The Enhanced Fujita Scale for Wind Damage Rating

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Canada

Outline

- Brief history of wind damage rating
- The EF-scale – why and how?
- EF-scale evaluation in Canada
- Problems and solutions
- Using the EF-scale

Fujita Scale

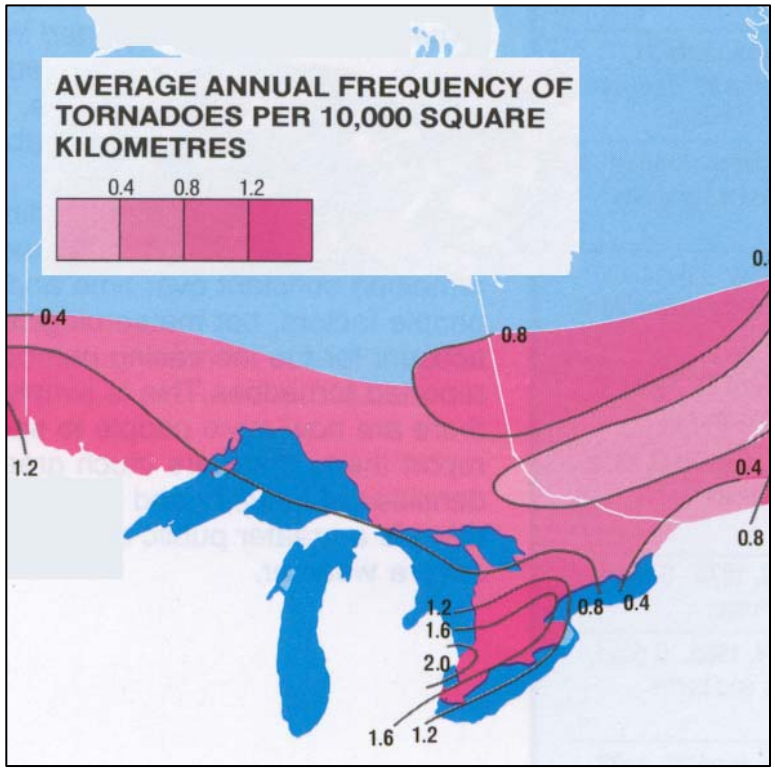
- Developed by Ted Fujita at Univ. of Chicago in the 1960s
- Wind speeds were educated guesses
- Limited number of damage indicators
- Used for tornadic and non-tornadic wind damage
- Implemented in US by NWS in 1970s

F-scale Category	Estimated Wind Speed Range (mph)	Typical Damage
F0	40 - 72	*Light damage*. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	73 - 112	*Moderate damage*. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
F2	113 - 157	*Considerable damage*. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	158 - 206	*Severe damage*. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207 - 260	*Devastating damage*. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	261 - 318	*Incredible damage*. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yds); trees debarked; incredible phenomena will occur.

From Fujita (1981)

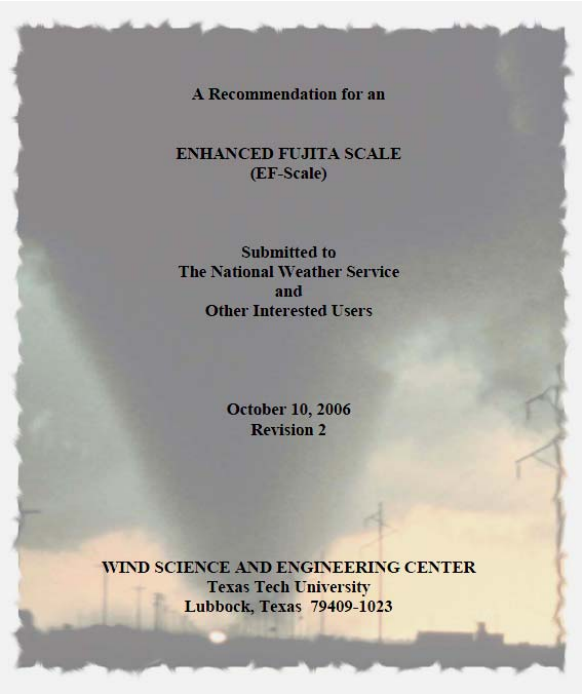
Fujita Scale in Canada

- Mike Newark of EC began assembling Canadian tornado database shortly after, making use of F-scale
- Published 1950-1979 climatology (Newark, 1984)
- Introduced a few new damage indicators after developing experience with wind damage assessment (e.g. silos, gravestones, etc.)



