A surface mechanism for midlatitude extreme wind intensification

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Introduction

Variable-resolution climate models can better represent local drivers of wind extremes and make more reliable predictions of their evolution under climate change

Experiments with the variable-resolution [Gettelman et al. 2018] configuration of the Community Earth System Model (VR-CESM) [Hurrell et al. 2013] predict **intensified cold-season wind extremes in the Great Lakes region in the 2090s**, despite predicting reduced strength of the extratropical cyclones that drive extreme winds in this region [Morris et al. 2024]. The enhanced wind signal was **attributed to a surface signature** of static destabilization due to increased sensible heat fluxes. This mechanism does not result in stronger winds in the standard version of the model, likely due to its lack of skill at capturing mesoscale turbulence.

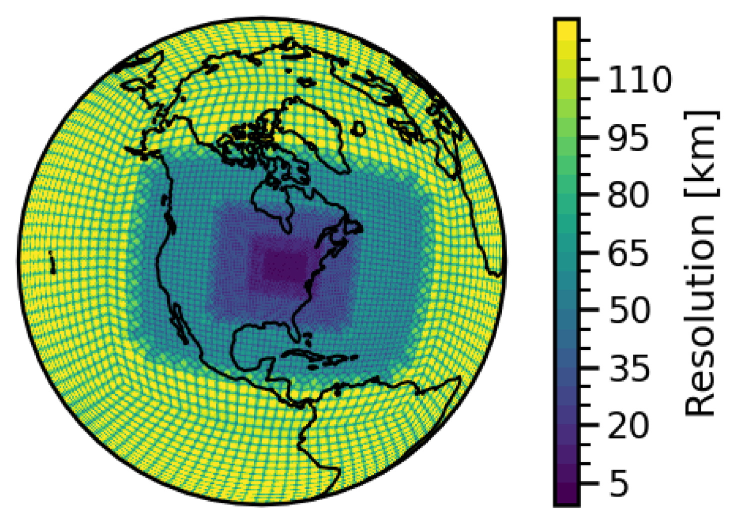

Fig 1: Resolution of the cubed sphere grid used in this study.

Changes to the fastest winds in the Great Lakes region are consistent with shifting seasonal means

