

WindThrow 1.2

The aerodynamics ice throw toolbox, now with a (better) GUI

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Motivation

WECC: Known advantages, but ...

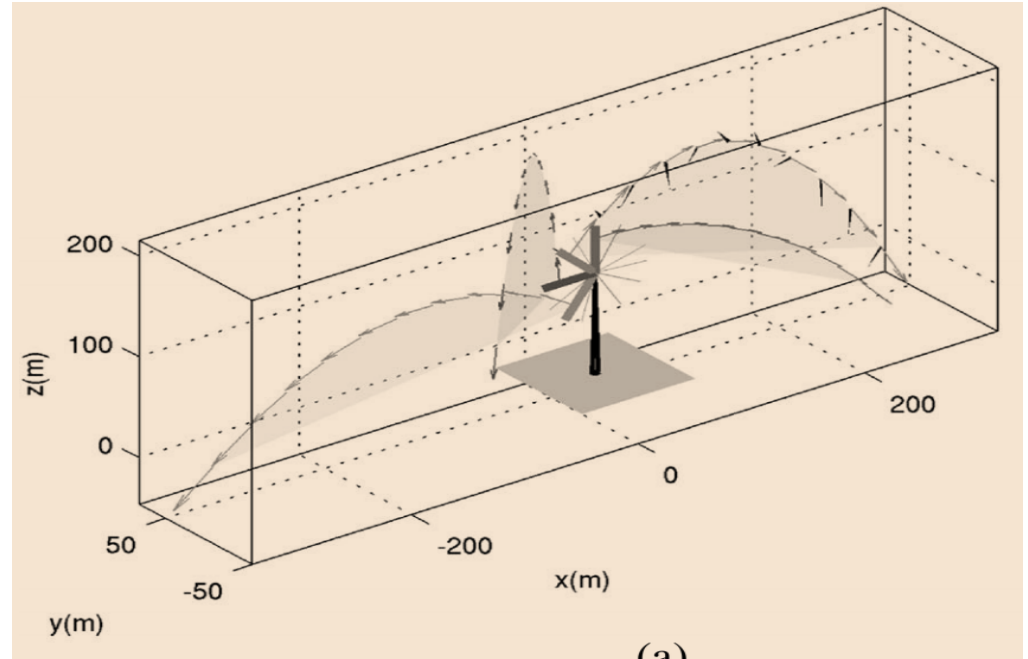
- Increases in fatigue loads due to load imbalance
- Ice risks are much more significant than blade/fragment failure (Frequency blade failure 10^{-3} /year; ice throw > 10 /year)
- According to local legislations, the danger of getting hit by ice fragments needs to be assessed already during planning phase



<https://www.eologix.com/en/hoarfrost-rime-ice-and-glaze-ice/>

Ice throw calculation classification

- Empirical formulas: e.g. $d = 1.5 (D + H)$ for Ice throw
- Simple ballistic models (vacuum)
- More detailed aerodynamic models
- Higher fidelity tools and methods + AI (?)

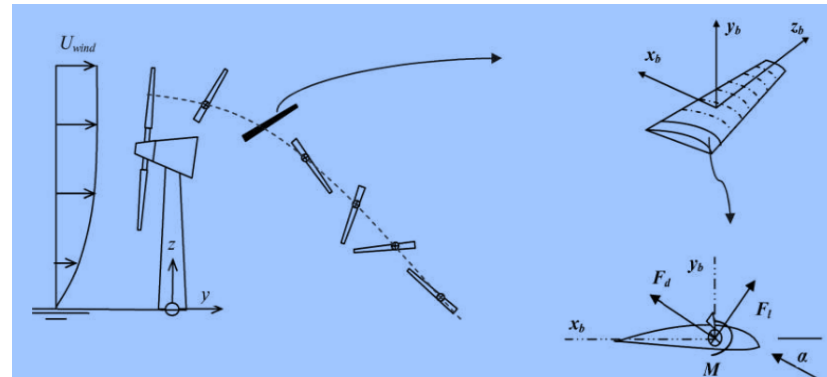


windThrow's Ice throw model

- Blade element theory is used
 - Aerodynamic loads calculated on fragments and corresponding motions translated into a global coordinate system

