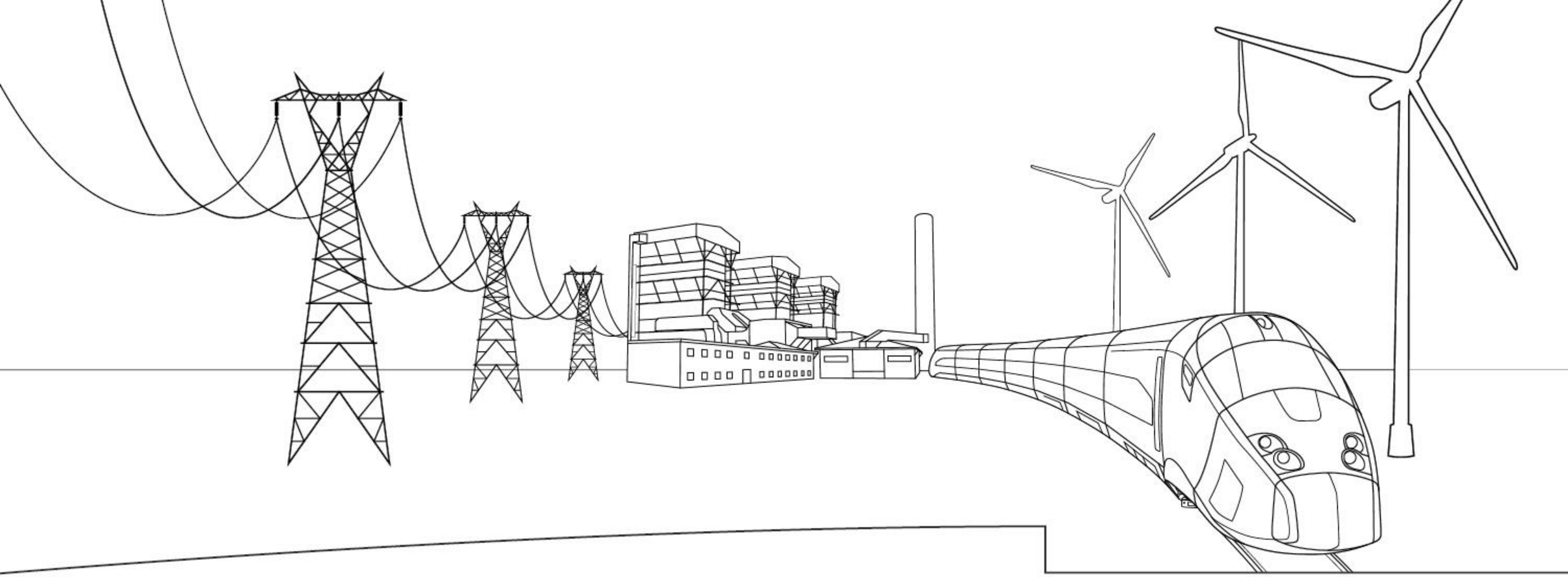


Extreme Wind in the Asia Pacific:

A guessing game or an exact science?

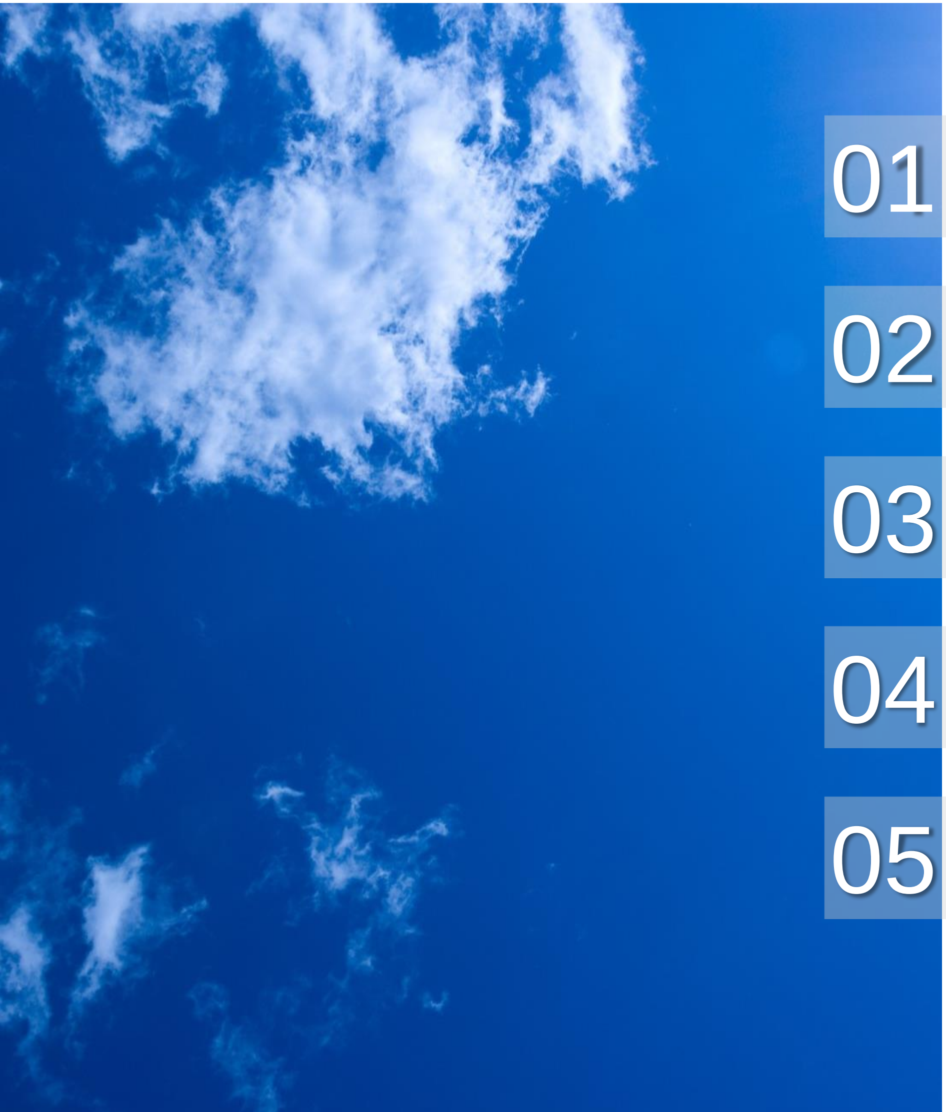
Megan Briggs

April 2014

ALSTOM
Shaping the future

Agenda

Agenda



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IEC standard 61400-1 Ed 3: Wind Turbine Class

Site specific assessment :

- Turbulence
- Shear (0.2)
- Air density (1.225kg/m^3)
- Inflow angle (±8˚)

- V_{ref} = reference 10 min wind speed average
- V_{ave} = mean wind speed (weibull distribution)

  Where: $V_{ave} = 0,2\ V_{ref}$
- V_{e50} = extreme wind (3-sec) with a recurrence of 50 years

  Where $$V_{e50}(z) = 1,4\, V_{ref} \left(z / z_{hub} \right)^{0,11}$$

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values
A	I_{ref} (-)	0,16			specified
B	I_{ref} (-)	0,14			by the
C	I_{ref} (-)	0,12			designer

Source: 61400-1 IEC:2005

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Extreme Wind: How

Three types of weather systems:

- Severe thunderstorm
- Supercell
- Mesoscale convective systems (Cyclonic)

Extreme winds in Australia and NZ: Severe thunderstorm

- Warm moist air rises (updraft)
- Moist air cools & condenses into droplets (clouds)
- Droplets enlarge & fall (downdrafts)
- Downdrafts hit ground & spread strong horizontal winds
- Topographical speedups & channeling

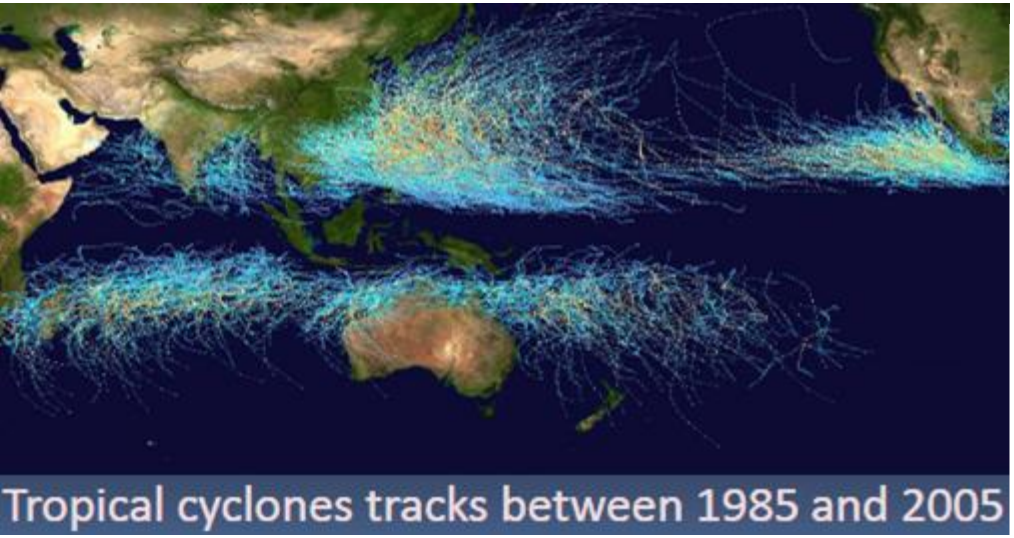
Extreme Winds in Cyclonic Regions

Extreme winds highly influenced by the occurrence of cyclones and typhoons (TC)

