

Wave Prediction Leveraging Multiple Measurement Sources – A Sensor Fusion Approach

Project #: EE0008099

Marine and Hydrokinetics Program

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Project Summary

- Development & testing of a wave prediction system that leverages wave radar and measurement buoys.
- Leveraged Wave Radar Hardware developed using Navy funding under their ESMF (Environmental Ship Motion Forecasting) program.
- Development of Data Assimilation and Wave Prediction Algorithms.
- HW development and at sea testing system.

Project Objective & Impact

Objectives

- Improve wave prediction accuracy over buoy-based approach
- Enable new applications within the Blue Economy space
- Enable wave prediction that is “good-enough” for Model Predictive Control (MPC)

Impact

- Wave prediction is an essential building block to enable MPC control systems in WEC devices
- Enabled constrained optimal control at sea, which is essential to controls co-design and to achieve techno-economic optimality

Project Information

Project Principal Investigator(s)

Mirko Previsic (mirko@re-vision.net)

WPTO Lead

William McShane

Project Partners/Subs

- US Navy (In-Kind)
- HT Harvey & Associates
- Monterey Bay Research Vessels

Project Duration

- Project Start Date: 9/1/17
- Project End Date: 3/30/20

Marine and Hydrokinetics (MHK) Program Strategic Approaches

Data Sharing and Analysis

Foundational
and
Crosscutting
R&D

Technology-
Specific
Design and
Validation

Reducing
Barriers to
Testing

Foundational and Crosscutting R&D

- Drive innovation in components, controls, manufacturing, materials and systems with early-stage R&D specific to MHK applications
- Develop, improve, and validate numerical and experimental tools and methodologies needed to improve understanding of important fluid-structure interactions
- Improve MHK resource assessments and characterizations needed to optimize devices and arrays, and understand extreme conditions
- Collaboratively develop and apply quantitative metrics to identify and advance technologies with high ultimate techno-economic potential for their market applications

- Development of a wave prediction framework that can be universally applied to enable optimal control in a wide range of WEC archetypes.
- Improve wave prediction accuracy in a wide range of sea-states.
- Validate wave measurement and prediction accuracy with at-sea testing.
- Benchmark phase-resolved wave propagation models.

Project Budget

Total Project Budget – Award Information

| DOE | Cost-share | Total |
|--------|------------|----------|
| \$953K | \$238K | \$1,192K |

| FY17 | FY18 | FY19 (Q1 & Q2 Only) | Total Actual Costs FY17–FY19 Q1 & Q2 (October 2016 – March 2019) |
|--------|--------|------------------------|--|
| Costed | Costed | Costed | Total |
| \$15K | \$289K | \$321K | \$625K |

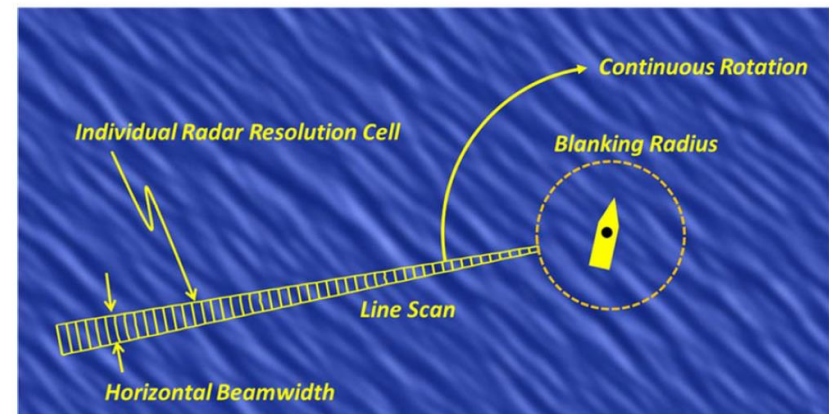
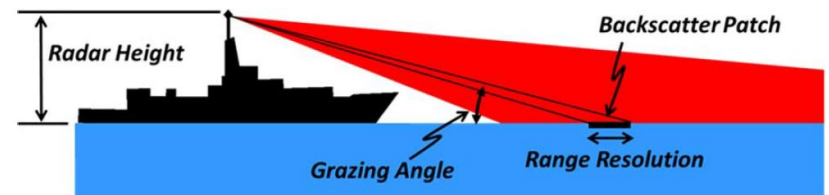
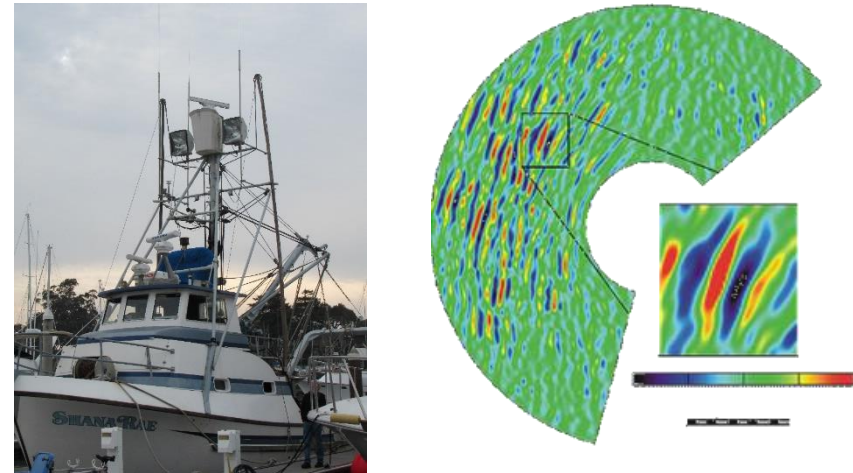
Management and Technical Approach

