A model of the weathering crust and microbial activity on an ice-sheet surface

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Work done with Ian Hewitt

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What is the weathering crust?

EGU Blogs/Eva Doting

The weathering crust is important because it...
- transports meltwater
- affects the surface albedo
- is home to microbes

Step 1: understand the weathering crust **structure**.

How does the weathering crust respond to **changing weather conditions**?

What effect do **microbes** have on the weathering crust and melting?

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Weathering crust structure

Structure

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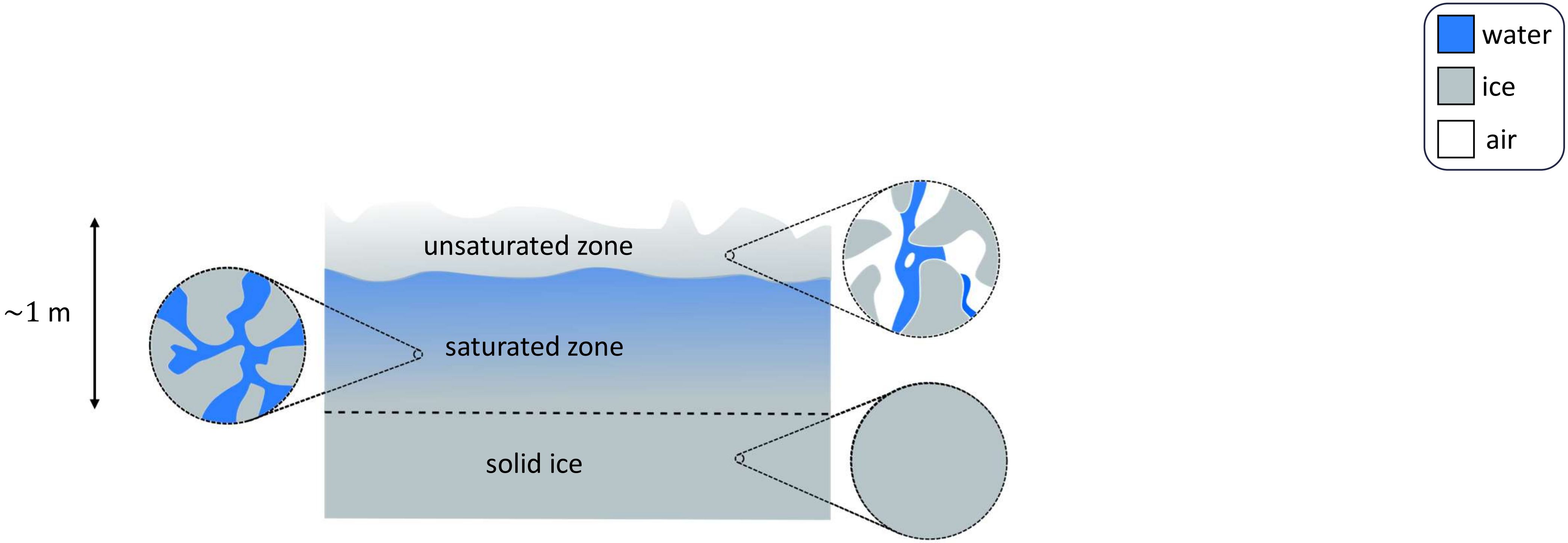
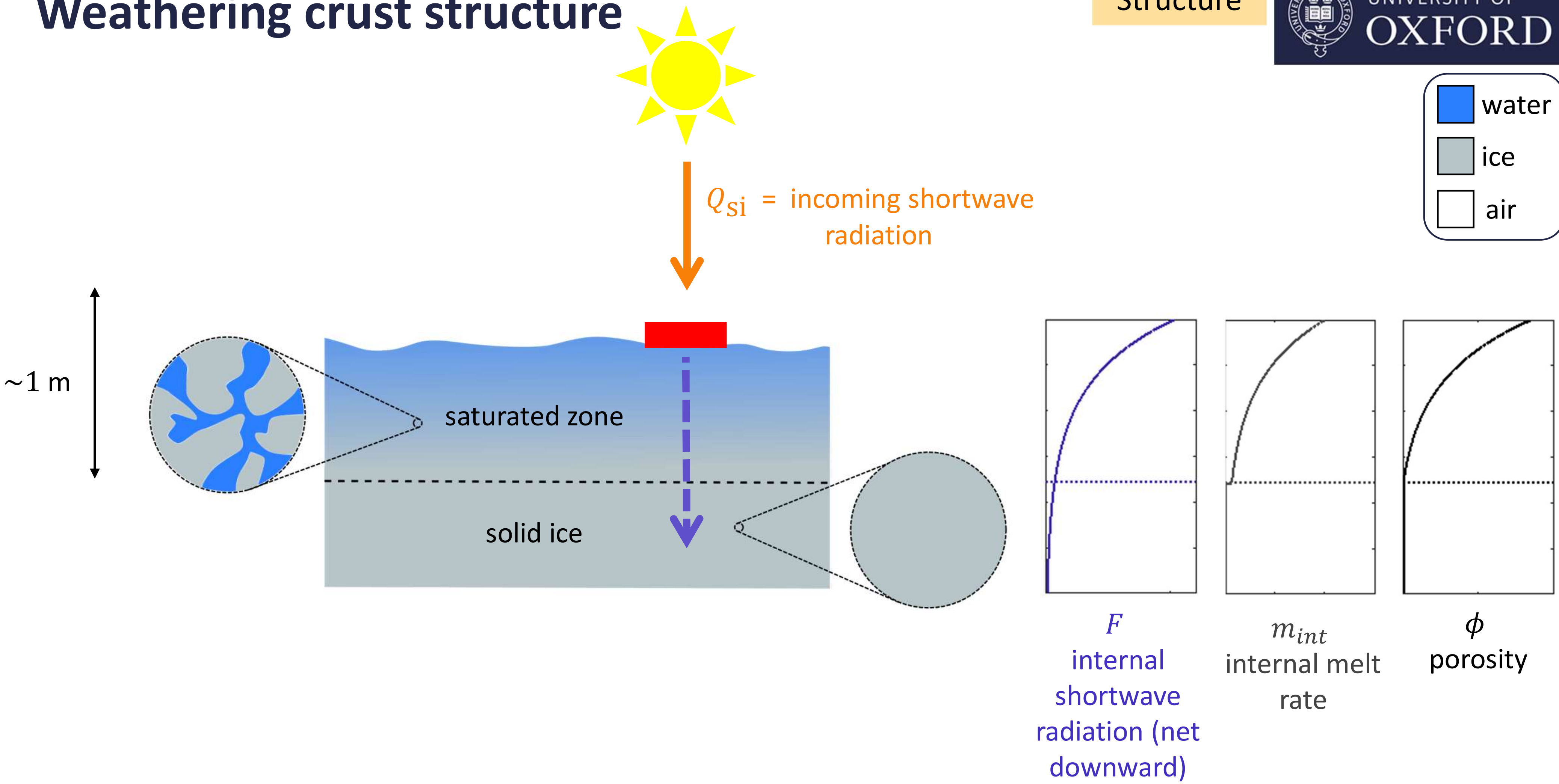


