Surface Roughness Length for Offshore Wind Energy

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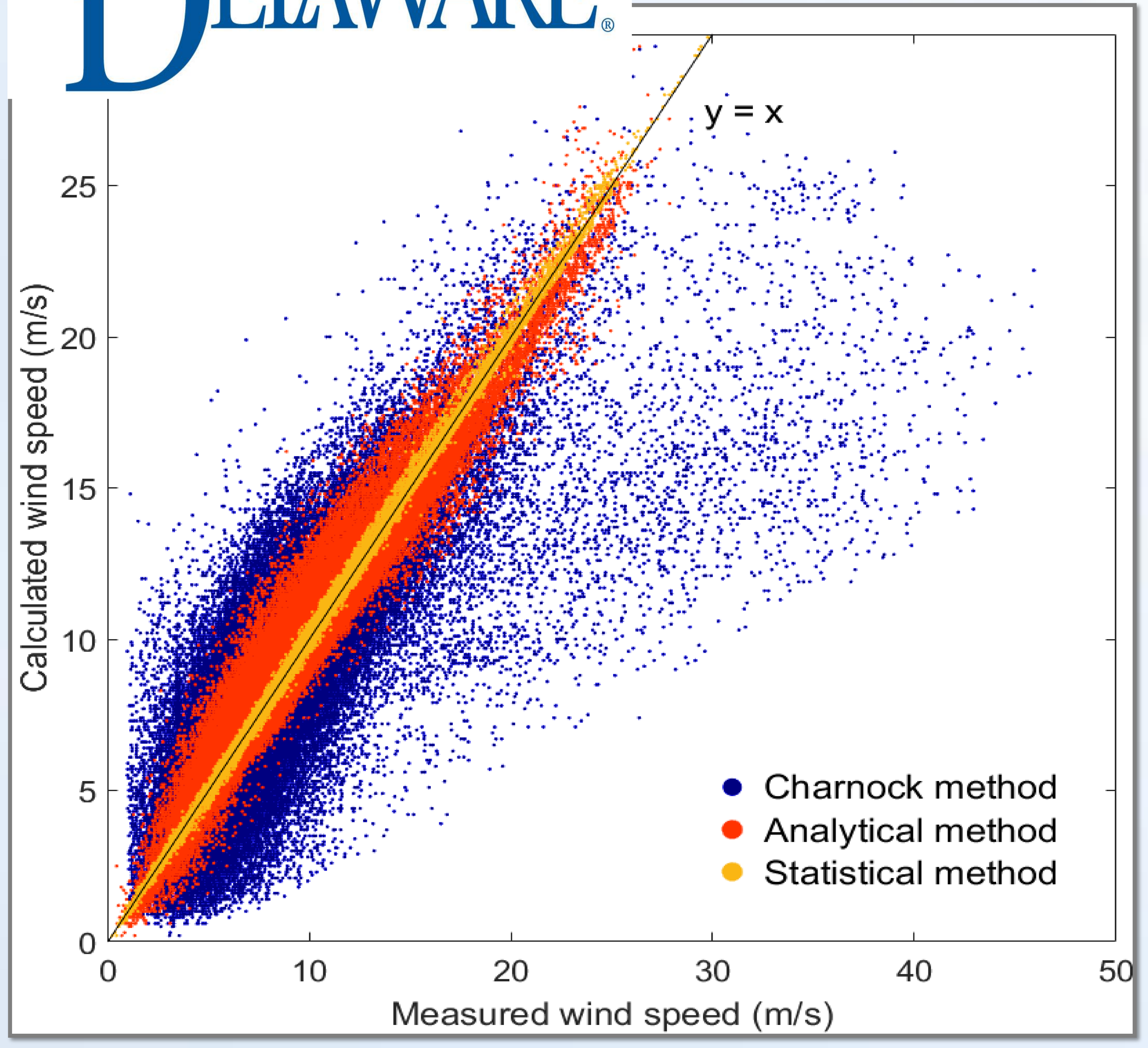

Figure 1. Correlation between measured and calculated wind speed at 60 m by each of the three methods.

INTRODUCTION:

- The Northeastern U.S. coast will increase its offshore wind capacity to 86 GW by 2050 [1].
- The power production of the turbines is proportional to the cube of wind speed at hub height [2].
- Measurements of wind speeds are usually not available offshore at the hub height of the wind turbines.
- Extrapolation is often required using the surface roughness length z_0 .

