Climatology of storm reports as a function of jet streak quadrant and system morphology

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Motivation: Jet Streaks

- The 4 quadrant model predicts rising motion in the right entrance and left exit regions of linear jet streaks
- Curvature can result in a 2 quadrant pattern
- Is severe weather favored in these quadrants where the models predict lift?
- Are there differences in types of storm reports?
- Does orientation (direction) matter?

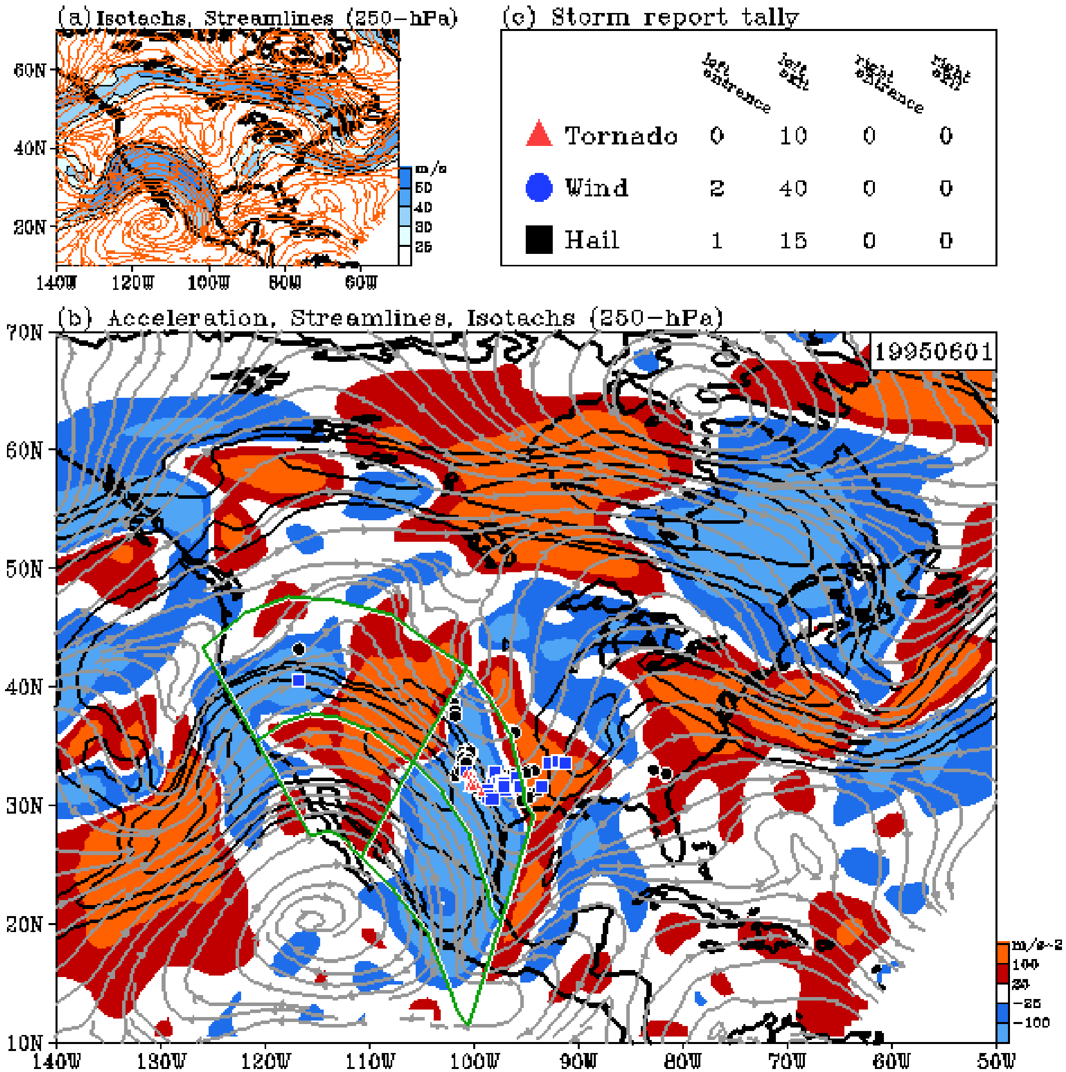
Work extends Rose et al. 2004 who looked at F1+ tornadoes

Methodology

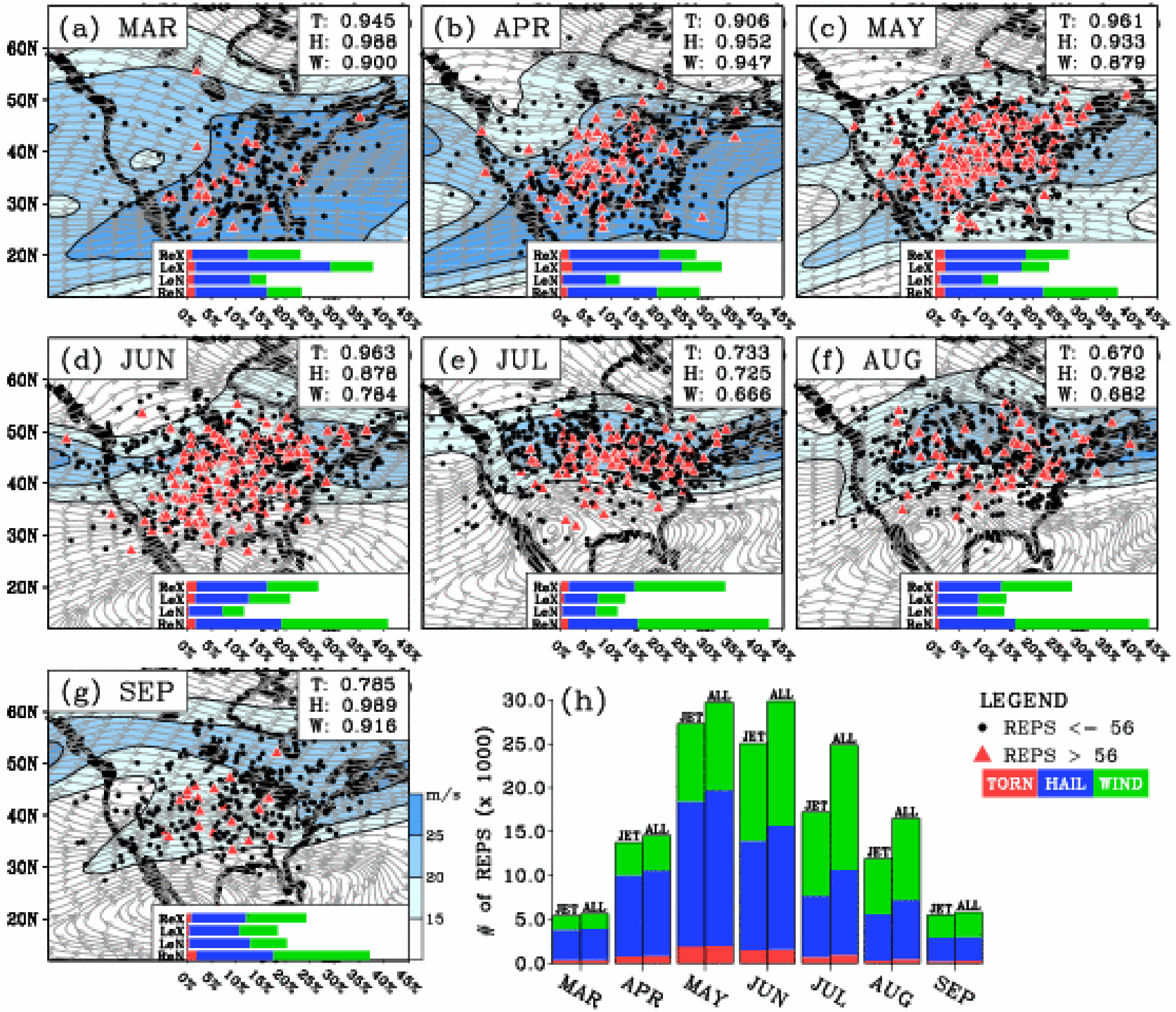
- NARR dataset with 32km grid spacing used for March-Sept 1994-2004
- Analysis valid for 00 UTC with storm reports +/- 3 h (from Storm Data)
- GRADS used for 250 mb winds, with jet streaks > 25 m/s, and reports examined within 1000 km right/left of jet (as in Rose et al.)

Methodology (cont.)

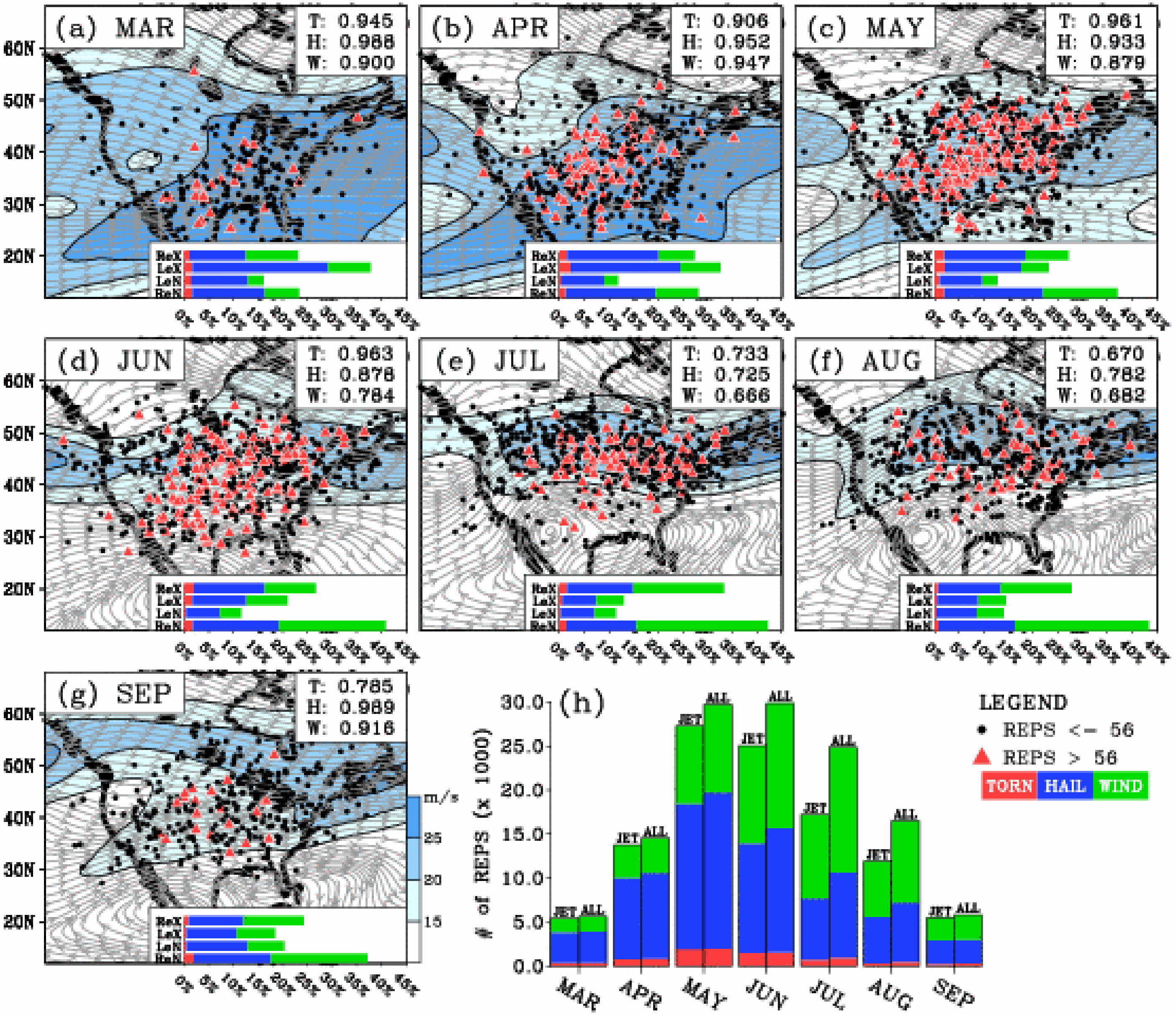
- Jet streak assumed to start/stop where acceleration became zero
- Total of 3179 jet streaks were analyzed, containing 105,987 storm reports
- Another 20,877 reports occurred without a jet streak being present (so 84% of all reports WERE associated with a jet streak).
- 13.8% of reports were counted more than once, occurring in quadrants of >1 streak



Example of GRADS interface used to define jet streaks, with 250 mb streamlines in upper-level and shading for isotachs, 250mb acceleration in bottom (shaded) with storm reports overlaid, and the count of each is shown in upper-right.

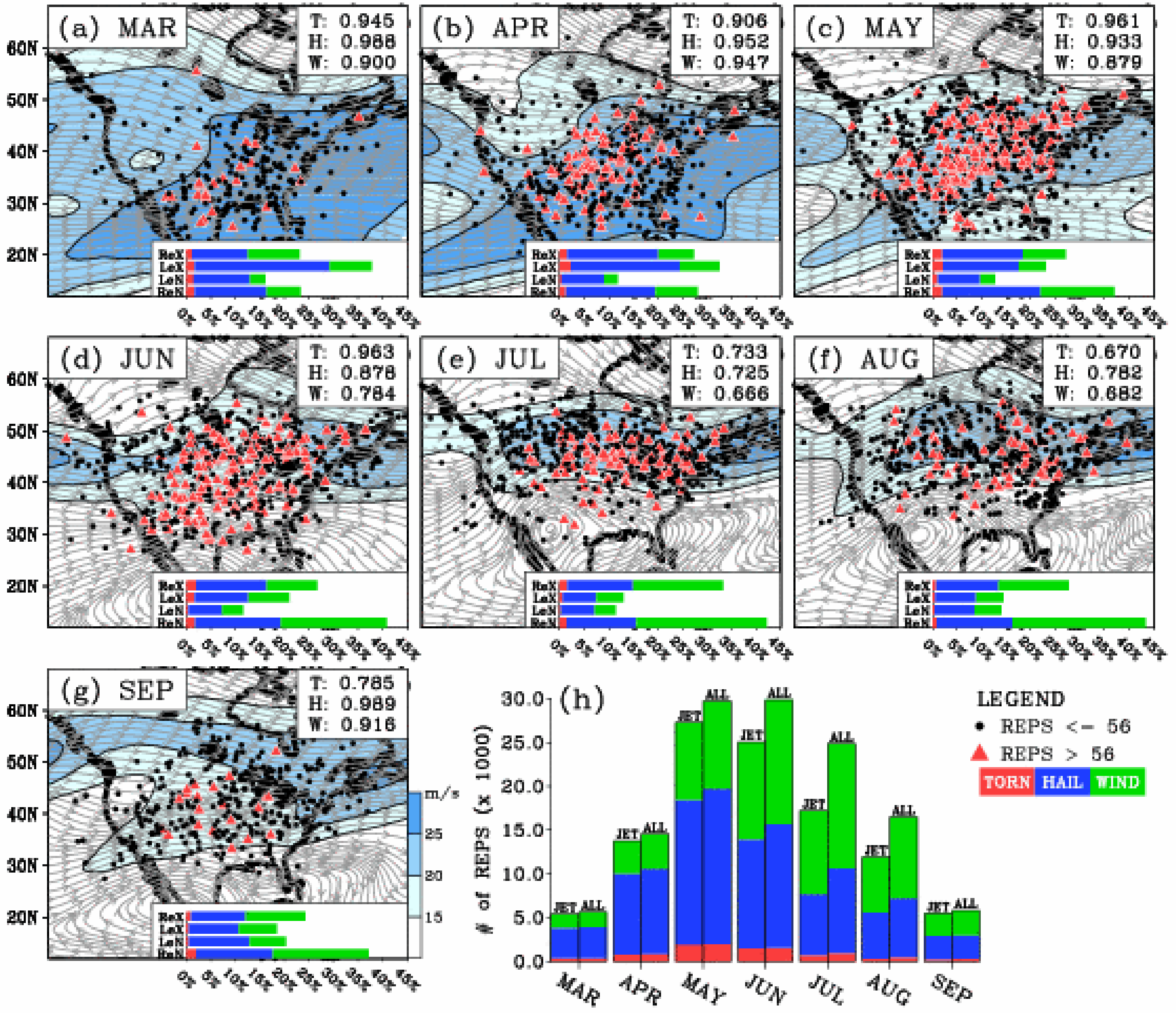


Monthly distribution of jet streaks superimposed with wind speeds (shaded) and storm reports > 56.

