Climatology and Evolution of the Antarctic Peninsula Föhn Wind-induced Melt Regime from 1979-2018

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Abstract

Warm and dry föhn winds on the Antarctic Peninsula (AP) cause surface melt that can destabilize vulnerable ice shelves. Topographic funneling of these downslope winds through mountain passes and canyons can produce localized wind-induced melt that is difficult to quantify without direct measurements. Our Föhn Detection Algorithm (FonDA) identifies the surface föhn signature that causes melt using data from twelve Automatic Weather Stations on the AP, used to train a machine learning model to detect föhn in 5km Regional Atmospheric Climate Model 2 (RACMO2.3p2) simulations and in the ERA5 reanalysis model. We estimate the fraction of AP surface melt attributed to föhn and possibly katabatic winds and identify the drivers of melt, temporal variability, and long-term trends and evolution from 1979-2018. We find föhn wind-induced melt accounts for 3.1% of the total melt on the AP but can be as high at 18% close to the mountains where the winds are funneled through mountain canyons. Föhn-induced surface melt does not significantly increase from 1979-2018, despite a warmer atmosphere and more positive Southern Annular Mode. However, a significant increase (+0.1Gt y-1) and subsequent decrease/stabilization occurred in 1979-1998 and 1999-2018, consistent with the AP warming and cooling trends during the same time periods. Föhn occurrence more than föhn strength drives the annual variability in föhn-induced melt. Long-term föhn-induced melt trends and evolution are attributable to seasonal changes in föhn occurrence, with increased occurrence in summer, and decreased occurrence in fall, winter, and early spring over the past 20 years.

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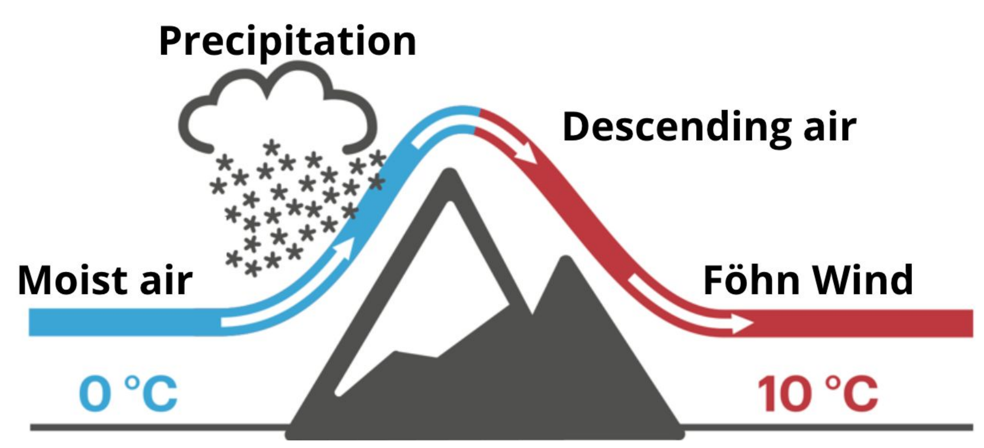
Introduction

Warm and dry föhn winds cause surface melt on the Antarctic Peninsula in all seasons.



We use AWS observations to train a machine learning (ML) model to identify the föhn signature in ERA5 reanalysis and RACMO2 output. We quantify the spatial and temporal extent, drivers, evolution of föhn-induced surface melt from 1979-2018.

Approach

Data

- **12 Automatic Weather Stations** (Figure 1)
- **ERA5**: Satellite derived reanalysis data, 30 km x 30 km resolution
- **RACMO2.3p2**: Regional Climate model data, 5.5 km x 5.5 km resolution

Föhn Detection and Machine Learning

- Created a **Föhn Detection Algorithm (FonDA)** to identify föhn wind events in AWS data.
- We use **XGBoost Gradient Boosting** decision tree Machine Learning.
- We use AWS identified föhn events to train two Machine Learning models to identify föhn in ERA5 and RACMO2 output.

