Intrisic variability in wave parameters and effect on wave statistics

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Banff, 28 October 2013

MANAGING RISK

EXTREME SEAS
Design for Ship Safety in Extreme Seas

- **Work Programme:**

  2008, Cooperation Theme 7, Transport,

  7.2 Sustainable Surface Transport (SST),
  FP7- SST – 2007- RTD-1

- **Activity:** 7.2.4 Improving Safety and Security

- **11 Partners from six European countries**.

- **Starting Date:**

  1st Sept. 2009 – 30 April 2013

- **Coordinated by DNV; with the overall objectives:**

- To develop **technology and methodology that need to be a part of design for ship safety in extreme seas**.

- To develop **warning criteria for extreme sea states** for marine structures **.**

- To help shipping industry **to adapt to climate change.**

- **Budget: 4.1 million Euro**

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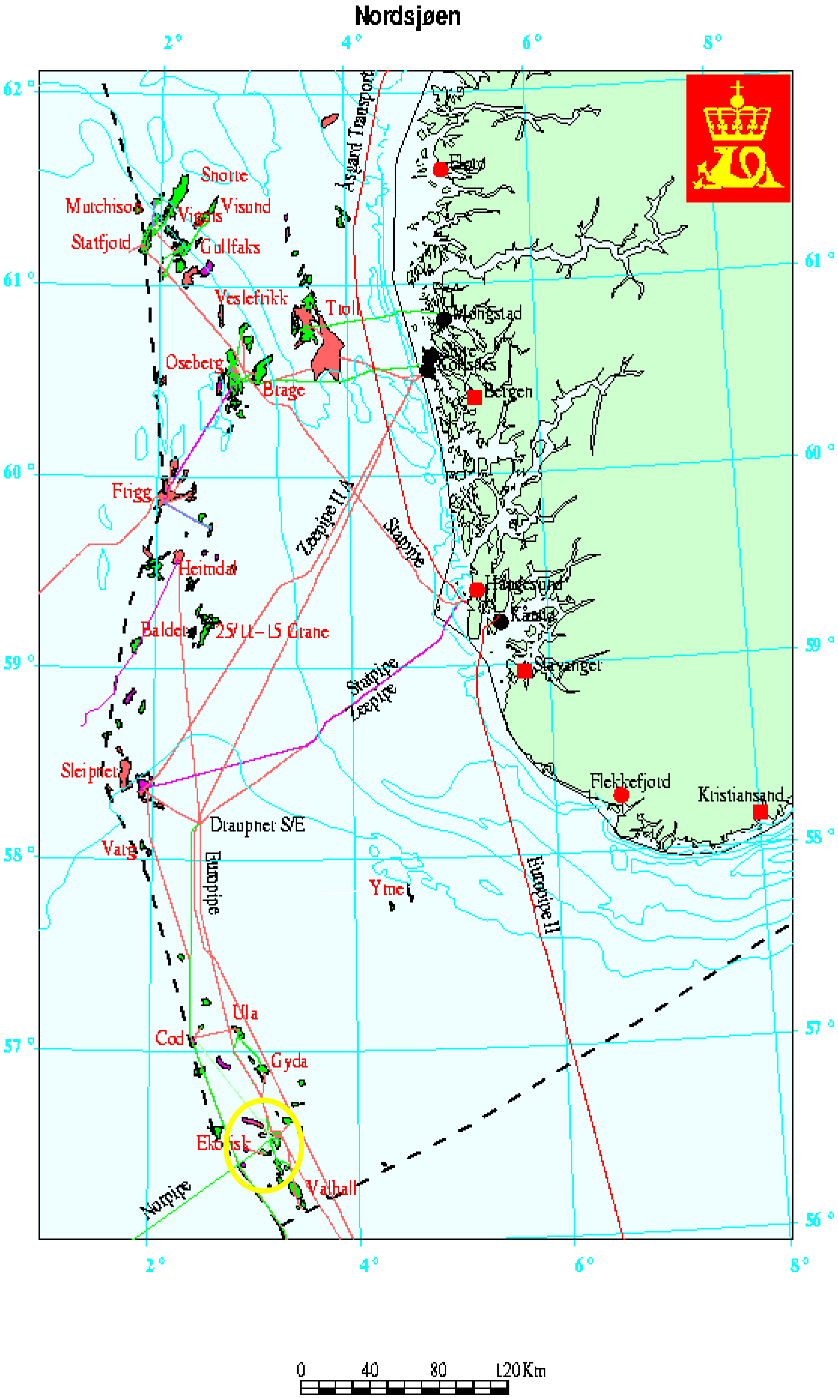