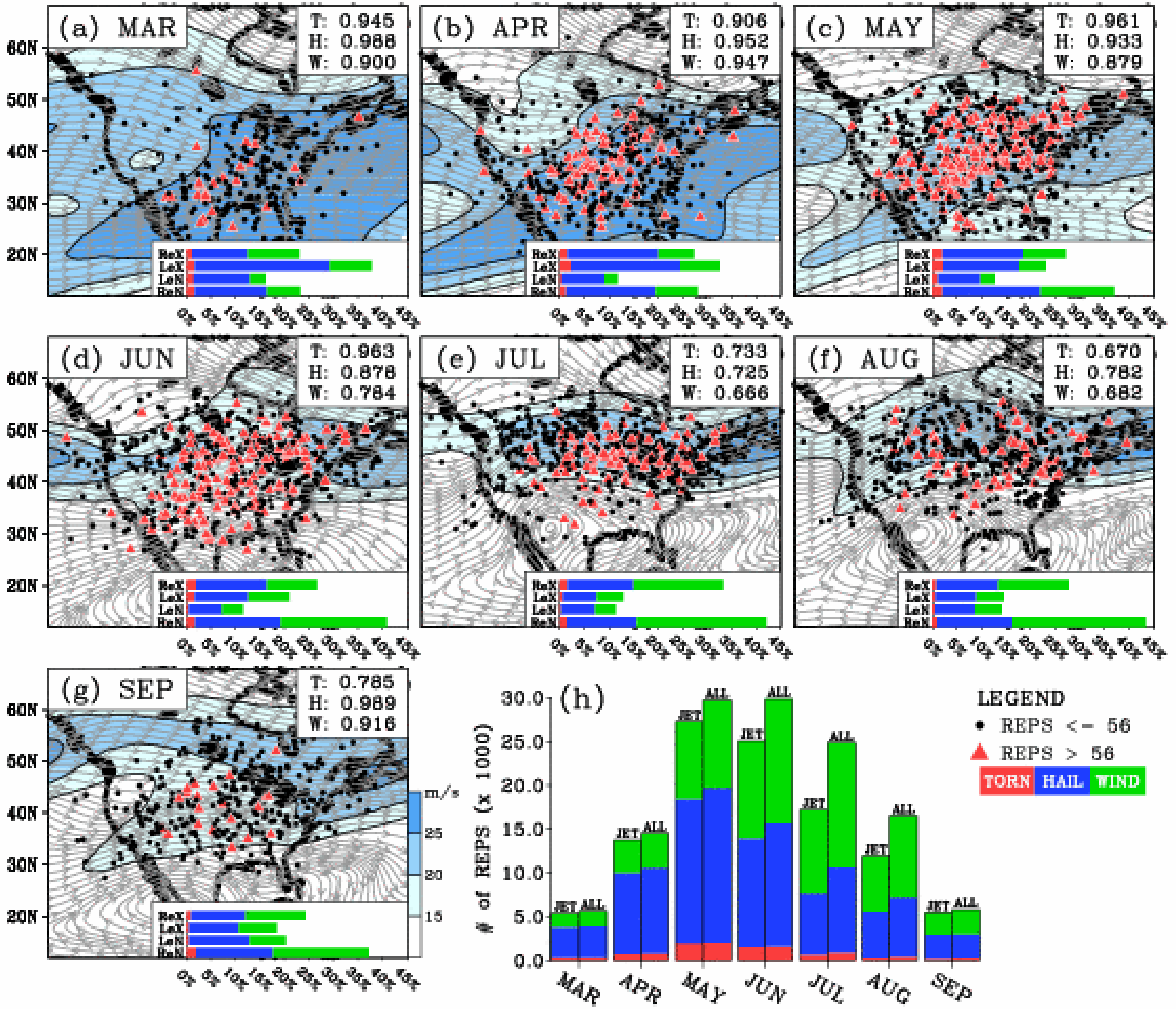


Peak month for storm reports is June (May close).

Percentage of jet-related reports declines over summer, so May is peak for jet-related reports

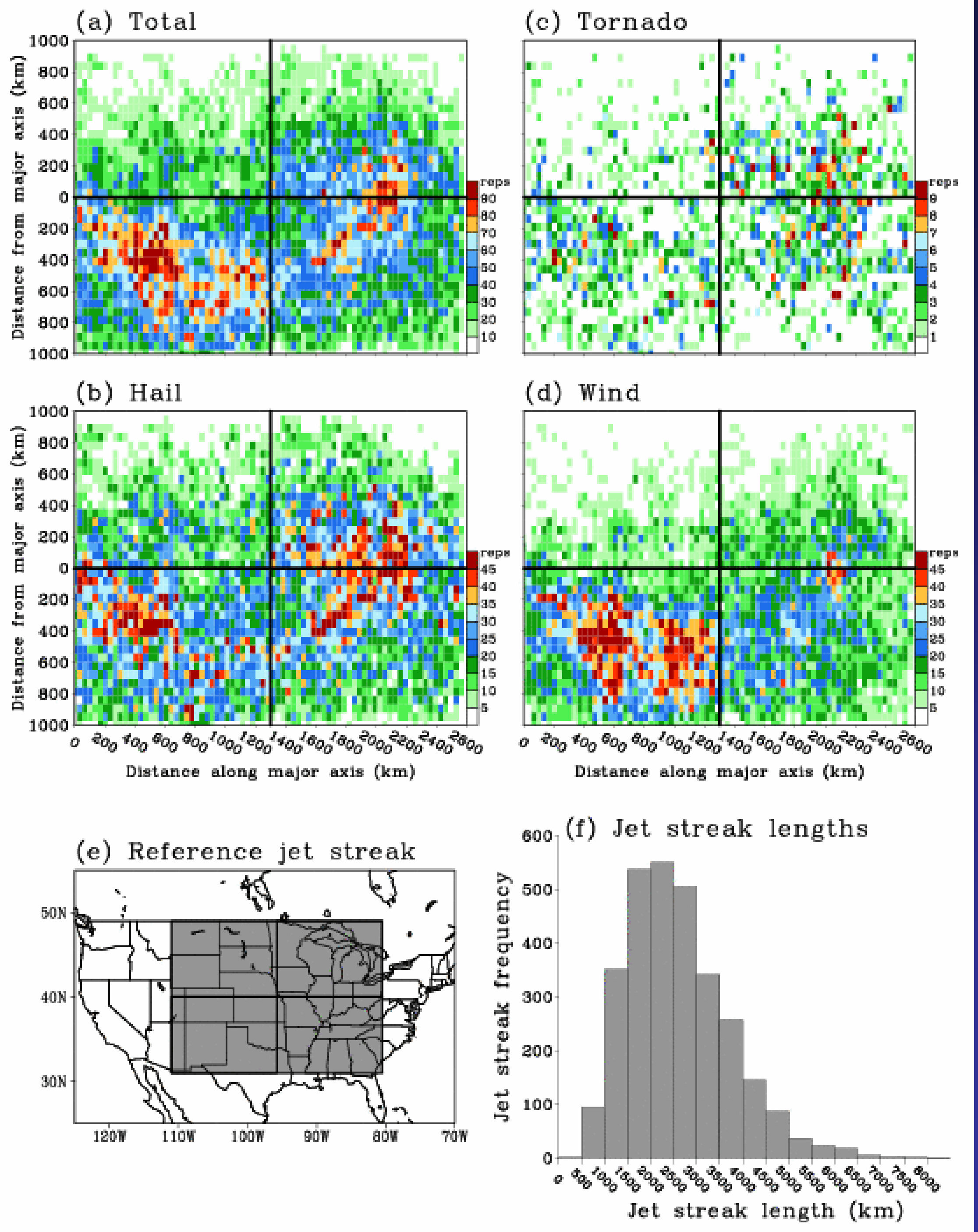


March/April have majority of reports in left exit quad, while May-Sept favor right entrance



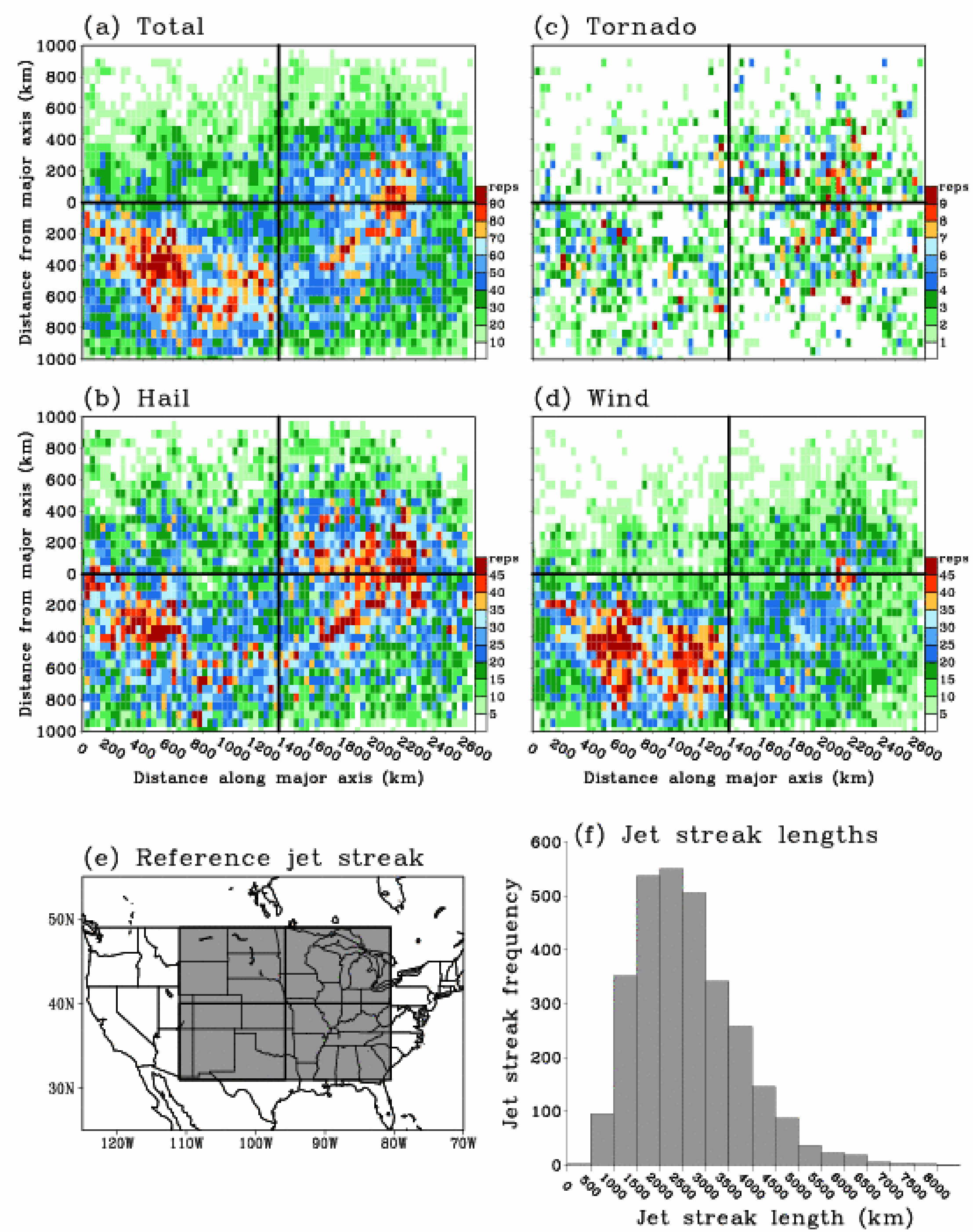
Only March/April have distributions of all reports consistent with quadrant model theory

Note, May – Sept, right exit has more than left exit

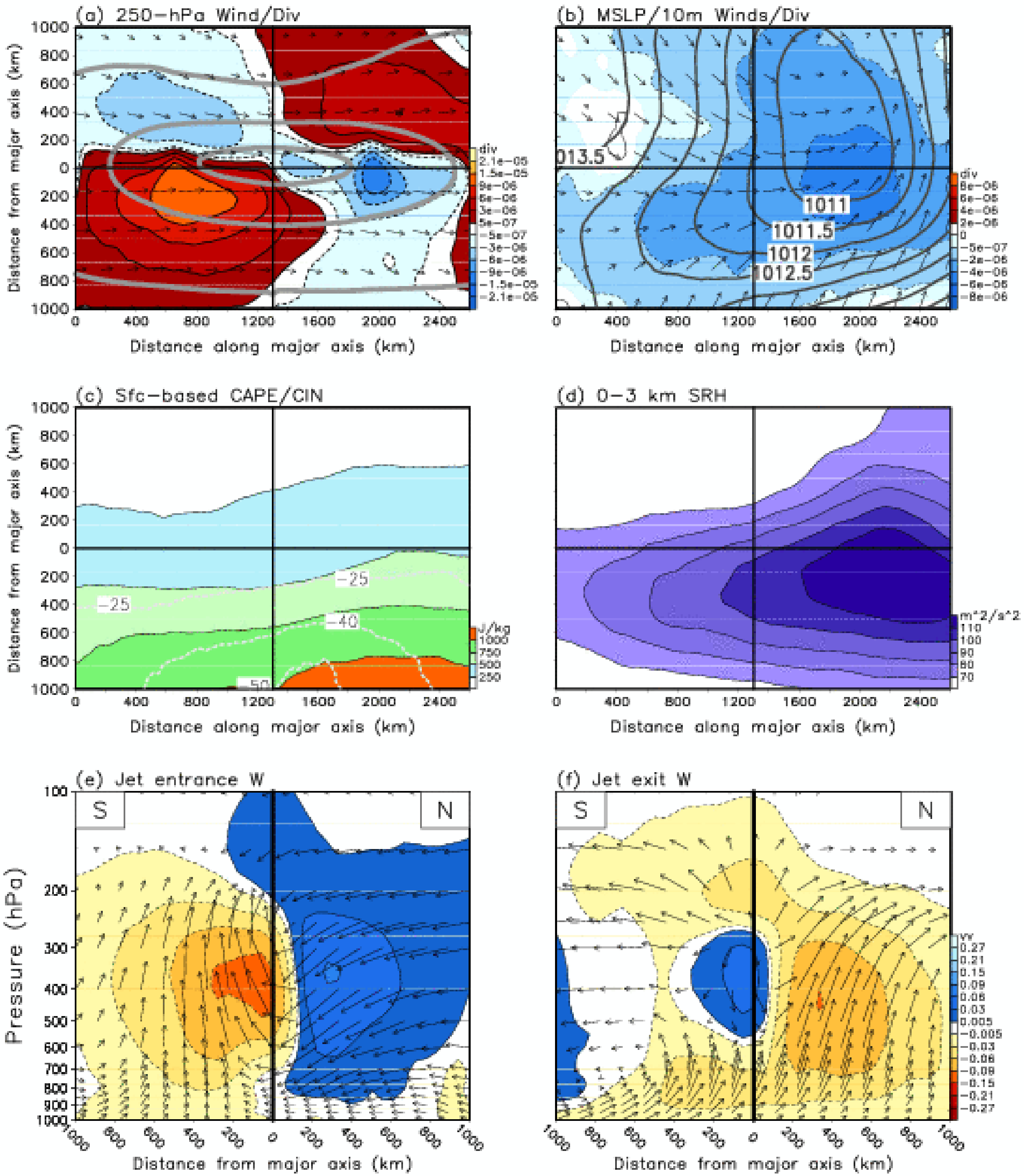


Composite storm report frequencies within a jet streak with lines delineating quadrants

Ave jet streak overlaid on US map. Lengths also shown



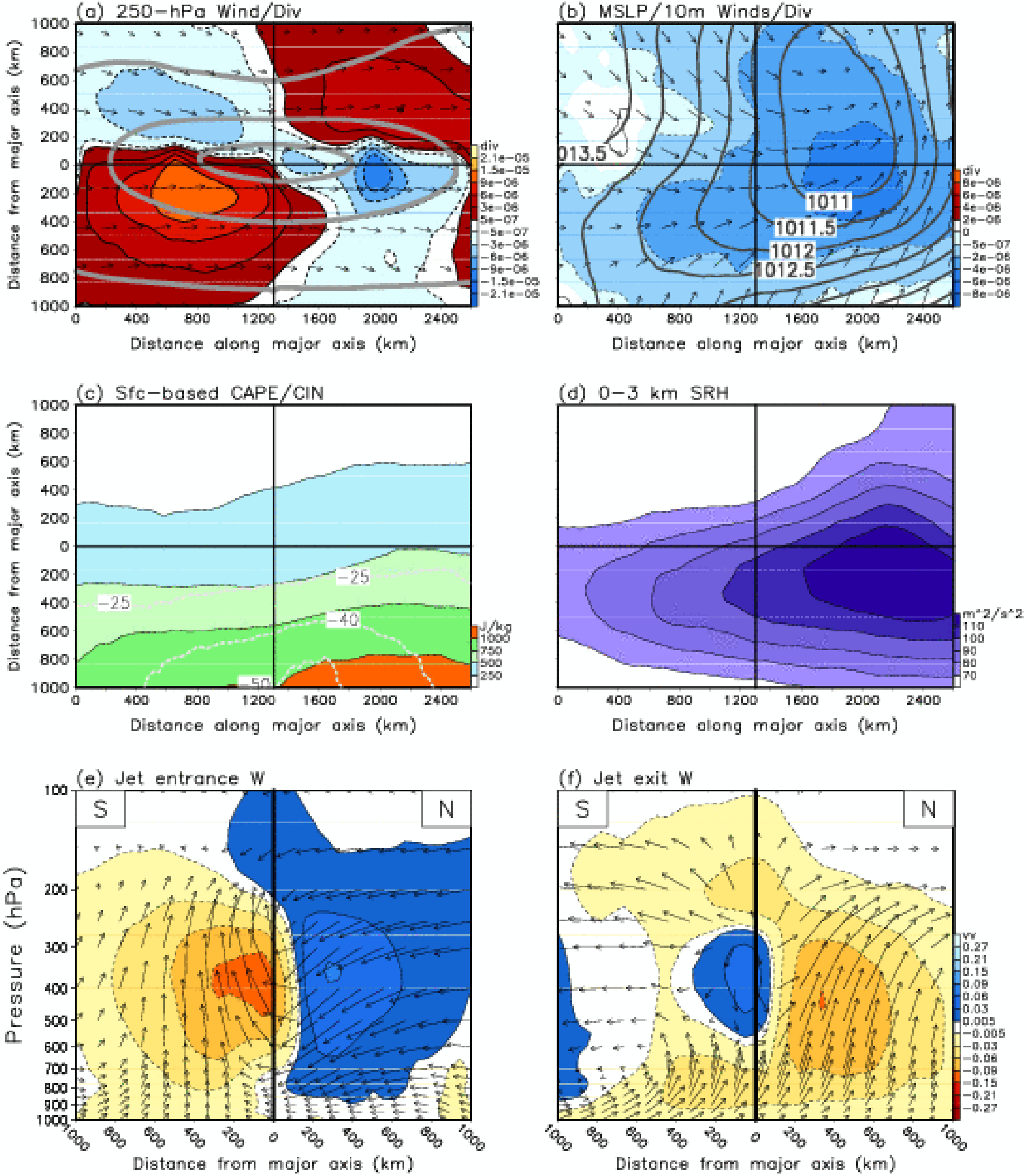
- •Tornadoes especially favor exit quadrants
- •Hail evenly distributed between exit and entrance quads,
- •Wind concentrated in right entrance



