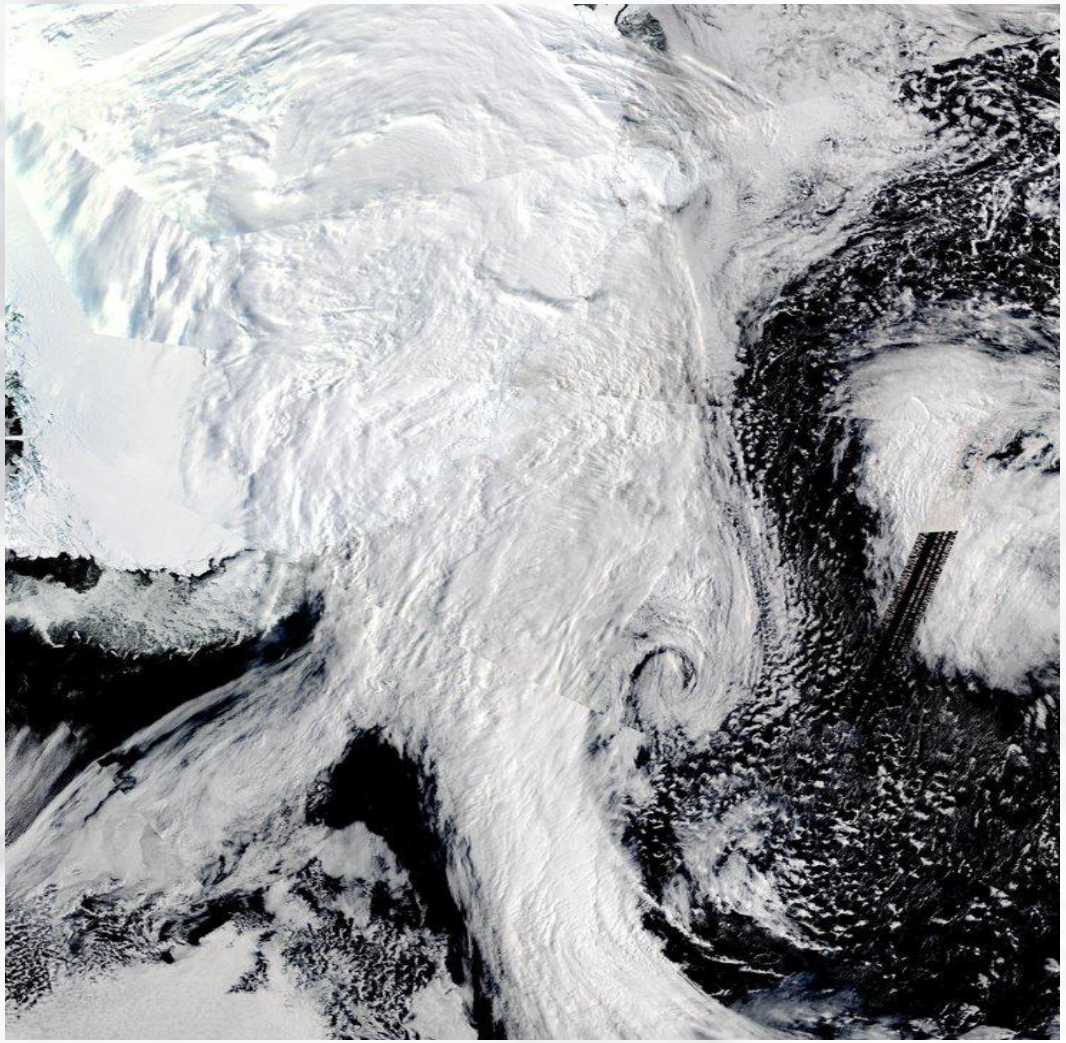
Atmospheric Rivers Impact on Antarctic Climate



Christine A. Shields
NSF NCAR/CATALYST

Michelle Maclennan
British Antarctic Survey

Jonathan Wille
ETH, Zurich, Switzerland

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CU, Boulder

CESM Polar Climate Working Group

March 4th, 2025

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catalyst

Overview

- Definition and Mechanisms
- Climatology, Trends
- Model simulations

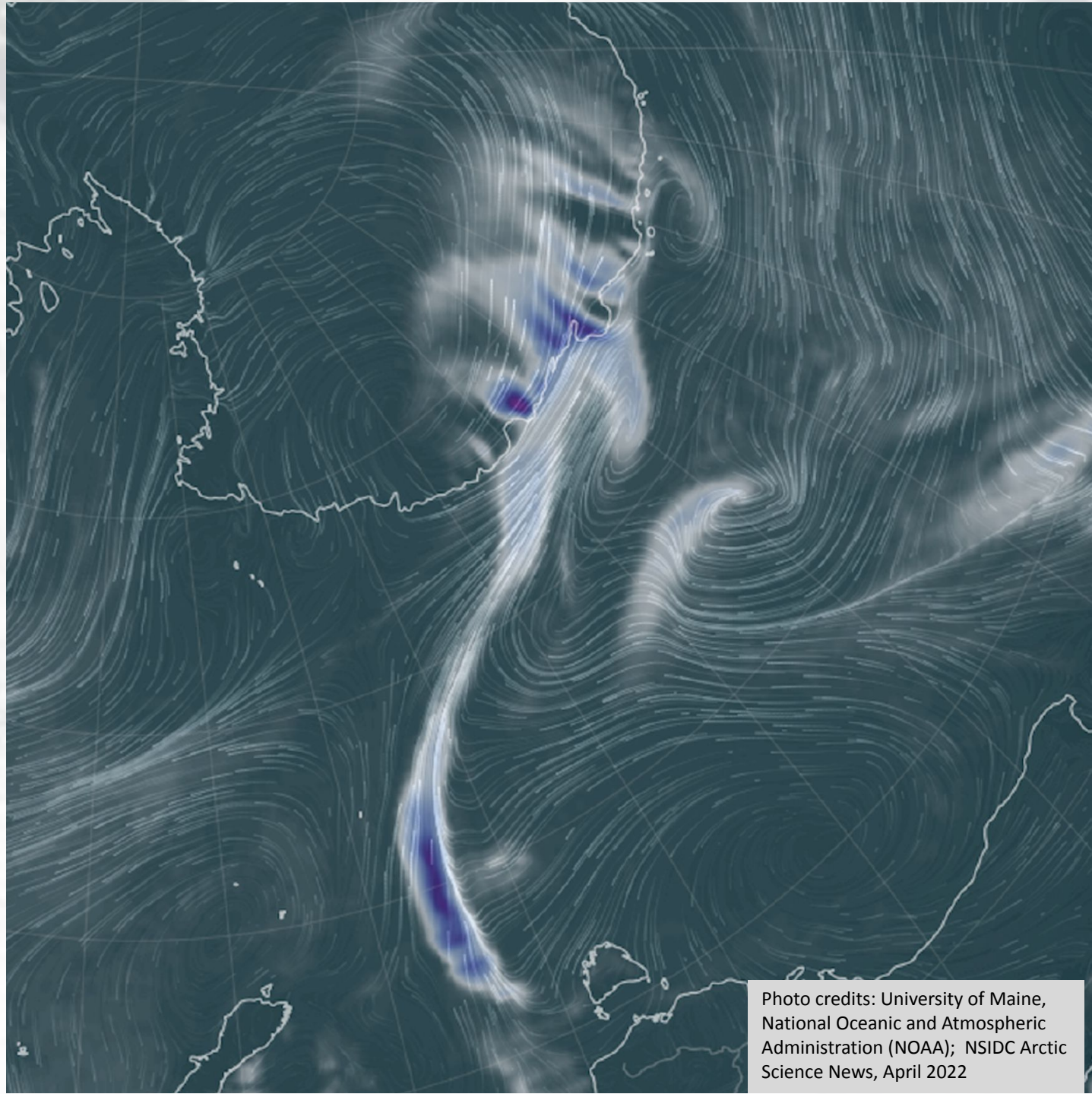

Photo credits: University of Maine, National Oceanic and Atmospheric Administration (NOAA); NSIDC Arctic Science News, April 2022