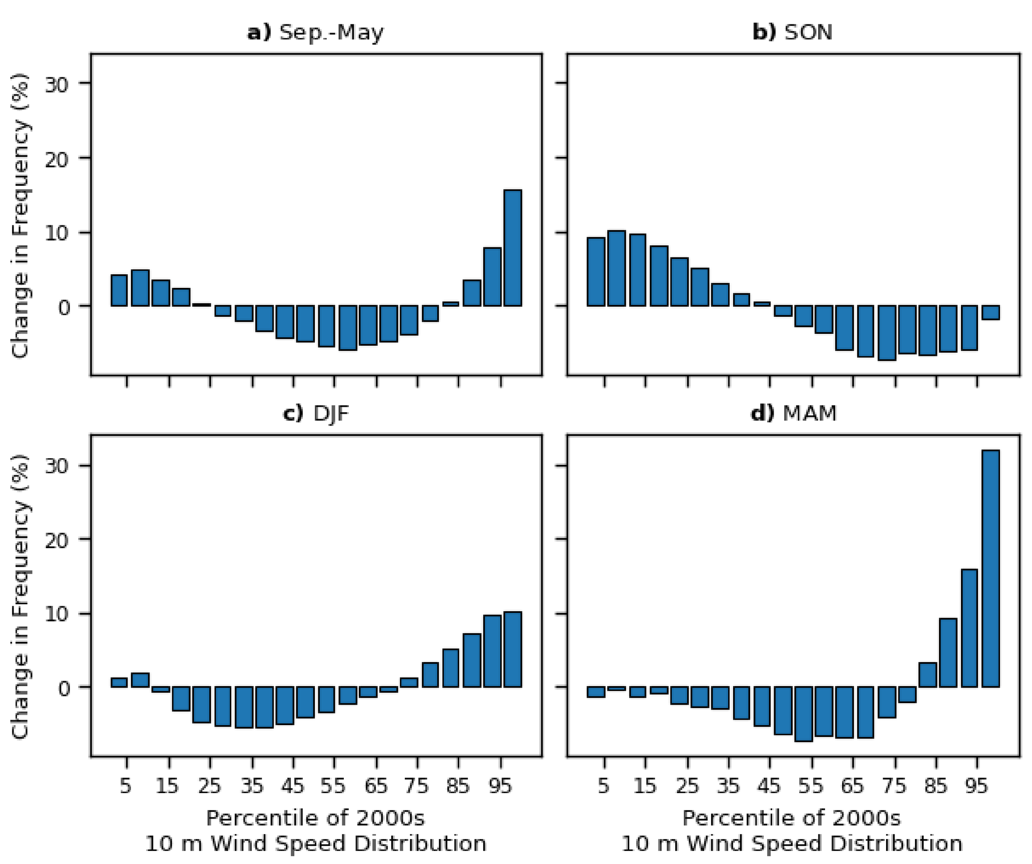

Fig 2: Change to percentile bins of 2000s 10 m wind speed distributions. Cold-season (Sep.-May) stagnant and strong wind extremes both increase, consistent with enhanced future wind variance. Analysis of the constituent seasons reveals that this effect is a manifestation of shifting seasonal mean wind speeds. This result motivates an understanding of the relationship between the changing seasonal mean conditions and the seasonality of wind extremes.

What is the role of changing surface conditions in the seasonal wind extreme response in VR-CESM?

Methods

This study uses two 42-year long model simulations**:** a **year-2000 control simulation** and a **2090s climate change scenario** under RCP8.5 forcing (considered a high-emissions scenario). These simulations employ sea surface temperatures and sea ice concentrations prescribed from the CESM2 Large-Ensemble [Kay et al. 2015]. The model grid is pictured in Fig 2, with 7 km resolution over the Great Lakes.

An extreme wind event occurs when wind speeds over 25% of the region **exceed the local 98th percentile.** To ensure statistical independence, only the strongest event within a 24-hour period is kept.

Results

Spring season intensification is associated with static destabilization and increased sensible heat flux