Weathering crust structure

Structure



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Weathering crust structure

Structure

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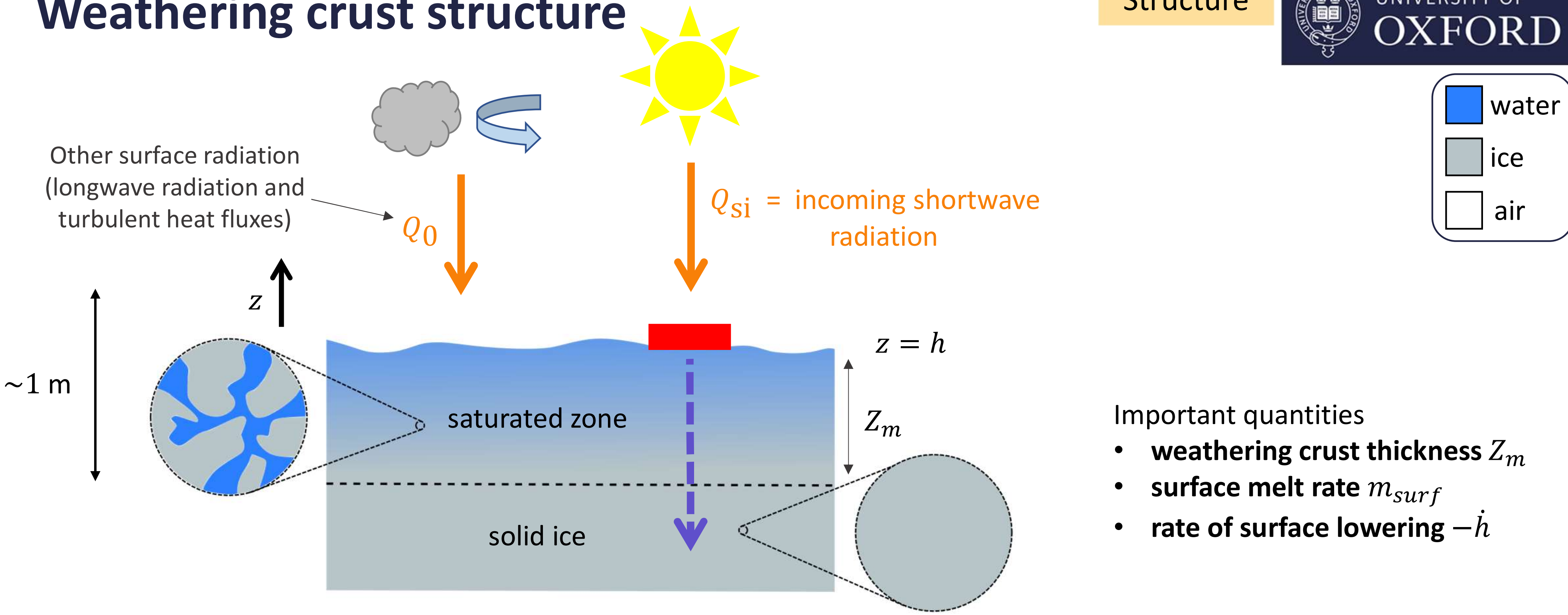

