THE OHIO STATE UNIVERSITY
BYRD POLAR AND CLIMATE RESEARCH CENTER

Quantification and Analysis of Mechanisms for the Foehn Effect in the January 2016 West Antarctic melt event

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Outline

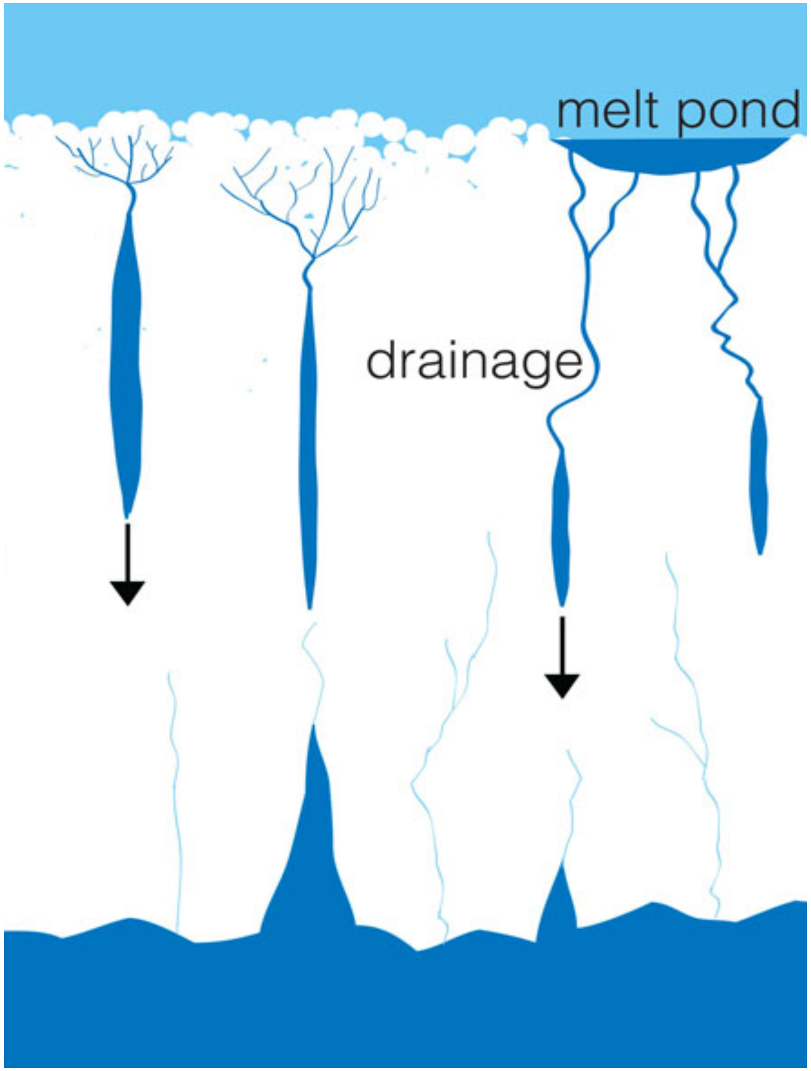
1. Background
2. Data and Methods
3. Synoptic Circulation during the Melt Event
4. Foehn Effect
5. Conclusions

Background

Antarctic ice shelves have undergone thinning and retreat over the past two decades.

Surface melting plays an important role in the breakup of ice shelves and thus promotes glacier acceleration.

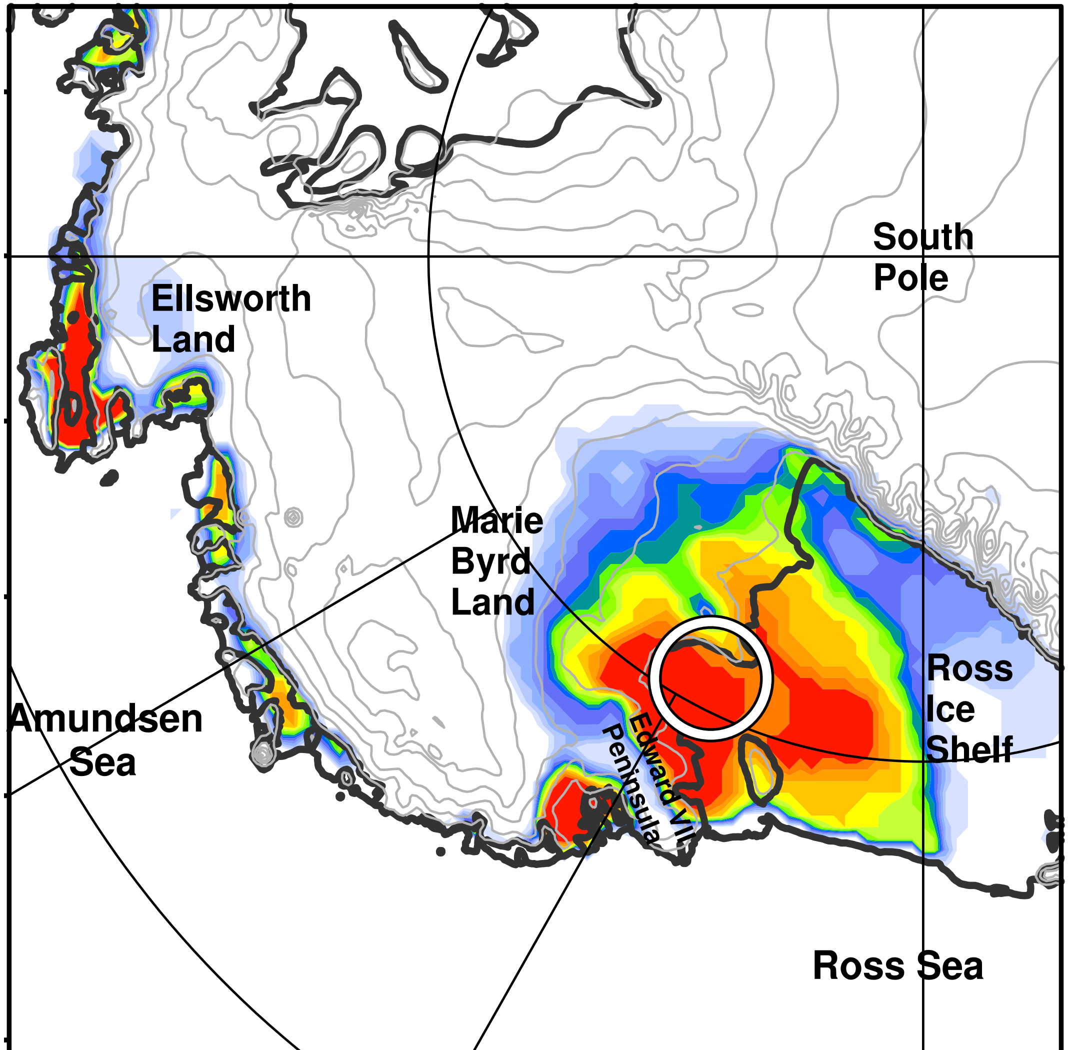
Modeling studies suggest that **substantial surface melting** may occur over the West Antarctic ice shelves in the future (DeConto and Pollard, 2016).



(Kuipers Munneke et al., 2014)

2016 Melt Event

Total Melt Days in January 2016



A major melting event over the Ross Ice Shelf (RIS) occurred in January 2016 (Nicolas et al, 2017). Two topographic barriers

Similar melt events occurred at this location before (e.g. 2004/05).

Pattern: the melting begins near Siple Dome/Shirase Coast (the white circle) and then expands to the rest of the RIS.

- **Question**: Why does the melting favor this place?

Data and Methods

This study uses model data from the **Antarctic Mesoscale Prediction System (AMPS)** to:

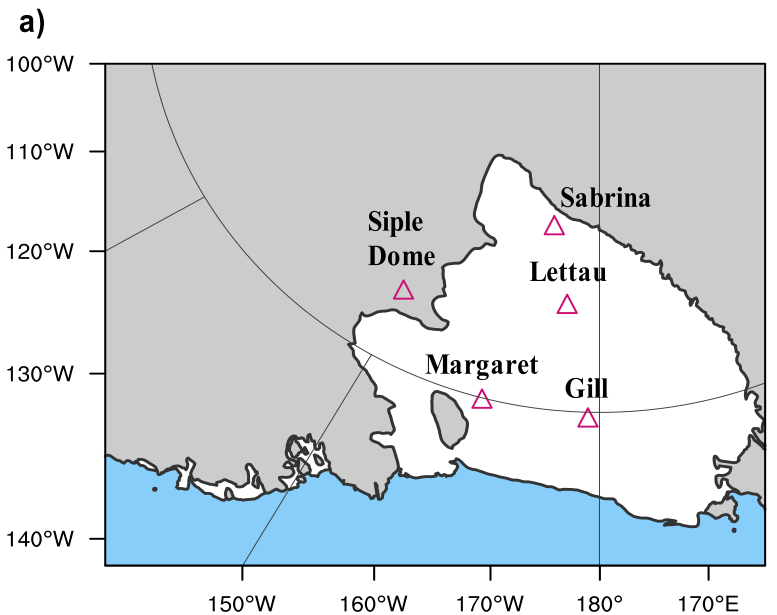
- Understand the **synoptic circulation** during the melt event.
- Analyze the contribution of the **foehn effect** to the surface warming at the beginning of the melt event.

