Physically-based numerical framework for wind energy forecasting and wind turbine noise prediction

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Hydro One Campus Visit

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http://www.neo-aerodynamic.com/images/Wake.JPG

openWind, created by AWS Truewind, is an open-source **wind farm design software**

[http://www.awsopenwind.org/]

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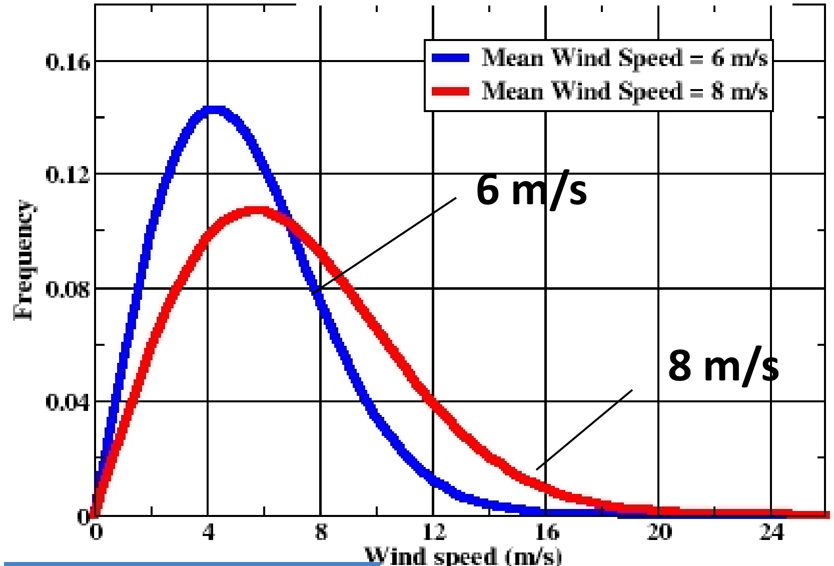
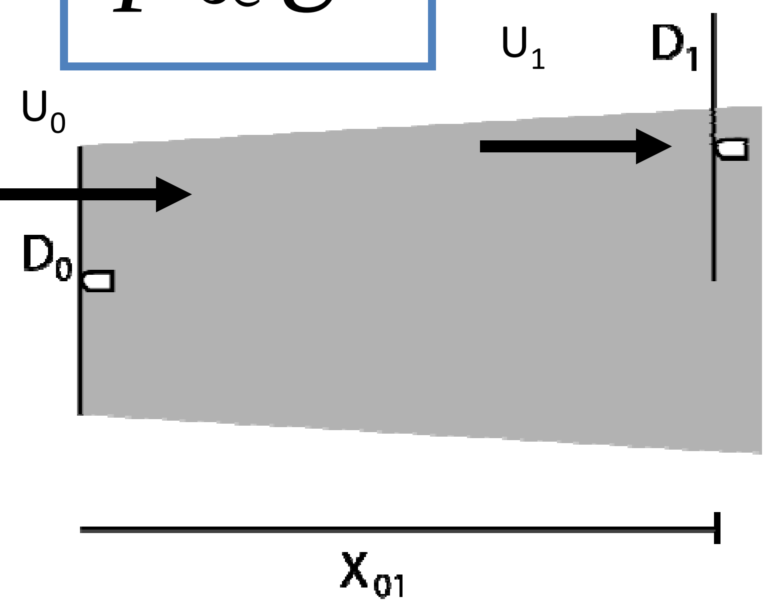
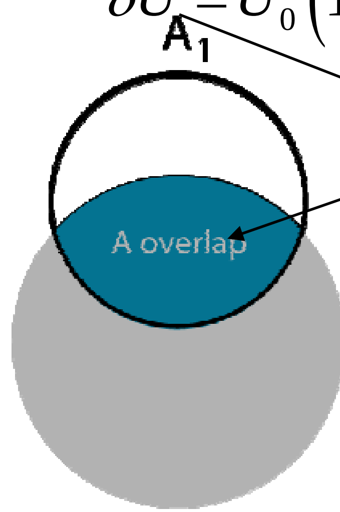
Weibull Distribution



$$P \propto U^3$$



$$\delta U = U_0\left(1-\sqrt{1-C_t}\right)\left(\frac{D_0}{D_0+2kX_{01}}\right)^2\left(\frac{A_{overlap}}{A_1}\right)$$



Method 1

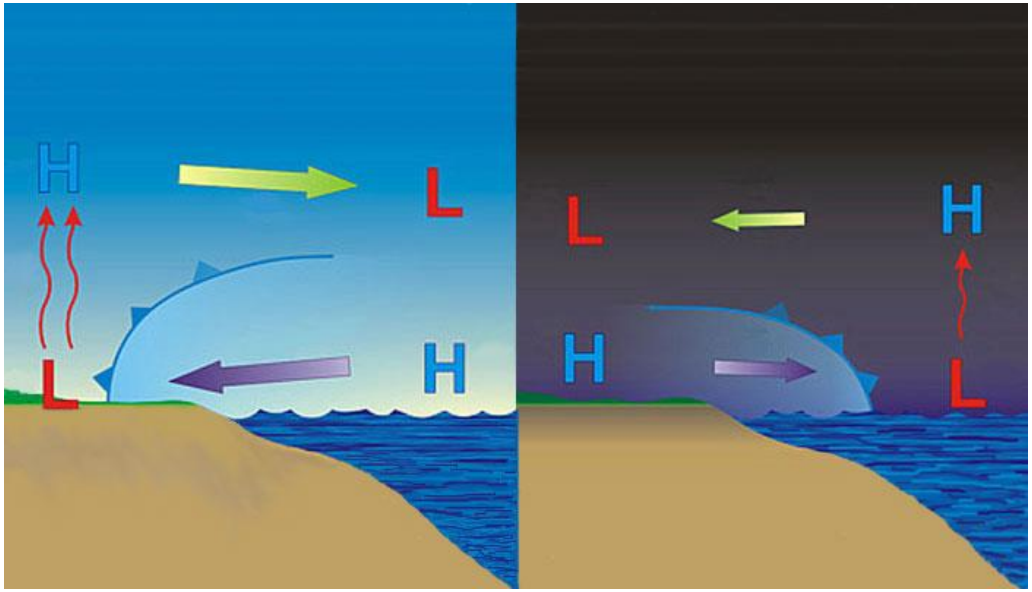
$$U_1 = U_0 - \delta U < U_0$$

Can we do better?

