What do large hail, tornado and severe thunderstorm wind environments have in common across continents?

Mateusz Taszarek[1,2], Tomas Pucik[3,4], Cameron Nixon[5], John T. Allen[6], Pieter Groenemeijer[3,4], John M. Peters[7], Francesco Battaglioli[3,4], Bruno Ribeiro[8], Hernan Bechis[9,10,11], Andrew Dowdy[12], and Harold Brooks[13]

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[2] - Skywarn Poland, Warsaw, Poland
[3] - European Severe Storms Laboratory - Science & Training, Wiener Neustadt, Austria
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[6] - Department of Earth and Atmospheric Sciences, Central Michigan University, Mount Pleasant, Michigan
[7] - Department of Meteorology and Atmospheric Science, The Pennsylvania State University, University Park, Pennsylvani
[8] - School of Meteorology, University of Oklahoma, Norman, Oklahoma
[9] - Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Buenos Aires, Argentina
[10] - CNRS–IRD–CONICET–UBA, Instituto Franco-Argentino para el Estudio del Clima y sus Impactos, Buenos Aires, Argentina
[11] - CONICET – Universidad de Buenos Aires, Centro de Investigaciones del Mar y la Atmósfera, Buenos Aires, Argentina
[12] - University of Melbourne, Melbourne, Victoria, Australia
[13] - NOAA/OAR National Severe Storms Laboratory, Norman, Oklahoma

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Motivation

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  → Test skill of convective parameters
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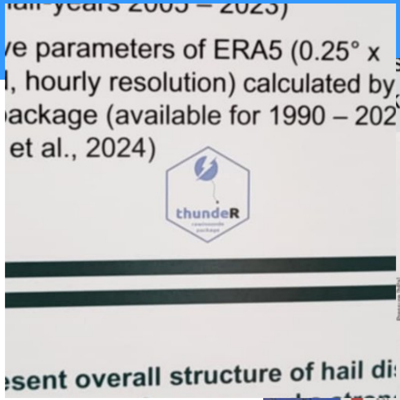
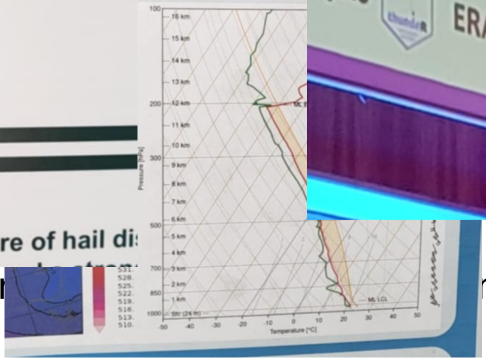
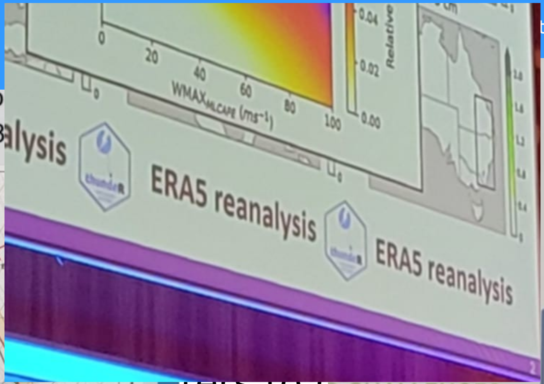
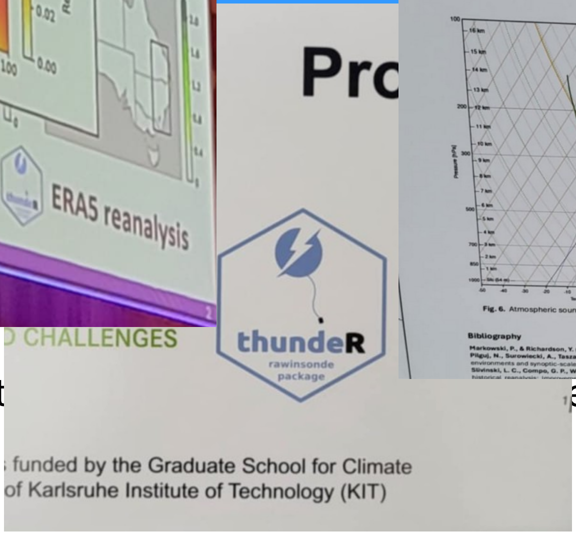
- Development of thundeR package with international collaboration (**35x** peer-reviewed studies, **24x** ECSS 2025 presentations / posters)

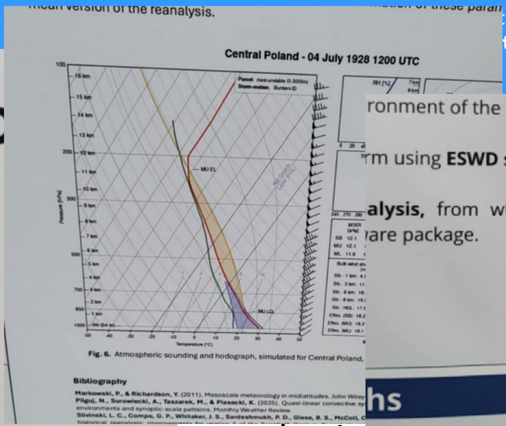
thundeR rawinsonde package

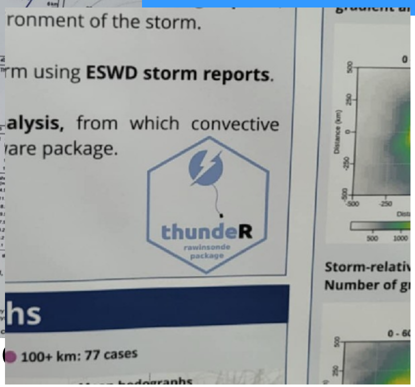












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- New convective parameters & operational products (e.g. Effective Lifted Index, CIN_4km)

Data shared with the community at

www.rawinsonde.com

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Sounding browser **World**

ERA5 sigma levels browser **Europe**

ERA5 sigma levels browser **USA**

ERA5 sigma levels browser **Australia**

ERA5 sigma levels browser **South America**

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Automated Severe Thunderstorm Outlook from thundeR Package **Europe**

Automated Severe Thunderstorm Outlook from thundeR Package **USA**

thundeR rawinsonde package – **Sounding** browser **World**

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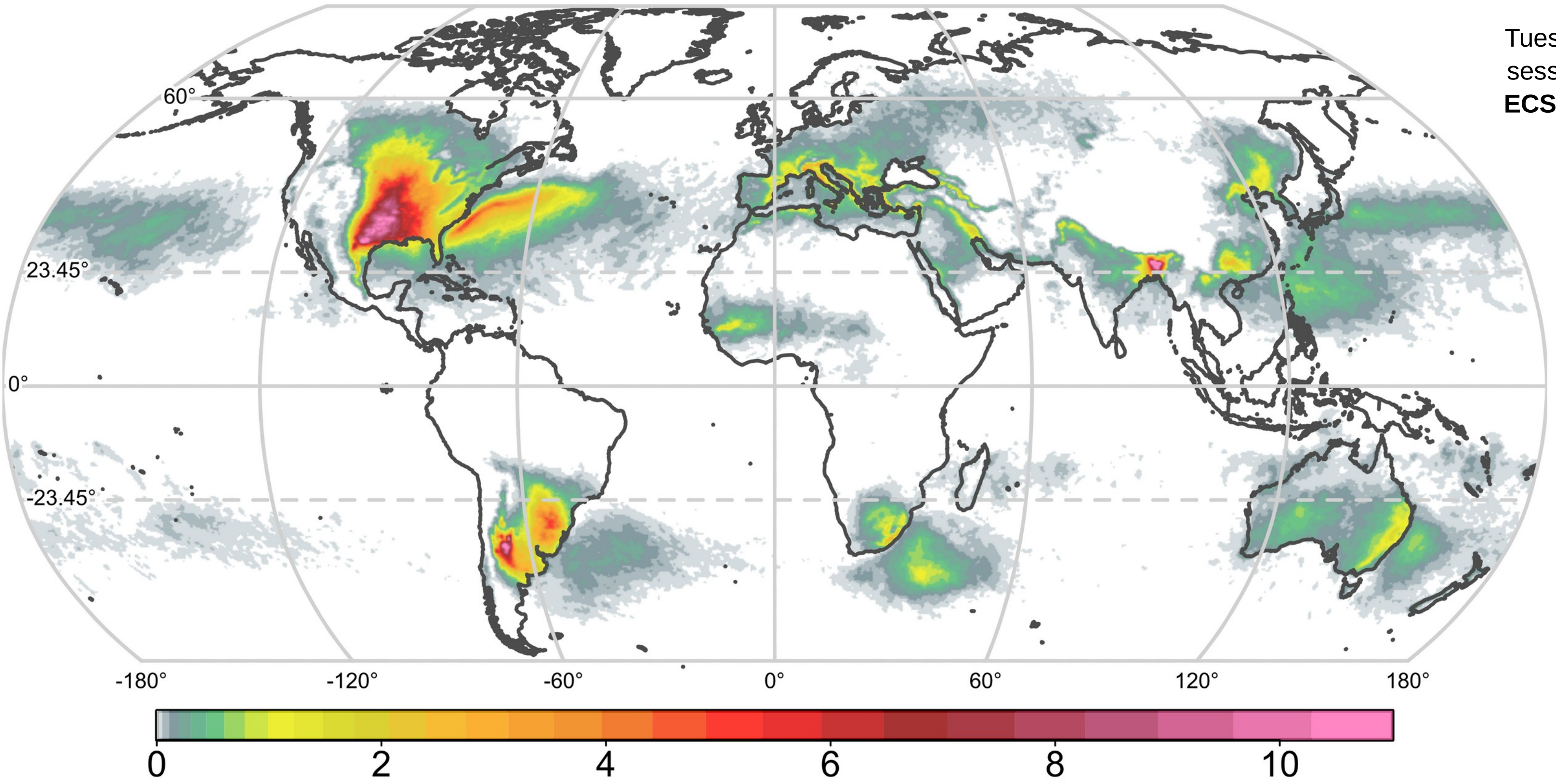
Modeled frequency of NOAA SPC **enhanced risk**

(ERA5 1950-2024)

Tuesday poster session (P100)
ECSS2025-219



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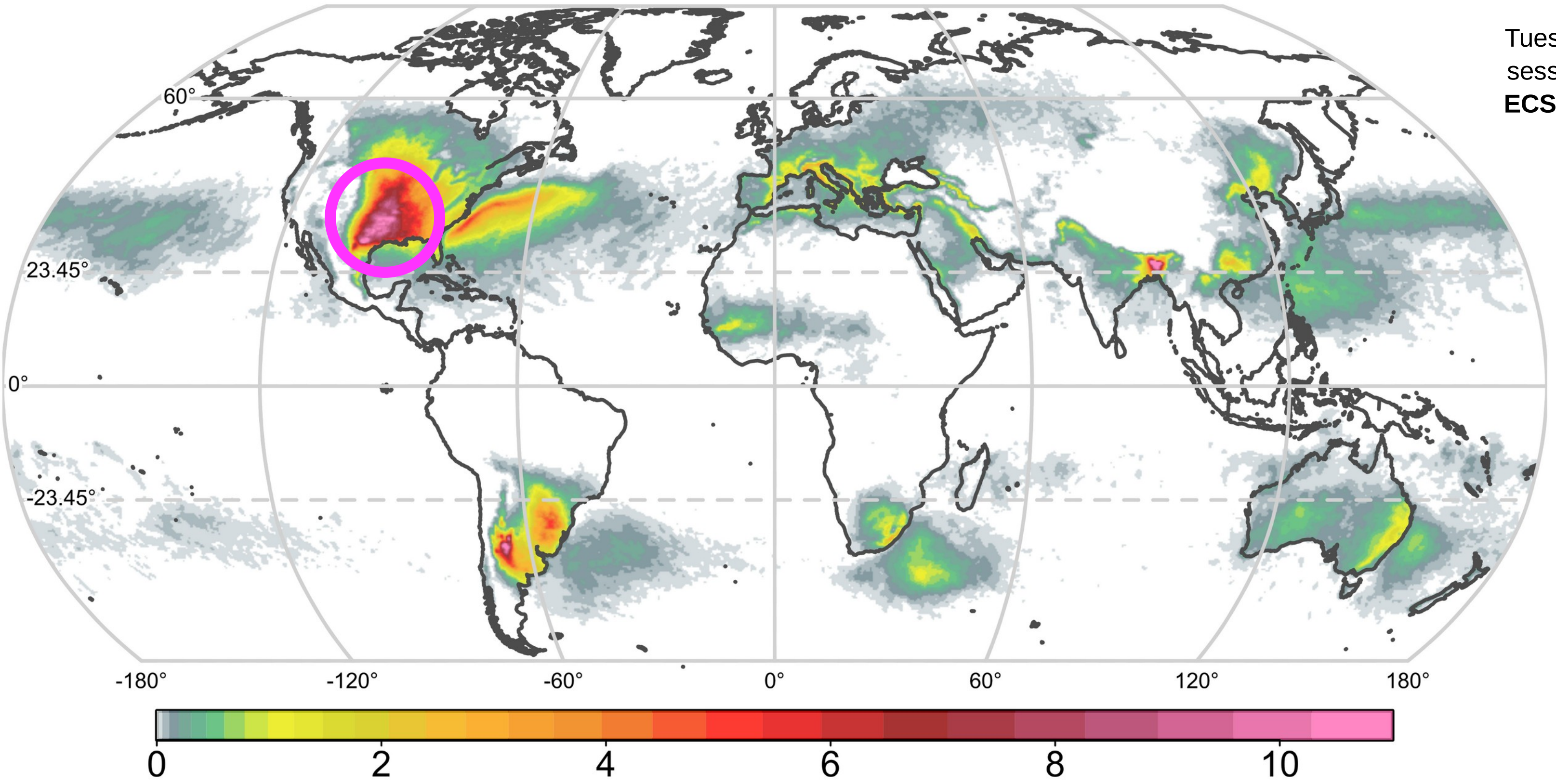


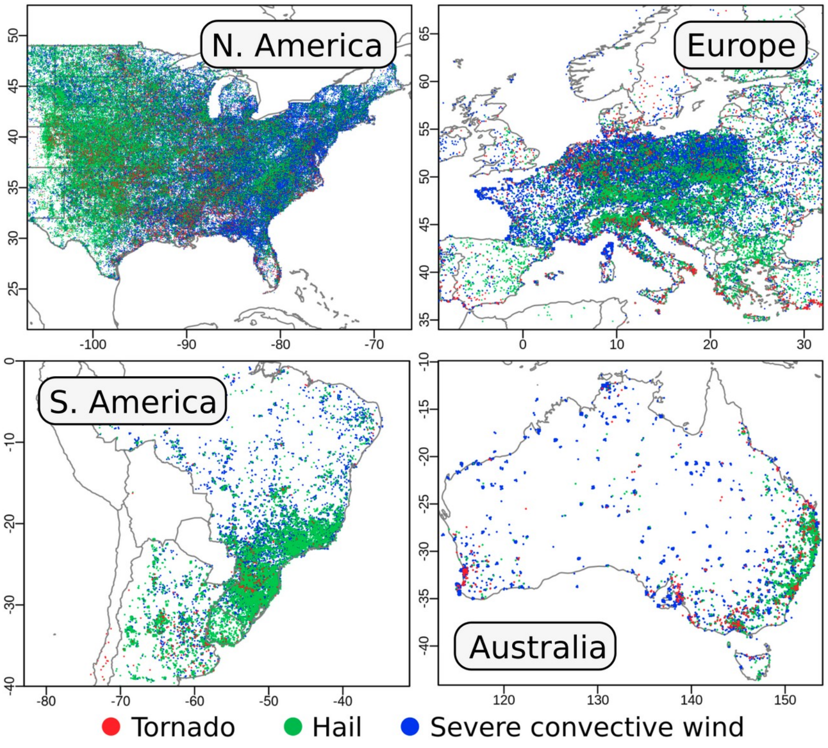
Tuesday poster session (P100)
ECSS2025-219

Datasets

Severe weather reports:

- N. America: SPC Storm Reports Database
- S. America: South American High-Impact Weather Reports Database
- Europe: European Severe Weather Database
- Australia: Storm Reports of Australian Bureau of Meteorology