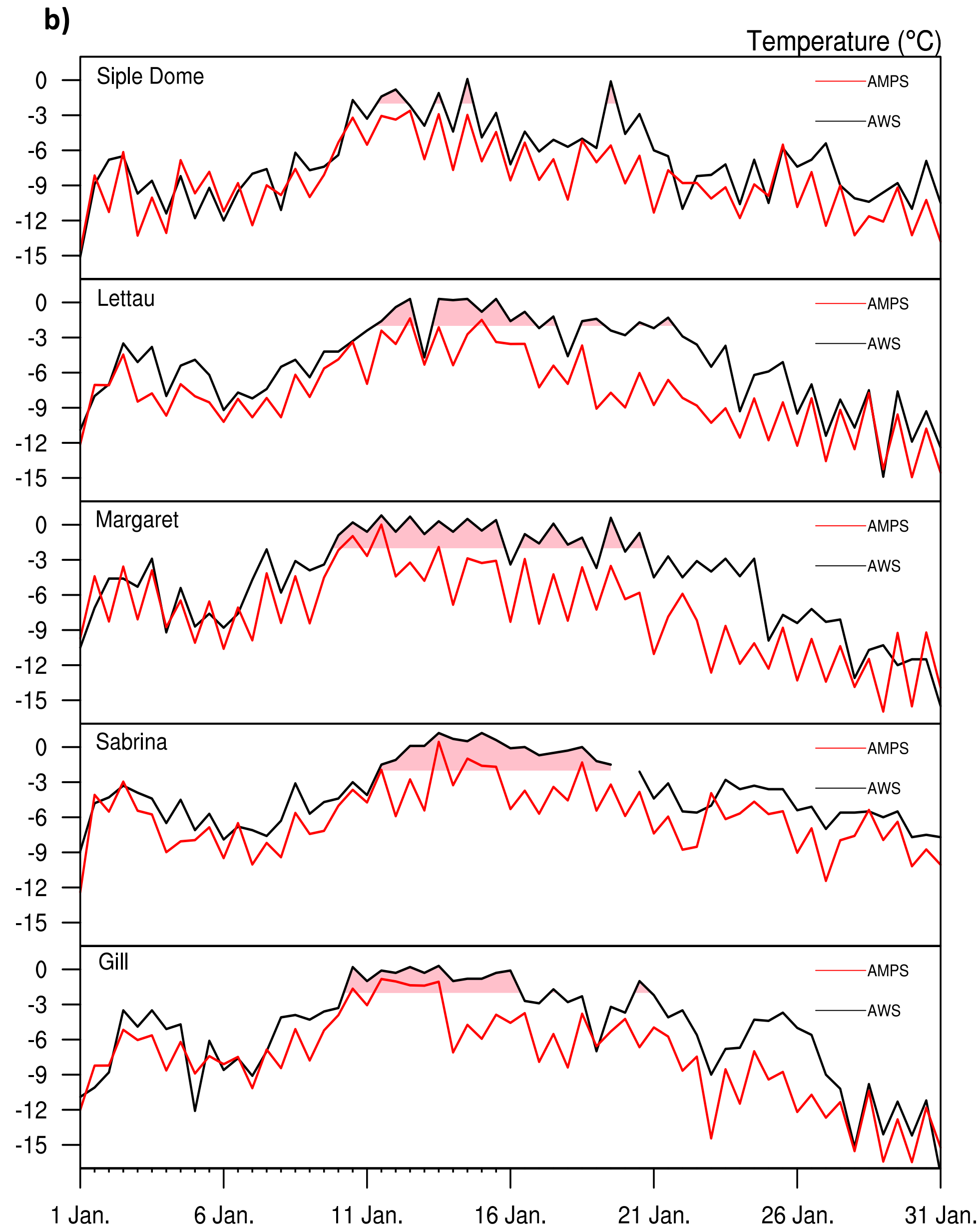
Foehn Effect

Signatures: temperature, wind, and precipitation have been analyzed to explore potential drivers of the surface warming.

Quantification: AMPS forecast data are used as input to run the trajectories via the Read Interpolate Plot (RIP4) software and track the movement of warm air parcels.

Comparison between AWS and AMPS





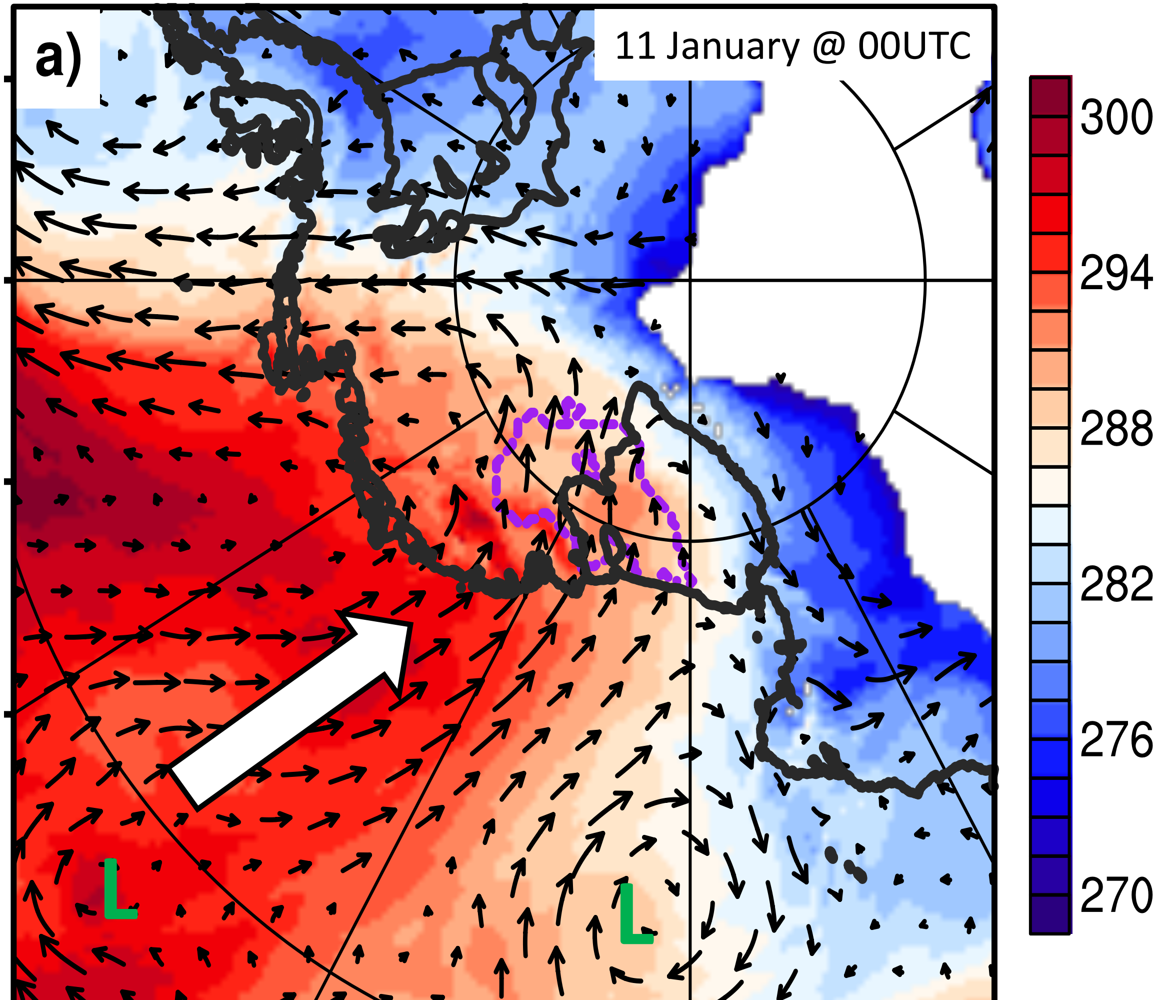
AMPS – AWS (January)

- Siple Dome: -2.0 ºC
- Lettau: -3.2 ºC
- Margaret: -3.8 ºC
- Sabrina: -2.4 ºC
- Gill: -2.9 ºC

AMPS data tends to underestimate the temperature by ~3 ºC during the 2016 melt event.

