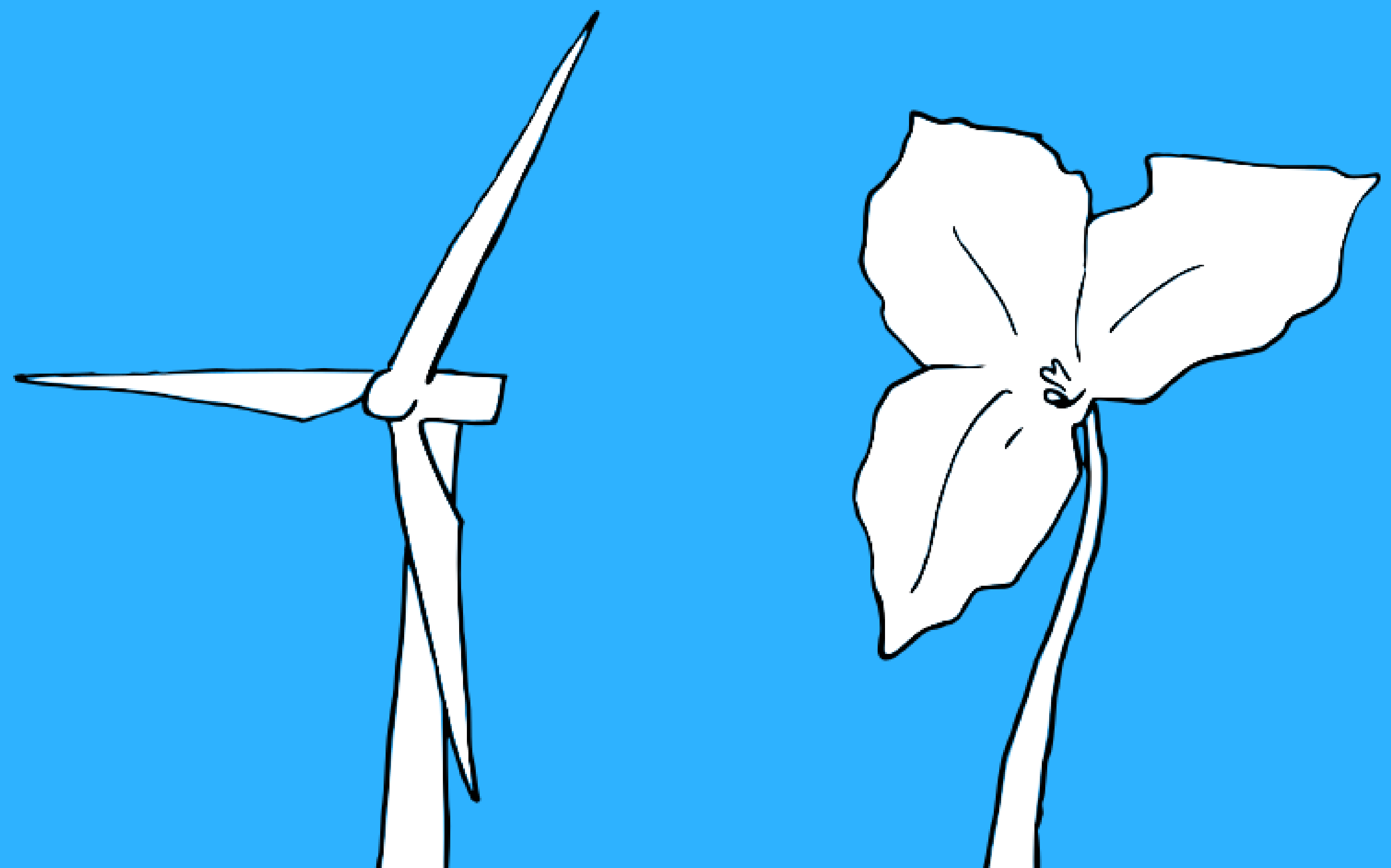
XIANGYUE WANG

WIND TURBINES WAKE LOSS MODEL

Rutgers University, April 2021



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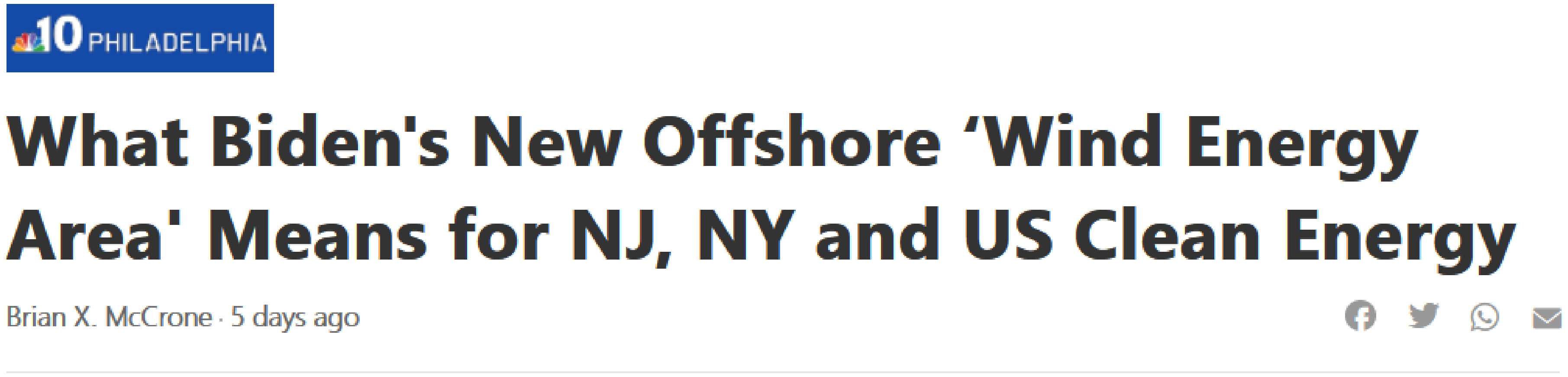
INTRODUCTION

AP ASSOCIATED PRESS

Biden boosts offshore wind energy, wants to power 10M homes

By MATTHEW DALY, Associated Press 5 days ago



10 PHILADELPHIA

What Biden's New Offshore 'Wind Energy Area' Means for NJ, NY and US Clean Energy

Brian X. McCrone · 5 days ago

The New York Times

Biden Administration Announces a Major Offshore Wind Plan

The White House said the program could create tens of thousands of new jobs while moving the country toward clean energy

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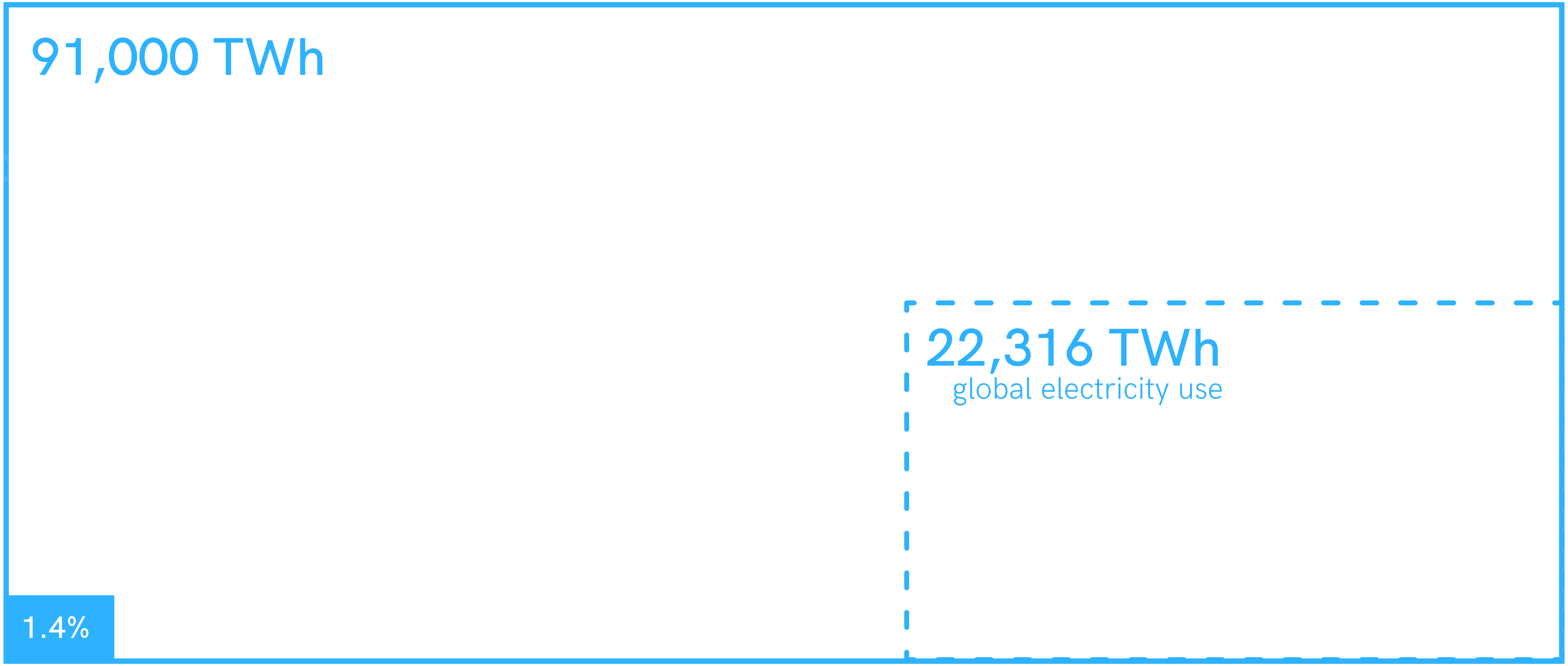
This kinetic energy ultimately dissipates through friction on land or water surfaces.

Through turbines and generators, we could convert this energy into electricity.

Accounting for areas unsuitable for wind turbine installations, we see great potential for energy generation.

Wind Annual Energy Generation Potential*



91,000 TWh

22,316 TWh
global electricity use

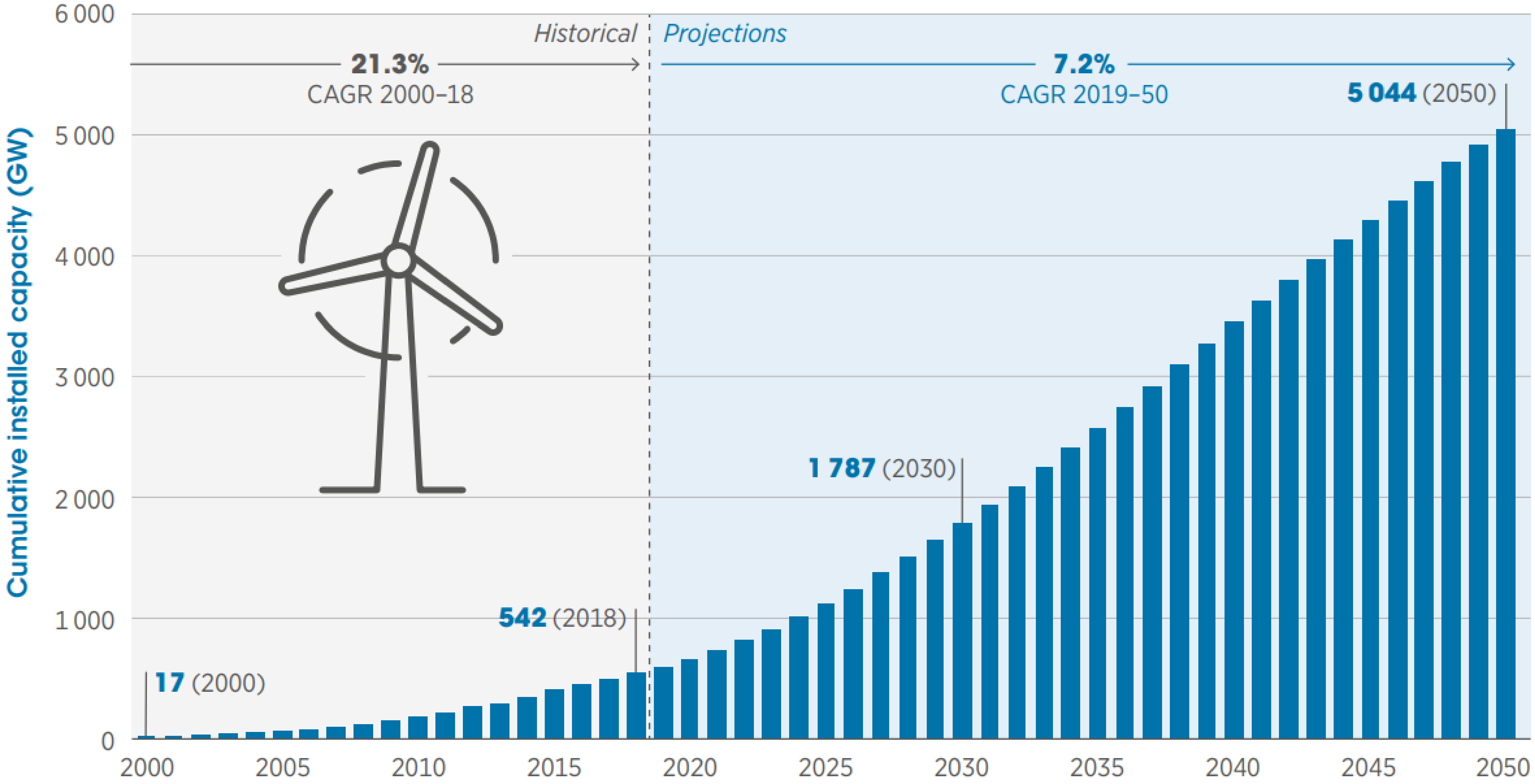
1.4%

current wind energy production

XI. LU
IEA

*assuming weather variability and wake loss.

