Wind-Resilient Greenhouse Design:

Integrating Wind Data and CFD Simulation in Hammond, Indiana

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What if we build the greenhouse in Hammond?

Greenhouse Collapse

Integration of Statistical Analysis & Computational Fluid Dynamics (CFD)

✓ Wind Data Analysis

✓ CFD Simulation

Optimized Structure of Greenhouse against wind pressure

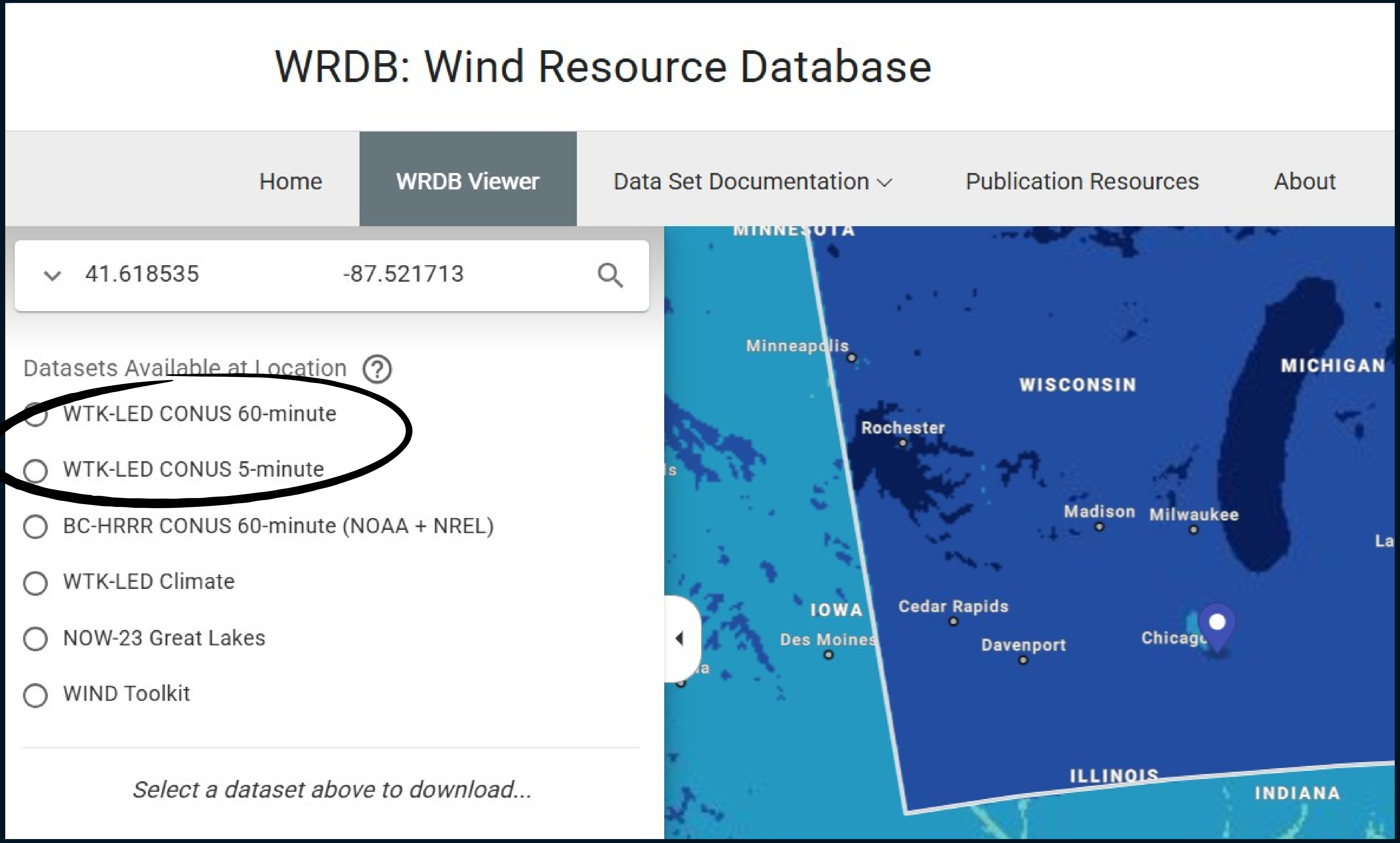
Two Major Tasks

1. Wind Data Processing & Analysis
    - Data from WRDB (Wind Resource Database)
    - Identify dominant wind characteristics

2. CFD Modeling & Simulation of Greenhouse
    - Wind flow Scenarios Simulation using processed data
    - Determine optimal structure types and forms for wind resilience

Wind Data Processing & Analysis

Data Collection



WRDB: Wind Resource Database

Purdue Indiana Mesonet Data Hub

Automated Wind Data Processing with Excel and Python

2020 Average Wind Speed at 10m	3.883400685	k	2.157703
2020 Wind Speed Standard Deviation	1.912798841	c	4.385028
2020 Average Wind Direction at 10m	181.4115194		
Spring Wind Speed Average (3,4,5)	4.063609601	k	2.036795
Spring Wind Speed Standard D (3,4,5)	2.110717189	c	4.586629
Spring Wind Direction Average (3,4,5)	153.4479303		
Summer Wind Speed Average (6,7,8)	3.59942029	k	2.191244
Summer Wind Speed S.T(6,7,8)	1.747917765	c	4.064317
Summer Wind Direction Average (6,7,8	157.7820697		
Fall Wind Speed Average (9,10,11)	3.981204212	k	2.212792
Fall Wind Speed S.T (9,10,11)	1.915974314	c	4.495266
Fall Wind Direction Average (9,10,11)	198.7956319		
Winter Wind Speed Average (12,1,2)	3.881643441	k	2.122316
Winter Wind Speed S.T (12,1,2)	1.941267979	c	4.382858
Winter Wind Direction Average (12,1,2	169.9469918		

Month	Wind Speed Aaverage	Wind Speed S.T	Wind Direction Average	K-value	C-value
1	3.510887097	1.856754652	216.5278091	1.997355199	3.961515339
2	4.182782738	1.822474815	209.4298661	2.465090659	4.715811275
3	4.137217742	2.051292912	166.2209274	2.142314558	4.671578315
4	4.009791667	2.211731796	164.4468056	1.908142618	4.519377806
5	4.042083333	2.071042504	130.0308602	2.067245468	4.563143375
6	4.045847222	2.009682087	157.4886944	2.138040756	4.568383314
7	3.370416667	1.651125955	147.4049059	2.170476464	3.805784978
8	3.396397849	1.46894655	168.4431452	2.484949941	3.828503636
9	3.898388889	1.563957629	166.7874444	2.696329436	4.383946718
10	3.775	1.951768981	206.5298253	2.047041085	4.261153822
11	4.277097222	2.15166489	222.8118194	2.108796611	4.829218582
12	4.006370968	1.726719402	223.072379	2.494393228	4.515669804

1. Weibull Distribution

Positive Shape Parameter k

$$\left(\frac{\sigma}{\bar{v}}\right)^{-1.086}$$

Positive Scale Parameter c

$$\frac{\bar{v}}{\Gamma(1+1/k)}$$

Weibull Probability Density Function (PDF)

$$p(V_w) = \frac{k}{c}\left(\frac{V_w}{c}\right)^{k-1} \exp\left[-\left(\frac{V_w}{c}\right)^k\right]$$

2. Rayleigh Distribution

Mean wind speed

$$\bar{V}_w = \int_0^\infty V_w p(V_w) dV_w$$

Rayleigh Probability Density Function

$$p(V_w) = \frac{\pi}{2}\left(\frac{V_w}{\bar{V}_w^{\,2}}\right) \exp\left[-\frac{\pi}{4}\left(\frac{V_w}{\bar{V}_w}\right)^2\right]$$

Parameter Calculation

For 2020 Wind Data

$\bar{v} = 3.883400685$ m/s $\sigma = 1.912798841$

Shape Parameter K

$$\left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \Rightarrow \left(\frac{1.912798841}{3.883400685}\right)^{-1.086} = 2.157703$$

K

Scale Parameter C

$$\frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \Rightarrow \frac{3.883400685}{\Gamma\left(1+\frac{1}{2.157703}\right)} = 4.385027587$$

