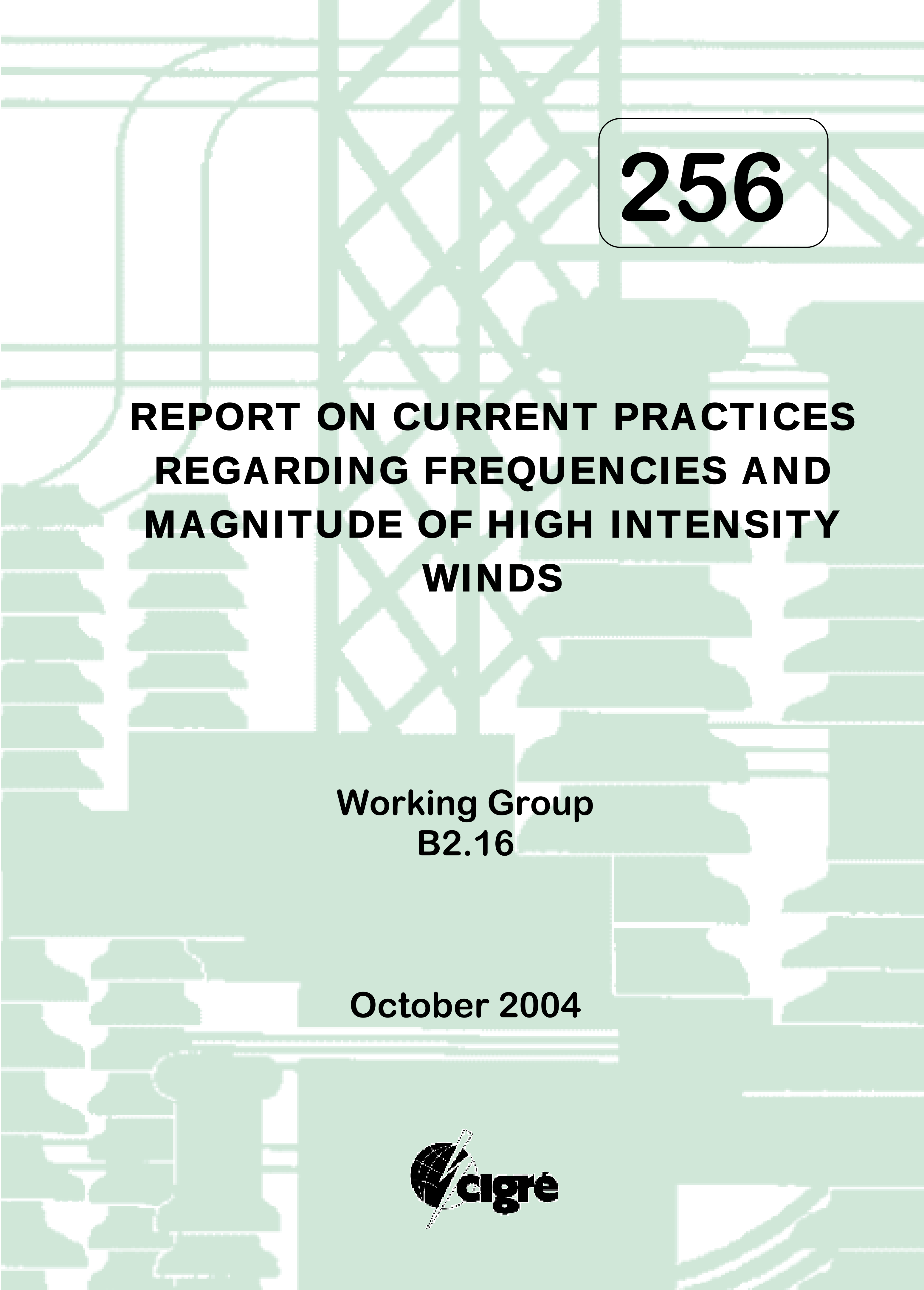

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REPORT ON CURRENT PRACTICES REGARDING FREQUENCIES AND MAGNITUDE OF HIGH INTENSITY WINDS

Working Group
B2.16

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REPORT ON CURRENT PRACTICES REGARDING FREQUENCIES AND MAGNITUDE OF HIGH INTENSITY WINDS

1.LIST OF CONTENT

2.ABSTRACT

The structural design of overhead lines is governed to a major extent in most parts of the world by wind gusts and the loads that they impose on the structural system elements.

These high winds have also been one of the major causes internationally of failures of the overhead line networks. In some regional areas of the globe it is an annual expectation that there will be severe windstorm events that will significantly disrupt electricity supplies. Overhead line networks have a high exposure to such wind events due to their spatial extent and exposure to topographical and locality variations.

This report attempts to consolidate information about each significant extreme wind storm type; and present a review of international practice and code requirements in relation to over head line design; as a reference for overhead line designers.

In particular it reviews the characteristic of generic wind storm types and associated storm cells exhibiting high intensity wind gusts and their influence on transmission line design standards and practices throughout countries in regions impacted by these events.

For the purpose of clarifying definitions of these events, high intensity wind gusts are those having velocities exceeding 45m/s or those likely to cause structural damage to property.

The report also reviews current practices adopted to mitigate catastrophic failures and to limit cascade effects.

Information presented in this report has been assembled from contributions received from a survey of the international overhead line community and from specialist wind engineering and meteorological sources.

The wind gust characteristics and guidelines provided is based expert advice and the most recent investigations and research results. It forms a basis for determining the relevant design load application for overhead line design.

3.INTRODUCTION

This report reviews the characteristic of generic windstorm types and associated cells exhibiting high intensity wind gusts, and their influence on transmission line design standards and practices throughout countries in regions impacted by these events.

Figure 1 prepared by the Munich RE insurance group provides a high level review of the extent of the world exposure to high wind storm events and the potential impact to overhead line networks.

For the purpose of clarifying definitions of these events, high intensity wind gusts are those having velocities exceeding 45m/s or likely to cause structural damage to property.

The report also reviews current practices adopted to mitigate catastrophic failures and to limit cascade effects.

Information presented in this report has been assembled from contributions received from the international overhead line community and from specialist wind engineering and meteorological sources.

4.CHARACTERISTICS OF SEVERE WIND STORM EVENTS

4.1Subtropical Thunderstorms

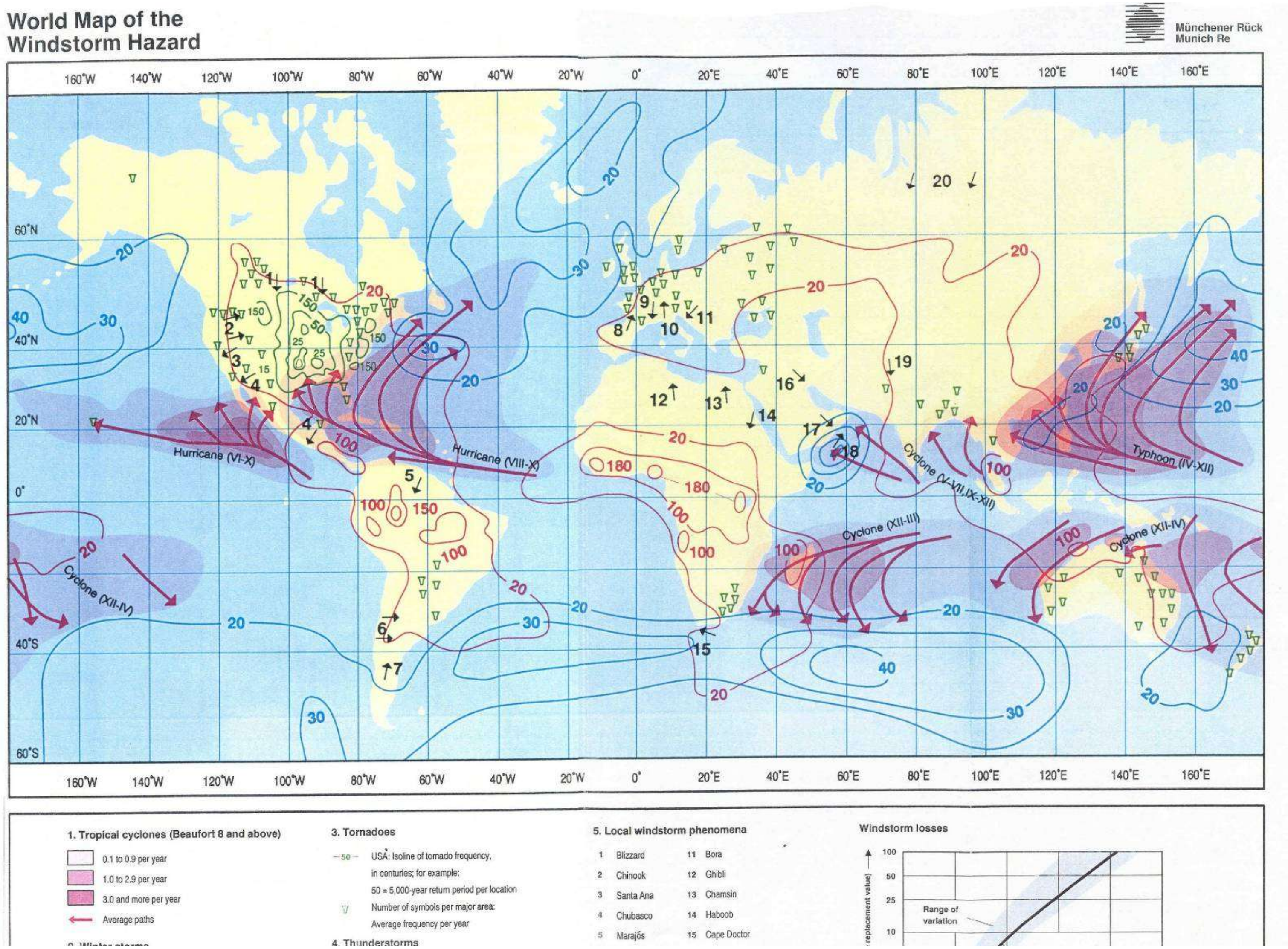
Thunderstorms often develop in regions where the troposphere (from the surface to 10 km) is sufficiently moist and unstable for convective clouds to develop, which can grow up to 20 km in height (Australian Bureau of Meteorology 1995a)[2]. The name “thunderstorm” relates to the typical occurrence of lightning and associated thunder with these events, which is due to the separation of charged particles in the storm circulation. There is, however, no known direct relationship between the incidence of lightning and the potential severity of other storm parameters such as damaging wind or hail. To break this nexus with lightning, “thunderstorms” are also termed “local” storms in the US context and to differentiate from larger scale synoptic features such as fronts. Doswell (1985)[4], for example, prefers to call the process “deep moist convection”. In basic terms, the thunderstorm is capable of accumulating vast amounts of potential energy that can then be converted into dangerous turbulence and shear in the atmosphere and often damaging impacts at the surface.

“Severe” thunderstorms are simply those convective storms whose individual characteristics exceeds one or more of the following arbitrary criteria, defined as follows (Ryan1989)[10]:

- Heavy rain and flash floods - based on an hourly rainfall rate in excess of the accepted local 10 yr return period
- Hail with diameter $\geq$ 20 mm
- Tornado(es)
- Wind gusts $\geq$ 90 km h^{-1} (25 m/s or 48.5 kts) at +10m above the surface.

Severe thunderstorms with wind velocities exceeding 45 m/s, account for approximately 10% of all thunderstorms but for 90% of all damage and injury. A significant problem in the classification of severe thunderstorms lies in the detection and reporting of their characteristics, which often produce very localised effects. Although remote sensing capabilities such as advanced radar are being progressively developed and extended, community reporting is an important link in the growing knowledge base of severe thunderstorm impacts.

Figure 1 Munich RE Wind Hazard Map of World (next Page)



Annex: World Map of the Windstorm Hazard

The world map opposite shows not only the geographical distribution of tropical cyclones (with their general paths, regional names and main seasons), extratropical storms, tornadoes and thunderstorms (as an indication of the risks of hail and wind gusts), but also a number of local windstorm phenomena (with their

4.2Thunderstorm Formation, Classification and Organisation

As a general rule, the following conditions must exist for the development of thunderstorms:
- availability of low level moisture
- a source of instability
- a lifting mechanism to initiate updrafts

Conceptual models of the complex processes of atmospheric convection are then used to form a basis for the classification of thunderstorms. The most fundamental concept is that a single thunderstorm may consist of one or more convective building blocks termed “cells”. A cell is a compact region of relatively strong upward air motion, triggered by atmospheric instability due to the temperature and density differences in the vertical dimension.

Conceptually there are two types of thunderstorm cells, classified as follows:

(a) The *Ordinary Cell*
- is the most common type
- forms in weak vertical wind shear environments
- may be isolated but commonly occurs with other similar cells
- has a lifetime typically up to 1 hour
- has an on-ground horizontal scale of 5 to 10 km
- can produce short bursts of severe weather

(b) The *Supercell*
- is rarer
- forms in strong vertical wind shear environments
- is usually isolated
- exhibits a deep, persistent rotating updraft (a mesocyclone)
- has a lifetime of 1 to 2 hours or more
- has an on-ground horizontal scale of 10 to 40 km
- almost always produces severe weather

A schematic diagram of a mature supercell thunderstorm is presented in Figure 2.1. The primary feature is the deep and persistent rotating updraft that originates as low-level moist inflow ahead of the storm. Much of this updraft is dissipated at the upper levels, forming the characteristic anvil and overshoot, but some re-circulate as downdraft that appears at the surface as the familiar gust front. Hail and heavy rain areas are also associated with the downdraft zones, in addition to the severe winds. Under specific sets of conditions, none of which are fully understood, a tornado may form towards the left rear flank of the supercell (southern hemisphere, observer travelling with the storm). The tornado is thought to result from the tilting of horizontal vorticity present in the lower layers. This allows a small but rapidly rotating column of air to descend below the cloud base, often reaching the surface with devastating consequences. Supercell sub-categories include “*high*” and “*low*” precipitation varieties, the “high” being more common and is typically associated with large hail and high rainfall intensities and a high probability of associated extreme downdrafts.

