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Ocean Testing of a Wave-Capturing Power Buoy

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10 April 2013

Objective

- **Describe deployment of an Autonomous PowerBuoy® (APB) off the coast of New Jersey**
- **Summarize APB ocean performance**
  - Overall ocean operation
  - Electric power output

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The Company: Ocean Power Technologies

- **Ocean-tested, proprietary technology for producing electrical power from ocean waves. 51 patents issued.**
- **35 employees include engineers and scientists**
- **Commenced active operations in 1994. Headquarters in Pennington, NJ. Subsidiaries in Warwick, UK and Melbourne, Australia**
- **Listed on NASDAQ (symbol OPTT)**

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PowerBuoy® Schematic

- Converts linear motion of float along spar into electrical power to grid (utility systems) or to a payload (autonomous systems)
- OPT Autonomous PowerBuoy business unit focuses on opportunities in defense and homeland security, oil and gas operations and oceanographic data collection

Example Payload

Surface Float

Spar Containing Power Takeoff

Heave Plate Constraining Spar's Motion

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LEAP Project

- **Littoral Expeditionary Autonomous PowerBuoy**
- **Naval Undersea Warfare Center (NUWC) Keyport**
  Contracting Officer's Representative (COR): Matt Binsfield
- **Autonomous power source for HF radar payload requiring continuous power delivery independent of wave conditions**
- **Rutgers and CODAR: coastal radar network**
- **Completed 3-month ocean test off NJ (Oct 2011)**

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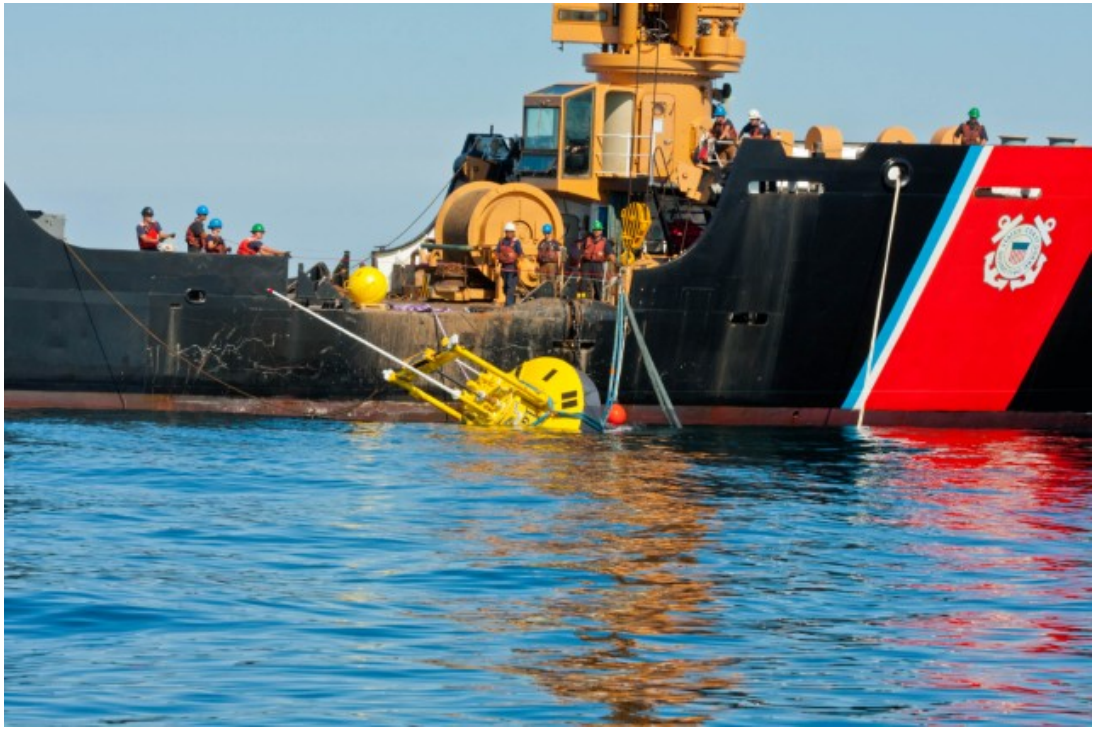
LEAP Location

LEAP Deployment



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System Components

- **Power takeoff –** Convert mechanical to electrical power
- **Power management –** Regulate variable wave power: Store during high waves, deliver in low, dump excess.
- **Control algorithm –** Automate system functions
- **Data acquisition** – Collect sensor measurements and transmit in real time. Input to control algorithm. Used in reporting.
- **Operator interface** – Monitor and change parameters
- **Mooring system** – Maintain station
- **Wave measurements** – Collected with RDI Acoustic Doppler Current Profiler

