

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

Mateusz Taszarek

Department of Meteorology and Climatology
Adam Mickiewicz University in Poznań
Poland



- PhD in Earth Sciences in 2017 (AMU)
- 5 years in Norman, Oklahoma (U.S.)
- Severe storm forecasting & research
- Member of ESSL, Skywarn
- Stormchaser



Convective hazards

- Lightning



Convective hazards

- Lightning
- Large hail



Convective hazards

- Lightning
- Large hail
- Severe wind gust



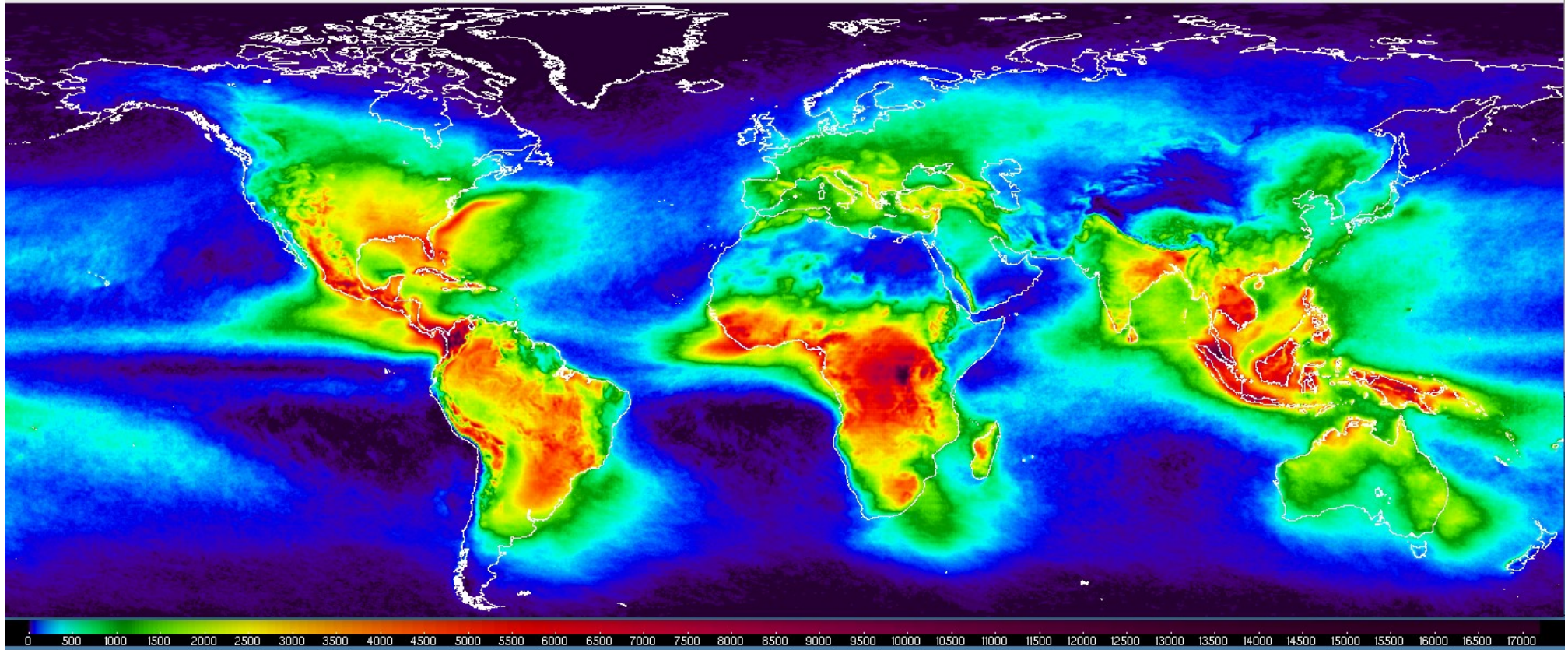
Convective hazards

- Lightning
- Large hail
- Severe wind gust
- Tornadoes



Mean annual number of lightning hours between 2014-2023

(Earth Networks Global Lightning Detection Network)



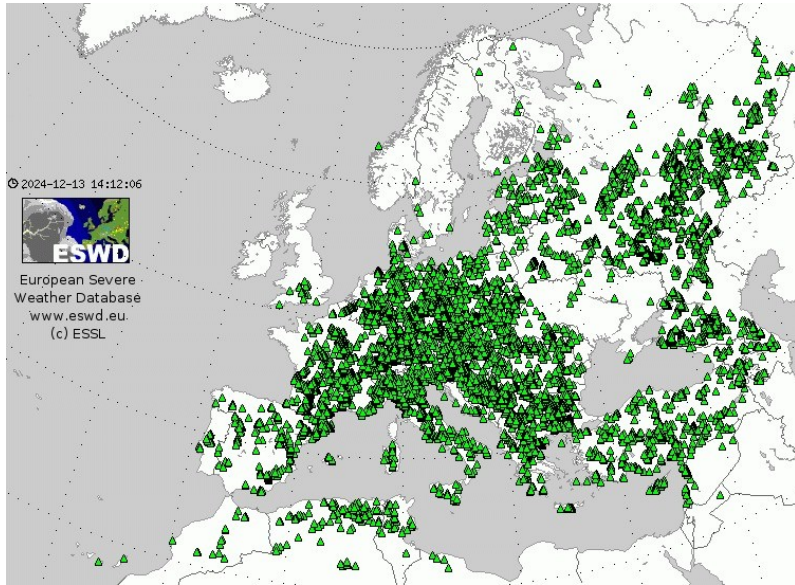
Global frequency of large hail, tornadoes, severe convective wind



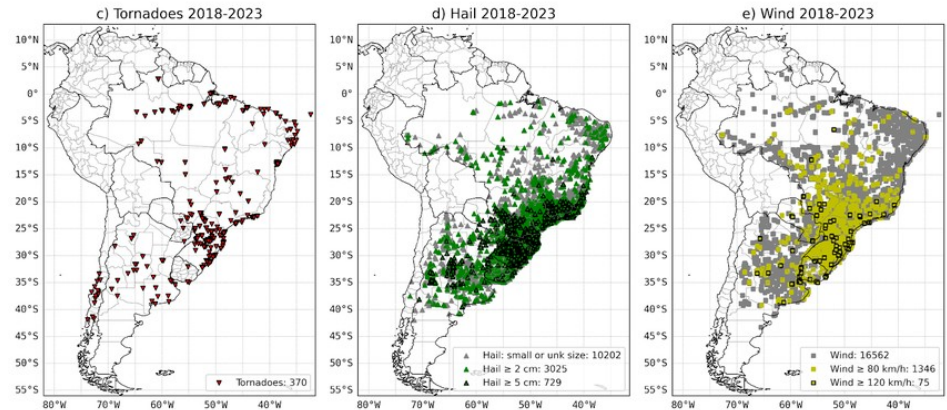
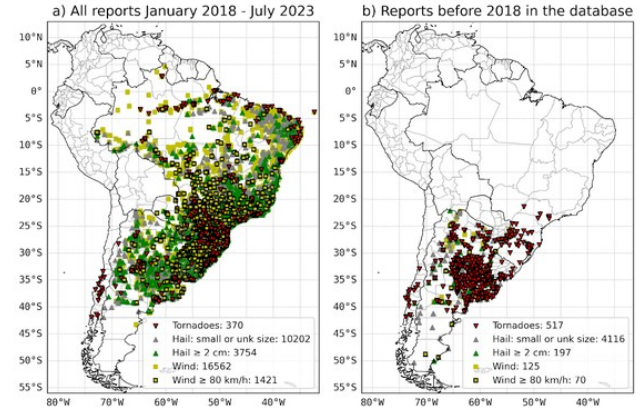
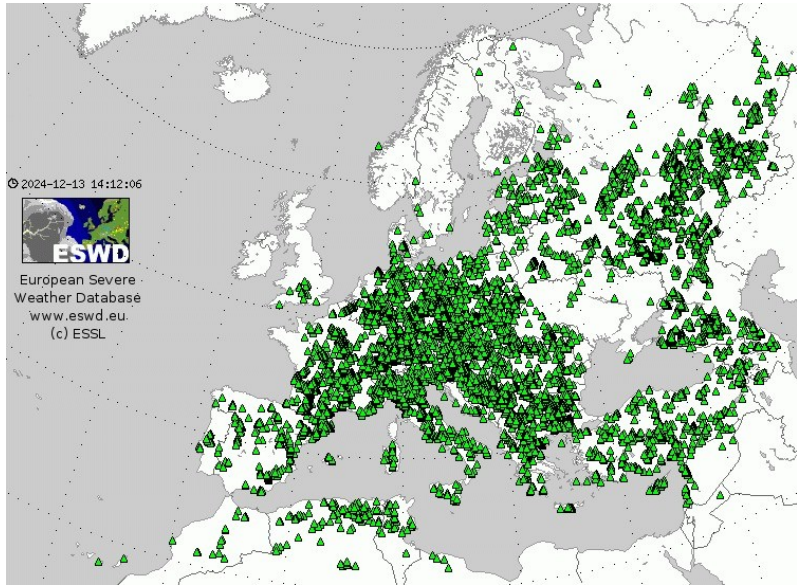
Observer is needed to witness convective event and report it



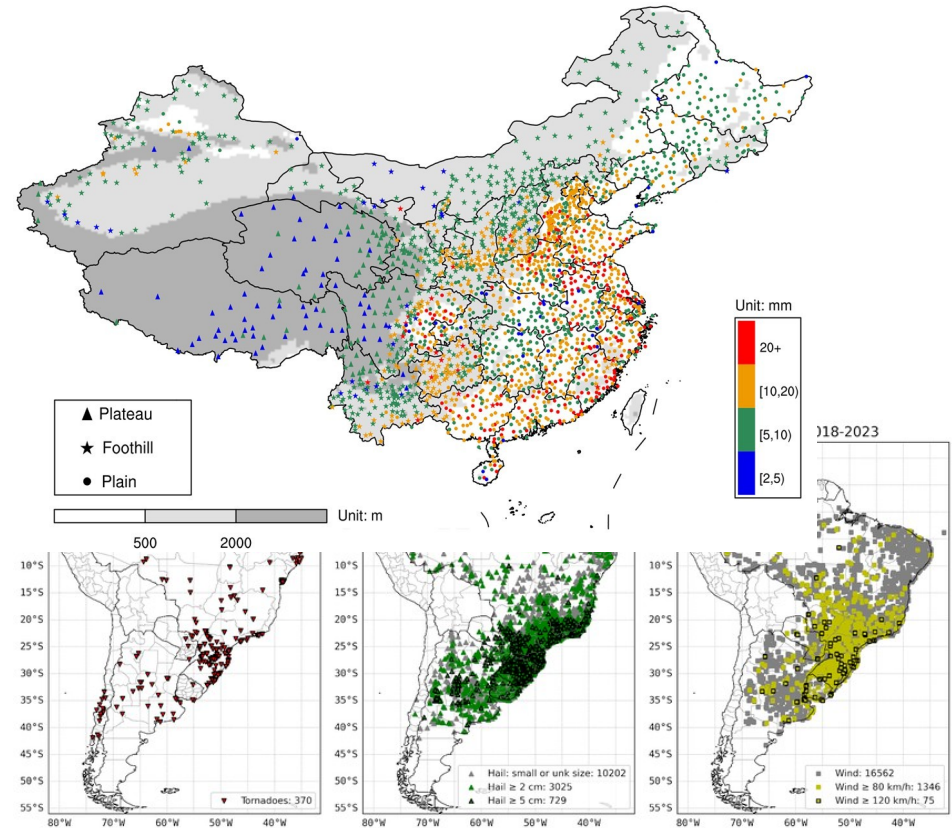
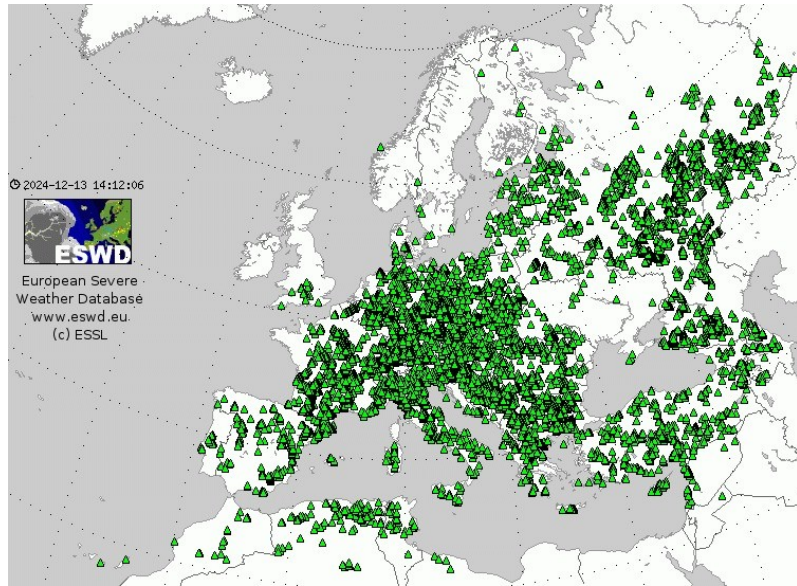
Regional convective event datasets



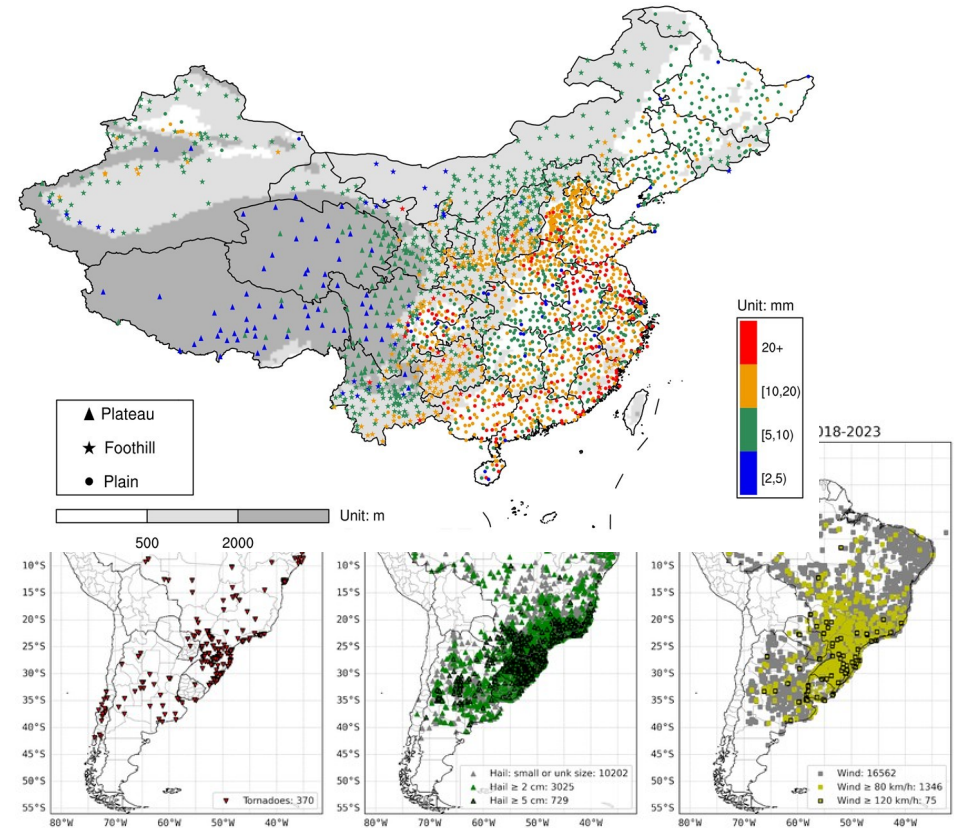
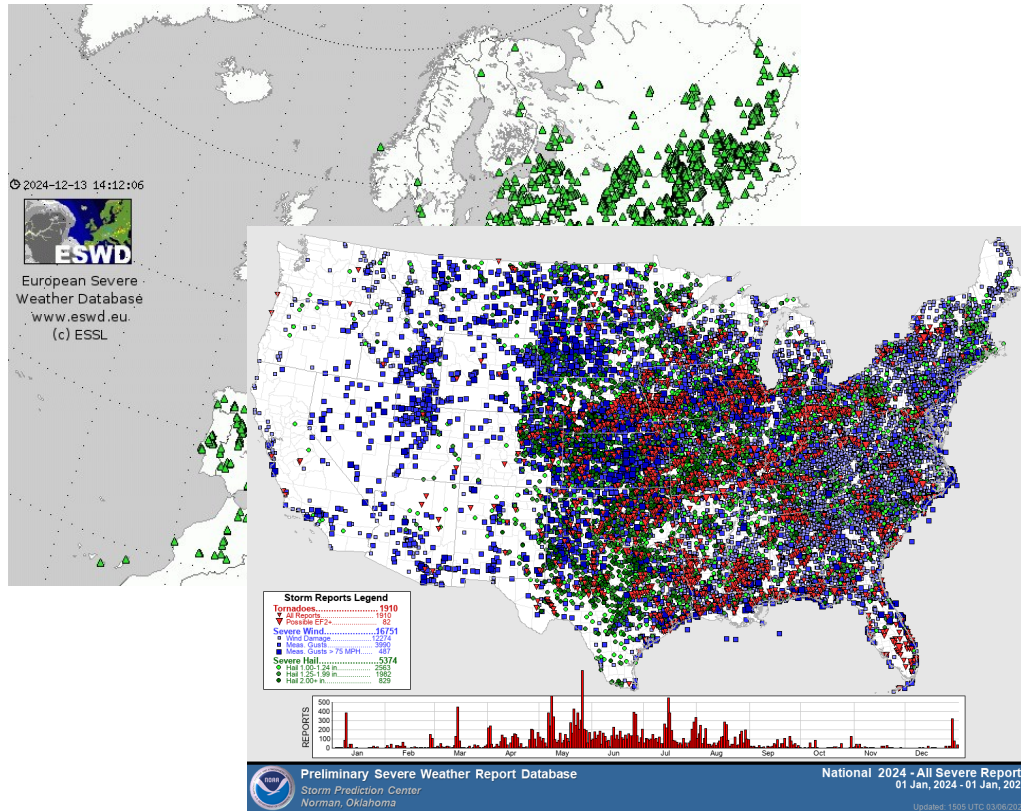
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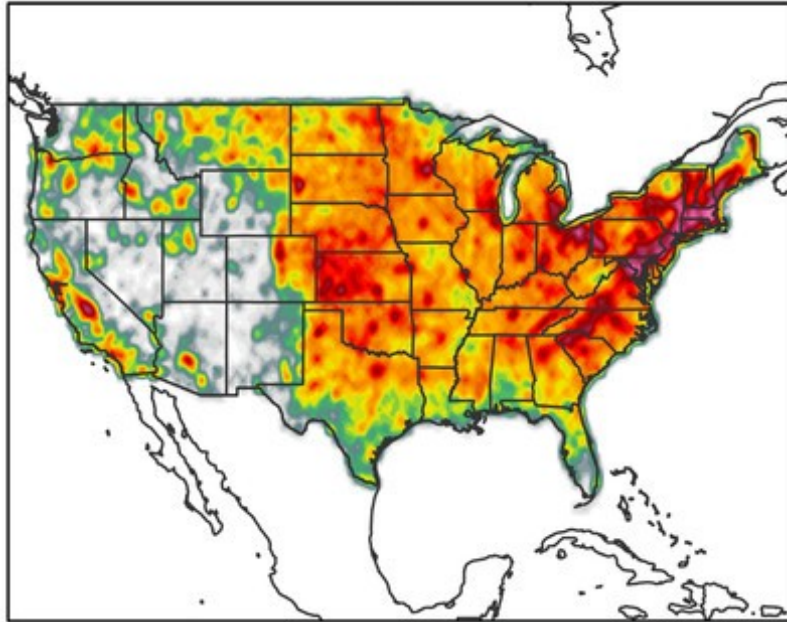


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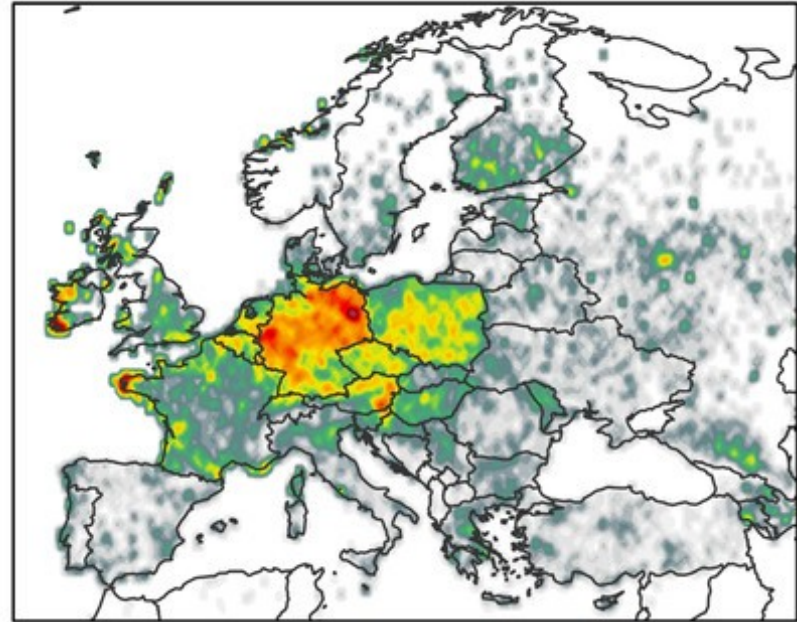


Fraction of hours with lightning associated with severe weather report (based on 1989-2018 for USA and 2006-2018 for EU)

All reports



All reports

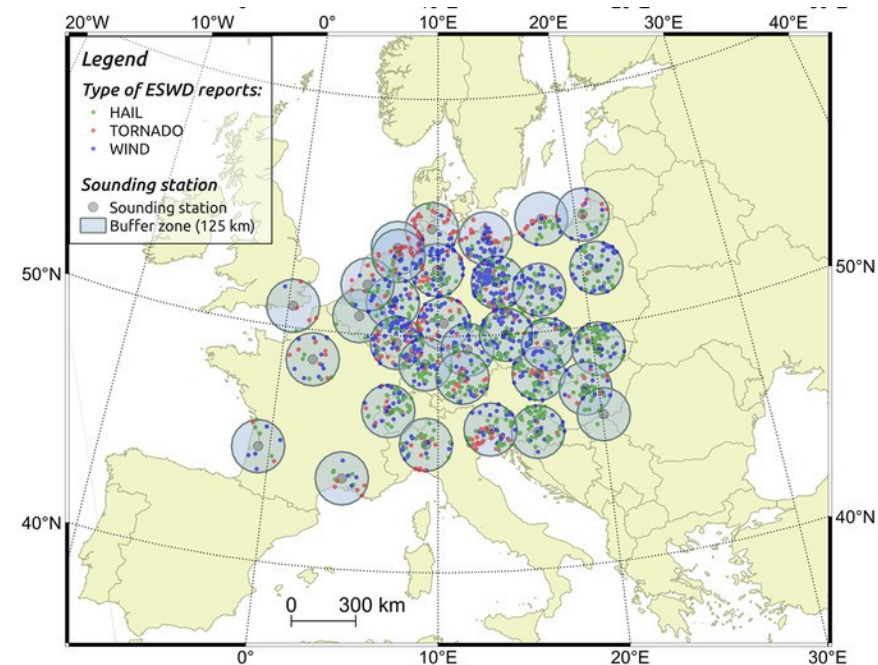
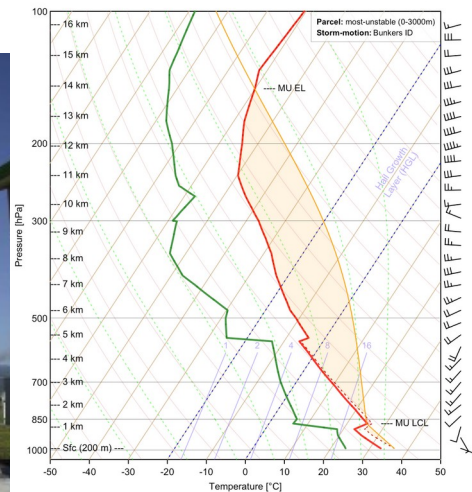


Global frequency of large hail, tornadoes, severe convective wind



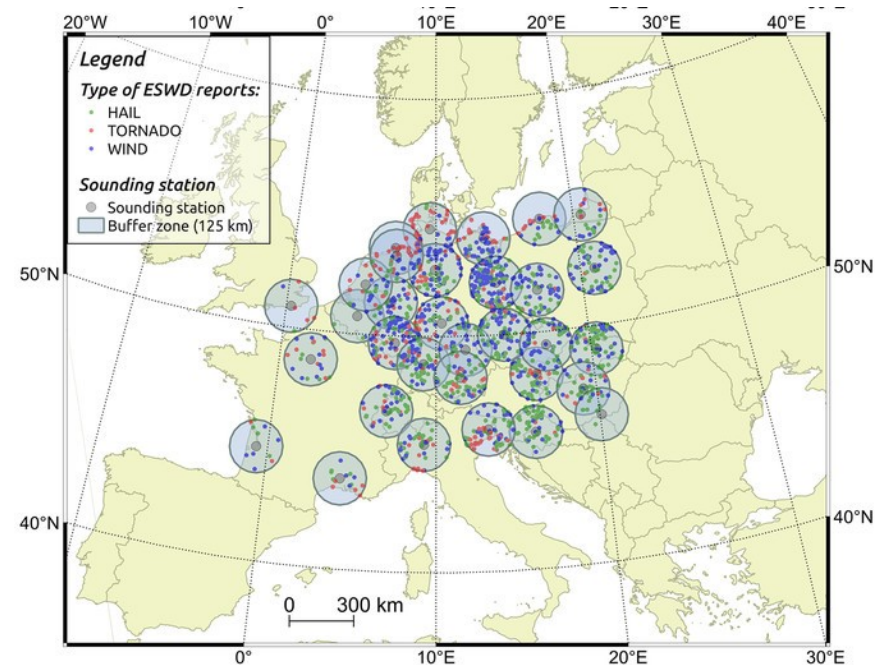
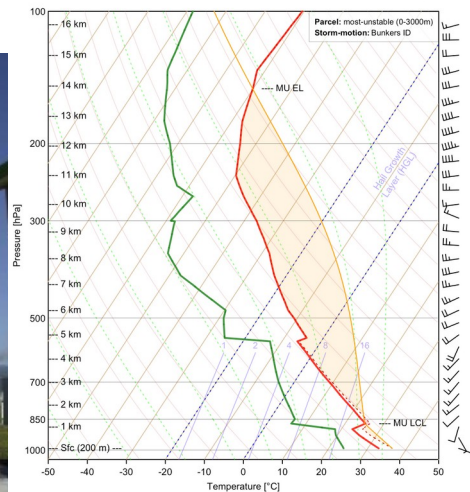
Convective storm modeling based on the physical state of the atmosphere

- Obtaining information about atmospheric conditions at the time of the hazard occurrence (rawinsonde observation or reanalysis profile).



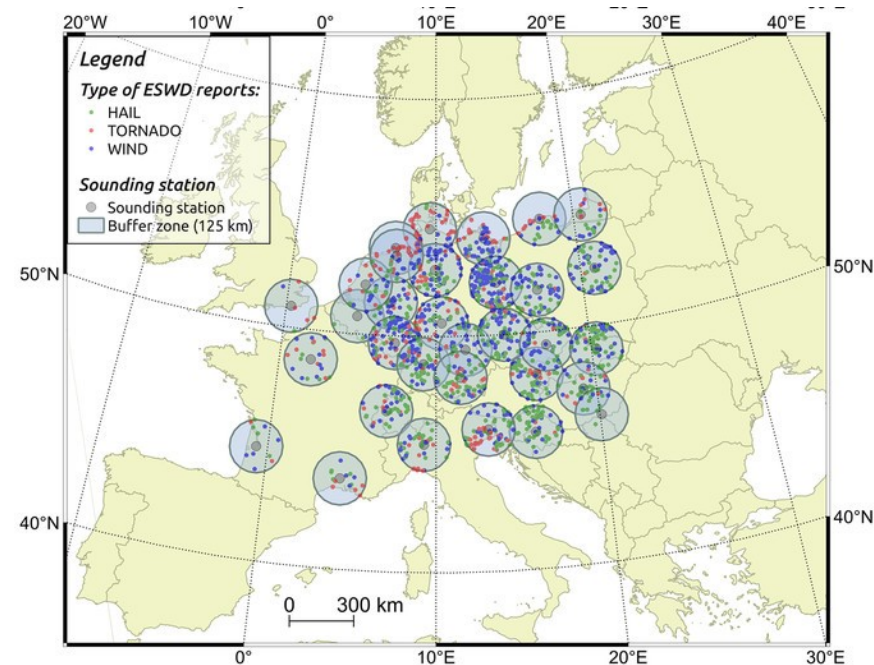
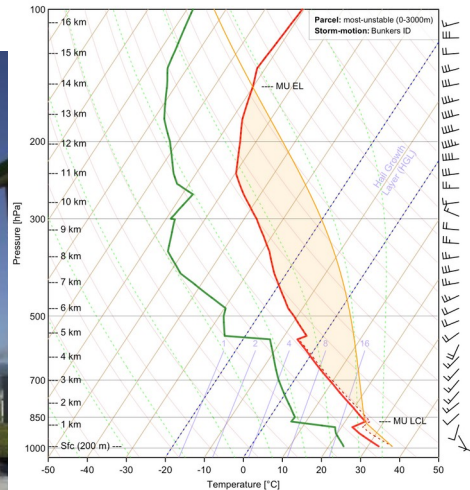
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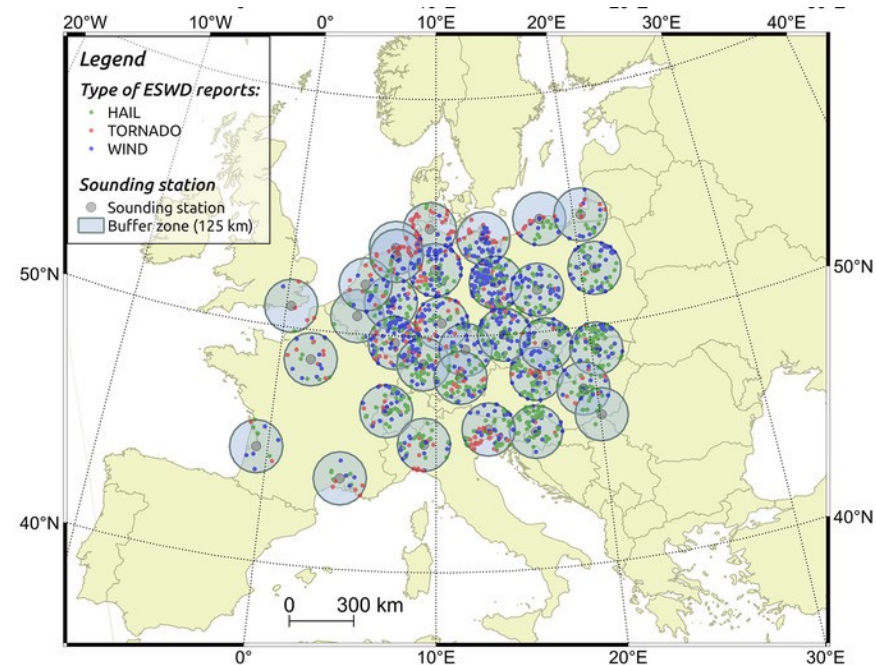
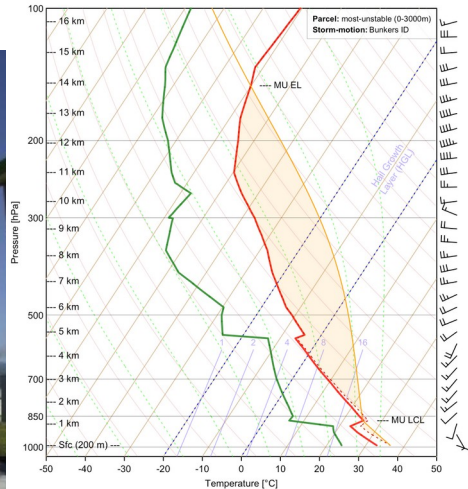
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- Developing a statistical model.



