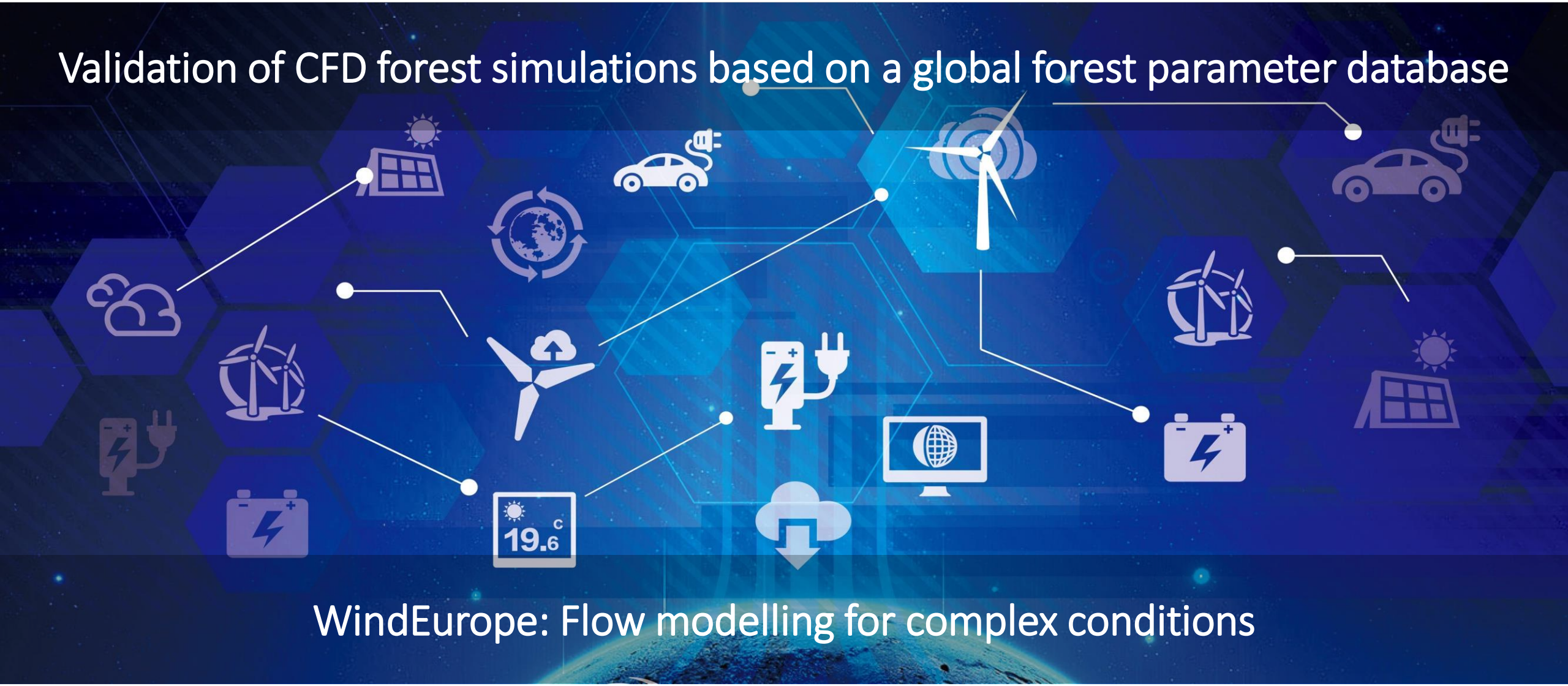
# Validation of CFD forest simulations based on a global forest parameter database