C

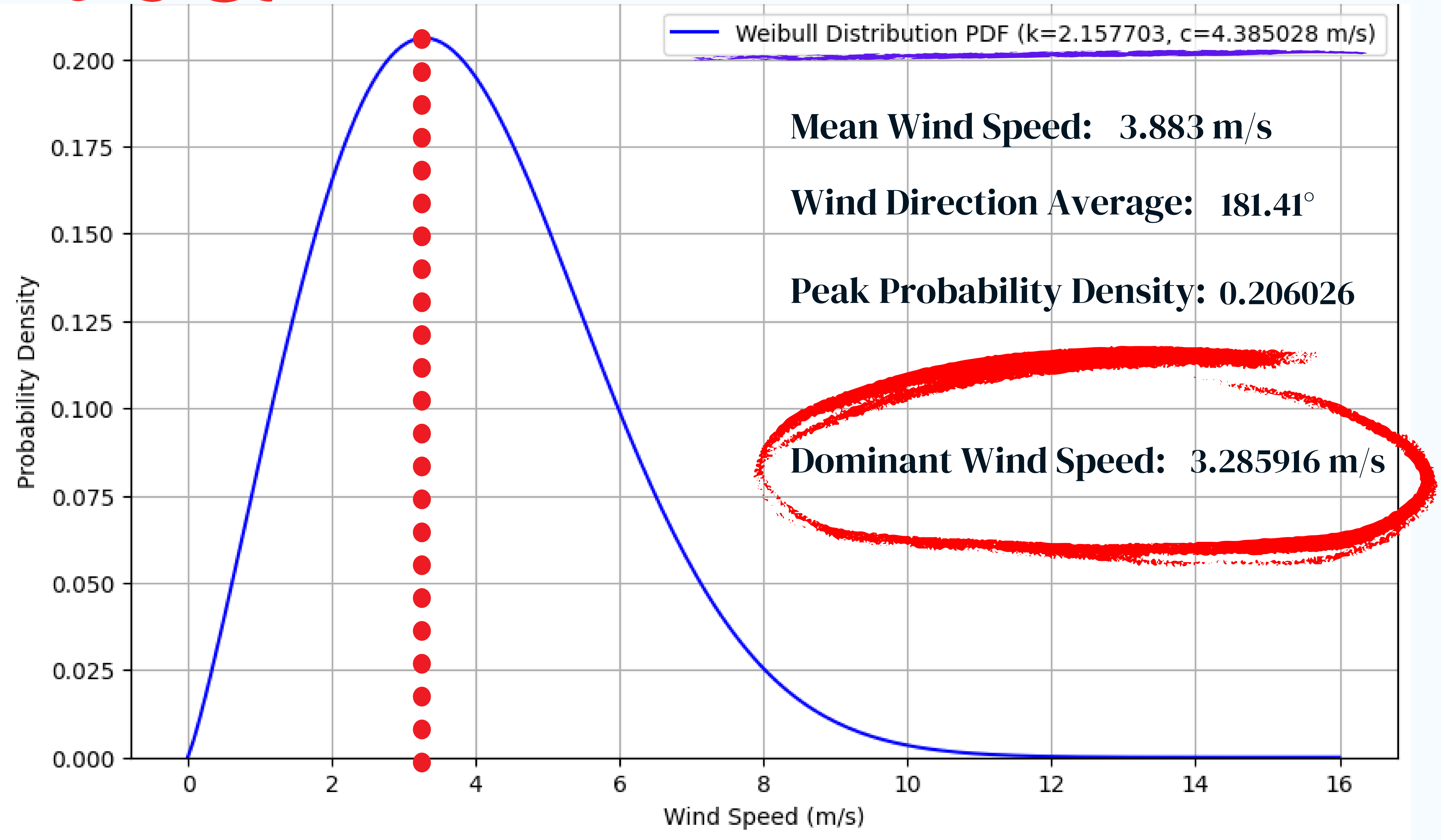
Weibull Probability Density Function (PDF)

$$p(V_w) = \frac{k}{c}\left(\frac{V_w}{c}\right)^{k-1} \exp\left[-\left(\frac{V_w}{c}\right)^{k}\right]$$

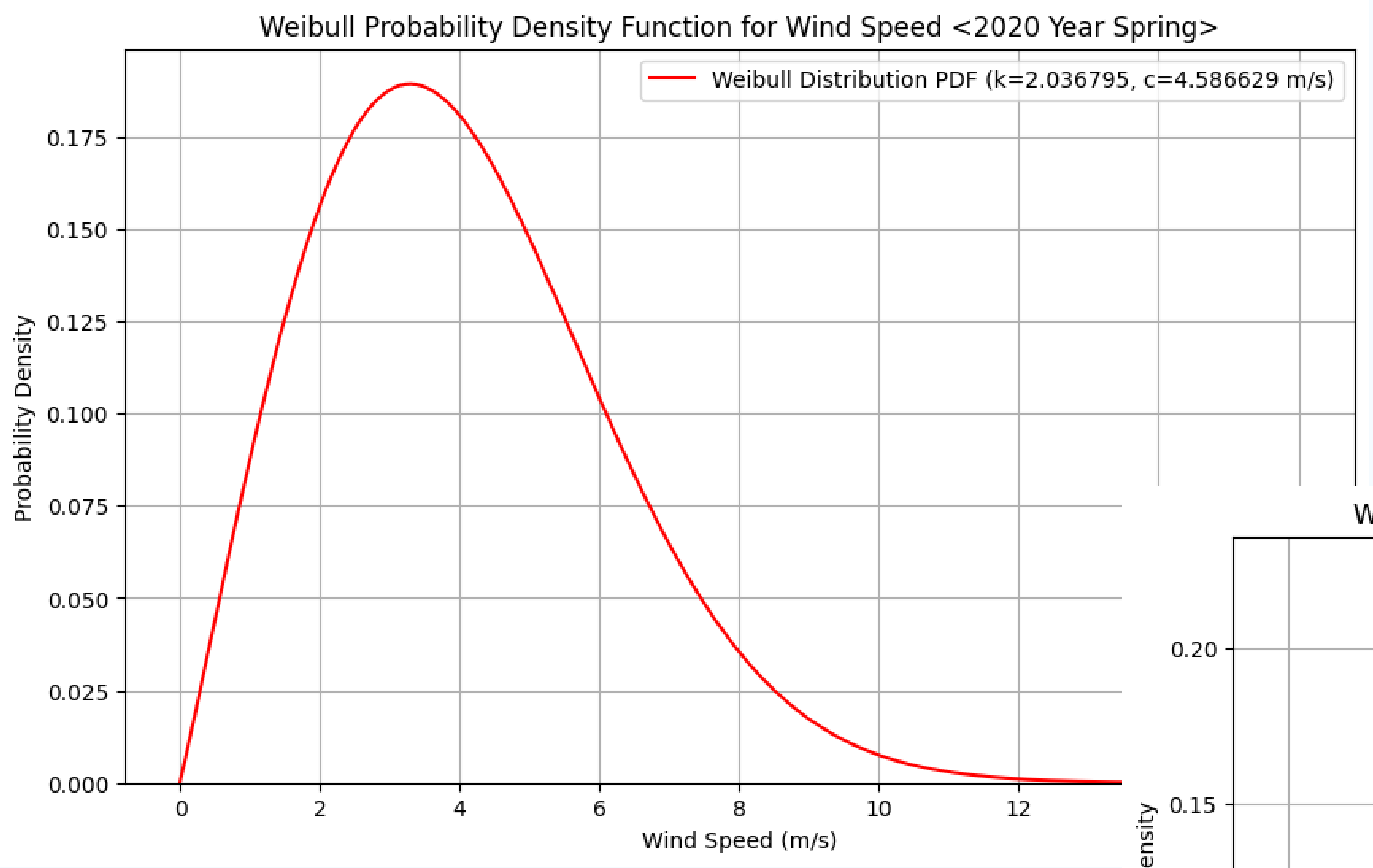
$$\left(\frac{2.157702638}{4.385027587}\right) \times \left(\frac{v}{4.385027587}\right)^{2.157702638-1} \times \exp\left[-\left(\frac{v}{4.385027587}\right)^{2.157702638}\right]$$

$$0.492 \times \left(\frac{v}{4.385}\right)^{1.158} \times e^{-\left(\frac{v}{4.385}\right)^{2.158}}$$

