Experimental Investigation of Risk from Ice Shed and Ice Throw

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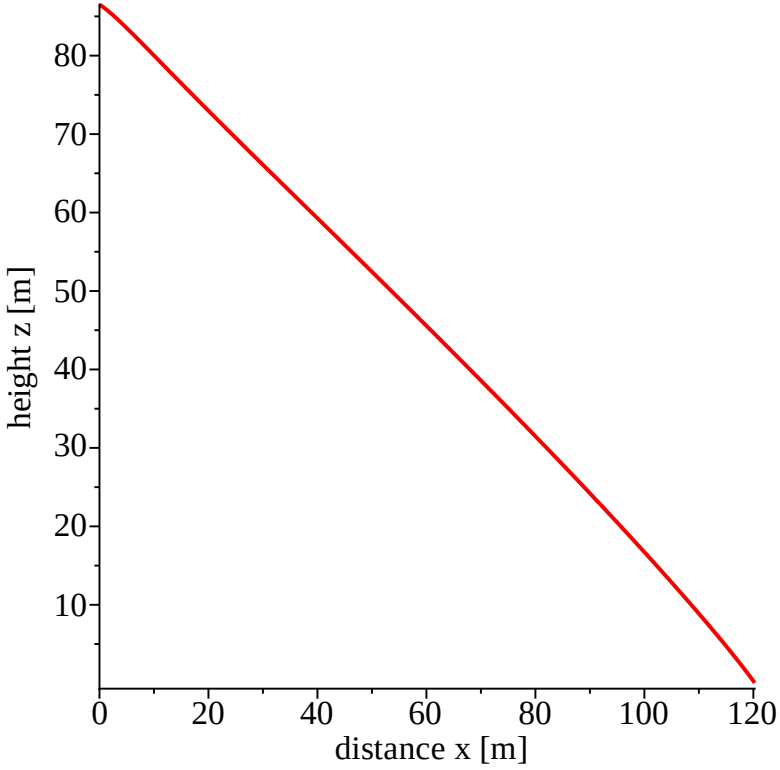
Overview

- Motivation
- Methodolgy
- Results
- Outlook

Formulas for estimation of ice throw distances

- Equations of motion:
- $m\ddot{x} = -\frac{1}{2}\rho A c_D v_{rel}(\dot{x} - v_w)$
- $m\ddot{z} = -mg - \frac{1}{2}\rho A c_D v_{rel}\dot{z}$
- $v_w = \frac{v_*}{k}\ln\frac{z+z_0}{z_0}$ (wind profile)

- For ice shed ($\dot{x}(t=0) = 0$) almost linear



Collected ice fragments from monitoring

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3D scans of collected fragments

