

windThrow

An open source toolbox for ice [and blade] throw simulations

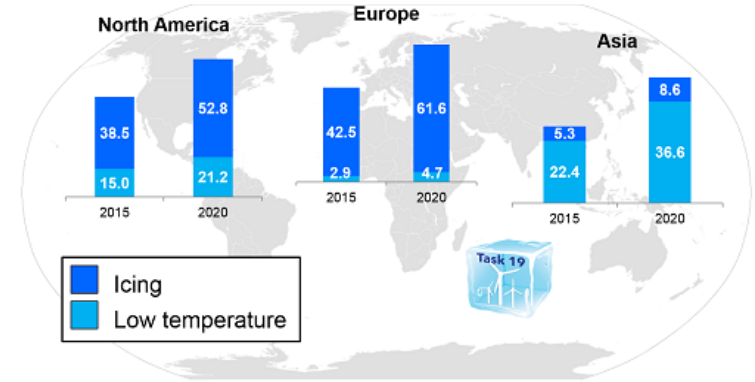
Hamid Sarlak, Franck Bertagnolio

Dept. Wind Energy, Technical University of Denmark (DTU), 2800 Kgs. Lyngby, Denmark
hsar@dtu.dk

Motivation

- Known advantages, but:
- Increases in fatigue loads
- Decrease in power production
- Ice risks are much more significant than blade/fragment failure (Frequency blade failure 10 -3 /year; ice throw > 10/year)
- According to the legislations, the danger of getting hit by ice fragments needs to be assessed already during planning phase

Cold climate markets 2015-2020 [GW]



Media considerations

Wind turbine's deadly ice shower

Published on Saturday 29 November 2008 13:07

Residents were left fearing for their safety after shards of melting ice fell from the blades of a giant wind turbine. Residents were left fearing for their safety after shards of melting ice fell from the blades of a giant wind turbine. For about 10 hours people in King's Dyke, Whitby, had to take cover as huge lumps of ice fell from the 80 metre high tower on...

"No one wants to leave the house because they are frightened and worried about the ice falling."

"My son's partner is pregnant and she is now worried sick about her unborn baby."

You can call it the influence of media, in any case WE NEED TO CONSIDER IT!

<http://www.peterboroughtoday.co.uk/news/local/wind-turbine-s-deadly-ice-shower-1-120837>

Failed sensor caused ice shards

The failure of a sensor to halt a giant wind turbine when temperatures fall is blamed for shards of ice crashing into nearby homes in Cambridgeshire.

The Cornwall Light and Power 80m (262ft) turbine was put up in August, near an industrial estate and close to homes in King's Dyke, Whitby.

On 29 November chunks of ice started crashing into gardens. Residents contacted some of the smaller shards of ice that fell.

DTU
WIND ENERGY PRODUCTION IN COLD CLIMATE (WECC) Tamminen, Cavalere, Hottinen, Morgan, Selker, Särki, FINNISH METEOROLOGICAL INSTITUTE.

Ice throw calculation methods

- Empirical formulas: e.g. $d = 1.5 (D + H)$ for Ice throw
- Simple ballistic models (vacuum)
- Realistically detailed aerodynamic models
 - Risk assessment
 - Other modelings
- High fidelity CFD

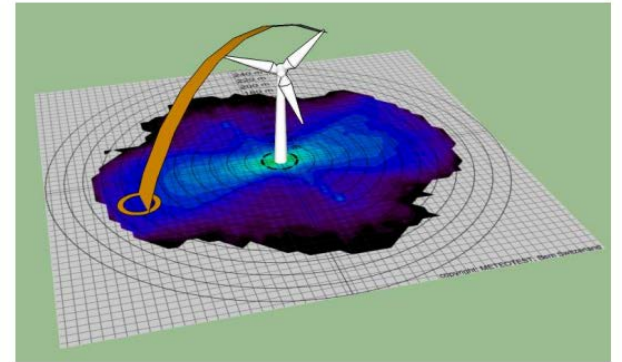


Figure 2: From one trajectory to a probability distribution (Source: courtesy of Meteotest)