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- Determining which parameters are associated with the hazard occurrence.
- Developing a statistical model.
- Applying the model to the reanalysis data.

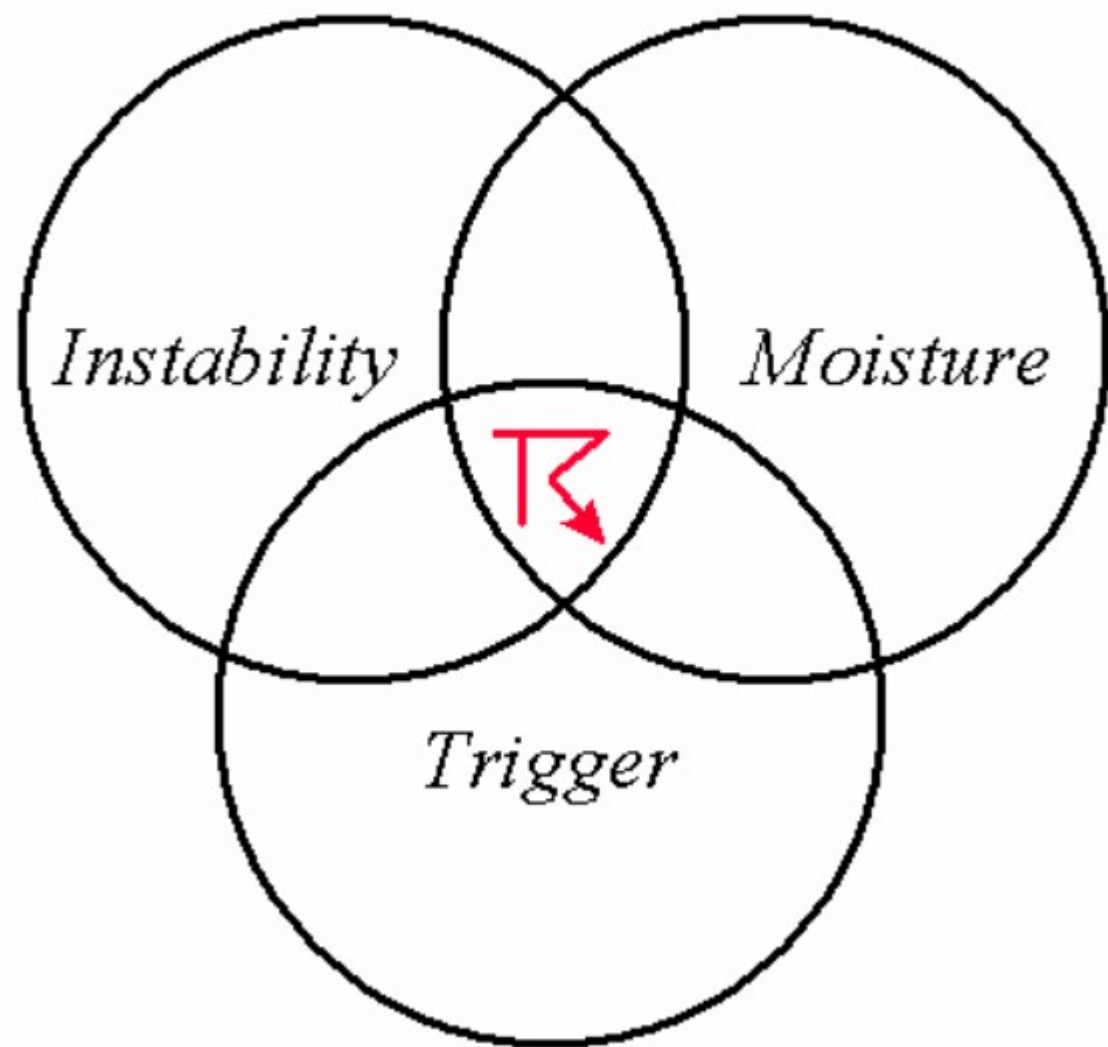


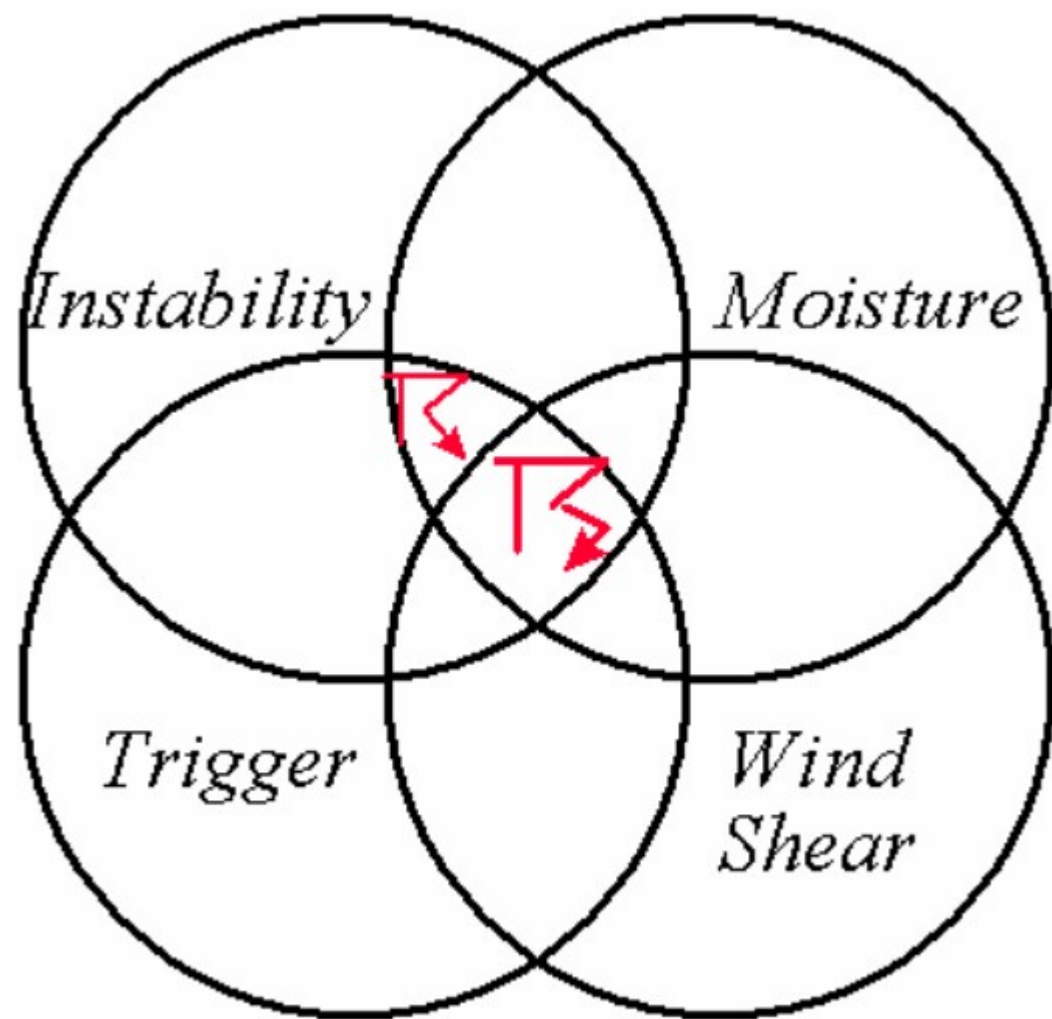


LIFT, INSTABILITY, MOISTURE

If any one of these ingredients is missing,
deep moist convection simply will not occur.

- Charles A. Doswell III





Everything is about a right recipe



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Moisture



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Moisture

Instability

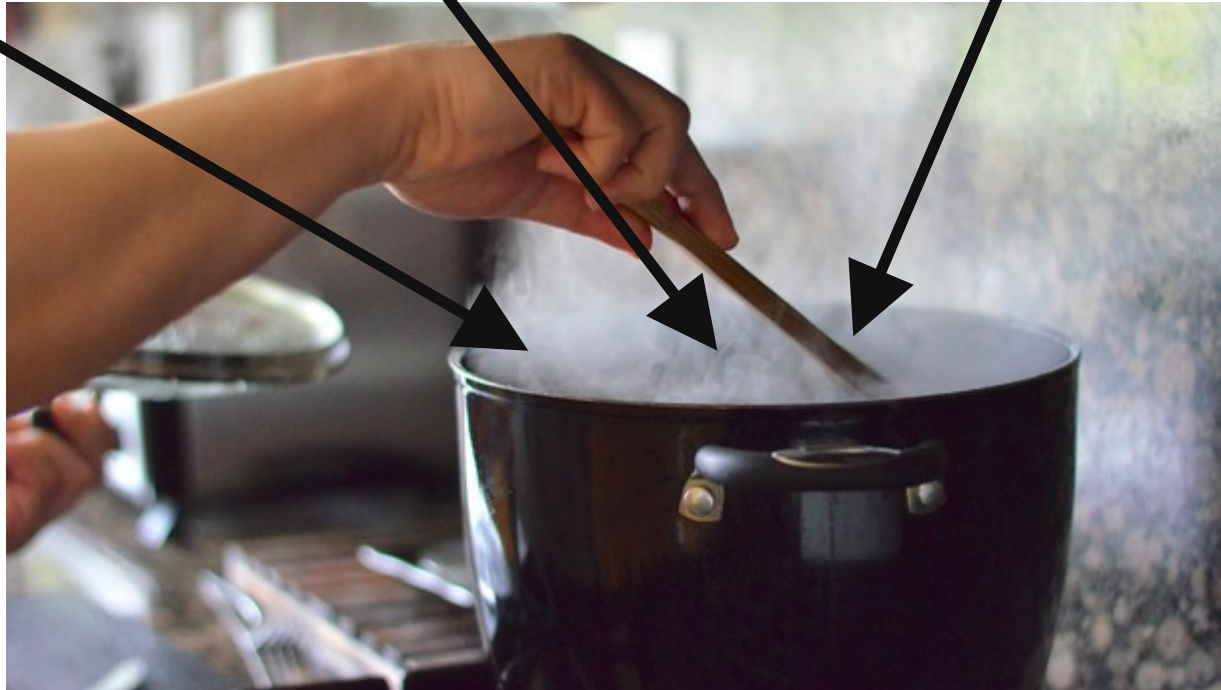


Everything is about a right recipe

Moisture

Instability

Lift



Everything is about a right recipe

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Wind shear



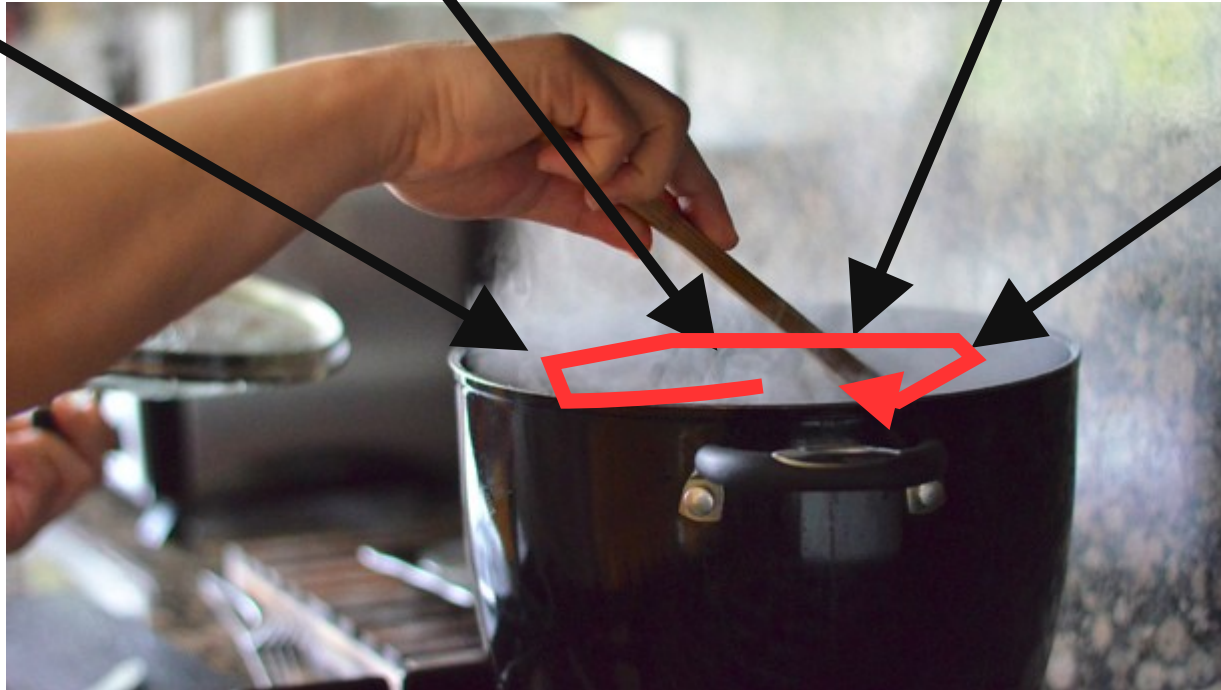
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Some problems with convective storm modeling

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Some problems with convective storm modeling

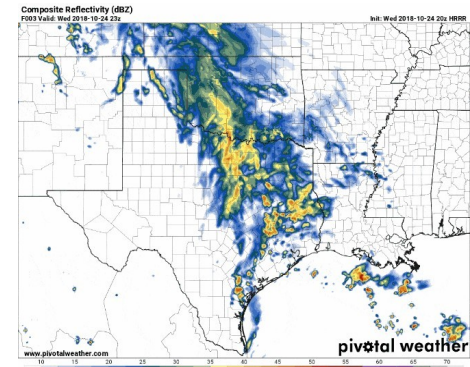
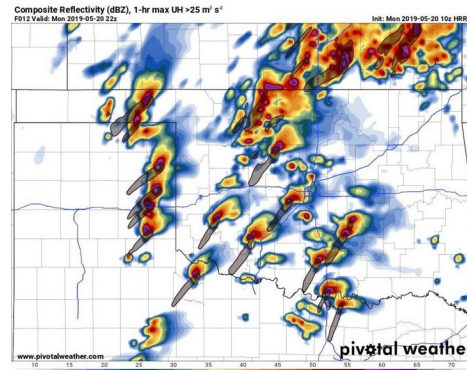
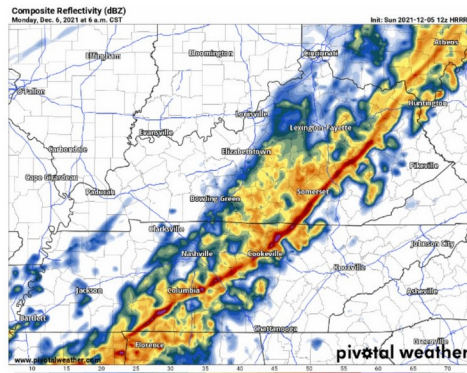
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Some problems with convective storm modeling

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- Severe storm environments are still not well understood (new parameters and concepts need to be developed and tested).

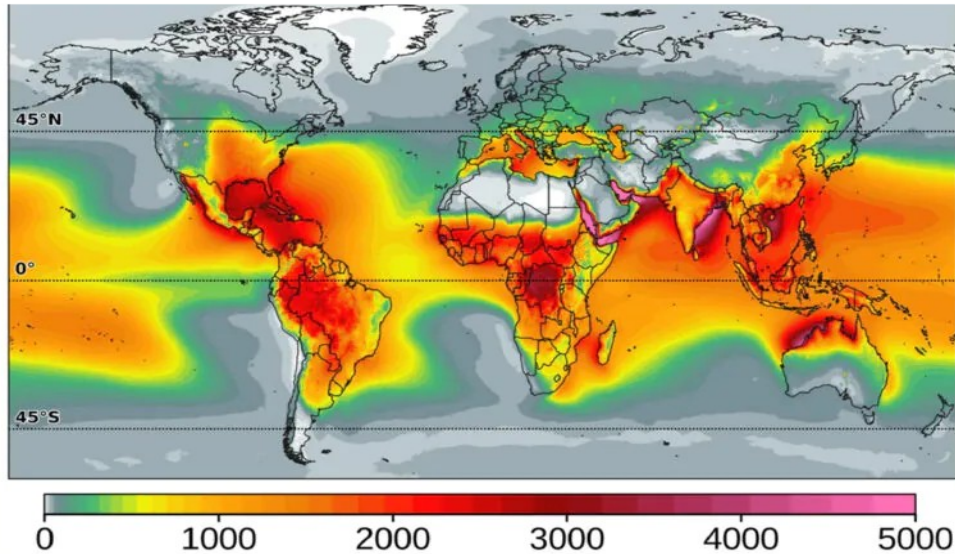
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- Models trained on data from one region may not perform in other parts of the world.
- Severe storm environments are still not well understood (new parameters and concepts need to be developed and tested).
- The modeling does not take into account "convection modes" (e.g., squall lines, supercells, poorly organized clusters).

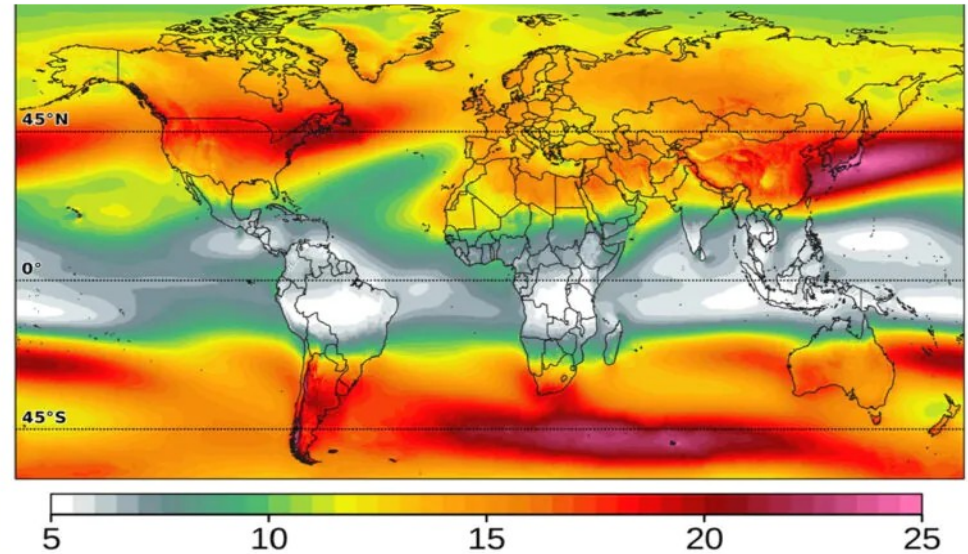


Global distribution of CAPE and SHEAR

95th percentile of CAPE [J kg^{-1}]

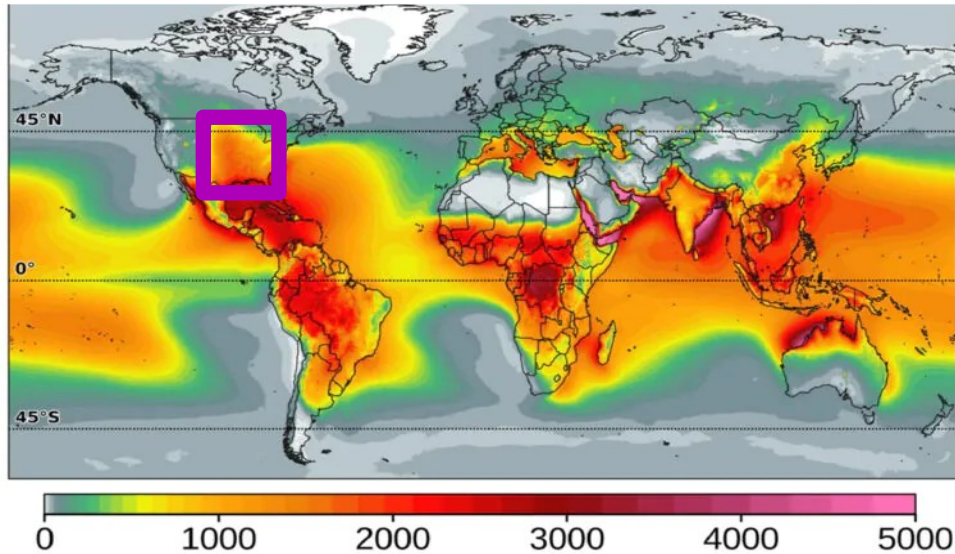


50th percentile of S06 [m s^{-1}]

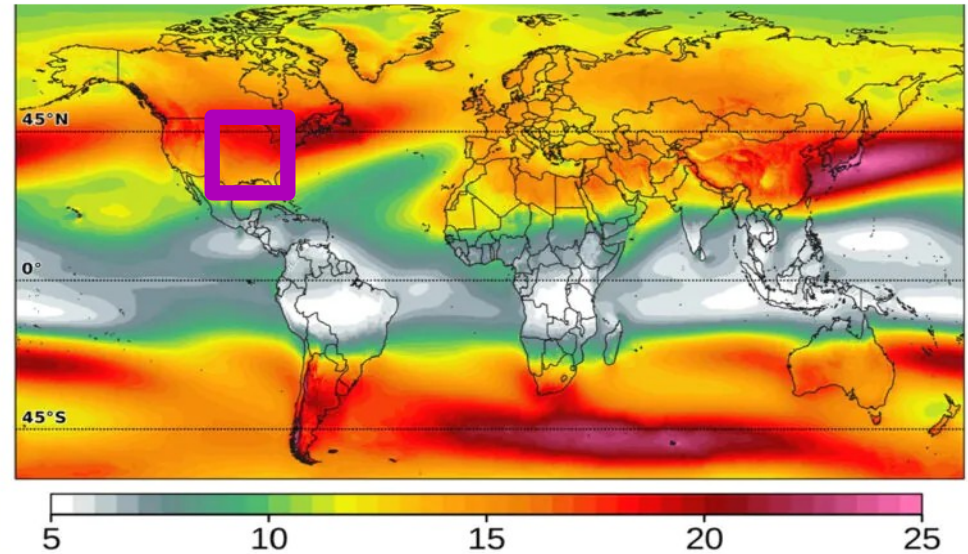


Global distribution of CAPE and SHEAR

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Limitations of past work

- Regional studies on storm environments feature biases.
- Primary focus on existing parameters with little development of new approaches.
- Lack of climatological context — skillful compared to what?

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Goals

- To identify, which environmental features are common for storms producing convective hazards in different parts of the world.
- Highlight which parameters are important for hazard occurrence, and which for hazard intensity.
- Develop tools that can be applied globally and used in the operational prediction of severe storms and climate research.

What was required to reach our goals?

- Develop own software to have a full control on the calculation of environmental parameters - computationally efficient and flexible in the context of modifications.
- Construct inter-continental datasets of severe weather reports and lightning.
- Construct global dataset of convective environments.

What was required to reach our goals?

- Develop own software to have a full control on the calculation of environmental parameters - computationally efficient and flexible in the context of modifications.
- Construct inter-continental datasets of severe weather reports and lightning.
- Construct global dataset of convective environments.
- **Interact with smart people who have new ideas and think out of the box!**

Outcomes over 5 years:

- Development of thundeR package with international collaboration, 37 peer-reviewed studies including Nature Geoscience (as of March 2026)
- Data included in 3 PhD theses + support to multiple students
- Contribution to international projects, e.g.:
 - NASA/FAA aircraft ice crystal icing research
 - ESSL AR-CHaMo model development
- Development of new parameters and operational products
- Collaboration with researchers from all around the world



Data shared with the community at
www.rawinsonde.com

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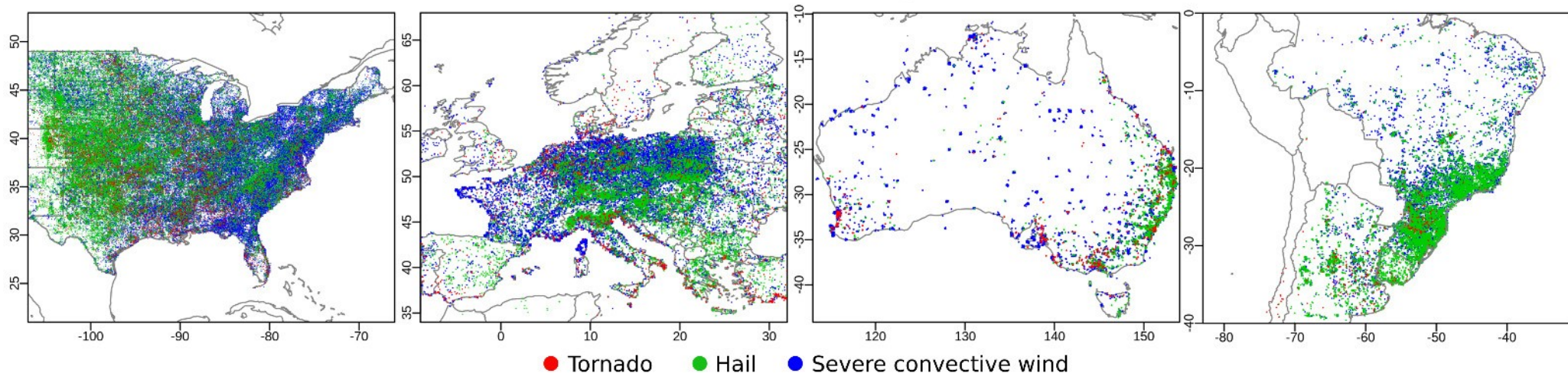


Datasets used in the most recent modeling research

Severe weather reports (0.25° x 0.25° grid)

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

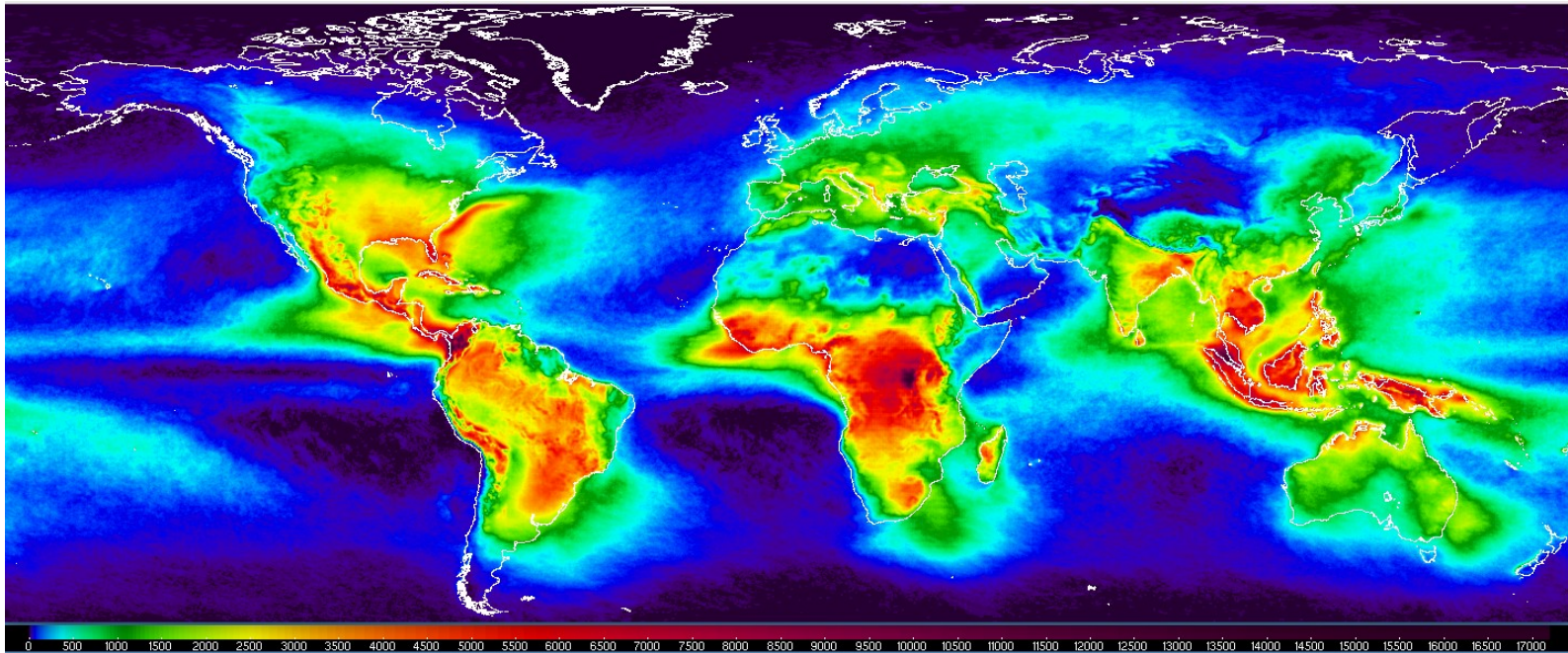
Severe weather reports



Global lightning data (0.25° x 0.25° grid)

