety factors for the anticipated loads. Steel quality and component dimensioning should be considered for the expected degree of corrosion over the deployment period. Where mooring vibration is expected, 4-part shackles shall be used.

4.6 Mooring analysis

All moorings incorporating ADCPs require analysis to determine: the knockdown of the instrumentation (i.e., how far below the planned elevation the instrument may be), the inclination of the in-line mooring components and the motions of the ADCP (for example natural frequency of the mooring). The only exception would be short moorings that are not subject to high currents or wave action.

Static mooring design is a balancing act between the restoring force provided by buoyancy elements and the hydrodynamic drag. Drag acts on all components of the mooring: ADCP flotation, wire rope, shackles, releases, etc. Manufacturers recognize that provision of reliable characterization of drag characteristics is required for mooring analysis and these are increasingly available leading to better data to support the mooring analysis. Static design provides the following outputs for a given current profile:

- In-line tension
- Horizontal excursion
- Inclination at nodes
- Knockdown

The mooring design should include a number of pressure sensors to enable the mooring performance to be evaluated and the instrument depths to be considered in post processing.

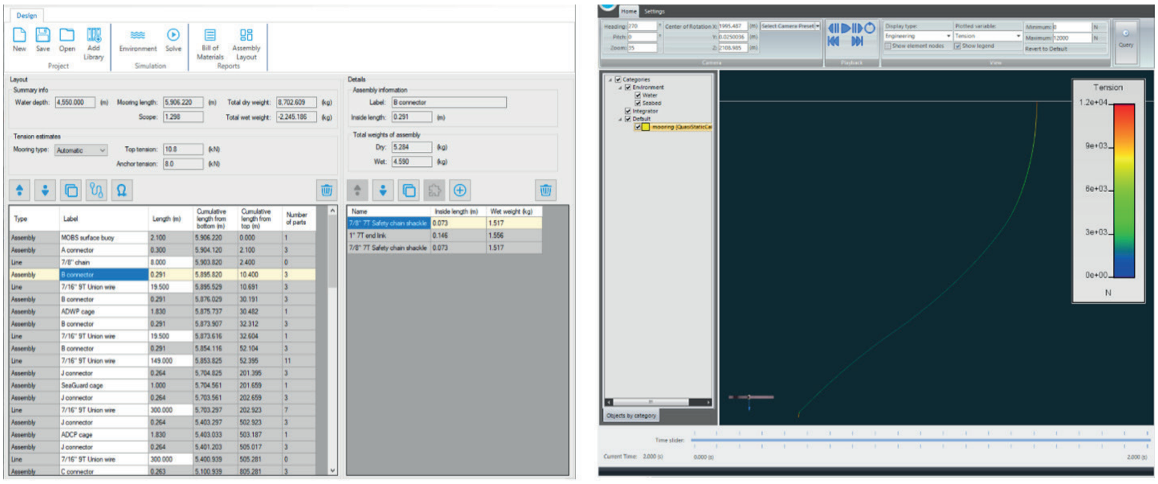
High quality ADCP data requires the pitch/roll of the ADCP to be low (see Section 1.6.1). Therefore, inclination at the ADCP flotation device should be minimized to optimize the data quality. Knockdown will likely result in the measurement cells being inconsistent during a deployment and may also preclude measurement within the water column if the knockdown places the instrument at an elevation that does not allow the range to provide sufficient coverage.

The horizontal excursion may result in the mooring line and/or instruments contaminating the ADCP data. This is particularly true of surface/near surface mounted ADCPs, and care would be required in the QA/QC of the data.

For many subsea moorings, static analysis is sufficient to understand the behaviour of the mooring and hence impact on the data. However, it does not allow assessment of loads during freefall of the mooring to the seabed. Given these loads may be higher than the in-situ case, it is recommended they are considered in the mooring analysis, and this will require dynamic analysis. In-line tension should be utilized to select appropriate strength for elements of the mooring under load. Typically, a safety factor of 1.67 is utilized in accordance with ISO 19901-7:2013. An iterative approach will likely be required to optimize buoyancy and mooring integrity.

Where components of the mooring are likely to be influenced by wave motion, dynamic analysis is required to address the dynamic loading and the motion of the flotation supporting ADCP instrumentation. The frequency of motion should be considered when selecting a ping interval to avoid aliasing of the current data. Where long deployments are utilized in areas subject to large waves, dynamic analysis may also be required to address fatigue load failure. The motions of both surface buoys and subsurface buoys influenced by waves should be addressed. It is recommended that combinations of wave and current loading are utilized to inform the motion assessment and its potential impact on data quality.

A range of commercial mooring software packages are available to support mooring analysis, and example input/output is illustrated in Figure 12. Mooring design should be considered part of the tendering process as it impacts on the choice of buoyancy, cost of wire rope, sinker weights, etc.



Layout

Summary info

Water depth: 4,550.000 (m) Mooring length: 5,906.220 (m) Total dry weight: 8,702.609 (kg)

Scope: 1.298 Total wet weight: -2,245.186 (kg)

Tension estimates

Mooring type: Automatic Top tension: 10.8 (kN)

Anchor tension: 8.0 (kN)

Type	Label	Length (m)	Cumulative length from bottom (m)	Cumulative length from top (m)	Number of parts
Assembly	MOBS surface buoy	2.100	5,906.220	0.000	1
Assembly	A connector	0.300	5,904.120	2.100	3
Line	7/8" chain	8.000	5,903.820	2.400	0
Assembly	B connector	0.291	5,895.820	10.400	3
Line	7/16" 9T Union wire	19.500	5,895.529	10.691	3
Assembly	B connector	0.291	5,876.029	30.191	3
Assembly	ADWP cage	1.830	5,875.737	30.482	1
Assembly	B connector	0.291	5,873.907	32.312	3
Line	7/16" 9T Union wire	19.500	5,873.616	32.604	1
Assembly	B connector	0.291	5,854.116	52.104	3
Line	7/16" 9T Union wire	149.000	5,853.825	52.395	11
Assembly	J connector	0.264	5,704.825	201.395	3
Assembly	SeaGuard cage	1.000	5,704.561	201.659	1
Assembly	J connector	0.264	5,703.561	202.659	3
Line	7/16" 9T Union wire	300.000	5,703.297	202.923	7
Assembly	J connector	0.264	5,403.297	502.923	3
Assembly	ADCP cage	1.830	5,403.033	503.187	1
Assembly	J connector	0.264	5,401.203	505.017	3
Line	7/16" 9T Union wire	300.000	5,400.939	505.281	0
Assembly	C connector	0.263	5,100.939	805.281	3

Details

Assembly information

Label: B connector

Inside length: 0.291 (m)

Total weights of assembly

Dry: 5.284 (kg)

Wet: 4.590 (kg)

Name	Inside length (m)	Wet weight (kg)
7/8" 7T Safety chain shackle	0.073	1.517
1" 7T end link	0.146	1.556
7/8" 7T Safety chain shackle	0.073	1.517

Heading: 270 °

Pitch: 0 °

Zoom: 35

Center of Rotation X: 1995.487 (m)

Y: 0.0250036 (m)

Z: 2108.985 (m)

Display type: Engineering

Plotted variable: Tension

☐ Show element nodes

☑ Show legend

Minimum: 0 N

Maximum: 12000 N

Revert to Default

Time slider:

Current Time: 2.000 (s) 0.000 (s) 2.000 (s)

Figure 12: Example of mooring analysis software. Courtesy of DSA Ocean.

5. ADCP Configuration

This section examines an instrument's transducer configuration options and the options available within the manufacturers' setup software. Each manufacturer has a slightly different approach but addresses similar controls on the instruments:

Table 5: ADCP Configuration inputs and outputs

Inputs	Outputs
Sampling interval	Memory utilized/required
Burst/Averaging sampling including compass	Battery utilization
Number of pings/measurement load	Precision of current speed estimate
Ambiguity velocity	Instrument range
Battery capacity	Profile resolution
Deployment duration	
Number of cells	
Cell size	
Blanking zone	
Power input level	
Speed of sound in water	
Coordinate system	
Tidal range	
Compass sampling regime	

The inputs are utilized in a series of trade-offs, detailed in Table 6, to optimize the measurement programme for its application. These also have to be considered with respect to the cost of the measurement programme, particularly service visits.

Table 6: ADCP Configuration Trade offs

Goal	ADCP setup	Trade-off
Greater depth resolution	Smaller cell size	Reduction in profiling range Lower precision
Increase precision	Larger depth cells Longer averaging interval Large number of pings	Lower depth resolution Decreased temporal resolution Increased power consumption
Longer profiling range	Narrowband operation	Decreased precision
Real time transmission	Surface buoy deployment Acoustic modems Narrowband operation	Increased motion Increased cost Decreased precision

5.1 Sampling interval/averaging interval/number of pings

Manufacturers allow users to select a number of sampling approaches. Very high frequency sampling (2+Hz) over short periods is utilized in high frequency instruments to measure turbulence and is not considered here. The sampling interval is the period between ensemble averages, whereas the averaging interval is the duration of the ensemble. Adoption of a common ensemble interval, which would be ideal for both operational and engineering purposes, is problematic due to the compromises required to optimize the setup precision with respect to the power capacity of the instrument and the potential for aliasing. This is illustrated in Figure 13, which shows a 15-second swell wave form over a ten-minute sampling interval. For this example, the required instrument precision is achieved by 120 pings. In the top panel, the pings are distributed at 5-second intervals (green plus signs) to provide a 10-minute ensemble average. In the lower panel the pings are distributed at 1-second intervals to provide a 2-minute ensemble average. In this example, the 2-minute sampling is likely to provide higher quality data as the impact of aliasing will be lower. Further information on the optimisation of ping interval, to avoid aliasing, may be found in Brumley and Deines (1999).

