
Wind, Waves and Currents
Specifying Design Conditions for Offshore Wind Farms

BS EN 61400-3:2009

BSI British Standards

Wind turbines —

Part 3: Design requirements for offshore wind turbines

Design Cases For Offshore Turbines

Table 1 – Design load cases

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
1) Power production	1.1	NTM $V_{in} < V_{hub} < V_{out}$ RNA	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL	For extrapolation of extreme loads on the RNA	U	N (1,25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL		F	*
	1.3	ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.4	ECD $V_{hub} = V_r - 2$ m/s, V_r, $V_r + 2$ m/s	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	MIS, wind direction change	NCM	MSL		U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.6a	NTM $V_{in} < V_{hub} < V_{out}$	SSS $H_s = H_{s,SSS}$	COD, UNI	NCM	NWLR		U	N
	1.6b	NTM $V_{in} < V_{hub} < V_{out}$	SWH $H = H_{SWH}$	COD, UNI	NCM	NWLR		U	N

For Scenario: Case 1.1

operational conditions:

$$V_{in} < V_{hub} < V_{out}$$

NSS	normal sea state (see 6.4.1.1)
MSL	mean sea level (see 6.4.3)
NCM	normal current model (see 6.4.2.4)
COD	co-directional (see 6.4.1)
UNI	uni-directional (see 6.4.1)
U	ultimate strength (see 7.6.2)

Design Cases For Offshore Turbines

6) Parked (standing still or idling)	6.1a	EWM Turbulent wind model $V_{hub} = k_1 V_{ref}$	ESS $H_s = k_2 H_{s50}$	MIS, MUL	ECM	EWLR		U	N
	6.1b	EWM Steady wind model $V(z_{hub}) = V_{e50}$	RWH $H = H_{red50}$	MIS, MUL	ECM	EWLR		U	N
	6.1c	RWM Steady wind model $V(z_{hub}) = V_{red50}$	EWH $H = H_{50}$	MIS, MUL	ECM	EWLR		U	N
	6.2a	EWM Turbulent wind model $V_{hub} = k_1 V_{ref}$	ESS $H_s = k_2 H_{s50}$	MIS, MUL	ECM	EWLR	Loss of electrical network	U	A
	6.2b	EWM Steady wind model $V(z_{hub}) = V_{e50}$	RWH $H = H_{red50}$	MIS, MUL	ECM	EWLR	Loss of electrical network	U	A
	6.3a	EWM Turbulent wind model $V_{hub} = k_1 V_1$	ESS $H_s = k_2 H_{s1}$	MIS, MUL	ECM	NWLR	Extreme yaw misalignment	U	N
	6.3b	EWM Steady wind model $V(z_{hub}) = V_{e1}$	RWH $H = H_{red1}$	MIS, MUL	ECM	NWLR	Extreme yaw misalignment	U	N
	6.4	NTM $V_{hub} < 0{,}7\ V_{ref}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL		F	*

For Scenario: Case 6.1c
(with alterations)

Extreme conditions

RWM reduced wind speed model (see 6.3)
EWH extreme wave height (see, 6.4.1.6)
ECM extreme current model (see 6.4.2.5)
EWLR extreme water level range (see 6.4.3.2)

COD co-directional (see 6.4.1)
UNI uni-directional (see 6.4.1)

U ultimate strength (see 7.6.2)

Operational Case

Wind: higest operational

$V(z) = V_{hub}(z/z_{hub})^{\alpha}$ for normal wind conditions α, is 0,14

Current: NCM = wind-generated + breaking wave currents

Scenario assumption: no breaking wave current

The wind generated current may be characterised as a linear distribution of velocity $U_w(z)$ reducing from the surface velocity $U_w(0)$ to zero at a depth of 20 m below SWL:

