Surface Effects on Long-ranger Moored ADCP (RREX case study)

- Technical note -

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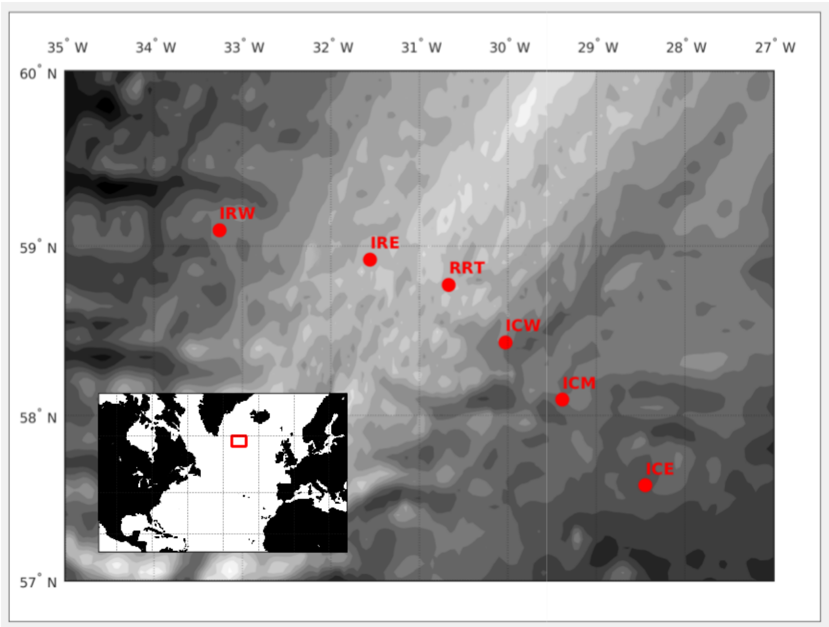
Contents



35° W
34° W
33° W
32° W
31° W
30° W
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60° N
59° N
58° N
57° N
IRW
IRE
RRT
ICW
ICM
ICE

Context & objectives

This document reports on the data of upward-looking moored Acoustic Doppler Current Profilers (MADCP) near the surface (down to 300m deep). Five 75kHz MADCP, also called long ranger, are more particularly studied. They were moored at 450m deep during several months in north Atlantic Ocean [Thierry et al., 2004], and are part of a large in-situ dataset from LOPS RREX project [Thierry et al., 2018]. Those ADCPs (figure 1) show sometimes spurious behavior near the surface, induced by surface wave and lack of particles. The objective here is to discuss these behaviors for a better understanding of our datasets and maybe a better configuration of our instruments in the future.

