UNIVERSITY OF EXETER

The response of extreme extratropical cyclone wind fields to climate change

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AS1.11: Mid-latitude Cyclones and Storms: Diagnostics of Observed and Future Trends, and related Impacts

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Overview

- In previous literature there is disagreement as to whether cyclones will intensify or weaken in the future (Catto et al., 2019, Chang et al., 2017, Zappa et al., 2013, Sinclair et al., 2020), with this often dependent on the variable used to quantify the change (Ulbrich et al., 2009) or the subset of cyclones used (Pfahl et al., 2013, Michaelis et al., 2017).

Overview

- Changes in overall cyclone number (decrease) and precipitation rate (increase) are well understood, however, there is less consensus on the changes to near-surface wind speeds.
- Near-surface wind important for understanding cyclone dynamics and future risk potential for areas such as NW Europe.

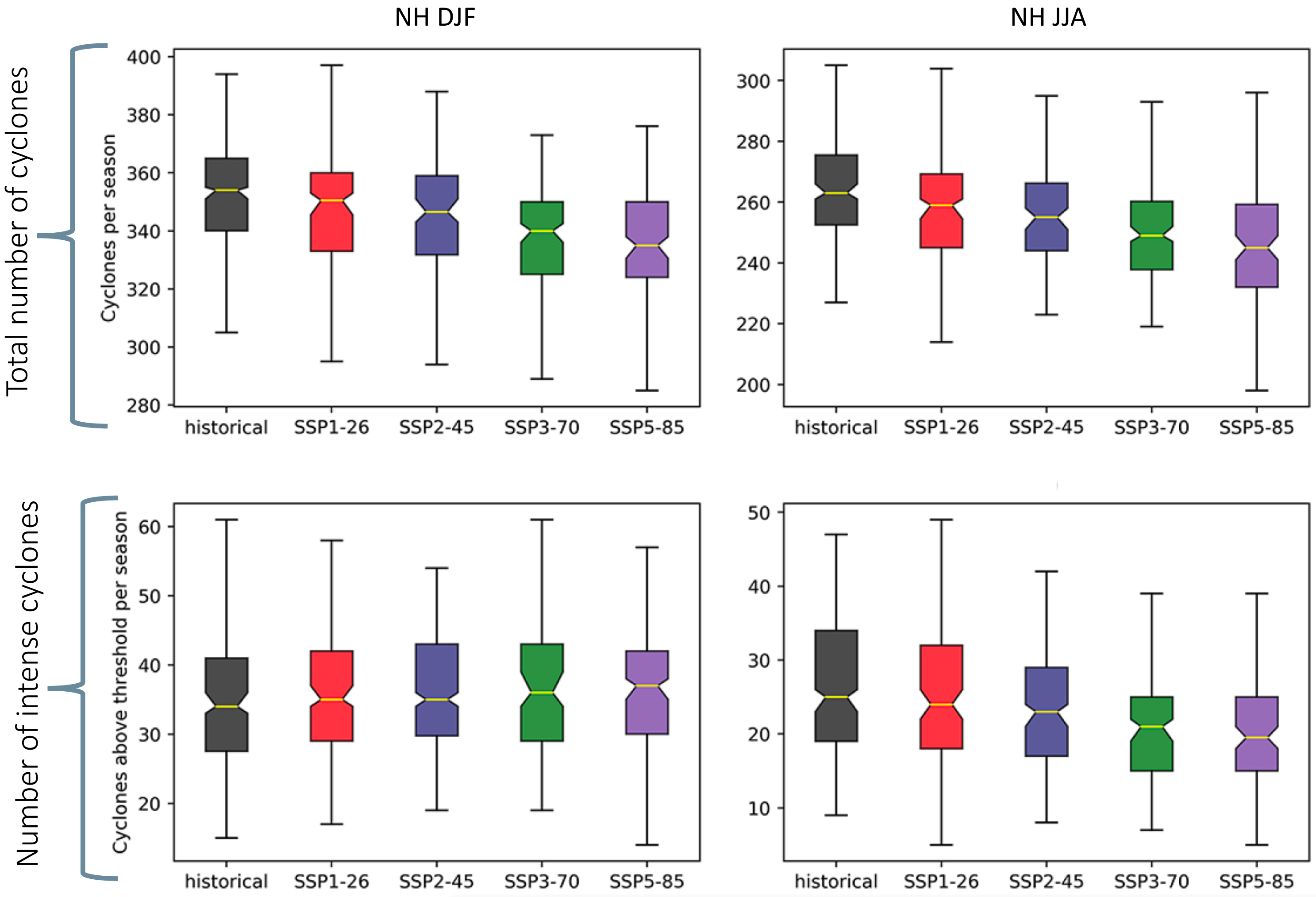
Research Questions

- Will the frequency of intense cyclones change in the future?
- How are cyclone wind structures projected to change in the future?
- Are any changes dependent on the level of future warming?

Data Usage & Identification Method

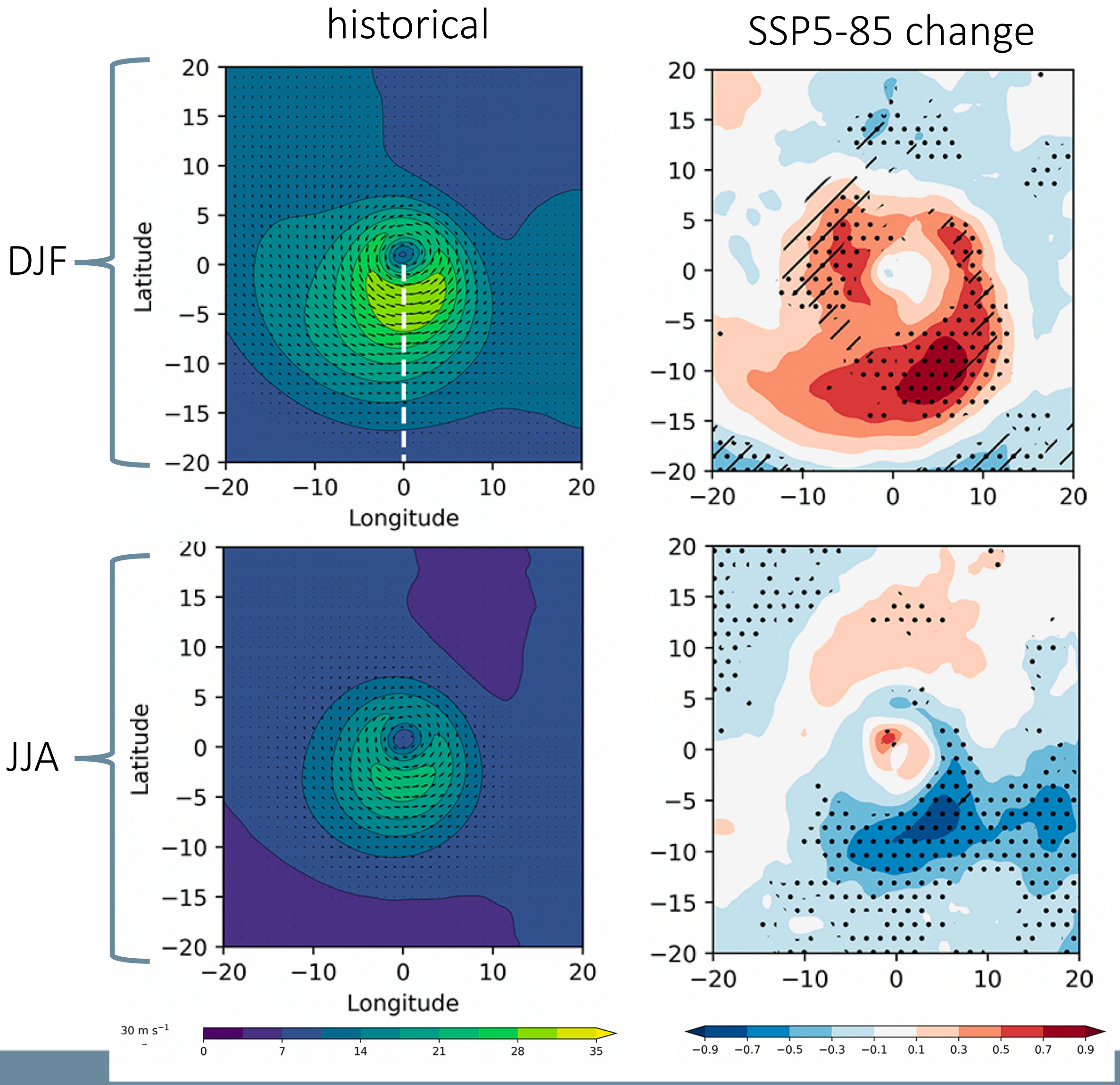
- 9 CMIP6 models that have data for the historical period (1979-2014) and for the 4 core SSPs (2080-2100)
  - SSP 1-26, 2-45, 3-70, 5-85
- Cyclones identified and tracked using Hodges (1994, 1995) method
  - Identifies cyclones using 6-hourly relative vorticity filtered to T42
- Use a cyclone compositing technique to investigate change in cyclone structure and circulation (Bengtsson et al., 2009, Catto et al., 2011, Dacre et al., 2012, Sinclair et al., 2020)
  - Use wind speed at 850 hPa
- Filter only to cyclones in the top 10% of the intensity distribution