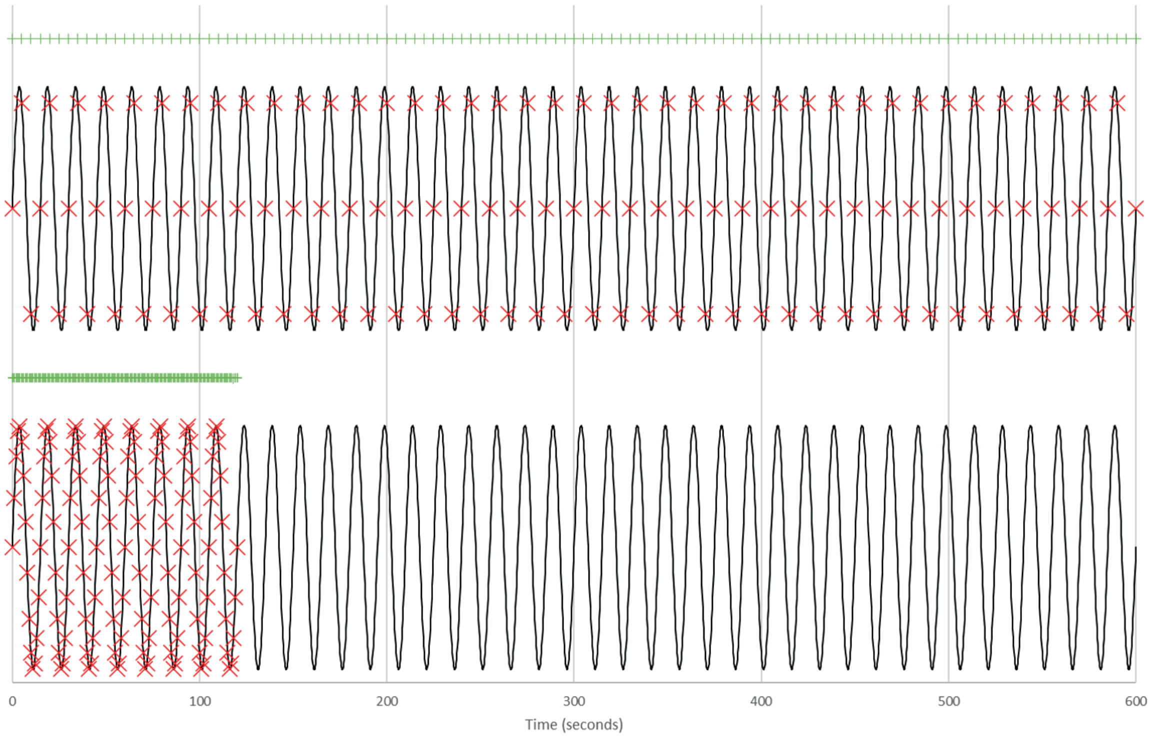


Figure 13: Sampling trade-offs. Image © Blue Ocean Consulting, Ltd.

Although the theory suggests this approach is beneficial, some trials conducted by a contractor in a moderate wave regime did not demonstrate conclusively that a higher ping rate provided better data. Therefore, if the power capacity of the instrument allows continuous single ping data (at a ping interval that avoids aliasing) to be recorded, it is recommended that single ping data be collected in beam coordinates. This will permit the ensemble averaging to be optimized in post processing.

All ADCP data should include metadata related to the ensemble averaging interval, the sampling interval and predicted standard deviation of the instrument setup. It is also important for contractors to communicate the rationale for ADCP setups based on potential aliasing of the mean current signal, and the trade-off with battery consumption.

To obtain accurate directional measurements, the sampling regime for compass must address any potential rotation of the instrument during the acquisition of velocity data. For any deployment other than a seabed frame, recommended practice dictates the instrument heading should be sampled alongside the velocity measurement. This is addressed in the manufacturer's setup software and instrument firmware. Although a bed frame may be considered stationary, it is recommended practice to sample the compass routinely to confirm the frame has not been reoriented through dragging, and that pitch/roll have not varied through scour. Compass sampling is relatively low power so has minimal impact on power requirements.

5.2 Blanking zone/number of cells/cell size/ambiguity velocity

Typically, the blanking zone is longer in narrowband technology than broadband technology. It is also a function of transducer frequency, with lower frequency transducers requiring a larger blanking zone. The manufacturers provide clear guidance on required blanking zone and this should be adhered to avoid potential erroneous currents induced by transducer ringing.

The cell size and location are a function of time gating applied to the acoustic signal. Knowing the speed of sound allows the distance from the lower and upper cell boundaries to be converted into a time. The two-way travel time for the volume of a cell is used to identify return signals from that cell. Some ADCP systems allow the influence of tilt to be addressed, such that bin mapping identifies cells at a common elevation.

The cell size impacts both the precision of the current measurement and the power consumption of the instrument. This is illustrated in Figure 14 for a Nortek Signature 100 in addition to the influence of the sampling regime. Solid lines show precision and dashed lines duration – the blue line is for a 5-minute averaging interval and the orange line is for a 10-minute averaging interval at a 10-minute sampling interval. Both sampling regimes utilize a maximum measurement load, i.e., maximized number of pings, the power consumption and accuracy for a 10-minute averaging interval using 50% measurement load would be similar to the blue line).

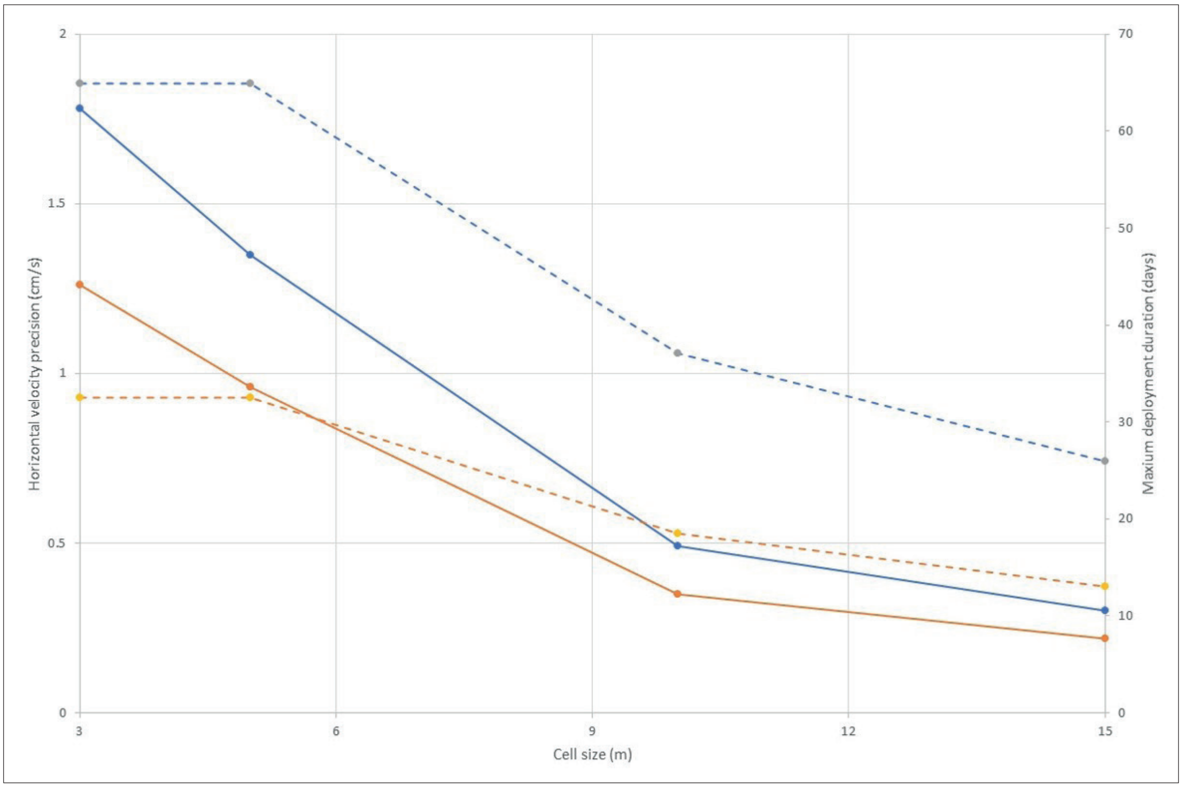


Figure 14: Illustration of influence of cell size on horizontal velocity precision and deployment duration. Image © Blue Ocean Consulting, Ltd.

The default ambiguity velocity (in the horizontal direction) may not be optimal for the expected currents. This should be set at the maximum expected current velocity at the location of interest. It is prudent to apply a safety factor as the instrument will suffer from poor correlation if the ambiguity velocity is exceeded, likely resulting in invalid data. This needs to consider the implication of a higher value which results in increased standard deviation.

5.3 Battery capacity

ADCP planning software provides estimation of the power requirements for the selected instrument configuration. It should be noted that battery capacity varies with deployment temperature, with effectively reduced power capacity in colder water. This should be considered at the planning stage.

Standard battery packs may be selected in the software to ascertain the possible duration under the instrument configuration. Typically, a 30-50% buffer is included for standalone mooring to allow for potential delays to recovery and to some degree battery malfunctions. A number of ADCP product lines offer different size housings to permit different number of battery packs to be deployed, whereas others utilize external battery packs. The latter are sometimes considered risky as the subsea connection introduces a point of failure, however subsea connector designs are generally robust and with appropriate deployment procedures the risk should be low.

The energy density of lithium batteries is far greater than alkaline batteries, however their transportation and disposal are more difficult. In addition, lithium batteries introduce a HSE risk of fire and explosion. It is recommended that contractors adhere to minimum expectations required to address specific risks associated with handling and storage of lithium batters contained in IOGP Report 432 - *Managing HSE in a geophysical contract*. Therefore, when selecting batteries, consider not only power requirements to achieve current precision, but also whether the batteries can be transported, required mobilization time, safe storage and handling practices, and whether safe/effective battery disposal is available.

Battery costs may not be insignificant, and as such contractors may optimize the instrument sampling through reducing the number of pings to provide a lower cost solution in a competitive bidding environment. This will likely decrease the precision of the current measurement. As such it is important to consider the required precision for an application, and potentially specify in tender documents. It must be remembered that the precision predicted by the manufacturer's software only accounts for instrument uncertainty, and not external factors such as reflectors, etc. When tendering work it may be prudent to request costed options for different battery choices versus current speed precision to ensure optimisation.

