An Observational Analysis of Potential Terrain Influences on Tornado Behavior

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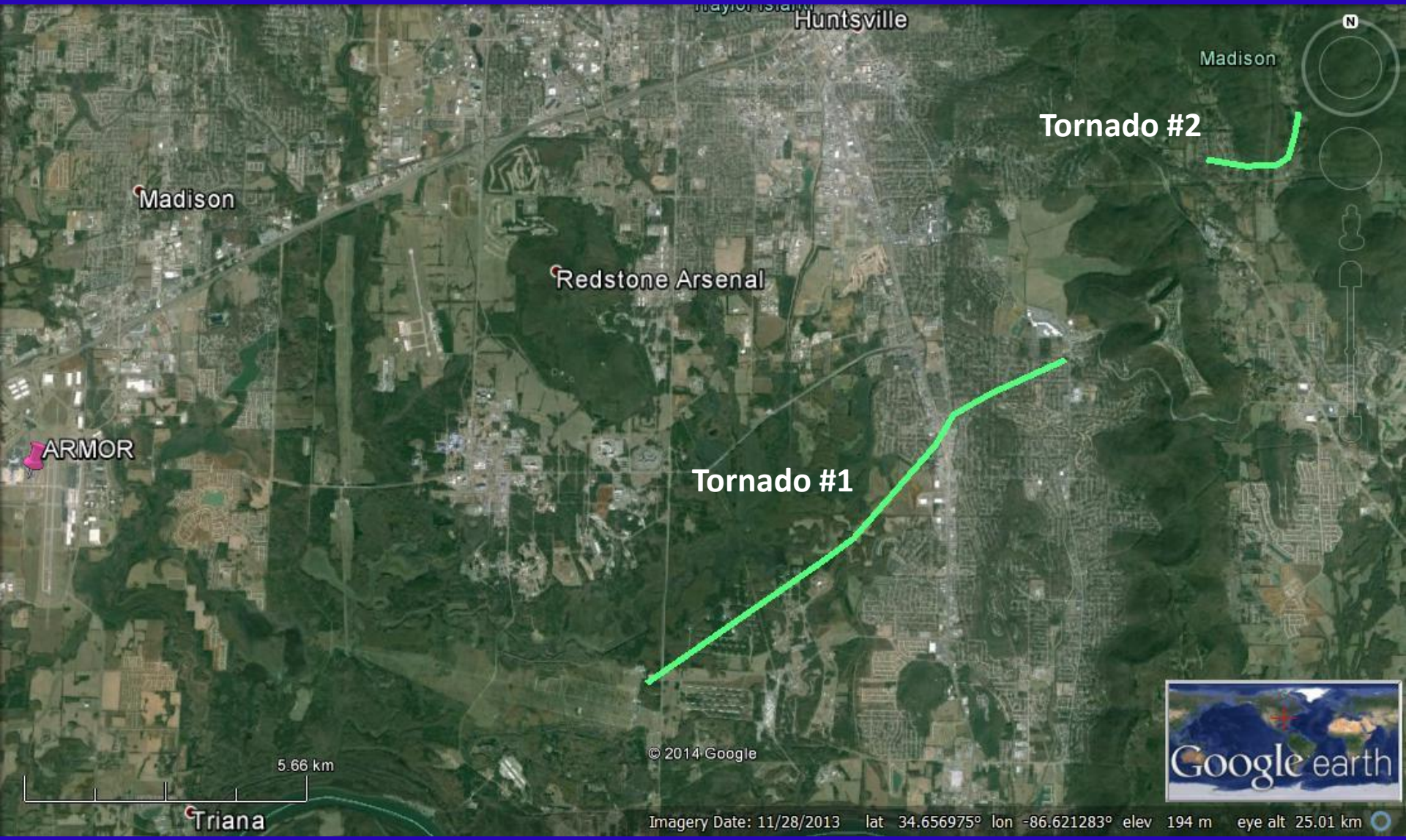
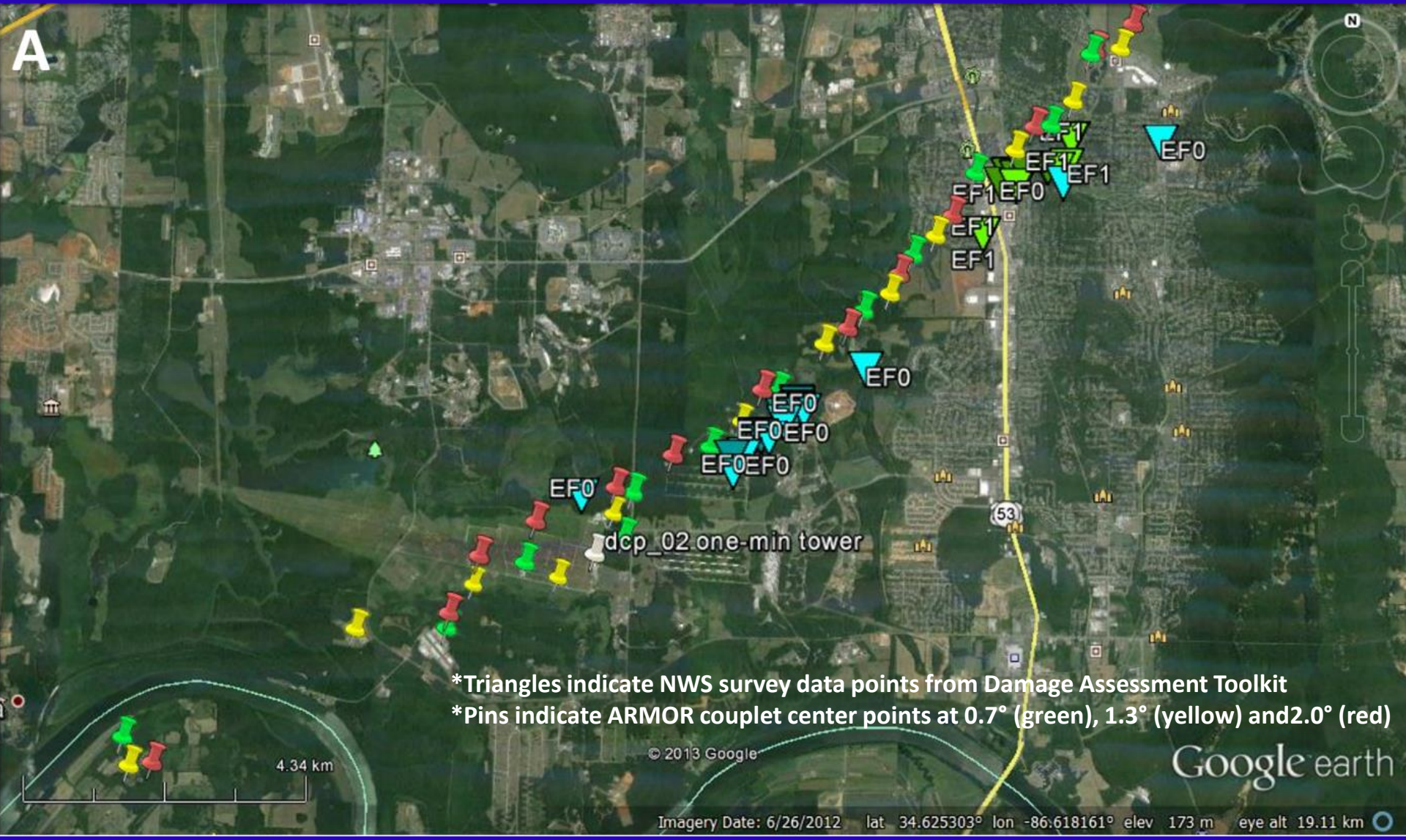
Does terrain affect tornado behavior?

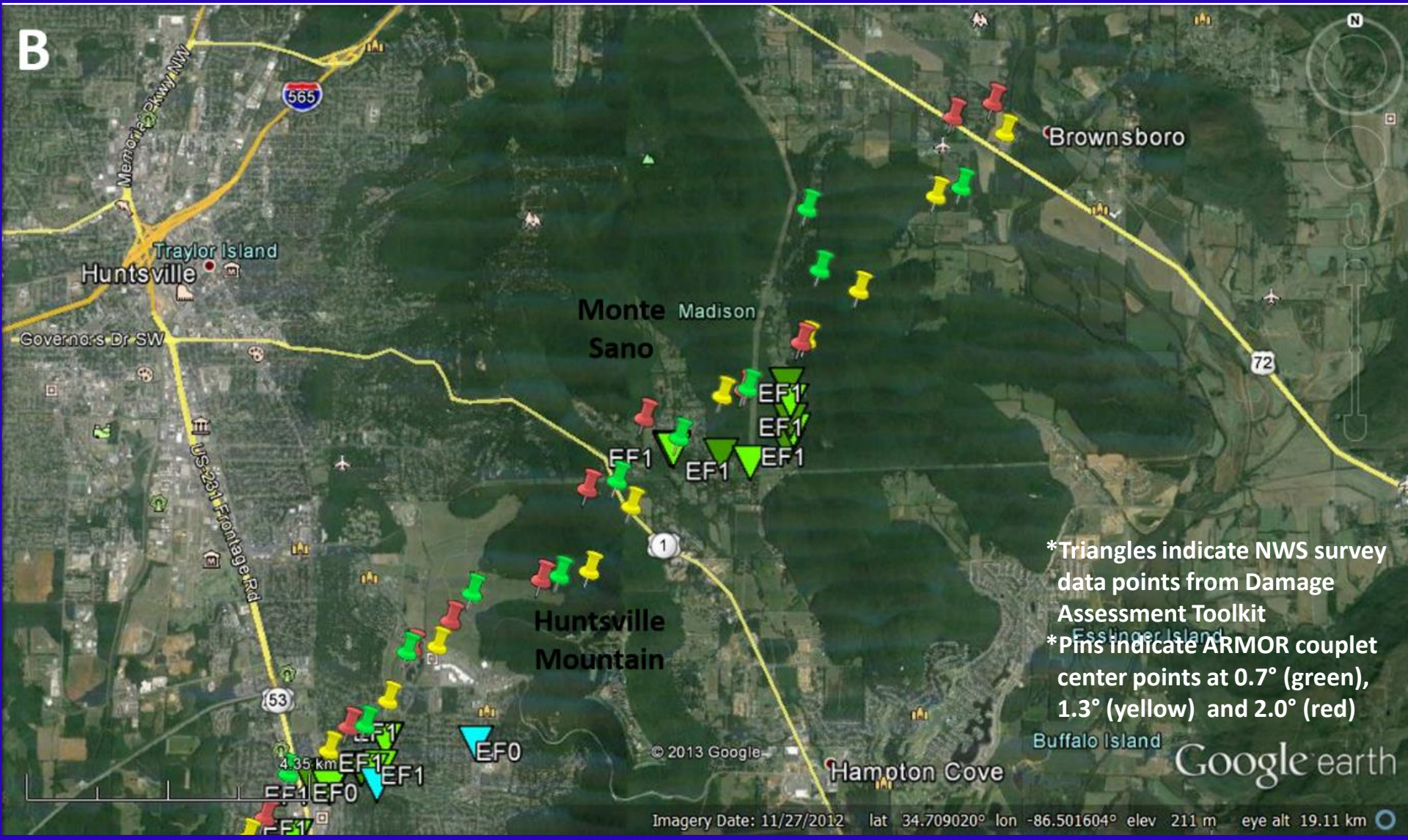
- Some past work has shown terrain influences in other cases (Fujita 1989, Forbes 1998, Seimon and Bosart 2004, LaPenta et al. 2005, Bosart et al. 2006, Gaffin 2012, Shamburger 2012, Karstens et al. 2013)
- Limited numerical simulations on supercells and tornadoes in the presence of significant terrain (Markowski and Dotzek 2011, Lewellen 2012)
- Let’s consider the following cases...