Important quantities

- **weathering crust thickness** Z_m
- **surface melt rate** m_{surf}
- **rate of surface lowering** $-\dot{h}$

Surface energy balance:

$$-k\frac{\partial T}{\partial z} + \chi(1-a)Q_{\text{si}} + Q_0 - \nu(T - T_{\text{m}}) = \rho\mathcal{L}m_{\text{surf}} \quad \text{at} \quad z = h$$

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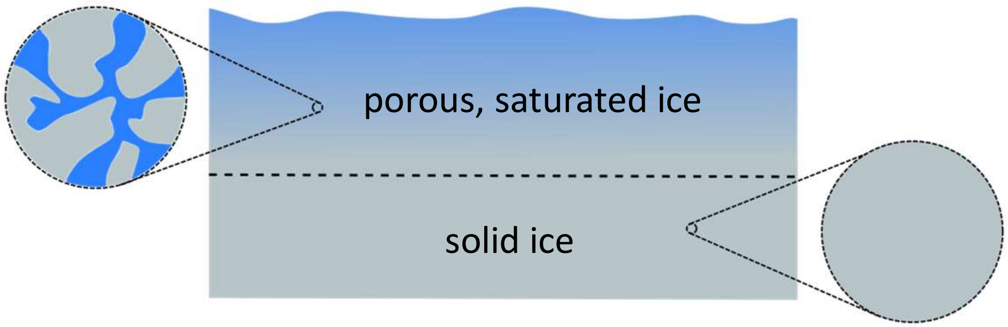
A 1D mathematical model

Structure



Thermodynamics

- Mass conservation
- Energy conservation
- Internal and surface absorbed radiation

How does the weathering crust respond to **changing weather conditions**?

Woods, T. and Hewitt, I. J.: *A model of the weathering crust and microbial activity on an ice-sheet surface*, EGUsphere [preprint], 2022

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Steadily melting solutions

Structure

Response to weather

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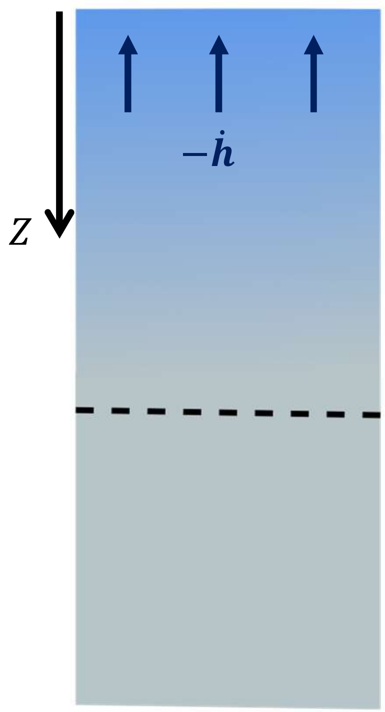