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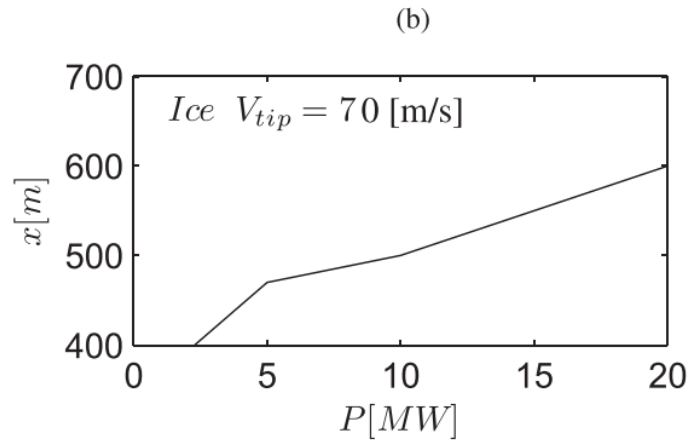
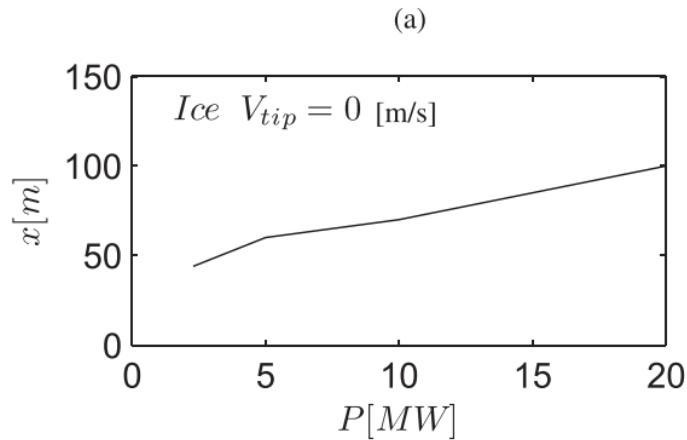
1: Program SAVBAL(ABL and turbine parameters, initial conditions)
2:   Call initiate ! Evaluate initial position,
3: orientation and velocities of fragment
4: at t0 in it's local coordinate
5:   while zg ≤ 0 do ! main loop of the program,
6: iteration until the body hits the ground
7:     Call trans1  $\vec{Y}^{old} \leftarrow [\mathbf{R}, \overline{og}_b, \vec{v}_b, \vec{\omega}_b]^{old}$  ! Arrange a set of 18 ODE's
8:     Call local velocity  $\vec{v}_{local} \leftarrow \mathbf{R}, \vec{v}_b, \vec{\omega}_b, \vec{v}_{wind}(h, t)$  ! Calculate relative
velocities
9:     Call aerodynamics  $\vec{F}_{total}, \vec{M}_{total} \leftarrow \mathbf{R}(\alpha), \vec{v}_{local}, \vec{\omega}_b$  ! Calculate loads
10:    Call RungeKutta  $\vec{Y}^{new} \leftarrow [\vec{Y}, \vec{F}_{total}, \vec{M}_{total}]^{old}$  ! time integration
11:    Call Trans2  $[\mathbf{R}, \overline{og}_b, \vec{v}_b, \vec{\omega}_b]^{new} \leftarrow Y^{new}$  ! update new values
12:  End while
13: End Program
    
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Results of ice throw simulations

Table IV. Aspect ratios, reference chord length C_{ref} and detached mass m of the ice fragments ($\rho_{ice} = 0.7 \text{ kg/m}^3$) used for throw simulation of turbines of different sizes.

Cases – AR	2.3 MW		5 MW		10 MW		20 MW	
	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)	C_{ref} (m)	m (kg)
AR = 1		0.18		0.43		0.97		2.16
AR = 2	0.1	0.36	0.15	0.87	0.2	1.95	0.3	4.33
AR = 3		0.54		1.31		2.94		6.49



Maximum throw distances obtained for the ice throw in (a) standstill operation, i.e., $V_{tip} = 0$ m/s and (b) normal operating condition, i.e., $V_{tip} = 70$ m/s as a function of turbines power.

New user interface and capabilities

windThrow v1.2

User friendliness

- Integration of other throw models
- Integration of guidelines and datasets
- Complex terrain
- Turbulence
- ...

The screenshot shows the windThrow v1.2 software interface. It is divided into several sections:

- INPUT PARAMETERS:** A table with columns for Name, Unit, and Input values. The values are: Turbine Power [MW] 2.3, Hub Height [m] 100.0, Blade Length [m] 50.0, Nb. of Blade Elmts. [-] 25, Wind Profile [-] uniform, Surface Roughness [m] 0.1, and Power law Exponent [-] 0.143.
- RANDOM VARIABLES (for Monte-Carlo analysis):** A section for choosing a sampling method (Purely stochastic or Multiplicative) and a random distribution (Static, Uniform, Gaussian, Weibull). It includes a table for Name, Unit, and Random distribution, and a section for Input values (Mean, Variance, Constant, Min., Max.) for each variable.
- MONTE-CARLO SIMULATION:** A section with an "Execute!" button and a reminder to validate data.
- PLOTTING:** A section with a "Plot!" button and options for Hit map, Energy map, Momentum map, Mass map, and Distance density histogram.

