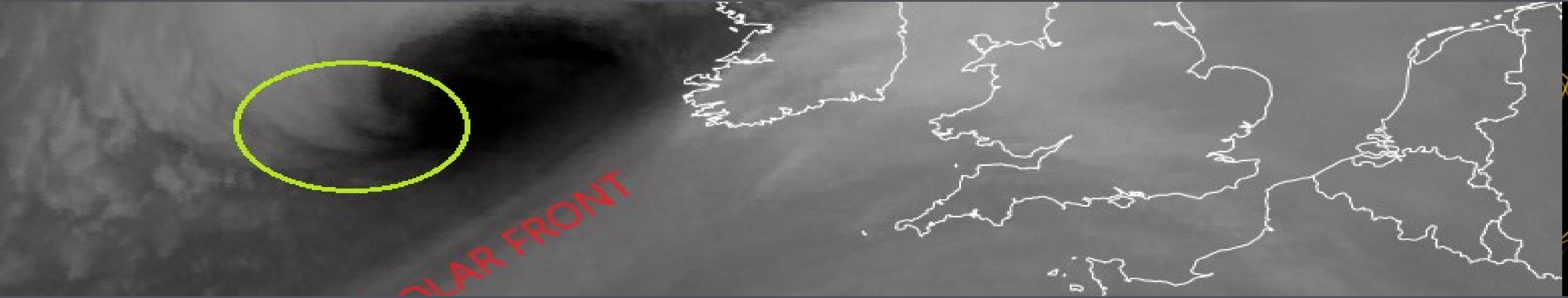
Department of Meteorology

University of Reading

A global climatology of sting-jet cyclones



Sue Gray

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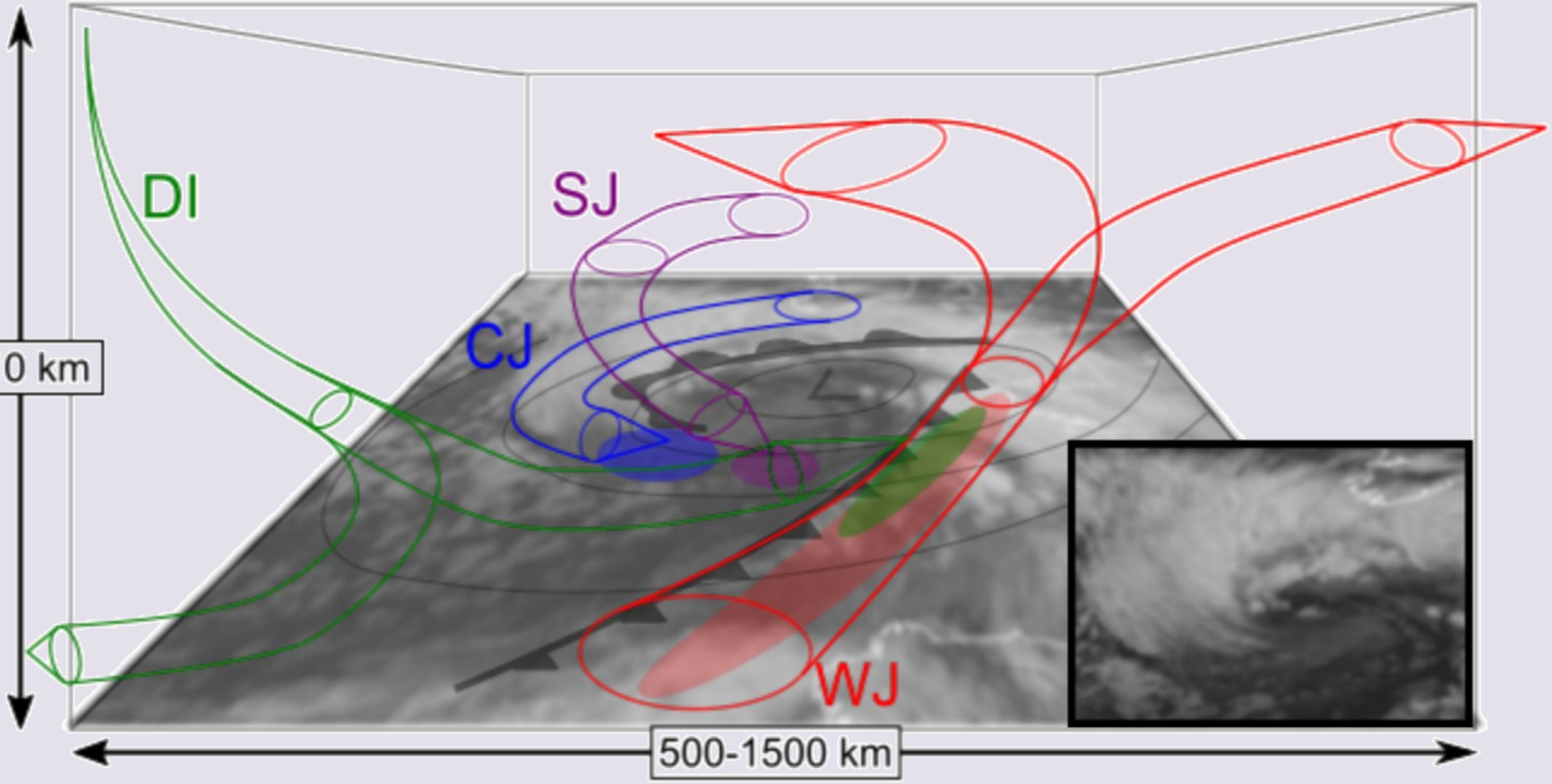
With thanks to Kevin Hodges[1]

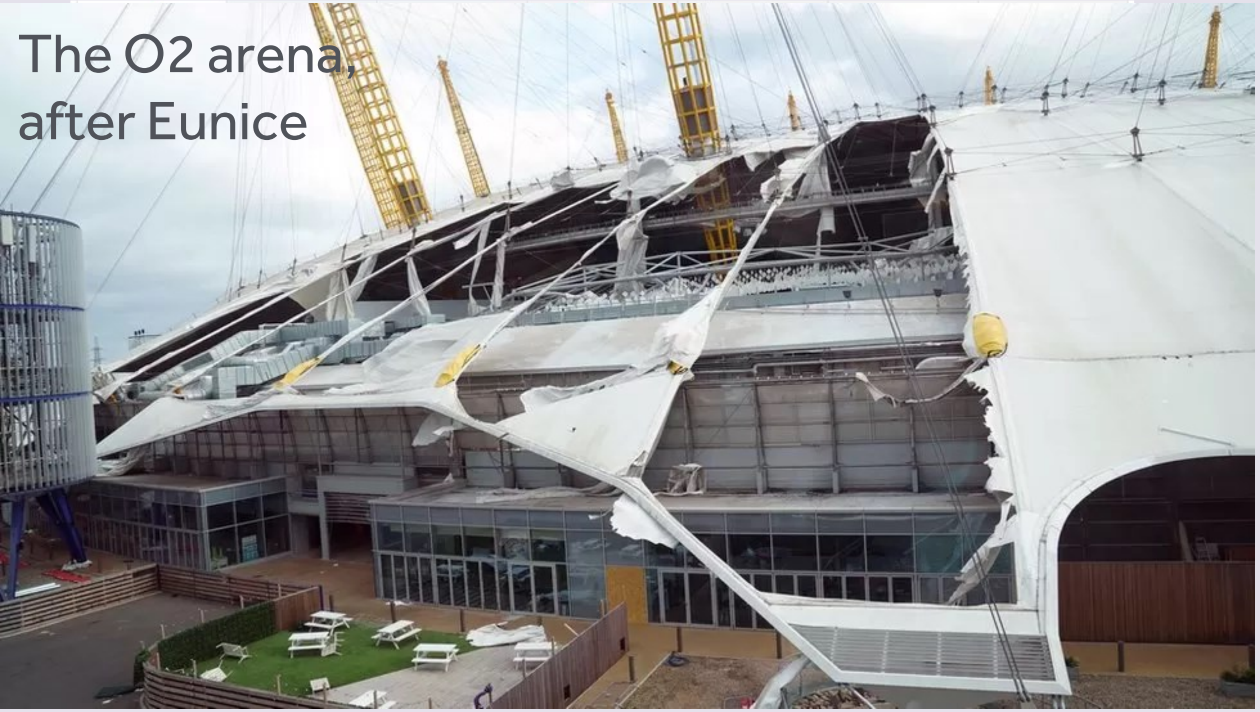
Cyclone airstreams

- Warm conveyor belt (WJ): a strong and well-defined flow of warm moist air advancing poleward ahead of the cold front.
- Cold conveyor belt (CJ): air ahead of and beneath the warm front which, relative to the advancing system, flows rapidly rearwards around the poleward side of the low centre,
- Dry intrusion (DI): air from the upper troposphere and lower stratosphere which after earlier descent approaches the centre of the cyclone as a well-defined reascending dry flow.
- Sting jet (SJ): Transient (few hours), mesoscale (~50km spread) jets of air descending from the tip of the hooked cloud head in the frontal fracture regions of some extratropical storms

