Design Load Estimation for Tidal Turbines from a Multi-Year Measurement Time Series

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Numerical Modelling – Critical Learning before Getting Wet

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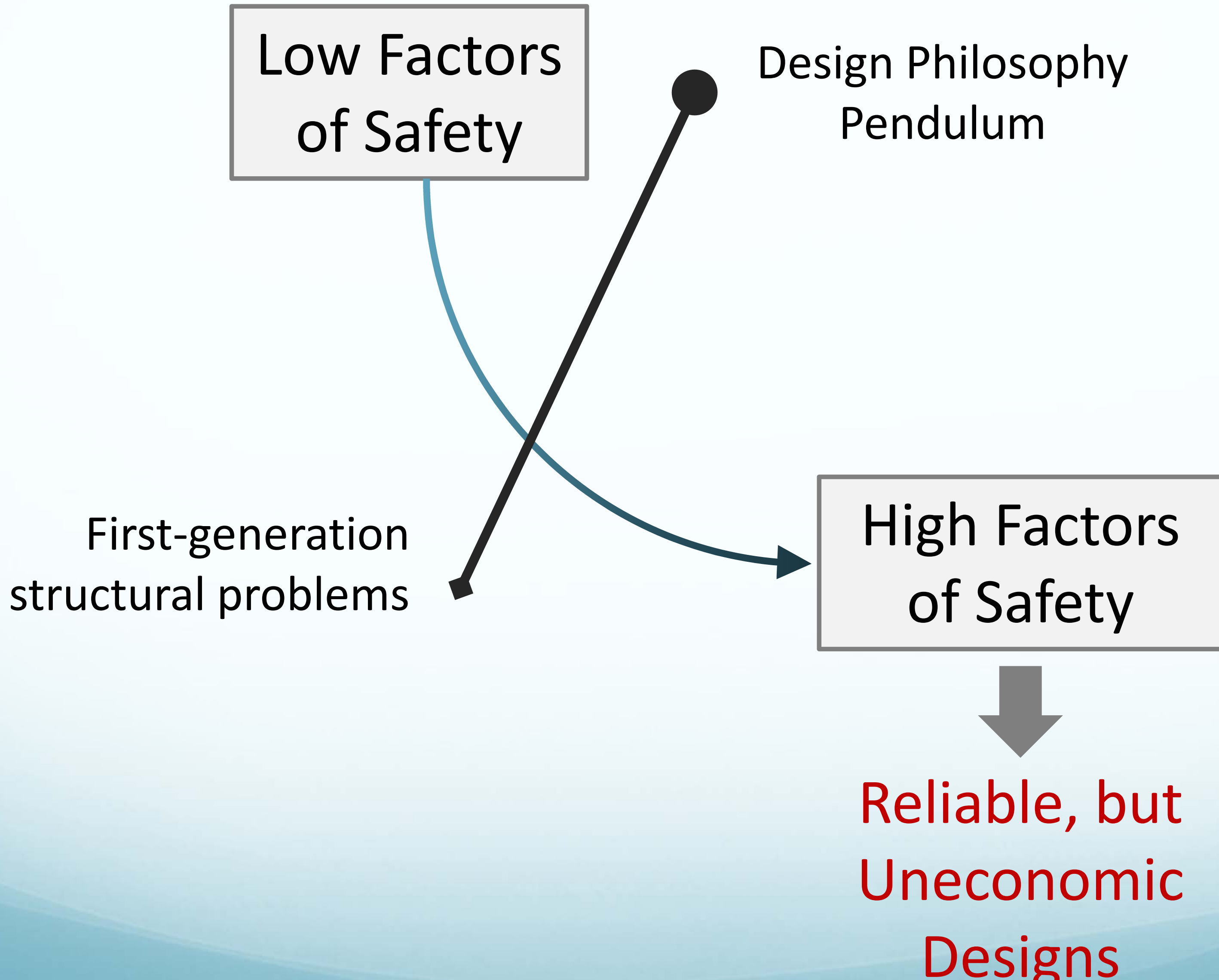
Motivation


Low Factors of Safety
Design Philosophy Pendulum
First-generation structural problems
High Factors of Safety
Reliable, but Uneconomic Designs

Components of Currents at Tidal Sites

$$\vec{U}(x,y,z,t) = U_{d} + U_{m} + U_{t}$$

Currents

$$\vec{U} = u\hat{i} + v\hat{j} + w\hat{k}$$

Meteorological

- Waves U_{m}^{w} — *t < 20 seconds*
- Storm surge U_{m}^{s} — *t > 10 minutes*
- Density driven U_{m}^{r} — *t > 10 minutes*

