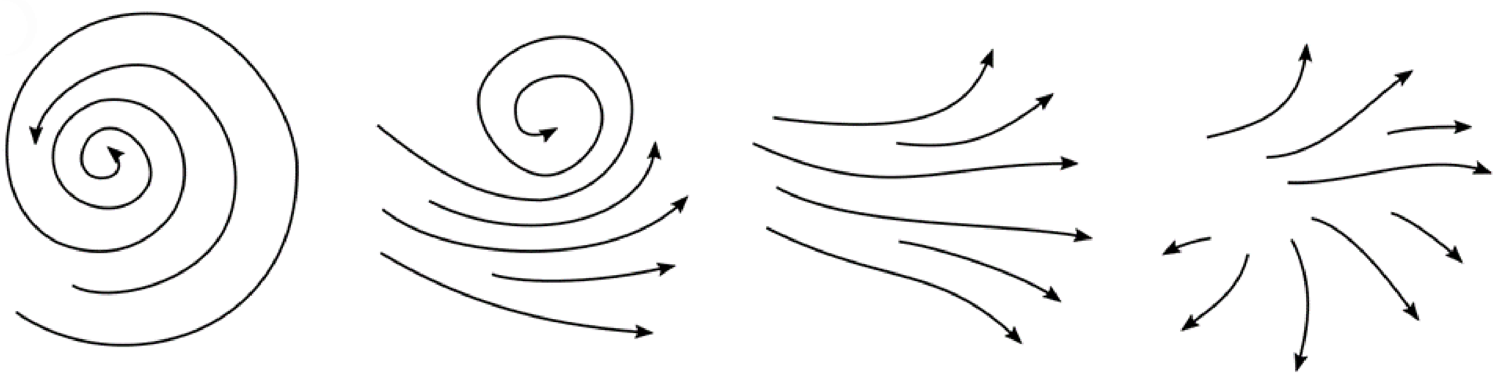
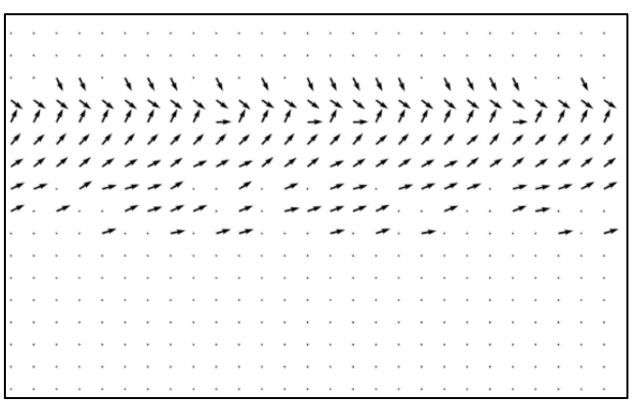
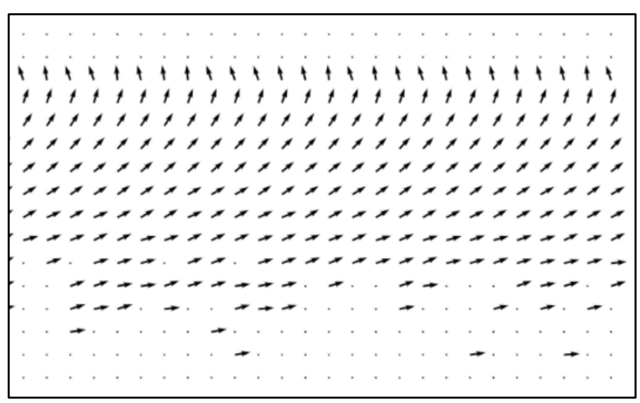
European Severe Storms Laboratory

The International Fujita (IF) Scale

for tornado and wind damage assessments



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Contents

1 Introduction

1.1 This document version

The current version of this document is the first complete version of the IF-scale, published 1 August 2023.

1.2 The content of this document

This document consists of two parts. First, a description of the International Fujita scale, or IF-scale, is given. Second, in Chapter 5, recommendations are provided on conducting a damage survey and interpreting the collected data.

The purpose of the IF-scale is to enable expressing the intensity of tornadoes and local wind phenomena in a generic way that allows international comparisons. The international focus contrasts it with other scales, hence the adjective “International” in its name. However, additional guidance will be needed to apply the scale in other regions than Europe, since most given examples originate from Europe. The development of the IF-scale was needed because a sufficiently detailed scale that was consistent with past tornado rating practice at ESSL, was not available. ESSL developed this scale in collaboration in collaboration with individuals from various other institutions.

After extensive preparatory work had been conducted in a series of workshops of tornado and wind damage by the European Severe Storms Laboratory since 2011, the first draft of this document resulted from a workshop on 4 – 7 September 2018 organized in Wiener Neustadt, and it has since evolved into the present version.

The latest in person workshop on tornado and wind damage assessment took place 29 August – 1 Sept 2023. At the 2023 ESSL workshop, a number of issues with the preliminary version 0.10 were raised, which were taken into account. After a commenting phase for the resulting document, final minor changes were made to result in the current version 1.0.

2 Motivation

2.1 History of wind speed scales for tornadoes

Several scales have been developed to help compare events by comparing the inflicted damage (Figure 2-1). Most prominently, Dr Tetsuya Theodore Fujita developed what has become known as the Fujita scale (Fujita, 1980). Other wind speed scales include the TORRO- or T-scale (Meaden, 1976) and the newer Enhanced Fujita or EF-scale (McDonald and Mehta, 2006), and a national and regional adaptations to it, discussed below.

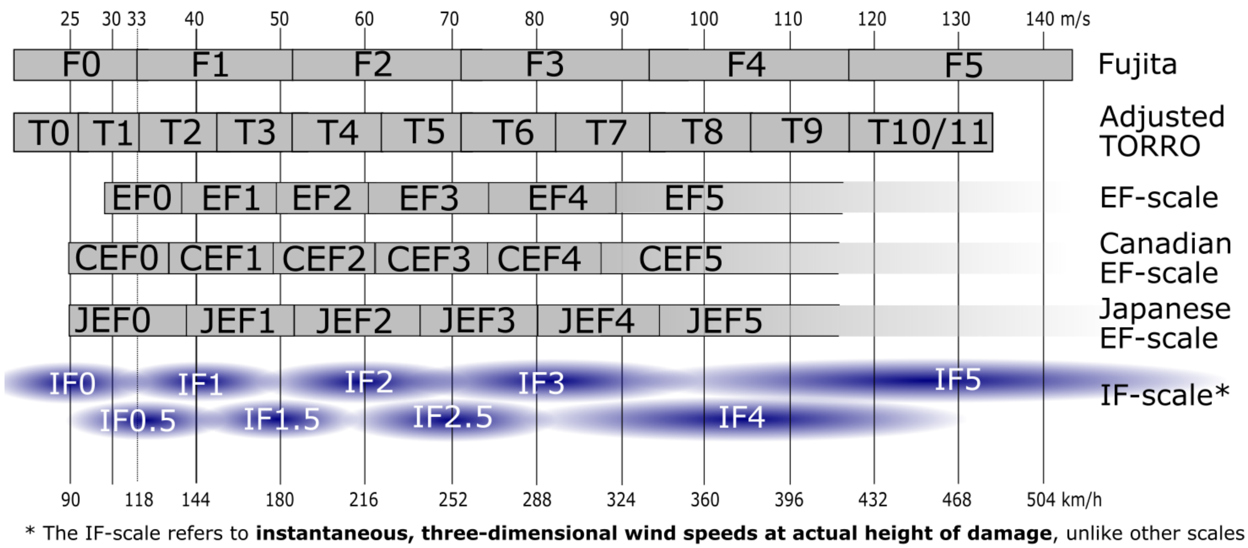


Figure 2-1. Pre-existing wind speed scales used for tornado damage assessment and the IF-scale.

These scales are numbered series of descriptions of increasingly serious wind effects on various objects, along with ranges of wind speeds thought to be responsible for causing the respective damage. For the earliest scales by Fujita and TORRO, a scientific motivation for the posited wind speed estimations was absent. The Fujita-scale has been used in the United States until 2007 and is still used by some organisations, including the European Severe Storms Laboratory.

Near the end of Fujita’s scientific career, he wrote that his scale requires refinement by taking the sturdiness of damaged structures into account when assessing damage to buildings (Fujita, 1992; Figure 2-2). In Europe, the European Severe Storms Laboratory developed an adapted version of the scale to aid rating tornadoes in Europe with the Fujita scale (Feuerstein et al 2012; see Figure 2-2 right).

THE FUJITA TORNADO SCALE

Damage f scale		Little Damage	Minor Damage	Roof Gone	Walls Collapse	Blown Down	Blown Away
		f0	f1	f2	f3	f4	f5
Windspeed F scale (17 m/s, 32, 50, 70, 92, 116, 142; 40 mph, 73, 113, 158, 207, 261, 319)		F0	F1	F2	F3	F4	F5
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 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
A	weakest outbuilding	F0+	F0+	F1-	F1-	F1+	F2-
B	outbuilding	F0+	F1-	F1+	F2-	F2+	F3-
C	strong outbuilding/ weak framehouse	F0+	F1+	F2-	F3-	F3+	F4-
D	weak brick structure/ strong framehouse	F1-	F1+	F2+	F3+	F4-	F5
E	strong brick structure	F1-	F2-	F3-	F4-	F5	F5
F	concrete building	F1-	F2+	F3+	F4+	F5	F5

Figure 2-2. Left: The Fujita (F-) scale allowing for various building types with varying sturdiness. The extent of damage expressed various with both windspeed and sturdiness of structures. From: Fujita (1992). Right: F-scale ratings as a function of building sturdiness (A-F), and of loss ratio and Fujita damage class (f0-f5), as used by ESSL. Adapted from: Feuerstein et al (2012).

2.2 The Enhanced Fujita (EF-) scale and its adaptations

In 2007, Texas Tech University introduced a series of refinements and revisions to wind speed estimates for specific damages, distinguishing between many more types of wind damage, resulting in the Enhanced Fujita (EF) scale (McDonald and Mehta 2006). A tornado damage assessment framework was introduced by systematically categorizing the effects of severe winds using the concepts of damage levels and damage indicators. A damage indicator (DI) is a specific object that may be affected by the wind, and a damage degree (DoD) is the extent to which that object was damaged.

New wind speed estimates for a particular DoD of a particular DI were obtained through expert elicitation: A small number of people, experts in engineering and meteorology, provided estimates for the responsible wind speed for each DoD/DI combination. As a result, the EF scale provides a range of the possible responsible wind speed for a large inventory of potential damage to properties typically found in the United States.

Since then, a number of adaptations of the EF scale have been developed, for example in Canada (Environment Canada, 2015; Sills et al., 2014) and Japan (JMA, 2015). These adaptations and modifications were necessary because the EF scale assumes that damage indicators such as schools, shopping malls and residential buildings have the robustness typical of the United States, which results from building codes and construction practices there and does not necessarily correspond to those in other countries. In addition, some common damage indicators were missing such as damage to vehicles. Since then, proposals for new damage indicators have been made, for example by Mahieu and Wesolek (2016) and by Hubrig (2015), who proposed extensions that reflect damage to trees. Some of these efforts were limited to extending the EF scale, while others significantly changed the wind speed estimates of a given damage type DoD/DI combination, which of course complicates international comparison.

Acknowledging some of the complications of using the EF-scale, a process was started in the USA to develop an updated and formalized EF scale standard to be officially adopted by the American Society of Civil Engineers (ASCE, 2022). The issues being addressed concerned a number of the concerns that spurred the development of the IF scale (e.g., missing DIs, emphasis on building function rather than building construction). This process has still not concluded.