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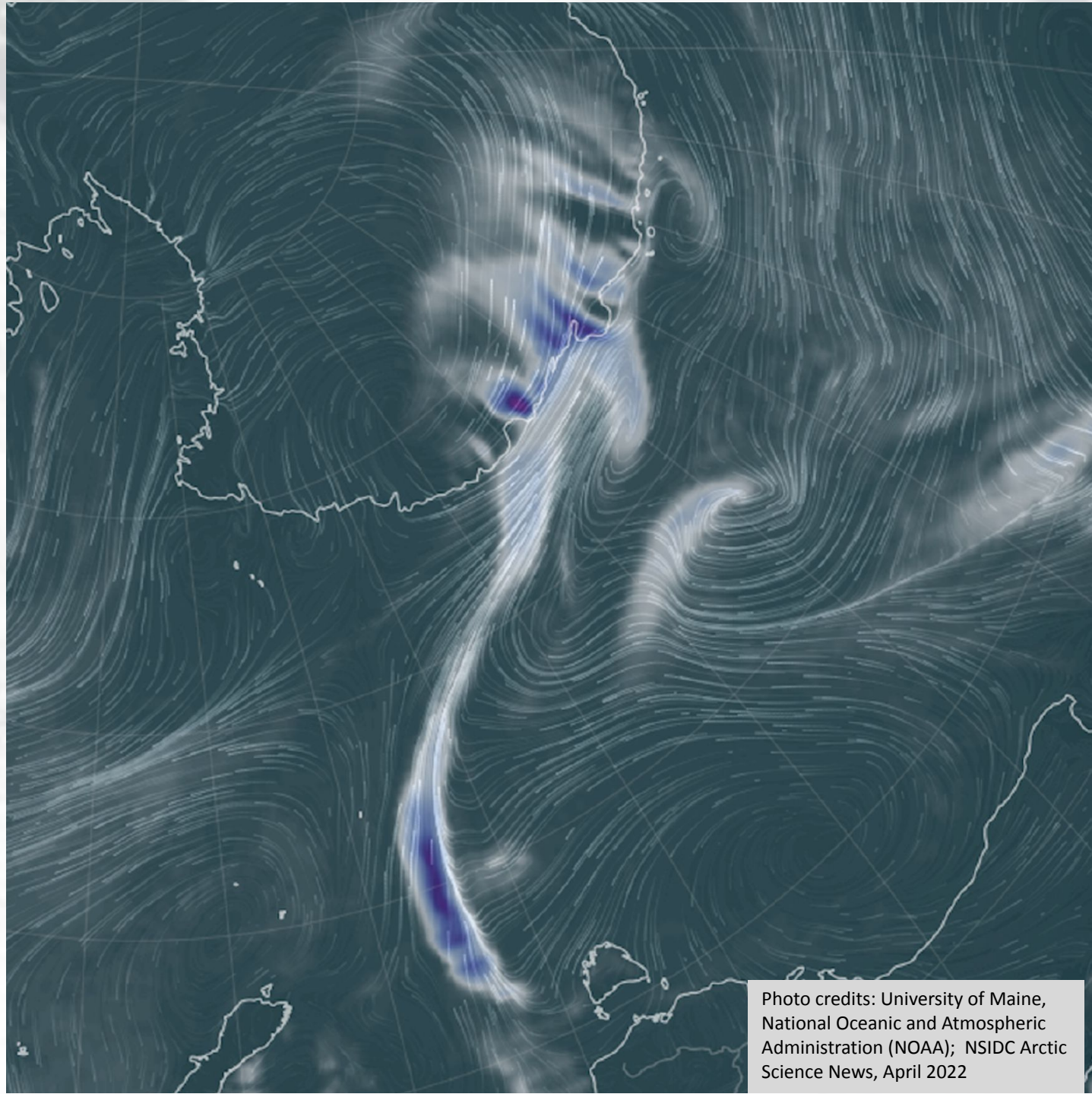

Photo credits: University of Maine, National Oceanic and Atmospheric Administration (NOAA); NSIDC Arctic Science News, April 2022

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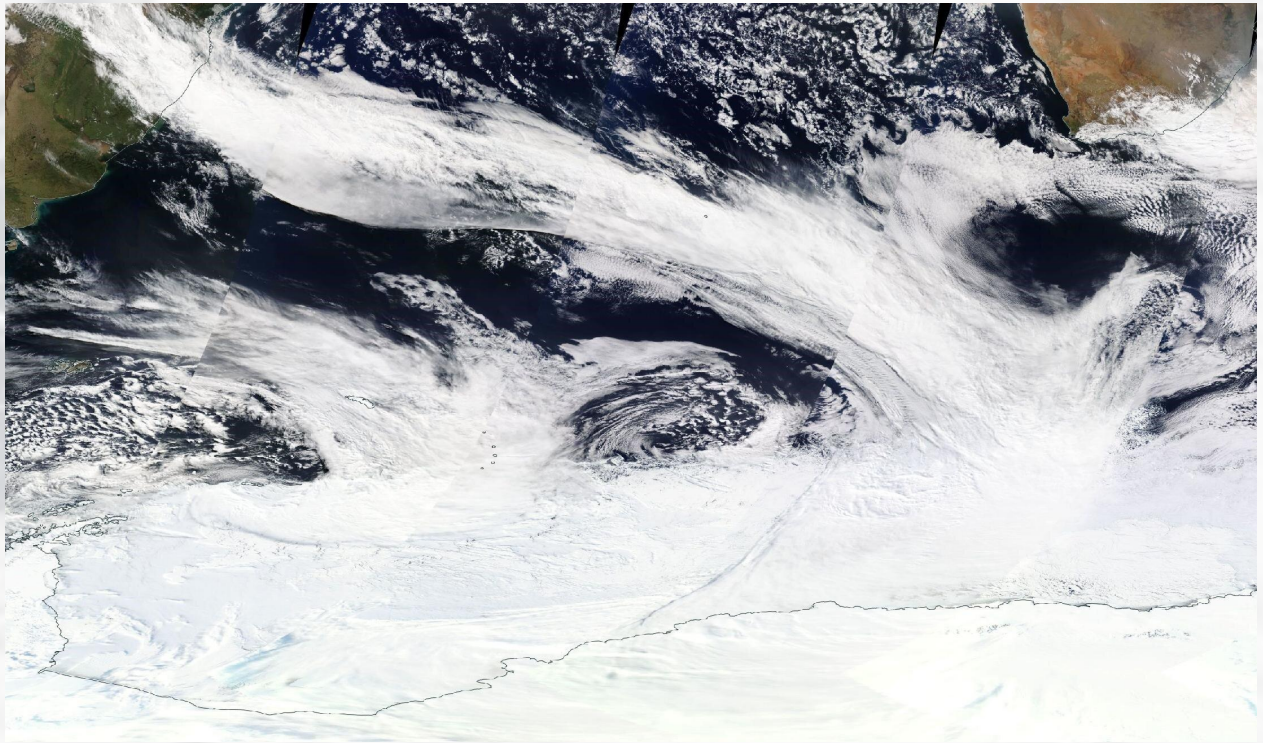
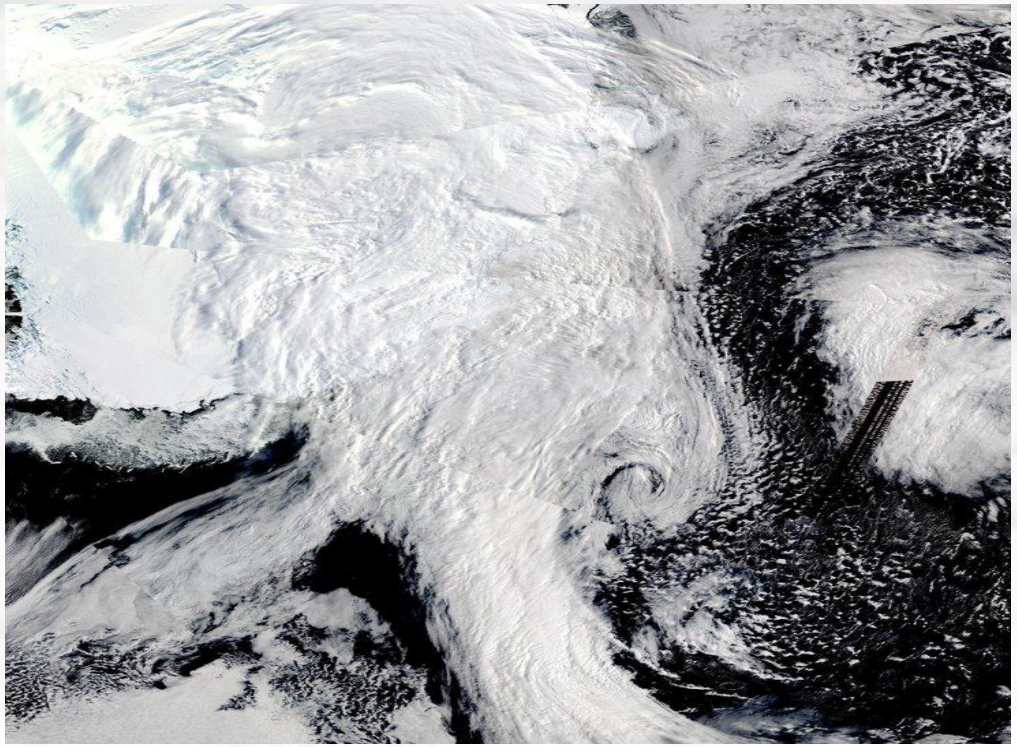
Identification via satellites: “I’ll know it when I see it”