5.4 Coordinate system

As stated earlier, collection of velocity data in beam coordinates provides the rawest form of data which may help in post processing if data are problematic.

As such, it is recommended that the ADCP is set up to collect data in beam coordinates, where single ping data is utilized. Post processing of single ping raw beam data allows true vector averages to be calculated. However, if ensemble data is collected on the instrument, it is better to collect data in earth coordinates as this ensures true vector averaging is achieved.

6. Specifying measurement programmes

This section aims to provide guidance on the information required by a contractor to design an effective ADCP installation, and configuration. The information provides key inputs into the decision trees contained in Section 7.

Table 7: Input information and the corresponding purposes for decision trees in Section 7

Information	**Purpose**
Water depth	To permit mooring design and appropriately selected depth ratings.
Water column coverage	To allow appropriate instrument(s) to be selected to achieve required coverage.
Measurement vertical resolution	To allow ADCP setup and mooring design
Sampling interval	Typically, continuous sampling is required to capture current processes however there may instances when less regular measurement is acceptable.
Current velocity averaging interval	The averaging interval can be specified but the actual averaging interval utilized will likely be dependent on battery capacity and ping interval required to avoid aliasing.
Current precision / accuracy	Accuracy is determined by the instrument bias so may require a certain frequency instrument to be deployed. The precision is a function of many selections, however specifying an accuracy may help to ensure that battery costs do not drive a commercial decision that compromises the technical solution.
Wave climate	Minimum of joint frequency tables of significant wave height versus peak period (Hs/Tp) to inform sampling strategy to avoid aliasing and to inform mooring design. Spectral characterization may also be required by the mooring analysis software.
Maximum expected horizontal current	Enables selection of appropriate ambiguity velocity in ADCP setup.
Design current profile(s)	Enables design of moorings.
Water properties	If known, water profile properties will allow appropriate speed of sound to be considered in the ADCP setup. Higher temperatures lead to lower ranges.
Fishing / vessel traffic information	These data are often available to operators, and if shared with contractors help them to design the measurement programme to minimize risk as far as possible.
Total duration of measurements	Allows determination of service interval which needs to consider battery life, memory capacity, marine growth and data security.
Rig / Vessel draught (if applicable)	To determine ADCP position in water column

7. Decision tree

The decision tree process is illustrated in a series of flow diagrams:

Figure 15	ADCP frequency selection and nominal instrument elevations
Figure 16	Mooring Design and Analysis
Figure 17	Instrument setup decision tree

The green boxes represent inputs obtained from the requirements outlined in Section 9. The orange boxes represent design/analysis activities, blue boxes represent considerations and the grey boxes the outcomes from the decision tree. Where the outcomes are taken forward into other decision trees, they are shown in the same colour. Yellow boxes represent checks against requirements that drive an iterative process.

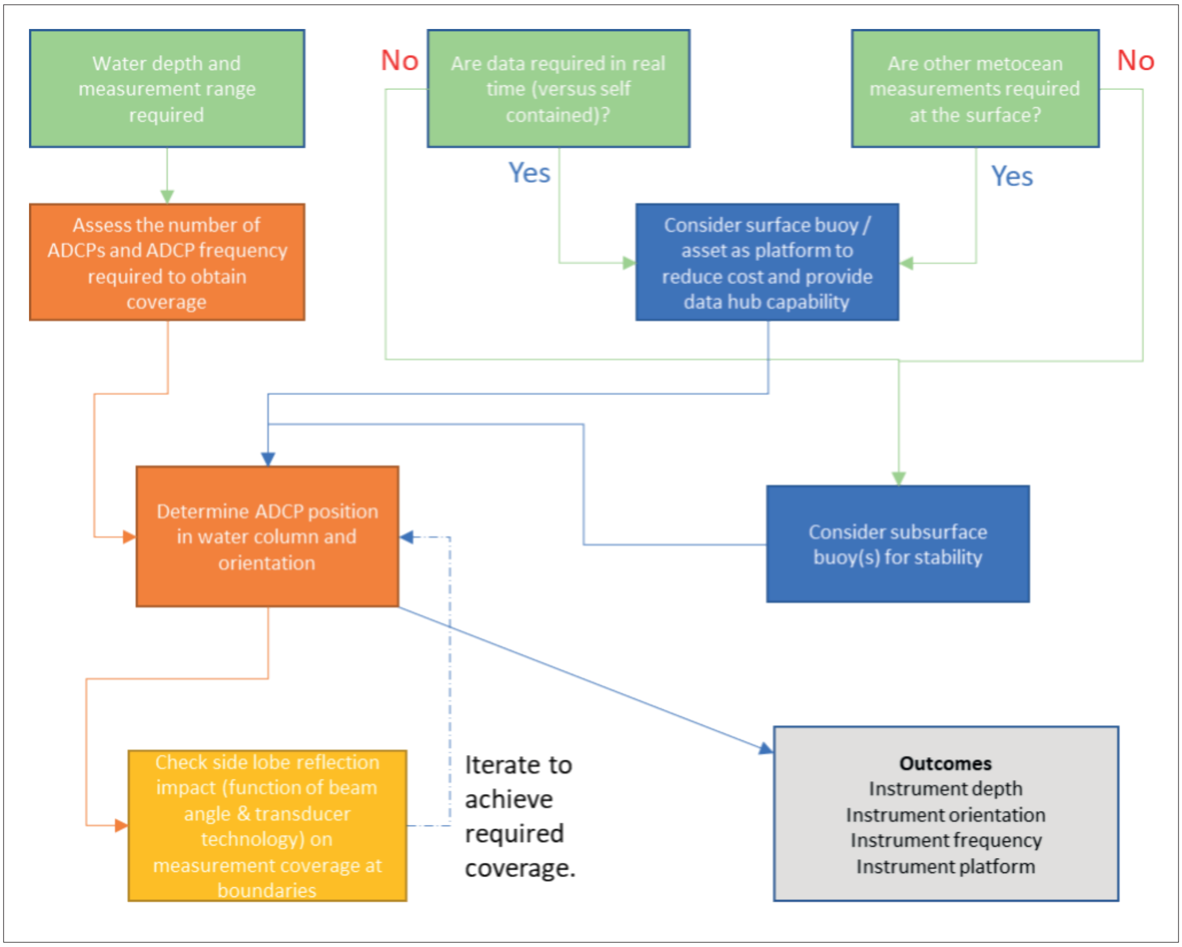


Figure 15: Decision tree to determine ADCP frequency selection and nominal instrument elevation. Image © Blue Ocean Consulting, Ltd.

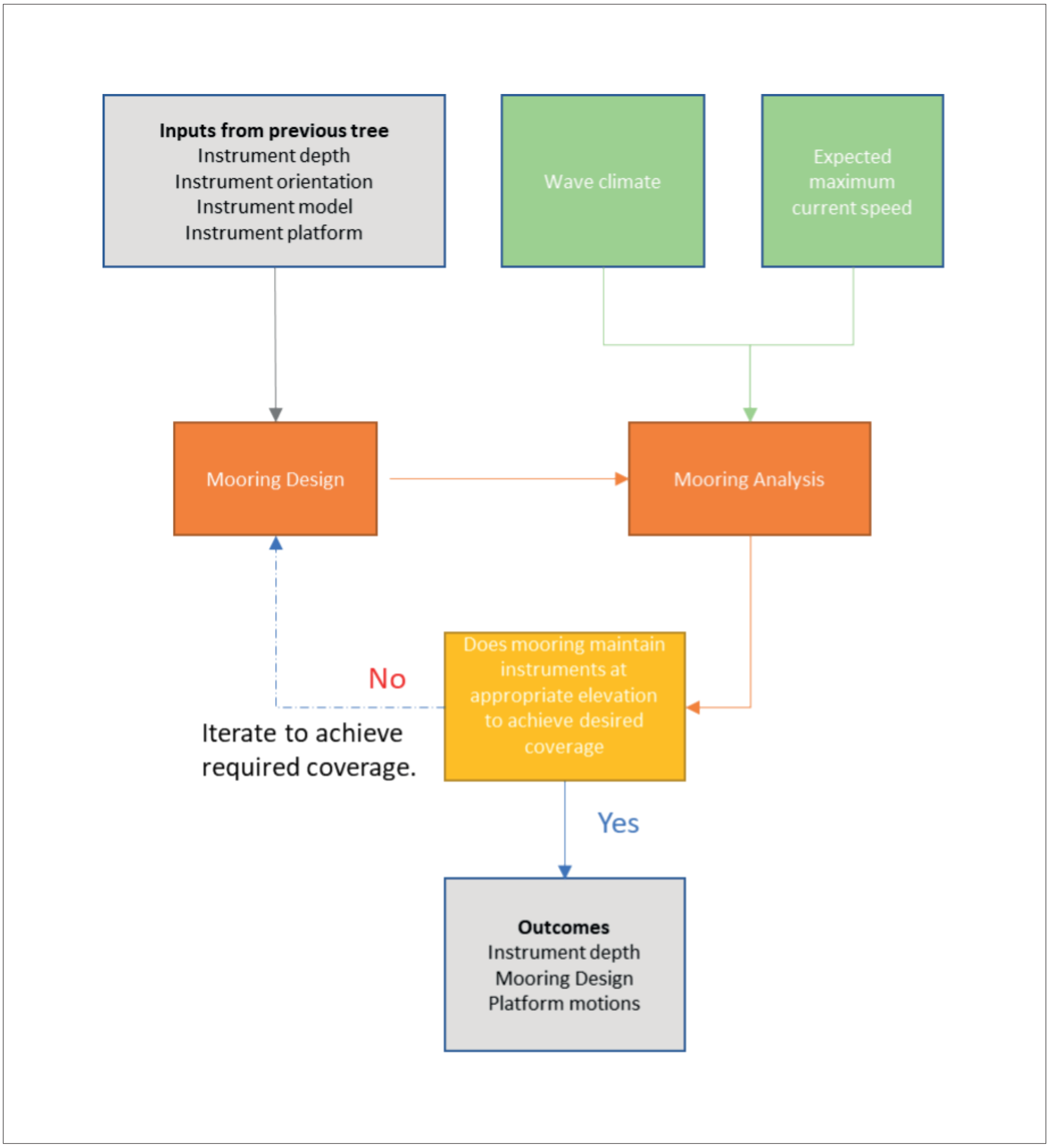


Figure 16: Mooring Design and Analysis. Image © Blue Ocean Consulting, Ltd.