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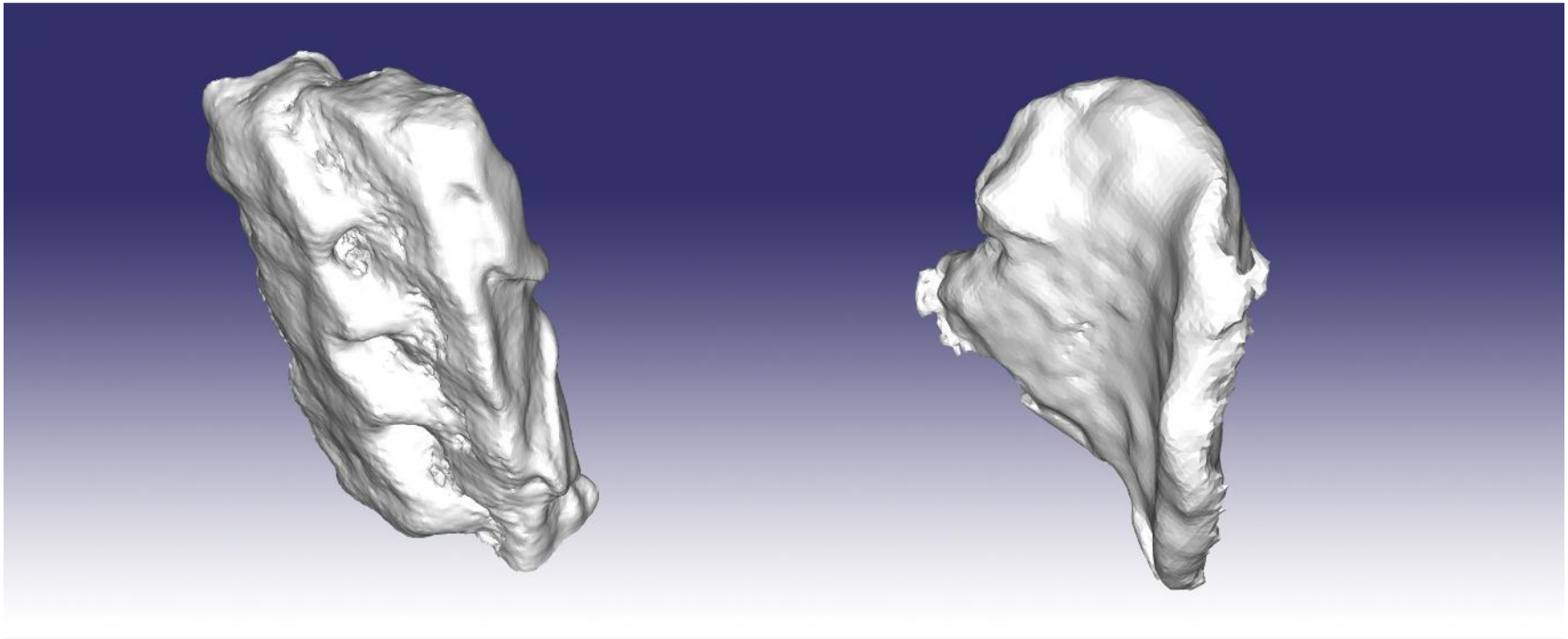

Samples - simplification

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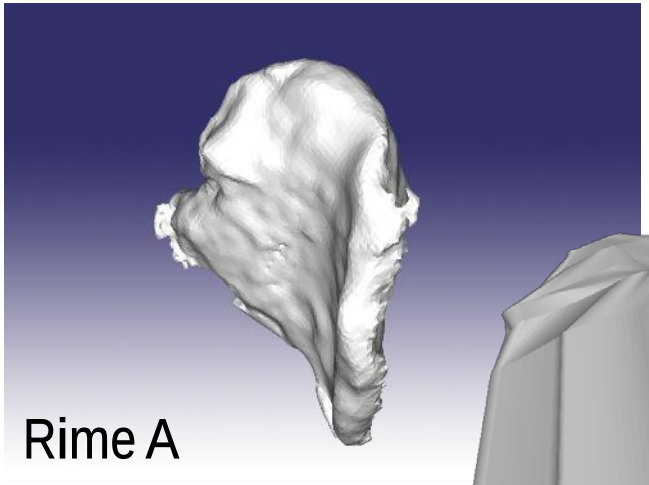