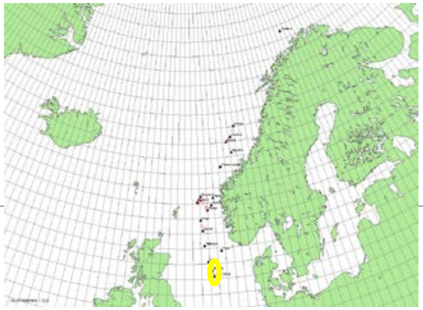
EKOFISK and EXWW

(Ekofisk eXtreme Wave Warning)

The sea floor at the Ekofisk field is subsiding due to the oil extraction, and constructions are therefor more and more exposed to wave forces.

«EXWW» are **special procedures** developed between Phillips Petroleum - now ConocoPhillips - and MET-Norway to ensure **safe activity offshore.**

In this, **monitoring of environmental parameters in real time is of primary importance**.



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ExWaCli

Extreme waves and climate change: Accounting for uncertainties in design of marine structures

Forskningsrådet

- **The Research Council of Norway (RCN) project**
- **Funded**: 40% by RCN, 60% by the Partners
- **Partners**
  - DNV
  - The Norwegian Meteorological Institute
  - The University of Oslo
  - Expected external participants
- **Starting Date:**

1st January 2013 – 30 December 2015

- **Managing by DNV; with the overall objectives:**
  - To understand how **climate change** will impact **wave conditions** in the northern areas **the 21st century** and specifying **uncertainties** associated with the predicted changes;
  - To suggest **an integrated approach** that handles the uncertainties associated in climate change projections and to take this **into account in current design and operation** of marine structures.
  - **Recommendations f**or design and operations of marine structures.
- **Budget: ca. 1.3 million Euro**

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Background for the study
Uncertainties

- **The oceanographic community** has always been concerned with providing environmental models and data which approximate the physics of the ocean in the most accurate way.

- **The marine industry,** on the other hand, needs accurate data and models **for design purposes.**
- Although **uncertainties** of data and models were discussed **before the 1980's**, they **were not systematically quantified**.
- Further development of the **Structural** R**eliability Analysis (SRA) methodology (Madsen et al., 1986)** and their implementation by some parts of the industry in the 1980's has brought **much focus onto the uncertainties associated with environmental description**. **SRA allows quantification, in a probabilistic way**, **of the uncertaintie**s in the different parameters that govern structural integrity.

Background for the study
Uncertainties

Uncertainties

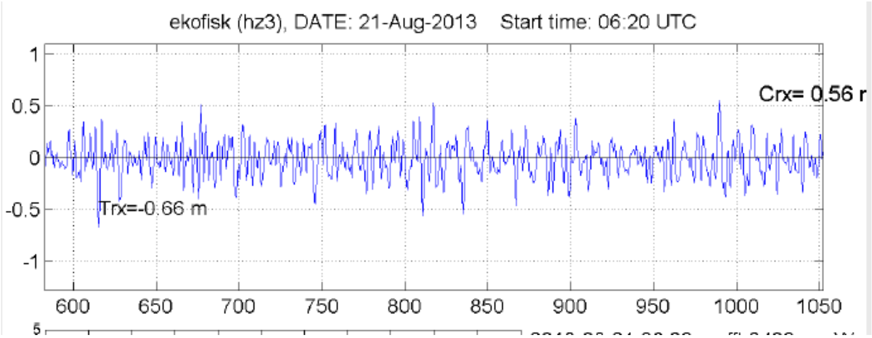
- **Aleatory (physical) uncertainty**
- **Epistemic (knowledge) uncertainty**

Bitner-Gregersen and Hagen (1990, J. Marine Safety) proposed classification of met-ocean uncertainties. The proposed definitions were later generalised and included in **DNV Rules (DNV, 1992)**.

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

- The ***true value τ*** of a quantity considered is an ideal number which can be known only if all sources of error are eliminated (bias and precision).
- **Sampling variability – uncertainty due to limited numbers of observations.**

- Usually measurements **17.5-30 min..**



- **Random sea.**
- **Statistics of sea surface** will be **influenced** by this uncertainty.