Tornadoes can also form along convergent boundaries that are not associated with supercells. An example is the “waterspout”, often associated with heavy rain showers over the sea. Supercells are often identifiable by distinctive radar signatures such as the so-called “bow”, “comma” and “hook” echoes in plan form and the “bounded weak echo” region in the vertical. These regions of high (or low) radar reflectivity indicate the presence of highly organised motion within the supercell environment and are pointers towards possible tornado development.

While supercells are generally isolated from other storm cell types, the ordinary cell can often become organised in a *multi-cellular* form comprising a progression of cells (typically up to 6) at various life cycle stages. This results in a broader “storm” front able to propagate transverse to the environmental flow by the addition of new cells on the forward left flank and the removal of decaying cells on the right flank.

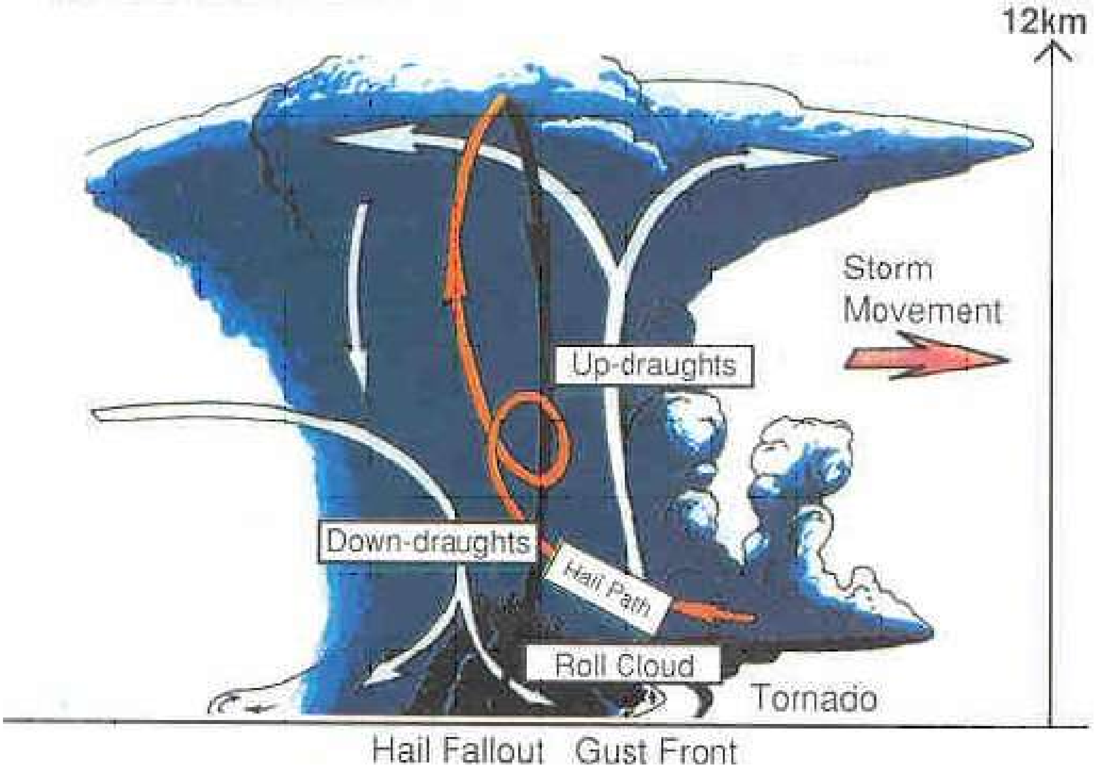


Figure 2.4.1 Schematic illustration of a mature supercell thunderstorm (Bureau of Meteorology – Australia)

Figure 2.2 Typical supercell roll cloud proceeding rain and hail column of a mature supercell thunderstorm

While the above descriptions cater for the majority of thunderstorm classes, other types of cell organisation include:

- "*Pulse*" storms which are generally isolated, short-lived and (largely) non-forecastable
- *Mid-latitude Cool Season* storm systems (with generation off polar region oceans)
- *Mesoscale Convective Systems*, normally consisting of a large cluster of ordinary cells
- *Mesoscale Convective Complexes* may originate in areas with weak vertical wind shear (such as in the tropics), typically become self-generating, and are often associated with monsoonal troughs or are precursors to tropical cyclone development
- *Squall Lines* form with narrow gaps between cells and are self-generating systems able to keep pace with their own gust front

4.3Severe Winds

Whilst it is convenient to describe the thunderstorm in terms of conceptual classes of events and behaviour, the chaotic nature of the convective process is able to generate a wide range of potential effects over a broad scale of motion. Fujita (1981)[5] presents an overview of extreme winds which is useful to illustrate the range of possible situations.

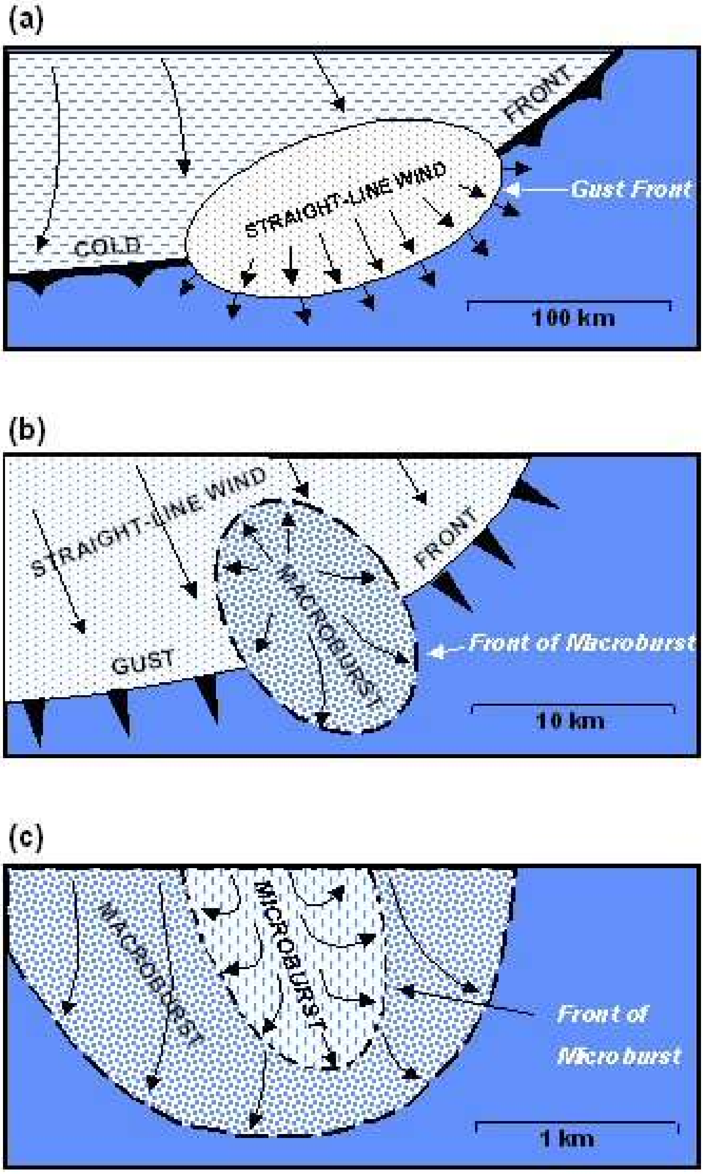
There are essentially three types of severe wind phenomena associated with thunderstorms:

- *Straightline winds* (non-divergent), typically associated with advancing gust fronts sometimes referred to as outflow gust fronts
- *Downbursts* (high pressure flows), highly divergent with straight or curved paths, divergence increasing at smaller scales
- *Tornadoes* (low pressure flows), highly convergent, narrow paths

Figure 2.3 is adapted from Fujita's overview of planetary scales of motion, with terminology re-classed to suit the thunderstorm perspective. Figure 2.3a shows the upper limit of scale of interest in the thunderstorm problem where severe but essentially *straight-line* winds can accompany a gust front ahead of a cold frontal system. This scale of motion is typically of order 100 km. Within a gust front, Figure 2.3b shows the potential further development of a *macroburst* within this flow at a scale of order 10 km. Finally, a *microburst* may develop at a scale of order 1 km as shown in Figure 2.3c.
Tornadoes occur at a scale similar to microbursts but, being convergent flows, exhibit long narrow paths that are often characterised by an intermittent surface contact.

Following Fujita (1981) [15] again, Figure 2.4 presents an overview of wind severity based on the terminology developed above. Horizontal scale decreases to the right-hand side in these illustrations while speed increases vertically. For "high pressure" systems, potential wind gust speeds begin from a base of 20 m/s acting over several hundred kilometres. Progression is then through the range of gust fronts (30 m/s over 50 km), then *macrobursts* (50 m/s over 5 km) and *microbursts* (70 m/s over 1 km) - before peaking near 80 m/s at an anticipated scale of 100m or less. For "low pressure" systems, the highest scale flow is provided by synoptic lows, peaking in intensity for *hurricanes (typhoons or tropical cyclones*) at around 90 ms^{-1} on a 500 km scale, then with a lower intensity of around 50 m/s at the *mesocyclone* scale of 20 km. The *tornado* scale builds from below 1 km in width scale, peaking in intensity around 140 m/s at the sub 1 km scale. These speed and scale figures should be regarded largely as descriptive overviews of the interplay of these various scales of motion.

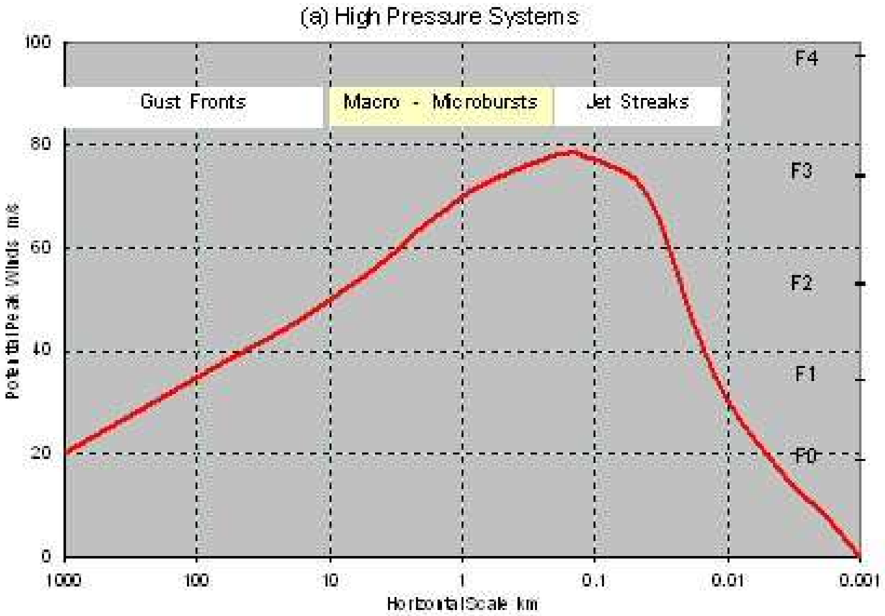
Also shown on Figure 2.4 are the midpoint values of the empirical "F" scale range for damaging winds. These were developed by Fujita based on many hundreds of subjective damage assessments. It was designed to extend the Beaufort Scale beyond Force 12 and has arguably served a useful purpose over time. From an engineering perspective, however, there are many potential errors in estimating wind speed from observations of damage to (especially) domestic standard construction. For example, Minor et al (1982)[9] presents a detailed engineering investigation into damage caused by tornado effects. The conclusion then was that the majority of historical US damage would have occurred due to winds in the range 36 m/s to 56 m/s. Furthermore, no conclusive evidence at that time was found for ground-level wind speeds in excess of 112 m/s when based on engineering analysis. However, recent direct observational evidence with fine-scale Doppler radars does support tornado speeds at least in the range of 125 m/s (Bluestein et al 1993) [1] and from a limited data set only at this time.

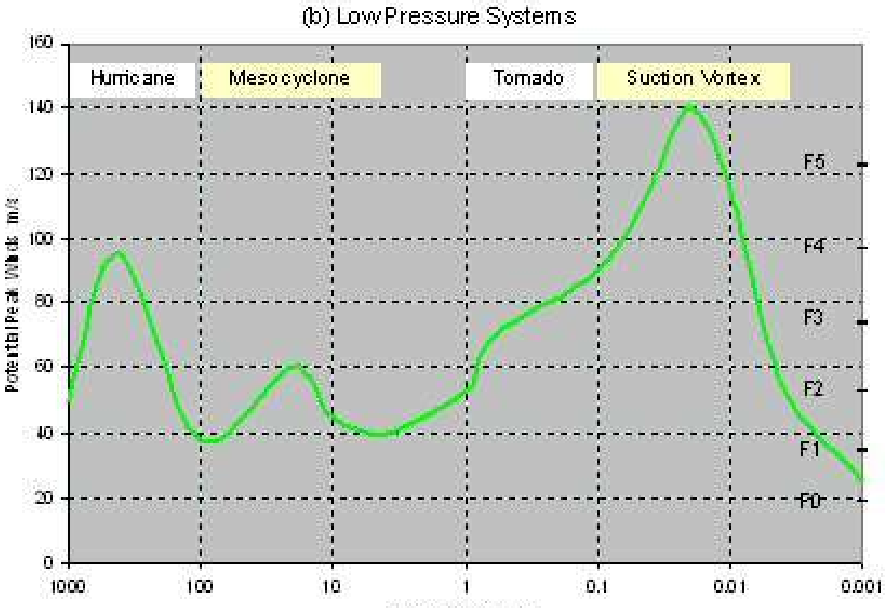


(after Fujita (1981))

Figure 2.3 Typical scales of motion of ground-level winds.

