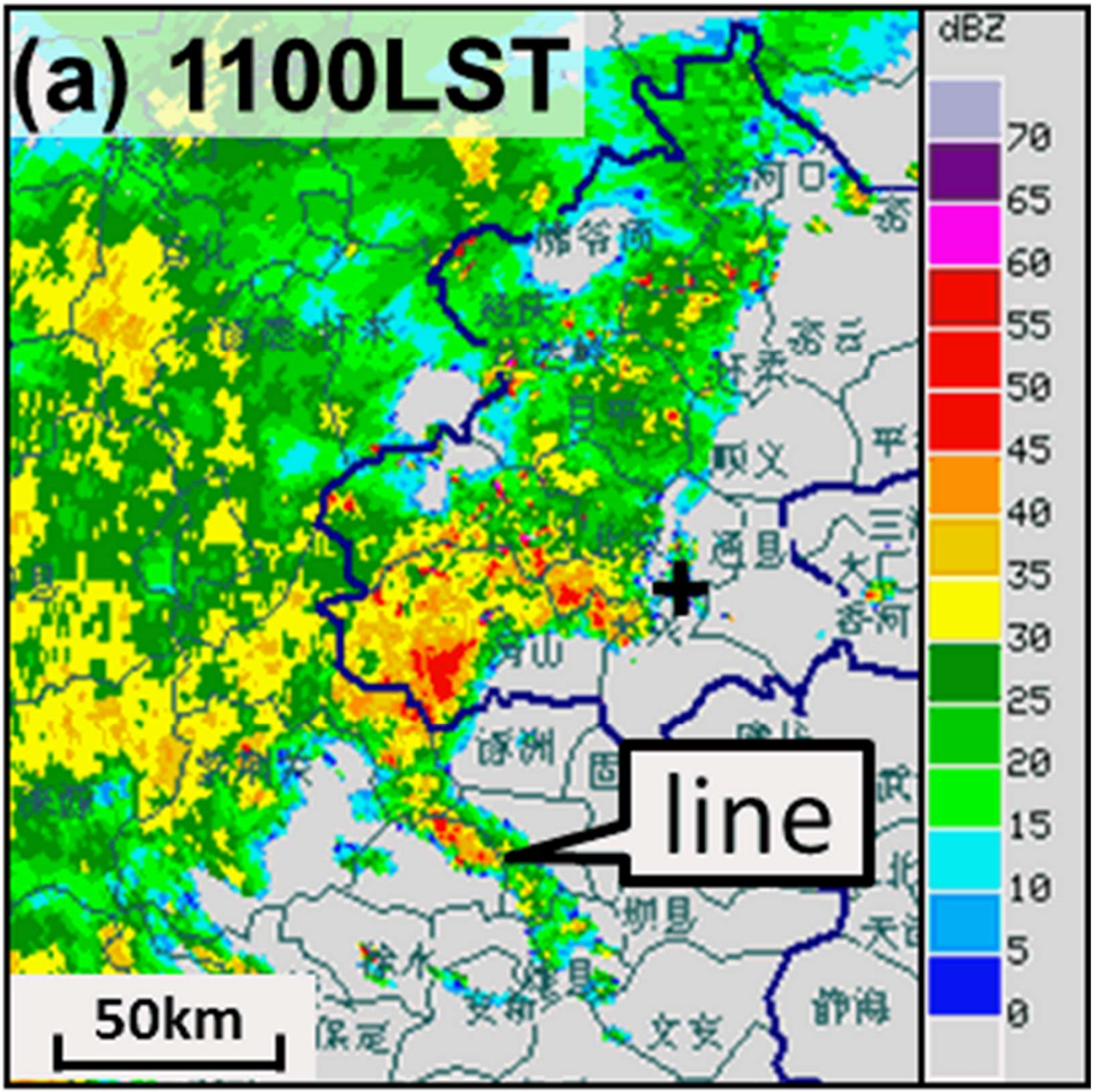

(a) 1100LST
dBZ
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
line
50km

北京大学
PEKING UNIVERSITY

我国几次龙卷风灾调回顾

孟智勇

北京大学 物理学院

大气与海洋科学系

合作者：姚聃、白兰强、张慕容、黄龄、郑永光、薛明、伍志方、炎利军、李兆慧、麦雪湖、王明筠、 赵坤、李兆明、黎立页、田付友、李巍、韩经纬、朱宇宁、周瑞琳、李飒 等

http://faculty.pku.edu.cn/mengzhiyong

什么是强对流天气?

发生突然、天气剧烈、破坏力极大

强对流天气

- 伴有雷暴的短时强降水： 20 毫米/小时
- 雷暴大风： 2分钟平均风速≥17.2 m/s, 瞬时风速≥20m/s
- 冰雹
- 龙卷风：任何级别




什么是龙卷风?

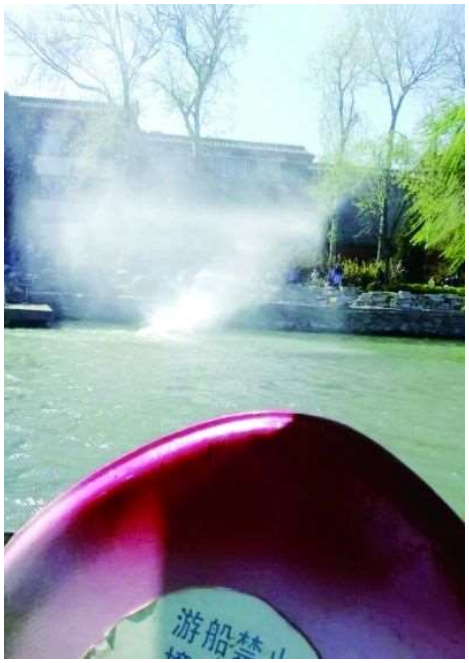
A rotating column of air, in contact with the surface, pendant from a cumuliform cloud, and often visible as a funnel cloud and/or circulating debris/dust at the ground

(AMS glossary http://glossary.ametsoc.org/wiki/Tornado).

尘卷风不是龙卷风

3-30m宽, 高100m, 持续几分钟

2016.4.20. 甘肃酒泉

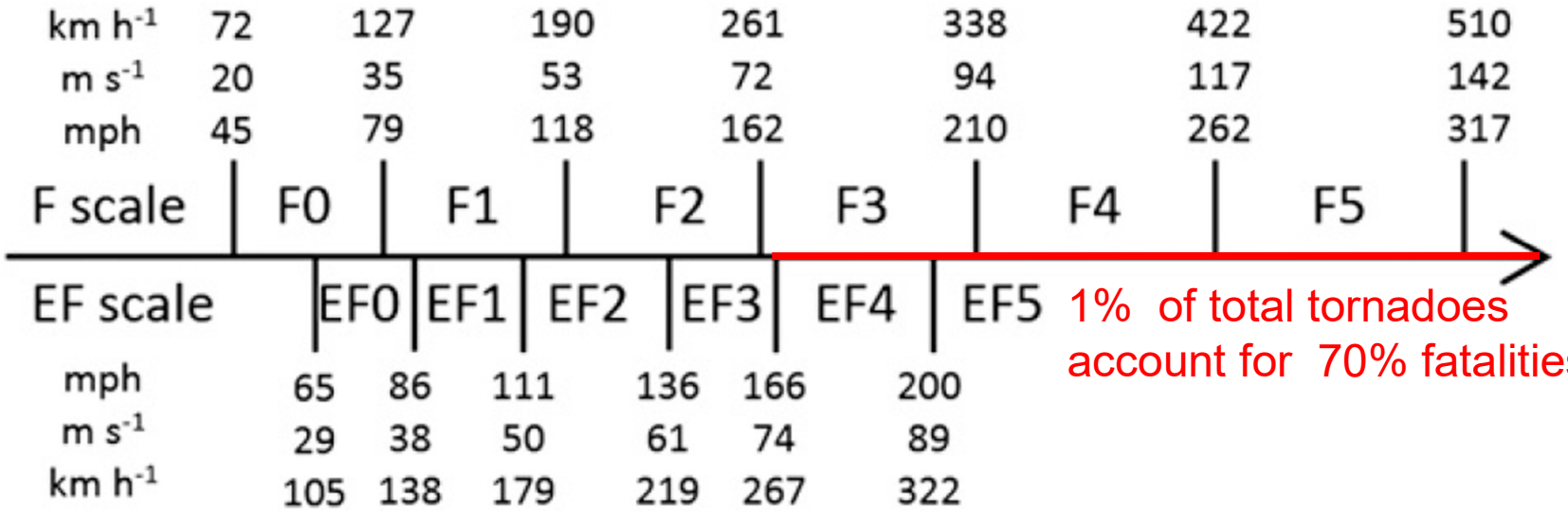


2016.4.3. 北京北海公园

2019.3.31. 河南商丘

Enhanced Fujita (EF) scale

Became operational on February 1, 2007 in the U.S.



气象行业标准QX/T478-2019《龙卷强度等级》

等级		龙卷强度	阵风风速 m/s	致灾程度
一级	EF0	弱	$V_{max} \leqslant 38$	轻度
二级	EF1	中	$38 < V_{max} \leqslant 49$	中等
三级	EF2-3	强	$49 < V_{max} \leqslant 74$	严重
四级	EF4-5	超强	$V_{max} > 74$	毁灭性

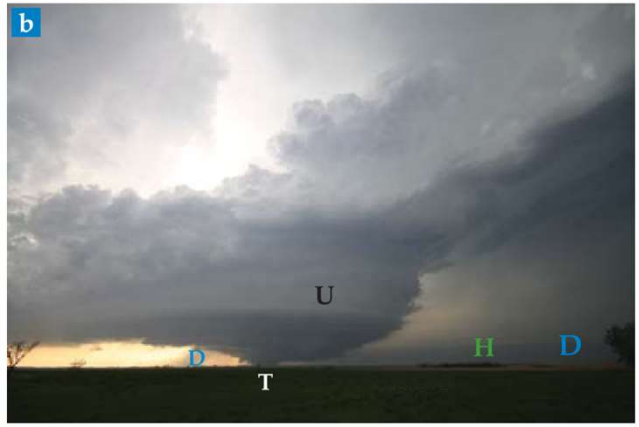
DI

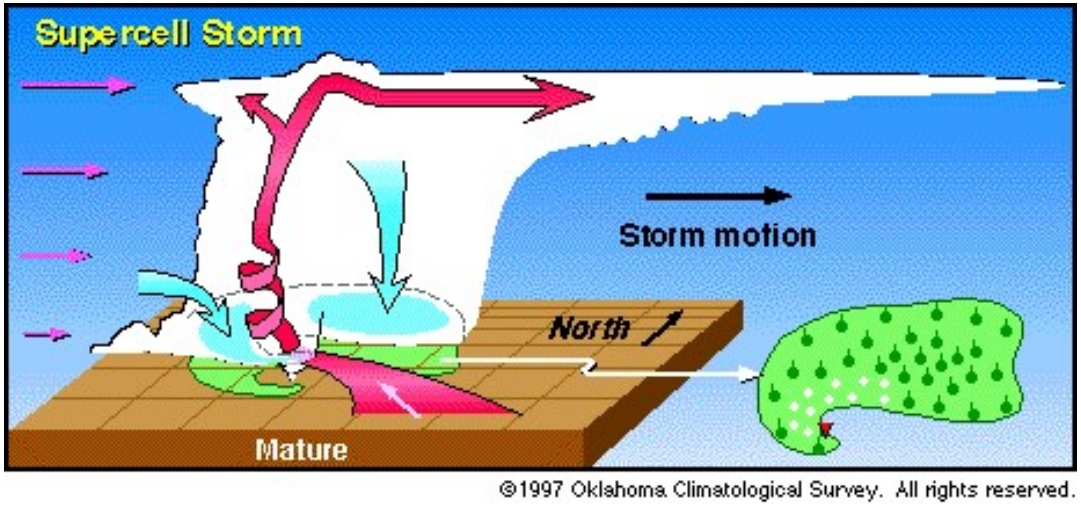
Damage Indicators for EF Scale

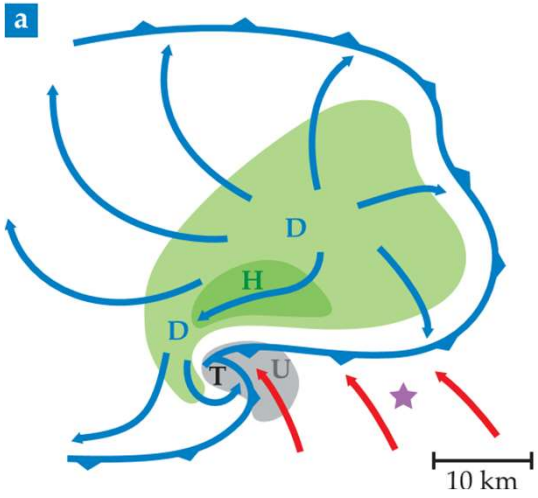
DI No.	Damage indicator (DI)
1	Small Barns or Farm Outbuildings (SBO)
2	One- or Two-Family Residences (FR12)
3	Manufactured Home – Single Wide (MHSW)
4	Manufactured Home – Double Wide (MHDW)
5	Apartments, Condos, Townhouses [3 stories or less] (ACT)
6	Motel (M)
7	Masonry Apartment or Motel Building (MAM)
8	Small Retail Building [Fast Food Restaurants] (SRB)
9	Small Professional Building [Doctor's Office, Branch Banks] (SPB)
10	Strip Mall (SM)
11	Large Shopping Mall (LSM)
12	Large, Isolated Retail Building [K-Mart, Wal-Mart] (LIRB)
13	Automobile Showroom (ASR)
14	Automobile Service Building (ASB)
15	Elementary School [Single Story; Interior or Exterior Hallways] (ES)
16	Junior or Senior High School (JHSH)
17	Low-Rise Building [1-4 Stories] (LRB)
18	Mid-Rise Building [5-20 Stories] (MRB)
19	High-Rise Building [More than 20 Stories] (HRB)
20	Institutional Building [Hospital, Government or University Building] (IB)
21	Metal Building System (MBS)
22	Service Station Canopy (SSC)
23	Warehouse Building [Tilt-up Walls or Heavy-Timber Construction](WHB)
24	Transmission Line Towers (TLT)
25	Free-Standing Towers (FST)
26	Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)
27	Trees: Hardwood (TH)
28	Trees: Softwood (TS)

龙卷一般特征

- Vertical vorticity: 1 /s, most cyclonic
- Diameter (width of EF0 area) : ~ 100 m
- Life span: 10 min–1 h
- Environmental system
  - most significant tornadoes (F2 or above) and all violent tornadoes are associated with supercell storms.



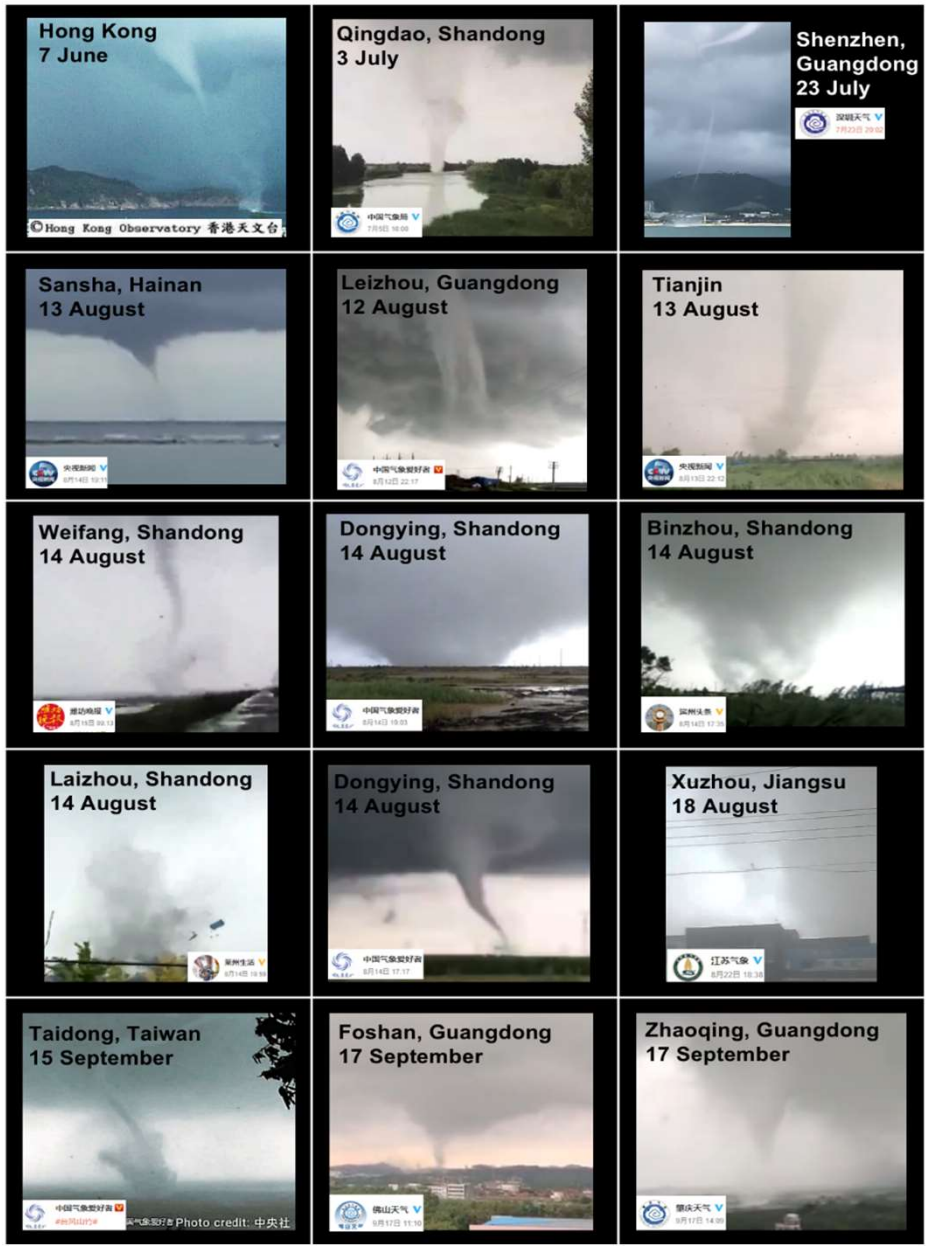




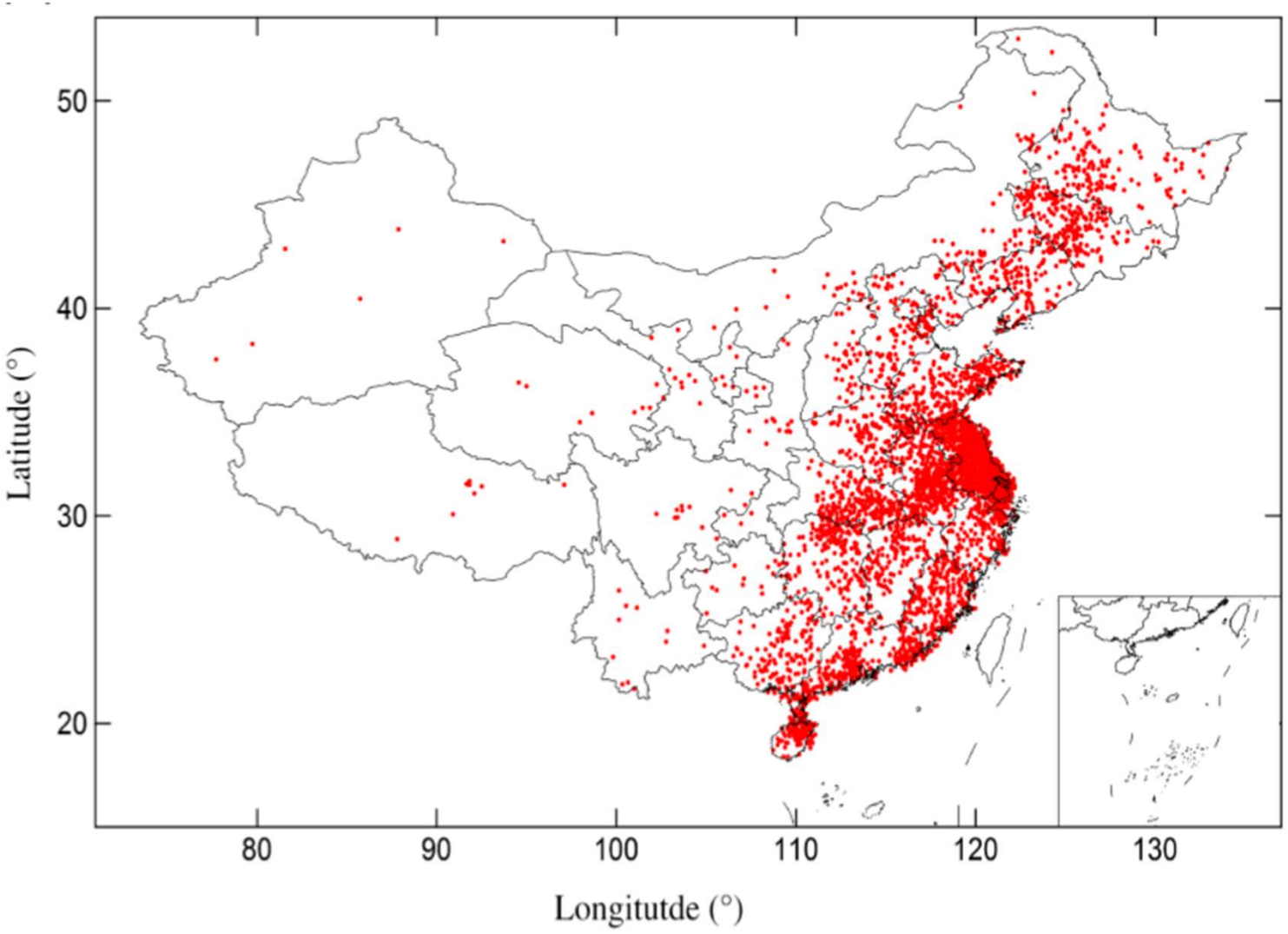
龙卷的漏斗云


锡林浩特2019.6.24


佛山2015.10.4


Hong Kong
7 June
©Hong Kong Observatory 香港天文台
Qingdao, Shandong
3 July
Shenzhen, Guangdong
23 July
Sansha, Hainan
13 August
Leizhou, Guangdong
12 August
Tianjin
13 August
Weifang, Shandong
14 August
Dongying, Shandong
14 August
Binzhou, Shandong
14 August
Laizhou, Shandong
14 August
Dongying, Shandong
14 August
Xuzhou, Jiangsu
18 August
Taidong, Taiwan
15 September
Photo credit: 中央社
Foshan, Guangdong
17 September
Zhaoqing, Guangdong
17 September

我国龙卷分布 (1948-2012)



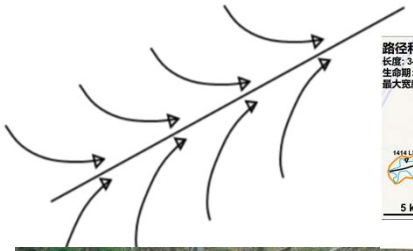
(Chen et al. 2017, International Journal of Climatology)

