SEAMOCS Workshop

Implication of climate change for marine and coastal safety

Waves, wave climate, extreme waves – knowledge from direct observations, space-born retrievals, and modelling

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October 11-12, 2007

Picture taken by the officer on board of the **handymax bulk carrier Selkirk Settler** in the **N. Atlantic, Feb.1987**.

Existing Wave Data

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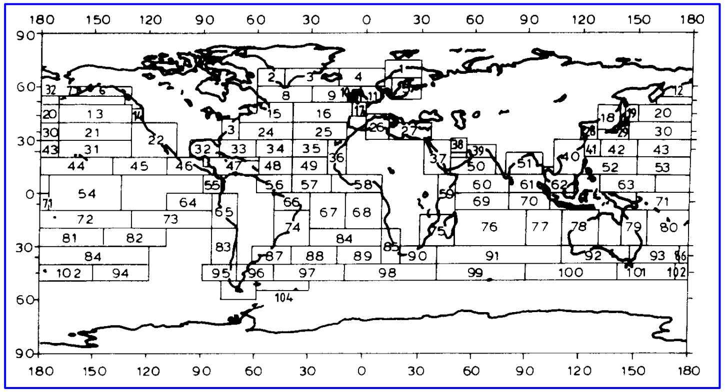
- Need for **improving** the **availability**, **quality** and **reliability** of **environmental databases** for marine structures' design & operational criteria - **international professional organisations, Classification Societies** and **offshore companies**.

- **High uncertainty** - **over-design** or **under-design** of **marine structures'** ⇒ significant **economic/risk impac**t, e.g. Guedes Soares and Trovão (1991), and Bitner-Gregersen et al. (1995).

- **Wave data**

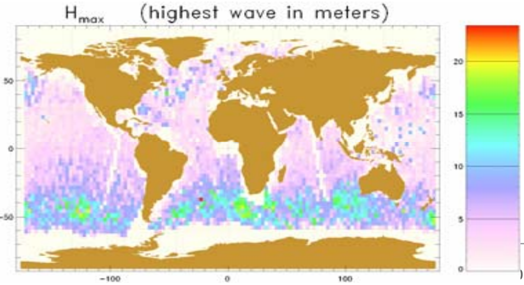
  - instrumental; location specific

  - *Global Wave Statistics (GWS)*



  - numerical generated data calibrated by in-situ & satellite data

  - satellite data



DLR

Questions:

- Is observed climate change a real trend or is it a result of climatic variations in the nature?
- How reliable are wave observations collected in the last 1-2 decades?
- What is the accuracy of numerical wave climate models?

- How consistence are predictions of the existing global wave databases ?
- Can the existing global wave databases be utilized fully by the industry?

The results presented were partly developed in collaboration with Prof. Carlos Guedes Soares.

