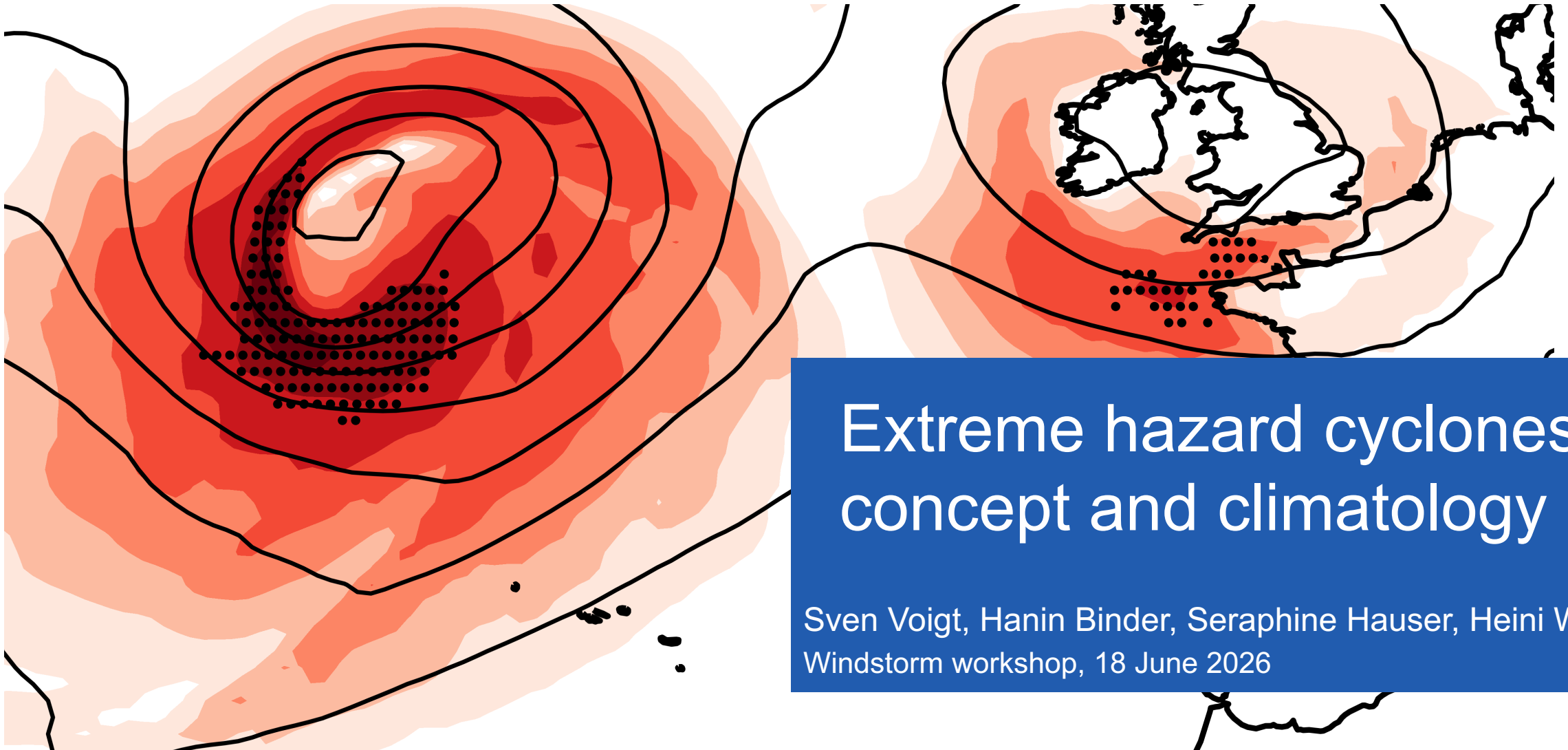


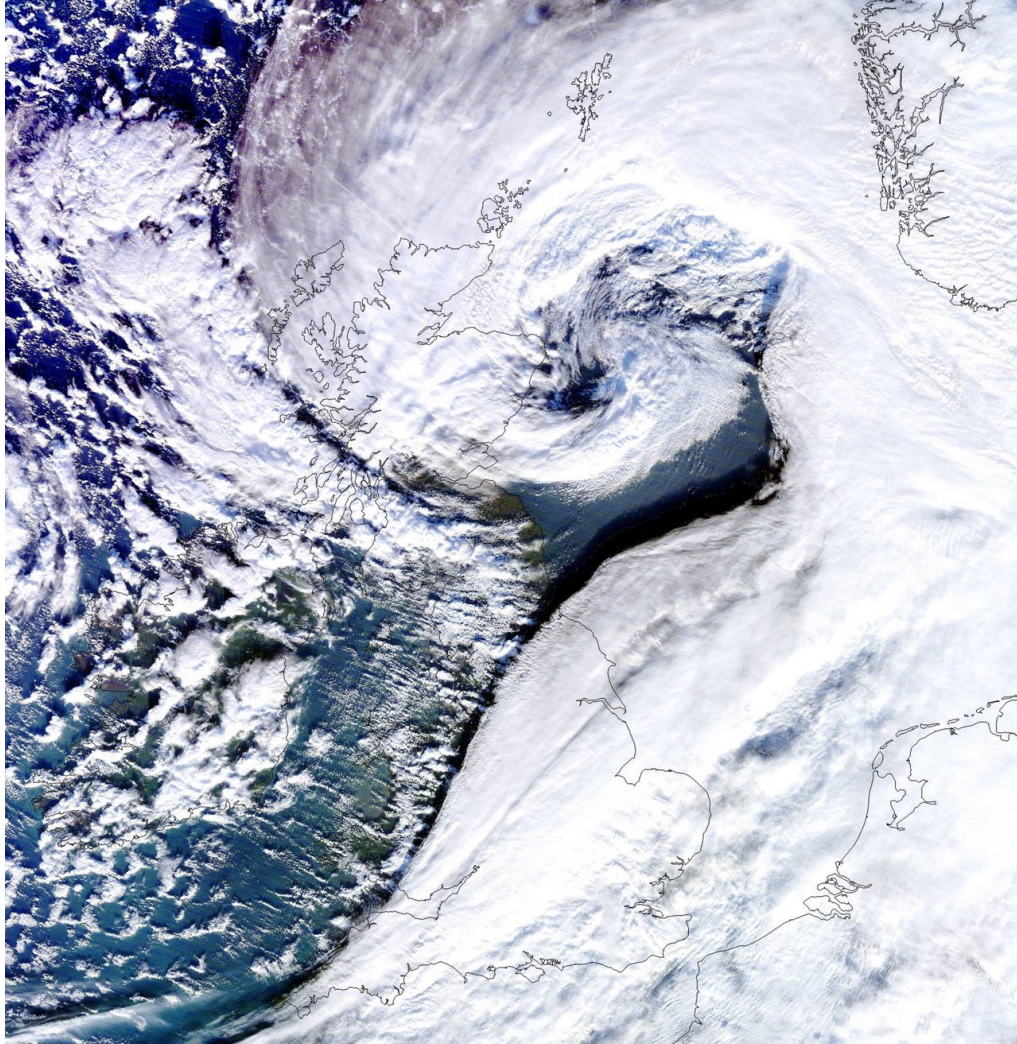


Extreme hazard cyclones: concept and climatology

Sven Voigt, Hanin Binder, Seraphine Hauser, Heini Wernli
Windstorm workshop, 18 June 2026

Introduction

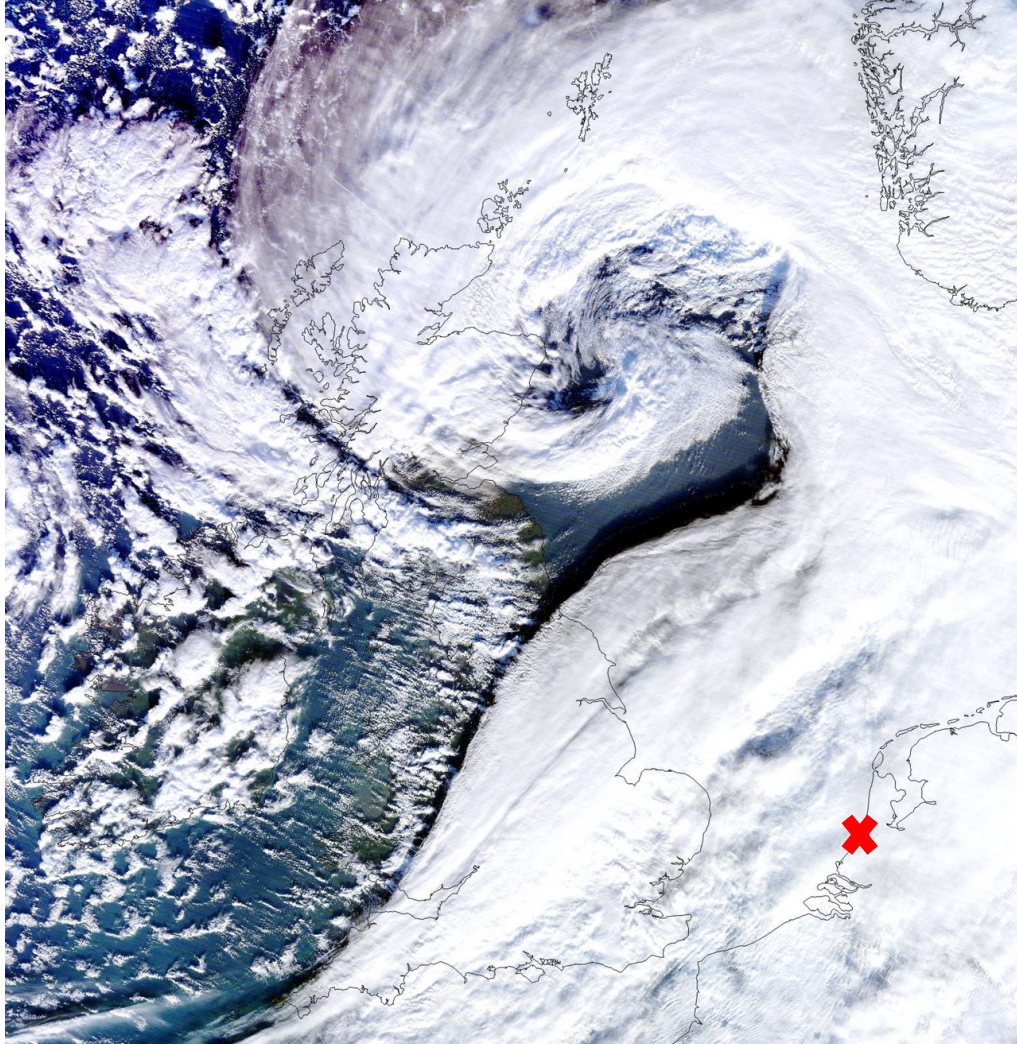
Highest measured winds in the NL – Cyclone Ulli, January 2012



worldview.earthdata.nasa.gov

Introduction

Highest measured winds in the NL – Cyclone Ulli, January 2012

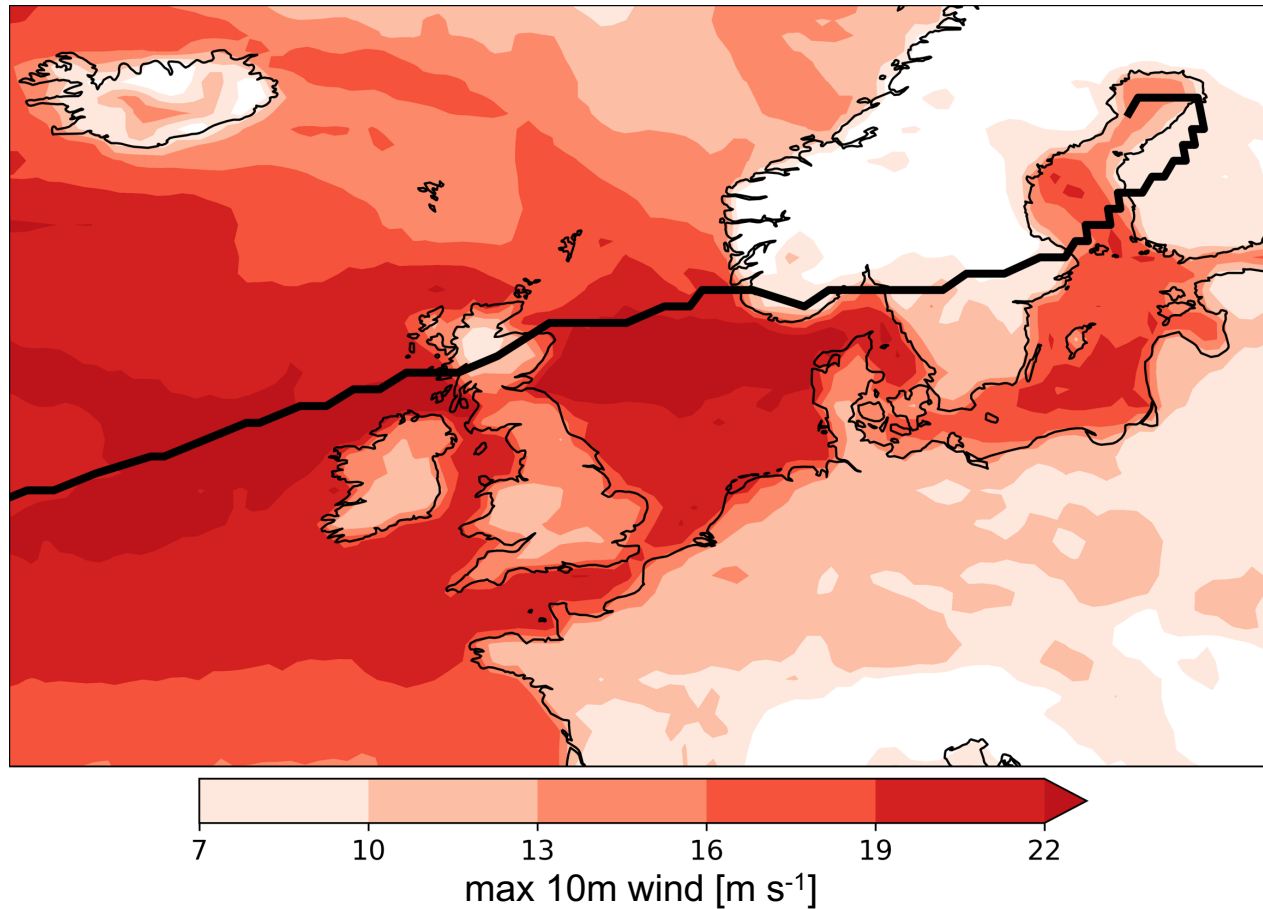


- **Extreme local gusts:** 48 m/s in IJmuiden
- **Grid disruption:** 150'000+ homes left without power across UK, NL, and DE
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Highest measured winds in the NL – Cyclone Ulli, January 2012

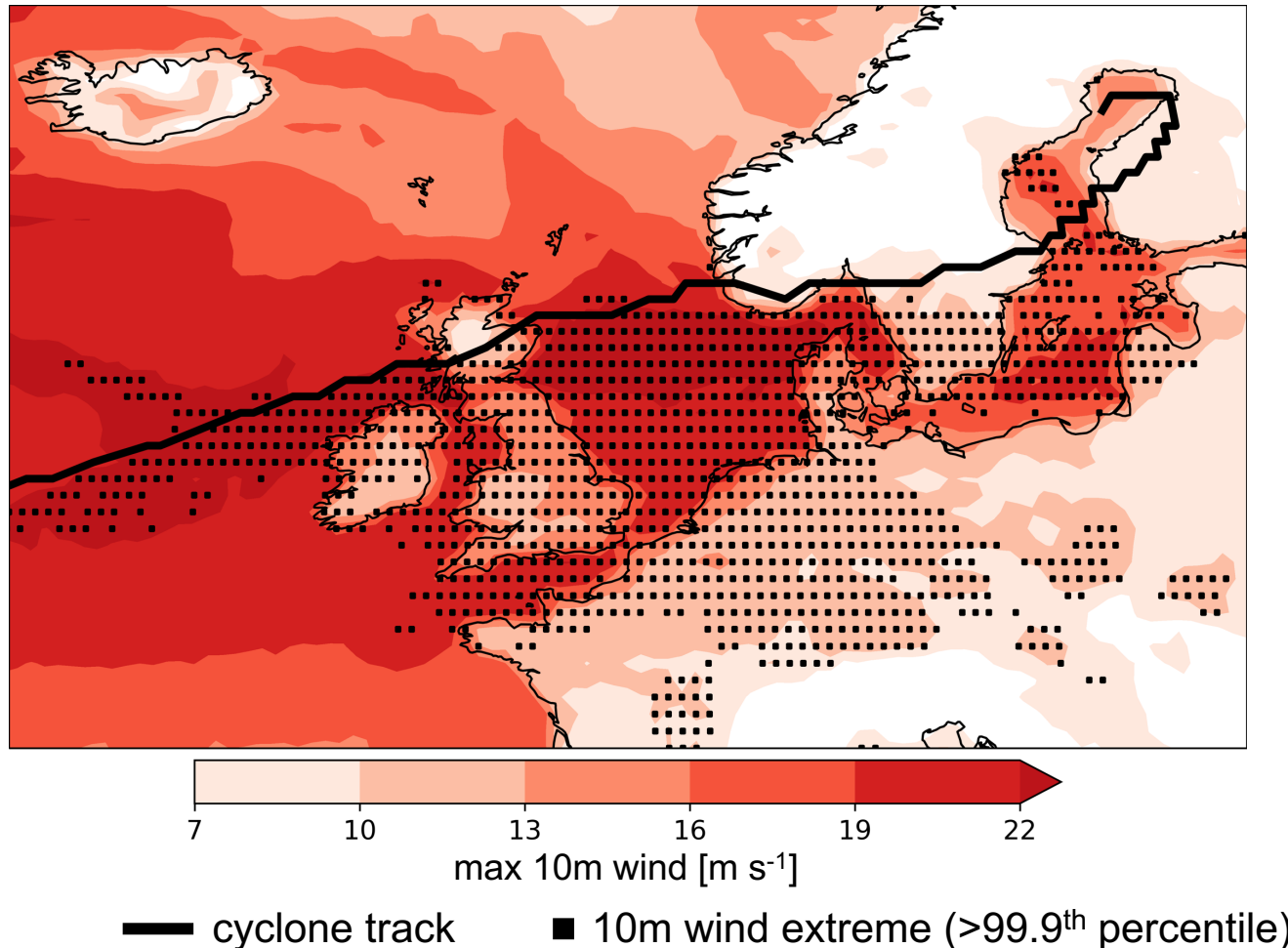


— cyclone track

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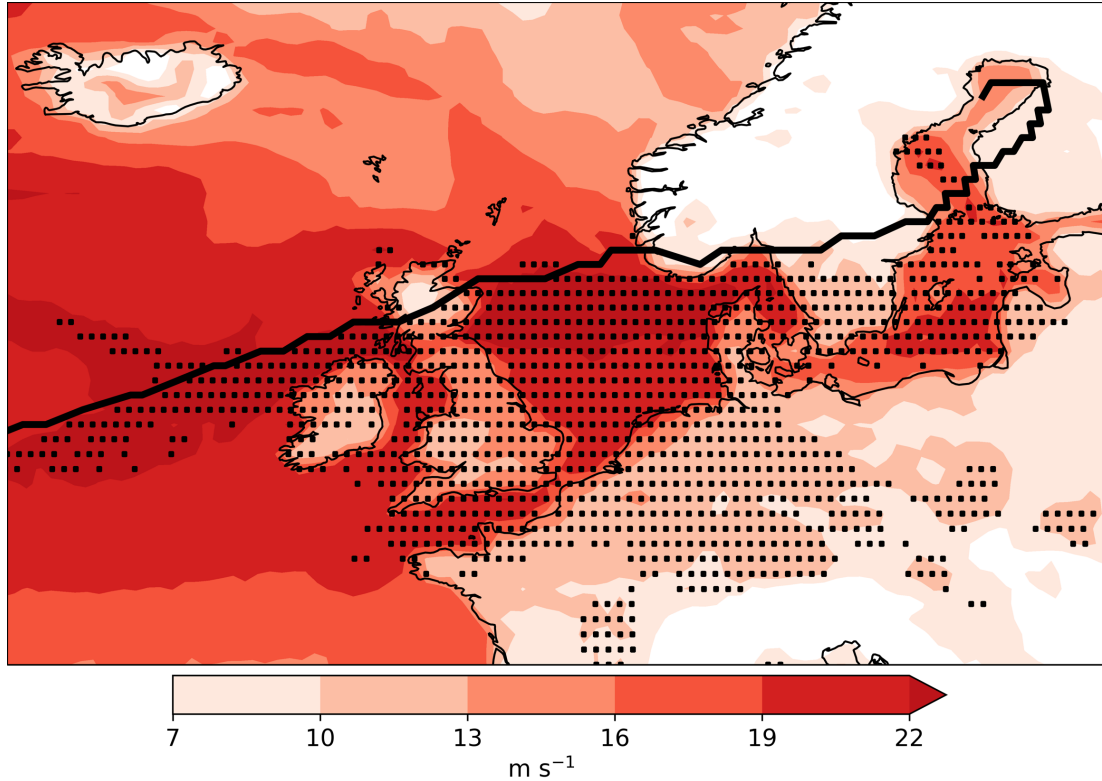


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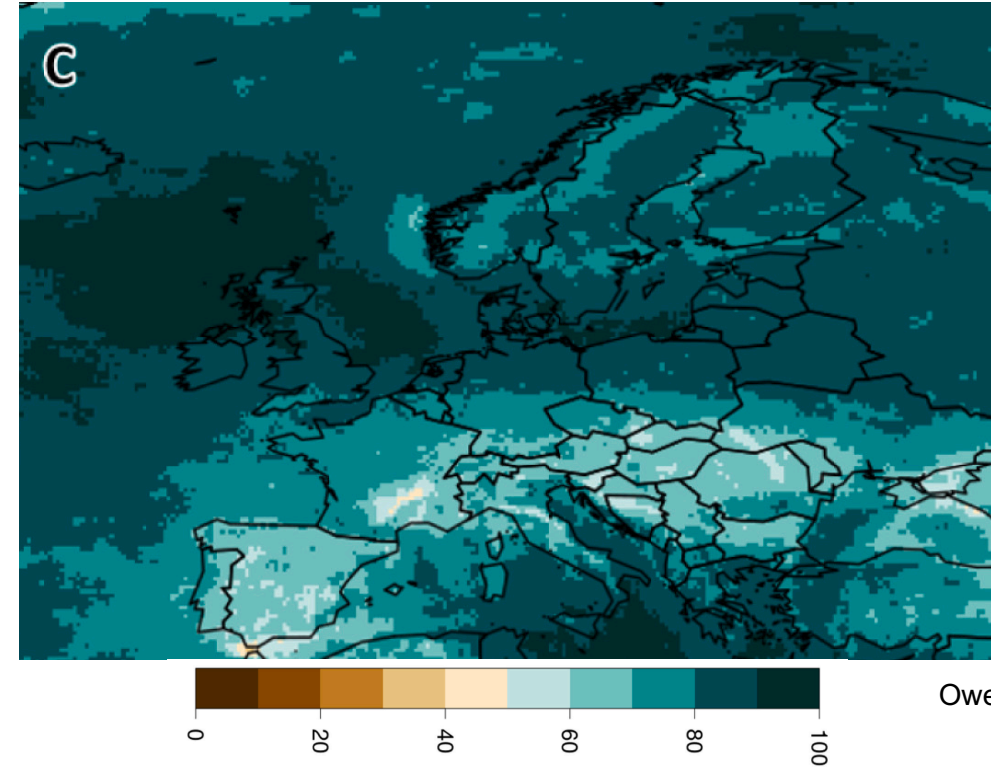
Introduction

