

Forest flow

Ebba Dellwik, Louis-Etienne Boudreault, Andrey Sogachev,
Abhijit Chougule, Andreas Bechmann and Jakob Mann

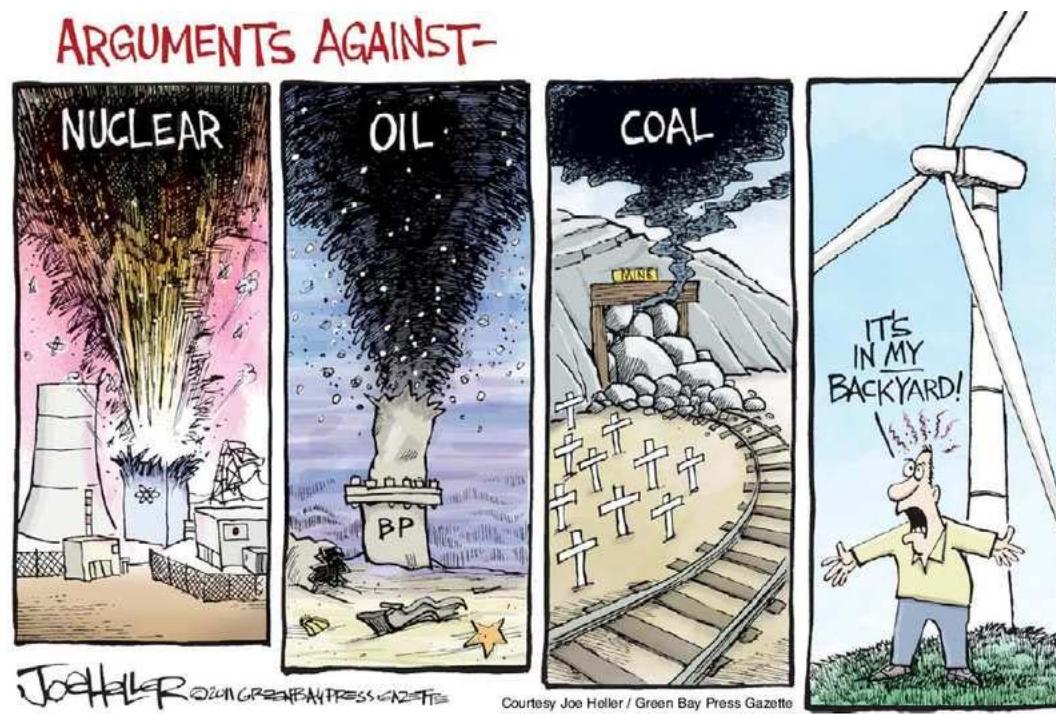


$$f(x+\Delta x) = \sum_{n=0}^{\infty} \frac{(\Delta x)^n}{n!} f^{(n)}(x)$$

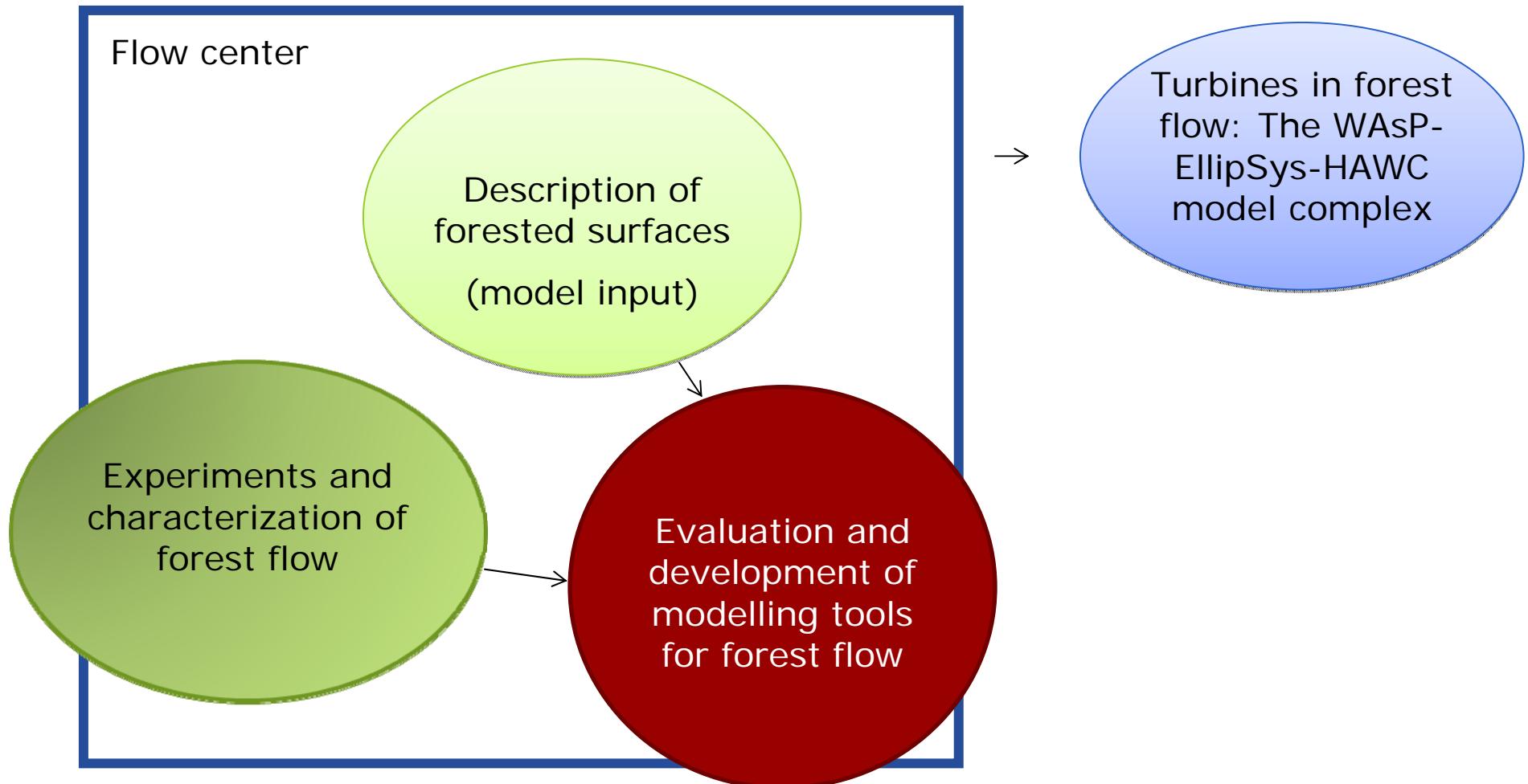
Mathematical symbols and equations are overlaid on the right side of the slide, including:
 Δ , \int_a^b , Θ , $\sqrt{17}$, Ω , $\delta e^{i\pi}$, ∞ , Σ , x^2 , $>$, $=$, $\{2.7182818284\}$, and an exclamation mark.

Motivation

- Siting in forested areas is attractive because of fewer regulations on land use, but turbines generally perform poorly in/near forests.
- Forests represent a "problem" land use class in many wind models.
- In heterogeneous landscapes, small forest patches may be relatively dominant for the turbulence and mean wind levels.