Cyclone Frequency



- There are less cyclones identified in both winter and summer
    - Larger reduction with more warming
- There is an increase in the frequency of cyclones exceeding the historical intensity threshold that is largest in SSP5-85 in NH DJF (+4%), but a decrease in JJA (-21%).
- Does the increased frequency of extreme cyclones have larger wind risks?

Cyclone Wind Speed – 850 hPa



- Strongest wind speeds are found on the equatorward flank of the cyclones
    - Speeds are stronger with larger footprint in DJF

- Increases around the cyclone center in DJF
- Largest increase on the S/SE flank, in the warm sector
    - Increase by up to 0.9 m s^{-1}.

- In JJA have a decrease in wind speed in the warm sector by up to 0.9 m s^{-1}.

- For both DJF and JJA the largest changes are not associated with the maximum wind speeds
    - Suggests a change in area of wind speeds rather than in peak wind speed.

* All composites are for 10% strongest cyclones

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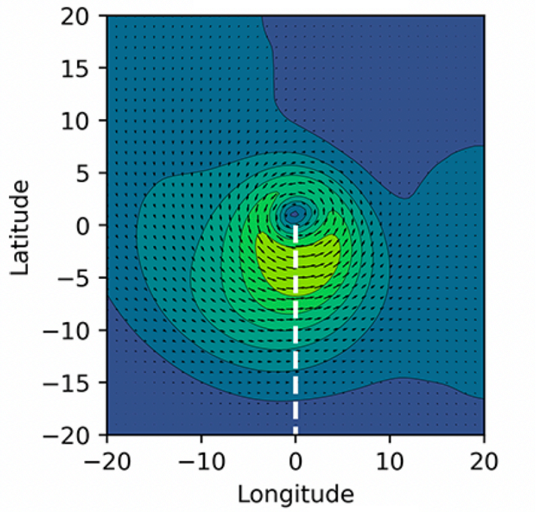
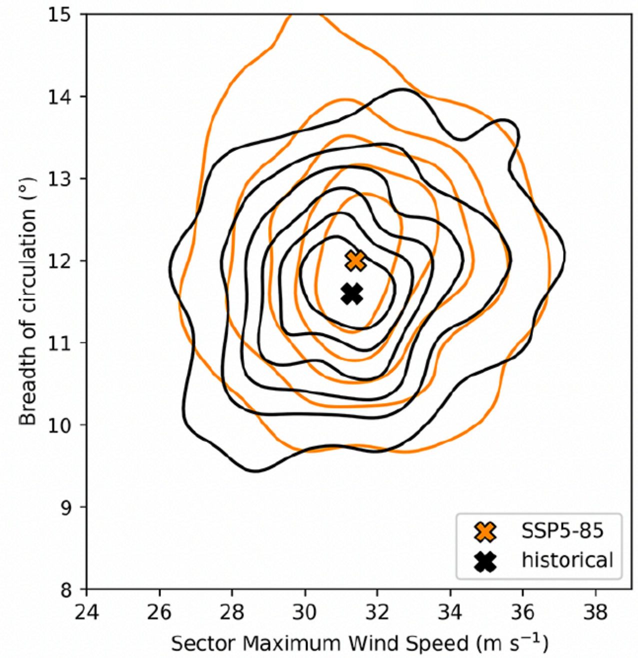
Cyclone Wind Speed – 850 hPa - broadness