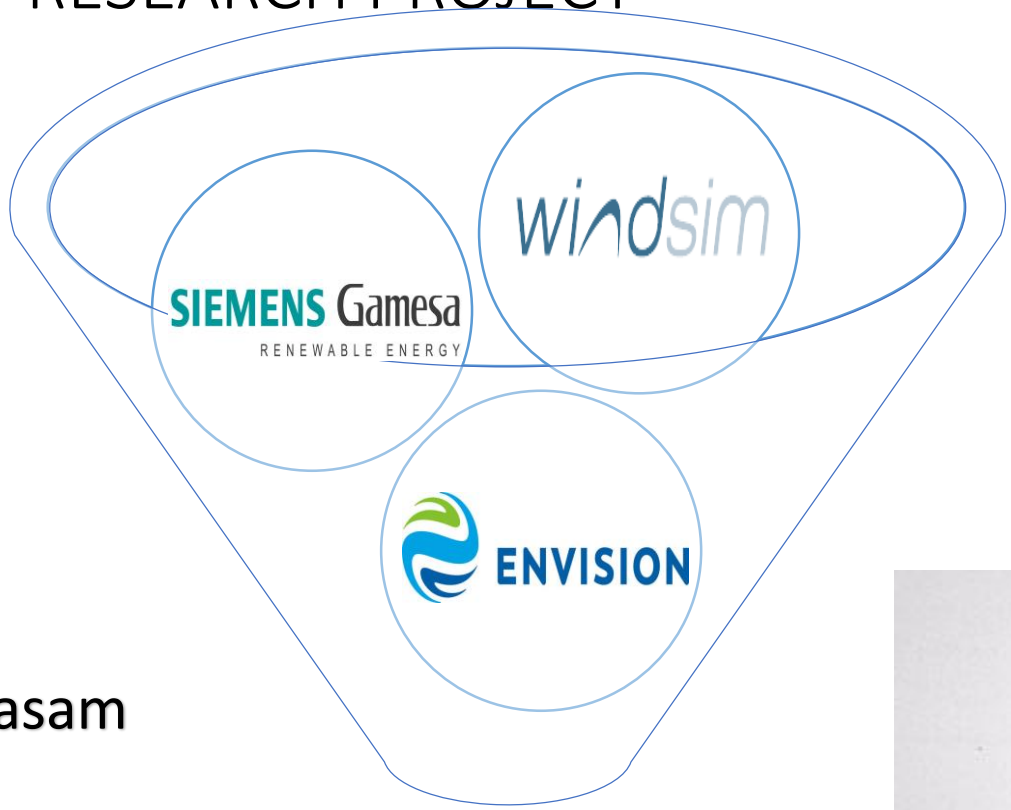

## WindEurope: Flow modelling for complex conditions



Peter Enevoldsen, Catherine Meissner, Venkatesh Jothiprakasam

# MULTI-COMPANY RESEARCH PROJECT

Venkatesh Jothiprakasam

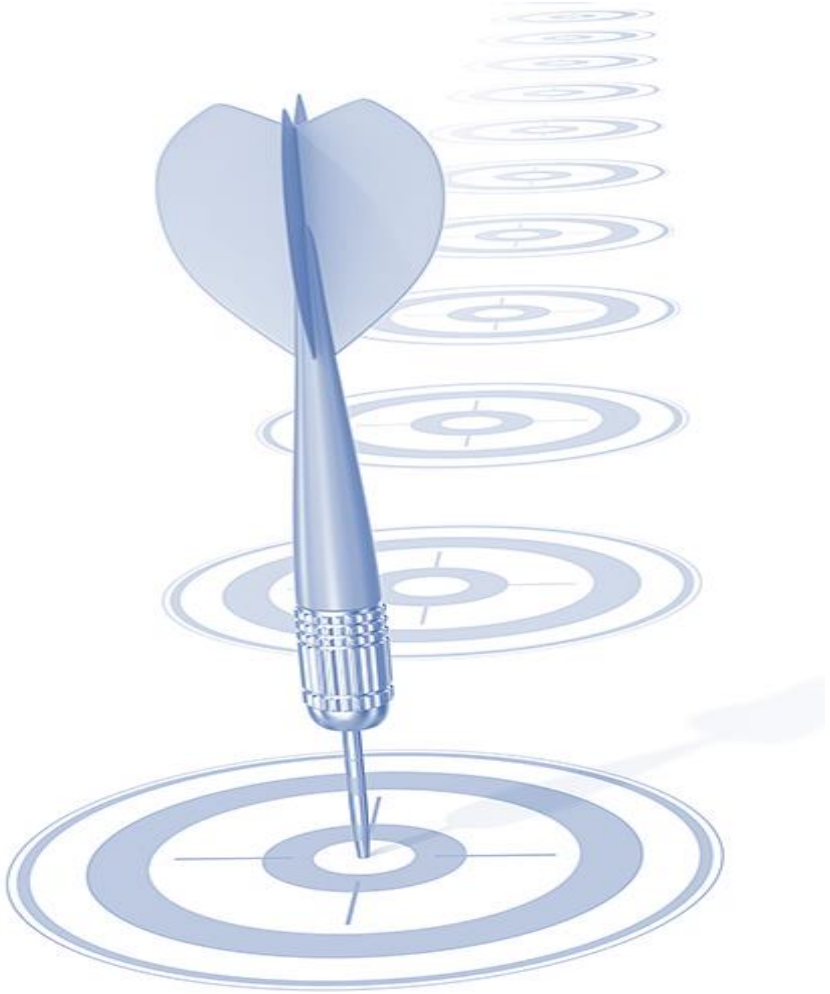



Catherine Meissner

Peter Enevoldsen

# AGENDA

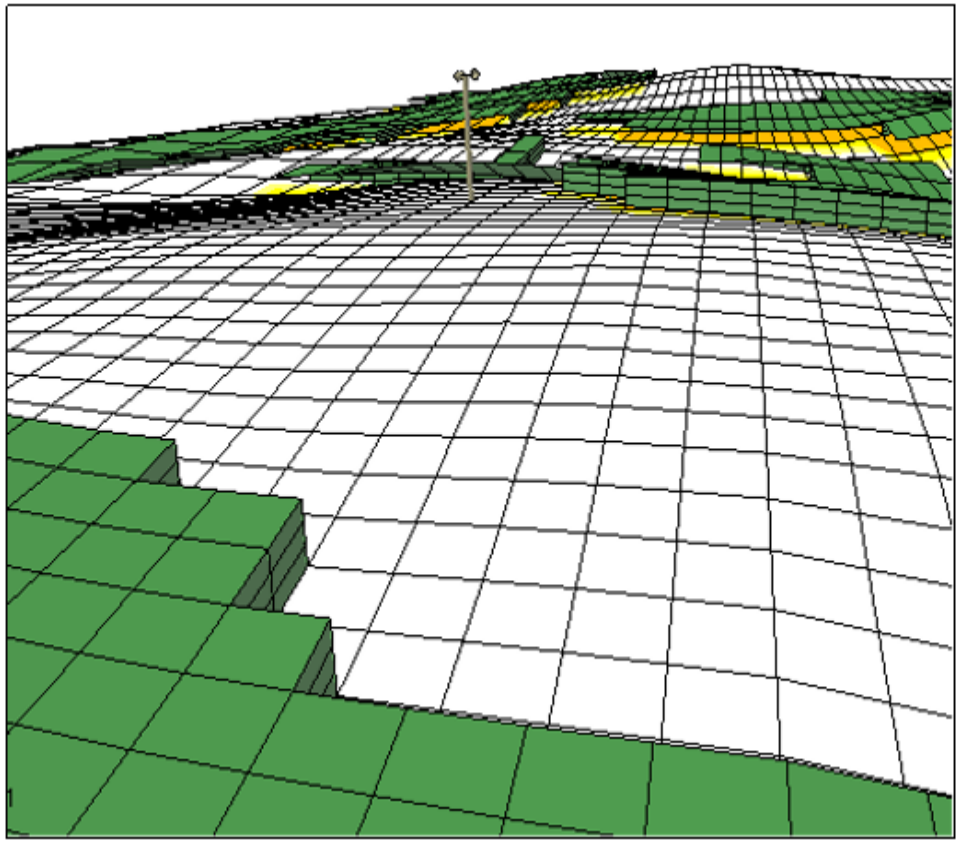
- Motivation
- The WindSim Forest Model
- Obtaining Data for the Forest Model
- Database Example
- Results based on optimized data analysis
- Recommendations



# MOTIVATION

- The data quality applied in forest modelling is causing good models to make bad predictions (Bergström et al, 2013; Arnqvist et al, 2015)
- Wind turbines operating in forested areas have been underperforming (Enevoldsen, 2017)
- Previous recommendations have applied unrealistic C2-values
- Technological innovations have rendered it possible to apply free high quality data (Dellwik et. al, 2016)

# WINDSIM FOREST MODEL



- The model takes account for tree heights and resistive forces.
- Inspired by the work from Sanz (2003) and Katul et al. (2004).
- Inside the can… …tions present an additional…

**Let us investigate the $C_2$ parameter**

$[S$ … $\vec{U}$

- TKE: … $\rho\varepsilon + S_k$
- The source and sink due to the forest: $S_k = C_2\left(\beta_p\sqrt{u_i u_i}^3 - \beta_d u_i k\right)$

