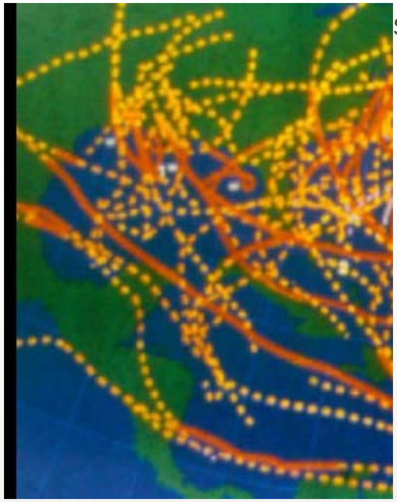

Status: Draft

GoM: 1983-1993,
Source: MMS

Katarina: 2005,
Source: MMS

EXTREME RESPONSE IN A HURRICANE GOVERNED OFFSHORE REGION:

UNCERTAINTIES RELATED TO:

- LIMITED AMOUNT OF DATA

AND

- CHOICE OF METHOD OF PREDICTION

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Motivasjon I DESIGN OF STRUCTURES

- Rule requirent:

ULS design response: γ_E * 10^{-2} – annual probability response

Factor accounting for uncertainties in the predictied 10^{-2} – annual probability response
Norwegian Continental Shelf. γ_E = 1.3
Gulf of Mexico: γ_E = 1.35

- 10^{-2} – annual probability response is a linear or ”slightly” non-linear function of wave characteristics.

➔ An uncertainties of 15% in waves would represent 15% uncertainty in the response for a linear response problem while for a quadratic response problem it could be 30% .

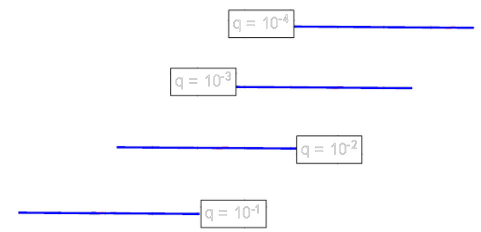
(In addition the safety factor are also to cover other uncertainties related to the load prediction.)

Motivasjon II

Practical design work procedure:

1) Data of peak hurricane significant wave height, and associated spectral peak period: $(h_{s,p}, t_{p,p})_i$, i = 1, 2, …, N .

2) Distribution of weather characteristics are estimated, e.g.:



3) We <u>assume</u> fitted distributions to be good approximation to the underlying distribution functions.

4) We base our predictions of weather extremes and response extremes on this assumption. Uncertainties are expected covered by standard partial safety factors.

5) If our data cover say about 50 years which includes about 25 hurricanes, out of which about 5 define the upper tail (= the interesting tail) of the distribution, how accurate is our assumption presented in 3)?

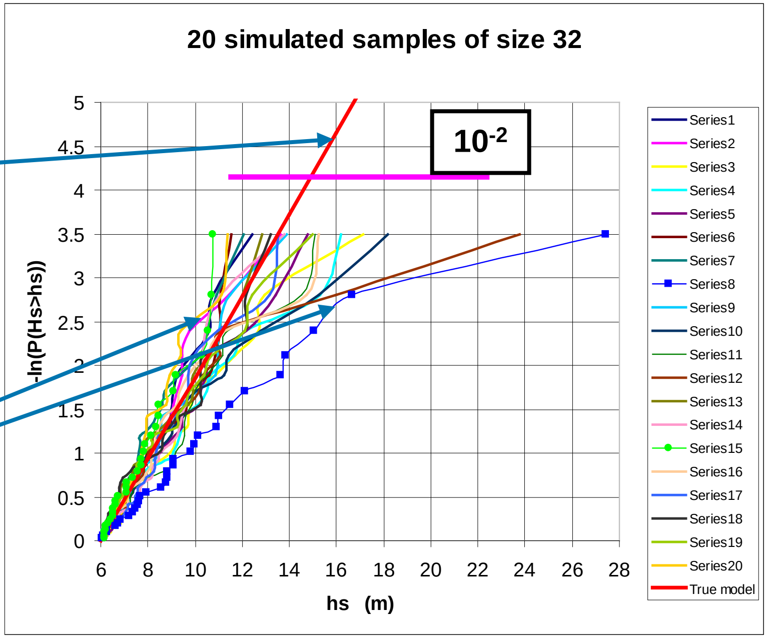
Motivation III

The inverted problem (procedure):

1) Assume that we know the underlying true distribution functions.

