Tornado and Windstorm Damage Assessment

Rainer Kaltenberger

EUMeTrain Wind Event Week – March 1st, 2022

ZAMG
Zentralanstalt für
Meteorologie und
Geodynamik

Contents

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

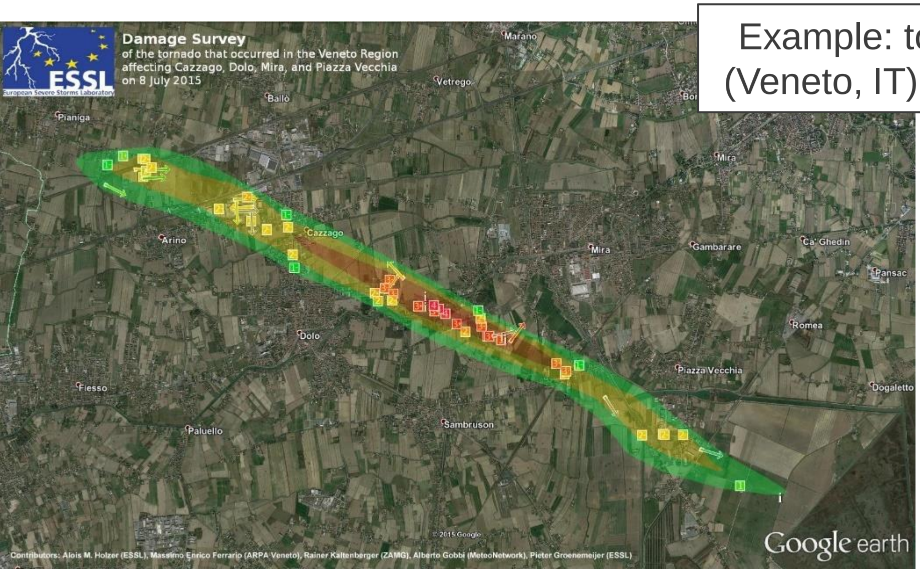
Tornado and Windstorm Damage Assessment

Damage Assessments (1/15)

Tornados: Challenges

- Rare events, but potentially extreme impact
- Small scale and (usually) short-lived
- Forecasts and warnings are very difficult!
- Usually no direct wind speed measurements => ex post intensity rating via damage assessment

Example: tornado in Dolo (Veneto, IT) on 8 July 2015



© ESSL

© Federico Calzavara

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (2/15)

Convective wind gusts: Challenges

- Wind gusts, which occur in connection with convective showers or thunderstorms (also: downbursts, squalllines, (nontornadic , damaging) straight line winds)
- Often small scale, sometimes very suddenly and only for a short time
- Squall lines due to organized thunderstorms/bow echoes/derechos are responsible for most windstorm-related damages (and victims!) in Central Europe in summer season
  - Sudden acceleration of wind speed to gale force or hurricane strenght, sometimes within 20 seconds!
  - Squall lines have the potential to „rush ahead“ thunderstorm cells, especially at the edges of mountainous terrain (e.g. northern side of Alps)

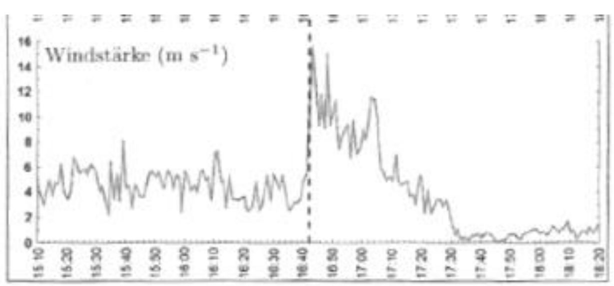


Abb. 8.14. Messungen von Temperatur, Taupunkt, Druck und Wind am Meteorologischen Institut der Universität Bonn vom 14. 7. 2010

Bott, A. (2016). Synoptische Meteorologie: Methoden der Wetteranalyse und-prognose. Springer-Verlag.

Frauschereck/Upper Austria
Fire Brigade Festival Disaster
August 18th, 2017

© Lisa Penz/Mein Bezirk.at

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (3/15)

Motivation: Why damage assessments?

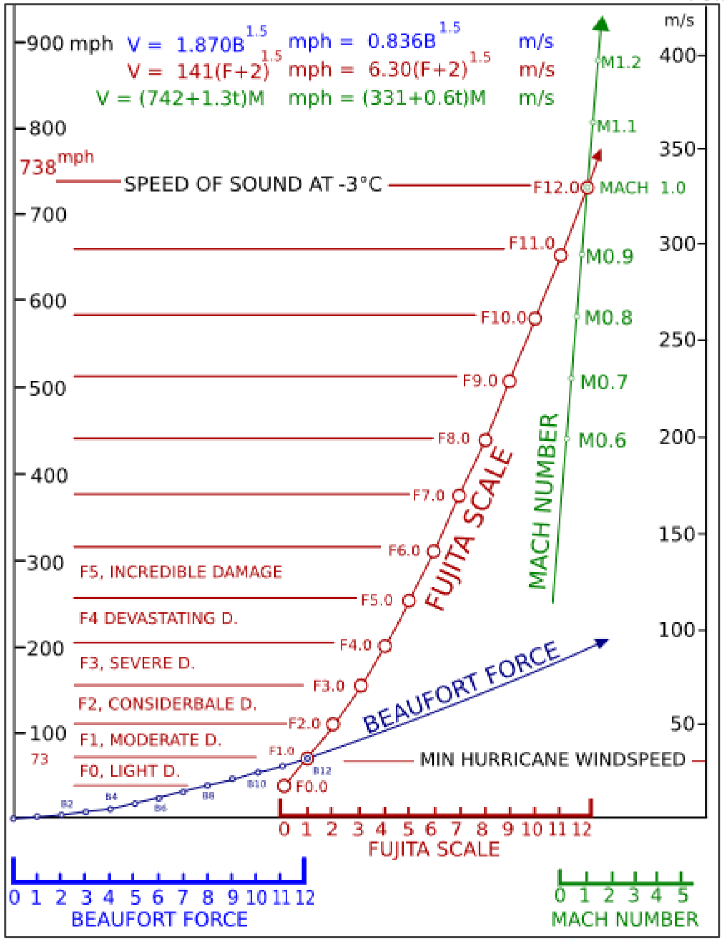
- Tornados and downbursts are small scale and short lived phenomena → mostly no in situ measurements are available
- Squall lines usually have local maxima of windgusts, which are not covered by weather stations
- Climatology
  - Knowledge of tornado and downburst events as basis for risk assessments
  - Understanding of regional effects (e.g. acceleration of gust fronts at the Northern edge of the Alps)
- Process understanding: under which conditions do tornadoes or damaging straight line winds occur?
- Forensic meteorology: Expert opinion for courts' or prosecutor's offices (e.g. liability, negligence), insurances…
- Public relations
- Impact-based warnings
  - E.g. identification of weather situations or radar signatures connected with past tornadoes

