Major Surface Melting over the Ross Ice Shelf, Antarctica

Xun Zou\textsuperscript{1}, David Bromwich\textsuperscript{1,2}, Alvaro Montenegro\textsuperscript{1,2}, Sheng-Hung Wang\textsuperscript{1}, and Lesheng Bai\textsuperscript{1}
\textsuperscript{1} Polar Meteorology Group, Byrd Polar and Climate Research Center, The Ohio University
\textsuperscript{2} The Geography Department, The Ohio State University.
Research Background

- The West Antarctic Ice Sheet (WAIS)
  - accelerated ice loss over the past two decades (Smith et al., 2020).
  - sea level rise (Joughin and Alley, 2011).
- Ice shelves – restrain or buttress the flow of outlet glacier ice from Antarctic continent.
- Surface melting
  - risk of ice-shelf break-up
  - increase the instability of ice sheet (DeConto and Pollard 2016; Trusel et al., 2015)
  - More frequent surface melting over the RIS (Scott et al., 2019)

Substantial surface melting may occur in West Antarctica ice shelves in the future (Lenaerts et al., 2016).
Previous Major Surface Melt Events

  Chosen based on melt index calculated from passive microwave satellite data (Nicolas et al., 2018).
- Climatic Mode: El Niño + Negative Southern Annular Mode (SAM) will benefit the melting the most – impacts on regional circulation (Nicolas et al., 2017).

Table ENSO and SAM index during the melt events

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>SAM index</td>
<td>-2.06</td>
<td>-1.30</td>
<td>-2.12</td>
<td>1.43</td>
</tr>
<tr>
<td>ENSO</td>
<td>2.6</td>
<td>1.7</td>
<td>0.1</td>
<td>1.9</td>
</tr>
</tbody>
</table>

*Multivariate ENSO Index Version 2: positive value represents the El Niño condition, and negative value represents the La Niña condition.*

- Regional impacts: foehn effect, cloud impact, warm air advection (Zou et al., 2021 a&b)

Data source: https://data.bas.ac.uk/metadata.php?id=GB/NERC/BAS/PDC/01074
(Produced by Julien P. Nicolas)
## Data and Methods

- ECMWF Reanalysis Data (ERA5)
- Satellite Data (CERES + MODIS)
- Polar WRF

<table>
<thead>
<tr>
<th>Feature</th>
<th>PWRF V4.1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Resolution</td>
<td>20 km / 4 km</td>
</tr>
<tr>
<td>Vertical levels</td>
<td>71</td>
</tr>
<tr>
<td>Temporal Resolution</td>
<td>hourly</td>
</tr>
<tr>
<td>Spin-up</td>
<td>24 h</td>
</tr>
<tr>
<td>Microphysics</td>
<td>Morrison</td>
</tr>
<tr>
<td>PBL Scheme</td>
<td>MYNN</td>
</tr>
<tr>
<td>Shortwave and Longwave</td>
<td>Both RRTMG</td>
</tr>
<tr>
<td>Land Surface Options</td>
<td>Noah-LSM</td>
</tr>
<tr>
<td>Surface Layer Options</td>
<td>MYNN</td>
</tr>
<tr>
<td>Surface Albedo</td>
<td>MODIS</td>
</tr>
</tbody>
</table>

![Map of the region](image_url)
Recurring Foehn Effect

Favorable conditions:
✓ Surface high-pressure system over coastal MBL (90 – 120 °W).
✓ Strong low-pressure over the Ross Sea close to the RIS.
✓ Usually with moderate or strong import of moist flux towards coastal MBL.

Impacts:
✓ Impact the eastern RIS, around the Siple Coast and western MBL.
✓ Warm air descending on the leeside and form a “warming belt” in 2-m temperature field.
✓ Can lead to clear sky and extensive downward shortwave radiation on the leeside.
Recurring Foehn Effect - MRX (Group 1, 2016 case)

Vertical profiles of the trajectories over MRX

- In the 2016 case, the marine air blows almost perpendicularly towards the MRX
- The low-level air is blocked (as Fr $\sim 0.4 – 0.5$), and the upper-level air descends on the leeside.

Fr number for start days

<table>
<thead>
<tr>
<th>Year</th>
<th>Fr number</th>
<th>Blocking</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/05/1983</td>
<td>0.24</td>
<td>limited</td>
</tr>
<tr>
<td>12/30/1991</td>
<td>0.55</td>
<td>yes</td>
</tr>
<tr>
<td>01/04/2005</td>
<td>0.58</td>
<td>yes</td>
</tr>
<tr>
<td>01/10/2016</td>
<td>0.4</td>
<td>yes</td>
</tr>
</tbody>
</table>
Recurring Foehn Effect - MRX