2.3 Desired properties of the IF-scale

In developing the IF-scale, the following properties formulated by Doswell et al. (2009) were our guidance. First, the scale must be *consistent* in the sense that it can be applied consistently over time and across many regions, preferably globally. Second, it must be *accurate*, i.e., as accurate as possible given the available data. Last, it must be *broadly applicable*, covering the wide range of observed wind effects and wind speeds. We next describe how the IF scale attempts to meet those requirements.

1. *Consistency*

To ensure that the scale can be applied consistently in areas where the Fujita- or T-scale have been used in the past, the IF-scale uses wind speeds that are compatible with those scales. For example, the IF3 wind speed value corresponds to the wind speed of F3.

2. *Broad applicability and wind speed definition*

The aim of IF-scale is to present an approach that is fundamentally applicable. It specifies the common denominator, to which further regional refinements can be made. The fact that the building damage indicator is categorised according to **its sturdiness, rather than its function** (cf. EF scale: small retail building, single-family house, primary school, et cetera), should facilitate this.The scale includes the effects of the wind on a wide range of objects and structures and integrates suggestions made by regional adaptors of the EF scale.

Broad applicability also means **that the scale can be applied to the entire range of observed wind speeds**. Since Doppler radar measurements have shown that wind speeds of up to F5 can occur in some tornadoes, the scale should be able to account for the potential impacts of such wind speeds.

Broad applicability is also understood to mean that **the scale should be applicable to all types of wind events**, not just tornadoes. Although the type of damage caused by tornadoes may differ from that caused by downbursts, e.g., due to larger pressure differences or sudden changes in wind speed and direction, there is currently no full scientific understanding of whether similar wind speeds would lead to differing levels of damage in tornadoes and in downbursts. This is why the working hypothesis of the IF scale approach is that they can be treated equally.

To apply wind speed estimates to tornadoes and other wind phenomena, the IF-scale must define precisely what type of wind speed measurement it relates to.

Videos of tornado damage and Doppler radar measurements have shown that winds of extremely short duration can be responsible for severe impacts, such as vehicles that are being lifted within a fraction of a second. Therefore, it is reasonable to assume that a wind speed measured during only a fraction of a second right at the location of the damage has a stronger correlation to the observed damage than, for instance, a three second average wind speed. Furthermore, all three wind components, including the vertical, contribute to the pressure differences that cause damage.

Therefore, the IF-scale wind speeds listed are understood to be **the instantaneous three-dimensional wind speed at the height of the observed damage** (see Section 0).

3. Accuracy

To ensure high accuracy, **wind speed estimates should be based on scientific research**, including actual wind speed measurements where available, and engineering calculations and wind tunnel experiments where they are not. Only if measurements are not available and calculations are not possible, or have not been made yet, subjective expert estimates are to be used. Such estimates are to be updated as soon as calculations, or, preferably, measurements become available.

Aside from being as accurate as possible, the scale must also convey its (lack of) accuracy correctly. Where the F-scale is expressed by adjacent ranges of wind speeds for each class of the scale, **the IF-scale instead provides a central value**. For example, where the Fujita scale defines F3 as wind speeds from 71 – 92 m/s, the IF-scale definition is 80 m/s. Rounded values, and the remark that a range of wind speeds starting about 20% lower and higher than this value is meant should help to avoid the impression of a very high accuracy.

Low wind speeds, which occur much more frequently, are rated with higher accuracy, as more experience with rating such winds has been gained. To enable a higher precision, **the IF-scale uses half steps for the lower half of scale**, i.e., IF0.5, IF1.5, and IF2.5. This renders the step size similar to that of the EF-scale (cf. Figure 2-1). Old tornado records can be compared rather easily to new IF ratings because the damages of a given F category and a given IF category should be similar because they correspond to the same wind speed.

2.4 The wind speed definition

For the wind speeds of the scale, the **instantaneous three-dimensional wind speed** at the and height of the observed damage was chosen. This contrasts with other speed scales that, implicitly or explicitly, take these wind speeds to refer to a longer duration wind gust, e.g., 1 s or 3 s duration gust, or an *equivalent* wind speed where equivalent means the speed of a 3 s duration gust that causes the same impacts.

The choice for the instantaneous wind speed is motivated by the following arguments:

1. **Damage in tornadoes often occurs within a fraction of a second**. This is shown by many video recordings of tornadoes in which cars are lifted in rapidly translating vortices that affect it for a period much shorter than a second, or debris that are accelerated to 100 m/s within a fraction of a second. Such quick effects are to be expected, considering that the wind produces damage by means of the differential pressures on an object. These pressures interact with the wind field at the speed of sound. A simple scale analysis shows that the characteristic timescale of a 10^2 m/s wind affecting a 10^1 m large object is 10^{-1} s. This suggests that wind speed measurements averaged over 1 or 3 seconds will be more poorly correlated with the observed wind effects than shorter duration measurements, at least when ignoring cases of failure due to repeated wind/pressure peaks that have shown to be important at least in some cases (Morrison and Kopp, 2011).

2. **For intense events, rare available measurements almost never include 3 second average wind speeds**, but, instead, measurements from mobile Doppler radars (Kosiba and Wurman 2013; Kosiba and Wurman 2023), or the speeds can be deduced from photogrammetric analyses. While these are not absolutely instantaneous and local measurements, their effective average time is much smaller than three seconds.

   In a rare case where an anemometer measurement was available in a tornado, the speed averaged over a 0.05 s period was at least 18% higher than a 1-second, and 60% higher than a 3-second averaged speed (Blanchard 1992; Lombardo 2018). The duration of averaging, thus, has a big effect on the wind speed value at least in some cases. The net effect of considering the instantaneous rather than an averaged wind speed is that the IF-scale wind speeds are higher for a given class than in the EF-scale and its regional adaptations. The conversion between the instantaneous and 3-second averaged wind speed is not straightforward in tornadoes, and certain assumptions need to be made. New computational or real simulations of tornadoes and downbursts (Hangan, 2014) will likely improve our knowledge in the coming years. Outside of tornadoes, there are estimates for the conversion factor between instantaneous and 3-second averaged wind speeds. In non-tornadic strong wind events, one can expect a 0.1 s duration wind gust to be 17% higher than 3 s wind gusts according to a particular study (see footnote[1]), while other estimates exist as well.

3. **The range of maximum observed wind speeds by Doppler radar measurements in tornadoes in the USA corresponds well with the proposed wind speeds** of the Fujita scale, that the IF-scale continues to use, ranging up to 144 m/s, and with 5% of their best sampled tornadoes having measured wind speed ≥ 127 m/s (Wurman, 2021). For comparison, the central values of the (I)F4 and (I)F5 classes are 105 and 130 m/s.

With respect to the height of measurement, the implications of the wind speeds are smaller, since, although the wind speed at an altitude of 10 m AGL may not be representative of that where damage is produced, but it may be a fair estimate on average. Speeds may be lower closer to the ground than 10 m, because of the effects of turbulent friction in case a balanced flow has developed where turbulent friction and pressure gradient forces are in balance. On the other hand, it may be higher, since radar measurements show that the wind speed in a tornado reaches a maximum very close to the ground, likely lower than 15 m above it (Kosiba and Wurman, 2023).

The full 3D wind speed vector is always larger than or equal to the horizontal component. Near the core of tornadic vortices, the vertical component may even be much larger than the horizontal component as can be seen in videos where tornadic debris are lofted. The strongest vertical speeds occur near the centre of a tornado and its potential sub-vortices, but the horizontal wind component is smaller there. A vertical wind component is, however, just as well capable of producing damage as the horizontal wind as it induces differential pressures as well. The net effect of including the vertical component of the wind near the damage does not render these speeds much different from horizontal winds far away from a tornado's centre, but certainly higher than the horizontal wind close to it.

[1] The maximum wind speed found when measuring every 0.1s (i.e., 10 Hz) is typically about 3.5 times the standard deviation of the turbulent wind $\sigma_{0.1s}$, i.e., 3.5 $\sigma_{0.1s}$, which compares to 2.45 $\sigma_{0.1s}$ when measuring the gusts over a 3s averaging interval (Beljaars, 1987, Figure 10). Estimating $u_{max,3s} \approx 1.6\ u_{avg}$ in a non-tornadic storm (Vickery and Skerlj, 2005), it follows that $\sigma_{0.1s} \approx 0.25\ u_{avg}$. This means that where $u_{max,3s} \approx 1.6\ u_{avg}$, the maximum 0.1 s gust $u_{max,0.1s} \approx 1.875\ u_{avg}$, i.e., ≈ 17% higher.

2.5 The IF-scale speeds

Table 1. IF-scale instantaneous wind speeds corresponding to the classes. They are rounded to the nearest multiple of 10 or 5, except where this would introduce a large percentual error.

IF scale class	Instantaneous wind speed			
	m/s	km/h	mph	knots
IF0	25	90	55	50
IF0.5	33	120	75	65
IF1	40	150	90	80
IF1.5	50	180	110	100
IF2	60	220	135	120
IF2.5	70	250	160	140
IF3	80	290	180	160
IF4	105	380	230	200
IF5	130	470	290	250

Table 1 shows the wind speeds of the IF-scale whereby each class is defined by one value. These central values have been chosen so that the distances that there is a considerable overlap between the classes when assuming errors of 20 in which case the lower bound of a given level of the scale is close to the central value of the class below and that above it.

We required that the steps be consistent with the original Fujita scale and introduced half steps. Above F2.5, such a subdivision was not made, and only full steps are used.

The formula for the wind speed as a function of step is identical to that of the Fujita-scale, i.e.:

$$IF(x) = 6.30\ (x + 2.5)^{1.5}\ \mathrm{m/s}$$
$$IF(x) = 22.7\ (x + 2.5)^{1.5}\ \mathrm{km/h}$$
$$IF(x) = 14.1\ (x + 2.5)^{1.5}\ \mathrm{mph}$$
$$IF(x) = 12.3\ (x + 2.5)^{1.5}\ \mathrm{knots}$$

Note that, in the original Fujita scale, the coefficient 2.5 in the above formulas is 2.0. We here want, e.g., IF1 to correspond to the middle of the range between x = 1.0 and x = 2.0 in the original scale, i.e., x = 1.5, and have increased to coefficient by 0.5 for that reason.

3 Damage Indicator Inventory

For the IF-scale, the following Damage Indicators have been defined. This list can be expanded in the future.

Damage Indicator		Subclasses	Degrees of Damage
BS	Building - structure	A,AB,B,C,D,E,F	0,1A,1B,2
BR	Building - roof	A,AB,B,C,D,E,F	0,1,2
BN	Building - non-structural elements	SW,SS,TW,TS,HW,HS	0,1,2,3
BM	Building - anchoring	SM,SI,DB	1
VH	Road Vehicles	C,E,L,T	0,1,2,3,4
TR	Trees	W,A,S	0,1,2,3,4,5,6,7,8,9
TS	Tree stands	WA,S	0,1,2,3,4
WT	Wind turbines		0,1,2,3
GH	Greenhouses	W,A,S	0,1,2,3
TC	Train cars	S,F	0,1
MH	Mobile homes / static caravans	-	0,1,2,3,4,5
PT	Poles and towers	W,S,T	0,1,2
SP	Solar Panels	-	0,1
FC	Fences	W,S	0,1
FW	Free-standing walls	Z,A,AB,B,C,D,E,F	1,2
SN	Signs and billboards	T,M	0,1,2
SW	Connected scaffolding	-	1
CP	Carports / garages	-	1
SS	Service Station Canopies	-	0,1,2,3
SC	Shipping Containers	A,B,C,D,E,F	1,2,3
CR	Cranes	G,T	1,2
OF	Outdoor Furniture	L,H	0,1,2
WM	Wind Speed Measurement	3,2,1,0	0,0.5,1,1.5,2,2.5,3,4,5

3.1 Interpretation of the IF-scale in the Damage Indicator sections

The following sections include tables that list a given IF scale value for each combination of a Degree of Damage and a Damage Indicator. Sometimes the symbols <, ≤, and ≥ are used. Their meaning is as follows:

Symbol	**Meaning**
<	the damage occurred with the wind speed lower than the indicated IF number
≤	the damage occurred with the wind speed of the indicated IF number, or with a lower wind speed
(no symbol)	the damage occurred with the wind speed of the indicated IF number
≥	the damage occurred with a wind speed of the indicated IF number, or with a higher wind speed

Wind speeds are understood to be estimates and errors are expected. These may easily be as high as 20 %.