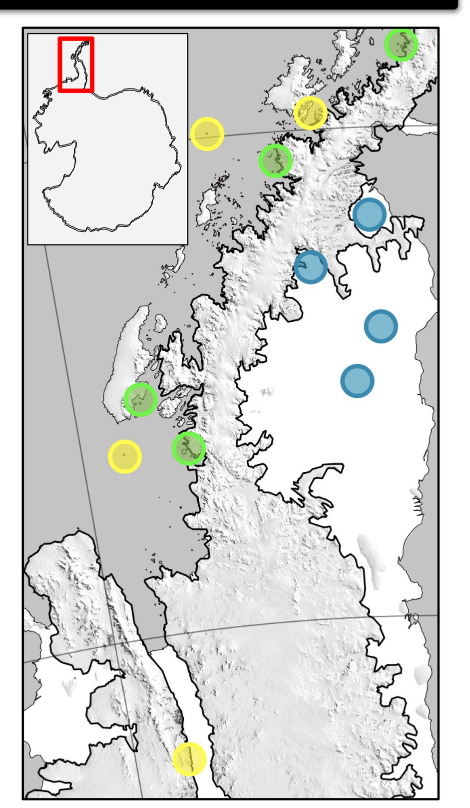


Figure 1: Study Domain and AWS locations. White shading indicates ice shelves, Grey shading indicates the ocean.

Table 1: ML Model performance showing each models ability to identify föhn-induced melt compared to AWS identified events and concurrent melt. Event classification is dependant on temperature; Strong (>7 °C), Moderate (>3.5 °C, <7 °C), Weak (<3.5 °C).

ERA5 föhn classification				
AWS classification	Model classified correct	Föhn melt	Occurrence	Melt captured
Strong	100.0%	7.1%	3.6%	7.1%
Moderate	98.9%	20.5%	23.1%	20.3%
Weak	87.8%	72.4%	73.3%	63.5%
		Total föhn-induced melt captured		**90.9%**
RACMO2 föhn classification				
AWS classification	Model classified correct	Föhn melt	Occurrence	Melt captured
Strong	100.0%	6.8%	3.0%	6.8%
Moderate	95.9%	19.5%	19.0%	18.7%
Weak	93.5%	73.7%	78.0%	68.9%
		Total föhn-induced melt captured		**94.4%**

Surface Energy Budget and Melt

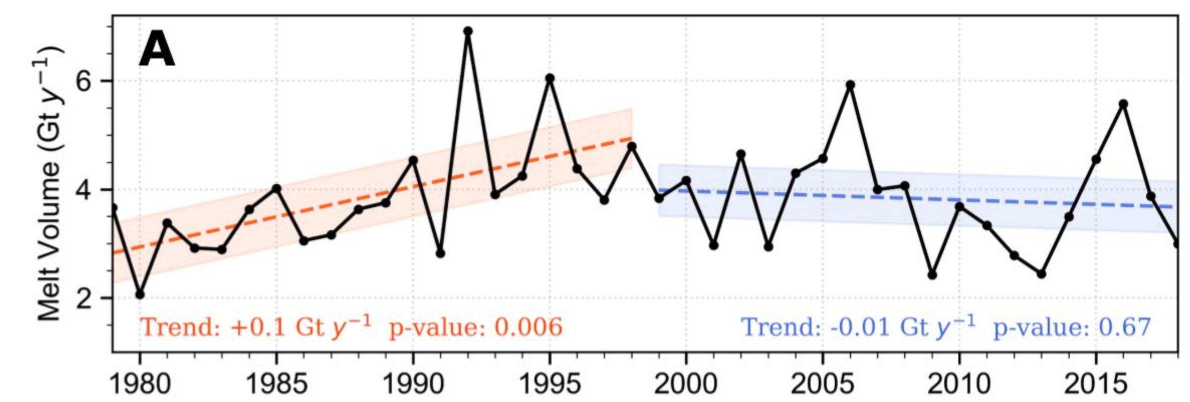
- Combine föhn events identified with Machine Learning models and the surface energy budget to create a climatology of surface melt and the surface energy budget.