Enhanced Fujita Scale

- The EF-scale was developed at Texas Tech Univ. involving many US interests
- Has much improved wind speed / wind damage correlation with large number of damage indicators while consistent with existing US database
- Adopted for use in the United States in 2007, Sills and McCarthy have been monitoring progress and improvements to EF-scale since that time
- Adopted officially at EC on April 1, 2013
- First tornado rated using the EF-scale occurred on April 18th, 2013, at Shelburne, ON – rated EF1



Why the EF-scale was created

- More damage indicators

The ‘framed house’ was one of only a small number of damage indicators used with the *original* F-scale

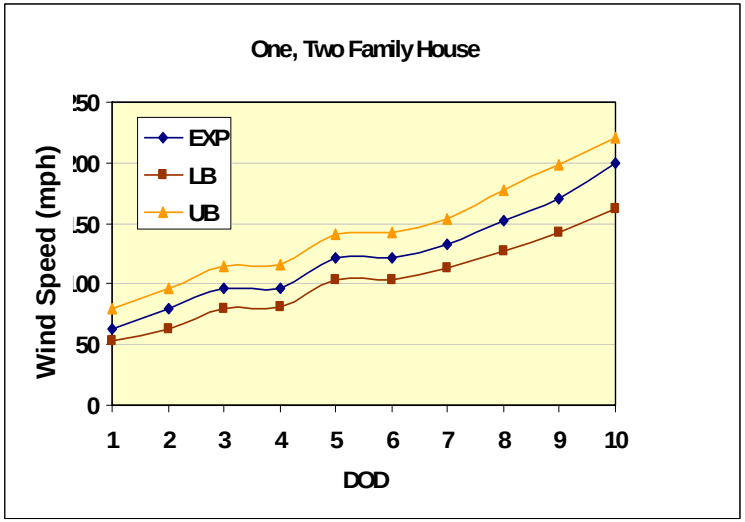
Why the EF-scale was created

- More damage indicators
- Better correlates wind speed and ratings

F-scale wind speeds extend too low. Evidence indicates a well-constructed house can be blown away (F5) by winds much less than 420 km/h (Phan and Simiu, 1998).

Why the EF-scale was created

- More damage indicators
- Better correlates wind speed and ratings
- Accounts for construction variability



'Expected' wind speed values, plus 'upper bound' and 'lower bound', are provided for each 'degree of damage' related to a damage indicator

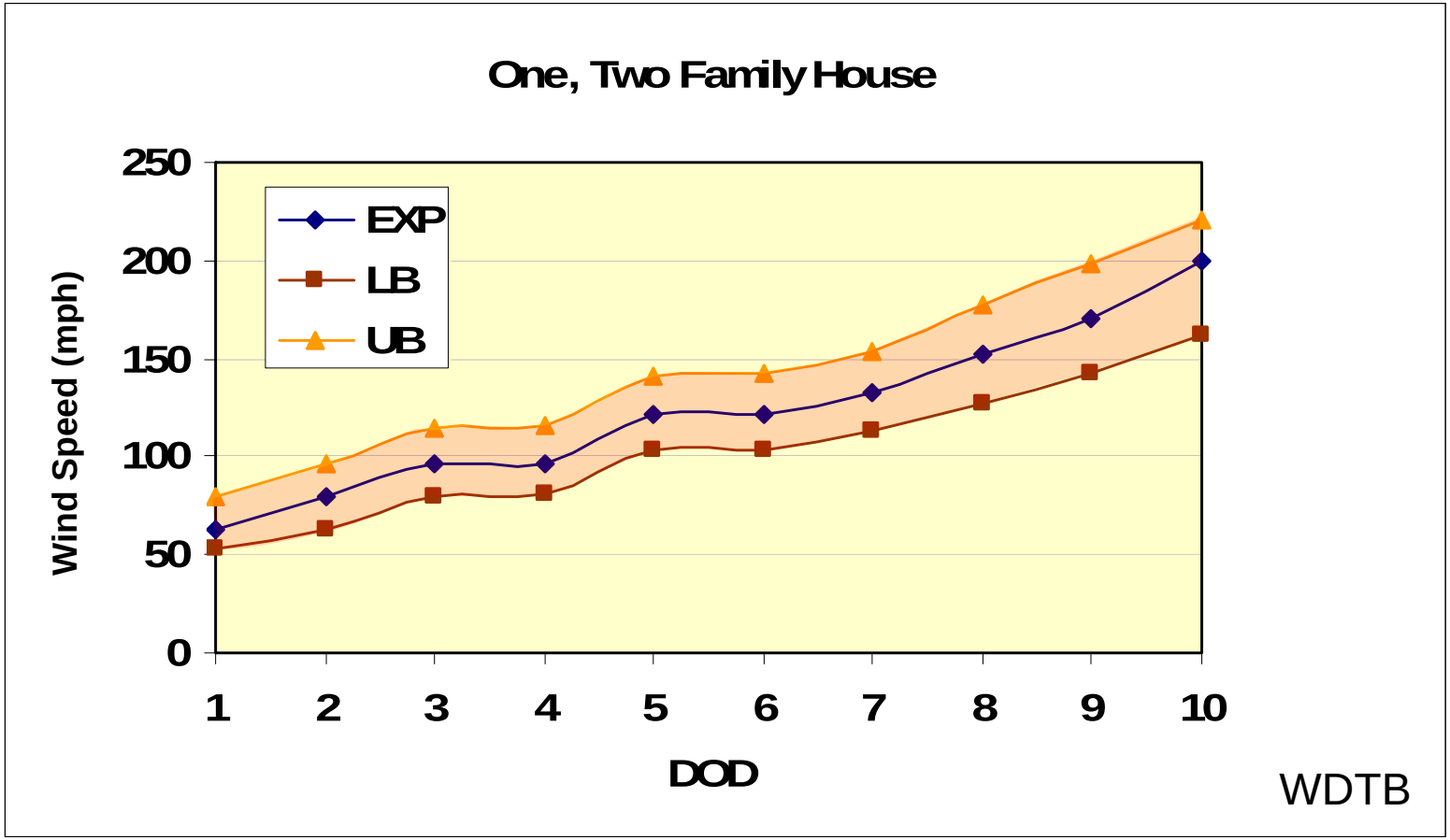
Degrees of Damage (DoD)