2) What would be the scatter between possible 50-year data sets?

3) Assuming we have the same number of hurricanes in each 50-year period, figure shows 20 different realization.



4) In practise we will have a varying number of hurricanes per 50-year period and we may have a long term variation in hurricane severity. (This will increase variability.)

5) There can be physical limitations regarding the severity of possible hurricanes. (This could reduce variability of the extremes.)

Classification of uncertainties

- **Epistemic uncertainty: Uncertainty due to lack of knowlegde or ignorance of knowledge.**

  Here: Focus will be on this class of uncertainty

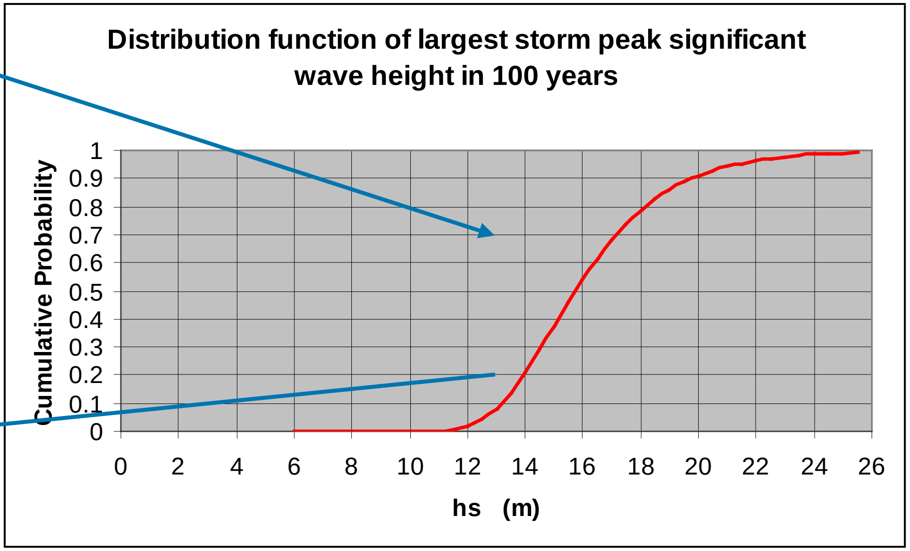
- **Aleatory uncertainty (inherent randomness).**

  Example: Long term distribution of hurricane peak significant wave height and the annual number of hurricanes are known. ➔ 10^{-2}-probability peak significant wave height is estimated (based on the reference data base the value is 14.6m).

  Observed largest value during 100 years period will show a variability around this 10^{-2}- probability value.

80% band of $H_{s,p}^{(100)}$:

13m – 20m

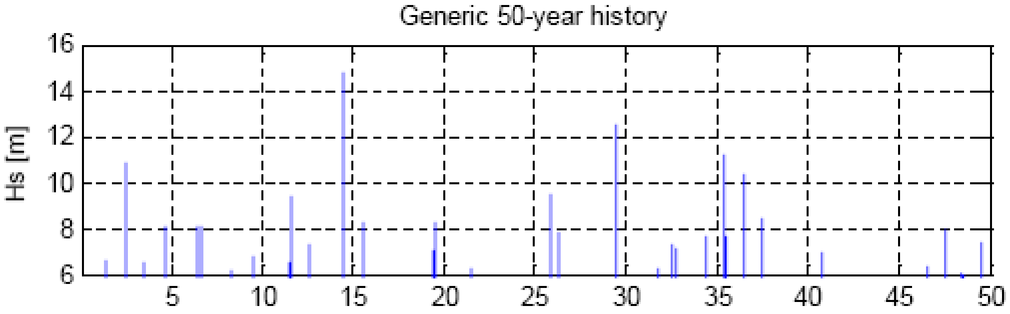


Simulated hurricane data

In order to illustrate these uncertainties in a simple way we need hurricane data for many 50-year periods!