$$Energy = SW_{net} + LW_{net} + H_S + H_L \ (W\ m^{-2})$$

Results

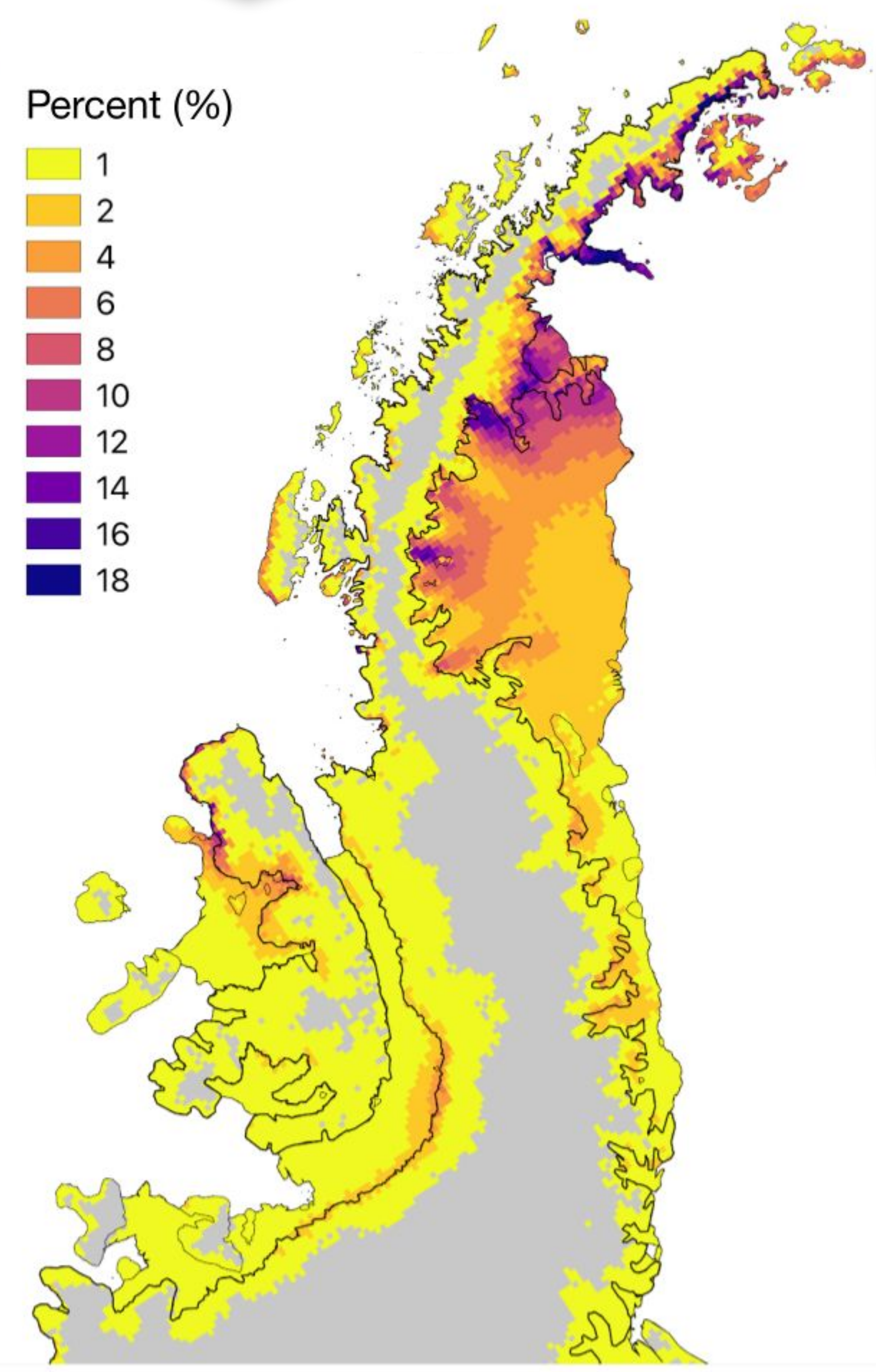
What fraction of the total AP melt is caused by föhn winds?

- Föhn wind-induced melt accounts for **3.1%** of the total melt.
- Can be as high at **18%** east of the AP mountains.



