IceRisk: Assessment of risks associated with ice throw and ice fall

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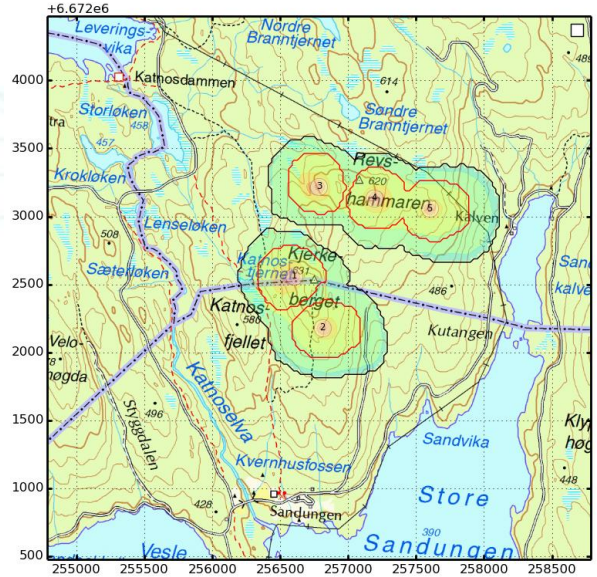
IceRisk: Assessing the risk related to ice throw and ice fall from turbines or other tall structures

- Example: The ice throw risk zones and safety distances calculated with IceRisk
- Methodology applied on a 209 m communication mast in Oslo
- Risk acceptance criteria



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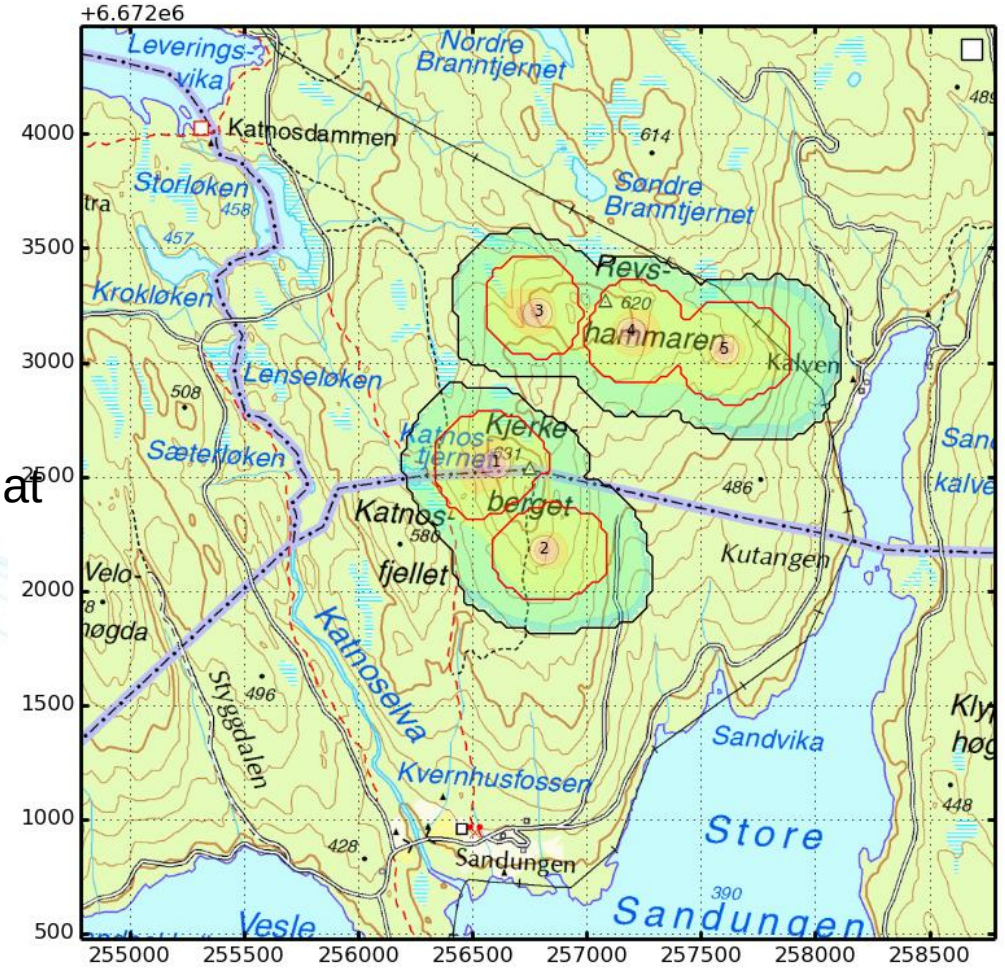
IceRisk zones for turbines operating without deicing

- Based on calculations with a trajectory model
- The risk zones are weighted with the windrose during periods with ice on the site.
- IceRisk is based on local ice load from either model calculations or observations at the site.
- IceRisk also consideres the local topography



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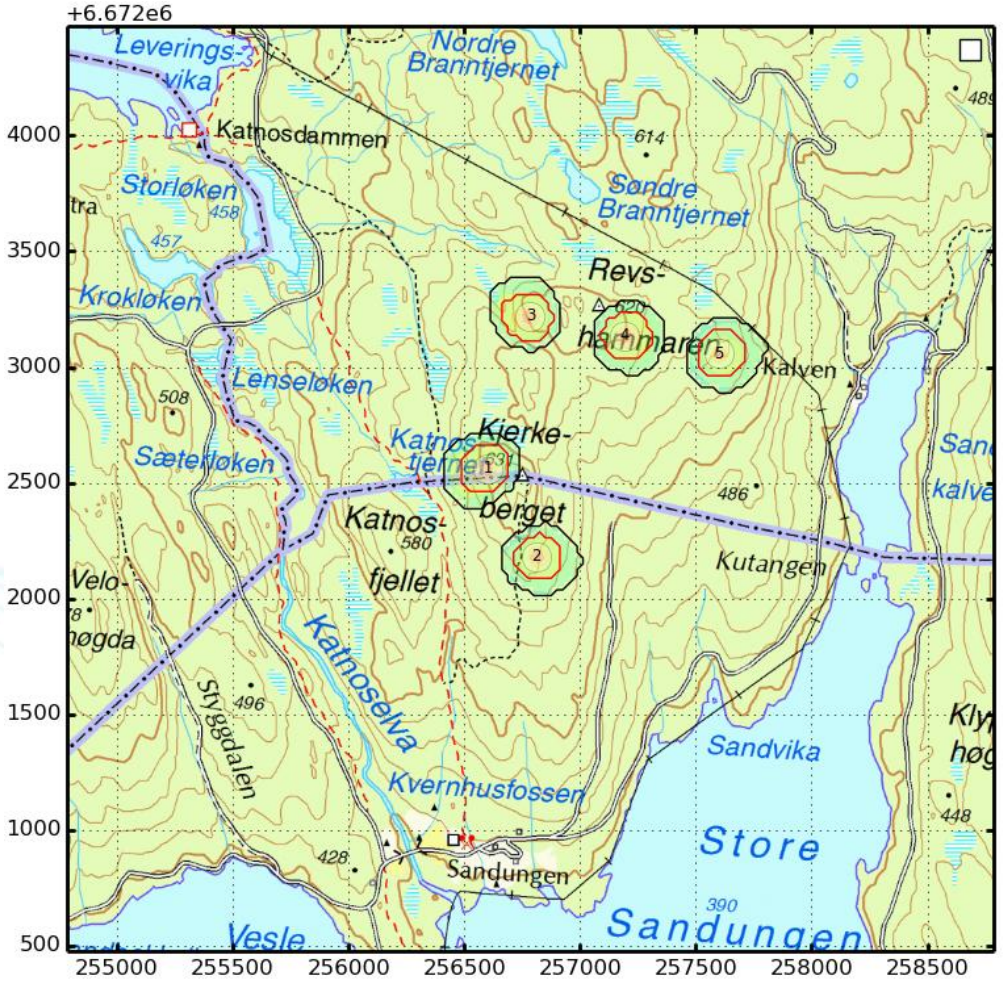
Icefall from stopped turbines

- IceRisk calculations for non rotating turbines during wind speed of 15 m/s
- The different risk maps can be combined to take into account the effect of sector management in the operation of individual turbines.



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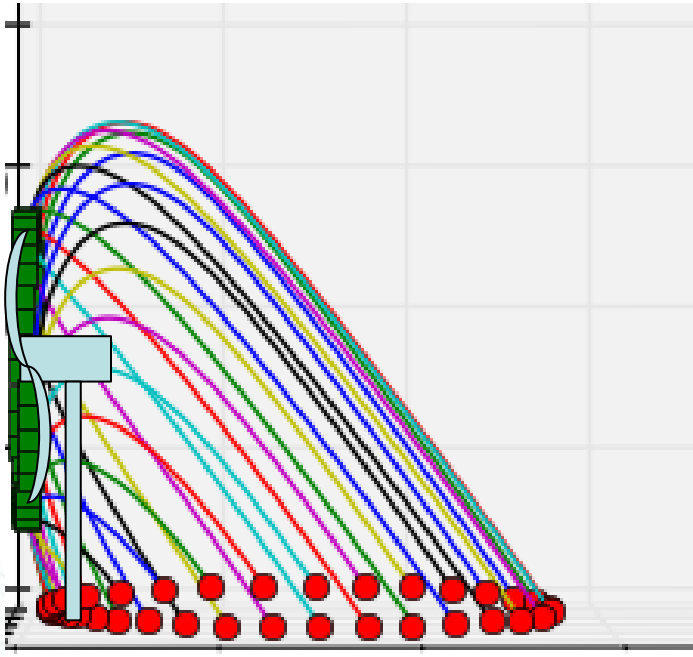
Calculation of ice throw distances with a trajectory model

- Tracks the movement of thrown or falling ice pieces
- Examples of trajectory calculations of ice throw:
  - the green boxes denote the position of the release of an ice piece
  - the red circles denote the position of where the ice piece hits the ground
- The trajectory calculations are combined with the distribution of icing events, wind direction, wind speed and terrain data to calculate risk zones.