Intercontinental severe weather **reports**



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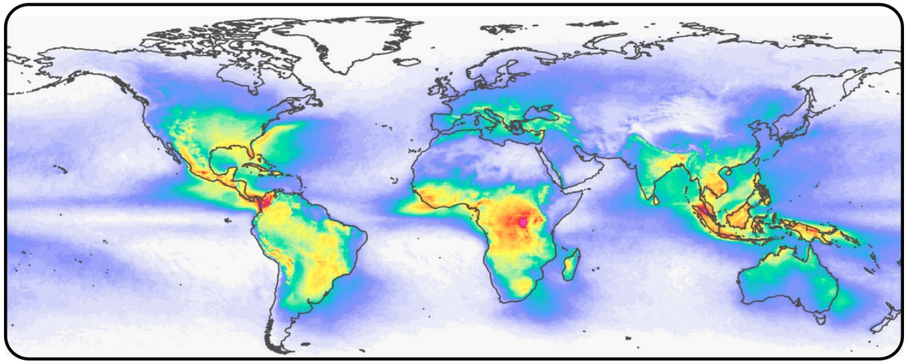
- Australia: Storm Reports of Australian Bureau of Meteorology

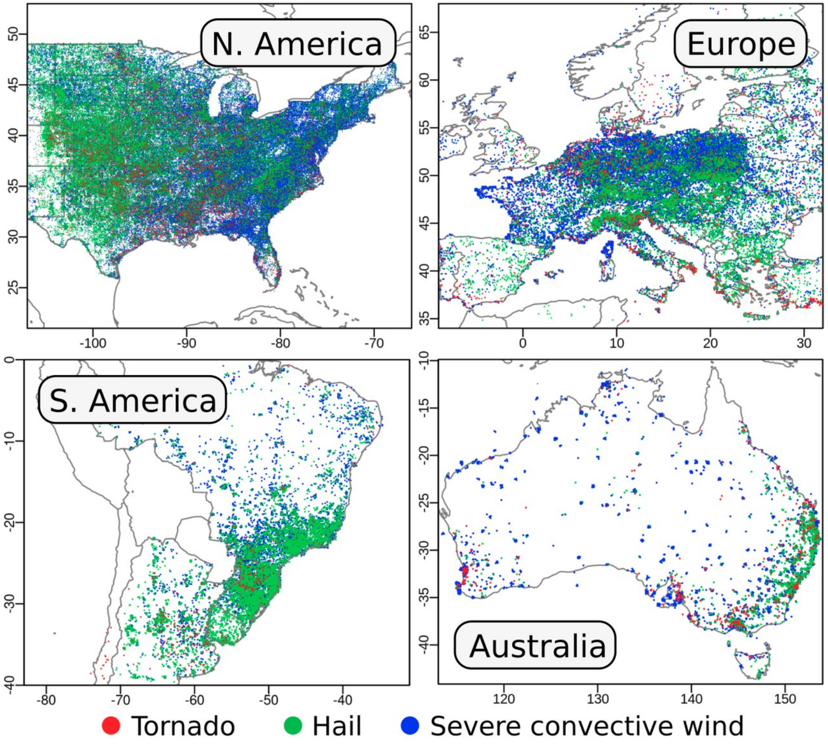
Global lightning data:

- Earth Networks Global Lightning Network

ENGLN global **lightning** observations

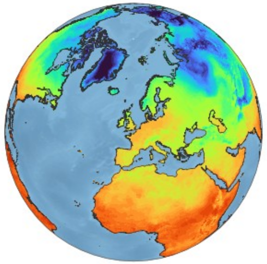


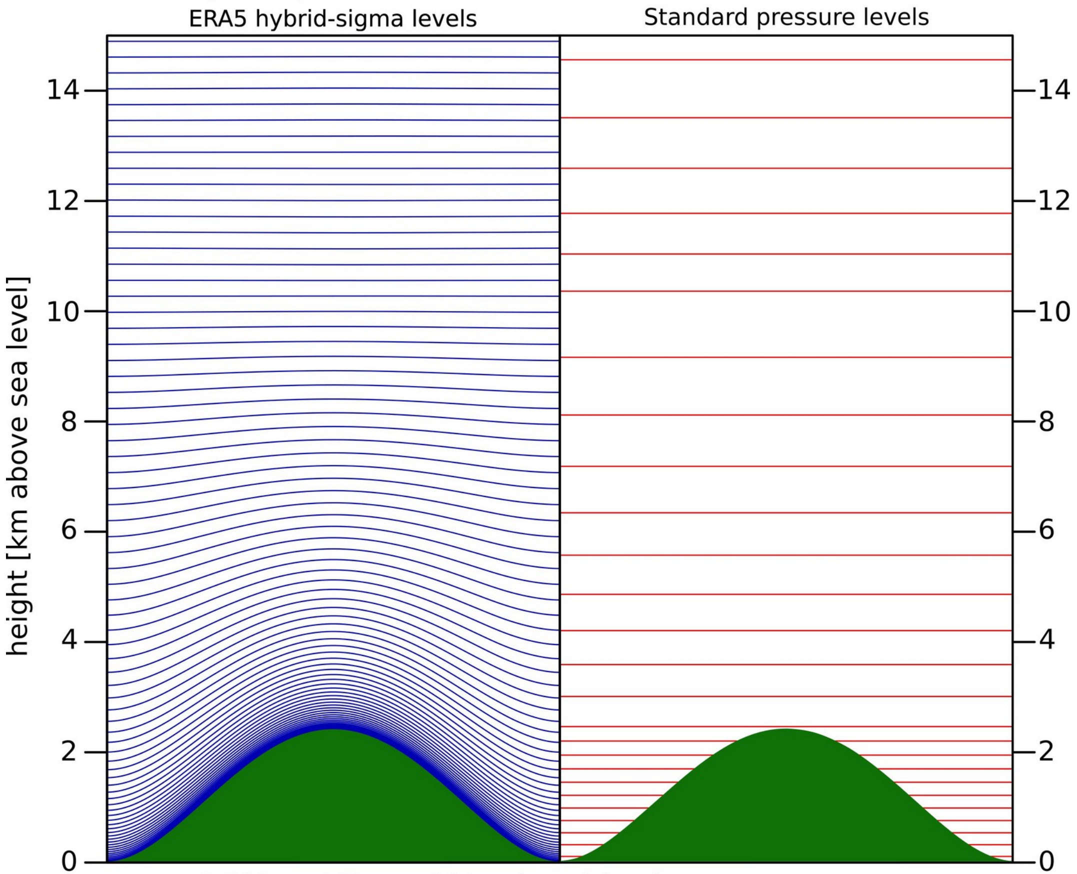
Intercontinental severe weather **reports**



ERA5 reanalysis

- hybrid-sigma levels
- 0.25° x 0.25°
- 1-hour step
- raw profiles of z, p, q, t, u, v





0-500m AGL : 14 levels vs 2 levels
0-1000m AGL : 21 levels vs 5 levels
0-2000m AGL : 28 levels vs 9 levels
(considering mean sea level)

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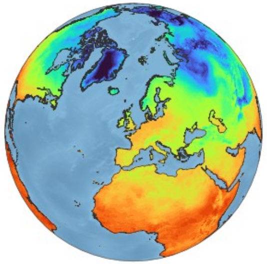
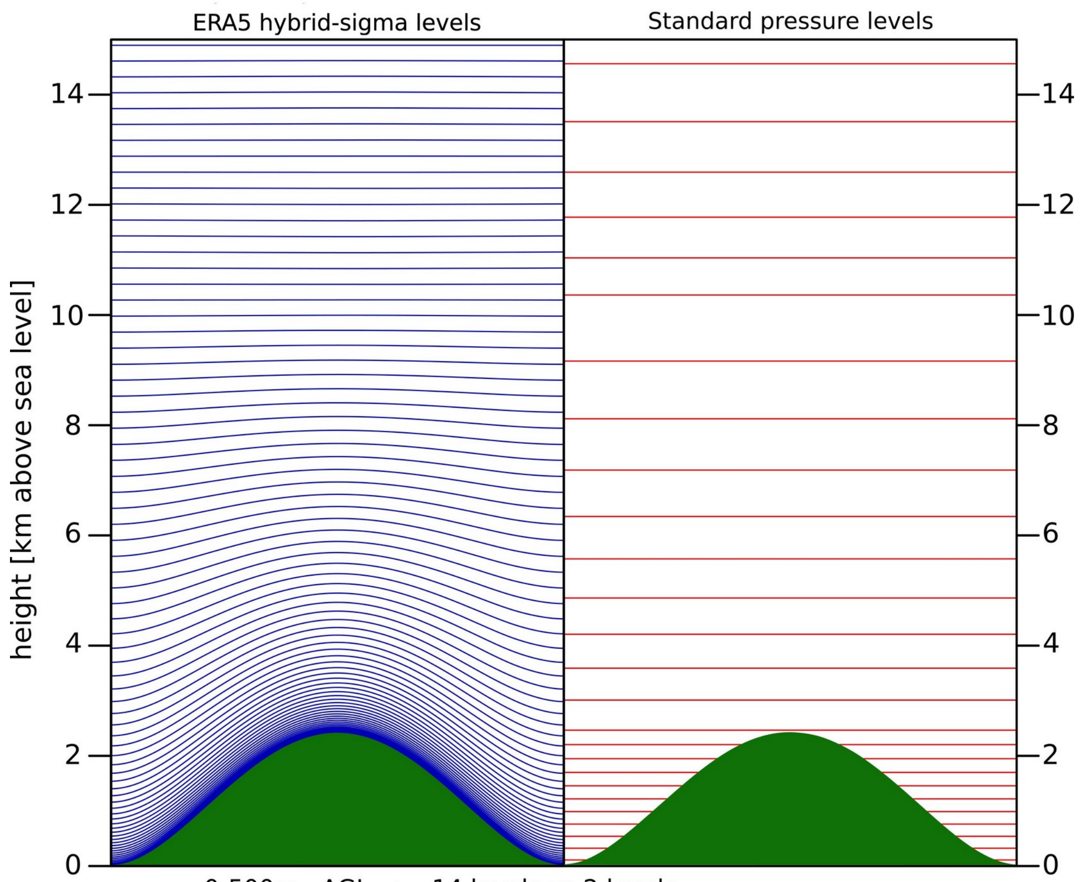


thundeR
rawinsonde package

700+
convective parameters



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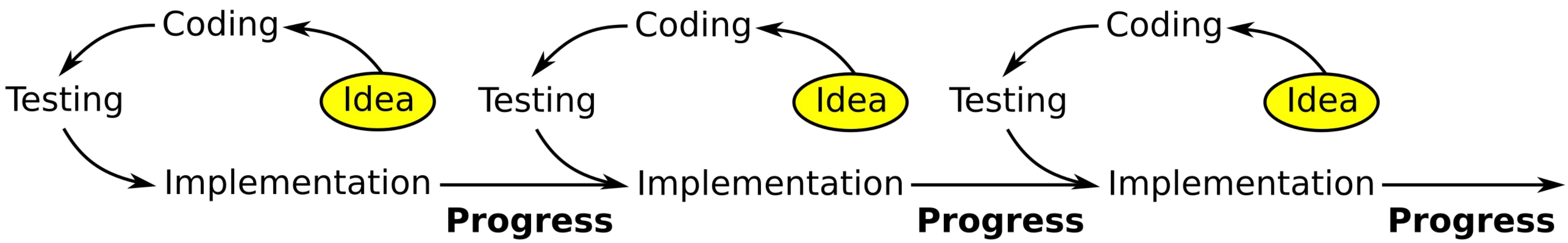
Once the multi-continental dataset was complete, it enabled rapid, iterative testing of new concepts



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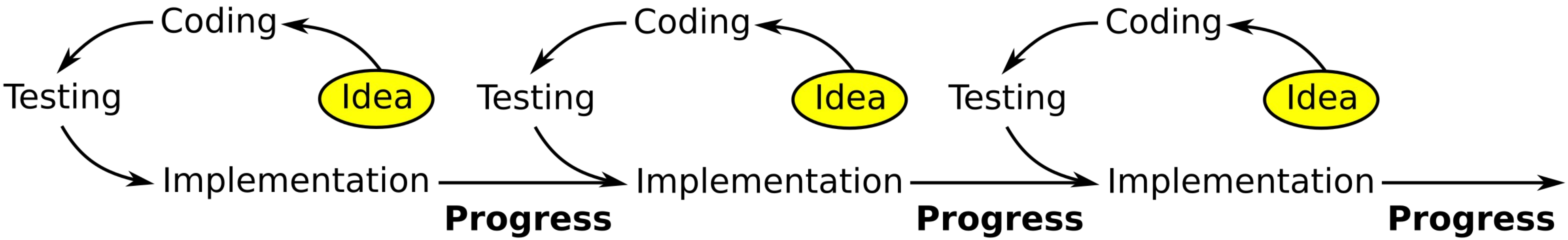
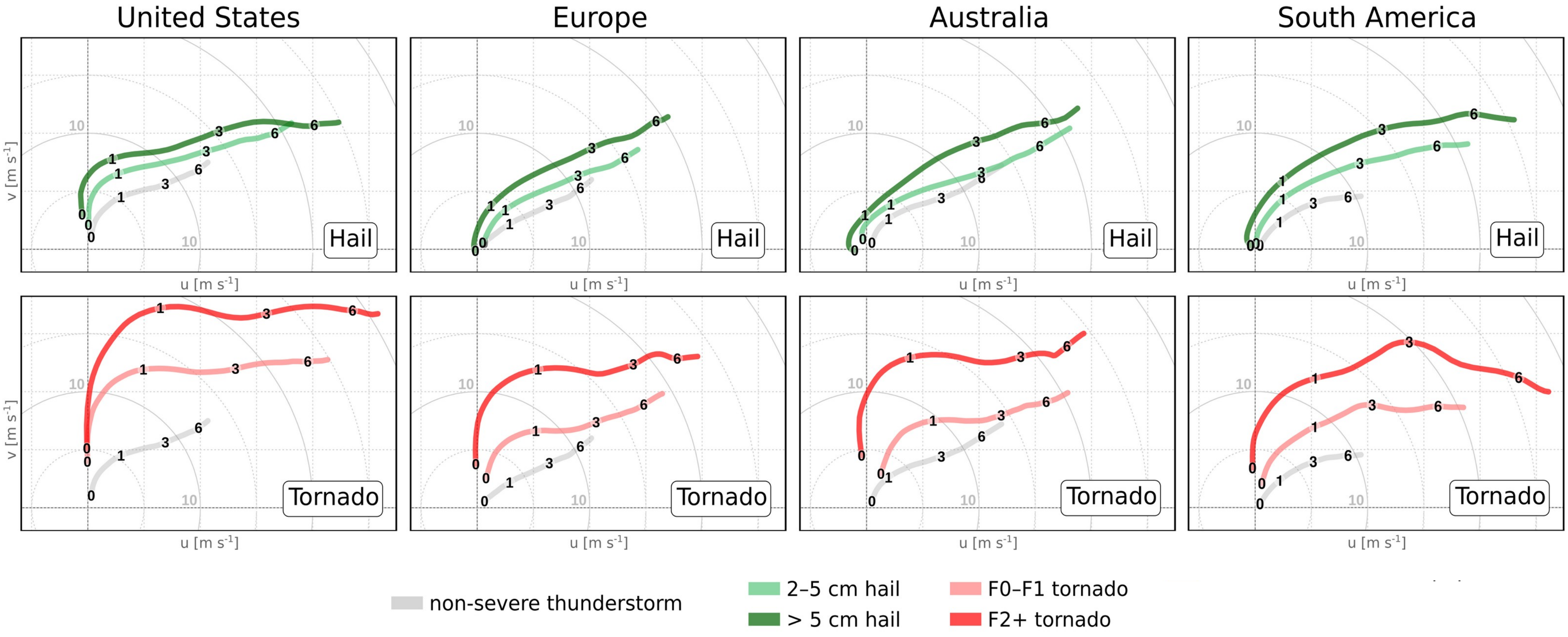


