UNIVERSITY OF THESSALY
School of Engineering - Department of Civil Engineering

The Use of Storm Models in the Field of Ocean Engineering

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In this seminar we will talk about **Storm Models** and their applications in the field of Ocean Engineering. Specifically, we will discuss about:

- what do they are;
- how to use them for applications in the context of wave energy ;
- how they can be used for long term analysis of wind speed.

What do they are?

They are models that allow the possibility of representing nonstationary event occurring at sea in a simplified way. More precisely, such event are known as sea storms and are carachterized by randomness in shape, intensity and duration. The basic idea behind STORM MODELS concerns the possibility of substituting the real storm event by another with simpler and standardized geometric shape, mantaining a kind of equivalence with the real storm event.

The geometric shapes can be different, depeding on the selected model. Further, the kind of equivalence is related with the specific aspect one wants to investigate and on the typology of application.

Potential applications of storm models in the field of Ocean engineering

- **Long-term Statistics**: calculation of design waves (return value associated to given return period), calculation of mean persistance above a given threshold, maximum expected wave height during a sea storm (Borgman approach) . In **time domain** and/or in **space-time domain;**

- **Structural damage of rubble mound breakwaters;**
- **Coastal Erosion;**
- **Wave energy ;**
- **Fatigue analysis;**

Kind of Equivalence between real storm and that by storm model

- Long-term Statistics Statistical Equivalence
- Structural damage of rubble mound breakwaters Magnitude, duration, or number of waves
- Coastal Erosion Magnitude, duration, or number of waves
- Wave energy Storm total energy or the same of long-term statistics
- Fatigue analysis Intensity and duration, number of waves

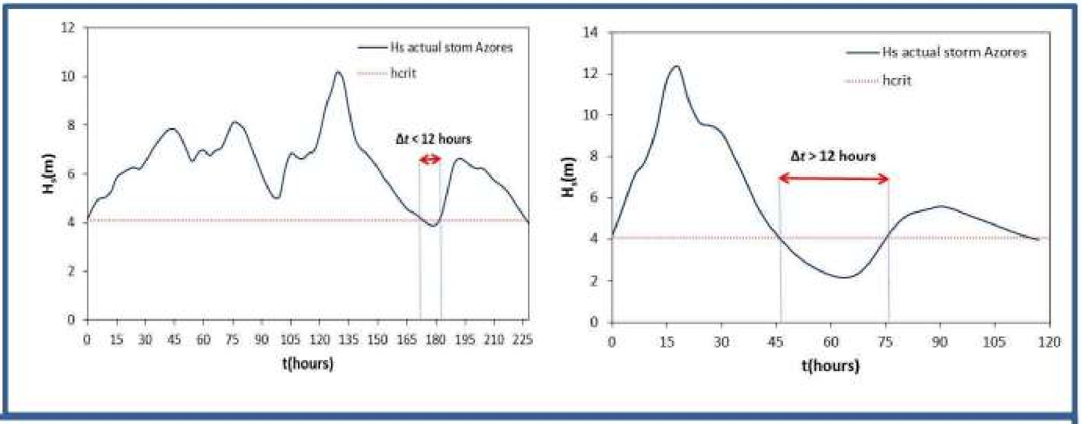
Equivalent Storm Models Approach

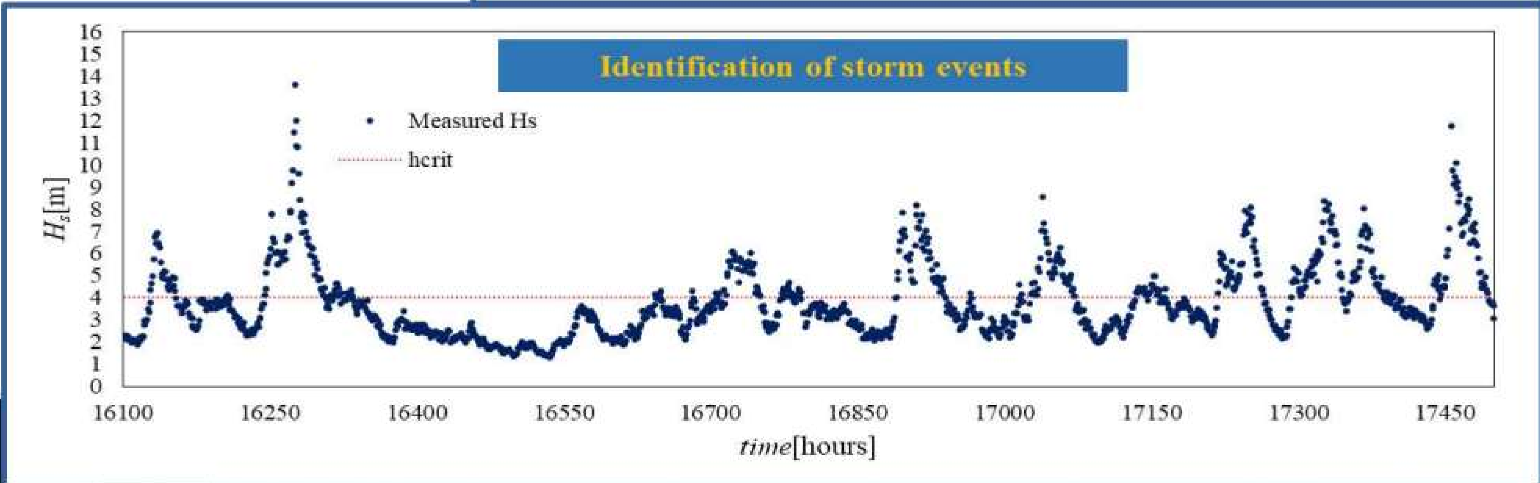
- **Equivalent Triangular Storm Model (ETS)** (Boccotti, 1987;2000;2014)
- **Equivalent Power Storm Model(EPS);** (Fedele and Arena, 2010)
- **Equivalent Exponential Storm Model (EES);** (Laface and Arena, 2016)
- **Trapezoidal Model (TS*) (Following DNV-GL guidelines).** (Laface et al., 2019)

SEA STORM DEFINITION

***Sea storm definition*:** A sea storm is a sequence of sea states in which the significant wave height H_s is above a certain, constant, threshold h_{crit} and does not fall below it for a certain time interval Δt (Boccotti, 2000). The values of the threshold and of the time interval Δt depend on the characteristics of the recorded sea states and, thus, on the location under study. Boccotti (2000) has proposed the following values:

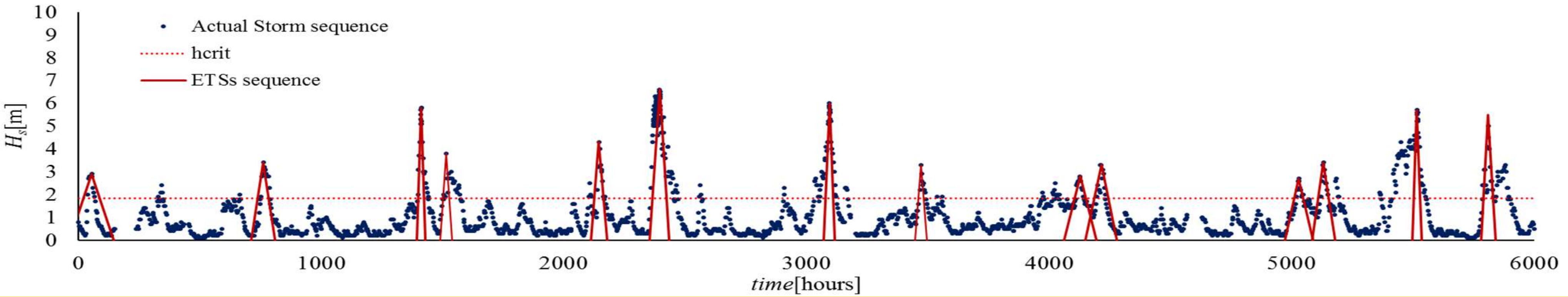
$$h_{crit} = 1.5\overline{H}_s$$
$$\Delta t = 12 \text{ hours}$$





BASIC CONCEPT BEHIND STORM MODELS

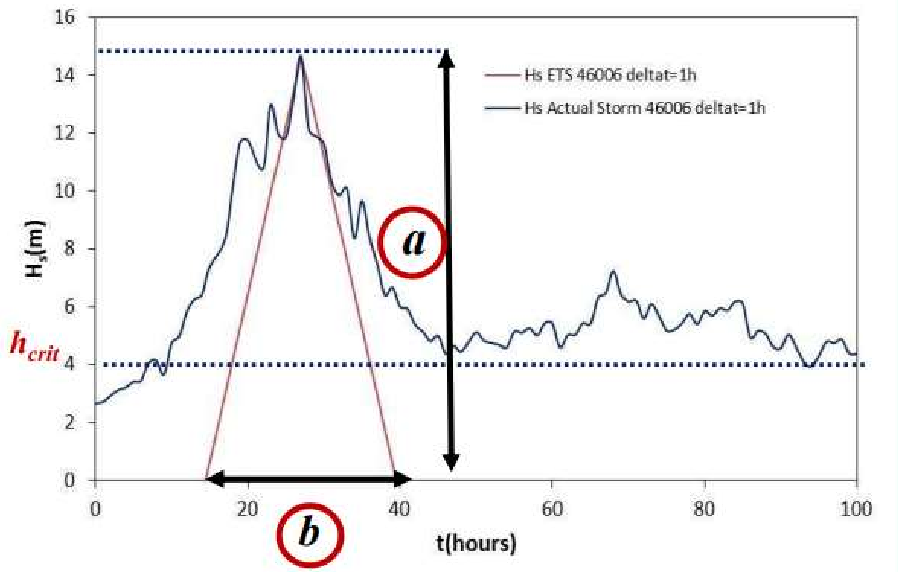
Actual storm sequence (events represented by blu dots) at a given site (named Actual sea) is replaced by an equivalent storm sequence (red line) (Equivalent Sea), keeping the same wave rysk.