DOD	Damage Description	EXP	LB	UB
1	Threshold of visible damage	63	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed except small interior rooms.	152	127	178
9	All walls collapsed	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	162	220

WDTB

DODs for Framed House DI (FR12), winds in mph

Degrees of Damage (DoD)



DODs for Framed House DI (FR12)

How was EF-scale created?

- Developed 2000-2004 by the Fujita Scale Enhancement Project led by the Wind Science and Engineering Research Center at Texas Tech (McDonald and Mehta, 2006)
- Wind speed / damage intensity relationships obtained through process of 'Expert Elicitation' – used various engineering studies and the field experience of meteorology and engineering experts
- Experts included two meteorologists, two engineers, one architect and one meteorologist / engineer – all with extensive experience

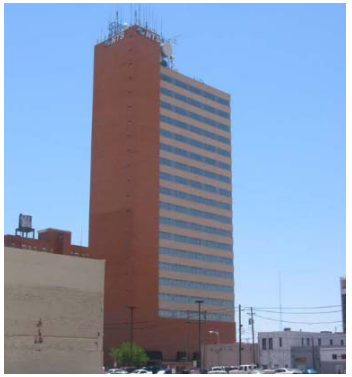
How was EF-scale created?

High-Rise Building

McDonald and Mehta (2006)

Bldg	Damage Indicator	Expected Values 1	2	3	4	5	6	Mean	Std Dev
HRB	1	65	80	70	75	60	70	70.00	7.07
	2	65	100	85	85	100	80	85.83	13.20
	3	85	100	95	100	80	100	93.33	8.76
	4	100	100	110	90	80	125	100.83	15.63
	5	75	110	100	110	130	100	104.17	18.00
	6	120	110	120	130	140	155	129.17	16.25
	7	120	130	110	120	250	125	142.50	53.08
	8	130	110	130	170	140	190	145.00	29.50
	9	120	130	140	140	270	155	159.17	55.54
	10	200	180	190	270	300	230	228.33	47.92

- Raw ‘expected value’ estimates in mph from the six experts (e.g. for high-rise buildings)
- Differences up to 150 mph (240 km/h) but most estimates similar



Deriving EF-scale

- A second Expert Elicitation process was undertaken to obtain mean expected winds for each DOD using the original F-scale
- Estimates in mph from six NWS assessment experts (e.g. for trees)
- Differences of up to 4 F-scale categories, but again most estimates similar

McDonald and Mehta (2006)