3.2 DI: Buildings – B (BS, BR, BN, BM)

Buildings include all structures with a roof and walls standing more or less permanently in one place. They include all forms of residential, commercial, and industrial buildings as well as outbuildings of any kind.

The damage to various components of buildings is to be assessed individually. Concretely, the following forms of damage are distinguished:

1. Damage to the building's structural elements, i.e., its frame and/or walls (sub DI: **BS**)
2. Damage to its roof structure (sub DI: **BR**)
3. Damage to non-structural elements of the roof and/or walls, such as cladding, tiles, shingles, or sheathing (**BN**)
4. Damage to anchoring, i.e., movement of the building off its foundation (**BM**)

Ratings for multiple forms of damage can be made. The highest rating is the rating for the object.

3.2.1 Damage to structural elements (walls or frame) – DI: BS

If any structural elements of a building fail, the sturdiness of the structure needs to be known to estimate the wind speed responsible for the damage. We distinguish between buildings in which a **frame** provides its sturdiness, and those where **mass walls** provide the sturdiness.

In frame structures, the frame gives the building its structural stability. The walls are made from panels of wood, metal, glass, or other materials that contribute little to the strength of the building. Frames are often made of wood, metal, but may also be constructed from reinforced concrete.

In the case of mass walls, building material is stacked, and may be connected by mortar or a similar material to form walls that carry the weight of the structure. Examples of mass wall construction are brick masonry walls, walls of concrete blocks, or wood logs. A special form of mass walls is cast concrete. Especially when cast concrete is reinforced by steel, the resulting structure is very wind resistant.

As a first step, the sturdiness class is to be assigned to any structure to determine the Damage Indicator. When assessing the sturdiness of both mass wall and frame structures, one should consider that buildings intended as (permanent) homes - in affluent areas - are often stronger than those which are not.

3.2.1.1 Frame structures

Following Fujita (1992), for frame structures, a number of classes of sturdiness are distinguished.

Table 2. Sturdiness classes for frame structures.

Class	Description	Comparable description by Fujita (1992)
A	exceptionally weak or faulty frames	weak outbuilding
AB	extremely weak frames	average outbuilding
B	very weak frames	strong outbuilding
C	weak frames	weak frame house
D	strong frames	strong frame house
E	very strong frames	brick structure
F	exceptionally strong frames	concrete building

The sturdiness of a frame structure can be difficult to assess and depends both on the thickness of the frame's elements, the material it consists of the strength of the connections between frame elements, and the geometry of the frame and its elements. A number of examples are given in 3.2.1.4. More research is needed to provide guidance on the classification of frame structures to be included in future editions of the IF-scale.

3.2.1.2 Mass wall structures

The sturdiness of mass wall buildings can be estimated by the thickness and quality of the wall.

Table 3. Sturdiness classes of mass wall structures. The bold letter class is the default, the class in brackets shall be chosen in case of a vulnerable 3D geometry or connection weaknesses (see text).

	Sturdiness class of a building (in brackets: building with vulnerable 3D geometry)				
<- Wall Quality	**Wall Thickness ->**	10 – 20 cm	20 – 40 cm	40 – 80 cm	> 80 cm
	stacked hollow masonry units without reinforcement and with little to no connections	**AB** (A)	**B** (AB)	**C** (B)	**D** (C)
	stacked heavy masonry units such as solid brick or stones, with little to very poor connections	**B** (AB)	**C** (B)	**D** (C)	**E** (D)
	weak brick masonry, unreinforced cast concrete	**C** (B)	**D** (C)	**E** (D)	**F** (E)
	strong brick masonry, filled concrete masonry units	**D** (C)	**E** (D)	**F** (E)	**F** (E)
	steel reinforced filled concrete blocks, or cast-in-place reinforced concrete	**E** (D)	**F** (E)	**F** (F)	**F** (F)

The sturdiness of the building can be estimated using Table 3 on the basis of the wall quality and wall thickness. The lower class (in brackets) shall be chosen in case the geometry of the 3D structure renders it comparatively sensitive to wind effects. An example is the presence of very large openings in the building (e.g., windows) or obvious weaknesses in wall-to-wall or wall-to-ceiling connections.

3.2.1.3 Degrees of Damage

Every combination of a sturdiness class and an observed degree of damage gives a rating on the IF scale and an associated wind speed. The fraction of walls that has been destroyed is the key quantity to be considered.

Any damage to walls above the highest ceiling are to be ignored here, as such damage is considered under the separate damage indicator for roof damage BR.

Table 4. IF ratings for building structural elements, i.e., the walls or frame as a function of sturdiness and DoD.

Degree of Damage to walls or frame:	**Rating for a given sturdiness class and DoD**						
	A	**AB**	**B**	**C**	**D**	**E**	**F**
DoD 0 *Negligible damage to structure* *except to gables above highest ceiling*	**≤IF0.5** ≤ 33 ≤ 120	**≤IF1** ≤ 40 ≤ 150	**≤IF1.5** ≤ 50 ≤ 180	**≤IF2** ≤ 60 ≤ 220	**≤IF2.5** ≤ 70 ≤ 250	**≤IF3** ≤ 80 ≤ 290	*
DoD 1A *Some damage to structure* *destruction of less than 1/5th of all walls*	**IF0.5** 33 120	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220	**IF2.5** 70 250	**IF3** 80 290	**IF4** 105 380
DoD 1B *Partial destruction* *but not more than 2/3*	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220	**IF2.5** 70 250	**IF3** 80 290	**IF4** 105 380	**IF5** 130 470
DoD 2 *Near complete destruction* *more than 2/3*	**≥IF1.5** ≥ 50 ≥ 180	**≥IF2** ≥ 60 ≥ 220	**≥IF2.5** ≥ 70 ≥ 250	**≥IF3** ≥ 80 ≥ 290	**≥IF4** ≥ 105 ≥ 380	**IF5** 130 470	**IF5** 130 470

* Because there is no upper bound to the sturdiness of class "F" there is no upper bound to the wind speeds when no damage is observed.

3.2.1.4 Examples

DI: Building structure, sturdiness AB (BSAB)
outbuilding
DoD: 1B, partially destroyed
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Thilo Kühne, ESSL

DI: Building structure, sturdiness C (BSC)
strong outbuilding
DoD: 1A, partially destroyed
Rating: IF2.5 (70 m/s, 250 km/h)

Photo: Thilo Kühne, ESSL

DI: Building structure, sturdiness C (BSC)
20 – 40 cm weakened brick wall
DoD: 1B, partially destroyed
Rating: IF2.5 (70 m/s, 250 km/h)

Photo: Pieter Groenemeijer, ESSL

DI: Building structure, sturdiness E (BSE)
20 – 40 cm brick wall
DoD: 0, negligible damage to structure
Rating: ≤IF3 (≤ 80 m/s, ≤ 290 km/h)

Photo: Pieter Groenemeijer, ESSL

Note: the roof damage is to be rated separately

DI: Building structure, sturdiness E (BSE)
wall 20 – 40 cm, brick masonry
DoD: 1A, some damage
Rating: IF3 (80 m/s, 290 km/h)

Photo: Tomas Púčik, ESSL

DI: Building structure, sturdiness E (BSE)
wall 20 – 40 cm, brick masonry
DoD: 1A, some damage
Rating: IF3 (80 m/s, 290 km/h)

Photo: Tomas Púcik, ESSL

DI: Building structure, sturdiness E (BSE)
wall 20 – 40 cm, brick masonry
DoD: 1A, some damage
Rating: IF3 (80 m/s, 290 km/h)

Photo: Tomas Púčik, ESSL

DI: Building structure, sturdiness D (BSD)
wall 20 – 40 cm, weakened brick masonry
DoD: 2, near complete destruction
Rating: IF4 (105 m/s, 380 km/h)

Photo: Alois M. Holzer, ESSL

DI: Building structure, sturdiness E (BSE)
20 – 40 cm brick wall
DoD: 1B, partial destruction
Rating: IF4 (105 m/s, 380 km/h)

Photo: Tomáš Púčik, ESSL

DI: Building structure, sturdiness D (BSD)
20 – 40 cm weakened brick masonry
DoD: 1B, partial destruction
Rating: IF4 (105 m/s, 380 km/h)

Photo: Tomas Púcik, ESSL

DI: Building structure, sturdiness E (BSE)
20 – 40 cm brick wall
DoD: 1B, partial destruction
Rating: IF4 (105 m/s, 380 km/h)

Photo: Alois M. Holzer, ESSL

3.2.2 Damage to roof structure – BR

The roof structure of a building is often most exposed to the wind and can have a lower strength than the remainder of the building, or the connection to the rest of the structure may fail.

If a building has a roof construction, such as a gable or mansard roof, it shall be rated separately. As a first guess, the sturdiness class of the roof structure can be assumed to be identical to that of the entire building, but a sturdiness one class class lower or higher may be chosen when the roof is evidently weaker or stronger than average.

Gables above the highest ceilings are also considered part of the roof structure. Roof covering is not considered here but shall be rated as non-structural elements.

Table 5. IF-ratings for DI: Building Roof Structure (BR). Speeds are given in m/s and km/h.

Degree of Damage (DoD) to roof structure:	**Rating for a given sturdiness class and DoD**						
	A	**AB**	**B**	**C**	**D**	**E**	**F**
DoD 0 *No visible damage*	**≤IF0** ≤ 25 ≤ 90	**≤IF0.5** ≤ 33 ≤ 120	**≤IF1** ≤ 40 ≤ 150	**≤IF1.5** ≤ 50 ≤ 180	**≤IF2** ≤ 54 ≤ 193	**≤IF2** ≤ 54 ≤ 193	*
DoD 1 *Damaged* *But less than 2/3 destroyed.*	**IF0** 25 90	**IF0.5** 33 120	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220	**IF2** 60 220	**IF2.5** 70 250
DoD 2 *Roof destroyed or blown away* *Any destruction of walls limited to gables of top floor.*	**≥IF0.5** ≥ 32 ≥ 120	**≥IF1** ≥ 40 ≥ 150	**≥IF1.5** ≥ 50 ≥ 180	**≥IF2** ≥ 60 ≥ 220	**≥IF2** ≥ 60 ≥ 220	**≥IF2.5** ≥ 70 ≥ 250	**≥IF3** ≥ 80 ≥ 290

Note
Because there is no upper bound to the sturdiness of class "F" there is no bound to the wind speeds when no damage is observed.

3.2.2.1 Examples

DI: Building roof, sturdiness B (BRB)
Weak brick masonry – weak roofing
3D vulnerable
DoD: 1 – Partial destruction (gable)
Rating: IF1 (40 m/s, 150 km/h)

Photo: Juan de Dios Soriano, AEMet

DI: Building roof, sturdiness E (BRE)
DoD: 1 – Damaged
Rating: IF2 (60 m/s, 220 km/h)

Photo: Lukáš Ronge

DI: Building roof, sturdiness D (BRD)
DoD: 1 – Damaged
Rating: IF2 (60 m/s, 220 km/h)

Photo: Tomáš Púčik, ESSL

DI: Building roof, sturdiness E (BRE)
DoD: 3 – Roof destroyed or blown away
Rating: IF2.5 (70 m/s, 250 km/h)

Photo: Pieter Groenemeijer, ESSL

DI: Building roof, sturdiness F (BRF)
DoD: 2 – Roof destroyed or blown away
Rating: IF3 (80 m/s, 290 km/h)

Photo: Tomáš Púčik, ESSL

3.2.3 Damage to non-structural elements (tiles, shingles, sheathing, ...) – BN

Table 6 gives IF-scale ratings for damage to various types of non-structural elements of buildings. A distinction is made between sheathing, roof tiles and thatched roofs, and within these classes between weak and strong attachment.

