# Land-Atmospheric Interactions over Heterogeneous Surfaces: Observation to Numerical Weather Prediction Models


Karlsruhe Institute of Technology

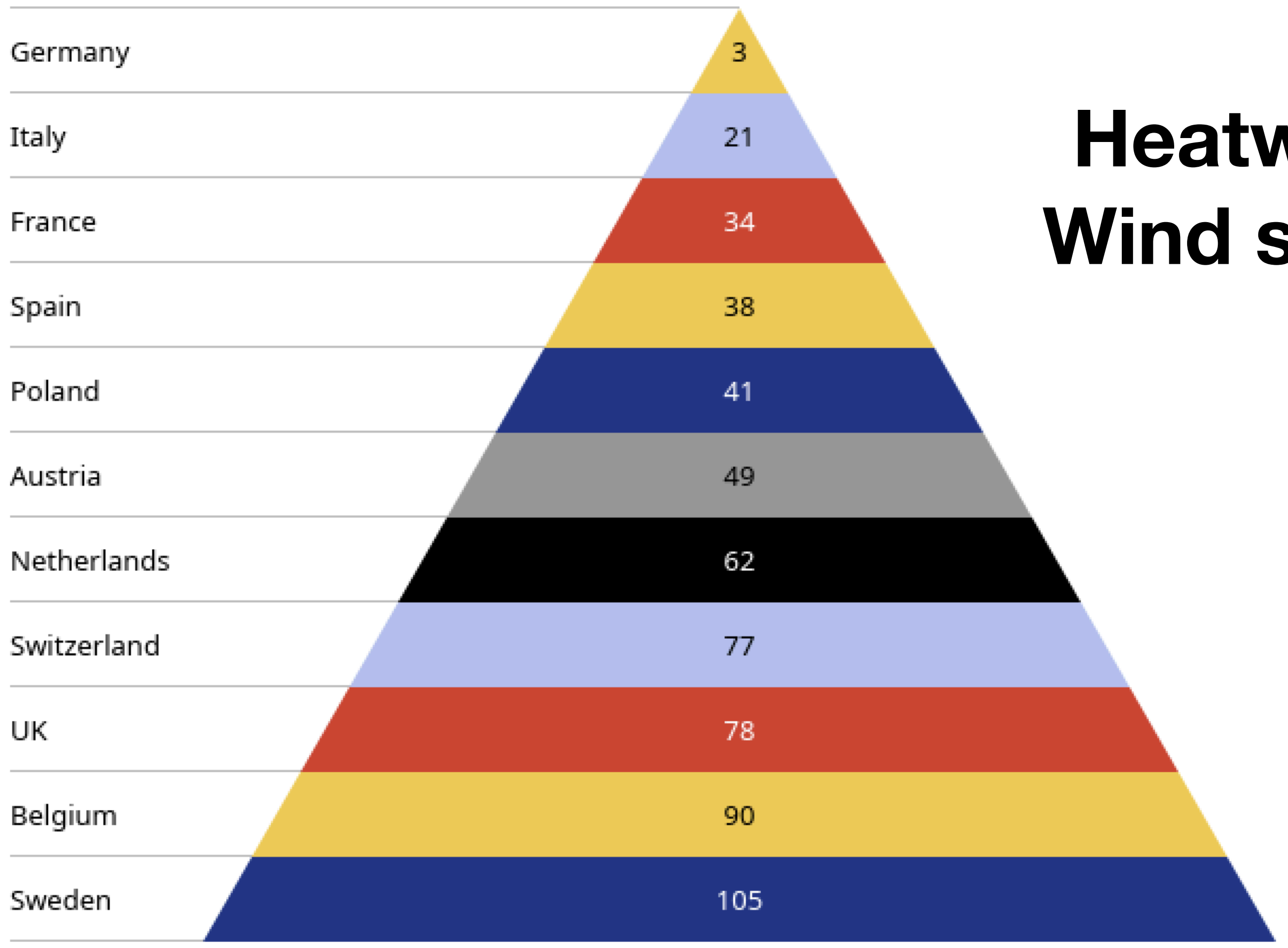
KIT-Campus Alpin
IMK-IFU: Atmospheric Environmental Research