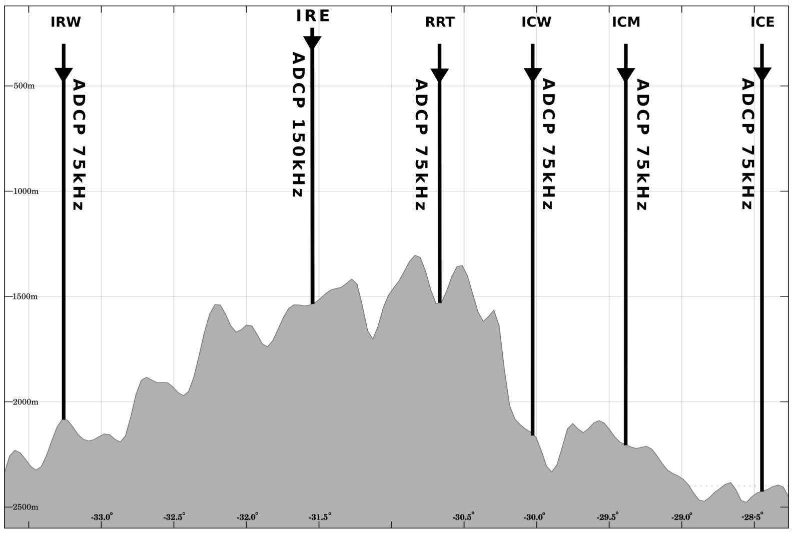


Figure 1: ADCP moored upward on RREX section

Chapter 1

Wave effects

1.1 What we see

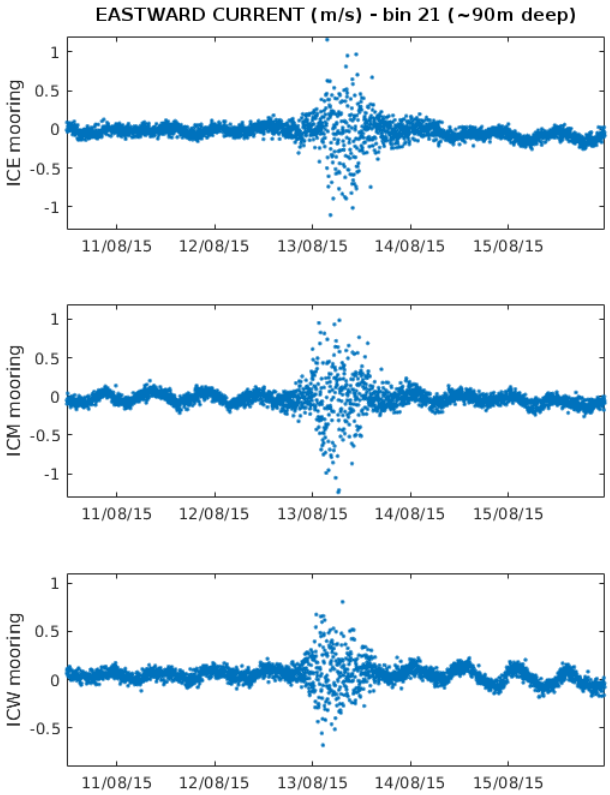
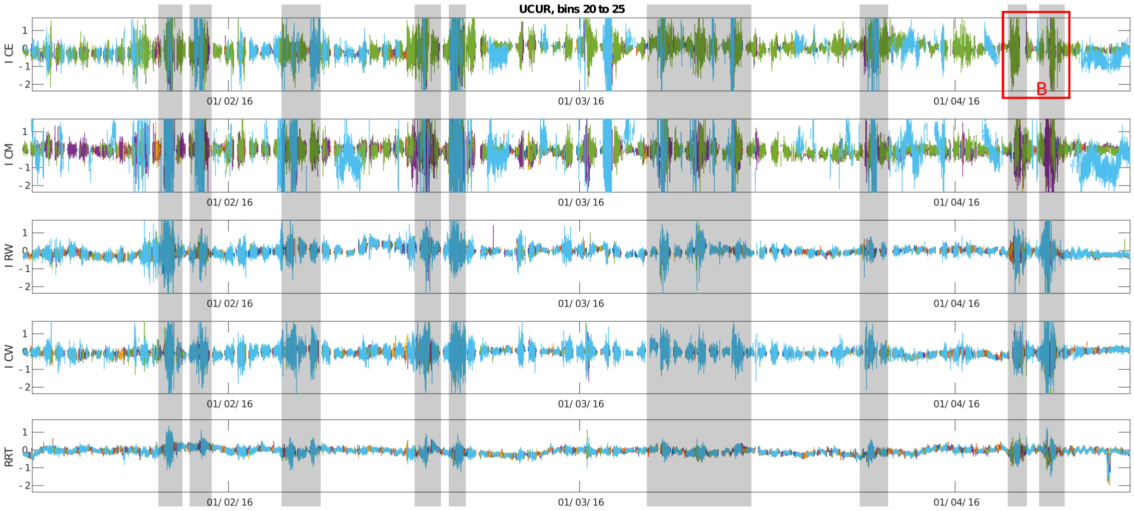


Figure 1.1: Same perturbation on 3 of the 5 long rangers on RREX array

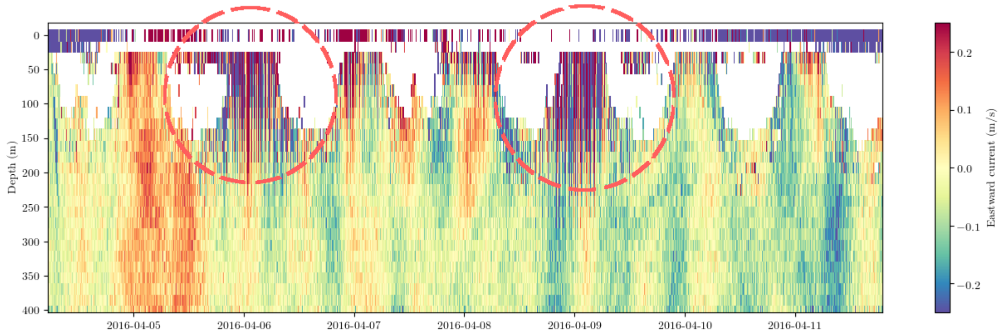
Our 5 long ranger ADCP (WorkHorse 75kHz), moored upward-looking at 300/450m deep, present intermittently noisy data in bins close to the surface. Those unusual noisy behaviors occur on all ADCP at the same time during the deployment, for periods of one to several days. The shape of the disturbance (figure 1.1), its irregular occurrences (a lot during a month, nearly nothing the next one), and the fact that it affects all 5 long rangers simultaneously leaded us to blame a surface phenomenon and probably big waves/swell episodes.