Often distinguishing between downburst and tornado damage is difficult.
A fast moving tornado may also exhibit near straightline damage characteristics. Where a radial pattern of damage is indicated, microbursts are likely. Tornado damage, on a small scale will generally exhibit eccentric swirl damage patterns in low vegetation; while on a large scale, may show evidence of circumferential flow that tends to be one directional form of damage. “Twisting” of trees, for example, will likely occur due to asymmetry of the tree form under all types of wind load.


(a) High Pressure Systems


(b) Low Pressure Systems

After Fujita (1981)

Figure 2.4 Range of peak winds for varying space scales.

(a) A typical wet downburst from a supercell.

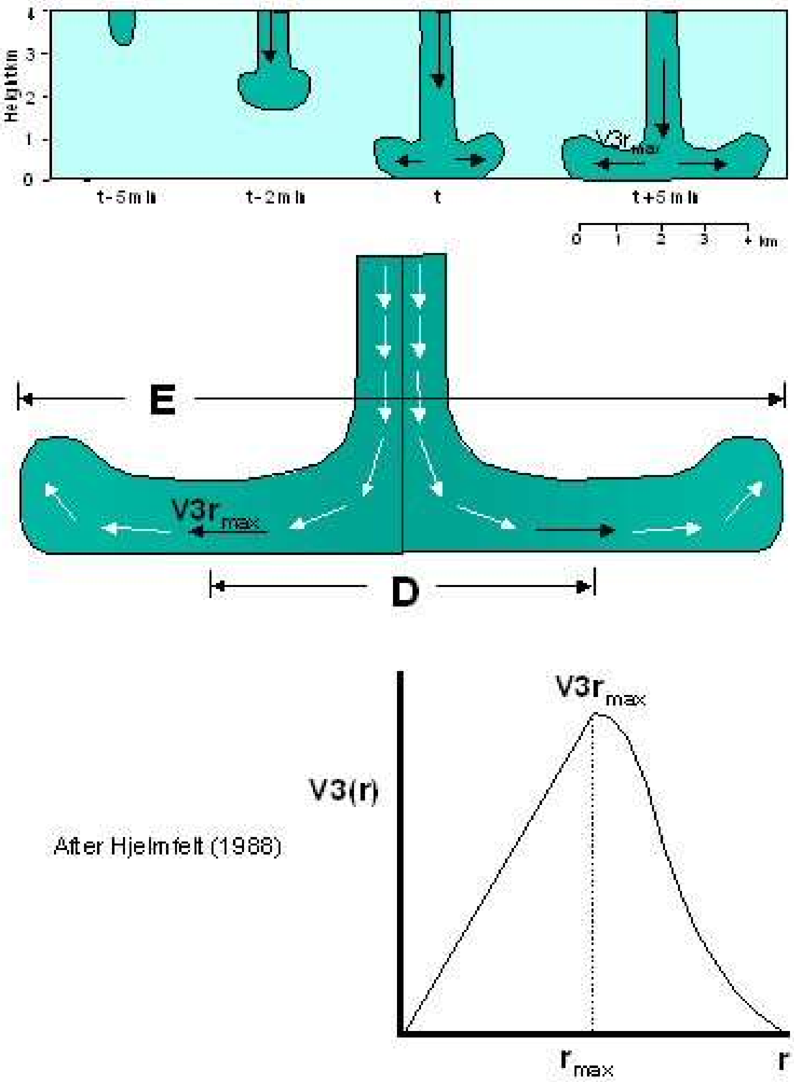
b) Typical tornadoes from supercells

Figure 2.5 Examples of severe wind events **(Photographs Bureau of Meteorology – Australia)**

Thunderstorm downbursts may occur over a range of time and space scales, as outlined earlier. In order to provide the most realistic description of these events the model incorporates a dynamic representation of downbursts based essentially on the observations by Hjelmfelt (1988)[6], modelling by Holmes (1992) [7], and the subsequent formulation of an empirical “moving jet” model by Holmes and Oliver (1996) [8].

Figure 2.6 illustrates a conceptual model of a single, isolated downburst which is stationary relative to the surface. In this scenario, a mass of cold, dense air reaches a point of instability with respect to the updrafts maintaining it aloft, and it begins to descend below the cloud base. Within a few minutes it has accelerated, widened through entrainment and, on impact with the ground, spreads radially out from the point of impact. The radial velocity profile has been shown to be well approximated by a theoretical “wall jet” model where the velocity decays rapidly beyond a core radius. When a downburst descends from a moving cloud base (the more common situation), the behaviour has been found to be basically identical to the stationary case but with the simple vector addition of the forward speed component, giving an asymmetric gust front impacting the ground. Wind tunnel tests at the University of Queensland Australia, using a moving jet further confirmed these static tests but also provided information of the velocity profile over the centre of the hill, and the presence of high velocity back flows at velocities the resultant of the velocity vectors. Further versions of this schematic model can be used to illustrate observed downburst situations in multi-cellular storm systems where the individual downbursts act to form an almost continuous gust line.

Figure 2.7 provides a typical Dynes anemograph record of a severe thunderstorm wind as the severe cell passes a given point and indicates the time duration and translation speed of such events.



After Hjelmfelt (1988)

Figure 2.6 Schematic of a single downburst.

The downburst model formulation after Holmes and Oliver (1996) [8] is given by:

$$V3r(r,t) = V3r_{max} \,.\, \exp(-t/Tcon) \,.\, \exp\{-[(r-r_{max})/R]^2\}$$

where $V3r$ = radial 3 second gust wind component at nominally +10m
$V3r_{max}$ = peak downburst 3 second gust strength
r_{max} = radial position of $V3r_{max}$
R = a radial scale parameter defining the outer velocity decay field
r = radial distance from the centre of the downburst
t = time since peak of downburst
$Tcon$ = downburst strength decay time constant

The resulting peak wind speed V3p at any given position is then assumed to be the vector addition of V3r and the forward velocity Vfm:

$$\overline{V3p} = \overline{V3r} + \overline{Vfm}$$

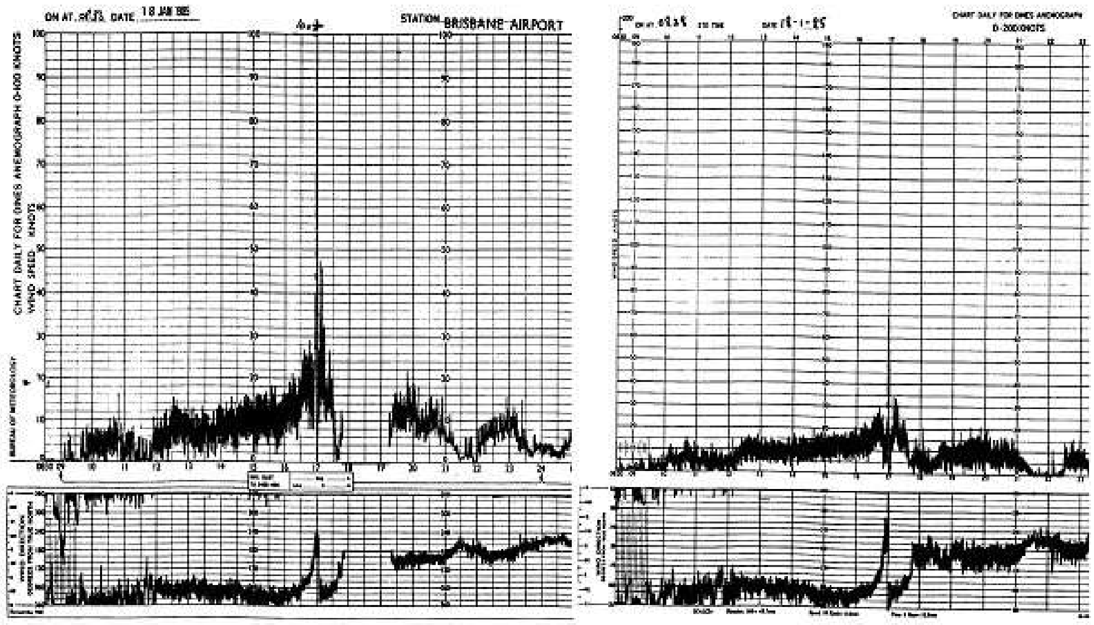


Figure 2.7 Typical Dines anemograph records of severe thunderstorm wind

4.4Tropical Cyclones, Typhoons and Hurricanes

Tropical cyclones / hurricanes and hurricanes are large scale and potentially very severe low pressure weather systems that affect the tropical coastal regions during the summer months. The strict definition of a tropical cyclone (WMO, 1995) [11] is:

A non-frontal cyclone of synoptic scale developing over tropical waters and having a definite organized wind circulation with average wind of 34 knots (17.5 m/s) or more surrounding the sustained winds at the centre.

The tropical cyclone is an intense tropical low pressure weather system where, in the southern hemisphere, winds circulate clockwise around the centre. In Australia, such systems are upgraded to *severe* tropical cyclone status (referred to as hurricanes or typhoons in some countries) when average, or sustained, surface wind speeds exceed 34 m/s. The accompanying shorter-period destructive wind *gusts* are often 50 per cent or more higher than this value. These high winds have a buffeting characteristic where the level of 'gustiness' can last for several hours from one direction, only to be followed shortly afterwards by winds of a similar but marginally less magnitude from the opposite direction as the eye of the storm passes a given point.

There are three components of these tropical events that combine to make up the total hazard - strong winds, intense rainfall and induced ocean effects including extreme waves, currents, storm surge and resulting storm tide. The destructive force of these storms is usually expressed in terms of the strongest wind gusts experienced. Maximum wind gust is related to the central pressure and structure of the system, whilst extreme waves and storm surge, are linked more closely to the combination of the *mean* surface winds, central pressure and regional bathymetry.

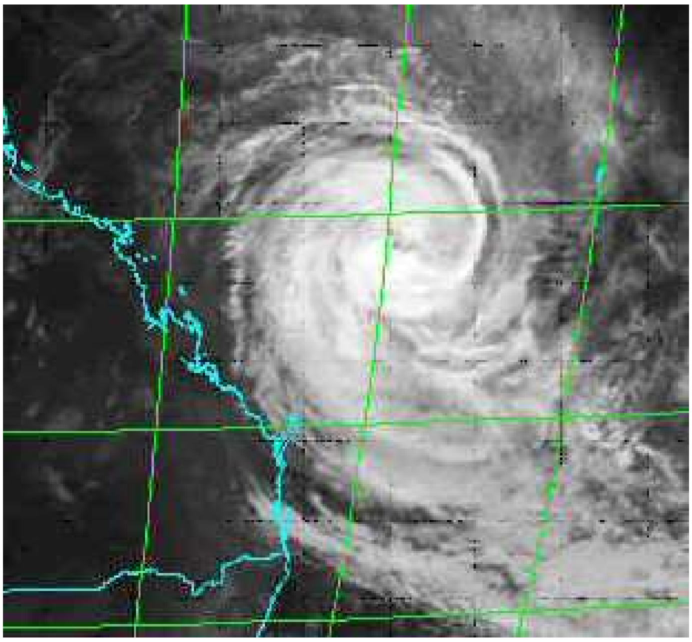


Figure 2.8 Tropical cyclone Fran approaching the Queensland coast in March 1992.
(**Photograph Bureau of Meteorology – Australia**)

The Australian Bureau of Meteorology (1999) [2] uses the five-category system shown in Table 2.1 for classifying tropical cyclone intensity in Australia. *Severe* cyclones are those of Category 3 and above.

Table 2.4.1 Australian Tropical Cyclone Category Scale.

Category	Maximum Wind Gust (m/s)	Potential Damage
1	<34	minor
2	34-47	moderate
3	47-63	major
4	63-77	devastating
5	>77	extreme

Tropical cyclone development is complex, but various authors (e.g. WMO 1995) [11], have identified the general conditions necessary for their formation and intensification. Requisite dynamic parameters include low-level *relative vorticity*, exceedence of a threshold value of the *Coriolis* effect of the earth's rotation, and minimal *vertical shear* of the horizontal wind between the upper and the lower troposphere. Ideal thermodynamic parameters include *sea surface temperature* (SST) above 26°C, through the *oceanic mixed layer* to a depth of about 60 m, *moist instability* between the surface and the 500 hPa level (approximately 5600 m above sea level), high values of middle tropospheric *relative humidity*, and warm upper troposphere air.

The main structural features of these storms at the earth's surface are the eye, the eye wall and the spiral rainbands (refer satellite image in Figure 2.6). The eye is the area at the centre of the storm at which the surface atmospheric pressure is lowest. It is typically 20 to 50 km in diameter, skies are often clear and winds are light. The eye wall is an area of cumulonimbus clouds, which swirls around the eye. Recent studies (e.g. Wakimoto and Black 1994) suggest that unusually high winds can occur in the vicinity of the eye wall due to instabilities as the storm makes landfall. Tornado-like vortices of even more extreme winds may also occur associated with the eye wall and outer rain bands. The rain bands spiral inwards towards the eye and can extend over 1000 km or more in diameter. The heaviest rainfall and the strongest winds, however, are usually associated with the eye wall.

For any given central pressure, the spatial size of individual tropical cyclones can vary enormously. Generally, smaller cyclones occur at lower latitudes and larger cyclones at higher latitudes but there are many exceptions.

For example, because it is difficult for a cyclone to form south of 25ºS in the Australian region, the vast majority affecting south-east Queensland have travelled from further north and are likely to be either fully *mature*, undergoing decay or tending *extra-tropical*. In those circumstances, small cyclones are relatively rare.

