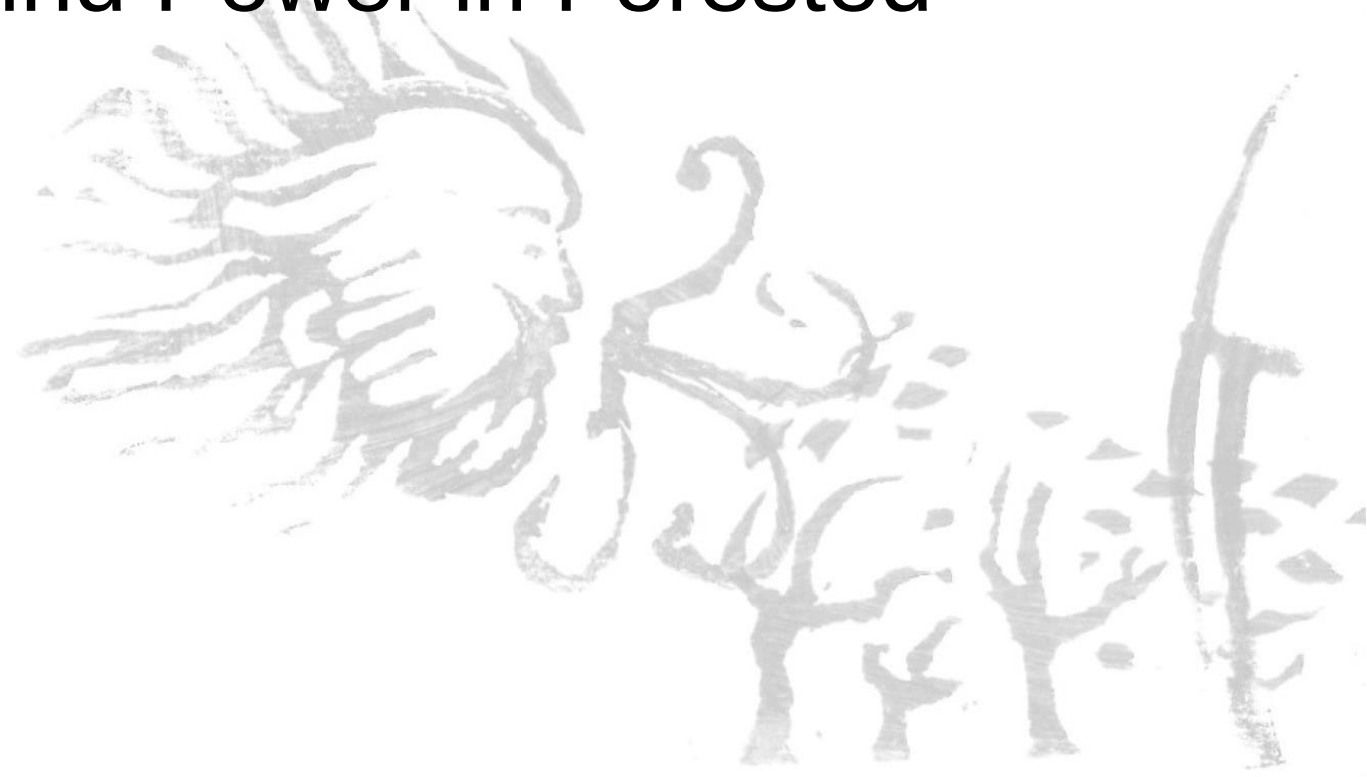
SWC Webinar: Understanding Wind Power in Forested Landscapes



Outline

- Introduction, with some historical background (Johan)
  - What defines the boundary layer above forests and what are the challenges when modelling wind power in forested areas?
  - How does current industrial standards compare to observations?
  - Important modelling concepts
- Progress in the model development during the last decade (Hugo)
  - The influence of the surface
  - The diurnal cycle
  - Moving into wake modelling over forests
- Our current state of the art (Memo)
  - Large eddy simulation over heterogeneous forest including realistic turbine simulations
- Outlook and current research gaps (Everyone)

