PNNL-30947

Lidar Buoy Data Dictionary

For the 2020 – 2021 California Deployments

May 2021

Mark A Severy
Alicia M Gorton
Raghavendra Krishnamurthy
Maxwell S Levin

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Summary

Pacific Northwest National Laboratory (PNNL) manages two AXYS WindSentinel^{TM} buoys (Buoys #120 and #130) on behalf of the U.S. Department of Energy (DOE) that collect a comprehensive set of meteorological and oceanographic (metocean) data to support resource characterization for wind energy offshore. The buoys have been deployed off the California coast in partnership with the Bureau of Ocean Energy Management (BOEM) from September 2020 through October 2021. One buoy was deployed within the Morro Bay Call Area offshore central California; the other buoy was deployed within the Humboldt Call Area off the coast of northern California. The measurements from the buoys are used to characterize the metocean conditions near potential locations for offshore wind lease areas and are uploaded to DOE's Data Archive and Portal (DAP). Plots are updated on the DAP webpage to visualize the recent metocean measurements. This document serves as a data dictionary – or reference guide – for understanding and interpreting the data available from the buoys. This document includes:

- specifications for the buoy instrumentation (Section 2.0)
- description of each plot and definition of measured parameters (Section 3.0)
- description of data files and naming convention (Appendix A)
- reference guide of measurements and variables (Appendix B)

Acronyms and Abbreviations

ADCP	acoustic Doppler current profiler
AIS	automatic identification system
ASIT	Air-Sea Interaction Tower
ASL	above sea level
BOEM	Bureau of Ocean Energy
CNR	carrier to noise ratio
CTD	conductivity, temperature, depth
DAP	Data Archive and Portal
DOE	U.S. Department of Energy
GPS	Global Positioning System
IMU	inertial measurement unit
LOS	line of sight
PDF	probability density function
UTC	Coordinated Universal Time
VHF	very high frequency

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1.0 Introduction

Pacific Northwest National Laboratory (PNNL) manages two AXYS WindSentinel™ buoys (Buoys #120 and #130) on behalf of the U.S. Department of Energy (DOE) that collect a comprehensive set of meteorological and oceanographic (metocean) data to support resource characterization for wind energy offshore. The buoys have been deployed off the California coast in partnership with the Bureau of Ocean Energy Management (BOEM) from September 2020 through October 2021. One buoy was deployed within the Morro Bay Call Area off the coast of Central California (Buoy #130); the other buoy was deployed within the Humboldt Call Area off the coast of northern California (Buoy #120). Measurements from the buoys are used to characterize the metocean conditions near potential locations for offshore wind lease areas and are uploaded to DOE's Data Archive and Portal (DAP). Plots are updated on the DAP webpage to visualize the recent metocean measurements. These data can be used by the offshore wind industry, government, regulators, and researchers to help inform decision making processes and atmospheric models that evaluate the offshore conditions.

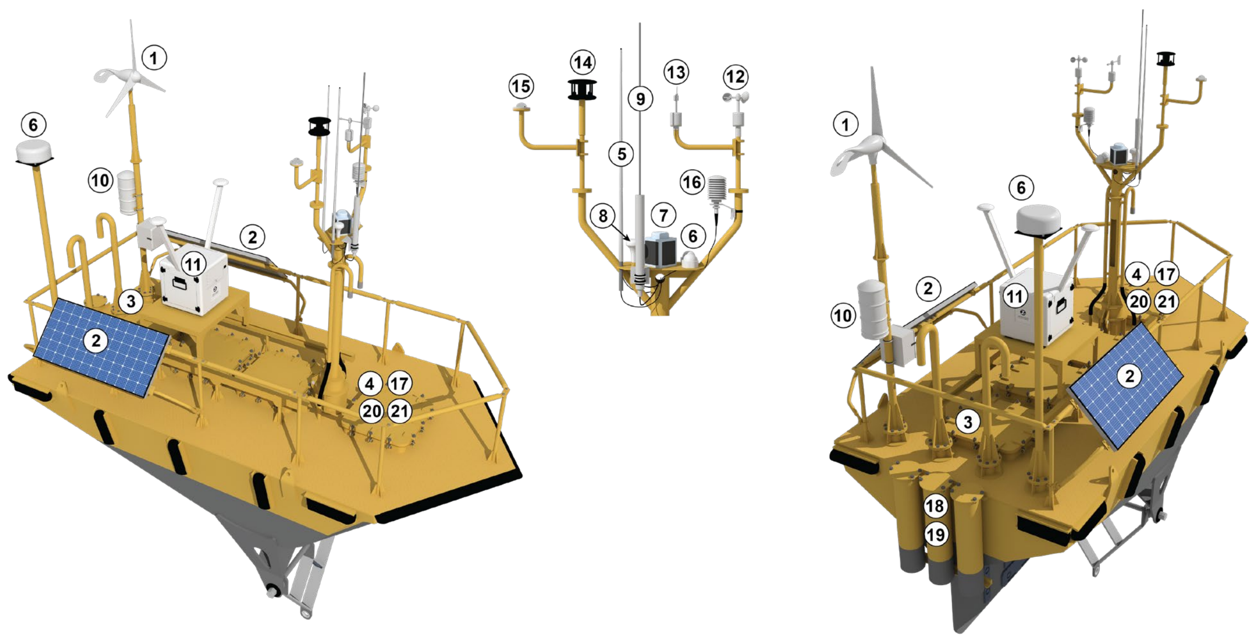
The buoys have been deployed on the East Coast and West Coast of the United States. Data collected during the measurement campaigns are accessible through the DAP. During the deployment, select measurements are transmitted to shore and made available at the end of each day on the DAP. A complete data set is uploaded after recovering the primary data files during maintenance visits and at the end of a deployment. Plots of recent data are posted on the DAP to help users visualize the recent trends and measurements from the buoy.

The purpose of this document is to serve as a reference for understanding the buoy measurements, data files, and plots available on the DAP. In Section 2.0, the document describes the instrumentation included on the buoy. Section 3.0 provides a description of the plots generated on the DAP and definitions of the parameters displayed in the charts. The data files available on DAP are described in Appendix A and a reference list of measurements and variables is provided in Appendix B.

2.0 Buoy Information

The DOE owns two AXYS WindSentinel™ buoys that collect metocean data. The buoys are generally deployed for annual data collection campaigns in different locations off the coast of the United States to support resource characterization for offshore wind energy. The Doppler lidars on the buoys are validated against a reference mast or lidar once every two years. The most recent lidar validation was conducted at the Woods Hole Oceanographic Institution's Air-Sea Interaction Tower (ASIT) near Martha's Vineyard, Massachusetts, between January and April 2020 (Gorton and Shaw 2020, 40-41).

The centerpiece of the instrumentation suite for each buoy is a motion-corrected Doppler lidar system that provides vertical profiles of wind speed and direction from 40 meters to 250 meters above the sea surface. In addition to a lidar, each buoy collects *in-situ* sea surface temperature, salinity, ocean currents, and wave data as well as near-surface air temperature, humidity, and horizontal wind speed and direction. The buoy is shown in Figure 1 with instrumentation details provided in Table 1.



Power, Data, Communication, & Navigation

1. **Turbine**
2. **Solar panels**
3. **Diesel generator (compartment)**
4. **Data loggers (compartment)**
5. **Cellular antenna**
6. **Satellite antenna**
7. **Navigation light**
8. **AIS GPS antenna**
9. **AIS VHF antenna**
10. **Radar reflector**

Meteorological

11. **Wind profile**
12. **Wind speed (cup anemometer)**
13. **Wind direction**
14. **Wind speed & direction (ultrasonic anemometer)**
15. **Solar radiation**
16. **Air temperature & relative humidity**
17. **Barometric pressure (compartment)**

Oceanographic

18. **Water velocity profile (moonpool)**
19. **Salinity & water temperature (moonpool)**
20. **Wave spectrum (compartment)**
21. **Water temperature (compartment)**

Figure 1. Lidar buoys with instrument type and location (courtesy of Mike Perkins, PNNL).

