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Wave Data Assimilation In Support Of Wave Energy Converter Power Prediction: Yakutat, Alaska Case Study

Ann Dallman[1], Mohammad Khalil[1], Kaus Raghukumar[2], Craig Jones[2], Jeremy Kasper[3], Christopher Flanary[2], Grace Chang[2], Jesse Roberts[1]

[1]Sandia National Laboratories, [2]Integral Consulting, Inc., [3]University of Alaska Fairbanks

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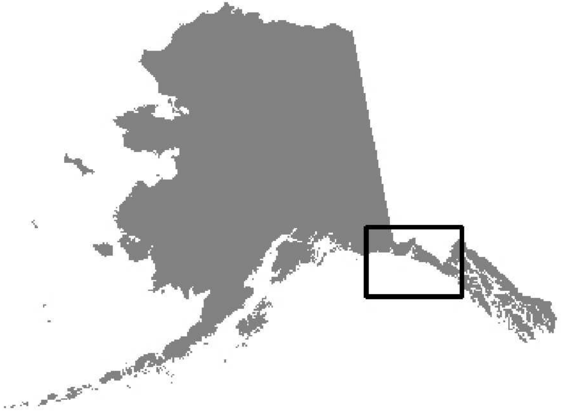
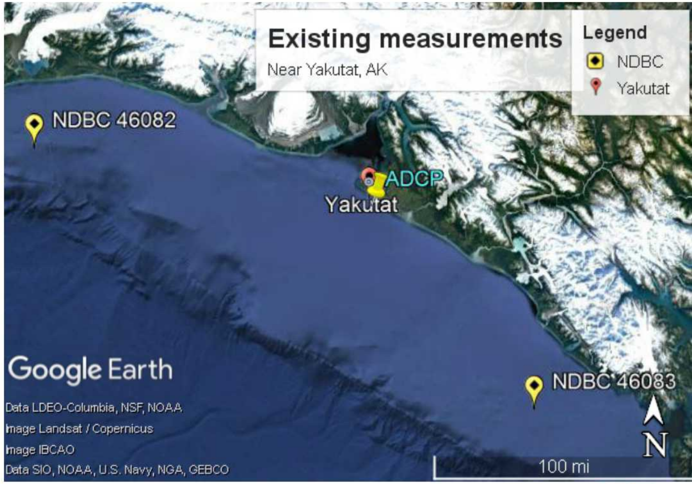
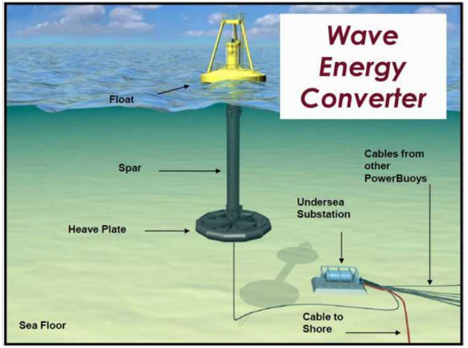
INTRODUCTION

- **Wave energy** is an **emerging renewable energy source**, particularly promising for remote (near-shore) communities and military bases.
- **Alaska has excellent MHK (wave and current energy) potential** that could benefit numerous remote communities.
- **Accurate forecasts of waves**, coupled to device/array performance and grid models are **needed for Smart Grid integration**. (Maximizes array power production and provides understanding of loads on a grid, the need for control and/or storage).





Incoming conditions (buoy + model)