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (4/15)

Fujita Scale (F Scale)

- Tetsuya (Ted) Fujita, University of Chicago, USA
- Implemented in 1973 in the USA
- Upward extension of Beaufort scale
- Links damages to most likely wind speeds
- Today in use in Europa except for UK (TORRO scale instead)



ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (5/15)

Fujita Scale (F Scale)

Scale	Wind speed estimate[6]		Path width[7]	Potential damage[6]	
	mph	km/h			
F0	40–72	64–116	6–17 yards (5.5–15.5 m)	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.	
F1	73–112	117–180	18–55 yards (16–50 m)	Moderate damage. The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving vehicles pushed off the roads; attached garages may be destroyed.	
F2	113–157	181–253	56–175 yards (51–160 m)	Significant damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; highrise windows broken and blown in; light-object missiles generated.	
F3	158–206	254–332	176–566 yards (161–518 m)	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.	
F4	207–260	333–418	0.3–0.9 miles (0.48–1.45 km)	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.	
F5	261–318	419–512	1.0–3.1 miles (1.6–5.0 km)	Incredible damage. Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air farther than 100 meters (110 yards); trees debarked; steel reinforced concrete structures badly damaged and skyscrapers toppled	

Damage Assessments (6/15)

Fujita Scale vs. Torro Scale

	Unterkritisch (Sub–critical)				Schwach (Weak)			
Fujita	F-2		F-1		F0		F1	
TORRO	T-4	T-3	T-2	T-1	T0	T1	T2	T3
Beaufort	B0, B1	B2, B3	B4, B5	B6, B7	B8, B9	B10, B11	B12, B13	B14, B15
v in m s^{-1}	0 – 3	3 – 7	7 – 12	12 – 18	18 – 25	25 – 33	33 – 42	42 – 51
v in km h^{-1}	0 – 11	11 – 25	25 – 43	43 – 65	65 – 90	90 – 119	119 – 151	151 – 184
Δv in m s^{-1}	3	4	5	6	7	8	9	9
$\bar{S}_-$ in %	0.0	0.0	0.0	0.01	0.05	0.10	0.25	0.80
$\bar{S}_+$ in %	0.0	0.0	0.0	0.0	0.01	0.05	0.10	0.25
	Signifikant (Significant)							
	Stark (Strong)				Verheerend (Violent)			
Fujita	F2		F3		F4		F5	
TORRO	T4	T5	T6	T7	T8	T9	T10	T11
Beaufort	B16, B17	B18, B19	B20, B21	B22, B23	B24, B25	B26, B27	B28, B29	B30, B31
v in m s^{-1}	51 – 61	61 – 71	71 – 82	82 – 93	93 – 105	105 – 117	117 – 130	130 – 143
v in km h^{-1}	184 – 220	220 – 256	256 – 295	295 – 335	335 – 378	378 – 421	421 – 468	468 – 515
Δv in m s^{-1}	10	10	11	11	12	12	13	13
$\bar{S}_-$ in %	3.0	10.0	30.0	90.0	100	100	100	100
$\bar{S}_+$ in %	0.80	3.0	10.0	30.0	60.0	80.0	90.0	95.0

FIG. 1: Overview of the F- and T-scale, the related wind speeds, and typical loss ratios S for light (S–) and strong (S+) buildings in Central Europe.

- Fujita Scale (F Scale, Fujita 1971) – F0-F5 (F6) levels
- Torro Scala (T Scale, Meaden 1976) – T1-T10(T11), based on windspeed

- Torro Scala double as fine as Fujita Scale
- Central European Practice „Lower“- or „Upper“ F classes
- Example: F1- corresponds to T2 (119-151 km/h)

Feuerstein, B., Dirksen, E., Dotzek, N., Groenemeijer, P., Holzer, A. M., Hubrig, M., & Rauch, E. (2009, October). An illustrated verbal description of the TORRO and Fujita scales adapted for Central Europe considering building structure and vegetation characteristics. Preprints. In *5th European Conference on Severe Storms, Landshut, Germany* (pp. 357-358).

Dotzek, N. (2009). Derivation of physically motivated wind speed scales. *Atmospheric Research*, *93*(1), 564-574.

