The Spectrum of Progressive Derecho Formation Environments

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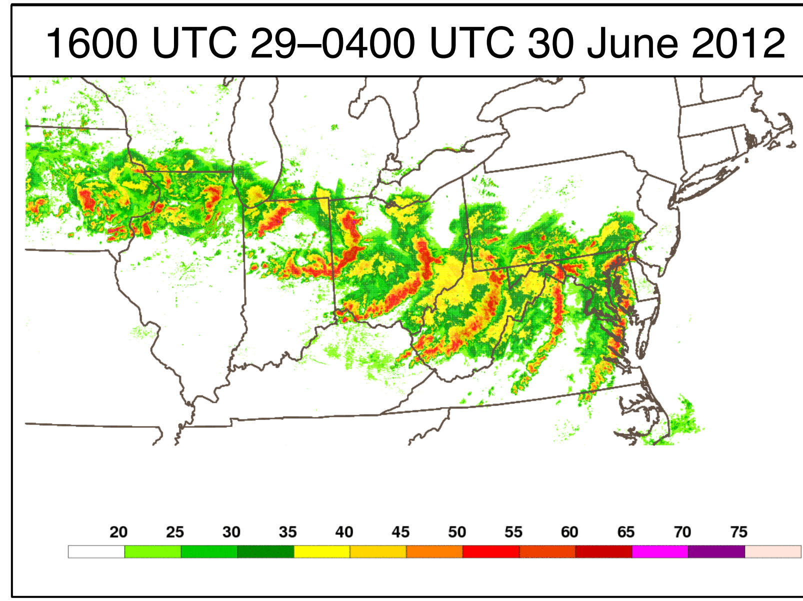
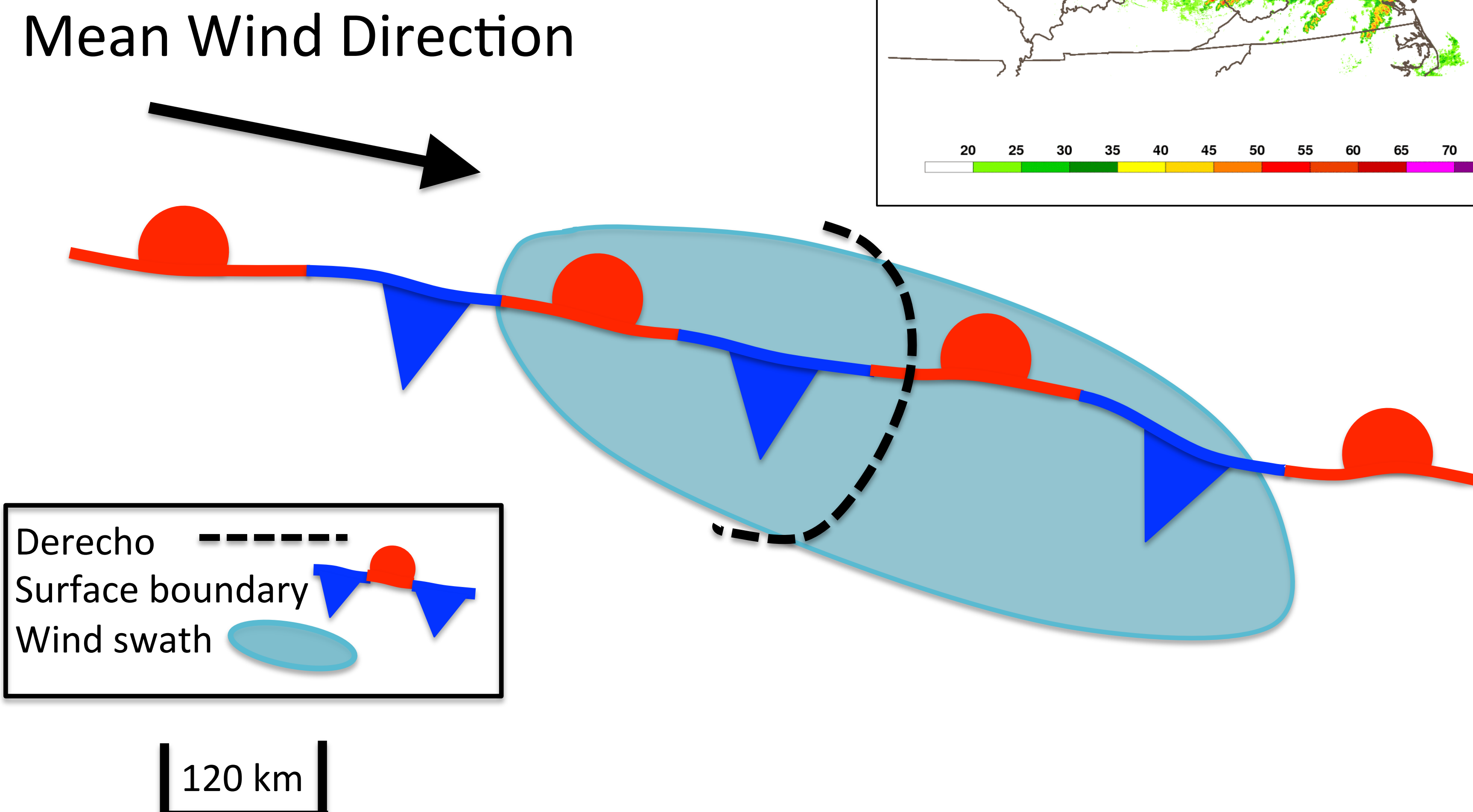
Derecho: a swath of severe winds 400 km long or greater caused by bowing mesoscale convective system (MCS)

Two types:

- Progressive
- Serial

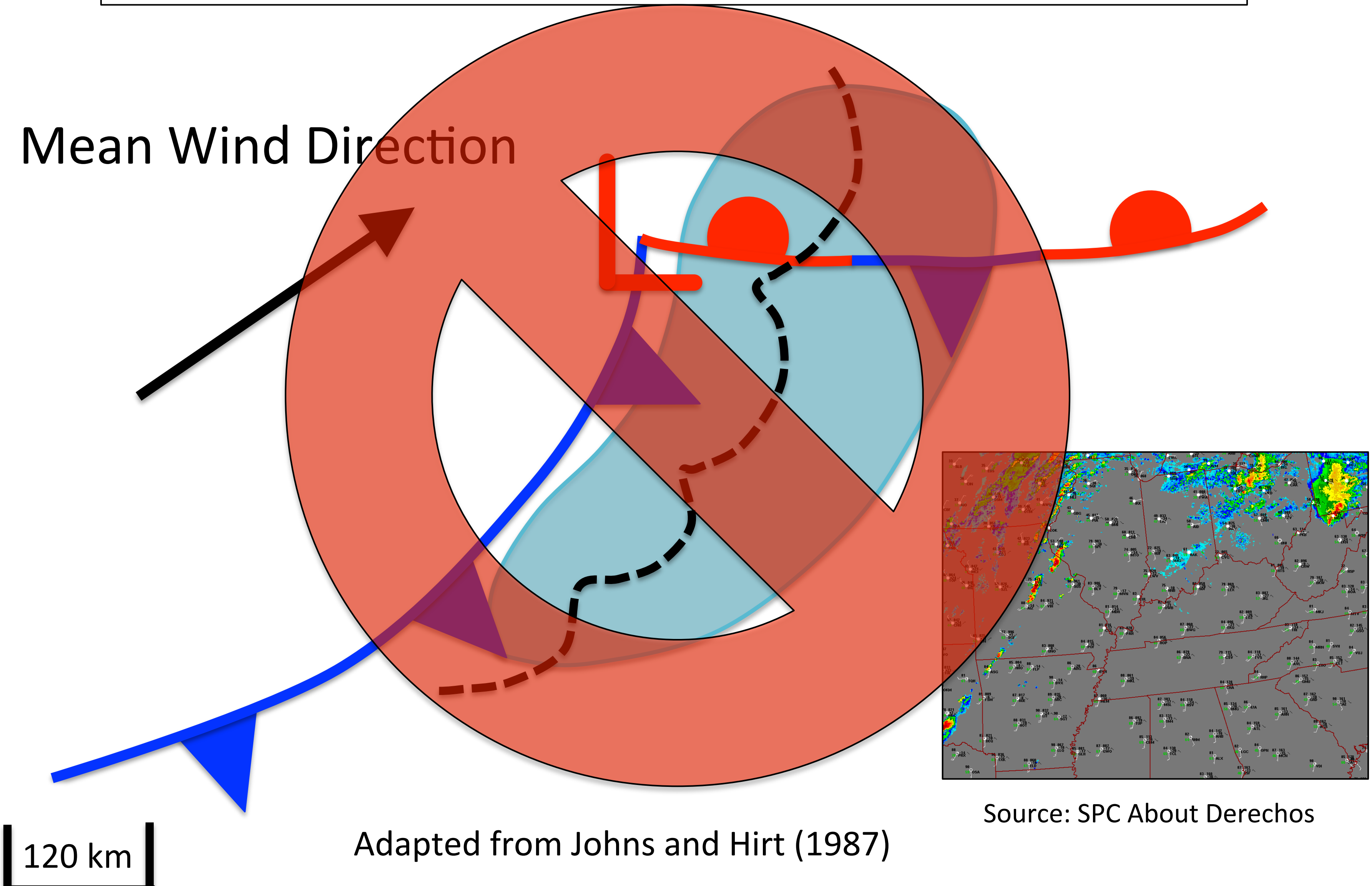
Progressive Derecho Schematic





Adapted from Johns and Hirt (1987)

Serial Derecho Schematic



Adapted from Johns and Hirt (1987)

Source: SPC About Derechos

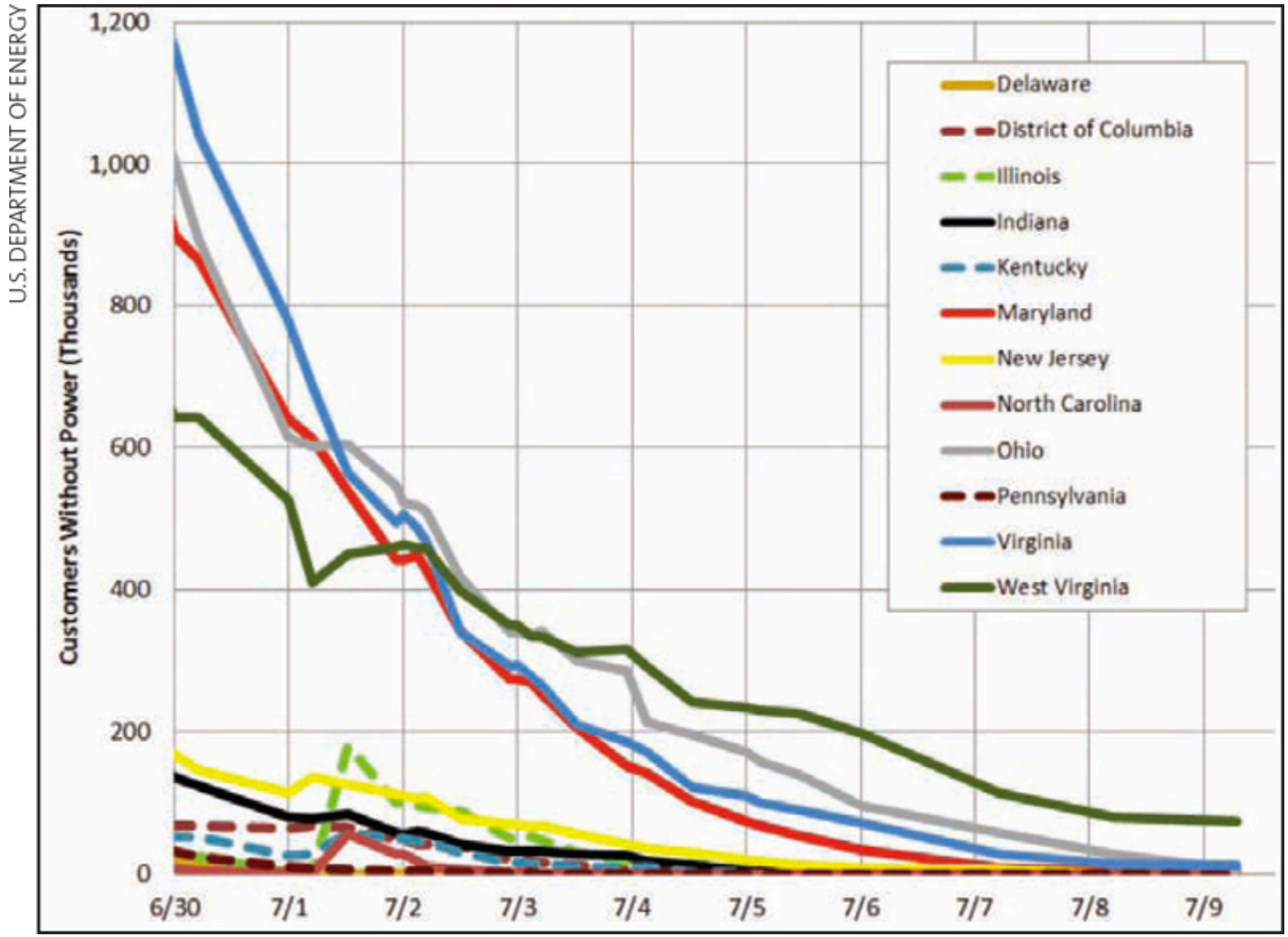
Motivation

- Progressive derechos are high impact events
- Progressive derechos may be poorly predicted due to the benign synoptic environments in which they form
  - Able to sustain themselves through cold pool dynamics far away from initial forcing for ascent as long as unfavorable environment not encountered
  - Predicting extent of storm track difficult
- Can progressive derecho formation environments be systematically categorized?

29–30 June 2012 Derecho: Statistics

- Duration: ~11 h (1700-0400 UTC)
- Length: ~1200 km (IL/IN to DE/MD)
- Fatalities: 13 direct, 31 indirect
- Peak wind gust: 79 kt (Fort Wayne, IN)
- Damage: $1+Billion (source: NCDC)
- Power outages: ~4 million **customers**
- Heat stress: Millions of people
- Source: http://www.ncdc.noaa.gov/news/preliminary-info-2012-us-billion-dollar-extreme-weatherclimate-events

Power outage recovery

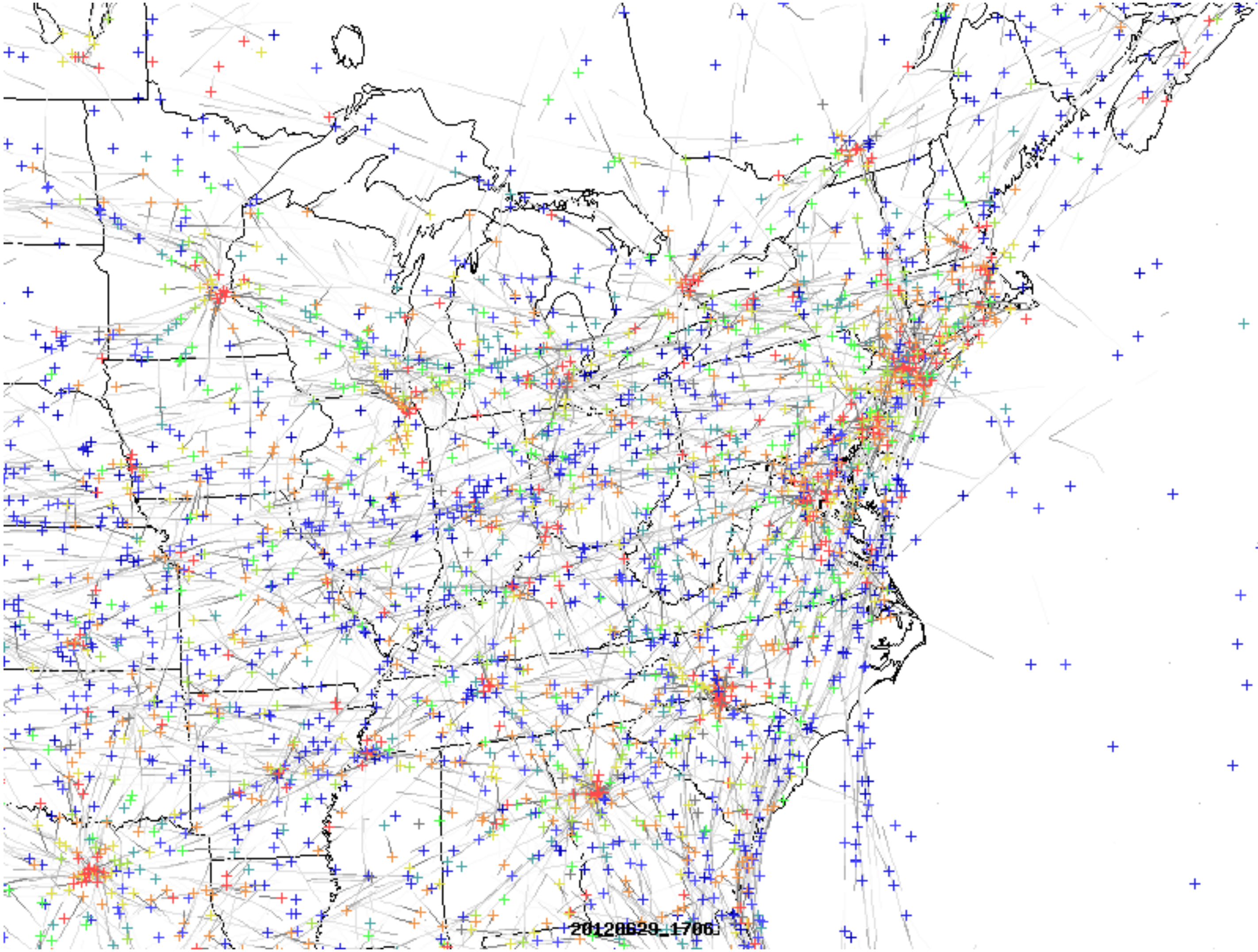


Flight tracks: 1700 UTC 29 June to 0500 UTC 30 June 2012

A look at how the FAA and the airlines managed flight tracks during the long-lived derecho of 29-30 June 2012

- Source: Daniel Vietor[1] and David Bright[2]
  - 1: Senior Research Meteorologist, CIRA-CSU and NCEP Aviation Weather Center
  - 2: Chief, Aviation support Branch, NCEP Aviation Weather Center

Flight tracks



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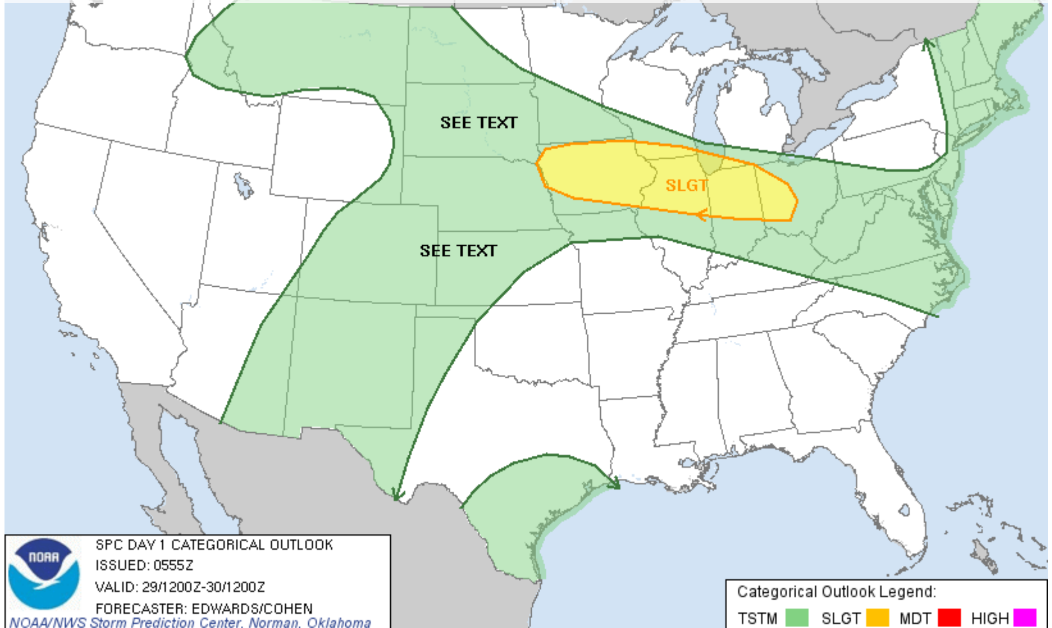
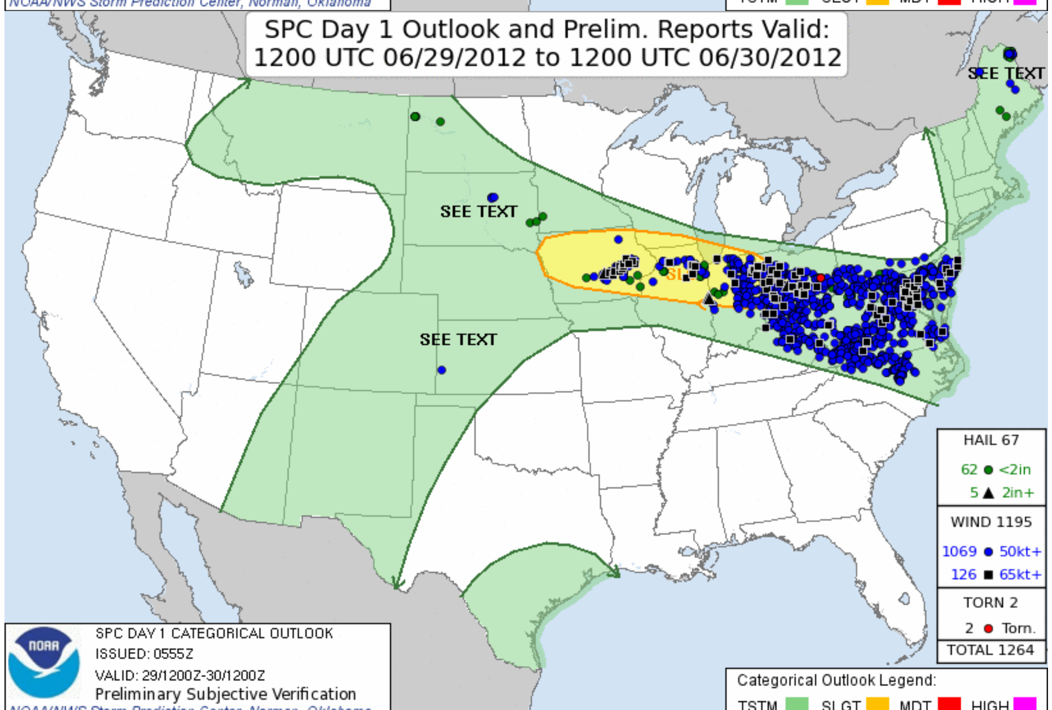
0600 UTC 29 June 2012 Day 1 Convective Outlook





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Outline

- Partial extension of existing climatology
  - Warm season (May–August) progressive derechos
    - Storm Prediction Center severe storm reports and NCDC radar archive
- Subjective composites
  - Formation spectrum
    - 0.5° Climate Forecast System Reanalysis (CFSR) data
- Two case studies
  - Ends of formation spectrum
    - North American Regional Reanalysis (NARR), sounding, satellite, radar, surface observations
- Science and forecasting issues

Origin of Derecho Climatologies

- Derecho first coined in 1888 (Hinrichs)
- First attempt to systematically identify derechos by Johns and Hirt (1987) using the following criteria based on Fujita and Wakimoto's (1981) definition of a family of downburst clusters:
  - Concentrated area of wind reports > 26 m s^{-1} (50 kt) at least 400 km long
  - Reports must exhibit a pattern in a singular swath
  - Must be at least three reports separated by 64 km or more of either F1 damage and/or gusts of 33 m s^{-1} or greater
  - No more than three hours can elapse between successive wind reports

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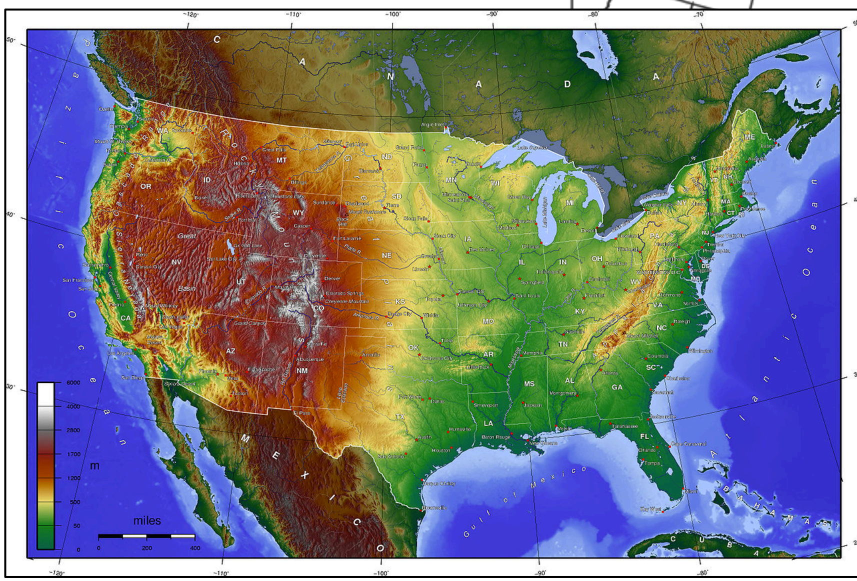
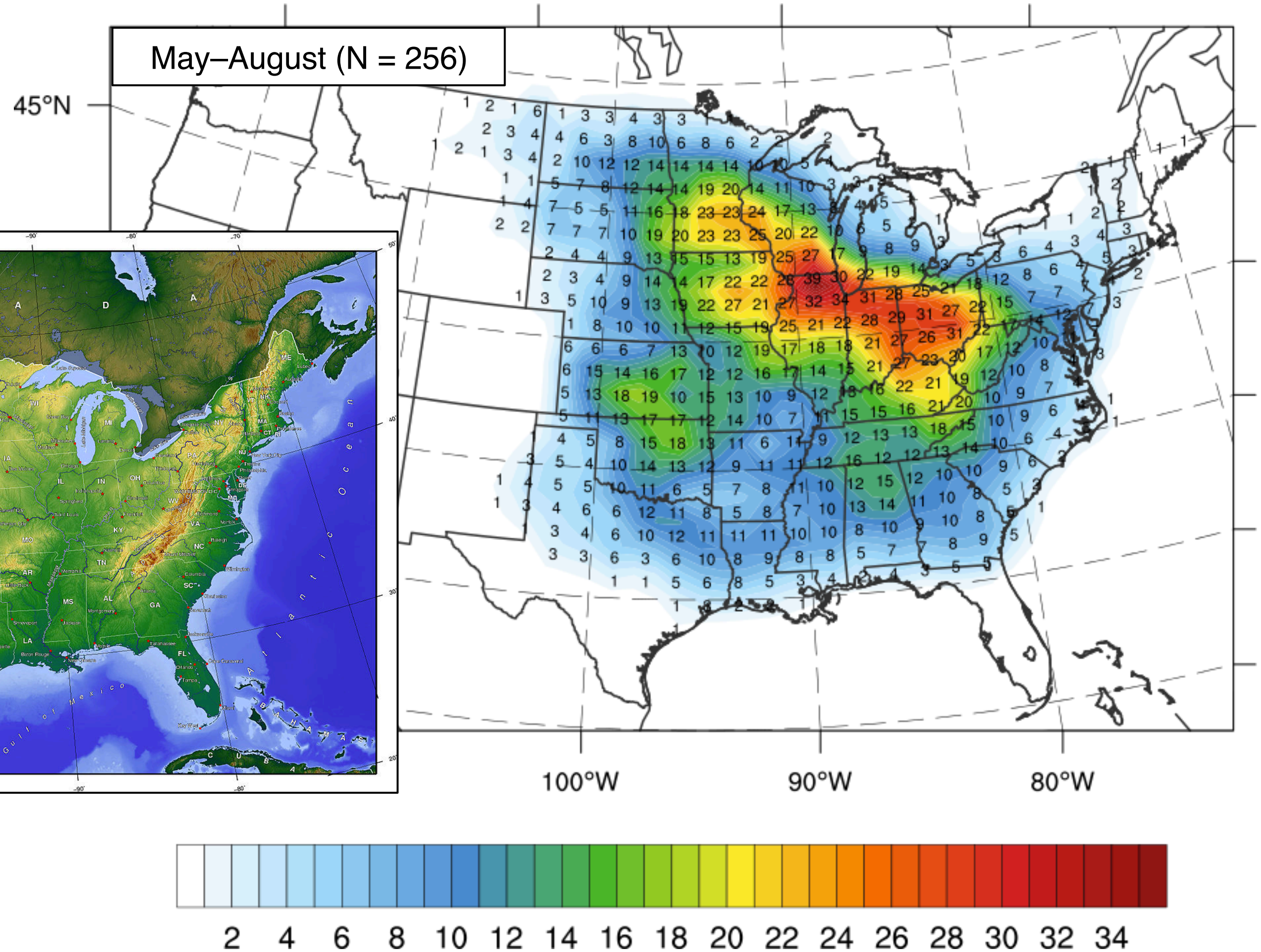
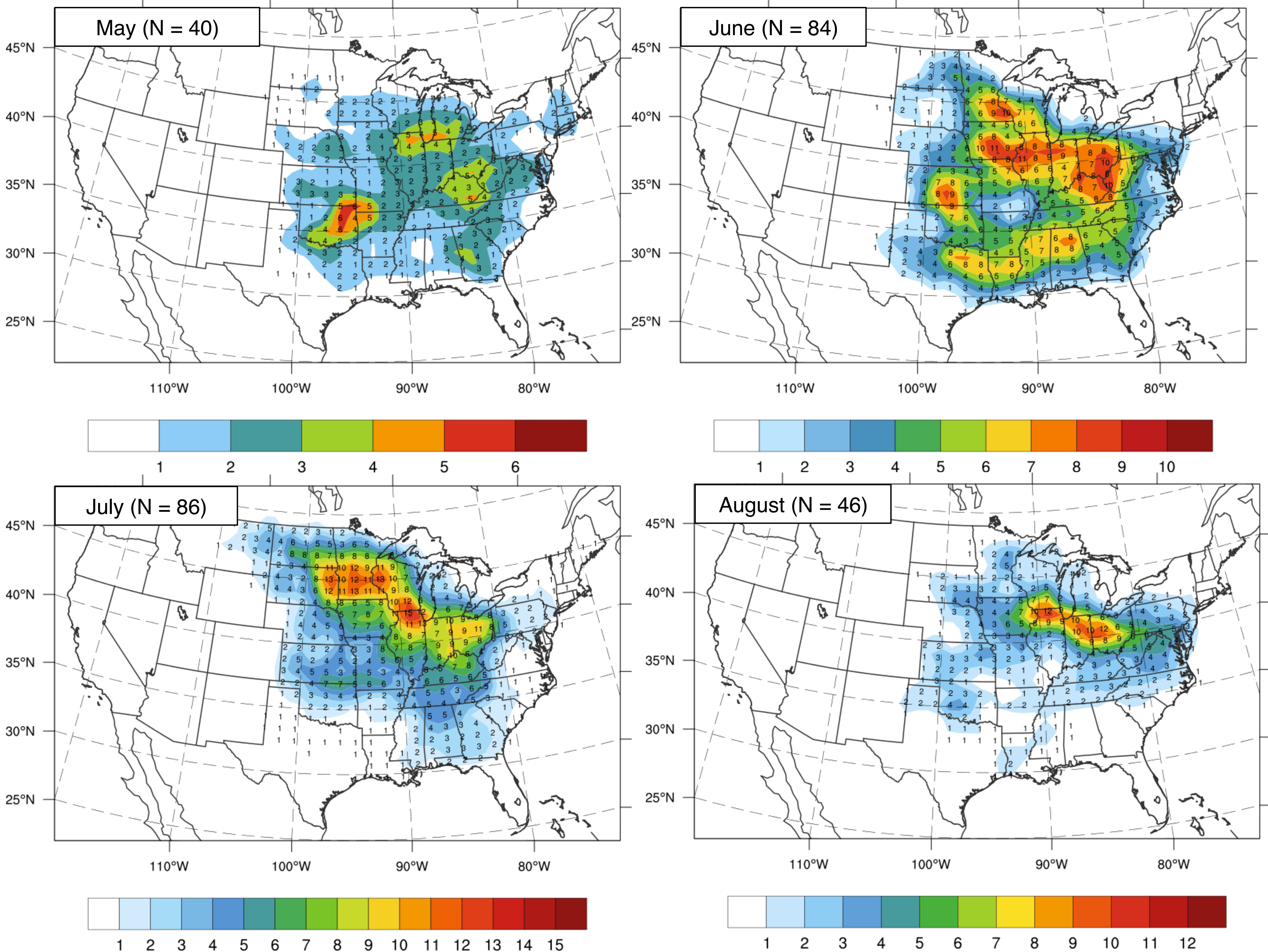
1996–2013 progressive derecho climatology