**Hawwa Kadum**
**Urban & Eco-Climatology**

# Motivation

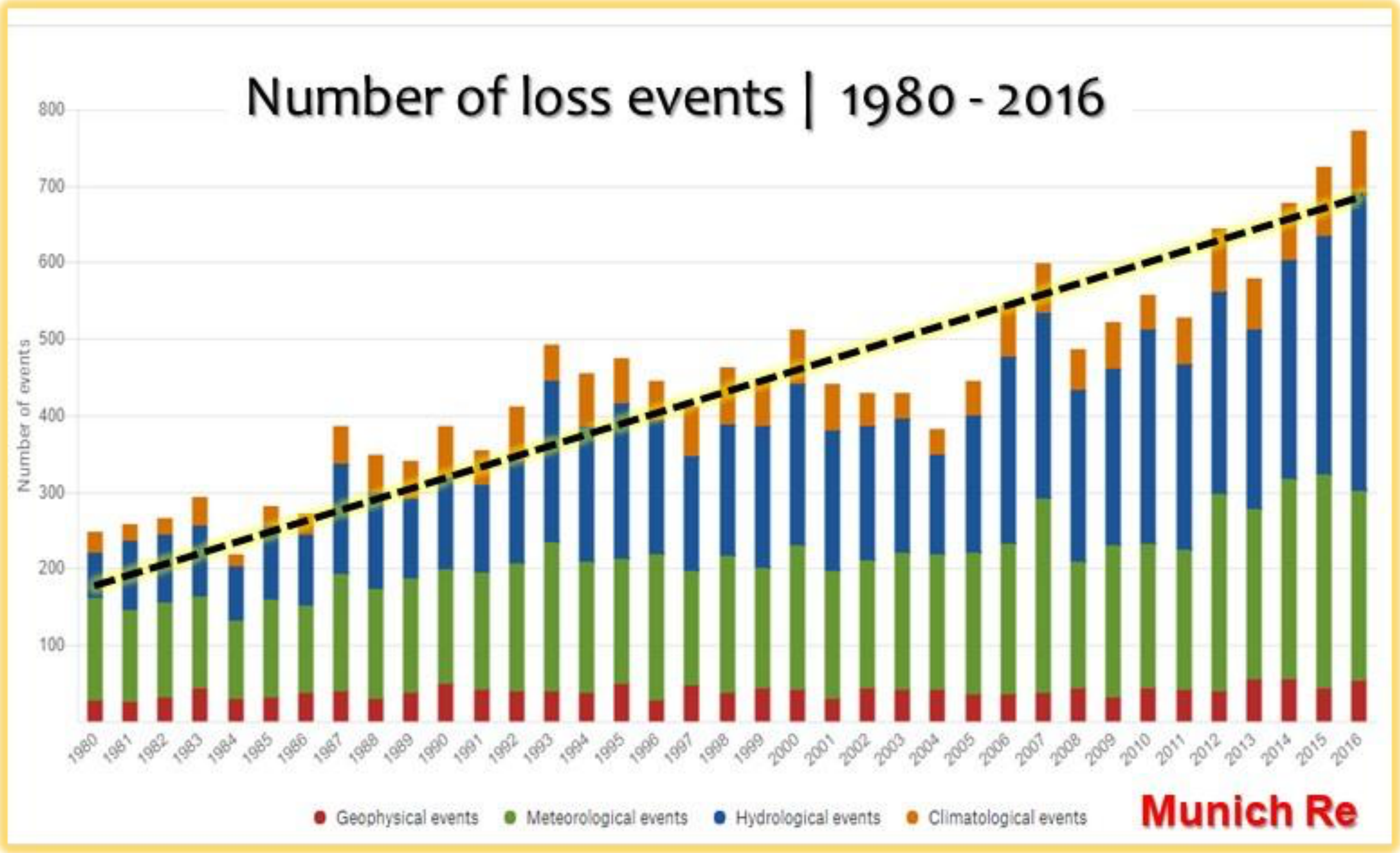
## Extreme Weather Events

CRI ranking for Europe's largest economies in 2018



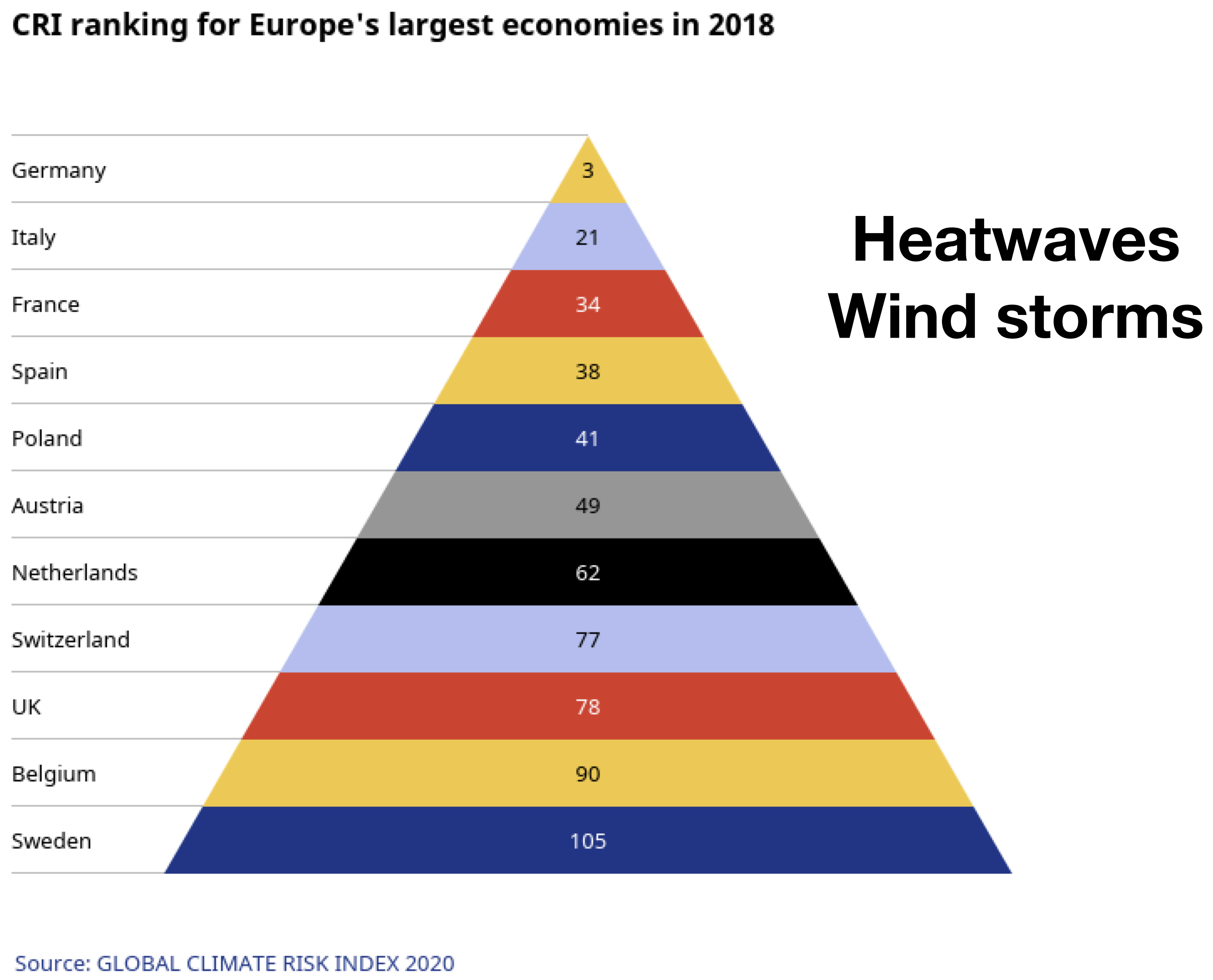

Source: GLOBAL CLIMATE RISK INDEX 2020

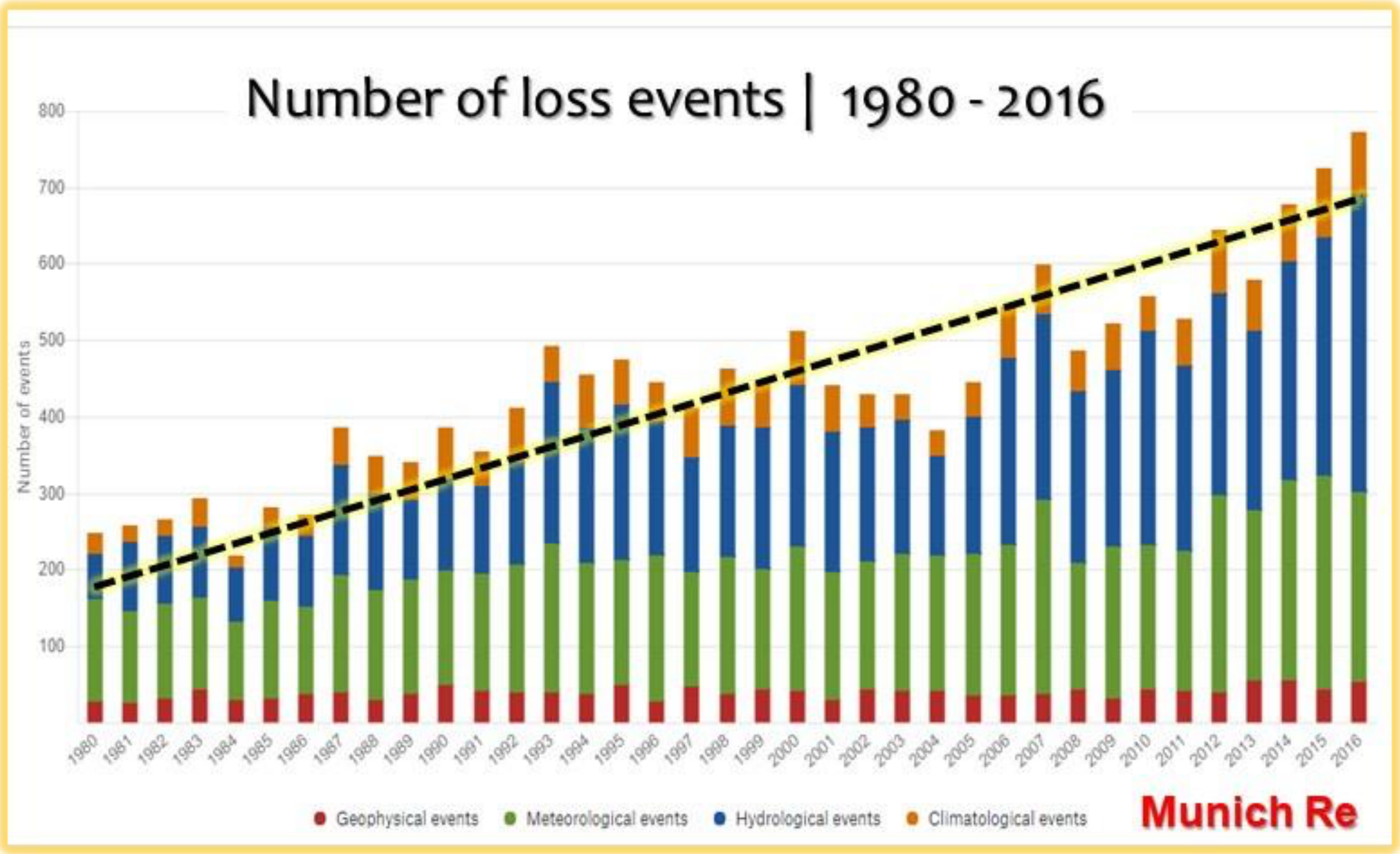
**Heatwaves**
**Wind storms**



# Motivation

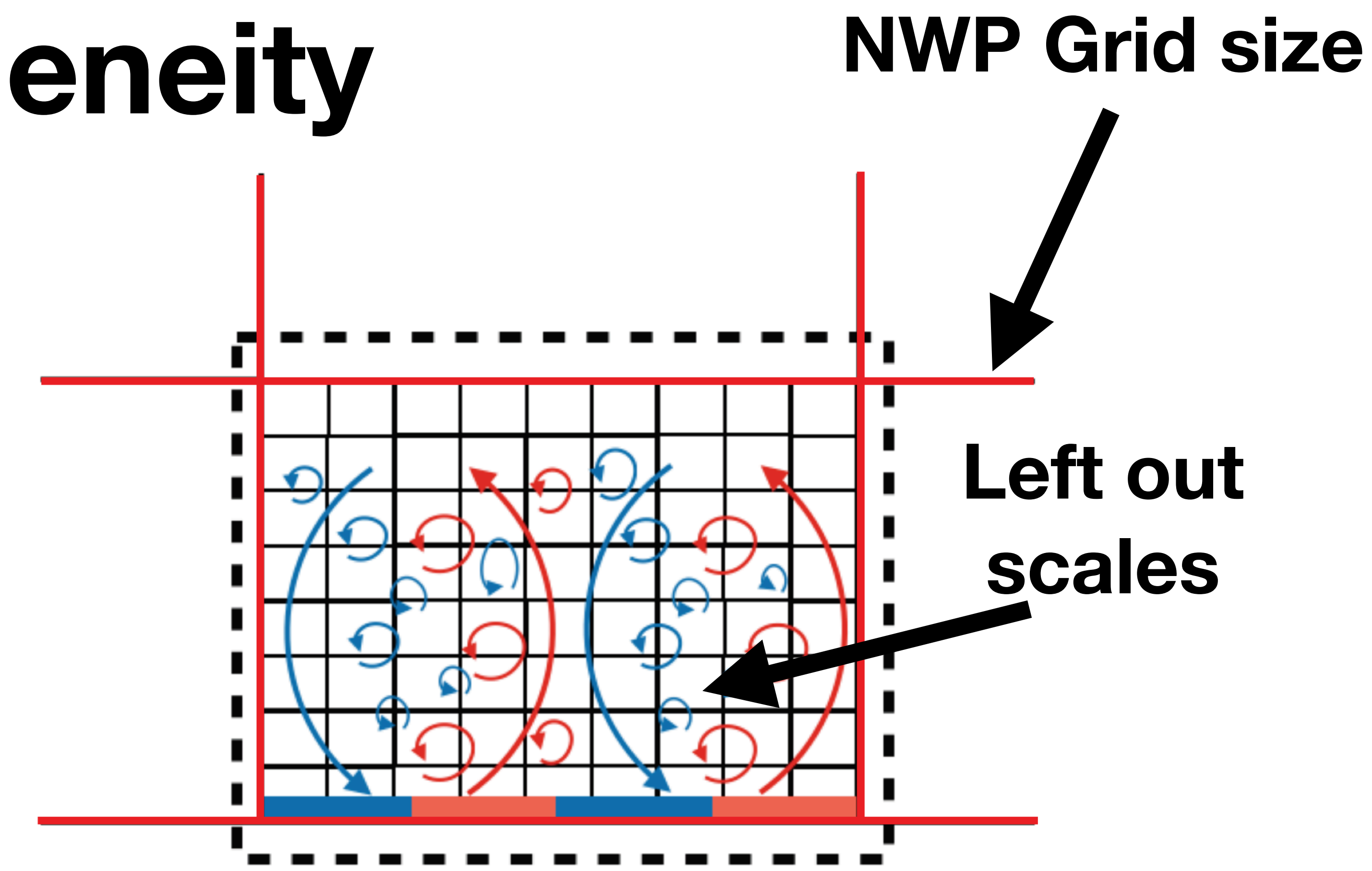
## Extreme Weather Events




**1) Statistical homogeneity assumptions.**

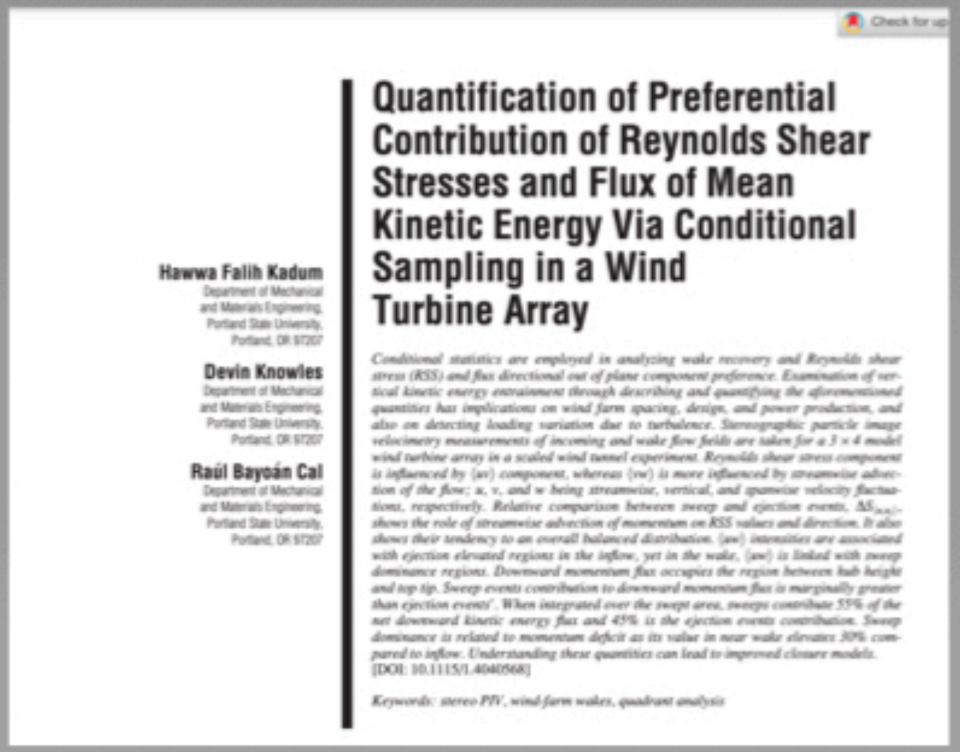
**2) Model grid size.**




**3) Heterogeneity quantification.**

**NWP:** numerical weather prediction model

# Previous Work



# Quantification of Preferential Contribution of Reynolds Shear Stresses and Flux of Mean Kinetic Energy Via Conditional Sampling in a Wind Turbine Array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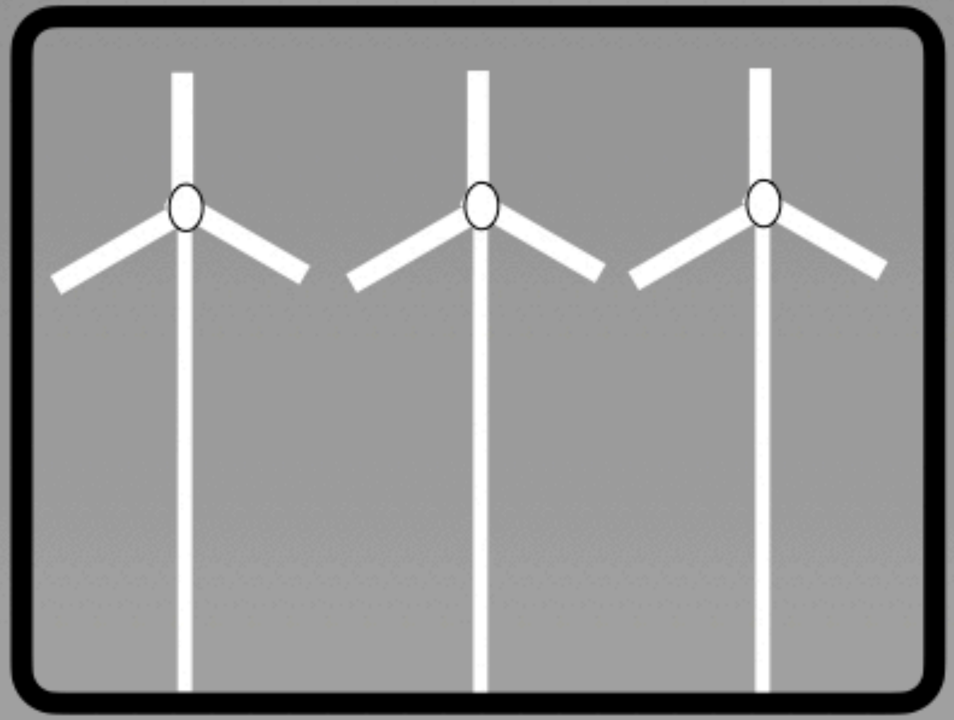
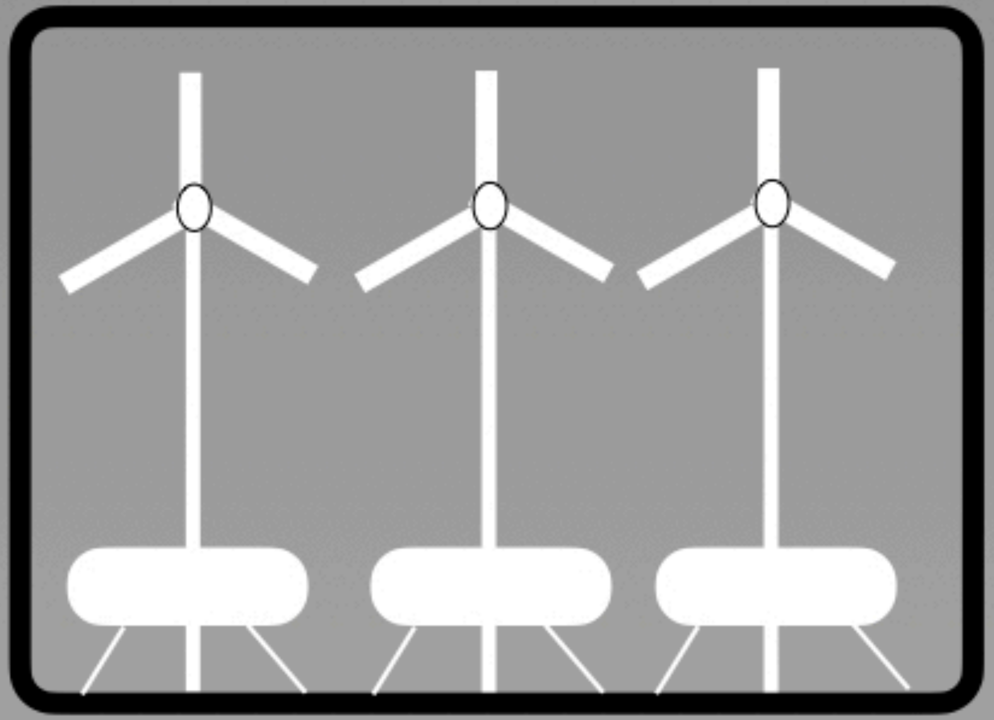
*Conditional statistics are employed in analyzing wake recovery and Reynolds shear stress (RSS) and flux directional out of plane component preference. Examination of vertical kinetic energy entrainment through describing and quantifying the aforementioned quantities has implications on wind farm spacing, design, and power production, and also on detecting loading variation due to turbulence. Stereographic particle image velocimetry measurements of incoming and wake flow fields are taken for a 3 × 4 model wind turbine array in a scaled wind tunnel experiment. Reynolds shear stress component is influenced by ⟨uv⟩ component, whereas ⟨vw⟩ is more influenced by streamwise advection of the flow; u, v, and w being streamwise, vertical, and spanwise velocity fluctuations, respectively. Relative comparison between sweep and ejection events, $\Delta S_{(u,v)}$, shows the role of streamwise advection of momentum on RSS values and direction. It also shows their tendency to an overall balanced distribution. ⟨uw⟩ intensities are associated with ejection elevated regions in the inflow, yet in the wake, ⟨uw⟩ is linked with sweep dominance regions. Downward momentum flux occupies the region between hub height and top tip. Sweep events contribution to downward momentum flux is marginally greater than ejection events'. When integrated over the swept area, sweeps contribute 55% of the net downward kinetic energy flux and 45% is the ejection events contribution. Sweep dominance is related to momentum deficit as its value in near wake elevates 30% compared to inflow. Understanding these quantities can lead to improved closure models.*