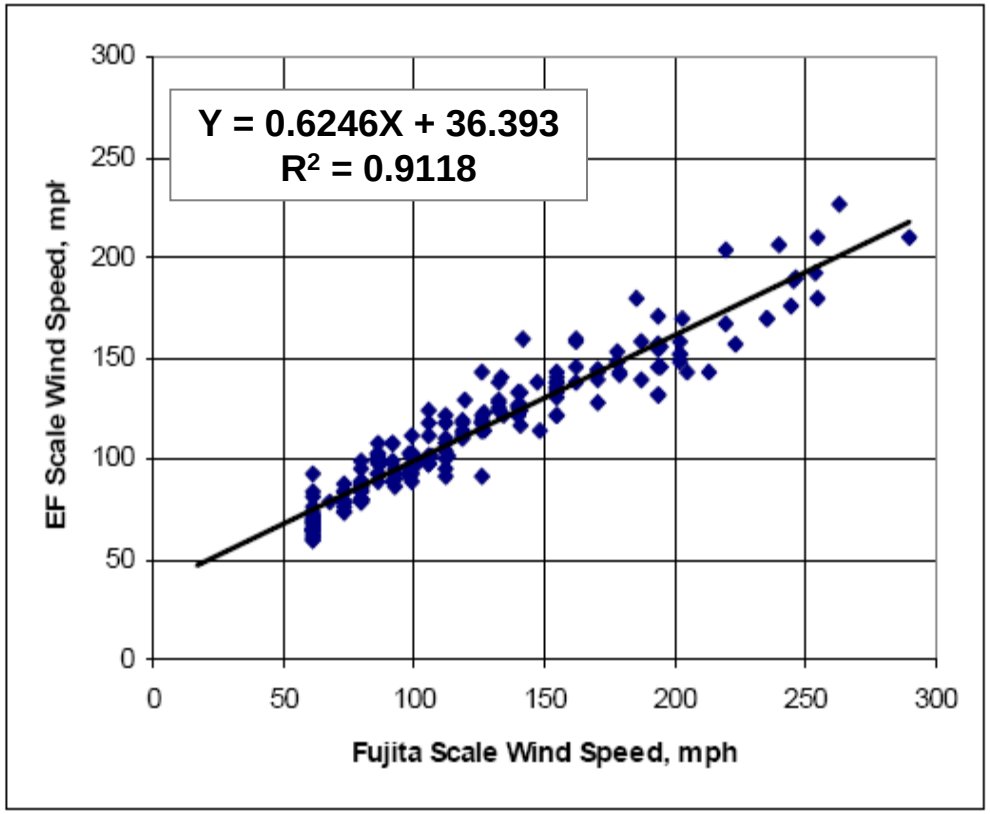
27. Trees: Hardwood (TH)

DOD	Damage description	1	2	3	4	5	6	1	2	3	4	5	6	Mean	Mean
1	Small limbs broken	0	0	0	0	0	0	61.25	61.25	61.25	61.25	61.25	61.25	61	60
2	Large branches broken	0	1	1	0	0	0	61.25	98.20	98.20	61.25	61.25	61.25	74	74
3	Trunks snapped	2	2	2	2	1	1	139.60	139.60	139.60	139.60	98.20	98.20	126	91
4	Trees uprooted	1	2	1	2	1	2	98.20	139.60	98.20	139.60	98.20	139.60	119	110
5	Trees debarked with only stubs of largest branches remaining	1	4	4	5	3	4	98.20	235.60	235.60	289.85	185.25	235.60	213	143

28. Trees: Softwood (TS)

DOD	Damage description	1	2	3	4	5	6	1	2	3	4	5	6	Mean	Mean
1	Small limbs broken	0	0	0	0	0	0	61.25	61.25	61.25	61.25	61.25	61.25	61	60
2	Large branches broken	0	1	1	0	0	0	61.25	98.20	98.20	61.25	61.25	61.25	74	74
4	Trunks snapped	1	2	1	2	1	1	98.20	139.60	98.20	139.60	98.20	98.20	112	110
3	Trees uprooted	1	2	1	1	1	2	98.20	139.60	98.20	98.20	98.20	139.60	112	91
5	Trees debarked with only stubs of largest branches remaining	1	4	4	5	3	3	98.20	235.60	235.60	289.85	185.25	185.25	205	143

Deriving EF-scale



McDonald and Mehta (2006)

- Mean 'expected' values from the two different expert elicitation processes plotted
- *Linear* regression chosen, high R^2 value indicated good correlation
- Regression equation used to convert F-scale wind speeds to new EF-scale wind speeds