Global Wave Databases

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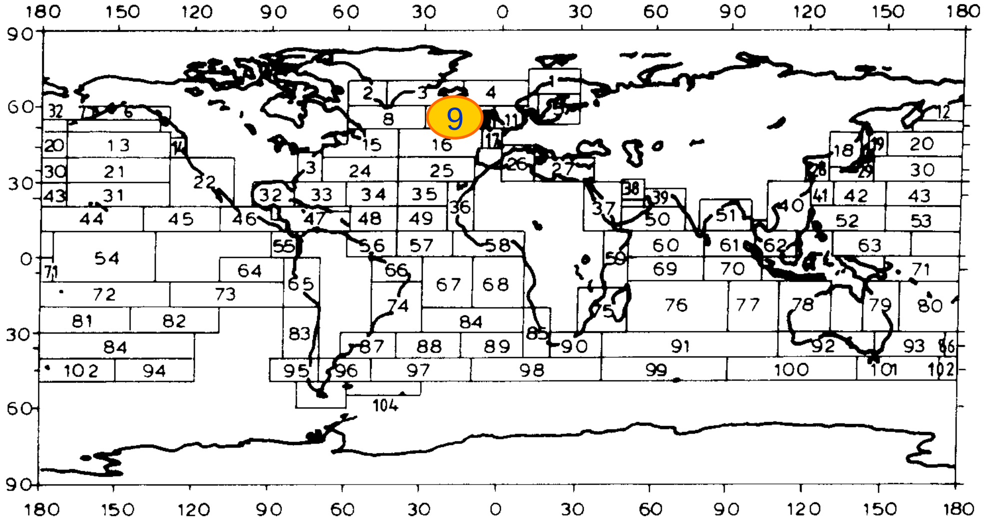
- **HIPOCAS** (Guedes Soares et al. 2002) - period **(1958 – 2002)**
- **Fugro OCEANOR** (Barstow et al. 2003) - period **(1984-2003)**
- **ARGOSS** (Valk et al. 2004) - period **(1990-2002)**
- ***Global Wave Statistics (GWS)***, Hogben et al. (1986) - period **(1949-1986)**
- **SBWR data** (Draper and Whitaker 1965) – period **(1952-1964)**
- **Altimeter data** - period **(1990-2002)**



Average Wave (Sea State) Steepness

- **Important characteristic of a sea state**
- **Critical parameter for the design of marine structures**

Guedes Soares, C.; Bitner-Gregersen, E., and Antão, P. (2001), "Analysis of the **Frequency of Ship Accidents** under Severe **North Atlantic Weather Conditions"** **;** U.Leuven (2003)

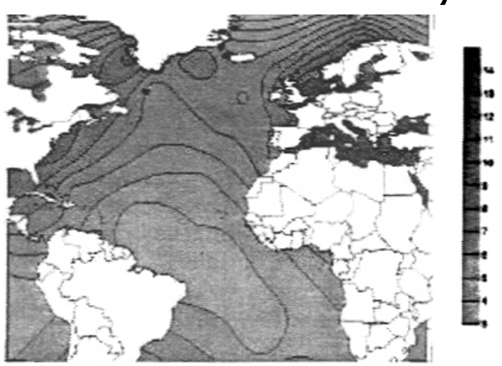


Figure 3 - Distribution of 20-years extreme wave steepness (data from Bitner Gregersen et al, 1995

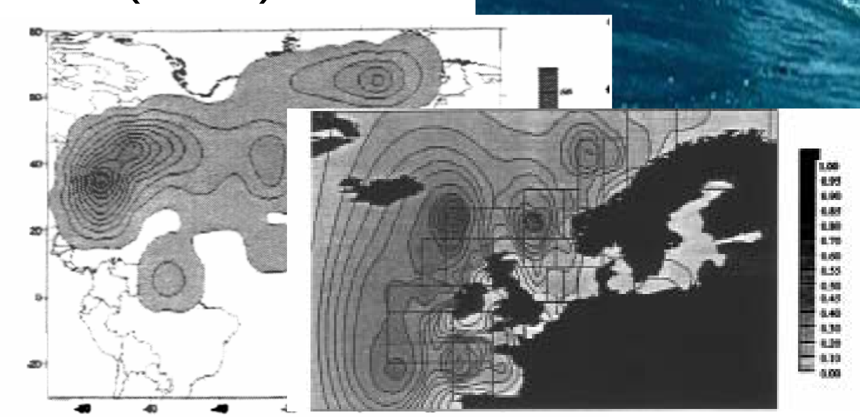


Figure 16 – Geographical distribution of the frequency of weather related accidents (n=355)

Average Wave Steepness

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Average wave steepness is usually defined as

$$S_t = 2\pi H_s / g T_z^2$$

Corresponding the ***N*-year steepness is**

$$S_t = 2\pi H_{s_N} / g T_{z_N}^2$$

For **design purposes** **extreme values** of the **average wave steepness** are of particular interest. May be determined:

- Existing standards
- Empirical expressions
- Theoretical formulas
- Directly from wave data.