For a number of 50-year periods, data are obtained by means of Monte Carlo simulations assuming hurricane occurrences to agree with a Poisson process.

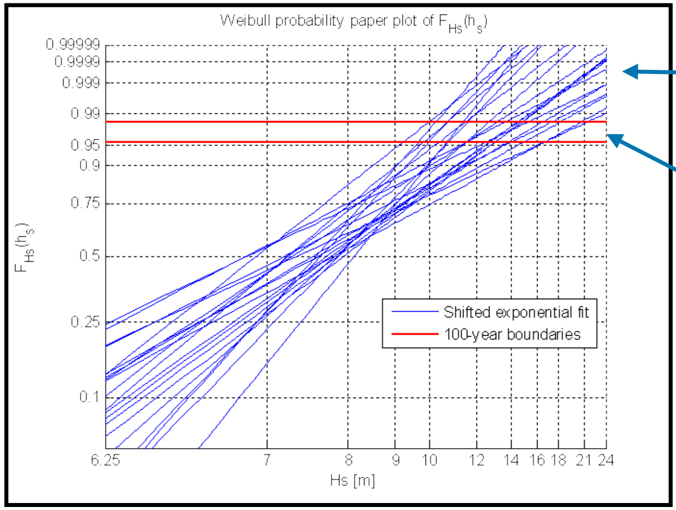
Keep in mind results are based on simulated data not accounting for underlying physics. ➔ Results should be taken as illustrative figures.



Concluding remarks : Wave conditions

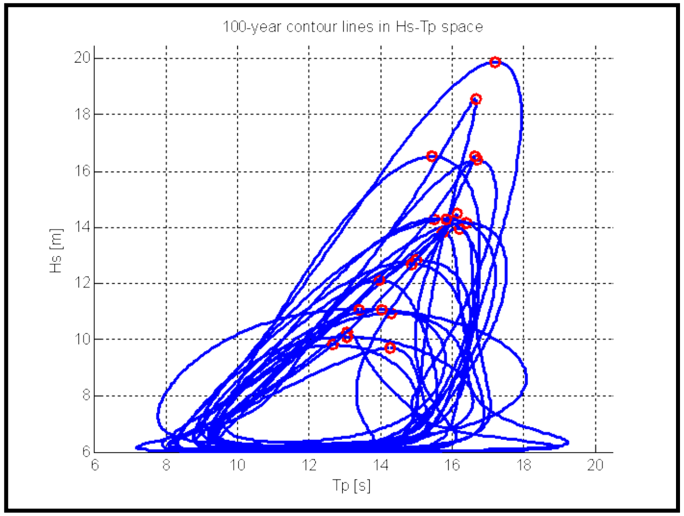
- Predicted 10^{-2} – (annual) probability hurricane peak significant wave height, $h_{s,p,0.01}$, vary from 9.7m to 19.9m for 20 simulated 50-year hurricane data bases.

- Number of hurricanes in 50 years vary from 12 – 32 causing an uncertainty in predicted $h_{s,p,0.01}$ of up to 20%, .i.e. much less important than uncertainties in fitted model for $H_{s,p}$.