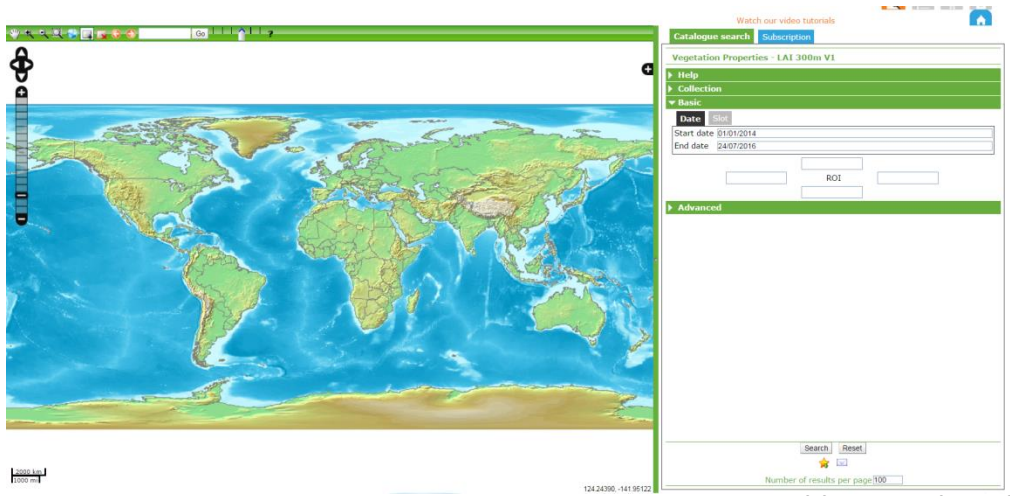
# RESEARCH TARGETS

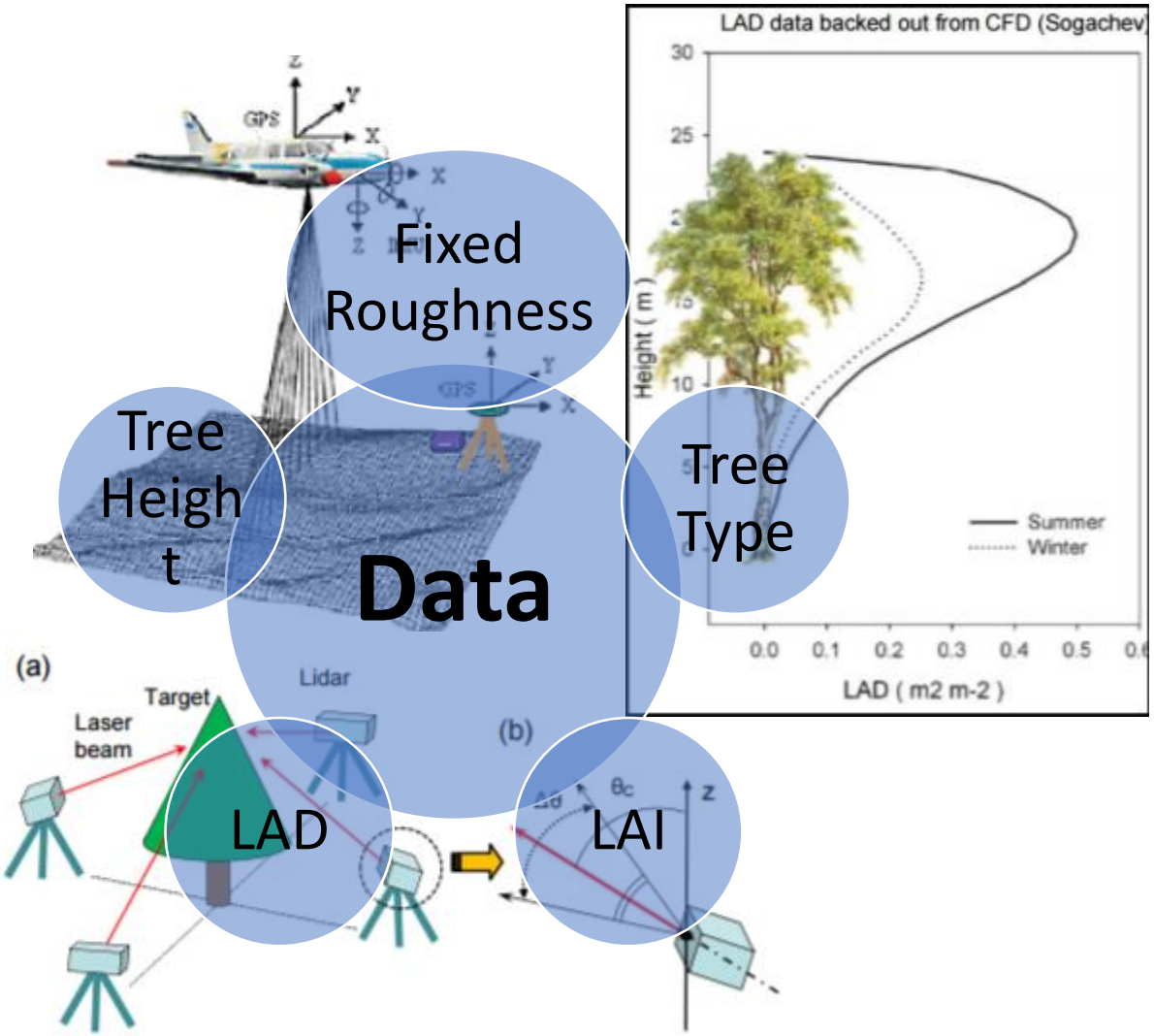
- **How to apply a proper C2-value?**
- *The required data input*
- *Impact of such factor*
- **How to apply a proper roughness model?**
- *The required data input*
- *Impact of such model*

# OBTAINING DATA TO DETERMINE C2

- **Seeking to determine Tree Heights, LAI, etc.**
- **Can be obtained using various methods**

- Airborne laser scans
- Drones
- Satellites
- Ground measurements
- Copernicus
- Database



# THE LEAF AREA INDEX DATABASE

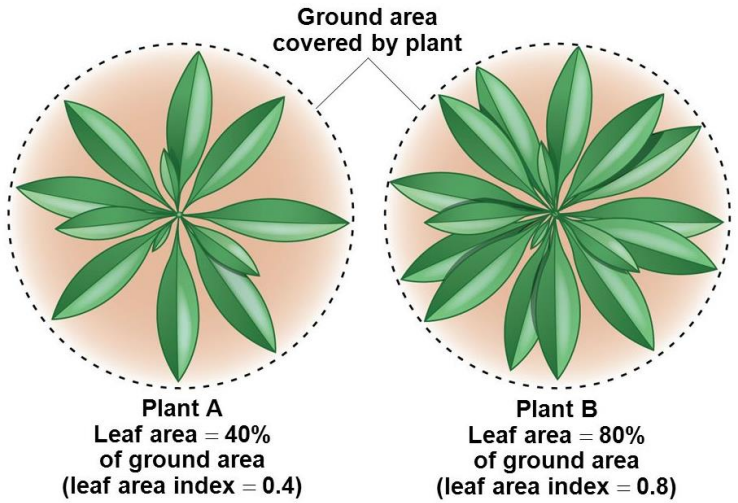
| Dominant Family | Location | Dominant species (Latin) | Altitude | Stand age | LAI | C2 | CD |
|---|---|---|---|---|---|---|---|
| **The family of the dominating tree type in this location** | Coordinates for the obtained sample (Geo [deg]). | The dominating species in Latin. | The altitude for the obtained sample (m) | The age of the obtained sample | The leaf area index | The C2 value | The drag coefficient |

# CONTENT OF DATABASE

- Based on 144 observations collected and analyzed by Lio & Ito (2011)
- Constantly improved with data from Copernicus
- Parameters considered
- Introducing:

1. Leaf Area Index (LAI)

The key parameter in this dataset. The leaf area index describes the leaf area per ground area ($m^2/m^2$). This value can furthermore be applied as an input factor for other forest models.



# CONTENT OF DATABASE

- Parameters considered
- Introducing:

~~1. Leaf Area Index (LAI~~)

2. C2

**C2** is the second momentum sink in WindSim's forest model. The C2-value is calculated following $C2 = \frac{LAI}{Tree\ Height} CDs$, why the tree height is the only input required by the user.

We can also estimate the Leaf Area Density (LAD), as we have the tree height and the LAI

# CONTENT OF DATABASE

- Parameters considered
- Introducing:

~~1. Leaf Area Index (LAI)~~

~~2. C2~~

3. Drag Coefficient ($C_D$)

- **$C_D$** is the drag coefficient of a tree expressed as $C_D = \frac{D}{1/2\rho U^2 A}$,
- In this dataset the drag coefficient is expressed as fixed values, which defines the average drag coefficient for three categories of forest (Evergreen, Broadleaf, and Mix).
- In reality, the drag coefficient tends to decrease with increased wind speeds.

# EASY ESTIMATION OF C2-VALUE

| LAI | | 1 | | | |
|---|---|---|---|---|---|
| **Tree Type** | | Single Deciduous Tree | Mixed forest | Row of Deciduous Trees | Evergreen Coniferous |
| **Drag coefficient (Cd)** | | 0,15 | 0,2 | 0,5 | 1 |
| **Tree Heights (m)** | 5 | 0,0300 | 0,0400 | 0,1000 | 0,2000 |
| | 10 | 0,0150 | 0,0200 | 0,0500 | 0,1000 |
| | 20 | 0,0075 | 0,0100 | 0,0250 | 0,0500 |
| | 30 | 0,0050 | 0,0067 | 0,0167 | 0,0333 |

# OPTIMIZED ROUGHNESS APPROACH (ORA)

According to Enevoldsen (2016 & 2017B) the conversion from tree height to roughness length ($Z_0$) should follow:

| Parameter | Coniferous Trees | Deciduous Trees |
|---|---|---|
| $Z_0$ | $0.3 \cdot (tree\ height - Z_d)$ | |
| With a displacement height of | | |
| $Z_d$ | $0.66 * tree\ height$ | $0.70 * tree\ height$ |