$$U_w(0) = 0{,}01 V_{1-hour}(z = 10\text{ m}) \qquad U_w(z) = U_w(0)(1 + z/20)$$

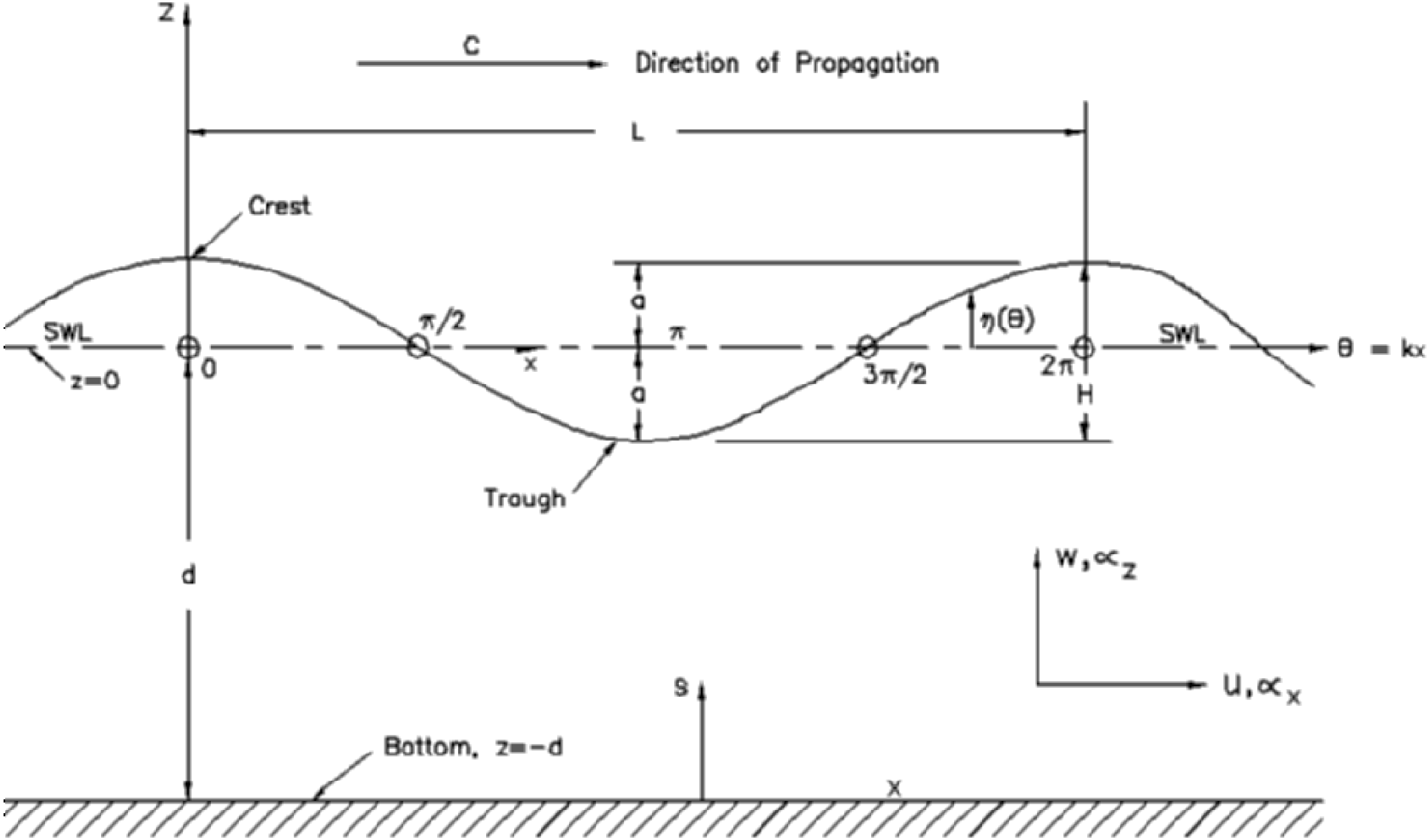
Waves: normal sea state associated with highest operational wind

BS 6349-1:2000 „Maritime structures – Part 1: Code for practice for general criteria“

