Improving Offshore Wind Energy Resource Estimates Using Wind Lidar: Research to Operation

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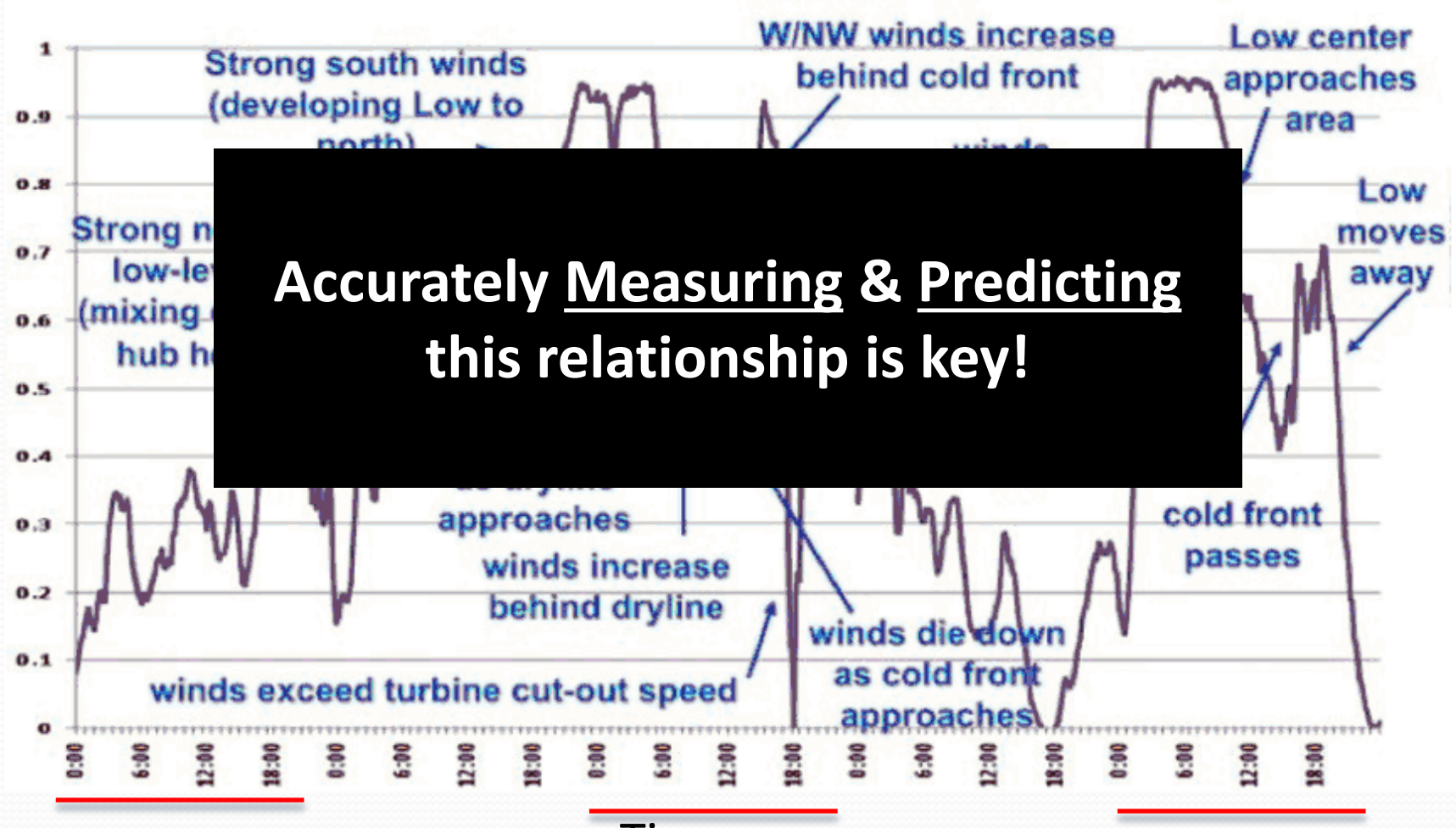
lidar.umbc.edu/wind-energy

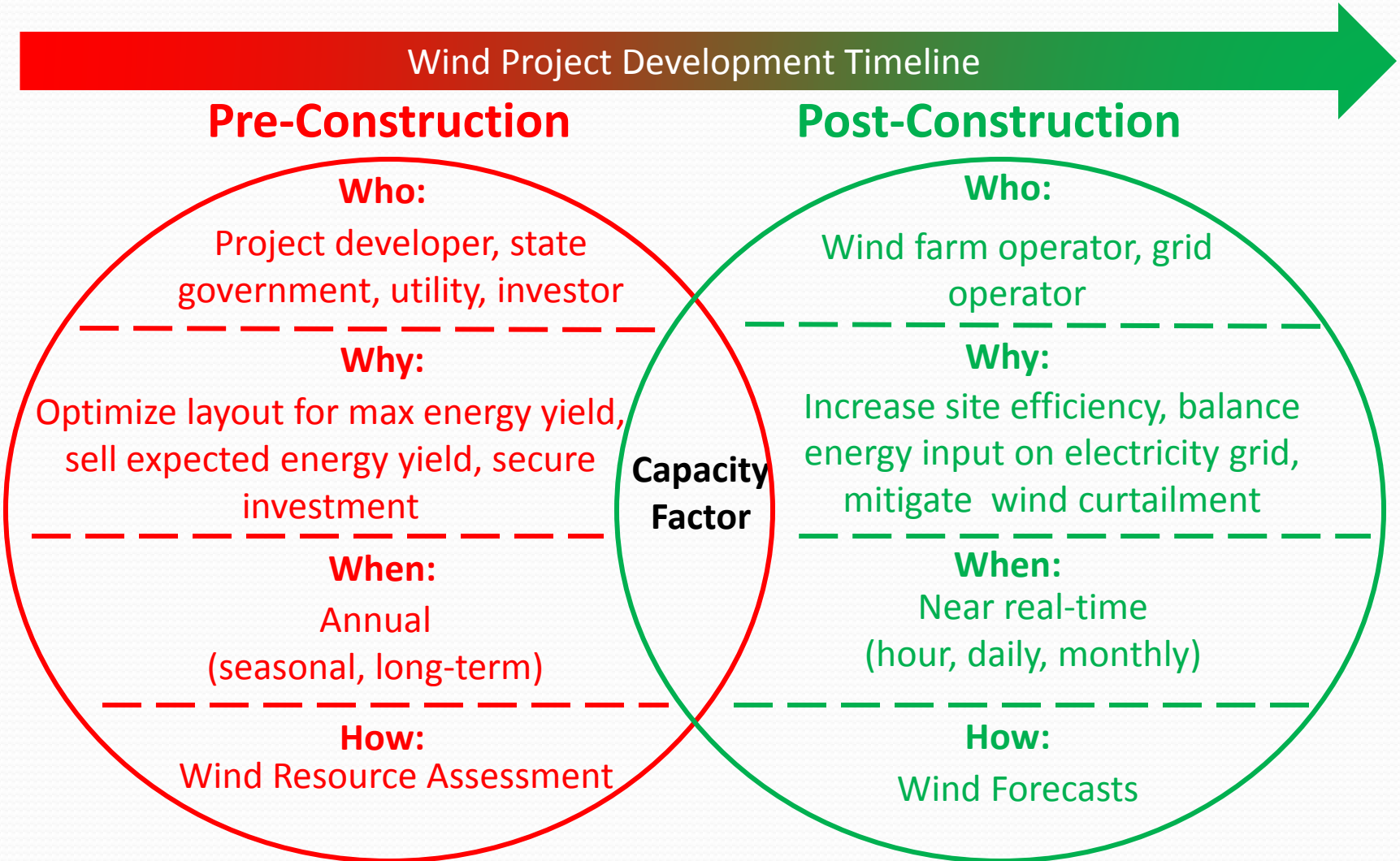
Intermittent Wind Resource & Turbine Performance



Accurately <u>Measuring</u> & <u>Predicting</u> this relationship is key!