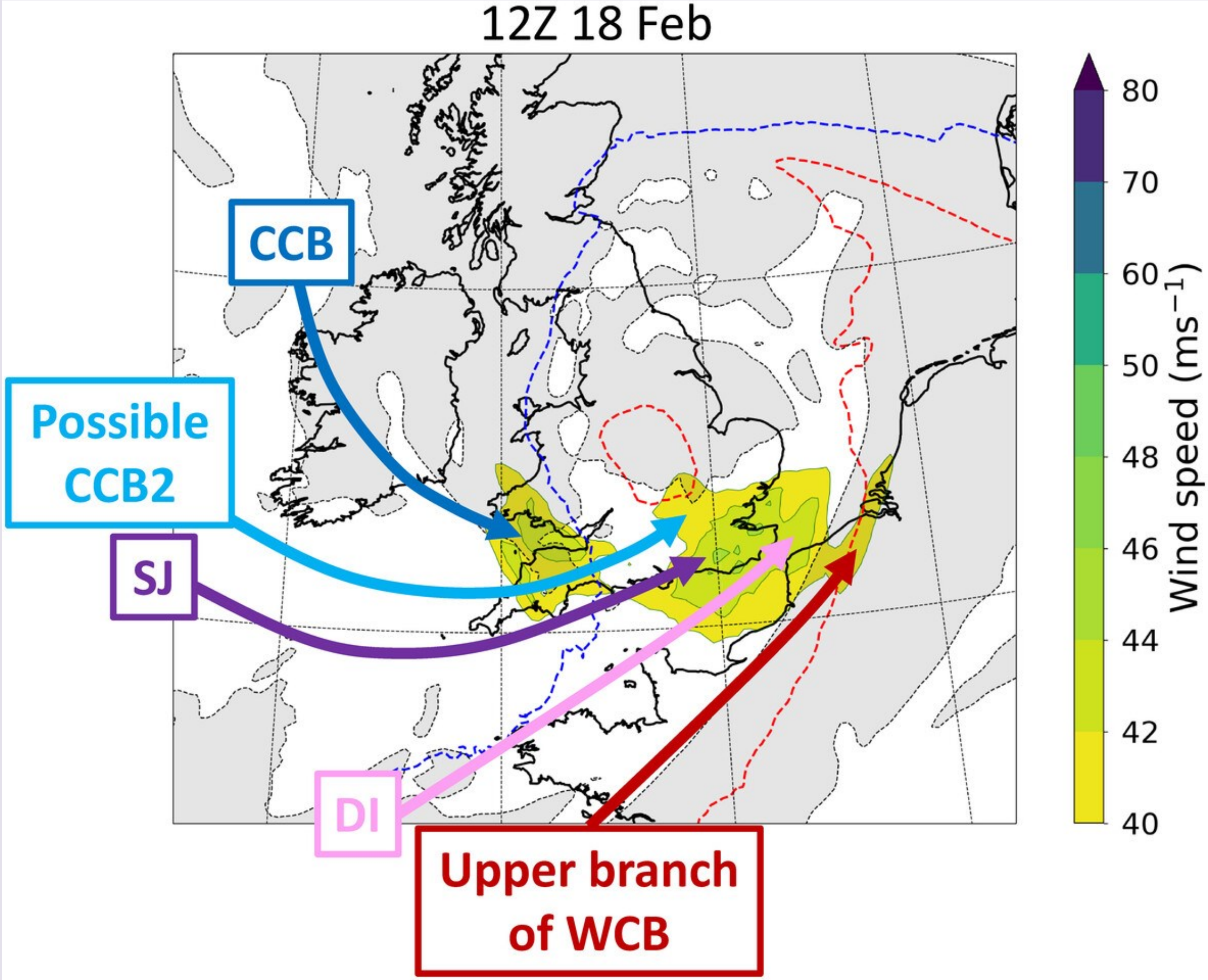


Recent sting jet storms

Storm Eunice (Zeynep, Nora) 18 Feb. 2022



The O2 arena, after Eunice



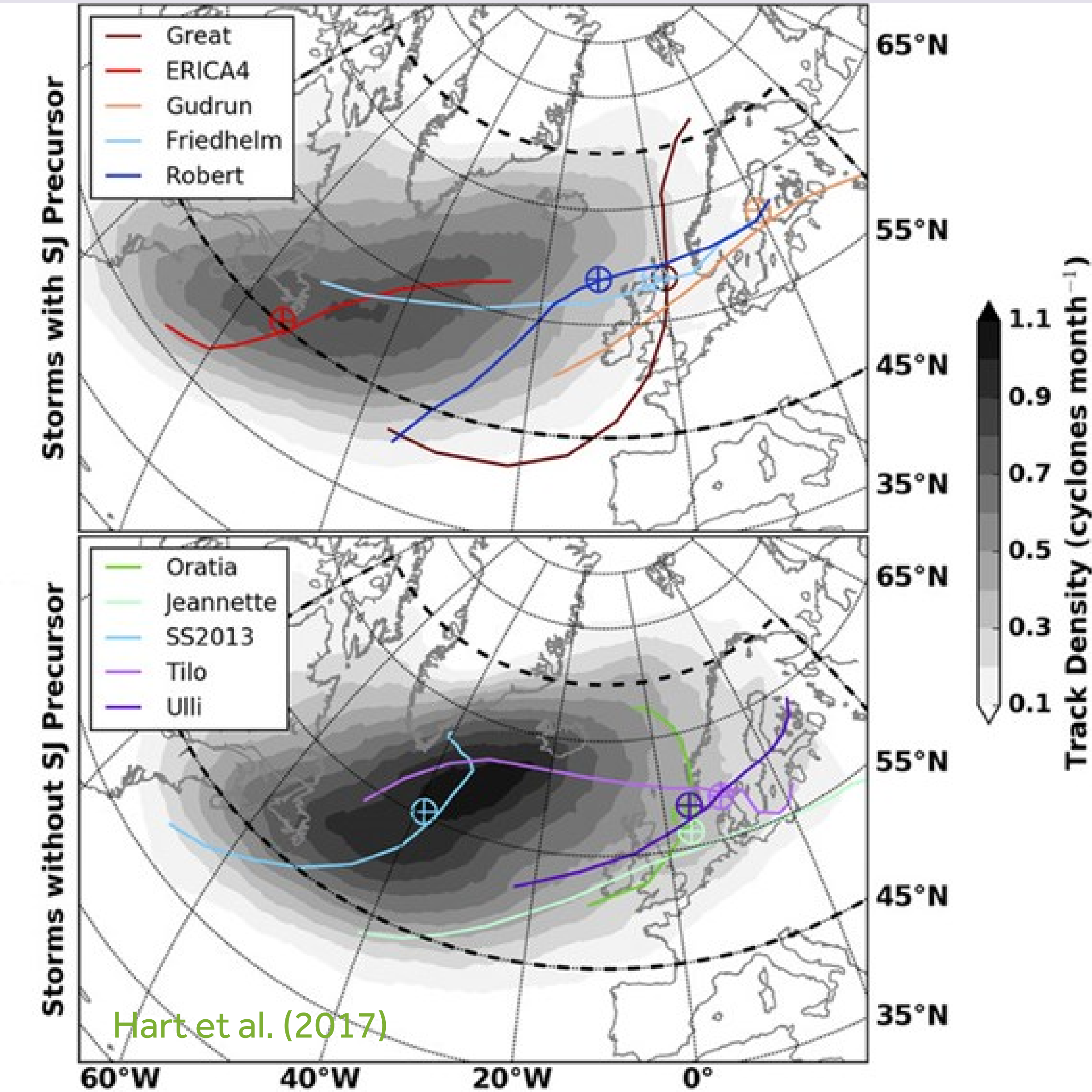
Volonté et al. 2023: **Strong surface winds in Storm *Eunice*** *(Parts 1 and 2), Weather.*

Gray and Volonté 2024: **Extreme low-level wind jets in Storm *Ciarán*,** *Weather.*

The need for a global climatology

- Our understanding of sting jet dynamics has advanced considerably since their first identification, but mostly through analysis of case studies of cyclones crossing the North Atlantic to affect northwest Europe
- Global climatologies exist for the dry intrusion and warm conveyor belt.
- But a published long-term sting jet cyclone climatology only exists for the North Atlantic region (Hart et al., 2017).
- This climatology suggests 1 in 3 cyclones may contain a sting jet.
- There is no physical reason why sting jets should not occur in other regions.

