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# Towards an improved wind speed scale and damage description adapted for Central Europe

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*F4 tornado damage: Hautmont, France, 3 August 2008 (Photo: Bjoern Stumpf)*

## Determination of tornado or downburst intensity in terms of wind speed is a difficult task

**Phenomena are very localized and short-lived:
usually not recorded by meteorological station networks.**

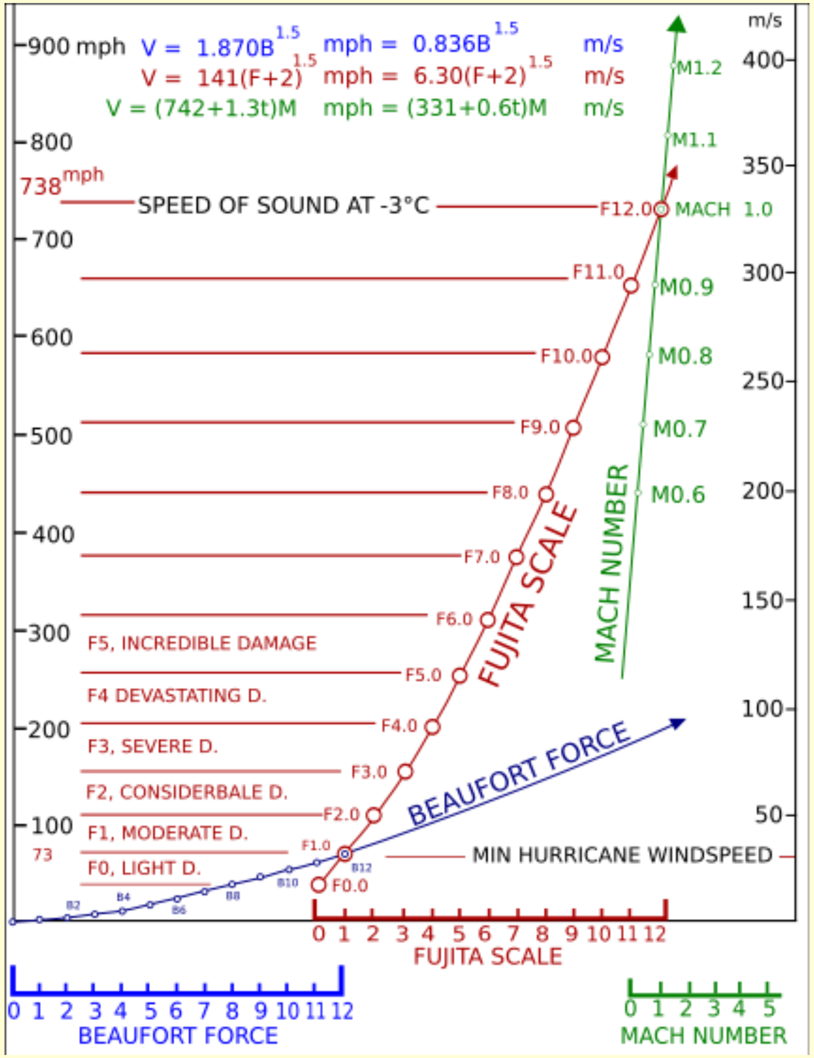
**Even if they were, measurement devices are often destroyed or record inaccurate data since the wind speed often exceeds the range they are designed for.**

**In a few cases, remote sensing by mobile radar systems (DOW) or direct measurements by tornado pods have been successful in measuring wind profiles of tornadoes.**

**But: their successful deployment is (still) rare compared with the occurrence of tornadoes and downbursts.**

**Event intensity grading is usually derived *ex post* from the resulting damage.**

**But: climatologists are interested in wind speed rather than damage!**




# Wind speed scales:

Beaufort (1805/1946, originally for wind effect over sea): empirically ~ $v^{2/3}$

F-scale (Fujita 1971/1981): interpolation ($v^{2/3}$) between Bft 12 and Mach 1

T-scale (Meaden 1976): extension of Bft scale – one T class comprises two Bft classes

What is the physical meaning of the 2/3 exponent?
(section modulus of a mast ~$d^3$)

~$v^2$: wind force (elastic)
~$v^3$: kinetic energy of the wind flow and debris impact (inelastic)
~$v^5$: heavy debris impact?

## A tornado/downburst intensity rating system should be

**broadly applicable, i. e. resolve all physically possible wind speeds and provide enough damage indicators to be broadly applicable, whatever the local conditions along a given event's path.**

**accurate in order to provide a climatology of intensity for all reported events. Given the difficulty of estimating wind speeds from damage, this is a challenging requirement.**

**consistent, i. e. the same process for ratings should be used everywhere through all time, to remove secular trends in the database.**

*On the implementation of the enhanced Fujita scale in the USA*
Doswell, Brooks, Dotzek: Atm. Res. **99** 554, 2009

**Enhanced Fujuta (EF) Scale adopted by the NWS in the USA 2007 based on 28 damage indicators + degree of damage for each indicator. Significant downscaling of wind speeds at upper part of the scale.**

**Desirable: *regional* indicators + degree of damage descriptions for full range of wind speeds physically possible in tornadoes.**