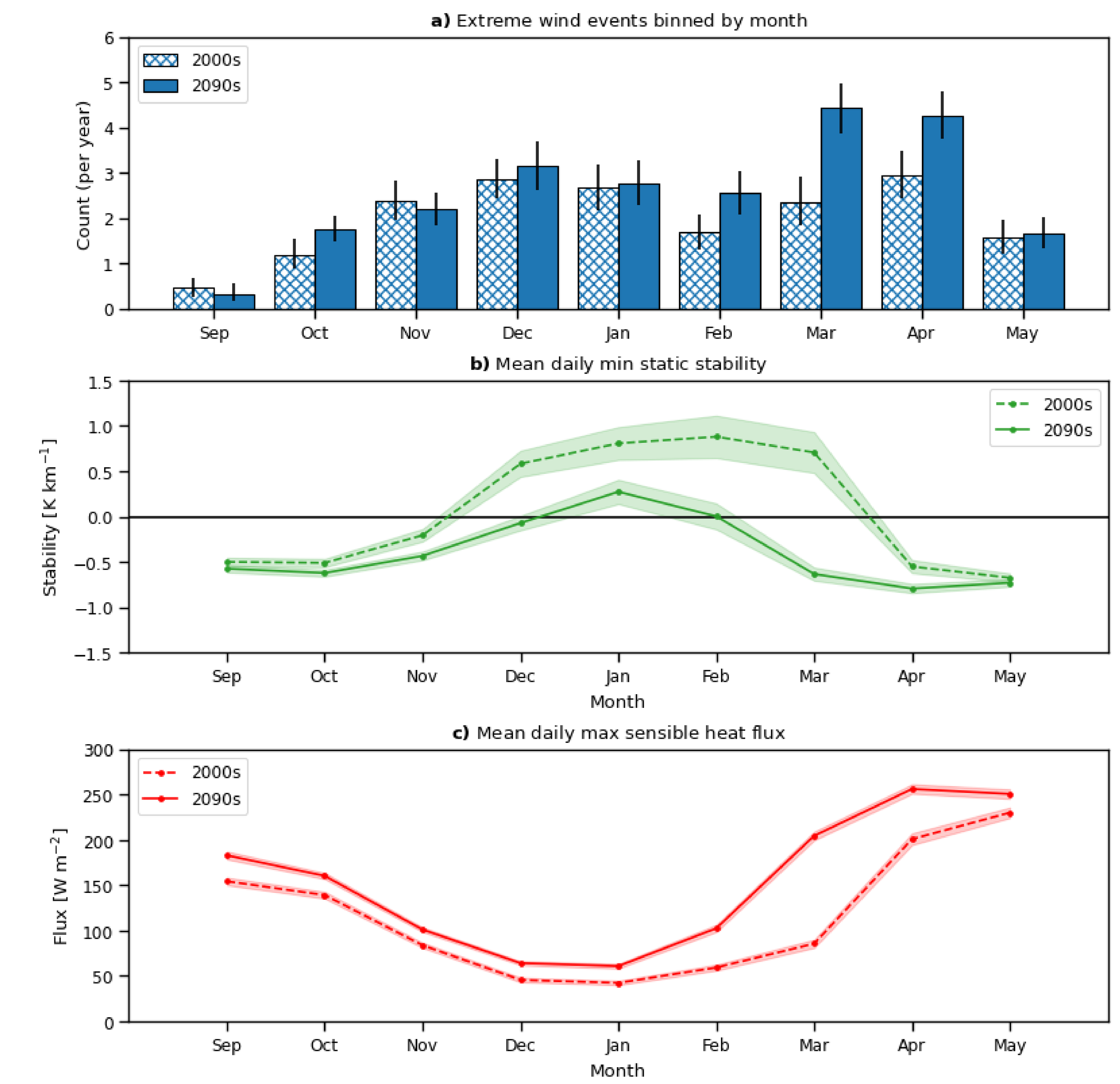

Fig 3: a) 2000s and 2090s extreme wind events binned by month. Here, extreme wind events for both periods are calculated with respect to a Sep.-May year-2000 threshold wind speed. Seasonal cycles of daily minimum static stability **(b)** and daily maximum sensible heat flux **(c)**.

Extreme wind events become more common overall, especially in the spring season. These months tend to have the largest changes to sensible heat flux and static stability.