These perturbations are visible from the surface down to 250/300m deep. On the figure 1.2a, showing multiple cells from different ADCP during the complete deployment, we can spot several common periods of perturbation on the 5 instruments.

The figure 1.2b show the section of one ADCP during one of these smaller periods, we can see that the perturbation affects our signal down to ∼250m. Since the 150 KHz ADCP have a smaller range, the data do not reach the surface so it's a little bit less affected by this perturbation (but we still some perturbations in its signal).



(a) Several periods of high variance are noticable on the 5 long rangers. Greyed out areas show some periods where perturbations affect all instrument simultaneously.



(b) Temporal zoom on the eastward current measured by one of the long rangers. In the red circles, the data are highly variable down to ∼250m deep

Figure 1.2

1.2 What's happening

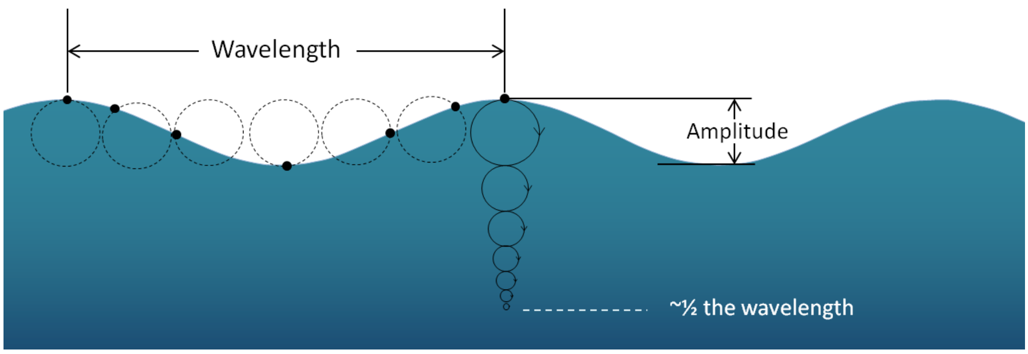


Figure 1.3: Orbital velocities basics

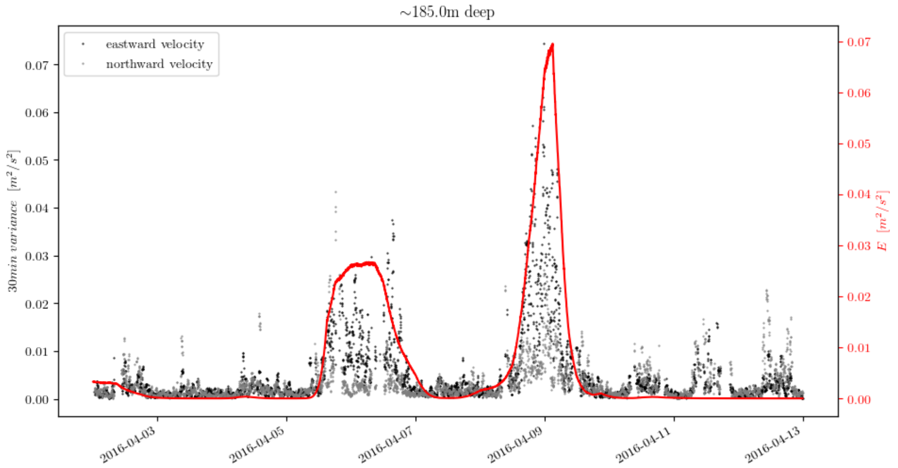
This kind of perturbation is coherent with swell-induced orbital velocities [Ardhuin, 2018](figure 1.3). Their impact is much visible with high swell periods (low frequency, so high wavelength). Swell induced velocities decrease vertically in $\exp(k.z)$, k being the wave number.

$$k \approx \frac{2\pi}{T0m1} \; \frac{1}{g} \quad with \quad \begin{array}{l} T0m1 : \text{swell period} \\ g = 9.81 \; m.s^{-2} \end{array}$$

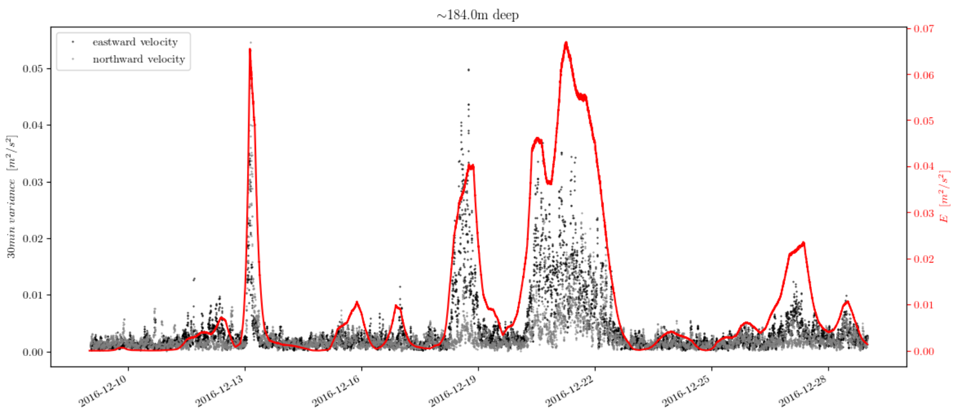
We approximate the orbital velocities variance E at depth z with :