Global Onshore Wind Capacity, present - 2050



Offshore Wind Capacity, 2018 and 2040

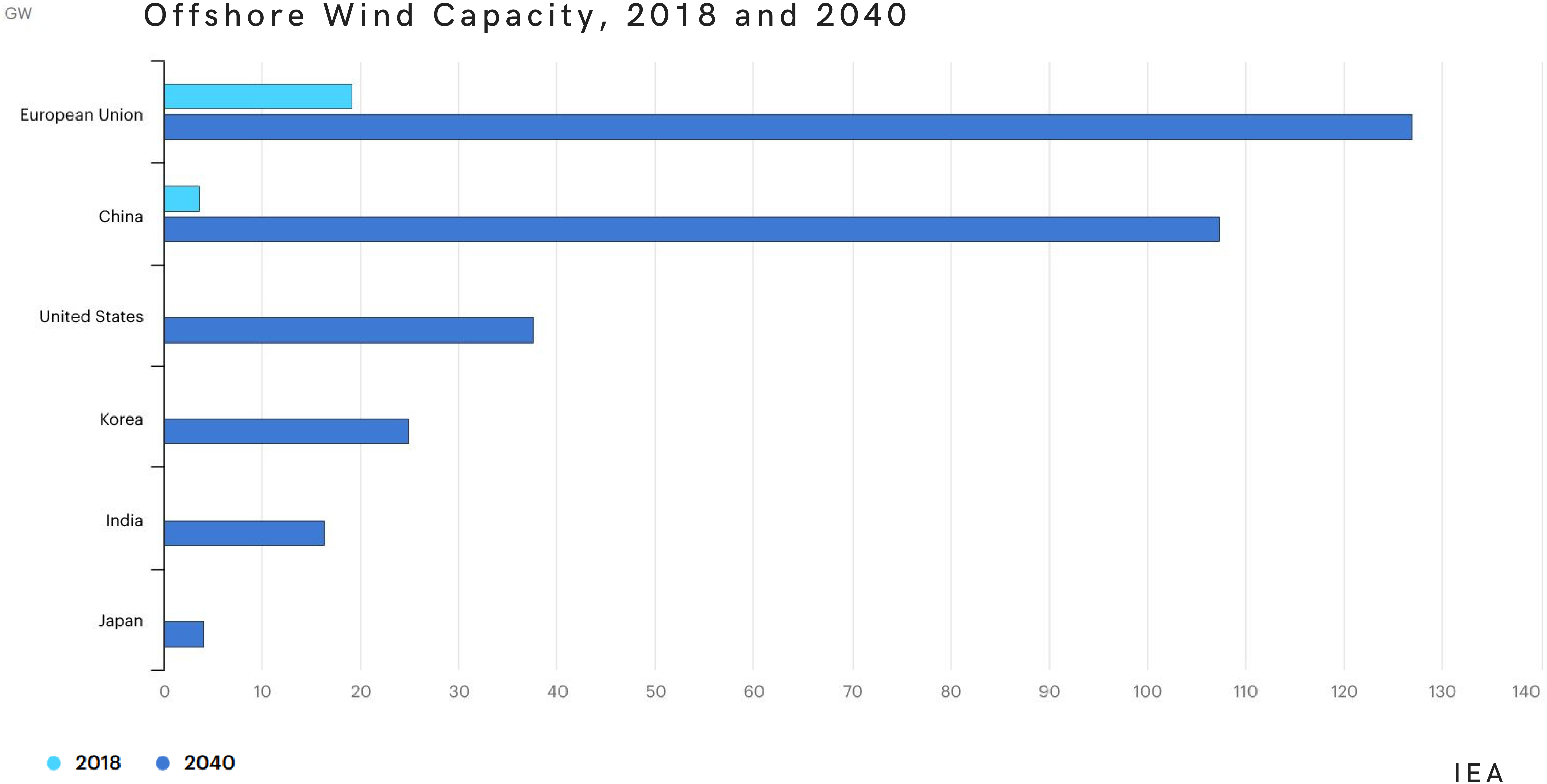
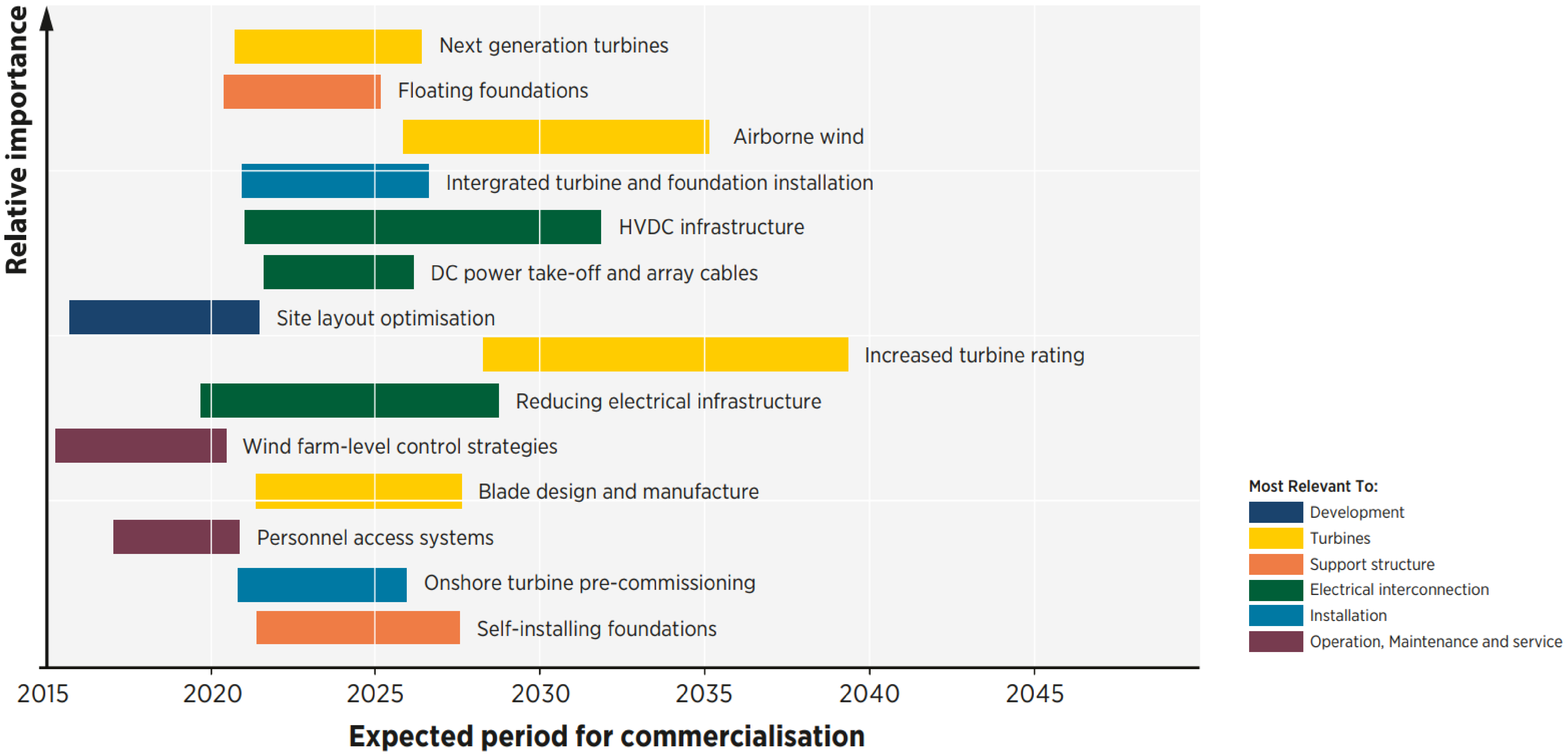


Figure 28: Anticipated timing and importance of innovations in offshore wind technology.



In a world with increasing reliance on wind energy, **precise forecast** of wind power production is crucial.

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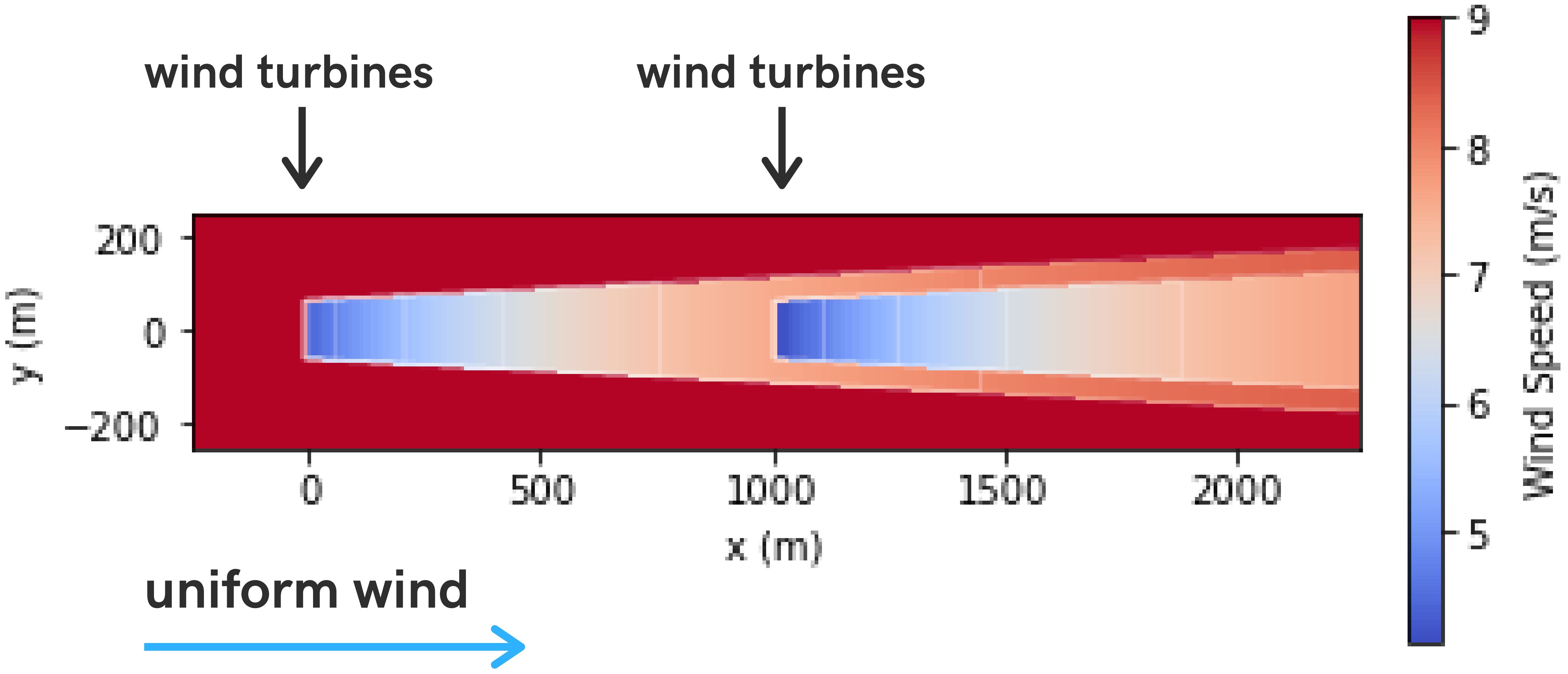
Wake: the cylinder of wind downstream from a wind turbine.



wind turbines

wind turbines

uniform wind

Wake loss reduces power generation by up to

30%

For wind farms, wake loss is one of the most significant sources of power loss.

Our aim is to efficiently and accurately model wake loss.

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Introduction

Wake Loss

Jensen Model

Benchmark Data

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There exist several types of wake loss models.

Geometric Model

Great choice for time-consuming optimization algorithms.

Jensen Model

Simple and efficient model that consistently provides accurate forecast.

Frandsen Model

Analytical model that applies the momentum equation and assumes self-similarity.

XA Model

Gaussian model that accurately predicts the shape of wake loss.

Larsen Model

Analytical model recommended by EWTS II for wake loading calculation.

BPA Model

Gaussian model that is effectively axis-symmetric.

We decide to investigate the Jensen Model.

The Jensen Model is a simply analytic wake model used widely in wake loss forecast.

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The Jensen Model is a simply analytic wake model used widely in wake loss forecast.

Although more sophisticated and accurate models exist, the Jensen Model remains relevant for its general accuracy and low computational cost.