22.2 Wave prediction

22.2.4 Prediction by significant wave charts

Wave Parameters



3.5.9

significant wave height

average height of the highest one third of the waves

Significant Wave Prediction Chart

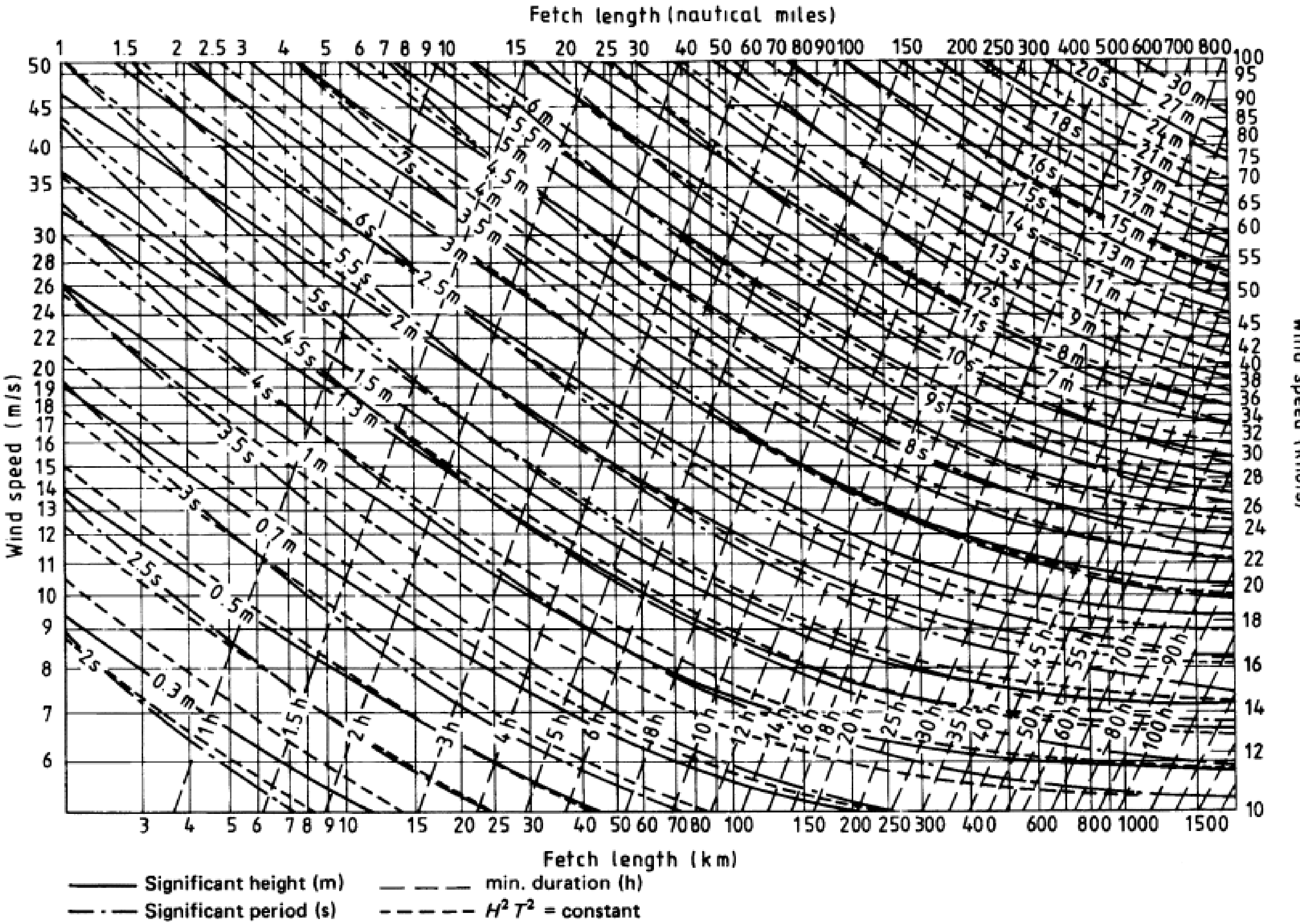


Figure 5 — Significant wave prediction chart — Fetch lengths up to 1 500 km

Extreme Case

Wind: Reduced Extreme Wind Speed

$$V_{red50}(z) = 1{,}1\, V_{ref}\,(z/z_{hub})^{0{,}11}$$

V_{ref} reference wind speed

Current: Extreme Current Model, 50 years extreme

Scenario assumption: Subsurface current only $U_{ss}(z) = U_{ss}(0)\,[(z+d)/d]^{1/7}$

Waves: 50 years extreme

BS 6349-1:2000 „Maritime structures – Part 1: Code for practice for general criteria“

