DANGEROUS SEAS FROM AN INSTALLATION CONTRACTORS PERSPECTIVE

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1. INTRODUCTION

Talking about dangerous seas one usually mean high sea states. But from an Transport & Installation contractors perspective 'dangerous' can have a totally different meaning. This paper is meant to bring some nuance in what is generally understood by 'dangerous' and to create awareness what exactly is important during offshore operations. This will strengthen the mutual understanding of science and end-user of wave models.

First it will be shown that for a transportation the situation is different than during installations. For transportations the dangerous seas are more in line with the general perception: usually steep waves or rogue waves. Then the focus will move to all other important aspects that arise during an offshore operation including vessel motions and the use of weather forecasts. The paper ends with some examples of experienced shortcomings and some conclusions that can be drawn from them.

2. TRANSPORT AND INSTALLATION

Transportation
Although transportation and installation are often mentioned in the same sentence, there is a big gap between the wave conditions that determine the success of each of these two stages. The duration of a transport normally exceeds the forecasting horizon of 3 to 5 days. Hazardous sea conditions can often not be avoided due to the relatively low sailing speed. Hence, wave forecasting is of less importance. Such a transport is classified as a un-restricted operation and must be designed to the conditions that can be expected during the transport. The design conditions are set by regulations and in consultation with a warranty surveyor, agreed by the owner of the structure. But ultimately, it remains a compromise between costs and risk. By selecting the right vessels, barges and using a sea fastening in line with the design premises, hazardous wave conditions become inconvenient but are generally still manageable.

Offshore operations
Once arrived at the installation site very different issues become important. Instead of the highest sea sates that may occur, the conditions in which a structure can still be installed safely becomes governing. In case of float-over operations there will be a constrain on the maximum allowed surge, sway and heave motions or impact forces. For heavy lifts operations the roll limitations of the crane, but also the hook load fluctuations and the motion in which the crew is able to hook-up safely can be limiting.

Vessel motions
As said, the success of an offshore operation does not directly depend on the wave conditions but on the induced motions and forces. A vessel acts like a filter on waves. A vessel may not respond at all to certain wave periods. These are normally the lower (wind) wave periods. At other wave excitation periods especially close to or coinciding with the natural periods of the vessel, the motion can become resonant. The response on head or beam seas also differs significantly.

Feasibility
The feasibility of an installation depends on the structure itself, the wave climate at the site but also on the characteristics of the installation vessel and barge. Semi-submersible crane vessels such as the HMC SSCV Thialf (Figure 1) are superior in areas with dominant wind seas. These vessels can normally work to much higher (wind) sea states compared to monohulls or sheerlegs. But this advantage may become less in the presence of very long swell.
Ideally an installation contractor is involved in an early stage of the design of the installation. He can use his expertise to review the feasibility to install it safely and in time. A rather small adaption to the construction may

have significant effects on the workability, both positive and negative.

Figure 1.Thialf in transit condition.

Response Amplitude Operator
Often the motion response of a vessel on waves can be given by a linearized Response Amplitude Operator (RAO). The spectral response is then the product of a polar wave spectrum and the square of the RAO. An example of a roll response is given in Figure 2.

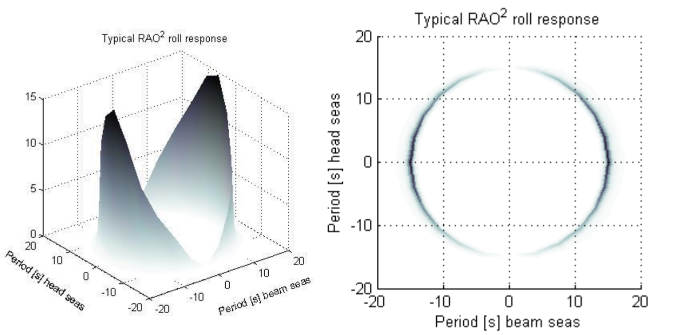

Figure 2. Typical roll Response Amplitude Operator for a float-over barge.