[1]

The Need for Accurate *Prediction* of Wind Resource & Turbine Performance Relationship



The Capacity Factor

- **Capacity Factor (CF)** = proxy for turbine & plant performance (i.e. higher capacity factor means a given size generator will produce more energy over the year)

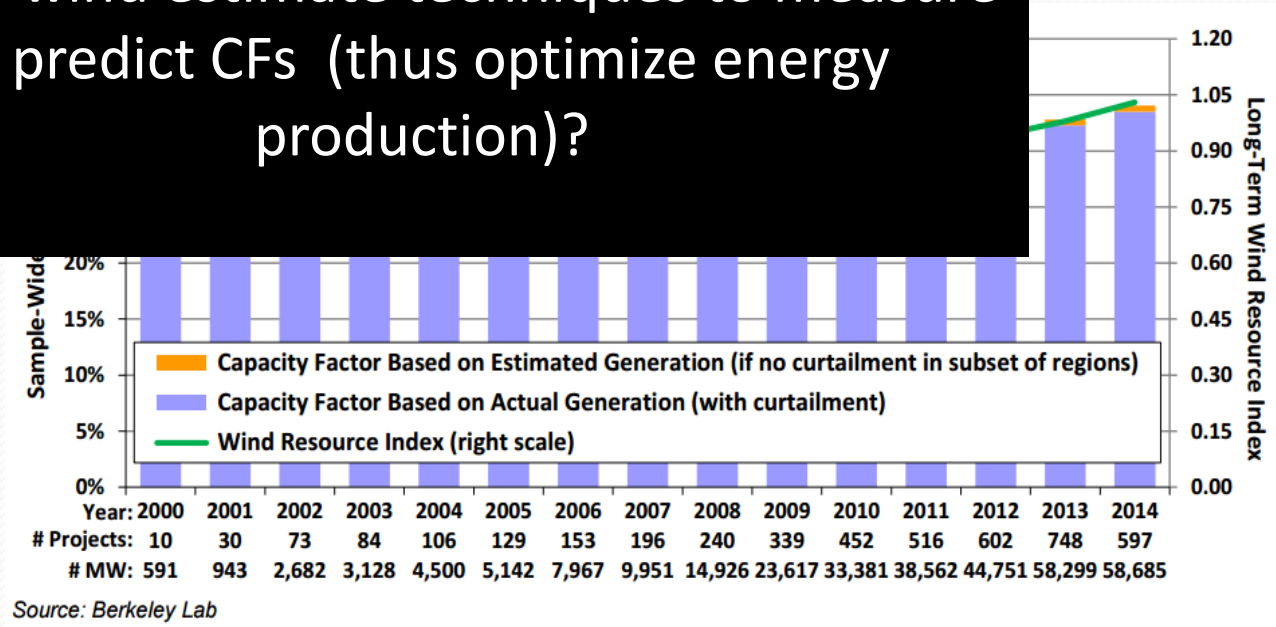
Represents avera… power output ove… year period to it… nameplate rating, w…

$$\mathbf{CF} = \frac{\boldsymbol{Avg\ Pwr\ Outpt}}{\boldsymbol{Installed\ \ Pwr} *}$$

where H_t is hours in time pe…

…ty factors

Better wind estimate techniques to measure & predict CFs (thus optimize energy production)?



Source: Berkeley Lab

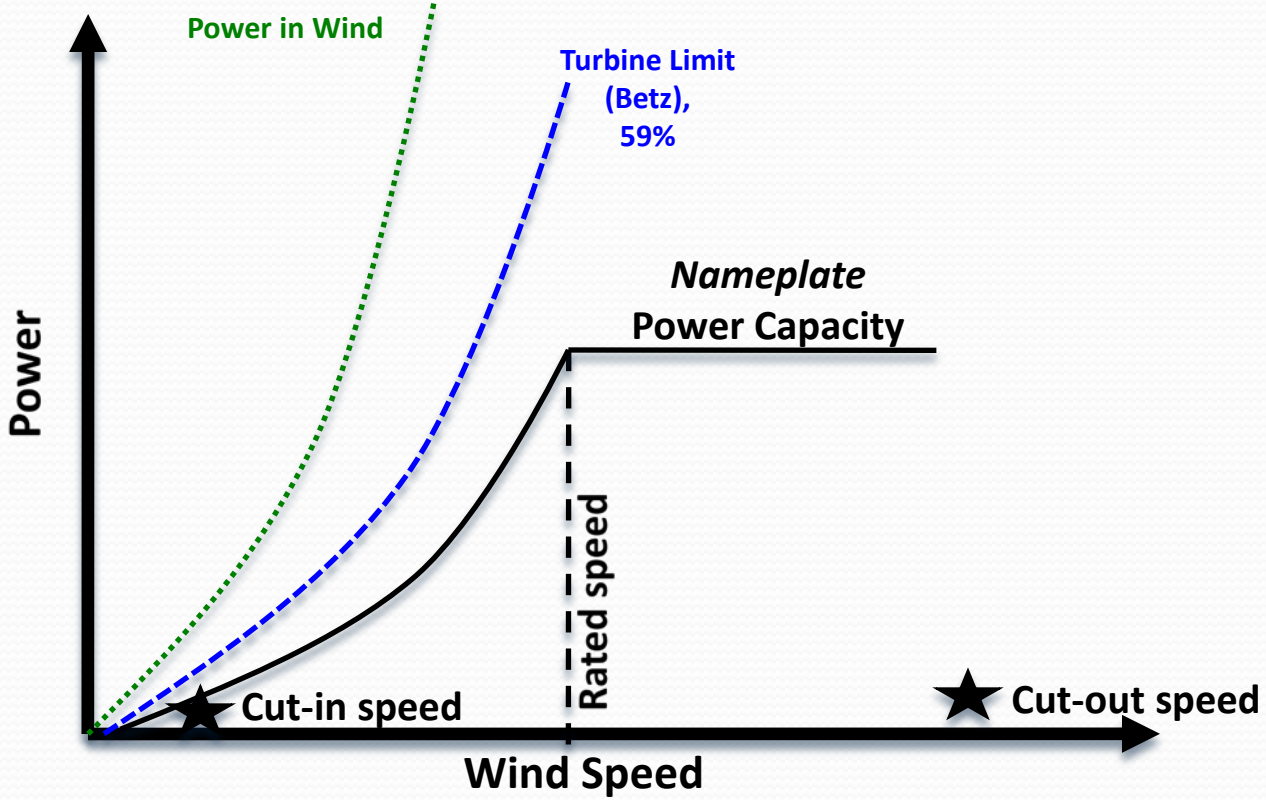
[2]