The weak category should be chosen where tiles or sheathing are not physically attached but kept in place by their own weight and are light. When tiles or sheathing are well-attached, or when roof tiles are exceptionally heavy, the strong category applies. For thatched roofs, whenever the roof has small eaves and is smooth, the strong category applies; otherwise, the weak category must be used.

Table 6. IF-scale ratings for DI Building: Non-structural elements (BN). Speeds are given in m/s and km/h.

Degree of Damage (DoD) to non-structural elements	**Rating for a given category and DoD**					
	sheathing (metal, cement, wood or other)		**tiles or shingles solar panels***		**thatched roof (straw, reed, ...)**	
	SW weak	**SS** strong	**TW** weak	**TS** strong	**HW** weak	**HS** strong
DoD0 *No elements lost (0%)*	**≤IF0.5** ≤ 33 ≤ 120	**≤IF1** ≤ 40 ≤ 150	**≤IF0.5** ≤ 33 ≤ 120	**≤IF1** ≤ 40 ≤ 150	**≤IF1** ≤ 40 ≤ 150	**≤IF1.5** ≤ 50 ≤ 180
DoD 1 *Some elements lost (< 25%)*	**IF0.5** 33 120	**IF1** 40 150	**IF0.5** 33 120	**IF1** 40 150	**IF1** 40 150	**IF1.5** 50 180
DoD 2 *Many elements lost (25 – 75%)*	**IF1** 40 150	**IF1.5** 50 180	**IF1** 40 150	**IF1.5** 50 180	**IF1.5** 50 180	**IF2** 60 220
DoD 3 *Most elements lost (> 75%)*	**≥IF1** ≥ 40 ≥ 150	**≥IF1.5** ≥ 50 ≥ 180	**≥IF1.5** ≥ 50 ≥ 180	**≥IF1.5** ≥ 50 ≥ 180	**≥IF1.5** ≥ 50 ≥ 180	**≥IF2** ≥ 60 ≥ 220

* solar panels not fixed to the roof are meant here, and they should be considered in the TS category. Physically connected solar panels are part of the roof structure and should be rated using the DI Building – Roof structure (BR).

3.2.3.1 Examples

DI: Roof tiles, strong (BNTS)
DoD: 1 – Some elements lost
Rating: IF1 (40 m/s, 150 km/h)

Photo: Thilo Kühne, ESSL

DI: Roof tiles, strong (BNTS)
DoD: 2 – Many elements lost
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Thilo Kühne, ESSL

DI: Roof tiles, strong (BNTS)
DoD: 2 – Many elements lost
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Délia Gutierrez Rubio, AEMet

DI: Sheathing, strong (BNSS)
DoD: 3 – Most elements lost
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Thilo Kühne, ESSL

DI: Roof tiles, weak (BNTW)
DoD: 3, Most elements lost
Rating: ≥IF1.5 (≥ 50 m/s, ≥ 180 km/h)

Photo: Tomáš Púčik, ESSL

3.2.4 Failing anchoring: Structure moved off foundation – BM

This failure can occur with frame structures, e.g., wooden houses that moved off their foundation. It only occurs when the anchoring was less wind-resistant than the frame structure of the building.

Table 7. IF-scale table for DI Building: Structure moved off foundation (BM). Speeds are given in m/s and km/h.

Degree of Damage (DoD) to anchoring:	**Rating for a given category and DoD**		
	SM small frame shed or outbuilding	**SI** one-storey frame building	**DB** two-storey or higher frame building
DoD 1 *Building moved off foundations or overturned*	**≥IF0.5** 33 120	**≥IF1** 40 150	**≥IF2** 60 220

Note: Similar DI's exist in the EF-scale (DI FR12 / DoD 5) and JEF-scale (DI 4 / DoD 2-3 and DI 10 / DoD 1,2). Speeds were adjusted upward to account for the instantaneous wind speed definition.

3.3 DI: Road Vehicles – VH

Table 8. IF-scale ratings for DI Road Vehicles (VH). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Rating for a given category and DoD**			
	T towed trailers	**E** empty trucks/lorries other vehicles with large surface area	**L*** large heavy vehicles: buses, loaded trucks/lorries	**C** cars, vans
DoD 0 *No movement*	**≤IF1** ≤ 40 ≤ 150	**≤IF1** ≤ 40 ≤ 150	**≤IF1.5** ≤ 50 ≤ 180	**≤IF1.5** ≤ 50 ≤ 180
DoD 1 *Sliding of vehicle*	**IF1** 40 150	**IF1** 40 150	**IF1.5** 50 180	**IF1.5** 50 180
DoD 2 ** *Overturning or lifting*	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220	**IF2** 60 220
DoD 3 *Displacement over large distance (> 10 m) by overturning*	**IF1.5** 50 180	**IF2** 60 220	**IF2.5** 70 250	**IF2.5** 70 250
DoD 4 *Displacement over large distance (> 10 m) by lofting*	**≥IF2** ≥ 60 ≥ 220	**≥IF2.5** ≥ 70 ≥ 250	**≥IF3** ≥ 80 ≥ 290	**≥IF3** ≥ 80 ≥ 290

* For trucks/lorries (L) with several tonnes of load, the DI for shipping containers shall be used instead.

** Any overturning should be caused by the wind, and cannot be applied to vehicles being driven into or through the high wind with considerable speed. In that case, choose DoD1.

Note
These estimates were based on combining JMA(2015), Schmidlin et al. (2002), Haan et al (2017) and then adjusted upward to account for the instantaneous wind definition.

3.3.1 Examples

DI: Cars, vans (VHC)
DoD: 1 – Sliding
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Tomáš Púčik, ESSL

DI: Towed trailers (VHT)
DoD: 4 – Displacement >10 m by lofting
Rating: IF2 (60 m/s, 220 km/h)

Photo: Tomáš Púčik, ESSL

DI: Cars, vans (VHC)
DoD: 2 – Overturning
Rating: IF2 (60 m/s, 220 km/h)

Photo: Thilo Kühne, ESSL

DI: Cars, vans (VHC)
DoD: 4 – Displacement >10 m by lofting
Rating: IF3 (80 m/s, 290 km/h)

Photo: Tomáš Púčik, ESSL

DI: Large, heavy vehicles(VHL)
DoD: 4 – Displacement >10 m by lofting
Rating: IF3 (80 m/s, 290 km/h)

Photo: Tomáš Púčik, ESSL

3.4 DI: Trees - TR

3.4.1 Introduction

Damage to trees can be divided in to categories. Either parts of the tree, such as branches or the trunk, sustained structural failure, or the connection of the tree to the ground was broken, i.e. uprooting occurred. Moreover, at high wind speeds, sandblasting may remove the bark off the tree, which is called debarkation.

The wind speed needed fro structural failure to occur depends on the strength of the tree, which is influenced by

- the tree geometry
- the strength of the wood
- whether the tree is bearing leaves

The resistance of trees against uprooting is controlled mostly by

- the size, health, and geometry of the root system
- soil type and soil condition, in particular its water content

If the anchoring of the root system in the ground is stronger than the strength of the trunk, the trunk will break before the root system fails. Trunk snapping is probably most likely in quickly varying winds, such as in tornadoes. Some tree types are prone to deformation failure, which occurs in trunks with high flexural strength but lower pressure resistance.

Some trees may be ill, and be (very) weak as a result. If there are signs for this to be the case, damage to the tree cannot be rated except by an expert.

Apart from unhealthy trees, trees in built-up areas or along roads and streets can have their stability compromised by impairments to their root systems or by the fact that the soil type on which they stand is not natural. Such trees should not be used for a wind intensity rating.

Especially when single trees are used to rate a tornado or wind event, they should be well documented by photos to allow assessment by an expert.

The assessment of damage to trees starts with establishing tree strength and subsequently combine the respective Damage Indicator subclass with the observed DoD in

Table 10. To rate the uprooting or snapping of a group of trees (a tree stand), see Section 3.5. For rating single trees, use this DI.

3.4.2 Tree strength

Tree strength depends on a number of factors. The tree species can give a first indication. A list of fragile sturdy tree species is given in Table 9. However, this list is not exhaustive, and this list would optimally be adapted regionally to include fragile (sub-)species and to exclude strong subspecies common in a certain region. To rate tree damage, the tree strength number is to be determined.

Table 9. List of weak tree species.

Common name	Scientific name
Spruce	*Picea sp.*
Douglas	*Pseudotsuga sp.*
Fir	*Abies alba*
Poplar, Aspen	*Populus sp.*
Willow	*Salix sp.*
Birch	*Betula sp.*
Eucalyptus	*Eucalyptus sp.*
Ash[2]	*Fraxinus excelsior*

To find the strength of the tree, start with the number 3 and follow these steps:

- **Subtract 1** if the tree species is a fragile tree species listed in Table 9.
- **Subtract 1** if uprooting occurred and the tree was rooted in unstable, e.g., saturated, soil.
- **Add 1** if the tree is a very stable tree, for example because it
  - has a small height/diameter ratio, or
  - is very well rooted (in case of uprooting), or
  - it grows in a location frequently exposed to strong winds
- **Add 1** if the tree is a deciduous tree without any leaves.

The resulting number indicated tree strength can range from 1 to 5.

[2] Healthy ash (Fraxinus exclesior) trees are not weak, however many trees are suffering from ash shoot dieback and should then be regarded as a weak tree.

Table 10. IF-scale ratings for DI tree (TR). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Rating per category**		
	W ***Weak trees (strength 1 or 2)***	**A** ***Average trees (strength 3)***	**S** ***Strong trees (strength 4 or 5)***
DoD 0 *No damage*	**≤IF0** < 25 < 90	**≤IF0** < 25 < 90	**≤IF0.5** < 33 < 120
DoD 1 *Minimal debranching** *Multiple small branches or a single large branch broken off*	**IF0** 25 90	**IF0.5** 33 120	**IF0.5** 33 120
DoD 2 *Minor debranching** *Multiple large branches or part of crown broken off, but not more than 1/3 of all large branches*	**IF0.5** 33 120	**IF1** 40 150	**IF1.5** 50 180
DoD 3 *Uprooting*	**≥IF0.5** ≥ 33 ≥ 120	**≥IF1** ≥ 40 ≥ 150	**≥IF1.5** ≥ 50 ≥ 180
DoD 4 *Compression failure* *wood of tree stem permanently deformed*	**IF0.5** 33 120	**IF1** 40 150	**IF1.5** 50 180
DoD 5 *Trunk snapping* *possibly with removal of parts of the bark as a result*	**≥IF1** ≥ 40 ≥ 150	**≥IF1.5** ≥ 50 ≥ 180	**≥IF2** ≥ 60 ≥ 220
DoD 6 *Major debranching** *More than 1/3 of large branches broken off; some leaves may be remaining; the trunk is not snapped*	**IF1.5** 50 180	**IF2** 60 220	**IF2.5** 70 250
DoD 7 *Complete debranching** *All branches broken off; most large branches broken off close to the remaining stem; no leaves left on the remains of the tree; the trunk is not snapped*	**	**≥IF3** ≥ 80 ≥ 290	
DoD 8 *Minor debarking (<60%) due to sandblasting* *or impact of other small debris*	**≥IF3** ≥ 80 ≥ 290		
DoD 9 *Major debarking (>60%) due to sandblasting* *or impact of other small debris*	**≥IF4** ≥ 105 ≥ 380		

