Spectral shape parameters in storm events from different data sources

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Motivation

- The shape of the wave spectrum with associated gamma parameter is of significant importance in assessment of
  - loads and responses of ships and offshore structures.
  - occurrence of abnormal waves, also called freak or rogue waves.
  - Behaviour of wave power systems
- There are uncertainties related to estimation of the peakedness parameter (gamma / γ) when different sources of wave data are used (models and observed).
- How do recommendations in engineering compare with observed and hindcasted data?

Conclusions

- NORA10 gamma values peak at around 3, seldomly when Hs is at max, but that can be a consequence of retrieving data from outside field of extremes (peak of very severe storms are constrained, and there is large gradients in the field)
- MIROS radar gives alike peakedness values as NORA10, though slightly higher.
- Other wave sensors (buoys, downlooking lasers –> In-situ measurements!) give twice as high gamma values.
- Gamma as retrieved from fitting J-spec to measured or modelled spectra seems to have a close to linear dependence on wave peak steepness (when the wave energy has one peak).

Content

- Gamma values as modelled with WAM model (10km)
- Storm events
- Values as measured with different sensors
- Comparison to standards for spectral shapes in design with reference to DNV recommended practise

Spectral shapes commonly used in the marine industry

- **Shipping industry:**
  - **For design: Pierson Moskowitz spectrum (1964) ,** (JONSWAP spectrum with γ=1.0)**.**
  - **For ship operations:** The **JONSWAP (1973)** and **Torsethaugen (1996)** are starting to be used

$$S_{PM}(\omega) = \frac{5}{16} \cdot H_S^2 \omega_p^4 \cdot \omega^{-5} \exp\left(-\frac{5}{4} \left(\frac{\omega}{\omega_p} \right)^{-4} \right)$$

where $\omega_p = 2\pi/T_p$ is the angular spectral peak frequency.

- **Offshore industry**:
  - **For design and operations: JONSWAP(1973)**, **Torsethaugen (1996**)(double peaked).

$$E_{JON}(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp\left(-\frac{5}{4} \left(\frac{f}{f_m} \right)^{-4} \right) \gamma^{\exp \frac{-(f-f_m)^2}{2\sigma^2 f_m^2}}$$

Spectral values commonly used in the marine industry

- Design offshore structures:
  - often 3.3 is used, but is location specific

- Design of ships:
  - $\gamma = 1$ (IACS, International Association of Certifying Societies).

- Spectral shapes values in marine operations:

  (for example: when criteria for an operation has to be defined).
  Hydrodynamic models are run for calculations of maximum loads / accelerations. Models are often taken from DNV-Recommended Practise

Typical for

- North Atlantic: $\gamma = 1.5\text{-}2.0$, $\sigma_a = 0.07$, $\sigma_b = 0.09$

Recommended Practice, the legacy DNV-RP-C205, April 2014

3.5.5.4 The zero upcrossing wave period T_z and the mean wave period T_1 may be related to the peak period by the following approximate relations ($1 \le \gamma < 7$).

$$\frac{T_z}{T_p} = 0.6673 + 0.05037\gamma - 0.006230\gamma^2 + 0.0003341\gamma^3$$

$$\frac{T_1}{T_p} = 0.7303 + 0.04936\gamma - 0.006556\gamma^2 + 0.0003610\gamma^3$$

For $\gamma = 3.3$; $T_p = 1.2859 T_z$ and $T_1 = 1.0734 T_z$

For $\gamma = 1.0$ (PM spectrum); $T_p = 1.4049 T_z$ and $T_1 = 1.0867 T_z$

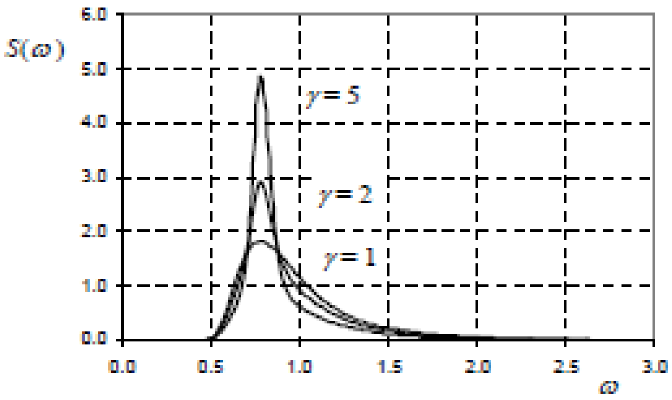


Figure 3-9
JONSWAP spectrum for $H_s = 4.0$ m, $T_p = 8.0$ s for $\gamma = 1$, $\gamma = 2$ and $\gamma = 5$.

Recommended Practice
the legacy DNV-RP-C205, April 2014

3.5.5.5 If no particular values are given for the peak shape parameter γ, the following value may be applied:

$$\gamma = 5 \quad \text{for} \quad T_p / \sqrt{H_s} \leq 3.6$$

$$\gamma = \exp\left(5.75 - 1.15 \frac{T_p}{\sqrt{H_s}}\right) \quad \text{for} \quad 3.6 < T_p / \sqrt{H_s} < 5$$

$$\gamma = 1 \quad \text{for} \quad 5 \leq T_p / \sqrt{H_s}$$

where T_p is in seconds and H_S is in metres.

Gran, Sverre (1992). *A Course in Ocean Engineering*. Book, Series Development in Marine Technology 8, Published by Elsevier.

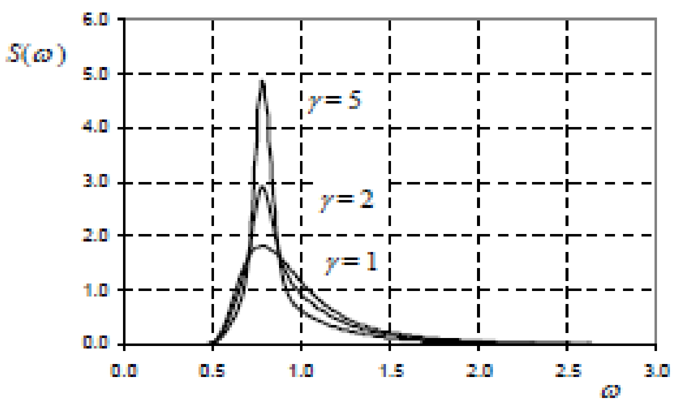
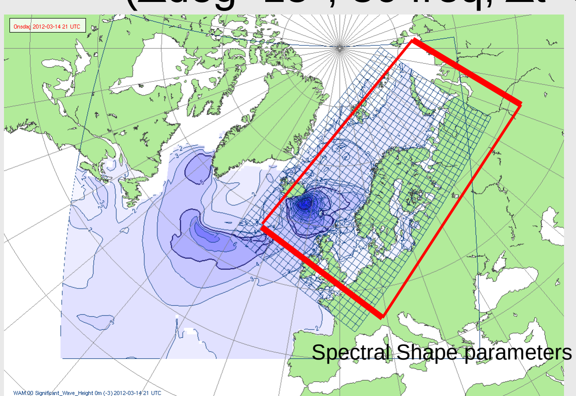


Figure 3-9
JONSWAP spectrum for H_s = 4.0 m, T_p = 8.0 s for γ = 1, γ = 2 and γ = 5.