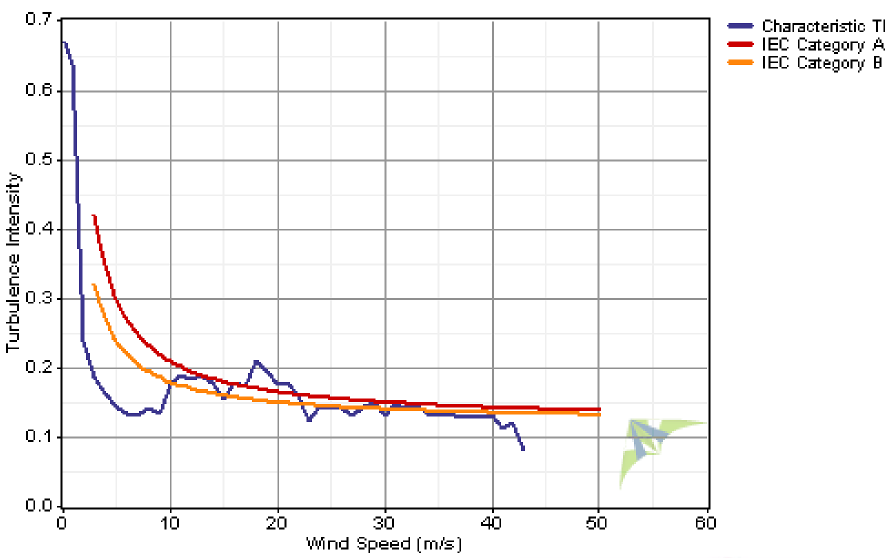
- Circulating low pressure wind systems

Clockwise Southern Hemisphere, counter clockwise Northern Hemisphere

- Condensation of water vapour supplied by warm sea surface (needs 26˚C)
- Two wind speed peaks, one for each of the two passages of the eyewall
- Wind direction changes 180˚
- Turbulence high between 15 - 25 m/s, however decreases above 30 m/s



Source: NOAA



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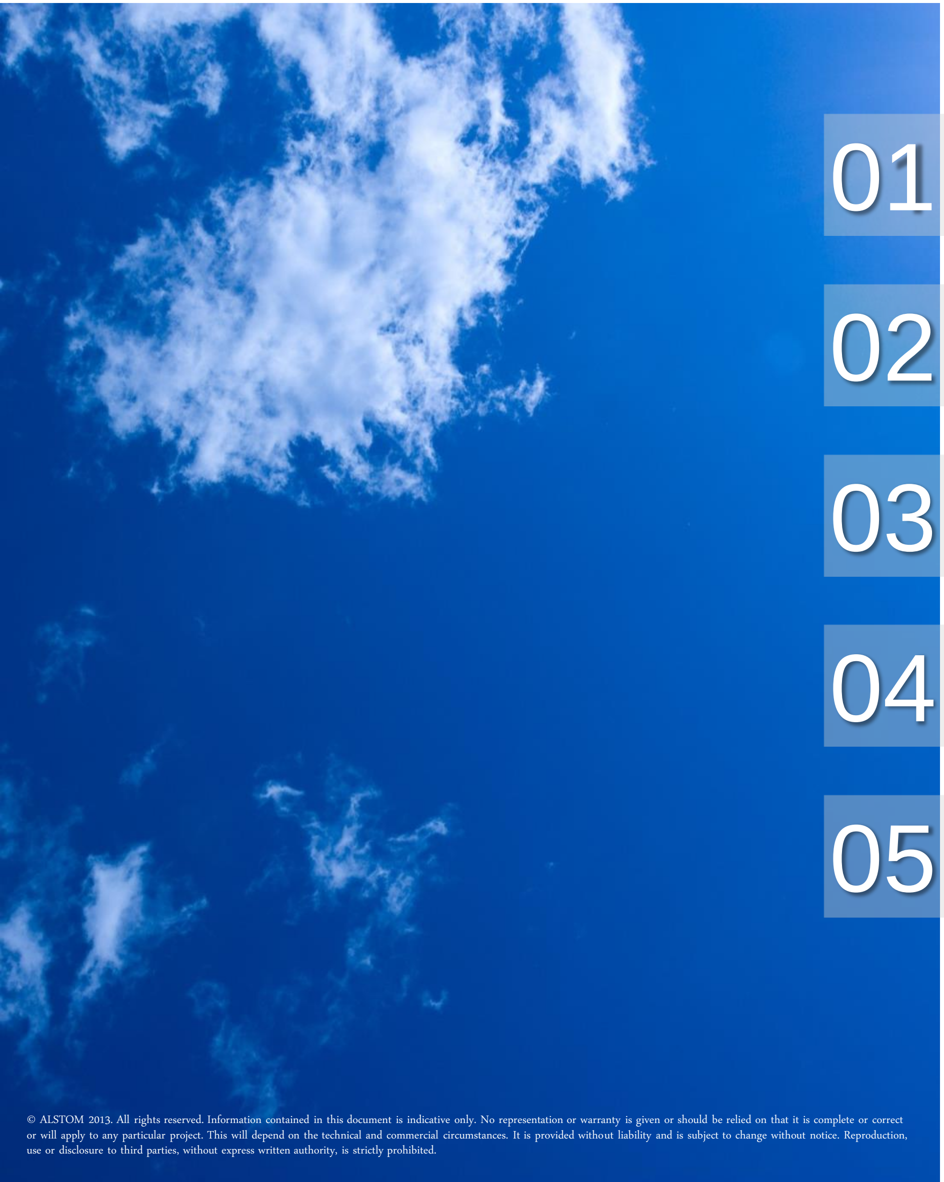

01 Introduction to Extreme Wind

02 **Conventional Methods**

03 Extreme Winds in Aus/NZ

04 Extreme Winds in Northern Pacific

05 Turbine Loads & Alstom solutions

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Extreme Wind – methodology

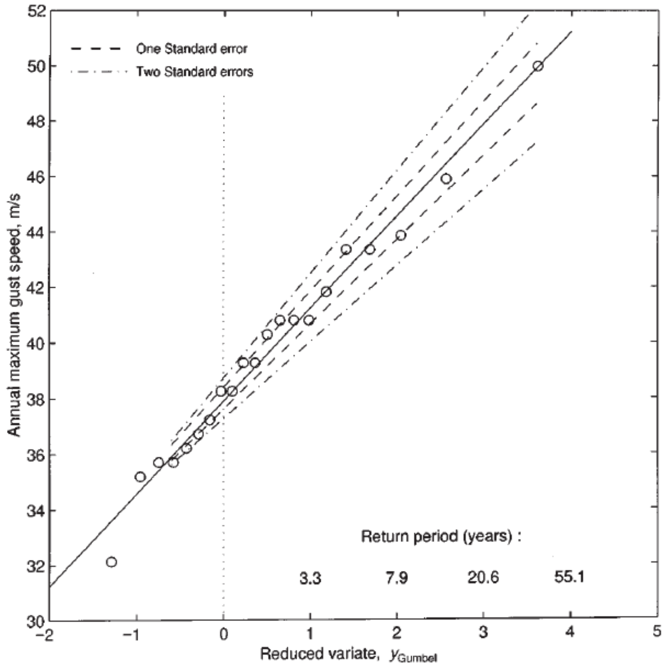
IEC standard 61400-1 does not prescribe any preferred method for calculating V_{ref}

Most common:

- National Building Codes
- Gumbel
- Method of Independent Storms (MIS) or Peak Over Threshold (POT)
- Periodic Maxima
- Mesoscale virtual long term data: ie MERRA/ERA/CFSR

Extreme Winds – Gumbel Distribution

- Annual maxima fit to a gumbel distribution
- 50 years of data is ideal!
- At least 20 years for reliability!
- 10 years as a minimum!



Source: Meteorol. Appl. 6, 119-132 (1999)

Pros

- Safe to assume independence from extremes

Cons

- Requires at least 10 - 20 years of data!