Deterministic

- Harmonic U_{d}^{h}
- Aharmonic U_{d}^{a}

t > 10 minutes

Turbulence

U_{t}

t < 10 minutes

Design Velocity Framework

- Partition design velocity according to time scales
- Treat wave contribution separate from currents

$$\tilde{U}(x,y,z) = \left(\sum \alpha_{\mathrm{d}}^{i} \tilde{U}_{\mathrm{d}}^{i} + \sum_{j \neq \mathrm{w}} \alpha_{\mathrm{m}}^{j} \tilde{U}_{\mathrm{m}}^{j} \right) \tilde{I}_{U} + \cancel{\alpha_{\mathrm{m}}^{\mathrm{w}} \tilde{U}_{\mathrm{m}}^{\mathrm{w}}}$$

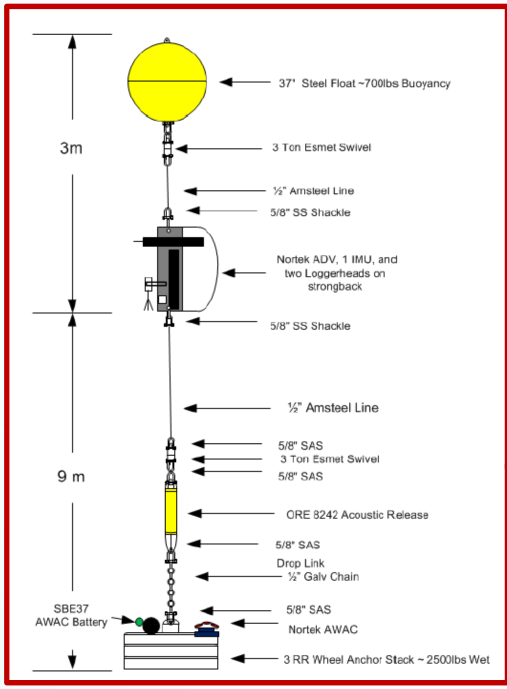
Design Velocity (m/s)

Design Velocity Component (m/s)

Simultaneous Occurrence Factor

Turbulence Multiplier

Case Study Overview

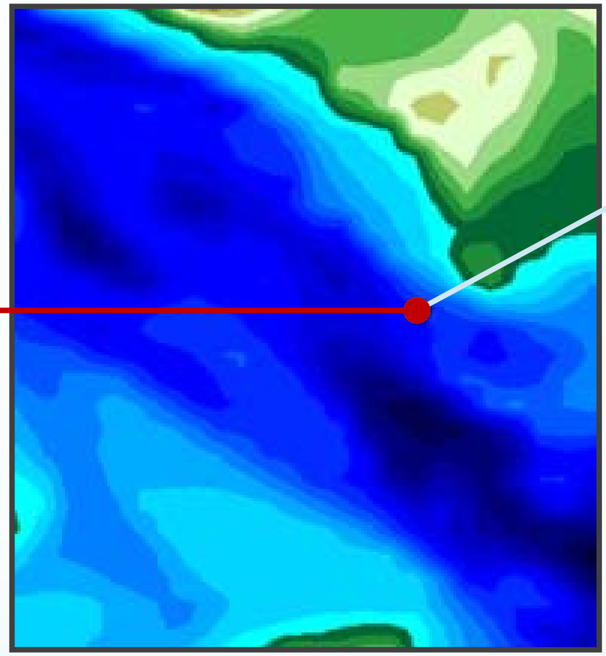


TTM

- 2 days
- $z \approx 13$ m
- $\Delta t \approx 0.1$ s

Thomson, J., L. Kilcher, M. Richmond, J. Talbert, A. deKlerk, B. Polagye, M. Guerra, and R. Ceinfuegos (2013) Tidal turbulence spectra from a compliant mooring, *Proceedings of the 1st METS Symposium*.

Admiralty Inlet
Puget Sound, WA (USA)