Obviously the vessel roll is most sensitive to beam seas and will not respond to pure head seas. In this case the response is very narrow banded to waves with periods around 15s. This example illustrates well that a small error in the forecast of the swell period of about 1s or a directional error of about 10 degrees will have large consequences in the predicted roll motions. Wave reports are generally only providing some average wave parameters such as wave height, peak period and mean wave direction of wind seas and swell. The spectral shape (peakness, directional spread) is normally missing. The recent further expansion into a primary and secondary swell partition was a real improvement but still assumptions has to be made about the spectral shape. This makes it very difficult to accurately predict the motions from these weather reports. Using full wave spectra instead, the predicted motion will be as accurate as the performance of the wave model and how well the hydrodynamics of the vessel are known. Combining wave spectra and RAOs automatically ensures zooming in on that part of the spectrum that really matters and that no wave partitions are missed.

3. DAILY PRACTICE

Given a structure, installation and support vessels, the wave conditions only become an operational concern. That is, the success of a project highly depends on the number of available weather windows but also on the predictability of these windows. During execution one simply has to wait until the right weather window arrives. In contrast with the transport, the decision to install will now fully depend on the weather and wave forecasting. Any imperfection in the forecast may have large consequences. A false window may lead to a dangerous situation and even to loss of capital. So just to be sure, one tends to wait a bit longer but at the risk of missing a costly window. This is the dilemma a decision maker is facing each time. Any support of whatever kind such as an ensemble forecast, a backtrack of historical similar events or statistics on false alarm (actual window was not predicted) or hit rates (correctly predicted window), can be of support.

Wave forecasting
Wave forecasting is subcontracted. Prior to the execution of a project an estimate is made whether a standard wave model will do or enhanced modeling is needed. The latter depends on the specific geographical situation such as local bathymetry and the proximity of sheltering coasts or island. To answer this question reference or validation data would be very helpful but generally this isn't available prior to the project execution. During the execution in-situ measurements will become available but the tight installation schedule does not allow to collect sufficient data to tune, set-up and to implement another wave model. The measured data will be biased anyway because the whole project will generally only last for a couple of days or weeks. What remains is experience and intuition and sometimes this does not work out very well.

Validation
Another problem an end-user has to face is the fact that validation studies on the spectral characteristics are very rare. Most studies are limited to an inter-comparison of

the significant wave height only. Wave models are generally tuned to buoy data. Practically this works out in models ‘tuned’ to perform best along the North American coast and in the Gulf of Mexico as most public available buoy observations are situated in these areas. Others are using satellite altimeter sensors but these sensors only provide the significant wave height. Consequently one might experience an unbiased significant wave height but a large error in the spectral wave distribution, simply because the wave energy from the wave model was linearly scaled to in-situ altimeter wave height observations. Sometimes this even leads to artificial results especially in case of a significant intercept in the applied correction or in case the wave steepness was not conserved.

Dedicated on-site Meteorologist

The value of hiring an on-site dedicated meteorologist is irrefutable. A offshore decision maker will feel much more comfortable, but the presence of an on-board meteorologist is no guarantee the wave forecasts will become more accurate. The weather risk can be reduced, but not be excluded. A meteorologist will analyze the weather systems, give warnings for strong winds, squalls, visibility and other mainly atmospheric phenomena. However, its knowledge about the wave propagation is generally not that developed compared to atmospheric phenomena and his options are limited. Some agencies are not running the wave model in house and fully rely on second parties or public available sources. Others do offer an in-house wave forecasting system, but as the whole process is fully automated there are not that many opportunities for manual interventions. Wave synoptic are adapted but this is generally limited to an adjustment of the wave height and even more sporadically, the timing of the swell arrival. It never leads to a correction of the expected wave spectra, and certainly not to a correction in the boundary or initial conditions of the wave model. The latter is although comprehensible, difficult to explain to the offshore crew. After all, long swell has to travel over a long distance before it reaches the installation site. So why is it so difficult to correct the swell 1 or 2 days ‘upwind’? Why are there hardly any differences in swell on a 3-5 days horizon and the nowcast? Questions which are apparently quite easy to answer from the lack of ‘upwind’ measurements and the limited options a meteorologist has to break into the wave forecasting system, but in practice still very hard to accept.

