# Changing wind extremes in the Great Lakes Region in VR-CESM

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## Background

Changes to midlatitude extreme winds are controlled by a tug-of-war between **large-scale** and **local-scale** processes

**Large-Scale:**
Midlatitude wind extremes are often associated with Extratropical Cyclones (ETCs) [Morris et al. 2023]. These low-pressure systems tend to form under baroclinic instability, which may weaken under global warming as the Arctic warms faster than the tropics.

**Local-Scale:**
The contrast in heat capacity between land and air may lead to increased sensible heat fluxes from the surface under global warming, thereby increasing turbulent momentum mixing during ETCs, leading to stronger winds at the surface.

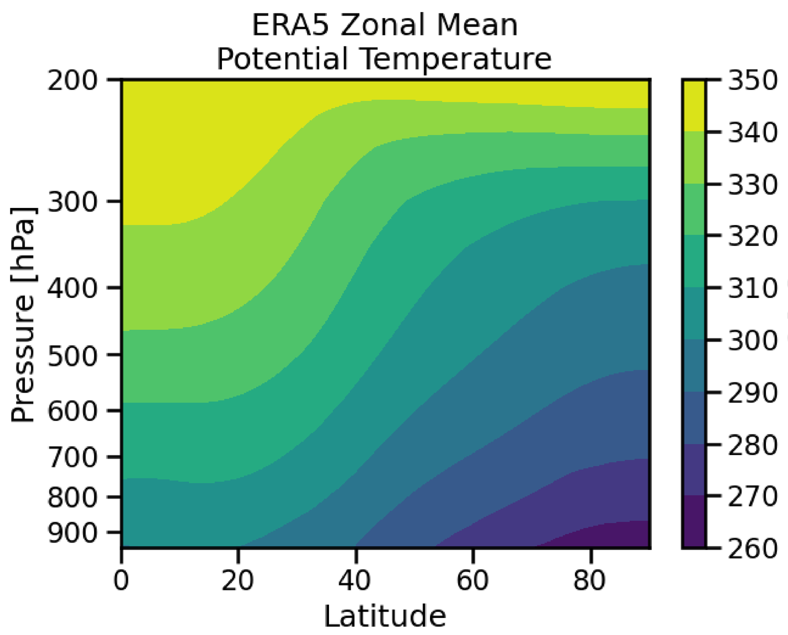



**Fig 1:** Zonal mean potential temperature calculated from ERA5 pressure levels [Hersbach et al. 2020]. Tilted potential temperature surfaces indicate available potential energy, which can be converted to kinetic energy under baroclinic instability.

**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 wind extremes in the Great Lakes region in the 2090s**, despite predicting reduced ETC strength [Morris et al. 2024]. The study **attributed this signal to a reduction in static stability** due to increased sensible heat fluxes under global warming. Since this mechanism is not resolved by the standard version of the model, these results indicate that the refined resolution of VR-CESM makes its predictions more reliable.

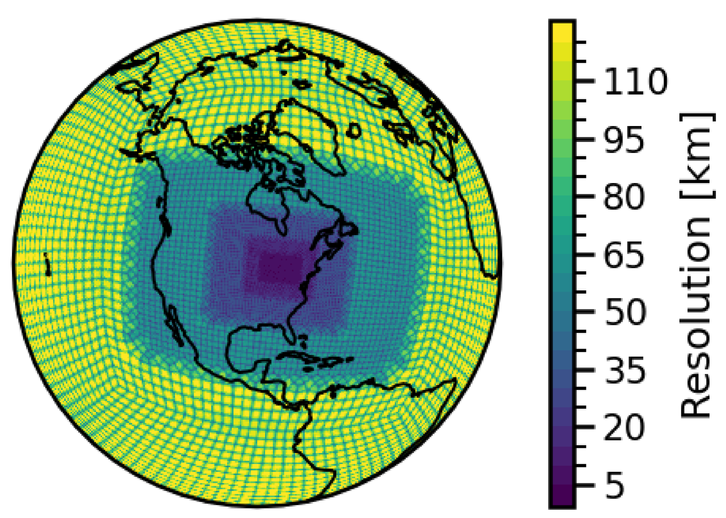



**Fig 2:** Resolution of the cubed sphere grid used in this study, ranging from 110 km in the far field to 7 km over the Great Lakes region.