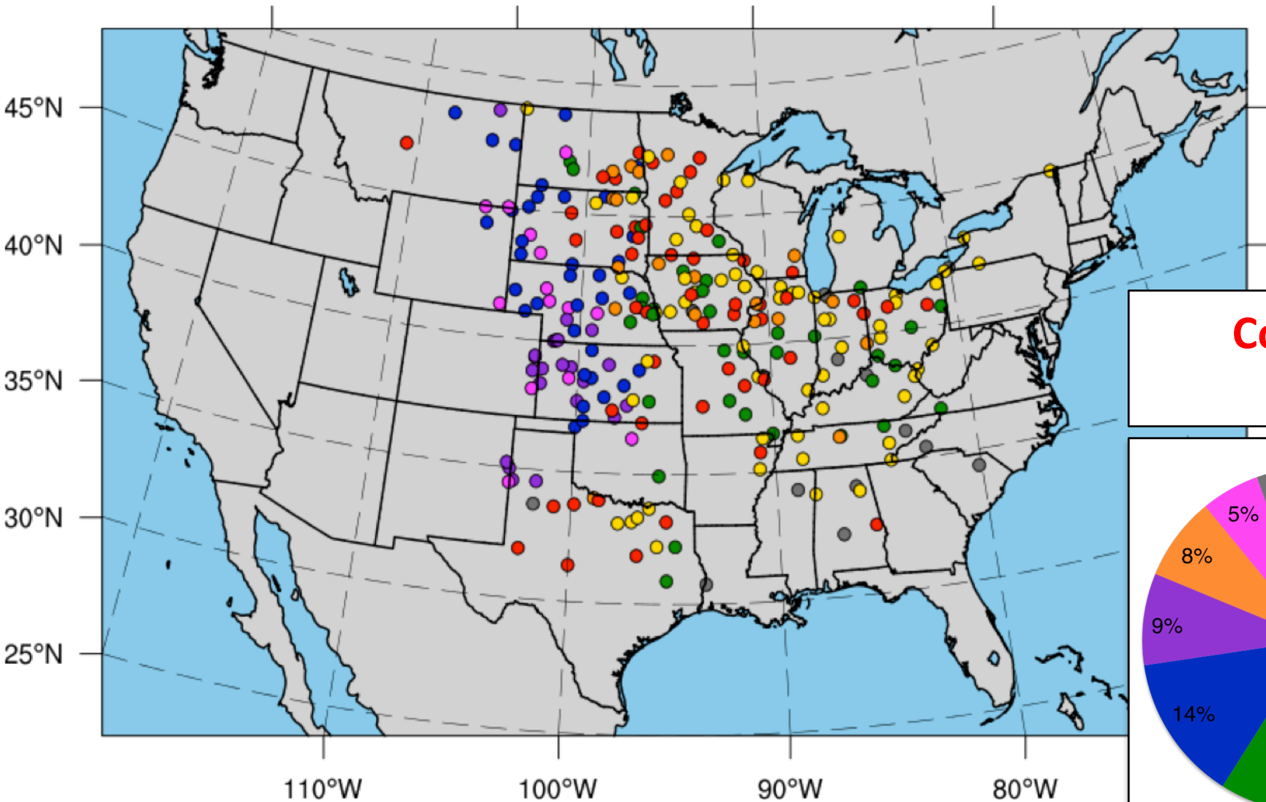

May (N = 40)
June (N = 84)
July (N = 86)
August (N = 46)
45°N
40°N
35°N
30°N
25°N
110°W
100°W
90°W
80°W
1 2 3 4 5 6
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
1 2 3 4 5 6 7 8 9 10 11 12

Composite categories

Subjective Composite Categories

- 0.5° Climate Forecast System Reanalysis (CFSR) data
  - Create plots using analysis closest to derecho initiation time (time of first wind report) from surface to 250 hPa
  - Independently group ➔ meet ➔regroup ➔ repeat until relatively simple classification scheme agreed upon

Derecho initiation location colored by composite category



Orographic Influence

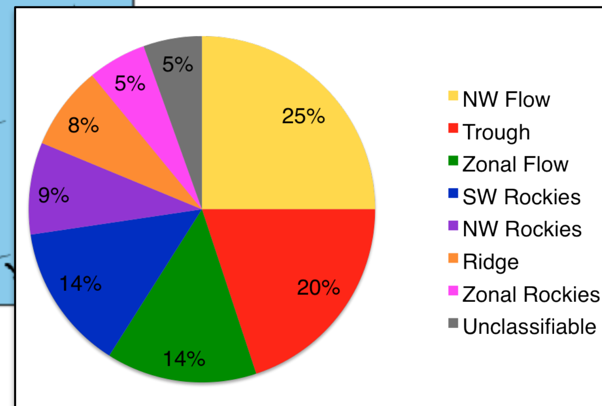
- Southwest flow across Rockies
- Northwest flow across Rockies
- Zonal flow across Rockies

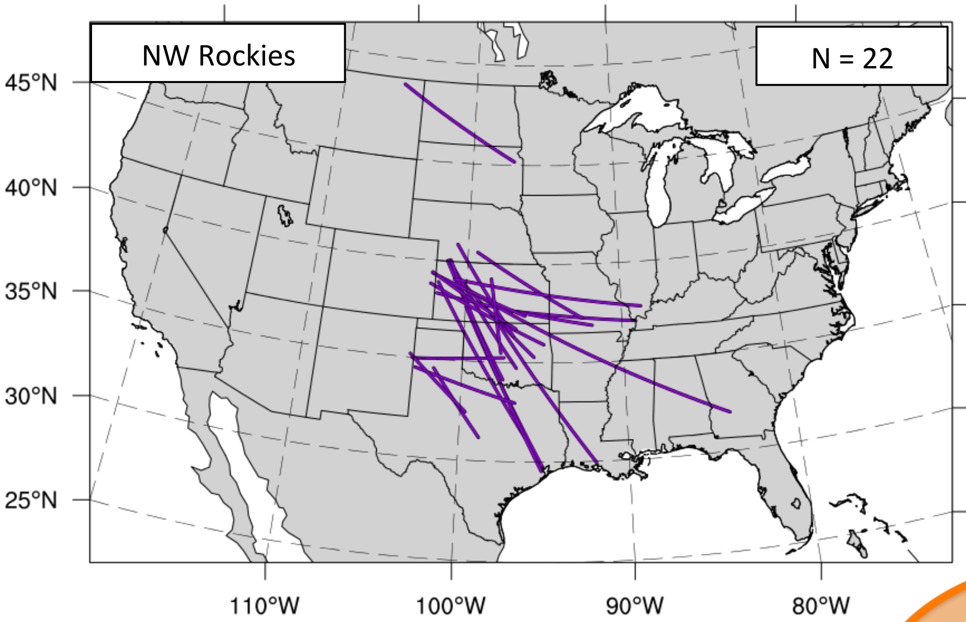
No Orographic Influence

- Upper-level trough
- Ridge environment
- Northwest flow
- Zonal flow

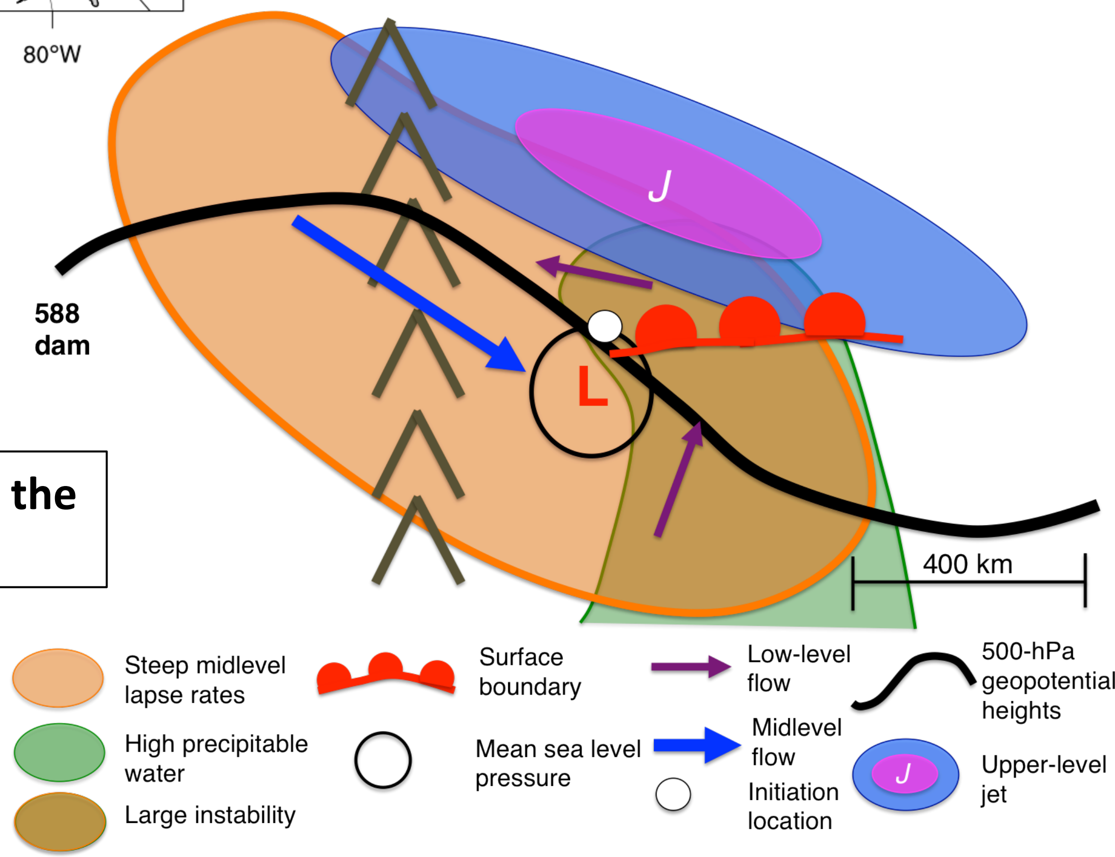
- Unclassifiable

Composite category frequencies

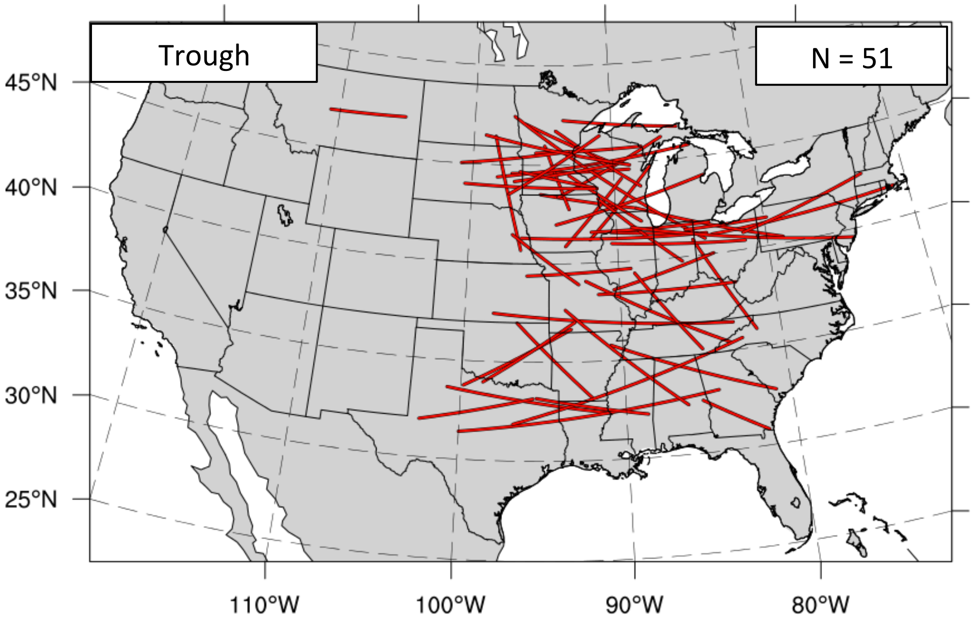




Northwest flow across the Rockies derecho tracks

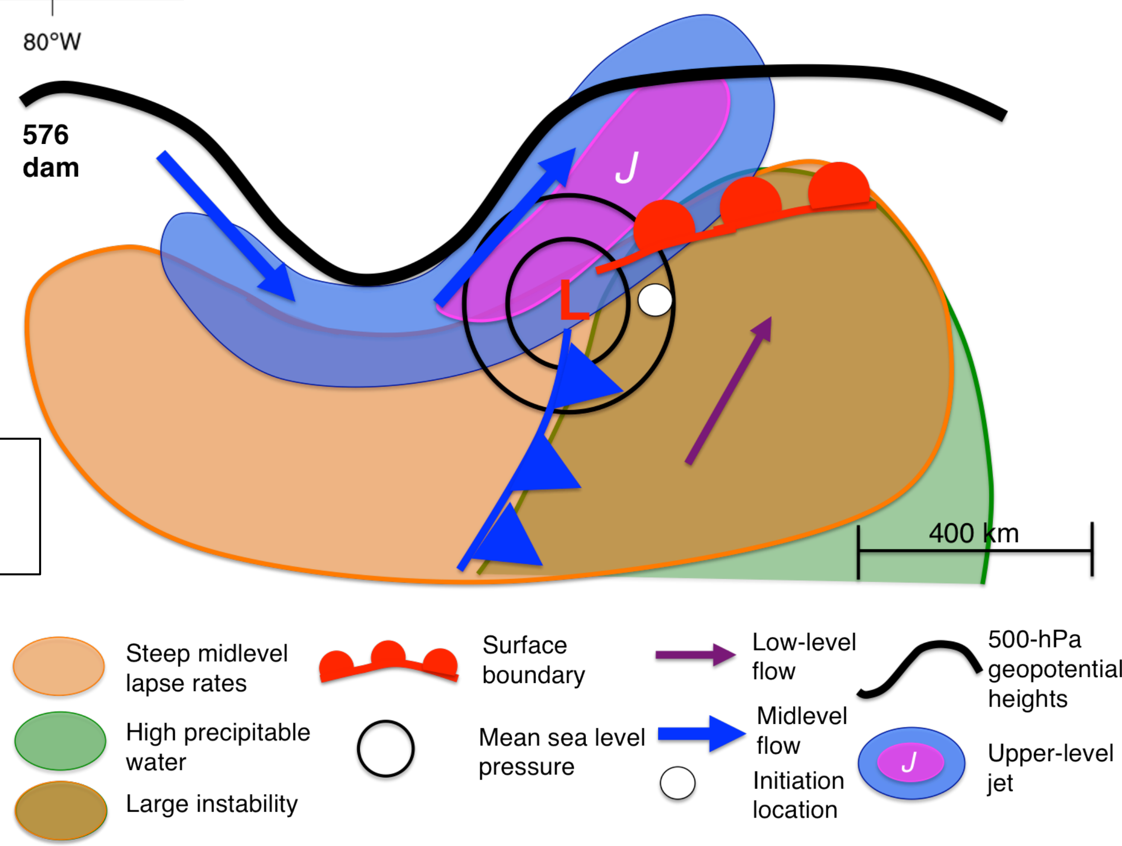


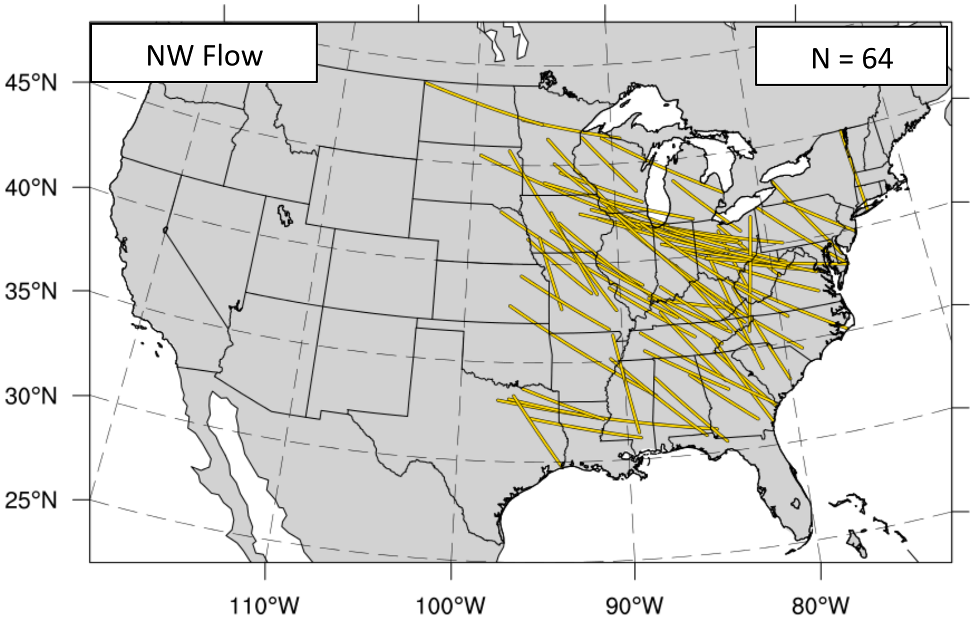
Northwest flow across the Rockies schematic



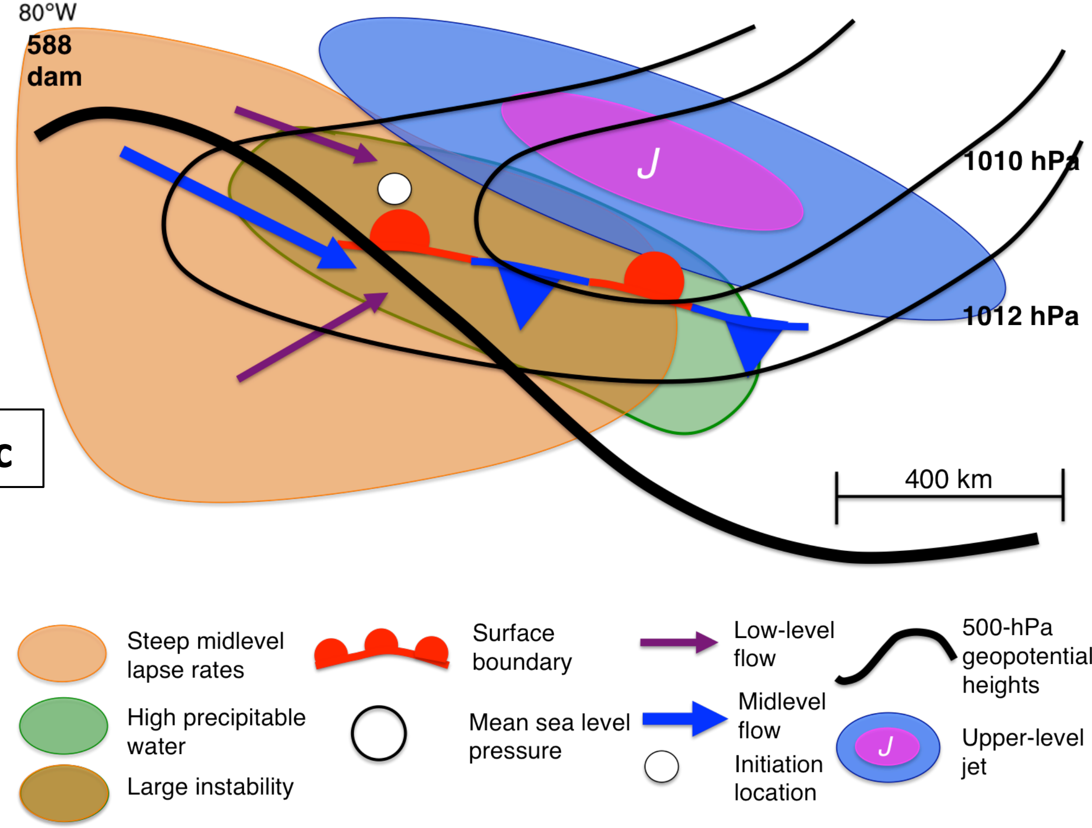
Upper-level trough derecho tracks

Upper-level trough schematic





Northwest flow derecho tracks

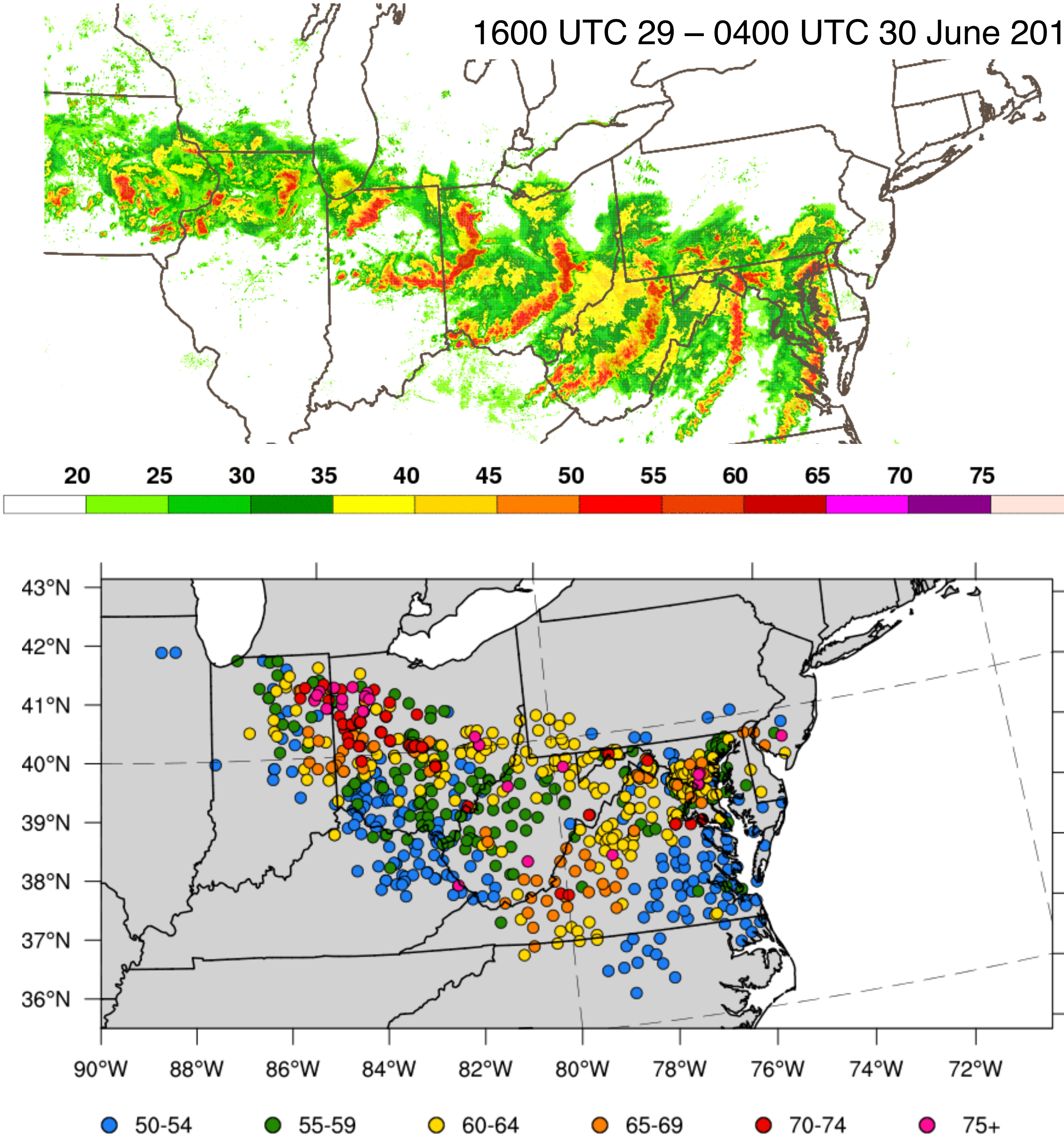


Northwest flow schematic

Case study

Northwest flow

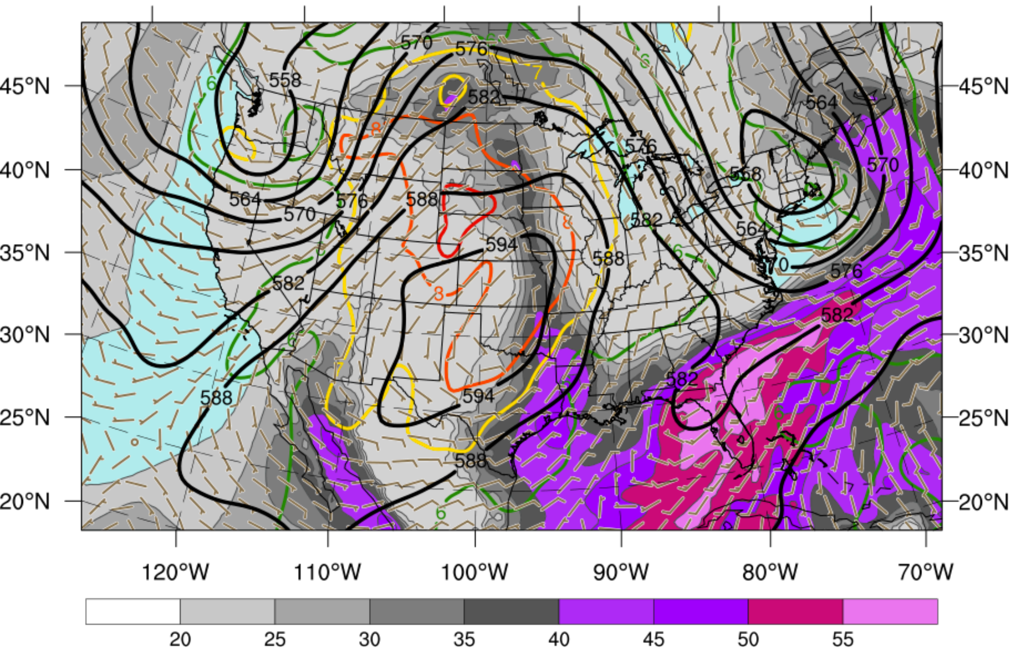
29–30 June 2012



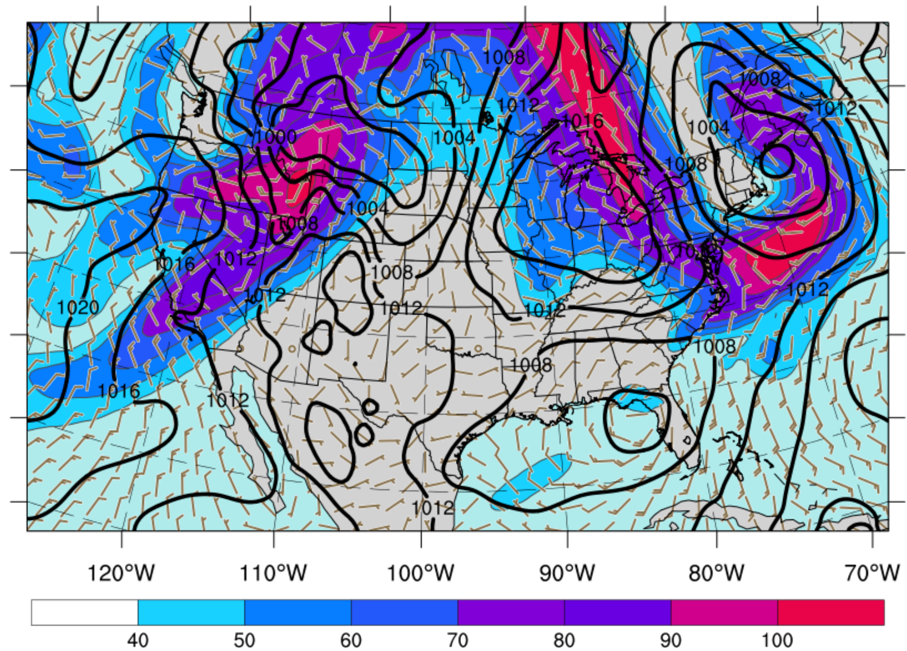
1600 UTC 29 – 0400 UTC 30 June 2012
20 25 30 35 40 45 50 55 60 65 70 75
43°N
42°N
41°N
40°N
39°N
38°N
37°N
36°N
90°W 88°W 86°W 84°W 82°W 80°W 78°W 76°W 74°W 72°W
50-54
55-59
60-64
65-69
70-74
75+

1500 UTC 26 June 2012
(72 hours prior to initiation)

Precipitable water (gray and purple fill; mm), 700–500-hPa lapse rates (colored contours; C km^{-1}), 500 hPa geopotential heights (black contours; dam), and 700–500-hPa layer averaged winds (barbs; kt)

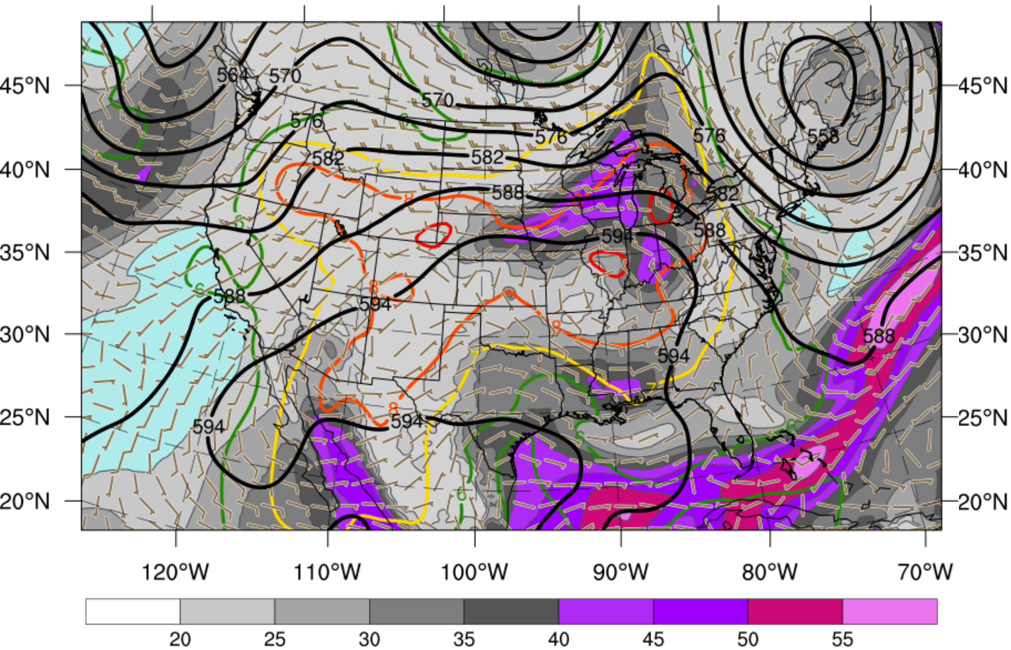


250-hPa wind magnitude (fill; kt), mean sea level pressure (contours; hPa), and surface winds (barbs; kt)



1500 UTC 28 June 2012
(24 hours prior to initiation)

Precipitable water (gray and purple fill; mm), 700–500-hPa lapse rates (colored contours; C km^{-1}), 500 hPa geopotential heights (black contours; dam), and 700–500-hPa layer averaged winds (barbs; kt)



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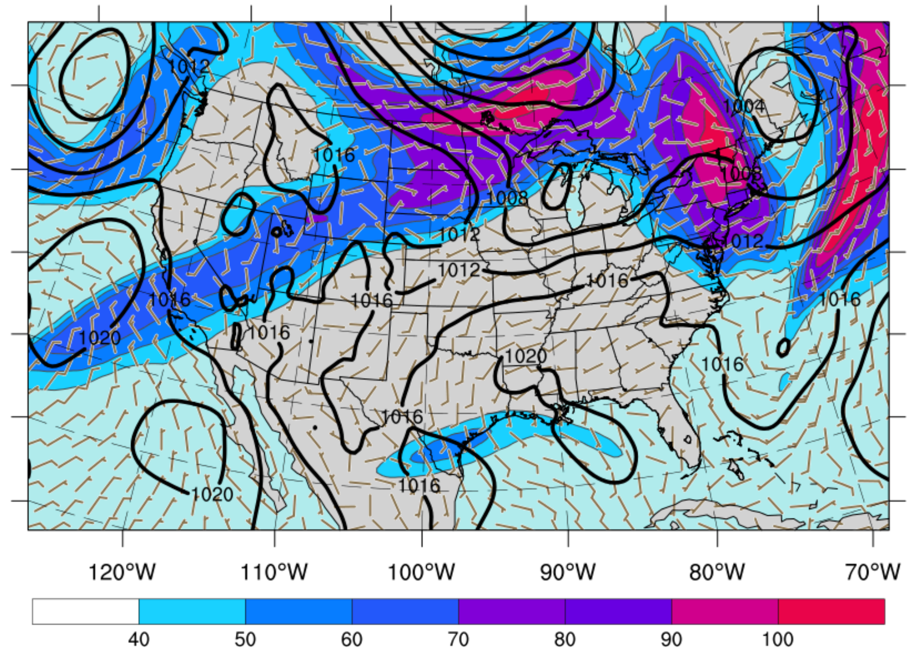
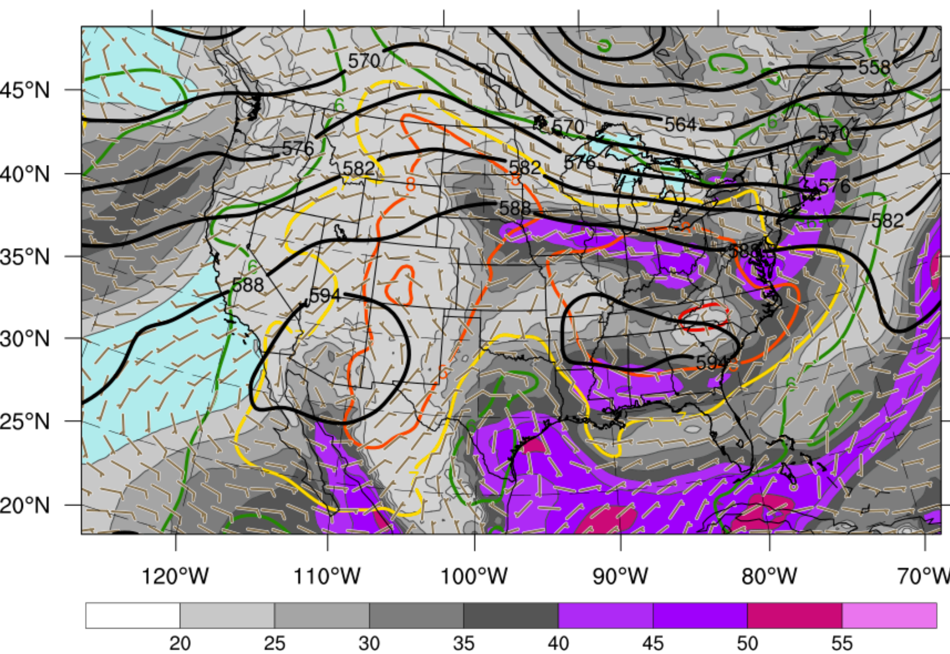