The model assumes

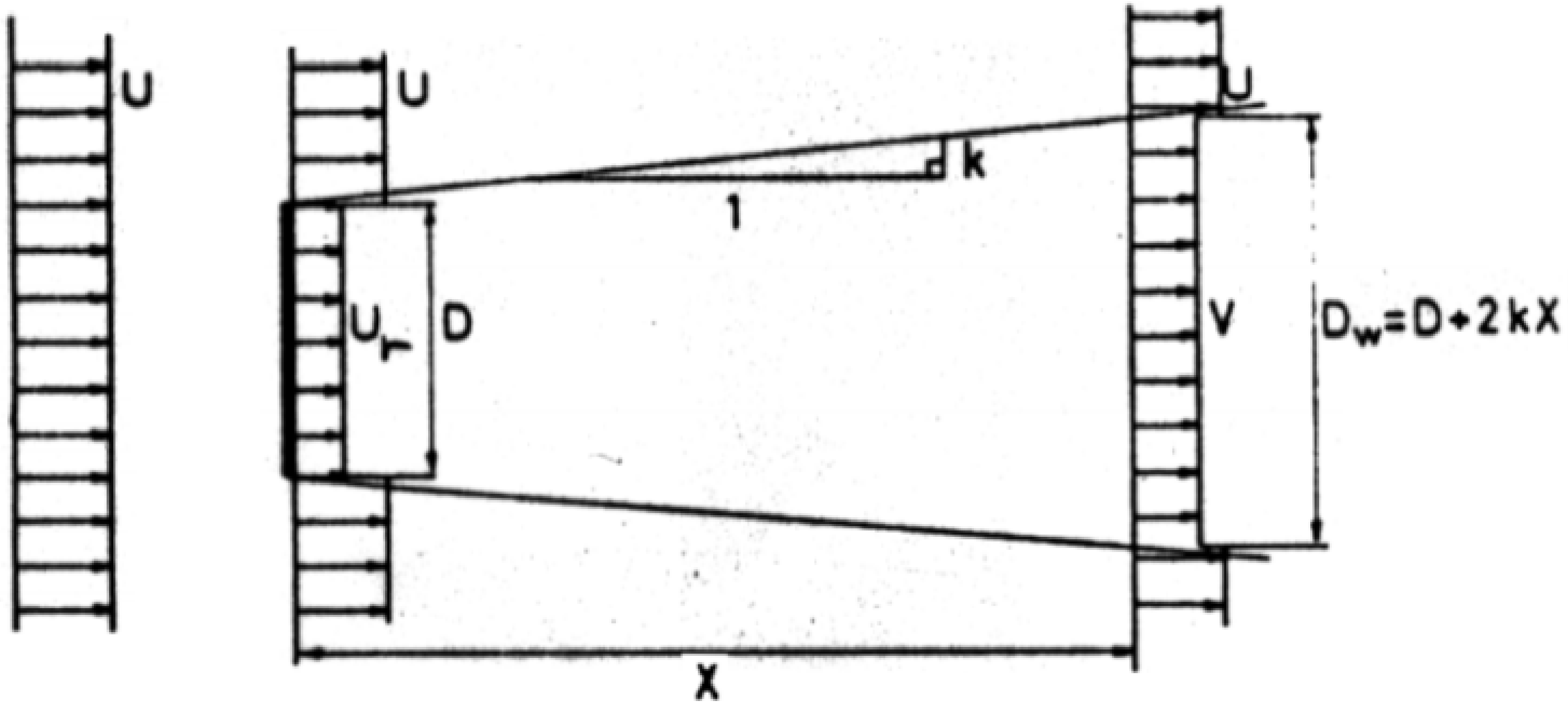
The rate of expansion, described by the wake decay parameter, k, is constant.

The model assumes

The rate of expansion, described by the wake decay parameter, k, is constant.

In other words, wind velocity is constant in the horizontal direction of the wake.

The end result is a top-hat wake distribution.



The Jensen Model is driven by the following equation

$$1 - \frac{U}{U_a} = \frac{1 - \sqrt{1 - C_t}}{(1 + \frac{kx}{r})^2}$$

x = distance from the upstream turbine

U = wind speed of interest

Ua = ambient wind speed

r = rotor radius

Ct = thrust coefficient

k = wake decay coefficient

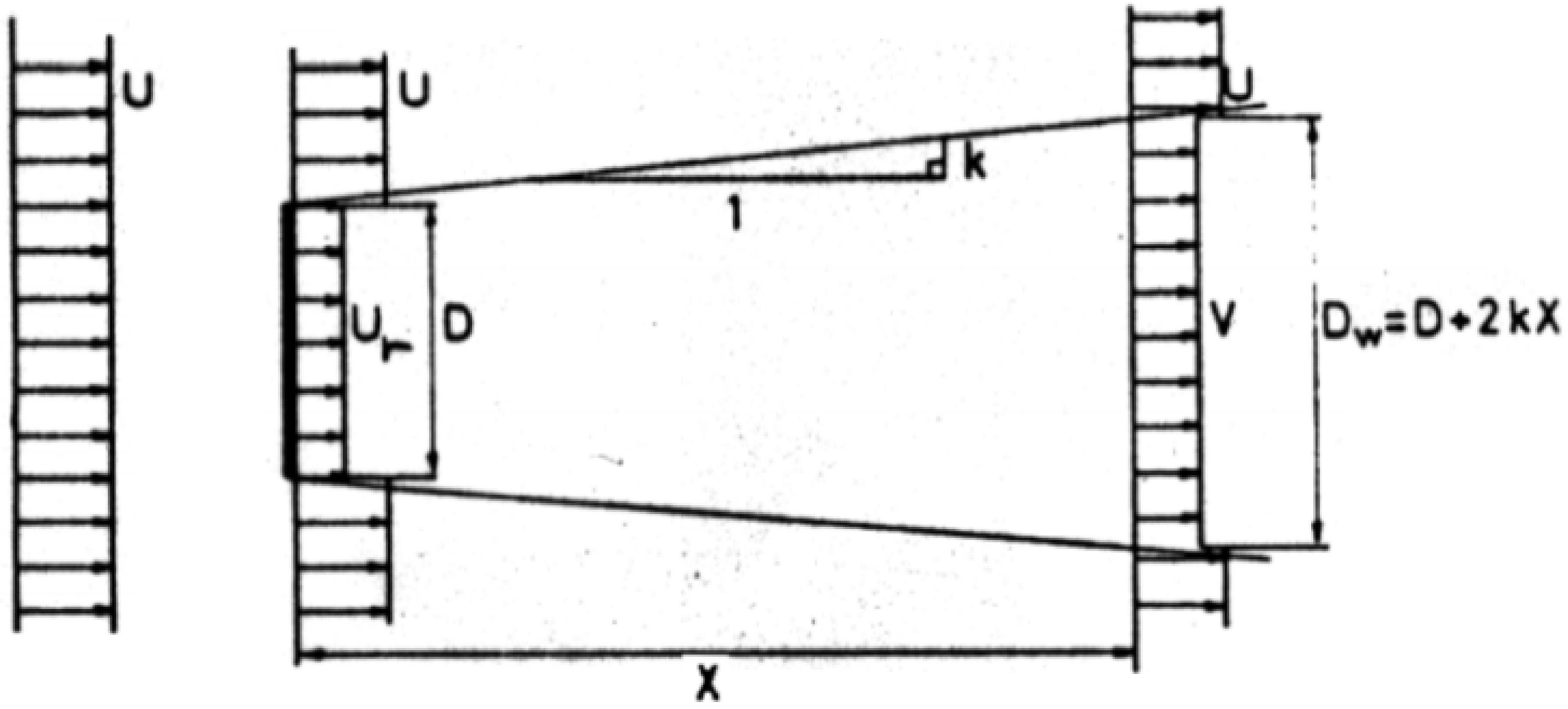
The thrust coefficient, Ct, depends on both wind speed and the characteristics of the wind turbines.

$$C_t = -\frac{T}{1/2\rho A U_a^2}$$

u1 = ambient wind speed
ρ = air density
A = rotor disk area
T = wind turbine thrust

Since the Jensen model assumes wake to be rectangular-shaped, we can approximate T as

$$T = -\rho A_w U(U_a - U)$$



Aw = wake area
D = rotor diameter

$$A_w = 1/2x[D + (D + 2kx)]$$

Therefore

$$C_t = \frac{Ux(U_a - U)(2D + 2kx)}{1/4D^2\pi U_a^2}$$

$$1 - \frac{U}{U_a} = \frac{1 - \sqrt{1 - C_t}}{(1 + \frac{kx}{r})^2}$$

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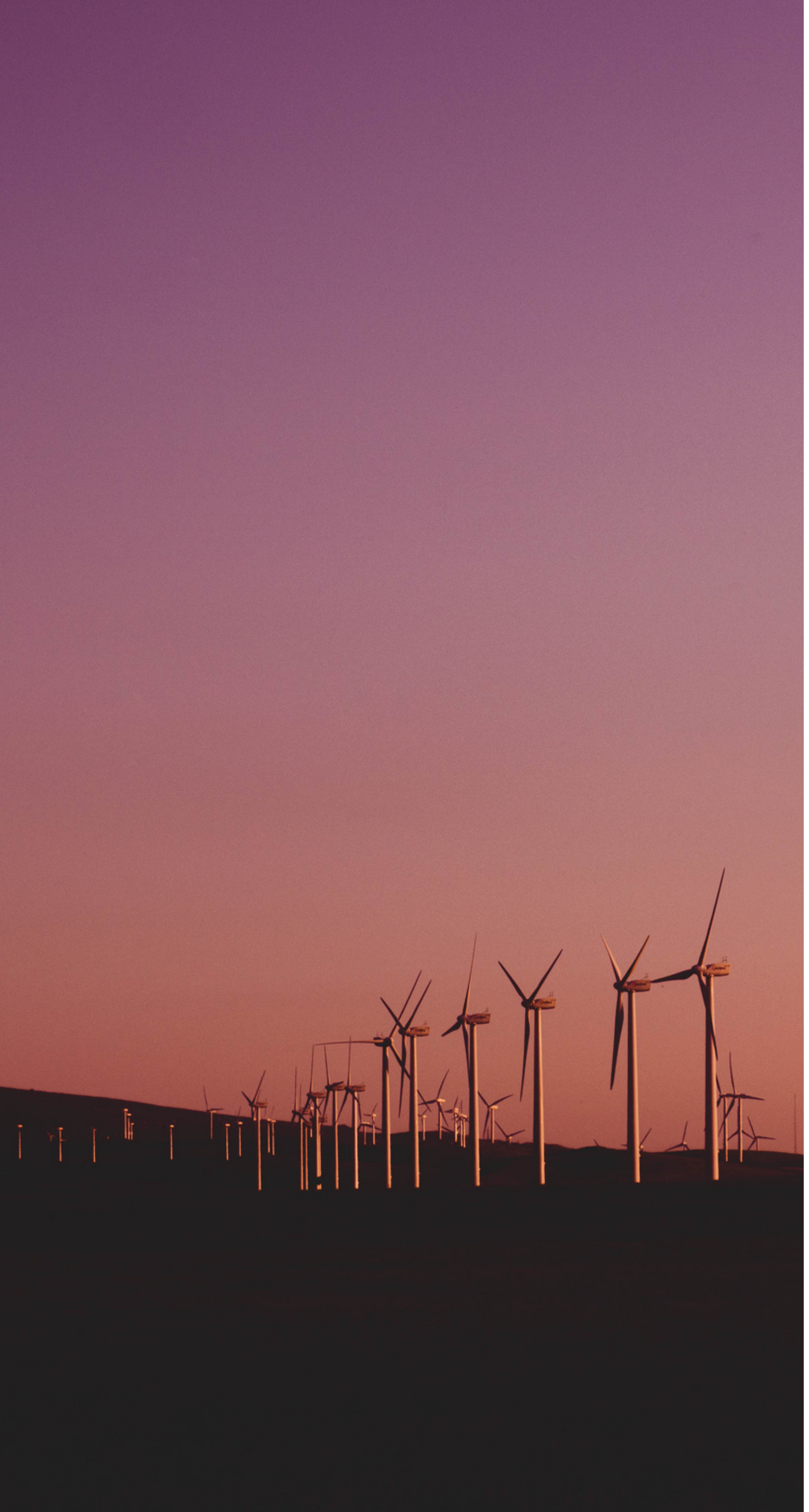
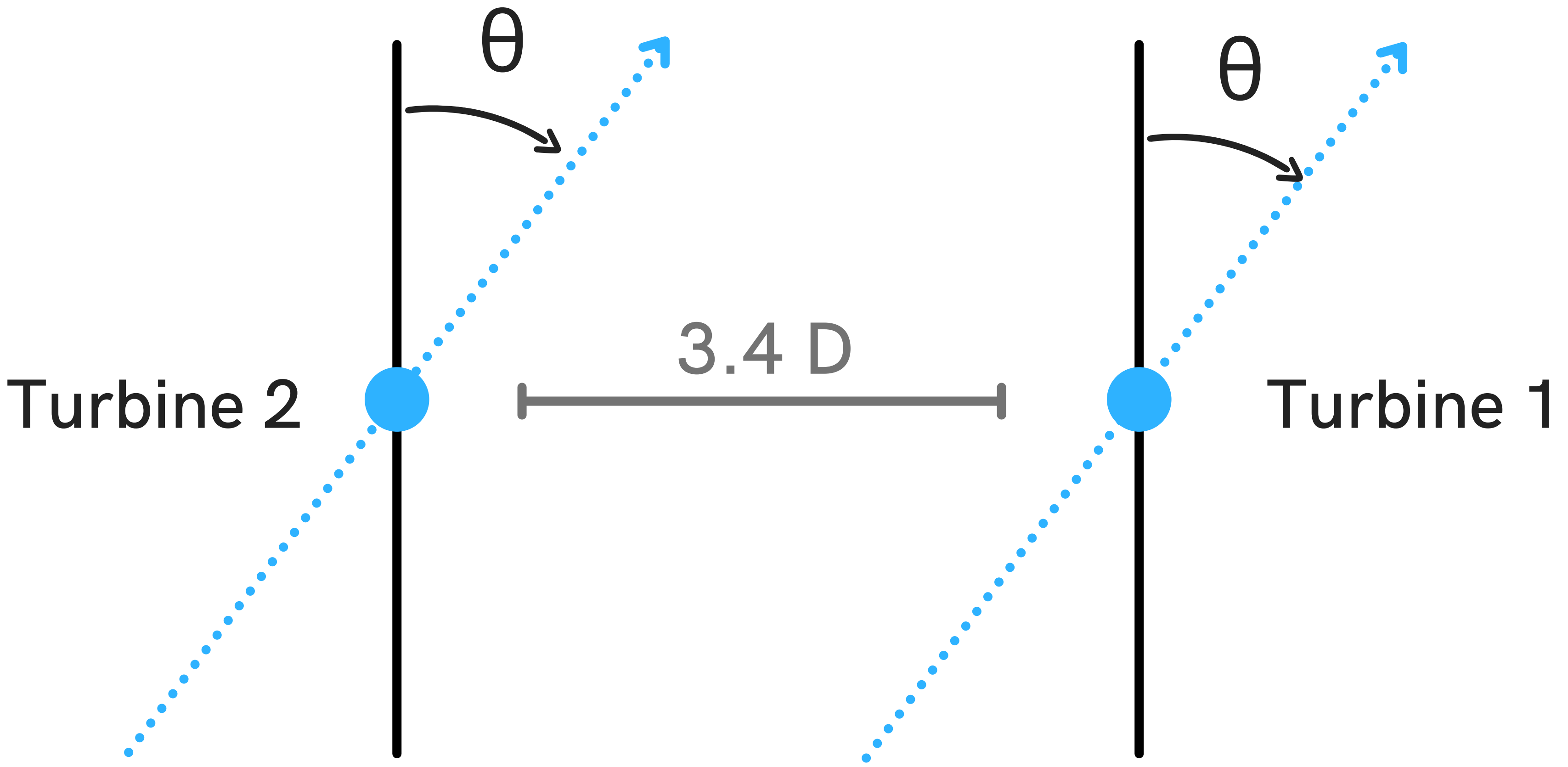
Using a set of benchmark data, we aim to evaluate the accuracy of a Jensen Model across a range of k values.