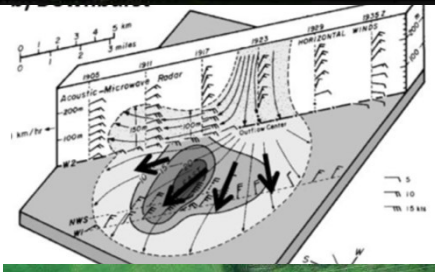
龙卷的判定

1）**目测**：夜里很难看清楚， 与降雨混在一起也很难看清楚

2）**灾害调查**结合**雷达观测特征**得到风暴灾害特点加以估计

狭长灾害范围



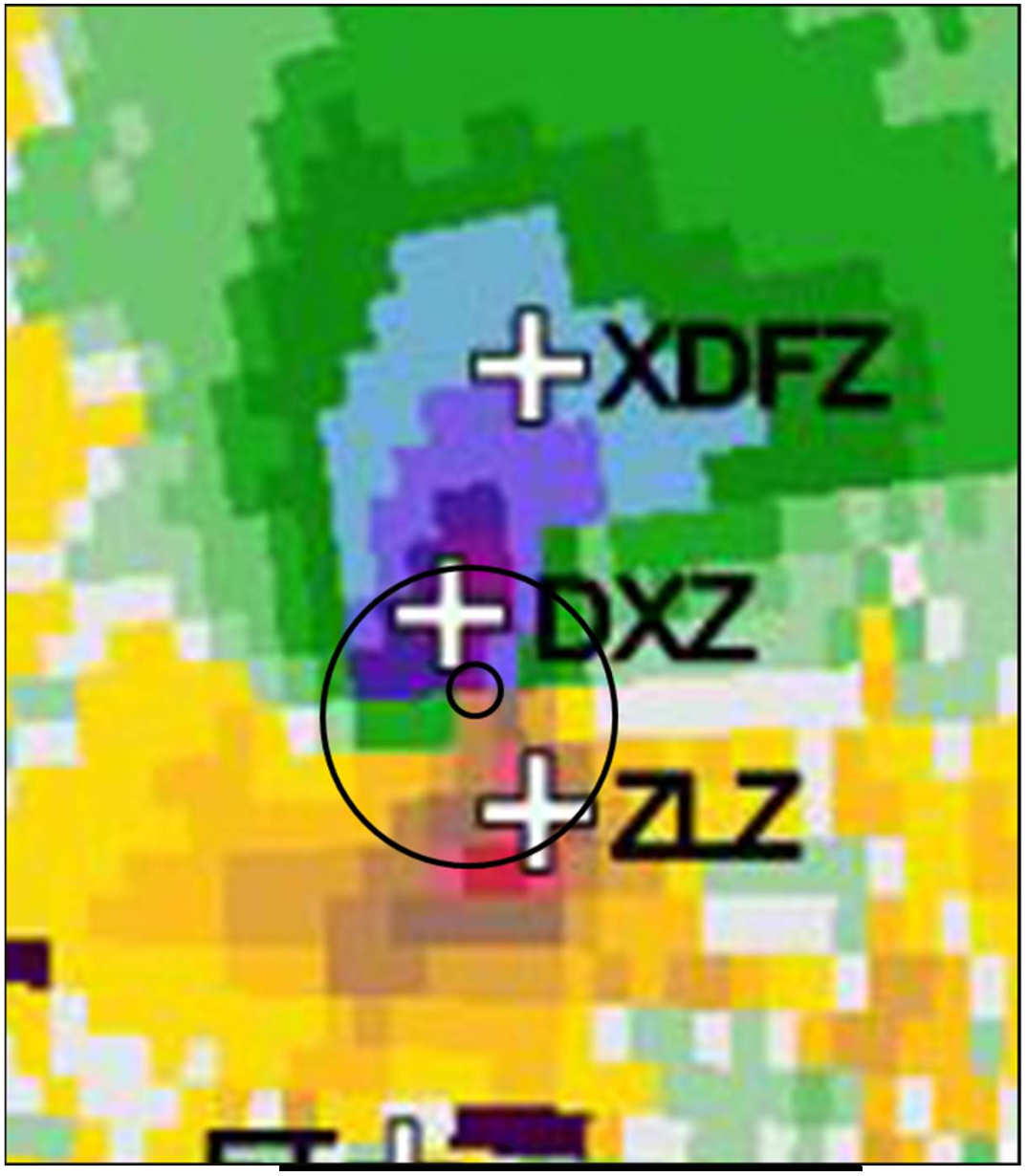


雷暴尺度的辐合或旋转或杂乱倒树

龙卷的判定

中气旋 (Mesocyclone)
A cyclonically rotating vortex, around 2–10 km in diameter, in a convective storm. Vertical vorticity is 0.01 s^{-1} or greater

龙卷涡旋（TVS）
The Doppler velocity signature of a tornado or of an incipient tornado-like circulation aloft. Gate-to-gate radial velocity difference: 20 m s-1 or greater



我国强风灾害调查状态

灾害调查

对灾害现场和天气背景情况的勘察、取证、评估和分析，以确定是否为龙卷以及龙卷的灾损程度、影响范围和强度等级。

我国的灾害调查现状

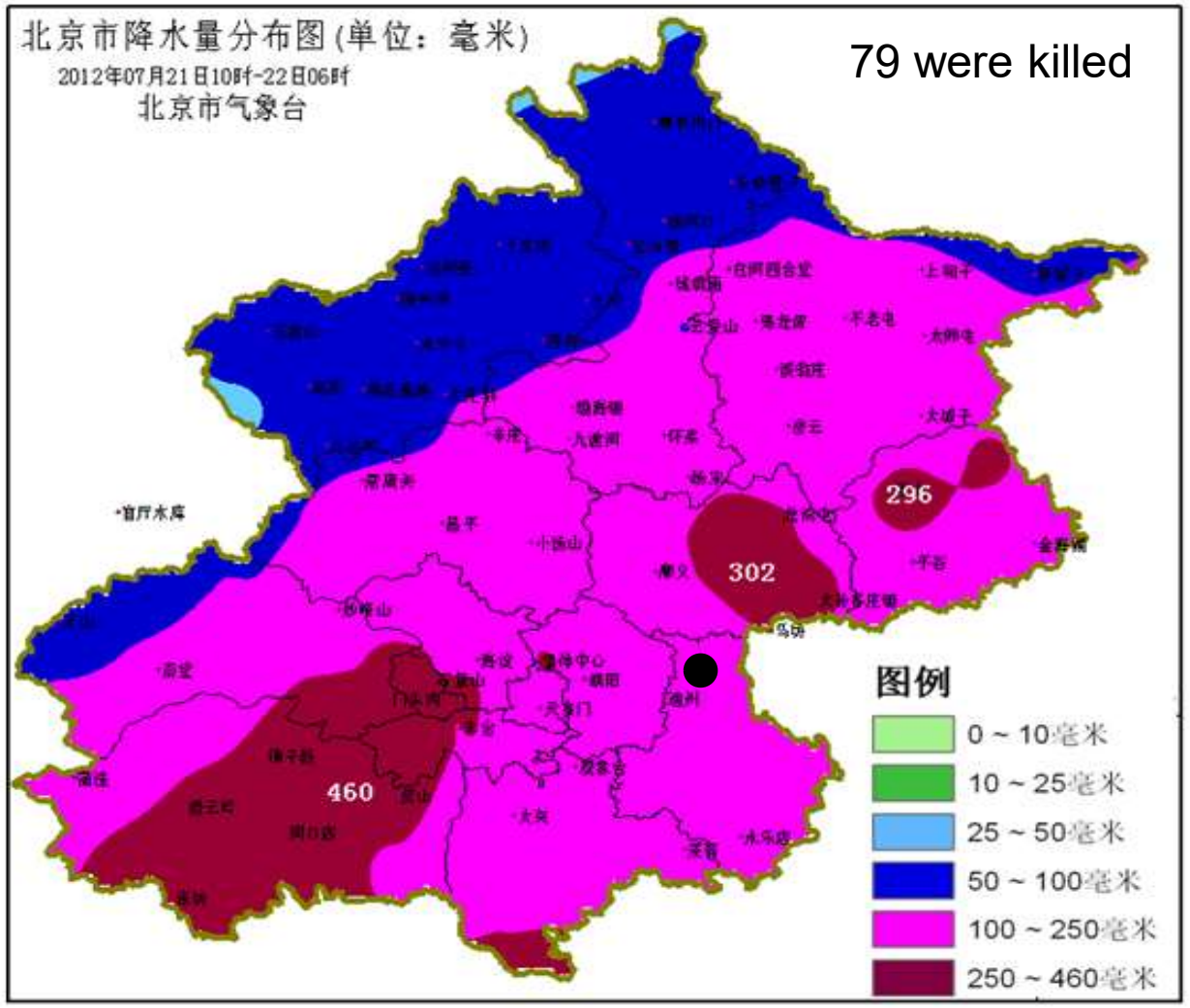
- **以前往往不完整**
- **GBT34301-2017龙卷灾害调查技术规范**
- **气象行业标准QX/T478-2019《龙卷强度等级》**

几次龙卷灾害调查回顾

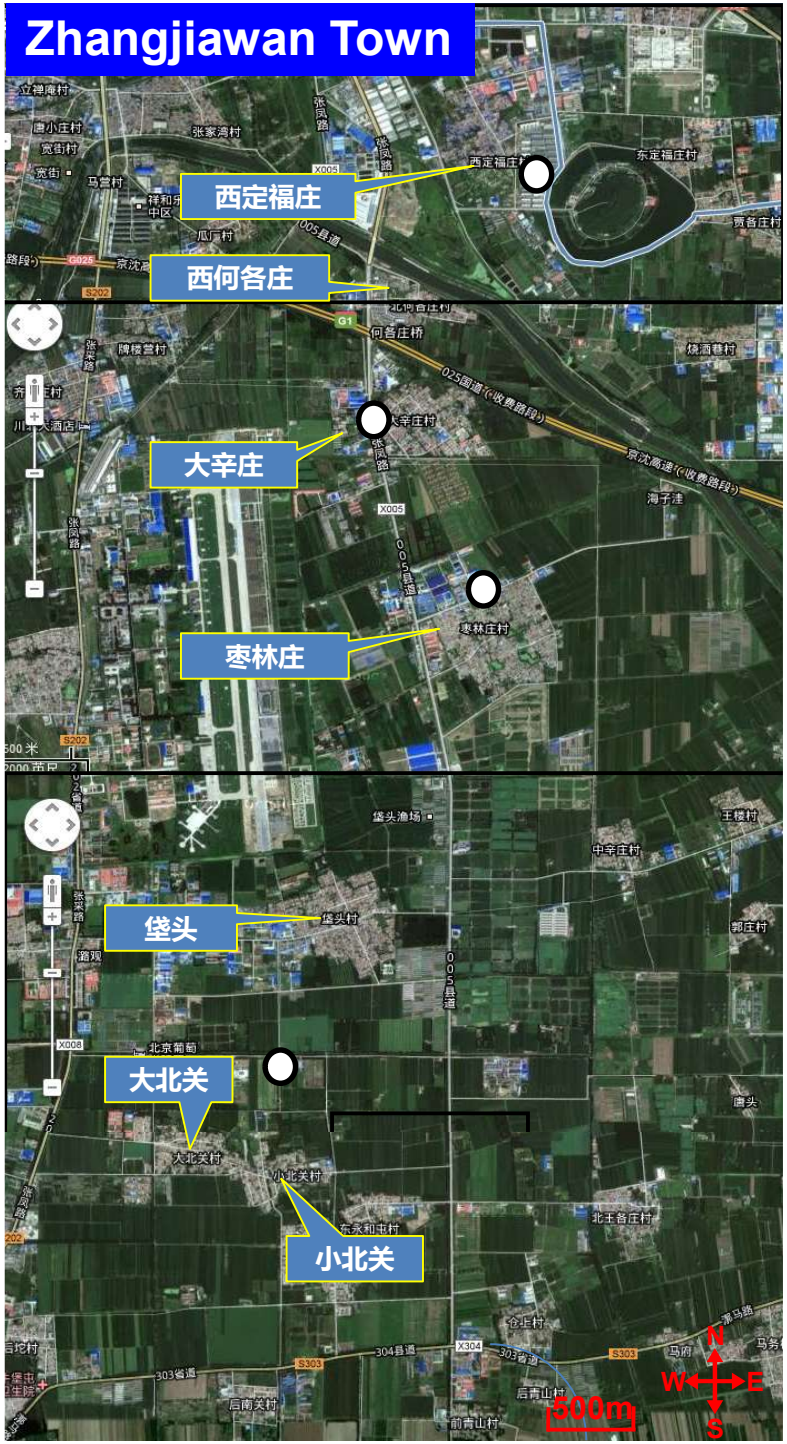
- **2012年北京通州EF3龙卷**
  - **证实龙卷的发生**（Meng and Yao WAF 2014）
- **2015年彩虹台风登陆触发的佛山EF3龙卷**
  - **首次台风龙卷综合分析** (Bai, Meng Huang et al. BAMS 2017)
- **2015年东方之星倾覆**
  - **证实是下击暴流而非龙卷**（Meng et al. Science Bulletin 2016）
- **2016年阜宁EF4龙卷**
  - **42年来死亡人数最多**（Meng Bai Zhang, et al. WAF，2018）
- **2017年赤峰EF4龙卷**
  - **复杂下垫面龙卷**
- **2019年开原龙卷**