Note: If the mooring performance is such that excessive knockdown is found at the depths determined from the previous decision tree, it may be necessary to revisit the ADCP instrument selection and placement in an iterative manner.

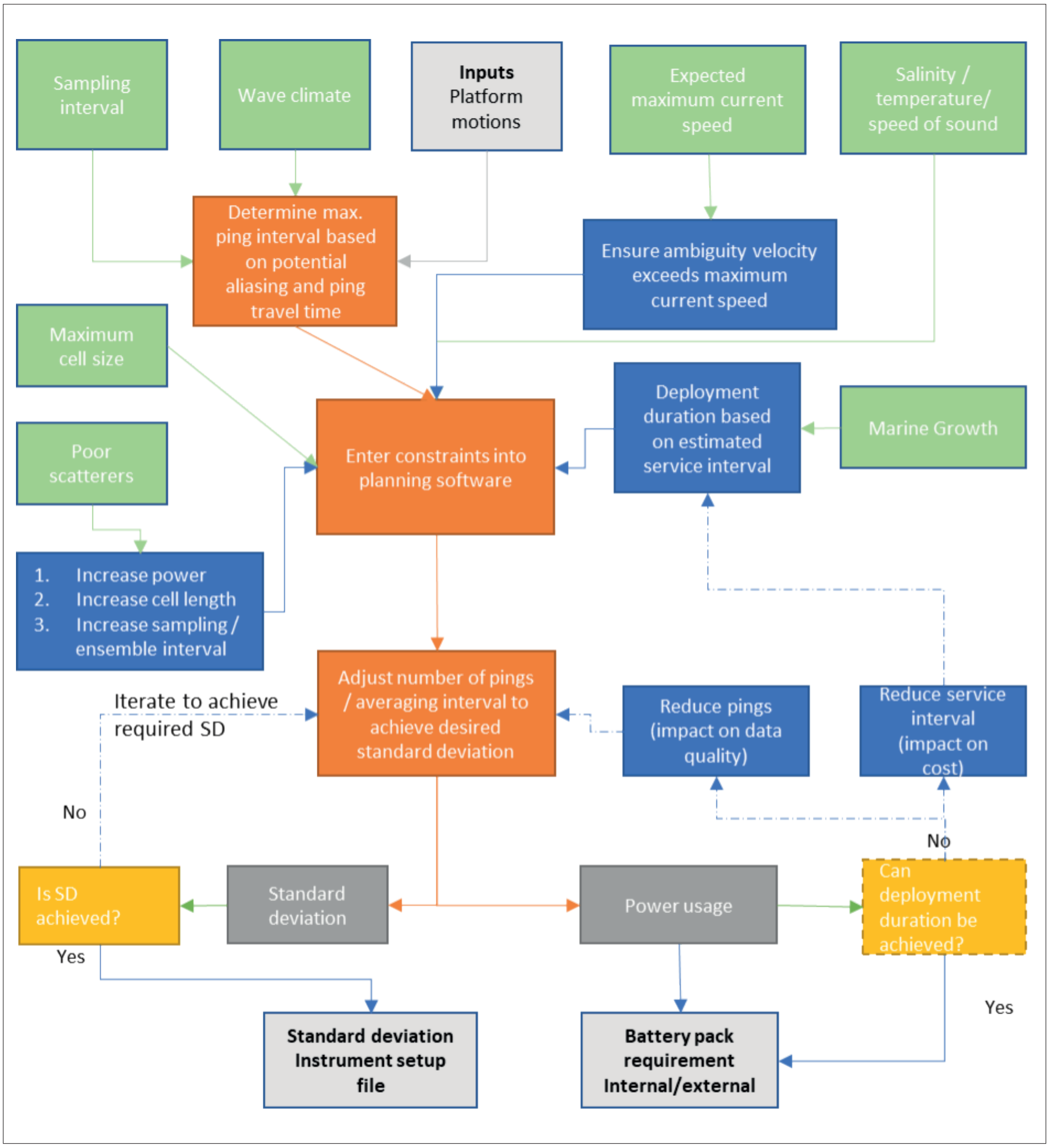


Figure 17: Instrument setup decision tree. Image © Blue Ocean Consulting, Ltd.

Note: Platform motions are derived from mooring analysis in previous decision tree.

8. Example deployments

The aim of this section is to demonstrate the use of the decision tree process for a range of deployment types in the marine environment. Generic solutions are not suitable for each environment due to the different external factors that may impact the measurements, as such the solutions provided should be considered in the context of the requirements defined.

8.1 Rig ADCP – Measurement range of 1000m

8.1.1 Requirements

Table 8: Requirements for real-time measurements over 1000m

Information	Inputs
Water depth	1200m
Water column coverage	5-1000m depth
Measurement resolution	Maximum 20m
Real time data	Yes
Sampling interval	10-minutes
Current velocity averaging interval	10-minutes
Current precision / accuracy	1cm/s
Maximum expected horizontal velocity	2.5ms^{-1}
Design current profile(s)	Not considered as this is location specific
Wave climate	Gulf of Mexico
Water properties	Water temperature 20C
Fishing / vessel traffic information	Not applicable due to restriction zone
Total duration of measurements	90 day well
Pontoon depth	(19m)
Other information	Poor scatterers

8.1.2 Solutions

8.1.2.1 Decision Tree to determine ADCP instrument, position in water column, and orientation (Figure 18)

1) **What water depth and instrument range are required?**
   The range requirements of 1000m, limit the instrument choice to instruments with a frequency of 55kHz or less, if a single instrument is utilized.
2) **Is data required in real time or self-contained?**
   Given the real time requirement, the optimal solution will be deployed from the rig. It would also be possible to deploy on a sub-surface mooring, but this would require acoustic data transmission and a deployment vessel, hence the rig-based solution is likely more economical.
3) **Are other metocean measurements required at the surface?**
   No, but given real time requirement and platform availability, rig based solution is the best approach.
4) **How is the number of ADCPs and ADCP frequency required to obtain coverage assessed?**
   To avoid magnetic influence and the impact of the rig on currents, the instrument needs to be deployed at a depth of 30m, or 1170m above seabed. Both Nortek and Teledyne RDI offer instruments that may measure a real time current profile of nominally 1000m, subject to external factors such as availability of scatterers, ambient noise, etc. Both companies offer ADCP models with differing range and precision configurations, both of which can be used to observe current features such as Loop Current Eddies, which can impact operations in the upper water column. The cell size and number of cells were selected as 20m and 50 respectively for both systems to provide 1000m range. Both instruments have a 20° beam angle which results in a 28m side lobe reflection zone adjacent to the seabed. They both have similar bias of ±0.005ms-1 or ±1% of measured value. During loop current events the latter is likely to limit the accuracy. Ideally the high precision, low range solution would be implemented during the passage of shallow high current events, for example to capture the structure of eddy currents. Neither instrument offers adaptive sampling, but contractors could provide innovative solutions to implement such an approach within their real time software that controls the ADCP, although compliance with regulatory requirements would need consideration.

The Ocean Surveyor 38kHz (OS38) is also considered. The coverage provided by these instruments is illustrated in Figure 18, with a nominal instrument range of 1000m included.

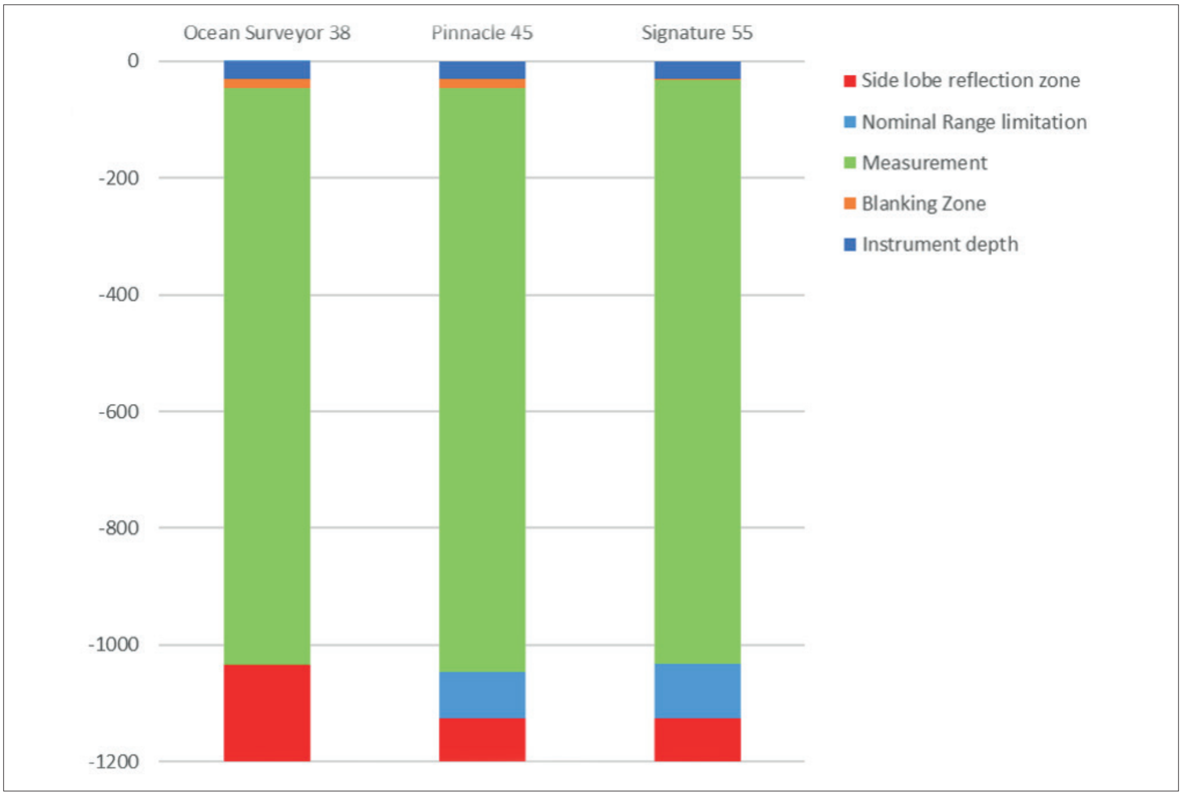


Figure 18: Illustration of water column coverage from the Ocean Surveyor 38, Pinnacle 45 and Signature 55

The water column coverage provided by the low frequency systems requires a higher frequency system to be deployed to capture the upper water column. To achieve this a Teledyne RDI 300kHz horizontal Workhorse (300HWH) instrument or Nortek Signature 2D Horizontal Profiler - 400 kHz (SH400) was used.