historical

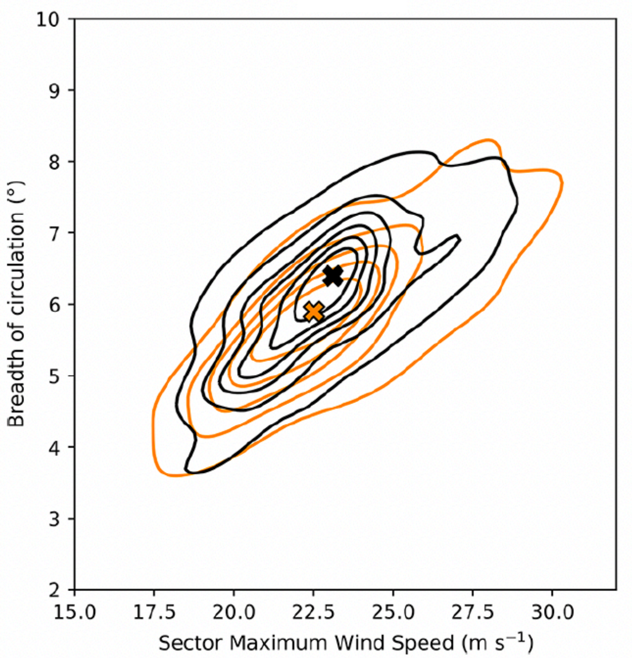


- Take a transect through the equatorward flank of the cyclone (dashed white line).
- Extract maximum wind speed and fraction of transect above a threshold (17 m s^{-1}.)

DJF



JJA

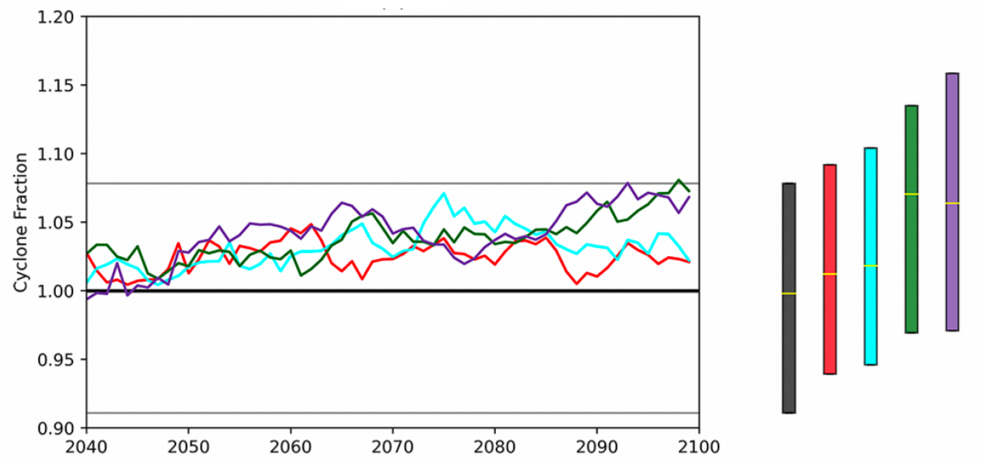


- The maximum wind speed in DJF does not change and is on average 31 m s^{-1}.
- The breadth of circulation generally increases so there is a larger fraction of high wind speeds

