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How to use CFD for long-term energy assessments

Bechmann, Andreas

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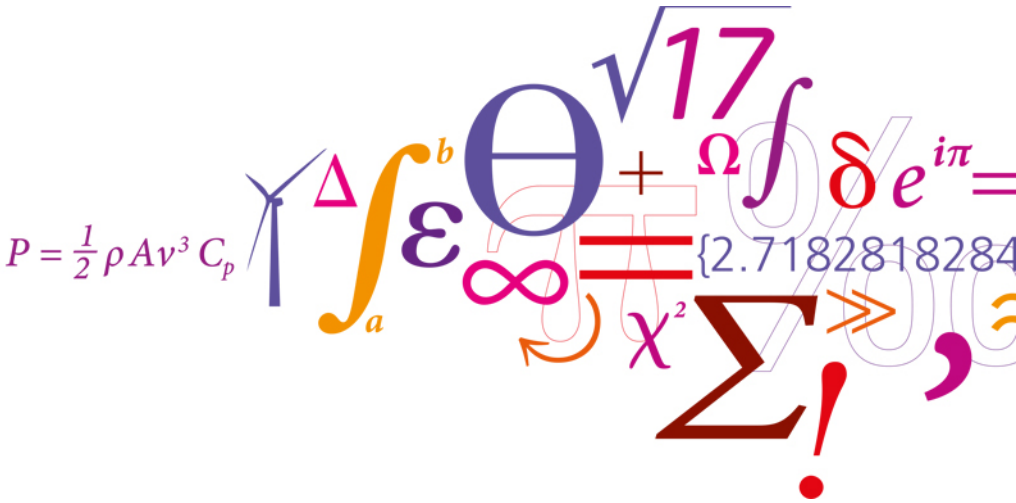
How to use CFD for long-term energy assessments

Andreas Bechmann

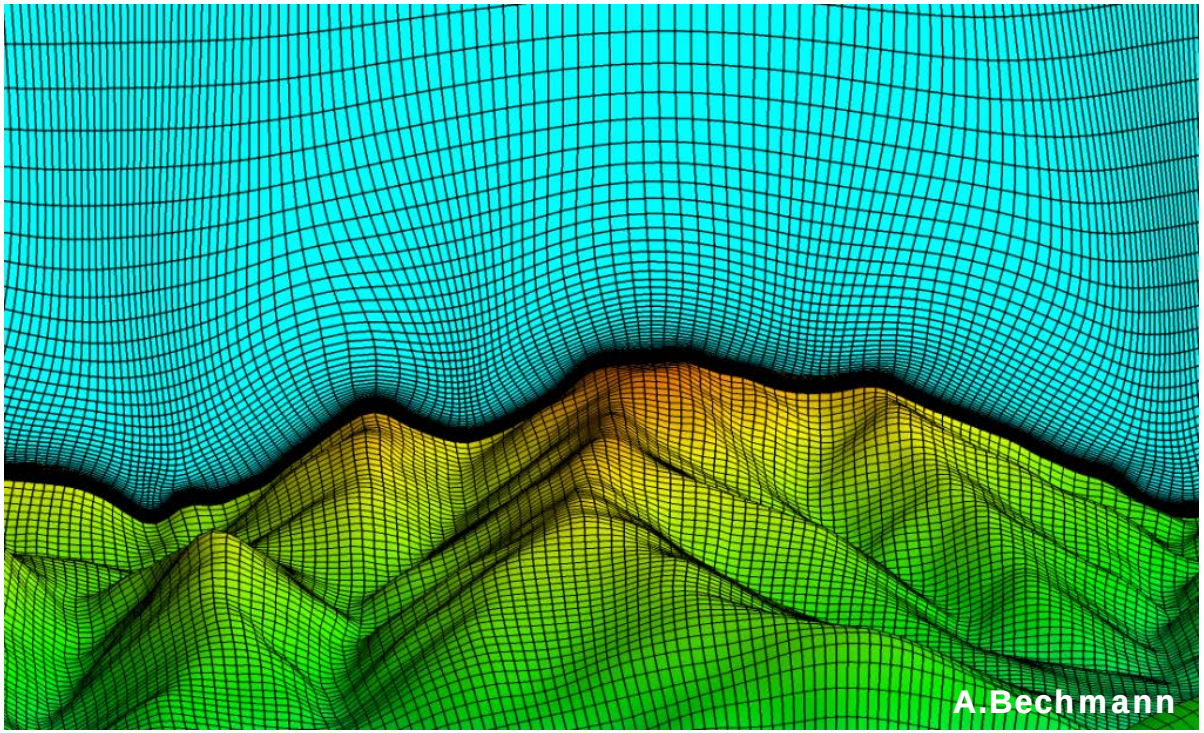
08/04-2014



DTU Wind Energy
Department of Wind Energy

How to use CFD for long-term energy assessments

1. Modelling of Wind Resources
2. Example: WAsP CFD
3. Example: Forestry modeling based on aerial LIDAR scans



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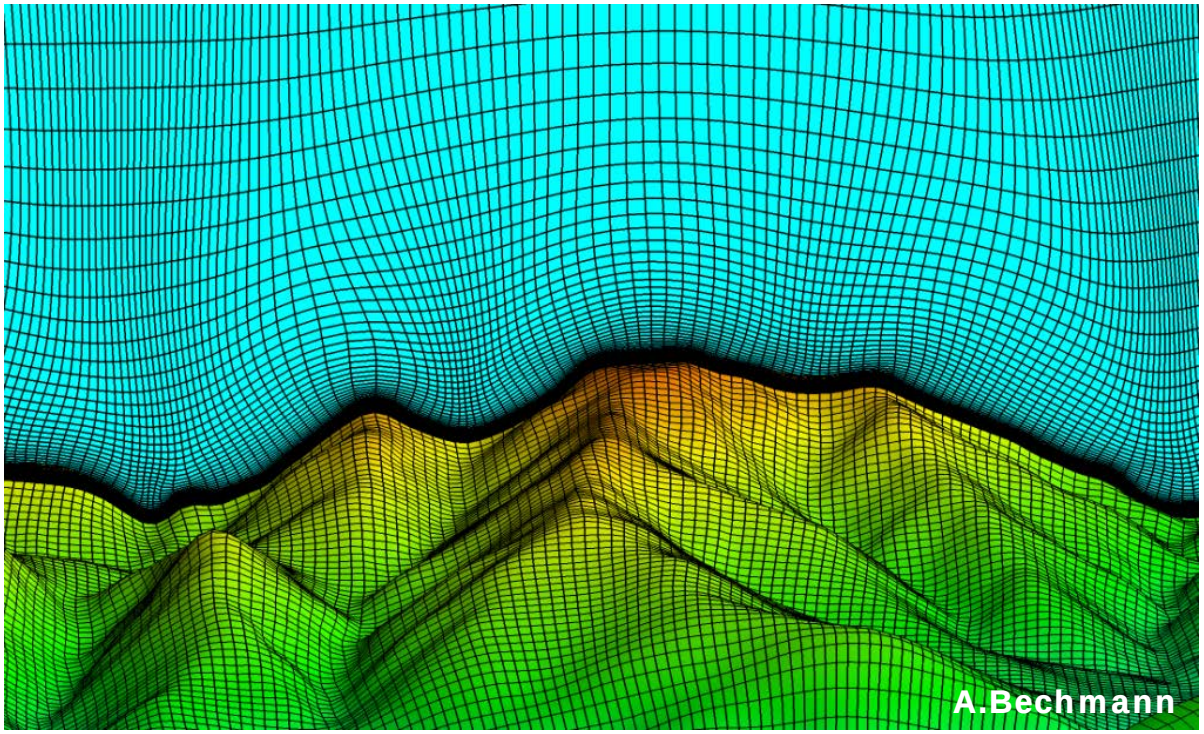
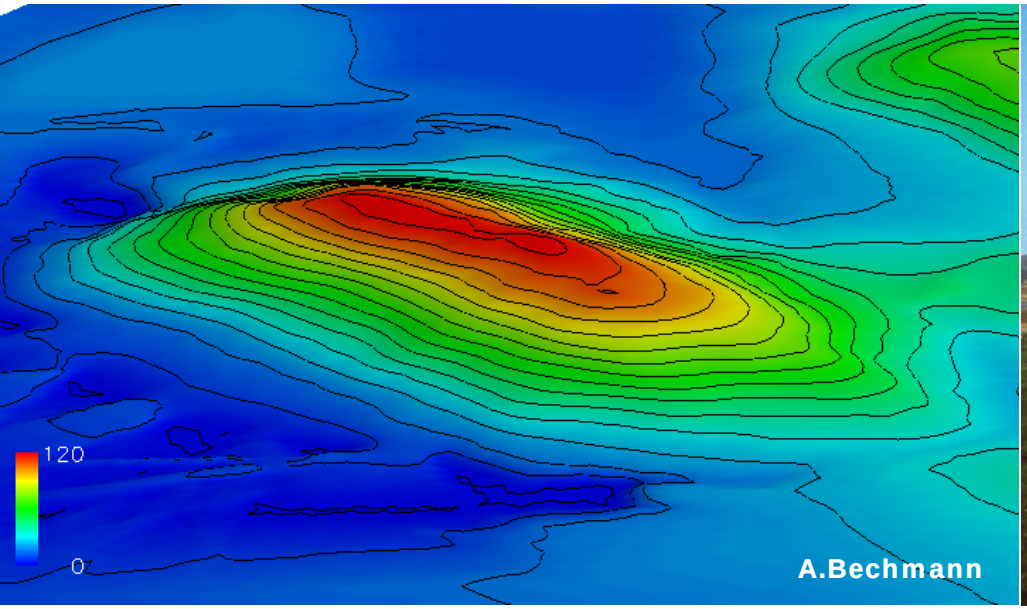


Modelling of wind resources

RANS equations:

$$\frac{\partial(\overline{u}_i\overline{u}_j)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\nu_T)\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right)\right] - C_d LAD\, u_i |U|$$

Askervein Experiment 1983:



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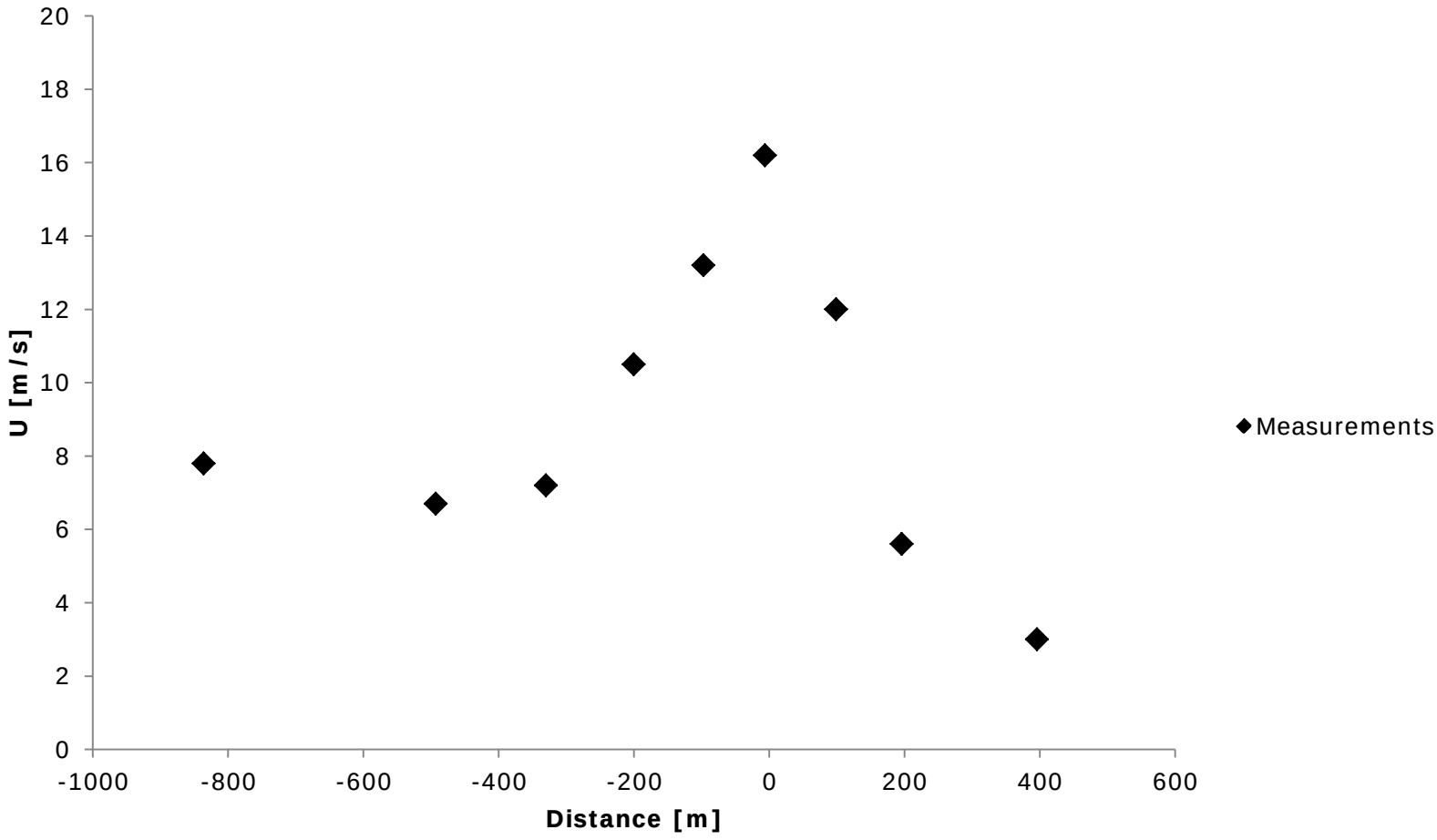

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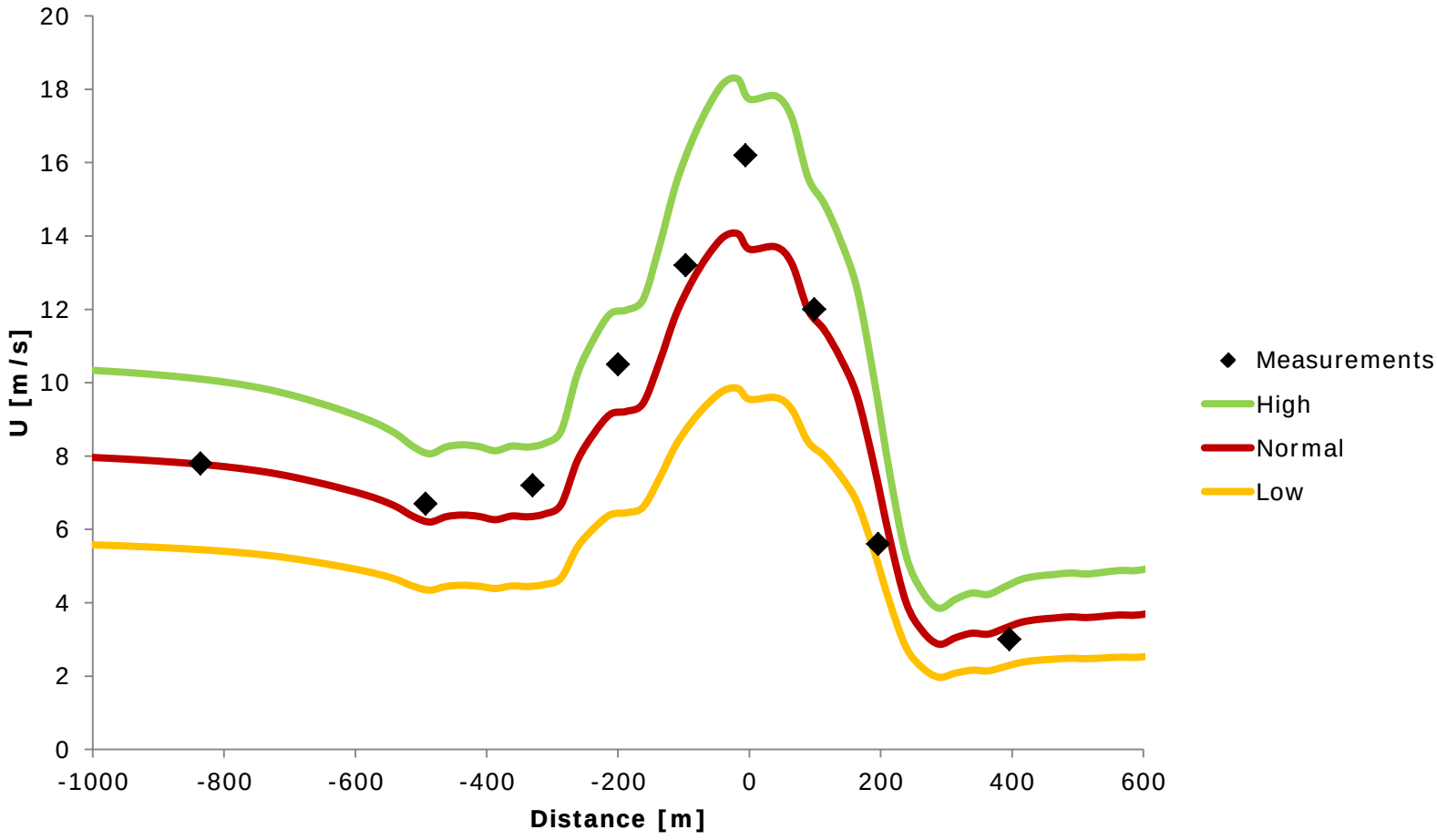

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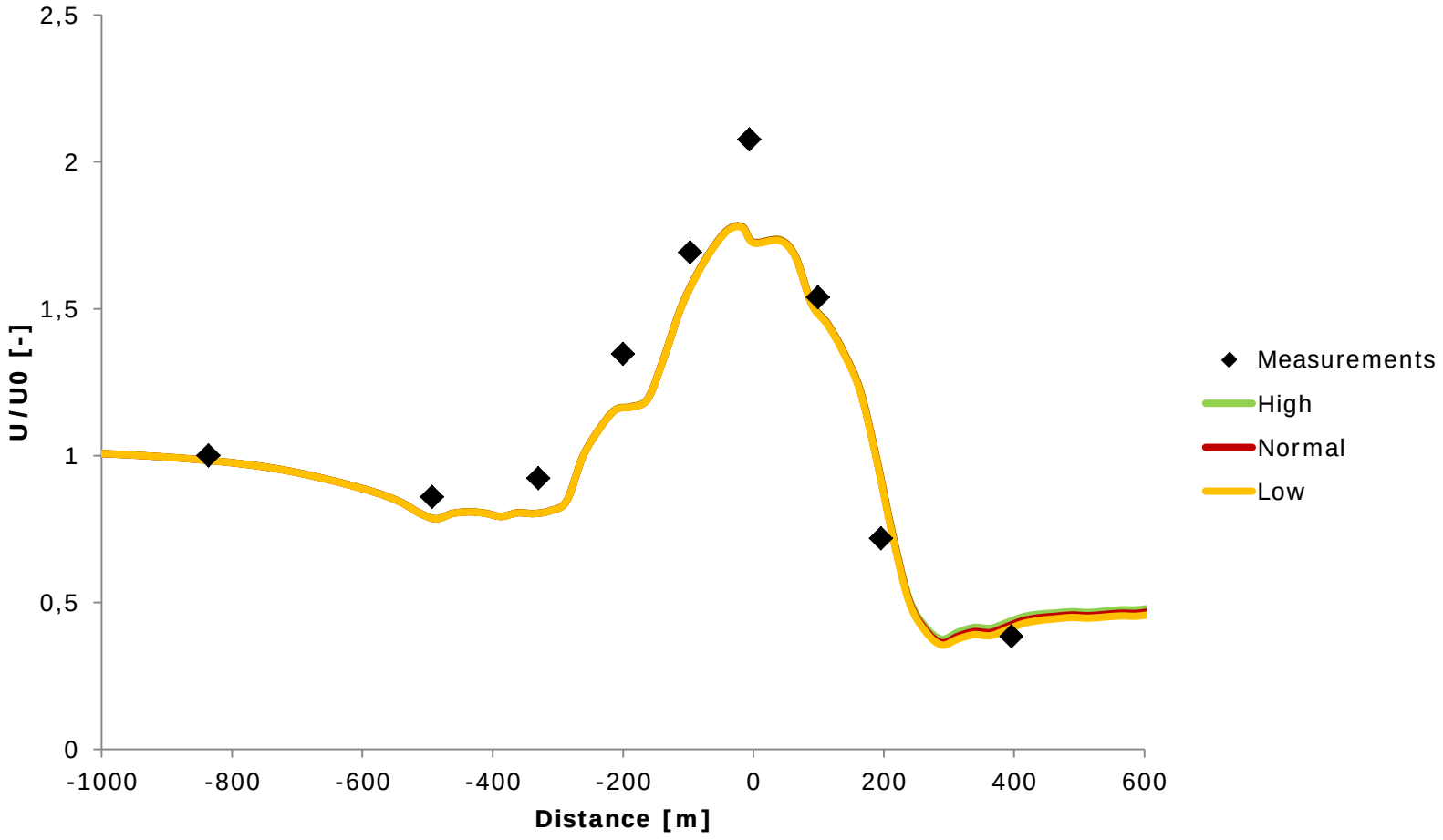


Modelling of wind resources

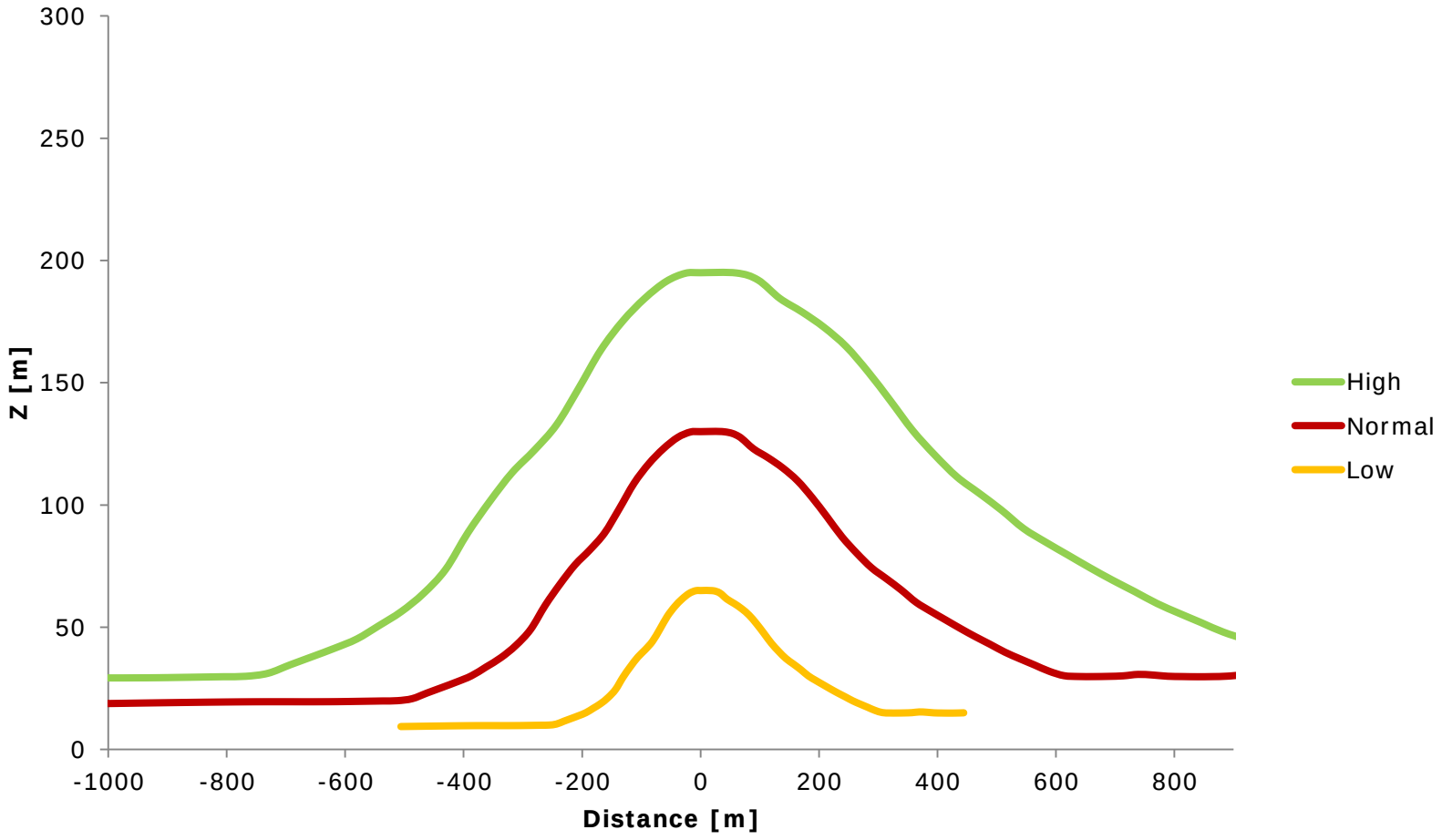
Reynolds number: $Re = U_0 L_0 / \nu$

$\Delta S = U/U_0$ (Speedup)

Jensen number = L_0 / z_0

$\Delta L = L/L_0$

Modelling of wind resources



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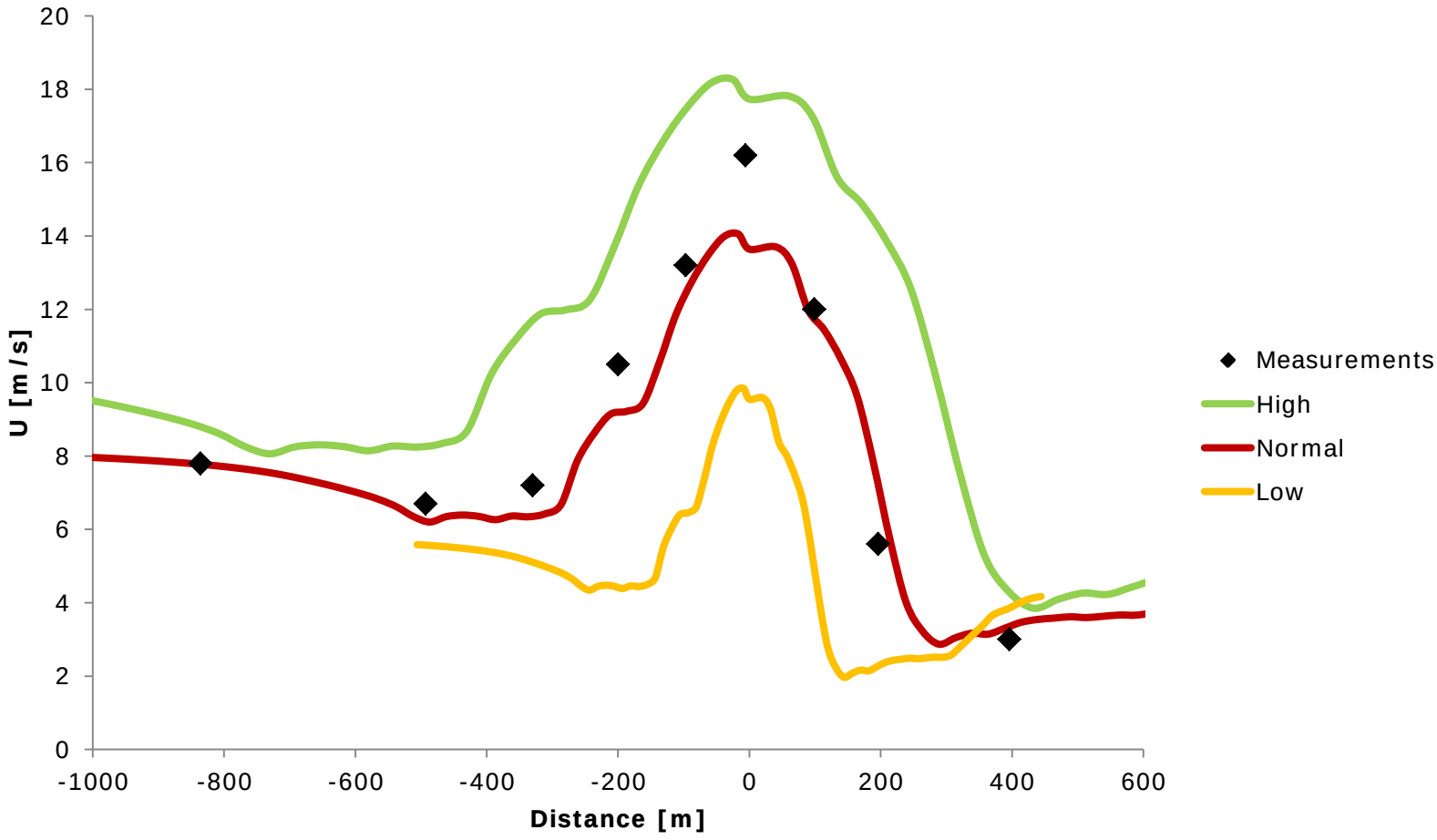