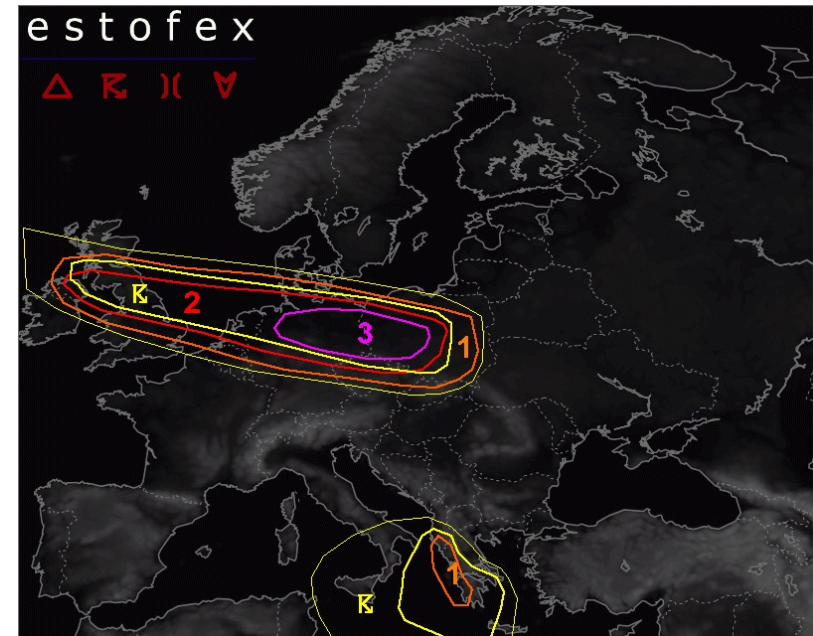
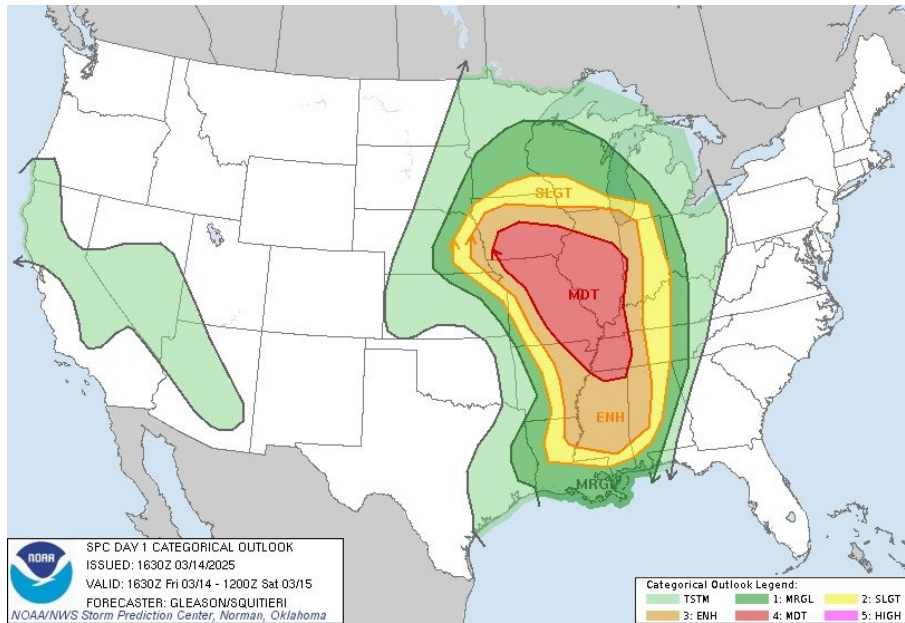
- Earth Networks Global Lightning Detection Network
- 1h step, 0.25 deg grid

Hours with detected lightning (2015 - 2024)

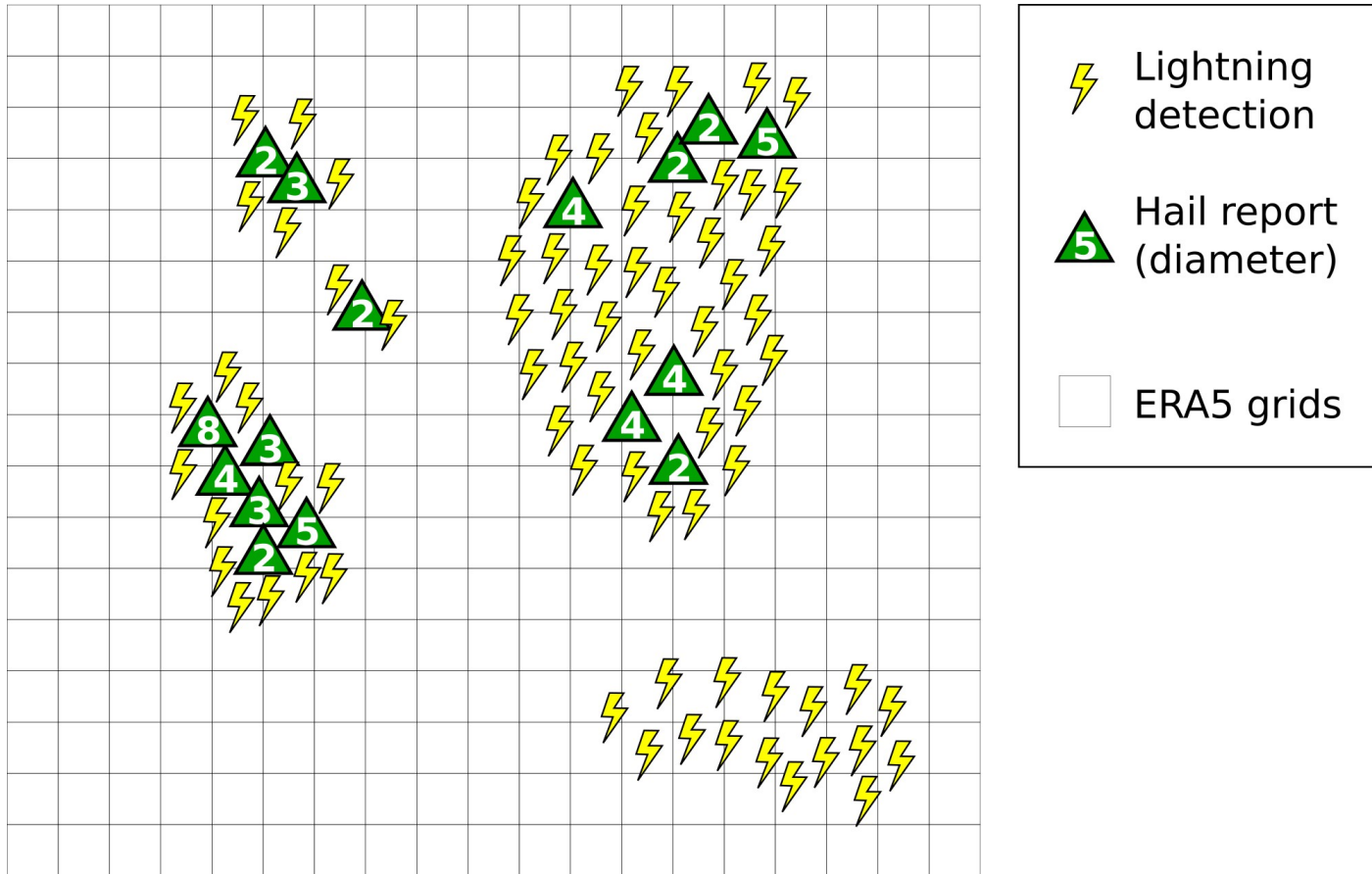


Operational convective outlooks (2014-2023)

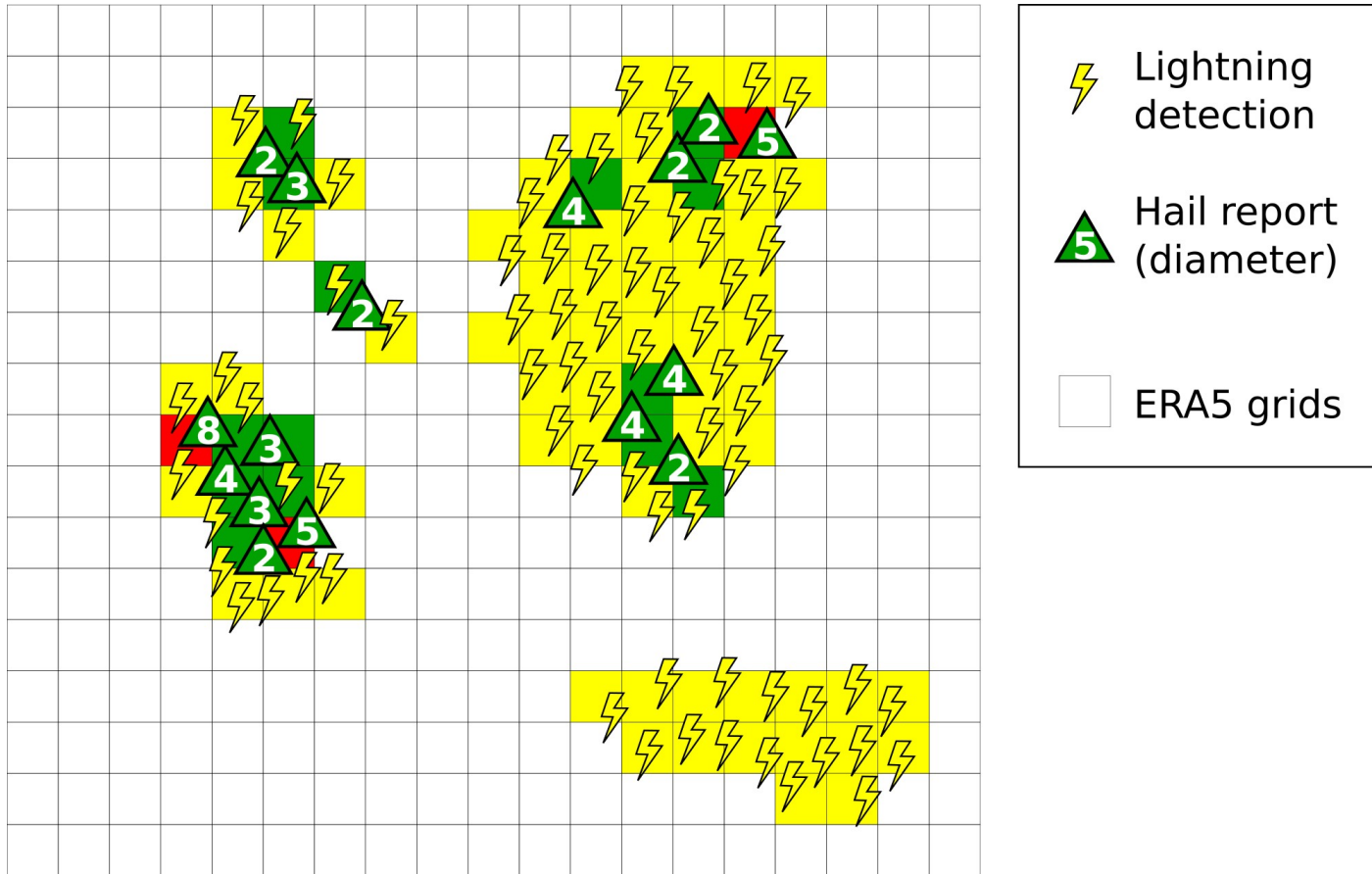
- United States: NOAA Storm Prediction Center (SPC)
- Europe: European Storm Forecast Experiment (ESTOFEX)



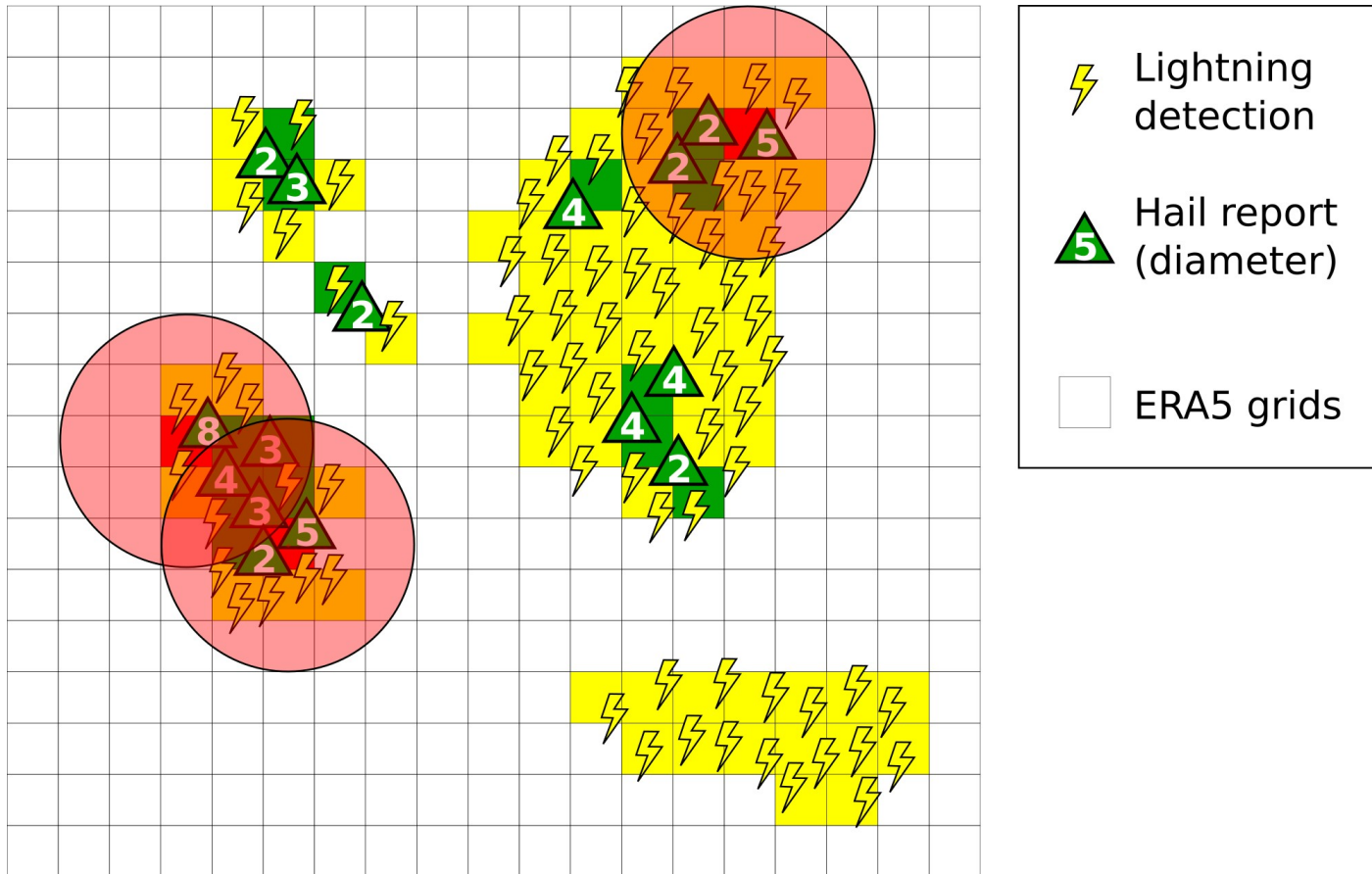
Importance of independent categories in constructing a training dataset



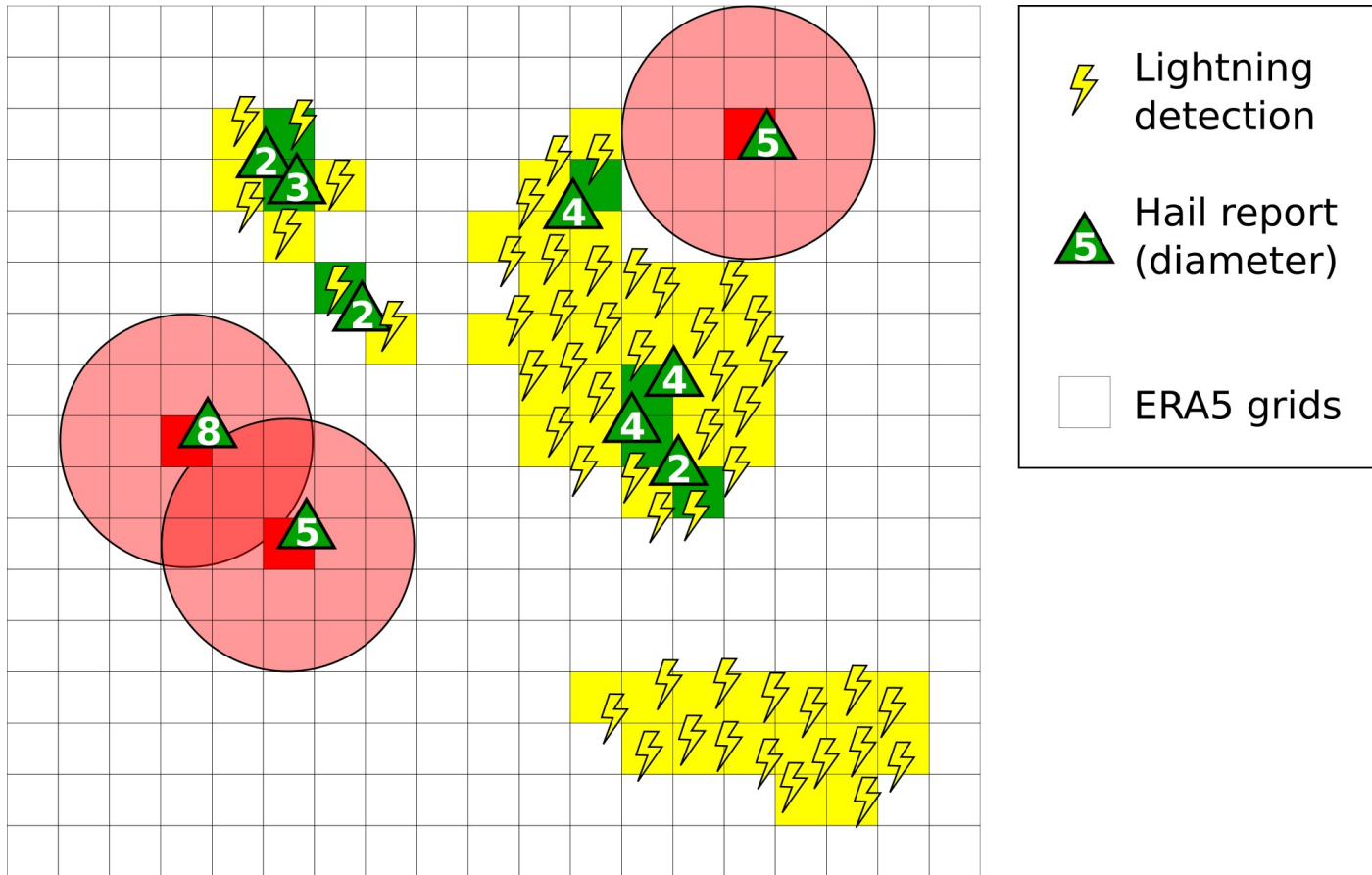
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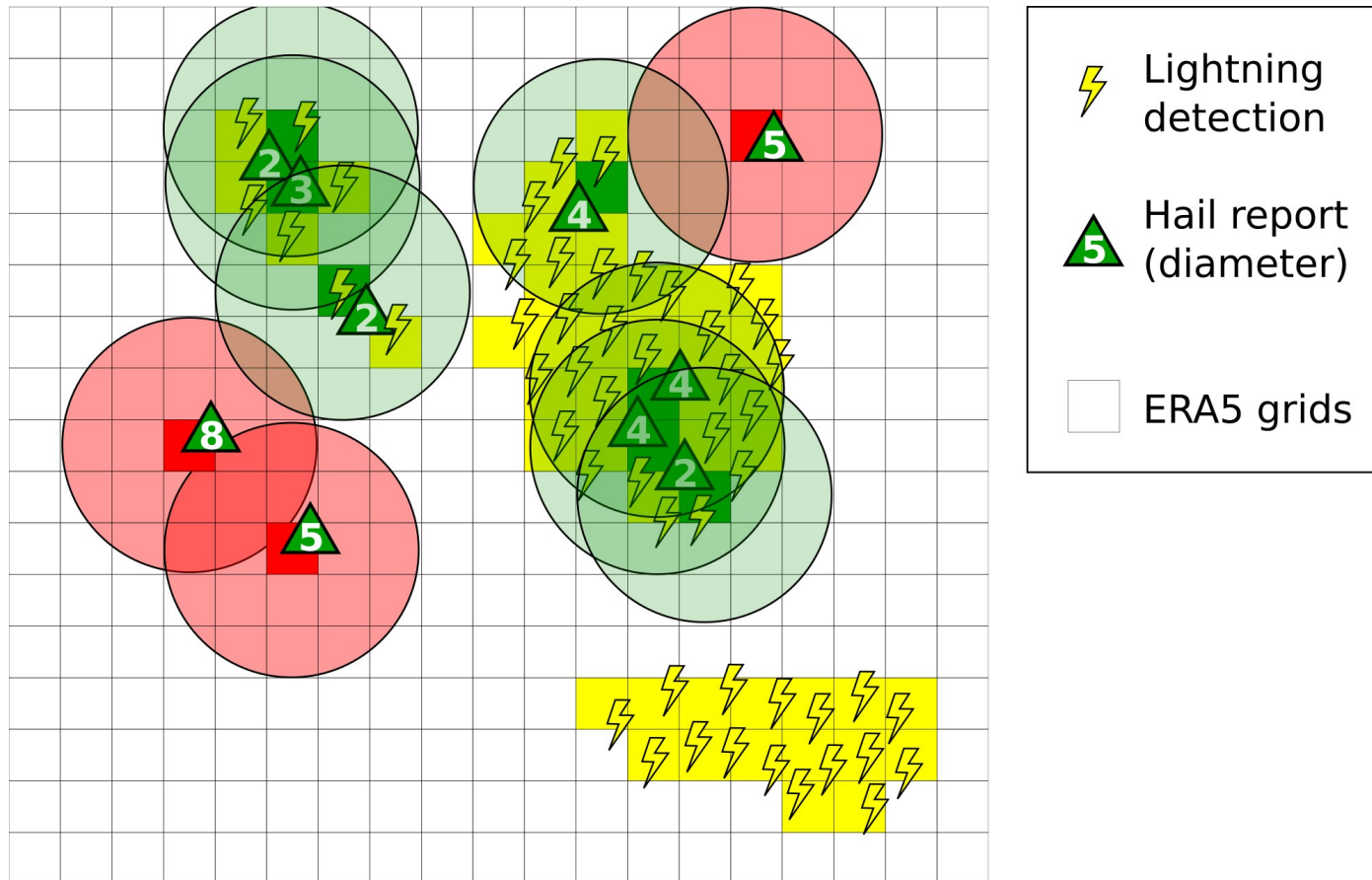
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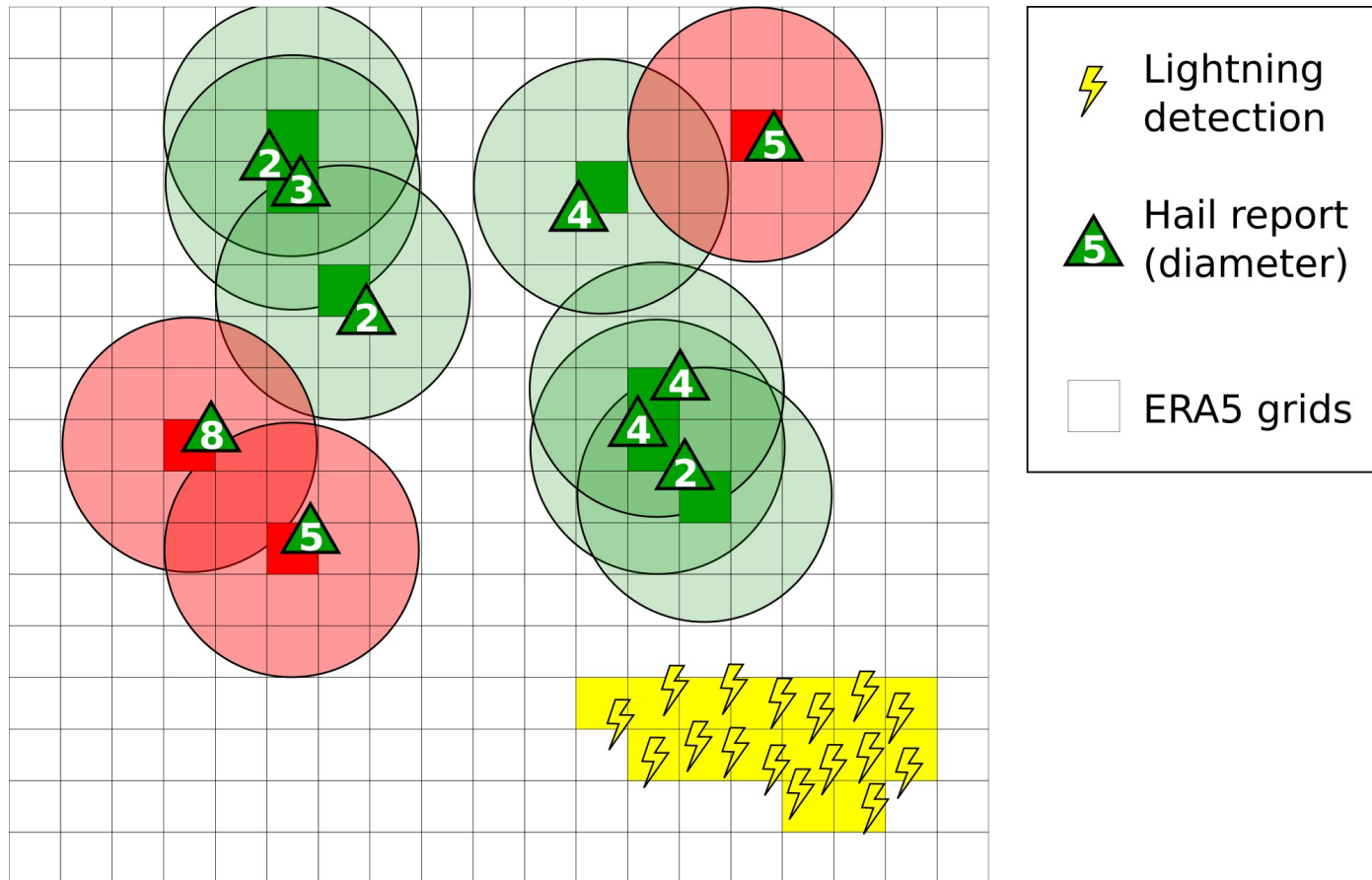
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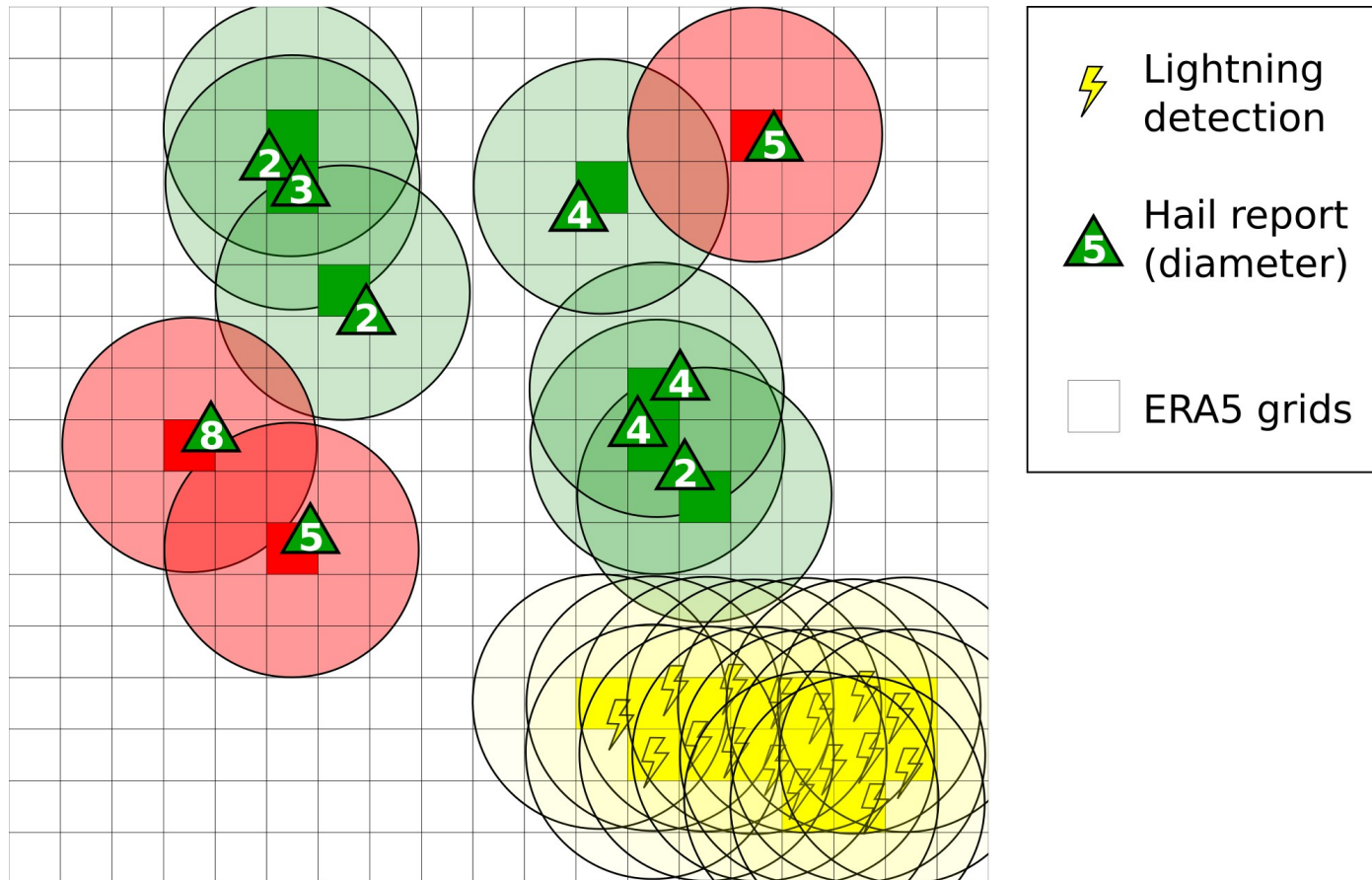
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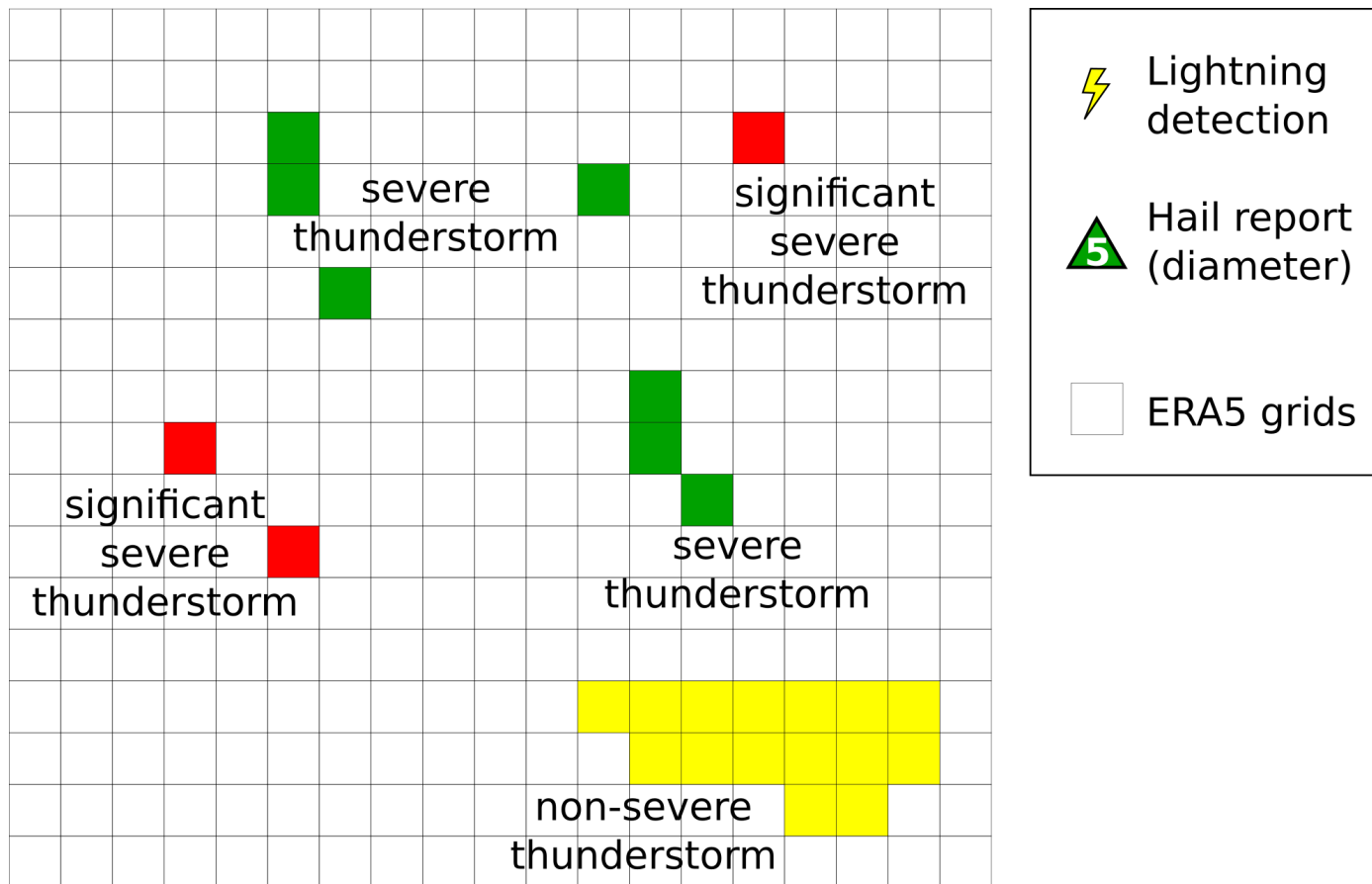
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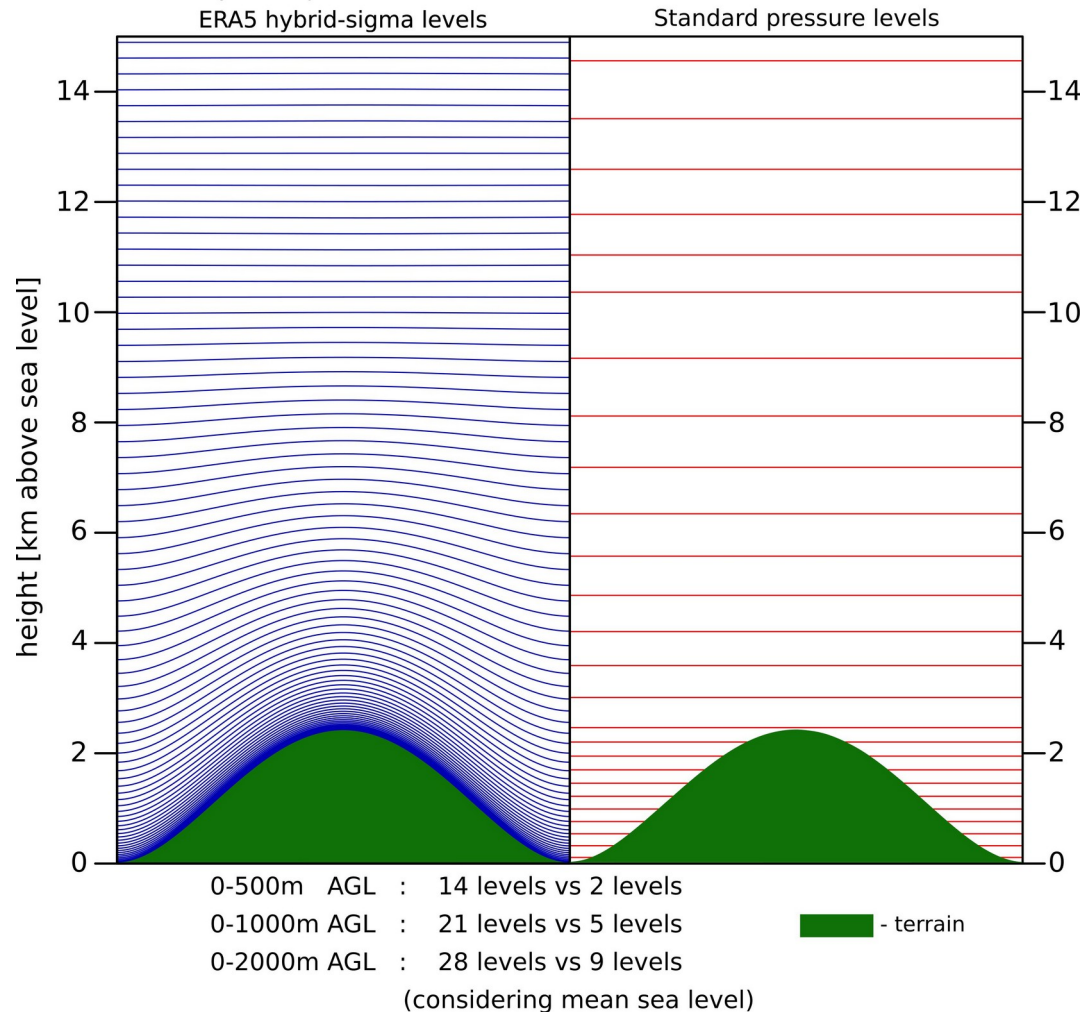
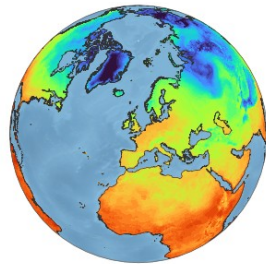