** Dead branches are not included*

*** This is not expected for weak trees, since snapping of the trunk or uprooting will happen first.*

3.4.3 Examples

DI: Tree, weak (TRW)
oak (3) poorly rooted (-1):
strength = 2 (weak)
DoD: 3 – Uprooting
Rating: IF0.5 (33 m/s, 120 km/h)

Photo: Martin Hubrig

DI: Tree, weak (TRW)
pine (2), poorly rooted (-1)
strength = 1 (weak)
DoD: 3 – Uprooting
Rating: IF0.5 (33 m/s, 120 km/h)

Photo: Martin Hubrig

DI: Tree, weak (TRW)
strength 2 (weak)
DoD: 4 – Compression failure
Rating: IF0.5 (33 m/s, 120 km/h)

Photo: Martin Hubrig

DI: Tree, average (TRA)
spruce (2), very well rooted (+1)
strength = 3 (average)
DoD: 3 – Uprooting
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Martin Hubrig

DI: Tree, average (TSA)
pine (2),
strength = 2 (average)
DoD: 5 – Trunk snapping
Rating: IF1 (40 m/s, 150 km/h)

Photo: Délia Gutierrez Rubio, AEMet

DI: Tree, strong (TRS)
species: 3
oak (3), tree without leaves means (+1)
strength = 4 (strong)
DoD: 3 – Uprooting
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Martin Hubrig

DI: Tree, weak (TRW)
tree (2)
strength = 2
DoD: 6 – Major debranching
Majority of large branches (> 50 %) broken off. The trunk is not snapped.
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Mortimer Müller

DI: Tree, average (TRA)
oak (3), frequently exposed to strong winds (+1)
strength = 4 (strong)
DoD: 6 – Major debranching
Majority of large branches (> 50 %) broken off. The trunk is not snapped.
Rating: IF2.5 (70 m/s, 250 km/h)

Photo: Oliver Schlenczek

DI: Tree (TRA)
DoD: 7 – Complete debranching
All large and small branches broken; most large branches broken off close to the remaining stem; no leaves left on standing tree remains; the trunk is not snapped
Rating: IF3 (80 m/s, 290 km/h)

- Note that the bark was not partially removed by sandblasting but was ripped off when the branches were blown off.

Photo: Tomáš Púčik/Alois M. Holzer, ESSL

DI: Tree (TRA)
DoD: 7 – Complete debranching
All large and small branches broken; most large branches broken off close to the remaining stem; no leaves left on standing tree remains; the trunk is not snapped
Rating: IF3 (80 m/s, 290 km/h)

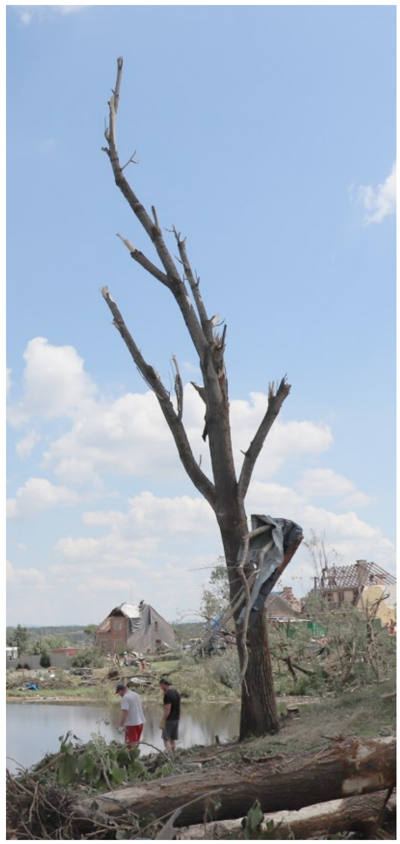


Photo: Tomáš Púčik (ESSL)

DI: Tree, average (TRA)
DoD: 7 – Complete debranching
Rating: ≥IF3 (≥ 80 m/s, ≥ 290 km/h)
All large and small branches broken; most large branches broken off close to the remaining stem; no leaves left on standing tree remains; the trunk is not snapped
and
DoD: 8 – Minor debarking due to sandblasting
Rating: ≥IF3 (≥ 80 m/s, ≥ 290 km/h)

Photo: Rainer Kaltenberger

DI: Tree, average (TRA)
DoD: 7 – Complete debranching
Rating: ≥IF3 (≥ 80 m/s, ≥ 290 km/h)
All large and small branches broken; most large branches broken off close to the remaining stem; no leaves left on standing tree remains; the trunk is not snapped
and
DoD: 9 – Major debarking due to sandblasting
Rating: ≥IF4 (105 m/s, 380 km/h)

Photo: Tomáš Púčik/Alois M. Holzer, ESSL

DI: Tree
The tree is rotten from the inside and therefore prone to be blown over. It cannot be used to obtain a rating.
DoD: 5 – Trunk snapped
Rating: unrated

3.5 DI: Tree stand – TS

A tree stand is a number of trees close together that were exposed to more or less the same winds, such as in a park, or forest, where assessing the sturdiness of every single tree is not feasible. To use this as a Damage Indicator, we need the average tree strength (see: 3.4.2) for the tree stand and the percentage of snapped or uprooted trees.

Table 11. IF-scale ratings for DI Tree Stand (TS). Speeds are given in m/s and km/h.

	W *Weak trees (strengths 1 or 2 dominate)*	**A** *Average trees (strengths 3 dominates)*	**S** *Strong trees (strengths 4 or 5 dominate)*
DoD 0 *No trees snapped or uprooted*	**≤ IF0** < 25 < 90	**≤ IF0.5** < 33 < 120	**≤ IF0.5** < 33 < 120
DoD 1 *Isolated trees snapped or uprooted (< 10 %)*	**IF0.5** 33 120	**IF1** 40 150	**IF1** 40 150
DoD 2 *Fewer than half of the trees snapped or uprooted (10 – 50 %)*	**IF1** 40 150	**IF1** 40 150	**IF1.5** 50 180
DoD 3 *More than half of the trees snapped or uprooted (50 – 90 %)*	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220
DoD 4 *(almost) all trees snapped or uprooted (90 – 100 %)*	**≥IF1.5** ≥ 50 ≥ 180	**≥IF2** ≥ 60 ≥ 220	**≥IF2.5** ≥ 70 ≥ 250

Note
This table is similar to the equivalent DI in the CEF scale.

3.5.1 Examples

DI: Tree Stand (TSA)
trees, strength 3
DoD: 1 - Isolated trees snapped or uprooted
Rating: IF1 (40 m/s, 150 km/h)

Photo: Lukáš Ronge

DI: Tree Stand (TSA)
trees, strength 3
DoD: 2 – Fewer than half of trees snapped or uprooted
Rating: IF1 (40 m/s, 150 km/h)

Photo: Lukáš Ronge

DI: Tree, weak (TRW)
spruce, strength 2, weak
DoD: 5 – (almost) all trees snapped or uprooted
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Martin Hubrig

DI: Tree Stand (TSA)
trees, strength 2 (mainly birch trees)
DoD: 3 – more than half of trees snapped or uprooted
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Lukáš Ronge

DI: Tree Stand (TSW)
Trees, strength 2
DoD: 4 – (almost) all trees snapped or uprooted
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Thilo Kühne, ESSL

DI: Tree Stand (TSA)
trees, strength 2 (birch trees)
DoD: 4 – (almost) all trees snapped or uprooted
Rating: IF2 (60 m/s, 220 km/h)

Photo: Lukáš Ronge

3.6 DI: Wind turbines – WT

Table 12. IF-scale ratings for DI Wind Turbines (WT). Speeds are given in m/s and km/h.

	A average	**S** strong
DoD 0 *No visible damage*	**≤IF1.5** ≤ 50 ≤ 180	**≤IF2** ≤ 60 ≤ 220
DoD 1 *Broken or shredded turbine blade*	**IF1.5** 50 180	**IF2** 60 220
DoD 2 *Permanent deformation of tower or blades*	**IF2** 60 220	**IF2.5** 70 250
DoD 3 *Tower collapse*	**≥IF2.5** ≥ 70 ≥ 250	**≥IF3** ≥ 80 ≥ 290

Note

Speeds are based on US ASCE EF-scale V2 standard proposal, adjusted upward to account for the instantaneous wind speed definition.

3.7 DI: Greenhouses - GH

Table 13. IF-scale ratings for DI Greenhouses (GH). Speeds are given in m/s and km/h.

Degree of Damage	**Category**		
	W weak	**A** average	**S** strong
DoD 0 *No damage*	**<IF0** < 25 90	**≤IF0** ≤ 25 ≤ 90	**≤IF0.5** ≤ 33 ≤ 120
DoD 1 *Cover damaged, or partially lifted*	**IF0** 25 90	**IF0.5** 33 120	**IF1** 40 150
DoD 2 *Cover (almost) completely gone*	**IF0.5** 33 120	**IF1** 40 150	**IF1** 40 150
DoD 3 *Collapse, lifting or overturning*	**≥IF1** ≥ 40 ≥ 150	**≥IF1** ≥ 40 ≥ 150	**≥IF1.5** ≥ 50 ≥ 180

3.7.1 Sub-categories

For Greenhouses, the following sub-categories are defined:

W (weak):
Plastic / PVC cover
Aluminium frames
(agricultural)

A (average):
Glass / PVC cover
Wood or light pipe metal
frames

S (strong):
Glass cover
Pipe metal frames
(agricultural)

3.7.2 Examples

DI: Greenhouse, weak (GHW)
DoD: 2 – Cover damaged
Rating: IF0 (25 m/s, 90 km/h)

Photo: Juan de Dios Soriano, AEMet

DI: Greenhouse, weak (GHW)
DoD: 2 – Cover (almost) completely gone
Rating: IF0.5 (33 m/s, 120 km/h)

Photo: Délia Gutierrez Rubio, AEMet

DI: Greenhouse, weak (GHW)
DoD: 3 – Collapse
Rating: IF1 (40 m/s, 150 km/h)

Photo: Juan de Dios Soriano, AEMet

3.8 DI: Train cars – TC

Table 14. IF-scale ratings for DI Train cars (TC). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Sub-categories:**	
	S Stationary, or operating at < 25 m/s	**F** Operating at normal speed, ≥ 25 m/s
DoD 0 *No flipping or derailment*	**≤IF1.5** ≤ 50 ≤ 180	**≤IF1** ≤ 40 ≤ 140
DoD 1 *Flipping or derailment*	**≥IF2** ≥ 60 ≥ 220	**≥IF1.5** ≥ 50 ≥ 180


Photo: Phil Richards from London, UK - 21.04.10 Sofia 31005, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=26695298
Photo: Phil Richards from London, UK - 26.03.95 La Pobla de Segur, https://commons.wikimedia.org/w/index.php?curid=23047753
Photo:Doug Sim - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=30305173

3.9 DI: Mobile Homes / Static Caravans – MH

Table 15. IF-scale ratings for DI Mobile Homes/ Static Caravans (MH). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	
DoD 0 *No damage*	**≤IF0.5** ≤ 33 ≤ 120
DoD 1 *Light damage to roof or siding*	**IF0.5** 33 120
DoD 2 *Unit slides*	**IF1** 40 150
DoD 3 *Roof gone*	**IF1** 40 150
DoD 4 *Overturned*	**IF1.5** 50 180
DoD 5 *Complete destruction or becoming airborne*	**≥IF2** ≥ 60 ≥ 220

Note
Estimates based on EF-scale (McDonald and Mehta, 2006), adjusted upward for instantaneous wind speed definition.