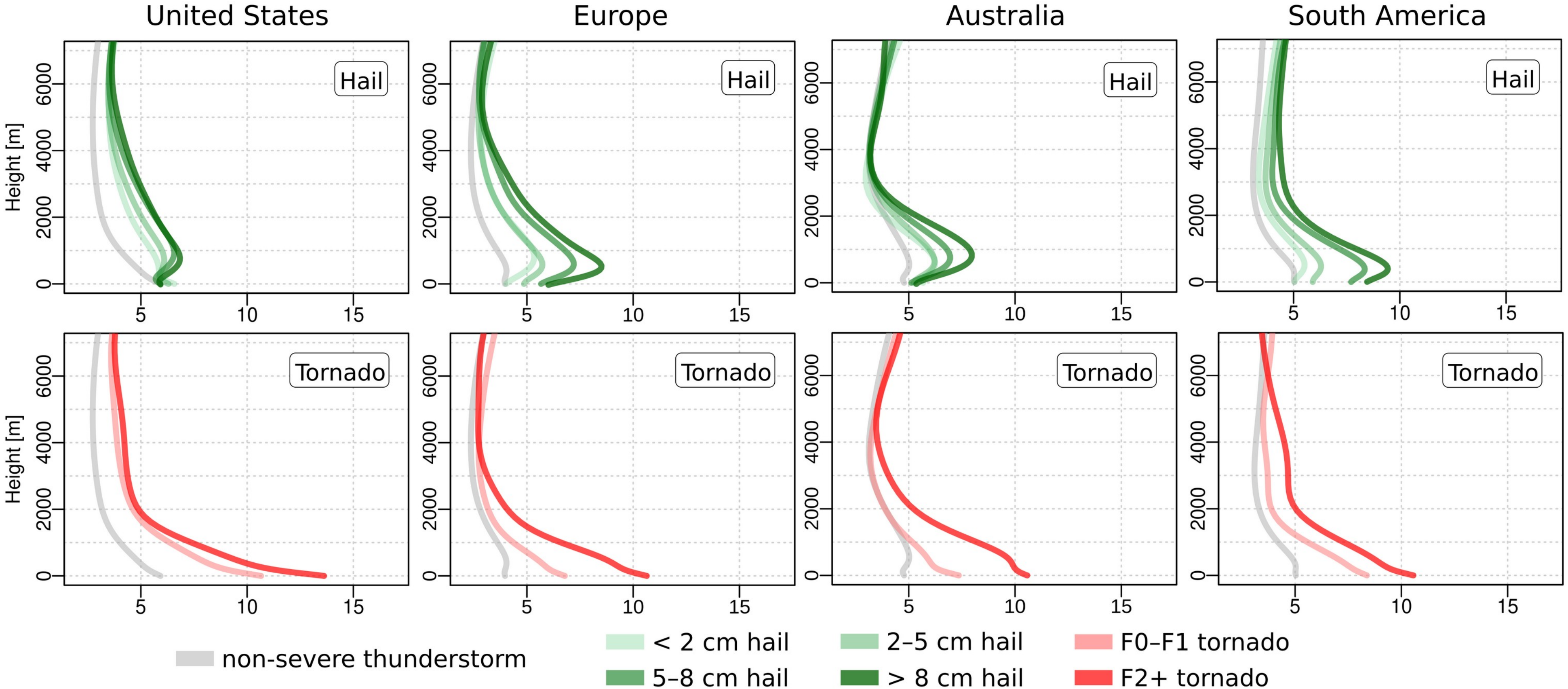
Among dozens of tested ideas, only several led
to improvements in the skill of parameters.

Results

Mean hodographs



Vertical profile of bulk wind shear (1 km moving window)



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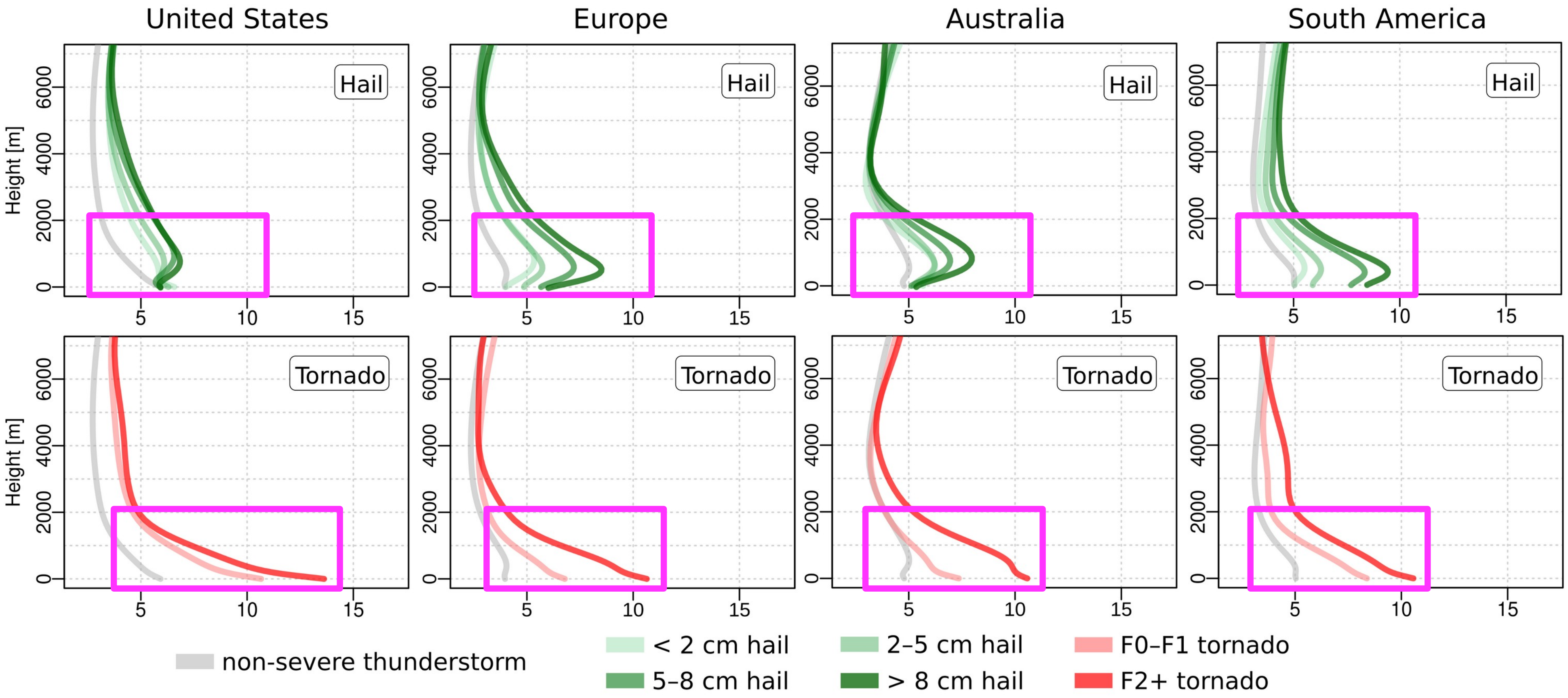
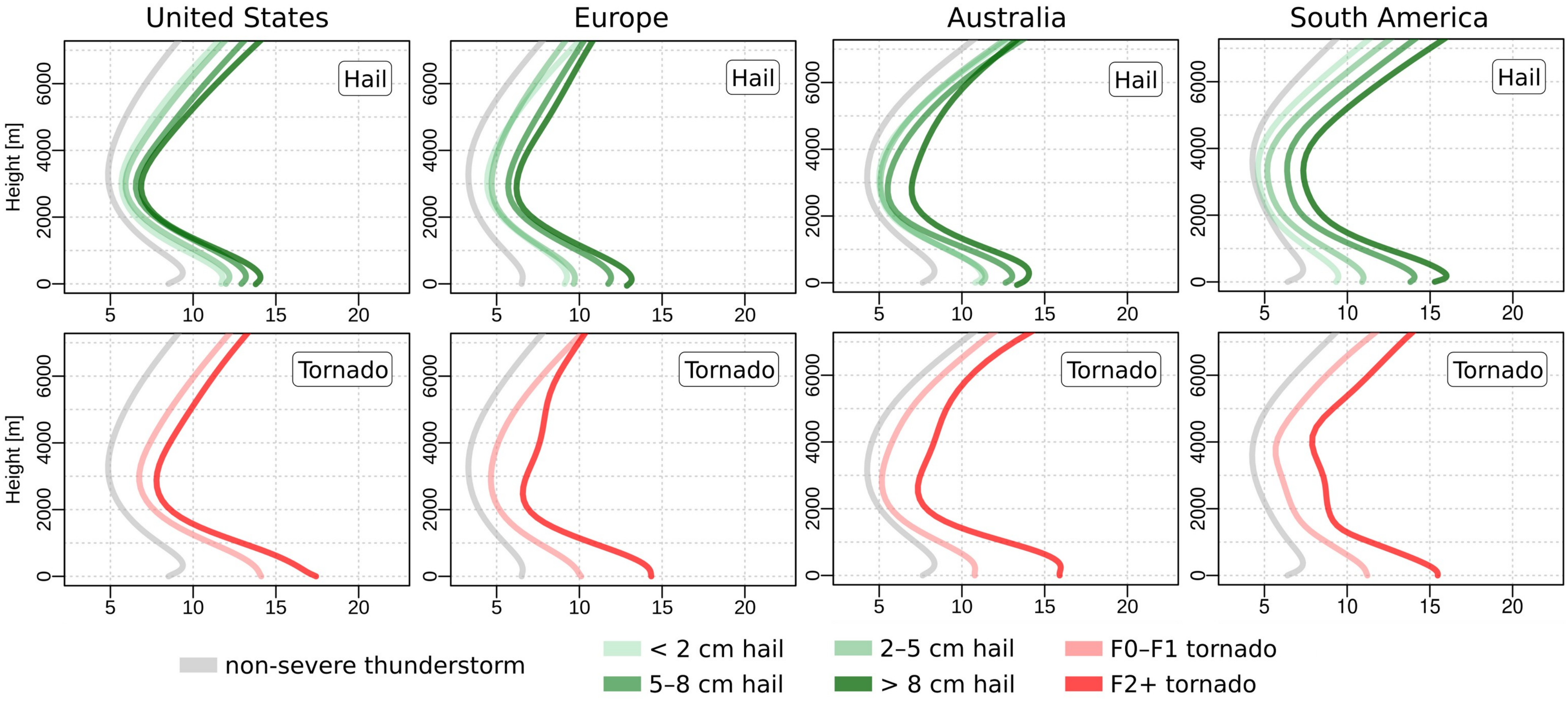


Vertical profile of storm-relative wind



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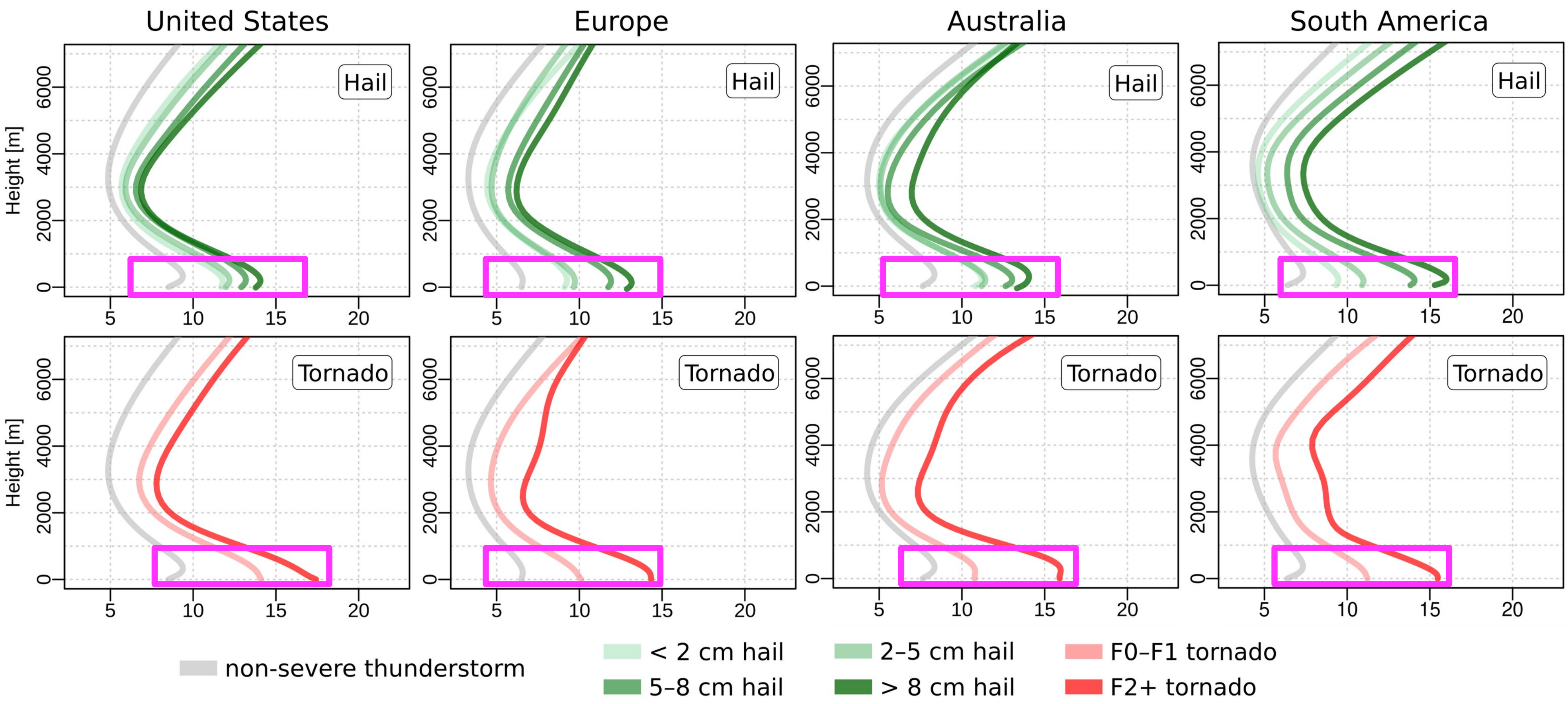
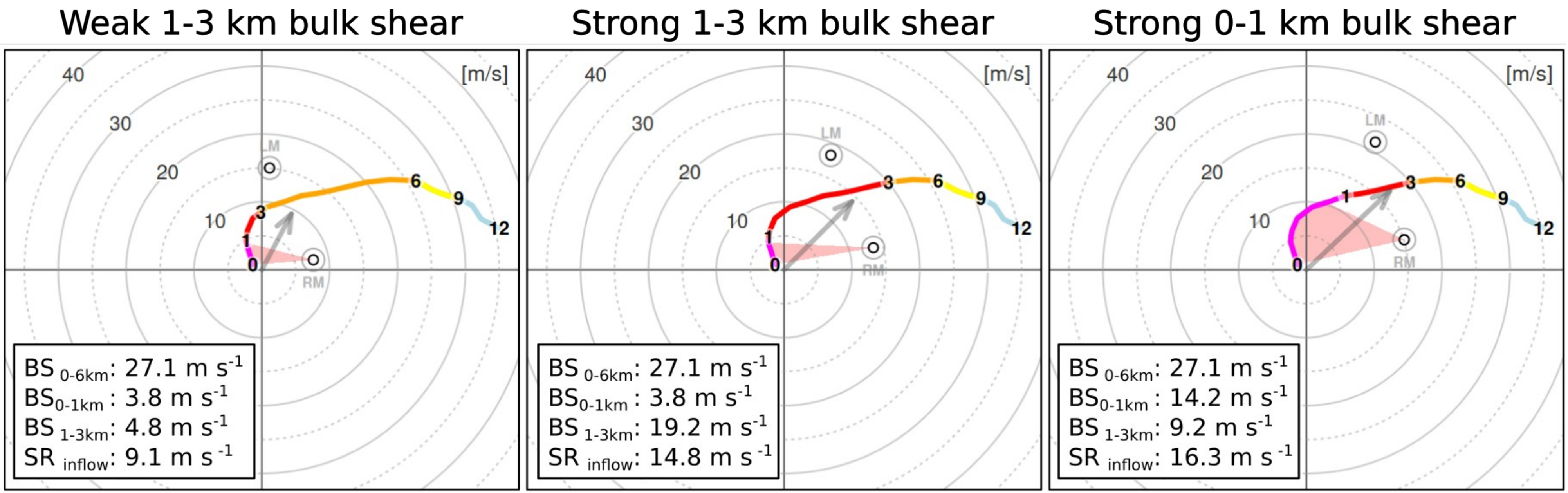


All 3 profiles have identical shape and 0-6 km shear but different low- and mid-level shear.