Deriving EF-scale

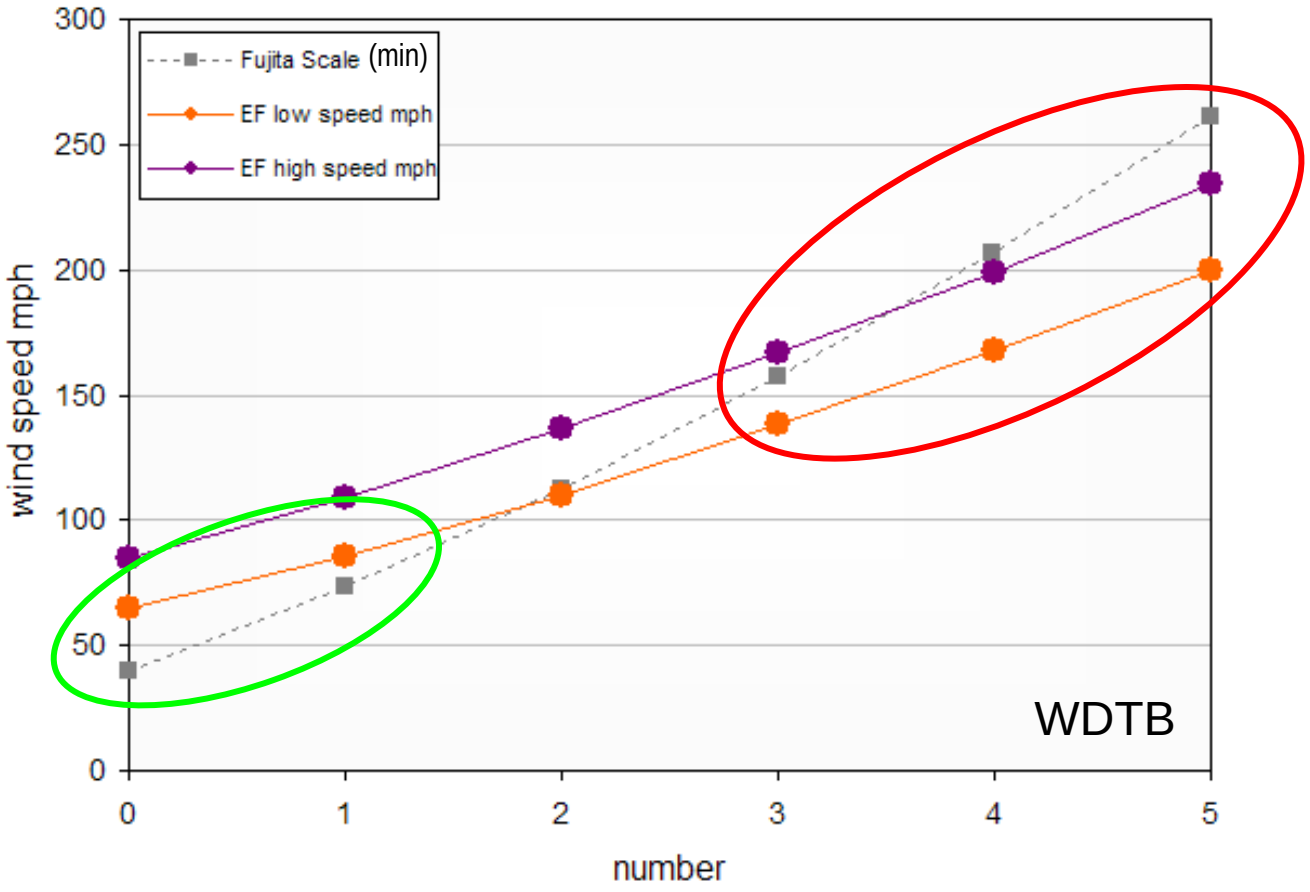
McDonald and Mehta (2006)

Fujita Scale			EF Scale	
Fujita Scale	Fastest 1/4/-mile Wind Speeds, mph	3-Second Gust Speed, mph	EF Scale	3-Second Gust Speed, mph
F0	40 - 72	45 - 78	EF0	65 - 85
F1	73 - 112	79 - 117	EF1	86 - 109
F2	113 - 157	118 -161	EF2	110 - 137
F3	158 - 207	162 - 209	EF3	138 - 167
F4	208 - 260	210 - 261	EF4	168 - 199
F5	261 - 318	262 - 317	EF5	200 - 234

All winds at 10 m

Y = 0.6246x + 36.393

F-scale vs EF-scale



F-scale vs EF-scale

- Though F-scale and EF-scale *wind speeds are different*, both still have the *same damage scales*
- Hence, ratings based on damage will be the same for older events rated with the F-scale and newer events rated with the EF-scale
- For example, the roof removed from a framed house is F/EF2, and a framed house swept from its foundation is F/EF5.

2011 Parallel Test at EC

- Only two weak tornadoes remotely surveyed in Prairie Region, 17 tornadoes in Ontario from F0-F3
- Some results:
  - Many F/EF-scale ratings the same
  - Metal truss hydro towers: F2 vs EF3 (Watford, ON)
  - Double-brick house: F3 vs EF2 (Goderich, ON)
  - Snapped power poles: F1 vs EF2 (Shauvavon, SK)
  - Major differences in tree damage ratings
  - A number of missing DIs: farm silos / grain bins, heritage churches, sheds, etc.