Average Wave Steepness

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An **upper limit** of **the average wave steepness** based on **field data** and **theoretical models:**

- **Carter (1982)** for a **Pierson-Moskowitz spectrum** the steepness was **1/19.7**.
- **Carter (1982)** for **growing seas** in open waters for which the steepness was generally **higher** than about **1/16**. **For limited fetches** the waves were considerably steeper, in **the range 1/11.1 –1/14.8**. Confirmed by Battjes (1972) and Draper (1976).
- **Bjerke et al. (1990), Mathiesen and Torsethaugen (1992), and Torsethaugen (1993), Bitner-Gregersen et al. (1998)** for the Norwegian Continental Shelf in **the range 1/15 –1/14.3.**
- **DNV Rules** (DNV 2000) allow S_{Tz} **=1/15 for** high sea states, for lower S_{Tz} **=1/10.**
- **UK Department of Energy (1990)** S_{Tz} **=1/16-1/20.**

Average Wave Steepness

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- **Extreme wave steepness** is calculated by **fitting the data** by a **joint environmental model** due Bitner-Gregersen the 3-parameter Weibull distribution for **significant wave height**

$$f_{H_{mo|\varpi}}(h\,|\,\theta_i) = \frac{\beta}{\alpha}\left(\frac{h-\gamma}{\alpha}\right)^{\beta-1}\exp\left(-\left(\frac{h-\gamma}{\alpha}\right)\right)^{\beta}$$

where α = scale parameter, β = slope parameter, γ= location parameter, and is the main wave direction, and the conditional (on *Hmo*) lognormal distribution for **zero-crossing wave period**

$$f_{T_z|H_{mo,\Theta}}(t\,|\,h,\theta_i) = \frac{1}{\sqrt{2\pi}\sigma\cdot t}\exp\left[\frac{(\ln t-\mu)^2}{2\sigma^2}\right]$$

μ = *E(lnTz)* = $a_1 + a_2 h^{a_3}$

σ = *Std(lnTz)*= $b_1 + b_2 h^{b_3}$

***N*-year characteristic largest value of H_{m0}**

$$h_{m0_N} = \gamma + \alpha(\ln N)^{1/\beta}$$

Extreme Average Wave Steepness

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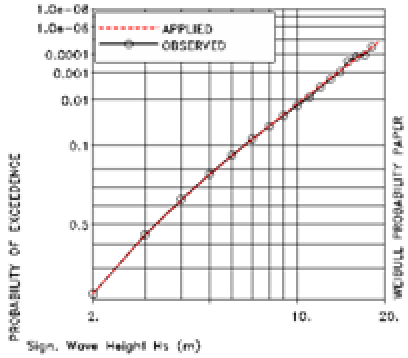
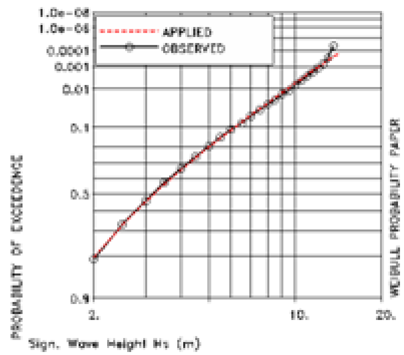
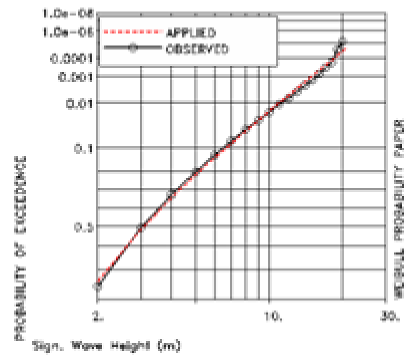
- **Fit of the joint model**