Cyclone-linked surface wind extremes

1h wind extremes during passage of Ulli



6h-wind extremes co-occurring with a cyclone

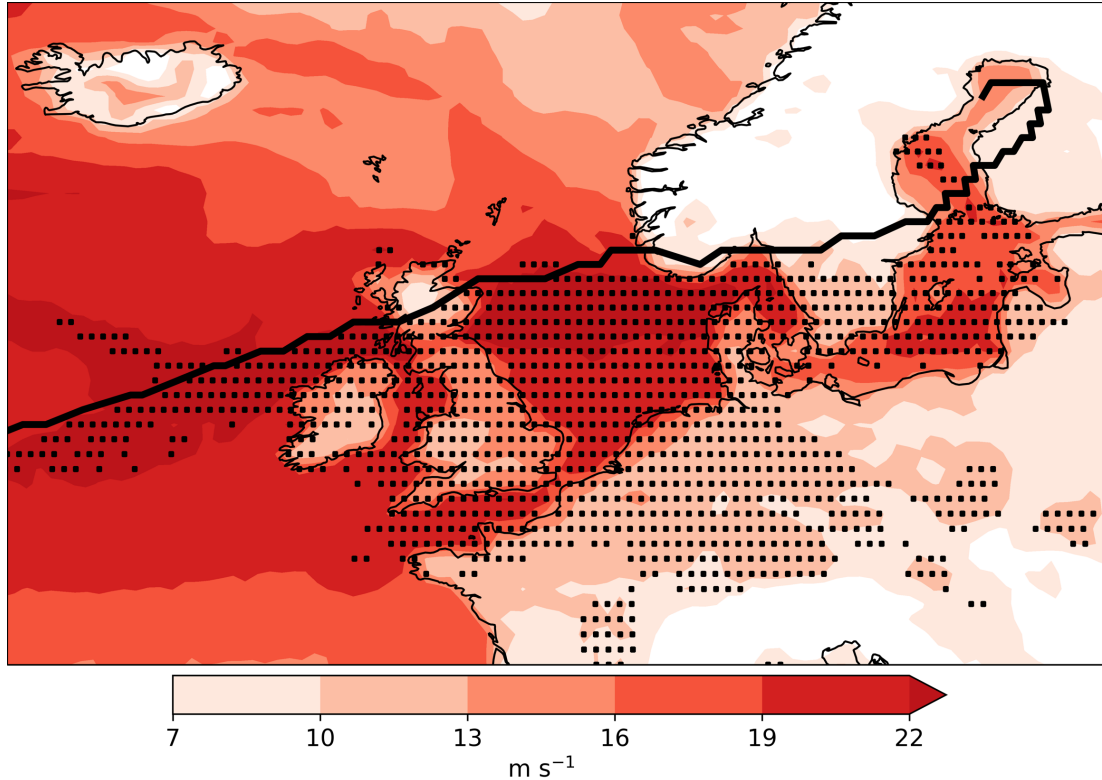


Owen et al. (2021)

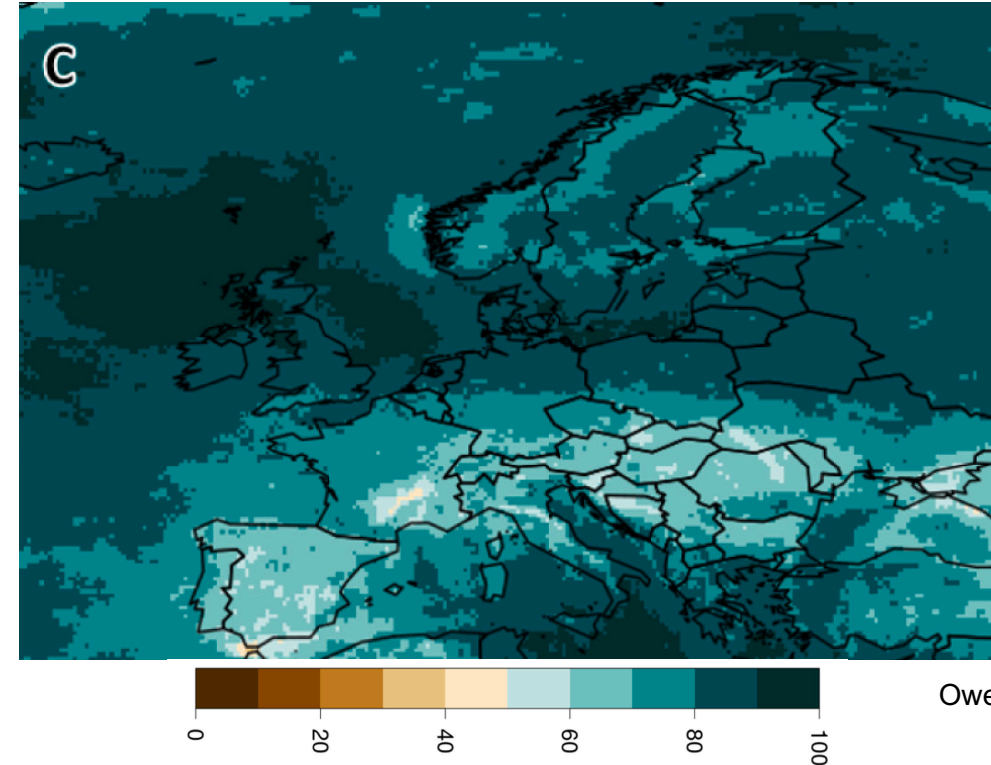
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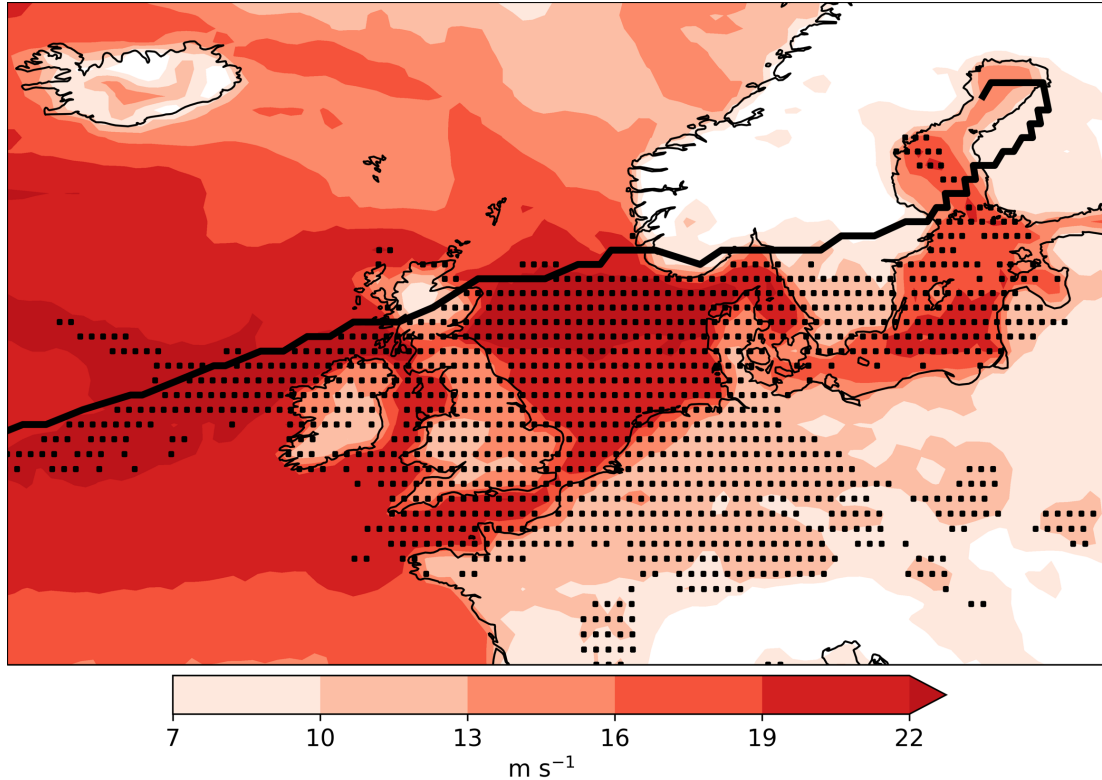
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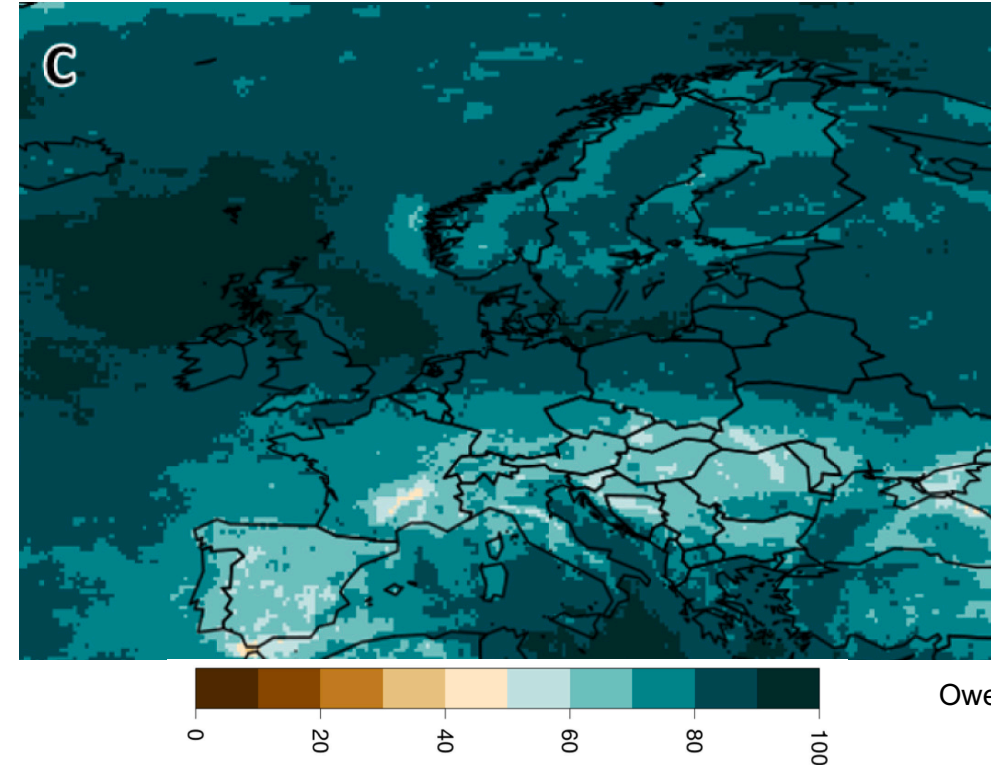
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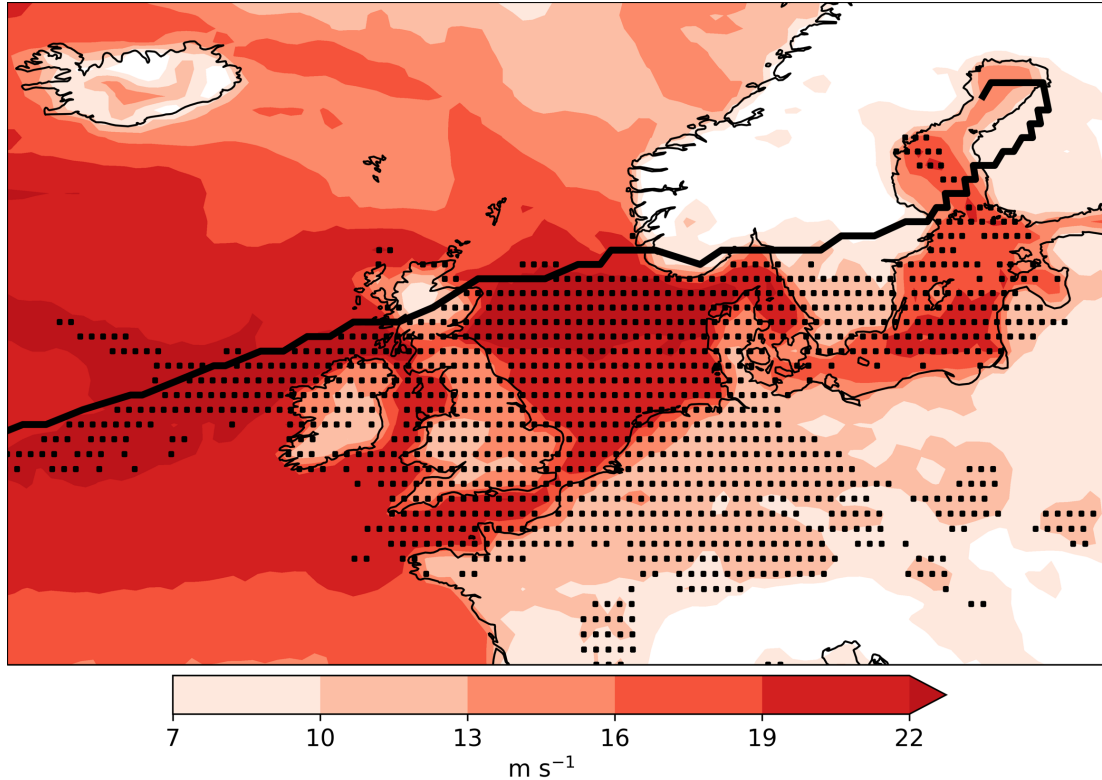
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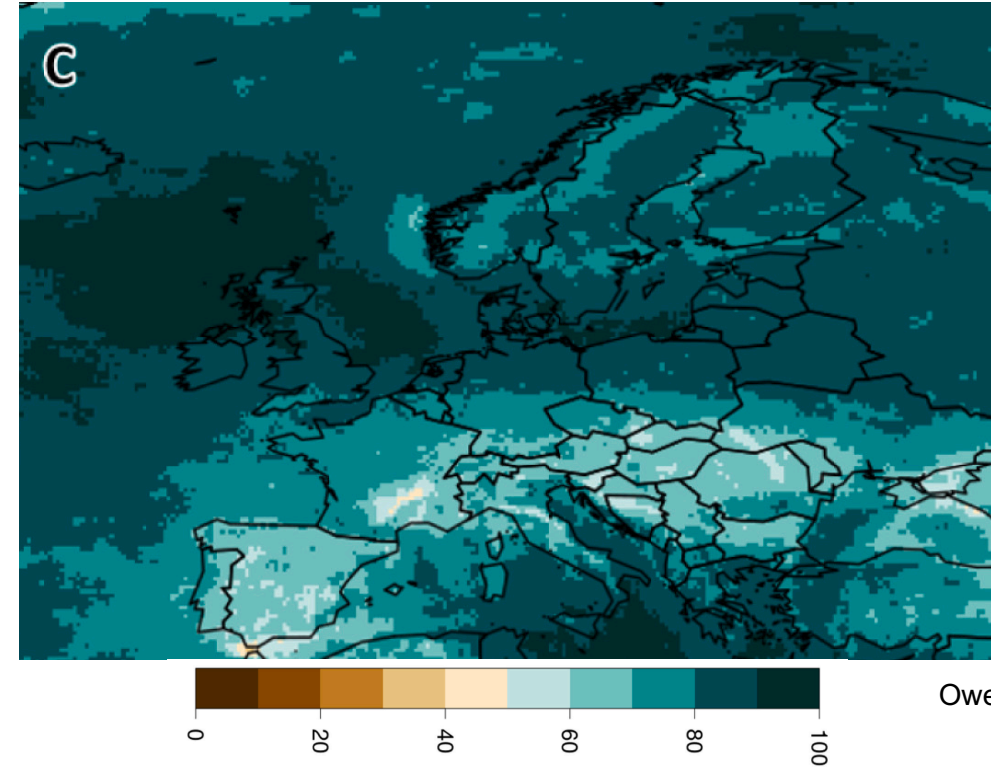
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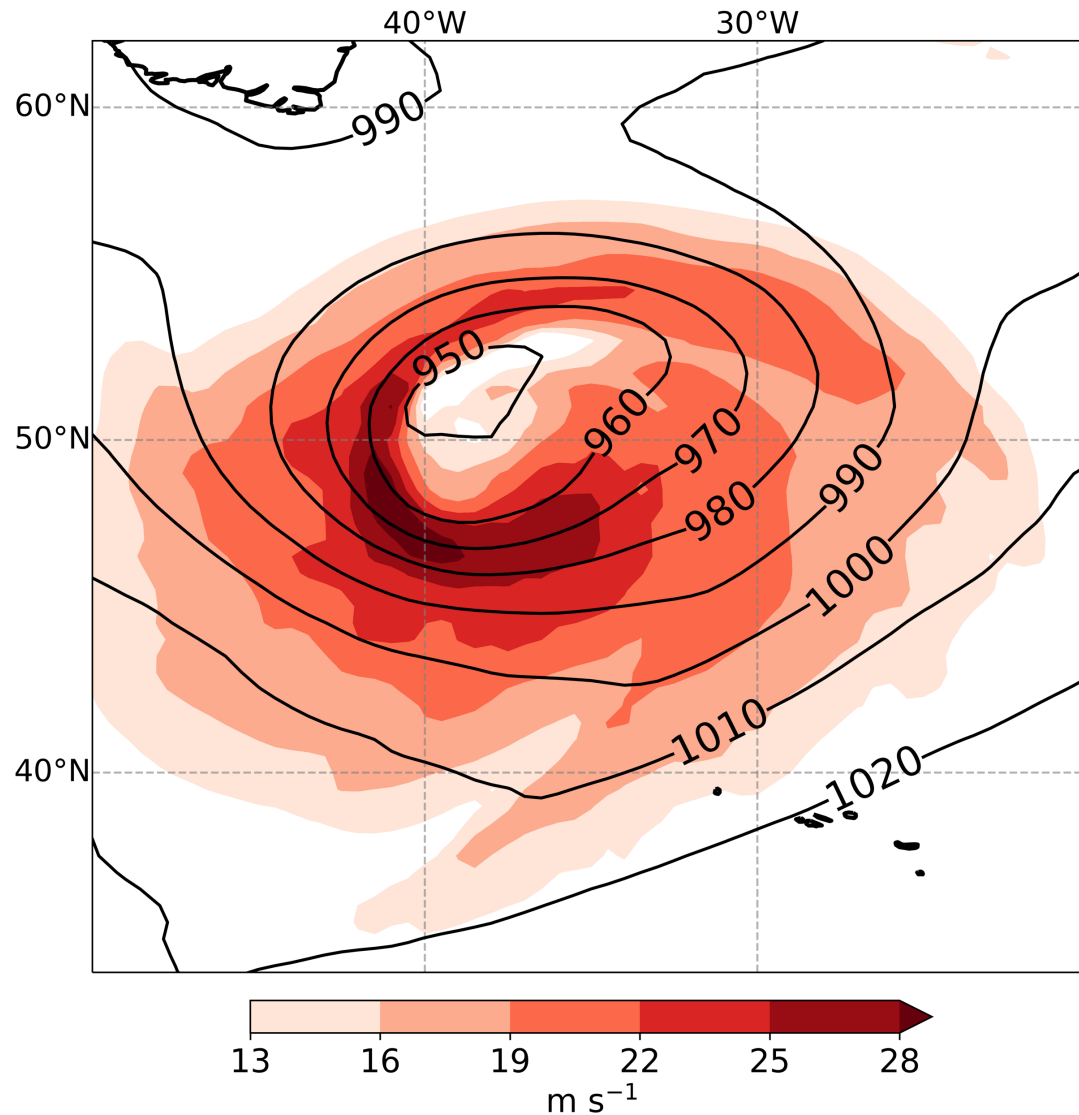
1. Which cyclones accumulate the largest number of 10m wind extremes along their track?
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3. How do these properties vary with the duration of the extreme?

Data & Methods

How to link extremes to cyclones

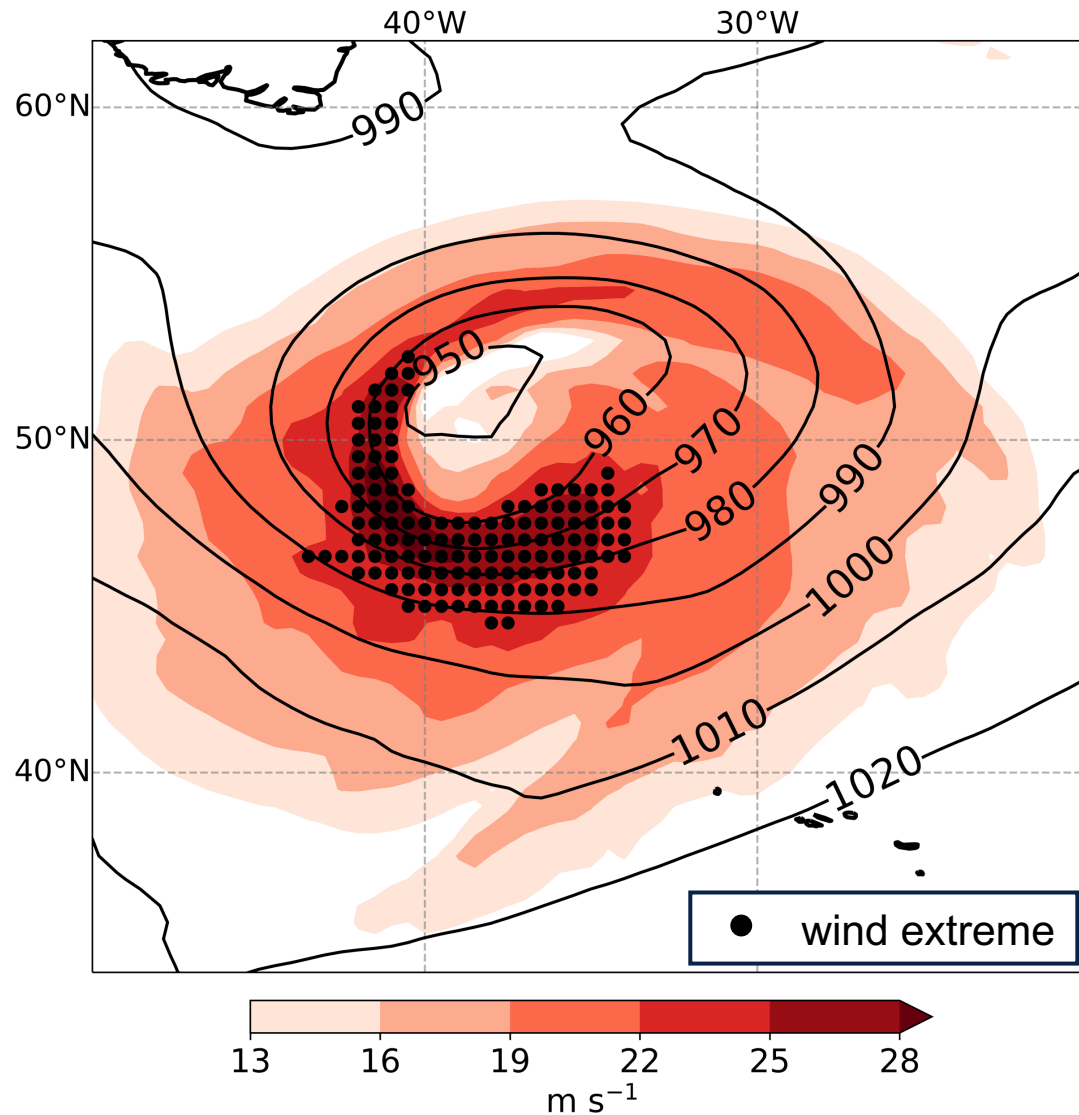
Data

- 75 years of ERA5 data (1950-2025)
- Resolution: 1h temporal, $0.5^\circ \times 0.5^\circ$ spatial



Data & Methods

How to link extremes to cyclones



Data

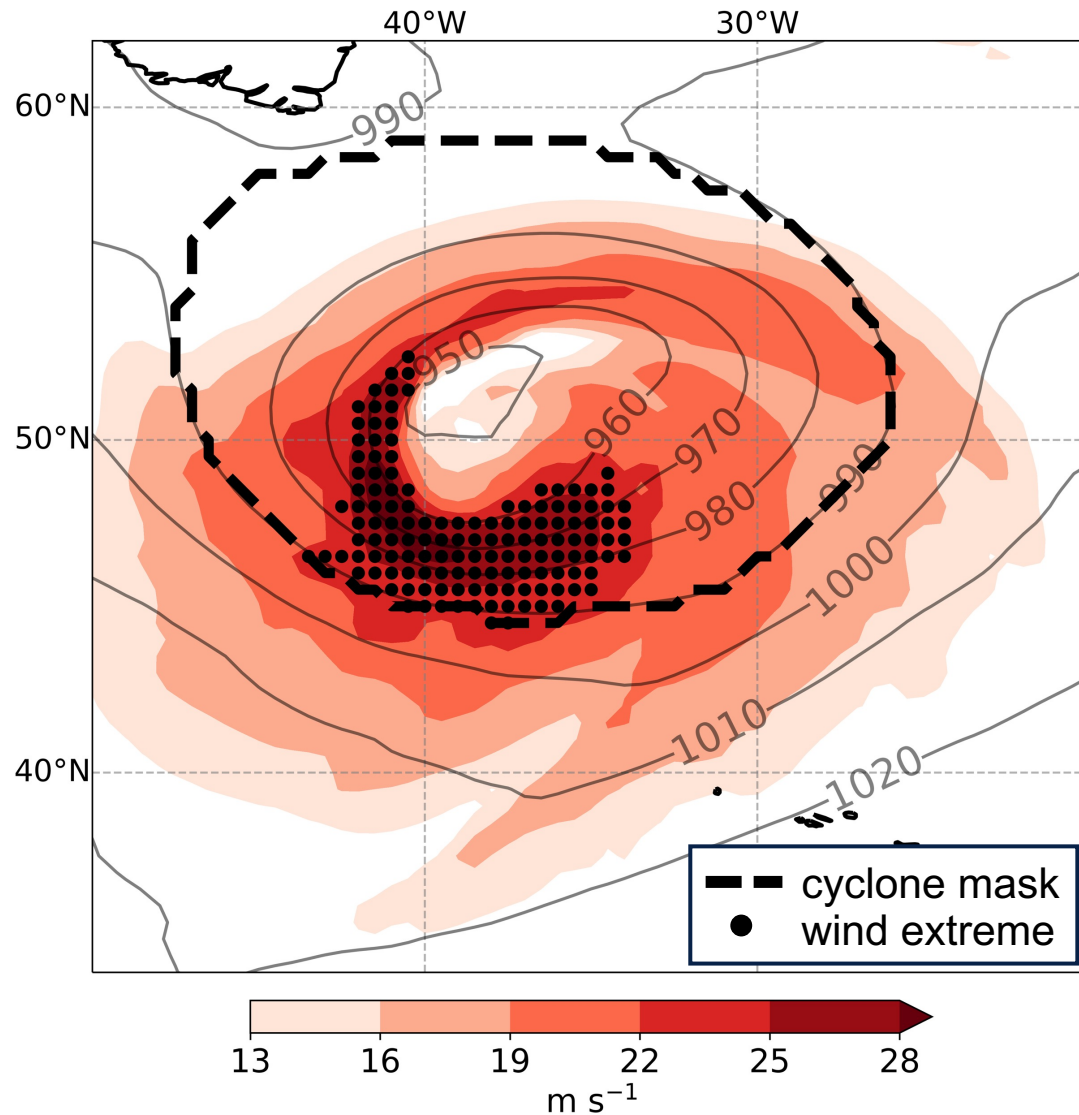
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Data & Methods