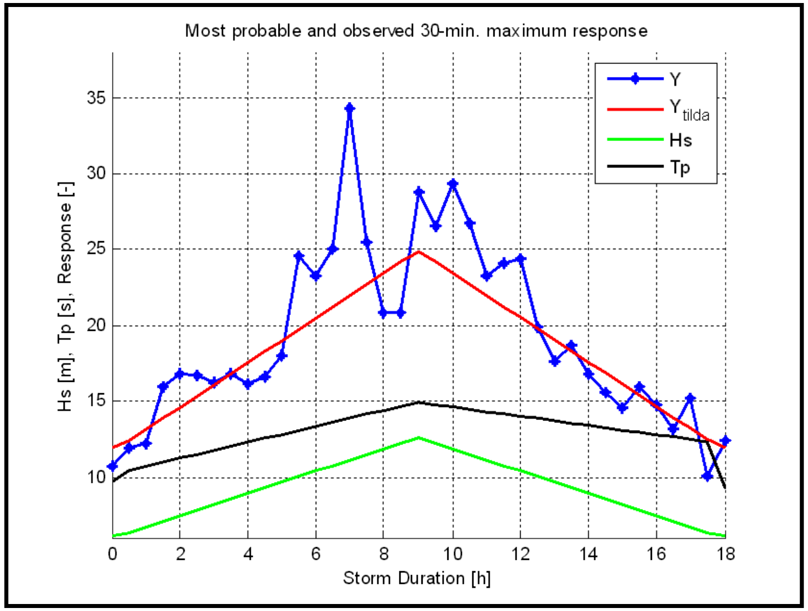
Fitted Weibull models to H_s-6

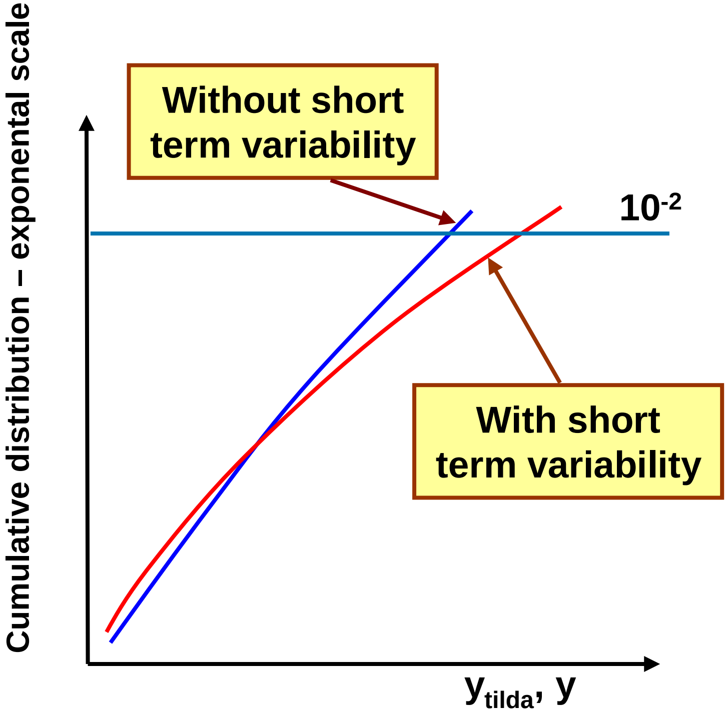
Range of 10^{-2} annual exceedance probability



Concluding remarks : Importance of short term variability

- **Short term variability of the hurricane peak significant wave height. Neglecting this source of variability will result in a considerable underestimation of target extremes.**





Conclusions: Uncertainties in predicted 10^{-2} – probability response

- For a linear generic response problem estimated 10^{-2}- probability response vary from 26.3 to 47.6 for the simulated (20) 50-year data bases.

- For a quadratic generic response problem values from around 324 to 1051 are estimated for the 20 50-year periods.

➔ Uncertainty in response seems rather large in view of partial safety factor for the load side of e.g. 1.35.

Buuut it must be kept in mind that work is based on simulations with no physics.

Summary of conclusions

In order to reduce wave induced uncertainties we need to do something.

What can we do:

*** Increase sample of hurricanes used for response predictions!**

Pooling of data from near by grid points can be one possibility?

Simulate artificial hurricanes with ”correct” physics?

OR

*** Establish some upper bound for hurricane severity assumed to correspond to an annual probability of being exceeded of 10^{-4}.**

Variation of observed 10-year maxima from hindcast data and from simulated data

Hindcast data (10-year extremes):

9.3m, 14.3m, 8.7m, 7.0m, 15.9m, 15.3m

Mean:	11.7m
St.Dev.:	3.5m
CoV:	30%

Simulated data (10-year extremes):

10.9m, 14.8m, 12.6m, 11.3m, 7.9m

Mean:	11.5m
St.Dev.:	2.3m
CoV:	21%

These results may suggest that severity of hurricanes varies in cycles with periods of 10-20 years.

Mixing this variability with variability observed within a given severity may result in an over estimation of the very low probability extremes e.g. 10^{-4} – probability extremes.

Variation in estimated 100- year values from 20 50-year simulated samples:

Mean:	13.5m
St. Dev.:	3.0m
CoV.:	22%

Remember to stop here

END

Comments/Questions?