Ensemble Forecast

Occasionally a subcontractor forecaster provides an ensemble forecast system (EFS) of various wave models. At first, the diversity of all these models may look quite confusing but eventually an EFS appeared to be very helpful in making decisions. Each model is optimized for a typical wave system such as wind sea or swell, wave direction or forecast horizon. Of course, all these models do have their strengths and weaknesses. Some perform better for swell, others for wind sea or in wave direction and some provide an extended forecast horizon. In case these characteristics are fully understood, EFS can be fully utilized. But these characteristics are not always clear to the end-user. This makes it very difficult to understand the differences between these models. In some situations directional consistency may be very important, during other activities it can be the swell wave period or wind sea wave height. If the model merits are fully understood by the end user it will be much easier for them to learn which model is expected to preform best from a contractors point of few. That is, in a specific part of the wave spectrum.

Buoy monitoring

During the offshore operation the spectral wave conditions and wind are constantly monitored and cross-checked with the forecasts. Generally a waverider buoy is deployed to measure the actual directional sea state. The observed and forecasted wave spectra are analyzed in different ways to get a good understanding of the active and arriving wave systems. Figure 3 shows a graphical presentation of the wave spectra which is helpful to identify the various wave systems.

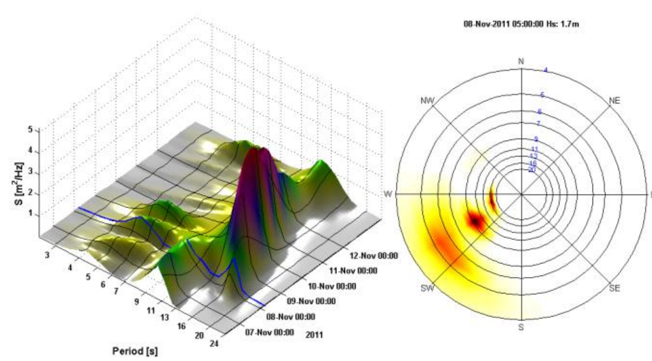

Figure 3. Analysis of wave forecast indicating arrival of swell trains and developing wind seas.

Compared to a conventional time series plot of wave height and wave period, the 3D plot of the wave spectrum over time makes it much easier to track both parameters

simultaneously. Especially in case of multi-modal sea states.
Time series of wave spectra are also expanded in narrow wave periods bands for which the operation is sensitive. Each of these bands are then compared to buoy observations in terms of wave height and wave direction to examine the accuracy in each band of interest. An example is given in Figure 4. These time series generally show a good match in total significant wave height but an increasing relative error with the wave period. Potential timing shifts or major directional problems are easily visually identified.
Additionally, this is repeated for multiple forecast horizons to check consistency. Normally one might expect to see an increasing variance with the horizon but for long swell generally hardly any differences are found. Without in-situ measurements, this can be misleading as it suggests a very reliable swell forecast.

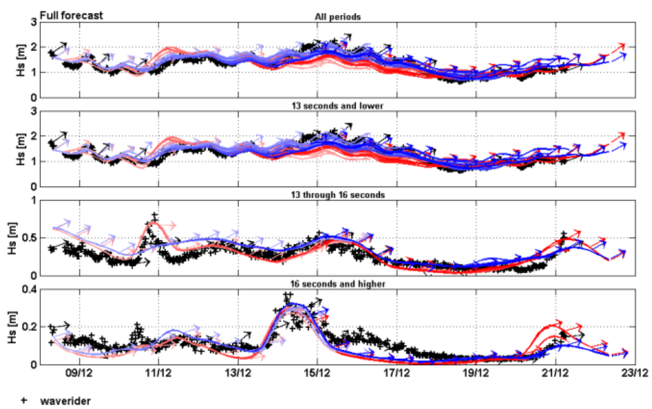

Figure 4. Buoy observations (black) compared various forecast sources(blue and red).