[DOI: 10.1115/1.4040568]

*Keywords: stereo PIV, wind farm wakes, quadrant analysis*

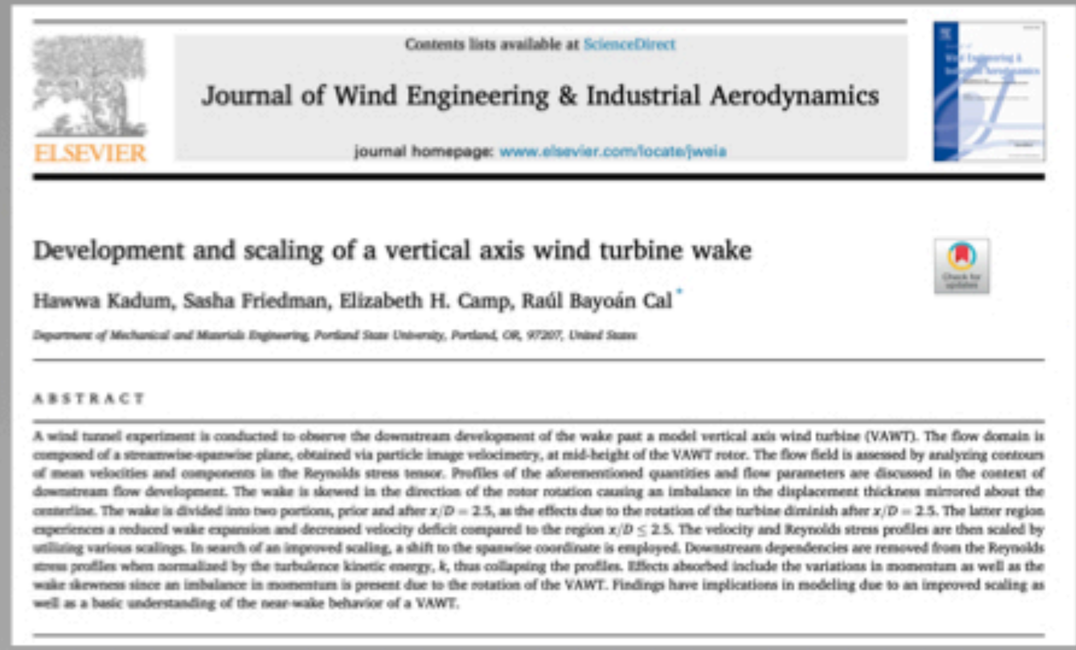


**Kadum, H., et al,** 2021, Journal of Renewable and Sustainable Energy.

**Kadum, H., et al,** 2019, Journal of Renewable and Sustainable Energy.

**Kadum, H., et al,** 2019, Journal of Fluids Engineering

**Kadum, H., et al,** 2018, Journal of Wind Engineering and Industrial Aerodynamics

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## Development and scaling of a vertical axis wind turbine wake


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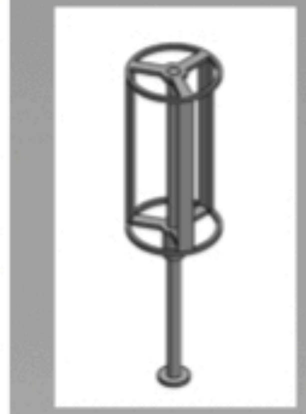
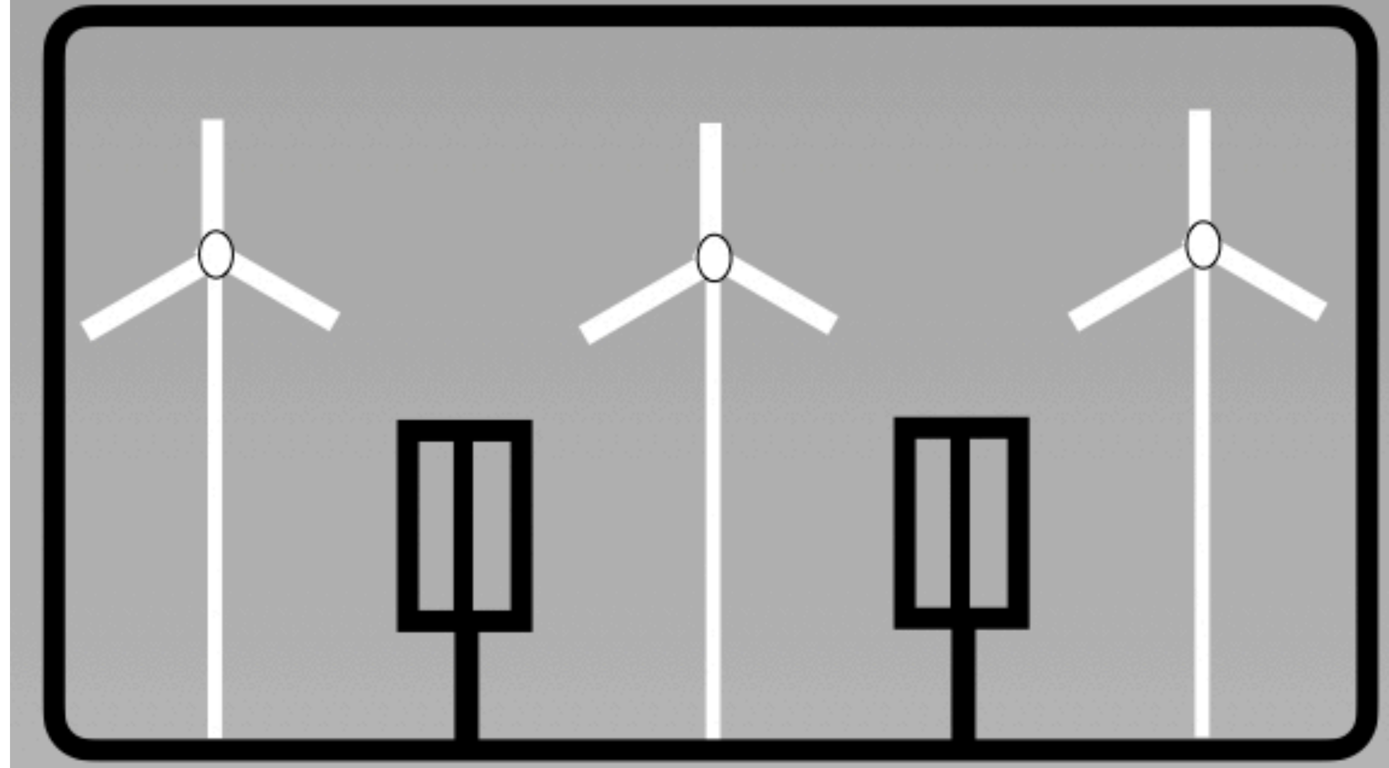
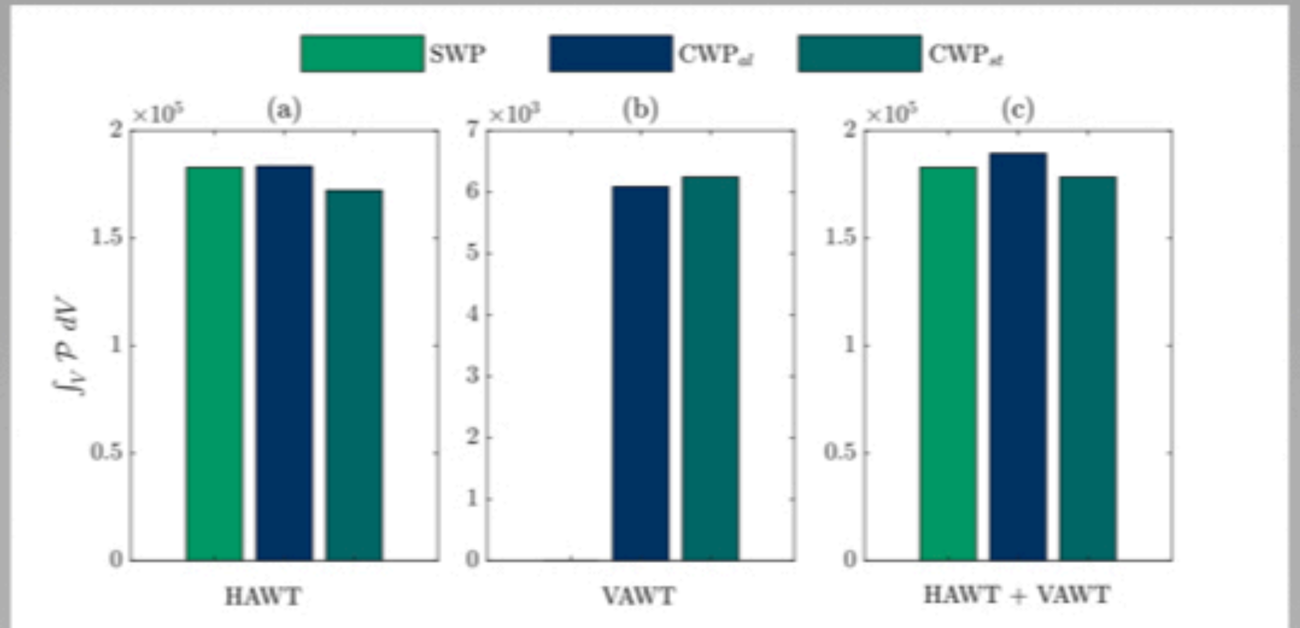
ABSTRACT

