RUNE

D3.1 Metocean Buoy Deployment
This report has been prepared under the DHI Business Management System certified by Bureau Veritas to comply with ISO 9001 (Quality Management)
RUNE

D3.1 Metocean buoy deployment

Prepared for                  DTU Wind Energy
Represented by                Dr. Alfredo Peña Díaz

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<tr>
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Buoy Description
A directional wave buoy equipped with an ADCP was deployed within the RUNE project (Reducing Uncertainty of Near-shore wind resource Estimates using onshore Lidars, funded by Energinet.dk, Forskel project No. 2015-1-12263). The deployment was from November 2015 to January 2016 at the west coast of Jutland, Denmark, at a water depth of 16.5 m. Integrated wave parameters and directional spectra were recorded together with current profiles with a 1 m vertical resolution. Two wave events reaching significant wave height ($H_{\text{m0}}$) of 6 m and peak period ($T_p$) of 13 s were measured. Data including integrated parameters, frequency and directional spectra, and current profile have been delivered to DTU and are available via the DTU database developed within the RUNE project.
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Introduction

The RUNE project (Reducing Uncertainty of Near-shore wind resource Estimates using onshore Lidars) is funded by Energinet.dk (Forskel project No. 2015-1-12263, February/2015) and aims at reducing the uncertainty of near-shore wind resource estimates by using onshore scanning Lidar technology combined with ocean and satellite information. The test site is located at the west coast of Jutland, Denmark (Figure 2.1).

Within RUNE, DHI deployed (56°30.00’ N, 007°59.80’ E) a directional wave buoy equipped with a down-looking ADCP (Acoustic Doppler Current Profiler) to measure waves and currents from November 2015 to January 2016 at a water depth of 16.5 m.

This report presents a description of the wave buoy, the deployment/recovery and an overview of the available data. A brief description of the buoy can be found in Appendix A.

Figure 2.1  RUNE area (yellow square) where Lidars among other instruments have been deployed together with the directional wave buoy.
3 Buoy Type and Set-up

A directional Triaxys wave buoy (Figure 3.1) was used to record sea state and calculate directional spectra. The buoy is powered by batteries supplemented by solar cells.

Time series of vertical and horizontal accelerations were recorded with a sampling frequency of 4 Hz, with burst of 20 min. Initially, the buoy was set up to record one burst every half hour, however, due to battery consumption and low solar radiation the measuring frequency was changed on 15/11/2015 to record one burst every hour. Directional spectra are obtained with a resolution of 121 directions and 129 frequencies (0.0 – 0.64 Hz).

A downward looking ADCP was integrated in the Triaxys wave buoy. The face of the ADCP transducer was 0.45 m below the surface, and the ADCP was configured for 1 m bin size and 300 pings per ensemble. Ensemble duration was 300 s, the ensemble was recorded at the same update rate as the wave data.

![Figure 3.1 Directional Triaxys wave buoy before deployment](image)

3.1 Data and Variables Available

Table 3.1 shows the integrated wave parameters (time domain) provided by the buoy. Additionally, time series of buoy velocity and elevation, and spectra (frequency and directional) are available (Table 3.2). Table 3.3 summarizes the data provided by the ADCP.
### Table 3.1 Integrated wave parameters provided by Triaxys software