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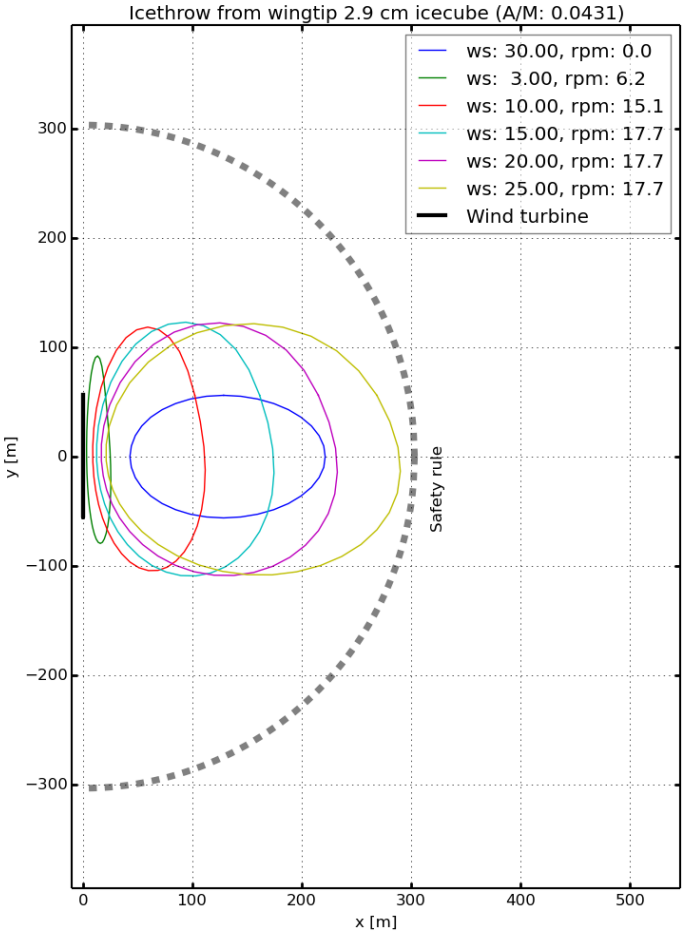
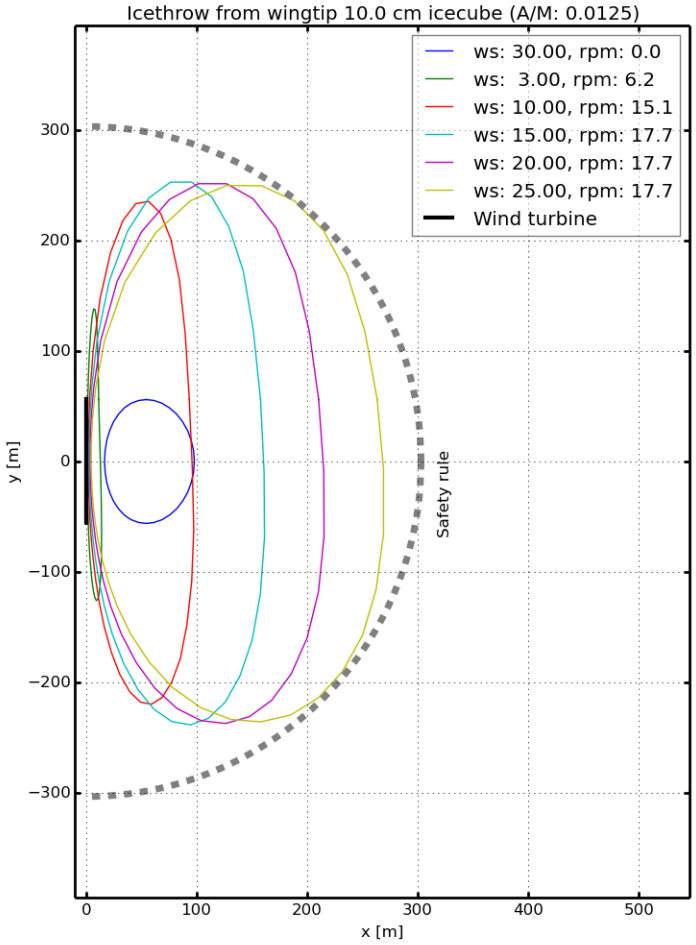
Icethrow from a turbine operating at different wind speeds (colors) landing within the danger zone (dashed grey).

Small (left) and large(right) icecubes, wind blowing from left to right.





Safety rule operating turbine: 1.5*(H+D)

rho= 800kg/m3, H=90m, D=112m

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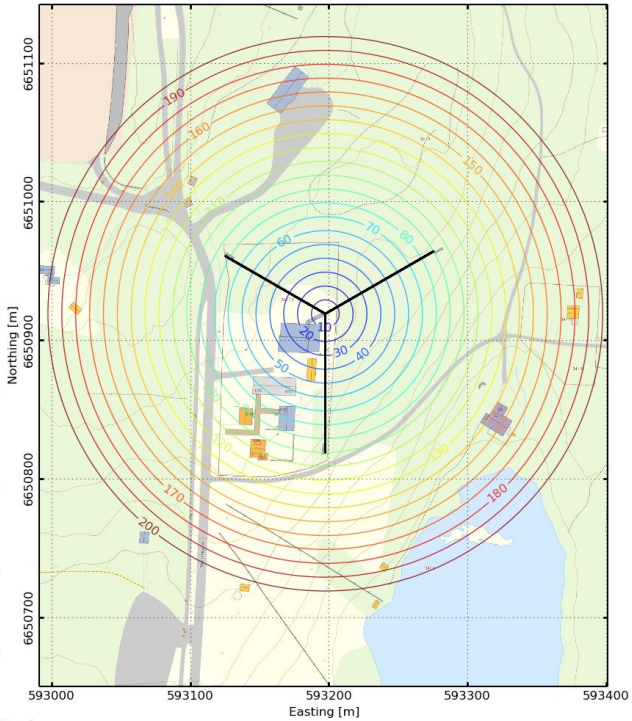
Case study: 209 m telecom mast in Oslo with public activity in the near surroundings



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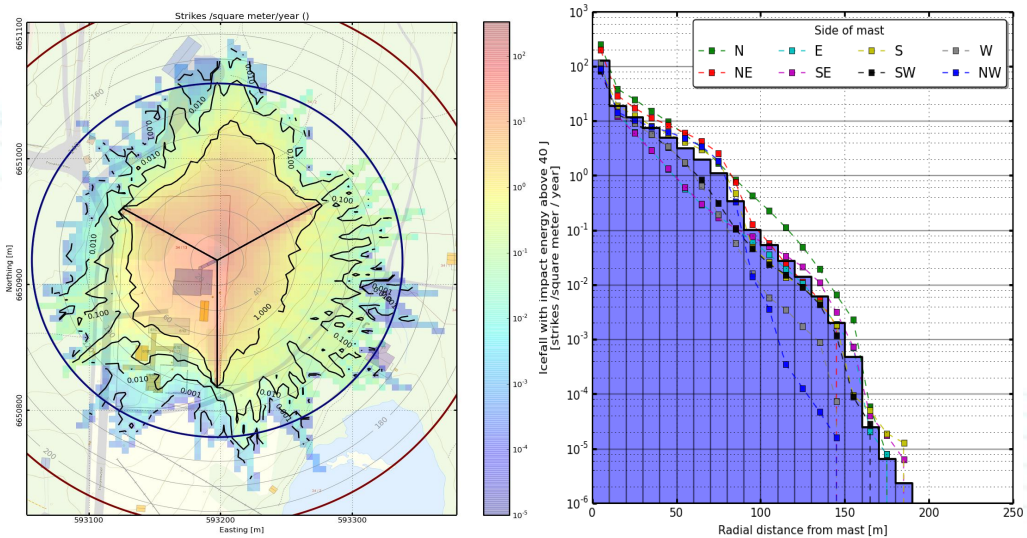
IceRisk – methodology

(results in spatial distributions and safety distances)

- **Meteorological modelling of the ice and wind condition at the site**
  - Standard body (3 cm rotating cylinder), historical data 1979-2012
- **Aggregation of ice in the construction**
  - 1 standard body for the guys
  - 5 standard bodys in lattice and top antenna
- **Statistics on wind conditions when ice is falling**
  - 90 % due to ice shedding at melting conditions, 10 % due to strong winds
- **Classification of icefall size distribution**
- **Calculation of trajectories and impact kinetic energy for each ice piece**
  - Consider ice pieces with impact kinetic energy above 40 J as dangerous
  - Combination of the statistics
- **Validation and verification**
- **Risk assessment**