Data used in the analysis

Hindcast data from NORA10

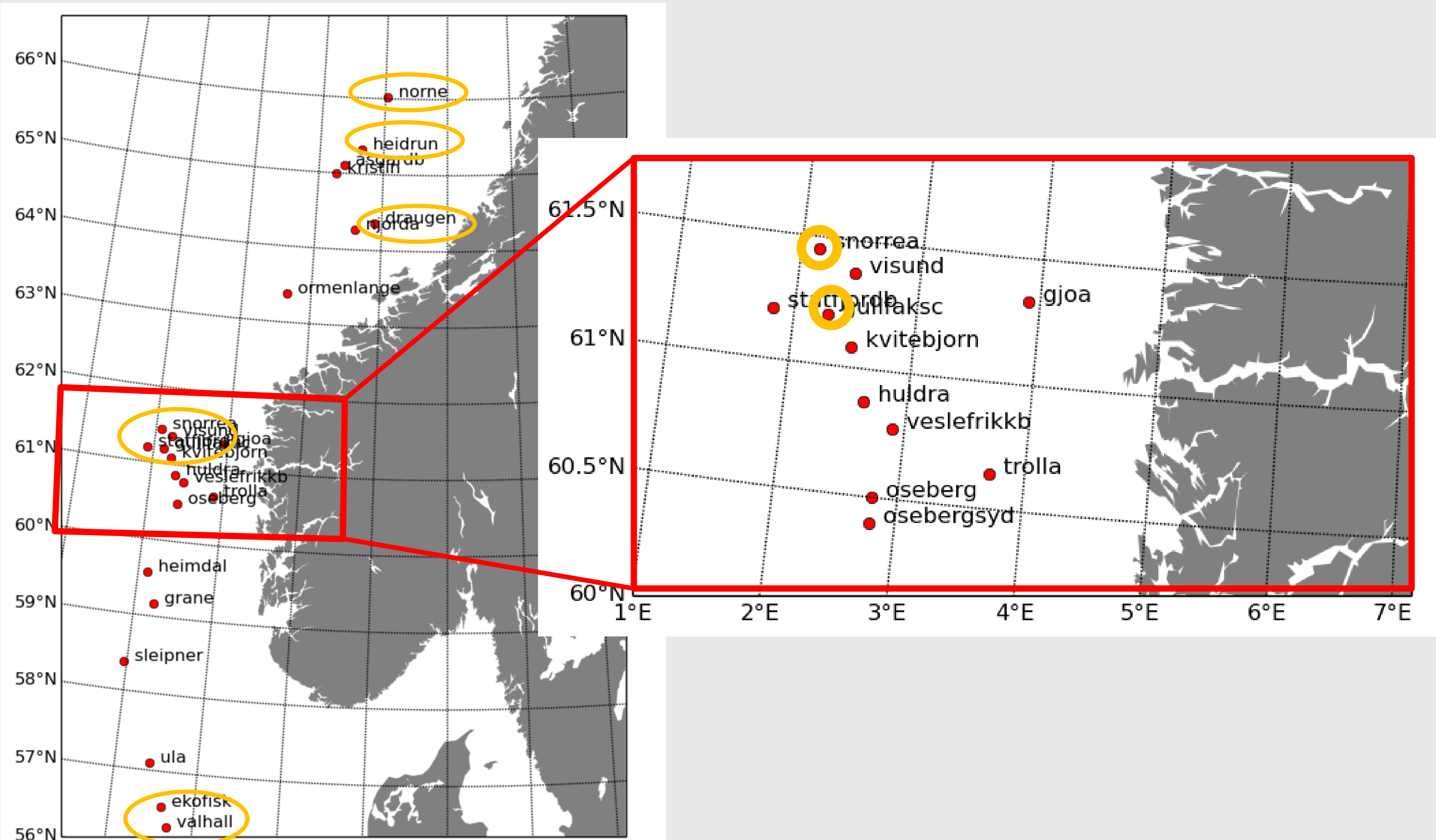
- WAM grid 10 km with BC from a 50km model run with ERA40 winds
- Winds from Atmospheric model HIRLAM 10km with BC from ERA40
- Sept 1957 to 2015
- Stored:
    - at all grid points, Δt=3 hours: **Parameters:** Wind, Hs,Tp, TM02, DDp, DDm (total sea, wind sea and swell)
    - at some grid points: **wave spectra** (Δdeg=15°, 36 freq, Δt=3 hours)



Measured data (limited to North Sea and Norwegian Sea)

- Buoys
- Marine radars (WAMOS)
- MIROS doppler radars
- Downlooking radars
    - Saab radars
    - MIROS Range Finder (MRF)
    - Optech lasers