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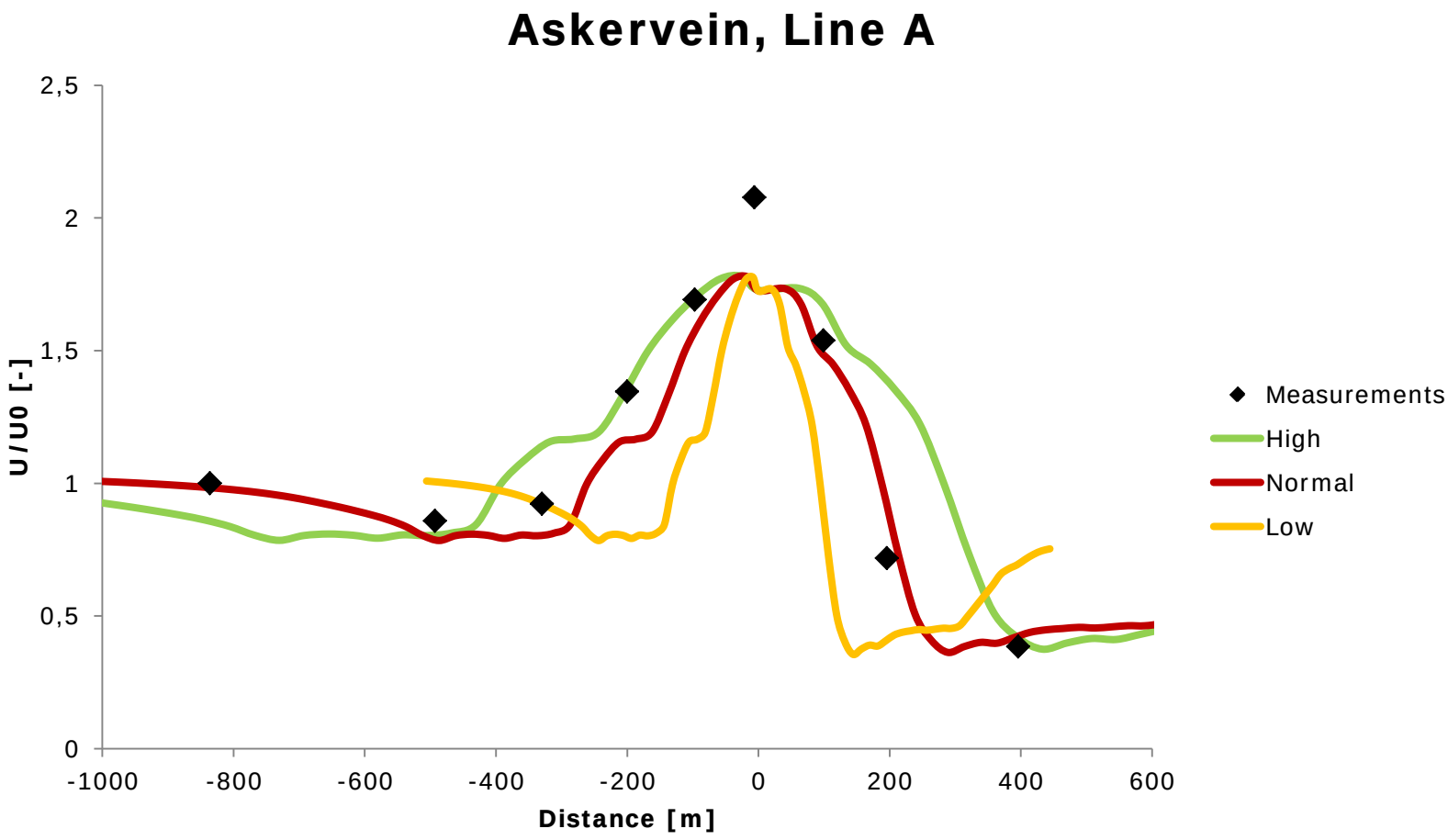

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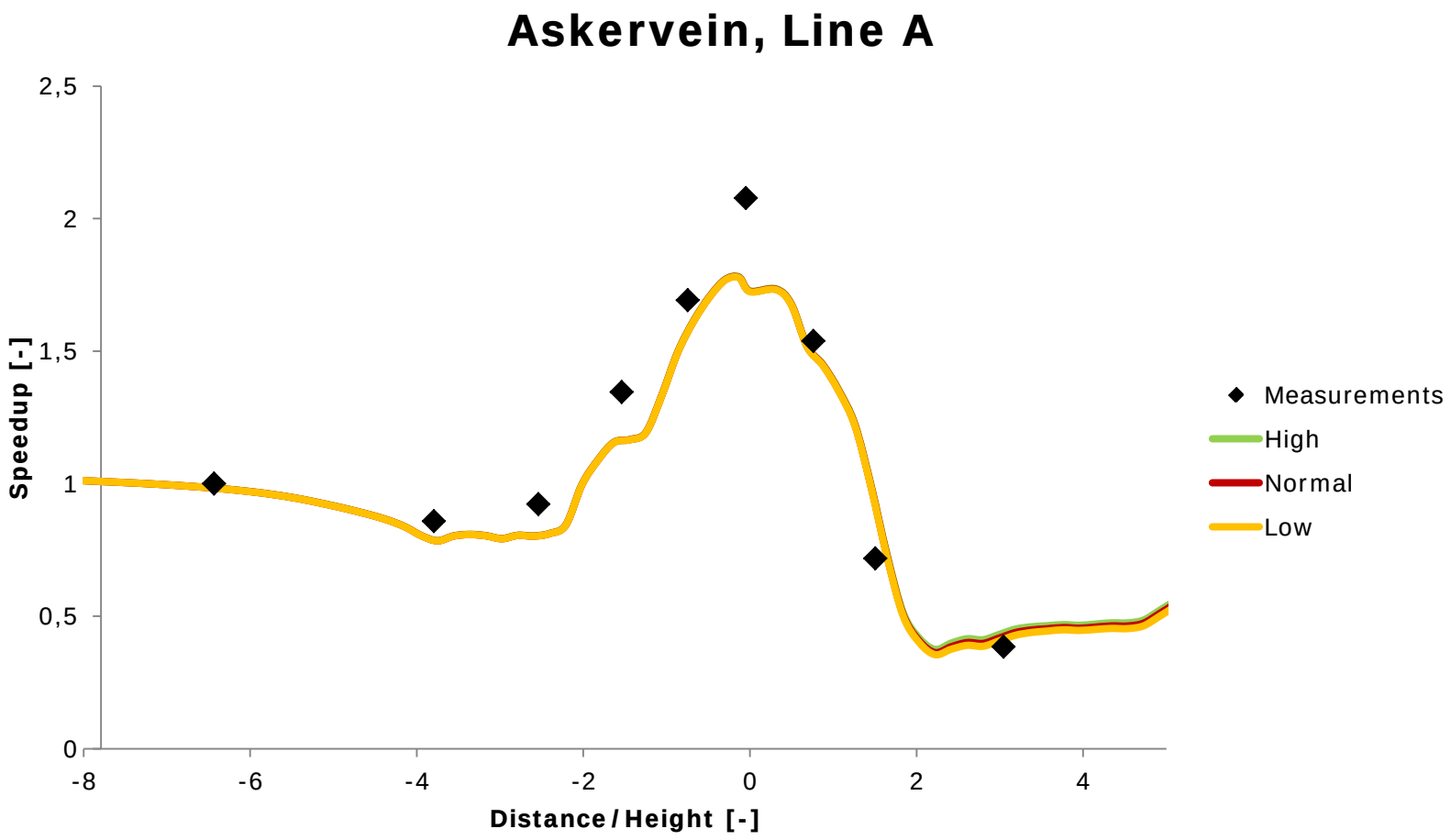

Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy

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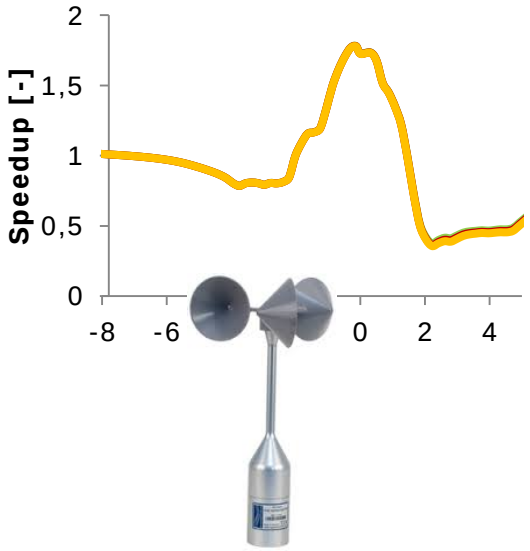

Extrapolate wind resources

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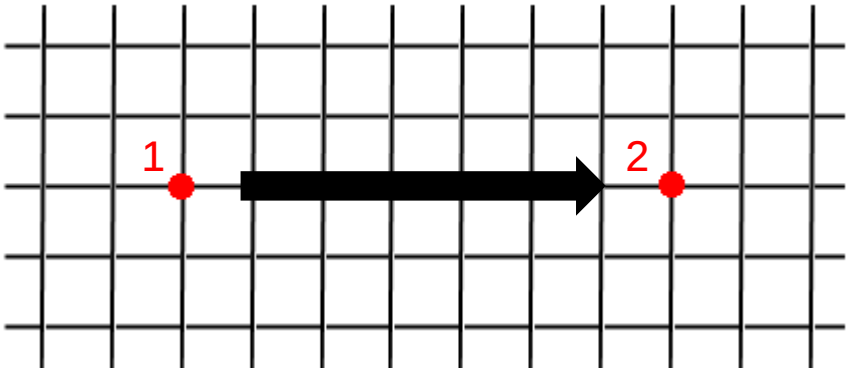

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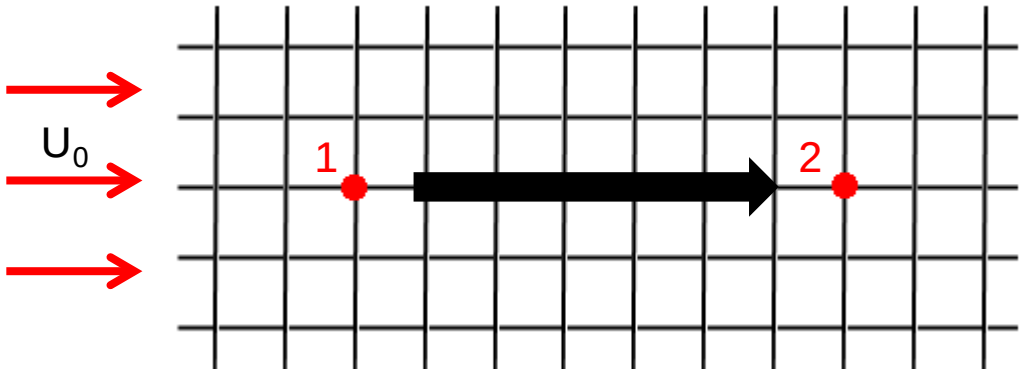

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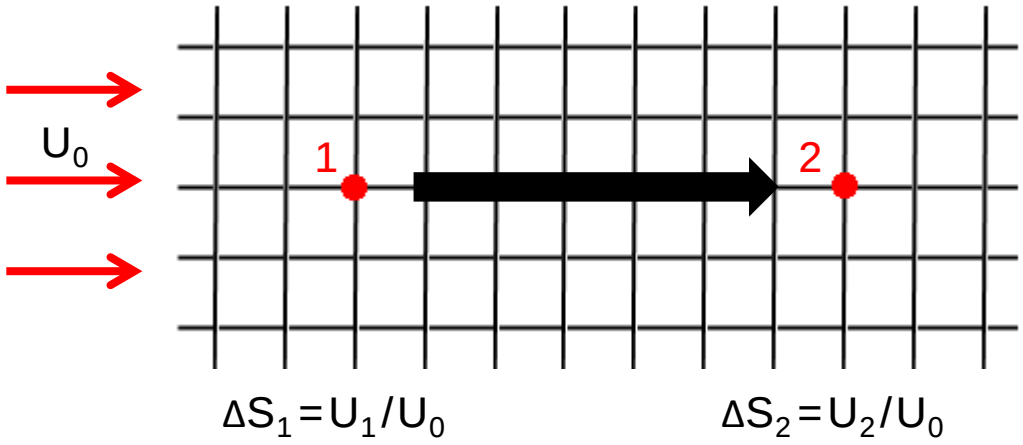

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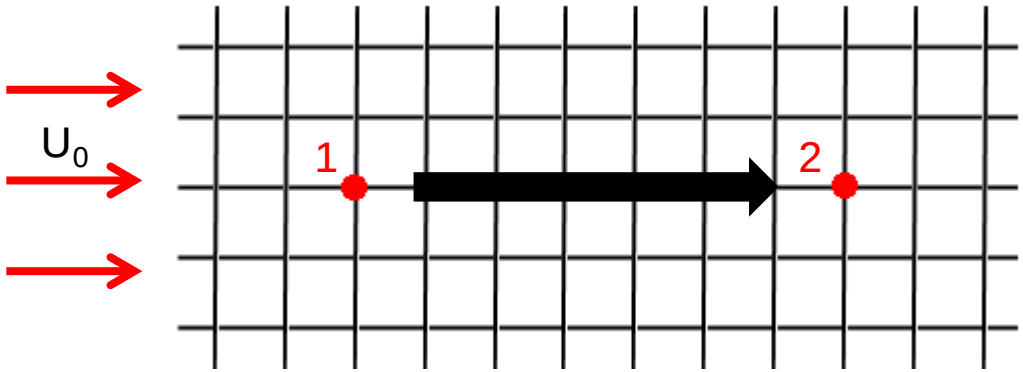
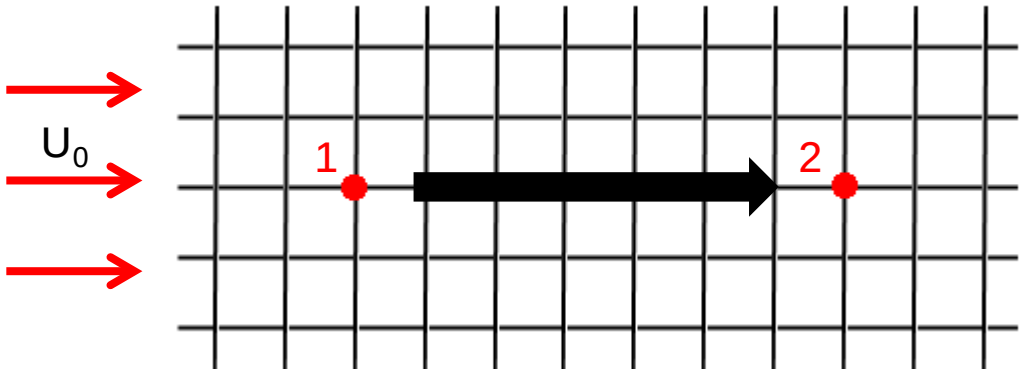


$$U_2/U_1 = \Delta S_2/\Delta S_1$$

Extrapolate wind resources



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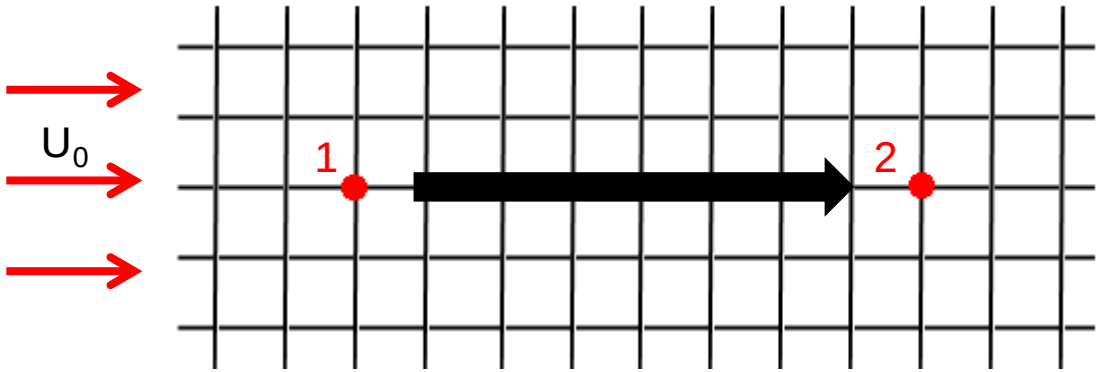

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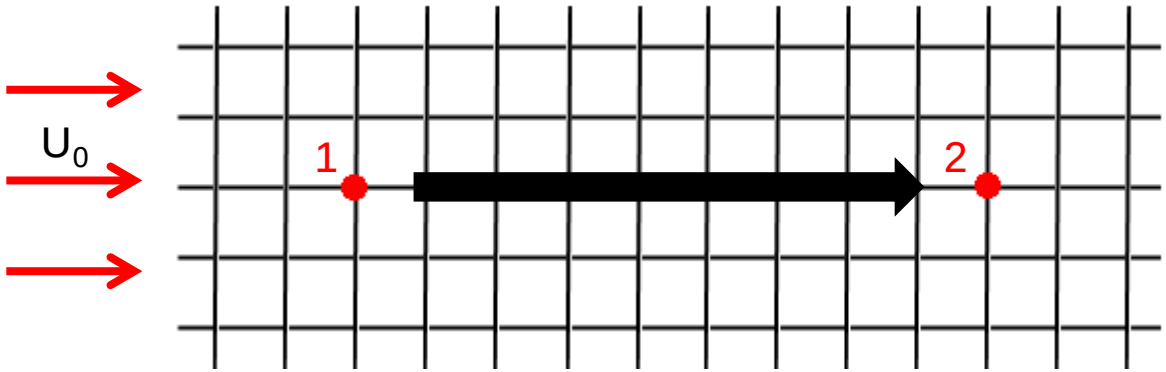

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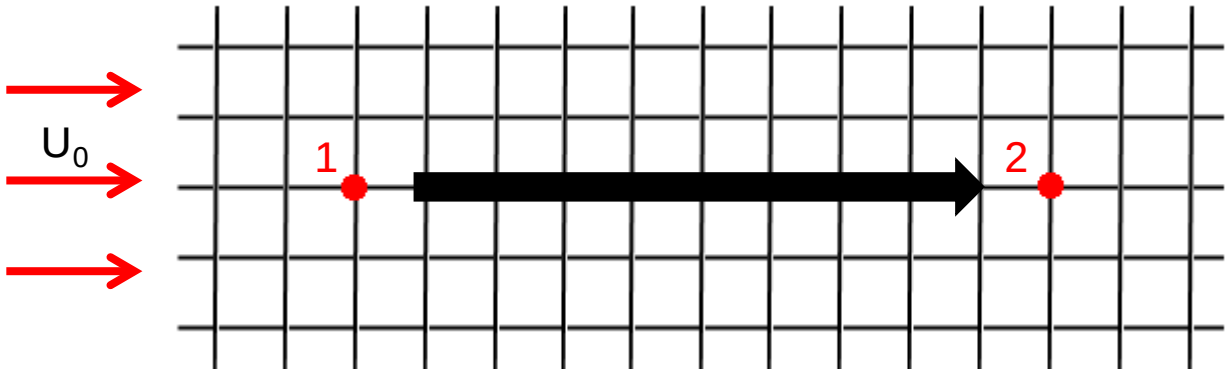

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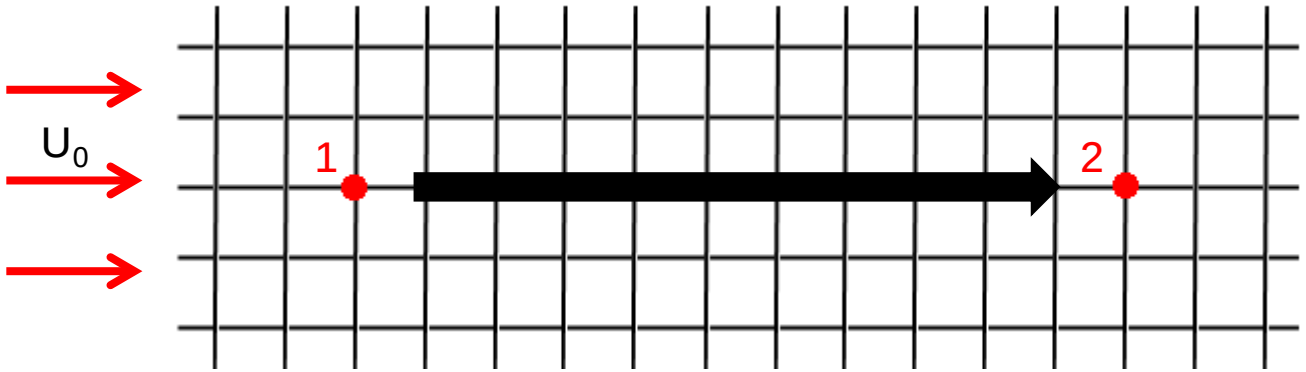

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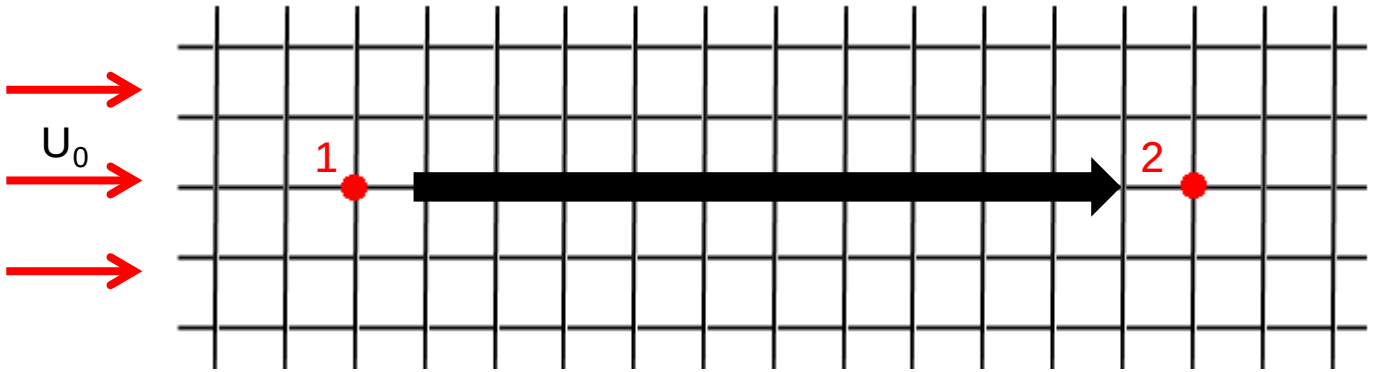
Extrapolate wind resources

Problem:

1. Large scale effects omitted (Coriolis, Bouyancy)
2. Large computational resources



Solutions:

1. Do nothing
2. Micro-Meso scale coupling
3. Micro model -> meso scales
4. Meso model -> micro scales

$$U_2/U_1 = \Delta S_2/\Delta S_1$$

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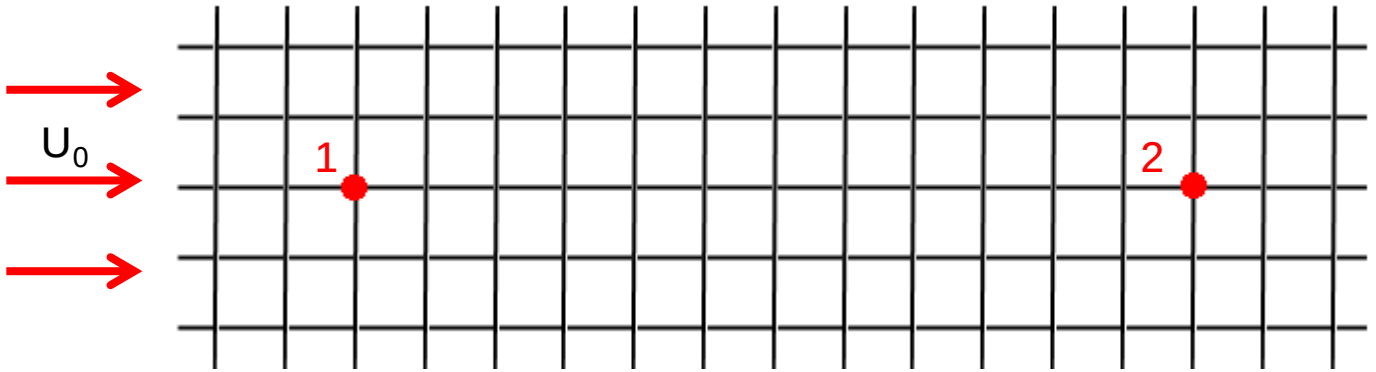

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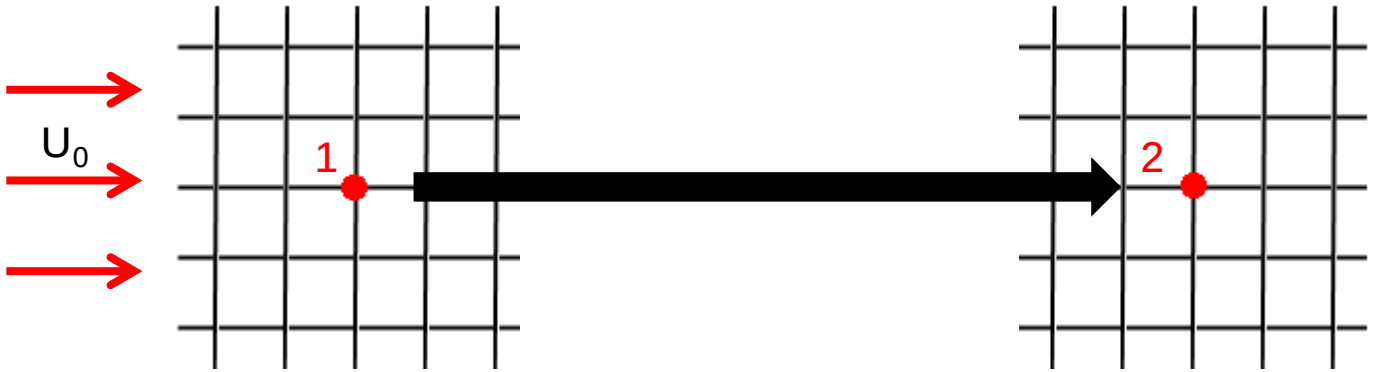

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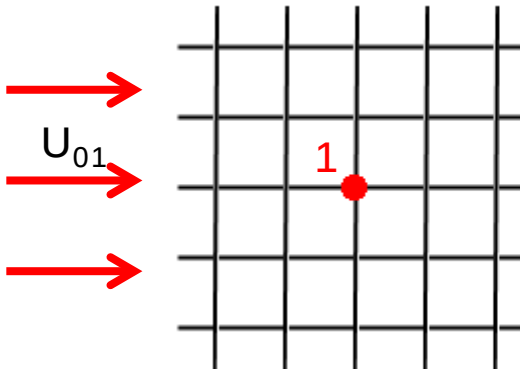

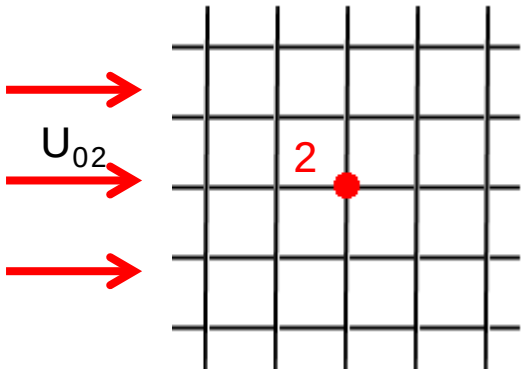

$$U_2/U_1 = \Delta S_2/\Delta S_1 * U_{02}/U_{01}$$

Micro Meso

Modelling of wind resources

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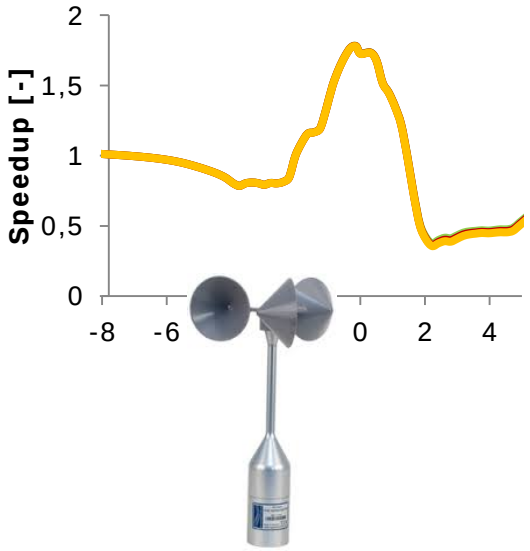