This is possible for two reasons:

- Each actual storm and associated equivalent storm are statistically equivalent;
- $P(H_s>h)$ of actual storm sequence and ETS sequence are the same.

Equivalent Triangular Storm Model (Boccotti, 2000)



$$\overline{H_{\max AS}} = \int_0^\infty 1-\exp\left\{\int_0^D \frac{\ln[1-P(H;H_s=(h(t))]}{\overline{T}(h(t))}\mathrm{d}t\right\}\mathrm{d}H$$

It is possible to rewrite the expression above for the case of a storm with an isosceles triangular shape as that represented in the figure on the left. It can be easily done by explicitating the integral over time *t* for the triangular storm. In particular, it can e rewritten as:

$$\int_0^D \frac{1}{\overline{T}(h(t))}\ln[1-P(H;H_s=h(t))]dt = 2\int_0^{b/2} \frac{1}{\overline{T}(h(t))}\ln[1-P(H;H_s=h(t))]dt$$

Then by considering the relationship between *h* e *t* (*h*(*t*) is known for ETS), which is given by

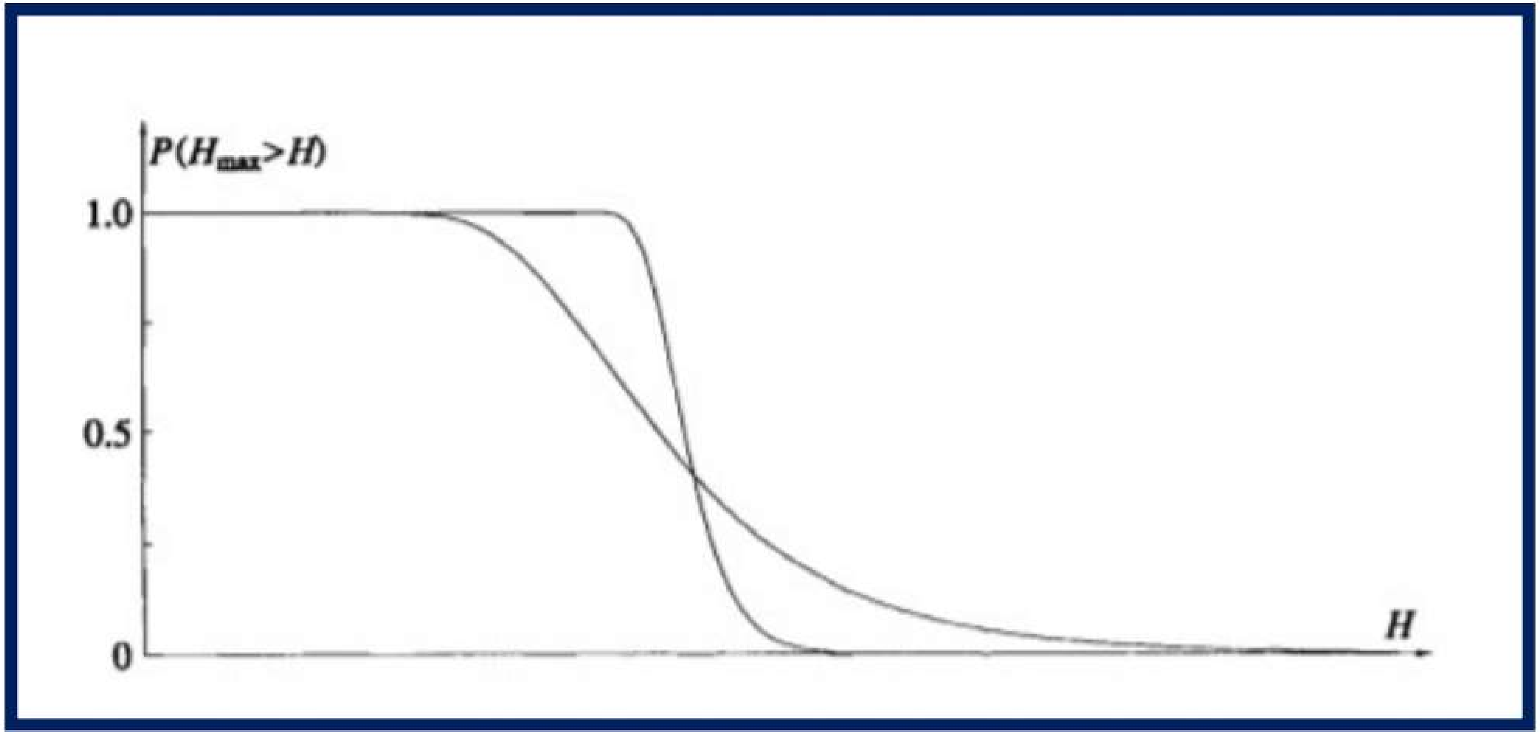
$$dt = \frac{b}{2a}dh$$

$$\overline{H_{\max ETS}}(a,b) = \int_0^\infty 1-\exp\left\{\frac{b}{a}\int_0^a \frac{\ln[1-P(H;H_s=h)]}{\overline{T}(h)}\mathrm{d}h\right\}\mathrm{d}H$$

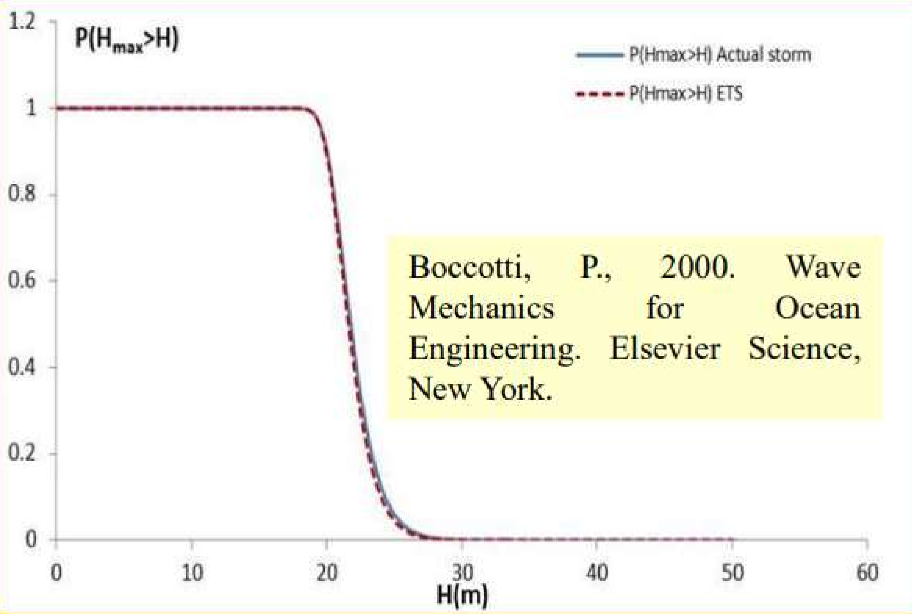
Maximum expected wave height of ETS Boccotti(1987,2000,2014)

Equivalent Triangular Storm Model (Boccotti, 2000)

As a consequence of imposing the equality between the two maximum expected wave heights, one would expect a behaviour of the two $P(H_{max}>H)$ as the following:



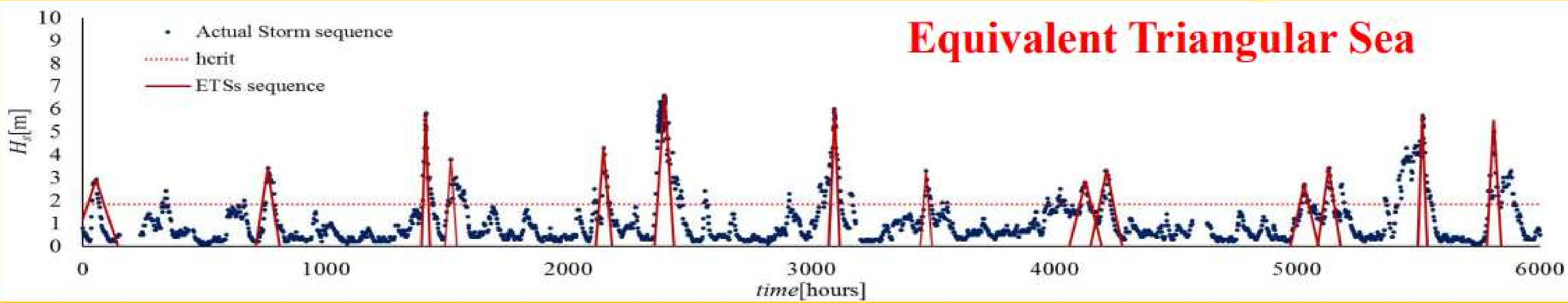
Equivalent Triangular Storm Model (Boccotti, 2000)



Boccotti, P., 2000. Wave Mechanics for Ocean Engineering. Elsevier Science, New York.