Table 9: ADCP Selection and elevation outcomes for Rig ADCP deployment

Outcome	OS38	P45	S55	300HWH	SH400
Instrument depth	30	30	30	30	30
Instrument orientation	Downward	Downward	Downward	Horiz	Horiz.
Instrument frequency	38	45	55	300	
Instrument platform	Rig	Rig	Rig	Rig	Rig
Nominal measurement zone (m below MSL)	46-1035	46-1406	32—1032	30-10	30-10

8.1.2.2 Mooring design and analysis decision tree (Figure 16)

Although a mooring analysis is not generally undertaken for ADCPs deployed from a Rig/drillship, it is probably worth considering the rig/vessel response to inform potential movement of the ADCP. Additionally, if an analysis of the suspension system is undertaken it may help to understand potential dynamic motions, particularly periodic motions.

The ADCP should be suspended in a marine grade stainless collar, using two support wires to enable riser reflections to be minimized. To prevent tilt of the instrument due to currents acting on the suspended assembly, lead weights should be utilized to hold the instrument close to the vertical. The weight should be designed based on the likely current regime.

8.1.2.3 Instrument setup decision tree

Determine max. ping interval based on potential aliasing (Figure 17)

This utilizes the inputs of wave climate and potential platform motion, together with the sampling interval requirement. Generally, the wave heights in the Gulf of Mexico will be low (<2m) and have short periods. Therefore, the rig supporting the ADCP is unlikely to respond and introduce aliasing through motions. Similarly, the waves are unlikely to have a significant orbital velocity at the measurement depths of the ADCP cells. Exceptions are likely to be the passage of northers and hurricanes. ADCPs are generally recovered during the passage of hurricanes, so it is only the passage of northers that may give rise to aliasing either through vessel motions or orbital wave velocities. Given that power is not limited as it is provided from the rig, the number of pings within 10-minutes is only limited by the two-way travel time of the signal and processing time.

Deployment Duration

As the power is provided from the rig, the deployment duration is not limited by power. The primary concern would be the physical condition of the suspension system. Marine growth is not generally a limiting factor.

Poor Scatterers

If the scatterers are known to be low there are a limited number of choices to be made in the planning software.

- Increasing the power, this will have a detrimental impact on the horizontal precision
- Increasing the cell length (effectively increases the number of reflectors)
- Increasing the sampling/ensemble averaging interval

Planning Software

The input values from the requirements are taken forward into the Pinnacle Utilities software for the Pinnacle 45 and Signature Deployment Software for the S55. Although the basic interfaces offer the ability to set up the instrument, it is sometimes necessary to provide direct commands to the ADCP.

Signature 55

It is recommended that an AHRS is utilized for this deployment to account for any motions of the suspended transducer head. As the head is likely influenced by wave motions, there is a possibility that the instrument experiences periodic motions, and this will help reduce such effects on the data. The standard velocity range of 1ms-1 is sufficient for the maximum expected velocity of 2.5ms-1. Utilizing a 10-minute ensemble average allows a horizontal precision of 0.66cm/s to be attained. The maximum number of pings is constrained by the signal travel, and is 100, which gives a ping interval of 6 seconds. This is likely to lead to somewhat noisy data in the upper bins due to wave orbital velocities, and potentially instrument motion, aliasing of the mean current signal. The limitations of the instrument suggest that the approach described above, interleaving coarse and fine profile measurements would provide the best approach. Careful consideration of how to display the currents would be required as the upper and lower water column would not be coincident but 10-minutes different. Table 10 shows the instrument setup. The setup table illustrates the predicted outcomes from an ensemble mean undertaken utilizing PC processing. For low scatterers, the power level is increased from -3dB to -2dB and the average interval increased from 10-minutes to 20-minutes.

Table 10: Signature 55 setup for Rig 1000m range

Inputs	**Normal Scatterers**	**Low Scatterers**
Power level (dB)	-3dB	-2dB
Long range mode	Yes	Yes
Number of pings	100	200
Ambiguity velocity (ms^{-1})	1	1
Blanking cell size(m)	2	2
Number of cells	54	54
Cell size (m)	20	20
Sampling interval (min:sec)	10:00	20:00
Average interval (min:sec)	10:00	20:00
Outputs		
Estimated measurement range (m)	1001	1022
Horizontal precision (cms^{-1})	0.66	0.47
Vertical precision (cms^{-1})	0.17	0.12
Memory usage (MB)	332	330
Power usage (Wh)	2851	3418
Ping interval (s)	6	6

Pinnacle 45

With normal scatterers, a 10-minute ensemble would be generated by the VMDAS software. The number of pings achievable in a 10-minute ensemble with the Pinnacle is 300, i.e., a 2 second ping interval. The 2-second ping interval is unlikely to mitigate any aliasing effect by the low frequency wave energy. The estimated precision of the setup is 1.9cm/s. The Pinnacle includes both heading field calibration and magnetometer data, similar to the Signature, so magnetic effects should be less than the Ocean Surveyor. The ND0 command should be utilized for rig installations, as this may improve the instrument range.

As the Gulf of Mexico is often subject to low scatterers, a second setup is included to address this scenario. This increases the sampling interval to 20-minutes and cell size to 30m. The power level could be increased but this would likely increase the ping interval due to automated heat management of the transducer. Selection of the following QA thresholds will be required; correlation threshold, error velocity threshold, and echo intensity. It is recommended that this should consider the data being returned and an iterative process applied that minimizes poor data through careful selection.

Table 11: Pinnacle 45 setup for Rig 1000m range

Inputs	**Normal Scatterers**	**Low Scatterers**
Power level (dB)	N/A	N/A
Long range mode	Yes	Yes
Number of pings	300	600
Ambiguity velocity (ms^{-1})	1.5	1.5
Blanking cell size(m)	16	16
Number of cells	50	35
Cell size (m)	20	30
Sampling interval (min:sec)	10:00	20:00
Average interval (min:sec)	10:00	20:00
Outputs		
Estimated measurement range (m)	1188	1254
Horizontal precision (cms^{-1})	1.7	0.83
Vertical precision (cms^{-1})	N/A	N/A
Memory usage (MB)	4,000	3,000
Power usage (Wh)	6812	8,098
Ping interval (s)	2	2

Ocean Surveyor 38

With normal scatterers, a 10-minute ensemble would be generated by the VMDAS software. The number of pings achievable in a 10-minute ensemble with the OS38 is 300, so nominally 2 second ping interval. Given the potential for reflections from the seafloor, this is increased to 2.5-seconds which results in 240 pings being utilized. The ping interval is unlikely to mitigate any aliasing effect by the low frequency wave energy. The manufacturer estimated precision of the OS38 is 30cm/s for 16m bins or 20cm/s for 24m bins. Therefore, to achieve the best precision a 24m cell size is selected which provides an estimated precision of 1.3cm/s.

As the Gulf of Mexico is often subject to low scatterers, a second setup is included to address this scenario. This increases the sampling interval to 20-minutes and cell size to 30m. Selection of the following QA thresholds will be required; correlation threshold, error velocity threshold, and echo intensity. It is recommended that this should consider the data being returned and an iterative process applied that minimizes poor data through careful selection.

Table 12: Ocean Surveyor 38 setup for Rig 1000m range

Inputs	**Normal Scatterers**	**Low Scatterers**
Power level (dB)	N/A	N/A
Long range mode	Yes	Yes
Number of pings	240	480
Ambiguity velocity (ms^{-1})	1.5	1.5
Blanking cell size(m)	24	16
Number of cells	42	35
Cell size (m)	24	30
Sampling interval (min:sec)	10:00	20:00
Average interval (min:sec)	10:00	20:00
Outputs		
Estimated measurement range (m)	1188	1254
Horizontal precision (cms^{-1})	1.3	0.6
Vertical precision (cms^{-1})	N/A	N/A
Ping interval (s)	2.5	2.5

Horizontal 300 WHADCP

The horizontal range of this instrument is nominally 148m. This enables a near surface current measurement to be made at a distance from the structure. The instrument is deployed on the spreader bar above the low frequency ADCP. The recommended angle from the horizontal is 2-5 degrees but up to 15 degrees is acceptable. An angle of 10 degrees should allow for measurement at about 10m below the surface at 110m from the instrument transducer. Due to short range of the 300Khz instrument, and hence travel time, the number of pings can be maximized by using a ping interval of 1s, to achieve 600 and 1200 pings for normal and low scatterer conditions respectively. The short ping interval will help reduce aliasing by wave effects and provides a good horizontal precision of <0.1cms-1 for both setups.