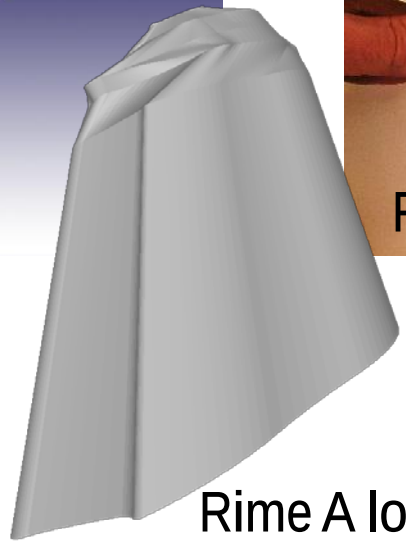

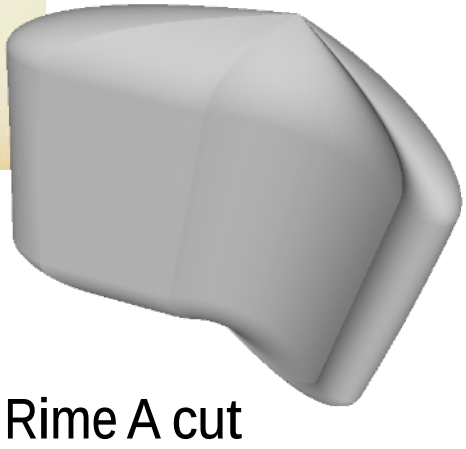

Samples - simplification

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Clear Ice A5 curved

Clear Ice A5 flat

Overview of clear ice specimens

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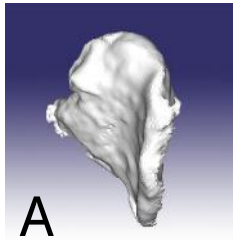
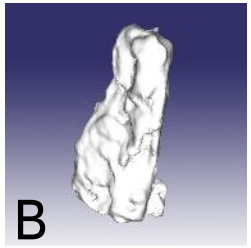
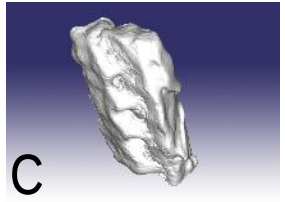
Name	Size [cm]	Mass [g]	Quantity
Clear Ice A5 flat	15x10x1	200	10
Clear Ice A5 curved	15x10x1	200	10
Clear Ice A4 flat	20x30x1	400	10
Clear Ice A4 curved	20x30x0.5	200	10

Name	Variations	Mass [g]	Quantity/Variation
Rime A	4	200	1
Rime B	2	220	2
Rime C	2	400	10







Experimental setup

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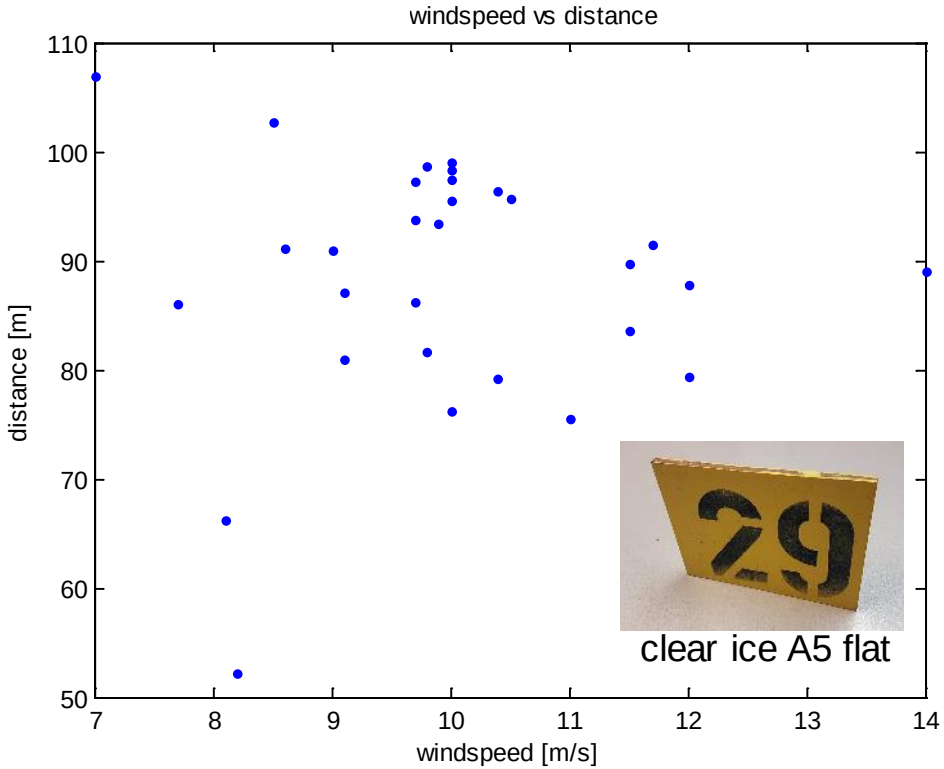
Correlation wind speed - distance