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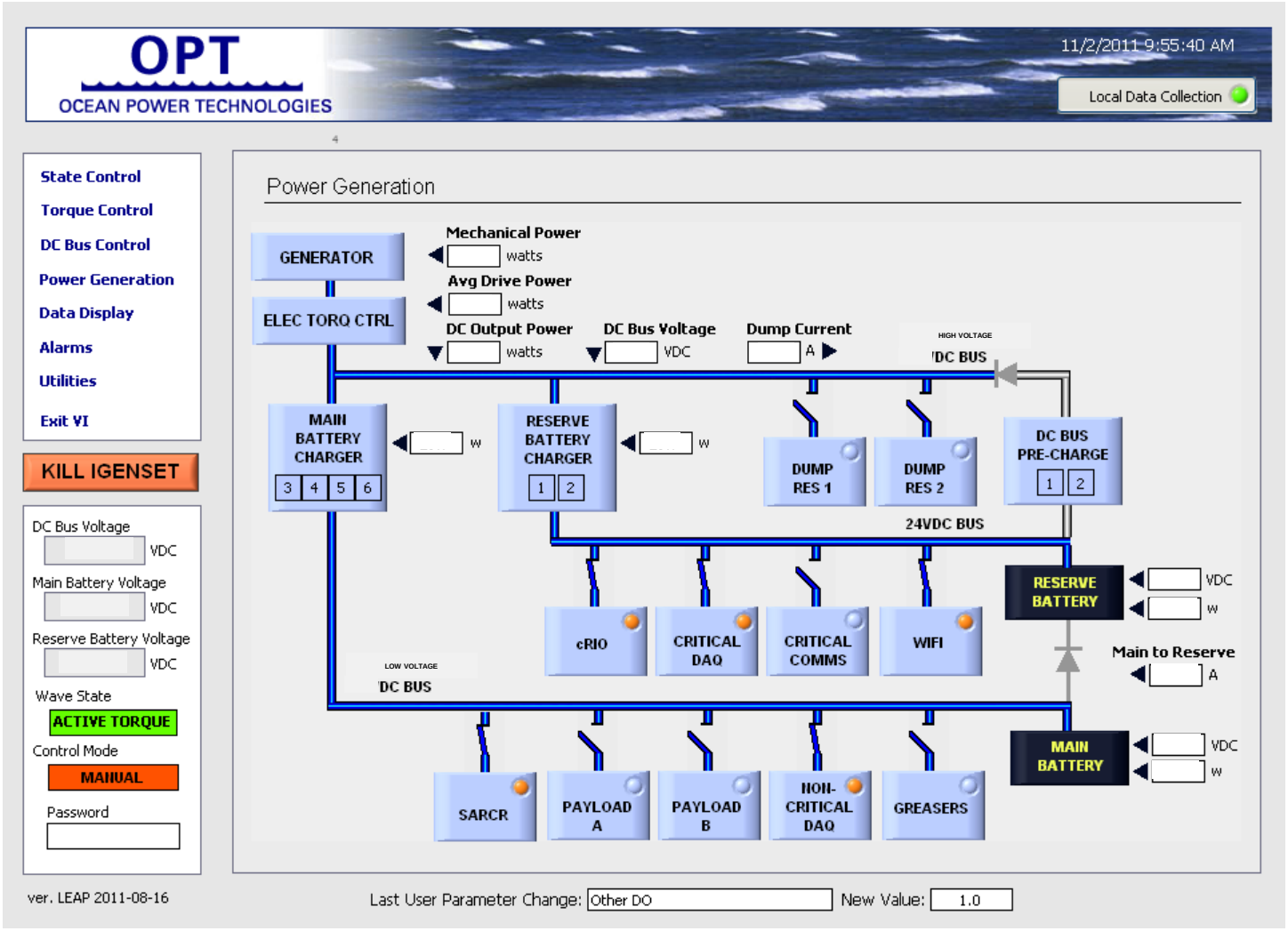
System Control

- **Designed for full autonomous operation**
  - Control algorithm governs power capture and delivery in high, moderate, and low waves
  - Careful regulation of battery arrays
- **Minimal operator intervention after deployment**

Operator Interface



- **System monitoring**
- **Update system parameters if needed**

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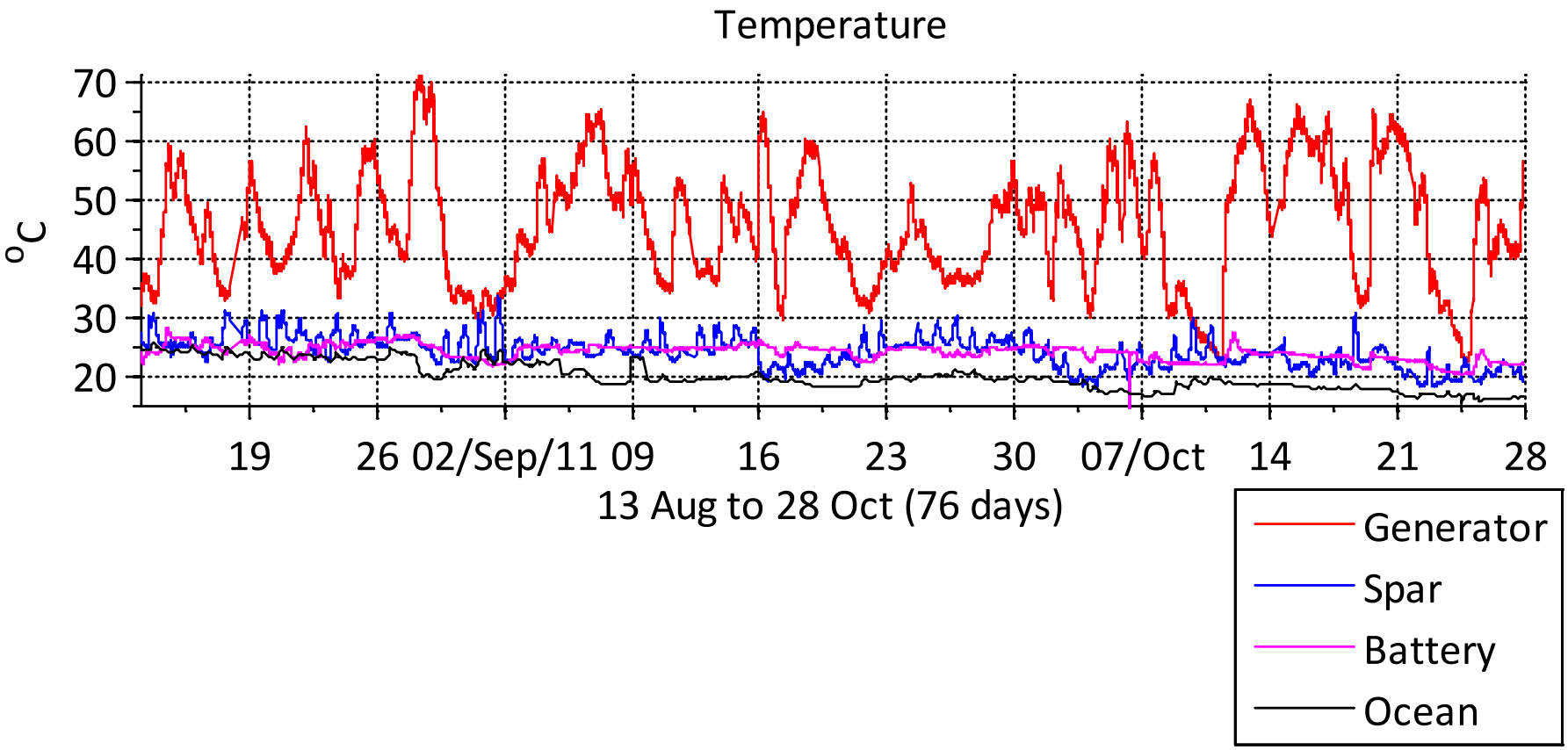
Measurements