How to link extremes to cyclones



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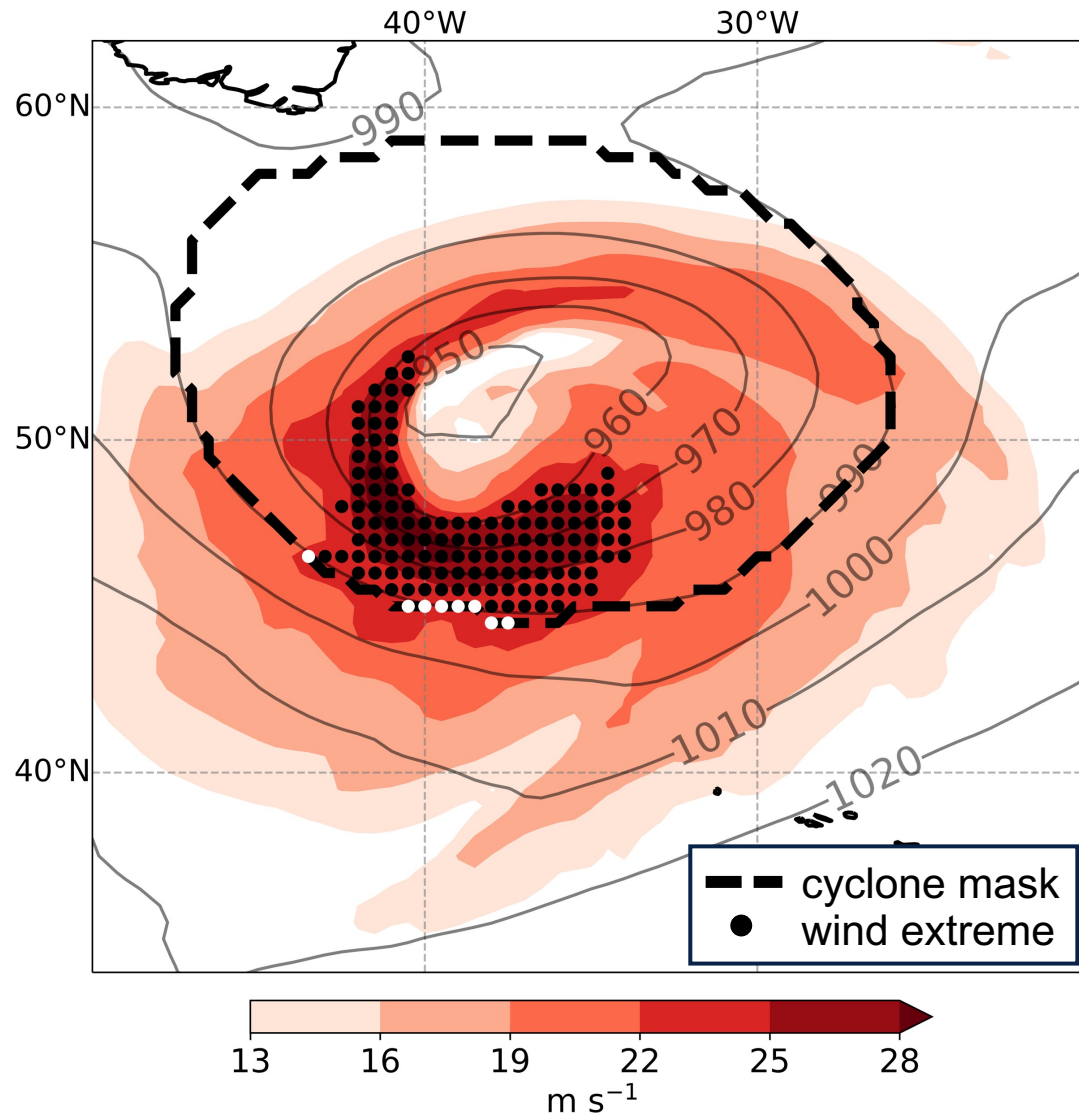
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2. Check for overlapping cyclones

Data & Methods

How to link extremes to cyclones



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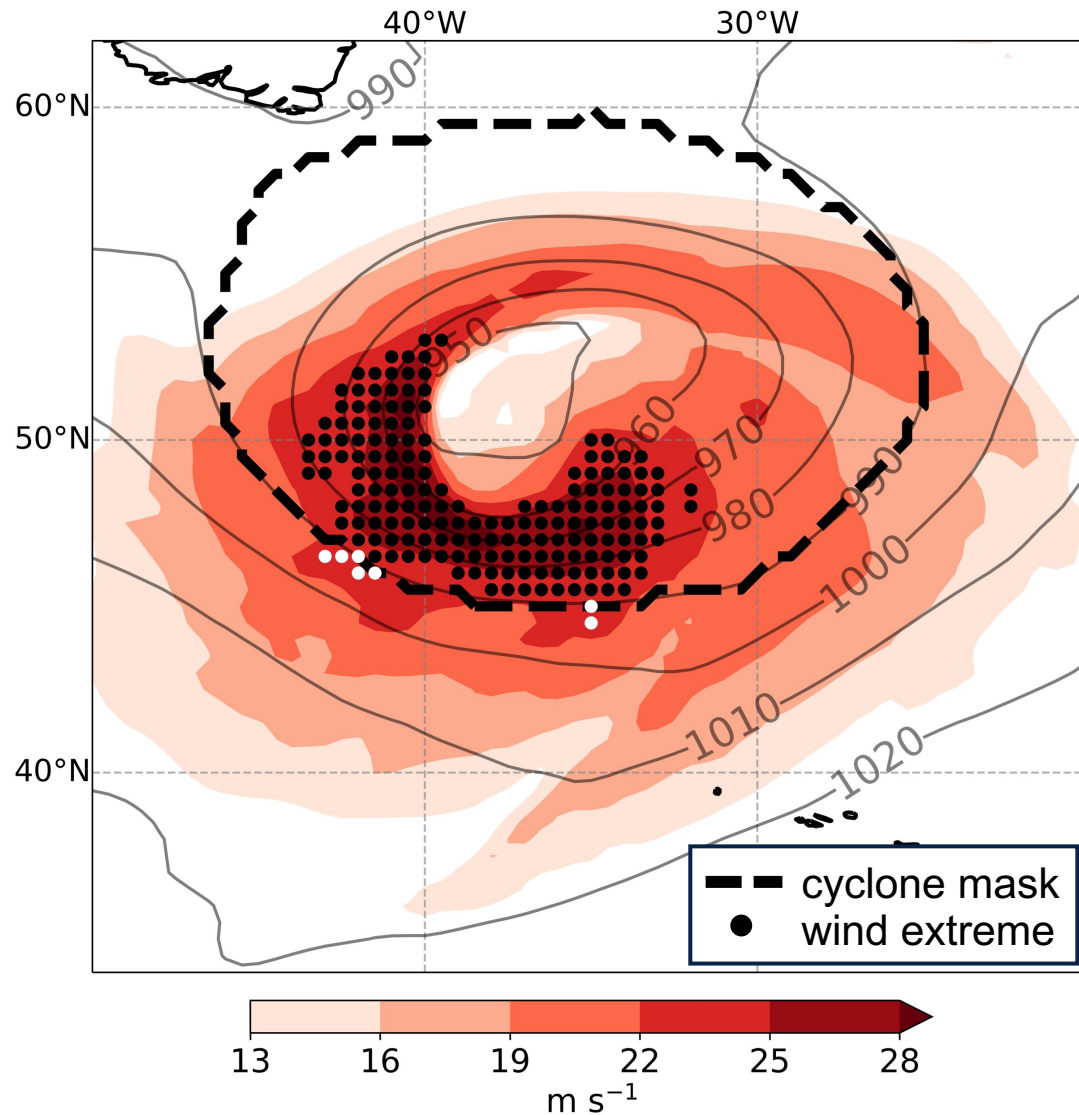
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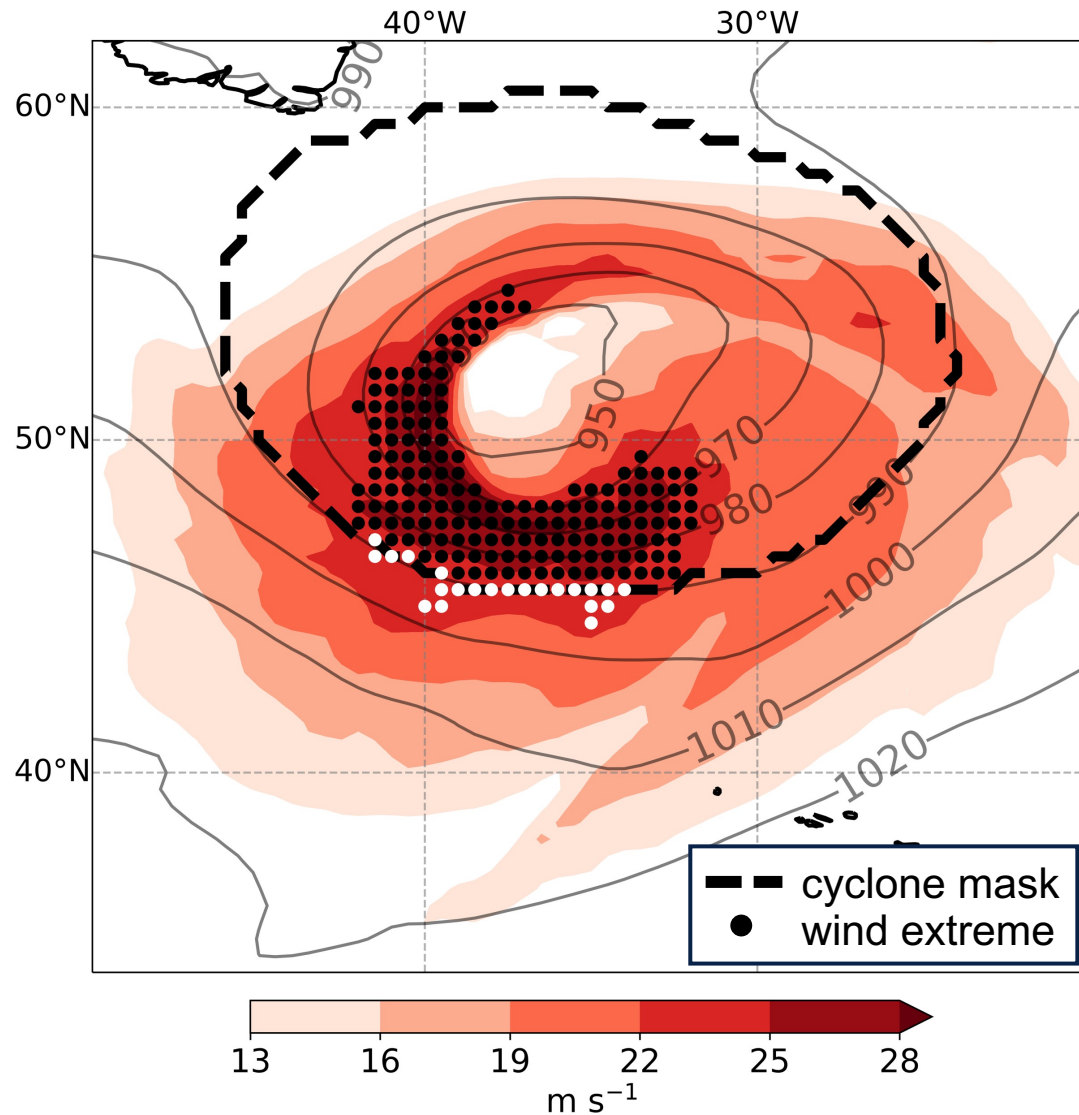
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Data & Methods

How to link extremes to cyclones



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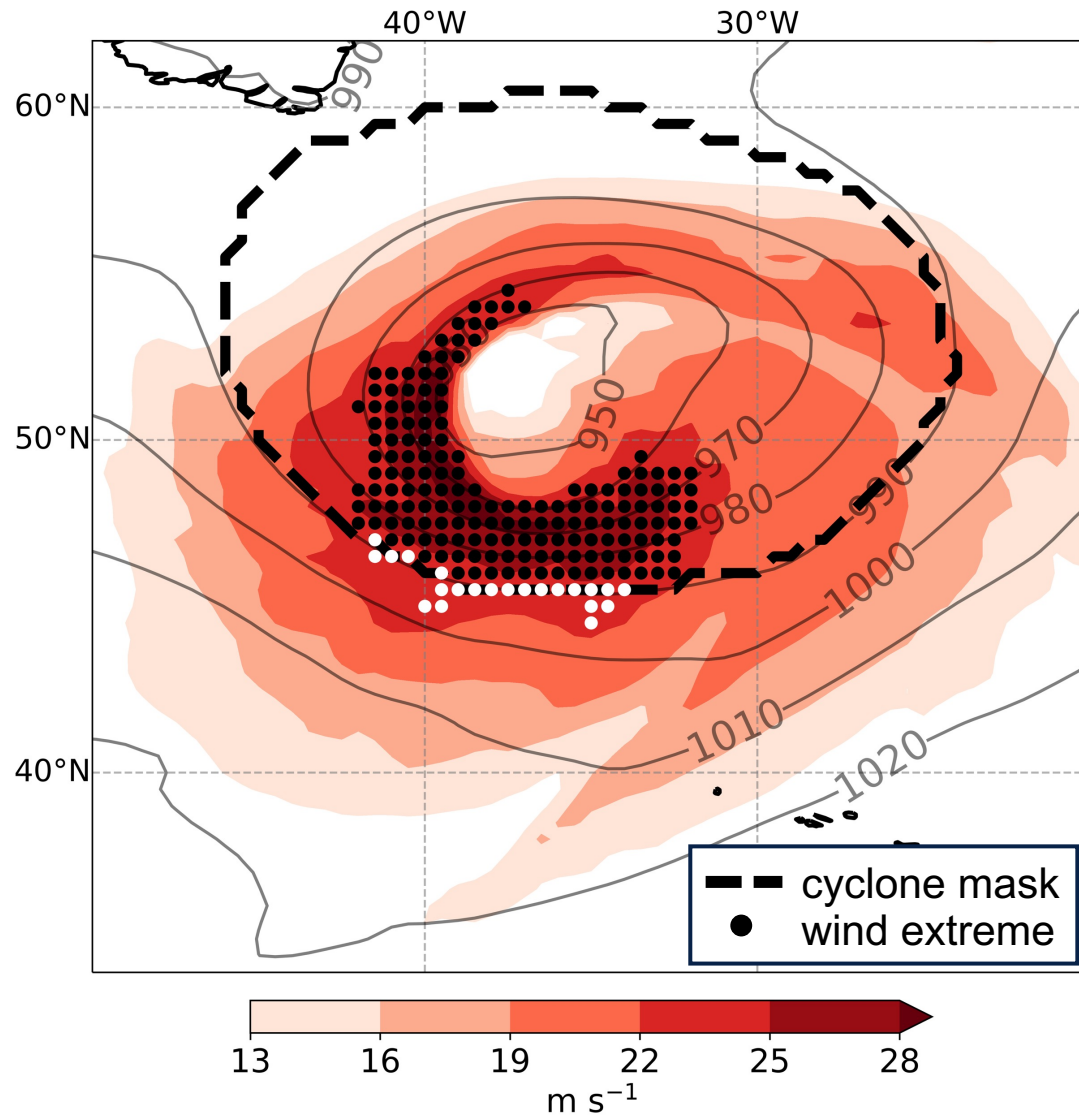
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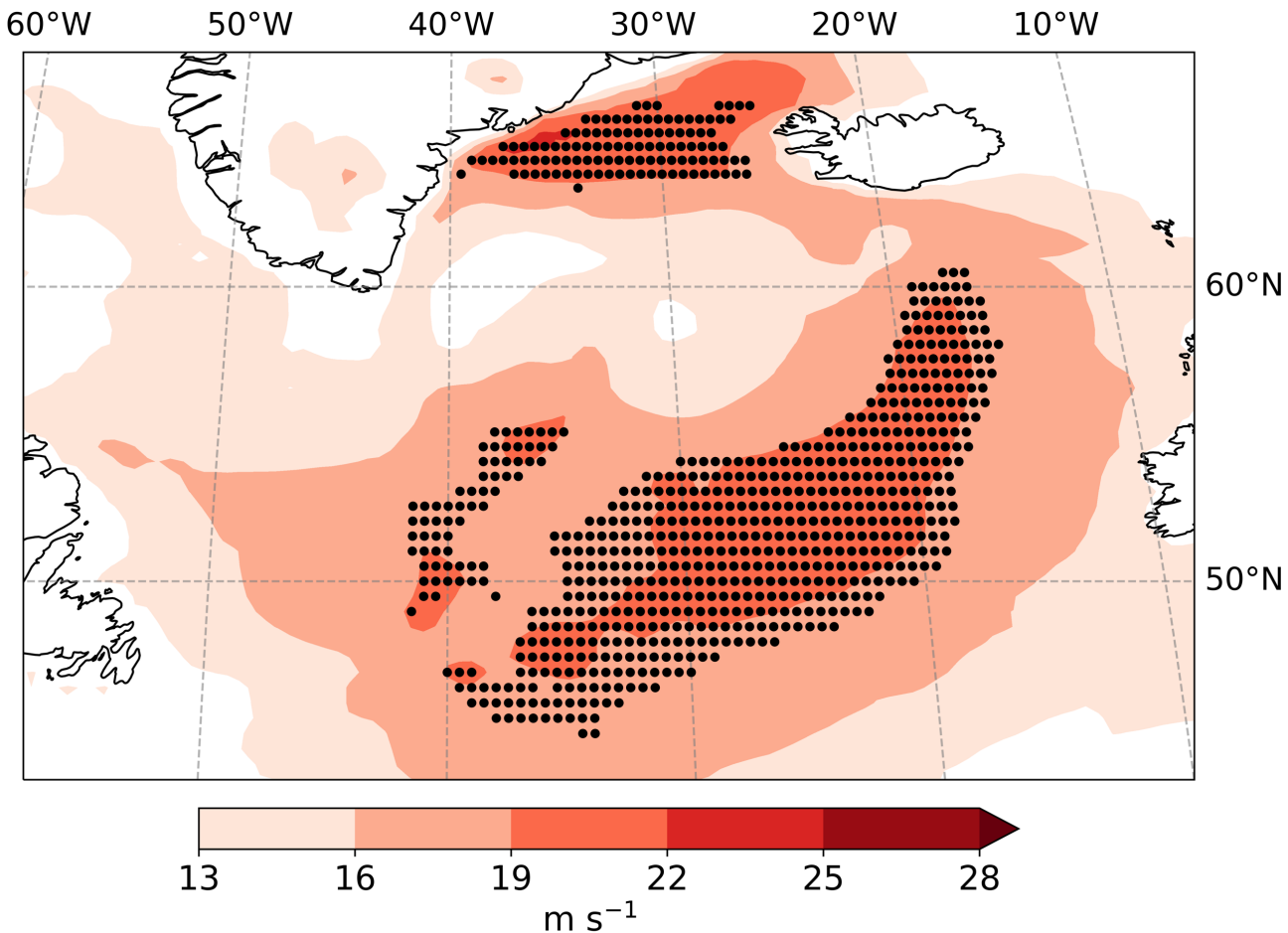
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Data & Methods

How to link 72h extremes to cyclones



Data

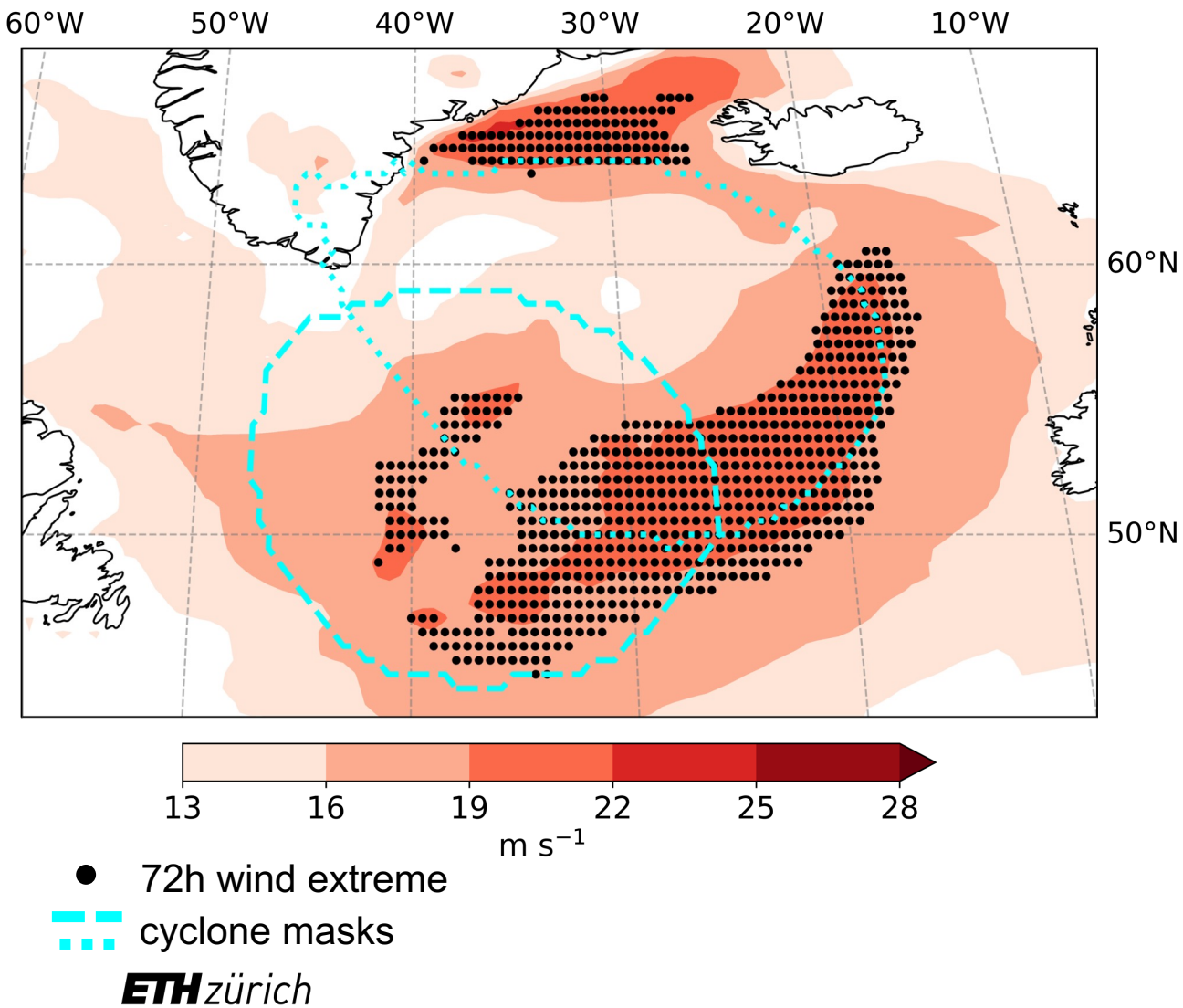
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Data & Methods