Sea Spider

- 782 days (gaps)
- < 10 m cluster
- $\Delta z = 1$ m
- $\Delta t = 1$ minute

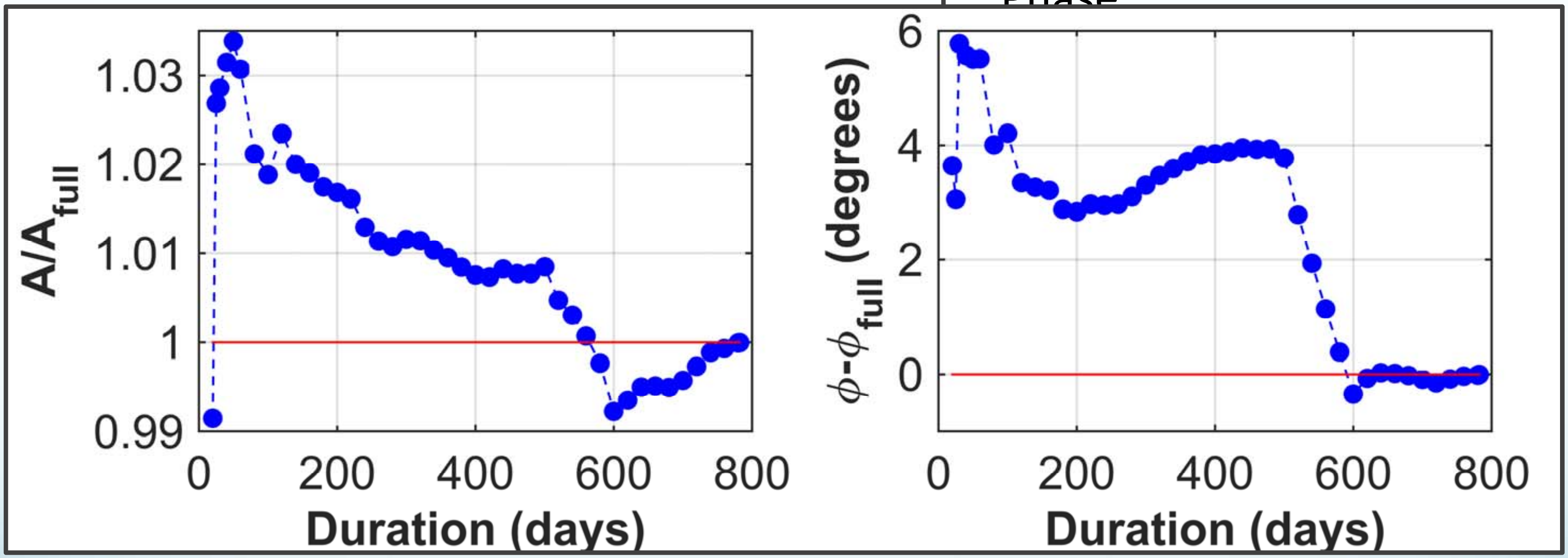
Polagye, B. and J. Thomson (2013) Tidal energy resource characterization: methodology and field study in Admiralty Inlet, Puget Sound, US, *Proc. Inst. MechE, Part A: J. Power and Energy*.