1500 UTC 29 June 2012
(at initiation)

Precipitable water (gray and purple fill; mm), 700–500-hPa lapse rates (colored contours; C km^{-1}), 500 hPa geopotential heights (black contours; dam), and 700–500-hPa layer averaged winds (barbs; kt)



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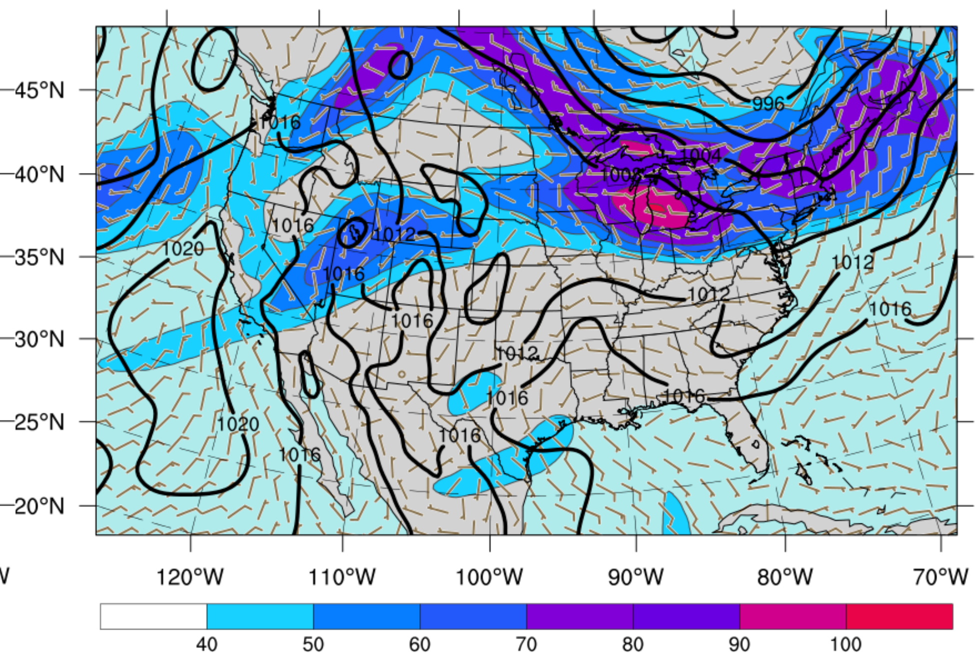
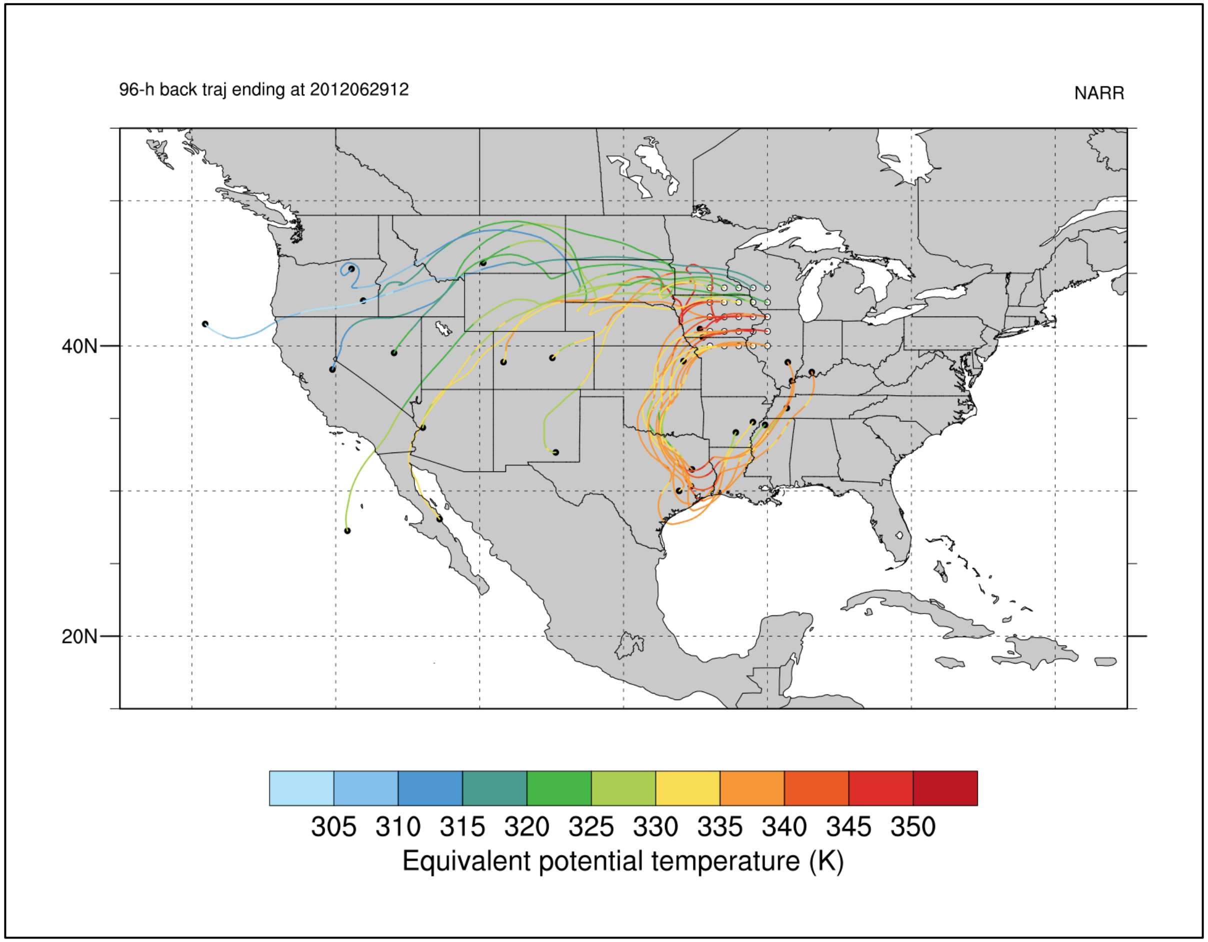
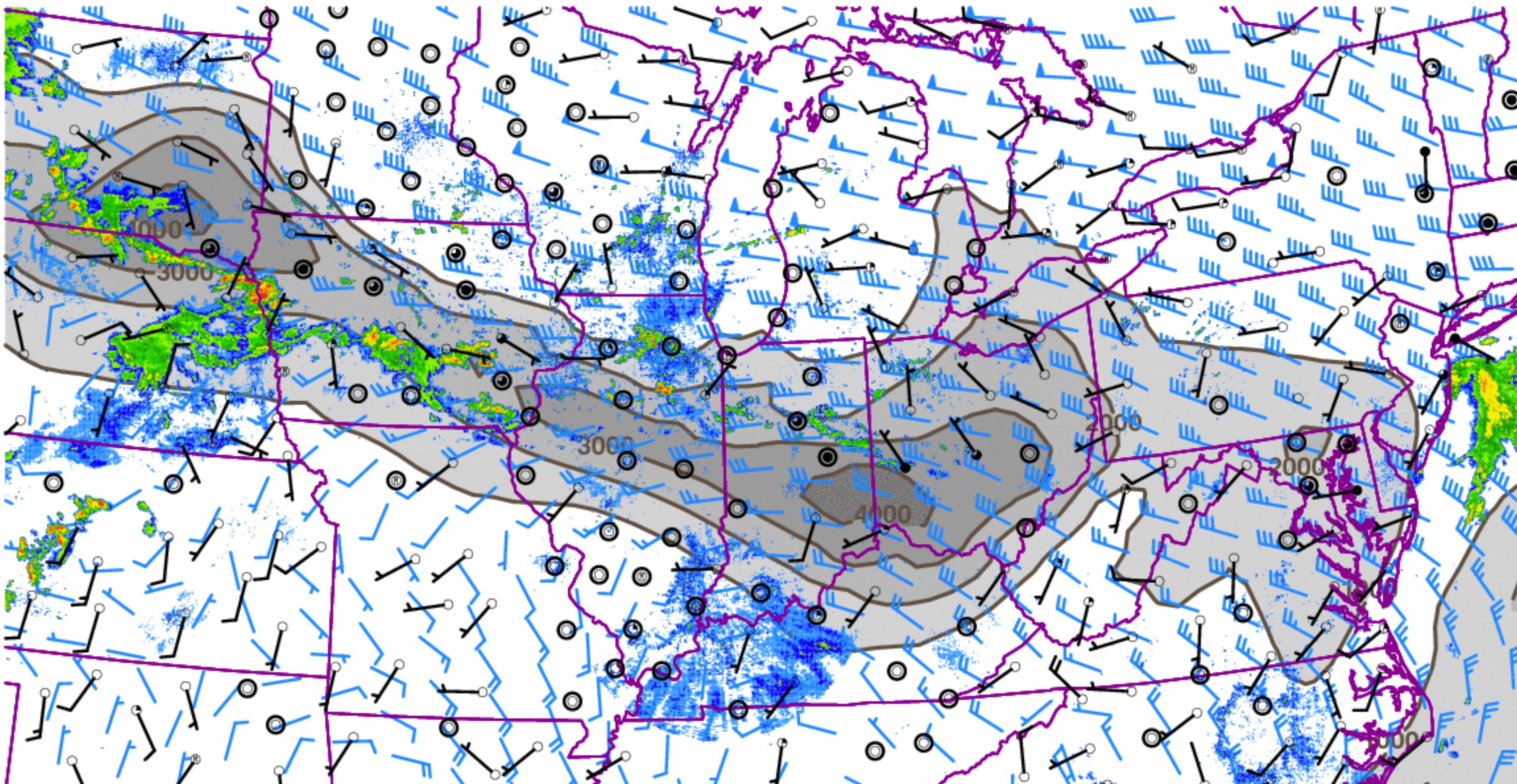


96-hour back trajectories ending at 850-hPa at 1200 UTC 29 June 2012



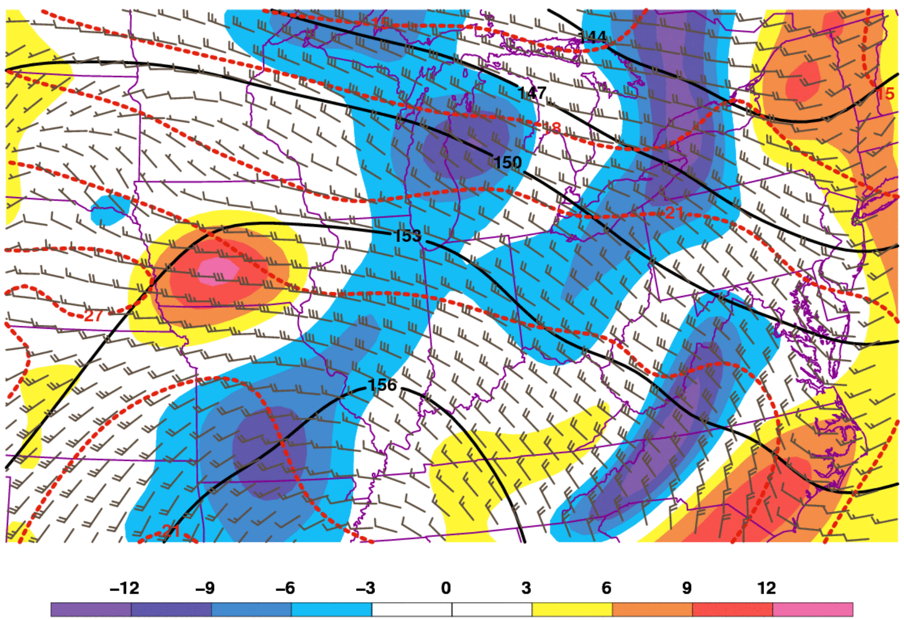
1200 UTC 29 June 2012
Overlap of instability and vertical wind shear

Composite reflectivity overlaid on NARR CAPE (grayscale; J kg^{-1}), winds derived from surface observations (black barbs; kt), and surface–500 hPa wind shear (blue barbs; kt)

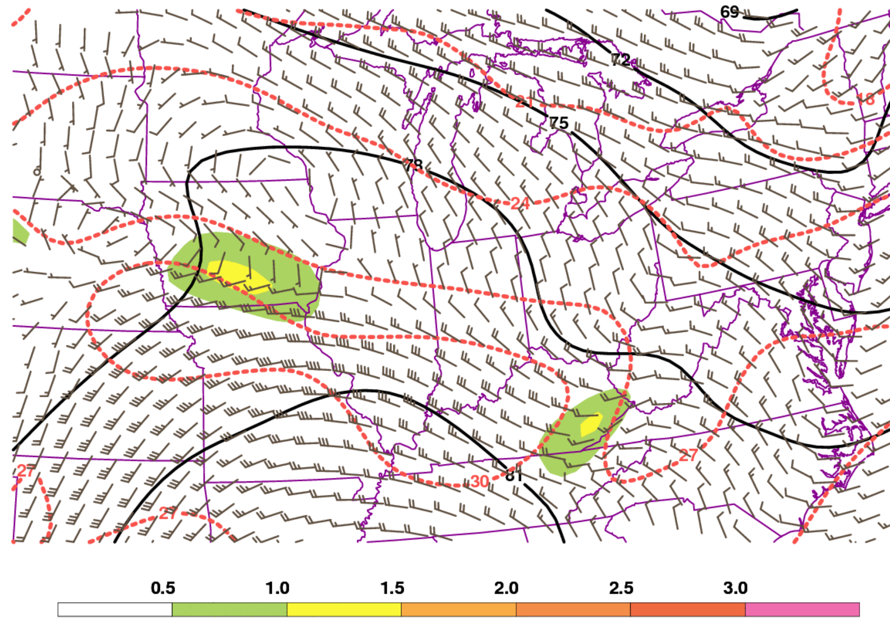


1200 UTC 29 June 2012
Convection initiation mechanism

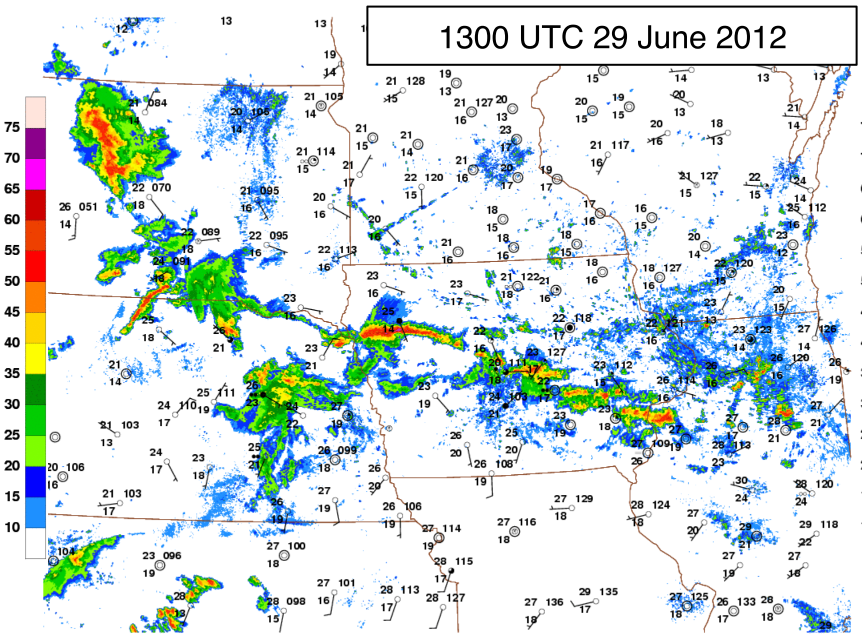
Temperature advection at 850 hPa (fill; $\times 10^{-5}$ C s^{-1}), 850-hPa temperatures (red dashed contours; C), and 850-hPa geopotential heights (black contours; dam).

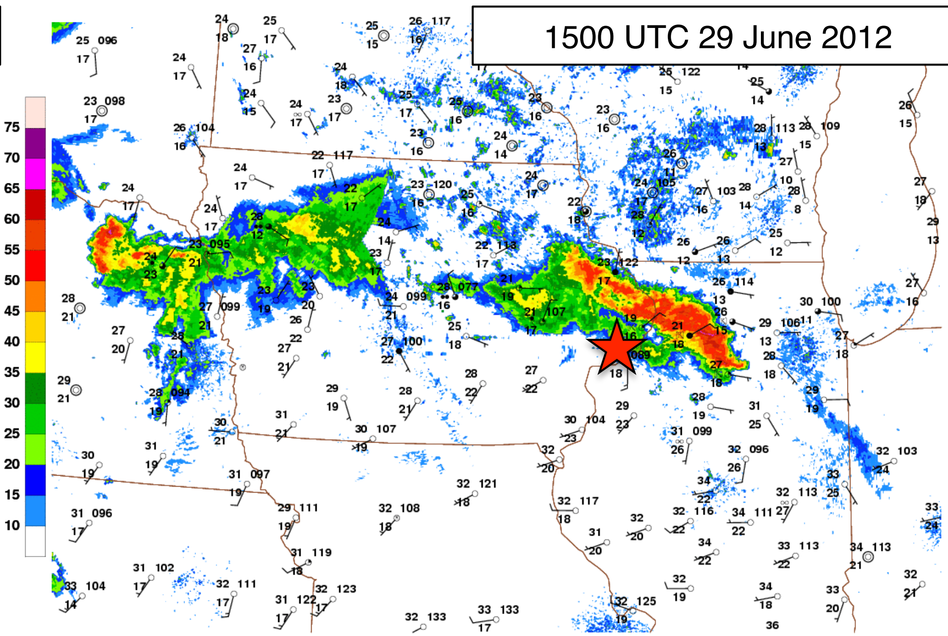


Frontogenesis at 925 hPa (fill; C 3 h^{-1} 100 km^{-1}), 925-hPa temperature (red dashed contours; C), and 925-hPa geopotential heights (black contours; dam)



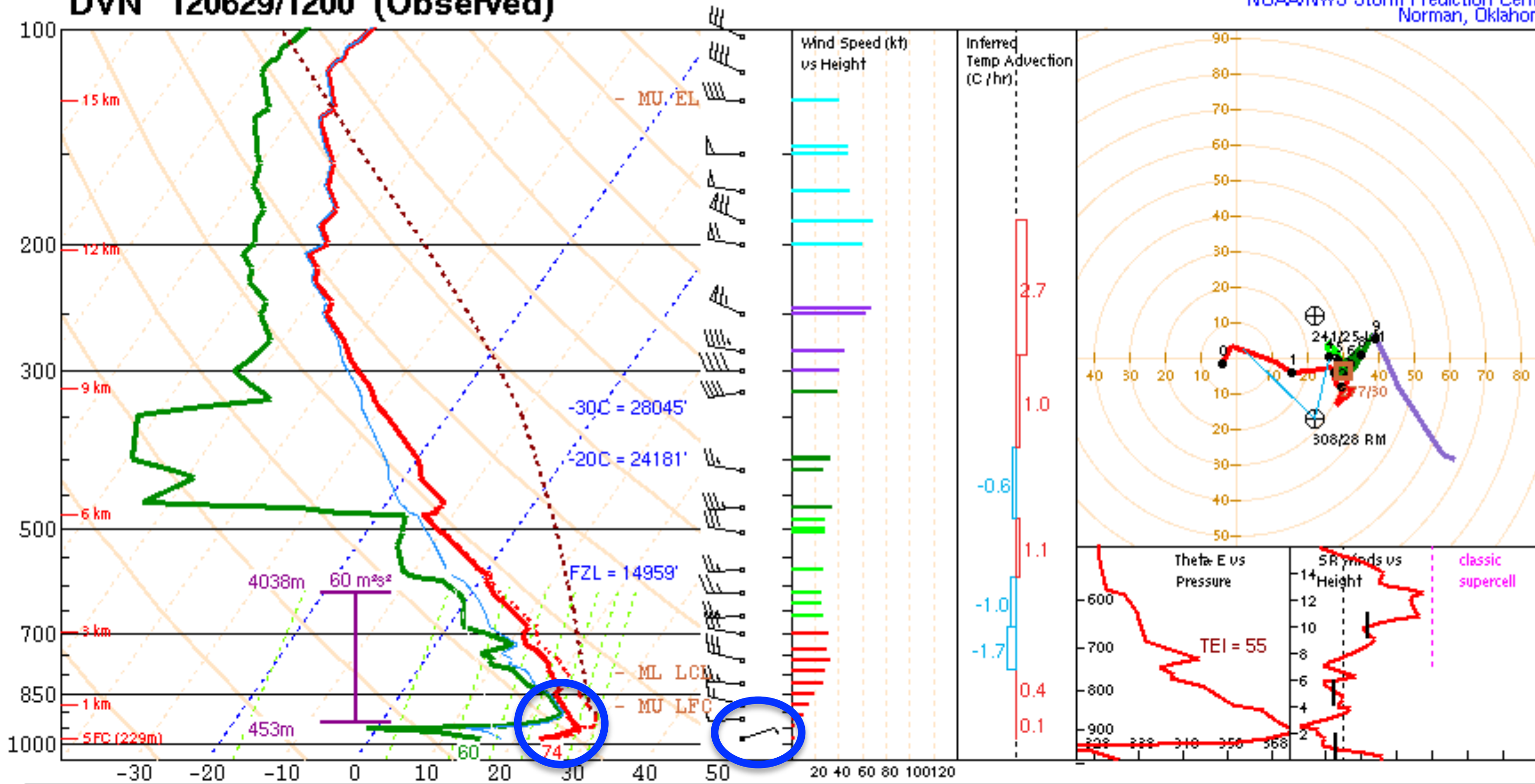
Early MCS evolution





DVN 120629/1200 (Observed)

NOAA/NWS Storm Prediction Center
Norman, Oklahoma



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	18	-1161	1045m	-1	5562m	19887'
MIXED LAYER	799	-477	1857m	-5	4367m	37617'
FCST SURFACE	1602	-163	2385m	-7	3733m	39721'
MU (907 mb)	6711	-0	822m	-16	921m	49352'

PW = 1.98 in | 3CAPE = 0 J/kg | WBZ = 13496' | WNDG = 0.0
K = 48 | DCAPE = 1334 J/kg | FZL = 14959' | ESP = 0.0
MidRH = 67% | DownT = 64 F | ConvT = 105F | MMP = 0.98
LowRH = 56% | MeanW = 11.6 g/kg | MaxT = 95F
SigSevere = 14656 m3/s3

Sfc-3km Agl Lapse Rate = 4.3 C/km
3-6km Agl Lapse Rate = 8.8 C/km
850-500mb Lapse Rate = 8.0 C/km
700-500mb Lapse Rate = 8.6 C/km

Supercell = 6.6
Left Supercell = -13.8
Sig Tor (CIN) = 0.0
Sig Tor (fixed) = 0.0
Sig Hail = 3.7

	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	95	20	268/4	134/25
SFC - 3 km	152	35	283/17	159/14
Eff Inflow Layer	60	24	279/23	184/13
SFC - 6 km		36	277/20	174/15
SFC - 8 km		39	277/22	180/15
Lower Half Storm Depth		32	276/25	191/15
Cloud Bearing Layer		28	277/30	210/16

BRN Shear = 66 m²/s²
4-6km SR Wind = 201/17 kt

.....Storm Motion Vectors.....
Bunkers Right = 308/28 kt
Bunkers Left = 241/25 kt

Corfidi Downshear = 273/52 kt
Corfidi Upshear = 272/21 kt

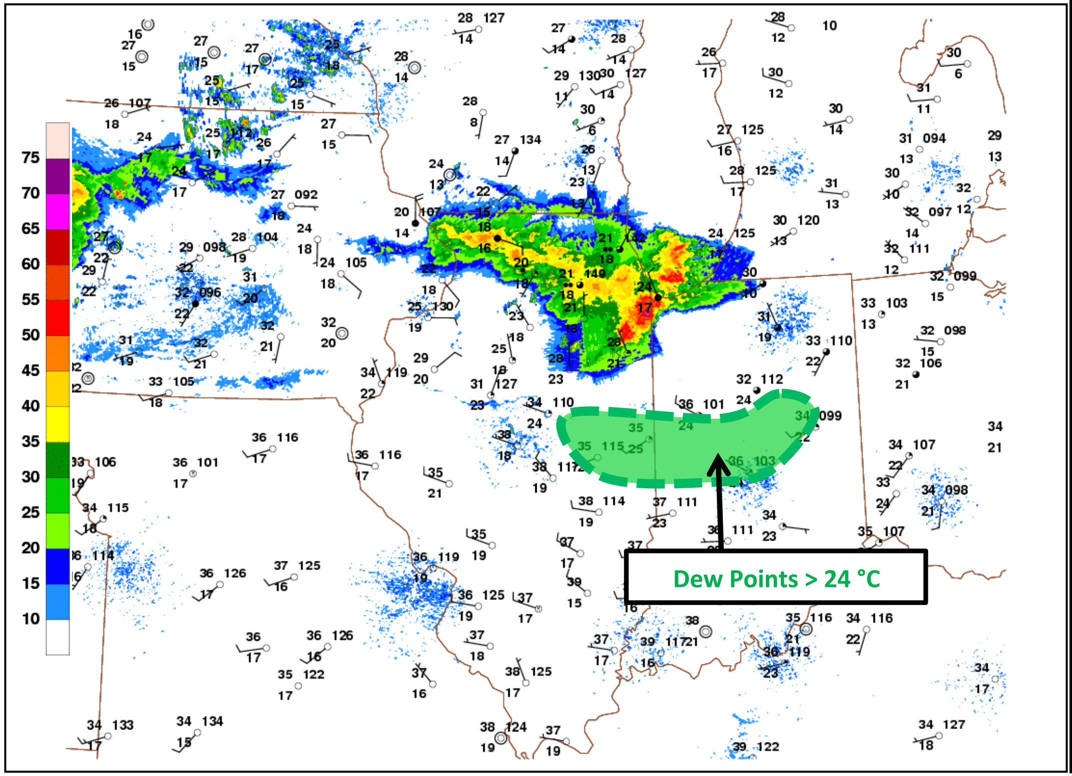
1km & 6km AGL Wind Barbs

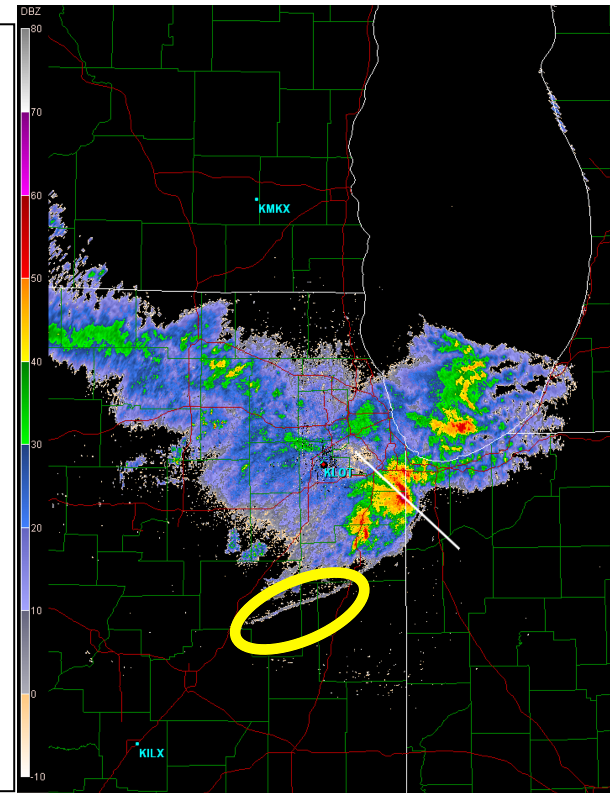
* * * BEST GUESS PRECIP TYPE * * *
Rain.
Based on sfc temperature of 74.5 F.

