Foehn Winds on Larsen C Ice Shelf During Polar Night: Impacts on the Surface Energy Budget and Melt

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Abstract

Larsen A and B ice shelves were affected by surface melt which preconditioned them for rapid disintegration due to hydrofracture and densification. Recently, warm and dry foehn winds have been discovered to melt the vulnerable Larsen C Ice Shelf (LCIS) surface via sensible heat transfer during polar night. The climatological extent and intensity of polar night surface melt and their effects on the ice surface energy budget are unknown. Here we quantify the spatial pattern and temporal variability of foehn winds and associated melt events during polar night to understand the ice shelf surface mass balance and indirect implications for ice shelf vulnerability. Our Foehn Detection Algorithm (FonDA) uses events identified from in situ Automated Weather Stations (AWS) to calibrate foehn detection from reanalysis data covering all of Antarctica and Greenland. We present a climatology of foehn-driven surface melt days, melt water equivalent, fraction of melt that occurs during polar night, and the surface energy budget. Preliminary results show that foehns perturb sensible heat fluxes by up to 300 Wm-2 and surface air temperatures by up to 13 °C in the absence of shortwave radiation.

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Introduction

- Surface melt depletes firn air in Antarctic ice shelves and can lead to shelf disintegration, glacier acceleration, and sea level to rise.
- Foehn winds enhance melt through large fluxes of sensible heat.
- Automatic Weather Stations (AWS) provide in-situ measurements during foehn events with limited spatial representation.
- ERA5 reanalysis data can expand the spatial pattern of foehn winds, however do not represent surface conditions well.

We use machine learning (ML) to calibrate ERA5 reanalysis data using AWS data. We quantify the spatial and temporal extent of foehn wind melt events during polar night and their contribution to the total annual melt on the Larsen C Ice Shelf (LCIS).

Approach

Data

- AWS data: (AAWS) - University of Wisconsin-Madison and (IMAU)-Utrecht, University, Netherlands.
- Satellite derived reanalysis data: ERA5, 0.25 ° x 0.25 °
- Use Justified Automated Weather Station (JAWS) software for tilt correction and AWS data harmonization (Github: jaws/jaws)

Foehn Detection Algorithm (FonDA)

- Created FonDA to identify foehn wind events in AWS data.
- Use AWS FonDA to calibrate FonDA for ERA5 using gradient boosting decision tree Machine Learning (See Machine Learning)

FonDa uses variable thresholds to identify foehn wind during polar night (Figure 1)

- Temperature > 0 ℃
- Relative Humidity (RH) < 30th percentile
- Wind Speed > 60th percentile

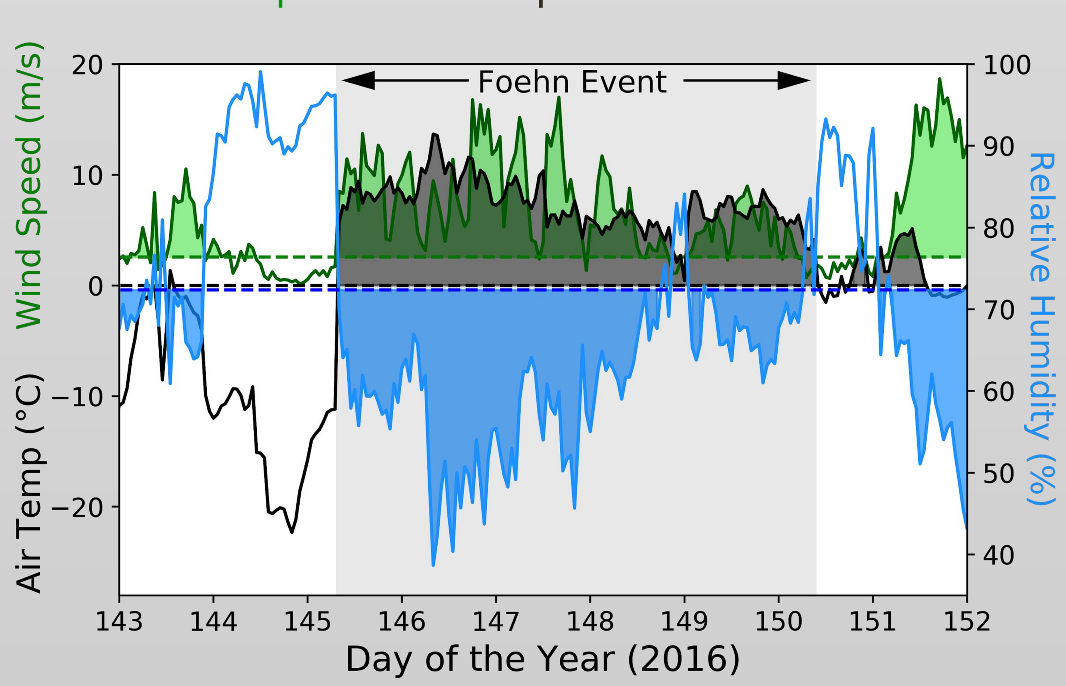

Figure 1: Foehn event at AWS 18 on LCIS, indicated by light grey shading.