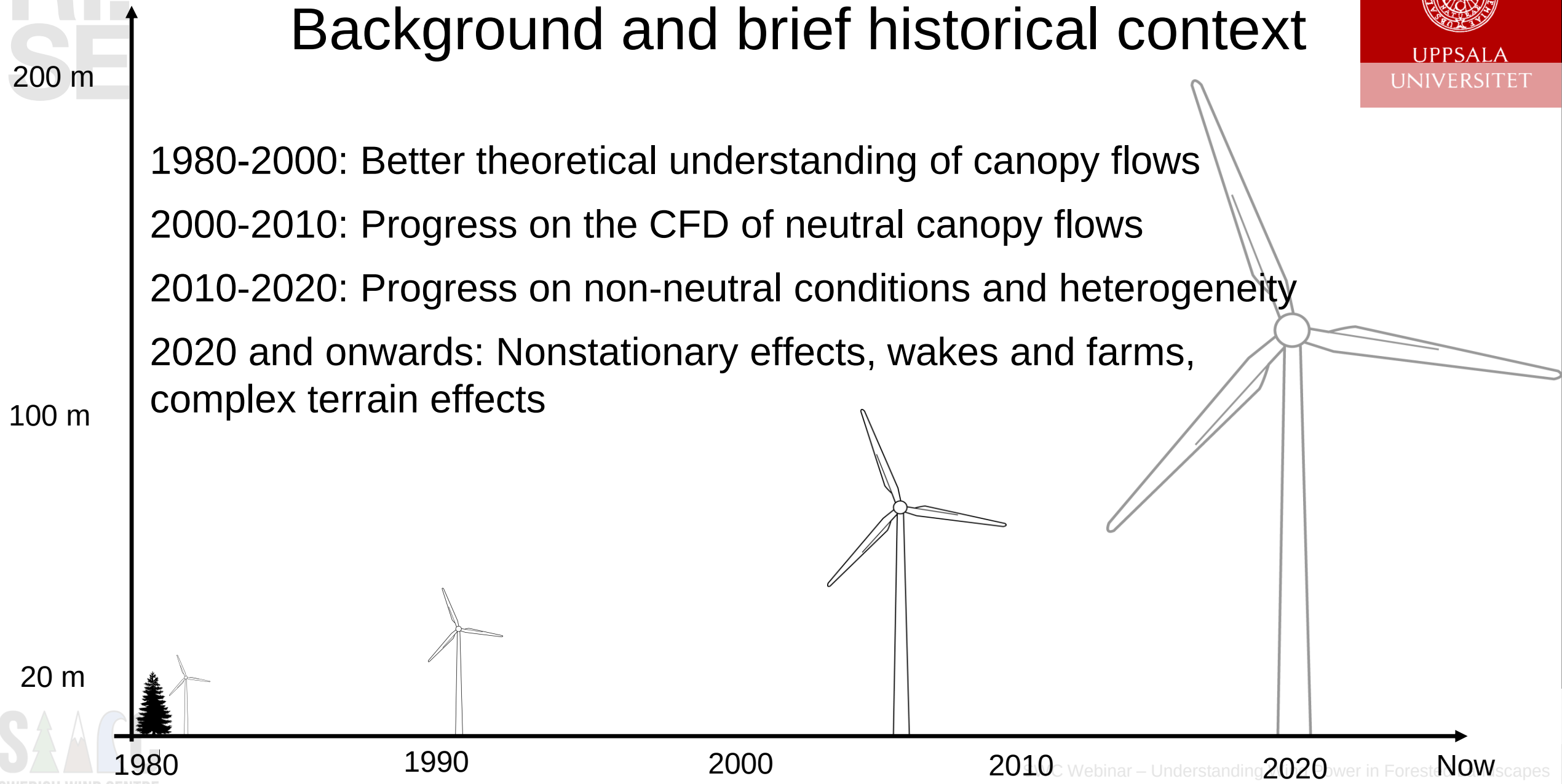
Background and brief historical context

1980-2000: Better theoretical understanding of canopy flows

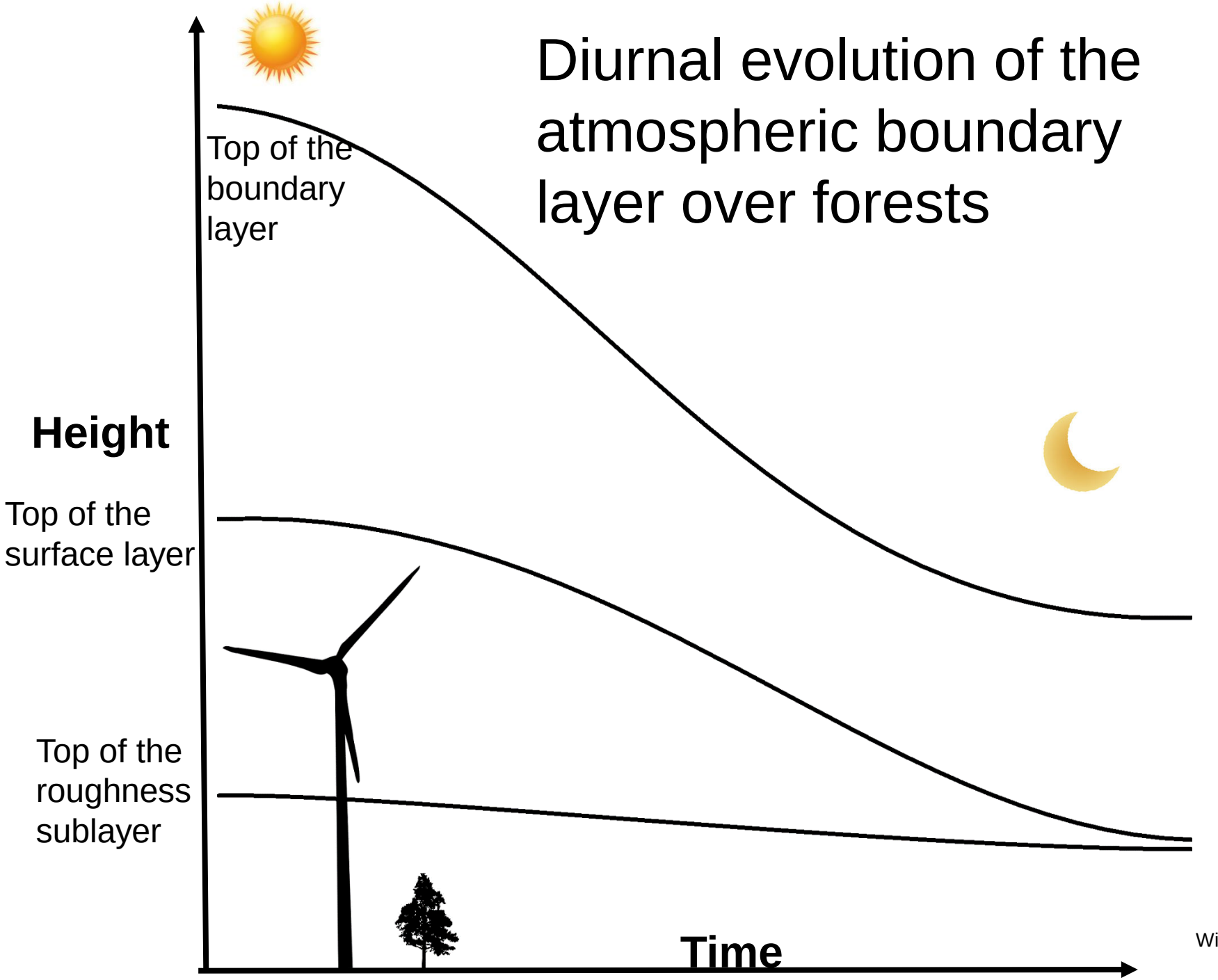
2000-2010: Progress on the CFD of neutral canopy flows

2010-2020: Progress on non-neutral conditions and heterogeneity

2020 and onwards: Nonstationary effects, wakes and farms, complex terrain effects



