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Technical Report

Inspection of possible mooring related problems in wave data from the Faroe Shelf

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Samandráttur

Undir kanningum av dátu frá aldumátingunum kring Føroyar, sum høvdu til endamáls at kanna ávirkanina av sjóvarfallinum á aldu parumetrar, var ein ivasom variatión varnast við periodu uppá umleið 6 tímar. Tann einasta funna frágreiðingin higartil, sum kann greiða eina slíka variatión, er ávirkan frá fortoyningini á máti boyðuna samantvinna við í høvuðsheitum hálvdagligt sjóvarfalsrák á staðnum.

Henda frágreiðingin gevur eitt sindur av innliti í hvussu trupuleikar tengdir at fortoyningini undir ávísum umstøðum kunnu varnast í tíðarrøðum við aldu dátu. Uppskot til eitt hátt at kanna dáta er givin, og roynd á mátingar gjørdar á føroyska landgrunninum. Harumframt eru nøkur møgulig hjáárin av trupuleikum tengdum at fortoyningini givin, og nøkur ráð fyri tað serstaka dømi eru viðgjørd.

Abstract

During the inspection of the tidal influence on wave parameters measured of the Faroe Islands, a spurious 6-hour variation was observed. The only explanation found, so far, which can induce such variations, is the influence of the buoy mooring, combined with a mainly semidiurnal variation in the strength of the tidal current.

This report gives some insight into how mooring related problems can be detected in wave parameter series under given circumstances. A method for data inspection will be outlined, and applied to buoy data from the Faroease shelf. Some possible side effects of mooring related problems are outlined, and some recommendations for the specific case are discussed.

Introduction

There are many different methods used to measure local wave characteristics, but the moored accelerometer buoy seems to be one of most popular choices worldwide (Tucker and Pitt, 2001). This method has, even if it is executed properly, some inherent weaknesses related to the buoys Lagrangian path (Magnusson et al., 1999), and the need to filter out low frequency components of the data (Prevosto et al., 2000). One other point often made is that the mooring might steer the buoy around the peaks of high short crested waves and thus artificially reducing the measured wave height.

Under some conditions the mooring might even cause the buoy to submerge and the detection of such events is not as trivial as it may seem. Detection of these clipped sea states depends on the data transition system used. If a online connection is used (Radio or similar) where the data are transmitted “live” to shore, the presence of clipped crests will be observed as “flat spots” in the raw time series, that is if the buoys antenna is fully submerged and the connection is lost. But if the antenna is not fully submerged or the data is stored onboard the buoy and transmitted later (ARGOS or similar dialup or backup systems), no flat spots will appear in the time series, thus making it virtually impossible to evaluate if the true sea state is recorded or not. Such problems could be detected and corrected if a high resolution pressure sensor were mounted underneath the buoy.

In the following paragraphs a simple test applicable to wave buoy data from coastal Faroese waters will be outlined. This test will give a first indication of whether or not the mooring is flexible enough or if clipped sea states are a recurrent problem in the recorded data.

Background

In 1979 a wave measurement program was started at four locations around the Faroe Islands. A technical overview of the original setup, consisting of four waverider-buoys is given in Davidsen and Hansen (1981). The main purpose of the measurements (witch are broadcasted on local radio daily), is to inform the local fishermen of the present sea state and also trough time to give a better understanding of the local wave climate. In the first deployments the standard rubber band mooring was used, but in the course of time the buoys mooring setup was simplified due to operational considerations (Heinesen, 2001b).

Recently a cooperation of oil companies interested in the Faroe area (Atlanticon) contracted Oceanweather to do a comparative analysis of their North Atlantic hindcast (AES40) and satellite altimeter data (ERS1/2 and TOPEX) with the Faroe buoy data. In their report the south buoy (1979-88 operated by Landsverk) was chosen to be the best suited common point of reference. In their conclusion it is stated, that it seems as if the buoy data are somewhat clipped for extreme events (Ceccacci and Cardone, 2001).

As a part of a PhD project the buoy data were recently investigated in order to see to what extent the current influenced the measured wave parameters. Under this investigation it became clear that 6-hour variations in the Hs, H_{max} and T_{m02} series, that at first sight seemed to be generated by wave-current interaction, was in fact an indication of a mooring problem, which was made detectable by the oscillating character of the tidal current.