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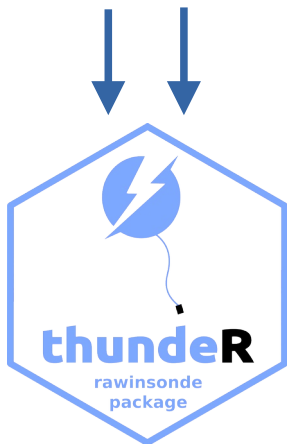
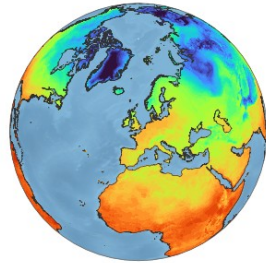
ERA5 reanalysis

- hybrid-sigma levels
- $0.25^\circ \times 0.25^\circ$
- 1-hour step
- raw profiles of z , p , q , t , u , v
- processed globally

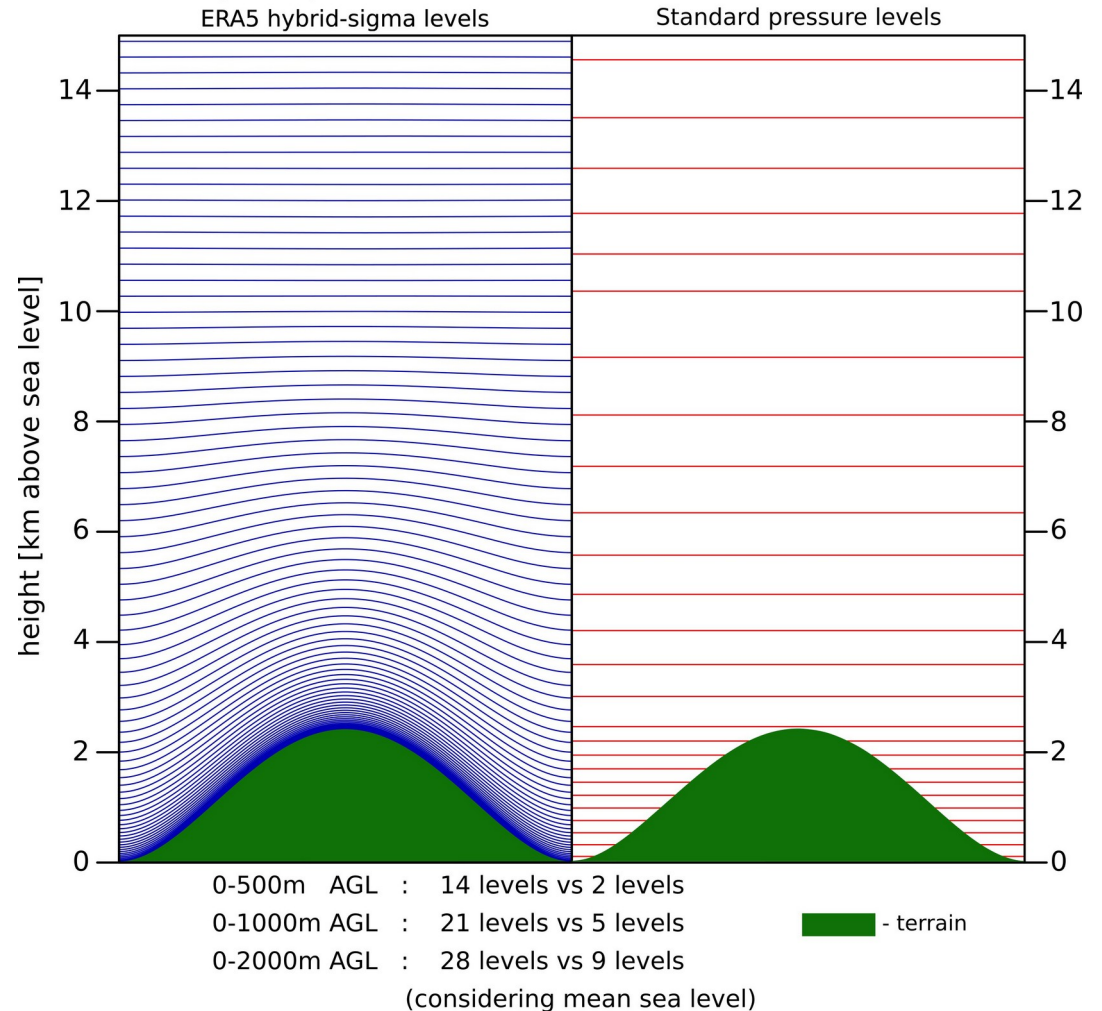


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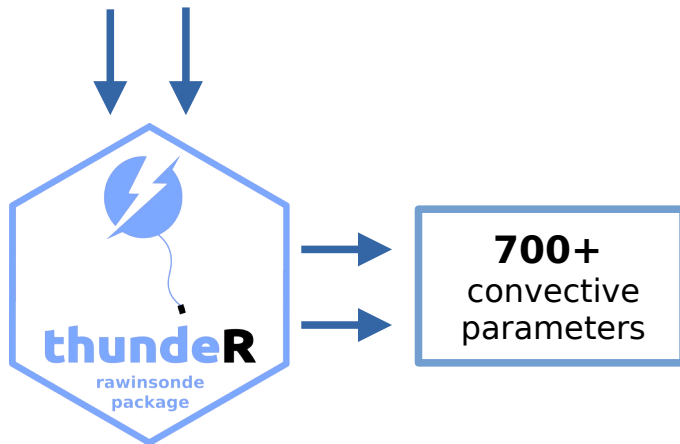
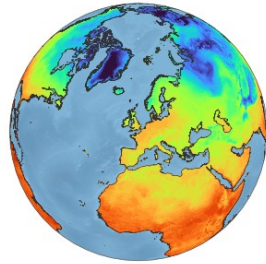


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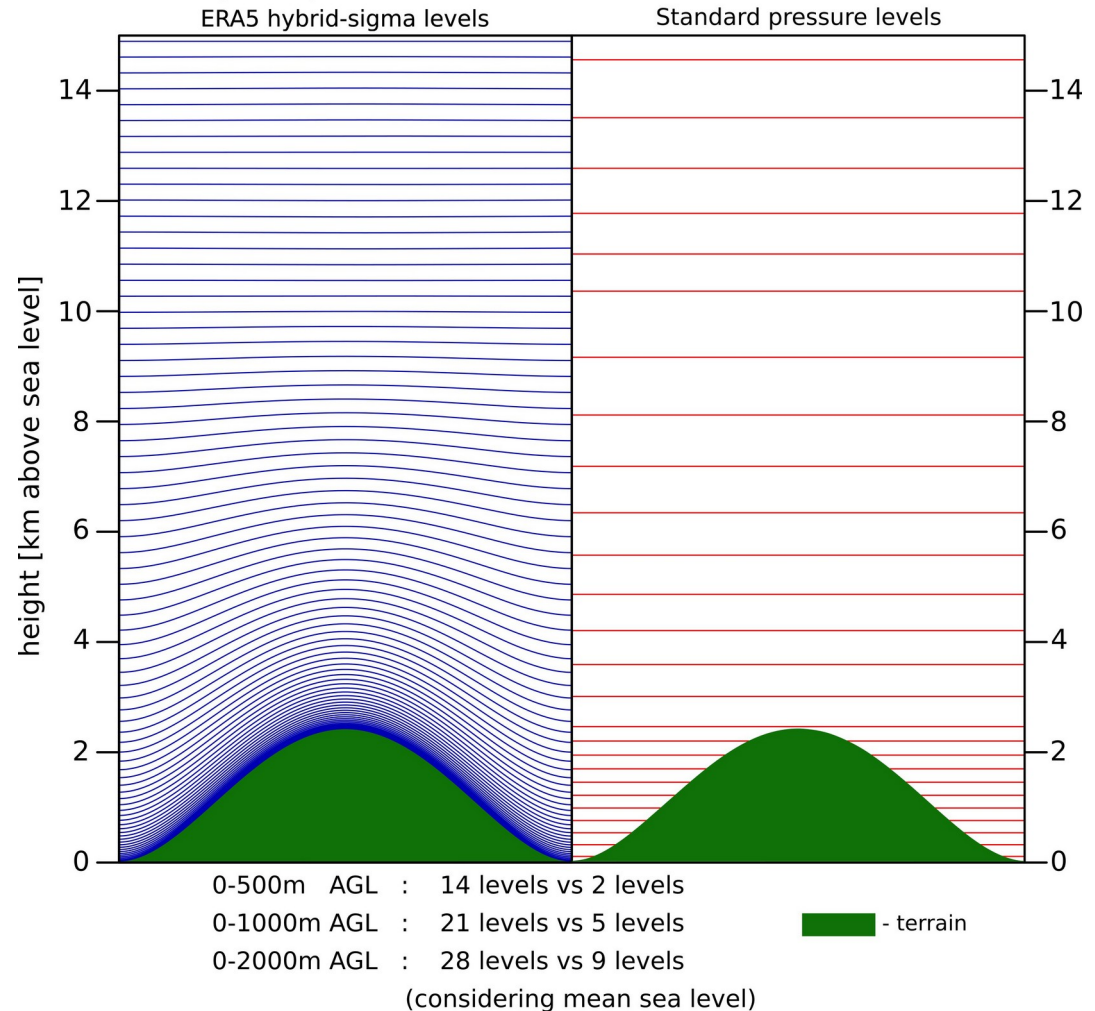


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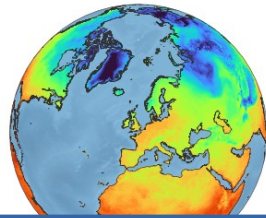


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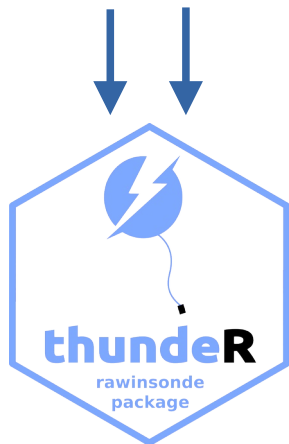


498,531,600,000 profiles
(~500 TB of data)

Thanks to **PCSS!**

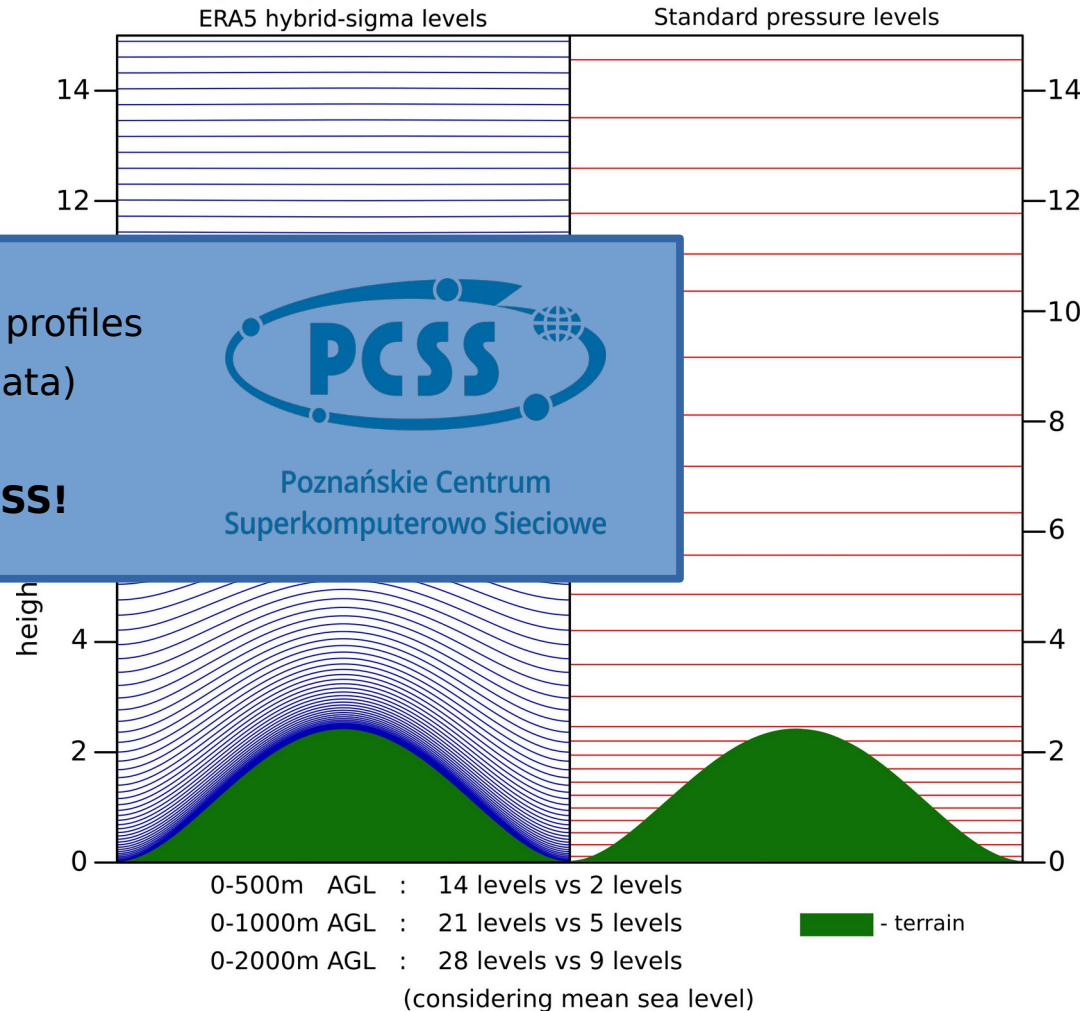


Poznańskie Centrum
Superkomputerowo Sieciowe



700+
convective
parameters

www.rawinsonde.com





Station
11952 POPRAD/GANOVCE LO

Source
TEMP

Date (UTC) 2008-08-15 **Hour (UTC)** 12

Parcel curve
Mixed-layer (0-1000m)

Entrainment CAPE
no

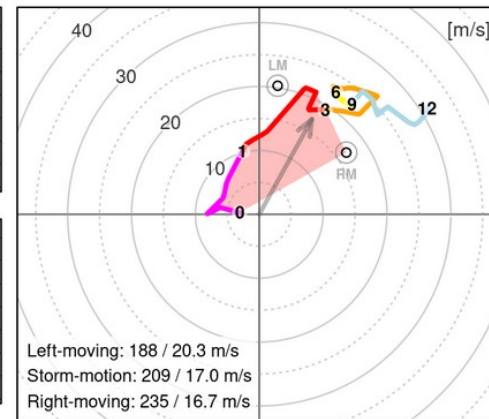
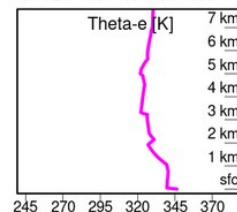
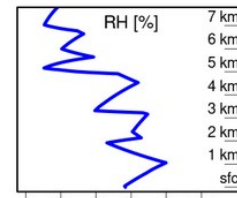
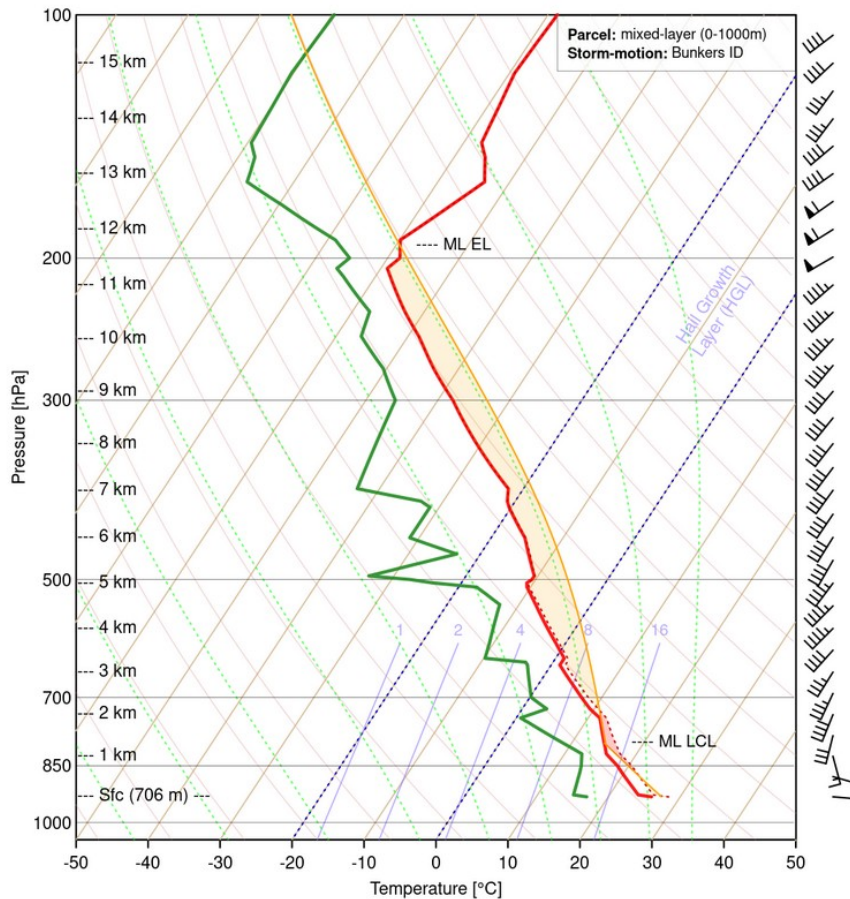
DCAPE area no **SRH area** 0-3km RM

Manual storm-motion
Speed: none **Direction**: none

Generate!
(wait several seconds)

Visualisation Parameters Raw Data Raw Data - editable (experimental) About

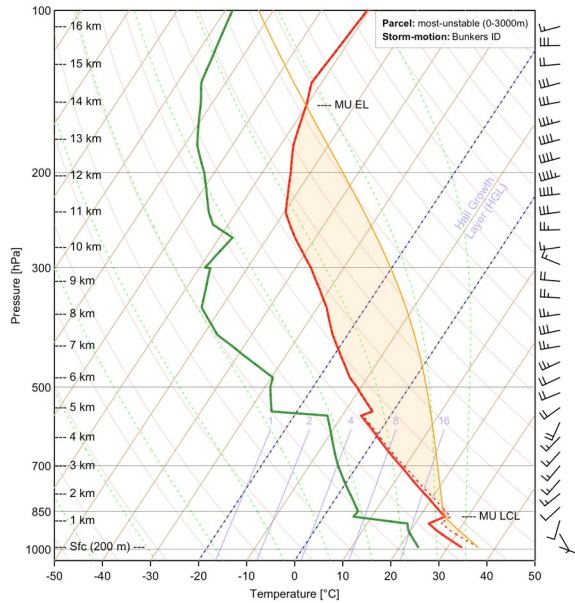
WMO ID: 11952 (20.32 E 49.03 N), 15 Aug 2008 (Friday) 1200 UTC



	MIXR [g/kg]	CAPE [J/kg]	CAPE03 [J/kg]	CAPEHGL [J/kg]	CIN [J/kg]	LI [K]	LCL [m]	LFC [m]	EL [m]	WMAXSHEAR [m2/s2]
SB	13.2	2584	132	1166	0	-7	1140	1140	11990	1739 (E 1739)
MU	13.2	2584	132	1166	0	-7	1140	1140	11990	1739 (E 1739)
ML	11.6	1507	51	714	-32	-5	1320	2105	11705	1328 (E 1327)

Bulk wind shear [m/s]	SRH RM [m2/s2]	SRH LM [m2/s2]	Mean wind [m/s]	Lapse rate [K/km]
Sfc - 1 km: 9.7	Sfc - 100 m: 41	74	Sfc - 1 km: 6.4	Sfc - 1 km: 9.7
Sfc - 3 km: 21.0	Sfc - 500 m: 62	78	Sfc - 2 km: 9.5	Sfc - 3 km: 7.8
Sfc - 6 km: 24.2	Sfc - 1 km: 195	85	Sfc - 1 km: 17.6	Sfc - 3 km: 5.9
Sfc - 8 km: 23.9	Sfc - 3 km: 357	43	Sfc - 6 km: 17.0	500700 hPa: 6.6
Sfc - HGL: 27.6				
Effec. (SB): 24.2	Precip. water [mm]: 30		Moisture flux [g/s/m2]: 93	SHIP: 1.4
Effec. (MU): 24.2	2 - 5 km RH [%]: 58		4 km DCAPE [J/kg]: 801	SCP: 18.5
Effec. (ML): 24.2	Sfc - 2 km RH [%]: 64		4 km delta theta-e [K]: 20	STP: 0.7

Conceptual model for testing skill of parameters

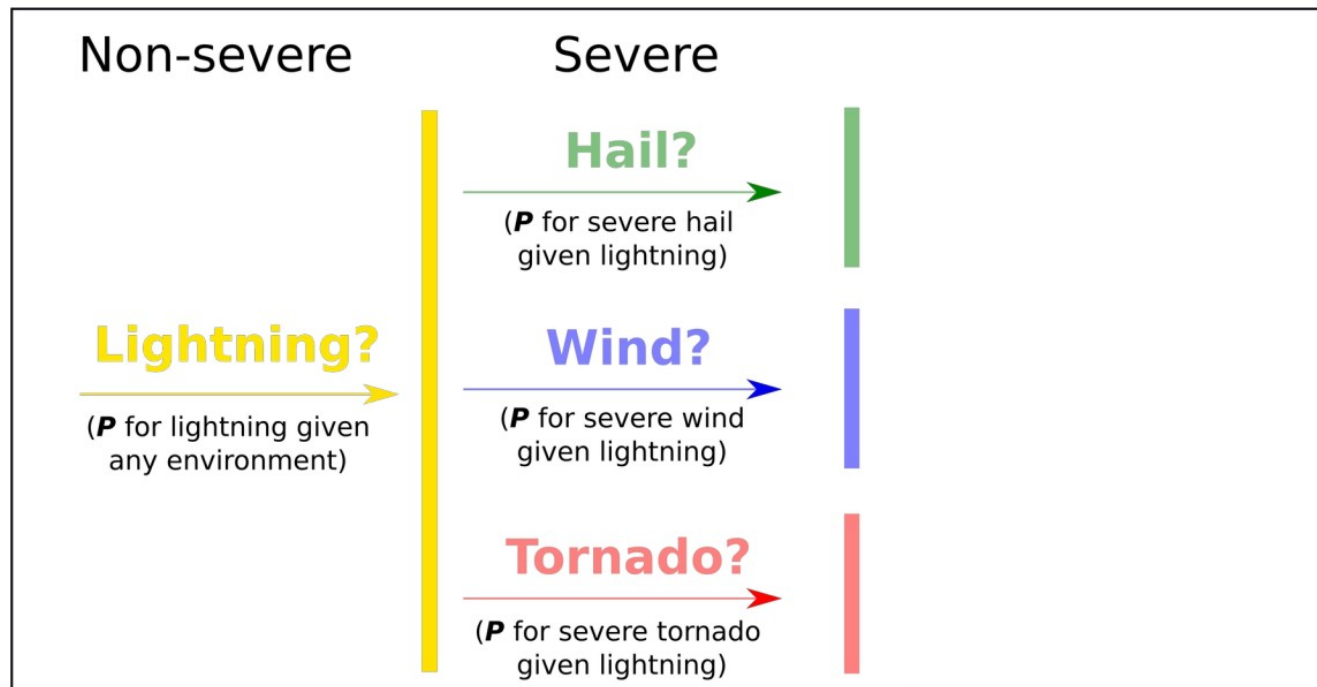
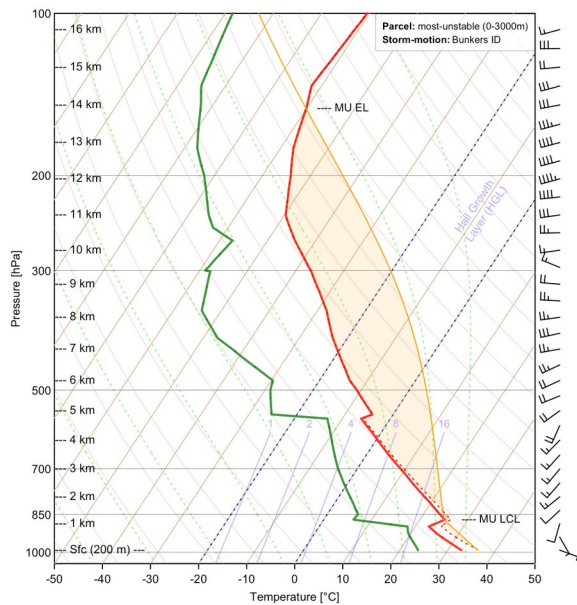


Non-severe

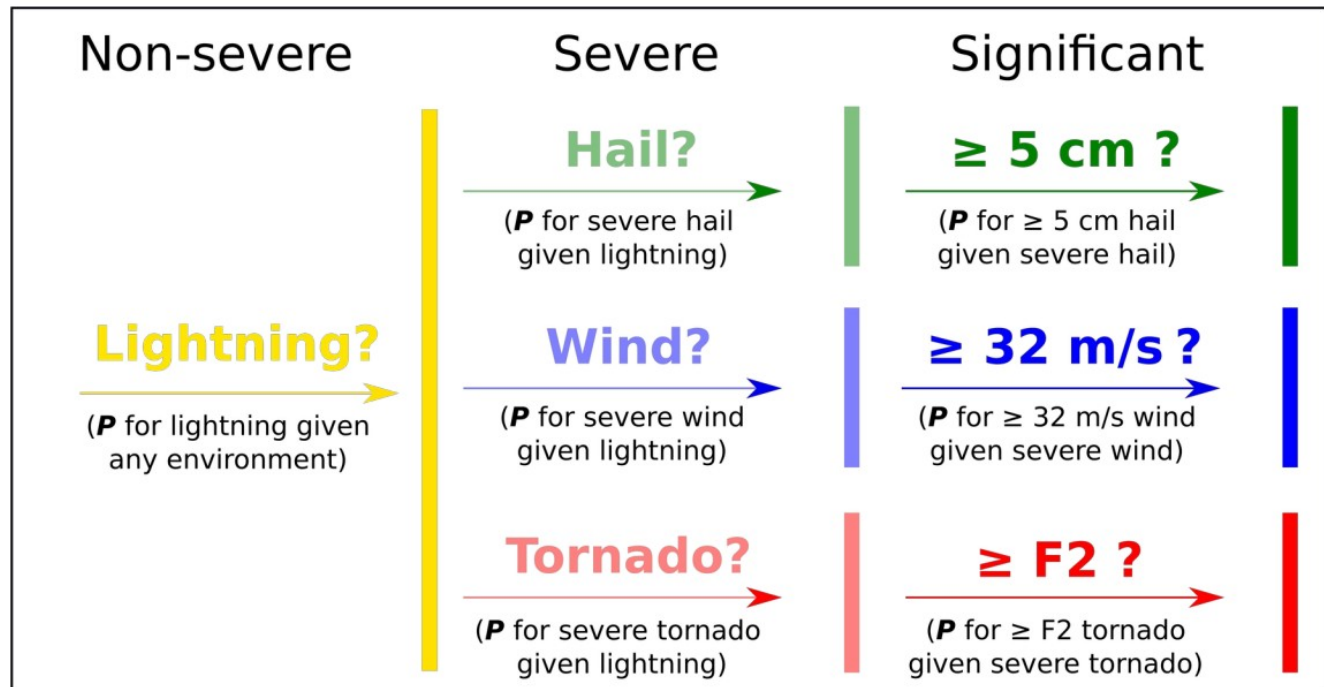
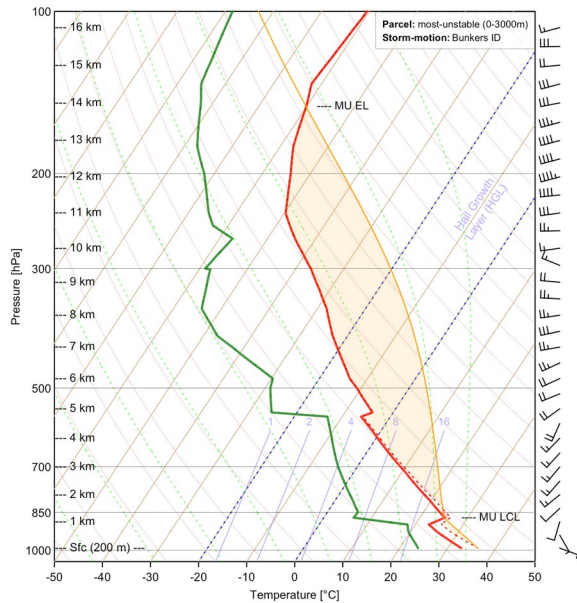
Lightning?