SARS - Sounding Analogs

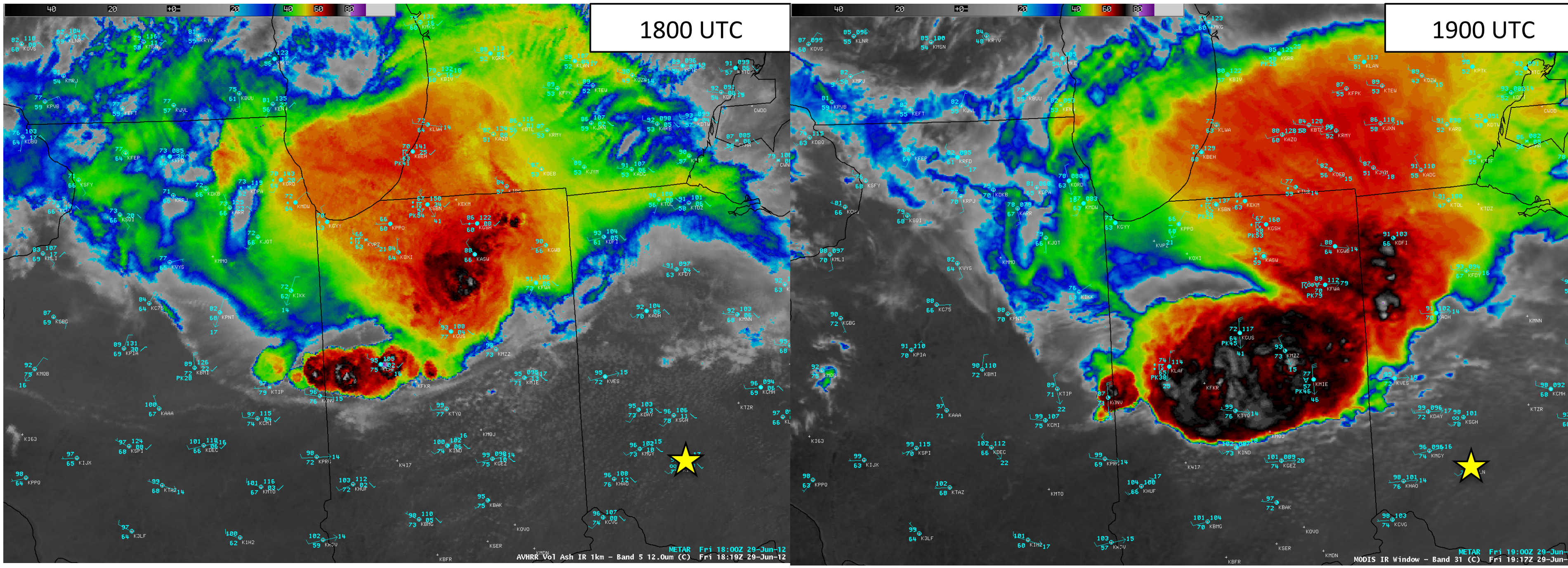
SUPERCELL	SGFNT HAIL
No Quality Matches	No Quality Matches
	(4 loose matches) SARS: 50% SIG

Elevated to surface-based transition
1700 UTC 29 June 2012





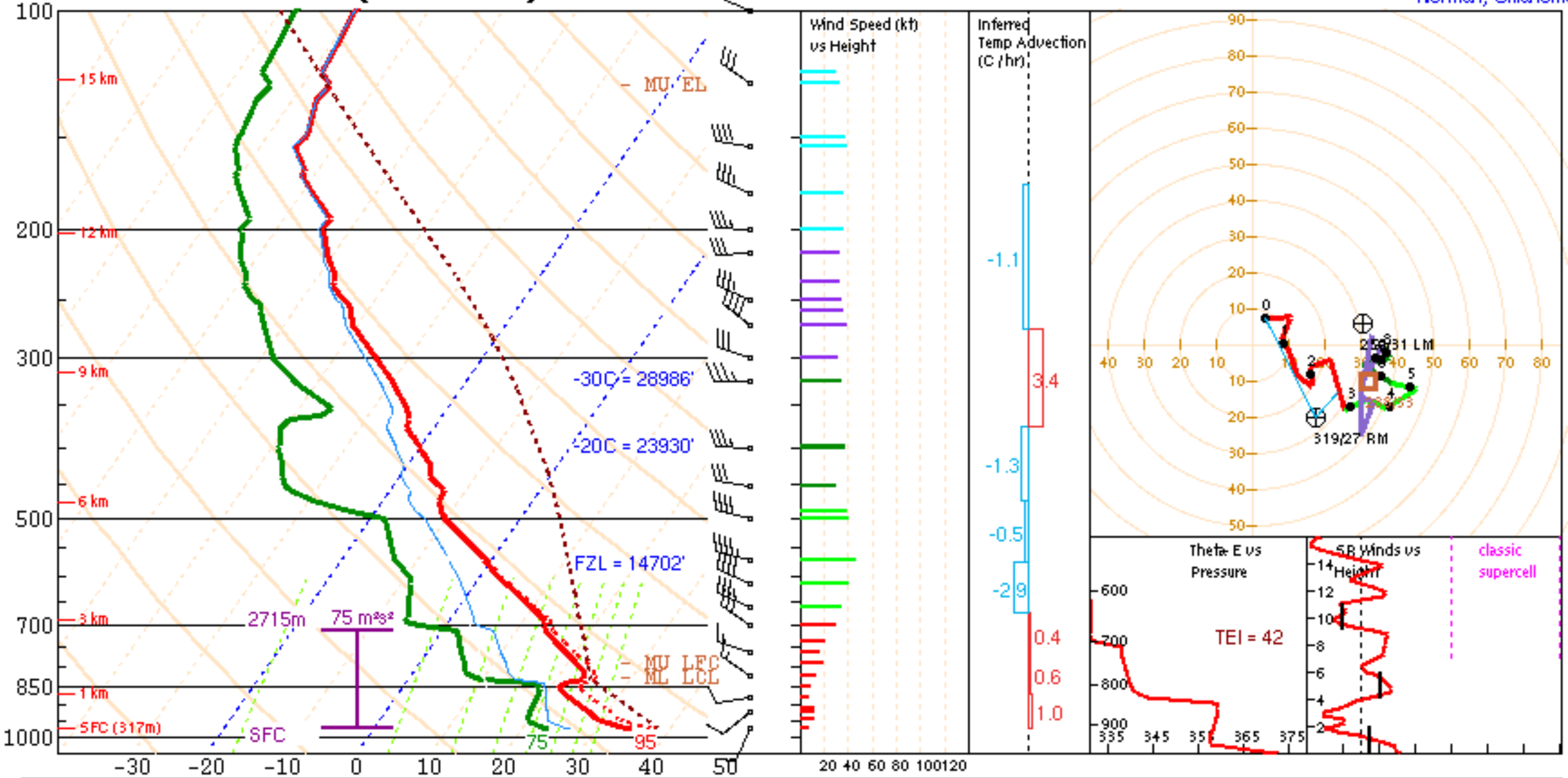
Elevated to surface-based transition
IR satellite imagery



Source: CIMSS Satellite Blog

ILN 120629/1800 (Observed)

NOAA/NWS Storm Prediction Center
Norman, Oklahoma



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	6383	-7	1406m	-15	1817m	48815'
MIXED LAYER	3894	-93	1465m	-11	2543m	46314'
FCST SURFACE	4333	-53	1679m	-12	2426m	47019'
MU (974 mb)	6383	-7	1406m	-15	1817m	48815'

PW = 1.56 in	3CAPE = 10 J/kg	WBZ = 12050'	WNDG = 0.0
K = 33	DCAPE = 1609 J/kg	FZL = 14702'	ESP = 0.3
MidRH = 35%	DownT = 62 F	ConvT = 100F	MMP = 0.98
LowRH = 61%	MeanW = 16.7 g/kg	MaxT = 94F	

SigSevere = 72157 m3/s3

Sfc-3km Agl Lapse Rate = 8.3 C/km
3-6km Agl Lapse Rate = 8.7 C/km
850-500mb Lapse Rate = 7.7 C/km
700-500mb Lapse Rate = 8.8 C/km

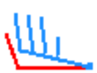
Supercell = 8.6
Left Supercell = -15.5
Sig Tor (CIN) = 0.4
Sig Tor (fixed) = 0.4
Sig Hail = 3.3

	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	24	9	233/10	160/28
SFC - 3 km	86	34	277/13	165/19
Eff Inflow Layer	75	29	275/12	164/20
SFC - 6 km		36	285/22	194/15
SFC - 8 km		35	284/23	198/15
Lower Half Storm Depth		36	284/23	198/15
Cloud Bearing Layer		20	289/31	230/16

BRN Shear = 50 m²/s²
4-6km SR Wind = 252/25 kt

.....Storm Motion Vectors.....
Bunkers Right = 319/27 kt
Bunkers Left = 259/31 kt

Corfidi Downshear = 292/57 kt
Corfidi Upshear = 299/25 kt

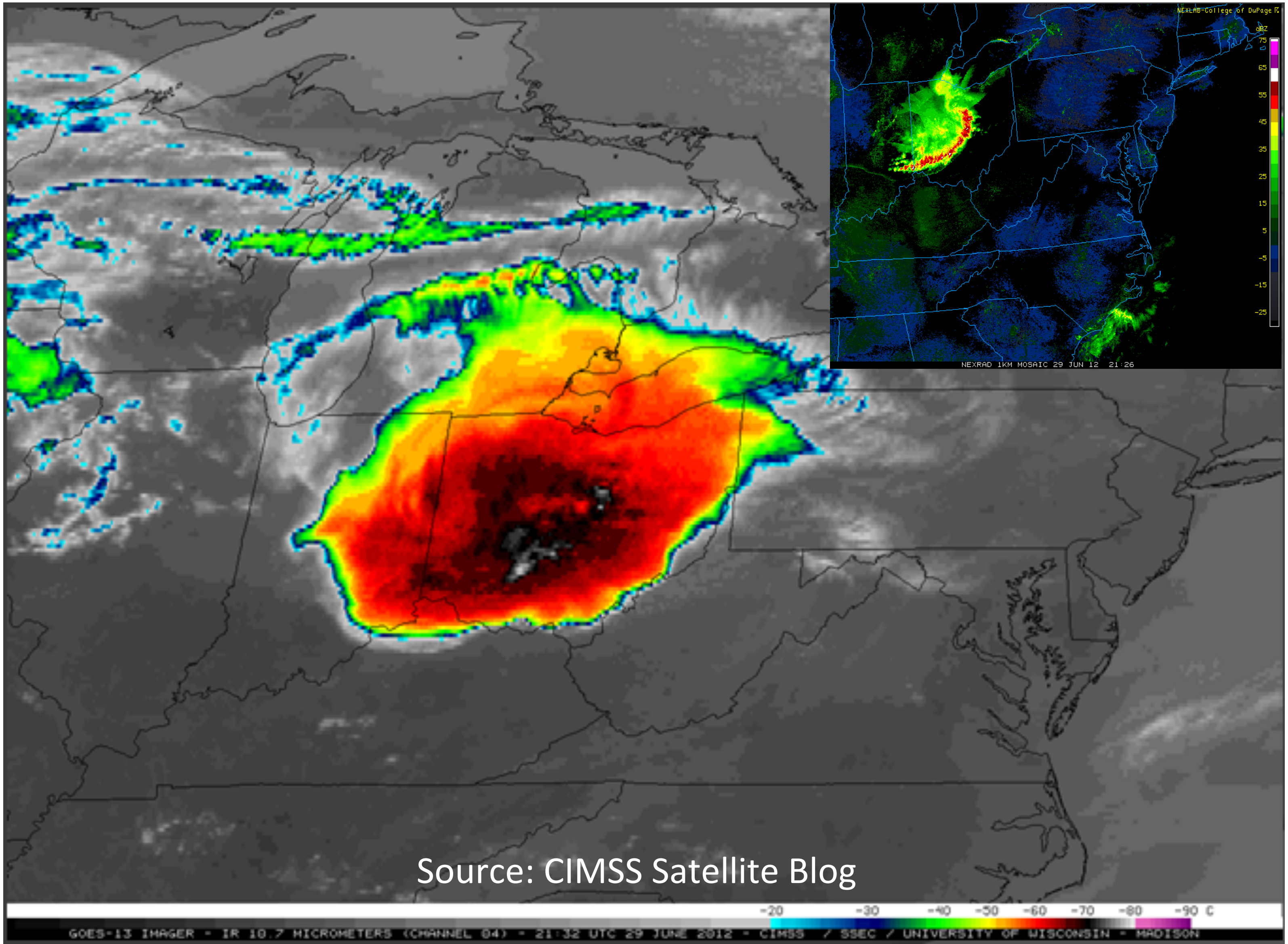


*** BEST GUESS PRECIP TYPE ***
None.
Based on sfc temperature of 95.0 F.

SARS - Sounding Analogs

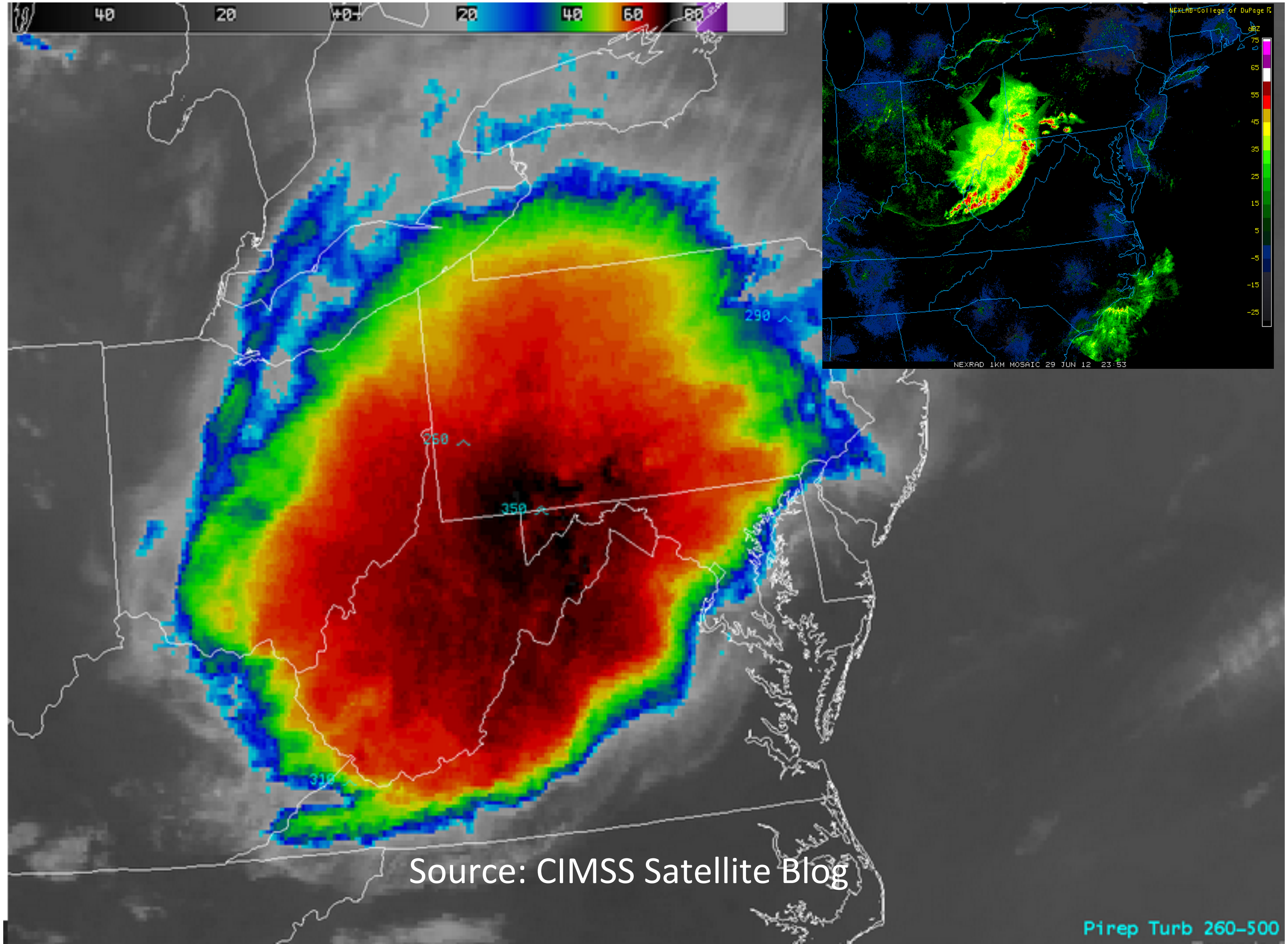
SUPERCELL	SGFNT HAIL
No Quality Matches	No Quality Matches
(4 loose matches)	(33 loose matches)
SARS: 75% TOR	SARS: 76% SIG

2130 UTC 29 June 2012 IR/Radar

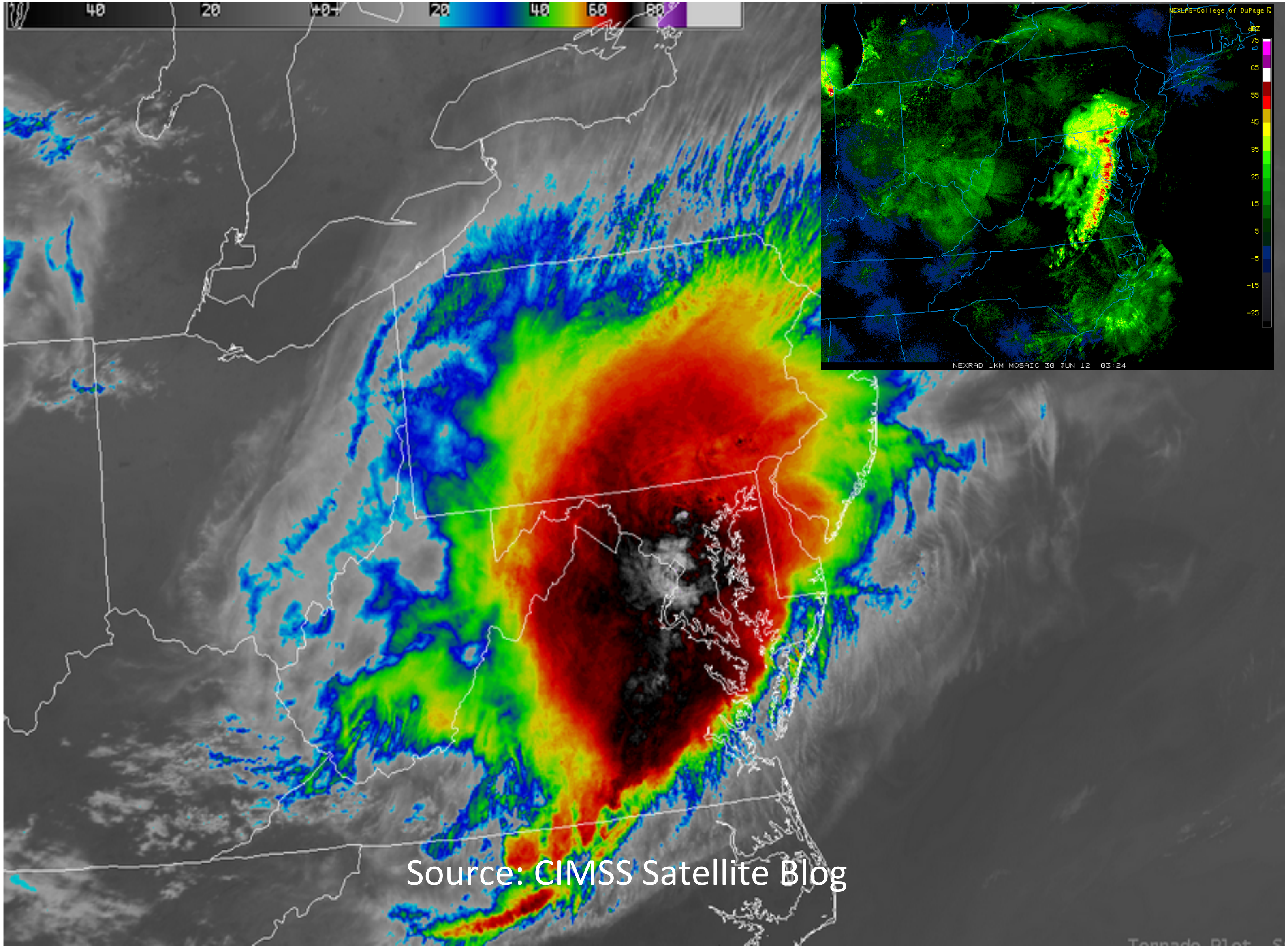


Source: CIMSS Satellite Blog

0000 UTC 30 June 2012 IR/Radar

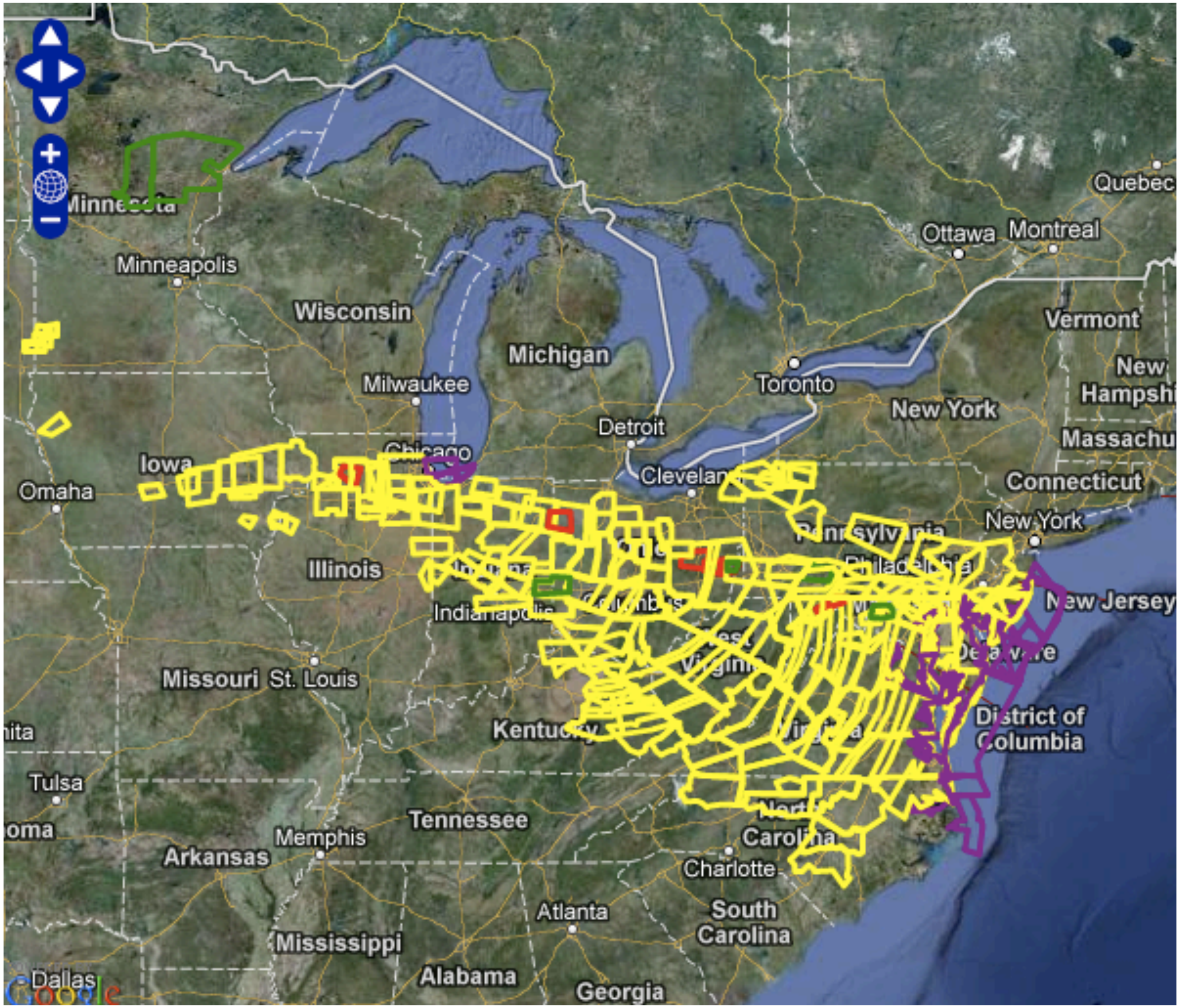


0300 UTC 30 June 2012 IR/Radar



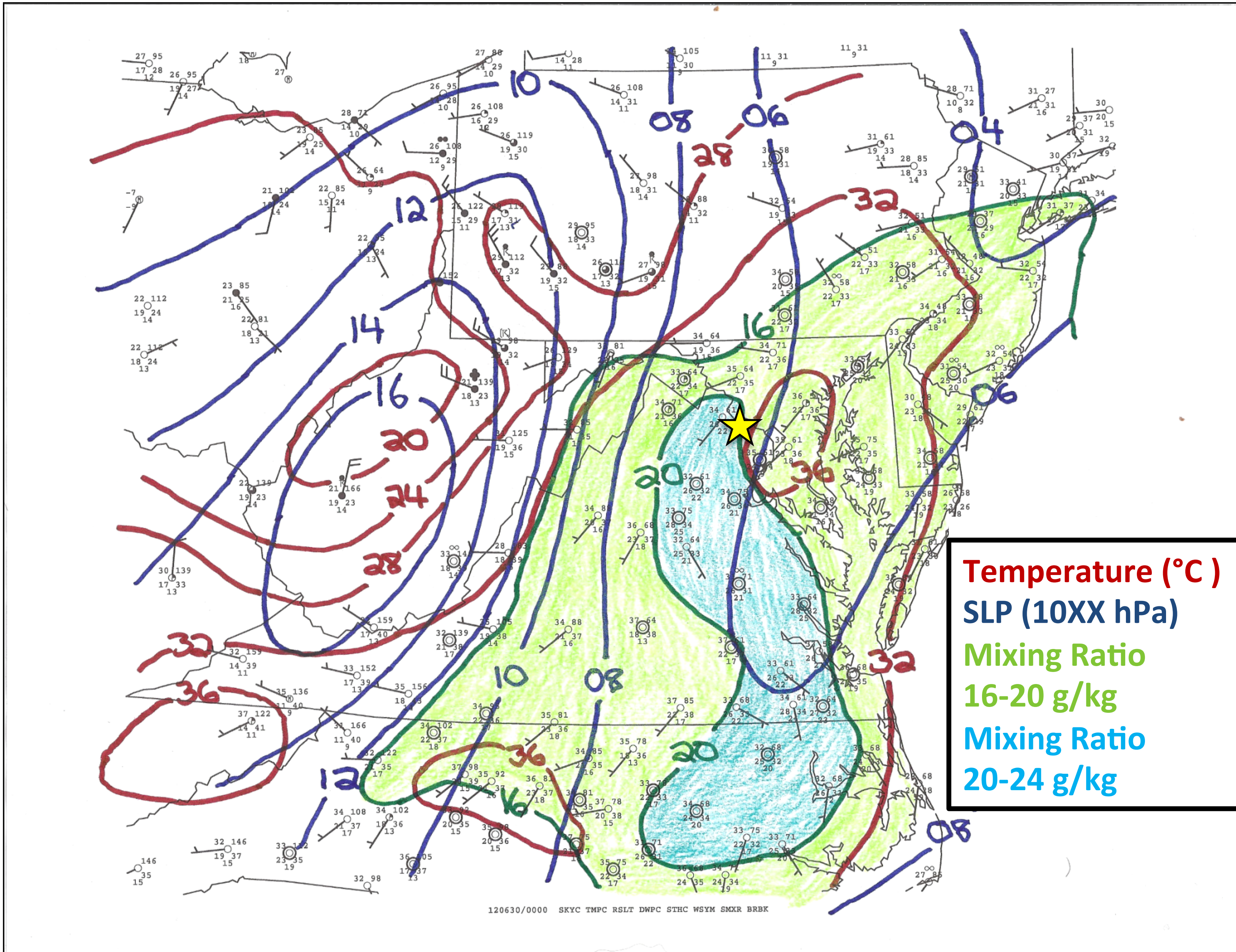
Source: CIMSS Satellite Blog

Coastal Impact



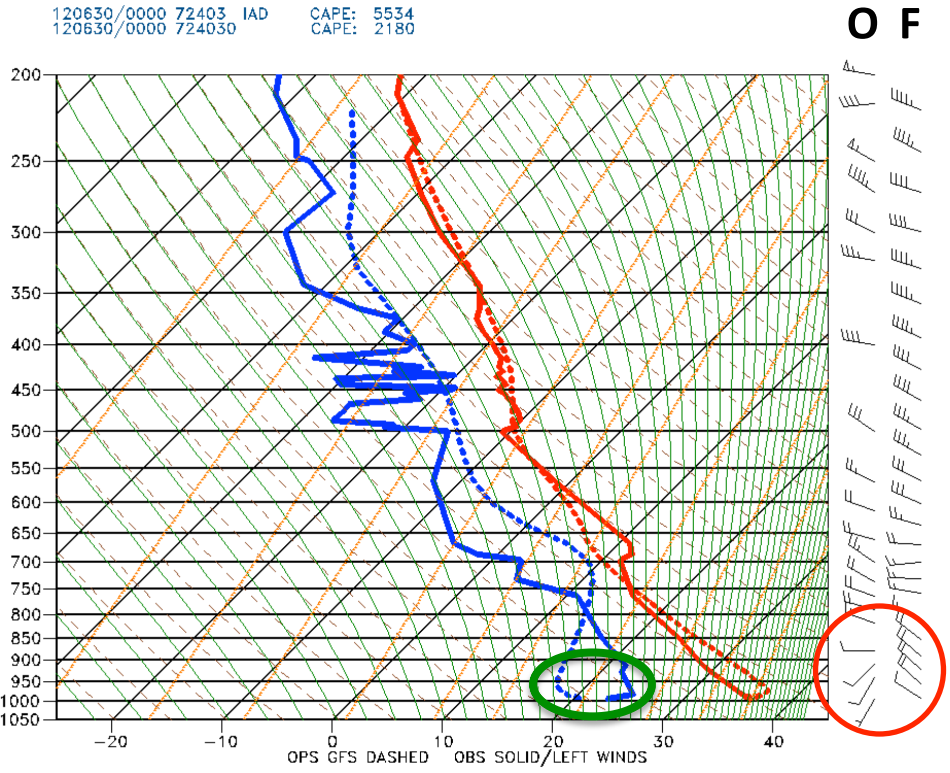
Source: Iowa Environmental Mesonet

0000 UTC 30 June 2012 Surface Analysis

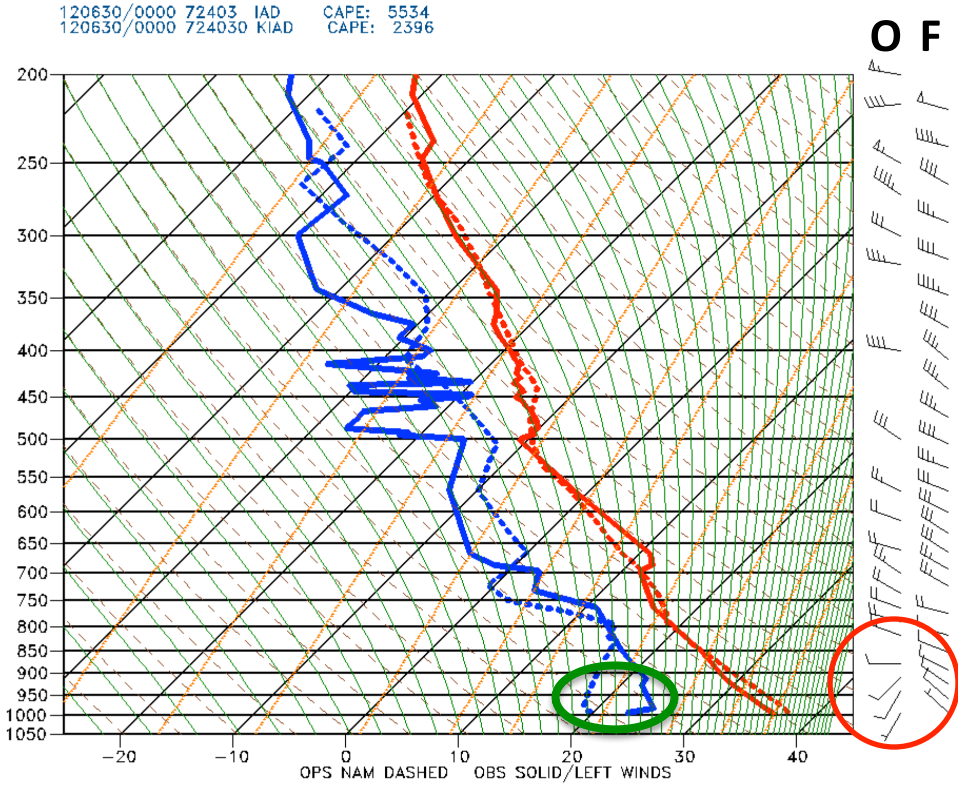


IAD 12 Hour Forecast Soundings (dashed) vs. Observed (solid) for 0000 UTC 30 June 2012

GFS



NAM

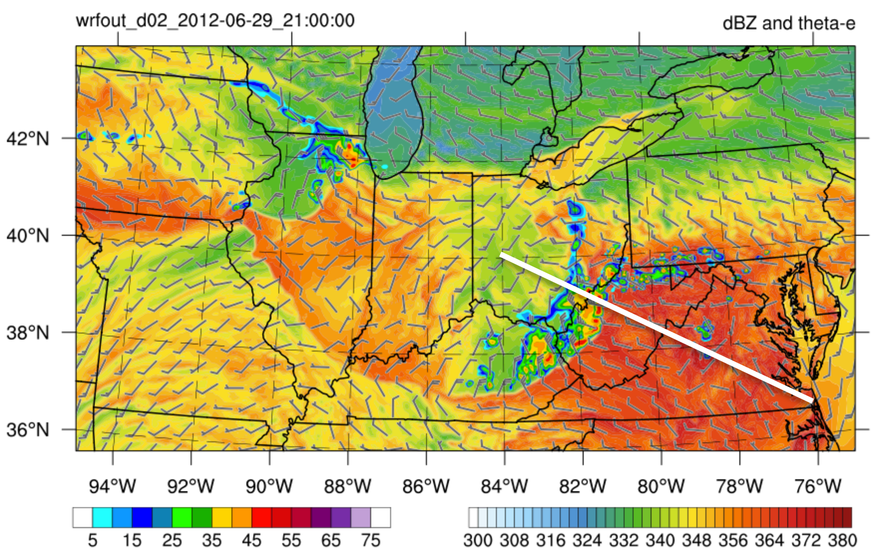


Source: Geoffrey Manikin

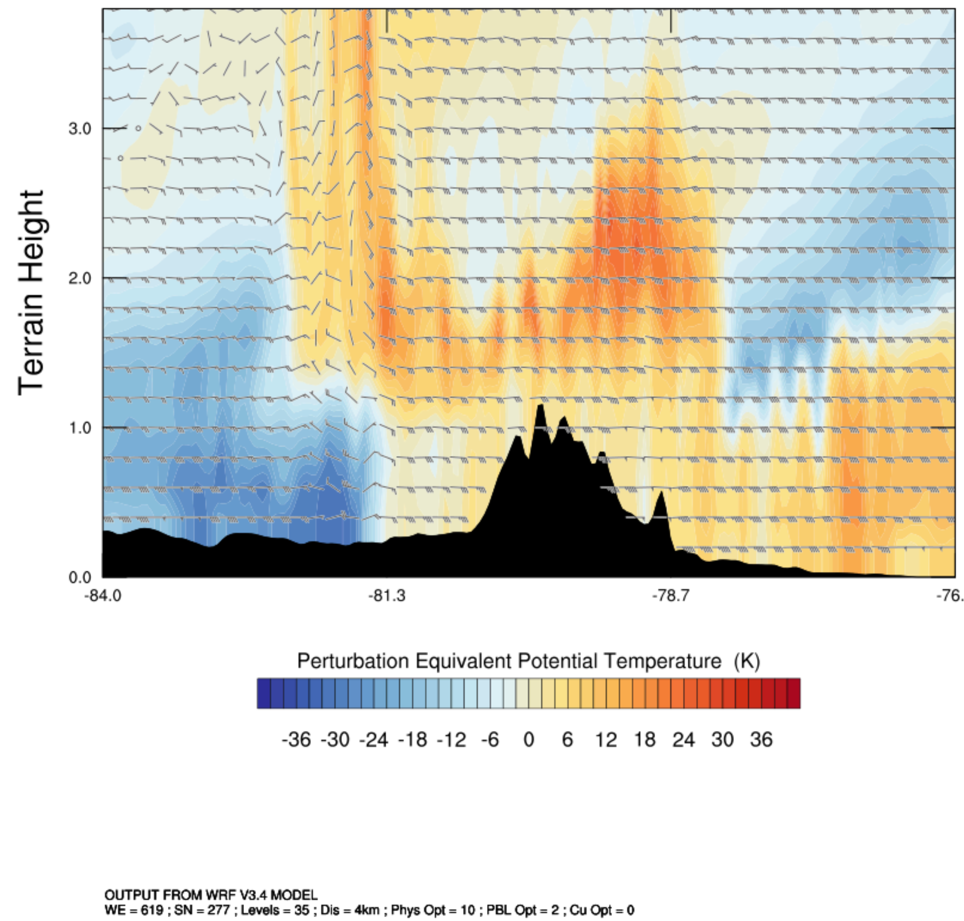
29–30 June 2012 WRF Run

- Initialized at 0000 UTC 29 June 2012 with NAM data
- 12 km outer grid with 4 km nested grid
- Convection explicitly resolved in 4km grid
- Morrison double-moment microphysics
- Mellor-Yamada-Janjic PBL scheme