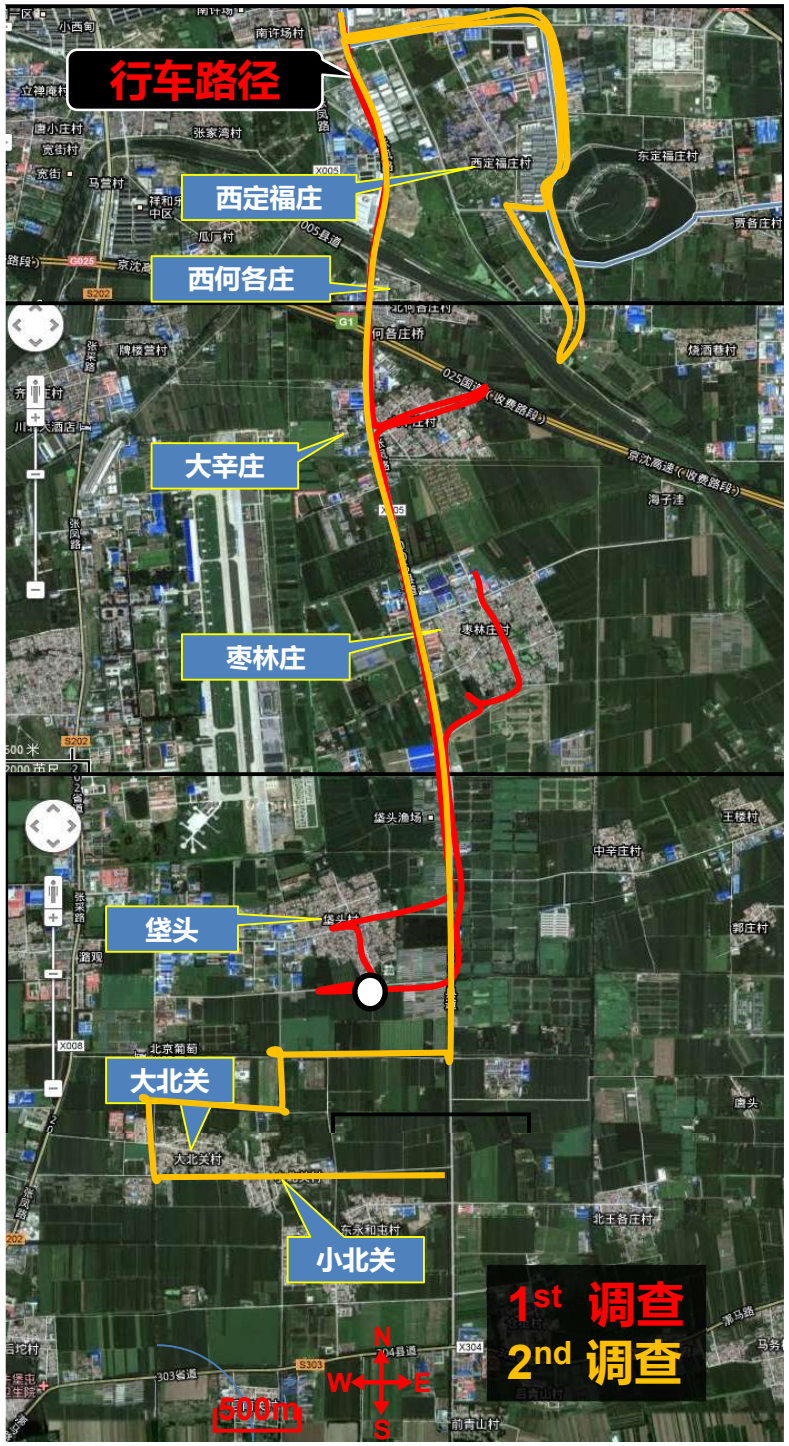
2012年北京通州EF3龙卷

北京721暴雨分布



Zhangjiawan Town

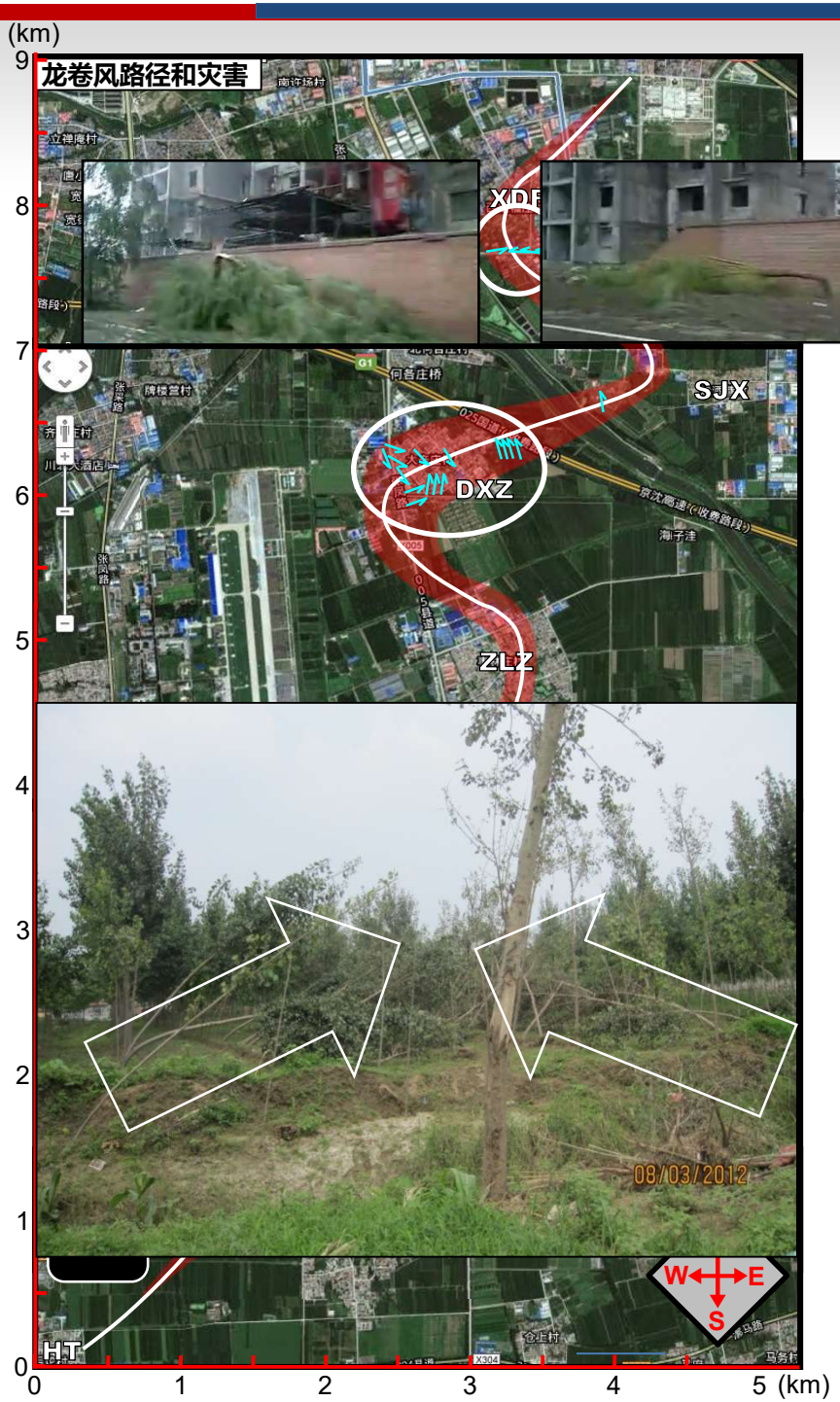




7.21 灾害调查

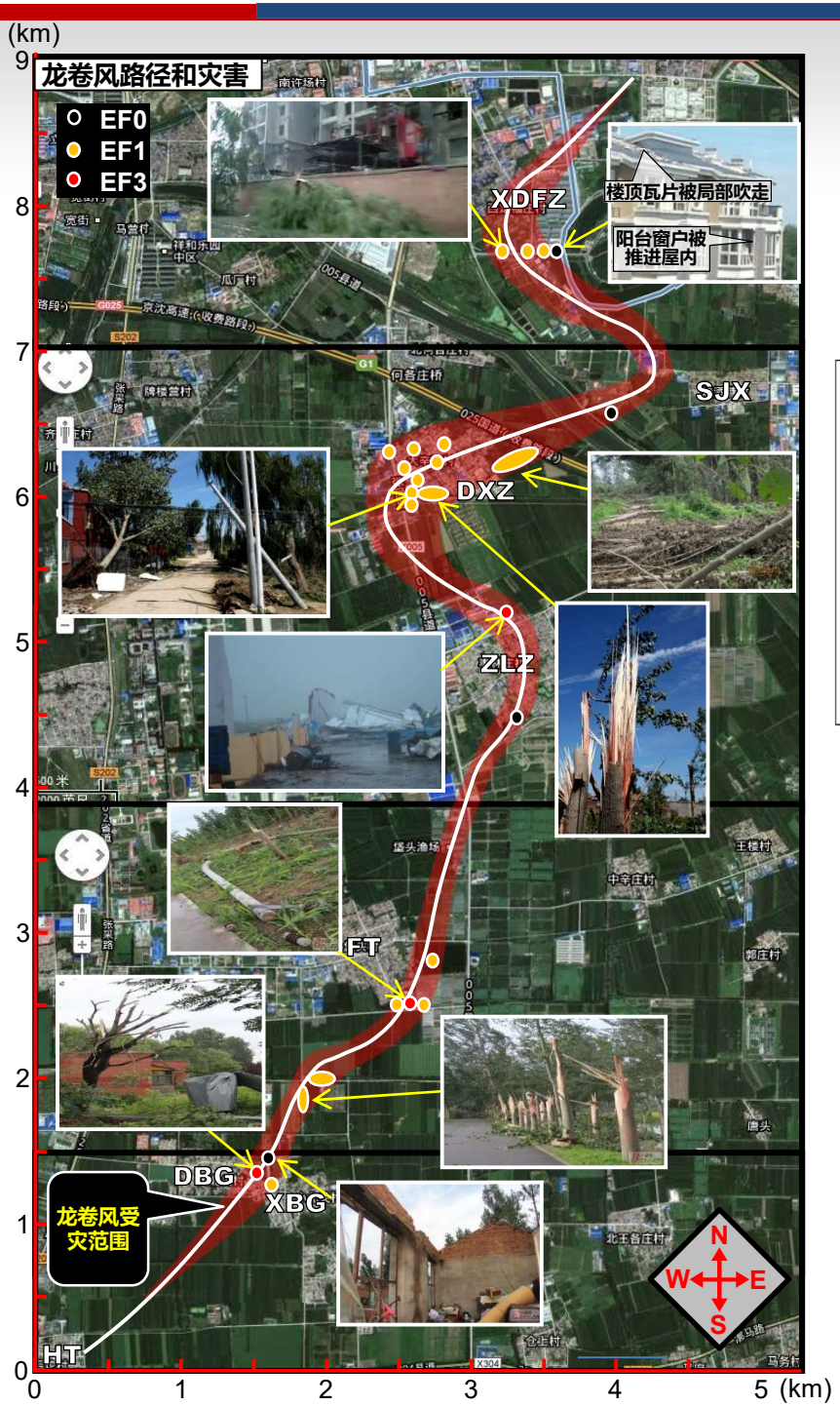
时间: 2012年8月3日
2012年8月24日

我们访问了7个村子共20个当地居民、村委会成员、农民、工人、和镇政府工作人员



龙卷风观测证据

- 细长的受灾范围
- 风暴尺度的地面辐合风



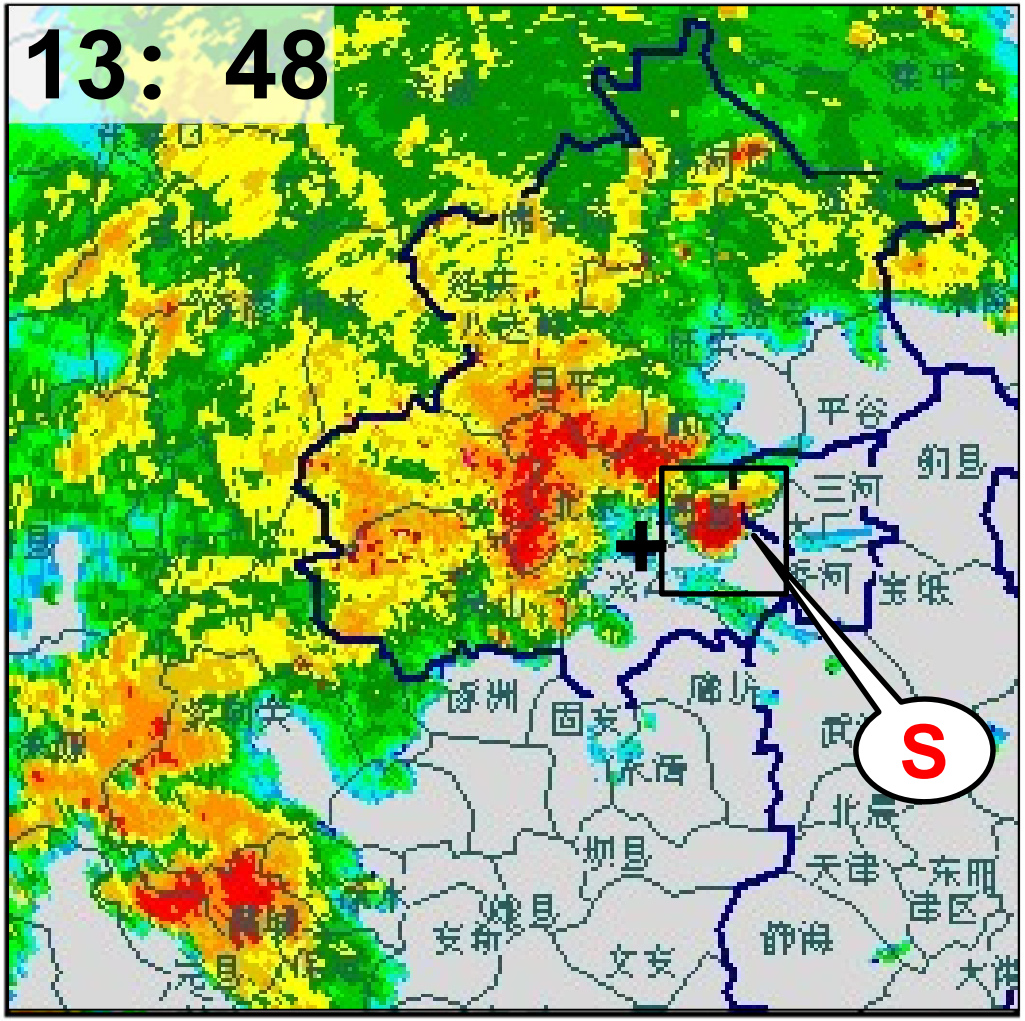
本次龙卷风有多强？

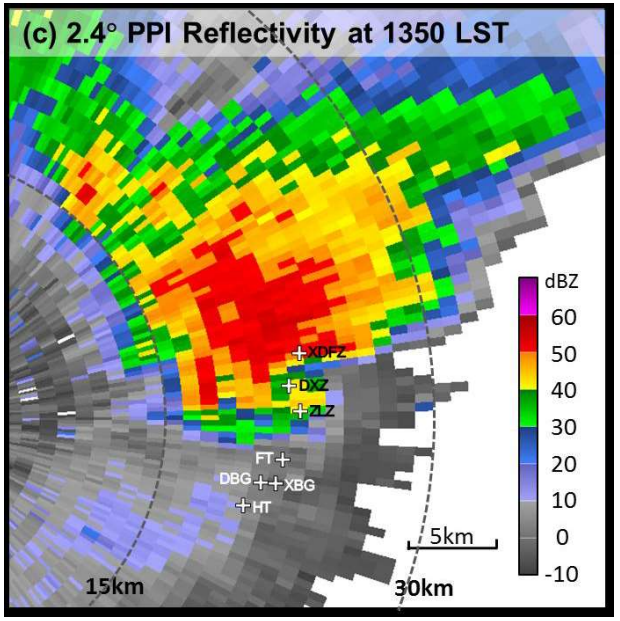
EF 龙卷分级

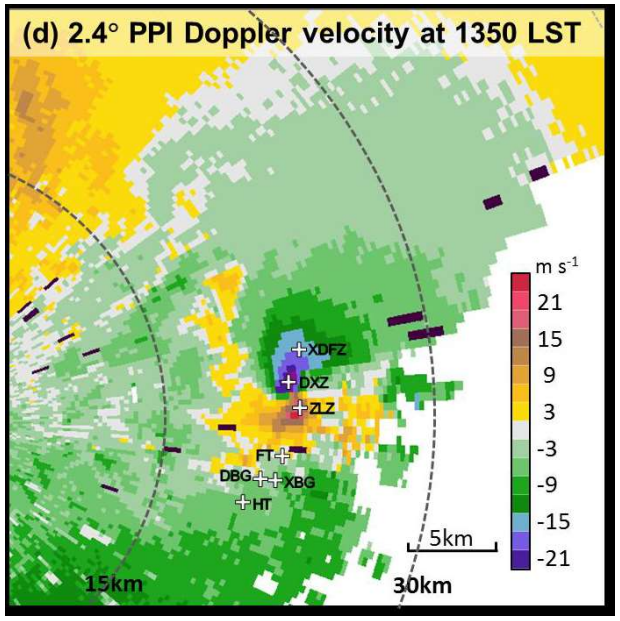
km h^{-1}	72		127		190		261		338		422	510
m s^{-1}	20		35		53		72		94		117	142
mph	45		79		118		162		210		262	317
F scale		F0		F1		F2		F3		F4		F5
EF scale			EF0		EF1		EF2	EF3		EF4		EF5
mph		65	86		111		136	166		200		
m s^{-1}		29	38		50		61	74		89		
km h^{-1}		105	138		179		219	267		322		

灾害定级所用受灾物：
房屋，电线杆,和树木

雷达特征

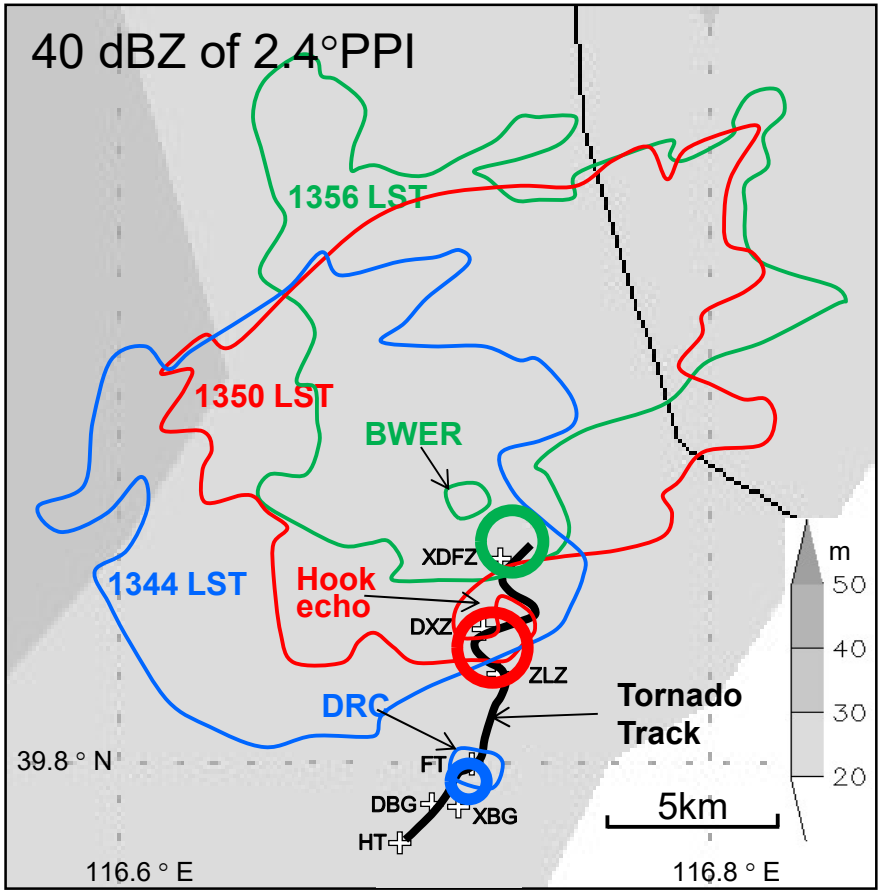

13：48
S


(c) 2.4° PPI Reflectivity at 1350 LST
dBZ
60
50
40
30
20
10
0
-10
XDFZ
DXZ
ZLZ
FT
DBG
XBG
HT
5km
15km
30km

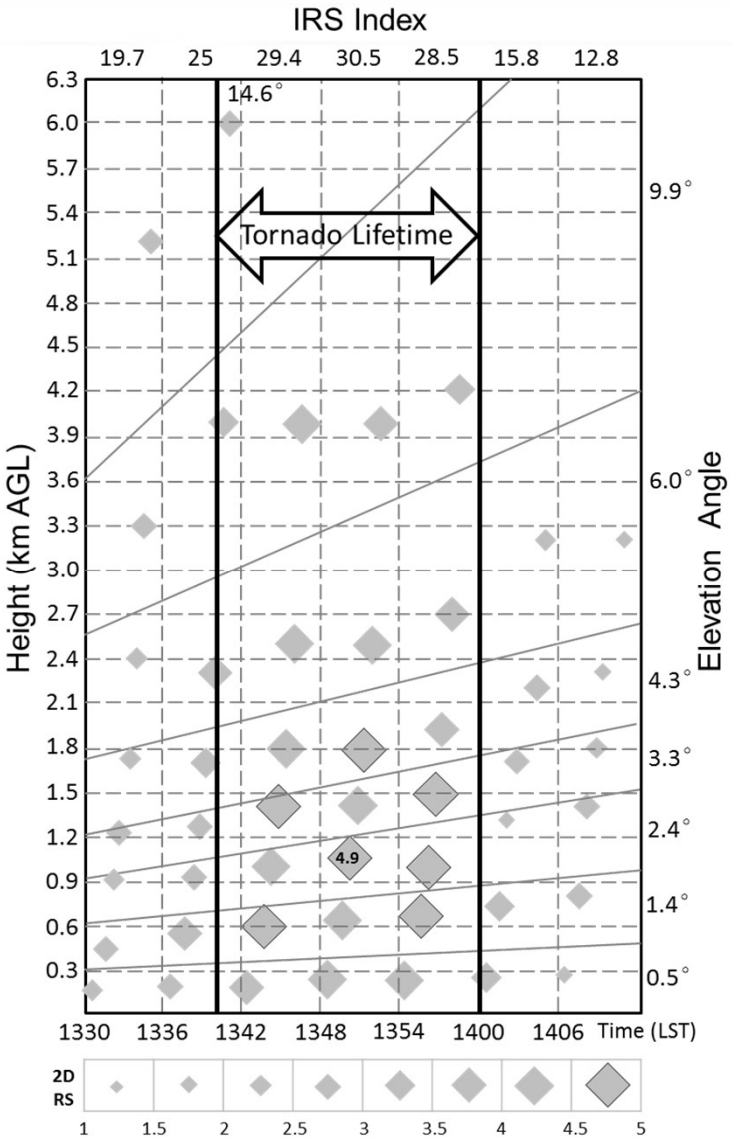

(d) 2.4° PPI Doppler velocity at 1350 LST
m s-1
21
15
9
3
-3
-9
-15
-21
XDFZ
DXZ
ZLZ
FT
DBG
XBG
HT
5km
15km
30km

中气旋

与龙卷的关系

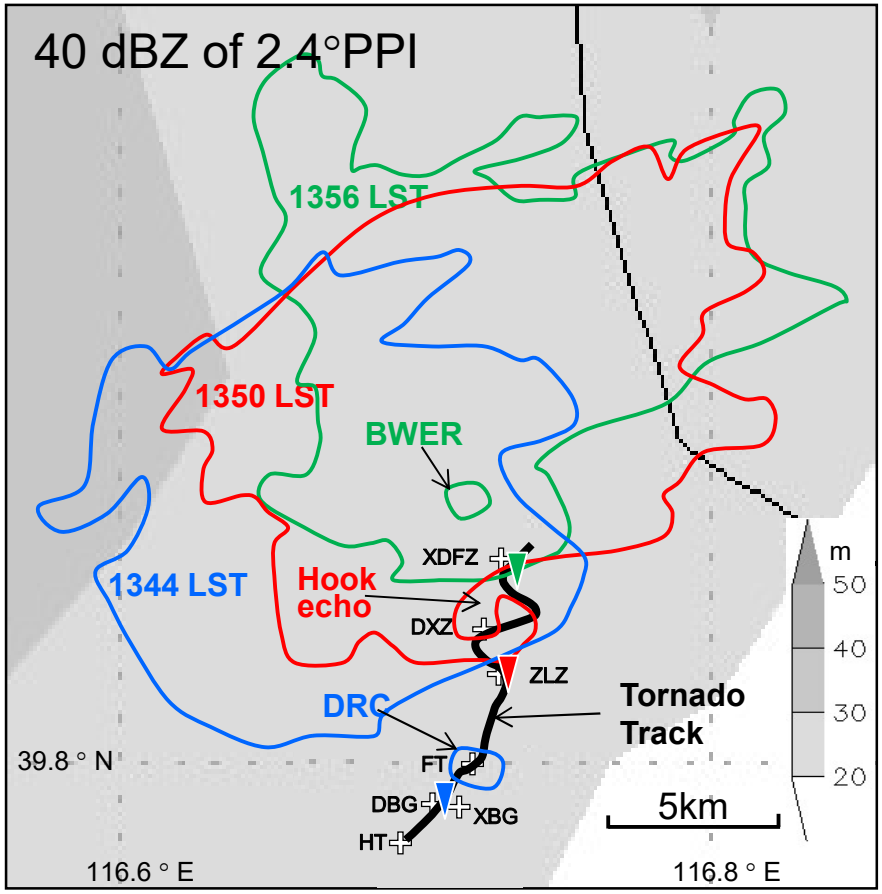


强度变化

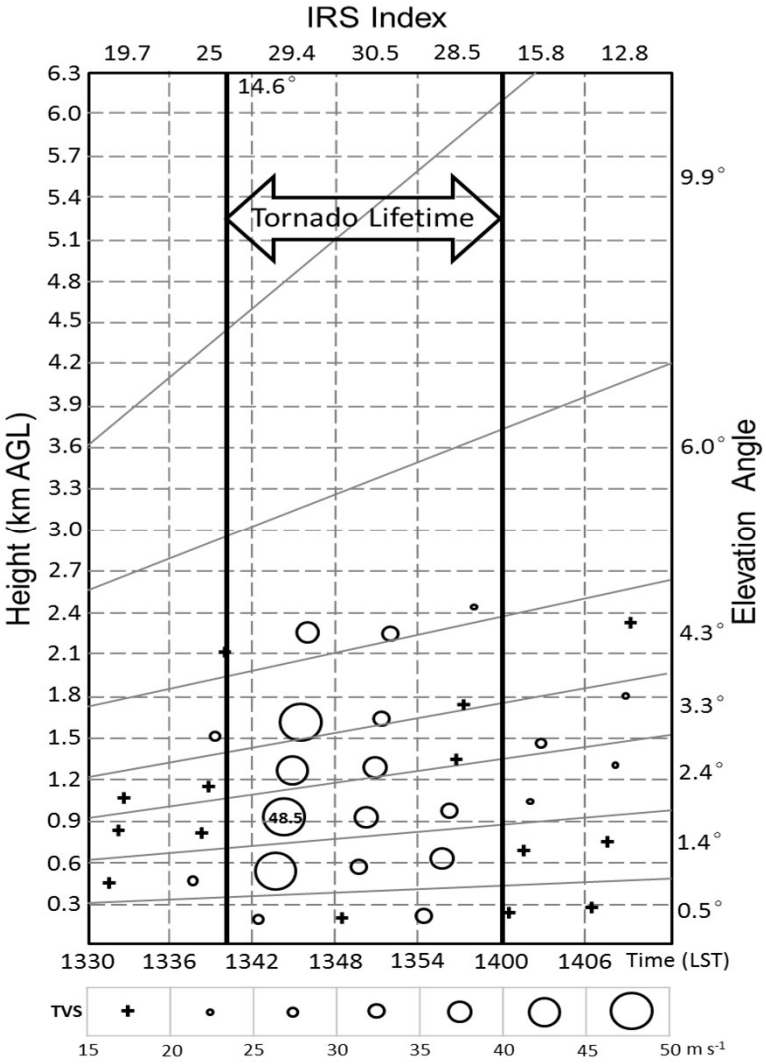


TVS: 龙卷涡旋

与龙卷的关系



强度变化



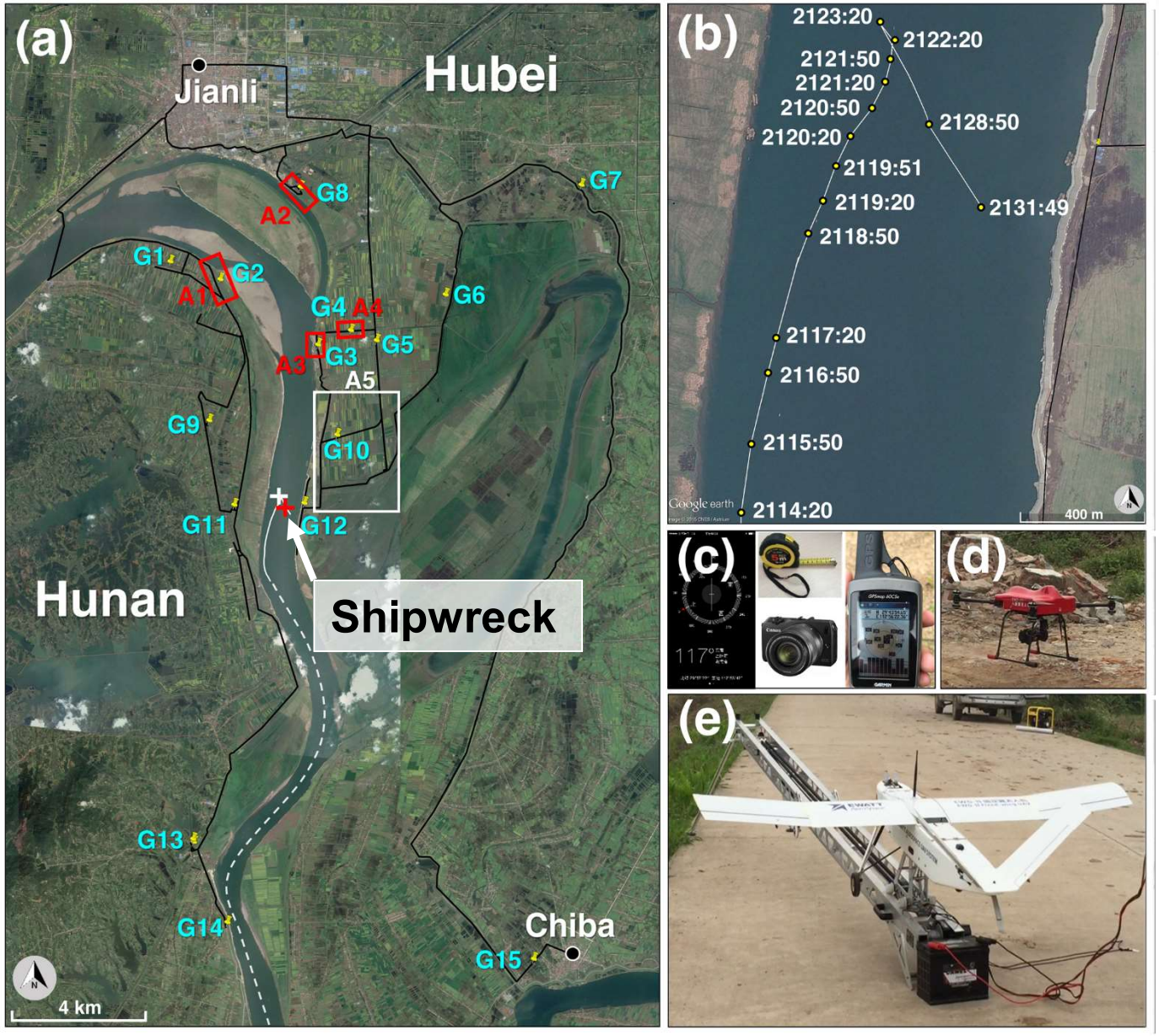
“东方之星”倾覆

2015.6.1

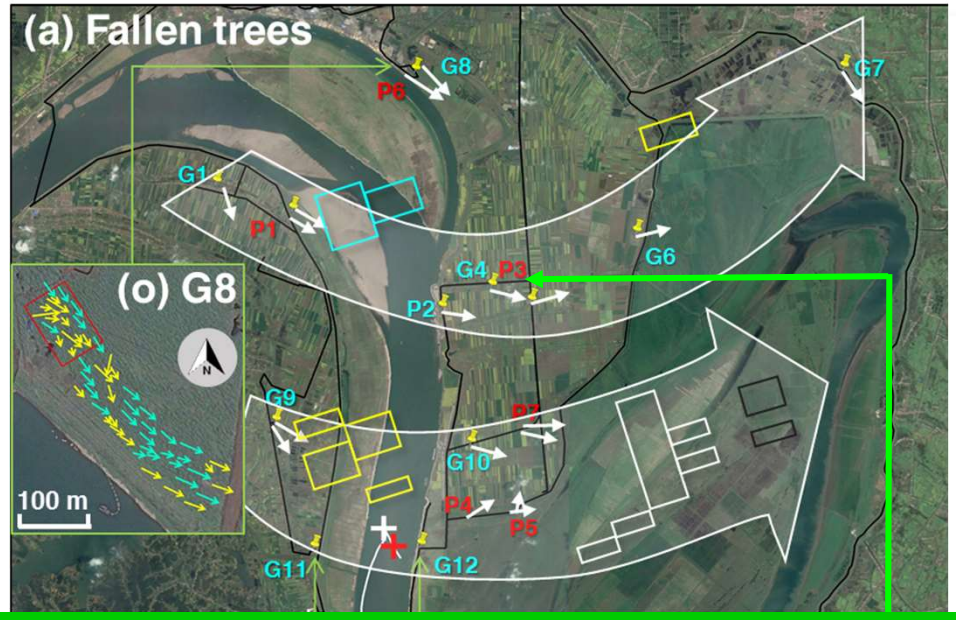
灾害调查

北京大学
南京大学
国家气象中心
海事局
湖北省气象局
监利气象局
等

灾害调查


(a)
Jianli
Hubei
Hunan
Chiba
Shipwreck
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
G11
G12
G13
G14
G15
A1
A2
A3
A4
A5
4 km
(b)
2123:20
2122:20
2121:50
2121:20
2120:50
2120:20
2128:50
2119:51
2119:20
2131:49
2118:50
2117:20
2116:50
2115:50
2114:20
Google earth
400 m
(c)
(d)
(e)