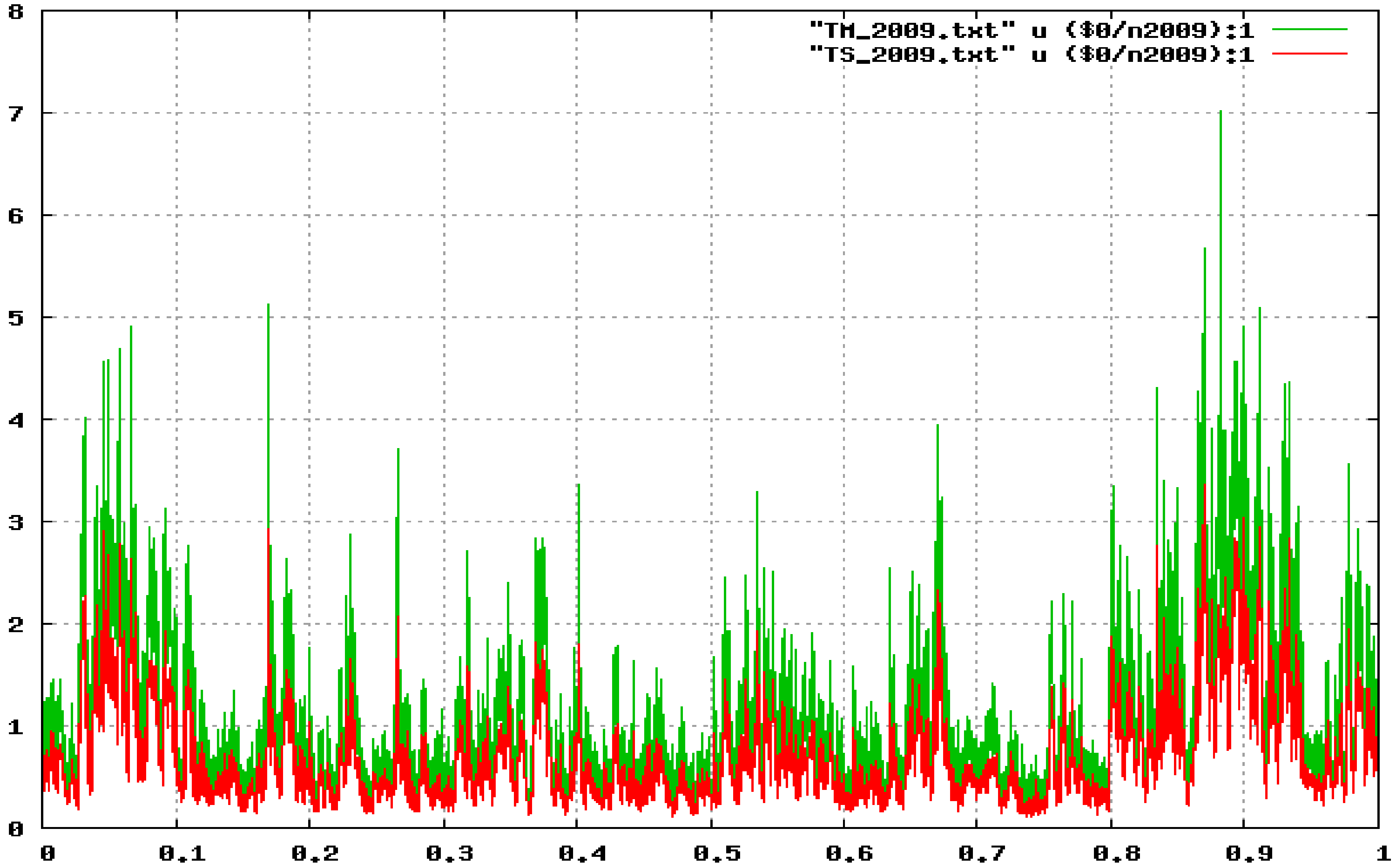
21.3 Sea state properties

21.3.8 Return period and design wave condition

27 Extrapolation of wave data

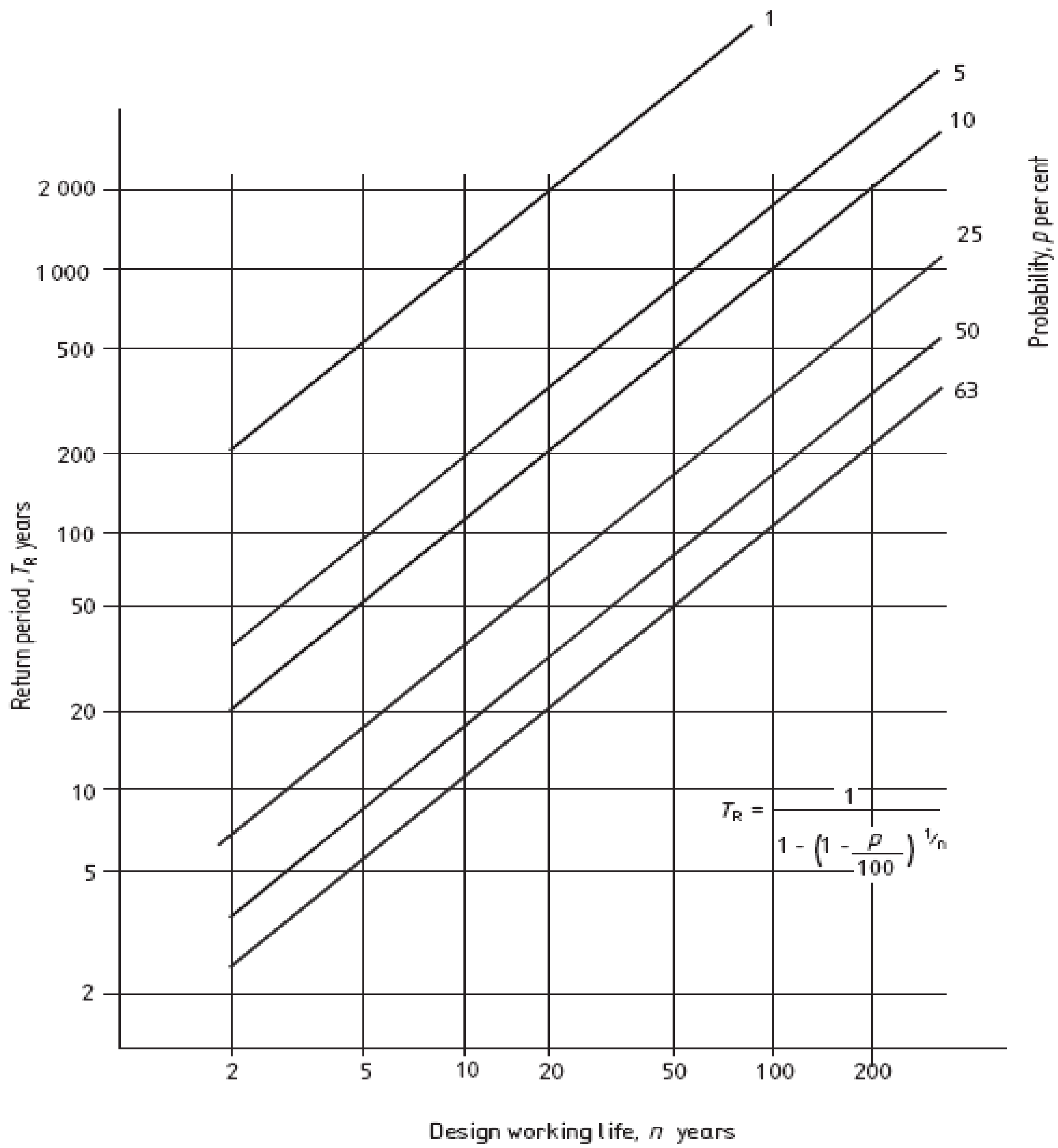
27.2 Extrapolation to extreme wave conditions

Typical Wave Data



Wavehight (m) vs Time (years): Hs – red; Hmax - green

Return Period and Probabylity



Probability Distributions

For a set of n_x values of representative heights H the probability, p_n, that H_n is equalled or exceeded is given by:

$$p_n = 1 - \frac{n}{n_x + 1}$$

The following distributions may be appropriate

a) *Weibull distribution*. Plot $\log_e \log_e (1/p_n)$ against $\log_e (H_n - H_L)$.

b) *Fisher-Tippet distribution*. Plot $-\log_e \log_e (1/(1 - p_n))$ against $-\log_e(H_L - H_n)$.