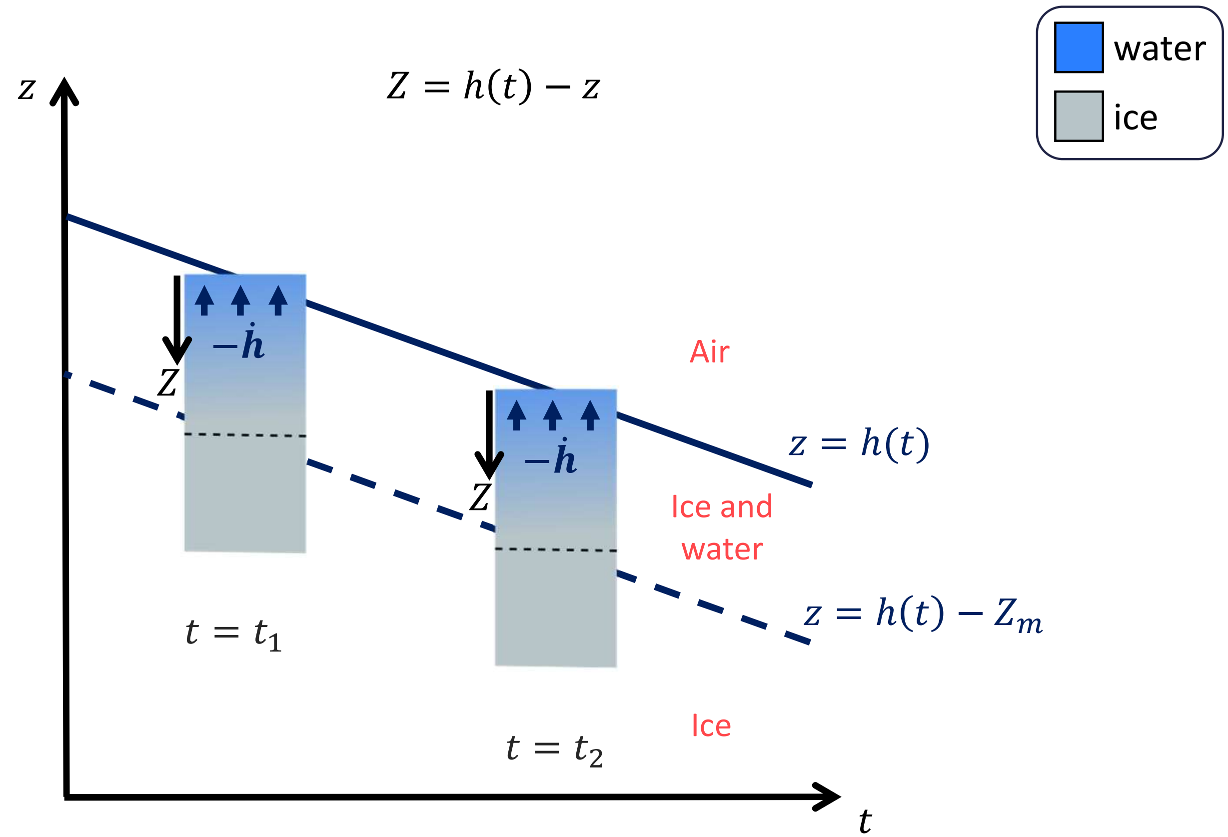

Internal melting balances surface lowering.

How does the weathering crust respond to changing **weather conditions**?

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Observations:

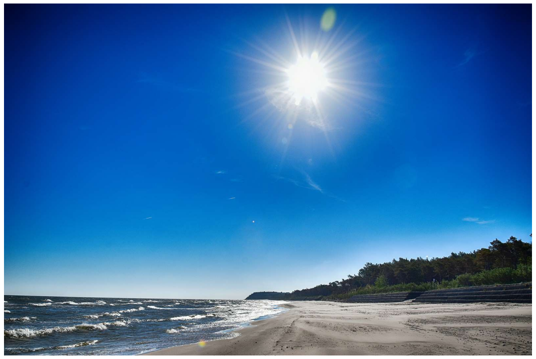
Image: www.thebluestsky.com

Weathering crust **growth**: clear, sunny

"High Q_{si}, low Q_0."


Image: www.quotesgram.com

Weathering crust **decay**: warm, windy, overcast

"Low Q_{si}, high Q_0."

Müller, F., & Keeler, C. (1969). *Errors in Short-Term Ablation Measurements on Melting Ice Surfaces*. Journal of Glaciology.
Schuster, C. J. (2001), *Weathering crust processes on melting glacier ice (Alberta, Canada).* Thesis.