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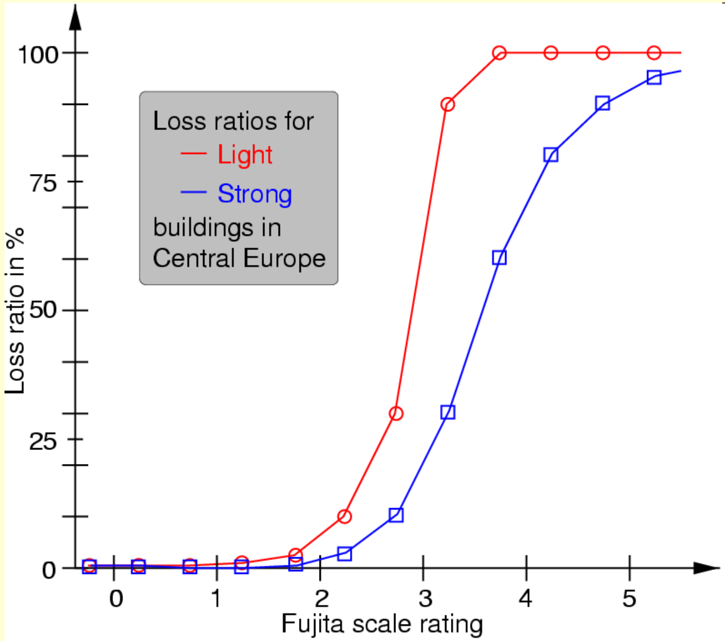
| Damage: / f scale | | Little Damage | Minor Damage | Roof Gone | Walls Collapse | Blown Down | Blown Away |
|---|---|---|---|---|---|---|---|
| | | f0 | f1 | f2 | f3 | f4 | f5 |
| Windspeed: / F scale | | F0 (18 m/s – 33; 65 km/h – 119) | F1 (33 – 51; 119 – 184) | F2 (51 – 71; 184 – 256) | F3 (71 – 93; 256 – 335) | F4 (93 – 117; 335 – 421) | F5 (117 – 143; 421 – 515) |
| To convert f scale into F scale, add the appropriate number | | | | | | | |
| Weak Outbuilding | -3 | f3 | f4 | f5 | f5 | f5 | f5 |
| Strong Outbuilding | -2 | f2 | f3 | f4 | f5 | f5 | f5 |
| Weak Framehouse | -1 | f1 | f2 | f3 | f4 | f5 | f5 |
| Strong Framehouse | 0 | F0 | F1 | F2 | F3 | F4 | F5 |
| Brick Structure | 1 | - | f0 | f1 | f2 | f3 | f4 |
| Concrete Building | 2 | - | - | f0 | f1 | f2 | f3 |

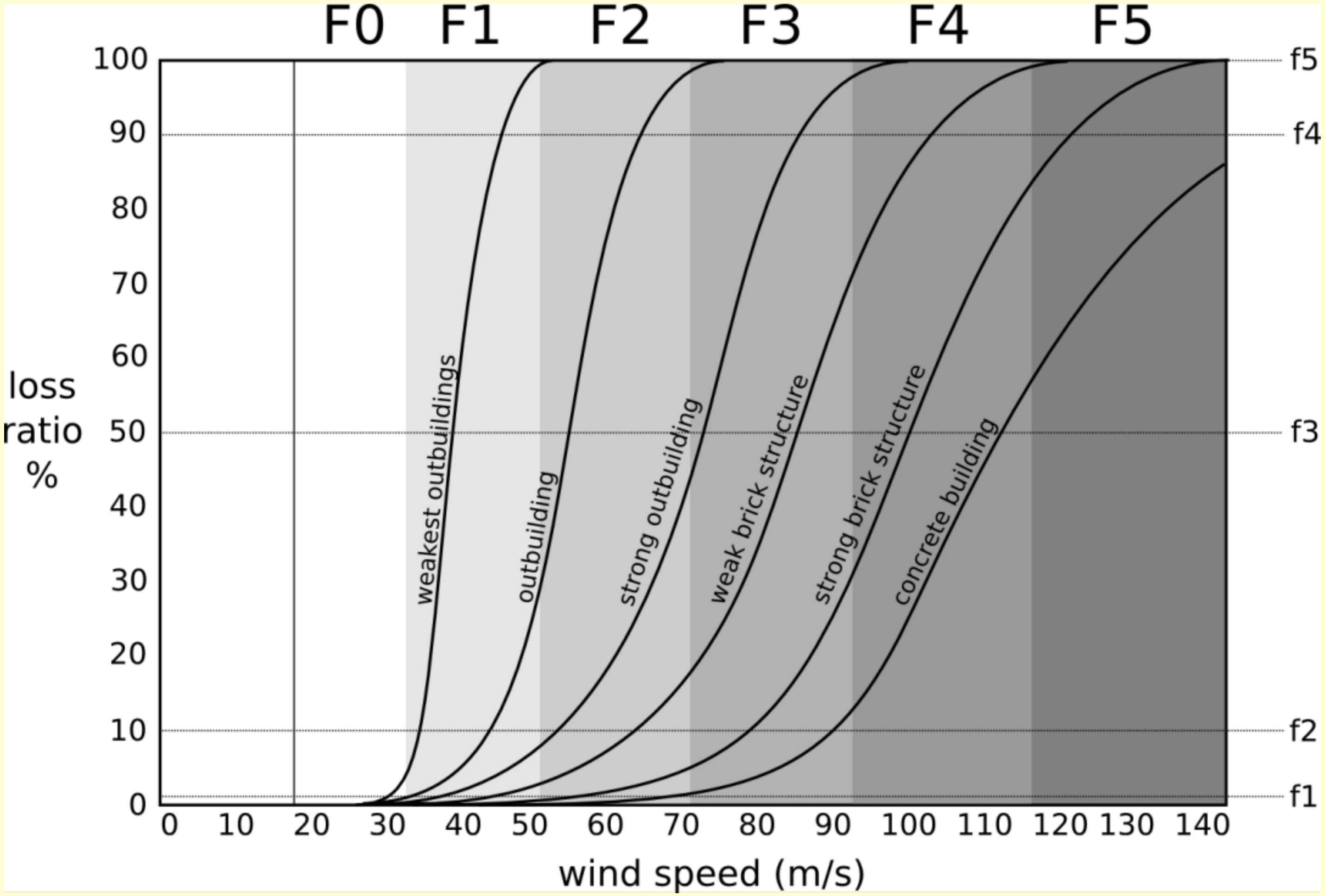
**Fujita's f-scale matrix for 6 damage indicators (1992)**