Physics

If the current at the buoy location can be approximated by one dominating tidal ellipse, in the Faroe area this is M2 with a period of 12.4 hours, the minor- and major axes in the tidal ellipse will typically not be equal. The buoy and mooring are therefore caused to experience a slow variation in the drag force triggered by the current, and the period of this variation will (because of symmetry) be half the tidal period (~ 6.2 hours).

If the drag force exerted by the current is too large compared to the flexibility of the buoy mooring (or the buoys up drift), the movement of the buoy might be restricted to the level that the buoy at times will be fully submerged. The recorded wave profile will therefore include some clipped waves and the recorded significant wave height will be reduced relative to its true value.

If the measured Hs series is modulated/(less valued) every half tidal period, the energy of the half tidal period would be visible in the Hs power- or wavelet spectrum. As will be mentioned later, it is this property which makes it possible to check the measured wave parameters for mooring related problems.

Data

The approximated positions of the waverider buoys are depicted in Figure 1, and rough bottom contours and semidiurnal tidal ellipses are sketched in Figure 2. Some basic information concerning the measurement sites and information related to the tidal current at the sites is given in Table 1.

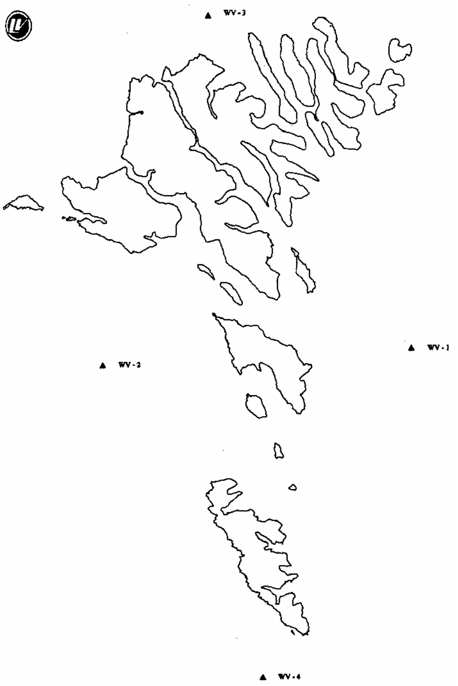
Landsverk has been in charge of the measurements at the deployment sites WV-1 (East), WV-2 (West), WV-3 (North), WV-4 (old South buoy) and the first two years of WVD-4 (new South buoy).

The measurements to the South of Faroe Islands (WV-4) went out of operation in 1988, but measurements started again, at WVD-4, in 1999 on behalf of a consortium of oil companies. Since 2001 the south measurements (WVD-4) have been conducted by Sp/f Data Quality.

Datawell recommends a mooring system based on a false bottom (i.e. an underwater buoy) and a rubber cord mooring to the waverider (Heinesen, 2001a). The south buoy (WVD-4) uses a recommended mooring system, but the buoys operated by Landsverk (WV-1 to WV-4) use a rope, with a certain amount of slack, instead of the rubber cord.

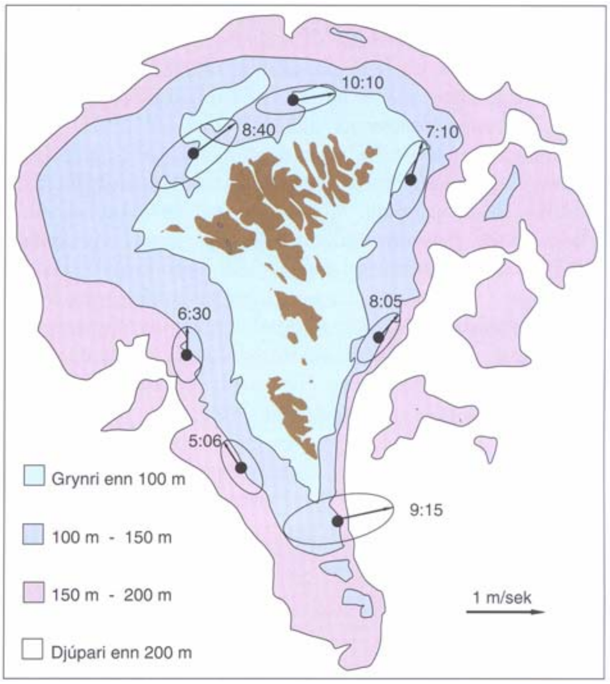
The WVD-4 buoy used a fixed number of waves (1024) for each data storing, in the first 8 deployments. This setup resulted in storing sequences from 2-6 hours in some cases. From deployment 9 (date 7/1-2003) and forwards there is one storing each hour based on 20 minutes of data (Heinesen, 2004). The WV1-4 buoys have used different setups at different times. One period data was stored every third hour, another period at random clock hours and later once an hour (Heinesen, 2001a). The dates corresponding to these shifts, are not precisely specified, but from 1988 and forwards hourly storing rates are used.