A global climatology of sting-jet cyclones is needed to determine their global prevalence and characteristics, and to highlight the associated wind risks

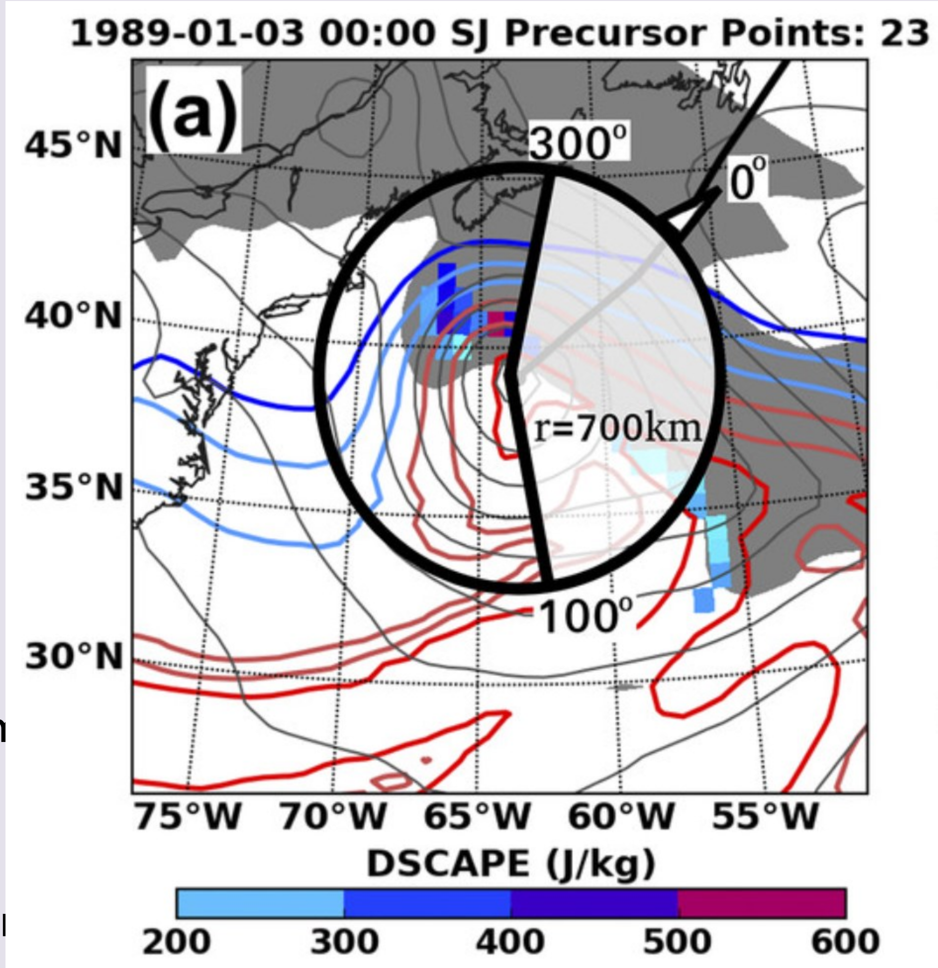


Hart et al. (2017)

Diagnostic approach

Extend the methodology of Hart et al. (2017) to global ERA5 data spanning 1979-2022:

1. Extended winter seasons: Oct.-March (NH) and April-Sept. (SH).
2. Track cyclones using 850-hPa relative vorticity (TRACK algorithm, Hodges (1995,1999)).
3. Consider top 10% in terms of max intensity (measured by relative vorticity).
4. Subset to those intense extratropical cyclones with a Shapiro-Keyser structure (containing a warm seclusion identified using a watershed algorithm).
5. Extract data around the centre of each storm within 42 h of the maximum intensity time.
6. Classify a cyclone as having a sting-jet precursor (SJP) if there is sufficient mesoscale instability in the cloud head. Specifically, we look for conditional symmetric instability (CSI) through analysis of Downdraught Slantwise Convective Available Potential Energy (DSCAPE).
7. Refine approach using “expert judgement” of a list of 33 notable storms.



Hart et al. (2017)

Notable storms

Storms include
Eunice (2022)
Kyrill (2007)
Klaus (2009)
Friedhelm (2011)
Tini (2014)
Lothar and Martin (1999)
Daria (Burns' Day) (1990)
The Great October storm (1987)