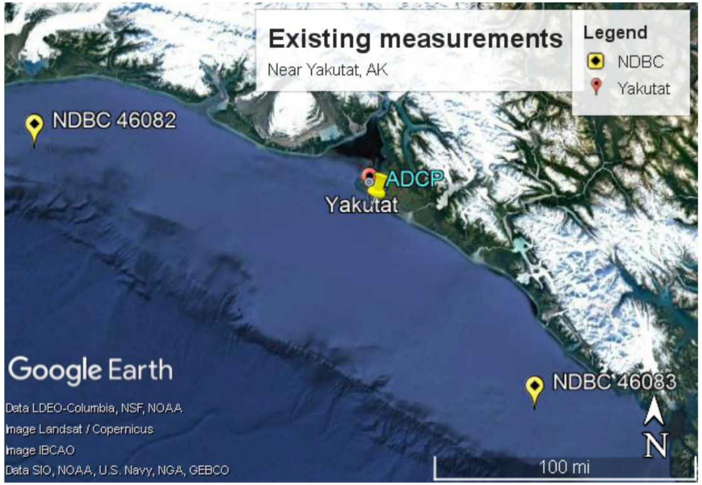


Grid

INTRODUCTION

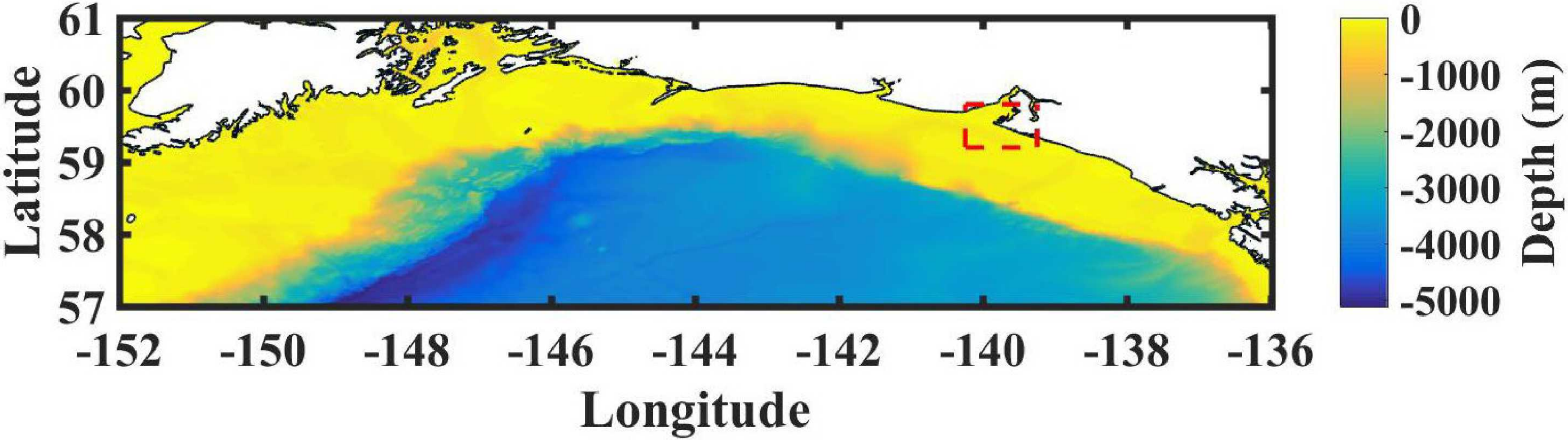
- This project focused on improving accuracy of wave forecasts
  - by applying **real-time data assimilation**,
  - reducing hour-by-hour forecast errors compared to existing nearshore wave forecast models.

- Recently developed, low cost and **highly accurate wave buoys** were **deployed** offshore of Yakutat, AK.
- The measurements were injected into the data assimilation workflow, improving the accuracy of the forecast.