Table 1. Description of instrument manufacturer and models.

Instrument Number	Sensor Type	Make / Model	Measurements
11	Wind profiling lidar	Leosphere / Windcube 866	Vertical profile of wind speed and direction, wind dispersion, and spectral width
12	Cup anemometer	Vector Instruments / A100R	Horizontal wind velocity, near surface
13	Wind vane	Vector Instruments / WP200	Horizonal wind direction, near surface
14	Ultrasonic anemometer	Gill / WindSonic	2D wind velocity and direction, near surface
15	Pyranometer	Licor / LI-200	Global solar radiation
16	Temperature, relative humidity	Rotronic / MP101A	Air temperature, and relative humidity
17	Barometer	RM Young / 61302V	Atmospheric pressure
18	Acoustic Doppler current profiler (ADCP)	Nortek / Signature 250	Ocean current velocity and direction from sea surface to 200 m water depth
19	Conductivity temperature depth (CTD)	Seabird / SBE 37SMP-1j-2-3c	Conductivity and sea surface temperature
20	Directional wave sensor	AXYS / TRIAXYS NW II	Directional wave spectra, wave height, wave time period,
21	Water temperature	AXYS / YSI	Sea surface temperature
NA	Buoy built-in inertial motion unit (for wind vane correction)	MicroStrain / 3DM GX3 25	Yaw, pitch, roll, and global position
NA	DOE inertial motion unit (for Doppler lidar motion compensation)	MicroStrain / 3DM GX5 45	Yaw, pitch, roll, linear velocity, global position, magnetometer, and gyroscope
NA	Leosphere inertial motion unit (for Doppler lidar motion compensation)	--	Yaw, pitch, roll, linear velocity, global position

A partial set of the data files from the buoy are transmitted back to shore and uploaded onto the DAP once a day. A complete set of data are made available on DAP after recovering all of the recordings during a maintenance visit and at the end of a deployment. See Appendix A for a description of the data files and naming conventions. MATLAB scripts to read, process, and plot buoy data are available on GitHub (https://github.com/rkpnnl/DOE_Buoy_DAP.git).

The measurements and data collected from the buoy instruments are cataloged in a measurement reference list in Appendix B.

3.0 Data Analysis and Charts

Measurements collected from the buoys are displayed in several charts on the DAP to visualize the trends and correlations between different parameters (https://a2e.energy.gov/data/viz). The plots shown in the subsections below are updated on the DAP using data from the previous day. This section describes each plot, defines the information presented, and identifies which instruments collected the data. The plots described below are:

- Section 3.1 – Surface Meteorological Parameters
- Section 3.2 – Lidar Wind Speed, Direction, and Data Availability
- Section 3.3 – Lidar Wind Speed Profile
- Section 3.4 – Conductivity and Sea Surface Temperature
- Section 3.5 – Wave Statistics
- Section 3.6 – Ocean Current Velocity and Direction
- Section 3.7 – Buoy Motion Histogram

3.1 Surface Meteorological Variables

The Surface Meteorological Parameters plot (Figure 2) shows the daily measurements of wind speed, pressure, temperature, and relative humidity just above the sea surface. The figure includes the three following plots:

- Wind speed and direction plot – shows wind speed (blue lines, left axis) and wind direction (orange lines, right axis) from two separate instruments. The solid lines show data collected from a cup anemometer and wind vane (Instruments 12 and 13, respectively) and the dashed lines show measurements from an ultrasonic anemometer (Instrument #14). This plot can be used to identify any inconsistencies between the two surface wind measurement instruments.
    - *Note:* The motion compensation for the surface wind direction measurements from the wind vane ($\bar{\theta}_{Vane}$) and ultrasonic anemometer ($\bar{\theta}_{Gill}$) were not corrected for the buoy yaw angle properly during the beginning of the deployment in Morro Bay. The wind direction data will be post-processed to correct the surface wind direction for the Morro Bay deployment and uploaded to the DAP once a month. Therefore, the daily plots on the DAP might not indicate the true wind direction observed at the site.
- Pressure and relative humidity plot – shows atmospheric pressure (blue line, left axis) and relative humidity (orange line, right axis)
- Air and sea surface temperature plot – shows air temperature measured at the buoy height (blue line, left axis) and bulk sea surface temperature (SST) of the water (orange line, right axis). This plot shows the air-sea temperature difference, which can affect atmospheric stability and the vertical wind speed profile.

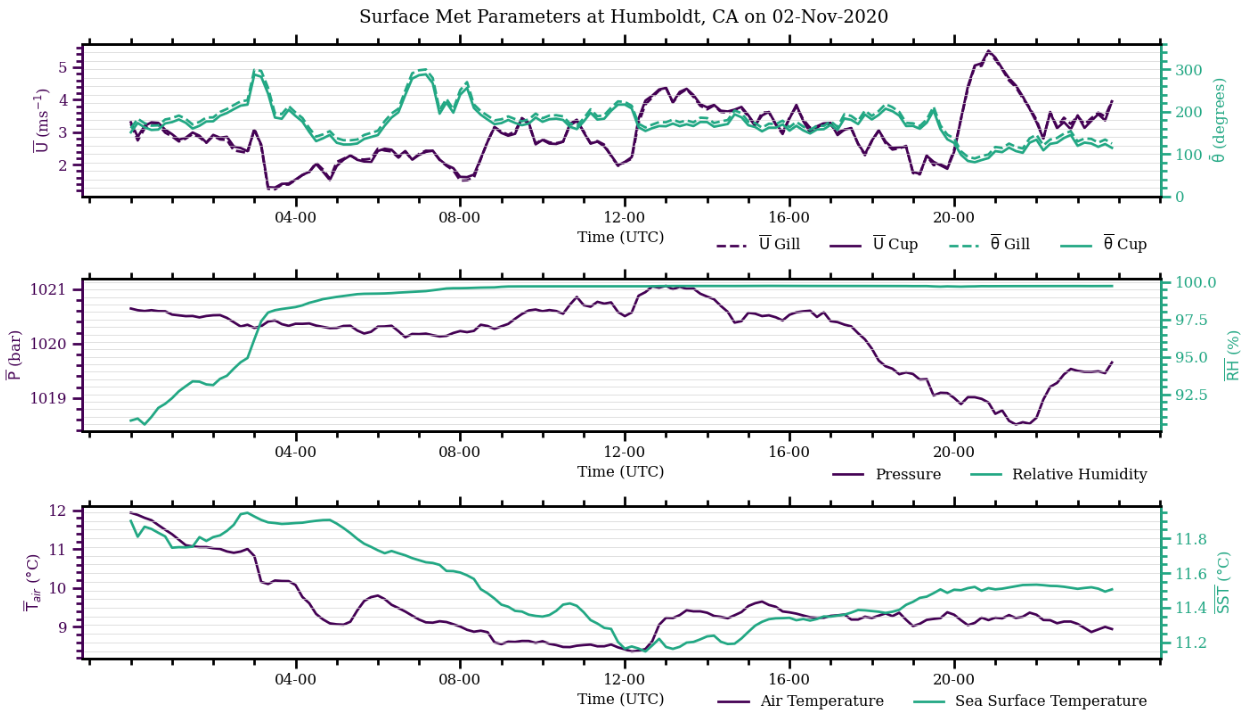


Figure 2. Surface meteorological measurements on November 2, 2020 at Humboldt buoy location.