Similar effects occur in other subtropical regions with typhoons and hurricanes.
Cyclonic / typhoon / hurricane winds circulate clockwise in the Southern Hemisphere and anti clockwise in the Northern Hemisphere. The wind field within a moving storm cell, however, is generally asymmetric so that, in the Southern Hemisphere, winds are typically stronger to the left of the direction of motion of the system (the 'track'). This is because on the left-hand side the direction of cyclone movement and circulation tends to act together; on the right-hand side, they are opposed. During a coast crossing in the Southern Hemisphere, the cyclonic wind direction is onshore to the left of the eye (seen from the cyclone) and offshore to the right.

Given specifically favourable conditions, tropical cyclones, hurricanes and typhoons can continue to intensify until they are efficiently utilizing all of the available energy from the immediate atmospheric and oceanic sources. This *maximum potential intensity* (MPI) is a function of the climatology of regional SST and atmospheric temperature and humidity profiles.

In the Northwest Pacific Ocean near Japan tropical cyclones referred to as Typhoons have a similar classification as that used in the Australian region. Table 2.2 provides the comparative classifications.

Table 2.2 Typhoon Category Scale.

Category	Maximum Wind Gust (m/s)	Potential Damage
Typhoon	17-34	minor
Strong Typhoon	34-44	moderate
Very Strong Typhoon	44-54	major
Devastating Typhoon	>54	devastating

In addition within this region the typhoons are also classified in relation to size by referring to the radius of winds >15m/sec. as indicated in Table 2.3

Typhoons on average strike Japan more than ten times per year, and extra large typhoons strike once in over ten years. Even then, however, there are relatively limited areas where especially high wind velocities are recorded. Peak gusts produced by a typhoon are generally in the range of 35 m/s to 40 m/s, but have been estimated to sometimes exceed 70 m/s.

Table 2.3 Typhoon Size Classification

Classification	Radius (km)
Typhoon	< 500
Large Typhoon	500 < 800
Extra LargeTyphoon	> 800

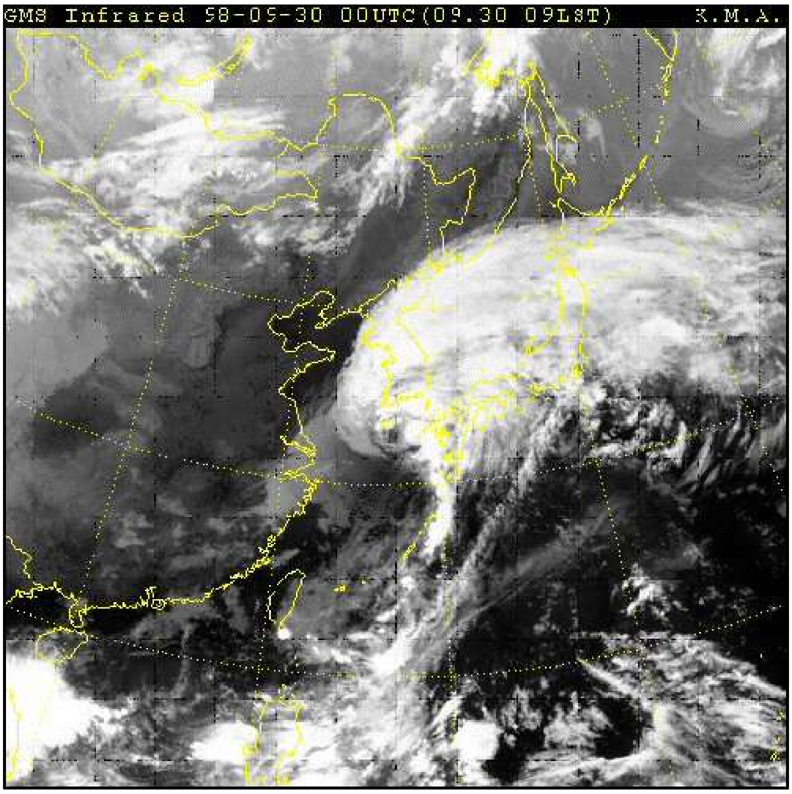


Figure 2.9 Satellite image of Typhoon 'Lupi' 2 December 2003 approaching the coast of Korea and Japan - Ref KMA

Hurricanes in the American region have similar characteristics to the above. Experience in recent times in the eastern coastal region of the USA around the state of Florida resulted in significant damage to infrastructure. Hurricanes 'Floyd' in 1999 and 'Andrew' in 1992 were of particular note. Maximum recorded gust wind speeds during Hurricane Floyd was 69.5 m/s on the sea coast.

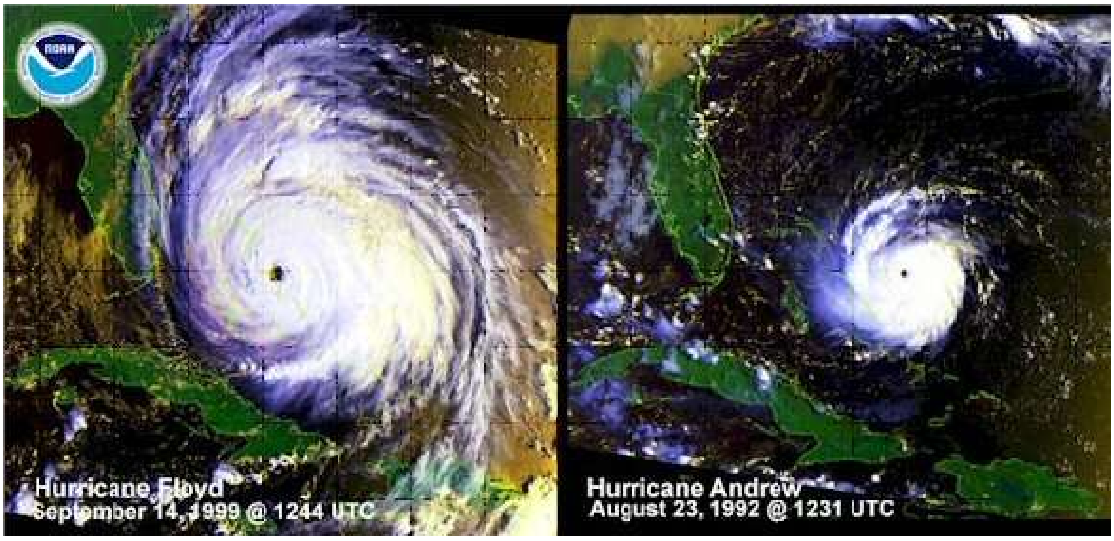


Figure 2.10 Satellite images of Hurricanes Floyd in 1999 and Andrew 1992

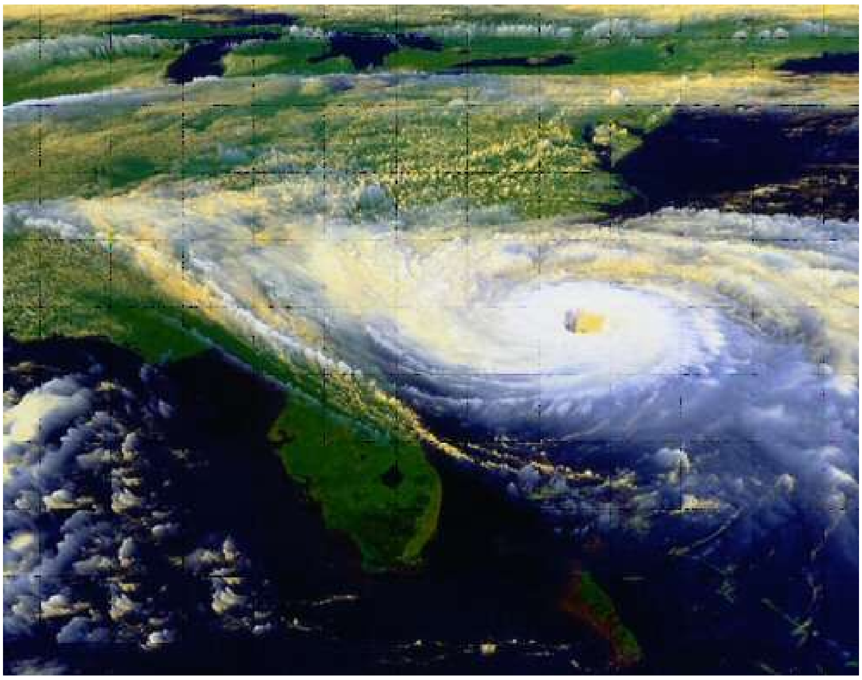


Figure 2.11 Satellite image of Hurricane Floyd in 1999 showing spatial extent over the Atlantic Ocean seaboard prior to landfall. **(Photographs – WMO web site)**

4.5Extratropical Storms / Winter Storm Events

Extratropical storms, or polar front cyclones, are formed on the “Polar front” which persists as a relative sharp divide into the atmosphere between cold, arctic air on the polar side and warmer and more humid air on the tropical side. This frontal divide is circumpolar, in general undulating around 60° on the northern hemisphere. (It is connected to the “jet stream” in higher atmosphere.) The polar front is normally in a situation of unstable equilibrium (like a small ball resting on the top of a larger ball.) Following a disturbance on this front a cyclone, or low pressure system, is formed where the warm, sub-tropic air penetrates as a wedge (warm sector) into the colder air mass and slides over the colder, downwind air (warm front), like sliding up on an inclined plane. On the rear side, the colder air penetrates into the warmer air like a sail (cold front). Simultaneously the air pressure near the surface of the earth is lowered.

A typical example of such a system is illustrated in Figure 2.12.

The diameter of these cyclonic systems range between 500 and 3000 km, the smaller ones being often the most intense. In the North Atlantic region they start as small disturbances outside the eastern coast of North America and reach the strongest stage usually as they reach the northeastern side of the Atlantic and the coastal states of northern Europe from France to the Nordic countries.

The wind then blows counterclock-wise around the depression on the northern hemisphere and clockwise on the southern, with a minor component towards the center due to the friction forces from the surface. The stronger the pressure gradient is (from the center of the depression to the surrounding air), the stronger is the wind speed.

These systems move in a general West to East direction and increase in translation speed as they develop, often achieving translation speeds up to 40km/hour. The most gusty winds occur along the cold front, where also a sharp change in wind direction often is found (from WSW to NW on the northern hemisphere and from WSW to SW on the southern hemisphere). Also very intense shower clouds (Cumulonimbus, sometimes with thundercells) form along this cold front.

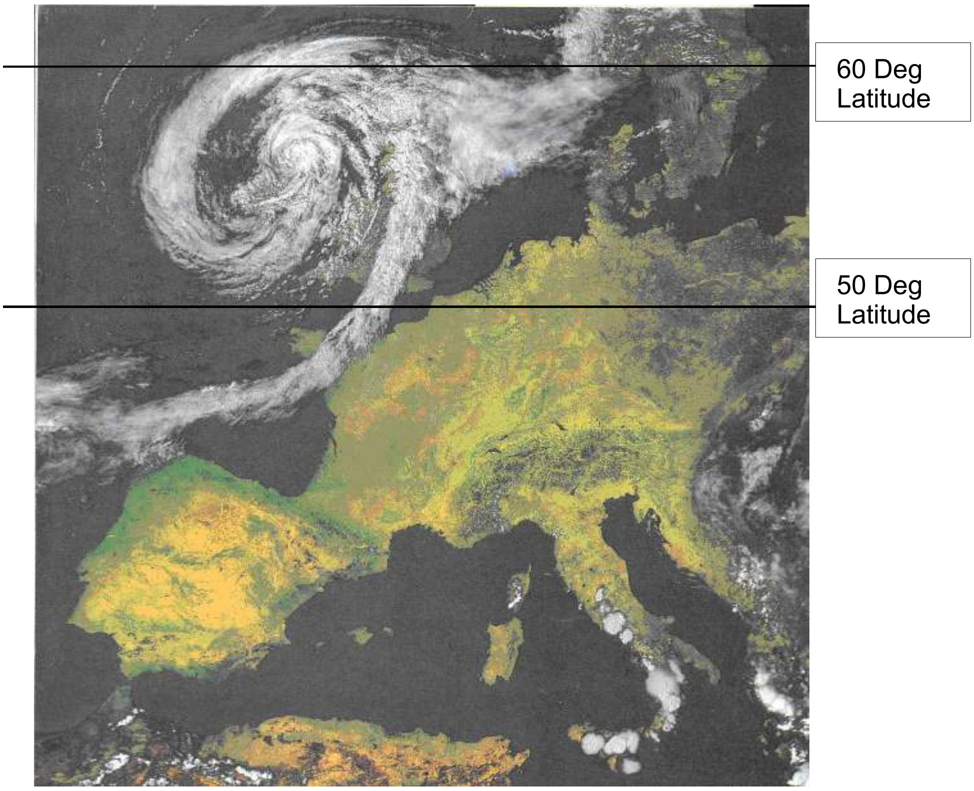


Figure 2.12 Satellite Image of Extratropical Storm in Northern European Region
Thunderstorm activity is also evident over Italy **(Photograph Ref Munich RE)**

The energy connected to such fronts is connected to both the jet stream aloft and the sea temperature. The most intense cyclones occur in the months October – January in the northern hemisphere. The gust wind speeds may exceed 50 – 60 m/s over sea or exposed land areas, mostly in northern regions.

Storm fronts that develop in the southern Antarctic ocean region occur over more expansive areas of ocean at low temperature, and as such tend to be predominately frontal rather that cyclonic. Impact of these southern storm fronts with wind velocities in the range indicated above, are limited to those land masses around latitude 40 degree S .

Within the western Pacific Region, the Japanese Archipelago is located in the boundary of cold air and warm air currents, and strong winds from extratropical cyclones can also be frequently observed, but wind velocities under such a situation are significantly lower than those of typhoons that also occur.

4.6Other Effects

4.6.1Instability depressions in cold air

These cyclonic mechanisms occur in late winter (mostly January – February) over the northern polar regions, are the so-called ‘*instability depressions*’. They originate in very cold (-35 to -40°) air streams flowing out from the Arctic over the warm North Atlantic Ocean. When the surface air is heated up from below, small and often very intense cyclones may form and hit countries like Iceland, Faro and Shetland Islands and Norway with similar strengths as the extratropical cyclones described above.