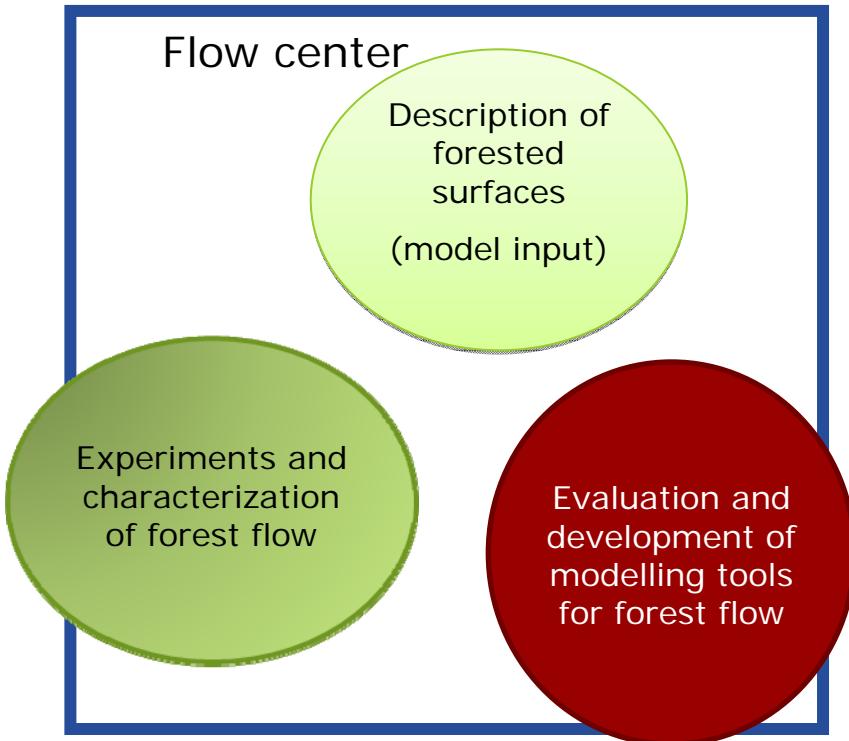


How do we work?



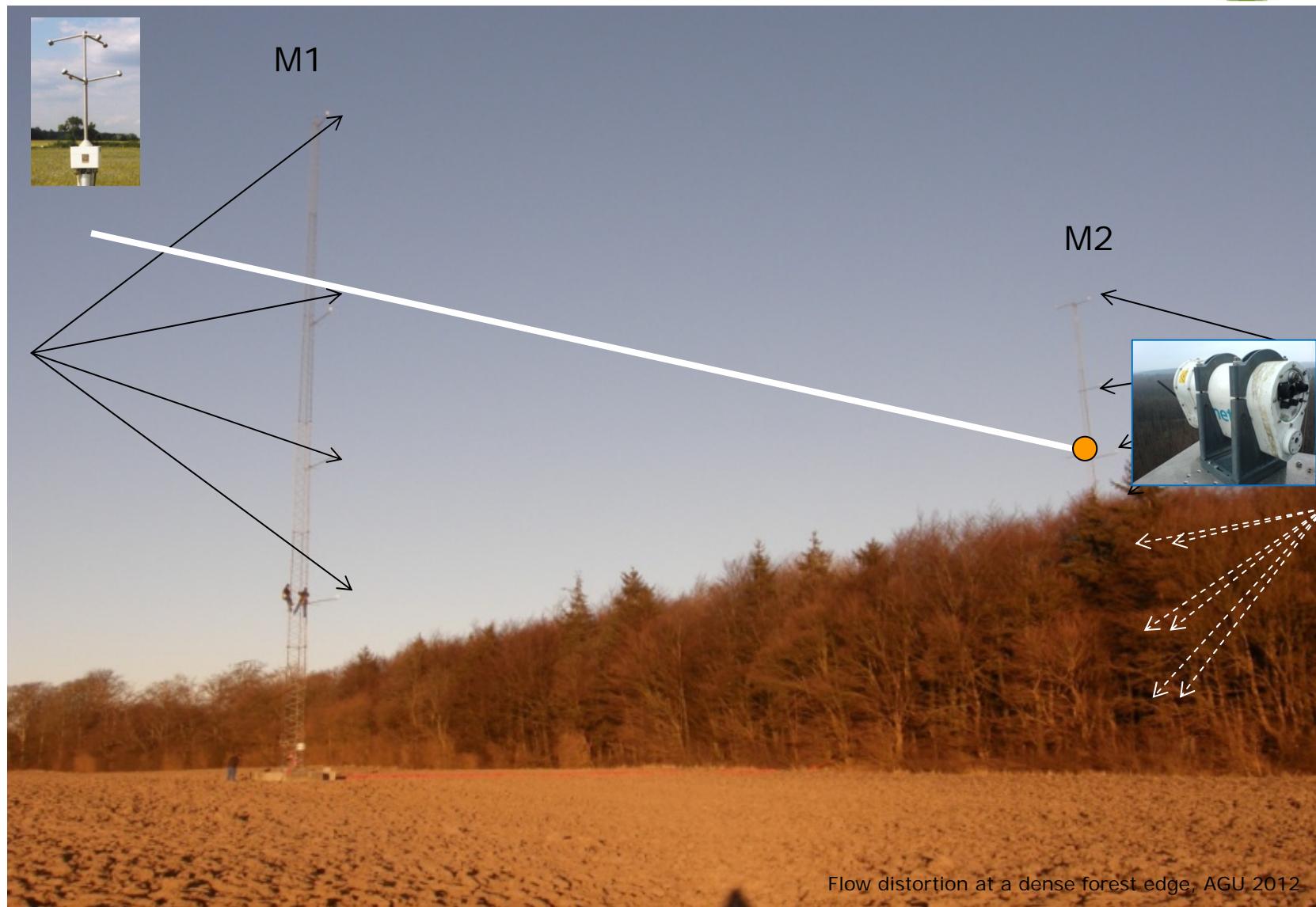
Outline

- Experiments and instruments
- Characterization of forested surfaces for flow modelling
- Modelling results and comparison with measurements



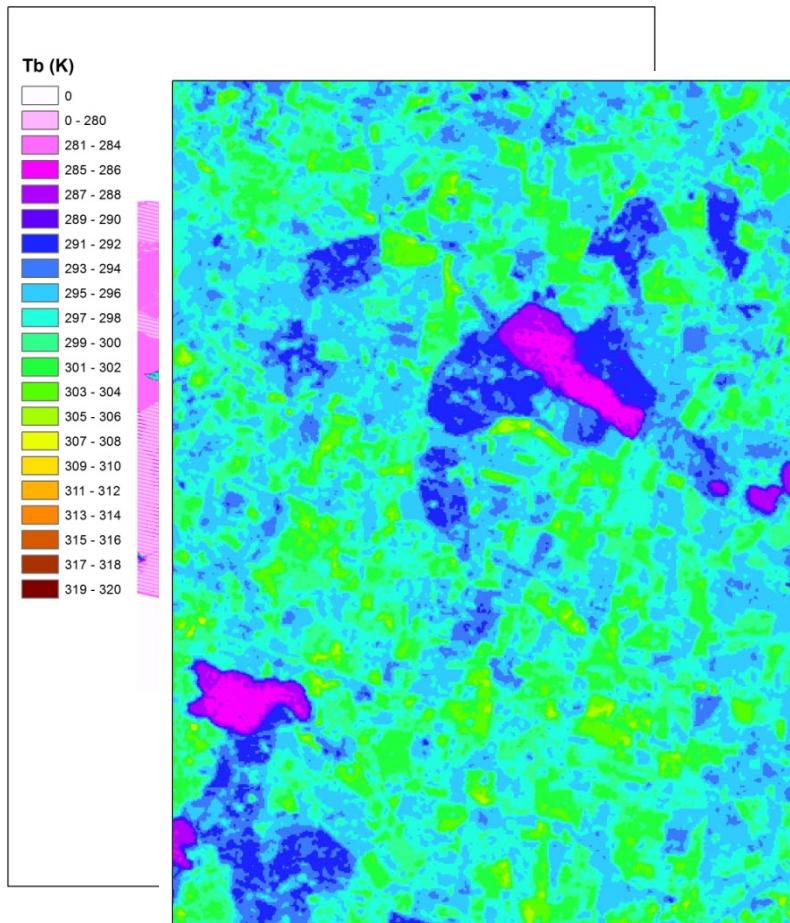
Falster forest edge: mast based wind measurements