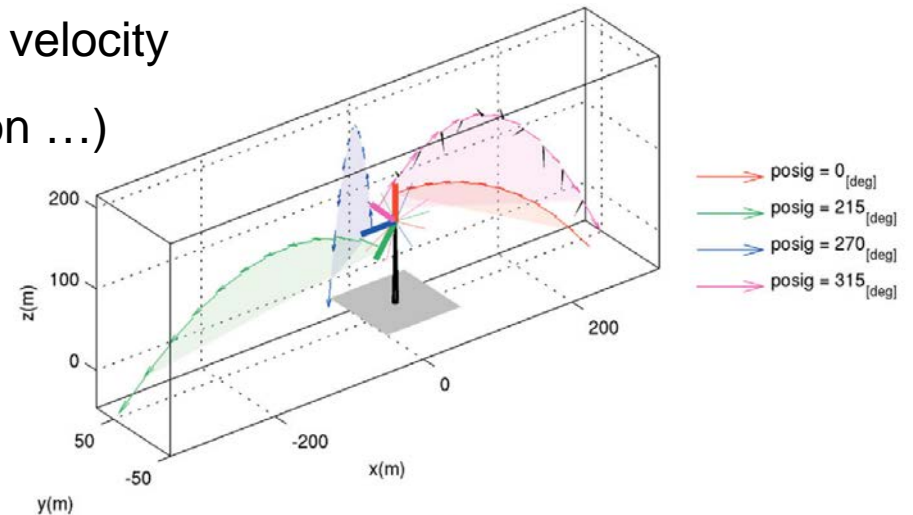
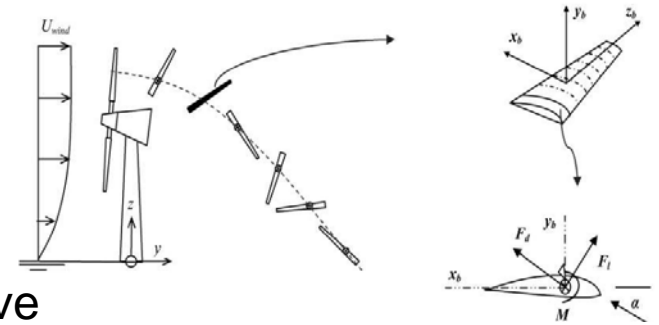
Ice throw model at DTU

Originally developed in the 80s: SAVBAL, FORTRAN 77

For blade throw

Enhanced:

- Program restructure, new features from F90 and above
- Dyn. Stall, Inflow turbulence, non-uniform inlet velocity
- Ability for ice throw simulations (time integration ...)
- Coupled with Matlab (postprocessing)
- Ice throw unit named “windThrow”
- Monte-Carlo toolbox added
- Received a GUI (Python)



Numerical model

Gov. equations and transformation matrix

$$\begin{bmatrix} \vec{r}_1 \\ \vec{r}_2 \\ \vec{r}_3 \end{bmatrix} = [\mathbf{R}] \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} \text{ and similarly, } \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix} = [\mathbf{R}^{-1}] \begin{bmatrix} \vec{r}_1 \\ \vec{r}_2 \\ \vec{r}_3 \end{bmatrix}$$

$$m\ddot{\underline{x}}_g = \underline{F} + m\underline{g}$$

$$\underline{\underline{I}}\dot{\underline{\omega}}_b = \underline{\omega}_b \times (\underline{\underline{I}}\underline{\omega}_b) = \underline{\underline{M}}$$

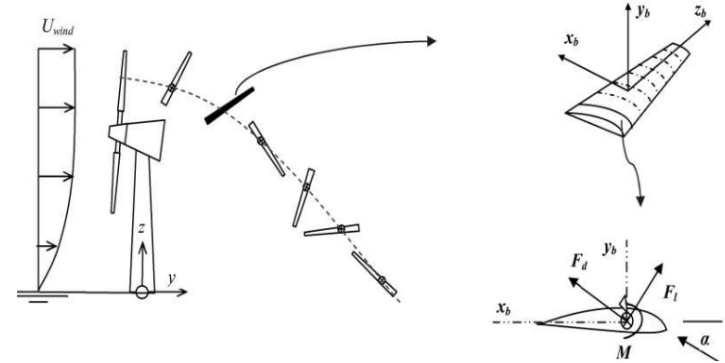
$$\dot{\underline{r}} = \underline{\omega} \times \underline{r}$$

(1)

(2)

(3)