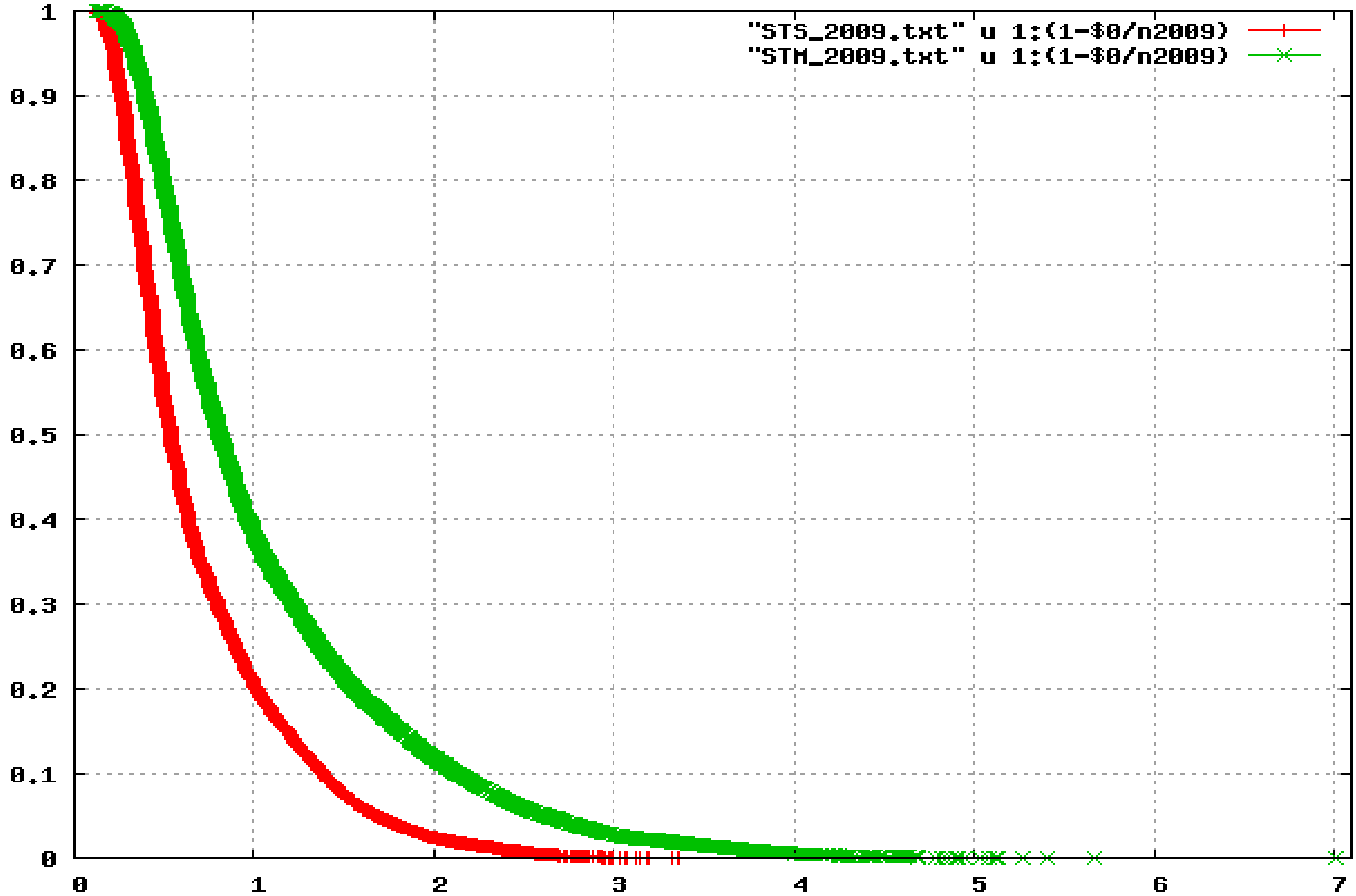
c) *Frechet distribution*. Plot $-\log_e \log_e(1/(1 - p_n))$ against $\log_e(H_n - H_L)$.

d) *Gumbel distribution*. Plot $-\log_e \log_e(1/(1 - p_n)$ against H_n.

e) *Gompertz distribution*. Plot $\log_e \log_e(1/p_n)$ against H_n.

