Projection of near-surface winds in Antarctica using Earth System Models downscaled by a regional atmospheric model (MAR)

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ABSTRACT

Near-surface winds play a major role in shaping the climate of Antarctica. Notably, they influence sea-ice formation at the ocean margins & the stability of the boundary layer over the ice sheet. They result from large-scale and surface forcing, whose relative magnitude and future evolution is yet uncertain. We study projections of winds up to 2100 using **4 Earth System Models** (ESMs) and we show that their **downscaling with the regional atmospheric model MAR reduces near-surface wind biases** when compared to observations. Using this downscaling and a momentum budget decomposition, we compute the relative evolution of each drivers of near surface winds. We show that **inter-model differences in summer, on the continent are linked to changes in the synoptic circulation** and that the **weakening of the katabatic layer with global warming is compensated by an increase in large-scale forcing.**

How & why are surface winds changing during the 21st century?

CONSENSUS

- **Westerlies strengthening** & shifting poleward *(Turner et al. 2005[1])* & **Easterlies weakening** *(Neme et al. 2022[7])*
- **Weak changes on the continent** *(Bracegirdle 2008[3])*

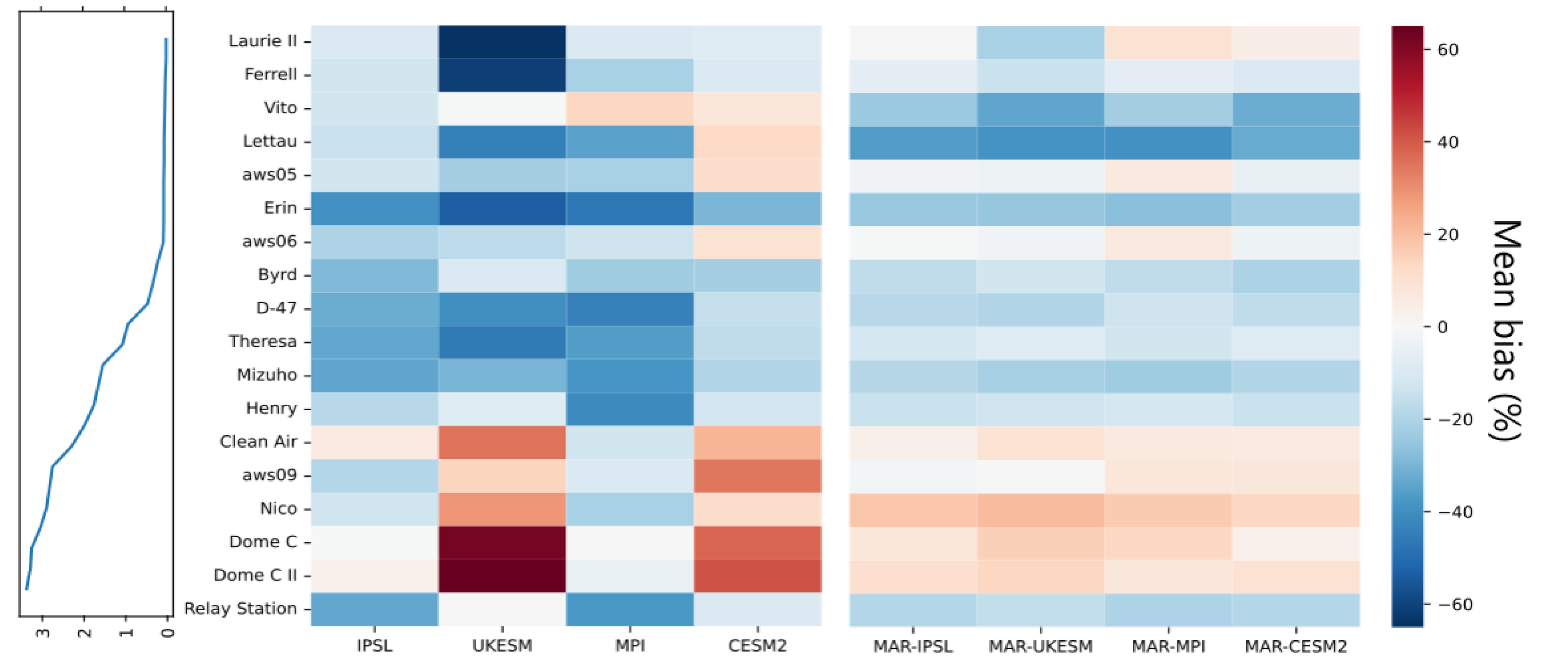
QUESTIONS

- Are these results **robust across different models?**
- Is the **large-scale forcing compensating the decrease of katabatic** on the continent?