An Additional Problem

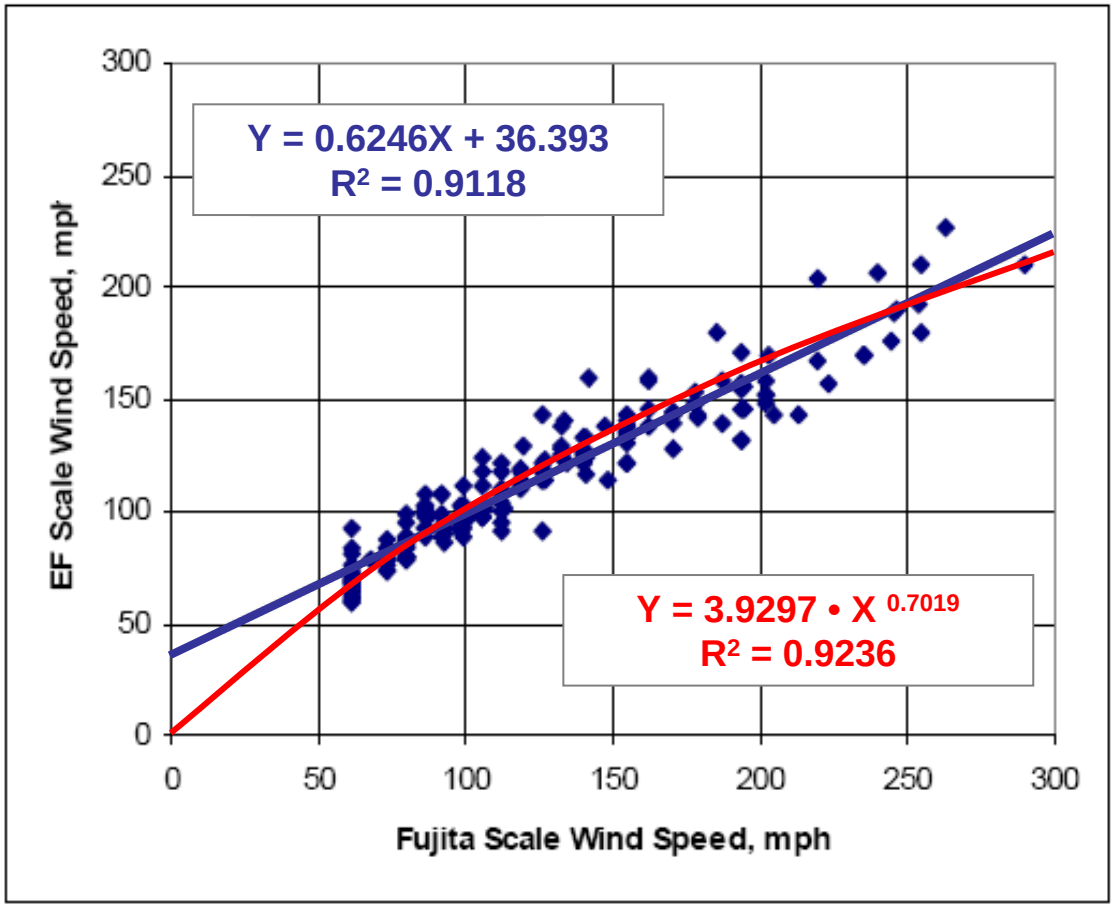
Lower bound of EF0 too high

- EF0 lower bound = 65 mph = 105 km/h
- 90 km/h threshold for damage wind gusts used for warning program
- Even in US, 58 mph (93 km/h) threshold is used for severe thunderstorm warnings
- So a wind speed gap is present; best if lower bound of EF0 changed to ~90 km/h

Solutions: Speed Scale

If *power law* regression used instead of *linear* :

- Better fit
- Goes through origin
- Lower bound of EF0 becomes ~90 km/h instead of 105 km/h



After McDonald and Mehta (2006)

Enhanced Fujita Scale @ EC

F/EF Rating	F-Scale Wind Speed Rounded to 10 km/h	EF-Scale Wind Speed Rounded to 5 km/h
0	60 – 110	90 – 130
1	120 – 170	135 – 175
2	180 – 240	180 – 220
3	250 – 320	225 – 265
4	330 – 410	270 – 310
5	420 – 510	315 or more

Solutions: DI / DODs

New and Revised DI/DODs for the following:

- Electrical Transmission Lines
- Trees
- Heritage Churches
- Solid Masonry Houses (e.g. double brick)
- Farm Silos / Grain Bins
- Sheds, Fences or Lawn Furniture

31 Damage Indicators

Number	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 (ACT)
6	Motel (M)
7	Masonry Apartment or Motel (MAM)
8	Small Retail Building (SRB)
9	Small Professional Building (SPB)
10	Strip Mall (SM)
11	Large Shopping Mall (LSM)
12	Large, Isolated Retail Building (LIRB)
13	Automobile Showroom (ASR)
14	Automobile Service Building (ASB)
15	Elementary School (ES)
16	Junior or Senior High School (JHSH)
17	Low-Rise Building: 1 - 4 Storeys (LRB)
18	Mid-Rise Building: 5 - 20 Storeys (MRB)
19	High-Rise Building: Greater than 20 Storeys (HRB)
20	Institutional Building (IB)
21	Metal Building System (MBS)
22	Service Station Canopy (SSC)
23	Warehouse Building (WHB)
25	Free-Standing Towers (FST)
26	Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)
C1	Electrical Transmission Lines (ETL)
C2	Trees (T)
C3	Heritage Church (HC)
C4	Solid Masonry House (SMH)
C5	Farm Silos or Grain Bins
C6	Sheds, Fences or Lawn Furniture (SFLF)

Farms / Residences

Commercial / retail structures

Schools

Professional buildings

Metal buildings / canopies

Towers / poles

New Canadian DIs!

