Turbulence Intensity Model for Offshore Wind Energy Applications

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Outline

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- Turbulence Intensity Model (TIM)
- Estimation of Gust Factor based on TIM
- Further Studies
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Motivation

Offshore standards:

- Use: Design of offshore structures
- Focus: High wind speed

Need of a model

Valid for:

- All wind conditions

Can be used for:

- Design
- Operation and Fatigue Analysis

Wind Parameters

Mean Wind Speed:

$$U$$

Turbulence Intensity:

$$I = \frac{\sigma_U}{U}$$

Gust Factor:

$$G = \frac{U_{gust}}{U}$$

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Offshore Standard: ISO 19901-1:2005

Wind Profile:

$$U(z) = U_0 \cdot \left[1 + C \cdot \ln\left(\frac{z}{z_r} \right) \right]$$

$$C = 5.73 \cdot 10^{-2} \cdot \left[1 + 1.5 \cdot \frac{U_0}{U_{ref}} \right]^{\frac{1}{2}}$$

Turbulence Intensity: $I = 0.06 \cdot \left[1 + 0.43 \cdot \frac{U_0}{U_{ref}} \right] \cdot \left(\frac{z}{z_r} \right)^{-0.22}$

Wind Gust: $U_{gust}(z,t) = U(z) \cdot \left[1 - 0.41 \cdot I(z) \cdot \ln\left(\frac{t}{t_0} \right) \right]$

z_r :	Reference elevation above mean sea level, z_r = 10 m
U_o :	1 hour mean wind speed at the reference elevation z_r
U_{ref} :	Reference wind speed, U_{ref} = 10 m/s
t_0 :	1 hour

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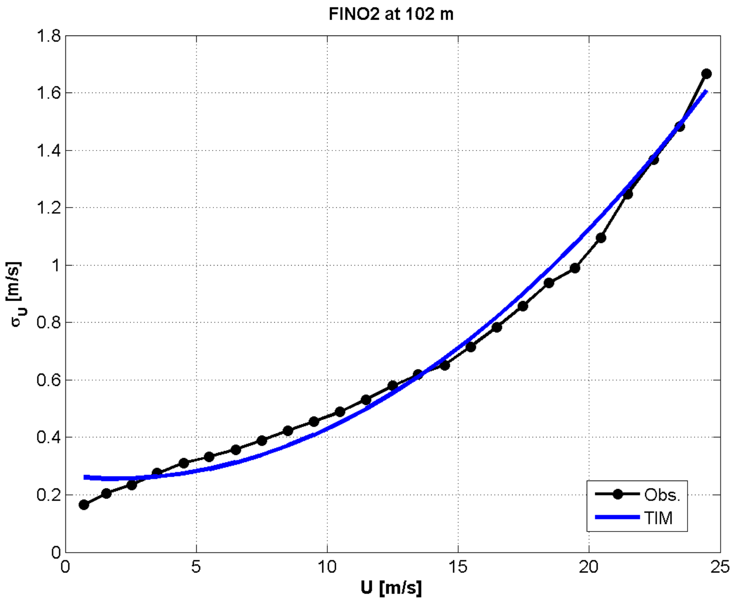
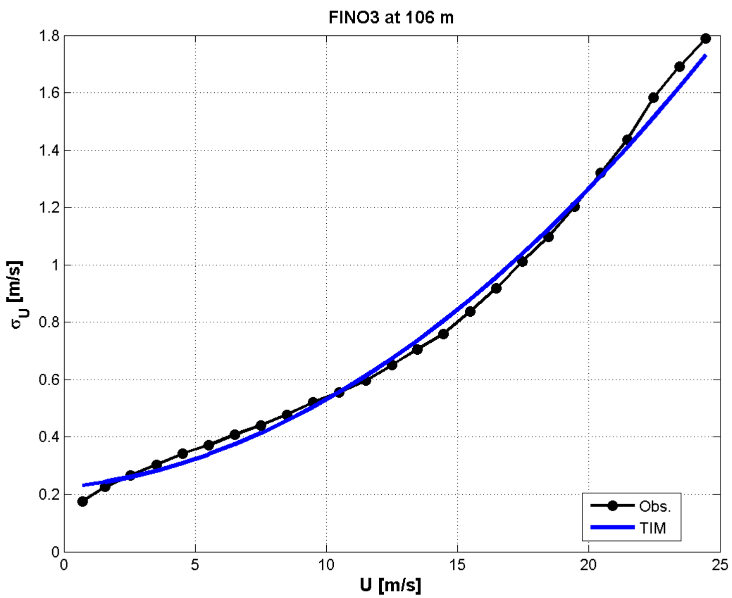
Turbulence Intensity Model (TIM; #1)