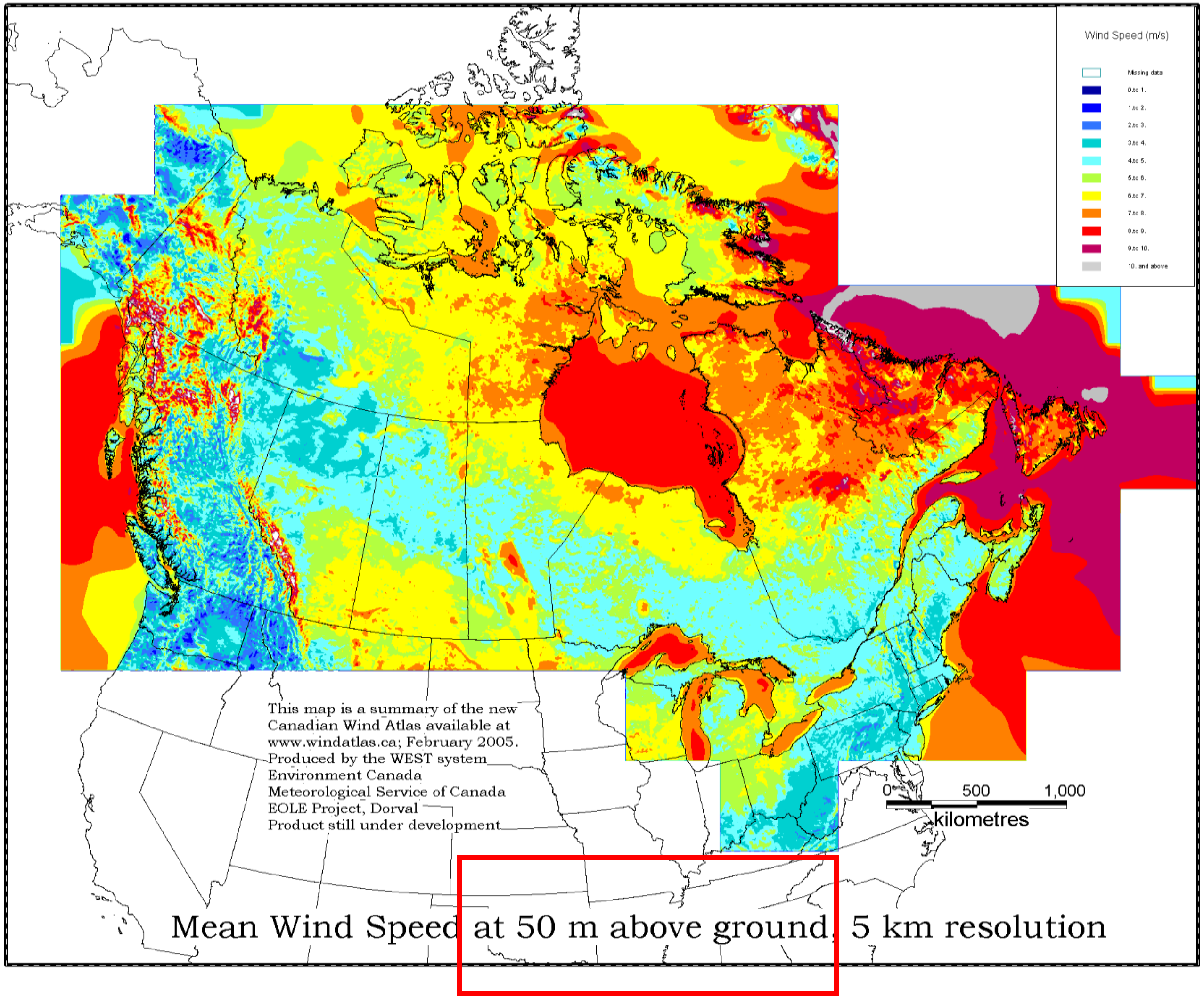
Mesoscale modelling

- A mesoscale model is a **numerical weather prediction (NWP)** model with sufficiently high horizontal (**≈30 km**) and vertical resolution to forecast **mesoscale weather phenomena in coastal and mountainous regions.**