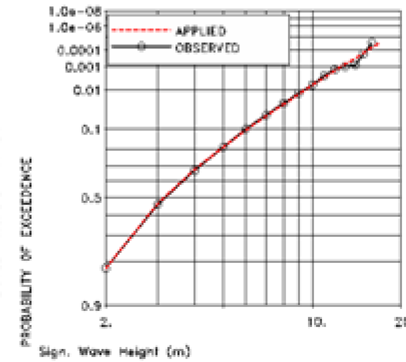
MARGINAL DISTRIBUTION – PRIMARY VARIABLE
Omnid. Database 1



MARGINAL DISTRIBUTION – PRIMARY VARIABLE
Omnid. Database 2

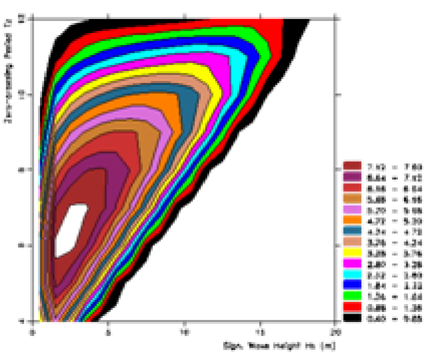


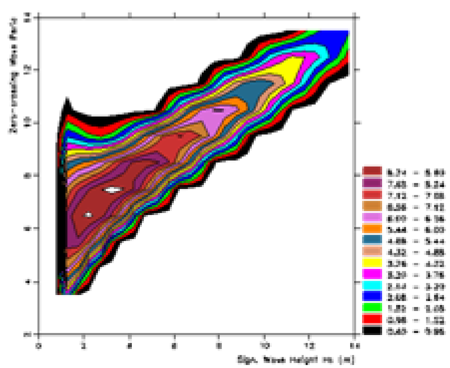
MARGINAL DISTRIBUTION – PRIMARY VARIABLE
Omnid. Database 3

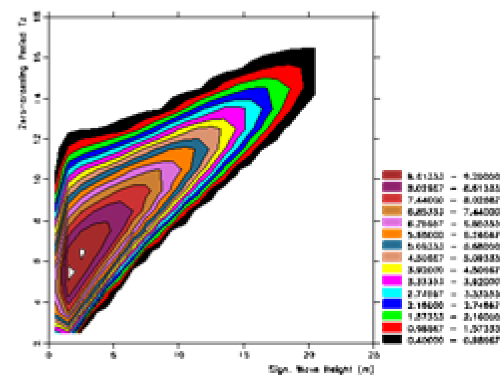


MARGINAL DISTRIBUTION – PRIMARY VARIABLE
St.India altimeter

altimeter data







Extreme Average Wave Steepness

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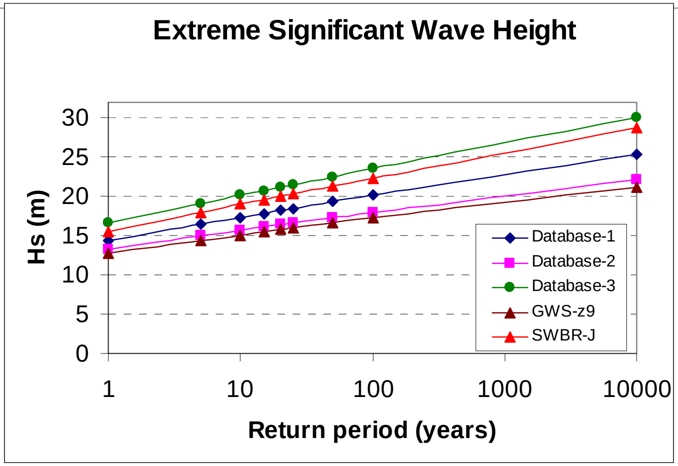
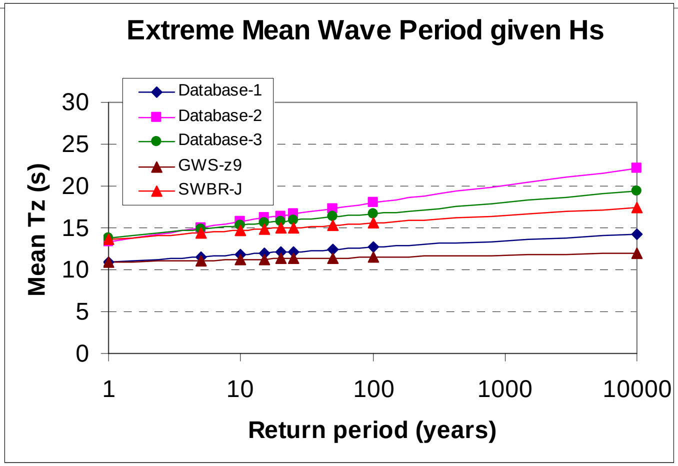