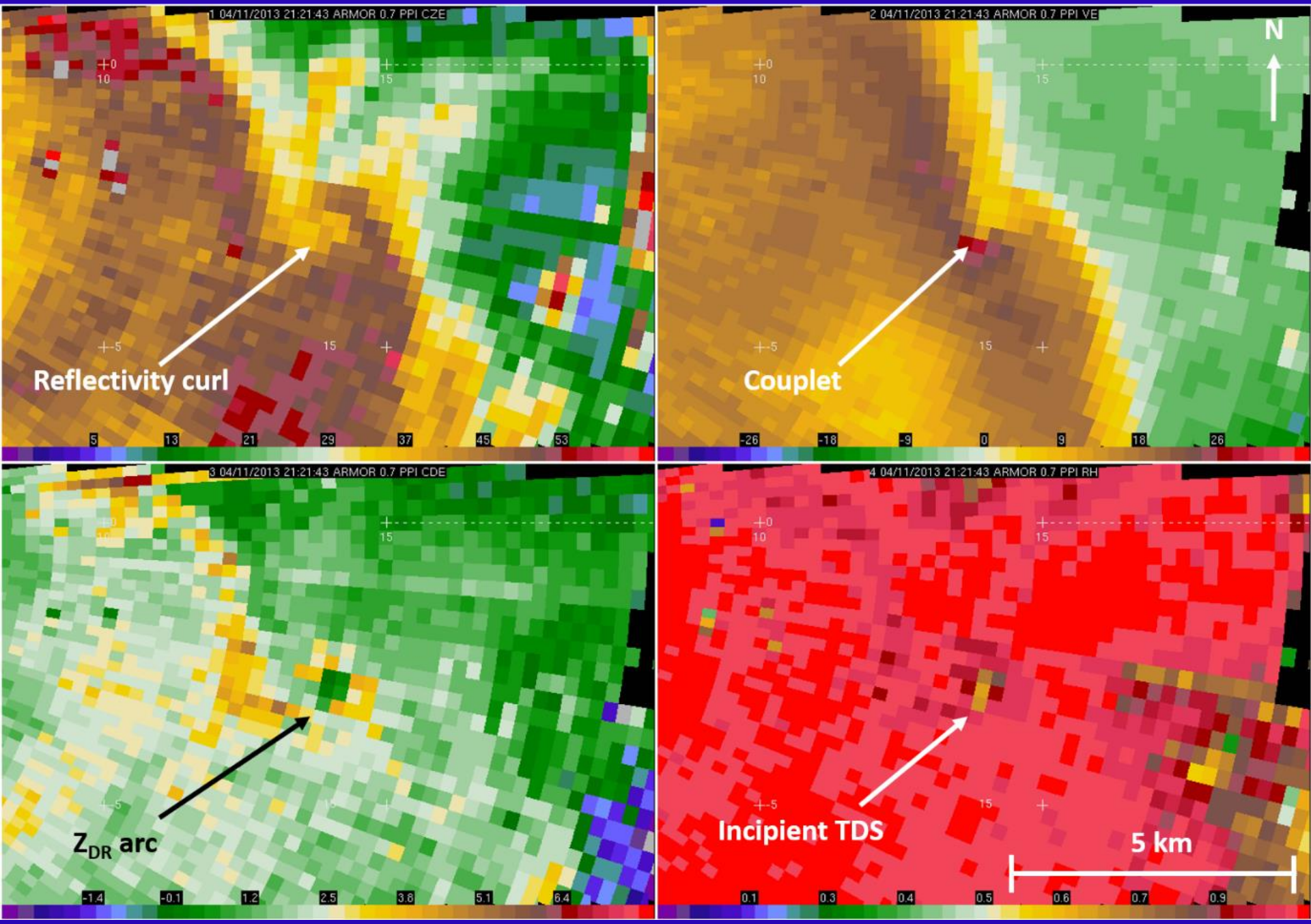
11 April 2013: Huntsville, AL

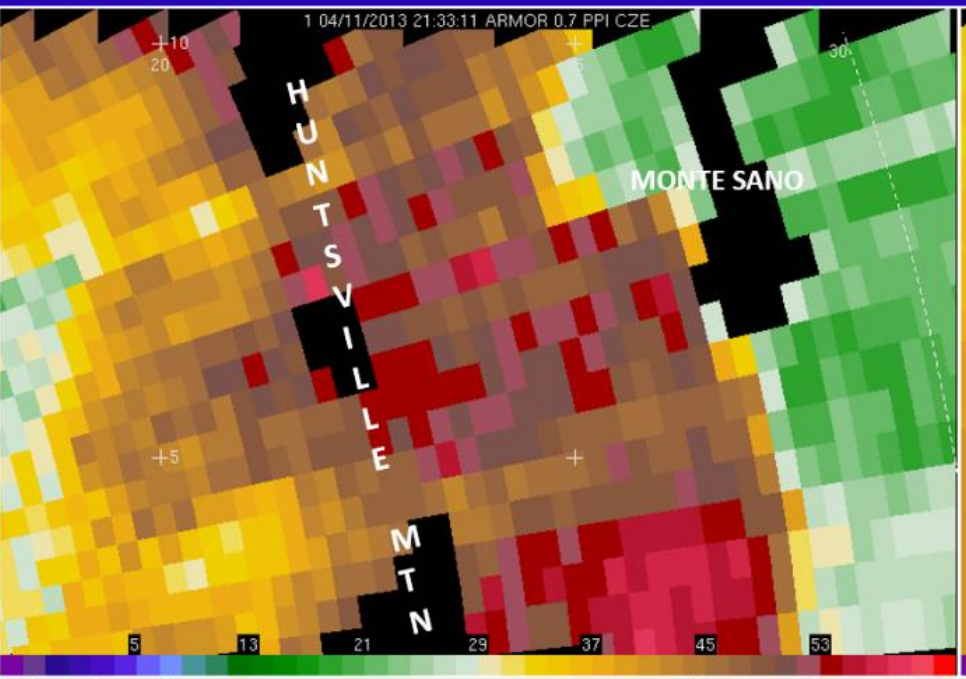
- QLCS mesovortex formed rapidly on the south side of Redstone Arsenal
- A pair of EF1 tornadoes were produced by the mesovortex across the southern and eastern portions of Huntsville
- Entire evolution was within 25 km of ARMOR, which was sampling at 0.7° (lowest tilt) approximately every 60-80 seconds

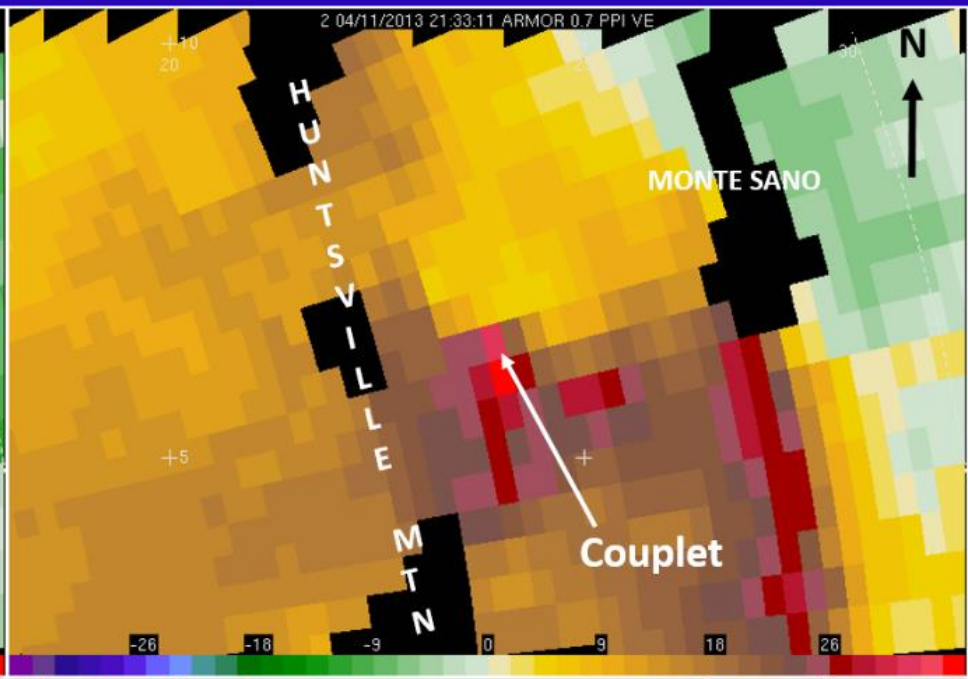

Huntsville
Madison
Tornado #2
Madison
Redstone Arsenal
ARMOR
Tornado #1
© 2014 Google
5.66 km
Triana
Google earth
Imagery Date: 11/28/2013 lat 34.656975° lon -86.621283° elev 194 m eye alt 25.01 km

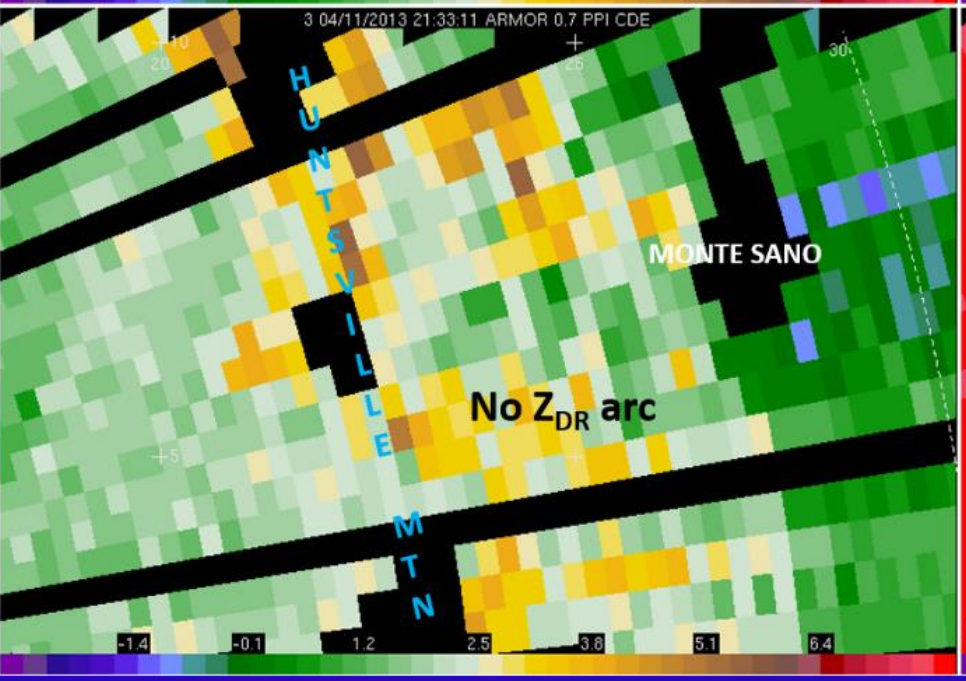

A
EF0
EF1
EF1
EF1
EF1 EF0
EF1
EF1
EF0
EF0
EF0 EF0
EF0 EF0
EF0
dcp_02 one-min tower
53
*Triangles indicate NWS survey data points from Damage Assessment Toolkit
*Pins indicate ARMOR couplet center points at 0.7° (green), 1.3° (yellow) and2.0° (red)
4.34 km
© 2013 Google
Google earth
Imagery Date: 6/26/2012 lat 34.625303° lon -86.618161° elev 173 m eye alt 19.11 km