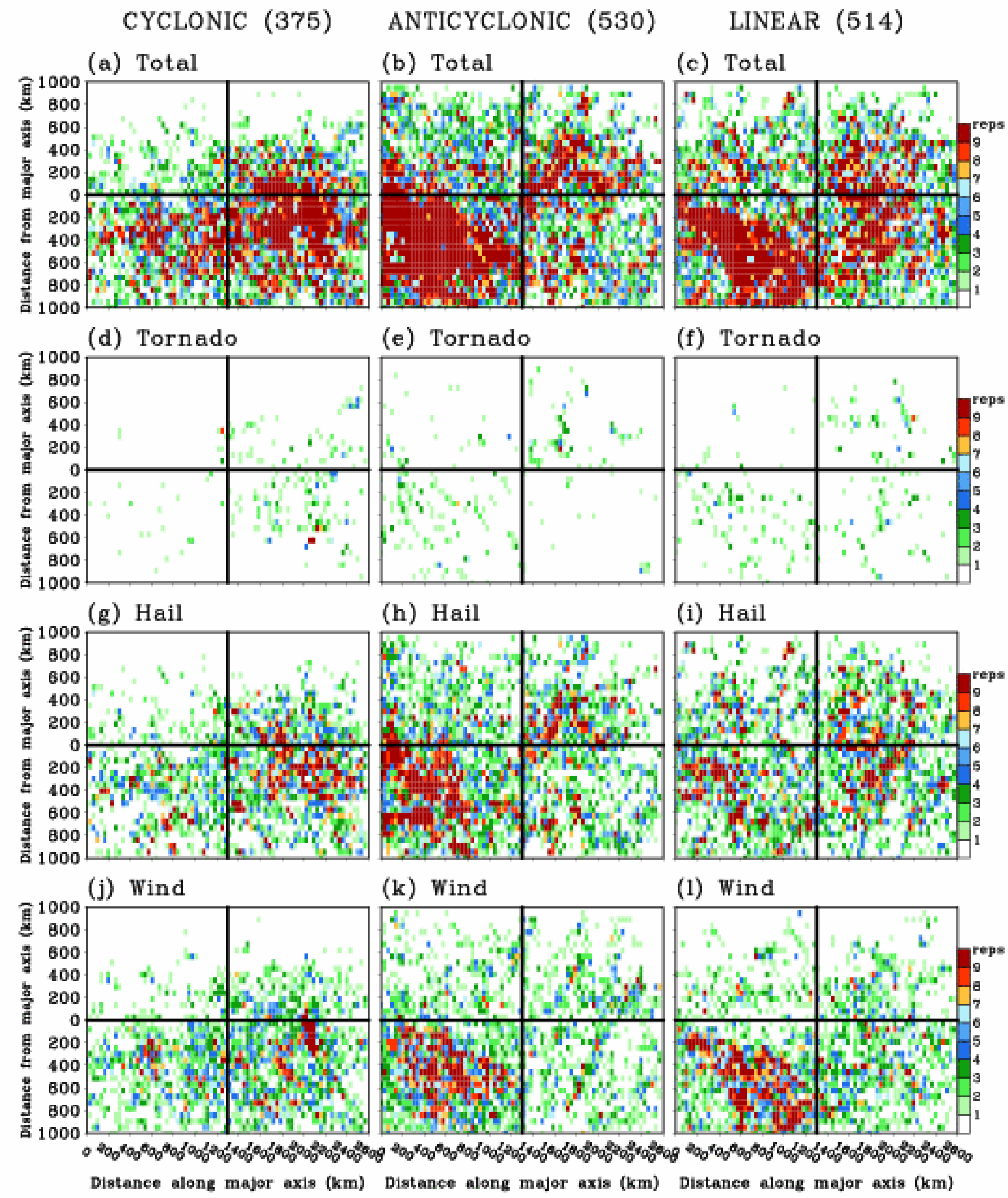
Jet streak composite of :

a) **250 isotachs, divergence(shaded) and wind vectors,**
b) **b) MSLP and divergence,**
c) **c) sfc-based CAPE/CIN**
d) **d) 0-3 km SRH.**

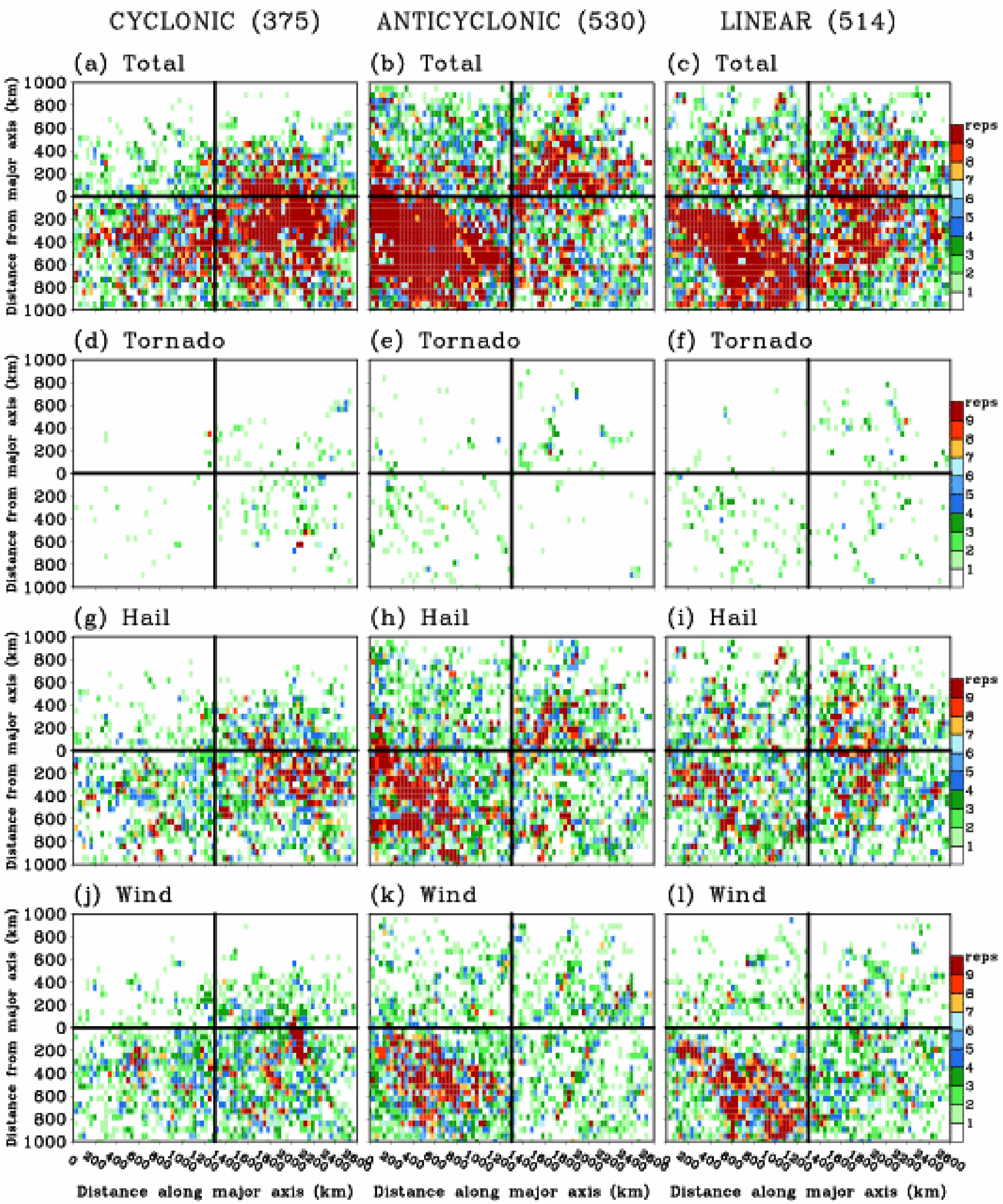
Jet-transverse x-sections of vert.vel. (shaded) and circulation vectors in e) and f).



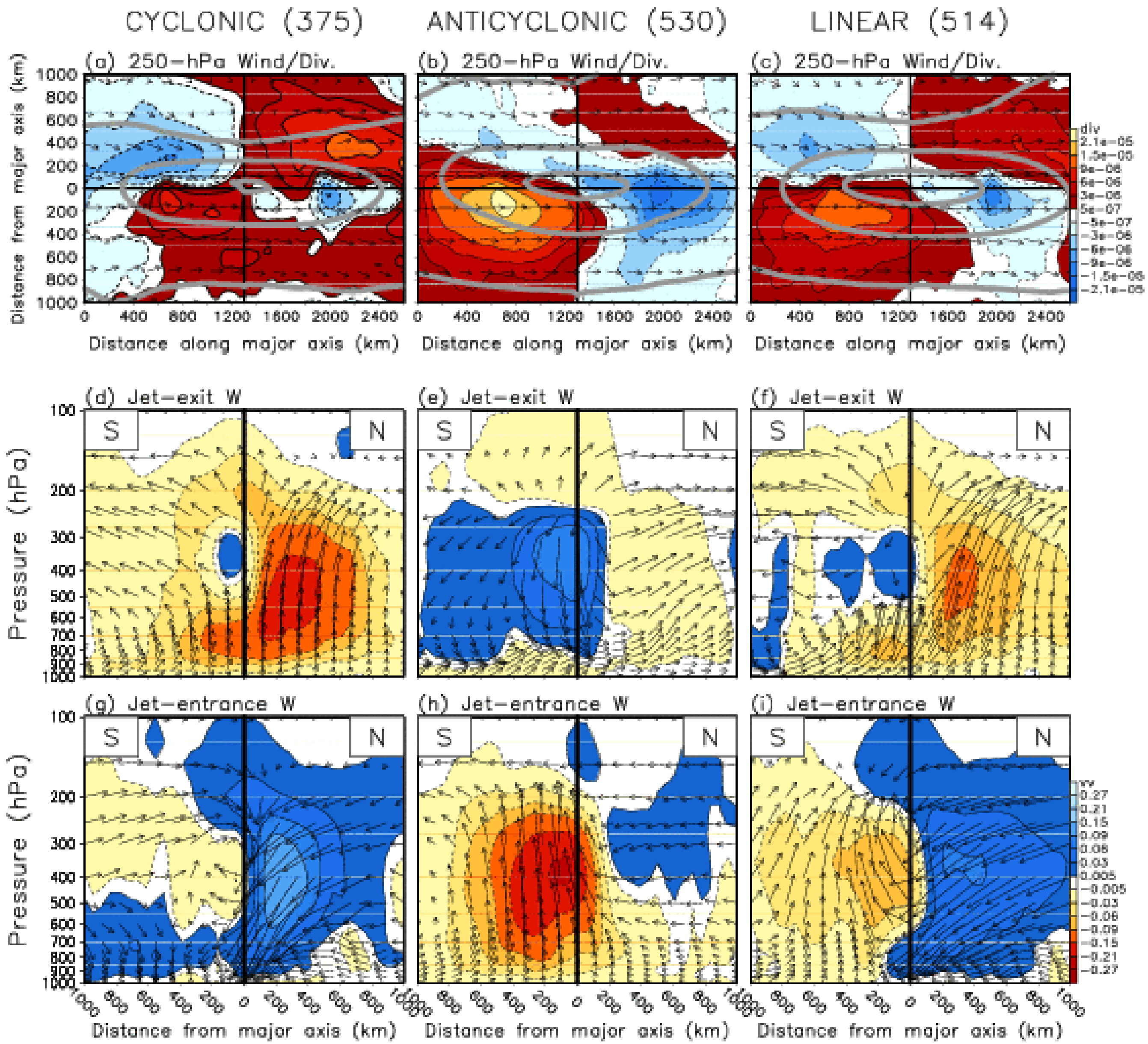
- •Convergence/ Divergence dipoles not centered on jet axis but displaced slightly toward cyclonic side
- •Surface low usually found in left exit with trof back into right entrance – note low-level conv. in right exit (despite upper-level conv.)
- •Svr Wx parameters best in right exit
- •Circulation stronger in entrance than in exit regions – consistent with average curv. being slightly anti-cyclonic



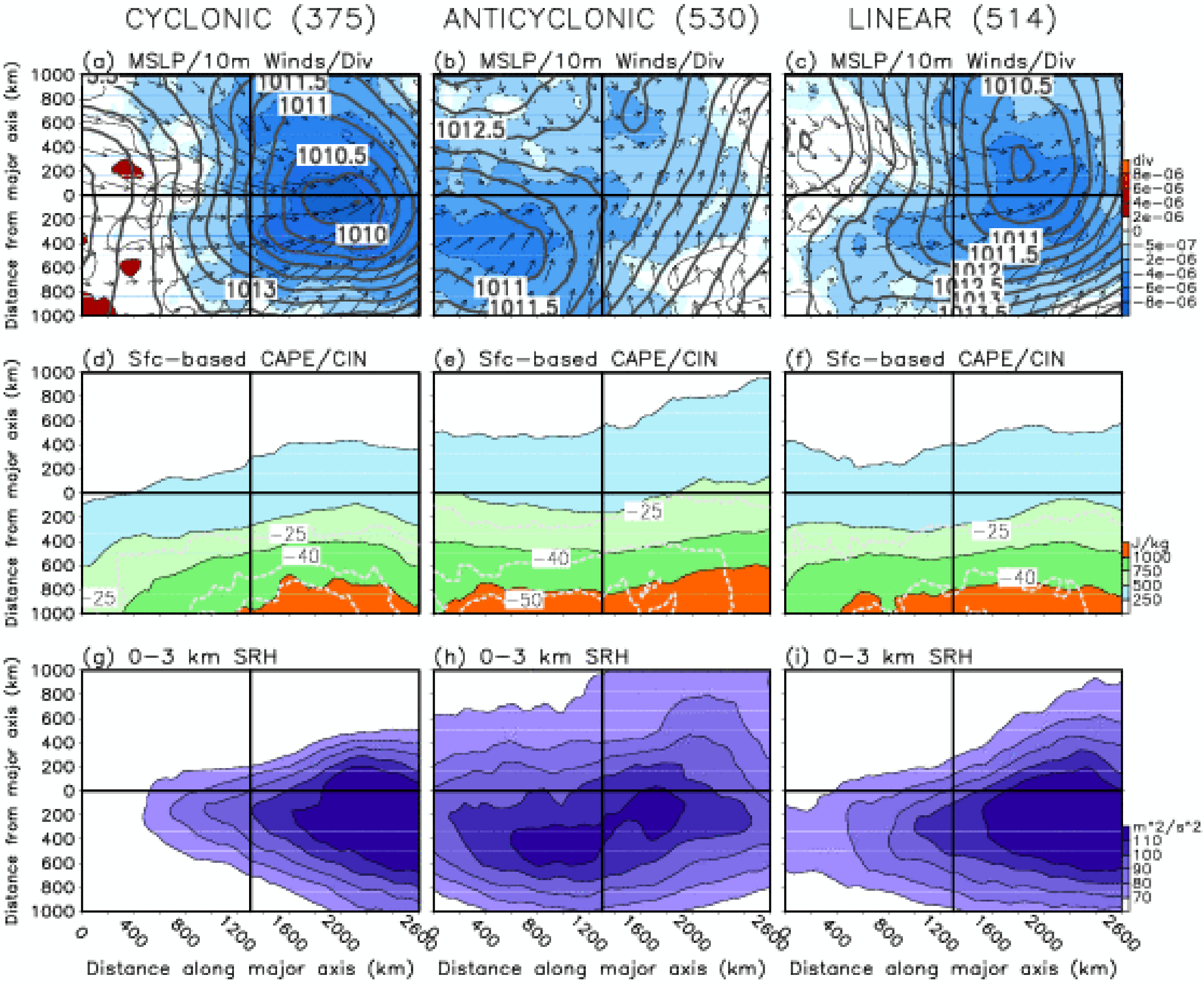
Distribution of total storm report frequencies associated with different types of jet streaks (cyclonic, anti-cyclonic, and linear), along with tornadoes, hail, and wind alone



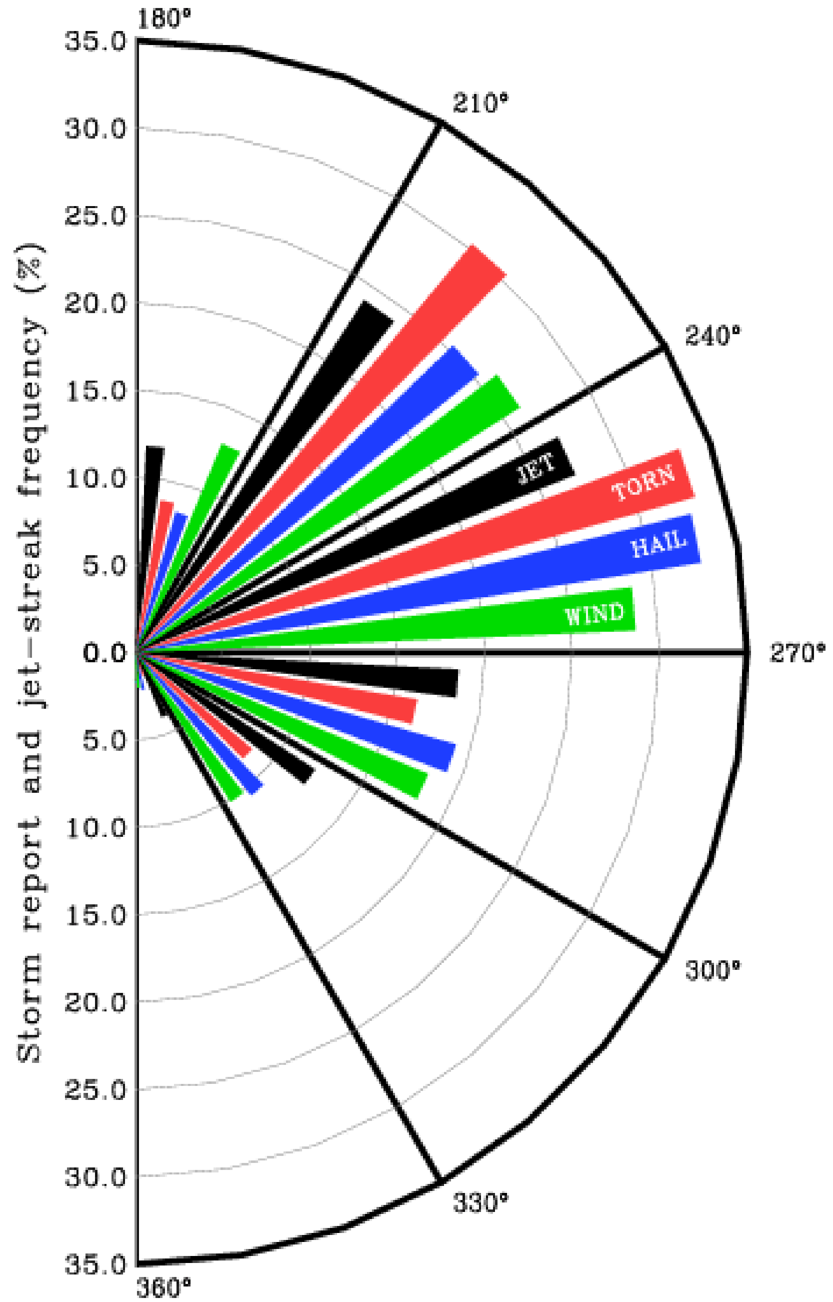
Reports generally match theory for where upward motion should dominate – cyclonic favors exit of 2quad model, anticyclonic favors entrance