Experiments
and data



Sorø Lille Bøgeskov: temperature effects and forests

Experiments
and data



Mast-based energy balance instrumentation: $R_n = H + LE$

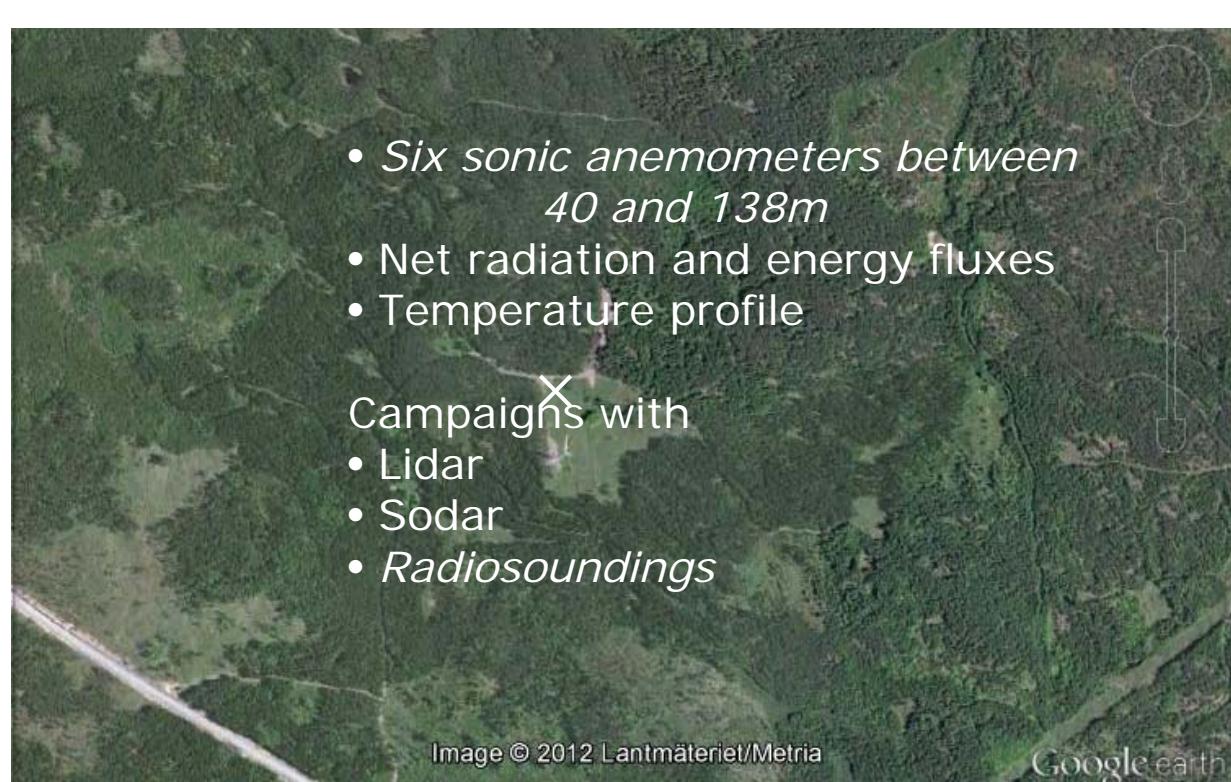
Experiments
and data

- 4 component radiation sensor, sonic anemometer, water vapor concentration



Rynningsnäs: tall mast in extensively forested region

Experiments
and data



Forest
description

Model input parameters

Displacement height and surface roughness for roughness models.

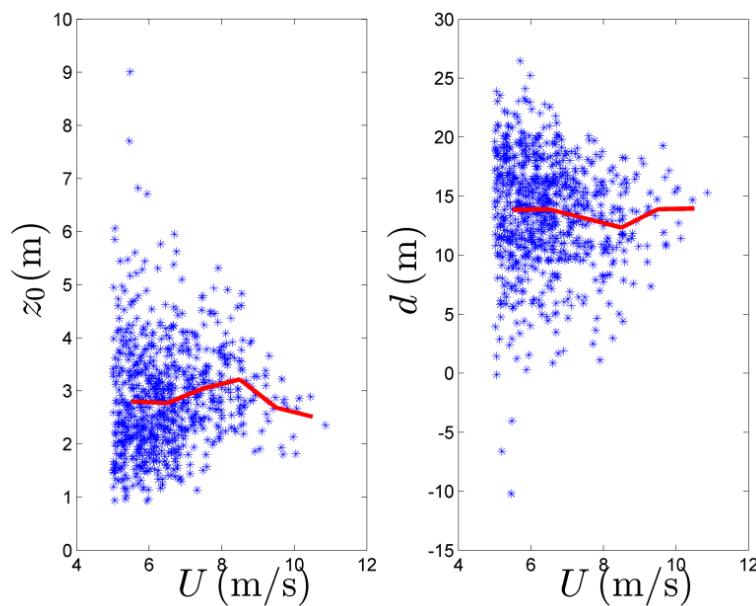
- Properties that can be assessed via wind measurements

Forest parameters for CFD models.

- Properties that can be assessed without wind measurements.

$$U = \frac{u_*}{\kappa} \log \left(\frac{z - d}{z_0} \right) + \cancel{\Psi_m}$$

- Assumption of homogeneous flat terrain



Forest
description

Model input parameters

Displacement height and surface roughness for roughness models.

- Properties that can be assessed via wind measurements

Forest parameters for CFD models.

- Properties that can be assessed without wind measurements.

- Modification of RANS $k - \epsilon$ equations to account for forest effects

Canopy model: [Sogachev, 2009]

Momentum:

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

Dissipation:

$$\frac{\partial \epsilon}{\partial t} = \dots - 12 C_\mu^{1/2} C_d PAD(z) |U| (C_{\epsilon 1} - C_{\epsilon 2}) \epsilon$$