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (7/15)

Enhanced Fujita Scale (EF Scale)

- Wind Science and Engineering Research Center, Texas Tech University, 2004
- Concept of „Damage indicator“ (DI) and „Degree of Damage“ (DoD) to account for different building standards and include vegetation damages, “correction” of F Scale windspeeds
- EF Scale in use only in USA (since 2007) and Canada (since 2013)
- Criticism:
  - Technically designed to U.S. building standards
    → Hardly representative for European construction methods / building standards
  - DIs for vegetation only very rudimentary („hardwood“ vs. „softwood“)
  - Mobile Doppler radar measurements do not necessarily confirm EF Scale

Fujita Scale		Enhanced Fujita Scale* * In use since 2007	
F–0	40–72 mph winds	EF–0	65–85 mph winds
F–1	73–112 mph	EF–1	86–110 mph
F–2	113–157 mph	EF–2	111–135 mph
F–3	158–206 mph	EF–3	136–165 mph
F–4	207–260 mph	EF–4	166–200 mph
F–5	261–318 mph	EF–5	>200 mph

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (8/15)

Towards an International Fujita Scale (IF Scale)

- Practice in Europe (ESSL, some National Weather Services):
  - Concept of DI and DoD adopted
  - DIs generalized for European building standards and vegetation
  - But: Rating still in F classes, not EF classes
  - F classes represent „most probable“ range of wind gusts
- USA: Working group on redesign of EF Scale (with involvement of ESSL)
- Japan: „Japanese Enhanced Fujita Scale“ (JEF Scale)
- ESSL: International Fujita Scale (IF Scale)
  - Damage Indicators internationally applicable, taking account building codes of different regions
  - Practice-oriented – Contains flowcharts for damage assessments
  - Draft available at https://www.essl.org/cms/international-fujita-scale/
- Recommended practice for Central Europe to assess tornado-/windstorm-related damage: Fujita-(Torro)-Skala

Damage Assessments (9/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 1: Buildings

	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

A ... like a doghouse or unanchored light outbuildings
B ... like huts and barns, anchored light outbuildings
C ... like the typical US-midwest framehouses, if weakly anchored/connected to the foundation
D ... like the typical US-midwest framehouses, if well anchored and connected. I Europe typically single-row brick strucktures (mainly 2-dimensional single-row brick walls – like garden walls – fall into B or C). This category best corresponds to the original Fujita-scale.
E ... the typical central European masonry house
F ... steel-reinforced concrete buildings. Some historic fort-like buildings (castles) and some Mediterranean-style buildings in wind-prone-areas (like in Dalmatia) also fall into this category with their extremely thick stone-walls (if well-built and kept renovated).

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (9/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 1: Buildings

	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

A ... like a doghouse or unanchored light outbuildings
B ... like huts and barns, anchored light outbuildings
C ... like the typical US-midwest framehouses, if weakly anchored/connected to the foundation
D ... like the typical US-midwest framehouses, if well anchored and connected. I Europe typically single-row brick strucktures (mainly 2-dimensional single-row brick walls – like garden walls – fall into B or C). This category best corresponds to the original Fujita-scale.
E ... the typical central European masonry house
F ... steel-reinforced concrete buildings. Some historic fort-like buildings (castles) and some Mediterranean-style buildings in wind-prone-areas (like in Dalmatia) also fall into this category with their extremely thick stone-walls (if well-built and kept renovated).

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (9/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 1: Buildings

	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

A ... like a doghouse or unanchored light outbuildings
B ... like huts and barns, anchored light outbuildings
C ... like the typical US-midwest framehouses, if weakly anchored/connected to the foundation
D ... like the typical US-midwest framehouses, if well anchored and connected. I Europe typically single-row brick strucktures (mainly 2-dimensional single-row brick walls – like garden walls – fall into B or C). This category best corresponds to the original Fujita-scale.
E ... the typical central European masonry house
F ... steel-reinforced concrete buildings. Some historic fort-like buildings (castles) and some Mediterranean-style buildings in wind-prone-areas (like in Dalmatia) also fall into this category with their extremely thick stone-walls (if well-built and kept renovated).

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (10/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 1: Buildings

	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

A ... like a doghouse or unanchored light outbuildings
B ... like huts and barns, anchored light outbuildings
C ... like the typical US-midwest framehouses, if weakly anchored/connected to the foundation
D ... like the typical US-midwest framehouses, if well anchored and connected. I Europe typically single-row brick strucktures (mainly 2-dimensional single-row brick walls – like garden walls – fall into B or C). This category best corresponds to the original Fujita-scale.
E ... the typical central European masonry house
F ... steel-reinforced concrete buildings. Some historic fort-like buildings (castles) and some Mediterranean-style buildings in wind-prone-areas (like in Dalmatia) also fall into this category with their extremely thick stone-walls (if well-built and kept renovated).

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (10/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 1: Buildings

	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

A ... like a doghouse or unanchored light outbuildings
B ... like huts and barns, anchored light outbuildings
C ... like the typical US-midwest framehouses, if weakly anchored/connected to the foundation
D ... like the typical US-midwest framehouses, if well anchored and connected. I Europe typically single-row brick strucktures (mainly 2-dimensional single-row brick walls – like garden walls – fall into B or C). This category best corresponds to the original Fujita-scale.
E ... the typical central European masonry house
F ... steel-reinforced concrete buildings. Some historic fort-like buildings (castles) and some Mediterranean-style buildings in wind-prone-areas (like in Dalmatia) also fall into this category with their extremely thick stone-walls (if well-built and kept renovated).