- **Data collected by sensors throughout PowerBuoy**
- **Measurements transmitted by satellite in near real-time**
- **Transmission was reliable and sufficient for test monitoring and reporting**

Example of Reported Information



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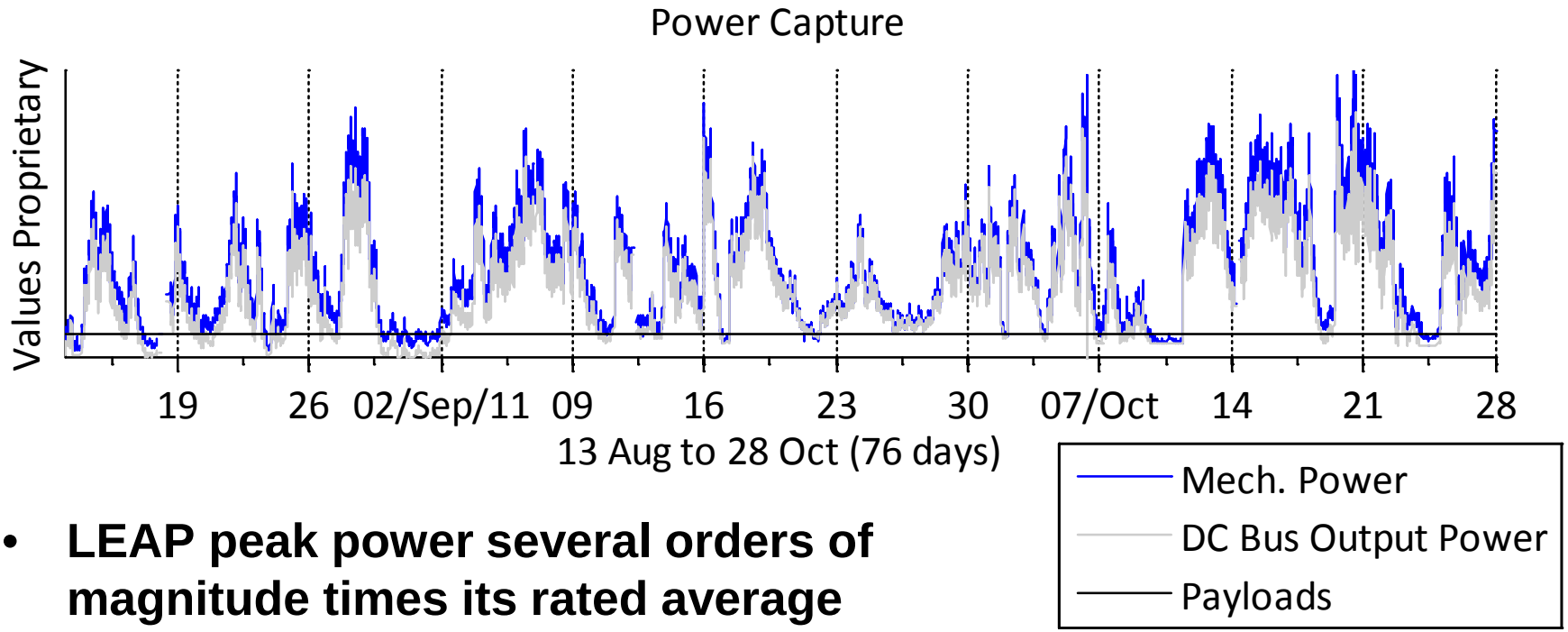
LEAP Power Capture



- **LEAP peak power several orders of magnitude times its rated average output; reached 3.5kW**
- **Hourly averaged power up to 2kW, test average >500W**
- **Data composited to obtain a measured power matrix (power vs. sea state)**

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Power Assessment

- **Evaluation of power matrix**
  - Measured power matrix can be used to estimate power at any location given its wave climate
  - Comparison with power prediction model for better understanding of model's performance and limitations
- **Source of wave measurements**
  - Teledyne RDI ADCP deployed at LEAP ocean test site
    - Accurate wave data available at end of test
  - Wave measurements from National Data Buoy Center (NDBC)
    - Provided real-time data from remote wave buoys for daily reporting

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Sea States Observed during LEAP

Sea States Observed during LEAP

Wave States Observed during LEAP Ocean Test (*10^4)
Measured during LEAP Ocean Test (2.5 months)