# OPTIMIZED ROUGHNESS APPROACH (ORA)

**ORA**

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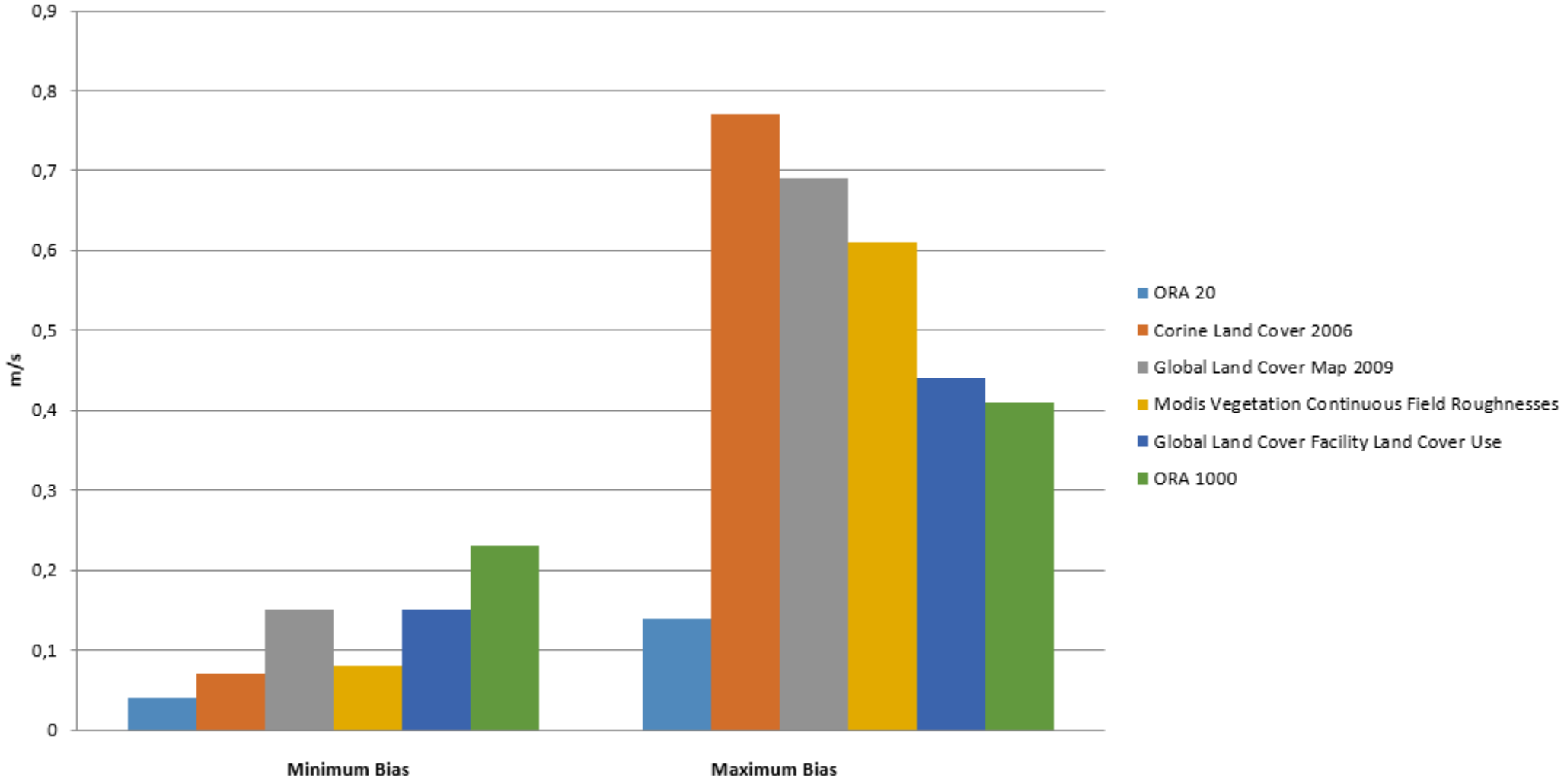
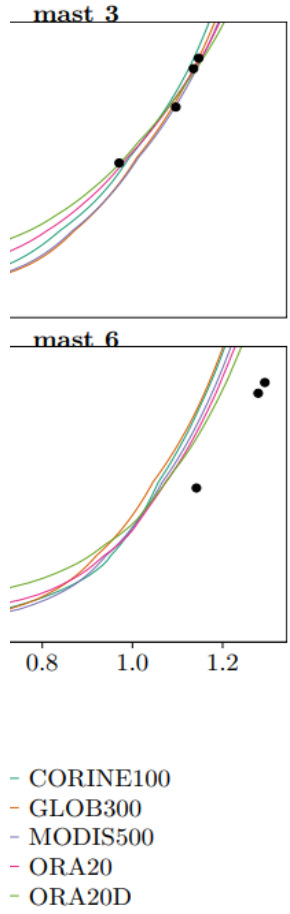
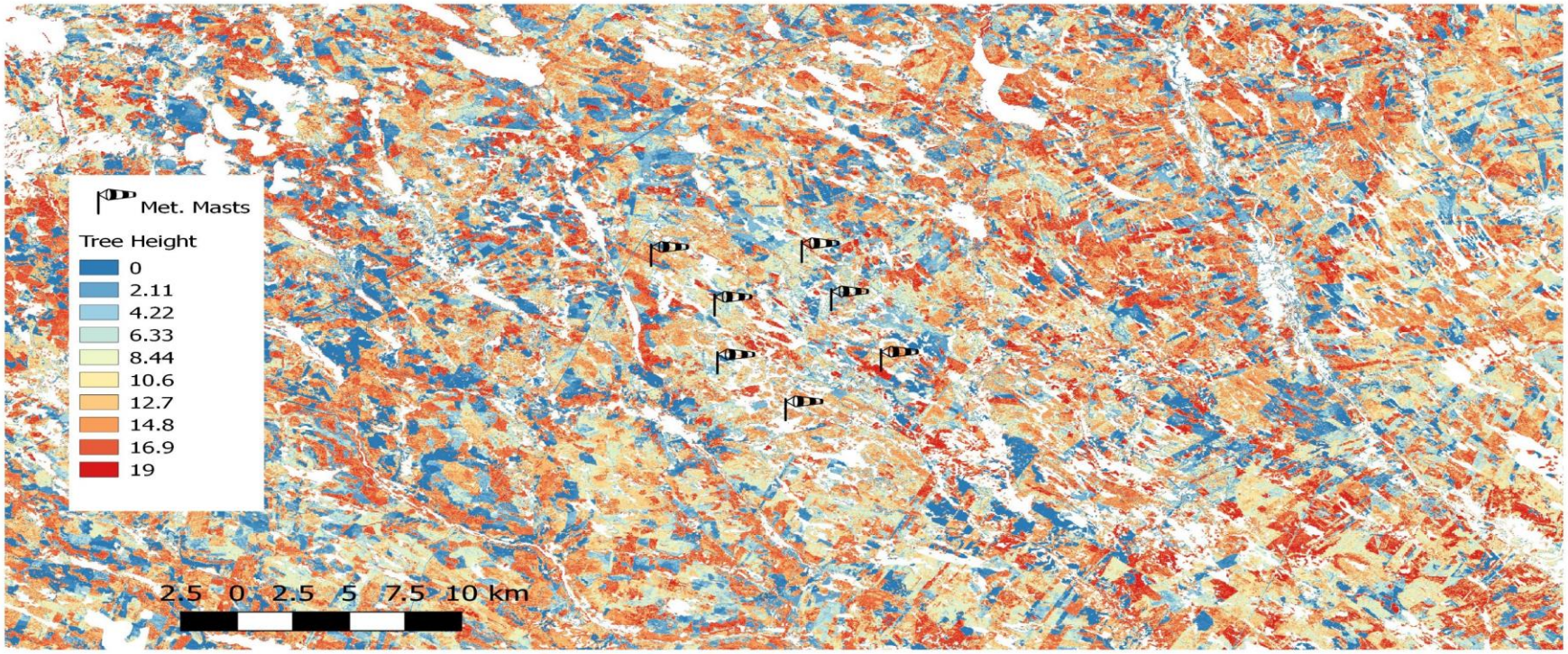