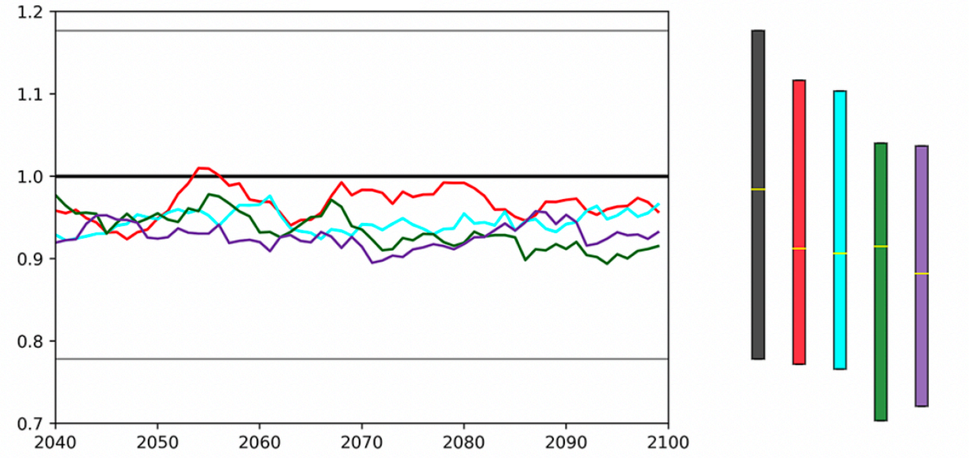
- In JJA the maximum wind speed decreases by an average of 1.5 m s^{-1}.
- The breadth of circulation also decreases