**ESSL (TorDACH)**
**Skywarn Germany**
**Munich Re**
Dotzek, N., Berz, G., Rauch, E., Peterson, R.E., 2000.
**Degree of damage**
**+ vegetation damage**




L in % = monetary damage / reinstatement value

→ **Combination of both concepts**
(Feuerstein et al. Atm. Res. **100**, 547, 2011)


F0
F1
F2
F3
F4
F5
loss ratio %
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
wind speed (m/s)
f5
f4
f3
f2
f1
weakest outbuildings
outbuilding
strong outbuilding
weak brick structure
strong brick structure
concrete building

| Fujita damage class | f0 | f1 | f2 | f3 | f4 | f5 |
|---|---|---|---|---|---|---|
| loss ratio (%) | 0.1 | 1 | 10 | 50 | 90 | 100 |
| degree of damage → / ↓ damage indicator | light roof damage | significant roof damage | roof gone | walls partly collapsed | largely blown down | blown away |
| weakest outbuilding | **F0+** | **F0+** | **F1-** | **F1-** | **F1+** | **F2-** |
| outbuilding | **F0+** | **F1-** | **F1+** | **F2-** | **F2+** | **F3-** |
| strong outbuilding/ weak framehouse | **F0+** | **F1+** | **F2-** *10* | **F3-** *12* | **F3+** | **F4-** |
| weak brick structure/ strong framehouse | **F1-** *8* | **F1+** *9* | **F2+** *11* | **F3+** *13* | **F4-** *14* | **F5** *16 17* |
| strong brick structure | **F1-** | **F2-** | **F3-** | **F4-** *15* | **F5** | **F5** |
| concrete building | **F1-** | **F2+** | **F3+** | **F4+** | **F5** | **F5** |

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## WEAK

### T0 F0⁻

65–90 km/h


Leaves, small twigs and dead branches snapped. Downburst 04.06.2003 – Schillig (Germany).

Tiles slightly displaced. Downburst 18.01.2007 – Pulheim (Germany).

**Vegetation damage:**
Few weak branches start to break; path is visible in meadows or grain fields. Diseased (e. g. rotting) or particularly unstable trees (slender stem; elevated crown; poor shallow rootage) can break or be uprooted (root rotting or unstable wet soil).

**Property damage ($S_- = 0.05$ %, $S_+ = 0.01$ %):**
Loose light objects lifted from the ground. Scaffolding can be overthrown; light damage to marquees and tents can occur. Tiles at exposed positions can become loose. No damage supporting structures.

### T1 F0⁺

91–117 km/h


Shallow-rooted spruce on very wet soil uprooted. Downburst 19.04.2003 – Melle (Germany).

Garden fence panels destroyed. Downburst 18.01.2007 – Pulheim (Germany).

**Vegetation damage:**
Strong and healthy branches break more frequently, particularly during growing season (leafy deciduous trees). Diseased (e. g. rotting) or particularly unstable trees (slender stem; elevated crown; poor shallow rootage) break or are uprooted frequently (in particular in cases of root rotting or unstable wet soil).

**Property damage ($S_- = 0.1$ %, $S_+ = 0.05$ %):**
Light objects and garden furniture can be overthrown or become airborne; wooden fences can be overthrown. Light roof damage (tiles and metal sheeting can become loose and may be blown down). Marginal damage to light outbuildings; no structural damage.

### T2 F1⁻

118–150 km/h


Permanently bent spruces. Downburst 06.06.1998 – Steinfurt (Germany).

Roof partially untiled. Tornado 17.01.2007 – Melle-Reimsloh (Germany).

**Vegetation damage:**
Numerous strong and healthy branches break, particularly during growing season (leafy deciduous trees). Most trees with rotting or other structurally relevant damage, unstable trees (slender stem; elevated crown; poor shallow rootage) or trees on unstable or wet soil are broken or uprooted throughout. Even healthy trees can be broken or uprooted in cases of unfavourable gust direction or timing or sodden soil. During growing season trees with stable rooting but unstable stem become permanently bent.

**Property damage ($S_- = 0.25$ %, $S_+ = 0.10$ %):**
Heavier objects are lifted from the ground an can become dangerous projectiles. Caravans and trailers can be overthrown. Noticeable damage to tiled roofs and unstable flat roofs. Marginal to medium damage to light outbuildings; first damage to structural elements of solid buildings possible.

### T3 F1⁺

151–183 km/h


Spruce forest with bending and snapping; edge intact. Tornado 29.05.2007 – Borler (Germany).

Roof largely untiled. Tornado 01.03.2008 – Uttershausen (Germany).

**Vegetation damage:**
Numerous strong and healthy branches break, even out of growing season (bare deciduous trees). Even stable and healthy trees are increasingly uprooted or already broken. Quite frequent permanent bending during growing season. Substantial damage to stable wood, where the most stable trees and underwood, which features small aerodynamic drag, predominantly survive.