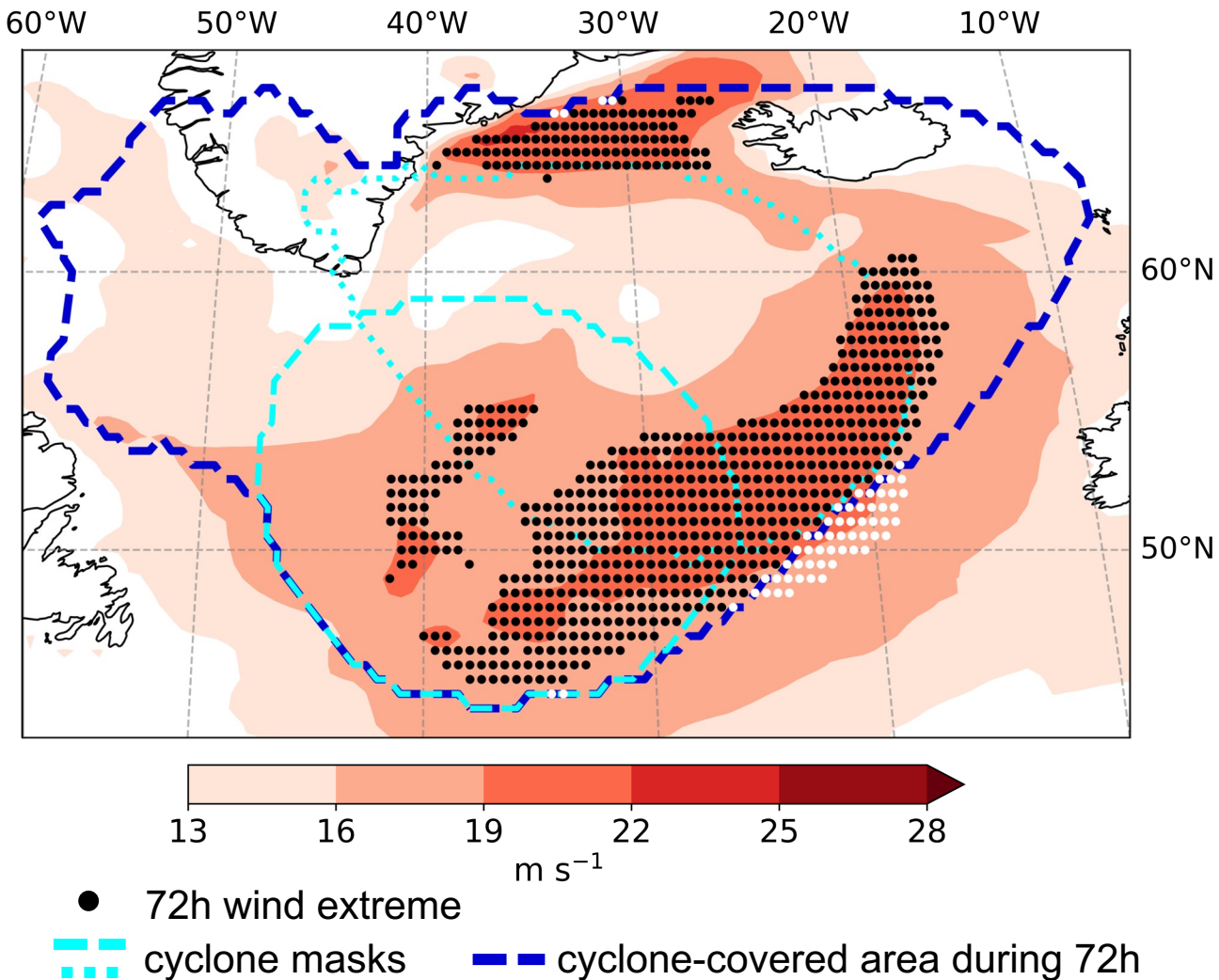
How to link 72h extremes to cyclones

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- 75 years of ERA5 data (1950-2025)
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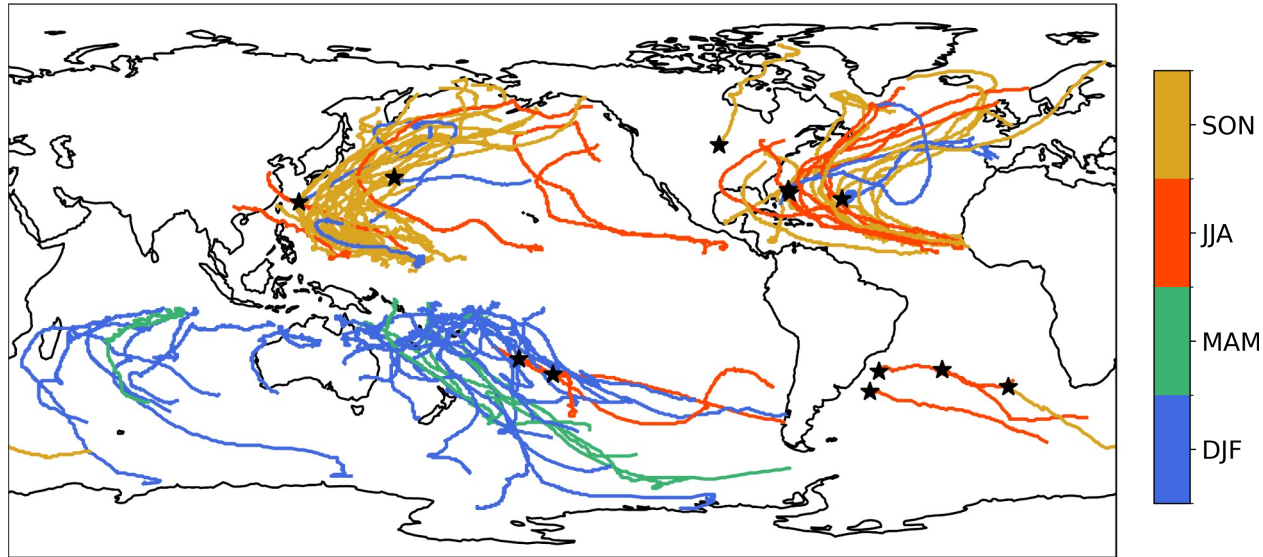
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Tracks of extreme hazard cyclones

Where and when do they develop?

★ : genesis >25° latitude

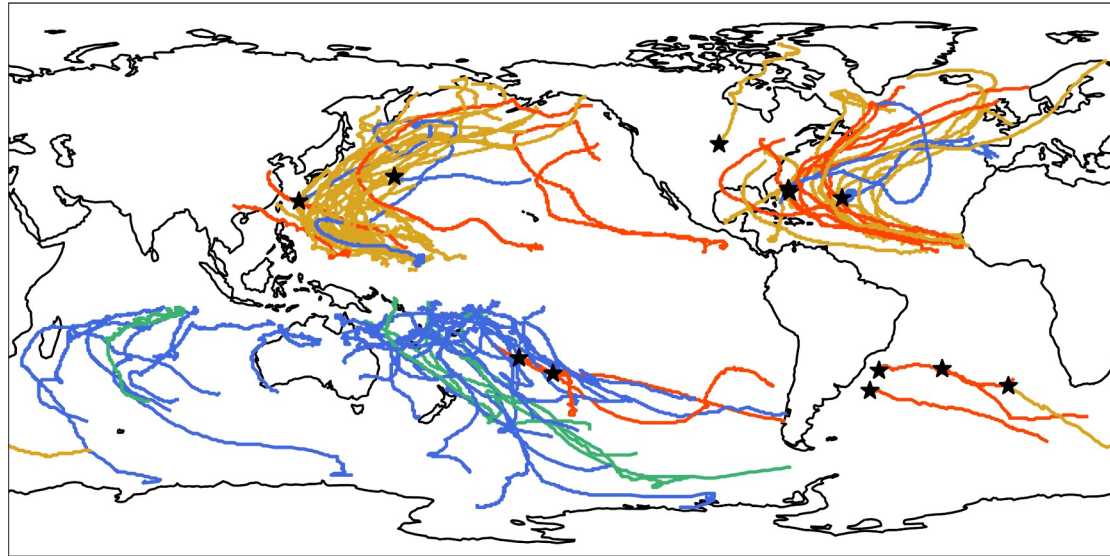


1h wind:

- Cyclones often undergo extratropical transition
- Exceptionally long lifetime and tracks
- Seasonal cycle of tropical cyclones

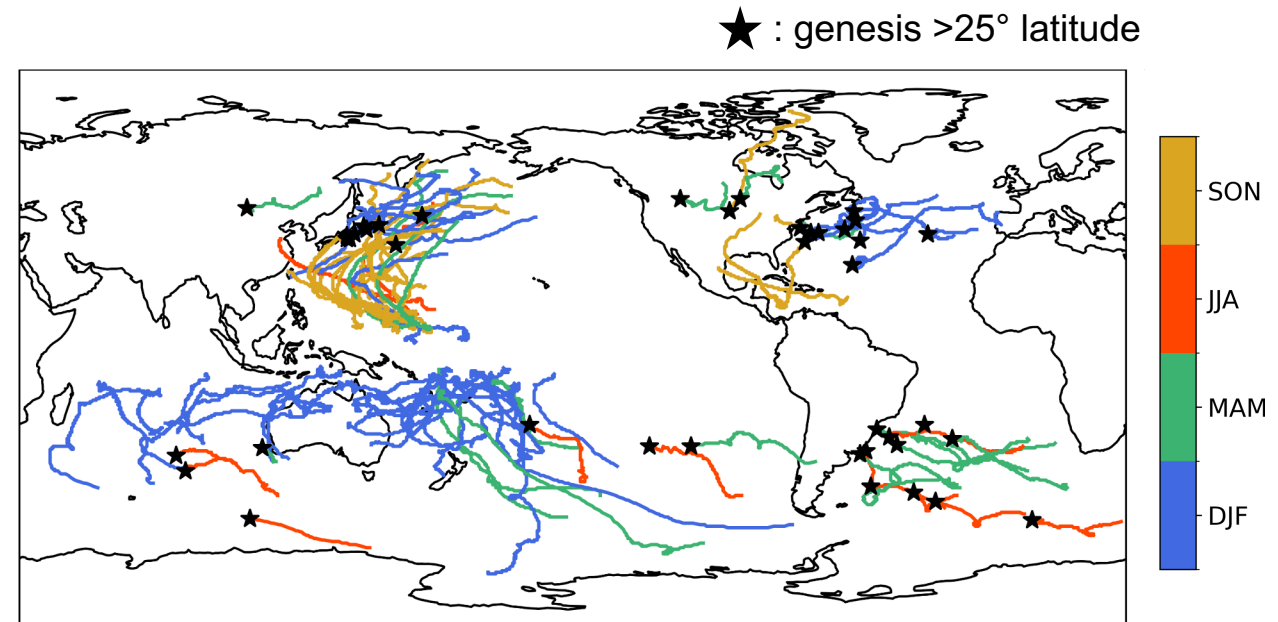
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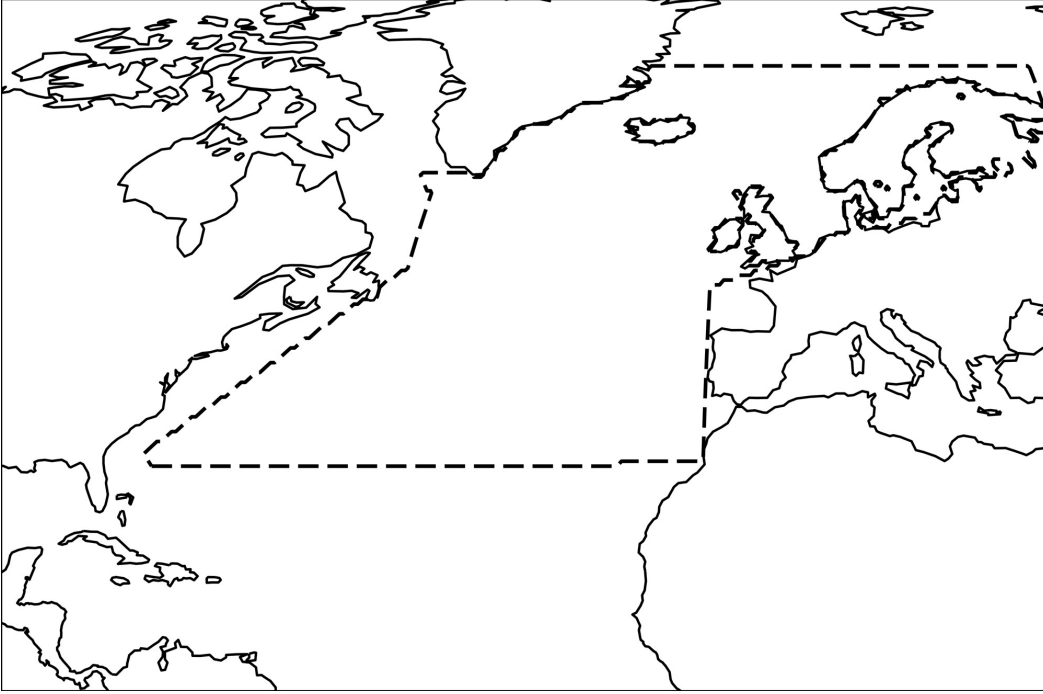


72h wind:

- More cyclones forming in the extratropics
- Shorter lifetime and tracks
- More DJF cyclones in Northern Hemisphere

Extreme cyclones in the North Atlantic

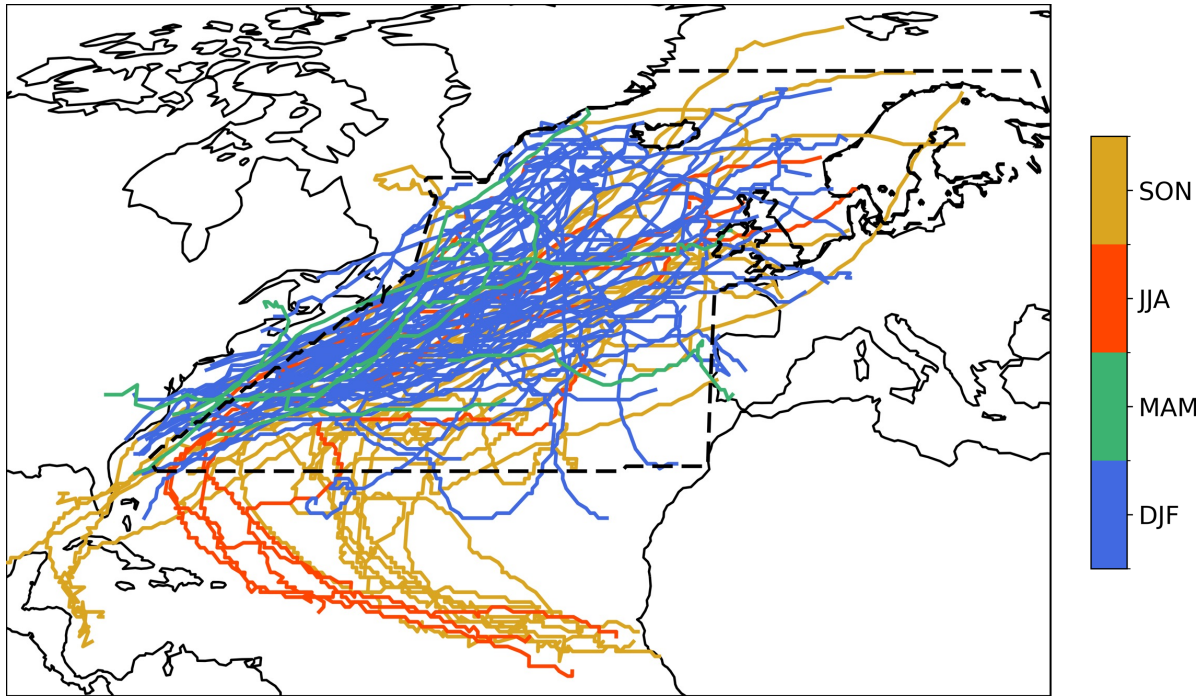
Where and when do they develop?



Extreme cyclones in the North Atlantic

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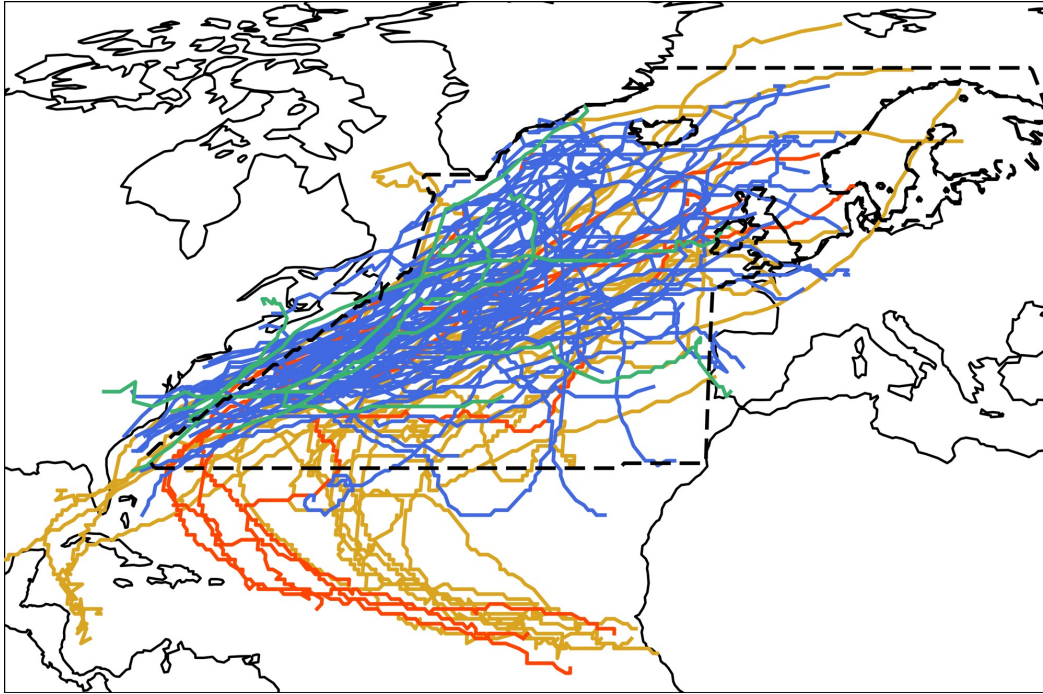
1h wind



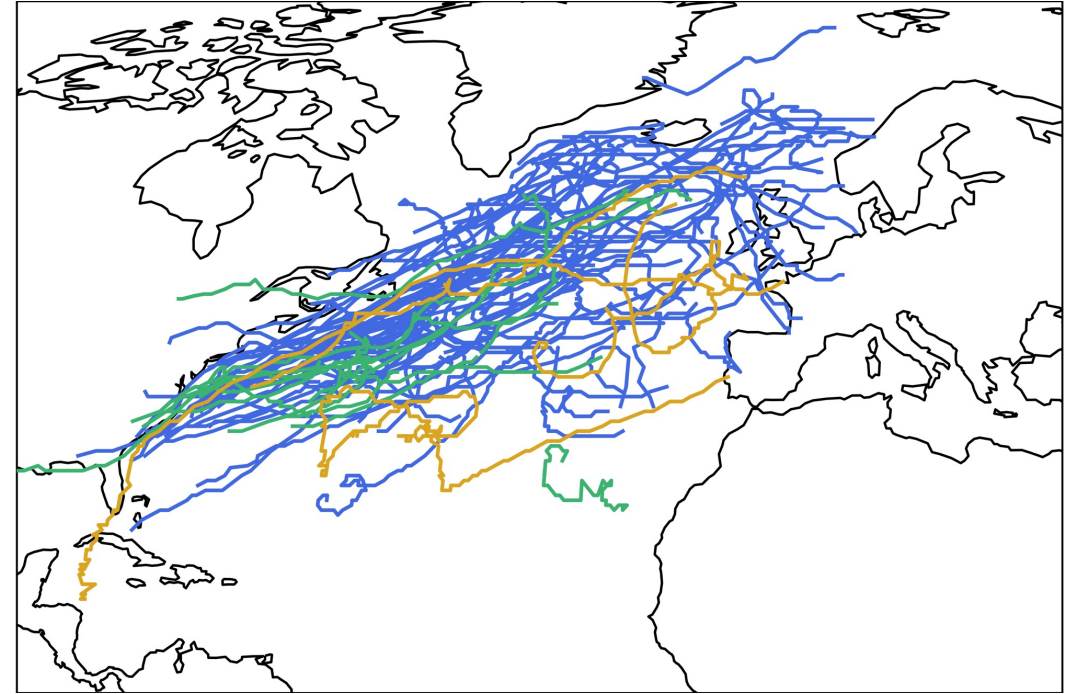
Extreme cyclones in the North Atlantic

Where and when do they develop?

1h wind



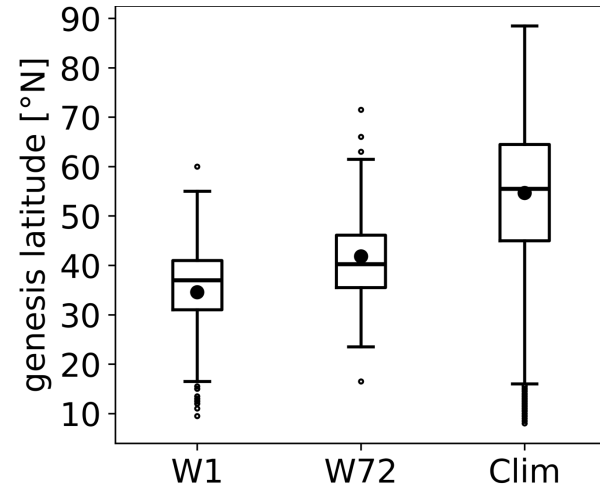
72h wind



Extreme cyclones in the North Atlantic

How do they compare to climatology?

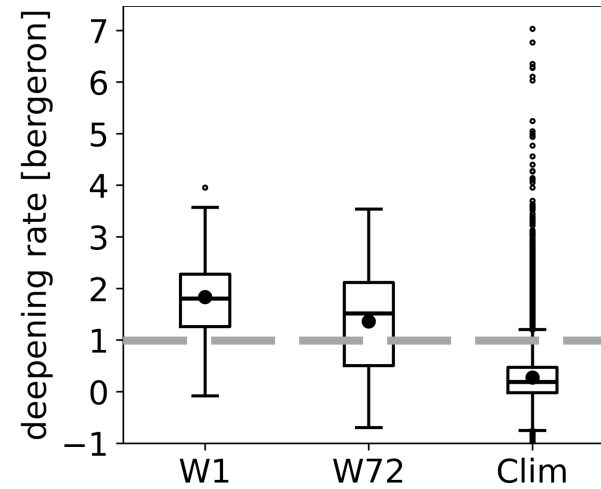
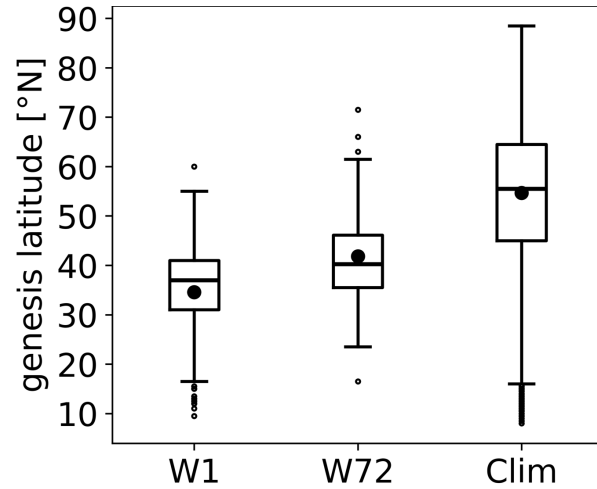
Genesis & Intensity:



Extreme cyclones in the North Atlantic

How do they compare to climatology?