Tree height

PAD ~

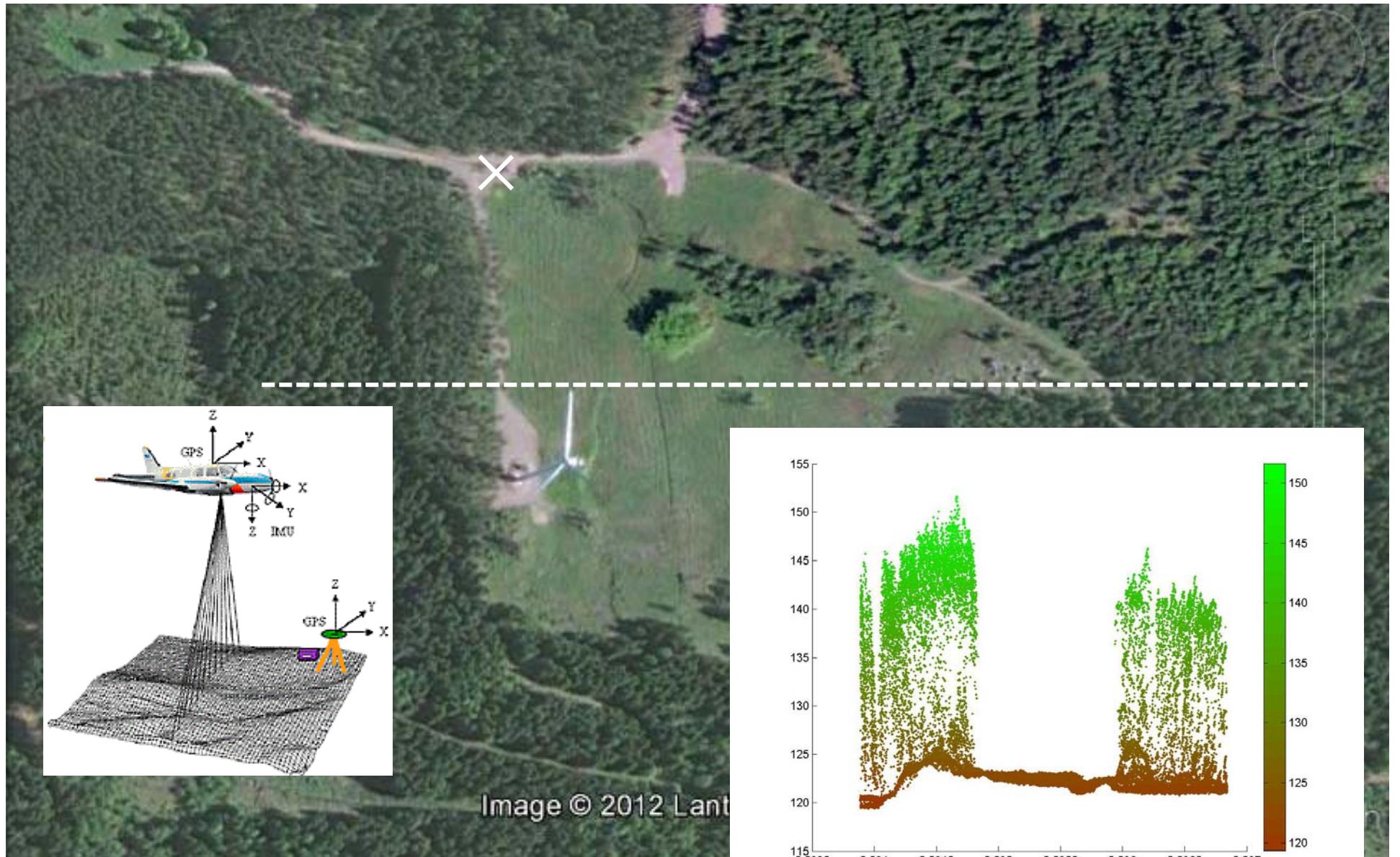
shape of tree

PAI ~

total drag of forest
on wind flow

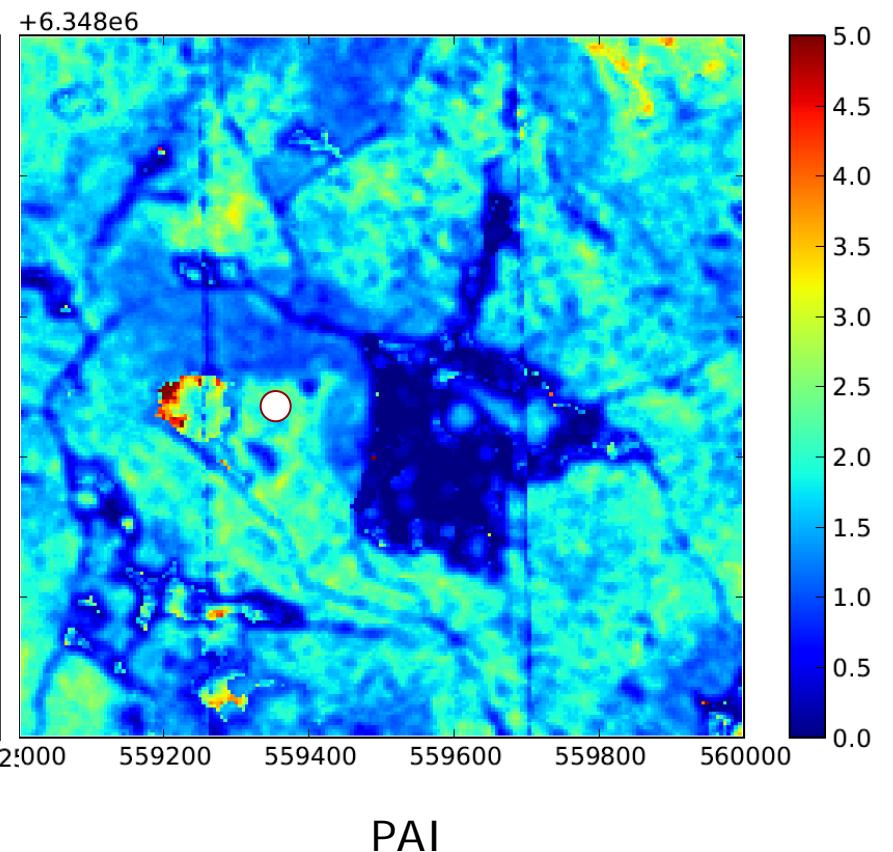
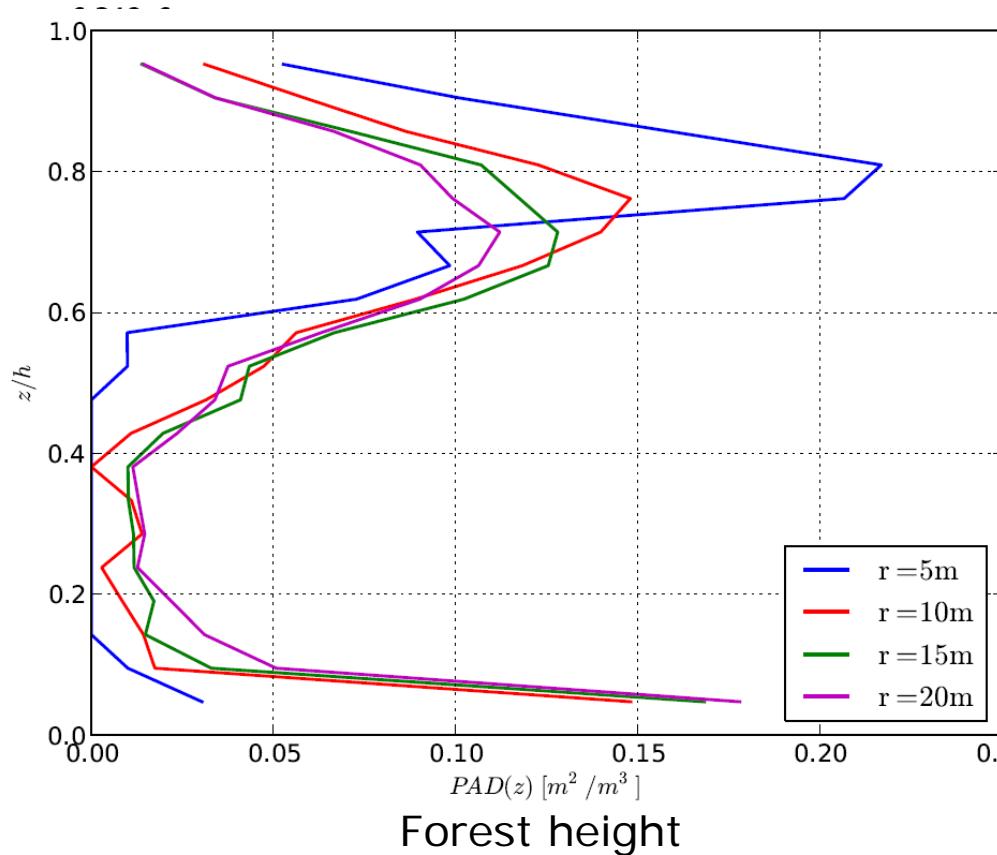
Point cloud from elevation surveys as sources for forest parameter estimation