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (11/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 2: Vegetation

	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
G	branches - leafy	< F0	F0+	F1-	F1+	F2-	F3-
H	- bare	F0-	F1-	F1+	F2-	F2-	F3-
I	tree stands - diseased/ unstable	< F0	F0-	F0+	F0+	F1-	F1-
J	- strong	F0+	F1-	F1+	F1+	F2-	F2-
K	edge trees, hedges, underwood	F1-	F1+	F2-	F2+	F3-	F3-

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

Damage Assessments (11/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 2: Vegetation

	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
G	branches - leafy	< F0	F0+	F1-	F1+	F2-	F3-
H	- bare	F0-	F1-	F1+	F2-	F2-	F3-
I	tree stands - diseased/ unstable	< F0	F0-	F0+	F0+	F1-	F1-
J	- strong	F0+	F1-	F1+	F1+	F2-	F2-
K	edge trees, hedges, underwood	F1-	F1+	F2-	F2+	F3-	F3-

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (11/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 2: Vegetation

	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
G	branches - leafy	< F0	F0+	F1-	F1+	F2-	F3-
H	- bare	F0-	F1-	F1+	F2-	F2-	F3-
I	tree stands - diseased/ unstable	< F0	F0-	F0+	F0+	F1-	F1-
J	- strong	F0+	F1-	F1+	F1+	F2-	F2-
K	edge trees, hedges, underwood	F1-	F1+	F2-	F2+	F3-	F3-

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

Damage Assessments (12/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 2: Vegetation

	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
G	branches - leafy	< F0	F0+	F1-	F1+	F2-	F3-
H	- bare	F0-	F1-	F1+	F2-	F2-	F3-
I	tree stands - diseased/ unstable	< F0	F0-	F0+	F0+	F1-	F1-
J	- strong	F0+	F1-	F1+	F1+	F2-	F2-
K	edge trees, hedges, underwood	F1-	F1+	F2-	F2+	F3-	F3-

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (12/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe

- Part 2: Vegetation

	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
G	branches - leafy	< F0	F0+	F1-	F1+	F2-	F3-
H	- bare	F0-	F1-	F1+	F2-	F2-	F3-
I	tree stands - diseased/ unstable	< F0	F0-	F0+	F0+	F1-	F1-
J	- strong	F0+	F1-	F1+	F1+	F2-	F2-
K	edge trees, hedges, underwood	F1-	F1+	F2-	F2+	F3-	F3-

Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.

Holzer, A., Groenemeijer, P. (2015). ESSLs Current Tornado and Storm Damage Rating Practice

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (13/15)

DI-DoD method: Adaptation of „Damage Indicators“ for Europe - vegetation

… further refinement with regards to wood species/soil type by Hubrig (2015)

DI 1 - 10	DI Subdivision a - f	DoD 1	DoD 2	DoD 3	DoD 4	DoD 5	DoD 6	DoD 7
Type of Tree	Stability Parameters	small limbs and dead branches broken	strong branches and crown parts broken	uprooting or compression failure	uprooting or trunk snapping	intensive debranching or tearing out, transport of big tree parts	beginning of debarking due to “sandblast effect”	nearly total debarking due to “sandblast effect”
1 Oak	a - fragile ground AND unstable forest stands	lower F0	upper F0	lower F1	lower F1	upper F2	upper F3	≥F4
	b - average ground in combination with unstable stands OR vice versa	lower F0	upper F0	F1	F1	upper F2	upper F3	≥F4
	c - average ground, average stock	lower F0	upper F0	F1	lower F2	upper F2	upper F3	≥F4
	d - firm, rocky ground, stable forest stands, only trees with healthy wood	lower F0	upper F0	lower F2	lower F2	upper F2	upper F3	≥F4
	e - forest edge situation & firm ground, only trees with healthy wood	lower F0	F1	lower F2	F2	lower F3	upper F3	≥F4
	f - solitaire trees & firm ground, only trees with healthy wood	lower F0	F1	lower F2	F2	lower F3	upper F3	≥F4
2 Beech	a - fragile ground AND unstable forest stands	lower F0	upper F0	lower F1	lower F1	upper F2	upper F3	≥F4
	b - average ground in combination with unstable stands OR vice versa	lower F0	upper F0	lower F1	F1	upper F2	upper F3	≥F4
	c - average ground, average stock	lower F0	upper F0	F1	upper F1	upper F2	upper F3	≥F4
	d - firm, rocky ground, stable forest stands, only trees with healthy wood	lower F0	upper F0	F1	lower F2	upper F2	upper F3	≥F4
	e - forest edge situation & firm ground, only trees with healthy wood	lower F0	F1	lower F2	F2	lower F3	upper F3	≥F4
	f - solitaire trees & firm ground, only trees with healthy wood	lower F0	F1	lower F2	F2	lower F3	upper F3	≥F4
5 Spruce	a - fragile ground AND unstable forest stands	lower F0	upper F0	upper F0	lower F1	lower F2	upper F3	≥F4
	b - average ground in combination with unstable stands OR vice versa	lower F0	upper F0	upper F0	lower F1	lower F2	upper F3	≥F4
	c - average ground, average stock	lower F0	upper F0	lower F1	F1	lower F2	upper F3	≥F4
	d - firm, rocky ground, stable forest stands,, only trees with healthy wood	lower F0	upper F0	F1	F1	lower F2	upper F3	≥F4
	e - forest edge situation & firm ground, only trees with healthy wood	lower F0	F1	F1	lower F2	upper F2	upper F3	≥F4
	f - solitaire trees & firm ground, only trees with healthy wood	lower F0	F1	F1	lower F2	upper F2	upper F3	≥F4

Hubrig (2015): Wooden Plants: A New Damage Indicator / Degree of Damage – Matrix, ECSS 2015, Wiener Neustadt

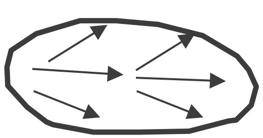
ZAMG Zentralanstalt für Meteorologie und Geodynamik

Damage Assessments (14/15)

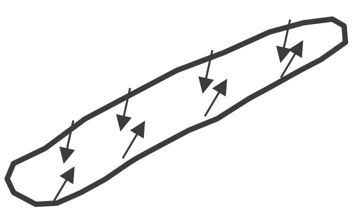
Tornado or Downburst?