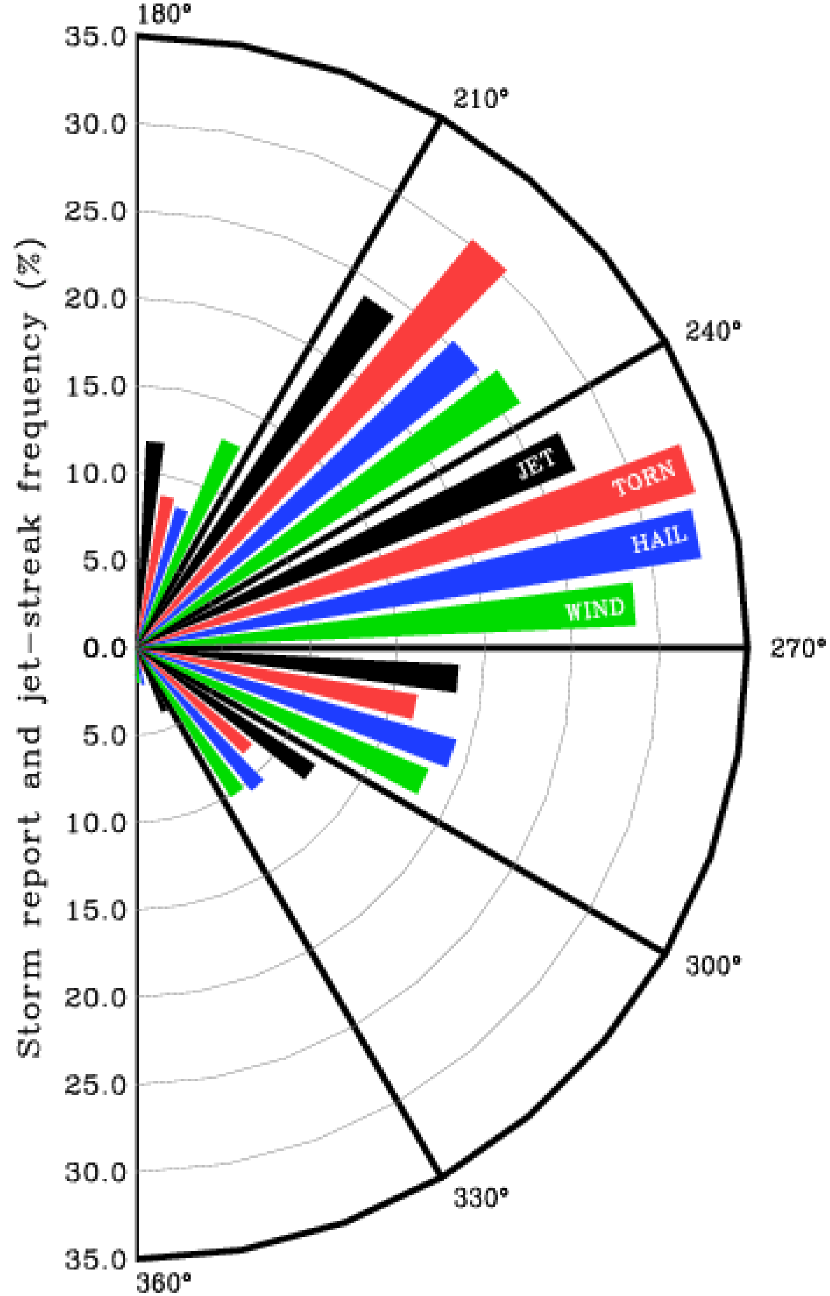
Flow characteristics as a function of jet region for different types of jets



MSLP and divergence, sfc-based CAPE/CIN, and 0-3km SRH as a function of jet quadrant and type of jet



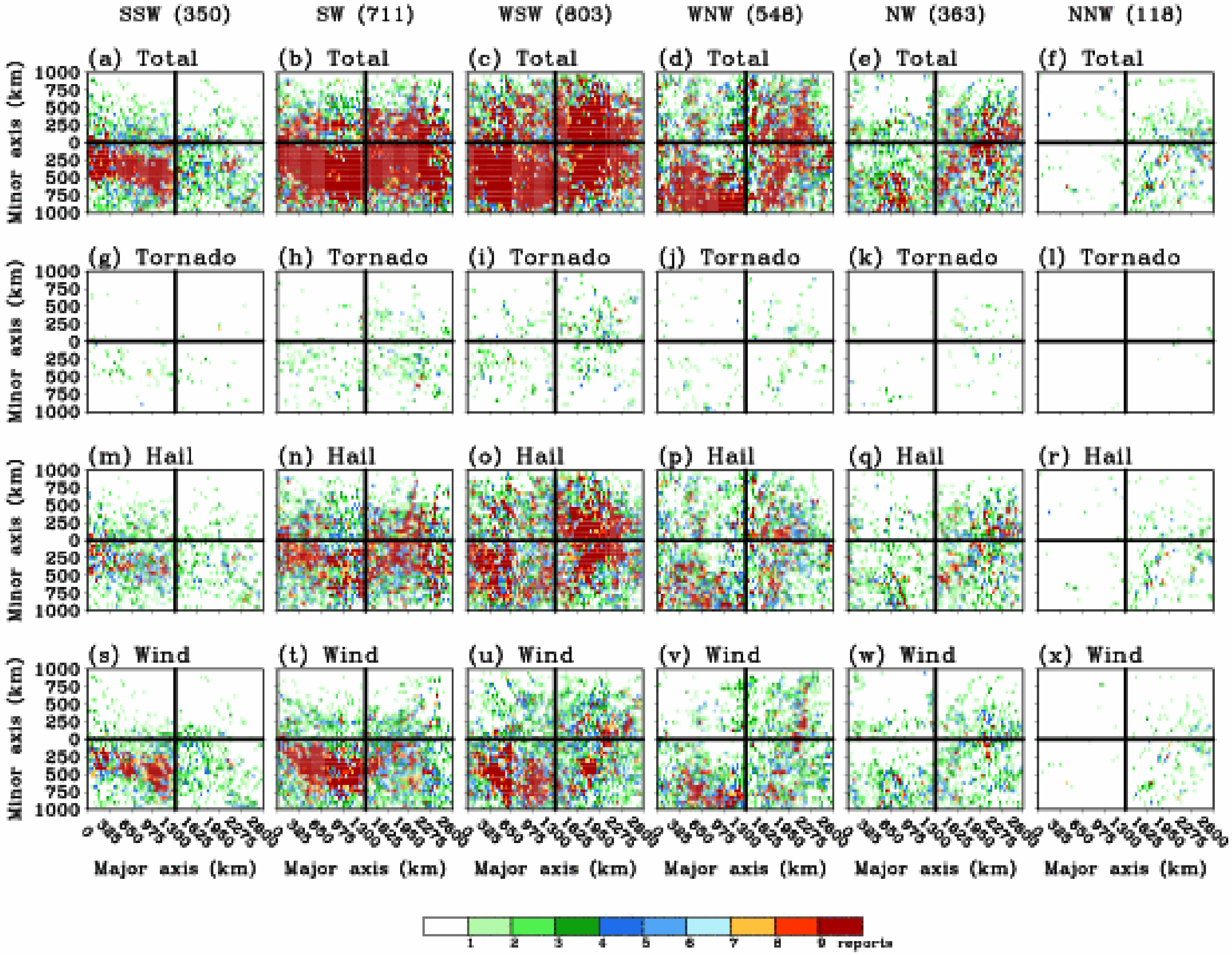
Percentage of jet streaks (black) within range of directions shown, and percentage of tornadoes, hail and wind associated with jet streaks from those directions.



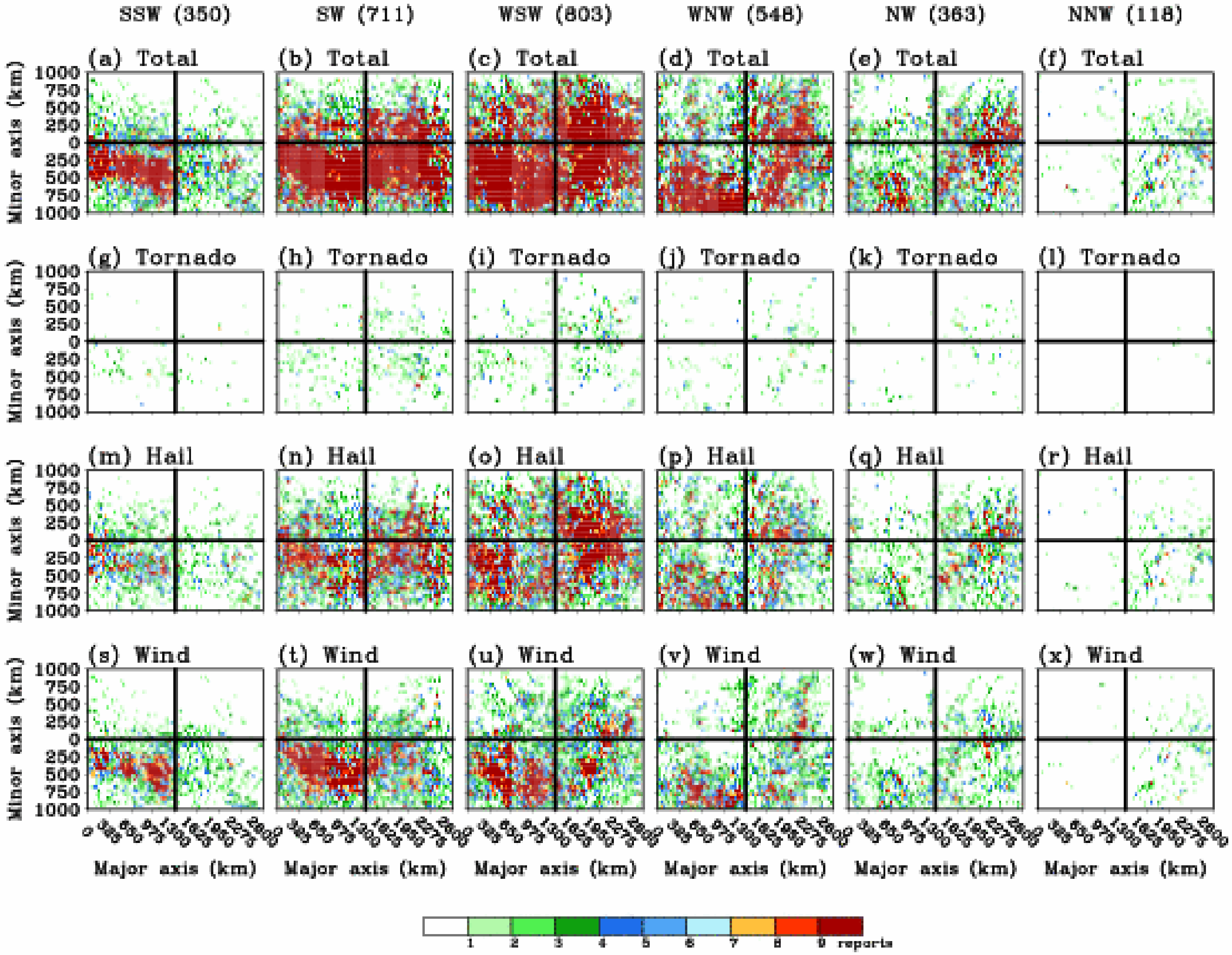
WSW and SW jets most common, and were especially active for storm reports

Note: tornadoes relatively rare for WNW and NW jets, although hail & wind still common

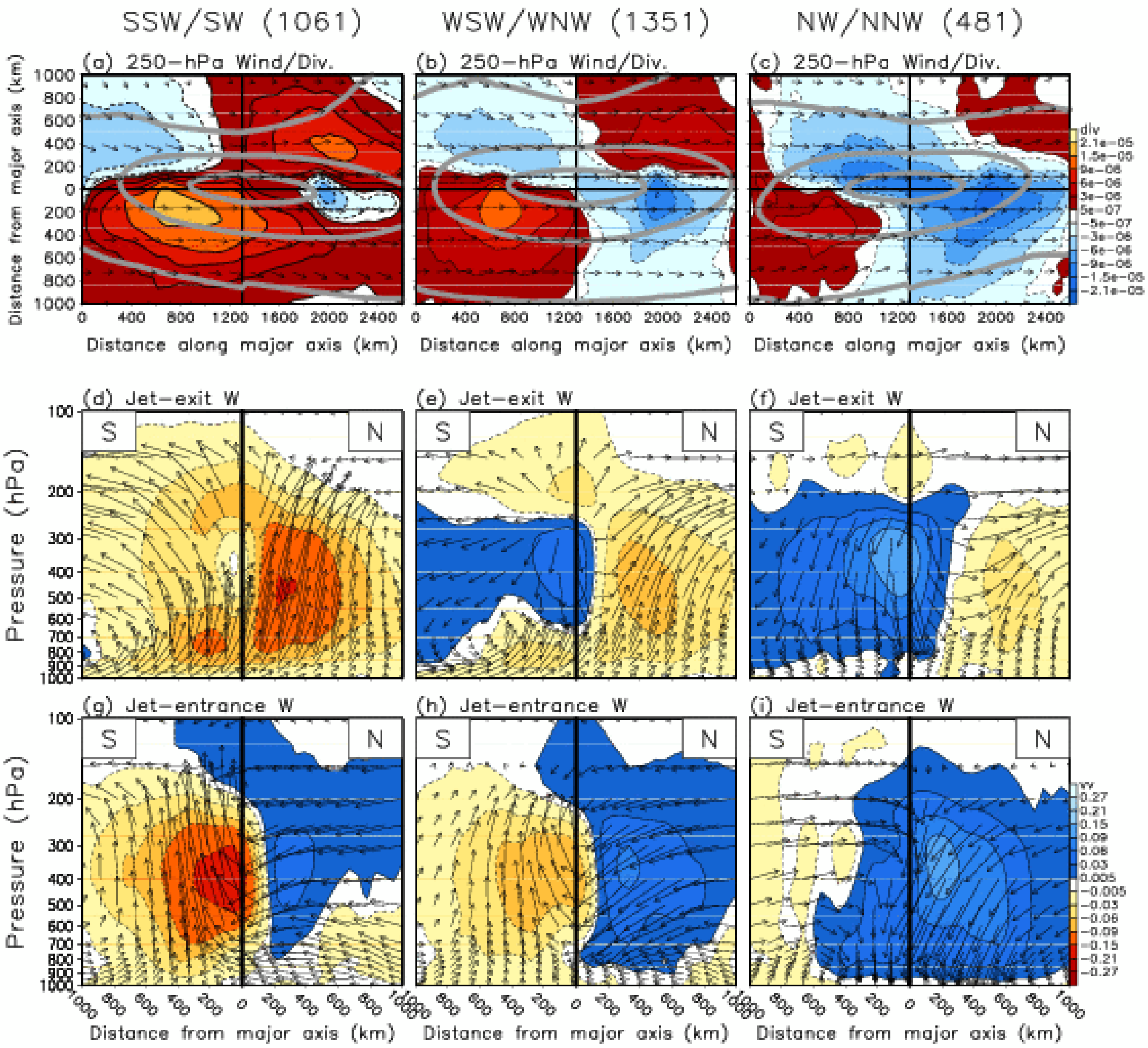
SSW jets more likely to bring wind than hail/tornadoes



Distribution of total storm report frequencies for different jet-orientations, and also for each type of storm report



- **SSW jets have reports concentrated in right-entrance quad**
- **Other S jets have more uniform distributions, but wind still favors right-entrance**
- **N jets favor exit quadrants**



Flow characteristics as a function of jet orientation

Conclusions from Jet Streak work

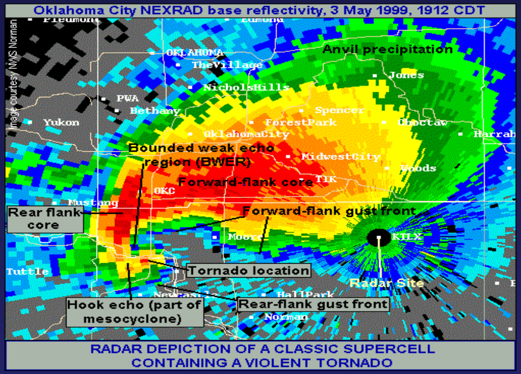
- **Composite distributions show reports concentrate along the major jet-axis in exit region, and also in right-entrance quadrant**
- **Tornadoes most common in exit region, hail evenly distributed, and wind mostly in right-entrance quadrant**
- **Flow/Div fields mostly match 2 or 4QM but downward motion is weak and only aloft in right exit quad, with low-level ascent.**
- **MSLP, CAPE/CIN and SRH all favor severe weather in right exit quad**

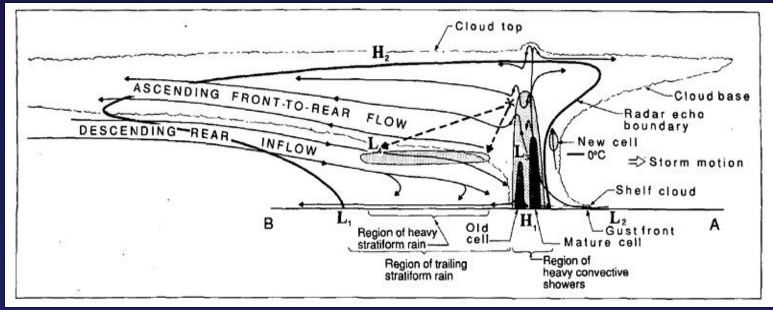
Conclusions from Jet Streak work

- **Linear jets had weakest vertical motion, but still had storm report frequencies comparable to cyclonic and anticyclonic jet streaks**
- **Linear jet streaks had wind much more common in right-entrance region than in left exit (similar to anticyclonic jets), which matches Coniglio et al. (2004) work showing derechos are favored here**
- **SSW jet streaks were associated with strongest upward velocities, with general decrease for clockwise turning, but most storm reports happen in SW and WSW jets, since better combination of low-level severe parameters juxtaposed with moderate shear occurs**

How do severe weather reports relate to convective morphology?