灾害调查

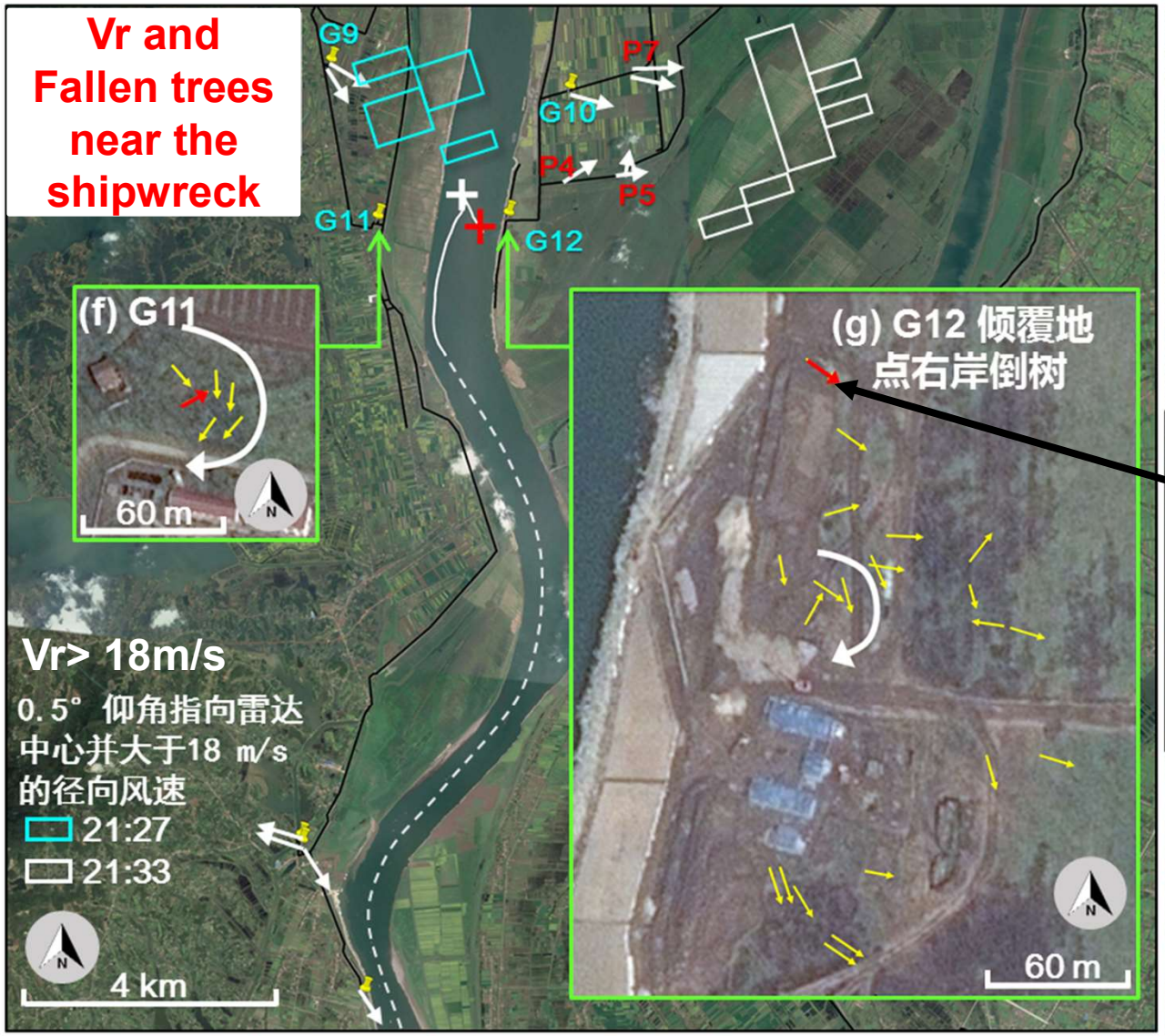

(a) Fallen trees
G8
P6
G7
G1
P1
G6
G4
P3
P2
(o) G8
G9
P7
G10
100 m
P4
P5
G11
G12

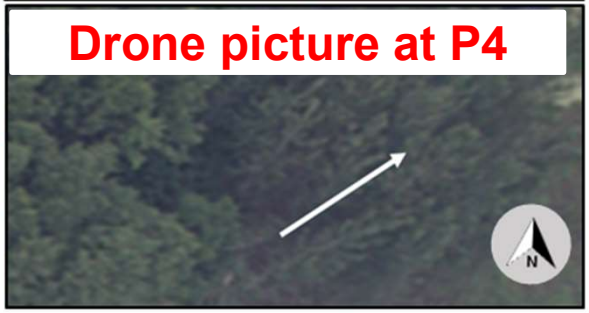

(a) 下击暴流地面图片
200m×70 m


(b) 下击暴流航拍图片

下击暴流

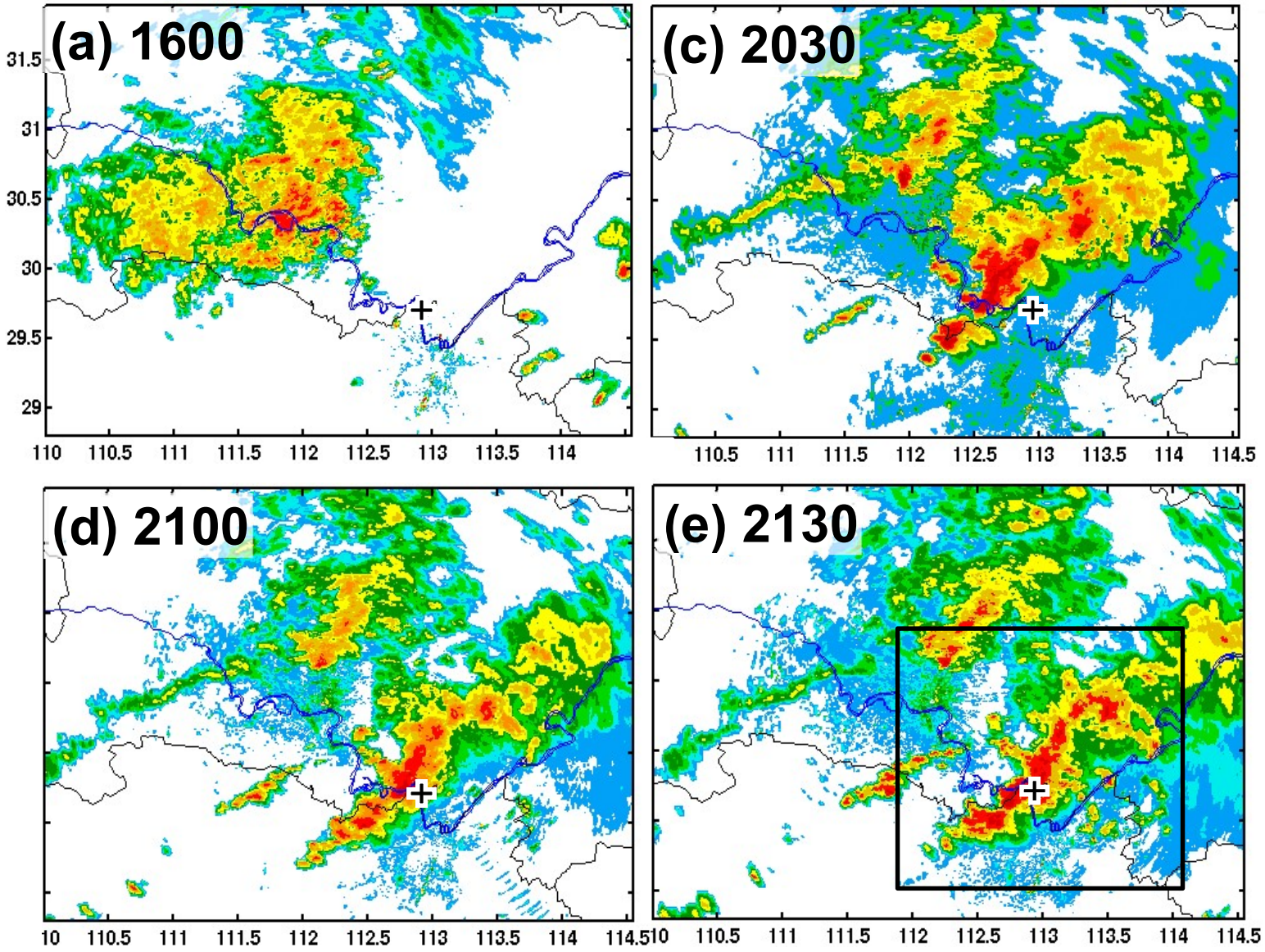
倾覆地点附近： 灾害不连续，无雷暴尺度辐合风





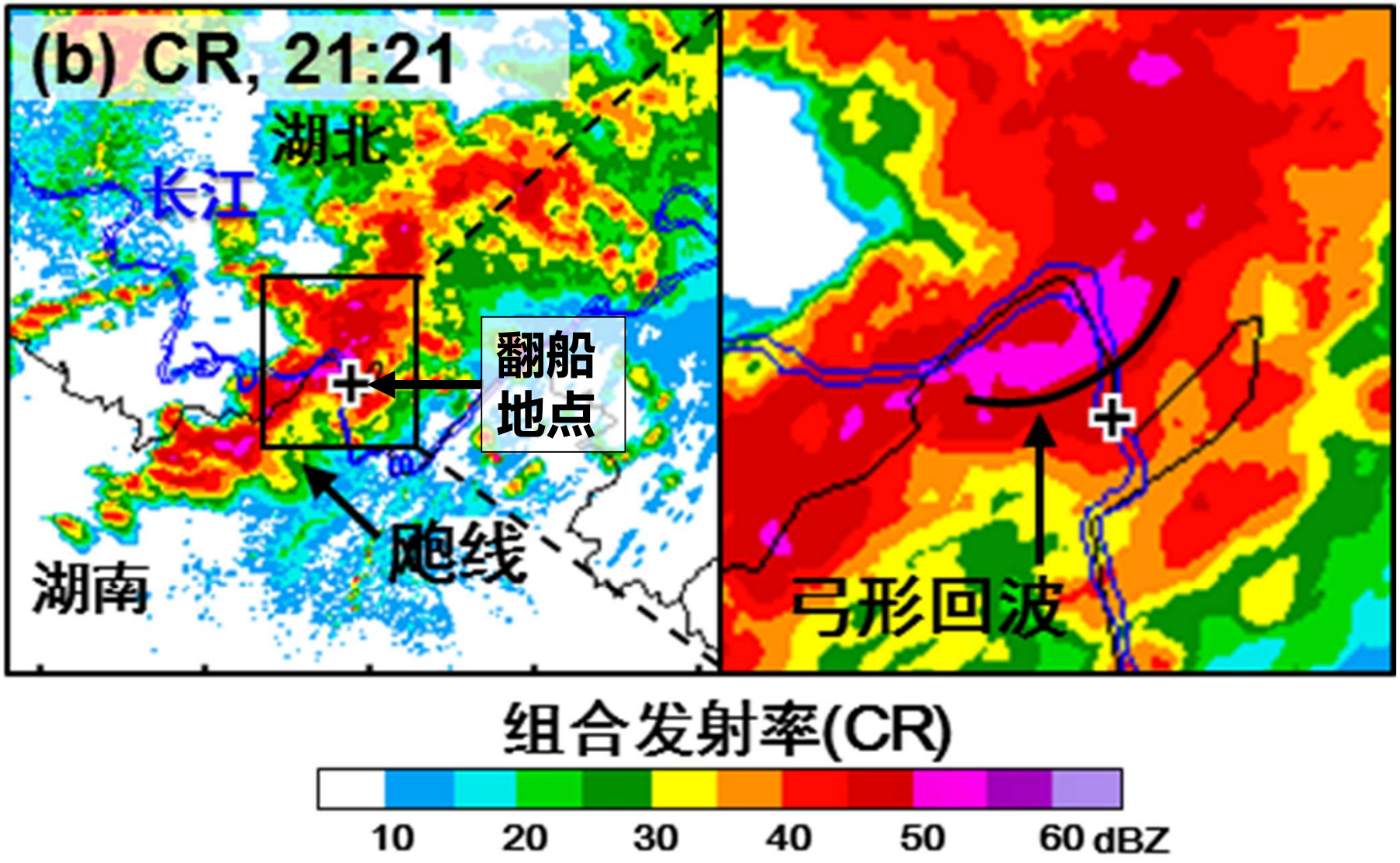
Snapped hardwood trees: 49 m/s (EF1: 38-49 m/s) ± 18 m/s ⇒ At least 31 m/s

雷达反射率演变：飑线

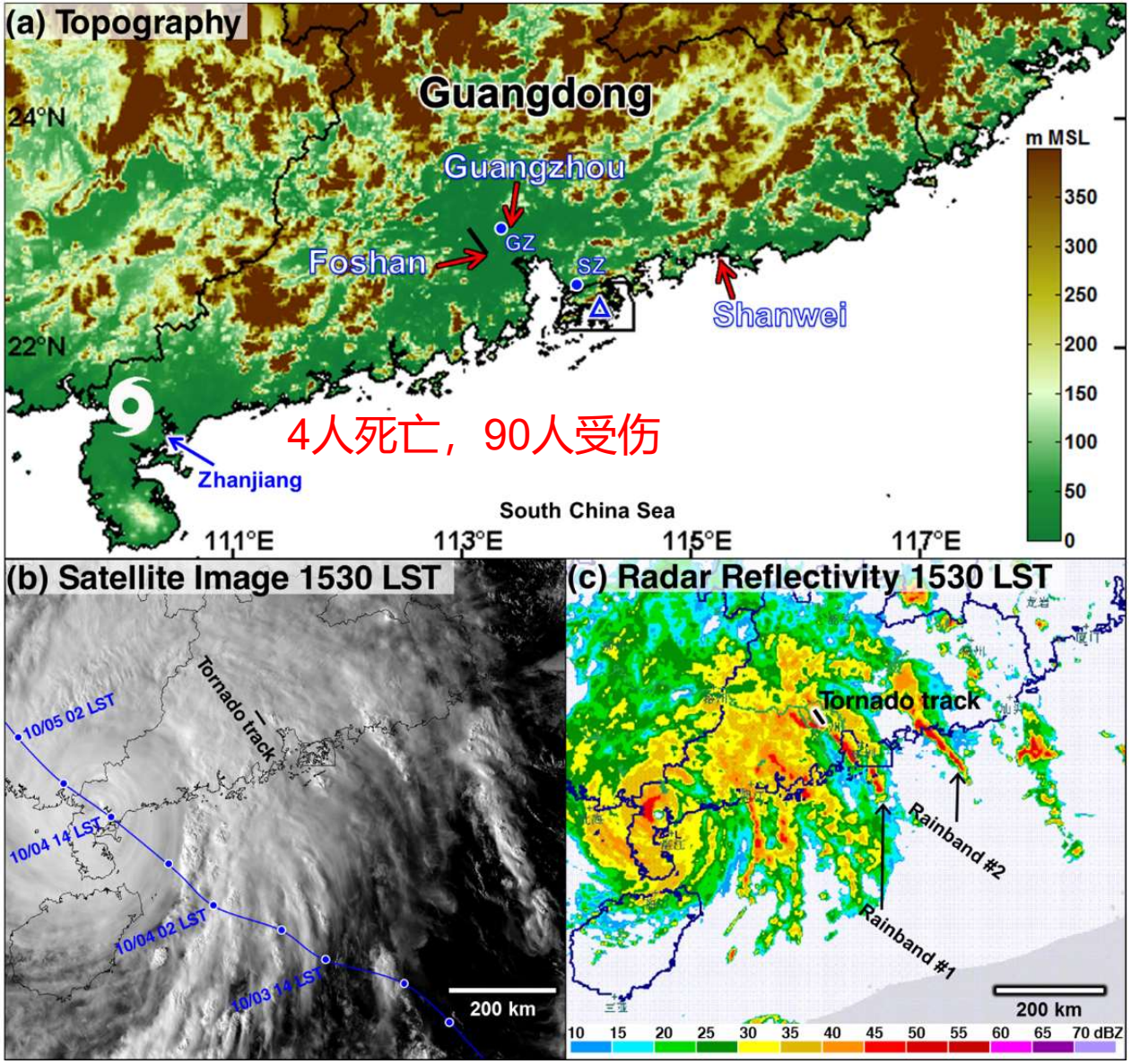

(a) 1600
(c) 2030
(d) 2100
(e) 2130
31.5
31
30.5
30
29.5
29
110
110.5
111
111.5
112
112.5
113
113.5
114
114.5

飑线：雷达反射率演变

(Meng,Yao,Bai,et al., Science Bulletin,2015)

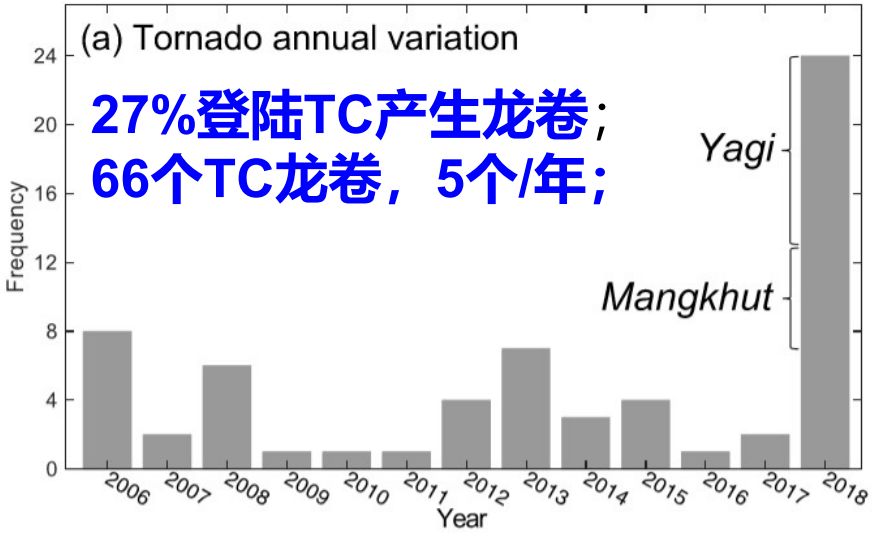


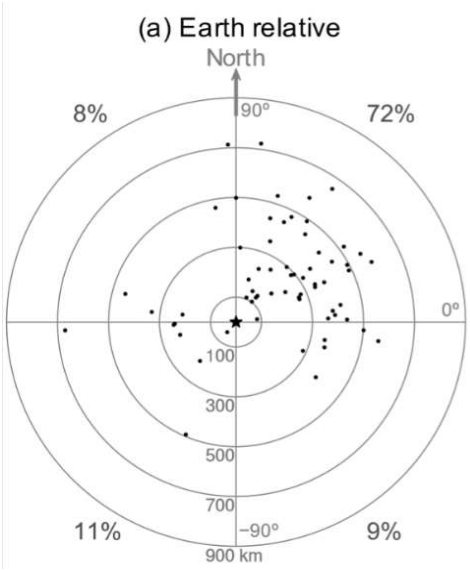
2015年彩虹台风造成的佛山EF3龙卷

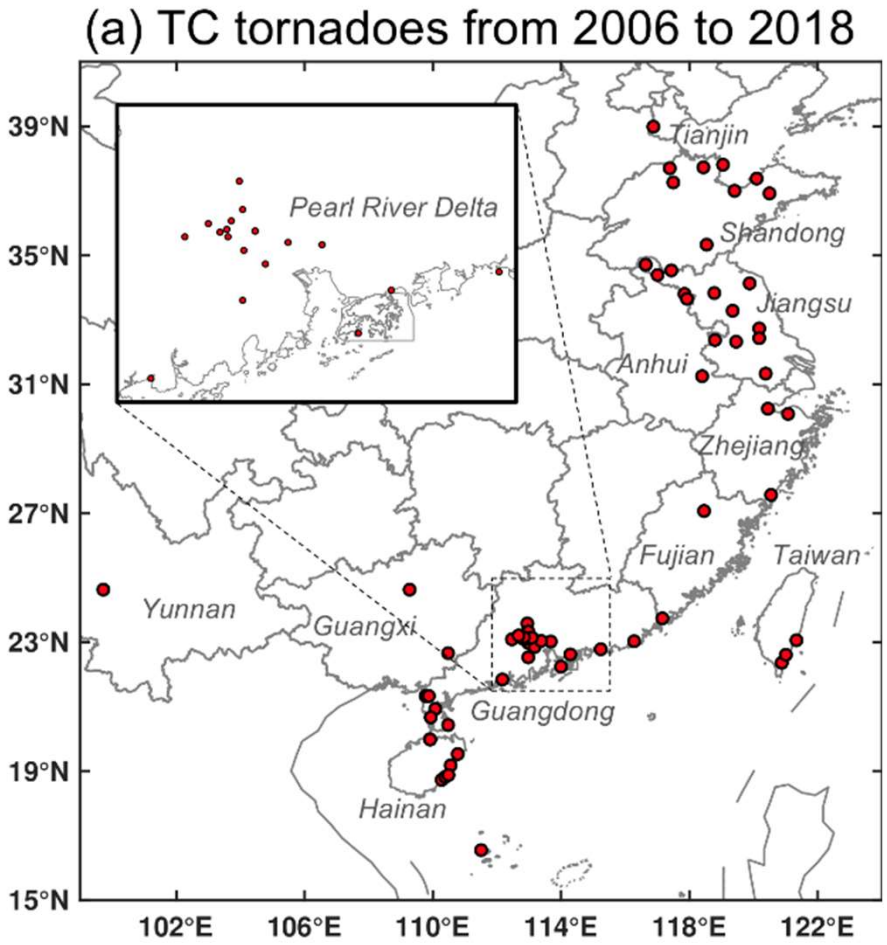


- 22 tornadoes were reported in Foshan during 2005-2014 (Huang et al. 2014)
- About 50% of which were spawned in the environment of landfall tropical cyclone.