# TEST SITES

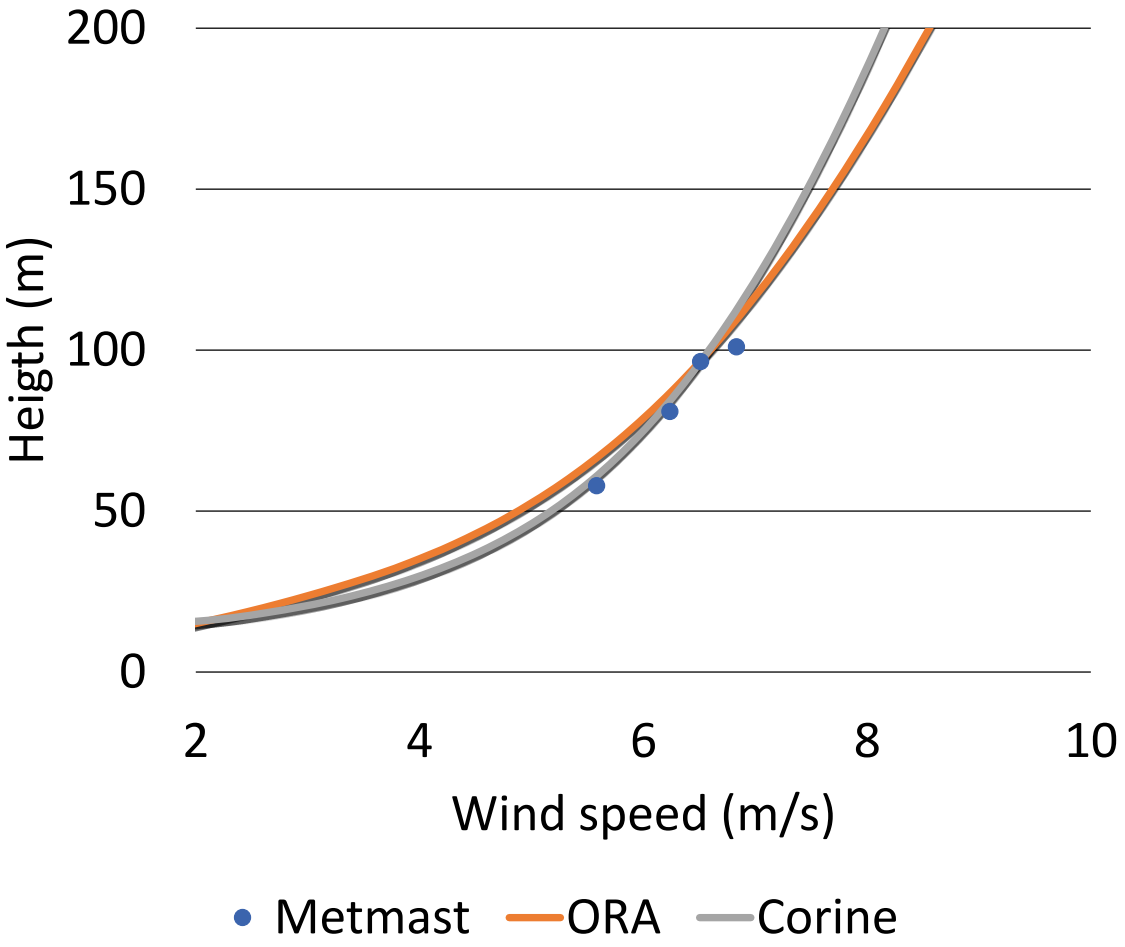
- 32 meteorological masts in forested areas located all over Europe

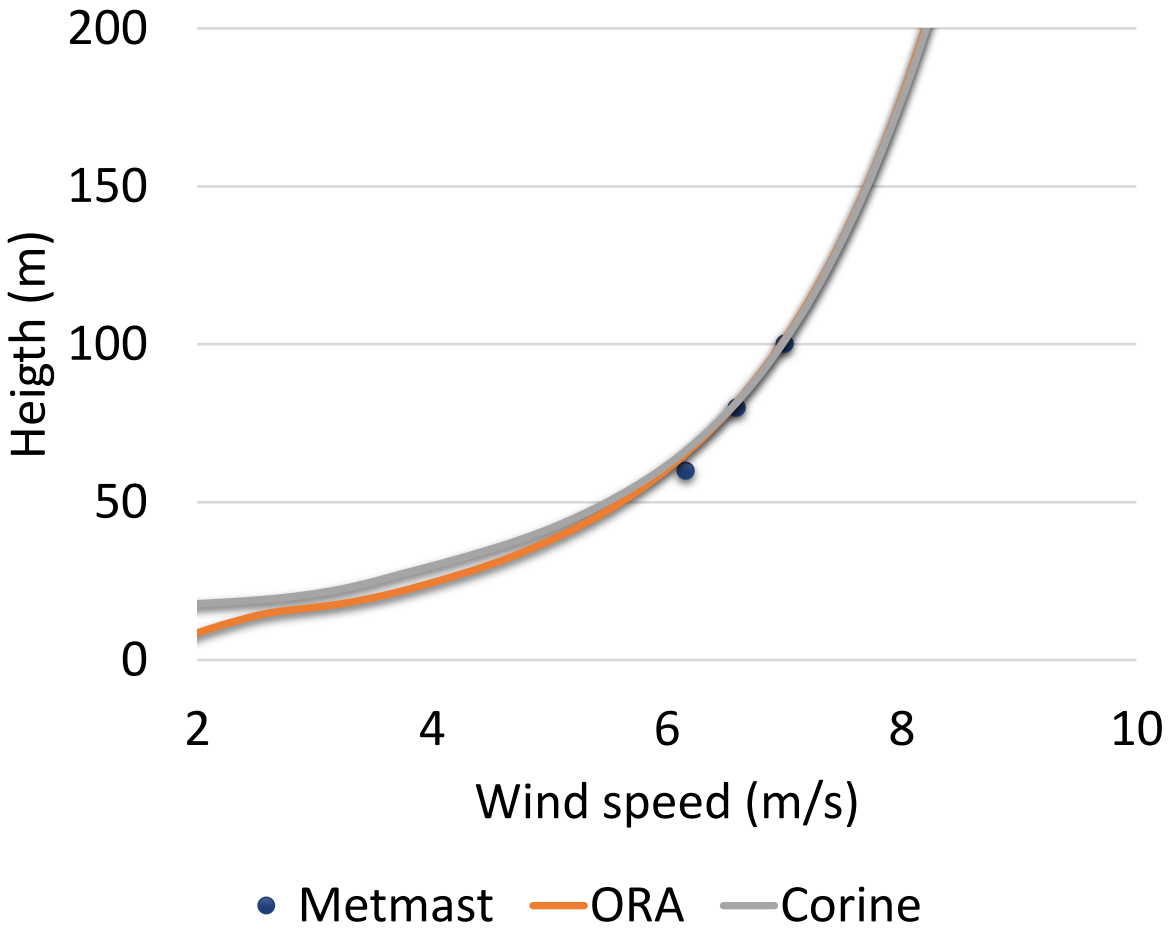


# WindSim Model Configurations

| Parameter | Value |
|---|---|
| Spatial resolution in the refinement area | 25 (m) |
| Convergence criteria | E-06 |
| Iterations | 600 |
| Number of cells in Z direction | 60 |
| Height above terrain | 2500 (m) |
| Height distribution factor | 0.02 |
| Solver | Modified k-e model |
| Forest height | 2.5 (m) |