The strongest heat flux signatures are driven by a reduction in surface albedo

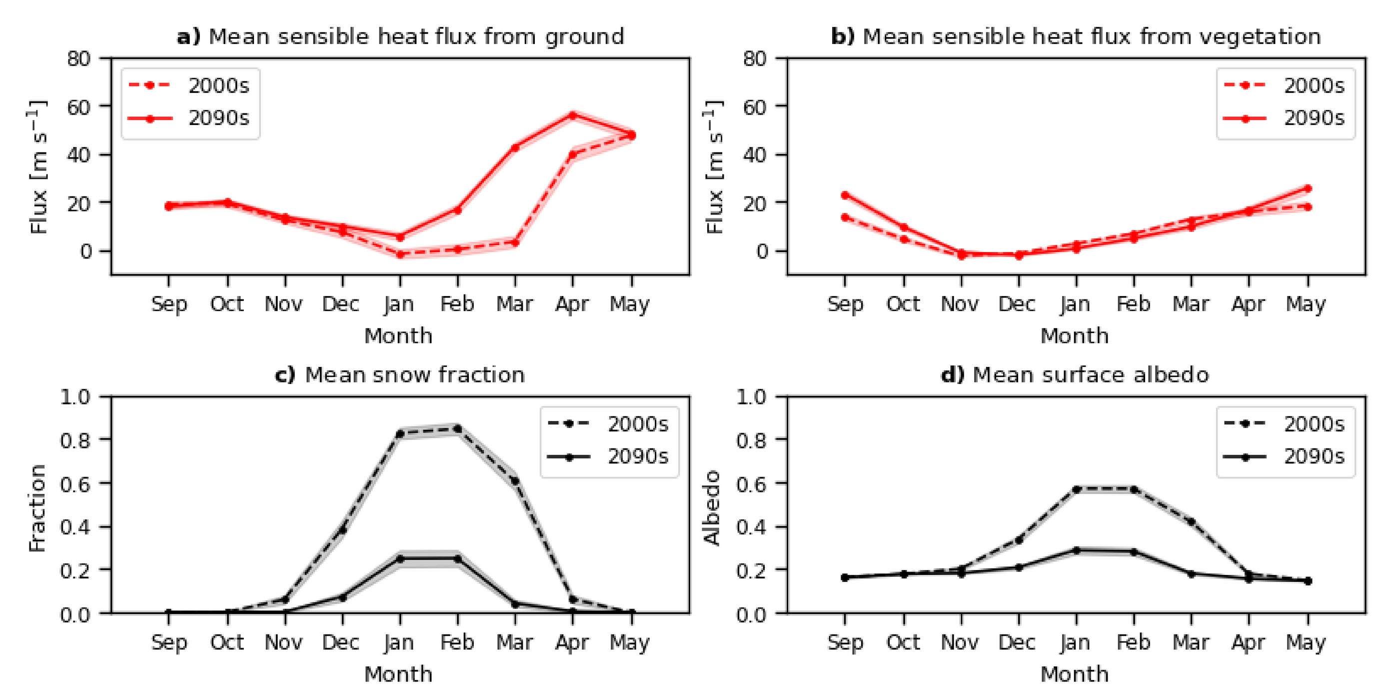

Fig 4: Sensible heat exchange between the atmosphere and the land surface can be partitioned into contributions by vegetation and the ground. The largest heat flux increases are attributable entirely to contributions from the ground, associated with a reduced surface albedo in a future with reduced snow cover.

Snow-covered surfaces inhibit static instability, thereby making strong winds less probable

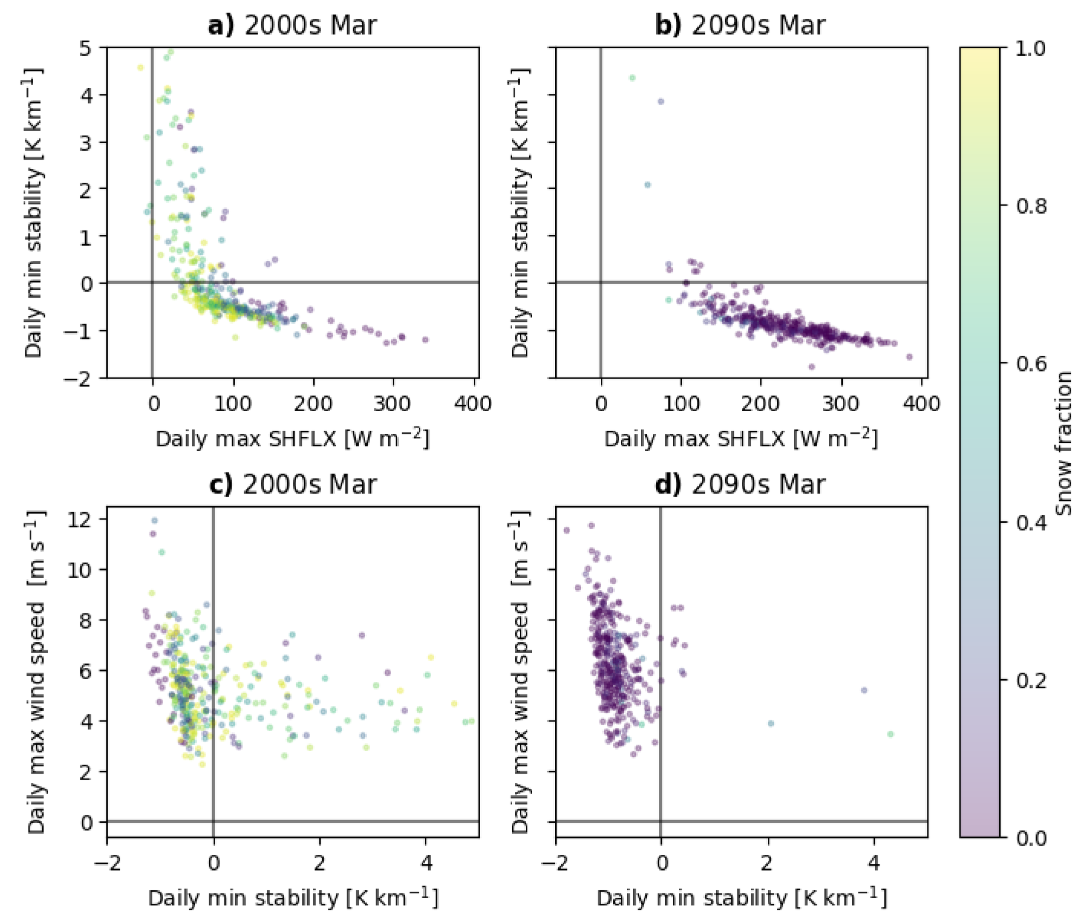

Fig 5: Scatterplots of stability vs. sensible heat flux for March 2000 **(a)** and March 2090 **(b)**. Panels **(c)** and **(d)** show wind speed vs. stability. Points are coloured according to the regional snow fraction.

Stability tends to decrease with increased sensible heat flux, and the fastest winds tend to occur under less stable conditions. In March, the surface transitions into a regime of low snow cover and high sensible heat, making strong winds far more probable.