- $\rho = 0.012$
- → No correlation

- Low resolution of wind measurement

Exemplary distribution of specimens

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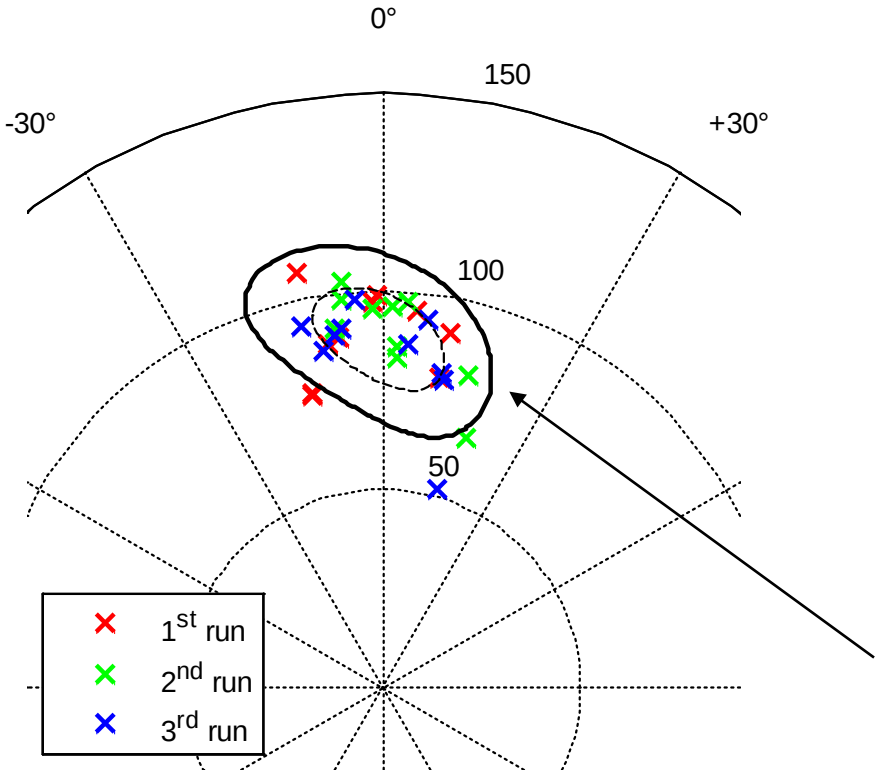
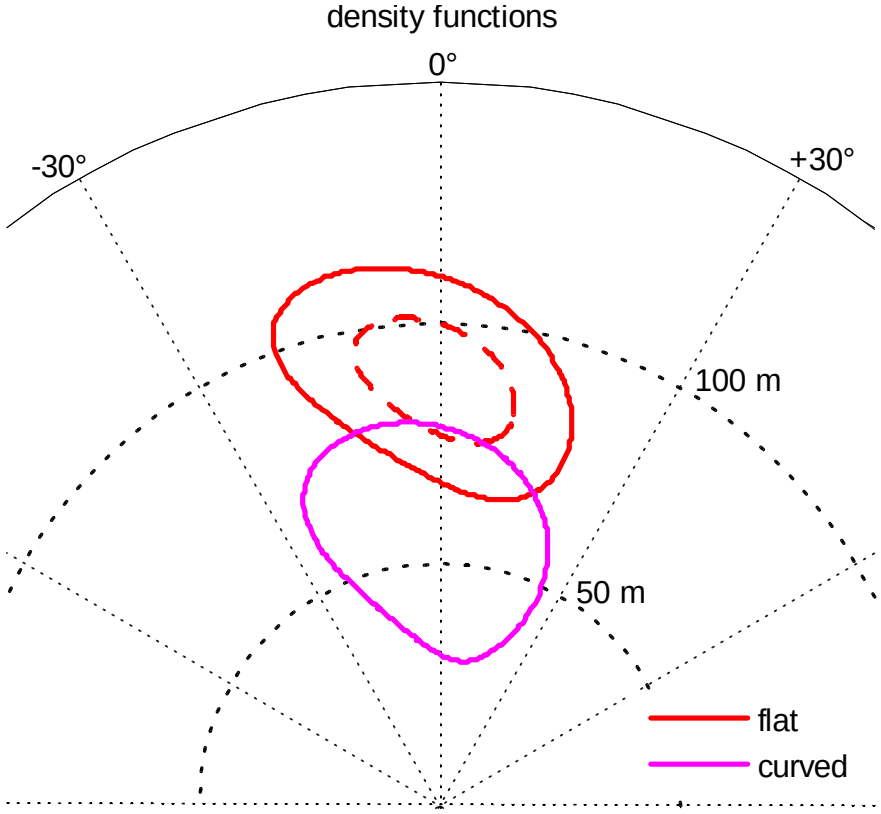