Synoptic Circulation during the Melt Event

700hPa Potential Temperature (K) and Wind Field



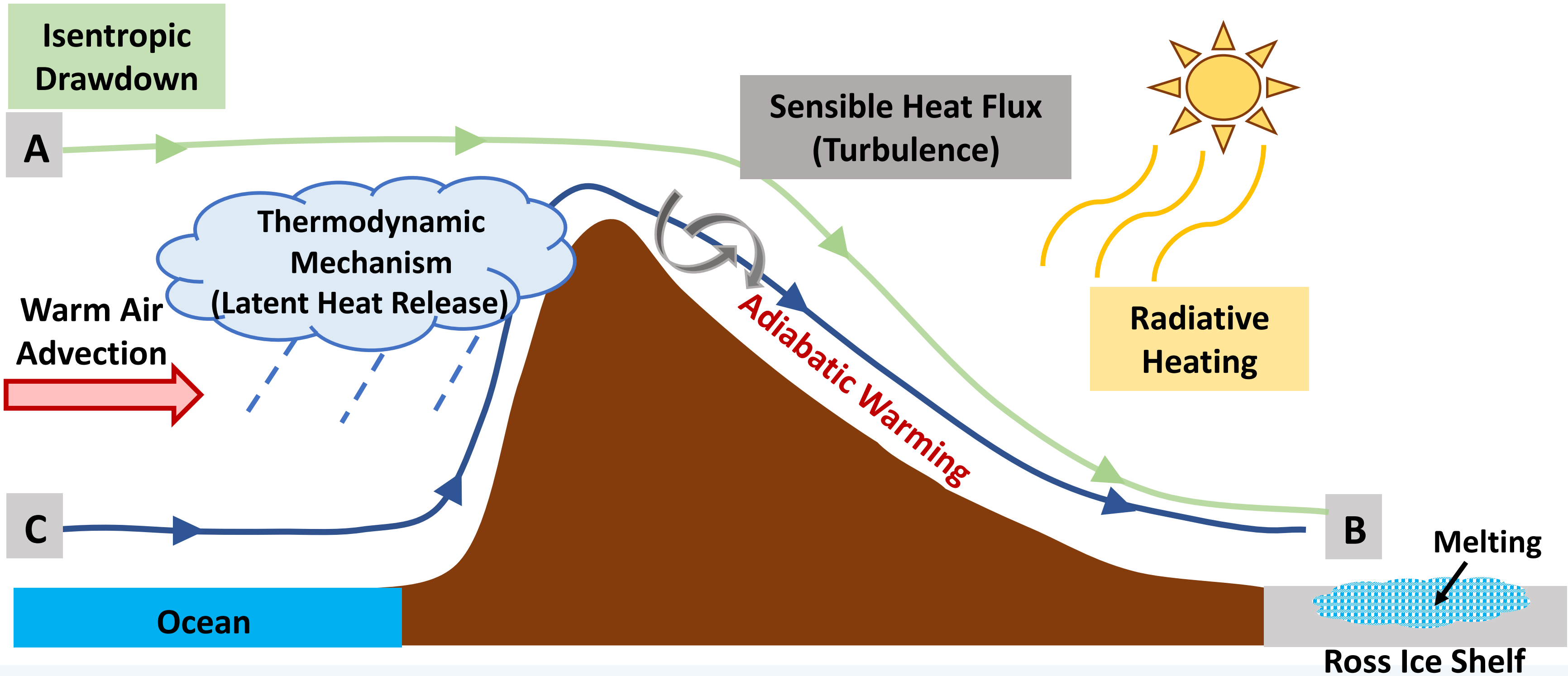
Purple dashed line represents the melting area

Amplified high-pressure ridge generated a strong north-south **warm air advection** towards West Antarctica (white arrow) (Nicolas et al, 2017).

Two cyclones were present over the Ross/Amundsen Sea region (labeled as L).

These brought **onshore wind** towards the coast of Marie Byrd Land.

Foehn Effect



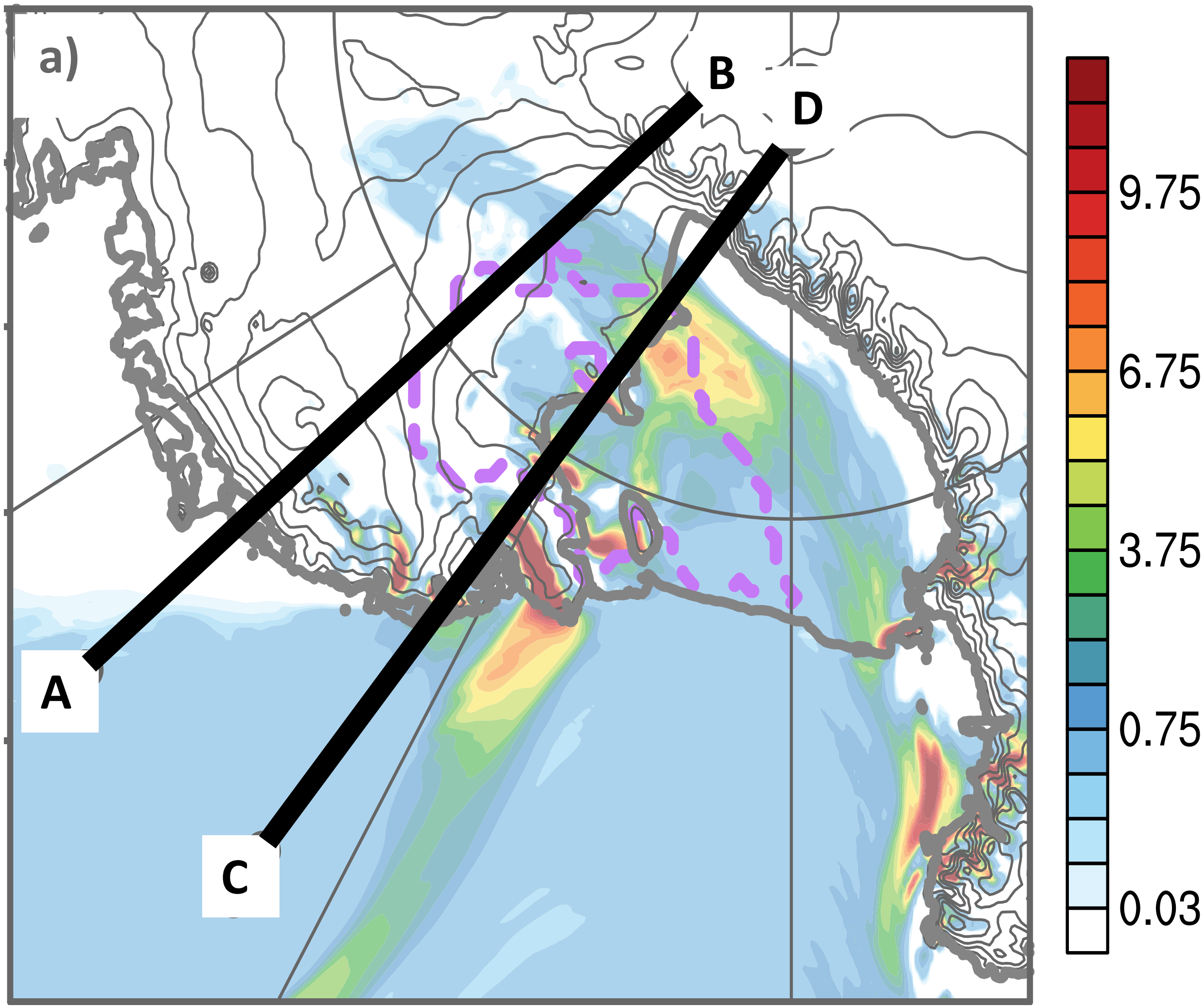
Elvidge and Renfrew (2016) proposed four mechanisms:

- **Thermodynamic Mechanism**: heat is released by **condensation** and absorbed by ice surface via **sublimation**.
- **Isentropic Drawdown**: **potentially warmer air** from higher level **climbs over** the mountain and **potentially colder air** from low-level is **blocked**.
- **Turbulence**: **transfer the sensible heat** into the lower foehn flow.
- **Radiative Heating**: **clear sky** on the leeside of mountains.