We need to be able to extract more independent events from short term datasets

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Extreme Winds - MIS

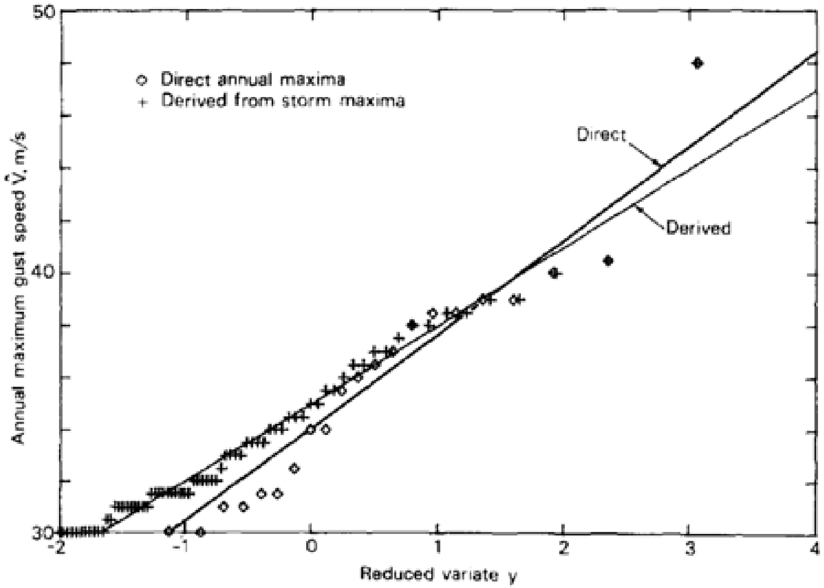
- Lull threshold is defined
- Storm events are identified between “lulls”
- Maximum wind selected from each storm

Pros

- More data points for gumbel distribution

Cons

- Requires 7 years for reliability (Cook 1985)
- Decision needs to be made on lull threshold
- Cannot guarantee independence



Journal of Wind Engineering and Industrial Aerodynamics, 9 (1982) 295—323
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

TOWARDS BETTER ESTIMATION OF EXTREME WINDS*

N.J. COOK
Building Research Station, Garston, Watford, Herts. WD2 7JR (Gt. Britain)

(Received June 1, 1981)

Methods are significantly influenced by the highest measured wind speed

Neither sufficiently capture the Pacific typhoon climate

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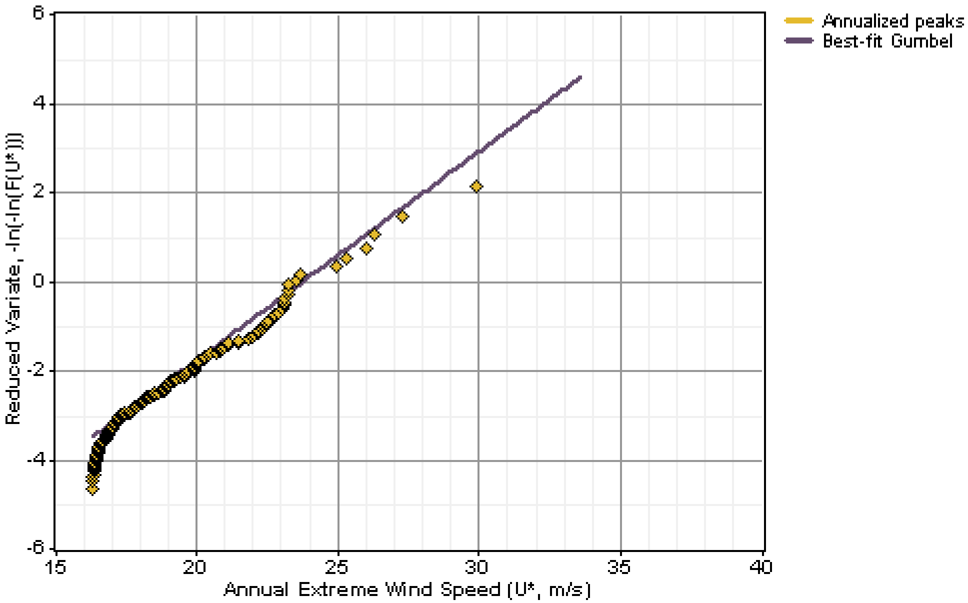
Extreme Wind: Australia Example

7 years of data measurement

MIS considered “reliable”

At 89m (ECO122 hub height):

- Max meas. = 29.7 m/s
- V_{ref} = 32.1 m/s
- *V_{e50} = 45 m/s*
- Class III



What about the AS/NZS1170.2:2002 Wind Loading Standard…

AS/NZS1170.2:2002 Wind Loading Standard

2.2 SITE WIND SPEED

The site wind speeds ($V_{sit,\beta}$) defined for the 8 cardinal directions (β) at the reference height (z) above ground (see Figure 2.1) shall be as follows:

$$V_{sit,\beta} = V_R M_d (M_{z,cat} M_s M_t) \quad \ldots 2.2$$

Multipliers:

1. Regional 3-sec gust wind speed
2. Wind direction and Shielding
    - assume = 1 (conservative)
3. Terrain to structure height multiplier (shear)
    - Based on Terrain Category (generally 1 or 2)
    - Hub Height = 89m (ECO122)
4. Topographic speedup

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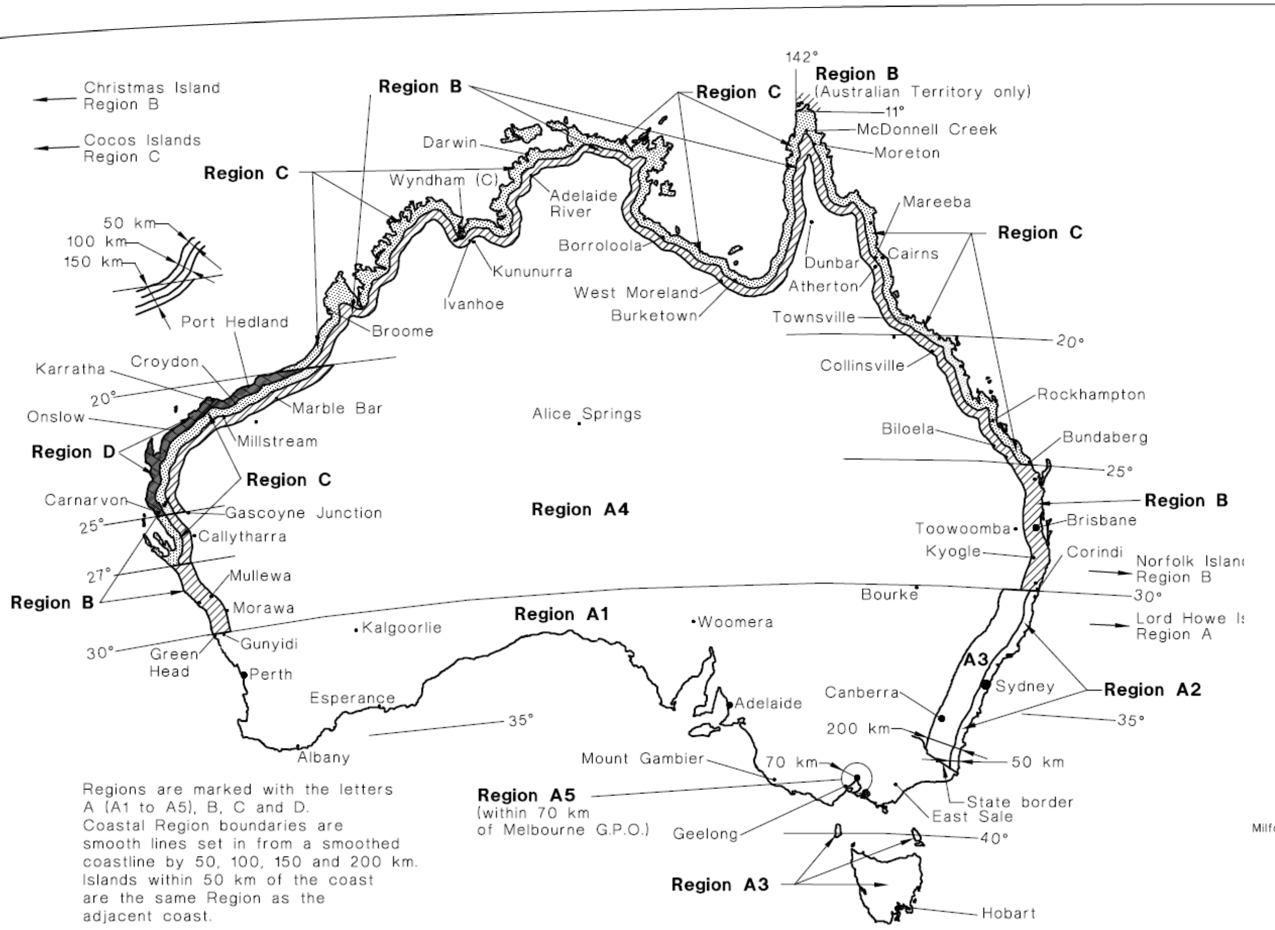
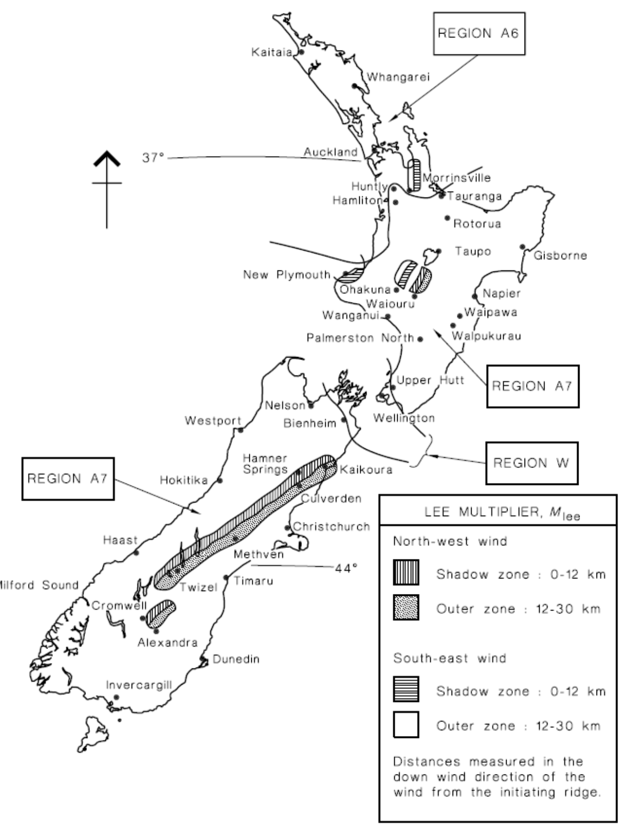
AS/NZS1170.2:2002 Wind Loading Standard