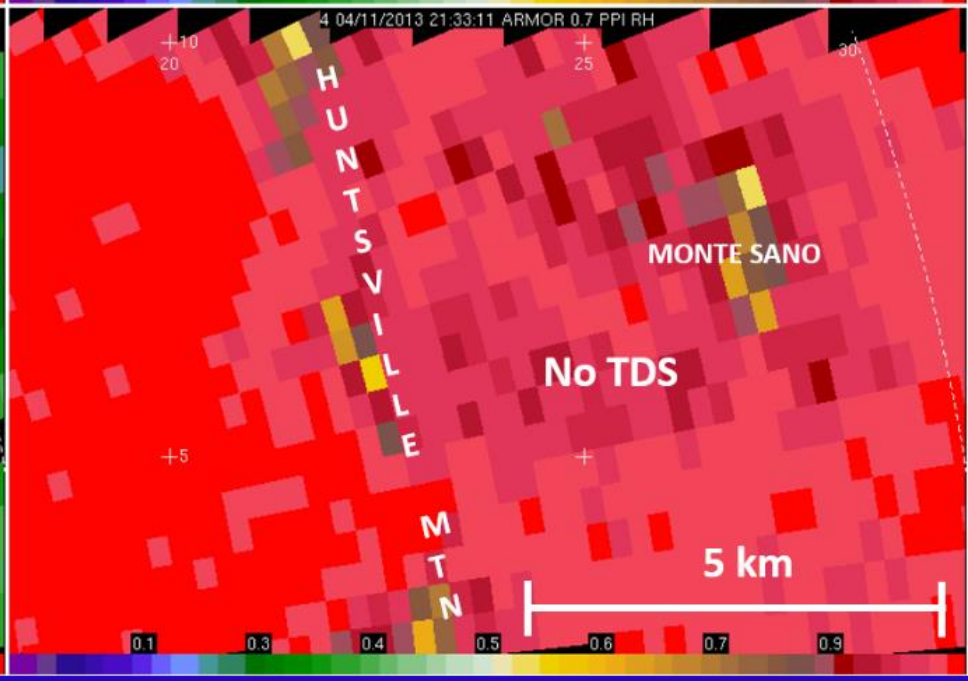

B
Brownsboro
Traylor Island
Huntsville
Governors Dr SW
Monte Sano
Madison
Huntsville Mountain
Buffalo Island
Hampton Cove
Memorial Pkwy NW
US-231 Frontage Rd
565
72
53
EF1
EF0
4.35 km
*Triangles indicate NWS survey data points from Damage Assessment Toolkit
*Pins indicate ARMOR couplet center points at 0.7° (green), 1.3° (yellow) and 2.0° (red)
© 2013 Google
Google earth
Imagery Date: 11/27/2012 lat 34.709020° lon -86.501604° elev 211 m eye alt 19.11 km

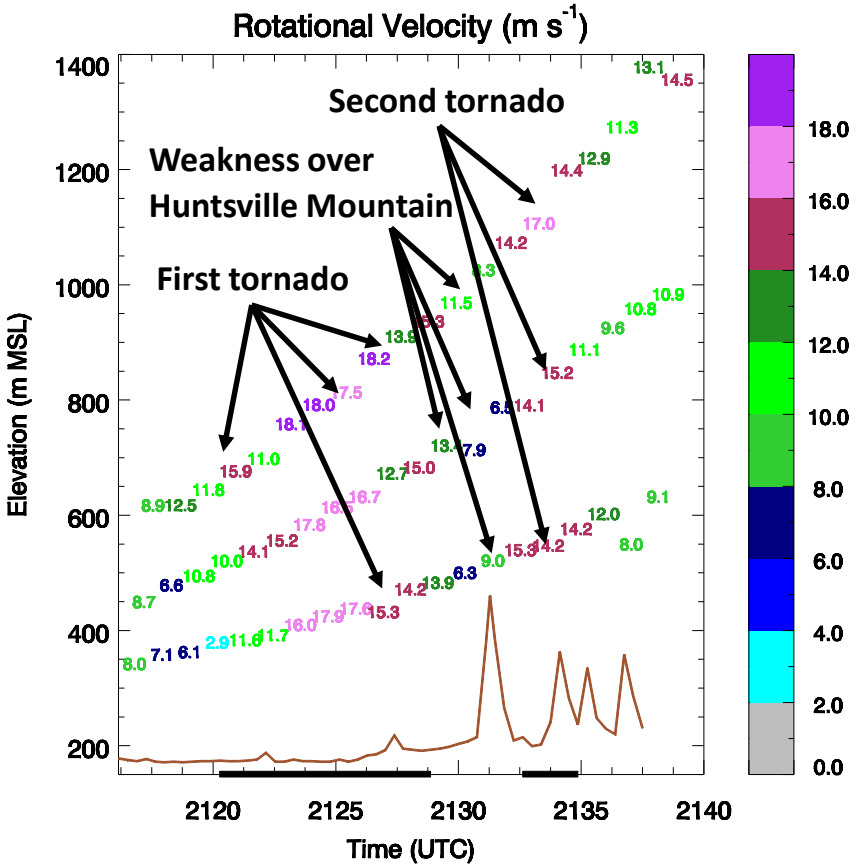

1 04/11/2013 21:21:43 ARMOR 0.7 PPI CZE
Reflectivity curl
5 13 21 29 37 45 53
2 04/11/2013 21:21:43 ARMOR 0.7 PPI VE
N
Couplet
-26 -18 -9 0 9 18 26
3 04/11/2013 21:21:43 ARMOR 0.7 PPI CDE
Z_{DR} arc
-1.4 -0.1 1.2 2.5 3.8 5.1 6.4
4 04/11/2013 21:21:43 ARMOR 0.7 PPI RH
Incipient TDS
5 km
0.1 0.3 0.4 0.5 0.6 0.7 0.9

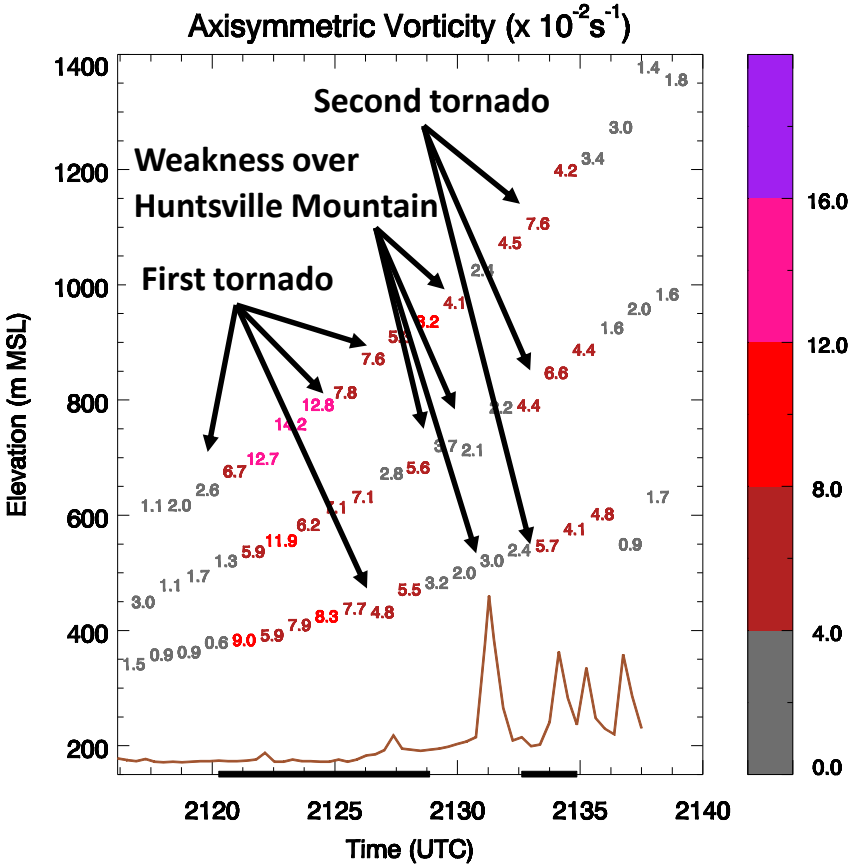

1 04/11/2013 21:33:11 ARMOR 0.7 PPI CZE
HUNTSVILLE
MTN
MONTE SANO
5
13
21
29
37
45
53


2 04/11/2013 21:33:11 ARMOR 0.7 PPI VE
HUNTSVILLE
MTN
MONTE SANO
N
Couplet
-26
-18
-9
0
9
18
26


3 04/11/2013 21:33:11 ARMOR 0.7 PPI CDE
HUNTSVILLE
MTN
MONTE SANO
No Z_{DR} arc
-1.4
-0.1
1.2
2.5
3.6
5.1
6.4


4 04/11/2013 21:33:11 ARMOR 0.7 PPI RH
HUNTSVILLE
MTN
MONTE SANO
No TDS
5 km
0.1
0.3
0.4
0.5
0.6
0.7
0.9


Rotational Velocity (m s-1)
Second tornado
Weakness over
Huntsville Mountain
First tornado
Elevation (m MSL)
Time (UTC)
1400
1200
1000
800
600
400
200
2120
2125
2130
2135
2140
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0


Axisymmetric Vorticity (x 10-2s-1)
Second tornado
Weakness over
Huntsville Mountain
First tornado
Elevation (m MSL)
Time (UTC)
1400
1200
1000
800
600
400
200
2120
2125
2130
2135
2140
16.0
12.0
8.0
4.0
0.0

