Questions and Method

How do we describe the turbulence that a tidal turbine will experience, with only a time series of observations at one location in space?

What are the physical characteristics – size, shape, frequency – of the turbulence?

Can we parameterize, or simply classify, turbulence without doing the full analysis of physical characteristics?

How well can we model these turbulent properties with a stochastic turbulence generator?

Using data from an acoustic Doppler velocimeter in Puget Sound, WA, we perform a detailed characterization of the turbulent flow encountered by a turbine in a tidal strait. These results will be useful for improved realism in modeling the performance and loading of turbines in realistic ocean environments.

Observations

The data used in this analysis were collected from an acoustic Doppler velocimeter (ADV) off Nodule Point in the Puget Sound (Thomson et al. 2012). For a more in-depth description of the sites and the data collection details, see Thomson et al. (2012).

Turbulence Metrics

Turbulence Intensity:  
\[ I_u = \frac{\sigma_U}{\langle u \rangle} = \frac{\sqrt{\left\langle u^2 \right\rangle - \left\langle u \right\rangle^2}}{\left\langle u \right\rangle} \]

Coherent Turbulent Kinetic Energy:  
\[ C_{TKE} = \frac{1}{2} \left( \left\langle u^2 v' \right\rangle + \left\langle v^2 u' \right\rangle + \left\langle w^2 \right\rangle \right) \]

Turbulent Kinetic Energy:  
\[ \text{TKE} = \frac{1}{2} \left( \langle u^2 \rangle + \langle v^2 \rangle + \langle w^2 \rangle \right) \]

Anisotropy Tensor:  
\[ \lambda_{ij} = \frac{u_i' u_j'}{2} - \frac{\delta_{ij}}{3} \]

A best captures:
- Anisotropy from barycentric maps
- Intermittency from pdfs
- Coherence from the Taylor scale

Anisotropy Magnitude:
\[ A = k \sqrt{\sigma_{a_i} \sigma_{a_j}} \]

Conclusions

Observational data results:
- Coherence was measured through autocorrelations, intermittency was measured through probability density functions, and anisotropy was measured based on the eigenvalues of the anisotropy tensor.
- Physical characteristics were parameterized by the turbulence intensity, turbulent kinetic energy, coherent turbulent kinetic energy, and anisotropy magnitude, which was introduced.
- A was shown to be the best at parameterizing coherence and anisotropy.

HydroTurbSim results:
- No coherent events are seen in the autocorrelation functions.
- Anisotropy is only captured when defined by the input (Reynolds shear stresses), but not the normal stresses, as seen in the pdf.
- HydroTurbSim does what it is built to do, but doesn’t capture coherent events.
- LES is expected to capture the coherent structures that HydroTurbSim cannot.

Stochastic Model

Output from the National Renewable Energy Laboratory’s HydroTurbSim model was analyzed to determine which aspects of the realistic flow a stochastic turbulence generator captures.

Input:
- Background mean flow profile
- Turbulent spectral density curve based on observations
- Turbulence intensity standard
- Reynolds Stresses

Method:
- Inverse fast Fourier transform
- Spatial correlation function

Output:
- Two-dimensional Fourier transform of the turbulence spectrum, and defines anisotropy based on random-phase correlations between Reynolds stresses, and proportions between normal stresses.

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References


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