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Measurement and modeling of wind directionality for better design and operation of floating offshore wind turbines

Krish Thiagarajan, Anthony Viselli, Habib Dagher, Andrew Goupee, Richard Kimball
Corresponding author: krish.thiagarajan@maine.edu

University of Maine & Maine Maritime Academy

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Abstract

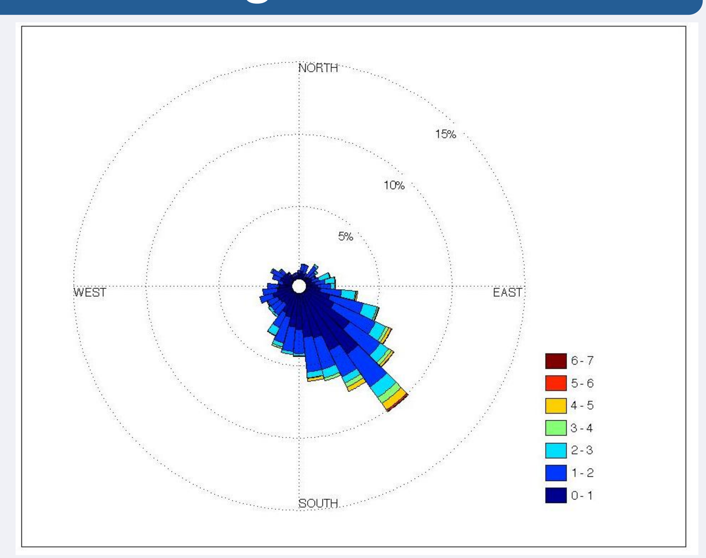
Environmental directionality is gaining importance in floating offshore wind turbine (FOWT) structure design. Often a non-collinear condition of major forces like waves and wind, can result in a more onerous operational, or fatigue loading condition for an FOWT. Understanding directionality can help in identifying severe load cases that can lead to robust design and reduce long-term costs. Better knowledge of the environment can lead to reduction of risk and needless conservatism. This paper highlights knowledge gained from analysis of field data from VolturnUS 1:8, a small prototype FOWT and its application to the development of a novel experimental multidirectional wind generation facility.

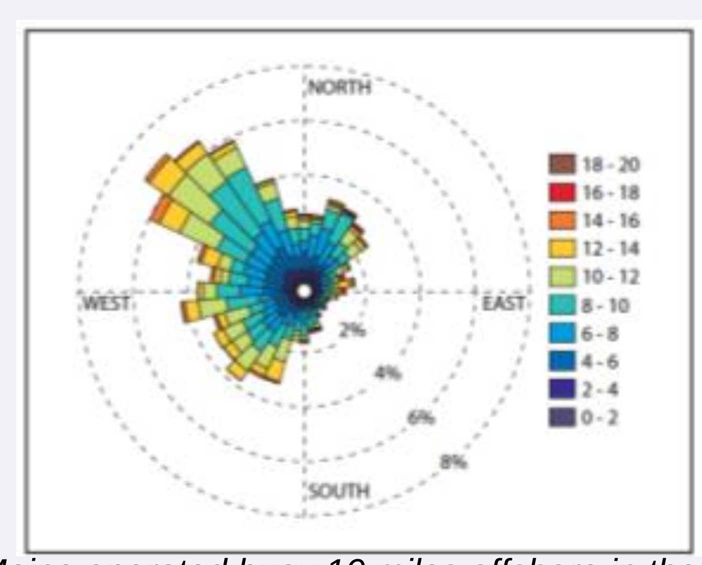
Multi-directional wind and wave loading

Over 10 years of buoy data exist for the Gulf of Maine5 which indicate there is a high likelihood of multi-directional wind and waves. Larger waves in the Gulf of Maine tend to come from the Southwest while winds primarily come from the Northwest.

Instrumentation:

- Metocean buoy including a LiDAR (Light Detecting and Ranging) for wind, wave, and current data.
- Acoustic Doppler Current Profiler (ADCP) mounted on the sea floor.