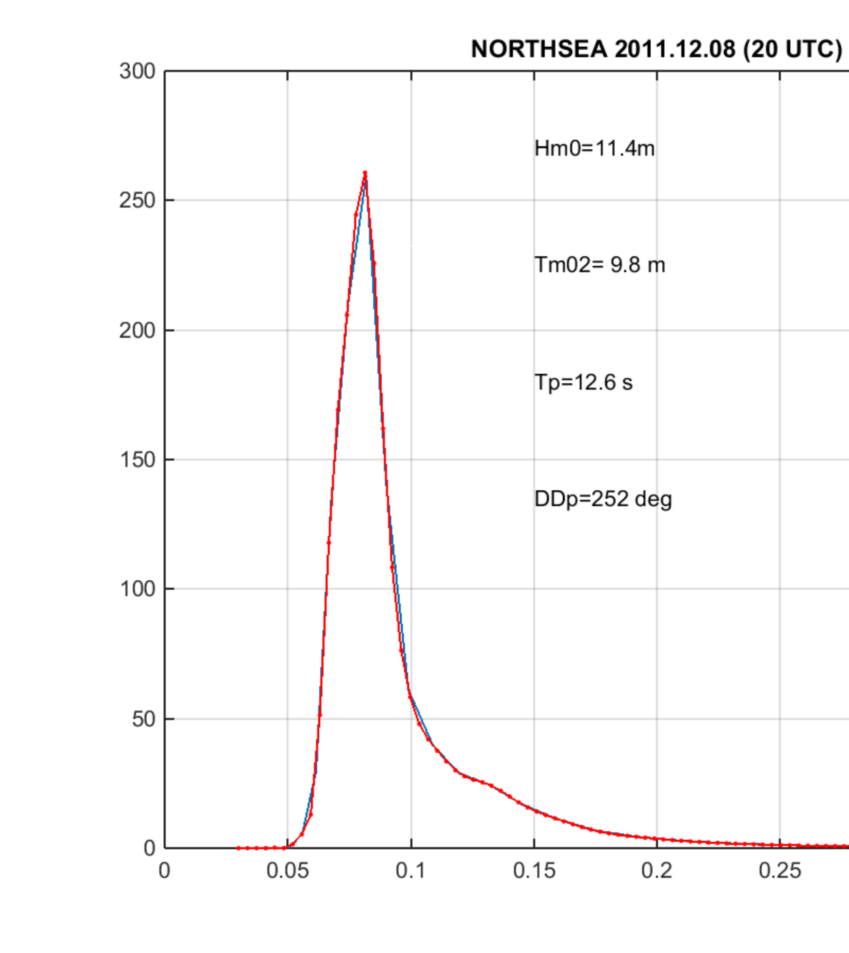
Observations stored at MET Norway



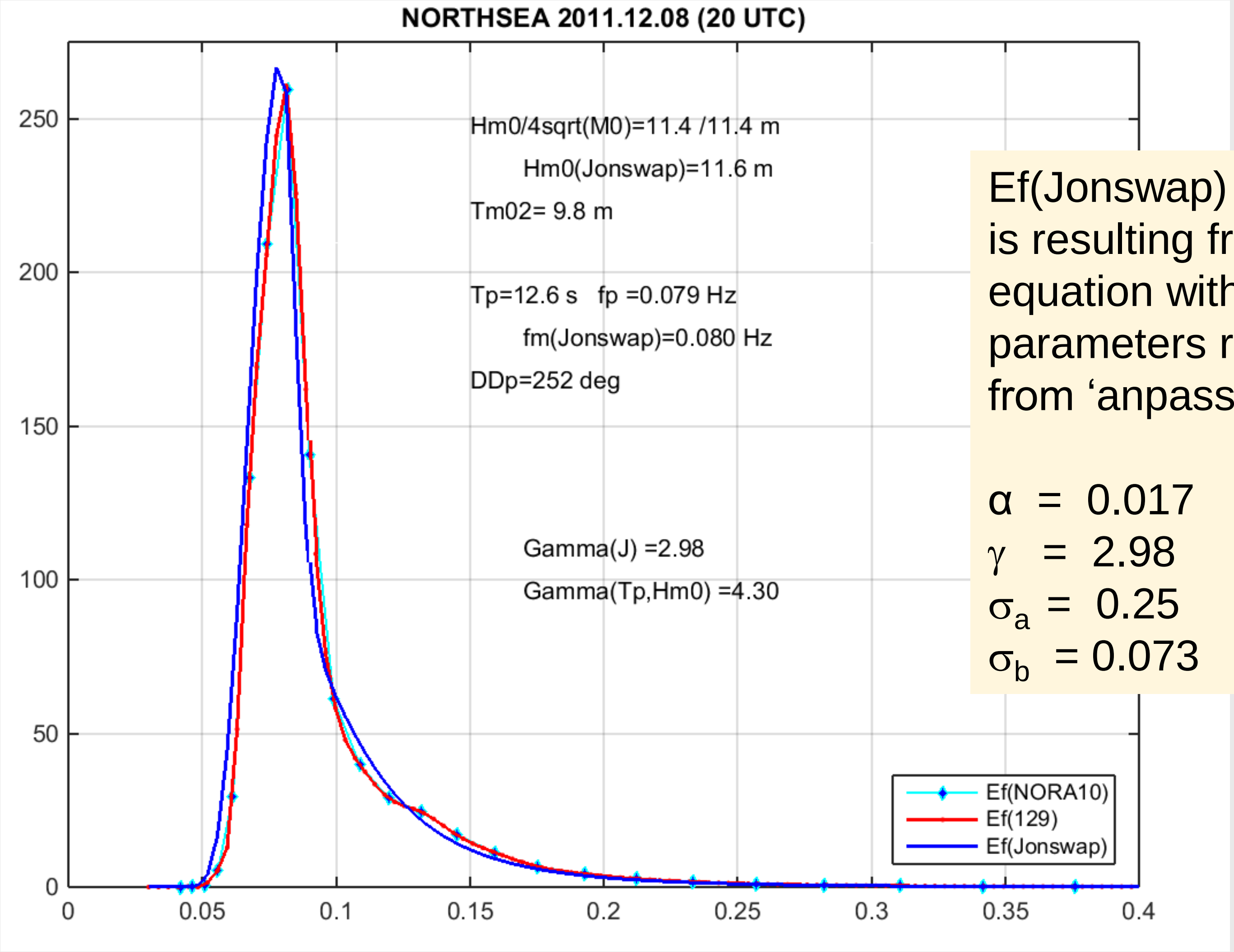
Calculation og ‘Gamma peakedness’

- Using *‘anpass.f’* (courtesy of Heinz Günther, program originally used for analysing the JONSWAP data).
- Required input: E(f) with 129 frequencies, and Δf = konstant
- E(f) from models and observations are interpolated with ‘spline’ function in matlab f=[0.03-0.5 Hz].

  (MIROS data in [0.03-0.3 Hz])
- The program iterates a number of times to try to fit a J-spec with different values of α, γ , σ_a and σ_b
- As expected not all (1D) spectra fit J-spec



Calculation og ‘Gamma peakedness’