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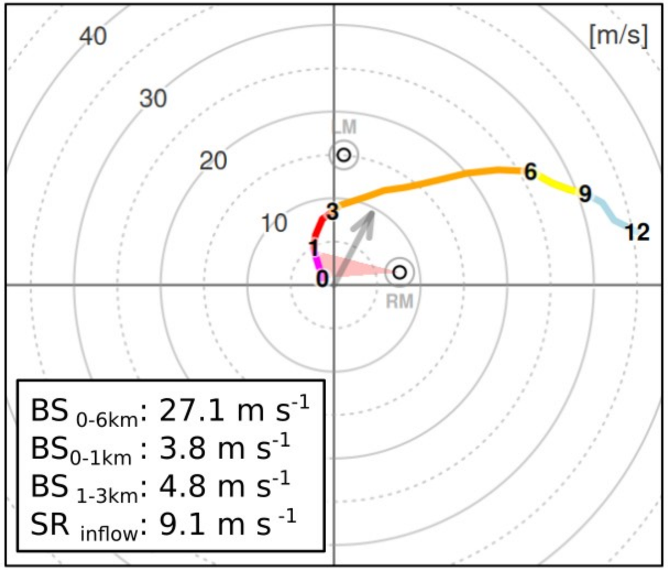

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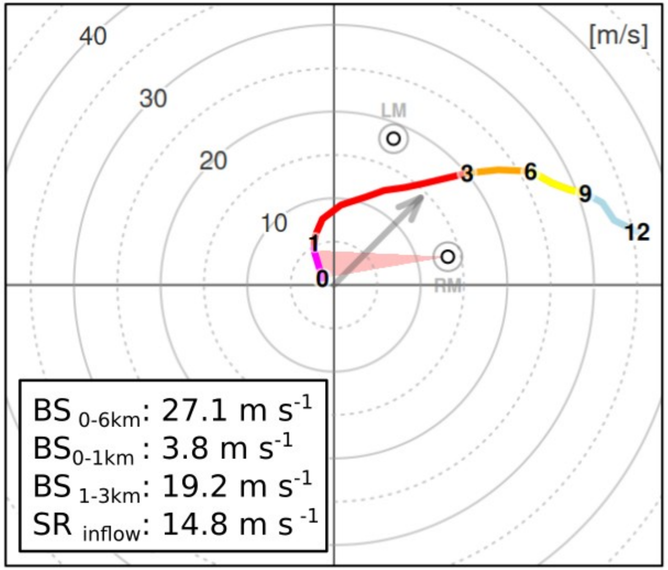
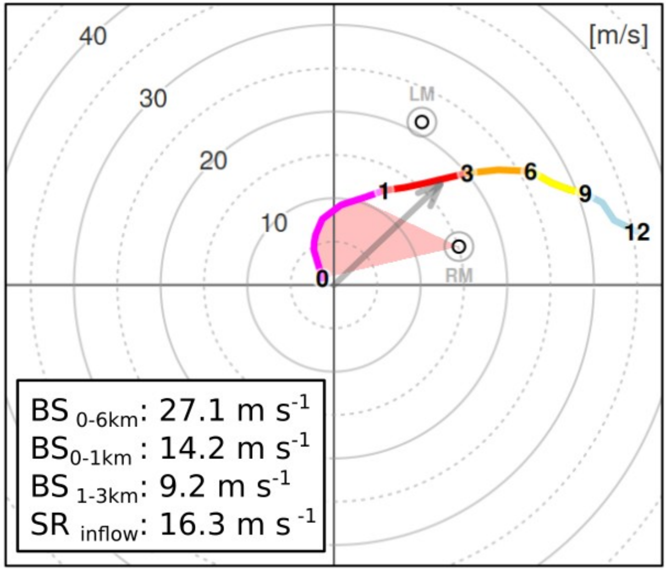


Strong 0-1 km bulk shear



Weak LL SRH (good)

Weak LL SR-wind (bad)

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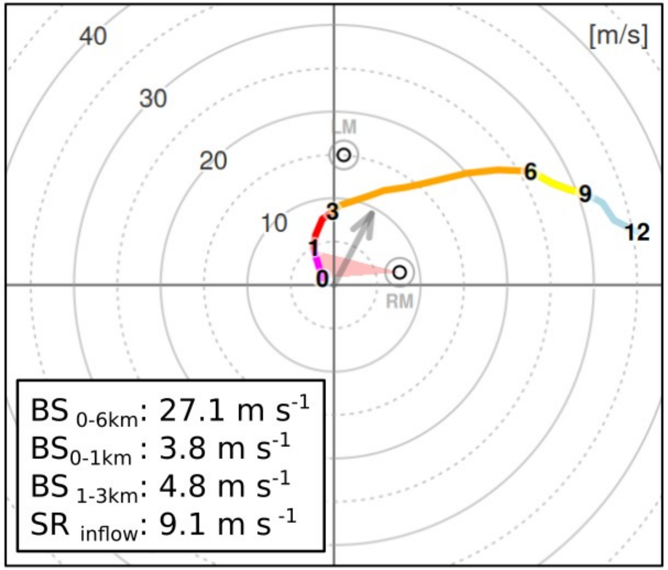

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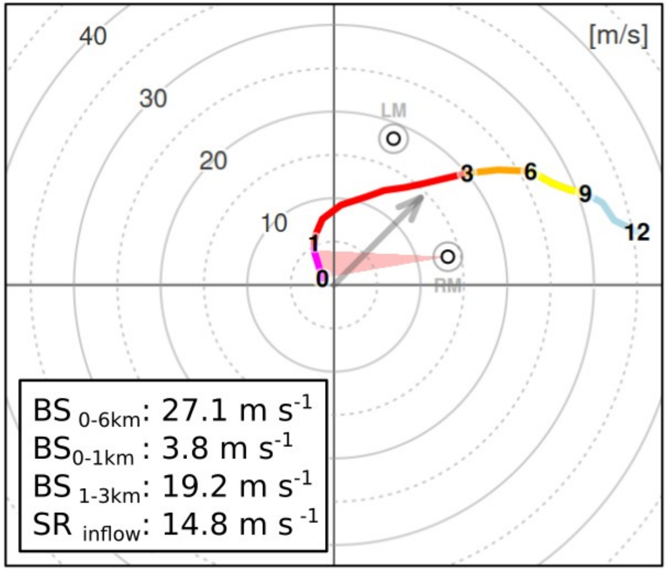

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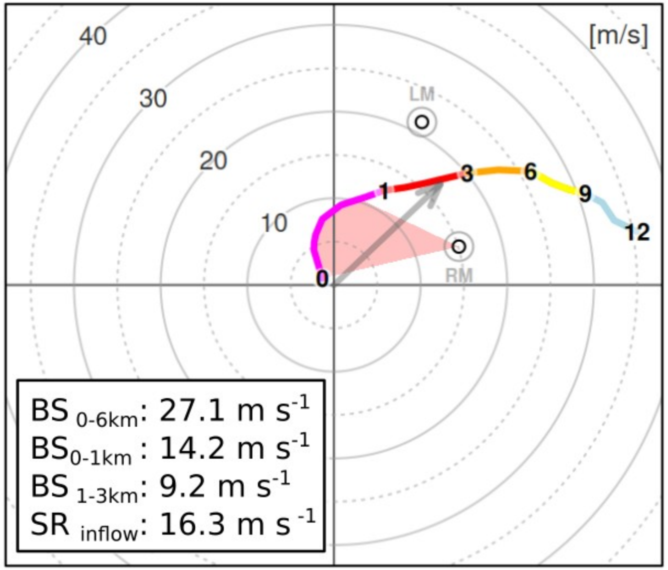

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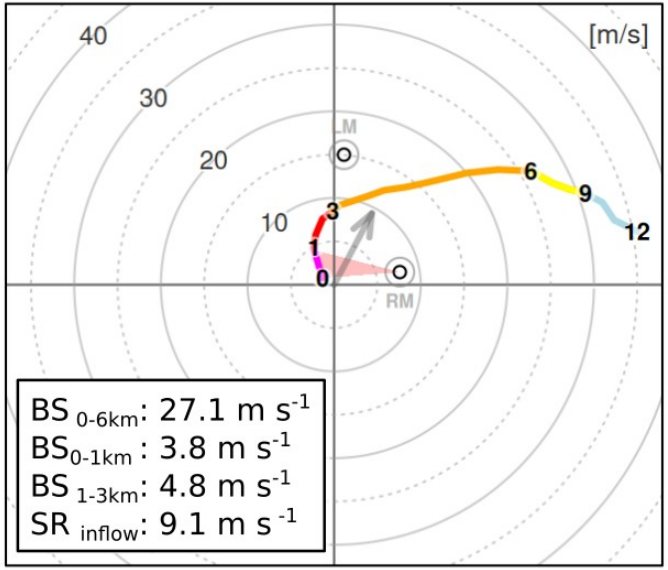

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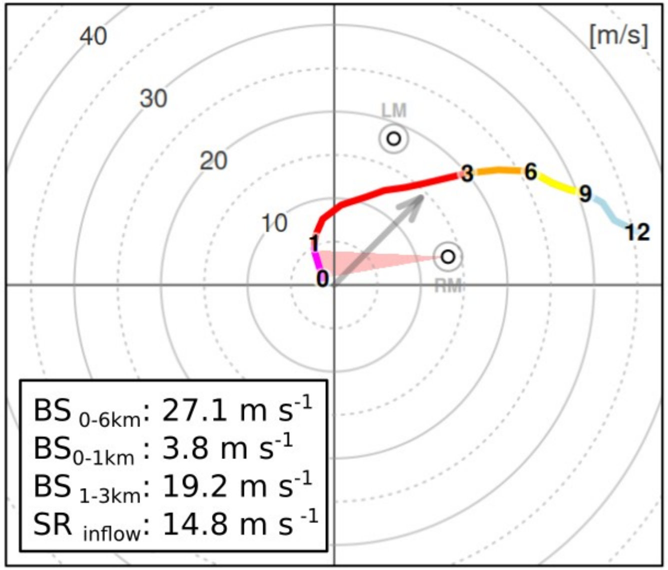

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Strong LL SR-wind (good)

Winner!

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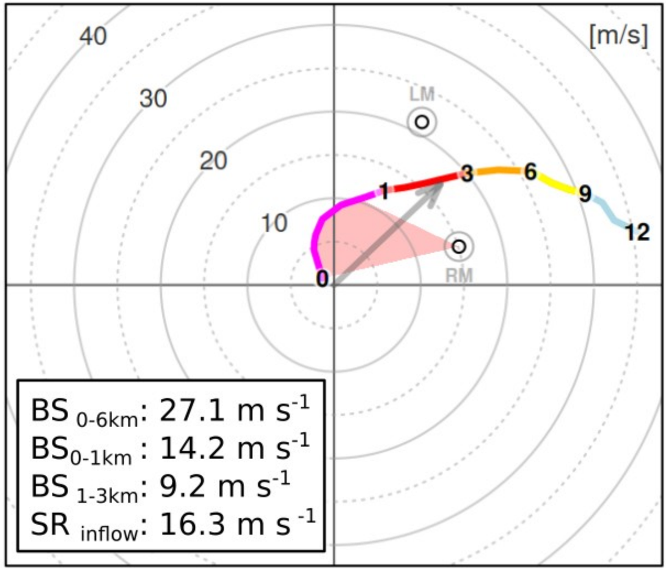

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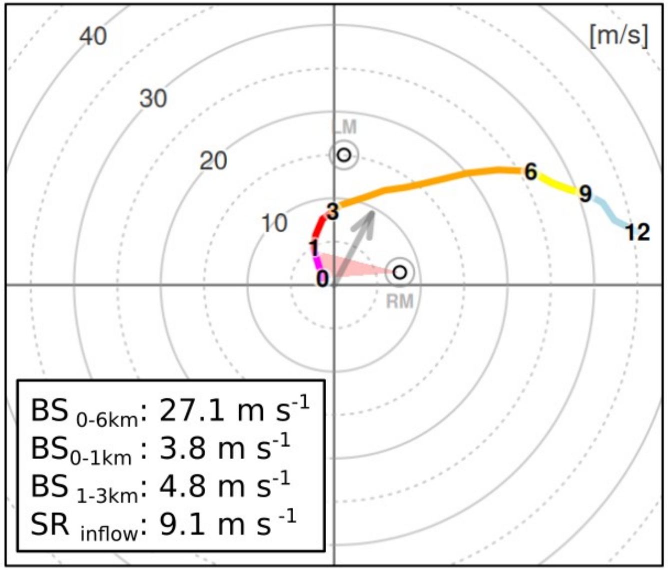

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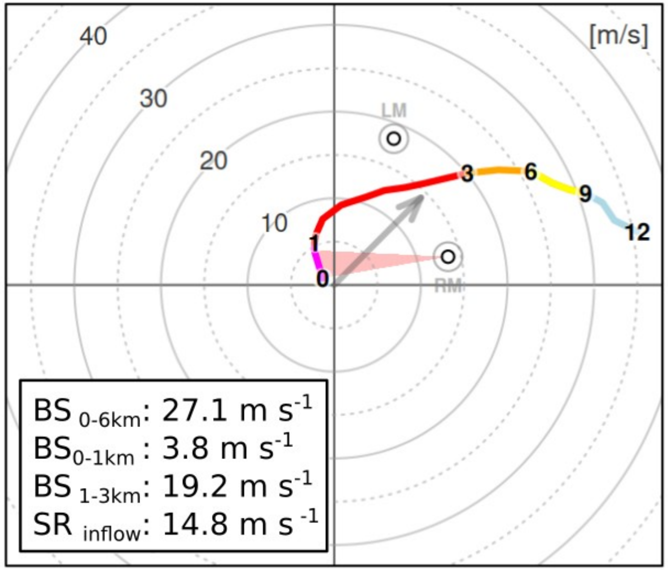

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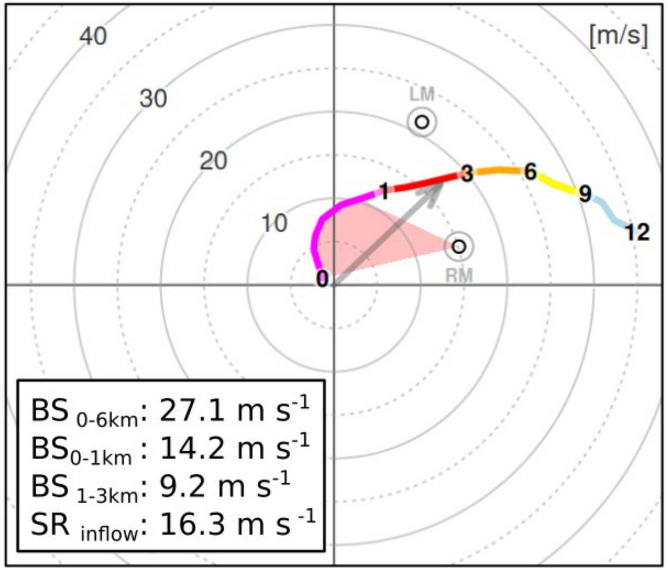

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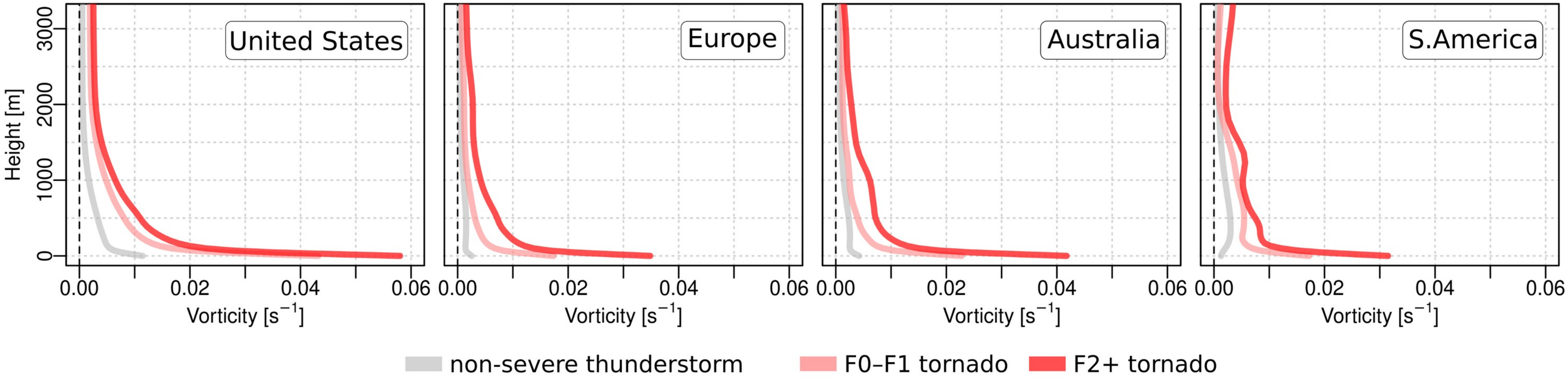
Vertical profile of streamwise vorticity