Generated hurricane data bases

Simulated reference data set

Year	Occurence Day	Occurence Month	Hs_max	Tp_max	Duration
2	12	August	6,61	9,01	14
3	4	September	10,89	12,41	22
4	2	September	6,53	12,32	6
5	10	October	8,09	12,44	16
7	6	September	8,12	13,86	8
7	9	October	8,16	15,96	8
9	3	August	6,25	10,82	4
10	9	September	6,81	10,59	11
12	5	September	6,61	12,63	4
12	23	September	9,40	11,89	15
13	15	September	7,31	12,65	23
15	3	September	14,84	17,50	10
16	18	September	8,29	10,68	2
20	9	August	7,10	10,04	7
20	2	September	8,27	12,21	7
22	5	September	6,29	9,67	11
26	25	October	9,56	11,35	19
27	15	August	7,85	11,35	12
30	1	September	12,60	14,93	18
32	24	October	6,29	11,16	2
33	17	September	7,39	9,98	7
33	15	October	7,13	10,04	16
35	14	August	7,73	12,26	4
36	12	August	11,29	14,19	20
36	16	September	7,72	11,36	3
37	16	September	10,35	13,74	3
38	6	September	8,51	14,81	24
41	26	October	7,02	11,70	7
47	16	September	6,37	12,68	43
48	15	September	7,92	13,93	19
49	9	September	6,06	11,50	11
50	20	September	7,47	13,82	2

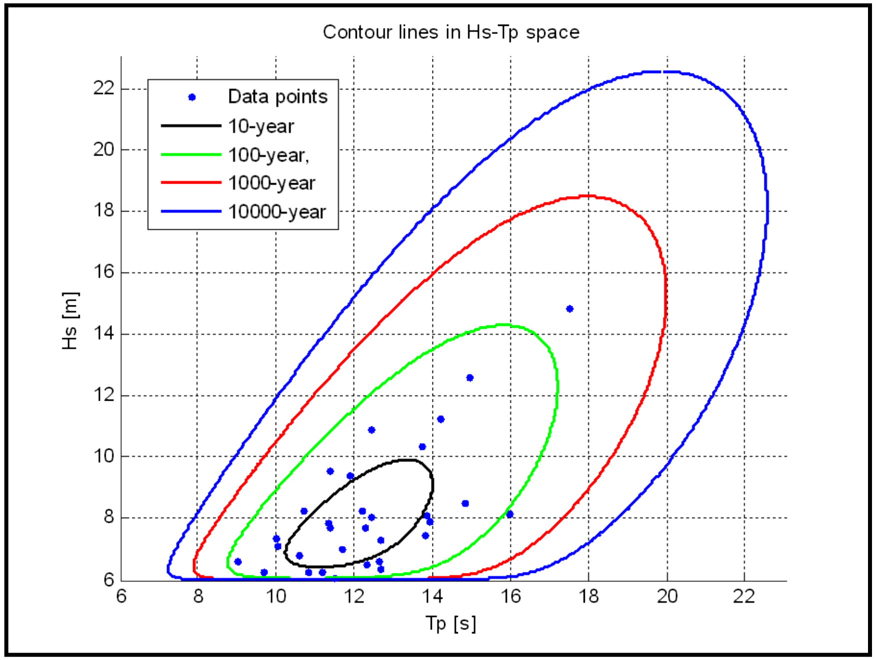
Characteristics of all generated sets

50-year database [#]	$h_{s,p,0.01}$ (m)	$t_{p,p} \mid h_{s,p,0.01}$ (s)	No. of hurricanes
Reference	**14.3**	**15.8**	32
1	16.5	15.4	19
2	14.0	16.2	23
3	14.2	16.4	22
4	13.8	15.8	22
5	19.9	17.2	23
6	12.8	15.0	22
7	12.1	14.0	20
8	10.9	14.3	20
9	12.7	14.9	24
10	10.3	13.1	17
11	18.6	16.7	19
12	9.8	12.7	12
13	10.1	13.1	25
14	11.1	13.4	18
15	14.5	16.1	24
16	11.1	14.0	21
17	16.4	16.7	30
18	14.3	15.5	24
19	16.6	16.6	25
20	9.7	14.3	22
Mean (#1 - #20)	13.5	15.1	21.6
St. dev. (#1 - #20)	3.0	1.4	3.7