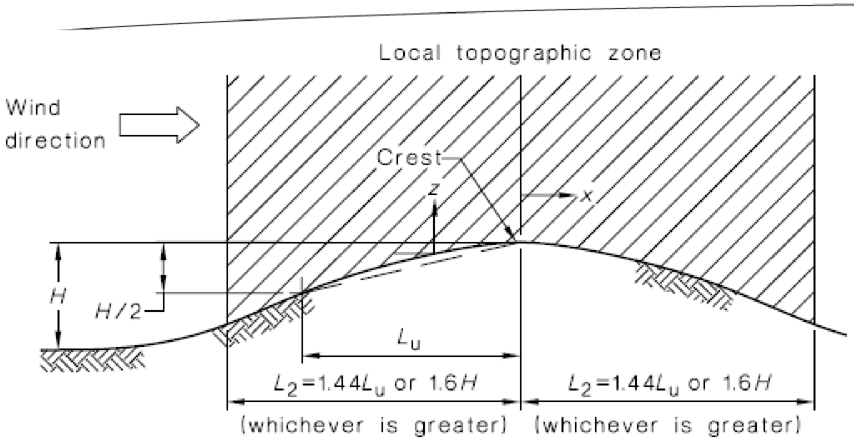


(a) Australia



(b) New Zealand

AS/NZS1170.2:2002 Wind Loading Standard

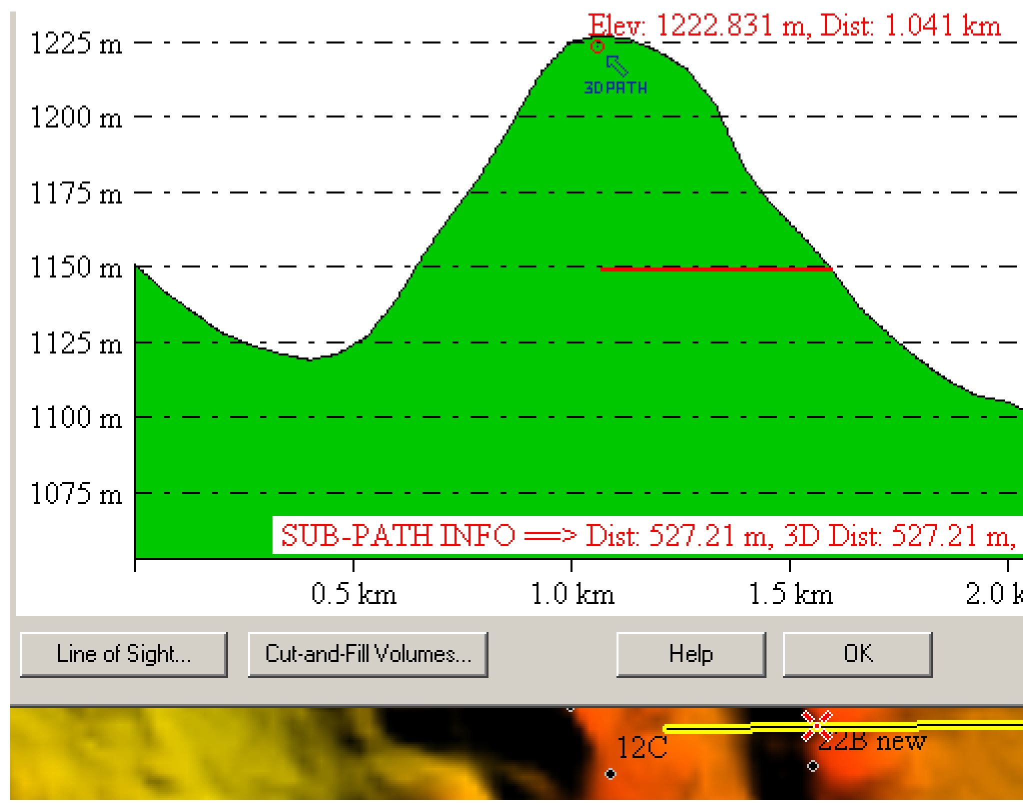


(a) For $H/(2L_u) < 0.05$, $M_h = 1.0$

(b) For $0.05 \le H/(2L_u) < 0.45$,

$$M_h = 1 + \left(\frac{H}{3.5(z+L_1)}\right)\left(1-\frac{|x|}{L_2}\right)$$

H	**158**
Lu	**527**
L2	**759**
L1	**190**
Clause (a) 0.05>	**0.10**
x	**0**



M_t = 1.16

AS/NZS1170.2:2002 Wind Loading Standard

$$V_{sit,\beta} = V_R\, M_d\, (M_{z,cat}\, M_s\, M_t)$$

V_{50} = 39 m/s

M_d = 1

$M_{z,cat}$ = 1.23

M_s = 1

M_t = 1.16

V_{e50} = 56.2 m/s

Class	I	II	III	S
V_{ref} (m/s)	50	42.5	37.5	Values specified by the designer
V_{e50} (m/s)	70	59.5	52.5	
V_{ave} (m/s)	10	8.5	7.5	
A I_{ref}	0.18			
B I_{ref}	0.16			

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AS/NZS1170.2:2002 Wind Loading Standard

Compared with:

Site near Wellington (Non-Cyclonic)

V_{e50} = 45 m/s

M_d = 1

$M_{z,cat}$ = 1.23

M_s = 1

M_t = 1.2

V_{e50} = 66.4 m/s

Site near Cairns (Cyclonic)

V_{e50} = 52 m/s

M_d = 0.95

$M_{z,cat}$ = 1.23

M_s = 1

M_t = 1.16

V_{e50} = 70.4 m/s

Class	I	II	III	S
V_{ref} (m/s)	50	42.5	37.5	Values specified by the designer
V_{e50} (m/s)	70	59.5	52.5	
V_{ave} (m/s)	10	8.5	7.5	
A I_{ref}	0.18			
B I_{ref}	0.16			

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Typhoon Analysis: Southern Japan