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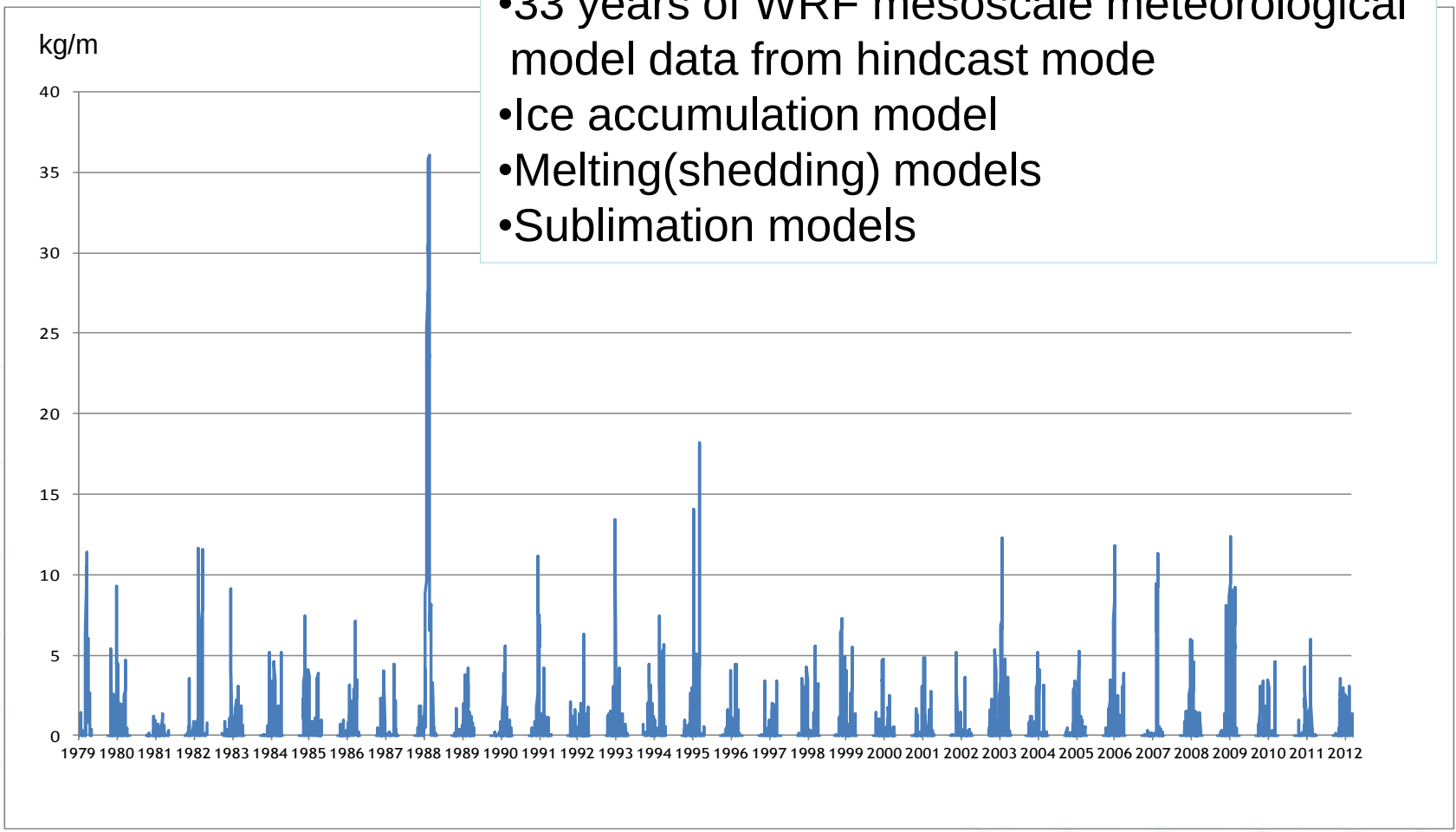
Ice weight calculations at Tryvann communication mast

- 33 years of WRF mesoscale meteorological model data from hindcast mode
- Ice accumulation model
- Melting(shedding) models
- Sublimation models



Plot of daily maximum ice weight at a standard body in the top of the mast, 209 magl. Mast ground level: 510 masl

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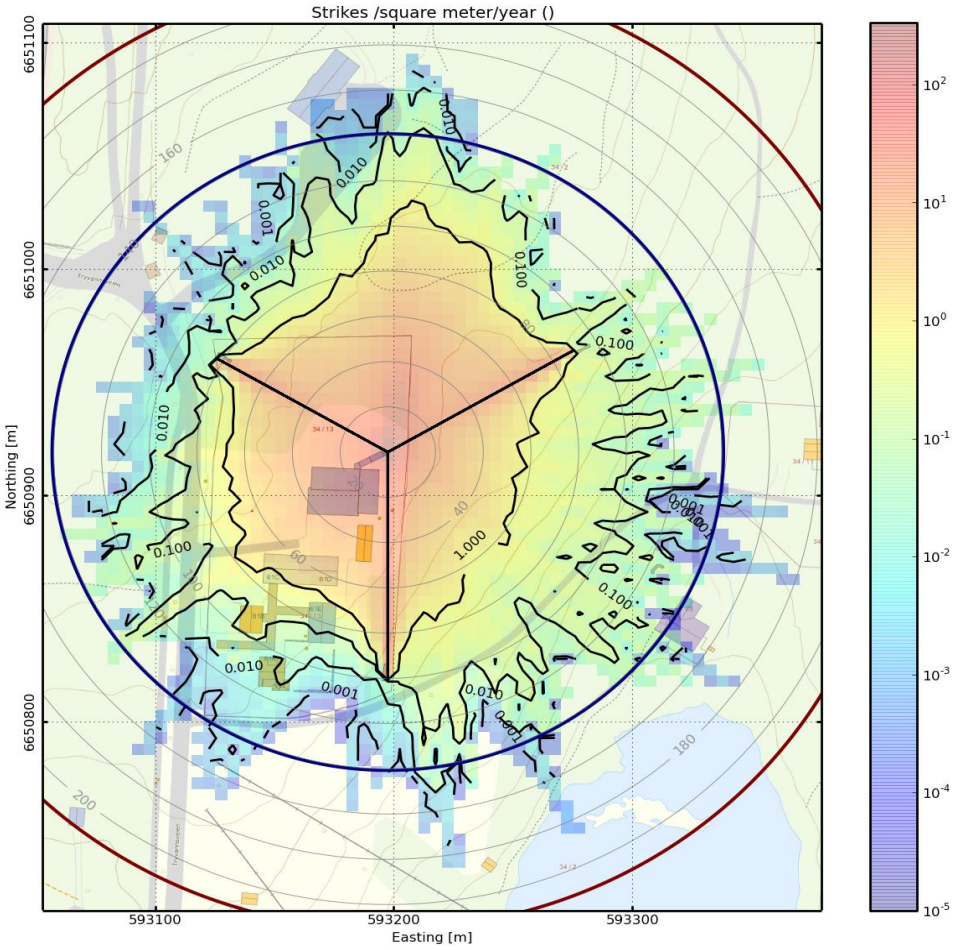
Dangerous icefall within the height of the construction (red)



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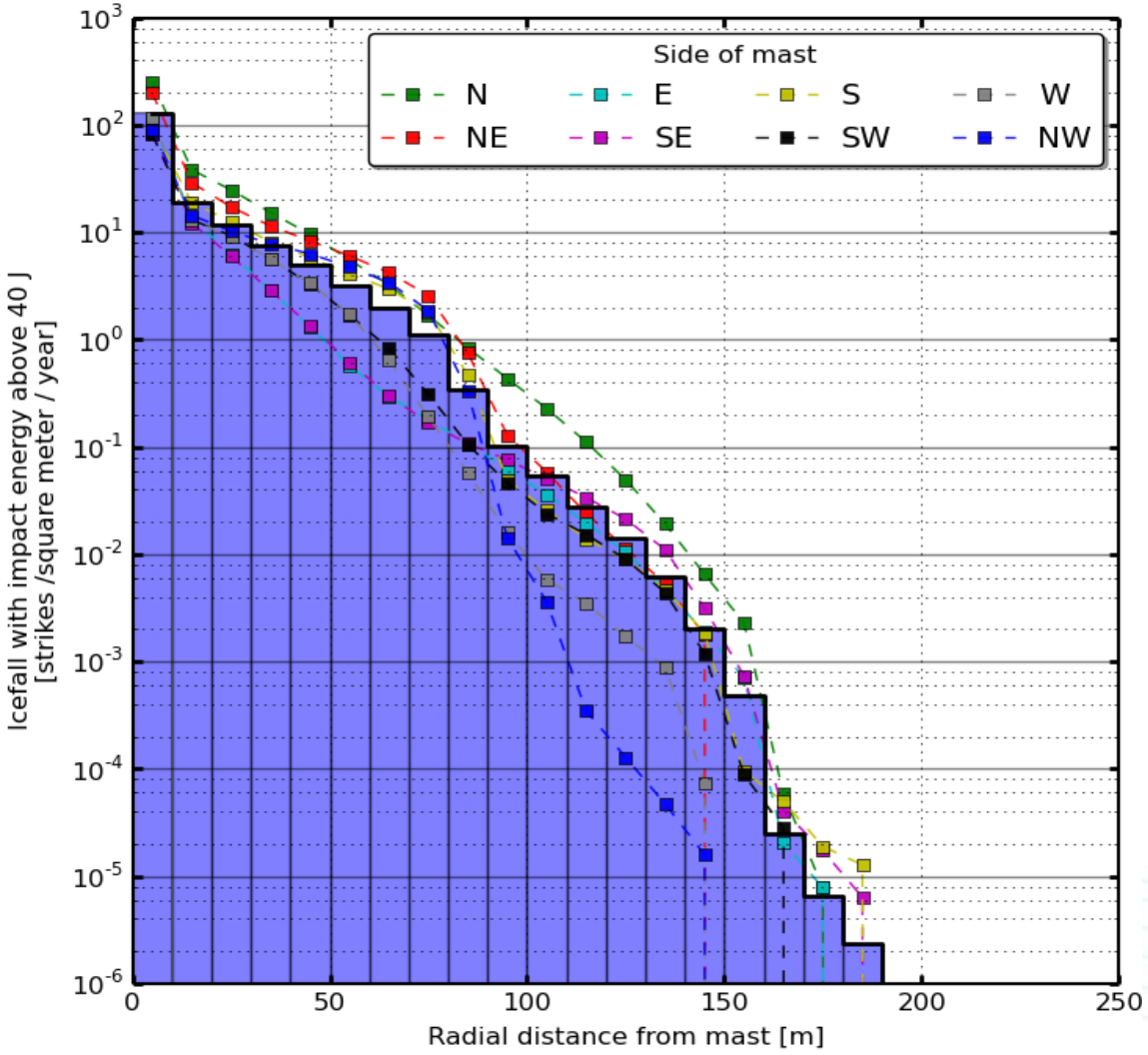
Directional distribution of dangerous ice fall