Surface energy budget and melt

- Estimated the ice surface energy budget by iteratively solving for surface temperature with bulk formulas.
- Combined foehn events identified with Machine Learning FonDA and surface energy budget model to create a climatology of polar night melt and the surface energy budget on LCIS.

Results

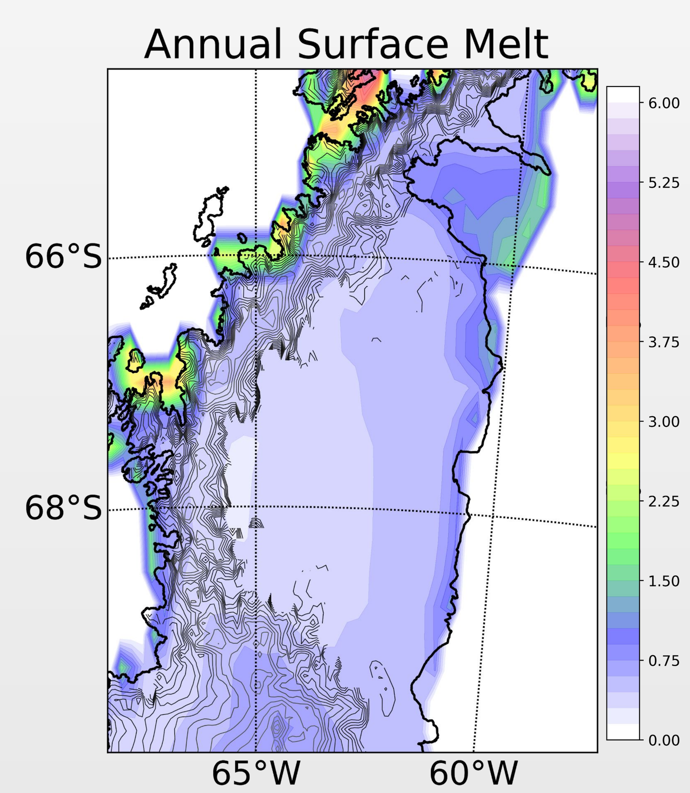

Figure 2: Climatology of annual surface melt on LCIS (2007-2017).

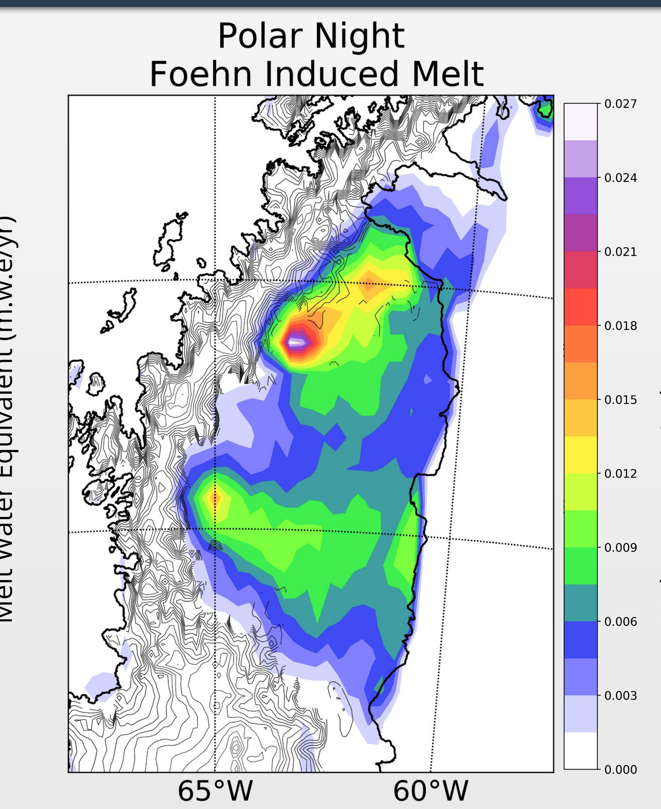

Figure 3: ★ Climatology of polar night surface melt on LCIS (2007-2017).