Forest
description



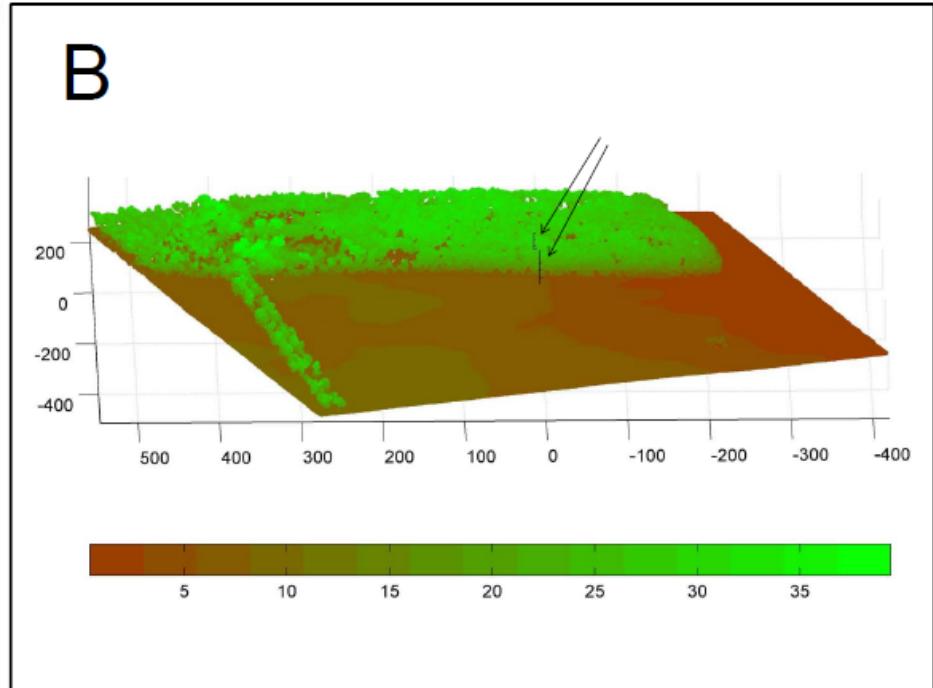
Rynningsnäs gridded data

Forest
description



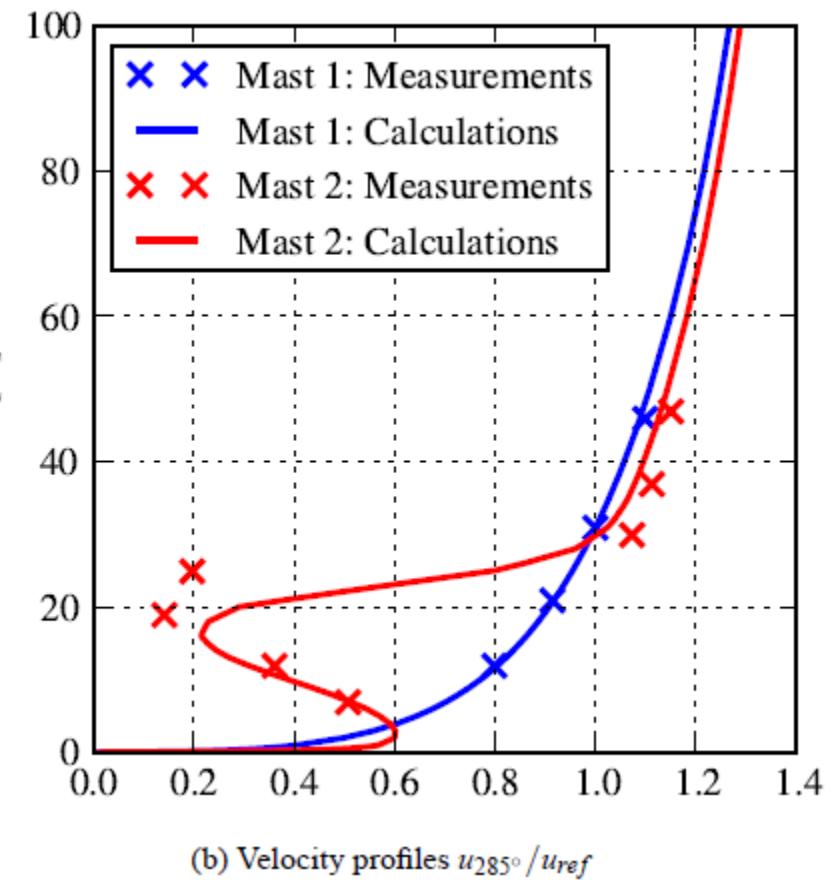
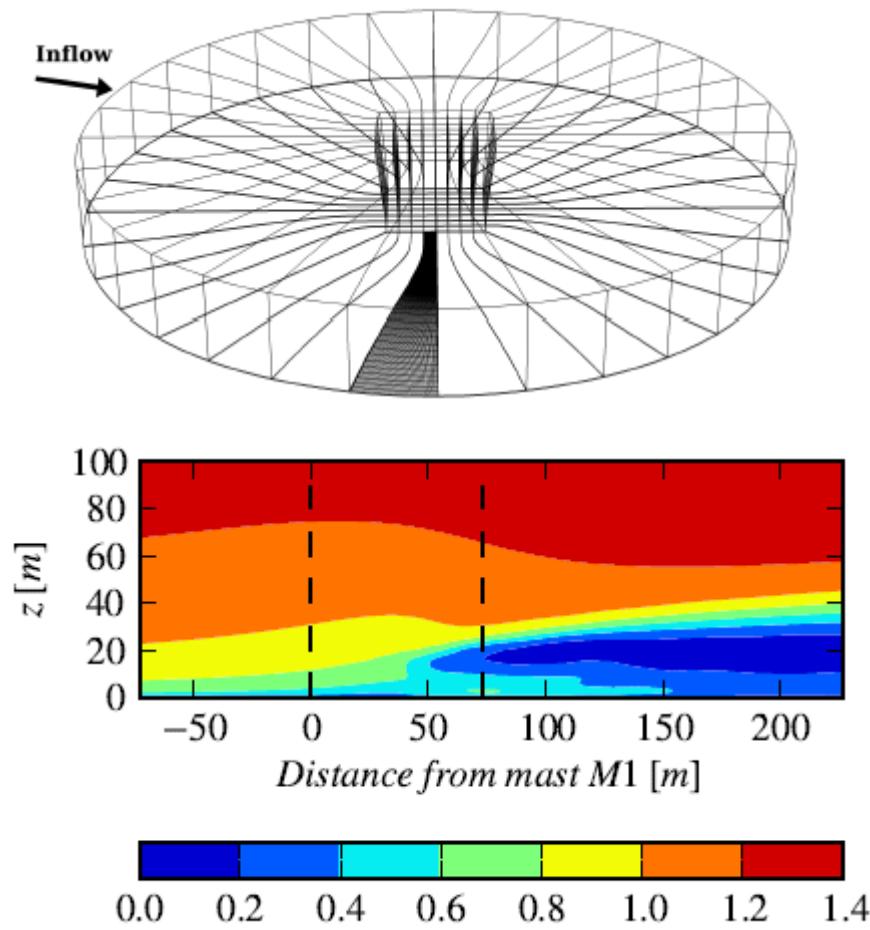
Falster forest edge: (EllipSys)