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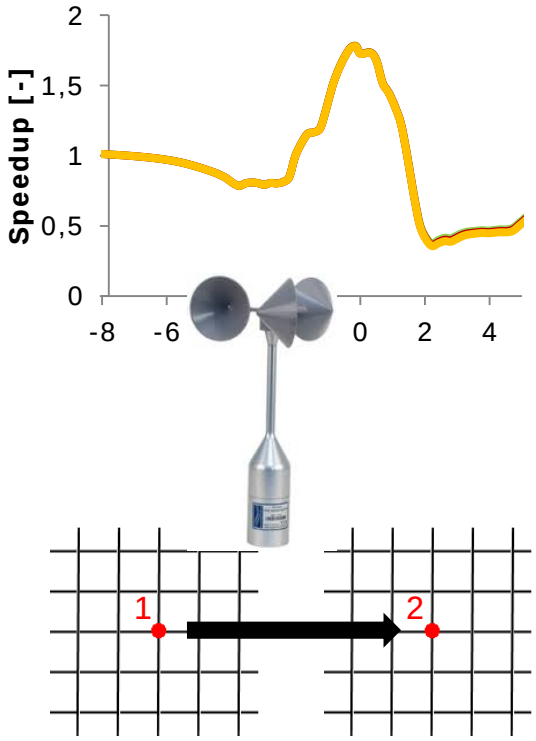


Micro - Meso coupling

Micro - Meso coupling

Micro scale inflow:

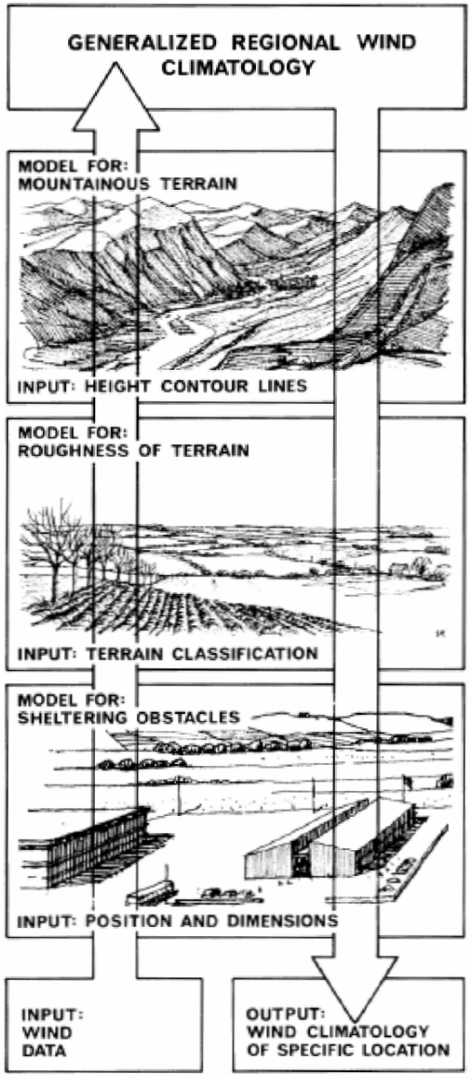
$$\frac{\langle M \rangle}{u_{*0}} = \frac{1}{\kappa} \ln\left(\frac{z}{z_0}\right) = C_D^{-1/2}$$

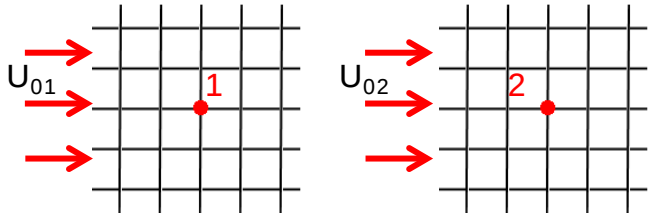
Meso scale, Geo. drag Law:

$$\frac{G}{u_{*0}} \cos\theta = \frac{1}{\kappa}\left[\ln\left(\frac{u_{*0}}{|f_c| z_0}\right) - A\right] = C_D^{-1/2}$$

1. The inflow is defined by a surface z_{01}
2. z_{01} represents a “large-scale” terrain roughness

- The inflow should balance the “large-scale” z_{01}.
- The CFD model simulates the micro-scale varians from the meso-scale mean.



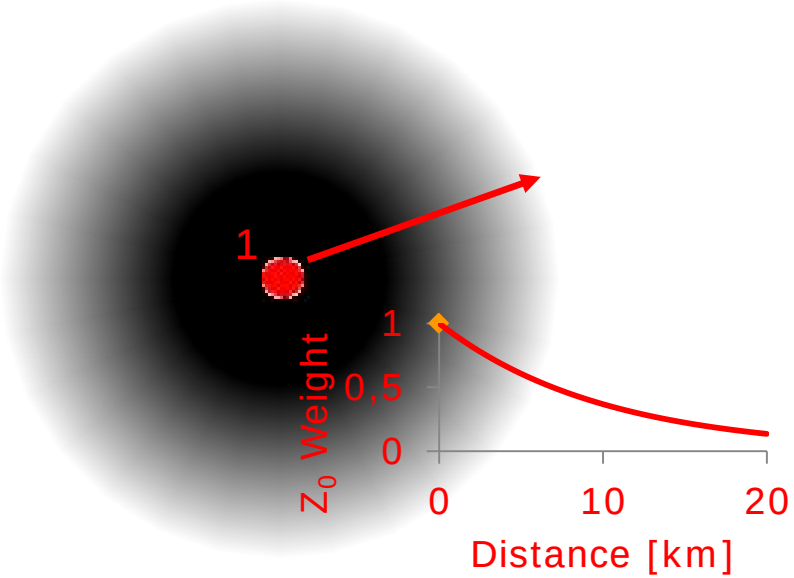


Micro - Meso coupling

Large-scale roughness length:
Rossby radius: G/f ≥ 10km

Inflow boundary condition:
For homogeneous farfield terrain

$$\frac{\langle M \rangle}{u_{*0}} = \frac{1}{\kappa} \ln\left(\frac{z}{z_0}\right) \qquad k = \frac{u_{*0}^2}{\sqrt{C_\mu}}$$



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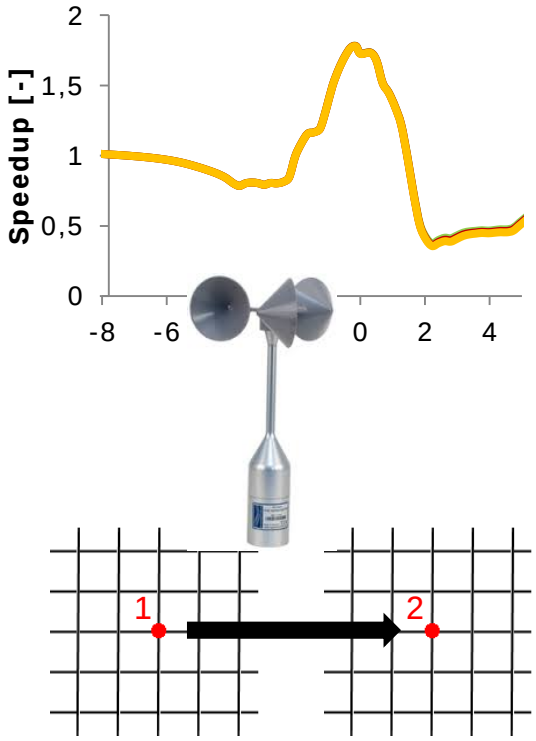

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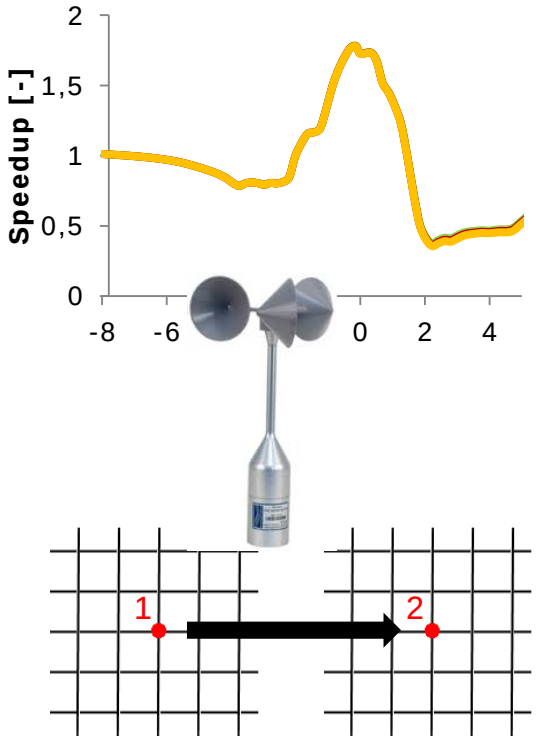
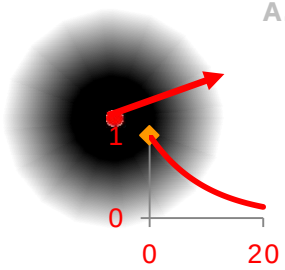
4. Farfield conditions should balance the meso-scale mean



A.Bechmann



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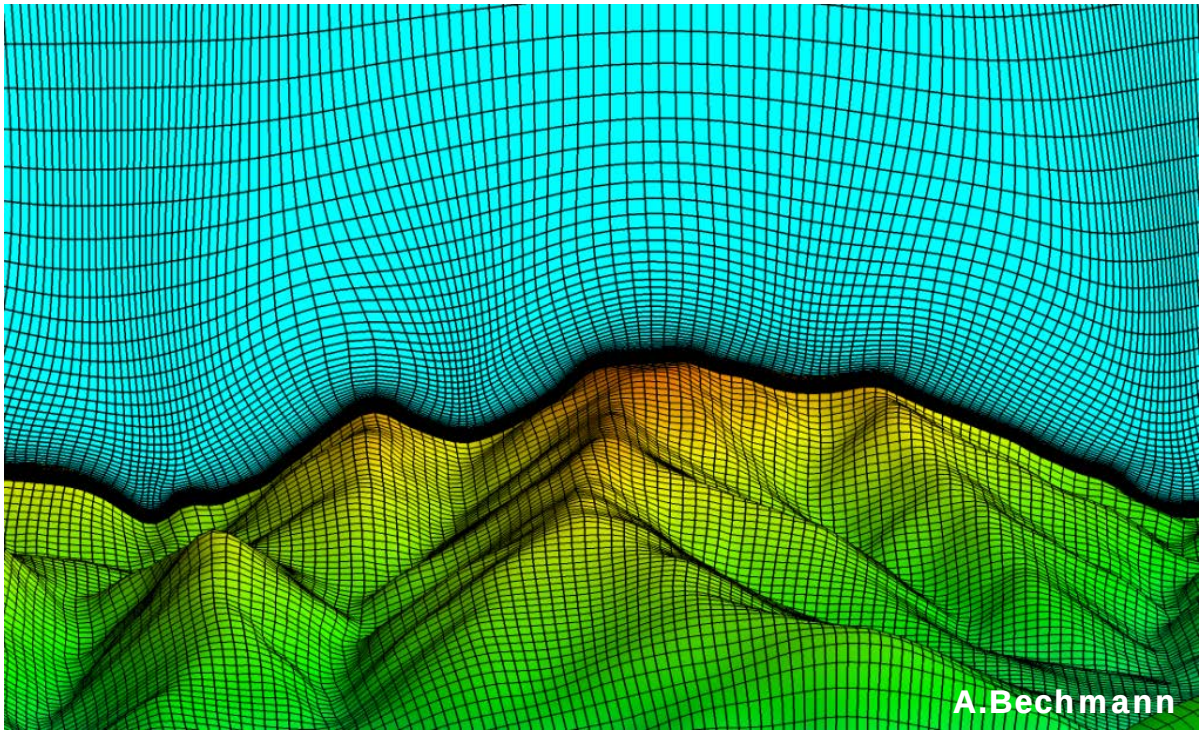

Example: Prepare Terrain

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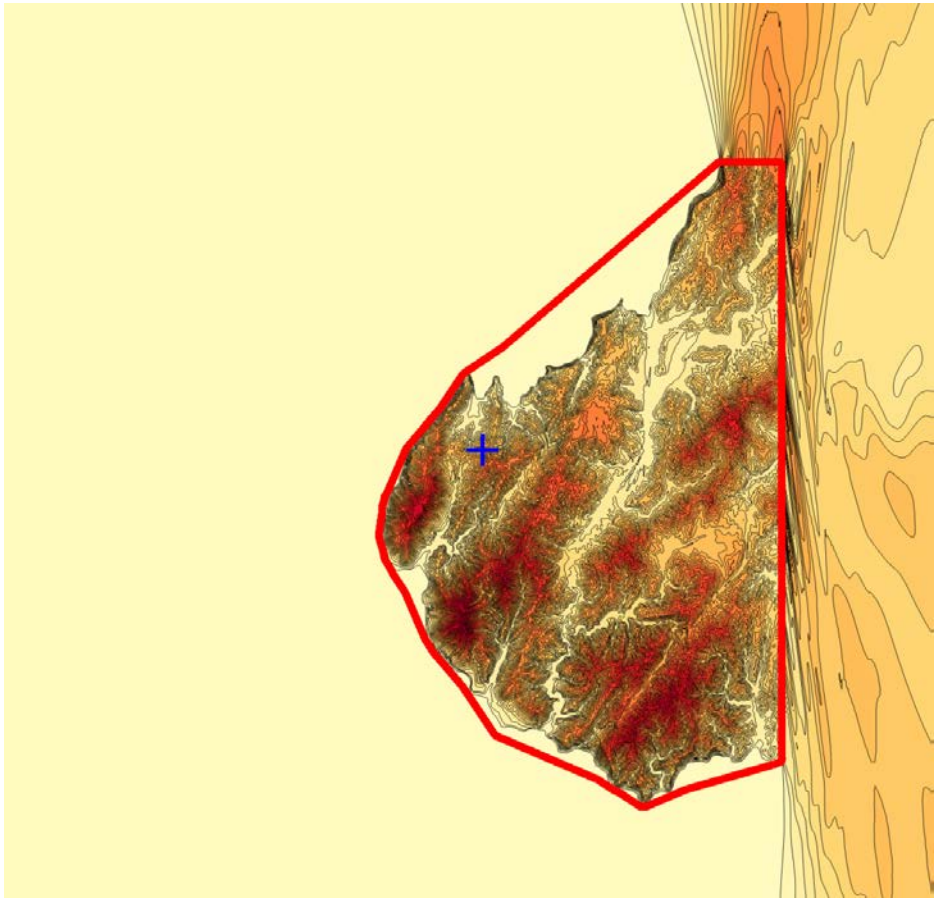

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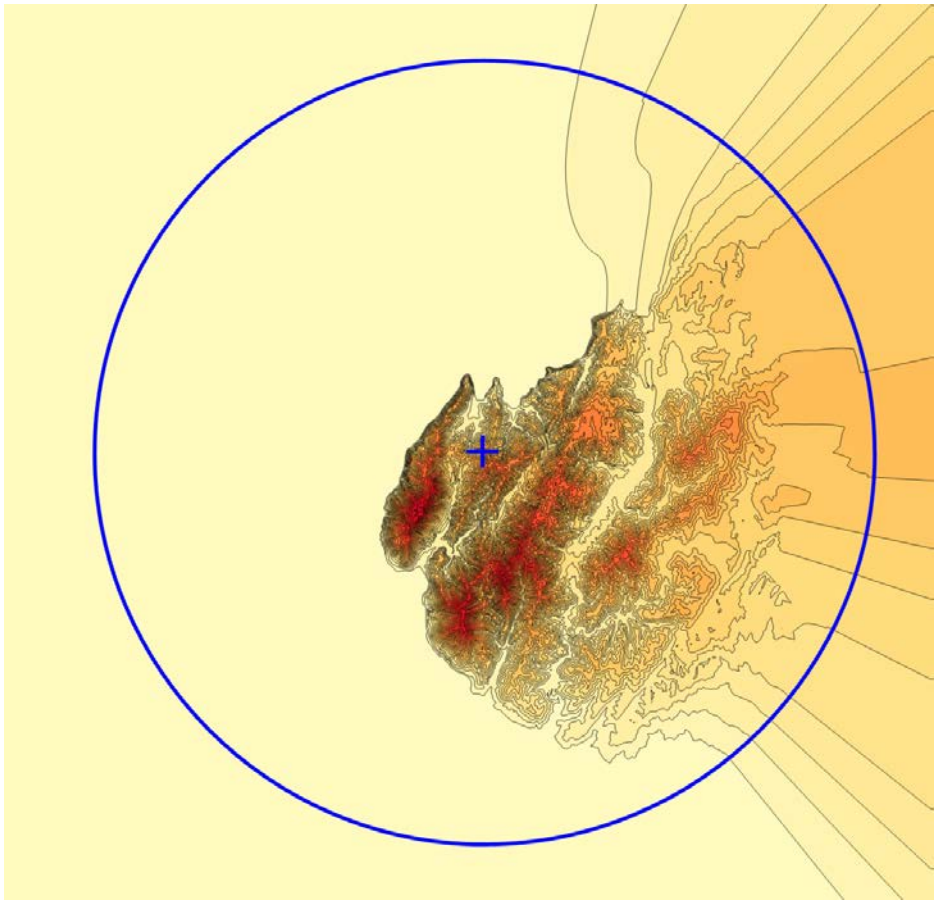

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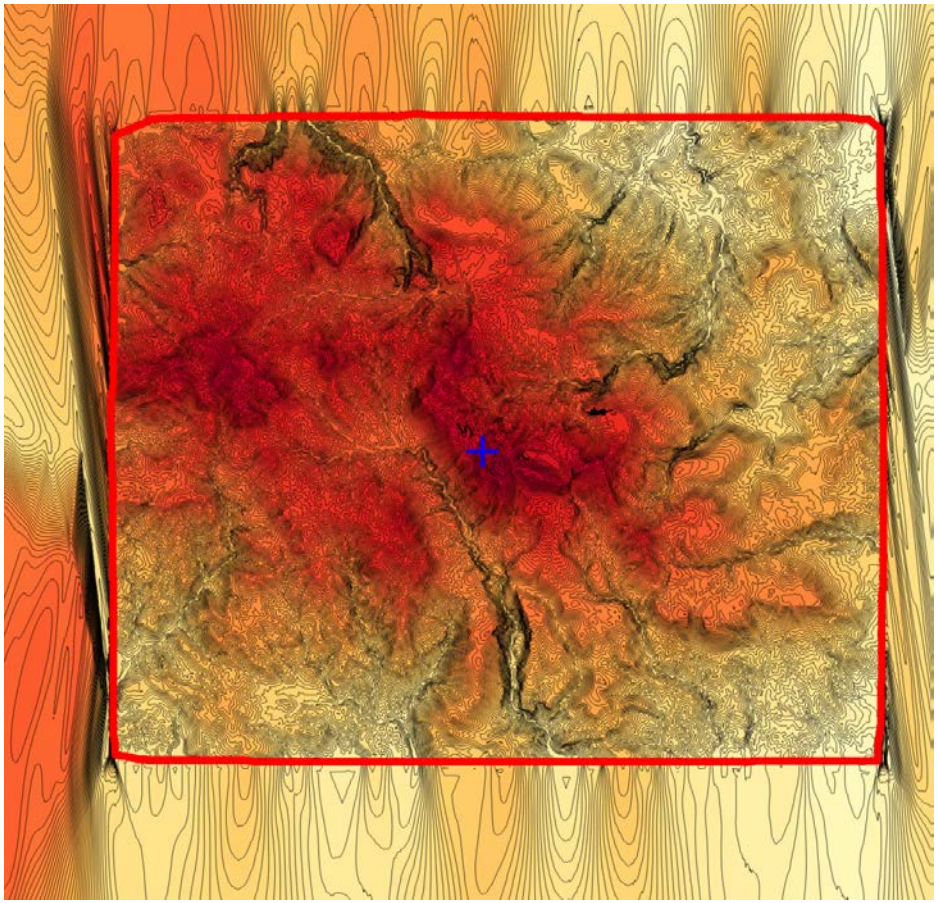

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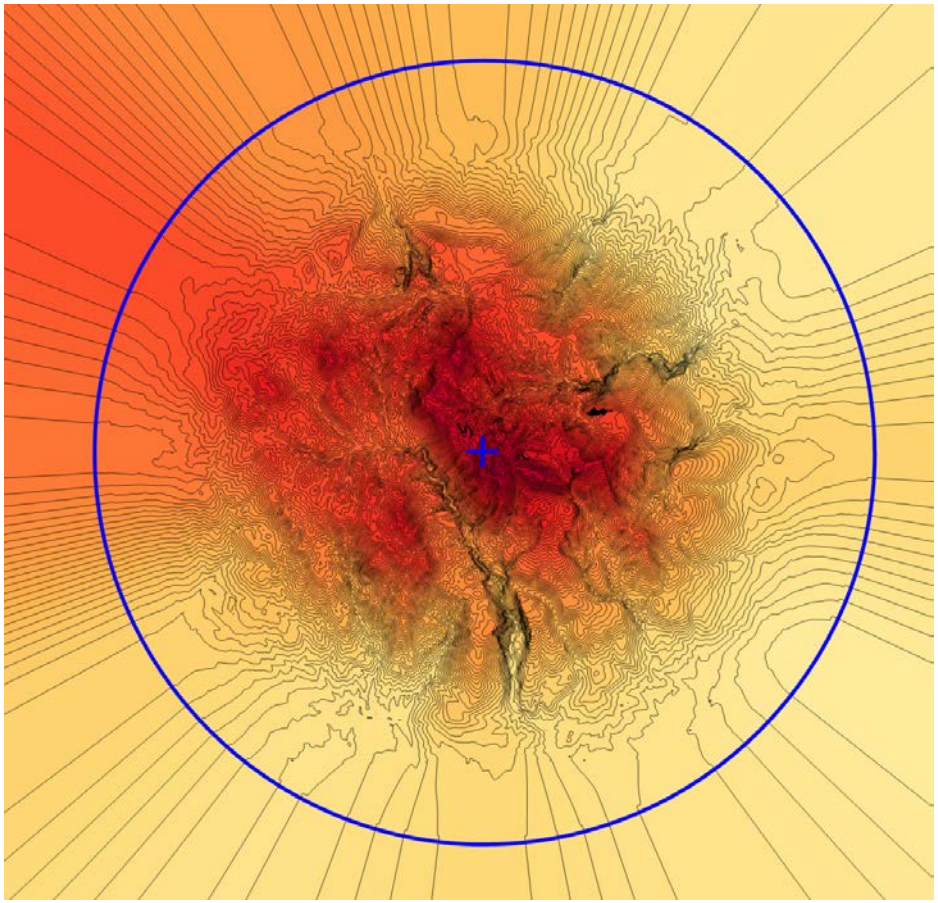

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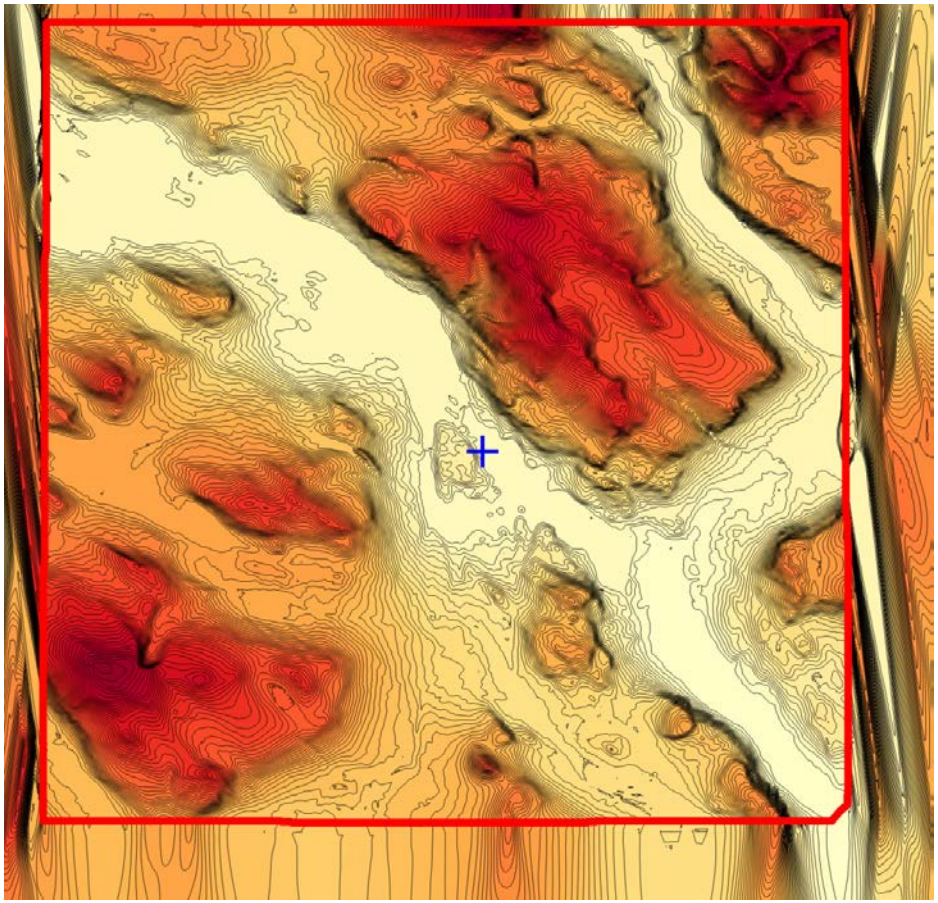

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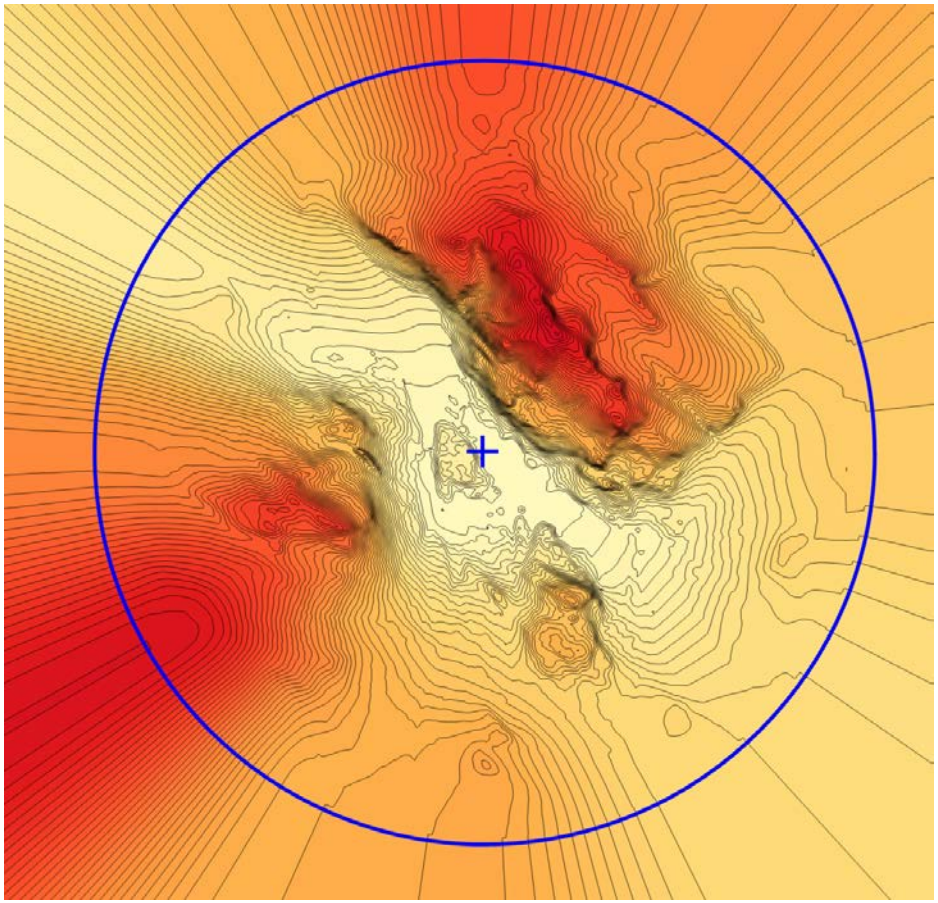