Description of Variables in Plot

The measurements included in this plot are described with the information provided below.

Variable symbols with an overbar ($\bar{X}$) indicate that the measured variable is being averaged over a time interval. Wind speed measurements from the cup anemometer, for example, are collected once every second, but the data displayed in the chart ($\bar{U}_{Cup}$) is the average of the measurements over a 10-minute interval.

Wind Speed, Cup anemometer

Symbol: $\bar{U}_{Cup}$

Definition: Wind speed is the measurement of how fast wind is moving past a fixed location in the horizontal plane. This measurement is made at the height of the instrument, which is mounted on a buoy mast 4 meters above the sea surface. Instantaneous wind speed measurements are averaged over a duration of time; for example, in Figure 4 wind speed data are averaged over rolling 10-minute period.

Instrument: Vector Instruments A100R (Instrument 12)

Units: meters per second [m s^{-1}]

Wind Speed, Gill ultrasonic anemometer

Symbol: $\bar{U}_{Gill}$

Definition: Wind speed is the measurement of how fast wind is moving past a fixed location in the horizontal plan. This measurement is made at the height of the instrument, which is mounted on a buoy mast 4 meters above the sea surface.

Instrument: Gill WindSonic (Instrument 14)

Units: meters per second [m s^{-1}]

Wind Direction, Gill ultrasonic anemometer

Symbol: $\bar{\theta}_{Gill}$

Definition: Wind speed direction is the direction from which the wind is originating. Measured at buoy height with an ultrasonic anemometer.

Instrument: Gill WindSonic (Instrument 14)

Units: Degrees from true north, starting at 0º and increasing in the clockwise direction [deg]

Note: The plot may appear to have vertical discontinuities as the measurement changes between 359º and 0º. While this appears drastic on the plot, it is merely a small change in direction that goes from the top to the bottom of the direction axis.

Wind Direction, Vane

Symbol: $\bar{\theta}_{Vane}$

Definition: Wind speed direction where the wind is originating, where 0º is true north and increases in the clockwise direction. Measured at buoy height with a wind vane.

Instrument: Vector Instruments WP200 (Instrument 13)

Units: Degrees from true north, starting at 0º and increasing in the clockwise direction [deg]

Note: The plot may appear to have vertical discontinuities as the measurement changes between 359º and 0º. While this appears drastic on the plot, it is merely a small change in direction that goes from the top to the bottom of the direction axis.

Atmospheric Pressure

Symbol: $\bar{P}$

Definition: Atmospheric pressure – or barometric pressure – is the force per unit area exerted on a surface from the air in the atmosphere column above. Atmospheric pressure changes with elevation and weather patterns. If the pressure is recorded at a constant elevation, the pressure fluctuations are due to weather patterns.

Instrument: RM Young, 61302V (Instrument 17)

Units: millibar [mbar]

Relative Humidity

Symbol: $\overline{RH}$

Definition: Relative humidity is the ratio of the partial pressure of water vapor contained in the air compared to the saturation pressure of water at that temperature. This represents the percentage of water vapor contained in the air against the total amount of water vapor the air can hold before reaching saturation.

Instrument: Rotronic Instrument Corporation, MP101A (Instrument 16)

Units: %

Note: Measuring relative humidity in high humidity environments (such as offshore) can be challenging because the temperature of the probe is near or below the saturation temperature of the air. In some cases, water vapor can condense on the sensor and saturate the probe. In these cases, the RH probe consistently reads 100% or provides no reading for a period before drying out.

Air Temperature

Symbol: $\bar{T}_{air}$

Definition: Air temperature measures how hot or cold the atmosphere is at the location of the sensor.

Instrument: Rotronic Instrument Corporation, MP101A (Instrument 16)

Units: Degrees Celsius [ºC]

Sea Surface Temperature

Symbol: $S\bar{S}T$

Definition: The bulk sea surface temperature (SST) is the temperature of sea water just below the surface, between approximately 1 centimeter to 1 meter depth.

Instrument: Seabird Scientific, SBE 37SMP-1j-2-3c (Instrument 19)

Units: Degrees Celsius [ºC]

Note: The bulk SST reported here, is different than the skin SST, which is the temperature of the water directly on the surface, within the first few millimeters.

3.2 Lidar Wind Speed, Direction, and Data Availability

The lidar system measures the wind speed and direction from 40 meters to 250 meters above sea level (ASL). The lidar wind speed and direction plot (Figure 3) shows measurements and data availability in two plots:

- Wind profile – The top chart shows the wind speed and direction changing over time (x-axis) at all measurement heights (y-axis). The color on the chart is the wind speed at that time and height where warmer colors are higher speeds (orange, red) and cooler colors are lower speeds (green, blue). Contours on the color map are separate regions in 0.5 m s^{-1} increments. The wind direction is represented by black arrows on the plot pointing in the direction of the wind. Blank areas, which appear in white, show times and heights where no data were recorded from the lidar.

- Data availability – The bottom chart shows the data availability (y-axis) at each measurements height (x-axis) from the 24-hour reporting interval. Data availability is the percentage of lidar measurements recorded compared to the expected number of measurements over the same time interval.

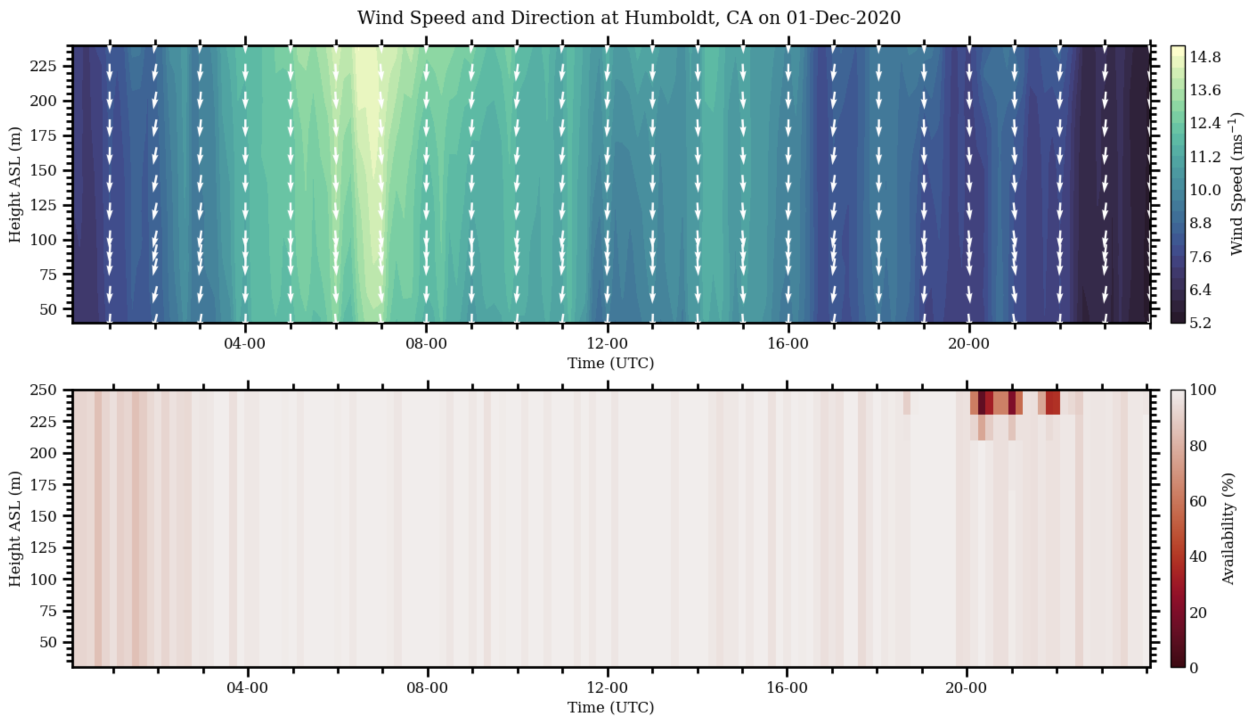


Figure 3. (top) Time-height Hovemöller plot of motion-compensated Doppler Lidar wind speed, direction, and (bottom) lidar wind speed data availability observed for the 24-hour duration above.