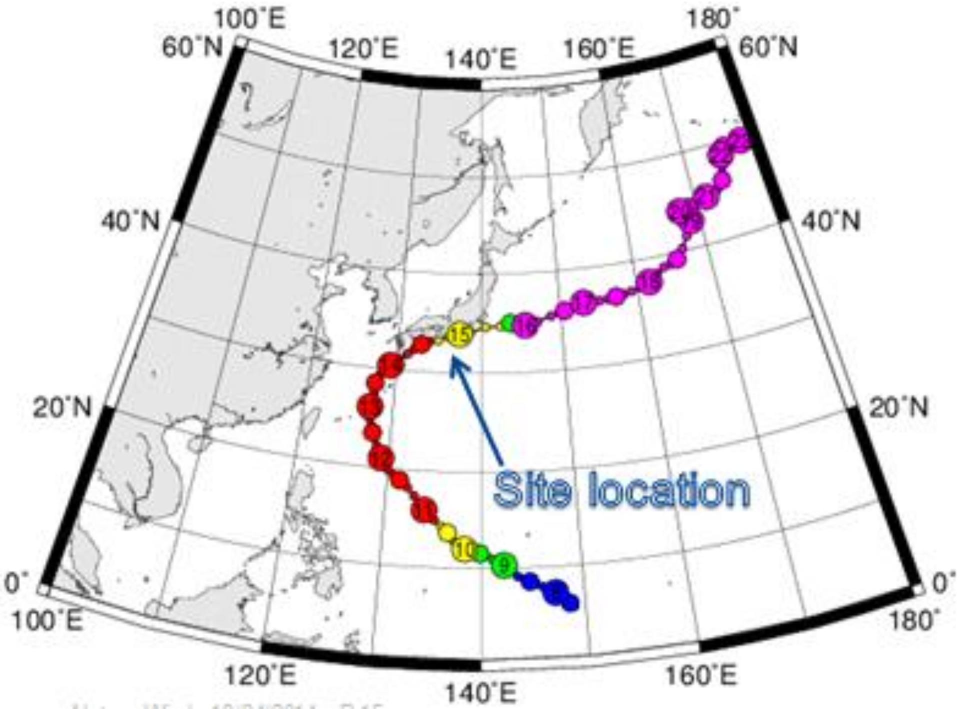
Typhoon MANI-YI 14th July 2007

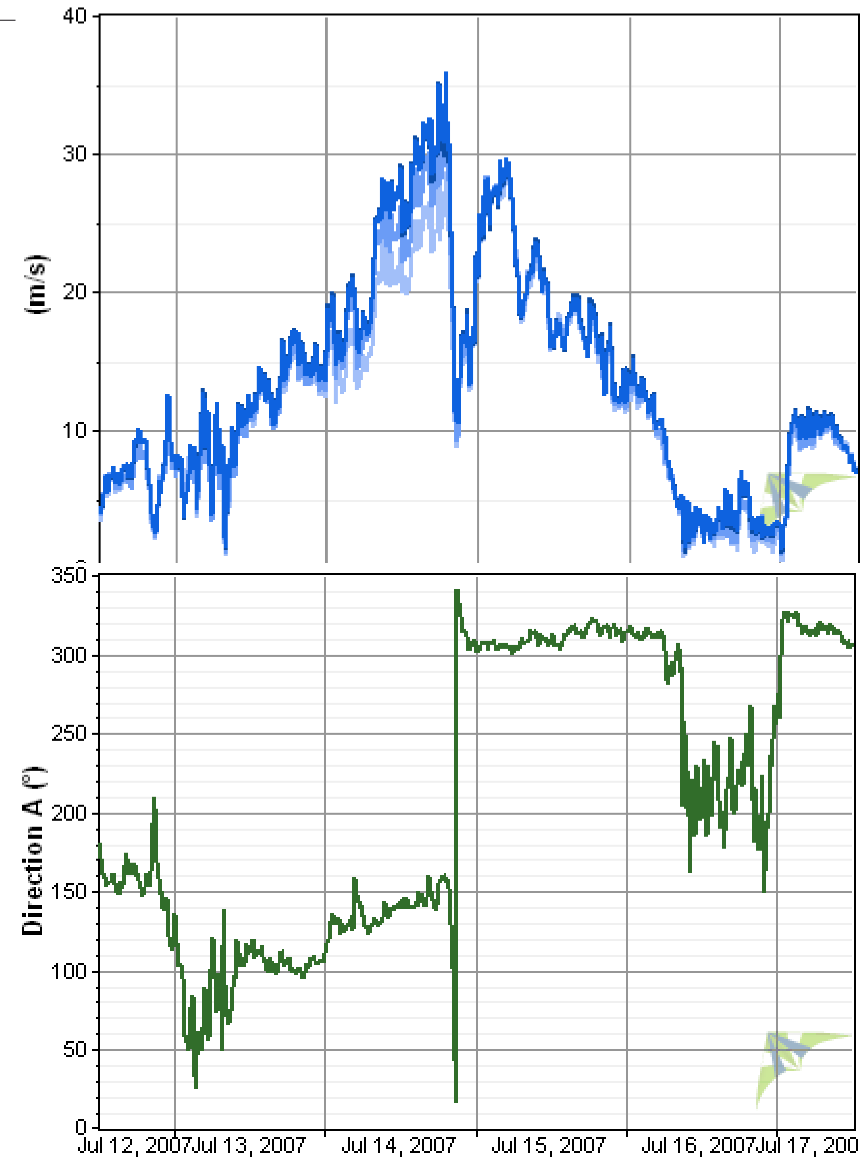
Passed 17km from project

Typhoon air pressure: ~960 hPa

Two wind speed maxima: 36 m/s & 30 m/s @ 60m

180 direction shift: 1˚/min





Source: KITAMOTO Asanobu @ National Institute of Informatics

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Typhoon Climate Extreme Wind Analysis

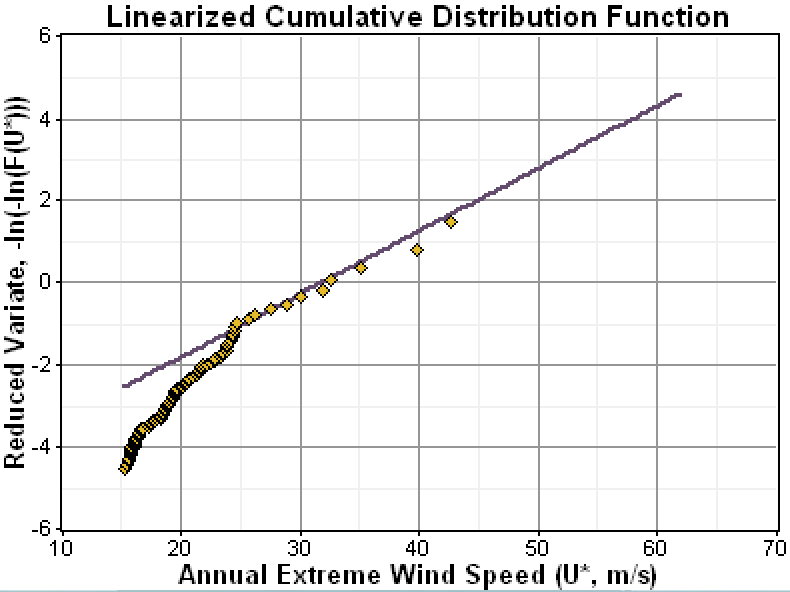
MIS with 4.5 years of data:

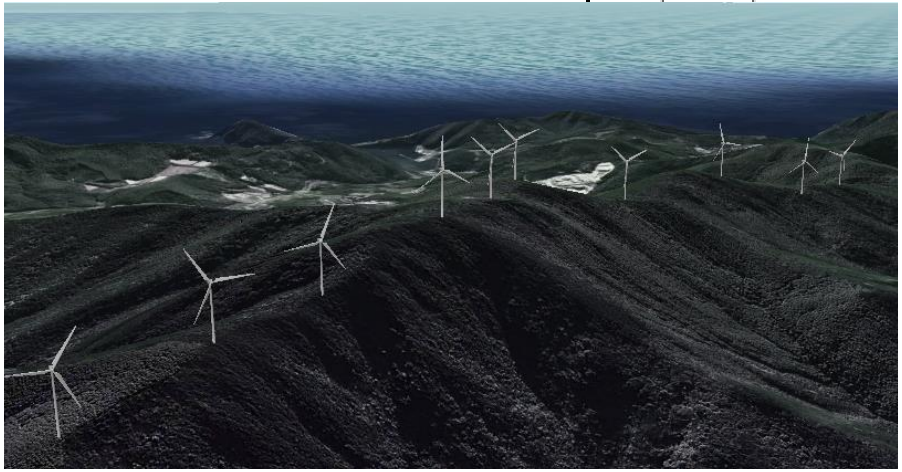
Hub height (75m) V_{ref} = 64.6m/s

Max measured wind speed = 42.8 m/s

MIS highly influenced by max wind speed

METI (Japanese Trade & Industry Dept) requires wind turbines to be certified for V_{ref} calculated by National Building Code





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Extreme Wind Analysis: 2010 Japanese Building Code

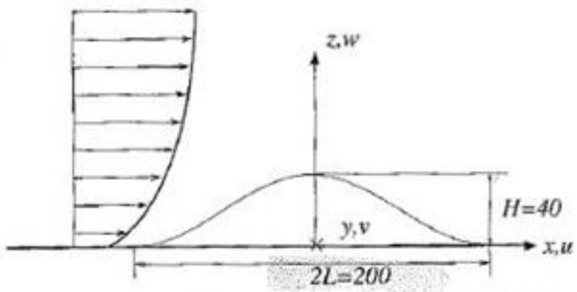
Table 1: 2010 Japanese Building Codes Formulae