The resulting high intensity hurricane force winds on the right hand side of the cells reach up to 50 –60 m/s at sea and on exposed coastal locations, exposed ridges and mountains.

4.6.2Katabatic or Downslope Winds

Katabatic winds develop on the leeward side of mountains and ridges where the air mass approaching on the windward side is colder than that on the leeward side. Due to its higher density the cold air plunges down from the ridge of a mountain range into the valley below, and can develop speeds of up to 60 m/s in extreme cases. The wind velocity of these winds increases with temperature differentials and mountain or fall height. The velocity is also increased when the wind currents are in the same direction.

This type of wind characteristically frequently occurs at the same location within a valley where wind channeling effects occur, particularly in and adjacent to mountainous regions.

These winds occur frequently in close proximity to high Alpine mountain ranges and the wind velocity and frequency fluctuate highly and depend to a major extent on the topography. In the city of Mendoza in Argentina, a maximum wind gust of 43m/s was recorded on 27 May I986 over a 20 year recording period. At this location there are on average 7-8 of these ‘Zonda’ Katabatic wind events recorded each year with I – 2 of in the severe damaging wind category.

50km to the southwest of Mendoza these ‘Zonda’ wind events have been recorded on 200 days in one year at an elevation of 2000 metres as the cold air masses fall down the slopes from the Andes Mountain ranges which rise 4000 to 6000 metres in elevation.

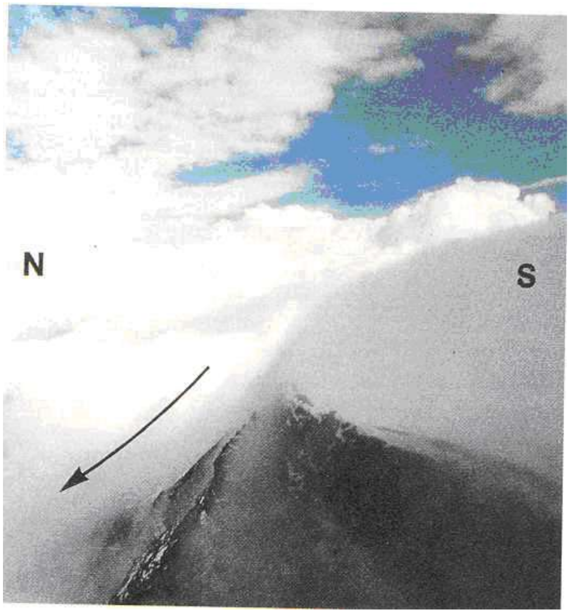


Figure 2.13 Katabatic winds developing over high mountain ridge before falling to valley below (Photograph ref Munich RE)

There are several regions of New Zealand where downslope winds are a recognised hazard. They are west of the Kaimai range; on either side of Mt. Ruapehu; west of Mt.Egmont; and east of the Southern Alps. In these areas downslope winds are recognised locally as important features of the climate, and occur with a frequency of perhaps 2 per year.
Wind speeds would normally reach to about 40 m/s and in some rare instances to 65 m/s. Evidence also exists of wake turbulence from large mountain features in association with these winds.

Along the Adriatic sea coast region katabatic winds called ‘Bora’ (Refer Figure 1) occur regularly with gust wind velocities ranging up to 50m/s. These winds occur due to large pressure changes at sea level due to cyclonic activity, following a cold air outbreak with the falling pressure from air masses of the adjoining mountain ranges that rise 3500 to 4500 m in elevation. These strong winds generally last for extended durations of up to 15 days with severe gusts periods lasting several hours.

Similar winds called ‘Sarma’ in Siberia occur adjacent to Lake Baykal with wind velocities ranging up to 45m/s for extended periods of time.

4.6.3Jet Streaks

This type of phenonema are normally very narrow high speed winds in the velocity range of >45m/s as a laminar blast of air that strikes the ground as part of the inner wind shear or shear wall of larger storm systems such as mesocyclones , hurricanes , cyclones and typhoons. Damage patterns observed has characteristic widths typically 50m wide and extend over 2 to 5km in length. Damage debris is always in the direction of the wind blast, as distinct from the swirling pattern of tornado and the elliptical pattern of a down bursts.

Generally these wind gusts have limited effect on overhead lines unless a support structure is in the line of direct attach from the wind blast.

4.6.4Rotor Effects

These effects occur under two principal conditions, either as a result of topographical effects channeling a wind gust as it impacts with the ground to cause a horizontal rotating barrel of wind that rolls away from the down draft column; or as a result of laminar wind forming horizontal rotating barrels of wind on the leeward side of mountain ridges. They were observed and reported by Fujita in his work on severe thunderstorms, and are well known and respected aviation hazards.

There is also the potential for similar horizontal eddies to occur in airport take off corridors as a result of wake turbulence from large aircraft.

While these effects are known to occur and wind velocities are in the range of 30 –50m/s there is no reported evidence of them causing damage to or failures to overhead lines.

4.7Impact of Severe wind gusts on Overhead Lines

4.7.1Subtropical Thunderstorms –Downbursts, Microbursts, and Tornadoes

Performance of overhead lines in regions impacted by subtropical thunderstorms with related high intensity wind gusts derived predominately from downbursts, microbursts, and tornadoes has been poor where these events directly impact on support structures, and the 2-3 s wind gusts exceed 45m/s.

It can be generally expected that very few older lines will have been structurally designed to resist these phenomena.

Downbursts and microbursts can generate wind gusts ranging from 40 –60m/s in most subtropical regions and when interacted with terrain effects can be expected to cause structural failures of overhead lines and general building structures. These failures will be generally characterised by transverse high wind shear failures of 3-10 consecutive structure, depending on line design details.

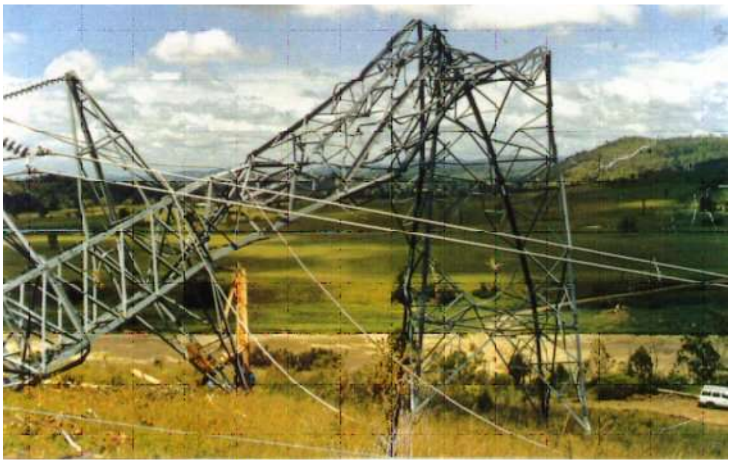


Figure 2.14 Failure of a 275kV transmission line tower due to downburst winds

Downburst winds are usually characterised by damage burst swath devastation to surrounding vegetation. Large mature trees in the direct path of such winds can be snapped off near ground.

Figure 2.15 Downburst Bust Swath damage to vegetation and Towers (Note trees snapped off above ground) – (Red Electrica –Spain)

Tornadoes classified F2 and above, impacting directly on overhead line support structure will generally cause structural failure due to the extreme turbulence and rotational wind structure. These failures will be generally characterised by distinctive torsional actions and can result in the collapse of from one to several structure depending on the line design details and the size of the wind cell.

While tornadoes in some regions appear as isolated cells associated with frontal storm activity, in other regions they are embedded within a very complex storm structure including downbursts and microbursts as shown in Figure 2.16.

Complex storm systems such as that illustrated while relatively rare, can be expected to cause widespread damage to overhead line networks.

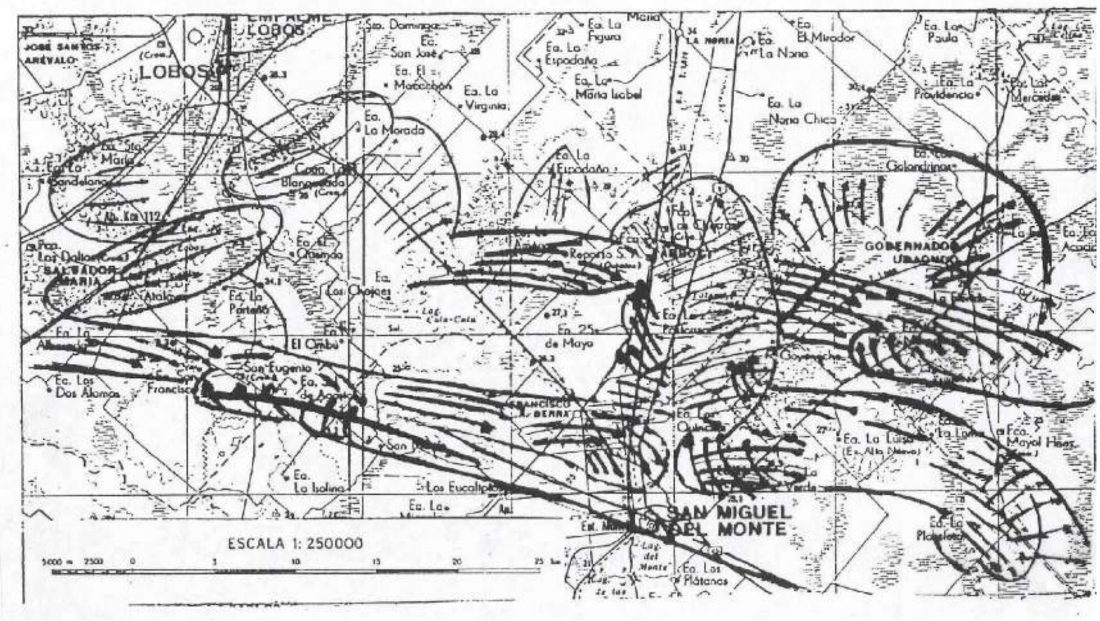


Figure 2.16 Illustration of Complex Structure of Severe Storm at San Miguel Del Monte –Argentina - Tornado (lower trace) and associated burst swathe damage patterns of downbursts. (Illustration courtesy of M.L. A. de Schwarzkopf - University of Buenos Aires)

4.7.2Tropical Cyclones, Hurricanes, and Typhoons.

Performance of distribution and sub transmission overhead lines in regions impacted by tropical cyclones can be expected to be severely effected by the direct impact of these storms. The Category 3 Cyclones / Very Strong Typhoons and Hurricanes and above can be expected to strip vegetation and building materials with buffeting winds gusts exceeding 50m/s that may last up to 12 hours. These airborne materials easily fell aerial conductors but have lesser impact on support structures.

High voltage transmission lines generally perform well due to normal design allowance for high wind.

Similar to tropical cyclones the performance of distribution and sub transmission overhead lines in regions impacted by Extratropical Storms / Winter Storm events, in the Atlantic Ocean and North Sea seaboard regions can be expected to be severely effected by the direct impact of these storms, depending on the magnitude of the wind gusts. Airborne materials and large falling trees easily fell aerial conductors but generally the direct winds have lesser impact on support structures

4.7.3Katabatic or Downslope Winds

Performance of overhead lines in regions impacted by Katabatic or Downslope winds can be expected to be severely effected by the direct impact of these wind storms. Failures of transmission lines have occurred in New Zealand and in other regions due to these high velocity winds and associated wake turbulence off mountain ranges.

Regional winds such as the Bora in the areas adjoining the Adriatic Sea can have devastating effects when wind gusts exceed design values, see Figures 2.17 and 2.18.

Figure 2.17 Failure of Tower during 'Bora' Wind Storm in Croatia - Jan 2003
(Photograph courtesy F Jakl**)**

Figure 2.18 Conductor blow out during 'Bora' Wind Storm in Croatia- Jan 2003
(Photograph courtesy F Jakl**)**

5.CURRENT INTERNATIONAL DESIGN STANDARD PROVISION FOR HIGH INTENSITY WINDS

The following information is a review of current codes and published standards that exist within each regional area and their relevance and application to the design of overhead lines.

5.1Australia

No design standards directly applicable to the Australian region for the design of overhead lines existed prior to 1999. Very loosely worded electrical industry guides did exist in an attempt to set minimum wind loading but these make no reference to the design for high intensity winds apart from a general 33% increase in wind load for cyclonic areas. Standards Australian has a General Wind Loading Code AS/NZS1170.2, however this does not make any specific reference to HIW loadings. Overhead line structural systems are excluded from coverage in part.

In 1999 the ESAA in association with Standards Australia prepared and issued ‘Guidelines for the design and maintenance of overhead distribution and transmission lines’ - HB C(b)1-1999. This document provides guidelines for a wind loading to be determined on a Relative Reliability basis for synoptic winds and provides application guidelines for HIW from microbursts and tornadoes.

For microbursts it recommends span factors >0.9 and design velocities as for synoptic winds based on 2-3 s gusts, to which is applied a regional wind direction multiplier ranging from 0.8 – 1.0.

For Tornadoes it recommends a wind on structure only from a wind velocity of 60.0m/s be applied with a regional load factor ranging from 1.33 to 1.76. No torsional effects are specified.

5.2Brazil

Within Brazil the following standards are used in relation to design of overhead lines:
ABNT NBR 5422 - Brazilian National Standards Association – ‘Design of Overhead Power Transmission Lines’ and IEC60826 - ‘Loading and Strength of Overhead Transmission Lines’. Standard recommendations for wind loading are based on either a 10 minute average or 3 s gusts.

No provision is defined for tornadoes, downbursts or microbursts. Normal design winds vary with regions and are in the range of 22 – 50 m/s in terrain roughness B at a 10m reference height. Allowance is made for topographical effects and variation in height in IEC 60826.