Surface θ_e (K, fill), surface winds (kt, barbs), and lowest model level reflectivity

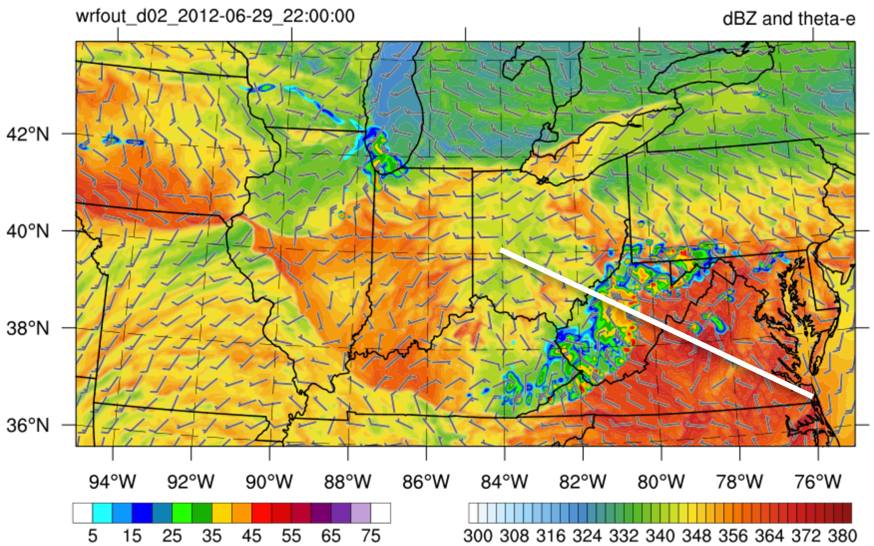


Perturbation θ_e (K, fill) and system relative winds (kt, barbs)

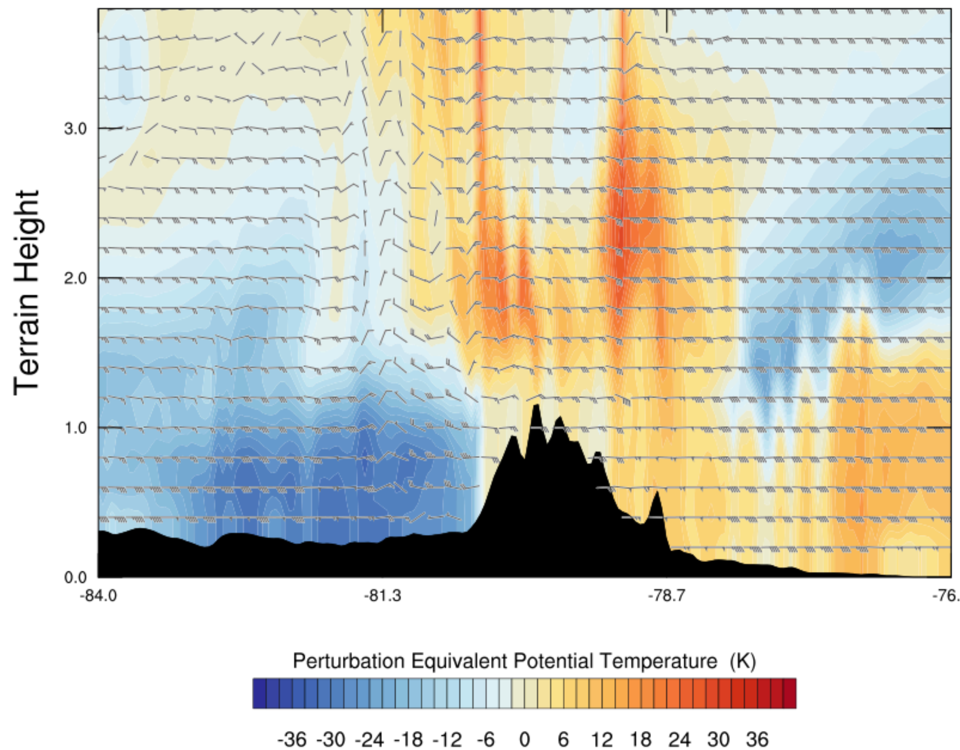


- Morrison double-moment microphysics
- Mellor-Yamada-Janjic PBL scheme

Surface θ_e (K, fill), surface winds (kt, barbs), and lowest model level reflectivity



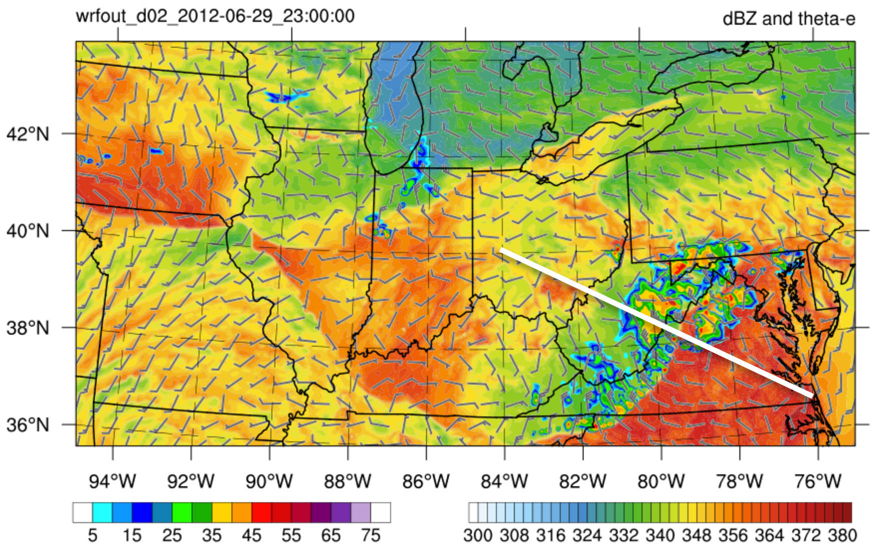
Perturbation θ_e (K, fill) and system relative winds (kt, barbs)



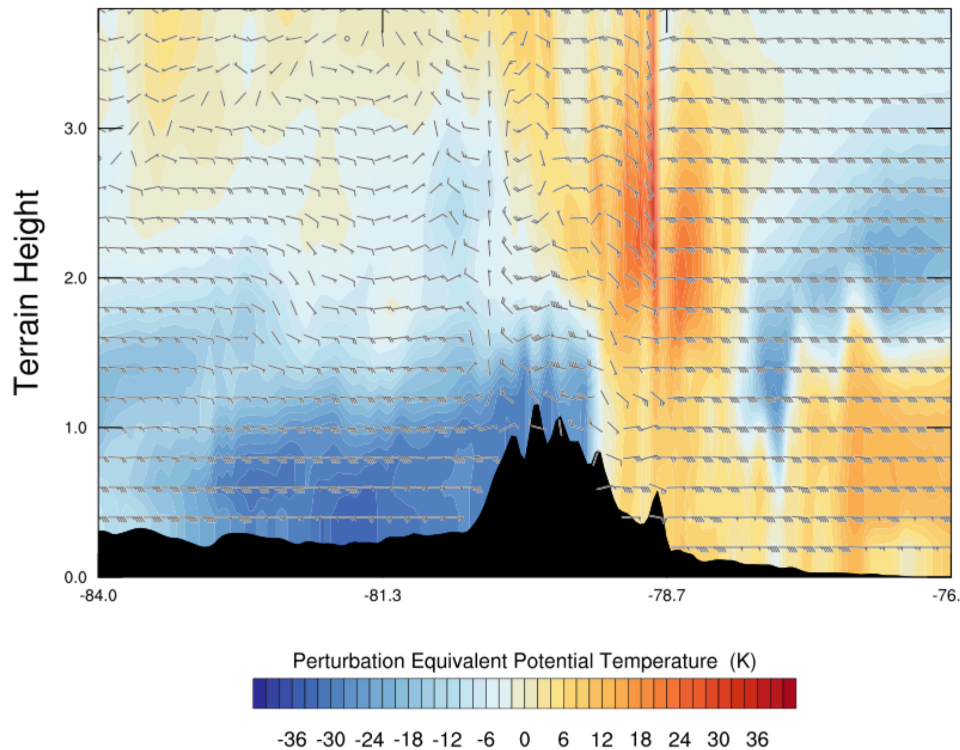
- Morrison double-moment microphysics
- Mellor-Yamada-Janjic PBL scheme

OUTPUT FROM WRF V3.4 MODEL
WE = 619 ; SN = 277 ; Levels = 35 ; Dis = 4km ; Phys Opt = 10 ; PBL Opt = 2 ; Cu Opt = 0

Surface θ_e (K, fill), surface winds (kt, barbs), and lowest model level reflectivity



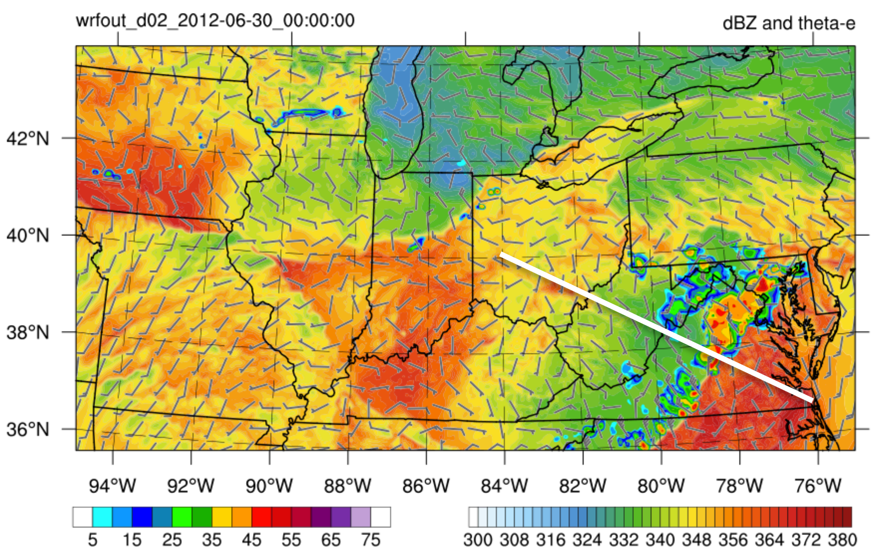
Perturbation θ_e (K, fill) and system relative winds (kt, barbs)



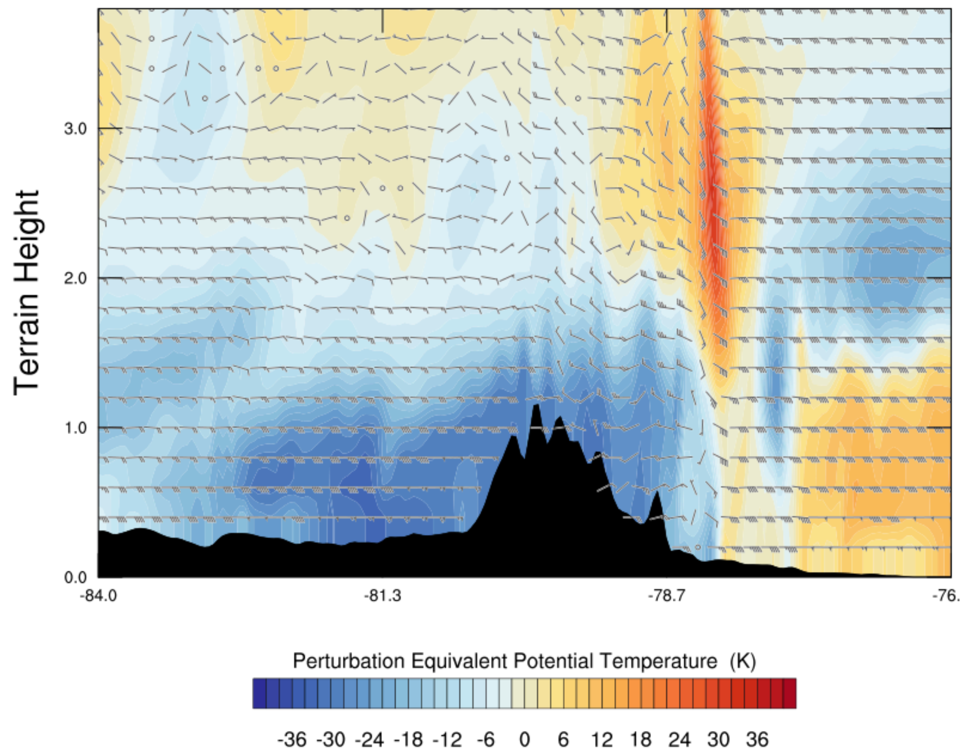
- Morrison double-moment microphysics
- Mellor-Yamada-Janjic PBL scheme

OUTPUT FROM WRF V3.4 MODEL
WE = 619 ; SN = 277 ; Levels = 35 ; Dis = 4km ; Phys Opt = 10 ; PBL Opt = 2 ; Cu Opt = 0

Surface θ_e (K, fill), surface winds (kt, barbs), and lowest model level reflectivity



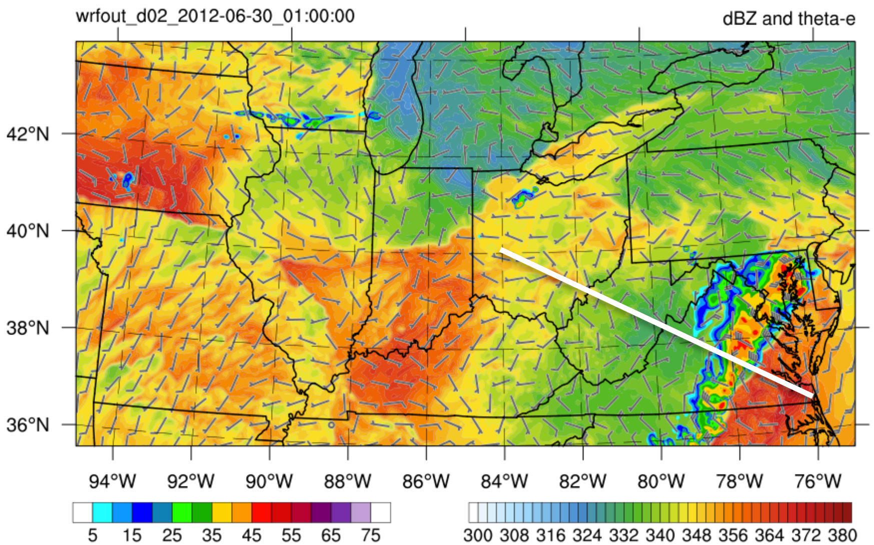
Perturbation θ_e (K, fill) and system relative winds (kt, barbs)



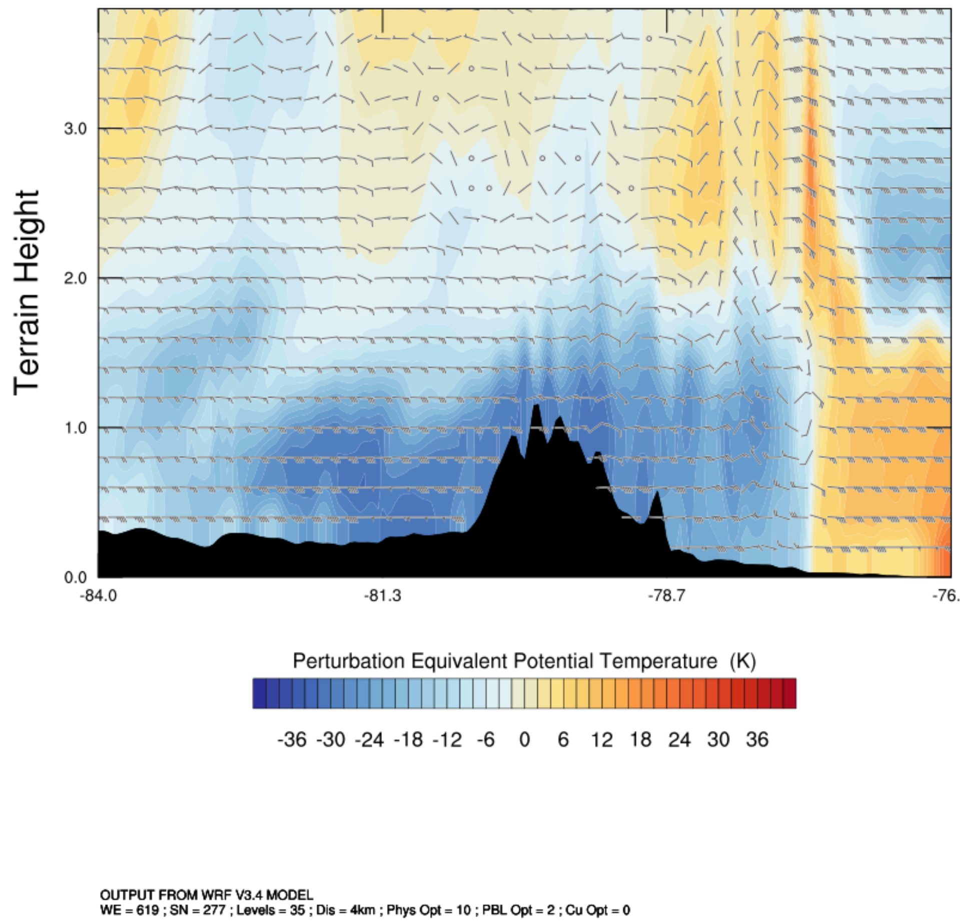
- Morrison double-moment microphysics
- Mellor-Yamada-Janjic PBL scheme

OUTPUT FROM WRF V3.4 MODEL
WE = 619 ; SN = 277 ; Levels = 35 ; Dis = 4km ; Phys Opt = 10 ; PBL Opt = 2 ; Cu Opt = 0

Surface θ_e (K, fill), surface winds (kt, barbs), and lowest model level reflectivity



Perturbation θ_e (K, fill) and system relative winds (kt, barbs)

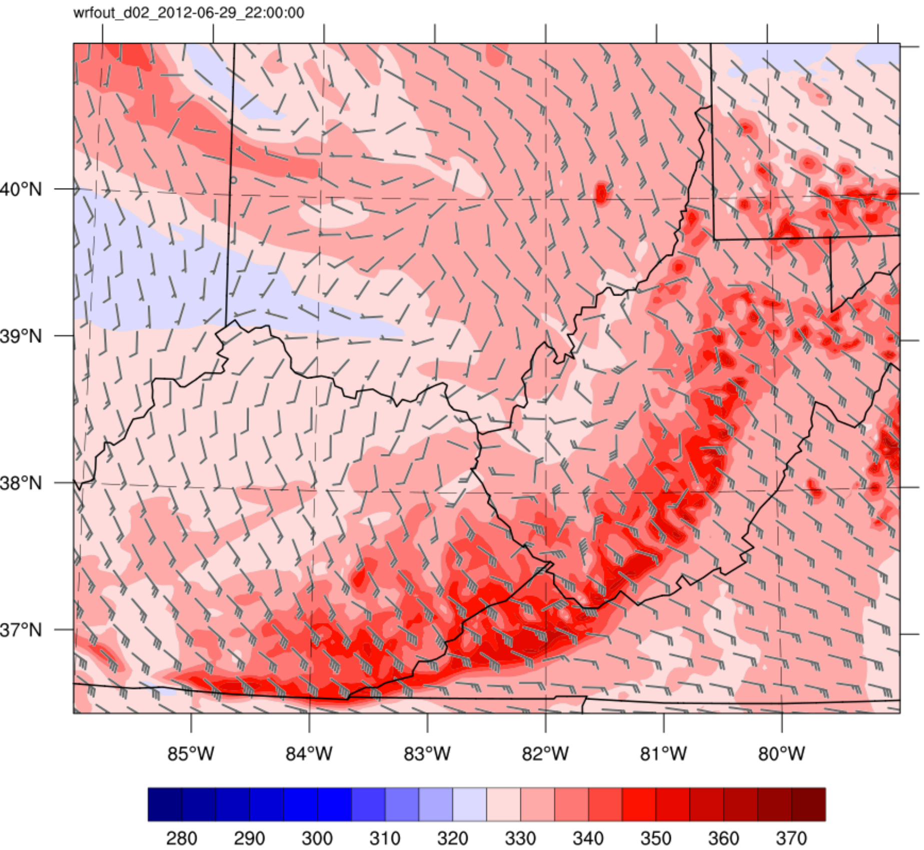


- Morrison double-moment microphysics
- Mellor-Yamada-Janjic PBL scheme

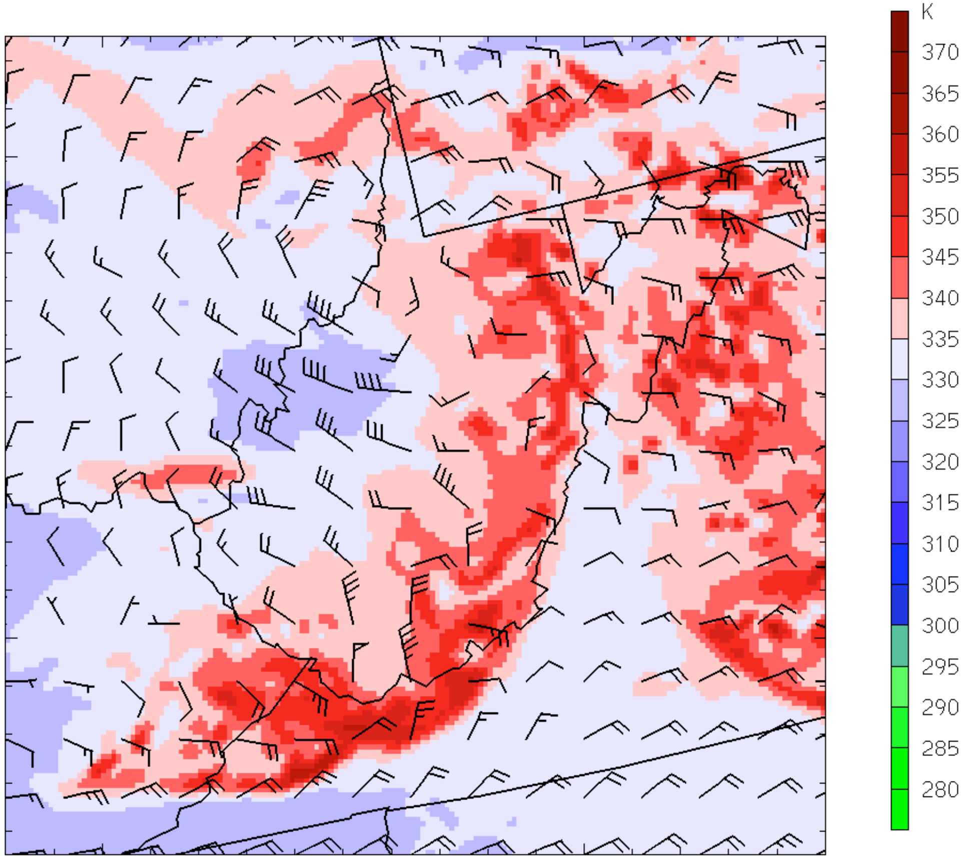
Brief comparison to WRF-ARW run presented by Morris Weisman

700-hPa Theta-e

2200 UTC



0000 UTC

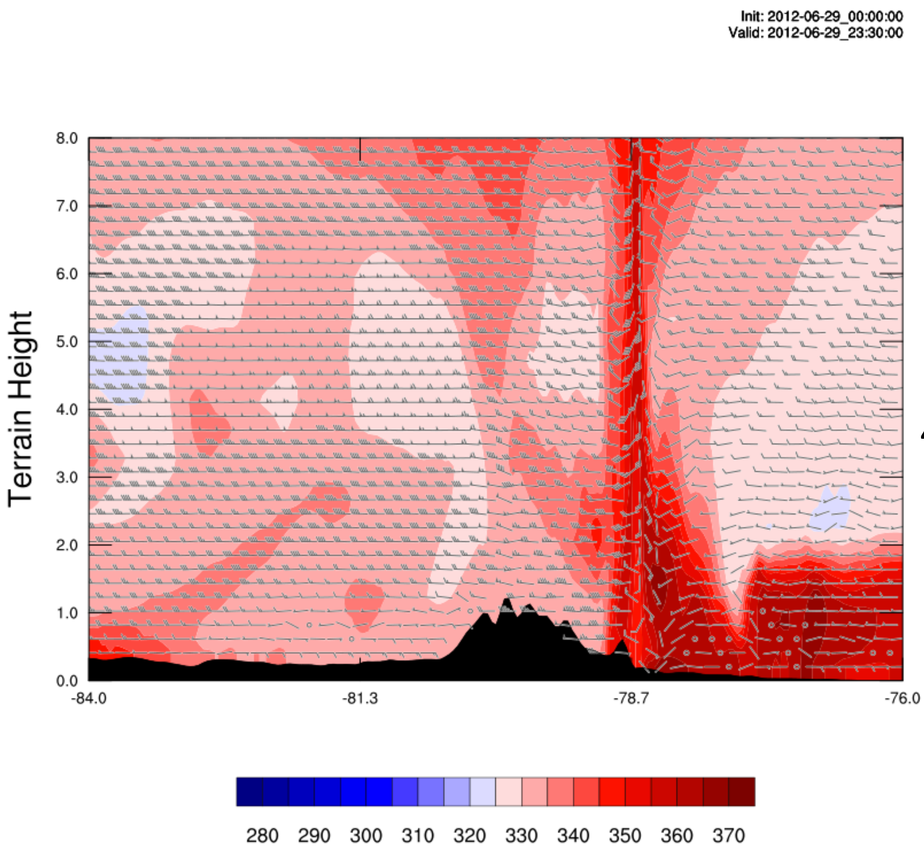


0000 UTC initialization
4km
NAM
Morrison
MYJ

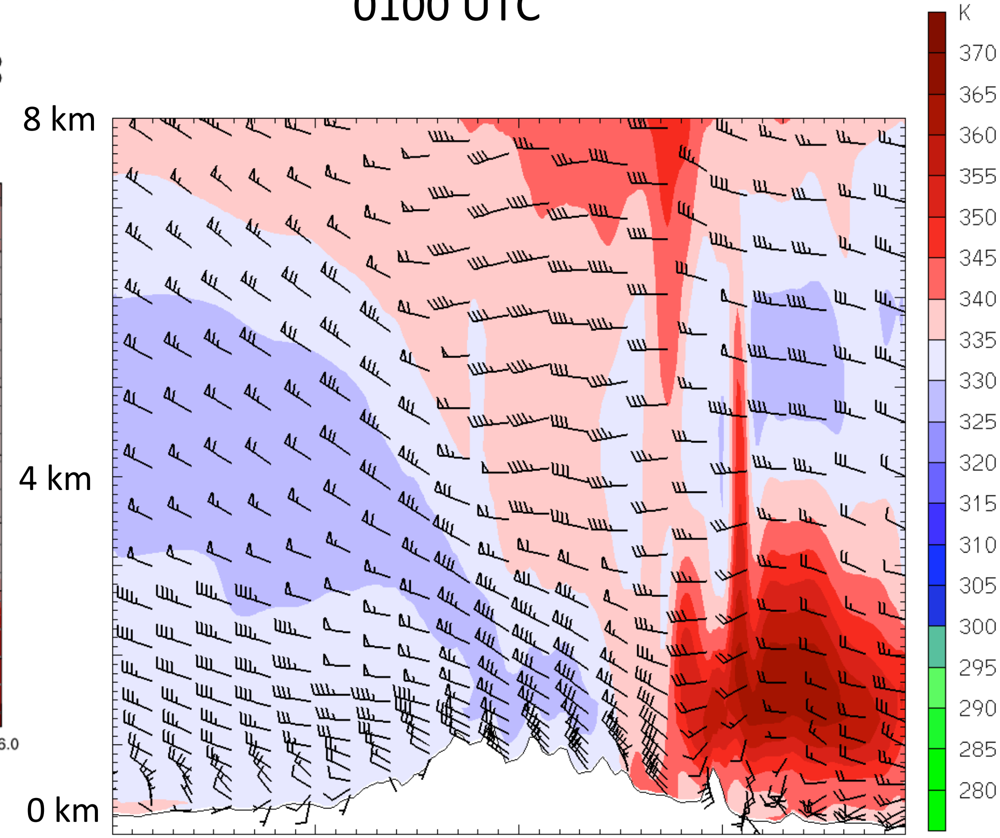
1200 UTC initialization
3km
DART Analysis
Morrison
MYJ