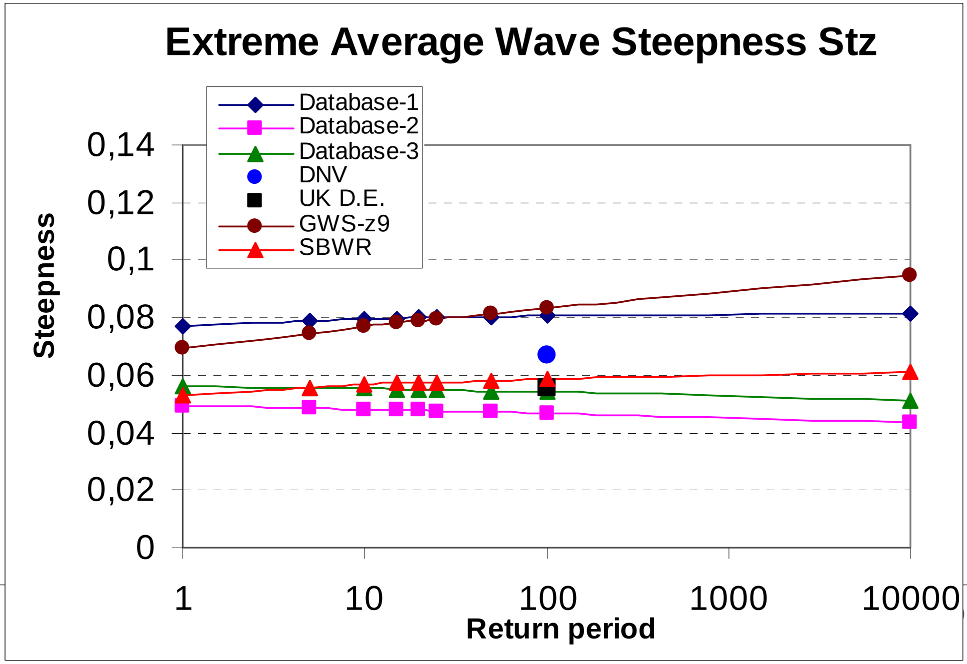
Extreme N-year H_{m0}

Extreme Tm_{02} given N-year H_{m0}

13-year observations

Date	Altimeter	Hs (m)
19930120	224900	14,8
19930120	224900	**15,8**
19930120	224900	**16,2**
19930120	224900	14,1

H_{s100}=19.6m



N-year extreme wave steepness

Environmental contours, Winterstein et al. (1993)

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- The contours are found from the (Hs, Tz) dist. by relating Hs and Tz (or Tp) to **standard normal variables** U1 and U2

$$h_s = F_{H_S}^{-1}(\Phi(u_1)) \qquad t_z = F_{Tz|H_S}^{-1}(\Phi(u_2))$$

where $\Phi(.)$ is the standard normal distribution function.