Sea breeze

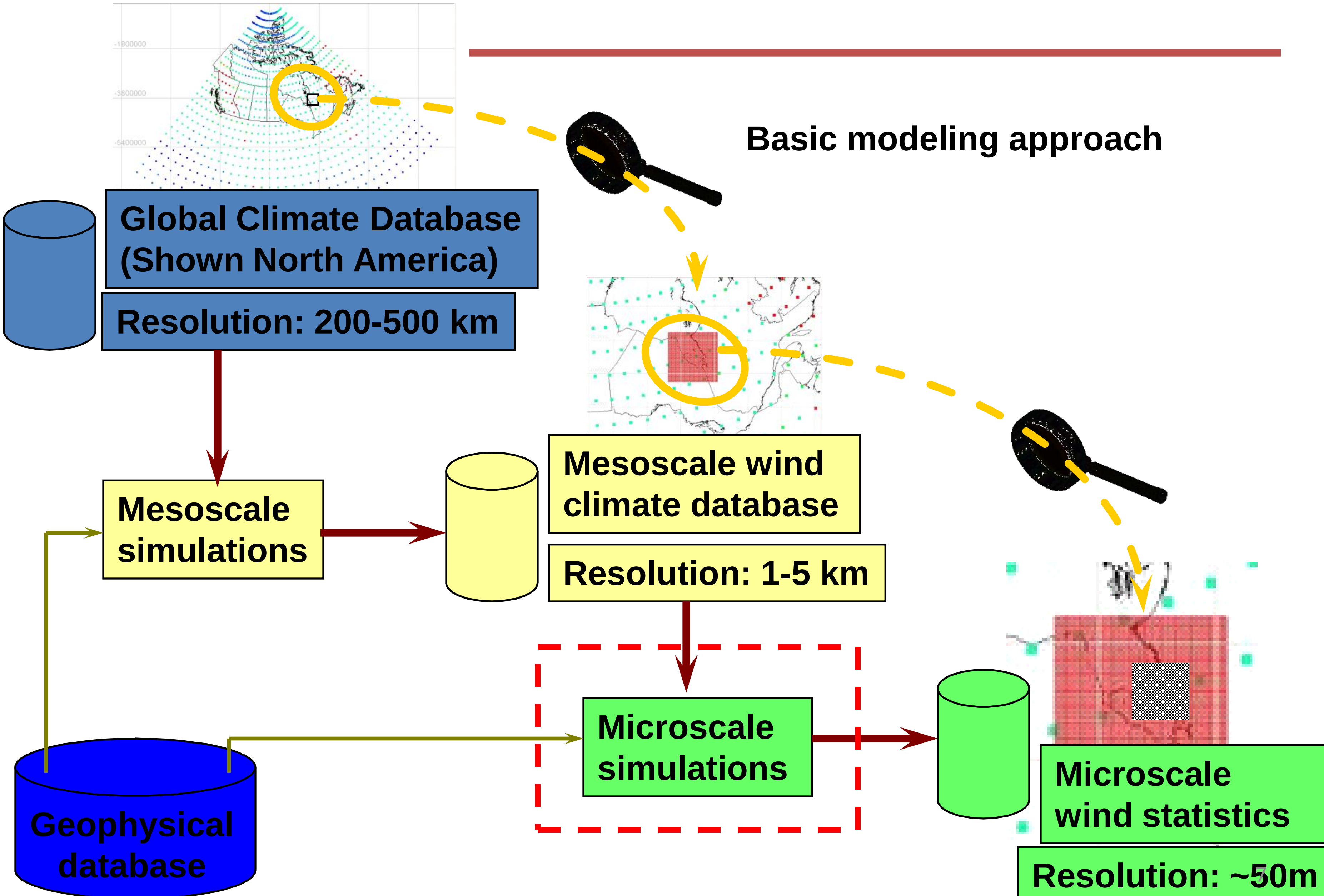


Canadian Numerical Wind Atlas



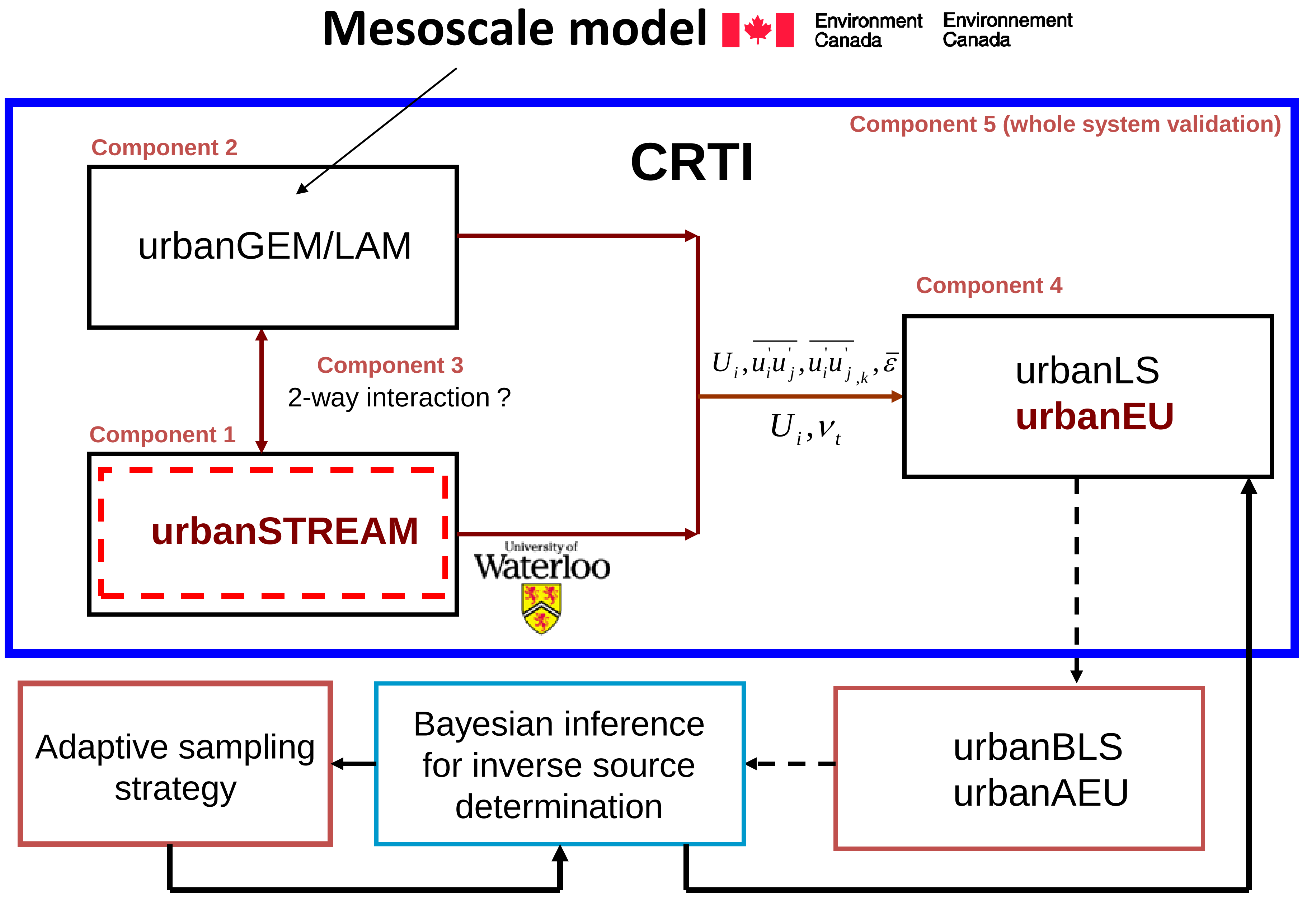
by **Wei Yu**, email: Wei.Yu@ec.gc.ca

Wind Energy Simulation Toolkit (WEST)



MS-micro

- Based on the theory of Jackson & Hunt (1975)
- A **neutrally stratified** flow is assumed
- Simple **mixing-length turbulence model**
- Does not resolve circulation
- Ability in complex terrain?



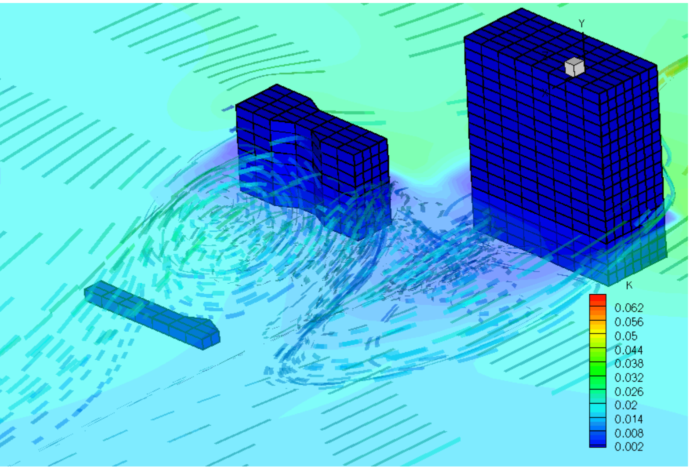
Mesoscale model
Environment Canada
Environnement Canada
Component 5 (whole system validation)
CRTI
Component 2
urbanGEM/LAM
Component 4
$U_i, \overline{u_i'u_j'}, \overline{u_i'u_j'}_{,k}, \bar{\varepsilon}$
urbanLS
urbanEU
Component 3
2-way interaction ?
U_i, ν_t
Component 1
urbanSTREAM
University of Waterloo
Adaptive sampling strategy
Bayesian inference for inverse source determination
urbanBLS
urbanAEU

CFD software

ANSYS FLUENT is a *commercial* flow modeling software

http://www.ansys.com/products/fluid-dynamics/fluent/

urbanSTREAM is an *in-house* CFD code developed at U of Waterloo (CANADA)