中国登陆TC龙卷的统计特征







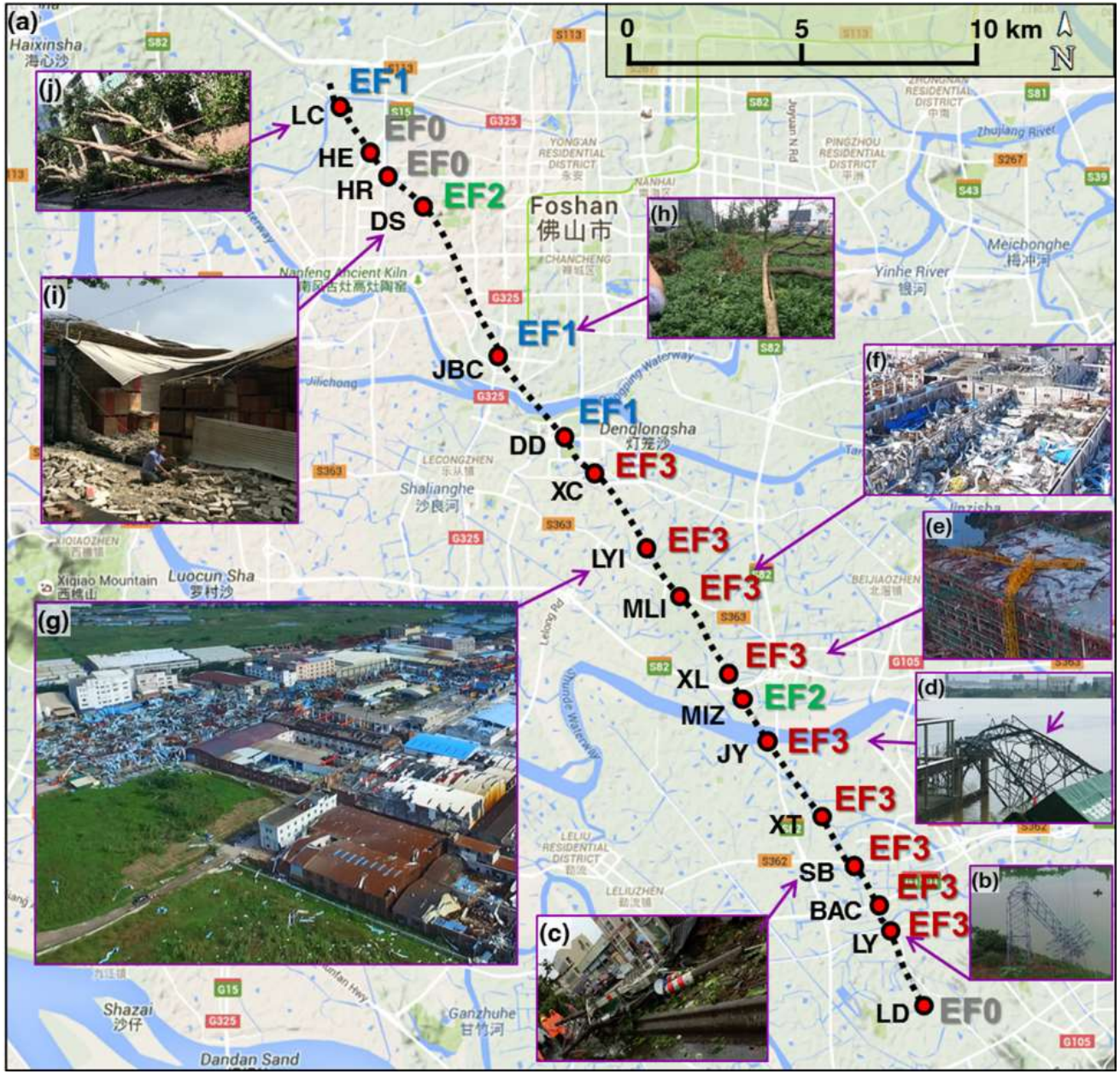
佛山龙卷现场灾害调查

参加单位：北京大学
佛山市局
佛山龙卷中心
顺德气象局
广东省局
广州市局
南京大学
国家气象中心

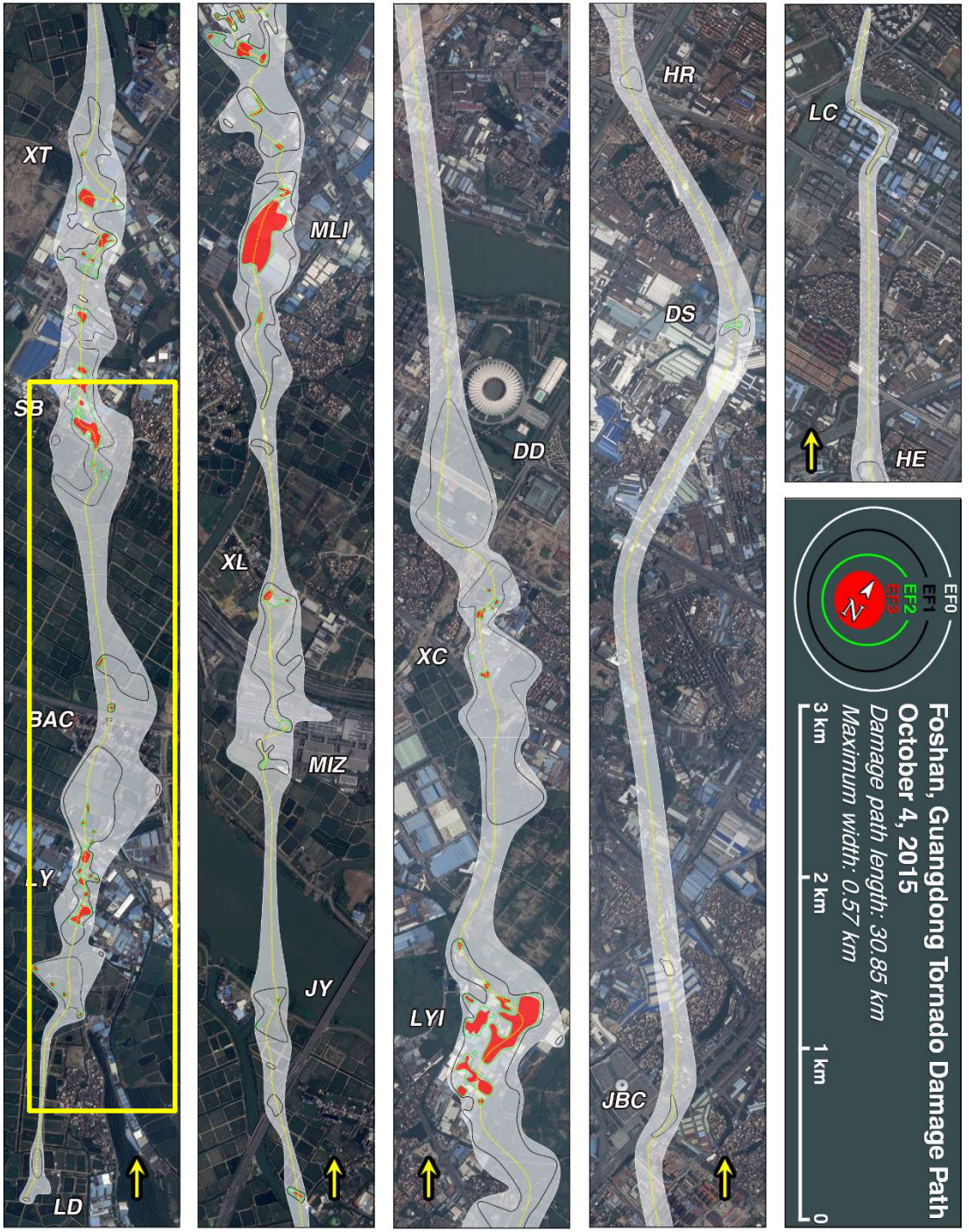
调研时间：10月5-10日

龙卷路径

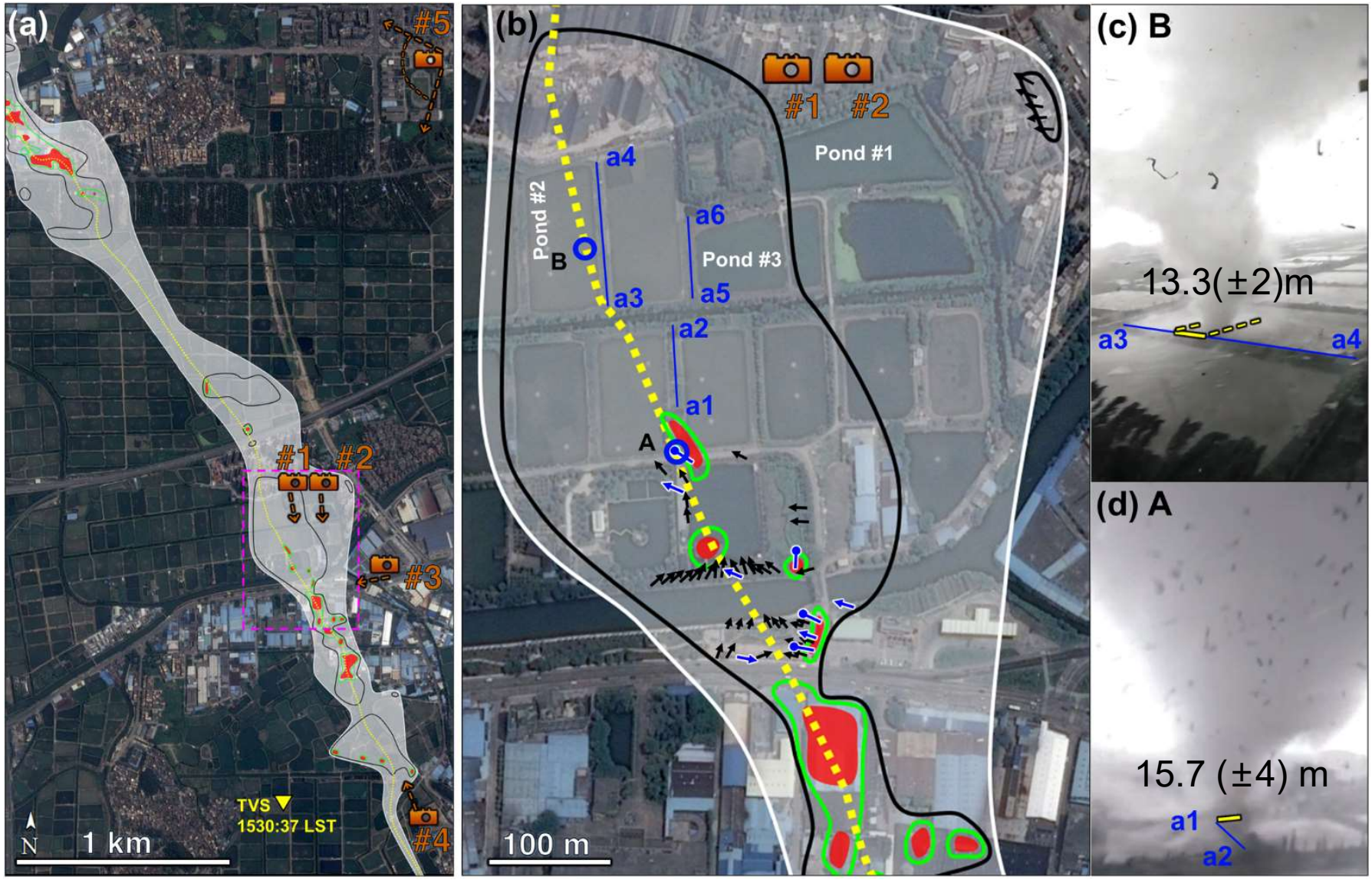
- 30km长
- 持续~30分钟 (1530-1600)



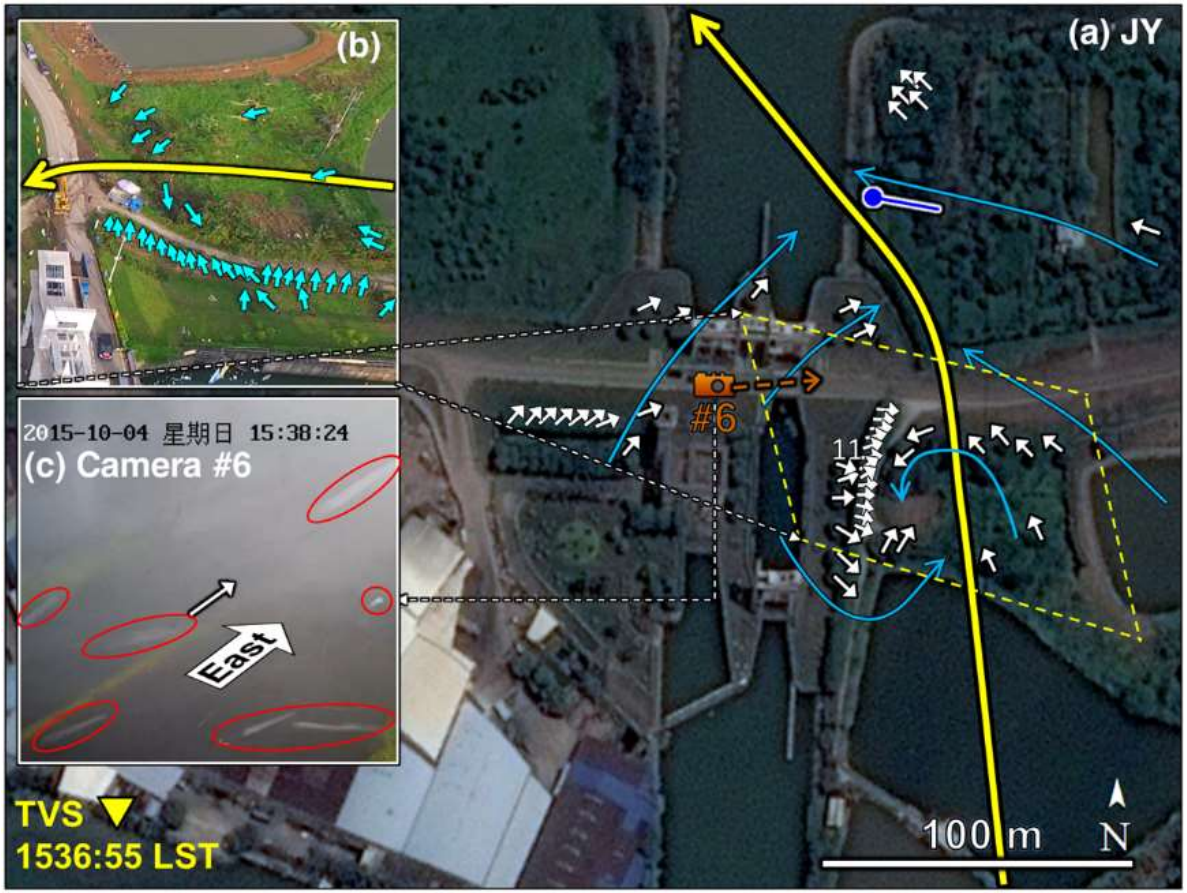
龙卷灾害
EF级分布

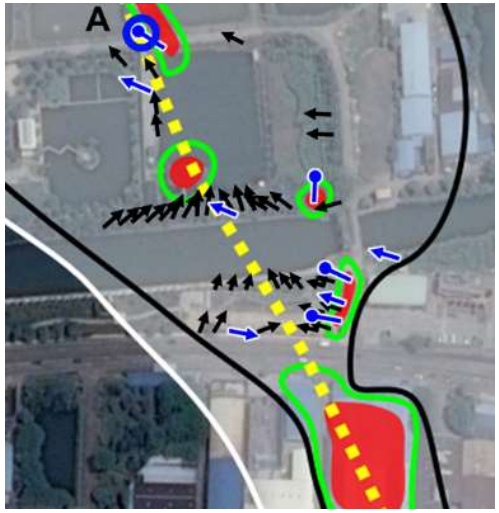

XT
SB
BAC
LY
LD
MLI
XL
MIZ
JY
DD
XC
LYI
HR
DS
JBC
LC
HE
EF0
EF1
EF2
EF3
Foshan, Guangdong Tornado Damage Path
October 4, 2015
Damage path length: 30.85 km
Maximum width: 0.57 km
3 km
2 km
1 km
0