3.9.1 Examples

DI: MH
DoD: 4 Complete destruction or becoming airborne
Note: the caravan was lifted over a garage
Rating: IF2 (60 m/s, 220 km/h)

Photo: Tomáš Púčik, ESSL

3.10 DI: Poles and Towers – PT

Table 16. IF-scale ratings for DI Poles and towers (PT). Speeds are given in m/s and km/h.

Degree of Damage	**W** utility pole, light pole, or traffic light pole, weak	**S** utility pole, light pole, or traffic light pole, strong	**T** power transmission tower
DoD 0 *No damage*	**≤IF0.5** ≤ 33 ≤ 120	**≤IF1.5** ≤ 50 ≤ 180	**≤IF1.5** ≤ 50 ≤ 180
DoD 1 *Deformed, bent, or leaning*	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220
DoD 2 *Collapsed*	**≥IF1.5** ≥ 50 ≥ 180	**≥IF2** ≥ 60 ≥ 220	**≥IF2** ≥ 60 ≥ 220

Note

Estimates based on EF-scale (McDonald and Mehta, 2006) with upward adjustments of speeds to adapt for instantaneous 3D wind speed definition.

3.10.1 Examples

DI: Light pole, strong (PTS)
DoD: 1 – Deformed, bent or leaning
Rating: IF1.5 (50 m/s , 180 km/h)

Photo: Tomáš Púčik, ESSL

DI: Traffic light pole, strong (PTS)
DoD: 1 – Deformed, bent, or leaning
Rating: IF1.5 (50 m/s , 180 km/h)

Photo: Tomáš Púčik, ESSL

DI: Light pole, strong (PTS)
DoD: 2 – Collapsed
Rating: IF2 (60 m/s , 220 km/h)

Photo: Tomáš Púčik, ESSL

DI: Utility pole, strong (PTS)
DoD: 1 – Collapsed
Rating: IF2 (60 m/s, 220 km/h)

Photo: Délia Gutierrez Rubio, AEMet

DI: Utility pole, strong (PTS)
DoD: 2 – Collapsed
Rating: IF2 (60 m/s, 220 km/h)

Photo: Tomáš Púčik, ESSL

DI: Power transmission tower (PTT)
DoD: 2 – Collapsed
Rating: IF2 (60 m/s, 220 km/h)

Photo:Lukáš Ronge, AMS

3.11 DI: Solar Panels – SP

This DI is for solar panels that are located in a field rather than on a roof. Solar panels fixed to a roof are part of the roof structure and shall be rated using the DI (BR: Building – roof). Solar panels not attached to a roof can be considered as strong roof tiles/shingles.

Table 17. IF-scale ratings for DI Solar Panels (SP). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	
DoD 0 *No damage, or damaged by debris impact*	**≤IF1.5** ≤ 50 180
DoD 1 *Detachment or structural failure*	**≥IF2** 60 220

3.11.1 Examples

DI: SP (Solar panels)
DoD: 1 – Detachment or structural failure
Rating: IF2 (60 m/s, 220 km/h)

Photo: Lukáš Ronge, AMS

DI: SP (Solar panels)
DoD: 1 – Detachment or structural failure
Rating: IF2 (60 m/s, 220 km/h)

Photo: Juan de Dios Soriano, AEMet

3.12 DI: Fences - FC

Table 18. IF-scale ratings for DI Fences (FC). Speeds are given in m/s and km/h.

	Sub-class	
Degree of Damage (DoD):	**W** Metal wire or wooden fence, weak	**S** Metal wire or wooden fence, strong
DoD 1 *Partial or complete collapse*	**≥IF0.5** ≥ 33 ≥ 120	**≥IF1** ≥ 40 ≥ 150

3.12.1 Examples

DI: Weak fence (FCW)
DoD: 1 – Bent, leaning, deformed or collapsed
Rating: ≥IF0.5 (33 m/s, 120 km/h)

Photo: Délia Gutierrez Rubio, AEMet

DI: Strong fence (FCS)
DoD: 1 – Bent, leaning, deformed or collapsed
Rating: ≥IF1 (40 m/s, 150 km/h)

Photo: Délia Gutierrez Rubio, AEMet

DI: Strong fence (FCW)
DoD: 1 – Bent, leaning, deformed or collapsed
Rating: ≥IF1 (40 m/s, 150 km/h)

Photo: Délia Gutierrez Rubio, AEMet

DI: Strong fence (FCS)
DoD: 1 – Bent, leaning, deformed or collapsed
Rating: ≥IF1 (40 m/s, 150 km/h)

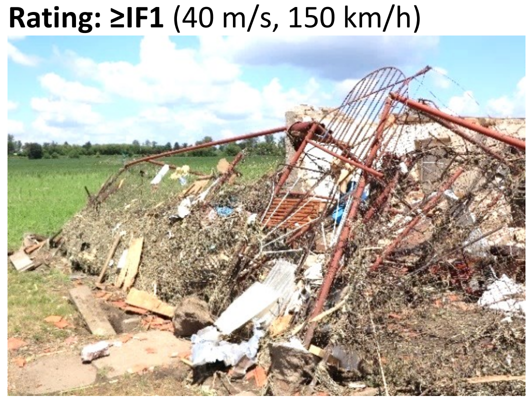


Photo: Tomáš Púčik, ESSL

3.13 DI: Free-standing walls – FW

To rate damage to free-standing walls, first determine the wall sturdiness, by combining the wall building material and width of the wall.

Damage to the walls by the impact of airborne debris is excluded.

In case only sidings of the walls are damaged, these can be rated as Non-structural elements (tiles, shingles, sheathing, etc.) – DI: BN.

Table 19. Table to determine sturdiness class of free-standing wall.

	Sturdiness class for free-standing walls * **				
Wall Quality	**Wall Thickness:**	10 – 20 cm	20 – 40 cm	40 – 80 cm	> 80 cm
	hollow concrete blocks, unreinforced	**Z**	**A**	**AB**	**B**
	stacked solid bricks or stones, unreinforced concrete	**A**	**AB**	**B**	**C**
	weak brick masonry, concrete blocks (reinforced)	**AB**	**B**	**C**	**D**
	brick masonry	**B**	**C**	**D**	**D**
	reinforced concrete	**C**	**D**	**F**	**E**
	* select the next higher sturdiness in case the wall is supported by buttresses or side walls. ** select the next lower sturdiness in case the wall is taller than 8 times its width.				

Table 20. IF-scale ratings for DI Free-standing walls (FW). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Rating for each sturdiness class and DoD**								
	Z	**A**	**AB**	**B**	**C**	**D**	**E**	**F**	
DoD 1 *Partial destruction but not more than 2/3*	**IF0.5** 33 120	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220	**IF2.5** 70 250	**IF3** 80 290	**IF4** 105 380	**IF5** 130 470	m/s km/h
DoD 2 *(Near) complete destruction more than 2/3*	**≥IF1** ≥ 40 ≥ 150	**≥IF1.5** ≥ 50 ≥ 180	**≥IF2** ≥ 60 ≥ 220	**≥IF2.5** ≥ 70 ≥ 250	**≥IF3** ≥ 80 ≥ 290	**≥IF4** ≥ 105 ≥ 380	**IF5** 130 470	**IF5** 130 470	m/s km/h

3.13.1 Examples

DI: Wall, sturdiness Z (FWZ)
Stacked hollow concerte blocks – 10-20 cm
DoD: 2 – Complete destruction
Rating: IF1 (40 m/s, 150 km/h)

Photo: Juan de Dios Soriano, AEMet

DI: Wall, sturdiness Z (FWZ)
Stacked hollow concerte blocks – 10-20 cm
DoD: 2 – Complete destruction
Rating: IF1 (40 m/s, 150 km/h)

Photo: Tomáš Púčik, ESSL

DI: Wall, sturdiness AB (FWAB)
Weak brick masonry – 10-20 cm
DoD: 1 – Partial destruction

Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Juan de Dios Soriano, AEMet

DI: Wall, sturdiness C (FWC)
reinforced concrete 20 – 40 cm, but with an extreme height/width ratio
DoD: 1 – Partial destruction
Rating: IF2.5 (70 m/s, 250 km/h)

Photo: Juan de Dios Soriano, AEMet

3.14 DI: Signs and billboards – SN

Billboards or traffic signs with a wooden frame have varying degrees of firmness, because of their design or inadequate maintenance. This makes them poor damage indicators. For that reason, they are not included here.

Table 21. IF-scale ratings for DI Sings and billboards (SN). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Sub-class**	
	T traffic signs	**M** metal frame billboards
DoD 0 *No damage*	**≤IF1** 40 150	**≤IF1** 40 150
DoD 1 *Inclination or buckling of pillar(s)*	**IF1.5** 50 180	**IF1.5** 50 180
DoD 2 *Collapse of pillar(s) or destruction*	**≥IF2** 60 220	**≥IF2** 60 220

3.14.1 Examples

DI: Traffic sign (SNT)
DoD: 1 – Inclination or buckling of pillar
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Délia Gutierrez-Rubio, AEMet

DI: Traffic sign (SNT)
DoD: 2 – Inclination or buckling of pillar
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Délia Gutierrez-Rubio, AEMet

DI: Metal frame billboard (SNM)
DoD: 2 – Collapse of pillar(s) or destruction
Rating: ≥IF2 (≥ 60 m/s, ≥ 220 km/h)

Photo: Tomáš Púčik, ESSL

DI: Traffic sign (SNT)
DoD: 2 – Collapse of pillar(s) or destruction
Rating: ≥IF2 (≥ 60 m/s, ≥ 220 km/h)

Photo: Tomáš Púčik, ESSL

3.14.2 Examples (undamaged)

Metal frame billboards (M) - undamaged

Left: Photo:Kolforn (Kolforn) https://commons.wikimedia.org/w/index.php?curid=43306855
Right: Photo:Lišiak - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=39072776

3.15 DI: Connected scaffolding – CS

Table 22. IF-scale rating for DI Scaffolding connected to walls (SW). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Rating**
DoD 1 *Breakage of connections to walls*	**≥IF0.5** ≥ 33 ≥ 120

Notes:
There is no DoD0, because some scaffolding may be very well connected so that an upper bound to the wind speed cannot be given.

3.15.1 Examples (undamaged)



Left: by Plaats - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=17360290
Centre: by TheRunnerUp - Own work, CC BY-SA 3.0 at, https://commons.wikimedia.org/w/index.php?curid=28031152
Right: by Globetrotter19 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=44053732

3.16 DI: Carports / Garages – CP

Table 23. IF-scale rating for DI Carports / garages (CP). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Rating**
DoD 1 *Collapse*	**≥IF1.5** ≥ 50 ≥ 180

3.16.1 Examples (undamaged)

Left: Photo:Aarp65 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=30872535
Centre: Photo:Ra Boe / Wikipedia, CC BY-SA 3.0 de, https://commons.wikimedia.org/w/index.php?curid=18077883
Right: Photo:Dr.Ing.S.Wetzel, de:Benutzer: Analemma - Own work (Original text: Eigenfoto), CC BY-SA 3.0 de, https://commons.wikimedia.org/w/index.php?curid=47928444

3.17 DI: Service station canopies – SS

Table 24. IF-scale ratings for DI Service station canopies (SS). Speeds are given in m/s and km/h.

Degree of Damage (DoD):	**Rating for given DoD**
DoD 0 *No damage*	**≤IF1** ≤ 40 ≤ 150
DoD 1 *Damage to siding or roof material*	**IF1.5** 50 180
DoD 2 *Partial or full collapse*	**≥IF2** ≥ 60 ≥ 220
DoD 3 *Full destruction of canopy*	**≥IF2.5** ≥ 70 ≥ 250

3.17.1 Examples

DI: CP
DoD: 1 Damage to siding
Rating: IF1.5 (50 m/s 180 km/h)

Photo: Tomáš Púčik, ESSL

DI: CP
DoD: 1 Damage to siding
Rating: IF1.5 (50 m/s 180 km/h)

Photo: Délia Gutierrez Rubio, AEMet

3.17.2 Examples (undamaged)

Left: Photo:Kulja - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=837123 5
Right: Photo:Tiia Monto - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47617270

3.18 DI: Shipping containers – SC

The three weight ranges of the contents are given for 40 ft, 20 ft, and 10 ft containers, respectively, whereby 1 t = 1000 kg. The weight ranges have been calculated using the relation that the exerted force is proportional to the square of the wind speed.