Classification of convective systems





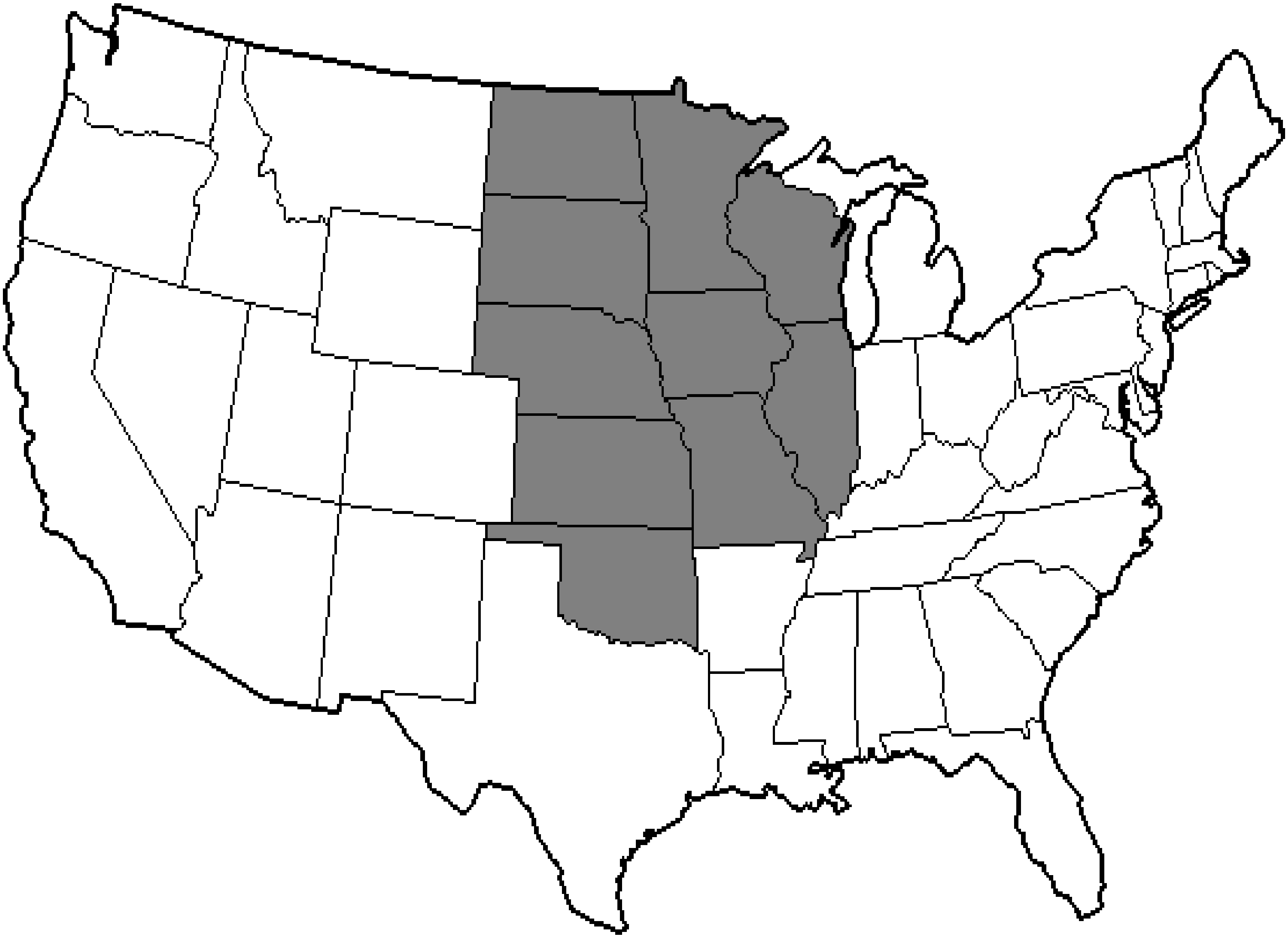
- **Early classifications: Squall lines (e.g. Newton 1950), supercells (e.g., Browning and Ludlam 1962), bow echoes (Fujita 1978), MCCs (Maddox 1980)**
- **Squall Line Developmental classification (Bluestein and Jain 1985) – broken line, back building, broken areal, embedded areal**
- **Symmetric and Asymmetric Squall Lines (Dodge and Houze 1990)**

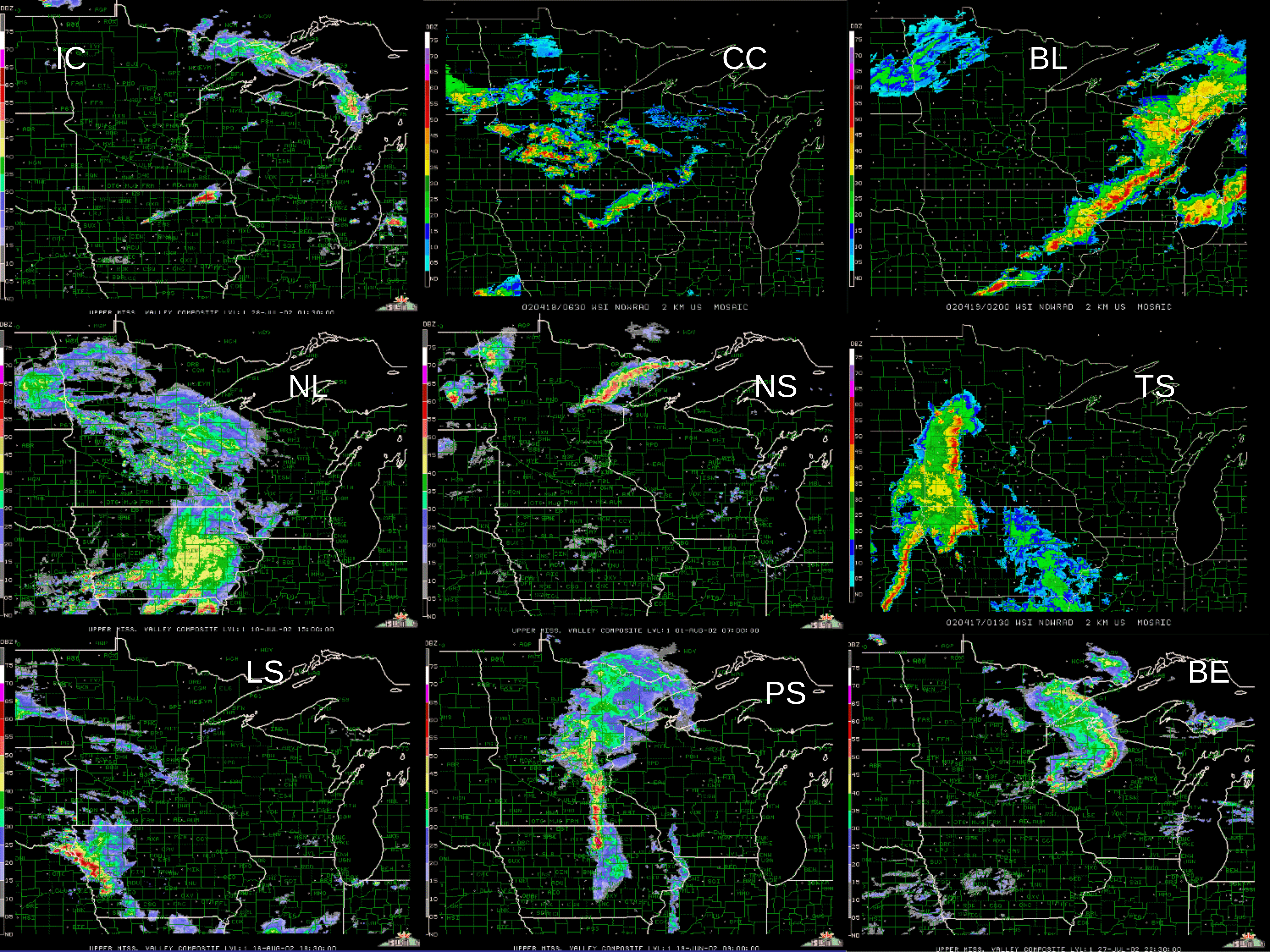
Classification of convective systems

- Squall line stratiform rain (TS, LS, PS) – Parker and Johnson (2000)
- Fowle and Roebber (2003) – model vs obs. for linear, multicellular, isolated
- Done et al. (2004) – model vs obs with non-squall, quasi-linear, and bow echo
- Grams et al. (2006) – model verified via Ebert-McBride technique – continuous linear, bowing, nonlinear, discontinuous areal, isolated cells in obs.

How do severe storm reports vary as a function of morphology?

- Fujita (1978) mentioned that bow echoes were associated with severe winds
- Moller et al. (1994), among others, mentions supercells as being most common producers of tornadoes
- Trapp et al. (2005) discuss tornadoes in squall lines (QLCS)
- Pettet and Johnson (2003) mention leading stratiform and parallel stratiform squall lines as having flash flood threats





IC
CC
BL
020418/0630 WSI NOWRAD 2 KM US MOSAIC
020419/0200 WSI NOWRAD 2 KM US MOSAIC
NL
NS
TS
020417/0130 WSI NOWRAD 2 KM US MOSAIC
LS
PS
BE

Data and Methodology

- 2 km radar data with 30-60 minute temporal resolution at NCAR archive were examined from April 1 – August 31, 2002
- All convective systems in the 10 state area were classified into 9 morphologies
- Storm reports were then examined and associated with each event
- Systems had to contain > 10 dBZ echo over 6 x 6 km or greater area, with at least one pixel > 30 dBZ

Classification details

- Events had to last for at least 2 images (> 1 hour)
- Cellular categories (3) had to have some separation between the 30 dBZ elements
- Linear categories had to have connected strong echoes in line at least 75 km long, and > 3 times as long as wide
- Nonlinear systems had strong radar echoes connected but not in linear fashion
- Multiple modes could be assigned at different times as long as they lasted for over an hour – storm reports then assigned to the corresponding mode. Any mode lasting less than 2 images was ignored and the storm reports were assigned to the mode that dominated over time

Dataset

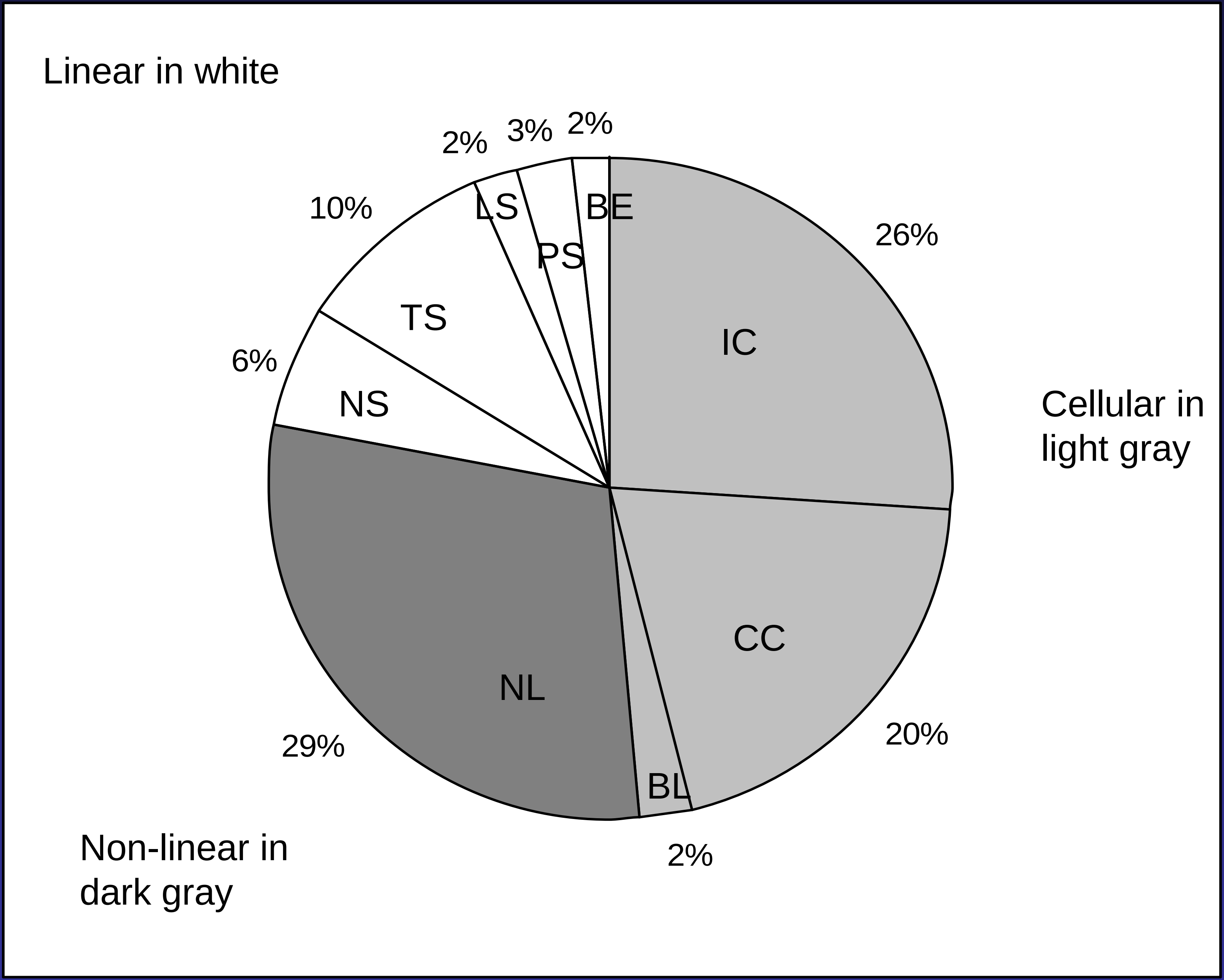
- 925 systems identified during 2002 – but this was supplemented by 24 extra LS and PS cases from M. Parker since only 5 of each of these modes occurred in 2002. Parker sample was from same 10 state region and same April-August period in 1996-1997.
- This total of 949 systems was associated with 9678 severe reports and 1122 flooding reports

Severe criteria

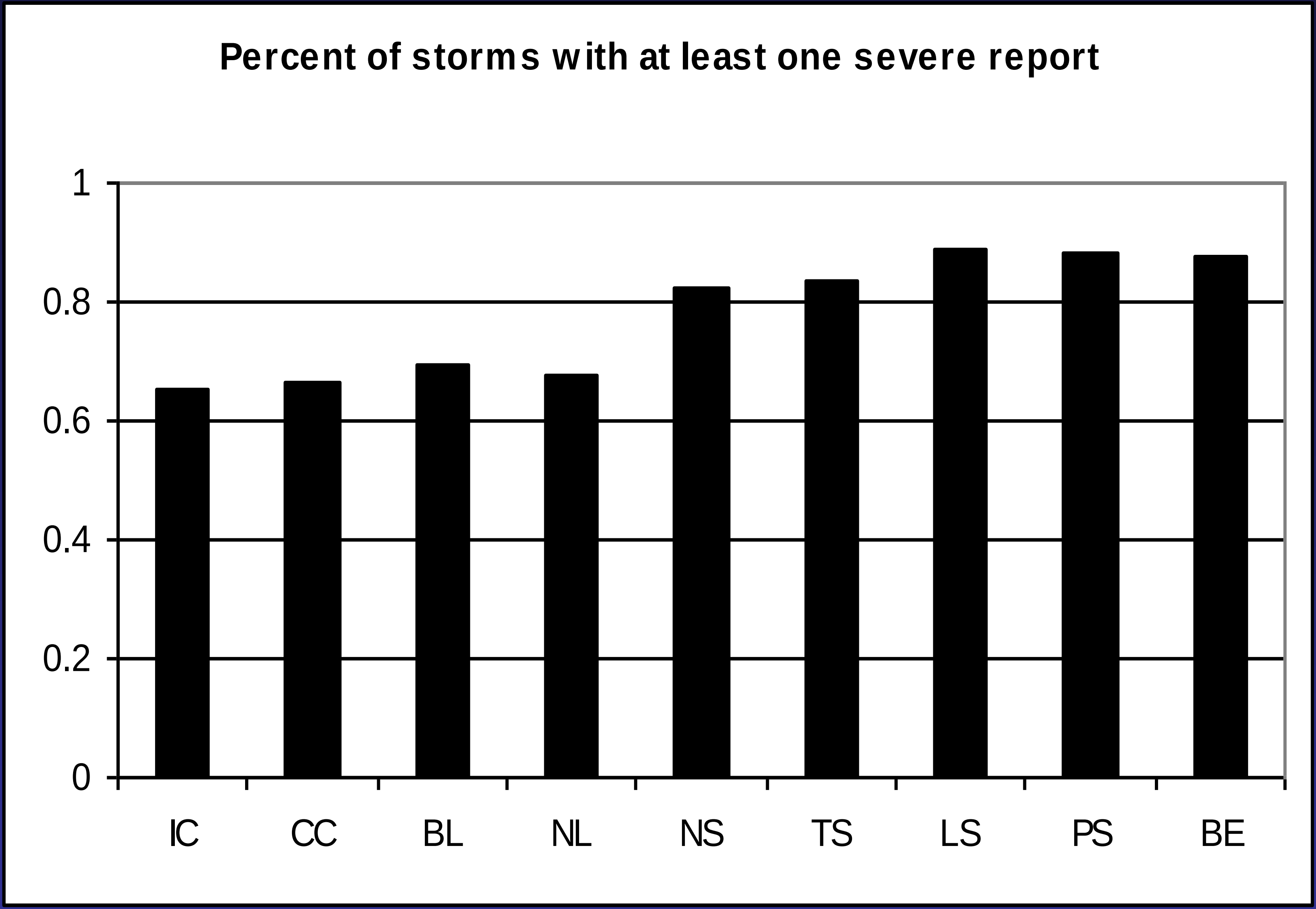
- Severe hail < 1 inch in diameter
- Hail < 2 inches but ≥ 1 inch
- Hail ≥ 2 inches
- Severe wind < 65 knots (or no speed reported)
- Severe wind ≥ 65 knots
- Tornadoes
- Flooding