H_s (m) \ T_a (s)	3	4	5	6	7	8	9	10	11	12	13
7.5	-	-	-	-	-	-	-	1	3	-	-
7	-	-	-	-	-	-	-	3	2	-	-
6.5	-	-	-	-	-	-	1	4	-	-	-
6	-	-	-	-	-	-	3	6	-	-	-
5.5	-	-	-	-	-	-	15	1	-	-	-
5	-	-	-	-	-	4	11	-	-	-	-
4.5	-	-	-	-	-	3	1	-	-	4	-
4	-	-	-	-	2	6	-	9	20	14	2
3.5	-	-	-	5	50	11	2	47	39	2	-
3	-	-	-	46	95	1	24	16	3	-	-
2.5	-	-	46	191	145	65	15	12	-	-	-
2	-	2	399	292	70	40	7	-	-	-	-
1.5	-	831	1135	511	172	17	2	3	2	-	-
1	536	2175	734	357	371	137	7	-	-	-	-
0.5	434	236	209	158	193	43	-	-	-	-	-

Expected Sea States at LEAP Site

Wave JPD for NDBC 44025, Hs Scaled (*10^4)
18 Years of Data

H_s (m) \ T_a (s)	3	4	5	6	7	8	9	10	11	12	13
7.5	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-
6.5	-	-	-	-	-	-	1	-	-	-	-
6	-	-	-	-	-	2	1	-	-	-	-
5.5	-	-	-	-	-	4	-	-	-	-	-
5	-	-	-	-	4	4	-	-	-	-	-
4.5	-	-	-	-	19	4	1	-	-	-	-
4	-	-	-	6	33	6	2	-	-	-	-
3.5	-	-	-	49	42	9	2	-	-	-	-
3	-	-	4	147	47	12	2	1	-	-	-
2.5	-	-	155	271	74	20	4	2	1	1	-
2	-	3	623	245	99	31	9	5	2	1	-
1.5	-	428	1086	391	164	44	14	4	1	-	-
1	13	1593	1371	600	185	42	8	1	-	-	-
0.5	114	836	699	341	92	17	1	-	-	-	-

- **Goal: collect data in many different sea states in order to fill out power matrix used in power projections**
- **Need enough observations within a sea state for robust statistics**

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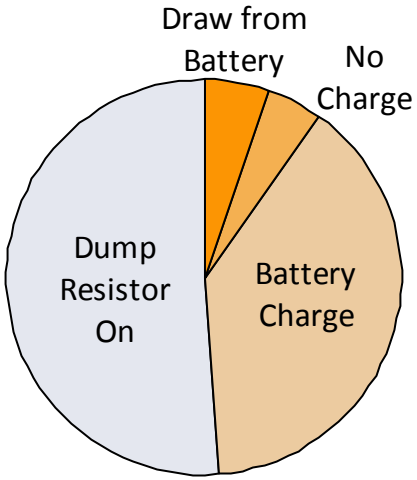
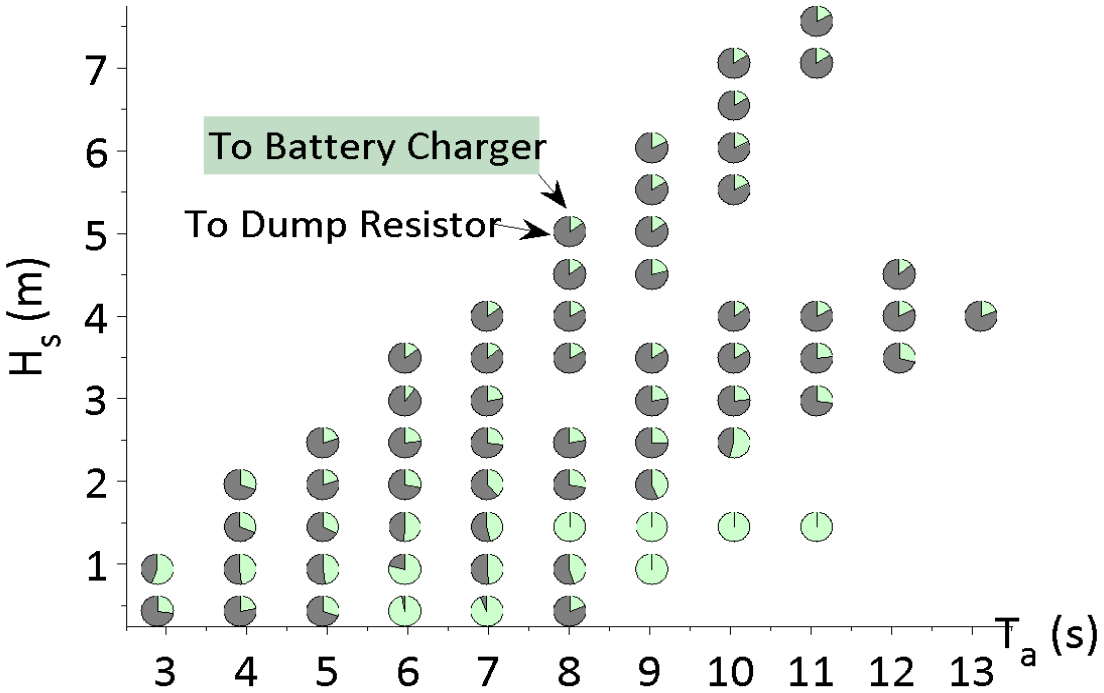
LEAP Power Delivery

Time Spent in Power Delivery Modes



- **In low waves, powered payloads from battery**
- **Payload power delivery uninterrupted throughout ocean test**