Table 25. Determination of sub-class on the basis of the weight of the container contents in tonnes (t = 1000 kg) and length.

Class: ***Container length***	**A**	**B**	**C**	**D**	**E**	**F**
Standard 10 ft	< 0.5 t	0.5 – 1.5 t	1.5 – 2.5 t	2.5 – 3.5 t	3.5 – 5 t	> 5 t
Standard 20 ft	< 1 t	1 – 2 t	2.5 – 4 t	4 – 6 t	6 – 8 t	> 8 t
Standard 40 ft	< 2 t	2 – 5 t	5 – 8 t	8 – 12 t	12 – 16 t	> 16 t

Table 26. IF-scale ratings for DI Shipping containers (SC). Speeds are given in m/s and km/h.

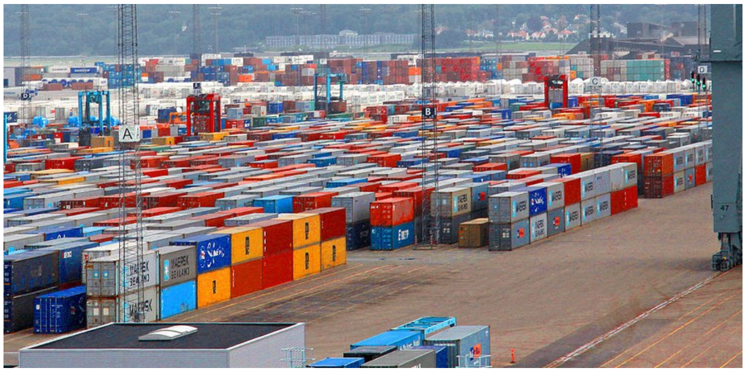
Degree of Damage (DoD):	**Rating for a given sub-class and DoD**					
	A	**B**	**C**	**D**	**E**	**F**
DoD 1 *Shifting or sliding*	**IF1** 40 150	**IF1.5** 50 180	**IF2** 60 220	**IF2.5** 70 250	**IF3** 80 290	**IF4** 105 380
DoD 2 *Lifting > 1 m above ground*	**IF1.5** 50 180	**IF2** 60 220	**IF2.5** 70 253	**IF3** 80 290	**IF4** 105 380	**IF5** 130 470
DoD 3 *Lifting and transportation over 50 m or more*	**≥IF2** ≥ 60 ≥ 220	**≥IF2.5** ≥ 70 ≥ 253	**≥IF3** ≥ 80 ≥ 290	**≥IF4** ≥ 105 ≥ 380	**IF5** ≥130 ≥470	**IF5** ≥130 ≥470

3.18.1 Example

DI: Shipping container, sub-class A
DoD: 2 – Lifting
This was an almost empty 20ft container
Rating: IF1.5 (50 m/s, 180 km/h)

Photo: Tomáš Púčik, ESSL

3.18.2 Examples (undamaged)



Left: Photo:IAEA Imagebank - 02510199, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=36209242
Right: Photo:Guillaume Baviere, https://www.flickr.com/photos/84554076@N00/6133222589, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=37188939

3.19 DI: Cranes – CR

Table 27. IF-scale ratings for DI Cranes (CR). Speeds are given in m/s and km/h.

Degree of Damage	**Sub-class**	
	G **gantry crane**	**T** **tower crane**
DoD 1 ***Collapse when in operation***	**IF1** 40 150	**IF1** 40 150
DoD 2 ***Collapse when not in operation***	**≥IF2** ≥ 60 ≥ 220	**≥IF1.5** ≥ 50 ≥ 180

3.19.1 Example

DI: Tower crane (CRT)
DoD: 2 – Collapse when not in operation
Rating: ≥IF1.5 (≥ 50 m/s, ≥ 180 km/h)

Photo: https://vertikal.net/en/news/story/42090/fatal-crane-overturn

3.19.2 Examples (undamaged)

Figure 3-1. Container / gantry cranes

Left: Photo:Alf van Beem - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=51959144
Centre: Photo:Alf van Beem - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=26869428
Right: Photo:Polska Zielona Sieć from Kraków, Poland - Ostatni dzwonek dla Klimatu, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=17899828

3.20 DI: Outdoor furniture – OF

Degree of Damage	**Sub-category**	
	L **light unanchored objects such as plastic chairs or tables, unanchored trampolines**	**H** **heavier unanchored objects**
DoD 0 *Not moved*	**<IF0** < 25 < 90	**≤IF0.5** ≤ 33 ≤ 120
DoD 1 *Overturned or shifted*	**IF0** 25 90	**IF0.5** 33 120
DoD 2 *Carried through the air for several metres*	**≥IF0.5** ≥ 33 ≥ 120	**≥IF1** ≥ 40 ≥ 150

Note:
Comparable to Canadian DI C-SFOF "Sheds, fences or outdoor furniture" (Sills et al.), adjusted for instantaneous wind speed definition.

3.20.1 Examples

DI: Outdoor Furniture, light (OFL)
DoD: 1 – Overturned or shifted
Rating: IF0 (25 m/s, 90 km/h)

Photo: Délia Gutierrez Rubio, AEMet

3.21 DI: Wind Speed Measurement – WM

Wind gust measurements at a standard measurement height of 10 m or lower may be used to obtain an IF-scale rating. A conversion to estimate the instantaneous rate is to be made, depending on the duration of wind speed averaging to obtain the gust speed. The conversion in Table 28 below assumes that the speed of 3 s, 2 s, and 1 s wind averaged gusts are 88.8 %, 90.9%, and 92.5%, respectively, of the instantaneous gust[3].

Radar measurements can be considered wind speed measurements if they are taken at an altitude where they can do damage. Since wind speeds in the tornadic boundary layer are typically comparable to those anywhere below 60 m, measurements below that height qualify as well. As averaging time, the time it takes the air to traverse a bin shall be taken, e.g., for a 50 m/s measurement in a 50 m bin, 1 s shall be taken to be the averaging time.

Wind speeds from photogrammetric analyses that reveal an object propelled by the wind in the plane of view no hgher than 60 m above the surface may also be considered as a measurement.

Table 28. IF-scale ratings for DI Wind Measurement (WM).

	3S 3s gust	**2S** 2s gust	**1S** 1s gust	**0S** 10Hz or higher sample rate		**Rating**
DoD 0 ***Measured IF0 speed***	19 – 25 69 – 91	20 – 26 70 – 94	20 – 26 71 – 95	22 – 28 77 – 103	m/s km/h	**IF0** 25 90
DoD 0.5 ***Measured IF0.5 speed***	26 – 32 92 – 120	27 – 33 95 – 120	27 – 34 96 – 123	29 – 36 104 – 132	m/s km/h	**IF0.5** 33 120
DoD 1 ***Measured IF1 speed***	33 – 40 119 – 146	34 – 40 121 – 150	35 – 42 124 – 152	37 – 45 133 – 164	m/s km/h	**IF1** 40 150
DoD 1.5 ***Measured IF1.5 speed***	40 – 49 147 – 176	42 – 50 150 – 180	43 – 51 153 – 183	46 – 55 165 – 198	m/s km/h	**IF1.5** 50 180
DoD 2 ***Measured IF2 speed***	50 – 57 177 – 208	51 – 59 180 – 213	52 – 60 184 – 220	56 – 65 199 – 234	m/s km/h	**IF2** 60 220
DoD 2.5 ***Measured IF2.5 speed***	58 – 70 209 – 242	60 – 68 214 – 248	61 – 70 218 – 252	66 – 75 235 – 273	m/s km/h	**IF2.5** 70 250
DoD 3 ***Measured IF3 speed***	68 – 82 243 – 296	69 – 84 249 – 303	71 – 85 253 – 308	76 – 92 274 – 333	m/s km/h	**IF3** 80 290
DoD 4 ***Measured IF4 speed***	83 – 103 297 – 373	85 – 106 304 – 382	86 – 107 309 – 388	93 – 116 334 – 420	m/s km/h	**IF4** 105 380
DoD 5 ***Measured IF5 speed***	≥ 104 ≥ 374	≥ 107 ≥ 383	≥ 108 ≥ 389	≥ 117 ≥ 421	m/s km/h	**IF5** ≥ 130 ≥ 470

[3] These estimates are based on Fig. 10 of Beljaars (1987) assuming a 1.6 gust factor and are valid for a 20 m/s sustained wind. We assumed the values to be similar for higher wind speeds.

4 Conducting a damage survey

4.1 Surveying

In this chapter, we provide guidance on how to conduct a damage survey and how to interpret the collected data. More guidance, in particular on the output of a damage survey, can be found in Rodriguez et al. (2020).

First, the survey must be done **as early as possible** with permission of public authorities. All public authorities who have or may feel a responsibility related to the event should be invited to take part. It is obviously important to respect the rights and privacy of the people affected by the tornado. Moreover, good equipment such as safety shoes and helmets are needed. A good coordination from a crucial point and in the field is required, in particular when multiple teams are involved. Psychological support may be needed, in particular after events with injuries and loss of life.

Second, **all individual Damage Indicators and Degrees of Damage should be recorded and geo-referenced**, along with the resulting IF-rating. Optimally, georeferenced photos of the damage from the survey are stored with as well in conjunction with, and optionally a description. The result will be a table such as listed in Table 29.

Table 29. Example of a table with damage survey data.

#	Lat.	Lon.	DI	DoD	IF	Dir.	Description	Photo URL
1	45.4461	12.0393	BSB	1A	1.5		Light damage to shed	http://....
2	45.4482	12.0471	BRTS	1	1	160	Some shingles blown off	http://....
3	45.4478	12.0476	TRS	3	1.5	180	Uprooted olive tree	http://....
4	45.4484	12.0482	PTS	2	2	320	Light pole collapsed	http://....

To complement the surveying at ground level, areal surveying using drones, or an aircraft can be conducted. This may also be useful in the initial stages when the extent of the affected areas is not yet known but can be seen from a high altitude. A limitation is that from a too high altitude it will not always be possible to make a sufficiently accurate assessment of the damage for single objects.

To help determine the nature of a damaging wind event, e.g., a tornado, downburst or other event, the direction of falling of trees, or transportation of debris must be recorded as well. The direction the object originated from is to be recorded, i.e., 180° is correct for a tree fallen towards the north, or an object displaced from the south to the north. This is the convention in meteorology, but opposite of that used in aviation.

The process of recording all this data can be streamlined using an application on a mobile device. ESSL has developed such an app. Of course, if this is not available, a table can be created manually. As a concise way of noting down instances of wind damage, Damage Indicators, and their subclasses (see later sections) each have a short abbreviation, and degrees of damage a number, occasionally followed by a letter (e.g., “1”, “1B”, “2”). Any particular type of damage foreseen in this guide is unambiguously defined by writing down the Damage Indicator and the Degree of Damage. The IF rating for each instance of damage specifies the wind speed thought to be responsible for having caused the damage. The IF-scale is not suited to rate damage from winds below IF0 (25 m/s) or above IF5 (130 m/s).

Examples are:

DoD: BSC, DI: 1B, Rating: 2.5
A building’s structure [BS] with sturdiness [C] has sustained a Degree of Damage 1B ('partially destroyed'), resulting in a rating of IF2.5.