Based on offshore wind statistics at FINO platforms, the standard deviation of wind speed is modelled as a function of wind speed using a 2nd order polynomial:

$$\sigma_U = a_1 \cdot U^2 + a_2 \cdot U + a_3$$





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Turbulence Intensity Model (TIM; #1)

$$\sigma_U = a_1 \cdot U^2 + a_2 \cdot U + a_3$$

$$I = \frac{\sigma_U}{U}$$

$$I = a_1 \cdot U + a_2 + \frac{a_3}{U}$$

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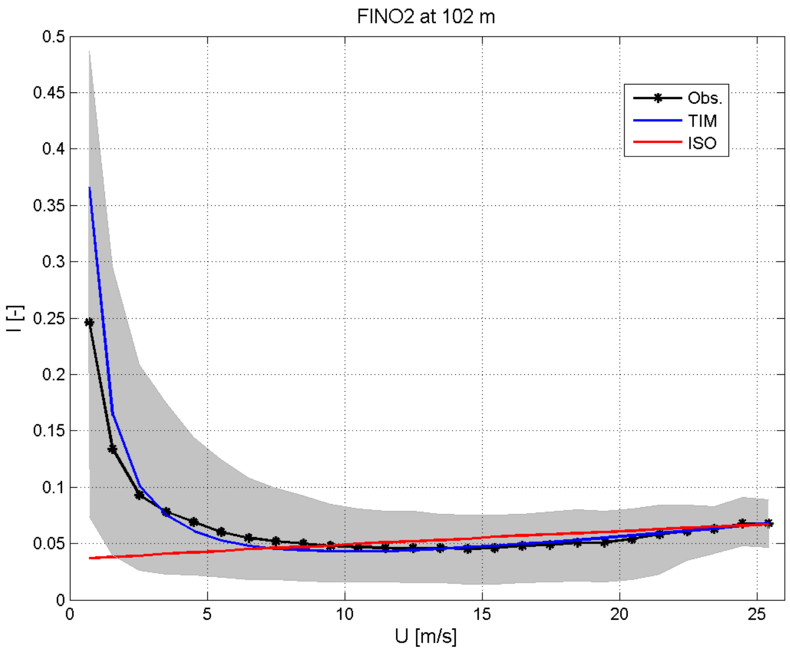
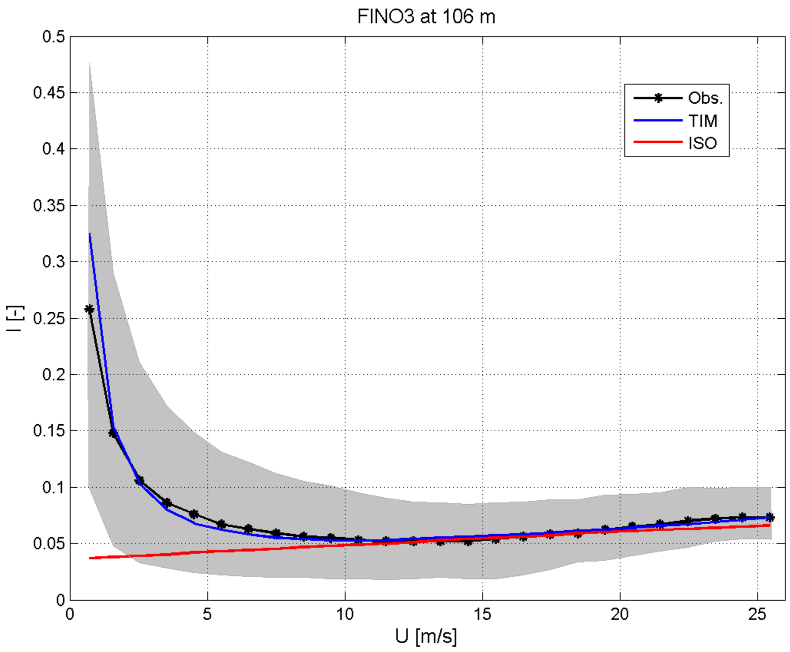
Turbulence Intensity Model (TIM; #1)