Description of Variables in Plot

The measurements included in this plot are described with the information provided below.

Wind Speed

Definition: Wind speed is the measurement of how fast wind is moving past a fixed location in the horizontal plane. The lidar wind profiler, which is mounted on the buoy hull, measures wind speed at heights between 40 m to 250 meters above the sea surface by detecting the reflection of laser signals sent into the atmosphere.

Instrument: Leosphere, Windcube 866 (Instrument 11)

Units: meters per second [m s^{-1}]

Wind Direction

Definition: Wind speed direction is the direction from which the wind is originating. Wind direction is measured at multiple heights between 40 to 250 meters above the sea surface using the lidar wind profiler mounted on the buoy.

Instrument: Leosphere, Windcube 866 (Instrument 11)

Units: degrees from true north [deg]

Lidar Data Availability

Definition: Data availability is the ratio of measurements recorded against the number of measurements that were expected over the same interval. For example, if measurements are expected to be made once a minute for 100 minutes, but only 99 measurements are recorded, the data availability is 99%.

Instrument: Leosphere, Windcube 866 (Instrument 11)

Units: %

3.3 Lidar Wind Speed Profile

The lidar wind speed profile plot displays a time series of wind speeds at different measurement heights. Wind speed measurements are shown at 40 meters (blue), 90 meters (red), 140 meters (yellow), and 200 meters (purple) above the sea surface. This plot is used to visualize both the change in wind speed over time and the difference between wind speeds at lower and higher elevations, also known as the wind shear.

Wind shear is the change in wind speed at different elevations. A positive wind shear value means wind speed increases with elevation, wind shear of zero (0) means that the wind speed is the same at all elevations, and a negative wind shear means wind speeds decrease at higher elevation. Offshore wind speeds most commonly increase with elevation (positive wind shear) with varying degrees depending on the atmospheric and oceanographic conditions. All types of wind shear have been observed on the buoys and have been investigated further for deployments in New Jersey and Virginia in Section 6 of Shaw et al. (2020, 6.1–6.5). The intensity of wind shear can be observed on this plot by looking at how the lines are separated vertically at different times. In Figure 4, positive wind shear is observed from 0:00 to 5:00, and a negative wind shear event is observed between 8:00 and 14:00.

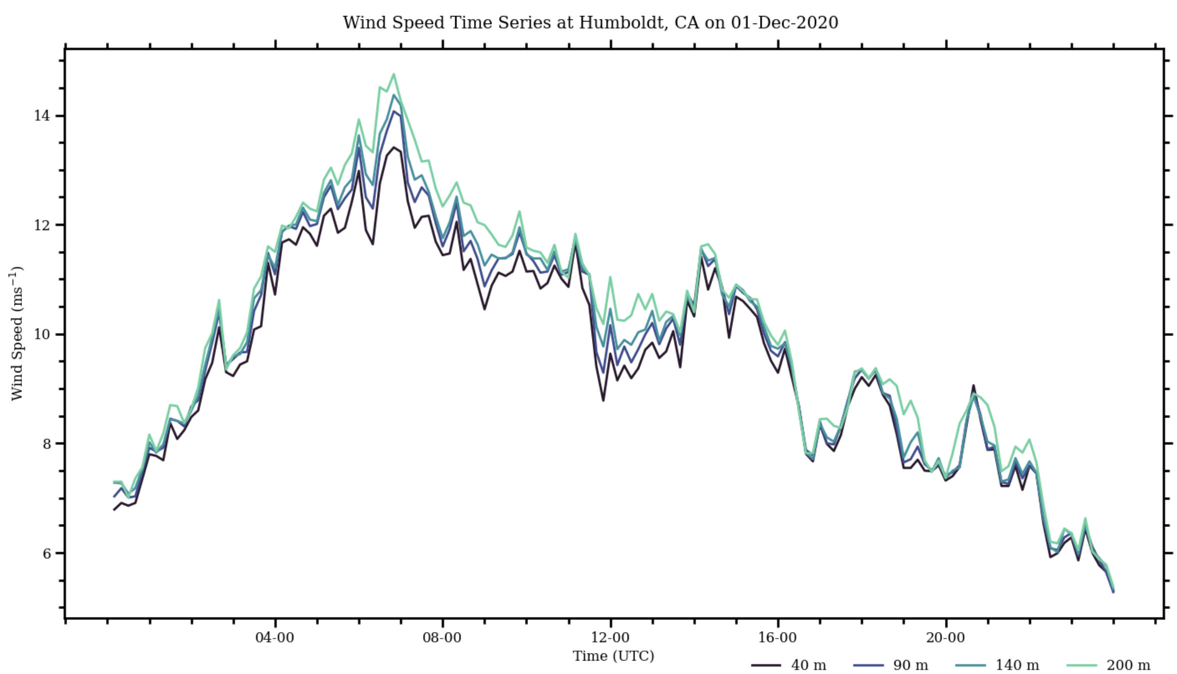


Figure 4. Time series of motion-compensated Doppler Lidar wind speed measurements at 40 m, 90 m, 140 m, and 200 m above sea level.

Description of Variables in Plot

The measurements included in this plot are described with the information provided below.

10-minute Average Wind Speed

Definition: Wind speed is the measurement of how fast wind is moving past a fixed location in the horizontal plane. The lidar wind profiler, which is mounted on the buoy hull, measures wind speed at heights between 40 m to 250 meters above the sea surface by detecting the reflection of laser signals sent into the atmosphere.

Instrument: Leosphere, Windcube 866 (Instrument 11)

Units: meters per second [m s^{-1}]

3.4 Conductivity and Sea Surface Temperature

This plot shows a time-series of sea surface temperature and water conductivity. The water conductivity (blue line, left axis) is measured in Siemens per meter, and the bulk sea surface temperature (SST) is measured in degree Celsius.