**What is the relationship between static stability and extreme winds on diurnal and seasonal time-scales?**

## Methods

This study uses two 30-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 SSTs and SICs 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 winds** over 25% of the region **exceed the local 98$^{th}$ percentile.** To ensure statistical independence, only the strongest event within a 24-hour period is kept. Events are categorized by wind direction (NE, NW, SE, SW). **The focus of this study on south-westerly events in the Great Lakes region**, as this is the class of event which is most sensitive to climate change [Morris et al. 2024].

## Results

The **timing of the fastest winds** is controlled by the **diurnal cycle**

Lag composites reveal that the fastest winds during extreme events tend to occur in the afternoon, characterized by **low stability**, **high sensible heat fluxes**, and **reduced wind shear**.

This behaviour is qualitatively similar to the turbulent mixing that occurs on a typical afternoon in the boundary layer, but extreme wind events occur in an increased wind shear environment, leading to more momentum transport to the surface in the mid-afternoon.

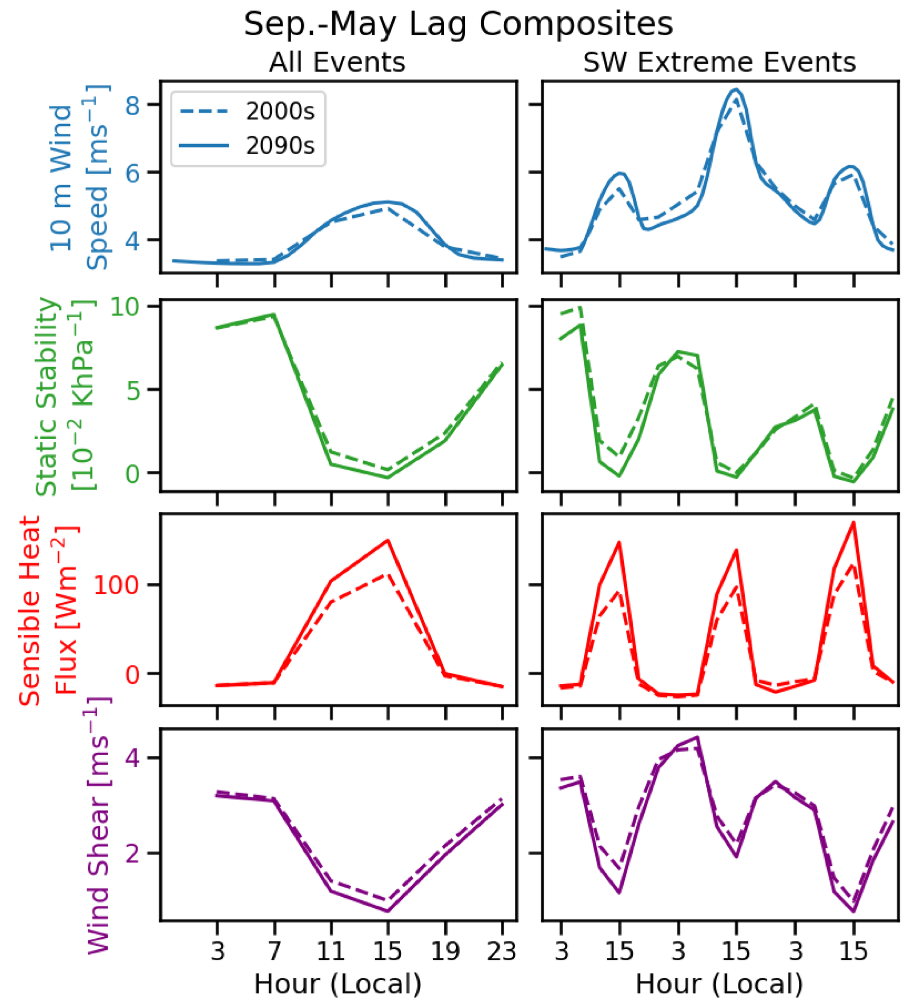



**Fig 3:** Regionally averaged lag composites for all south-westerly wind events (left) and all south-westerly extreme wind events (right) during Sep-May. The extreme event time series are 3-days long, centered on the day of the extreme.