Total contribution of foehn effect = T_B-T_C

Foehn Effect - Signatures

12h accumulated precipitation (mm) at 00 UTC 11 January 2016

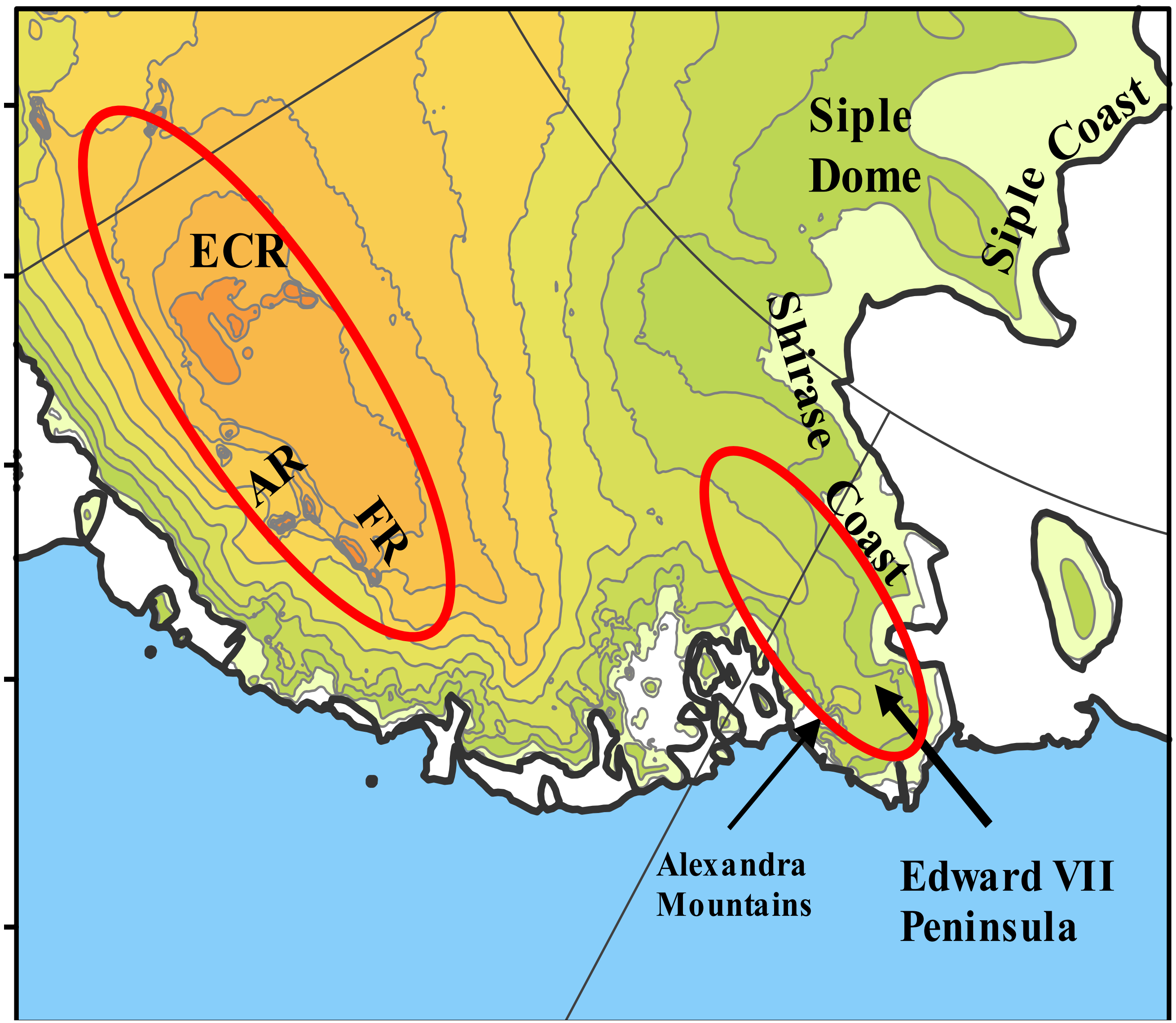


Precipitation on the upwind side of the mountains.

Two cross sections were selected for further analysis. **AB** crosses the higher elevations, while **CD** crosses the lower elevations.