RESEARCH GOALS:

- To estimate the surface roughness length off the Northeastern coast of the U.S.
- To analyze the accuracy of three methods used to calculate z_0 .

DATA:

- Field measurements from Nantucket Sound, MA.
- Data are from two field campaigns, Cape Wind (CW, 2003-2011) and IMPOWR (2013-2014). CW measurements were at 20, 41, and 60 m AMSL, IMPOWR's at 12 m AMSL [3, 4].

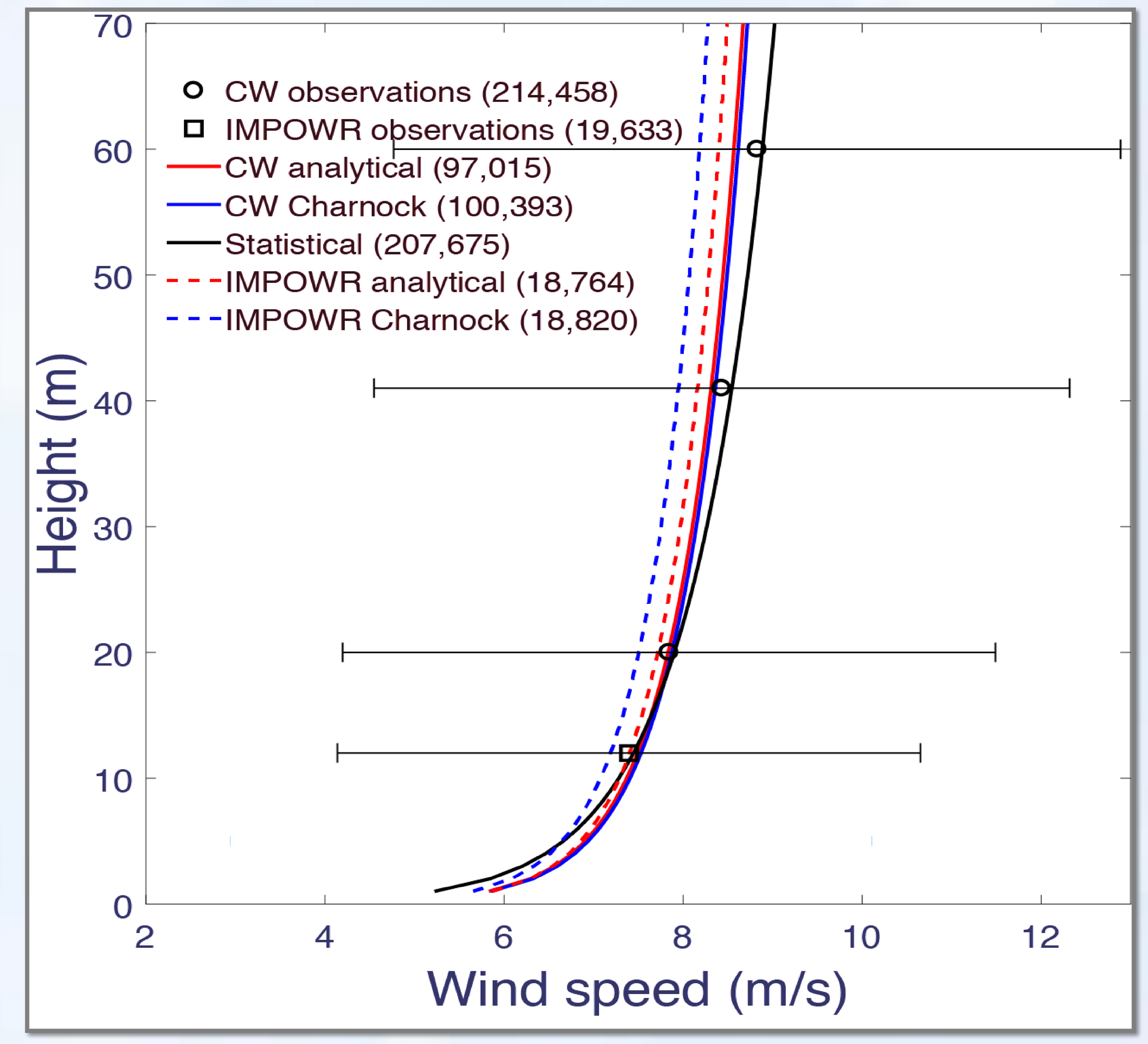

Figure 2. Mean wind speed profiles predicted using z_0 values obtained with the three methods presented here.