**Property damage ($S_- = 0.8$ %, $S_+ = 0.25$ %):**
Numerous caravans and trailers are overthrown. Tiled roofs and unstable flat roofs suffer major damage. Medium damage to light outbuildings; isolated damage to structural

## STRONG

### T4 F2⁻

184–219 km/h


Swath in beech forest with remaining edge trees. Tornado 13.05.2007 – Kall-Sistig (Germany).

Barn ruined. Tornado 13.05.2007 – Kall-Sistig (Germany).

**Vegetation damage:**
Even stable trees and woods are almost completely uprooted or broken. Large trees break most likely if well-enrooted. Trees which survive suffer the loss of most of their branches (even bare trees out of growing season). The fraction of permanent bending is strongly reduced compared to snapped trees.

**Property damage ($S_- = 3.0$ %, $S_+ = 0.8$ %):**
Heavy damage to vehicles and trailers. High threat and damage due to flying debris. Roofs are completely untiled. Severe Damage to light outbuildings; increasing damage to structural elements of solid buildings; gables can collapse.

### T5 F2⁺

220–254 km/h


Heavily damaged edge trees. Tornado 29.06.1997 – Bissendorf (Germany).

Aged roof structure partly destroyed. Tornado 18.07.2004 – Tönisvorst (Germany)

**Vegetation damage:**
Even most stable woody plants as edge trees, wind-proof hedges and bushes are strongly damaged or destroyed either by uprooting, stem or crown break or due to tearing off most of the branches, in particular almost complete loss of brushwood.

**Property damage ($S_- = 10$ %, $S_+ = 3.0$ %):**
Severe damage to roofs, annexes and light outbuildings. Increasing damage to structural elements of solid buildings. Collapse of single weak buildings (agricultural structures and storage depots). Vehicles can be lifted from the ground.

### T6 F3⁻

255–294 km/h


Completely destroyed stable but exposed forest edge. Downburst 01.03.2008 – Braunau am Inn (Austria).

Largely demolished and partly collapsed outbuilding. Tornado 10.06.2003 – Acht (Germany).

**Vegetation damage:**
No native woody plants survive – if the stem remains – such a strong wind without severe damage. Remaining trees are extensively debranched.

**Property damage ($S_- = 30$ %, $S_+ = 10$ %):**
Light outbuildings are widely destroyed. Severe damage to structural elements of solid buildings. Single buildings collapse. Heavy vehicles are lifted or overthrown.

### T7 F3⁺

295–334 km/h


Destroyed solitaire trees with isolated debarking. Tornado 22.07.2007 – Turiysk (Ukraine).

Upper storey of outbuilding completely destroyed. Tornado 23.06.2004 – Micheln (Germany).

**Vegetation damage:**
No native woody plants survive – if the stem remains – such a strong wind without severe damage. Remaining trees are extensively debranched and isolated debarking due to debris impact starts to take place.

**Property damage ($S_- = 90$ %, $S_+ = 30$ %):**
Widespread complete destruction of light outbuildings and severe damage to solid buildings. Numerous buildings collapse.

## VIOLENT

### T8 F4⁻

335–377 km/h


Ruined beech trees with distinct partial debarking. Tornado 01.06.1927 – Auen (Germany).

Prefabricate house with brick facing blown down. Tornado 03.08.2008 – Hautmont (France).

**Vegetation damage:**
Significant debarking of tree ruins due to debris impact.

**Property damage ($S_- = 100$ %, $S_+ = 60$ %):**
Severe damage to solid buildings. Widespread collapse of buildings; furniture is blown away. Vehicles are thrown over large distances.

### T9 F4⁺

378–420 km/h


Largely debarked Tree. Tornado 10.08.1925 – Borculo (Netherlands).

Massive (brick) house ruined down to base walls. Tornado 03.08.2008 – Hautmont (France).

**Vegetation damage:**
Total debarking of tree ruins due to debris impact.

**Property damage ($S_- = 100$ %, $S_+ = 80$ %):**
Predominant total loss of solid buildings. Trains are dragged from their track.

### T10 F5⁻

421–467 km/h


Widely debarked tree and destroyed pickup truck. Tornado 03.05.1999 – Moore, OK (USA).

Complete destruction (total loss) of buildings. Tornado 03.05.1999 – Moore, OK (USA).

**Vegetation damage:**
Total debarking of tree ruins due to debris impact. Exceptional damage: brittle tree stubs are ripped out and drift over large distances.

**Property damage ($S_- = 100$ %, $S_+ = 90$ %):**
Predominant total loss of solid buildings.

### T11 F5⁺

468–515 km/h


Completely debarked solitaire tree ruins. Tornado 03.05.1999 – Moore, OK (USA).

Building blown away from foundation. Tornado 03.05.1999 – Moore, OK (USA).

**Vegetation damage:**
Total debarking of tree ruins due to debris impact. Exceptional damage: well-rooted tree stubs are ripped out and drift over large distances.

**Property damage ($S_- = 100$ %, $S_+ = 95$ %):**
Almost exclusively total loss of solid buildings. Inconceivable damage occurs.