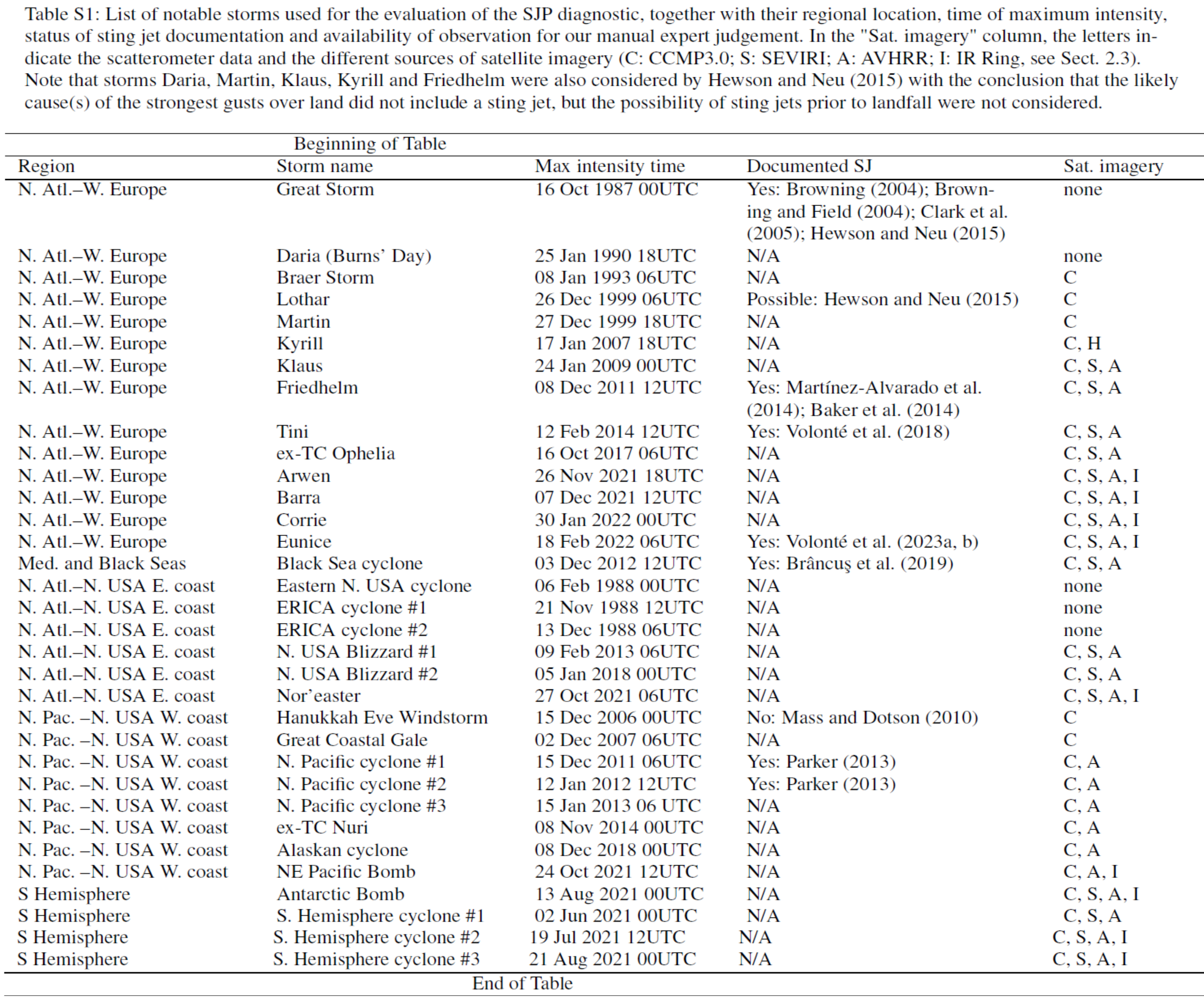


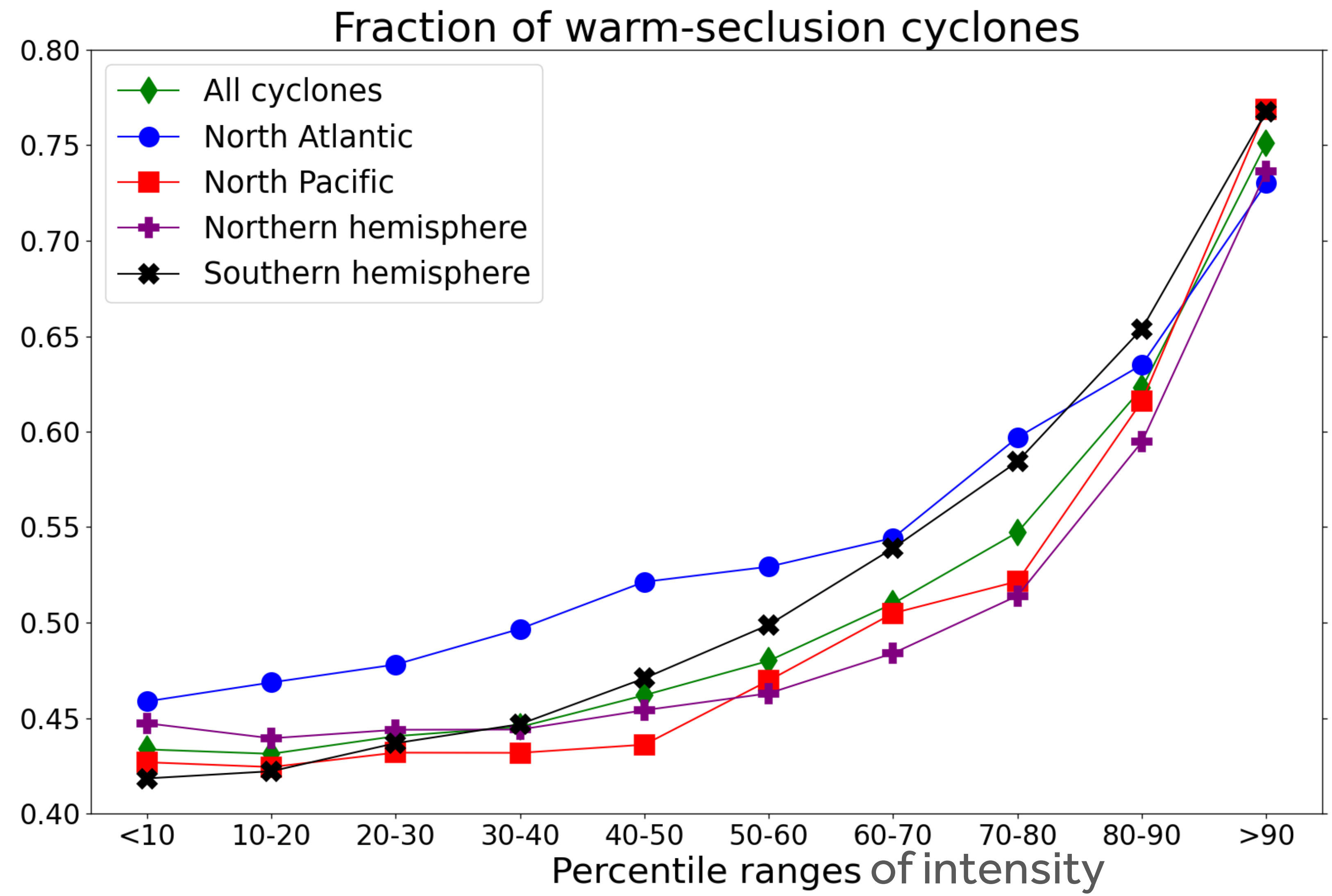
Table S1: List of notable storms used for the evaluation of the SJP diagnostic, together with their regional location, time of maximum intensity, status of sting jet documentation and availability of observation for our manual expert judgement. In the "Sat. imagery" column, the letters indicate the scatterometer data and the different sources of satellite imagery (C: CCMP3.0; S: SEVIRI; A: AVHRR; I: IR Ring, see Sect. 2.3). Note that storms Daria, Martin, Klaus, Kyrill and Friedhelm were also considered by Hewson and Neu (2015) with the conclusion that the likely cause(s) of the strongest gusts over land did not include a sting jet, but the possibility of sting jets prior to landfall were not considered.

Beginning of Table

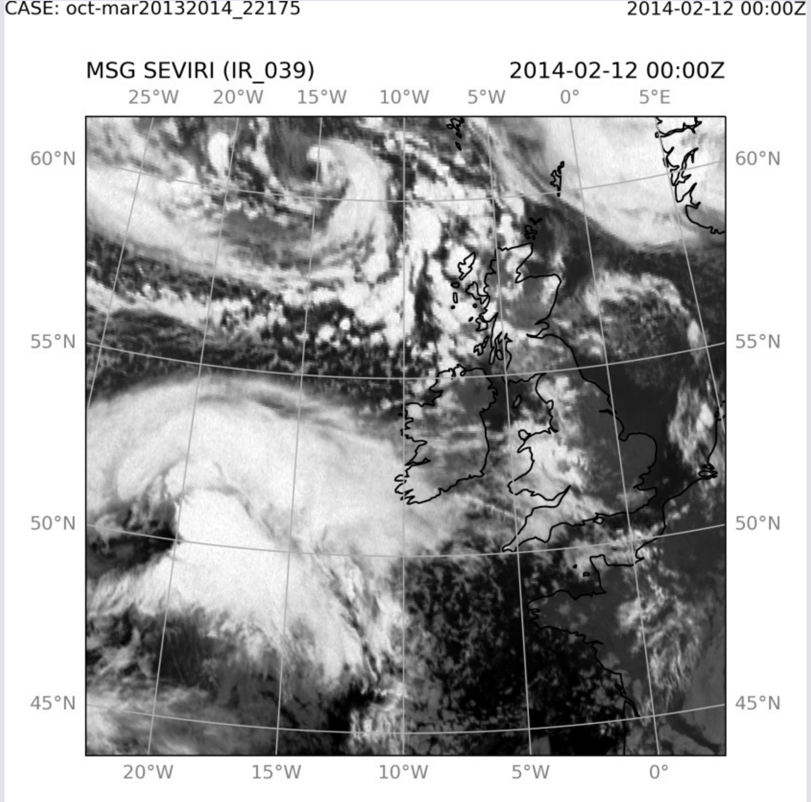
Region	Storm name	Max intensity time	Documented SJ	Sat. imagery
N. Atl.–W. Europe	Great Storm	16 Oct 1987 00UTC	Yes: Browning (2004); Browning and Field (2004); Clark et al. (2005); Hewson and Neu (2015)	none
N. Atl.–W. Europe	Daria (Burns' Day)	25 Jan 1990 18UTC	N/A	none
N. Atl.–W. Europe	Braer Storm	08 Jan 1993 06UTC	N/A	C
N. Atl.–W. Europe	Lothar	26 Dec 1999 06UTC	Possible: Hewson and Neu (2015)	C
N. Atl.–W. Europe	Martin	27 Dec 1999 18UTC	N/A	C
N. Atl.–W. Europe	Kyrill	17 Jan 2007 18UTC	N/A	C, H
N. Atl.–W. Europe	Klaus	24 Jan 2009 00UTC	N/A	C, S, A
N. Atl.–W. Europe	Friedhelm	08 Dec 2011 12UTC	Yes: Martínez-Alvarado et al. (2014); Baker et al. (2014)	C, S, A
N. Atl.–W. Europe	Tini	12 Feb 2014 12UTC	Yes: Volonté et al. (2018)	C, S, A
N. Atl.–W. Europe	ex-TC Ophelia	16 Oct 2017 06UTC	N/A	C, S, A
N. Atl.–W. Europe	Arwen	26 Nov 2021 18UTC	N/A	C, S, A, I
N. Atl.–W. Europe	Barra	07 Dec 2021 12UTC	N/A	C, S, A, I
N. Atl.–W. Europe	Corrie	30 Jan 2022 00UTC	N/A	C, S, A, I
N. Atl.–W. Europe	Eunice	18 Feb 2022 06UTC	Yes: Volonté et al. (2023a, b)	C, S, A, I
Med. and Black Seas	Black Sea cyclone	03 Dec 2012 12UTC	Yes: Brâncuş et al. (2019)	C, S, A
N. Atl.–N. USA E. coast	Eastern N. USA cyclone	06 Feb 1988 00UTC	N/A	none
N. Atl.–N. USA E. coast	ERICA cyclone #1	21 Nov 1988 12UTC	N/A	none
N. Atl.–N. USA E. coast	ERICA cyclone #2	13 Dec 1988 06UTC	N/A	none
N. Atl.–N. USA E. coast	N. USA Blizzard #1	09 Feb 2013 06UTC	N/A	C, S, A
N. Atl.–N. USA E. coast	N. USA Blizzard #2	05 Jan 2018 00UTC	N/A	C, S, A
N. Atl.–N. USA E. coast	Nor'easter	27 Oct 2021 06UTC	N/A	C, S, A, I
N. Pac. –N. USA W. coast	Hanukkah Eve Windstorm	15 Dec 2006 00UTC	No: Mass and Dotson (2010)	C
N. Pac. –N. USA W. coast	Great Coastal Gale	02 Dec 2007 06UTC	N/A	C
N. Pac. –N. USA W. coast	N. Pacific cyclone #1	15 Dec 2011 06UTC	Yes: Parker (2013)	C, A
N. Pac. –N. USA W. coast	N. Pacific cyclone #2	12 Jan 2012 12UTC	Yes: Parker (2013)	C, A
N. Pac. –N. USA W. coast	N. Pacific cyclone #3	15 Jan 2013 06 UTC	N/A	C, A
N. Pac. –N. USA W. coast	ex-TC Nuri	08 Nov 2014 00UTC	N/A	C, A
N. Pac. –N. USA W. coast	Alaskan cyclone	08 Dec 2018 00UTC	N/A	C, A
N. Pac. –N. USA W. coast	NE Pacific Bomb	24 Oct 2021 12UTC	N/A	C, A, I
S Hemisphere	Antarctic Bomb	13 Aug 2021 00UTC	N/A	C, S, A, I
S Hemisphere	S. Hemisphere cyclone #1	02 Jun 2021 00UTC	N/A	C, S, A
S Hemisphere	S. Hemisphere cyclone #2	19 Jul 2021 12UTC	N/A	C, S, A, I
S Hemisphere	S. Hemisphere cyclone #3	21 Aug 2021 00UTC	N/A	C, S, A, I