Stronger future wind extremes are a manifestation of an intensified diurnal cycle

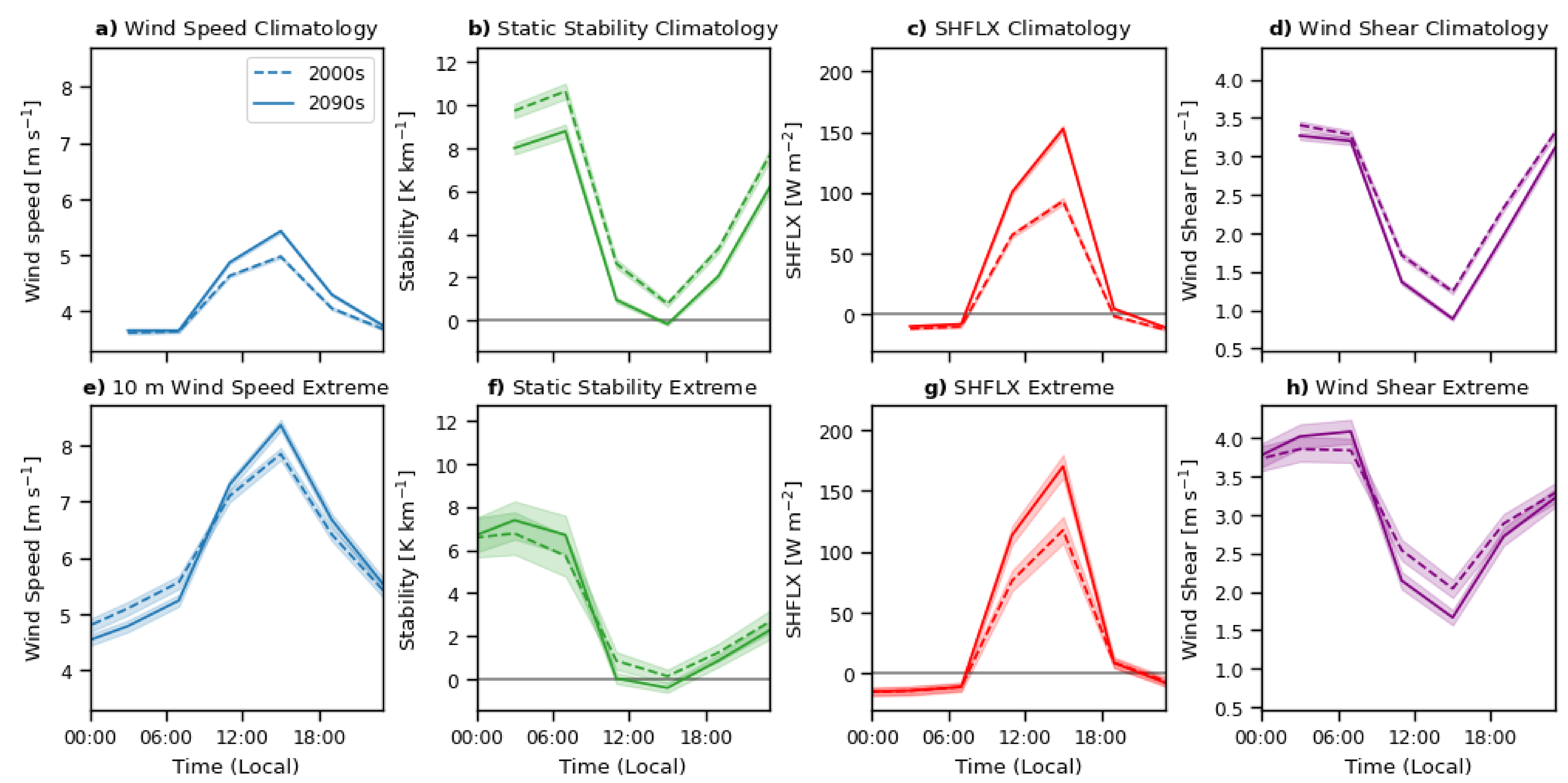

Fig 6: Composite diurnal cycles for all Jan.-Apr. days **(a-d)** and extreme wind events **(e-h)**. Stronger afternoon sensible heat flux induces a reduction in static stability, allowing enhanced afternoon winds due to increased vertical momentum mixing. This mechanism is reflected in the extreme wind event composite diurnal cycle.

References & Acknowledgements

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