ハブ高さにおける設計風速U_hは，基準風速V_0に地形による平均風速の割増係数E_{tV}と高度補正係数E_{pV}を乗じたものとし，式(3.1)により定める。

$$U_h = E_{tV} E_{pV} V_0 \tag{3.1}$$

Multiplier	Alstom Value	Formula
V_0	36 m/s	 図3.1 日本全国の設計基準風速分布 Figure3.1 Distribution of design reference wind speeds throughout Japan

Extreme Wind Analysis: 2010 Japanese Building Code

<table>
<tr><th colspan="3">Table 1: 2010 Japanese Building Codes Formulae</th></tr>
<tr><td colspan="3">ハブ高さにおける設計風速U_hは，基準風速V_0に地形による平均風速の割増係数E_{tV}と高度補正係数E_{pV}を乗じたものとし，式(3.1)により定める。
$$U_h = E_{tV} E_{pV} V_0 \qquad (3.1)$$</td></tr>
<tr><th>Multiplier</th><th>Alstom Value</th><th>Formula</th></tr>
<tr><td>E_{pV}</td><td>1.345
(Class II, Zb = 5m, Zg = 350 m, α = 0.15)</td><td>$$E_{pV} = \begin{cases} 1.7\left(\frac{H_h}{Z_G}\right)^{\alpha} & Z_b < H_h \le Z_G \\ 1.7\left(\frac{Z_b}{Z_G}\right)^{\alpha} & H_h \le Z_b \end{cases} \qquad (3.2)$$
表 3.2　平均風速の高度補正係数を定めるためのパラメータ
<table><tr><th>地表面粗度区分</th><th>I</th><th>II</th><th>III</th><th>IV</th></tr><tr><td>Z_b (m)</td><td>5</td><td>5</td><td>10</td><td>20</td></tr><tr><td>Z_G (m)</td><td>250</td><td>350</td><td>450</td><td>550</td></tr><tr><td>α</td><td>0.1</td><td>0.15</td><td>0.2</td><td>0.27</td></tr></table></td></tr>
<tr><td>E_{tV}</td><td>1.25
(H = 180 m, L = 546 m at T5)</td><td>

図解 3.4　本指針で用いた 2 次元尾根の断面図</td></tr>
</table>

Extreme Wind Analysis: 2010 Japanese Building Code

V_{ref} = 60.7 m/s

V_{e50} = 85 m/s

→ **Class S!**

However this assumes an air density of 1.225kg/m^3

Average site density is 1.16 kg/m^3 – *during a typhoons it would be significantly lower*

- The Dvorak method and Boyle's law calculates site typhoon air density as 1.02 kg/m^3

… therefore

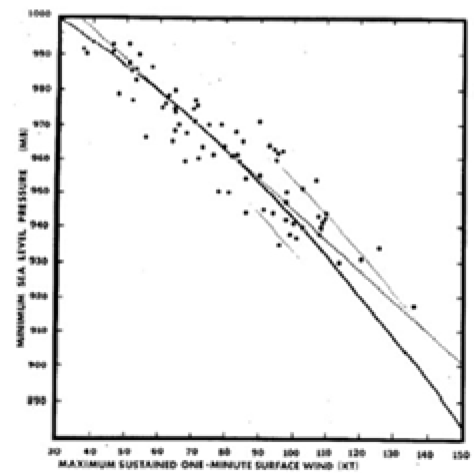
Dynamic pressure equivalent Vref is 55.5 m/s

Why is this important?

Dynamic pressure is what drives component loading

ρ=(1/R).(P/T)
Where:
R=287 J/kg.°K
P=Pressure (Pa)
T=Temperature (°K)

Boyle's law governing density



Dvorak Method for typhoon pressure (Risoe RIS-R-1544)

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Typhoon analysis: South Korea

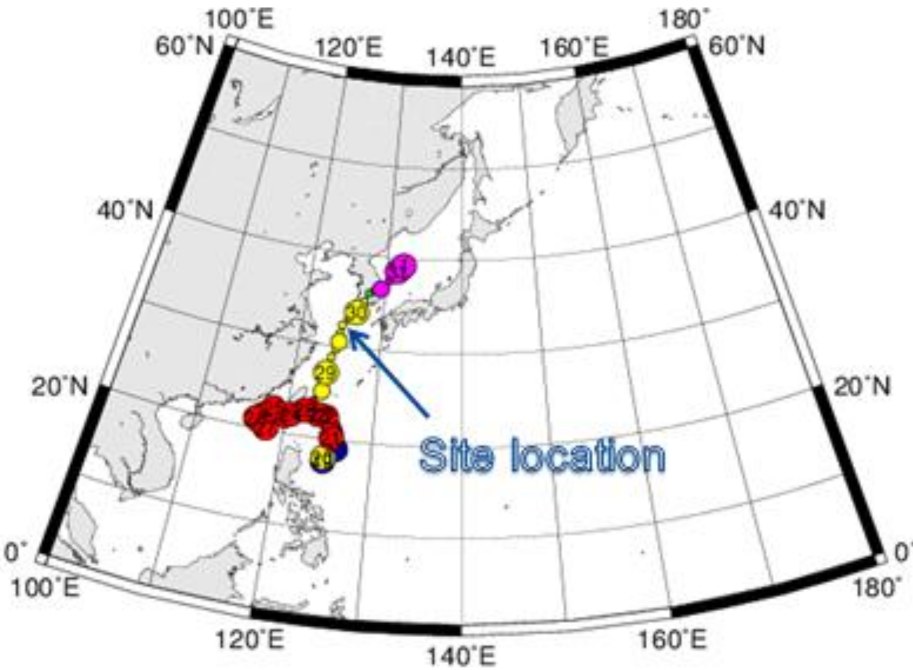
Typhoon TEMBIN, Aug 30th 2012

Passed 27km from project

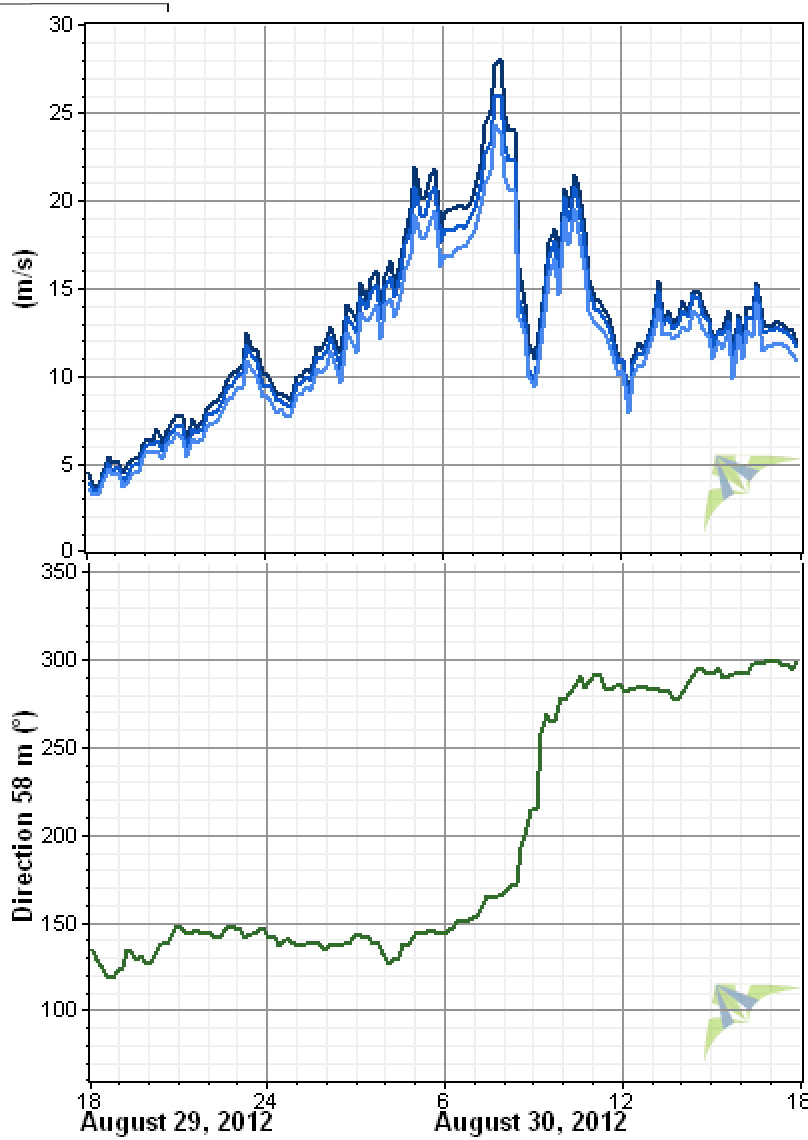
Typhoon air pressure: ~985 hPa

Two wind speed maxima: 28 m/s & 21.5 m/s @ 60m

180 direction shift: 1˚/min



Source: KITAMOTO Asanobu @ National Institute of Informatics



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Extreme Wind Atlas – South Korea