Example: Mesh

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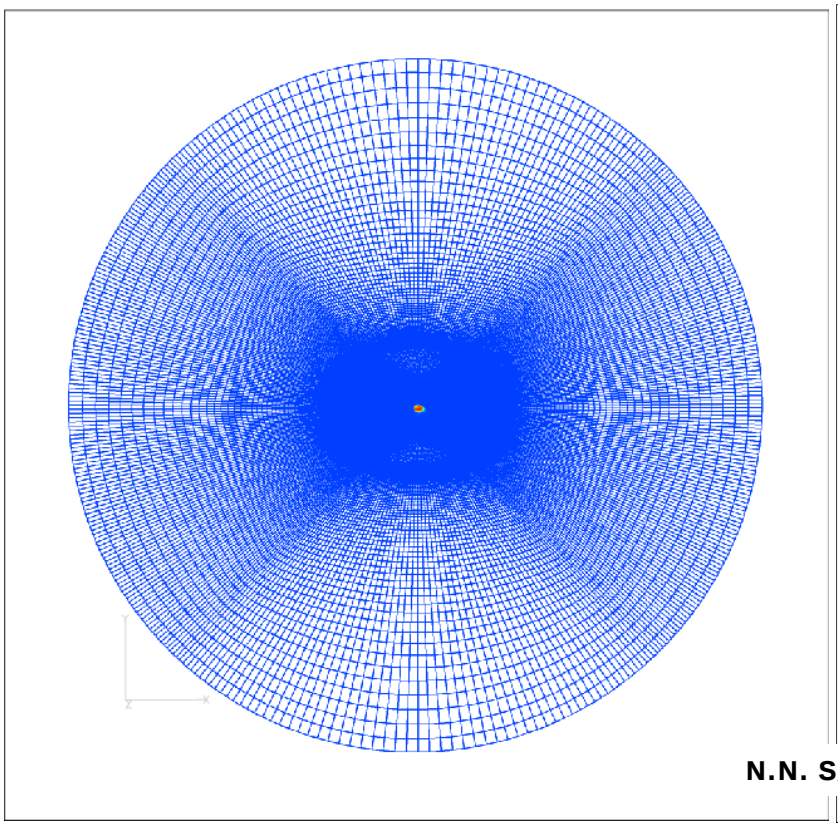
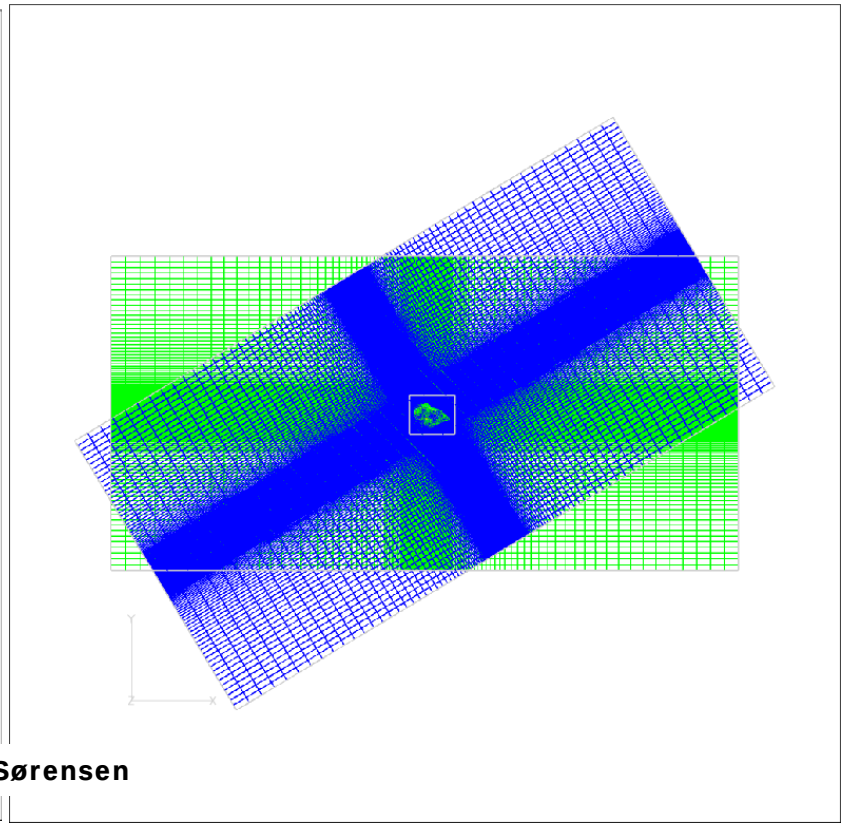


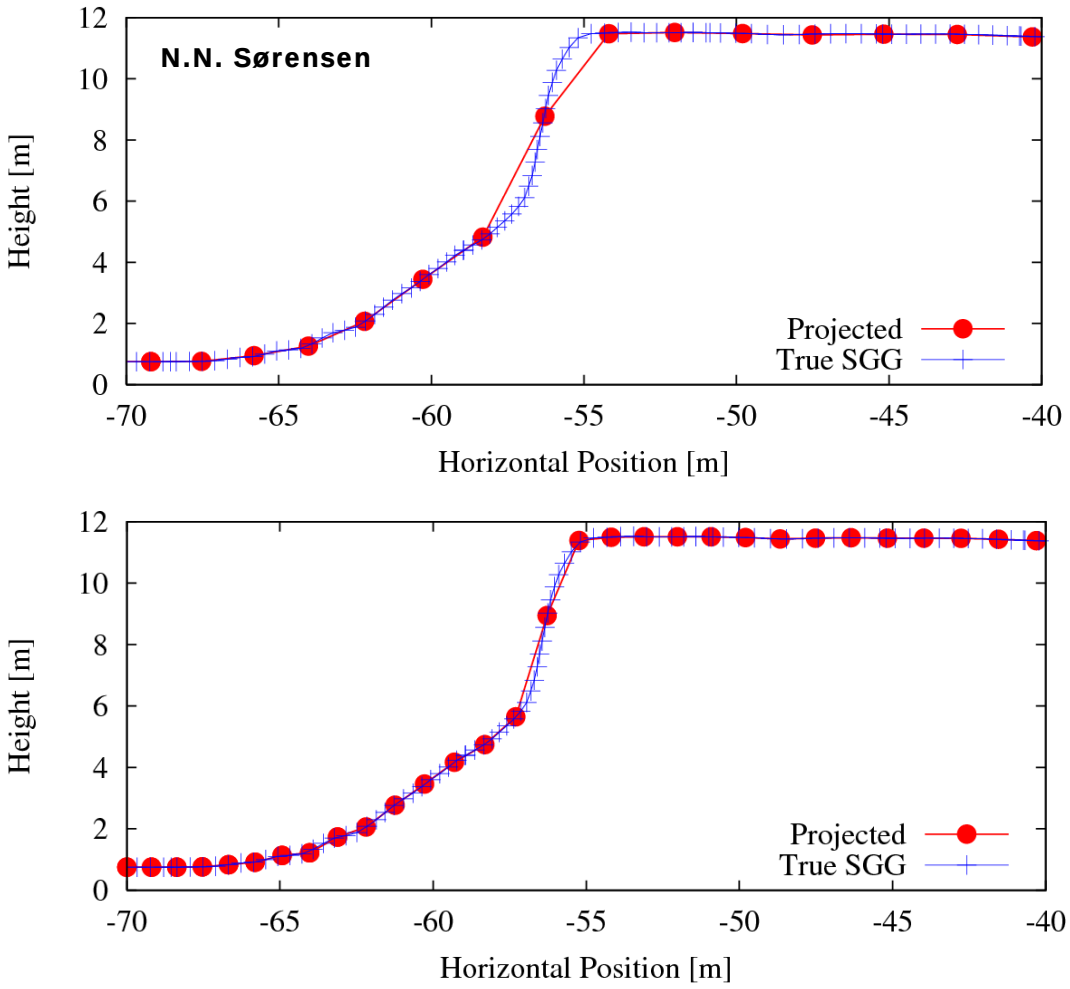


N.N. Sørensen

One domain for all comp.

A dedicated mesh for each direction

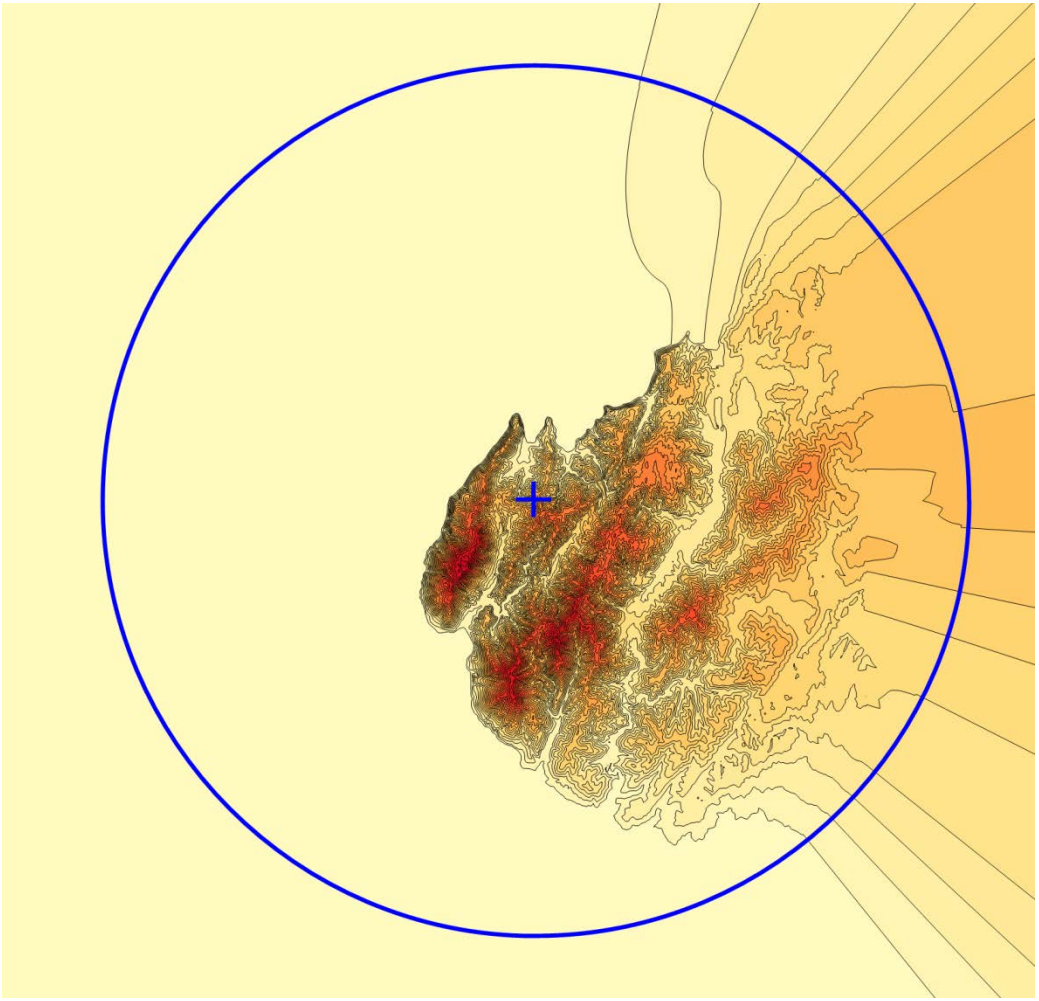
Example: Mesh



- Simple projection of a surface grid onto terrain, leads to coarse cells at steep slops. Not suited for grid convergence studies.

Example: Mesh

34km



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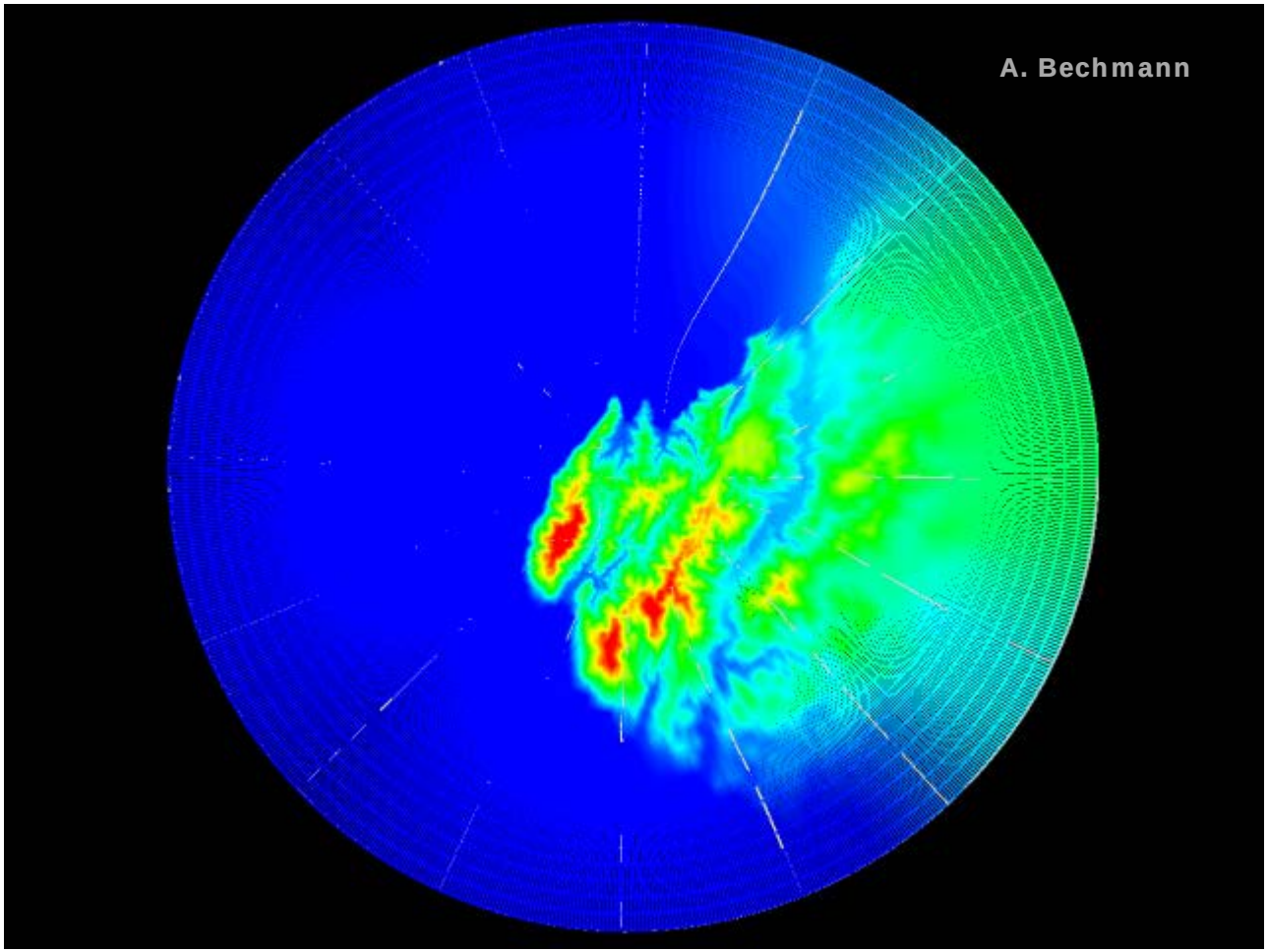
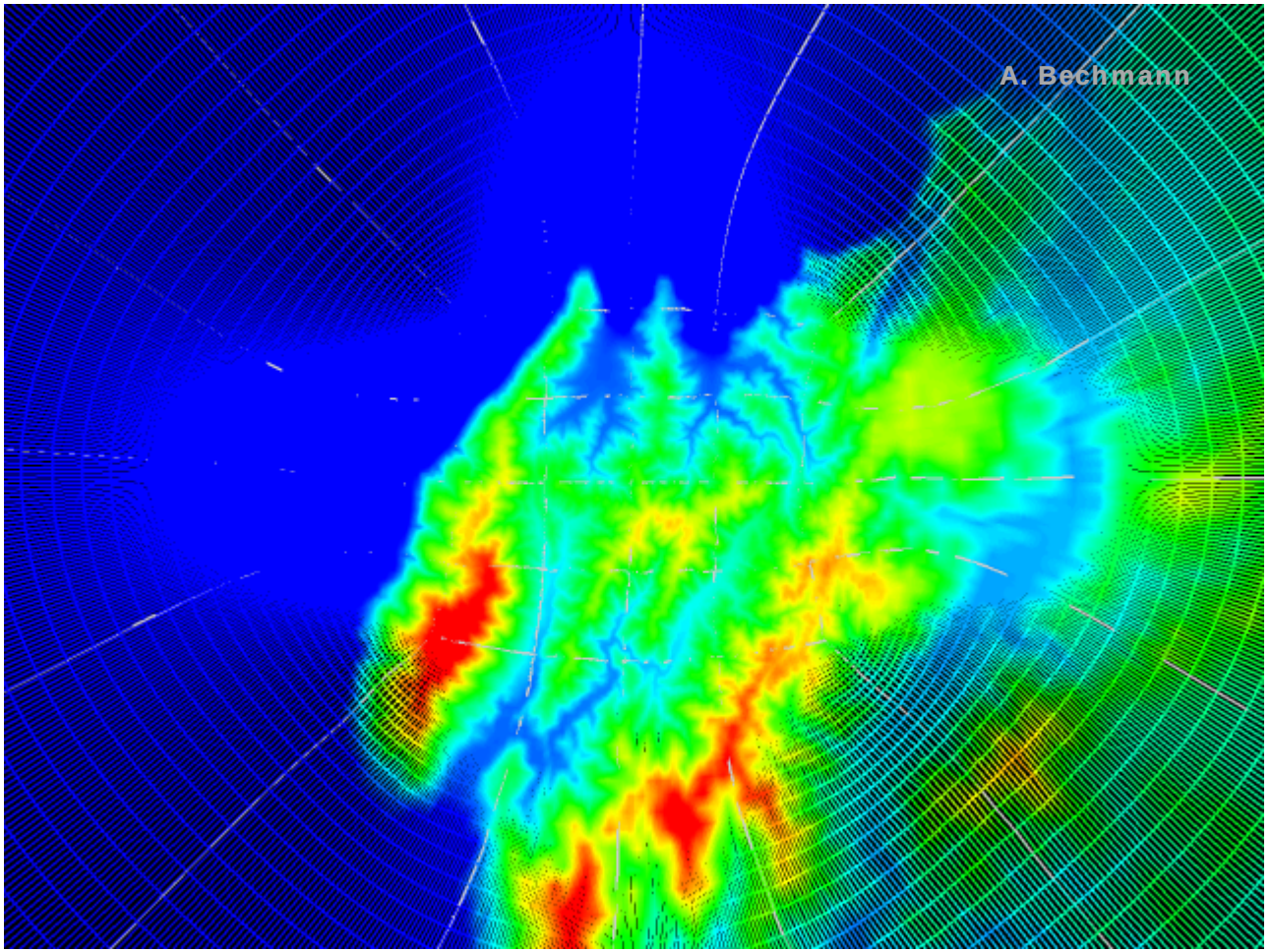