Analysis of wave data: Reference period

- **Joint distribution of $H_{s,p}$ and $T_{p,}$.**

  ➔ **q-probability contour lines of these variables.**



Response methodology

a) Response variables:

Y = hurricane maximum response

$\tilde{Y}$ = hurricane most probable maximum response

b) By calculating response for all hurricanes we can estimate:

$$\boxed{F_{Y|\tilde{Y}}(y\,|\,\tilde{y}) \;\&\; f_{\tilde{Y}}(\tilde{y})}$$

c) Long term distribution of hurricane maximum response:

$$\boxed{F_Y(y) = \int_{\tilde{y}} F_{Y|\tilde{Y}}(y|\tilde{y})\, f_{\tilde{Y}}(\tilde{y})\, d\tilde{y}}$$

d) 10^{-2} – probability response, $y_{0.01}$:

$$\boxed{1 - F_Y(y_{0.01}) = \frac{0.01}{n_1}}$$

Expected annual number of hurricanes

Response results

50-year database [#]	Case 1			Case 2			Case 3			Case 4		
	$\tilde{y}_{0.01}$	$y_{0.01}$ [1]	ε [2]	$\tilde{y}_{0.01}$	$y_{0.01}$	ε	$\tilde{y}_{0.01}$	$y_{0.01}$	ε	$\tilde{y}_{0.01}$	$y_{0.01}$	ε
Reference	**27.8**	**34.4**	**0.88**	**21.9**	**28.8**	**0.85**	**375**	**571**	**0.87**	**296**	**464**	**0.91**
1	32.2	39.5	0.87	25.4	32.2	0.83	524	780	0.89	390	625	0.91
2	27.4	34.6	0.91	21.6	28.0	0.96	389	554	0.89	271	413	0.96
3	33.1	40.4	0.99	21.0	27.7	0.91	459	622	0.94	290	414	0.91
4	28.3	34.4	0.92	22.7	31.9	0.99	419	625	0.96	276	419	0.95
5	37.5	46.1	0.82	25.3	32.1	0.82	757	1051	0.83	438	669	0.90
6	25.9	33.7	0.96	20.1	26.7	0.81	307	518	0.94	245	355	0.77
7	24.4	32.6	0.97	22.1	29.5	0.96	310	461	0.94	275	421	0.95
8	22.2	28.5	0.95	18.7	24.3	0.84	237	374	0.94	209	335	0.93
9	26.4	34.0	0.97	21.2	29.5	0.96	318	443	0.86	241	374	0.87
10	22.2	28.5	0.98	20.7	26.7	0.97	240	365	0.98	222	357	0.98
11	38.7	47.3	0.94	23.4	32.3	0.98	650	855	0.74	424	582	0.89
12	22.0	28.3	0.99	19.4	23.7	0.89	224	366	0.99	214	294	0.93
13	22.4	29.2	0.99	20.7	28.1	0.98	233	358	0.98	223	342	0.97
14	23.5	32.7	0.99	22.7	29.9	0.97	279	426	0.97	273	359	0.92
15	26.8	35.4	0.90	20.4	26.2	0.96	359	558	0.83	253	389	0.91
16	23.9	33.3	0.99	21.2	28.2	0.97	295	452	0.99	258	403	0.98
17	32.0	41.6	0.94	22.3	34.2	0.99	515	785	0.91	333	535	0.95
18	29.1	36.6	0.94	23.0	29.6	0.90	410	623	0.93	309	491	0.94
19	30.9	38.2	0.81	23.1	32.4	0.99	475	723	0.82	354	532	0.96
20	19.0	26.3	0.97	16.8	24.8	0.98	190	324	0.97	158	239	0.89
Mean	27.4	35.1	0.94	21.6	28.9	0.93	379.5	563.2	0.91	282.9	427.4	0.92
St. Dev.	5.3	5.8	0.05	2.1	3.0	0.06	149.7	195.6	0.07	73.3	112.0	0.05
C.o.V.	0.19	0.17	0.06	0.10	0.10	0.07	0.39	0.35	0.08	0.26	0.26	0.05