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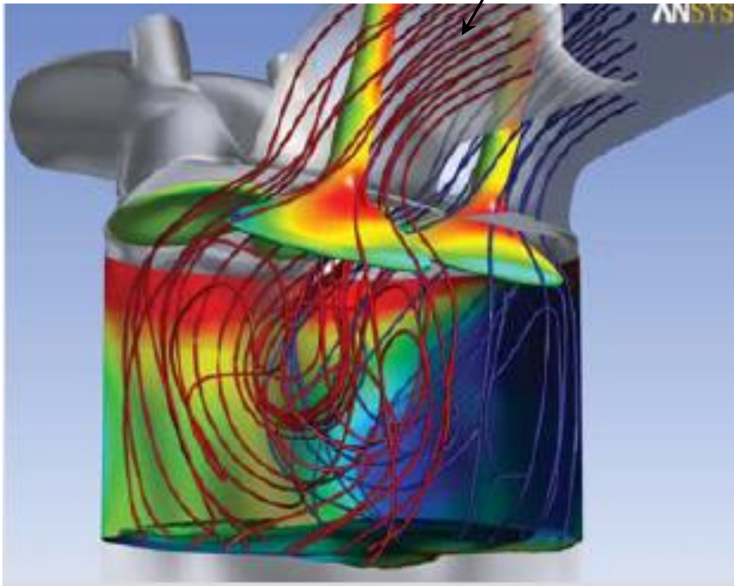


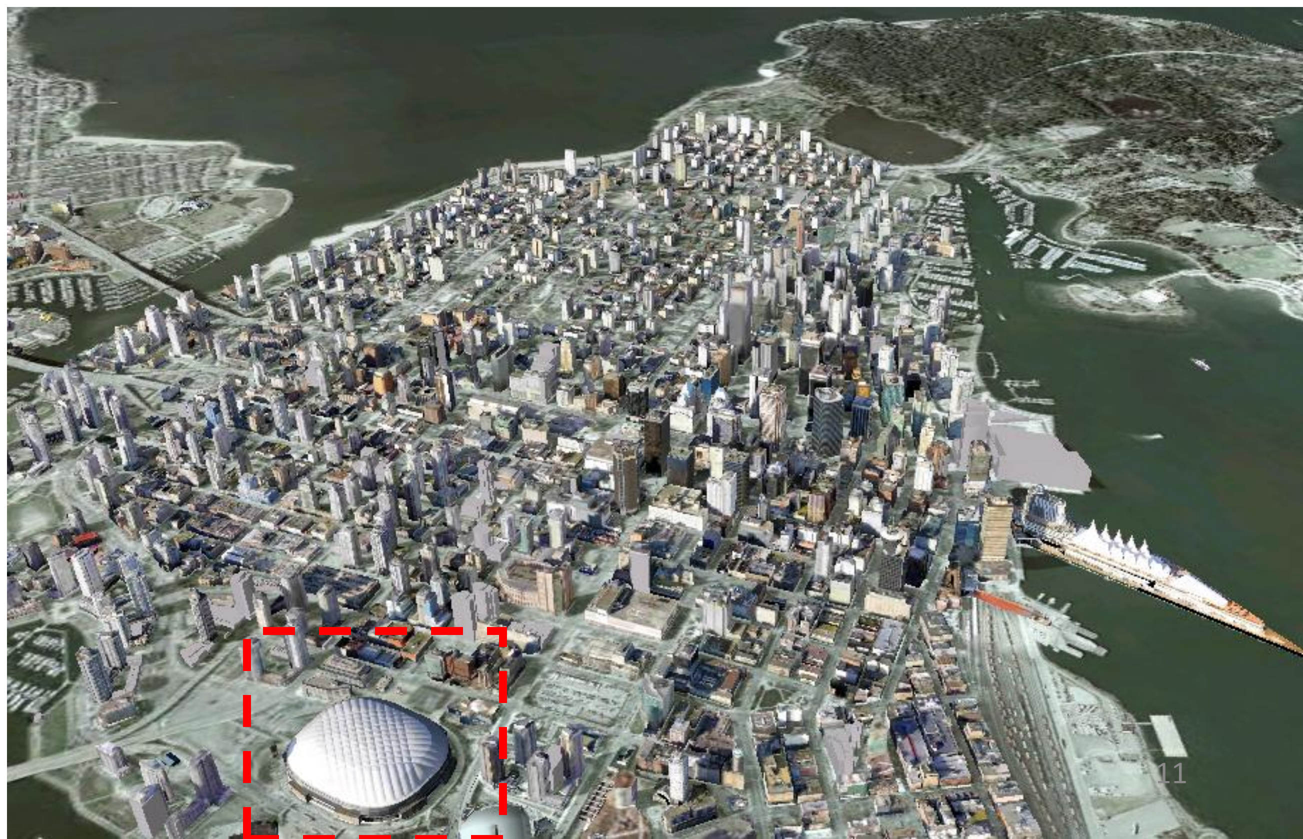
Internal combustion engine and the flow inside modeled using ANSYS FLUENT software

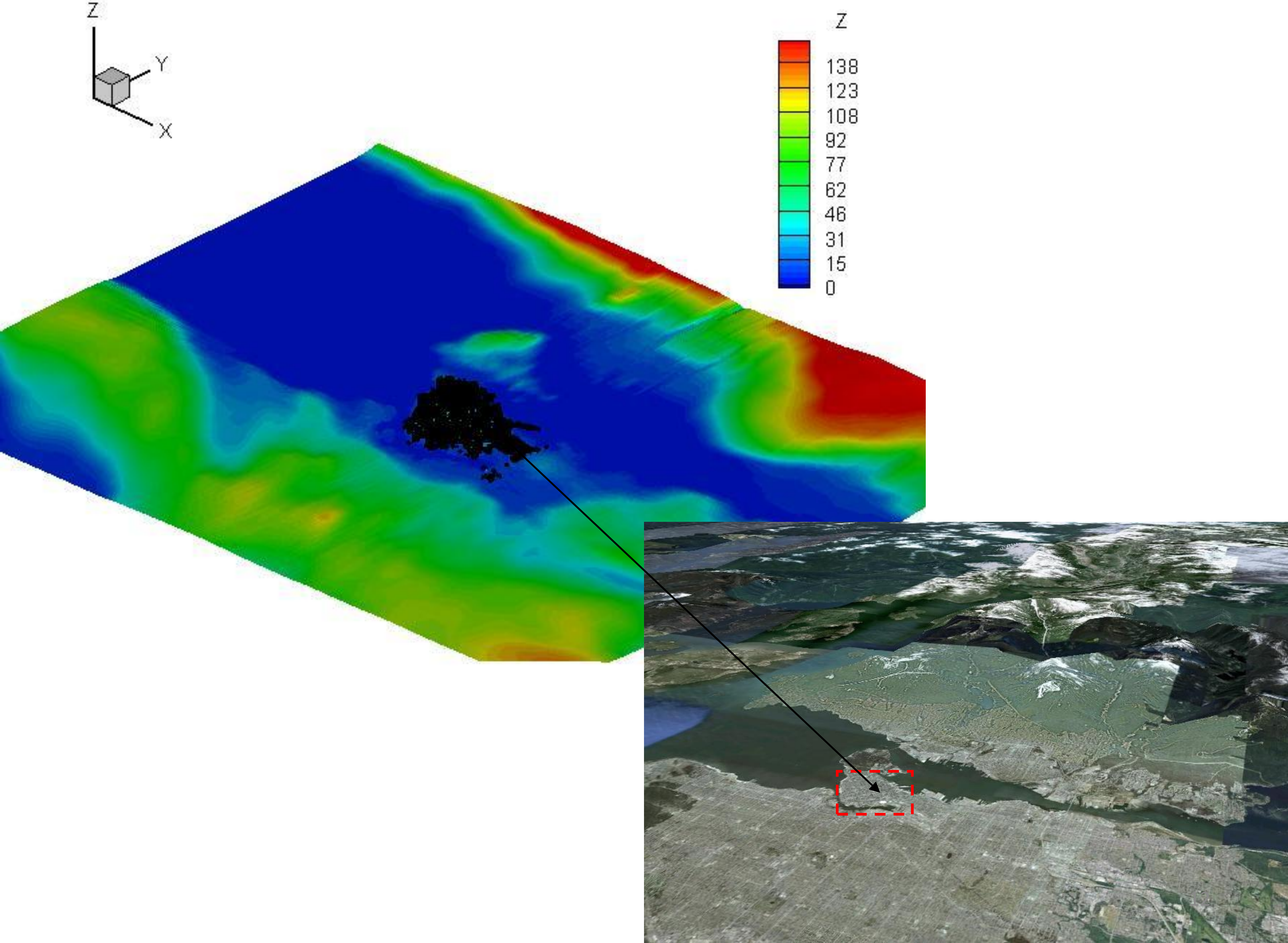
Support for 2010 Winter Olympics in Vancouver City