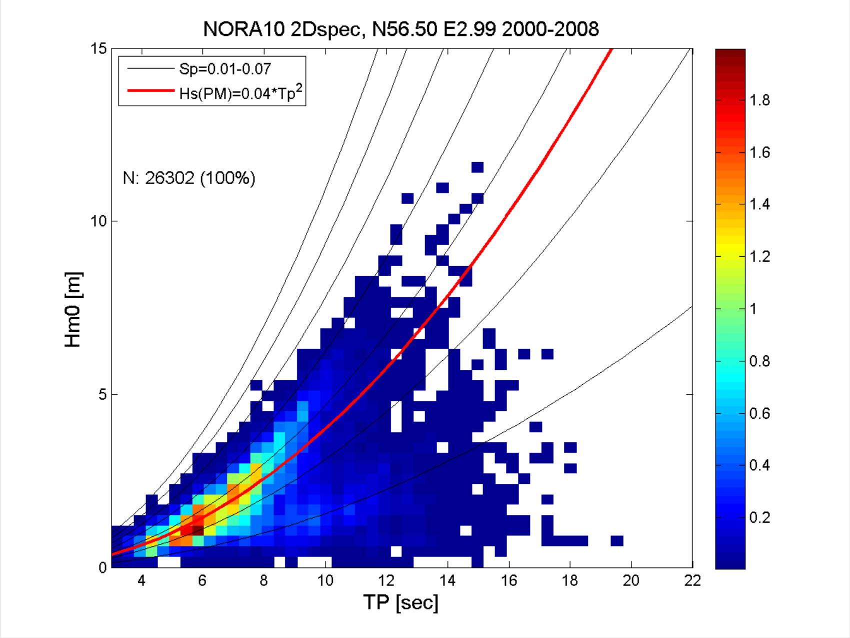


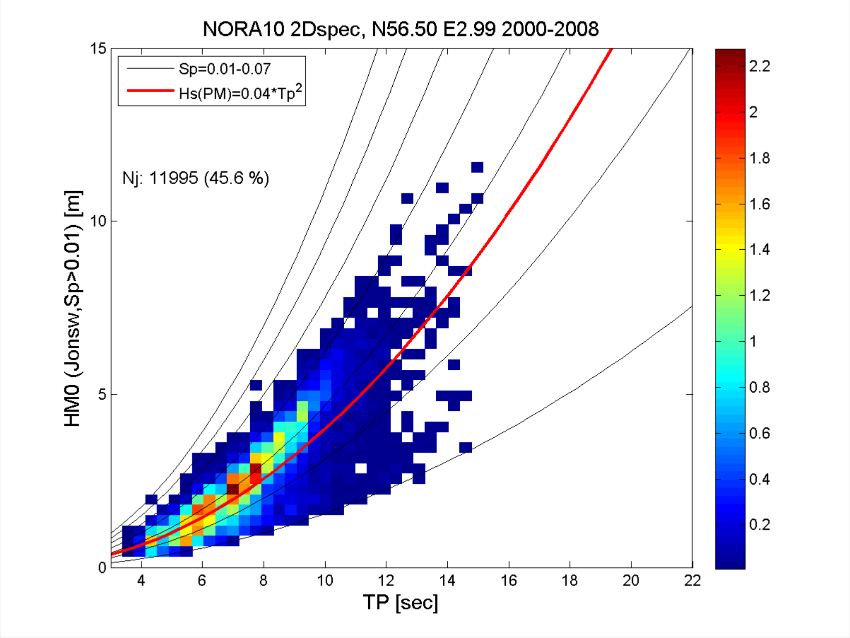
Ef(Jonswap) in blue is resulting from J-equation with parameters resulting from ‘anpass.f’ :

α = 0.017
γ = 2.98
σ_a = 0.25
σ_b = 0.073

Distribution of Hs vs Tp at Ekofisk

(work presented in EXTREME SEAS meeting in Berlin, March 2011)