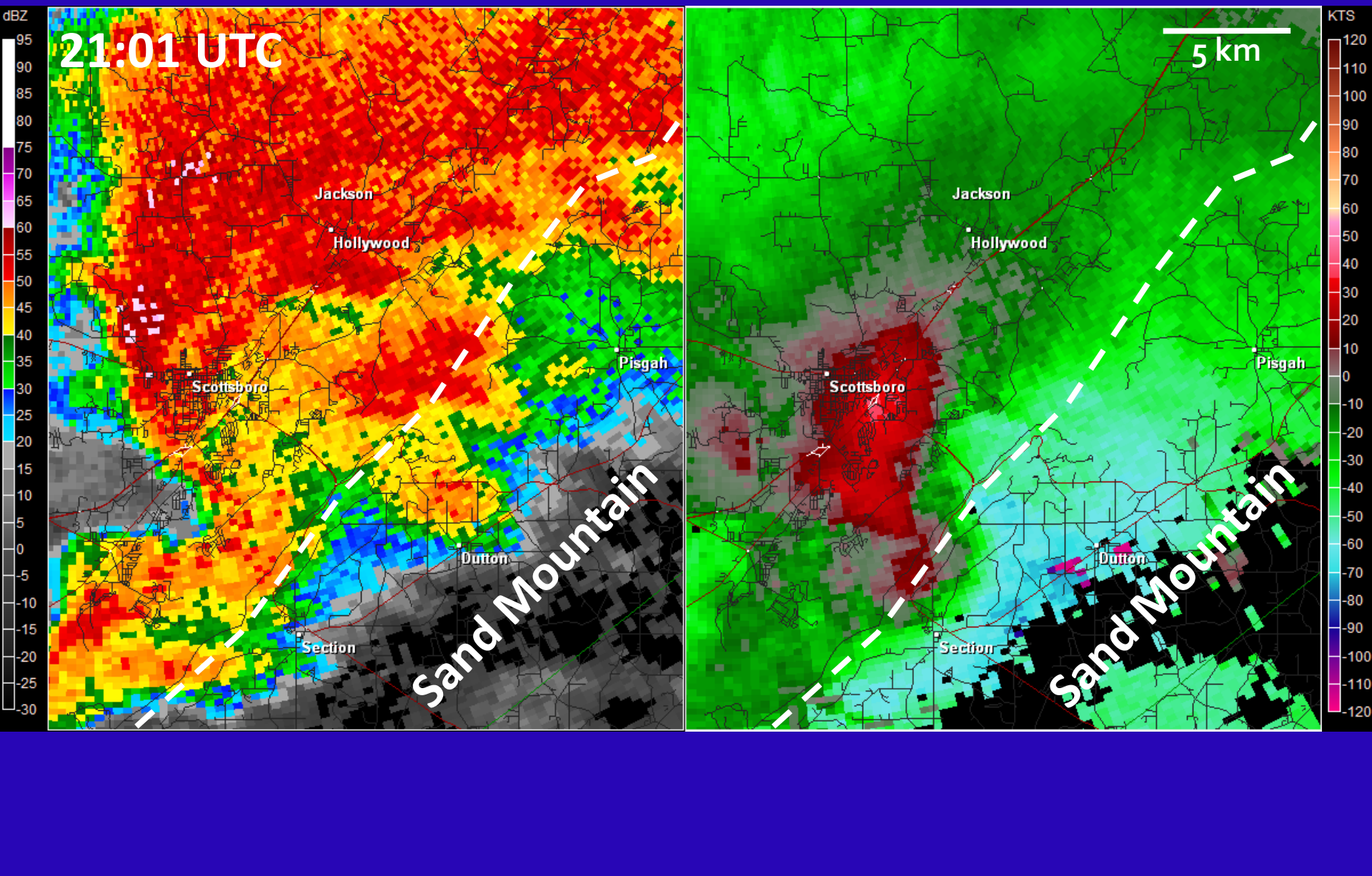
Huntsville observations

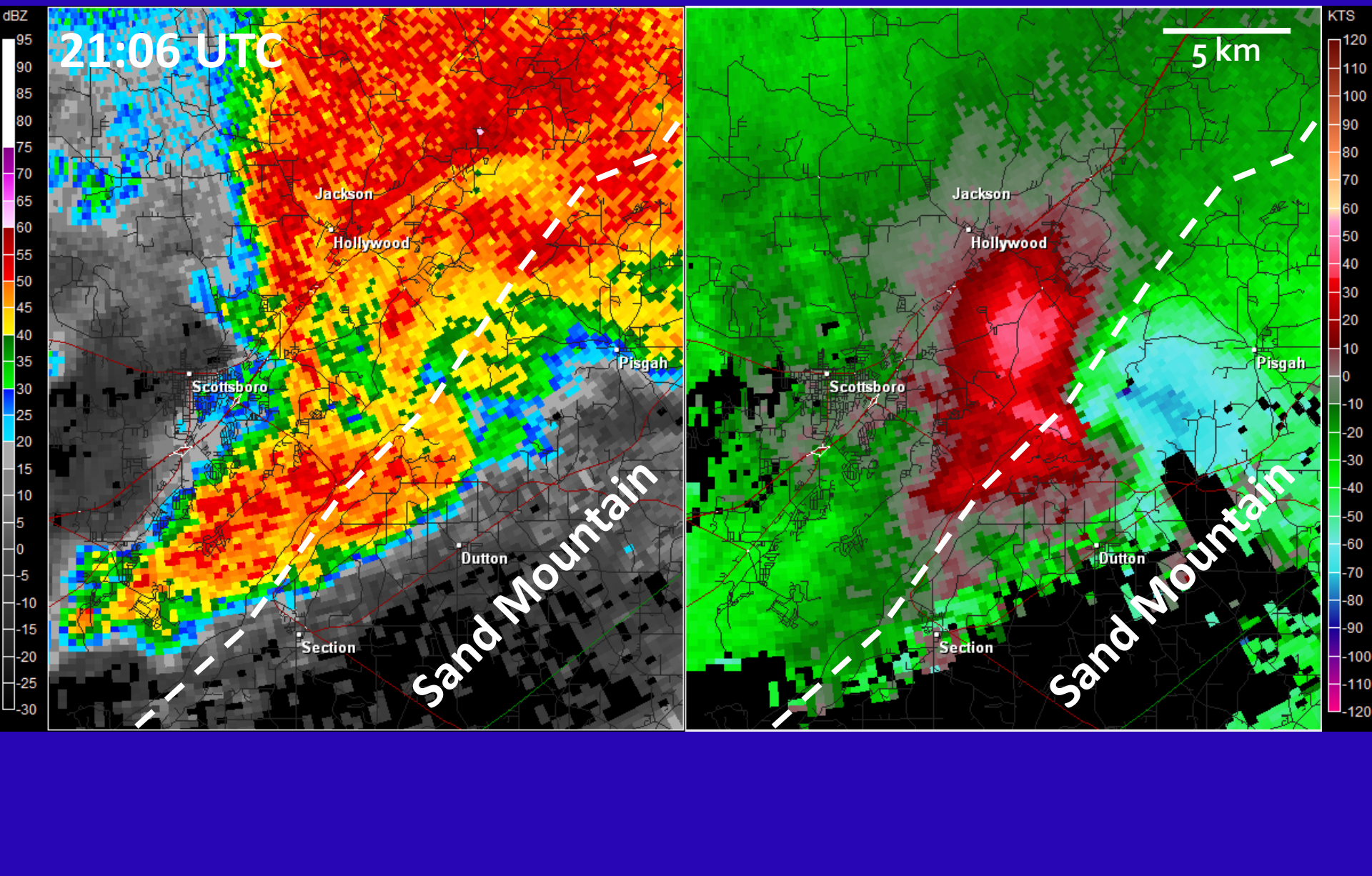
- The two tornadoes were separated by Huntsville Mountain, a 250-m relief over the Tennessee Valley floor
- First tornado had all the characteristics of a typical tornado signature from ARMOR
  - Velocity couplet
  - Dual-pol TDS
  - Z_{DR} arc and Z_{DR}/K_{DP} separation
- Only a velocity couplet apparent with second tornado, despite producing slightly more intense-appearing damage

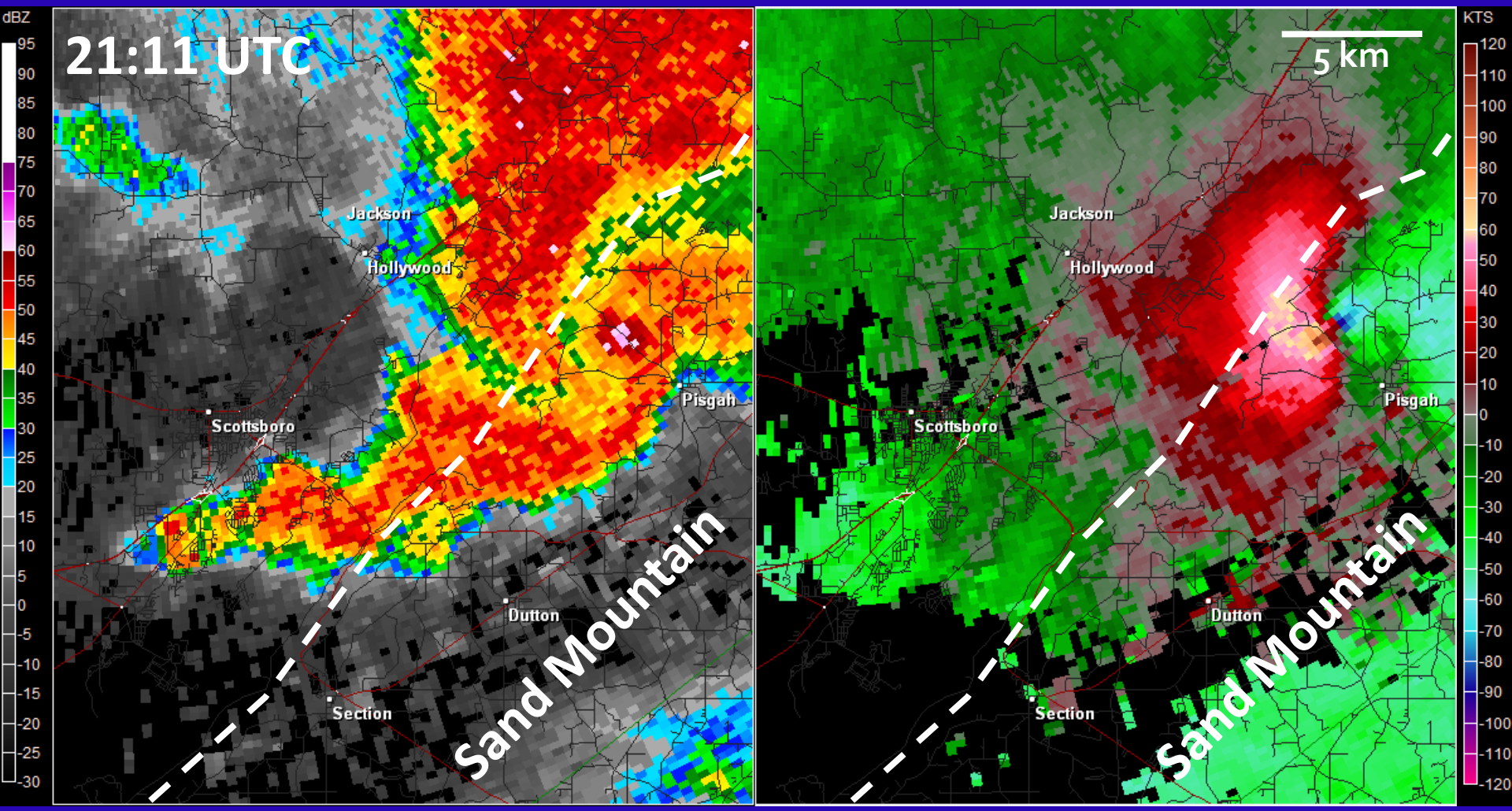
27 April 2011: Pisgah, AL (#2)

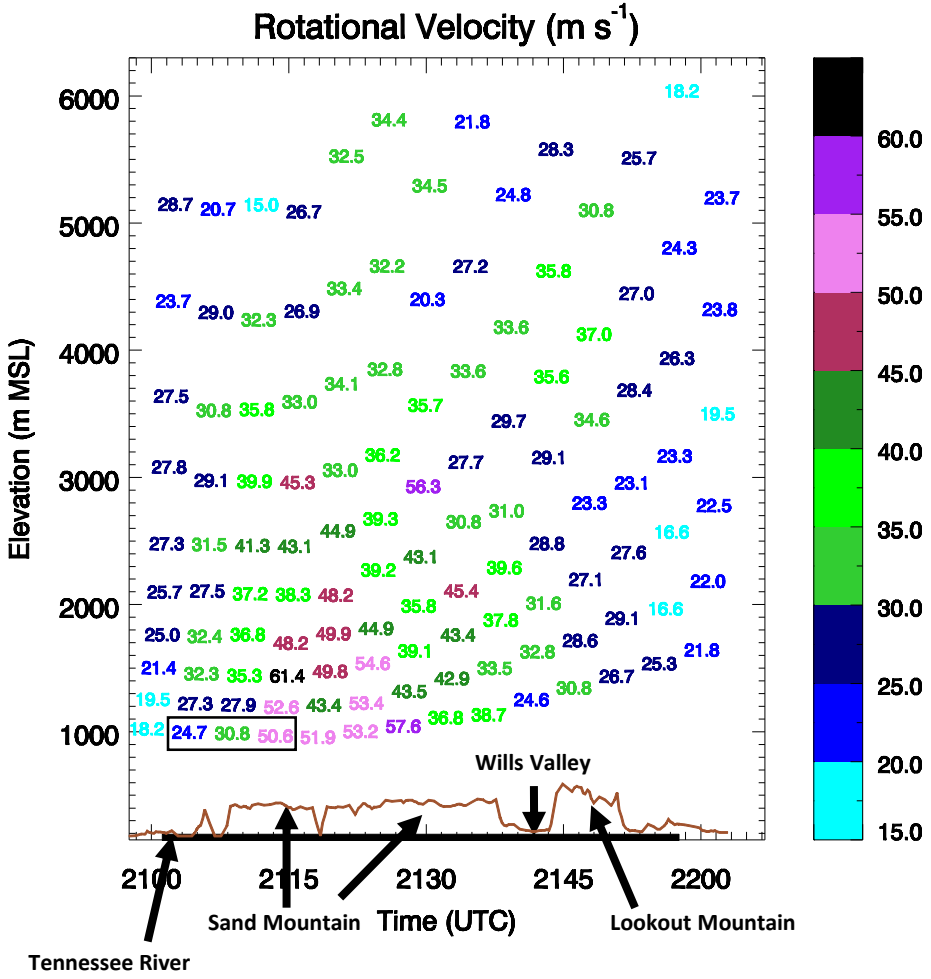
- 2nd tornado from the infamous Cullman supercell during the afternoon round of violent tornadoes
- High-end EF4 moved 75.0 km and was up to 1600 m wide
- Killed 14 people (12 in AL, 2 in GA)
- Second of two tornadoes to strike the same portion of Jackson/DeKalb Counties – first tornado struck during the morning QLCS