Harmonic Analysis

$$\overline{U}_p(t) = \sum A\cos(\omega t + \phi)$$

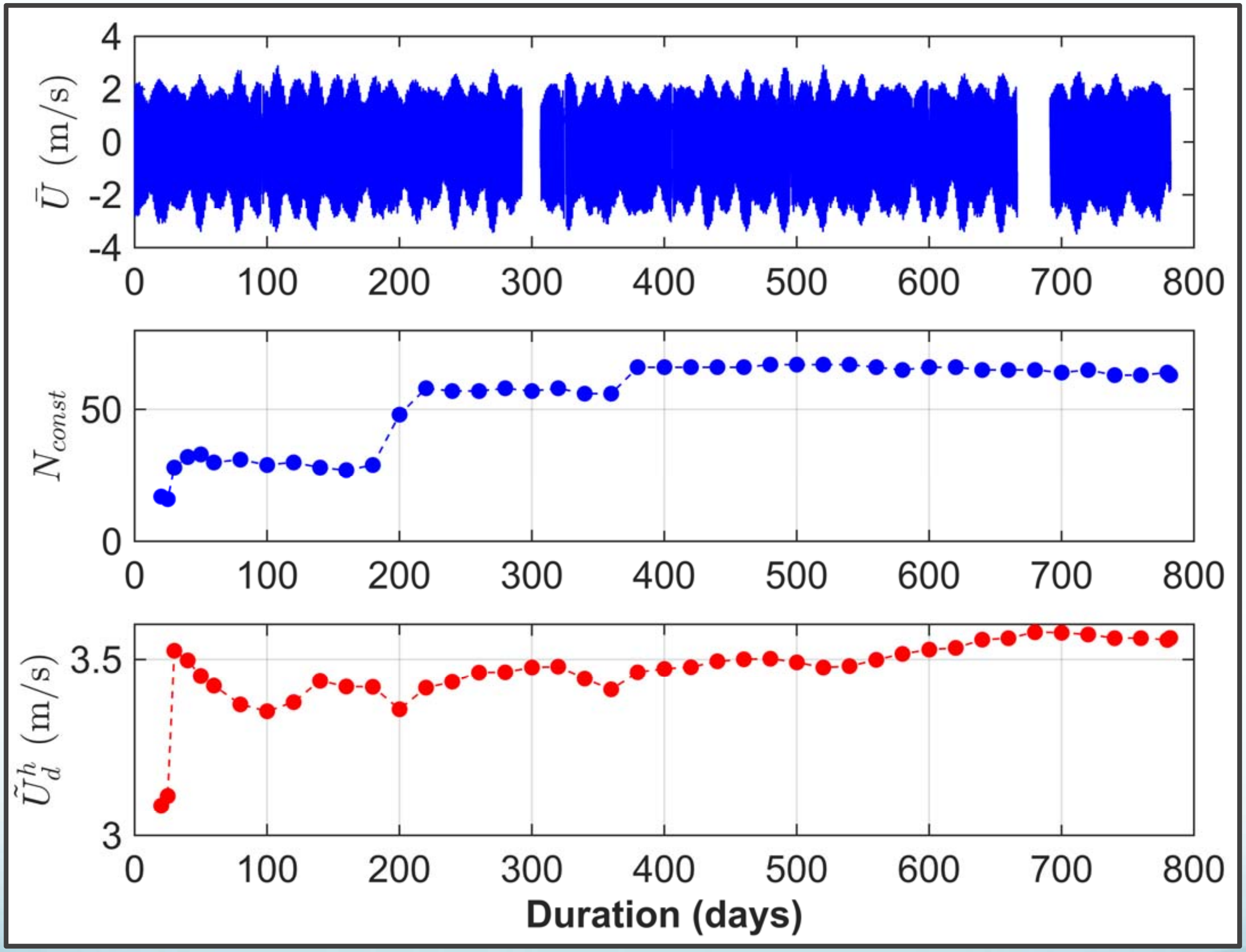
Velocity Amplitude Phase

Example: M2 – Primary Semidiurnal Constituent



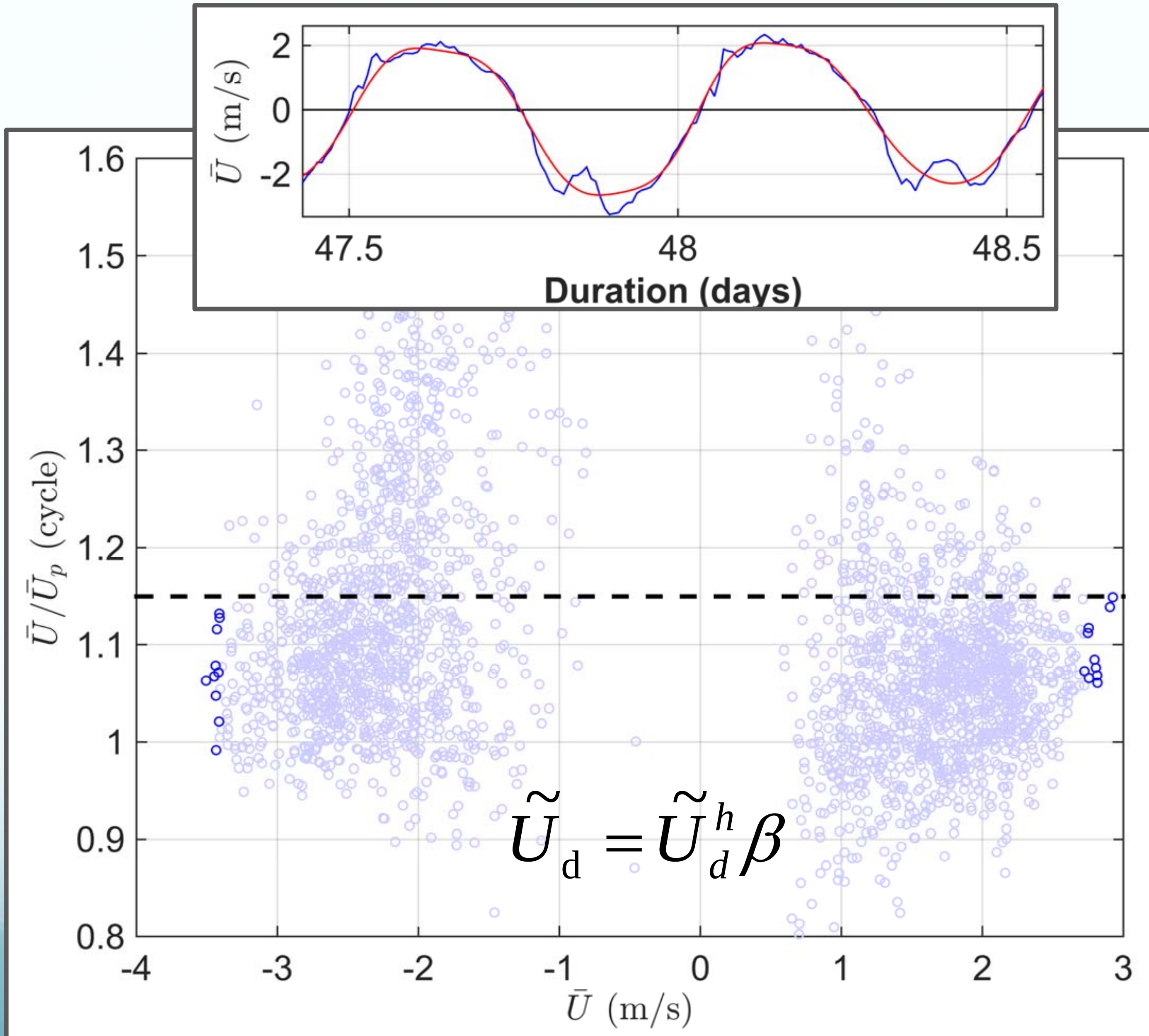
Slow convergence in constituent amplitude and phase