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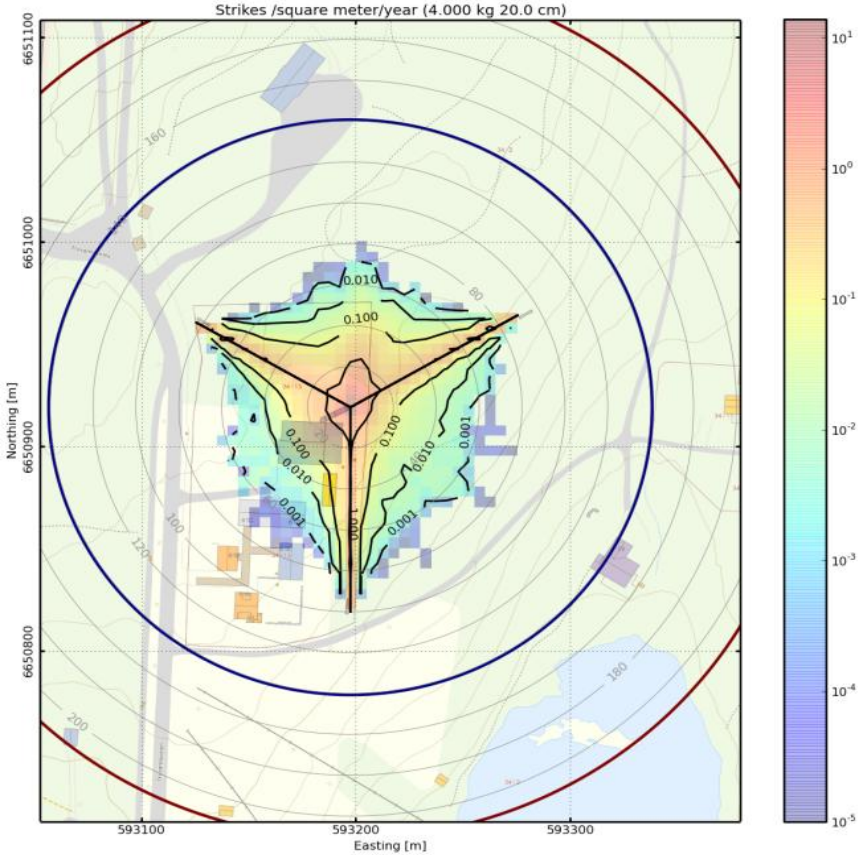
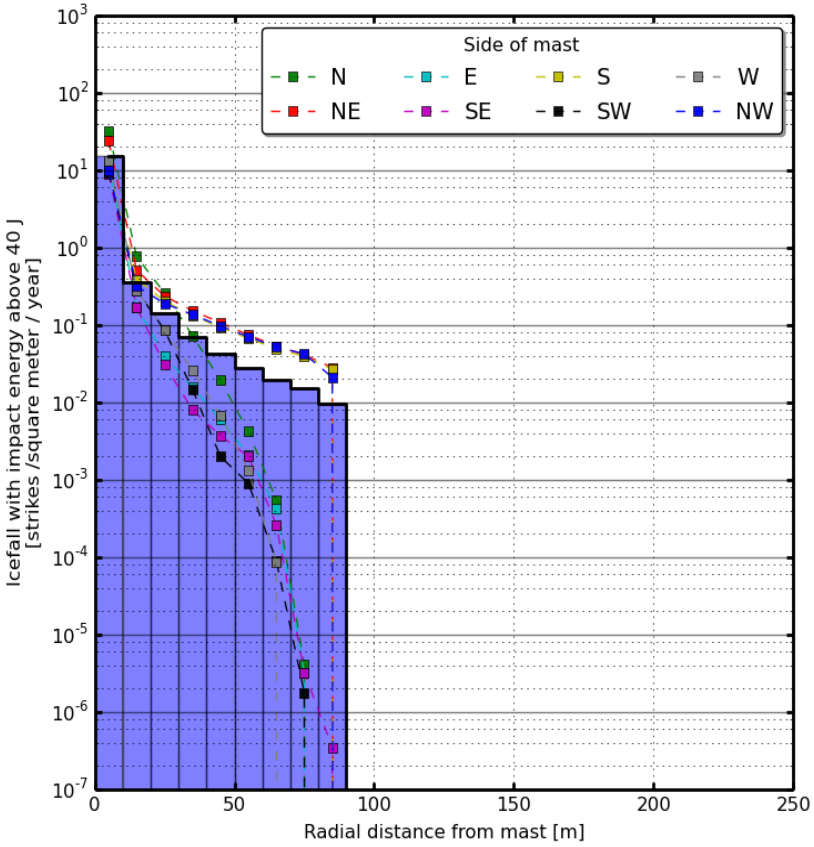
Statistics for dangerous icefall in the 20 cm icecube class (4 kg)





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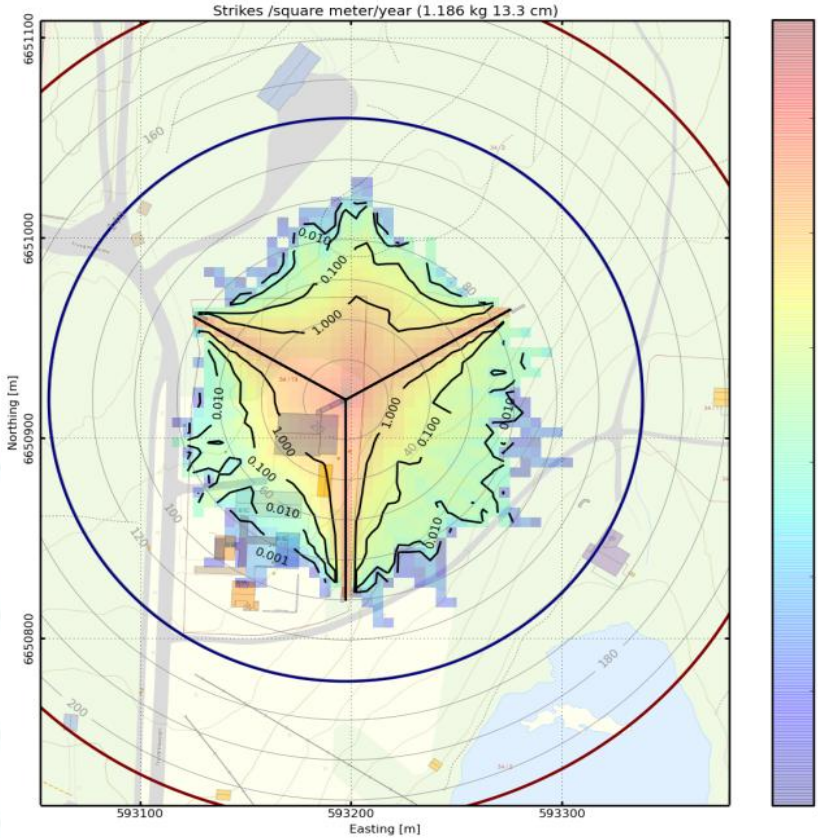
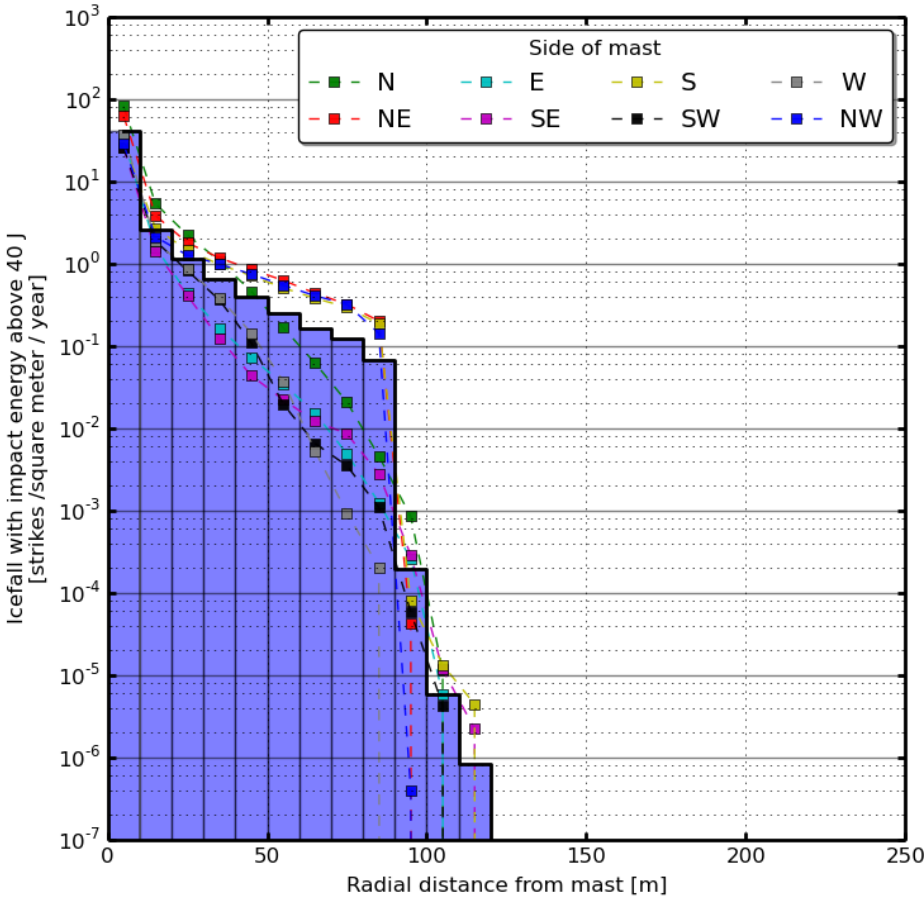
Statistics for dangerous icefall in the 13.3 cm icecube class (1.2 kg)