(P for lightning given any environment)

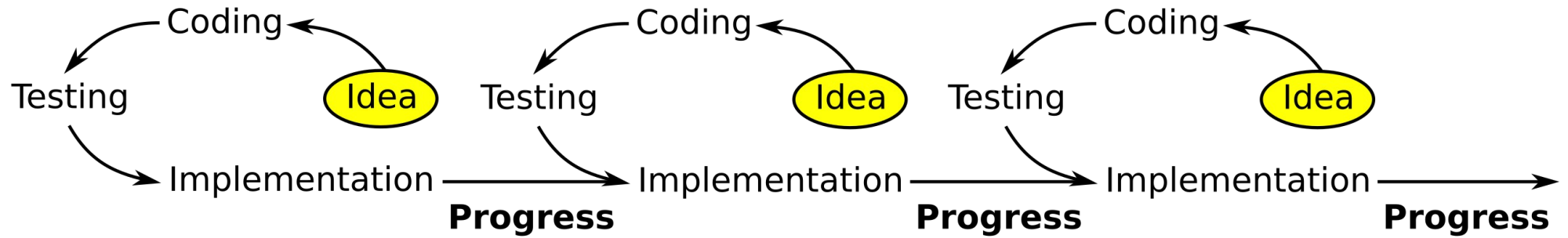
Conceptual model for testing skill of parameters



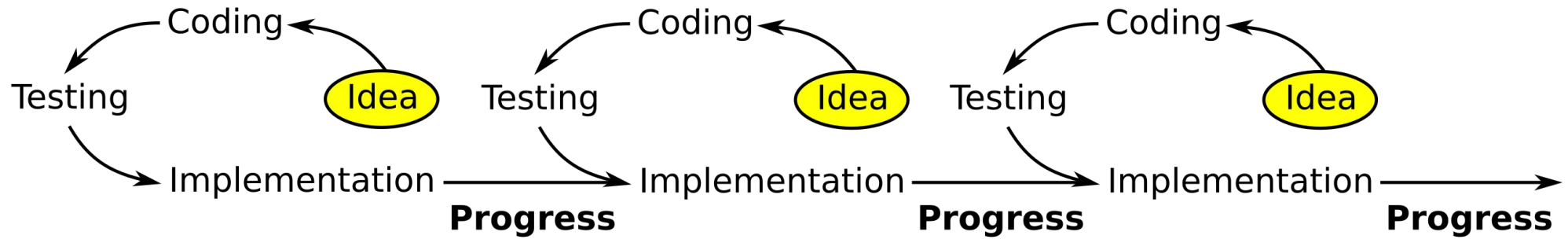
Conceptual model for testing skill of parameters



Once environmental dataset collocated with observations was completed, it was possible to iteratively test new concepts



Once environmental dataset collocated with observations was completed, it was possible to iteratively test new concepts

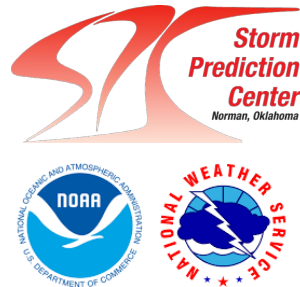


... among dozens of tested ideas (> 700 parameters), only several led to improvements in the skill of convective parameters.

Probability of convective hazard occurring



Probability of convective hazard occurring

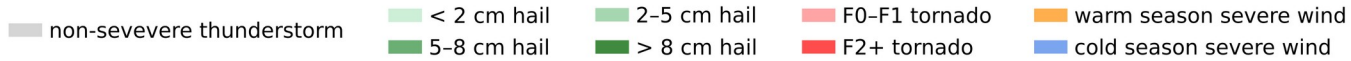
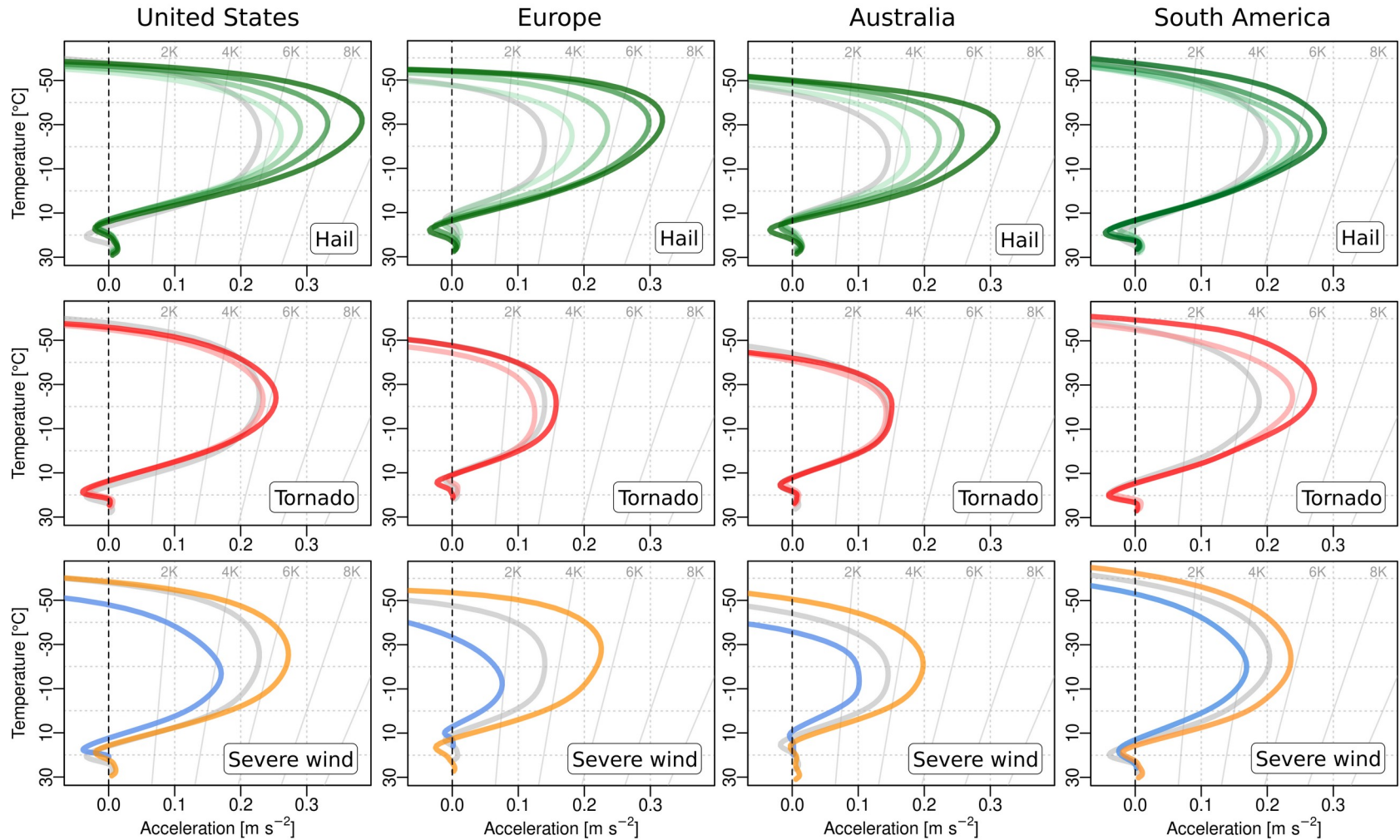


Definition of threat levels used by SPC

Probability	Lightning	Tornado	Wind	Hail
>10% lightning	TSTM	N/A	N/A	N/A
>2% severe	N/A	MRGL	N/A	N/A
>5% severe	N/A	SLGT	MRGL	MRGL
>10% severe	N/A	ENH	MRGL	MRGL
>15% severe	N/A	ENH	SLGT	SLGT
>15% severe >10% sig sev	N/A	MDT	SLGT	SLGT
>30% severe	N/A	MDT	ENH	ENH
>30% severe >10% sig sev	N/A	HIGH	ENH	ENH
>45% severe	N/A	HIGH	ENH	ENH
>45% severe >10% sig sev	N/A	HIGH	MDT	MDT
>60% severe	N/A	HIGH	MDT	MDT
>60% severe >10% sig sev	N/A	HIGH	HIGH	MDT

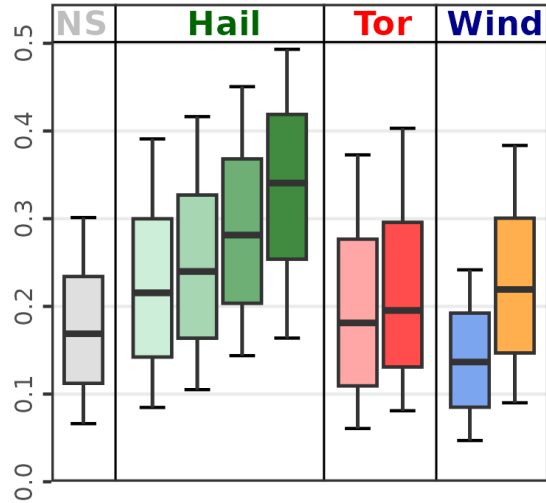
Environments

Vertical profile of parcel buoyancy

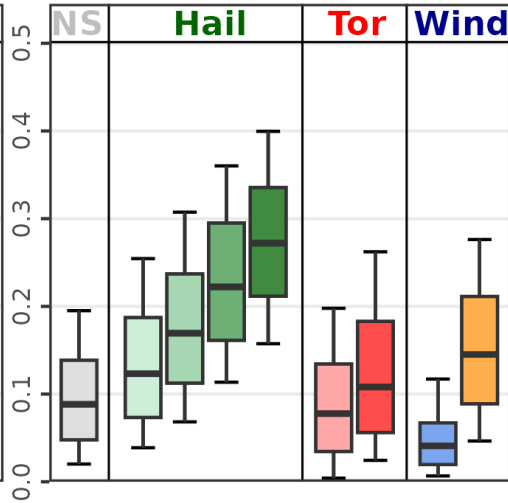


Peak buoyancy between -10°C and -40°C

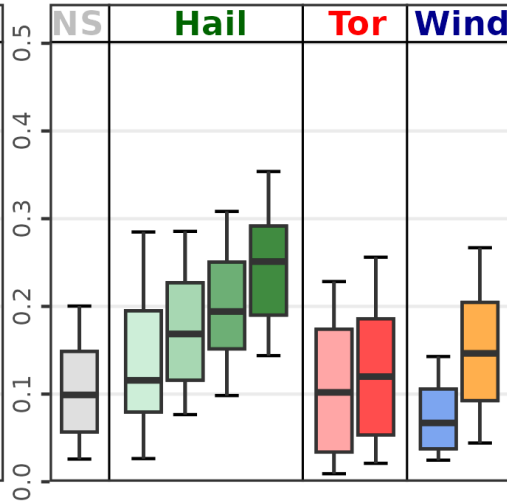
United States



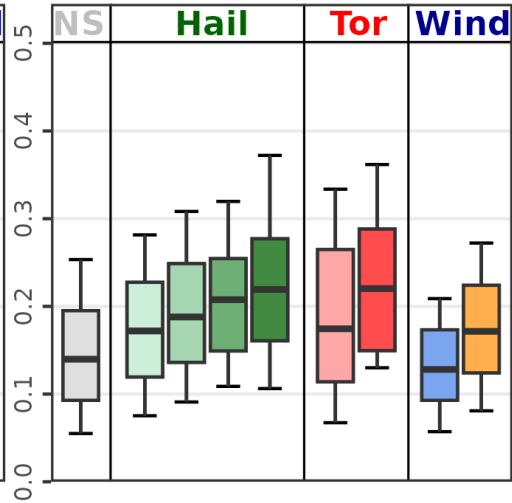
Europe



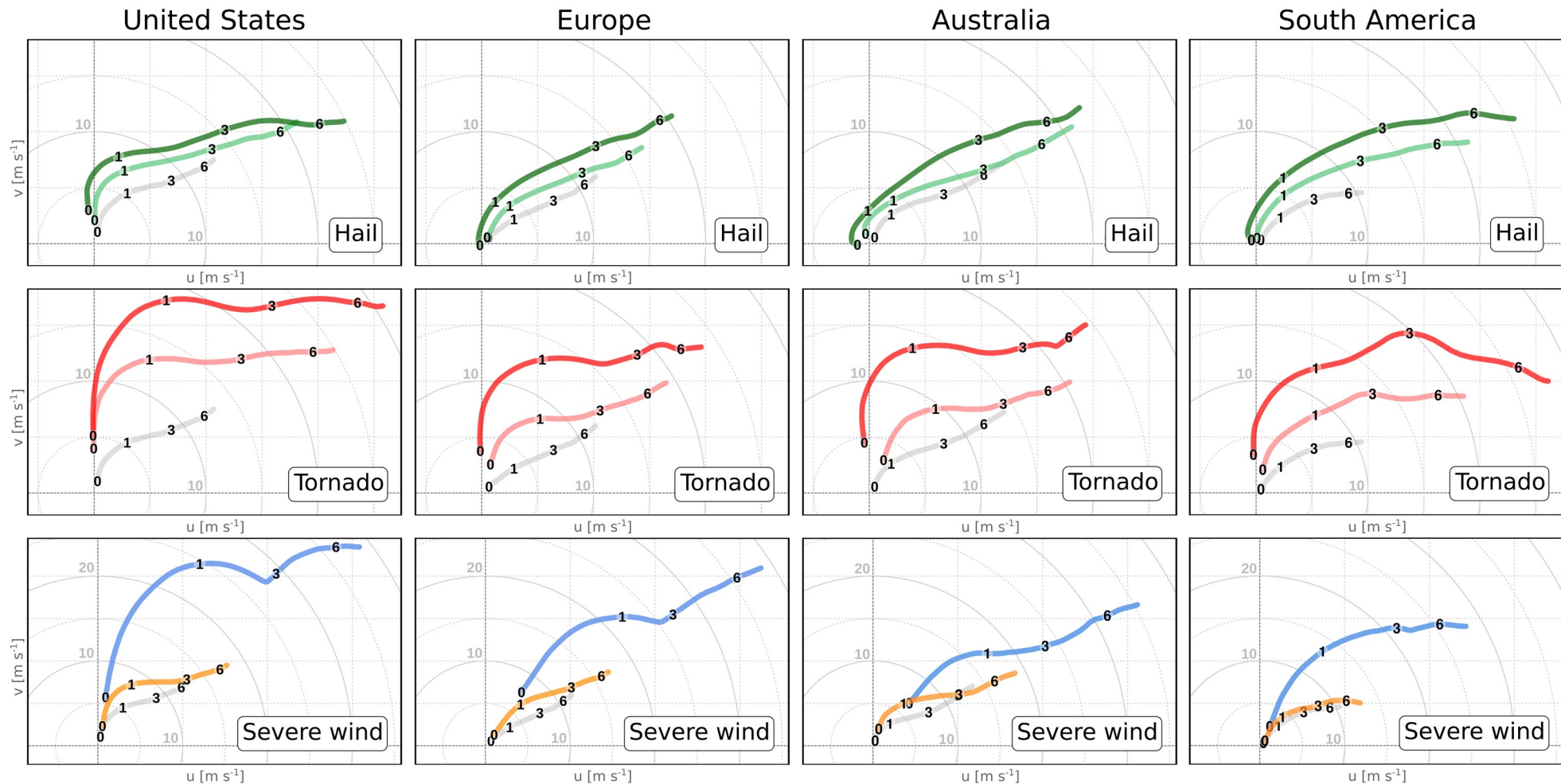
Australia



South America

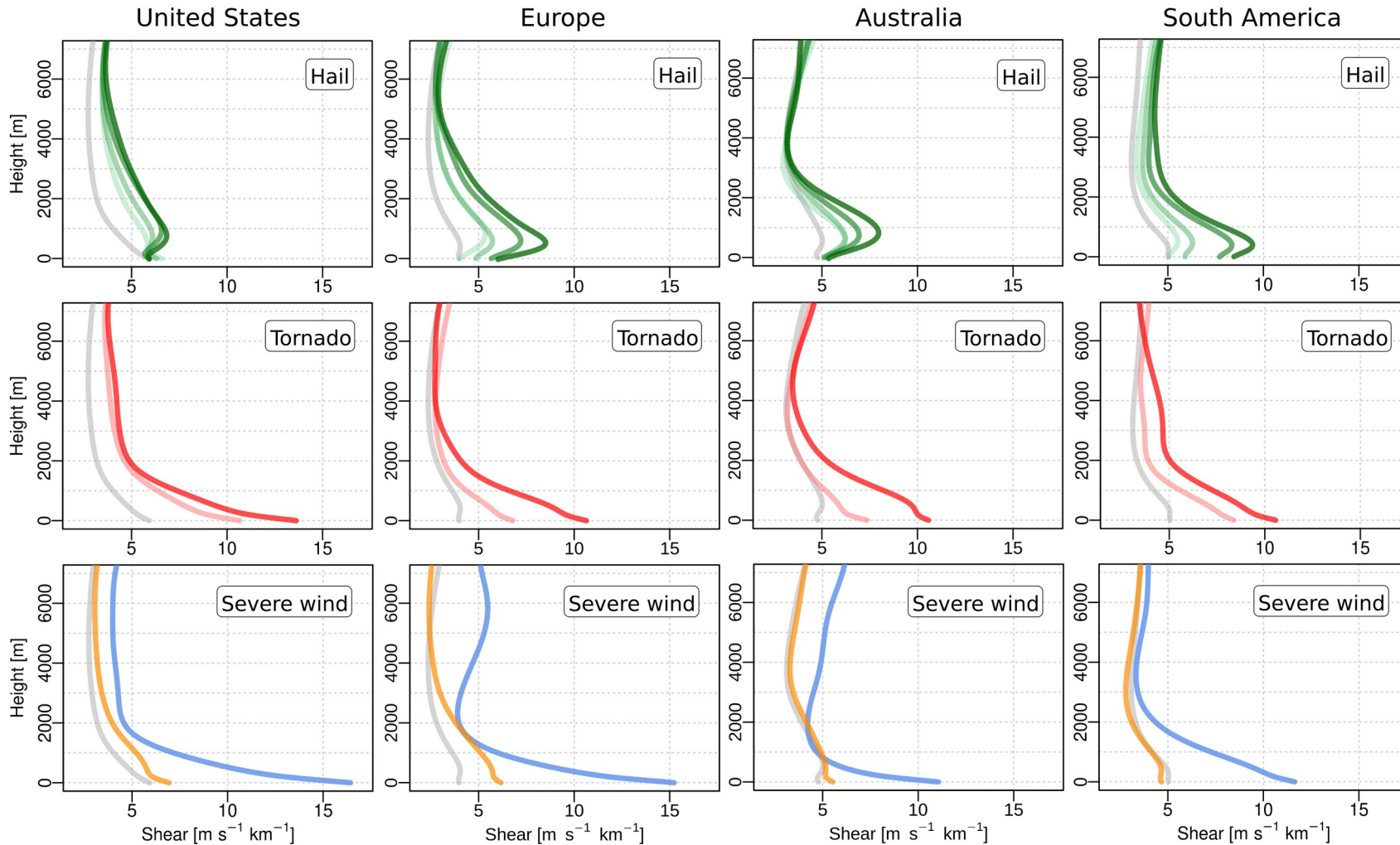


Mean hodographs



non-severe thunderstorm
 2-5 cm hail
 F0-F1 tornado
 warm season severe wind
 > 5 cm hail
 F2+ tornado
 cold season severe wind

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



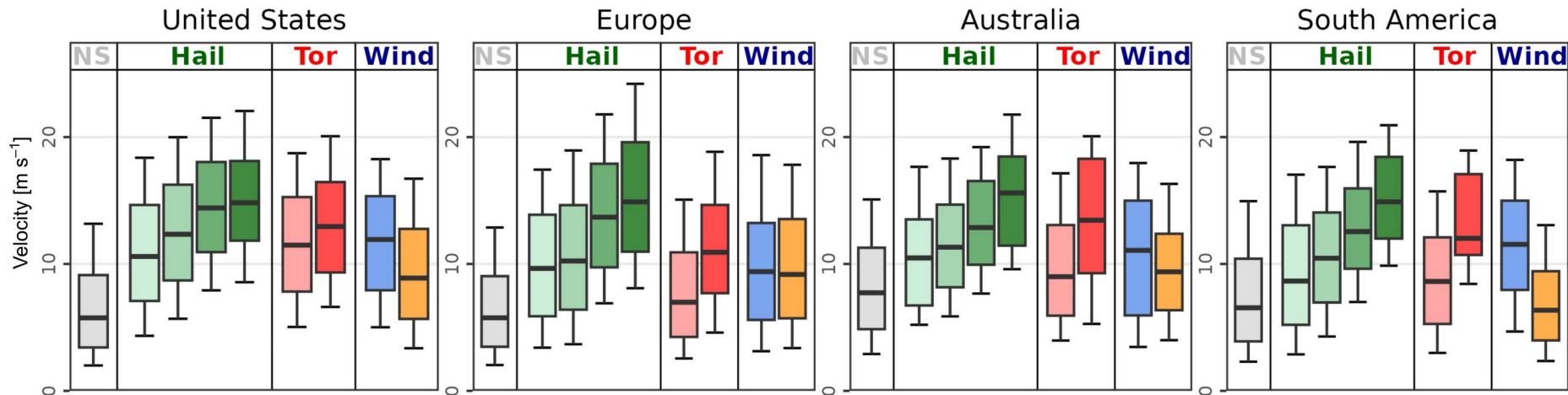
grey non-severe thunderstorm

light green < 2 cm hail
 medium green 2-5 cm hail
 dark green 5-8 cm hail
 very dark green > 8 cm hail

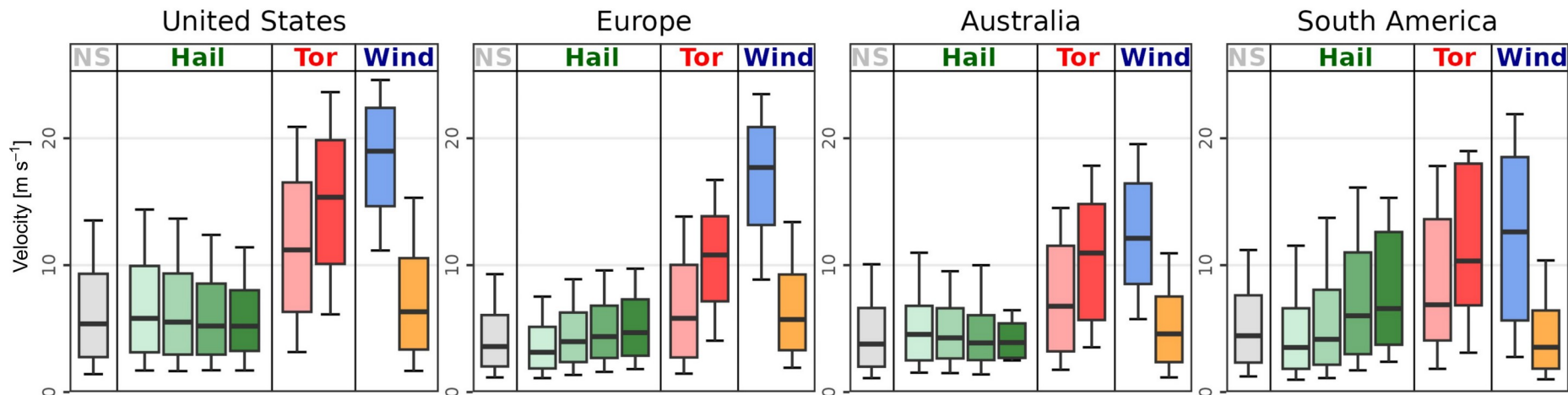
light red F0-F1 tornado
 dark red F2+ tornado

orange warm season severe wind
 blue cold season severe wind

a) **Bulk wind shear between 1 and 3 km AGL**

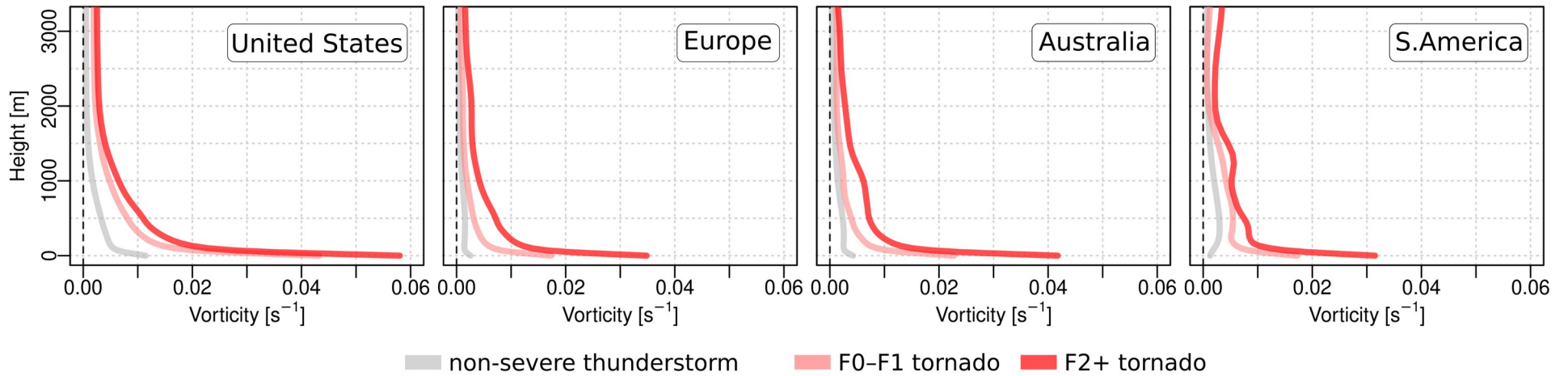


b) **Bulk wind shear between surface and 1 km AGL**

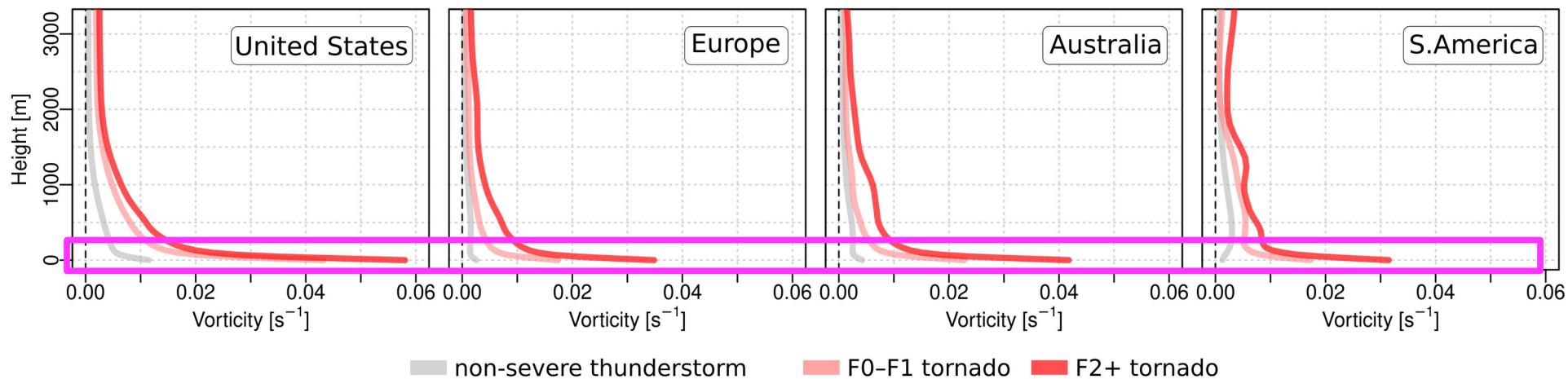


non-severe thunderstorm
 2-5 cm hail
 > 5 cm hail
 F0-F1 tornado
 F2+ tornado
 warm season severe wind
 cold season severe wind