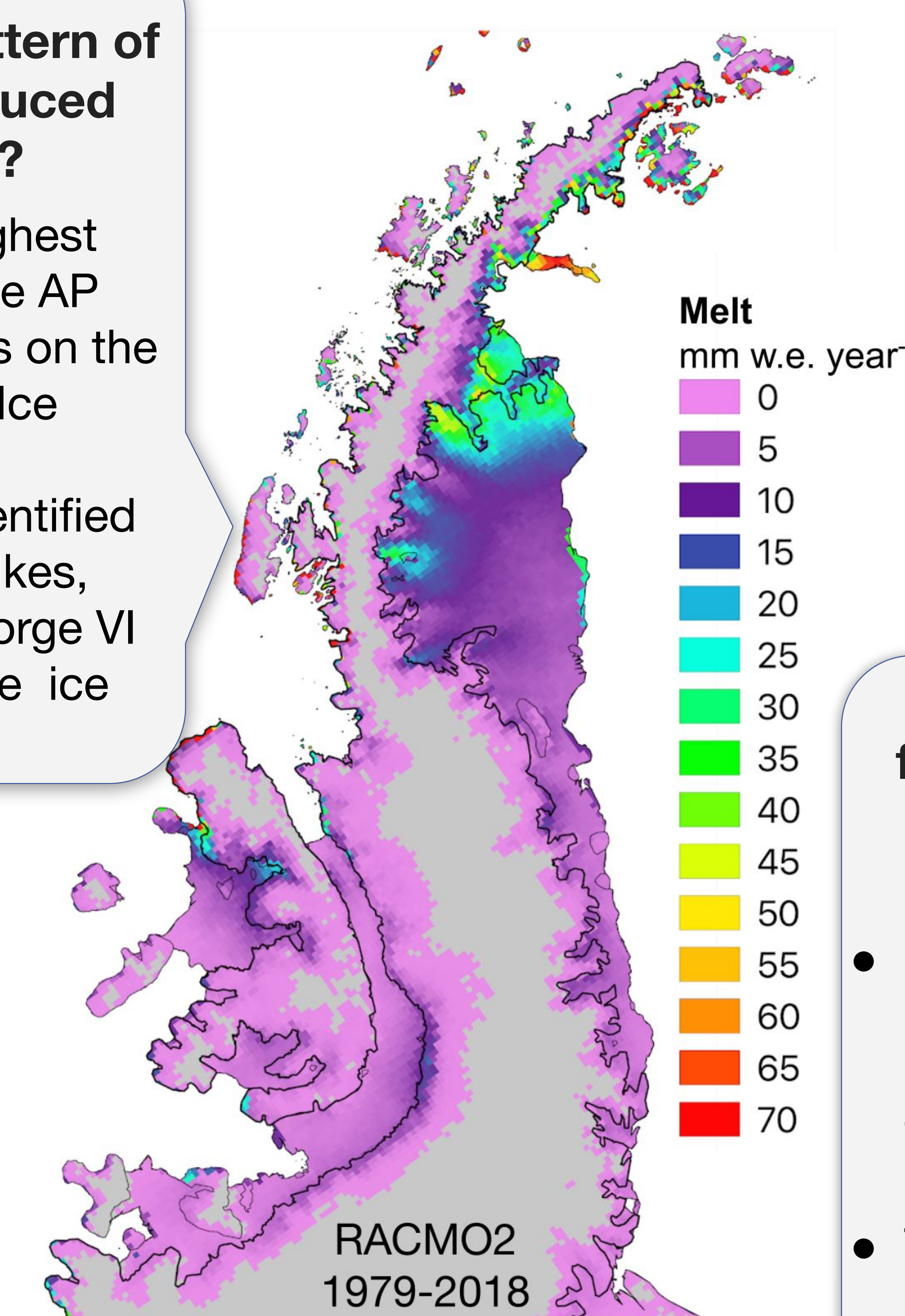
How does föhn-induced melt vary?