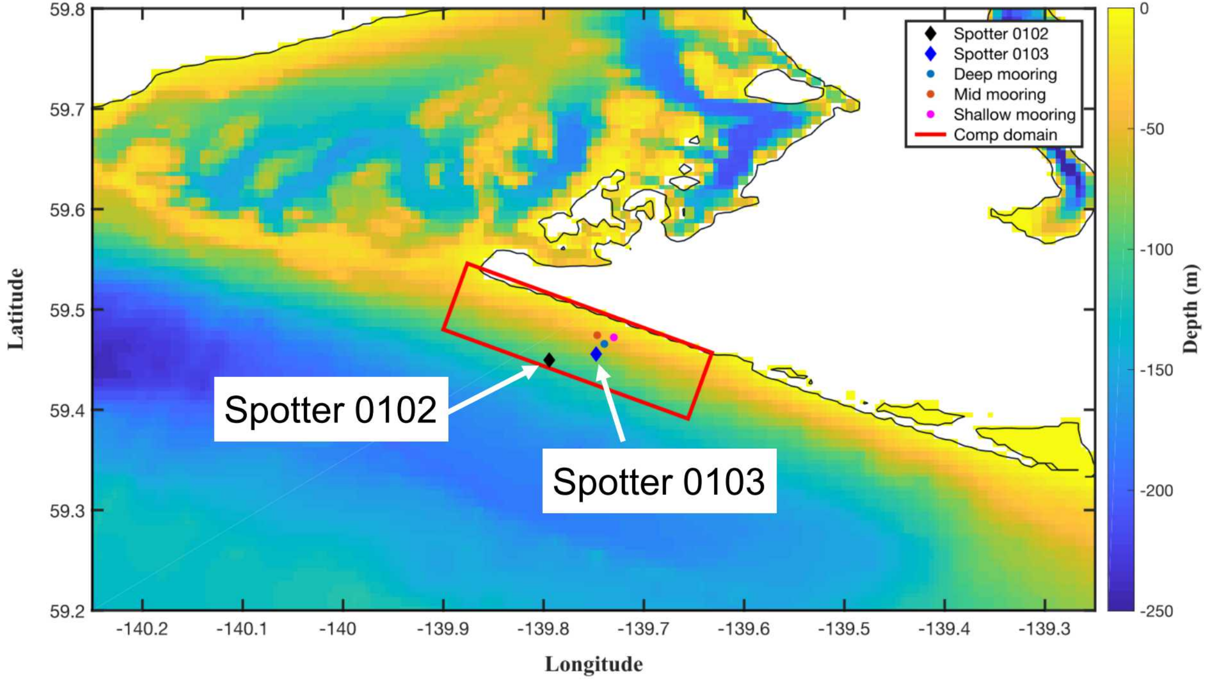


Model Domain

- Coarse SWAN domain of Southern Alaska
- Outline of finest SWAN domain in red dotted line



Model Domain



“Spotter 0102”

near model boundary, used in data assimilation methodology

“Spotter 0103”

inside model domain, representative of WEC array location; used for model performance assessment