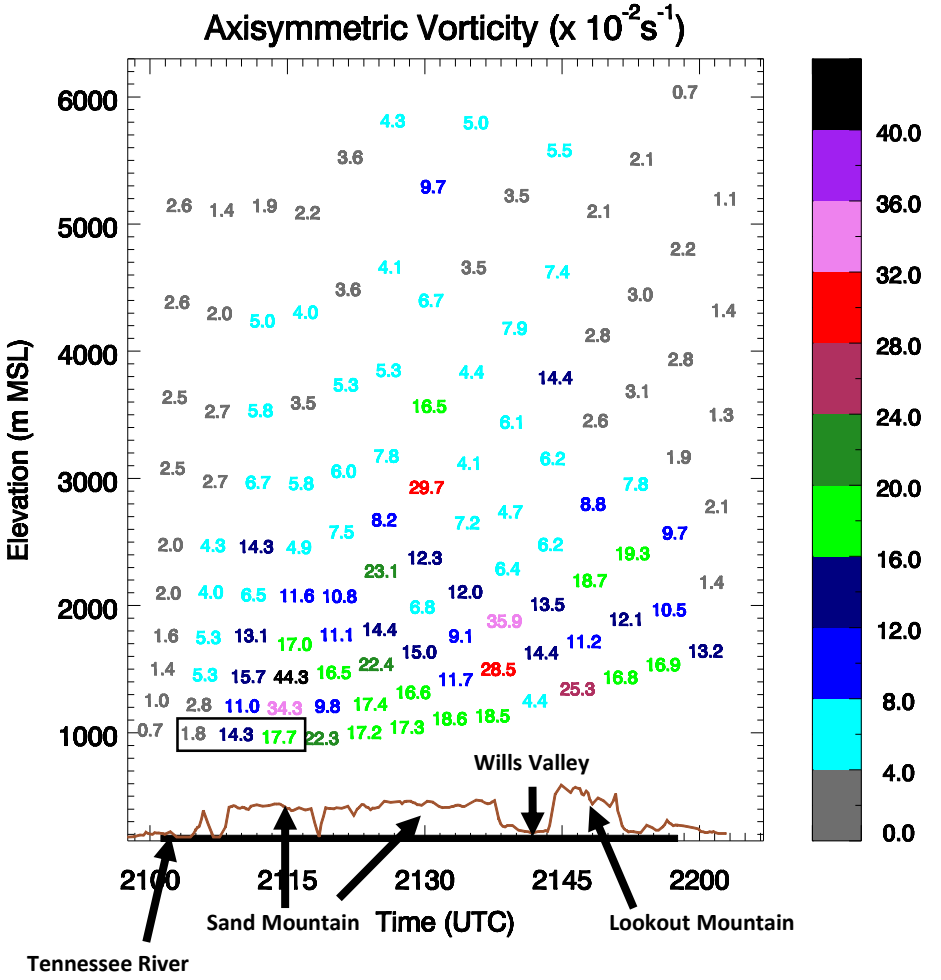

Tennessee
Alabama
Georgia
Chattanooga
Pisgah Tornado Ends
Pisgah Tornado Begins
Scottsboro
194 m
0 m
0.4%
27 km
Dalton
Image Landsat
© 2014 Google
Google earth
Imagery Date: 4/9/2013 lat 34.776821° lon -85.521269° elev 317 m eye alt 111.45 km
Graph: Min, Avg, Max Elevation: 183, 355, 557 m
Range Totals: Distance: 83.9 km
Elev Gain/Loss: 2042 m, -2019 m
Max Slope: 30.9%, -30.2%
Avg Slope: 4.1%, -4.0%
557 m
400 m
300 m
183 m
Wills Valley
Sand Mountain
194 m
0.4%
0 m
10 km
20 km
30 km
40 km
50 km
60 km
70 km
83.9 km

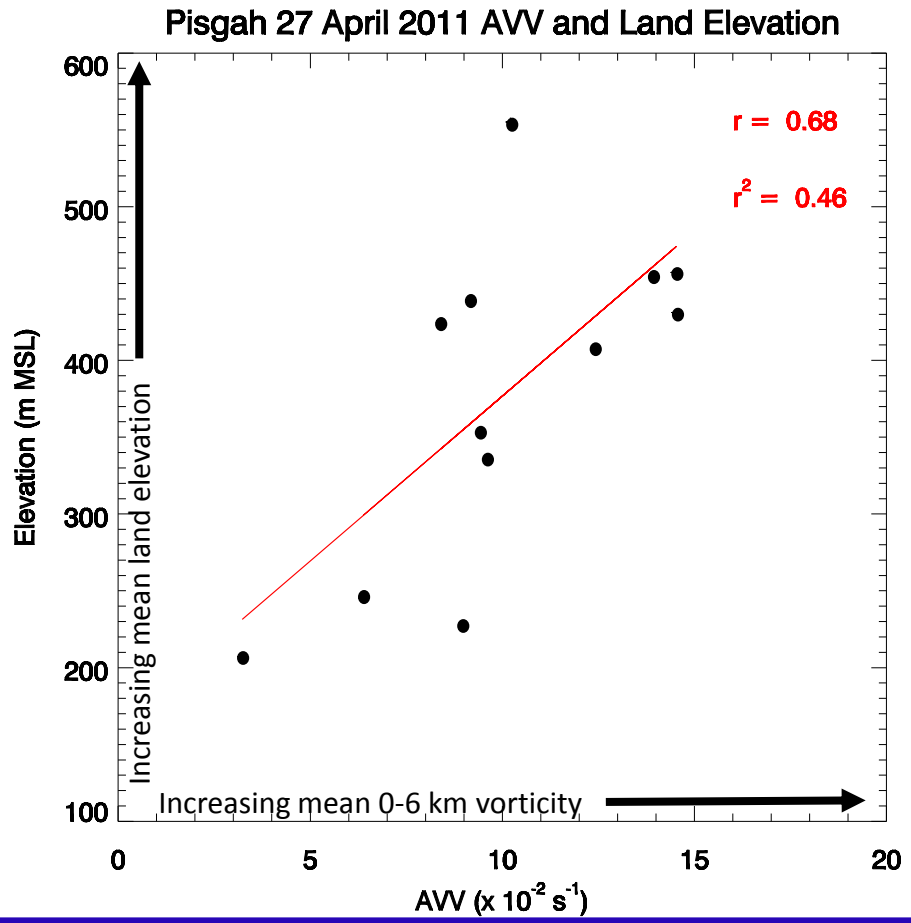

21:01 UTC
dBZ
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
Jackson
Hollywood
Scottsboro
Pisgah
Dutton
Section
Sand Mountain
5 km
KTS
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120

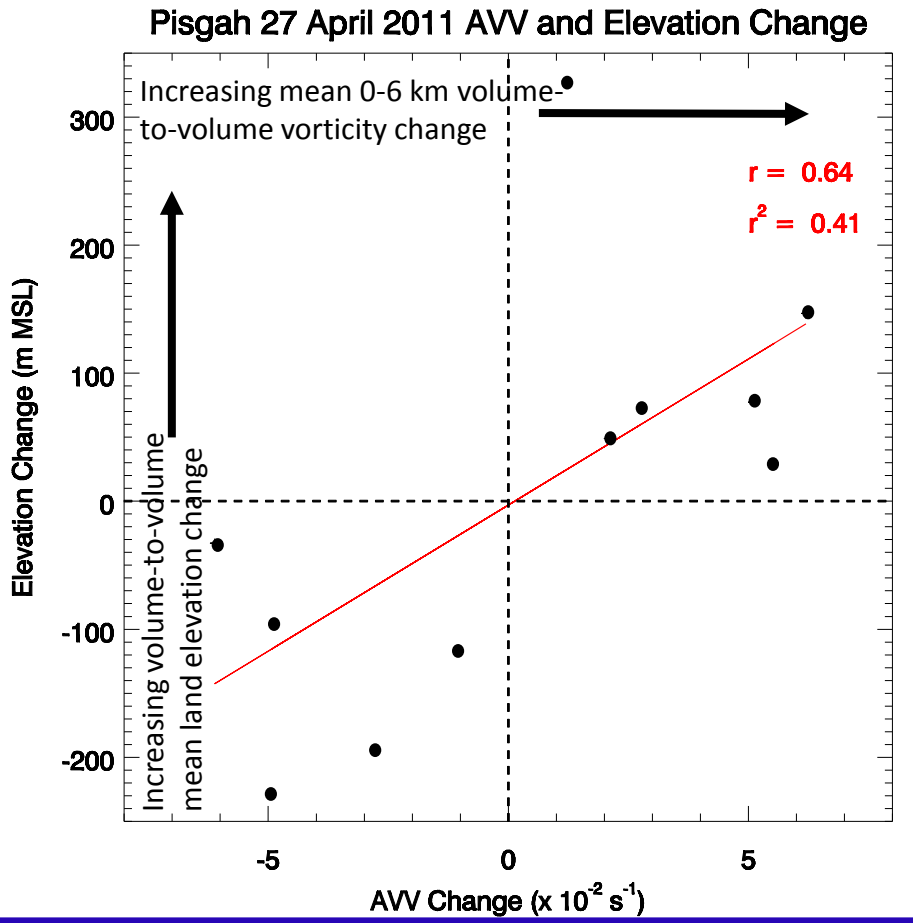

dBZ
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
21:06 UTC
Jackson
Hollywood
Pisgah
Scottsboro
Dutton
Section
Sand Mountain
5 km
KTS
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120


dBZ
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
21:11 UTC
Jackson
Hollywood
Scottsboro
Pisgah
Dutton
Section
Sand Mountain
5 km
KTS
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120


Rotational Velocity (m s-1)
Elevation (m MSL)
6000
5000
4000
3000
2000
1000
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
Wills Valley
2100
2115
2130
2145
2200
Sand Mountain
Time (UTC)
Lookout Mountain
Tennessee River


Axisymmetric Vorticity (x 10-2s-1)
Elevation (m MSL)
6000
5000
4000
3000
2000
1000
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
Wills Valley
2100
2115
2130
2145
2200
Sand Mountain
Time (UTC)
Lookout Mountain
Tennessee River


Pisgah 27 April 2011 AVV and Land Elevation
r = 0.68
r² = 0.46
Increasing mean land elevation
Increasing mean 0-6 km vorticity
Elevation (m MSL)
AVV (x 10⁻² s⁻¹)
600
500
400
300
200
100
0
5
10
15
20