(4)



Local rel. wind velocity seen by the blade fragment,

$$\vec{u}_{pb} = [\mathbf{R}] \cdot (\vec{u}_{wind} - \vec{u}_g) - \vec{\omega}_b \times \vec{r}_{pb}$$

Aerodynamic loads

$$L_i = \frac{1}{2} \rho v_i^2 A_i C_{Li}, \quad D_i = \frac{1}{2} \rho v_i^2 A_i C_{Di}$$

Dyn. Stall, irrelevant for ice throw $C_{l,dyn} = f_s C_{l,inv}(\alpha) + (1 - f_s) C_{l,fs}(\alpha)$

Wind profile (incl. ABL stability)

$$u_z = \frac{u_*}{\kappa} \left[\ln \left(\frac{z}{z_0} \right) + \psi(z, z_0, L) \right]$$

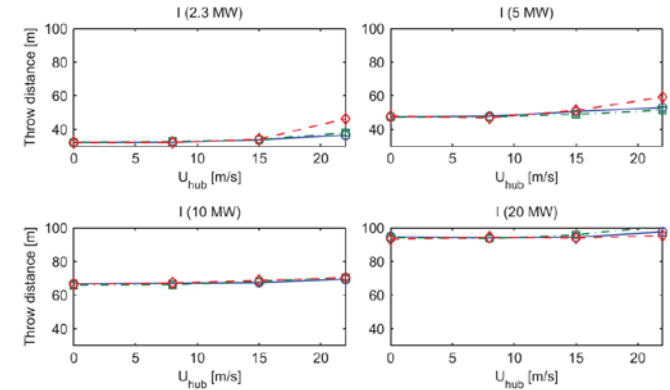
1d von Karman Turbulence spectrum

- 1: **Program SAVBAL**(ABL and turbine parameters, initial conditions)
- 2: **Call** initiate ! Evaluate initial position,
- 3: orientation and velocities of fragment
- 4: at t_0 in it's local coordinate
- 5: **while** $z_g \leq 0$ **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
- 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 $[\mathbf{R}, \overline{og}_b, \vec{v}_b, \vec{\omega}_b]^{new} \leftarrow \vec{Y}^{new}$! update new values
- 12: **End while**
- 13: **End Program**