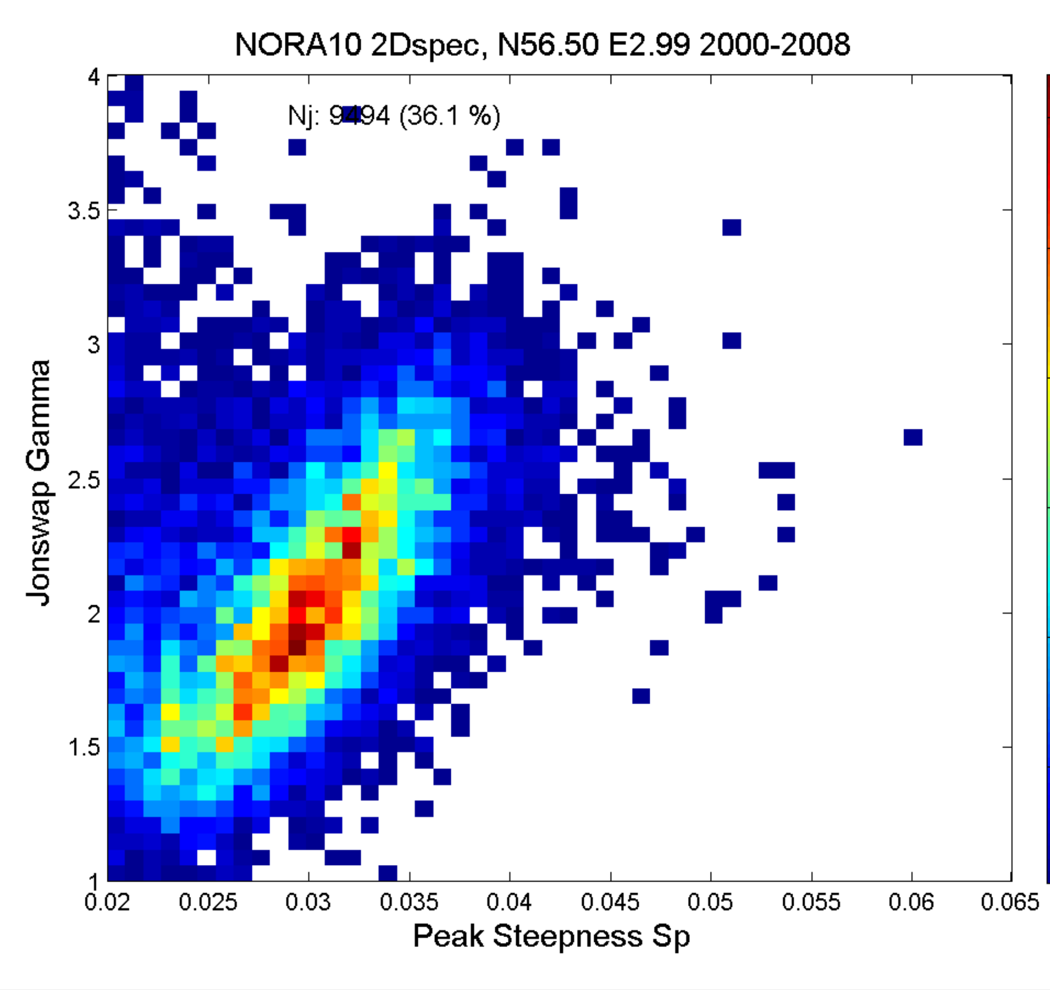
All cases 2000-2008

45.6% of cases,
Jonswap shapes and Sp>0.01

NORA 10 data, γ vs Sp

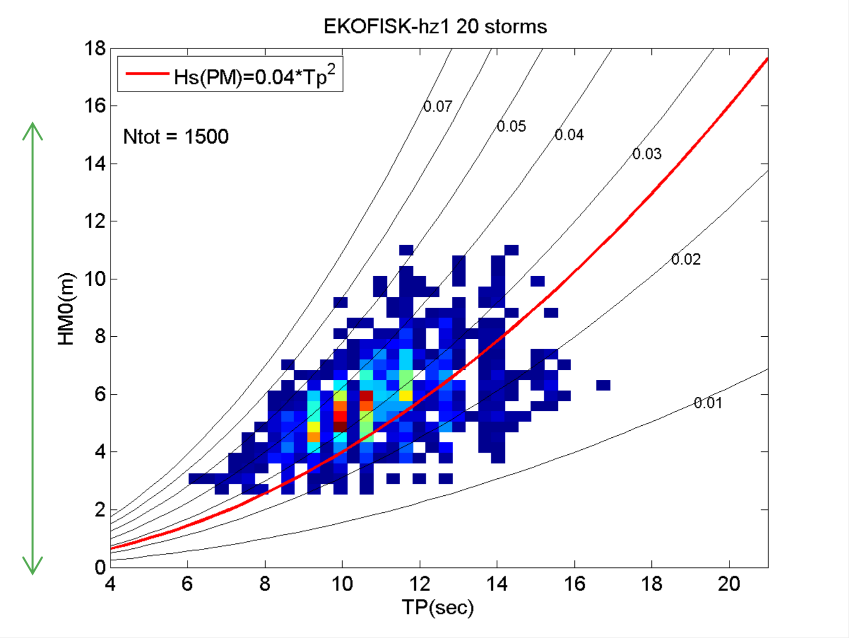
- 36.1% of cases at Ekofisk have Jonswap-similar shape with Sp>0.02.

How does hindcast, measurements and the industrial standards compare?

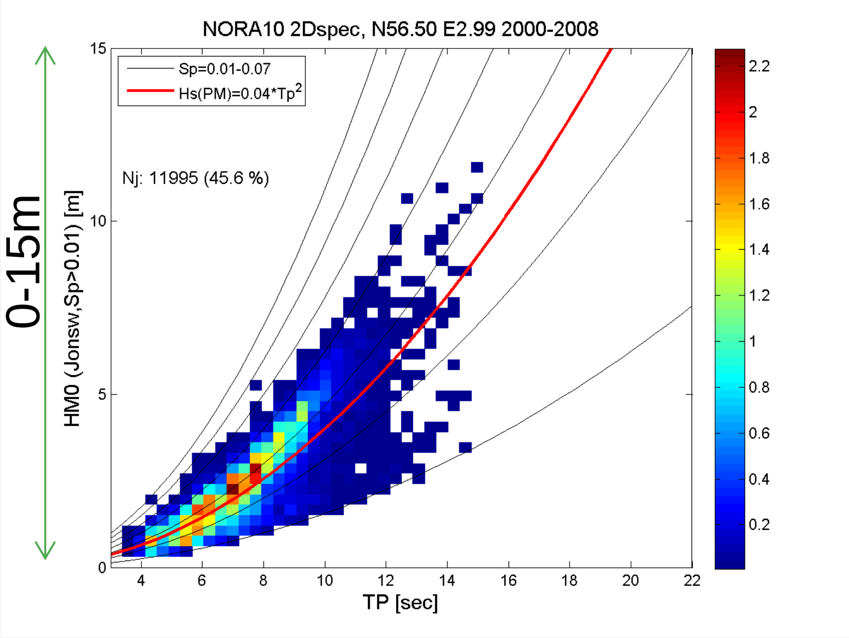


Observations compared to model ?
Ekofisk, Waverider in 20 storms 2007-2008

Waverider Hs-Tp dist.