Diurnal evolution of the atmospheric boundary layer over forests



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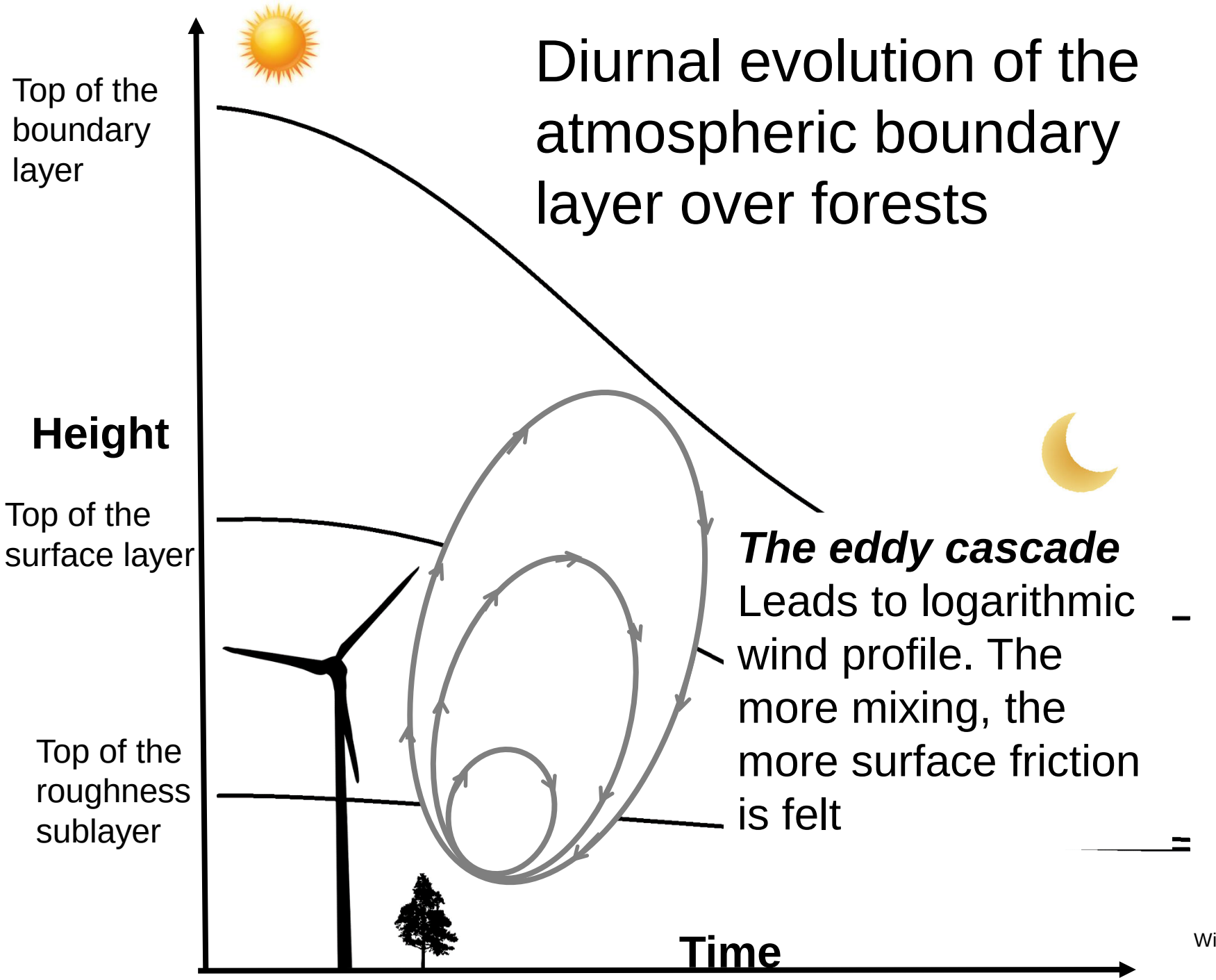
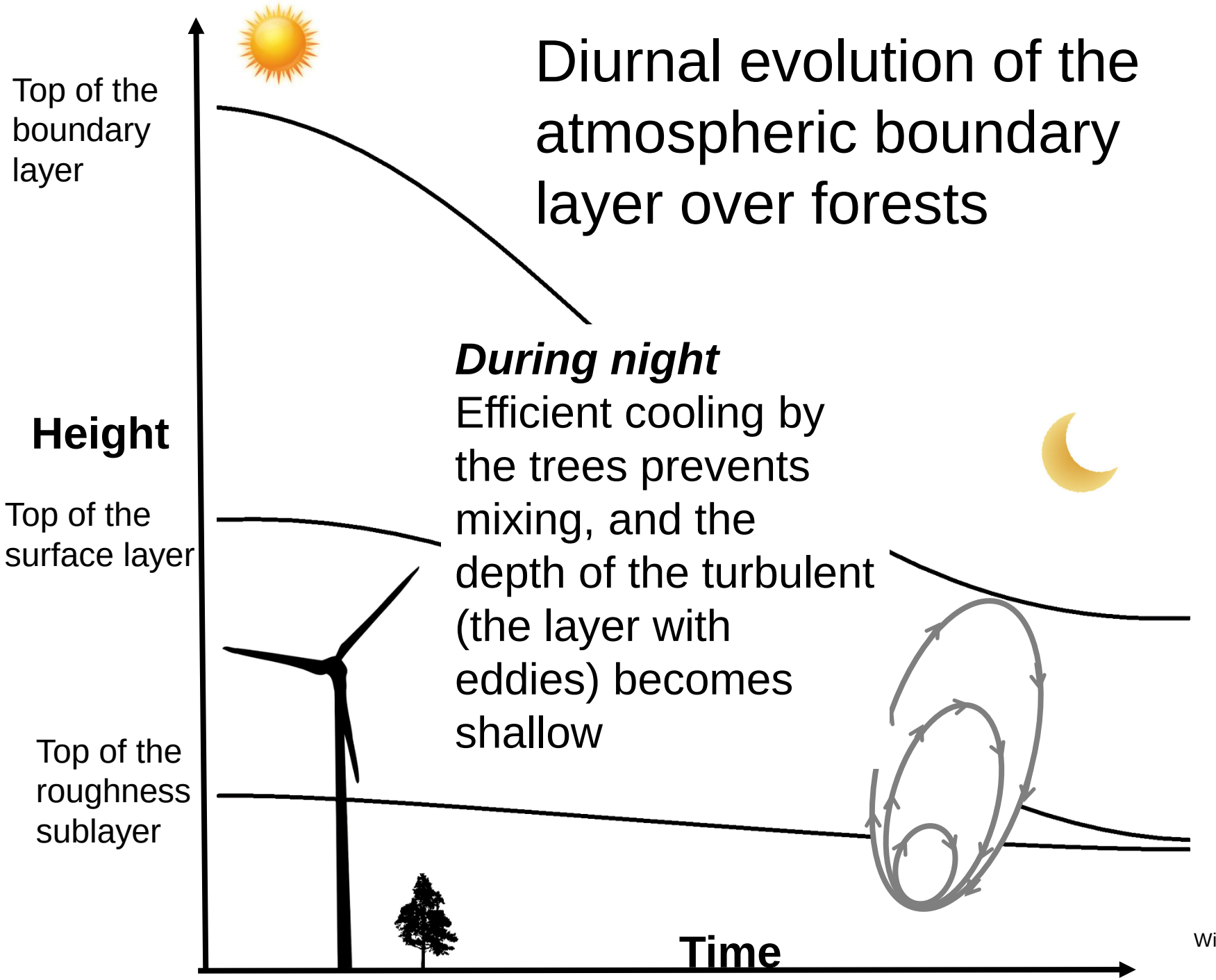


The eddy cascade

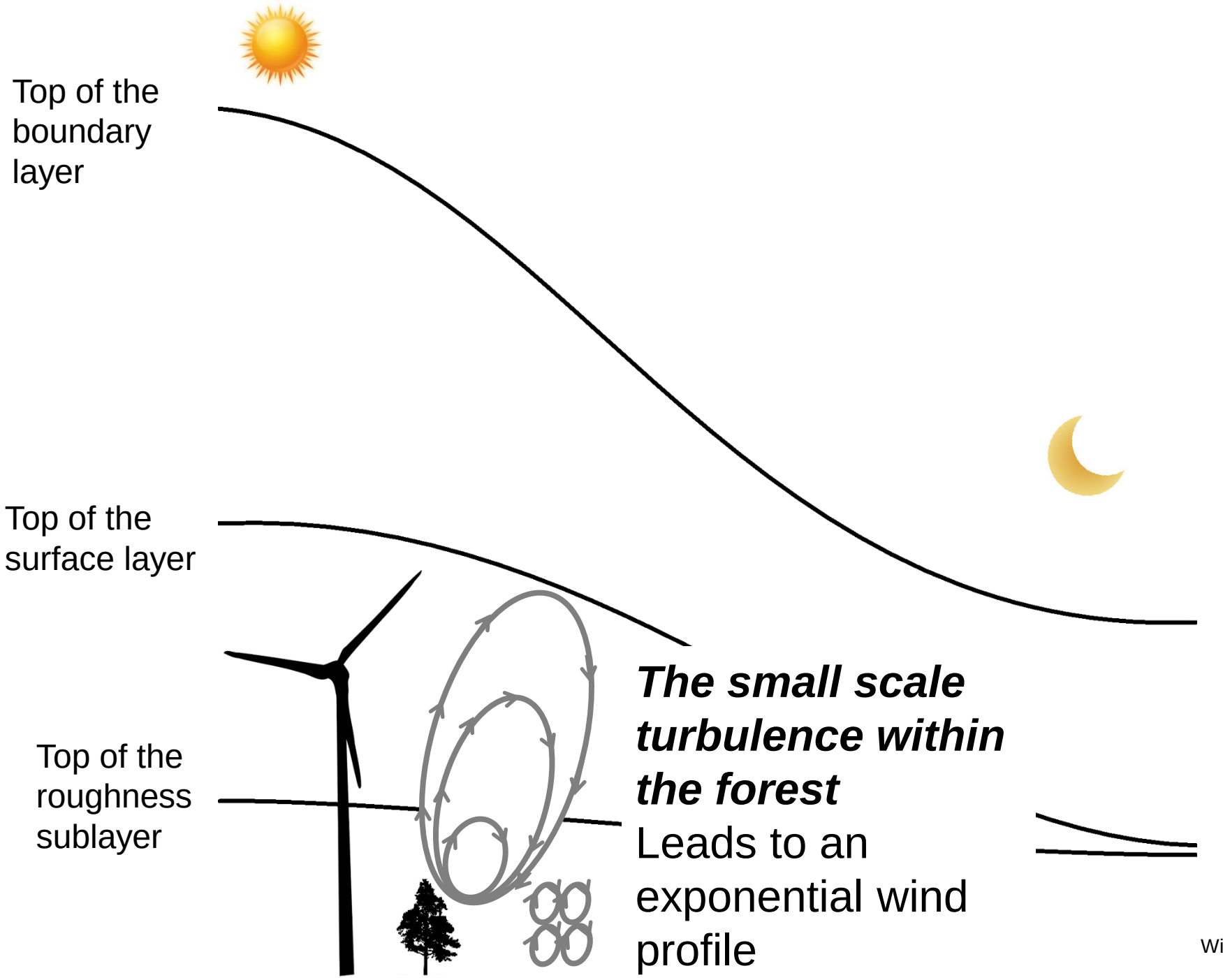
Leads to logarithmic wind profile. The more mixing, the more surface friction is felt