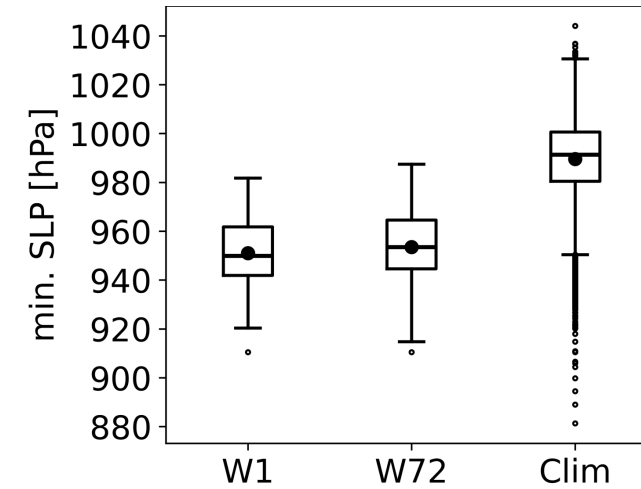
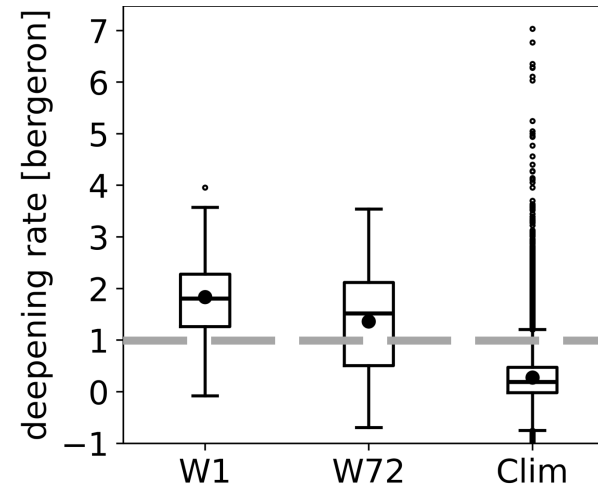
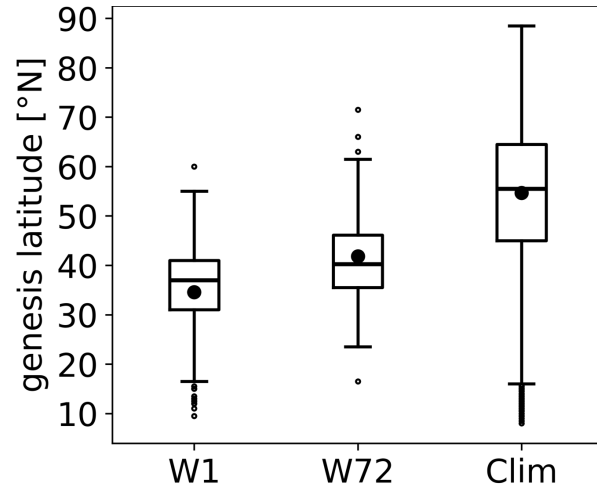
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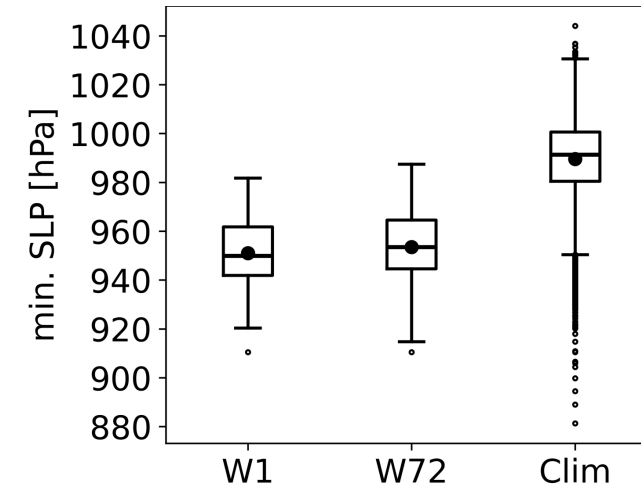
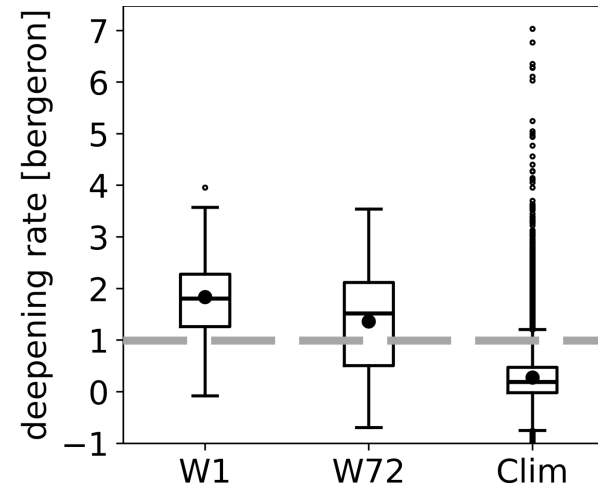
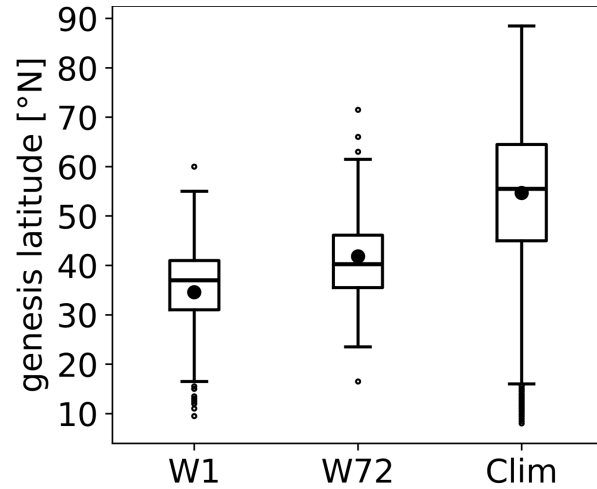
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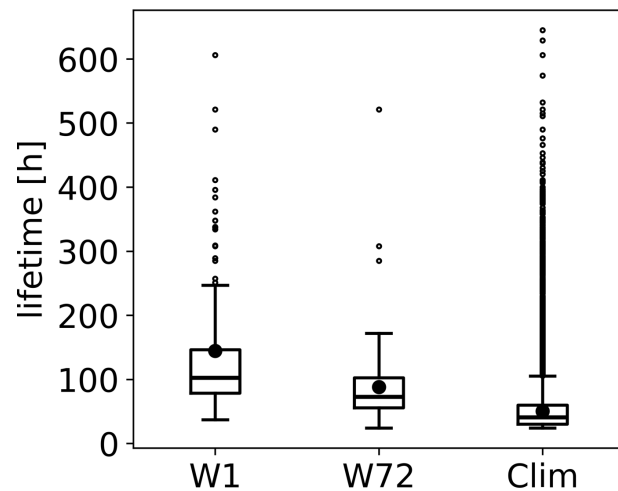
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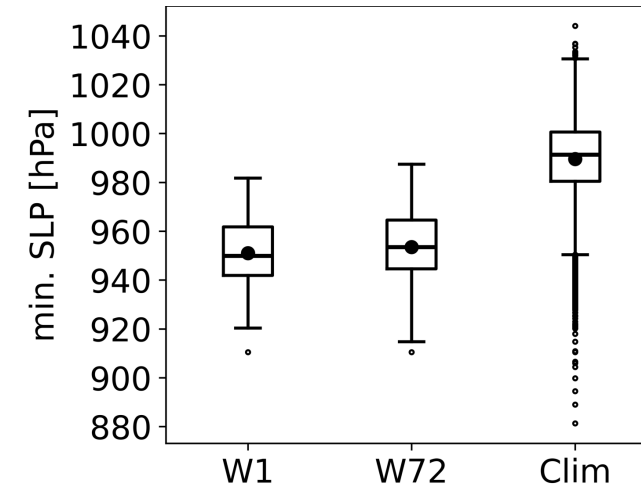
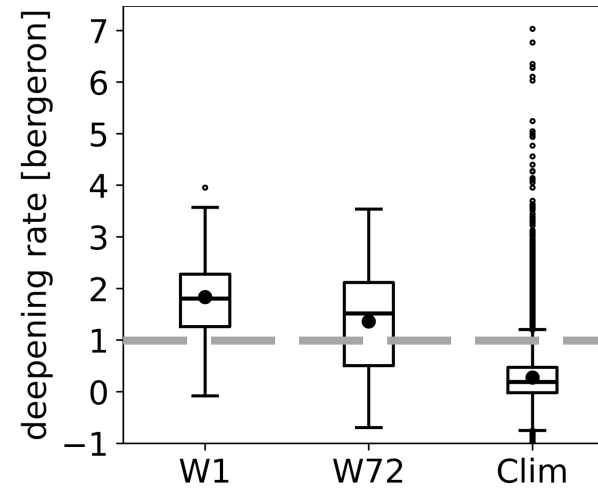
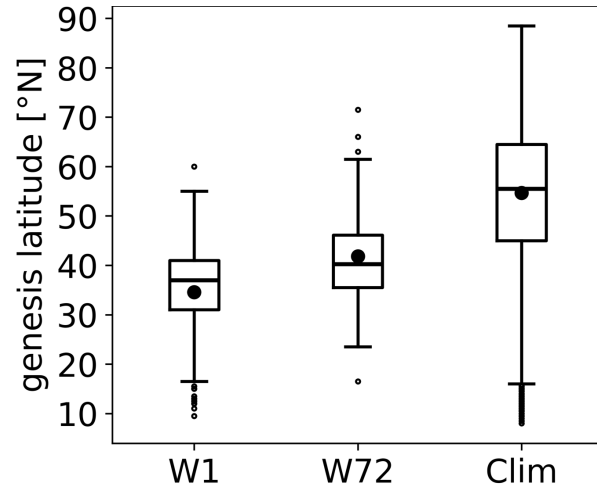
Duration & Size:



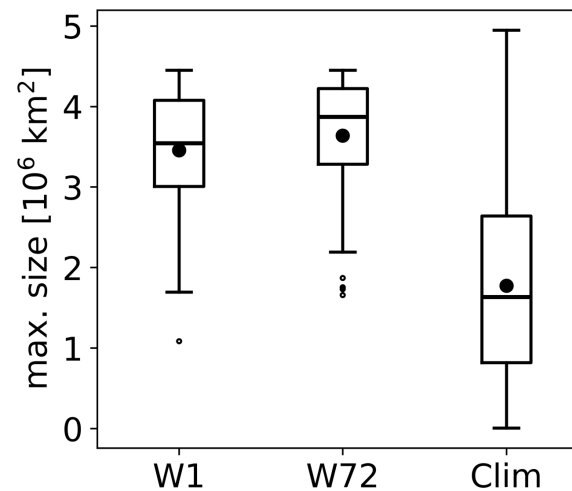
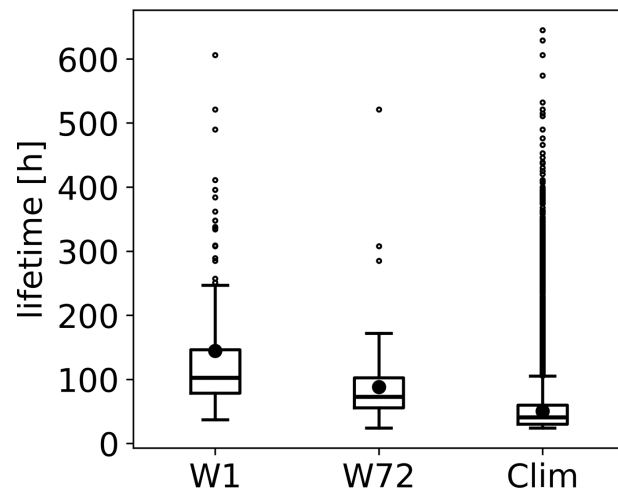
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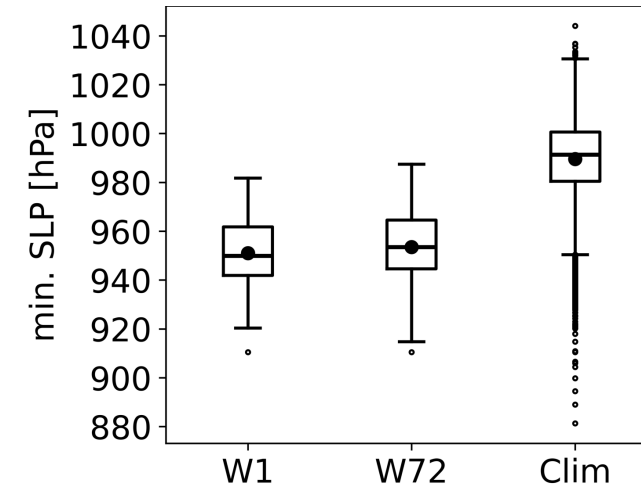
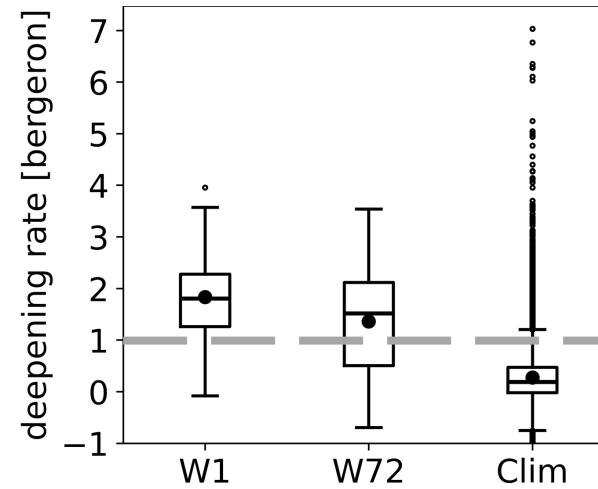
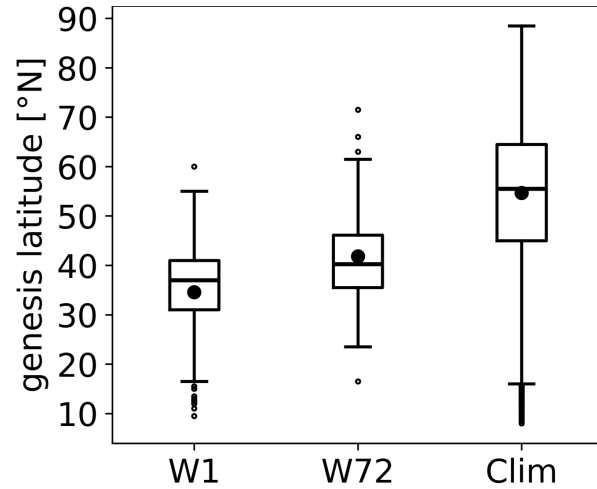
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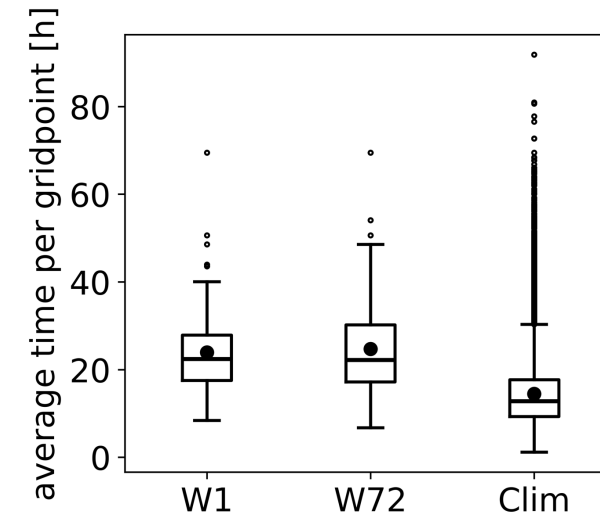
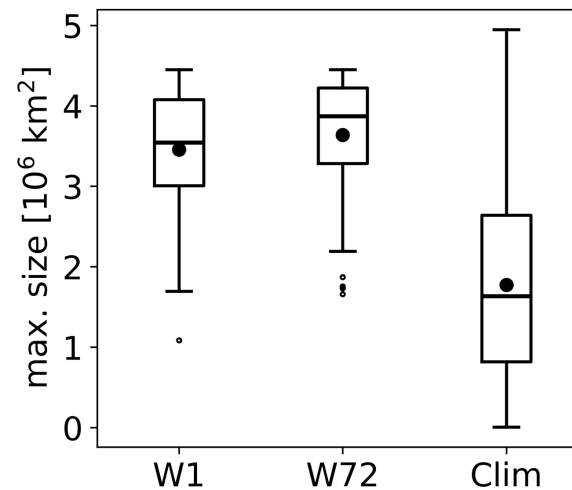
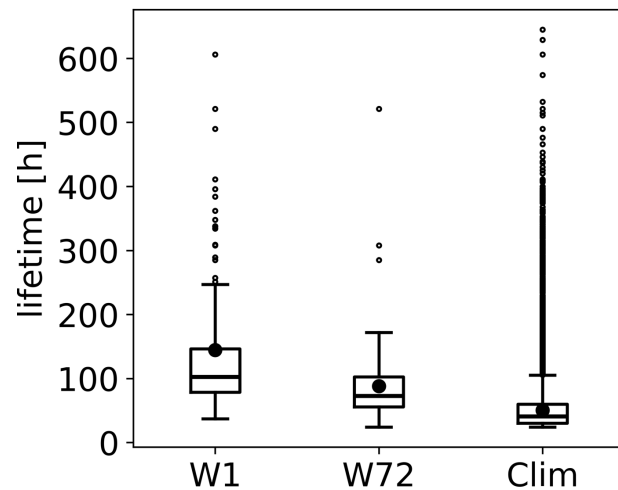
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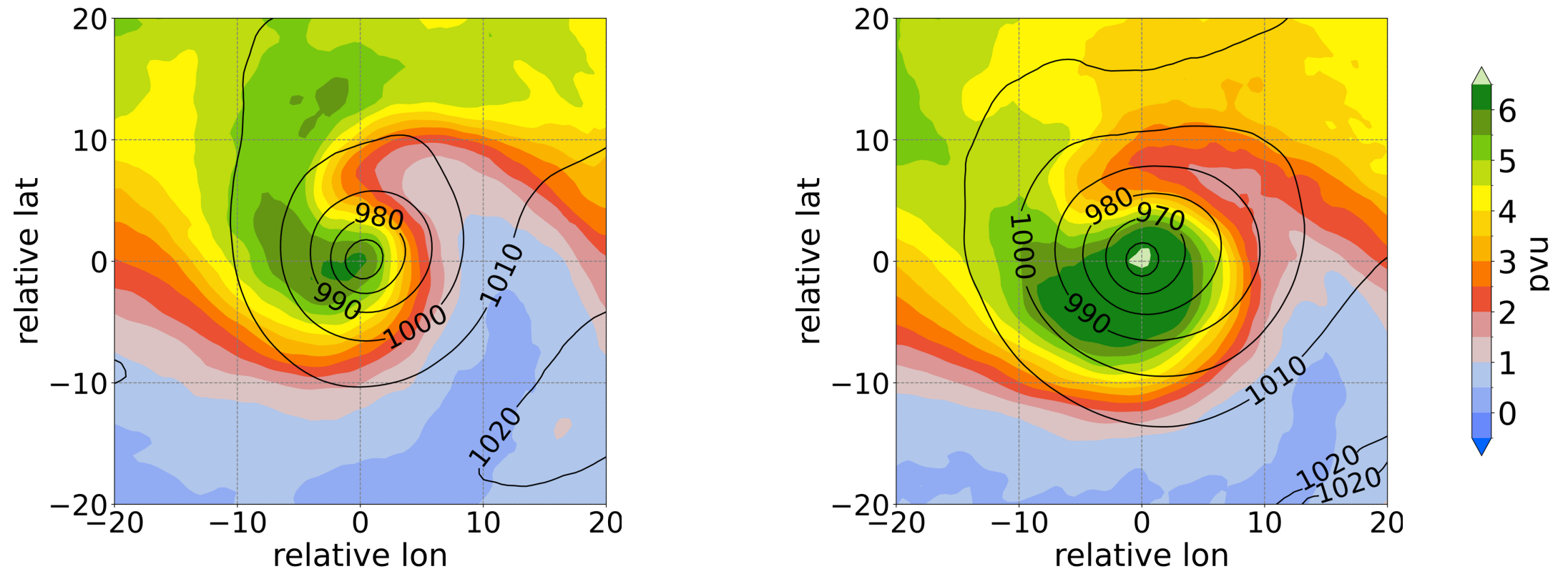


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Extreme cyclones in the North Atlantic

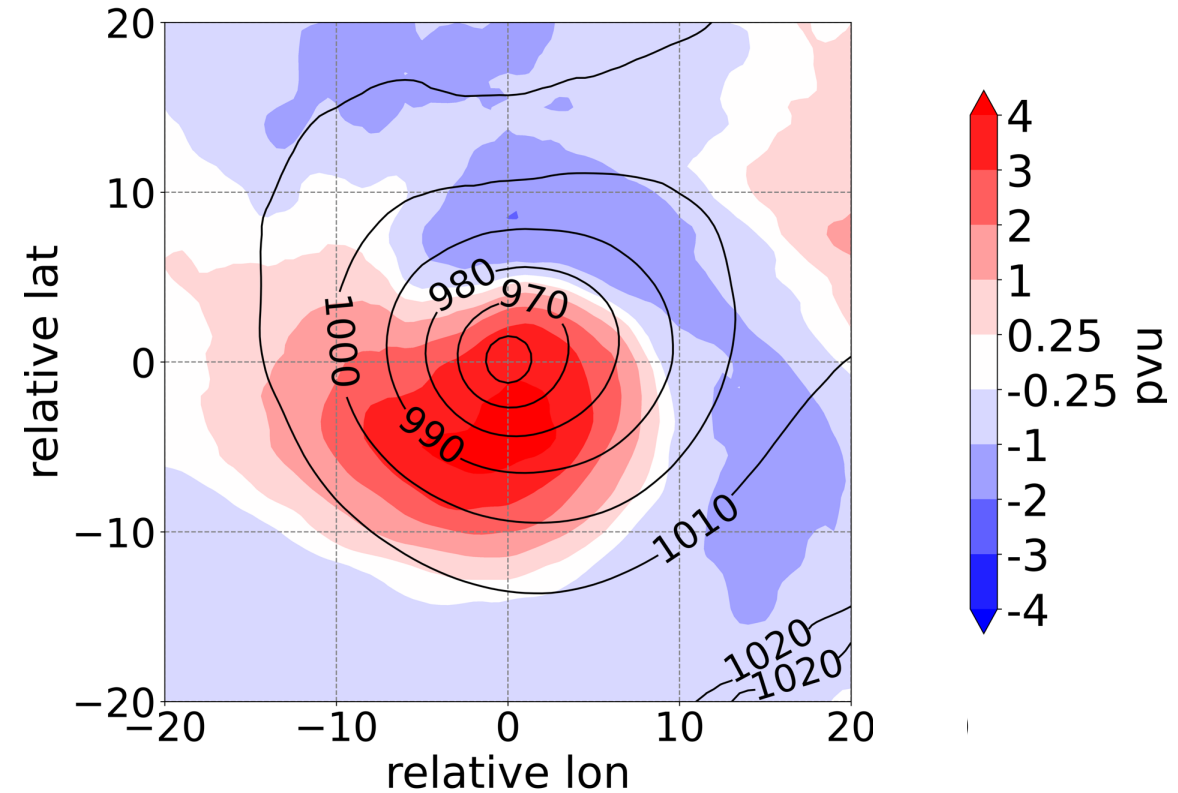
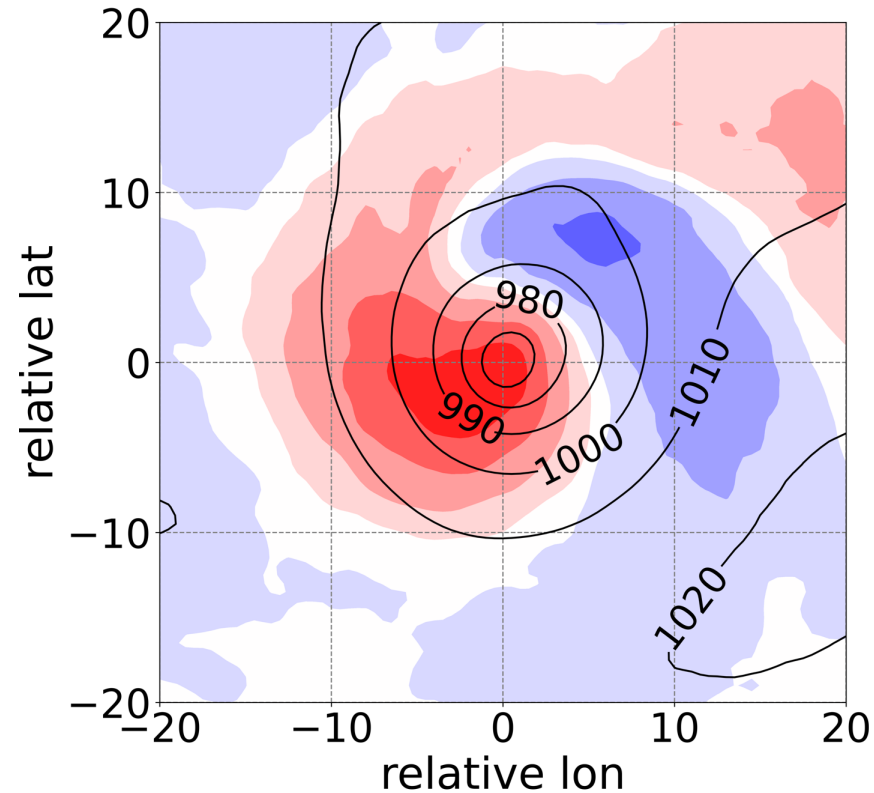
250 hPa potential vorticity when linked to the largest number of extremes