Harmonic Currents



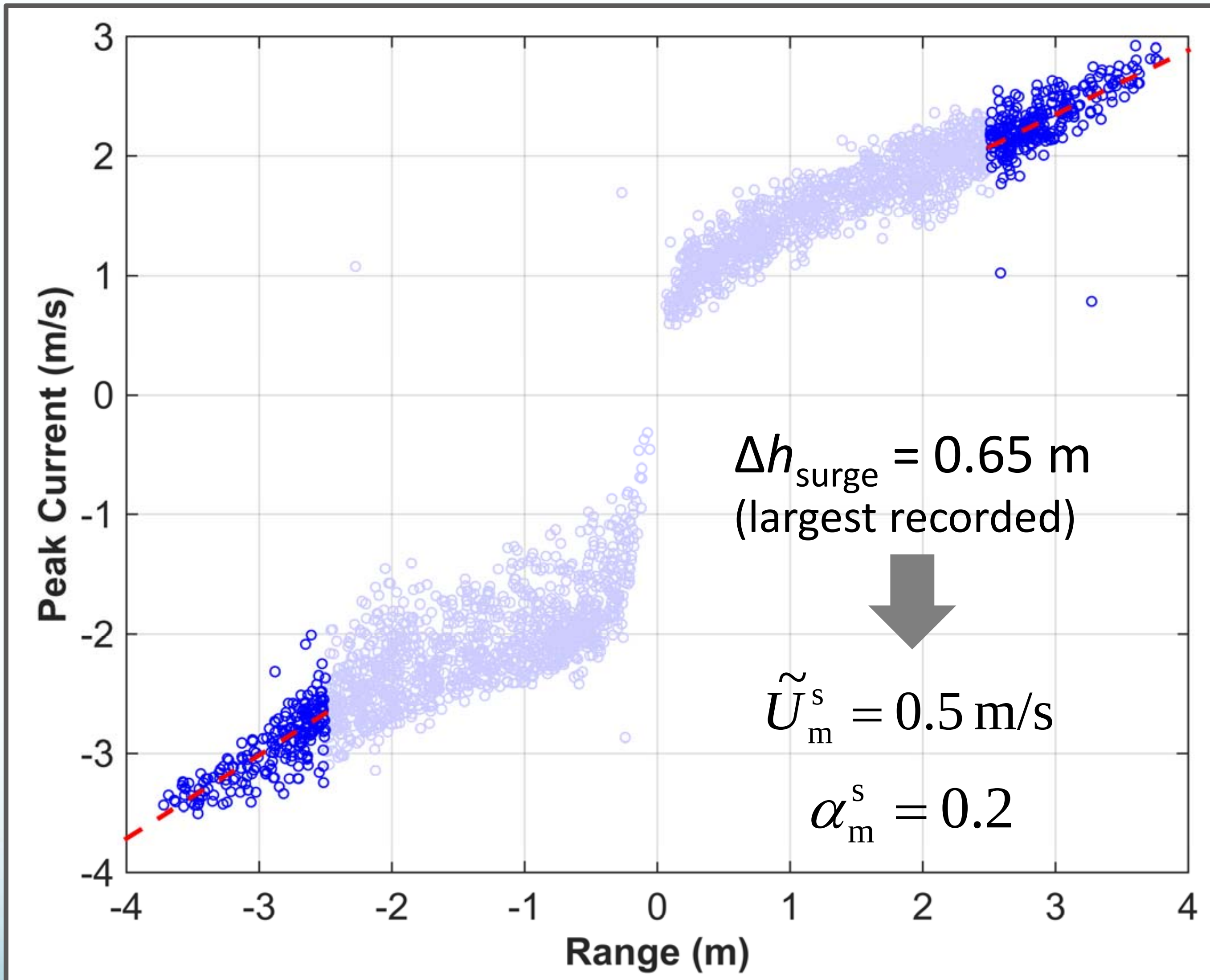
Slow change in predictions of epoch extreme