Evaluation
and
development



Falster forest edge: Experimental results and EllipSys predictions

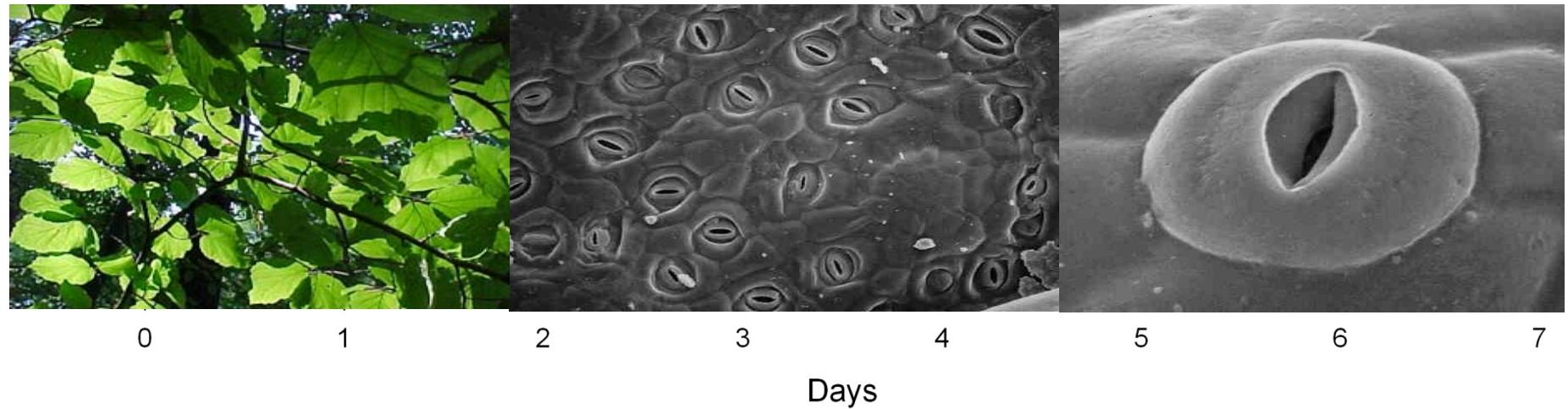
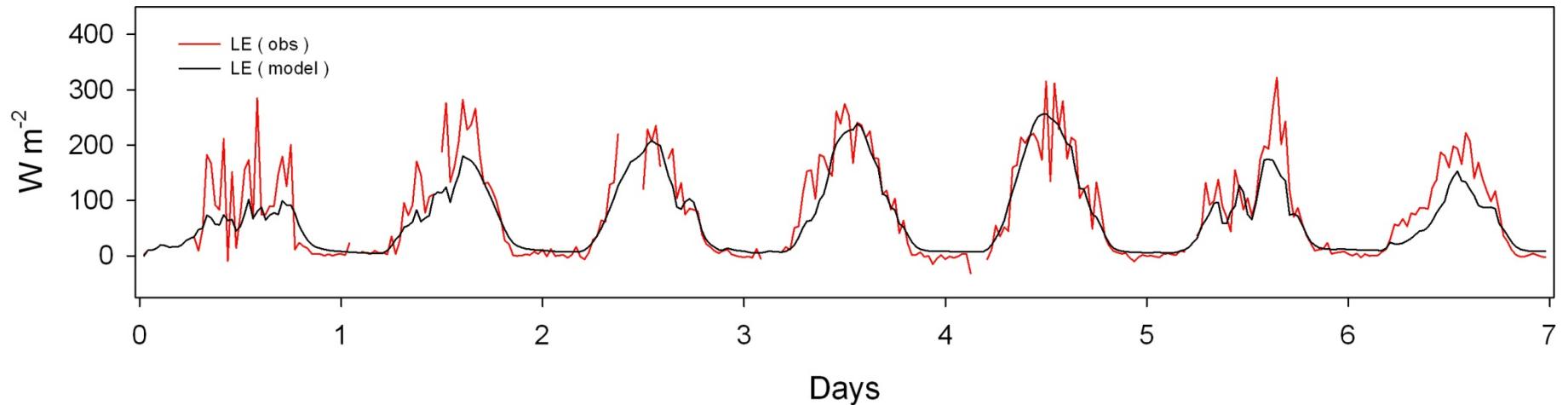
Evaluation
and
development



(b) Velocity profiles u_{285° / u_{ref}

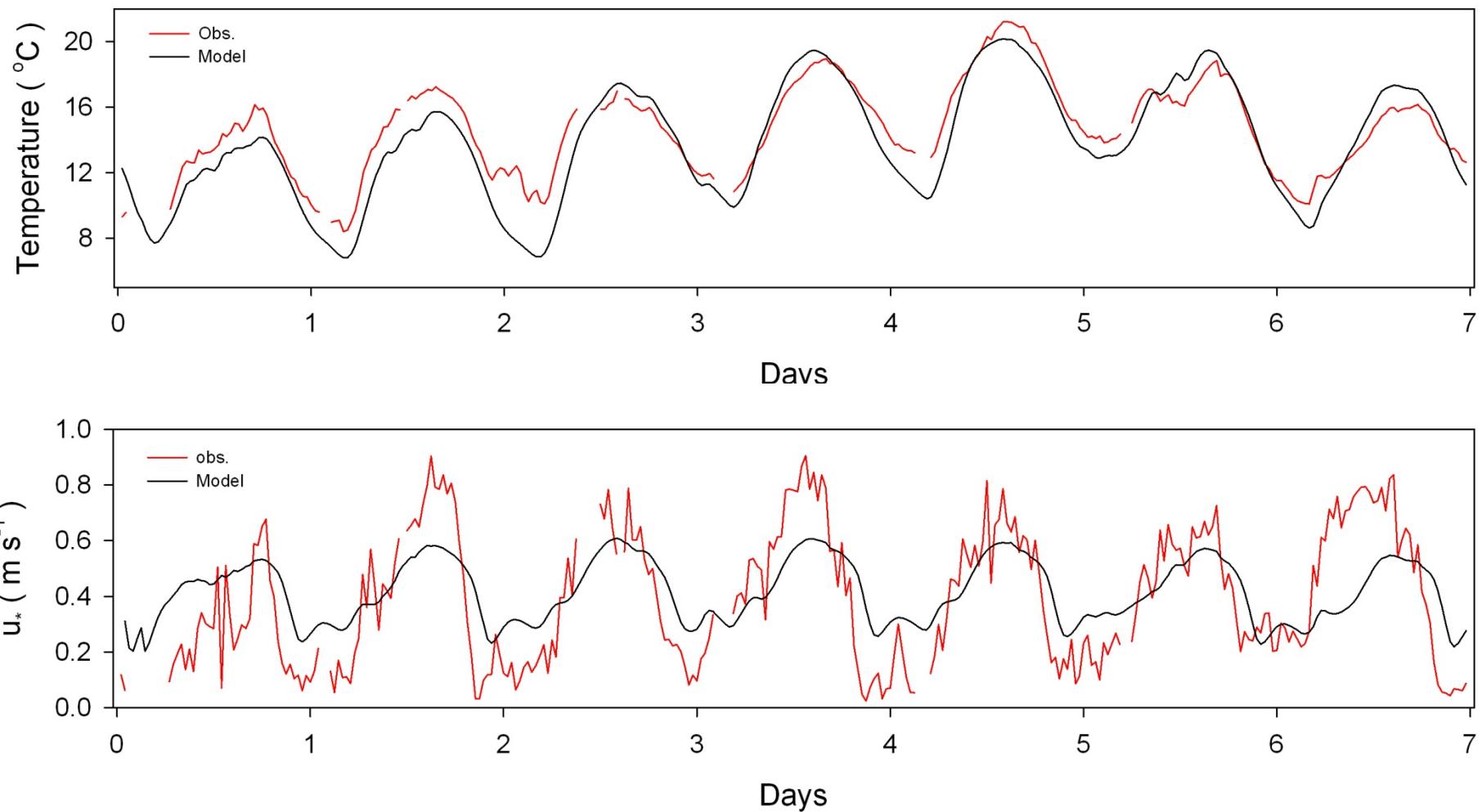
Sorø Lille Bøgeskov: Experimental results and SCADIS predictions