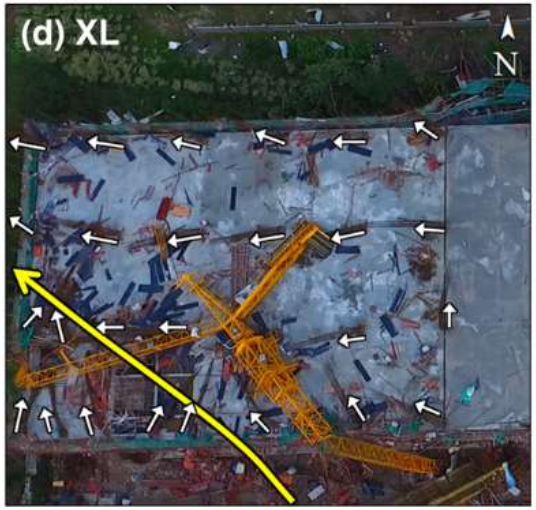
龙卷漏斗云地面尺度和EF2范围相似



漏斗云附近和外围风向

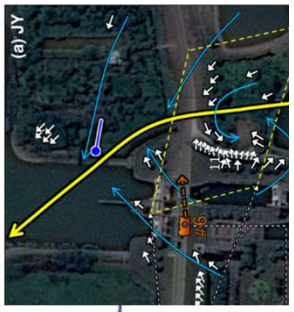

(a) JY
(b)
2015-10-04 星期日 15:38:24
(c) Camera #6
East
#6
TVS
1536:55 LST
100 m
N


A

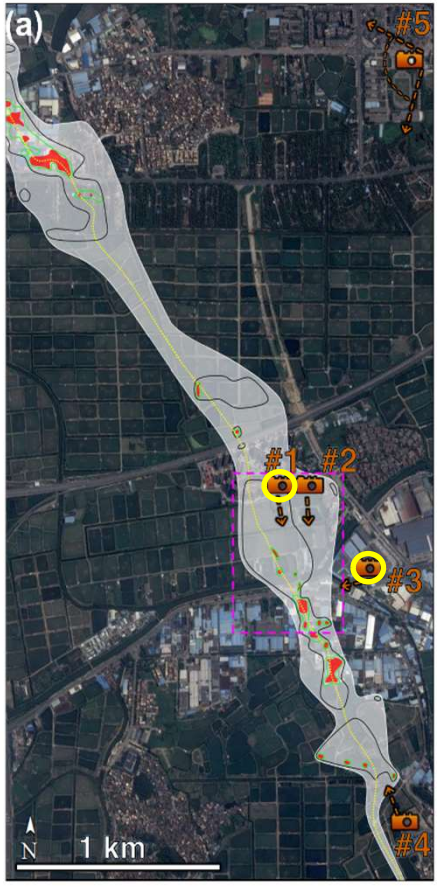

(d) XL
N

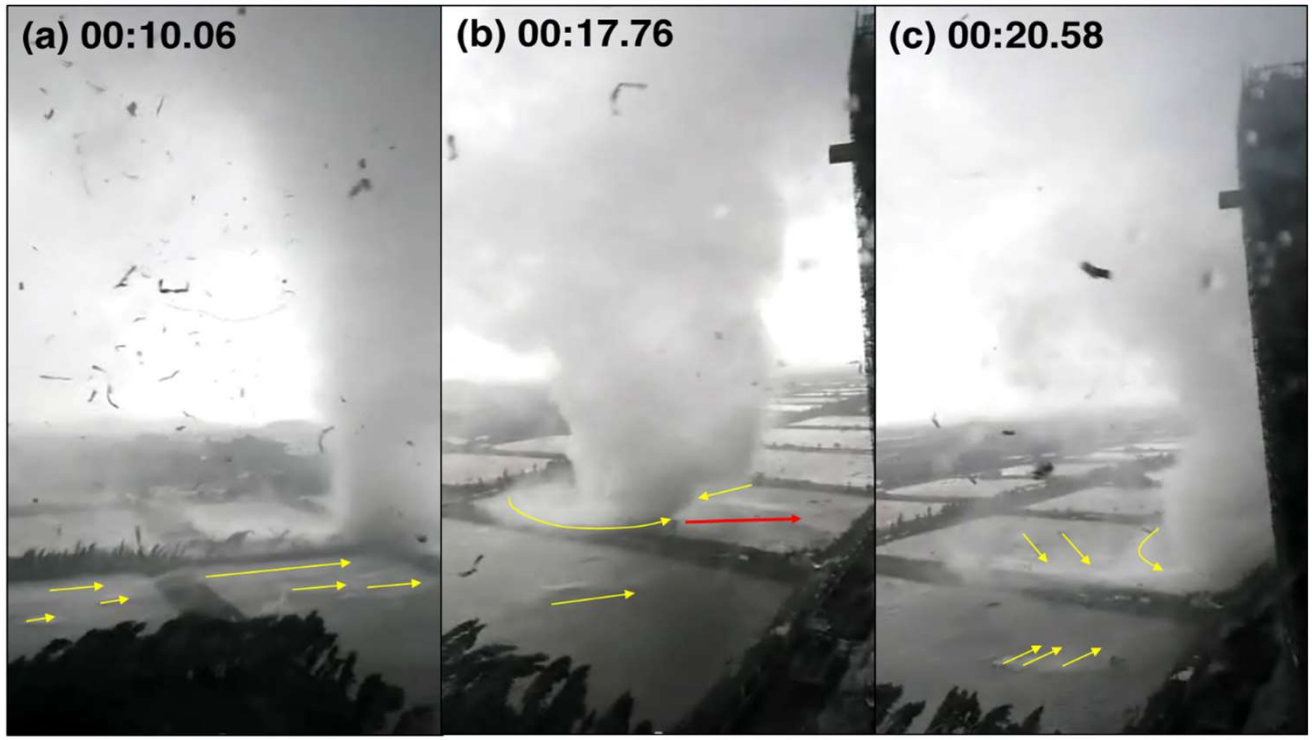

(e) DD
N
50 m

#6龙卷视频



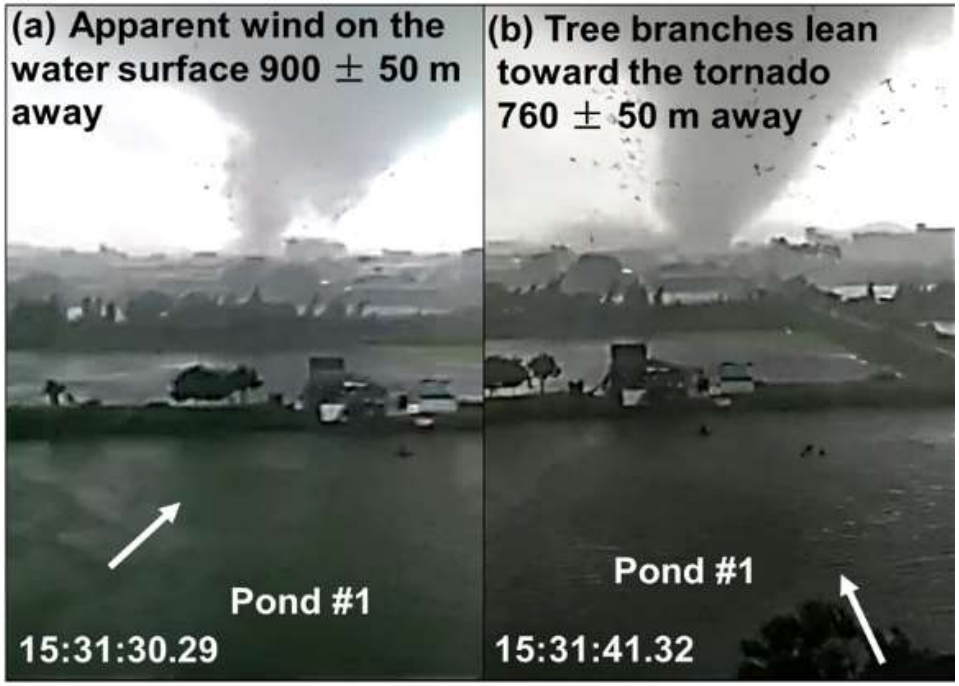
漏斗云附近和外围风向


(a)
#5
#1
#2
#3
#4
N
1 km

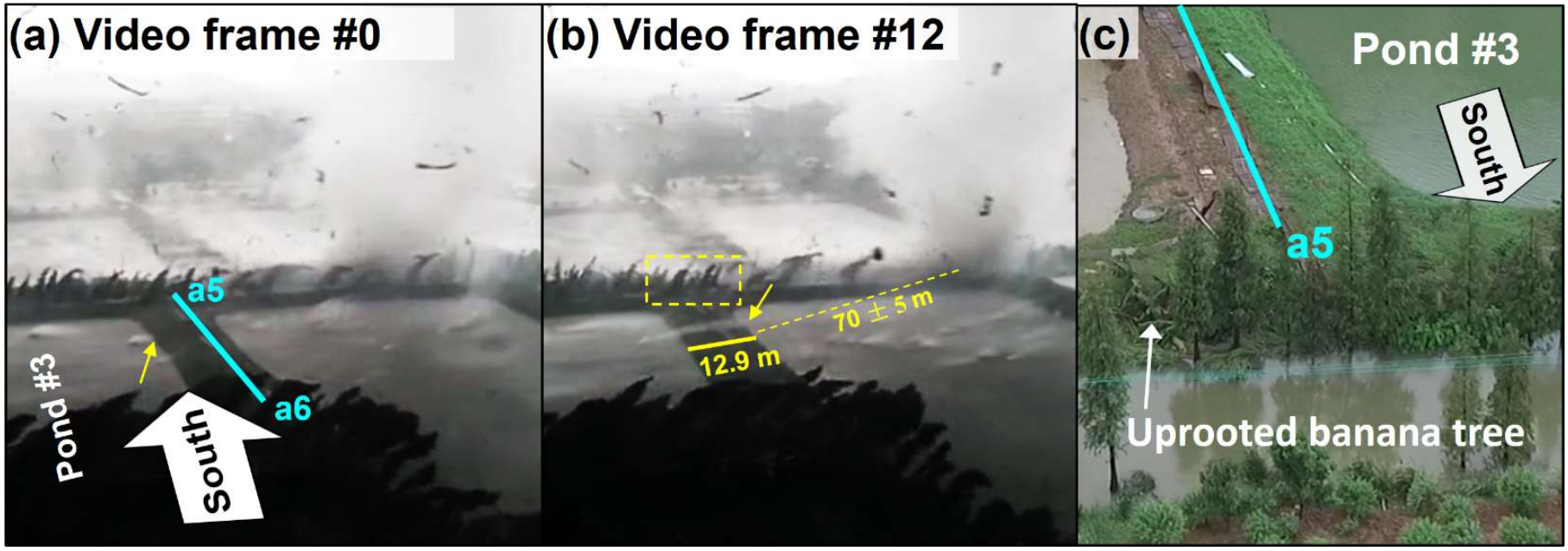

(a) 00:10.06
(b) 00:17.76
(c) 00:20.58


(d) 00:07.61
B
A
(e) 00:07.73
B
A
(f) 00:10.43
A

距龙卷中心不同距离处风影响特征



基于视频和灾害估计的龙卷近地面风速



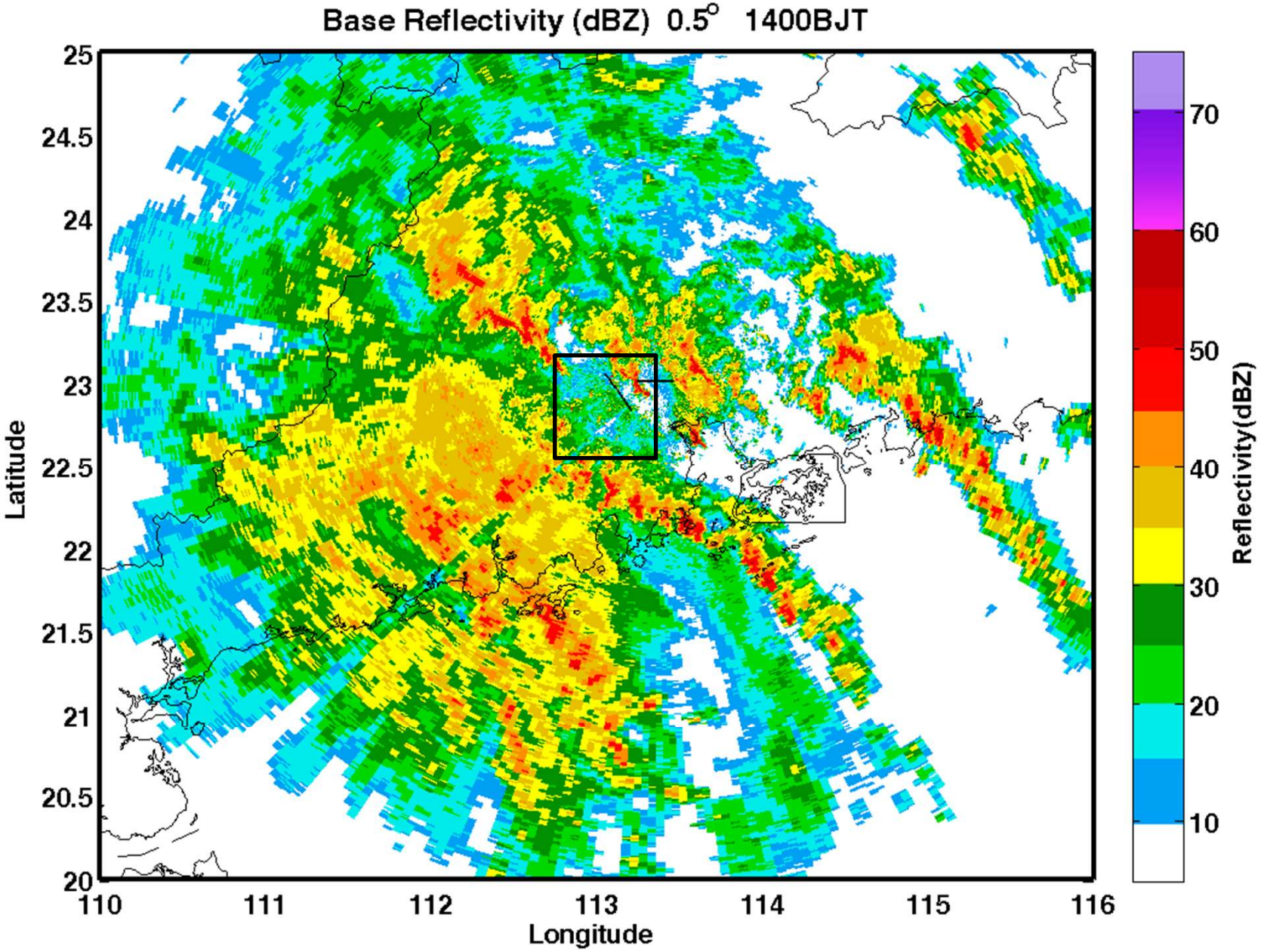
32.2 (±2.9) m s^{-1}

EF0 (29–38 m s^{-1})

龙卷涡旋两次分裂

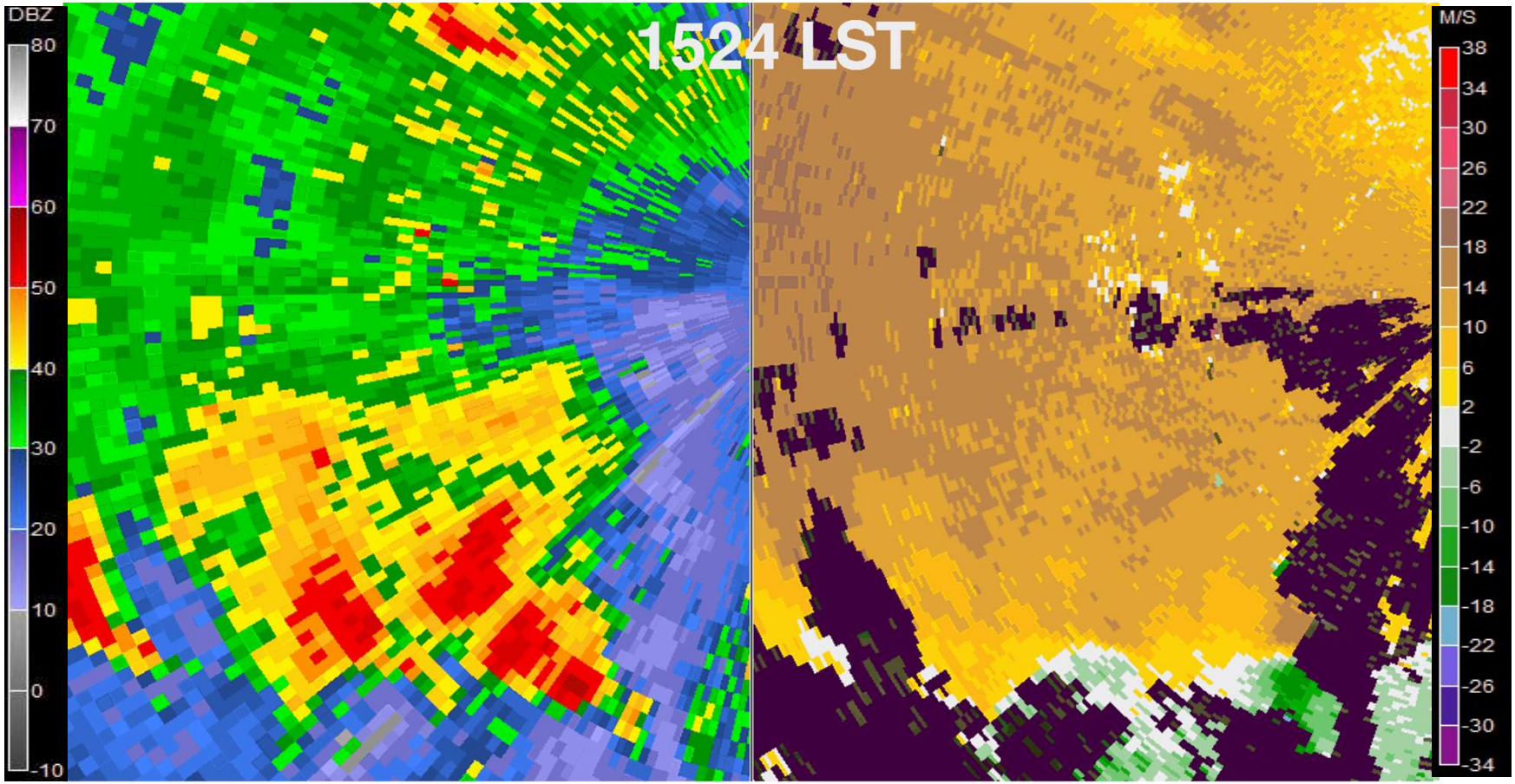
龙卷水平涡管

雷达演变


Base Reflectivity (dBZ) 0.5° 1400BJT
Latitude
Longitude
25
24.5
24
23.5
23
22.5
22
21.5
21
20.5
20
110
111
112
113
114
115
116
Reflectivity(dBZ)
70
60
50
40
30
20
10