AS and ETS are **statistically equivalent** because they have the same maximum expected wave height (imposed in the calculation of b) and the same probability $P(H_{max}>H)$ that the maximum wave H_{max} exceeds a given threshold H.

Equivalent Triangular Sea



Keeping unchanged the wave risk

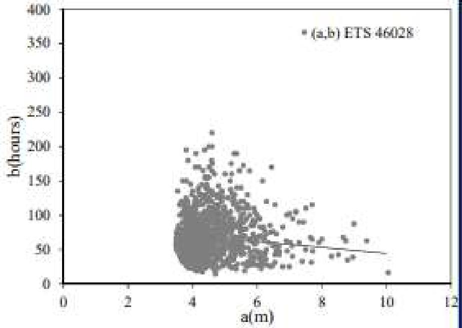
ANALYTICAL SOLUTION OF THE RETURN PERIOD OF A STORM WITH GIVEN CHARACTERISTICS ARE DEVELOPED, BASING ON THE SIMPLIFIED STORM SHAPE :

- Return period $R(H_s>h)$ of a storm whose maximum Hs exceeds the threshold h; (coastal structures)
- Return period $R(H)$ of a storm whose maximum wave exceeds the threshold H. (offshore structures)

RETURN PERIOD $R(H_s>h)$

$$R(H_s > h) = \frac{\tau}{N(\tau; A > h)}$$

$$N(\tau; A>h) = \int_{a=h}^{\infty}\int_{b_E=0}^{\infty} dN(a,b_E) = N(\tau)\int_h^{\infty} p_A(a)\,da$$



$$p_A(a) = -\frac{a}{\bar{b}(a)}\frac{\tau}{N(\tau)}\frac{d^2P}{da^2}$$

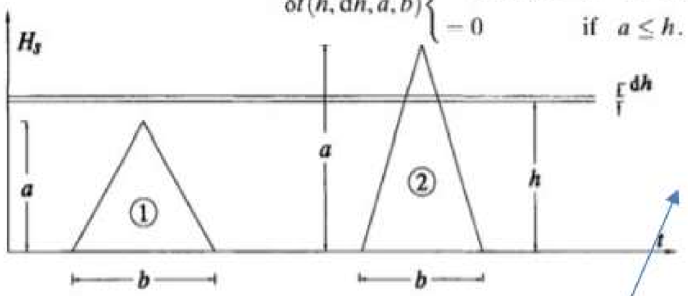
$$R(H_s > h) = \frac{\bar{b}(h)}{hp(H_s = h) + P(H_s > h)}$$

$$\bar{b}(h) = \bar{b}(a) = k_1 a + k_2$$

$$p(H_s = h) = -\frac{dP(H_s > h)}{dh} \qquad P(H_s > h) = \exp\left[-\left(\frac{h-h_l}{w}\right)^u\right]$$

$$R(H_s > h) = \frac{k_1 h + k_2}{1 + (u/w)h\left(\frac{h-h_l}{w}\right)^{u-1}}\exp\left[\left(\frac{h-h_l}{w}\right)^u\right]$$

$$\delta t(h, dh, a, b)\begin{cases} = (dh/a)\,b & \text{if } a > h, \\ = 0 & \text{if } a \le h. \end{cases}$$



$$\tau P(H_s > h)$$

Total time above h in Actual Sea

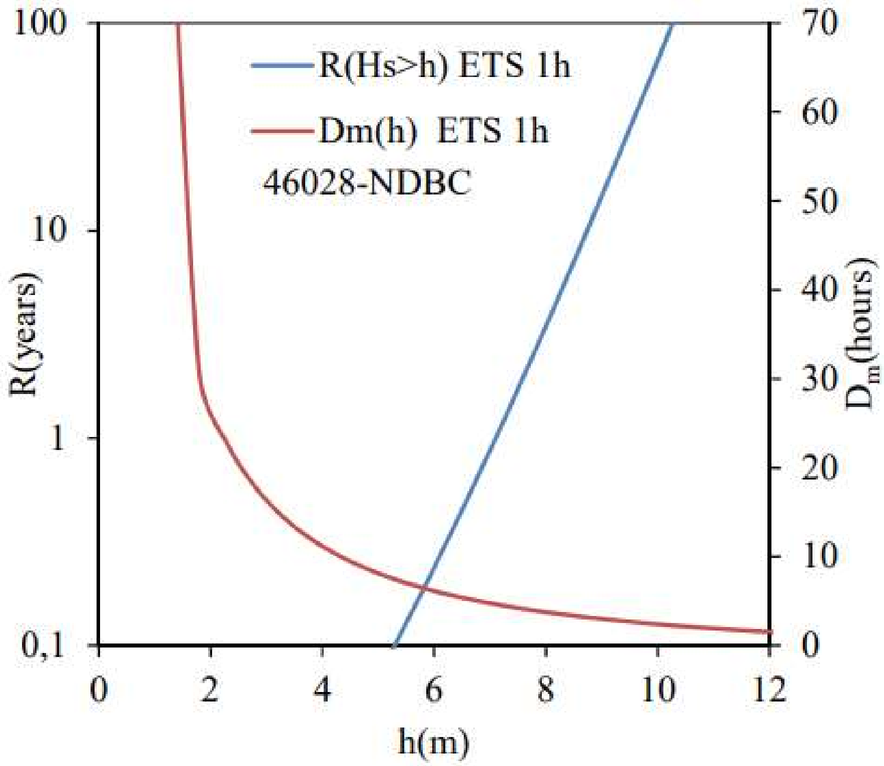
$$\Delta t(h, dh, \mathcal{T}) = \int_0^{\infty}\int_0^{\infty} p_A(a)\,\mathcal{N}(\mathcal{T})\,p_B(b|a)\,\delta t(h, dh, a, b)\,db\,da$$

Total time above h in Equivalent Triangular sea

$$p_A(a) = -\frac{a}{\bar{b}(a)}\frac{\tau}{N(\tau)}\frac{d^2P}{da^2}$$

Equivalent Triangular Storm(ETS) model:

Mean persistance $D_m(h)$ above h



Average time during which H_s is above h in the storm exceeding the threshold h. It is the ratio between the total time above h and the number of storms $N(\tau;h)$ h;exceeding h, during τ .

$$D_m(h) = \frac{\tau P(H_s > h)}{\left(\dfrac{\tau}{R(H_s > h)}\right)}$$

$$D_m(h) = P(H_s > h) R(H_s > h)$$

$$Dm(h) = \frac{k_1 h + k_2}{1 + (u/w) h \left(\dfrac{h - h_l}{w}\right)^{u-1}}$$