Cyclone Wind Speed – 850 hPa - broadness

DJF



JJA



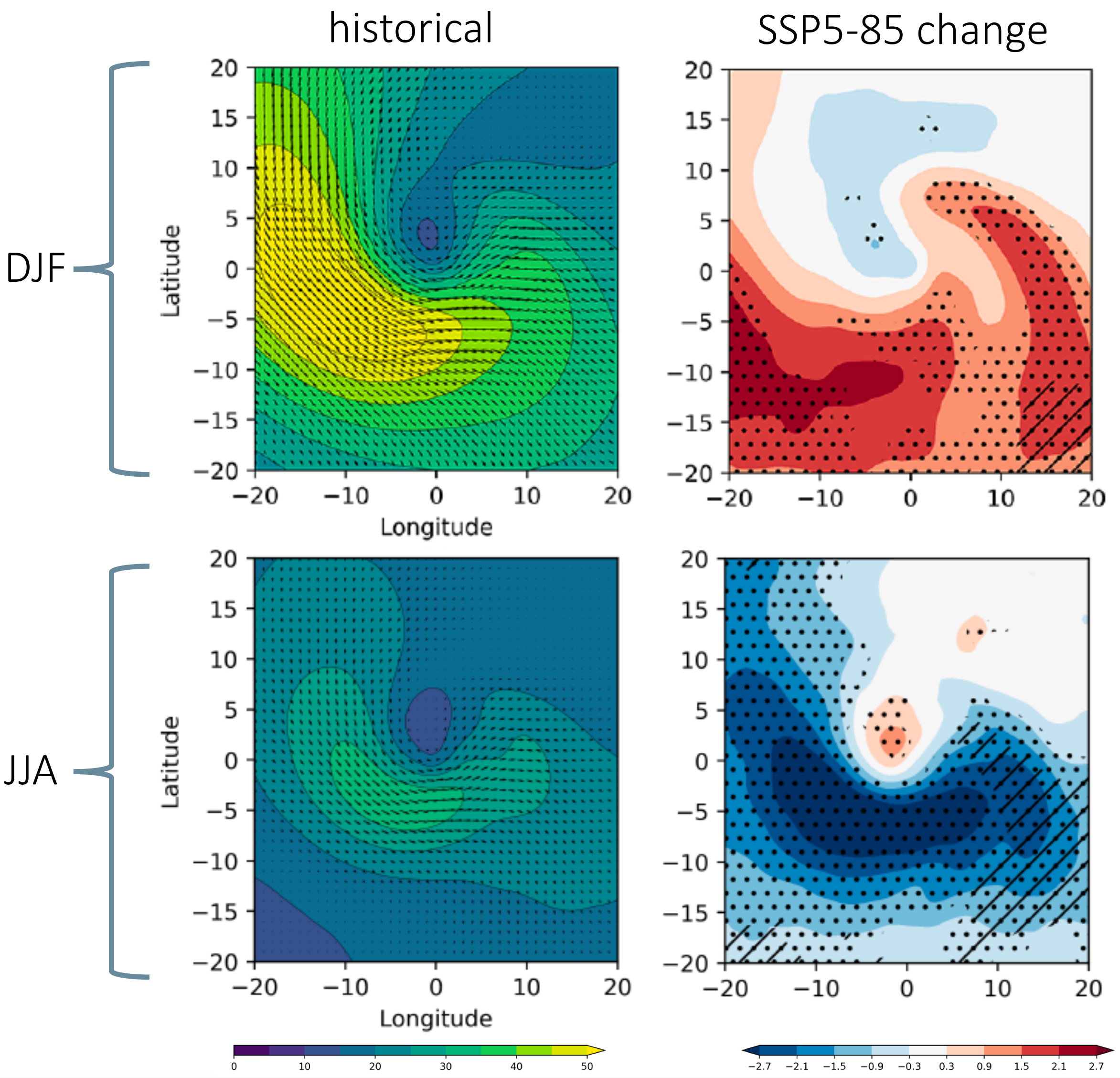
- We can define the area of a cyclone above the 17 m s^{-1} threshold and track its evolution through time.
- In DJF there is an average of 8% more of the cyclone area above this threshold by 2100 in the SSP3-70 and SSP5-85 experiments
  - This could be as high as +15% and outside historical variability when accounting for the model spread

- Coupled with an increase in cyclone frequency, this may have significant implications for windstorm impacts

- In JJA there is a general decrease in the area of above threshold winds by ~10%.
  - The change could be as large as -25%

* All data is for 10% strongest cyclones

Cyclone Wind Speed – 250 hPa



- The dominant identifiable feature is the upper-level jet in the historical composite
- In DJF there is a strengthening on the cyclone forward flank by up to 2 m s^{-1}.
  - Dominated by increased southward/turning motion – implies stronger WCB outflow
- Also stronger circulation near centre where ascent rate is largest
- In JJA there is a weakening of both the jet and the flow on the forward flank of the cyclones