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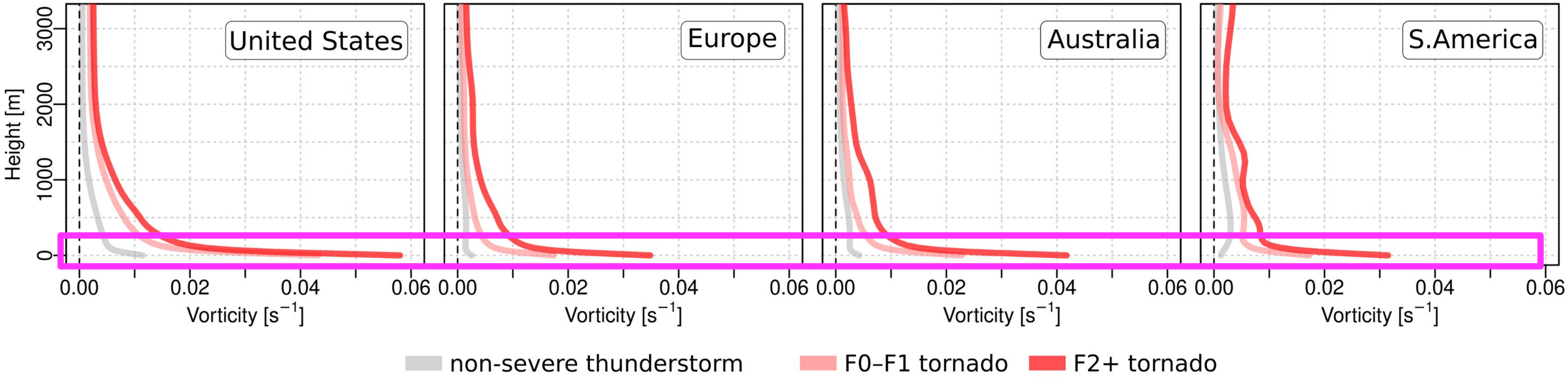
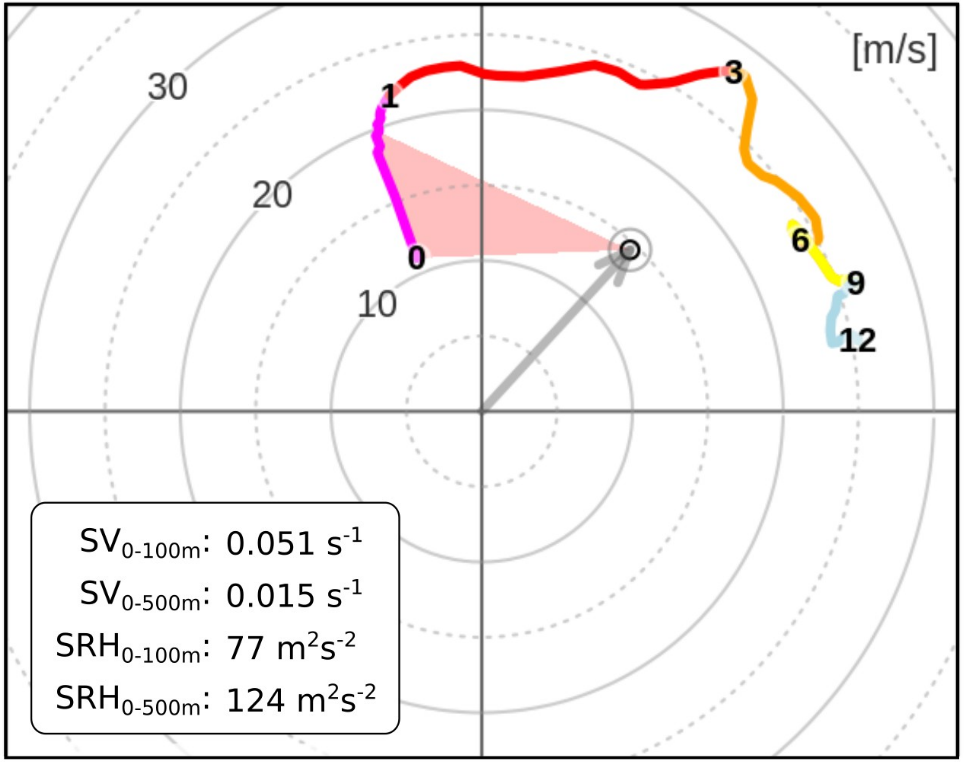


Most of the signal is right **near the ground**

Pre-convective wind profile for F4 tornado in Pilger (Nebraska) on 16 June 2014

No correction



$SV_{0\text{-}100m}$: 0.051 s^{-1}
$SV_{0\text{-}500m}$: 0.015 s^{-1}
$SRH_{0\text{-}100m}$: 77 m^2s^{-2}
$SRH_{0\text{-}500m}$: 124 m^2s^{-2}

Pre-convective wind profile for F4 tornado in Pilger (Nebraska) on 16 June 2014

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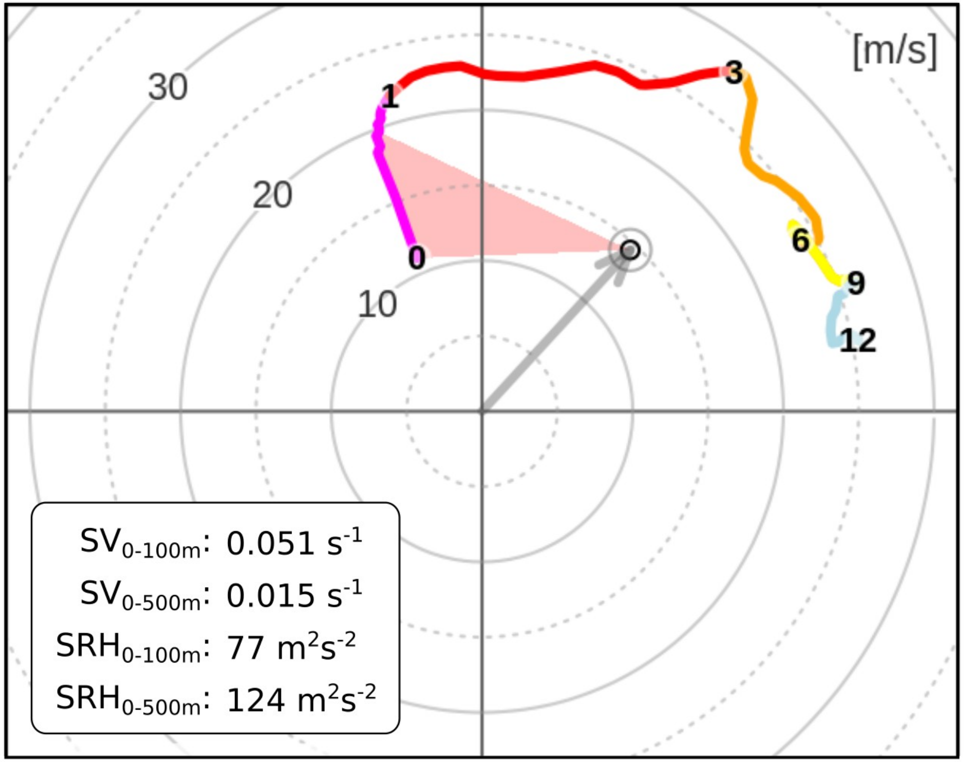
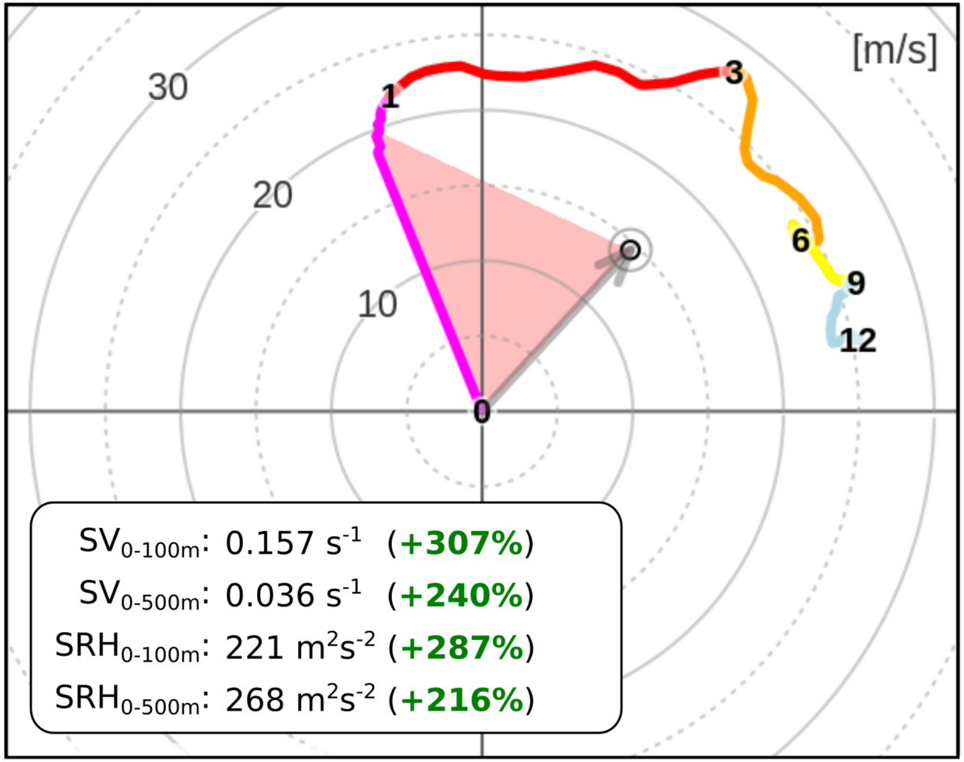


Hodograph extension



Can this correction improve prediction of tornadoes?

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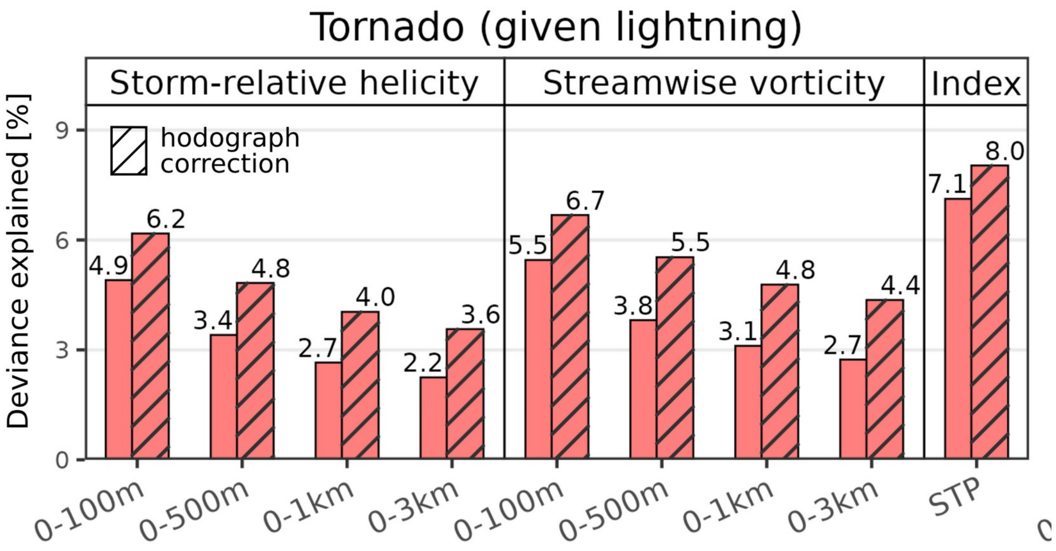
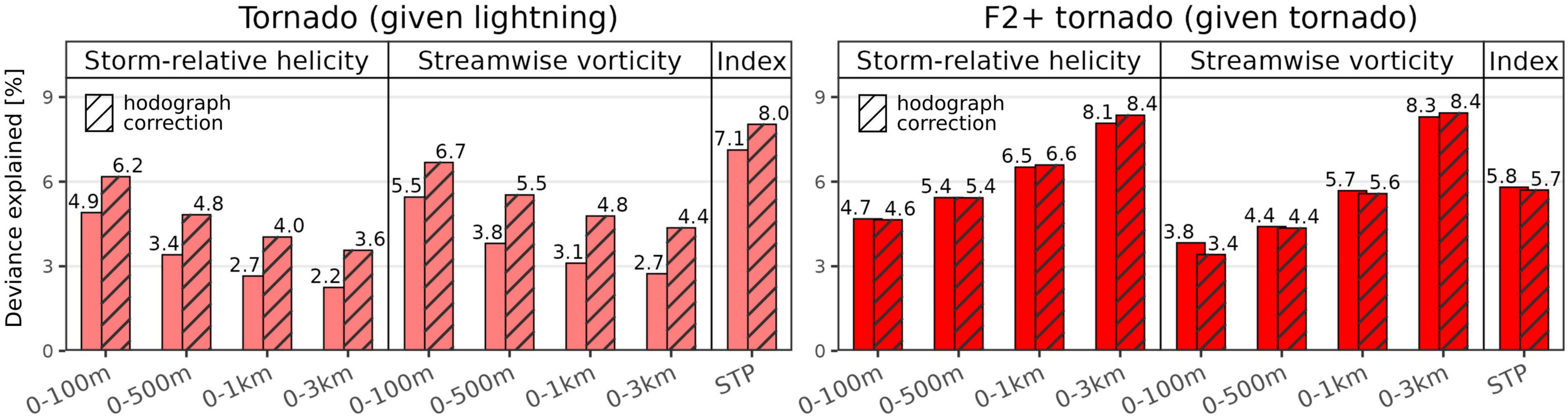
Yes!



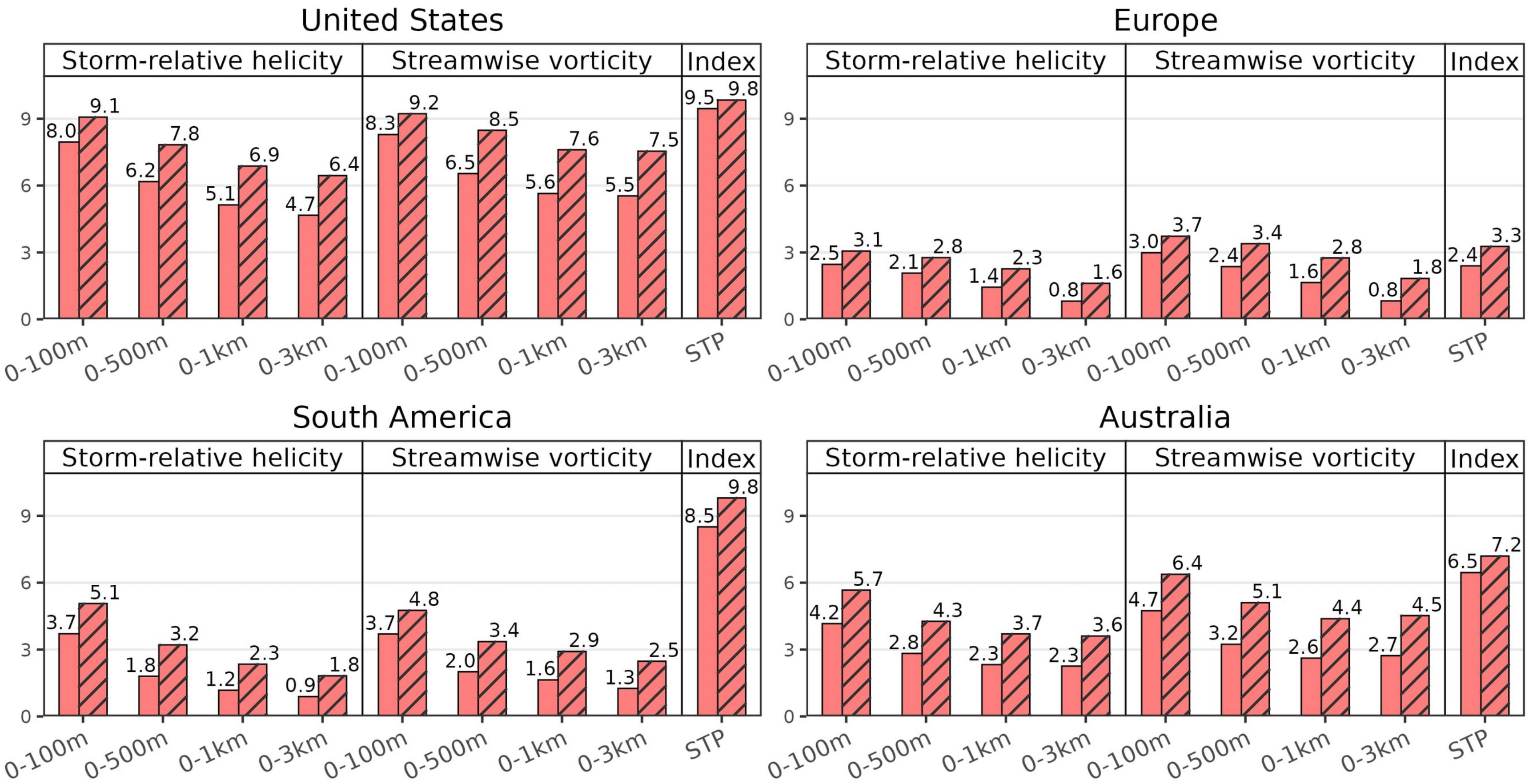
Can this correction improve prediction of tornadoes?