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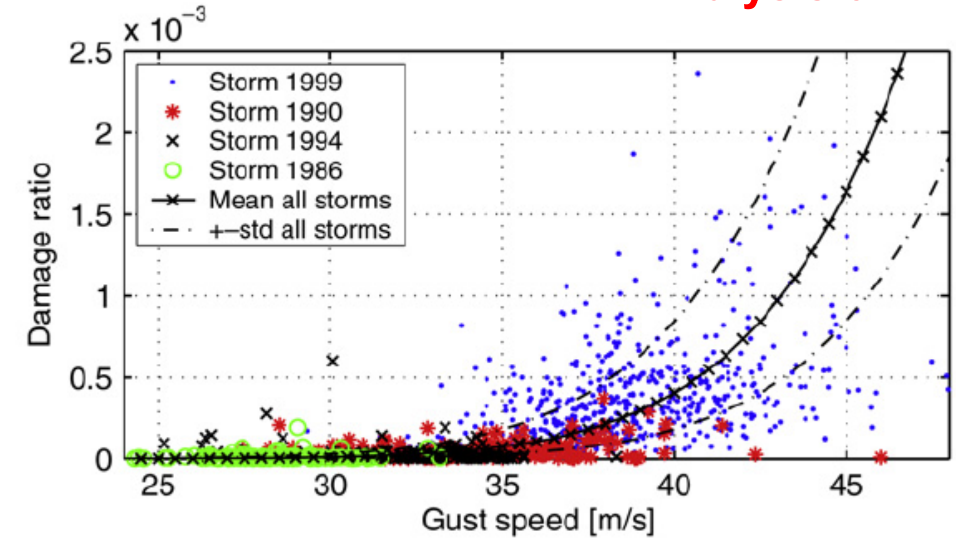
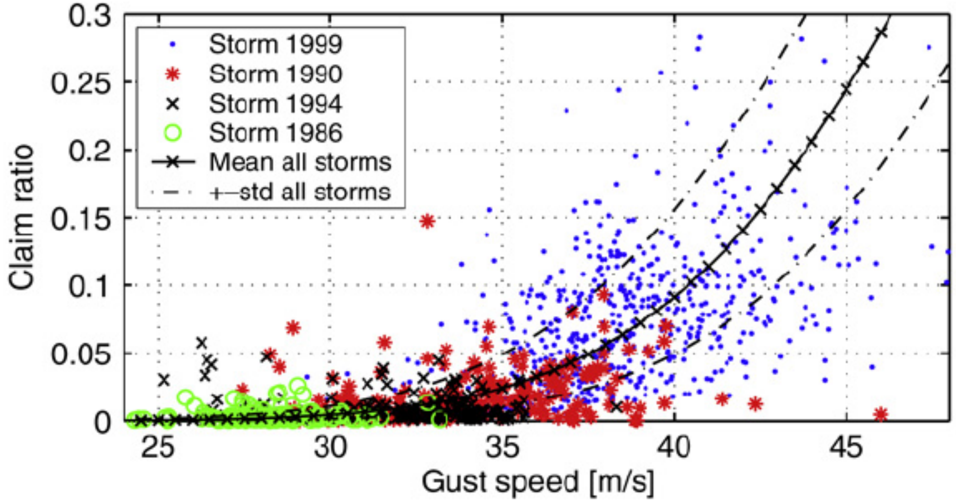
**Engineering Structures 30 (2008) 3603**

A damage model for the assessment of storm damage to buildings

Patrick Heneka[a,b,*], Bodo Ruck[a]