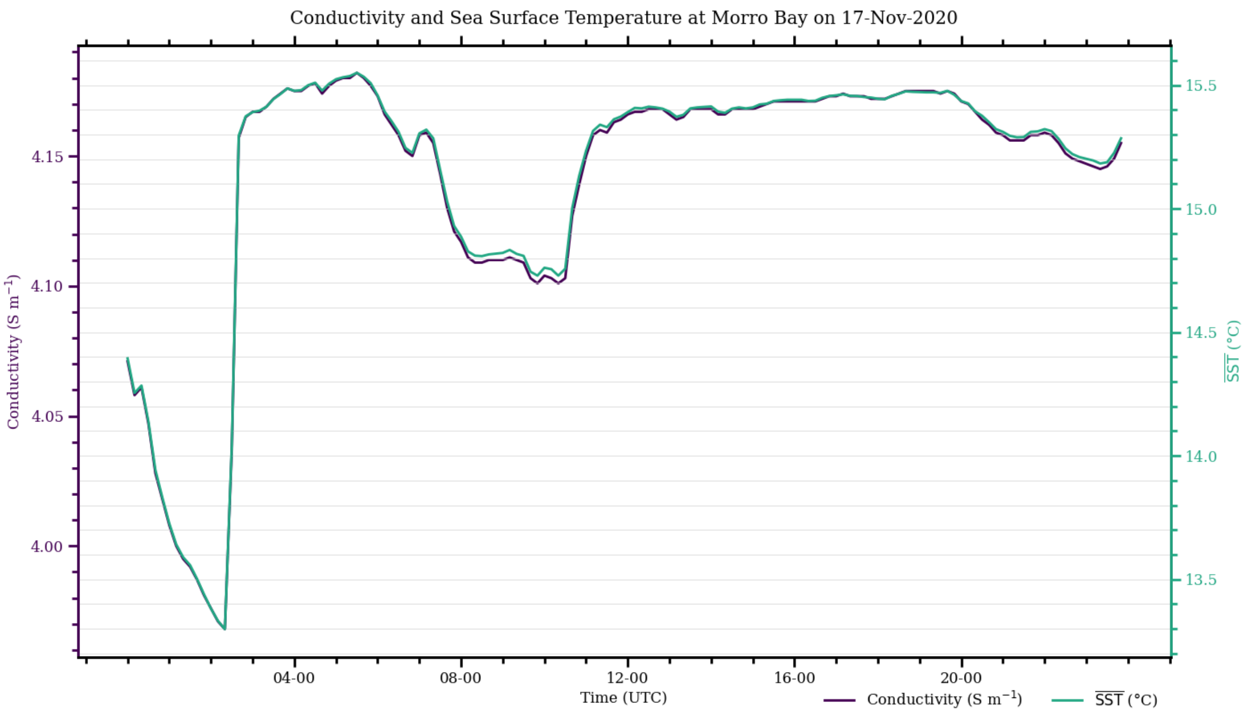


Figure 5. Ocean conductivity and sea surface temperature measurements at Morro Bay buoy location on November 17, 2020.

Description of Variables in Plot
The measurements included in this plot are described with the information provided below.

Conductivity

Symbol: $Conductivity$

Definition: The electrical conductivity measures the ability of a solution to conduct electric flow. The conductivity is directly related to the number of ions in the solution. Pure water has a very low conductivity, but salt water has higher conductivity. More ions – or more salt – will result in greater conductivity. Temperature also influences water conductivity, where higher temperature results in higher conductivity.

Instrument: Seabird Scientific, SBE 37SMP-1j-2-3c (Instrument 19)

Units: Siemens per meter [S m^{-1}]

Sea Surface Temperature

Symbol: $S\bar{S}T$

Definition: The bulk sea surface temperature (SST) is the temperature of sea water just below the surface, between approximately 1 centimeter to 1 meter depth.

Instrument: Seabird Scientific, SBE 37SMP-1j-2-3c (Instrument 19)

Units: Degrees Celsius [ºC]

Note: The bulk SST is reported here, not the skin SST. The skin SST is the temperature of the water directly on the surface, within the first few millimeters.

3.5 Wave Statistics

The Wave Statistics plot (Figure 6) describes the wave conditions measured at the buoy site. Wave statistics are reported from the buoy in 20-minute time intervals. The figure includes three plots:

- Wave height – displays a time series of wave heights. The plot shows the average (cyan), significant (black), and maximum (grey) wave height for each 20-minute measurement period.

- Wave period – displays a time series of average wave period (magenta) and significant wave period (green).

- Average wave height and direction – displays a time series of average wave height (blue, left axis) and wave direction (orange, right axis).

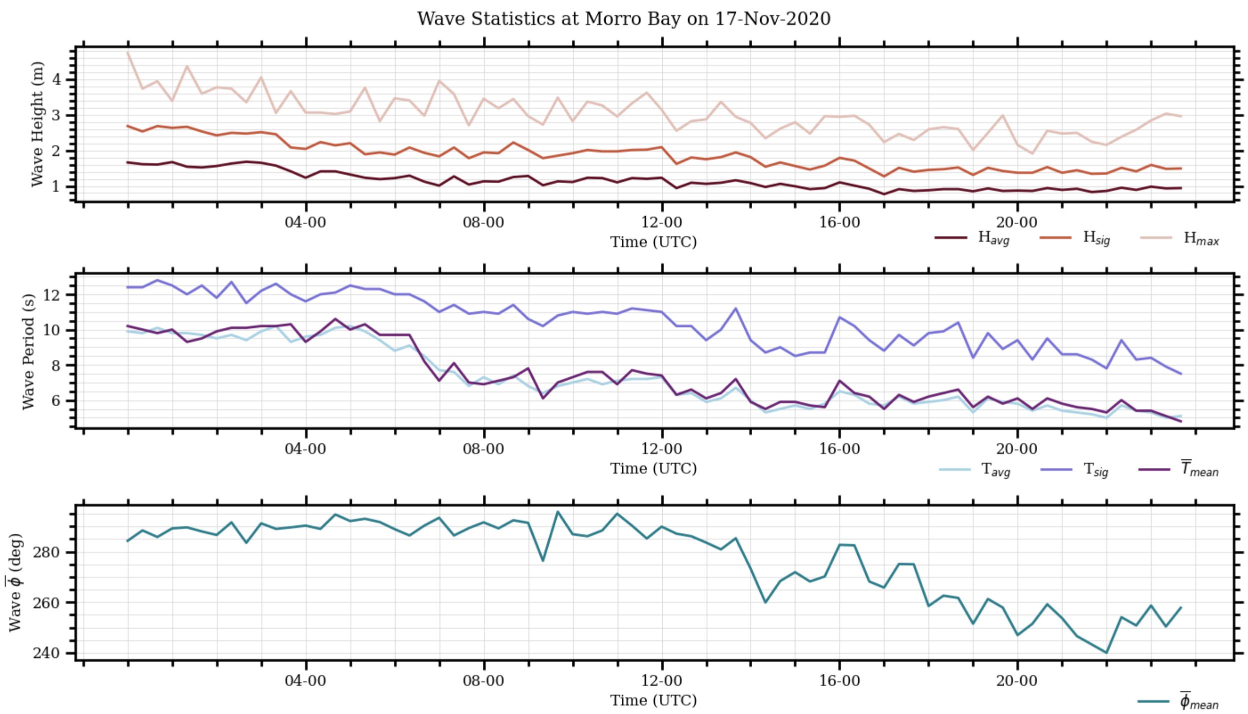


Figure 6. Time series of wave height (average, significant, and maximum), wave period and wave direction at Morro Bay on 17-Nov-2020.

Description of Variables in Plot
The measurements included in this plot are described with the information provided below.

Wave Height

Symbol: H

Definition: Wave height is measured as vertical distance between the trough and peak of a wave.

Instrument: AXYS, TRIAXYS NW III (Instrument 20)

Units: meters [m]

Average Wave Height

Symbol: H_{avg}

Definition: The average wave height is the mean wave height measured during the reporting time interval.

Significant Wave Height

Symbol: H_{sig}

Definition: The significant wave height is the average wave height of the top third highest waves measuring during the reporting time interval.

Maximum Wave Height

Symbol: H_{max}

Definition: The maximum wave height is the highest wave measured during the reporting time interval.

Wave Period

Symbol: T

Definition: The wave period is the duration of time between the crest of two subsequent waves.

Instrument: AXYS, TRIAXYS NW III (Instrument 20)

Units: seconds [sec]

Average Wave Period

Symbol: T_{avg}

Definition: The average wave period is the mean time between wave peaks during the reporting time interval.

Significant Wave Period

Symbol: T_{sig}

Definition: The significant wave period is the average wave period of the highest third of all waves measured during the reporting time interval.

Mean Wave Period

Symbol: $\bar{T}_{mean}$

Definition: The mean wave period calculated from the spectral moments.