Where Power Was Delivered In Different Sea States



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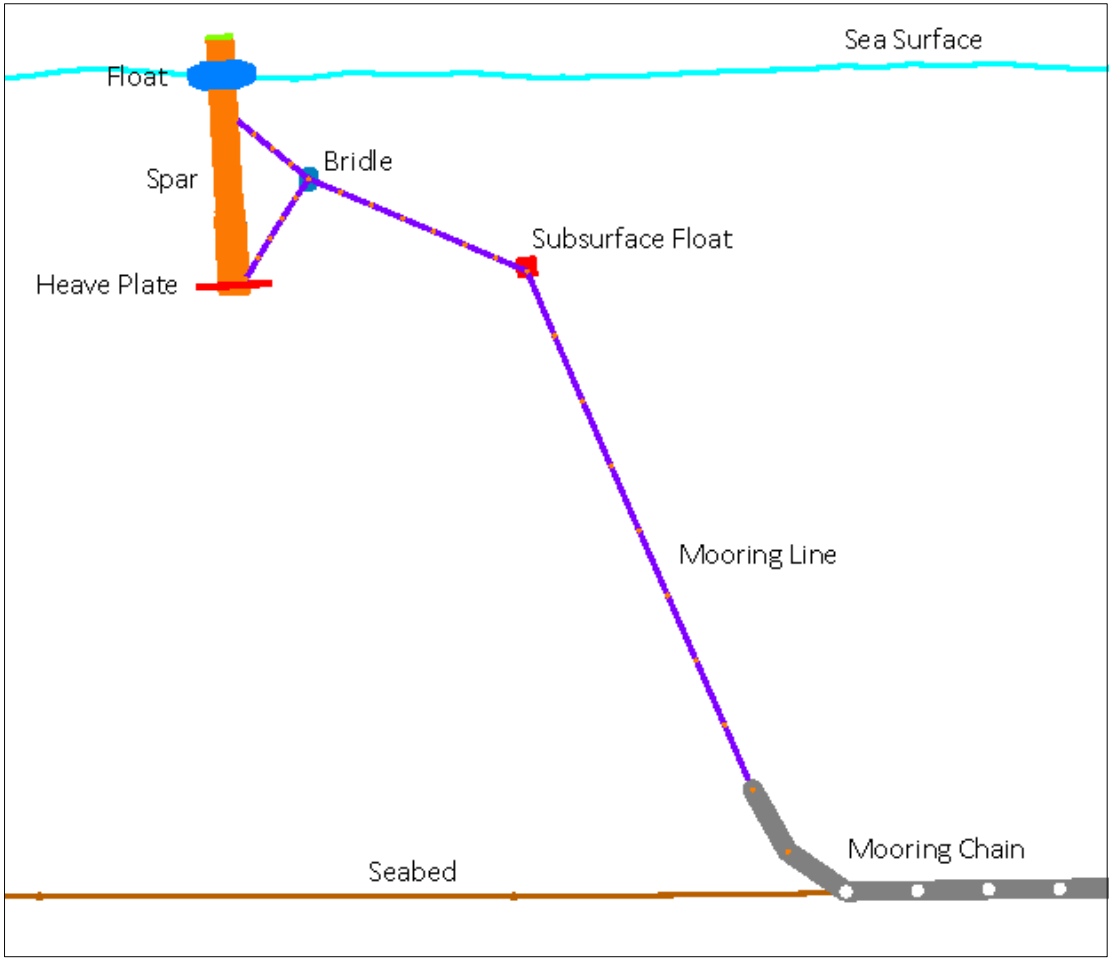
LEAP Payload Performance

- First wave-powered deployment of HF radar payload
- Radar transmission powered continuously during deployment, except for planned shutdowns for testing
- Radar signal received at all shore stations
- Design accommodates other payloads

LEAP Mooring

- **Single-point mooring designed for survival wave and currents**
- **Mooring loads estimated with OrcaFlex (commercial software)**



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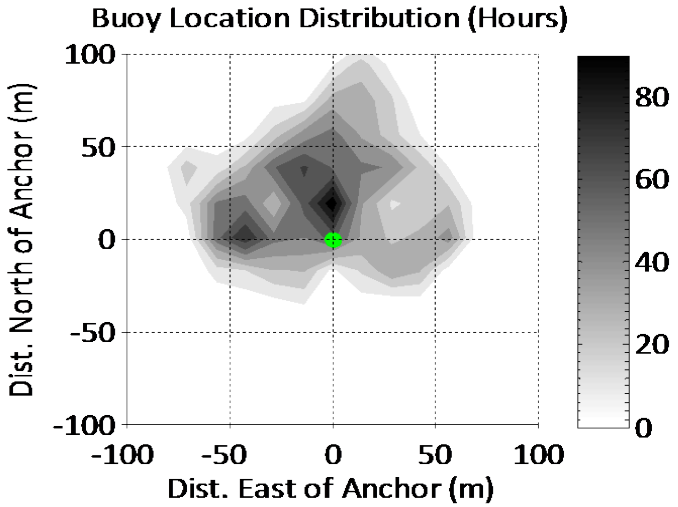
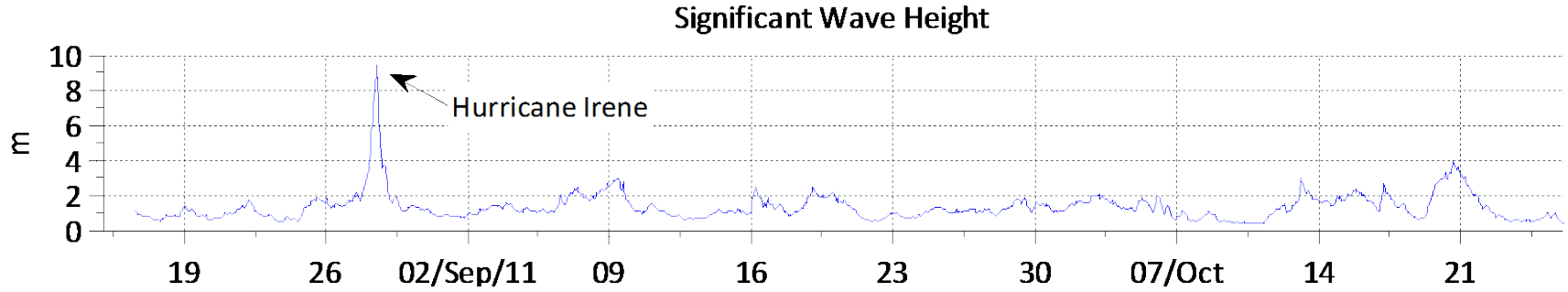
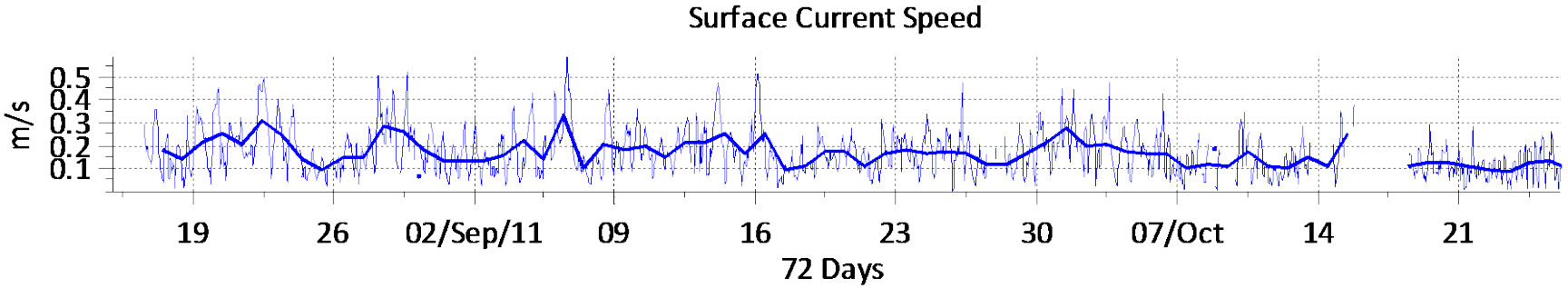
Position of PowerBuoy in Mooring Watch Circle