- These equations give **a contour with return period 100 years** by varying U1 and U2 along the circle

$$\sqrt{u_1^2 + u_2^2} = \beta$$

- where $$\beta = \Phi^{-1}(1 - p_f) = \Phi^{-1}(1 - \frac{1}{100 \cdot 365 \cdot 8}) = 4.5$$

See DNV Offshore standards (2001).

Environmental Contours

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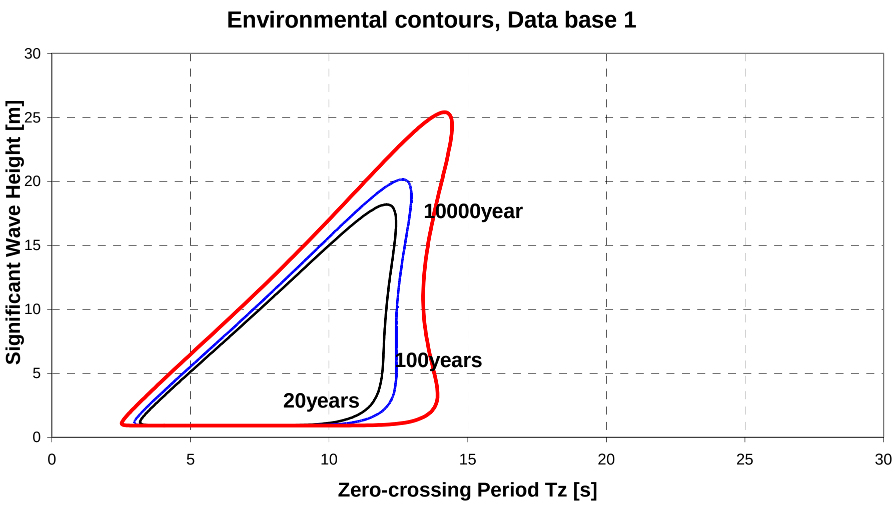