Yes!

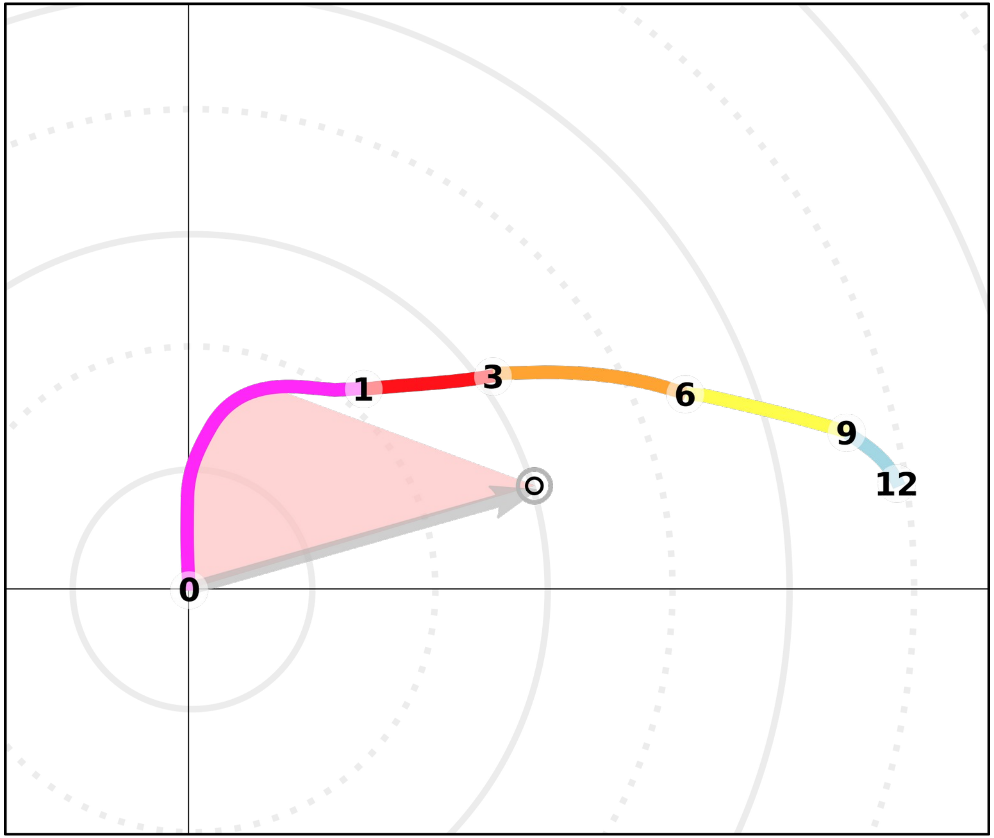
but...

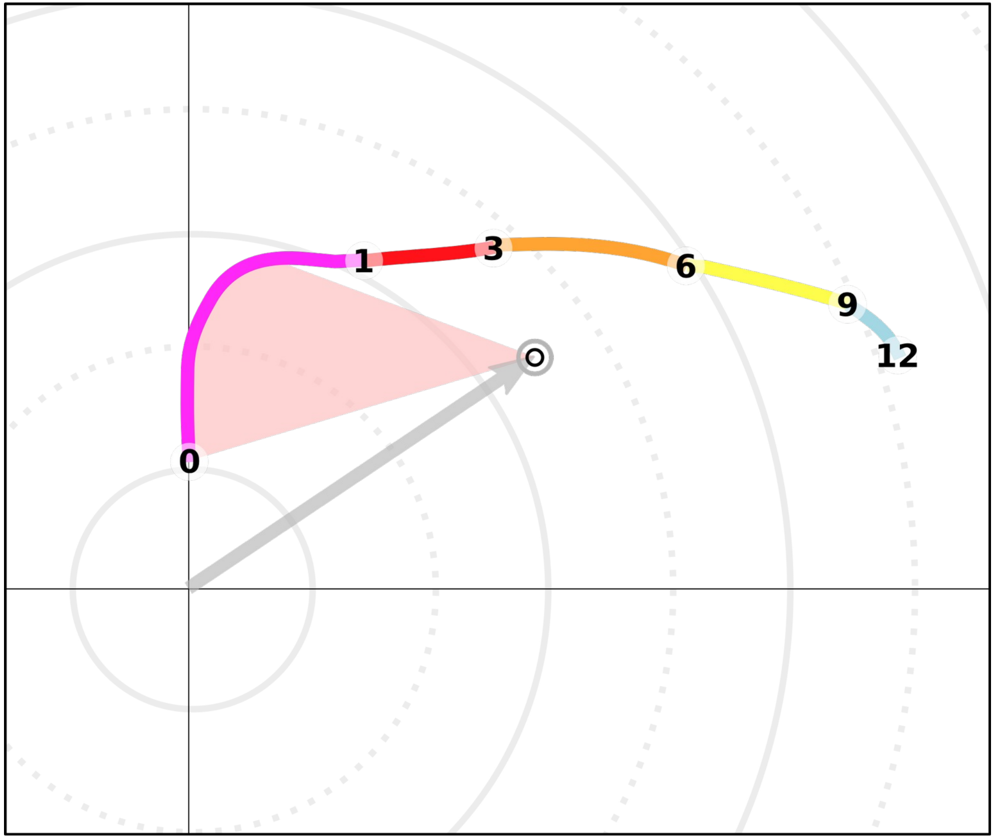


Result consistent on all 4 continents (extension improves skill)



Hodographs with **identical shear** and storm-relative wind but different **ground-relative winds**





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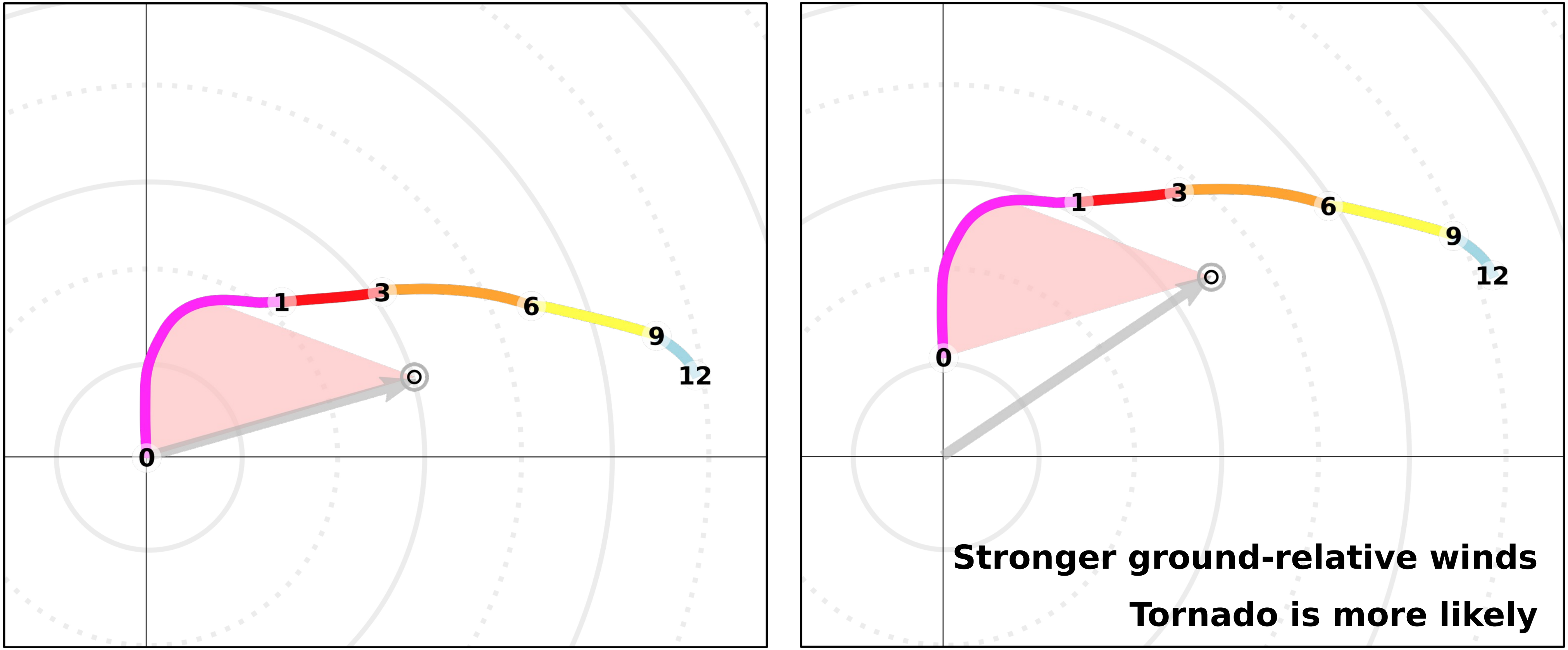
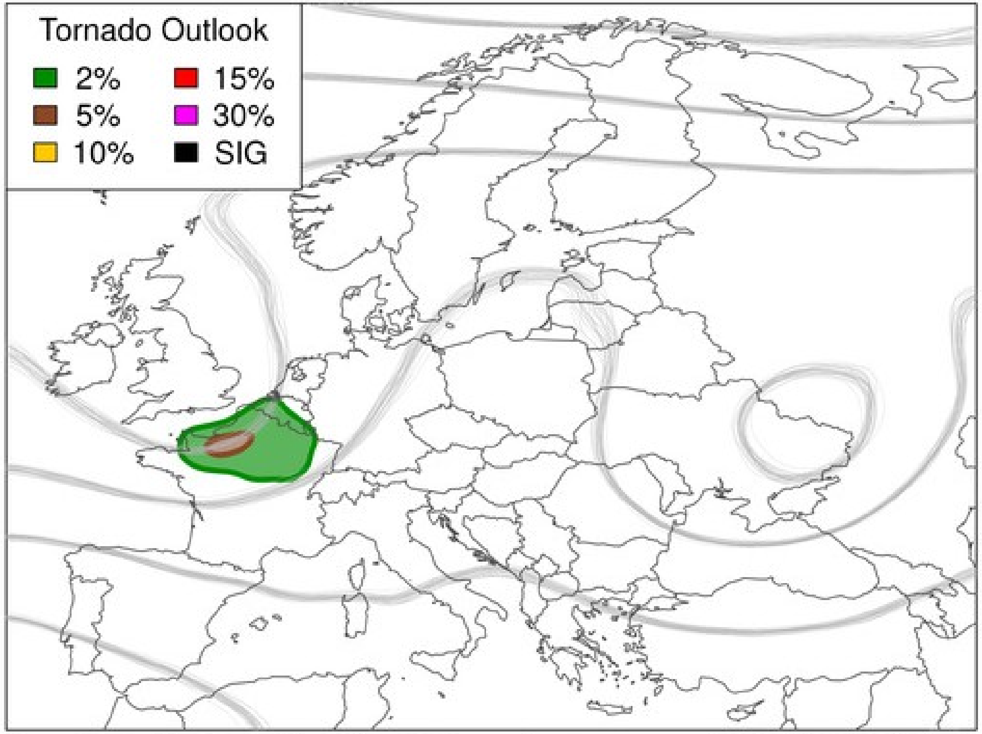


Hodograph extension results have been implemented in **ASTORP** convective outlooks

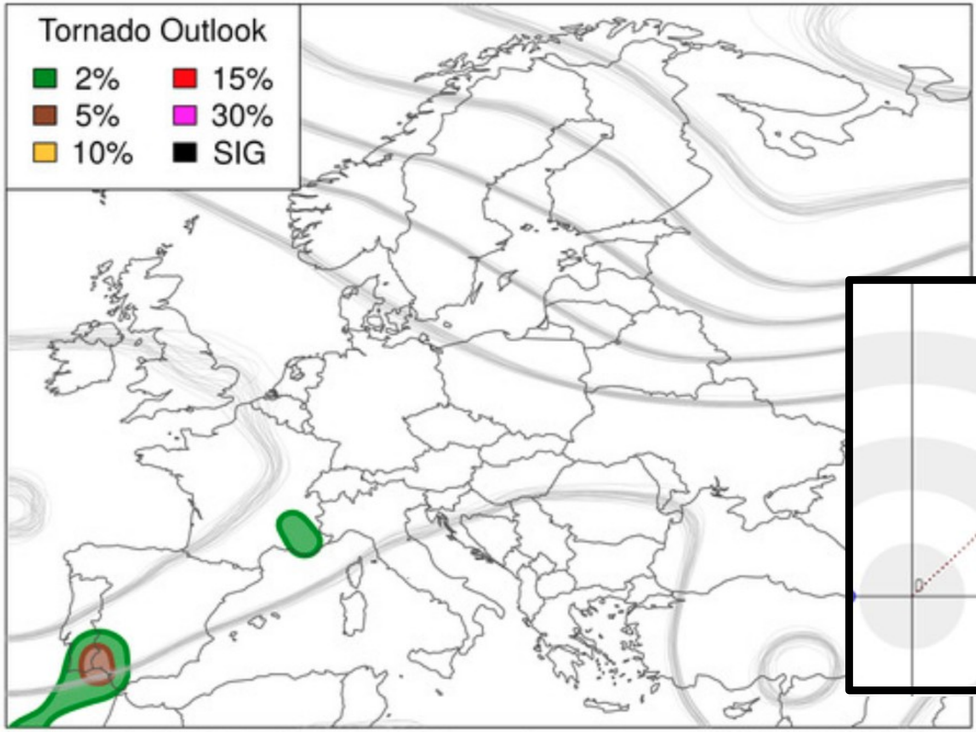
Automated **tornado outlook** for 20 Oct 25 (15Z-18Z)



EF2 tornado in France on 20 Oct 2025 ~ 17Z
(Keraunos Observatorie)

Hodograph extension results have been implemented in **ASTORP** convective outlooks

Automated **tornado outlook** for 15 Nov 25 (12Z-15Z)



Source: x.com/Djpuco

Strong tornado in S. Portugal (15 Nov 2025)

