SAND2013-10401C

Temporal Variation of Velocity and Turbulence Characteristics at a Tidal Energy Site

B. Gunawan* ,V.S. Neary* and J. Colby [+]

***Sandia National Laboratories**

[+]Verdant Power

AGU Fall Meeting 2013

San Francisco, CA, December 9-13

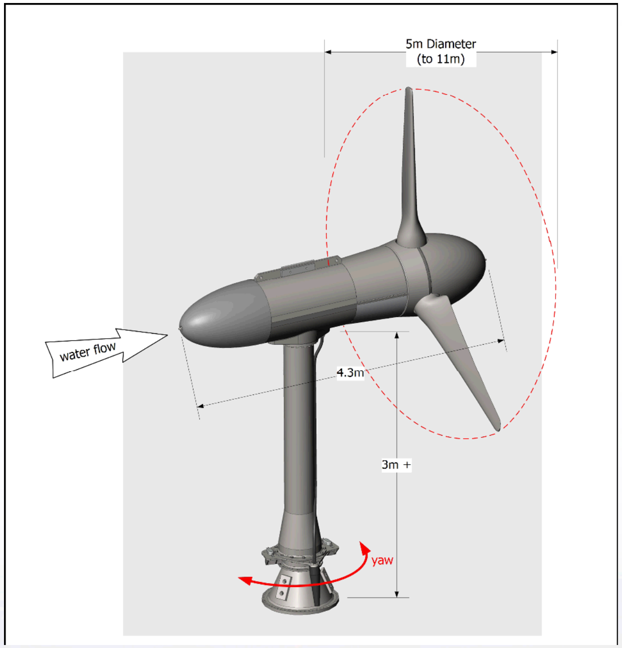
Introduction

Velocity and turbulence information are required for siting and designing tidal energy sites:

- Estimate energy production over a representative period of record
- Determine hydrodynamic forces acting on the tidal energy converter (TEC) – design structural loading
- Determine array configuration
- Validate and calibrate modeling tools

Project aim:

Conduct two-month hub-height velocity measurements at Verdant Power's Roosevelt Island Tidal Energy (RITE) site, East Channel, East River, New York City



Rotor diameter = 5 m
Cut-in speed = 1 m/s
Rotational rate = ~ 40 RPM
Yaw system = passive

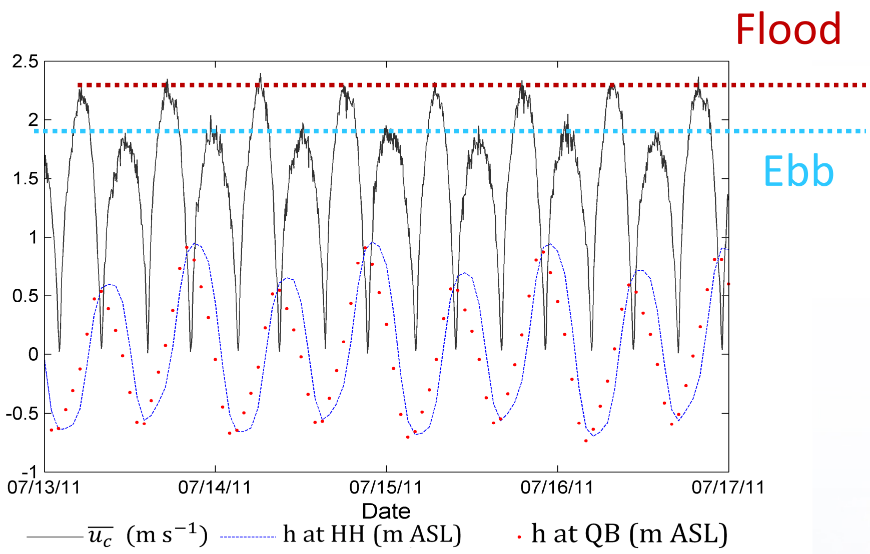
RITE Site

- Channel width ~200m
- Depth ~10 meter
- Semi-diurnal tides
- Channel's Reynolds Number ~10^7
- Mean tidal range = 1.3 m
- Hub-height is at 4.25 m from bed