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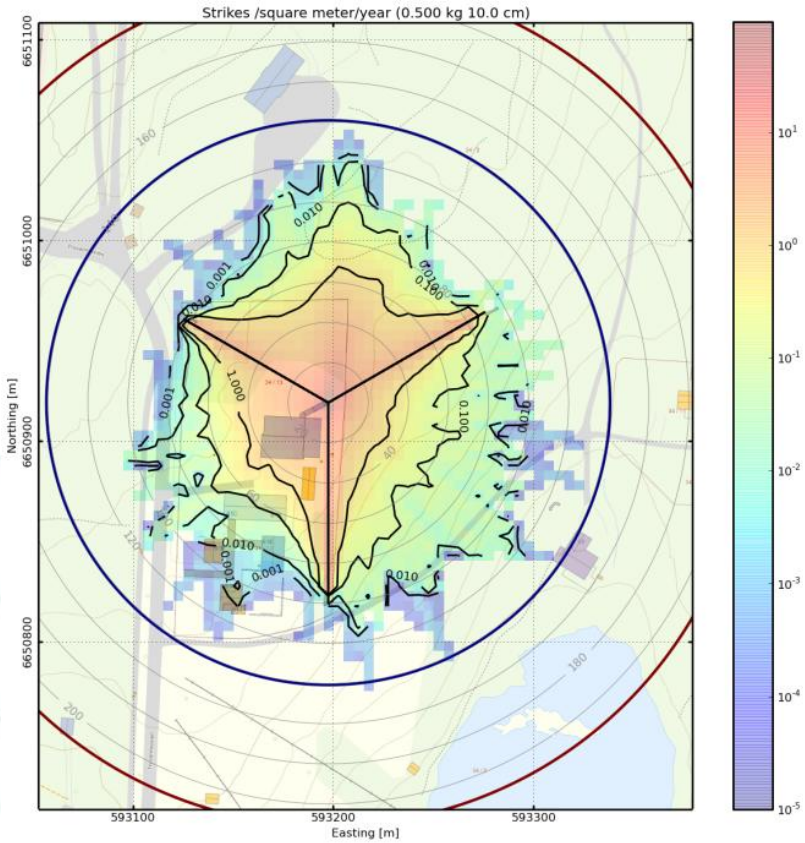
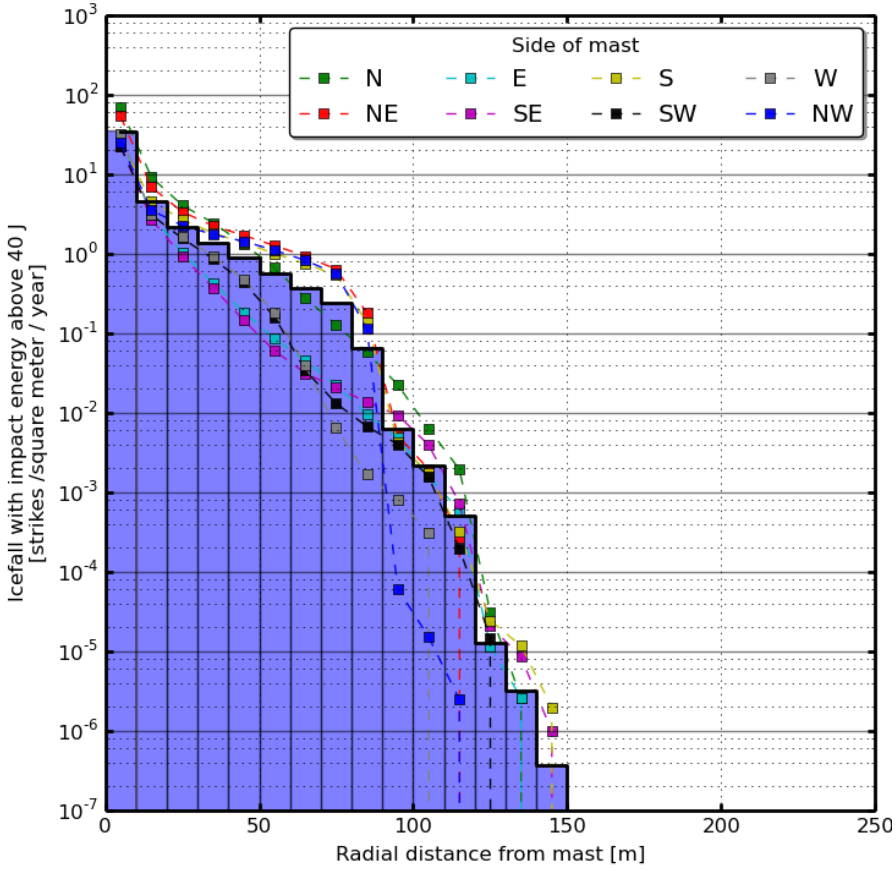
Statistics for dangerous icefall in the 10 cm ice cube class (500 g)





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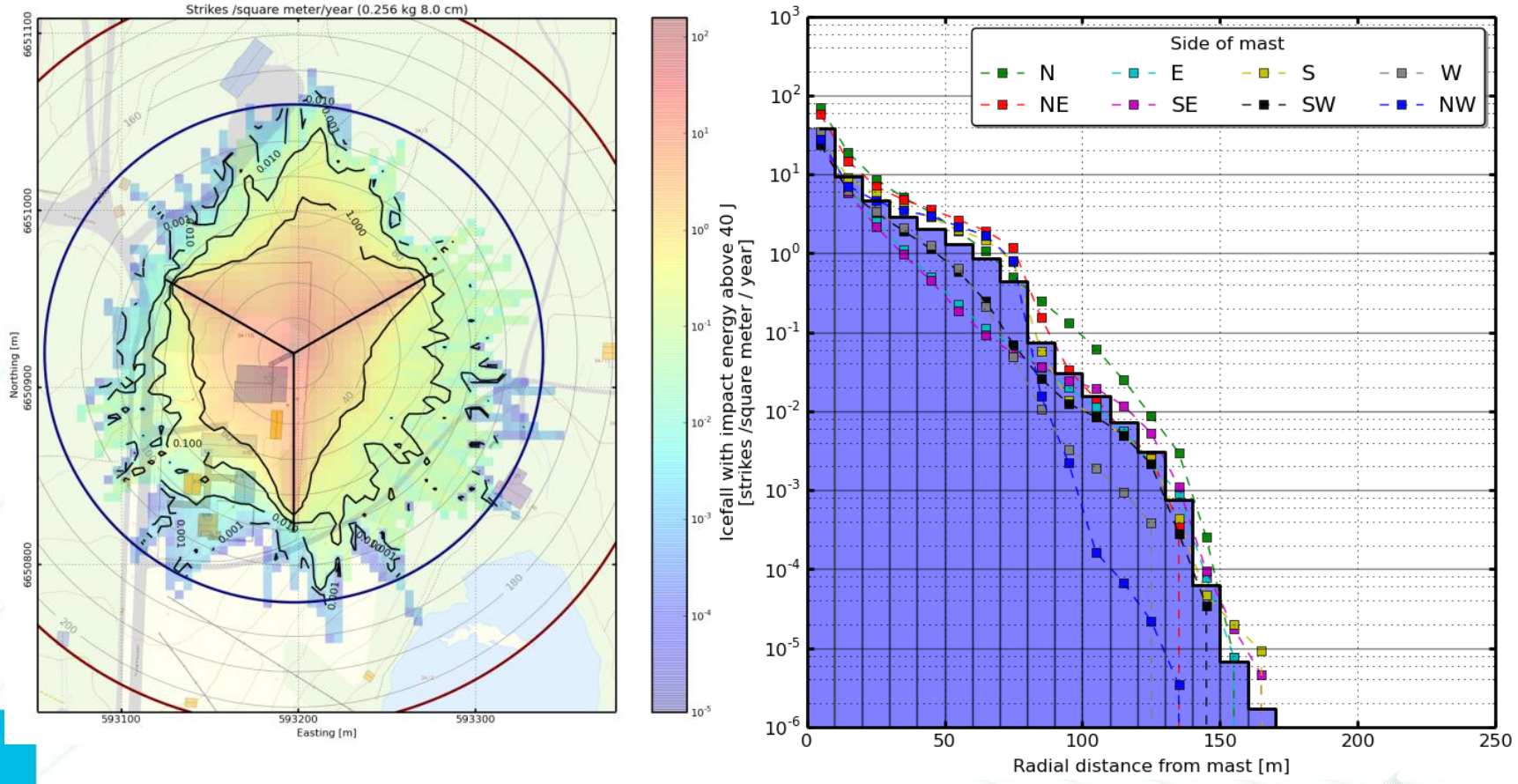
Statistics for dangerous icefall in the 8 cm ice cube class (250 g)