$$I = a_1 \cdot U + a_2 + \frac{a_3}{U}$$





Grey Area: P05 – P95 curves

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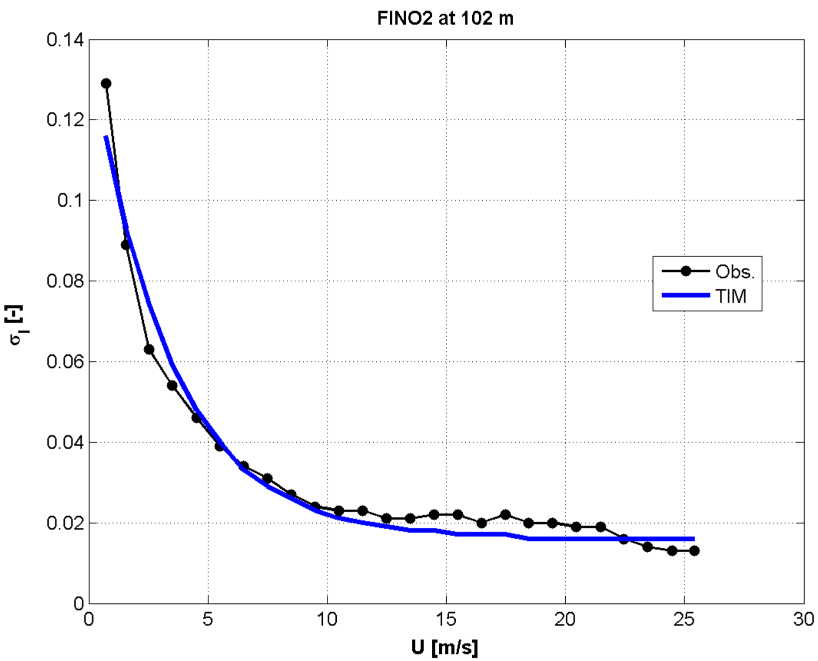
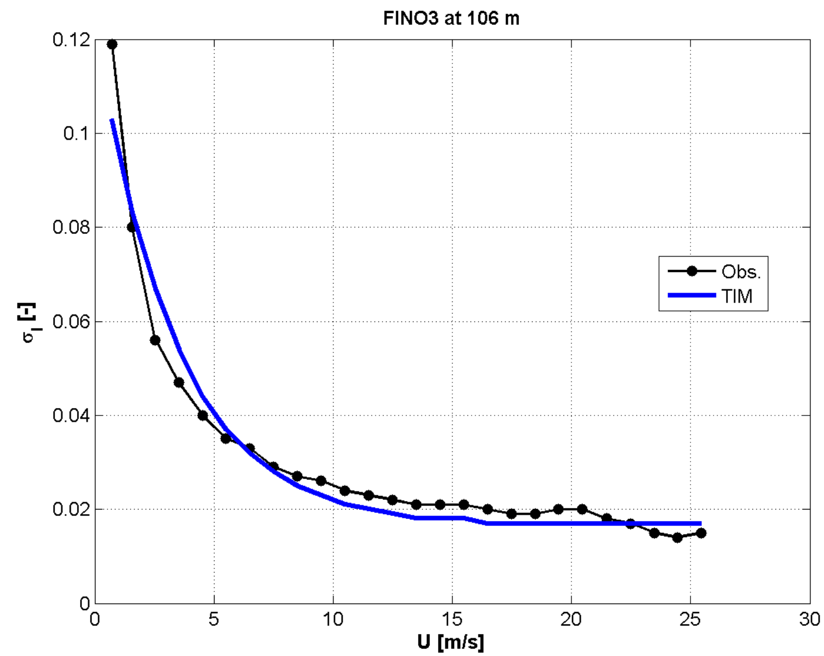
Turbulence Intensity Model (TIM; #2)

For wind speed higher than 2 m/s, the standard deviation of turbulence intensity (σ_I) is modelled by:

$$\sigma_{\mathrm{I}} = c_1 + c_2 e^{-c_3 U}$$





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Estimation of Gust Factor based on TIM

ISO Wind Gust: $$U_{gust}(z,t) = U(z)\cdot\left[1-0.41\cdot I(z)\cdot\ln\left(\frac{t}{t_0}\right)\right]$$