Our benchmark data come from an U.S. onshore wind farm with about 200 wind turbines.

The data are composed of wind speed, wind direction of a pair of wind turbines at 10 min intervals over one year.

The pair of turbines is chosen such that no other turbines are within 10D.

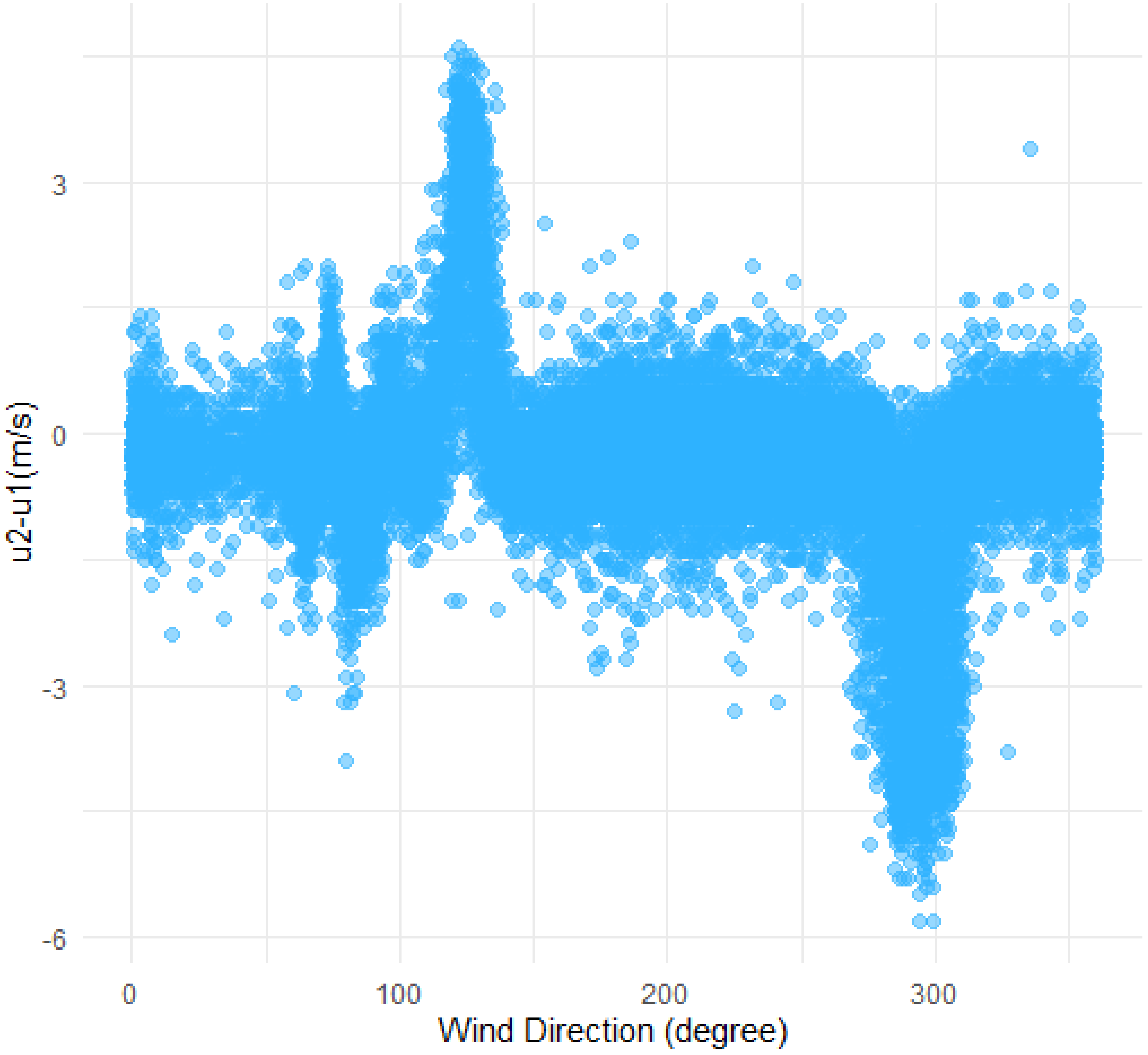


θ = wind direction (degree)
D = rotor diameter (90 m)

Wind Direction vs. Difference of wind speeds at two wind turbines

u1 = wind speed at wind turbine 1

u2 = wind speed at wind turbine 2



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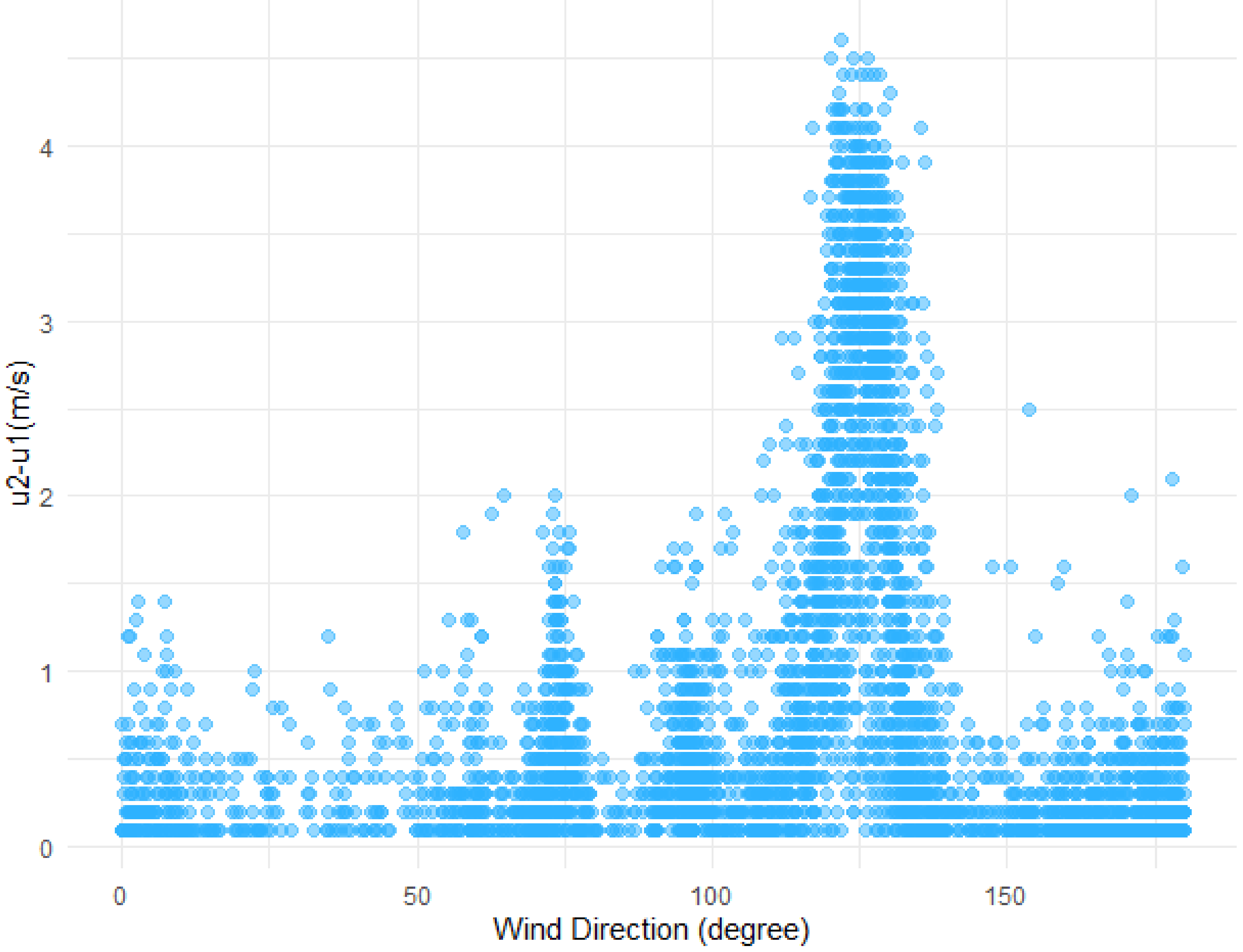
Wind Direction vs. Difference of wind speeds at two wind turbines