- F Scale, EF or IF Scale are likewise applicable to tornadoes, downbursts and other windstorm damage
- Different damage characteristics:

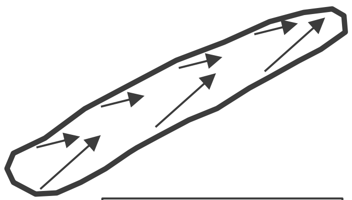
Damage	Downburst	Tornado
Shape:	length ≳ width	length ≫ width
Borders:	diffuse	sharp
Fall pattern of trees:	divergent (outward)	convergent (inward)
Fall direction of trees:	rather uniform	often very different



Downburst



Slow-moving tornado



Fast-moving tornado

Damage Assessments (15/15)

Squall lines/bow echoes/derechoes

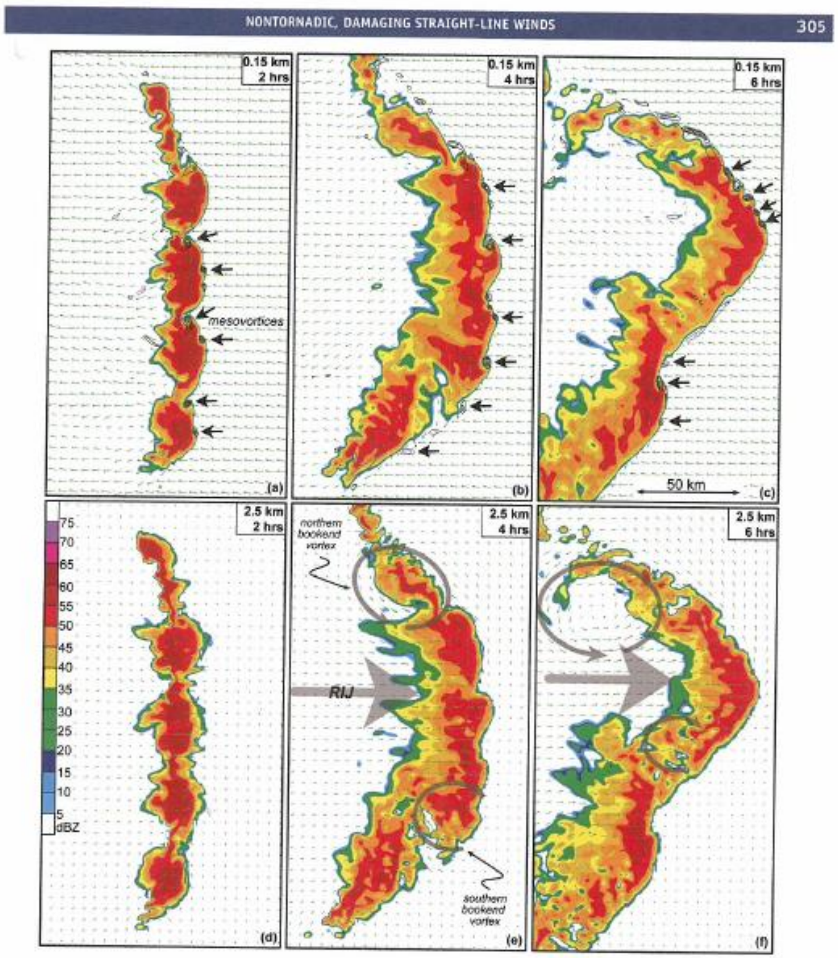
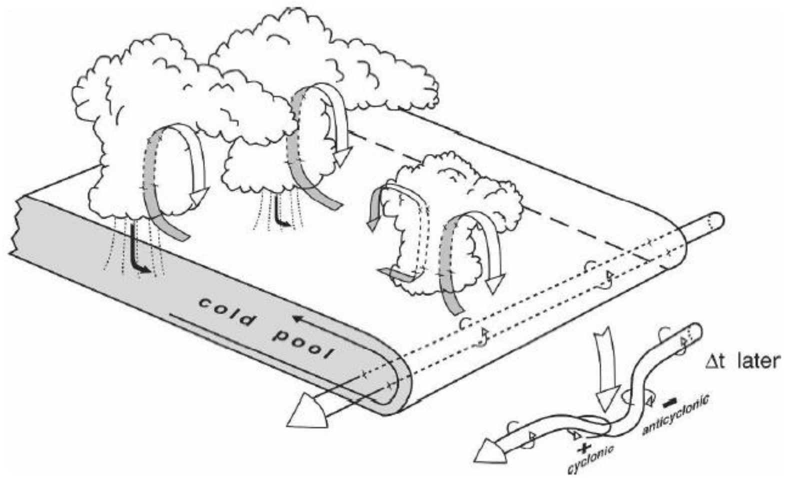


Figure 10.36 Simulation of a bow echo, depicting radar reflectivity (dBZ) in color, along with storm-relative winds (m s^{-1}, green) and vertical vorticity ($\times 10^{-3}$ s^{-1}, black) at 2, 4, and 6 h. Data at 0.15 km and 2.5 km are shown in (a)–(c) and (d)–(f), respectively. Locations of prominent mesovortices at 0.15 km are shown with black arrows. 'RIJ' indicates the rear-inflow jet, and additional broad gray arrows indicate the circulations associated with bookend vortices. (From Atkins and Cunningham [2006]. Courtesy of the American Meteorological Society.)