Extreme Wind Atlas derived from the Japanese Meteorological Agency (JMA) typhoon tracks

Estimates V_{e50} (m/s) at 10m a.s.l

Therefore for the site indicated

V_{e50} = 45 m/s

Extrapolating to hub height

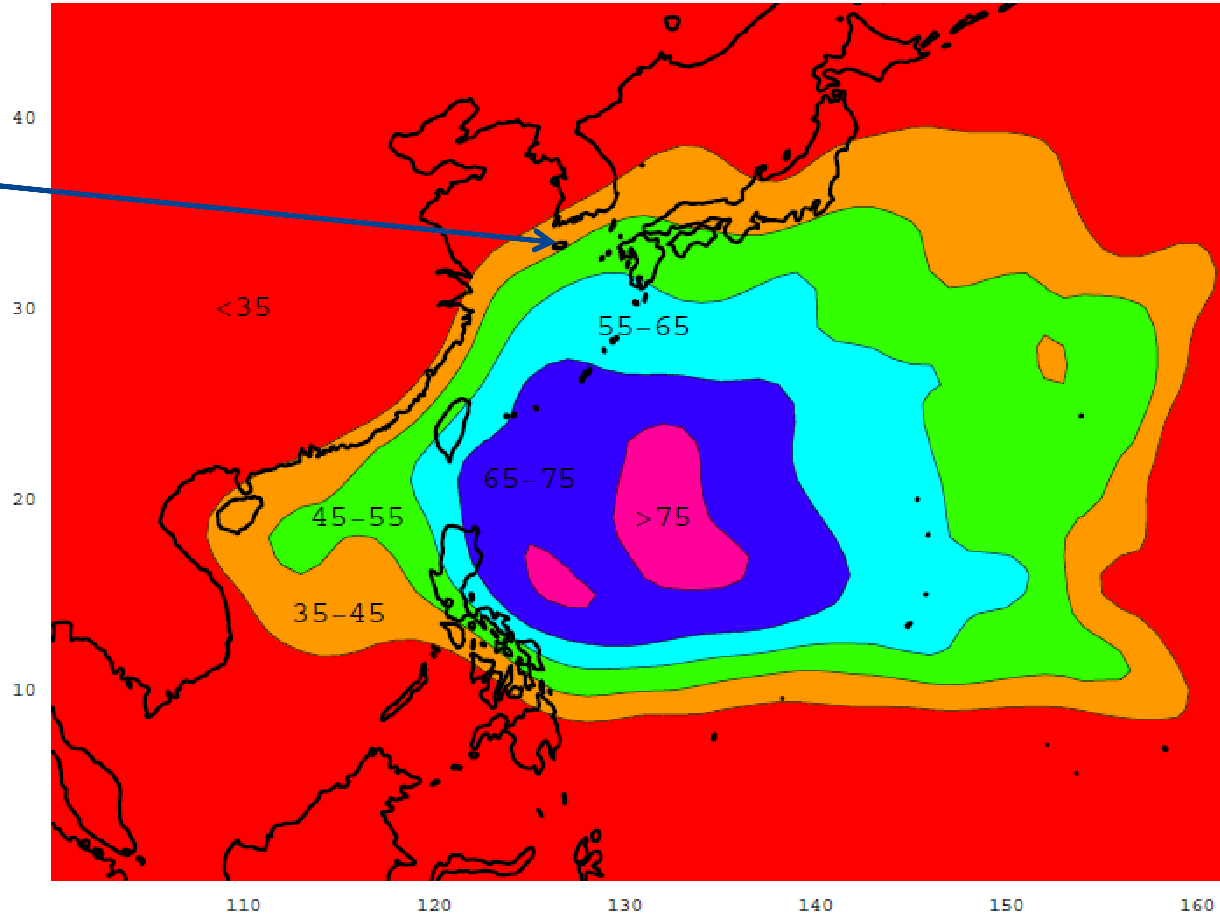
(assuming typhoon shear 0.11)

V_{e50} = 56 m/s @ 1.225kg/m^3

Dynamic pressure equivalent:

V_{e50} = 53 m/s @ 1.09 kg/m^3

Class II



Source: RIS-R-1544 Extreme Winds in the Western North Pacific: Soren Ott 2006

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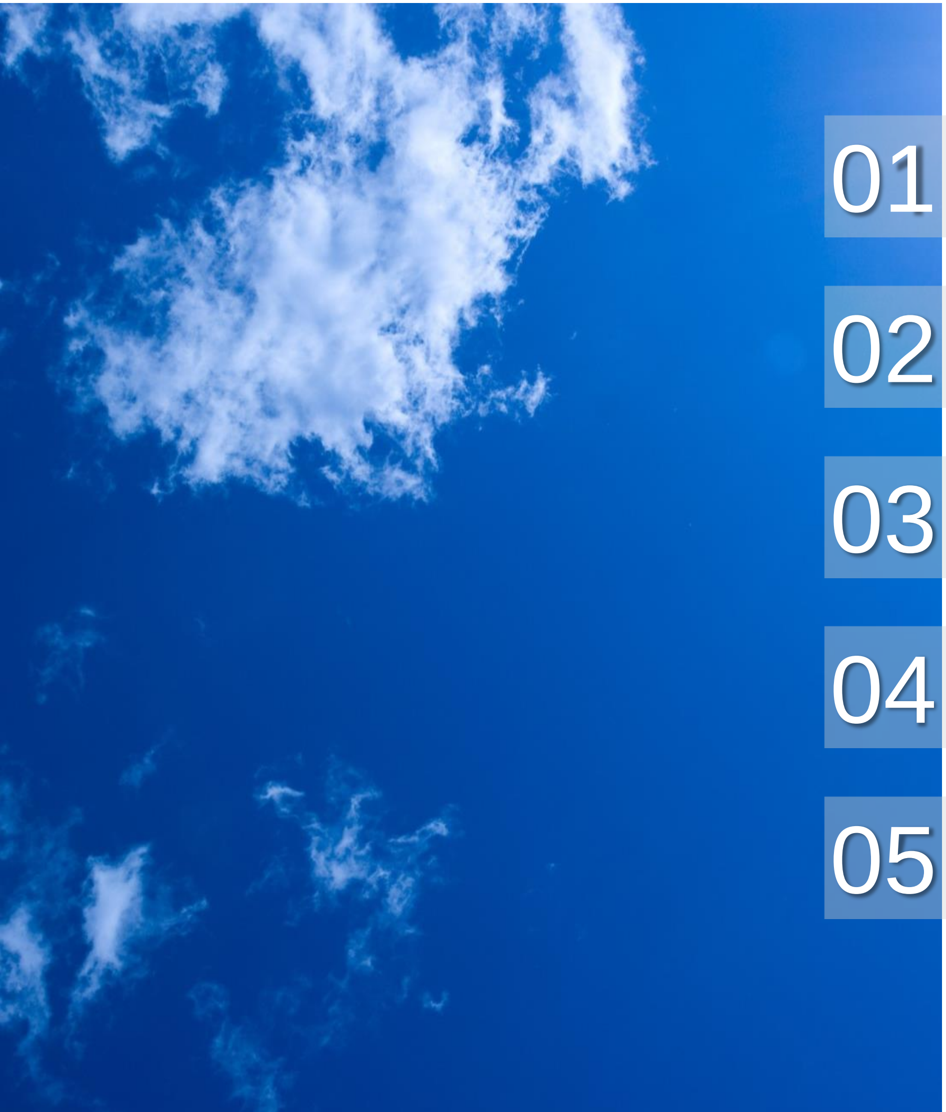

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IEC Load Conditions in Extreme Winds

IEC standard 61400-1 Design Load Cases (DLC)

- Normal design situations
- Fault design situations
- Transportation, installation and maintenance design situations

Fatigue loads evaluate fatigue strength

Ultimate loads evaluate max-strength, fatigue failure and blade tip deflection

DLC 6: Parked or Idling Turbine

- 6.1: Extreme Wind Speed condition (EWS)
- 6.2: EWS combined with loss of grid
- 6.3: EWS combined with yaw misalignment

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Turbine operation in Typhoons

Extreme Wind speed alone is not the cause of WT failure

- Considering that blade tip velocity is ~72 m/s

During extreme conditions WT is parked & not subjected to dynamic component loads

Failure usually occurs due to cascading faults:

- Loss of electrical network
- Loss of turbine control system
- Yaw error/misalignment
- Blade pitch misalignment
- WT Ultimate loads may be exceeded