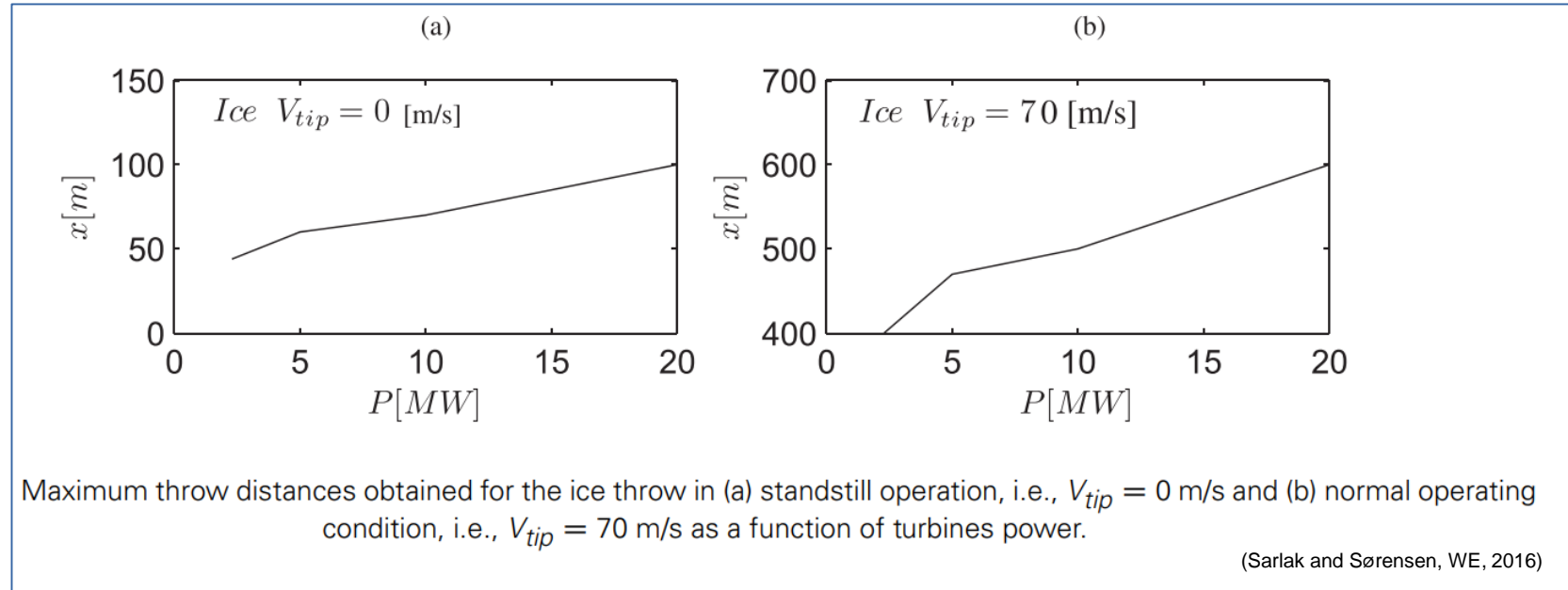
Results of ice throw simulations

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

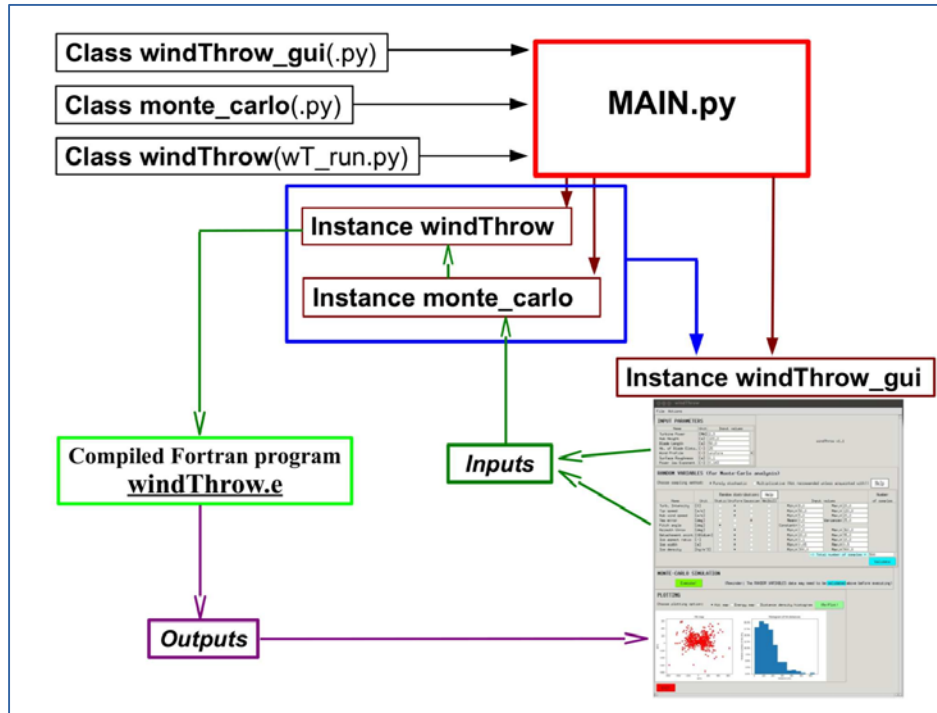


Throw distance calculations of ice fragments for three different aspect ratios for 2.3, 5, 10 and 20 MW turbines in standstill operation ($V_{tip} = 0 \text{ m/s}$). \diamond : AR = 1; \square : AR = 2; and \circ : AR = 3.



New user interface and capabilities

windThrow v1.1



The screenshot shows the windThrow v1.1 user interface. It is divided into several sections:

- INPUT PARAMETERS:** A table with columns for Name, Unit, and Input values. The parameters 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 configuring random variables. It includes a "Choose sampling method" section with radio buttons for "Purely stochastic" (selected) and "Multiplicative (Not recommended unless acquainted with!)". Below is a table of variables with columns for Name, Unit, Random distribution (Static, Uniform, Gaussian, Weibull), and Input values (Min., Max., Mean, Variance, Constant). The variables are: Turb. Intensity [%], Tip speed [m/s], Hub wind speed [m/s], Yaw error [deg], Pitch angle [deg], Azimuth throw [deg], Detachment point [%BlDLen], Ice aspect ratio [-], Ice width [m], and Ice density [kg/m^3].
- MONTE-CARLO SIMULATION:** A section with an "Execute!" button and a reminder: "(Reminder: The RANDOM VARIABLES data may need to be validated above before executing)".
- PLOTTING:** A section with a "Plotting in pop-up window for editing and printing (e.g. to file)" and a "Choose plotting option" section with radio buttons for "Hit map", "Energy map", "Momentum map", "Mass map", and "Distance density histogram". A "Plot!" button is also present.
- EXIT:** A red button at the bottom left.

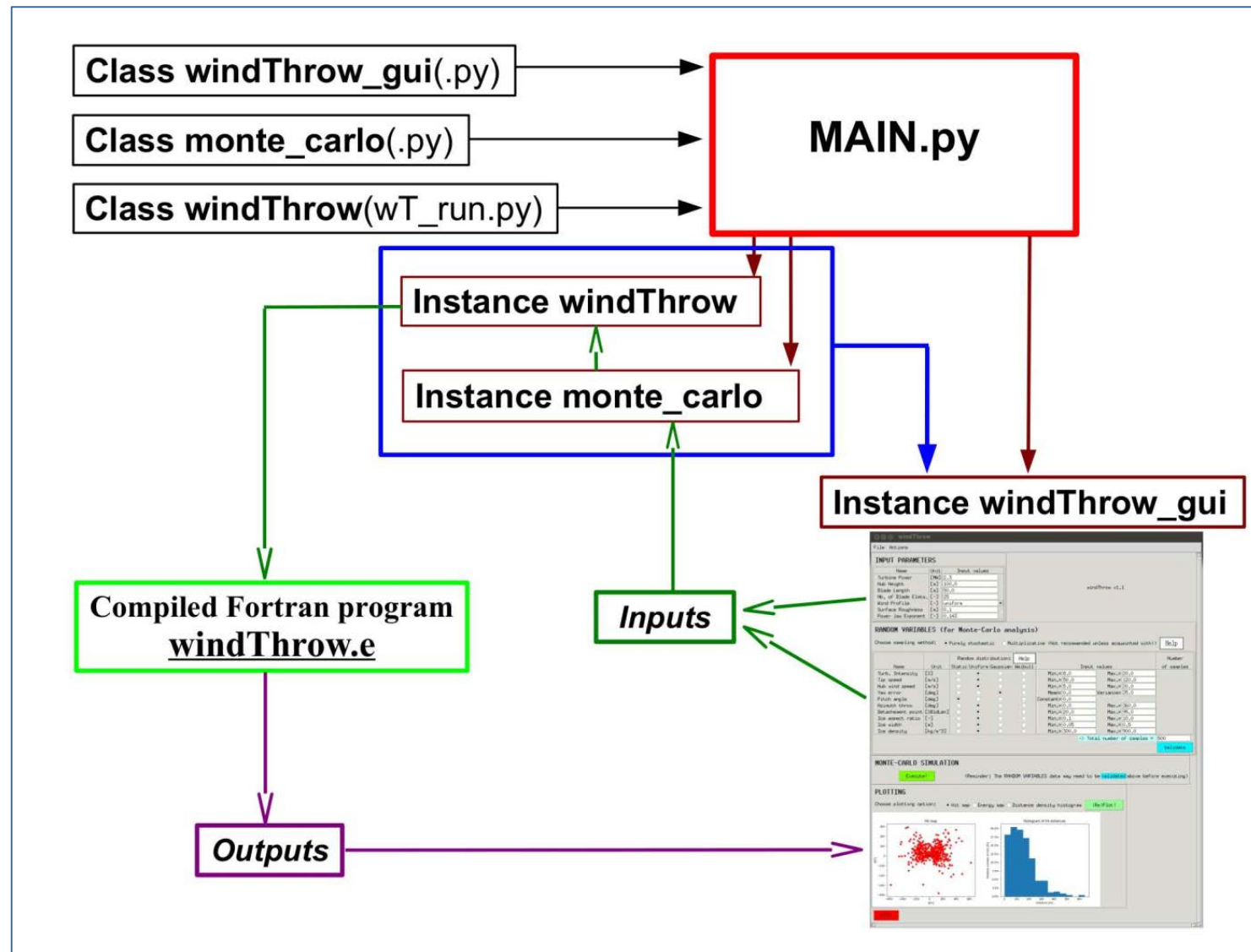
(Bertagnolio and Sarlak, Tech.report under preparation)