RETURN PERIOD *R*(*H*)

$$R(H) = \frac{\tau}{N(H;\tau)}$$

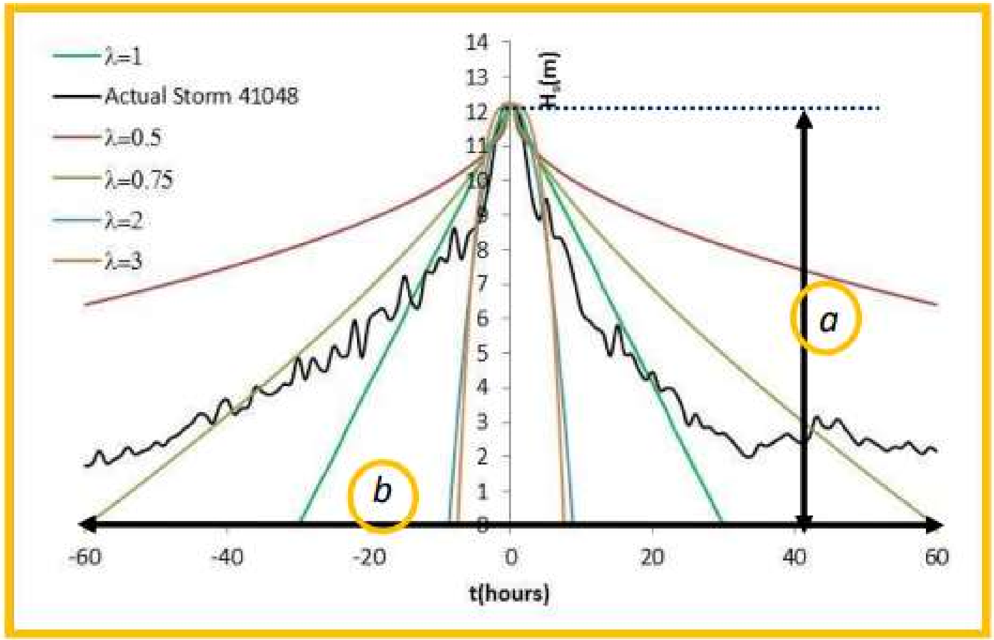
Long time interval

Number of storm during τ whose maximum wave exceeds H

$$N(H;\tau) = N(\tau) \int_H^\infty \int_0^\infty \int_h^\infty \int_0^\infty p_{A(a)} p_B(b|a) \frac{b}{a} \frac{1}{\overline{T}(h)} p(x; H_s = h) \cdot \{P(H_{max} < x; a, b)/[1 - P(x; H_s = h)]\} dbdadhdx$$

$$R(H) = \left\{ \int_H^\infty \int_0^\infty \frac{1}{\overline{T}(h)} p(x; H_s = h) \int_h^\infty - \frac{dp(H_s = a)}{da} \cdot exp\left[\frac{\overline{b}(a)}{a} \int_0^a \frac{1}{\overline{T}(h')} ln[1 - P(x; H_s = h')]\, dh' \right] dadhdx \right\}^{-1}$$

Equivalent Power Storm (EPS) Model (JPO, 2010)



Fedele, F., and Arena, F., 2010. The equivalent power storm model for long-term predictions of extreme wave events. J. Phys. Oceanogr. 40, 1106–1117.

$$\overline{H_{\max AS}} = \int_0^\infty 1-\exp\left\{\int_0^D \frac{\ln[1-P(H;H_s=(h(t))]}{\overline{T}(h(t))}\,dt\right\}dH$$

$$\overline{H_{\max EPS}}(a,b) = \int_0^\infty 1-\exp\left\{\frac{b}{\lambda a}\int_0^a \frac{\ln[1-P(H;H_s=h)]}{\overline{T}(h)}\left(1-\frac{h}{a}\right)^{\left(\frac{1}{\lambda}-1\right)}dh\right\}dH$$

$$h(t) = -\left(\frac{2}{b_\lambda}\right)^\lambda a\cdot t^\lambda + a$$

$$\overline{H_{\max ETS}}(a,b) = \int_0^\infty 1-\exp\left\{\frac{b}{a}\int_0^a \frac{\ln[1-P(H;H_s=h)]}{\overline{T}(h)}\,dh\right\}dH$$

Equivalent Power Storm (EPS) Model (JPO, 2010)

Fedele, F., and Arena, F., 2010. The equivalent power storm model for long-term predictions of extreme wave events. J. Phys. Oceanogr. 40, 1106–1117.

λ_{opt}=0.75 less than linear!!

$$R(H_s > h) = \frac{1}{\int_h^{\infty} \frac{a}{\overline{b}(a)} G(\lambda, a)\, da}.$$

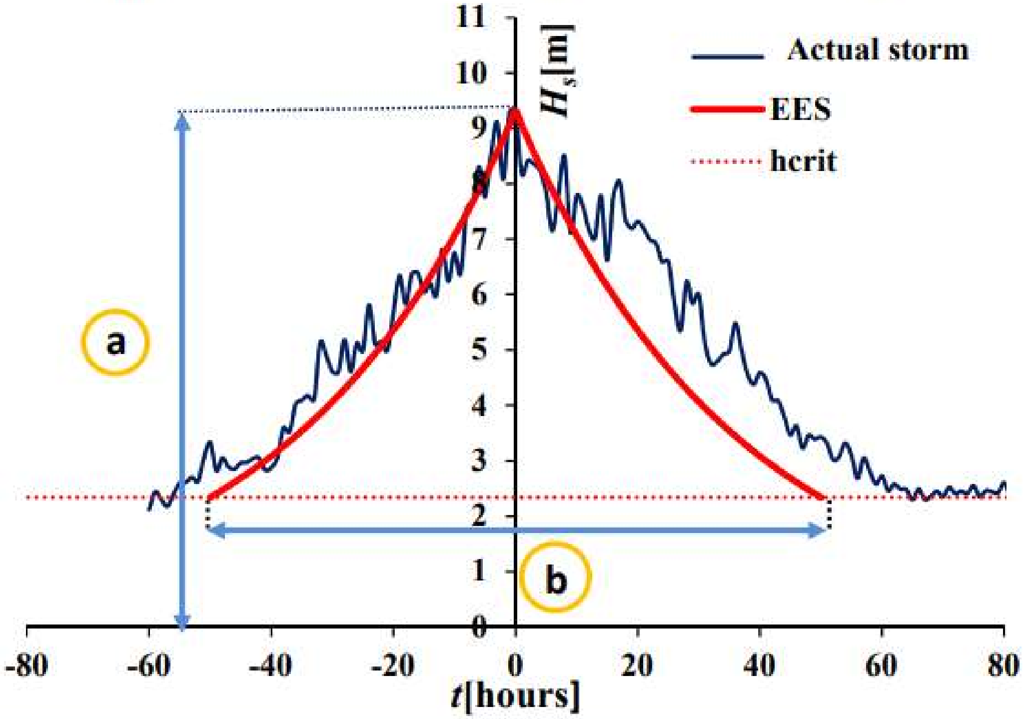
$$R(H_{\max} > H) = \frac{1}{\int_h^{\infty} \frac{a}{\overline{b}(a)} G(\lambda, a) P[H_{\max} > H; a, \overline{b}(a)]\, da},$$

$$G(\lambda, a) = \begin{cases} \frac{\sin(\pi/\lambda)}{\pi/\lambda} \int_1^{\infty} \left.\frac{d^2 P}{dz^2}\right|_{a,x} (x-1)^{-1/\lambda}\, dx, & \text{if} \quad \lambda > 1 \\ \frac{d^2 P}{da^2}, & \text{if} \quad \lambda = 1 \\ \frac{(-1)^n a^n}{n!} \frac{\sin(\pi\mu)}{\pi\mu} \int_1^{\infty} \left.\frac{d^{n+2} P}{dz^{n+2}}\right|_{a,x} (x-1)^{-\mu}\, dx, & \text{if} \quad \lambda = (n+\mu)^{-1} < 1 \end{cases}$$

Equivalent Exponential Storm (EES) Model

The EES is defined by means of three parameters:

- ***a*** which gives the storm intensity and it is equal to the maximum significant wave height during the actual storm;
- ***b*** which is representative of storm duration and it is such that the maximum expected wave height is the same in the EES and in the actual storm;
- h_{crit} critical threshold of significant wave height used to identify storms.



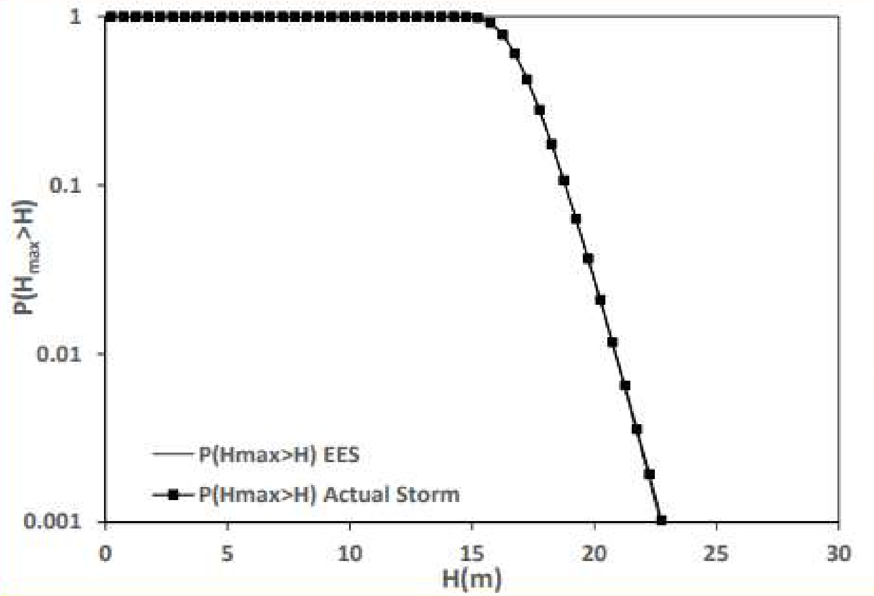
<u>***Laface V.***</u>, et al. (2016), A new equivalent exponential storm model for long-term statistics of ocean waves, **"Coastal Engineering"**, n.116 pp. 133-151 CENG3144 DOI:10.1016/j.coastaleng.2016.06.011

$$h(t) = a \exp\left[\frac{2}{b}\ln(h_{crit}/a)|t|\right]$$

Equivalent Exponential Storm (EES) Model: calculation of b and statistic equivalence between EES and AS