Evaluation
and
development



Sorø Lille Bøgeskov: Experimental results and SCADIS predictions

Evaluation
and
development



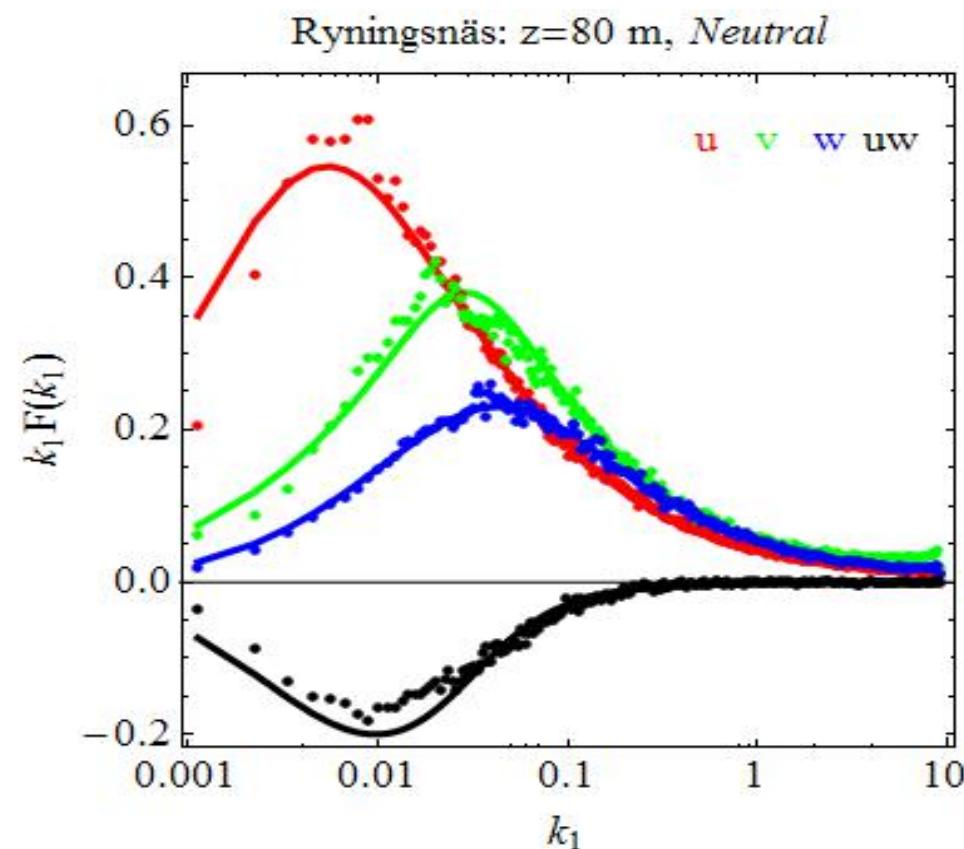
Rynningsnäs – Høvsøre: characterization of turbulence