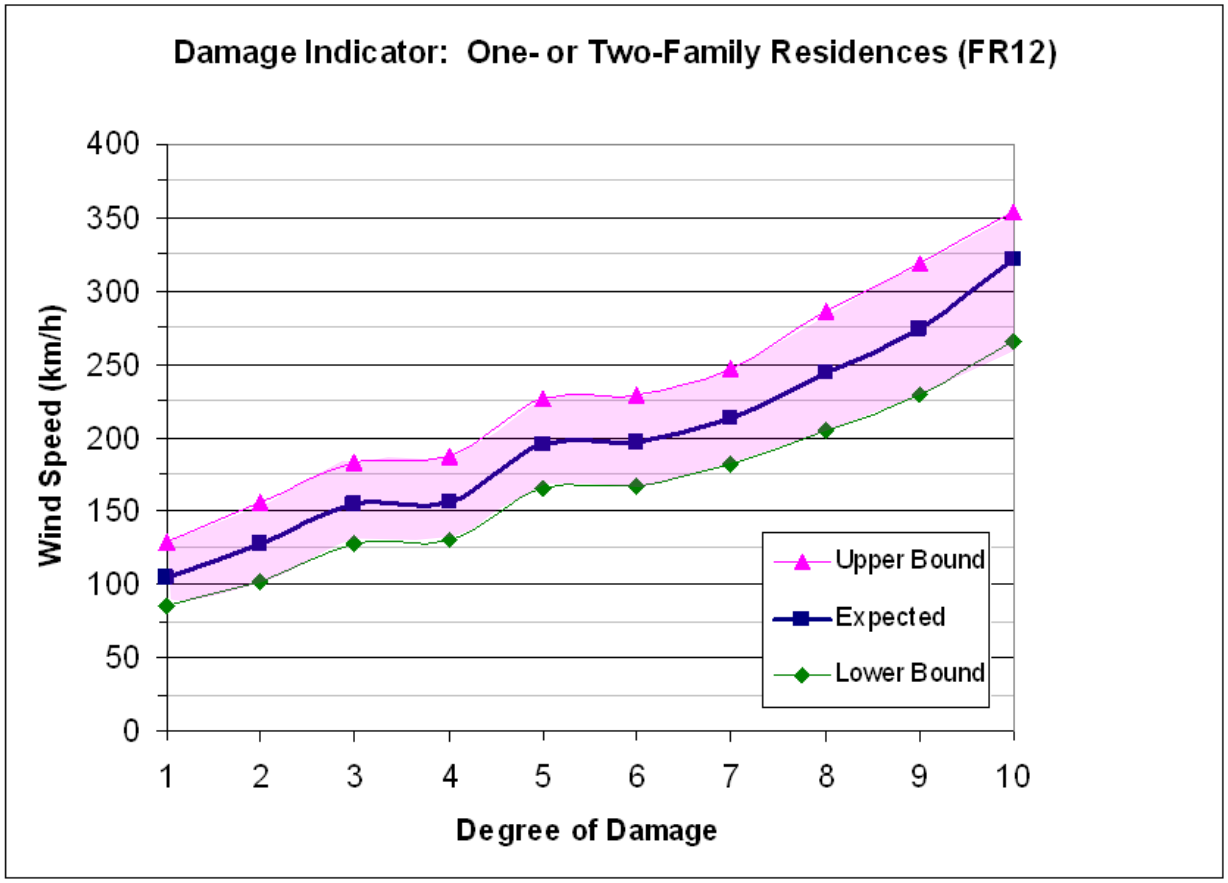
Degrees of Damage (DoD)

km/h

DOD	Damage Description	EXP	LB	UB
1	Threshold of visible damage	105	85	129
2	Loss of roof covering material (less than 20%), gutters and/or awning; loss of vinyl or metal siding	127	101	156
3	Broken glass in doors and windows	154	127	183
4	Uplift of roof deck and loss of significant roof covering material (20% or more); collapse of chimney; garage doors collapse inward; failure of porch or carport	156	130	187
5	Entire house shifts off foundation	195	166	227
6	Large sections of roof structure removed; most walls remain standing	196	167	229
7	Exterior walls collapsed	212	182	246
8	Most walls collapsed, except small interior rooms	245	204	286
9	All walls collapsed	274	229	319
10	Destruction of engineered and/or well-constructed residence; slab swept clean	322	266	354