$$E \approx (\frac{Hs}{2})^2 \; (\frac{2\pi}{T0m1})^2 \; e^{k.z} \quad with \quad Hs : \text{Wave height}$$

Using Wave Watch III model [L. Tolman et al., 2016] outputs for $T0m1$ and Hs, we calculate E for the RREX moorings locations and the different time periods and depths of perturbation. The figure 1.4 shows examples of the 30-minute variance of the ADCP signal at a given depth, along with the calculated variance of swell induced orbital velocities for this same depth. Note that the ADCPs ping once every 3 minutes, so variances are calculated on 10 points. The consistency between both quantities means that the measured signal is mainly driven by swell induced velocities during periods of high variance, even down to ∼200m deep.



(a) April 2016



(b) December 2016

Figure 1.4: 30 minutes variance from ADCP measurements, compared to swell induced orbital velocities variance calculated with Wave Watch III outputs.

If we look at the directions in which our ADCP signal is disturbed (figure 1.5), we see that during these big swell episodes, the variance of our signal is mainly in the same direction that the waves. This is coherent with the Airy solution [Ardhuin, 2018] that implies that highest orbital velocities are in the waves direction plane (figure 1.3).

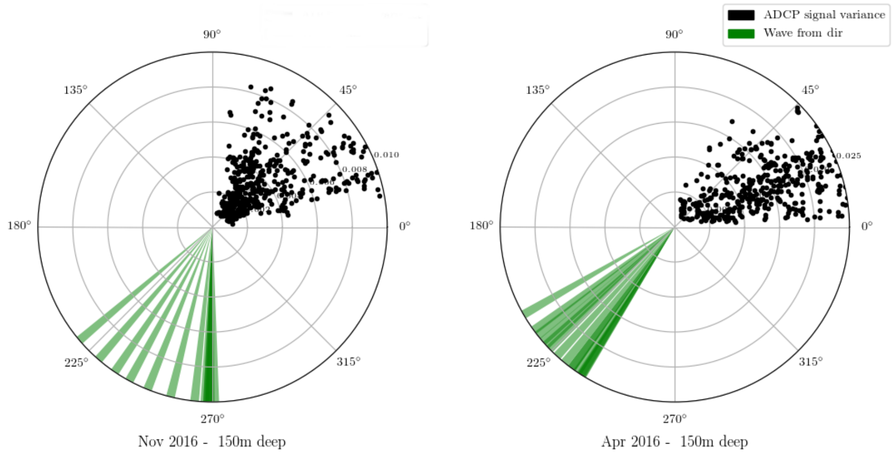


Figure 1.5: Direction of signal perturbation compared to wave direction (output from Wave Watch III) during 2 examples of big swell episodes.

1.3 How we qualified

The qualification of the ADCP data was processed without any consideration of the sea state. We just analyzed the variance of the signal per ADCP and per cell and define, by trial and error, a threshold value for each case to flag bad the highly variable data. The figure 1.6 shows and example of how this process removes the perturbations.
Maybe these threshold values could be defined more precisely using swell-induced velocities theory. If the analysis presented here is correct, the removed velocities are not bad, since they reflect the orbital velocities induced by the swell. However, the ping rate is too low to correctly characterize those velocities since the periods of the swell are around 10s while the ADCPs ping every 3 minutes.