Technical Approach:

- Leverage and build on Navy work under their ESMF program.
- Leverage previous efforts to predict ocean waves using buoy measurements.
- Develop algorithm frameworks to measure and predict waves.
- Collect real data as early as possible and build algorithms around that data.
- Core focus on developing “industry-ready” wave prediction capabilities that can be applied to other WEC device developments.

Project Management:

- Lead at Re Vision Consulting. Core technical team in-house (7 team members).
- Accounting, contract compliance, and audited financials at Re Vision Consulting.
- Weekly Team Meetings with active external team partners to keep project on track.
- Quarterly meetings with DoE to review progress, address major issues and make strategic adjustments to our approach.

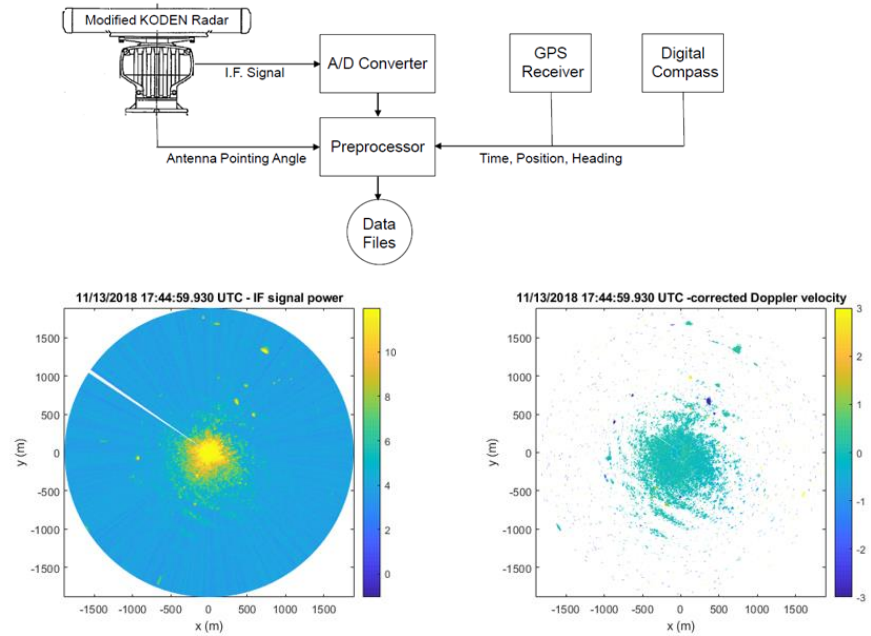


Technical Approach(continued):

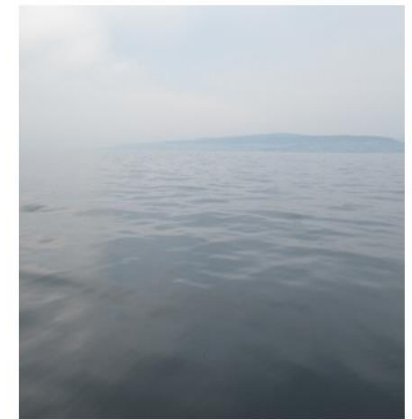
- Use of doppler-shift of radar signal to measure the radial velocity of wave free-surface.
- Standard X-band radar with modified electronics to improve timing.
- Radial velocity is converted to a local wave-field using linear wave theory.
- Wave-field measurement radius of ~1.5 miles.
- Core focus on developing “industry-ready” wave prediction capabilities that can be applied to other WEC device developments.