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Intrisic variability in wave parameters and effect on wave statistics
Sampling variability of Hs and Tz

- **Significant wave height Hs** is defined as an average of one third of the largest waves in a wave time series and is commonly evaluated using 17.5 or 30 minutes long recordings. It can also be calculated from a wave spectrum Hm0.
- **Zero-crossing wave period Tz** (or Tm02)
- **Donelan and Pierson (1983)** investigated both laboratory and field data and obtained 8% variability for Hs.
- Sampling variability of Hm0 and Tm02 - the formulaes are given in **Bitner-Gregersen and Hagen (1990)**.Uncertainties of data for the offshore environment. *Structural Safety*, Vol. 7.

$$\mathrm{var}(H\hat{M}0) = \frac{4}{\hat{M}_0}\,\mathrm{var}(\hat{M}_0)$$

$$\mathrm{var}(T\hat{M}02) = \pi^2\left(\frac{\mathrm{var}(\hat{M}_0)}{\hat{M}_0\hat{M}_2} - 2\frac{\mathrm{cov}(\hat{M}_0,\ \hat{M}_2)}{\hat{M}_2^2} + \frac{\hat{M}_0\,\mathrm{var}(\hat{M}_2)}{\hat{M}_2^3}\right)$$

$$\mathrm{cov}(H\hat{M}0,\ T\hat{M}02) = 2\pi\left(\frac{\mathrm{var}(\hat{M}_0)}{\hat{M}_0\sqrt{\hat{M}_2}} - \frac{\mathrm{cov}(\hat{M}_0,\ \hat{M}_2)}{\hat{M}_2^{3/2}}\right)$$

Sampling variability of Hs and Tz

- **The sampling variability standard deviation (in %) of for the JONSWAP spectrum; Bitner-Gregersen and Hagen (1990)**

Hs

The sampling variability is recommended to be modelled as a normally distributed variable.

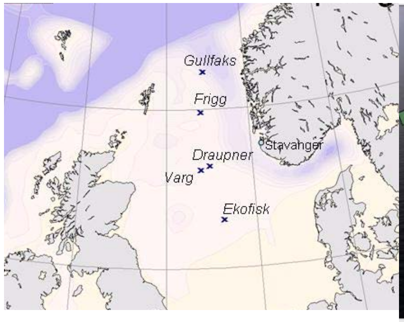
H_{M0} (m)	T_{M02} (sec) 3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	Average
0-1	3.3	3.8	4.1	4.4	4.8	5.1	5.5	5.6	5.9	6.2	6.5	6.7	5.2
1-2	4.5	3.7	4.1	4.4	4.8	5.1	5.5	5.6	5.9	6.2	6.5	6.7	5.3
2-3		5.1	4.5	4.4	4.8	5.1	5.5	5.6	5.9	6.2	6.5	6.7	5.5
3-4			5.3	4.7	4.8	5.1	5.5	5.6	5.9	6.2	6.5	6.7	5.6
4-5			5.5	5.7	5.0	5.1	5.5	5.6	5.9	6.2	6.4		5.7
5-6				6.1	5.6	5.2	5.5	5.6	5.9	6.2	6.4		5.8
6-7				6.3	6.4	5.6	5.5	5.6	5.9	6.2	6.4		6.0
7-8					6.7	6.3	5.6	5.6	5.9	6.2	6.4		6.1
8-9						6.8	6.0	5.7	5.9	6.2	6.4		6.2
9-10							6.8	6.1	5.9	6.2	6.4		6.3
10-11							7.0	6.5	6.0	6.2	6.4		6.4
11-12								7.0	6.3	6.2	6.4		6.5
12-13								7.4	6.8	6.3	6.4		6.7
13-14								7.8	7.2	6.6	6.4		7.0
14-15								7.9	7.5	6.9	6.5		7.2
Average	3.9	4.2	4.7	5.1	5.4	5.5	5.8	6.2	6.2	6.2	6.4	6.7	