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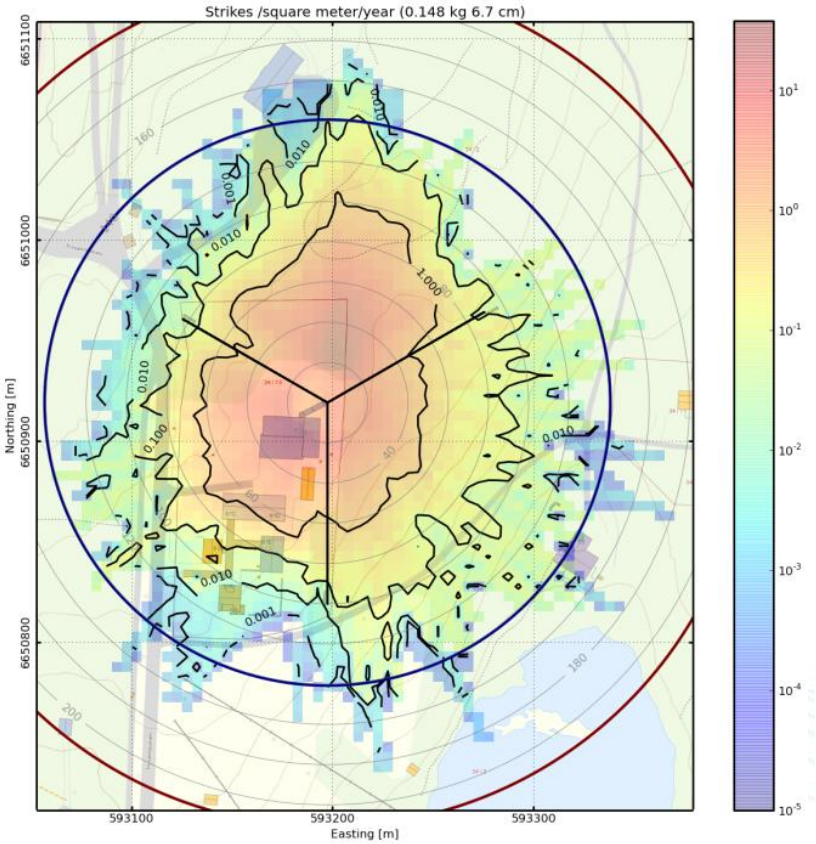
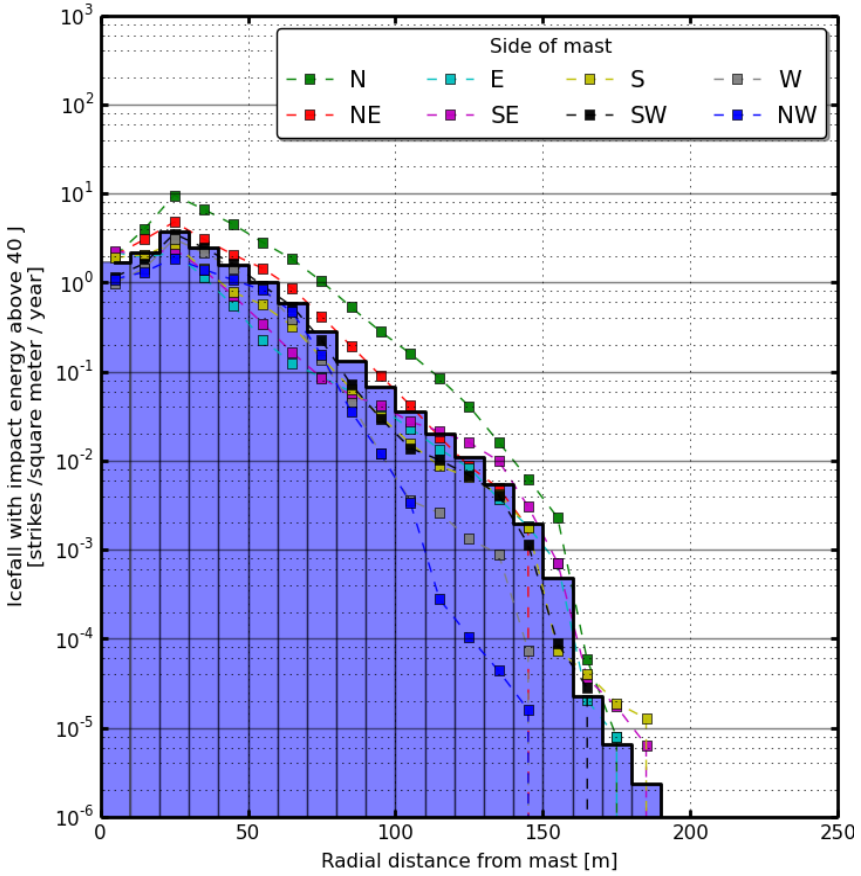
Statistics for dangerous icefall in the 6.7 cm ice cube class (150 g)





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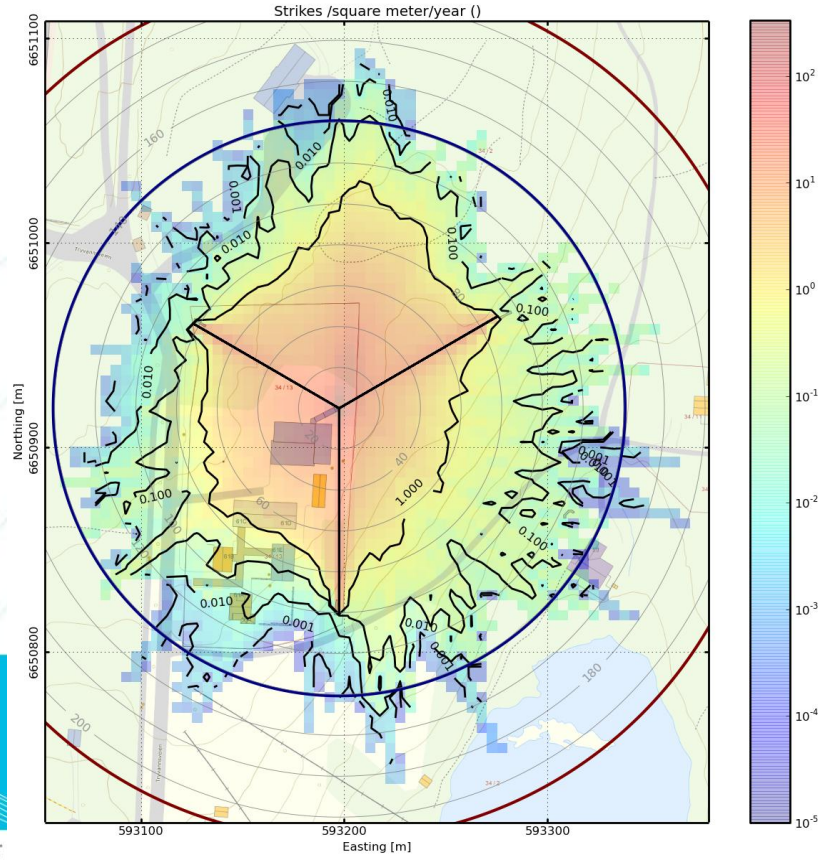
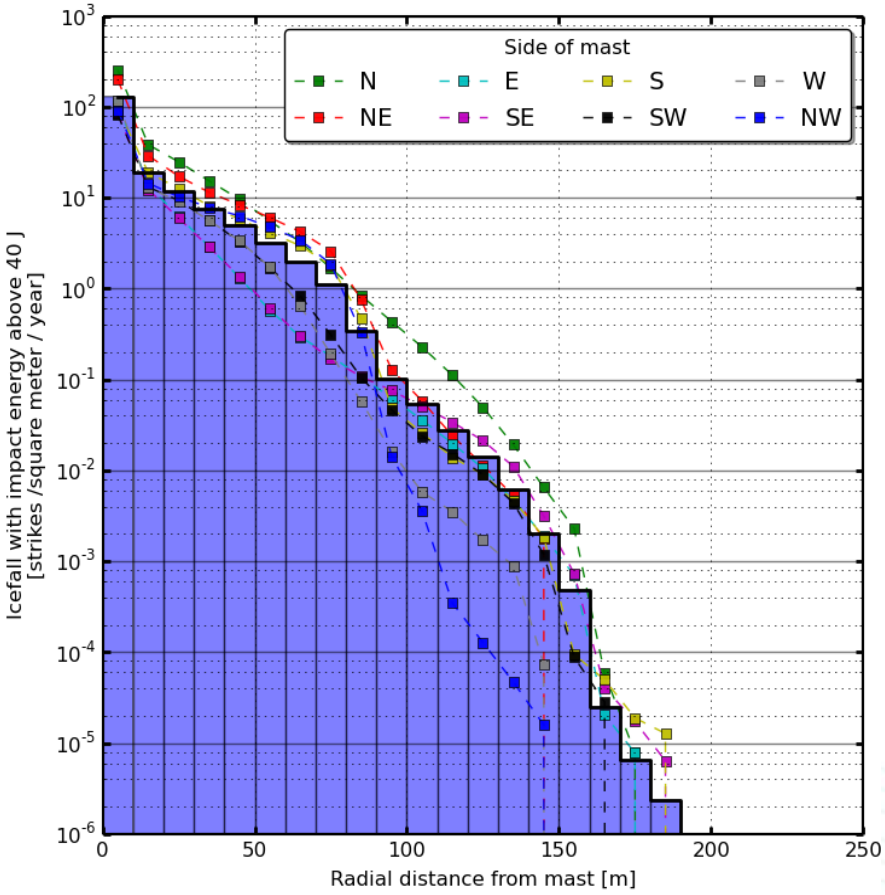
Spatial distribution and safety distances