Mean Wave Direction

Symbol: $\bar{\phi}$

Definition: The wave direction is the direction from which the wave is coming. A wave starting from the north heading towards the south has a wave direction of north. The mean wave direction is the average direction measured over the reporting time interval.

Instrument: AXYS, TRIAXYS NW III (Instrument 20)

Units: degrees from magnetic north, starting at 0º and increasing in the clockwise direction [deg]

Note: The plot may appear to have vertical discontinuities as the measurement changes between 359º and 0º. While this appears drastic on the plot, it is merely a small change in direction that goes from the top to the bottom of the direction axis.

3.6 Ocean Current Velocity and Direction

Ocean current is the movement of ocean water. Ocean currents are driven by water temperature and salinity differences, wind patterns, and tidal cycles. The current profiler installed on the buoys measures the current velocity and direction at several depths below the sea surface. The Ocean Current plot (Figure 7) shows a time series of ocean current velocity (top chart) and direction (bottom chart). The vertical axis of each plot shows the ocean depth. The color within the plot displays the velocity or direction measurement at that particular time and depth. This plot helps visualize how a current velocity and direction changes in speed and depth over time.

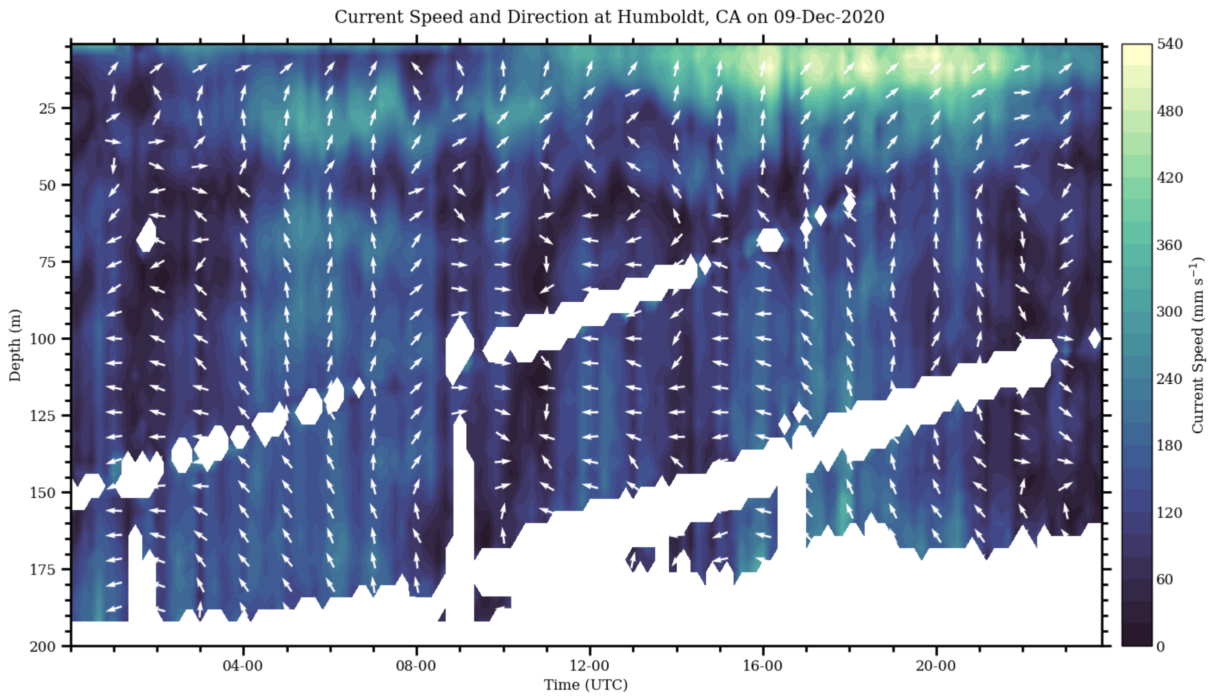


Figure 7. Time-Height Hovemöller diagram of Ocean current speed and direction at Humboldt on 9th December 2020. The data gaps represent poor signal to noise ratio of the ADCP measurements.

Description of Variables in Plot
The measurements included in this plot are described with the information provided below.

Current Velocity

Definition: Ocean current velocity is the horizontal velocity at which water is moving at the measurement point. The measurement is made at several ocean depths to see how current changes in the water column.

Instrument: Nortek, Signature 250 (Instrument 18)

Units: millimeters per second [mm s^{-1}]

Current Direction

Definition: Ocean current direction is the direction from which the current is coming from. A current from the north to the south would have a direction of north, or 0°. The measurement is made at several ocean depths to see how current changes in the water column.

Instrument: Nortek, Signature 250 (Instrument 18)

Units: degrees from magnetic north, starting at 0º and increasing in the clockwise direction [deg]

3.7 Buoy Motion Histogram

The Buoy Motion Histogram (Figure 8) shows the distribution of roll angle (black) and pitch angle (red) of the buoy. The vertical axis on the chart shows how often different angles were recorded and the horizontal axis shows the buoy's angle; these values are plotted as a frequency distribution. The histogram represents measurements taken during a one-hour period. The highest points on the curves represent the most common buoy angles.

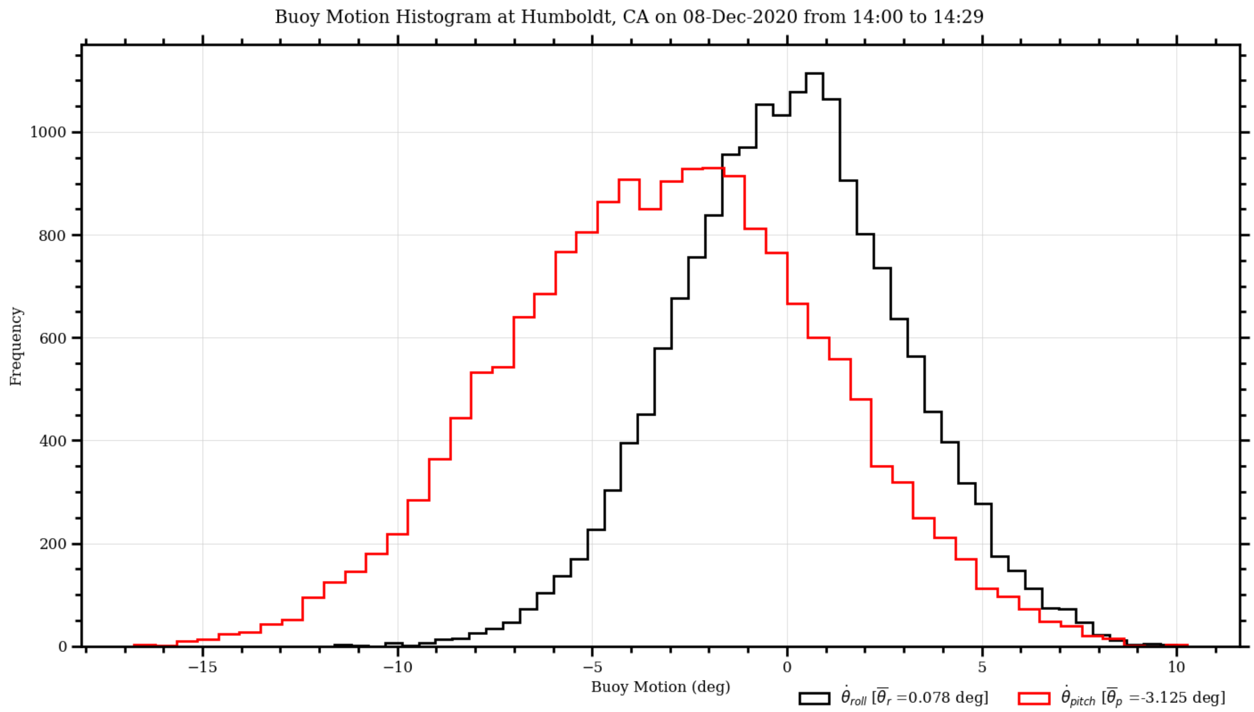


Figure 8. Histogram of PNNL IMU sensor roll and pitch angles at the Morro Bay buoy location for a one-hour time period.