0<θ<180

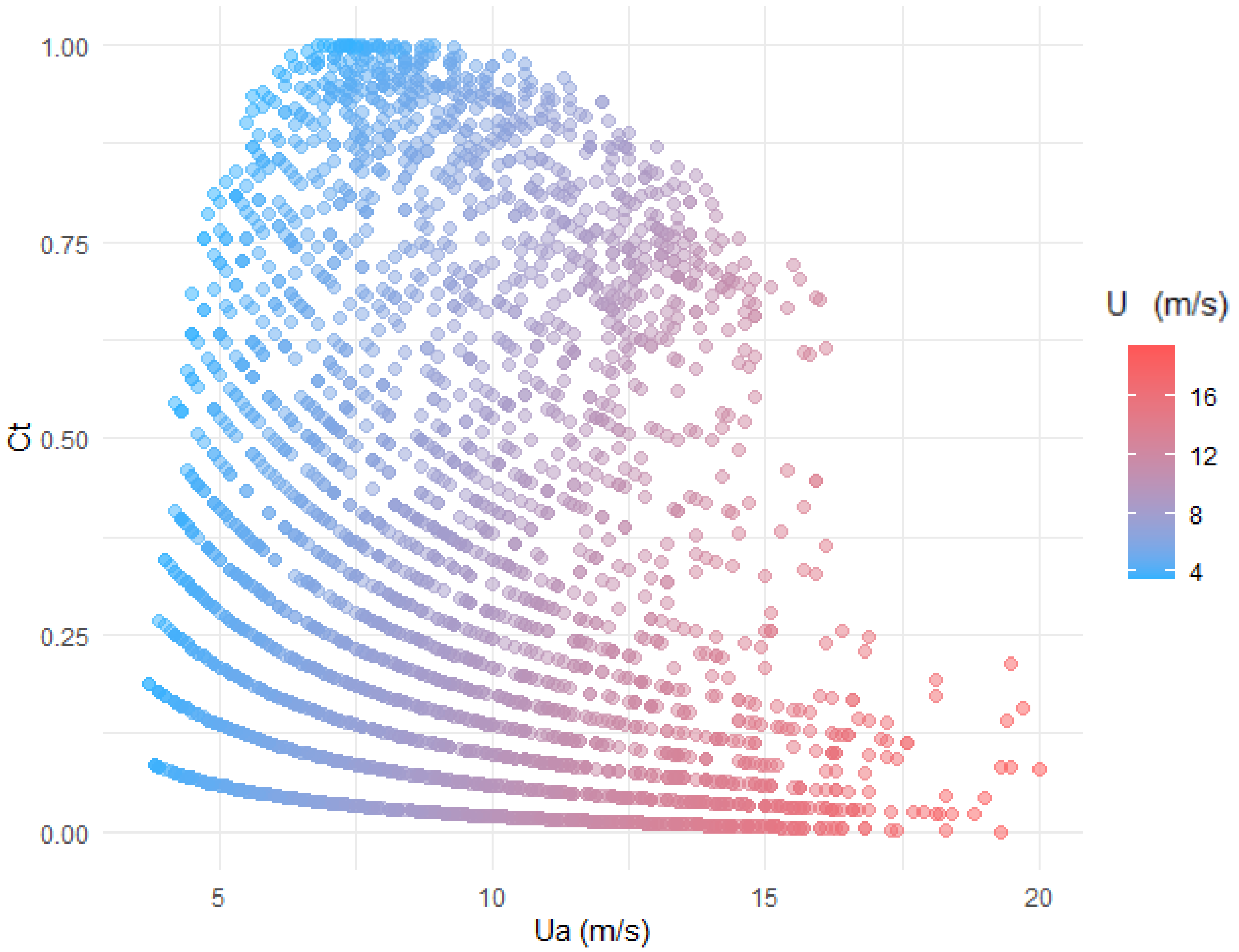
V2 - V1 >0



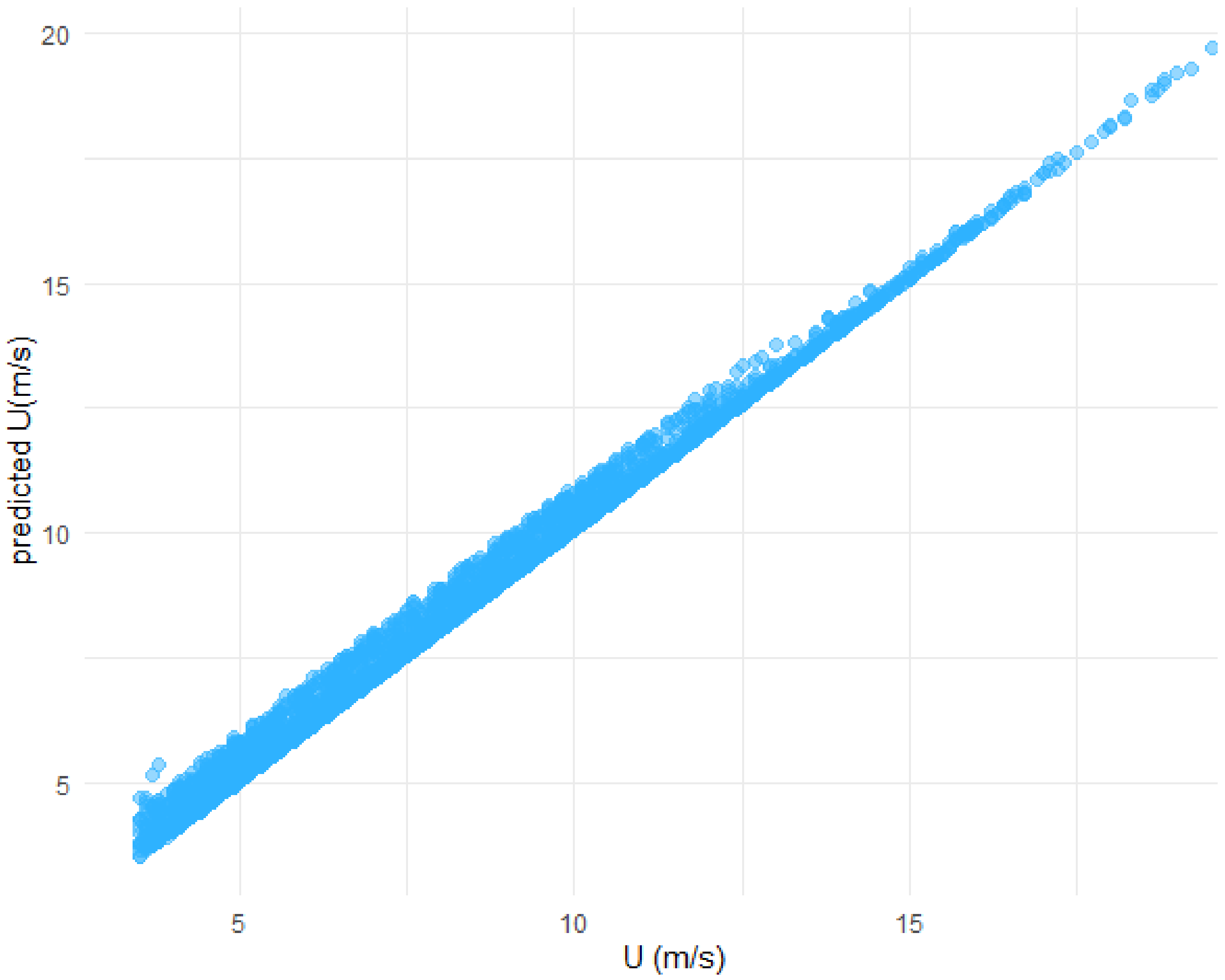
Ambient Wind Speed (Ua) vs. Thrust Coefficent (Ct)

with k = 0.06

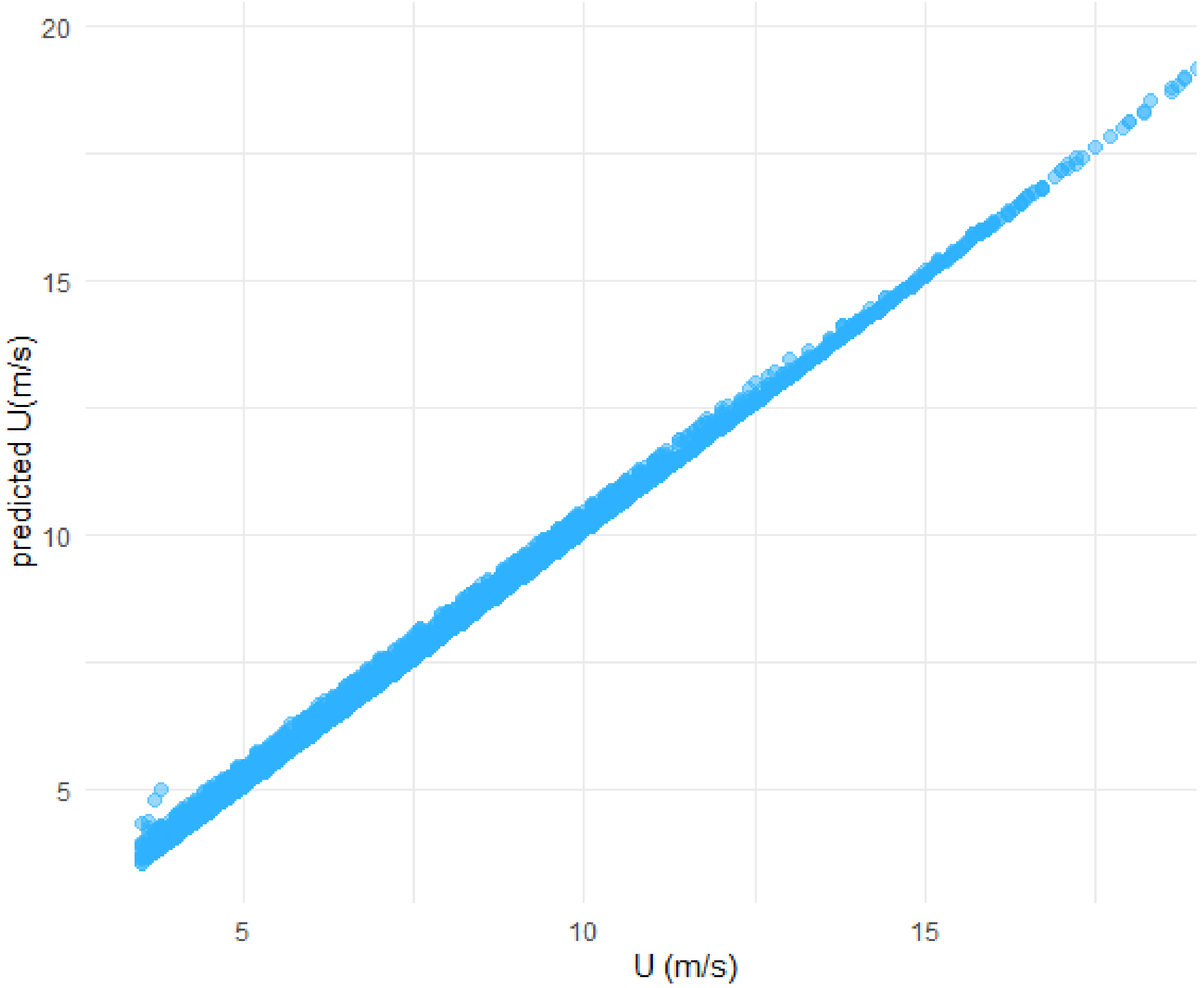
0<θ<180



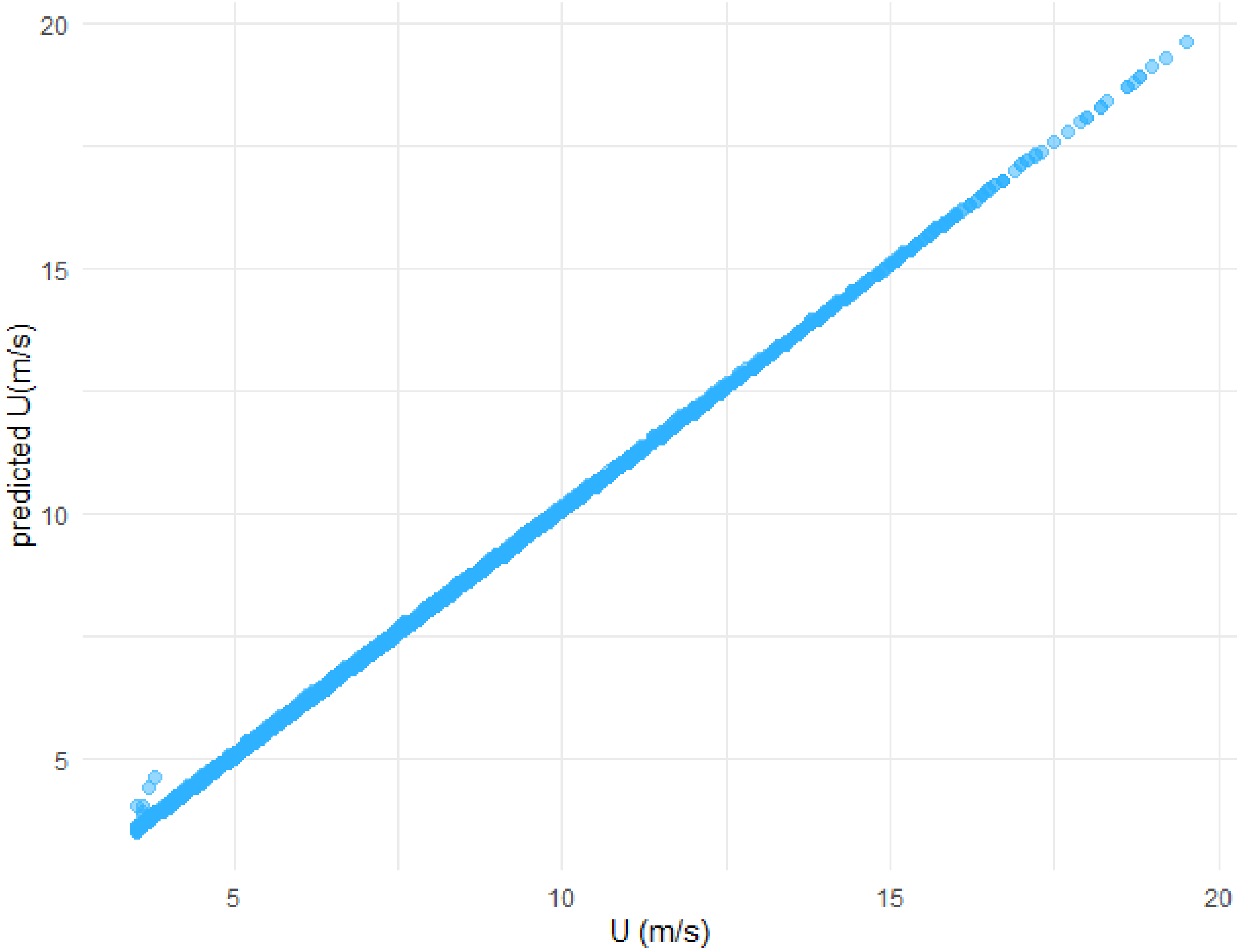
Wind Speed vs Predicted Wind Speed Across k (0 to 180 degrees)