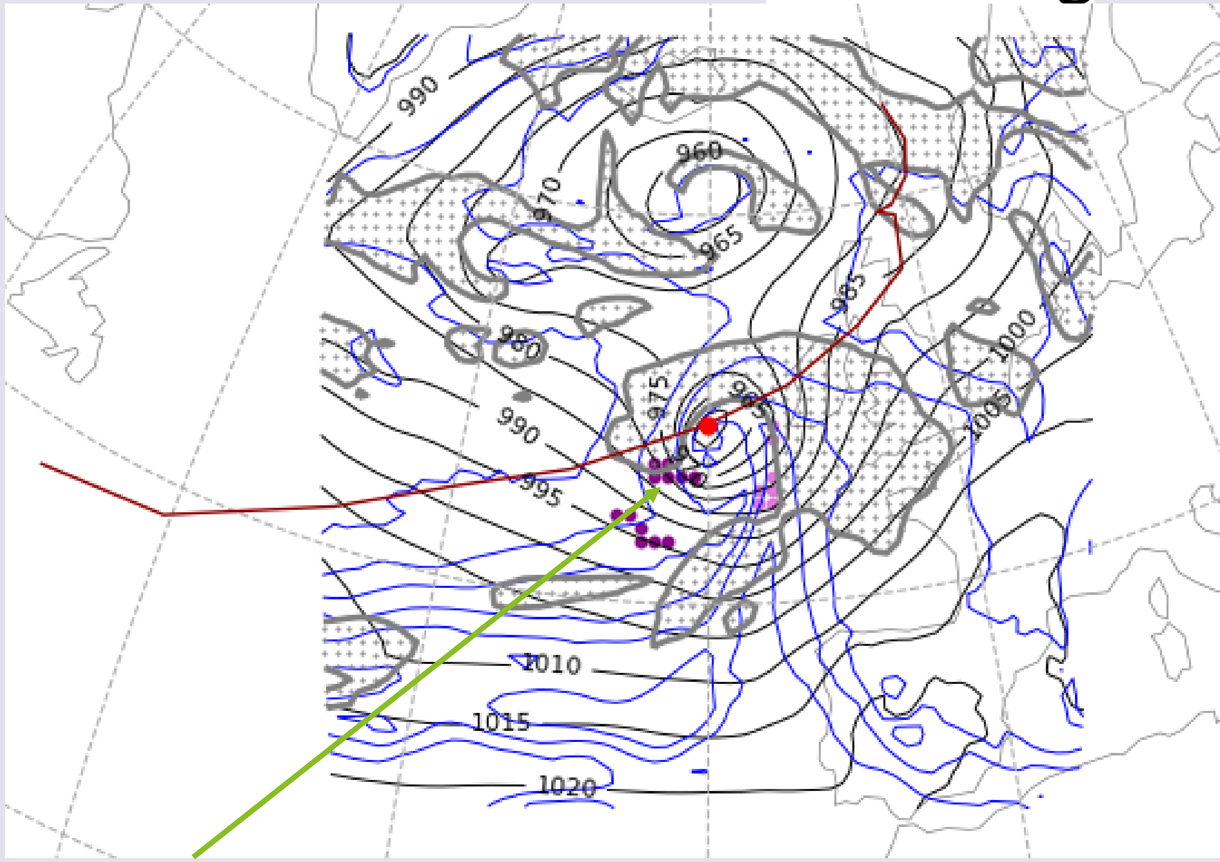
End of Table

Warm seclusion cyclones



Example 1: Windstorm Tini



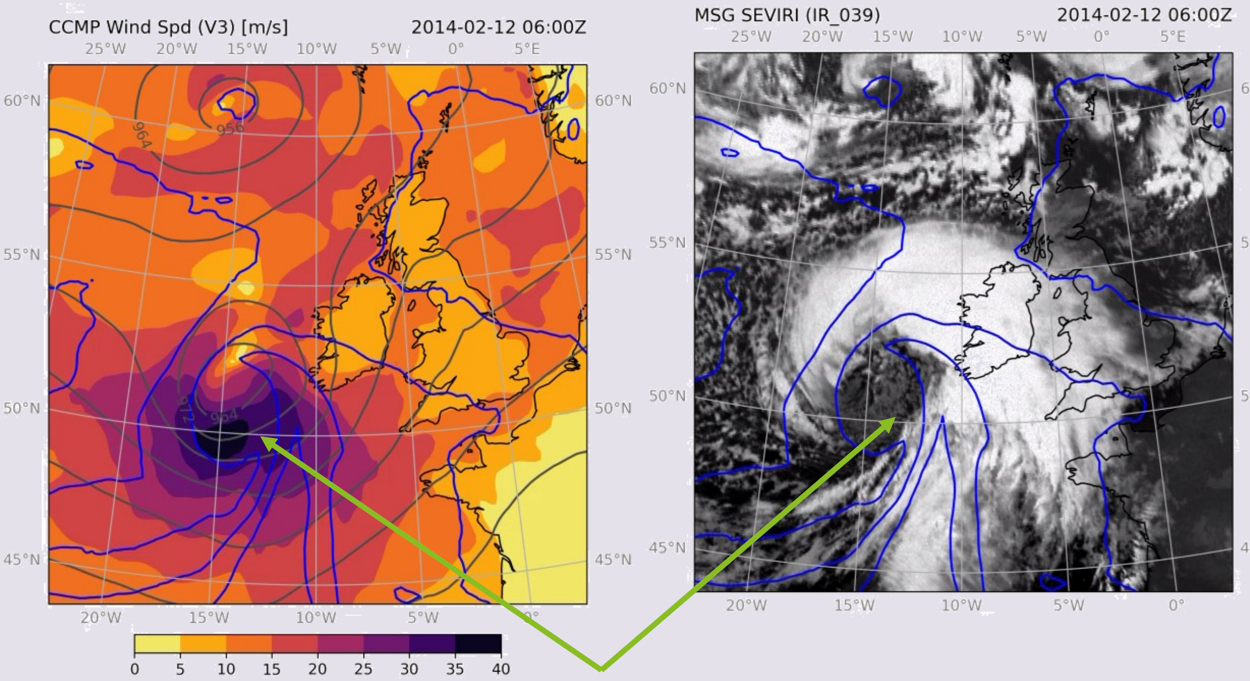


- Selected as an impactful storm with prior evidence of sting jet from Volonté et al 2018.
- Methods of sting jet identification in the literature: cloud-head banding, Wind profiler observations, and3D wind structure and trajectory analysis using high resolution simulations
- Max. intensity: 12 February 2014 12 UTC