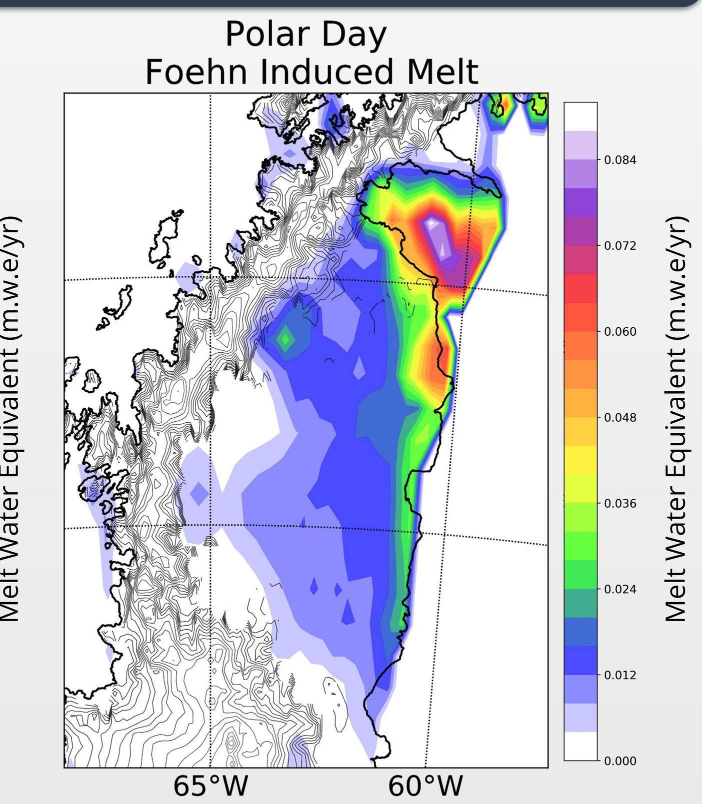

Figure 4: Climatology of polar day surface melt on LCIS (2007-2017).

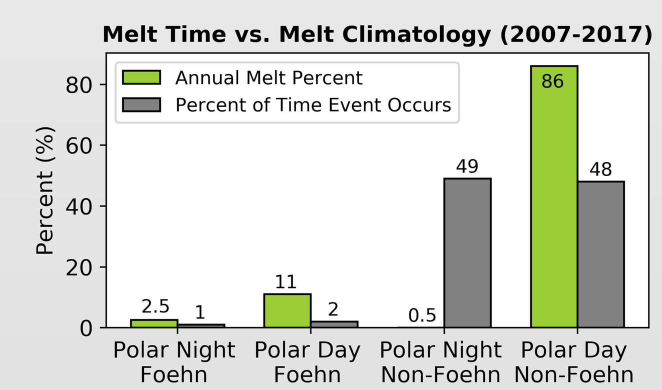

Figure 5: ★ Mean annual melt vs. mean annual time foehn and non-fohn occur over LCIS during polar night (April-Sept) and polar day (Oct-March).

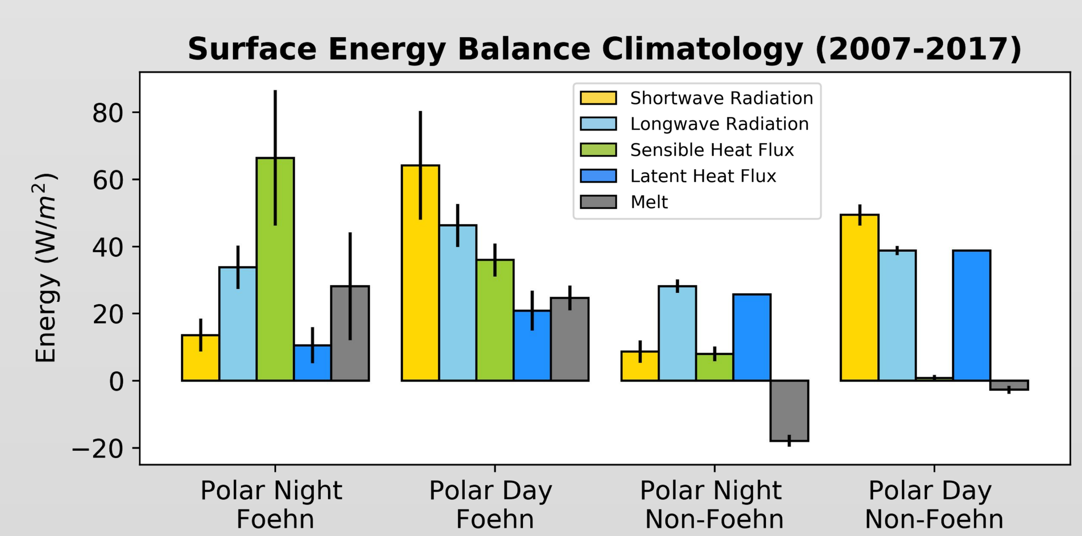

Figure 6: ★ Mean ice surface energy budget over LCIS during polar night (April-Sept) and polar day (Oct-March).