**Analysis of 4 winter storms**



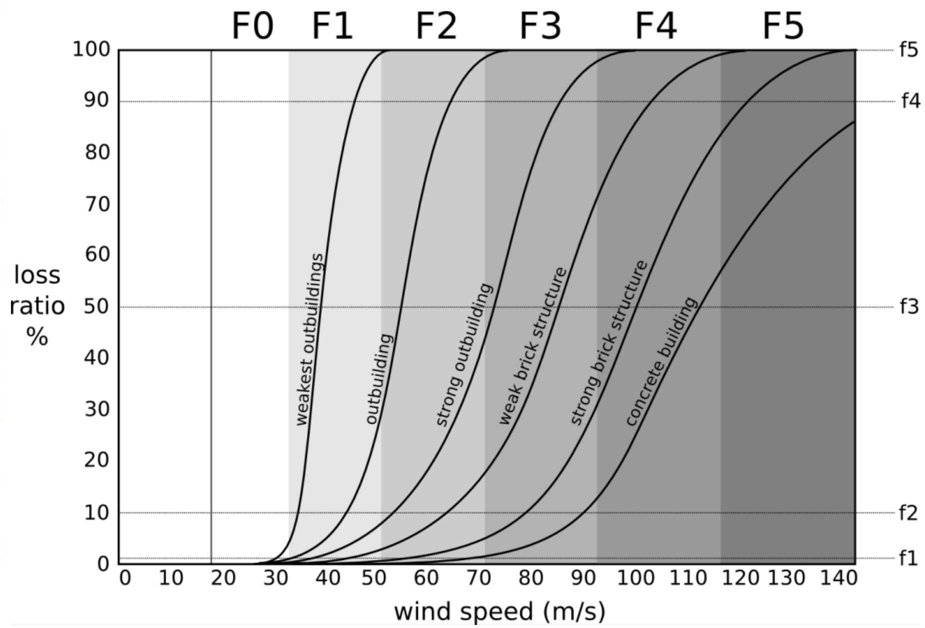




**Results from their model**

**critical windspeed: 50(8) m/s**
**[50% of buildings show damage (>1% loss)]**

**damage ~ v²**

**total damage: >120 m/s**



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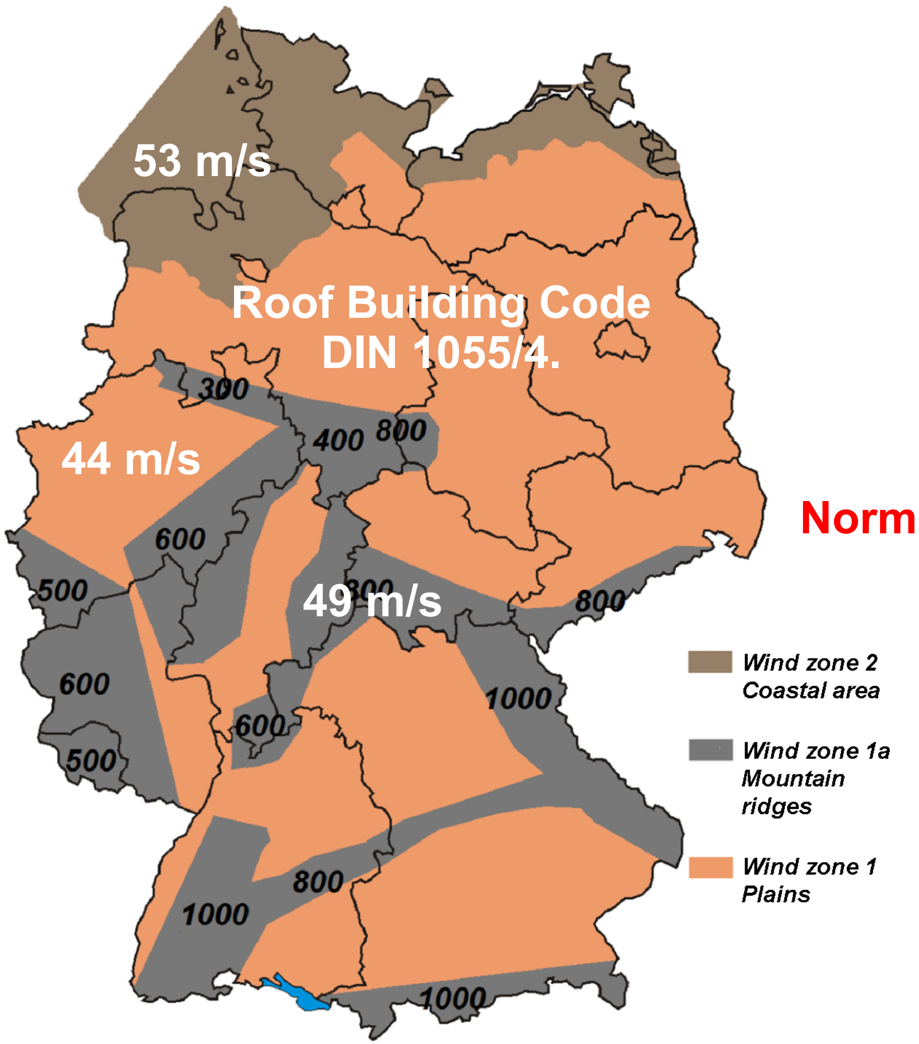
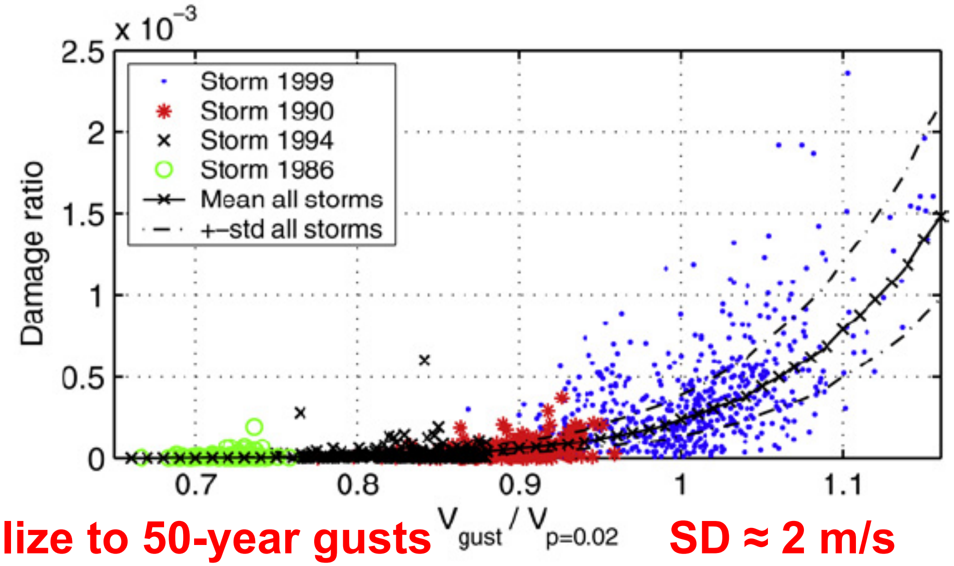
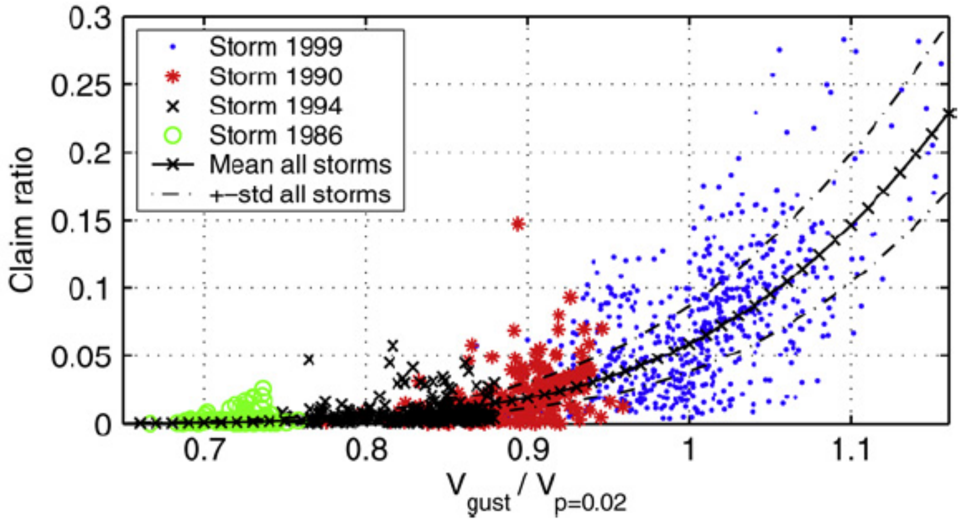