DATASET

- 4 Earth System Models (ESMs)
- Downscaled by a polar oriented regional Atmospheric model (MAR) with a good representation of the boundary layer physics (*Agosta et al. 2019[2], Kittel et al., 2021[6], Amory et al. 2017[1]*)
- Validation against the AntAWS dataset (*Wang et al. 2021[9], Genthon et al, 2021[5]*)
  - **267** automatic weather stations
  - **23** stations with long enough time-series
  - Evaluation on **19** stations (exclusion of 4 stations with complex orography and unreasonable biases)

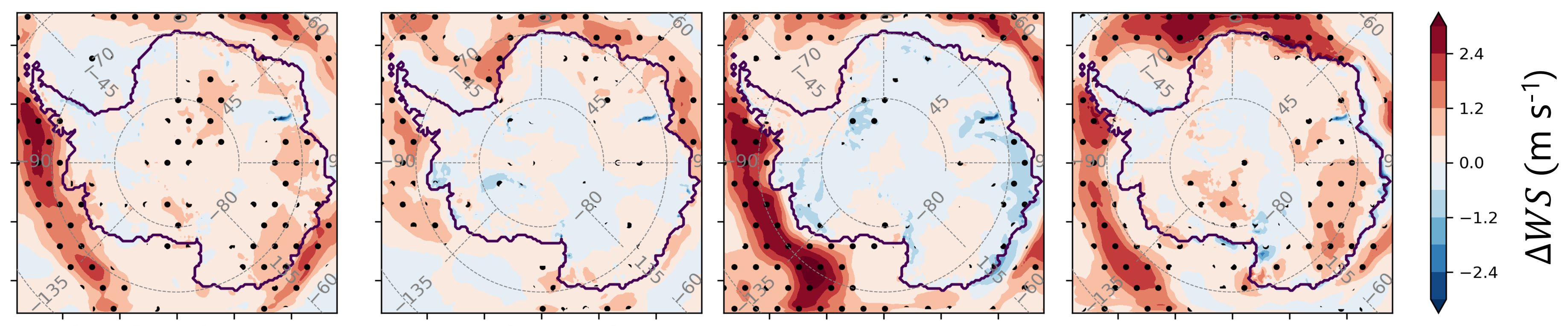
MAR increases the ESMs ability to represent near-surface winds



(b) Altitude (km) (c) July biases for each ESM at each station (d) July biases for each ESM downscaled by MAR at each station

Different ESMs predict different changes in near-surface winds intensity (WS)

10m WS July 2100-2080- WS July 1980-2000



What drives near-surface wind changes?
What drives the inter ESMs differences?

MOMENTUM BUDGET

Enables a **quantification of the drivers** of wind-speed changes (*van den Broeke & van Lipzig, 2003, Davrinche et al. 2024*)

$$\vec{f} \times \overrightarrow{WS} + \overrightarrow{KAT} + \overrightarrow{LSC} + \overrightarrow{THW_{TD}} + \overrightarrow{ADVH} + \overrightarrow{TURB} \approx \frac{\partial \overrightarrow{WS}}{\partial t}$$