METHODS:

Three commonly used methods in the literature were considered:

1. **Charnock relationship:**

$$z_0 = \alpha \frac{u_*^2}{g},$$

- No explicit dependence of z_0 on atmospheric stability;
- z_0 depends on the friction velocity u_*.

2. **Analytical method:**

$$z_0 = \frac{z_R}{exp\left(\frac{\kappa U(z_R)}{u_*}+\psi\right)},$$

z_0 is a function of physical parameters of the atmosphere:

- atmospheric stability via the stability function ψ;
- friction velocity u_*.

3. **Statistical method**

$$z_0 = \frac{U(z_R)\{\sum[\ln(z_i)]^2-\ln(z_R)\sum\ln(z_i)\}-\ln(z_i)\sum\left[U_i\ln\left(\frac{z_i}{z_R}\right)\right]}{U(z_R)\sum\ln(z_i)-\sum\left[U_i\ln\left(\frac{z_i}{z_R}\right)\right]-NU(z_R ln(z_R))},$$

- A purely mathematical method [3].
- The equation for z_0 is derived by using the least square error approach.
- It effectively incorporates the impact of stability, friction velocity, and surface currents using the least-squares approach.

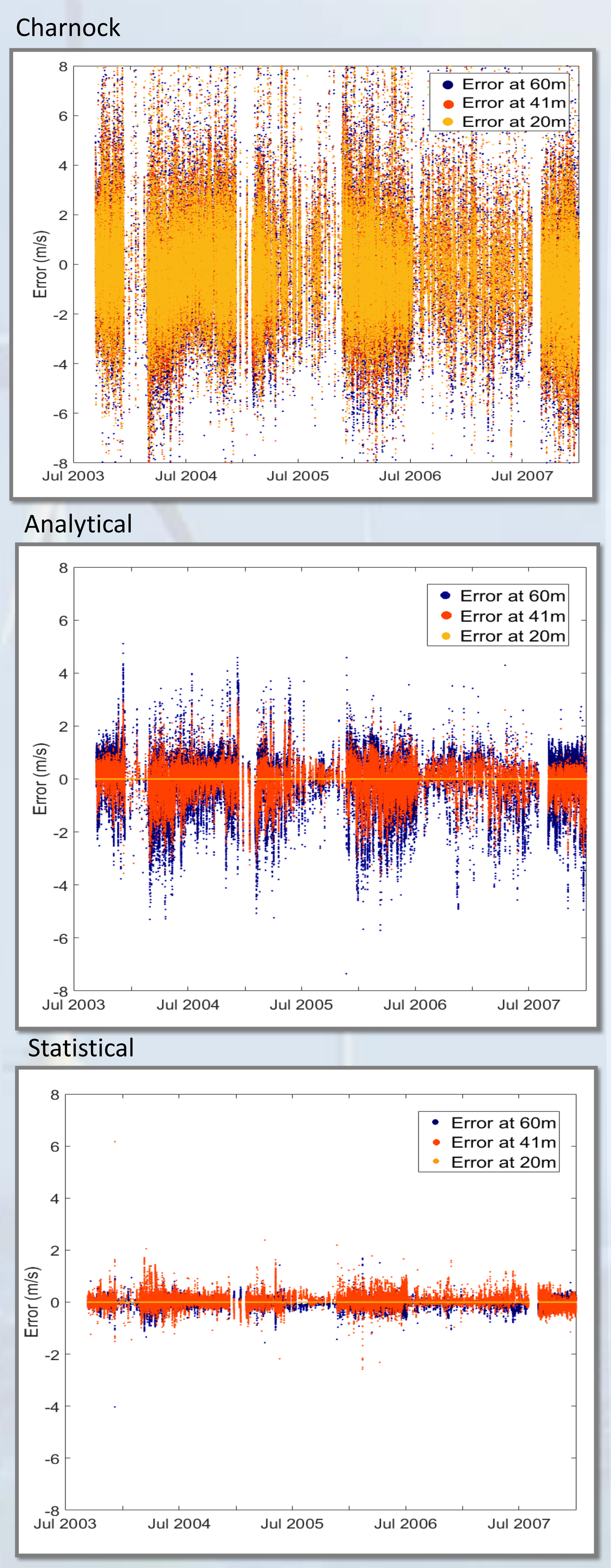

Figure 4, Error resulting from three methods at 20, 41 and 60 m.