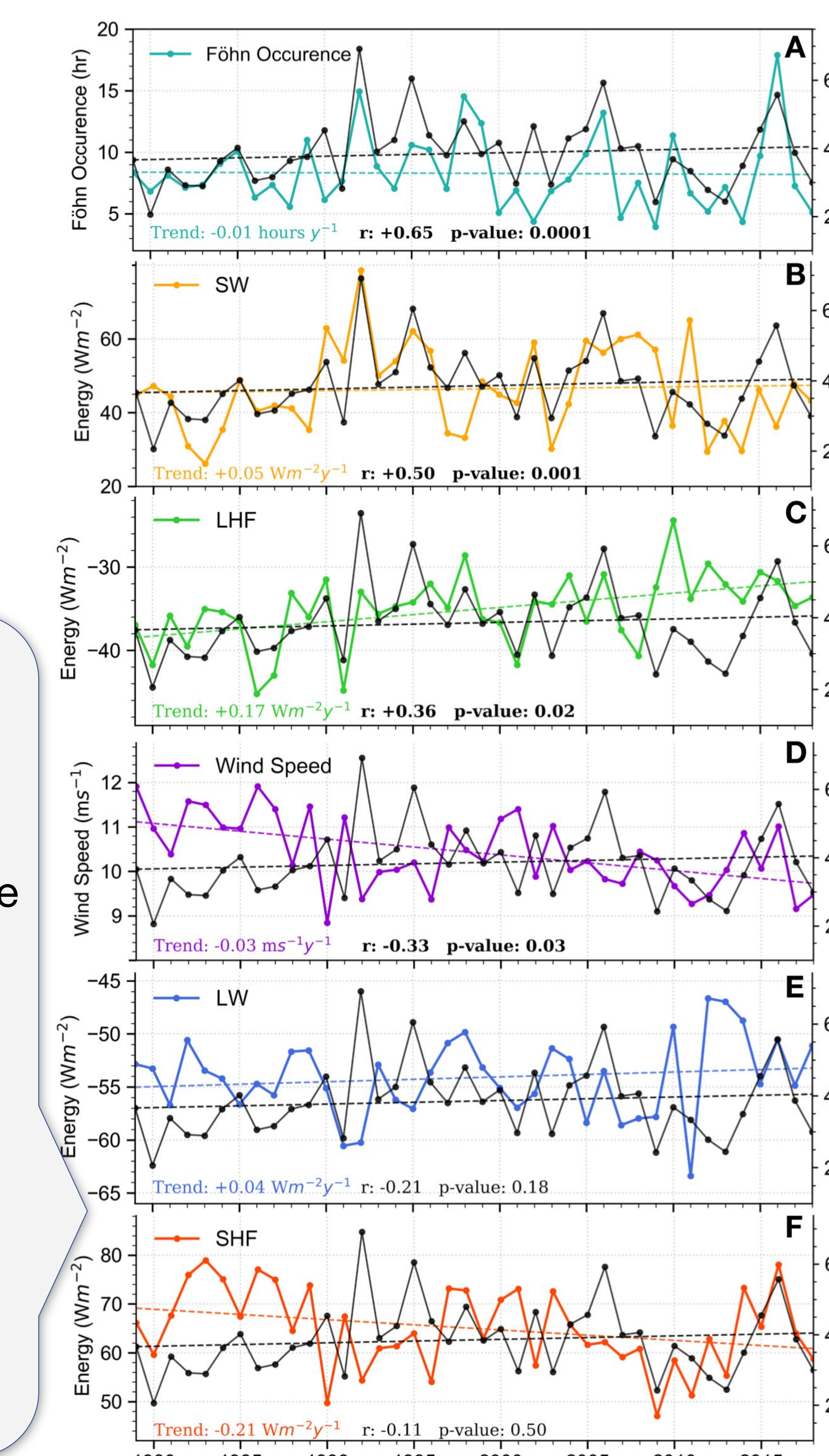
- Melt does not significantly increase from 1979-2018.
- A significant increase (+0.1Gt y-1) and subsequent decrease/stabilization occurred in 1979-1998 and 1999-2018, consistent with the AP warming and cooling trends.



What is the spatial pattern of föhn-induced melt?

- Melt is highest west of the AP mountains on the Larsen C Ice Shelf.
- Melt is identified on the Wilkes, Bach, George VI and Ronne ice shelves.