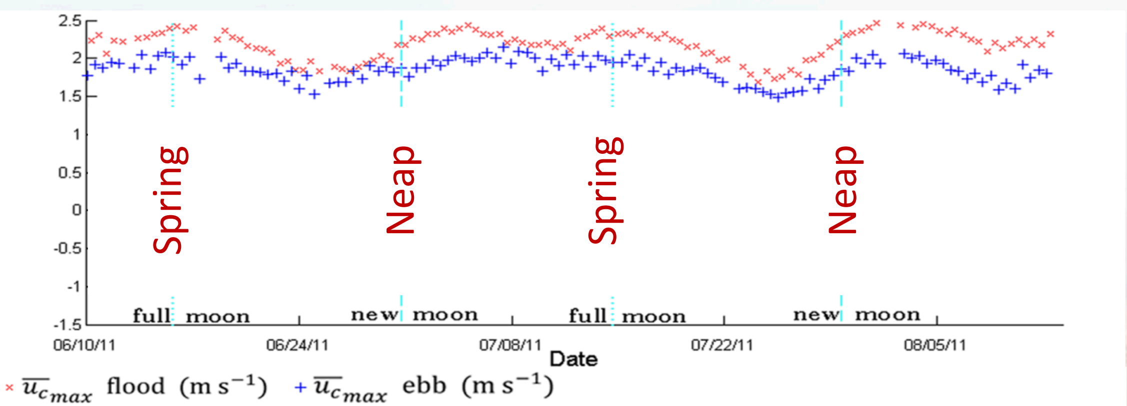
Measurement details

- 2-month baseline measurement (without turbine)
- 2 ADVs
- Data acquisition rate: mostly at 20Hz
- ADVs were cable-connected to the shore (~ 50 meters away)
- Issues: Hurricane!, Bio fouling, ADV synchronization

Current magnitudes and water levels



- Sinusoidal tidal current pattern (highly regular)
- Peak floods 18% higher than peak ebbs
- Peak spring tides 0.5 m/s higher than peak neap tides



Mean $\overline{u_c}$ = 1.4 m/s

Max $\overline{u_c}$ = 2.4 m/s (FD= 2.8 kN/m^2)