k=0.090, RMSD = 0.371

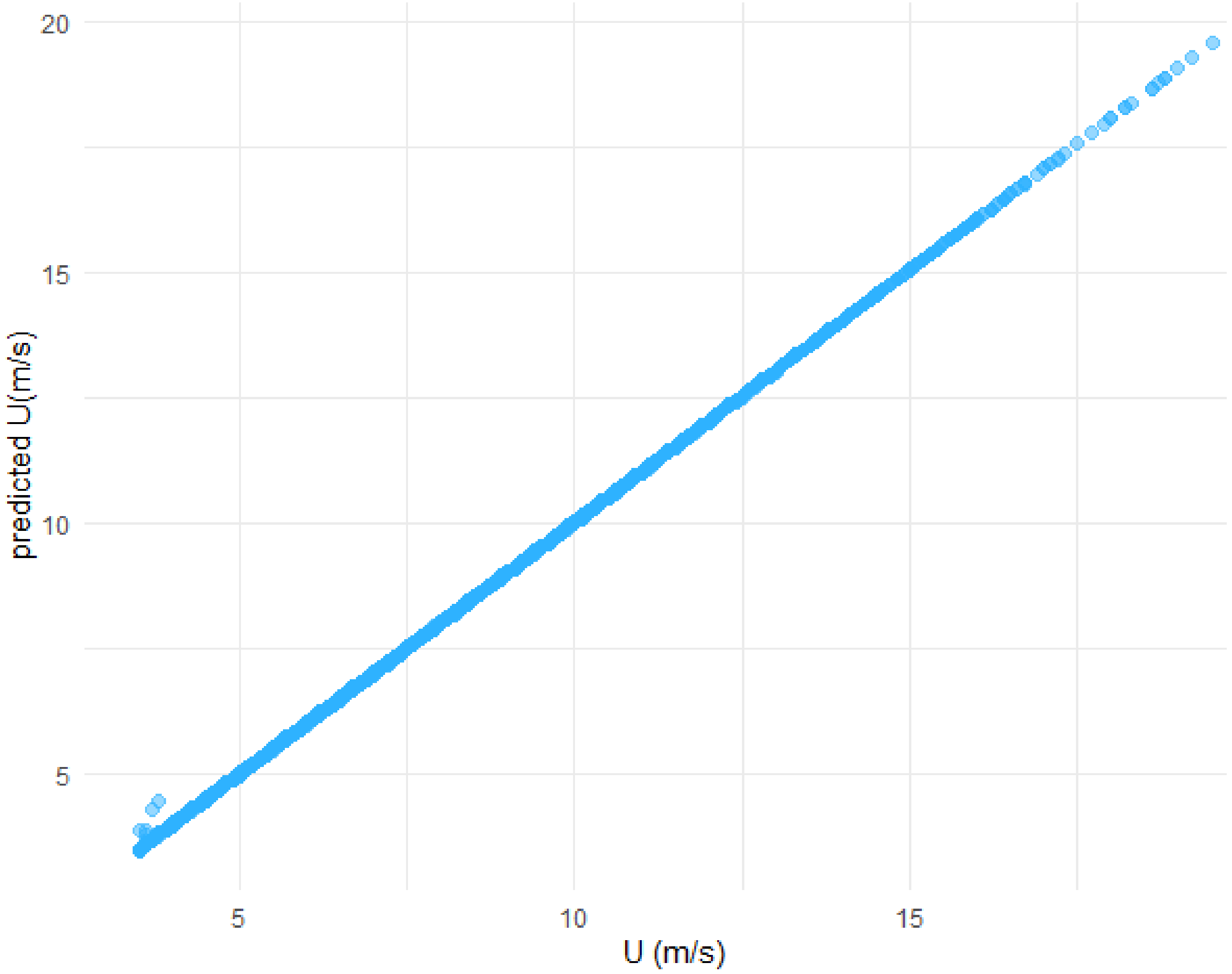


k=0.075, RMSD = 0.211

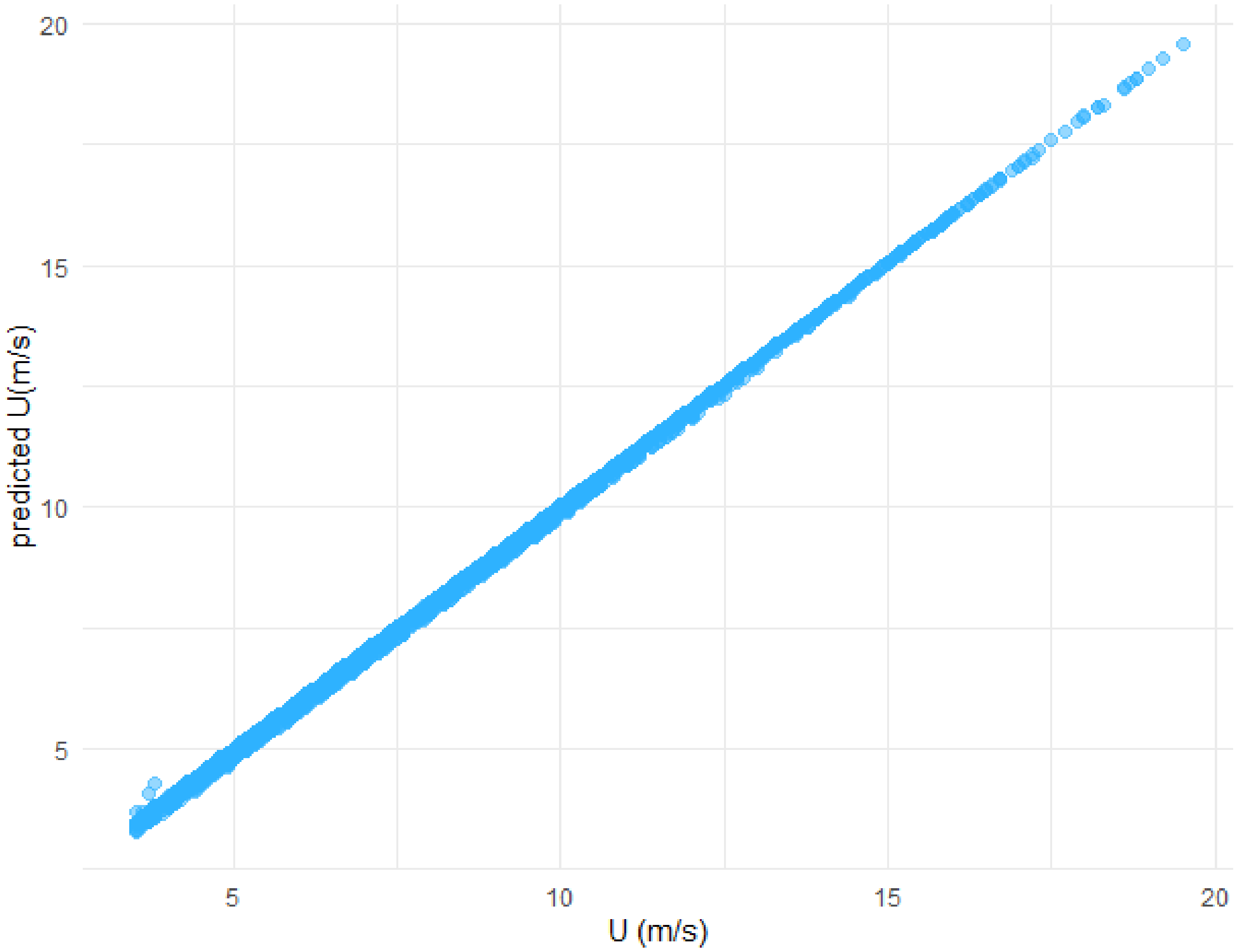


k=0.065, RMSD = 0.088

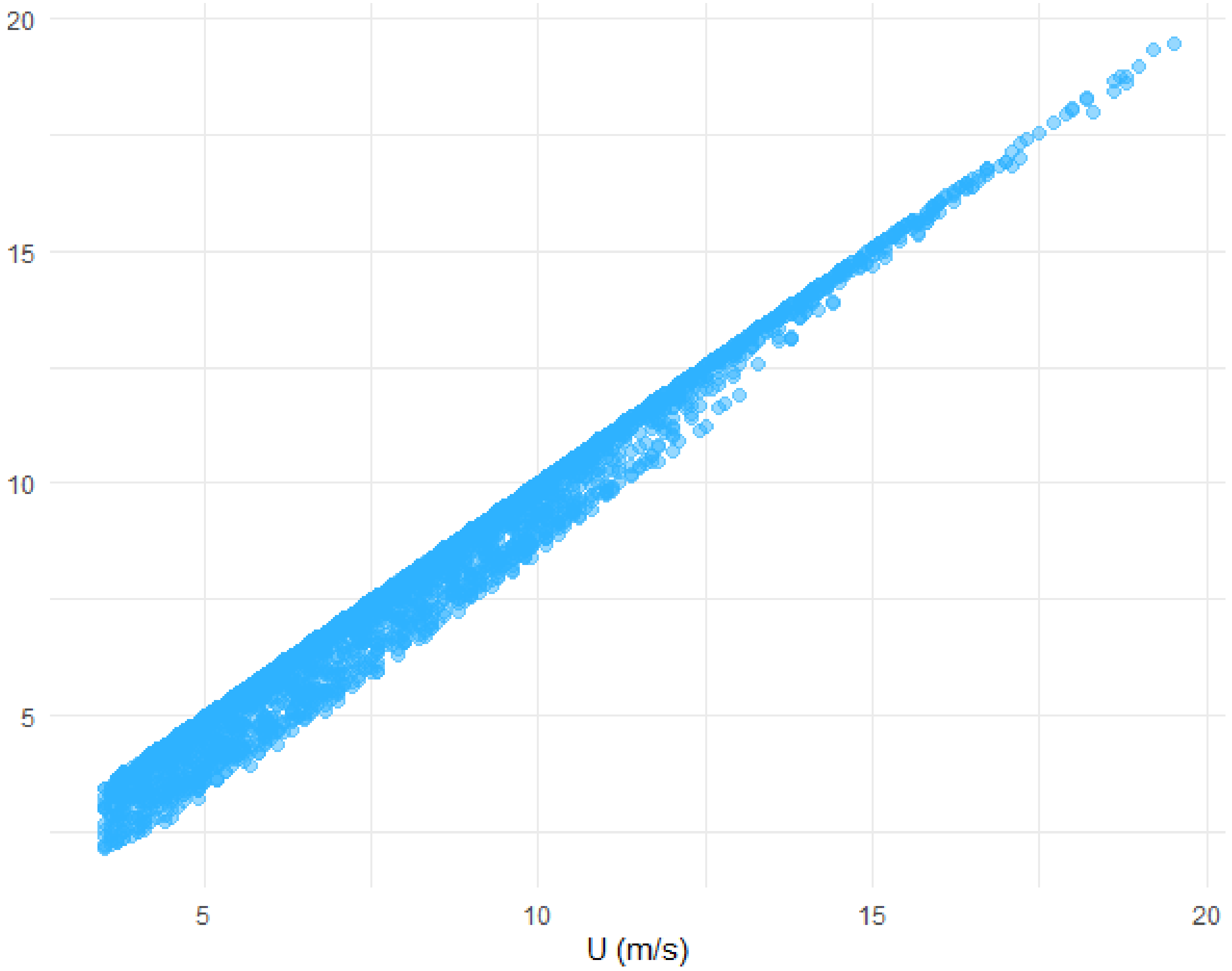
Wind Speed vs Predicted Wind Speed Across k (0 to 180 degrees cont.)