Antarctic sea ice zone on 16, Sep 2017

Credit: NASA



East Antarctic heat wave, 17 Mar 2022

https://worldview.earthdata.nasa.gov/

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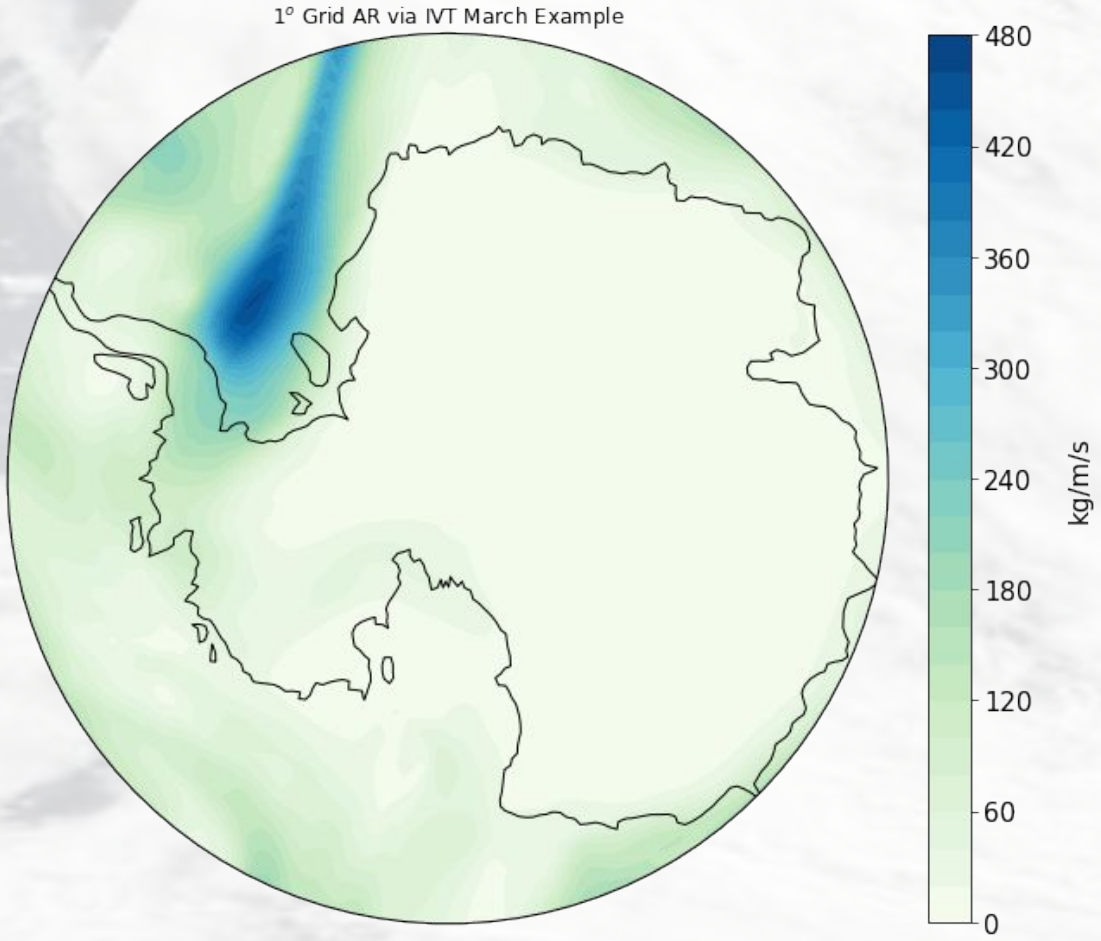
Identification in models/gridded datasets: ARDTs



ARDTs (Atmospheric River Detection Tools)

For polar locations, meridional–dominant is necessary to capture ARs on the ice sheet

Wille et al. 2019, 2021, Shields et al. 2022. focus on meridional geometry; 98th percentile vIVT (relative to climatology)

$$vIVT = -\frac{1}{g}\int_{surface}^{top} (q\ v_h)\ dp$$

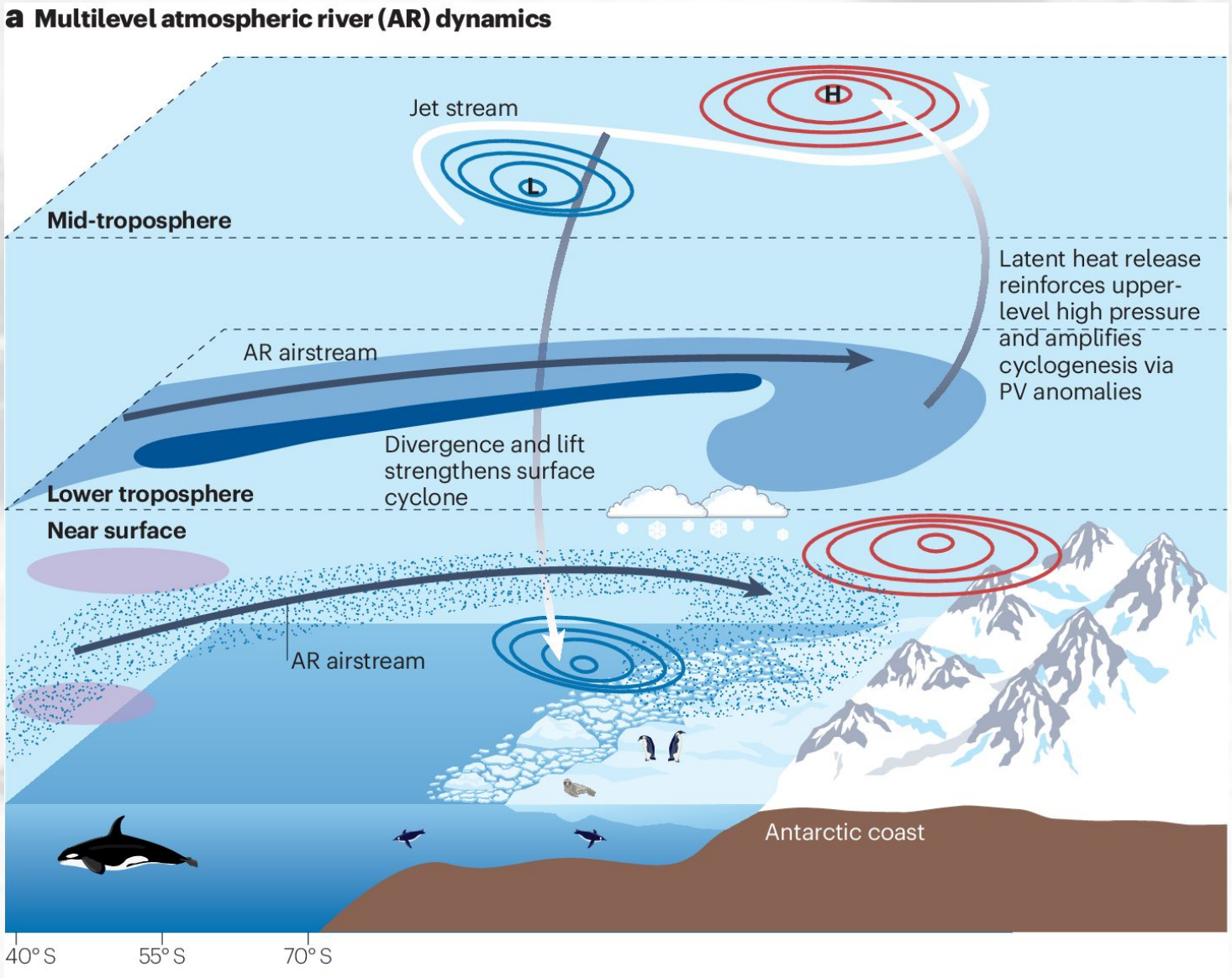
This is different from most global ARDTs equally weight zonal and meridional moisture transport and fluxes.

$$IVT = -\frac{1}{g}\int_{Pb}^{Pt} (q\ \boldsymbol{V}_h)\ dp$$

$$IWV = -\frac{1}{g}\int_{Pb}^{Pt} q\ dp$$

where $\boldsymbol{V}_h$ = U and V represent zonal and meridional components of the horizontal ($_h$) wind