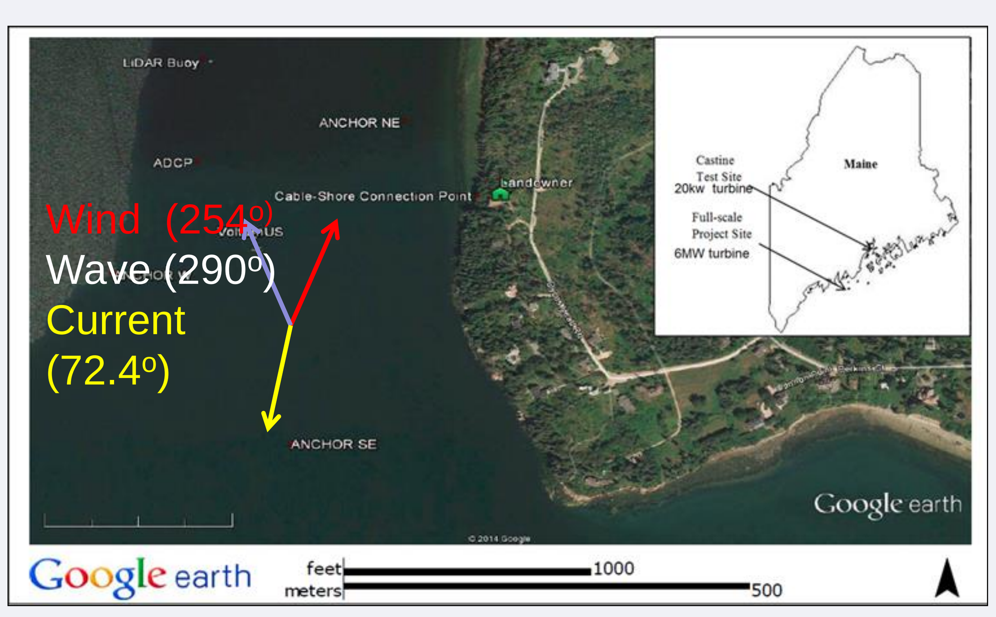


UMaine operated buoy 10 miles offshore in the Gulf of Maine . Top: Wave rose and bottom: Wind rose (right) for winter months

Sample Multi-directional Wind/Wave Event

Date: January 20th, 2014 at 12:50am

The 1-hour mean wind, wave, and current directions: wind coming from Northeast, the waves from Northwest and current going towards Southwest.



VolturnUS 1:8 project test site with mean wind, wave, and current directions. January 20th, 2014 12:54am

Sample data on Jan 20, 2014	VolturnUS 1:8
Hs (m) (measured from Leg C)	0.50
Tp (s)	3.51
Hmax (m)	0.78
Current Speed (cm/s)	5.7
Turbine Operating Status	75% of rated
Max Nacelle Acceleration (m/s^2)	0.62m/s^2
Max Heel Angle (degrees)	5.0

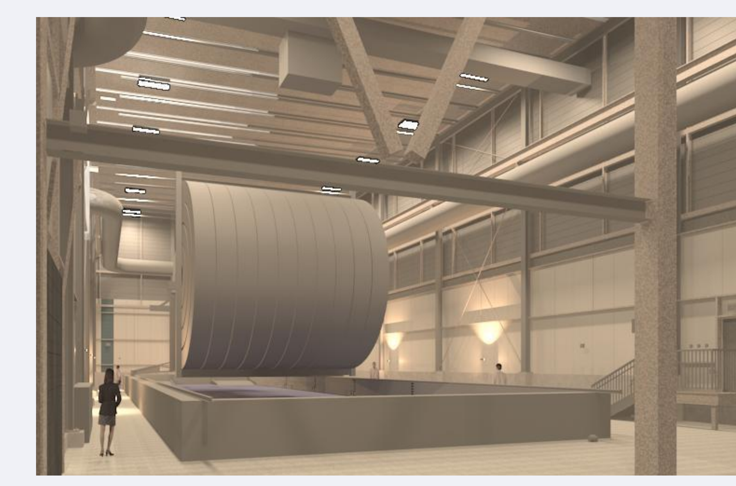
W2: A unique multi-directional wind wave laboratory

In conjunction with partners at the Sandia National Laboratories, the National Renewable Energy Laboratory (NREL), and Maine Maritime Academy, the University of Maine has developed and commenced construction of a unique multidirectional Wind-Wave generating system, called W^2. Currently ongoing activities include procurement of a wave generator, customized design, verification and construction of a rotating wind tunnel to operate in conjunction with the wave maker, system testing and calibration[4]. *By carefully developing a representative wind field over the wave tank, the W^2 equipment will be able to generate realistic offshore and coastal environments as seen by UMaine buoy data and the VolturnUS 1:8 prototype.* The facility will enable fundamental and applied research on various ocean related processes and energy harvesting devices.