The AS and the EES are statistically equivalent, because they are characterized by:

- **the same maximum significant wave height;**
- **The same probability of exceedance of the maximum wave height.**



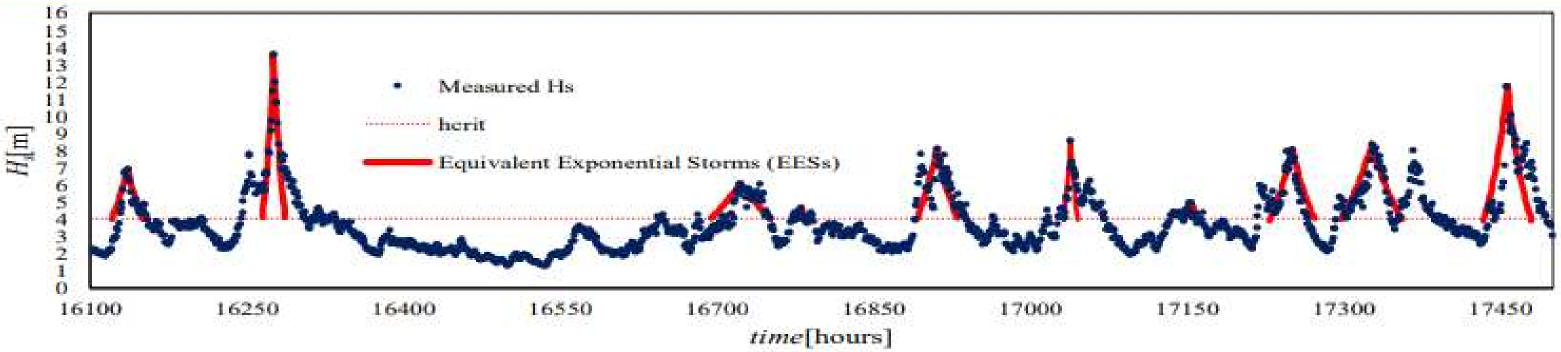
Actual Storm

$$\overline{H_{\max AS}} = \int_0^{\infty} 1 - \exp\left\{ \int_0^{D} \frac{\ln[1 - P(H; H_s = (h(t))]}{\overline{T}(h(t))} \mathrm{d}t \right\} \mathrm{d}H$$

Equivalent Exponential Storm

$$\overline{H_{\max EES}}(a, b, hc_{rit}) = \int_0^{\infty} 1 - \exp\left\{ -\frac{b}{\ln(h_{crit}/a))} \int_{h_{crit}}^{a} \frac{\ln[1 - P(H; H_s = h)]}{\overline{T}(h)} \frac{1}{h} \mathrm{d}h \right\} \mathrm{d}H$$

Return period $R(H_s>h)$ and mean persistance $D_m(h)$for EES

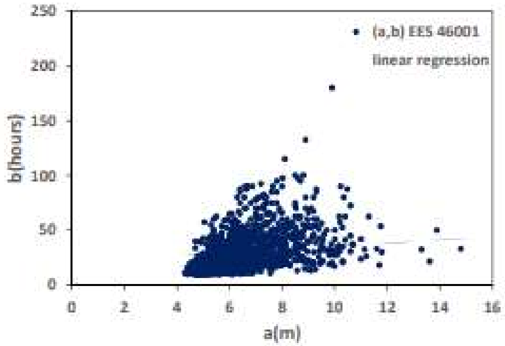


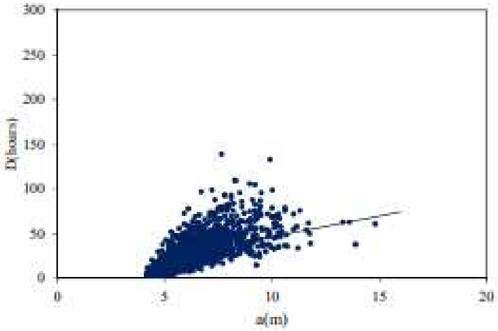
$$R(H_s > h) = \frac{\tau}{\mathrm{N}(\tau; A > h)}$$

$$\mathrm{N}(\tau; A > h) = \int_{a=h}^{\infty} \int_{b_E=0}^{\infty} \mathrm{d}N(a, b_E) = N(\tau) \int_{h}^{\infty} p_A(a)\mathrm{d}a$$

$$p_A(a) = -\frac{1}{\bar{b}(a)} \frac{\tau}{N(\tau)} \left(\frac{\mathrm{d}P(H_s > a)}{\mathrm{d}a} + a \frac{\mathrm{d}^2 P(H_s > a)}{\mathrm{d}a^2} \right) \ln\left(\frac{h_{crit}}{a} \right)$$

$$R(H_s > h) = \frac{\bar{b}(h)}{-h \ln\left(\frac{h_{crit}}{h}\right) p(H_s = h) + P(H_s > h)}$$





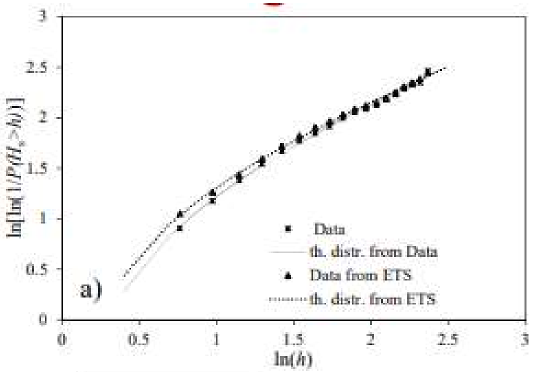
$$D_m(h) = \frac{\tau P(H_s > h)}{\mathrm{N}(\tau; A > h)}$$

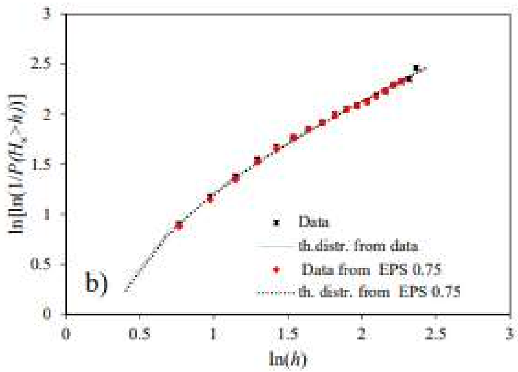
$$D_m(h) = P(H_s > h) R(H_s > h)$$

- **Laface, V.**, et al., Directional analysis of sea storms, "***Ocean engineering***", n. 107, 2015, pp. 45-53, ISSN:0029-8018, doi.org/10.1016/j.oceaneng.2015.07.027.
- **Laface V.**, et al., (2016) , Peak Over Threshold vis-à-vis Equivalent Triangular Storm: return value sensitivity to storm threshold, "***Coastal Engineering***", n. 116 pp. 220-235CENG3142 DOI:10.1016/j.coastaleng.2016.06.009.
- **Laface V.**, et al., (2016), A new equivalent exponential storm model for long-term statistics of ocean waves, "***Coastal Engineering***", n.116 pp. 133-151 CENG3144 DOI:10.1016/ j.coastaleng.2016.06.011.
- **Laface, V.**, et al. (2017), P.: Assessment of reliability of extreme wave height prediction models, ***Nat. Hazards Earth Syst***. Sci., 17, 409-421, https://doi.org/10.5194/nhess-17-409-2017, 2017.

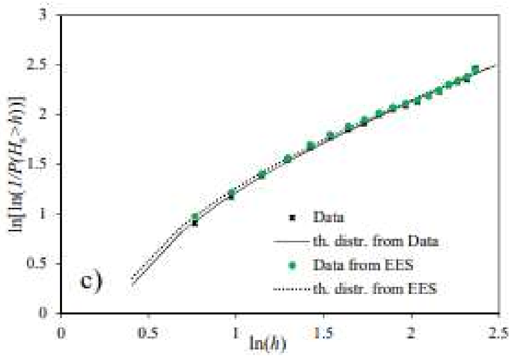
EES MODEL ADVANTAGES

- Closed form solution for $R(H_s>h)$;
- Duration b EES well repersents duration D of actual storm;
- Durations of both actual and EES storm increases for increasing intensity a;
- EES sea well represents actual sea.