Aharmonic Currents



$$\widetilde{U}_{\mathrm{d}} = \widetilde{U}_d^{h} \beta$$

Storm Surge



Peak Current (m/s)
Range (m)
3
2
1
0
-1
-2
-3
-4
-4
-3
-2
-1
0
1
2
3
4
Δh_{surge} = 0.65 m
(largest recorded)
$\tilde{U}_m^s = 0.5$ m/s
$\alpha_m^s = 0.2$

Turbulence

$$\bar{I}_U = \frac{\sigma_U}{\langle U \rangle}$$

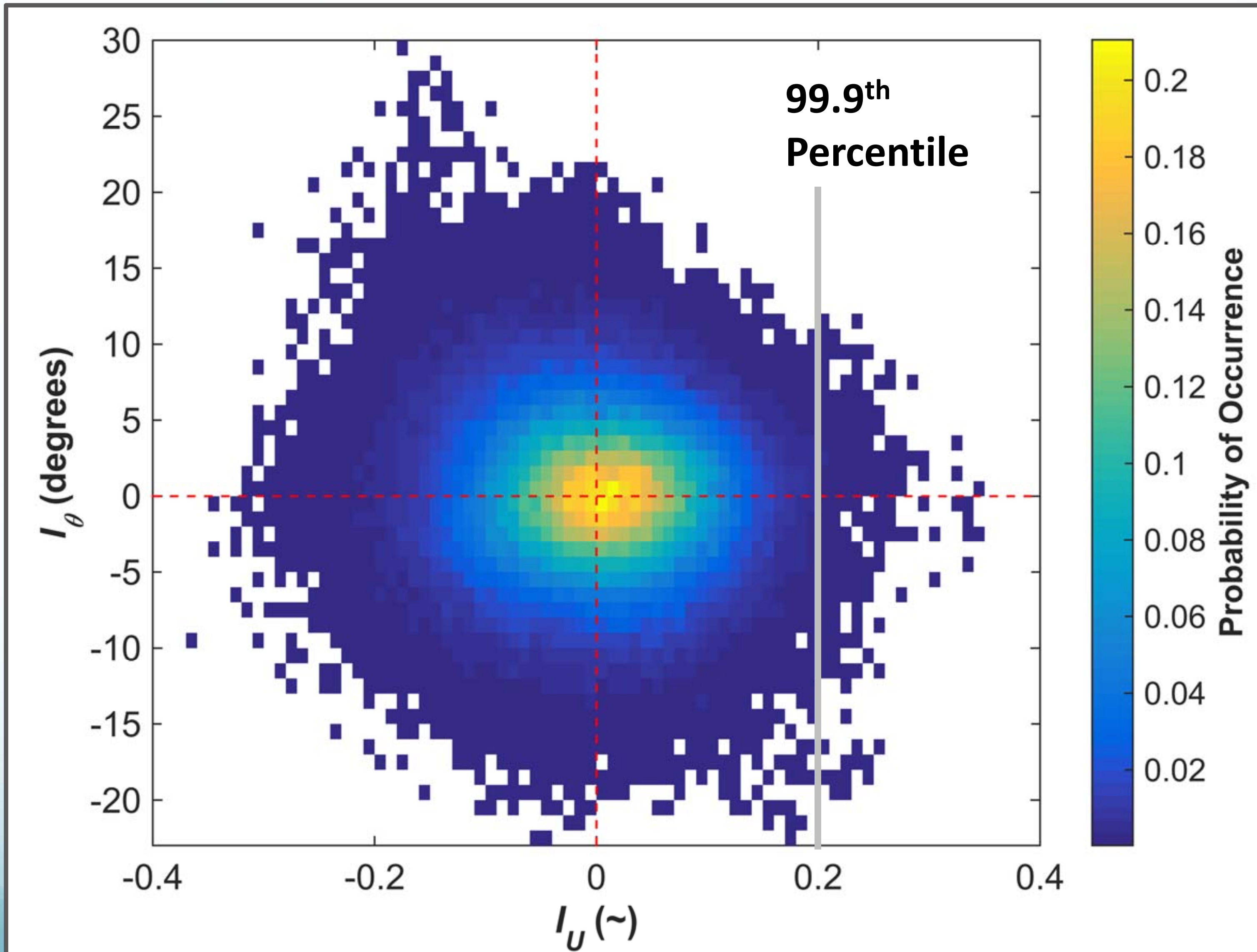
Statistical Quantity
(Observable by an ADCP)