Figure 1 (positions of the waveriders)



Source: (Heinesen, 2001a)

Figure 2 (depth contours and M2 tidal ellipses)



Source: (Hansen, 2000)

Table 1 (information related to the measurement sites)

Id	Name	Position		Depth	Start – End	M2 major	M2 minor	Direction	Phase Lag
WV-1	East	61° 48' N	06° 13' W	100	1980 -	39,7	10,1	52,4	232,4
WV-2	West	61° 52' N	07° 32' W	130	1981 -	32,8	19,9	117,8	164,7
WV-3	North	62° 30' N	06° 50' W	100	1979 -	48,1	12,5	17,3	291,9
WV-4	South	61° 13' N	06° 29' W	130	1979 - 1988	58,9	24,5	19,8	256,5
WVD-4	South	61° 18' N	06° 17' W	240	1999 -	33	3,7	38,6	248,1

Source: (Heinesen, 2001b) and (Simonsen, 1999)

Method

The first step in checking the wave data for mooring related issues, is to calculate the power spectrum of a parameter series (Hs series gives the clearest indication). The first test is then to observe for each deployment, if the 6.2-hour period is “over represented” in the power spectrum. An subjective evaluation can be obtained if significant testing, as described in (Torrence and Compo, 1998) is applied.

An energetic 6.2-hour period might be caused by wave current interaction. The relative magnitude of the 6.2- to the 12.4-hour tidal components in the region, auth therefore to be compared to the height of the corresponding peaks in the Hs power spectrum. As an example the largest tidal components close to the 6.2-hour period, for the Faroe offshore area, are approximate 1-2 orders of magnitude smaller than the 12.4-hour tidal components M2 (Hansen and Larsen, 1999).

If the 6.2-hour period is overrepresented, the next step is to examine if this is a general trend in the data or if it only occurs under specific conditions. Some time-frequency resolving method such as wavelet transform plot can be applied for this purpose.

Suppose the 6.2-hour period is only significant in stormy seas, then this might indicate a need to add extra flexibility to the mooring. Or if the 6.2-hour period only appears after a specific time, this might indicate that the stretching mechanism was damaged at this time, but if the 6.2-hour period is a reoccurring event, this indicates either wave-current interaction or mooring problems. Applying wavelet transform or similar techniques simplifies the task of locating events along the data series where the 6.2-hour period is overrepresented, thereby speeding up the visual inspection of the data.

If current measurements are available at the same location as the wave measurements are done, or it is possible to generate the tidal current at the site from a numerical tidal model, the final test is to compare wave height and simultaneous current strength for those time intervals where the 6.2-hour modulation is present in the wave series. If the wave height is continuously in opposite phase compared to the current strength, then this is an indication of possible mooring difficulties.

Limitations of the method

Given that the tidal ellipses are nearly symmetrical, or the measurement rate is too coarse to resolve 6.2 hour peak, the application of the procedure outlined above will not give any useful result.

If the time series consists of several discontinuous intervals, then the application of direct spectral analysis (FFT) will be influenced by the manner in which this problem is addressed. In the same manner the wavelet analysis will be influenced by edge effects, if the issue of the non continuous time series is not addressed. As can be seen in the Appendix F-G, the edge effects in the wavelet transform plots can be virtually eliminated if simple linear interpolating is done in the missing data points.