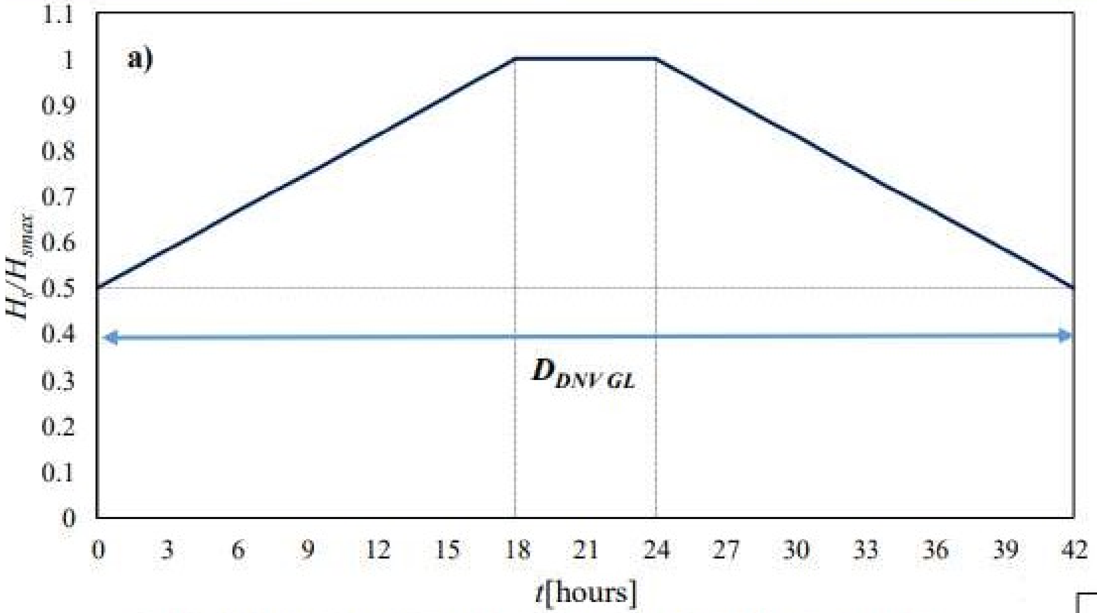
	ETS		EPS		EES		Actual storms
Buoy	$\rho_{a,b}$	$\rho_{b,D}$	$\rho_{a,b}$	$\rho_{b,D}$	ρ_{a,b_E}	$\rho_{b_E,D}$	$\rho_{a,D}$
42001	-0.154	0.216	-0.160	0.210	0.551	0.652	0.604
46042	-0.281	0.114	-0.286	0.108	0.495	0.640	0.673
46001	-0.263	0.095	-0.267	0.090	0.432	0.549	0.661



TRAPEZOIDAL STORM MODEL

- The Trapezoidal Storm (TS*) model aims to provide an analytical solution for calculating the return period $R(H_s>h)$ (or eqivalently $h(R)$) in a very simple e fast way and by referring the **DNV GL trapezoidal storm profile**;
- This is achieved by parameterizing the **DNV GL trapezoidal storm profile** and by following similar logic to that of ESMs.
- A simplification is introduced which consists in assuming all the TSs have the same duration whatever the intensity is.
- This assumption strongly simplify the model avoiding the determination of intensity-height regression function, but does not guarantee the equality on $\overline{H}_{max}$ and $P(H_{max}>H)$ of AS and TS.
- However, the TS profile leads to slight overestimation on both H_{max} and $P(H_{max}>H)$ with respect to the AS ones, thus is more conservative.

DNV-GL STORM PROFILE AND ITS PARAMETERIZATION



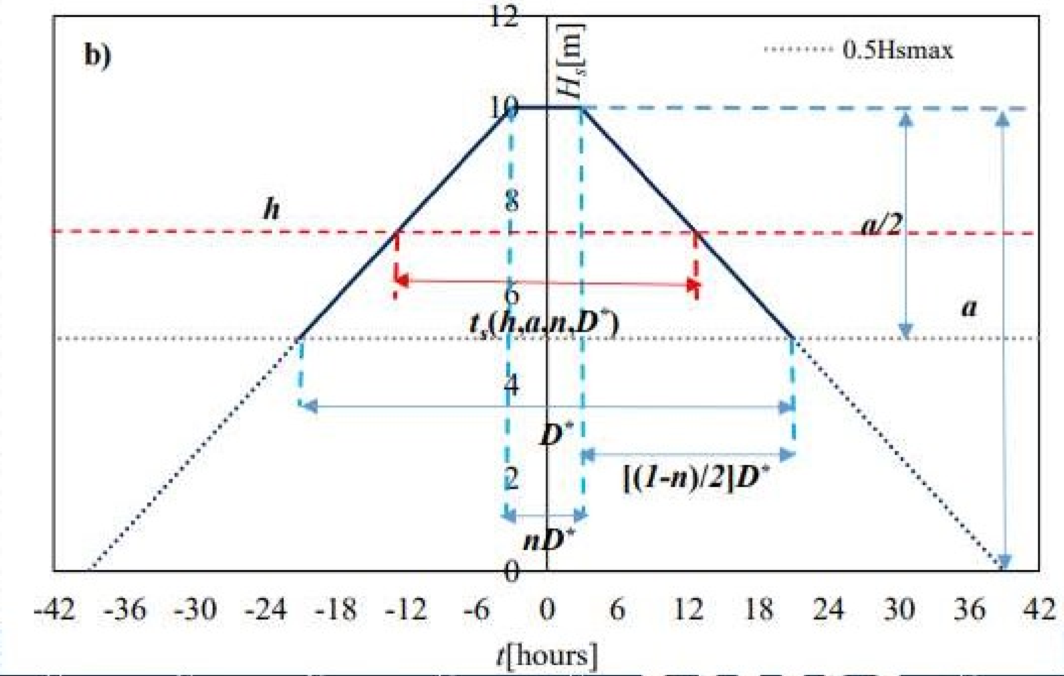
$D_{DNV\ GL}$=42 hours
Duration above $0.5H_{smax}$

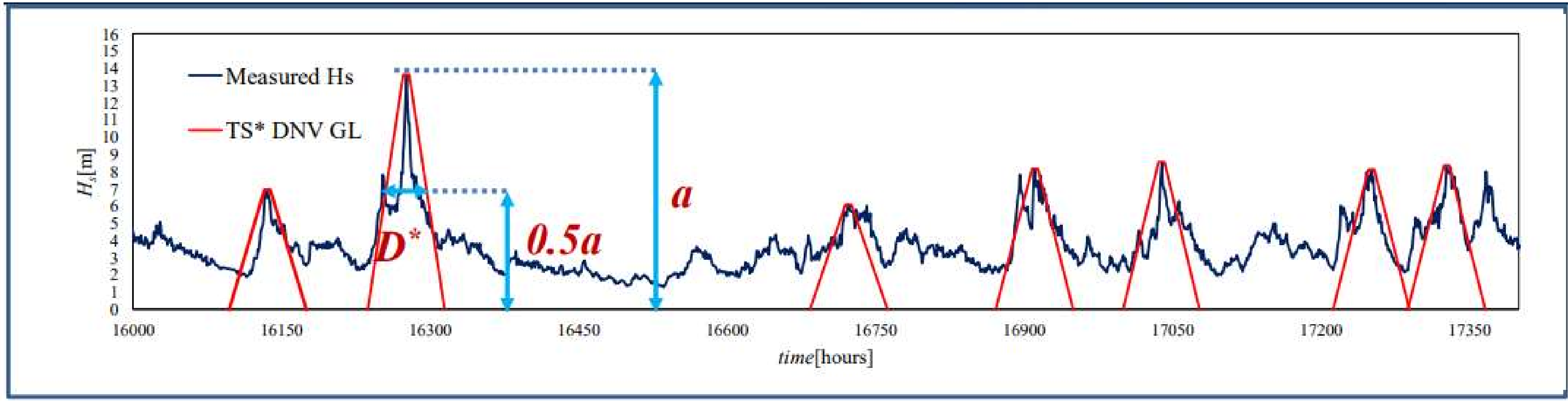
D^*=Duration above $0.5H_{smax}$
$a=H_{smax}$
Storm peak intesnity

Laface V., *Bitner-Gregersen E., Arena F., Romolo A., 2019. A parameterization of DNV-GL storm profile for the calculation of design wave of marine structures, Marine Structures, Vol. 68, doi.org/10.1016/j.marstruc.2019.102650.*

a) DNV GL STORM PROFILE AND
b) ITS PARAMETERIZATION

$$h(t)=\begin{cases} a & 0\le|t|\le\frac{n}{2}D^* \\ a\left\{1-\frac{\left[t-\frac{n}{2}D^*\right]}{(1-n)D^*}\right\} & \frac{n}{2}D^*\le|t|\le\frac{D^*}{2}\end{cases}$$