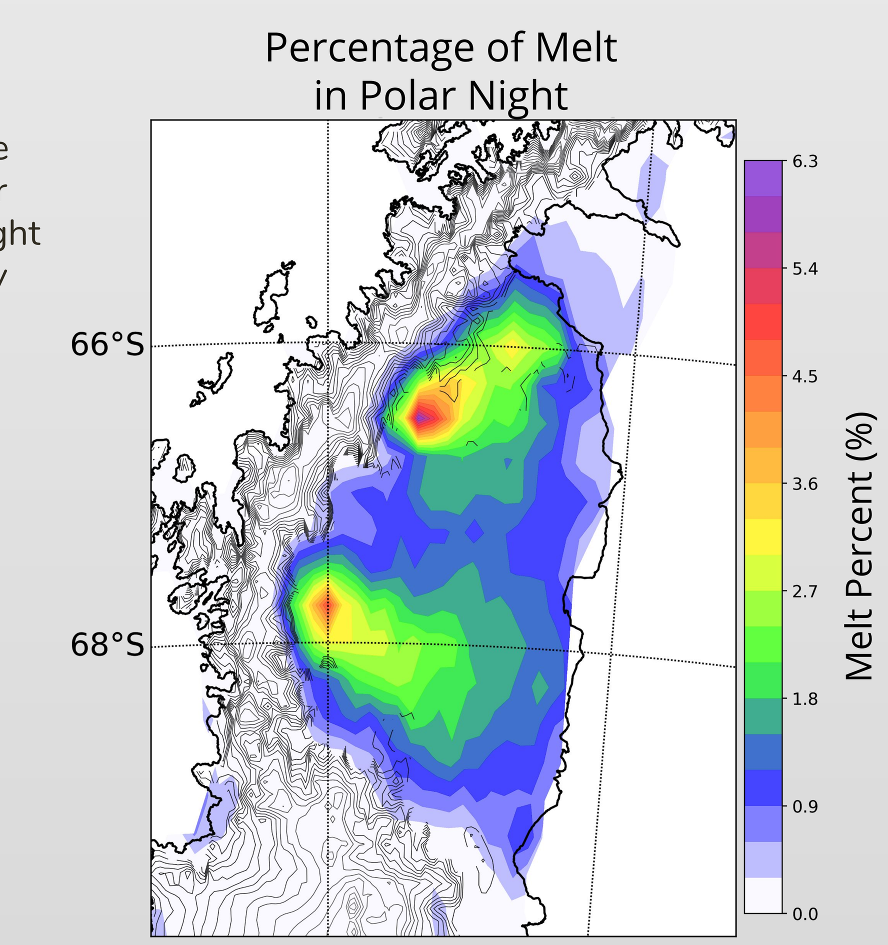

Figure 7: ★ Climatology of annual melt percent during polar night (2007-2017).

Machine Learning

Why use machine learning?

- Human driven FonDA requires extensive variable threshold analysis and only yields an F1-Score 0f 0.52 (Table 1a).
- ERA5 reanalysis data does not represent surface conditions during foehn wind events as compared to AWS data (Figure 8).