Motion monitoring and forecasting
Normally analyzing wave spectra already gives a good impression about the active and expected wave conditions and motion responses. Weather windows can be identified by translating motion or loads limits into limiting sea states. But to translate response limits into limiting sea states requires an assumption about the spectral shape. Moreover, it is quite easy to 'miss' something in case of multi modal sea states. Therefore the far most preferred and accurate method is to translate wave forecasts into motions on which limits can be applied directly, instead of determining limiting sea states. But it requires full polar wave spectra.

Linear Motion monitoring and forecasting
Observed and forecasted wave spectra are combined with the RAOs to estimate the responses. These motions could then be compared with the actual motions measured by a Motion Reference Unit (MRU) (Figure 5). The buoy is not only used to cross-check the wave forecast but in combination with a MRU it also proves the validity of the assumed hydrodynamics. Practically it is however not that simple as it sounds. The predicted motions from a buoy or wave forecast depends on the vessel heading and that one may continuously vary in time. A fixed heading doesn't help either as the directionality of the waves is often non-stationary as well. It can even get worse in case the heading in stand-off position, just prior to a critical activity, differs from the heading during the actual installation. Consequently, even a perfect match between predicted and actual motion just prior to the installation does not guarantee a match during the critical phase.

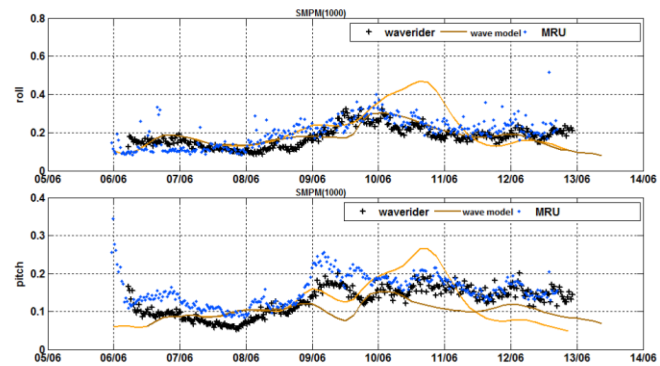

Figure 5. Observed(MRU) and estimated motions from observed waverider and forecasted model wave spectra.

Nonlinear response
When responses are non-linear the wave forecast or measurements can't be translated easily in a response time trace using a RAO. In this case time-consuming time domain simulations are needed. Normally there is no time to do such simulations on the job without the risk of missing a installation opportunity. In that case one still has to rely on the first method in which motion limits are converted into limiting seas states. An operability table is prepared including all possible wind sea and swell combinations. The forecasted wave spectra are split into multiple swell and wind sea partitions with a standard spectral shape using a advanced in-house developed spectral fitting tool (Figure 6). The algorithm is based on the method described by Hanson and Phillips (2000). The main difference of this tool with the partitions provided by most of the wave forecast providers is that they are not fully automatically generated. This may sound as a backward movement, but it is not. The tool still gives hints for partitioning but the operator is forced to check

them individually and to adjust the partitioning manually where necessary. The operator can tune the settings on the fly to get the best performance at the specific site. These partitions are then used to look-up whether the operational limits are met.

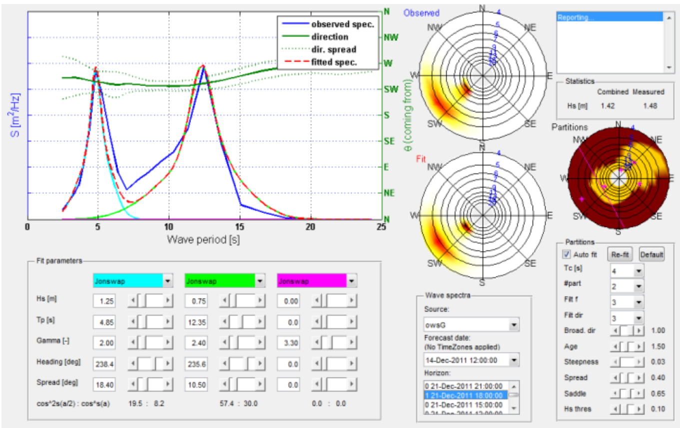

Figure 6. Spectral partitioning tool.