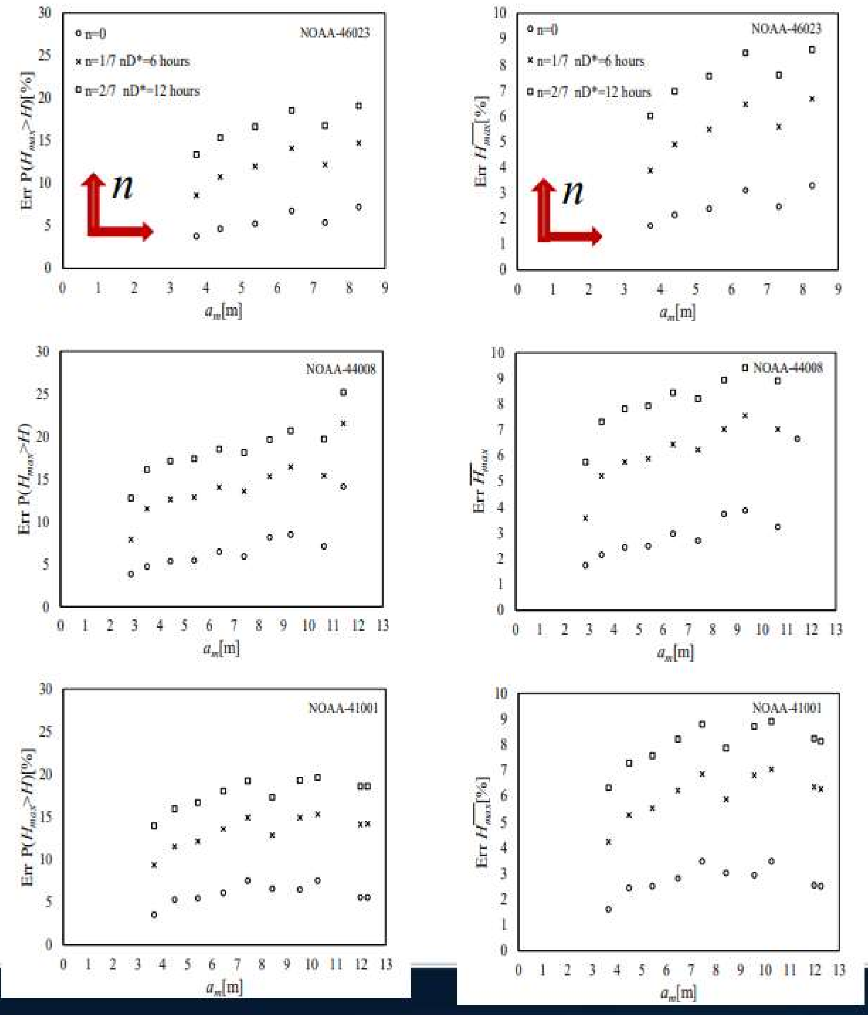
All the storms with the same duration D^* (above $0.5H_{smax}$) and different peak intensity a

D^*=Duration above $0.5H_{smax}$
$a=H_{smax}$
Storm peak intensity

No iterative procedure to determine D^*!!!

DATA ANALYSIS: Sensitivity of $P(H_{max}>H)$ and $\overline{H}_{max}$ with increasing n

Left: Average error on exceedance probability $P(H_{max}>H)$ for given classes of storm intensity a (am is the average of the considered class), for n=0, 1/7, 2/7.



Right: Average error on maximum expected wave height $\overline{H}_{max}$ for given classes of storm intensity a (am is the average of the considered class), for n=0, 1/7, 2/7.

***n* may be considered as a prudential factor!!!**

$$\overline{H}_{\max}(a,D^*,n)TS^*\int_0^{\infty}\left[1-\exp\left\{\frac{2(1-n)D^*}{a}\cdot\int_{0.5a}^{a}\frac{1}{\overline{T}(h)}\ln\left[1-P(H;H_s=h)\right]dh+nD^*\frac{1}{\overline{T}(a)}\ln\left[1-P(H;H_s=a)\right]\right\}\right]dH$$

Return period $R(H_s>h)$ for TS Model*

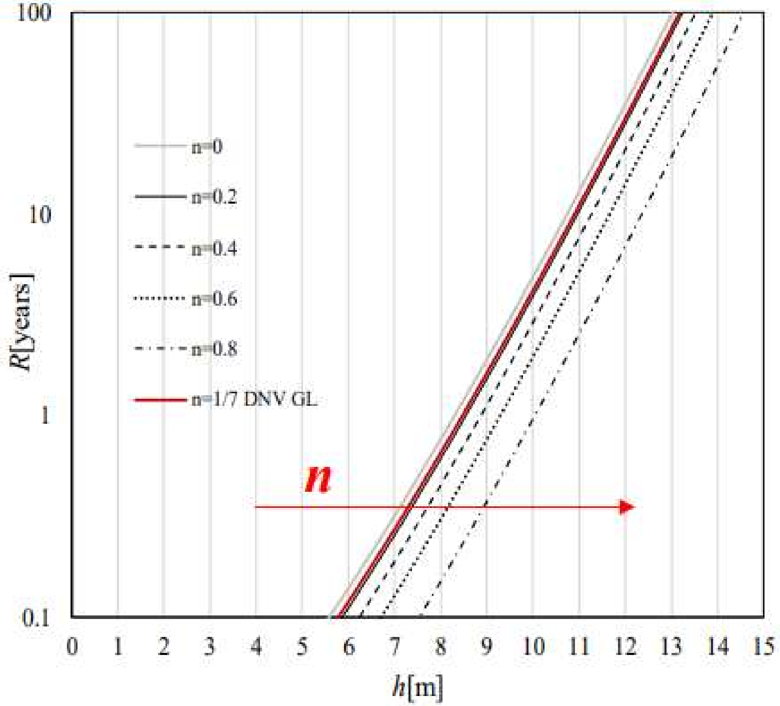
$$R(H_s > h) = \frac{\tau}{N(h;\tau)}$$

$$N(h;\tau) = N(\tau)\int_h^\infty p^*_A(a)da$$

$$\tau P(H_s > h) = \int_0^\infty\int_0^\infty N(\tau)p^*_A(a)p_D(D^*,a)t_s(h,a,n,D^*)dD^*da$$

$$p^*_A(a) = -\frac{\tau}{N(\tau)}\frac{a}{D^*}\frac{1}{2(1-n)}\frac{dp(H_s=a)}{da}$$

$$R(H_s > h) = \frac{2(1-n)D^*}{hp(H_s = h) + P(H_s > h)}$$



$R(H_s>h)$ FOR TS* WITH DURATION D^*=42 HOURS AND n RANGING BETWEEN 0 AND 0.8.

The only information required to apply the TS* model are the parameters of $P(H_s>h)$.

Comparison between ETS (Boccotti,2000) and TS Models*

$$\overline{H_{max}}(a,D^*,n)TS^*\int_0^\infty 1-\exp\left\{\frac{2(1-n)D^*}{a}\cdot\int_{0.5a}^{a}\frac{1}{\overline{T}(h)}\ln[1-P(H;H_s=h)]dh+nD^*\frac{1}{\overline{T}(a)}\ln[1-P(H;H_s=a)]\right\}dH$$

TS* (DNV GL)

$$\overline{H_{max\,ETS}}(a,b)=\int_0^\infty 1-\exp\left\{\frac{b}{a}\int_0^a\frac{\ln[1-P(H;H_s=h)]}{\overline{T}(h)}dh\right\}dH$$