Pre-Construction CF: Estimating Turbine Power

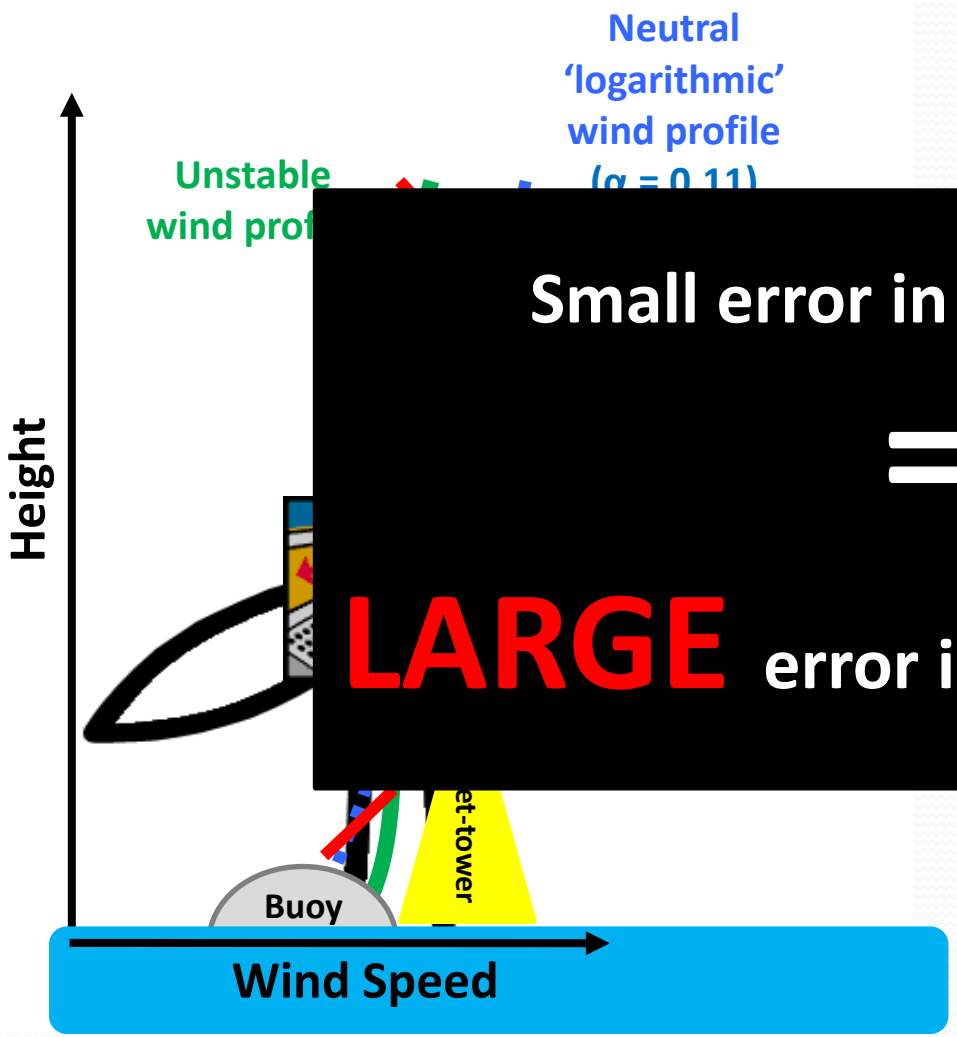
Performance

$$\mathbf{Power_T = 0.5 * \rho * A * U^3 * Cp}$$

ρ = air density, A= area of rotor layer , U = **hub-height** wind-speed, Cp= power coefficient



Pre-Construction CF: Estimating Offshore Wind *Speed*



'Power Law' wind profile
extrapolations assume the vertical
thmic, thus
c conditions