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>UTC</td>
</tr>
<tr>
<td>Zero-crossings</td>
<td>Number of waves</td>
</tr>
<tr>
<td>$H_{av}$</td>
<td>Average zero down-crossing wave height (m)</td>
</tr>
<tr>
<td>$T_2$</td>
<td>Average zero down-crossing wave period (s)</td>
</tr>
<tr>
<td>$H_{max}$</td>
<td>Maximum zero down-crossing wave height (trough to peak) (m)</td>
</tr>
<tr>
<td>$H_s$</td>
<td>Zero down-crossing significant wave height, $H_s$, where $H_s$ is the average height of the highest third of the waves (m)</td>
</tr>
<tr>
<td>$T_{sig}$</td>
<td>Average period of the significant zero down-crossing waves (s)</td>
</tr>
<tr>
<td>$T_p$</td>
<td>Peak wave period, $T_p$, in seconds. $T_p = 1/f_p$ where $f_p$ is the frequency at which the wave spectrum, $S(f)$, has its maximum value</td>
</tr>
<tr>
<td>$T_{ps}$</td>
<td>Peak wave period in seconds as computed by the Read method (Mansard and Funke, 1990). $T_{ps}$ has less statistical variability than $T_p$ because it is based on spectral moments. The $T_{ps}$ is determined from calculating $F_p$ which is the average frequency computed with the weighting function, $S(f)^2$, over a defined upper and lower frequency range. The algorithm is: $F_p = [\sum(F_i^2(E_i/E_{peak}))]/[\sum(E_i/E_{peak})]$ where: $i$ = number of frequencies; $F_i$ is frequency; $E_i$ is energy; $E_{peak}$ is energy of peak frequency. Thus, $T_{ps} = 1/F_p$</td>
</tr>
<tr>
<td>$H_m0$</td>
<td>Significant wave height in meters as estimated from spectral moment, $m0$. $H_m0 = 4.0 \times \text{SQRT}(m0)$ where $m0$ is the integral of $S(f)^2$ , df.</td>
</tr>
<tr>
<td>MWD</td>
<td>Mean wave direction in degrees (°N, “coming from”) obtained by averaging the mean wave angle ($\theta$) over all frequencies with a weighting function, $S(f)$. Theta ($\theta$) is calculated by the KVH method in the TRIAXYS™ Directional Wave Buoy</td>
</tr>
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Table 3.2  Other data provided by the buoy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S(f)$</td>
<td>Frequency spectra, resolution of 129 frequencies (0.0 – 0.64 Hz)</td>
</tr>
<tr>
<td>$S(f,\theta)$</td>
<td>Directional spectra, resolution of 121 directions and 129 frequencies (0.0 – 0.64 Hz)</td>
</tr>
<tr>
<td>$u, v, h$</td>
<td>East and north velocities, together with heave, resampled to a frequency of 7.14 Hz</td>
</tr>
</tbody>
</table>

Table 3.3  Data provided by the down-looking ADCP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u, v$</td>
<td>East and north velocity component (m/s) with 1 m vertical resolution</td>
</tr>
<tr>
<td>$d$</td>
<td>Water depth (m)</td>
</tr>
</tbody>
</table>
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4 Buoy Deployment and Recovery

The Triaxys directional buoy was deployed in the west coast of Jutland, Denmark at 56°30.00’ N, 007°59.80’ E (see Figure 4.1). The deployment took place on 04/11/2015 at a water depth of about 16.5 m relative to MSL.

Figure 4.2 shows a schematization of the wave buoy mooring. Figure 4.3 shows a photo of the buoy during deployment.

![Location of wave deployment at the west coast of Jutland.](image1)

![Schematization of the Triaxys wave buoy mooring.](image2)
Figure 4.3  Triaxys buoy during deployment.

The Triaxys buoy drifted on 11 January 2016 due to a failing flexible mooring (probably as a result of passing fishing gear). The buoy was recovered on 13 January. Data were recovered successfully, covering from 4 November 2015 09:00 UTC to 11 January 2016 13:00 hrs UTC.
5 Data Overview

5.1 Integrated Wave Parameters

Figure 5.1 presents time series of integrated parameters, $H_{m0}$ and $H_{\text{max}}$ (top panel), $T_p$ and mean period (centre panel) and mean wave direction (bottom panel).

$H_{m0}$ reached 6 m during two storms recorded on the last two days of November and between 4 and 6 December. Maximum individual height reached 11 m during the December storm, being significantly larger than the maximum during the November storm.

Peak period ($T_p$) reaches 15 s. Note that values around 20 s are present due to the very low wave state, producing a relatively flat spectra and apparent very large peak periods due to the significant noise in the low frequencies of the spectra.

Figure 5.2 presents the wave rose ($H_{m0}$) indicating a dominant wave coming from west and southwest as expected from the buoy location.
5.2 Surface Elevation Time Series

Figure 5.3 shows an example of the heave time series. The data show the individual waves where some wave groups can be identified. The time series duration is 18 min with data resampled to 0.14 s.
5.3 Wave Spectra

Figure 5.4 shows the contours of the frequency spectra evolution. Increase of spectral energy and a shift towards lower frequencies is evident during the storm events.

Figure 5.4  Time series of frequency spectra, colour bar represents spectral energy (m²/Hz).