**Changes to frequency** of extreme winds events are **dominated by a spring season signal**

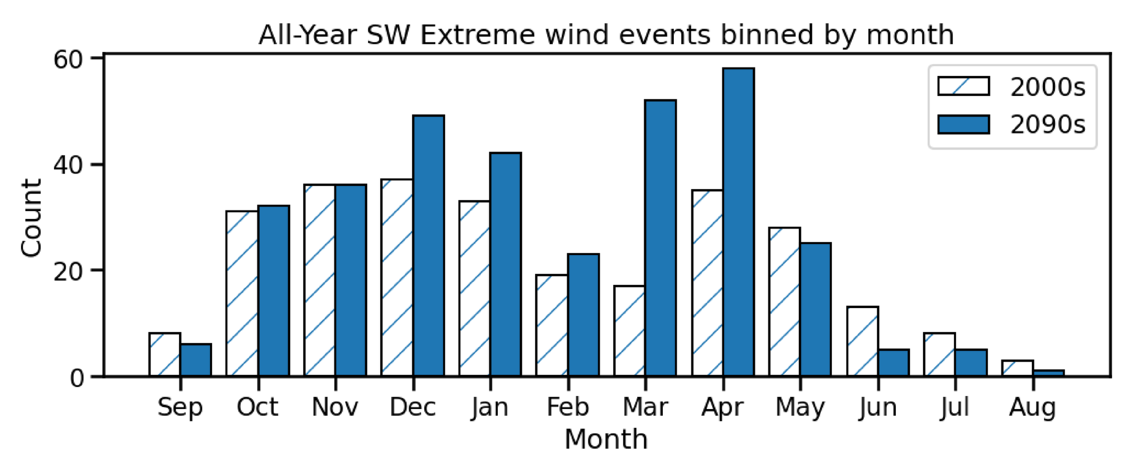



**Fig 4:** 2000s and 2090s south-westerly extreme wind events binned by month.

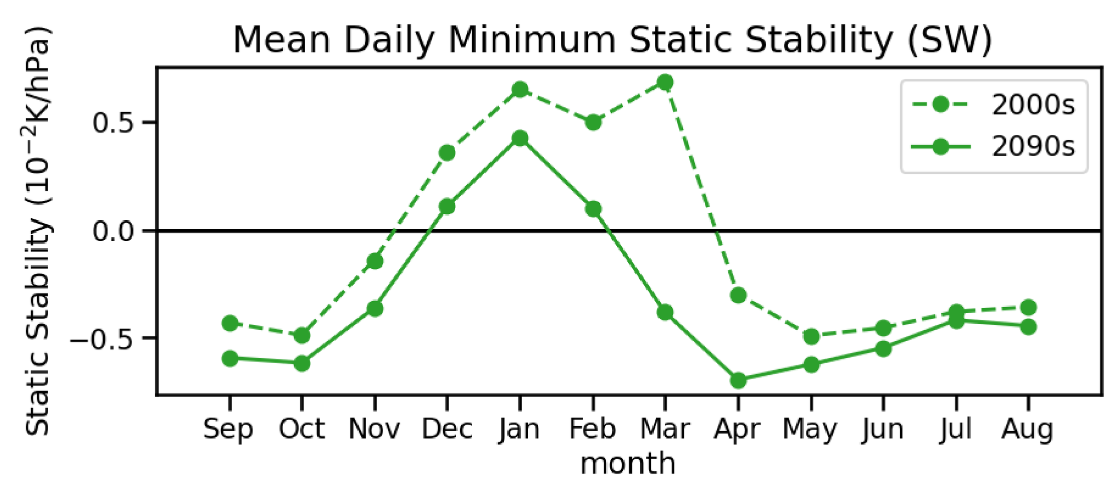
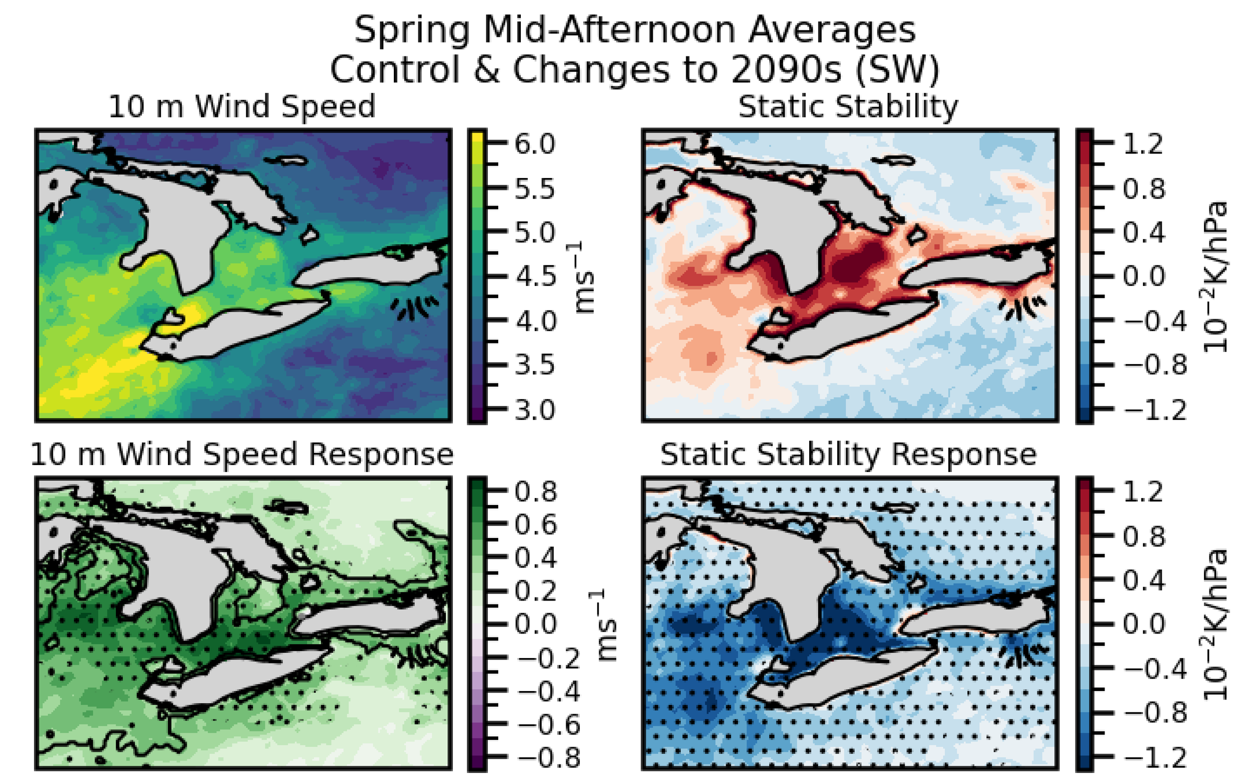



**Fig 5:** Regionally averaged daily minimum static stability, averaged by month for all south-westerly wind conditions.

The greatest change to the frequency of extreme wind events occurs in the spring, with March over doubling in the number of events between the 2000s and the 2090s. This is the only month to transition between statically stable and unstable daily minimum stability conditions between these two time periods.