Vertical profile of streamwise vorticity



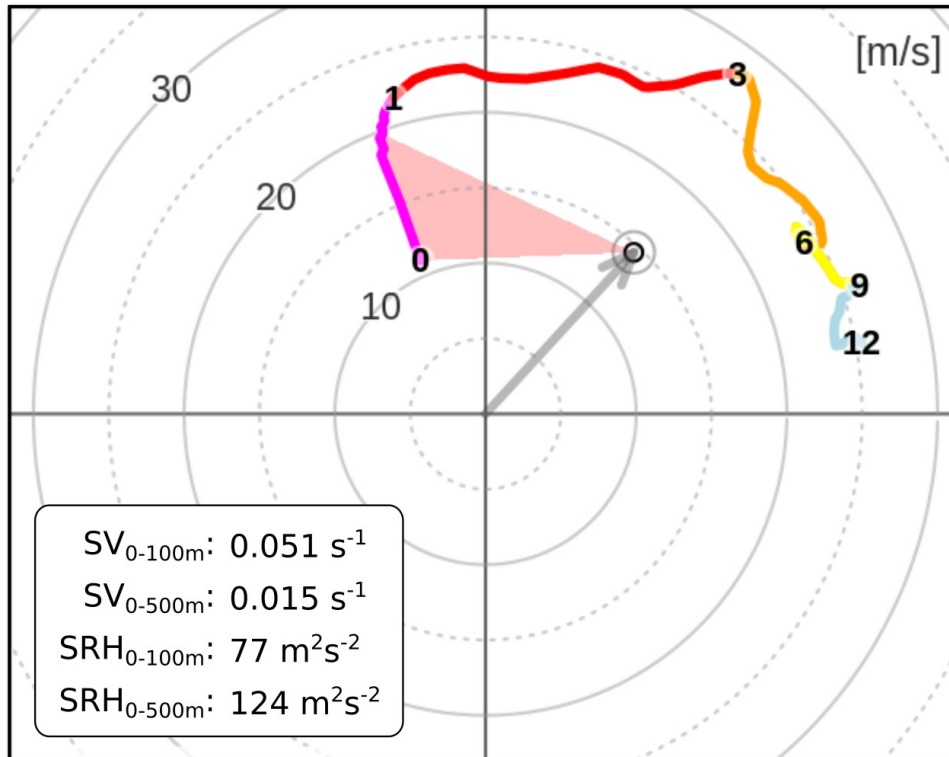
Vertical profile of streamwise vorticity



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

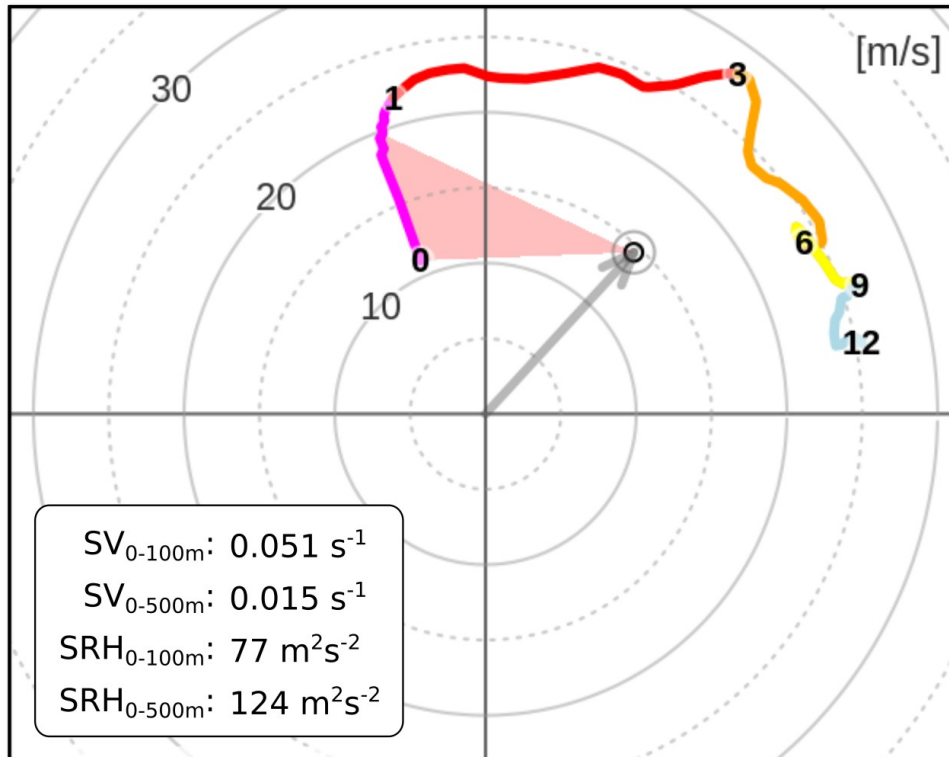
Pre-convective wind profile for F4 tornado in Pilger (Nebraska) on 16 June 2014

No correction

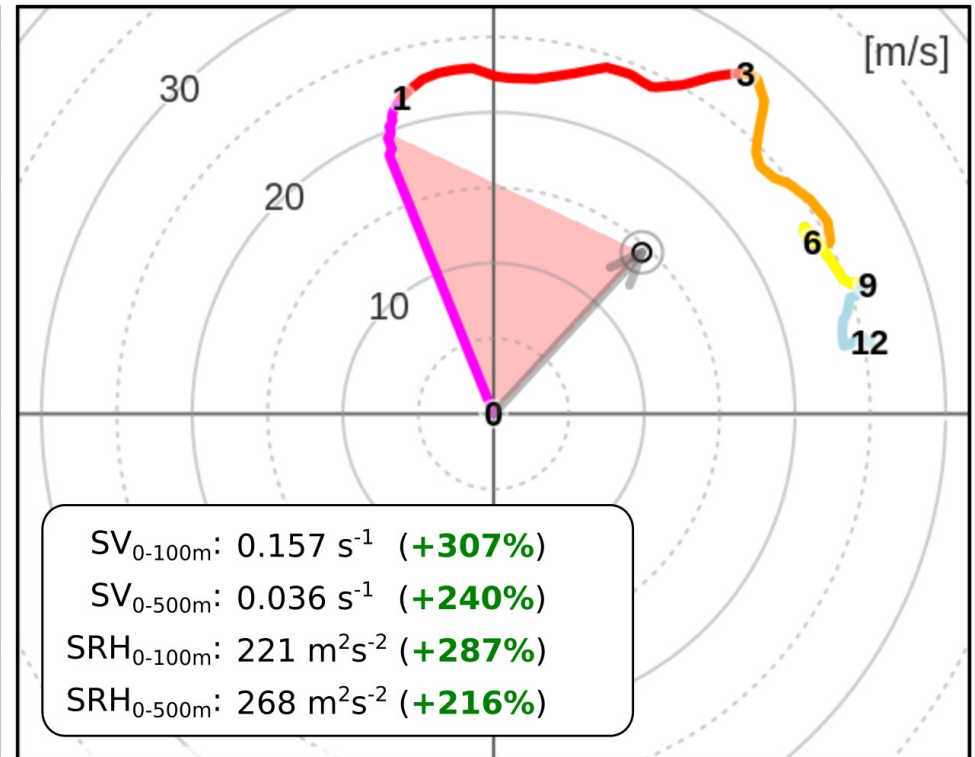


Pre-convective wind profile for F4 tornado in Pilger (Nebraska) on 16 June 2014

No correction



Hodograph extension

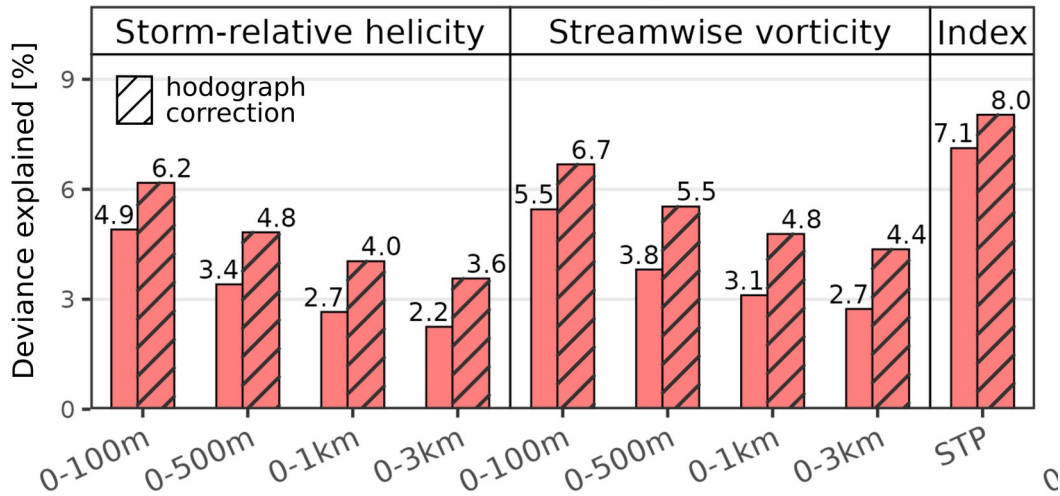


Can this correction improve prediction of tornadoes?

Can this correction improve prediction of tornadoes?

Yes!

Tornado (given lightning)

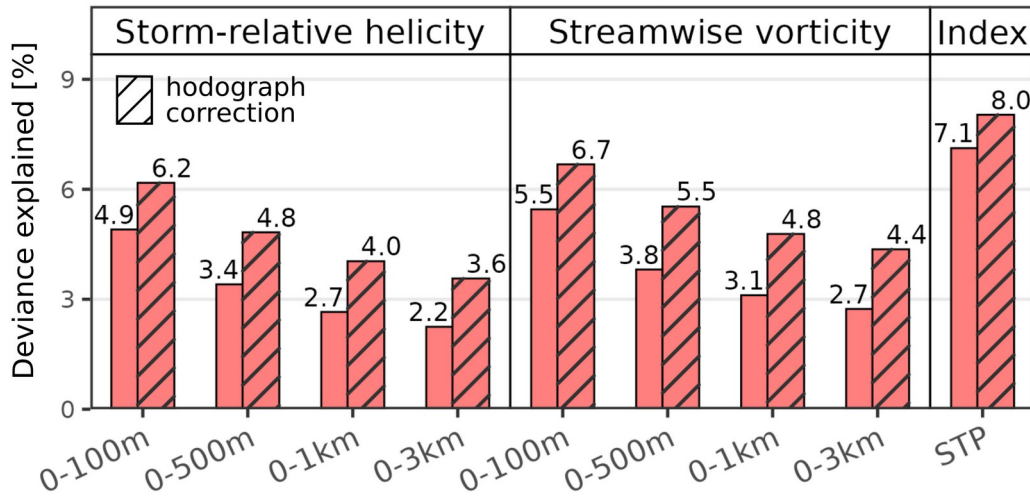


Can this correction improve prediction of tornadoes?

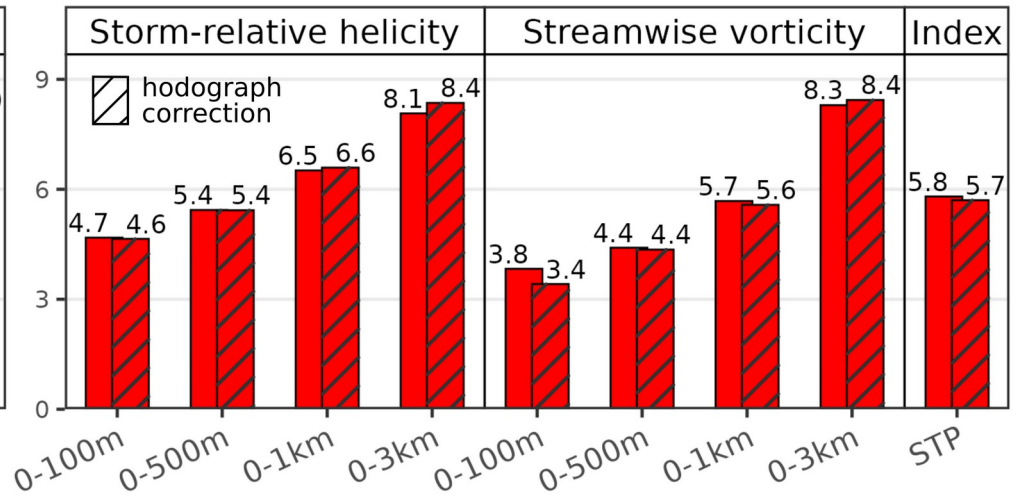
Yes!

but...

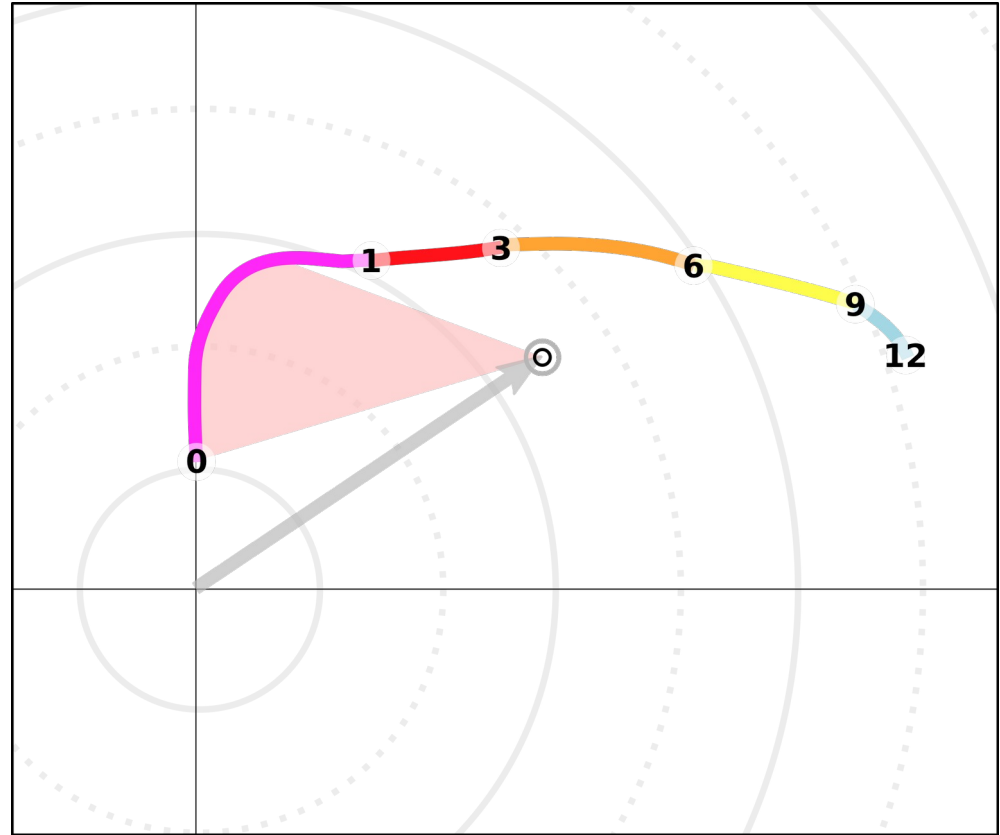
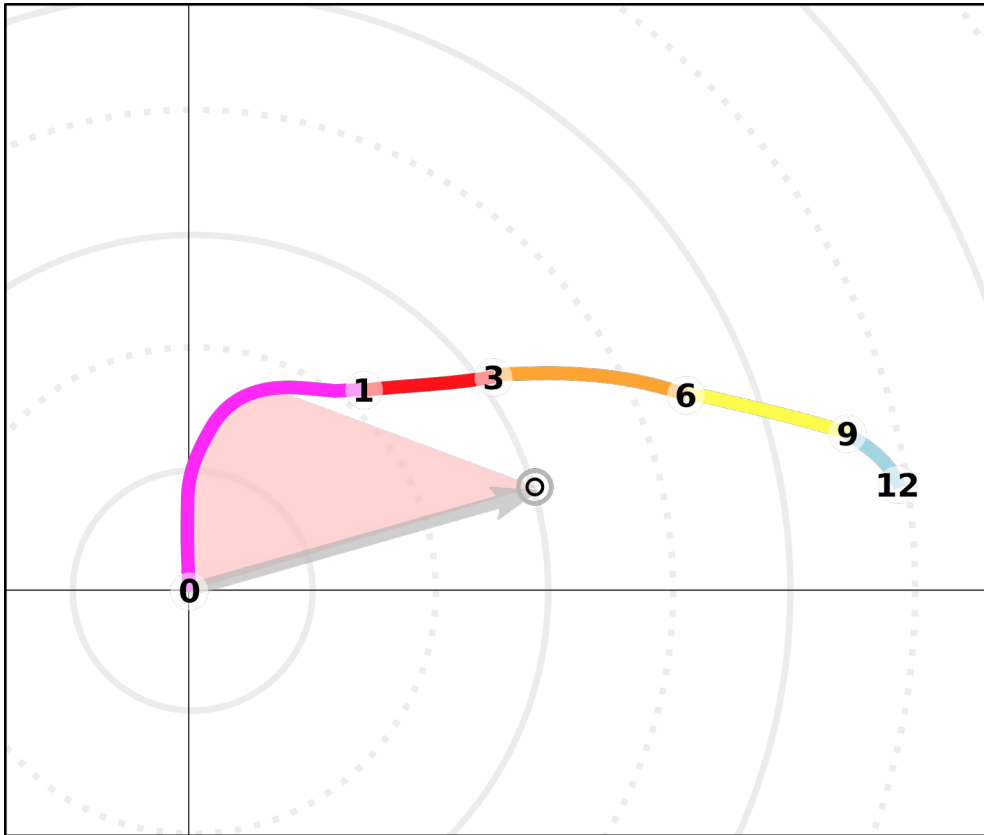
Tornado (given lightning)



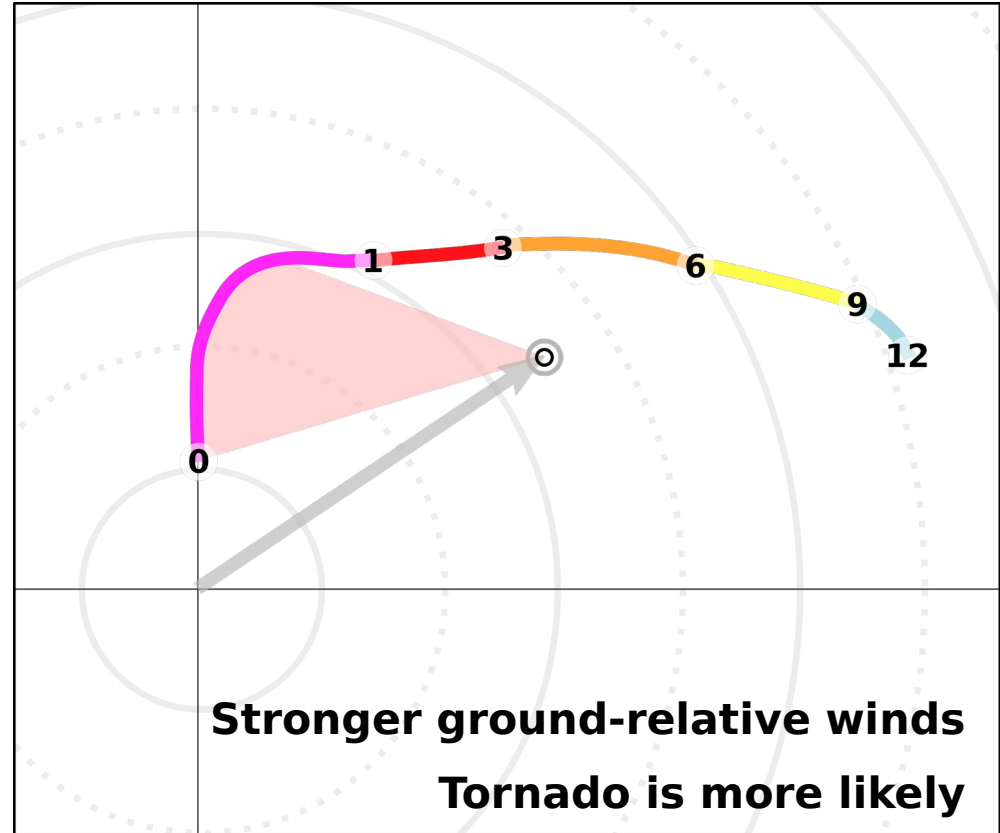
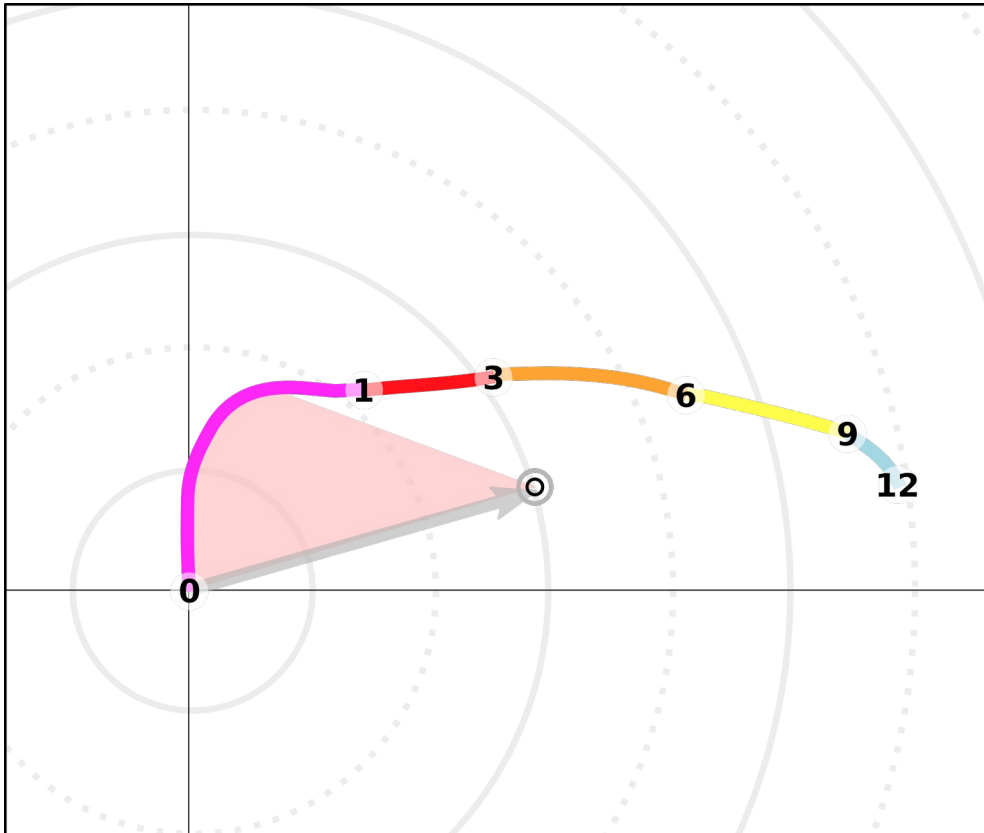
F2+ tornado (given tornado)



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

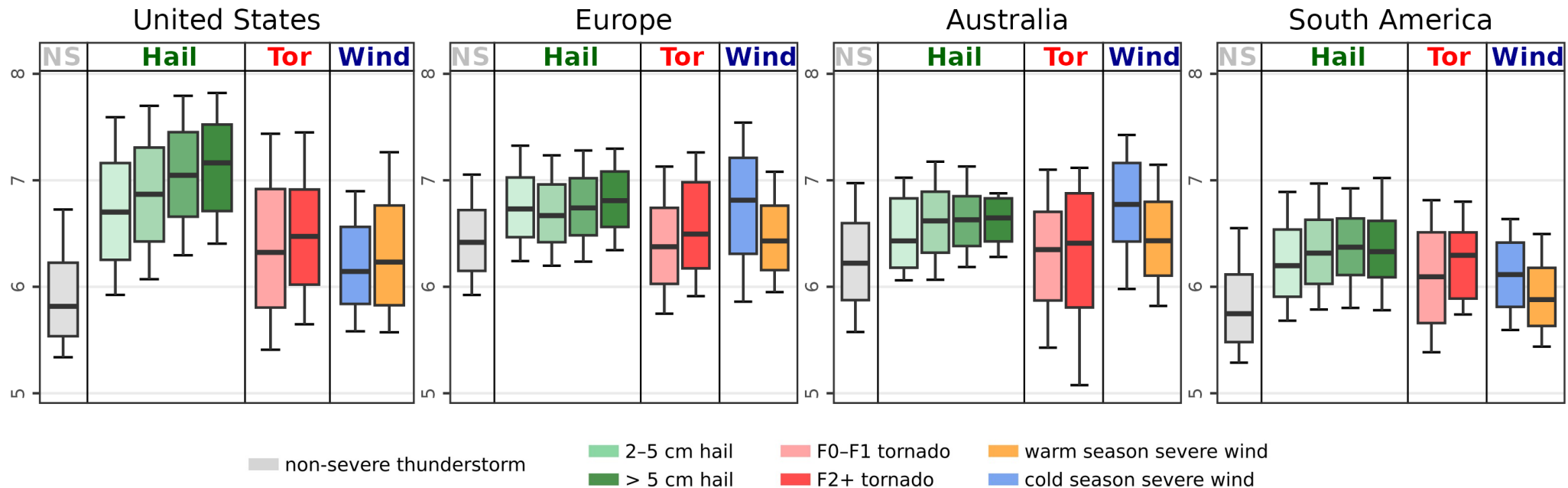


Hodographs with **identical shear** and storm-relative wind but different **ground-relative winds**



How about differences?

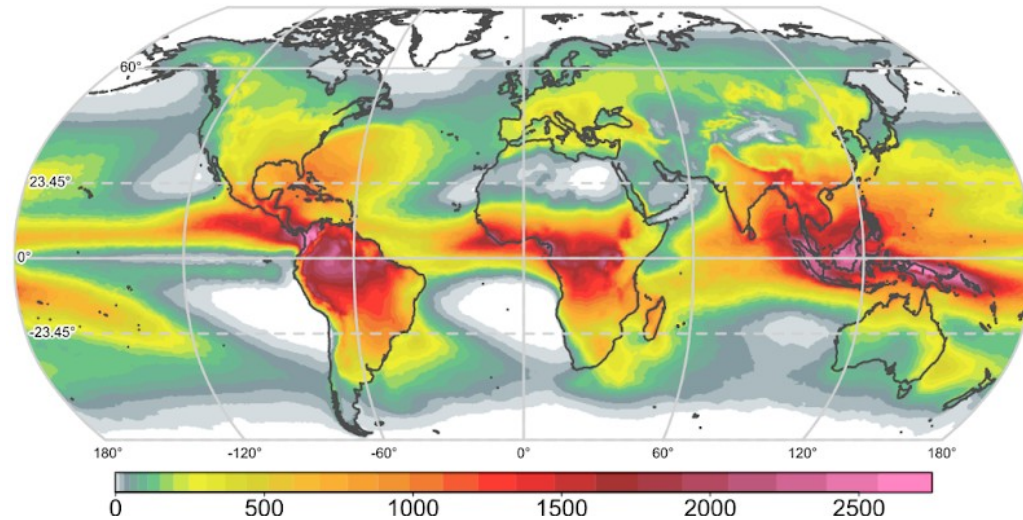
Lapse rate between 2 and 6 km AGL



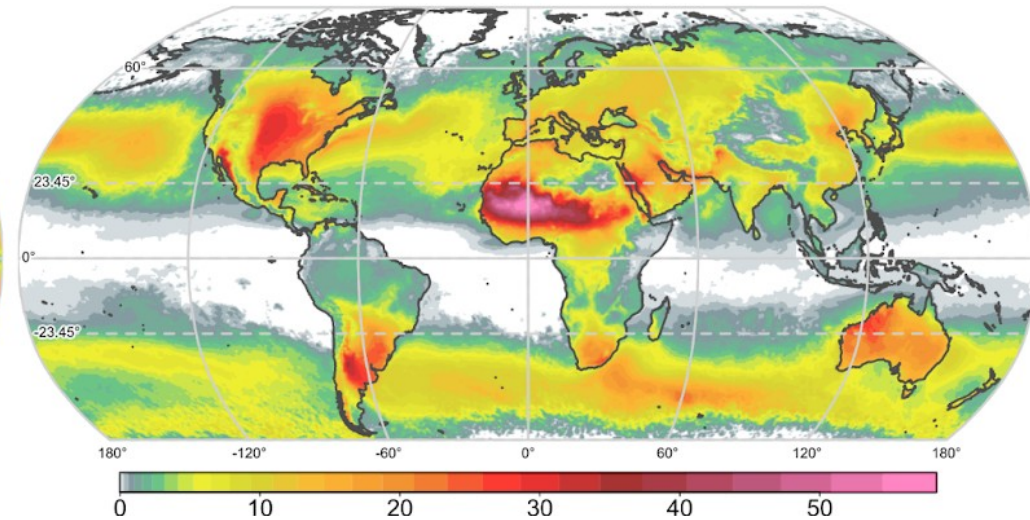
Climatology of modeled NOAA SPC risk levels (1950-2024)

Climatology of modeled SPC risk categories (1950-2024)