2020 Whole Year Weibull Probability Function for Wind Speed



2020 Year Spring & Summer Weibull PDF

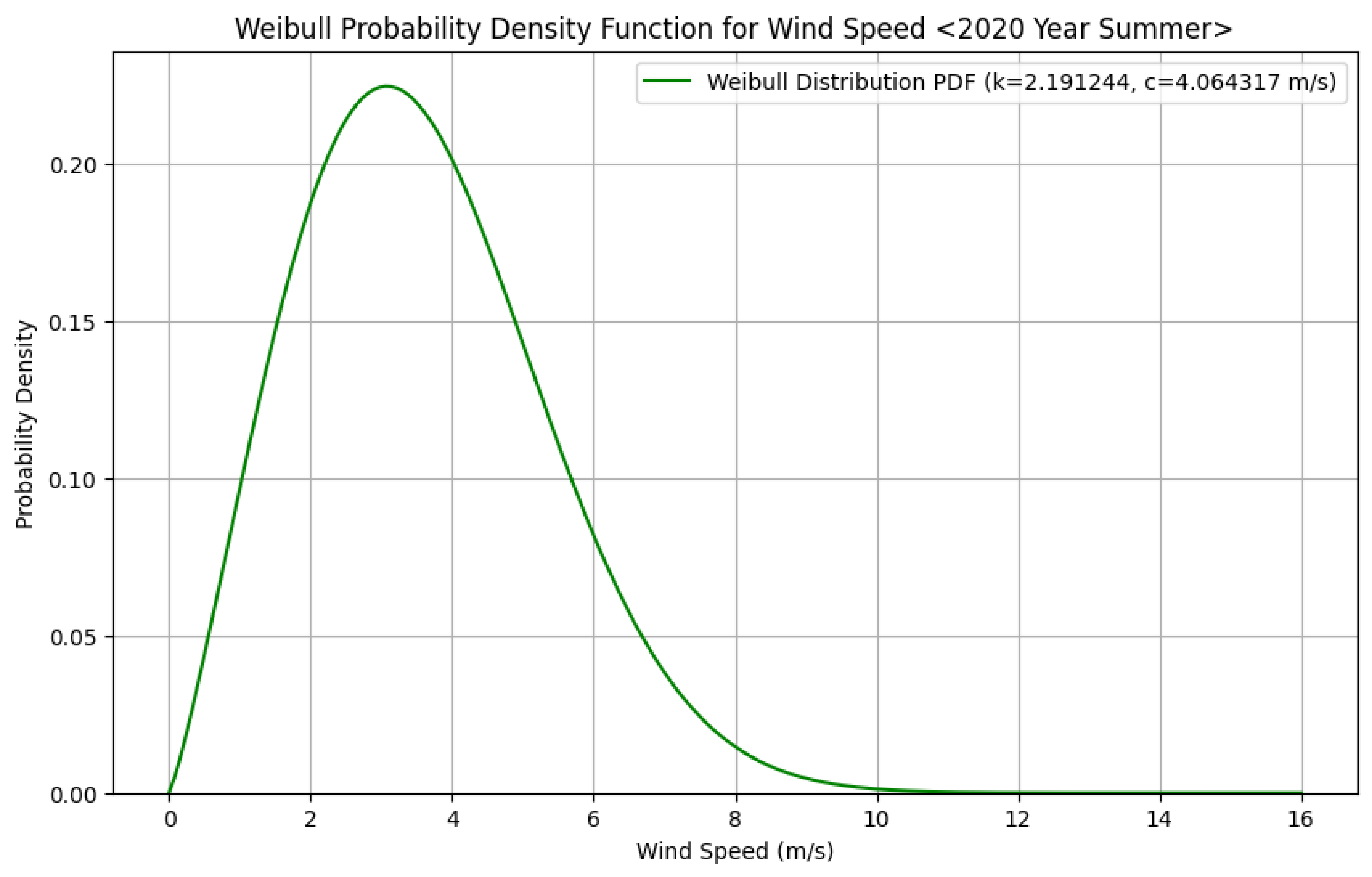


Mean Wind Speed: 4.064 m/s

Wind Direction Average: 153.45°

Peak Probability Density: 0.189281

Dominant Wind Speed: 3.292420 m/s



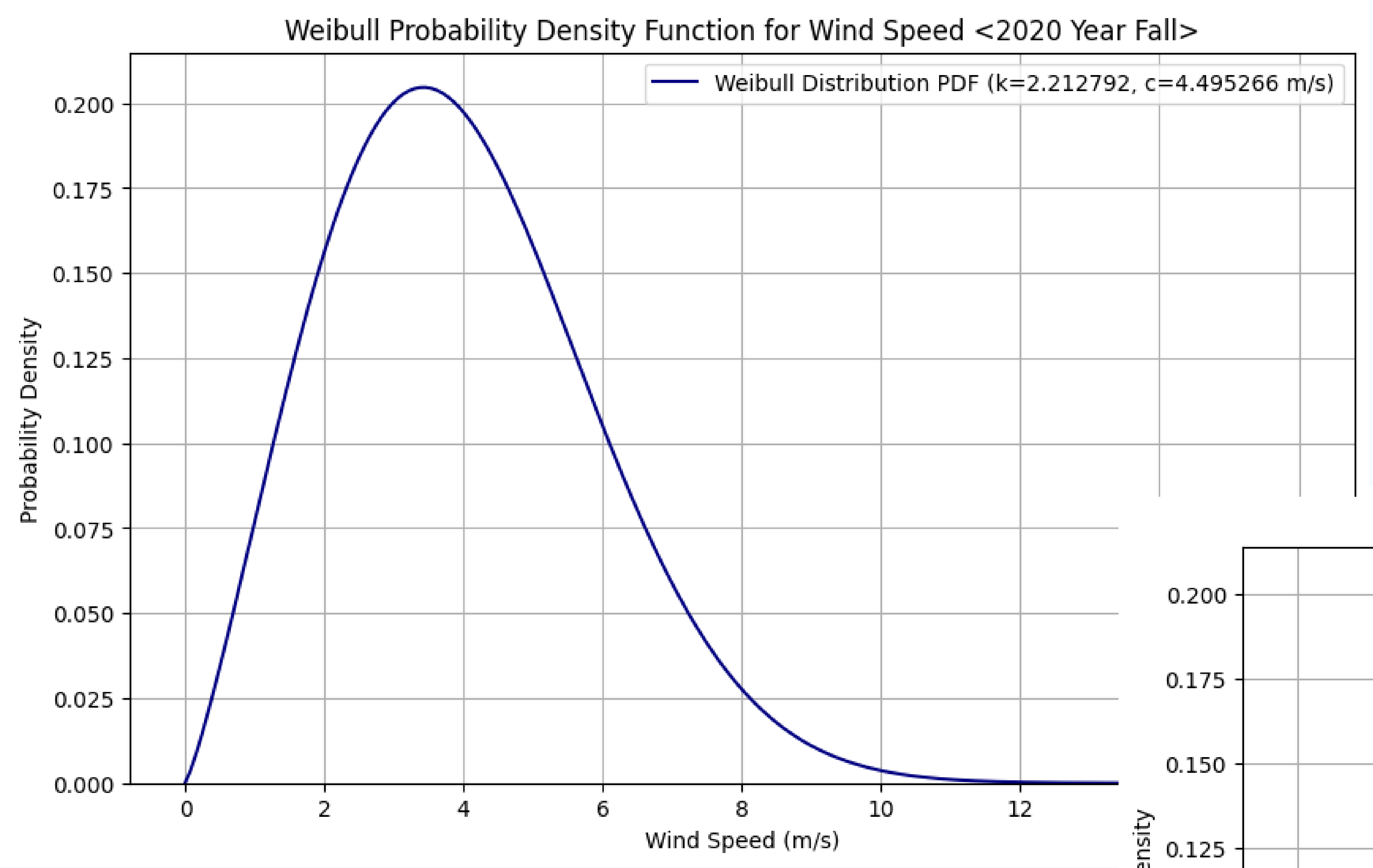
Mean Wind Speed: 3.599 m/s

Wind Direction Average: 157.78°

Peak Probability Density: 0.224755

Dominant Wind Speed: 3.077465 m/s

2020 Year Fall & Winter Weibull PDF