Insight from steadily melting solutions

Response to weather

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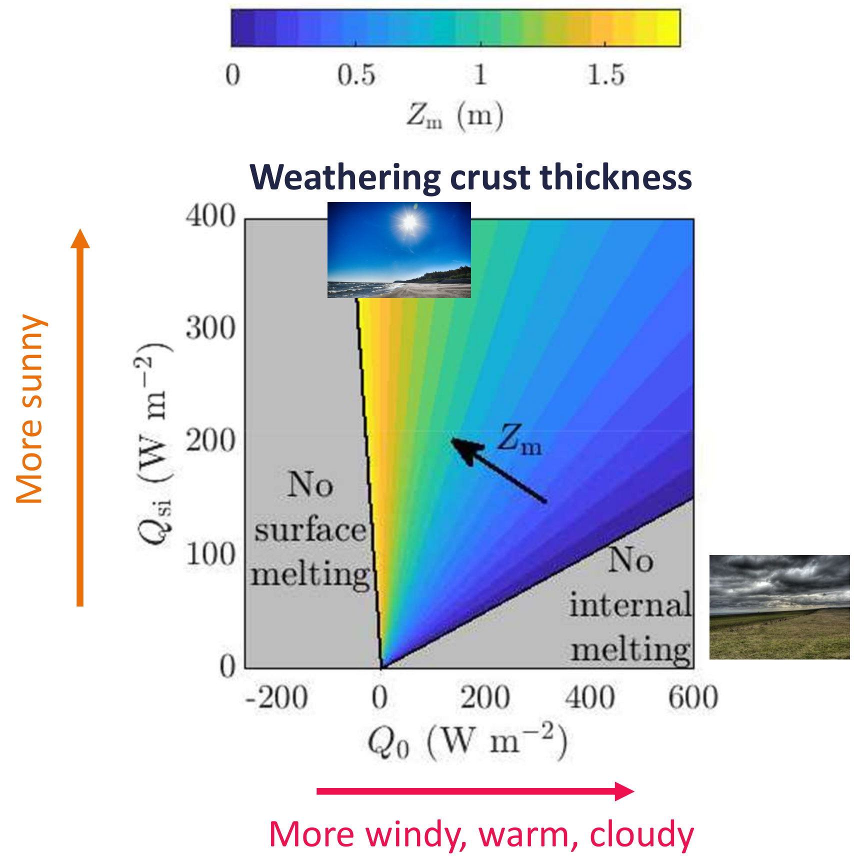

$$\text{“}\ Z_m \sim \frac{\text{internal melting}}{\text{surface lowering}}\ \text{”}$$

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Time-dependent solutions

Response to weather

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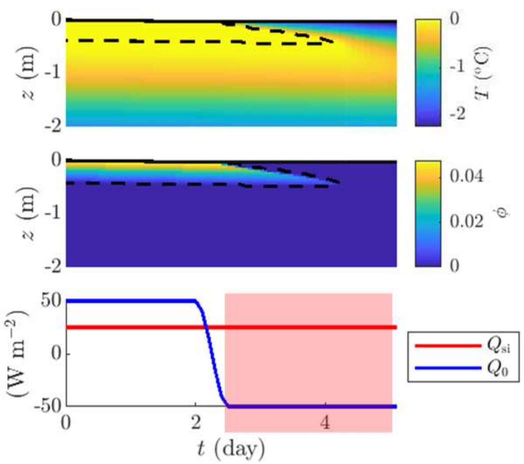
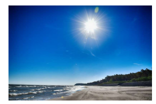
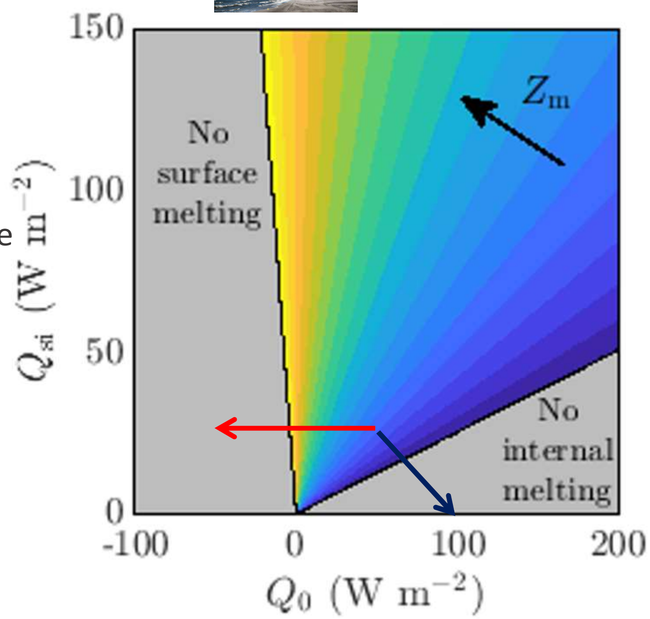
Can our model capture **removal** of the weathering crust?