k=0.060, RMSD = 0.042



k=0.055, RMSD = 0.082



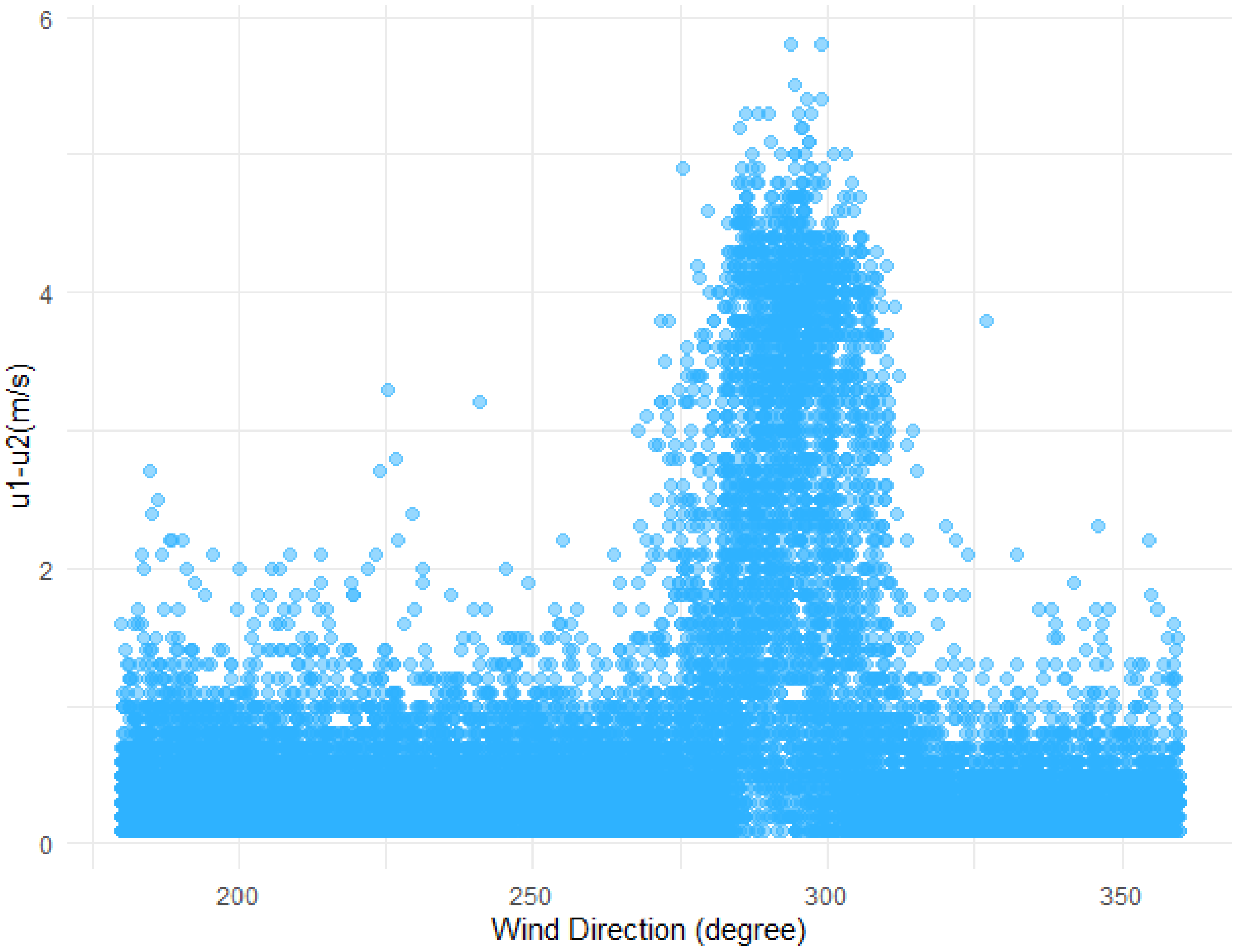
k=0.030, RMSD = 0.559

RESULT

Wind Direction vs. Difference of wind speeds at two wind turbines

180<θ<360

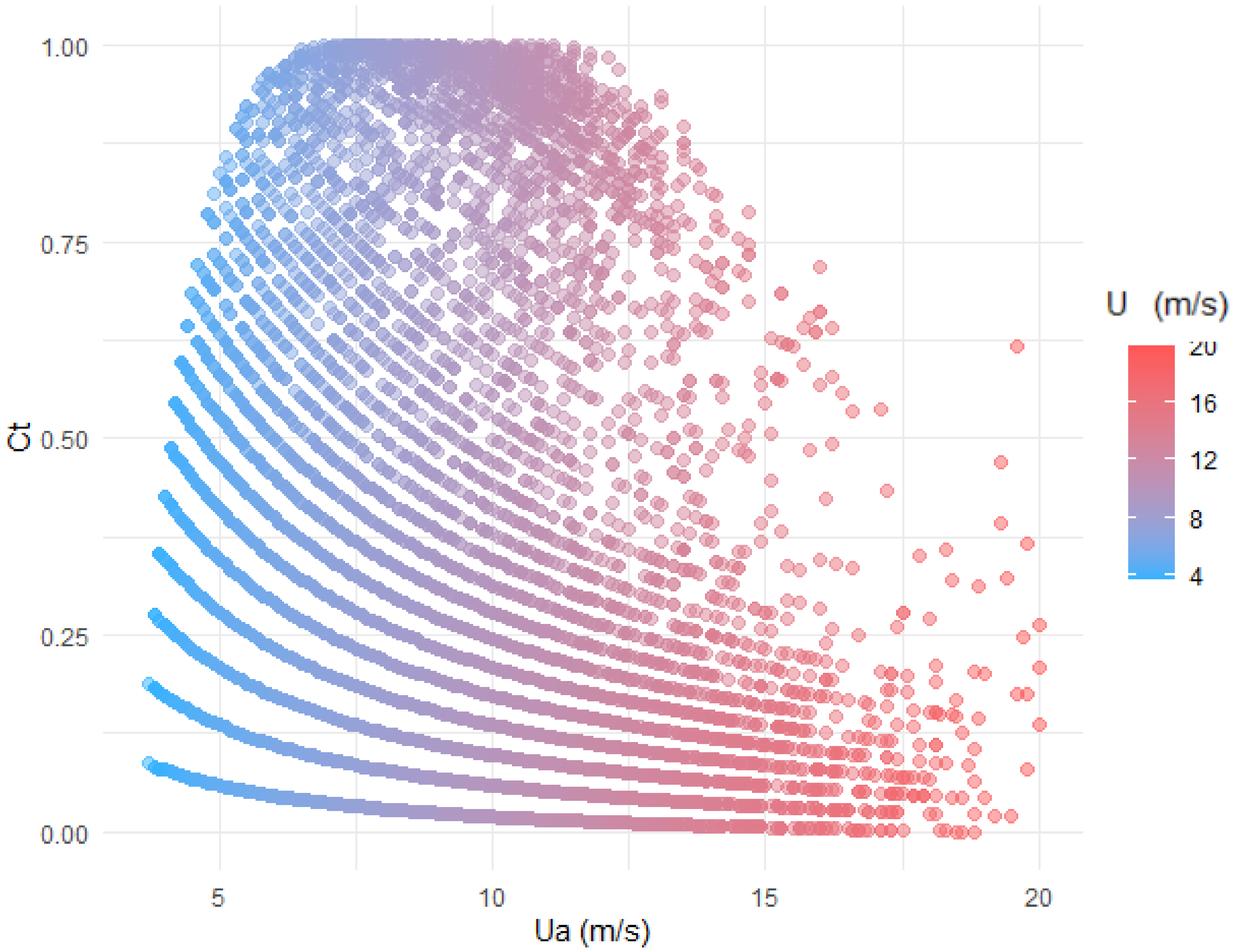
V1 - V2 >0



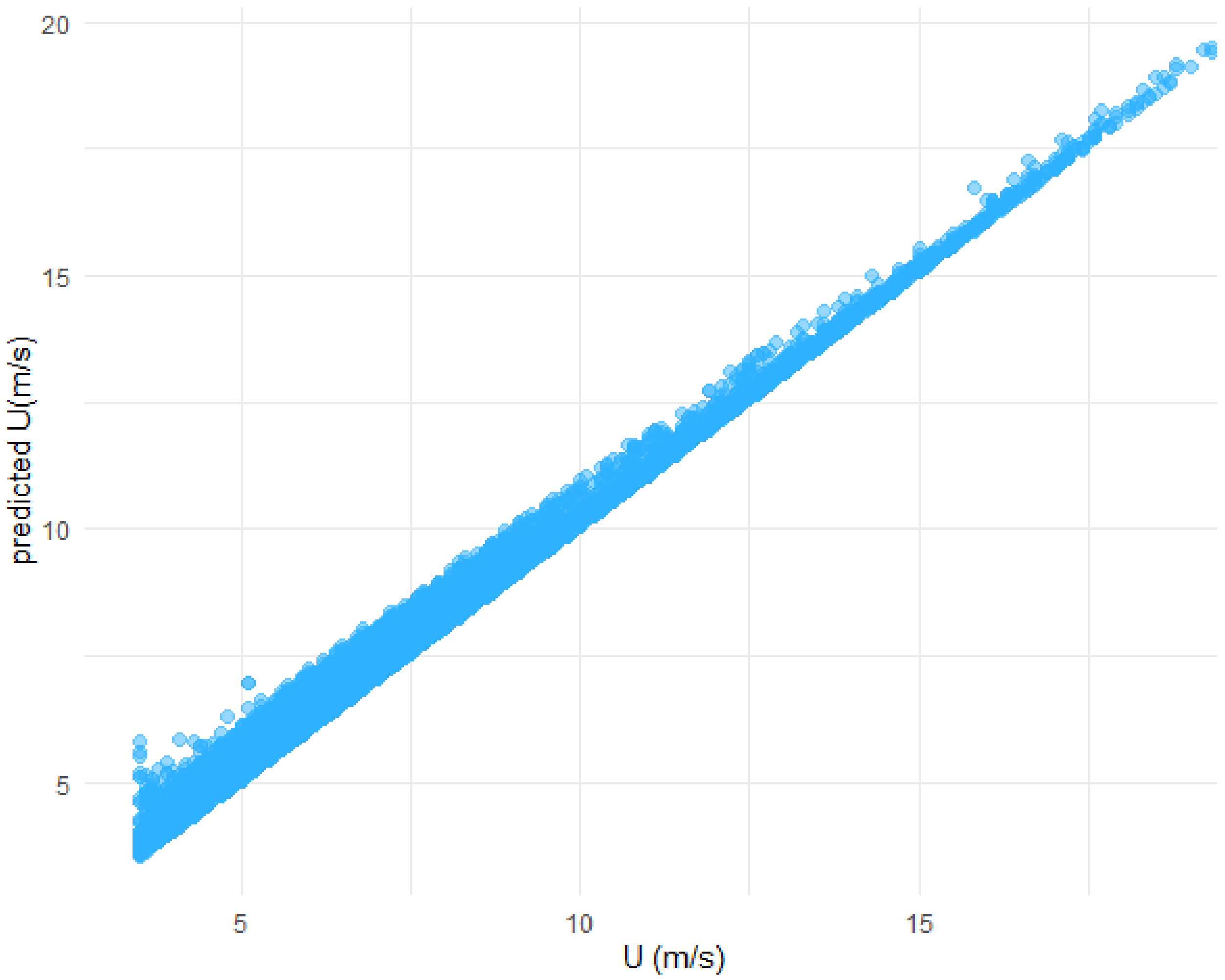
Ambient Wind Speed (Ua) vs. Thrust Coefficent (Ct)

with k = 0.06

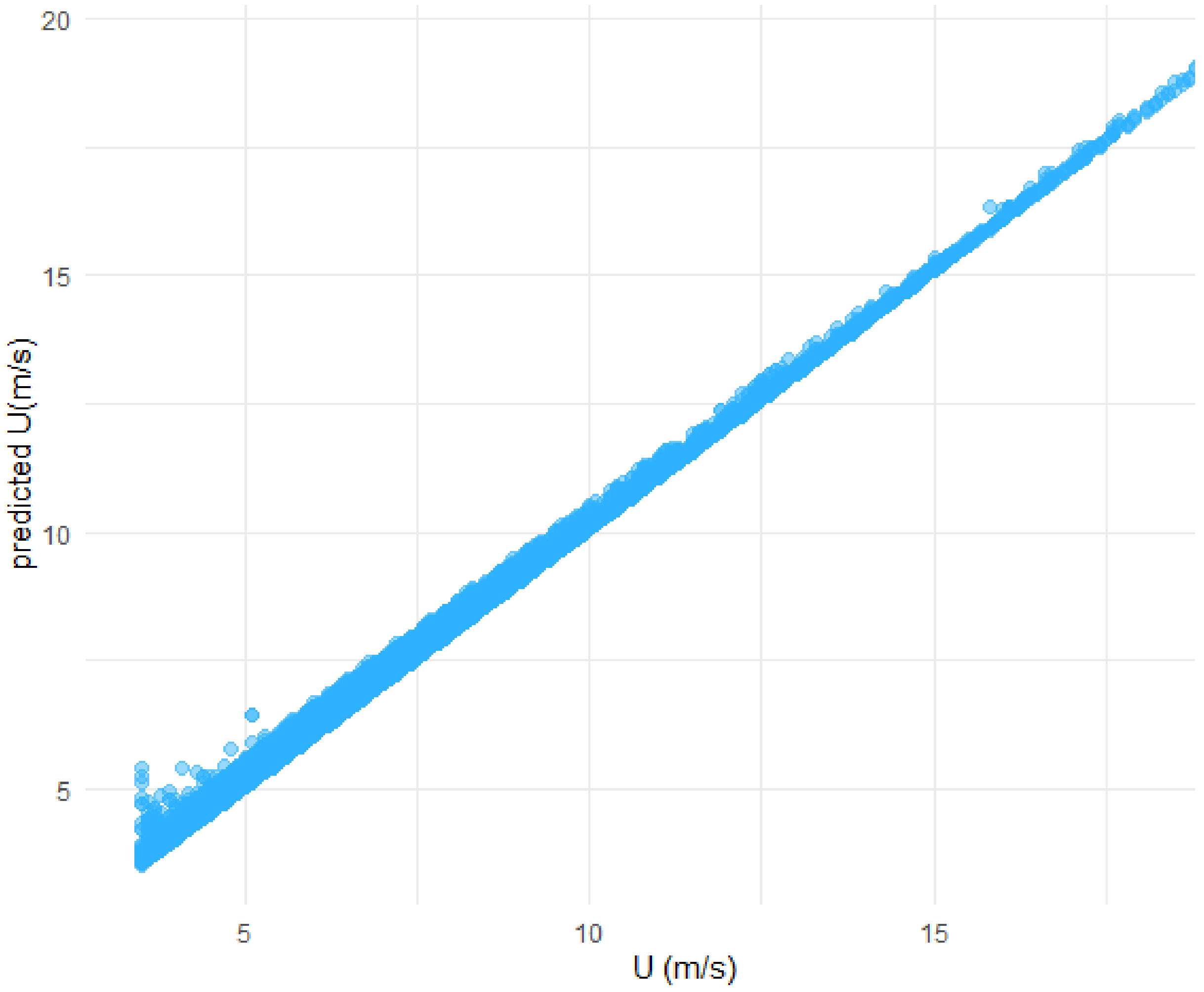
180<θ<360



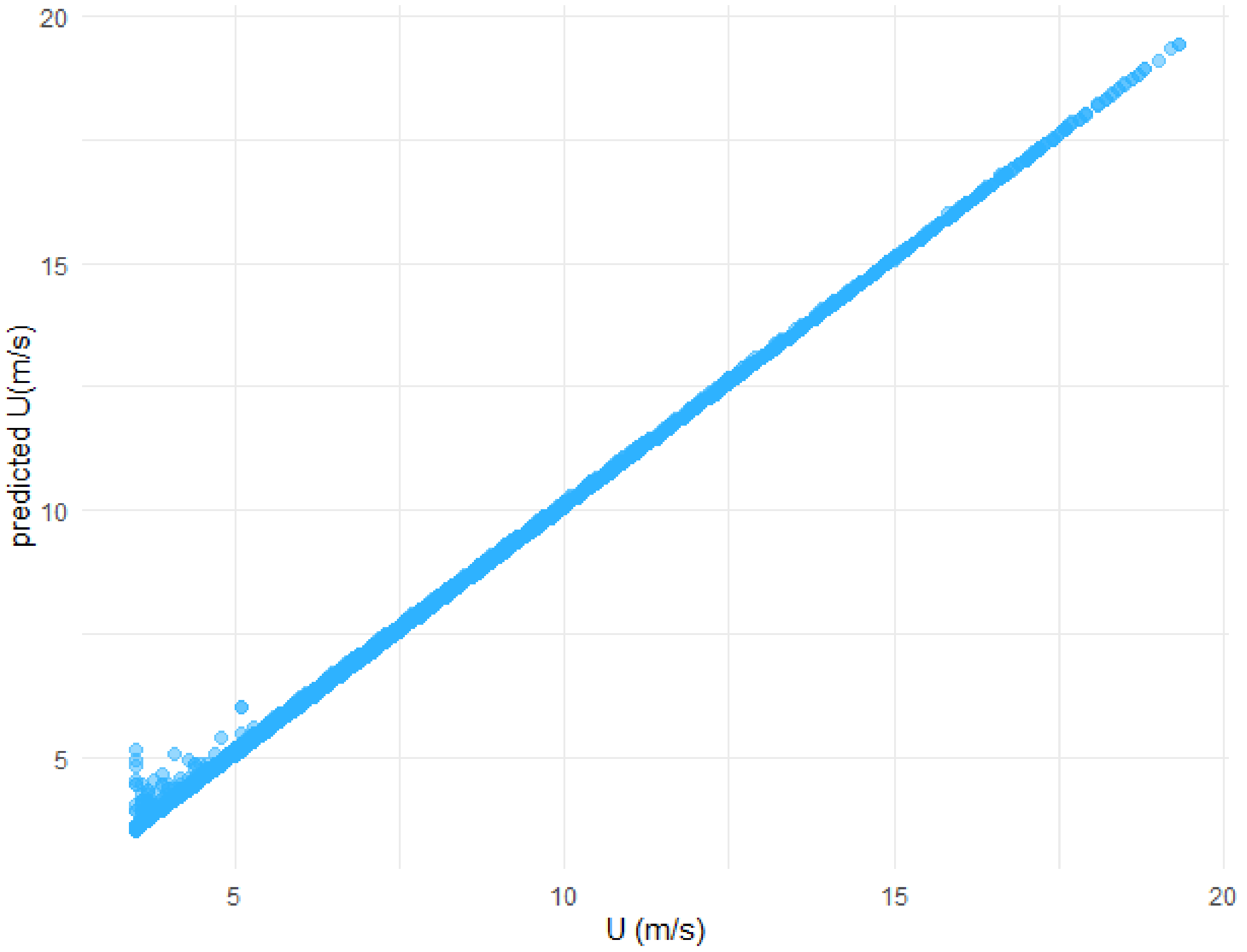
Wind Speed vs Predicted Wind Speed Across k (180 to 360 degrees)