Dynamical Drivers



Wille et al., NREE, 2025

- ✔ Surface and upper level feedbacks strengthen AR and impacts, synoptic scale
- ✔ Often associated with cyclone dynamics
- ✔ Important mesoscale processes connected to mountain meteorology

catalyst

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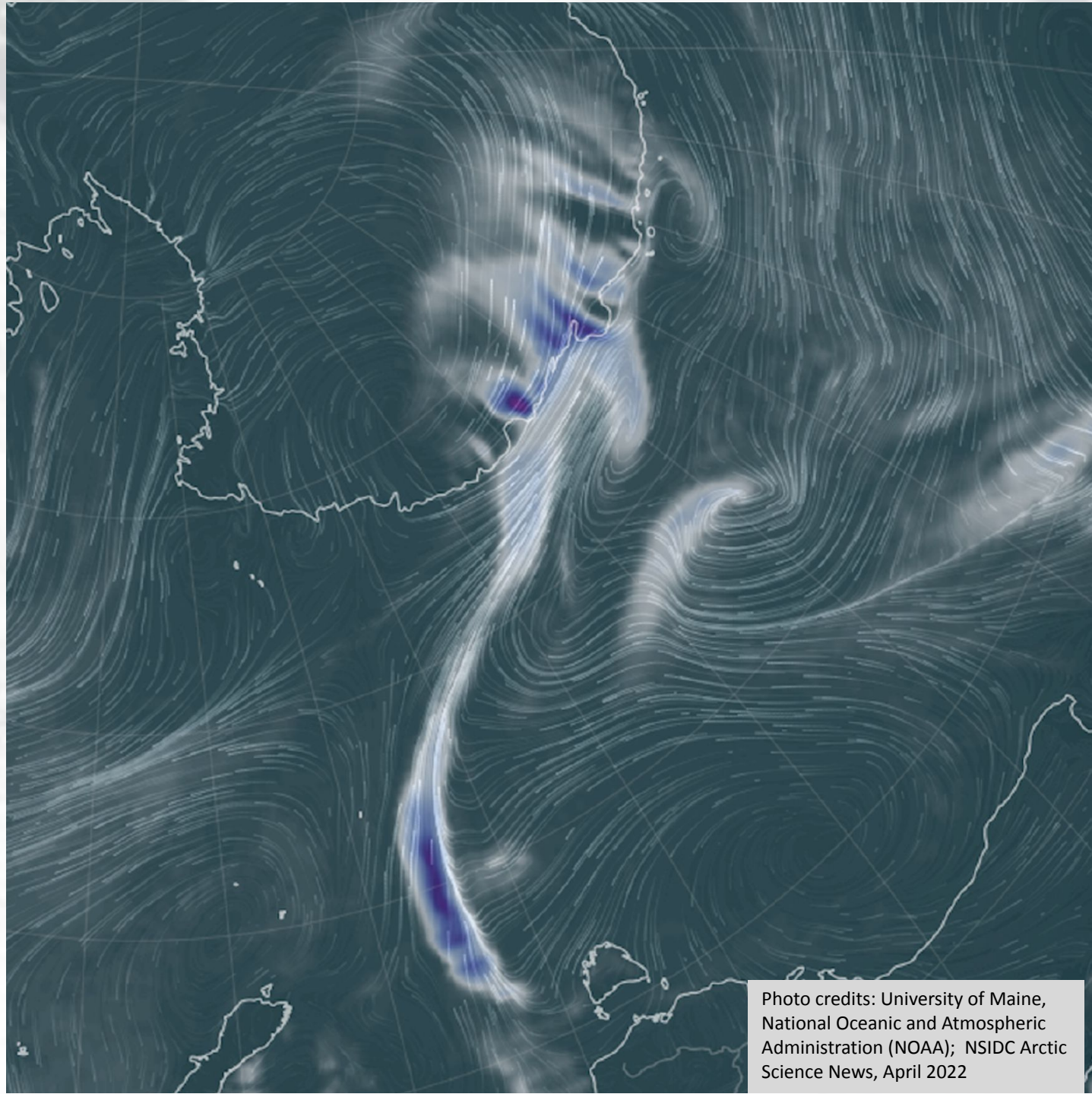

Photo credits: University of Maine, National Oceanic and Atmospheric Administration (NOAA); NSIDC Arctic Science News, April 2022

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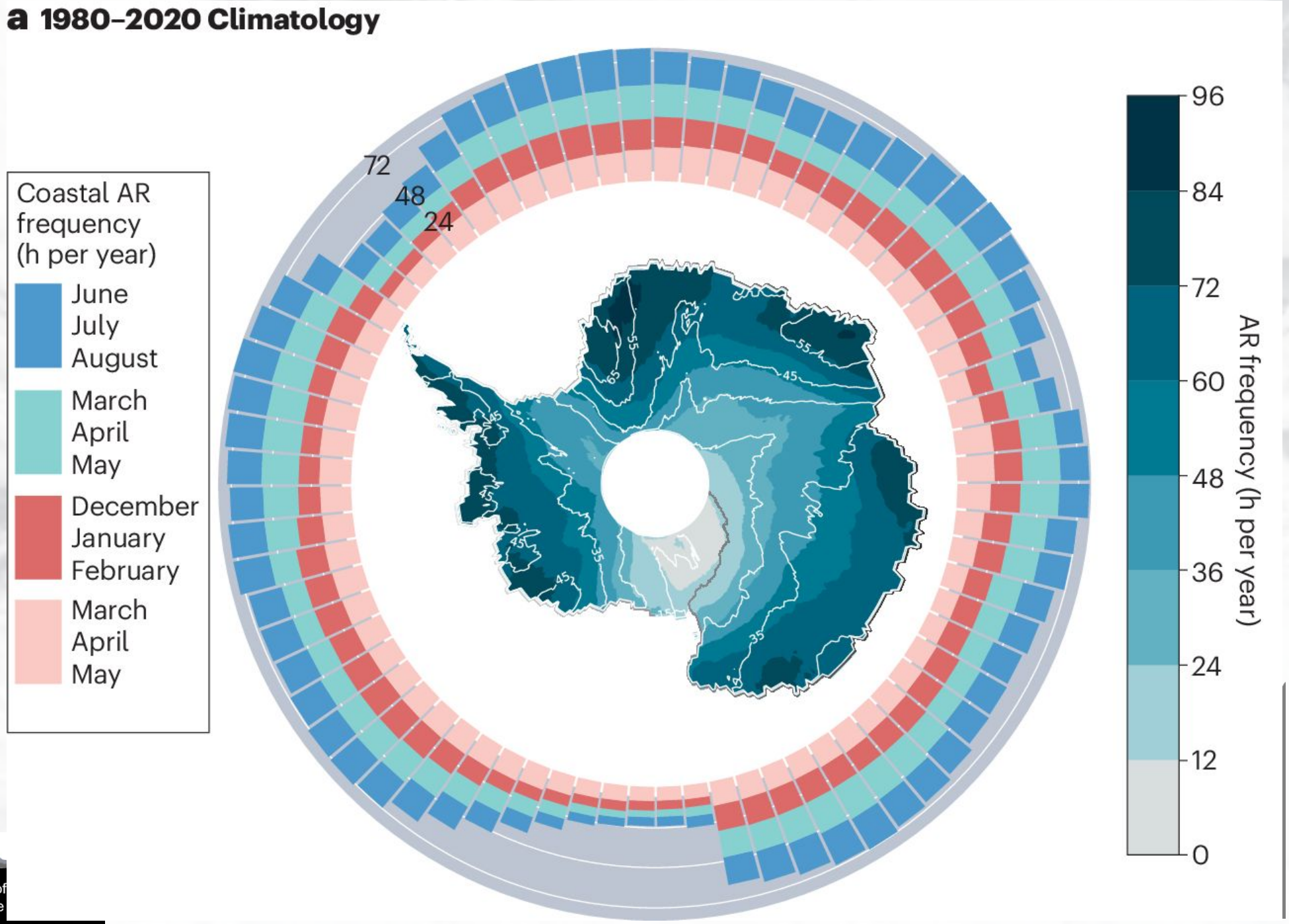
AR Climatology