A wind tunnel experiment is conducted to observe the downstream development of the wake past a model vertical axis wind turbine (VAWT). The flow domain is composed of a streamwise-spanwise plane, obtained via particle image velocimetry, at mid-height of the VAWT rotor. The flow field is assessed by analyzing contours of mean velocities and components in the Reynolds stress tensor. Profiles of the aforementioned quantities and flow parameters are discussed in the context of downstream flow development. The wake is skewed in the direction of the rotor rotation causing an imbalance in the displacement thickness mirrored about the centerline. The wake is divided into two portions, prior and after $x/D = 2.5$, as the effects due to the rotation of the turbine diminish after $x/D = 2.5$. The latter region experiences a reduced wake expansion and decreased velocity deficit compared to the region $x/D \leq 2.5$. The velocity and Reynolds stress profiles are then scaled by utilizing various scalings. In search of an improved scaling, a shift to the spanwise coordinate is employed. Downstream dependencies are removed from the Reynolds stress profiles when normalized by the turbulence kinetic energy, $k$, thus collapsing the profiles. Effects absorbed include the variations in momentum as well as the wake skewness since an imbalance in momentum is present due to the rotation of the VAWT. Findings have implications in modeling due to an improved scaling as well as a basic understanding of the near-wake behavior of a VAWT.