- Mesovorticies develop at the gust front of a simulated bow echo (Black arrows, meso gamma scale – 2-20km)
- Meso gamma vorticies are suspected to be responsible for damaging „straight“ line winds (damage paths or damage swaths in forests)
- Topic of current research



Markowski, P., & Richardson, Y. (2011). *Mesoscale meteorology in midlatitudes* (Vol. 2). John Wiley & Sons.

Wakimoto, R. M., Murphey, H. V., Davis, C. A., & Atkins, N. T. (2006). High winds generated by bow echoes. Part II: The relationship between the mesovortices and damaging straight-line winds. *Monthly weather review*, *134*(10), 2813-2829.

Case studies

Case 1: F4-Tornado Mira/Dolo (VE), Italy, July 8th, 2015 (1/4)

- July 8th, 2015, 17:25-17:45 CEST
- Affected communities: Baluello (Pianiga) Arino (Dolo), Pianiga (Cazzago), Cazzago, Dolo (San Bruson), Mira, Porto Menai (Mira), Piazza Vecchia
- Length of damage path: 11 km
- Mean width of damage path: 700 m
- Maximum width : 1000 m
- Maximum intensity: F4 (335-421 km/h), violent
- Number of fatalities: 1 (person was forced to stop car because of electric mast blocking the road, then car was picked up by the tornado)
- Number of injuries: 72
- Damage: about 100,000,000 EUR
- Accompanying hail: 5 to 7 cm

Holzer, A., Ferrario M.E., Kaltenberger., R., Gobbi, A., Groenemeijer, P. (2015): Corporate Report on the 8 July 2015 Tornado of Mira (VE), Italy, available at https://www.essl.org/cms/wp-content/uploads/20150902-Mira-Tornado-of-8-July-2015-Report.pdf

ESSL European Severe Storms Laboratory

arpav

ZAMG

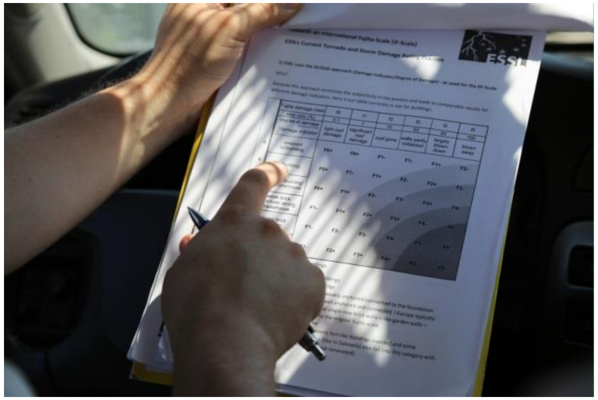
meteonetwork

Case 1: F4-Tornado Mira/Dolo (VE), Italy, July 8th, 2015 (2/4)

120 data points (mostly buildings) with intensity ratings or other relevant information and hundreds of damage photographs.

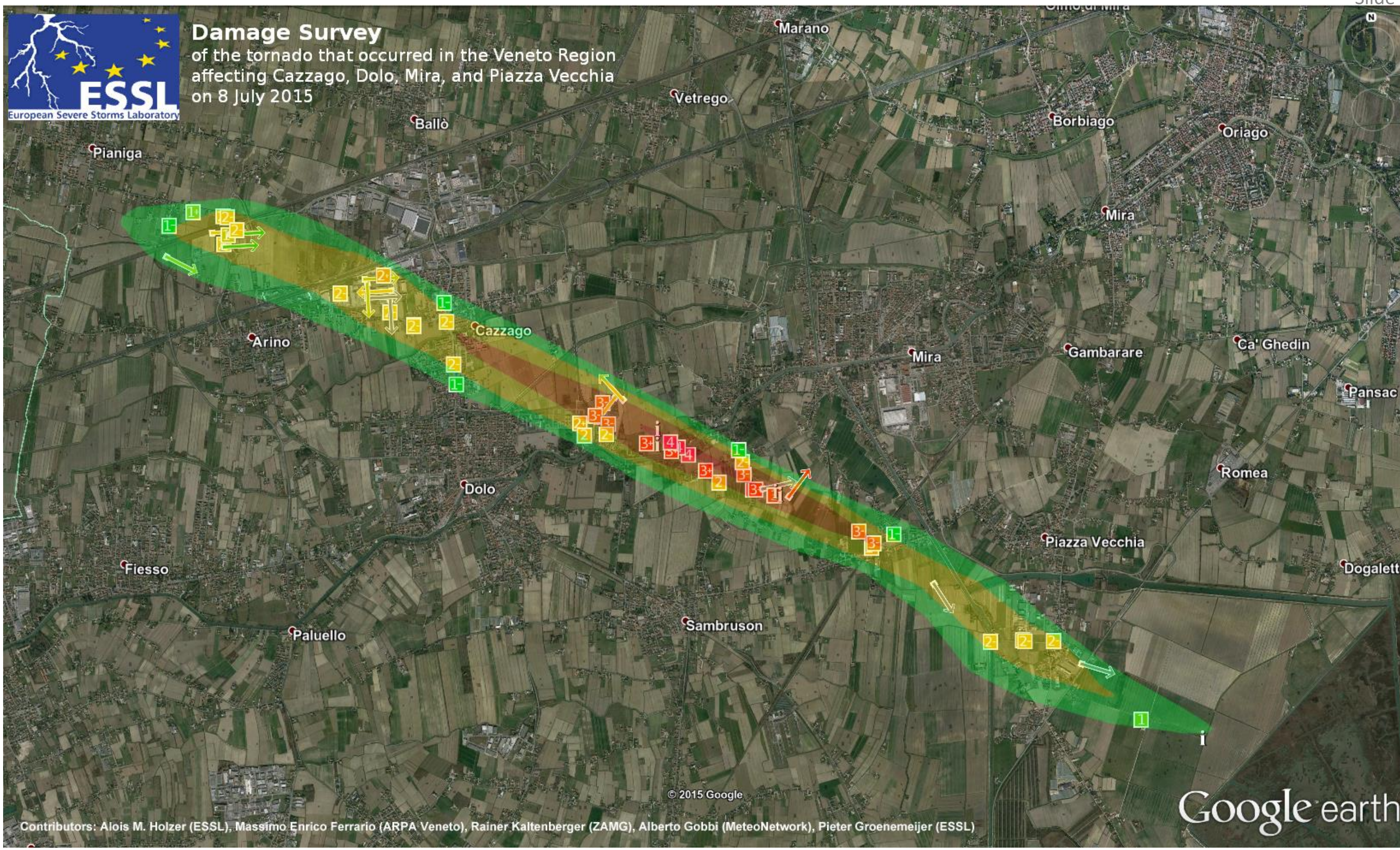
Corporate Report on the 8 July 2015 Tornado of Mira (VE), Italy **Attachment 2: List of damage ratings**