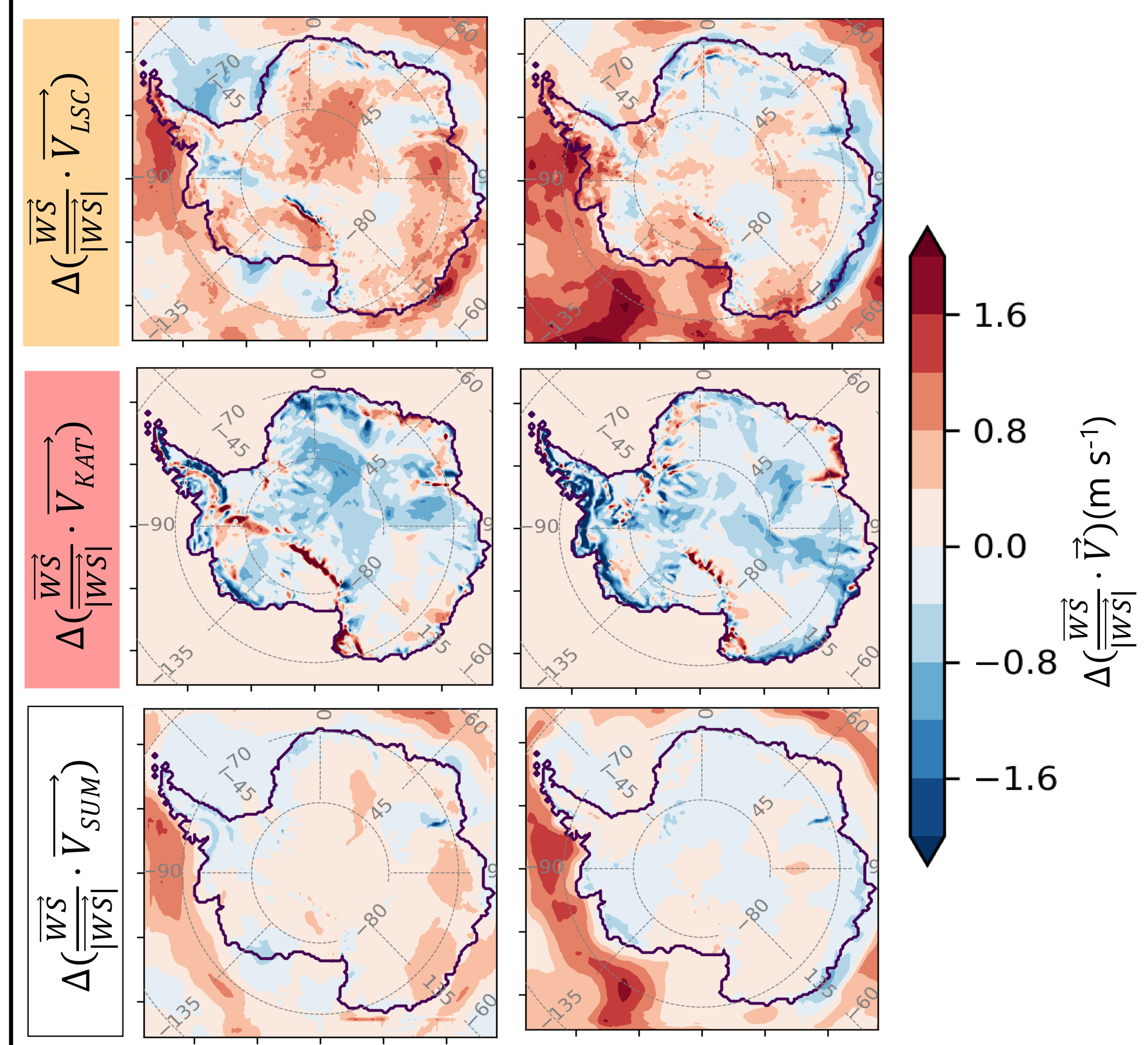
$$\overrightarrow{WS} \approx \overrightarrow{V_{KAT}} + \overrightarrow{V_{LSC}} + \overrightarrow{V_{THW}} + \overrightarrow{V_{ADVH}} + \overrightarrow{V_{TURB}}$$

$$\text{with } \overrightarrow{V_{ACCELERATION}} = -\frac{\vec{f}}{f^2} \times \overrightarrow{ACCELERATION}$$

CORIOLIS
KATABATIC
LARGE SCALE
THERMAL WIND
ADVECTION
TURBULENCE

Summer: decrease of katabatic compensated by an increase in large-scale acceleration

Changes between 1980-2000 & 2080-2100



$$\Delta WS \approx \Delta\left(\frac{\overrightarrow{WS}}{|\overrightarrow{WS}|} \cdot \overrightarrow{V_{KAT}}\right) + \Delta\left(\frac{\overrightarrow{WS}}{|\overrightarrow{WS}|} \cdot \overrightarrow{V_{LSC}}\right) + \Delta\left(\frac{\overrightarrow{WS}}{|\overrightarrow{WS}|} \cdot \overrightarrow{V_{THW}}\right) + \Delta\left(\frac{\overrightarrow{WS}}{|\overrightarrow{WS}|} \cdot \overrightarrow{V_{ADVH}}\right) + \Delta\left(\frac{\overrightarrow{WS}}{|\overrightarrow{WS}|} \cdot \overrightarrow{V_{TURB}}\right)$$

CONCLUSIONS

- ESMs downscaled by MAR are better suited for the analysis of near-surface winds
- In summer, decrease in KAT is compensated by an increase in LSC on the continent
- Changes in LSC explain most (but not all!) of the inter ESM differences

(1) Agosta et al. (2019), Estimation of the Antarctic surface mass balance using the regional climate model MAR (1979–2015) and identification of dominant processes,TC
(2) Amory et al. (2017). Seasonal variations in drag coefficient over a sastrugi-covered snowfield in coastal East Antarctica. Boundary-Layer Meteorology
(3) Bracegirdle et al. (2008) Antarctic climate change over the twenty first century, JGR
(4) Davrinche et al. (2023), Understanding the drivers of near-surface winds in Adelie land, East Antarctica. TC
(5) Genthon et al. (2021), Ten years of temperature and wind observation on a 45-m tower at Dome C, East Antarctic plateau. ESSDD
(6) Kittel et al. (2020), Diverging future surface mass balance between the Antarctic ice shelves and grounded ice sheet. TC
(7) Neme et al. (2022), Projected changes of surface winds over the Antarctic continental margin, JGR
(8) Turner et al. (2005), Antarctic climate change during the last 50 years. International journal of Climatology
(9) Van den Broeke & van Lipzig(2003), Factors controlling the near-surface wind field in Antarctica. MWR.
(9) Wang et al.(2022). The AntAWS dataset: a compilation of Antarctic automatic weather station observations. ESSDD