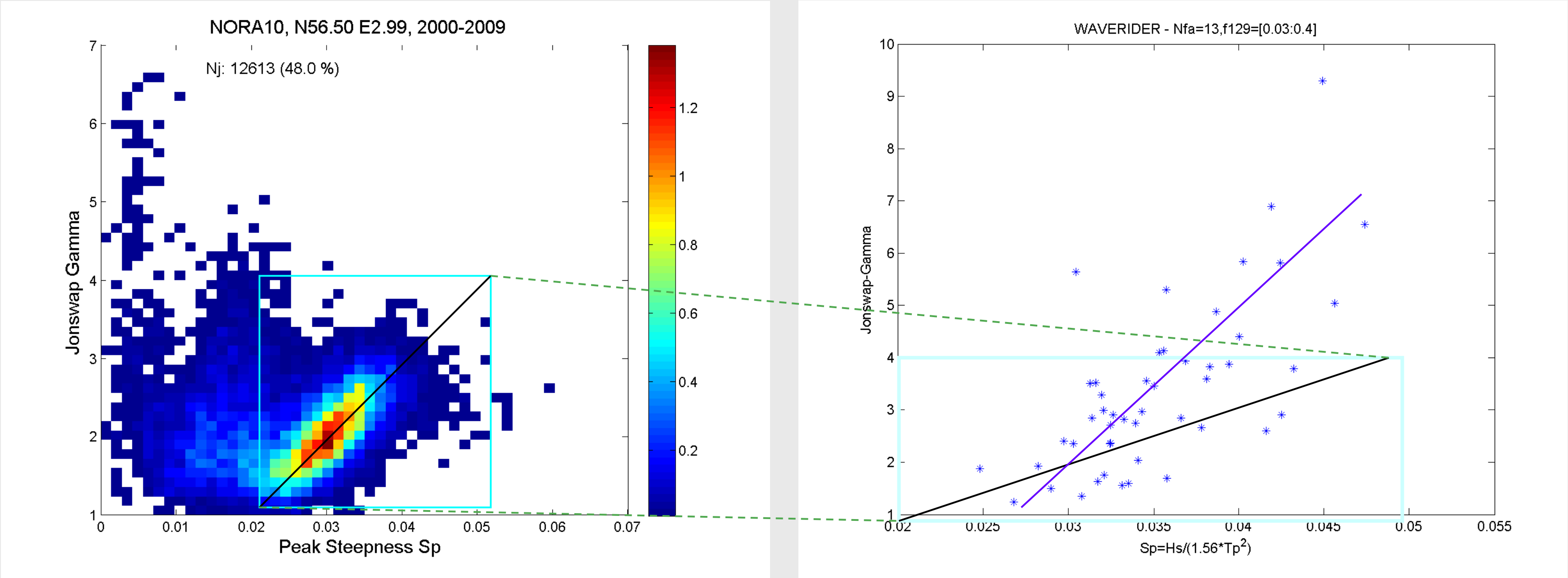
NORA10 Hs-Tp in Jspec shapes 2000-2008



Gamma vs Sp
NORA10 and Waverider

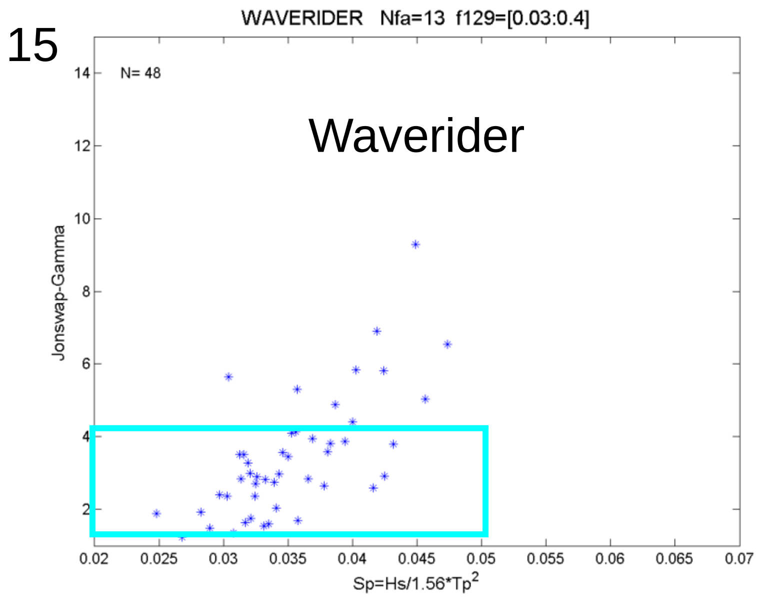
NORA10

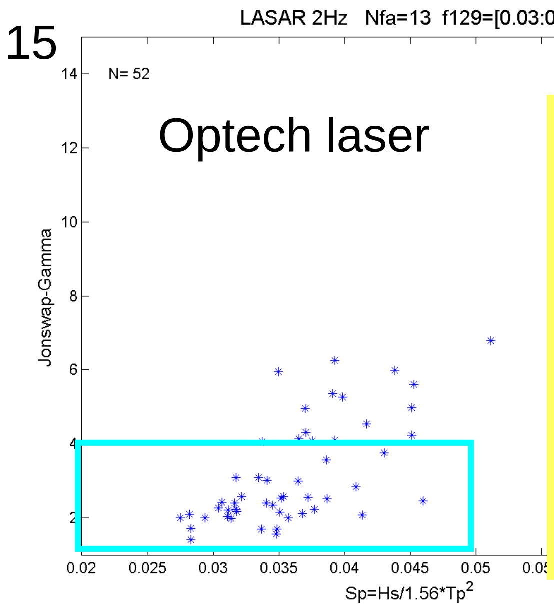
Waverider observations during one severe storm



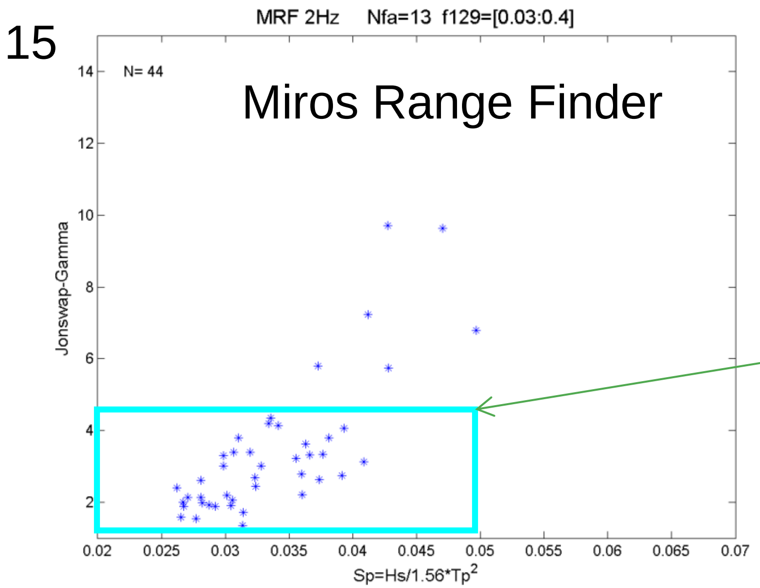
The black line shows how model values are distributed, and blue line how gamma from Waverider spectra in one storm are vs Sp. → observed spectra have much higher gamma values.

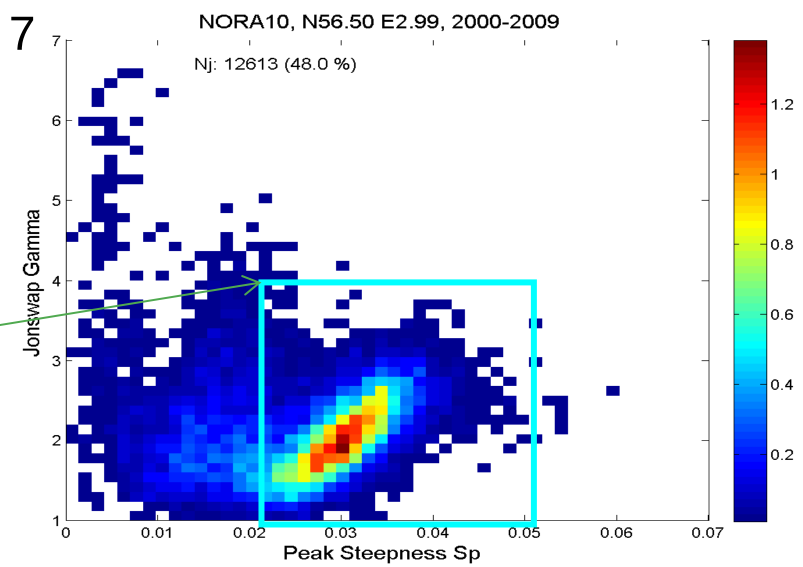
Gamma vs Sp
Three different sensors in one severe storm





Measured γ are higher than model
But: At what time scale do extreme events occure? 10, 30 or 60 minutes?





Some severe storms

- **11. January 2006 at Haltenbanken. Hm0 → 15-17?m** (ref: ‘Forecasting a 100 year event’, AK.Magnusson, M.Reistad, Ø.Breivik, R.Myklebust, E.Ash), proceedings of 9th WW, Victoria, sept. 2006.