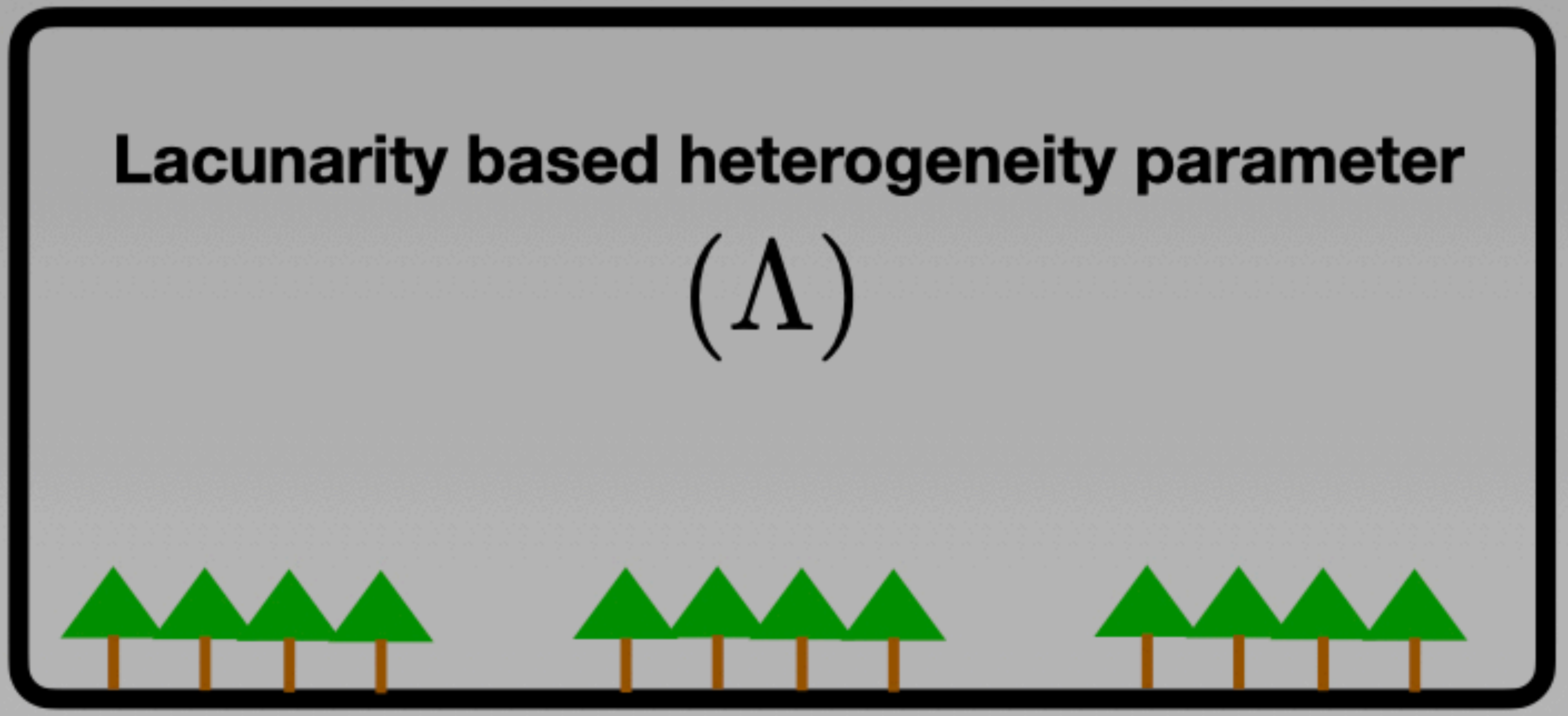





**Kadum, H.**,et al, 2020, Renewable Energy

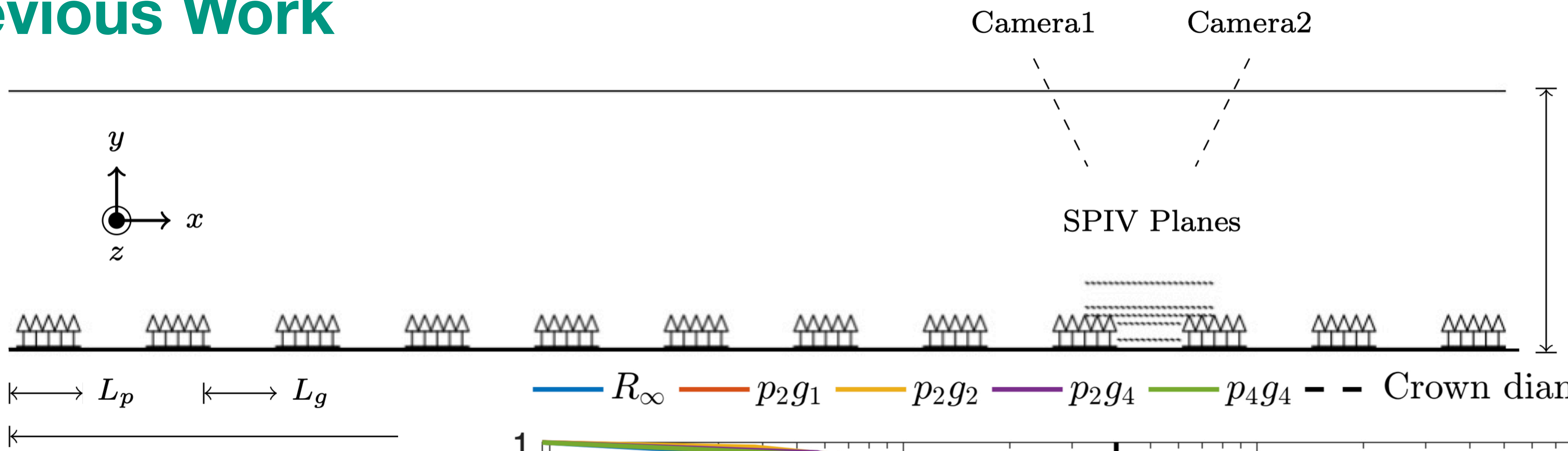


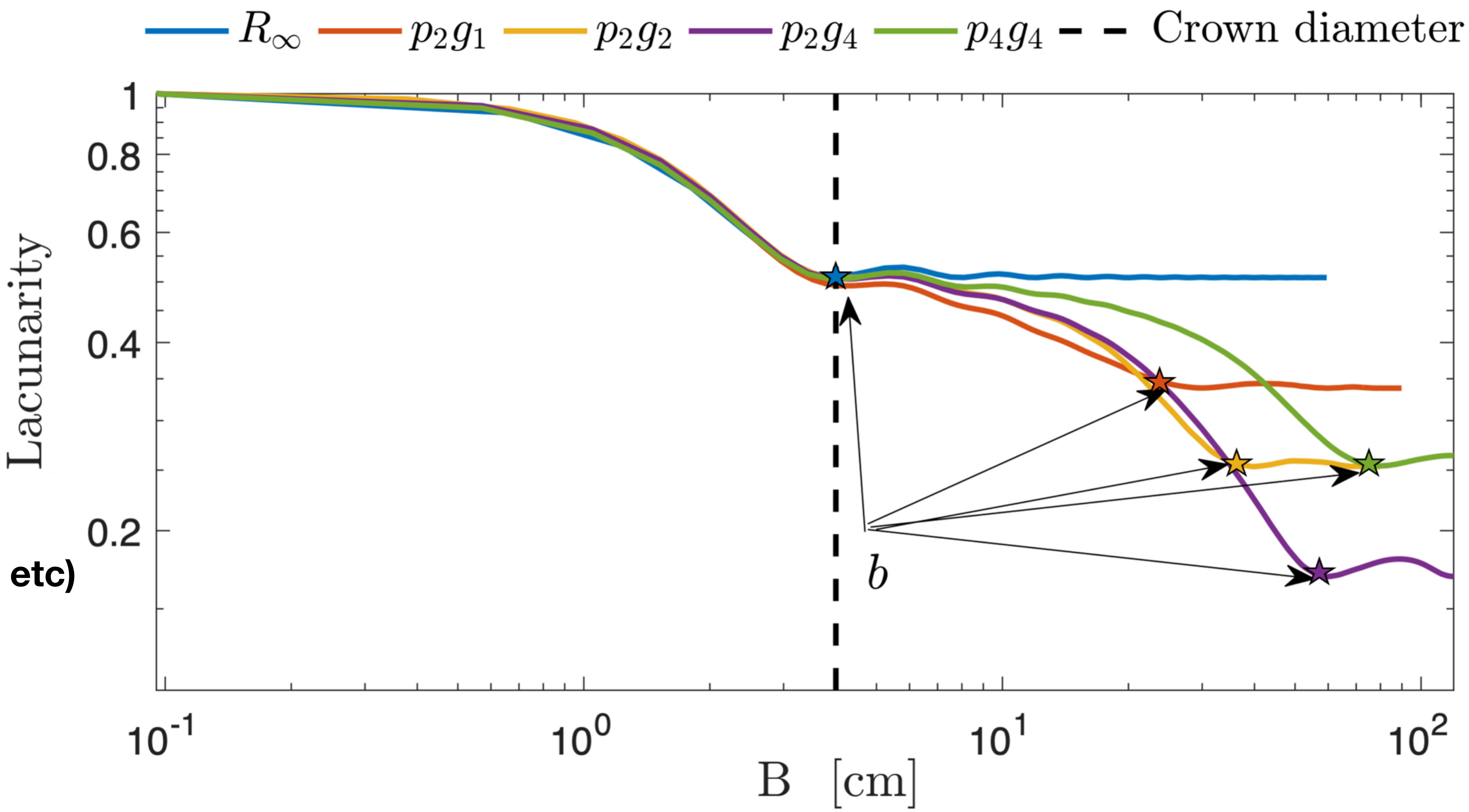

Power harvested per single isolated HAWT (a), VAWT cluster (b), and power harvested per an isolated HAWT and VAWTs cluster (c).




**Kadum, H.**,et al, 2021, Boundary-Layer Meteorology (submitted)

# Previous Work




$\Lambda$ or $L_c$

-Single value

- 1D, 2D, or 3D
- It is mathematical.
- (Height, distribution,heat, humidity, etc)
- Observation spatial resolution