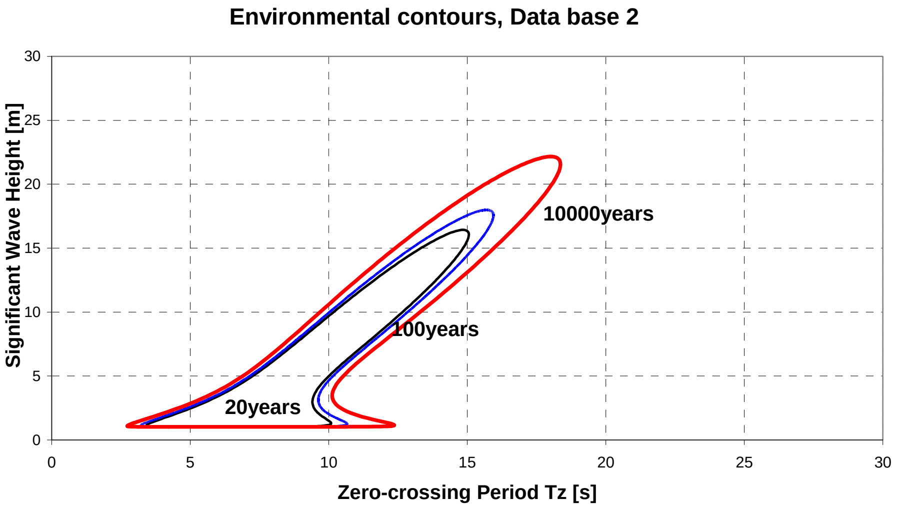

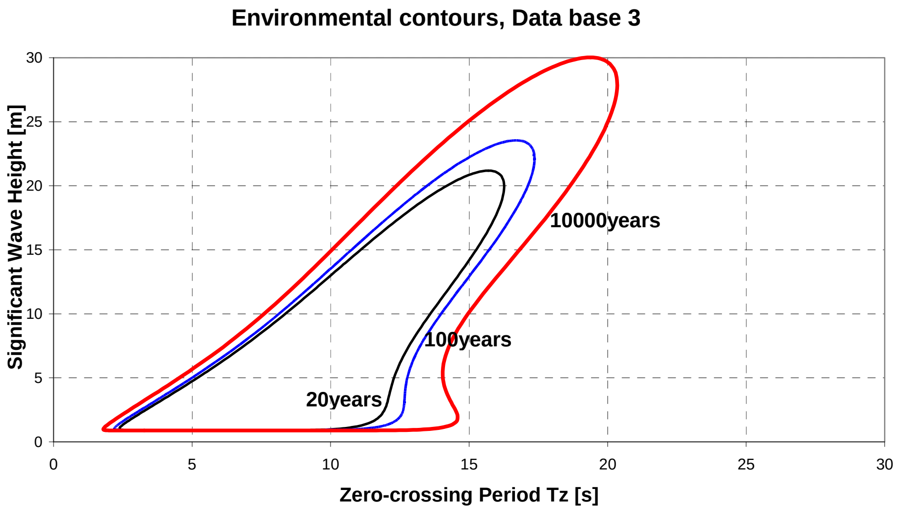

Extreme Average Wave Steepness

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Uncertainties as suggested by Bitner-Gregersen and Hagen:

- Data uncertainty
- Statistical uncertainty (sampling variability, fitting procedure)
- Model uncertainty (adopted model to fit the data)
- Climatic variations (different time periods which the data sources cover as well as different locations they represent).

As the **same joint model** as well as the **fitting procedure** has been used to fit the data the **discrepancies** of the **results** can **primarily be explained** by the **data** and **climatic uncertainty**.

It **was expected** to see some **convergence of** the **extreme wave steepness predictions.**