# RESULTS


200
150
100
50
0
Heigth (m)
2
4
6
8
10
Wind speed (m/s)
Metmast
ORA
Corine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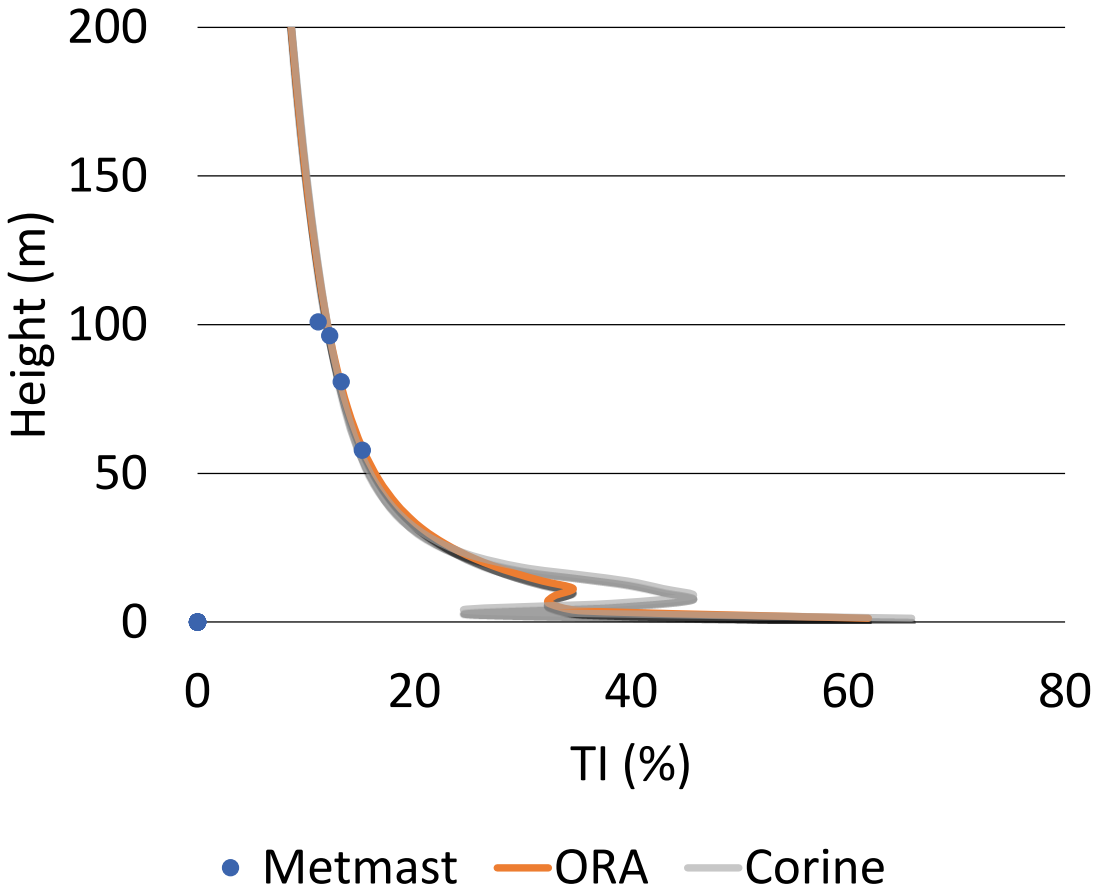
# RESULTS


200
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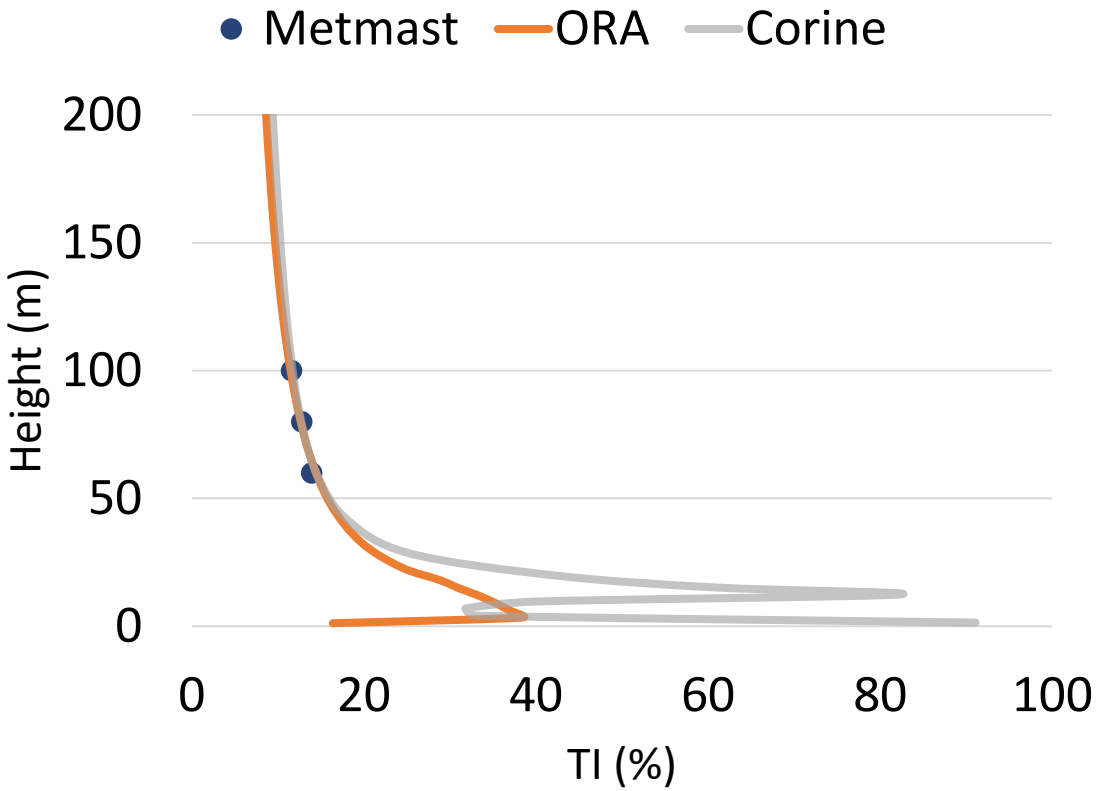
100
50
0
Height (m)
0
20
40
60
80
TI (%)
Metmast
ORA
Corine