fluctuate from
and **neutral**
eather regime

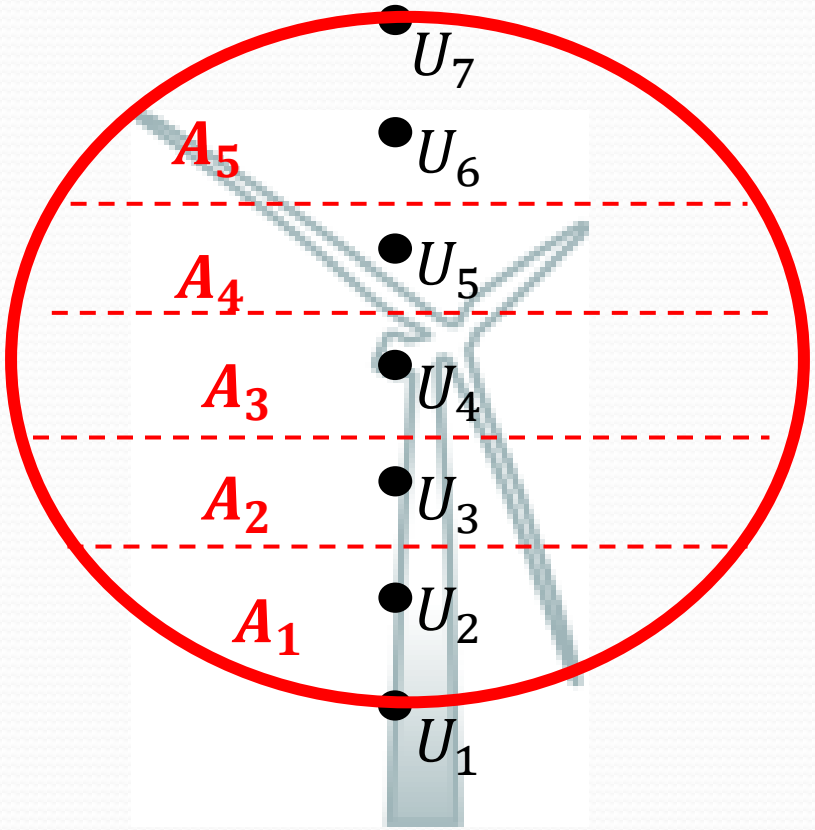
Small error in wind speed

=

LARGE error in expected power

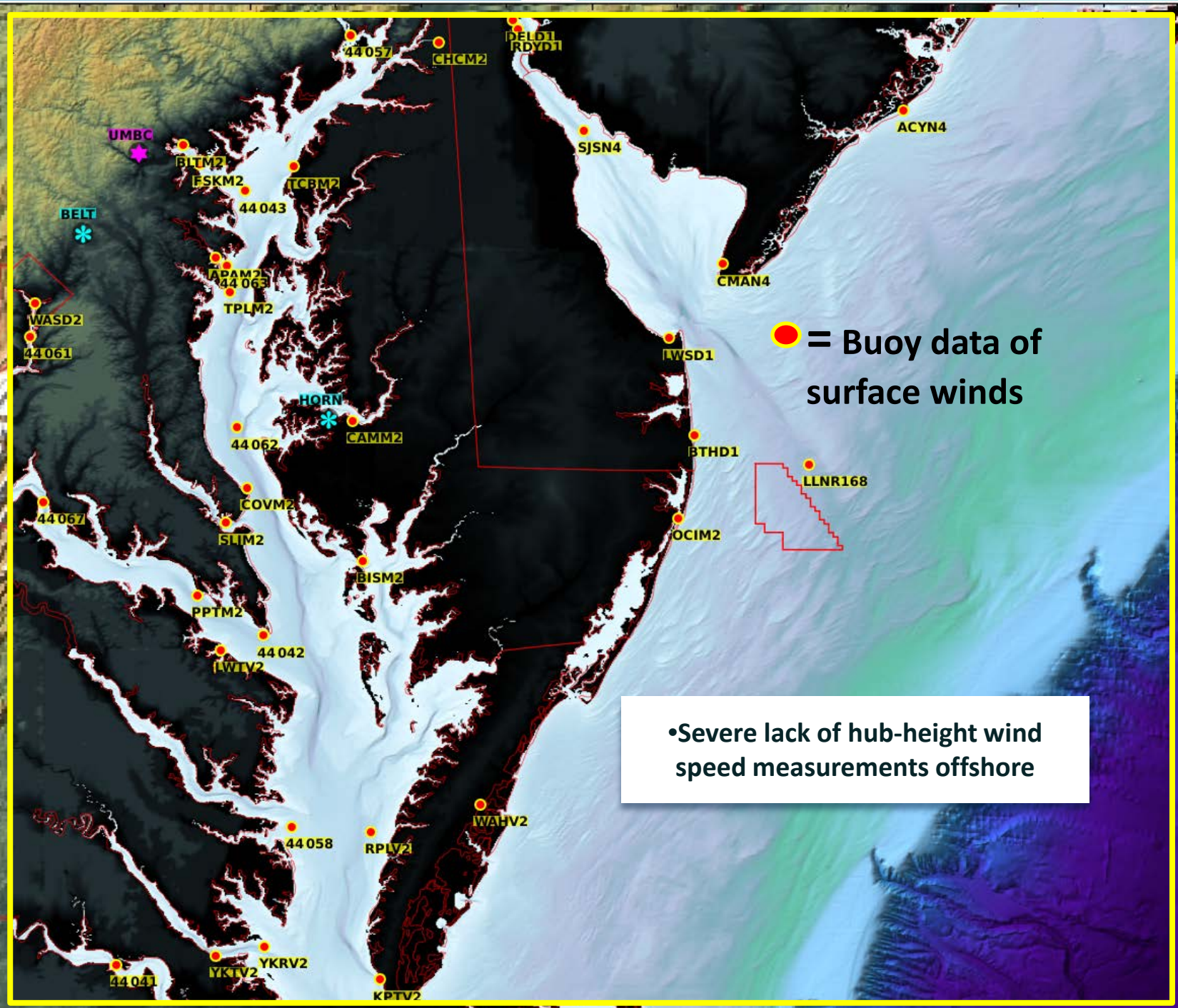
Wind Energy- Meteorology Research

- Is **hub-height** wind speed best way to **characterize** the **quality** of the **wind resource**?



Vertical wind profile interacting with a turbine, via **equivalent wind speed** measurements, rather than only hub-height, critical for predicting turbine performance

[4-6]


44057
CHCM2
DELD1
RDYD1
ACYN4
SJSN4
UMBC
BLTM2
FSKM2
TCBM2
44043
BELT
CMAN4
44063
TPLM2
WASD2
44061
LWSD1
= Buoy data of surface winds
HORN
CAMM2
44062
BTHD1
LLNR168
COVM2
44067
SLIM2
OCIM2
BISM2
PPTM2
44042
LWTV2
•Severe lack of hub-height wind speed measurements offshore
WAHV2
44058
RPLV2
YKRV2
YKTV2
44041
KPTV2

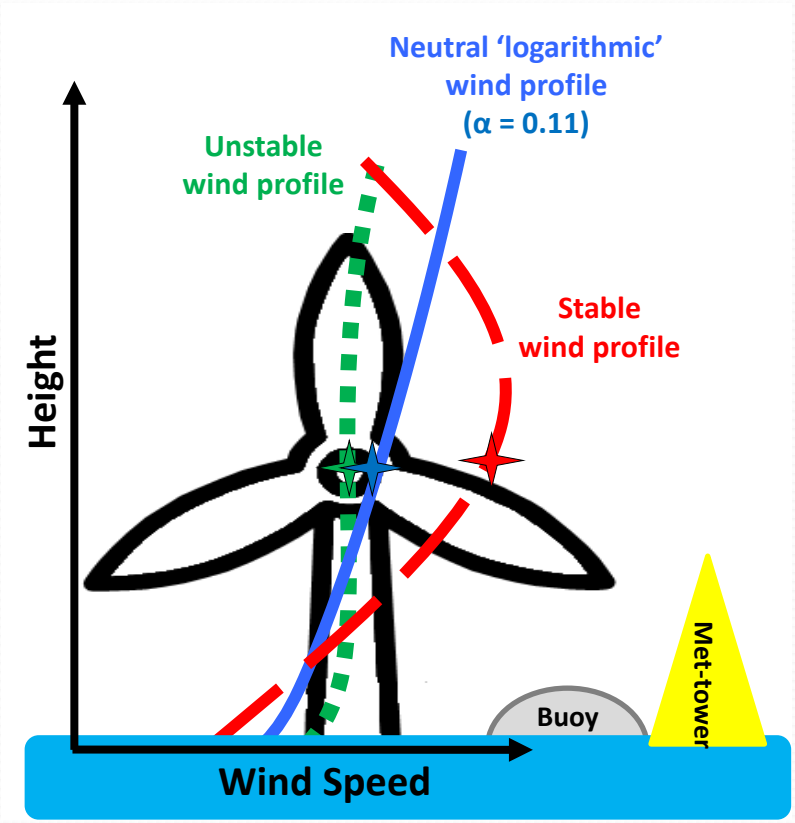
UMBC Wind Energy Research

- Maryland Energy Administration contract (2013)
  - Data Collection to support offshore wind resource assessment
    - July- August 2013: Offshore Measurements during MEA Geophysical Survey (Windcube V2 Offshore)

Research Questions

1 How **representative** are *standard* **wind estimate techniques** (α = 0.11) of ***offshore wind profiles*****?**

2 What are implications of **wind estimate techniques** on an offshore turbine's potential ***power output & expected performance*****?**