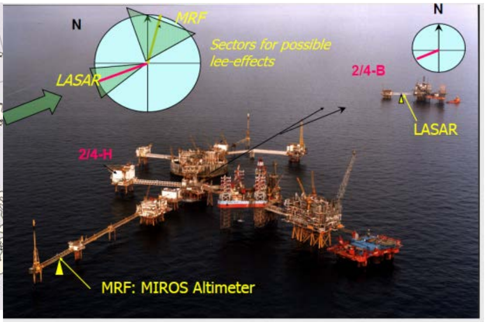
Tz

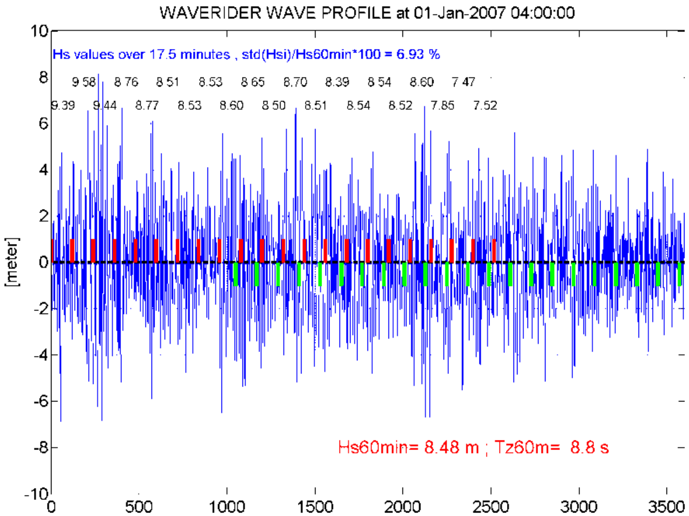
The sampling variability is recommended to be modelled as a normally distributed variable.

H_{Mo} (m)	T_{M02} (sec) 3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	Average
0-1	1.5	1.7	1.9	2.0	2.2	2.4	2.5	2.6	2.7	2.9	3.0	3.1	2.4
1-2	1.5	1.7	1.9	2.0	2.2	2.4	2.5	2.6	2.7	2.9	3.0	3.1	2.4
2-3		1.7	1.9	2.0	2.2	2.4	2.5	2.6	2.7	2.9	3.0	3.1	2.5
3-4			1.9	2.1	2.2	2.4	2.5	2.6	2.7	2.9	3.0	3.1	2.5
4-5			1.9	2.1	2.2	2.4	2.5	2.6	2.7	2.9	3.0		2.5
5-6				2.1	2.3	2.4	2.5	2.6	2.7	2.9	3.0		2.6
6-7				2.2	2.3	2.4	2.5	2.6	2.7	2.9	3.0		2.6
7-8					2.3	2.5	2.5	2.6	2.7	2.9	3.0		2.6
8-9						2.5	2.6	2.6	2.7	2.9	3.0		2.7
9-10							2.6	2.7	2.7	2.9	3.0		2.8
10-11							2.7	2.8	2.8	2.9	3.0		2.8
11-12								2.8	2.8	2.9	3.0		2.9
12-13								2.8	2.9	2.9	3.0		2.9
13-14								2.8	2.9	2.9	3.0		2.9
14-15								2.8	2.9	3.0	3.0		2.9
Average	1.5	1.7	1.9	2.1	2.2	2.4	2.5	2.7	2.8	2.9	3.0	3.1	