k=0.090, RMSD = 0.310

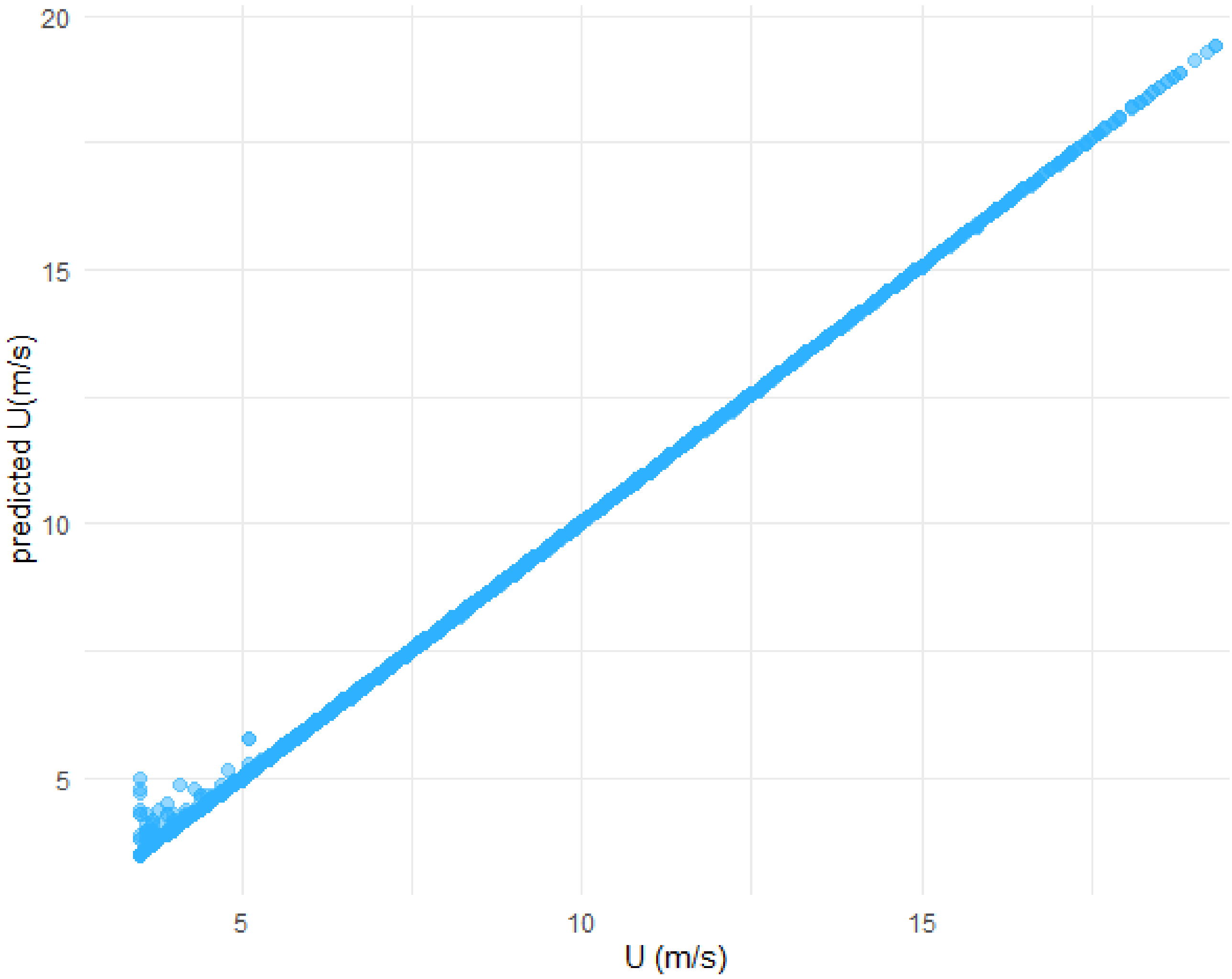


k=0.075, RMSD = 0.179

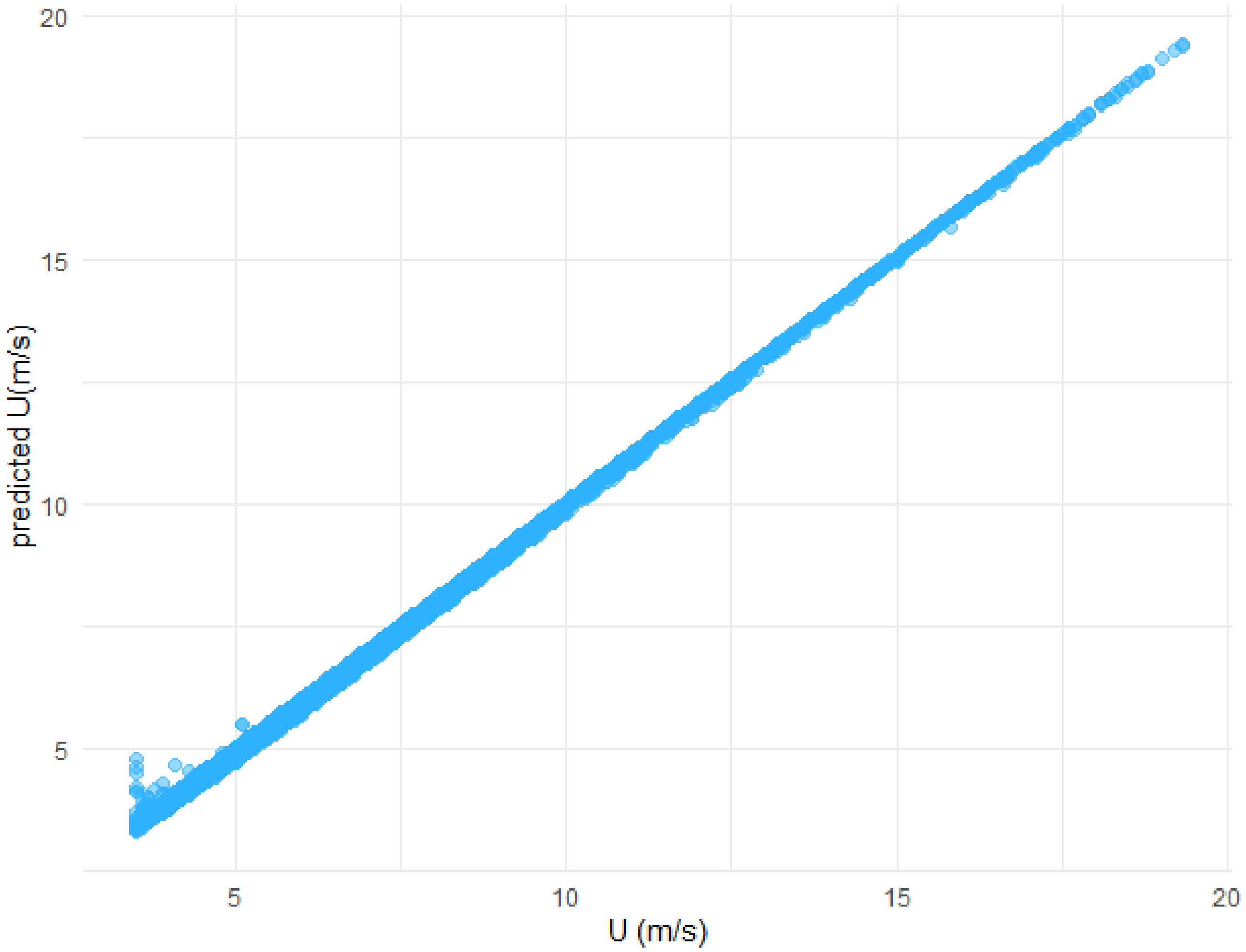


k=0.065, RMSD = 0.083

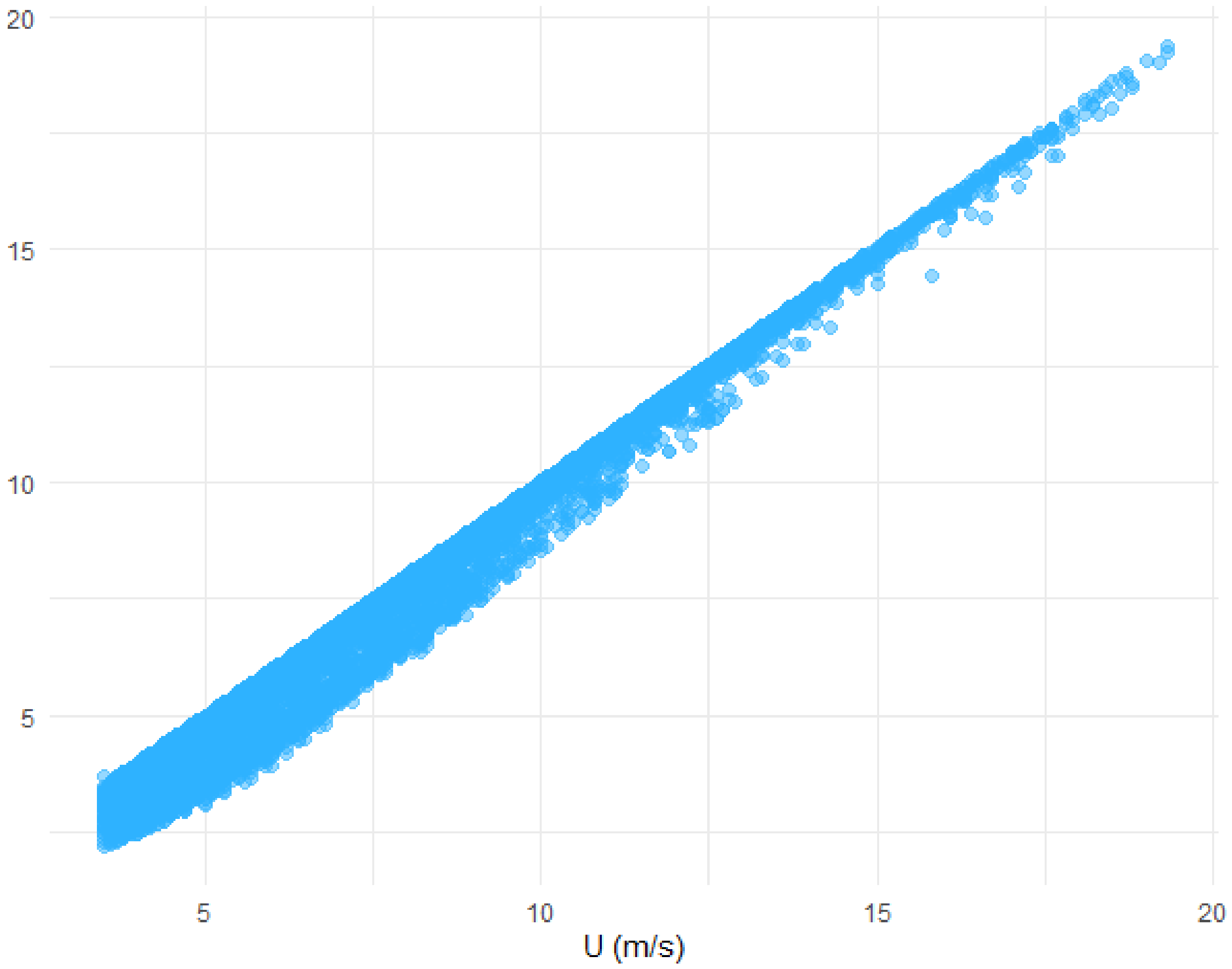
Wind Speed vs Predicted Wind Speed Across k (180 to 360 degrees cont.)



k=0.060, RMSD = 0.049



k=0.055, RMSD = 0.072



k=0.030, RMSD = 0.455

We found that the popular k value for onshore wind farms, k=0.075, underestimates the wake loss effect.

The most accurate k value is k = 0.060.

The Jensen Model is more accurate in higher wind speed conditions, and it losses its accuracy for wind speed < 5 m/s.

With a k value best suited for the given onshore wind farm, the Jensen Model has excellent accuracy.

The Next Steps

For future research, we wish to test the Jensen Model using offshore wind farm data.

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Credits

Ahmed Aziz Ezzat

Sincere thanks to Dr. Ezzat for his guidance and patience throughout the research.

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Austin Wang

Sincere thanks to Austin for studying together.

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Thank you.

Xiangyue Wang