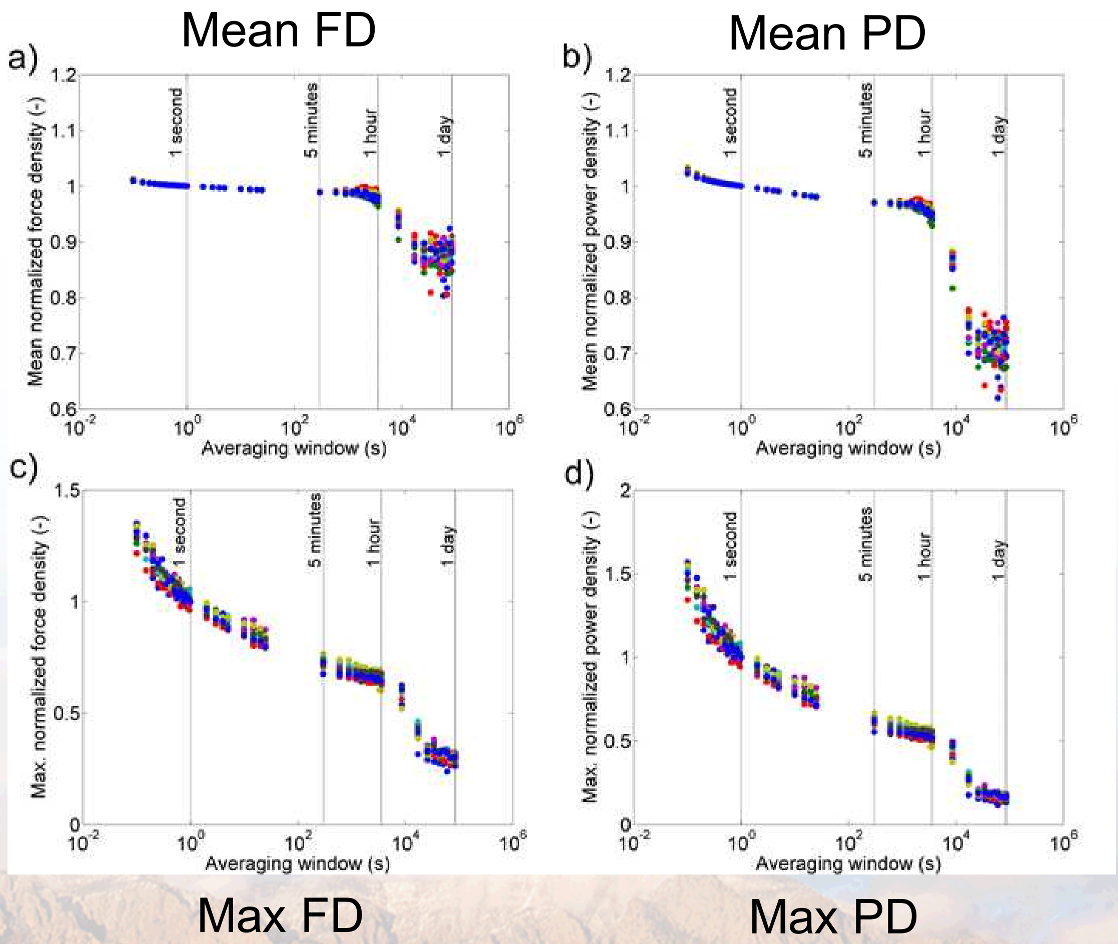
Max u_c= 3.5 m/s (FD= 6 kN/m^2)

Effects of averaging window length

Force density (FD) = $\frac{F}{A} = \frac{1}{2}\rho\, u_c{}^2$

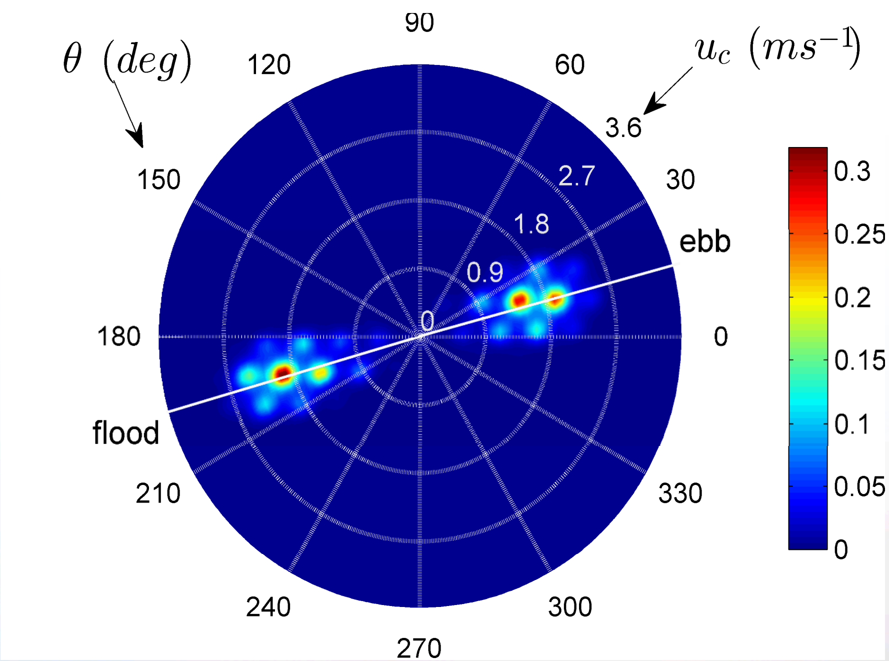
Power density (PD) = $\frac{P}{A} = \frac{1}{2}\rho\, u_c{}^3$