- **Validation by Ekofisk data**



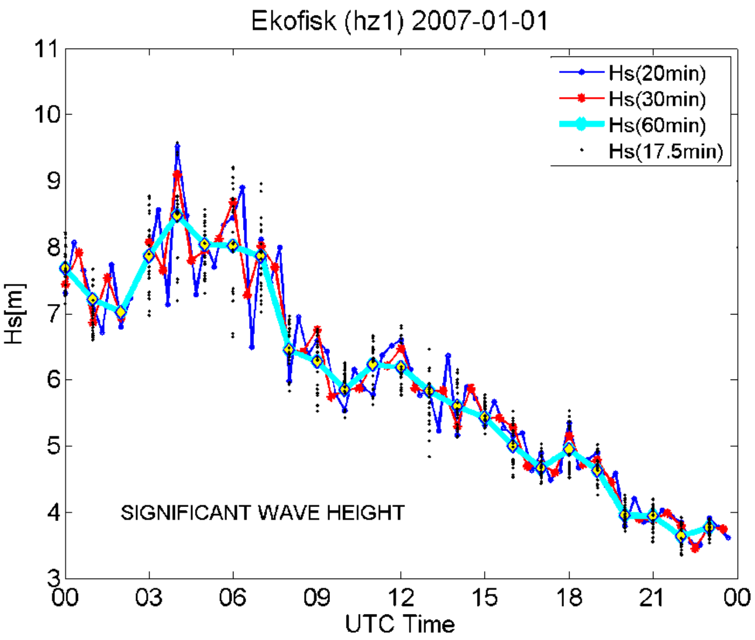




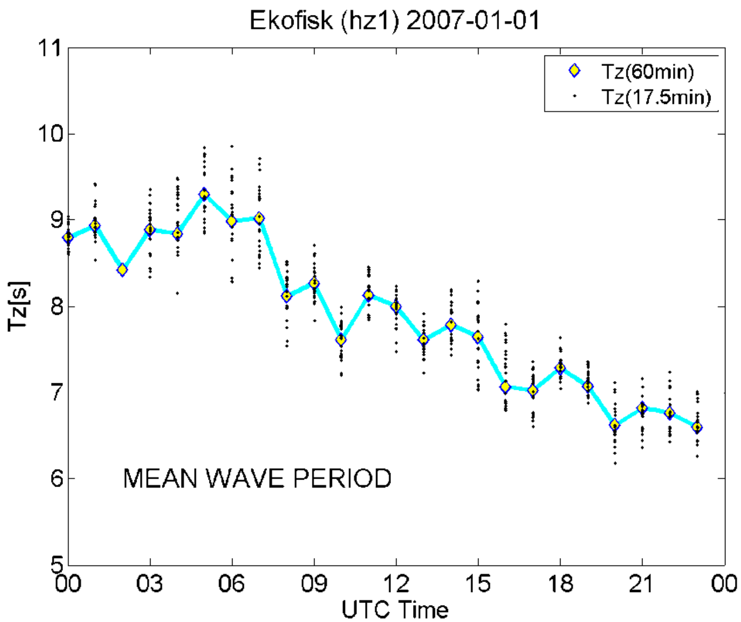
- **Continuous measurements** of wave profile at 2Hz sampling rate are gathered in **60 minutes time series.**
- **22 consecutive windows of 17.5 minutes length**, with increament of 2 min over each 60 minutes records, are used to evaluate **sampling variability of Hs and Tz.**

One day of Ekofisk data
Comparing Hs and Tz over different sampling periods

- **Significant wave height Hs**

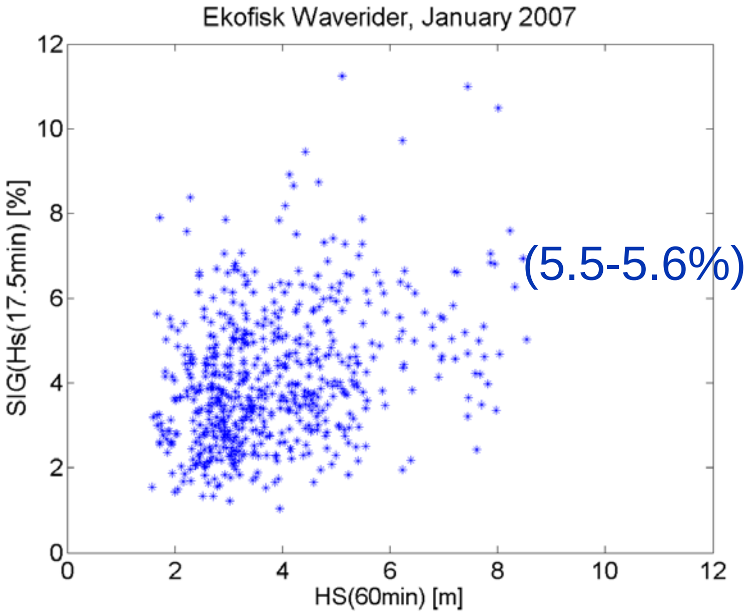


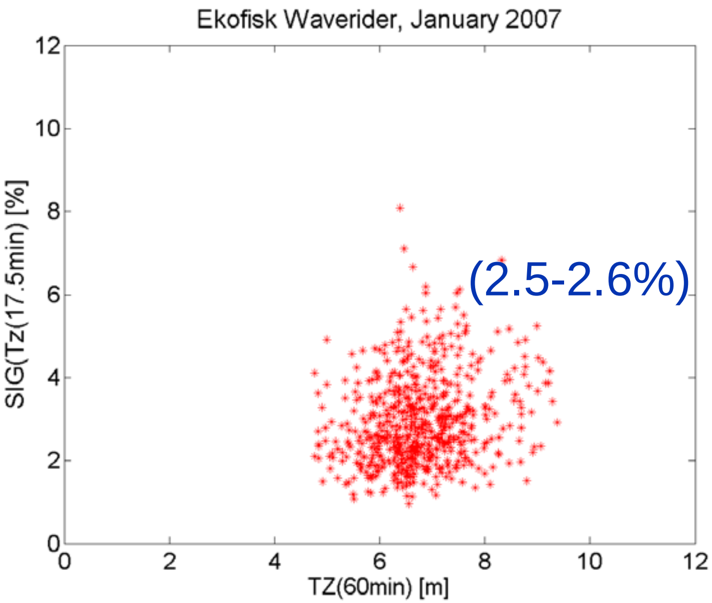
- **Zero-crossing wave period Tz**



Standard deviation in % of the 17.5 minute values of wave height or period as function of the 60 minutes values