Storm Data Problems

- Many authors have noted numerous problems in the Storm Data archive
- Human and population biases
- Changing reporting strategies
- Hail and Wind data shown as point measurements and not swaths like tornadoes
- No wind speeds assigned for majority of wind damage events

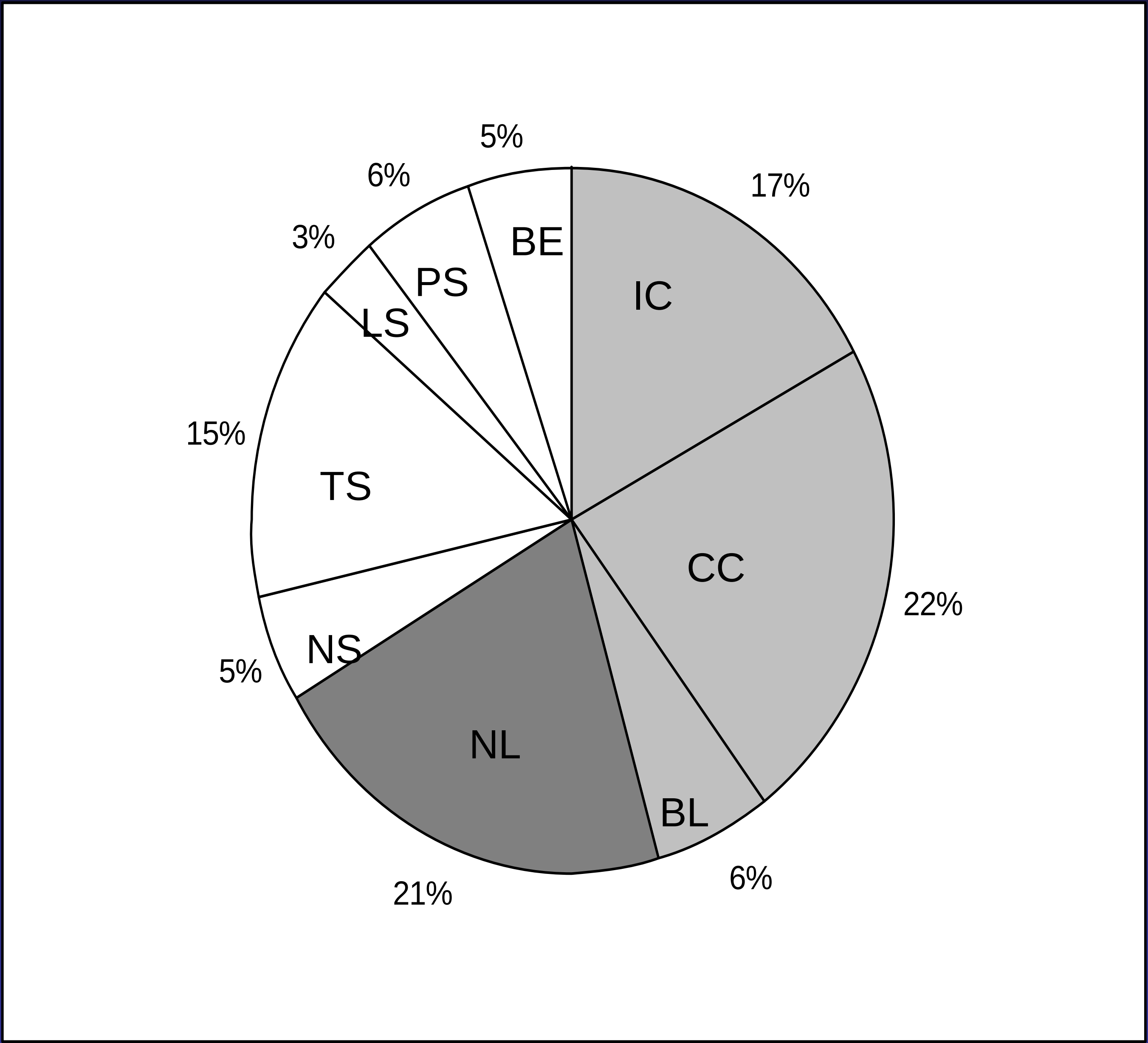


Distribution of the 949 "severe" systems by morphology



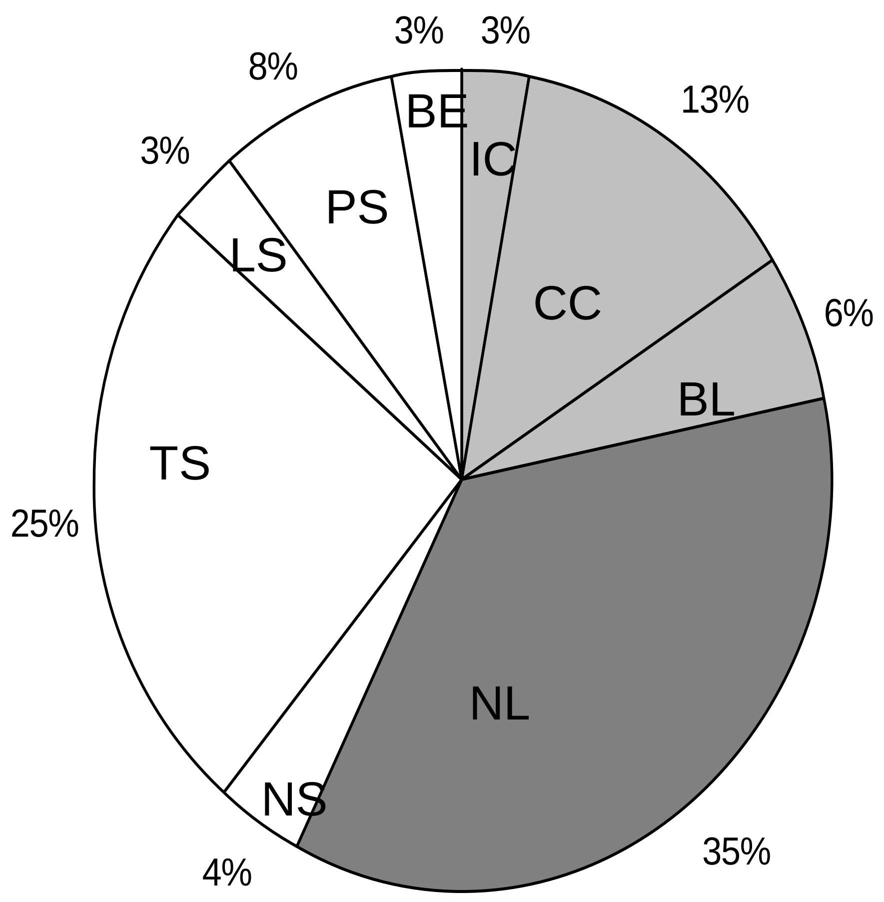
For the full sample, 71% of all systems produced some severe weather

Cellular and non-linear events had a lower frequency; linear events higher (up to nearly 90% in LS, PS and BE events)



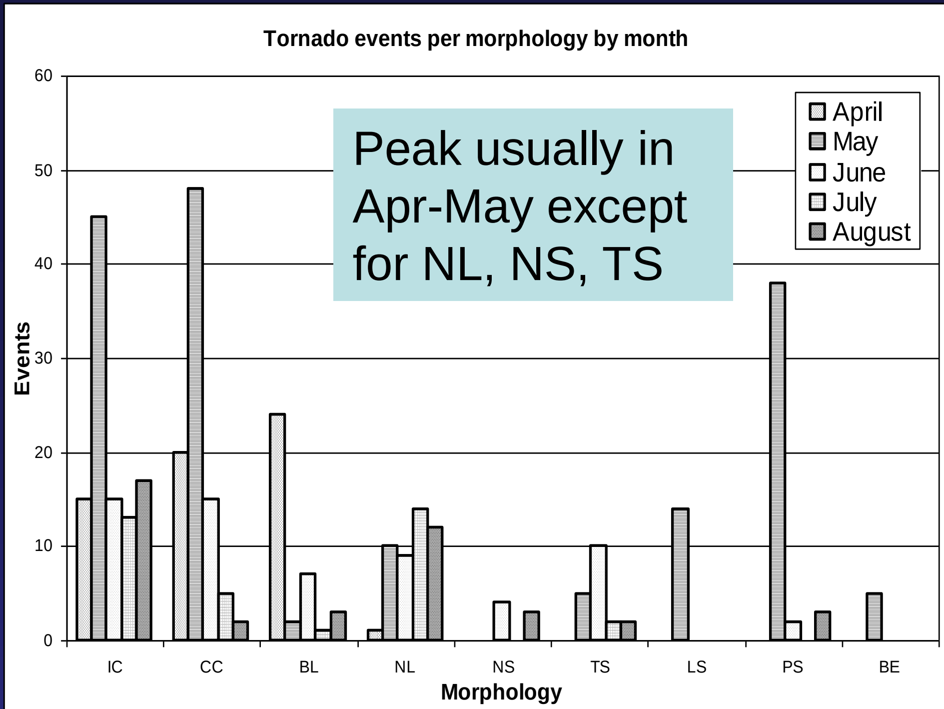
Distribution of severe weather reports as a function of morphology

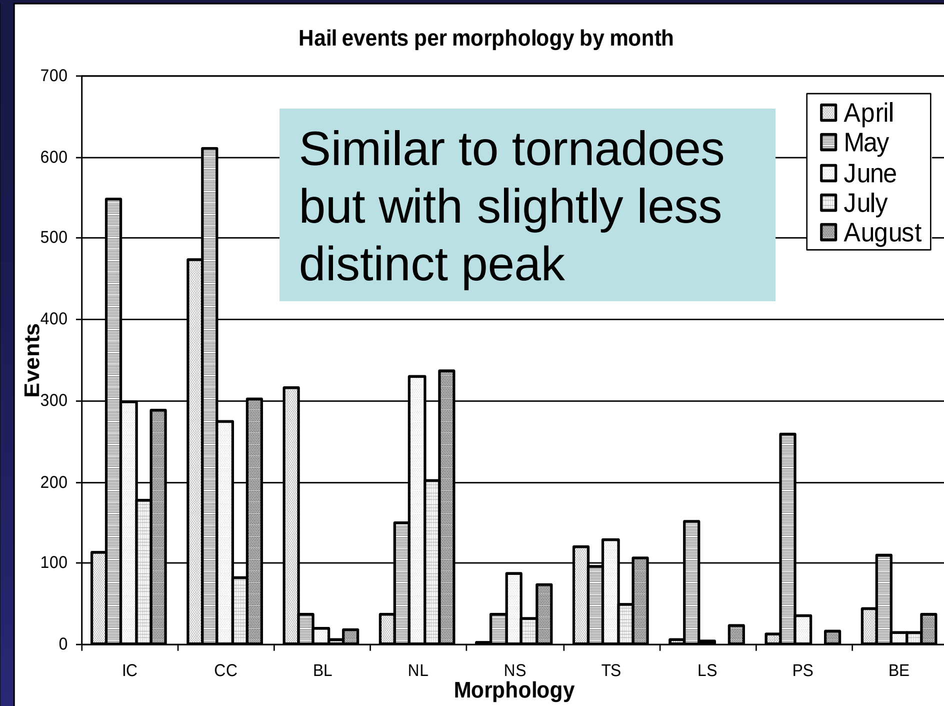
- note, nonlinear fraction of reports decreases relative to number of systems, while linear fraction increases

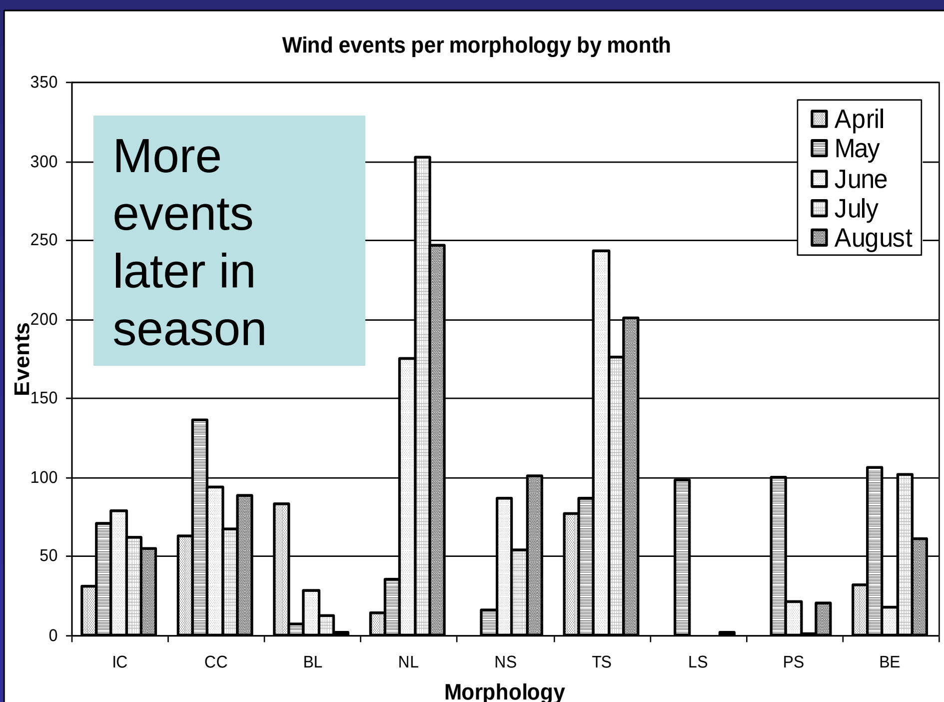


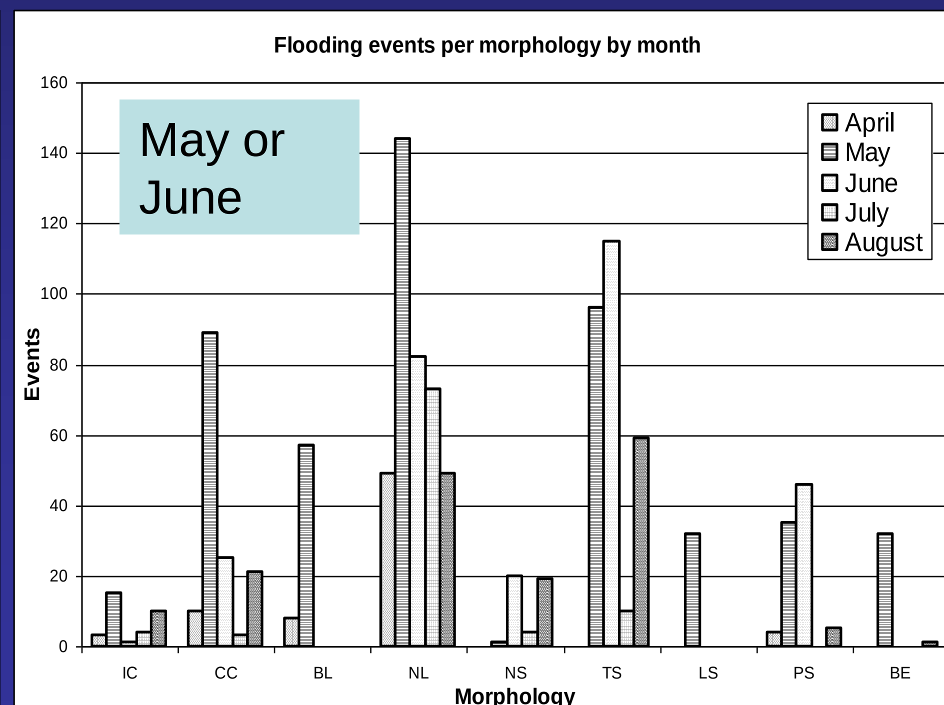
Distribution of flooding reports as a function of morphology