New user interface and capabilities

windThrow v1.1

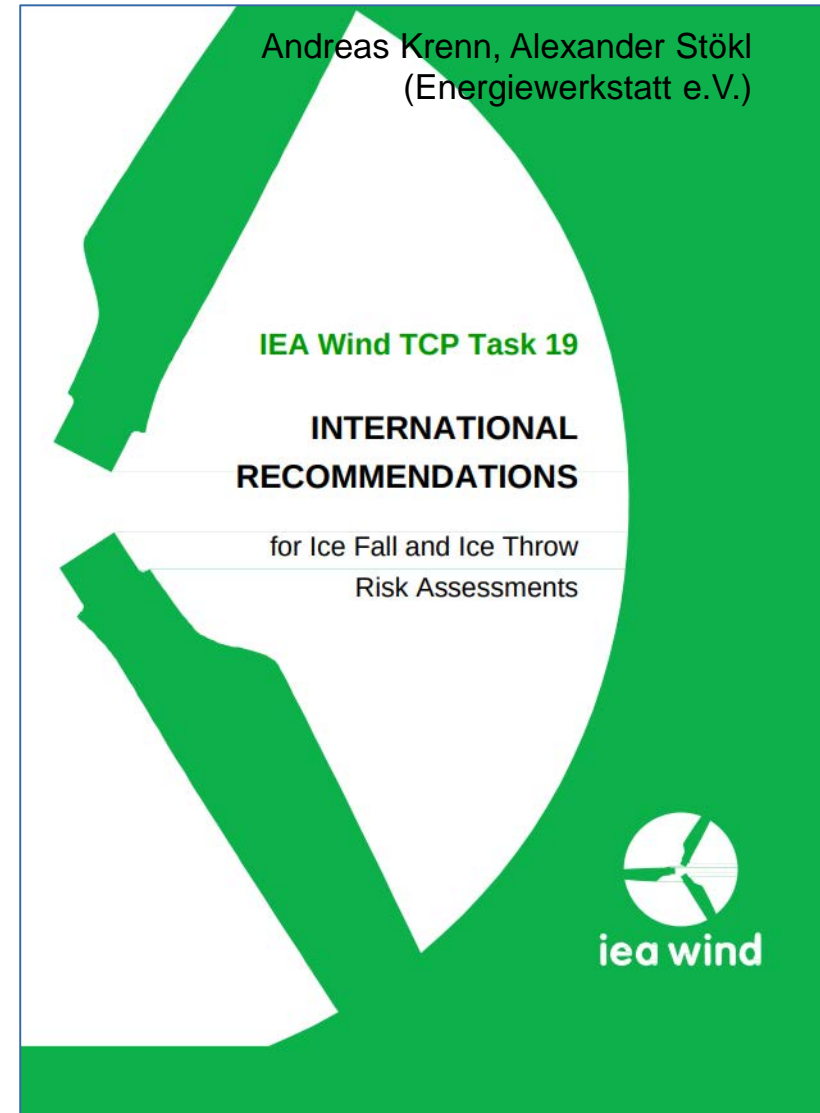
Idea is to make the code more useful to the community ...

Open source
Integration of other throw models
Integration of guidelines and datasets
Complex terrain
WRF integration (?)
...



Taking IEA recommendations into consideration

Trajectory Model,
Modelling the Ice Fragment,
Wind Turbine Characteristics,
Environmental Characteristics,
Amount of Ice,
Properties of Ice Pieces,
Site and turbine Icing Conditions,
Methods of Risk Analysis,
Risk Acceptance Criteria,
Effect of Risk Reducing Measures to the Result



Closure:

windThrow software will be freely available to the public for ice throw calculations

What is still needed?

- Improved databases, uncertainties and risk assessment methodologies
- Validation of windThrow against available databases
- Closer industry and academia collaboration needed (database)

Thanks. Willing to discuss?

Hamid Sarlak – DTU Wind Energy

hsar@dtu.dk