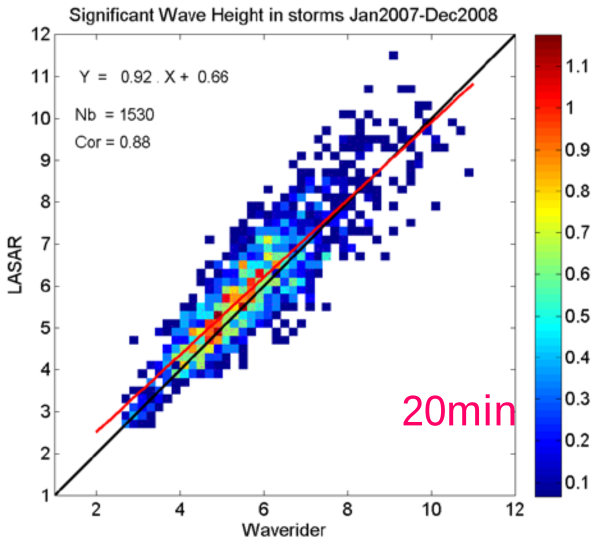
- **Significant wave height Hs**
- **Zero-crossing wave period Tz**

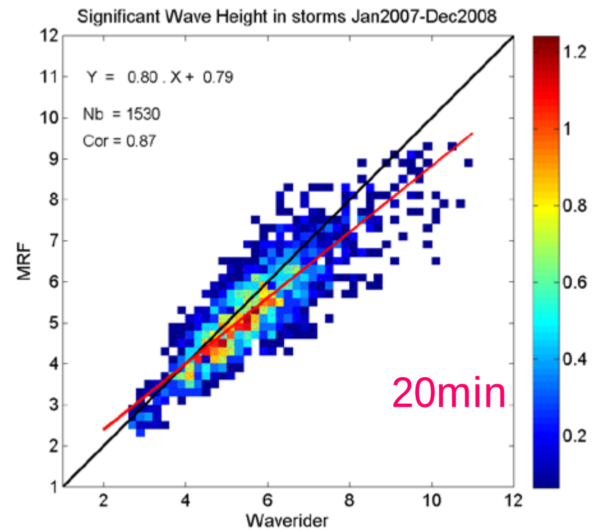




The standard deviations are seen to be very variable, The spread is though higher for Hs than for TZ (TM02), showing similarity with numbers given in the tables from Bitner-Gregersen and Hagen, 1990. *(ongoing work)*

Hs comparison (sensors and time averaging)

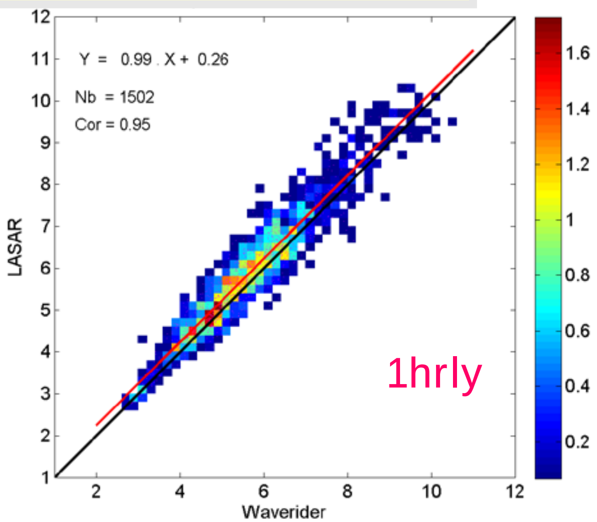


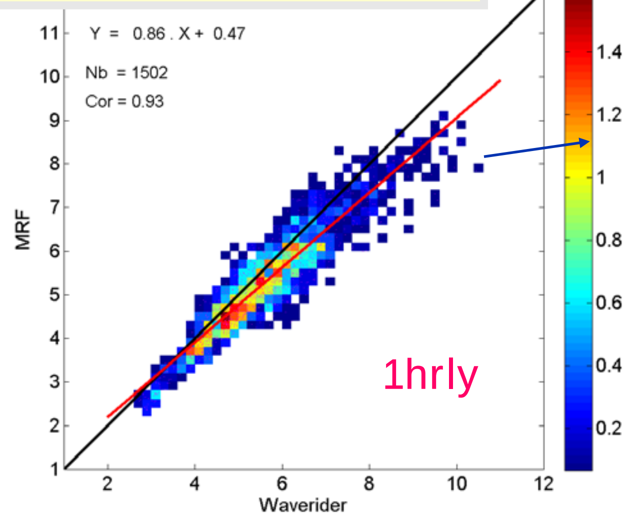


Hourly averages have higher correlations

$Hs_{LASAR} = 0.99.Hs_{WR} + 0.28$
Corr=0.95 (1-hourly)