Isolines for fitted 2D normal distribution

Distances clear ice A5 flat and curved



Area to mass ratio

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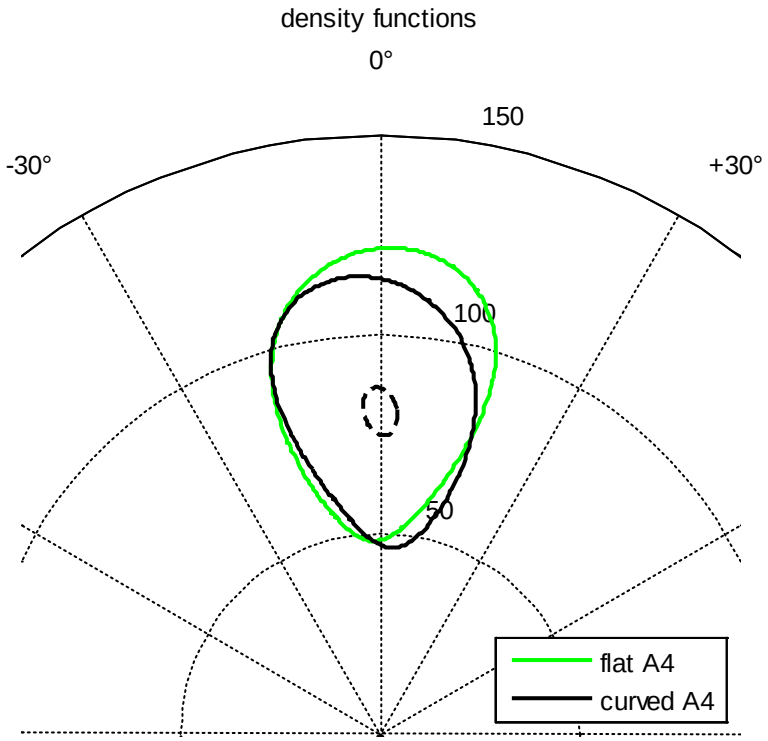
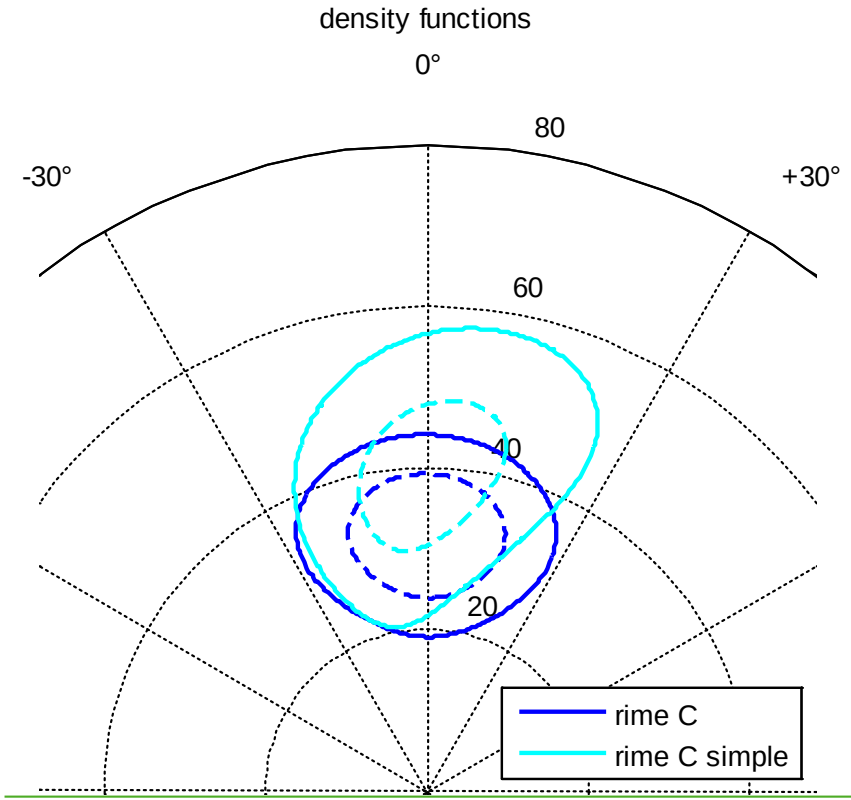
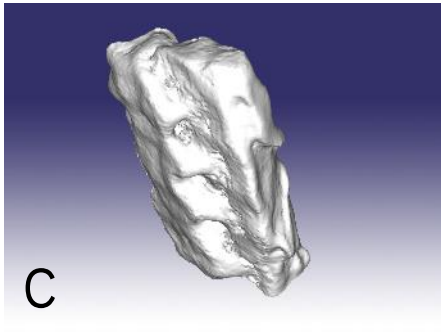
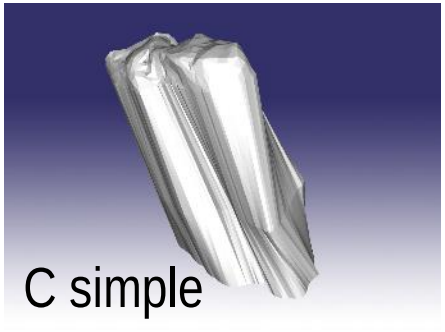