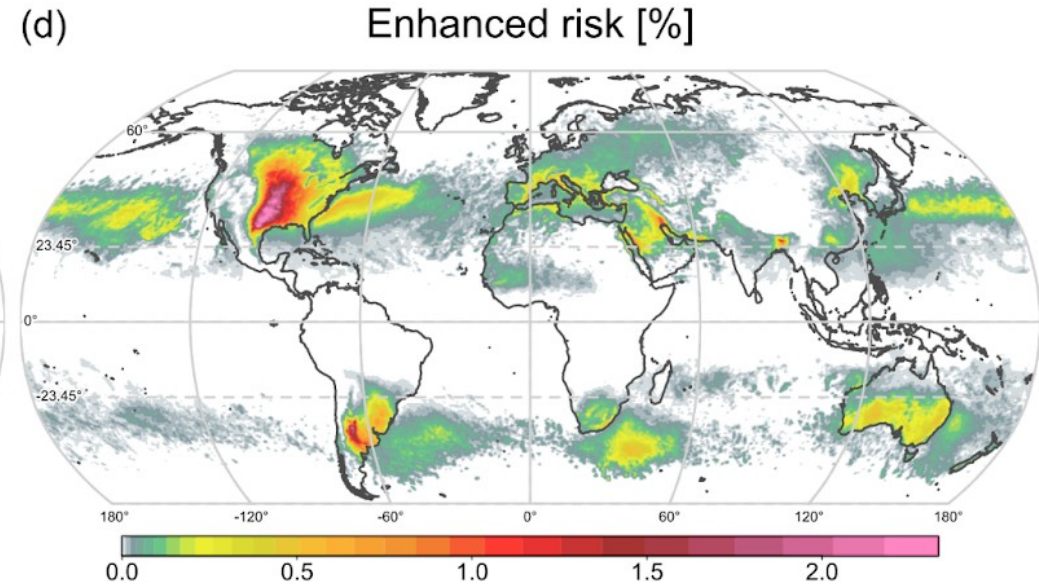
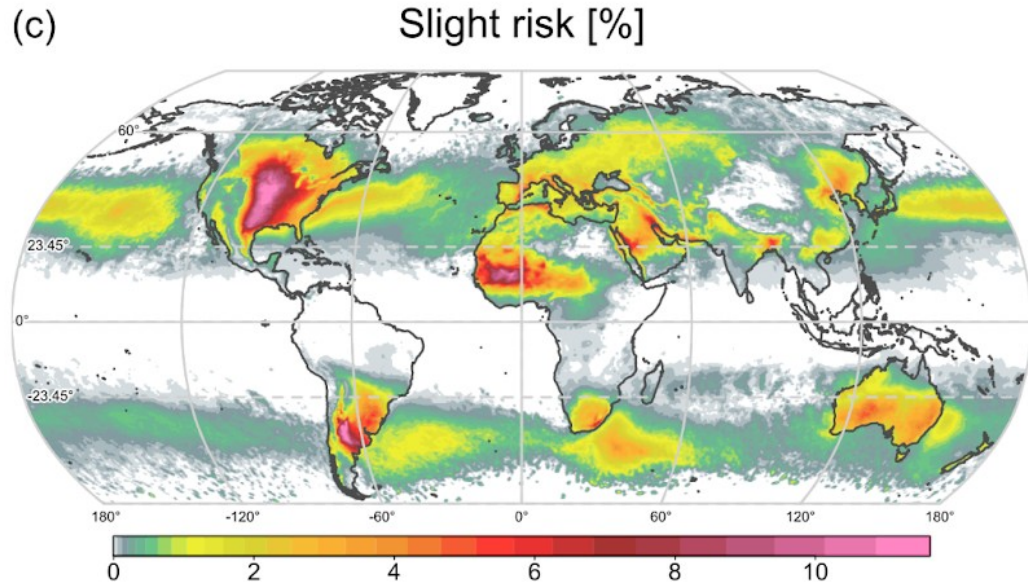
(a) Thunderstorm risk [hours]



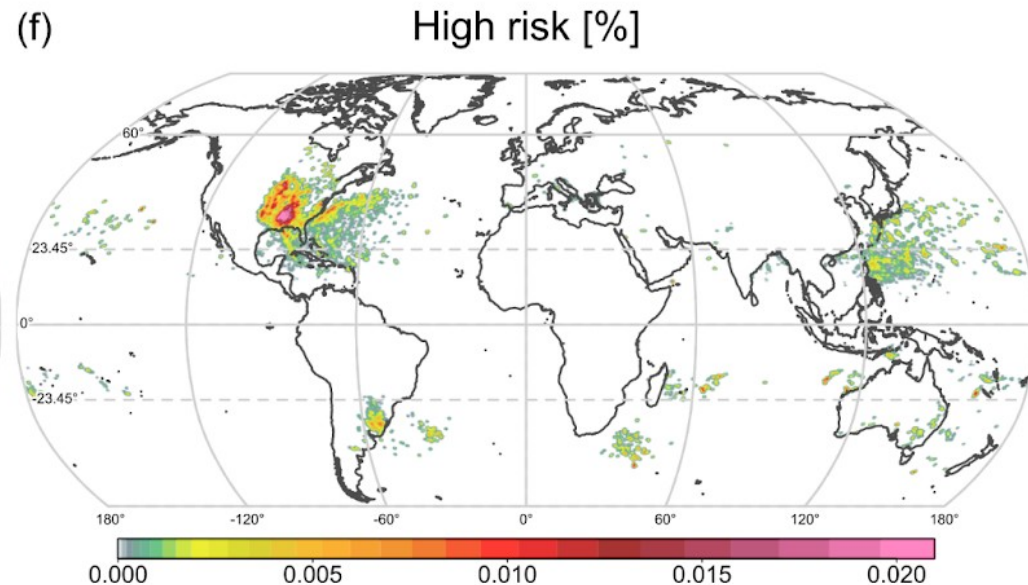
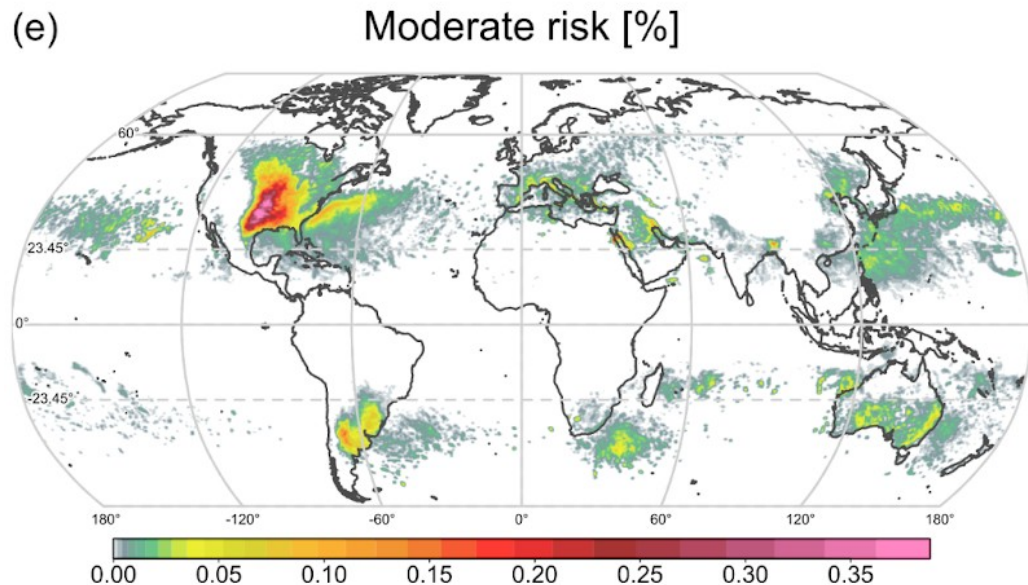
(b) Marginal risk [%]



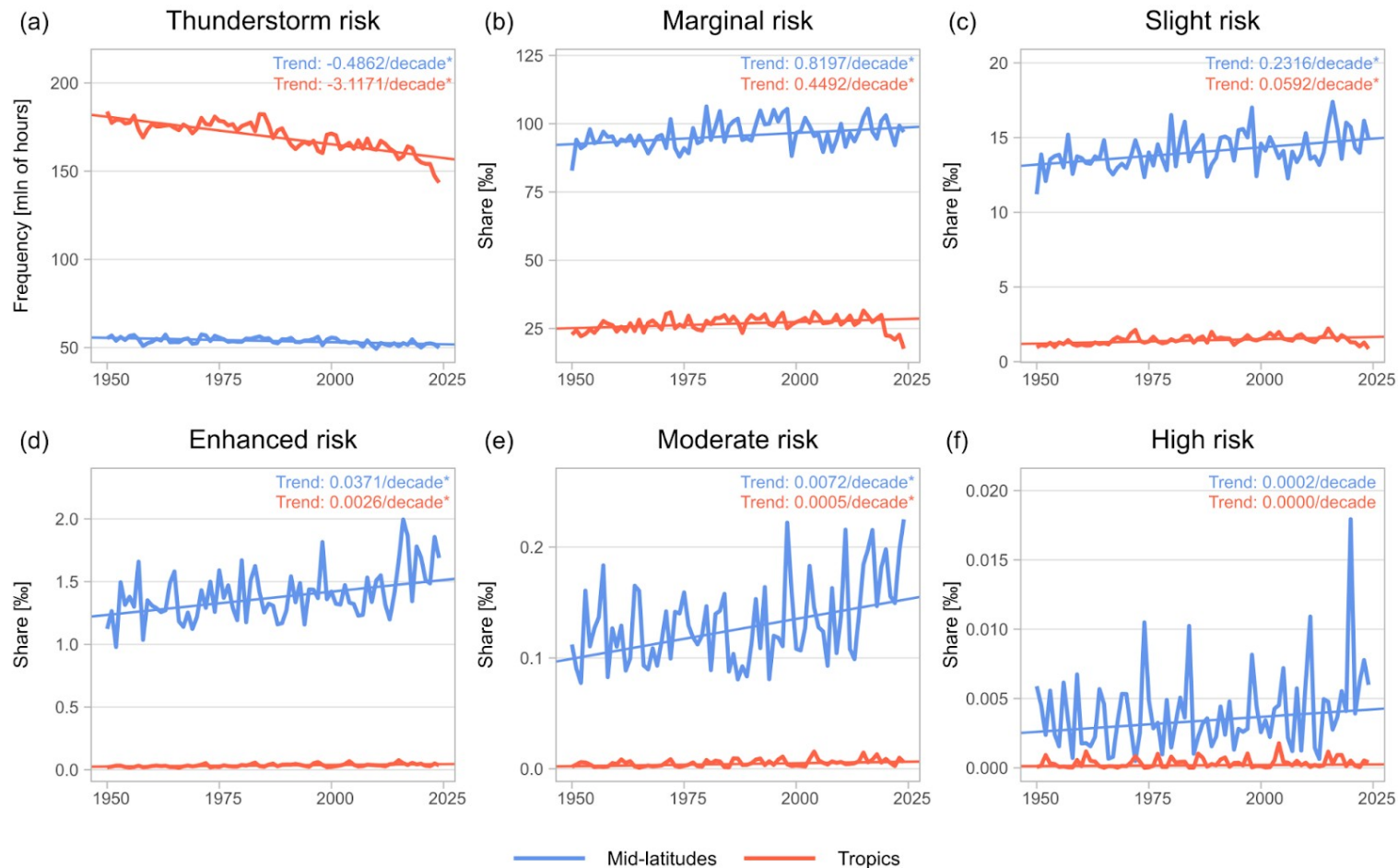
Climatology of modeled SPC risk categories (1950-2024)



Climatology of modeled SPC risk categories (1950-2024)

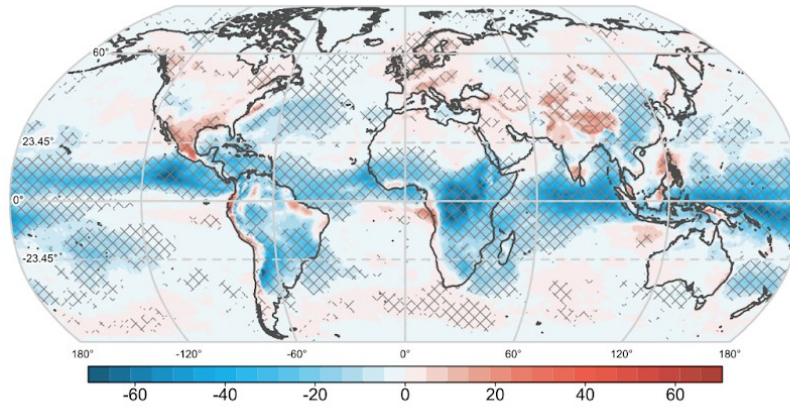


Multiannual variability in SPC risk categories



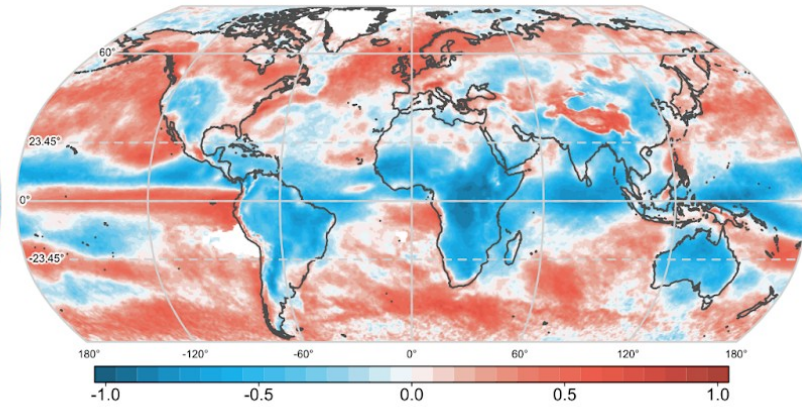
Long-term trends

(a) Thunderstorm risk [hours per decade]

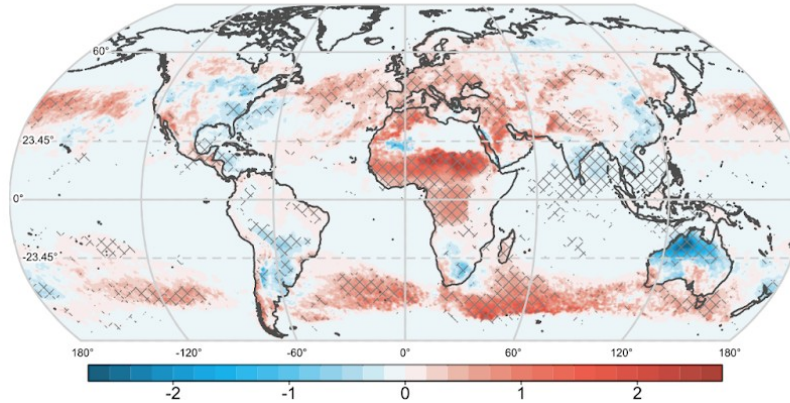


Correlation with 2-metre air temperature

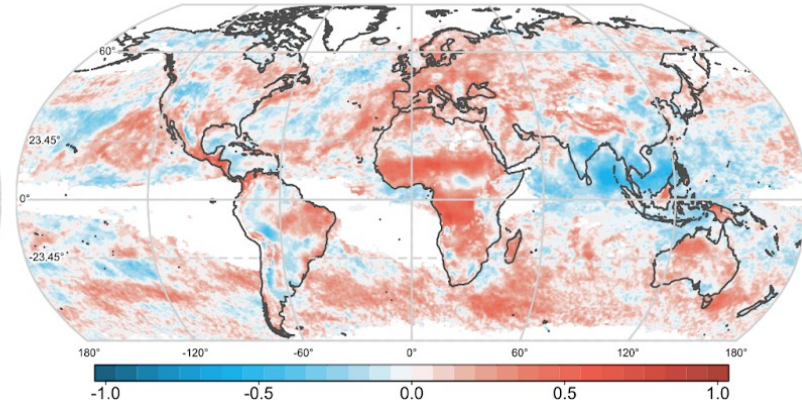
(b) Thunderstorm risk



(c) Marginal-high risk [% per decade]



(d) Marginal-high risk



**Application of developed models
in operational GEFS
(03.2025 - 08.2025)**

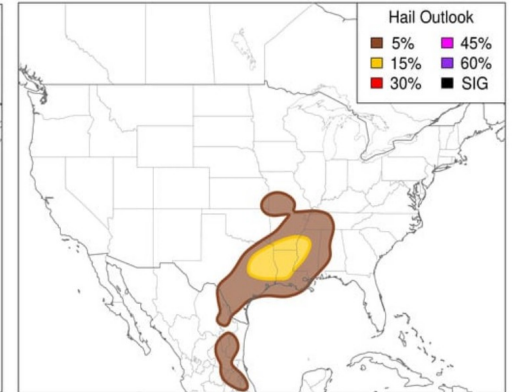
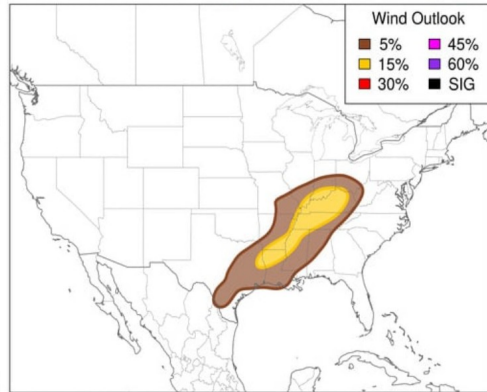
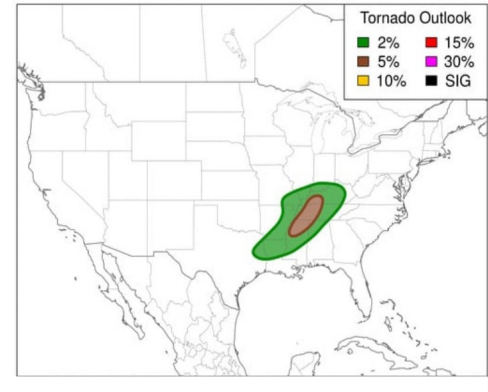
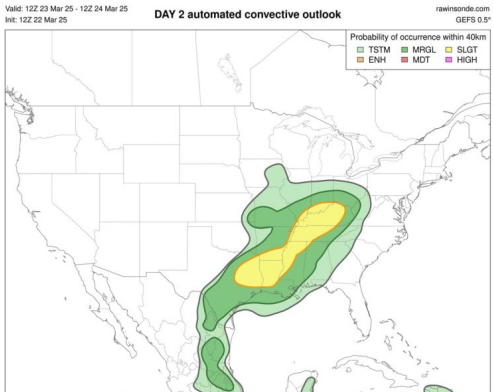
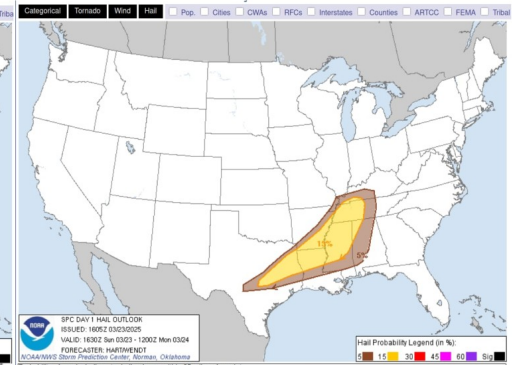
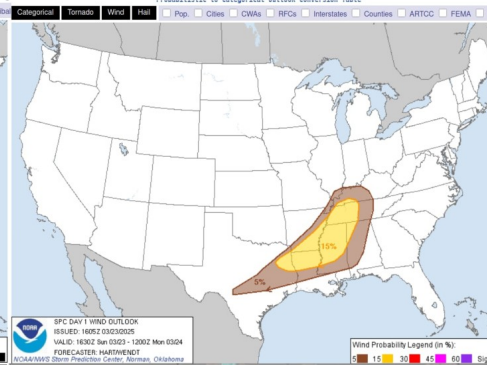
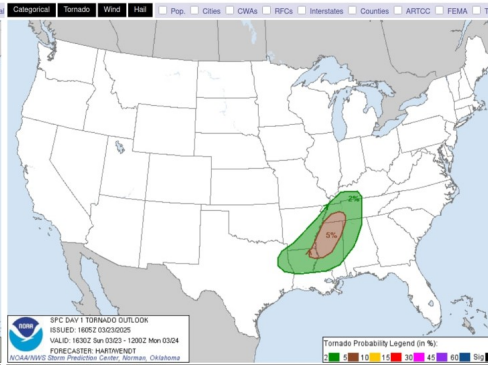
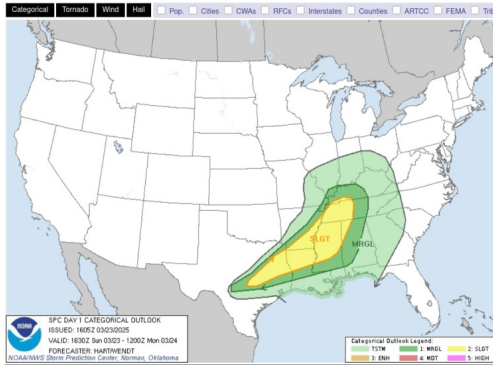
Comparison with SPC outlook (DAY1 for 23 March 2025)

Categorical

Tornado

Wind

Hail

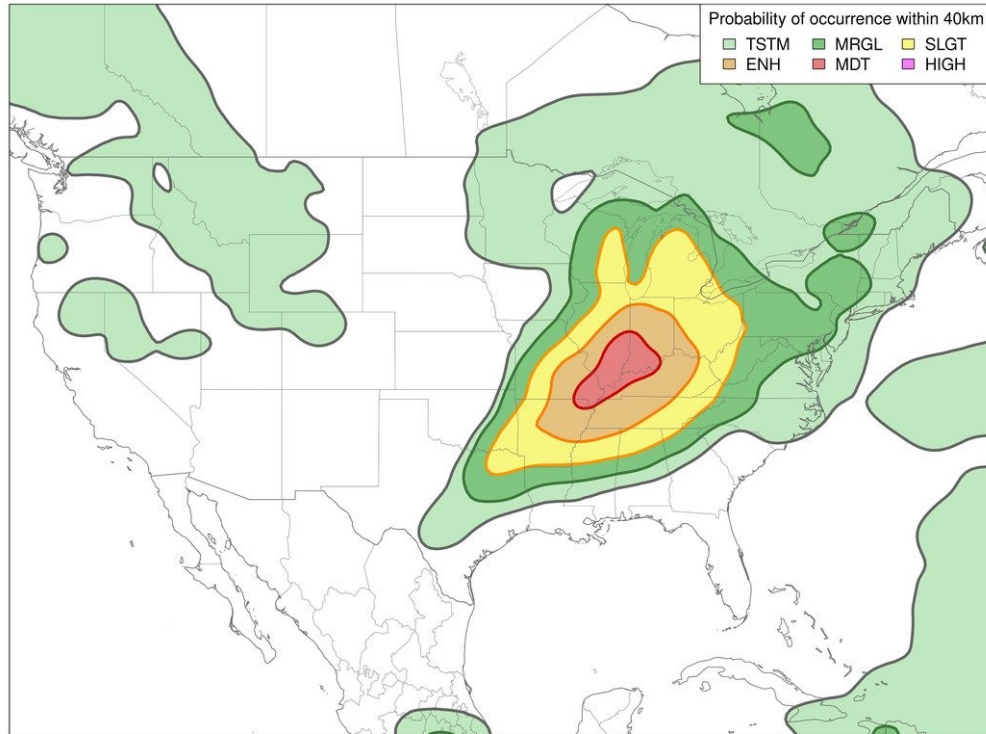


Comparison with SPC outlook (DAY2 for 16 May 2025)

Valid: 12Z 16 May 25 - 12Z 17 May 25
Init: 18Z 14 May 25

DAY 2 automated convective outlook

rawinsonde.com
GEFS 0.5°

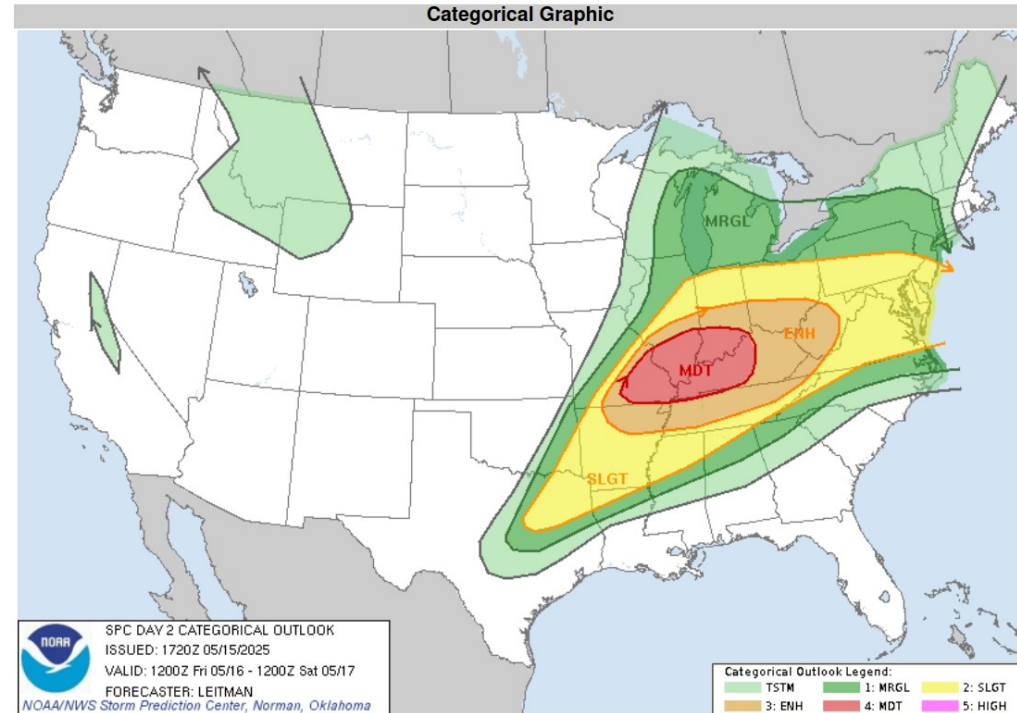


Developed by Mateusz Taszarek and partners using thundeR rawinsonde processing package, funded by the Polish National Science Centre grant no. 2020/39/D/ST10/00768

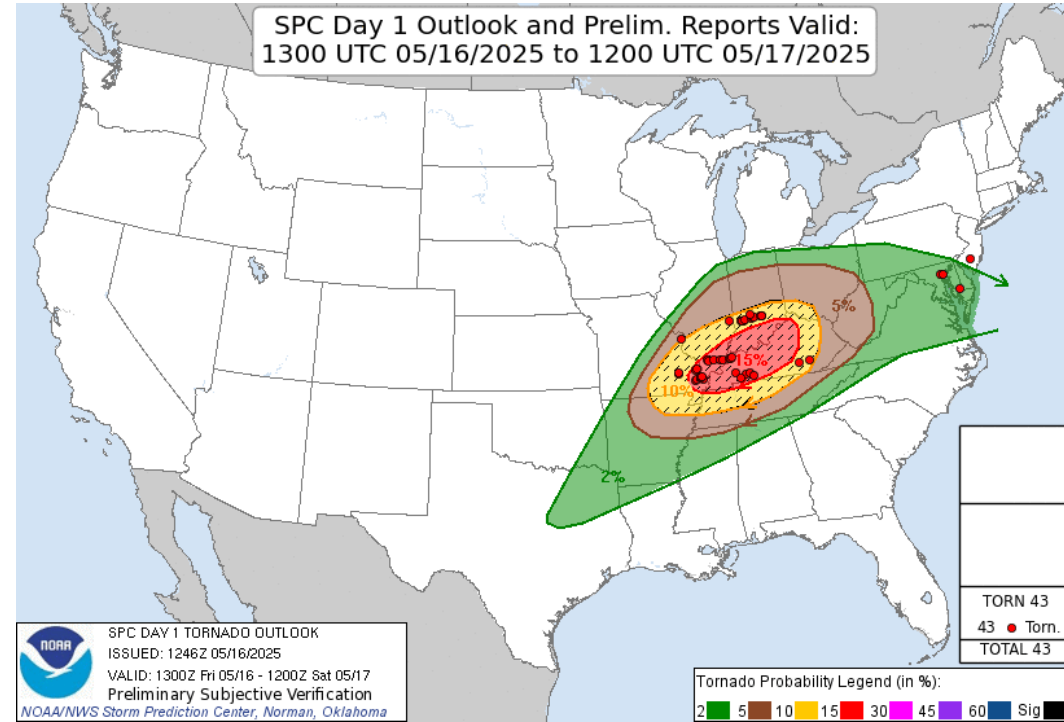
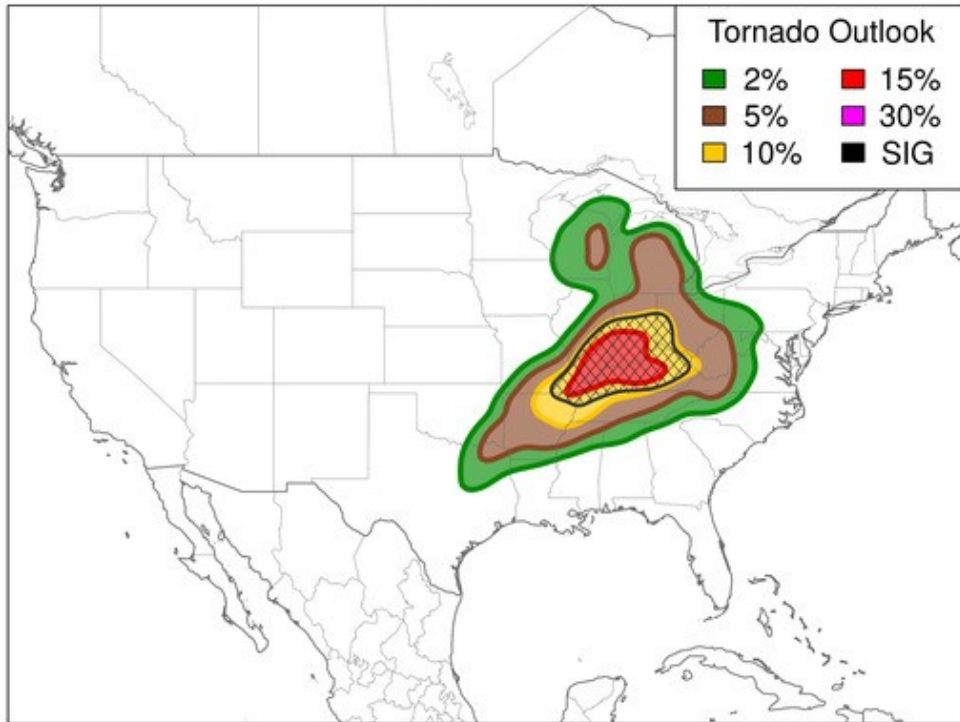
May 15, 2025 1730 UTC Day 2 Convective Outlook

Updated: Thu May 15 17:20:48 UTC 2025
Probabilistic to Categorical Outlook Conversion Table

Categorical Graphic



Comparison with SPC outlook (Tornado DAY1 for 16 May 2025)