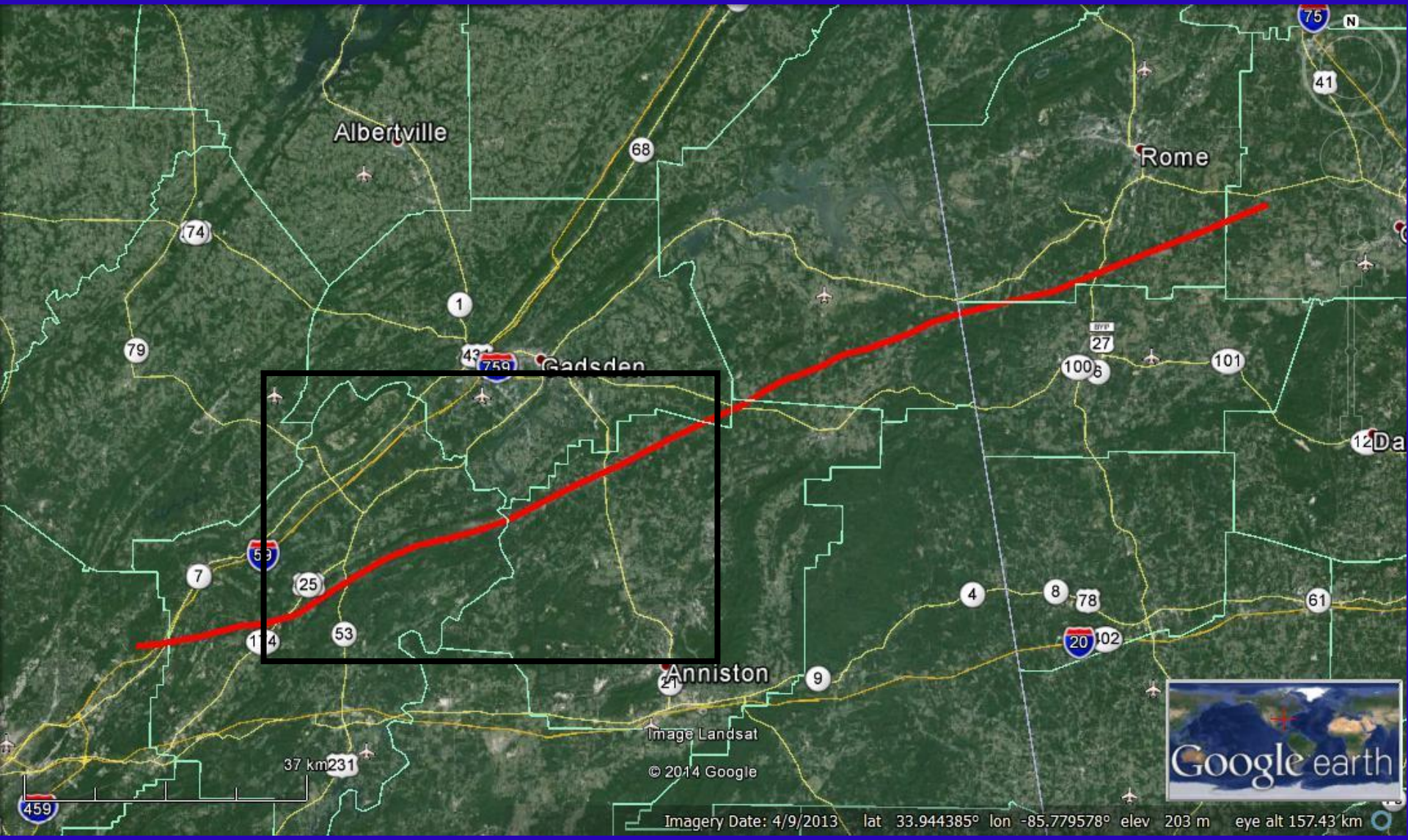

Pisgah 27 April 2011 AVV and Elevation Change
Increasing mean 0-6 km volume-to-volume vorticity change
r = 0.64
r² = 0.41
Increasing volume-to-volume mean land elevation change
Elevation Change (m MSL)
AVV Change (x 10⁻² s⁻¹)
300
200
100
0
-100
-200
-5
0
5

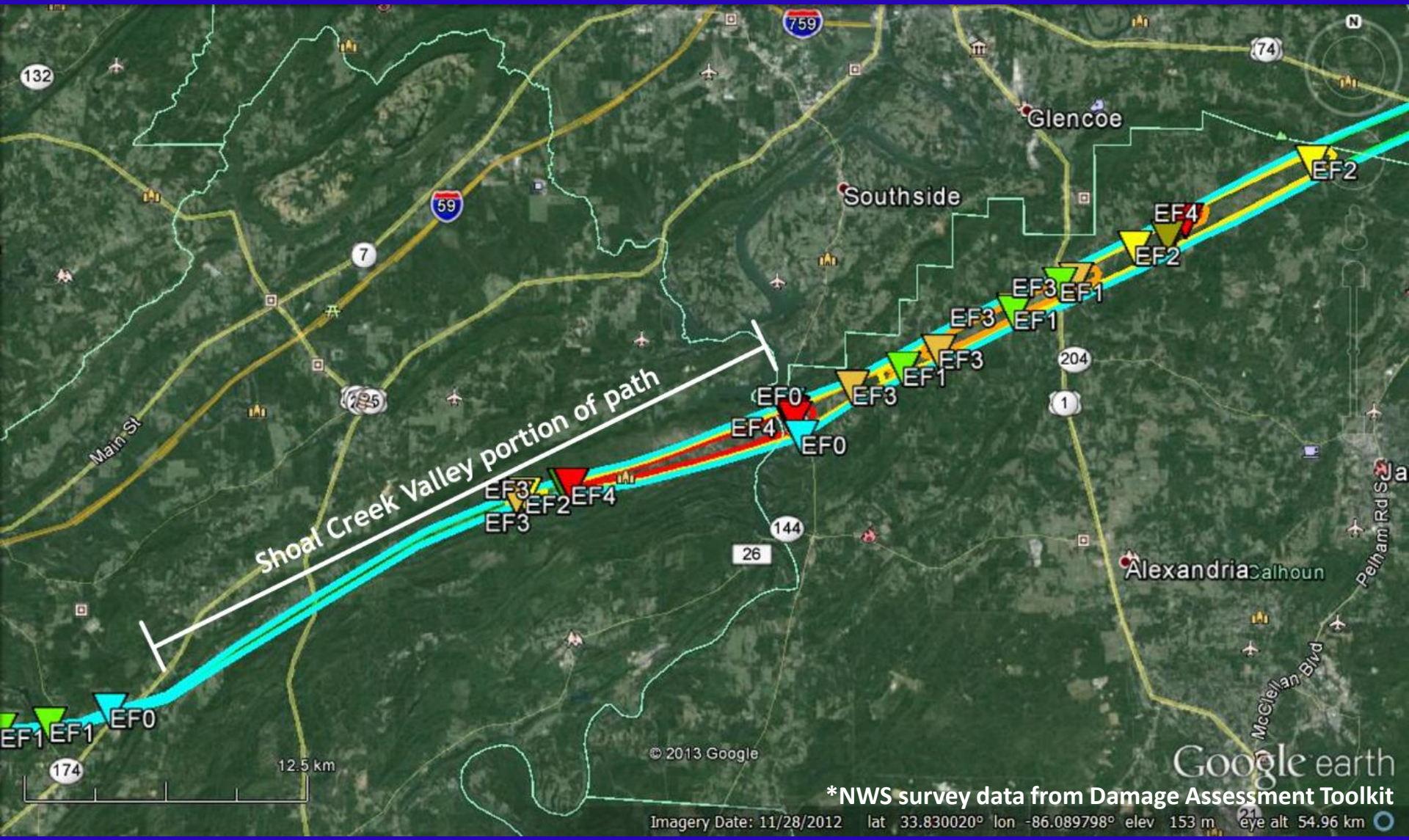
Pisgah observations

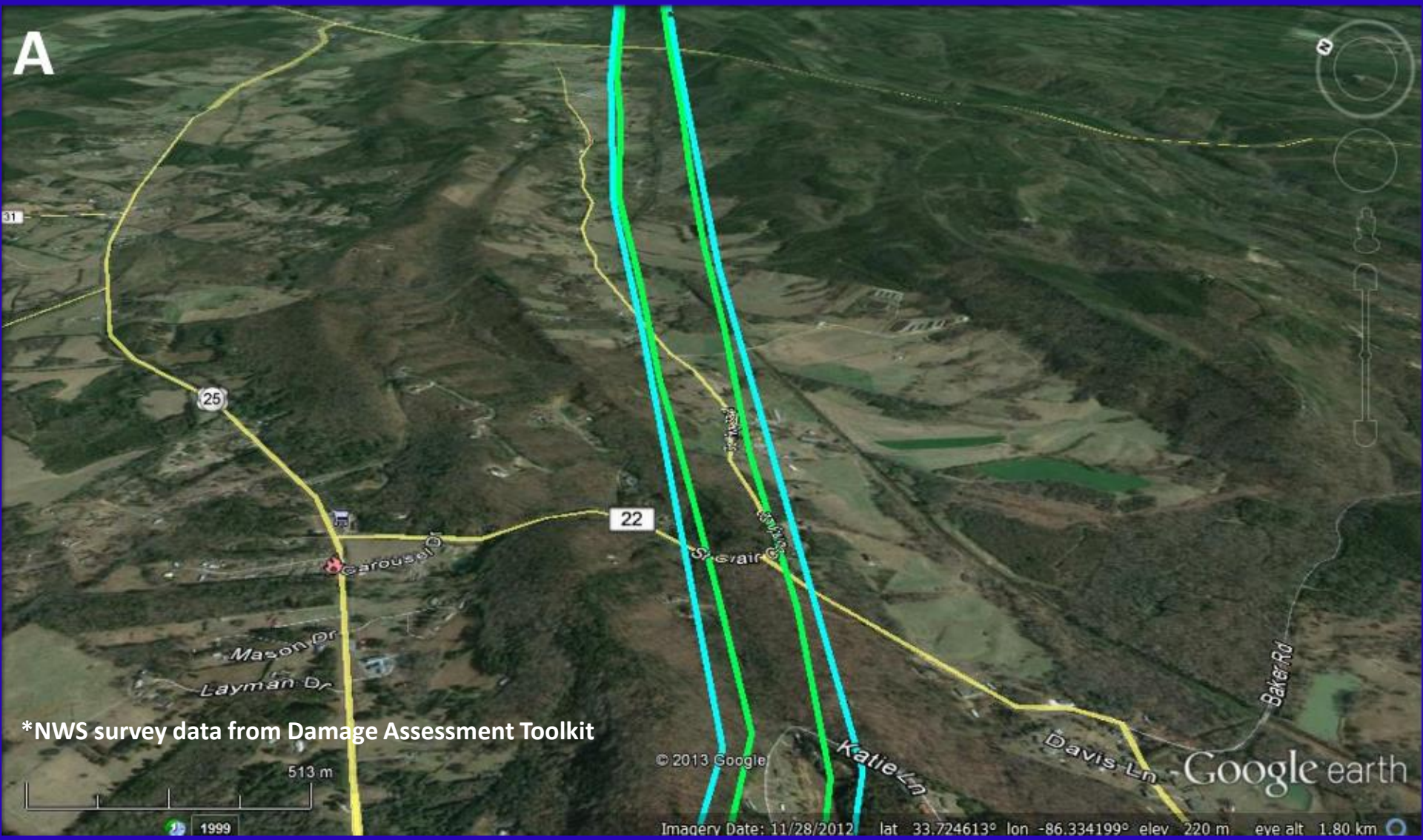
- Genesis of the tornado occurred on northwestern slope of Sand Mountain, followed by rapid intensification to EF4 intensity atop the plateau
- Tornado momentarily weakened as it moved into Wills Valley, then rapidly intensified back to near-EF4 intensity in Trenton GA
- Vorticity increased dramatically as vortex ascended Lookout Mountain in NW GA