Area to mass ratios		
	flat	curved
A5	0.13	0.08
A4	0.13	0.15

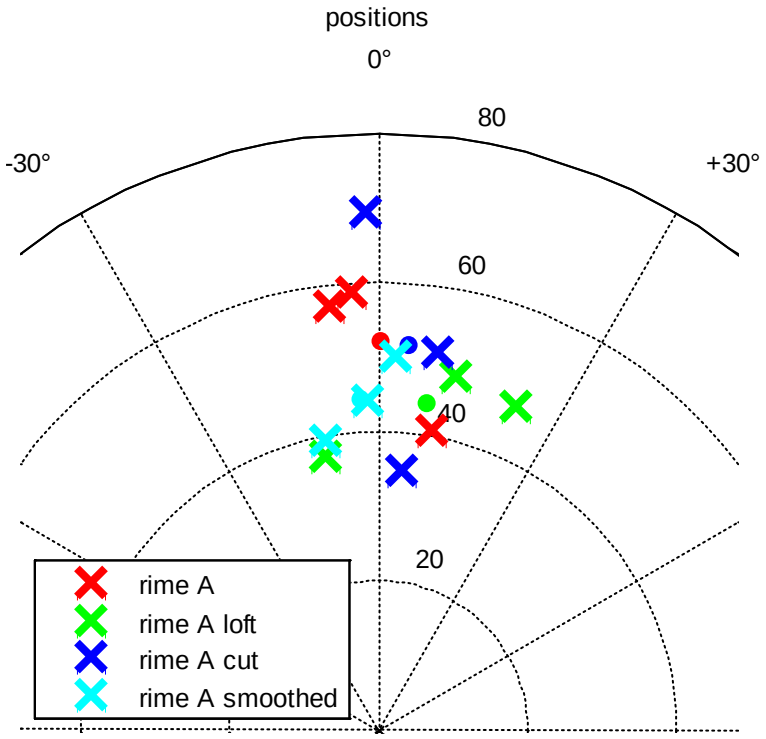
Rime C distances

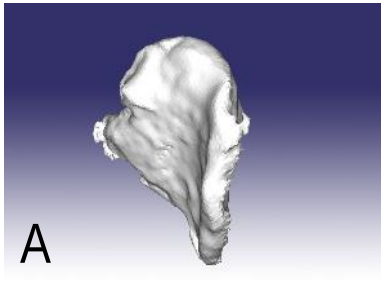


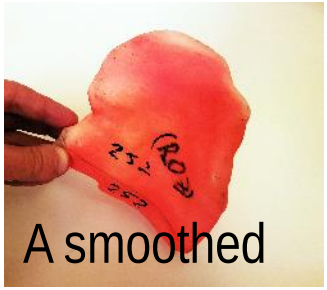


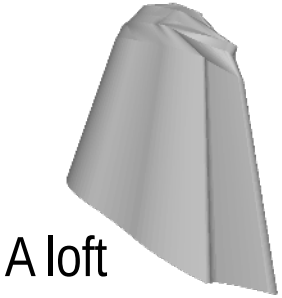


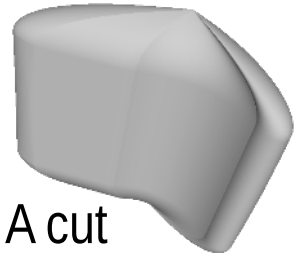
Rime A distances











Comparison of experimental distances with ice throw calculations

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	measured mean	calculated	difference
clear ice A5 flat	88.3	87.7	-0.7%
clear ice A5 curved	54.9	68.2	24.2%
clear ice A4 flat	85.1	132.0	55.1%
clear ice A4 curved	80.7	63.4	-21.4%
rime ice A	48.3	74.2	53.6%
rime ice B	43.9	60.2	37.1%
rime ice C	31.6	42.6	34.8%