When the measurements are done in an area where the tidal currents are of minor importance compared to other currents, the application of wavelet and power spectra will be of no help. Under this circumstance the current strength at the site must be known, and some alternative correlation test should be done.

Results

To make the analysis of the wave data faster, each year from each measurement site is in the following treated as it is one continuous measurement, instead of analyzing each deployment separately.

The parameters which will be investigated are H_{m0} and T_{m02}.

Power spectra

For each year the power spectra of the series are calculated and the high frequency part of the spectra are plotted in Appendix A-E. To make the spectral evaluation easier, that is recognizing the presence and relative magnitude of the 12.4 and 6.2 hour peaks, the x-axis in the spectral plots are converted into period (hour) instead of frequency (hour $^{-1}$).

The parameter series of H_{m0} and T_{m02} and their respective ‘power spectra’ for the different sites are placed in the appendix, in the following order:

East buoy (WV-1):	Appendix A
West buoy (WV-2):	Appendix B
North buoy (WV-3):	Appendix C
South buoy (WV-4):	Appendix D
New South buoy (WVD-4):	Appendix E

To make the results more transparent a table summarizing the rough trends in the data (with regard to the tidal influence) is placed on the first page of each of the appendixes.

Looking at the results it is clear that the tidal influence is only present if the storing rate is not too coarse. This means that the 6.2 hour check can only be applied to the newer part of the time series where the storing sequence is 1 hour.

The M2 or 12.4-hour peak is not present in all the inspected years. In the series with the fixed number of waves for each measurement, this might be caused by the coarse storing rate. The storing rate can on the other hand not be blamed for the disappearance of this peak for those years where the storing rate is 1 hour. Why the M2 peak disappears some years is not clear. The following trends can be observed:

- The 12.4-hour peak is present for most years in the T_{m02} power spectrum.
- The 12.4-hour peak disappears more often in the H_{m0} spectrum compared to the T_{m02} spectrum.
- The 12.4-hour peak is present in most years where the 6.2-hour peak is present.
- The 6.2-hour peak is detectable some years where the 12.4-hour peak is missing.
- The 6.2-hour peak occurs more often in the H_{m0} spectrum compared to the T_{m02} spectrum.
- The relative magnitude of the 6.2-hour peak to the 12.4 hour peak is larger in the H_{m0} spectrum.

Trends corresponding to the individual sites:
- In the WV-1 series the 6.2-hour peak appears in 8 out of 13 possible years, in the H_{m0} spectrum.
- In the WV-2 series the 6.2-hour peak does newer occur.

- In the WV-3 series the 6.2-hour peak appears in 8 out of 11 possible years in the H_{m0} spectrum.
- In the WV-4 series no conclusion can be reached, due to coarse storage rate all years.
- In the WVD-4 series the 6.2-hour peak does newer occur.

One possible reason that the 6.2-hour peak newer occurs in the data from the West buoy (WV-2), in spite of the fact that the mooring used here is similar to the ones used at WV-1 and WV-3, is the lack of asymmetry in the M2 tidal ellipse. Looking at Table 1, the ratio of the M2-major to the M2-minor component of the current strength is the following for the different sites:

WV-1 ~ 4
WV-2 < 2
WV-3 ~ 4
WV-4 ~ 2
WVD-4 ~ 9.

The fact that the 6.2-hour peak does not occur for the new South buoy, in spite of the clear asymmetry of the M2 tidal ellipse, suggests that the mooring used at this site (WVD-4) performs better than the altered mooring used at the other sites. To give examples of the presence and absence of the 6.2-hour peak in a power spectra, Figure 3 displays the time series and power spectra of H_{m0} and T_{m02} from the East buoy year 2002, and Figure 4 displays the time series and power spectra of H_{m0} and T_{m02} from the new South buoy year 2003.

Figure 3
Time series and spectra of H_{m0} and T_{m02} from WV-1 2002.