Diurnal evolution of the atmospheric boundary layer over forests



During night

Efficient cooling by the trees prevents mixing, and the depth of the turbulent (the layer with eddies) becomes shallow



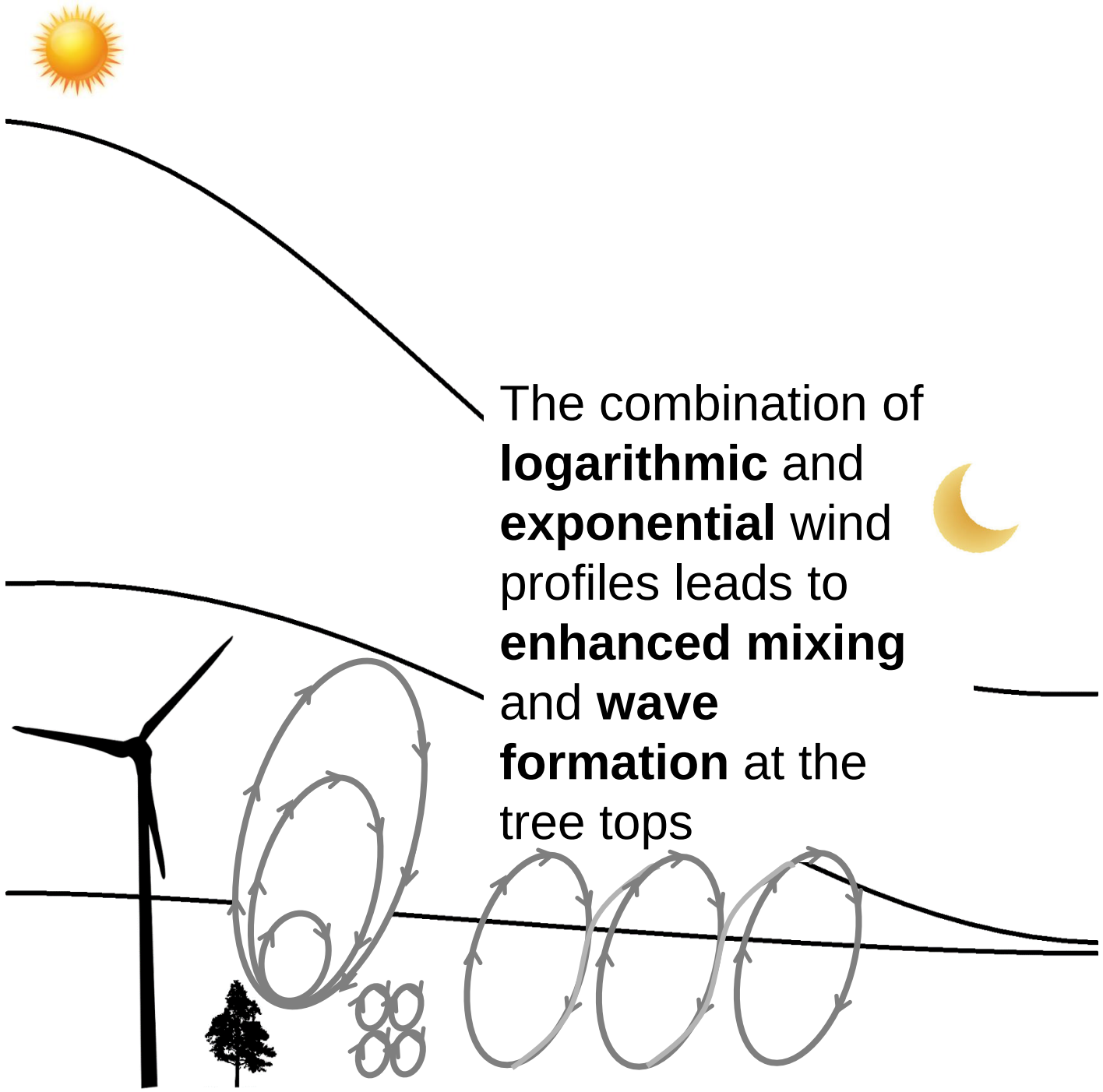
The small scale turbulence within the forest