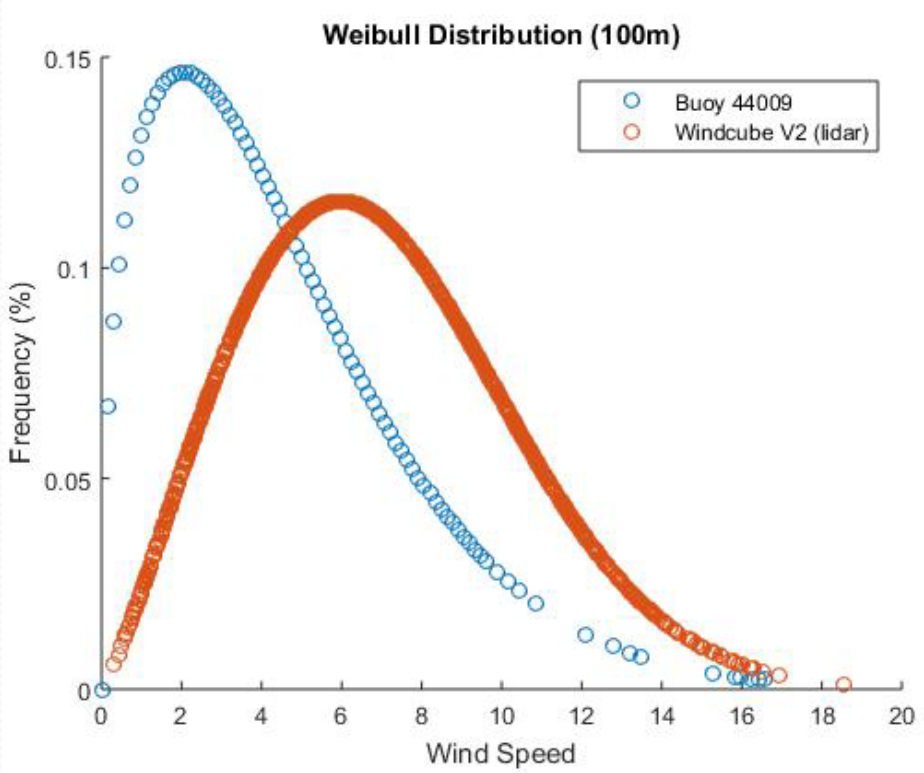


Results: Power Law vs. Measured Wind

Power Law Method:

$$\frac{u(z_2)}{u(z_1)} = \left(\frac{z_2}{z_1}\right)^{\alpha}$$

where ***u*** is mean wind speed, ***z*** is height (ASL) & wind shear exponent (α) = 0.11

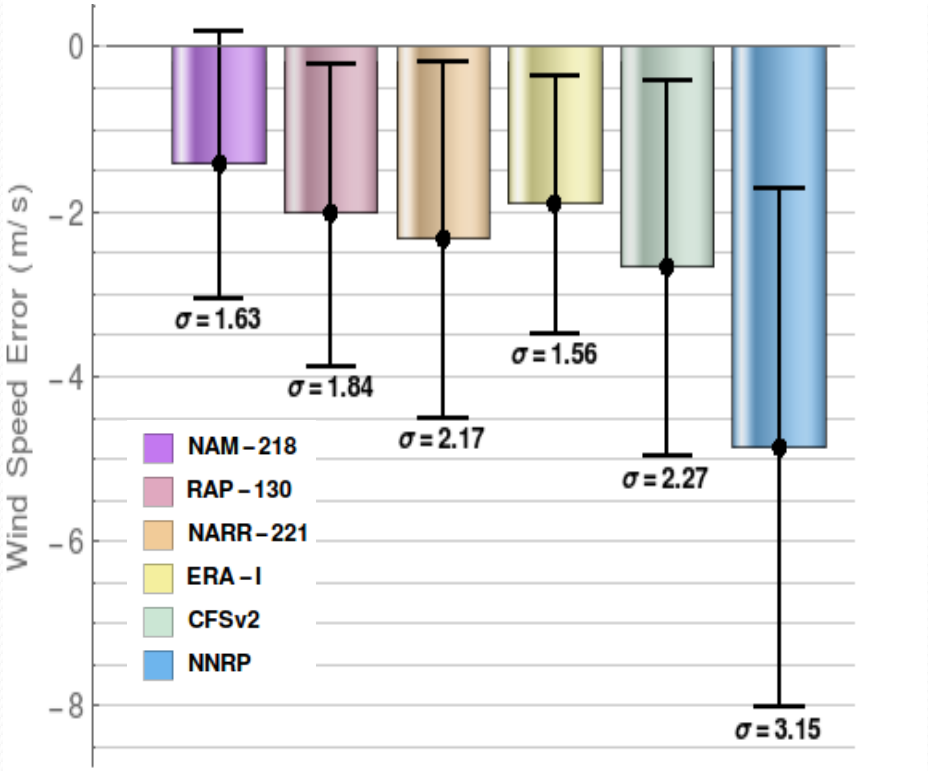


- Extrapolated buoy data **underestimated** hub-height wind speed by ~ 3 m/s

Weibull parameters	Buoy	Lidar
Shape parameter (k)	1.39	2.19
Scale parameter (c) - m/s	5.04	7.89