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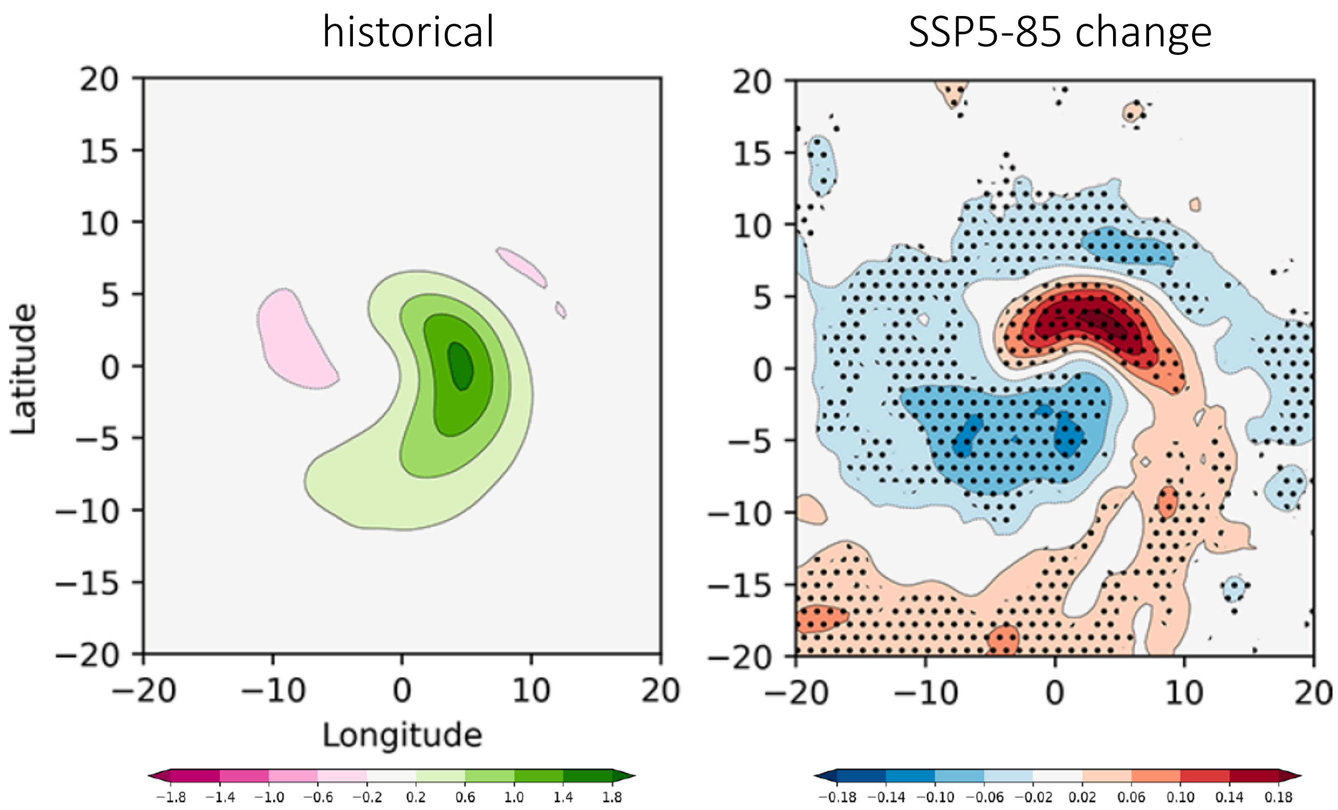
Divergence at 250 hPa - DJF



- 250 hPa dominated by divergent outflow
- Rate of divergence shifts slightly poleward and downstream
    - Increases on poleward flank
    - Changes in wind speed co-located with the divergence increase

- Minimal changes in convergence/divergence in the lower troposphere (850 hPa)
    - Suggests the increased divergence is not driven by surface convergence but likely by increased moist processes in the WCB in the mid-troposphere