- Cyclonic wrap up of upper-level wave for both 1h and 72h wind extremes

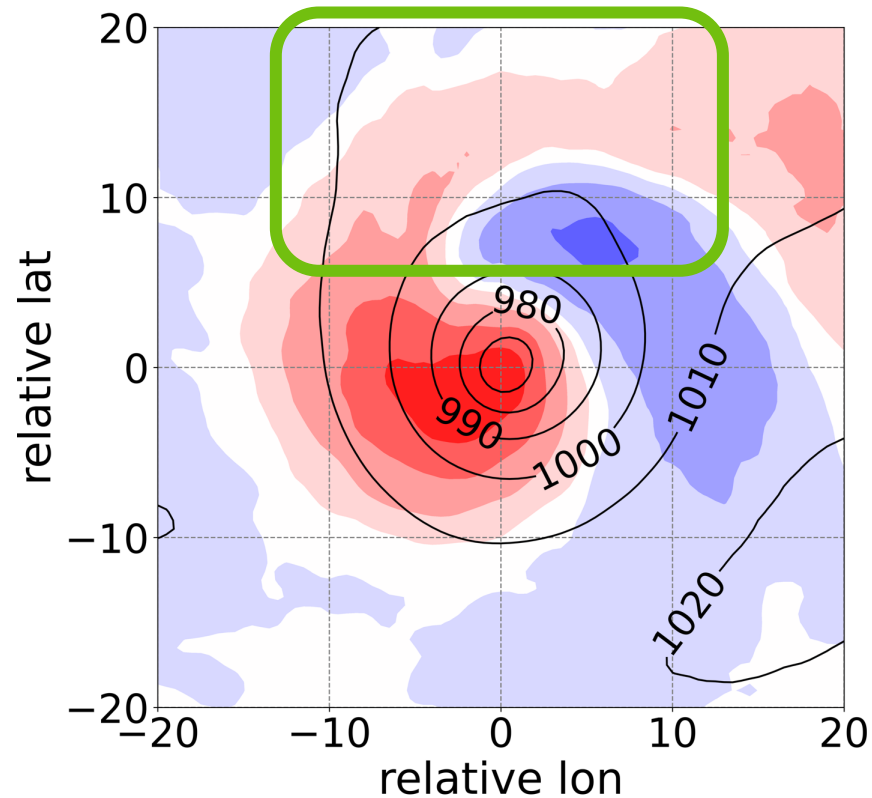
Extreme cyclones in the North Atlantic

250 hPa PV anomalies when linked to the largest number of extremes



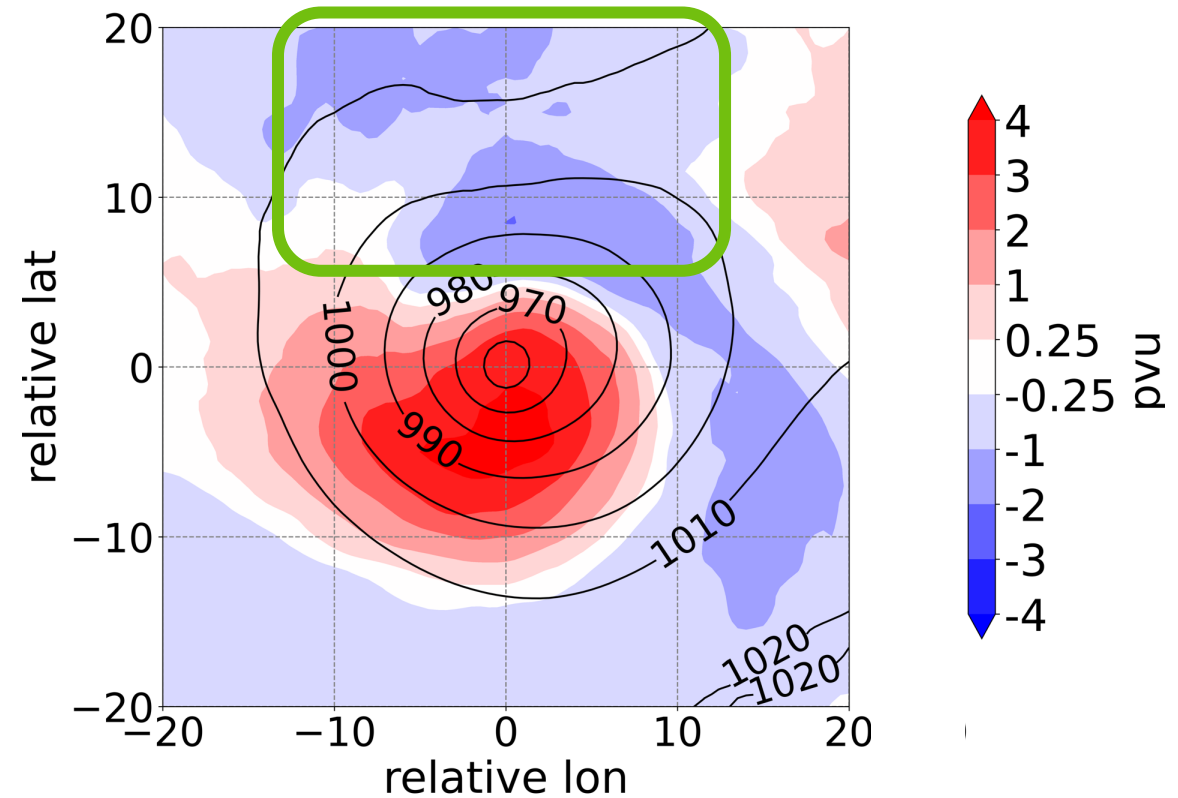
Extreme cyclones in the North Atlantic

250 hPa PV anomalies when linked to the largest number of extremes



1h wind

- PV streamer-like structure at 250 hPa

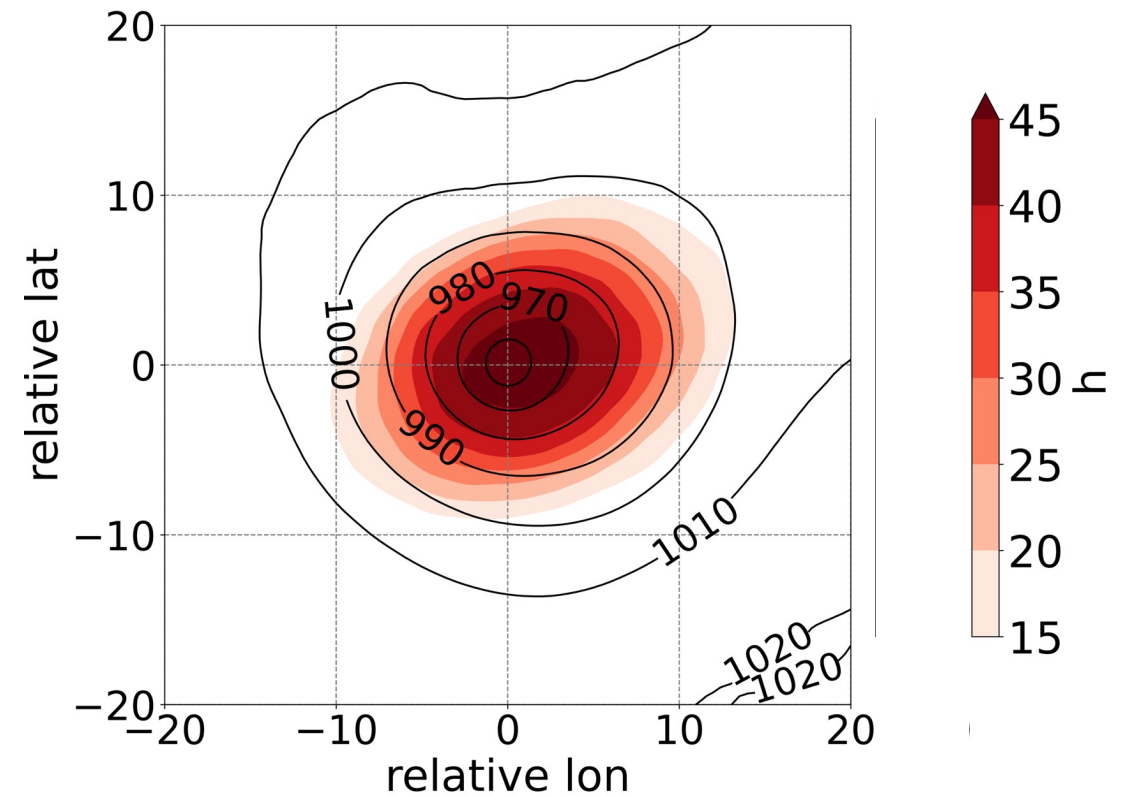
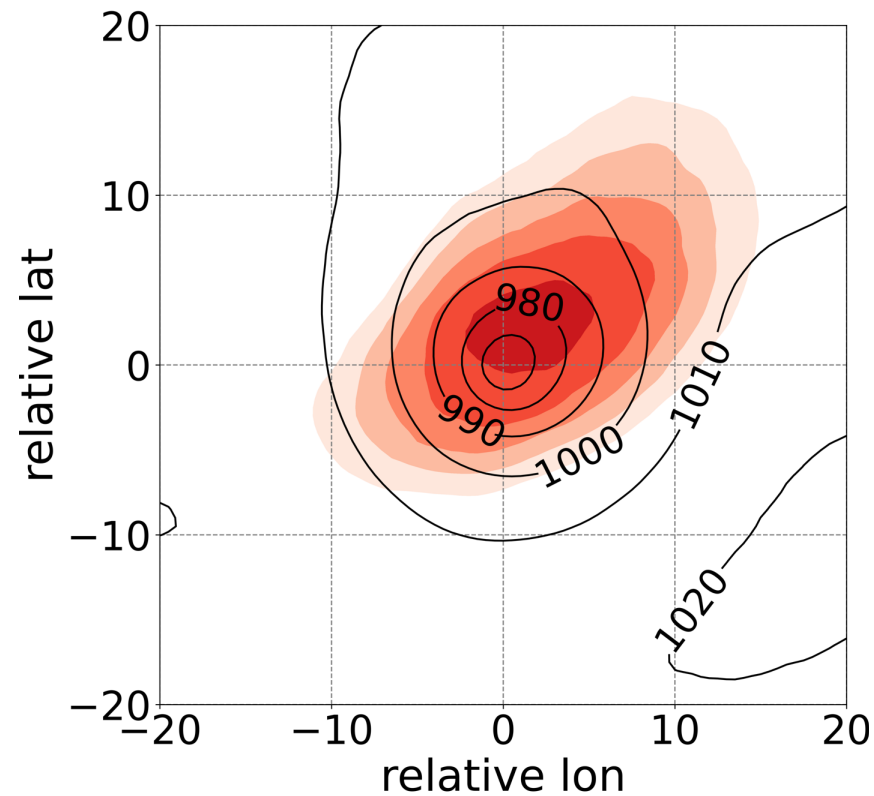


72h wind

- PV cut-off formed at 250 hPa

Extreme cyclones in the North Atlantic

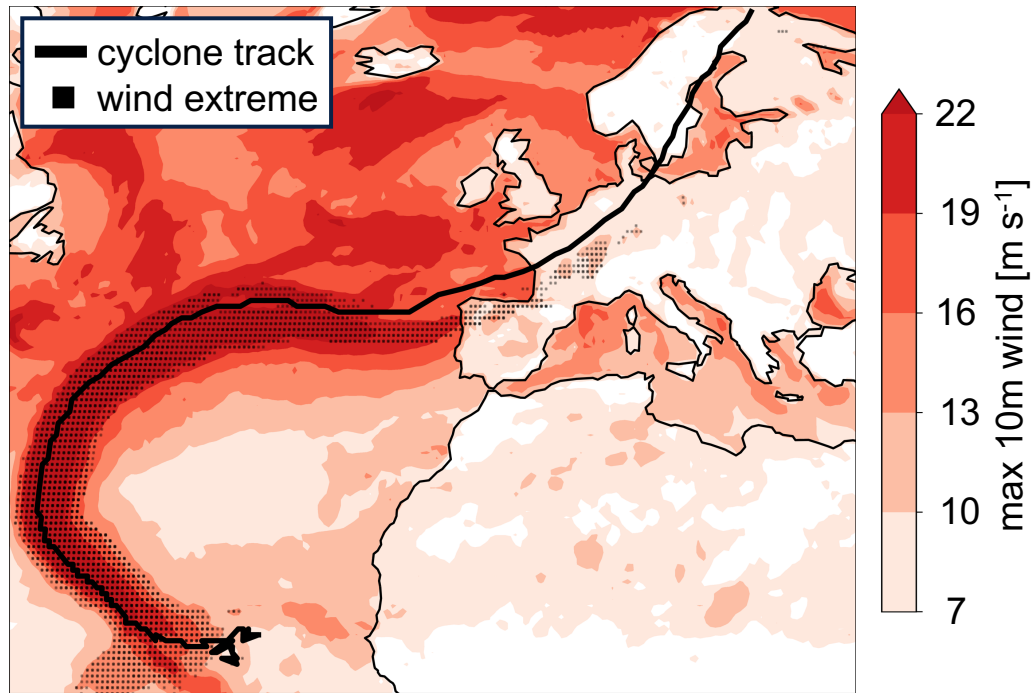
Stationarity when linked to the largest number of extremes



- **1h wind extremes:** Cyclones pass over region in ~1.5 days
- **72h wind extremes:** More stationary; region under cyclonic influence for prolonged time

Thermal structure during surface wind extremes

Cyclone Kirk in the cyclone phase space

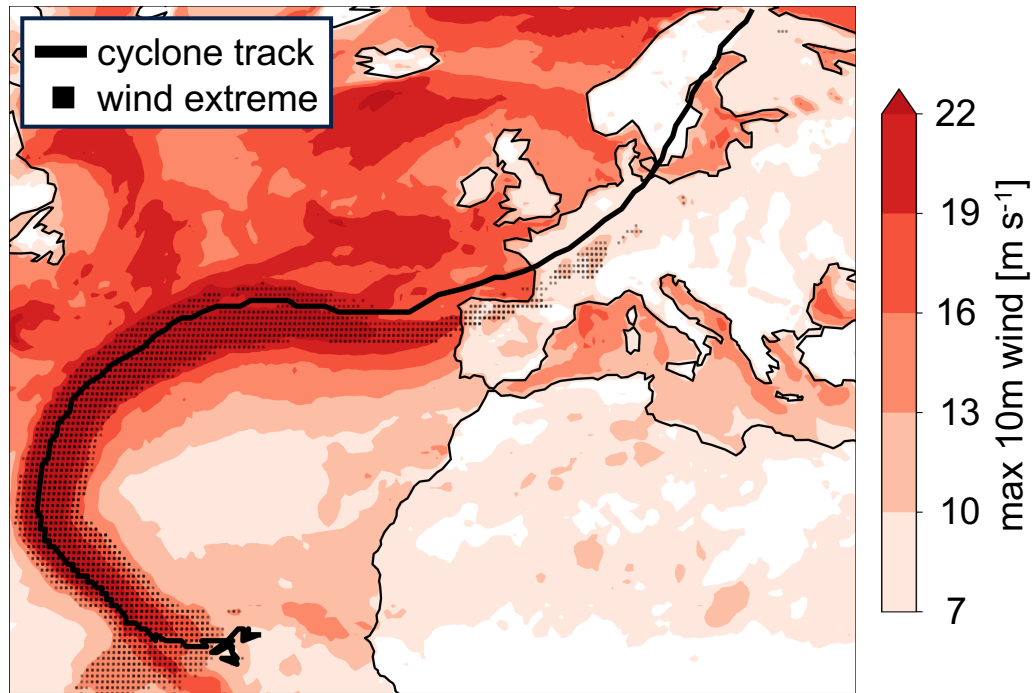


Kirk, 2024:

- Transition from tropical to extratropical system

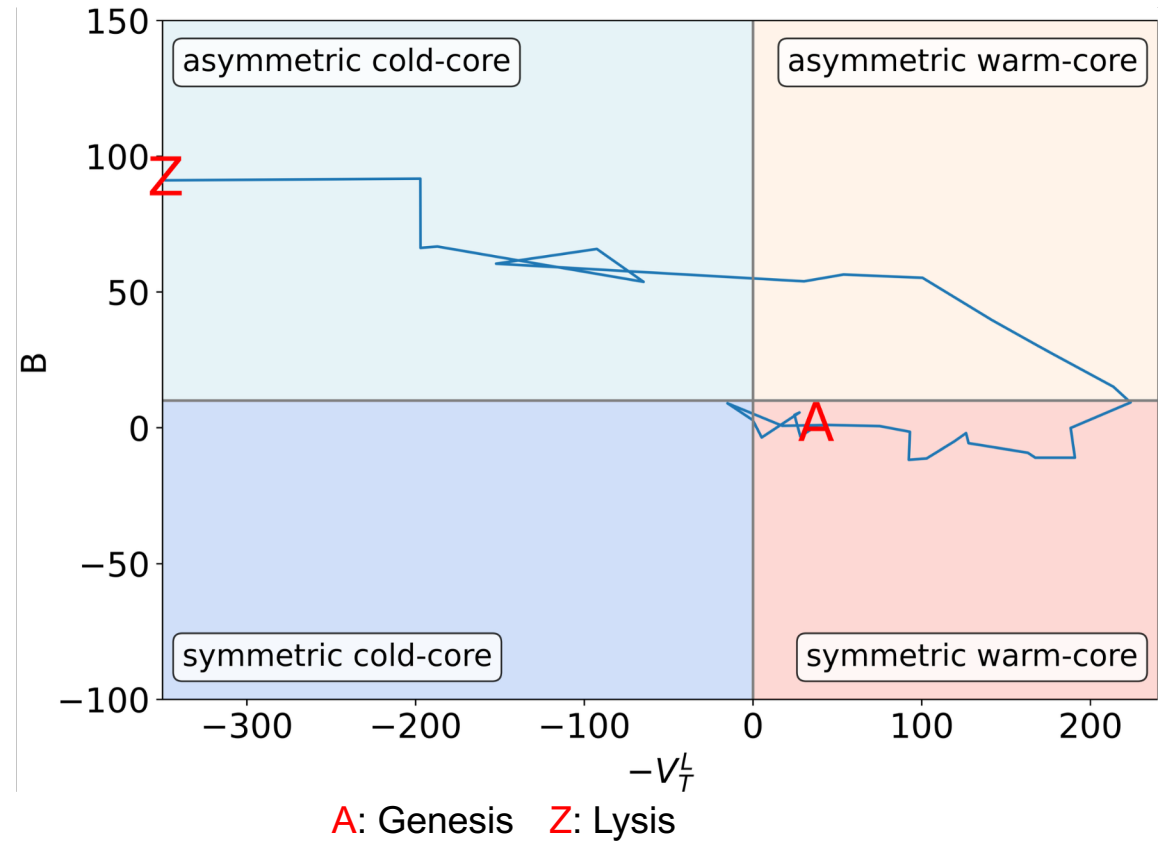
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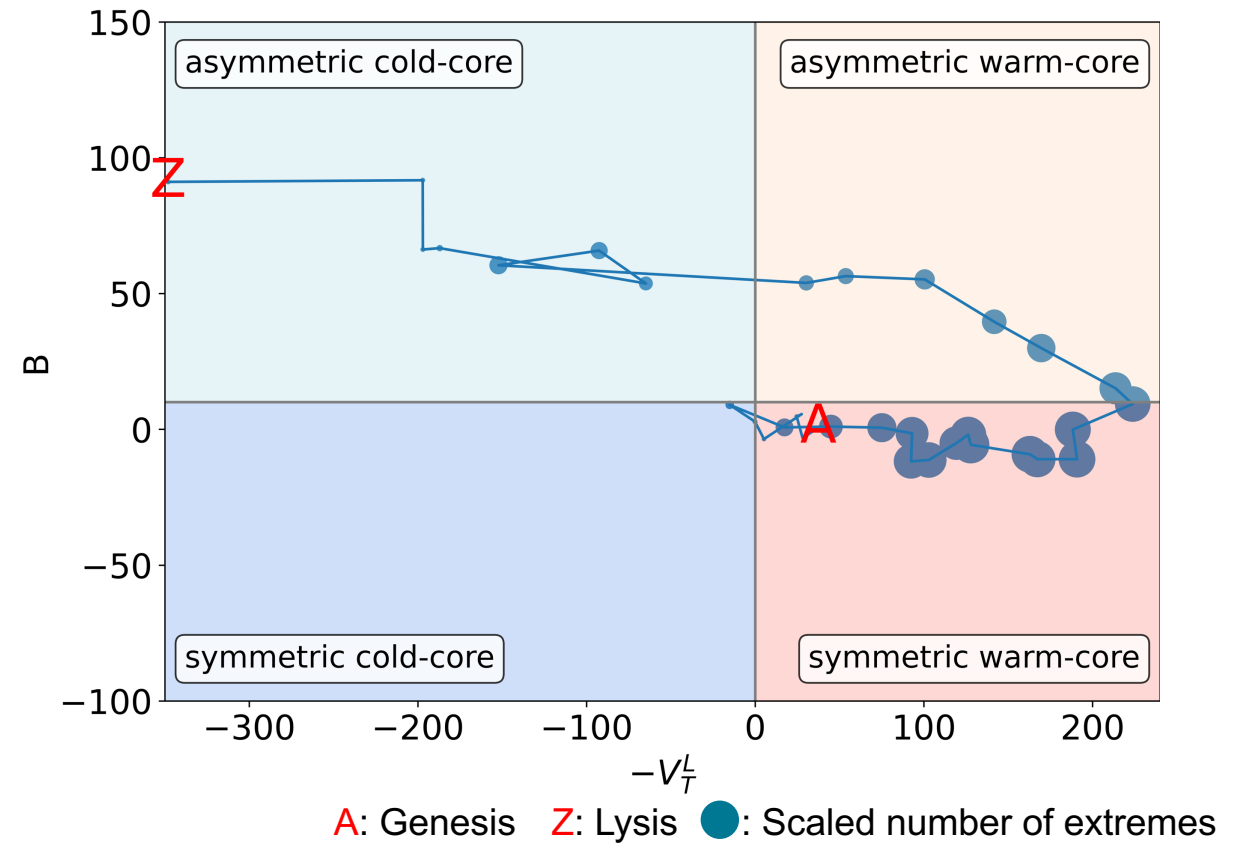
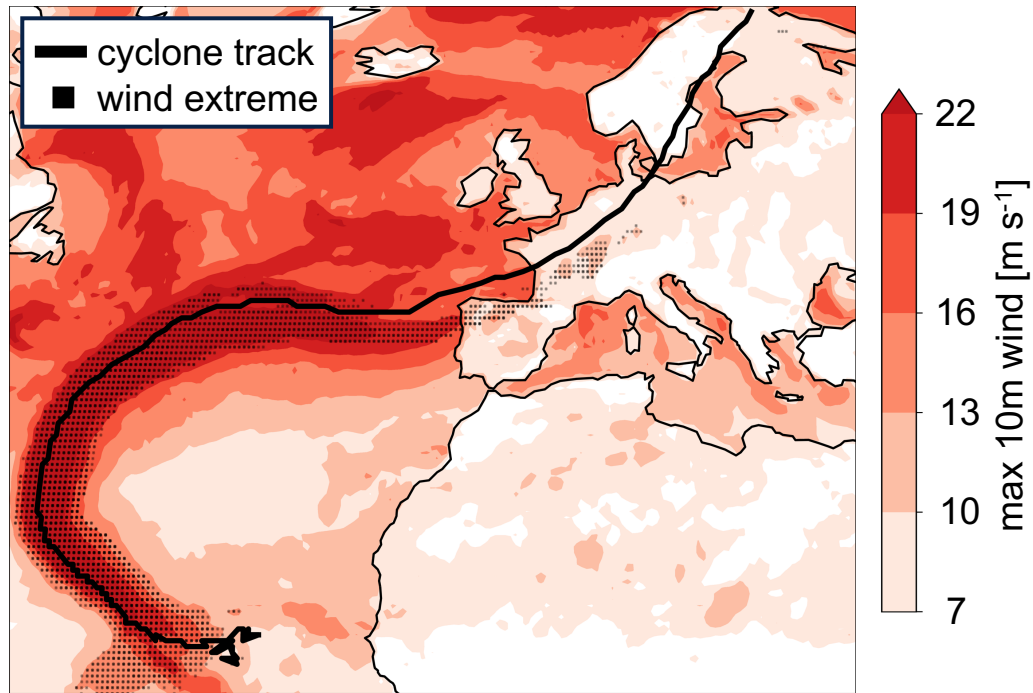
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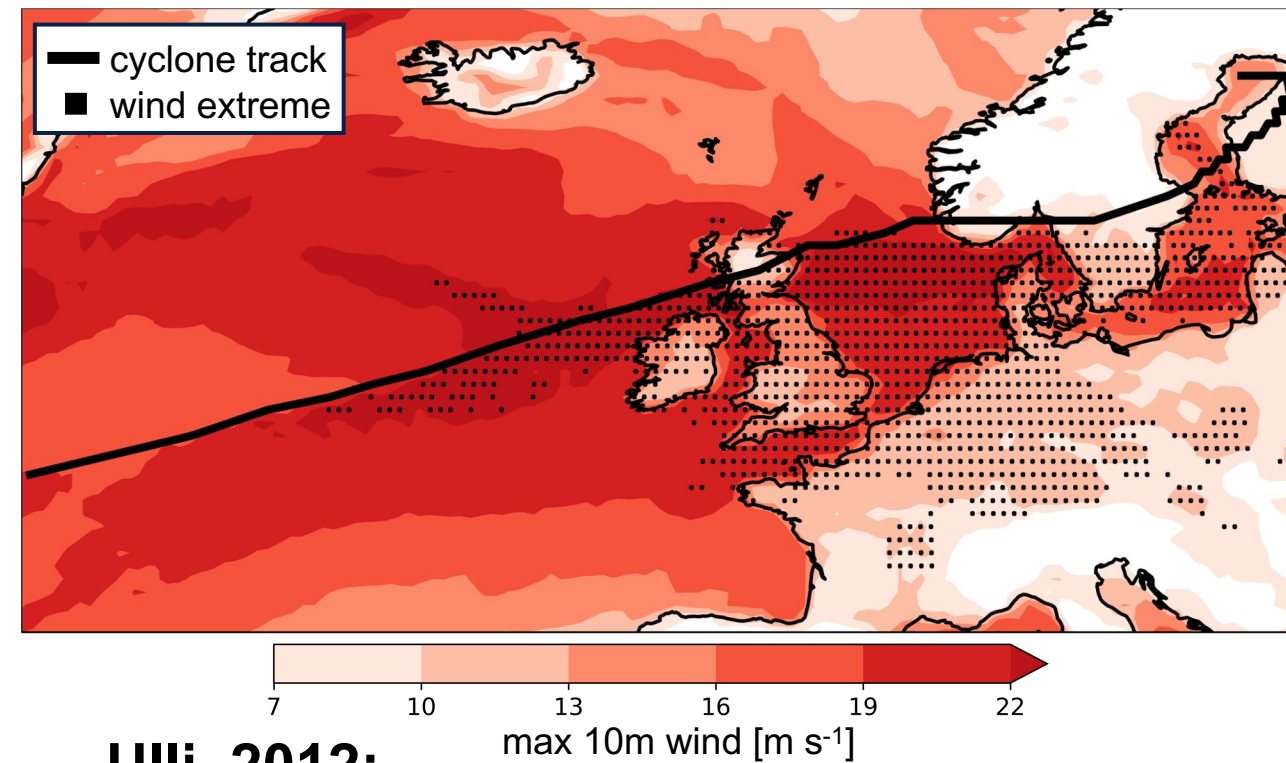