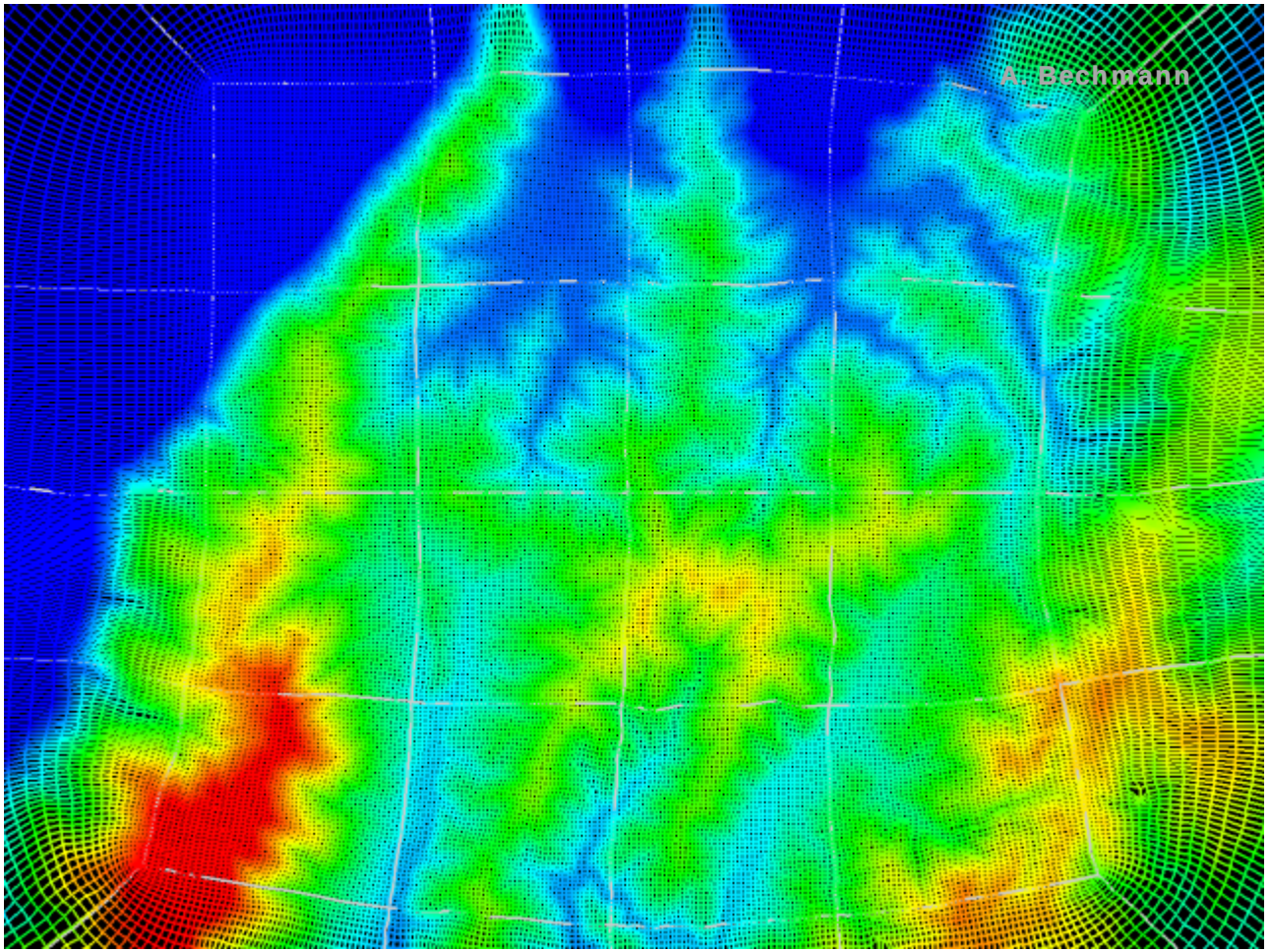
Example: Mesh

15km



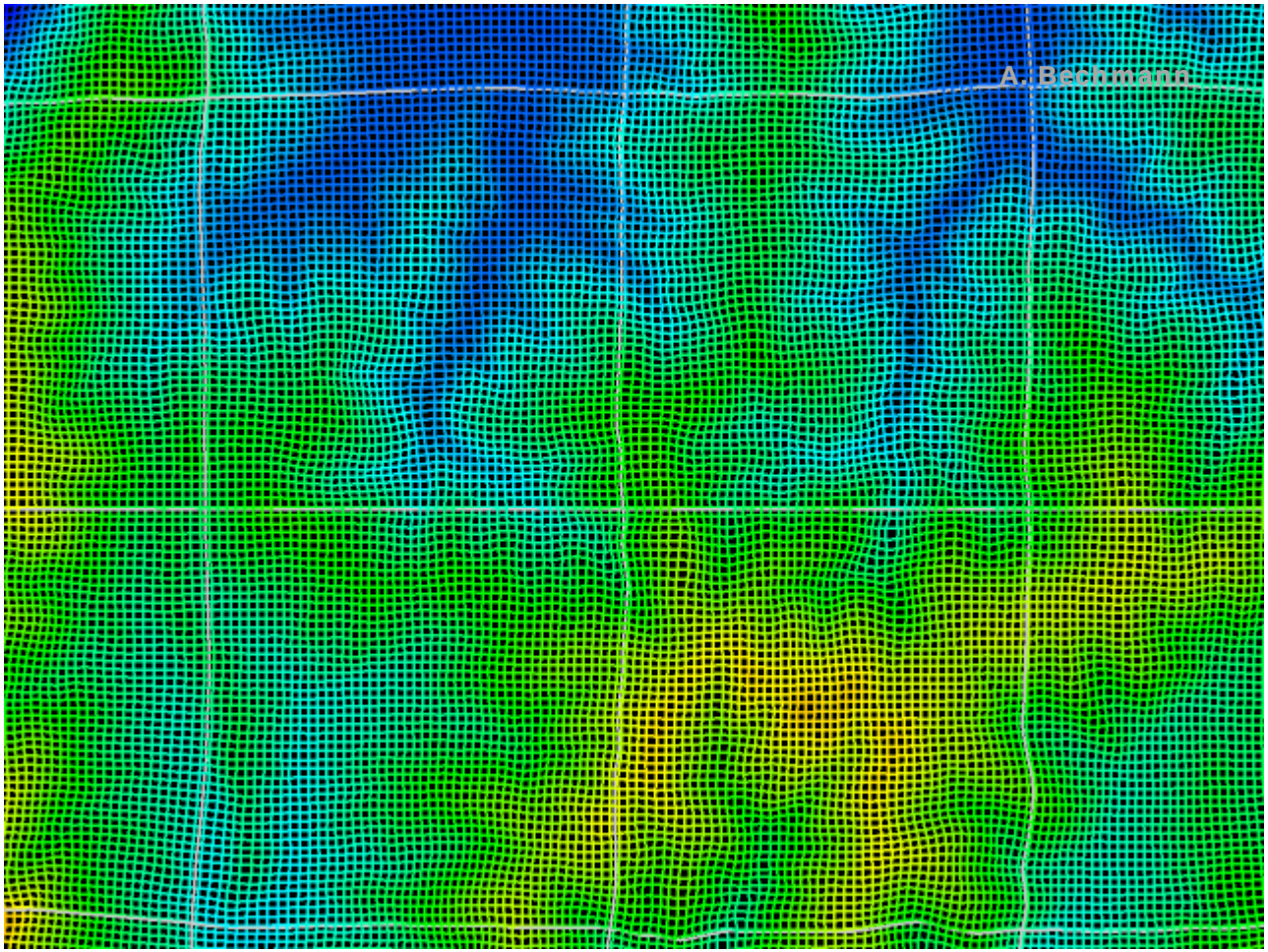
Example: Mesh

6km



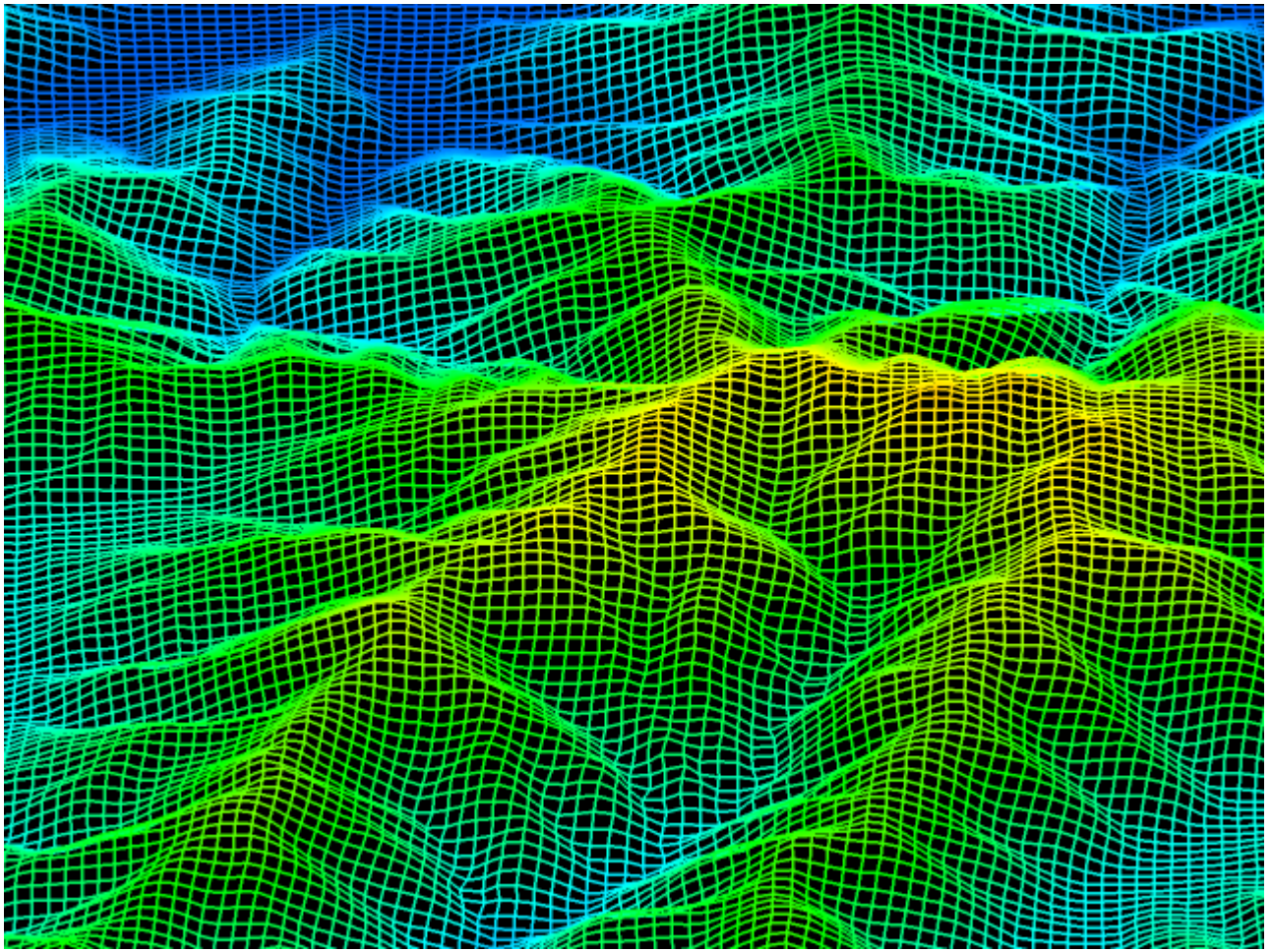
Example: Mesh

3km



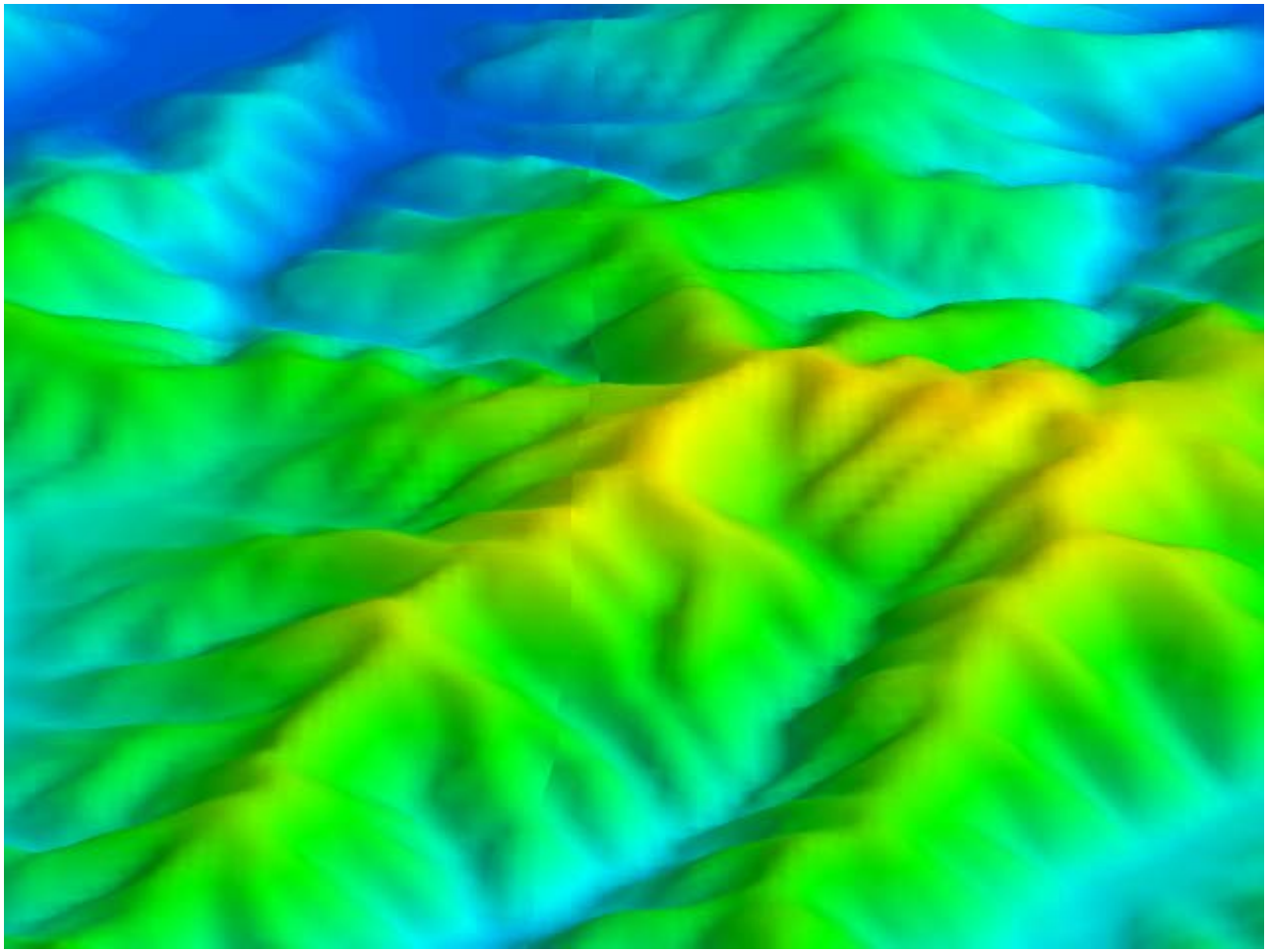
Example: Mesh

1km



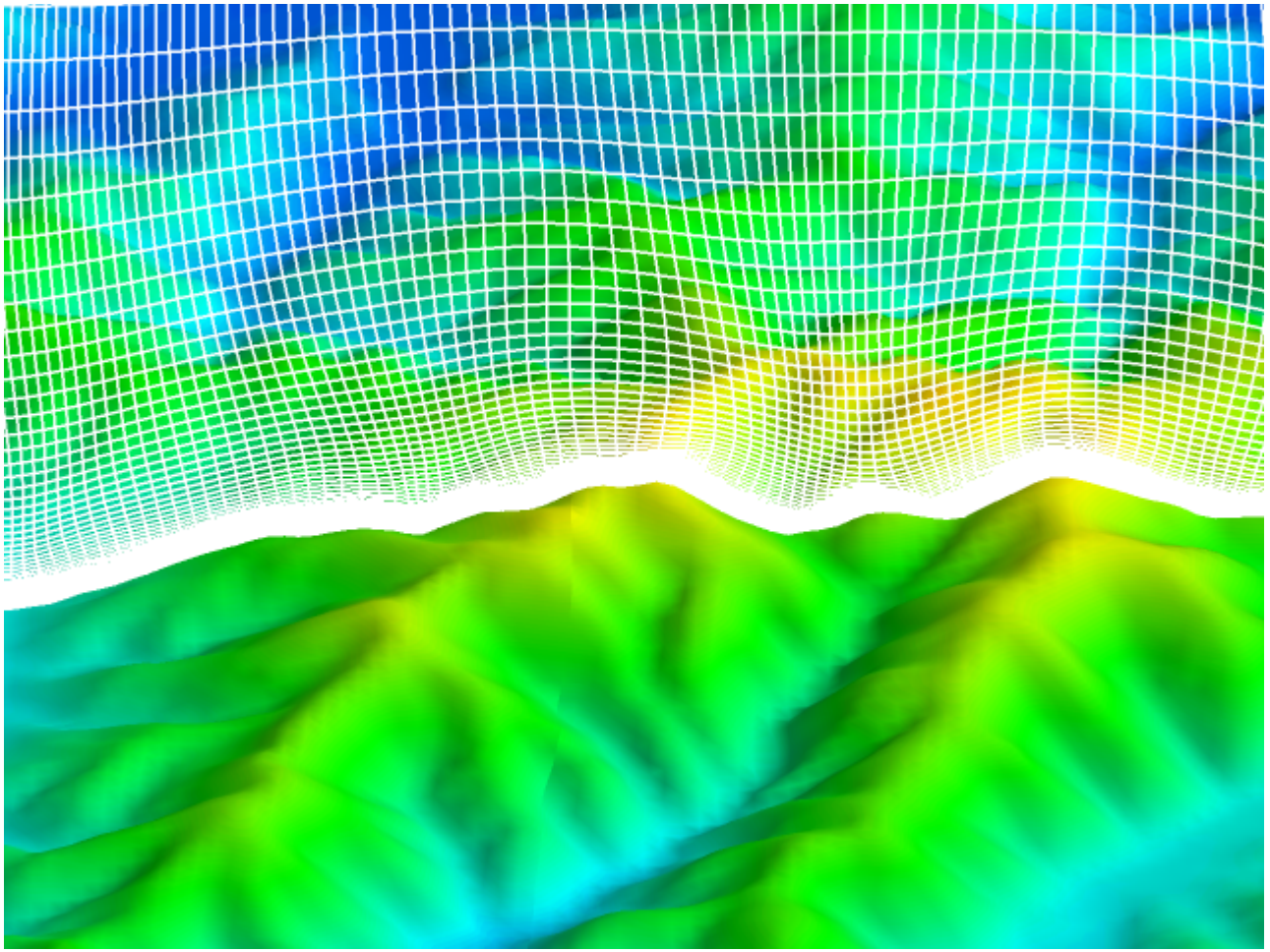
Example: Mesh

1km



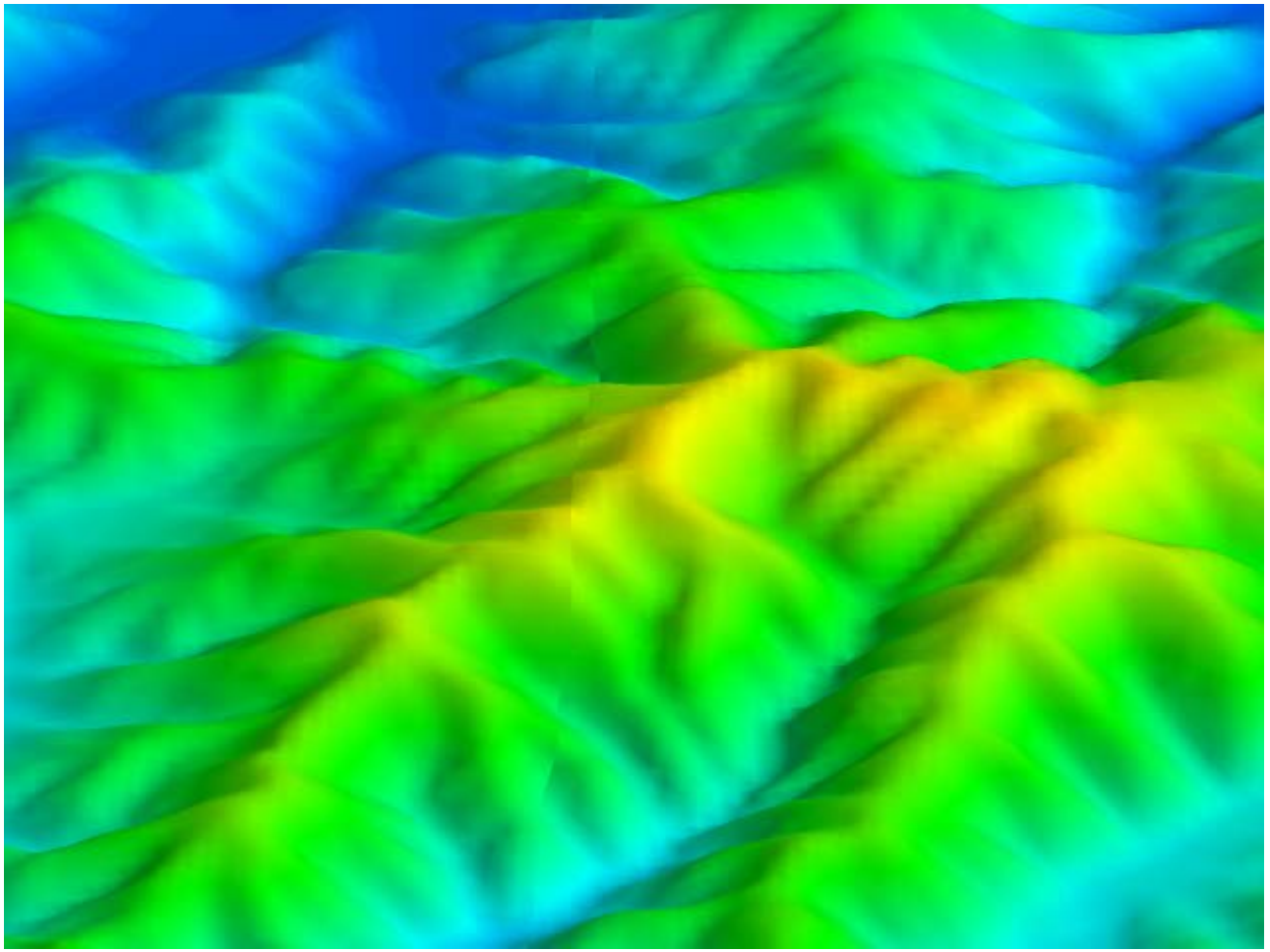
Example: Mesh

1km



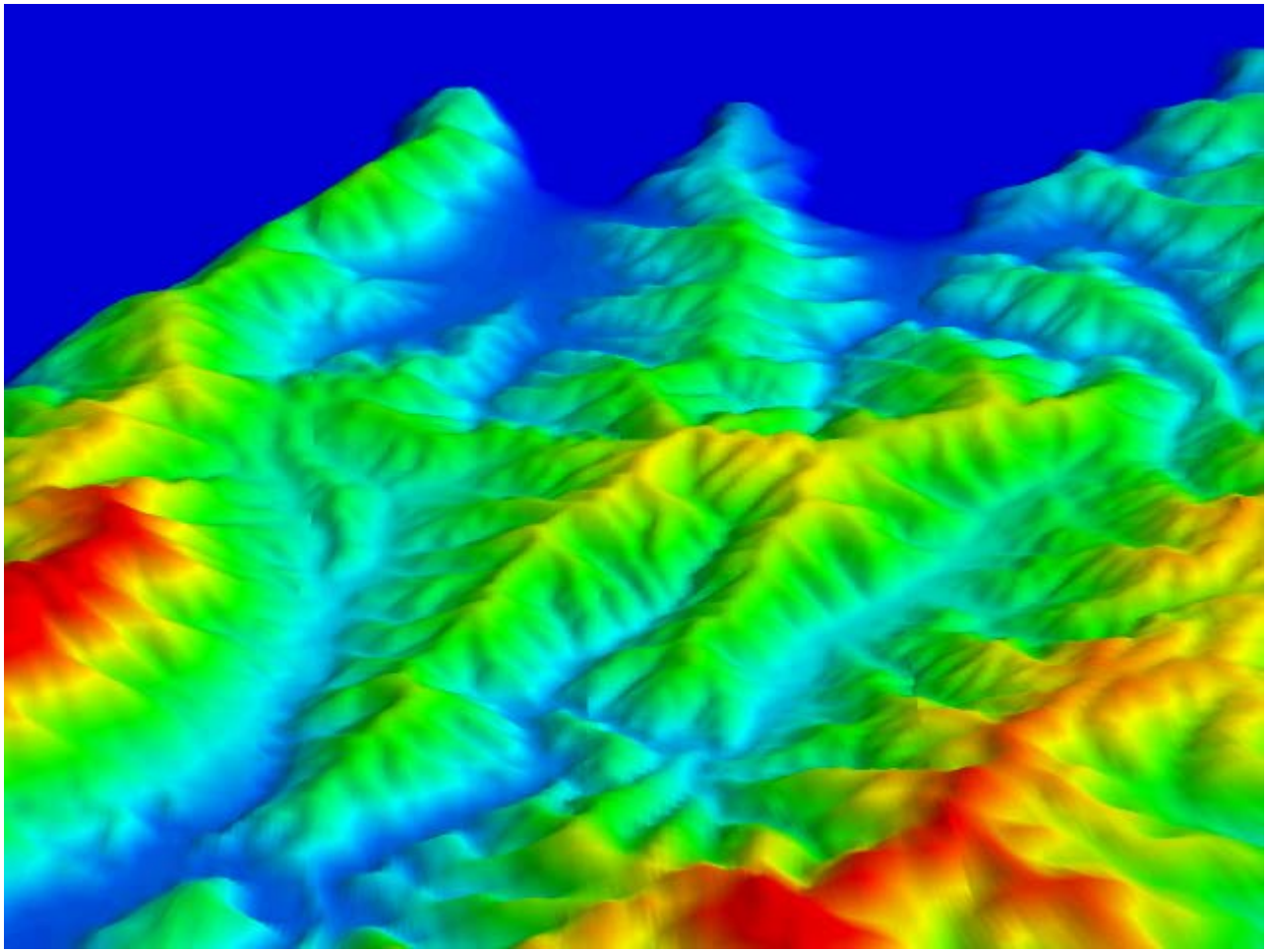
Example: Mesh

1km



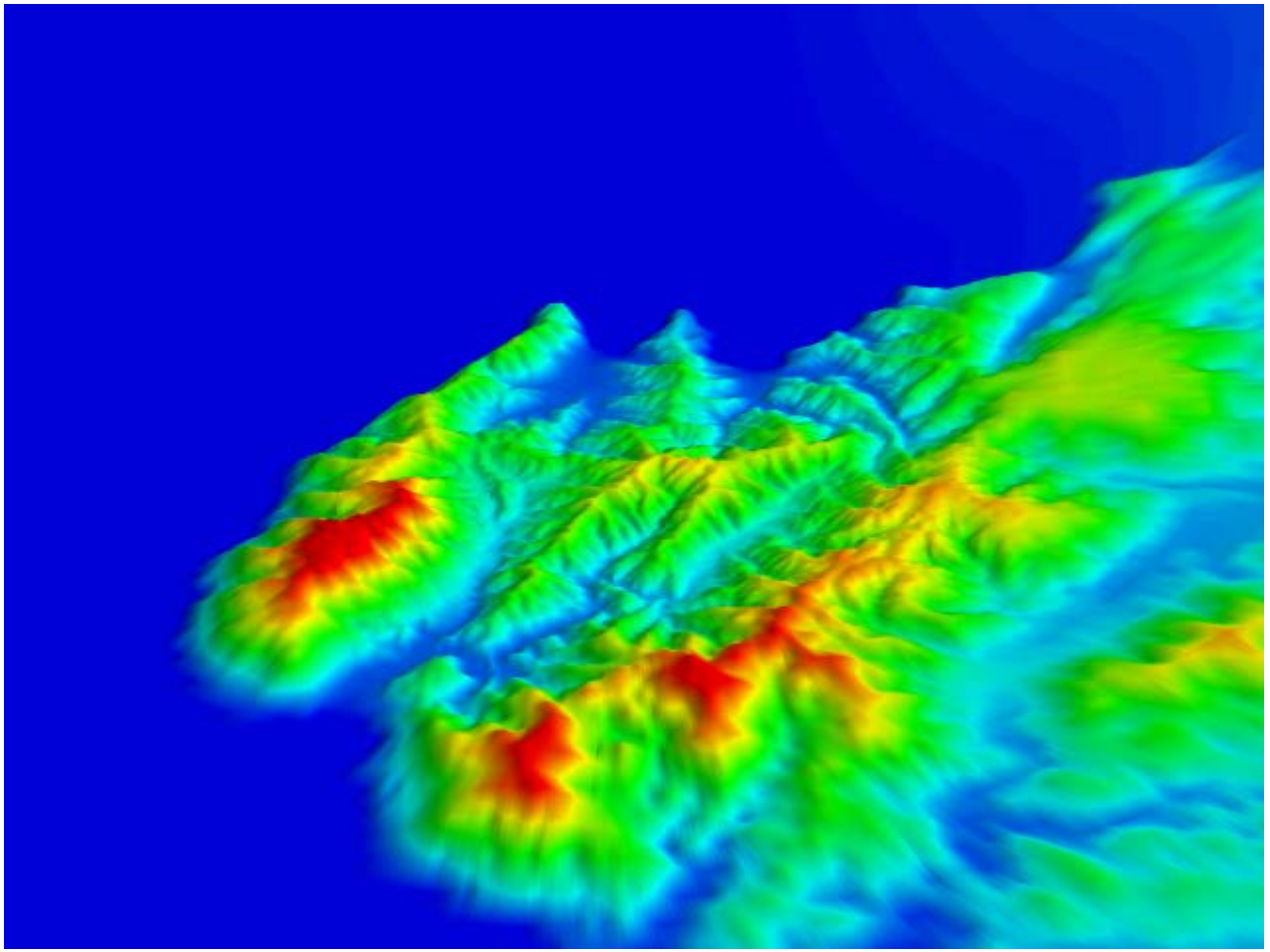
Example: Mesh

6km



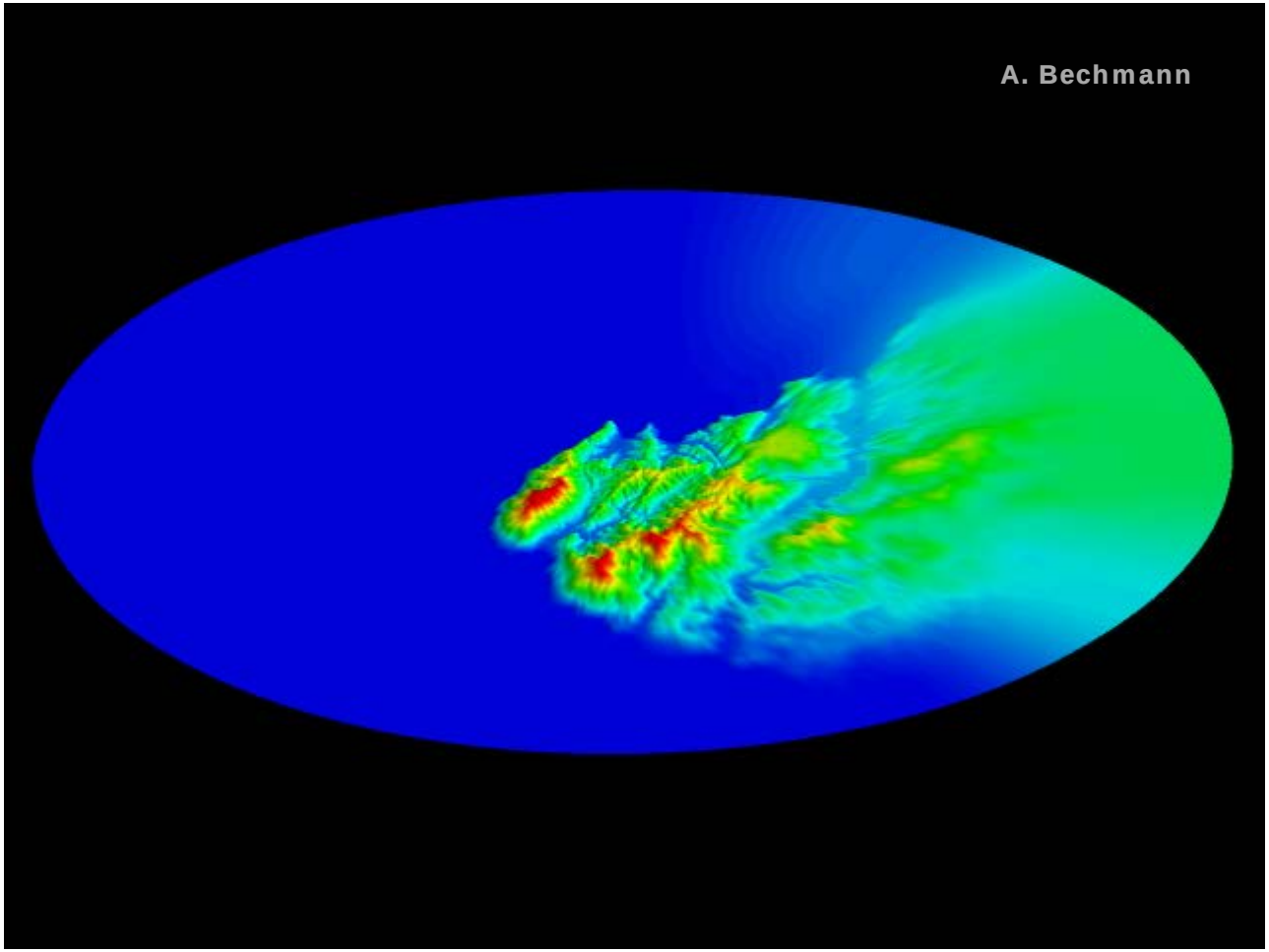
Example: Mesh

15km



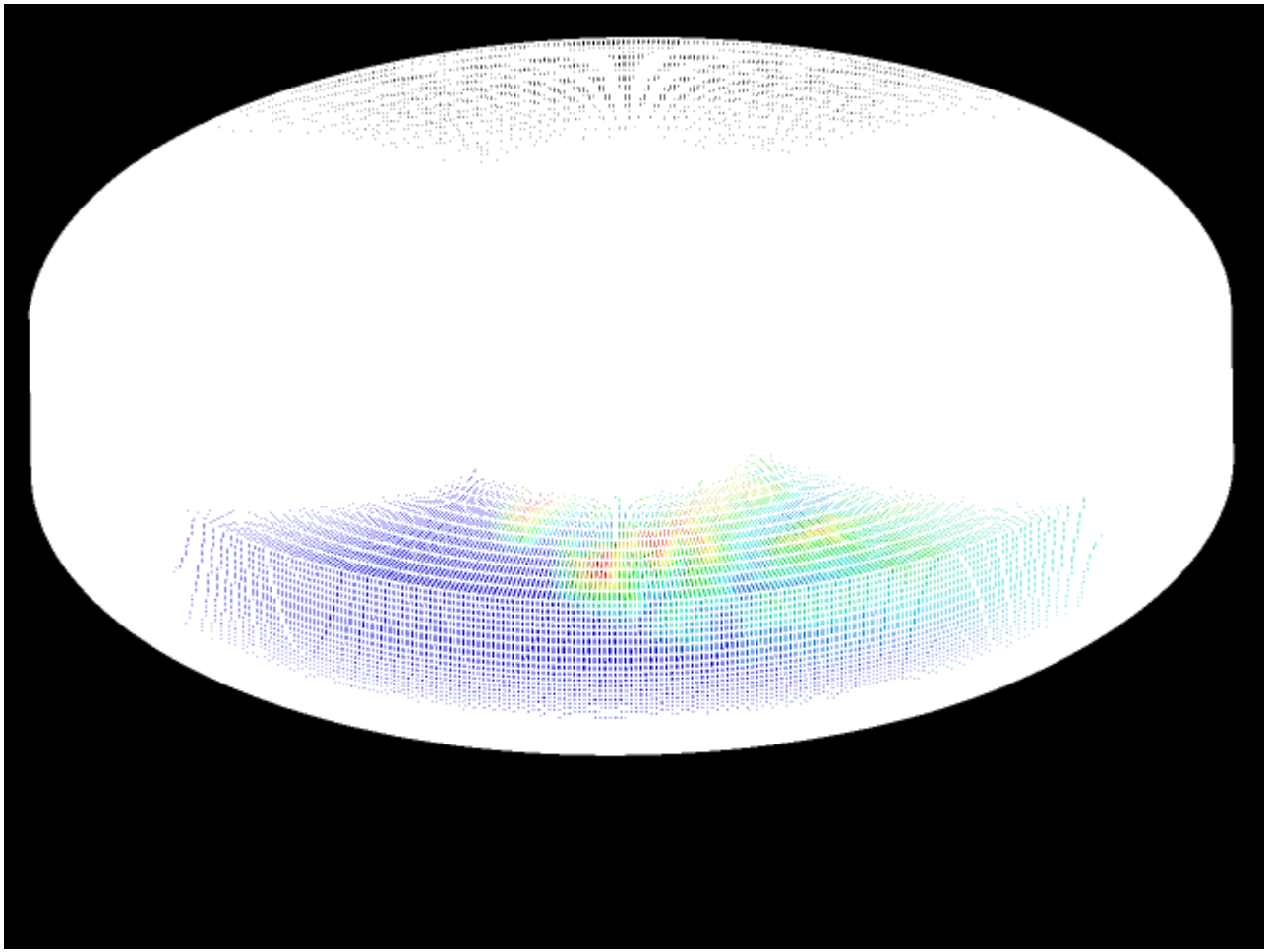
Example: Mesh

34km



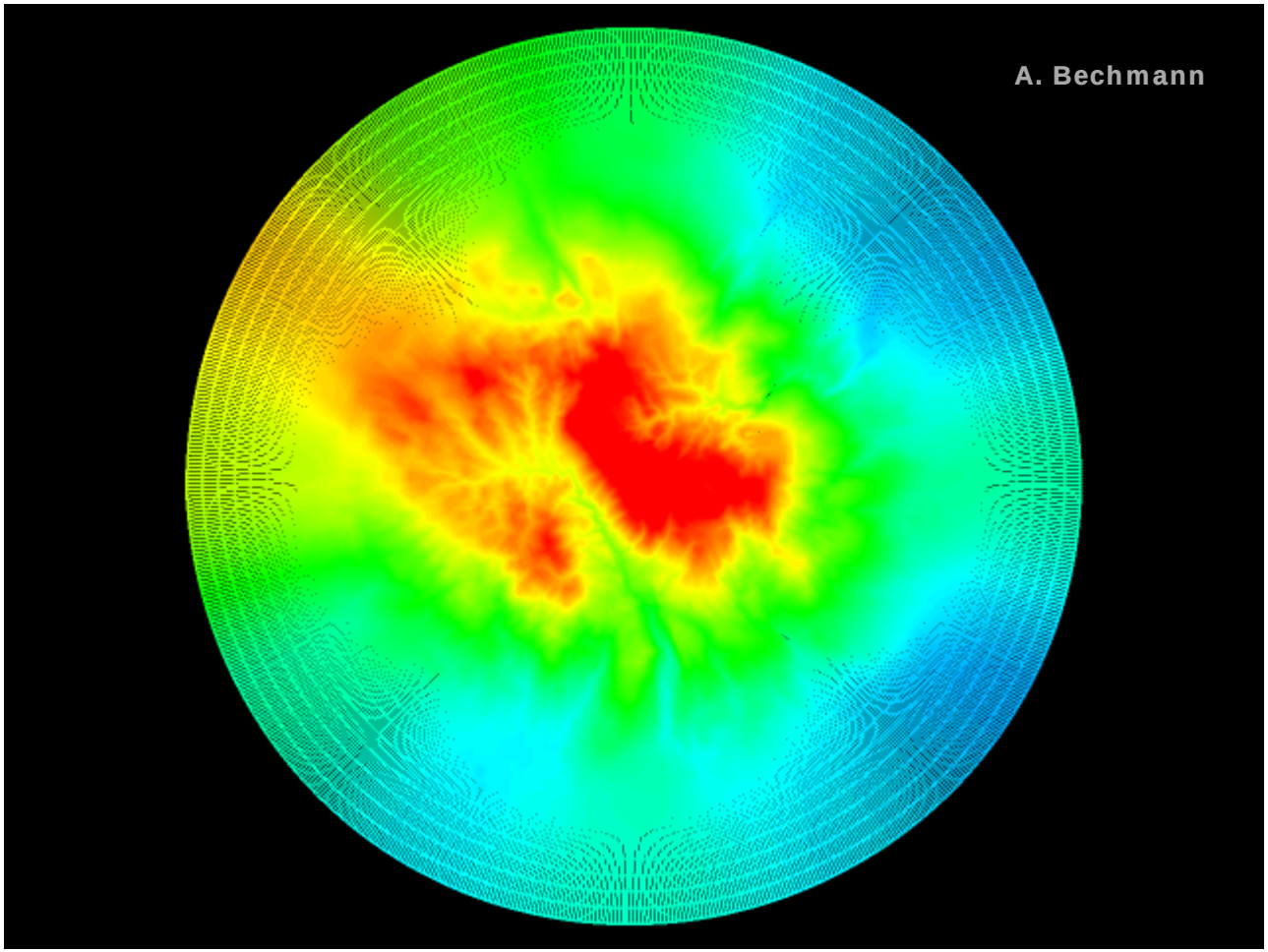
Example: Mesh

34km



