Climate forcing time step requirements for firn modelling

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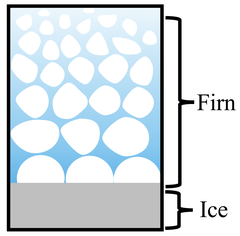
1. Firn what, why, and modelling

Firn, the transition between snow and ice, contains pore space that can prevent meltwater runoff into the ocean, by refreezing or retention. Total pore space in a firn column is expressed by the **firn air content (FAC)**.



Firn models require climate forcing at their upper boundary. Climate forcing time steps range from 1 day to 1 year, but the impact on simulated firn profiles is unclear. We aim to answer the question: **what is the effect of the climate forcing time step on the modelled firn layer?**

2. Model and setup

Model: IMAU-FDM

General: 1D, semi-empirical, Langrangian layering framework

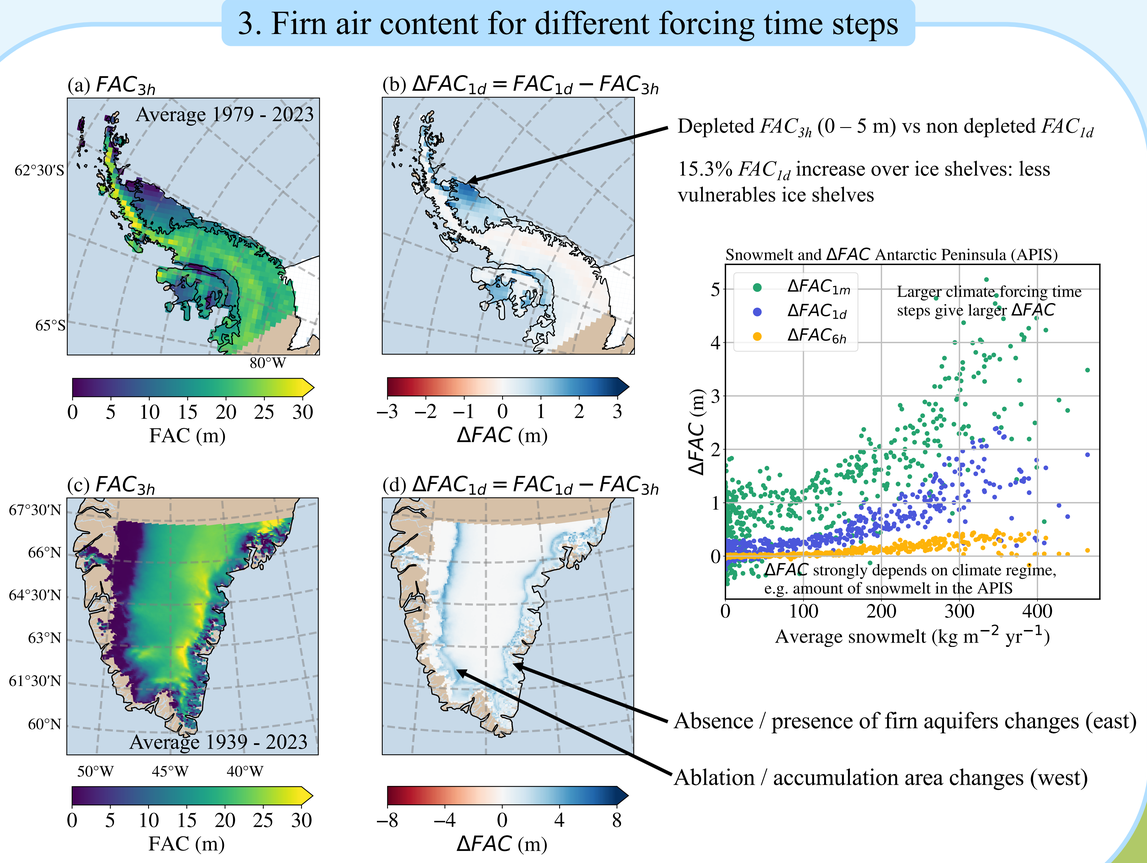
Input at surface: Surface temperature, 10 m wind speed, snowmelt, snowfall, precipitation, snow drift, sublimation

Output (per layer): Densification, water percolation, temperature evolution

Forcing: RACMO2.3p2, ERA5

Climate forcing time steps: **3 hours (3h), 6 hours (6h), 1 day (1d), and 1 month (1m)**

3. Firn air content for different forcing time steps



Depleted FAC_{3h} (0 – 5 m) vs non depleted FAC_{1d}

15.3% FAC_{1d} increase over ice shelves: less vulnerables ice shelves

Absence / presence of firn aquifers changes (east)

Ablation / accumulation area changes (west)

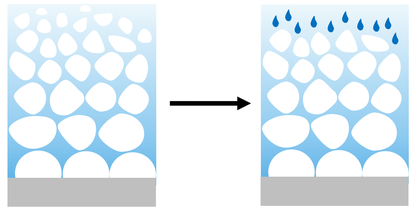
4. Mechanisms that explain ΔFAC

↓ = less / lower
↑ = more / higher

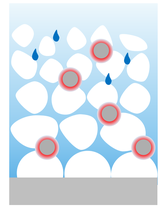
1. Melt and refreezing remove more FAC with greater forcing time steps

Melt event:

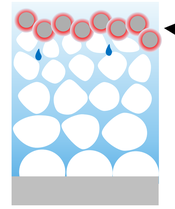
Melt is prescribed. Firn mass in the first layer is converted to the presribed amount of melt.



3-hour time step
- T_s = 273.15 K
- Refreezing at depth
- Deeper percolation
- ↓ Surface density



1-day time step (non-physical):
- T_s < 273.15 K
- Immediate refreezing at surface
- Shallower percolation
- ↑ Surface density



Melt event next time step: firn → liquid water
- ↑ **FAC removal**
- ↓ **FAC removal**

2. Greater forcing timesteps both increase and decrease densification

3h:
↓ FAC
↓ **densification**

1d:
↑ FAC
↑ **densification**

3h:
- Refreezing at depth
- Heat remains in firn
- ↑ T → ↑ **densification**
- ↑ T_b → ↓ **densification**

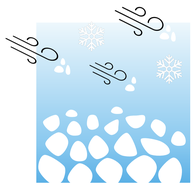
1d (non-physical):
- Refreezing at surface
- Heat releases to atmosphere
- ↓ T → ↓ **densification**
- ↓ T_b → ↑ **densification**

T = instantaneous layer temperature
T_b = instantaneous bottom layer temparature

3. Low wind speeds during snowfall increase FAC for smaller forcing time steps

3h:
↓ Wind during snowfall
↓ Crystal breaking
↓ Efficient packing
↓ **Surface density**

1d (non-physical):
↑ Wind during snowfall
↑ Crystal breaking
↑ Efficient packing
↑ **Surface density**



Conclusions

IMAU-FDM **requires** a **sub-daily** climate forcing time step.

A **1-day or larger** climate forcing time step results in **unphysical mechanisms**.

Snowmelt is the **main contributor** to the **positive ΔFAC** for different climate forcing time steps.

The FAC and hence the climate forcing time step are **critical** in assessing **ice shelf vulnerability, firn aquifer presence**, and **runoff limit.**

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