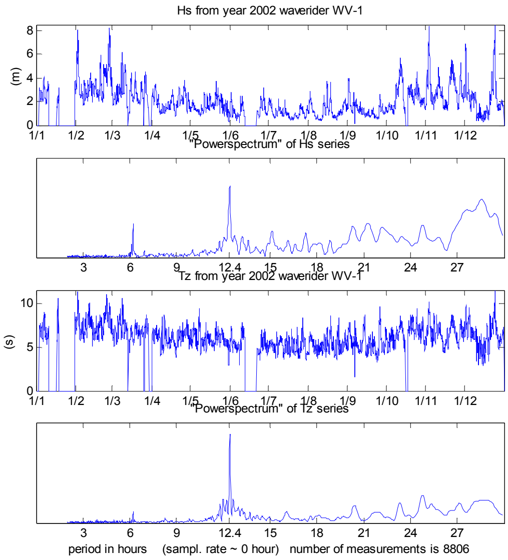
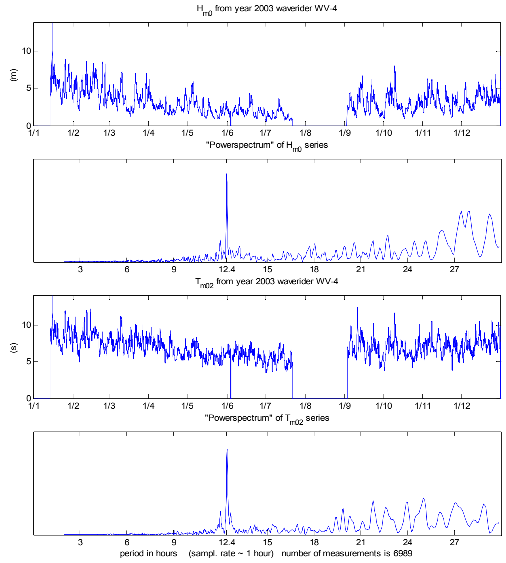


Figure 4
Time series and spectra of H_{m0} and T_{m02} from WVD-4 2003.



Wavelet spectra

The wavelet procedure used is the one described in Torrence and Compo (1998). This method is well suited for this purpose in many respects. The only effect one must be aware of, is that the tidal modulations in wave height are scale dependant. Therefore if the method is applied directly without any prior detrending of the data (as it is done here), the significance level will be to high compared to the tidal modulations in fair weather. This effect is visible in the wavelet power spectra, since there seems to be a lack of incidences with tidal influence in the summer time.

Only the newer series from WV-1 and WV-3 are inspected with wavelet spectra, since these were the only ones witch stood out in the power spectral test, as having possible mooring problems. The wavelet spectra concerning WV-1 and WV-3 are placed Appendix F and G respectively. Zoom plots of possible events where the 6.2 hour modulation is present, are given and plotted together with the strength of the tidal current at the site. The tidal current is generated from the numerical model developed by K. Simonsen, and based on the 8 main tidal constituents.

The general trends of the wavelet power spectra inspections and zoom plots results are summarized in a table given on the first page of the respective appendixes. These tables are also given here as table 2 an 3. More information on the tables is given in the respective appendix.

Table 2 Main results from the inspection of the East (WV-1) series

Year	Significant in whole series 6.2-h	 12.4-h	6.2-h present in zoom plots
1991	No	No	No
1992	No	No	No
1993	Almost	Almost	Yes
1994	Almost	Almost	Yes
1995	Almost	Yes	Yes
1996	No	Almost	No
1997	No	No	No
1998	No	Almost	No
1999	Yes	Yes	Yes
2000	Yes	Yes	Yes
2001	No data	No data	No data
2002	Almost	Almost	Yes
2003	Almost	Yes	?

Table 3 Main results from the inspection of the North (WV-3) series

Year	Significant in whole series 6.2-h	 12.4-h	6.2-h present in zoom plots
1989	No	Almost	No
1990	No	Yes	No
1991	Almost	Yes	Yes
1992	Almost	Yes	Yes
1993	Yes	Yes	Yes
1994	No data	No data	No data
1995	No data	No data	No data
1996	No data	No data	No data
1997	No	Yes	No
1998	No data	No data	No data
1999	Yes	Yes	Yes
2000	Yes	Yes	Yes
2001	*	*	*
2002	Yes	Yes	Yes
2003	No	Yes	No
2004	Almost	Yes	Yes

One thing which is visible in the wavelet spectra, is the trend that the 6.2-hour modulation is not constantly present, but only occurs only under some conditions. A further inspection into which these conditions are, is beyond the scope of this report.