Leads to an exponential wind profile

Top of the boundary layer

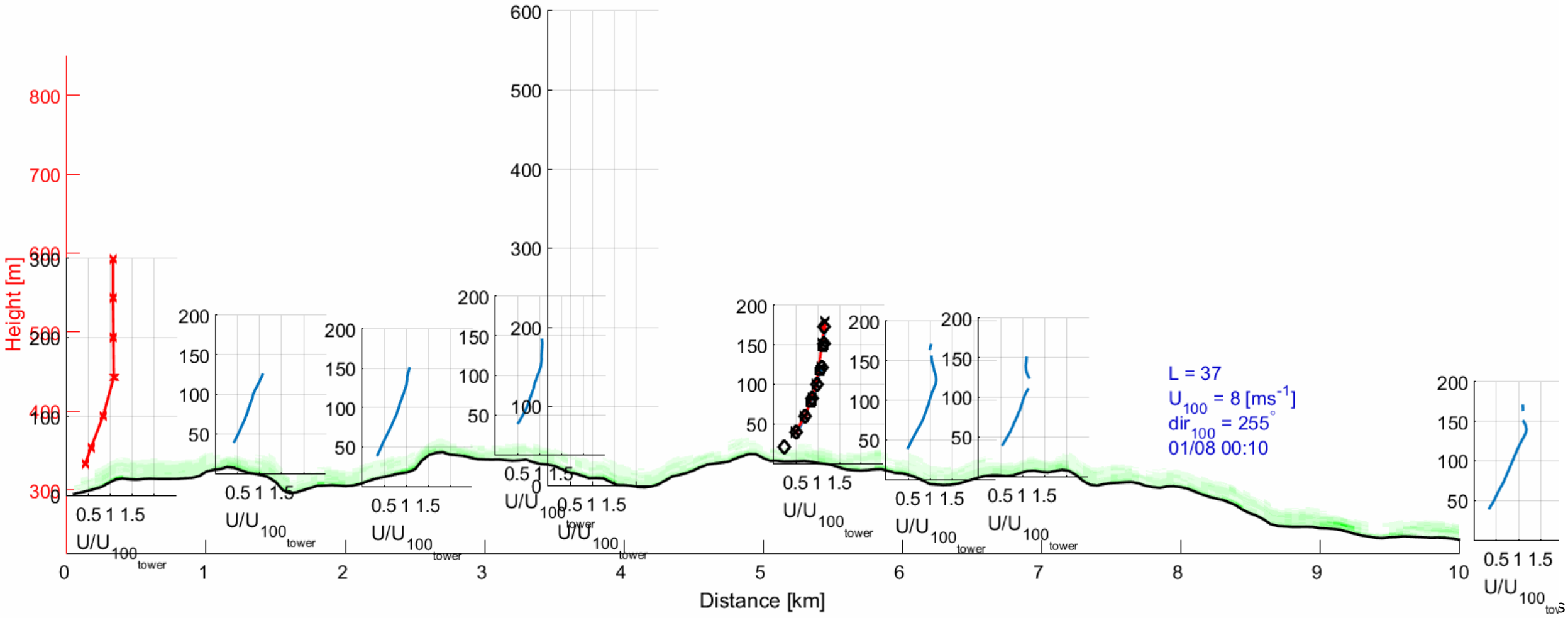
Top of the surface layer

Top of the roughness sublayer



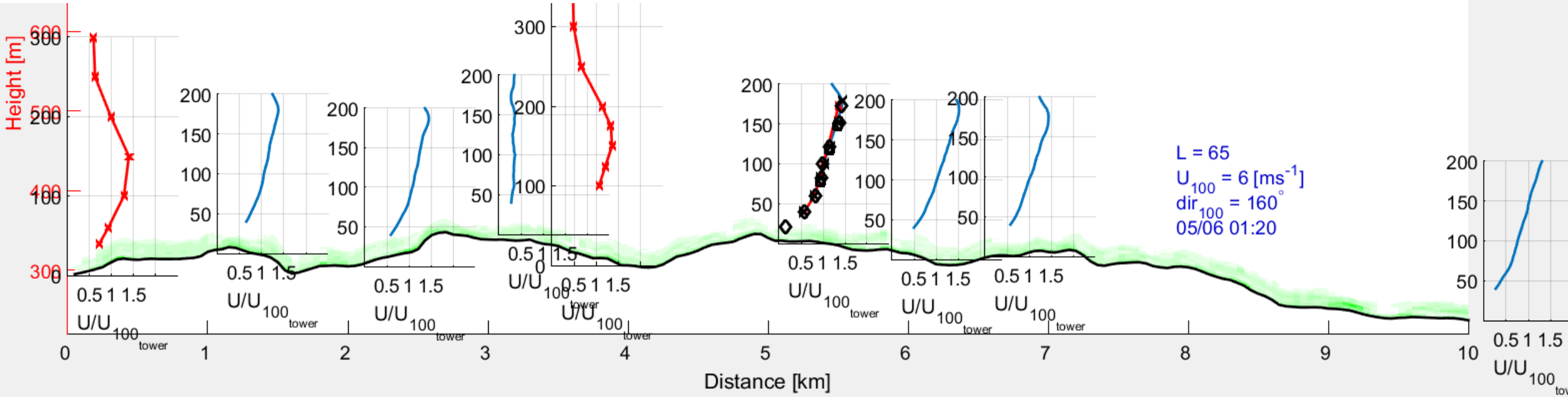
The combination of **logarithmic** and **exponential** wind profiles leads to **enhanced mixing** and **wave formation** at the tree tops

The rapid transitions between stable (night) and unstable (day) cause nonstationary effects, such as Low Level Jets (LLJ) and intermittent turbulence



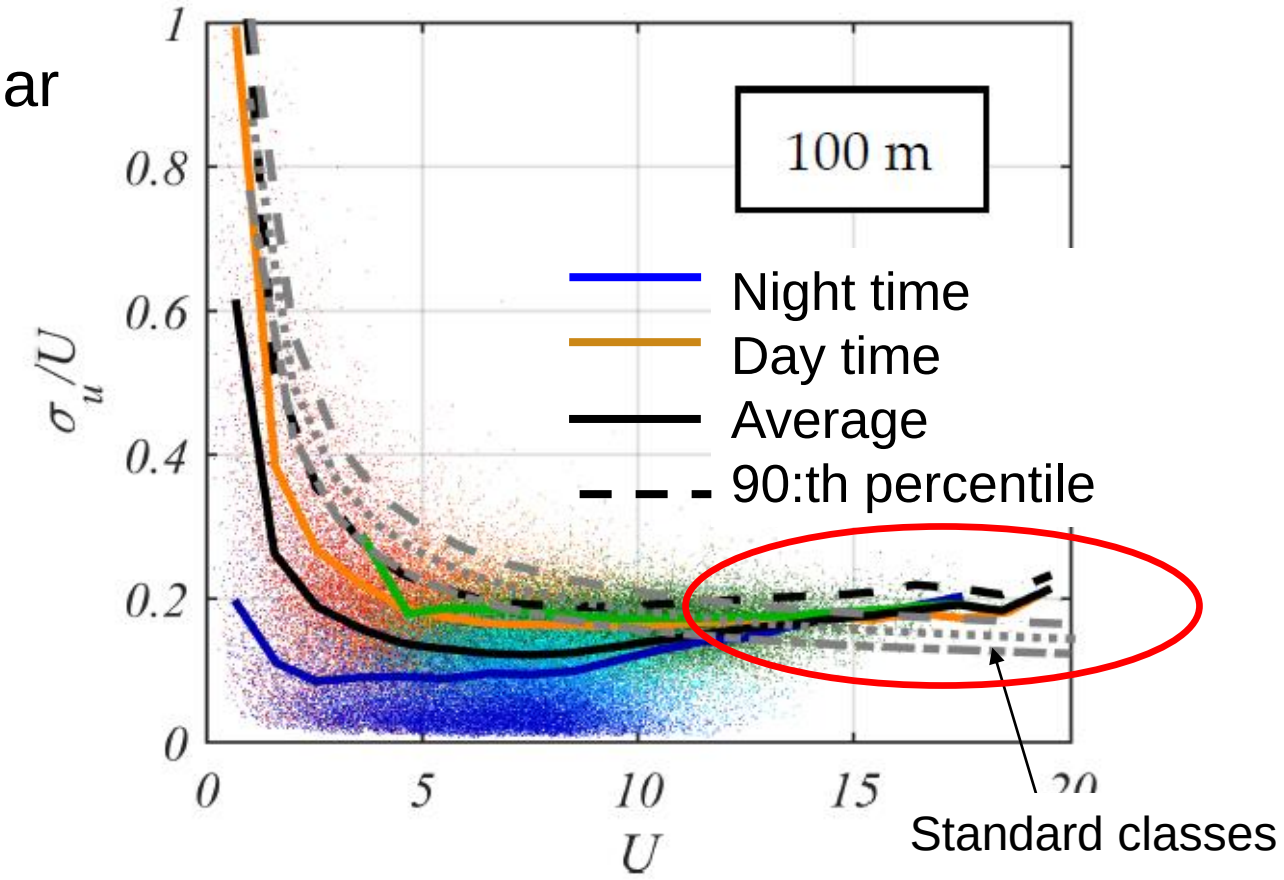
Challenges with wind power in forested areas

- Stable (Night)
  - High wind shear and directional shear
  - Very non-standard wind profiles
  - Rapid flow transitions