- Temporal averaging causes low-pass filtering effect
- Highest load was calculated using instantaneous measurements (1/20 second)
- Instantaneous Vs. 1-second averaging window:
  - Max FDs differ by ~25%
  - Max PDs differ by ~50%
  - Mean FDs differ by ~2%
  - Mean PDs differ by ~3%



Current directions

Joint probability distribution (JPD) of current magnitude and direction

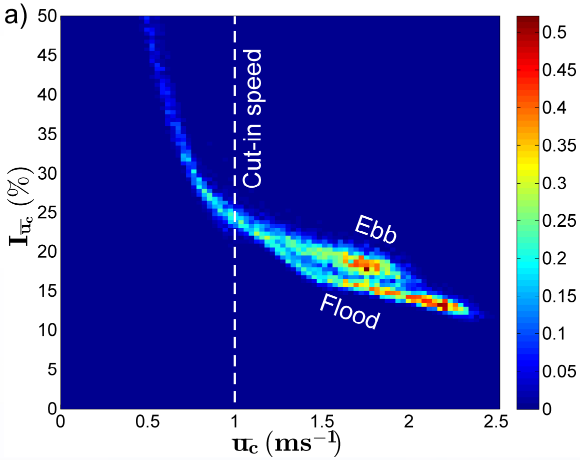


u_c bin size = 0.1 m/s ; θ bin size = 1 degree

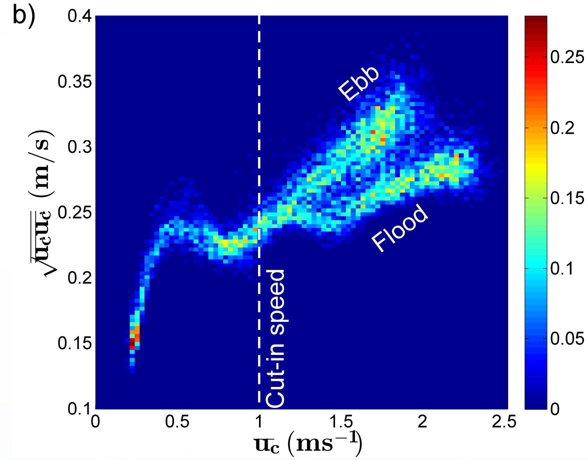
- **Nearly bi-directional (180.8° difference) flow direction**
- **Current directions change with current magnitudes – how does this affect turbine performance?**

Turbulence

Turbulence intensity (TI)