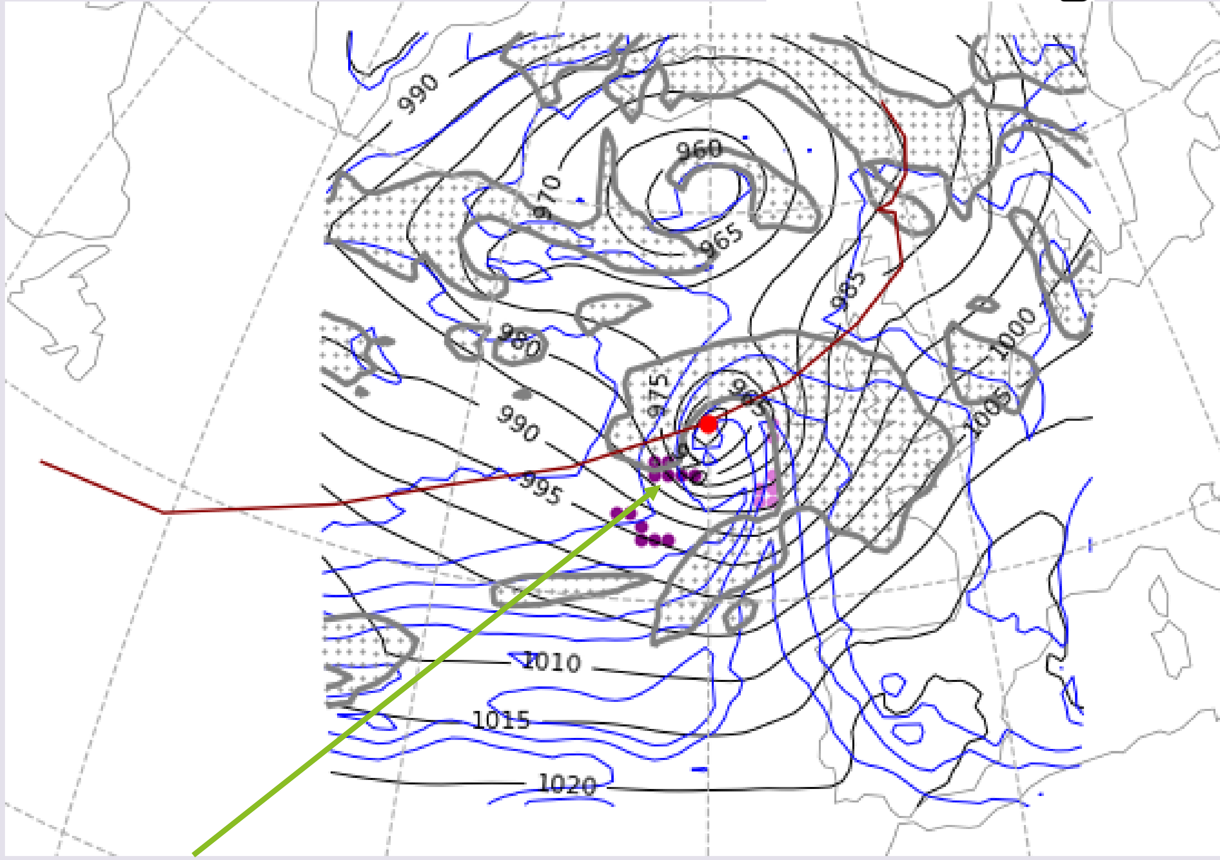
- Cloud-head DSCAPE: two areas of above threshold DSCAPE at cloud-head tip and in frontal fracture region at t-06h
- SJ Precursor status: positive
- Expert judgement: Agreement between observations, literature evidence and the precursor tool

Example 1: Windstorm Tini

CCMP satellite-based winds


CCMP Wind Spd (V3) [m/s] 2014-02-12 06:00Z

MSG SEVIRI (IR_039) 2014-02-12 06:00Z



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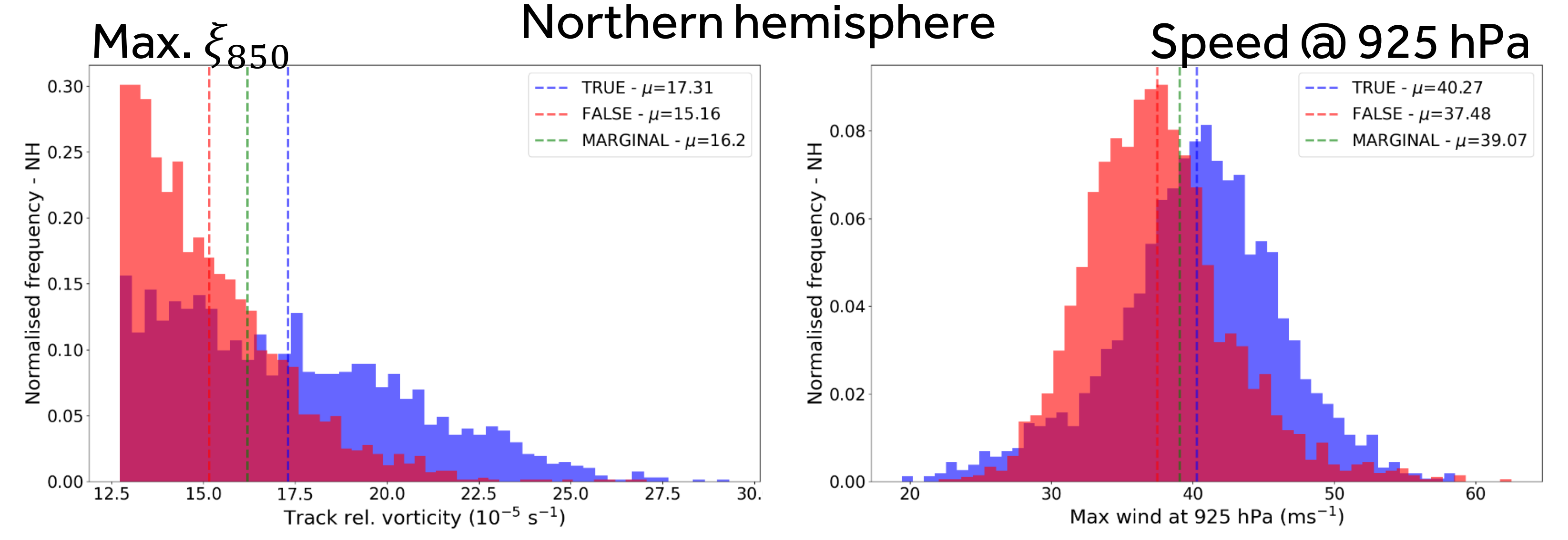
- SJ Precursor status: positive
- Expert judgement: Agreement between observations, literature evidence and the precursor tool

Basic statistics (at maximum intensity)

NH: TRUE: 2040 cyclones (**27% of all cyclones**, 37% of warm seclusion cyclones)

FALSE: 2541. MARGINAL: 969 cyclones

- SJP cyclones are more intense, deeper and have stronger winds than non-SJP ones
- They also have larger ΔP in their 300-km core


Northern hemisphere

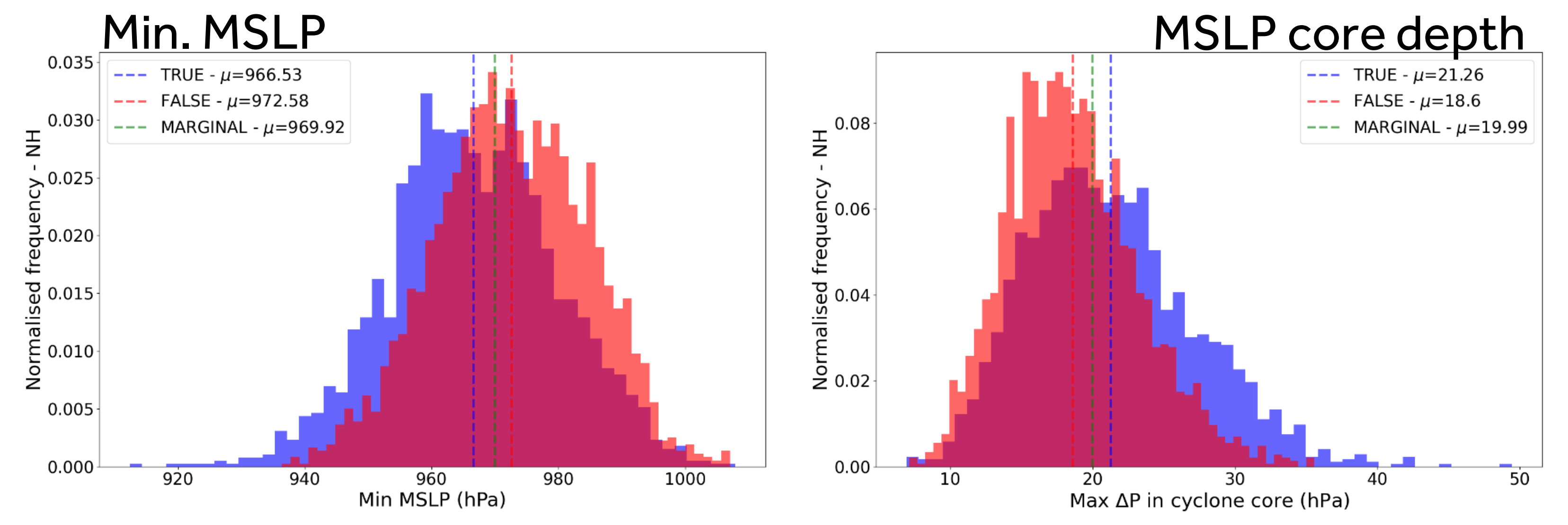
Max. ξ_{850}

Speed @ 925 hPa

SH: TRUE: 1028 cyclones (**15% of all cyclones**, 20% of warm seclusion cyclones)