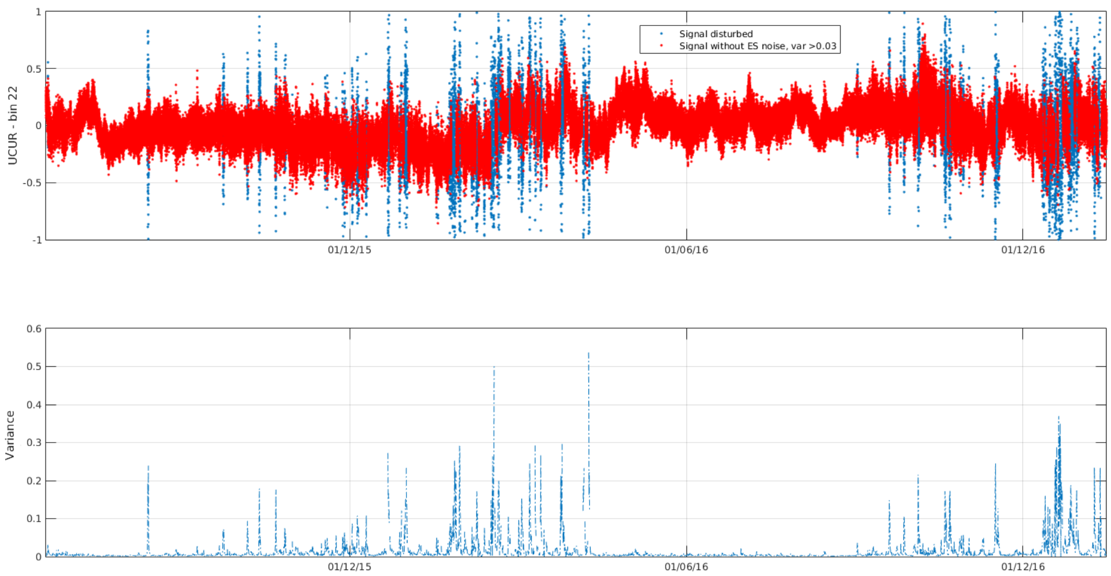


Figure 1.6: Example of qualification of the noisy periods on an eastward current signal, for a specific cell (bin 22) on one of our ADCP. We used a threshold on variance to detect most occurrences. Validated data are in red, while blue points have been flagged bad.

1.4 A word on frequencies

Since our signal is sampled at 1 measure every 180 seconds, we can not directly detect swell frequencies (period around 10-15s). But we can still try to isolate corresponding aliasing frequencies fa (figure 1.7) :

$$fa = abs(n.fs - ft) \quad with \quad \begin{array}{l} fs : sampling\ frequency\ (1/180s) \\ ft : target\ (swell)\ frequency\ (1/[8\ to\ 15s]) \\ n = round(ft/fs) \end{array}$$

We see that some lower frequencies remain after filtering the aliasing frequencies from swell signal (especially, we can observe the tide signal coming back). So for future studies on our time series, we know that we can keep these "noisy" periods, if, for example, we apply a daily low-pass filter on our signal.