Hurricane Irene Track

- LEAP site 40 km from storm center
- Several NDBC buoys in area went offline

Source: NOAA National Hurricane Center

Survived Hurricane Irene

- **Post-hurricane inspection: topside and mooring system down to anchor**
  - No damage
- **System provided power to payload during Irene**

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Upcoming Deployments

- **After recovery, improvements to the system's electrical and mechanical design**
- **Product renamed APB-350**
- **Preparing to deploy an APB-350 this summer off New Jersey. To demonstrate multi-sensor capabilities, the system will carry two payloads, a HF radar as well as a subsurface sonar unit.**
- **OPT is working toward a future APB-350 deployment for Homeland Security**

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Conclusions

- **Ocean test demonstrated manufacture, deployment, and functional performance of APB-350 design**
- **Autonomous power capture and continuous delivery of power to payload**
- **Compare measured and predicted power generation**
- Better understanding of physical processes
- Measured power matrix used to estimate power generation at any site

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PowerBuoy Design Workflow

Project Requirements
Client needs
System functions

Characterize site
Wave climate
Survival conditions

+ **Design Concept**
Modular components

Predict power
for site

Predict loads
Survival, fatigue

Structural Design

Mechanical subsystems
Mechanical to electrical power

Electrical subsystems
Power conditioning, storage, deliverability

Reliability, manufacturability, efficiency

Testing
In tank
On the bench
At sea

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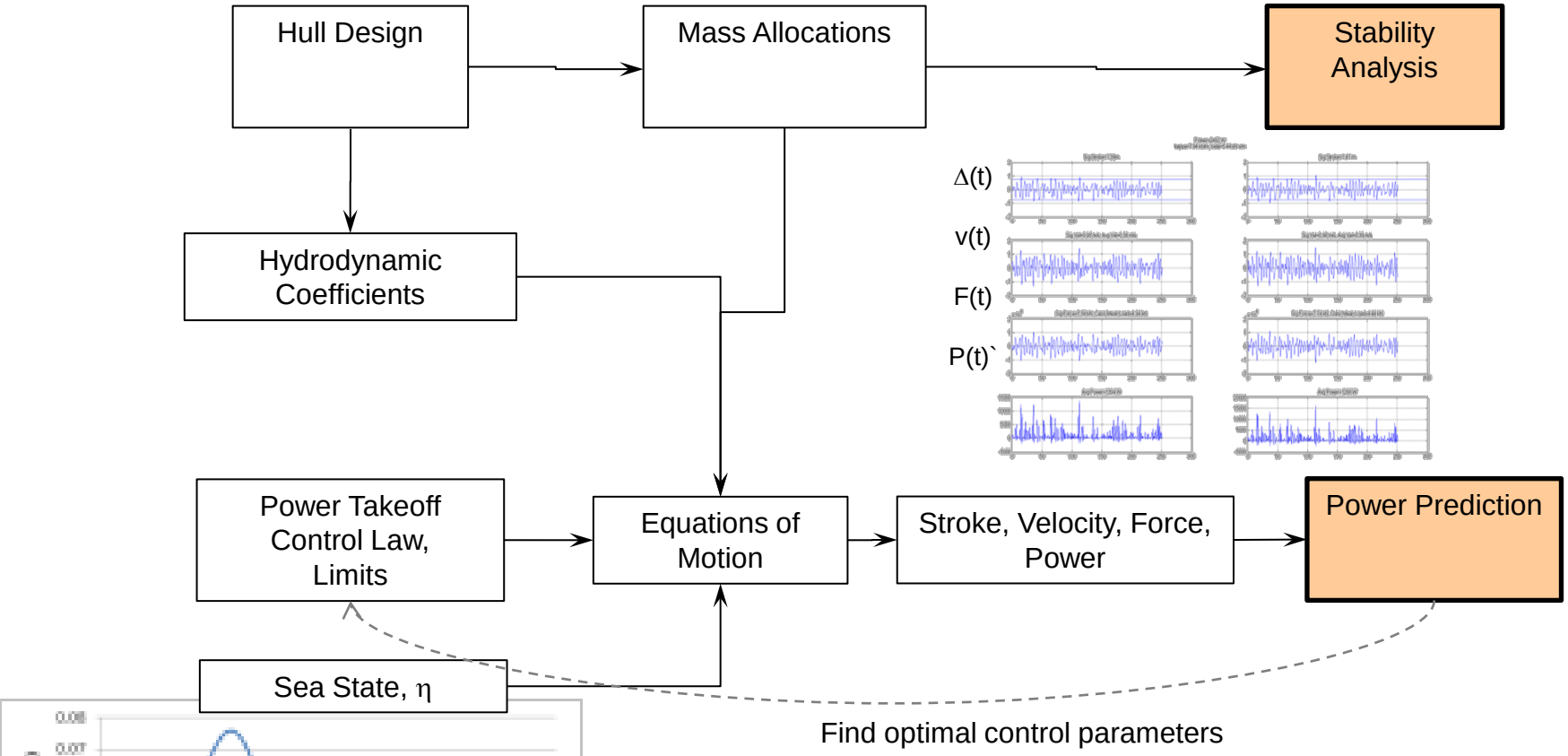
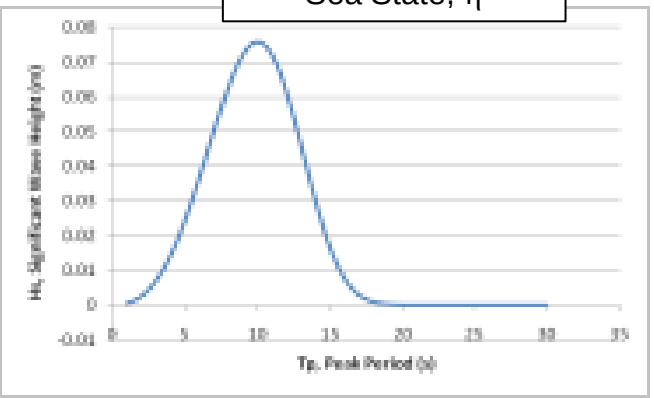
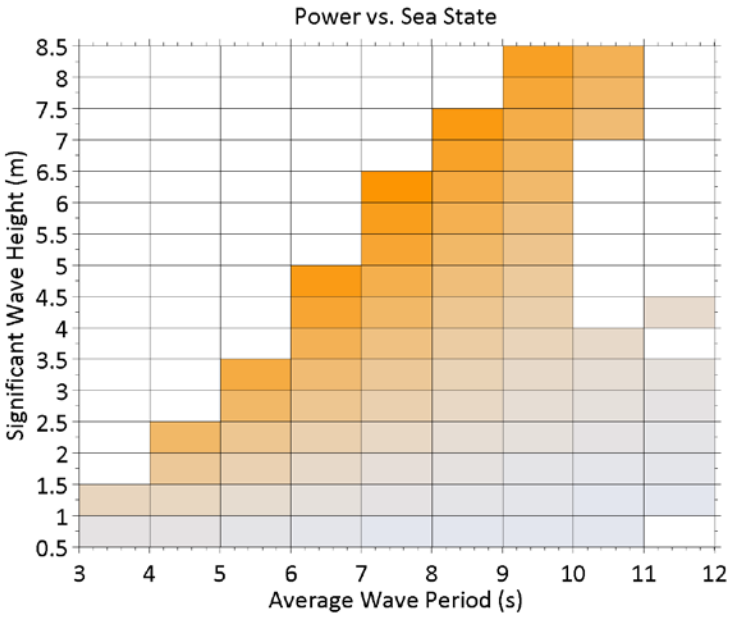
Power Prediction Model

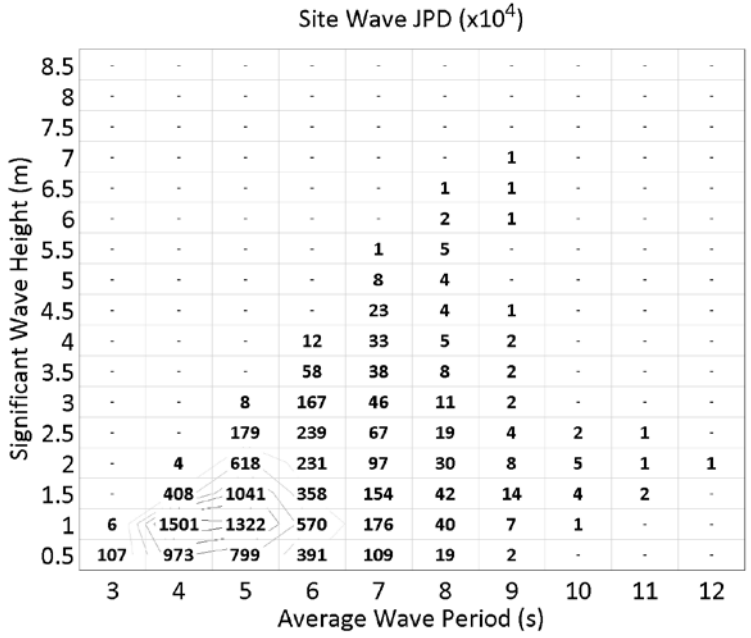




Site Power Projections

- **Each sea state: time-averaged power from model**
- **Include efficiency of mechanical input to electrical output**
- **Combine with site wave climate to obtain annual average power**