$Hs_{MRF} = 0.86 *Hs_{WR} + 0.5$
Corr = 0.93 (1-hourly)



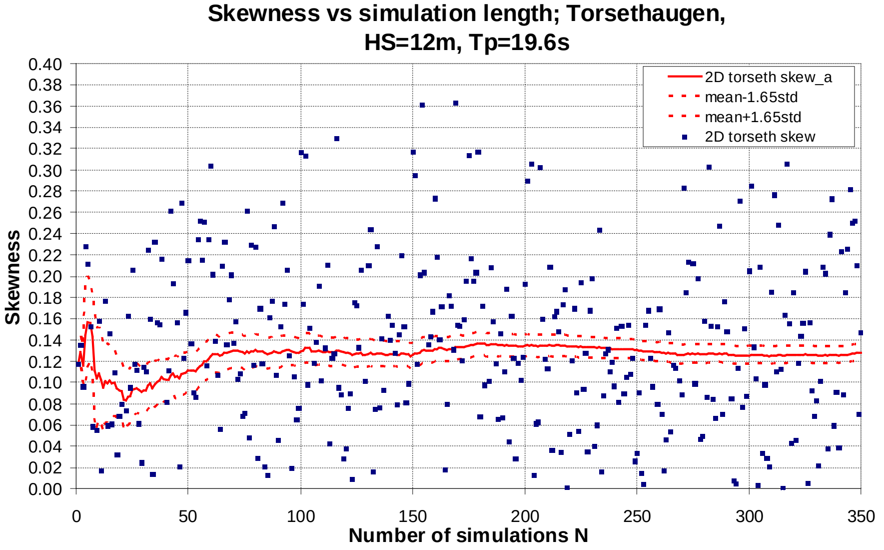


Hs = 5 m : 5 % lower
Hs = 10 m : 10 % lower

Sampling variability in wave parameters and effect on wave statistics

- **Higher order moments will be more affected**
- **Simulated skewness;** realizations per seastate and average value as function of number of simulations; Torsthaugen spectrum Hs=12m, Tp=19.6s

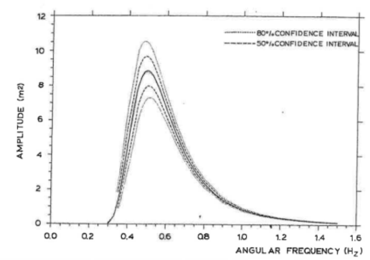
- **2D** - 350 simulations of a 1024s timeseries at 4Hz
- **3D** - 250 repetitions of a 1024s timeseries at 4Hz



Bitner-Gregersen and Hagen (2003)

- **Sampling variability will affect short-term and long-term description of sea surface**
- **Short-term description**
- Numerical simulations
- Laboratory tests
- Distributions of sea surface and wave parameters, e.g. crest distribution, see Hagen (2007).
- Spectral description

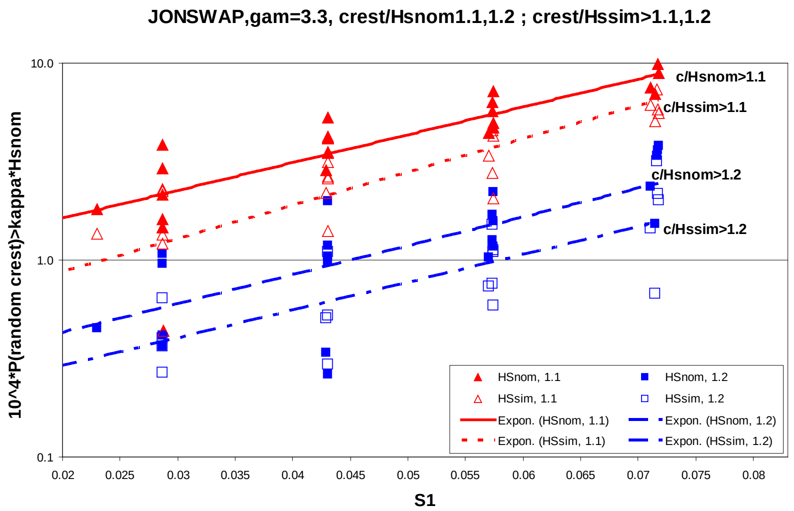
PM spectrum
Bitner-Gregersen and Hagen (1990)



- **Long-term description**
- Long-term distributions
- **Validation of wave spectral models**
- **Design and operational met-ocean criteria** → impact on design of marine structures.