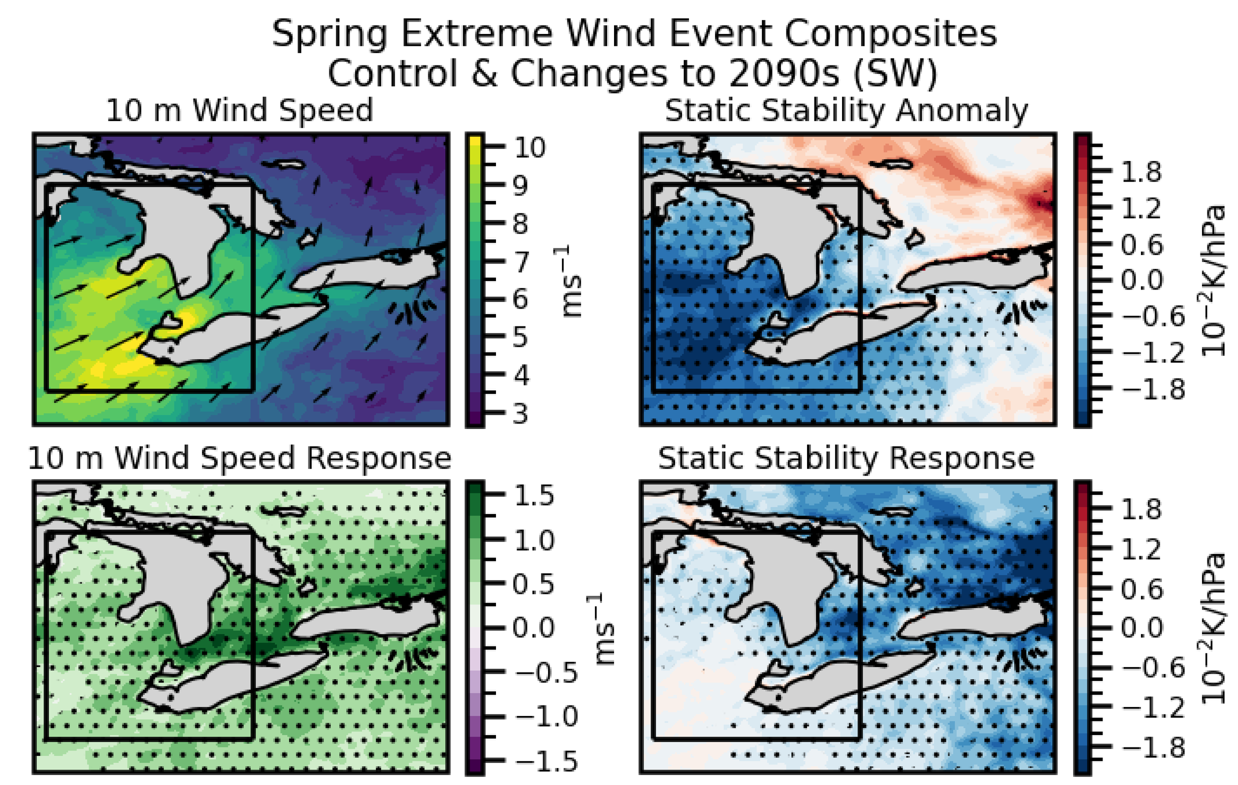
**Intensification** of extreme winds occur under a **transition between stable and unstable mid-afternoon conditions**

**Fig 6:** Top Row: Control period composites for Spring season mid-afternoons under south-westerly wind conditions. Bottom Row: Difference between 2090s and 2000s composites. Stripling indicates statistical significance at the 10% level. The black contour on the bottom left panel outlines the region which is statically stable in the control, and unstable in the 2090s.




Composites of spring mid-afternoons show typical wind speeds of up to 6 ms$^{-1}$ over Michigan, and a statically stable region over most of Southern Ontario and Michigan. Under climate change, this region becomes statically unstable and there is a corresponding increase in wind speeds of up to 0.8 ms$^{-1}$.

**Fig 7:** Same as Fig 6 but for south-westerly extreme wind events. The top right panel now represents an anomaly from the climatology. The black box indicates the region where the extreme winds are calculated.




The spatial pattern of winds in the extreme wind composite is like that of the typical mid-afternoon winds, but with more intense speeds of up to 10 ms$^{-1}$. These events are characterized by a low static stability anomaly in the control period. In the 2090s, wind speeds increase by up to 1.5 ms$^{-1}$, and static stability over much the region is reduced. The correlation between the midafternoon and extreme wind responses shows a clear relationship between changes to the seasonal mean and changes to extreme wind events.

## References & Acknowledgements

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