- note, cellular fraction decreases dramatically

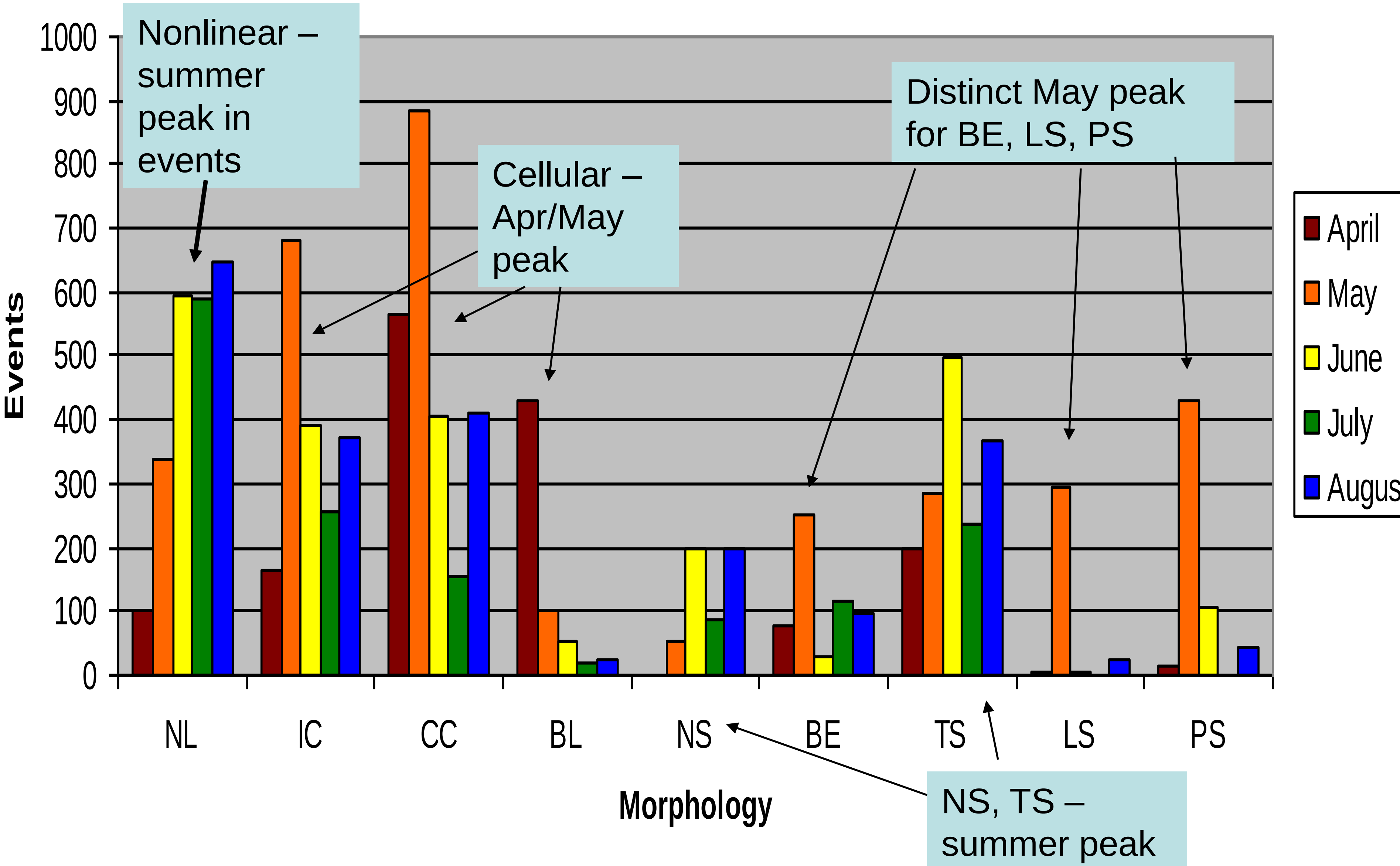

Tornado events per morphology by month
Peak usually in Apr-May except for NL, NS, TS
April
May
June
July
August
Events
Morphology
IC
CC
BL
NL
NS
TS
LS
PS
BE
0
10
20
30
40
50
60

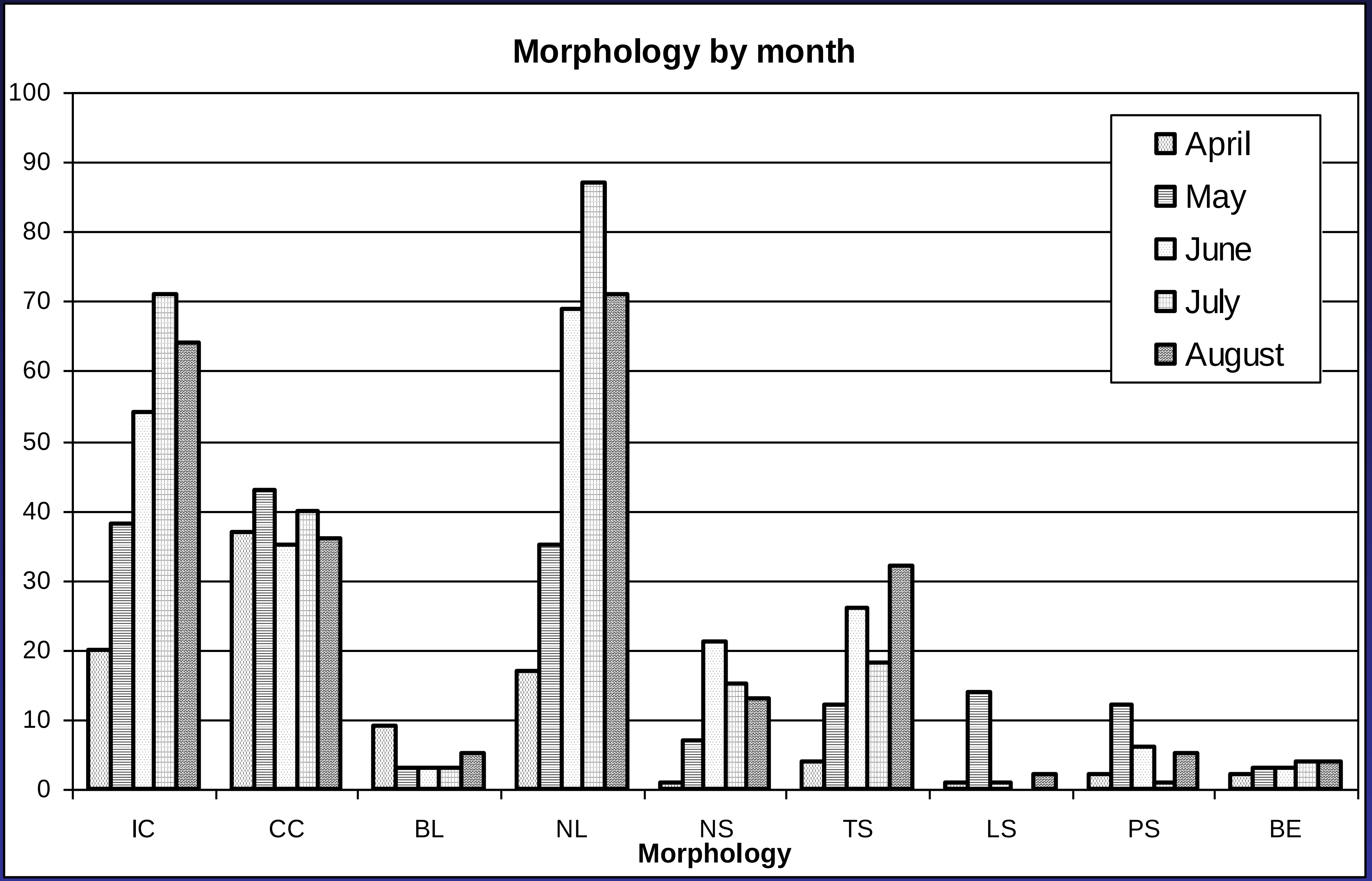

Hail events per morphology by month
Similar to tornadoes but with slightly less distinct peak
April
May
June
July
August
Events
Morphology
IC
CC
BL
NL
NS
TS
LS
PS
BE
0
100
200
300
400
500
600
700


Wind events per morphology by month
More events later in season
April
May
June
July
August
Events
Morphology
IC
CC
BL
NL
NS
TS
LS
PS
BE
0
50
100
150
200
250
300
350


Flooding events per morphology by month
May or June
April
May
June
July
August
Events
Morphology
IC
CC
BL
NL
NS
TS
LS
PS
BE
0
20
40
60
80
100
120
140
160

Total events per morphology as a function of month

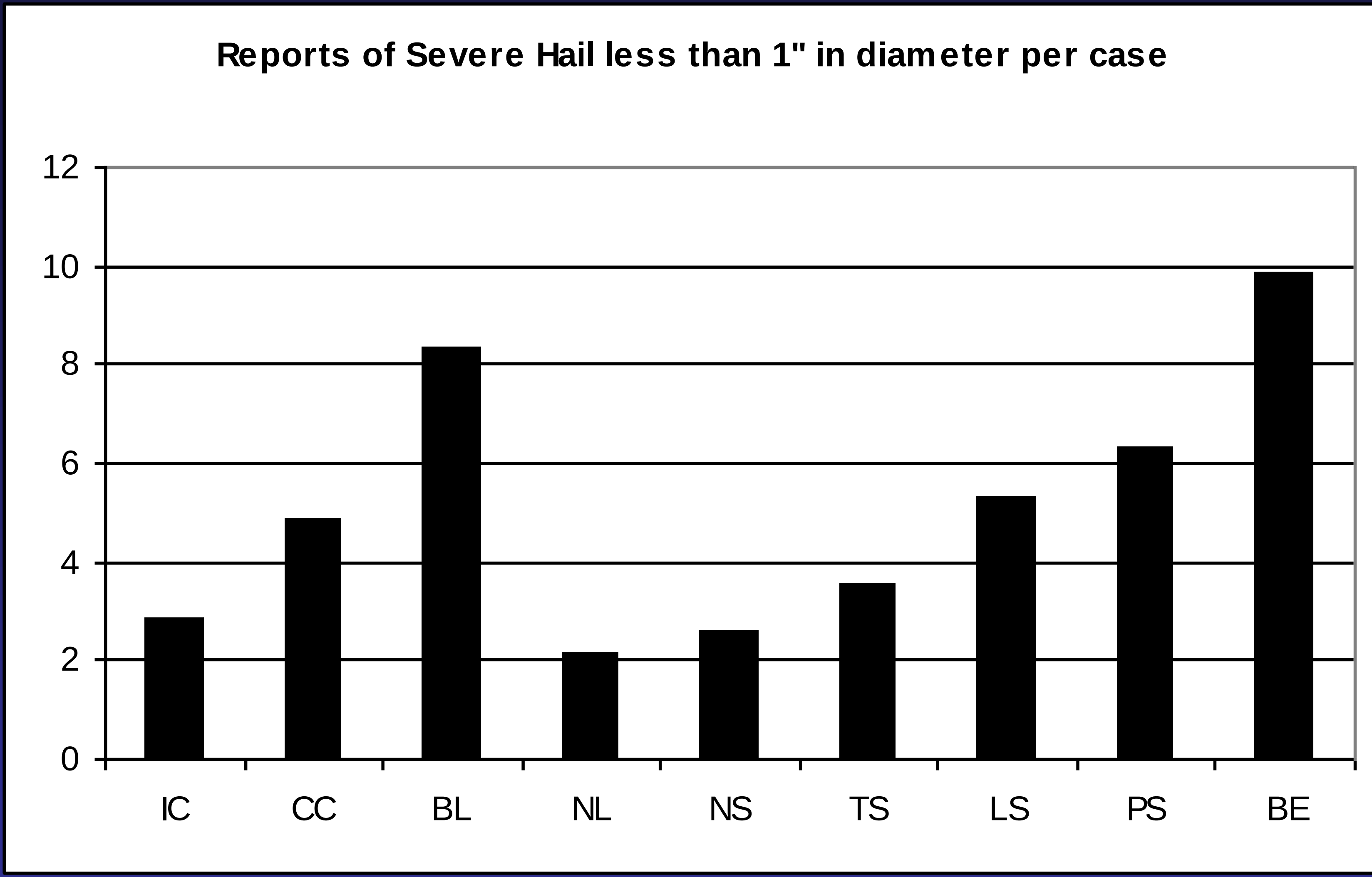




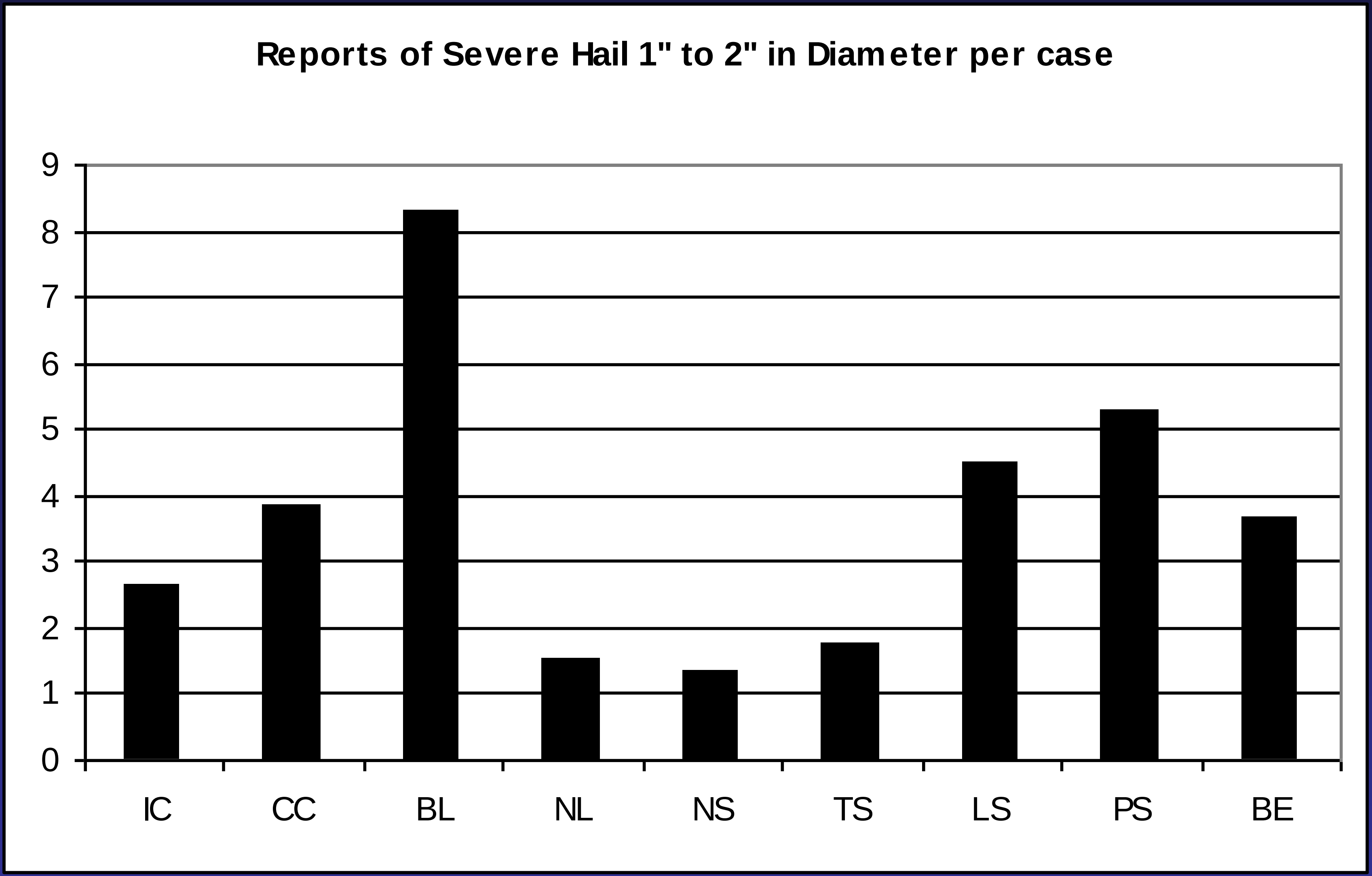
Cellular systems more common in summer (esp. IC) BUT most severe reports are in spring. For other morphologies, frequency of occurrence and frequency of severe reports show comparable trends

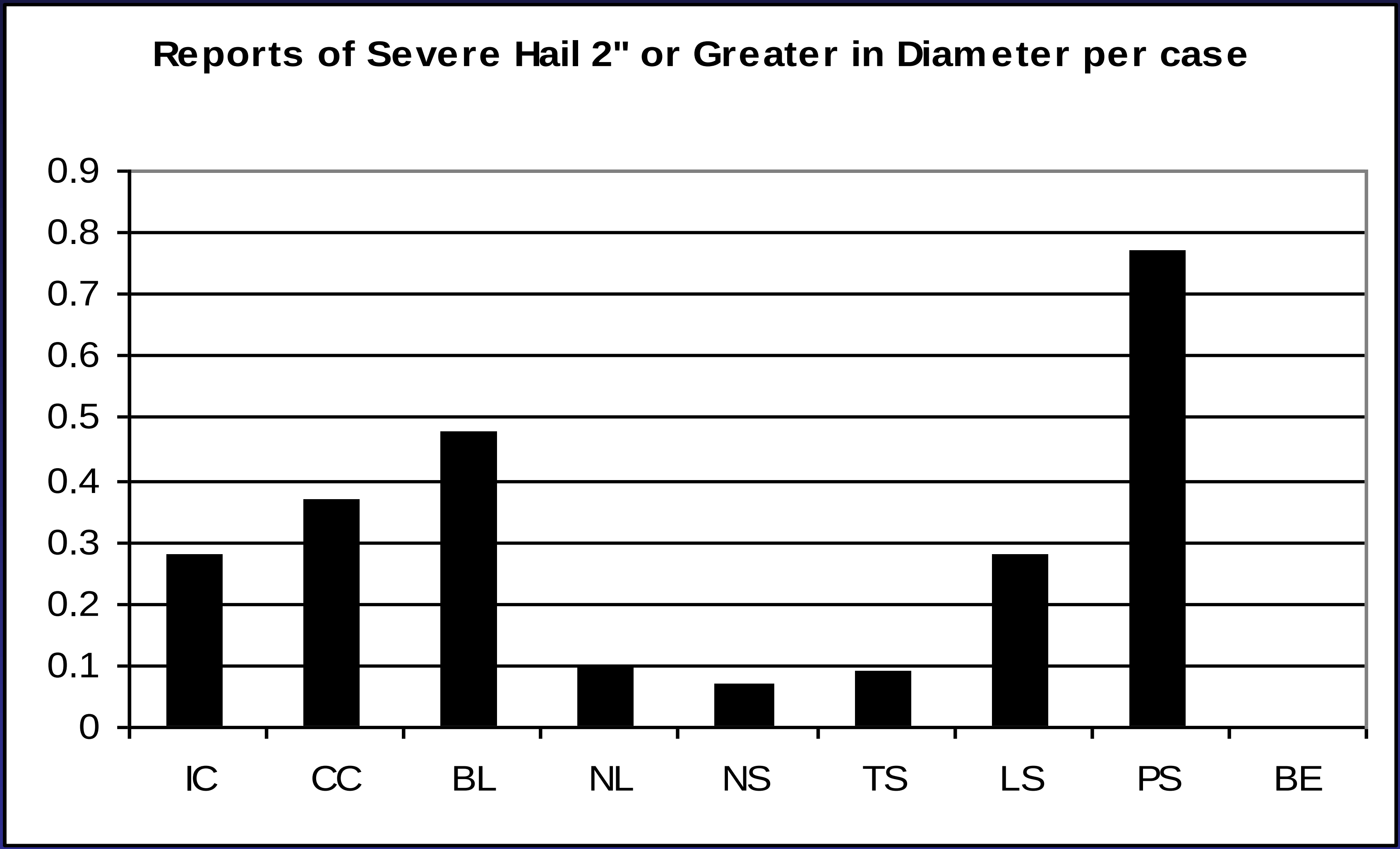
Normalization

- Graphs that follow were normalized by number of events
- Areal coverage obviously plays a big role – cellular systems are much smaller in scale than linear or nonlinear ones, but normalization based on area would require much additional work
- Reports will also depend on geography, time of day, human factors…