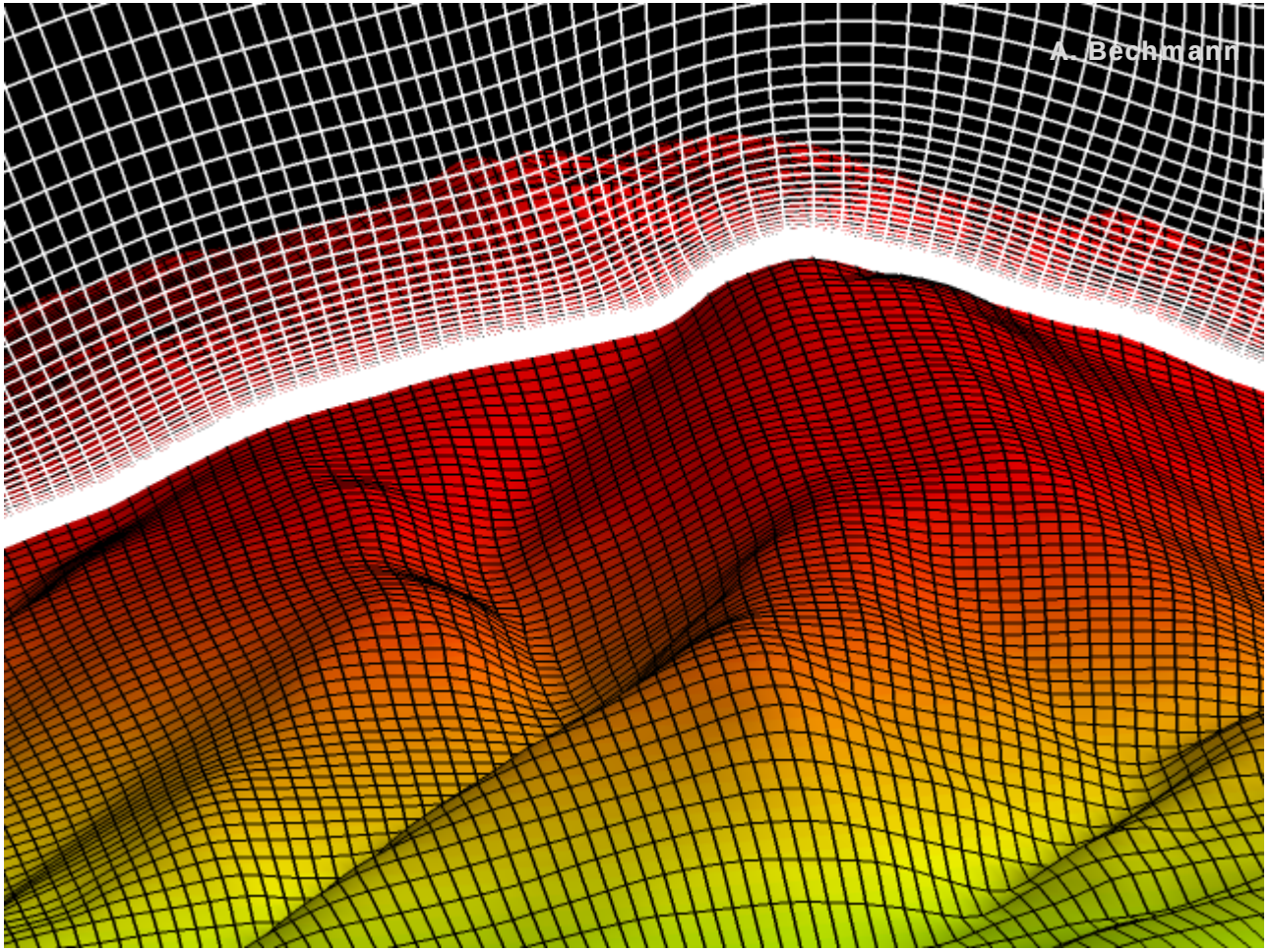
Example: Mesh

34km



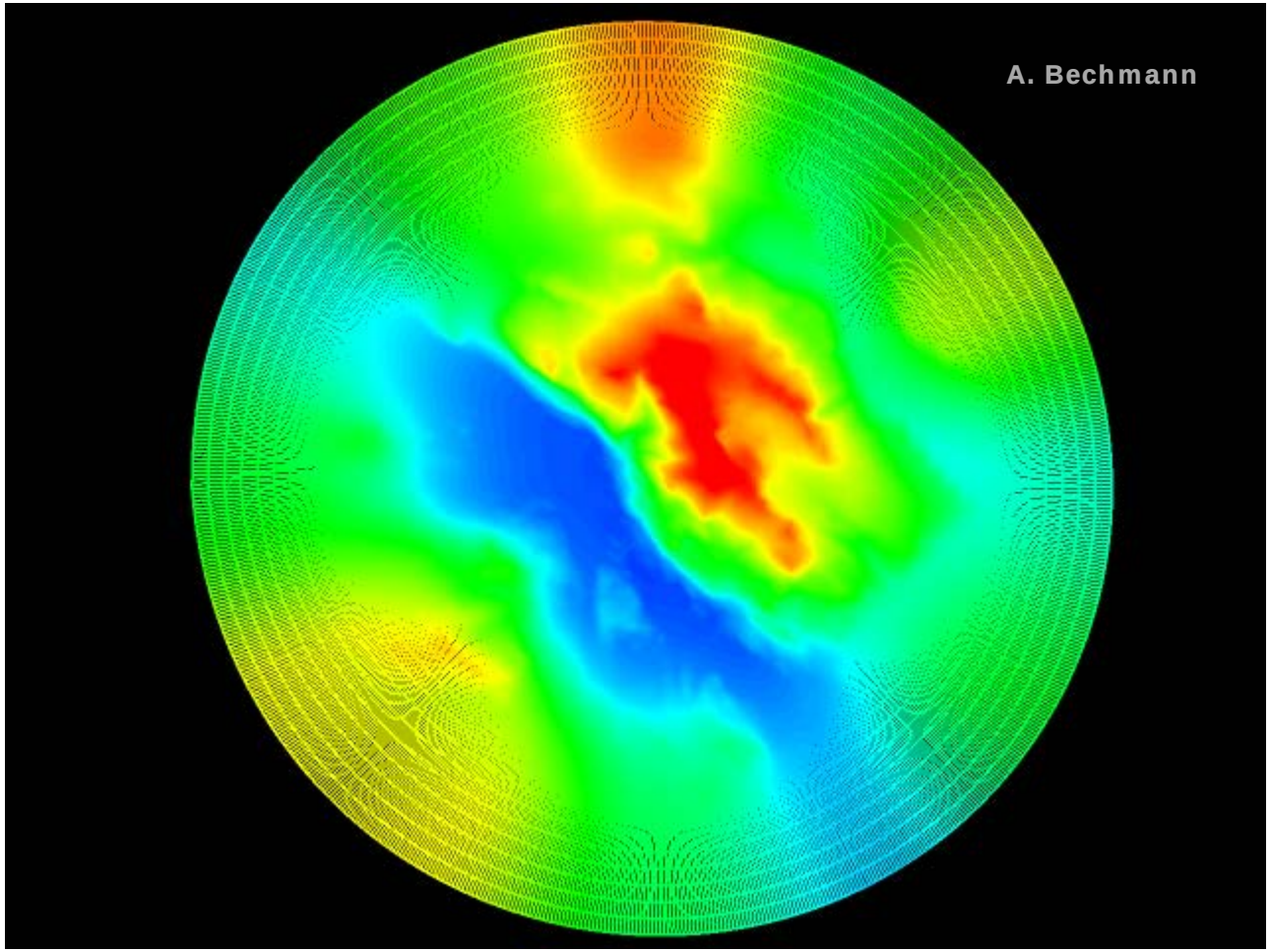
Example: Mesh

1km



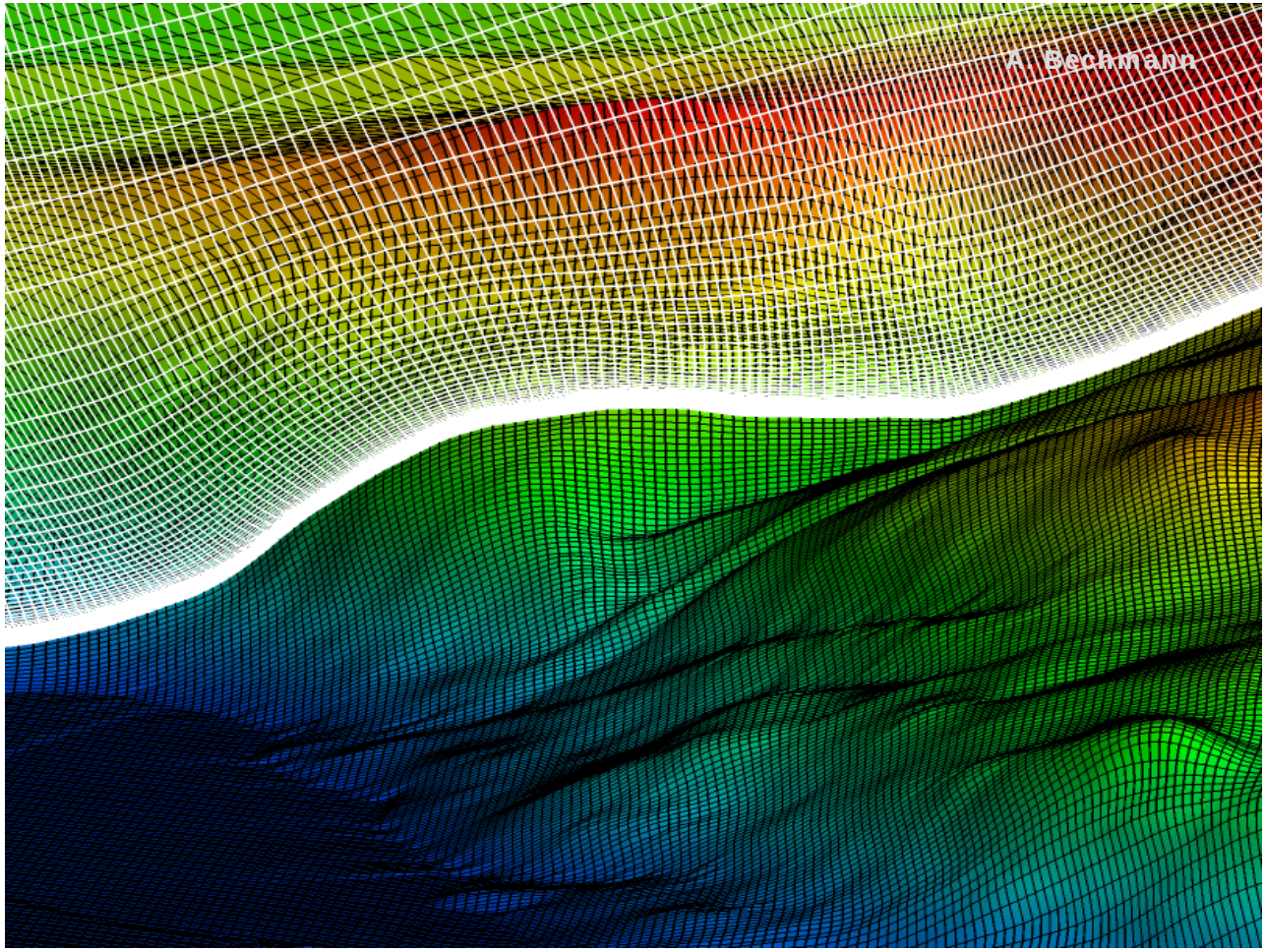
Example: Mesh

34km



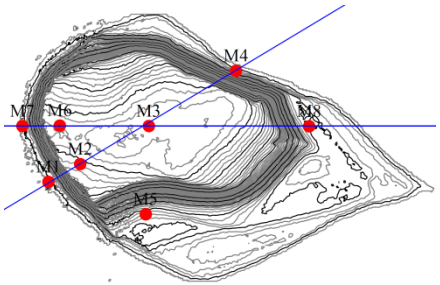
Example: Mesh

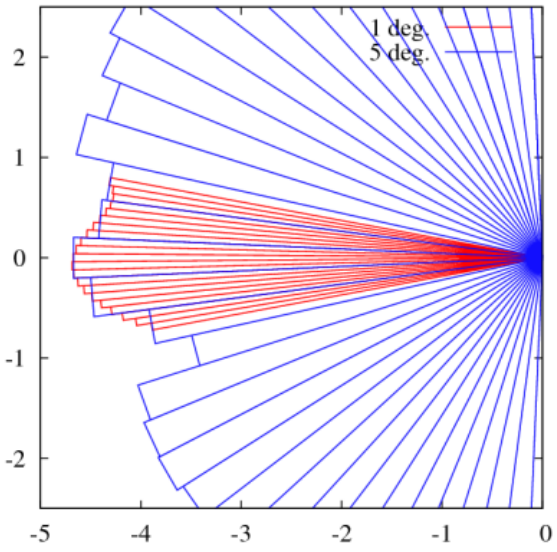
1km

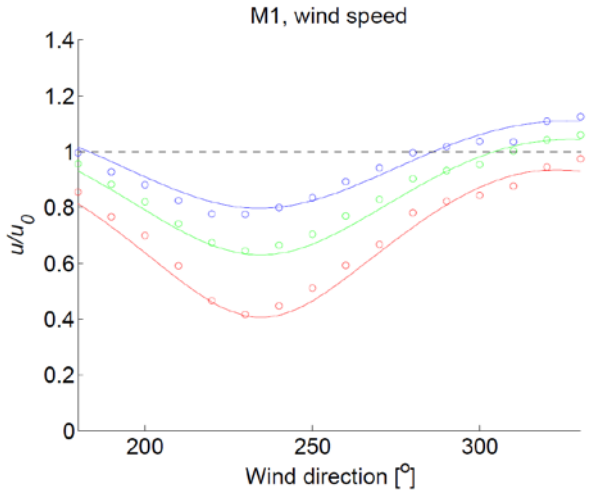


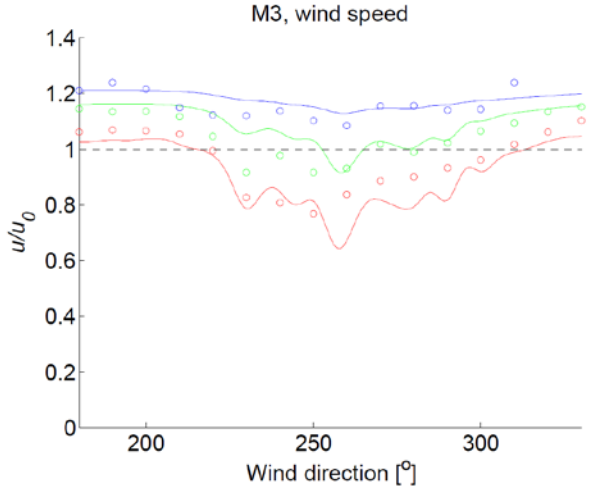
Example: CFD

Example: CFD

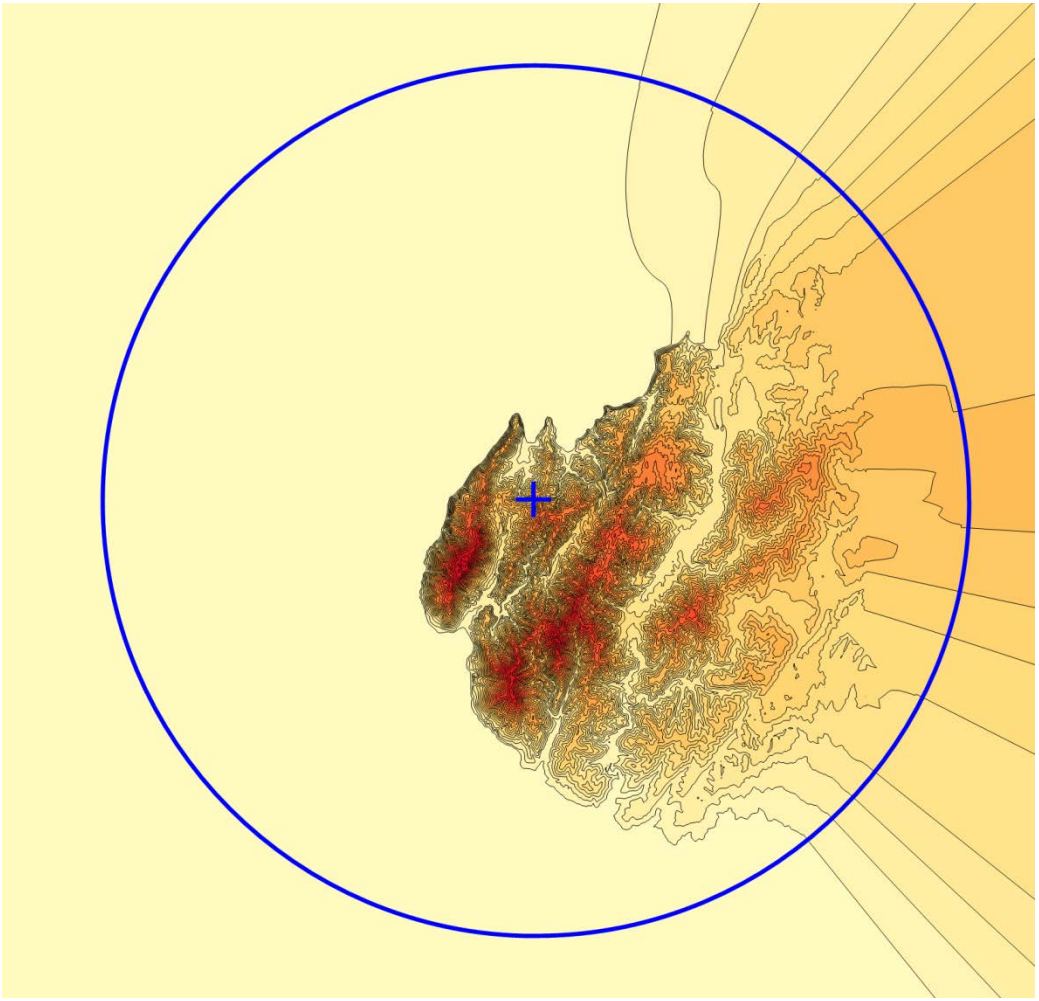

M4
M7
M6
M3
M8
M2
M1
M5


1 deg.
5 deg.
2
1
0
-1
-2
-5
-4
-3
-2
-1
0

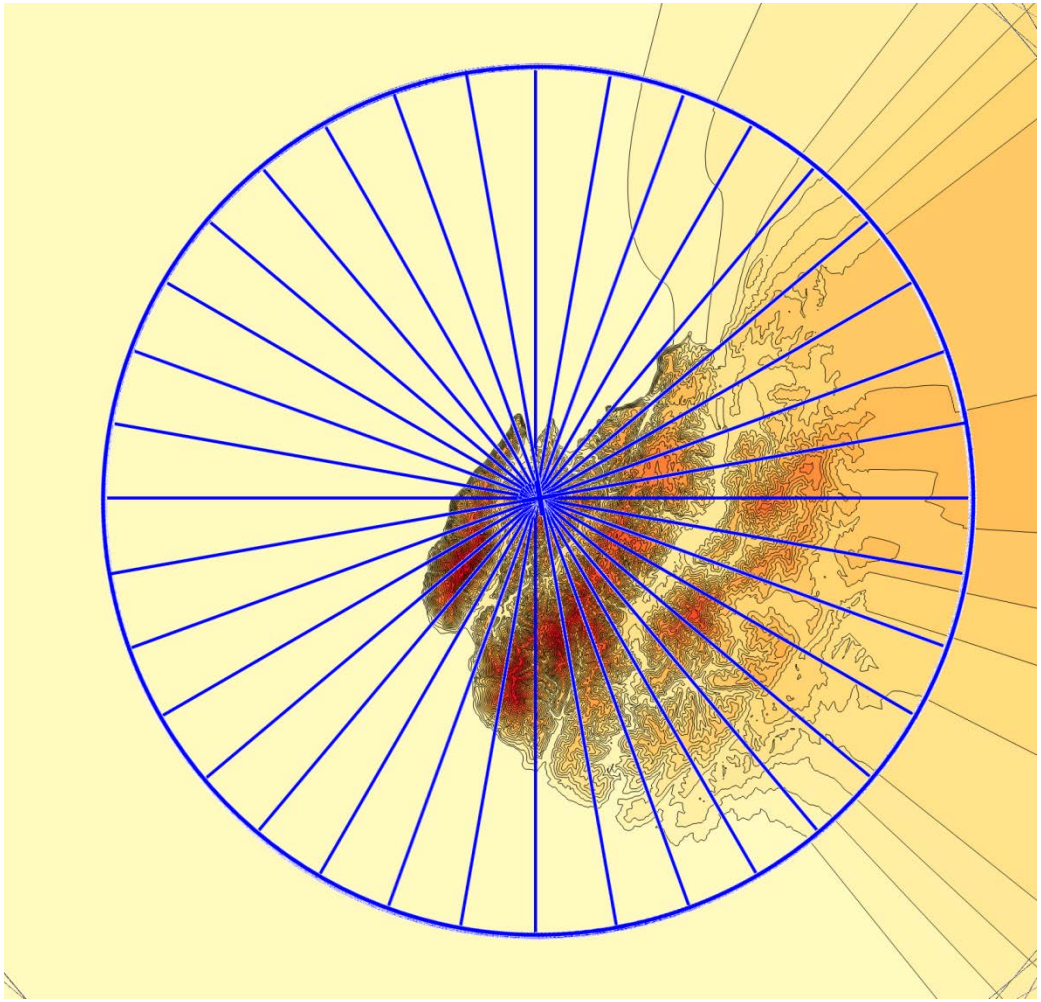

M1, wind speed
1.4
1.2
1
0.8
0.6
0.4
0.2
0
u/u_0
200
250
300
Wind direction [°]


M3, wind speed
1.4
1.2
1
0.8
0.6
0.4
0.2
0
u/u_0
200
250
300
Wind direction [°]