The main function of the wavelet power spectra is to localise events in time, where the 6.2-hour variation is present. Figures 5-6 give examples of how the 6.2-hour modulations can look like in the measured wave height.

Figure 5

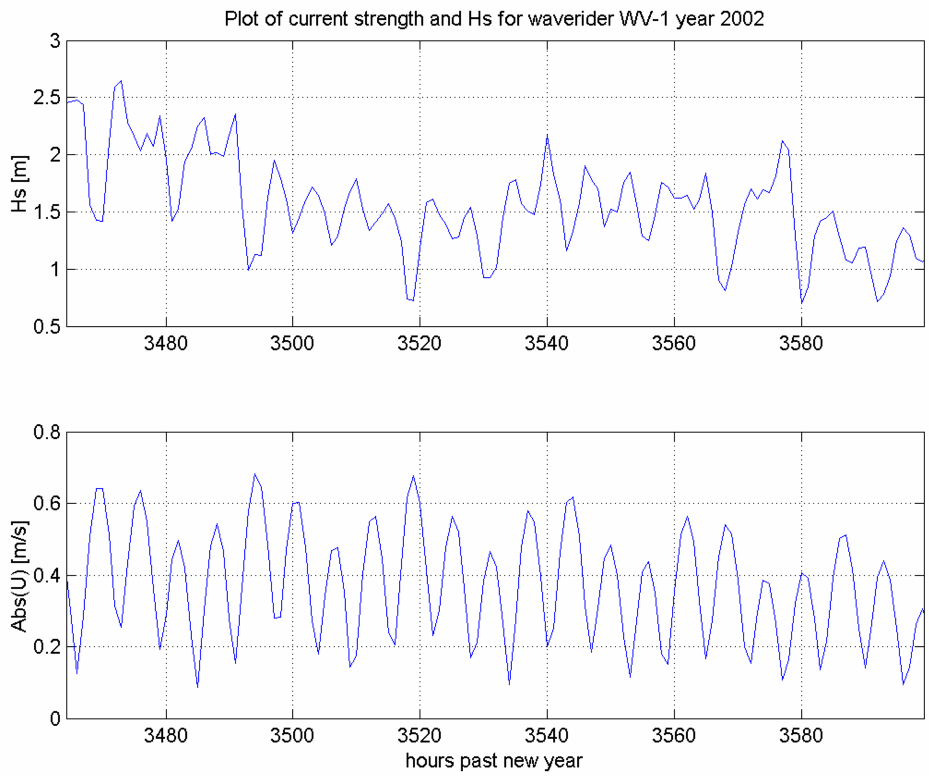


Figure 6

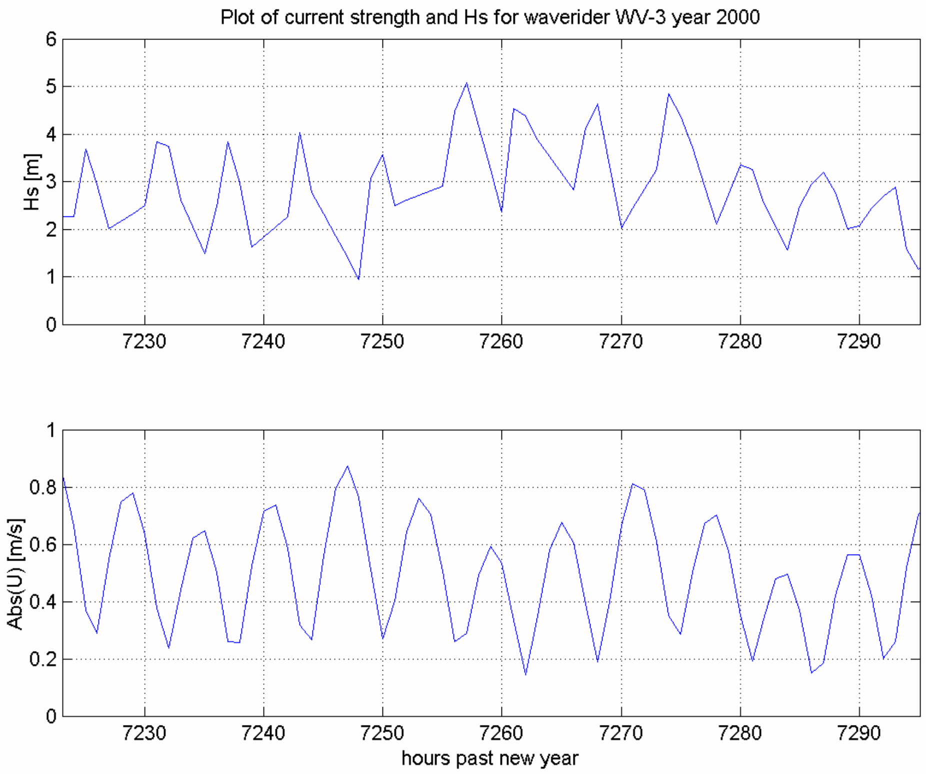


Figure 6 gives an example how much the mooring can alter the measured wave height. As can be seen the modulation can be up to 2-3 meters lower in the stronger current case compared to the intervals where the current strength is smaller.

The examples of the mooring influence vary much from time to time, and the event depicted in Figure 6 is one of the clearest. The example in Figure 5 shows one of several more subtle events where a 6-hour variation is on top of a 12-hour variation. The fact that these 12- and 6-hour variations often occur simultaneously makes it hard to distinguish between real tidal influence observed in the data and a possible artificial tidal influence generated by the mooring effect.

Rough event comparison

In order to get a first impression of whether some of the high seas recorded using the simplified mooring were clipped or not, a limited comparison of the WV-1 and WV-2 data to the WVD-4 data was made.

The first step was to find all events in the WVD-4 data (1999-2004) that had a significant wave height larger than some fixed value. A threshold of 8 meters was used for Hs which gave some 24 events.