雷达演变

0.5°　　反射率　　径向速度

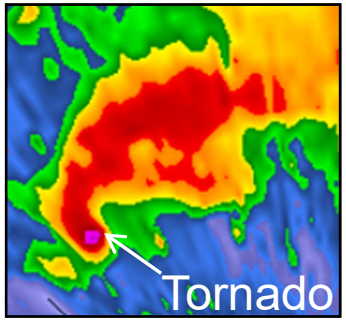


微超级单体

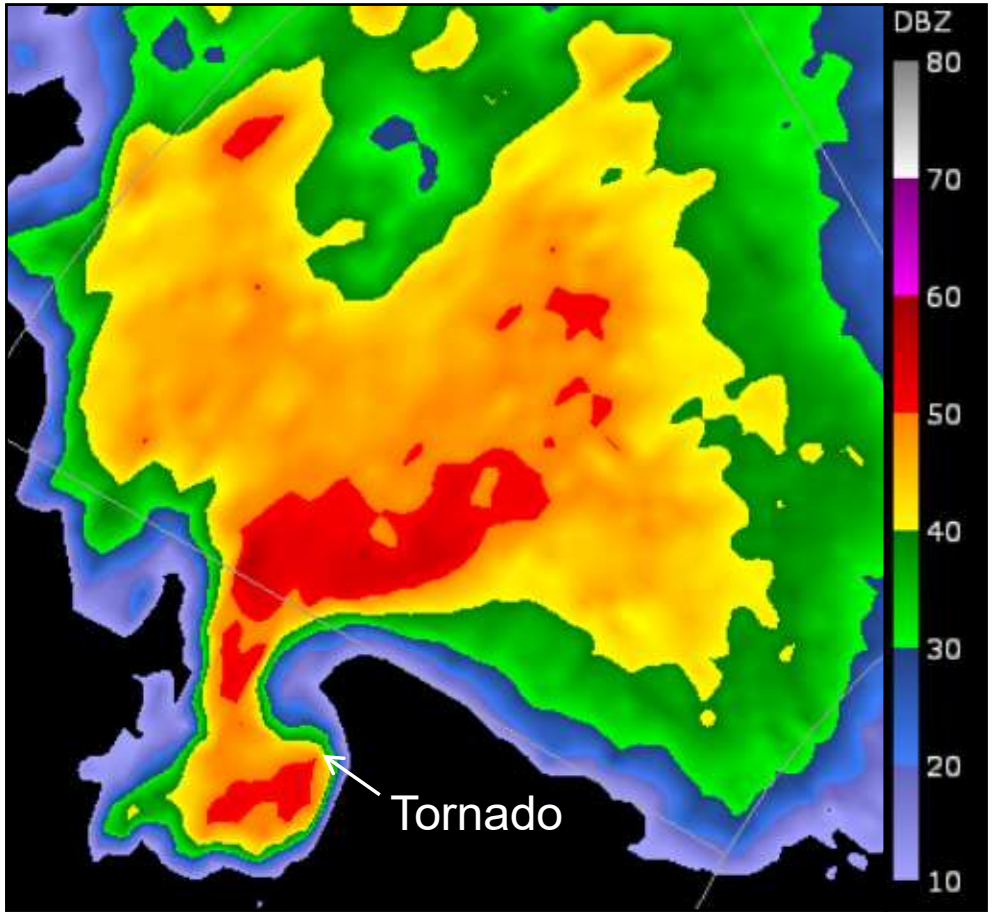
TC龙卷母体：79%为超级单体 (Edwards 2012)。

50 km

2015广东佛山 EF3 TC龙卷



2016江苏盐城阜宁 EF4 中纬度龙卷



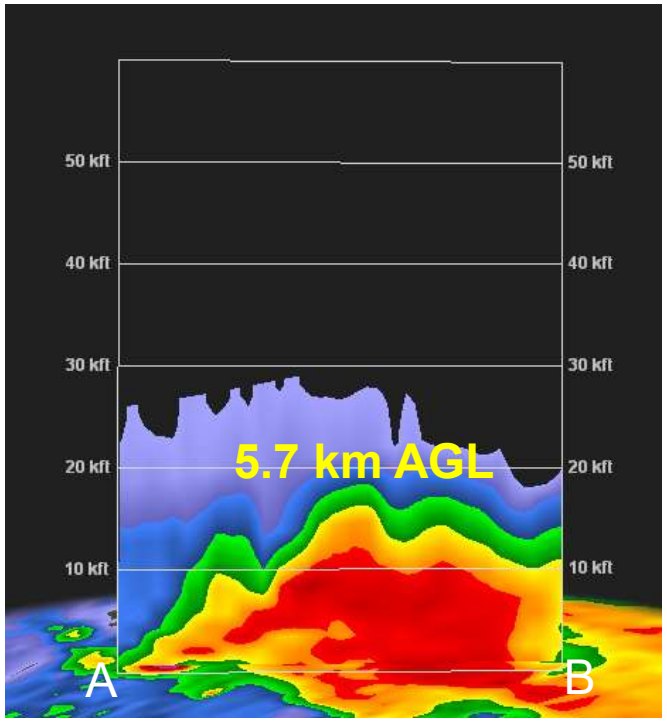
- **水平、垂直空间尺度均较小**
- **Low-echo top**

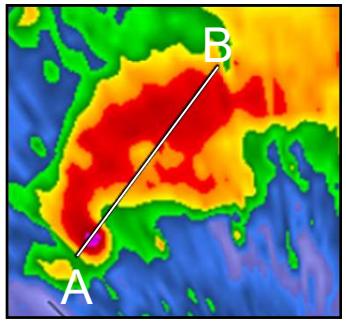
可能原因：
Shallower instability

微超级单体

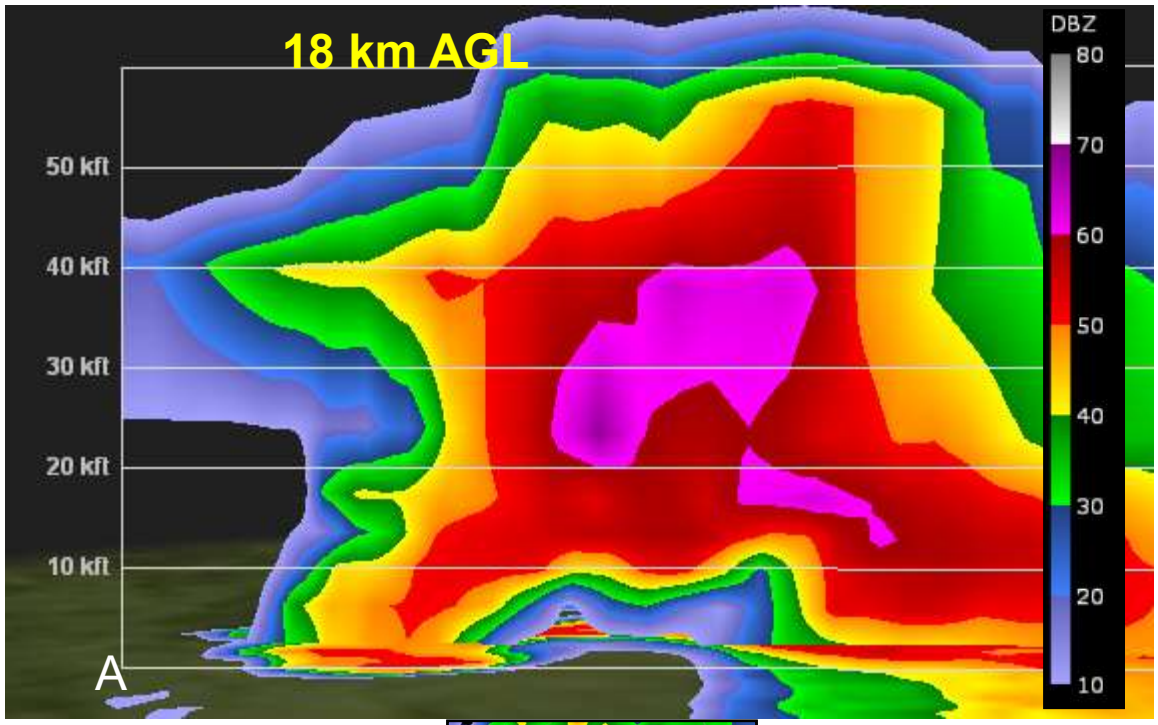
超级单体的垂直剖面对比。

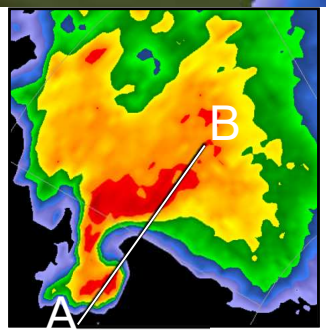
2015广东佛山 EF3 TC龙卷



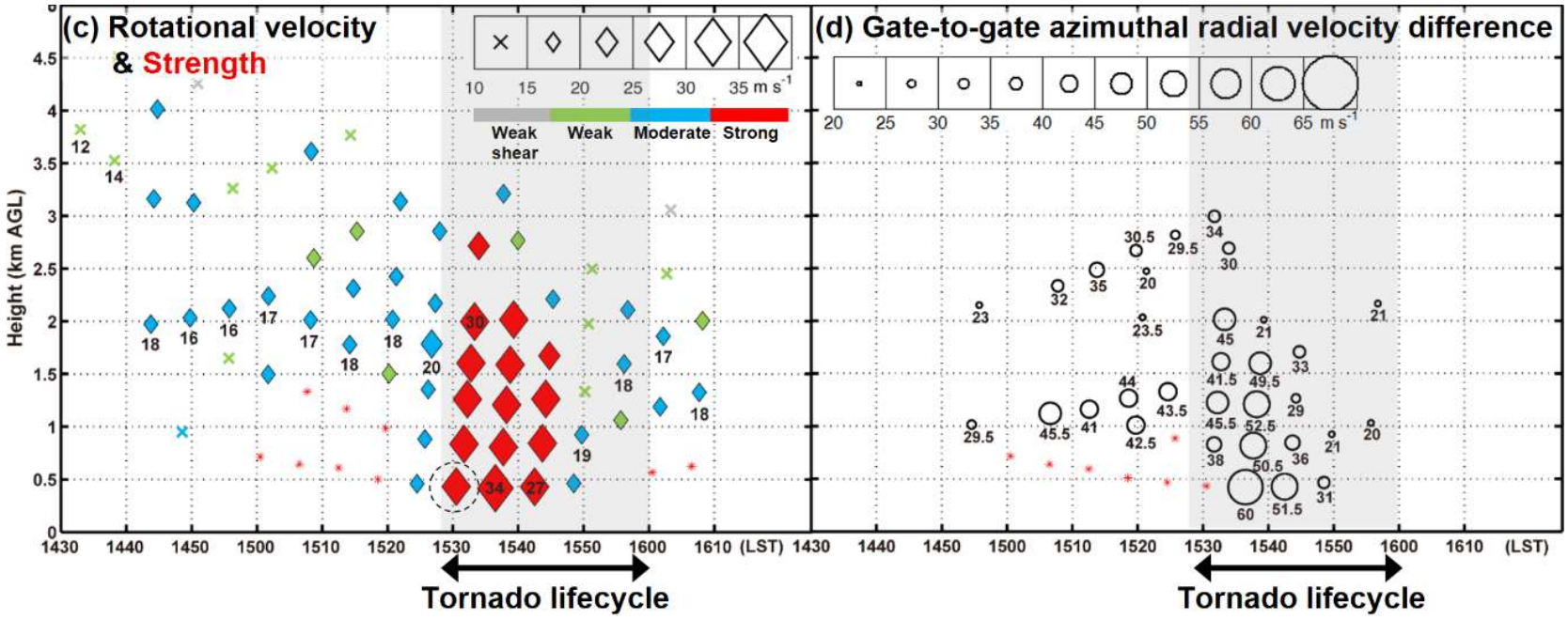


2016江苏盐城阜宁 EF4 中纬度龙卷

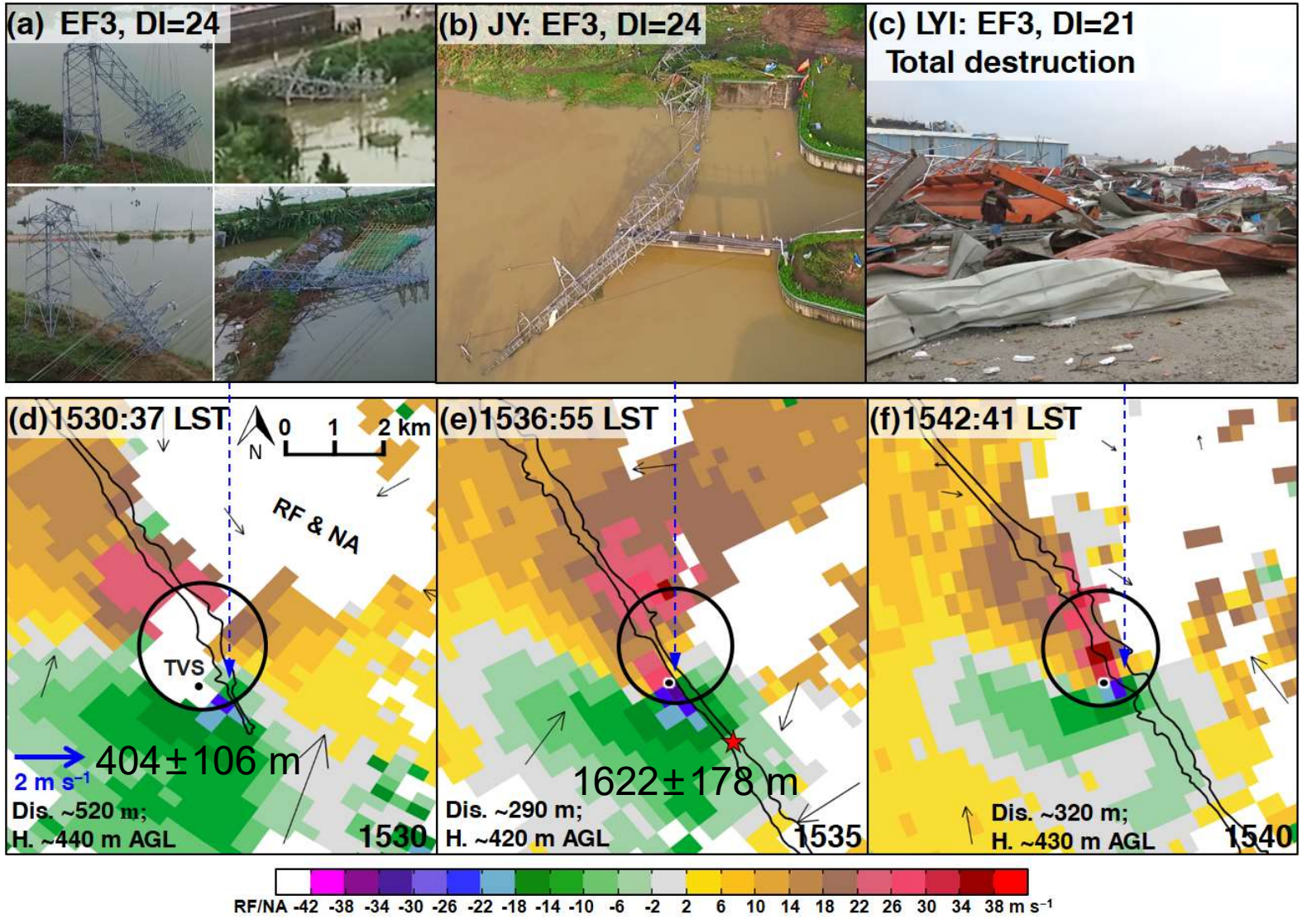




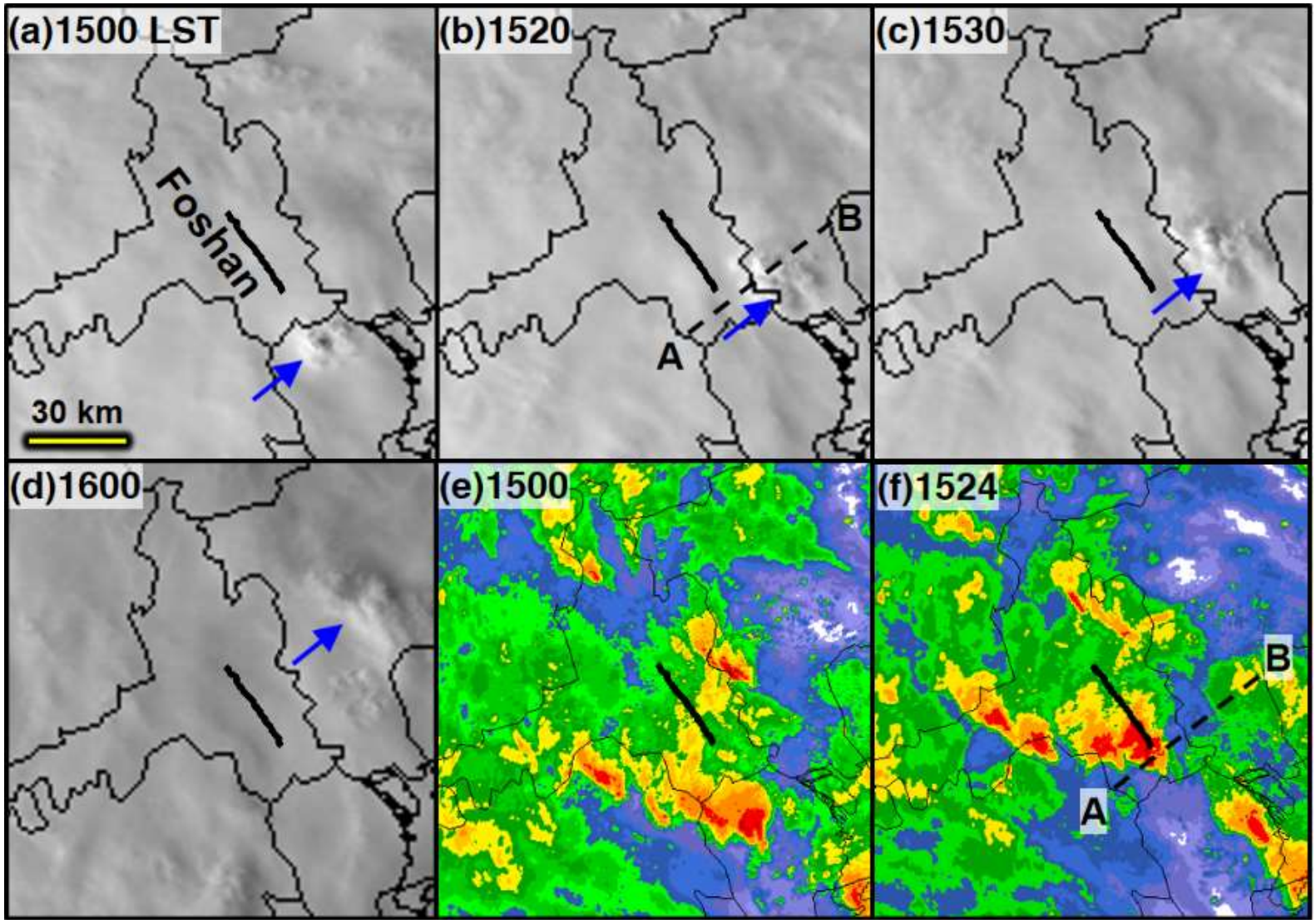
中气旋以及TVS强度的演变



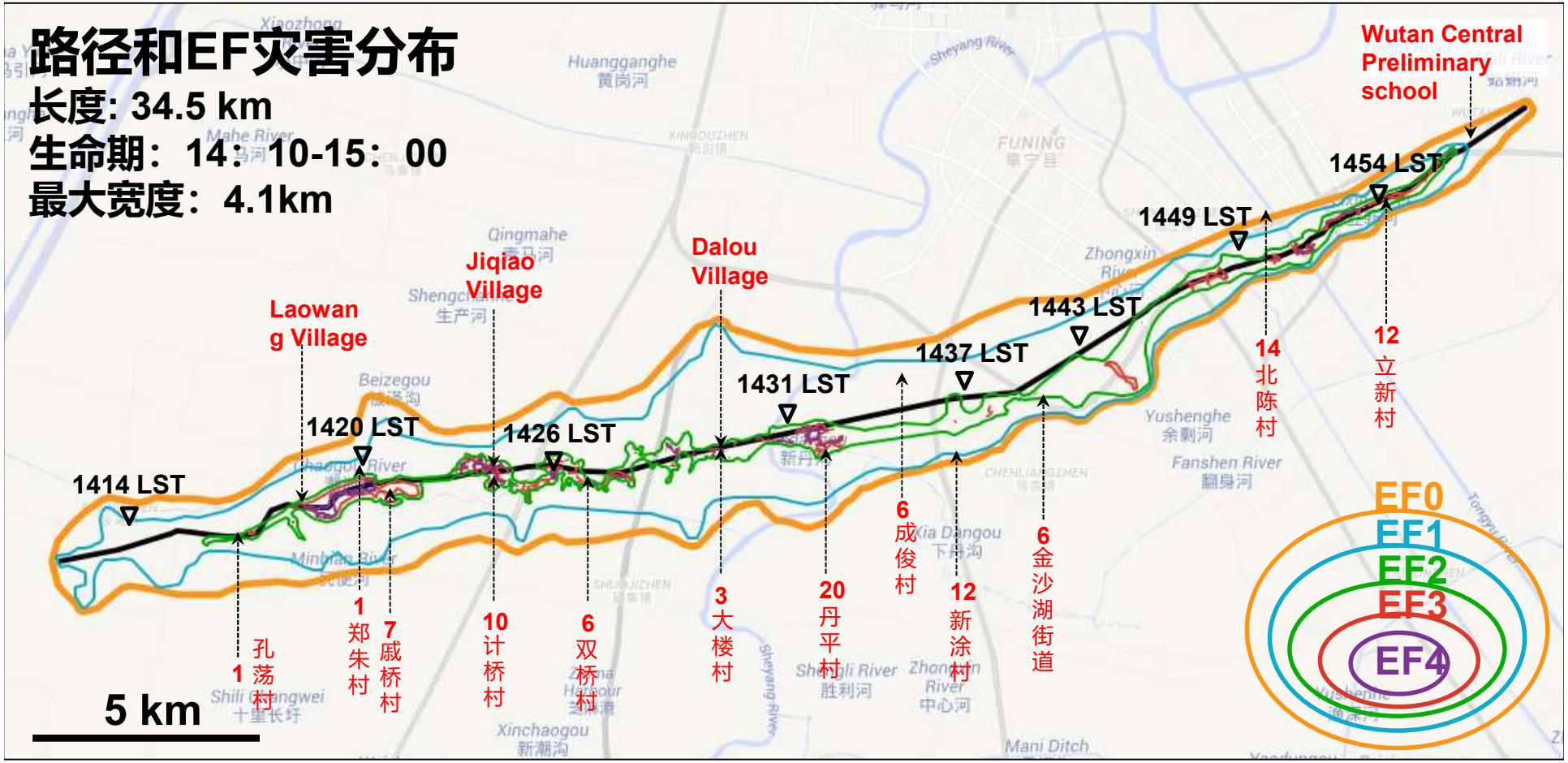
TVS和龙卷位置的关系



龙卷超级单体的垂直结构



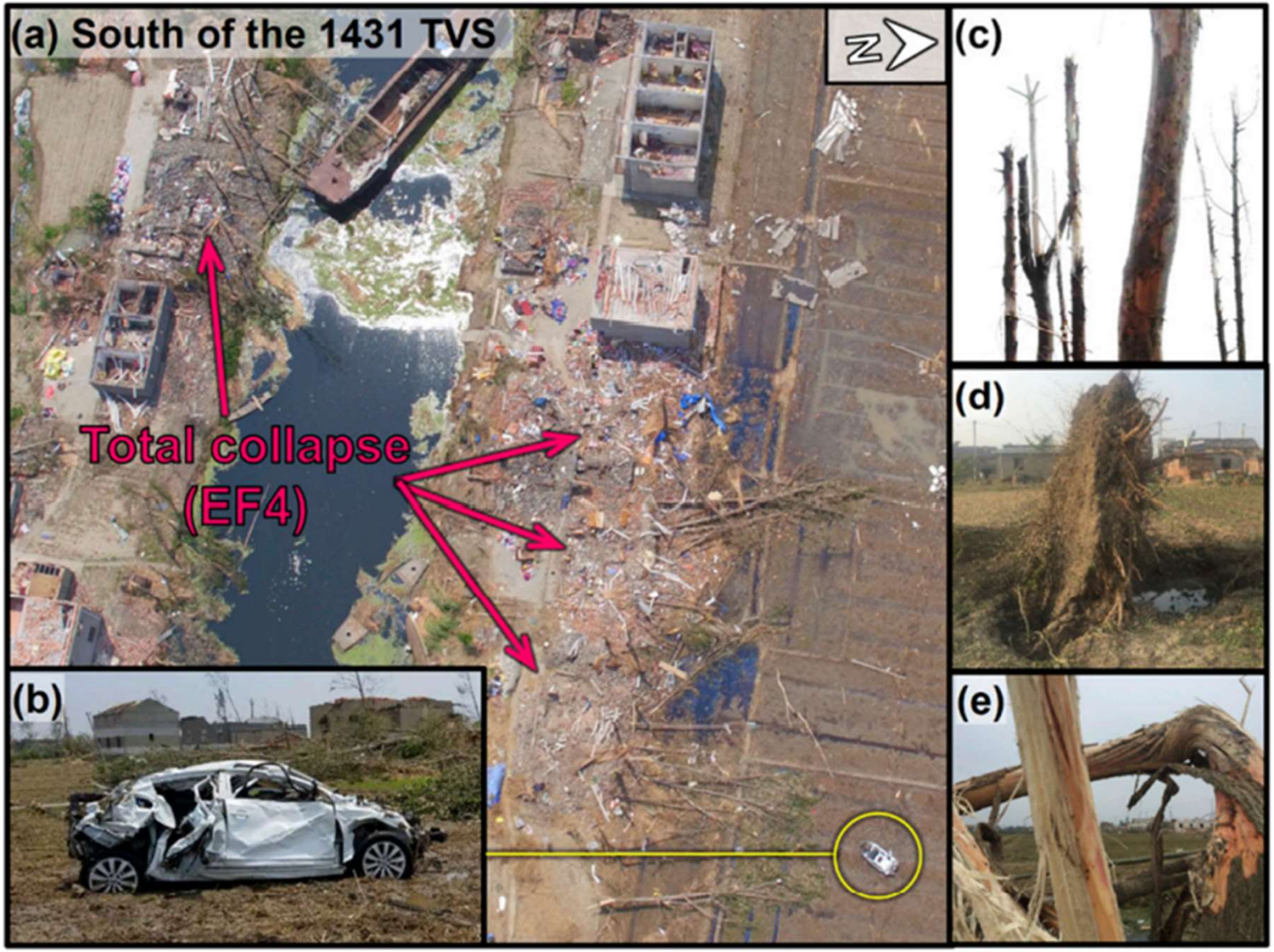
盐城阜宁龙卷（2016年6月23日）



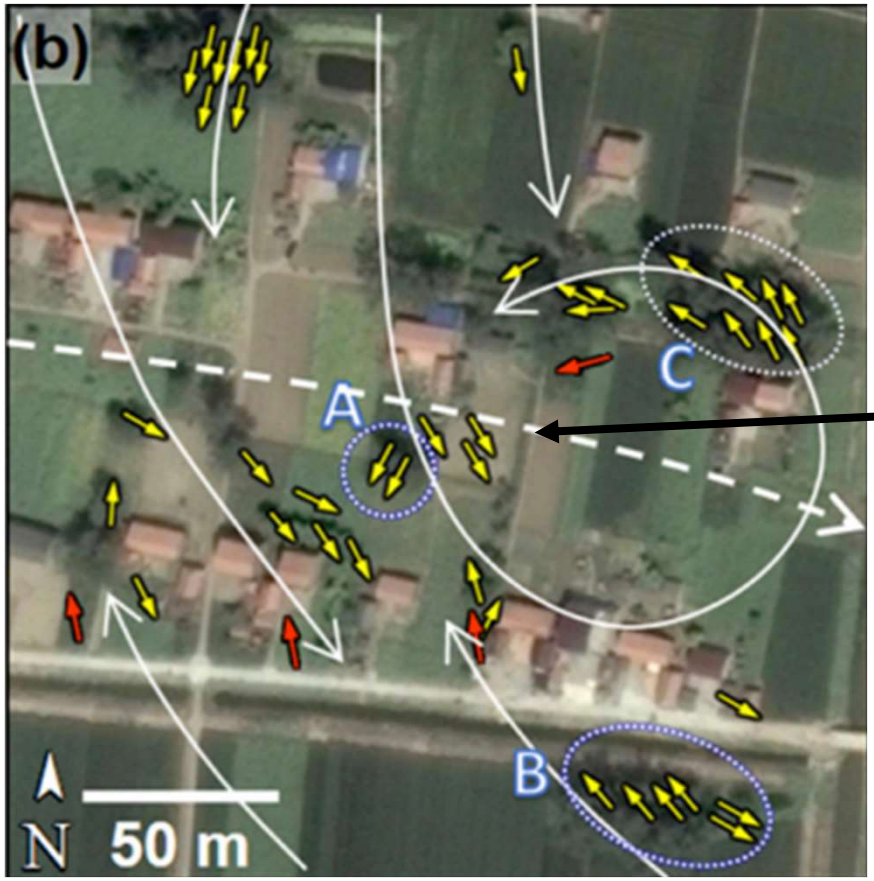
广东和北大的灾调团队

双桥村航拍视频

EF4

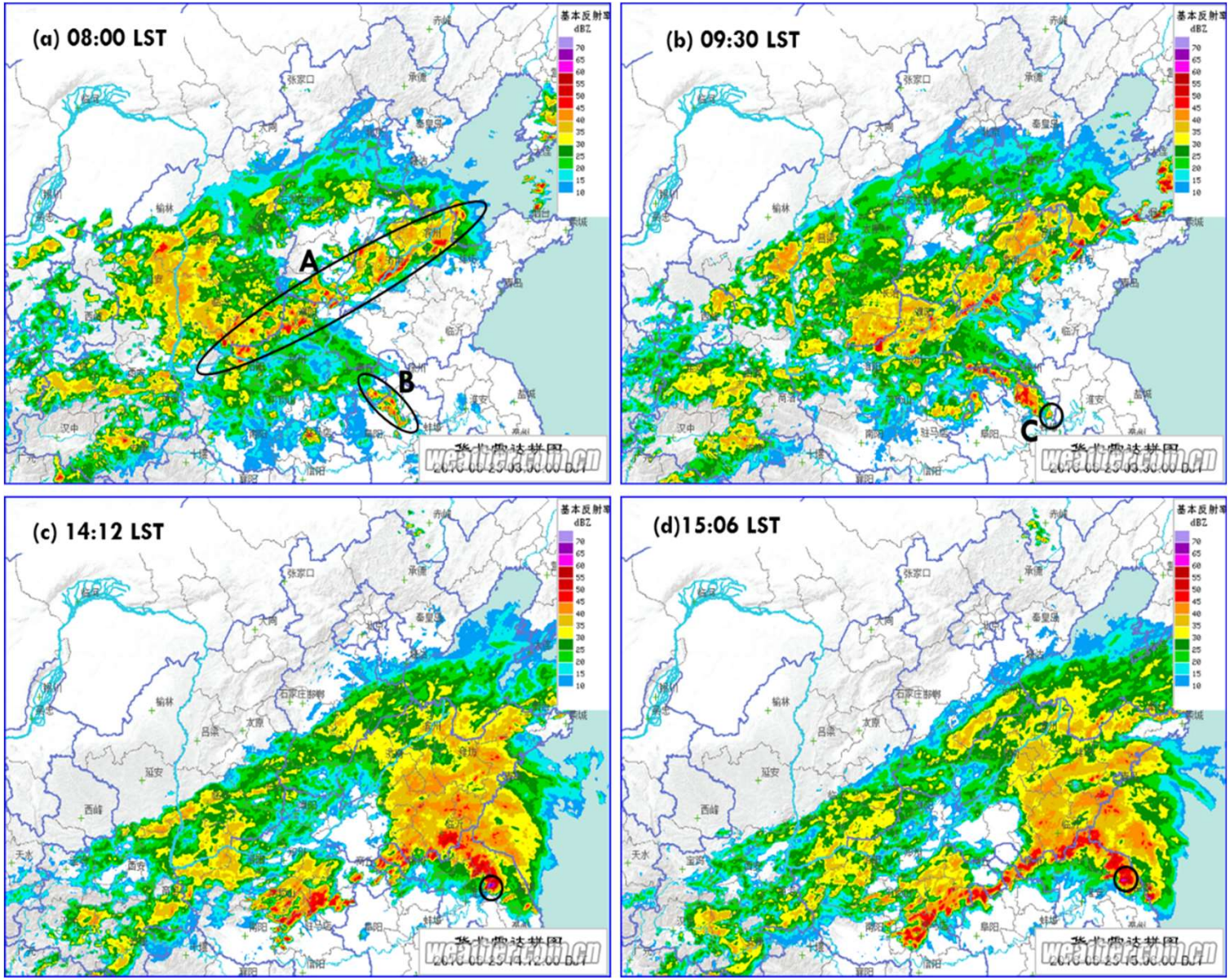


老王村龙卷中心的旋转风

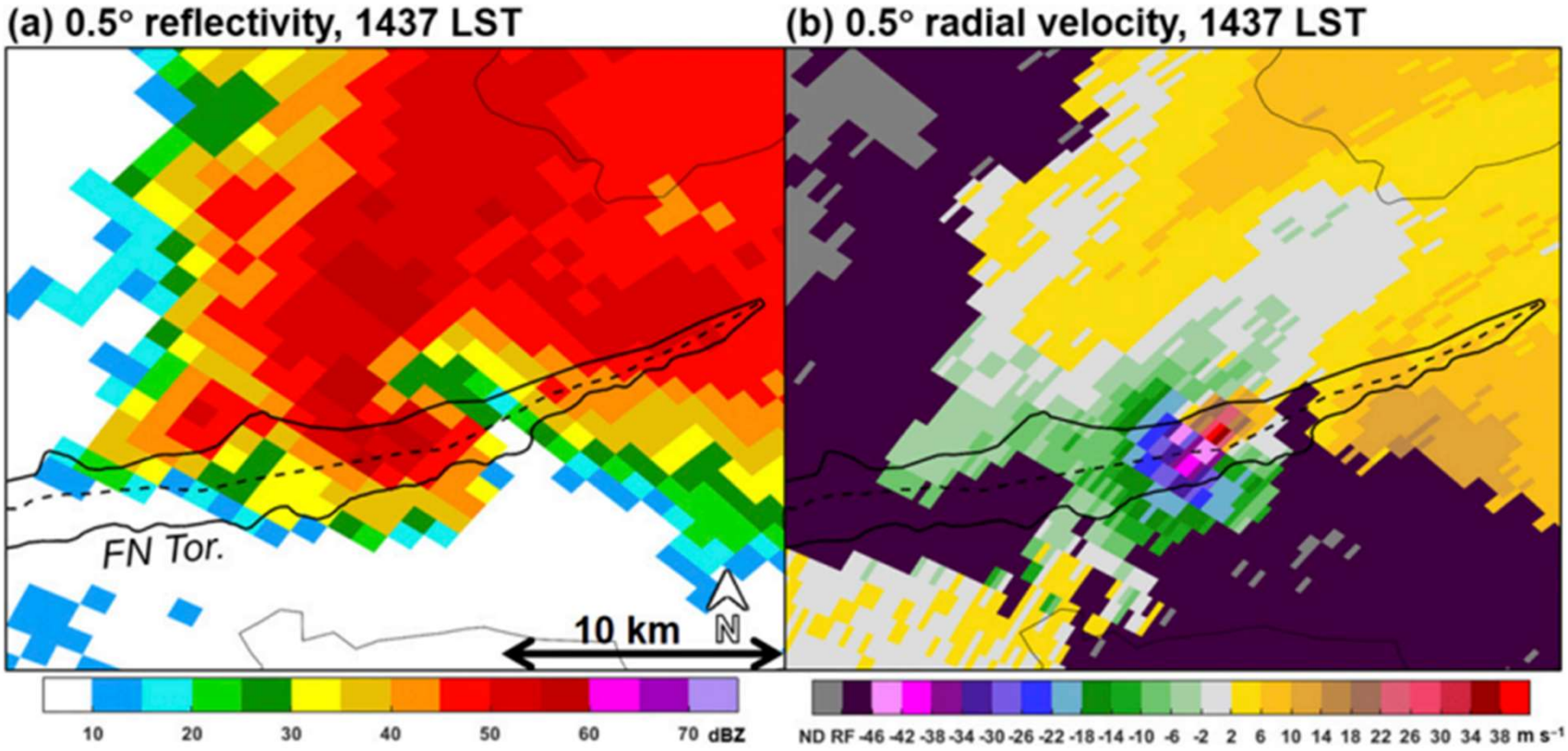


白兰强　　张慕容

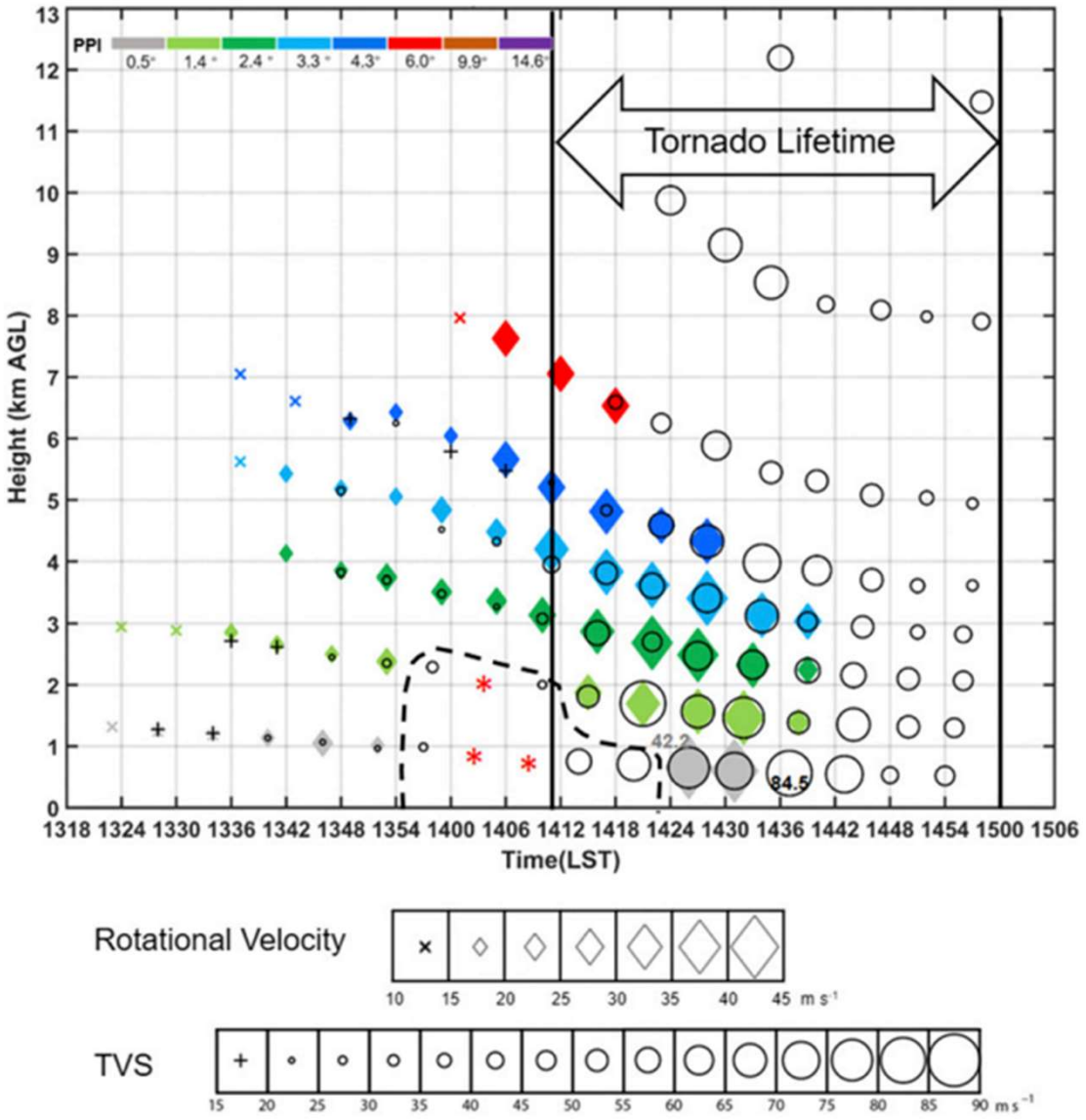
雷达观测特征