Mean Wind Speed: 3.981 m/s

Wind Direction Average: 198.80°

Peak Probability Density: 0.204655

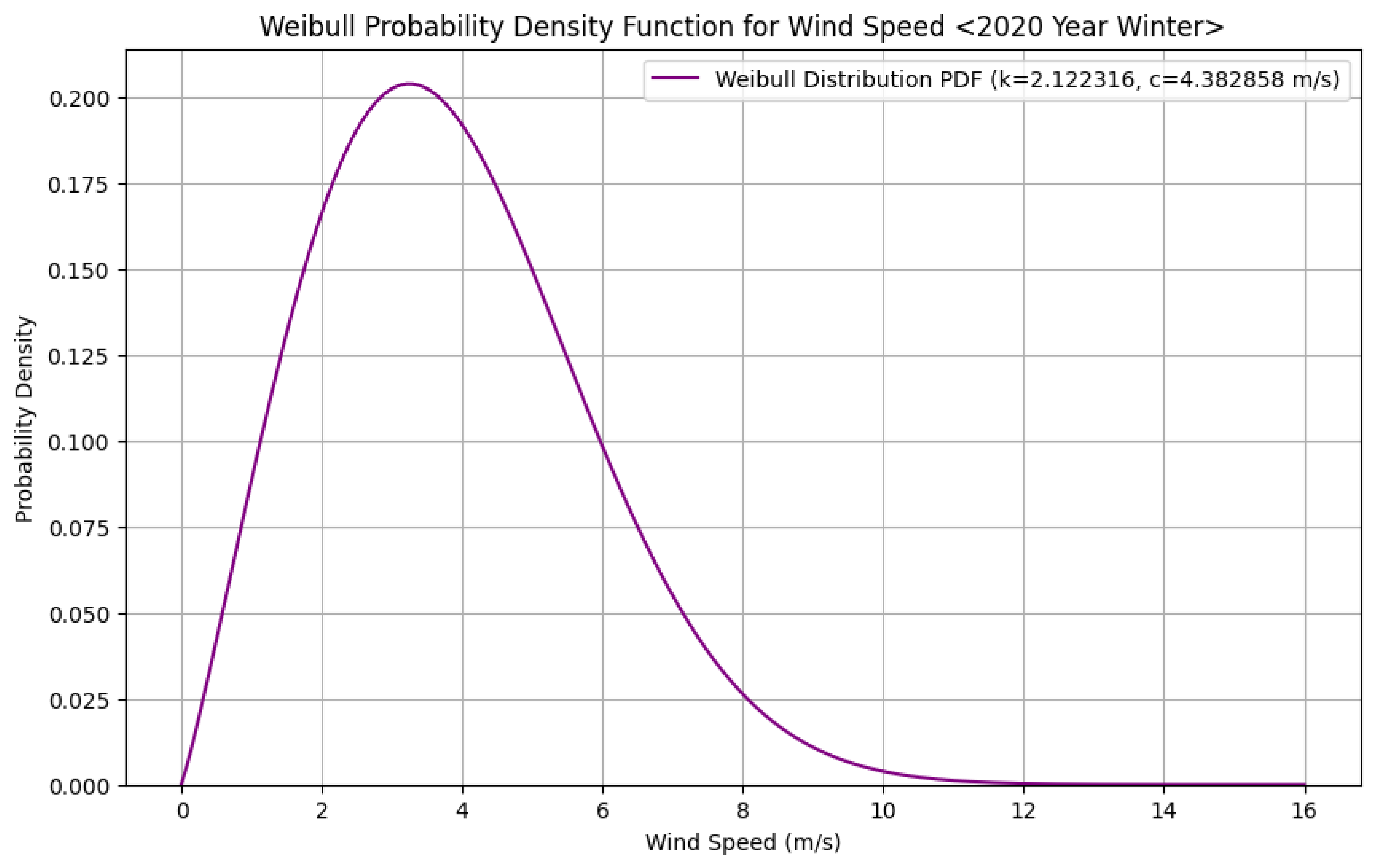
Dominant Wind Speed: 3.425588 m/s

Mean Wind Speed: 3.882 m/s

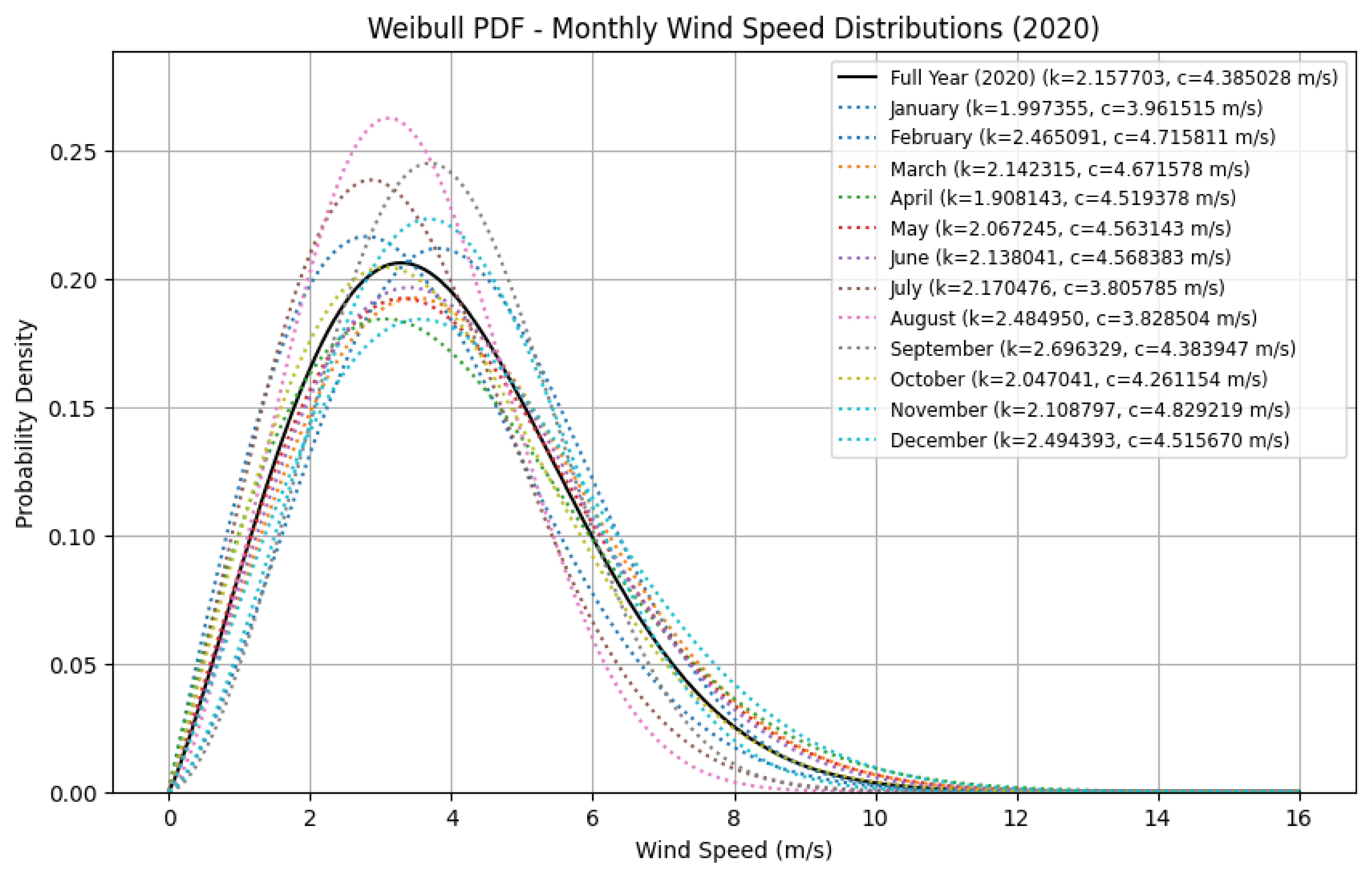
Wind Direction Average: 169.95°

Peak Probability Density: 0.203737

Dominant Wind Speed: 3.246261 m/s



2020 Year Monthly Weibull PDF



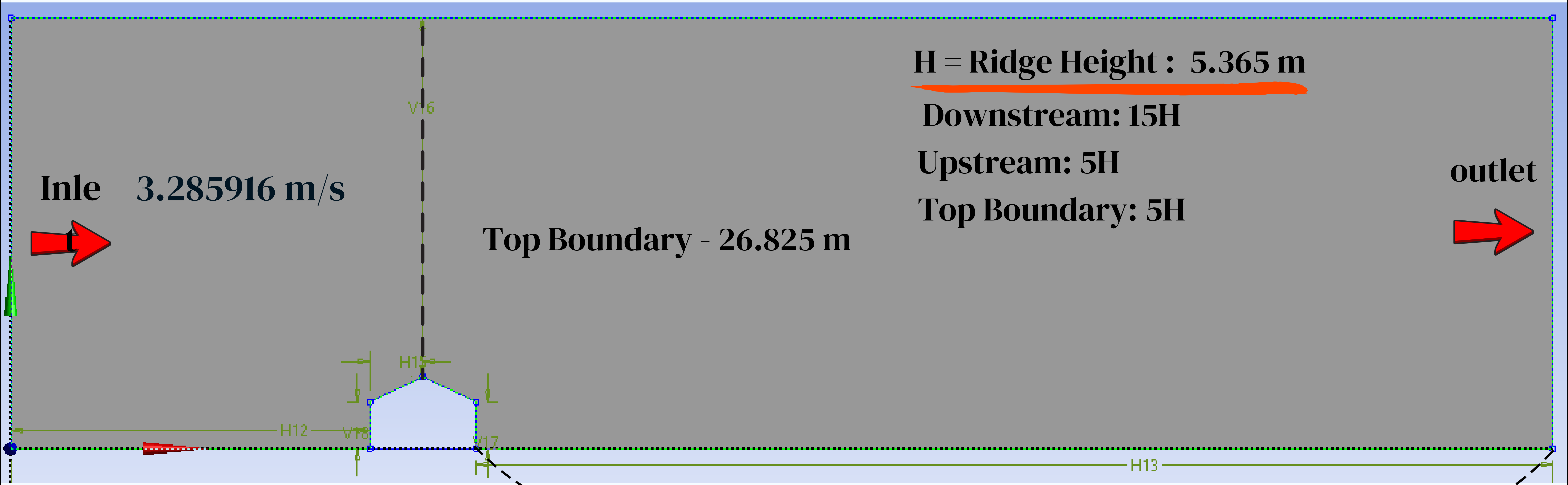
CFD simulation

CFD Setting _ a

CFD Domain