Crust decay – **freezing** from the surface

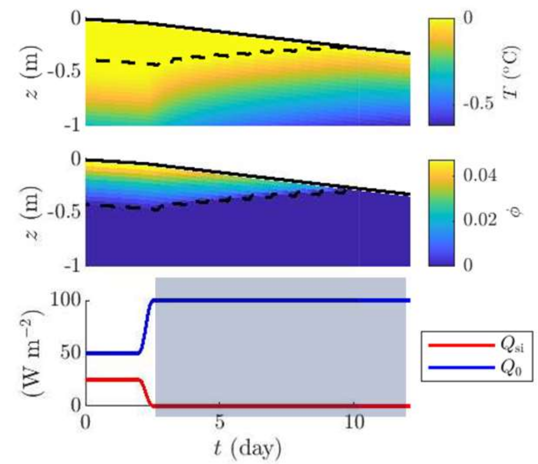
Shortwave (solar) radiation





Other surface radiation (longwave radiation and turbulent heat fluxes)

Crust decay – **melting** from the surface



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Time-dependent solutions

Response to weather

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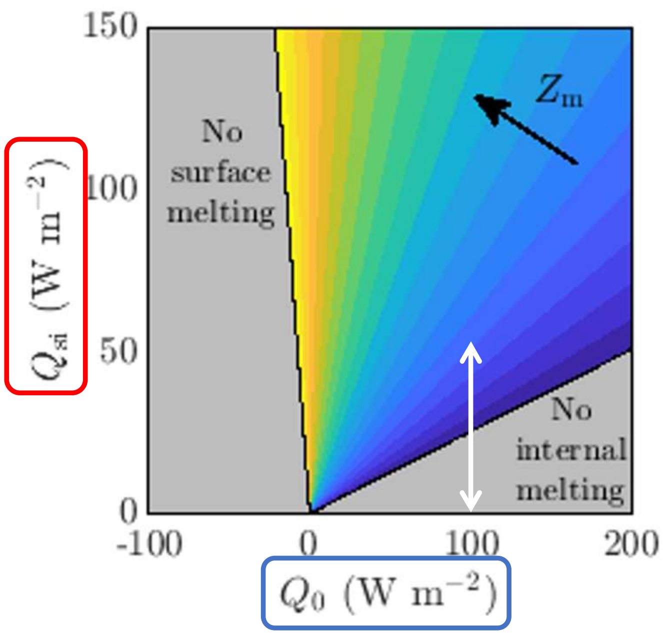
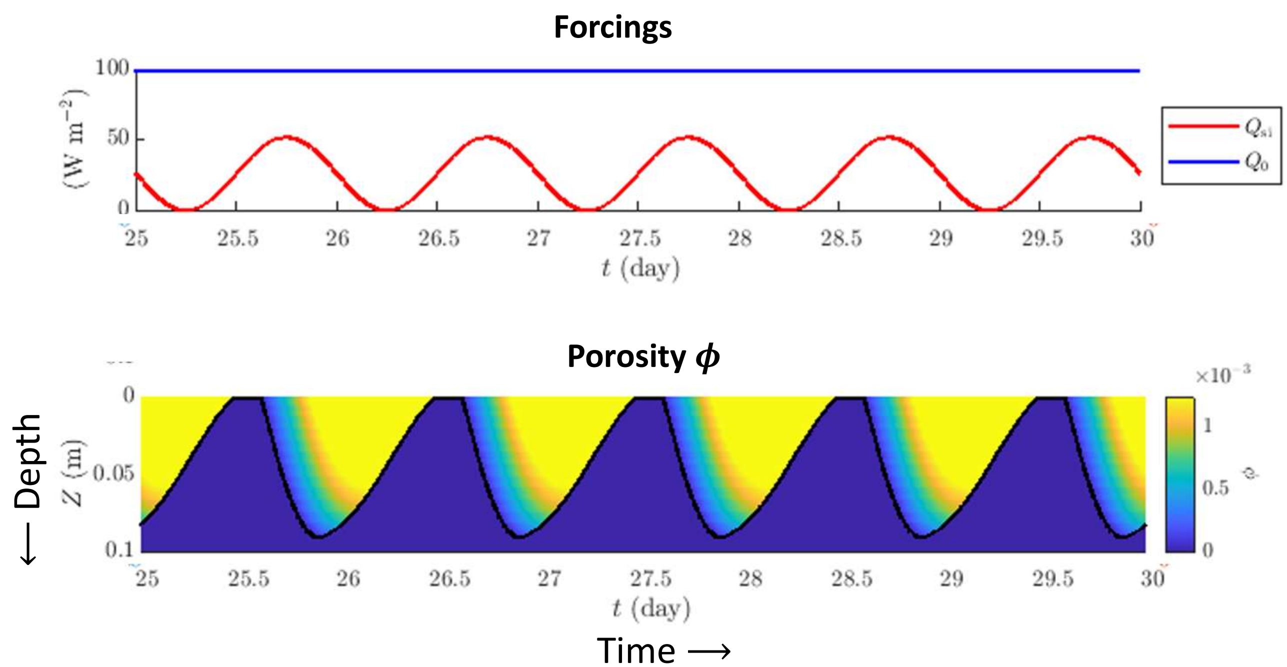
Can our model capture **periodic growth and removal** of the weathering crust?