Metmast
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Height (m)
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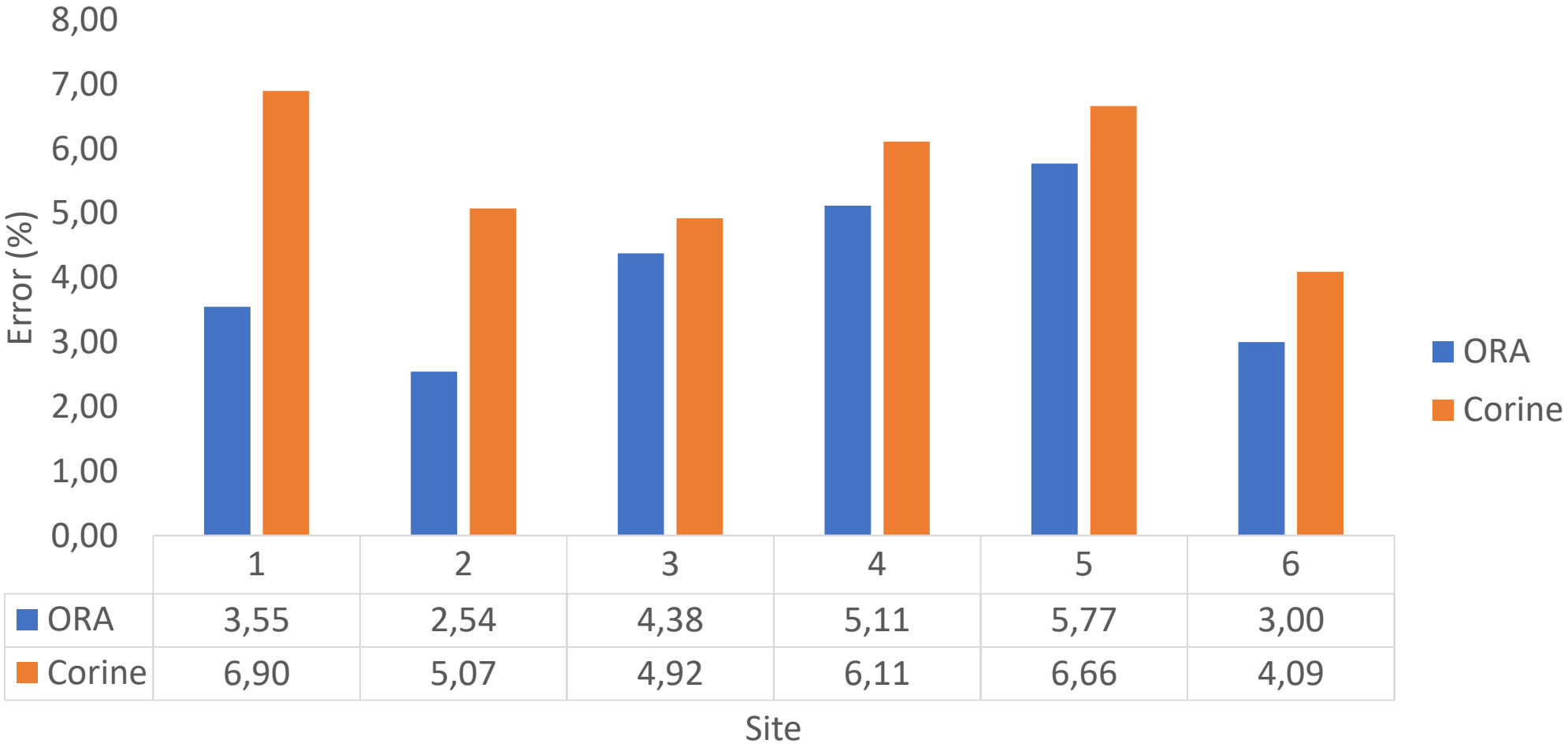
# RESULTS

## Wind Speed

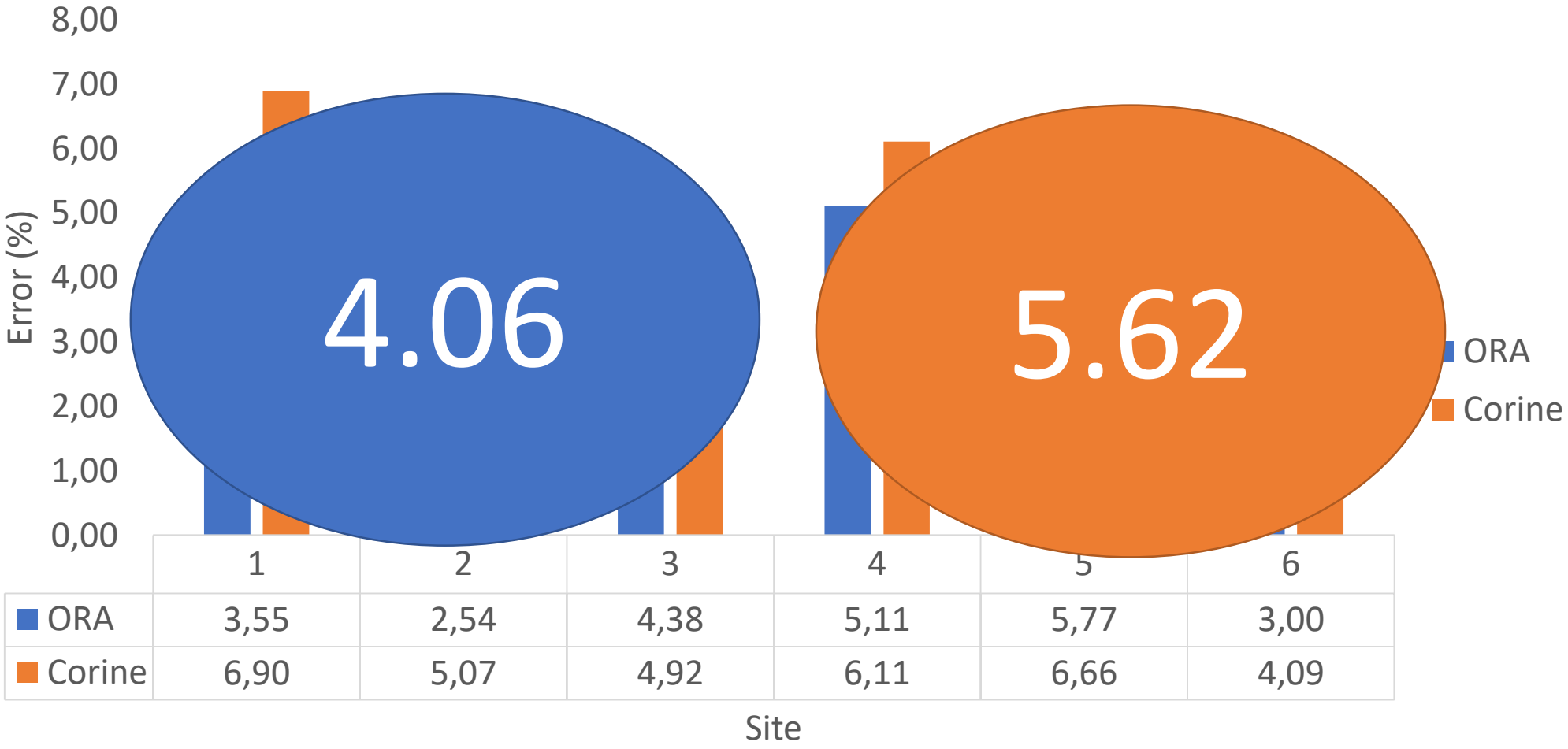



| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| ORA | 3,55 | 2,54 | 4,38 | 5,11 | 5,77 | 3,00 |
| Corine | 6,90 | 5,07 | 4,92 | 6,11 | 6,66 | 4,09 |