Example: CFD

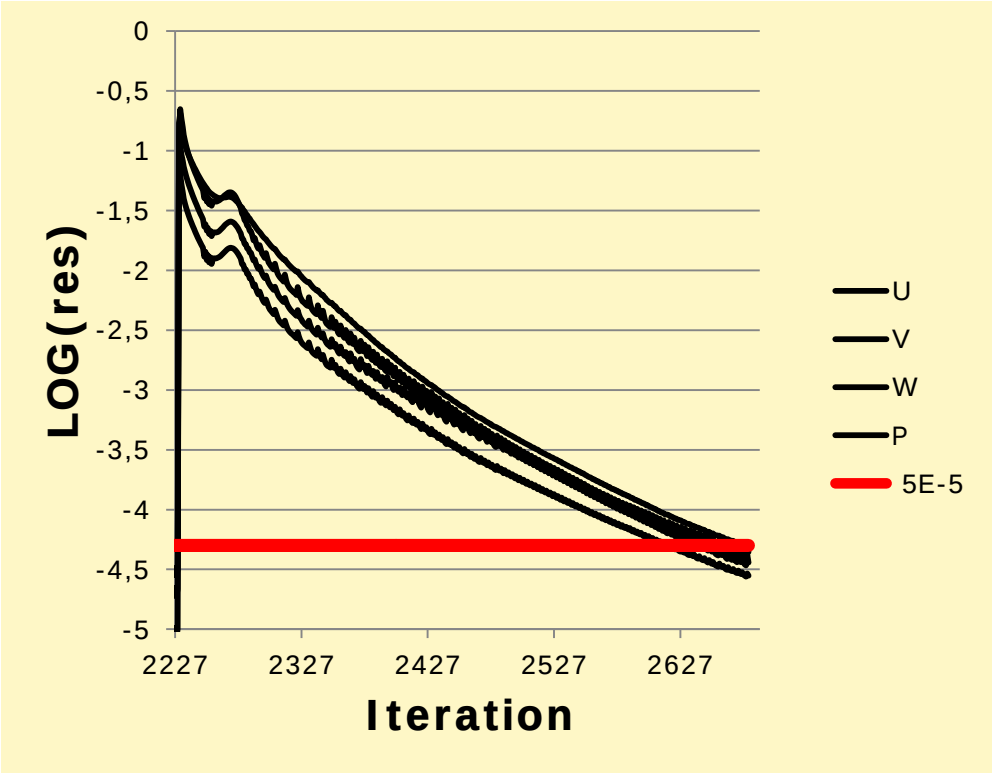


Example: CFD

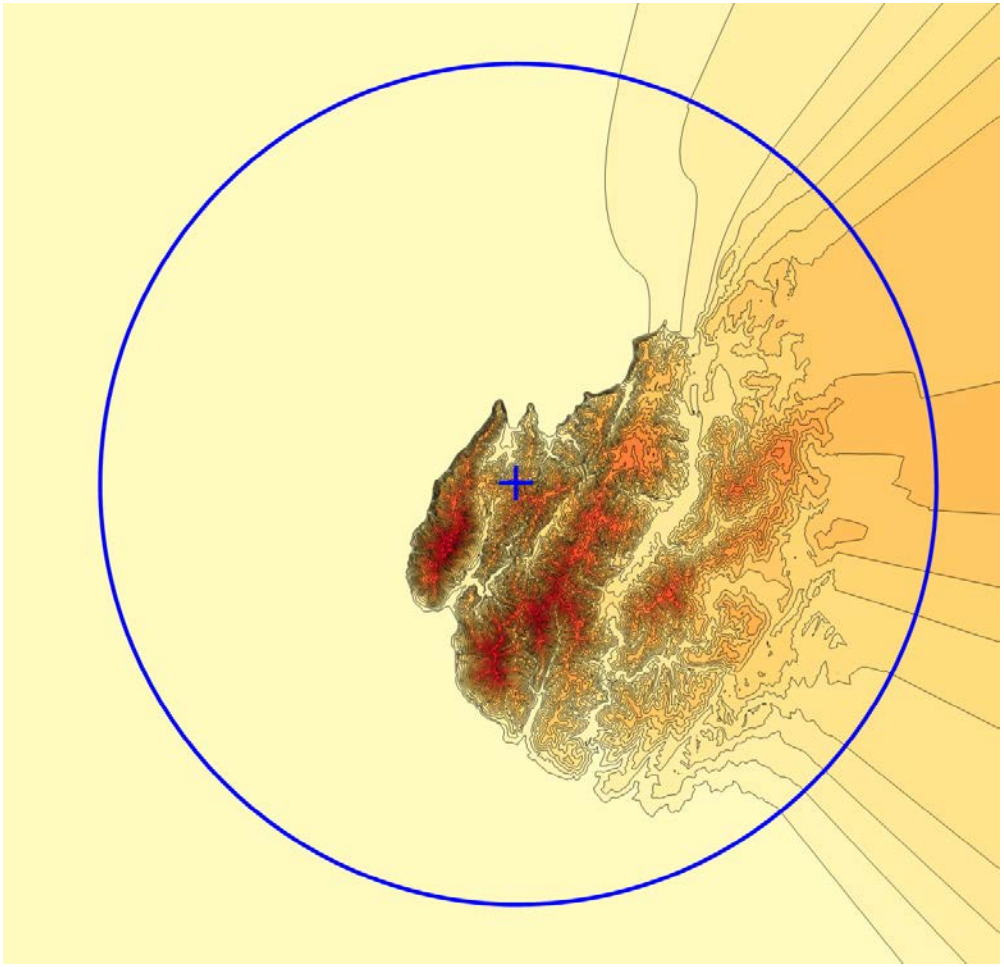


Example: CFD

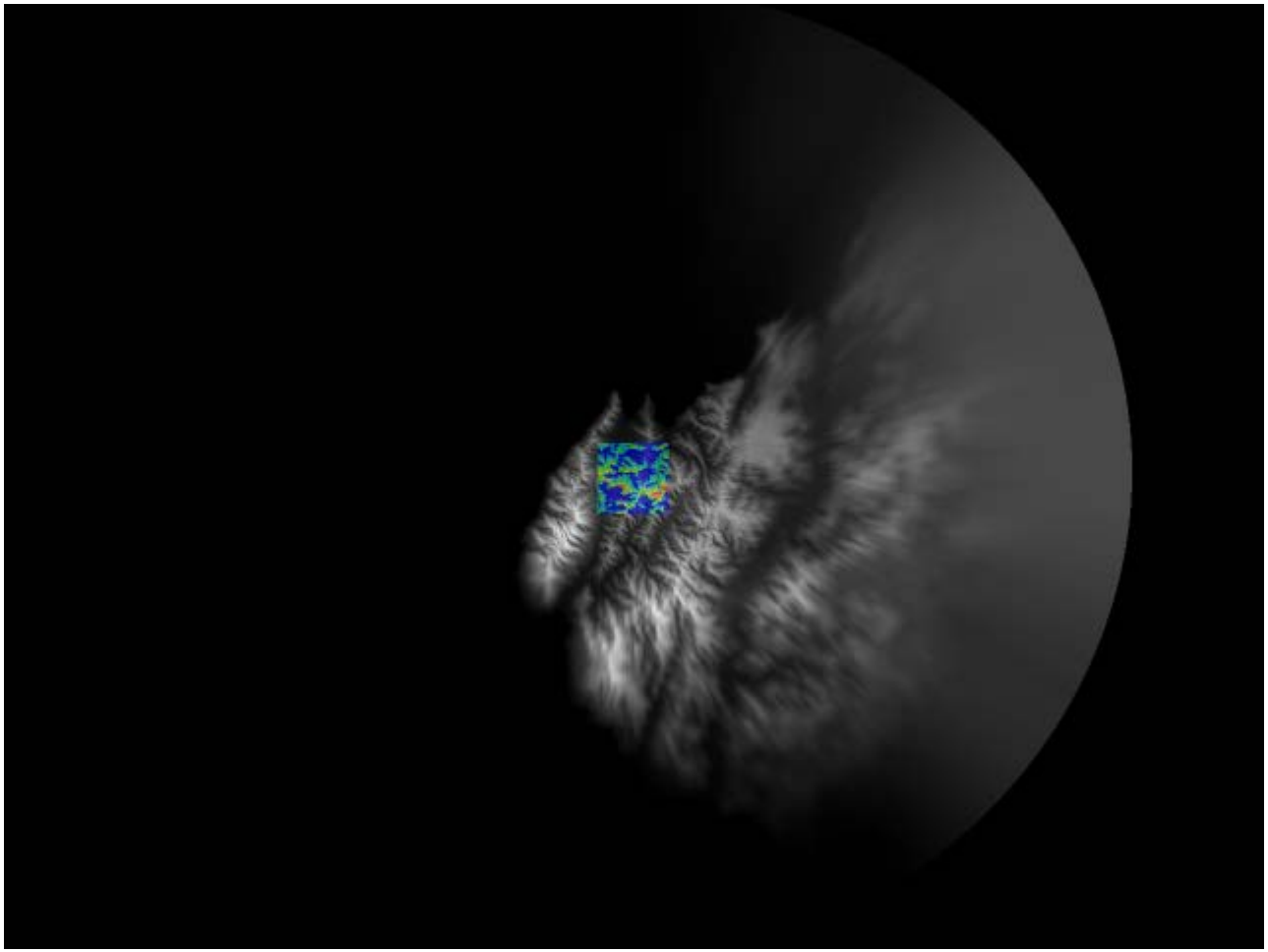
- Third order QUICK scheme
- RANS k-ε turbulence model
- Residuals < 5E-5



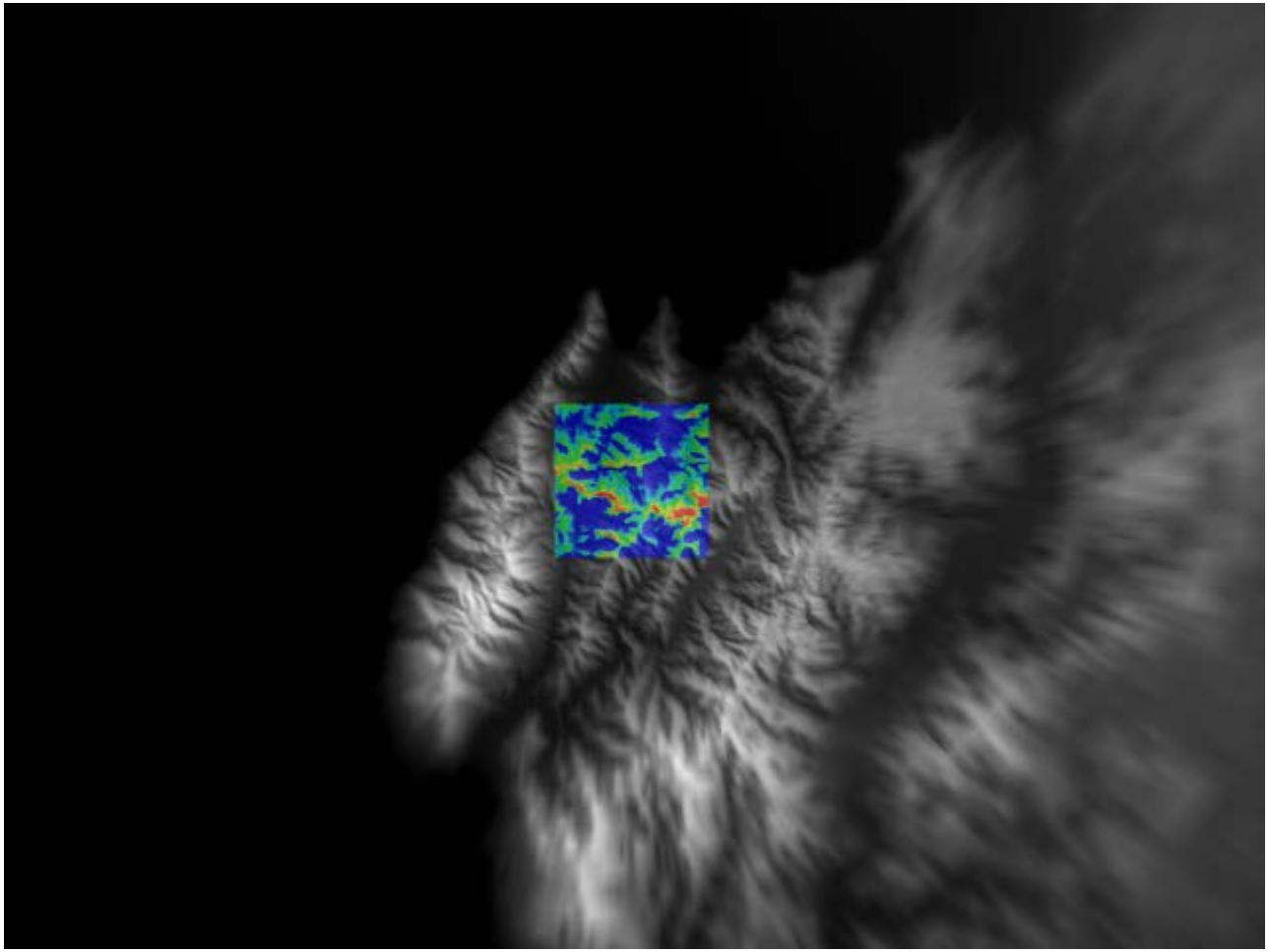
Example: CFD



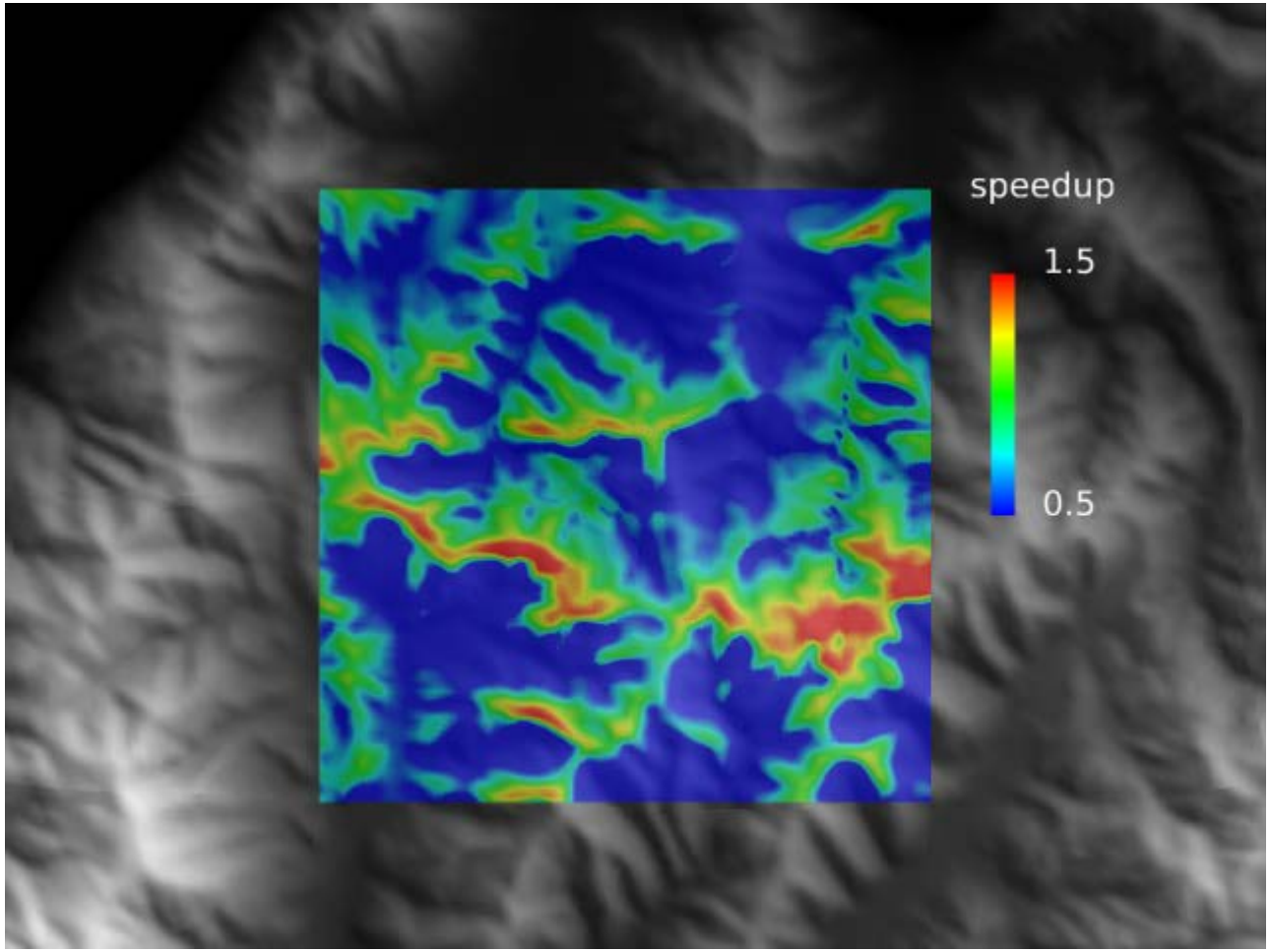
Example: CFD



Example: CFD

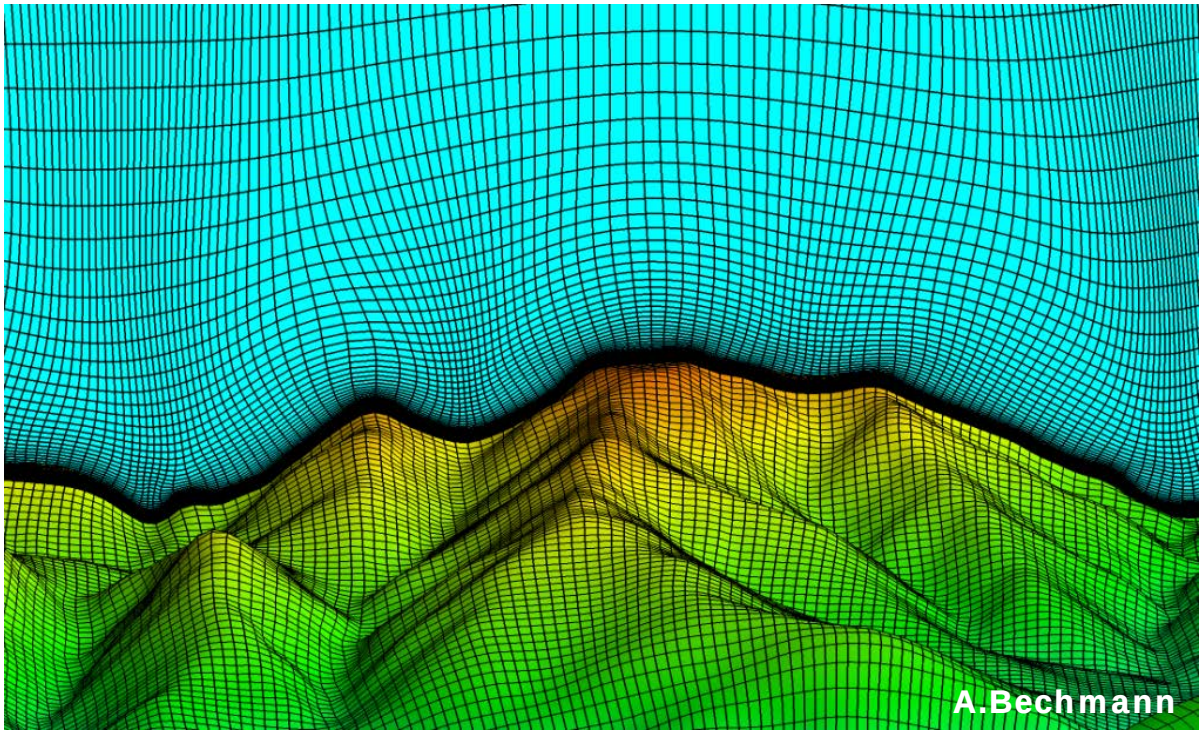


Example: CFD



How to use CFD for long-term energy assessments

1. Modelling of Wind Resources
2. Example: WAsP CFD
3. **Example: Forestry modeling based on aerial LIDAR scans**



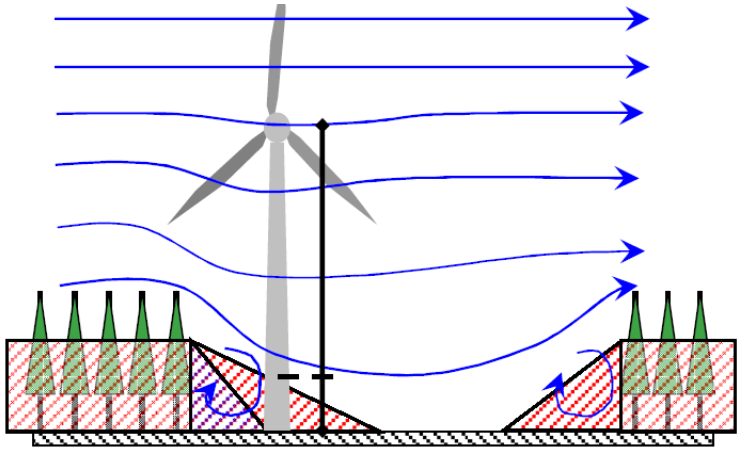
Example: Forest

Example: Forest

Roughness length model

$$\overline{u} = \frac{u_*}{k} \ln\left(\frac{z-d}{z_0}\right)$$

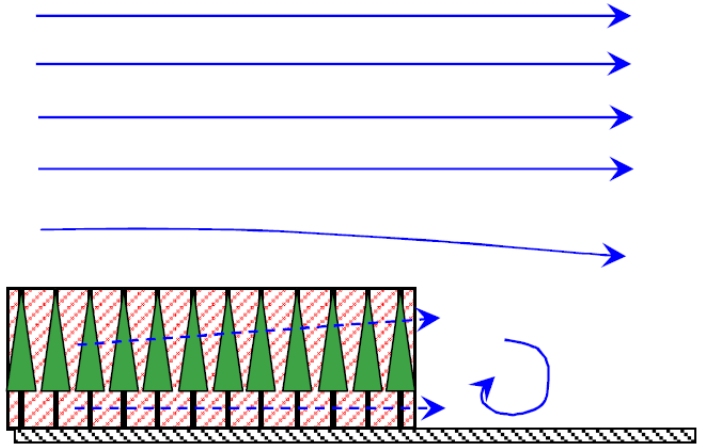
- z0: roughness length
- d: displacement height



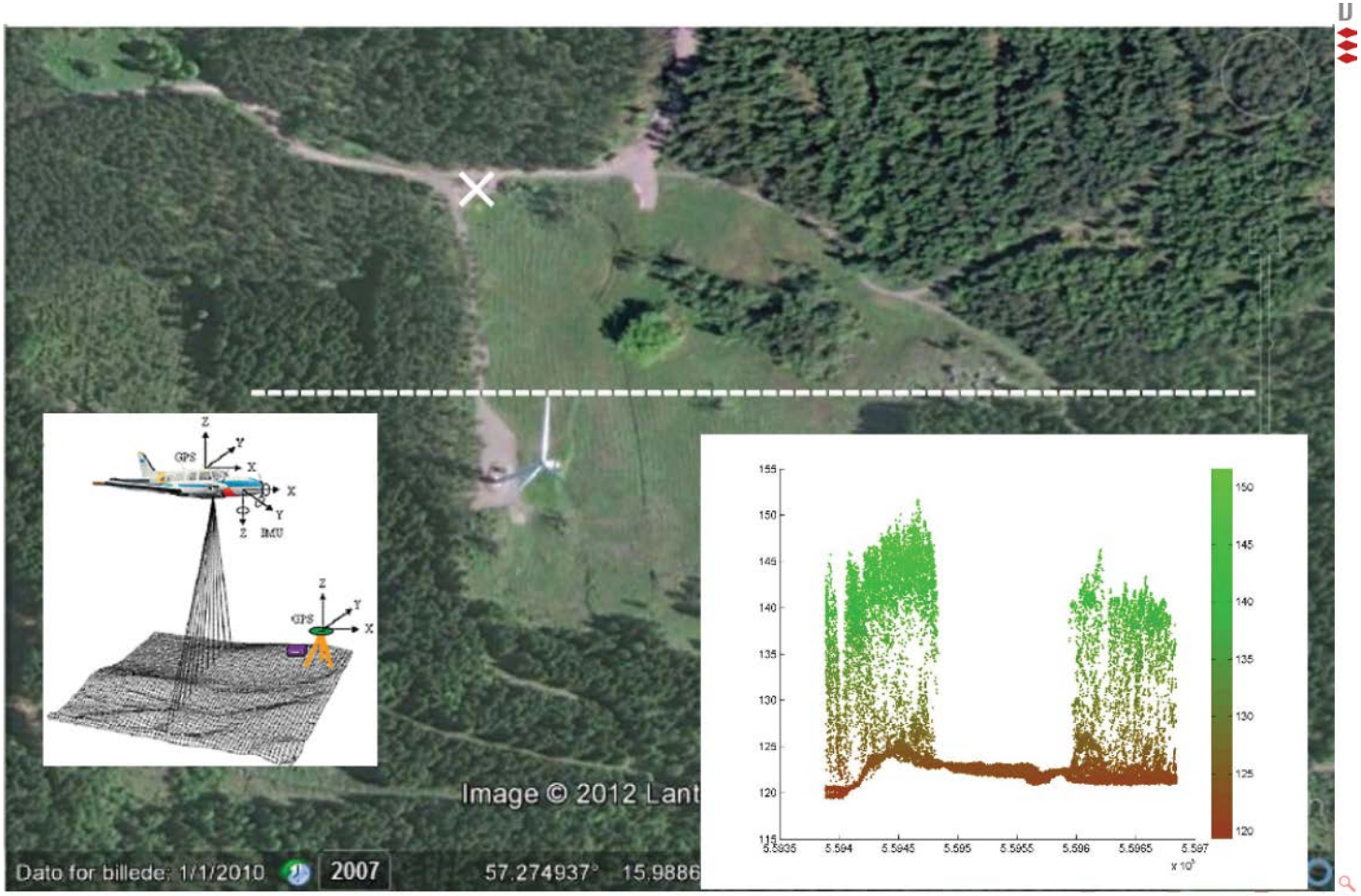
Porous drag model

$$\frac{\partial u_i}{\partial t} = \ldots - C_d LAD(z) u_i |U|$$

- LAD: leaf area density
- Cd: drag coefficient

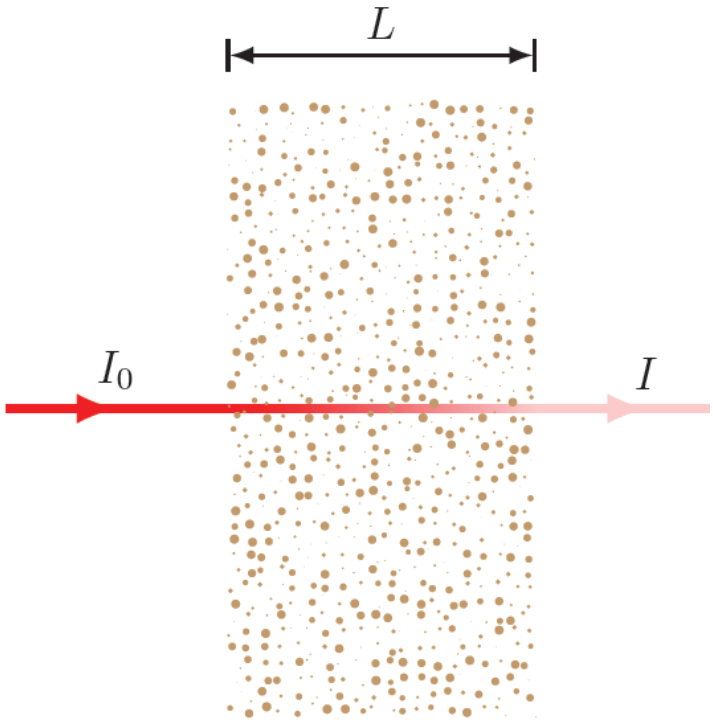


Example: Forest



Example: Forest

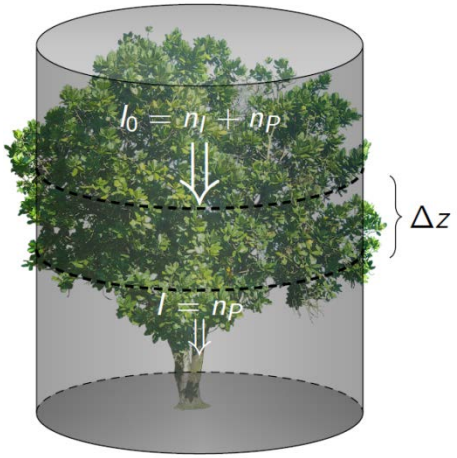
The Beer-Lambert law



$$\frac{I}{I_0} = \exp(-\gamma L)$$

Light attenuation in plant canopies:
[Monsi and Saeki, 2005]