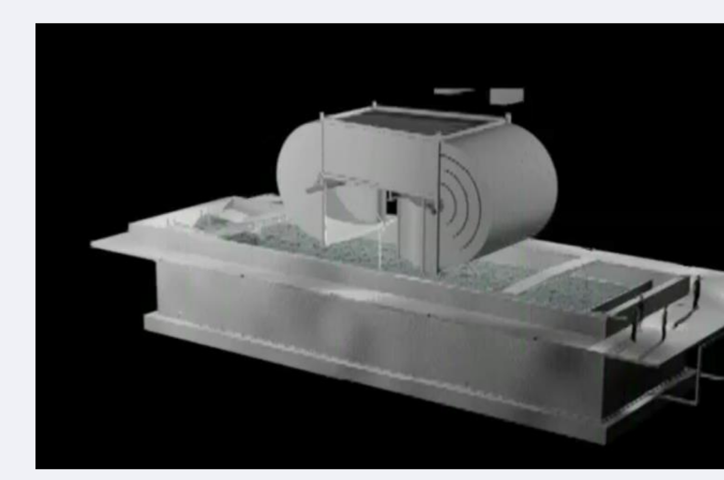
Sponsors:
Economic Development Agency
National Science Foundation
The University of Maine

Facility capabilities

- Operational and extreme wave conditions
- Multi-directional operational and extreme wind speeds.
- Stochastic (temporal and spatially varying) wind profile generation
- Full floater instrumentation including motion tracking and mooring forces
- Ability to test dynamic turbine effects such as aero-elastic effects and dynamic pitch control.
- Capability to measure turbine inflows and wakes.
- Other capabilities
  - Tow carriage
  - Overhead crane support
  - Model construction shop
  - Engineering analysis and design



Architectural rendering of the directional wind wave laboratory, showing the wind tunnel suspended above the wave tank



3D visualization of the directional wind wave laboratory, showing the wind tunnel suspended above the wave tank

Facility Specifications

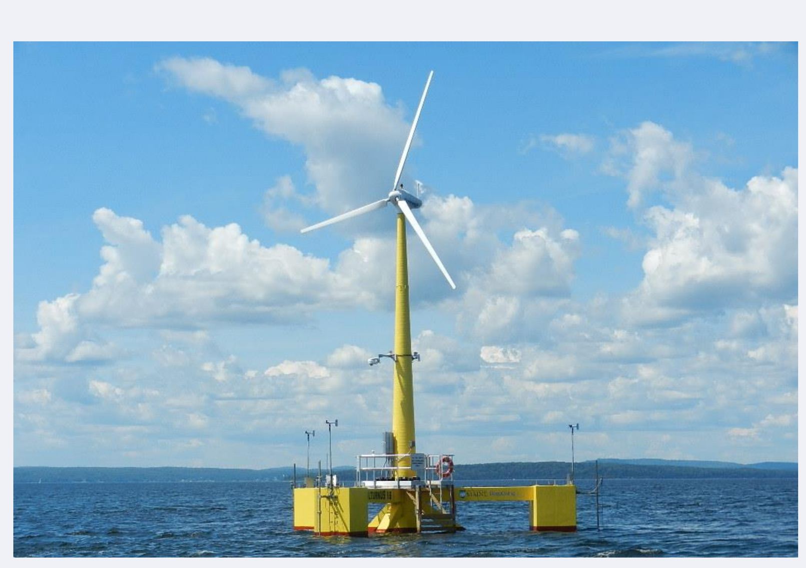
- 30 m x 9 m basin
- 4.5 m depth total
- Moveable floor with water depth ranging from 0 – 4.5 m
- Wind generator with 180º positioning system
- Directional wave generator
  - 0 – 45 deg multi-directional waves
  - Max wave height 0.7 m, range of periods.