DODs for Framed House DI (FR12), converted to km/h

Degrees of Damage (DoD)



DODs for Framed House DI (FR12)

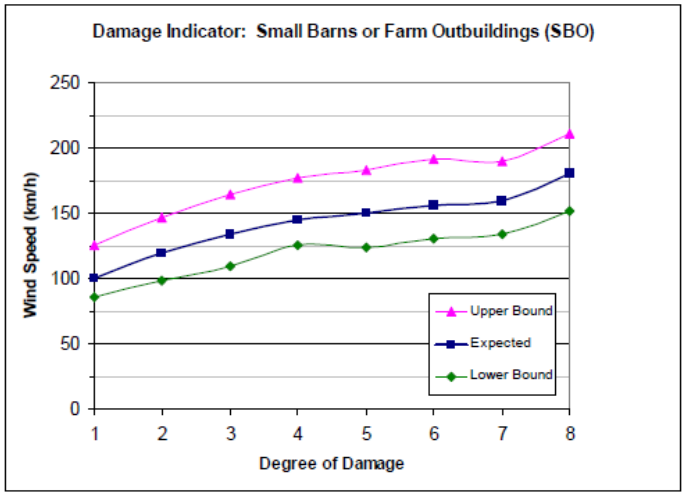
EF-Scale Rating Guide

1. SMALL BARNS OR FARM OUTBUILDINGS (SBO)

Typical Construction:

- Less than 250 m^2
- Wood or metal post and beam construction
- Wood or metal roof trusses
- Wood or metal panel siding
- Metal or wood roof
- Large doors

DOD	Damage Description	EXP	LB	UB
1	Threshold of visible damage	100	85	126
2	Loss of wood or metal roof panels	119	98	146
3	Collapse of doors	134	109	164
4	Major loss of roof panels	145	126	177
5	Uplift or collapse of roof structure	150	124	183
6	Collapse of walls	156	130	192
7	Overturning or sliding of entire structure	159	134	190
8	Total destruction of building	180	151	211



1. SMALL BARNS OR FARM OUTBUILDINGS (SBO)

Example of SBO DOD5 with partial loss of walls and roof structure (1999 Purple Valley, ON tornado)

Example of SBO DOD8 with barn (at centre) completely destroyed (2004 Gad's Hill tornado)

Using the EF-scale

1. Identify the appropriate Damage Indicator
2. Assess the Degree of Damage
3. Adjust the wind speed based on any deviations from typical construction quality and adjacent Damage Indicators
4. Assign a final EF-scale rating (e.g. EF2) *based on the adjusted wind speed*
5. Tornado rating is the max EF along path

EF-Scale Example

Primary damage indicator:

Poorly constructed barn totally destroyed
Damage Indicator = “1. SBO”

EF-Scale Example

Primary damage indicator:

Poorly constructed barn totally destroyed

1. SMALL BARNS OR FARM OUTBUILDINGS (SBO)

DOD	Damage Description	EXP	LB	UB
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Use lower bound of DOD8 due to poor construction

EF-Scale Example

Primary damage indicator:

Poorly constructed barn totally destroyed

151 km/h →

EF Rating	EF-Scale Wind Speed Rounded to 5 km/h
0	90 – 130
1	135 – 175
2	180 – 220
3	225 – 265
4	270 – 310
5	315 or more

⇨ **EF1** ⇦

EF-Scale Summary

• Regarding differences between the F-scale and EF-scale, the following is easy to remember:

"The wind speeds change, the ratings stay the same"

EF Rating	EF-Scale Wind Speed Rounded to 5 km/h
0	90 – 130
1	135 – 175
2	180 – 220
3	225 – 265
4	270 – 310
5	315 or more

Acknowledgements

- Patrick McCarthy (PASPC)
- Ed Mahoney / Jim LaDue at NWS Warning Decision Training Branch
- Greg Kopp (Western University)

References

Fujita, T.T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.,* **38**, 1511-1534.

McDonald, J. and K. C. Mehta, 2006: A Recommendation for an Enhanced Fujita Scale (EF-Scale), Revision 2. Wind Science and Engineering Research Center, Texas Tech University, Lubbock, TX, 111 pp.

Newark, M. J., 1984: Canadian Tornadoes, 1950-1979. *Atmos.-Ocean,* **22**, 343-353.

Phan, L.T. and E. Simiu, 1998: The Fujita tornado intensity scale: a critique based on observations of the Jarrell tornado of May 27, 1997. NIST Tech. Note 1426, U.S. Department of Commerce, Gaithersburg, MD, 20 pp.