- 16 CPUs on saw.sharcnet.ca
- 380×380×70=**10.108 million** nodes

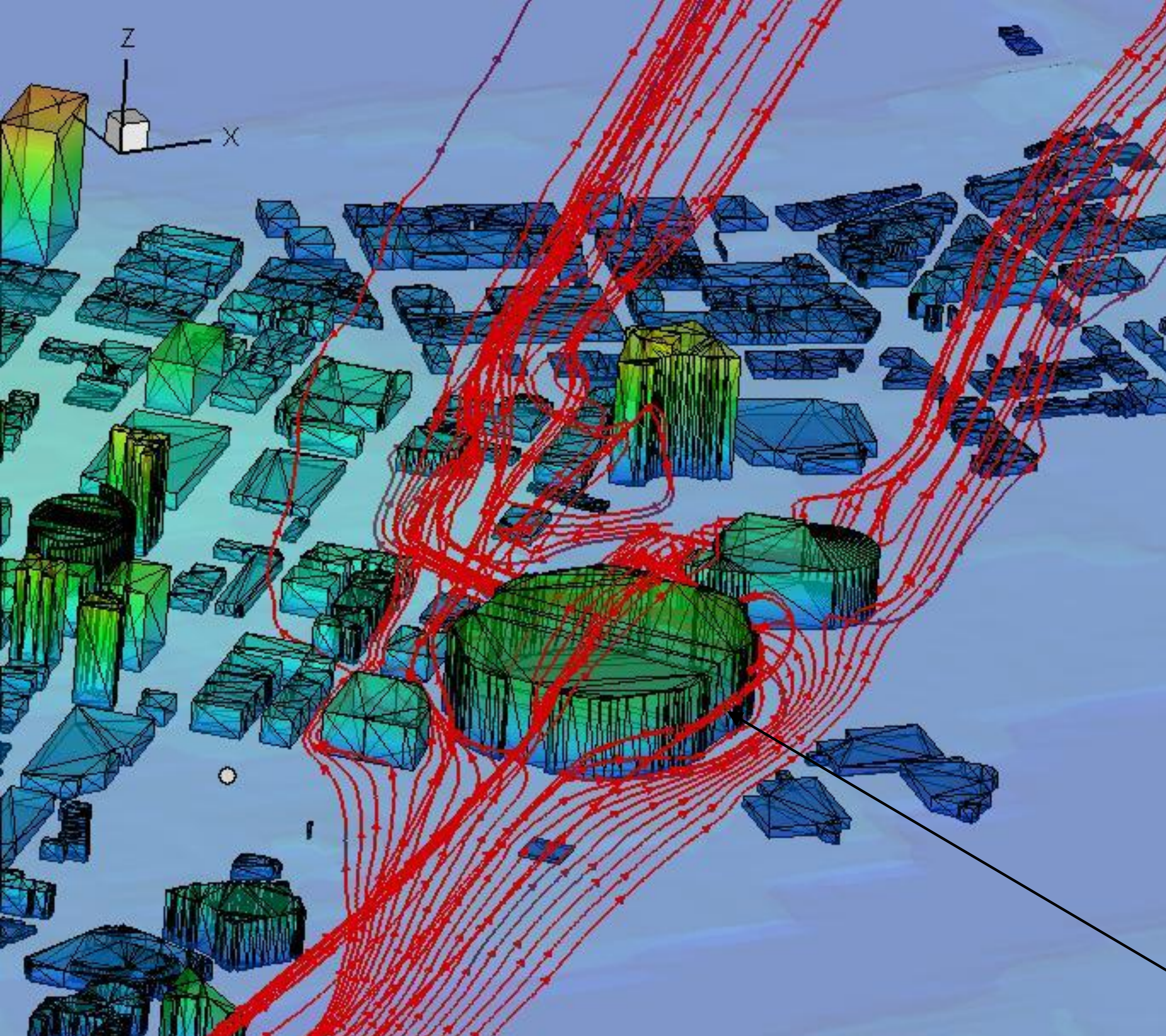
vancouver 2010

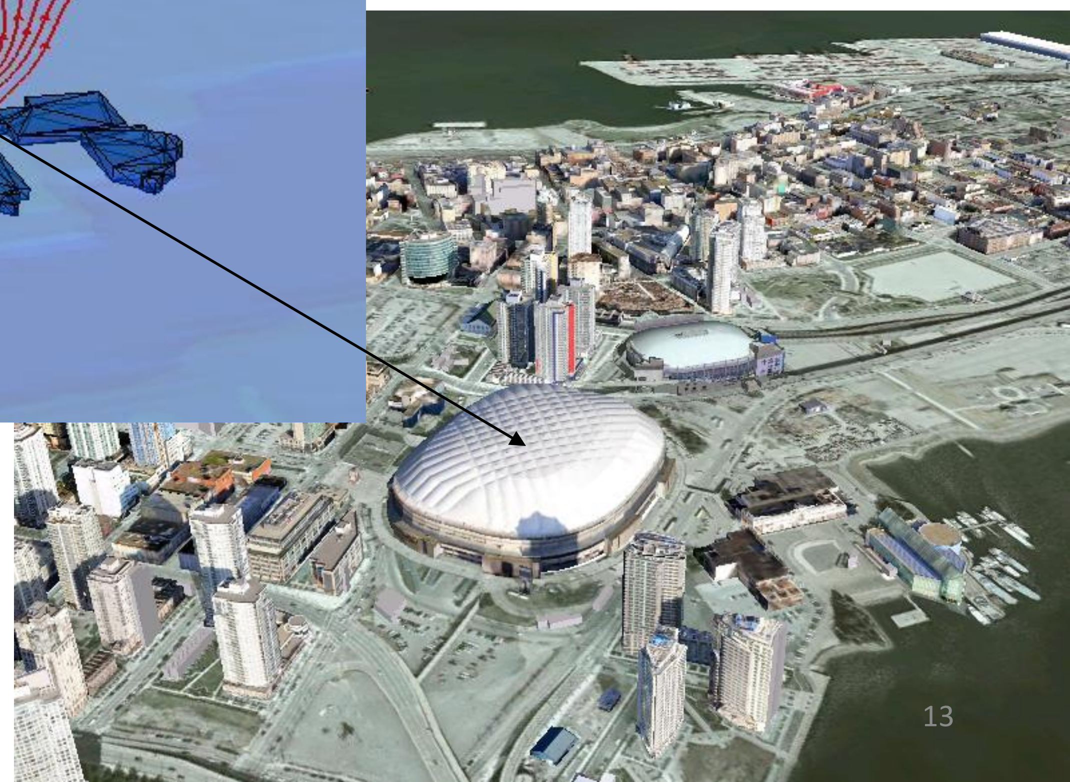
vancouver 2010
PARALYMPIC GAMES
JEUX PARALYMPIQUES