Domain X - 115.3 m

Domain Y - 32.19 M



Upstream - 26.825 m

Downstream - 80.475 m

From "Wind pressure acting on greenhouses: A review"

CFD Setting _ b

Cp value & Mesh

p ⟹ Local pressure on greenhous surface

ρ ⟹ air density ⟹ 1.225 kg/m^3

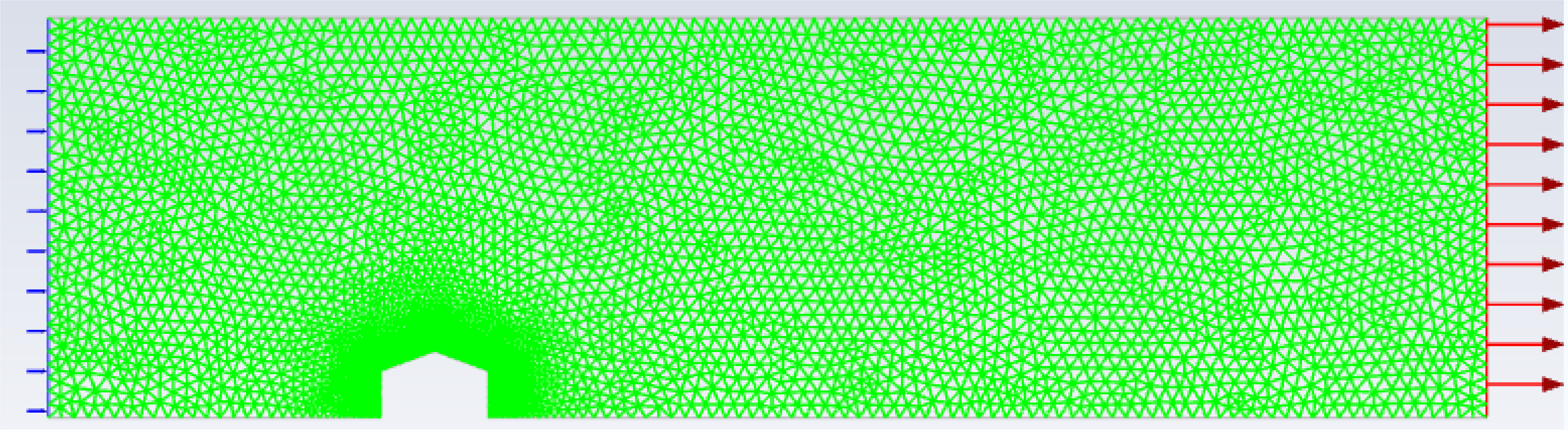
U ⟹ air velocity ⟹ 3.285916 m/s

p_∞ ⟹ atomospheric pressure ⟹ 101,325 Pa

Cp value

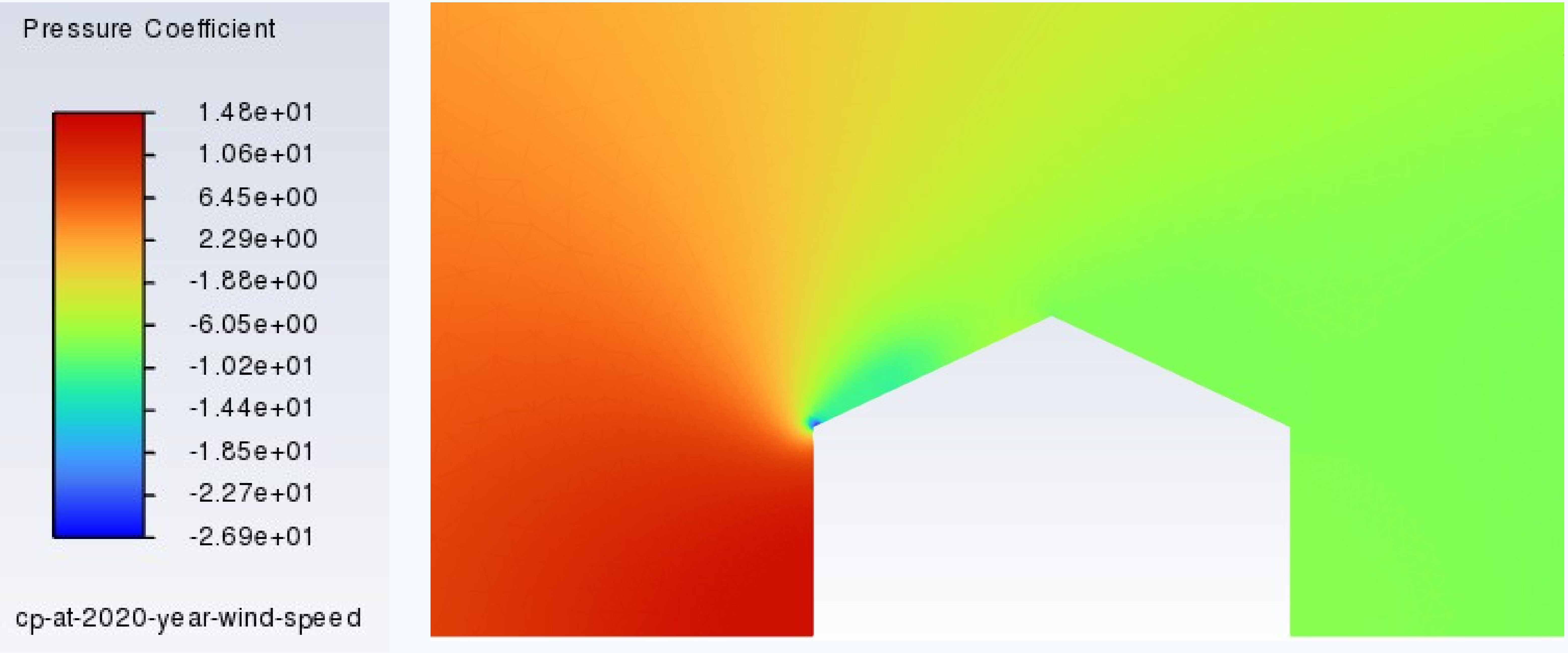
$$C_p = \frac{p - p_\infty}{0.5 \cdot \rho \cdot U^2}$$