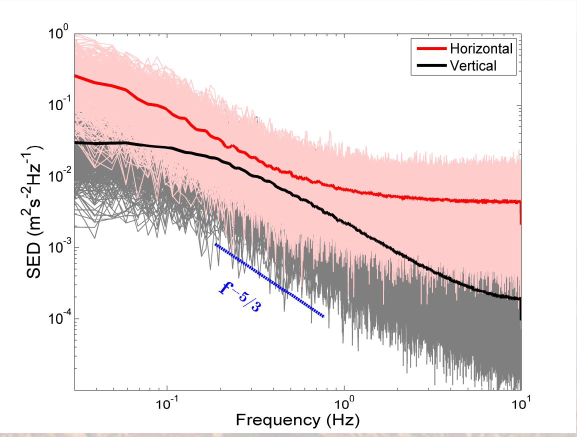
Current RMS



Channel geometry

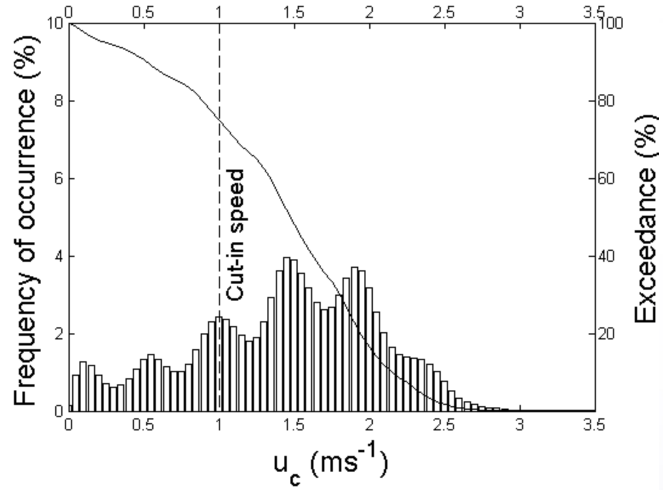
- TI above cut-in speed ~ 12-25%
- Current RMS bifurcates
- Current RMS (~device load) increase with current magnitude
- Anisotropic turbulence – Doppler noise?

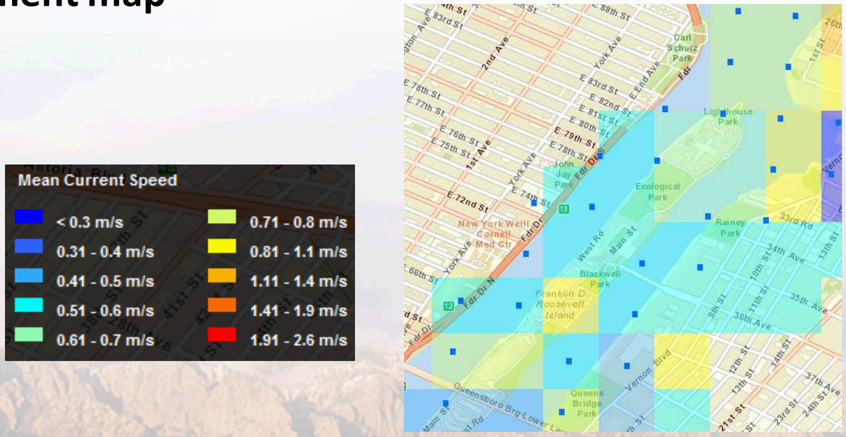
5-minute velocity spectra



Current histogram and distribution curve

- Current speed were 75% higher than Gen5 turbine cut-in speed
- Mean power density at the site **~ 2.31 kW/m²** , other energy sources:
  - solar insolation ~ **0.17 kW/m²**
  - 10 m/s wind ~**0.58 kW/m²**
  - wave generated by this wind ~ **8.42 kW/m²**
- US Tidal energy resource assessment map ~ **0.4 kW/m²**





Conclusions

Deployment consideration:

- Hurricane and biofouling may cause instrument malfunction

RITE site features:

- Sinusoidal tidal velocity time series
- Peak flood velocities are constantly higher than peak ebb velocities
- Bidirectional current direction

} Desirable - availability of power becomes more predictable

Other items:

- Temporal averaging caused low-pass filtering - need to be considered in load and annual energy production estimation
- Site measurement exhibits higher power density estimation than national resource assessment
- Tidal energy site classification that quantify key sites parameters is desired for turbine type selection and financing decision

Acknowledgements

- This research was supported by the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy, Wind and Water Power Technologies Program under the DOE Advanced Water Power Project Grant No. DE-FG36-08GO18168/M001, the DOE Advanced Water Power Project Contract No. DE -FG36-08GO18168.005, titled: "*Improved Structure and Fabrication of Large, High-Power KHPS Rotors.*" Sandia National Laboratories is managed by Lockheed-Martin for DOE under contract DE-AC05-00OR22725. The authors thank Dean Corren and Mary Ann Adonizio of Verdant Power, as well as the reviewers of this paper, for their useful comments and suggestions.