FALSE: 3426. MARGINAL: 753 cyclones

- SJP cyclones are more intense, have stronger winds, but are not deeper than non-SJP ones at maximum intensity


Min. MSLP

MSLP core depth

Storm tracks

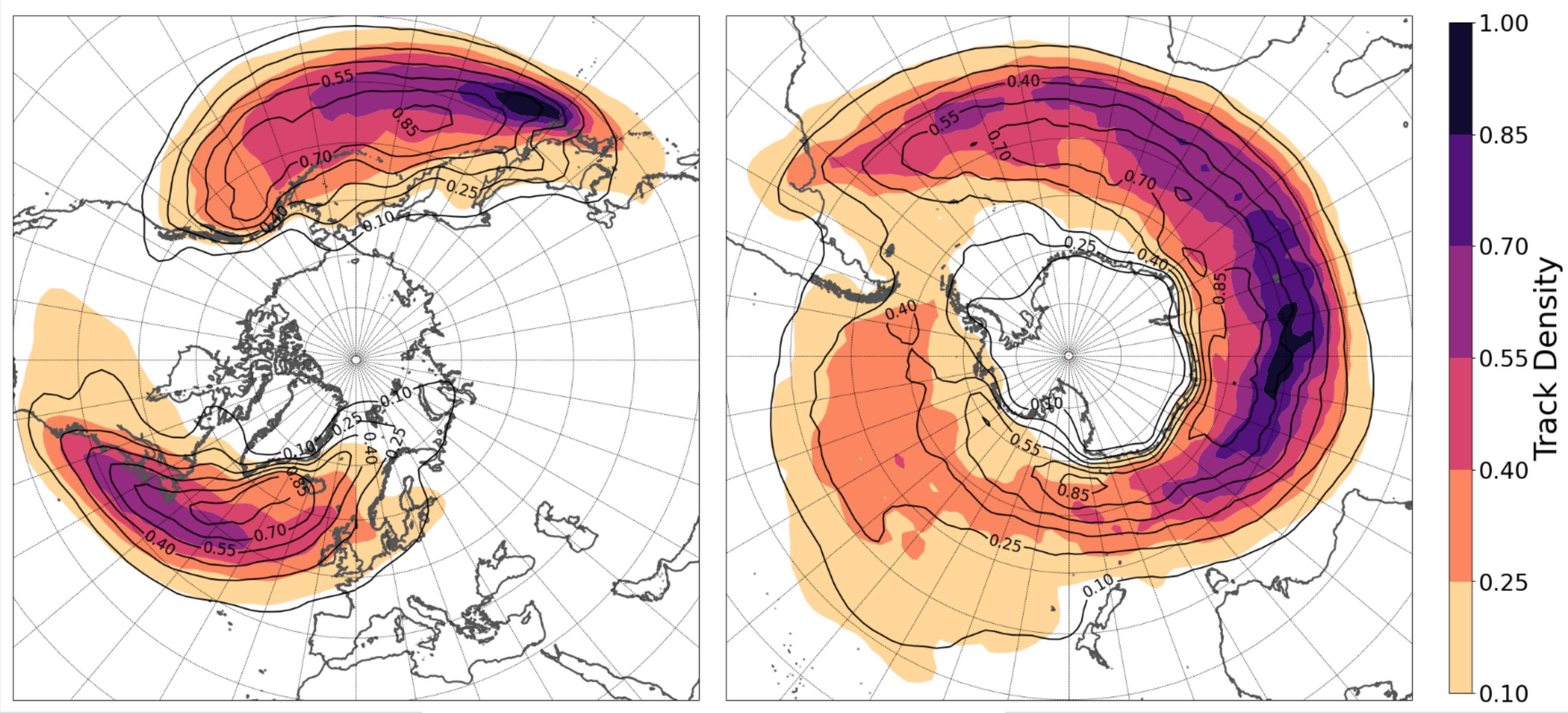
- SJP cyclones in shading and non-SJP cyclones in contours, each subset normalised independently (not showing marginal cyclones)

- SJP-cyclone tracks (and genesis) are more to the SW than non-SJP ones, in both NH oceans

- SJP-cyclones are at lower latitudes than their non-SJ counterparts in the Southern Ocean