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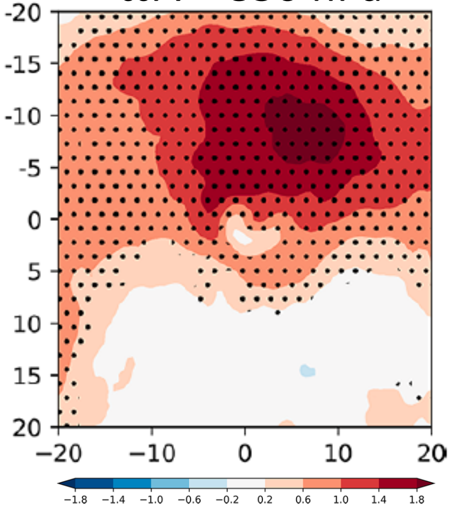
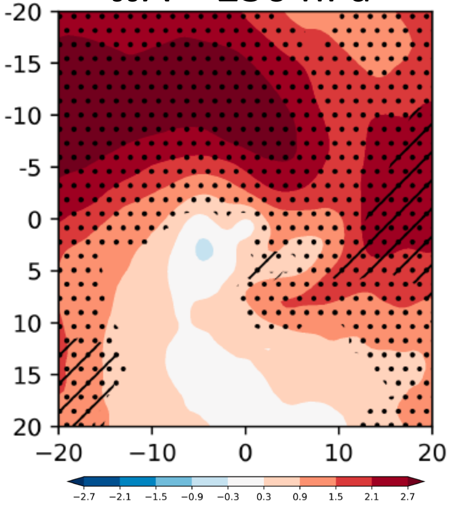
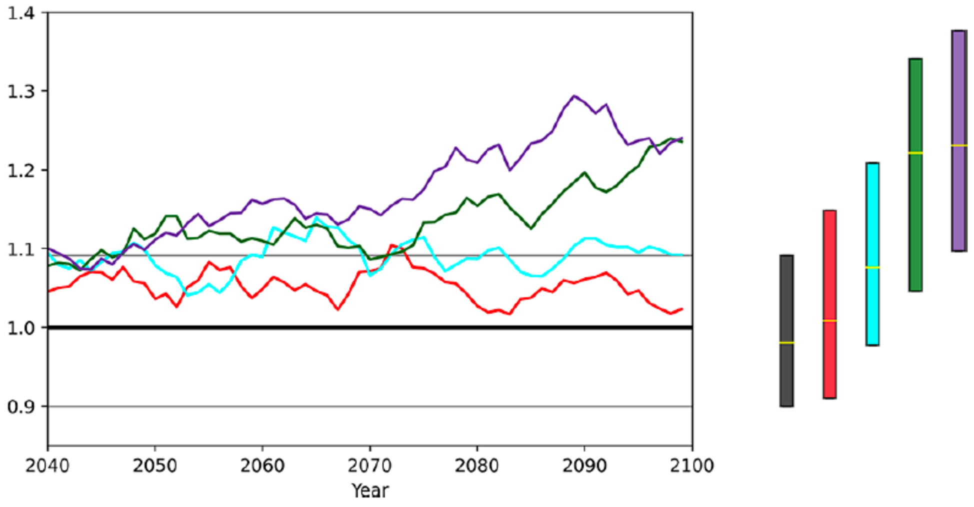
The Southern Hemisphere

JJA – 850 hPa



JJA – 250 hPa





- Changes in the SH are similar to that in NH DJF
  - Increase in intensity – stronger winds – larger area of strong winds
- Both the JJA and DJF seasons have similar responses (larger in the winter)
- Area of strong winds increases by ~20% on average in JJA for SSPs 3-70 and 5-85
  - This may be as large as 35% based on model uncertainty
- The lack of land influence, and lower magnitude Polar Amplification likely contribute to the stronger changes over NH DJF.

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Summary

- The frequency of intense cyclones will increase in NH winter
- Cyclones will feature stronger wind speeds
  - This manifests itself as an expansion of the area of strong winds rather than an increase in peak speed
- The area of strong winds will increase by an average of 8% in NH DJF by 2100
- In NH JJA the opposite responses is seen in all changes
- SH cyclones respond similarly to those in NH DJF with an increase in intensity, strength of winds, and area of strong winds.

Summary

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- SH cyclones respond similarly to those in NH DJF with an increase in intensity, strength of winds, and area of strong winds.

For full details please see our recent paper in Weather and Climate Dynamics:

'Future changes in the extratropical storm tracks and cyclone intensity, wind speed, and structure'

https://doi.org/10.5194/wcd-3-337-2022