Theta-e

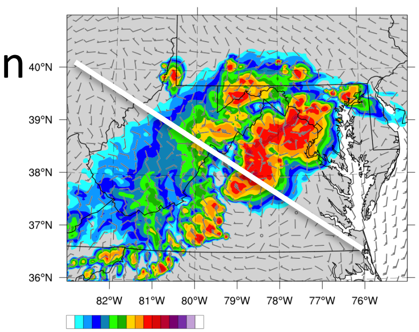
2330 UTC



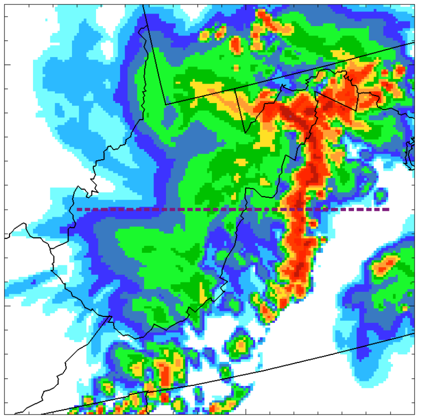
0100 UTC



0000 UTC initialization
4km
NAM
Morrison
MYJ



1200 UTC initialization
3km
DART Analysis
Morrison
MYJ

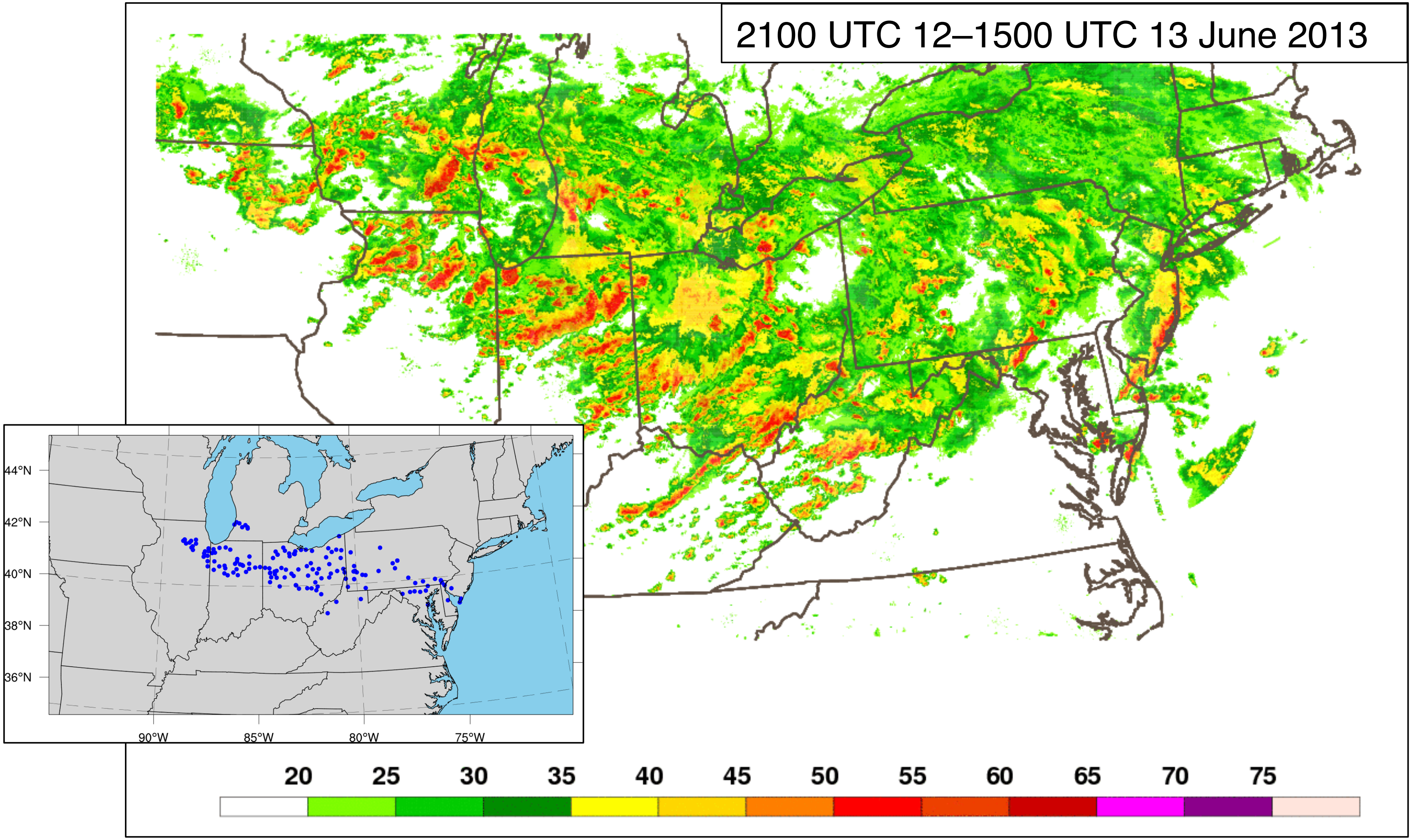


Case study

Upper-level trough

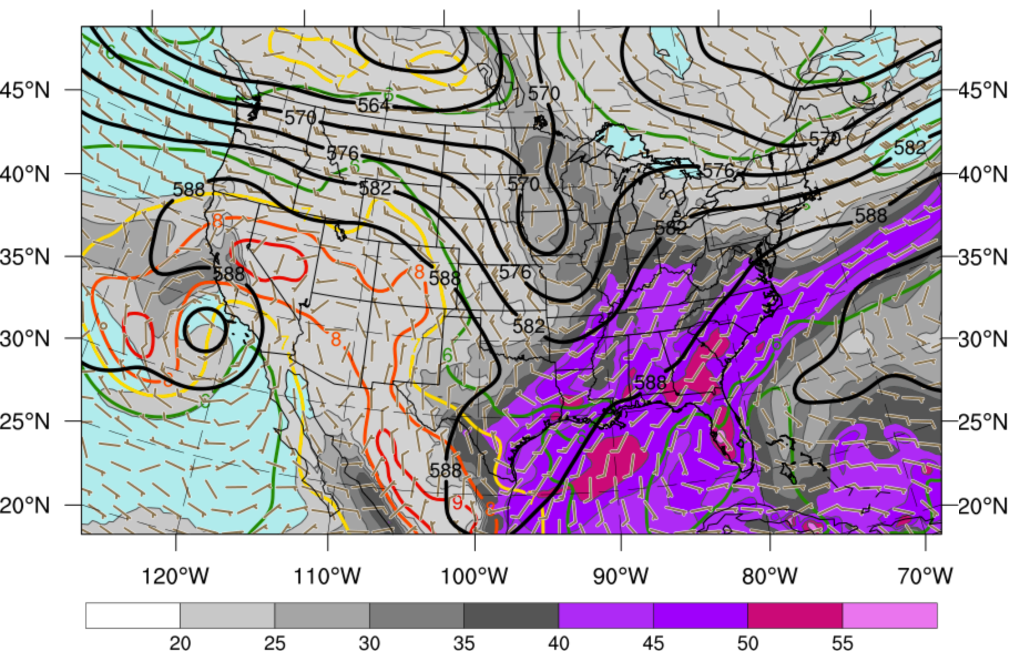
12–13 June 2013

Radar Continuity Map and Storm Reports

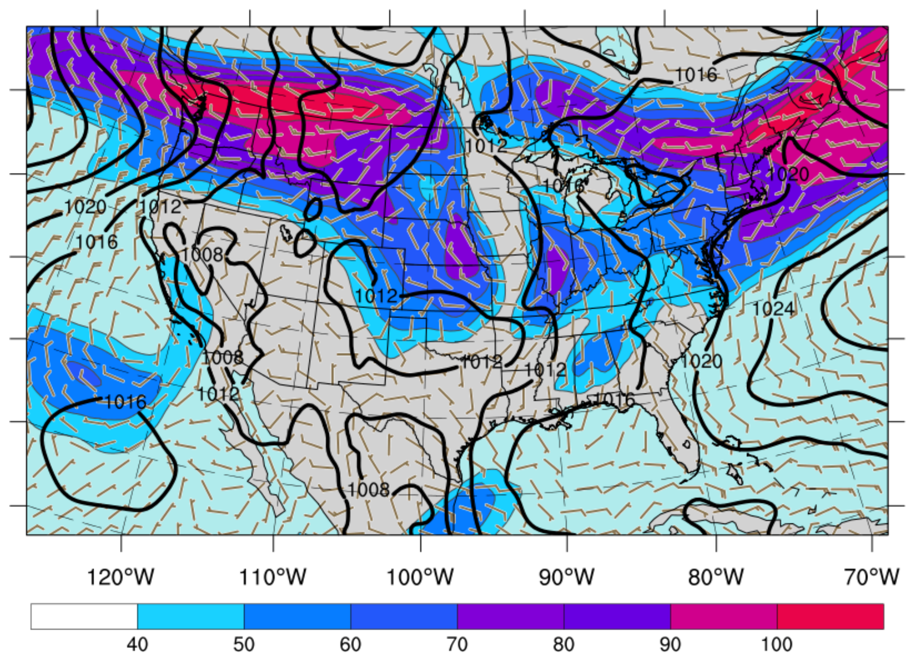


2100 UTC 9 June 2013
(72 hours prior to initiation)

Precipitable water (gray and purple fill; mm), 700–500-hPa lapse rates (colored contours; C km^{-1}), 500 hPa geopotential heights (black contours; dam), and 700–500-hPa layer averaged winds (barbs; kt)

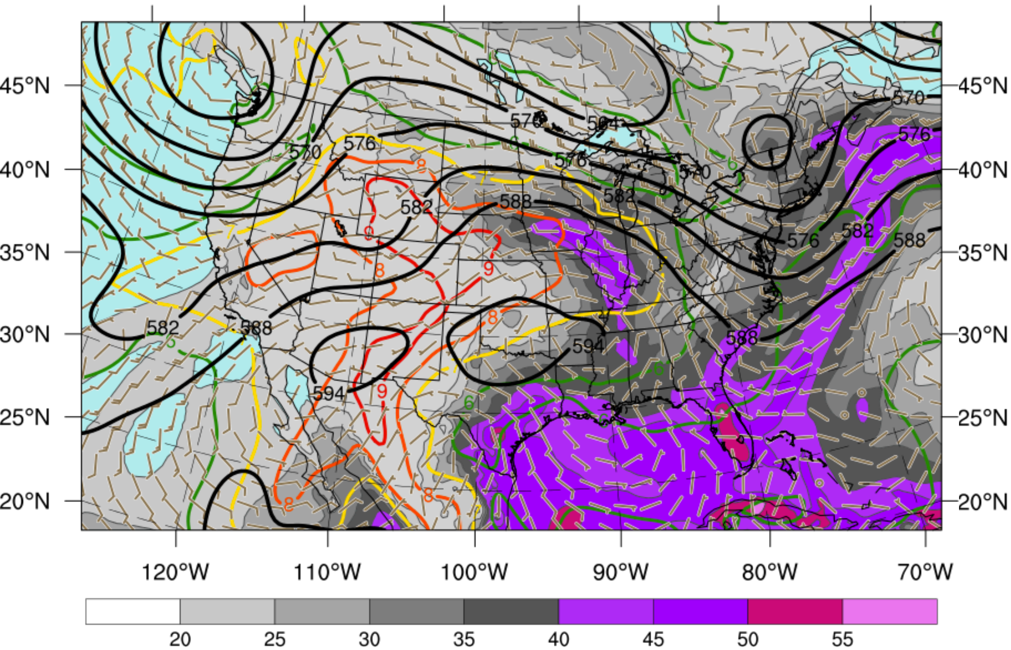


250-hPa wind magnitude (fill; kt), mean sea level pressure (contours; hPa), and surface winds (barbs; kt)

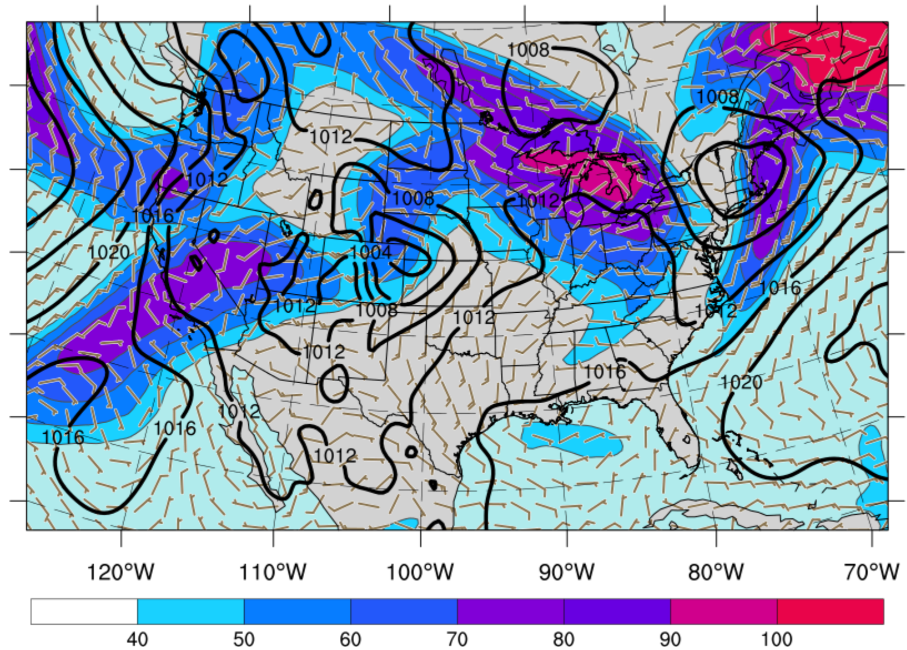


2100 UTC 11 June 2013
(24 hours prior to initiation)

Precipitable water (gray and purple fill; mm), 700–500-hPa lapse rates (colored contours; C km^{-1}), 500 hPa geopotential heights (black contours; dam), and 700–500-hPa layer averaged winds (barbs; kt)

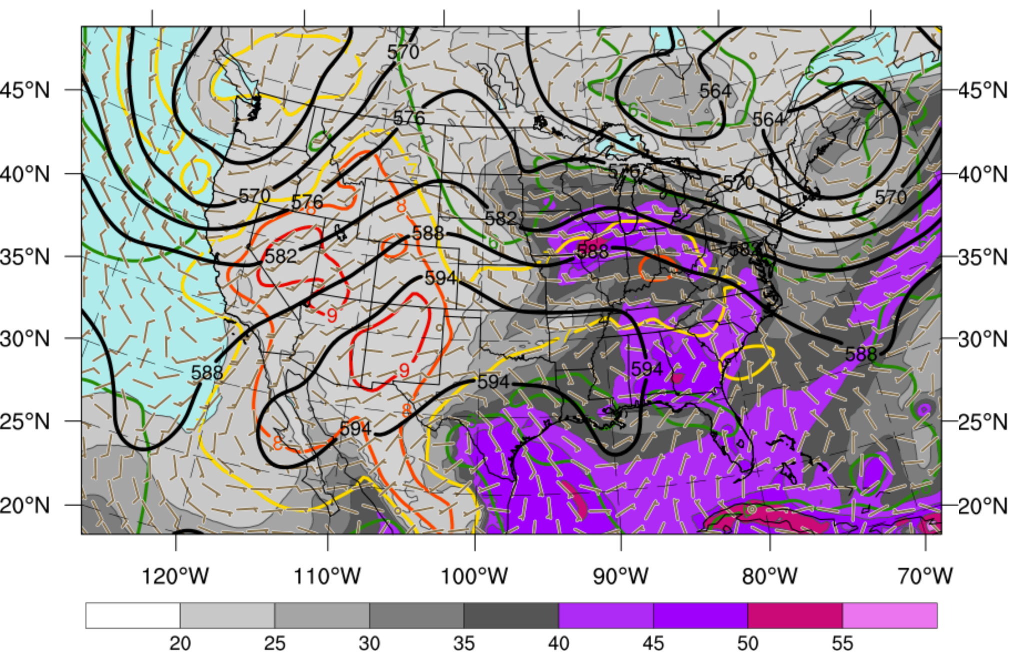


250-hPa wind magnitude (fill; kt), mean sea level pressure (contours; hPa), and surface winds (barbs; kt)

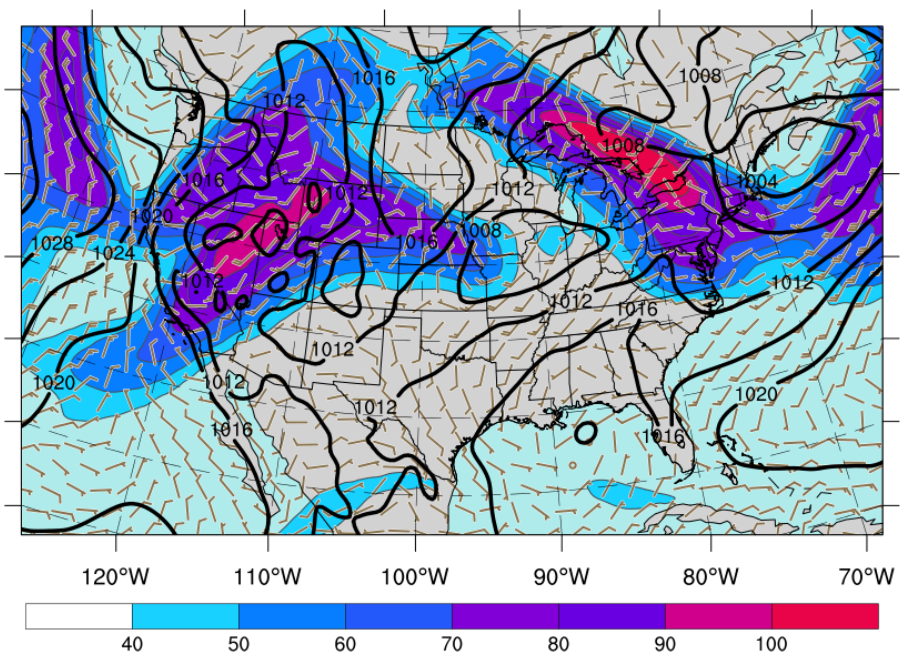


2100 UTC 12 June 2013 (at initiation)

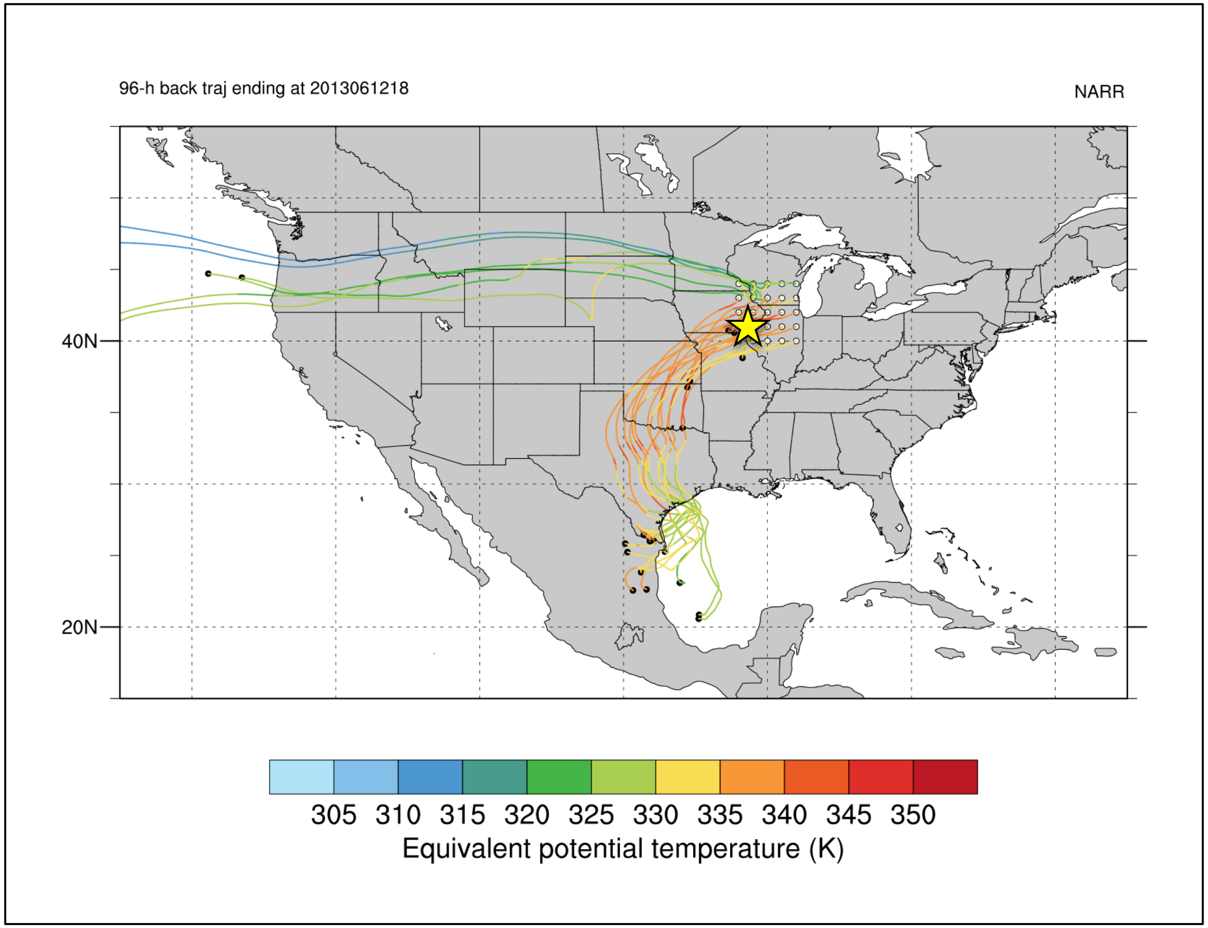
Precipitable water (gray and purple fill; mm), 700–500-hPa lapse rates (colored contours; C km^{-1}), 500 hPa geopotential heights (black contours; dam), and 700–500-hPa layer averaged winds (barbs; kt)



250-hPa wind magnitude (fill; kt), mean sea level pressure (contours; hPa), and surface winds (barbs; kt)

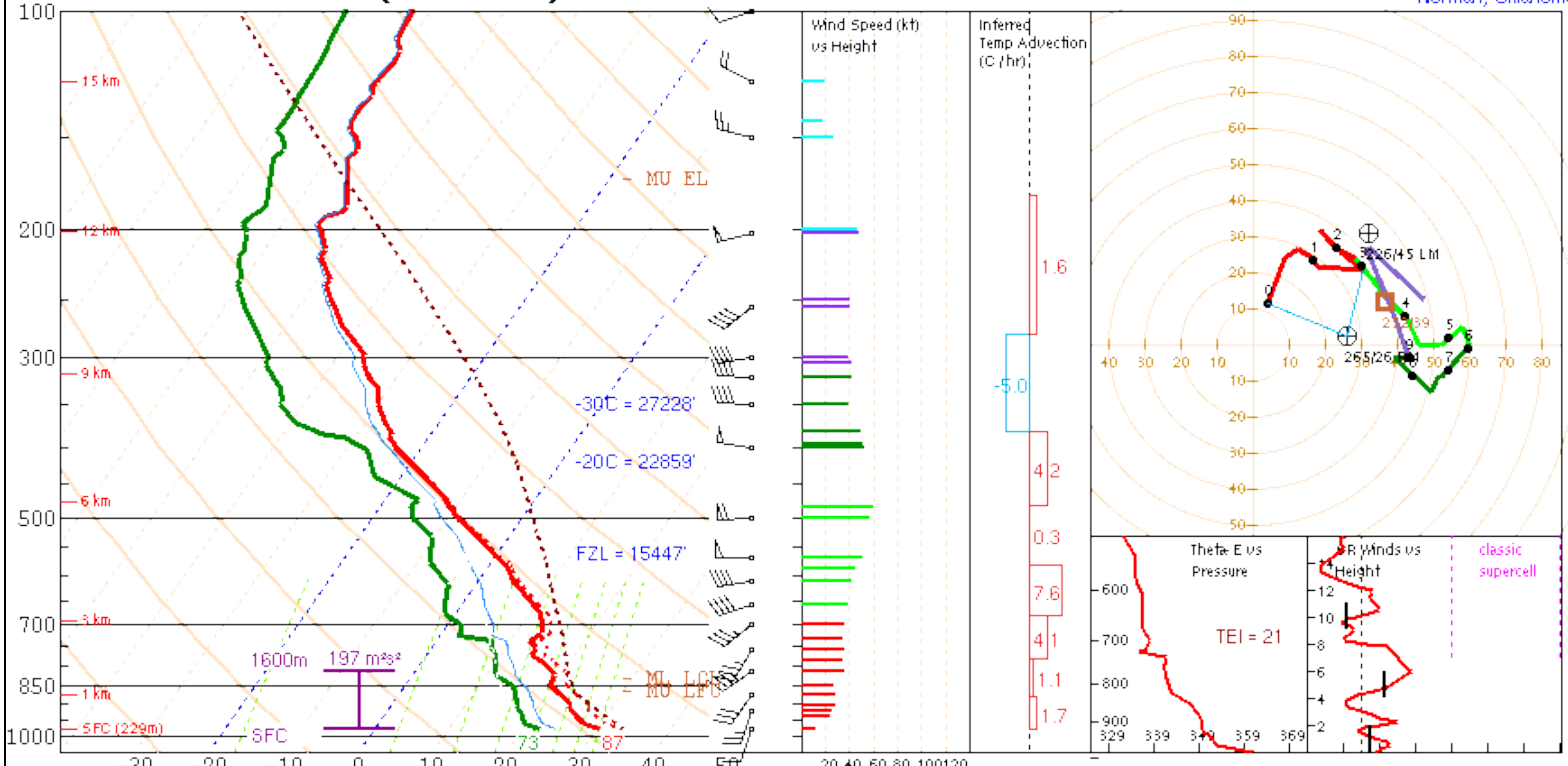


96-hour back trajectories ending at 850-hPa at 1800 UTC 12 June 2013



DVN 130612/1800 (Observed)

NOAA/NWS Storm Prediction Center
Norman, Oklahoma



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	4079	-1	1023m	-10	1073m	42820'
MIXED LAYER	2341	-100	1413m	-6	3685m	40827'
FCST SURFACE	2991	-9	1797m	-8	3429m	41281'
MU (980 mb)	4079	-1	1023m	-10	1073m	42820'

PW = 1.73 in	3CAPE = 0 J/kg	WBZ = 13386'	WNDG = 0.0
K = 32	DCAPE = 1109 J/kg	FZL = 15447'	ESP = 0.0
MidRH = 57%	DownT = 66 F	ConvT = 95F	MMP = 0.99
LowRH = 65%	MeanW = 14.6 g/kg	MaxT = 93F	

SigSevere = 68099 m3/s3

Sfc-3km Agl Lapse Rate = 6.8 C/km
3-6km Agl Lapse Rate = 8.2 C/km
850-500mb Lapse Rate = 6.9 C/km
700-500mb Lapse Rate = 8.1 C/km

Supercell = 16.1
Left Supercell = 1.3
Sig Tor (CIN) = 1.1
Sig Tor (fixed) = 3.4
Sig Hail = 2.5

	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	134	18	204/24	140/25
SFC - 3 km	197	28	217/29	158/22
Eff Inflow Layer	197	28	212/26	147/23
SFC - 6 km		57	235/32	180/15
SFC - 8 km		45	242/33	194/13
Lower Half Storm Depth		55	238/32	185/15
Cloud Bearing Layer		30	251/38	226/14

BRN Shear = 49 m²/s²
4-6km SR Wind = 270/26 kt

.....Storm Motion Vectors.....
Bunkers Right = 265/26 kt
Bunkers Left = 226/45 kt

Corfidi Downshear = 274/69 kt
Corfidi Upshear = 295/31 kt

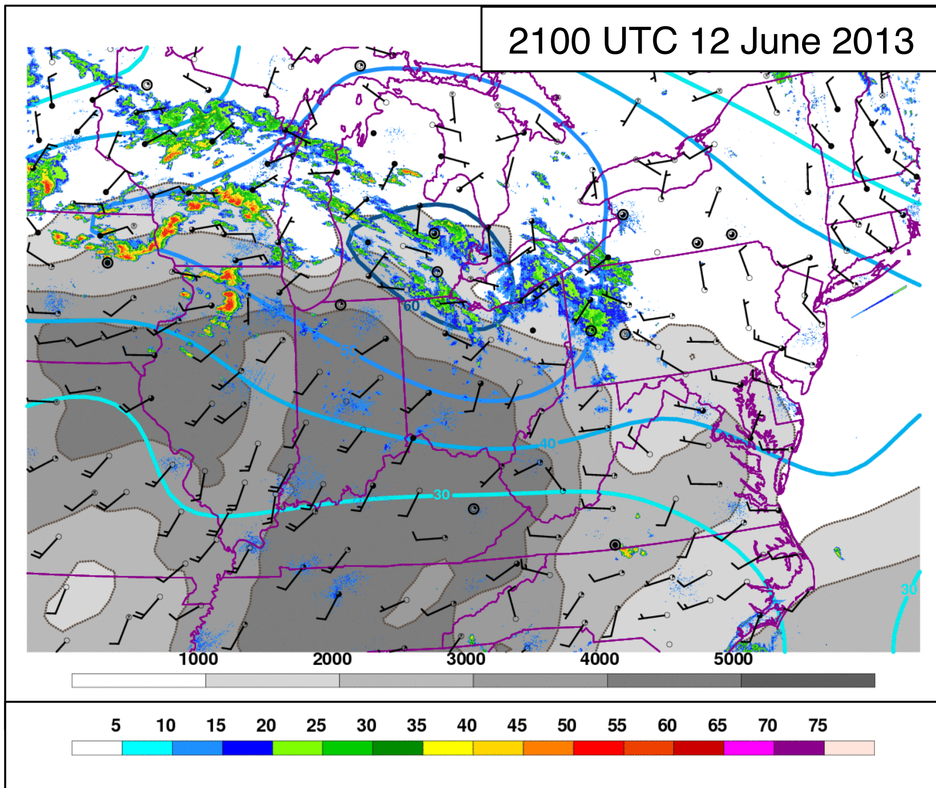
* * * BEST GUESS PRECIP TYPE * * *
None.
Based on sfc temperature of 87.1 F.

SARS - Sounding Analogs

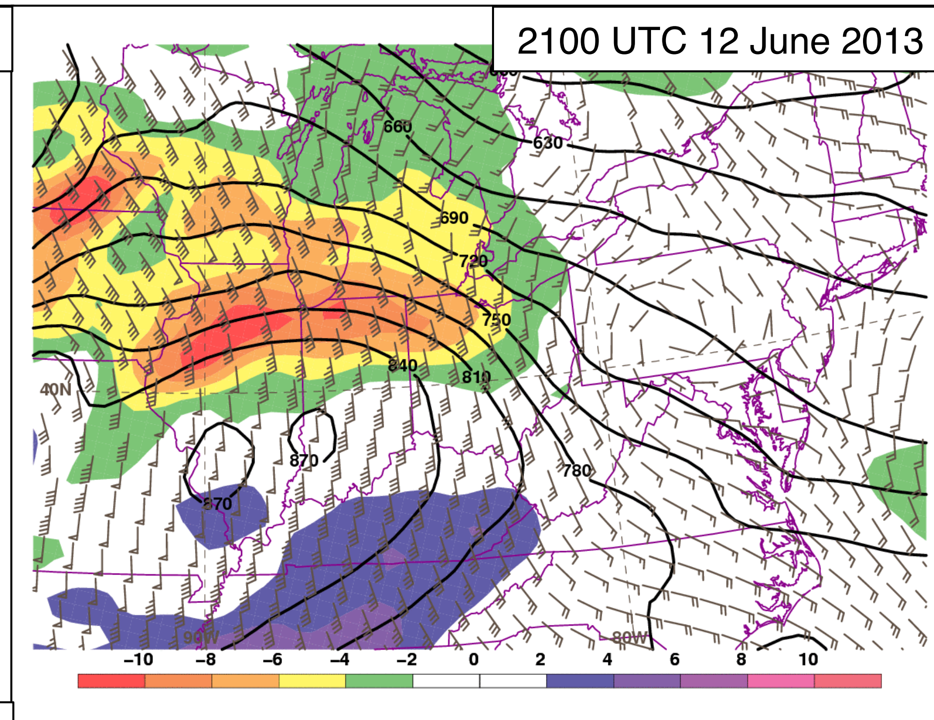
SUPERCELL	SGFNT HAIL
01053000.AMA SIG	01090800.OUN 2.00
99060100.CSM WEAK	
(5 loose matches)	(63 loose matches)
SARS: 80% TOR	SARS: 87% SIG

310 K isentropic analysis using system-relative winds

0.5° composite reflectivity, NARR CAPE (grayscale; J kg^{-1}), 1000 – 500-hPa shear magnitude (blue contours; kt), and surface observations

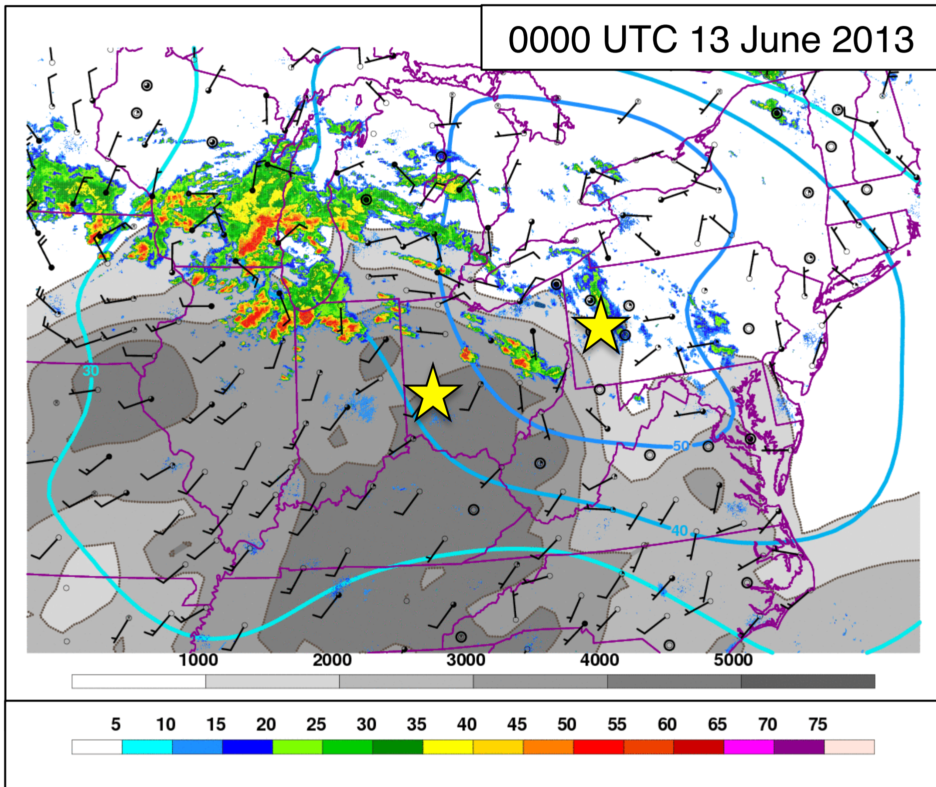


Omega (fill; hPa $s^{-1} \times 10^{-3}$), pressure (contours, hPa), and system relative winds assuming propagation to the southeast at 45 kt