The wind speed at higher elevations can be fit to one of two forms of the log-law equation:

$$U(z) = \frac{u_*}{\kappa}\left[\log\left(\frac{z}{z_0}\right)-\psi\right] \quad \text{or} \quad U(z) = U(z_R)\times\left(\log\left(\frac{z}{z_0}\right)/\log\left(\frac{z_R}{z_0}\right)\right)$$

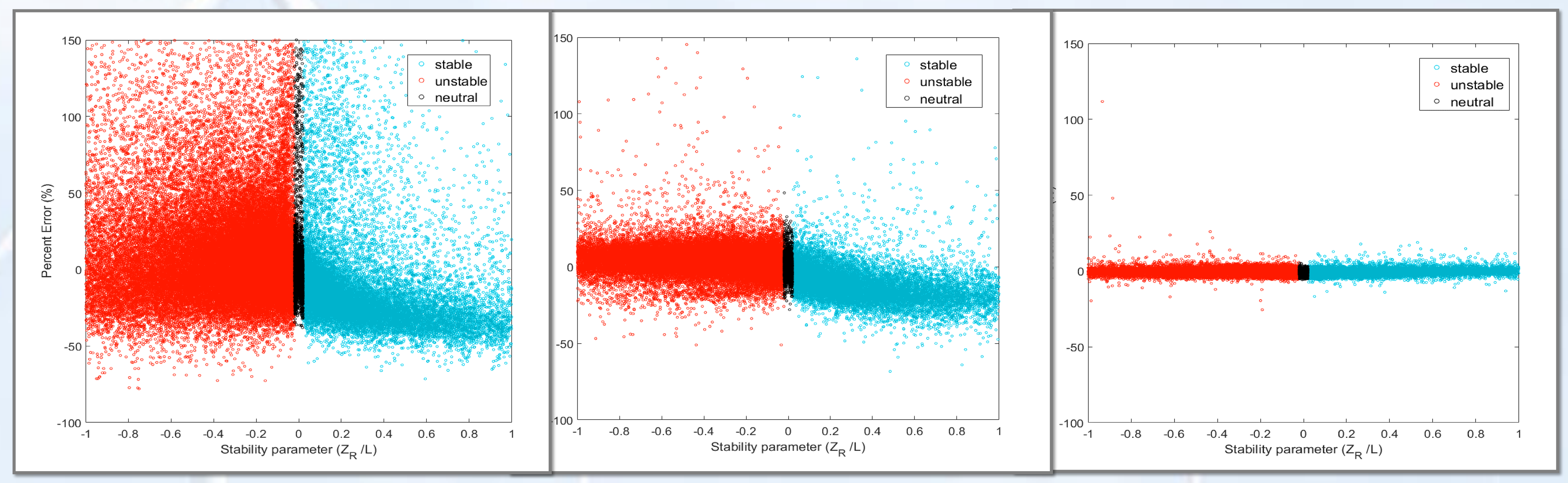

Figure 3. Prediction error versus the stability parameter at 60 m for the (a) Charnock (b) analytical and (c) statistical methods.

RESULTS:

- A correlation between the calculated and observed wind speeds is presented for each method (Fig. 1).
- A comprehensive error analysis for each of the three methods is provided.
- A recommended regional z_0 value of 6×10^{-3} m [3].
- A recommendation to use the median z_0 value rather than the mean, as it is a more robust statistic.
- Despite unrealistic z_0 values at times, the statistical method has better results than either of the other two methods.
- The unrealistic z_0 values obtained from the statistical method are caused by non-monotonic wind speed profiles, which occur approximately 41% of the time.
- Charnock and analytical methods underestimate the wind speeds in more stable cases (Fig. 3).
- The wider scatter in unstable cases indicates higher uncertainty by the Charnock method in unstable conditions that are dominant in the offshore (Fig. 3).

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