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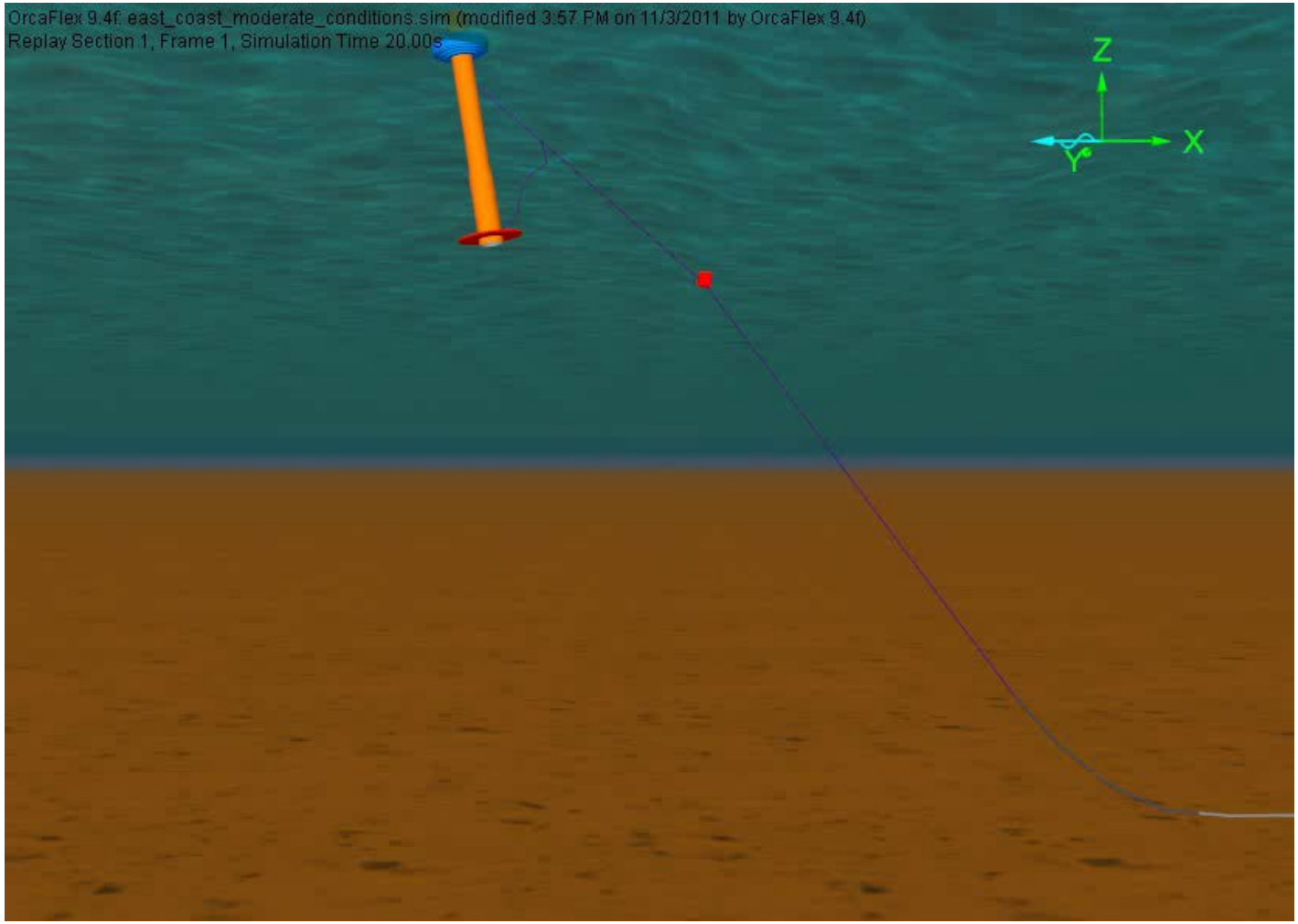
Animation of Mooring Design Model



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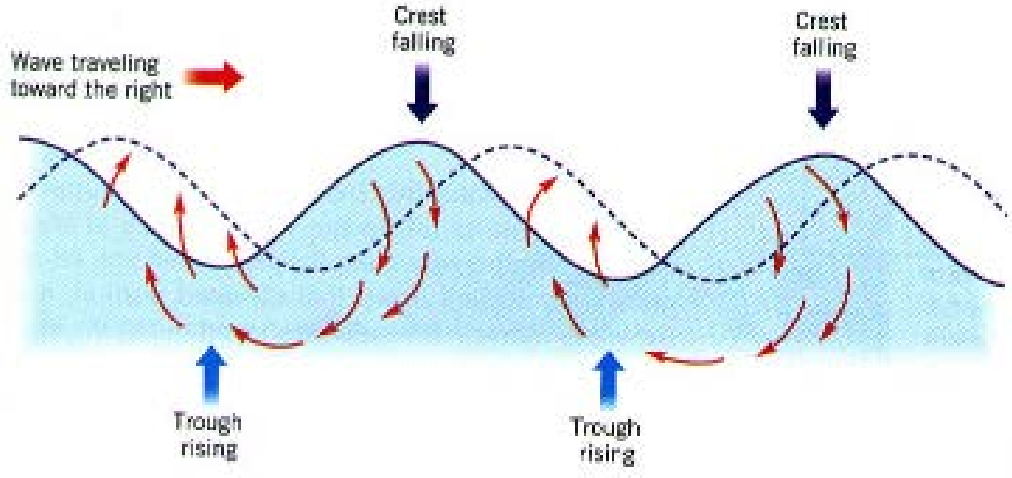
Energy in Waves

- **Waves transport energy**
  - Sun warms Earth, winds blow, make waves
- **Resulting motion of water that devices can capture**
  - Up and down (heaving)
  - Back and forth (pitching and rolling)



From S. Gillman, USC

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Recent PowerBuoy Activities

- **Working with Lockheed Martin towards wave farm in Australia**
- **Contracted by Mitsui Engineering & Shipbuilding to develop PowerBuoy for Japanese sea conditions**
- **Formed Autonomous PowerBuoy business unit to focus on smaller stand-alone systems**