rime ice C simple	39.1	50.7	29.7%

Comparison of experimental distances with ice throw calculations

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	measured max	calculated	difference
clear ice A5 flat	106.9	87.7	-18.0%
clear ice A5 curved	85.1	68.2	-19.9%
clear ice A4 flat	134.6	132.0	-1.9%
clear ice A4 curved	115.7	63.4	-45.2%
rime ice A	69.8	74.2	6.3%
rime ice B	56.7	60.2	6.2%
rime ice C	45.5	42.6	-6.4%
rime ice C simple	55.1	50.7	-8.0%

Monitoring of actual ice shed

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Exemplary trajectory of an ice fragment from monitoring

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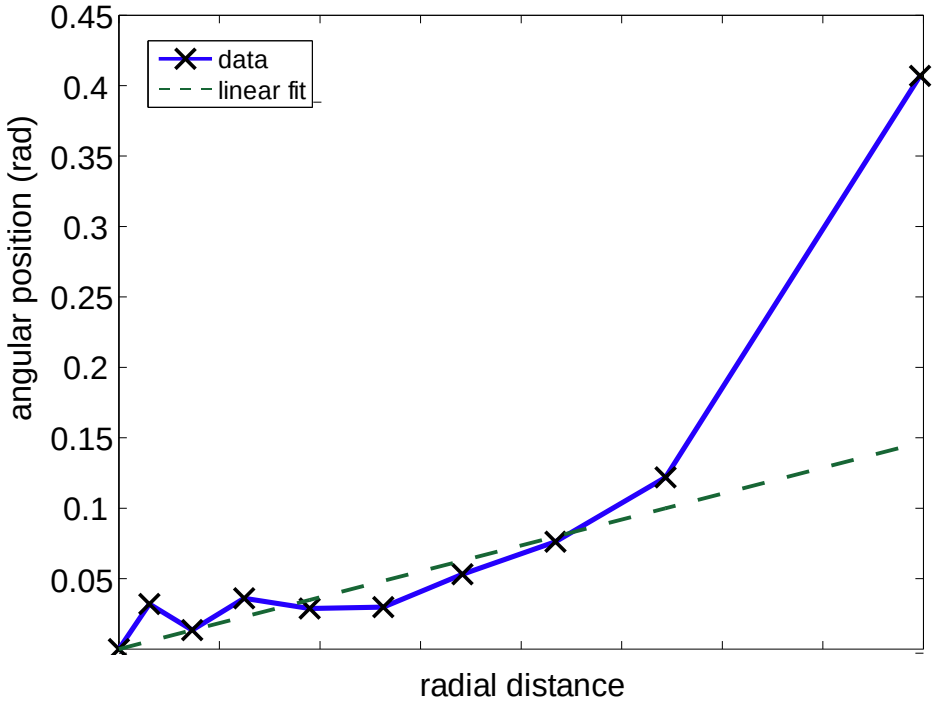