DoD: TRS, DI: 3, Rating: IF1.5
A tree [T] with strong firmness was uprooted [3], resulting in a rating IF1.5.

It is thinkable that wind speed estimates will require revision in the future as new scientific evidence becomes available. Scientific data may also show that certain wind events are associated with wind speeds that are higher or lower than previously thought. In case of the IF-scale such retroactive adjustments can be made, if all damage indicators–degrees of damage combinations that led to ratings are recorded and stored, primarily that which led to the highest rating of a given event.

4.2 Rating a tornado or wind event

The maximum intensity rating for an entire wind event has a big significance. It is the intensity usually reported in communication to the general public and is also relevant for statistical purposes even though the destructiveness of a wind event is better captured by a more elaborate analysis of the surface areas affected by specific wind speeds.

The maximum intensity is that of the combination of degree of damage and damage indicator which yields the highest IF-scale rating. That said, this maximum rating must be carefully assessed for consistency with ratings of nearby damage. **If only a single DI/DoD combination leads to this specific highest IF-scale rating, this is often too thin evidence that wind speeds corresponding to that rating have occurred**, as with all ratings of instances of damage that are conducted, likely a number will be overrated and a number will be underrated. The team of surveyors may on a case-to-case basis find that the particular single instance of damage that leads to the highest rating is solid enough to warrant counting as the maximum intensity rating for the whole event. **A maximum intensity rating shall never be based on a rating damage to a single tree**, which as a living organism is particularly prone to decay over time because of potentially undetected illnesses or other factors.

A tornado or downburst shall be assigned a maximum intensity rating of IF0 only if it passes over vulnerable objects, which are not damaged, but in case there were no objects to damage it shall be left unrated for lack of information to assess it intensity.

Whenever there is some but incomplete data about tornado or wind damage, the rating must be balanced between putting too high trust in very limited observations, and not adequately acknowledging that an extreme event has occurred. Both can lead to to incorrect conclusions regarding the true climatological frequency of such events. It is not good to trust an observation of a certain damage without knowing the circumstances that could have increased the probability of it to occur (for example, weaker than average construction practices), but neither is dismissing an event because the probability that it has occurred is climatologically very low. After all, extreme events are very rare by definition and what climatology is, is determined by how past events were assessed.

4.3 Determining the nature of an event

Besides the rating of an event, an important question is whether a rotating vortex produced the damage or another type of wind event, such as a downburst. The instantaneous wind field of a tornado (Figure 3-2 a.) is characterized by convergence and rotation, while a downburst (Figure 3-2 c. and d.) has a divergent wind pattern. Another possibility is a hybrid event where a downburst and a rapidly travelling vortex occur jointly (Figure 3-2 b.).

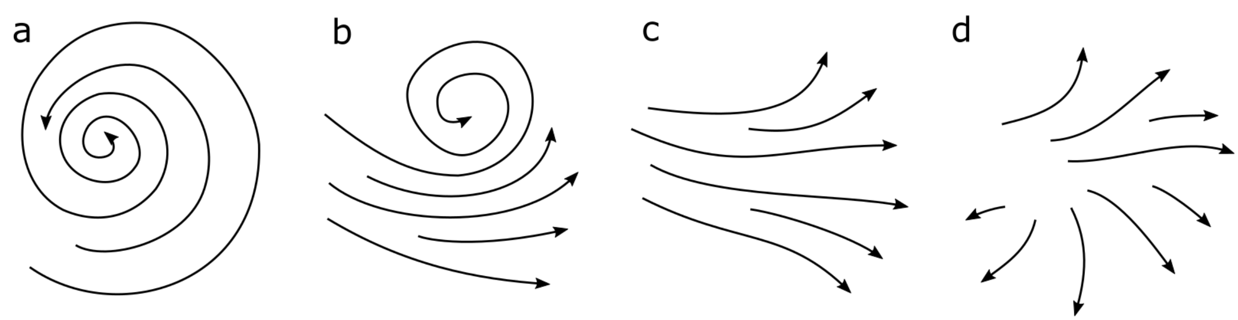


Figure 3-2. Near-surface wind patterns of a) a tornado, b) hybrid wind event, c) a translating downburst, and d) a quasi-stationary downburst.

To classify a wind event as a tornado, unambiguous evidence of a vortex must be present, i.e., evidence of convergent or rotating winds. In case the tornado was not observed directly, one must infer this from the damage. This is not always straightforward, because the archetypical tornado and downburst are only extremes on a spectrum of wind phenomena (Figure 3-2). It may be that not all wind damage in a given case was produced by convergent rotating winds of a tornado, but part occurred from divergent winds.

From single instance of damage, it is not possible to say if a tornado or other event occurred. It is thinkable that tornadoes could produce some types of damage more easily than quasi-horizontal winds, such as e.g., torsion of trees when ripped off, or uplifting of roofs. This could result from extreme horizontal wind shear or a vertical wind component. That said, scientific support for this notion is thin and a clear criterion non-existent and should not be considered.

Additionally, one can analyse the directions in which objects have been transported by the wind or and the directions trees have fallen toward and look for convergent damage patterns which occur with some tornadoes. That said, fast-moving tornadoes do not always produce convergent patterns, as was shown by Beck and Dotzek (2010; Figure 3-3). A divergent damage pattern is therefore not a reason to rule out a tornado. A thorough analysis can be undertaken using such a tree fall model to find out if the damage pattern is consistent with a tornado and not with a downburst.

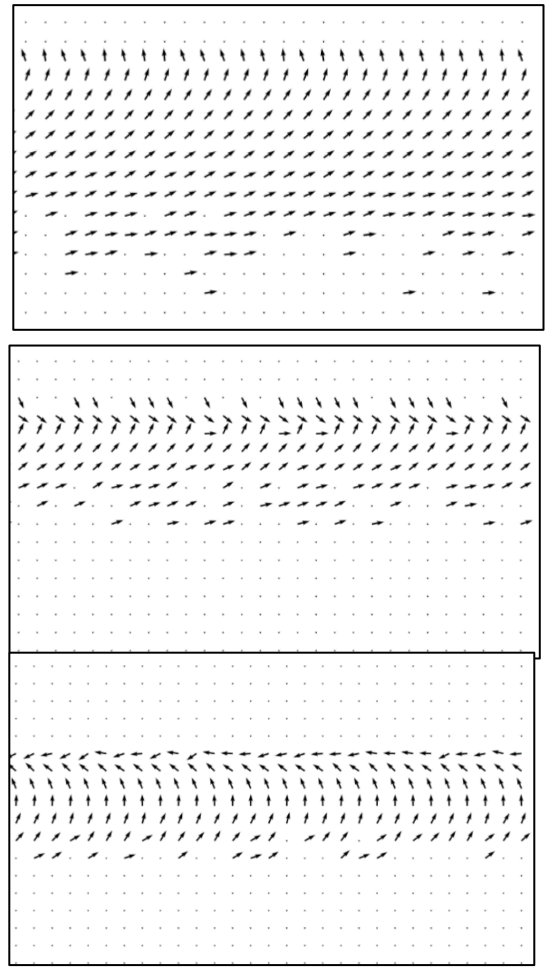


Figure 3-3. Simulated treefall patterns for tornadoes, simulated with a model similar to Beck and Dotzek's (2010), showing convergence in some, but not all patterns.

An easier method is to use the fact that tornadoes typically produce much longer and narrower tracks than other wind phenomena. If a damage track is more than 10 times longer than wide, one can safely classify the event as a tornado. Combining this, we can formulate the following criterion:

If either

1) **the damage track is more than 10 times longer than it is wide,**
2) **there is a convergent damage pattern over an extended area[4], or**
3) **there is evidence of lifting of heavy and compact objects by several metres[5],**

[4] The convergence must not be the result of two colliding downdrafts, and consistent means that the convergent damage must be more than one or two isolated instances

[5] The primarily horizontal displacement of objects from a high place, e.g. a roof, is not included

the event can be characterized as a tornado. In all other cases it shall be recorded as a severe wind event. Using this criterion, short-tracked tornadoes without a convergent pattern may not detected, but there is no simple solution for this.

4.4 Definition of track length, width, and number of events

The track length and width of tornadoes are important parameters for risk assessment models and need to be recorded. Determining the area affected by winds exceeding a particular speed is important as well. In case when, unfortunately, resourced do not allow surveying a track at very great detail, it is therefore important to make frequent cross-sections across the track while recording the damage while traversing it. Through interpolation between individual cross sections, a fairly accurate estimate of the areas affected by certain wind speeds can then still be made. For determining the path width within a cross section, the distance between the left most point of visible damage and the right most point of visible damage shall be taken.

A difficulty in determining track length may arise when the damage path is interrupted, and it is not clear if a persistent wind phenomenon was responsible. If the damage path is interrupted, but there are damage indicators that would be affected if the path were continuous, then the two areas of damage cannot be attributed to the same phenomenon, and they shall be considered two separate phenomena. However, if the damage path is interrupted because of a lack of damage indicators that would be affected, it is not possible to ascertain the continuity of the phenomenon. We suggest using the following practical rule:

> **Damages should be assigned to separate events if the gap between damages exceeds 3 km, unless a clear indication exists of continuous wind effects not described as damage indicators in this guide. In case damage indicators are present between two damage locations, which indicate that no damage was done at some point between them, and there is no other evidence that a continuous event has occurred, such a shorter gap already suffices for the damages to be assigned to two separate events.**

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Appendix

Photos and descriptions of undamaged buildings

4.4.1 Class A

Characteristics:

- Thin wooden or metal panels, glass, or mud walls
- Unanchored
- Lightweight

Typical examples:
sheds, weak outbuildings, with weak connections between walls and roof if any

very weak frame with metal panels

4.4.2 Class B

Characteristics:

- Wood or metal frame with wood, metal panel, or glass siding
- Fairly poor connections between roof and walls
- Weak anchoring

Typical examples: structures typically not intended for permanent inhabitation such as sheds, barns, stables, and garages.

weak wooden frame with wooden panels

metal frame structure with wooden panels

4.4.3 Class C

Characteristics:

- Wood or metal frame with wood or metal panels, with or without brick veneer, stucco, external insulation layers
- CMU block masonry without any reinforcement
- Brick structures with defunct connections between bricks, or stacked bricks or stones

Typical examples: Frame houses with comparatively weak frame as well as strong outbuildings, such are sturdy stables

weak wooden frame structure with brick veneer

Photo:25or6to4 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=66166439

weak wooden frame structure

Photo:Remisc at English Wikipedia - Remisc (talk), CC0, https://commons.wikimedia.org/w/index.php?curid=15371546

4.4.4 Class D

- Weaker mass wall construction of brick masonry, stone, concrete blocks, logs
- Strong frame structures, or brick/concrete block masonry structures with thin or degraded walls, e.g., because of aged cement.

Typical: one family residences, small commercial buildings

strong wooden frame structure

Photo:User: (WT-shared) Aiko99ann at wts wikivoyage, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=22848045

strong wooden frame structure brick veneer

Adapted from ProfReader - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=70432802

strong wooden frame structure

Photo:Werner Popken - taken by author, Panasonic FZ1, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=497074

weakened brick wall structure

Adapted from Kate Jewell, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=13470471

strong wooden frame structure with brick veneer

Photo:MelvinMelvinMelvin - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21200700

4.4.5 Class E

- Strong mass wall construction of brick masonry, stone, concrete blocks, logs
- Very strong frame structures

Typical: one family residences, commercial buildings

brick masonry mass wall structure

wood log (load carrying) building structure

concrete block mass wall structure

brick masonry mass wall structure

wood log (load carrying) building structure

brick masonry mass wall structure

4.4.6 Class F

concrete structure

Photo:Antoine - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=25895474

concrete structure

Photo:Ddogas - Own work, CC BY-SA 3.0 https://commons.wikimedia.org/w/index.php?curid=5763609