No.	latitude	longitude	DI	DoD	Rating	direction of fallen trees (direction opposite to wind direction)	Other information
1	45.446	120.393	J	2	F1+	120	NW-SE tree fell down
2	45.448	120.471	C	2.5	F1+		first touchdown according to house. Eyewitness house owner: trees were lifted up
3	454.478	120.476	I	5	F1-	90	vineyard flattened dir W-E
4	454.484	120.482	E	1	F2-		cone moved up and down according to eyewitness
5	454.467	120.467	I	5	F1-	90	vineyard flattened dir W-E
6	454.472	120.465	E	1	F2-		
7	45.448	120.453	J	4	F2-	90	few young trees snapped
8	454.491	120.397	E	0	F1-		some shingles gone
9	454.502	120.428	E	0.5	F1+		
10	454.497	120.466	E	1	F2-		roof damaged, some trees gone
11	454.496	120.471	E	1	F2-		tornadic convergence (street signs, corn)
12	454.496	120.471					electric pole bent
13	454.423	120.609	F	0.5	F2-		industrial fence broken. Around 17:40 wind noise: all doors closed - less damage than neighbors factory. Truck flipped over small wall
14	454.437	120.665	F	1	F2+		metal roof cover blown away
15	454.432	120.643	J	2	F1+	90	uprooted tree
16	454.427	120.643	J	2	F1+	180	iron fence, trees fell towards S
17	454.415	120.645				90	debris, waste containers
18	454.421	120.671	B	3	F2-	270	broken concrete wall
19	454.411	120.671				180	mais/corn bent
20	454.404	120.671	E	1	F2-		
21	454.391	12. Jul	E	1	F2-		
22	454.392	12. Jul	C	2	F2-		
22a	454.392	12. Jul	E	1	F2-		
23	45.441	12.074	E	0	F1-		
24	454.393	120.742	E	1	F2-		
25	454.355	120.748	E	1	F2-		
26	454.337	12.075	E	0	F1-		
27	454.286	120.909	J	4	F2		field of young trees snapped
28	454.315	120.958	J	4	F2	320	large tree



ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Case 1: F4-Tornado Mira/Dolo (VE), Italy, July 8th, 2015 (3/4)



Case 1: F4-Tornado Mira/Dolo (VE) (4/4)

The western neighborhoods of Mira experienced the worst tornado impact. A few buildings were rated F4, including the historical Villa Fini. This villa was assumed to be a "weak brick building" damage indicator because of the very aged and crumbly mortar in between the bricks. This building totally collapsed.

Remnants of Villa Fini (F4, collapsed weak brick structure) in western Mira (photo: Alberto Gobbi)

F4 damage (strong brick structure, walls partly collapsed) in western Mira close to the Villa Fini, on the other side of the streamer (photo: Alberto Gobbi)

Holzer, A., Ferrario M.E., Kaltenberger., R., Gobbi, A., Groenemeijer, P. (2015): Corporate Report on the 8 July 2015 Tornado of Mira (VE), Italy, available at https://www.essl.org/cms/wp-content/uploads/20150902-Mira-Tornado-of-8-July-2015-Report.pdf

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Case 2: F1-Squall line - Frauschereck, Upper Austria, August 18th, 2017

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Case 3: F2-Tornado near Vienna Int. Airport, July 10th, 2017 (1/2)

Damage Indicator: Alley trees next to L2063 road

- DI: hardwood tree (walnut), strong stand, solitary
- DoD: broken / uprooted

⇒ F2

Case 3: F2-Tornado near Vienna Int. Airport, July 10th, 2017 (2/2)

Damage Indicator: wall of straw cuboids

- DI: straw cuboids (220 x 110 x 65 cm; ca. 400 kg each)
- DoD: toppled over, a few carried up to 50m away

⇒ ???