超级单体和龙卷涡旋的雷达特征



中气旋和龙卷涡旋的强度变化



赤峰龙卷 2017.8.11

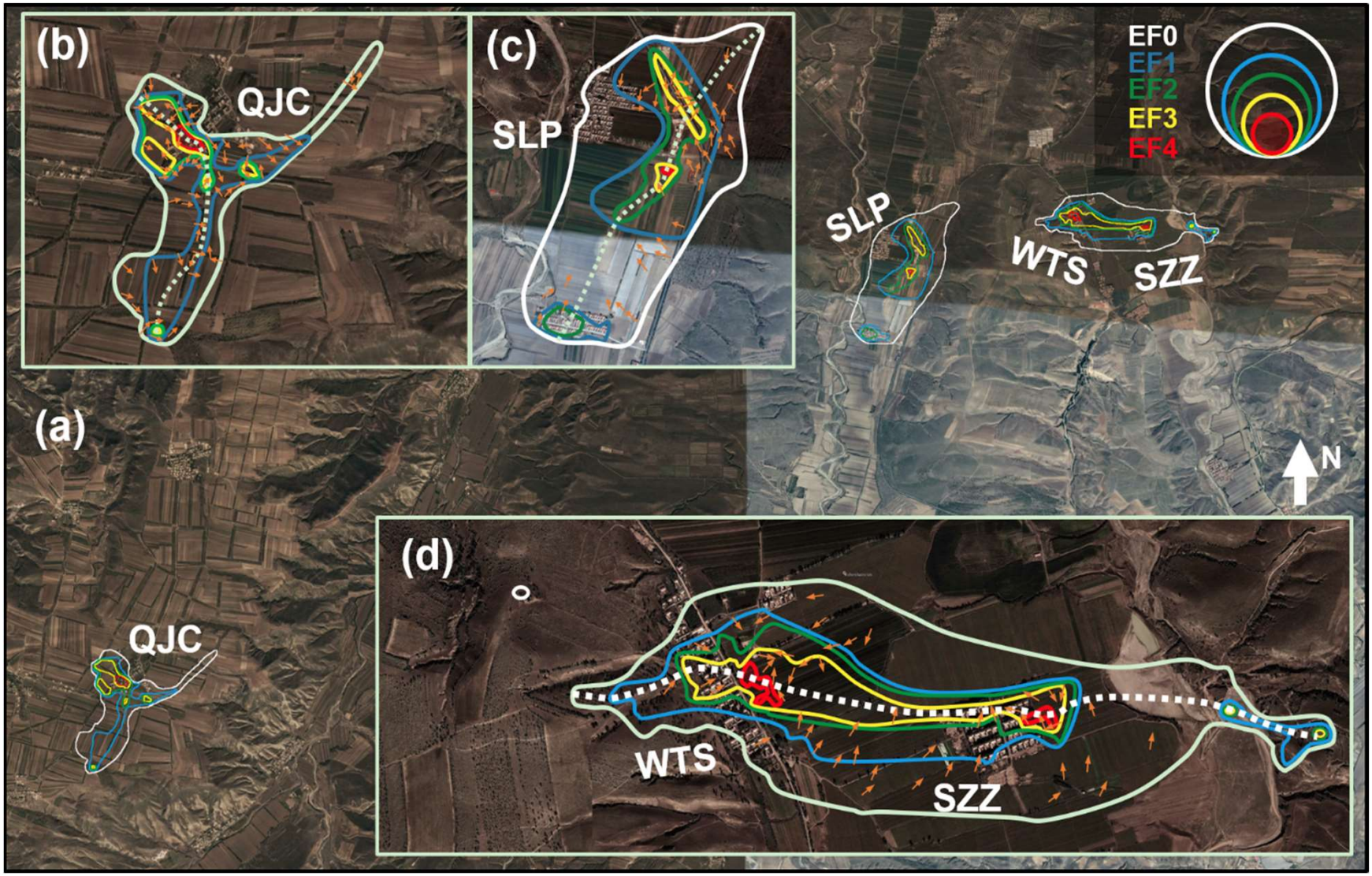
灾害

灾害

灾害调查

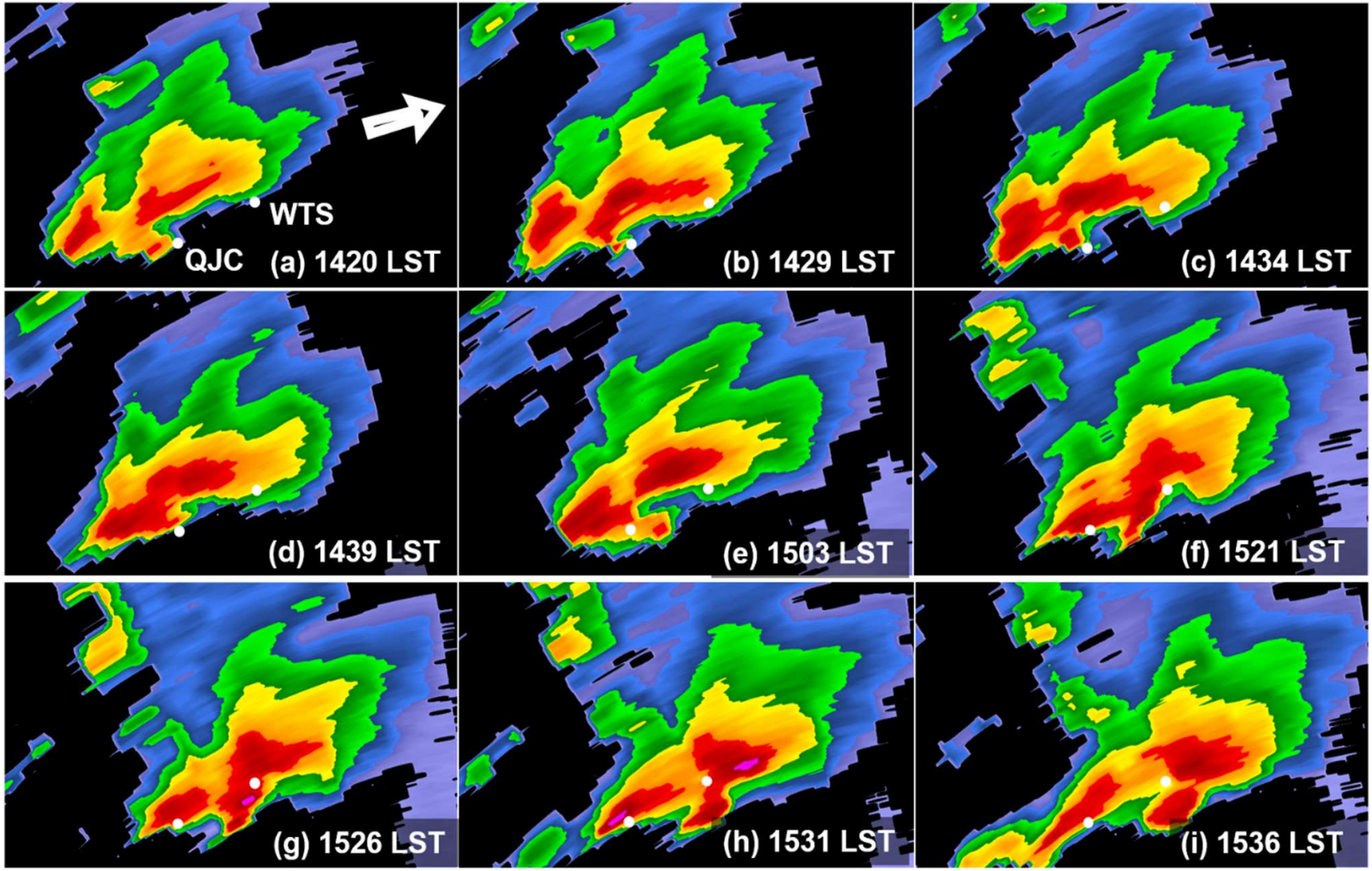
北京大学
佛山龙卷风研究中心
中国气象科学研究院
内蒙古气象局
赤峰气象局

EF等值线

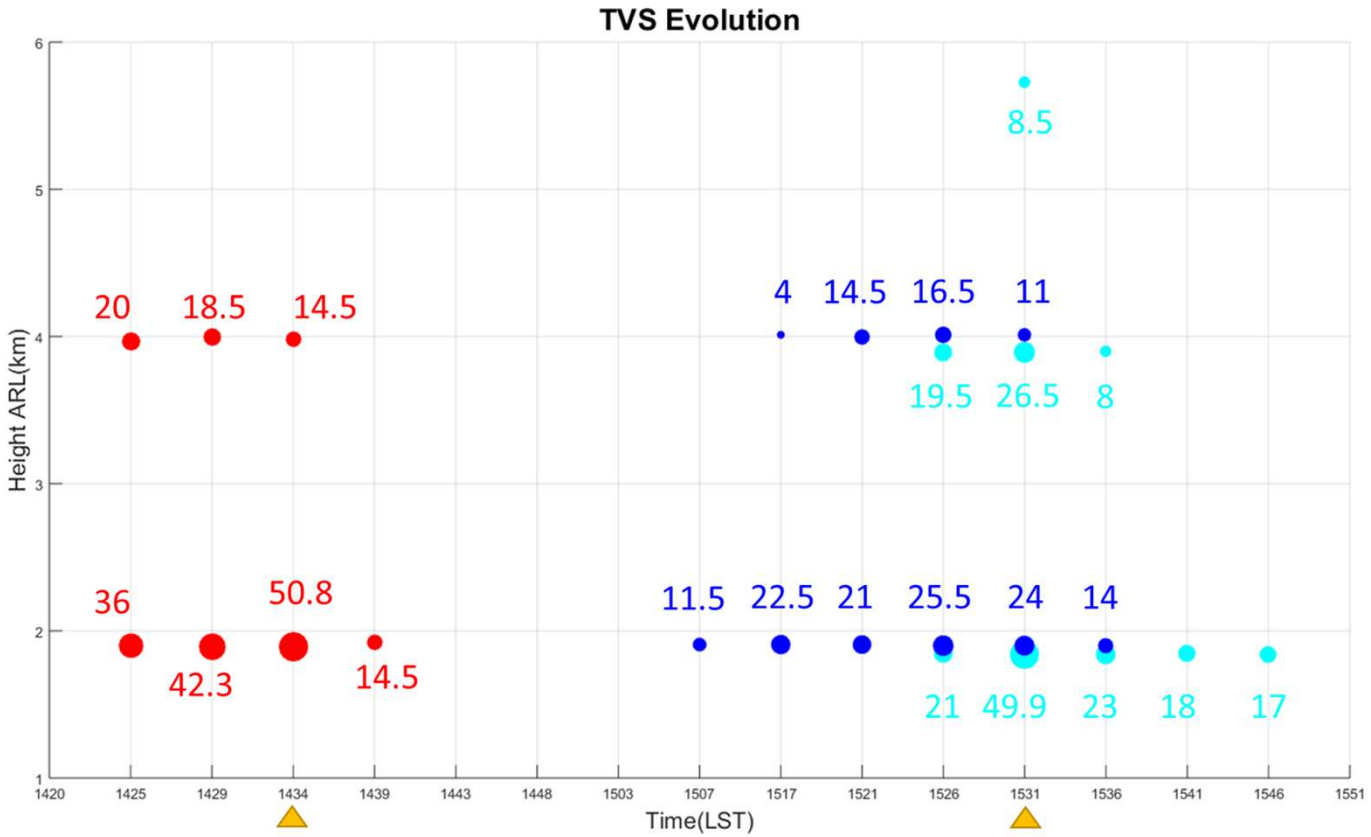


(Li et al. 2017)

雷达特征

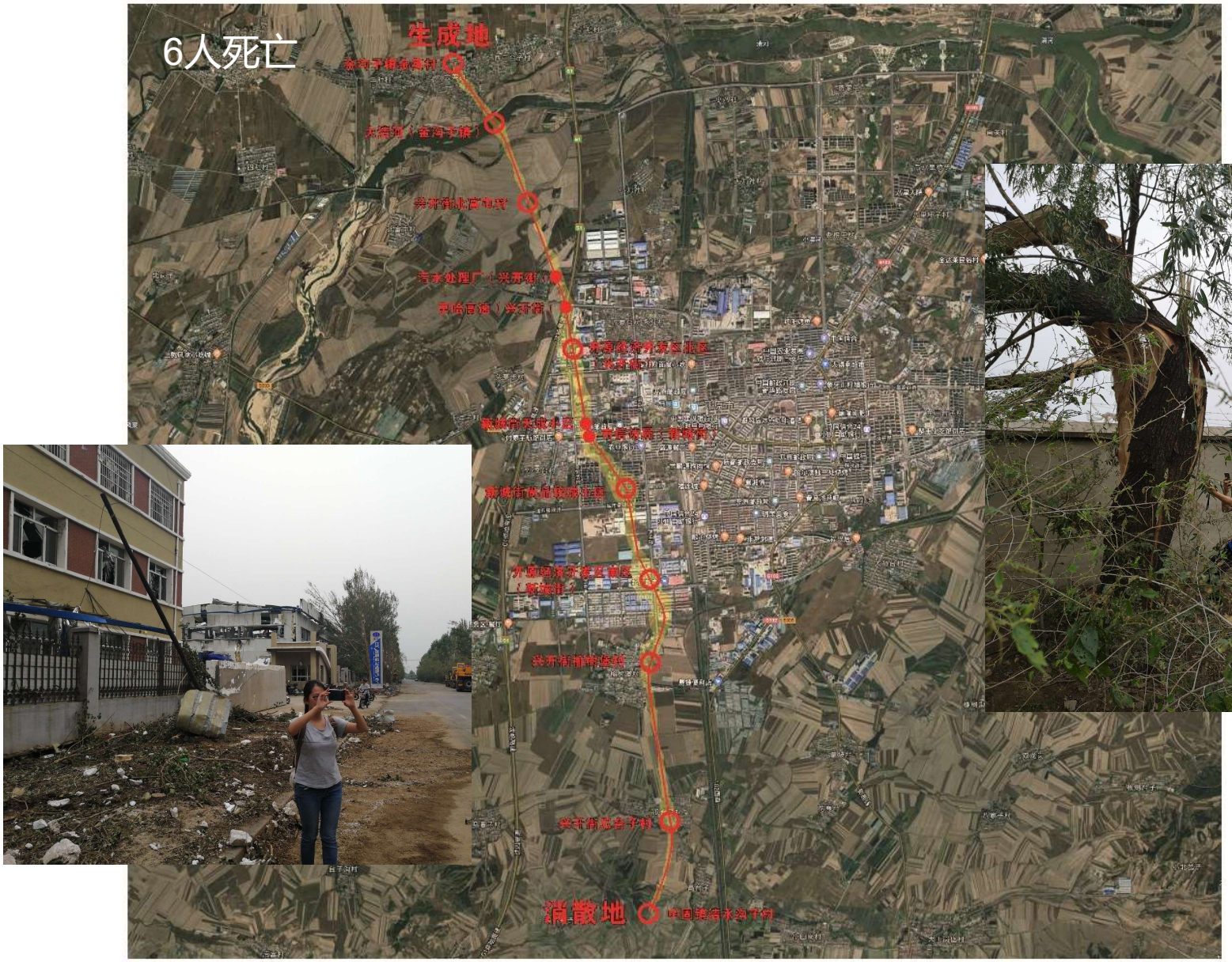

WTS
QJC
(a) 1420 LST
(b) 1429 LST
(c) 1434 LST
(d) 1439 LST
(e) 1503 LST
(f) 1521 LST
(g) 1526 LST
(h) 1531 LST
(i) 1536 LST

TVS



红色—前进村的TVS；浅蓝色—五台山的TVS；深蓝色—十里铺的TVS
圆点面积代表TVS强度。

开原EF4龙卷 2019.7.3



2019年7.3辽宁开原龙卷

结语

- 中气旋和TVS的路经与地面龙卷的路经基本一致
- 雷达可以很早就探测到中气旋的演变特征
- 雷达也一般能观测到TVS
- 加密地面自动站分钟观测反映地面阵风的变化
- 龙卷的判定：注意区分龙卷、尘卷、下击暴流

  方法：目测/雷达分析/灾害现场调查

“强天气分析和数值模拟”研究组

Severe Weather Analysis and Numerical Simulation (SWANS)

http://faculty.pku.edu.cn/mengzhiyong

白兰强 中山大学

17 papers
7 first-author

http://atmos.sysu.edu.cn/teacher/1415

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在读	2硕	2硕 2博	2硕 4博	5博	7博	8博	5博	5博	5博 1硕	4博 1硕	5博 1硕	6博 1硕
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