- **12.-13. January 2015 at Haltenbanken**

- **25.-26. December 2011 at GullfaksC/Snorre Hm0x → 16m**

  Hm0 increase: 8 m in 6 hours

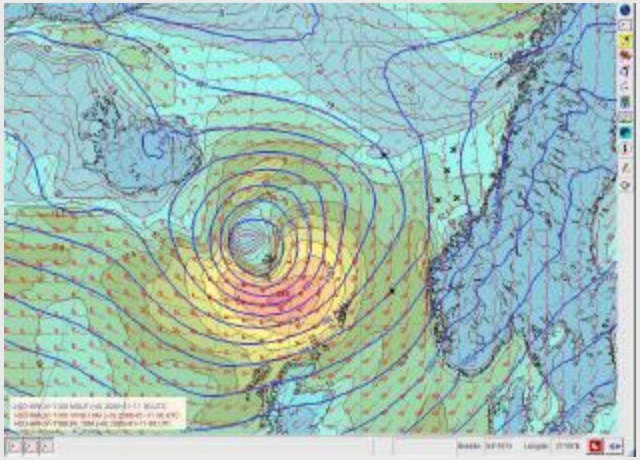
- **8.-9th December 2008 in Central North Sea. Hm0x ~11-12m**

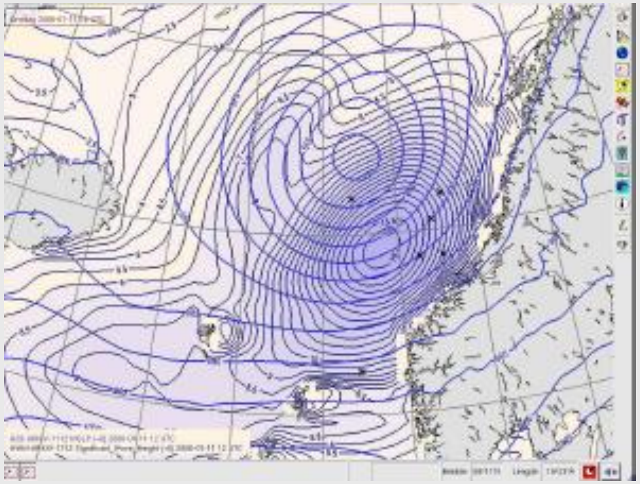
  Measured Hs increase 4 m in 1.5 hours.

Norwegian Meteorological Institute

Severe storms – typical features

- Hs close to 50 or 100 yr (!)
- Strong forcing, especially at first
- Veering of wind and wave field as low pressure center moves on
- Strong gradients in the Hs-field
  - Nearby platforms measure different values





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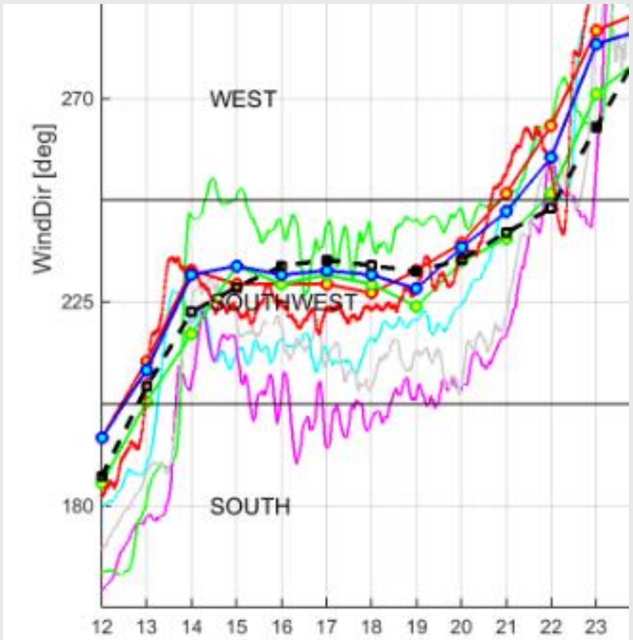
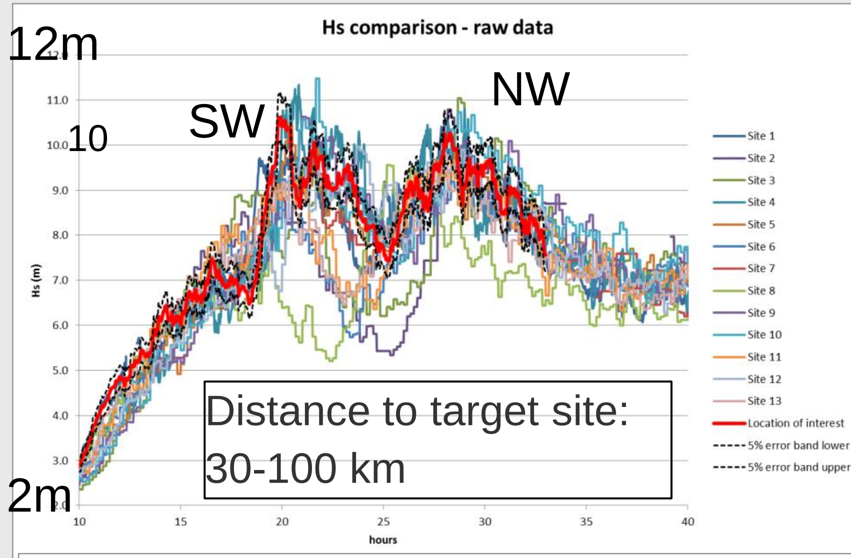
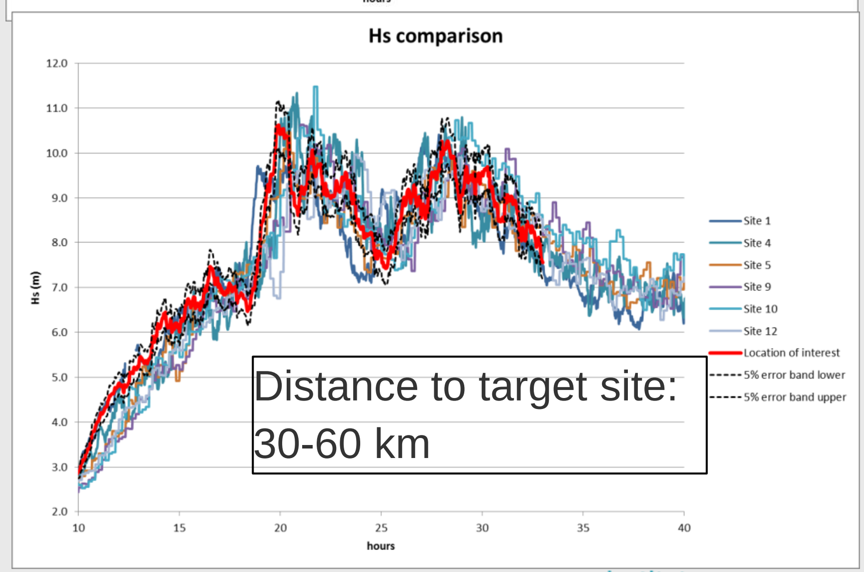
Question of gound truth







From presentation «*Hs in rapidly evolving environment, challenges to design*» at workshop «Advances in Ocean Wave measurements», London, Oct.21st 2015 (http://www.rsaqua.co.uk/events.php) by Eirini Spenza (DNV-GL). Co Authors: R.V.Ahilan, P.Tromans, L.Vanderschuren, AK.Magnusson and OJAarnes.