Challenges with wind power in forested areas

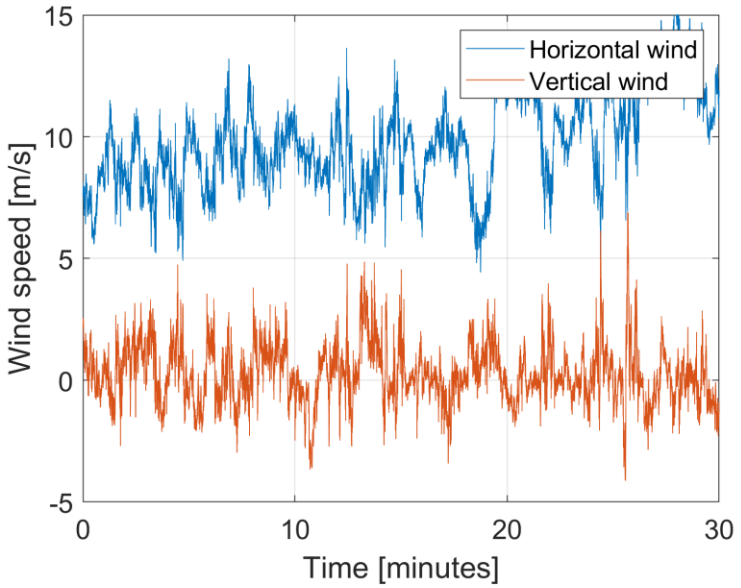
- Stable (Night)
  - High wind shear and directional shear
  - Very non-standard wind profiles
  - Rapid flow transitions
- Neutral and Unstable (Day)
  - Very high tubulence intensity
  - High fatigue loads above rated operation



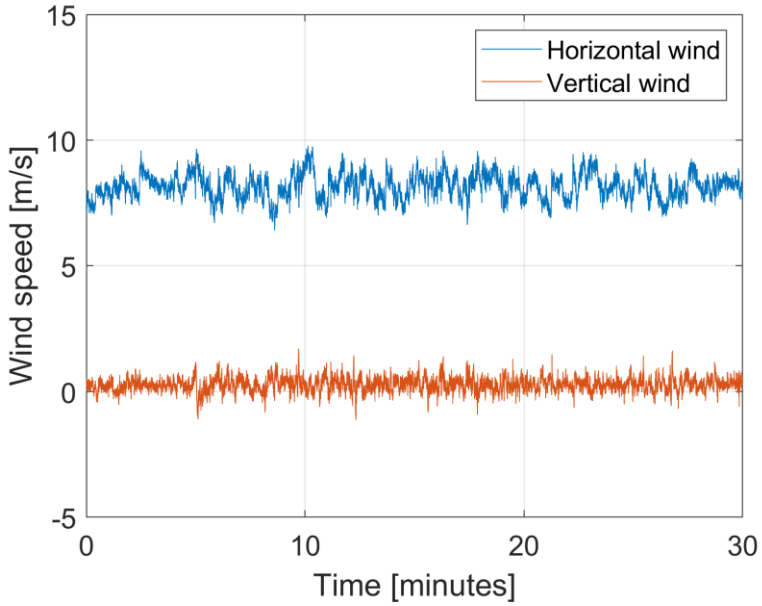
Challenges with wind power in forested areas

- Broadly two very distinct flow regimes
  - Neutral and unstable conditions: very high turbulence levels
  - Stable conditions : high veer and shear, rapid transitions

Time series at 15:00



Time series at 03:00



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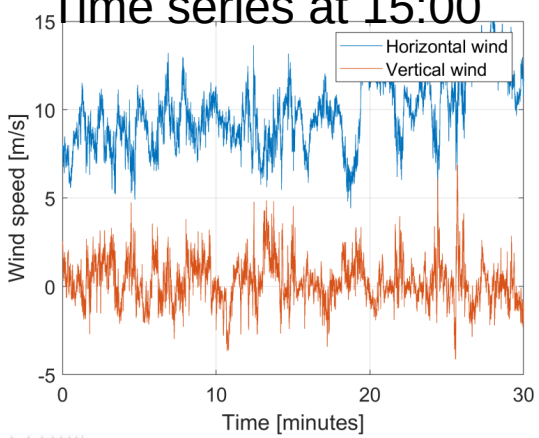

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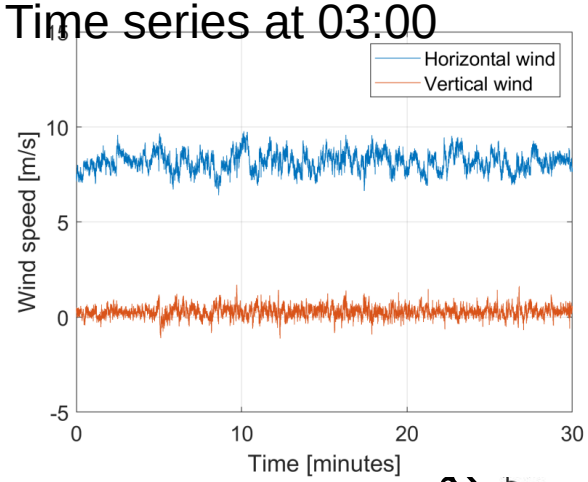
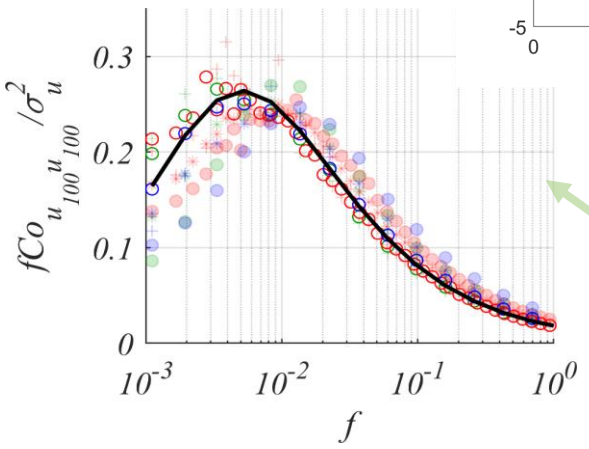