**Normalize to 50-year gusts** **SD ≈ 2 m/s**



## Where's the 'building code' for trees?

## It's in their DNA!

*F3 downburst damage: Braunau am Inn, Austria, 1 March 2008 (Photo: Alois M. Holzer)*

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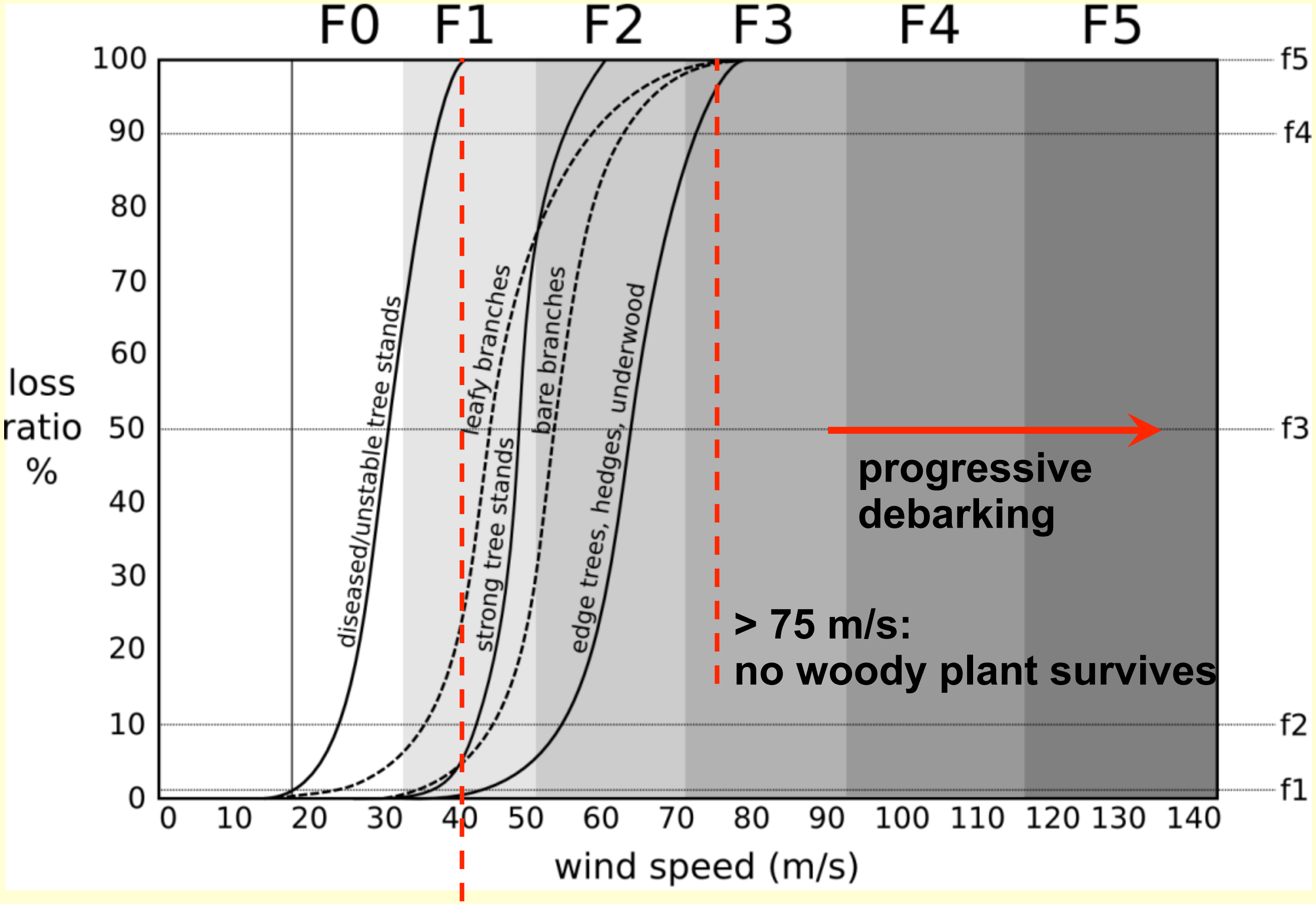