Instantaneous Quantities
(Not Observable by an ADCP)

$$U' = U - \langle U \rangle \qquad \theta' = \theta - \langle \theta \rangle$$

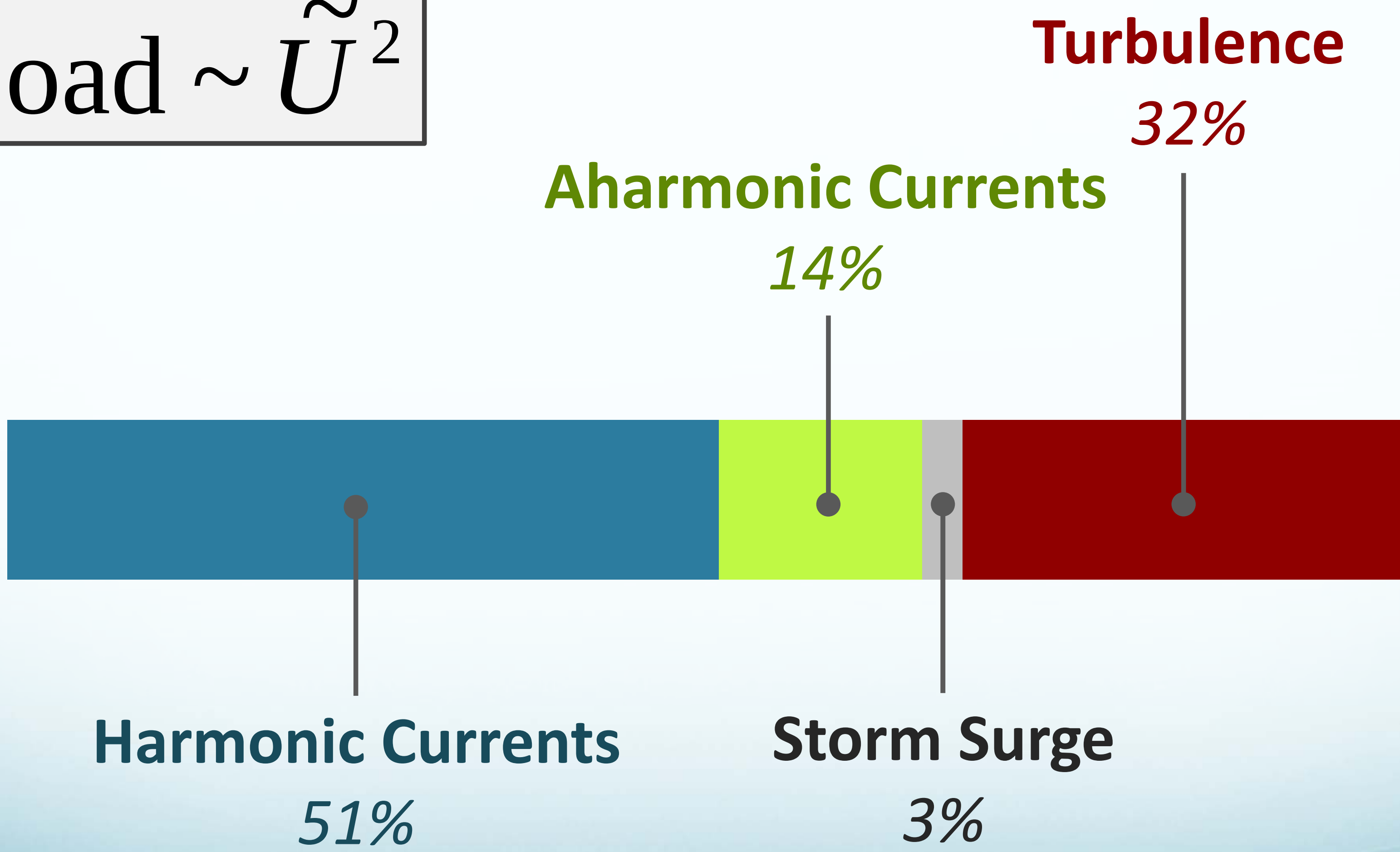
$$I_U(t) = \frac{U'}{\langle U \rangle} \qquad I_\theta(t) = \theta'$$