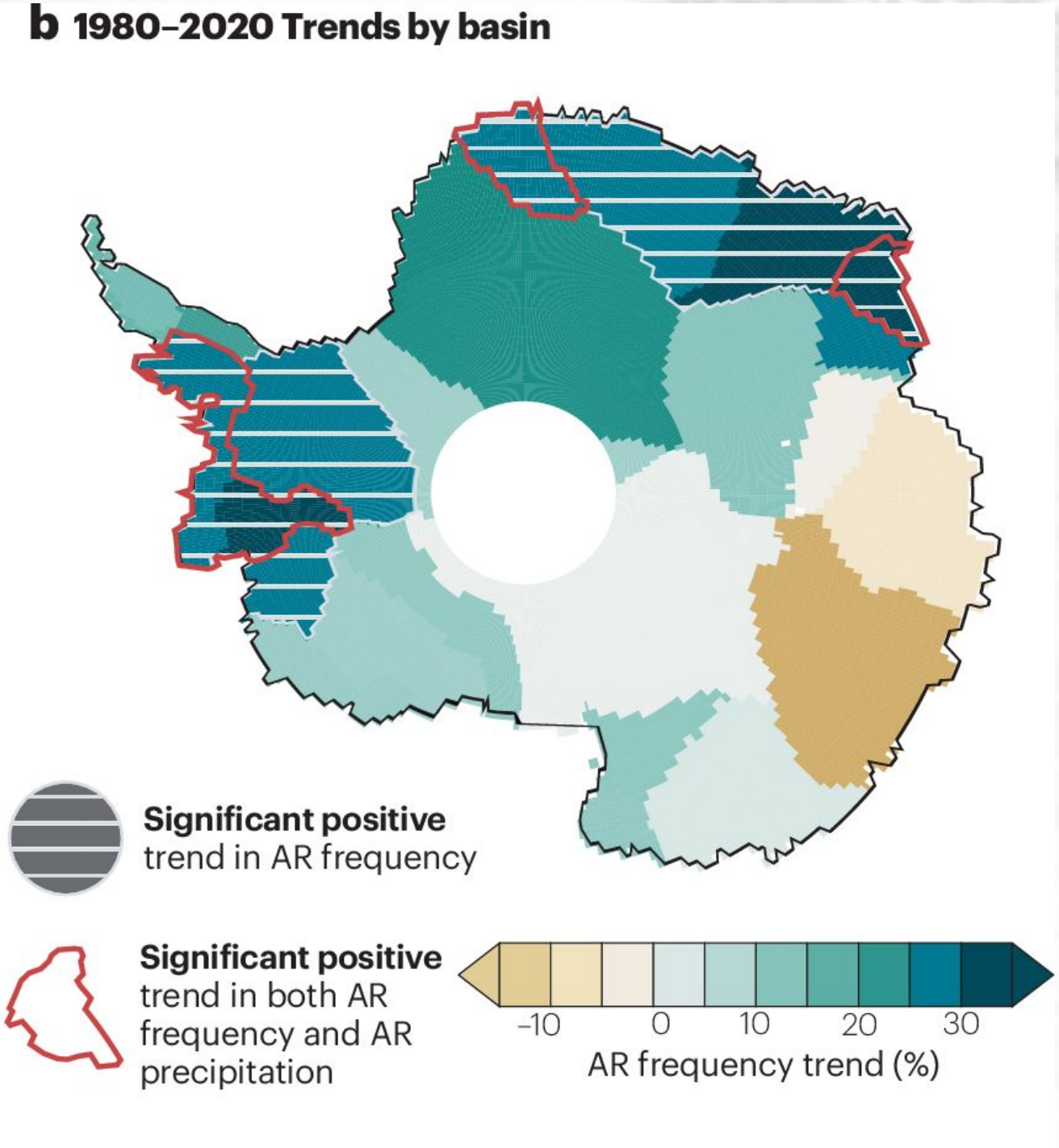
MERRA-2

Seasonal and regional variations

Hours per year

Wille et al, 2025,
Baiman et al 2024.





AR Trends by Basin

MERRA-2

Large differences by region

Hotspots in both West and East Antarctica but different processes

Wille et al, 2025, Maclennan et al 2022.

catalyst

Overview

- Background
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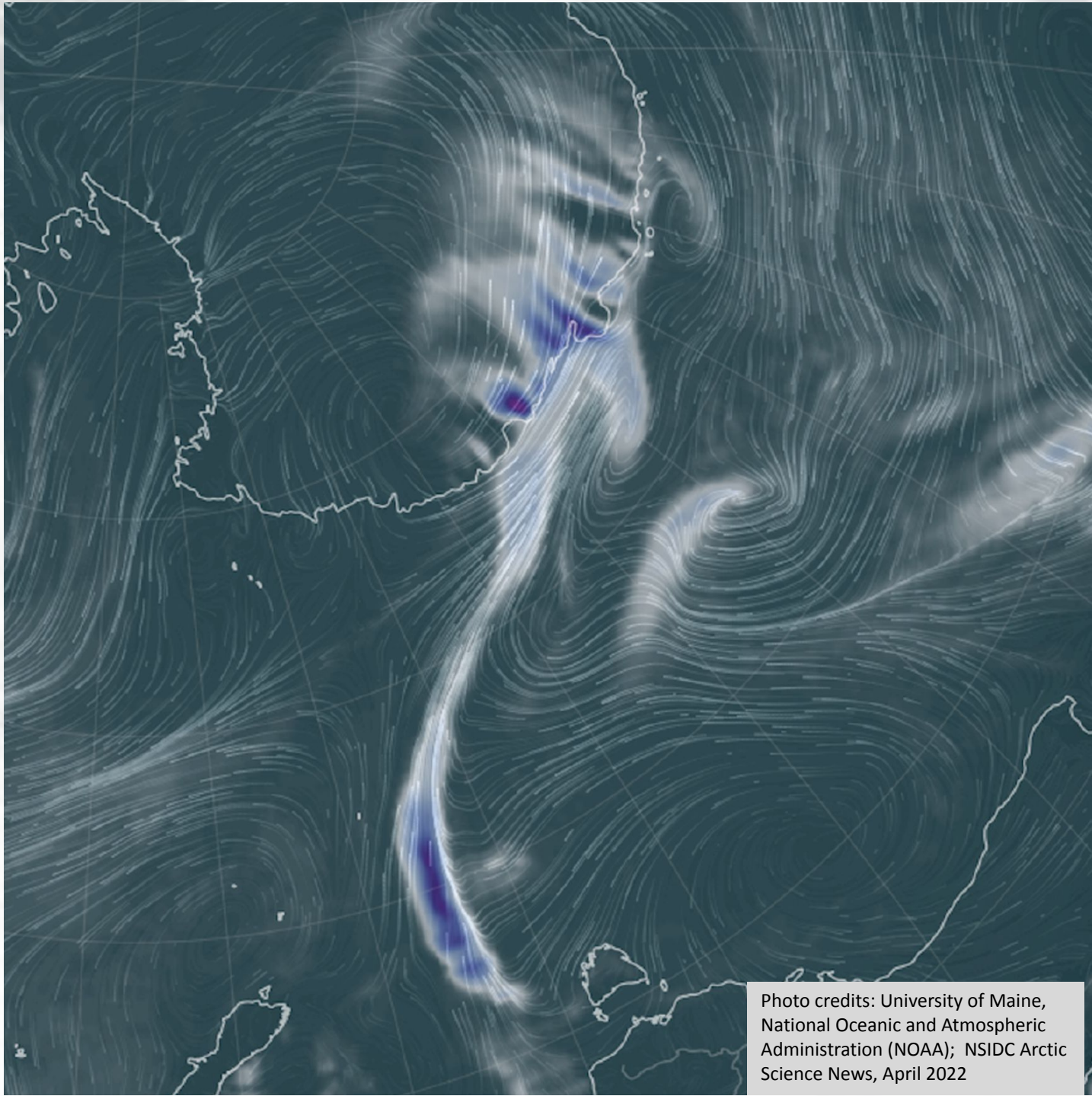

Photo credits: University of Maine, National Oceanic and Atmospheric Administration (NOAA); NSIDC Arctic Science News, April 2022

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AR Occurrences in CESM2-LE, biases

Maclennan et al., Communications Earth and Environment, in revision, 2025

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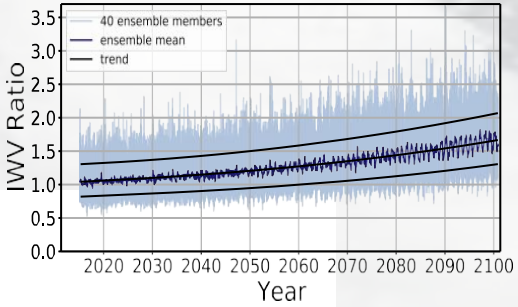
AR Occurrences in future climate in CESM2-LE