Description of Variables in Plot

The measurements included in this plot are described with the information provided below.

Roll Angle

Symbol: $\dot{\theta}_{roll}$

Definition: The roll angle measures the side to side motion of the buoy between the starboard and port side. The roll angle is measured in degrees around the longitudinal axis of buoy that runs fore and aft. A roll angle of 0° means that the buoy is flat with respect to the earth in the side to side direction. Buoy rotation towards the starboard (right) side is a positive roll angle

Instrument: MicroStrain, 3DM GX3 25 (Instrument # NA)

Units: degrees [deg]

Note: The mean roll angle, $\bar{\theta}_r$, is displayed in the legend of the chart.

Pitch Angle

Symbol: $\dot{\theta}_{pitch}$

Definition: The pitch angle measures the front to back motion of the buoy fore and aft. The pitch angle is measured in degrees around the lateral axis of buoy that runs from port to starboard. A pitch angle of 0º means that the buoy is flat with respect to the earth in the fore to aft direction. Buoy rotation towards the fore (front) is a positive pitch angle.

Instrument: MicroStrain, 3DM GX3 25 (Instrument # NA)

Units: degrees [deg]

Note: The mean pitch angle, $\bar{\theta}_p$, is displayed in the legend of the chart.

4.0 References

Gorton, Alicia M. and Will J. Shaw. 2020. “Advancing Offshore Wind Resource Characterization Using Buoy-Based Observations.” *Marine Technology Society Journal* 54, no. 6 (November/December): 37-43.

Shaw, William J., Draher, Jennifer, Garcia Medina, Gabriel, Gorton, Alicia M., Krishnamurthy, Raghavendra, Newsom, Rob K., Pekour, Mikhail S., Sheridan, Lindsay M., and Yang, Zhaoqing. Tue . 2020. *General Analysis of Data Collected from DOE Lidar Buoy Deployments Off Virginia and New Jersey*. PNNL-29823. Richland, WA. https://doi.org/10.2172/1632348.

Appendix A – Data Files and Naming Convention

Data collected from past and current buoy deployments are made available for public access within the DAP (https://a2e.energy.gov/data). Select buoy data are uploaded at the end of every day, without any quality control, depending on bandwidth limitations at a given location. All data (processed and raw) are uploaded after complete data sets are recovered from the buoy during schedule maintenance visits and after buoy recovery. The type and contents of the data files are described in Table 2. File names and descriptions. MATLAB scripts to read, process, and plot buoy data are available on GitHub (https://github.com/rkpnnl/DOE_Buoy_DAP.git).

A.1 Data Recovered Daily Throughout the Deployment

Data that are made available on the DAP at the end of each day during a deployment are:

- Lidar data: 10-minute averaged and 1 Hz data (with and without motion compensation)
- Surface meteorological data: 10-minute averaged data (wind, relative humidity, temperature) and global position data
- Oceanographic data: 20-minute averaged data (salinity, conductivity, sea surface temperature, wave statistics, ocean current profiles)
- Inertial motion unit (IMU) data: Platform motion data (Euler angles (roll, pitch, and yaw), linear velocity, GPS, gyroscope, and magnetometer) from a strapdown sensor underneath the lidar (GX5-45) and an internal IMU sensor within the lidar at 10 Hz.

A.2 Data Recovered during a Maintenance Visit or after Deployment

All raw data files that are not already collected will be made available on the DAP after scheduled maintenance visits and buoy recovery. These files are not described within this version of the data dictionary. Their contents will be described when the complete data files are recovered from the California buoy deployments and published on DAP in 2021.

A.3 File Naming Convention

The file naming convention used for the data files is:

AAAA.z##.00.yyyymmdd.hhmmss.BBB.ccc

where:

- AAA is data source, as shown in Column 1 of Table 2. File names and descriptions. Options are:
  - *buoy*
  - *lidar*
- ## is the buoy deployment number. For example,
  - *05* is for the Morro Bay deployment

  - *06* is for the Humboldt deployment
- yyyymmdd is the calendar date where the data file begins
- hhmmss is the time, in UTC, where the data file begins
- BBB is the measurement type as shown in Column 2 of Table 2. File names and descriptions.
- ccc is the file type as shown in Column 3 of Table 2. File names and descriptions. File types are:
  - *.7z*
  - *.bin*
  - *.csv*
  - *.txt*

Table 2. File names and descriptions

Data source	Measurement type	File type	Description	Instrument Number	Measurement frequency	File collection frequency
Near real-time Data Files, Uploaded to DAP Dail						
lidar	gyro	.7z [a] / .txt [b]	Lidar internal measurement unit	NA	~10 Hz	Hourly
lidar	rtd	.7z / .txt	Lidar line of sight (LOS) measurements after motion compensation; real time data (1 Hz)	11	~1 second data	Daily
lidar	sta	.7z / .txt	Lidar wind measurements after motion compensation; statistical data (10-min averaged)	11	10-min averaged	Daily
lidar	stdrtd	.7z / .txt	Lidar LOS measurements before motion compensation; real time data (1 Hz)	11	~1 second data	Daily
lidar	stdsta	.7z / .txt	Lidar wind measurements before motion compensation; statistical data (10-min averaged)	11	10-min averaged	Daily
buoy	conductivity	.csv	SST and conductivity	19	10-min averaged	Daily
buoy	currents	.csv	ADCP measurements	18	10-min averaged	Daily
buoy	gill	.csv	2D Ultrasonic anemometer measurements	14	10-min averaged	Daily
buoy	gnss	.bin	GPS, linear velocity data from GX5-45 IMU	NA	Binary data files (10Hz)	Hourly
buoy	gps	.csv	Buoy location	8	10-min averaged	Daily
buoy	imu	.bin	Euler angles, accelerometer, magnetometer and	NA	Binary data files (10Hz)	Hourly

			Gyroscope data from GX5-45 IMU			
buoy	pyranometer	.csv	Global solar radiation	15	10-min averaged	Daily
buoy	pressure	.csv	Atmospheric Surface pressure	17	10-min averaged	Daily
buoy	rh	.csv	Relative humidity	16	10-min averaged	Daily
buoy	temperature	.csv	Surface Air temperature	16	10-min averaged	Daily
buoy	waves	.csv	Wave measurements	20	20-min averaged	Daily
buoy	wind	.csv	Cup anemometer and wind vane measurements	12, 13	10-min averaged	Daily

[a] Compressed file format when downloaded from DAP
[b] After uncompressing the files

Appendix B – List of Measurements

Data available from the buoy data files include the measurements described in Table 3.

Table 3. Description of measurements, variables, and units.