Table 13: Horizontal 300 WHADCP setup for Rig 1000m range – near surface currents

Inputs	**Normal Scatterers**	**Low Scatterers**
Power level (dB)	N/A	N/A
Long range mode	No	No
Number of pings	600	1200
Ambiguity velocity (ms^{-1})	1.75	1.75
Blanking cell size(m)	1.8	1.8
Number of cells	22	13
Cell size (m)	5	10
Sampling interval (min:sec)	10:00	20:00
Average interval (min:sec)	10:00	20:00
Outputs		
Estimated measurement range (m)	112	138
Horizontal precision (cms^{-1})	0.10	0.03
Vertical precision (cms^{-1})	N/A	N/A
Ping interval (s)	1	1

2D Horizontal 400

The instrument is deployed in a similar manner to described above. The nominal range of the 400 is 130m, but given that the instrument would be deployed at an angle of 10 degrees, only 100m range is required, as previously discussed. The maximum measurement load of the instrument is 50% such that in a 10-minute interval the number of pings is 300 at a 2-s interval. The cell size is limited to 8m, so this is adopted for the low scatterer scenario. Utilising 12 bins, gives a measurement range of 96m, and measurement depth just over 5m.

Table 14: Horizontal 400 Profiler setup for Rig 1000m range – near surface currents

Inputs	**Normal Scatterers**	**Low Scatterers**
Power level (dB)	High	High
Long range mode	No	No
Number of pings	300	300
Ambiguity velocity (ms^{-1})	1.75	1.75
Blanking cell size(m)	1	1
Number of cells	24	12
Cell size (m)	5	8
Sampling interval (min:sec)	10:00	20:00
Average interval (min:sec)	10:00	20:00
Outputs		
Estimated measurement range (m)	120	96
Horizontal precision (cms^{-1})	0.2	0.1
Vertical precision (cms^{-1})	N/A	N/A
Ping interval (s)	2	2

8.2 Deepwater standalone – measurement range of 1200m

8.2.1 Requirements

Table 15: Requirements for real-time measurements over 1200m

Information	Inputs
Water depth	1200m
Water column coverage	5-1150m depth
Measurement resolution	Maximum 20m
Real time data	No
Sampling interval	10-minutes
Current velocity averaging interval	10-minutes
Current precision / accuracy	1cm/s
Maximum expected horizontal velocity	2.5ms^{-1}
Design current profile(s)	Not considered as this is location specific
Wave climate	West Africa
Water properties	Water temperature 20C
Fishing/vessel traffic information	Not applicable due to restriction zone
Total duration of measurements	1-year – 3 No. 4-month deployments balancing risk to mooring and cost
Other information	Previous 3rd party interference of surface buoys has occurred

8.2.1.1 ADCP frequency selection and nominal instrument elevations

There are a variety of ways to collect data over 1200m, and careful consideration needs to be given to the current regime to ensure proper characterization. The approach outlined here, is based on the potential for mesoscale eddies to depths of 800m, an engineering requirement to capture near surface and a relatively benign environment from 800-1200m depth. When selecting instrument locations, it is important to consider cross contamination of instrument signals. To avoid cross contamination all instruments will be upward looking. It is possible to have an upward/downward looking ADCP mid-column, but this creates more drag.

To capture near-surface currents, it is necessary to place a higher frequency instrument on a subsea buoy close to the surface. The sidelobe reflection zone is 3.6, 4,2, 3.8, 5.4 and 6 metres for an instrument placed at a depth of 60, 70, 80, 90 and 100 metres respectively. For this mooring design, the instrument will be placed at 80m to nominally measure to within 5m of the surface. This requires a nominal 1,100m of range to be addressed. An upward looking low frequency (55-75kHz) instrument would provide a nominal range of 500-1000m, with the latter having a side lobe reflection zone of 80, which would be fine given the high frequency instrument at 80m. However, this would require the instrument to operate in narrowband mode which reduces the precision of the current measurement. As such an instrument is selected to be deployed at 10m above the seafloor to cover the lower 600m of the water column, and another instrument is selected to be deployed at 600m above the seafloor to provide coverage in the water column from 590-80m water depth.

The near bed option is a 3,000m depth rated Workhorse Long Ranger (75kHz). The Nortek signature 55 is rated to 1500m so is not suitable. They can both provide 600m range with adequate precision and resolution. The selection of instruments and deployment depths is shown in Table 16.

Table 16: ADCP Selection and elevation outcomes for deepwater mooring

Outcome	WHLR 75	WHLR 75	S55	WH300	S250
Instrument depth	1180	600	600	80	80
Instrument orientation	Upward	Upward	Upward	Upward	Upward
Instrument frequency	75	75	250	300	250
Instrument platform	Subsurface buoy	Subsurface buoy	Subsurface buoy	Subsurface buoy	Subsurface buoy
Nominal measurement zone (m below MSL)	600-1160	100-600		5-80	5-80

8.2.1.2 Mooring Design and analysis decision tree

The mooring is likely to be subject to strong currents in the upper water column so the preferred buoyancy is likely to be torpedo shaped to minimize drag and ADCP motions. Given the mooring length it is likely appropriate to use synthetic rope to minimize the weight of the mooring line. Careful consideration would be needed with respect to potential stretching of the mooring line. A full dynamic analysis may not be required as the mooring should not be impacted significantly by wave motions, however the currents may give rise to orbital motions along the mooring line, so this should be addressed. A full mooring design and analysis is outside the scope of this document, so consideration should be given to the points raised in Section 7.

8.2.1.3 Instrument setup decision tree

The instrument is setup with 5m bins to allow a cell close to the surface. Although the instrument's planned deployment depth is 80m, 18 bins are selected to allow for 10m of knockdown. Initially the setup was planned using a single internal alkaline battery of 450Wh. This did not address the power requirements for a 120-day deployment, and resulted in a significant averaging interval compromise of just 50-s. The 50-second averaging interval is driven by the requirement to minimize aliasing of the current data due to wave aliasing, which drives a 1-s ping interval requirement, and the power limiting the number of pings to 50. To overcome this the setup was revisited with a single lithium battery, which allowed a 190-sec averaging interval at 1-s ping intervals. This still falls short of the 10-minute averaging requirement, in the end a compromise solution was adopted which required an additional lithium battery pack in an external case to provide sufficient power for a 5-minute average at 10s ping interval. The power usage provides 60 days redundancy, so the averaging period could be increased further if required.

Table 17: WH300 at 80m depth

Inputs	**Values**
Power level (dB)	N/A
Long range mode	No
Number of pings	90
Ambiguity velocity (ms^{-1})	1.75
Blanking cell size(m)	1.8
Number of cells	18
Cell size (m)	5
Sampling interval (min:sec)	10:00
Average interval (min:sec)	5:00
Outputs	
Estimated measurement range (m)	92
Horizontal precision (cms^{-1})	0.30
Vertical precision (cms^{-1})	N/A
Power usage (Wh)	2488
Ping interval (s)	1

Signature 250 at 80m below sea surface

The instrument is setup with 5m bins to allow a cell close to the surface. Although the instrument's planned deployment depth is 80m, a 100m profile is selected to allow for 20m of knockdown. The maximum ping rate of the Signature 250 is 1-s. In a similar manner to the WH300 it was decided to decrease the averaging interval from 10-minutes to 5-minutes to try to minimize the ping interval and potential aliasing. The measurement load was set to 100% to achieve this, which resulted in a power requirement of 5286Wh. To provide this level of power, one internal and two external lithium packs are utilized. This provides three days of redundancy so a three external pack may be considered prudent.

Table 18: WH300 at 80m depth

Inputs	**Values**
Power level (dB)	-6.0dB
Long range mode	No
Number of pings	85
Ambiguity velocity (ms^{-1})	1.75
Blanking cell size(m)	0.5
Number of cells	20
Cell size (m)	5
Sampling interval (min:sec)	10:00
Average interval (min:sec)	5:00

Outputs	Values
Estimated measurement range (m)	105
Horizontal precision (cms^{-1})	0.38
Vertical precision (cms^{-1})	0.1
Power usage (Wh)	16578
Ping interval (s)	1

WH Long Ranger at 600m

A depth cell size of 20m was initially selected in line with the requirement, this selection provide a range of 515m in normal broadband mode. The cell size was then reduced 10m to see if the required range was achievable at higher vertical resolution, however the maximum range was 477m which is insufficient to provide the required coverage. A 15m cell size provided sufficient range and improved resolution. The number of pings was gradually increased from the default setting (which utilizes alkaline batteries) to a value which optimized the precision, but provided redundancy based on three lithium battery packs. The optimum number is 32 pings which provides 20+days of power redundancy and a precision of 0.77cms-1.

Table 19: WH Long Ranger at 600m depth

Inputs	Values
Power level (dB)	N/A
Long range mode	No
Number of pings	30
Ambiguity velocity (ms^{-1})	1.75
Blanking cell size(m)	7.0
Number of cells	30
Cell size (m)	20
Sampling interval (min:sec)	10:00
Average interval (min:sec)	10:00
Outputs	
Estimated measurement range (m)	614
Horizontal precision (cms^{-1})	1.12
Vertical precision (cms^{-1})	N/A
Power usage (Wh)	5257
Ping interval (s)	20

8.3 Upper water column measurements

8.3.1 Requirements

Table 20: Requirements for upper water column measurements

Information	Inputs
Water depth	200m
Water column coverage	0-120m depth
Measurement resolution	Maximum 5m
Real time data	Preferred
Sampling interval	10-minutes
Current velocity averaging interval	10-minutes
Current precision / accuracy	1 cms^{-1}
Maximum expected horizontal velocity	1ms^{-1}
Design current profile(s)	Not considered as this is location specific
Wave climate	Northern North Sea
Water properties	Water temperature 10C surface, 4C near bed
Fishing / vessel traffic information	Minimal trawling
Total duration of measurements	365 assume nominal 120 day measurement period due to battery limitations

For this scenario two potential deployment solutions are considered. One is likely to provide higher quality data at increased cost for the real time data, so it is recommended that the implications of each solution are explored to determine the most appropriate solution for the available budget.