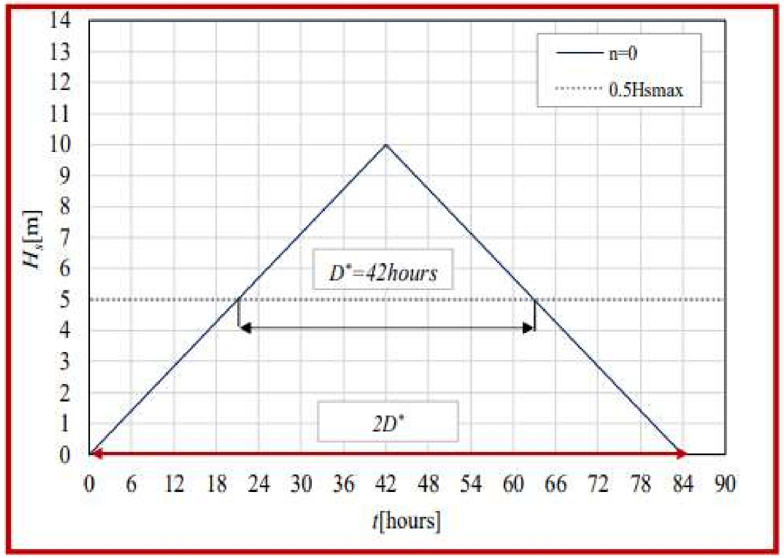
TS Boccotti

$$R(H_s>h)=\frac{2(1-n)D^*}{hp(H_s=h)+P(H_s>h)}$$

TS* (DNV GL)

$$R(H_s>h)=\frac{\overline{b}(h)}{hp(H_s=h)+P(H_s>h)}$$

TS Boccotti

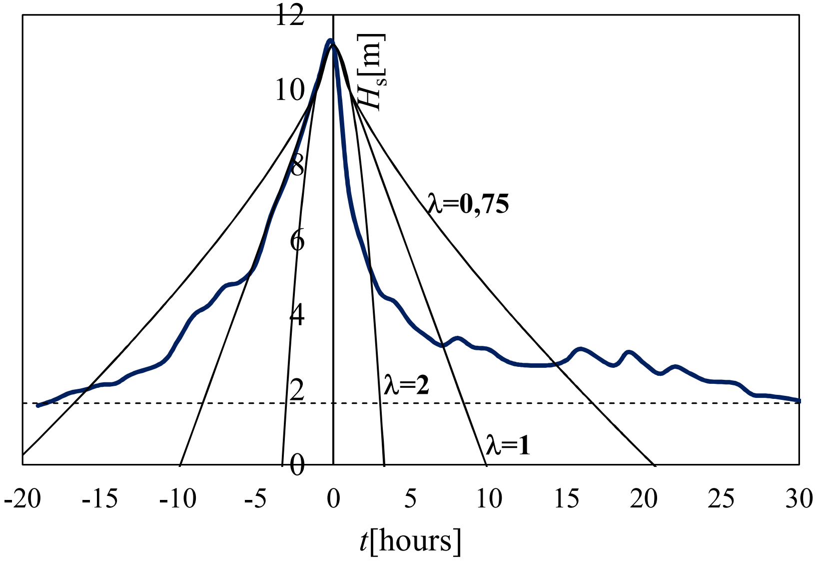


TS* coincides with TS when *n*=0 and $\overline{b(h)}$=cost=2*D***

USE OF STORM MODEL FOR ENERGY ESTIMATIONS:

Storm total energy and energy above fixed threshold

Time above the threshold t_{AS} for a given actual storm is estimated from data



Time above the threshold t_{EPS} for a given EPS is estimated from $H_s(t)$ function

$$h(t) = a\left[1 - \left(\frac{2|t-t_0|}{b}\right)^{\lambda}\right] \rightarrow t_{EPS}(h) = b\left(1-\frac{h}{a}\right)^{1/\lambda}$$

$$t_0 - b/2 \le t \le t_0 + b/2 \qquad t_0 = 0$$

Laface V., et al., Estimation of downtime and of missed energy associated with wave energy converters by the Equivalent Power Storm model, "Energies", n. 8, 2015, pp. 11575-11591, ISSN: 1996-1073, 8, doi:10.3390/en81011575.

Wave power for a given sea state

$$\phi = \frac{\rho g^2}{64\pi} H_s^2 \gamma_f T_m$$

Energy for a given sea storm

$$E_{AS} = \int_0^D \phi(t)\,dt \rightarrow E_{EPS}(a,b,h_{crit},\lambda) = ka^{1.5}\frac{b}{\lambda}\int_{h_{crit}}^{a}\left(\frac{h}{a}\right)^{2.5}\left(1-\frac{h}{a}\right)^{\left(\frac{1}{\lambda}-1\right)}dh$$

$h>h_{crit}$ ΔE_{EPS}

USE OF STORM MODEL FOR ENERGY ESTIMATIONS:
Average Missed Energy for Given Sequences of Sea Storms

$$\Delta E_{\mathrm{m}}(h_{\mathrm{tr}}) = \frac{E_{\mathrm{TOT}}(h_{\mathrm{tr}})}{N(h_{\mathrm{tr}})}$$

Laface V., et al., Estimation of downtime and of missed energy associated with wave energy converters by the Equivalent Power Storm model, "Energies", n. 8, 2015, pp. 11575-11591, ISSN: 1996-1073, 8, doi:10.3390/en81011575.

$$E_{\mathrm{TOT}}(h_{\mathrm{tr}}) = \tau \int_{h_{\mathrm{tr}}}^{\infty} \varphi(h)\, p_{H_s}(h)\,\mathrm{d}h$$

Total energy above the threshold h_{tr}

$$N(h_{\mathrm{tr}}) = \frac{\tau}{R(h_{\mathrm{tr}})}$$

Number of storms during τ whose H_s max exceeds h_{tr}

$$\Delta E_{\mathrm{m}}(h_{\mathrm{tr}}) = R(h_{\mathrm{tr}}) \int_{h_{\mathrm{tr}}}^{\infty} \varphi(h)\, p_{H_s}(h)\,\mathrm{d}h$$

Average missed energy above the threshold h_{tr}

EQUIVALENT TRIANGULAR STORM MODEL FOR WIND SPEED

From the analysis of wind speed data and a comparative analysis with significant wave height data it is possible to understand that the nonstationary wind and wave events exhibit similar charactestics.

In fact, if we consider an Ocean storm, it is characterised by a grow, peak and decay stages. Similarly, wind storms, present an increase, peak and decay phases in their temporal evolution.

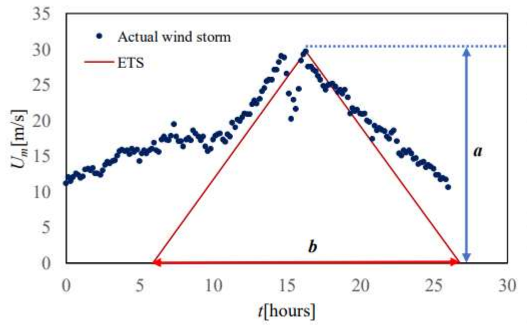
In analogy to Ocean wave storm, wind storms can be identified from average wind speed data, as a sequence of wind speed values exceeding a critical threshold, selected as 1.5 times the average wind speed at the site.

Each value of wind speed represents the average wind speed calculated over a time interval (of about ten minutes or less) compatible with the stationarity assumption and pertaints to a wind state characterised by given turbulence intensity TI and turbulence spectrum.

Laface V., and Arena F., 2021. On Correlation between Wind and Wave Storms. J. Mar. Sci. Eng. 2021, 9, 1426. https://doi.org/10.3390/jmse9121426.

EQUIVALENT TRIANGULAR STORM MODEL FOR WIND SPEED

Considering that the time evolution of wind and wave events is ver similar, the same shape used for wave storm analysis can be adopted for windstorm.



Assuming the same storm shape, that is selected as triangular, the analytical solution for the calculation of the return period $R(U_m>U)$ of a wind storm whose maximum average wind speed U_m exceeds the threshold U, is given by:

$$R(U_m > u) = \frac{\bar{b}(u)}{up(U_m = u) + P(U_m > u)}$$

Base-height regressing function of ETS for wind storm

Exceedance probability of average wind speed

The main difficulty in the adptation of ETS model for the wind storm events is to find a way to calculate the durations b and the base-heigh regression function for triangular wind storm.triangular wind storm

EQUIVALENT TRIANGULAR STORM MODEL FOR WIND SPEED

In the case of ETS for wave storm each b was determined by imposing the equality between the maximum expected wave heights of actual and storm and ETS, with the Borgman logic.
In the context of wind speed, wind gust is important, that is a significant variation of wind speed in a time interval of the order of second.
A wind gust G is defined here as amplitude of turbulence process. Thus, if wind turbulence is a gaussian process, its amplitude G follow a Rayleigh distribution

$$P(G;\sigma) = \exp\left[-\frac{1}{2}\left(\frac{G}{\sigma}\right)^2\right]$$

Further, applying the Borgman approach adopted for wave height, to wind gust G as defined above, the maximum expected gust G

$$\overline{G}_{\max AS} = \int_0^\infty 1 - \exp\left\{\int_0^D \frac{1}{\overline{T}(u(t))} \ln[1 - P(G;\sigma)]dt\right\}dG$$

$$\overline{G}_{\max ETS}(a,b) = \int_0^\infty 1 - \exp\left\{\frac{b}{a}\int_0^a \frac{1}{\overline{T}(u)} n[1 - P(G;\sigma)]du\right\}dG$$

Mean zero up crossing period, Rice Approach
Kaimal spectrum

Laface V., Romolo a., and Arena F., 2022. STORM MODELS FOR THE CALCULATION OF EXTREME WIND SPEED, Proceedings of the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering OMAE2022 June 5-10, 2022, Hamburg, Germany

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The Use of Storm Models in the Field of Ocean Engineering

THANK YOU VERY MUCH FOR YOUR ATTENTION!!!

Valentina Laface

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