Extreme Average Wave Steepness

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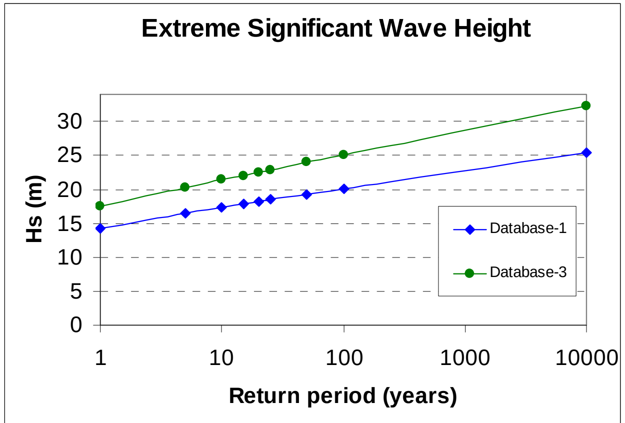
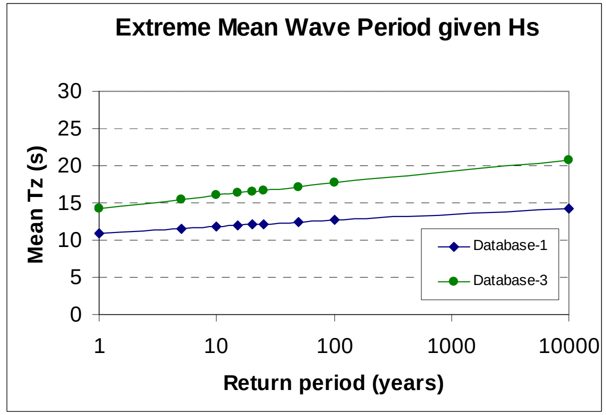
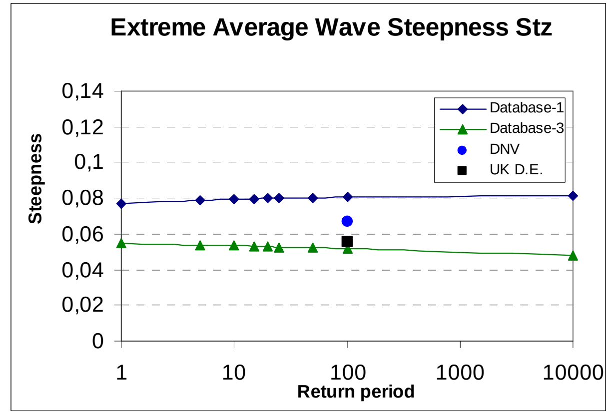
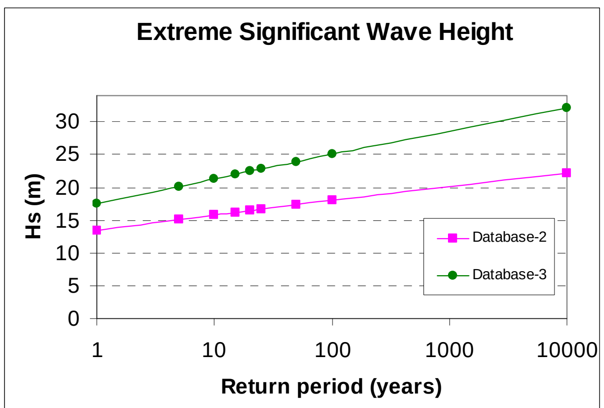
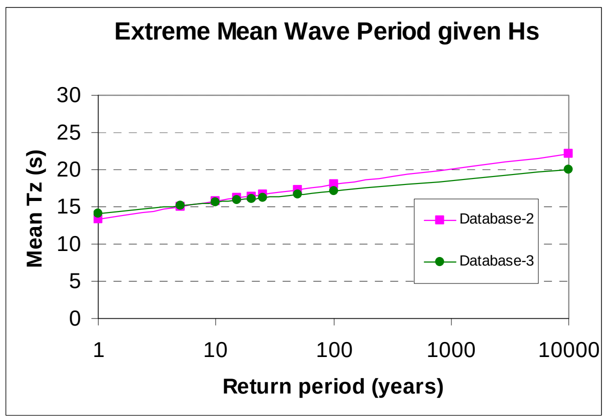


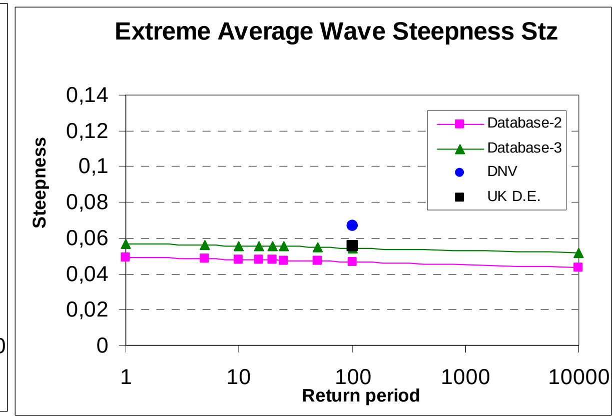




Extreme N-year H_{m0} — **Extreme Tm_{02} given N-year H_{m0}** — **Extreme steepness**







Extreme N-year H_{m0} — **Extreme Tm_{02} given N-year H_{m0}** — **Extreme steepness**

Discrepancies - H_{m0} : ≅ 5.5m , T_{m0}: ≅4s , S_{Tz} : ≅ 33%

Conclusions

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- There is still **need** for **further discussion** of **accuracy** of the recently developed **databases** and **uncertainties related** to them before they can be **fully utilized in engineering applications**.
- The **extremes predicted** by **three** considered herein **databases** **differ significantly**.
- Although given in the literature comparison of time series predicted by the databases and measured data show good agreement, **uncertainties** involved seem to **accumulate** resulting in **large discrepancies in extreme statistics.**

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