Evaluation
and
development



Mann model spectral fits and the model parameters

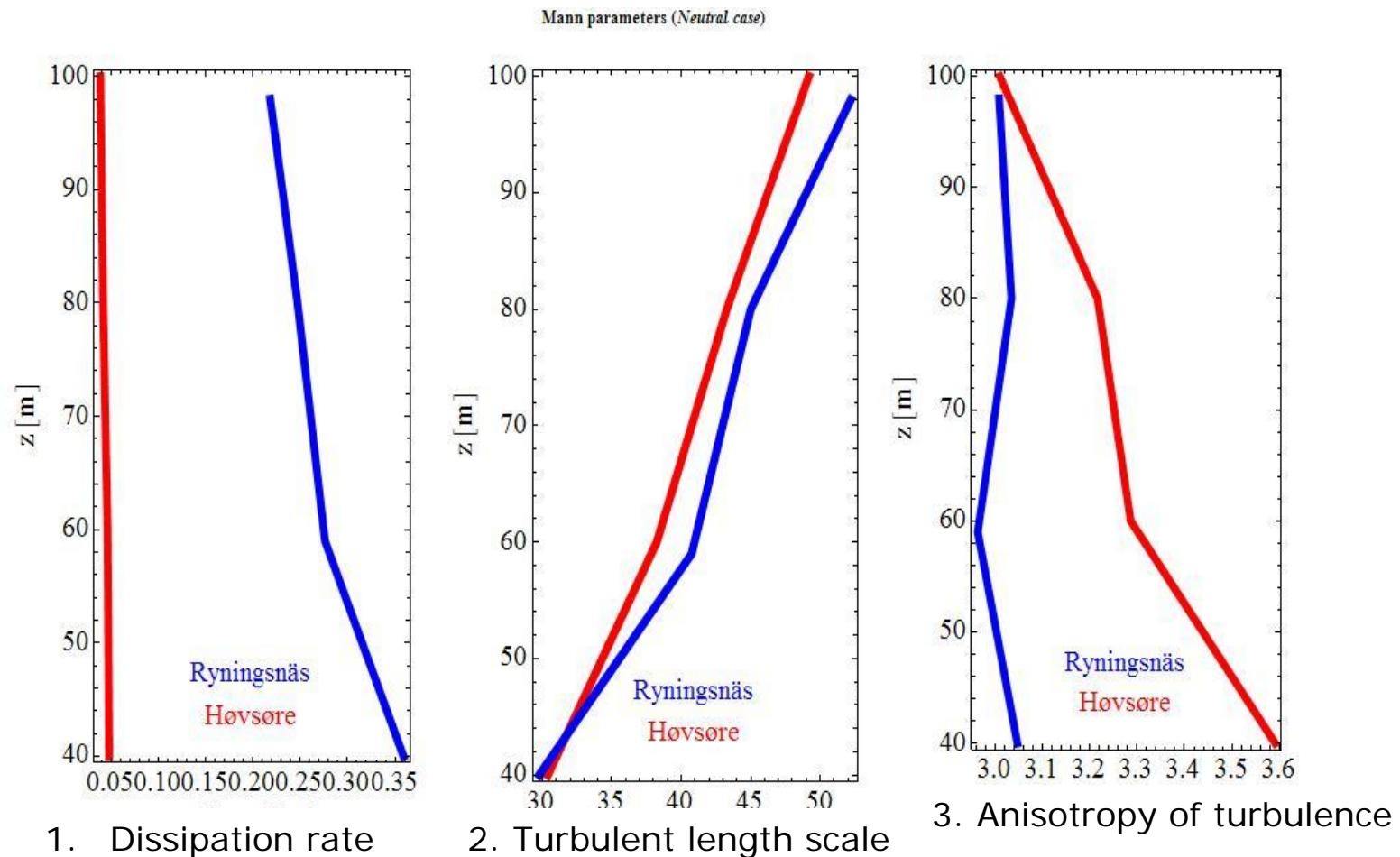
Evaluation
and
development



1. Dissipation rate
2. Turbulent length scale
3. Anisotropy of turbulence

Høvsøre vs. Rynningsnäs model parameters

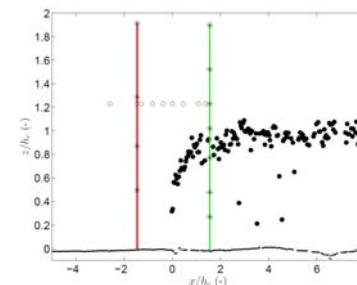
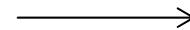
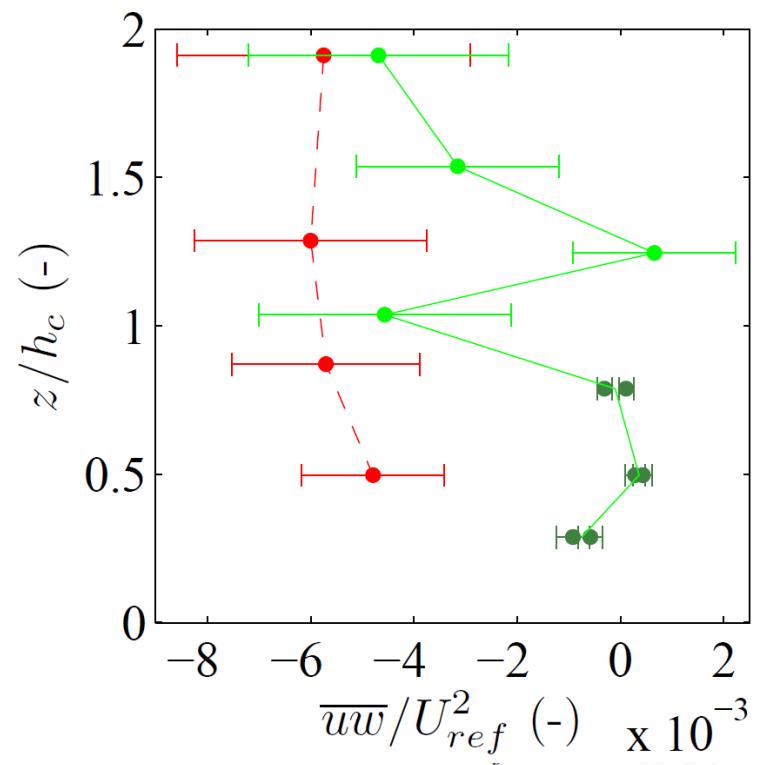
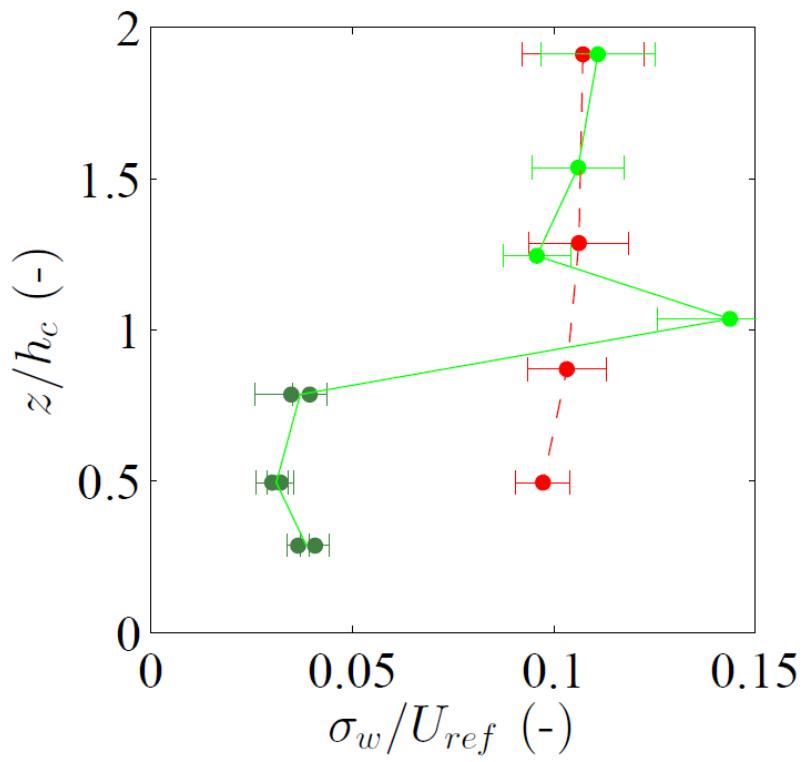
Evaluation
and
development



Conclusions and outlook

- Within the Flow Center project, we have access to data from several well-instrumented experiments in forested terrain.
- Raw data from aerial scanning of the land surface can be used to estimate flow model input parameters for forested areas.
- This input was used successfully in an EllipSys simulation for the forest edge.
- The RANS CFD model SCADIS can model the surface energy balance, which is an interesting way forward for modelling temperature effects on the wind field.
- The Mann (1994) model parameters can describe the measured spectra at a forest site. Studies on wind turbine loads in forest type wind climate can now be performed with a higher degree of confidence.

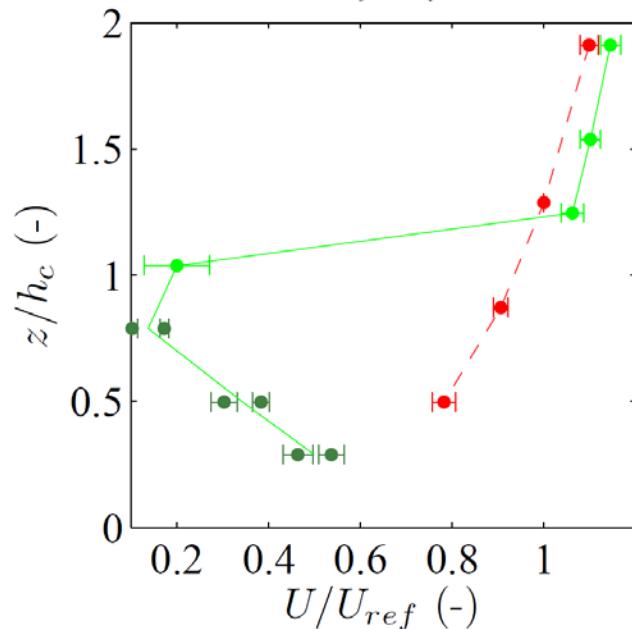
Key experimental results



gradient-diffusion and rapid distortion theory (RDT)

σ_u	σ_v	σ_w	$-\langle uw \rangle$
no change	small incr.	small decr.	large decr.

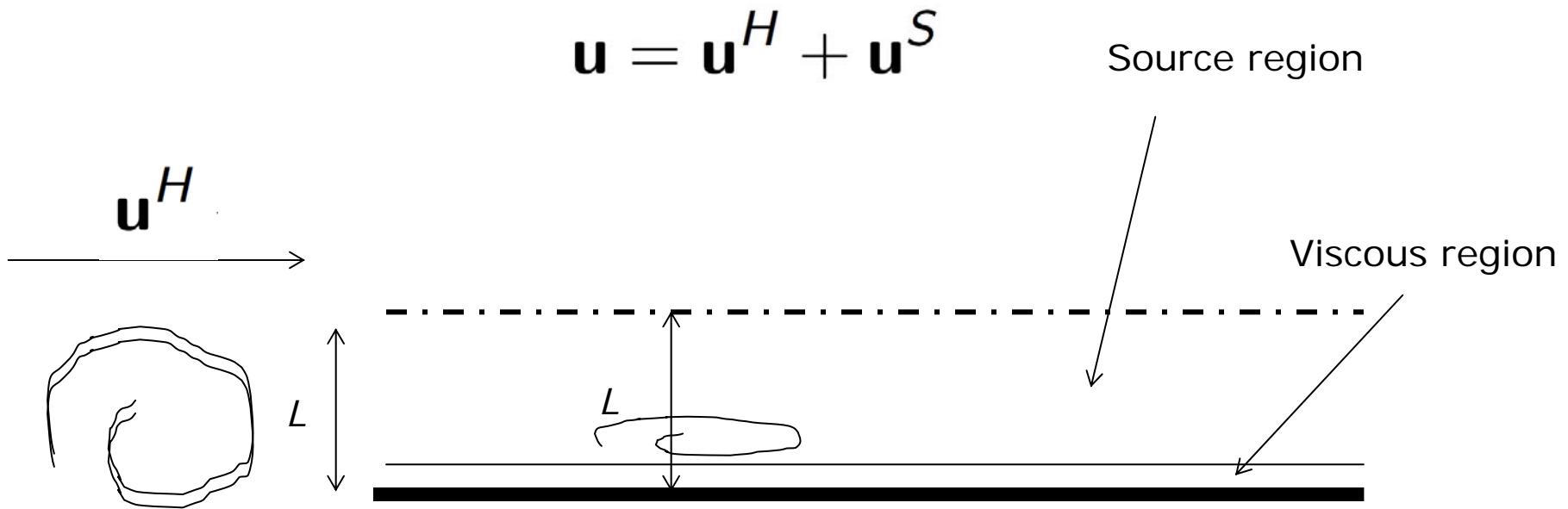
Decreased $-\langle uw \rangle$ not explained by reduced $\partial U / \partial z$, nor RDT



Simple RDT

$$\Delta\sigma_u^2/\sigma_u^2 = -\frac{4}{5}\frac{\Delta U}{U}$$
$$\Delta\sigma_v^2/\sigma_v^2 \approx 0$$
$$\Delta\sigma_w^2/\sigma_w^2 = +\frac{4}{5}\frac{\Delta U}{U}$$
$$\Delta\overline{uw} = \overline{uw} = 0$$

Distortion of turbulence by sudden blocking (Hunt and Graham, 1978, JFM)



$$\nabla \cdot \mathbf{u}^S = 0$$

$$\nabla \times \mathbf{u}^S = 0$$

$$u_3^S = -u_3^H \text{ for } z = \text{forest top}$$