Z
Y
X
Z
138
123
108
92
77
62
46
31
15
0

BC Place Stadium





Reason to develop a multiscale (meso-micro) system for wind power prediction

- If wind speed increases from 7 m/s to 7.5 m/s, it would yield 13% of gross profit per turbine

Accuracy of wind speed at hub height of a wind turbine is important!

Micrositing: to locate wind turbines in a wind farm to maximize annual energy production **using CFD**

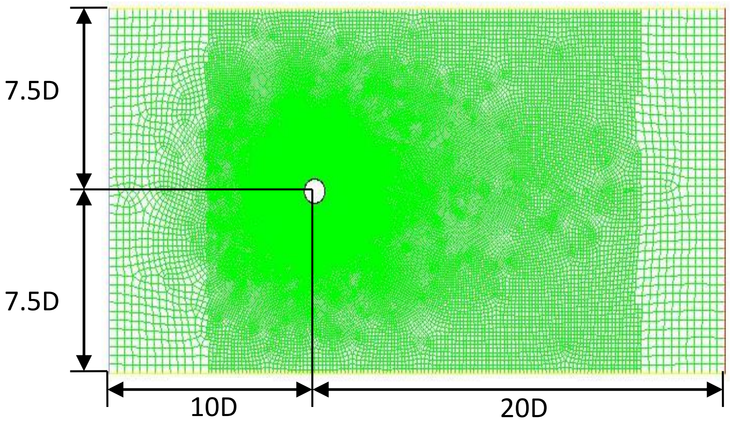
SINUS Soundbook

Acoustic imaging

Andy Metelka, Sound & Vibration Solutions (SVS) Canada Inc.

Flow over a single cylinder

- Computational domain:



D=0.019m Re=90,000

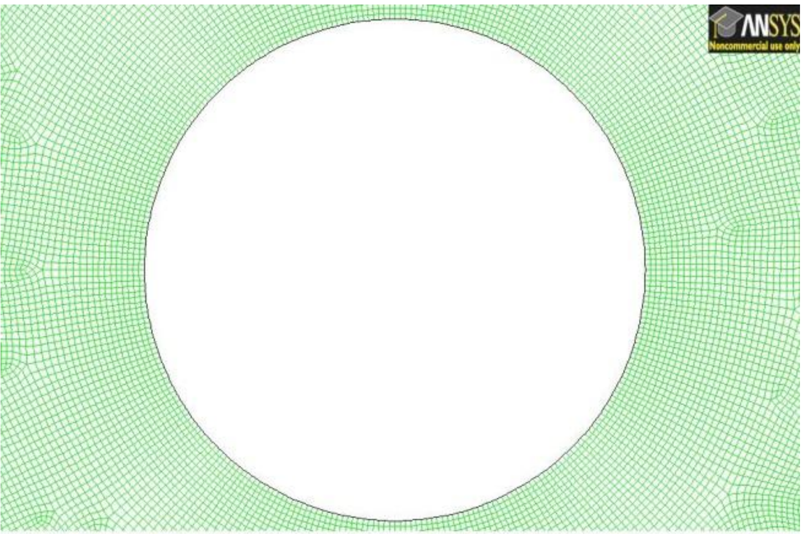
Inlet Mach=0.2

15°C air: ρ=1.225kg/m³

μ=1.7894E-05 kg/m/s

Δt=3.17E-07 s

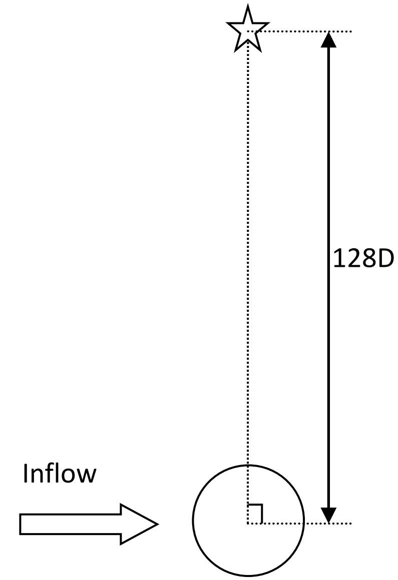
200,000 Δt before recording

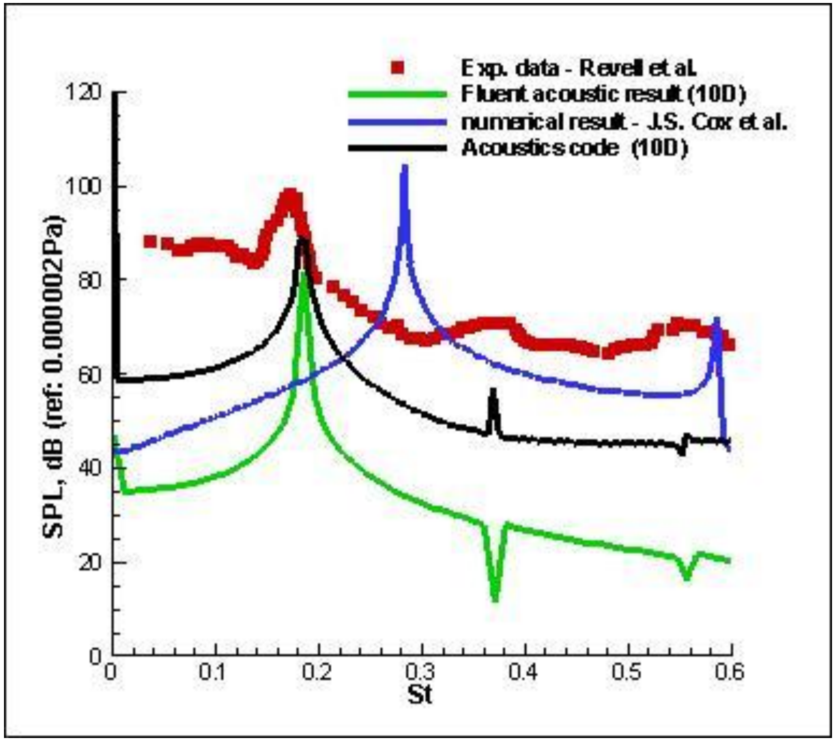


by Ping Ma

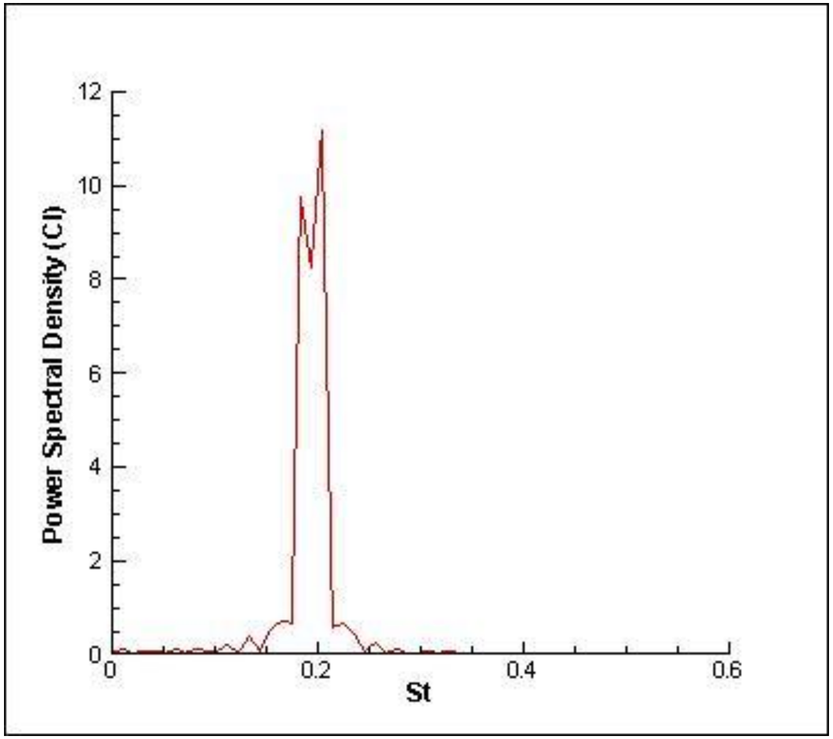
University of Waterloo

Receiver located at 90 degree from the free stream direction, **128 D away from the cylinder**



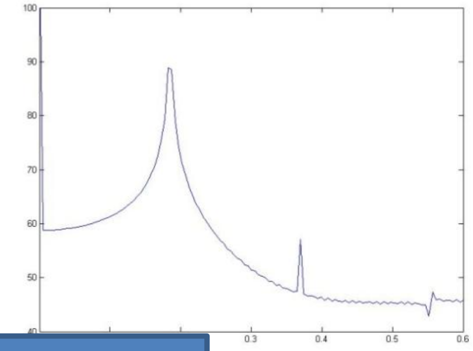


Noise prediction at receiver



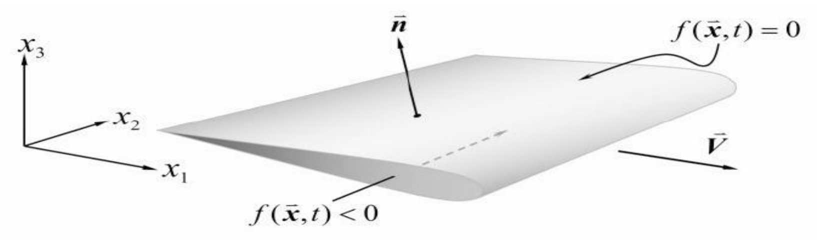
Cl Power Spectral Density (Fluent)

Flow chart



Fluent (static pressure on cylinder surface) → **3D acoustic code (sound pressure fluctuation at receiver's location)** → **Matlab FFT (SPL vs. St)**

Farassat 1 formulation



Thickness → p_T'

Loading → p_L'

$$4\pi p'(\mathbf{x},t) = 4\pi p_T'(\mathbf{x},t) + 4\pi p_L'(\mathbf{x},t)$$

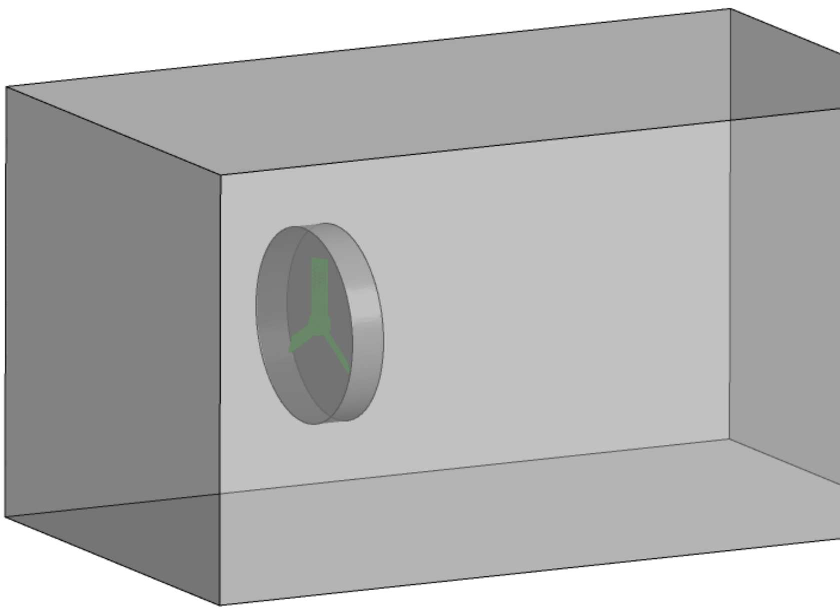
$$= \frac{\partial}{\partial t}\left\{ \int_{f=0} \left[\frac{\rho_0 v_n}{r(1-M_r)} + \frac{p\cos\theta}{cr(1-M_r)} \right]_{\text{ret}} dS + \int_{f=0} \left[\frac{p\cos\theta}{r^2(1-M_r)} \right]_{\text{ret}} dS \right\}$$