The next step was to select events that could be compared to WV-1 or WV-2 measurements. To insure that the effect of land-sheltering was unimportant, the mean wave-direction measured at WVD-4 should be between 30-150° if an event could be compared to WV-1 measurements and 200-250° if an event could be compared to WV-2 measurements, where direction is given clockwise from North (90° corresponds to waves coming from East etc.). This reduced the amount of events down to the 7 which are displayed in table 2.

Table 2

Time of event	WVD-4 Dir	WVD-4 Hs [m]	WV-1 Hs [m]	WV-2 Hs [m]
9/9-1999	~ 230°	9.4	-	9.4
17/6-2002	~ 215°	**10.7**	-	**9.1**
3/11-2002	~ 120°	8.3	8.4	-
15/1-2003	~ 235°	**14.1**	-	**12.0**
11/2-2003	~ 245°	8.7	-	9.1
24/2-2003	~ 205°	**8.5**	-	**6.4**
4/2-2004	~ 230°	8.0	-	7.5

In table 2 it can be seen that half the events in the intercomparison between site WVD-4 and WV-2, there is a negative lag in the measured wave height at WV-2 (displayed with bold letters in the table). It must of cause be realized that this comparison is very simplified, disregarding dynamic effects etc. and that it is not appropriate to base any conclusion on such a small data set.

Discussion

One central issue when discussing measurements is to recognize that there can be a difference in the motivating factors behind the measuring procedures. To put it roughly there are two different branches. The first we will call operationally-motivated, where the main emphasis is having a robust measuring system that is simple, cost-efficient and gives acceptable results. The second branch we will call statistically-motivated. Here the main motivation is gathering as accurate information as possible, as some large future investments might rely on the results.

In the case discussed here, the WV-1 to WV-4 sites, are mainly operationally motivated, whereas the WVD-4 site is motivated by possible future investments.