4. SHORTCOMINGS

North Sea

Late summer 2010 a project was executed in the Central North Sea about 100Nm offshore Denmark. At the beginning of September the weather was improving and the significant wave height and wind gradually seems to fall to a minimum around the 4th of September. The weather outlook was promising. However, around the 3th of September the predicted motions were surprisingly becoming more intense (Figure 7). The predicted motions were caused by a long swell of about 10 cm with period of 17 seconds or more. Since such long swells in the Central North Sea are most unlikely especially during the summer, this event lead to quite some discussions with the on-site meteorologist. At that time a remain of tropical storm Danielle was crossing the Northern Atlantic from the South West (Figure 8). One would not expect the swell caused by such a storm to 'refract' around the Scottish Islands and penetrate deep into the North Sea. But apparently it did, as the buoy did measure such a long swell a few days later (Figure 9). Luckily in this case the wave model did show some long swell, but this is quite an exception as the spectral wave bins at such high wave periods are normally sharp zero. Partly because of the finite resolution in the provided forecast bulletins but probably also because of numerical limitations in the wave model.

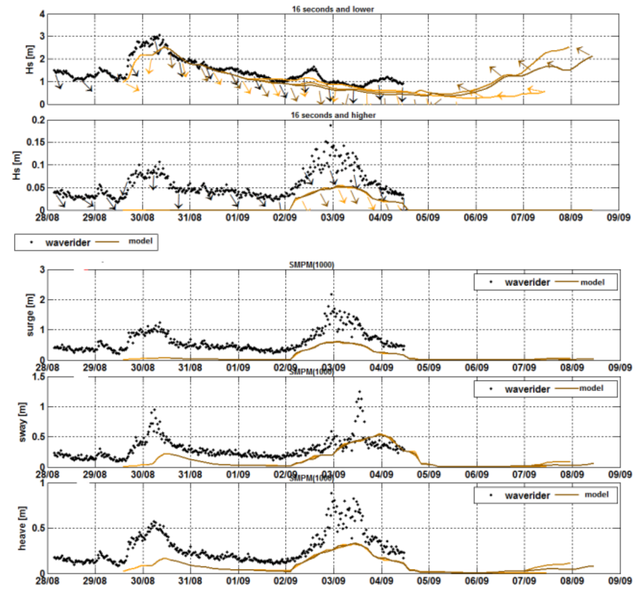

Figure 7. Predicted and 'observed' wave heights (top) and motions (bottom).

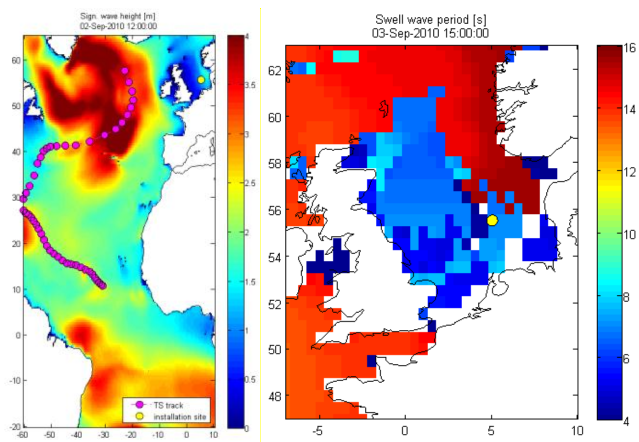

Figure 8. Track of tropical storm Danielle(left) and swell propagation in North Sea(right), Summer 2010.

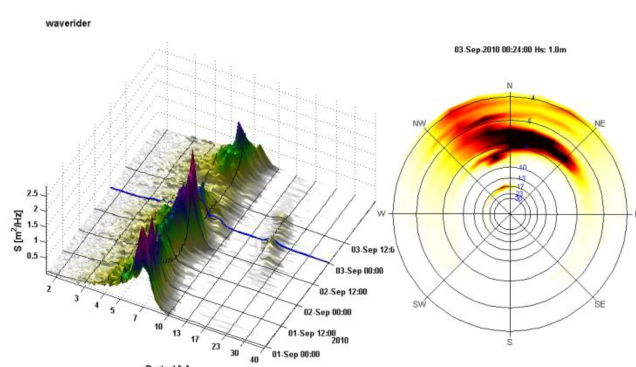

Figure 9.Observed long swell, September2010, Central North Sea.