Exemplary trajectory of an ice fragment from monitoring (distance vs height)

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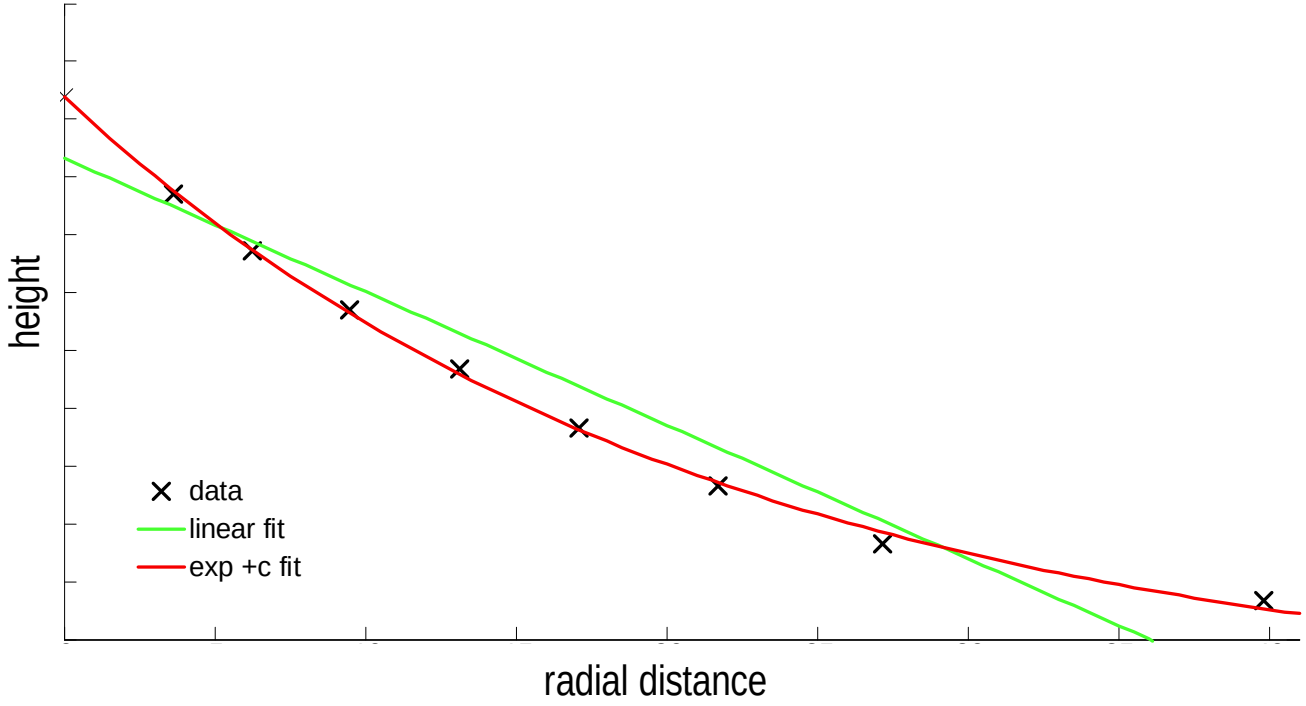

Conclusions

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- Rime ice specimen behavior yet inconclusive
- Clear ice shed distances higher than expected – lift forces a possible explanation
- Ice shed a special case of ice throw

- Existing equations underestimate some situations – possible safety implications?

Outlook

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- Experiments with larger rime ice specimen useful
- Trajectories from experiments
- More information on size of fragments and occurrence necessary for safety assessments
- Experiments for ice throw from small wind turbines are in preparation

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Thank you for your attention!

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