Site

# RESULTS

## Wind Speed

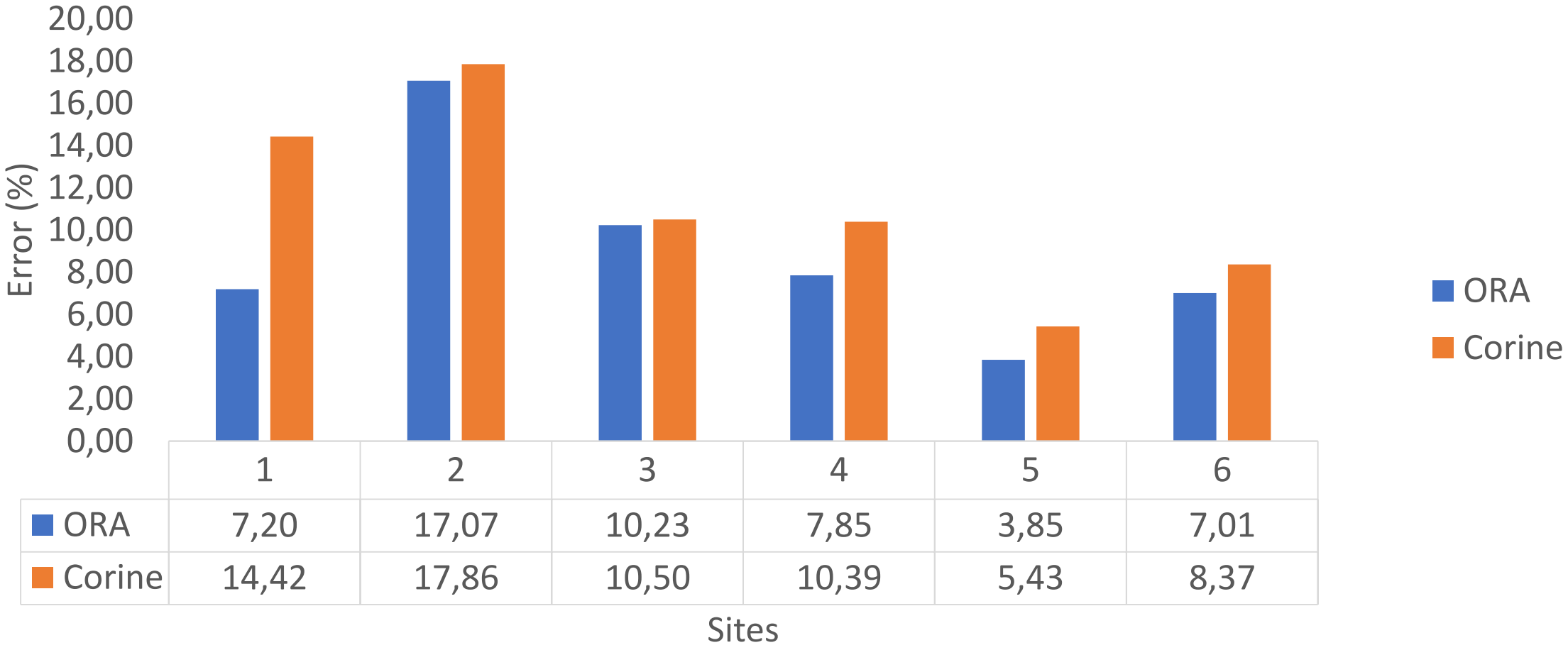



| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| ORA | 3,55 | 2,54 | 4,38 | 5,11 | 5,77 | 3,00 |
| Corine | 6,90 | 5,07 | 4,92 | 6,11 | 6,66 | 4,09 |

Site

# RESULTS

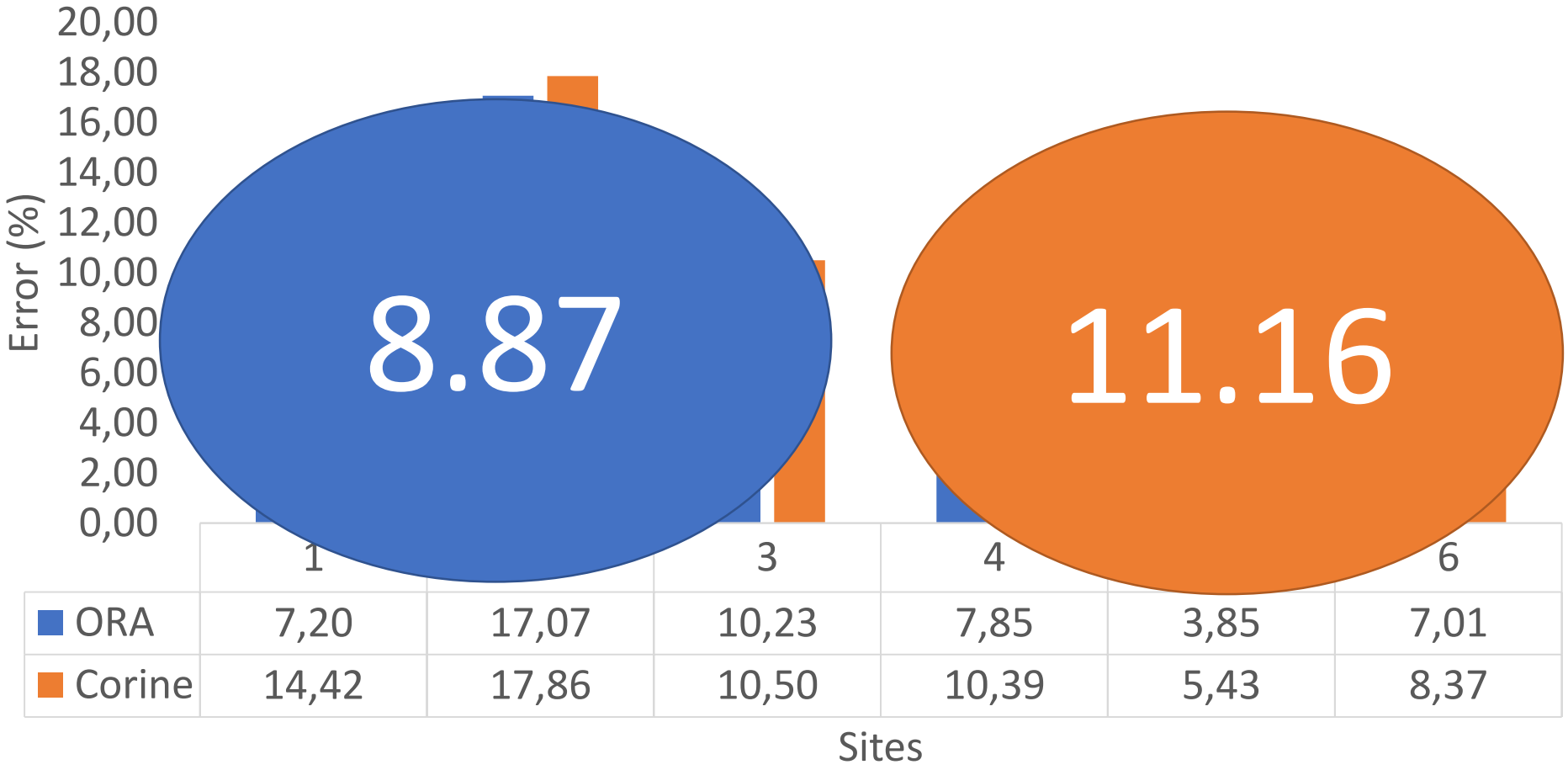
## Turbulence Intensity




| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| ORA | 7,20 | 17,07 | 10,23 | 7,85 | 3,85 | 7,01 |
| Corine | 14,42 | 17,86 | 10,50 | 10,39 | 5,43 | 8,37 |

# RESULTS

## Turbulence Intensity




| | 1 | 3 | 4 | 6 |
|---|---|---|---|---|
| ORA | 7,20 | 17,07 | 10,23 | 7,85 | 3,85 | 7,01 |
| Corine | 14,42 | 17,86 | 10,50 | 10,39 | 5,43 | 8,37 |

# RECOMMENDATIONS

- Forest Cell Counts: We recommend that you use 2.5 m forest cells for all trees with a height between 5 – 30 meters.
- When using high resolution input data The Optimized Roughness Approach (ORA) provides better results than the various online roughness sources for assessments of wind speed and turbulence intensity in forested areas.
- Tree height information can be considered a minimum requirement for estimations of wind conditions in forested areas.
- C2 predictions can now be used in areas with little information on forestry, by applying databases based on open source data ***(We will soon launch the one presented here)***

- Copernicus
- Iio & Ito (2014)
- WindSim 9.0

# CONTACT INFORMATION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