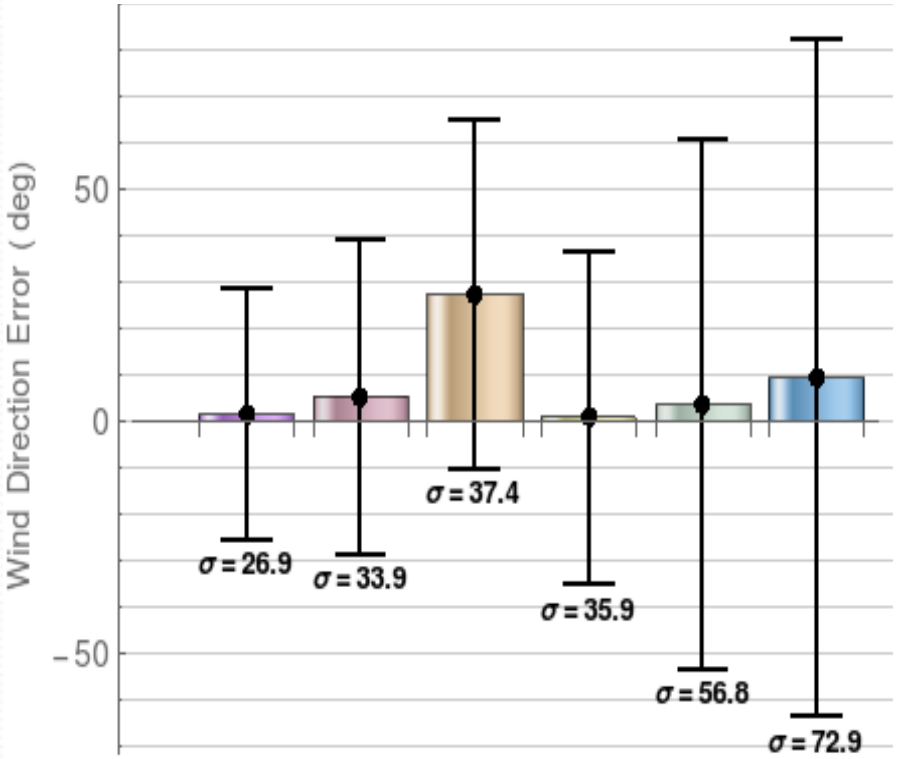
Results: Model Output vs. Measured Wind

Median Wind Speed Error at 100m



- Model and reanalysis output **underestimated** wind speed

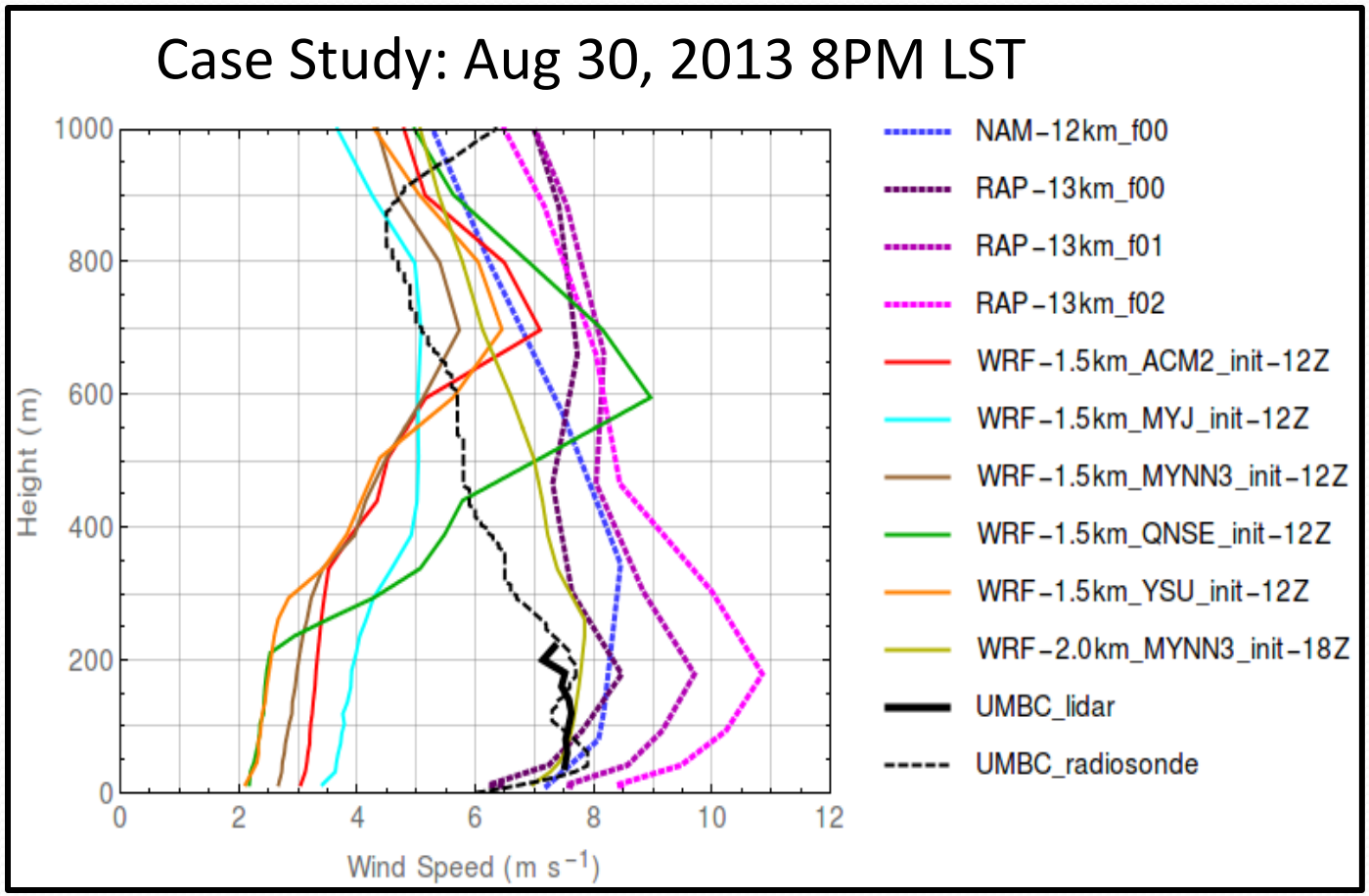
Median Wind Direction Error at 100m



- Also **large error** in estimated wind direction

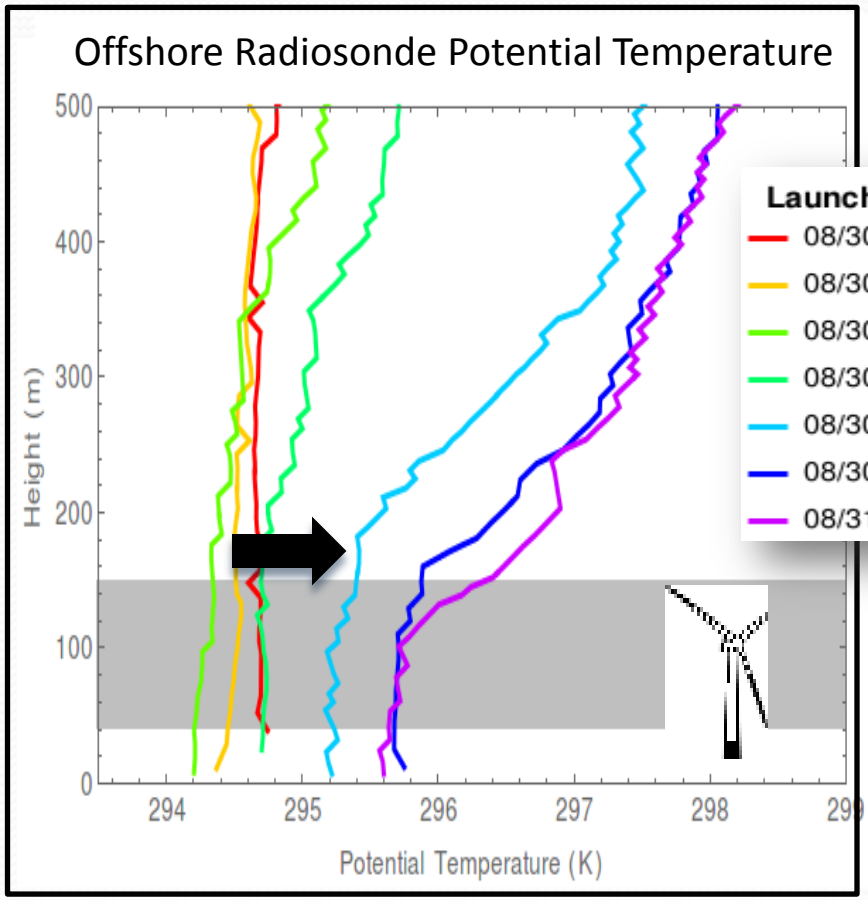
Results: *Why* Discrepancies?