Kirk, 2024:

- Transition from tropical to extratropical system
- Linked to most extremes during tropical / 'symmetric, deep warm core' phase

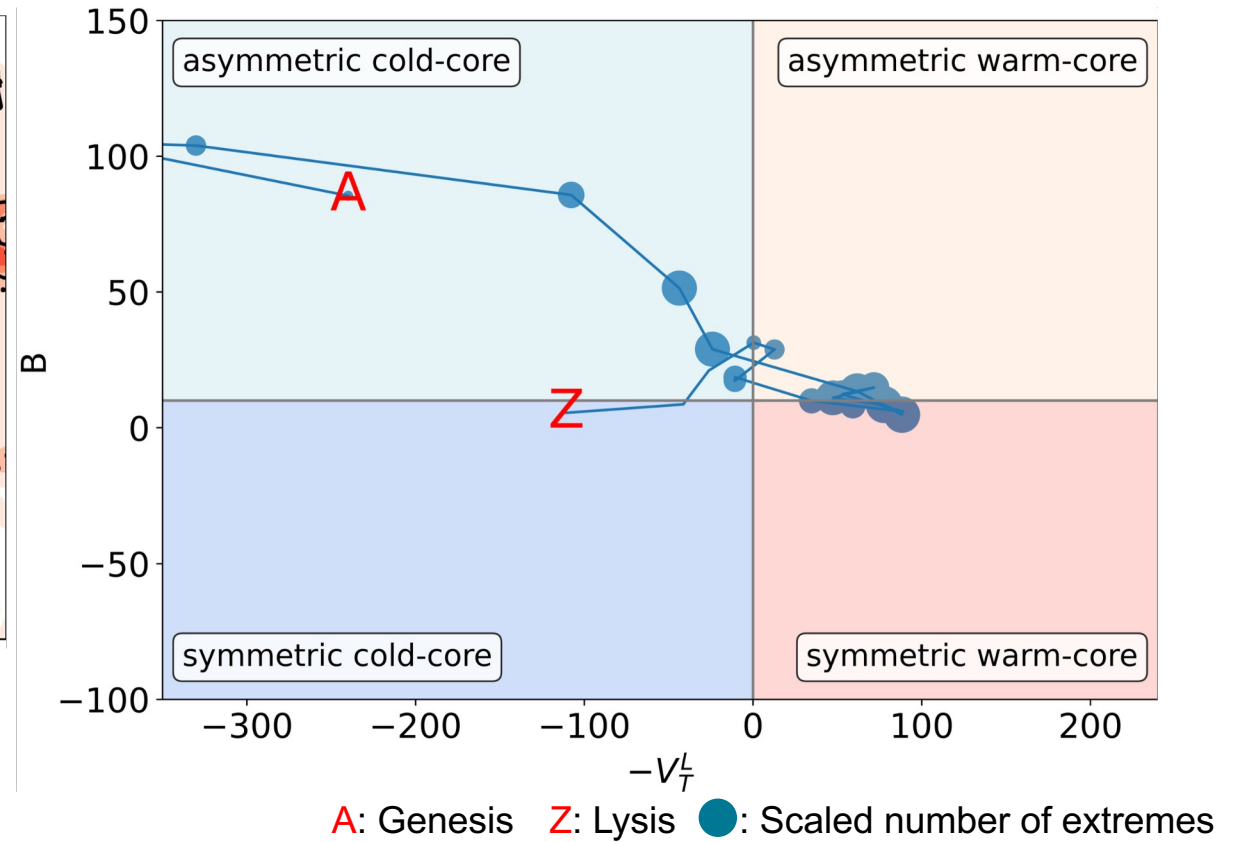
Thermal structure during surface wind extremes

Cyclone Ulli in the cyclone phase space



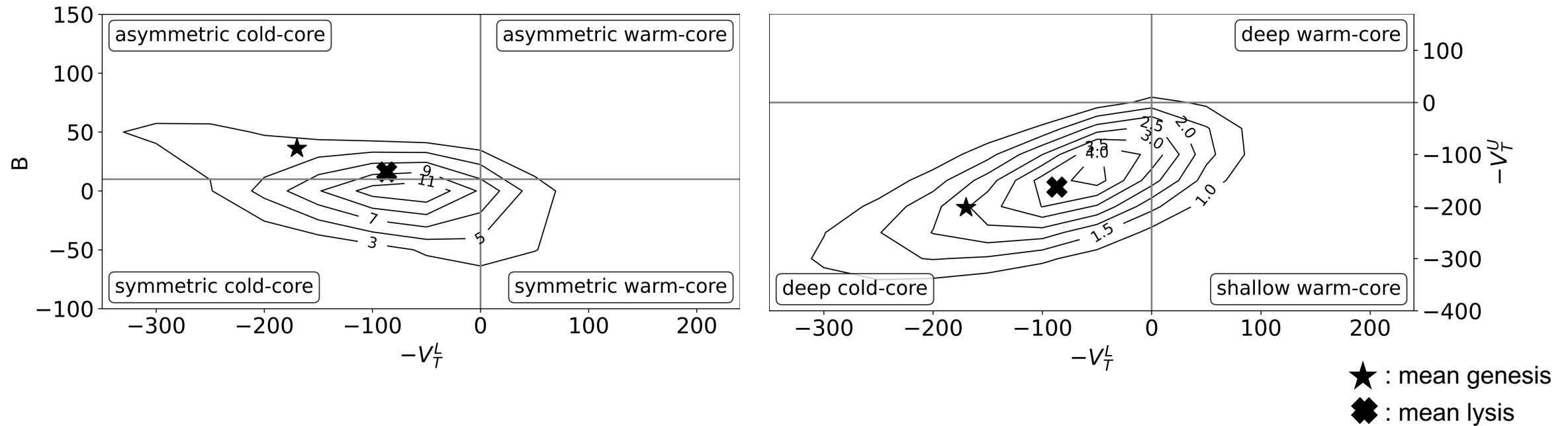
Ulli, 2012:

- Extratropical cyclone, undergoes tropical transition in CPS
- Linked to most extremes during 'symmetric, shallow warm core' phase



Thermal structure during surface wind extremes

When are cyclones linked to wind extremes?

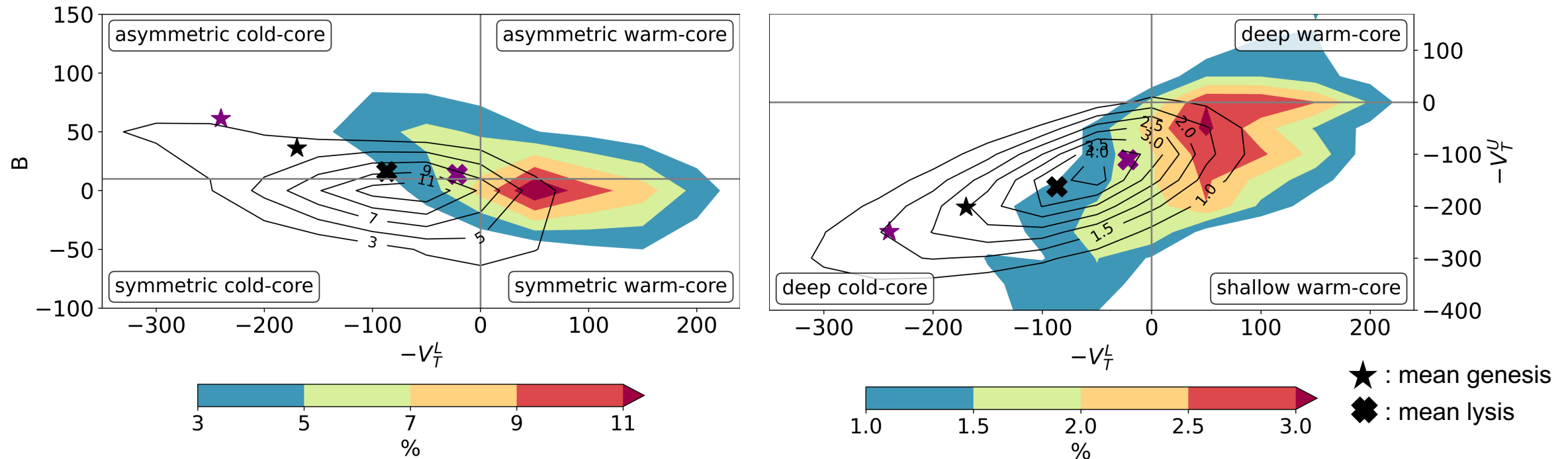


Climatology:

- Genesis as 'asymmetric, cold core' systems → become more symmetric during life cycle

Thermal structure during surface wind extremes

When are cyclones linked to wind extremes?



Climatology:

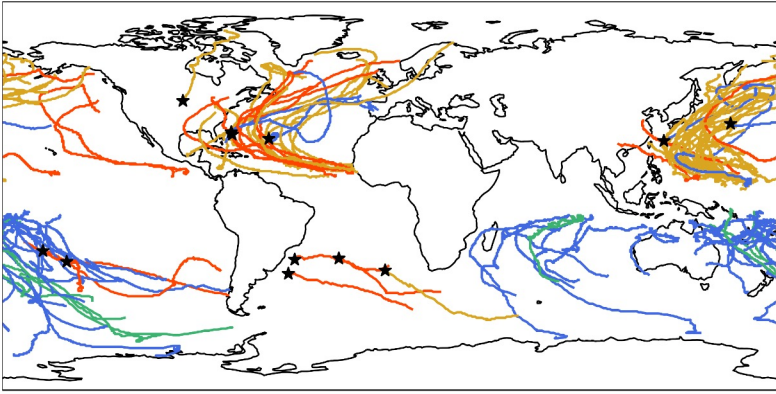
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Extremes:

- Wind extremes during 'symmetric, shallow warm core'-phase

Summary

Which cyclones accumulate the most extremes?

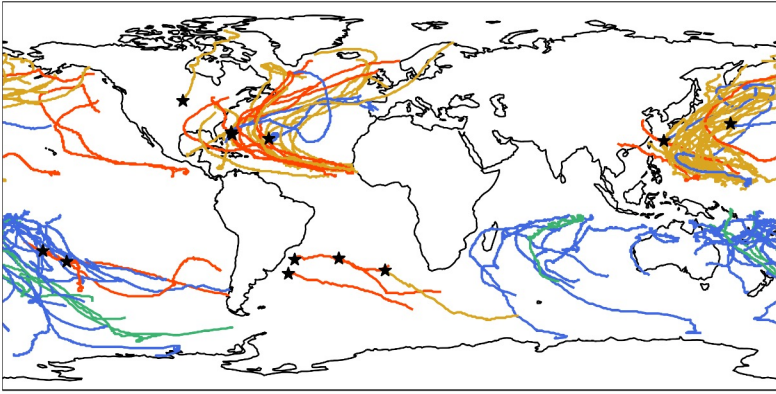


Cyclones with...

- Extratropical transition
- Long tracks
- Long lifetimes

Summary

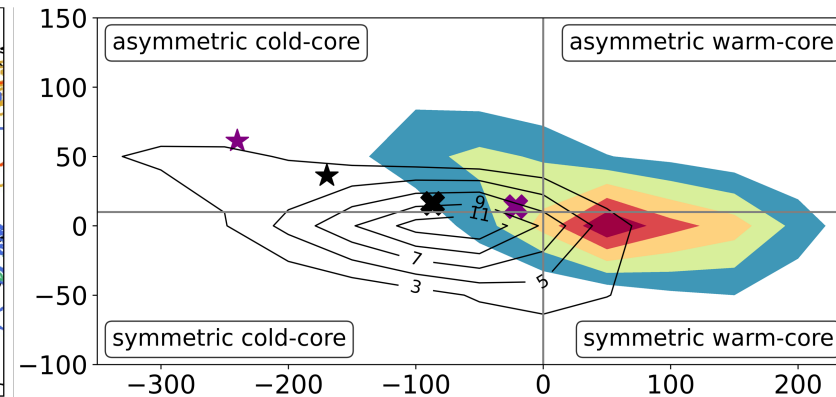
Which cyclones accumulate the most extremes?



Cyclones with...

- Extratropical transition
- Long tracks
- Long lifetimes

Properties compared to climatology?

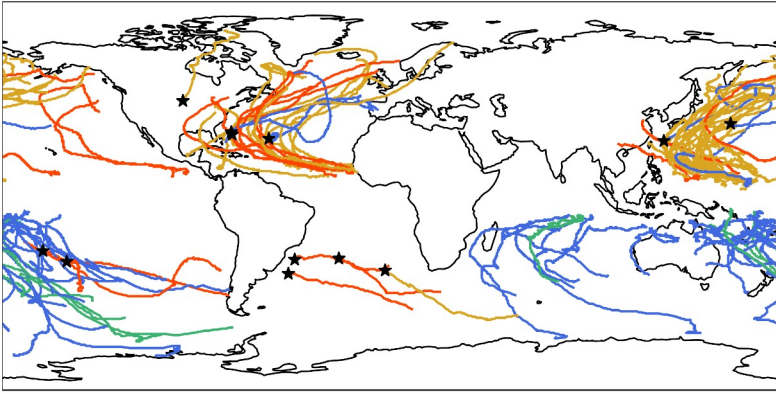


Extreme cyclones have...

- Lower sea-level pressure
- Larger area
- A symmetric phase in CPS

Summary

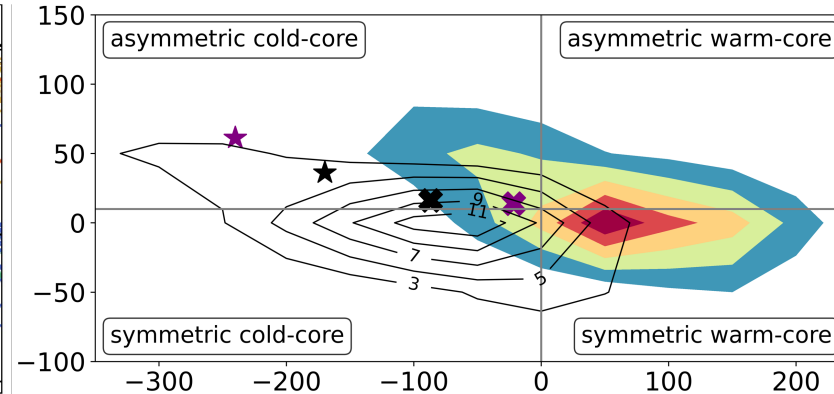
Which cyclones accumulate the most extremes?



Cyclones with...

- Extratropical transition
- Long tracks
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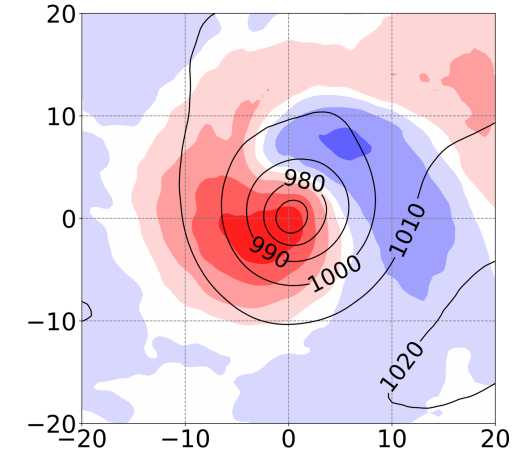
Properties compared to climatology?



Extreme cyclones have...

- Lower sea-level pressure
- Larger area
- A symmetric phase in CPS

Do properties vary with the duration of the extreme?



Cyclones linked to 72h extremes...

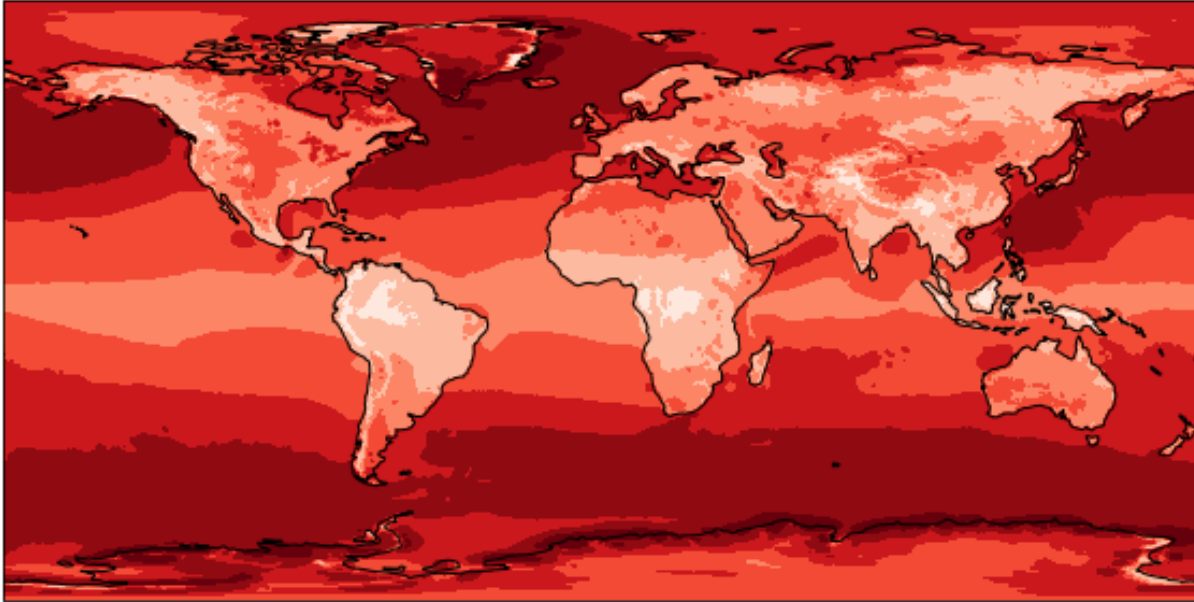
- transition less from TC to ETC
- are more stationary
- occur later in wave-breaking cycle

Backup-Slides

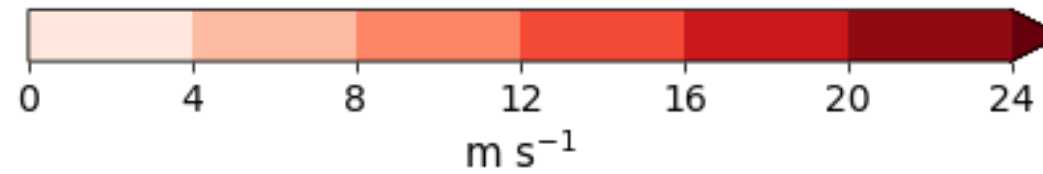
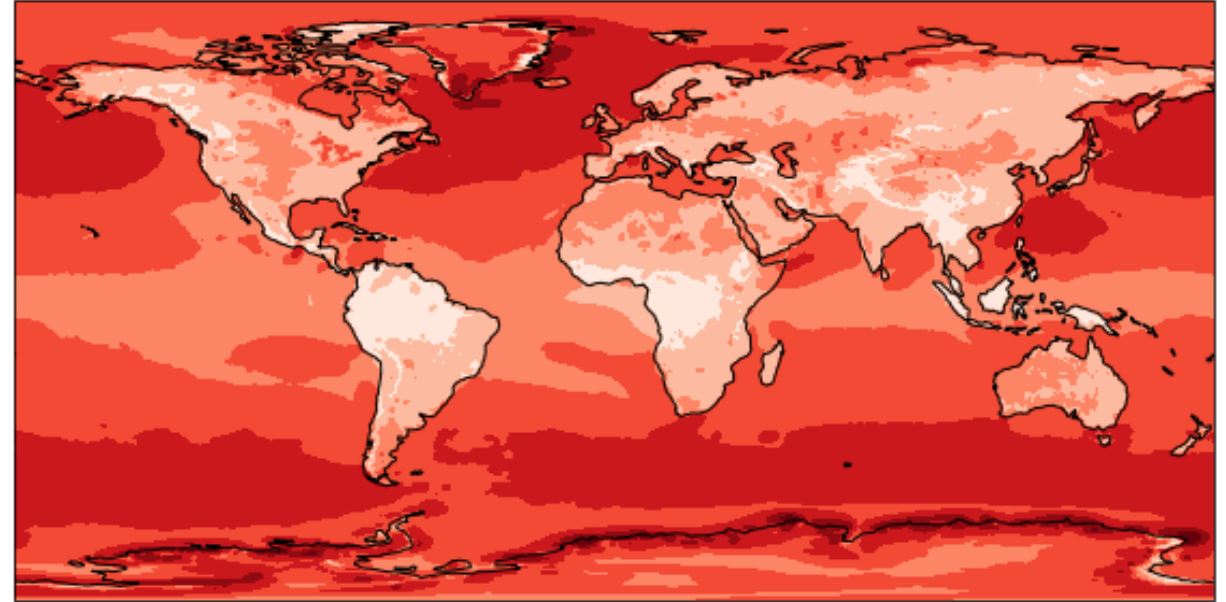
Backup-Slides