Determine the ADCP position in water column and orientation

There are primarily two options to measure the upper water column; a surface buoy mounted downward looking ADCP or a subsurface buoy mounted upward looking ADCP. Both approaches could provide real time data, if the subsurface buoy instrument exported the data to an acoustic transponder coupled to a data gateway buoy or similarly equipped maritime autonomous surface ship. This will likely add a degree of risk and cost to the data collection. High availability acoustic modem devices are available in the market, for example those controlling BOPs, however they are generally significantly more expensive than those typically used in oceanographic data transmission. This introduces a trade-off between cost and reliability.

The wave climate of the northern North Sea provides two challenges to surface buoys:

- During high sea states the potential for cavitation around the transducer head is high, which is likely to reduce the SNR and lead to noisy data. The buoy will also likely be subject to low frequency oscillations of the order of 10-20s.
- During low sea states the buoy is likely to be subject to high frequency oscillations of the order of 4-10s.

The decision to utilize a surface or subsurface buoy needs to consider potential aliasing of the current signal as discussed in the next section. This requires the dynamic motion of the surface buoy to be determined using the mooring analysis output.

If a subsurface buoy is utilized the influence of the side lobe reflection zone needs consideration. Placing an ADCP at 120m water depth would lead to a side lobe zone of 7.2m (20° beam angle). Thus, the upper 10m of the water column will not be measured. To minimize pitch/roll, it is generally accepted that deploying the ADCP 5-10m below the surface buoy is advantageous, which means that the upper 10m is not measured, therefore there is no advantage to either deployment position with respect profile coverage. The only way to capture the upper water column would be to utilize a single point current meter on the buoy, and this is likely to have similar problems with respect to wave impacts and buoy motions on the quality of the current data.

Determine max. ping interval based on potential aliasing

The potential for aliasing due to buoy motion is high. Bruserud and Haver (2017) demonstrated the impact of wave climate on ADCP measurements, and that wave height over 2.5m had a detrimental impact on current data quality, and that high frequency waves also can contribute to noisy data. To minimize the impact, the ping interval should be as low as possible, ideally 0.5 sec.

Deployment duration

The nominal deployment duration is 120 days. Given the high latitude, the potential for solar charging of the surface buoy is low during the winter months. Therefore a 3-monthly service visit is likely optimal. It is essential to consider the potential impact of longer durations on the ability to collect high quality data due to battery limitations. Innovative methods for energy harvesting may need to be implemented, for example wind power as used in Floating Lidar systems.

Mooring analysis

The mooring analysis would likely reveal potential heave of 3-7m of the surface buoy and periodic motions from 4 to 15s. As such, both buoy motions and the wave orbital velocities will likely drive the maximum velocities near surface, such that a high ambiguity velocity is selected. This will help to avoid potential phase wrapping which will contribute to noisy data. It also suggests that a ping interval close to 0.5s would be desirable to avoid aliasing.

8.3.2 Solutions

Sentinel V100

The ambiguity velocity is set at 3.5ms-1 for the subsurface buoy to ensure orbital wave velocities do not cause phase wrapping and erroneous data. The Sentinel V has a fifth beam and the vertical profile is implemented for the subsurface buoy to track the water surface and knockdown, which restricts the ping interval to 1s. A 10-minute average is implemented with 600 pings to achieve a horizontal precision of 0.25cms-1. This provides 74-day spare capacity using 2 lithium battery packs, so a longer service interval could be accommodated. Although the waves will penetrate over the measurement profile, it is expected that the buoy motion will be relatively small compared to the surface buoy. Therefore, although the horizontal precision is likely to be greater due to wave velocities, it is likely to be better than that achieved by the surface buoy. However, the additional cost of a surface transmission buoy and acoustic modem link needs consideration in the choice of deployment method.

For the surface buoy a different sampling strategy is utilized. The ambiguity velocity is set to 5.5 ms-1 to allow for added motions of the ADCP. A higher ping rate is desirable to minimize aliasing by both wave velocities and buoy motion. Therefore, the vertical profile is not enabled and a ping interval of 0.5s is implemented. Narrowband is also implemented in order to try to increase the Signal to Noise Ratio. This achieves a system horizontal precision of 0.42cms^{-1}. Power usage is higher than the subsurface system but still provides 20 days extra. It should be noted that the actual horizontal precision is likely to be greater than 0.42 due to external factors relating to buoy motion and wave velocities.

Table 21: Sentinel V100 Setup for upper water column measurement

Inputs	**Surface buoy**	**Subsurface buoy**
Power level (dB)	N/A	N/A
Long range mode	Yes	No
Number of pings	600	600
Ambiguity velocity (ms^{-1})	5.5	3.5
Blanking cell size(m)	1.6	1.6
Number of cells	40	40
Cell size (m)	2.5	2.5
Sampling interval (min:sec)	10:00	10:00
Average interval (min:sec)	10:00	10:00
Deployment duration (days)	120	120
Vertical profile	No	Yes
Outputs		
Estimated measurement range (m)	102	102
Horizontal precision (cms^{-1})	0.42	0.25
Vertical precision (cms^{-1})	N/A	N/A
Memory usage (GB)	8.88	5.47
Power usage (Wh)	3237	2749
Power available (Wh)	3800	3800
Spare power (days)	20	46
Ping interval (s)	0.5	1

Signature 250

AHRS should be implemented if the ADCP is deployed near surface to mitigate buoy motions. This has an impact on the power requirements as seen in Table 22. Due to wave climate an ambiguity velocity of 5ms-1 is selected for both the surface and subsurface deployments. 600 pings at 1s intervals are achievable using an external Lithium 5400Wh battery pack. The ping interval is likely to mitigate aliasing for swells, but not higher frequency wind seas.

It should be noted that both the horizontal and vertical precision estimates are likely to be lower in reality, due to the external factors of wave/buoy motion. The subsurface buoy is likely to have the better precision as the motions (heave/periodic) will be smaller. Although the surface buoy has lower spare power due to long range mode and AHRS being utilized, there is potential to provide power from the buoy which could overcome this. It should be noted that the subsurface buoy will require an acoustic modem and a surface buoy with transmission capability to provide real time data. Therefore, the cost of likely improved quality of data needs to be weighed against the additional cost.

Table 22: Signature 250 Setup for upper water column measurement

Inputs	**Surface buoy**	**Subsurface buoy**
Power level (dB)	N/A	-6.0
Long range mode	Yes	No
Number of pings	600	600
Ambiguity velocity (ms^{-1})	5	5
Blanking cell size(m)	0.5	0.5
Number of cells	52	52
Cell size (m)	2.5	2.5
Sampling interval (min:sec)	10:00	10:00
Average interval (min:sec)	10:00	10:00
Deployment duration (days)	120	120
AHRS	Yes	No
Outputs		
Estimated measurement range (m)	134	134
Horizontal precision (cms^{-1})	0.73	0.73
Vertical precision (cms^{-1})	0.19	0.19
Memory usage (MB)	9727	9727
Power usage (Wh)	6206	5532
Power available (Wh)	7200	7200
Spare power (days)	19	36
Ping interval (s)	1	1

8.4 Internal wave measurements

8.4.1 Specification

Table 23: Requirements for internal wave measurements

Information	Inputs
Water depth	100m
Water column coverage	100m depth
Measurement resolution	Maximum 10m
Sampling interval	2-minutes
Averaging interval	2-minutes
Current precision / accuracy	1cms^{-1}
Maximum expected horizontal velocity	2.5ms^{-1}
Design current profile(s)	Not considered as this is location specific
Wave climate	Low wave climate
Water properties	Water temperature 20C
Fishing / vessel traffic information	Busy vessel traffic, trawling likely
Total duration of measurements	120 days assume 2 nominal 60 day measurement periods

Additional information that should be provided for internal wave measurements, if available, includes the amplitude, thermocline depth, duration of internal waves as they passage the measurement site and the potential number of waves in a packet. This would help to determine whether ADCP technology is the appropriate technology for measurement of this process, and if so help to identify the required averaging interval and optimal position in the water column.

Determine the ADCP position in water column and orientation

Given the potential for a complex current profile within the water column it is appropriate to select a position in the water column that minimizes current profile impact on the mooring response, i.e., low in the water column. However, the lower the position in the water column, the greater the side lobe reflection – and hence lack of surface currents and the increased separation of measurements at the farthest cells. Due to the fishing risk, and advantages of a stable platform, a seabed frame is selected. Comparison of side lobe reflection shows that a near bed deployment has a surface side lobe reflection zone of 6m compared to 4.8m for a deployment at 20m ASB which necessitate a single point near bed current meter and be more exposed to fishing interference.

Determine max. ping interval based on potential aliasing

Potential aliasing of the signal may occur in the upper water column due to wave orbital velocities. The internal waves are unlikely to contribute to aliaising. A small ping interval is desirable to improve precision so aiming for a 1-sec ping interval will address both needs.

Deployment Duration

The planned deployment duration is 60 days due to potential for trawling and the need for data security.

Mooring Analysis

No mooring analysis is required. A surface buoy could be deployed as a marker to deter fishing activity and act as a real time data hub and consideration should be given to this. Ideally, subsea processing of the ADCP data would be implemented to enable transmission of comprehensive data for soliton events to provide greater data security.

8.4.2 Solutions

To characterize internal waves, high frequency sampling and averaging is required. A maximum sampling and averaging interval of 2-minutes is recommended in this instance; however, the software can be utilized to determine whether faster sampling can occur with acceptable precision. Both solutions include the collection of raw data that will the ensemble average in post processing to optimize the quality of the data. As the raw data are stored in beam coordinates this allows the untransformed velocity information to be utilized in understanding the internal wave structure, and it is anticipated that this approach could offer potential for improved understanding using innovative processing solutions.

Sentinel V100

An ambiguity velocity of 2.75 ms-1 was selected to ensure no phase wrapping occurred during the passage of internal waves. The V100 was setup with forty seven 2m cells and a 1.6m blanking zone. The ADCP is setup for 1-minute sampling, with 120 pings at 0.5s interval which gives a precision of 0.64cms-1. A vertical profile is enabled that will provide both vertical velocity along this beam and an echogram which might help to track the thermocline. Two lithium battery packs are required to provide 10 days of power redundancy. A summary of the instrument setup is provided in Table 24.