27 April 2011: Ohatchee, AL

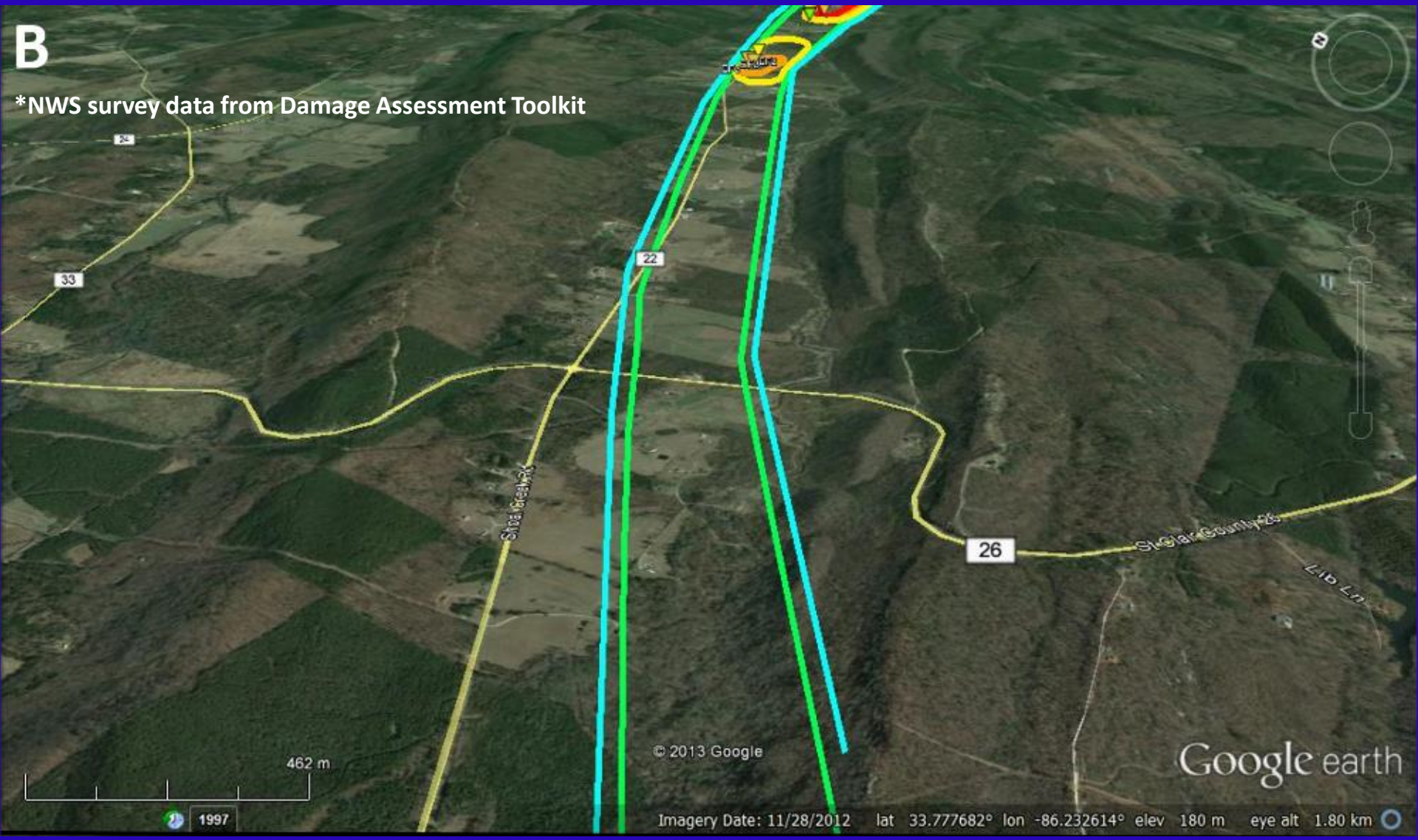
- Second tornado produced by the Tuscaloosa-Birmingham supercell
- EF4 tornado traveled 156.64 km and was up to 1600 m wide
- 22 people killed along the path, all in Alabama

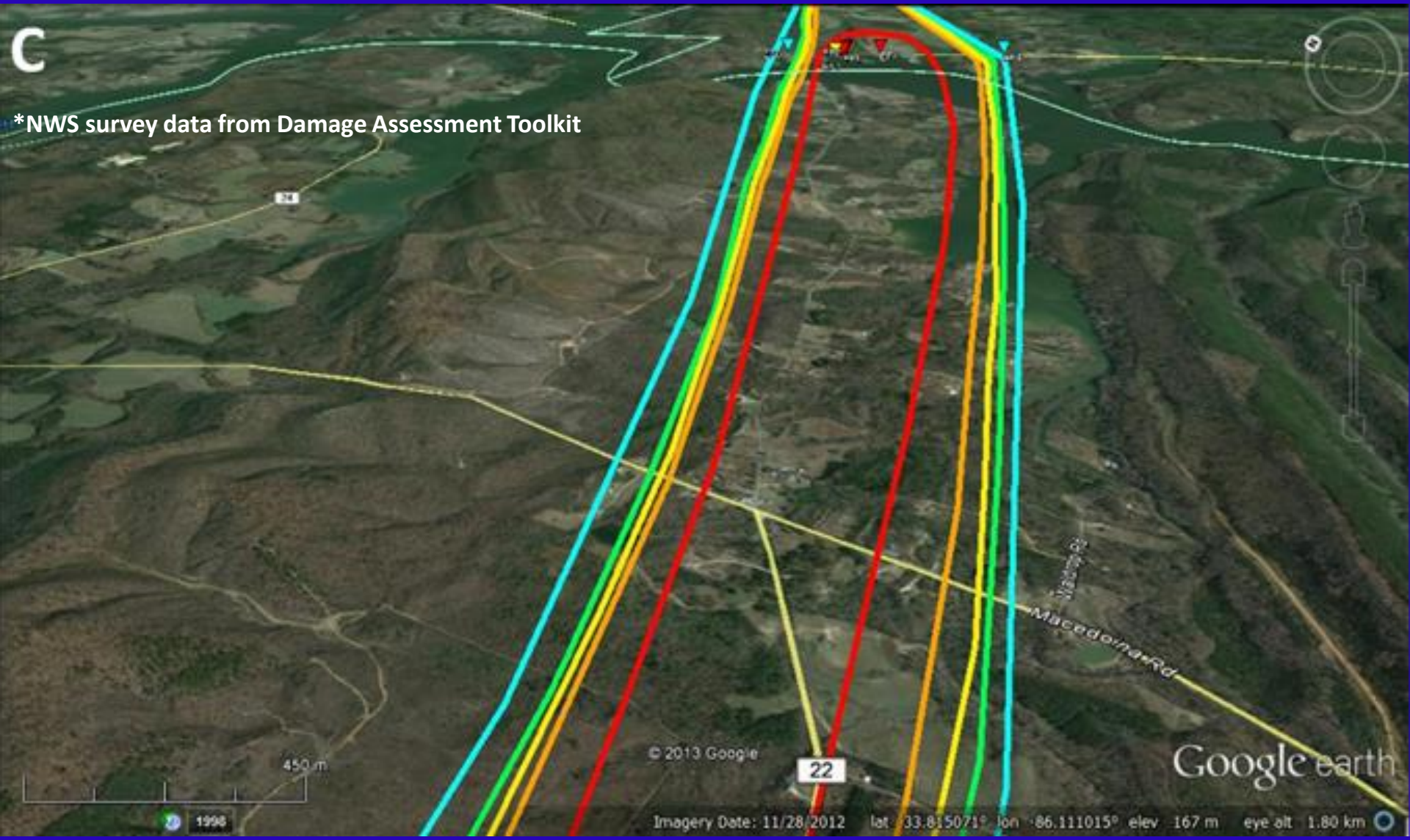

Albertville
Rome
Gadsden
Anniston
Image Landsat
© 2014 Google
37 km
Google earth
Imagery Date: 4/9/2013 lat 33.944385° lon -85.779578° elev 203 m eye alt 157.43 km


Shoal Creek Valley portion of path
Glencoe
Southside
Alexandria
Calhoun
Main St
McClellan Blvd
Pelham Rd S
EF0
EF1
EF2
EF3
EF4
12.5 km
© 2013 Google
Google earth
*NWS survey data from Damage Assessment Toolkit
Imagery Date: 11/28/2012 lat 33.830020° lon -86.089798° elev 153 m eye alt 54.96 km



*NWS survey data from Damage Assessment Toolkit


B
*NWS survey data from Damage Assessment Toolkit
22
33
26
462 m
1997
© 2013 Google
Google earth
Imagery Date: 11/28/2012 lat 33.777682° lon -86.232614° elev 180 m eye alt 1.80 km

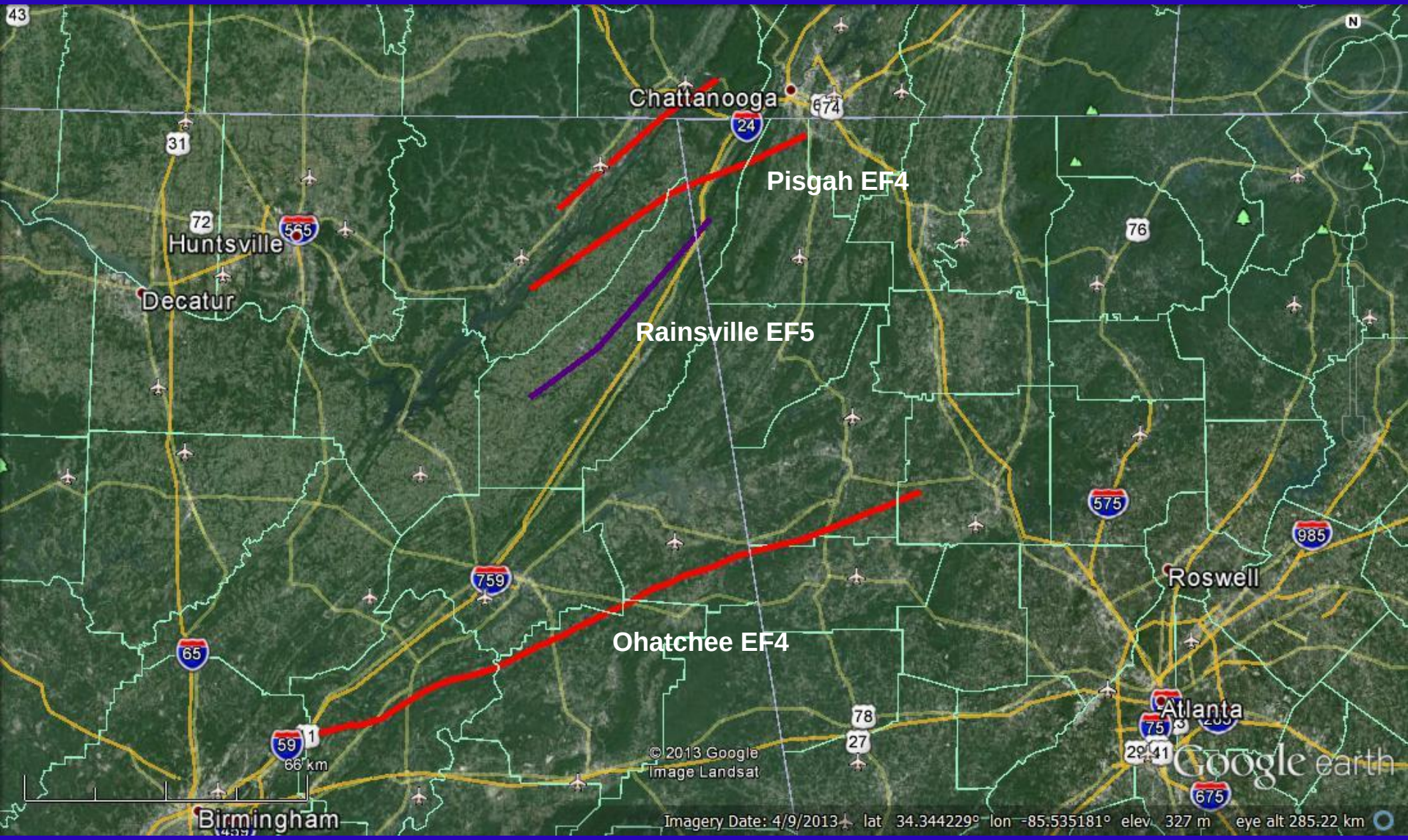

C
*NWS survey data from Damage Assessment Toolkit
Macedonia Rd
22
© 2013 Google
Google earth
Imagery Date: 11/28/2012 lat 33.815071° lon -86.111015° elev 167 m eye alt 1.80 km