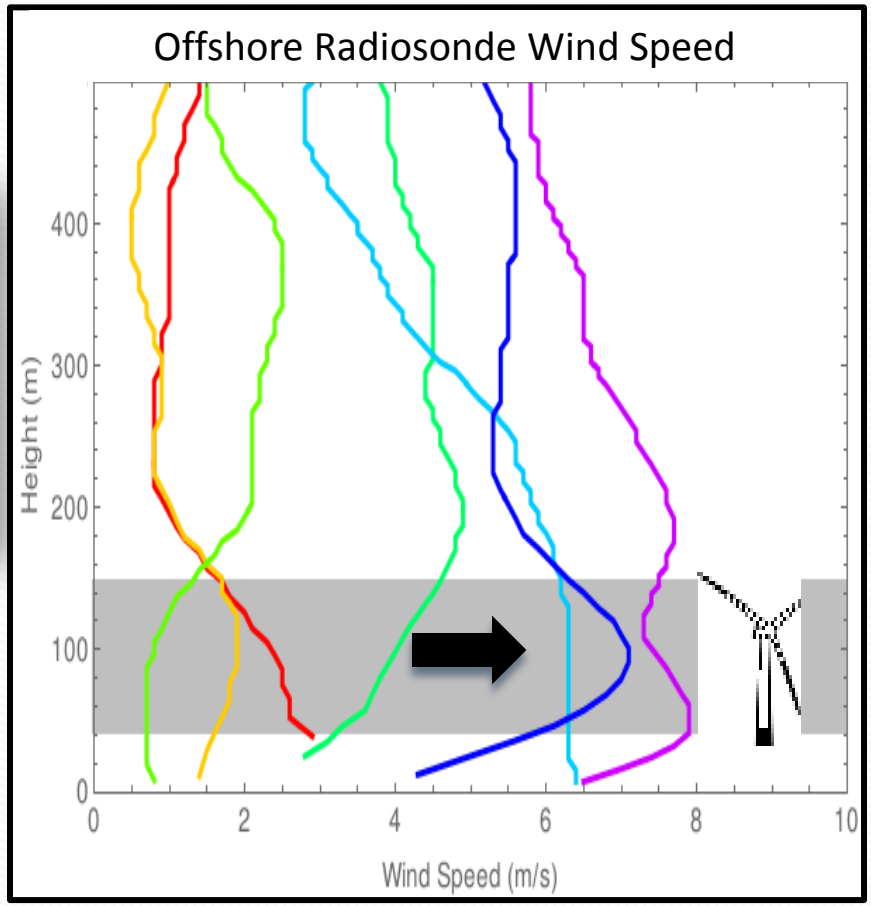
- Power law extrapolations & model/reanalysis output **struggle to characterize offshore vetical wind profile**



Results: *Why* Discrepancies?

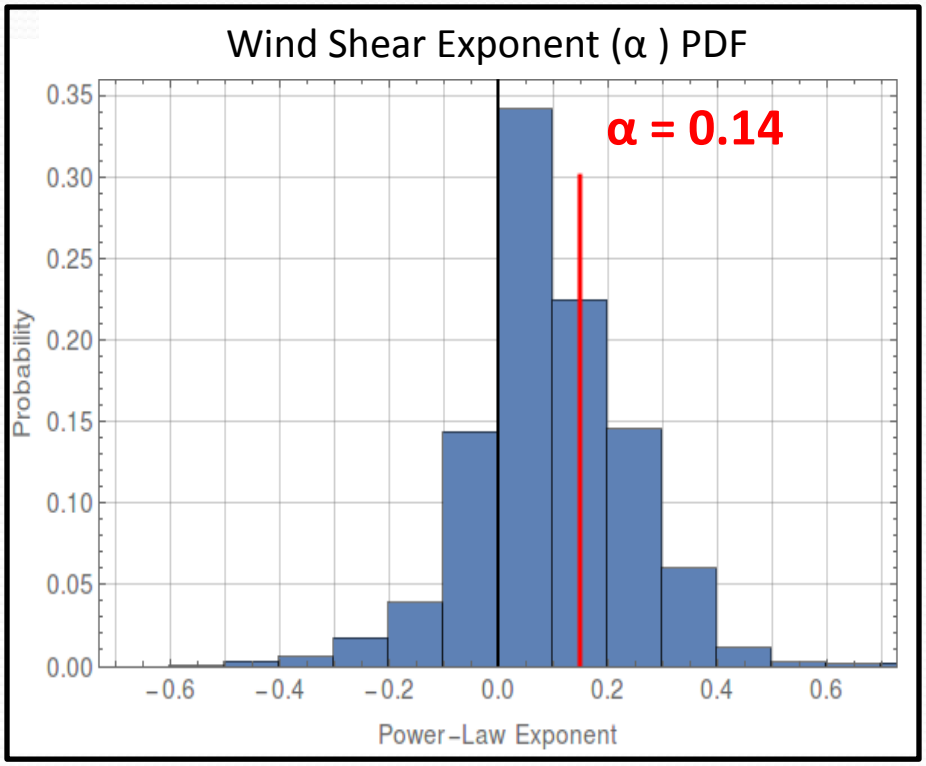
- Frequent development low-level wind maxima (LLWM)





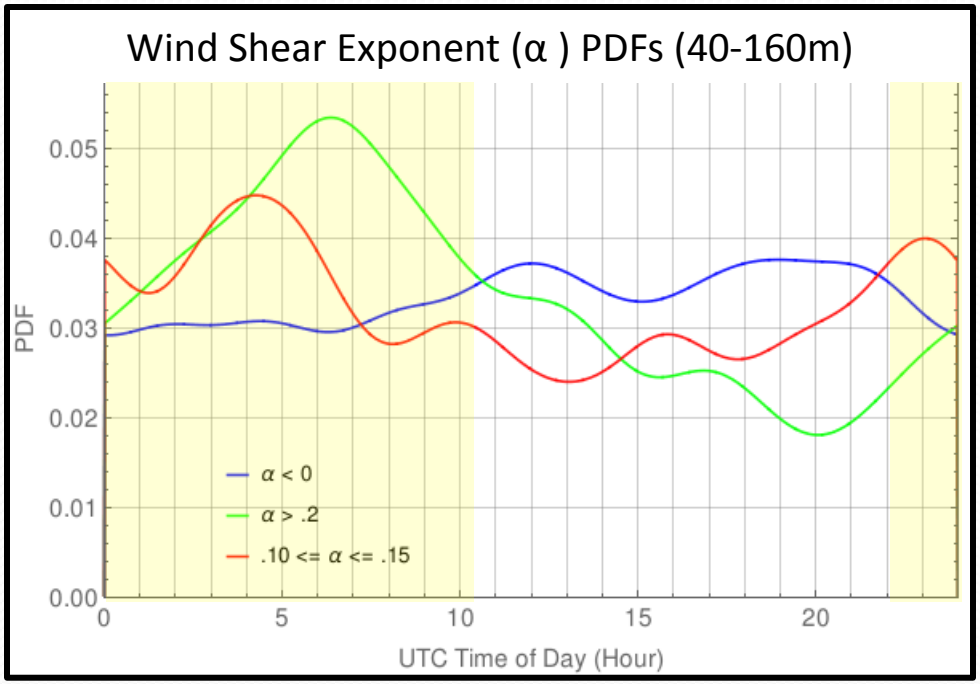
- Post 19 UTC, enhanced **stability**
- Post 19 UTC, development of **low-level wind max**

Results: *Why* Discrepancies?



