Motivation

- **Resource predictability is beneficial**
  - More accurate economic assessments
  - Easier for grid operators to integrate with other generation options
  - No extreme loading cases for device design

- **A presumed benefit to tidal hydrokinetic power generation is resource predictability**
  - Predictability of tidal heights is well-established
Tide and Current Comparison

Tides

Currents

North velocity (m/s)

East velocity (m/s)

Vertical velocity (m/s)
Study Area

Area of detail 350 m

Seattle 350 m

1 2 3 4

-50

350 m 150 m

Distance (km)

Distance (km)

Water Depth (m)

NNMREC
Data Collected

Deployment 1 - 05/20/09 - 08/03/09

Deployment 2 - 08/05/09 - 11/10/09

Deployment 3 - 11/12/09 - 01/29/10

Deployment 4 - 02/11/10 - 05/04/10

Current Velocity (m/s)

Deployment time (days)
Current Predictions for Hydrokinetics

Classical Problem
Predict horizontal current speed and direction throughout water column

Complications

- Predict kinetic power density (varies as $u^3$)

Simplifications

- Neglect direction
- Neglect velocities below device cut-in (0.7 m/s)
- Prediction for device hub height only
Approach

- Harmonic constituent analysis of horizontal velocity
  - \( u(t) = \sum_{i=1}^{N} u_i \sin(\omega_i t + \phi_i) \)
  - 15 minute ensemble average at 10m hub height

- Rayleigh criteria defines number of included constituents
  - \( (\omega_i - \omega_j)T > R \)
  - With 45 days of data and \( R=1 \), 35 constituents can be included

- Signal to noise ratio defines number of resolved constituent
  - Signal to noise ratio of 3, 29 constituents can be included

- Test ability to fit measurement with harmonic constituents

- Test ability to predict currents with harmonic constituents
  - At same location: 30 days at Deployment 1
  - At other locations: Deployments 2-4
Harmonic Fit of Measurements

[Graph showing speed (m/s) over deployment time (days)]

- Measurement (smoothed)
- Harmonic fit
- Harmonic residual

[Graph showing power density (kW/m²) over deployment time (days)]
## Accuracy of Harmonic Fit

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{\text{var}(K_{\text{fit}})}{\text{var}(K_{\text{measured}})}$</td>
<td>0.99</td>
<td>Ratio of variance in fit compared to variance in measurement</td>
</tr>
<tr>
<td>RMS error (kW/m$^2$)</td>
<td>0.5</td>
<td>RMS error between fit and measurement</td>
</tr>
<tr>
<td>Coefficient of determination ($R^2$)</td>
<td>0.96</td>
<td>Goodness of fit</td>
</tr>
<tr>
<td>$\frac{K_{\text{max,fit}}}{K_{\text{max,measured}}}$</td>
<td>0.98</td>
<td>Ratio of maximum kinetic power density in fit compared to measurement</td>
</tr>
<tr>
<td>$\left\langle \frac{K_{\text{fit}}}{K_{\text{measured}}} \right\rangle$</td>
<td>0.98</td>
<td>Ratio of mean kinetic power density of fit compared to measurement</td>
</tr>
</tbody>
</table>
Evaluating Predictive Accuracy

<table>
<thead>
<tr>
<th>Measure</th>
<th>Fit</th>
<th>Prediction</th>
</tr>
</thead>
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<tr>
<td>( \frac{\text{var}(K_{\text{fit}})}{\text{var}(K_{\text{measured}})} )</td>
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Deployment

NNMREC
Sources of Error in Harmonic Fit

- Measurements (smoothed)
- Harmonic fit
- Harmonic Residual

Deployment time (days)

Horizontal velocity (m/s)
Conclusions

- Predictions of mean flow conditions are possible
  - Requires long time series to resolve constituents
  - Requires empirical relations to predict topographic currents

- Predictions of mean flow are only valid over short spatial scales $O(100m)$

- Turbulent fluctuations cannot be predicted and may be operationally significant
Questions?

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- Joe Talbert for keeping all equipment in working order.
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- Captains Andy Reay-Ellers, Eric Boget, and Mark Anderson for piloting skills during instrumentation deployment.

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