Damaged Wind Turbines from Typhoon Maemi, Japan 2003

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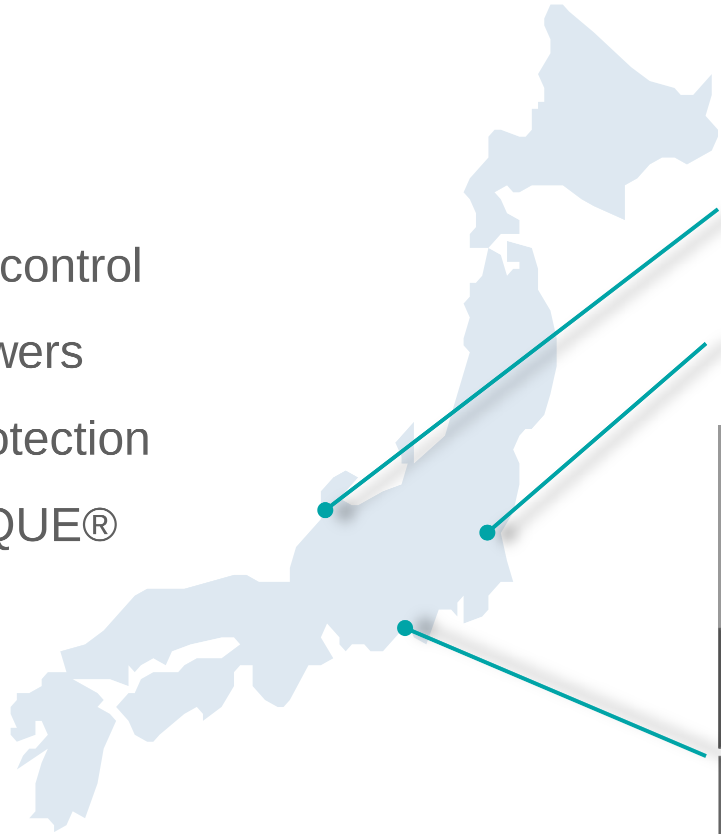
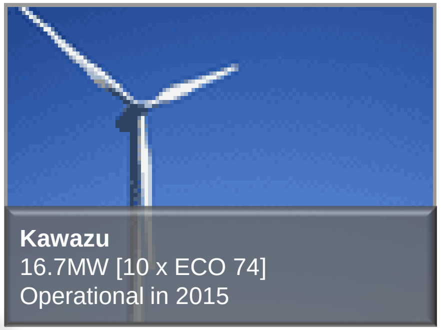
ECO100 Platform customisation for Typhoon Climate

- Yaw backup
- Active yaw breaks
- Redundant UPS pitch control
- Seismic + Typhoon towers
- Advanced lightning protection
- ALSTOM PURE TORQUE®



Hamada
48 MW [29 x ECO 74]
UNDER CONSTRUCTION

Satomi
10 MW [6 x ECO 74]
Operational since 2006



Kawazu
16.7MW [10 x ECO 74]
Operational in 2015

Higashi Izu II
18.37 MW [11 x ECO 74]
Operational in 2015

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Yaw Backup & Active Yaw Brake

During typhoon (10min average >30m/s) + grid loss

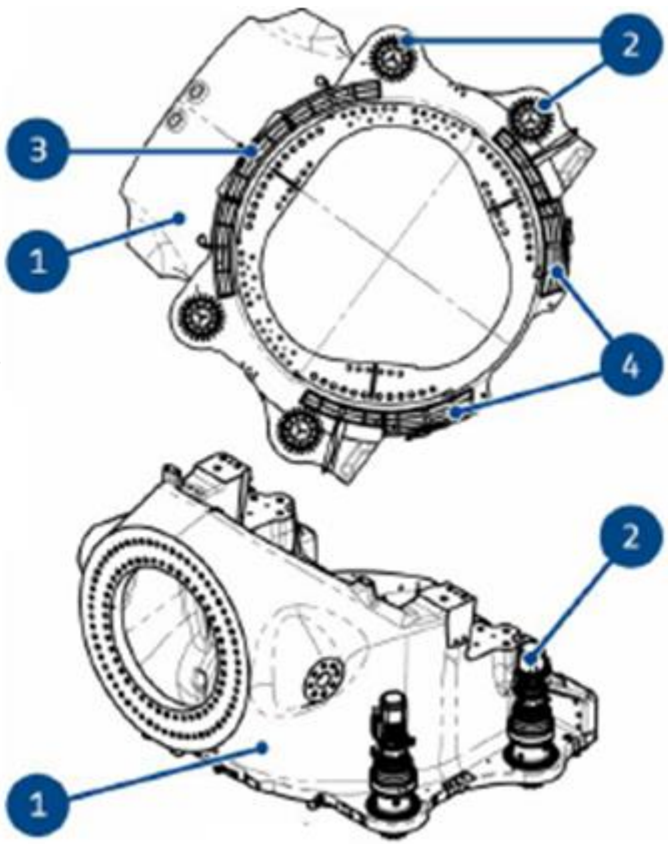
WT switches to TYPHOON MODE

Yaw System UPS allows:

- 180º yawing to <u>downwind</u> position
- Re-orientate WT 15º every 15min for at least 6hrs

Active yaw brakes:

- 6 hydraulic brakes & 4 yaw motors
- Engage after every yaw alignment
- No loading on yaw gear



IT.	DESCRIPTION	IT.	DESCRIPTION
1	Central frame	3	Top axial gliding pad
2	Yaw gear motor	4	Top axial gliding pad

Pitch Control System

Pitch-based aerodynamic braking system

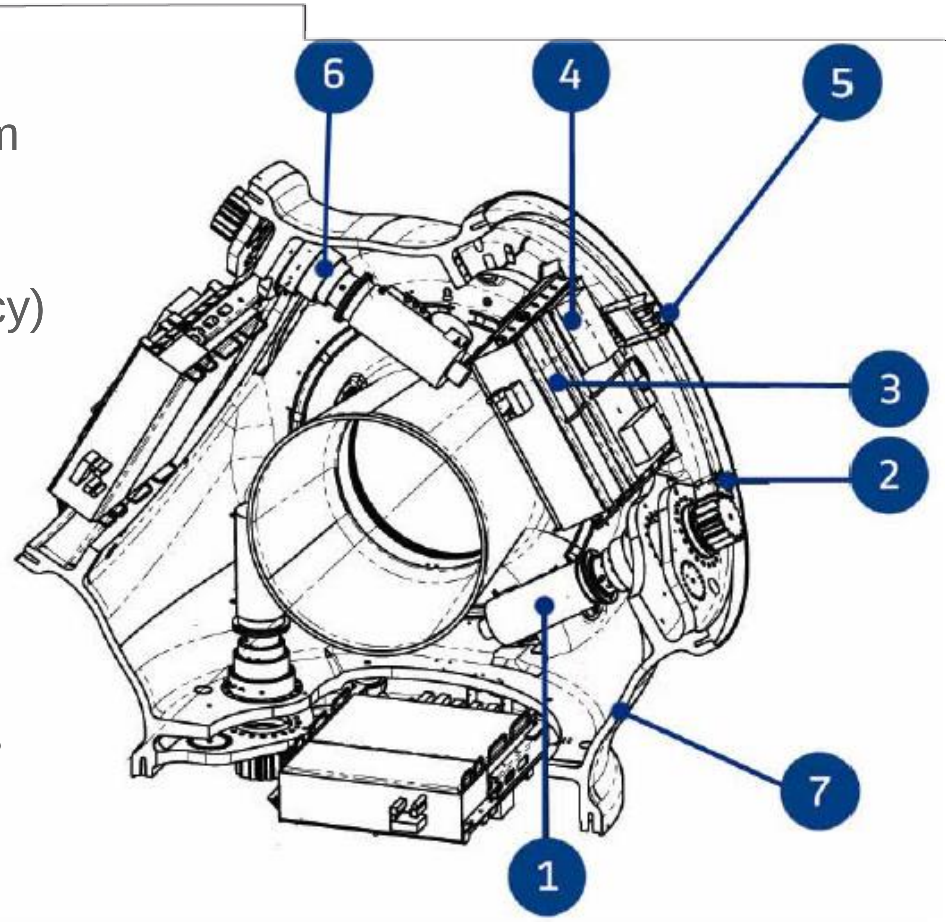
Default pitch at full feather (86º)

x3 independent pitch system (redundancy)

UPS for control system

During grid loss (typhoon):

- Control system connected to the UPS
- Blades are returned to default pitch



It.	Description	It.	Description
1	Pitch motor	4	Battery box
2	Blade redundant encoder	5	Limit switches
3	Axial box	6	Pitch gearbox
7	Hub		

Landes de Couesme

Summary

Calculating extreme wind is essential for certifying a turbine for the 20 year project lifetime

How do you calculate it?

- Commonly used classic methods (Gumbel, MIS)
- National Building Codes
- OTHER??
    - Typhoon tracks

How do you combat it?

- Innovation

(yaw backup, UPS)

Determination…

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Thank you for your attention!

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