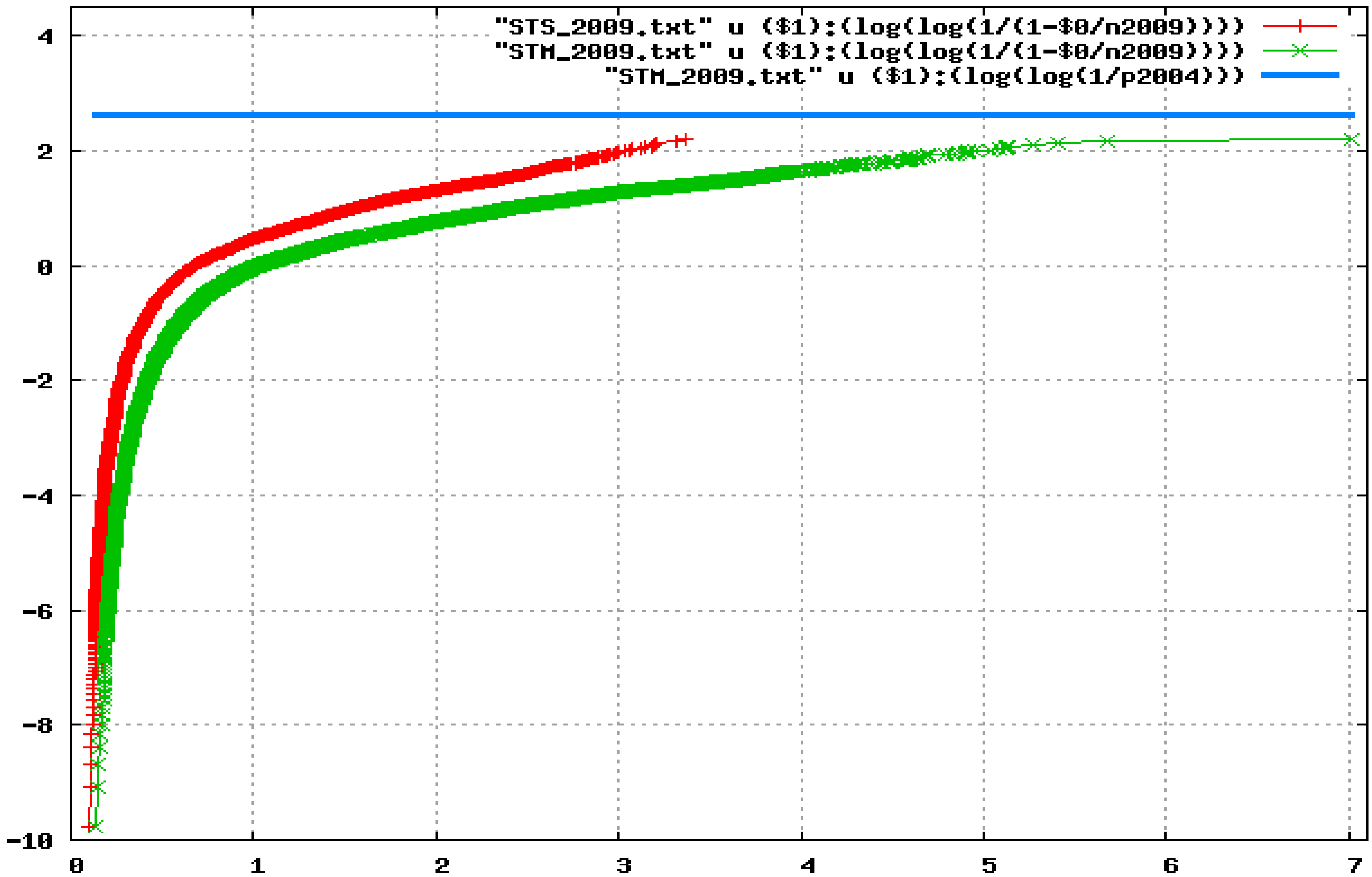
H_L represents a limiting value of H_n

Example from Data



Probability vs Wavehight (m): Hs – red; Hmax - green

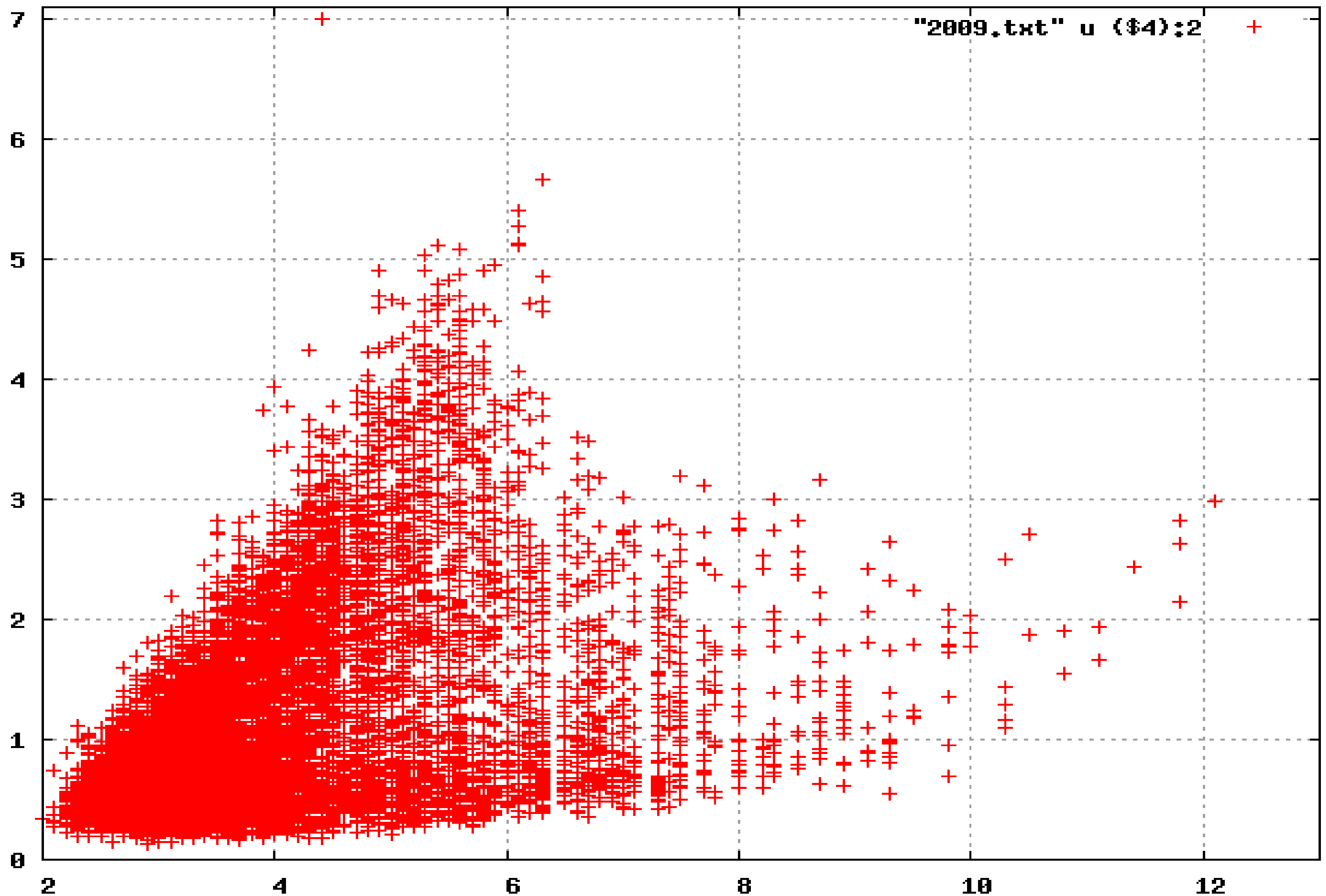
Example from Data



Same using Gumbel distribution

Hs – red; Hmax – green; probability of 50years event - blue

Wave Period



Wavehight (m) vs Period (s)

More Reading

Holthuijsen, Leo H. (2007). Waves in Oceanic and Coastal Waters. Cambridge University Press.

3. Description of ocean waves
    - 3.1 Key concepts
    - 3.2 Introduction
    - 3.3 Wave height and period
    - 3.4 Visual observations and instrumental measurements
4. Statistics
    - 4.3 Long-term statistics (wave climate)

Online version available at:
http://app.knovel.com/hotlink/toc/id:kpWOCW0002/waves-in-oceanic-coastal

Example of a Wave Data Report (available on MOODLE):

https://moodle.ucl.ac.uk/mod/resource/view.php?id=1534943