⇒ “Forensic Engineering” (Petty, 2013): F2- wind speeds needed to lift cuboids of such dimensions and mass

Practical guidance

Practical guidance (1/2)

Recommended approach

- As prompt as possible!
- Equipment: photo camera, GPS receiver, compass, maps, paper and pens, …
- In a team of at least two persons (more solid ratings through collaborative decision making)
- Damage swaths in forests often very dangerous to access – caution!
- Witnesses are often traumatized - Let them tell if they want to and be careful when asking questions (don‘t force anything)
- Rate damages in a conservative way
- Collaboration with local weather enthusiasts/spotter organizations has proven its worth, international networking important (e.g. via ESSL)
- A drone can be very useful, but cannot replace expert assessment on the ground

Practical guidance (2/2)

Recommended approach

- From individual damage to the overall picture!
- Identify Damage Indicators (DIs)
  - Buildings: individual ratings (roof, walls,…)
  - Vegetation: Damage swaths/groups of trees can be pooled
- Rate Degree of Damage (DoD)
- Assign each individual damage an (upper/lower) F class
- Note down: Damage ID (consecutive number), coordinates (lon./lat.), (upper/lower) F class and DI/DoD, falling direction of trees (degree), further comments. Take photos!
- Compare all individual damages, correct individual outliers if appropriate
- Be especially cautious /conservative with rating of maximum strength – consult other experts if needed

⇒ A pinch of subjectivity remains, but it can be minimized!

Literature

Damage scales, DI/DoD method

- Feuerstein, B., Dirksen, E., Dotzek, N., Groenemeijer, P., Holzer, A. M., Hubrig, M., & Rauch, E. (2009, October). An illustrated verbal description of the TORRO and Fujita scales adapted for Central Europe considering building structure and vegetation characteristics. Preprints. In *5th European Conference on Severe Storms, Landshut, Germany* (pp. 357-358).
- Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.
- Dotzek, N. (2009). Derivation of physically motivated wind speed scales. Atmospheric Research, 93(1), 564-574.
- Groenemeijer, P., Holzer A. M., Kaltenberger, R. et al. (2019): The International Fujita (IF) Scale, Tornado and Wind Damage Assessment Guide. Draft version as of 17th November 2019. Authored by the IF Scale Steering Group. https://www.essl.org/media/publications/IF-scale_v0.10.pdf
- Rodríguez, O., Bech, J., Soriano, J. D. D., Gutiérrez, D., & Castán, S. (2020). A methodology to conduct wind damage field surveys for high-impact weather events of convective origin. *Natural Hazards and Earth System Sciences*, *20*(5), 1513-1531.
- Skywarn Deutschland, Angepasste Fujita-Torro Skala für Vegetations- und Gebäudeschäden (2009). https://www.skywarn.de/downloads/schadensanalyse/schadensskala_bebildert.pdf
- Hubrig, M. (2015): Wooden Plants: A New Damage Indicator / Degree of Damage – Matrix, ECSS 2015, Wiener Neustadt
- Hubrig, M. (2004): Analyse von Tornado- und Downburst-Windschäden an Bäumen. Forst und Holz, 59, 78-84.

Case Studies

- Holzer, A., Ferrario M.E., Kaltenberger., R., Gobbi, A., Groenemeijer, P. (2015): Corporate Report on the 8 July 2015 Tornado of Mira (VE), Italy, available at https://www.essl.org/cms/wp-content/uploads/20150902-Mira-Tornado-of-8-July-2015-Report.pdf
- Pistotnik, G., Holzer, A. M., Kaltenböck, R., & Tschannett, S. (2011). An F3 downburst in Austria—A case study with special focus on the importance of real-time site surveys. Atmospheric research, 100(4), 565-579.
- Kaltenberger, R., Weber, M. (2017): Damage Assessment of the 2016 F2-Tornado near Karlstein, Lower Austria. Poster presentation at the European Conference on Severe Storms, Pula, Croatia

Literature

Damage scales, DI/DoD method

- Feuerstein, B., Dirksen, E., Dotzek, N., Groenemeijer, P., Holzer, A. M., Hubrig, M., & Rauch, E. (2009, October). An illustrated verbal description of the TORRO and Fujita scales adapted for Central Europe considering building structure and vegetation characteristics. Preprints. In *5th European Conference on Severe Storms, Landshut, Germany* (pp. 357-358).
- Feuerstein, B., Groenemeijer, P., Dirksen, E., Hubrig, M., Holzer, A. M., & Dotzek, N. (2011). Towards an improved wind speed scale and damage description adapted for Central Europe. Atmospheric Research, 100(4), 547-564.
- Dotzek, N. (2009). Derivation of physically motivated wind speed scales. Atmospheric Research, 93(1), 564-574.
- Groenemeijer, P., Holzer A. M., Kaltenberger, R. et al. (2019): The International Fujita (IF) Scale, Tornado and Wind Damage Assessment Guide. Draft version as of 17th November 2019. Authored by the IF Scale Steering Group. https://www.essl.org/media/publications/IF-scale_v0.10.pdf
- Rodríguez, O., Bech, J., Sor ... ind damage field surveys for high-impact we ... , *20*(5), 1513-1531.
- Skywarn Deutschland, Ang ... https://www.skywarn.de/ ...
- Hubrig, M. (2015): Woode ... Wiener Neustadt
- Hubrig, M. (2004): Analyse ... 78-84.

Case Studies

- Holzer, A., Ferrario M.E., K ... July 2015 Tornado of Mira (VE), Italy, available at https://www.essl.org/cms/wp-content/uploads/20150902-Mira-Tornado-of-8-July-2015-Report.pdf
- Pistotnik, G., Holzer, A. M., Kaltenböck, R., & Tschannett, S. (2011). An F3 downburst in Austria—A case study with special focus on the importance of real-time site surveys. Atmospheric research, 100(4), 565-579.
- Kaltenberger, R., Weber, M. (2017): Damage Assessment of the 2016 F2-Tornado near Karlstein, Lower Austria. Poster presentation at the European Conference on Severe Storms, Pula, Croatia

Thank you for your attention!
Questions?

Contact: rainer.kaltenberger@zamg.ac.at