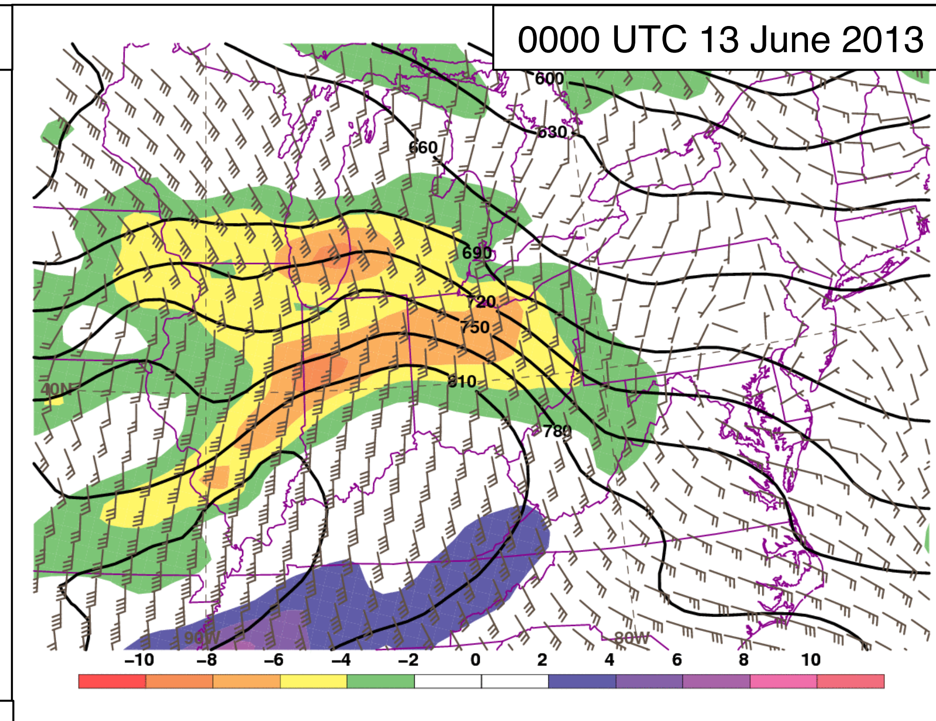


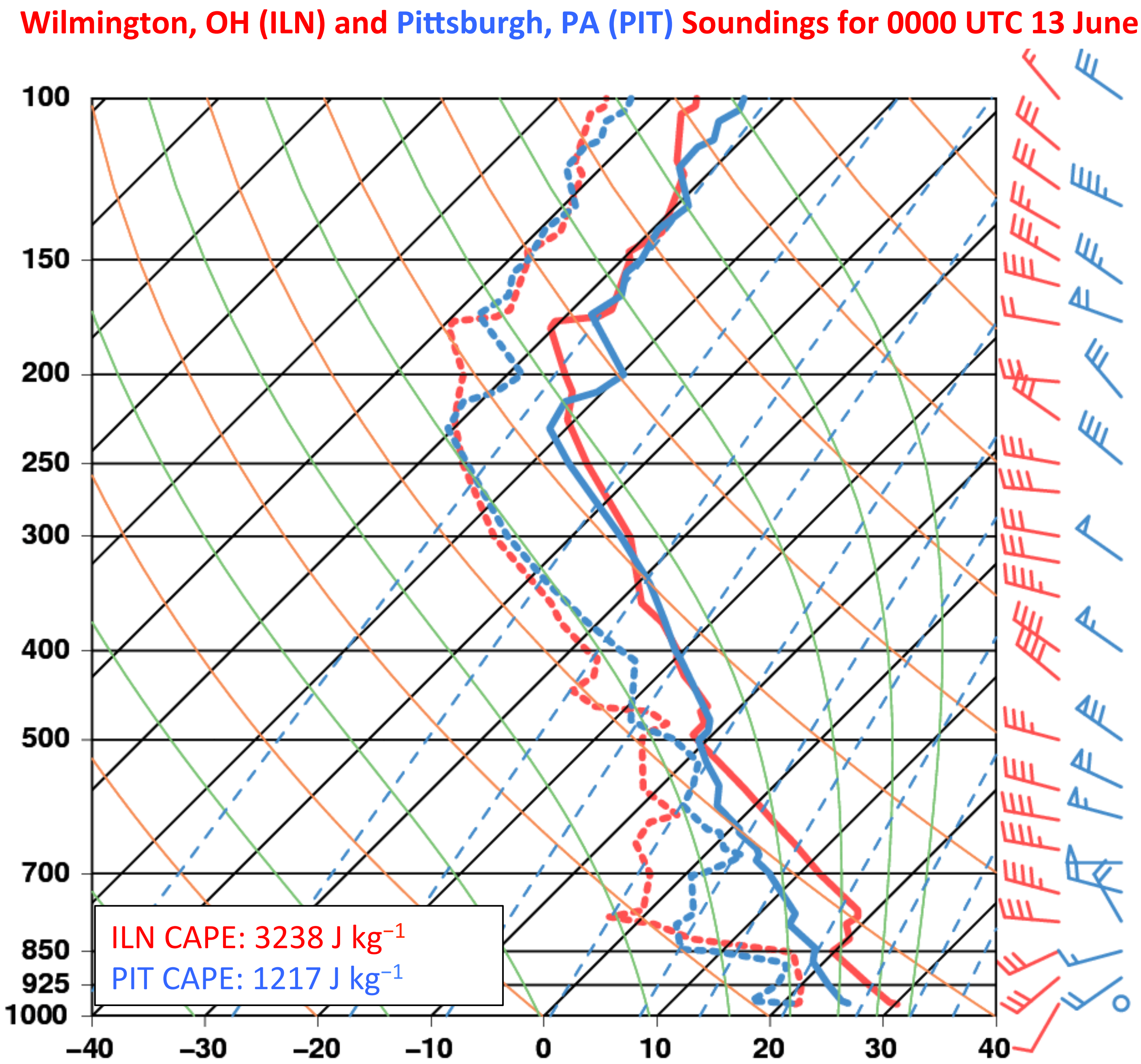
310 K isentropic analysis using system-relative winds

0.5° composite reflectivity, NARR CAPE (grayscale; J kg^{-1}), 1000 – 500-hPa shear magnitude (blue contours; kt), and surface observations



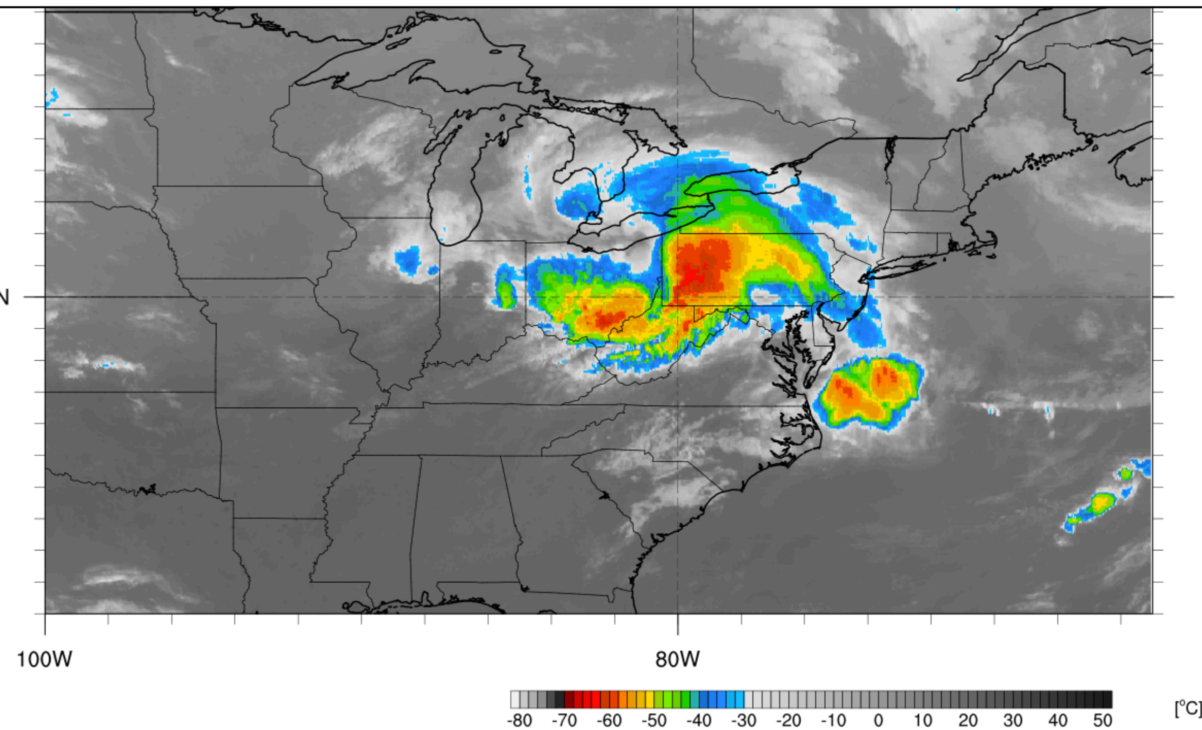
Omega (fill; hPa $s^{-1} \times 10^{-3}$), pressure (contours, hPa), and system relative winds assuming propagation to the southeast at 45 kt



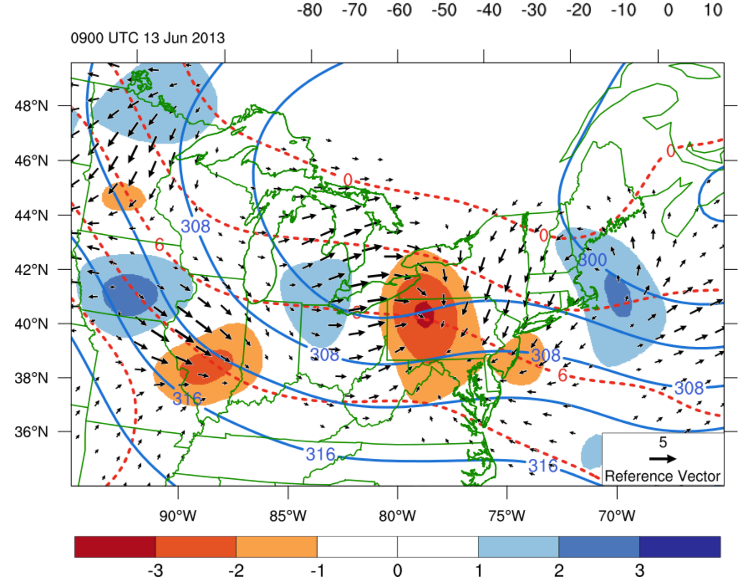

Wilmington, OH (ILN) and Pittsburgh, PA (PIT) Soundings for 0000 UTC 13 June 2013
100
150
200
250
300
400
500
700
850
925
1000
–40
–30
–20
–10
0
10
20
30
40
ILN CAPE: 3238 J kg–1
PIT CAPE: 1217 J kg–1

Encountering Appalachians and Atlantic Coast
0900 UTC 13 June 2013

IR Imagery

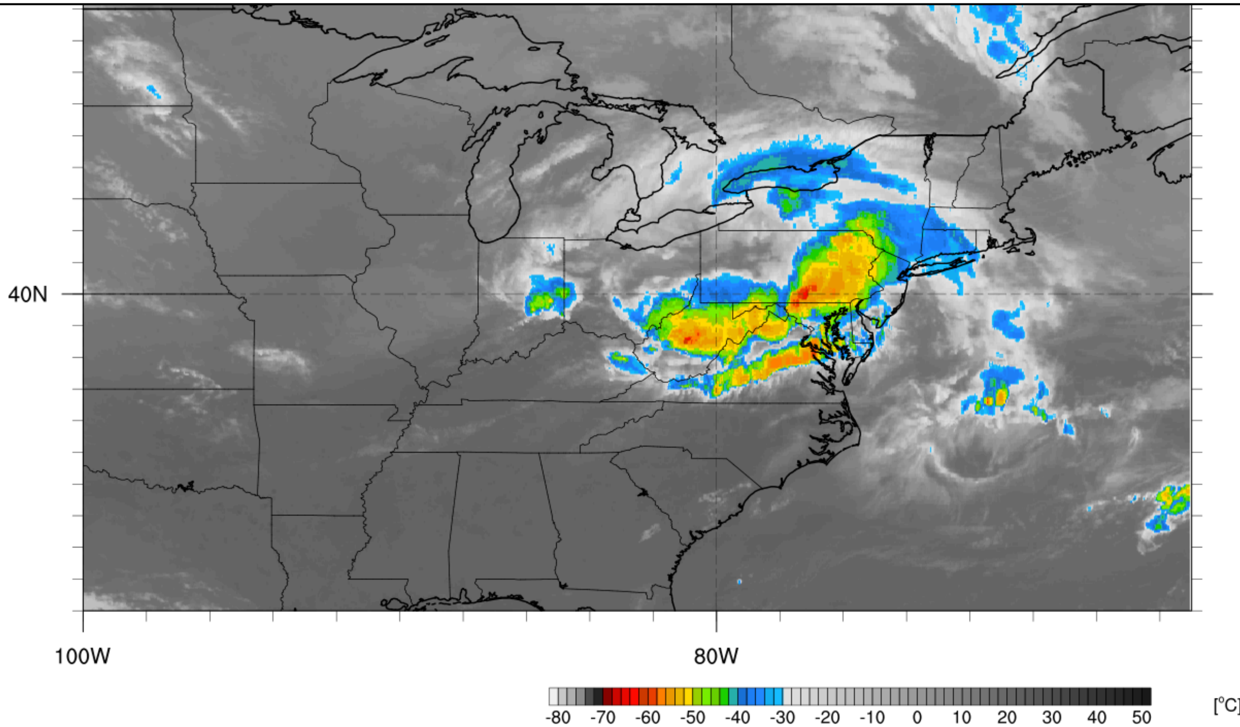


700-hPa Q-vectors, Q-vector convergence, geopotential heights, and temperature

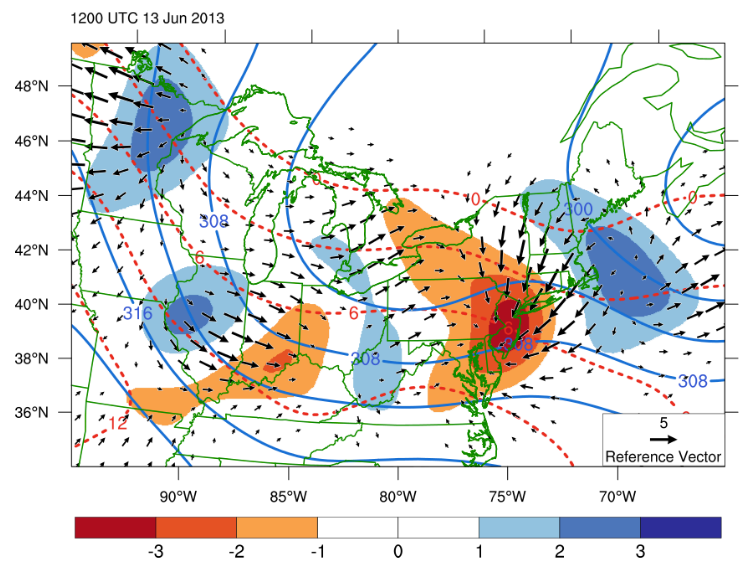


Encountering Appalachians and Atlantic Coast
1200 UTC 13 June 2013

IR Imagery

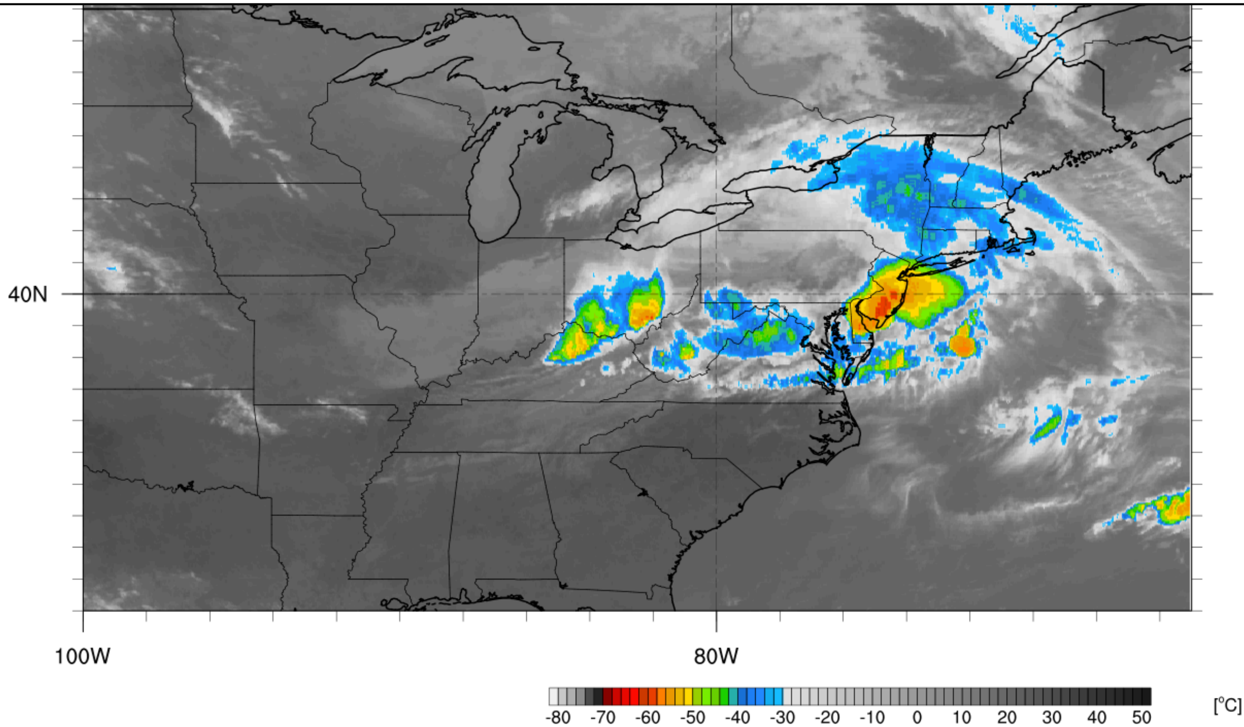


700-hPa Q-vectors, Q-vector convergence, geopotential heights, and temperature

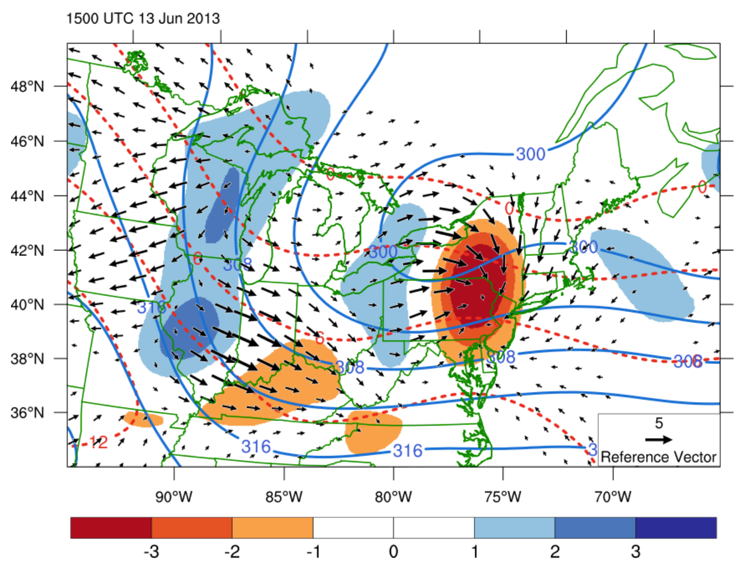


Encountering Appalachians and Atlantic Coast
1500 UTC 13 June 2013

IR Imagery

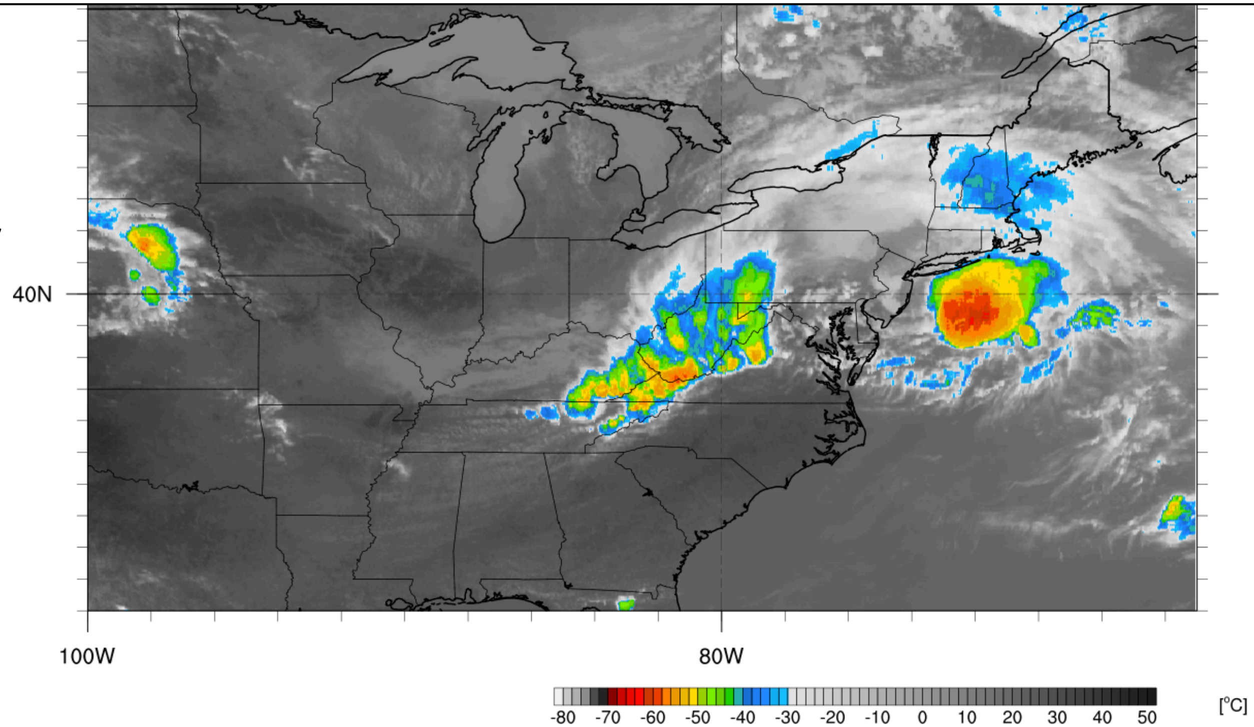


700-hPa Q-vectors, Q-vector convergence, geopotential heights, and temperature

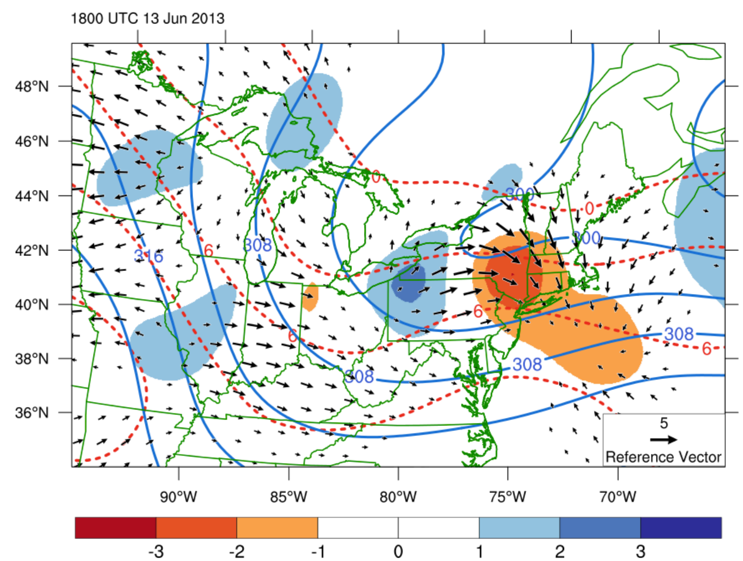


Encountering Appalachians and Atlantic Coast
1800 UTC 13 June 2013

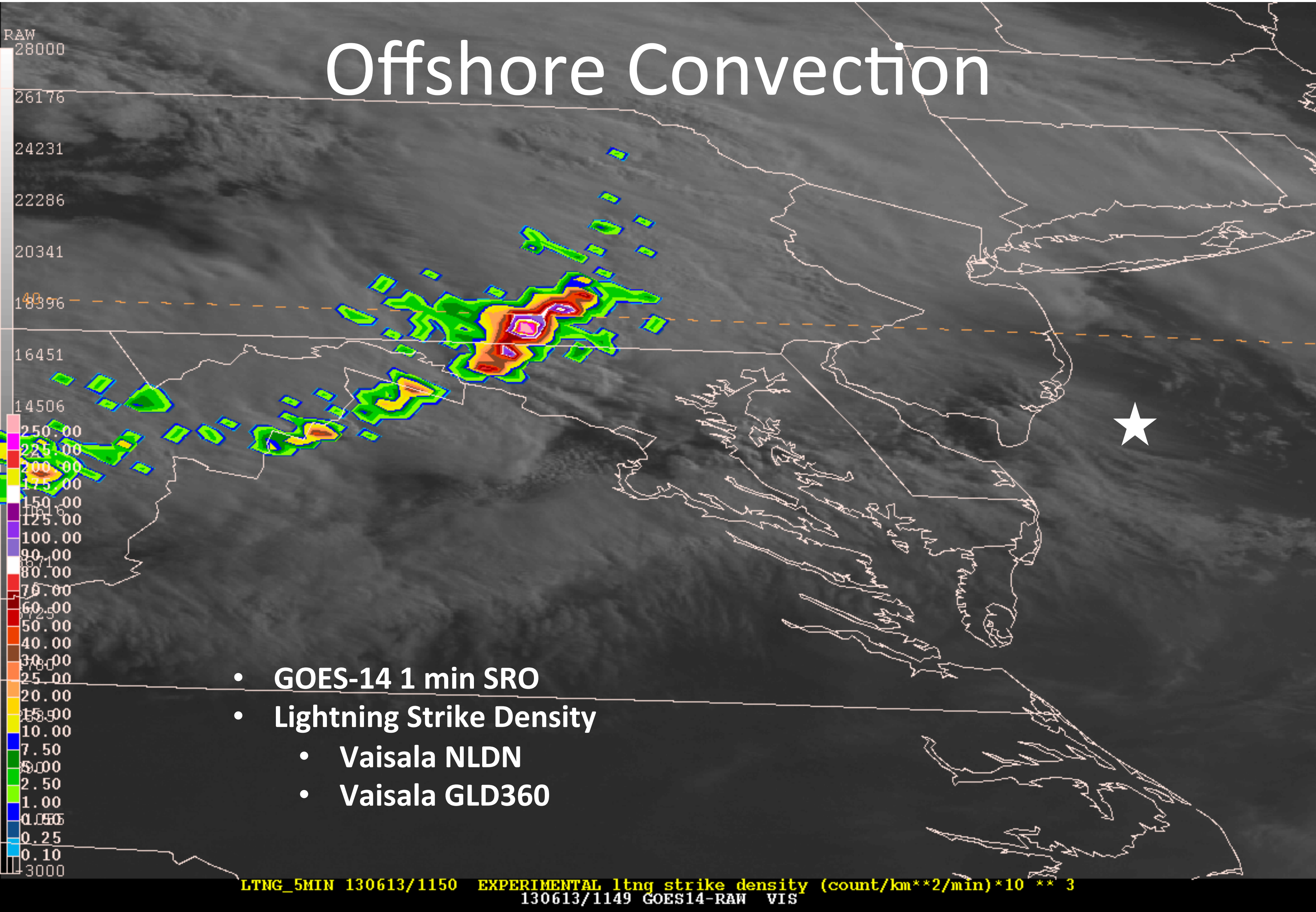
IR Imagery



700-hPa Q-vectors, Q-vector convergence, geopotential heights, and temperature



Offshore Convection



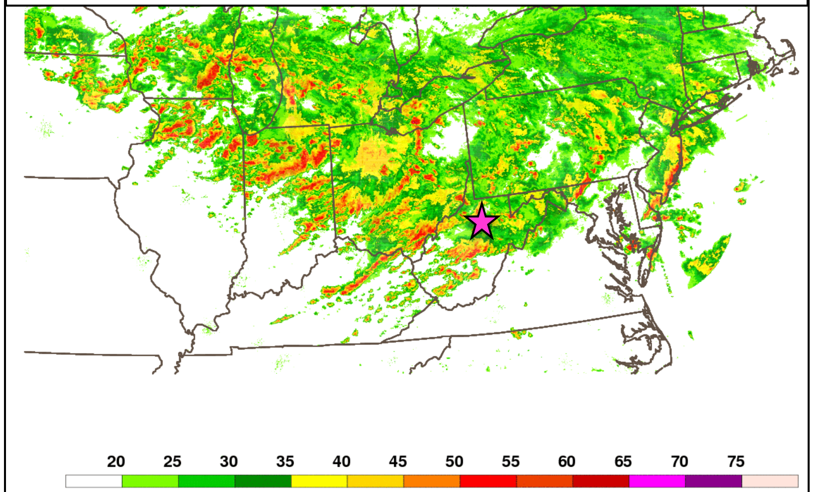
- GOES-14 1 min SRO
- Lightning Strike Density
  - Vaisala NLDN
  - Vaisala GLD360

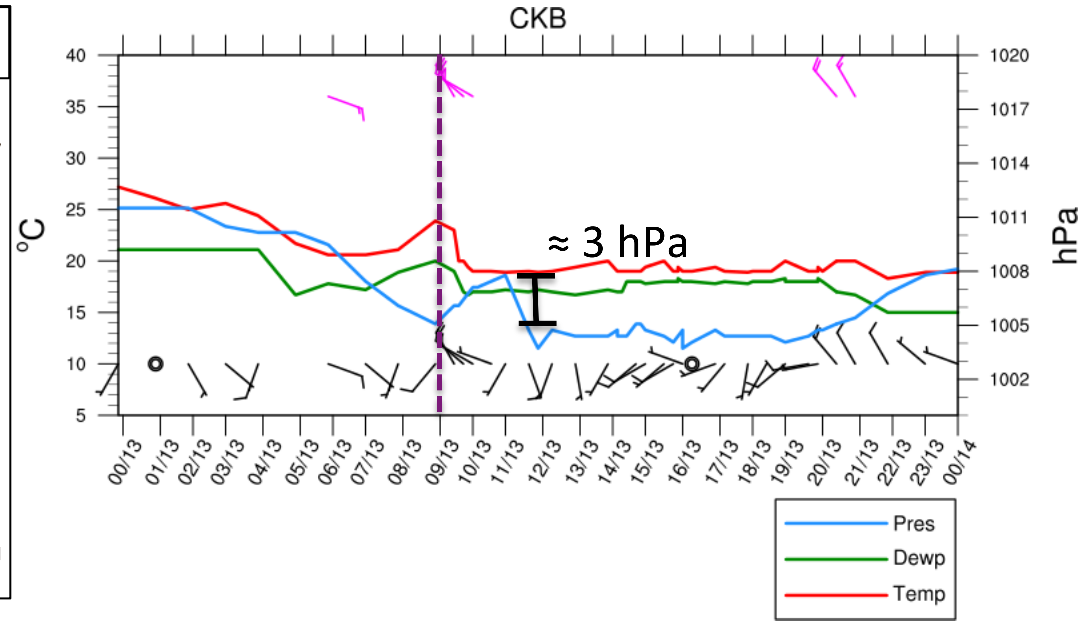
Source: Joe Sienkiewicz 2013 NCEP Production Suite Review

Comparison of 29–30 June 2012 and 12–13 June 2013 progressive derechos

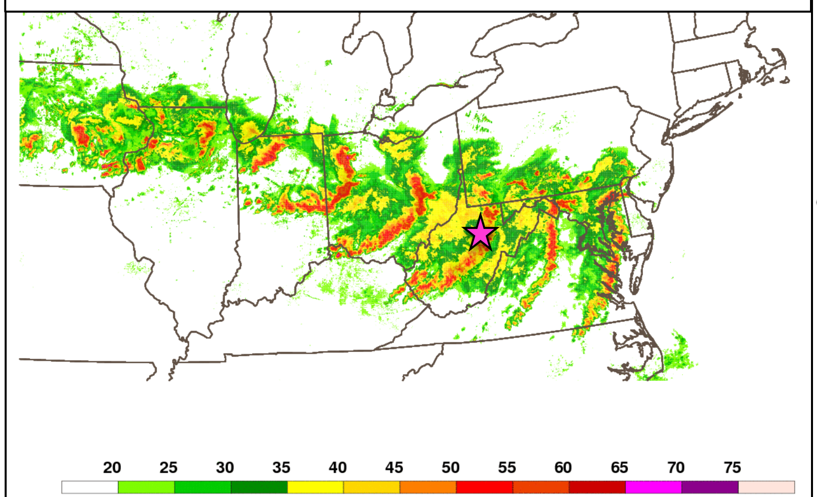
Comparison of June 2012 and June 2013 Progressive Derechos