10m wind speed percentiles

1h wind

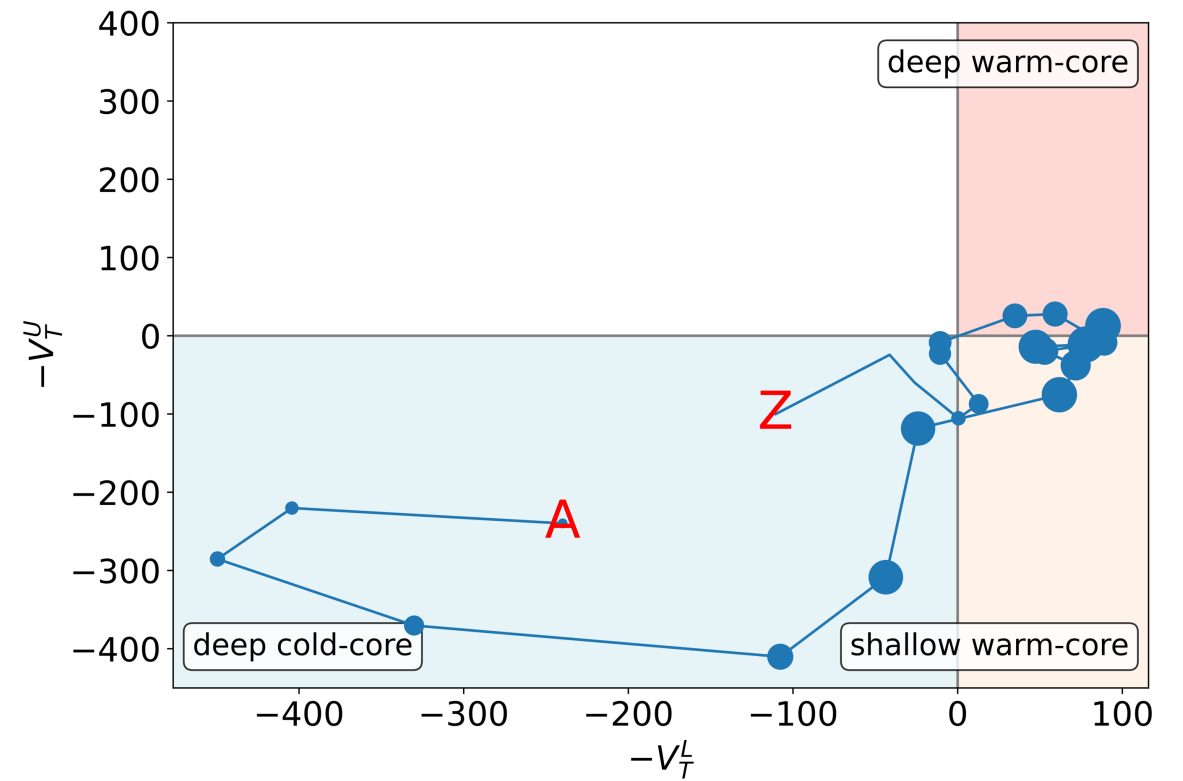
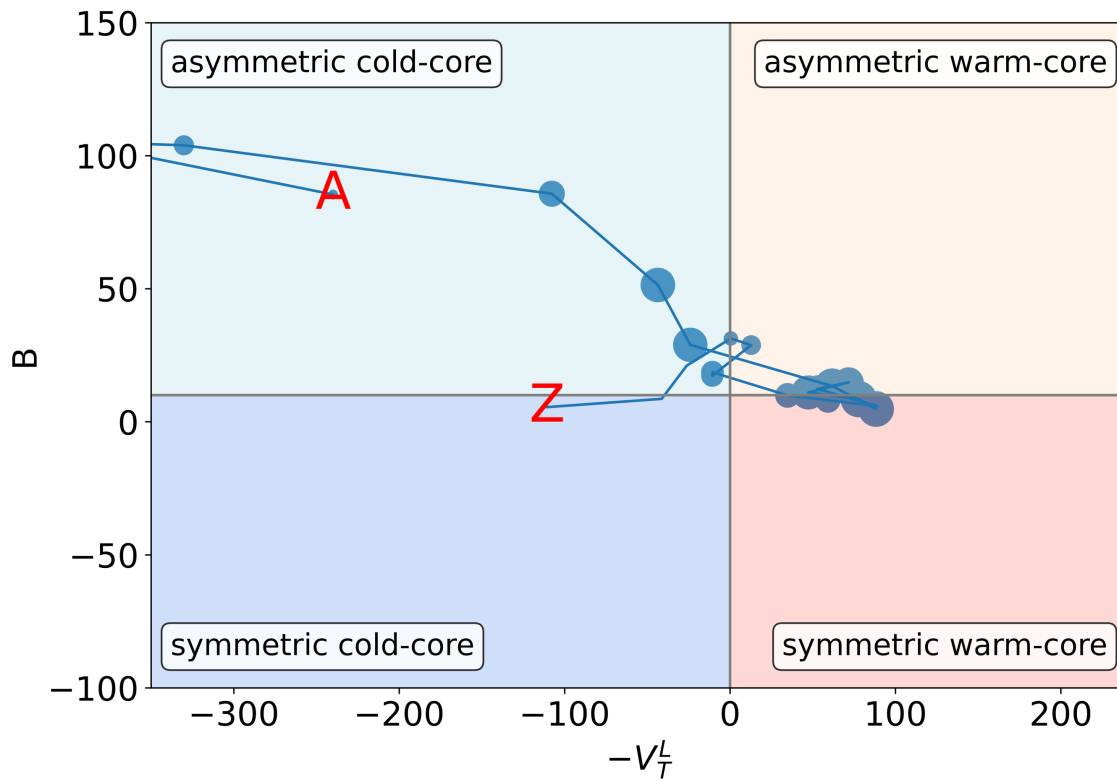


72h wind



Backup-Slides

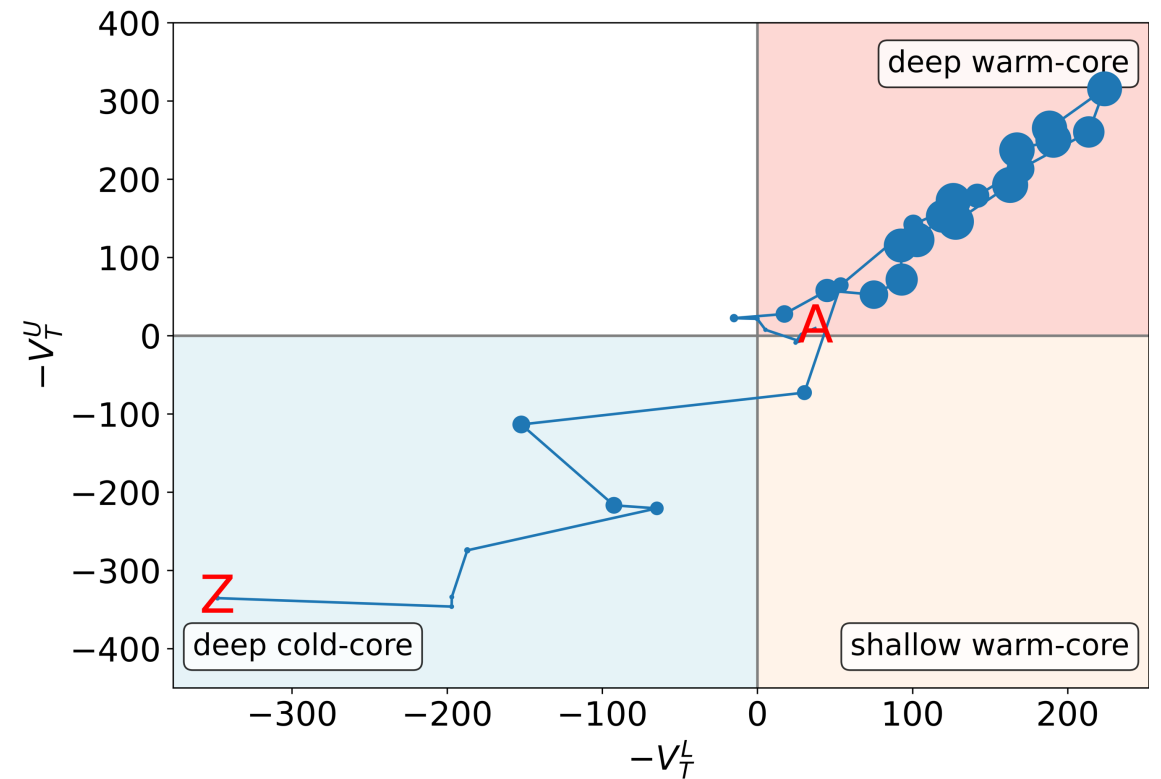
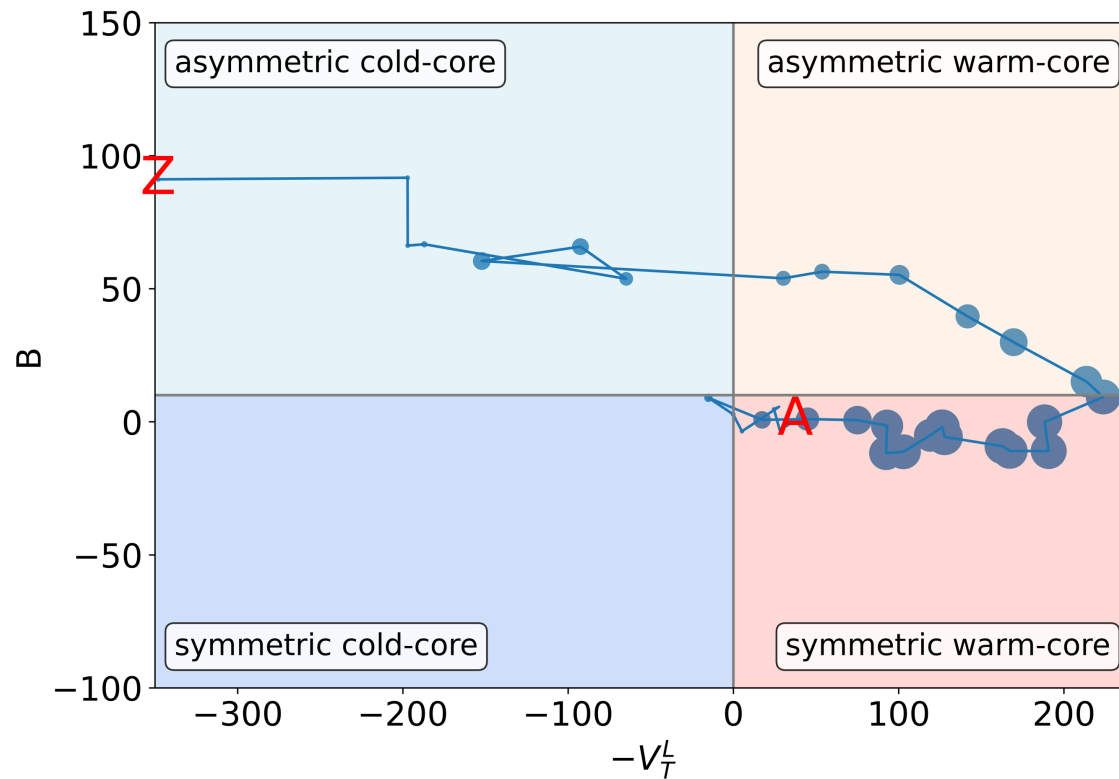
Cyclone Ulli in the cyclone phase space



A: Genesis **Z**: Lysis ●: Scaled number of extremes

Backup-slides

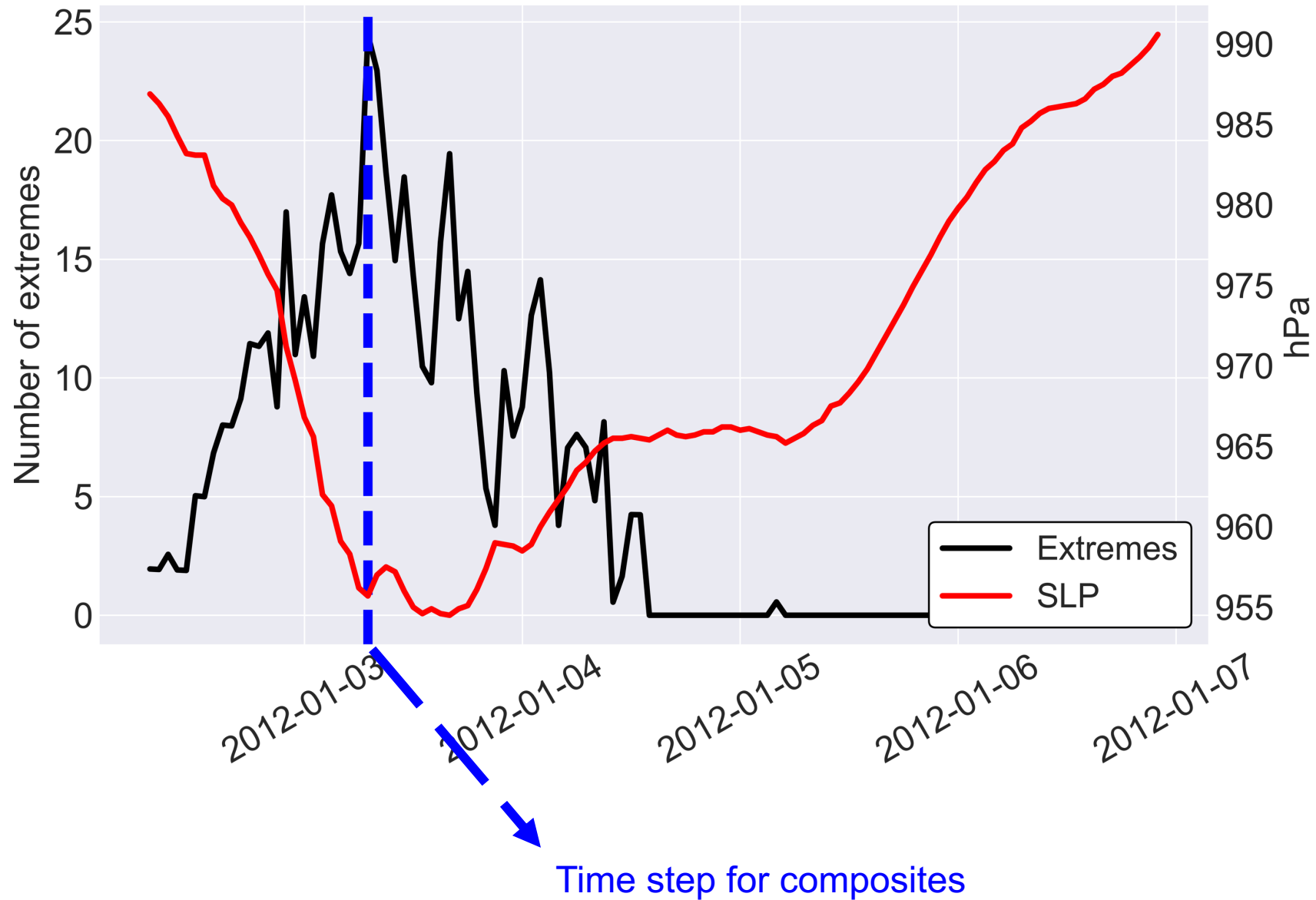
Cyclone Kirk in the cyclone phase space



A: Genesis **Z**: Lysis ●: Scaled number of extremes

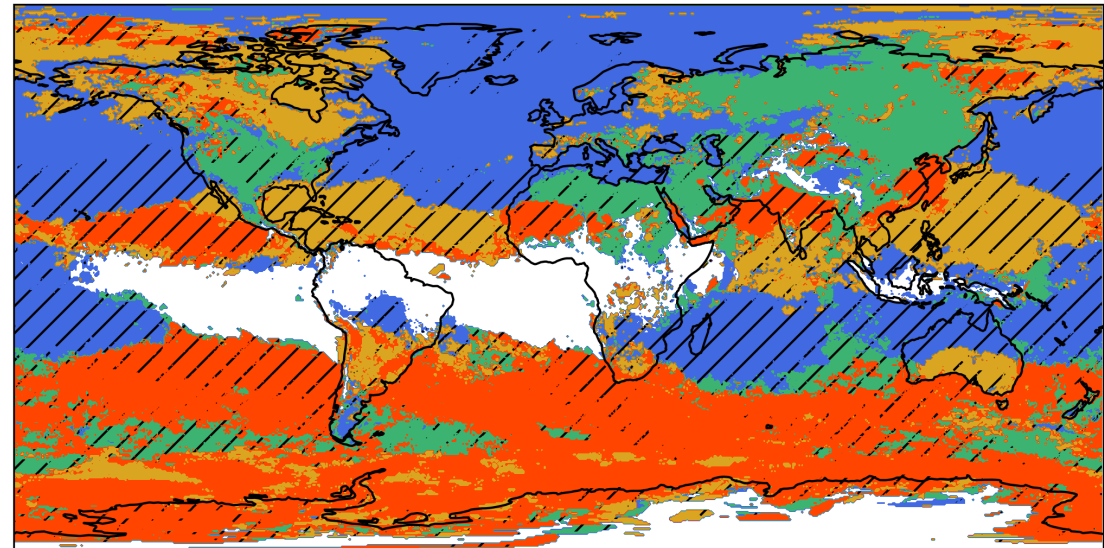
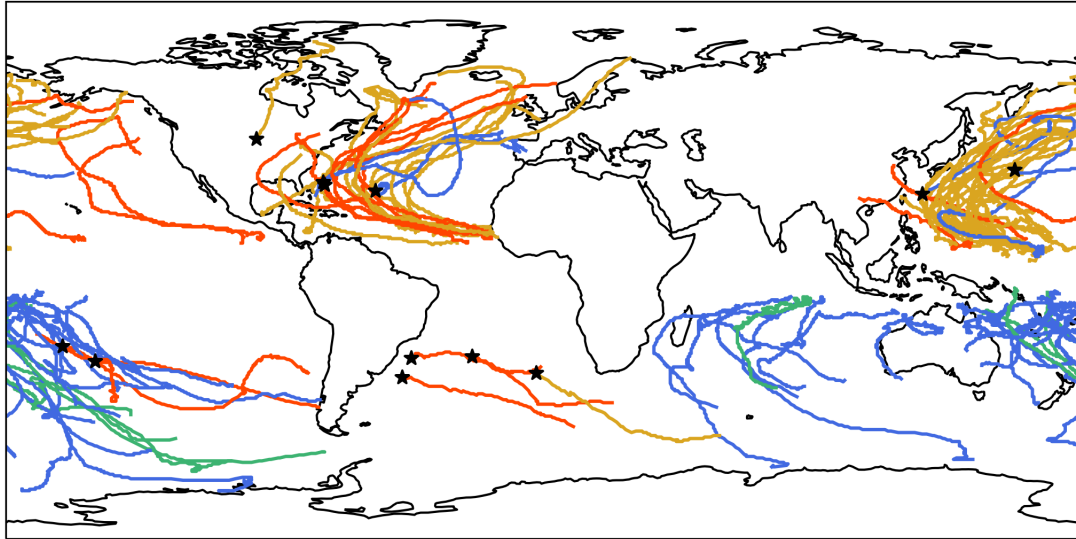
Backup-Slides

Which timestep to choose?



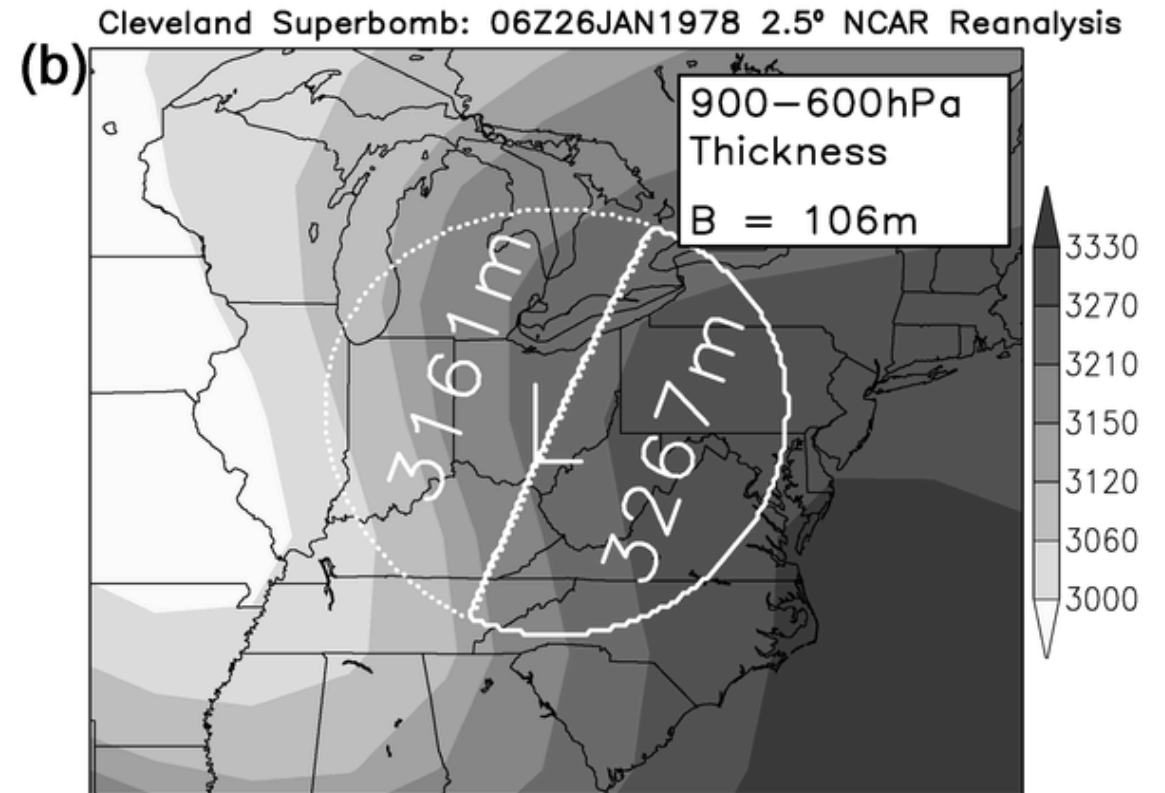
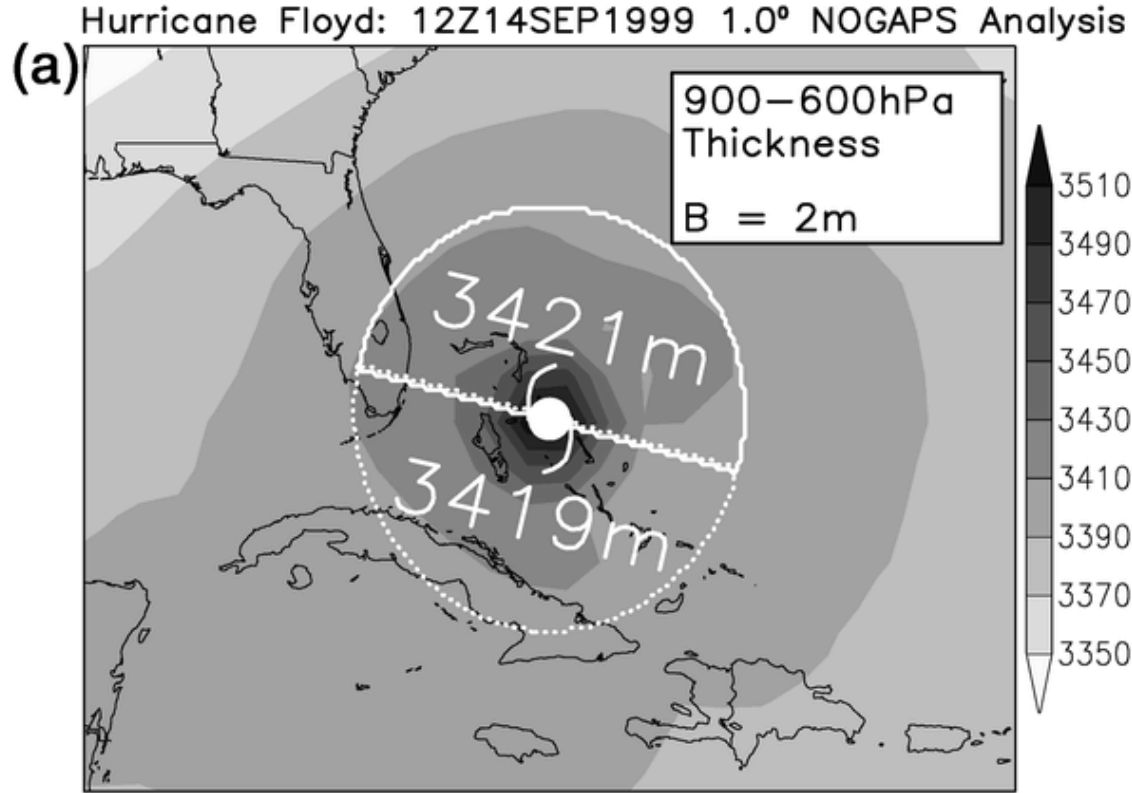
Backup-Slides

W1 tracks and seasonality



Backup-slides

Cyclone phase space: computation of B



Backup-slides

Cyclone phase space: computation of $-V_T^L$ and $-V_T^U$