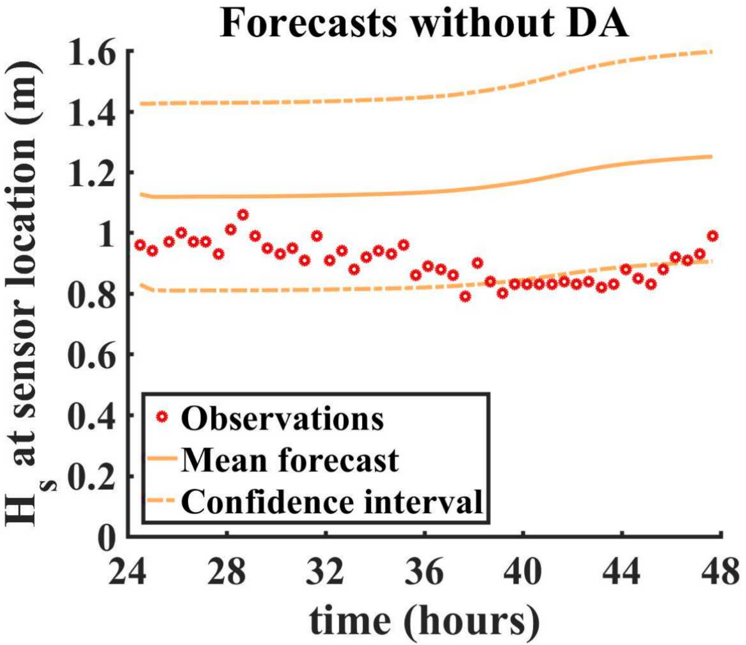
Data Assimilation

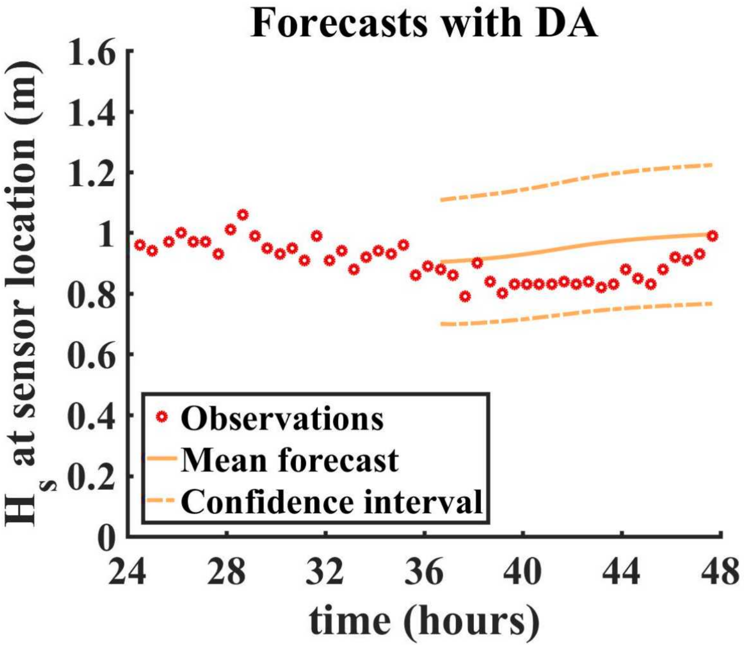
- Data assimilation seeks to optimally combine numerical model forecasts (based on theory/physical laws) with noisy and/or sparse observations.
- For this work, the main goal is to determine the optimal state estimate (spatially-varying wave spectrum) to enhance predictive accuracy.
- Data assimilation is distinguished from other forms of machine learning and statistical methods in that it incorporates a dynamical model of the system.
- We will rely on probabilistic approaches to quantify the uncertainty in the estimates/predictions.
- We target the simultaneous updating of boundary conditions through a simple multiplicative stochastic model which aims to correct the significant wave height relating to pre-specified boundary wave spectra

Data Assimilation Methodology

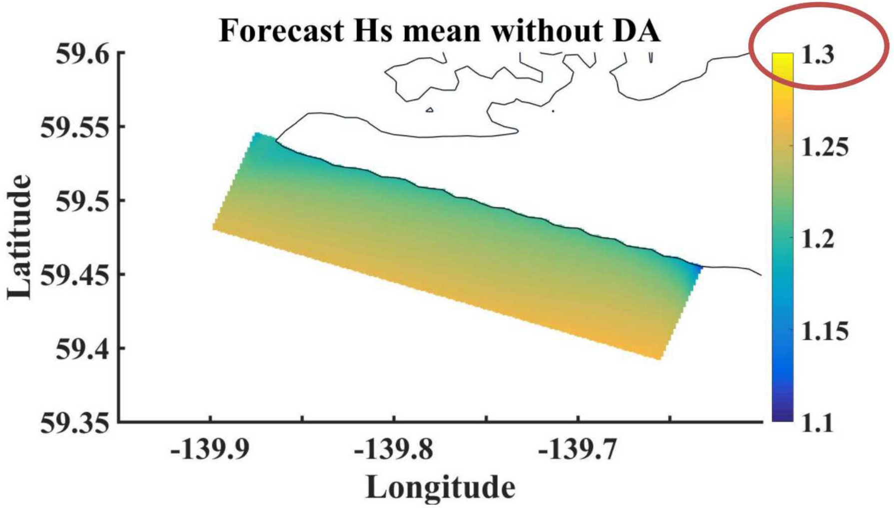
- Two popular data assimilation approaches are Optimal Interpolation (OI) and the ensemble Kalman filter (EnKF).
    - Both provide the mean state as optimal estimate
    - OI relies on assumed covariances while EnKF uses Monte Carlo sampling
    - EnKF is more adept at handling parameter estimation tasks since it estimates covariances between parameters and the system state.
- Data (significant wave height from Spotter 0102) is used to test the framework
- Small ensembles for EnKF (~10 Monte Carlo realizations) are sufficient due to long observed spatial correlation lengths in relation to the computational domain
- Framework extended to incorporate measured data, produce long term forecasts
- Significant wave height assimilated from Spotter 0102