Northern Hemisphere

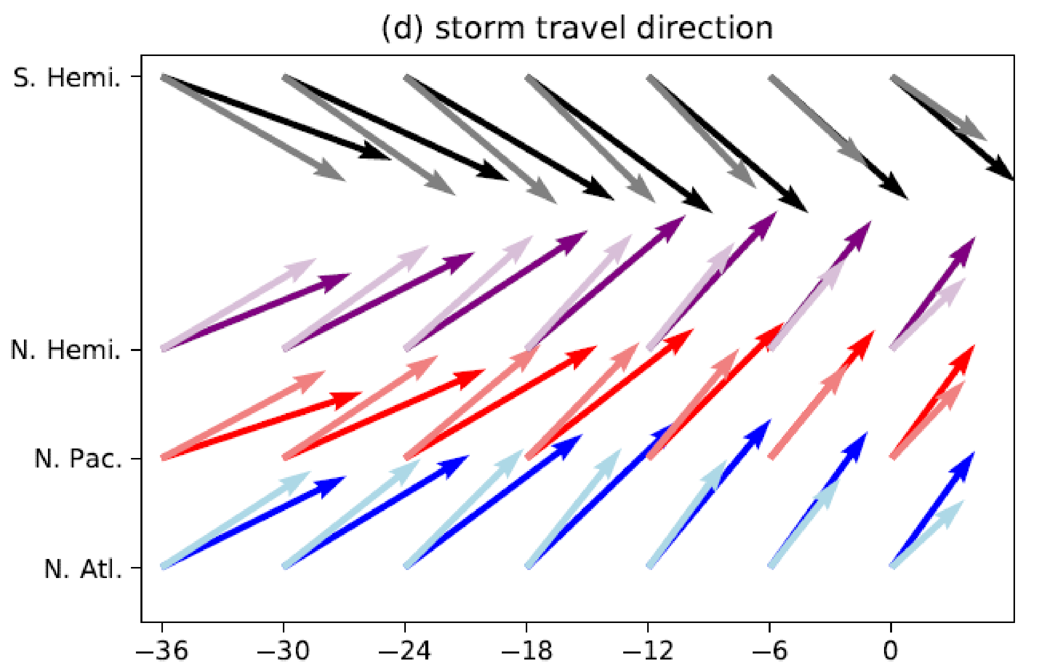
Southern Hemisphere



Track density

Cyclone composite evolution

Dark arrows = SJP
Pale arrows = non SJP

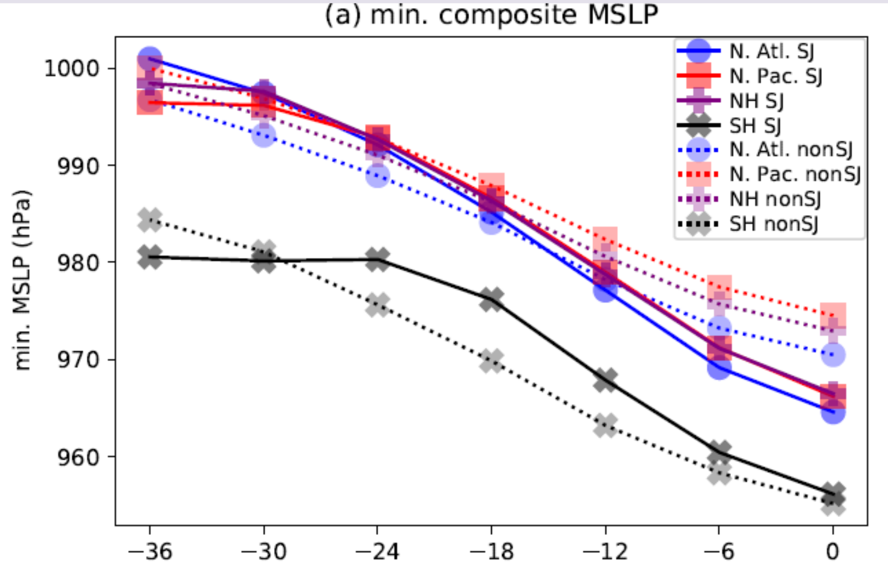


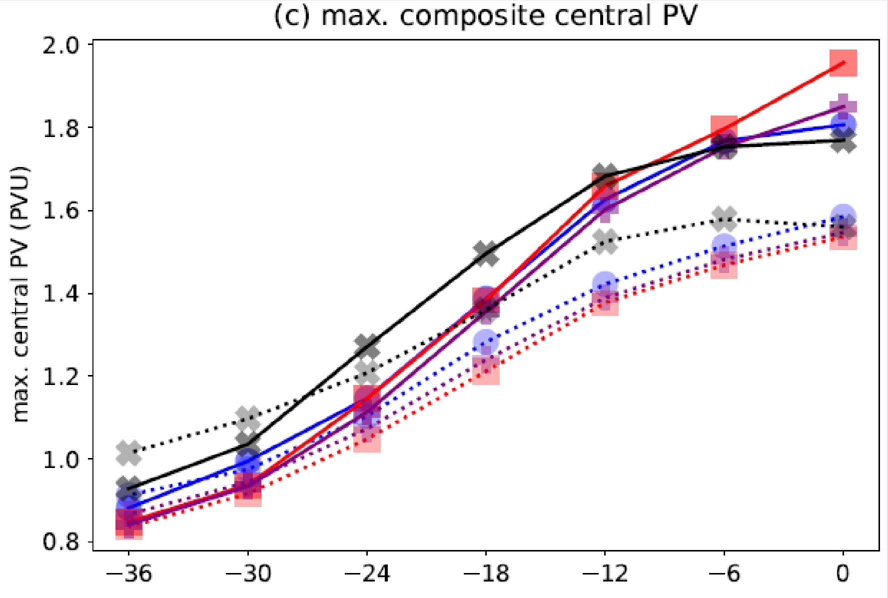
- SJP cyclones travel faster than non-SJ cyclones throughout their intensification period
- SJP cyclones initially travel more zonally than non-SJ cyclones but have greater poleward motion component at maximum intensity time.

- SJP cyclones deepen faster than non-SJP cyclones.
- SJP cyclones develop higher core midlevel potential vorticity (PV) values.

Also (not shown)

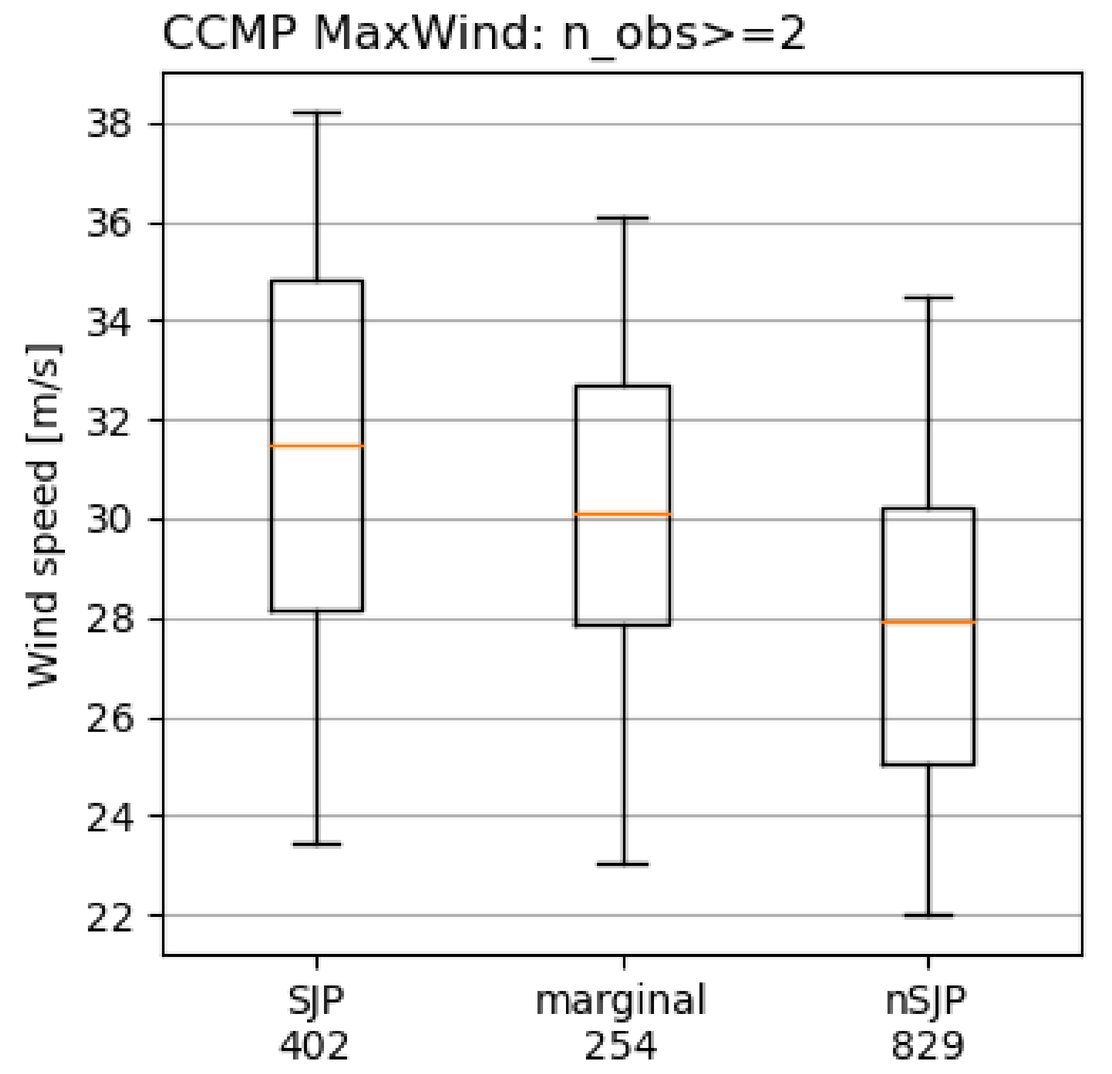
- SJP cyclones have warmer cores (in θ_w) than nSJP cyclones
- SJP cyclones have more mesoscale instability (symmetric instability) than nSJP cyclones (more –ve PV points).





Observational support

- SJP cyclones have faster “observed” winds than nSJP cyclones based on ocean wind measurements from satellite blended with ERA5 (consistent with findings from ERA5).
- The difference between the “observed” and ERA5 near-surface winds are also greater for the SJP than nSJP cyclones suggesting that a sting jet may be enhancing the observed winds. But, more work is needed to confirm this due to the non-linear nature of the bias correction applied to the satellite-derived winds.



Conclusions

Gray, S. L., Volonté, A., Martínez-Alvarado, O., and Harvey, B. J.: A global climatology of sting-jet extratropical cyclones, *Weather Clim. Dynam.*, **5**, 1523–1544, https://doi.org/10.5194/wcd-5-1523-2024, 2024.

- We have produced the first global climatology of SJ storms by applying a “SJ precursor” diagnostic based on slantwise convective instability to 43 extended winter seasons from the ERA5 dataset.
- The basic methodology was used previously to produce a North Atlantic climatology (based on ERA-Interim dataset) but is extended here by pre-selecting cyclones with a warm seclusion and refinements based on assessment of a 33-member notable storms dataset.
- Warm seclusions are far more common in stronger storms: over 70% in the top intensity (850-hPa relative vorticity) decile have warm seclusions in all three major ocean basins.
- Sting jet precursor (SJP) cyclones occur in all three main ocean basins but are more common in the NH (27% of all cyclones have the SJP) than in the SH (15%) for the top intensity decile.
- At maximum intensity time, SJP cyclones are more intense (in 850-hPa relative vorticity), have stronger low-level winds and larger ΔP in their 300-km core than non-SJP ones.
- SJP cyclones deepen (in MSLP) faster than non-SJP cyclones. At maximum intensity time, NH SJP cyclones are also deeper. SH SJP cyclones are not deeper (on average) than non-SJP cyclones, likely due to the different track characteristics.
- The storm tracks of SJP and non-SJP cyclones are distinct with SJP cyclones forming over typically warmer SSTs. SJP cyclones travel faster and initially have a more zonal track.
- The structural differences between SJP and non-SJP cyclones evidence the climatological consequences of strong diabatic cloud processes on cyclone characteristics, implying that strong near-surface winds, including sting jets, are likely to be enhanced by climate change.