$$I = a_1\cdot U + a_2 + \frac{a_3}{U}$$

$$G = \frac{U_{gust}}{U}$$

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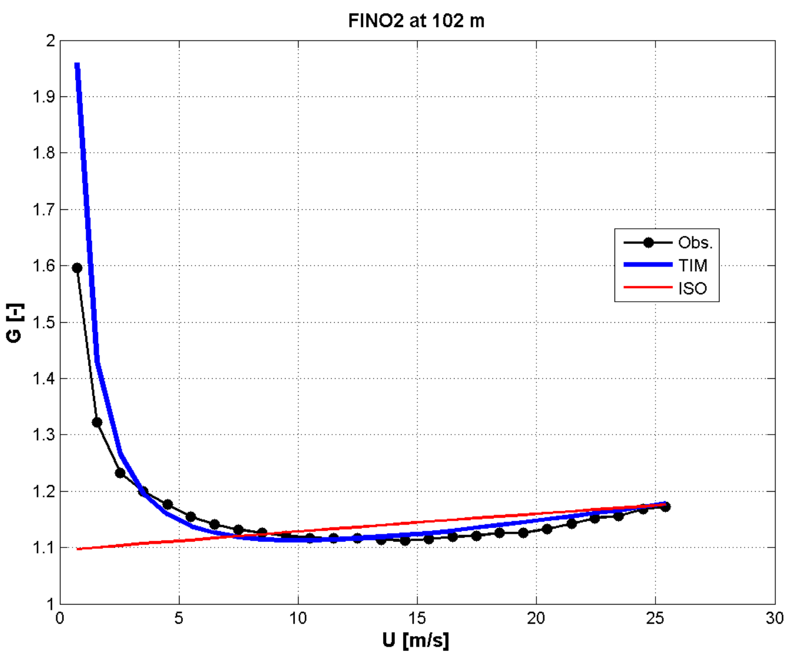
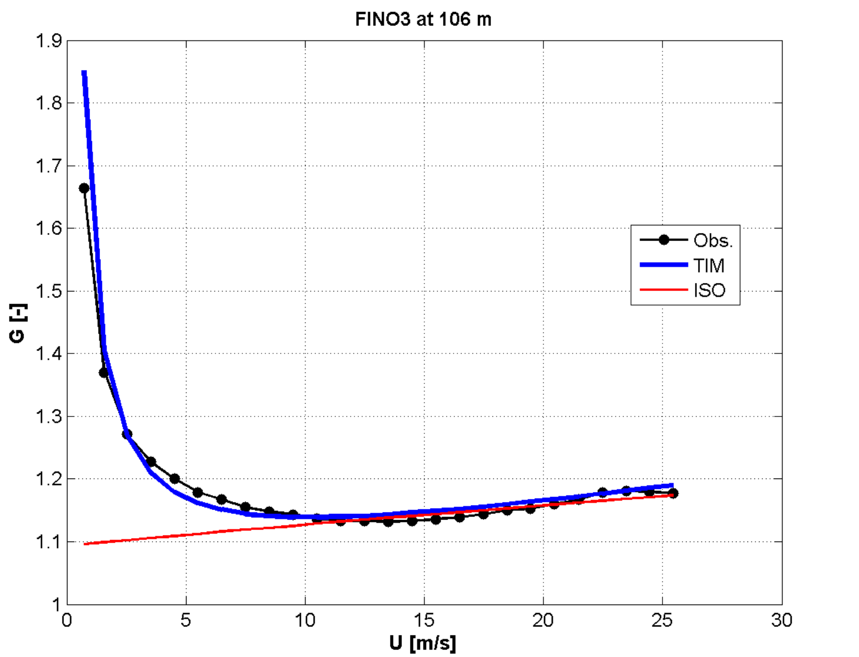
Estimation of Gust Factor based on TIM





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Further Studies

Apply the TIM to

- other offshore locations
- different heights (higher)

Investigate the possible relation between the TIM and

- atmospheric stability
- wind shear
- sea surface roughness (e.g. effect of waves)

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Summary

- Propose a model for:
- I (valid for all wind conditions)
- σ_I (valid for wind speed > 2m/s)
- Modelled turbulence intensity corresponds to ISO standards for high wind speed
- Model has been tested with good results using data from several locations including FINO 1,2 and 3

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Thank you

Turbulence Intensity Model (TIM; #1)

$$I = a_1 \cdot U + a_2 + \frac{a_3}{U}$$

Location	Height	Coefficients		
	[m]	a_1 [(m/s)$^{-1}$]	a_2	a_3[m/s]
Fino 1	100	0.0021	0.0104	0.2545
	33	0.0020	0.0351	0.1976
Fino 2	102	0.0027	-0.0102	0.2660
	30	0.0025	0.0252	0.1599
Fino 3	106	0.0021	0.0092	0.2233
	30	0.0025	0.0300	0.1794

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Turbulence Intensity Model (TIM; #2)

$$\sigma_{\mathrm{I}} = c_1 + c_2 e^{-c_3 U}$$

Location	Height	Coefficients		
	[m]	c_1	c_2	c_3 [(m/s)$^{-1}$]
Fino 1	100	0.019	0.101	0.237
	33	0.016	0.094	0.166
Fino 2	102	0.016	0.123	0.301
	30	0.012	0.126	0.270
Fino 3	106	0.017	0.107	0.299
	30	0.015	0.123	0.285

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