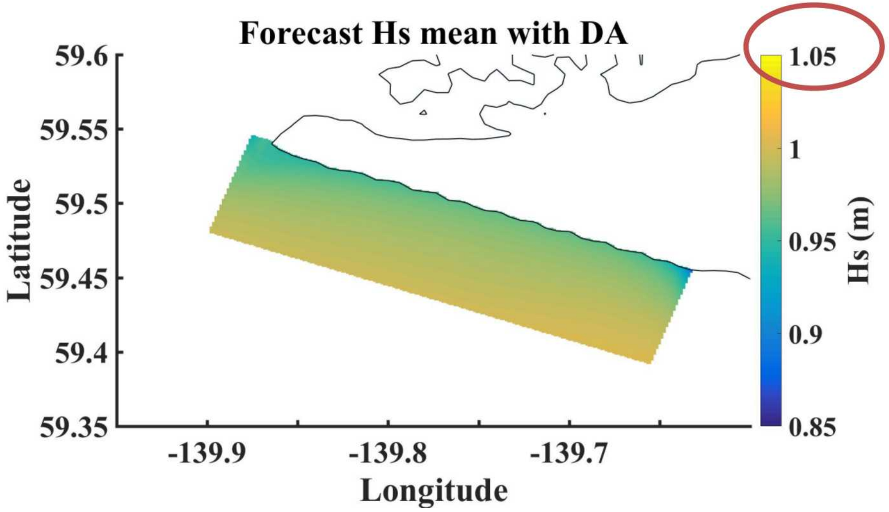
Data Assimilation Results





Data Assimilation Results



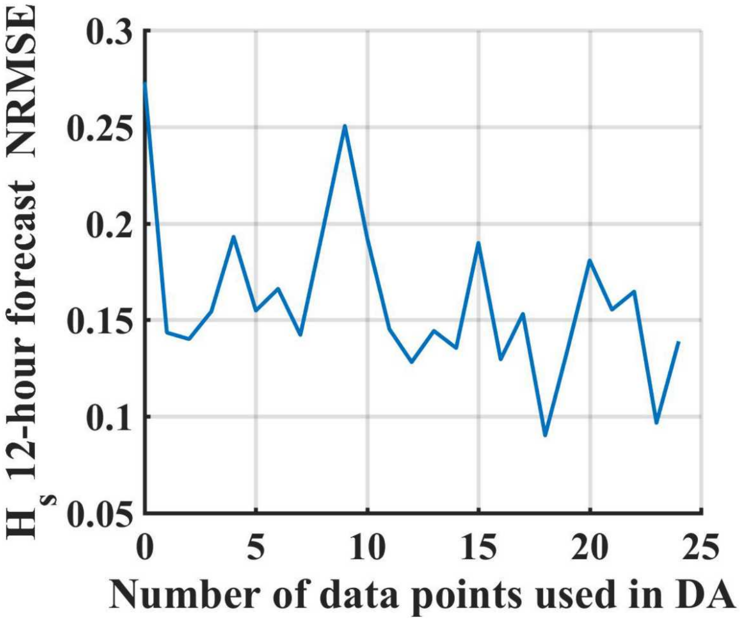


Data Assimilation Results

Forecasts, and NRMSE changes with the number of previous data points used in the assimilation

Over 12 hour period (24 data points):

- Significant wave height **NRMSE** reduced from **27%** (no DA) to average of **16%**
- Results in wave power **NRMSE** reduced from **73%** (no DA) to average of **43%**



Conclusions

- The normalized root mean square error (**NRMSE**) for **significant wave height** was reduced **from 27% to an average of 16%** over a 12 hour period where the boundary conditions did not represent the measured data well.
- This resulted in a decrease of NRMSE for **wave power** from **73%** to an average of **43%**.
- Substantially improved forecasting **accuracy** and **certainty** of wave energy using data assimilation.
- This provides **greater confidence** in the ability to correctly **forecast** electricity from a **WEC farm into a microgrid**.

Follow On Work

- Project team is working on improving forecast further with more sophisticated data assimilation workflows:
  - Investigate potential of increased accuracy by updating the boundary conditions using a time-varying (as opposed to static) multiplicative statistical model
  - Incorporate data in the form of other bulk parameters beyond significant wave height: information gained would potentially improve forecast accuracy while simultaneously decreasing uncertainties

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CONTACT INFO:
Ann Dallman, ardallm@sandia.gov
Moe Khalil, mkhalil@sandia.gov

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