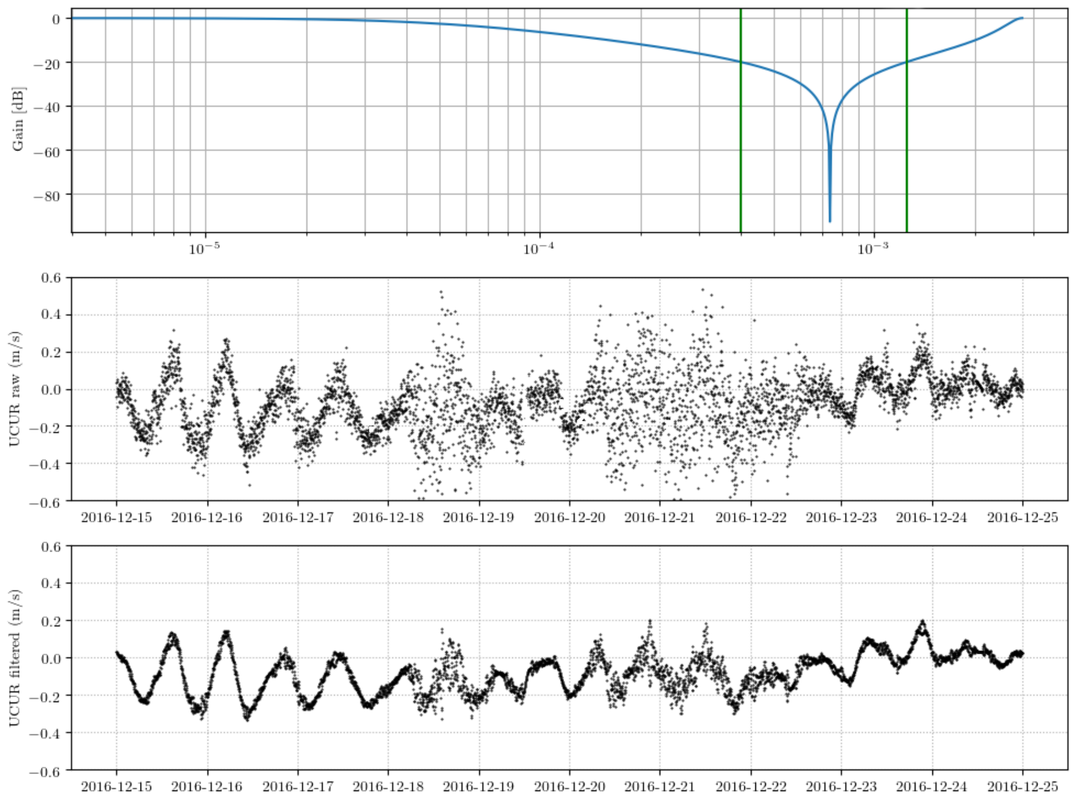


Figure 1.7: **(top)** Stop-band filter design, targeting the aliasing frequencies around 12s swell period. **(middle)** Raw (one sample every 180 seconds) time series of one ADCP at 150m deep where we clearly see the swell induced velocities disturbing our signal. **(bottom)** Filtered time series. We see that behind these higher frequencies (aliasing of swell periods), there still is a lower frequency signal that we can use.

Chapter 2

Lack of particles effects

2.1 What we see

During some daytime periods, we observe holes in the ADCP signal that can reach occasionally ∼200m (figure 2.1). It means that the ADCP could not calculate a proper current value according to its configuration. It appears to be occurring only at daytime repeatedly, and it affects all upward-looking long rangers moored at 450m.

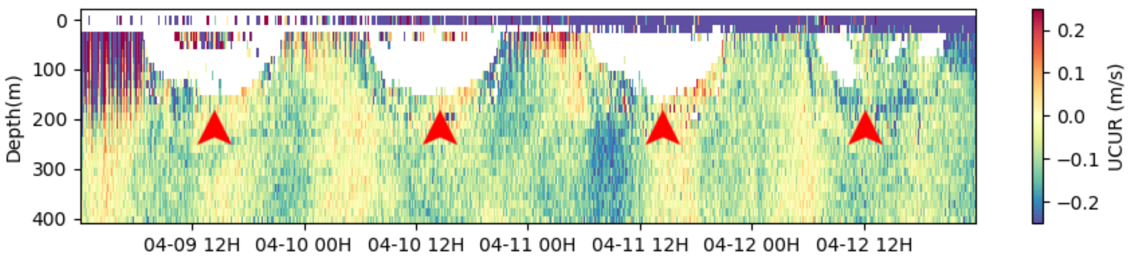


Figure 2.1: Holes in ADCP currents during daytime periods, in white.

This phenomena appears to be more frequent in winter. The figure 2.2 shows the parameter PERG3 (percentage of measurement with one or more bad beam) for the entire time series of one ADCP, showing the seasonality of this behavior.

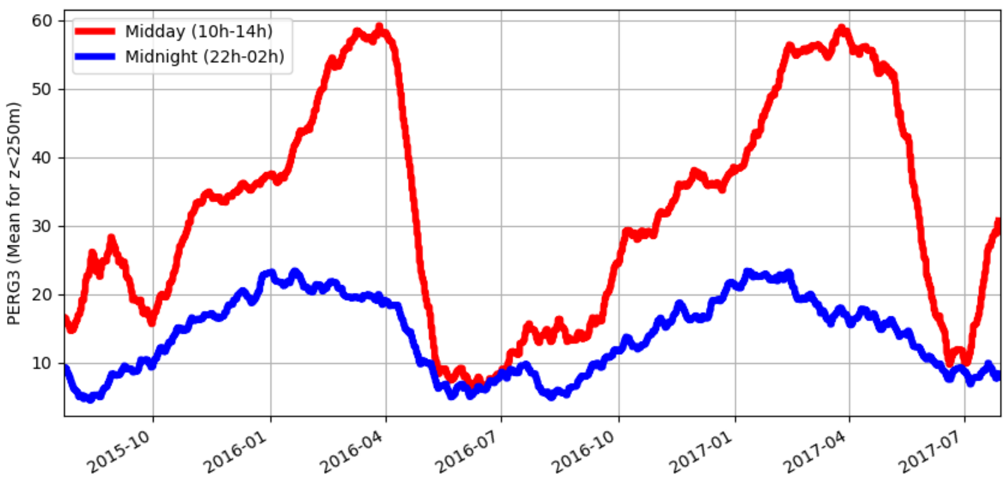


Figure 2.2: Mean percentage of bad measurements above 250m for one instrument during the deployment