Breakdown of the different mechanisms contributing to the foehn effect over MRX

- Over the MRX, the total contribution of foehn warming is ~ 4 °C
- Low-level air blocking – Positive isentropic drawdown (up to 4 °C). Can contribute up to 14 °C in other cases.
- The contribution of thermodynamic term can be compensated via sublimation on the leeside (2016).
- Fr number is around 1 (not <<1 or closer to infinity), the leeside is more likely to have fast downdraft – enhance turbulence – sensible heat flux (SRH). (0.3 - 40)
Favorable conditions:

- Surface high-pressure system over eastern Marie Byrd Land (MBL) close to the Sulzberger Ice shelf (120 – 150 °W)
- The low-pressure over the Ross Sea located eastward closer to the Roosevelt Island
- Usually with moderate or strong import of moisture

Impacts:

- Usually affect the coastal RIS
- Rarely impacts further inland to the central RIS and rarely leads to strong melting.
- Can import the moisture and benefit cloud formation, especially for the low-level liquid cloud (enhanced downward longwave radiation).
Overall, the central and coastal RIS has significant impact from low-level liquid cloud in 1982/83, 2005, and 2016 cases. For the 1991/92 case, the impact mainly focuses over the coastal RIS.
Surface Energy Balance - Overview

- Net shortwave radiation dominates the surface melting with a daily mean value over 100 W m\(^{-2}\) (Foehn clearance + surface meting => western Marie Byrd Land)
- Low-level liquid cloud favors the melting expansion over the middle and coastal RIS.
- Frequent foehn cases can enhance the turbulent mixing on the leeside (~20 W m\(^{-2}\)).
Summary

Regional factors for surface melting

- Sporadic foehn effect
  - High pressure: 90 – 120 °W
  - More than 40% of the melting time
- Direct Warm Marine advection: dominant contributor in 1991/92
  - High pressure: 120 – 150 °W; low pressure: Ross Sea.
  - Limited to the coastal RIS
- Cloud Impacts: significant for the expansion of the melting in 2005 and 2016
  - The central and coastal RIS: downward longwave radiation - low-level liquid cloud results from direct import of moisture from ocean.
  - The Siple Coast and western MBL: shortwave radiation – clear sky results from foehn clearance on the leeside.

For details:
Thank you!
References


**Recurring Foehn Effect**

Days experiencing foehn effect during the melting period.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Total melt days</td>
<td>29</td>
<td>33</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>Foehn days (%)</td>
<td>7 (24.1%)</td>
<td>14 (42.4%)</td>
<td>8 (61.5%)</td>
<td>13 (68.4%)</td>
</tr>
<tr>
<td>Strong Foehn days</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Underline marks strong foehn cases.

**MRX** \((Fr = [0.08, 0.65], \ll 1 \text{ or } \approx 1)\)
- Temperature inversion (upwind) (2005, 2016)
- Low-level air blocking (upwind), Warm air descending (leeside)

**MRY** \((Fr = [0.17, +\infty], \gg 1 \text{ or } \rightarrow \infty)\)
- Faster wind blowing towards the MRY
- Strong mountain waves on the leeside (hydraulic jump)

Froude Number and Corresponding Phenomena on the Leeside

<table>
<thead>
<tr>
<th>Fr number</th>
<th>Phenomena on the leeside</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Fr \ll 1)</td>
<td>Low-level air on the upwind side is blocked, and weak mountain waves occur on the leeside - <strong>Isentropic Drawdown</strong></td>
</tr>
<tr>
<td>(Fr \approx 1)</td>
<td>Violent waves and fast downdraft - <strong>benefits sensible heat transfer</strong></td>
</tr>
<tr>
<td>(Fr \gg 1)</td>
<td>Longer wavelength waves that might lead to reversed wind flow near the ground</td>
</tr>
<tr>
<td>(Fr \rightarrow \infty)</td>
<td>Banner cloud and strong turbulence</td>
</tr>
</tbody>
</table>

Open for discussions
Recurring Foehn Effect - Trajectories

Three groups of selected trajectories for the major melt events.

- Three regions are selected to conduct the trajectory analysis for the four melt cases (Group 1, 2 and 3), and each region contains around 800 trajectories.
- Twenty-five representative trajectories for Groups 1 are discussed in this presentation.

<table>
<thead>
<tr>
<th></th>
<th>4 melt cases</th>
</tr>
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<tbody>
<tr>
<td>Group 1 (MRX)</td>
<td>24 h</td>
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</tbody>
</table>
Recurring Foehn Effect - MRX

Total impact of the foehn effect over Mountain Range X

- Over the MRX, the total contribution of foehn warming is ~ 4 °C
- Unlike the classic foehn effect, the leeside of MRX has a wind speed decrease and, sometimes, an RH increase (e.g., 2016 case).
- Wind speed decrease – the mountain waves and the gentle slope on the leeside.
- RH increase in 2016 – direct marine air + sublimation/evaporation – above 0 °C air temperature along the trajectory on the leeside.