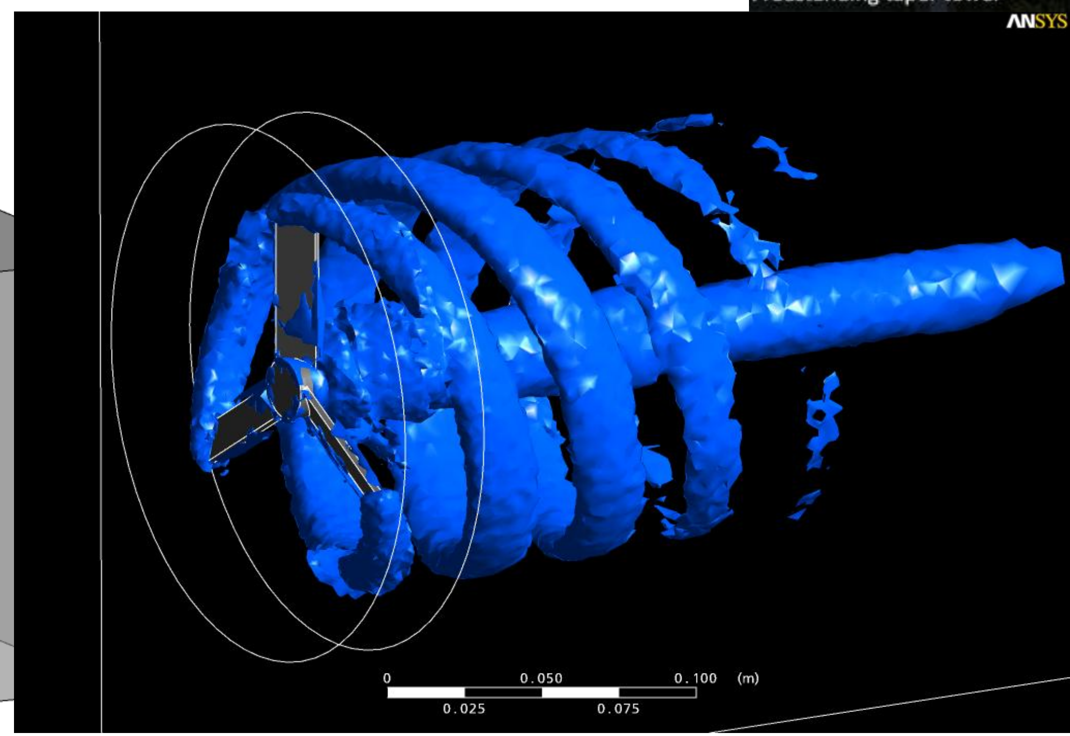
LES or URANS

retarded time at t-r/c

Single-rotor

Koda, 2011



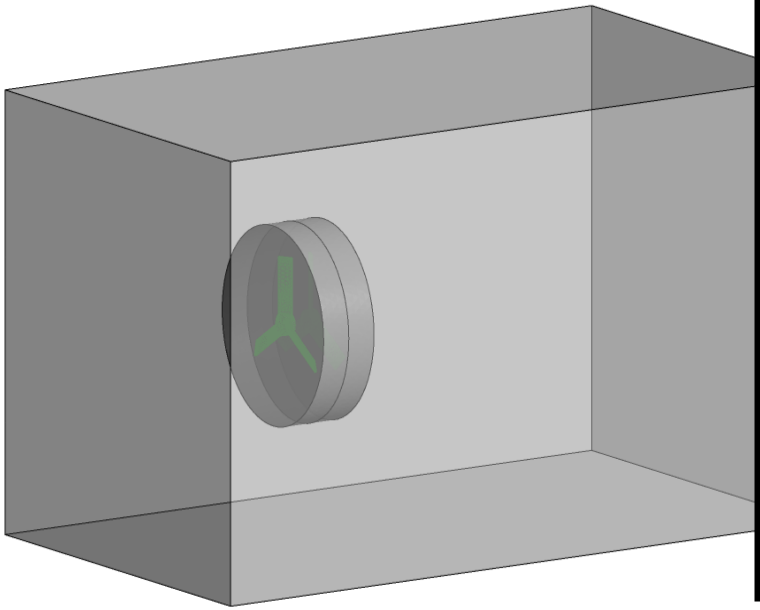


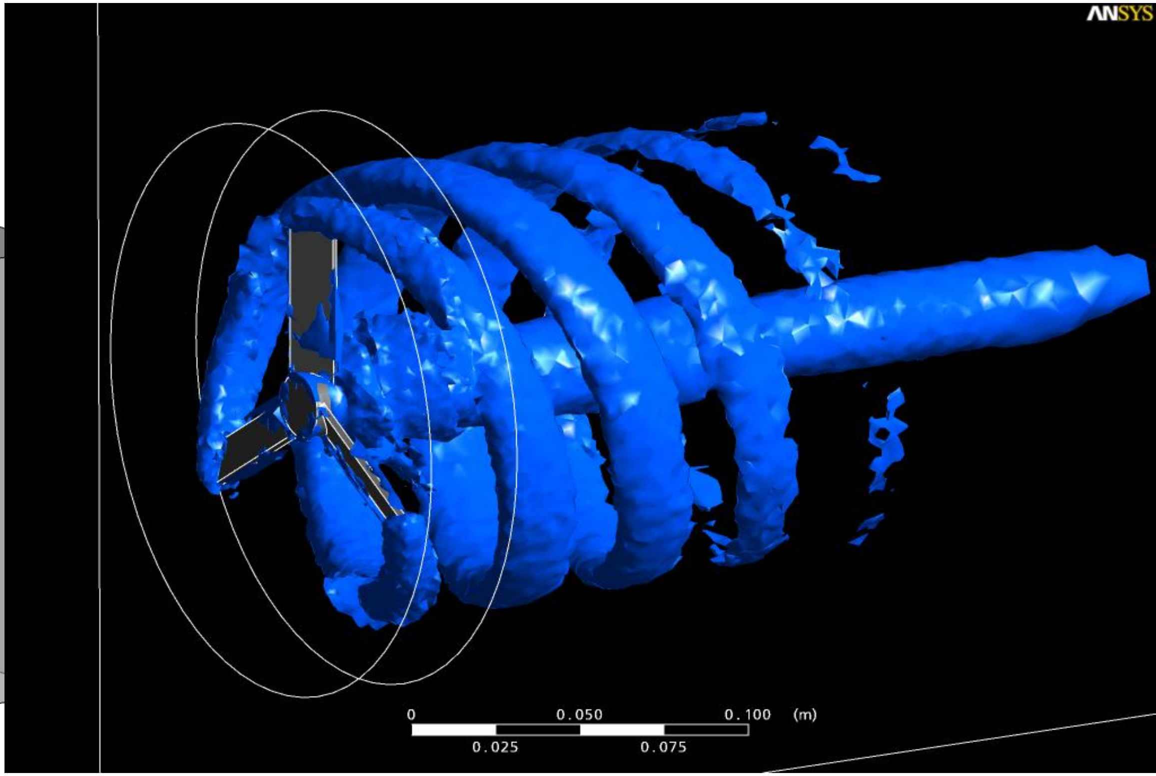
Isosurface plot of Z vorticity at 70[s^{-1}]

Counter-rotating wind turbine

http://www.ahaenergy.com/

Dual-rotor





Isosurface plot of Z vorticity at 120[s^{-1}]

What next?

Blade/tower interactions & noise prediction

Thanks & Questions?