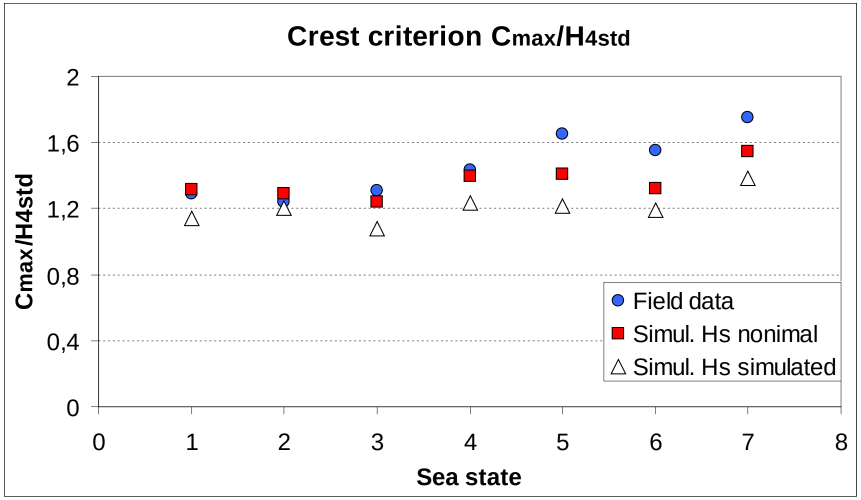
Sampling variability in wave parameters and effect on short-term wave statistics

- **Extreme waves, 2nd order wave model**



Simulated **exceedance probability** for **crest/hs=1.1** and **1.2** for a random crest. Results both for nominal H_s and random H_s. 2nd order wave model, long crested sea (2D), JONSWAP spectrum, **Bitner-Gregersen and Hagen (2004)**

- **2nd order wave model, Cmax/Hm0**



Wave crest factor for **nominal** and **simulated significant wave height,** long crested sea (2D), PM spectrum, **Bitner-Gregersen and Magnusson (2004)**

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Intrisic variability in wave parameters and effect on long-term wave statistics

- **The Torsethaugen spectrum**

Design values

Paramet Sea	*Hs* (m)	*Tp* (s)	Dominated sea acc. to the Torsethaugen spectrum
100-year return period			
Total sea	16.91	17.44	**swell**
Wind sea	3.08	7.42	
Swell	16.63	17.44	
10-year return period			
Total sea	14.55	16.36	**swell**
Wind sea	1.20	4.83	
Swell	14.50	16.36	
1-year return period			
Total sea	12.07	15.16	**swell**
Wind sea	0.075	2.5	
Swell	12.07	15.16	

Bitner-Gregersen and Toffoli (2009)

- Total H_s increased by **1m** (≈1σ)

Parameter Sea	(m)	(s)	Dominated sea acc. to the Torsethaugen spectrum
100-year return period			
Total sea	17.91	17.44	**Swell**
Wind sea	1.19	4.73	
Swell	17.87	17.44	
10-year return period			
Total sea	15.55	16.36	**windsea**
Wind sea	15.55	16.36	
Swell	0.32	18.47	
1-year return period			
Total sea	13.07	15.16	**windsea**
Wind sea	13.04	15.16	
Swell	0.939	17.55	

- **Sampling variability will impact long-term distributions**

Conclusions

- **Sampling variability** represent an important uncertainty in description of ocean waves; it needs to be accounted for.
- Sampling variability of **Hm0** and **Tm02 derived** from the **theoretical formulas** due to **Bitner-Gregersen and Hagen (1990)** compared well with **field data from Ekofisk**.
- It has **significant impact** on **short-term** and **long-term wave statistics**.
- It needs to be considered in **model tests**, **numerical simulations**.
- Important for **validation of wave spectral models.**
- It has impact on **met-ocean design and operational criteria.**
- The present **study** is **preliminary** and **on-going**.

Intrisic variability in wave parameters and effect on wave statistics

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