5.3Argentina

The following standard is used for overhead line design: National Overhead Transmission Line Standard CIRSOC – National Wind Standard CIRSOC 102. Prior to privatisation the Aqua y Energia specification ‘GC-IE -T No. 1’ was used. These standards are based on synoptic data and contain no provision for tornadoes, and downburst effects.

The GC-IE-T No. 1 specifies wind velocities varying according to region from 30 m/s where thunderstorms occur and 45m/s in the extreme South. To these a load factor of 1.6 is applied for lattice steel towers and 3.0 for concrete poles. Variation with height is provided.

5.4Venezuala

Within Venezuala, Edelca have been working based on in house design rules. In addition reference has been made to ASCE Manuals and Reports on Engineering practice N°17 “Guidelines for Electrical Transmission Line Structural Loading” and IE826 “Loading and Strength of Overhead Transmission Lines”, for specials crossing (span 1000m and towers height >70m)

No provisions are made for tornadoes or downburst effects.

5.5USA

Within the USA public safety is provided through compliance with the National Electric Safety Code C2-2002. General Practice is generally at individual utility discretion; however, many follow the ASCE Manual 74: Guidelines for Electrical transmission Line structural Loading.

Some states have legislated the NESC into law as their standard. In general it is considered the defacto minimum design requirement.

Synoptic wind velocities that normally occur, ranges from 40 m/s to 66 m/s.

Hurricane wind loads are provided in NESC and the ASCE manual addresses Hurricane, Tornado, and Topography wind regimes. No specific provisions relating to Tornadoes are made, however, the ASCE document describes the possible wind velocities and characteristics. In practice, however, these wind speeds are not used as part of the design criteria. No criteria are set for relating to Downburst or Microburst wind gusts.

Hurricane wind loads are designed for a range of wind velocities based on historical climatic data along the US coastline. Gust velocities are not added to the sustained wind velocity, defined by zones near the coast.

The United States utility industry has over 600 utility entities that set their own design criteria. General practice is to use the NESC as a minimum loading criteria which has velocity ranges of 26.5 m/s [59 mph] or 430 Pa [9psf] to 74 m/s [140 mph] or 2,389 Pa [50 psf]. Many utilities use these numbers as their maximum design criteria, while many more have their own loading agenda. Some are based on return period calculations of recorded data, many more are based on empirical perception of the utility standards engineer/committee.

Historically all wind velocities are based on the “fastest mile”. New code revisions and design guidelines are adopting the 2-3 s basis.

ASCE provides guidance for adjusting wind velocities for topographic features and anomalies, but no provision is made for predominately directional effects. NESC and ASCE provide guidance for adjusting wind velocities for height.

5.6Japan

Mechanical design of power lines in Japan should at least follow the “Regulations for Electric Power Facilities” established by Japanese law.

Depending on the significance of a facility, consideration may made for reinforcement using "Design Standard of Power Line Structures" (JEC-127 (1979)) which was enacted by the Japanese Institute of Electrical Engineers, as a base. However, the content covered by JEC-127 is the minimum guideline for overhead line design.

JEC adopts one design method for all voltage classes, and does not include an importance coefficient in order to simplify designing a great number of small-scale engineering works. Thus the values specified are conservative.

More detailed design concepts are also used for actual power line design with voltage classes of 275 kV or higher.

Provision is made for Typhoon wind gusts but no allowance is made for tornadoes, downbursts and similar effects.

For normal (not for snow accretion and strong wind)/working time, gust wind speed 17.5 m/s (dynamic wind pressure: 20kg/m^2) is taken into consideration.
Moreover, reference dynamic wind pressure is determined by area. However, areas at 1,000 m above sea level or higher are treated separately.

JEC-127 includes a dynamic wind pressure map by administrative district, which uses a return period of 50 years and 3 s gust wind speed of as a base. Gust wind speed is calculated as follows: 10 min averaged wind speed of the 50 year return period for each point is obtained and the results are multiplied and converted into gust wind speed.

- 10 min averaged wind speed: 30m/s or under, gust factor: 1.45
- 10 min averaged wind speed: 40m/s or over, gust factor: 1.35

For the typhoons, the Japan Archipelago is classified into six stages of dynamic wind pressure (240, 200, 175, 150, 125 or 100 kg/m^2).

For wind pressure combined with snow load, a wind pressure of 30 kg/m^2 equivalent to wind speed of 20 m/s is nominated.

5.7Netherlands

Design standard for overhead lines within the Netherlands is NEN-EN 50341-1 Overhead electrical lines exceeding AC 45 kV. No provision is made for any specific wind storm structure or effects.

Wind velocities used for overhead line design depend on distance from the coast, surrounding terrain and height. At 10 m height 2-3 s gusts velocities range between 29 – 41 m/s.

5.8New Zealand

Australian Standards /New Zealand Standards Wind Loading Code AS/NZS1170.2 applies to general structure design however this does not make any specific reference to HIW loadings. Overhead line structural systems are excluded from coverage in part.

Internal standards apply to the design wind loadings such as Transpower Standard TP.DL 12.01. No reference is made to High Intensity winds from tornadoes, downbursts, microbursts.

Terrain and topographical effects are considered as per the AS/NZS 1170.2. Variation of wind velocity with height above ground is considered.

5.9Belgium

The General Regulations of the Electrical Installations are given by the Belgian Royal Decree of March 1981 which has been published in the Belgian Statute Book of 29 April 1981; since 1981 several revisions have taken place

European Standard EN 50341 “Overhead electrical lines exceeding AC 45kV”
EN 50341 –1: Part 1: General requirements – Common specifications
EN 50341 –2: Part 2: Index of National Normative Aspects
EN 50341 –3: Part 3: Set of National Normative Aspects
EN 50341 –3: Part 3: National Normative Aspects for Belgium

No allowance is made for HIW effects such as tornadoes, microbursts, or downbursts.

Basic gust wind speed: 49 m/s based on 3 s gust speeds. (Height: 0 to 25 m); Dynamic basic wind pressure: 1500 N/m^2). Standard - Basic gust wind speed: 42 m/s (Height: 10m; 3s), dynamic basic wind pressure: 1054 N/m^2).

Provision is made for directional effects on new design applications following severe storms in 1990 and 1999. Variation in wind velocity is made with height above ground.

5.10Finland

Vahvavirtailmajohtomääräykset A4-93, High Voltage Overhead Line Regulations, 1993) Cenelec 50341 as alternative (+NNA/Fi for wind loads). Strong thunderstorms exist yearly but no special provisions have been made in design rules. Wind velocities and unit wind pressures provided for in normal overhead line design are as follows:

> Old standard: 700 N/m2 (h=0-30 m), factor 1,2 for h=30-50 m and 1,5 for h=50-80 m.
>
> Current Cenelec standard: 21 m/s (reference speed for terrain type II) and 25 m/s at offshore areas. These wind gusts are 3 s gust for old method and 10 min for Cenelec code.

5.11Norway

Norwegian Elecrotechnical Committee (NEK 609) “Mechanical design of overhead lines’. (Norsk Elektroteknisk Komite (NEK) 609: “Mekanisk dimensjonering av luftleidningar) has been the reference standard for design of overhead lines. This Code is now included (with minor adjustments) in: European Standard EN 50341-1: “Overhead electrical lines exceeding AC 45 kV”. The “general approach” (probabilistic approach) is recommended for Norway.

No provision is made for tornadoes and downburst wind gusts, however NEK 609 specifies that a meteorologist should be consulted in case of unusual and anticipated extreme locations.

The NEK609 refers to the new Norwegian Building Code “NS 3491-4. Prosjektering av konstruksjoner. Dimensjoerende laster. Del 4: Vindlaster” (Norwegian Standard (NS) 3491 Design of structures. Dimensioning loads. Part 4: Wind loads.” This standard gives particular descriptions on turbulence and wind gusts that are typical for Norwegian climate and topography.

The NS 3491-4 specifies 10 minute average wind speeds for each municipality in Norway. These are in the range of 22 – 32 m/s. Based on these, the given procedures may result in gust wind speeds in the order of 45 – 50 m/s. Provision is made for variation in wind velocity with height and topographical effects.

5.12Italy

Within Italy the National Normative law document IEC 11-4, May 1989 and following Amendments 1,2,3,4 (Decree of the Minister of Public Works 21 March 1988, 16 January 199, 05 August 1998). The upgrading of these standards has started (CENELEC – Overhead electrical lines exceeding AC 45kV). This European Standard was approved by CENELEC but as of January 2003 it hasn’t adopted by Italian Normative. No provision is made for Tornadoes, microbursts and downbursts wind gusts.

The wind loads on conductors, towers, crossarms, insulators, etc. are defined directly by the pressure of the wind at the following wind velocity:

Wind velocity	**Wind pressure q [daN/m^2]**		
m/s	*Flat surfaces*	*Cylindrical surfaces*	*Spherical surfaces*
26	4.71	2.82	1.18
50	17.41	10.45	4.36
65	29.43	17.66	7.36
100	69.65	41.79	17.41
130	117.71	70.63	29.43

This wind pressure includes the effects of drag coefficient and a conductor span factor. The wind pressure is not depending on altitude and temperature. The wind velocities are based on 10 minute averages and no allowance is made for directional effects or variation with height above ground.

5.13Canada

Within most states of Canada, Canadian Standard Association C22.3 No.1-01, Overhead Systems is used for the design wind loading on overhead lines. IEC 60826 is also used.

This standard does not refer to any specific wind storm structure types such as tornadoes, downbursts or microbursts. Maximum wind velocities are specified by a contour map. They vary from 90 k/hr to 140 k/hr depending on the location. These Code values are 50-year-return period values of hourly mean wind at 10 m above ground over flat open terrain of roughness category B as defined in IEC 60826.

Wind velocities and unit wind pressures applied in some states for normal overhead line design are 160 km /hr that equates to 1.2 kPa on wires and 3.2Kpa on towers (on 1.5 times the area of one face)

These wind velocities are based on 2s gusts

While not specifically considered up to now, it is proposed to design for F2 Tornadoes 67 m/s on towers only. Topographic effects are considered in some parts of Canada and the wind direction is normally taken transverse to the wires to produce the maximum wind force. Provision is made for variation of wind pressure with height.

5.14United Kingdom

Within the United Kingdom there are two distinct attitudes to wind loading standards. The distribution companies (up to 132kV) use wind and ice maps based on wind pressure steps of 190N/mm^2 to 950 N/mm2 in steps of 190N/mm2.The western and Northern Isles of Scotland include a further wind pressure of 1140 N/mm2. These maps are produced for land elevations in 100m steps up to 500m. This 1988 standard (EATS 43-40) was based on a UK meteorology survey contained in EAT 111 (1989).

Transmission lines are designed according to wind, wind and ice, and ice alone maps based on BS 8100. This is also the basis for the UK Building Code CP3. Both standards are based on 50 year return periods and no specific provisions are made for tornadoes even though they are a relatively frequent event in the Southern part of the UK.

The UK has agreed to adopt CENELEC EN 50341 code for lines > 45kV. As this covers BS8100 it provides no problem for transmission lines. However, the draft legislation EN50XXX FOR LINES <45kV will not allow the use of EATS 43-40 and will require the UK to abandon probabilistic standards at these voltages. It will be necessary to revert to deterministic modelling and then to include new factors of safety for different lines.

5.15South Africa

Within South Africa the design of overhead lines is governed by internal electricity industry standards developed by ESKOM in association with CSIR in 1990. South African design code SABS 0160 (1989) Code of Practice for general procedures is to be adopted for the Design of Buildings.

Regional basic wind velocities vary across the region and the maximum recorded wind velocity is 50 m/s. based on 2-3 s gust. Provision is made for variation in velocity with height and for topographical effects.

No specific provision is made for downburst wind gusts. While tornadoes do occur the level of risk is low and no specific provision is made.

5.16France

The French standard for the design of overhead lines is the national « arrete technique », edited by the national regulation authority (Energie electrique - conditions techniques de distribution - arrete du 17 mai 2001). This publication provides the minimum legal conditions to be respected while designing any OHL (transmission or distribution) in France.

No provisions are made with respect to downburst tornadoes and other specific wind storm events

Only the wind pressures are provided, with no reference to wind speeds or the basis of gust speed derivation.

The wind pressure depends on the location of the line. For transmission lines, 3 minimum levels of pressure on cables are allowed: 570 Pa (« normal wind zone »), 640 Pa (« strong wind zone ») and 720 Pa (« high wind pressure »). The corresponding pressures on supports and other equipment are consistent with these, taking into account the respective drag factors. Before the storms of December 1999, the pressure of 480 Pa was used for « normal wind zone ».

These pressures are applicable with « safety factors » on the resistance of equipment, depending on the type of material. The corresponding ultimate wind pressures on cables are 1008 Pa (former « normal wind zone »), 1197 Pa (new « normal wind zone »), 1344 Pa (« strong wind zone ») and 1512 Pa (« high wind pressure »).

The wind velocities corresponding to the pressures given before depend on the height, span length, type of site. Typical values of wind velocities (gust at 10 m, open field country) are 42-45 m/s (former « normal wind zone »), 45-47 m/s (new « normal wind zone »), 47-50 m/s (« strong wind zone ») and 50-53 m/s (« high wind pressure zone»).

No provision is made for topographical effects and the « arrete technique » specifies that these rules are general, and must be adapted for special lines or special sites.

Implicitly, the high pressure zone takes into account some « topographic » effects, as it concerns the shores of the sea (on a width of 2 km) and the estuaries.

No predominate directional effects are provided.

The « arrete technique » specifies that the pressures given before are applicable only for lines with average conductor heights below 30 m and supports heights below 60 m. For greater heights, a specific study must be done.

5.17Iceland

Transmission and Distribution companies in Iceland adopt their own internal rules similar to DIN – VDE 210 but now some parts of CENELEC EN 50341 and IEC 60826 have been implemented. No provision is made for tornadoes, downburst, or microburst wind types.