2.2 What's happening

To be able to calculate a velocity value, the ADCP needs a certain amount of particles (or scatterers). The dominant oceanic sound scatterer at ADCP frequencies is zooplankton with sizes on the order of one millimeter. Other scatterers can include suspended sediment, detritus, bubbles and density gradients. The amount of scatterers observed by the ADCP for which the return signal can be correctly correlated is found in CMAG variable (*particle distribution correlation magnitude from acoustic beam*, one for each beam of the instrument).
The default value above which the instrument calculates a velocity is 64 counts (this is the WC parameter in the ADCP configuration). This default value was used for all ADCPs. We can see from figure 2.3 that during periods of "blank", the distribution correlation is far below 64, so it's consistent with the absence of signal. According to the constructor, when CMAG is below 64 for several beams, it's not possible to get a clean velocity value so the instrument returns a NaN, but they claim that this situation happens very rarely. Unfortunately for us, it happens repeatedly in winter, and the shape of the holes clearly points to the zooplankton sinking during the day, leaving the surface layer with no scatterers. The 150Khz ADCP (moored at 300m) scan the water column between 300 and 100m deep, and in addition, at this frequency, the instrument can deal with smaller scatterers, so it's less affected by this phenomena (we still see the problem it's just a little bit less frequent).

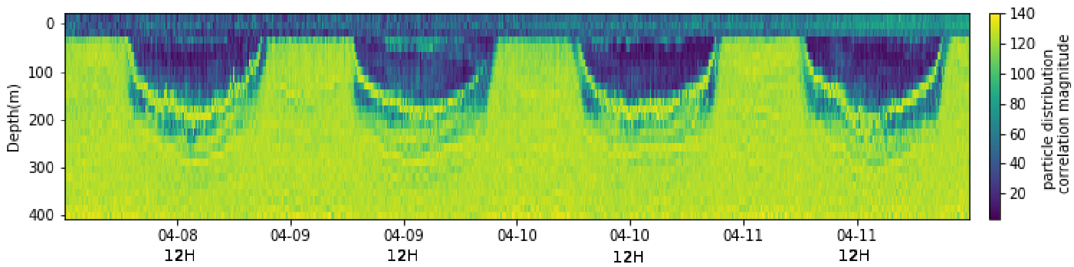


Figure 2.3: particle distribution correlation magnitude (CMAG): mean on beam 1 & 2), where daytime periods show a very low number of scatterers.

When we look at the same plot in summer (figure 2.4), we still see the correlation decreasing in daylight, but the correlation values are high enough to calculate a current velocity. Indeed, the development of the zooplankton is maximum around summer [Kaempf and Chapman, 2016] (figure 2.5).

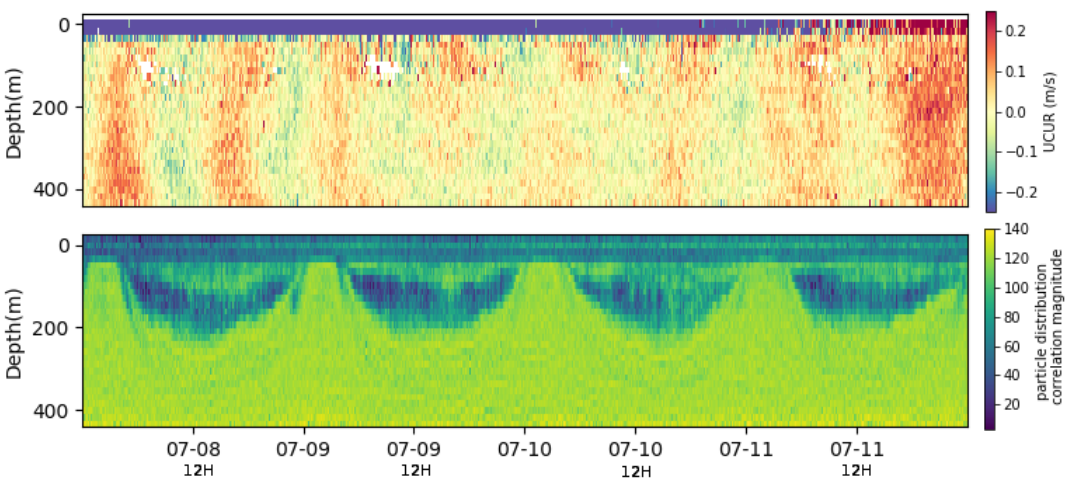


Figure 2.4: Eastward current velocity and particle distribution correlation magnitude (mean on beam 1 & 2) for a summer period

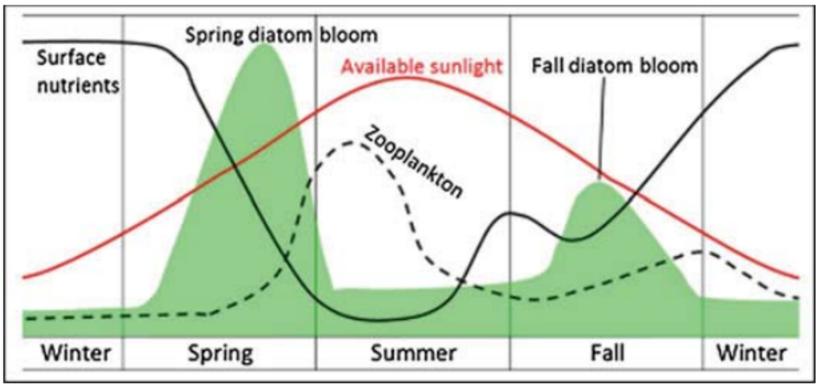


Figure 2.5: Schematic of ambient conditions that trigger the development of spring and fall (autumn) blooms in the North Atlantic [Kaempf and Chapman, 2016]