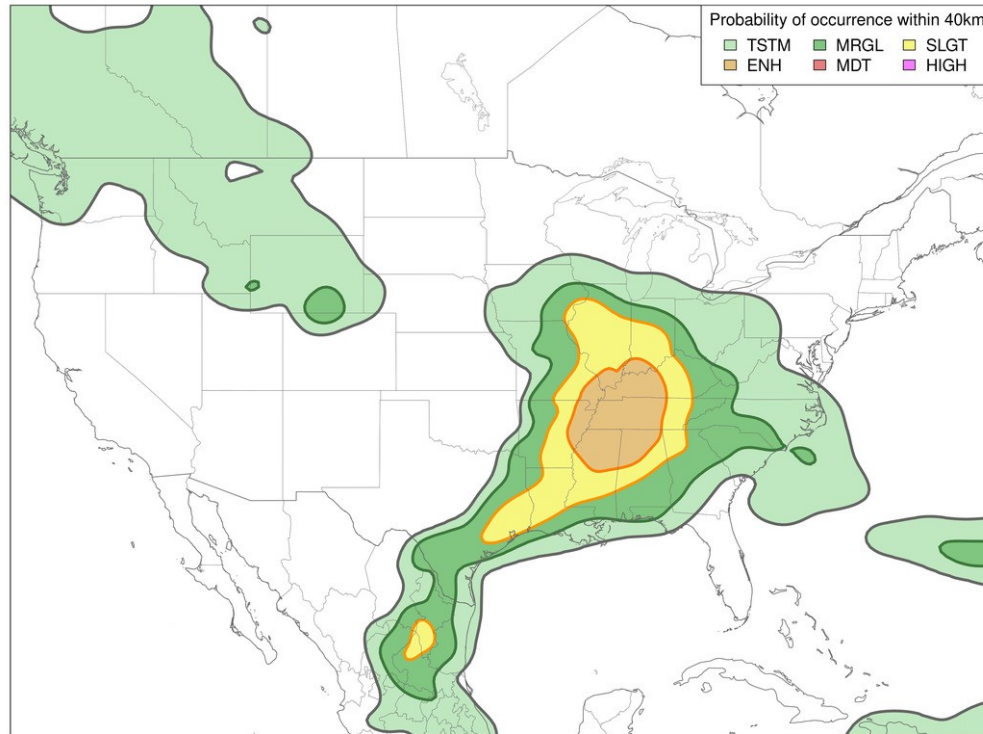


Comparison with SPC outlook (DAY1 for 20 May 2025)

Valid: 12Z 20 May 25 - 12Z 21 May 25
Init: 12Z 20 May 25

DAY 1 automated convective outlook

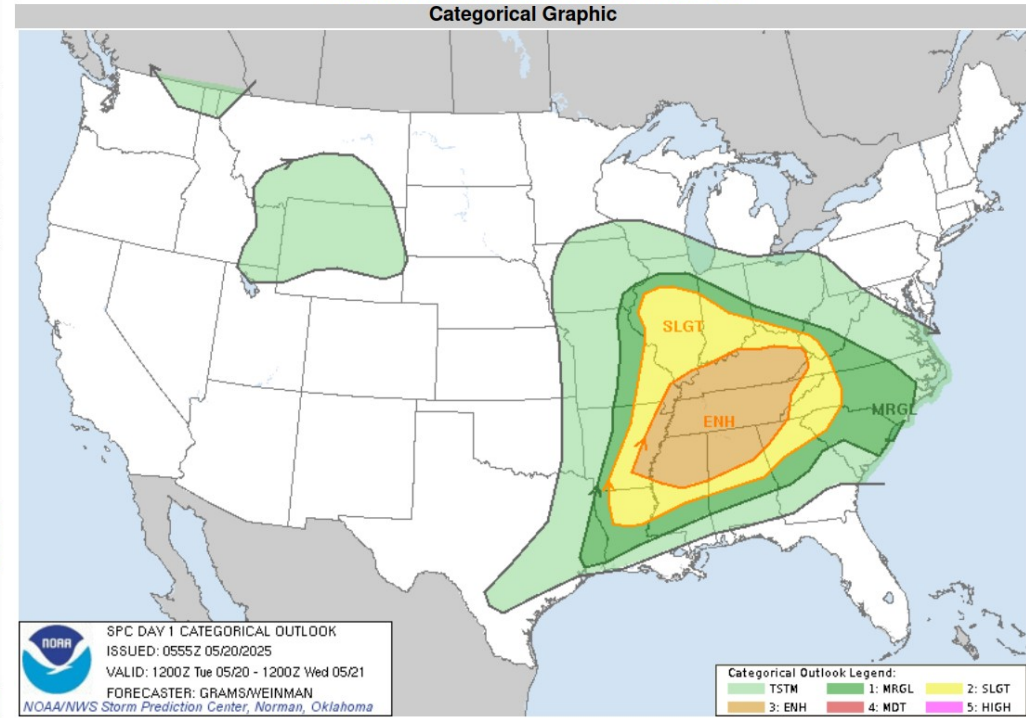
rawinsonde.com
GEFS 0.5°



May 20, 2025 0600 UTC Day 1 Convective Outlook

Updated: Tue May 20 05:55:45 UTC 2025
Probabilistic to Categorical Outlook Conversion Table

Categorical Graphic

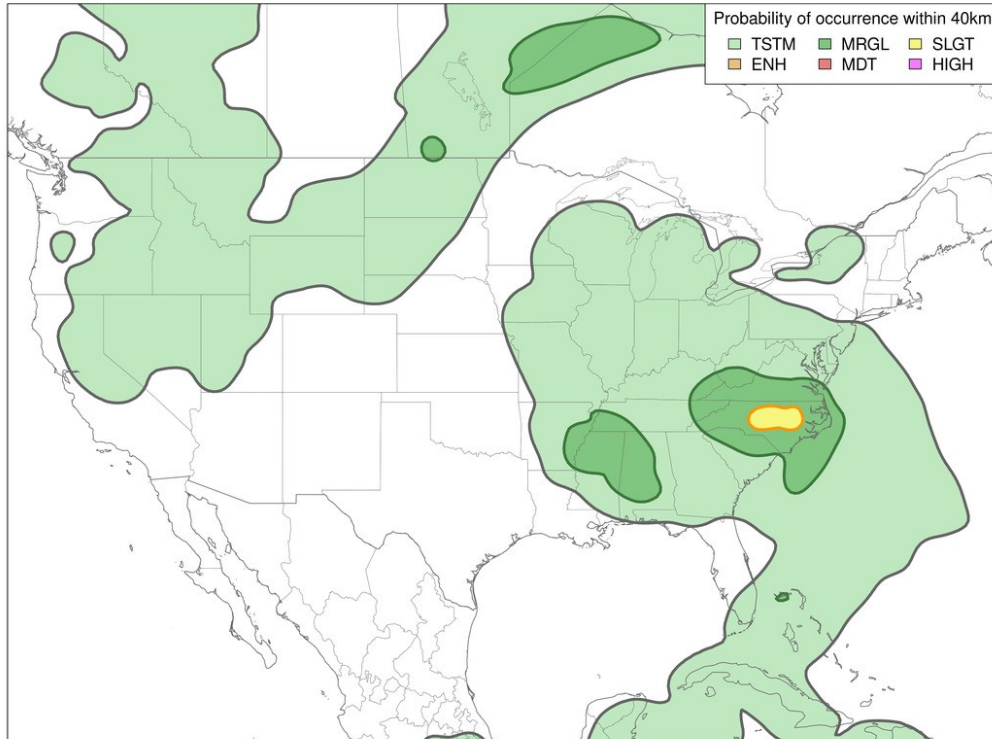


Comparison with SPC outlook (DAY1 for 13 May 2025)

Valid: 12Z 13 May 25 - 12Z 14 May 25
Init: 00Z 13 May 25

DAY 1 automated convective outlook

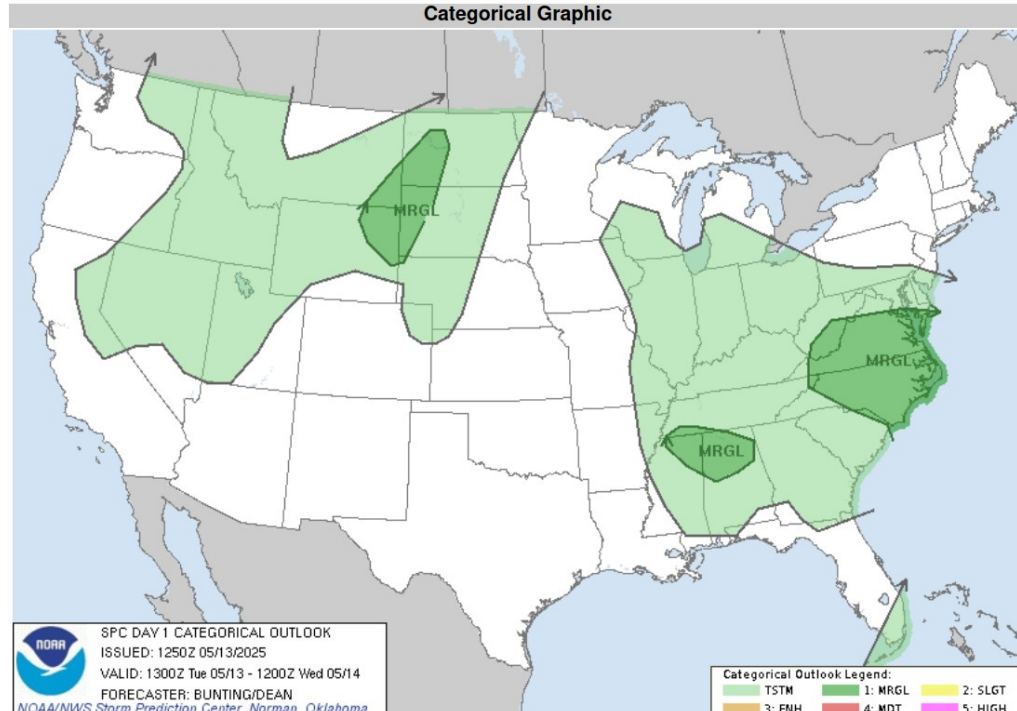
rawinsonde.com
GEFS 0.5°



May 13, 2025 1300 UTC Day 1 Convective Outlook

Updated: Tue May 13 12:50:45 UTC 2025
Probabilistic to Categorical Outlook Conversion Table

Categorical Graphic

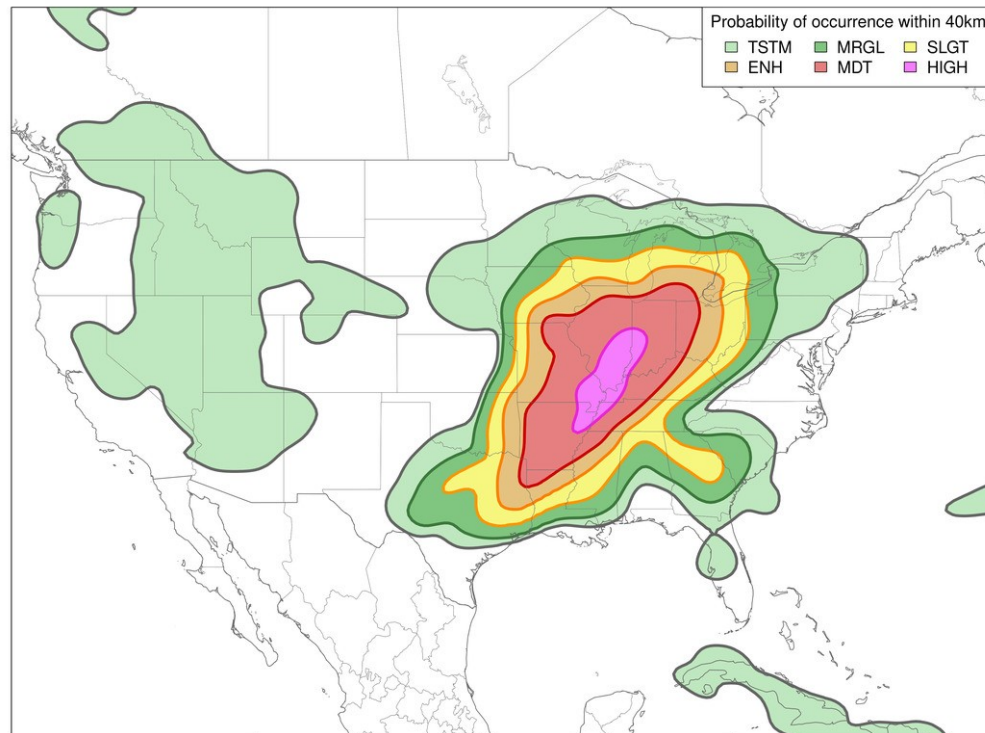


Comparison with SPC outlook (DAY1 for 02 April 2025)

Valid: 12Z 02 Apr 25 - 12Z 03 Apr 25
Init: 18Z 01 Apr 25

DAY 1 automated convective outlook

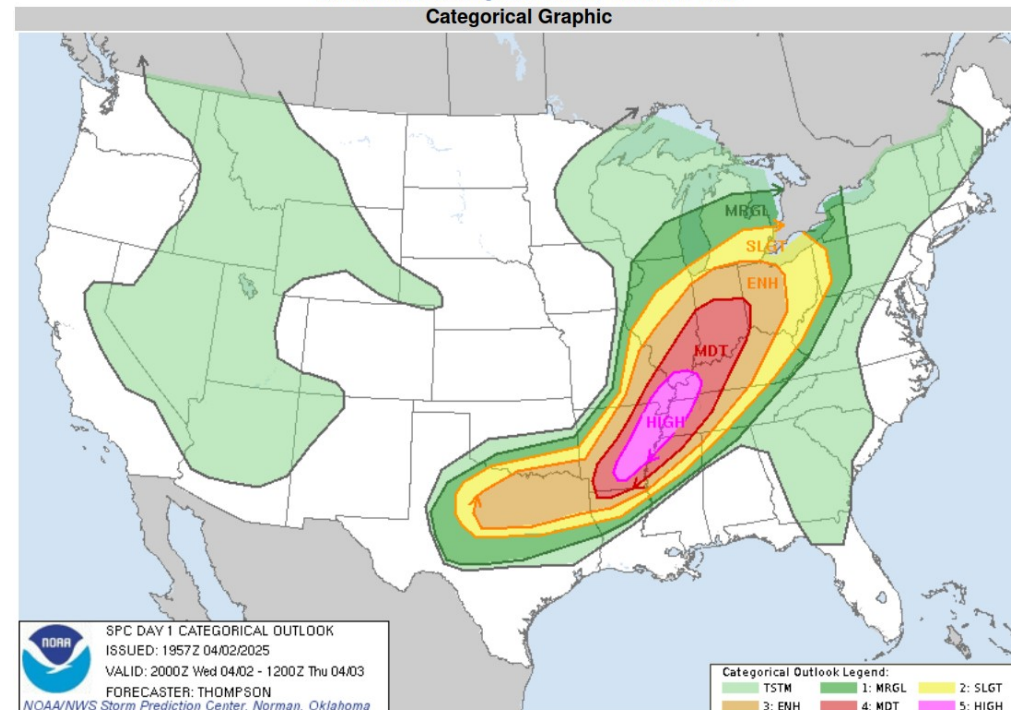
rawinsonde.com
GEFS 0.5°



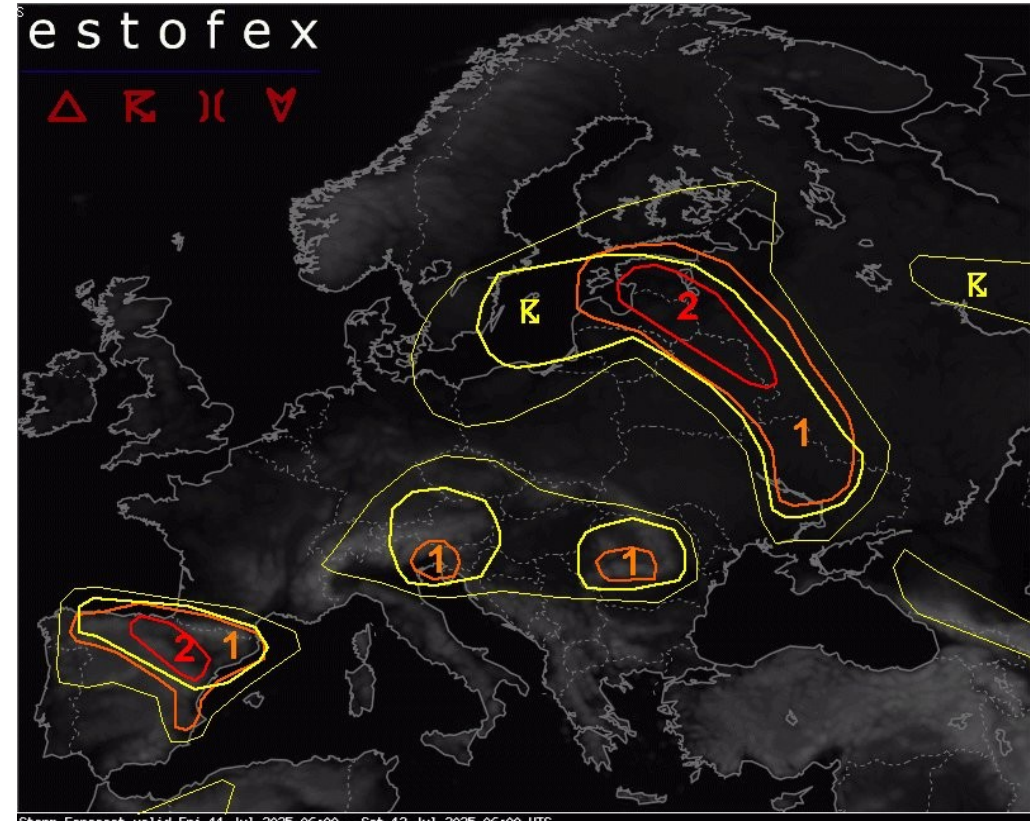
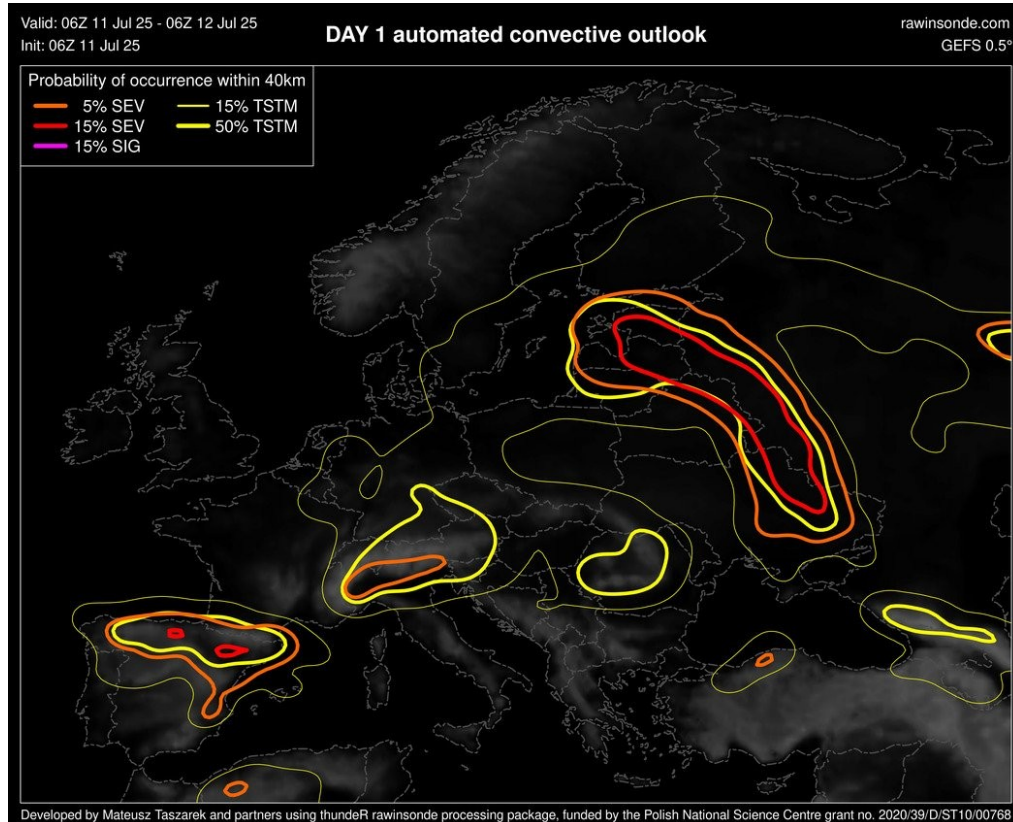
Apr 2, 2025 2000 UTC Day 1 Convective Outlook

Updated: Wed Apr 2 19:57:29 UTC 2025
Probabilistic to Categorical Outlook Conversion Table

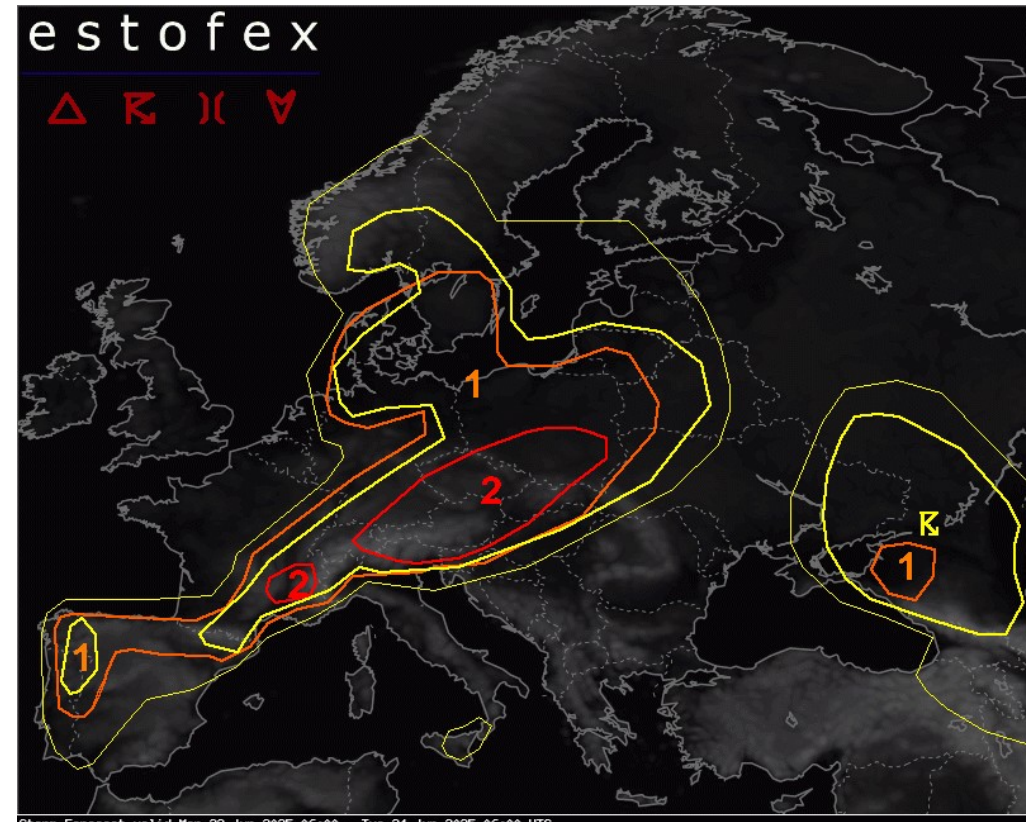
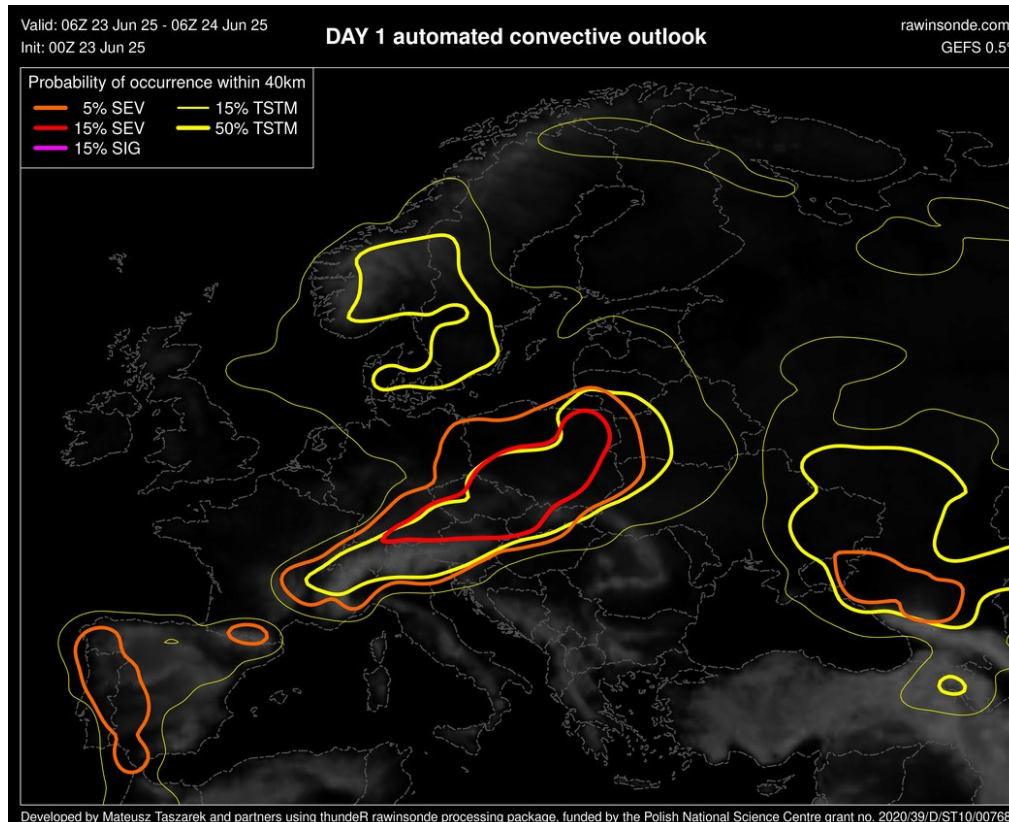
Categorical Graphic



Comparison with ESTOFEX outlook (DAY1 for 11 Jul 2025)



Comparison with ESTOFEX outlook (DAY1 for 23 Jun 2025)



**Thank you for
your attention!**



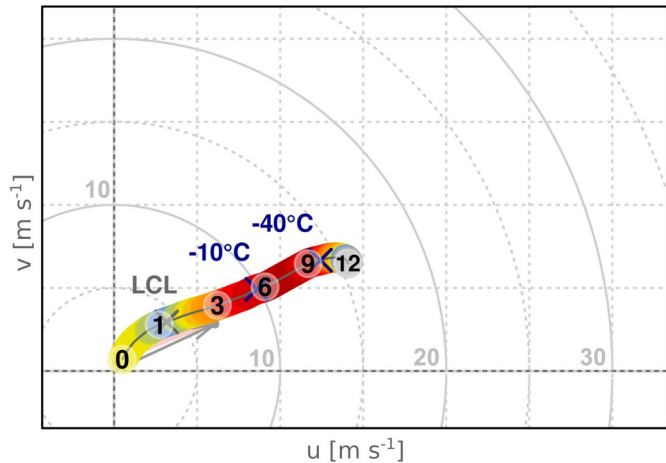
Mateusz Taszarek
tornado@amu.edu.pl

Department of Meteorology and
Climatology, Adam Mickiewicz University
Poznań, Poland

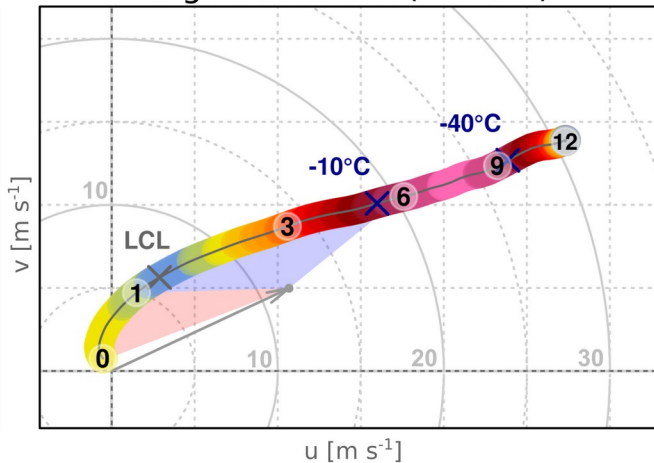
Intercontinental severe storm mean buoyancy hodographs

(equal weighted data among continents)

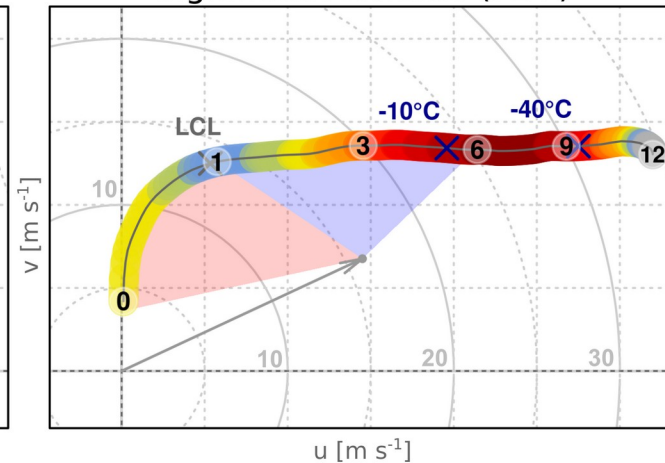
Non-severe thunderstorm



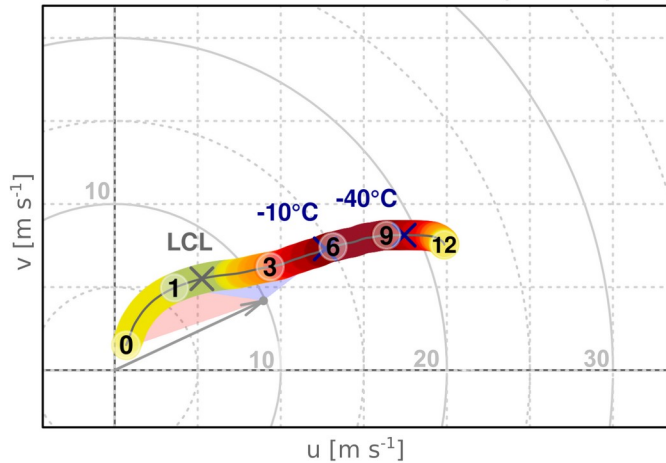
Significant hail (> 5 cm)



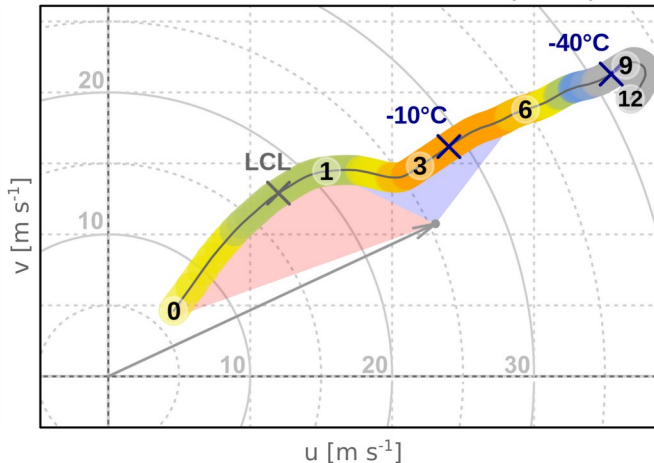
Significant tornado (F2+)



Severe convective wind (warm)



Severe convective wind (cold)



Legend

- Estimated storm-motion vector
- ① ③ 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]