Symbol	Measurement	Unit	Instrument Number	Data File[a]
SST	Sea surface temperature	ºC	19	conductivity
σ_c	Ocean electrical conductivity	S m^{-1}	19	conductivity
Dir_i	Current direction in bin number *i*	degrees	18	currents
Vel_i	Current velocity in bin number *i*	mm s^{-1}	18	currents
	Number of bins: number of measurements being taken in vertical profile	--	18	currents
	Bin spacing: vertical distance between each bin	m	18	currents
	Head depth: depth of instrument below ocean surface	m	18	currents
	Blanking distance – or the distance between the transducer head and the first measurement	m	18	currents
U_{Gill}	Surface horizontal wind velocity, 2D ultrasonic anemometer	m s^{-1}	14	gill
θ_{Gill}	Surface horizontal wind direction, 2D ultrasonic anemometer	degrees	14	gill
$North$	Velocity in north direction	m s^{-1}	NA	gnss
$East$	Velocity in east direction	m s^{-1}	NA	gnss
$Down$	Velocity in down direction	m s^{-1}	NA	gnss
$Speed$	Absolute velocity in direction of buoy heading	m s^{-1}	NA	gnss
Gnd_Speed	Horizontal velocity of buoy relative to Earth's surface	m s^{-1}	NA	gnss
$Heading$	Compass direction in which the buoy is moving	degrees	NA	gnss
Spd_Err	Magnitude of error in velocity	± m s^{-1}	NA	gnss
$Head\_Err$	Magnitude of error in heading	± degrees	NA	gnss
$lat.$	Latitude of buoy position	degrees	8	gps
$long.$	Longitude of buoy position	degrees	8	gps
$rpy.r$	Roll of buoy	radians	NA	imu
$rpy.p$	Pitch of buoy	radians	NA	imu
$rpy.y$	Yaw of buoy	radians	NA	imu
$gyro.x$	Rotation of gyroscope around x-axis	radians	NA	imu
$gyro.y$	Rotation of gyroscope around y-axis	radians	NA	imu
$gyro.z$	Rotation of gyroscope around z-axis	radians	NA	imu
$accel.x$	Acceleration in x-direction	m s^{-2}	NA	imu
$accel.y$	Acceleration in y-direction	m s^{-2}	NA	imu
$accel.z$	Acceleration in z-direction	m s^{-2}	NA	imu

Symbol	Measurement	Unit	Instrument Number	Data File[a]
$mag.x$	Magnetic field strength in x-direction	G	NA	imu
$mag.y$	Magnetic field strength in y-direction	G	NA	imu
$mag.z$	Magnetic field strength in z-direction	G	NA	imu
P	Atmospheric pressure	mbar	17	pressure
I	Global solar radiation on the plane horizontal to the buoy platform	W m^{-2}	15	pyranometer
RH	Relative humidity	%	16	rh
T_{air}	Air temperature	ºC	16	temperature
$Wave\ Type$	Not relevant to this deployment. A value of 0 indicates that the measurements describe the total wave spectrum statistics.		20	waves
ZCN	Number of zero down crossings		20	waves
H_{sig}	Wave height, significant, average of highest 1/3rd of waves	m	20	waves
H_{max}	Wave height, maximum of zero down crossing waves	m	20	waves
H_{avg}	Wave height, average of zero down crossing waves	m	20	waves
H_{110}	Wave height, average of highest 1/10th of waves	m	20	waves
H_{m0}	Wave height, significant, estimated from the spectral moment	m	20	waves
$Crest_{max}$	Maximum wave height above mean water level	m	20	waves
T_{max}	Wave period, associated with H_{max}	sec	20	waves
T_{peak}	Wave period, peak period associated with maximum energy value wave spectrum	sec	20	waves
$T_{peak,5}$	Wave period, peak period computed by the Read method	sec	20	waves
T_{sig}	Wave period, significant, average of highest 1/3rd of waves	sec	20	waves
T_{avg}	Wave period, average	sec	20	waves
T_{110}	Wave period, average of highest 1/10th of waves	sec	20	waves
T_{mean}	Wave period, average calculated from the spectral moments	sec	20	waves
T_e	Wave energy period, calculated from the spectral moments	sec	20	waves
ϕ	Wave direction, mean	degrees	20	waves
$\phi_{T,peak}$	Wave direction, mean, corresponding to peak wave period	degrees	20	waves
	Wave spread, mean	degrees	20	waves
	Wave spread corresponding to peak wave period	degrees	20	waves

Symbol	Measurement	Unit	Instrument Number	Data File[a]
U_{Cup}	Surface wind speed, cup anemometer	m s^{-1}	12	wind
θ_{vane}	Surface wind direction, wind vane	degrees	13	wind
U_i	Wind speed at height *i*	m s^{-1}	11	rtd, stdrtd, sta, stdsta
$U_{x,i}$	Wind component in x-direction at height *i*; horizontal component of wind in the N-S direction	m s^{-1}	11	rtd, stdrtd
$U_{y,i}$	Wind component in y-direction at height *i*; horizontal component of wind in the E-W direction	m s^{-1}	11	rtd, stdrtd
$U_{z,i}$	Wind component in z-direction at height *i*; vertical component of wind	m s^{-1}	11	rtd, stdrtd, sta, stdsta
$U_{rad,i}$	Radial wind component at height *i*	m s^{-1}	11	rtd, stdrtd
$U_{min,i}$	Wind speed minimum at height *i* over averaging time interval	m s^{-1}	11	sta, stdsta
$\sigma_{U,i}$	Wind dispersion (standard deviation) at height *i*	m s^{-1}	11	sta, stdsta
$\sigma_{U,z,i}$	Wind dispersion (standard deviation) in z-direction at height *i*	m s^{-1}	11	sta, stdsta
$\sigma_{U,rad,i}$	Radial wind dispersion (standard deviation) at height *i*	m s^{-1}	11	rtd, stdrtd
	Wind direction at height *i*	m s^{-1}	11	rtd, stdrtd
CNR_i	Lidar carrier to noise ratio (CNR) at height *i*	dB	11	rtd, stdrtd, sta, stdsta
CNR_{min}	Minimum lidar CNR at height *i* over averaging time period	dB	11	sta, stdsta
S_i	Doppler spectral width at height *i*	m s^{-1}	11	sta, stdsta
A_{lidar}	Data availability of lidar data at height *i*	%	11	sta, stdsta
α	Yaw angle from lidar IMU	degrees	11	rtd
β	Pitch angle from lidar IMU	degrees	11	rtd
γ	Roll angle from lidar IMU	degrees	11	rtd
$T_{lidar,int}$	Lidar temperature, internal	ºC	11	rtd, stdrtd, sta, stdsta
$T_{lidar,ext}$	Lidar temperature, external	ºC	11	sta, stdsta
P_{lidar}	Lidar pressure	hPa	11	sta, stdsta
RH_{lidar}	Relative humidity	%	11	sta, stdsta
V_{batt}	Battery voltage	V	11	sta, stdsta
	Wiper count	--	11	rtd, stdrtd
	Pitch	radians	NA	gyro
	Roll	radians	NA	gyro
	Yaw	radians	NA	gyro
	Yaw from Septentrio	radians	NA	gyro
	GPS True Heading	degrees	NA	gyro
	Latitude of lidar buoy IMU	degrees	NA	gyro
	Longitude of lidar buoy IMU	degrees	NA	gyro
	Altitude of lidar IMU GPS	m	NA	gyro

Symbol	Measurement	Unit	Instrument Number	Data File[a]
v_x	Velocity in the x direction	m s^{-1}	NA	gyro
v_y	Velocity in the y direction	m s^{-1}	NA	gyro
v_z	Velocity in the z direction	m s^{-1}	NA	gyro
	GPS horizontal accuracy	mm	NA	gyro
	GPS vertical accuracy	mm	NA	gyro
	GPS velocity accuracy	cm s^{-1}	NA	gyro
	IMU attitude accuracy	radians	NA	gyro
	IMU position accuracy	m	NA	gyro
	IMU position accuracy	m	NA	gyro
	IMU velocity accuracy	m s^{-1}	NA	gyro

[a] The Data File column refers to the name of the file as described by '*BBB*' in Section A.3 and Column 2 in Table 2

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