Conclusion

In the first part of this study, we concluded that the intermittent high variance periods in surface velocities were due to orbital velocities induced by high swell episodes. In the second part, we observed that lack of scatterers led to the absence of signal in the first 200m during daytime in winter. Can we blame the ADCP configuration ?

The chosen configuration depends on the memory and energy available for the deployment and what we want to observe in-fine. There's not much we can do in the configuration about wave effects on current signal. But to avoid blank signal due to the lack of zoo-plankton during winter daylight periods, we may want to force down the WC parameter of the ADCP, especially if we choose not to average multiple pings per ensemble. That way we may be able to raise the signal-to-noise ratio afterwards. However, this test on WC is also recommended by the constructor to remove bad velocity estimates, so it means that we would need to record data in beam coordinates so that we can recompute velocities afterwards with and without the threshold in correlation. If we record data directly in earth coordinate only, we lose this possibility. If possible (memory available and deployment duration) it may be preferable to set a burst mode and average multiple pings per ensemble when we anticipate that the area is oligotrophic.

Bibliography

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Appendix

RDI configuration file (RREX15 cruise)

```
CR1
WM1
CQ255
CF11101
EA0
EB0
ED0
ES35
EX11111
EZ1111101
WA50
WB0
WD111100000
WF704
WN35
WP1
WS1600
WV175
TE00:03:00.00
TP03:00.00
TF15/06/06 12:00:00
RN RREX_
CK
CS
;
;CR1 : reset ->parametres usine
;WM1 : Mode normal (pas LADCP)
;CQ255 : valeur par defaut 255. Allows the transmit power to be adjusted
;CF11101 : valeur par defaut 11111. Le 0 -> disable serial output
;EA0 : valeur par defaut 0. Heading Alignment
;EB0 : valeur par defaut 0. Heading Bias
;ED0 : valeur par defaut 0. Depth of Transducer
;ES35 : valeur par defaut 35. Salinity
;EX11111 : valeur par defaut 11111. Coordinate Transformation ->earth coordinate
;EZ1111101 : valeur par defaut 1111101. EZ1111101 means calculate speed of sound
     from readings.
;WA50 : valeur par defaut 50. False Target Threshold Maximum. 255=disable.
;WB0 : valeur par defaut 0.  Bandwidth Control 0 (Wide), 1 (Narrow)
;WD111100000 : valeur par defaut 111100000 . WD 111 100 000 (default) tells the ADCP
     to collect velocity,correlation magnitude, echo intensity, and percent-good.
;WF704 : valeur par defaut 704 pour 75kHz. Blank after Transmit en cm
;WN35 : Number of Depth Cells
```

```
;WP1 : Pings Per Ensemble.  (no averaging)
;WS1600 : default 1600 for a 75 kHz. Depth Cell Size in cm
;WV175 : default 175. Ambiguity Velocity
;TE00:03:00.00 : Time Per Ensemble
;TP03:00.00 : Time Between Pings
;TF15/06/06 12:00:00 : Start time
;RN RREX_ : Set Deployment Name
;CK : Stores present parameters to non-volatile memory
;CS : Go
;
;Instrument         = Workhorse Long Ranger
;Frequency          = 76800
;Water Profile      = YES
;Bottom Track       = NO
;High Res. Modes    = NO
;High Rate Pinging  = NO
;Shallow Bottom Mode= NO
;Wave Gauge         = NO
;Lowered ADCP       = YES
;Ice Track          = NO
;Surface Track      = NO
;Beam angle         = 20
;Temperature        = 5.00
;Deployment hours   = 17520.00
;Battery packs      = 8
;Automatic TP       = YES
;Memory size [MB]   = 512
;Saved Screen       = 2
;
;Consequences generated by PlanADCP version 2.06:
;First cell range   = 24.69 m
;Last cell range    = 568.69 m
;Max range          = 502.99 m
;Standard deviation = 3.93 cm/s
;Ensemble size      = 854 bytes
;Storage required   = 285.38 MB (299241600 bytes)
;Power usage        = 3018.25 Wh
;Battery usage      = 6.7
;
; WARNINGS AND CAUTIONS:
; Advanced settings have been changed.
```