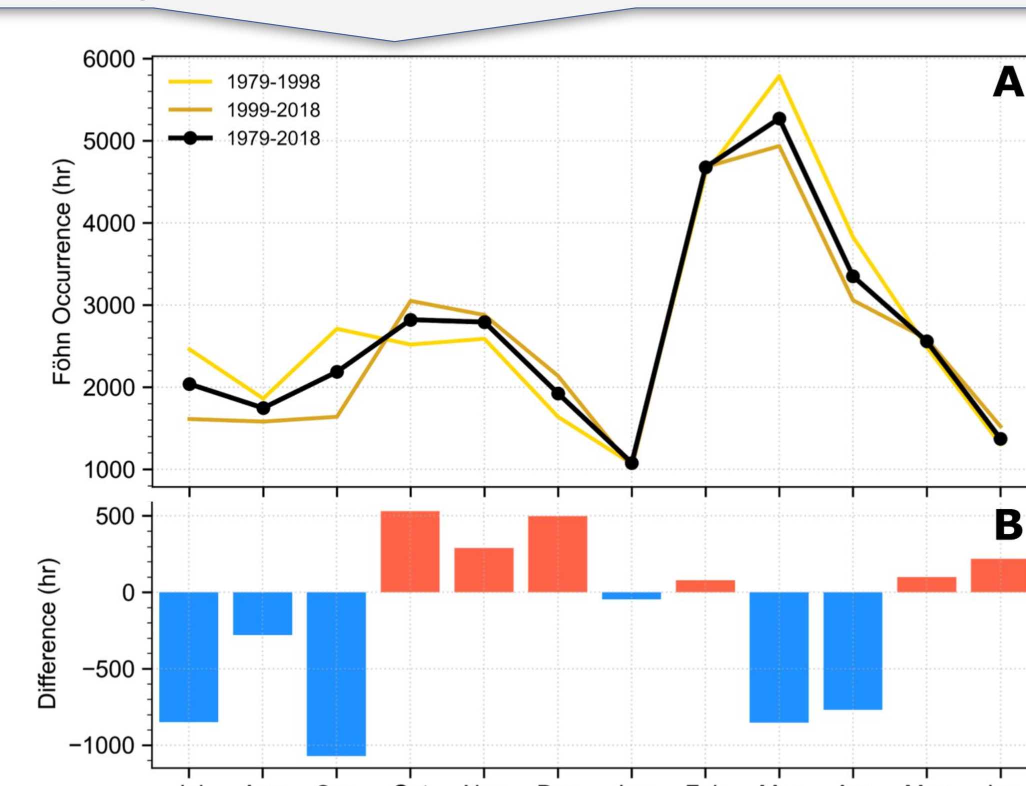


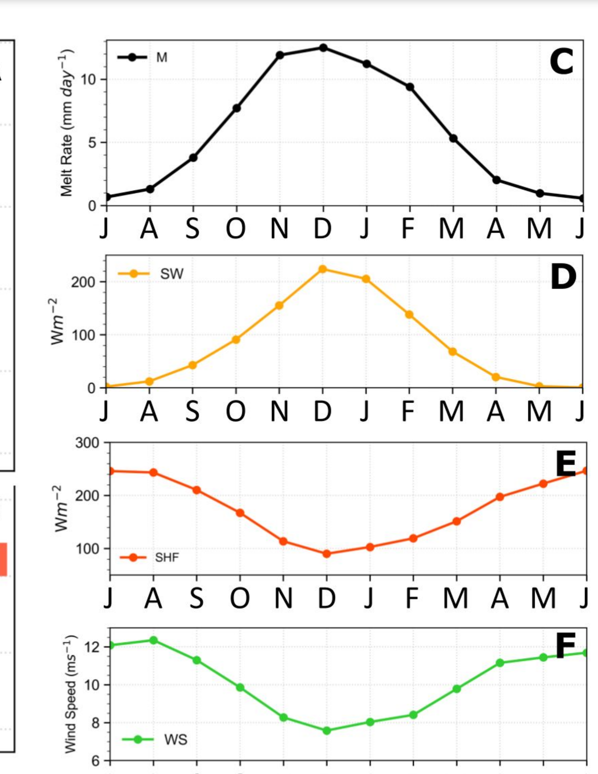
What drives föhn-induced melt annual variability?

- Föhn occurence drives annual variability in föhn-induced melt.
- Trends in föhn drivers suggest föhn-induced melt has changed through time.

How and why does föhn-induced melt evolve through time?

- Föhn-induced melt evolution is attributed to seasonal changes in föhn occurrence.
- More föhn melt events occur in summer and less events occur in fall, winter, and early spring.





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