Wind velocities provided for in normal overhead line design are 52-60 m/s at 10 m above ground based on 2-3 s wind gusts. Consideration is given for some large scale topographical effects during design and to variation of wind pressure with height above ground.

5.18Spain

Spanish Regulation is Reglamento de Líneas Aéreas de Alta Tensión RLAT, dated 1969. In this Standard maximum wind to be considered is 120 km/h , and a Safety Factor of 1.5 must be considered. This Standard will be replaced by EN- 50341 in 2004. Red Electrica, the Spanish network operator, consider for their lines the following wind speeds:

1. Normal wind zone 140 km/h (39m/s)
2. High wind zone 160 km/h. (45 m/s)
3. Very high wind zone 180 km/h. (50.00m/s) This condition only applies in very specific areas and is dependent on local topography.

Zones are defined in a wind map of Spain. The route of every line is studied, and the wind speed of every section to be considered is determined in function of the area.

5.19China and Hong Kong

China is a very large country with a range of extreme wind types ranging from severe gales derived from synoptic systems in Siberia in the north west to typhoons along the southern coastline. There are also regions in the central region prone to down slope winds.
The national loading code GBJ-9-87 provides wind loading as set out below:

Region	Wind Storm Type	50yr Return Period Winds (m/s)
Central Mainland	Thunderstorm	39
North west and inner southern coast	Thunderstorm	44
Outer southern coast and islands, Hainan	Typhoon	52

Hong Kong	Typhoon	59
Taiwan	Typhoon	60

No terrain effects are nominated and no specific allowance is made for other HIW wind effects

5.20India

India is a large sub-continental land mass with a range of high wind zones. Thunderstorm winds predominate the inland regions with tropical cyclones in the eastern Bay of Bengal region. The Indian standard IS 875 Part 3 (1987) sets out the following details

Region	Wind Storm Type	50yr Return Period Winds (m/s)
Tripura,Mizoram, and Ladakh (Bay of Bengal)	Tropical Cyclone	52
Coastal regions of TamilNadu,Andra Pradesh, Orissa,Assam West Bengal	Tropical Cyclone	44
Northern India , Delhi, central Tamil,Nadu	Thunderstorm	44
Coastal Strip on Arabian Sea	Thunderstorm	39
Southern India	Thunderstorm	39

No terrain effects are nominated and no specific allowance is made for other HIW wind effects

5.21Philippines

The Philippine islands are subjected predominately to the effect of typhoons off the Pacific Ocean and the South China Sea. The National Structural Code of the Philippines sets out the following:

Region	Wind Storm Type	50yr Return Period Winds (m/s)
Eastern Luzon	Typhoon	60
Remainder of Philippines	Typhoon	52
Mindanoa	Typhoon	44

No terrain effects are nominated and no specific allowance is made for other HIW wind effects

5.22Ukraine

The following normative standards of former Soviet Union are used in Ukraine for overhead transmission line design:

1. Electric Installation Code. USSR. Moscow. 1987. Part 2.5 – Overhead lines by voltage more than 1 kV.

For other structures:

2. SNiP 2.01.07-85. Loads and influences. USSR, Moscow. 1988. (SNiP – Building Norms and Rules).

The recommendations for wind loading on overhead lines are based on synoptic data with 2 minute average winds. For other structures recommendations are based on 10 minute average winds. These standards have no provisions for tornadoes, downbursts, or microbursts wind gusts nor for topographical effects.

The dynamic component of wind loading on different types of towers is in the range of 0,5 – 0.65 to static pressure or defines by means of dynamic calculation (SNiP 2.01.07-85).

The return period of wind loading (pressure) for overhead lines for voltages 500-750 kV is 15 years, 6-330 kV is 10 years, and 3-0.4 kV is 5 years.

Overloading coefficients (factors) for wind loading (pressure) on towers and wires without icing is 1.2, and for wind pressure on wires with ice is 1.4.

Coefficient on wind pressure variation with height is defined as:

Height above ground (m)	1-15	20	40	60	100	200	350 and more
Coefficient	1	1.25	1.55	1.75	2.1	2.6	3.1

Wind speeds for overhead line design:

Region	Wind speed for return period (m/s)		
	5 years	10 years	15 years
Standard territory	21-27	25-29	30
Mountainous and coastal territories	27-30	32-36	36

6.CURRENT DESIGN PRACTICES RELATING TO HIGH INTENSITY WIND LOADS

The following information is a review current practices being applied within each regional area in relation to wind storm types and wind velocities currently being applied to the design of new overhead lines.

6.1Australia

Varying practices are currently applied around the Australian region based on regional experience and an acceptance of risk from extreme wind events.

Designs for overhead lines generally comply with the ESAA (Electricity Supply Association of Australia) Guidelines for Design of Overhead Lines HB C(b)1 – 1999.

Each year there are on average 1-2 major structural failure events of transmission lines somewhere in Australia, and several reports of significant wind storm damage to overhead electricity distribution networks in towns and cities. Very few distribution lines are designed for high intensity winds, and it is only on lines designed and constructed in the last 10 years that any consideration of HIW has been made.

Measures applied have been to design for HIW of 60 –70m/s wind on structures; consideration of ‘patch wind loading’ on tall structures (greater than 30 m); use of higher span factors for microbursts (>0.9); and closer attention to fetch exposure on steep ridges and escarpment.

New initiatives now being undertaken in some states are risk modelling studies of the impact of HIW on existing lines (not specifically designed for HIW) with the intent to provide a higher level of reliability and security for more critical feeders.

6.2Brazil

General practice is to design overhead transmission lines based on the recommendations of IEC 60826

Practices vary slightly between network owners and different regions.

Ultimate wind velocity of 33.9 m/s is used based on a I0 m reference height with a return period of I50 years. In other areas either a I0 min average wind of 35 m/s at I0m height and a return period of 250 years or a 3 s gust of 50 m/s at I0 m height and a return period of 250 years is used.

Maximum synoptic wind of 20 m/s is reported to occur in inland regions. No allowance is made for tornadoes and downbursts or other effects, but these effects are being considered in future reviews of national standards.

Experience has shown that on average it can be expected that 2-4 transmission line failure events occur each year, due to the effects of high wind storms.

Severe tornadoes have caused transmission line in the southern regional area towards the border with Argentina. These severe events are generated from frontal systems moving from the Pacific Ocean across the Andes in a westerly air flow over Argentina and southern Brazil.

6.3Argentina

There is no single standard or code in universal use in Argentina. Specifications for new lines vary depending on utility and importance of the line, and often refer to more than one set of codes. A National Standard exists for wind loading determination in general, but it is seldom applied to transmission lines. There is a National code for transmission lines which has had little acceptance and is practically never applied.

For lines under 500 kV tender documents usually refer to pre-privatization utility Agua y Energía's specification “GC-IE-T No.1”, which was largely based on German VDE 210 (including loading hypothesis) and established its own wind zoning and velocities.

For 500 kV lines a different set of wind velocities has been in use for over 20 years without much change.

For velocity/pressure conversion IEC 826 is occasionally referenced.

A new code is in the making in an attempt to update and create uniformity of criteria.

Synoptic scale winds with a one year return period may reach 30~35 m/s in the South (Patagonia), and 25~30 m/s in most of the rest of the country where supercells also occur and where most transmission lines are located.

On 500 kV lines 50 m/s on spans and 55.6 m/s on supports. Typically IEC-826 or similar shape factors are applied, resulting in pressures of 1530 N/m² on conductors and approximately 6050 N/m² on (net front face of latticed steel) supports.

On other lines wind velocity (equivalent ultimate) varies according to region, from 39 to 50 m/s where thunderstorms occur, and 56 m/s in the extreme South. As span factor, only 60% of what exceeds 200 m is considered, shape factor for conductor is 1, for shield wire 1.2 and for (net front face of latticed steel) supports 2.8, which results in typical pressures (300m span) of 800, 1280 and 1670 N/m² respectively on conductors, 960, 1540 and 2000 N/m² on shield wires, and 2560, 4150 and 5400 N/m² on (net front face of latticed steel) supports.

On average approximately one failure event per year per 1000km of line can be expected. The maximum estimated velocity has been 100m/s during F4 tornados, which are too scarce to determine a return period.

Return period for F3 tornados is one every 3 to 5 years. Few of these hit transmission lines (last F3 hit was on December 26th, 2001, on a 500kV line).

Only on 500 kV lines is a distinction made between synoptic winds and severe storms, but for design purposes no distinction is made between tornado and downburst/microburst.

6.4Venezuela

Designs are based on EDELCA's in house rules, ASCE practice manual N° 17, and IEC 60826.

Designs are based on an ultimate wind velocity of 15 m/s only for tower design. The maximum wind velocity (5 minute mean wind) for conductors and overhead ground wire and the maximum wind gust velocity (5 s gust wind) is used for tower and insulators. Allowance is made for topographical effects and for variation of wind pressures with height.

The maximum wind velocity is estimated to be 36 m/s at 10 m above ground, and 100 years return period throughout Venezuela.

No allowance is made for high intensity wind gust effects from tornadoes, downbursts and other effects.

6.5USA

The United States utility industry has over 600 utility entities that set their own design criteria. General practice is to use the NESC as minimum loading criteria which have velocity ranges of 26.5 m/s or 430 Pa to 74 m/s or 2,389 Pa. Many utilities use these numbers as their maximum design criteria, while many more have their own loading agenda. Some are based on return period calculations of recorded data, many more are based on empirical perception of the utility standards engineer/committee.

Standard US practice does not think in terms of a synoptic event. ASCE provides guidance for adjusting wind velocities for topographic features and anomalies, and both the NESC and ASCE provide guidance for adjusting wind velocities for height.

High intensity wind storm gusts are experienced in coastal regions under hurricane conditions.

There are many line failures during a given year across the more than 600 utilities. However, the perception among utilities is that the failure rate is acceptable. Generically speaking, wind speeds in excess of 115 m/s have been recorded in events associated with severe hurricane eye walls and the tornadoes they spin off.

No utilities have a design loading case that specifically addresses tornadoes, downbursts or microbursts. No provisions are generally made for variation of wind velocity or pressure with height.

Utilities with coastal installations use hurricane wind velocities for their design. With only a few differences are the velocities different than the extreme numbers previously related.

Coastal wind maps provide zone reference to wind velocity for hurricane design. Ultimate design wind velocity used in design for Hurricanes ranges from 71.5 to 74 m/s depending on location and distance from sea coast.

6.6Japan

Mechanical design of power lines in Japan should at least follow the “Regulations for Electric Power Facilities” established by Japanese law.

Depending on the significance of a facility, we consider reinforcement using "Design Standard of Power Line Structures" (JEC-127 (1979)) which was enacted by the Japanese Institute of Electrical Engineers, as a base. However, the content covered by JEC-127 is the minimum guideline on power line design. More detailed design concepts are used for actual power line design with voltage classes of 275 kV or higher.

For normal design (not for snow accretion and strong wind)/working time, a gust wind speed of 17.5 m/s (dynamic wind pressure: 20 kg/m^2) is taken into consideration.

Moreover, reference dynamic wind pressure is determined by area. However, areas at 1,000 m above sea level or higher are treated separately.

For the typhoons, the Japan Archipelago is classified into six stages of dynamic wind pressure (240, 200, 175, 150, 125 or 100 kg/m^2).

The critical wind speed for dynamic wind pressure is shown below.

Table. 1 Critical wind speed for typhoons

Assumed load condition	Dynamic wind pressure (kg/m^2)	Critical wind speed (m/s)	
		10 min	Gust
I	240	46.8	63.2
II	200	42.7	57.7
III	175	40.0	54.0
IV	150	35.9	50.0
V	125	31.8	45.6
VI	100	28.1	40.8

Allowance is made for topographical effects and variation of wind pressure with height.

When a large-sized and high intensity typhoon hits, extremely strong wind with speeds of 70m/s or more have been experienced in some areas in Japan.

There have been some tower collapse accidents in Japan; 13 towers collapsed in 1999 and 36 towers collapsed 1992 due to high winds.

In September 1999, an exceptionally high intensity typhoon, Typhoon No. 9918, hit Japan and brought serious damage (13 steel towers collapsed). The wind observations in the case are as follows:

Table 2 Wind observations for Typhoon No. 9918 (1999) reported by the Japan Meteorological Agency.

Meteorological station	Wind direction	Max gust wind speed (m/s)	Max average wind speed (m/s)	Altitude of observatory (m)	Height of observation tower (m)
Ushibuka	ENE	66.2	27.7	3.0	20.6
Nobeoka	SSE	51.9	18.5	19.0	13.2
Hita	S	45.0	16.5	83.0	10.6

These wind speed values are taken as measured raw values.

The return period of the above wind speeds may equivalently represent more than 200 years. While this typhoon was very strong, the scale and range of the strong wind was narrow. Thus at the site where the steel towers collapsed, it is presumed that gust wind velocities were much larger than the values in Table 2.

6.7Netherlands

Design standard used for overhead lines within the Netherlands is NEN-EN 50341-1 Overhead electrical lines exceeding AC 45 kV. No provision is made for any specific windstorm structure or effects.

Wind velocities used for overhead line design depend on distance from the coast, surrounding terrain and height. At 10 m height, 2-3 s gusts velocities range between 29 – 41 m/s.

The 41 m/s design wind speed is regarded as the wind speed for a 50 year return period. The highest recorded wind speed in the last 100 years is about 45 m/s (gust wind) Operational experience indicates that about 1 tower in 100 years can be expected to fail during wind storms for the whole country

6.8New Zealand

Wind velocities in accordance with Australian Standards /New Zealand Standards Wind Loading Code AS/NZS1170.2 have been applied to the design of overhead lines. It also applies to general structure design, however no special allowance is made for HIW loadings but variations in velocity is made with height above ground. Maximum wind velocities recorded range up to 70m/s with most common regional values in the range of 40 –50 m/s.