Statistical Representation

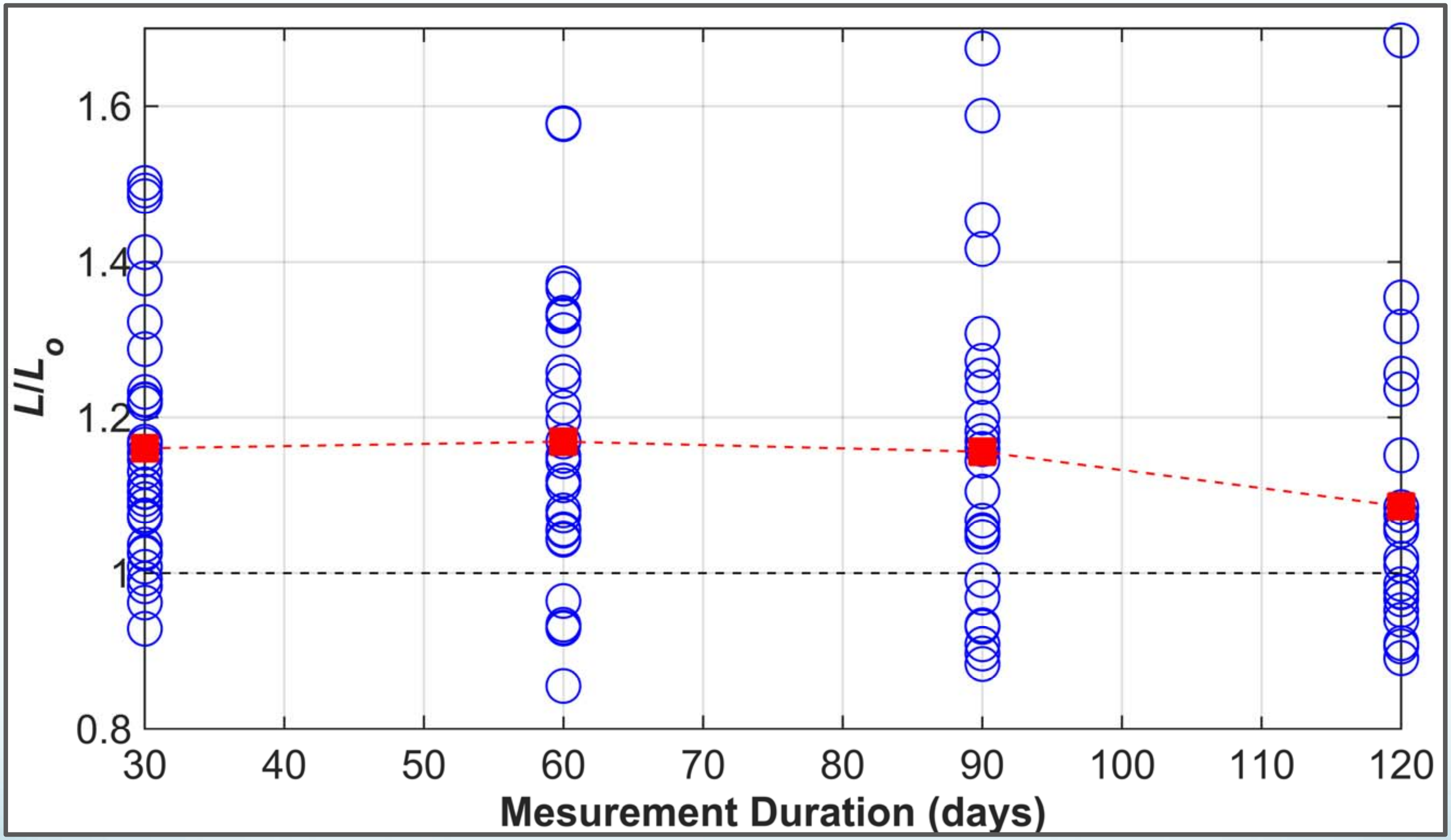


Contribution to Design Loads

$$\text{Load} \sim \tilde{U}^{2}$$



How about a Shorter Measurement?



Single Realization

Ensemble for Duration

Conclusions

Multi-year current records are helpful to explore hypotheses about shorter (*cheaper*) measurements

***Detailed* standards are needed to reverse pendulum motion on turbine design towards lower (*cheaper*) safety factors**

- Each component of design velocity
- Simultaneous occurrence factors

Acknowledgements

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