Meshing

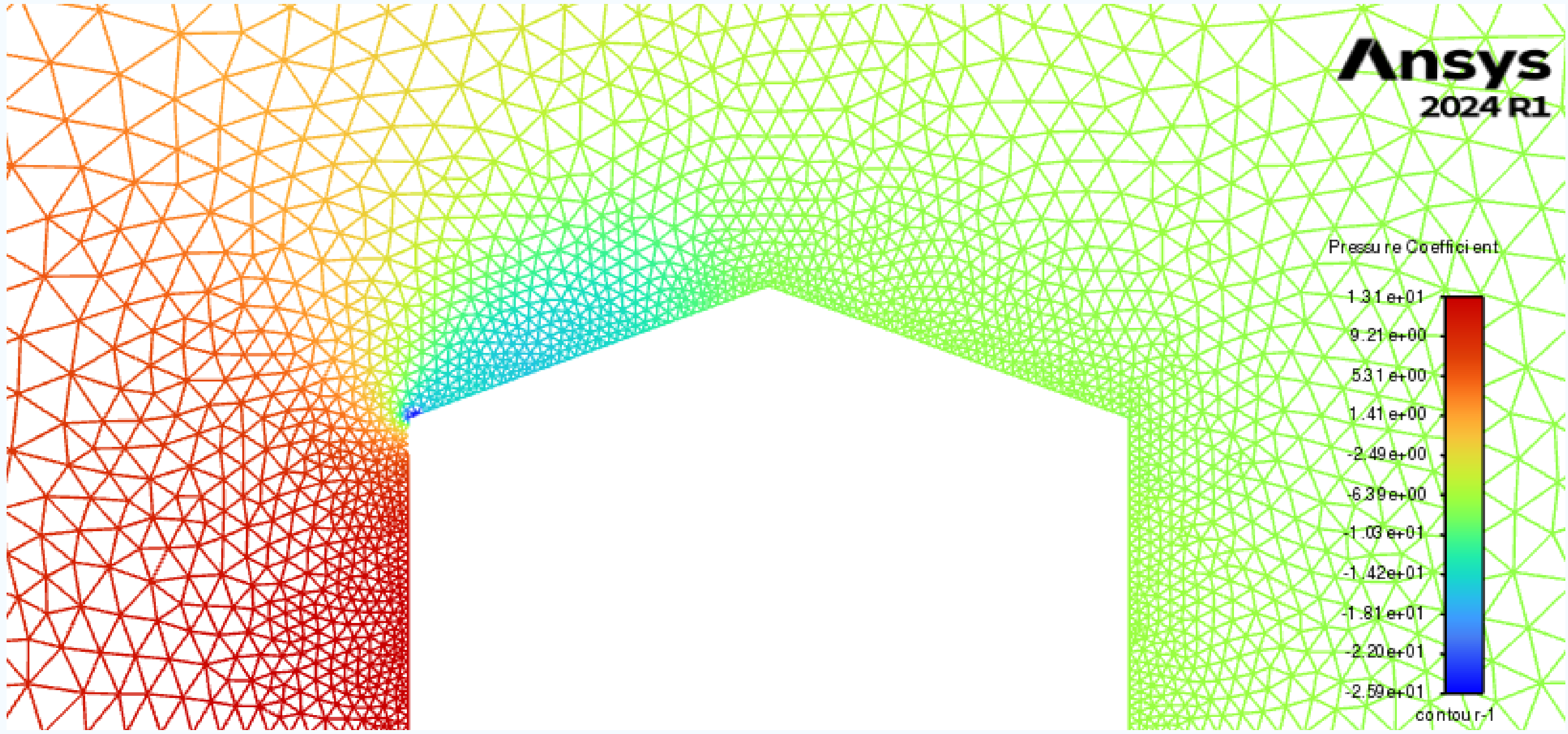


Cp Distribution on greenhouse

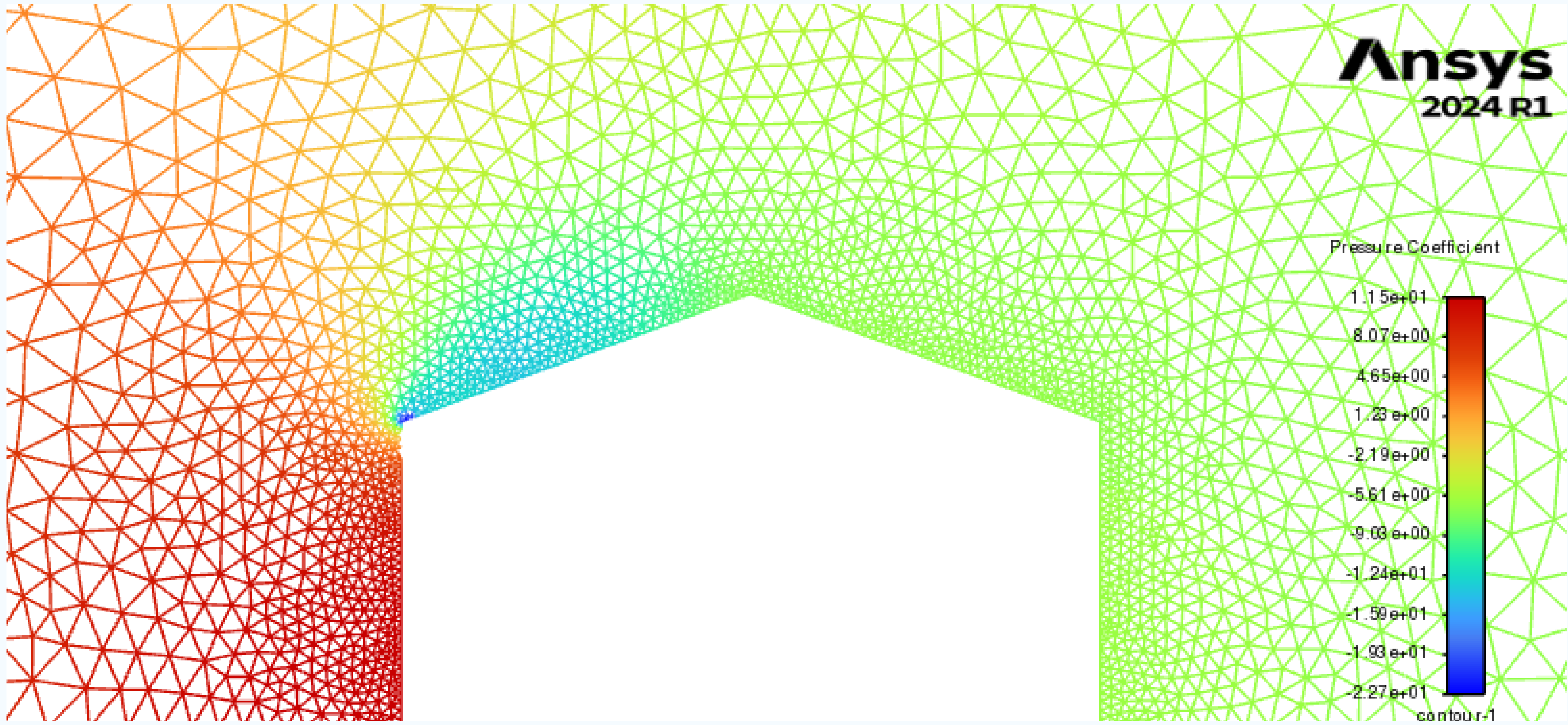
Based on 2020 Wind Data



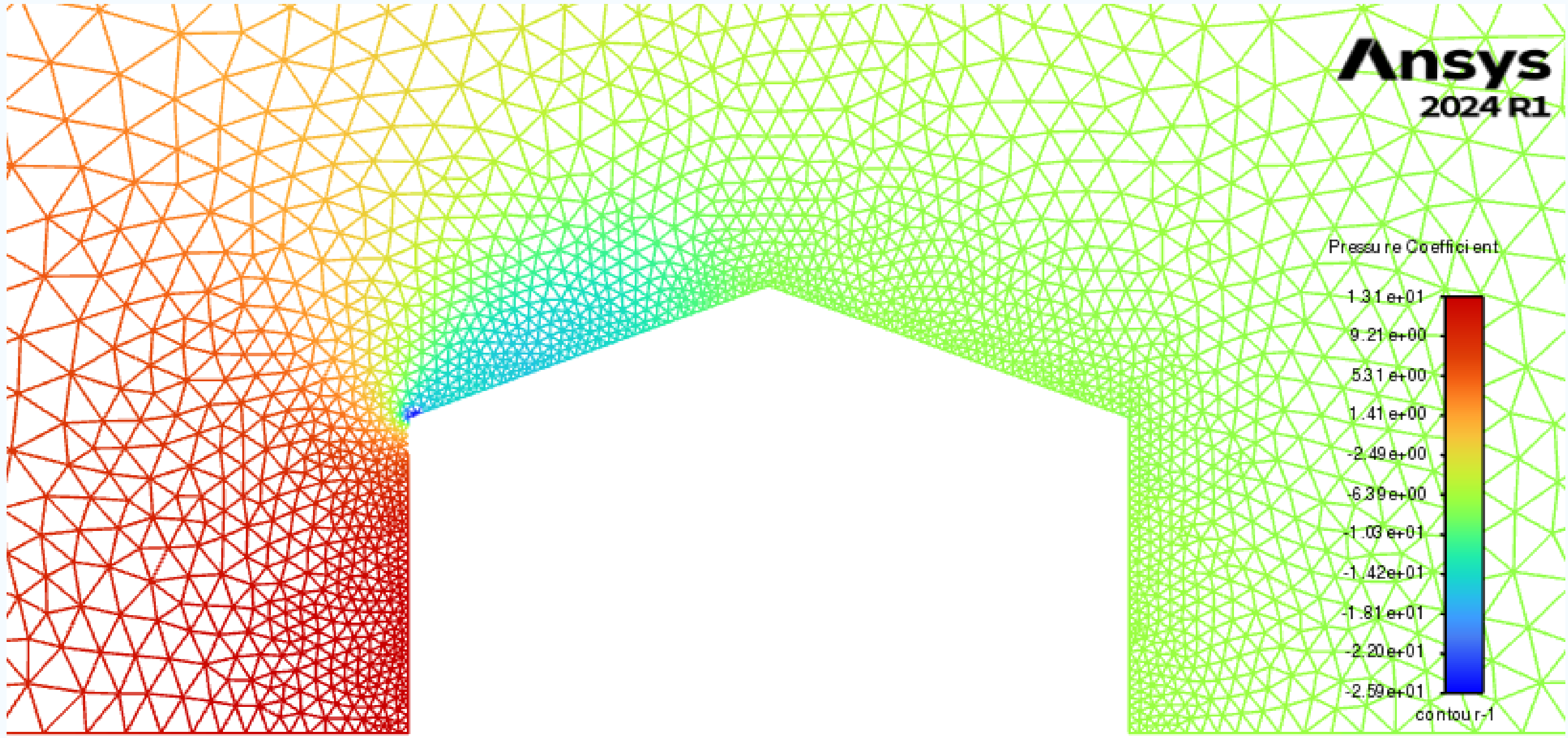
Spring



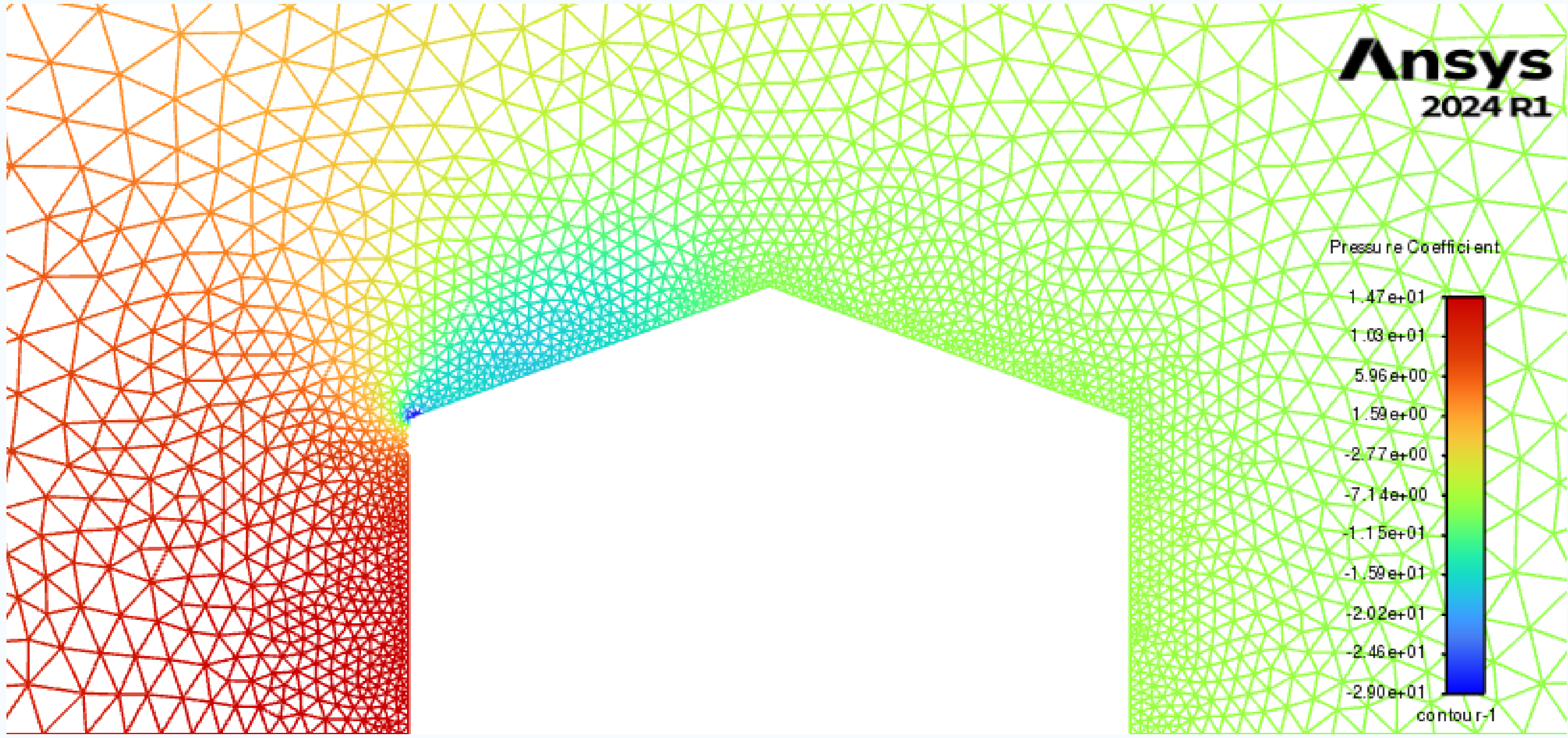
Summer



Fall



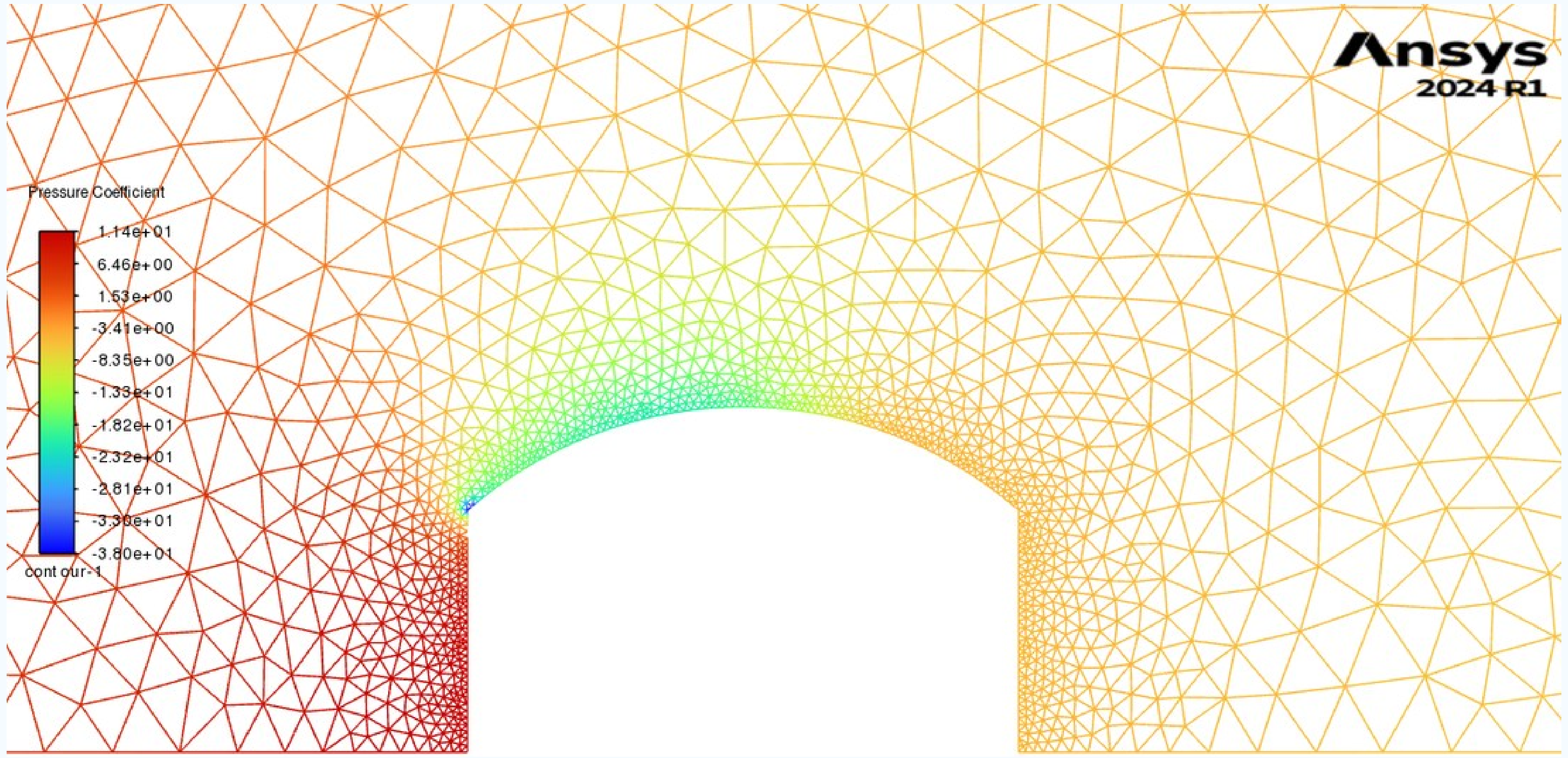
Winter



Various Geometry Conditions