5.4 ADCP Data, Water Depth and Averaged Current

Figure 5.5 top panel shows the time variation of the water depth during the deployment period showing a total variation of 4 m. Depth-averaged current is shown in the central panel and depth-averaged current direction is shown in the bottom panel. Figure 5.6 presents the current rose showing the clear north-south component due to currents travelling parallel to the coastline (isobaths) with a strong tidal component.
Figure 5.5 Time series of water depth (top panel, m), depth-averaged current speed (central panel, m/s) and depth-averaged direction (bottom panel, "N, "going to").
5.5 Current Profile

Figure 5.7 shows the current speed contours for the deployment period while Figure 5.8 shows individual current profiles separated for different depth-averaged velocities. It can be noticed that for depth-averaged velocities larger than 0.2 m/s a logarithmic-type of profile is more clearly seen.
Figure 5.7  ADCP current speed contour for the entire deployment. Colour bar is in m/s.
Figure 5.8 Individual current profiles clustered for different depth-averaged current speeds (m/s).
6 Delivered Data

Wave and current data have been provided to the RUNE project to be stored at the DTU database. The data consist of integrated wave parameters (excel file), current measurements (excel file), and text files containing individual frequency and directional spectra, as well as time series of buoy velocities and heave.
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APPENDIX A

Buoy Description
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The TRIAXYS™ Directional Wave Buoy is a precision instrument incorporating advanced technologies that make it an easy to use, reliable and rugged buoy for accurate measurement of directional waves.

**FEATURES & BENEFITS**

» Spin and impact resistant
» Reliable operation in extreme weather or geographical locations
» 5 year rechargeable battery life
» Supports any telemetry
» >5 years of data storage capacity
» Continuous wave sampling
» Solar powered
TRIAKYS™ Directional Wave Buoy

Economical and rugged, the TRIAXYS™ Directional Wave Buoy can withstand the rigours associated with deployment and recovery operations, specifically: impact shock, spinning, and temporary submergence.

The buoy’s modular components are easily accessed and the clear dome allows sunlight to reach the solar panels, while maintaining a low profile and impact resistance. The buoy is solar powered with rechargeable batteries to reduce annual operating costs. The buoy can operate for years before the batteries need replacement.

The heart of the TRIAXYS™ Directional Wave Buoy is developed from the AXYS WatchMan500™ controller, which integrates sensor systems and provides onboard data processing, data logging, telemetry, and diagnostic/set-up routines. The software performs a zero-crossing analysis to compute various time-domain wave parameters. The buoy is capable of accurate motion data for roll and pitch angles up to 60 degrees. Surge and sway velocities measure wave kinematics that define directional wave properties.

The data transmitted from the buoy can include wave statistics, HNE (Heave, North and East Displacements), MeanDir (Wave Direction and energy as a function of frequency), directional and non-directional wave spectra, buoy configuration, status data, position and WatchCircle™ alarm messages. All data is stored on the internal data logger.

Specifications

- PHYSICAL DESCRIPTION
  Diameter: 1.10m outside bumper
  Weight (including batteries): 230 kg
  Obstruction Light: Amber LED. Programmable IALA ODAS flash sequence with three miles visibility.

- MATERIALS
  Hull: Stainless steel
  Dome: Impact resistant polycarbonate
  Solar Panel Assembly: Fibreglass over foam
  Clamping ring: Stainless steel

- POWER SYSTEM
  Batteries: 4 @ 12 Volt, 100 Amp hr/battery
  Solar Panels: 10 @ 6 Watt
  Smart Charger: Sunsaver-6
  External On/Off Switch: Turns buoy on when Magnetic Key is removed.

- TELEMETRY OPTIONS
  - VHF/UHF
  - IsatData Pro
  - INMARSAT M2M
  - IRIDIUM
  - CDMA, GPRS, HSPA, LTE (cellular)

Resolution/Accuracy

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<th>ACCURACY</th>
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<td>±20 m</td>
<td>0.01 m</td>
</tr>
<tr>
<td>PERIOD</td>
<td>1.5 to 33 sec</td>
<td>0.1 sec</td>
</tr>
<tr>
<td>DIRECTION</td>
<td>0 to 360°</td>
<td>1°</td>
</tr>
<tr>
<td>WATER TEMP</td>
<td>-5 to +50°C</td>
<td>0.1°C</td>
</tr>
</tbody>
</table>

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