- Ice-shedding: shorter periods with falling ice during melting conditions
- Average of 4 yearly icing episodes (4 % the year with dangerous ice amounts in the mast
- Large intra-annual variations





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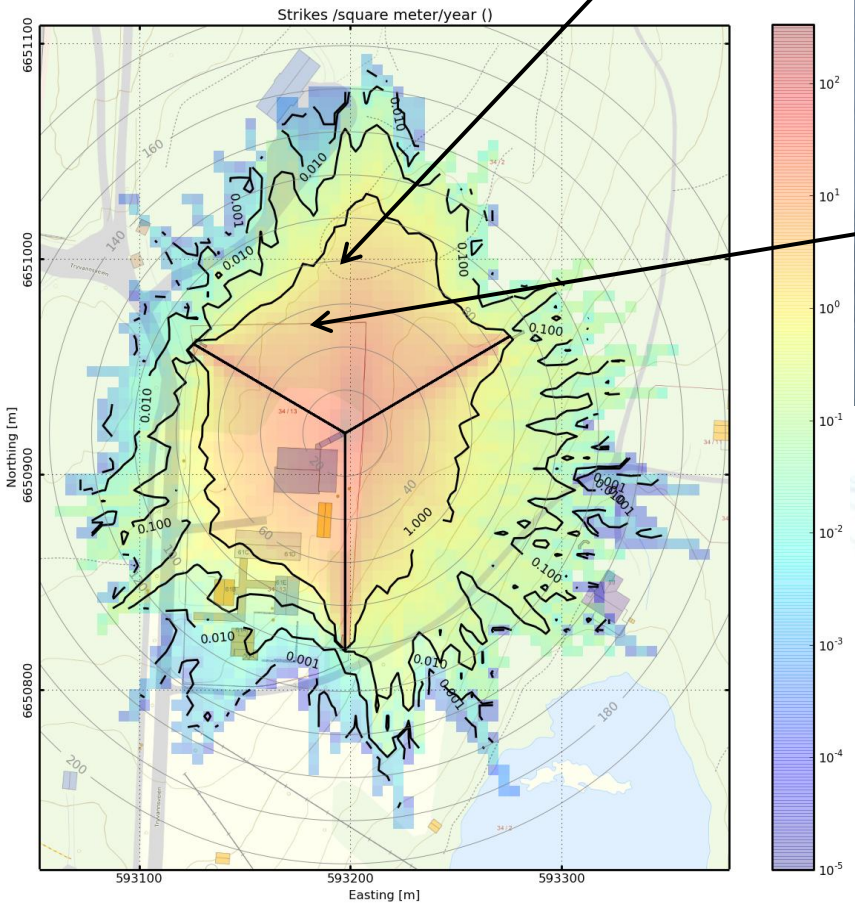
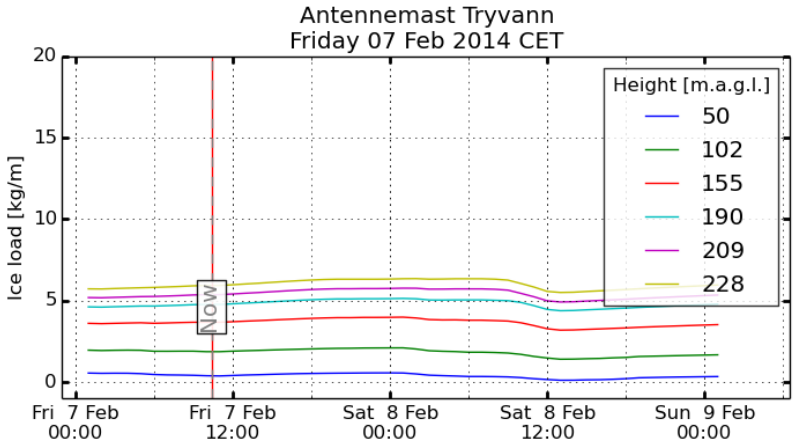
Ongoing validation work this winter





Ice piece found at 120 m distance, density above 700 kg/m3

Highest guy at 190 m

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At 55 m distance

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Suggested acceptance criteria for third person

- Acceptance criteria is given as annual probability for loss of life caused by the facility
- Based on guidelines from DSB for industrial facilities handling inflammable, reactive, pressurized or explosive substances
- Guidelines include examples of installations or activities that are allowed in different zones
- Key principle: Facility should not increase risk to public significantly compared to daily risk in society
- Personnel employed at the facility are better qualified to evaluate and take action to reduce risks, and a higher risk may therefore be excepted

Installation/ activity	DSB zone definition	Acceptance criteria
Kindergarten	Outside outer zone	$< 10^{-7}$
Café/bakery, ski lifts, houses	Outer zone	$< 10^{-6}$
Public roads, path/walkways, scattered houses	Middle zone	$< 10^{-5}$
Ski tracks, hiking areas	Inner zone (part of facility)	$< 10^{-4}$

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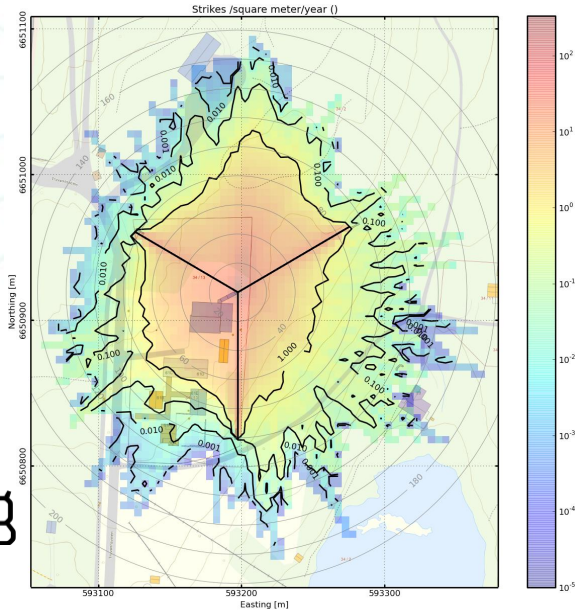
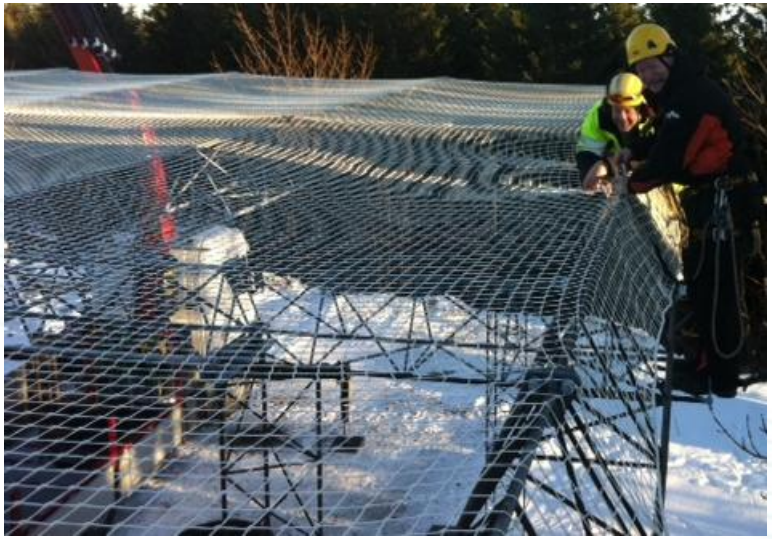
Acceptance criteria for ice risk not clearly defined, but owner is responsible for reducing risk to a minimum.

Permanent shielding structure is one measure to reduce risk





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Thank you for your attention!