Earlier that year, in the first part of July a similar swell event was experienced in the same area. But this time the swell was not caused by a Tropical Storm but just a deep depression West of the UK Islands and moving towards the North West. Although the North Sea is not known as a typical swell area these two events showed that long swell should also be considered in the Central North Sea and that it may cause unexpected motions as it is generally not very well captured in the spectral wave forecasts.

West of Africa
In the Eastern South Atlantic HMC experienced that the swell forecasts are generally (but not always) overestimated and that they will arrive later than predicted. A temporal shift of 12 hours is quite common but occasionally the timing is spot on (Figure 10). As one cannot rely on a constant shift, this shift and also the overestimation, practically works out in shorter weather windows. In the worst case a costly weather windows can be completely missed.

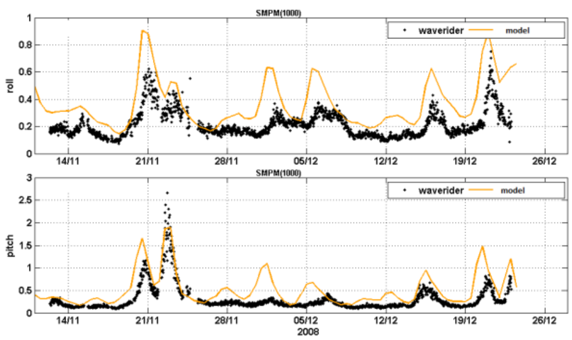

Figure 10. Typical pitch and roll motions offshore West Africa.

Directional errors
For a project in North West Australia several wave forecast models were in place. One of the models had a forecast horizon of 7-14 days. Although one should not expect too much accuracy on such a long horizon the model was still performing quite well. At least with regard to wave heights. However, the long term model showed a consistent bias in the incoming wave direction which resulted in a reduced operability caused by roll motions (Figure 11). Apparently the coarser grid didn't capture the wave refraction along the North West Shelf as accurately as the higher resolution short term models. This was not known during the initial phase of the project. Of course long term forecast need to be used with care, but the error was expected to have a random character and not to appear as a systematic bias of about 10 degrees in the wave direction.

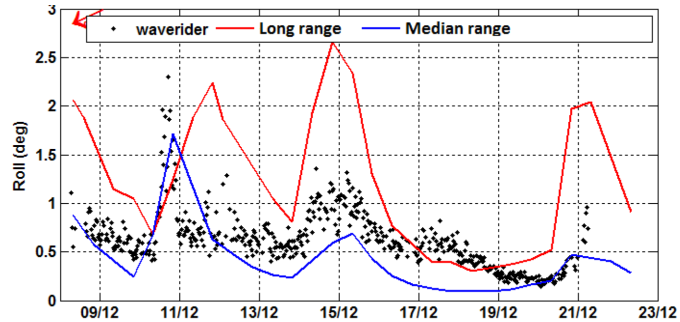

Figure 11. Long term verses median range roll motion forecasting.

SWAN
For a project South East off Bioko Island Equatorial Guinea (Figure 12), a standard global wave model at the nearest grid point south of Bioko Island, appeared to perform better than a SWAN model specifically set-up for this site. A closed explanation was not found but it appeared that the adjacent Bioko Island was not governing for the sheltering effects of the predominantly south-westerly swell but the remote 'windward' Islands. These Islands are already modeled in the global wave model as 'blocking' objects which appeared to work out very well. To include these islands in SWAN, the grid had to be extended. The combination of the large scale and the presence of significant swell, apparently lead to an significant overestimation of the 'local' wave grow by SWAN.