Key takeaways

Hail

→ Weak low-level bulk shear

→ Peak bulk shear around 1-3 km / 1-4 km

Tornadoes

→ Strong low-level SRH + strong ground-relative winds

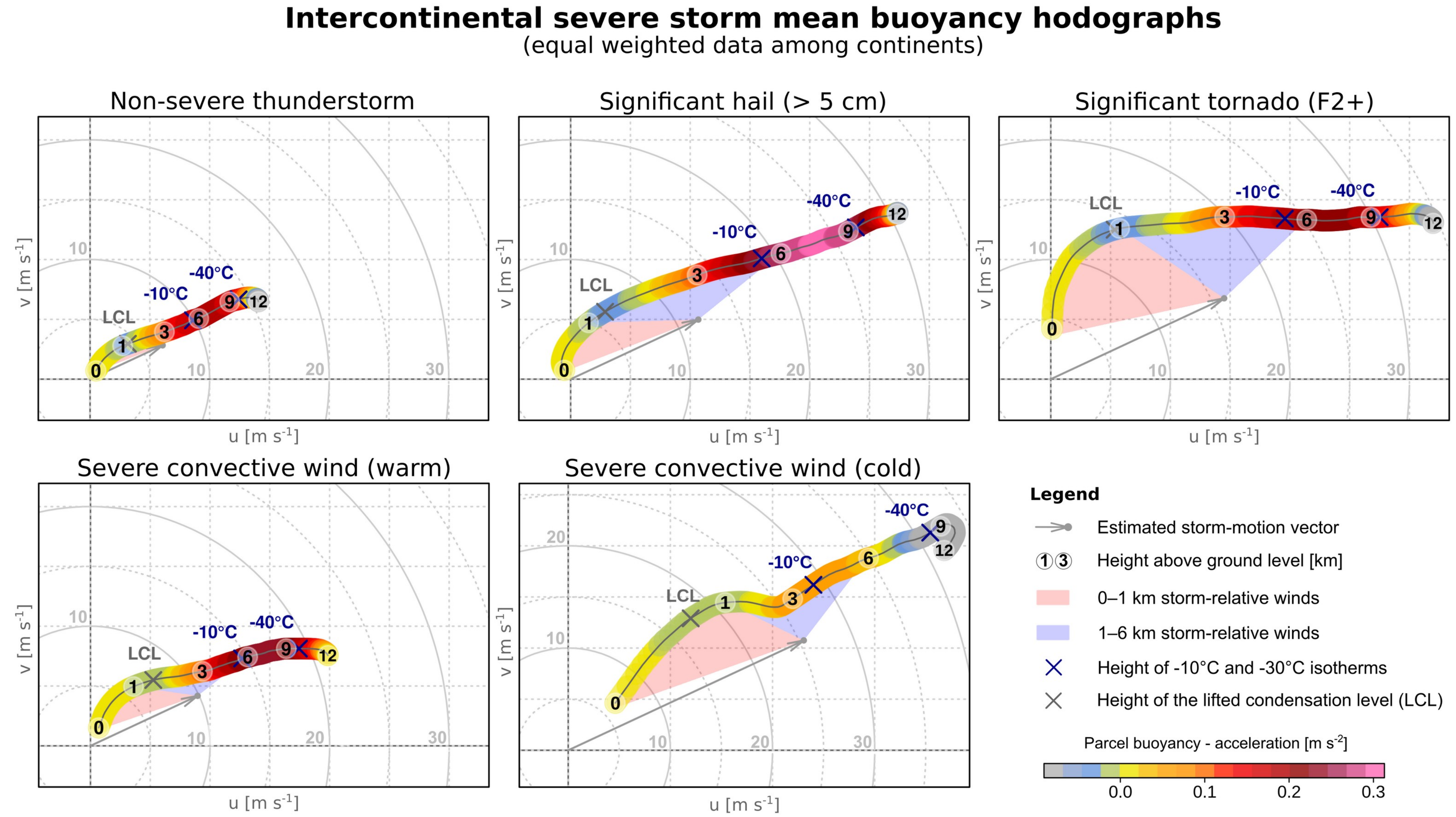
→ Hodograph extension improves skill

ThundeR v1.5 (upcoming)

→ 300+ revised & new convective parameter

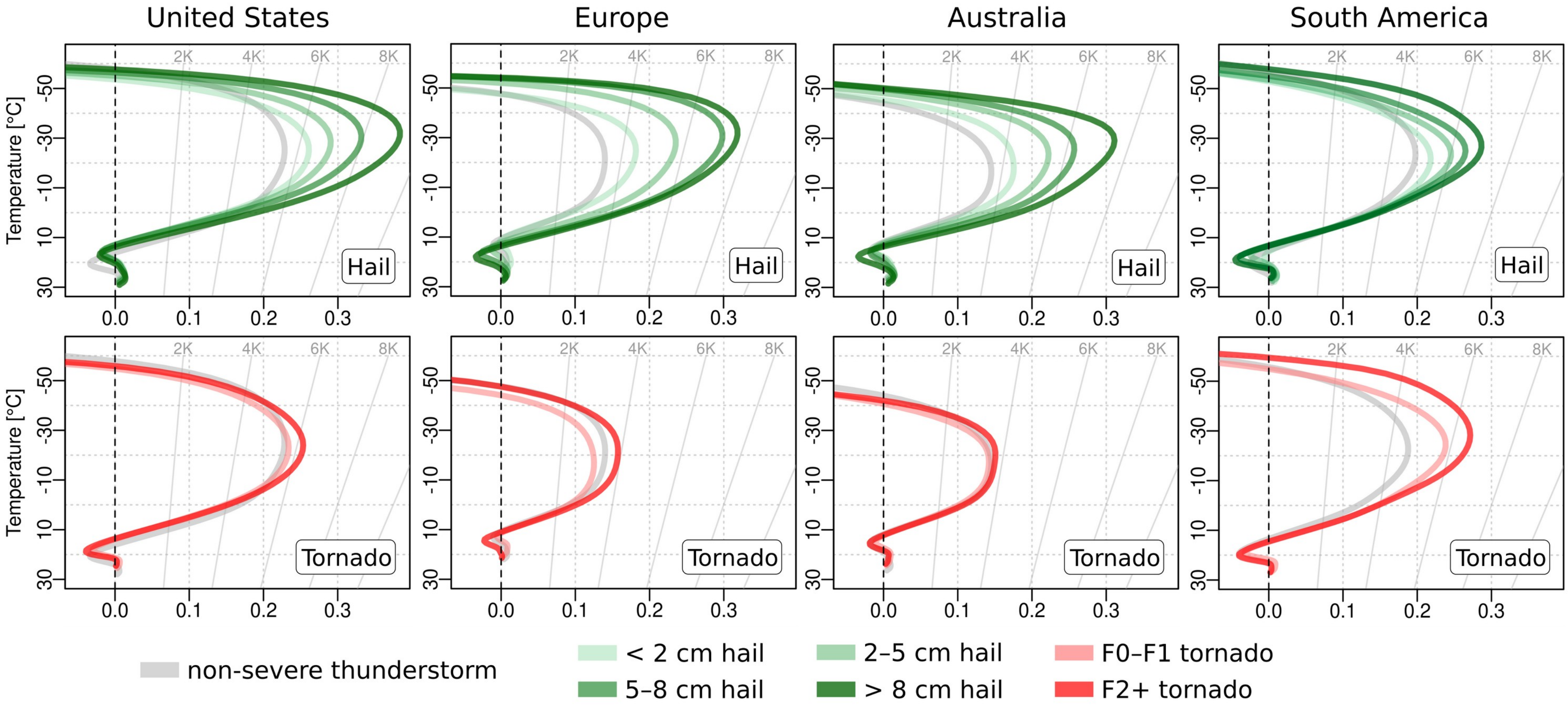
Thank you for your attention!

Mateusz Taszarek
tornado@amu.edu.pl
Department of Meteorology and Climatology, Adam Mickiewicz University
Poznań, Poland

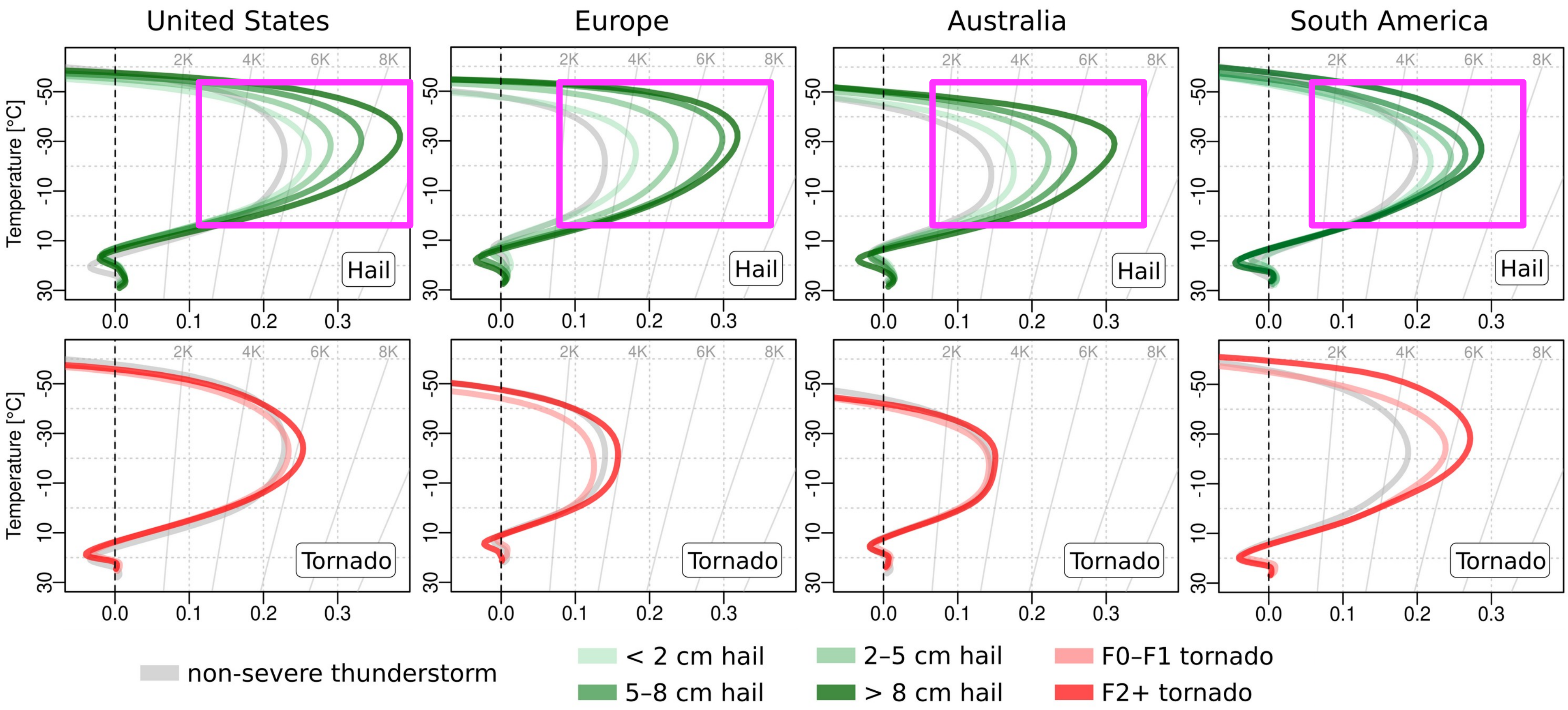


Intercontinental severe storm mean buoyancy hodographs
(equal weighted data among continents)
Non-severe thunderstorm
Significant hail (> 5 cm)
Significant tornado (F2+)
Severe convective wind (warm)
Severe convective wind (cold)
LCL
-10°C
-40°C
v [m s-1]
u [m s-1]
Legend
Estimated storm-motion vector
Height above ground level [km]
0–1 km storm-relative winds
1–6 km storm-relative winds
Height of -10°C and -30°C isotherms
Height of the lifted condensation level (LCL)
Parcel buoyancy - acceleration [m s-2]
0.0
0.1
0.2
0.3