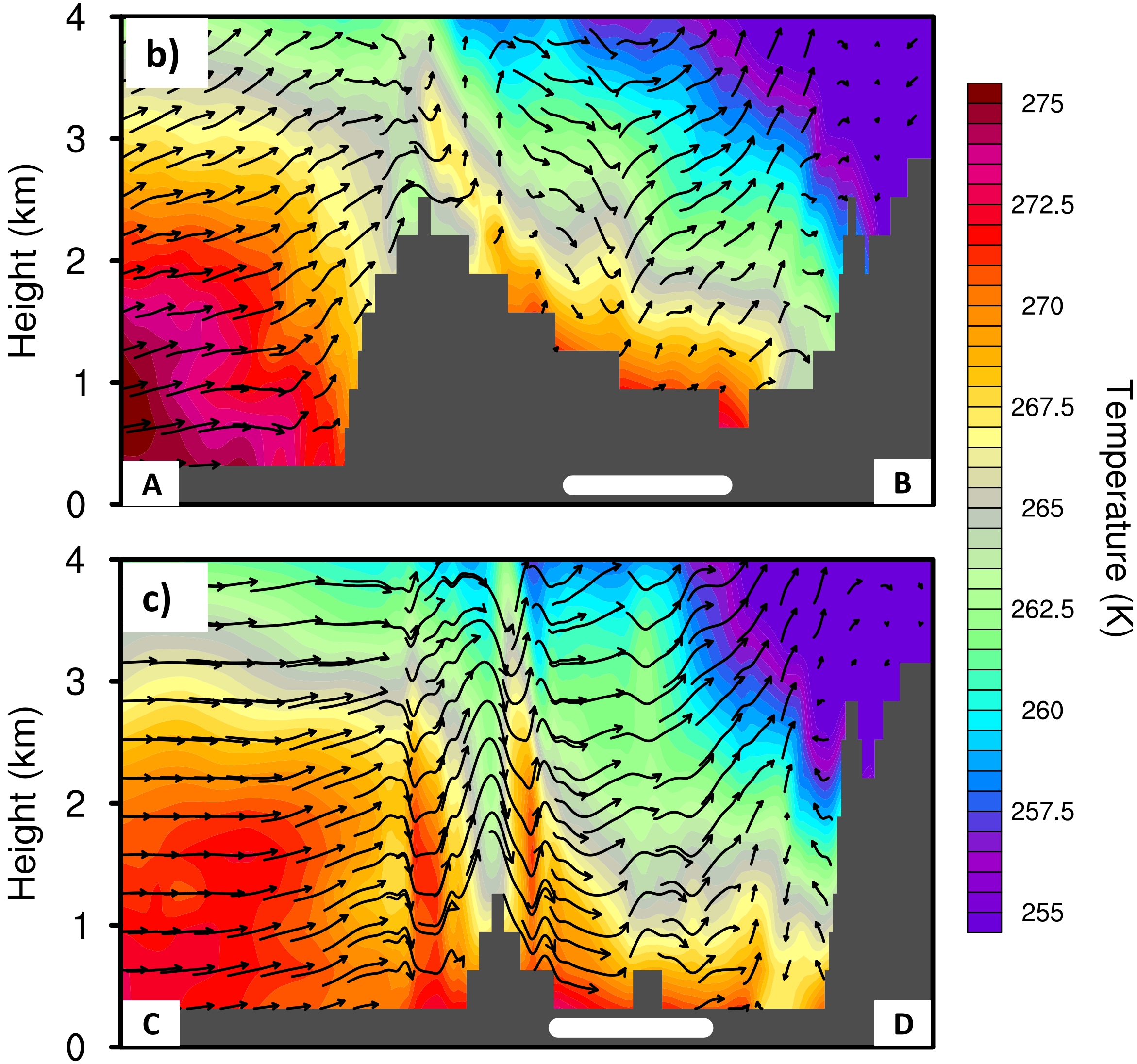
Foehn Effect - Signatures

Topography



Foehn Effect - Signatures

Cross Sections of Temperature and Wind on 11 January @ 00UTC

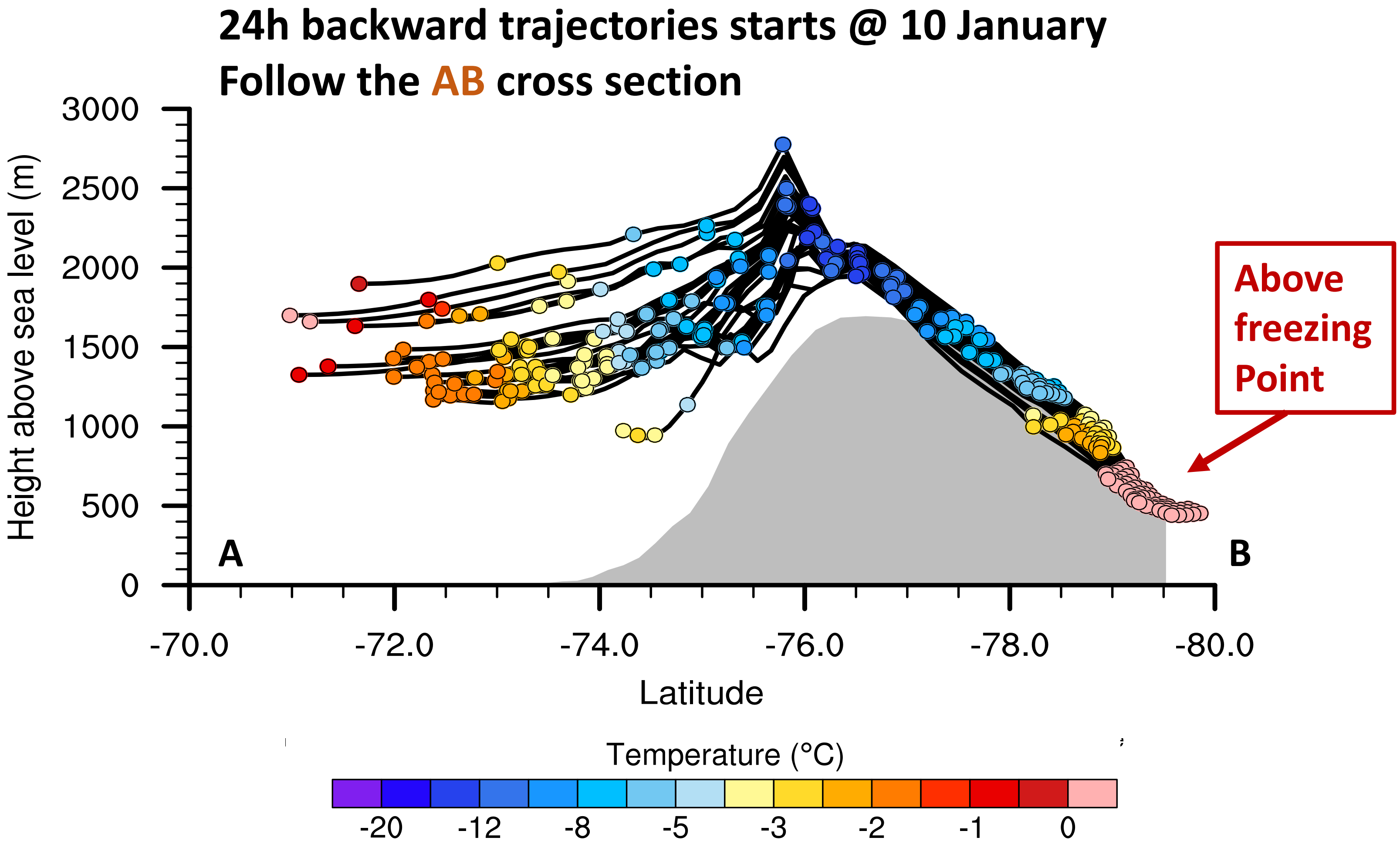


Grey area: Mountains
Black arrow: Wind
White line: Melting area.

There was **warm air advection** from the Amundsen Sea region.

There were **strong mountain waves** and **surface warming** on the leeside of the mountains.

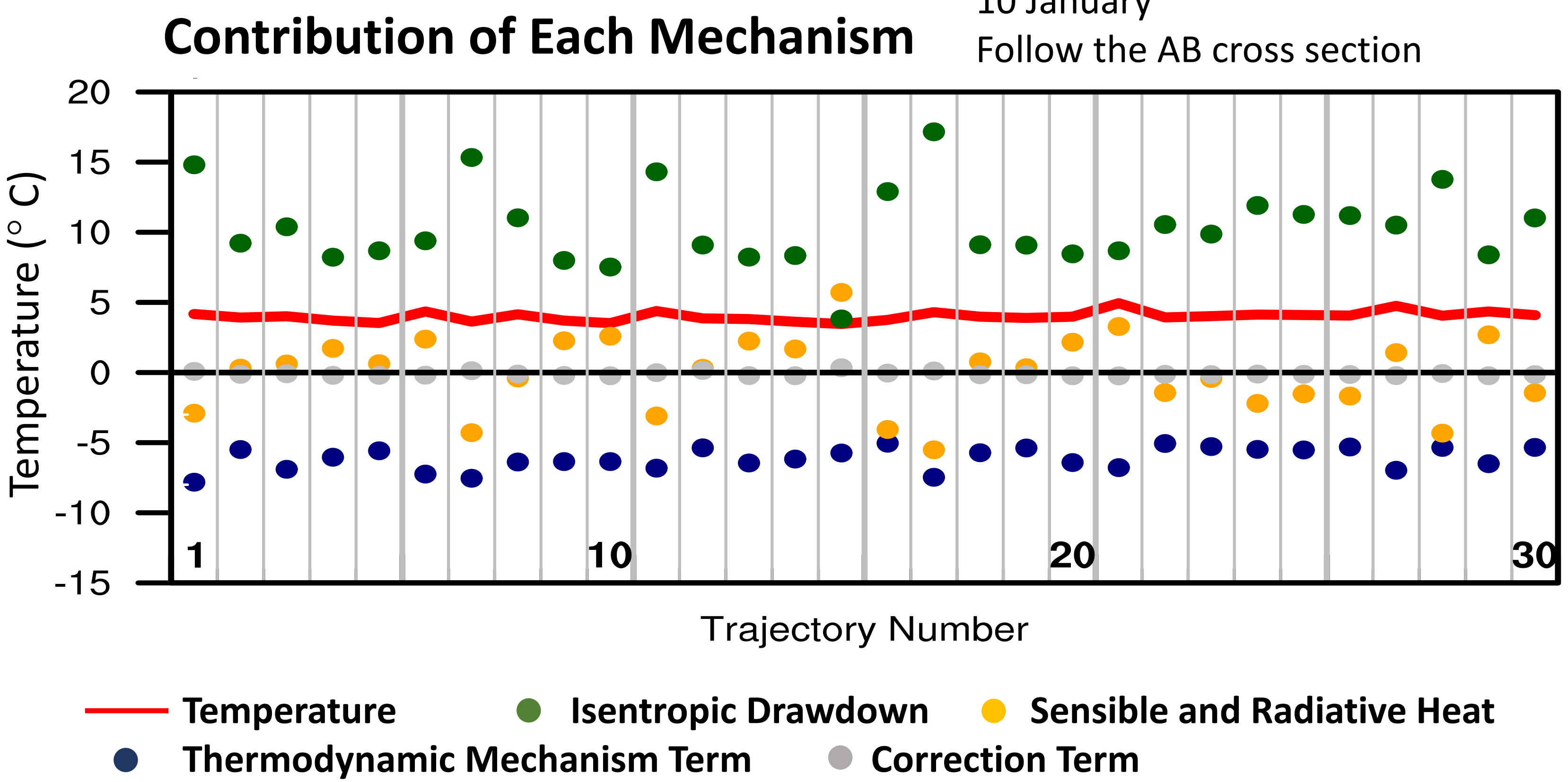
Foehn Effect – Quantification for AB



- On 10 January, warm air from upper levels on the upwind side moved towards the mountains, lifted by the topography, and then descended on the leeside.
- Total foehn warming: AB - around **4 °C**.