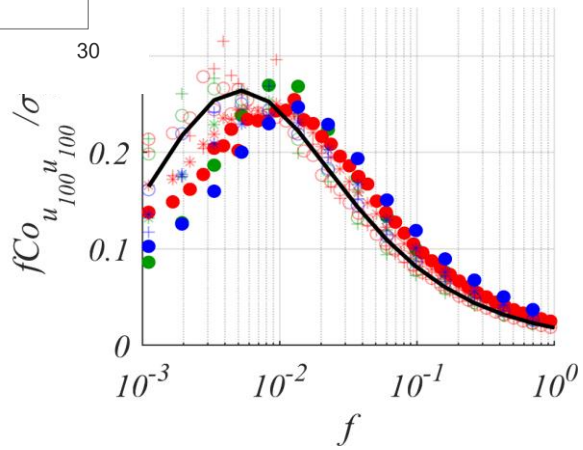
Daytime

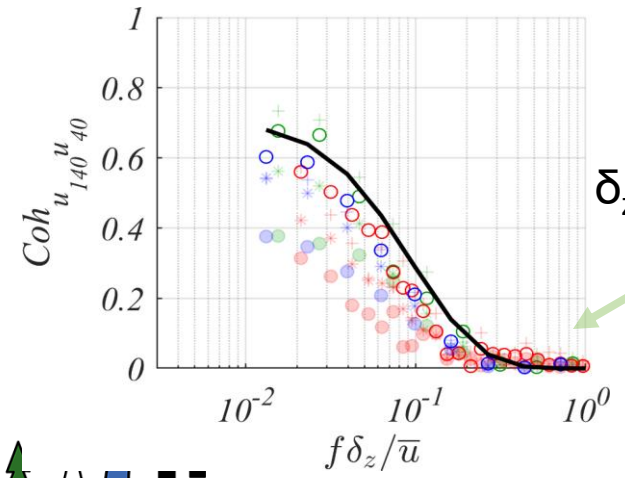
Nighttime

z=100 m

z=100 m







δ_z=100 m

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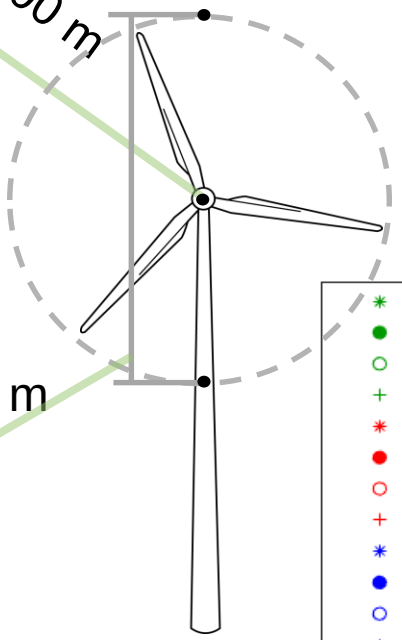
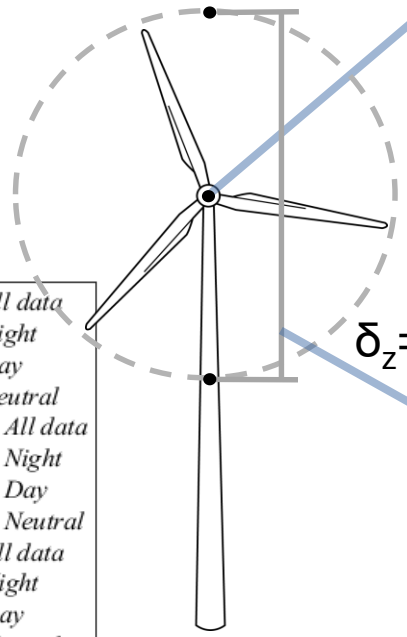
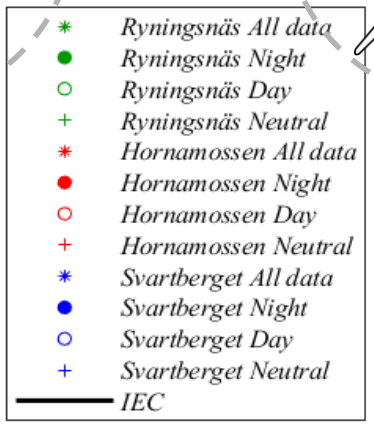
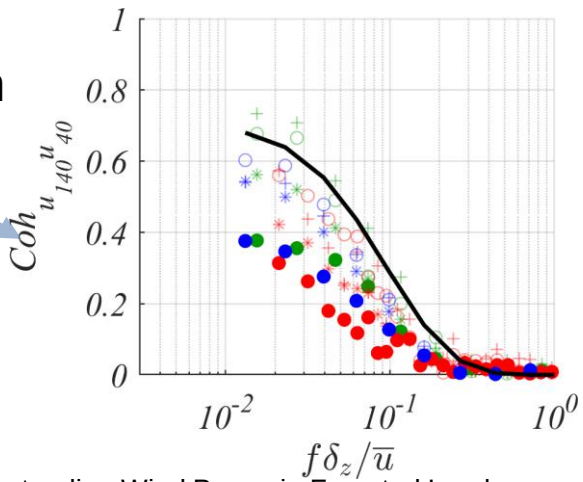