2066-2100 – 1980-2014

Maclennan et al., Communications Earth and Environment, in revision, 2025

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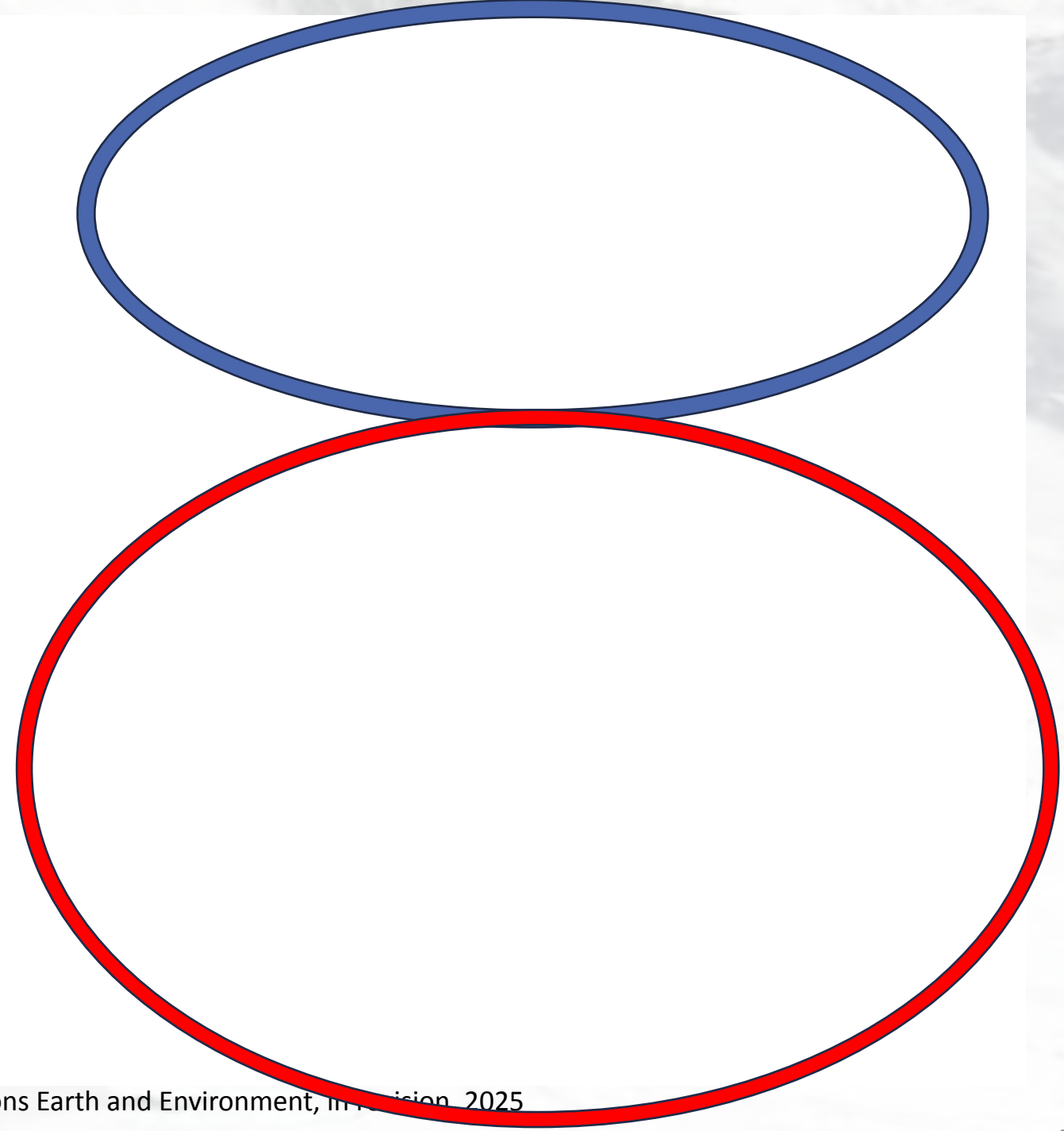

AR precipitation

Snow and Rain

Maclennan et al., Communications Earth and Environment, in revision, 2025

Different seasonal responses

Different mechanisms

Maclennan et al., Communications Earth and Environment, in revision, 2025

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Summer

- ✔ Easiest to interpret
- ✔ AR occurrences follow low level meridional wind trends

Maclennan et al., Communications Earth and Environment, in revision, 2025

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Summary

- Definitions and Mechanisms
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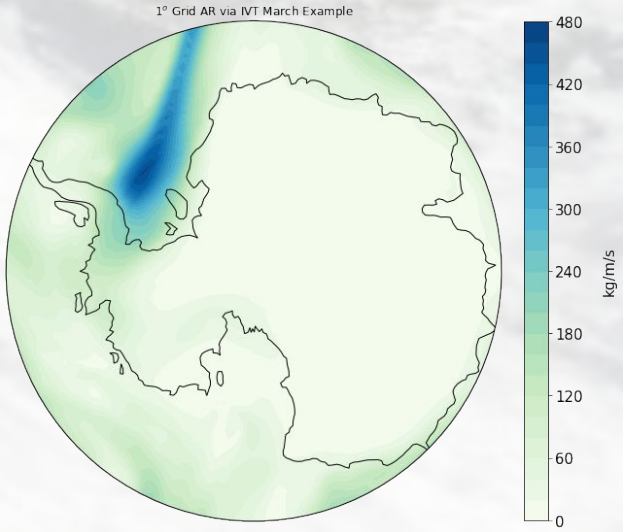
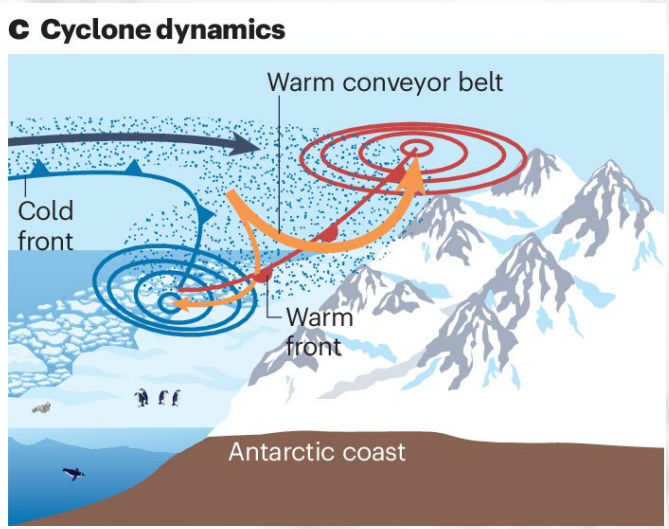
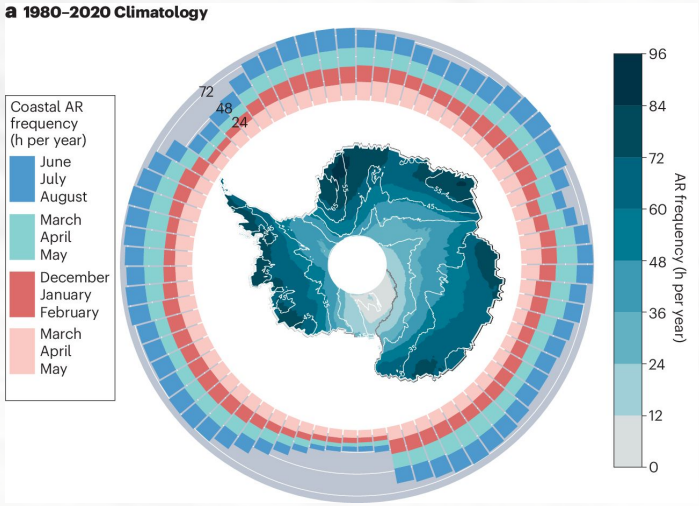
- Model simulations