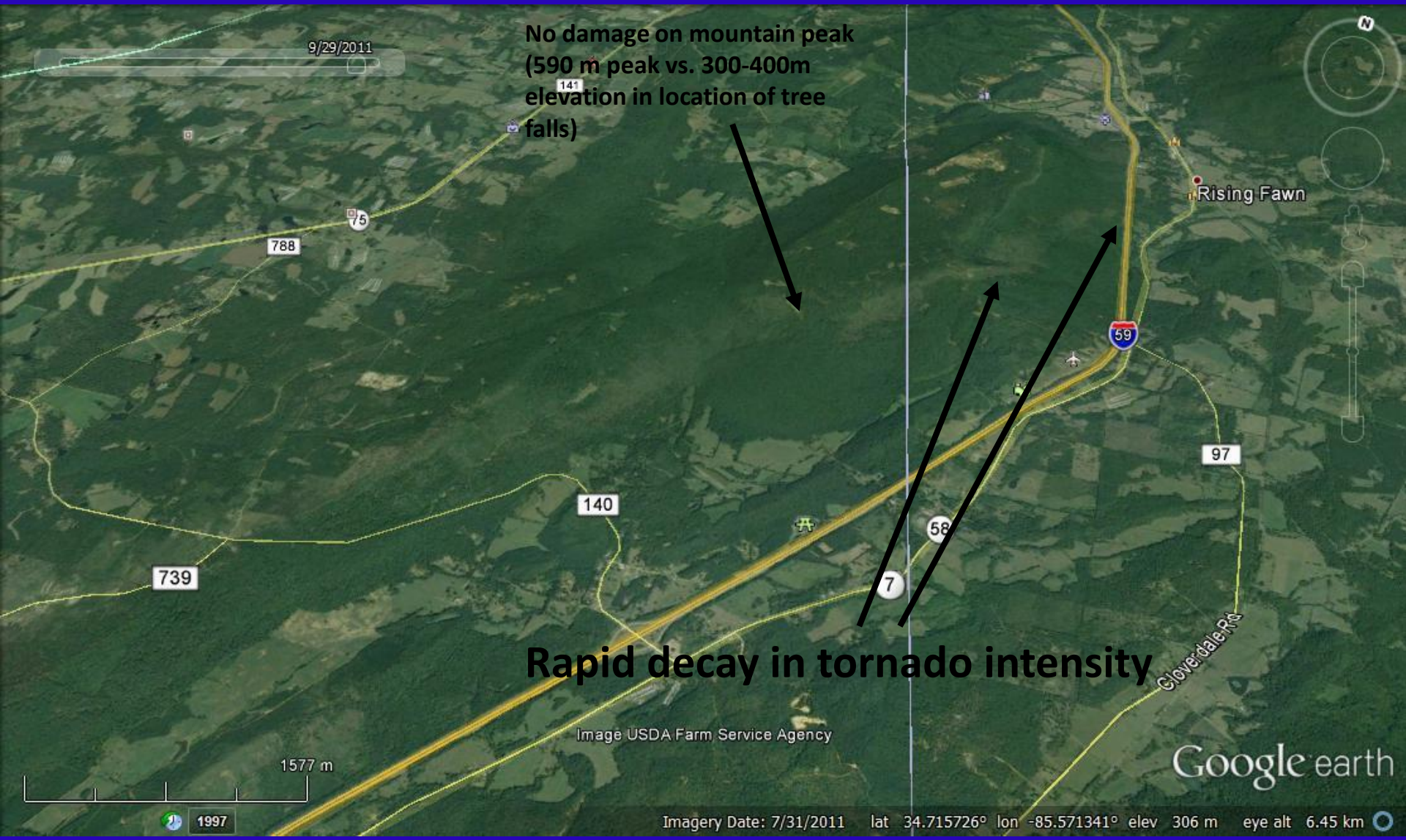
Ohatchee observations

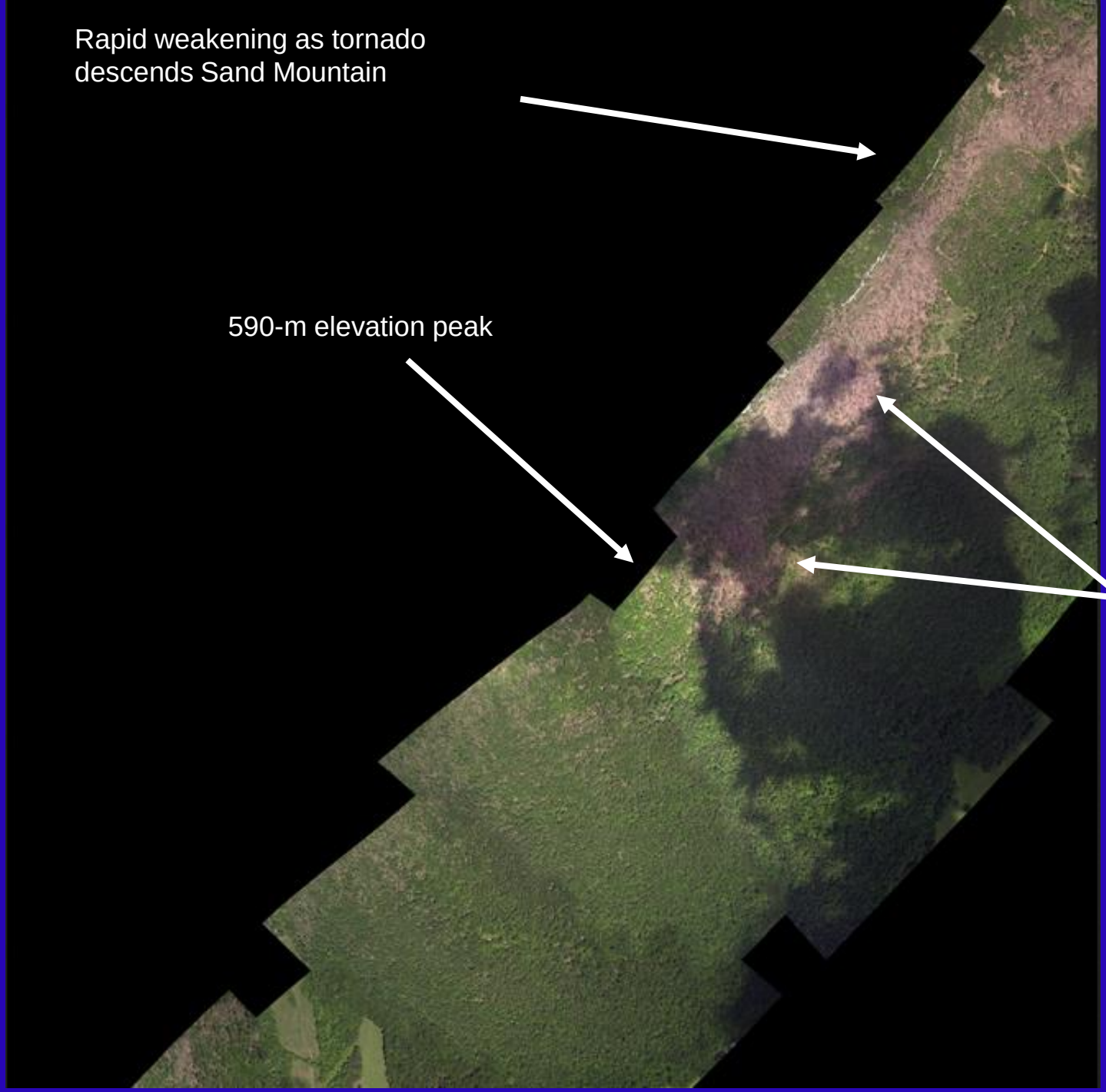
- Tornado formed just east of Birmingham and moved eastward to the Shoal Creek Valley at EF1 intensity
- Upon entering the Shoal Creek Valley, the tornado paralleled the curved valley all the way to Neely Henry Lake while intensifying to EF4 intensity

27 April 2011: Rainsville, AL

- Extremely violent EF5 tornado produced by the same supercell as the Cordova-Blountsville AL and Ringgold GA EF4 tornadoes
- Killed 25 people in DeKalb County AL on top of Sand Mountain
- Tornado traveled 58.89 km and was up to 1200 m wide


Chattanooga
Pisgah EF4
Huntsville
Decatur
Rainsville EF5
Roswell
Ohatchee EF4
Atlanta
Birmingham
66 km
© 2013 Google
Image Landsat
Google earth
Imagery Date: 4/9/2013 lat 34.344229° lon -85.535181° elev 327 m eye alt 285.22 km


No damage on mountain peak (590 m peak vs. 300-400m elevation in location of tree falls)
Rapid decay in tornado intensity
9/29/2011
Rising Fawn
788
75
141
59
97
140
58
7
739
Cloverdale Rd
Image USDA Farm Service Agency
1577 m
1997
Google earth
Imagery Date: 7/31/2011 lat 34.715726° lon -85.571341° elev 306 m eye alt 6.45 km



NOAA flyover imagery

Rainsville observations

- The track deviated to the left of several other violent tornado tracks in eastern Alabama during the outbreak
  - Mean motion of ~225° vs. motions of 230-250° for the other tornadoes
  - Motion for the last ~2/3 of its track was 220°, parallel to the southeastern edge of Sand Mountain
- Tornado displayed a clear weakness over a local peak atop Sand Mountain, with more severe damage immediately down-path
- Rapid dissipation occurred as the tornado left Sand Mountain and entered the Wills Valley

Four observed behaviors in the presence of terrain

1. **Mode I:** Weakening or dissipation of tornadoes on the upslopes of hills/mountains and strengthening or dissipation of tornadoes on the downslopes of hills/ mountains
   - Pisgah 2011, Rainsville 2011, Huntsville 2013
2. **Mode II:** Intensification of a circulation as it crosses onto a plateau or weakening of a circulation as it moves off a plateau
   - Pisgah 2011, Rainsville 2011
3. **Mode III:** Tracks that deviate slightly to follow valleys
   - Ohatchee 2011
4. **Mode IV:** Deviation to follow the edge of a plateau
   - Rainsville 2011

Summary

- 75 cases total, with many cases exhibiting multiple mode of behavior

Mode	EF0	EF1	EF2	EF3	EF4	EF5	S	Q	U	Total
I	0	14	7	6	6	2	21	14	0	35
II	3	12	4	6	5	1	17	14	0	31
III	0	7	3	2	3	0	4	9	2	15
IV	0	3	1	0	0	1	4	1	0	5

S - Supercell
Q - QLCS
U - Unknown

➢ See P.120 this afternoon for some of these modes observed during the 28-29 April 2014 tornado outbreak

Future Work

- We have created an *a posteriori* knowledge of repeated behaviors by tornadoes in the presence of significant terrain
- Future work must focus on taking this knowledge from an *a posteriori* state to an understanding of physical processes
- Need to separate the effects of terrain from other processes, such as internal processes, wave interactions, and cell mergers
- Additional sampling of severe storms in significant terrain in N Alabama
- More detailed analyses of select, quality cases, including advanced radar analyses (e.g. dual-Doppler synthesis and GBVTD)
- Expanding detailed survey efforts of severe weather events in rough terrain
- Differential profiling of flows around terrain in varied weather patterns
- Numerical simulations to verify or dispute the effects of terrain on these observed behaviors

- **ExCITE: External Controls and Influences on Tornado Evolution**

References

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Questions?

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