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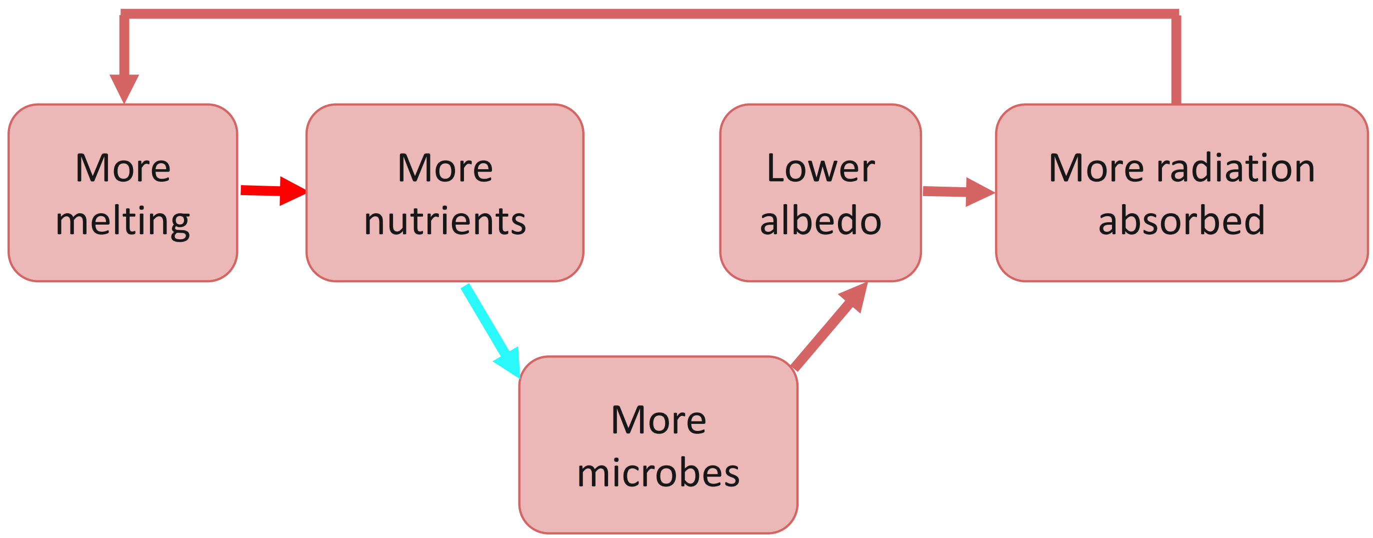
What effect do **microbes** have on the weathering crust and melting?

EGU Blogs/Eva Doting



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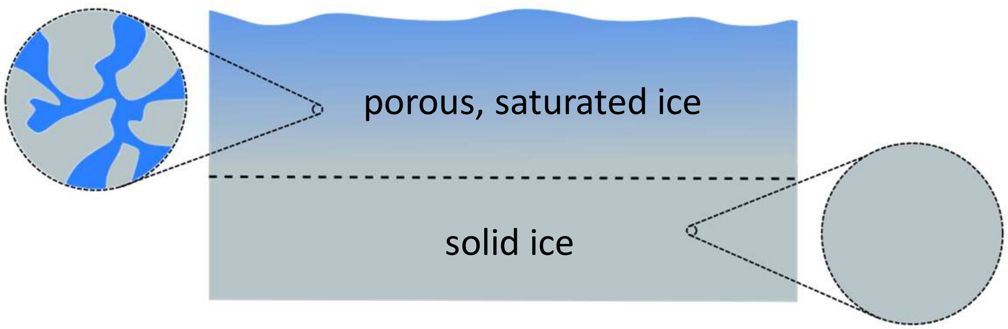
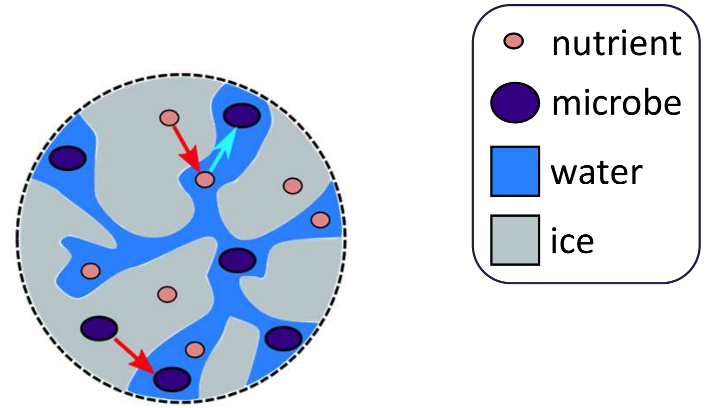
A 1D mathematical model