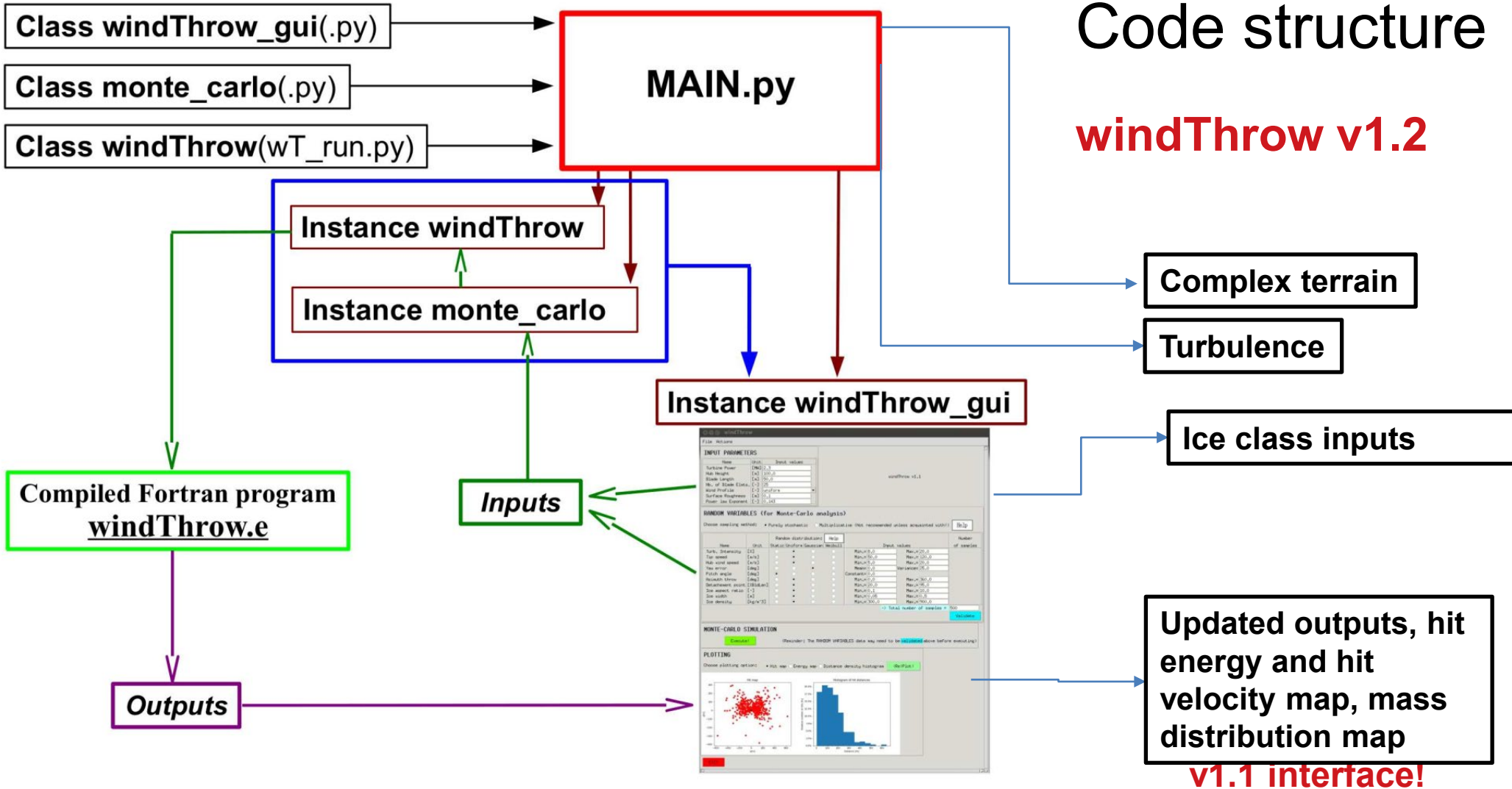
Annotations on the screenshot include:

- A box labeled "Operational WT inputs, ICE class" pointing to the Input Parameters table.
- A box labeled "Monte carlo inputs" pointing to the Random Variables section.
- A box labeled "Results" pointing to the Plotting section.

Old interface!

Code structure

windThrow v1.2



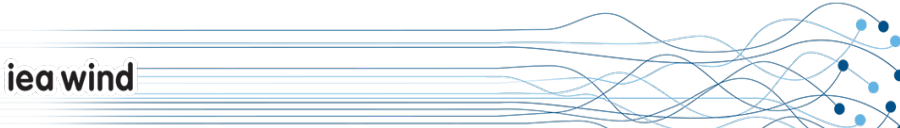
v1.1 interface!

Closure:

- Since the last time,
 - New inflow turbulence, complex terrain, further software development was added to the previously developed massive computations (Monte-Carlo) and GUI
- In the future,
 - Ice risk and mitigation module
 - Improving the database and validation (AI is the next step)
 - Robustness and software development aspects



iea wind



Thank you for your attention!

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