**50-year gusts: ca. 40 m/s**

## Decision matric based on comprehensive analysis by Hubrig (2004)

**Use ensembles: loss *and* claim ratios**

| Fujita damage class | f0 | f1 | f2 | f3 | f4 | f5 |
|---|---|---|---|---|---|---|
| loss ratio (%) | 0.1 | 1 | 10 | 50 | 90 | 100 |
| damage prevalence → / ↓ damage indicator | extremely isolated | isolated | significant | frequent | prevalent | total |
| branches - leafy | **< F0** | **F0+** | **F1-** | **F1+** | **F2-** | **F3-** |
| - bare | **F0-** | **F1-** | **F1+** | **F2-** | **F2-** | **F3-** |
| tree stands - diseased/ unstable | **< F0** | **F0-** | **F0+** *7* | **F0+** *8* | **F1-** | **F1-** |
| - strong | **F0+** | **F1-** | **F1+** | **F1+** *9* | **F2-** *10* | **F2-** |
| edge trees, hedges, underwood | **F1-** | **F1+** | **F2-** | **F2+** *11* | **F3-** *12* | **F3-** |

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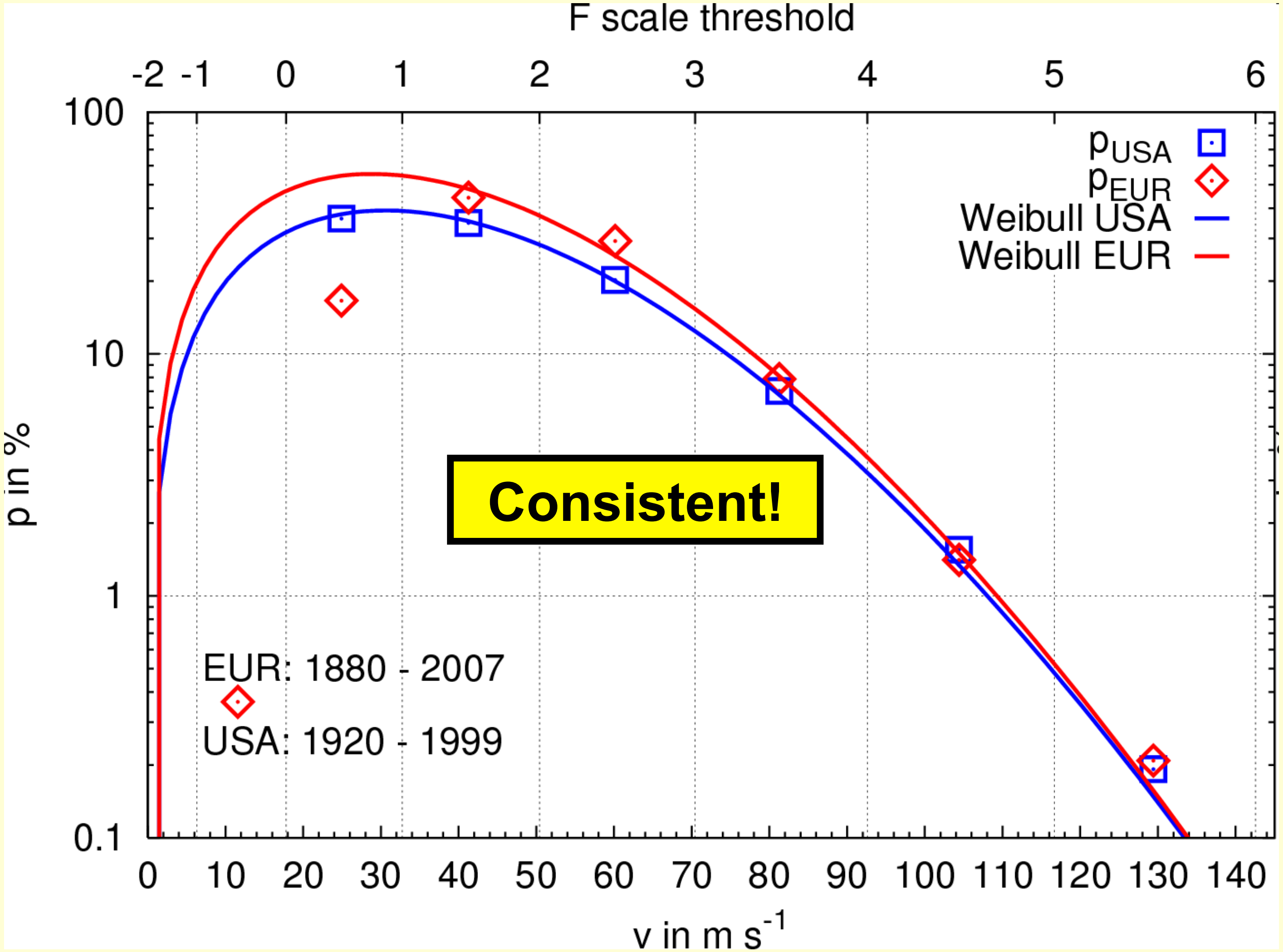
## F-scale rated climatology: EUR vs. USA



## Summary and outlook

**Broad applicability**
***Regional*** **(structural) DI & DOD descriptions are useful.**
**But: be aware of local climatology and related building codes.**
**Vegetation damage is helpful in sparsely populated areas (and provides information about wind field patterns).**
**But: restricted to lower F classes.**

**Accuracy**
**Windstorm data (Heneka & Ruck) support F-scale (50 m/s critical windspeed, 120 m/s total destruction).**
**But: absolute wind speed to damage relation still the most challenging task!**
**(climatology based on in-situ v-measurements, laboratory impact studies, investigate more large-scale windstorms)**

**Consistency**
**Tornado intensity distributions from USA and EUR are very similar:**
**F-scale is consistent at least on a relative scale.**
**Worldwide homogeneity of tornado rating is feasible!**