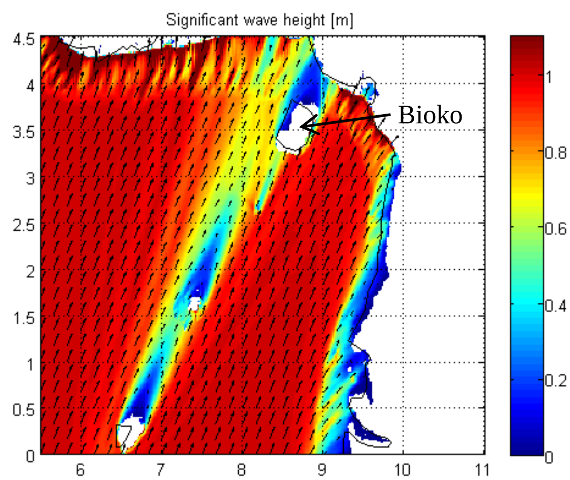

Figure 12. SWAN wave propagation towards Bioko Island.

Waverider
During critical operations a directional waverider is used to cross check the spectral wave forecast with in situ measurements. But forecast and waverider are also

indirectly checked by the experienced vessel motions. It was noted that even a proven instrument such as the waverider might give false alarms. During the execution of two projects, one North of the Shetland Islands and one in the Eastern Mediterranean, a very long swell with wave periods over 20 seconds was measured. At the Shetlands this is perhaps still physically possible and it did not have direct consequences for the operation. Hence, no attention was paid to it initially. Later in the season similar long swell was spotted in the Eastern Mediterranean. This triggered some alarm bells as it is very unlikely to spot such long waves in the Mediterranean. Although it concerned only a swell with a wave height of less than 10cm it still could affect this specific operation. It was noted that this abnormality seemed to correlate very well with the total significant wave height as shown in Figure 13. At the same time the wave model in place showed quite a good match with total seas but this time the wave energy of such long swell was sharp zero.

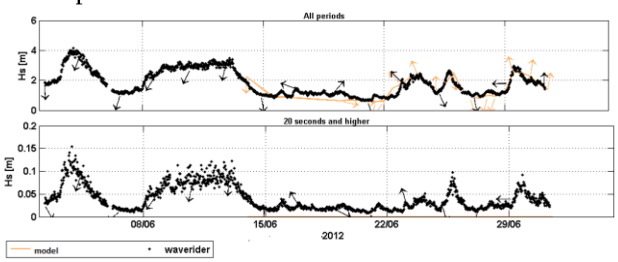

Figure 13. Long swell correlating with total(wind) seas.

In dialogue with the manufacturer no direct reasons for a malfunctioning of the instrument were found. Perhaps it is just a coincidence, but eventually it was noted that in both cases the waverider was carrying a flag (Figure 14). The flag was attached to the antenna to improve its visibility and to lower the collision risks with other support vessels in the field. Although it is a bit speculative, this action might have caused the problem. Let this be a lesson to be reluctant to mount any additions to an instrument. At least it avoids any grounds for suspicions and doubts. Also remember an instrument isn't always prefect either.

Figure 14. Deployment of waverider buoy.

5. CONCLUSION

Dangerous seas from an offshore installation contractors point of view are just ordinary (often swell) waves which happen to occur at one of the resonance periods of the vessel. When these waves are higher than forecasted, arrive earlier or were forecasted with a different period or heading, dangerous situations can occur during an offshore operation.

Wave forecasting is growing up but it is still a long way to evolve to a similar level as atmospheric modeling. Meteorologists are more experienced to phenomena above than on the ocean surface. In contrast to an offshore contractor who wants to put the wave conditions under a microscope, they generally limit themselves to analyze wave parameters rather than wave spectra. Adapting (spectral) wave forecasts still seems to be a mission impossible. This is not unwillingness but a direct result of limited awareness how critical offshore operations are. But also because the tools to analyze and even more to improve a wave outlook, are too limited.

REFERECES

Hanson, J.L. and Phillips, O.M., 2000: Automated Analysis of Ocean Surface Directional Wave Spectra. Journal of Atmospheric and Oceanic Technology, 18, 277-293