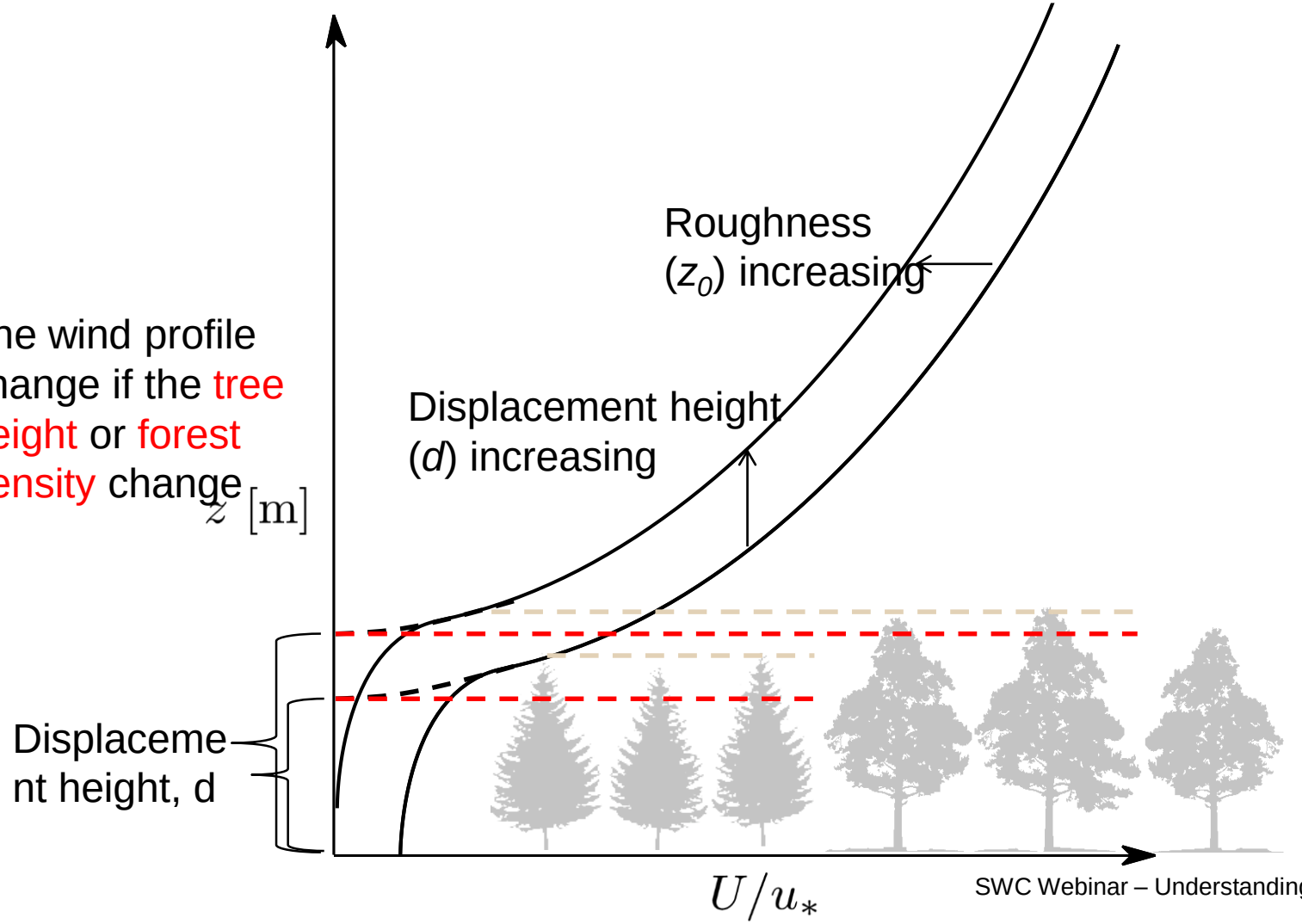






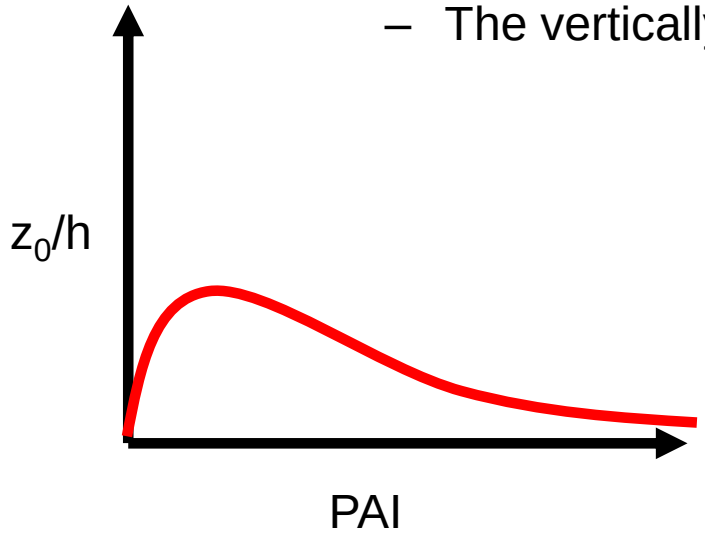
How the forest is modelled

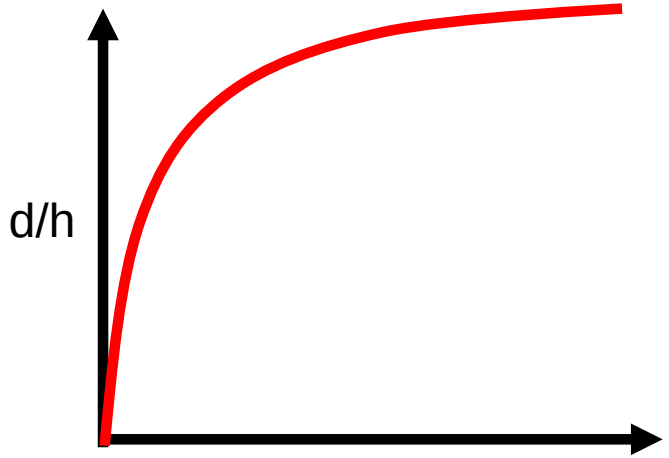
The wind profile change if the tree height or forest density change



In CFD, the forest can also be modelled through drag dependent on the forest density

- PAD – Plant Area Density (often called LAD – Leaf Area Density)
  - The frontal area of the forest in the wind direction
- PAI – Plant Area Index (Often LAI – Leaf Area Index)
  - The vertically integrated PAD





Given a site, how much upstream forest is important for the wind?

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PATCHY FOREST WITH SNOW (HIGH ROUGHNESS, LOW ALBEDO, COMPLEX CANOPY EFFECTS)

SWEDISH WIND CENTRE

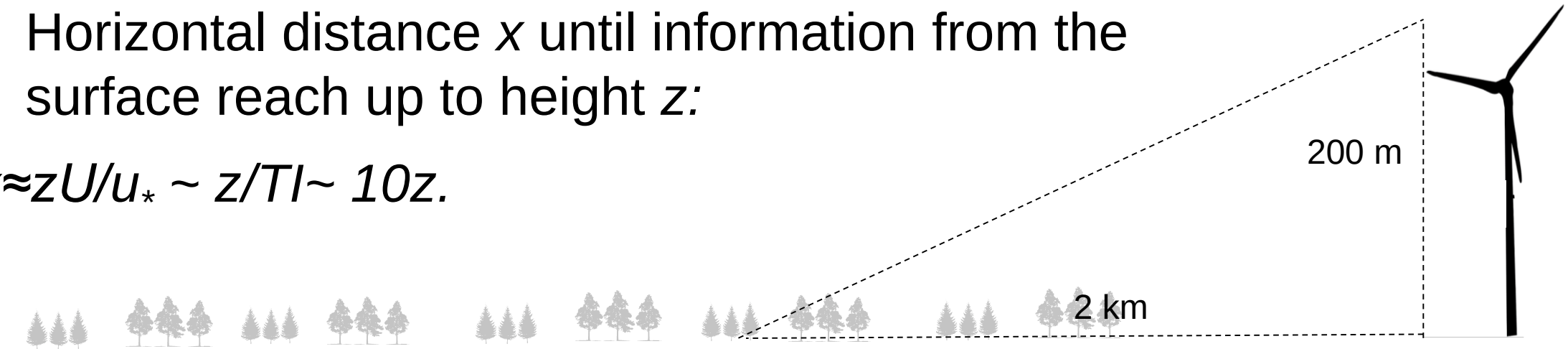
- The area where roughness is important is called **footprint**.
- Using scales we can estimate a rough idea of the footprint:

Velocity scale of horizontal transport: U (m/s)

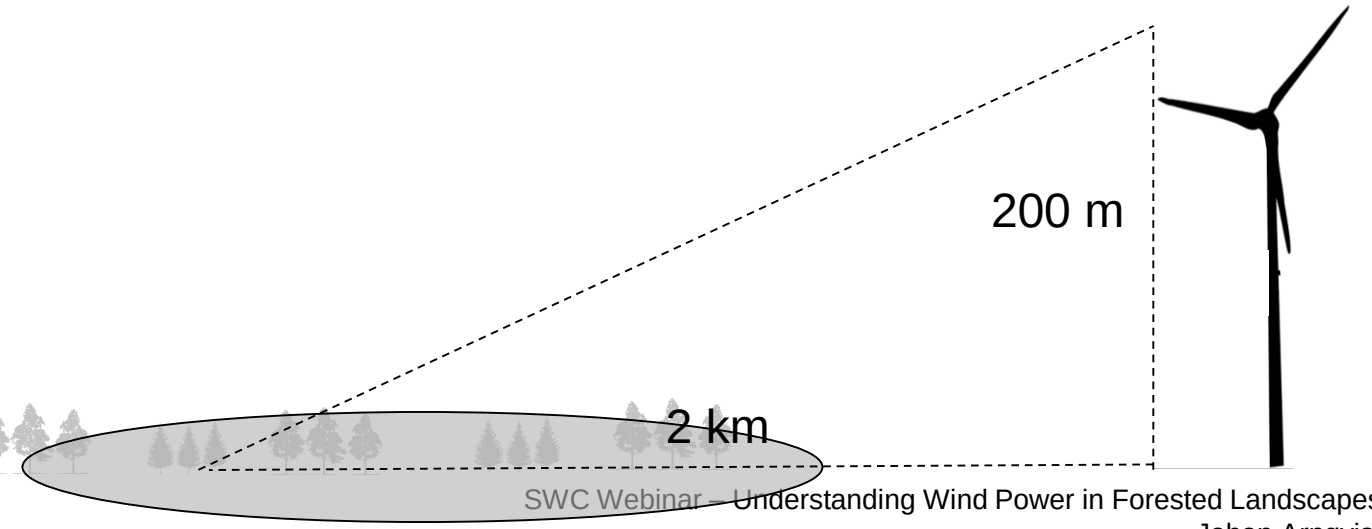
Velocity scale of vertical transport u_* (m/s)

- Horizontal distance x until information from the surface reach up to height z:

$x \approx zU/u_* \sim z/TI \sim 10z.$



- In practice the area of importance extends both closer than *10z* and further away, but 10*z* gives a good idea where the maximum impact originates in neutral conditions.



- In practice the area of importance extends both closer than *10z* and further away, but 10*z* gives a good idea where the maximum impact originates in neutral conditions.
- In stable conditions, the turbulence transport is much lower and the footprint becomes much longer