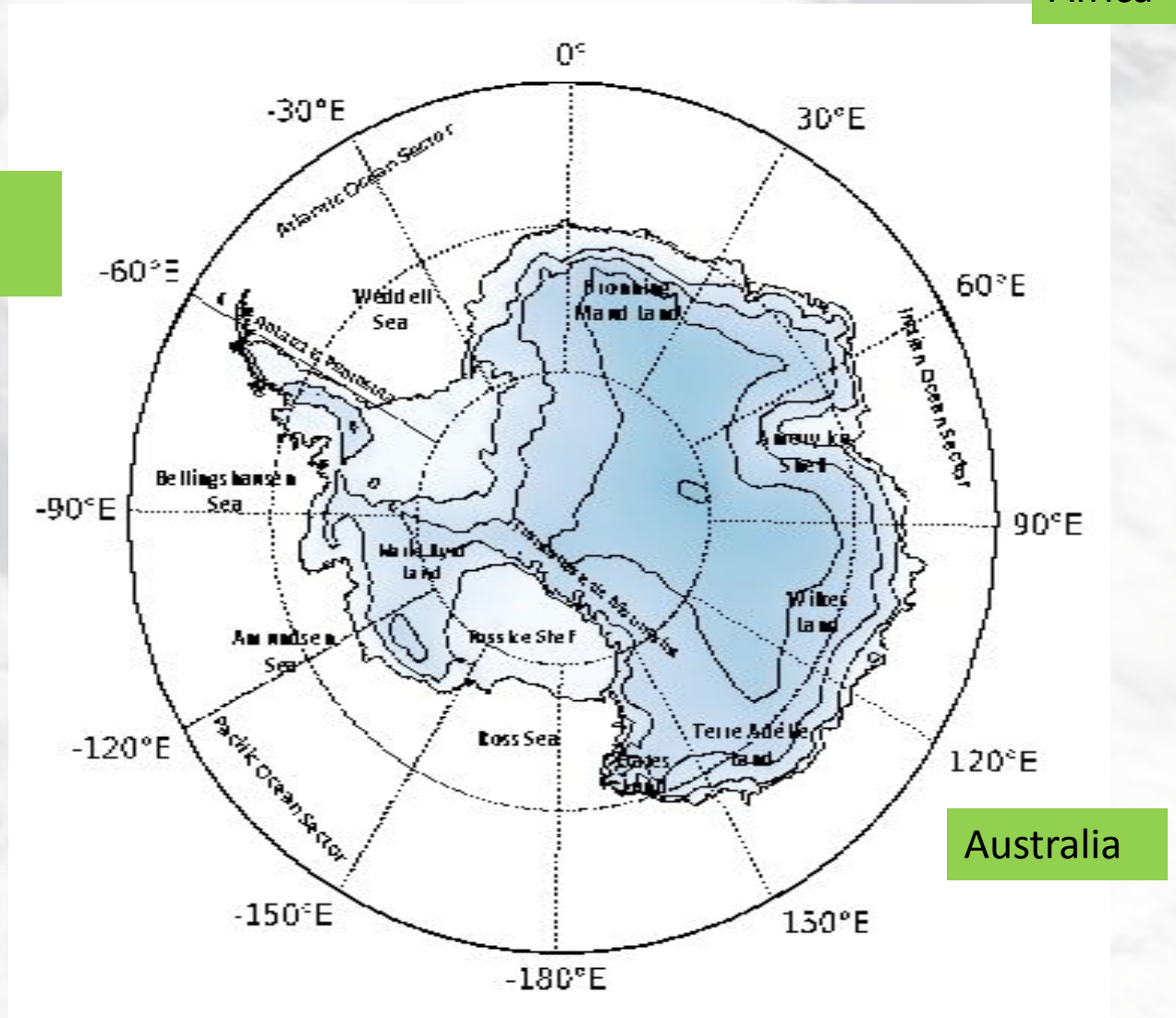
Extra Slides

West Antarctica

East Antarctica

Africa

South America



Australia

Antarctic geography

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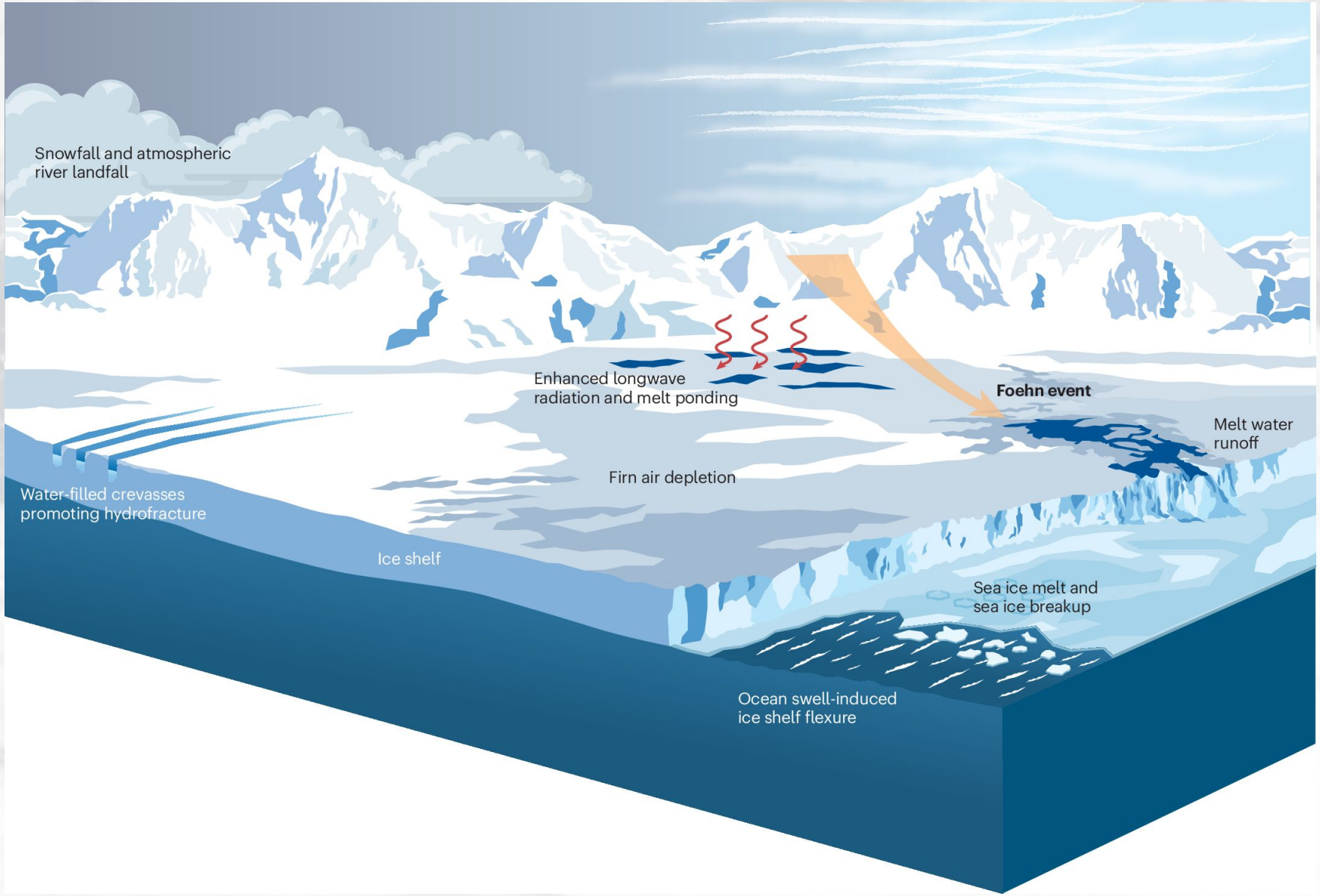
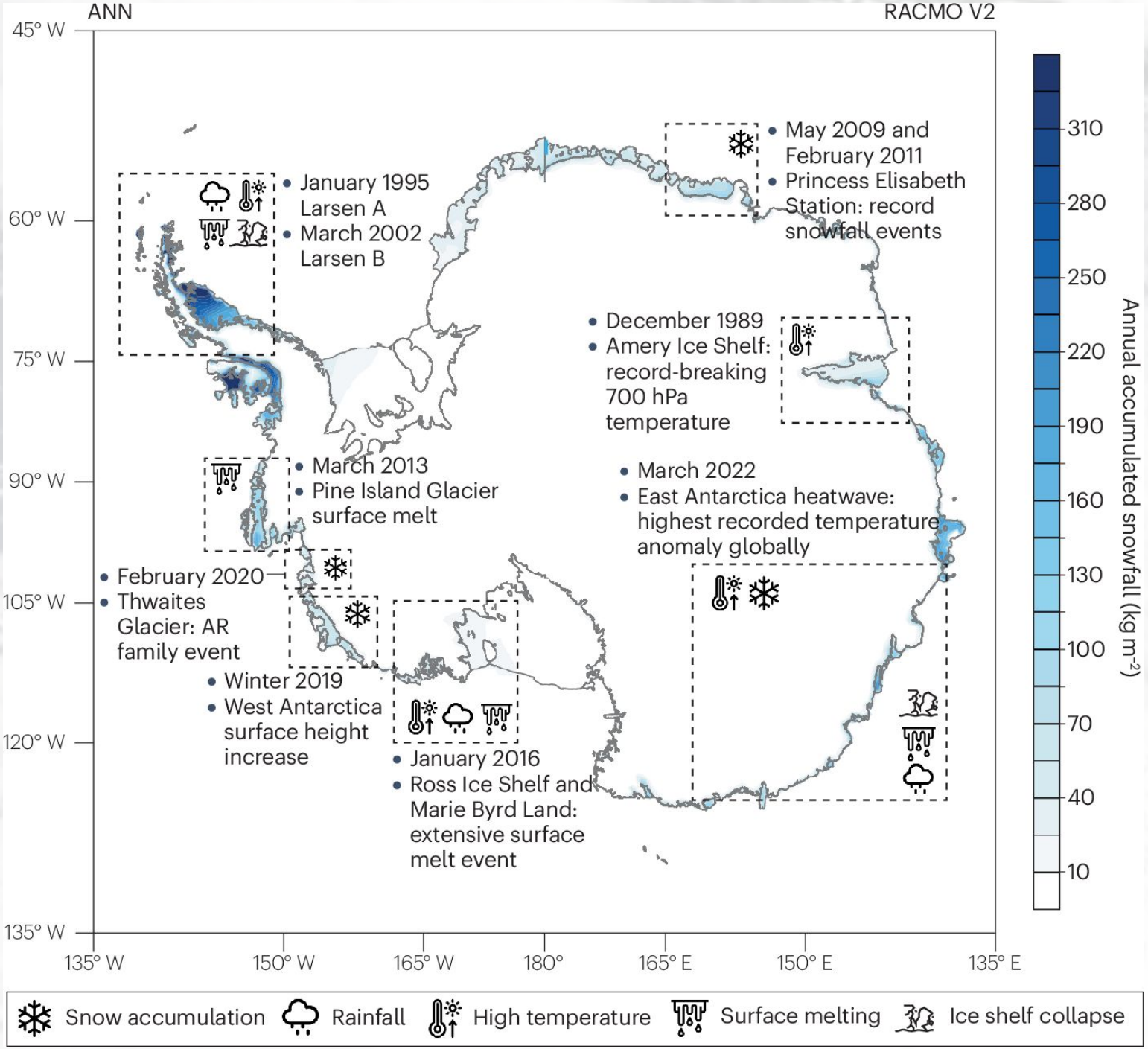