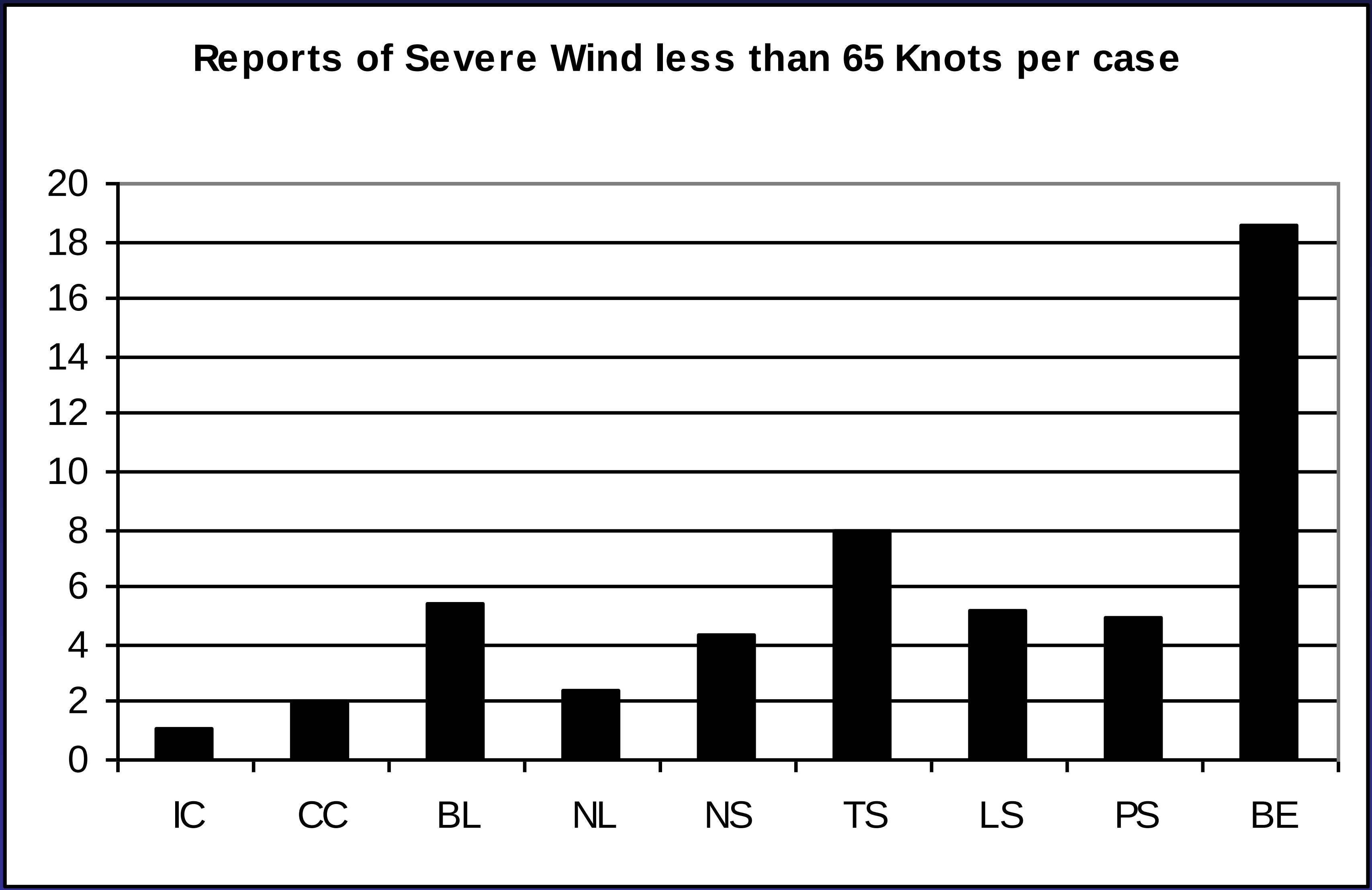


Note: Bow Echoes are associated with the most "marginally severe" hail reports

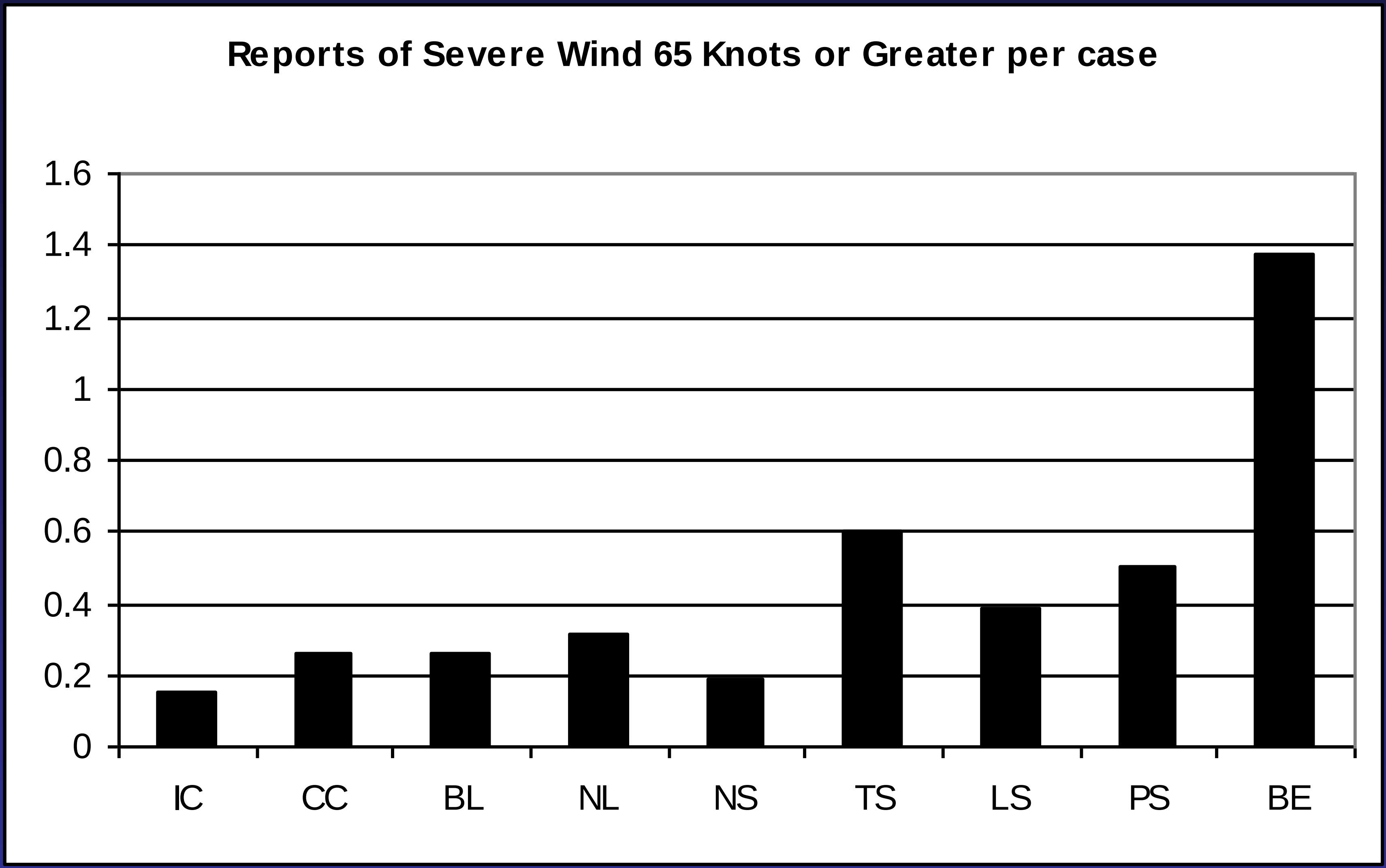

Reports of Severe Hail 1" to 2" in Diameter per case
0
1
2
3
4
5
6
7
8
9
IC
CC
BL
NL
NS
TS
LS
PS
BE

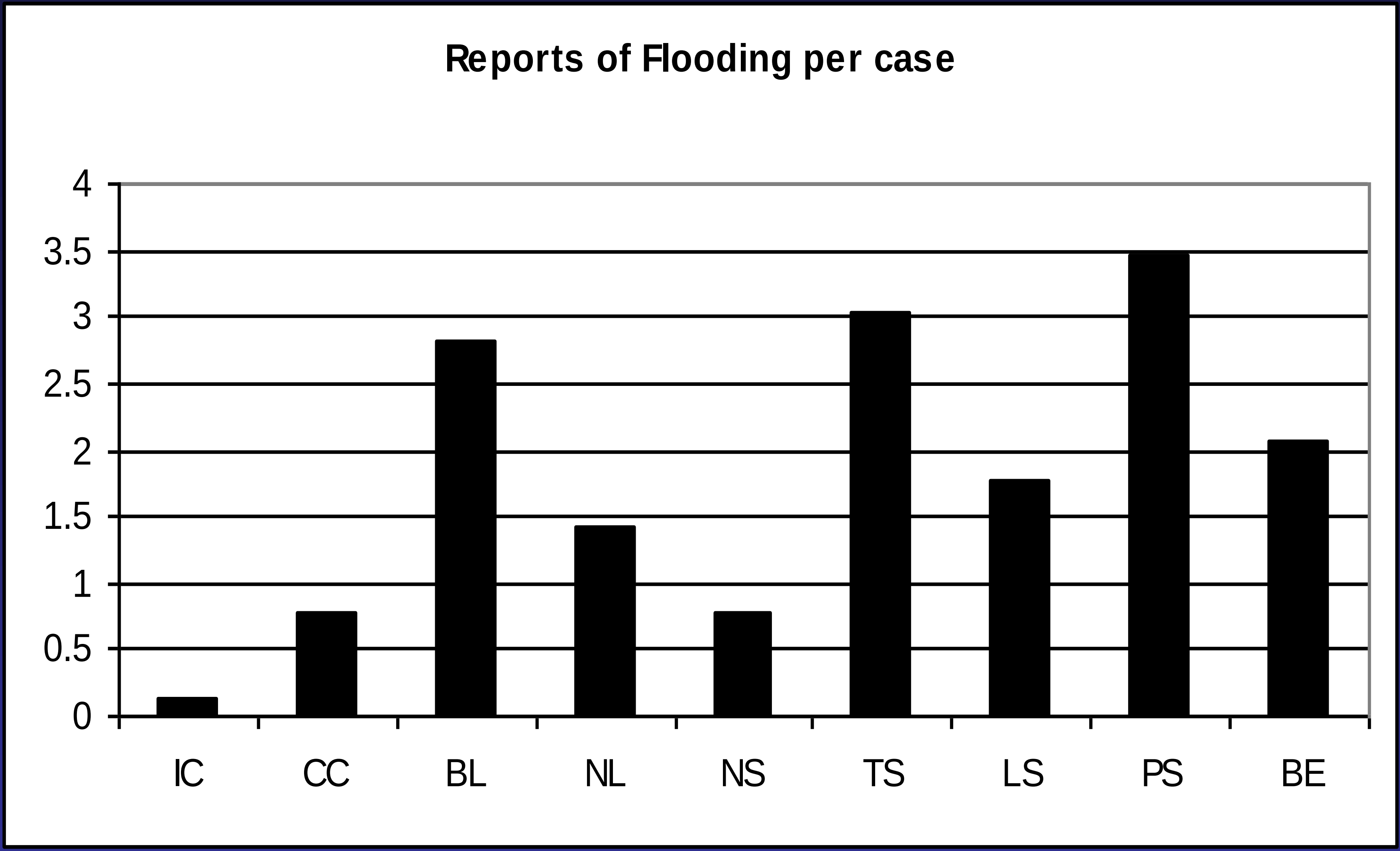


For the largest hail sizes, cellular morphologies are the cause relatively more often than for smaller sizes. Bow Echoes now have no reports. Leading Stratiform and Parallel Stratiform linear events are also dangerous – perhaps related to shear profiles that are more supercellular (e.g. Parker 2007a, b)

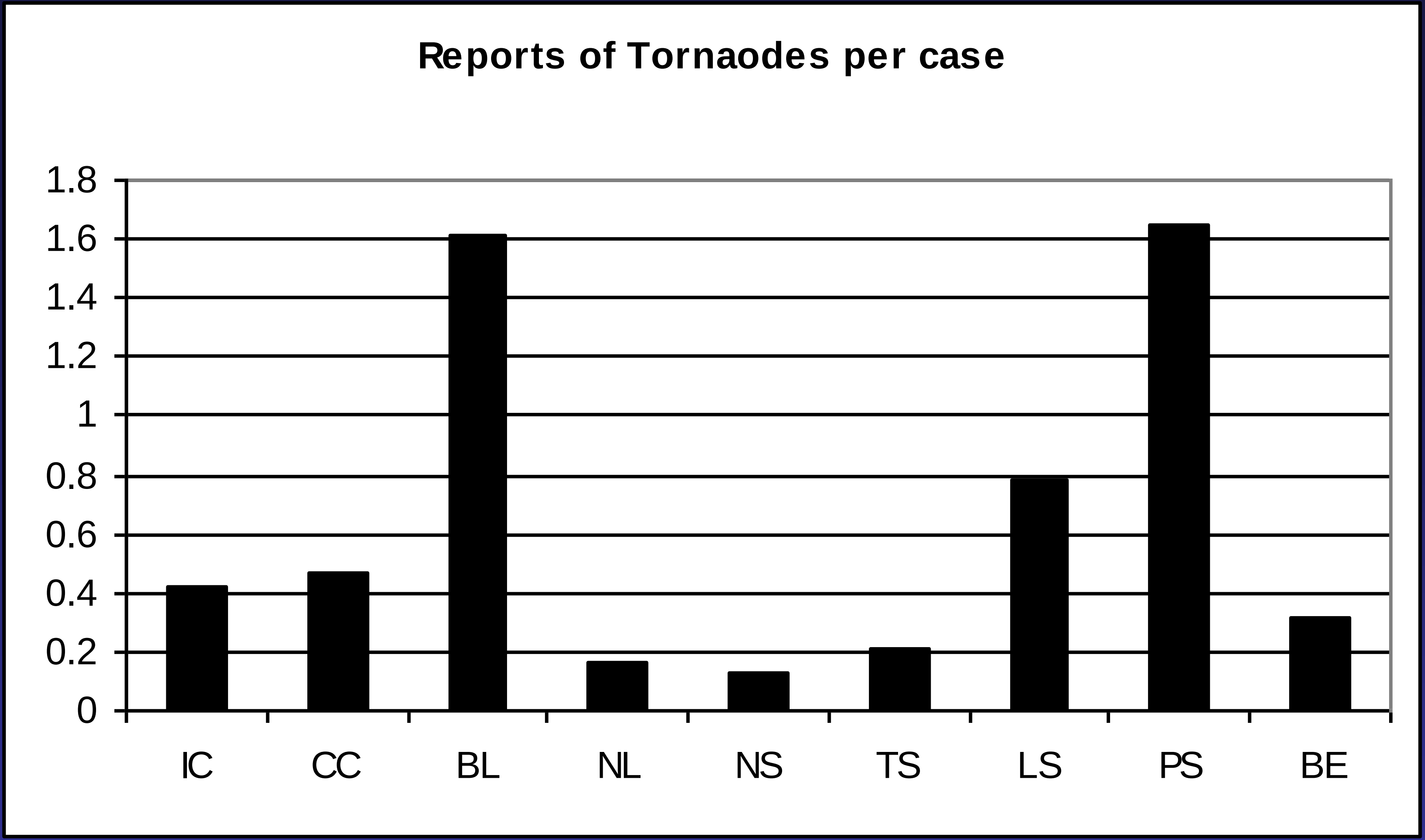


Bow Echoes and Trailing Stratiform systems dominate for severe wind reports. (Bow Echo is really a subset of TS).


Reports of Severe Wind 65 Knots or Greater per case
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
IC
CC
BL
NL
NS
TS
LS
PS
BE



Note: Location of stratiform rain plays a role in flooding likelihood. Surprising that Broken Line cellular events are such prolific flood producers.



Note: As might be expected, cellular categories have higher frequencies. But, LS and PS are also major producers of tornadoes (again agreeing with supercell environment characteristics). Also note BL is more favorable than IC or CC – may be a function of areal coverage, but CC tends to be similar to BL in area. May also reflect BL development near fronts (baroclinity = strong wind shear)

Morphology – Storm Reports Summary

- Noticeable differences are present in severe reports associated with different morphologies
- Nonlinear systems are not as active with severe weather
- Wide range of reports for different linear morphologies – PS and LS may be most dangerous
- Cellular storms are mostly hail and tornado producers, but BL also poses a flood threat

Acknowledgments

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- The morphology – storm report research was motivated in part by discussions with SPC/NSSL scientists during past Spring Program visits