# Objective

**Emmy Neother  - Junior research group**

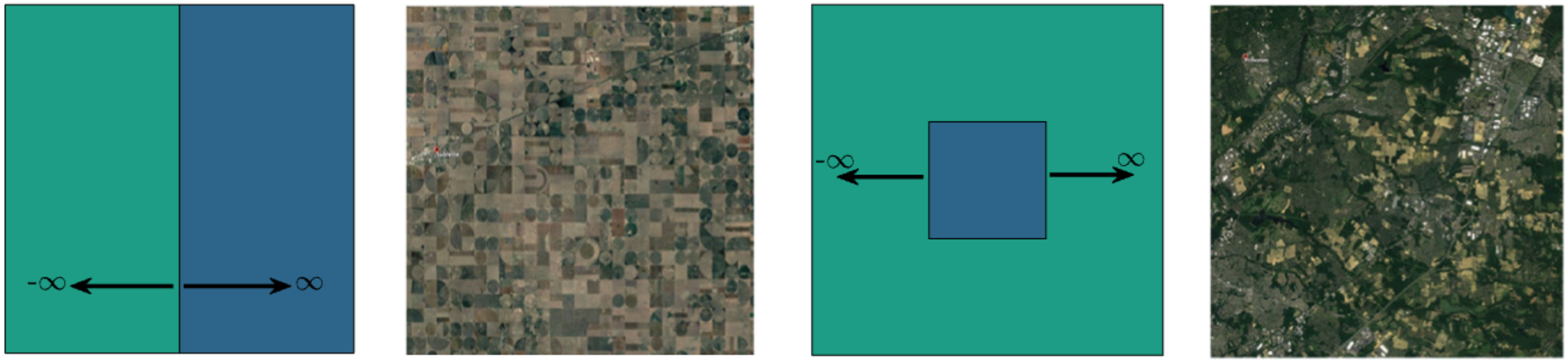
## Parameterization

(a) Class 1: Semi-infinit interface

(b) Class 2: Repeated patterns

(c) Class 3: Large individual patches

(d) Class 4: Unstructured heterogeneity

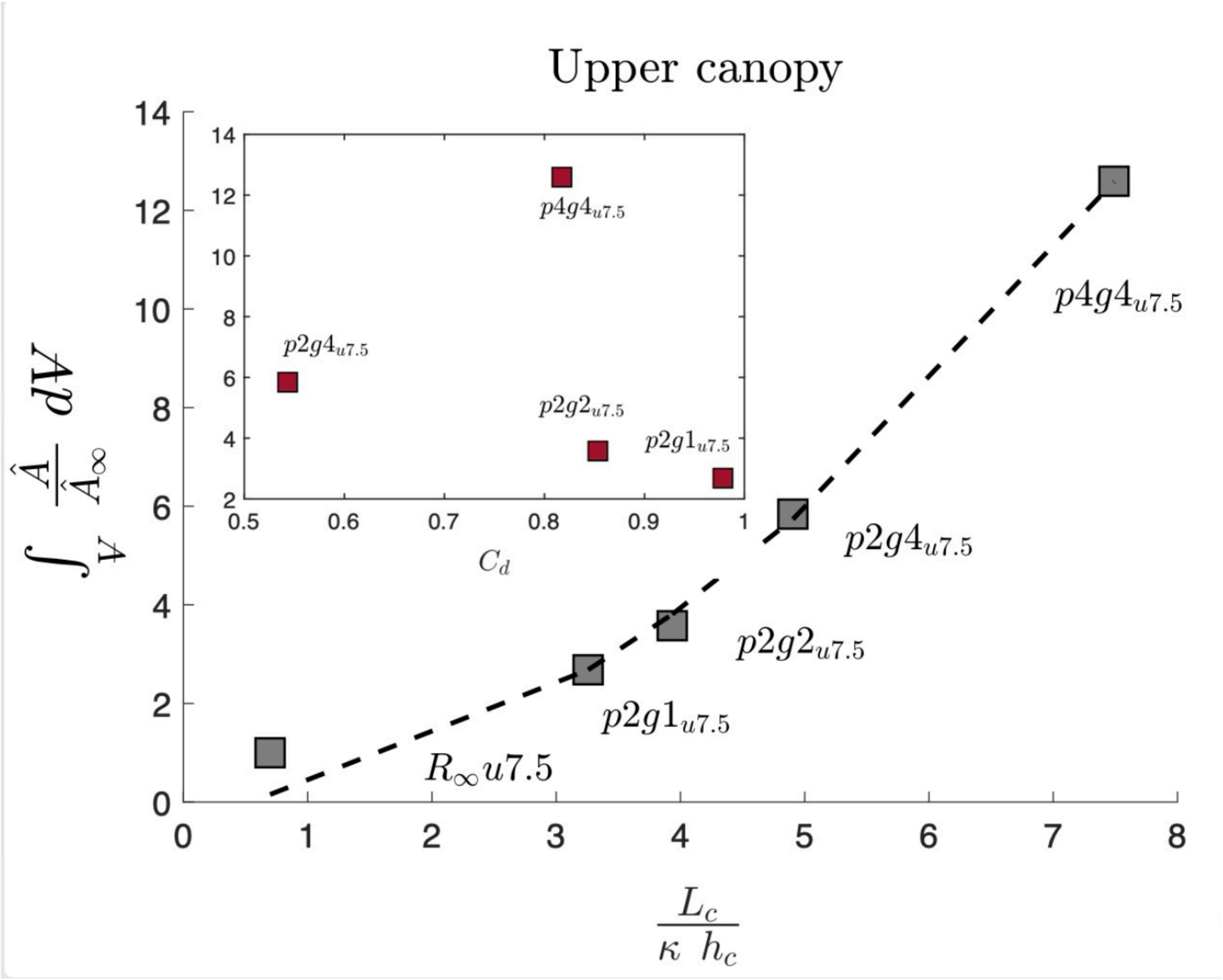



**Support : implementation and testing in ICON**

# How to incorporate it into NWP (ICON)?

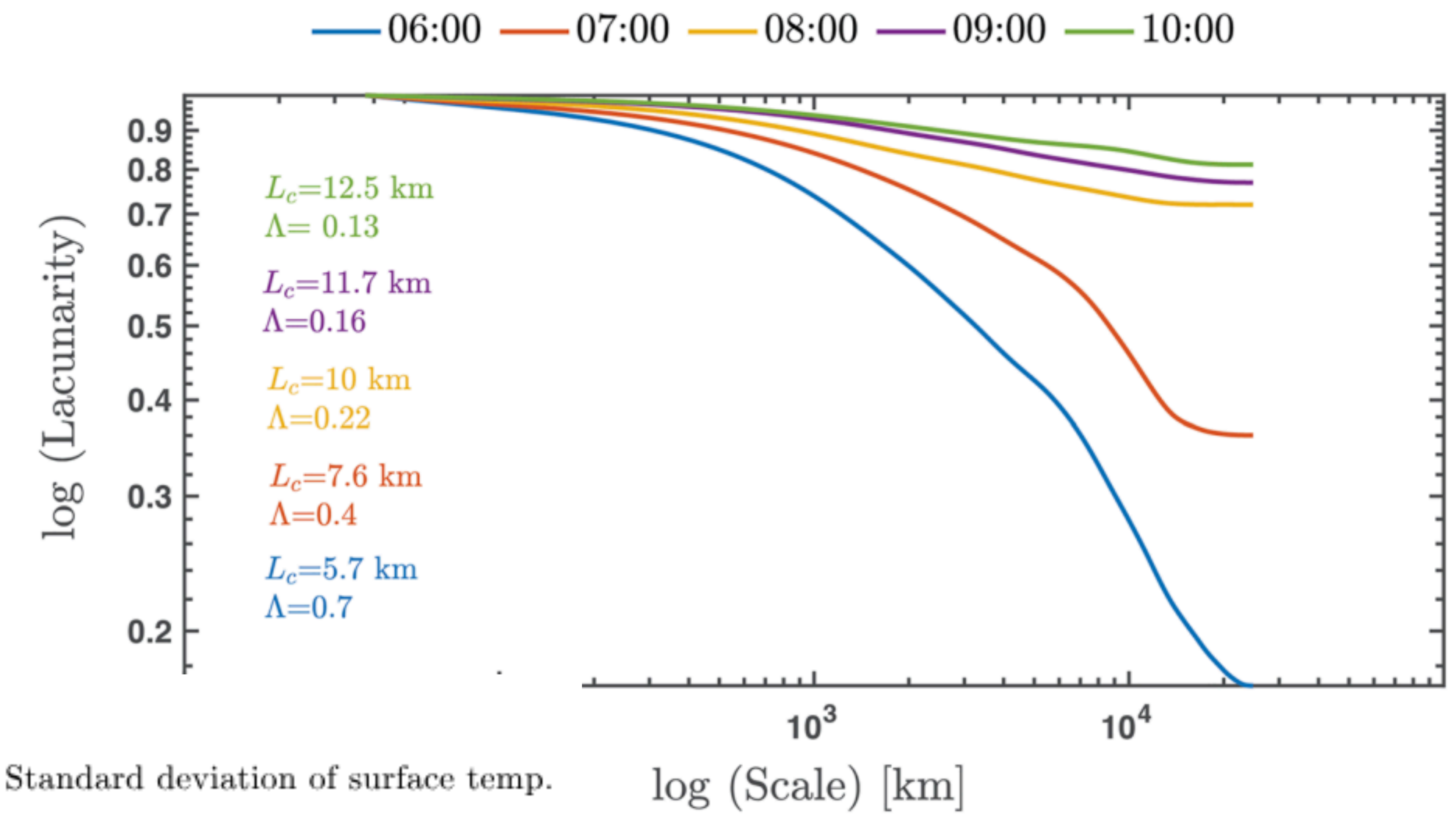
**1. Advection**

**Wind tunnel experiment at Portland State Uni.**

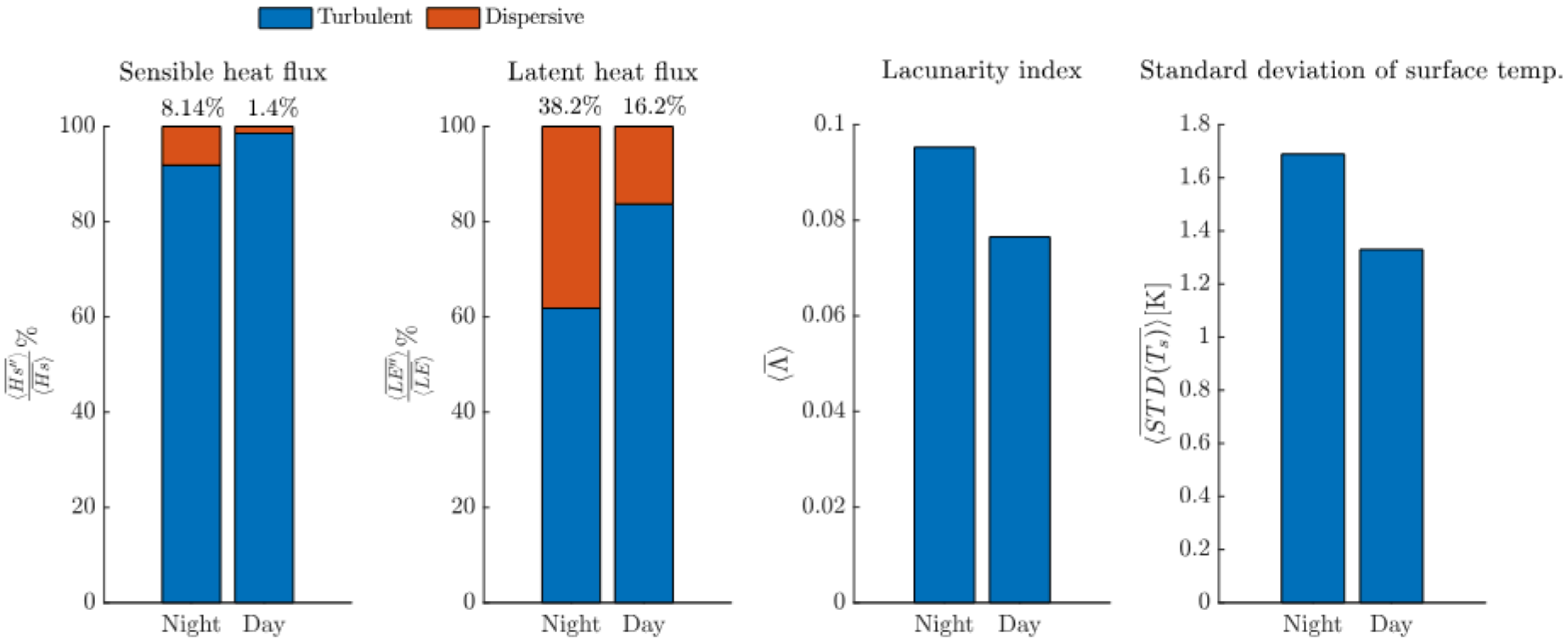


# How to incorporate it into NWP (ICON)?

## 2. Dispersive fluxes




**Field campaign**
**Uni of Wisconson & KIT**

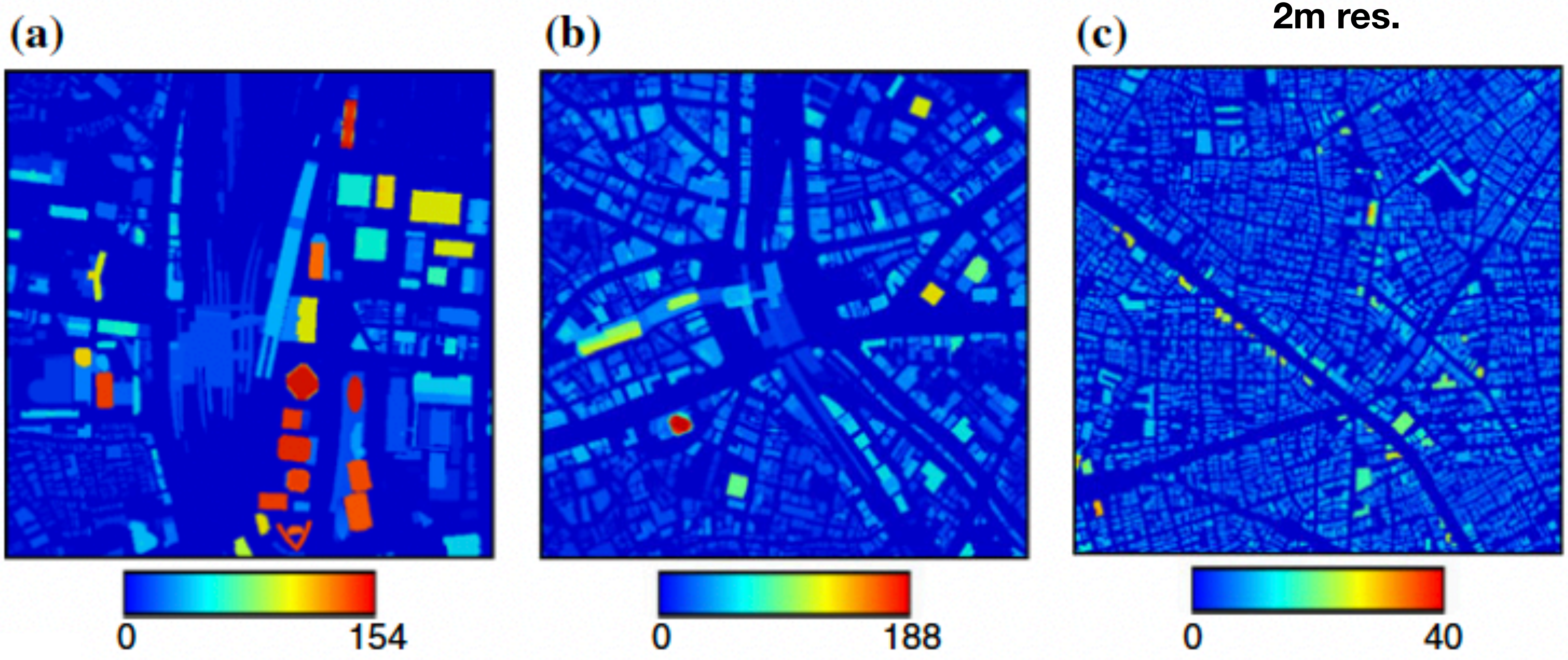



daytime avg.=23.4%
nighttime avg.=25%

# How to incorporate it into NWP (ICON)?

**3. Rougness length**

**Kanda et al 2013**
**Tokyo & Nagoya**
**1km x 1km**
**2m res.**



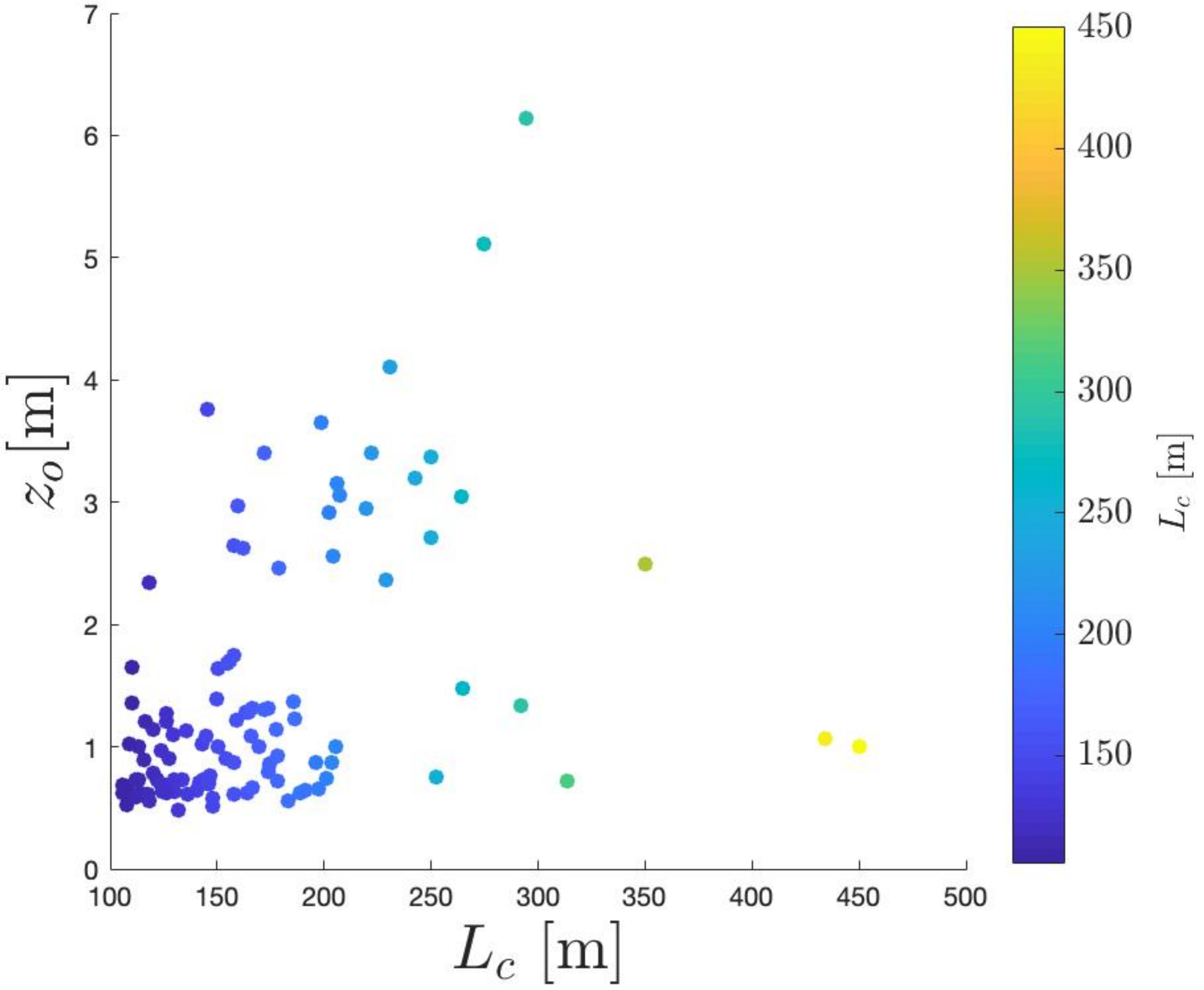