Foehn Effect - Mechanisms

10 January
Follow the AB cross section

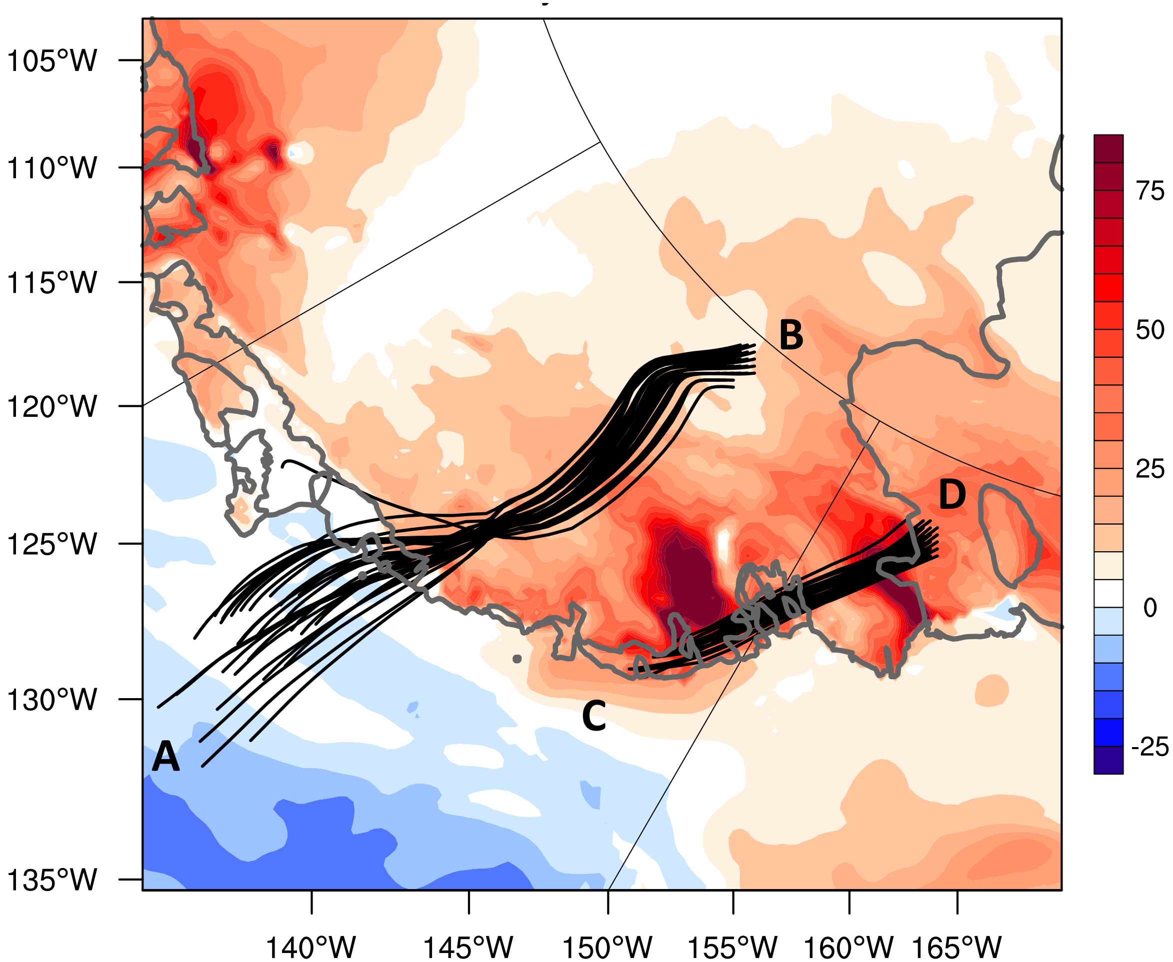


AB

- Dominant mechanism: **Isentropic Drawdown** (Green dots).
- **Thermodynamic Mechanism Term** is negative due to the **sublimation** along the trajectories (Navy blue dots). This hampers the foehn warming.

Foehn Effect - Mechanisms

Upward Latent Heat Flux (W m^{-2}) at 00UTC on 10 January



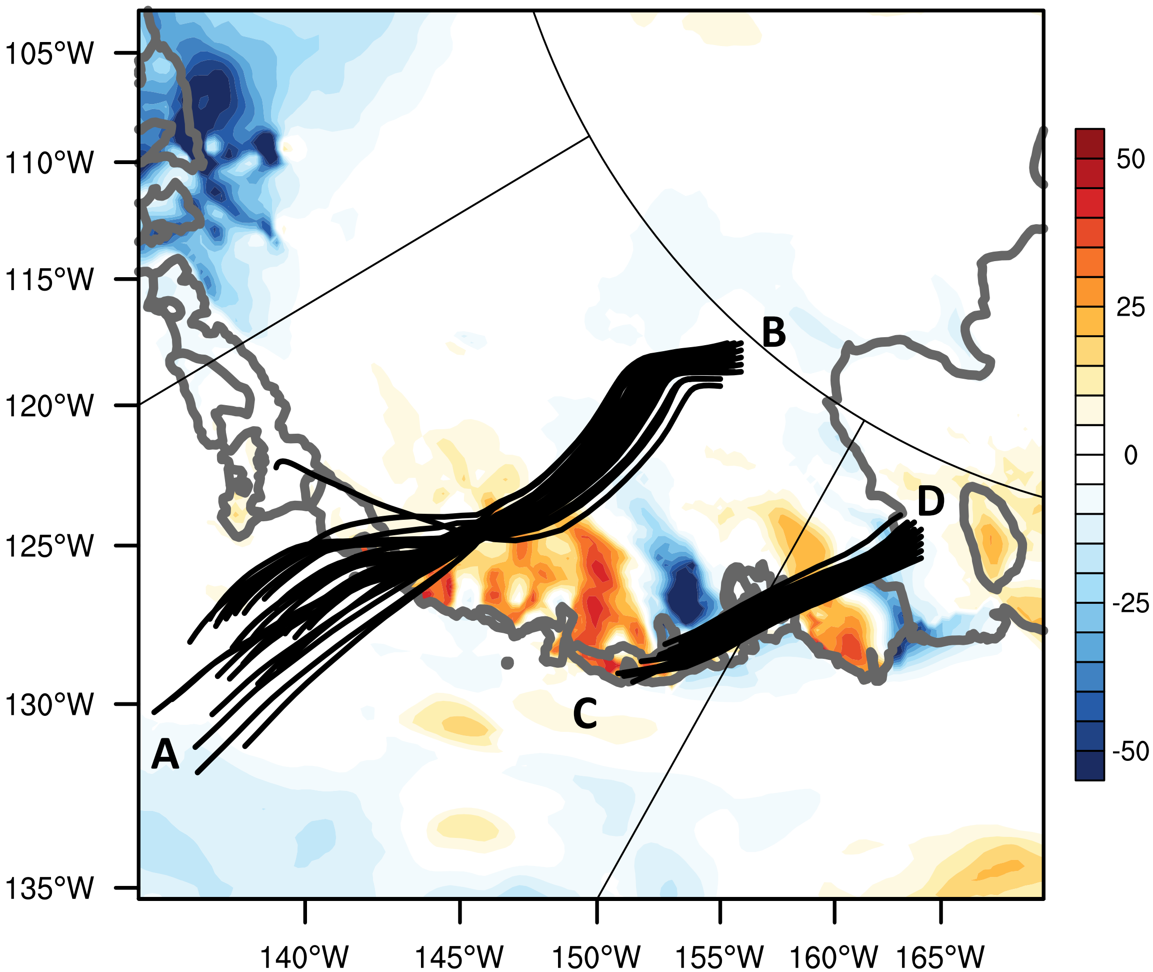
Red: A loss of latent heat from the surface – sublimation, evaporation, etc.

Blue: A gain of latent heat by the surface.

Ice surface loses energy via **sublimation** and the energy is carried away by the wind. The energy loss in the course of sublimation is made up by **sensible heat** gain.

Foehn Effect - Mechanisms

Upward Sensible Heat Flux (W m^{-2}) at 00UTC on 10 January



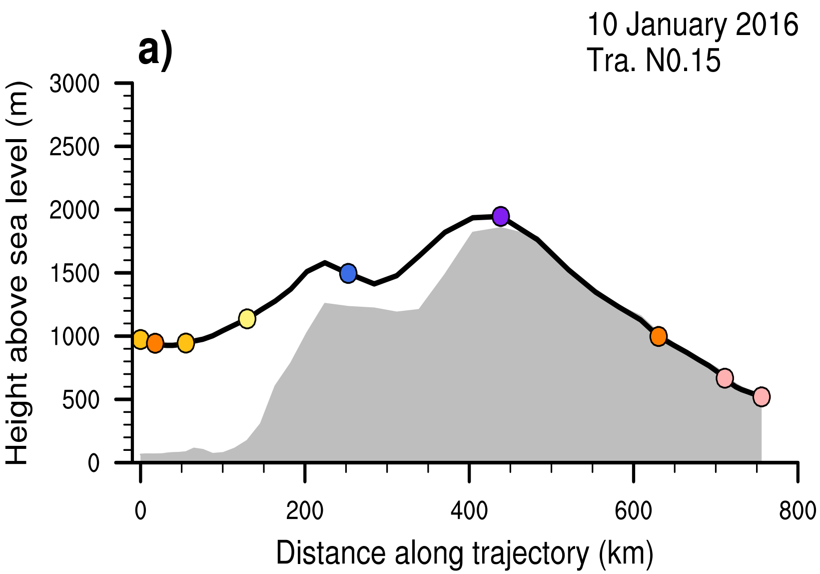
Red: A loss of sensible heat from the surface.

Blue: A gain of sensible heat by the surface. – **Warmer and drier** foehn wind descends on the leeside of the mountains and transfers the heat to the surface.