- **Atypical wind shear (α ≠ 0.14)**
  - **20%** negative shear

- Shear conditions **changing** throughout the day:
  - Strongest wind shear overnight & negative shear before sunrise/ late day



Results: Impact of Wind Estimate Technique on Potential Turbine Output & Performance

$$P_W = {}^1/_2 A\, U^3\, \rho Cp$$

where: ρ = air density
A= area of rotor layer
U = hub-height wind speed
Cp= power coefficient

Method	Short-Term CF
Ext Buoy	1.8%
$Lidar_{HH}$	23.6%
U_{EQ}	24.2%
$U_{EQ,TI}$	29.8 %
$U_{EQ,TID}$	29.8%

[4]

[5]

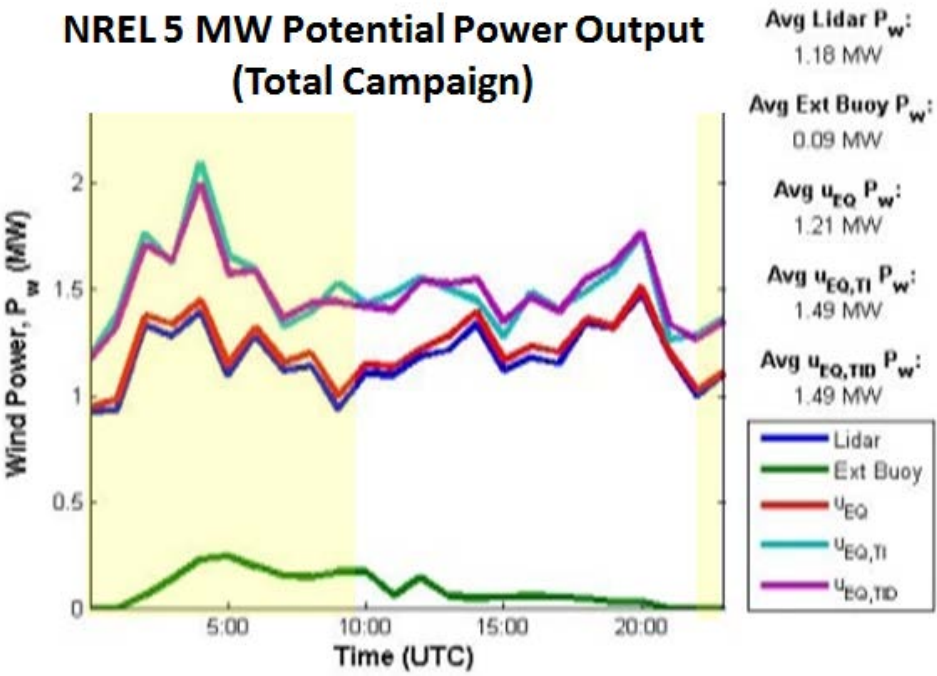
[6]

$$U_{EQ,TID} = \sqrt[3]{\frac{1}{A}\sum_{i=1}^{N} \bar{U}_i^3 [1 + 3(\frac{\sigma_{ui}}{\bar{U}_i})^2][1 - \frac{\sigma_i}{2} - \frac{\sigma_{\theta i}}{2}]^3 A_i}$$

where $\bar{\theta}_i$ is the angle of the wind (compared to rotor axis)

$$CF = \frac{Avg\ Pwr\ Outpt\ * H_t}{Installed\ \ Pwr * H_t}$$

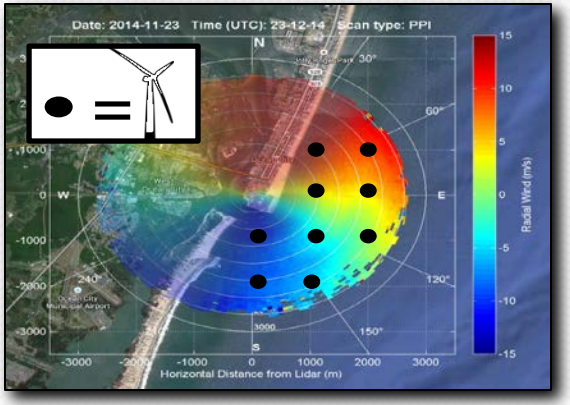
where H_t is hours in time period



- **Next step:** categorize relationships by **magnitude** of **low-level wind max events**

Summary & Future Work

- Wind Estimate Technique:
  - Power law extrapolated & model/reanalysis output ***underestimate*** average offshore hub-height wind speed compared to lidar measurement
- Potential Power & Expected Turbine Performance:
  - Power law extrapolated & lidar hub-height wind speed demonstrate ***lower potential power output and turbine performance*** compared to lidar derived equivalent wind speed techniques
- Future Work:
  - Use offshore scanning Doppler wind lidar measurements for similar analysis, except on the wind farm level (several turbines), to **assess wind estimate technique impact on optimal layout strategies** that are perceived to maximize energy yield (capacity factor)



Thank you! Questions?

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- Leosphere/Renewable NRG Systems
- CB&I/Coastal Planning and Engineering Environmental and Infrastructure

References

[1] Marquis, M., et al. 2011, Forecasting the Wind to Reach Significant Penetration Levels of Wind Energy. Bulletin of the American Meteorological Society, September, pg. 1159-1171.

[2] http://www.eia.gov/todayinenergy/detail.cfm?id=14611

[3] 2014 Wind Technologies Report, Department of Energy : http://energy.gov/sites/prod/files/2015/08/f25/2014-Wind-Technologies-Market-Report-8.7.pdf

[4] Sumner J and Masson C 2006 Influence of atmospheric stability on wind turbine power performance curves J. Sol. Energy Eng. 128 531–7.

[5] Wagner R, Antoniou I, Pedersen S M, Courtney M S and Jørgensen H E 2009 The influence of the wind speed profile on wind turbine performance measurements Wind Energy 12 348–62.

[6] Choukulkar et al. 2014.,"A New Formulation of Equivalent Wind Speed and Power Calculations Using Data from the High Resolution Doppler Lidar", AMS conference paper.

Extra

Model/Reanalysis	Resolution
NAM-218	12.19km
RAP-130	13.54 km
NARR-221	32.36 km
CFSv2	0.5 x 0.5 degree (55 x43 km)
ERA-I	0.703 x 0.702 degree (78 x 60km)
NNRP/R1	2.5 x 2.5 degrees (277 x 216km)