Mooring problems are a reoccurring problem where accelerometer buoys are used, and the detection of such problems isn't always a simple task. Given the storing rate used in the first many years, tidal-mooring interaction is not possible to detect in the data series. Since the deployment sites are so far from the shore, visual or other direct inspection of the buoys performance in all sea states, at their respective locations, has not been possible. Looking at the wavelet power spectra, it is also clear that the simplified mooring performs well most of the time. There have therefore not been any clear indications of mooring related problems. But now there are several arguments that seem to support the view that the simplified mooring does influence the measured wave height under some circumstances. The arguments are summarized below:

> The simplified mooring system does not meet the same criteria to flexibility and constant strain[1] as the standard/recommended rubber band mooring. Under such conditions the probability of wave clipping is increased.
>
> The investigation done by OceanWeather, where the old south buoy data (WV-4) were compared to their hindcast and satellite data, suggests that the measured wave height is clipped in extreme events (Ceccacci and Cardone, 2001).
>
> A direct comparison of a few simultaneous recorded rough events, as it is done in the previous section, indicates that there might be a negative lag in the recorded wave height, in high sea states, at sites where simplified mooring is used.
>
> Although there is no clear physical argument, besides the mooring effect, for a reoccurring 6.2-hour variation (at least not with the magnitude that are observed in the wave height), this variation does occur at the sites using the simplified mooring, and not in the data from the new South buoy which uses a rubber-band mooring.
>
> Zoom plots of the events, where the 6-hour variation are present, support the claim that the measured wave height is at times reduced when the tidal currents are at their strongest. As argued previously this variation is expected if there are problems with the mooring flexibility.

The arguments stated above clearly indicate that simplified mooring at times influences the measured wave height. It must therefore be recommended that the use of data, gathered with the simplified moorings, should be done with care. As an example the detailed inspection of wave

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[1] The constant strain is necessary to insure that the buoy describes the sea state as close to a point measurement as possible. If no strain and too much slack are present the buoy can travel around steep wave crests, and in this manner create a negative bias in the measured crest height.

current interactions should not be performed on such a series as it is hard to distinguish between the influence of the currents or the mooring.

If the mooring restricts the buoy movement in relative calm situations, which it sometimes seems to do, it might be suspected that this also is the case under rough circumstances. This seems to be supported by some of the findings in the OceanWeather report (Ceccacci and Cardone, 2001). The mooring might therefore have an influence on the wave climate and design criteria calculated from the measurement series. The possible effect that the mooring might have on the wave climate statistics, is of cause limited as the buoys usually give acceptable results.

If we assume that the AES40 North Atlantic Hindcast gives more reliable time series at the old south-buoy location compared to the buoy (which used the simplified mooring), then the error would be an underestimation of the 100-year sea state by 2m, as the 100-year Gumbel Hs from the buoy is 15.6m, whereas AES40 gives 17.6m (Ceccacci and Cardone, 2001).

To go into details of inspecting the local wave climate (preferably directional) based on data from the different sites etc., is beyond the scope of this investigation. But since these data are a large part of the foundation of our understanding of local wave conditions, this issue aught to be addressed at some time.

The buoys at sites WV-1, WV-2 and WV-3 recently are updated to measure directional information. Since directionally resolving buoys have stricter mooring requirements (DataWell home page) it is also recommended to examine if or to what extent the simplified mooring influences the directional measurements.

Recommendations related to inspection of the wave climate

There are several ways in which the mooring effect can be addressed, such that its influence on the wave climate can be reduced/eliminated. Some suggestions are given below.

> The simplest step is just to recognize that there might be a problem. So when the design conditions are calculated from these series, a safety margin might be added.
>
> Another simple step would be to run a low period maximum filter trough the data, and then downsample the whole series to corresponding to this filter. This would possibly correct most of the mooring influence in normal conditions, but would not solve the issue of clipped sea states in stormy events.
>
> Since the WVD-4 measurement series is not influenced by its mooring, some of the data could be reviewed using this series as a step stone. This could be done using a combination of numerical and statistical methods.
>
> Numerical models could also be used to transfer wave data, from numerical hindcasts covering our offshore area, to the buoy positions. An extra gain of this procedure is that the wave climate at the buoy positions would be founded on continuous time series, including directional information. If such a procedure were to be done, it is recommended first to validate the model against existing measurements which are done with proper moorings.

Conclusion

Wave data from the Faroese shelf have been investigated and it is found that buoy measurements made with a simplified mooring, are at times influenced by the mooring. It is therefore recommended to use these data with caution, as it is difficult to estimate when or how much the mooring has influenced the measurements.

It is found that the presence of semi tidal modulations in the wave height, might indicate mooring problems. A procedure is outlined which under certain circumstances can be used to inspect buoy data for unwanted mooring effects.

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