Records indicate some 44 transmission tower structures have failed in the last 54 years due to 13 major wind storm events.

6.9Belgium

Wind velocities as set out in 3.9 above are generally applied.

High intensity wind gusts rarely exceed 40m/s and the indicative frequency is 1/5 years
The maximum recorded wind gust is 46.9 m/s (3s, 10m) on the airfield of Beauvechain on 25.01.1990 – Return period = 221 years.

No provision is made in designs for tornadoes, however nearly 3.6 tornadoes (mean value) are registered each year in Belgium. The maximum wind speed is limited to approximately 40 m/s.

6.10Finland

Wind velocities used in design are generally as set out in 3.10 above

The maximum wind velocity recorded is 45 m/s at 100m height (measured in a radio mast), 10 min mean value. It is understood to be in winter (December-January) during 1998. Standard wind load pattern and height variation is used in all cases.

Strong and sudden thunderstorms do occur during winter months. These result in very narrow damage patterns in forest areas (100-200 m) but extending over a large distance (100-200 km). Very seldom is damage caused to overhead line structures and hence no need has been seen to investigate wind velocities further.

6.11Norway

Currently NEK 609 (as referred to in 3.11above) is applied, however in the future "*CENELEC (2002) EN 50341 -Overhead electric lines exceeding AC 45kV*" will be used. Normal synoptic wind velocities based on a 10 min mean wind speeds in the range of 20 – 25 m/s often occurs along the coast and in the mountains. In more sheltered, and more populated areas 10 – 15 m/s may be expected every year.

Ultimate design wind velocities in the range of 25 – 35 m/s are frequently used for design. In exposed areas 40 – 55 m/s may be used. The new Norwegian Wind Code NS3491-4 includes topographical effects. For geographical areas not covered by the Code it is recommended to consult an experienced meteorologist.

The NEK609 includes no wind variations below 20 m above ground, for simplicity reasons. Above this level variations according to NS3491-4 are recommended.

High intensity wind storms with velocities >40m/s are regularly experienced , however the frequency of overhead line failures due to high intensity winds remains very low (most failures are due to combinations of wind and ice).

The highest wind speed with return period 50 years, 10 m above ground, for an official weather station in Norway is 63 m/s (Hekkingen light-house). This station had a very short observation period which was "artificially" elongated by coupling to other stations. Many other stations along the western coast of Norway have similar values in the range of 55 – 60 m/s. There is no recorded incidence of tornadoes or significant wind storm downdraft effects.

Extratropical Cyclonic wind gusts are generally predominating extreme winds in Norway. Extreme wind statistics from weather stations in the country are considered in the NS3491-4.

6.12Italy

The **IEC 11-4**, May 1989 standard and Amendments 1,2,3,4 are used in relation to the design wind loading for overhead lines.

Synoptic wind velocities range from 22 to 33 m/s depending on location. Ultimate wind velocity and ultimate unit wind pressure used in design are as per table in 3.12 above. No provisions are made for topographic effects or variation in wind velocity / pressure with height above ground.

There are no records of high intensity wind storms with gust velocities >40m/s or the occurrence of tornadoes, downbursts, or microbursts.

6.13Canada

Within Canada most common practice is to use the Canadian Standard CSA C22.3 No. 1 “Overhead Systems” and internal design standard practices.

Maximum synoptic wind velocities that normally that occur have hourly mean wind speed of 31m/s based on 50 year return period.

This results in an ultimate wind velocity of 45m/s 2 s gust wind based on 50 year return period and ultimate unit wind pressure of 1.2 kPa wind pressure on wires.

No provisions made for topographic effects, but allowance is made for variation in wind velocity / pressure with height above ground.

Once every 3 or 4 years failures of a few towers (less than 7) occur due to Tornadoes but the line failure is usually contained.

The maximum wind velocity recorded for the region has been 45 m/s gust wind speed and 31 m/s hourly mean wind speed at a 10 m reference height based on 50 year return period

No provision has been made in the past for the design for tornado winds, however it is proposed to now consider F2 Tornadoes with wind velocity of 67m/s on towers only. Allowance will be made for torsional wind loading.

On river crossing towers (height above 60 m) allowance is made for varying horizontal wind shear effects with height. No allowance is made for downburst and microburst wind gusts.

6.14United Kingdom

Current practice in the UK on transmission line structures is that based on BS 8100 and this should not change under CENELEC EN 50341**.**

The distribution networks is based on existing standards BS 1320 (1947) revised to metric standards in ES143–10. These allow small conductors to be treated for one value of wind pressure only (760N/mm2) and no ice. For conductors >35mm2 copper equivalent the standard uses 380N/mm2 wind pressure and 9.5mm radial ice. No provision is made for tornadoes, microbursts or downburst wind gusts or for height variations above ground.

Corresponding wind loads on Structures are determined from BS8100.

At distribution levels the failures of overhead lines due to high wind storms represents about 4% of outages on the networks. This means around 0.2 faults/100 km /year, due mostly from trees being blown onto lines. At transmission levels the failures due to high wind are negligible.

The most recent major incident in recent years was a storm in 1987 which affected south east England with speeds gusting to 54m/s. Twice in the four years prior to 2003, wind storms gusting to 49m/s have occurred, but faults only due to trees falling on distribution lines.

6.15South Africa

Code of practice adopted is based on industry standards developed by ESKOM based on work completed by CSIR.

The country is divided into different regions with predominate windstorm types related to either inland generated severe thunderstorms or to coastal frontal systems. On average 10 severe thunderstorms occur in the inland region each year. Down bursts and tornadoes are also recorded in this same region. Maximum wind gusts generated range between 30 and 50m/s.

Coastal wind frontal systems in the southern region generate wind gusts between 25 and 50m/s during between 5 and 10 events each year. Extreme events are normally associated with failures of overhead lines.

6.16France

Based on the legal rules specified by the « arrete technique »and as referred to in 3.16 above, an internal code of practice called « lines Specifications » is used by RTE (French transmission grid operator).

The 50 years return period wind speed (gust at 10 m, open field country) range from 36 to 50 m/s, depending on location.

The ultimate wind velocity and ultimate unit wind pressure used are as set out in 3.16
No specific application of topographical effects is applied and specific studies are done for average conductor heights over 30 m and supports over 60 m.

Wind speeds above 50 m/s were measured inland during the storms of 1999.

Based on the past 20 years feedback:

- the average frequency of overhead line damages due to wind in France is 10/year (damage = need to repair an equipment)
- the events are mainly localized : 78% affect only 1 line
- the return period of a wind damage <u>per line</u> is about 300 years

NB: transmission lines in France ≈ 5500 lines / 100 000 km.

During the storm of October 1987, a wind speed reaching 60 km/h was recorded in Normandy on the shore and the local return period was estimated at 450 years.

Wind speeds reaching 50.0 m/s were measured inland during the storms of 1999, which correspond to a return period between 500 and 1000 years depending on localization.

No provision is made for downbursts, tornadoes and other high wind effects.

6.17Iceland

Transmission and Distribution companies in Iceland normally use their own internal rules similar to DIN – VDE 210, but now some parts of CENELEC EN 50341 and IEC 60826. No provision is made for tornadoes, downburst, or microburst wind types.

Normal maximum synoptic wind velocities based on 50yr return period of 10min average winds is in the range of 35 –54 m/s but more normally 37-38 m/s.

Maximum wind gusts (without ice) for 2-3 s gust is 52 –60 m/s at 10m height. This usually has a load factor of 1.5 applied. The maximum estimated wind gust range between 60 –80 m/s at elevated mountain sites during severe storms.

Failures of transmission lines in Iceland normally occur in association with ice. Ie Wind velocity 37m/s with ice diameter of 7 –10cm. Major failure event occur every 10 years or so on average.

6.18Spain

Refer Section 3.18 No provision is made for tornadoes, downbursts or microburst wind types. Failures of transmission lines have occurred in association with winds associated with subtropical thunderstorm activity and ice storms in other parts of the country. Recent failures due to high winds were from gust velocities estimated to exceed 50m/s.

6.19China and Hong Kong

No details are available on the standards applied for neither the design of overhead lines nor the performance of overhead lines under high winds.

6.20India

No details are available on the standards applied for neither the design of overhead lines nor the performance of overhead lines under high winds.

6.21Philippines

No details are available on the standards applied for neither the design of overhead lines nor the performance of overhead lines under high winds.

6.22Ukraine

Current practice for the design of overhead lines is to use wind loading estimation based on the Draft of Ukrainian Building Code. B.1.2.-…-200 Loads and influences. (This is based on 10 minute average winds; basis return period 50 years; with consideration for topographical effect calculation).

This standard has no provisions for tornadoes, downbursts and microbursts.

Wind speeds for return period 50 years, are between 29 -34.5 m/s for eastern and southern parts of Ukraine. For other areas in the region, values of 23-29 m/s (2 – minute average) apply.

The ultimate wind speed is 36 m/s, for 50 years and 2 minute average wind. The maximum wind velocity that was recorded in Ukraine was 38 m/s on 10 m above ground, for 10 minute average wind.

Reports on failures of overhead lines, with associated failures of trees, building roof damage, testified that wind speed in some cases reached more than 45 m/s. On average there are 1-2 failures per year on overhead lines of 220 kV and higher and more than 10 failures per year on lines 6 – 110 kV (this information is very approximate)

Tornadoes are observed on Ukrainian territory practically each year.

7.DESIGN RELATED CHARACTERISTICS FOR HIGH INTENSITY WINDS

In many countries, high intensity wind gusts exceeding 45 m/s are not considered when designing overhead lines, either because they do not exist, or they may be considered to have a low probability of occurrence, and as such present an acceptable risk to the network owner.

In other areas, they are more frequently occurring seasonal events that again most probably are not generally considered in design and have been assessed to provide an acceptable risk.

With the deregulation of electricity industry and open market trading in some regional areas and countries, the importance of maintaining higher availability of more important electricity networks may require a closer consideration be made to design provisions and to operational performance of existing and new overhead line works.

Based on recent research; investigation of some major overhead line failure events and current understanding of high intensity wind gust phenomena that can, and have caused severe damage to overhead lines around the world; information has been provided that will assist in formulating a reasonable basis for design.

It must be understood that these characteristics and frequency of occurrence will vary slightly from country to country. In applying this information the designer must take into consideration the probability of occurrence and the related risk and then make a value judgement as to the suitability of application.

Experience in some sub-tropical countries for example, has demonstrated that increased allowance in design loadings to provide for HIW gusts, has an associated incremental cost of construction of 2 –5% in order to provide for the increased HIW loading, and associated higher security against failure from wind overload. Adoption of a higher level of wind velocity and associated parameters, will not however, provide a guarantee against failure, but rather a reduction in the probability of failure.

The following Table 5.1 provides a summary of the wind gust phenomena characteristics and guidance on the application to design of overhead lines.

Use of this information will assist in mitigating the potential extent of damage to overhead lines due to high intensity wind gusts and at the same time provide a balance of acceptable cost benefits for design.

Table 5.1 Characteristics of High Intensity Wind Storm Phenomena and Design Guidelines

Wind Storm Phenomena Type	Classification	Gust Wind Velocity Range m/s (2-3 s gust)	Potential Wind Gust Width	Predominate Regional Area	Frequency of Occurrence Refer Note 5	Notes on Application to Design
Gust Front		45 - 50	10,000m	All regions	1/50	Normal Design and Span factor
Sub Tropical Thunderstorm				Subtropical Regions Refer Figure 1		
- Down Bursts		50 - 70	1,000m		1/50	Complete span over 1000m and >15m structure (Span factor 1.0) Refer Note 2
- Microbursts		70 - 80	100m		1/1000	
- Embedded tornado	F2	45 - 70	400m		1/1000	Provide for torsional loading and wind from any direction on structure only
	F3	70 - 95	300m		1/1000	Note 1
	F4	95 - 120	200m		1/4000	Note 1
	F5	>120	100m		1/10000	Note 1
Tornado				Severe Tornado Regions		
	F2	45 - 70	1000m		1/5	Provide for torsional loading and wind from any direction on structure only Refer Note 4
	F3	70 - 95	400m		1/1000	Note 1
	F4	95 - 120	200m		1/4000	Note 1
	F5	>120	200m		1/10000	Note 1
Cyclone / Hurricane / Typhoon				Subtropical Regions Refer Figure 1		
	2	35 - 47	20 –50 km		1/10	
	3	48 - 63	20 –50 km		1/100	Note 3
	4	64 - 78	20 –50 km		1/4000	Note 1
	5	>78	20 –50 km		1/10000	Note 1
Extratropical /Winter Storm		50 - 60	500 –3000m	Sea coast and land masses in close proximity to polar oceans	1/1000	Note 3
Instability Depression		50- 60		Northern polar sea coastal regions	1/50	Note 3
Katabatic /Down Slope Winds		40 - 70	1000m	Refer Figure 1	1/100	Refer local conditions

Note 1. Design consideration for wind velocities in this range is low probability and not considered viable for normal security overhead lines

Note 2. Design for Microburst and Macroburst winds should consider the effects of surface roughness on the wind approach to the line. This has the effect of introducing high wind shears above ground that may be more onerous on the structure design. It is recommended that no wind be applied below 15m and the full wind above this level. The wind gust will also engulf the complete wind span of conductor in this case and no reduction in span factor should be considered. Winds gusts must be considered from any direction.

Note 3. Cyclonic wind storms have a pronounced gustiness at maximum wind velocity that most likely will be sustained over a period of several hours. Spatial effects of this is to effectively provide some relief in wind span. A Span factor of 0.7 is recommended.

Note 4. Tornadoes generate high velocity swirling / rotational winds. Towers expected to withstand F2 tornadoes should be designed for torsional winds applied to the structure superstructure. Wind gusts >F2 do occur but are rare events.

Note 5. Frequencies provided are indicative values and may vary from region to region (Refer local Meteorology Office)

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