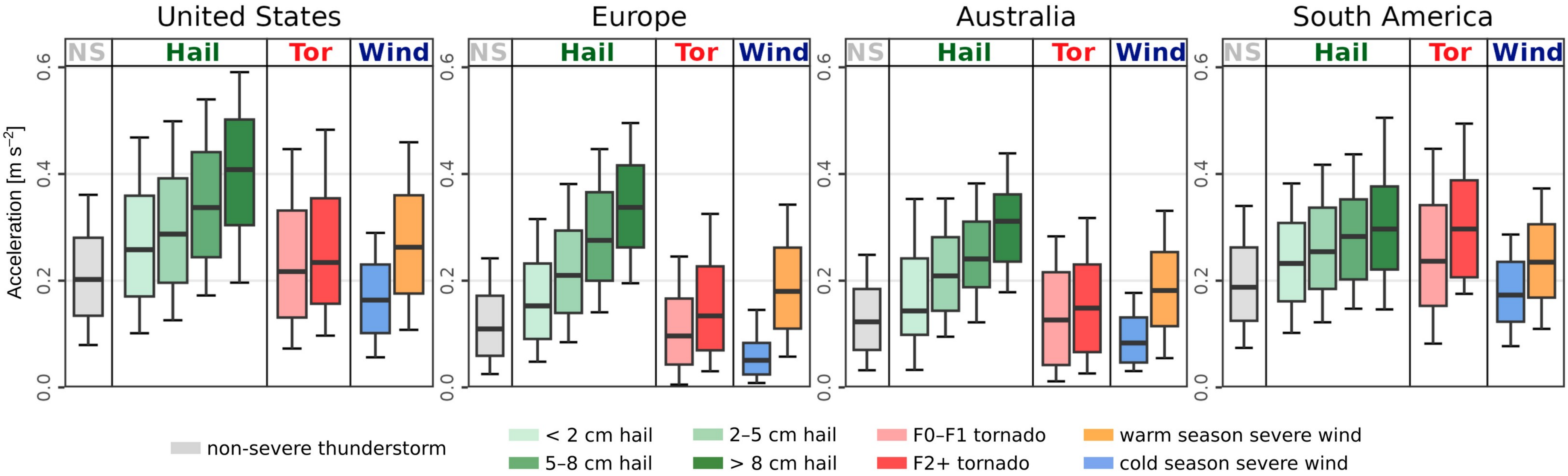
Vertical profile of parcel buoyancy



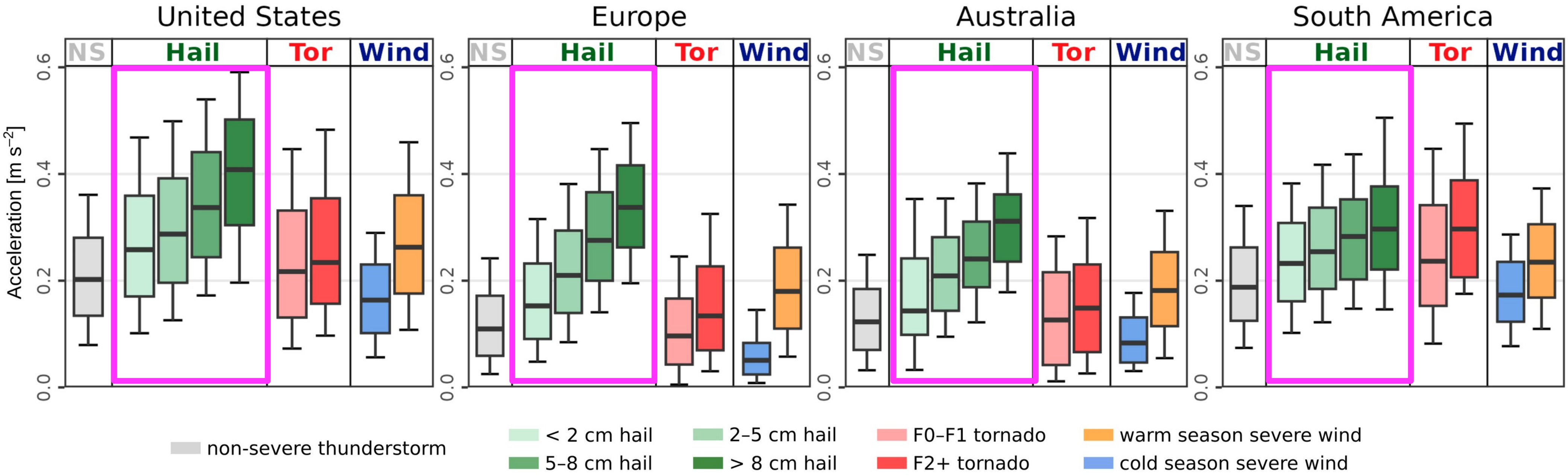
Vertical profile of parcel buoyancy



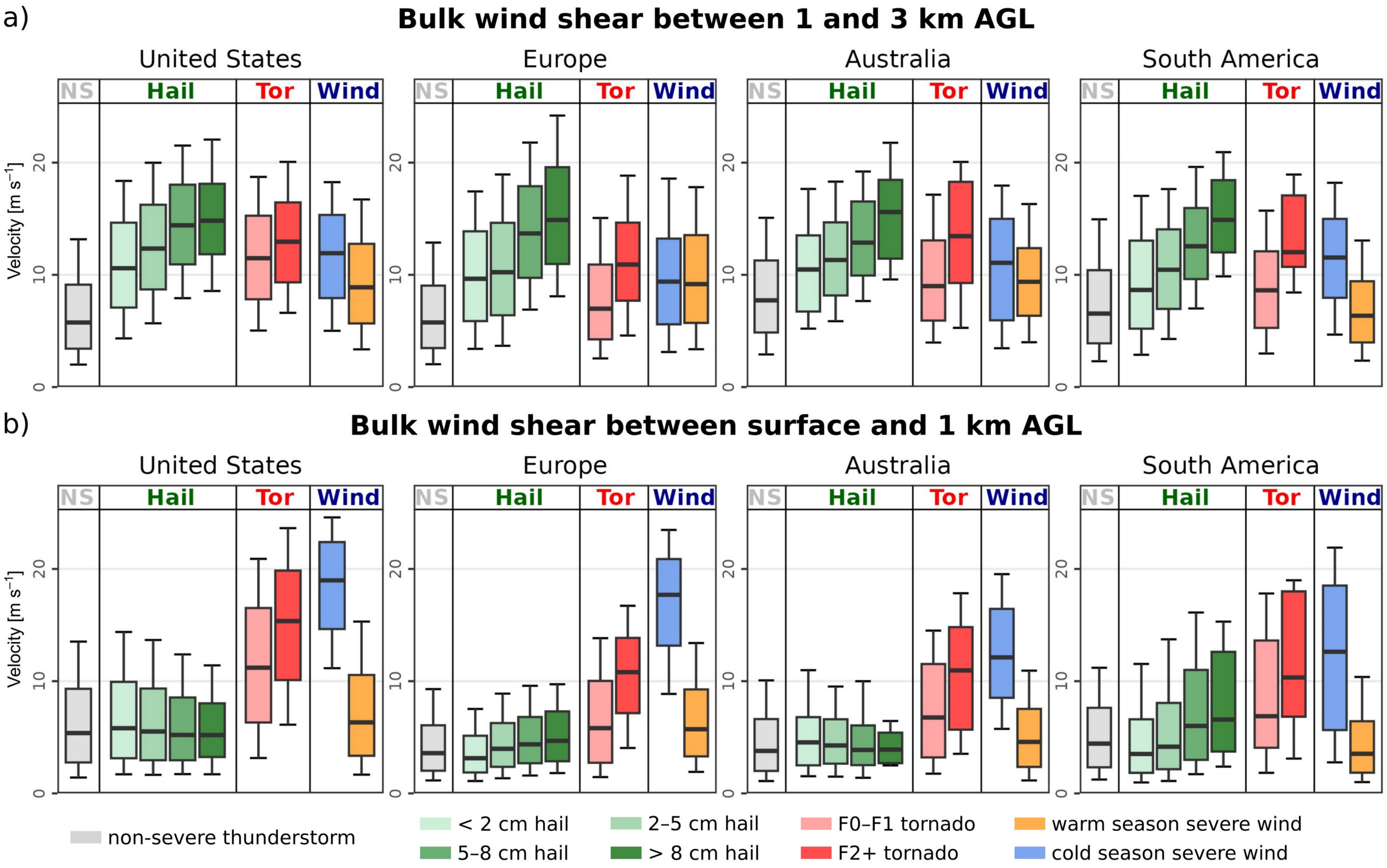
Maximum lifted parcel buyancy between -10 and -40 °C

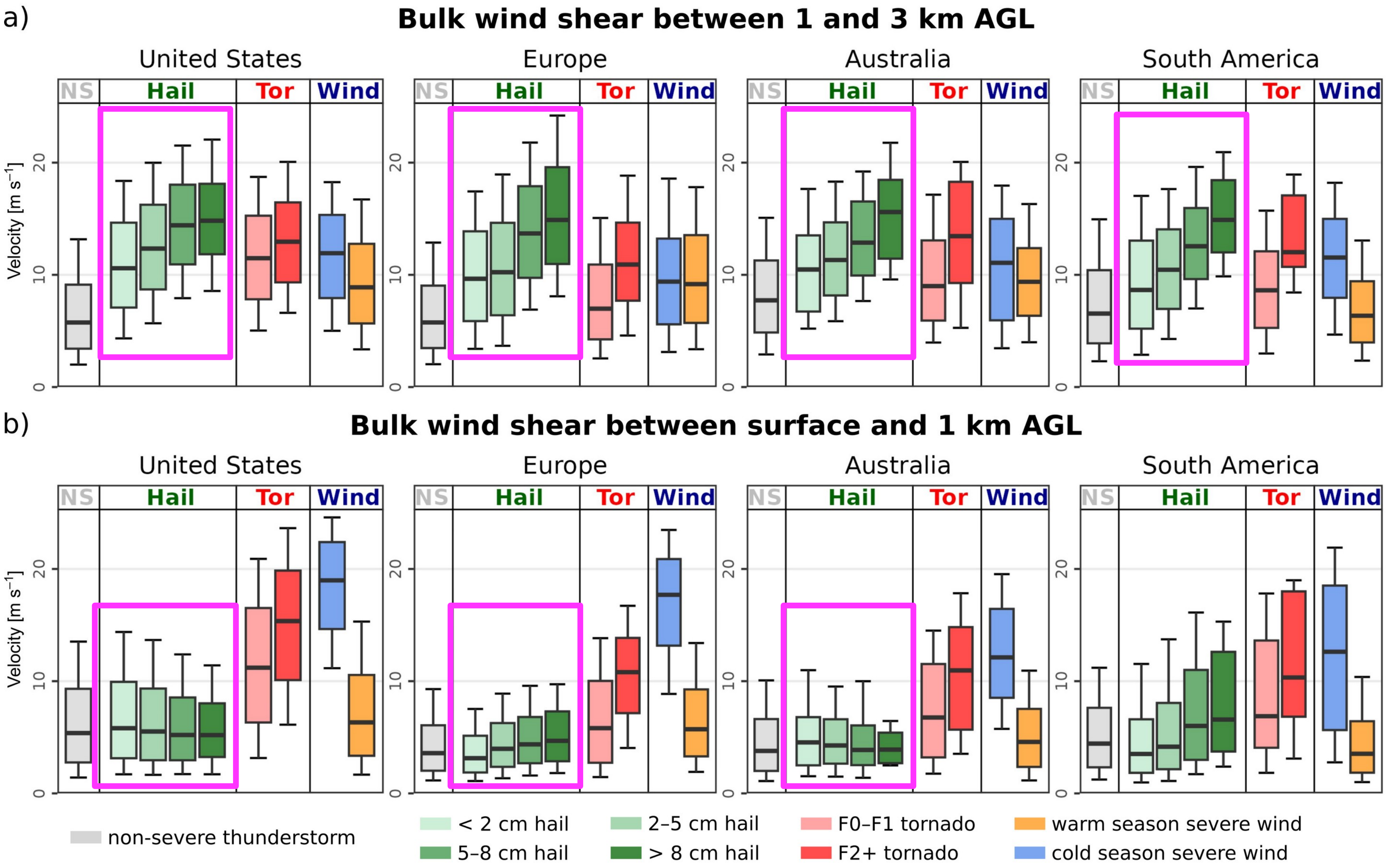


Maximum lifted parcel buyancy between -10 and -40 °C

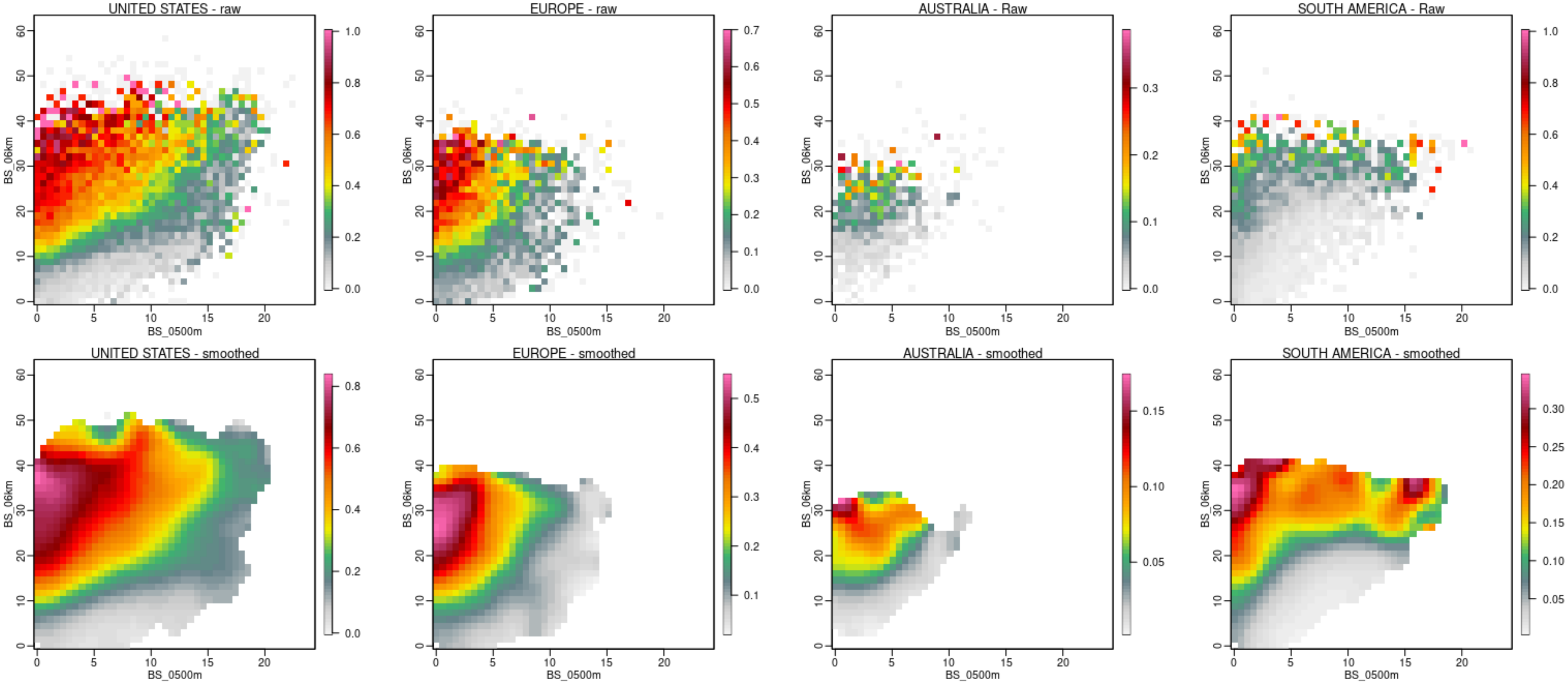


For hail, using profile's **peak parcel buoyancy** was slighly more skilful than **integrated instability** (CAPE)

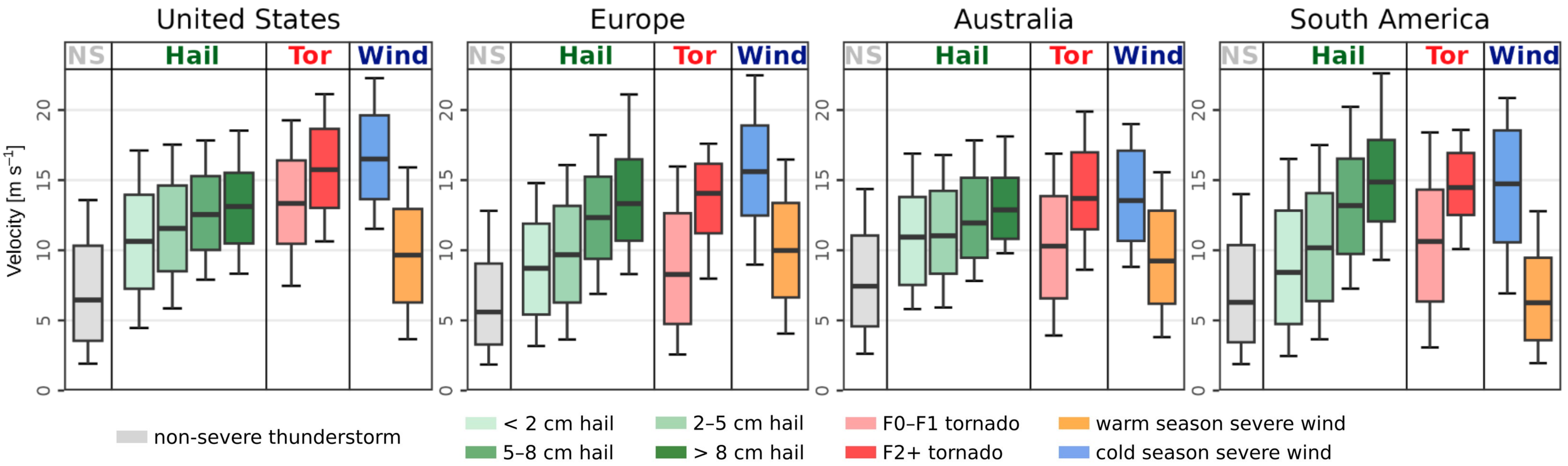

a)
Bulk wind shear between 1 and 3 km AGL
United States
Europe
Australia
South America
NS
Hail
Tor
Wind
Velocity [m s−1]
b)
Bulk wind shear between surface and 1 km AGL
non-severe thunderstorm
< 2 cm hail
2–5 cm hail
5–8 cm hail
> 8 cm hail
F0–F1 tornado
F2+ tornado
warm season severe wind
cold season severe wind


a)
Bulk wind shear between 1 and 3 km AGL
United States
Europe
Australia
South America
NS
Hail
Tor
Wind
Velocity [m s^{-1}]
0
10
20
b)
Bulk wind shear between surface and 1 km AGL
non-severe thunderstorm
< 2 cm hail
2–5 cm hail
5–8 cm hail
> 8 cm hail
F0–F1 tornado
F2+ tornado
warm season severe wind
cold season severe wind

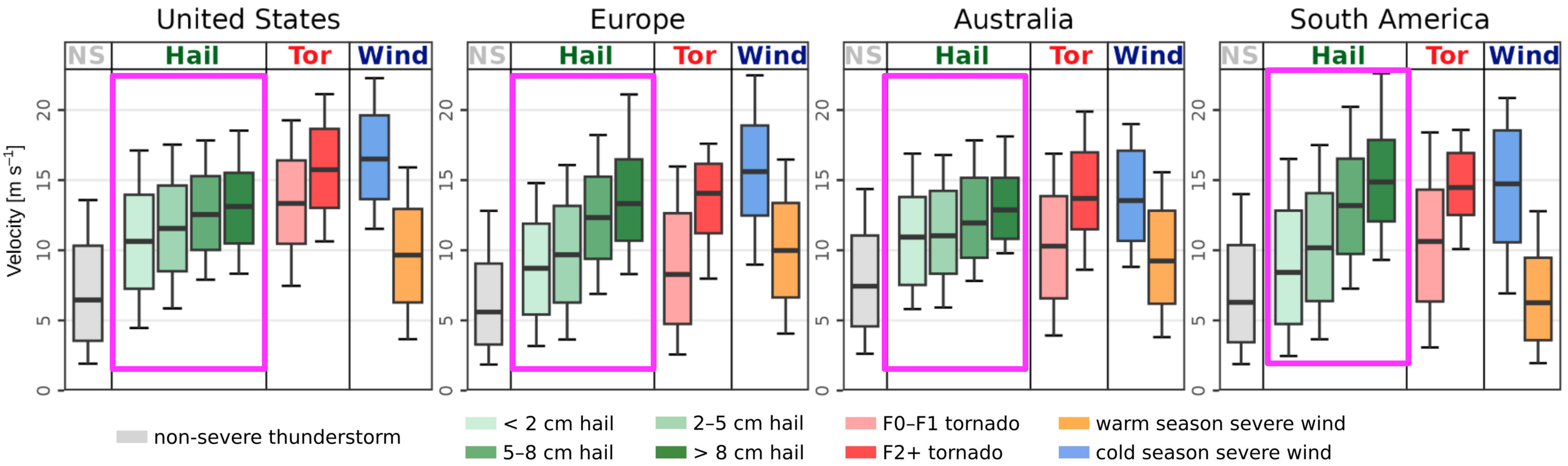
Conditional probability for HAIL given lightning



Mean storm-relative wind between surface and 500 m AGL



Mean storm-relative wind between surface and 500 m AGL



Hail doesn’t like strong **low-level bulk shear** but loves strong **low-level SR winds**!

(tornadoes like both)