From Wind of 2020 Year

Arch roof

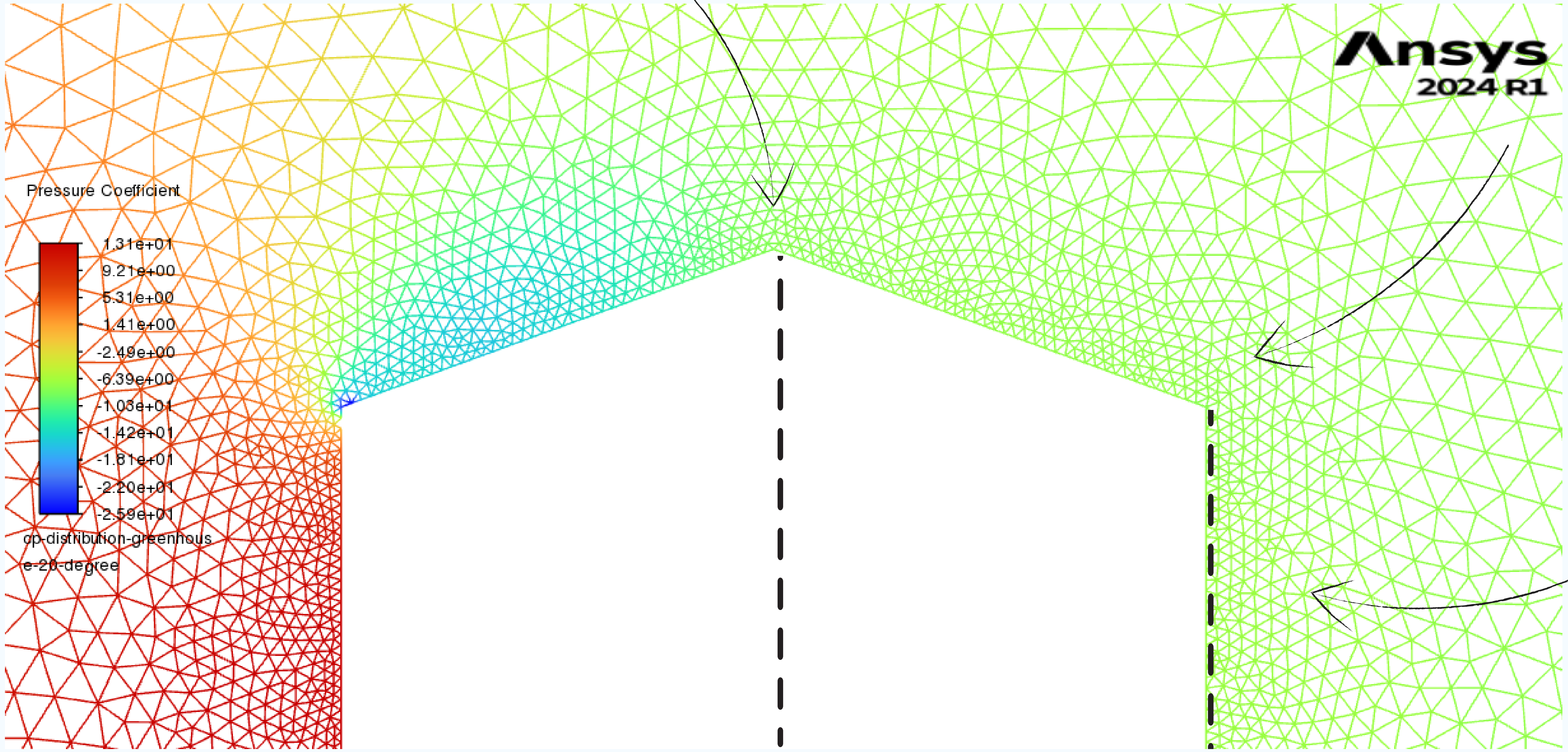


Best Greenhouse Structure

Under Hammond Wind Condition

Ridge Height	4.96 m
Roof Slope	20 degree
Wall Height	3.5 m
Width	8 m

Ridge Height



Roof Slope

Wall Height

Reflection

Statistics	Engineering
Python	ANSYS Fluent
Data Process	CFD
Data Analysis	Fluid Dynamic

Future Work

Variation of Geometry

3D

Greenhouse Group

Thanks

References

Wang, C., Nan, B., Wang, T., & Bai, Y. (2021). Wind pressure acting on greenhouses: A review. International Journal of Agricultural and Biological Engineering, 14(2), 1–8. https://doi.org/10.25165/j.ijabe.20211402.5261

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