Limitation:

- Wave radar measurements rely on Bragg surface wave ripples. Sufficient wind-speeds need to be present to enable accurate measurements.



(a) Ocean surface roughness when wind speed > 2m/s



(b) Ocean surface roughness when wind speed < 2m/s

End-user engagement:

- Engagement throughout the process with device developers.
- Engagement with a wide range of “alternate users” within the blue economy.

Dissemination:

- Published a total of 10 journal articles, white papers and conference papers.
- Final technical report is forthcoming.

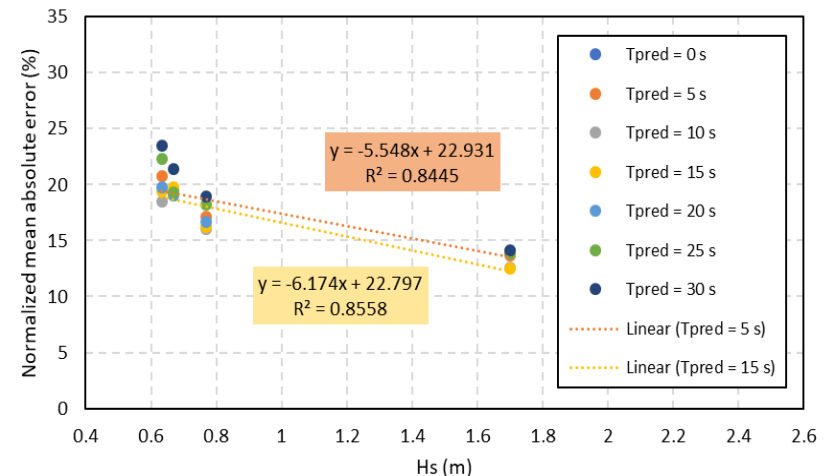
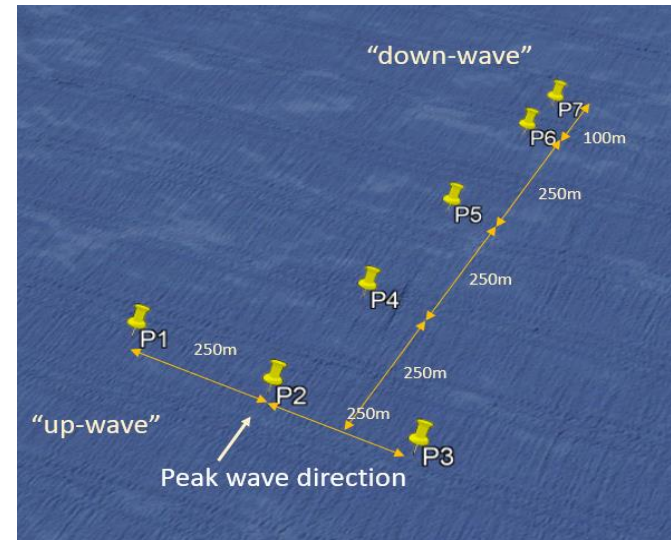
Commercialization Efforts:

- An off-the-shelf wave prediction system that can be used in any WEC application. Alternative markets are being evaluated.



Key accomplishments:

- Developed algorithm-base to process radar data and predict ocean waves from these measurements.
- Carried out 4 field campaigns leveraging US Navy radar hardware to collect data and validate algorithm base developed.
- Validated algorithm base.
- Several numerical advances made to process radar signals that have led to a demonstrably lower error.
- Developed sensor fusion methods to join different measurement sources.
- Benchmarked buoy measurement accuracy using survey grade RTK system.
- Re-wrote wave prediction algorithms in C to make it real-time capable.



Remaining Work:

- Testing of a new wave radar that promises to measure waves more accurately
- Further field-campaigns to test new radar hardware
- Further field-campaigns to test in larger waves
- Further algorithm refinements to improve accuracy in a wide range of conditions
- Develop a front-end GUI interface

While this project is sun-setting, there are various high-priority topics remaining to be addressed:

- R&D needs to be turned into commercial building blocks on the controls and wave-prediction aspects of this work.
- Controls system development needs to be turned into tools that can be made accessible to the broader industry. We would be willing to “open-source” our in-house tools developed if a suitable opportunity presented itself.

“If I have seen further it is by standing on the shoulders of Giants”

Isaac Newton, 1676