AR impacts via precipitation, winds, and radiation onto ice sheet and sea ice

- ✔ Rain (warm) snow (cold)
- ✔ Melt or accumulation
- ✔ Meltponds, runoff, firn structure

Wille et al., NREE, 2025

catalyst



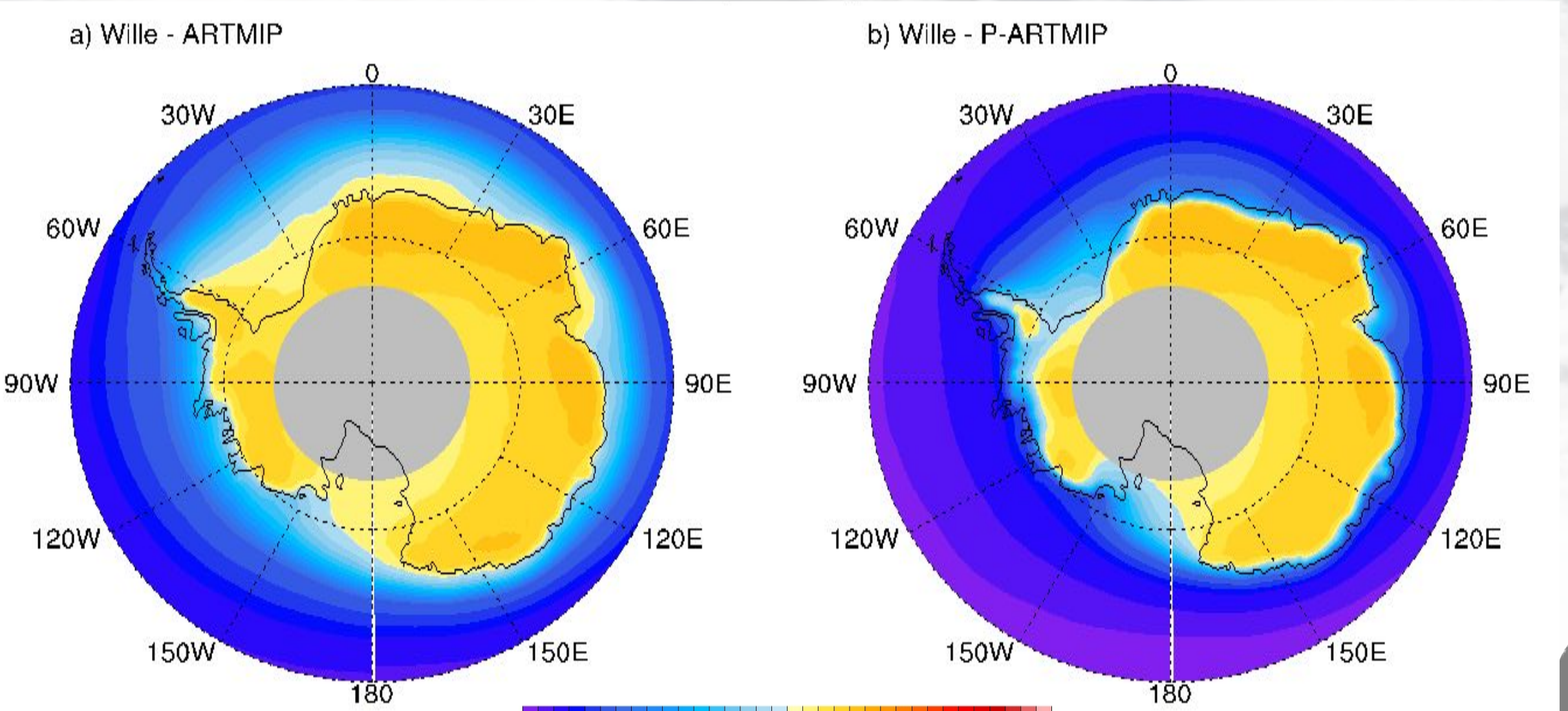
Antarctic AR extremes

- ✔ Examples of various extreme events in the literature
- ✔ Most melt events in West Antarctica or coastal ice shelves
- ✔ March 2022 E. Antarctic heat wave still generated snow at top of glacier

Wille et al., NREE, 2025; ***Figure by J. Xou (Scripps);*** *Wille et al., 2023 J. Clim Part I/II (East Antarctic Heat Wave)*

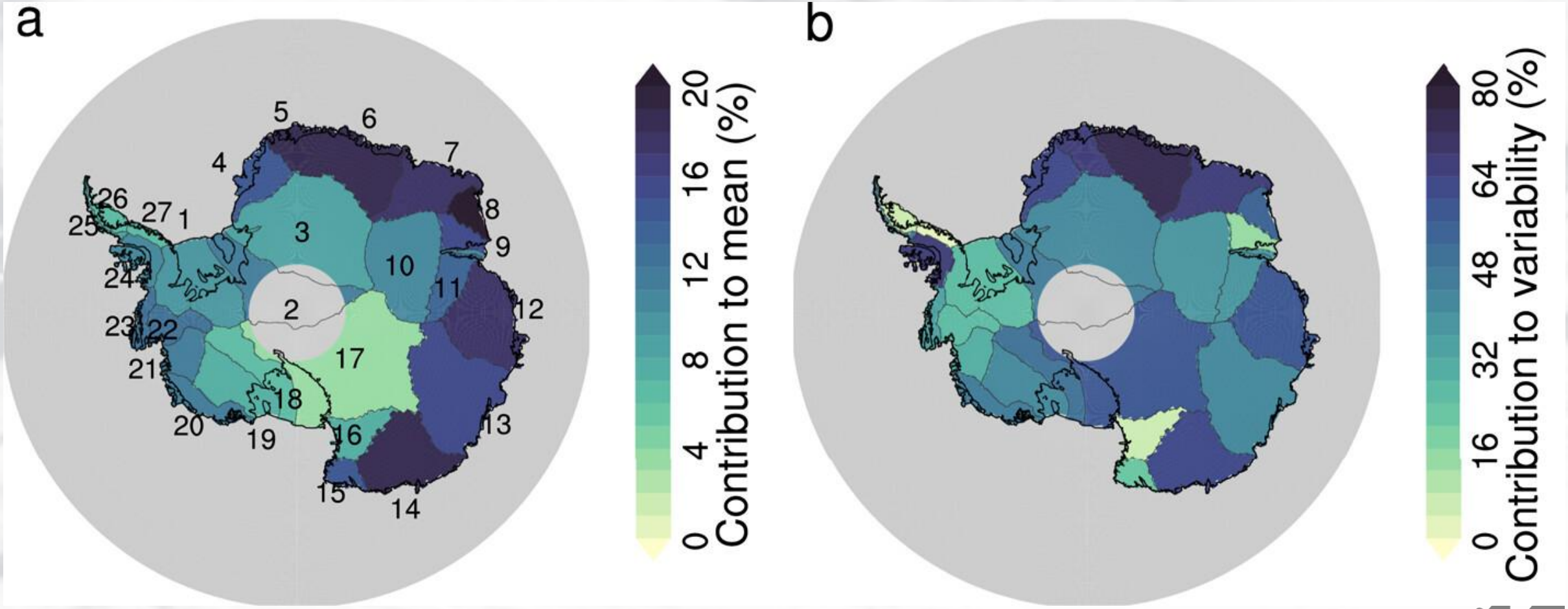
catalyst

Meridional ARDTs – Global ARDTs



Shields et al., GRL, 2022

Now via MERRA-2: Precipitation by drainage basin and interannual variability



(a) AR precipitation relative to total average precipitation
(b) AR precipitation contribution to interannual variability of total precipitation

Maclennan et al., GRL 2022