Thermodynamics

- Mass conservation
- Energy conservation
- Internal and surface absorbed radiation

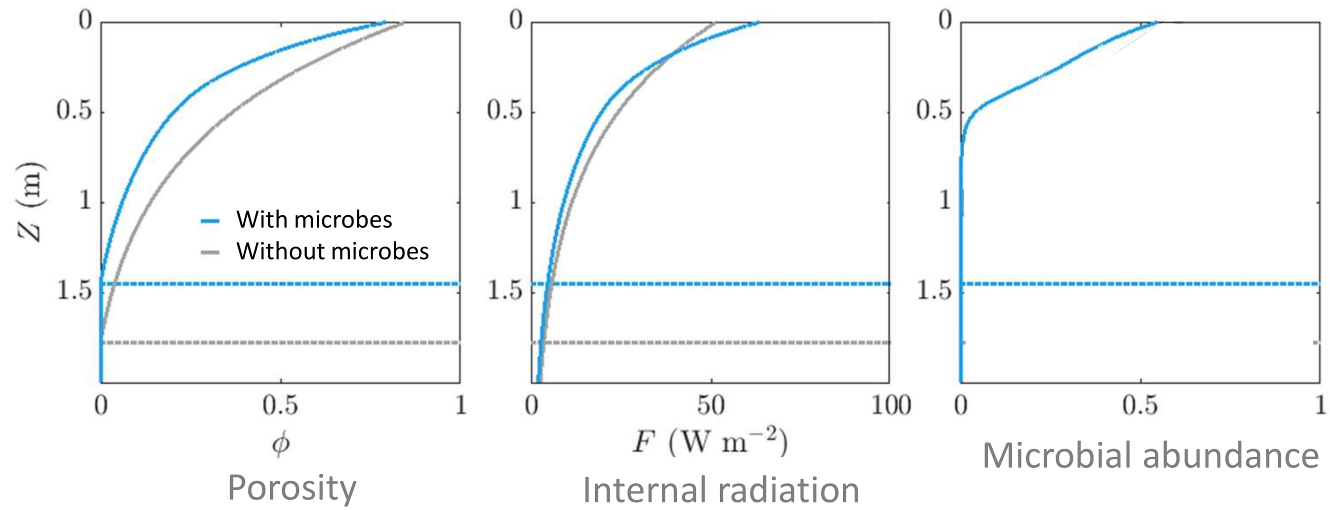
Population dynamics

- Logistic growth of microbes in water, driven by
  - Nutrients
  - Internal radiation

Radiation absorption is a function of microbial abundance.

Effect of microbes

Note: these are steadily melting solutions.



With microbes:

- Surface lowering $-\dot{h}$ **increases**
- Surface melt rate m_{surf} **increases**
- Weathering crust thickness Z_m **decreases**

The effect of microbes is to **increase surface melting and lowering.**

Woods, T. and Hewitt, I. J.: *A model of the weathering crust and microbial activity on an ice-sheet surface*, EGUsphere [preprint], 2022

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Summary

Modelling structure

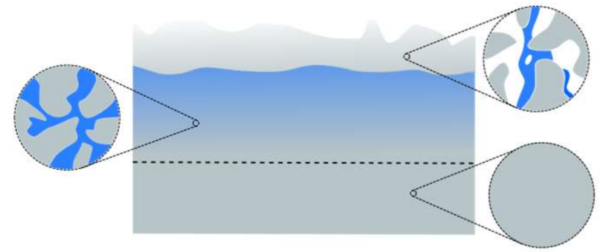
- We have developed a one-dimensional continuum model for the vertical structure of the weathering crust.

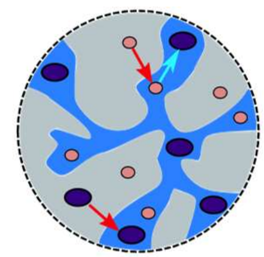
Response to weather

- Clear, sunny conditions lead to crust growth, and warm, windy, cloudy conditions lead to crust decay.

Effect of microbes

- Including a model for microbes and nutrients shows that microbes have the potential to enhance melting.





Future work:

- Comparisons with quantitative observations and real weather data.
- Evolution over a melt season.
- Higher dimensions – lateral spreading.

For more detail on the steadily melting results, see: Woods, T. and Hewitt, I. J.: *A model of the weathering crust and microbial activity on an ice-sheet surface*, EGUsphere [preprint], 2022