Maps of building height for three different urban surfaces. a Skyscrapers (ID97 in Table 1), b business district (ID 96 in Table 1), and c residential area (ID76 in Table 1)

# How to incorporate it into NWP (ICON)?

## 3. Rougness length

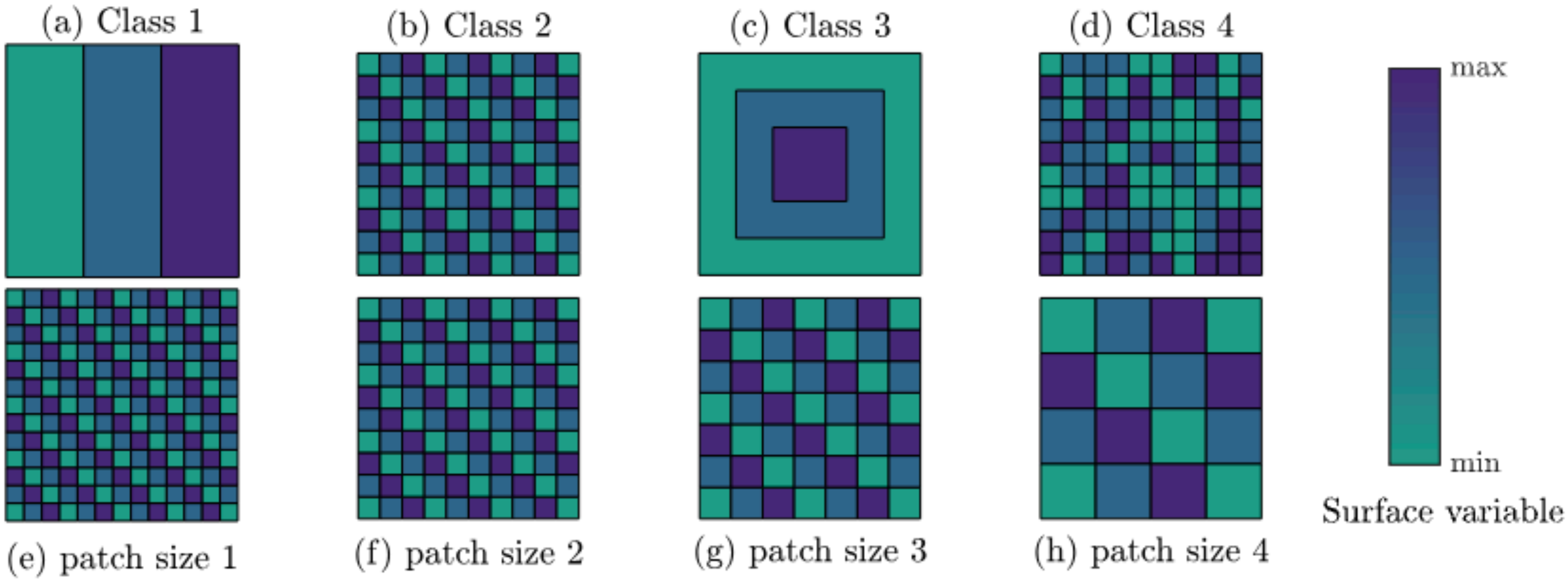
$$\frac{d}{H_{\text{ave}}} = 1 + A^{-\lambda_{\text{p}}} (\lambda_{\text{p}} - 1),$$

$$\frac{z_0(\text{mac})}{H_{\text{ave}}} = \left(1 - \frac{d}{H_{\text{ave}}}\right) \exp\left[ - \left\{ 0.5\beta \frac{C_{\text{lb}}}{\kappa^2} \left(1 - \frac{d}{H_{\text{ave}}}\right) \lambda_{\text{f}} \right\}^{-0.5} \right]$$



# How to incorporate it into NWP (ICON)?

## 3. Spatial distribution / Tile approach




**Correction function (Lc)**

# *Thank you for your attention*

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