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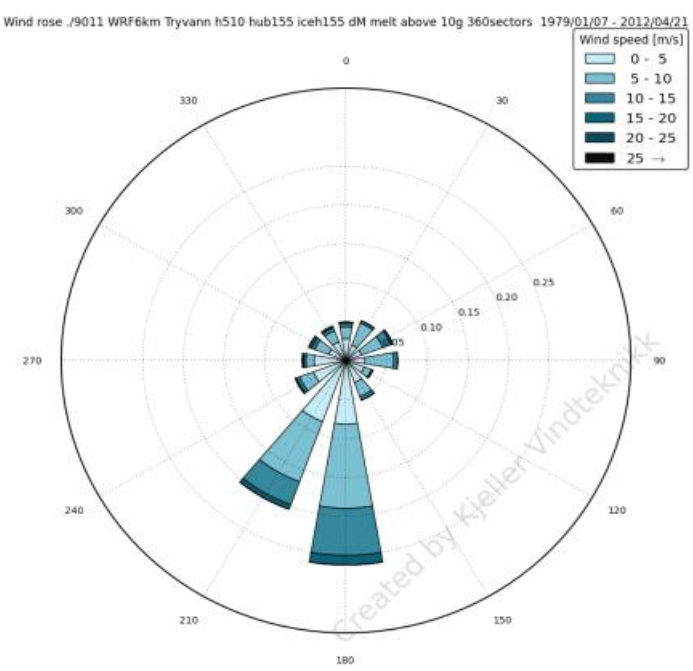
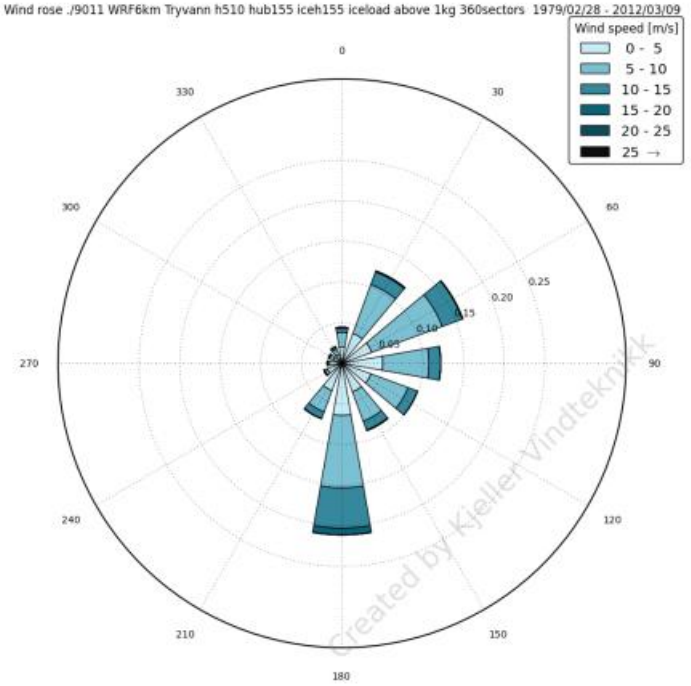
Wind conditions during melting (left) and ice present in mast (right)





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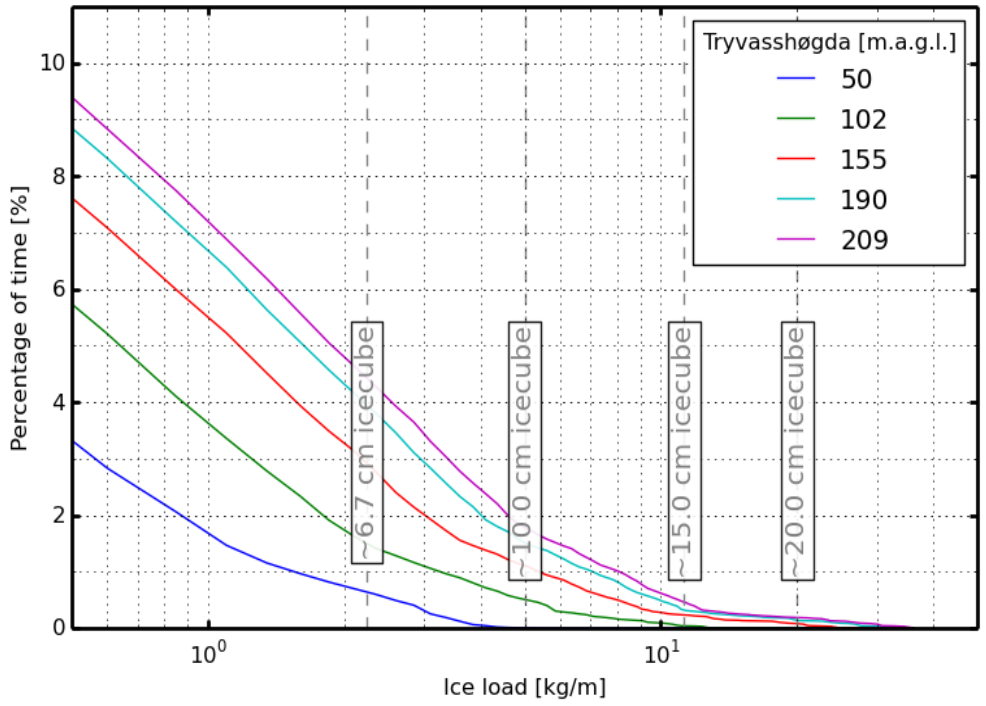
Size distribution of the dangerouse ice pieces

Dangerous icepieces (energy > 40 J) when the load is above 2 kg/m on a standard body

- Icefall with heavy ice pieces require sufficient ice load
- Distribute aggregated ice into cubes by the ice load on a standard body
- Dangerous ice pieces are present 4-5 % of the time in the construction



Icecube size [m]	Icecube weight [kg]	Ice load [kg/m]	Estimated icefall [kg/year]
0	0	0.010	9085
0.050	0.063	1.250	2416
0.057	0.093	1.633	761
0.067	0.148	2.222	**985**
0.080	0.256	3.200	**1305**
0.100	0.500	5.000	**1177**
0.133	1.185	8.889	**1453**
0.200	4.000	20.000	**654**
Sum			17837

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Statistics on dangerous icepieces

- 10 % of ice falls during conditions with aggregated ice in structure (strong wind etc.)
- 90 % of ice falls during melting conditions

- ~ **5 000 kg** with annual dangerous icefall (of 17 837 kg, energi > 40 J)
- Half of the icepieces in the **150 g class** is considered dangerous (reaches terminal veolcity)
- Maximum safety distance for a dangerous ice piece: **185 m**
- **The impact kinetic energy increases quickly with size**

Icecube size [m]	Icecube weight [kg]	Terminal velocity [m/s]	Kinetic energy at terminal velocity [J]	A/M [m^2/kg]	Maximum distance [m]	Icefall with energy>40J [cubes/year]	Icefall with energy > 40 J [kg/year]
0	0	0	0				
0.050	0.063	20.0	13	0.040	220		
0.057	0.093	21.4	21	0.035	203		
0.067	0.148	23.1	40	0.030	185	2723	404
0.080	0.256	25.3	82	0.025	164	4631	1186
0.100	0.500	28.3	200	0.020	141	2251	1126
0.133	1.185	32.7	633	0.015	114	1205	1429
0.200	4.000	40.0	3203	0.010	88	162	646
Sum						**10972**	**4790**

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Risk Evaluation by Lloyd's Register Consulting

- Acceptance criteria for ice risk not clearly defined, but owner is responsible for reducing risk to a minimum
- Suggested acceptance criteria for third person
- Risk evaluation for site
- Possible risk reducing measures for personnel permanent at site
- Possible risk reducing measures for third person

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Consequences of icefall can be fatal

icepieces with **impact kinetic energy above 40 Joule** assumed fatal

Weight of ice fragment	Type of injury	Damage potential from ice throw/fall
< 0.1 kg	Cutting injuries for sharp fragments with velocity >65 m/s	None
0.1 kg – 4.5 kg	Damages to body due to energy of impact	40-60 J: Serious injuries to forehead >79 J: Serious injury to human body

- Data from studies of industrial helmets and impact of debris from explosions
- Ice fall assumed to be fatal if weight of fragment > 0.1 kg and energy of impact > 40J
- Fatality criteria per square meter: 1/(0.5mx0.2m) = 10% fatality per icefall within 1 m^2

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abstract

- When ice that has built up on a turbine blade is released it can be thrown hundreds of meters in the worst cases. The piece of ice may hit people, animals or property around the turbine and consequently cause severe damage.
- IceRisk is a state-of-the-art method for assessing the risk related to ice throw and ice fall from turbines or other tall structures such as met- and telecom- masts. The ice throw risk zones and safety distances calculated with IceRisk can give useful information in the process of licensing of a wind farm project, development of preventive measures and routines for the personnel that will work in the wind farm during winter. The method has been utilized on large telecom masts and wind farms with public activity in the surroundings. The results are presented as maps showing how the probability for ice impact varies within the wind farm. The results are also supplemented with a damage risk evaluation which is performed in cooperation with Lloyd's Register Consulting.
- IceRisk calculates the impact position and impact energy of the ice pieces released from different positions on the blades. Heavier ice pieces can be thrown further than light pieces, but light pieces may drift larger distances in strong winds. The degree of danger associated with being hit by an ice piece depends mostly on the impact kinetic energy and the consistence of the ice piece.
- IceRisk have been used to assess the risks related to ice falling from a 209 m telecom mast at Tryvann, Oslo. Ice cubes (rime ice) with a weight of more than 150 g falling from the mast was considered dangerous as the impact energy can exceed 40 Joules.
- The IceRisk model is linked to a hindcast archive with timeseries of meteorological parameters such as icing, wind speed, wind direction and temperature from the last 33 years. This archive was used to define the periods of icing and the associated ice loads in the structure. In 4-5 % of the time (year) dangerous ice pieces could fall from the telecom mast. There are large variations from winter to winter but on average there are 4 yearly episodes with dangerous ice in the mast. The furthest drift distance was found from the model to be less than the height of the construction. Ice loads are forecasted with an operational forecast model during the winter 2013-2014, and systematic registration of ice fall will be performed during the season.

Results from IceRisk projects for wind farms have also been used to consider the risk on nearby roads and ski tracks.

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