Table 24: Sentinel V100 Setup for internal wave measurement

Inputs	Surface buoy
Power level (dB)	N/A
Long range mode	No
Number of pings	120
Ambiguity velocity (ms^{-1})	2.75
Blanking cell size(m)	1.6
Number of cells	47
Cell size (m)	2
Sampling interval (min:sec)	01:00
Average interval (min:sec)	01:00
Deployment duration (days)	60
Vertical profile enabled	Yes

Outputs	**Surface buoy**
Estimated measurement range (m)	95.6
Horizontal precision (cms^{-1})	0.64
Vertical precision (cms^{-1})	N/A
Memory usage (GB)	12.3
Power usage (Wh)	3252
Power available (Wh)	3800
Spare power (days)	10
Ping interval (s)	0.5

Signature 250

The Signature 100 was considered as it would provide a vertical echogram from its fifth beam. However, it cannot achieve the desired ping interval therefore, a 250kHz instrument is selected. The setup details and outcomes are shown in Table 25.

An ambiguity velocity of 2.5ms-1 is selected to accommodate the likely internal wave velocity. 54 depth cells of 2m are selected to provide the desired profile coverage. The Signature will store the raw data, which will allow post processing to optimize the ensemble averaging. However, for the purpose of this document a 2-minute sampling/averaging interval is used to demonstrate the measurement precision related to internal factors. 120 pings are utilized at a ping interval of 1s to give a precision of 0.84cms-1. Two lithium battery packs provide 3600Wh power capacity and 30 days redundancy.

Table 25: Signature 250 Setup for internal wave measurement

Inputs	**Seabed frame**
Power level (dB)	-6
Long range mode	No
Number of pings	20
Ambiguity velocity (ms^{-1})	2.5
Blanking cell size(m)	0.5
Number of cells	54
Cell size (m)	2
Sampling interval (min:sec)	02:00
Average interval (min:sec)	02:00
Deployment duration (days)	60
AHRS	No

Outputs	
Estimated measurement range (m)	128
Horizontal precision (cms^{-1})	0.84
Vertical precision (cms^{-1})	0.22
Memory usage (MB)	4739
Power usage (Wh)	2402
Power available (Wh)	3600
Spare power (days)	30
Ping interval (s)	1

8.5 Near-surface profile characterization for shallow depth features

8.5.1 Specification

Table 26: Requirements for shallow depth features

Information	**Inputs**
Water depth	120m
Water column coverage	Upper 5m depth
Measurement resolution	Maximum 0.2m
Sampling interval	10-minutes
Averaging interval	10-minutes
Current precision / accuracy	2 cms^{-1}
Maximum expected horizontal velocity	2.5ms^{-1}
Design current profile(s)	Not considered as this would be location specific
Wave climate	1-2m swells of 10-15 period
Water properties	Water temperature 20C
Fishing / vessel traffic information	n/a
Total duration of measurements	120 days during wet season.

Additional information required to inform the design of the solution would be the tidal range at the measurement location. For this example, it is assumed the tidal range is less than 0.5m, which is likely in open water offshore the Congo delta. This would help to ensure that the measurement range is sufficient to capture the current profile across the tidal cycle.

Determine the ADCP position in water column and orientation

The ADCP needs to be deployed in the upper water column to be able to measure in the required zone. A surface buoy or upward looking ADCP on a taut mooring are the two potential solutions. However, given the likely buoy motions, as explored in Section 11.3, an upward looking buoy is utilized

Determine max. ping interval based on potential aliasing

Aliasing of the signal is likely to come from the swell wave signal and the mooring response. However, given the short travel time for the pings a ping interval of 0.5s should be achievable to mitigate these impacts.

Deployment Duration

The planned deployment duration is 120 days to cover the wet season. Given low fishing activity now interim service visit is scheduled.

Mooring Analysis

The mooring analysis of the subsurface buoy will be critical to this application. It is anticipated that a torpedo shaped buoy would offer the most stable platform, but a dynamic analysis under the wave conditions would be required to confirm this. The torpedo may be affected by pitch/roll characteristics depending on the combined directional wave current loading, so multiple directional combinations will need to be considered. A gimbal system within the buoy might also be considered to overcome this potential impact.

8.5.2 Solutions

Measurement of the current profile close to a boundary requires careful consideration of bin size, blanking zone and side lobe reflection zone. Applications include shallow freshwater lens such as the Congo plume. The proposed mooring design would feature a low drag subsea buoy supporting a high frequency ADCP at a nominal elevation of 5m below MSL. The performance of the mooring would require careful consideration to ensure the measurements are made reliably in the upper 5m.

A high frequency instrument is required to provide the vertical granularity. As such, a Nortek Signature 1000 and a Teledyne Sentinel V20 are considered.

Sentinel V20

Given the potentially high currents in the surface layer an ambiguity velocity of 2.75ms-1 is selected which would be sufficient for currents of 7.5 ms-1. The V20 was setup with 0.25m cells and a 0.4m blanking zone, such that instrument target depth would be 5.5m. The surface side lobe reflection zone would be approximately 0.5m. The ADCP is setup for a 10-minute sample interval. A key consideration in the setup is how the water level above the instrument changes due to wave height, therefore a vertical profile is enabled to allow the water surface to be tracked. It is also recommended to utilize a high precision/accuracy pressure recorder to confirm the depth of the instrument.

Utilising 1200 pings with a 0.5 second interval achieves a standard deviation of 0.59cms-1. The small ping interval will help mitigate aliasing issues. A summary of the instrument setup is provided in Table 27.

Table 27: Sentinel V20 Setup for surface features

Inputs	**Seabed frame**
Power level (dB)	N/A
Long range mode	No
Number of pings	1200
Ambiguity velocity (ms^{-1})	2.75
Blanking cell size(m)	0.4
Number of cells	31
Cell size (m)	0.25
Sampling interval (min:sec)	10:00
Average interval (min:sec)	10:00
Deployment duration (days)	60
AHRS	No
Outputs	
Estimated measurement range (m)	8
Horizontal precision (cms^{-1})	0.59
Vertical precision (cms^{-1})	N/A
Memory usage (MB)	9.21
Power usage (Wh)	2069
Power available (Wh)	3600
Spare power (days)	44
Ping interval (s)	0.5

Signature 1000

The Signature 1000 offers similar functionality to the V100. A cell size of 0.2m is selected to maximize the vertical coverage with 32 cells to capture changes in water levels of up to 1.5m. A 10-minute sampling/averaging interval is selected. To minimize the aliasing of the signal rapid sampling is undertaken with 2400 pings spread across the ten minutes providing a 0.25s ping interval. This delivers a horizontal precision of 0.53cms-1. A single echosounder frequency of 1000kHz is utilized to track the surface. To enable the echosounder functionality a burst sample is required, however as this is unlikely to provide useful information, the sampling interval is set to its maximum value of 6-hours to reduce power consumption. The summary of this setup is shown in Table 28.

Table 28: Signature 1000 setup

Inputs	**Seabed frame**
Power level (dB)	0
Long range mode	No
Number of pings	2400
Ambiguity velocity (ms^{-1})	2.5
Blanking cell size(m)	0.1
Number of cells	32
Cell size (m)	0.2
Sampling interval (min:sec)	10:00
Average interval (min:sec)	10:00
Deployment duration (days)	60
AHRS	No
Outputs	
Estimated measurement range (m)	6.6
Horizontal precision (cms^{-1})	0.53
Vertical precision (cms^{-1})	0.18
Memory usage (MB)	61035
Power usage (Wh)	895
Power available (Wh)	1170
Spare power (days)	15
Ping interval (s)	0.25

Glossary

Term	Definition
Accuracy	Instrument accuracy is defined by the bias associated with long term errors.
AHRS	Attitude and Heading Reference System
Ambiguity velocity	The maximum measured along beam velocity that does not result in a phase shift ambiguity, i.e. a phase greater than +π.
Amplitude	Strength of transmit and return signal measured in decibel
Bandwidth	Frequency spread of the transmit signal
Beam Coordinates	Velocity direction referenced to transducer beams. Each instrument utilizes a beam as instrument north and direction is measured relative to this. The rawest form of ADCP measurements utilizes Beam coordinates.
Broadband	The wide bandwidth setting of a coded-pulse broadband technology ADCP.
Cell	The region of the water column over which the velocity is measured.
Correlation	Correlation is utilized to compare echoes from coded pulses within a single ping to determine phases changes. The correlation coefficient effectively provides a measure of the quality, and low values may relate to poor signal to noise ratio or exceedance of ambiguity velocity.
Echo	Return signal from scatterers
Echogram	Plot showing the echo intensity
Echo intensity	Also sometimes termed echo amplitude or backscatter intensity. Echo intensity is a measure of the signal strength received from the scatterers by the ADCP.
Earth (ENU) Coordinates	Direction is referenced to magnetic north and velocity components are east and north components.
Narrowband	The narrow bandwidth setting of a coded-pulse broadband technology ADCP.
Ping	Single transmit pulse
Precision	Velocity precision is estimated for both horizontal and vertical velocity, and is determined as the standard deviation of a velocity ensemble estimated on internal factors including; transducer frequency, averaging interval, number of pings and cell size.
Side lobe	The beam pattern of a transducer has a main lobe that contains the majority of the transmitted energy, however side lobes point out in different directions from the main lobe. The side lobe energy creates return signals that contaminate the velocity data at boundary layers (surface and seabed).
SNR	Signal to noise ratio
VMDAS	Vessel Mounted Data Acquisition Software – proprietary Teledyne RD Instruments software that supports real time acquisition on rigs.

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This Recommended Practice Guide for Acoustic Doppler Current Profiler (ADCP) deployments is designed to provide sufficient information to identify the most appropriate deployment method, instrument selection, and setup for a range of applications that utilize stationary deployments. An ADCP is a commonly used instrument in the offshore oil and gas industry to measure and monitor the current profiles, i.e., how fast water is moving across an entire water column.