Heat transfer might be enhanced by the strong **turbulence.**

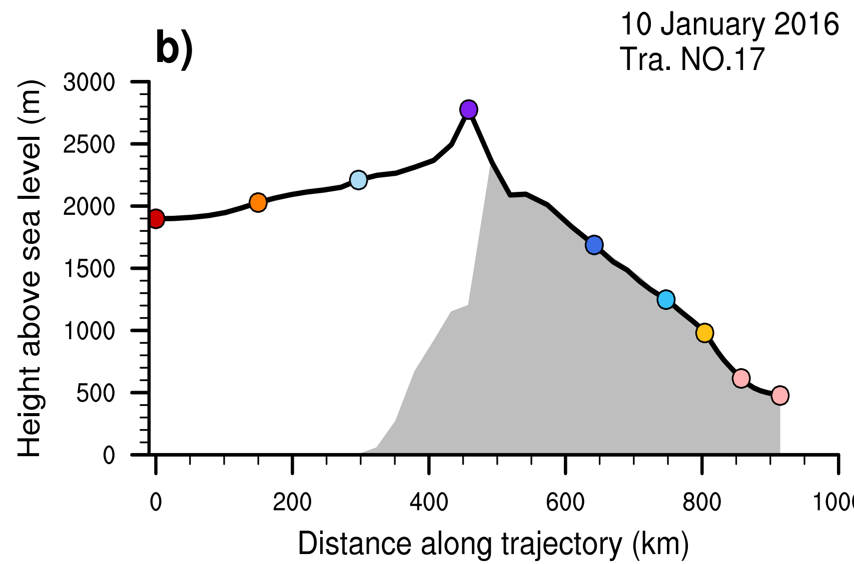
Foehn Effect - Mechanisms

Positive Sensible and Radiative Heat Flux Term



- The terrain on the upwind side is **gentler**.
- Over the **peak** of the mountain, the air flow is **closer** to the surface.

Negative Sensible and Radiative Heat Flux Term



- The terrain on the upwind side is more **precipitous**.
- Over the **peak** of the mountain, the air flow is **further** above the surface.

Conclusions

- The **foehn effect** has contributed to the surface warming and subsequent melting at the beginning of the melt event (up to 4 °C).

- The **strength** of the leeside foehn warming is related to the **dominant mechanisms**. In 2016 melt event, the dominant mechanism was **isentropic drawdown**. **Thermodynamic term** is negative and significantly compensates the foehn effect mainly because of the **sublimation**.

- The detailed mechanisms that contributed significantly to the foehn effect depend on:
  - **Topography**
  - The **wind** speed and direction

  Further research is necessary to explain how the different topographic features affect mechanisms of the foehn warming, especially the sensible and radiative heat flux.

References:

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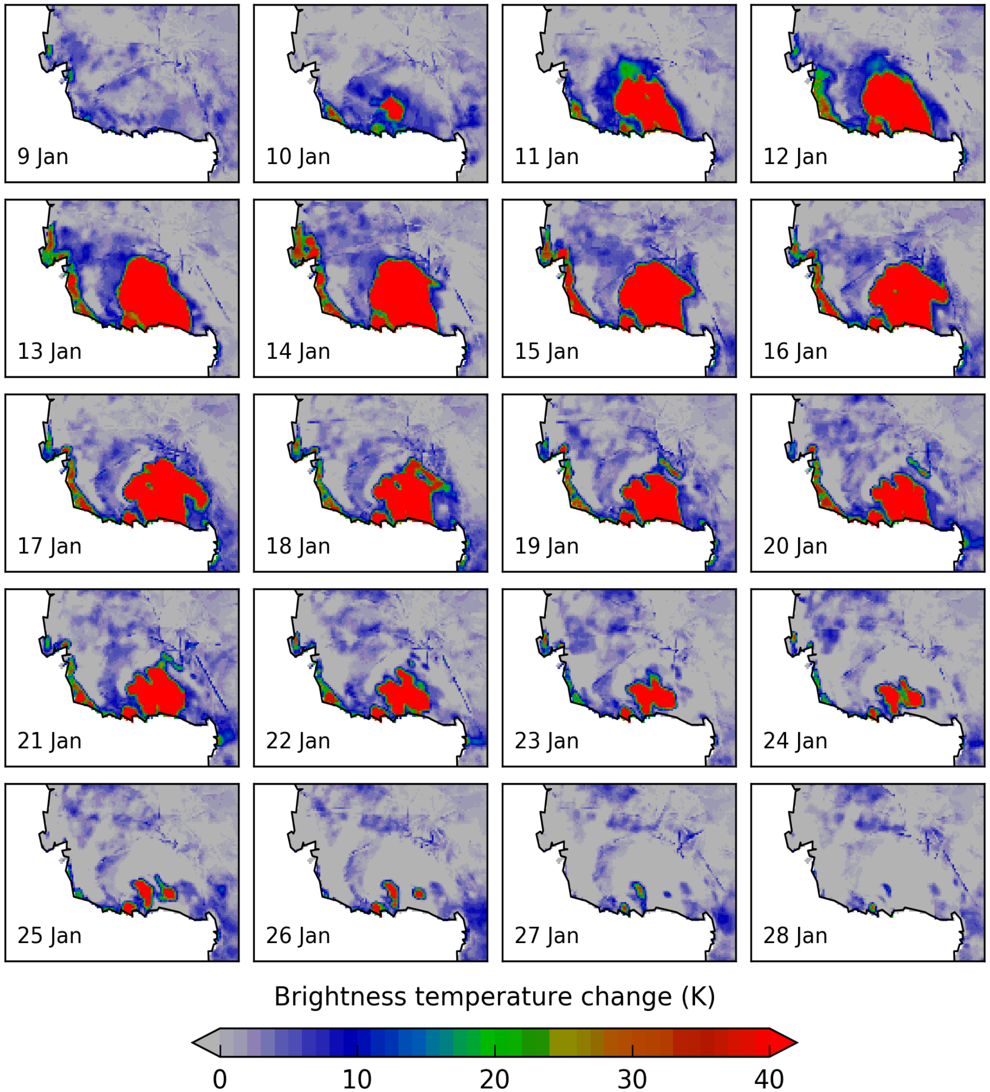
- DeConto RM, Pollard D. 2016. Contribution of Antarctica to past and future sea-level rise. Nature 531(7596): 591–597.
- Elvidge AD, Renfrew IA. 2016. The causes of foehn warming in the lee of mountains. *Bull. Am. Meteorol. Soc.* 97(3): 455–466.
- Nicolas JP, Vogelmann AM, Scott RC, Wilson AB, Cadeddu MP, Bromwich DH, Verlinde J, Lubin D, Russell LM, Jenkinson C, Powers HH, Ryczek M, Stone G, Wille JD. 2017. January 2016 extensive summer melt in West Antarctica favoured by strong El Niño. *Nat. Commun.* 8: 15799.

Thank you!

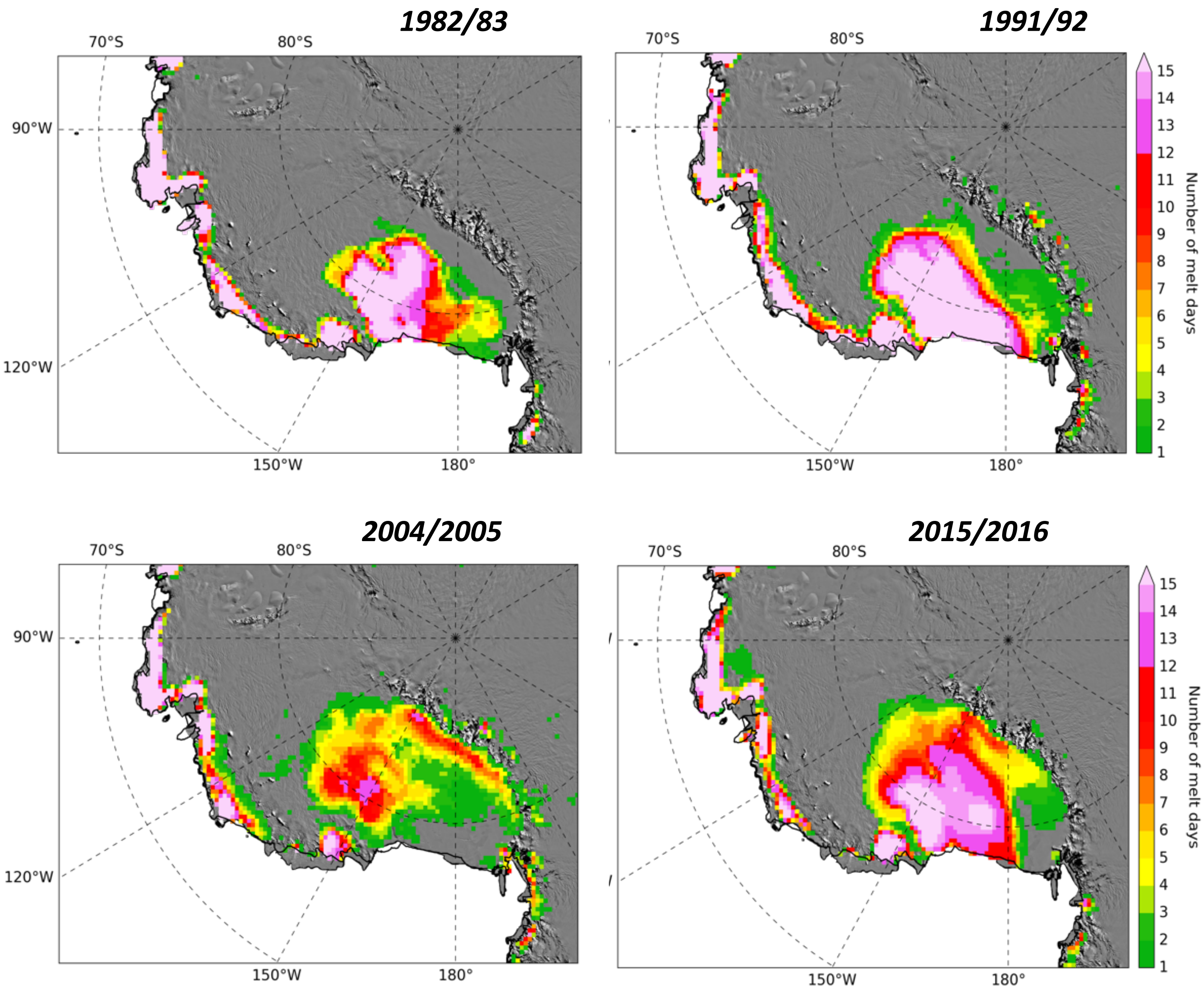
Q&A:

Daily melt maps



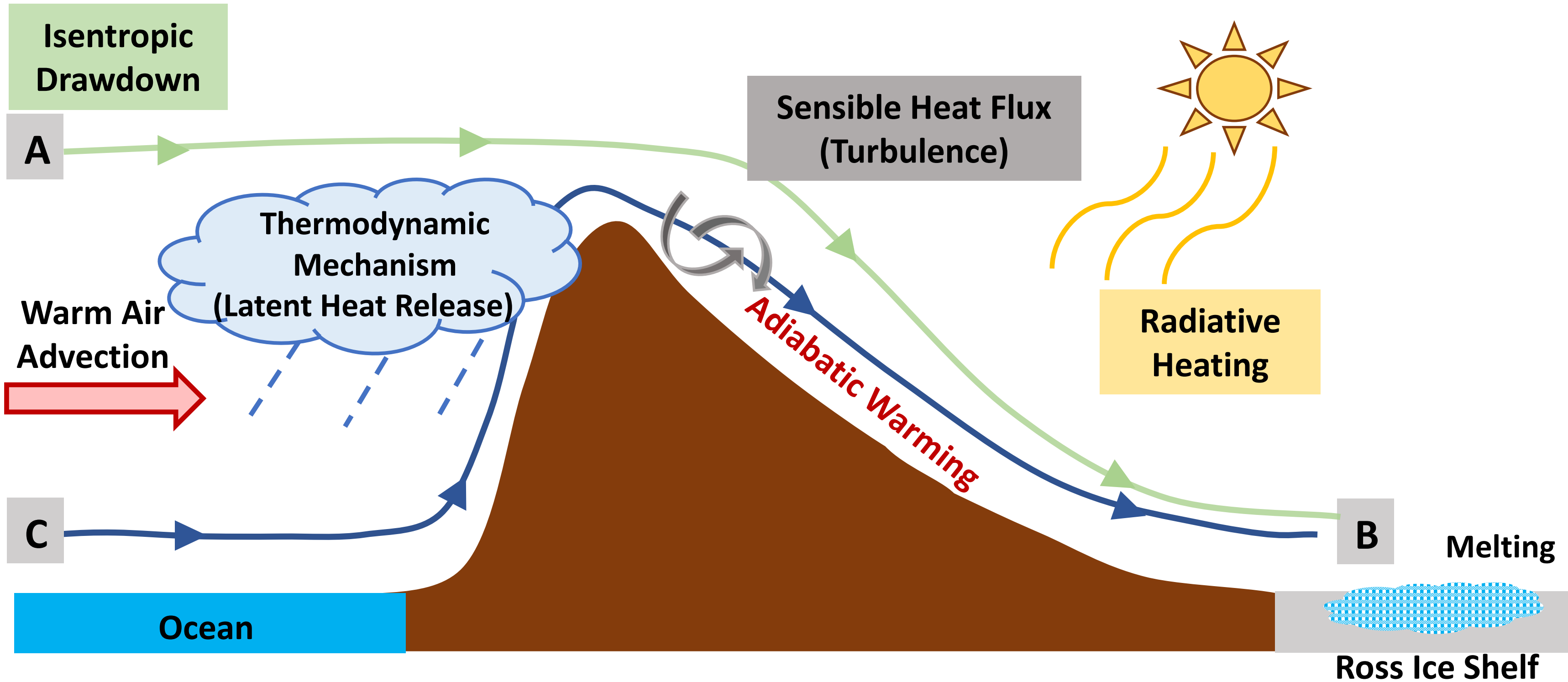
Surface Melting Map from 09 January 2016 to 28 January 2016 (Data and Figure courtesy of J. Nicolas)

Historical Melt Events



Data based on satellite observations provided by NSIDC, data and figure processed by Julien. P Nicolas

Quantification Calculation



$$\mathrm{TC} = T_B - T_C$$

$$\mathrm{ID} = \theta_A - T_C$$

$$\mathrm{TM} = (\theta_B - \theta e_B) - (\theta_A - \theta e_A)$$

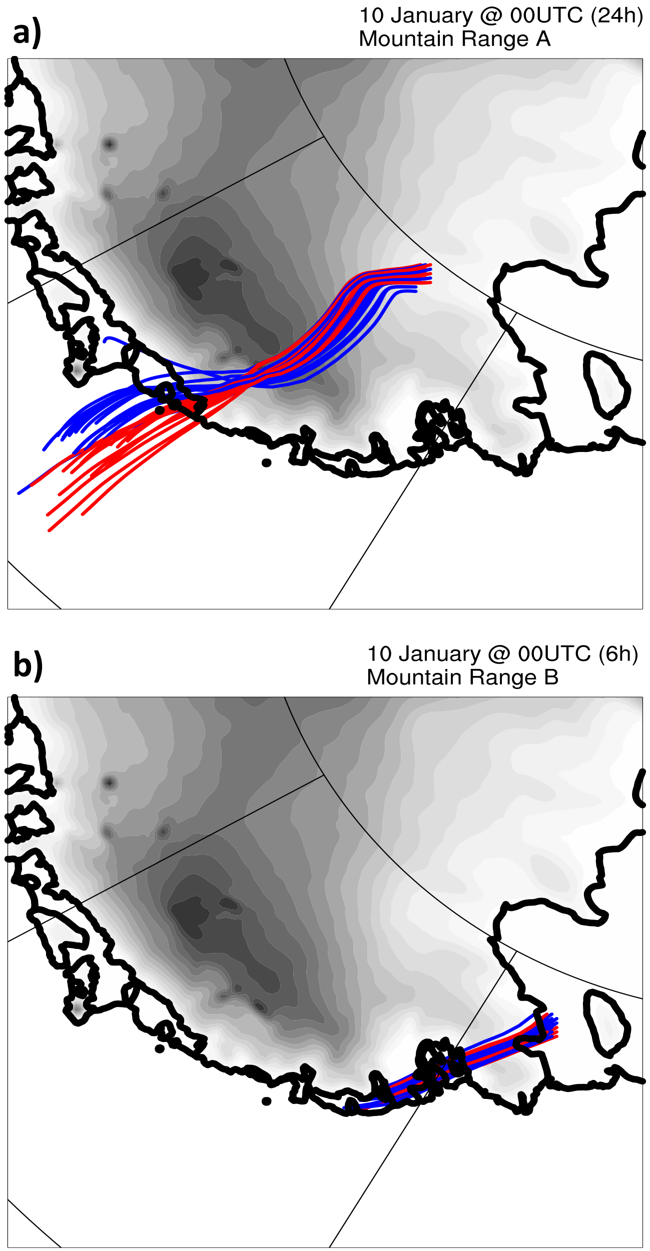
$$\mathrm{SHF} = (\theta e_B - \theta e_A - \int_A^B \Delta^{RH}\,\theta)$$

$$\mathrm{RH} = \int_A^B \Delta^{RH}\,\theta$$

$$\mathrm{CT} = T_B - \theta_B$$

$$\mathrm{TC} = \mathrm{ID} + \mathrm{TM} + \mathrm{SHF} + \mathrm{RH} + \mathrm{TC}$$

Horizontal view of all trajectories



Temp, RH, Wind Speed change along the trajectories