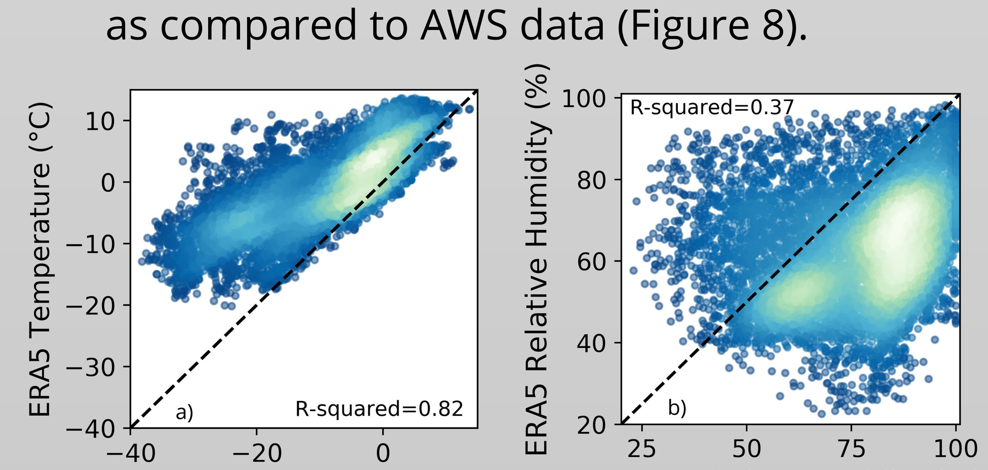

Figure 8: Light green to white shows increased density. a) AWS temperature compared to ERA5 temperature. b) AWS RH compared to ERA5 RH.

Machine Learning Model

- Gradient Boosting Decision Tree (GBDT) classification to train and predict foehn events in ERA5 data.
- 23 ERA5 variables trained to predict foehn against AWS FonDA identified foehn events.

Evaluation

- Used hyperparameter optimization to maximise F1-score.
- 10 fold cross-validation to ensure model accuracy.

Table 1: a) When Fonda is applied to ERA5 data to predict foehn. b) When machine learning FonDA is applied to ERA5 data to predict foehn.

	Precision	Recall	F1-Score
a) **ERA5 FonDA**	0.558	0.496	**0.525**
b) **Machine Learning FonDA**	0.771	0.664	**0.719**

Conclusions

- Despite lack of shortwave radiation LCIS experiences surface melt during polar night due to foehn winds, confirmed using AWS height measurements and satellite based radar (Figure 9)
  - ★ Large **sensible heat fluxes** dominate the surface energy budget during polar night foehn winds with a mean energy flux of **66.4 W/m^2** (Figure 6).
  - ★ **2.5 %** of the annual melt occurs during polar night (Figure 5).
  - ★ Mean melt of **0.01 m.w.e./yr** occurs on LCIS with a maximum of **0.027 m.w.e./yr** (Figure 3).
  - ★ Maximum polar night melt of **6.3 %** occurs in cabinet inlet close to the Antarctic Peninsula Range (Figure 7).
- Strong foehn signature east of the Peninsular Range due to topographic funneling of foehn winds and a change in topographic relief (Figures 3, 7).
- The use of ERA5 data and ML tends to underestimate surface melt by **20.4%** compared to AWS data, but is expected to improve with better ML algorithms.

Future Direction

We plan to...

- Further improve FonDA using machine learning to increase model accuracy and melt estimation.
- Expand the research methodology to all of the Antarctic Ice Sheet as well as the Greenland Ice sheet.
- Use other datasets such as MERRA-2 reanalysis data.

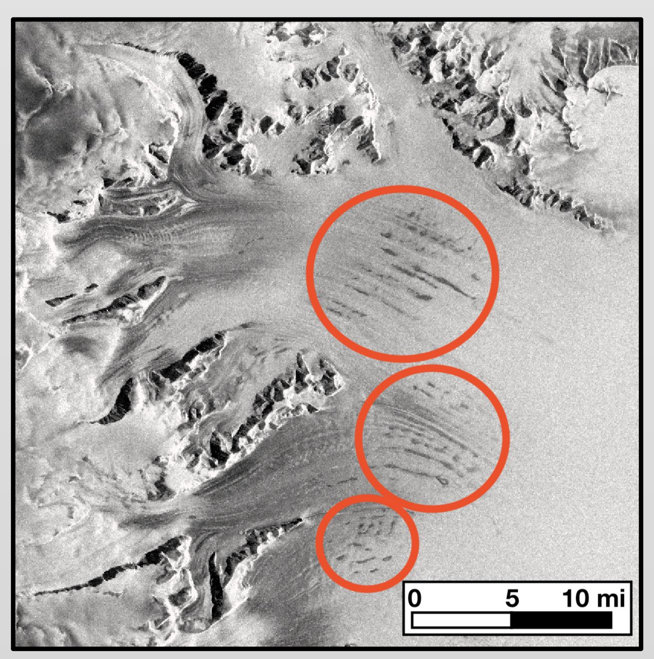

Figure 9: Sentinel 1A C-band synthetic aperture radar imagery from Cabinet Inlet on LCIS. Red circles indicate darker surface melt ponds in polar night (late May 2016).

Acknowledgements

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