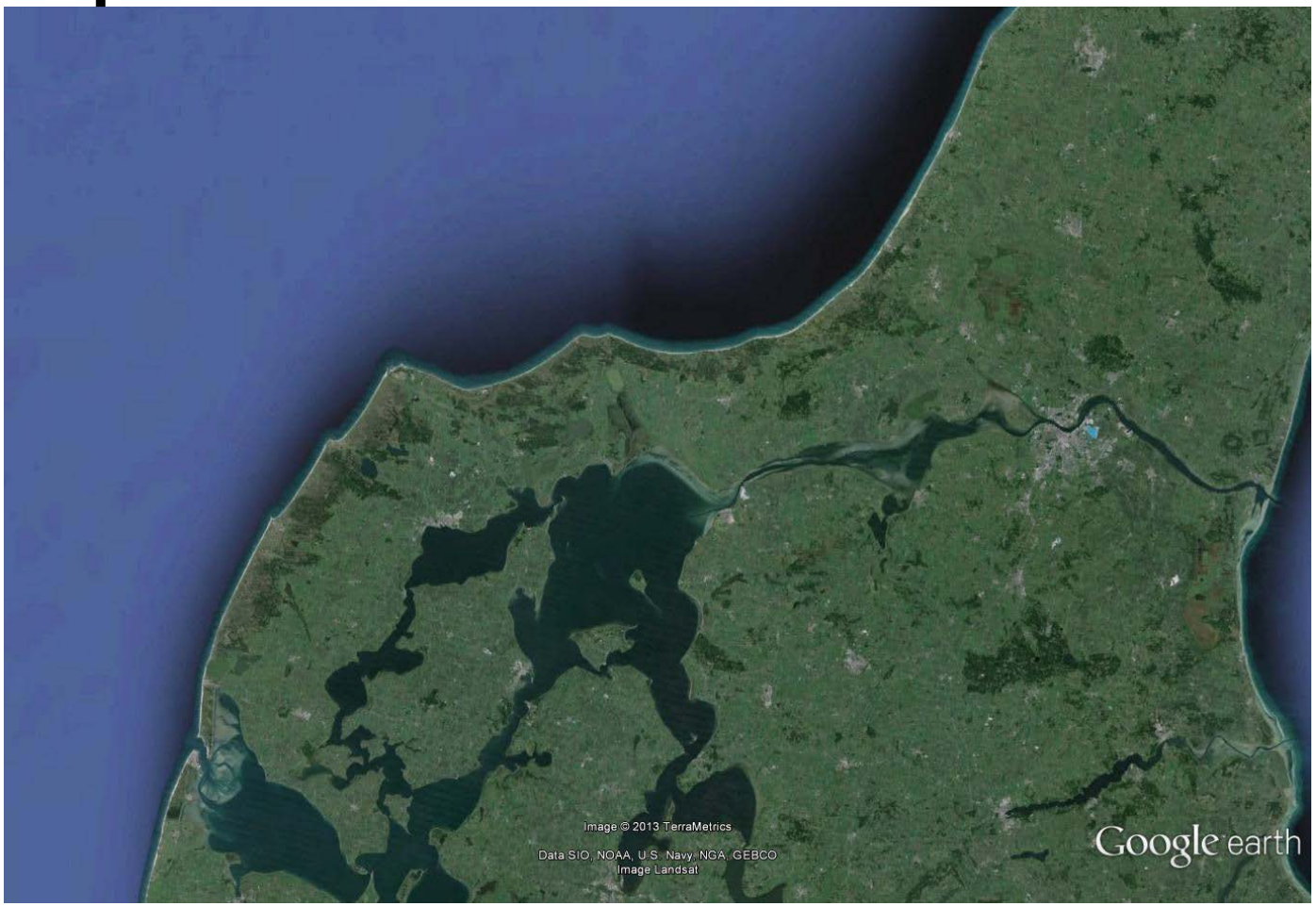
$$LAI = -\frac{1}{\gamma} \ln\left(\frac{I}{I_0}\right)$$



$$LAI = \int_0^z LAD\, dz \Rightarrow LAD = \frac{dLAI}{dz}$$

Example: Forest

Example: Forest



Example: Forest

Example: Forest

Example: Forest

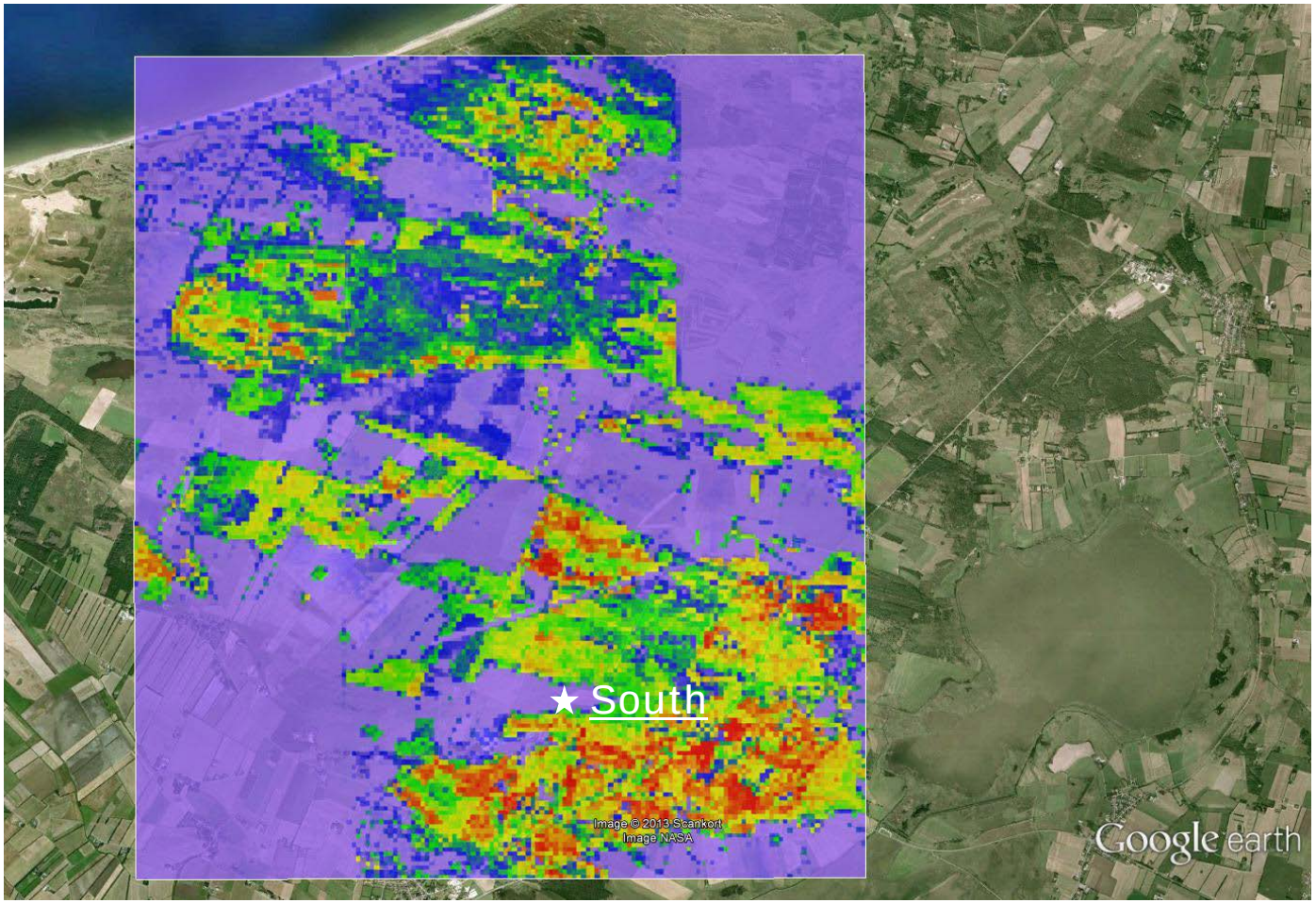
Example: Forest

Example: Forest

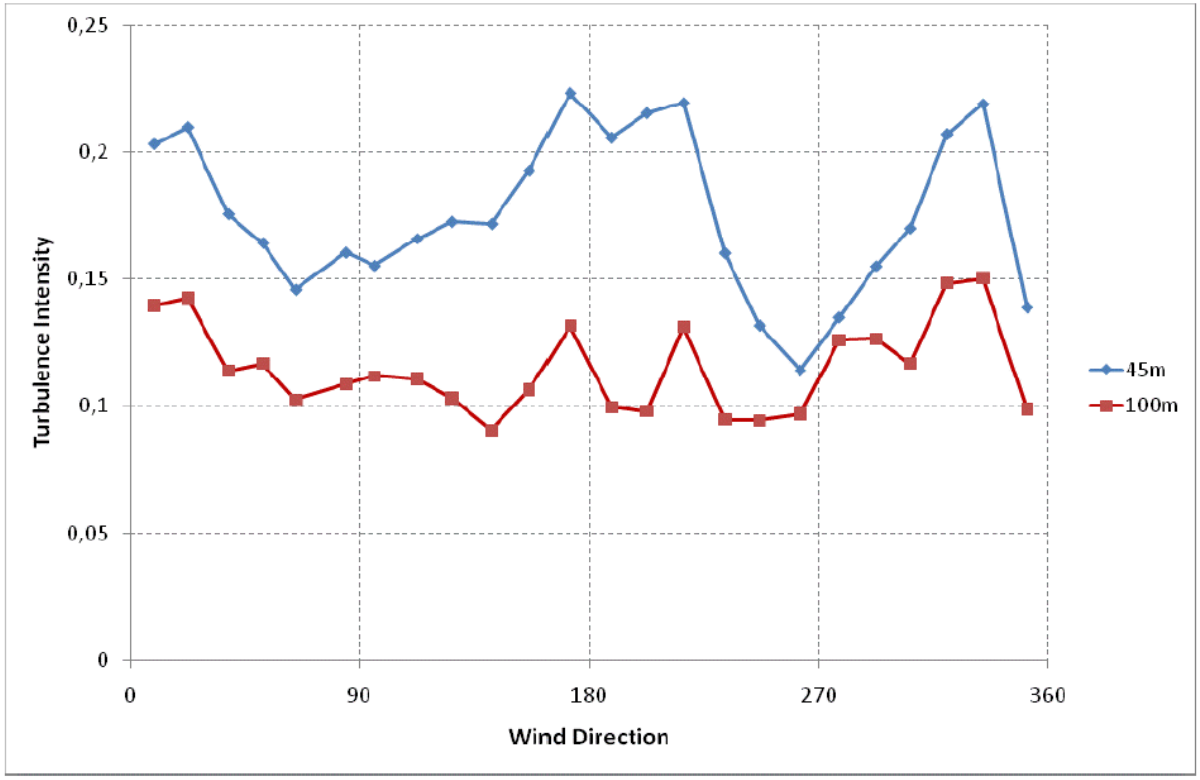
Example: Forest

Example: Forest

Example: Forest

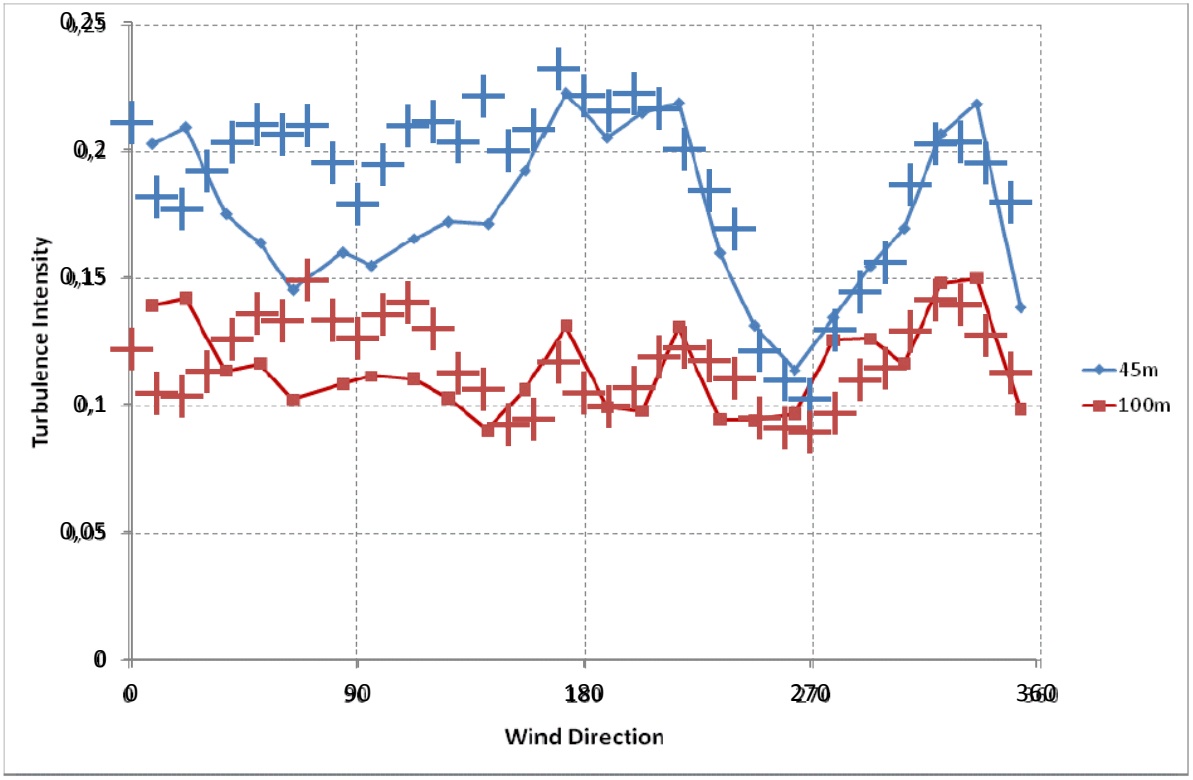


Example: Forest



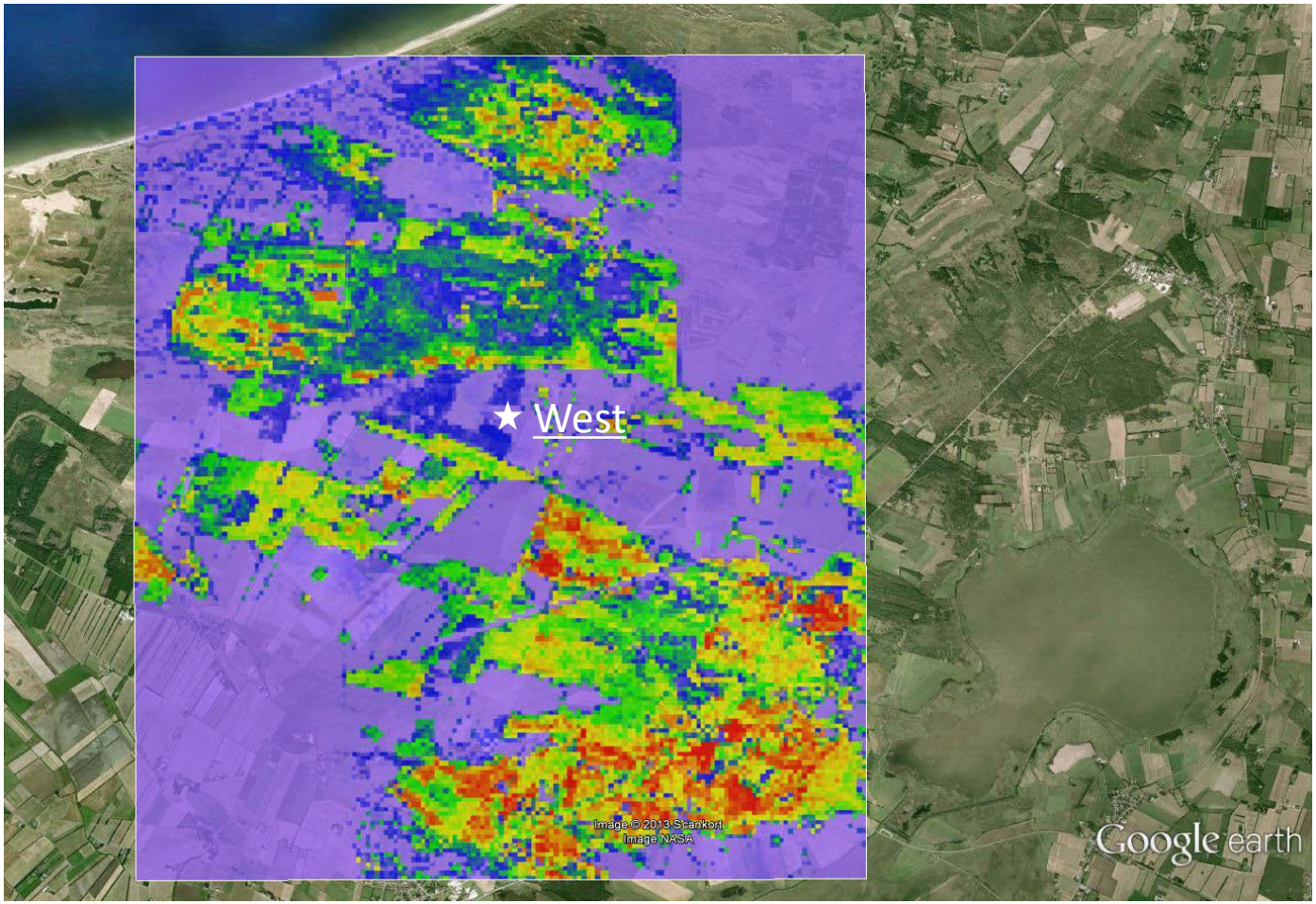
Figur 22 Turbulensintensitet som funktion af vindretning ved målestation Syd for 45m målehøjde (blå) og 100m målehøjde (brun).

Example: Forest

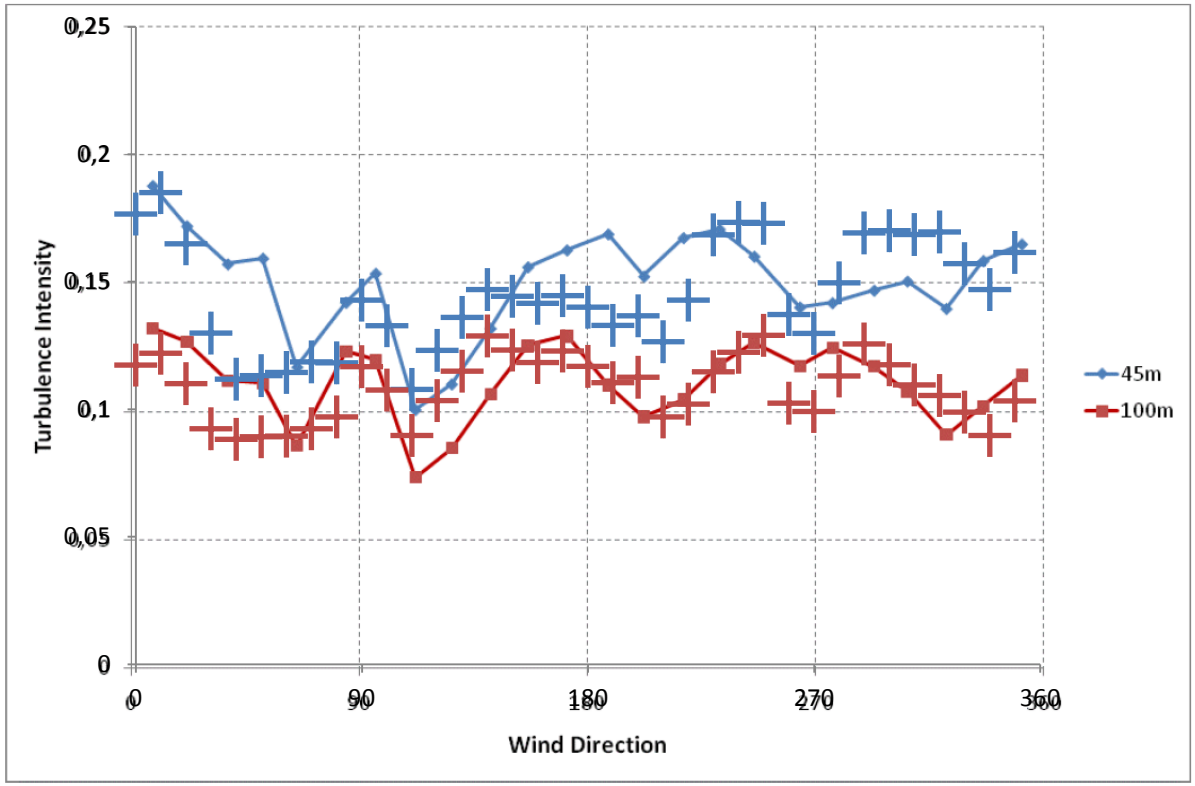


Figur 22 Turbulensintensitet som funktion af vindretning ved målestation Syd for 45m målehøjde (blå) og 100m målehøjde (brun).

Example: Forest

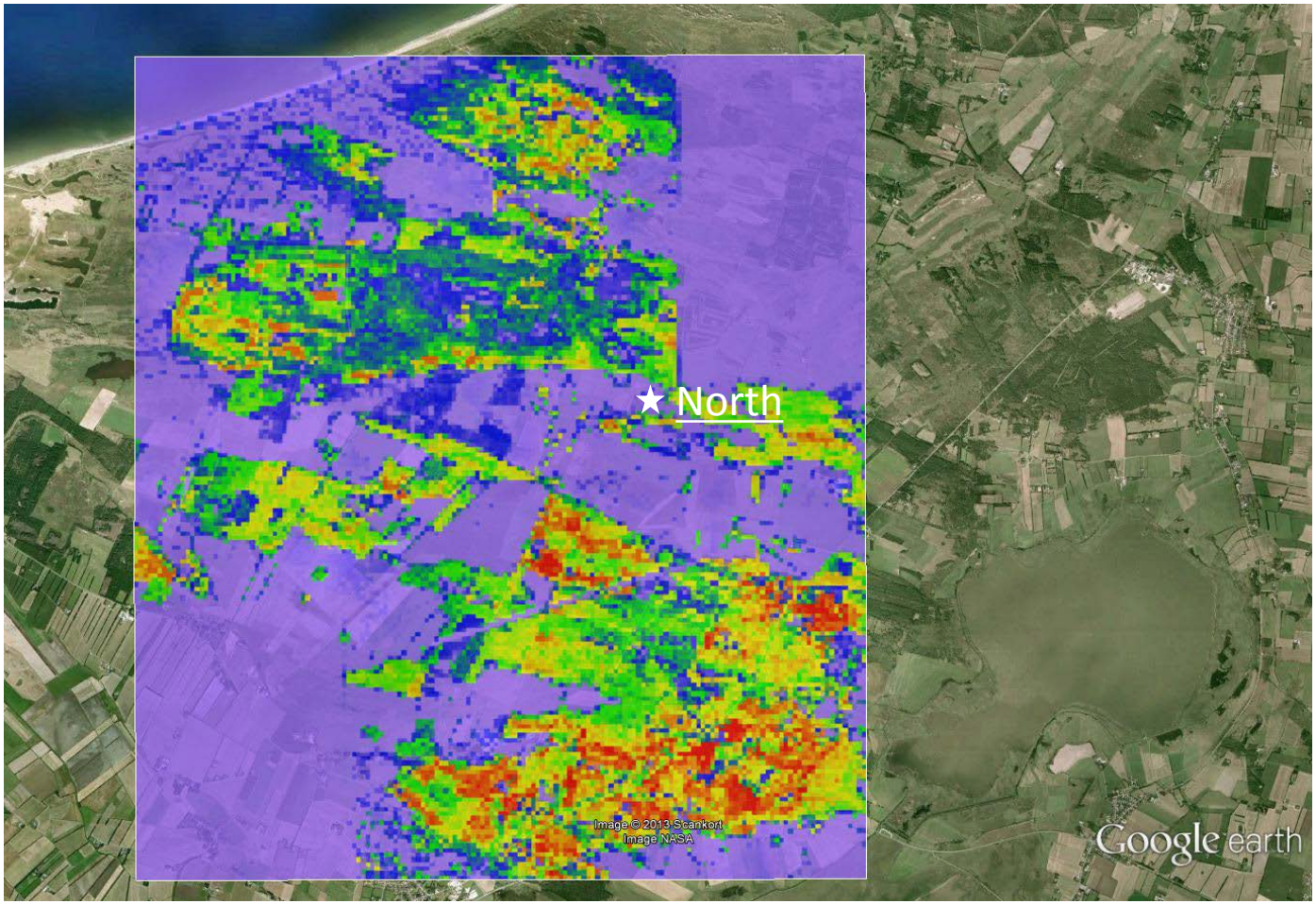


Example: Forest

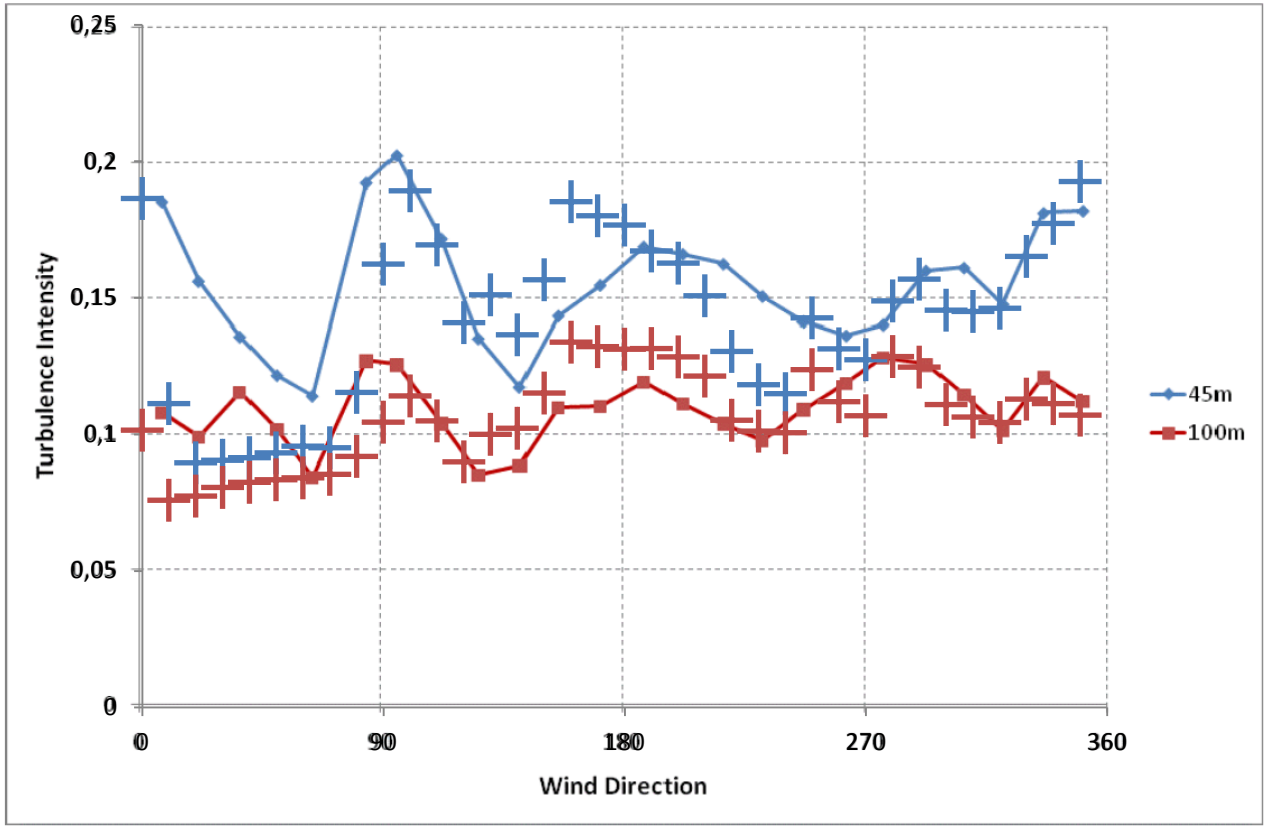


Figur 20 Turbulensintensitet som funktion af vindretning ved målestation Vest for 45m målehøjde (blå) og 100m målehøjde (brun).

Example: Forest



Example: Forest



Figur 21 Turbulensintensitet som funktion af vindretning ved målestation Nord for 45m målehøjde (blå) og 100m målehøjde (brun).

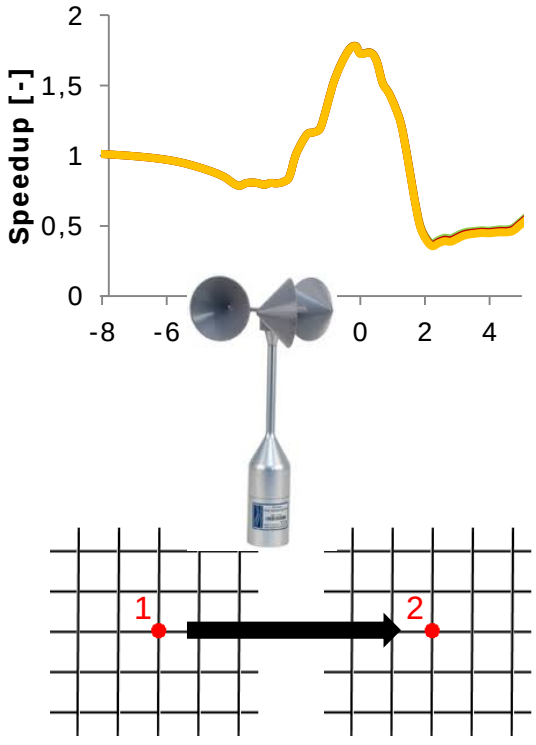
Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy

2. A model cannot predict wind resources; it extrapolates measurements

3. A method to couple micro- and meso-scales is needed

4. Farfield conditions should balance the meso-scale mean



A.Bechmann