Aerial photograph taken on February 15, 2015 showing the wind laboratory under construction

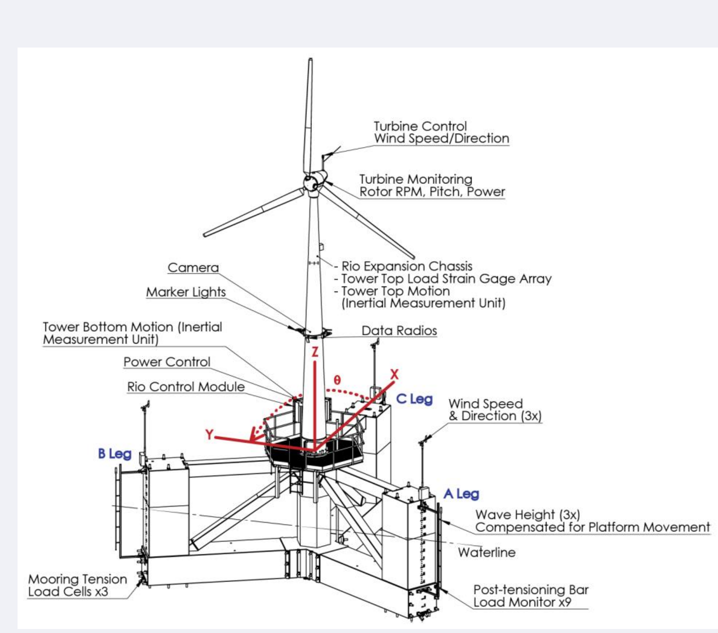
VolturnUS 1:8 field data: Multi-directional wind/ wave environment

VolturnUS 1:8 Characteristics

- 1:8-geometric scale of a 6 MW floating wind turbine
- Deployed in Castine, Maine, USA
- The model was designed to demonstrate the VolturnUS System full-scale system including:
  - Use of a pre-stressed concrete semi-submersible floating foundation design.
  - Demonstration of complete assembly quayside with availability of a 10m of water and towed out with low-cost tug boats from a number of assembly locations.
  - Anchoring in multiple ways depending on site conditions such as relatively inexpensive drag anchors in areas of sufficient sediment depth.
  - Ability to tow back to shore for major operations and maintenance activities.
  - Advanced light-weight composite tower (optional).
- Unit operated autonomously for 18-months offshore.
- Unit experienced representative operational and extreme scaled design load cases as specified in the American Bureau of Shipping Guide for Building and Classing Floating Offshore Wind Turbines[1].
- Numerical simulation of floating offshore wind turbines and comparison with experiments at MARIN[2 3] used to select site of the VolturnUS 1:8. Further numerical work on modeling directionality is continuing.



VolturnUS 1:8 installed off Castine, Maine, USA



Instrumentation systems onboard VolturnUS 1:8

Rotating open-jet wind tunnel specifications

Wind speed range	0-7m/s
Test section area	3m x 5m
Wind system	35-750W fans individually speed controlled
Fan frequency response	zero to full speed: < 3 sec
Swirl removal system	¼" x 3" aluminum honey comb
Swirl specification	Less than 1 % free stream
Turbulence intensity	5% or less in test section area
Flow uniformity in test section	5% of mean free stream
Flow direction relative to waves	0-180 degrees
Test section tilt	0-10 degrees
Vertical height adjustment (relative to water surface)	0-1 m above.

References

[1]American Bureau of Shipping, 2013, "Guide for Building and Classing Floating Offshore Wind Turbine Installations" Houston, Texas, USA
[2]Martin, H. R., Kimball, R., Viselli, A. M., Goupee, A. J., 2014, "Methodology for Wind/ Wave Basin Testing of Floating Offshore Wind Turbines," Journal of Offshore Mechanics and Artic Engineering, Vol. 136 May 020905.
[3]Goupee, A. J., Koo, B. J., Lambrakos, K. F., Kimball, R. W., 2012, "Model Test of Three Floating Wind Turbine Concepts", OTC 23470, Offshore Technology Conference, Houston, Texas.
[4]Thiagarajan, K. P., Kimball, R., Goupee, A., Cameron, M. (2014) "Design and development of a multi-directional wind wave ocean basin", Proceedings 19th Offshore Symp., Texas Section of SNAME, Houston, USA.