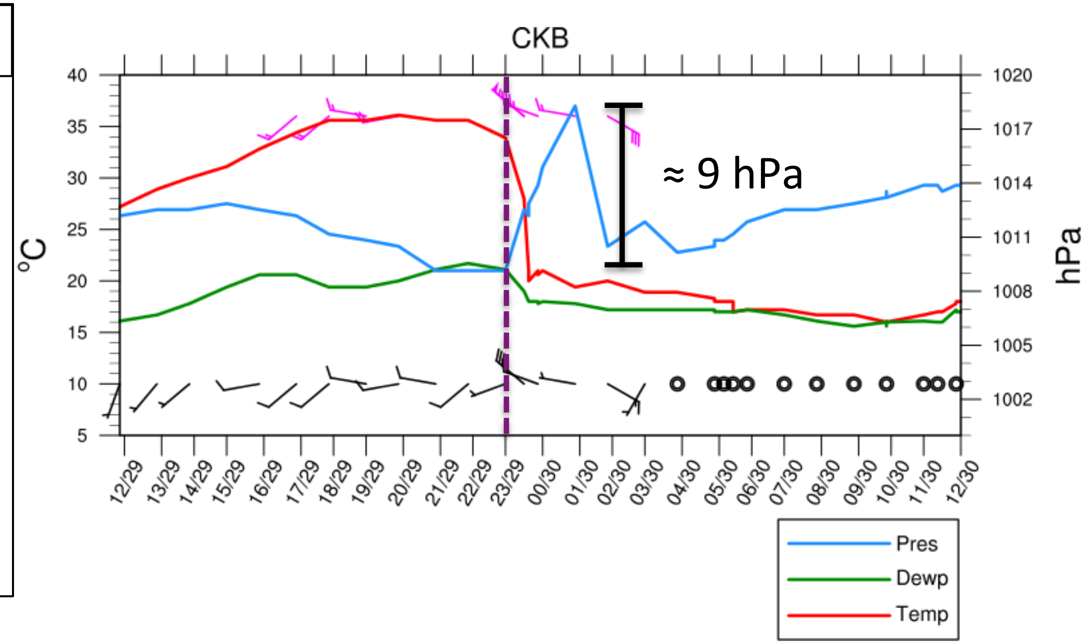
2100 UTC 12–1500 UTC 13 June 2013





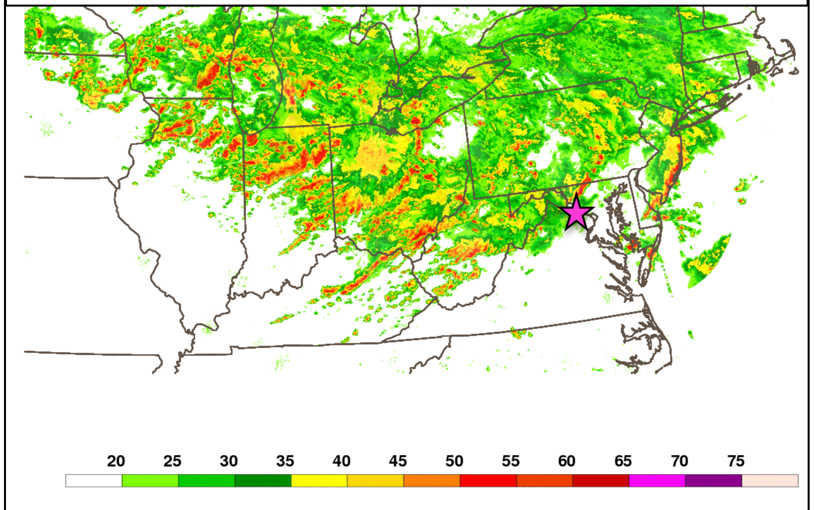
1600 UTC 29–0400 UTC 30 June 2012

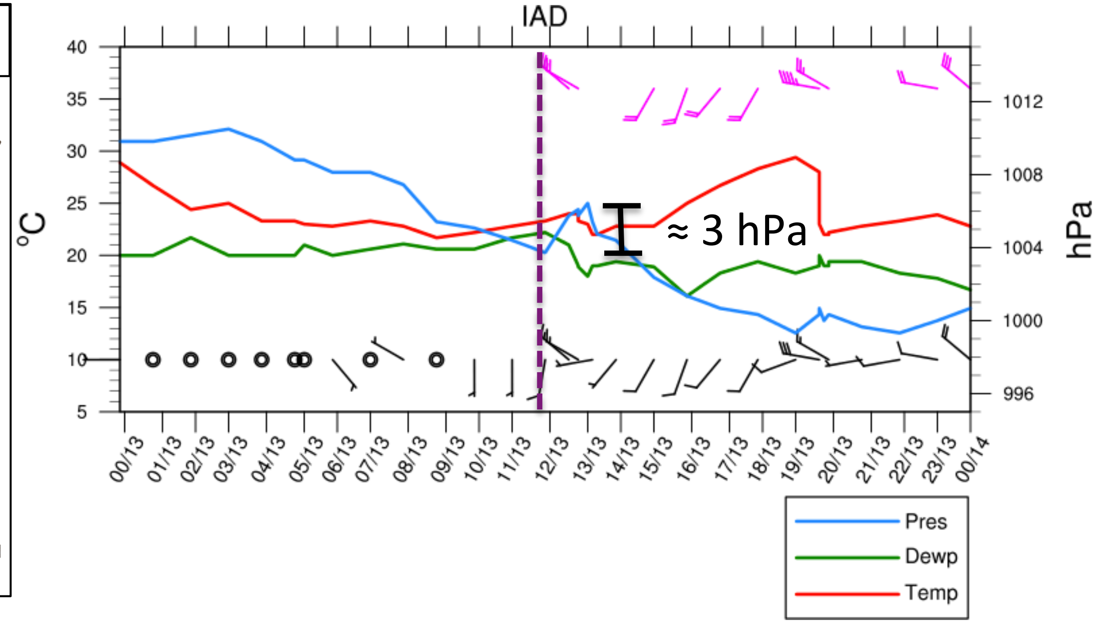




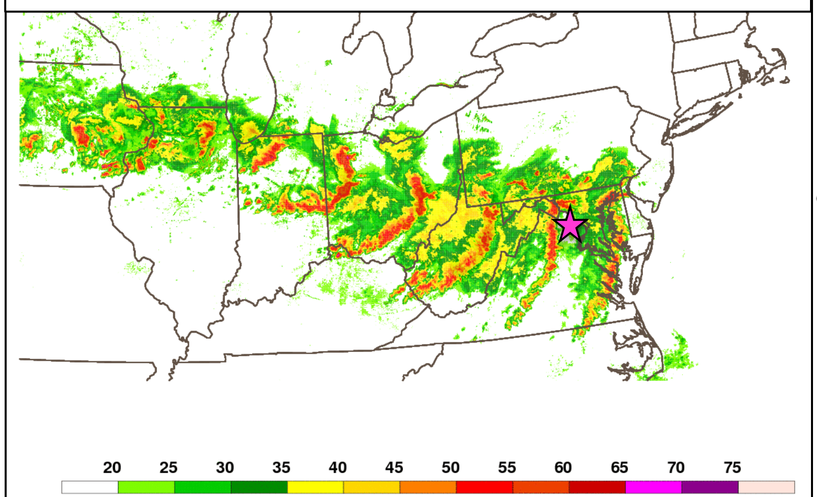
Comparison of June 2012 and June 2013 Progressive Derechos

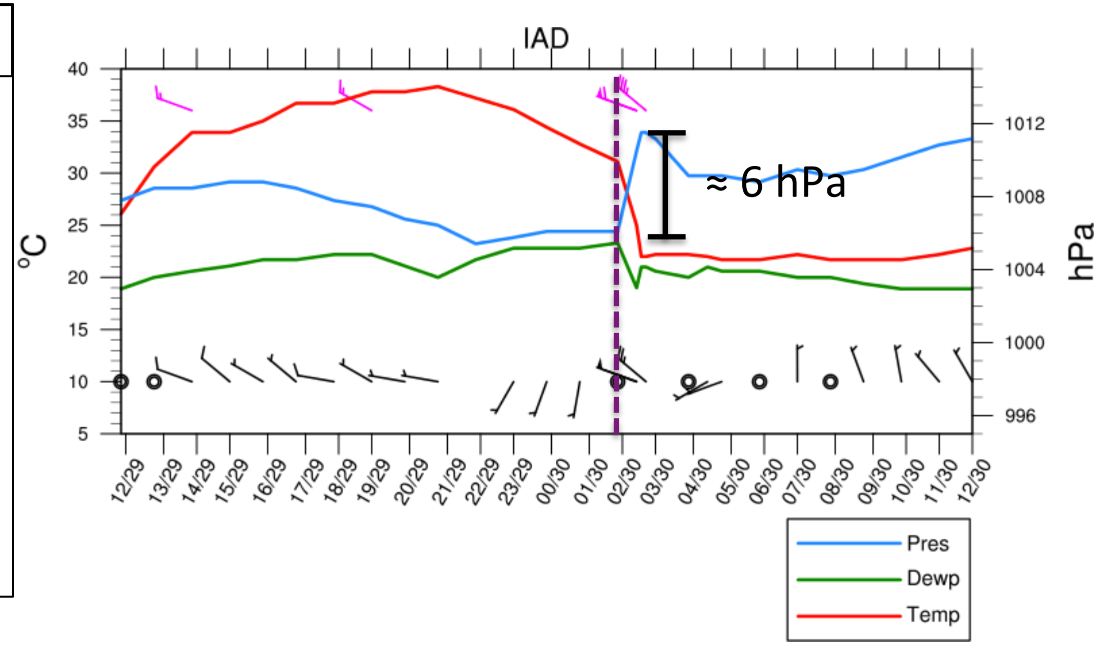
2100 UTC 12–1500 UTC 13 June 2013

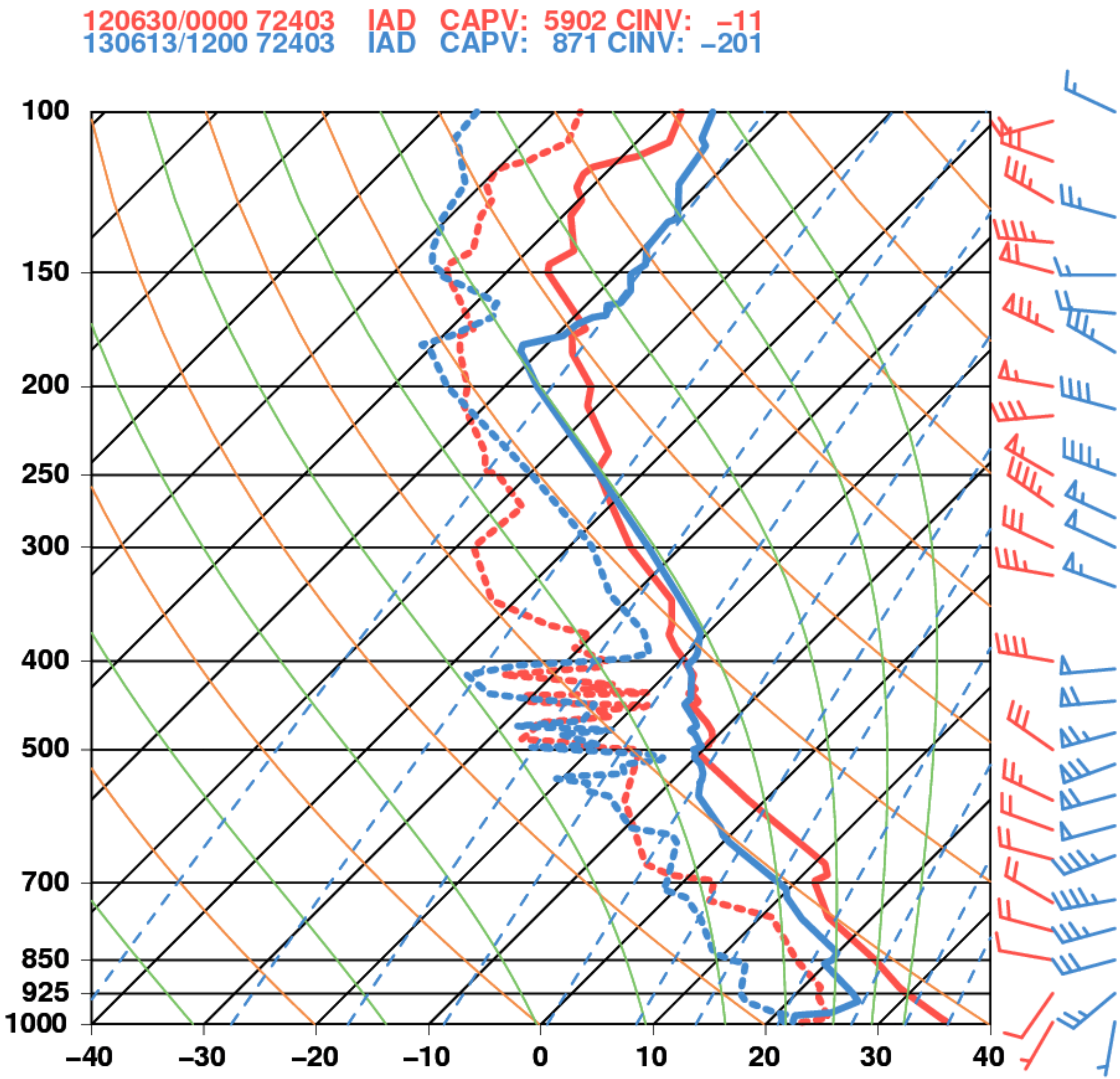




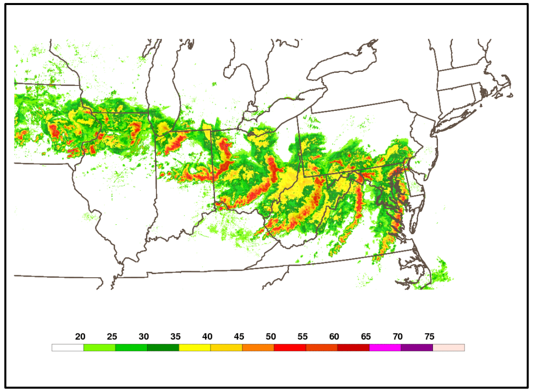
1600 UTC 29–0400 UTC 30 June 2012

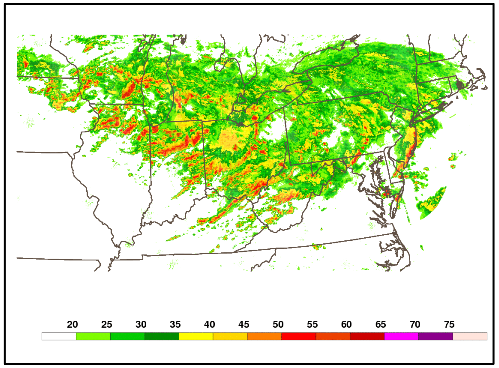






120630/0000 72403 IAD CAPV: 5902 CINV: −11
130613/1200 72403 IAD CAPV: 871 CINV: −201
100
150
200
250
300
400
500
700
850
925
1000
−40
−30
−20
−10
0
10
20
30
40





29–30 June 2012	**12–13 June 2013**
Zonally oriented instability corridor	Meridionally oriented instability corridor
Weak forcing for ascent (frontogenesis and low-level WAA) along east/west oriented surface boundary	Strong forcing for ascent (isentropic lift) associated with surface cyclone ahead of upper-level trough
Crossed Appalachians due to strong cold pool (~9 hPa) and extreme lee instability	Largely failed to cross Appalachians due to weak cold pool (~3 hPa) and moderate lee instability
Persistent weakly forced large-scale pattern through life cycle	Deepening upper-level trough through life cycle

Science issues

- Role of Rockies in derecho formation (e.g., lee troughs and upslope flow)

- Dynamic and thermodynamic processes associated with elevated to surface-based transitions

- Role of Appalachians in MCSs reaching the Atlantic Coast

- Impact of increasing synoptic-scale forcing on derecho maintenance and severity (June 2013 progressive derecho)

Forecast issues

- More accurate representation of planetary boundary layer temperatures, dew points, and winds
- Better understanding the extent to which cold pool depth and strength in a sheared environment controls MCS maintenance across the Appalachians
- Better understanding of the factors controlling MCS longevity in general

Questions?

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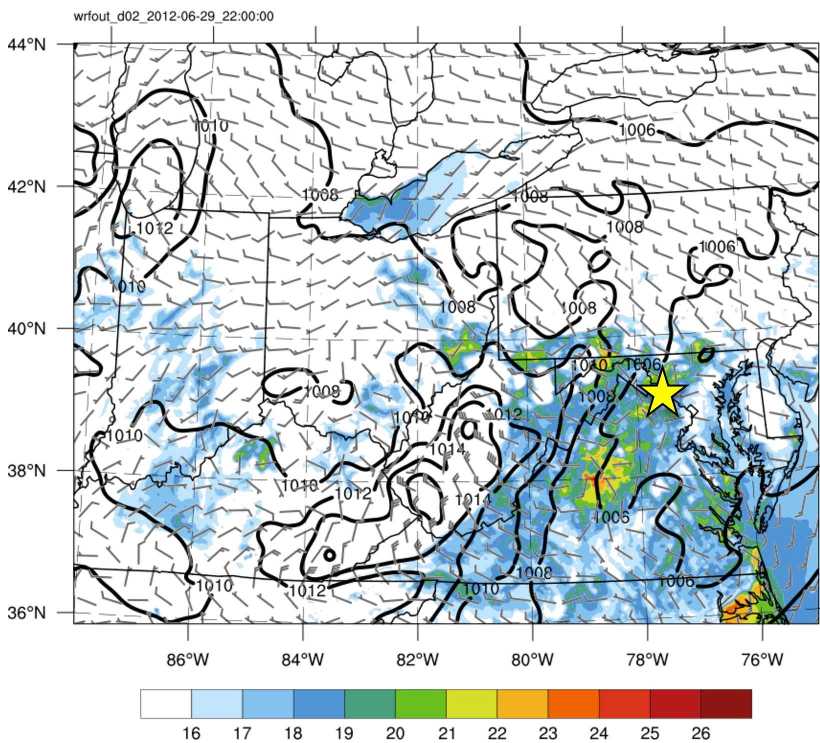
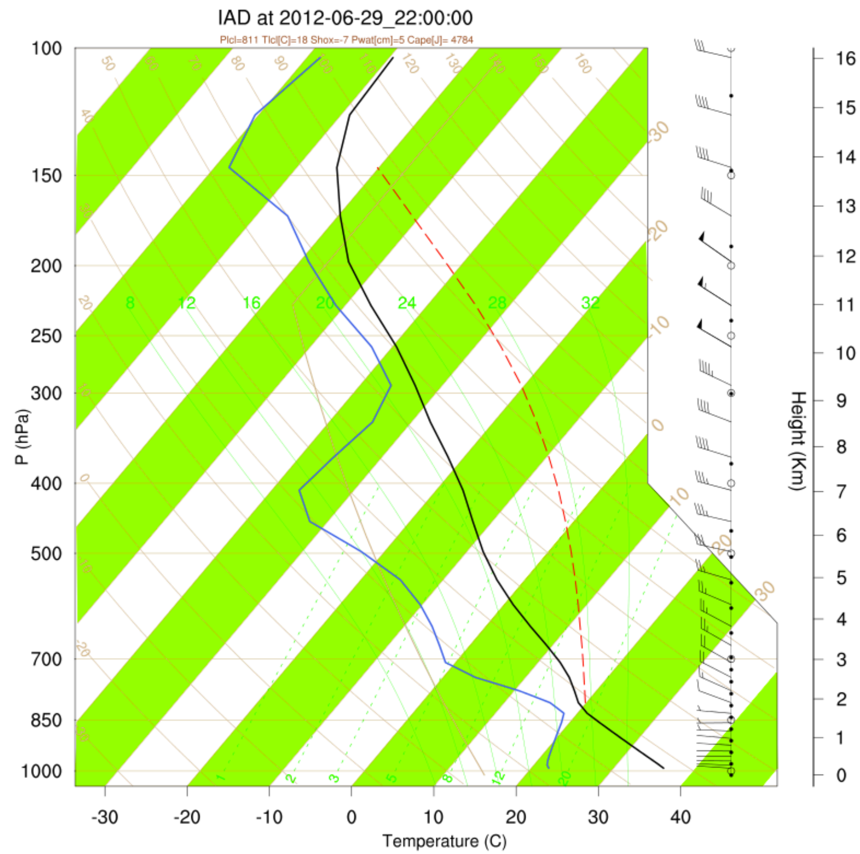
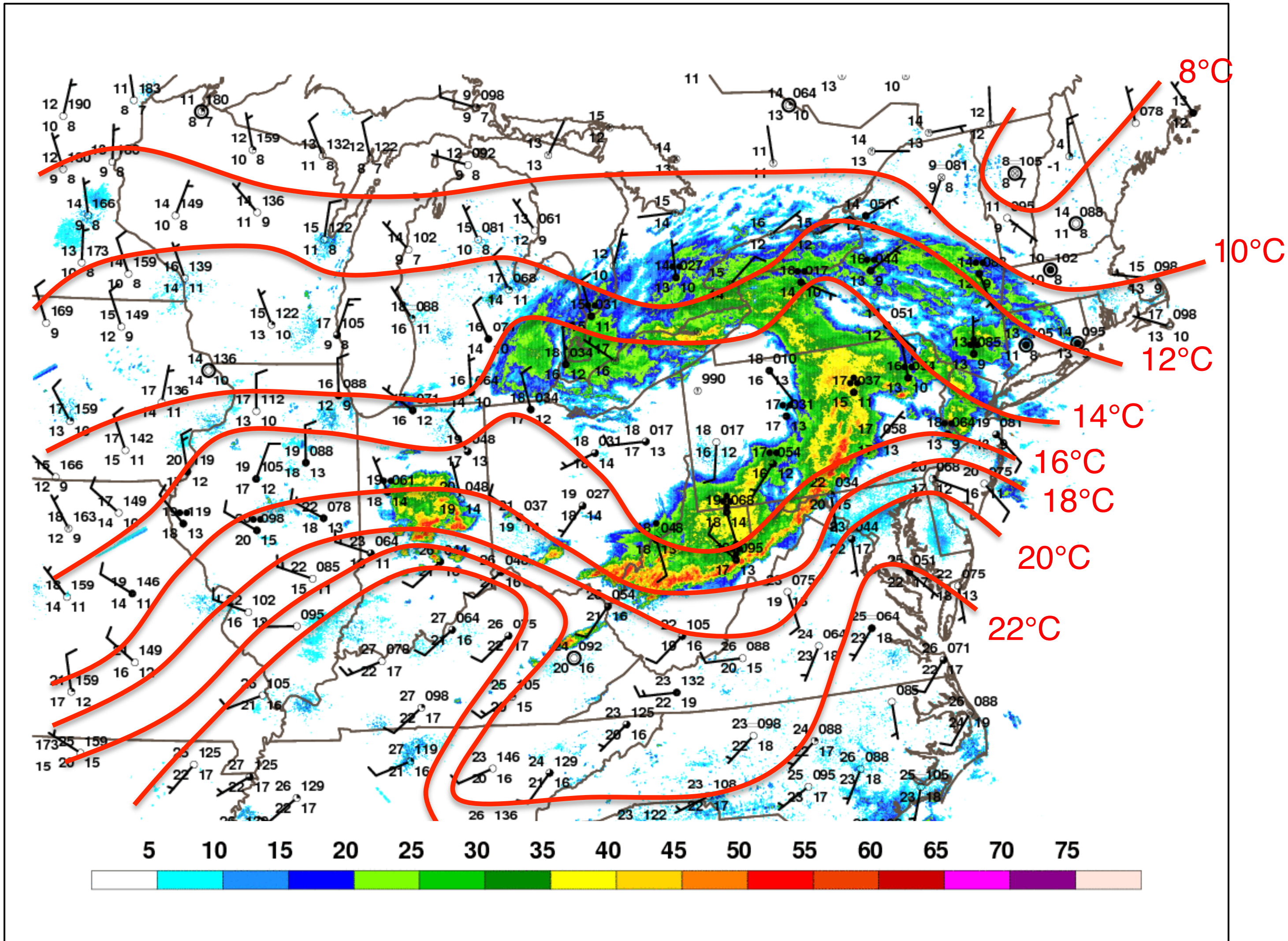
Extra

WRF IAD Sounding, Surface Mixing Ratio, Winds, and Sea-level Pressure

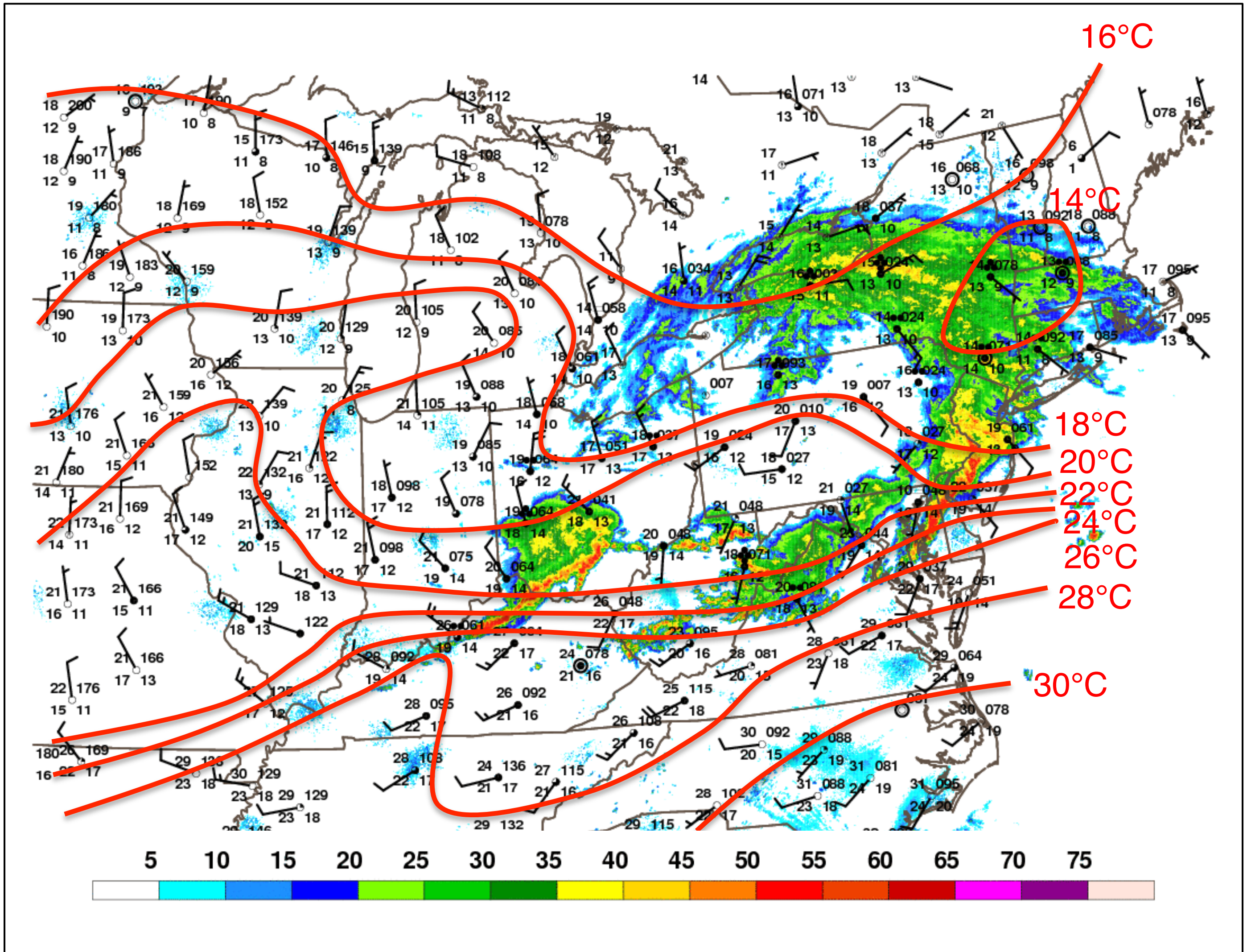


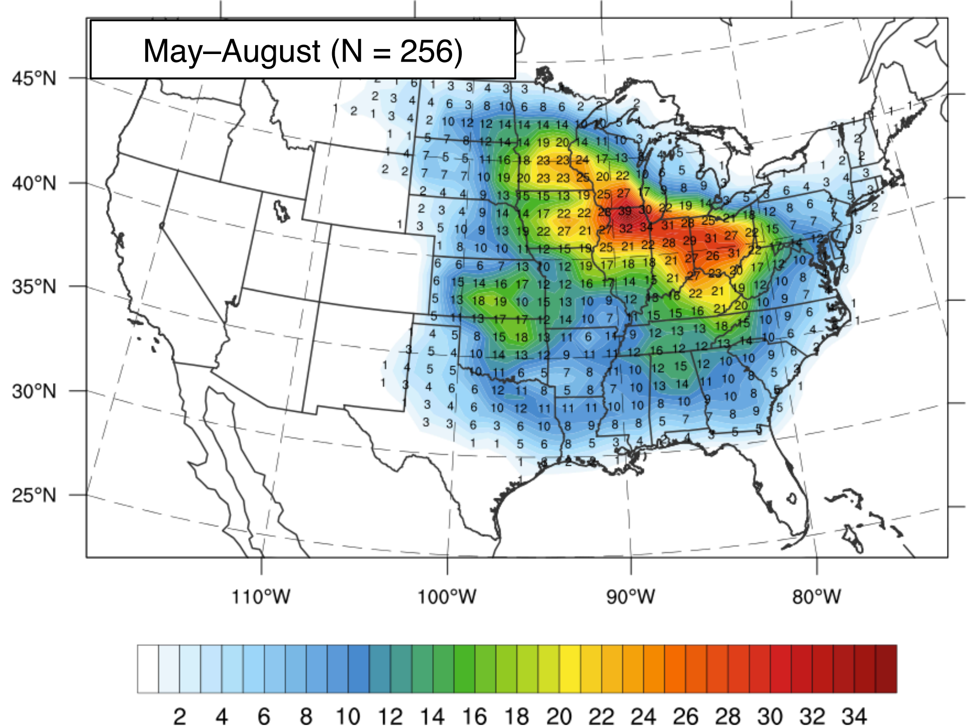


Composite Reflectivity, Surface Observations, and Hand-Analyzed Surface Temperature 1100 UTC 13 June 2013



Composite Reflectivity, Surface Observations, and Hand-Analyzed Surface Temperature 1400 UTC 13 June 2013





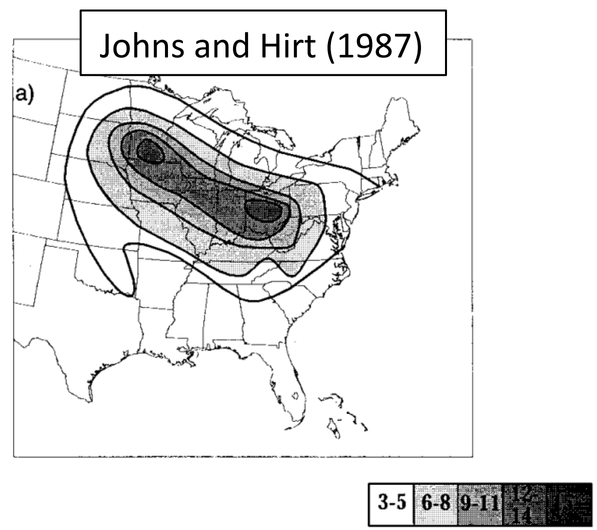
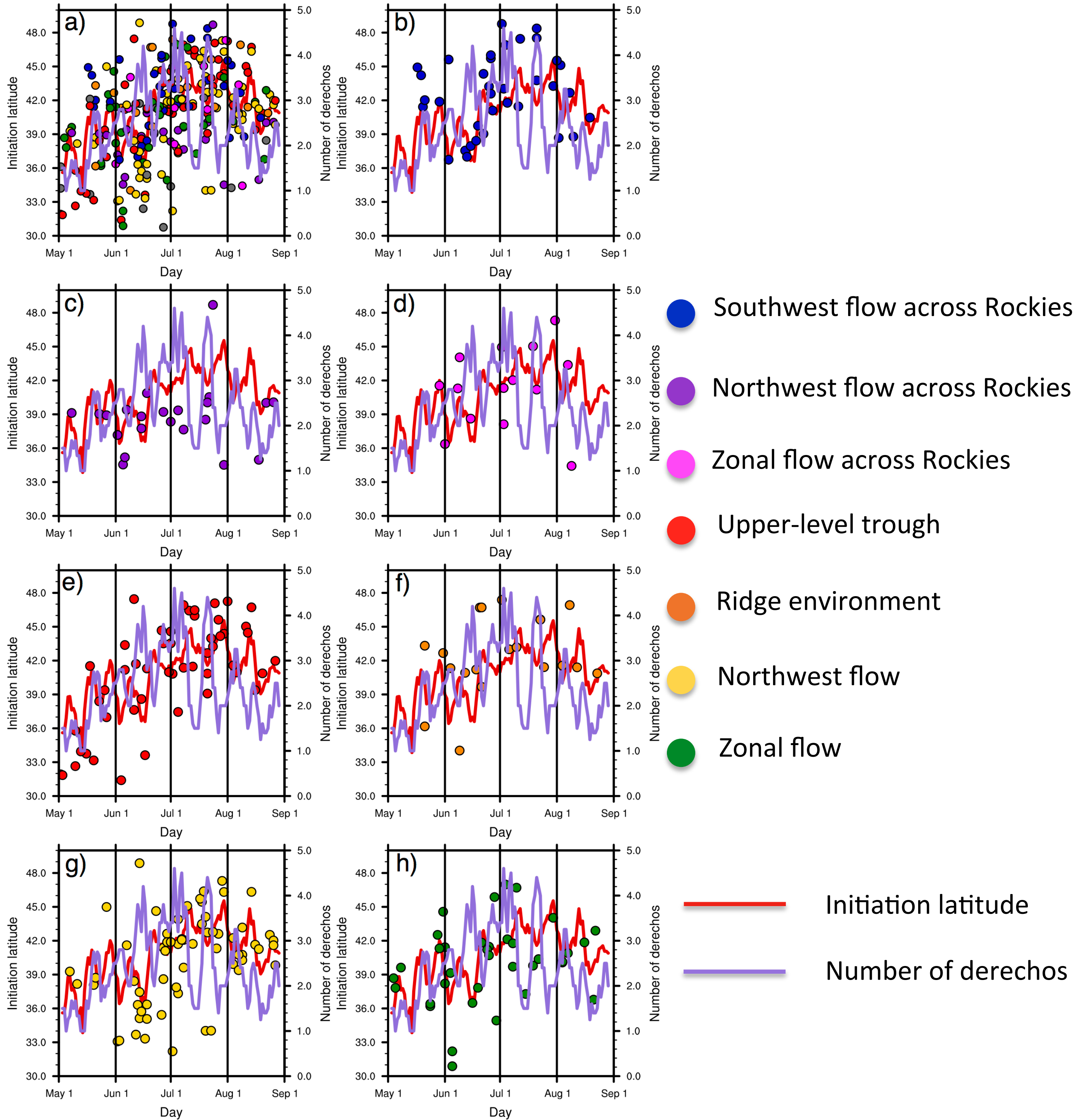


FIG. 1. (a) Total number of derechos occurring during the warm season, 1980–83 (JH87). (b) Total number of derechos occurring during the warm season, 1986–95.

Derecho initiation latitude through the warm season



Derecho initiation longitude through the day