Variability in wave measurements

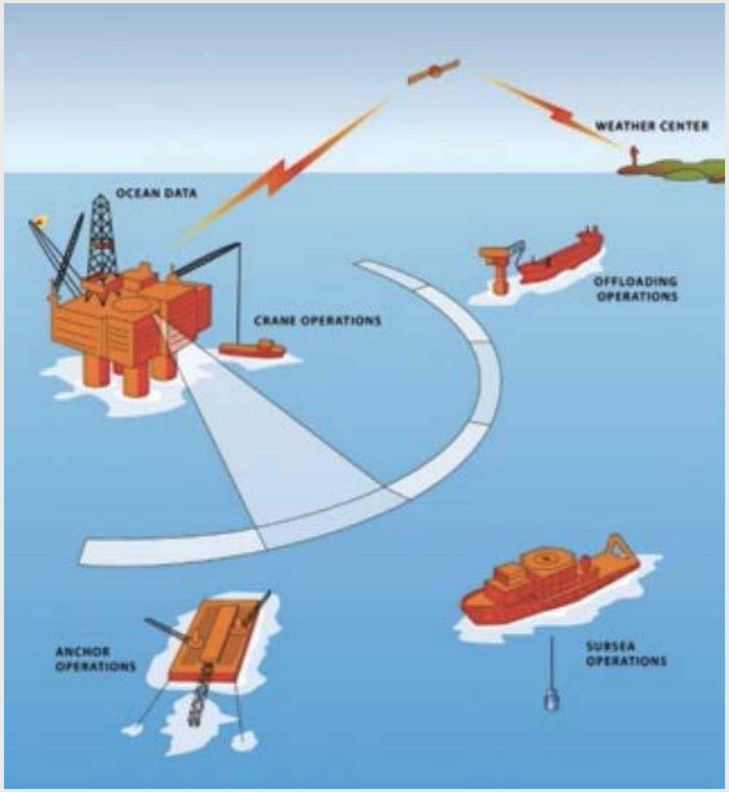
- Ref: (WW13th):
- Bitner-Gregersen, E. M. and A. K. Magnusson, 2014: *Effect of sampling variability on wave parameters and wave statistics,* Ocean Dynamics (2014), Theoretical, Computational and Observational Oceanography. ISSN 1616-7341. Vol 64, No 11. DOI 10.1007/s10236-014-0768-8

Norwegian Meteorological Institute

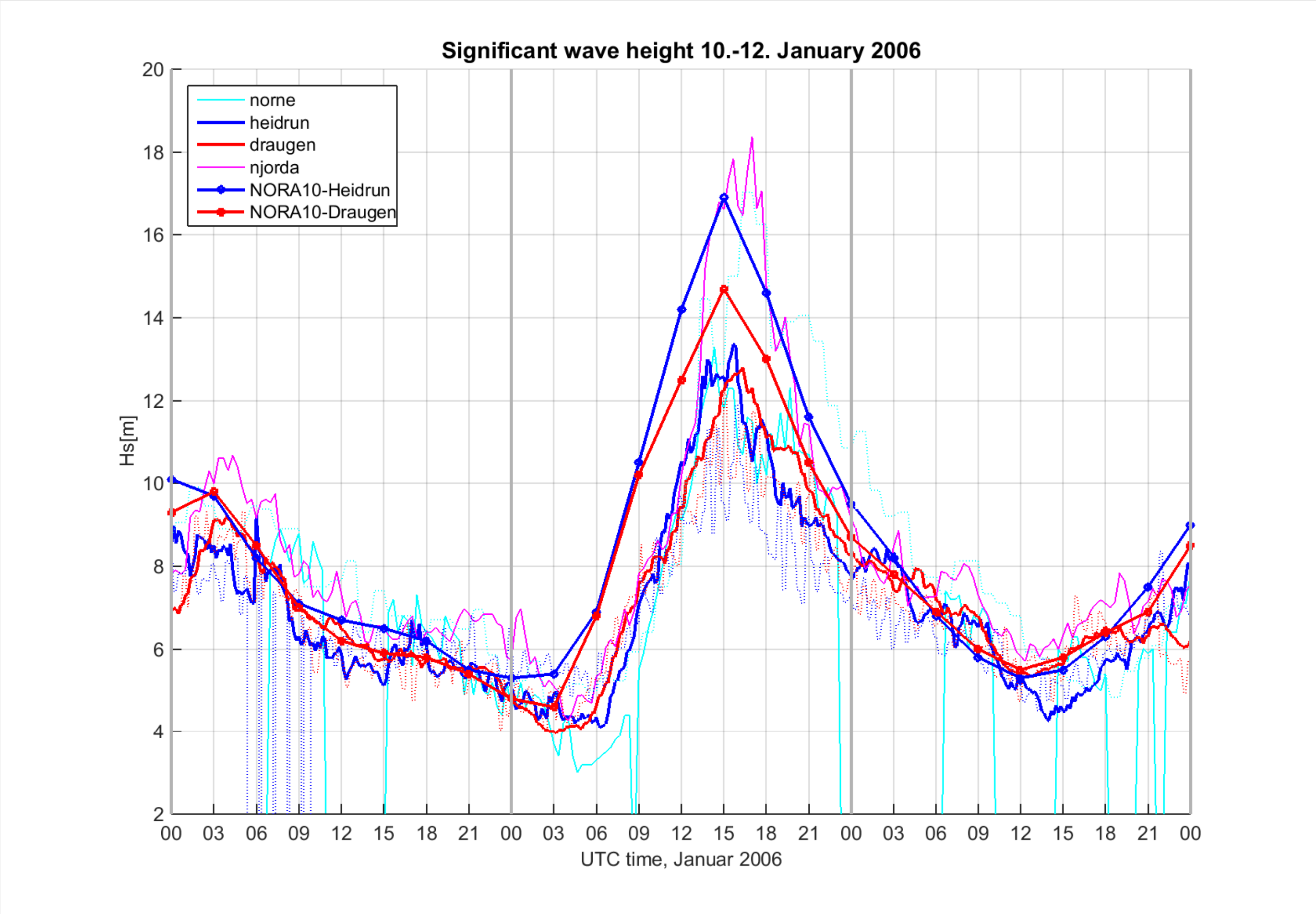
The MIROS Doppler directional wave radar

Evaluates wave parameters and wave directional spectra from

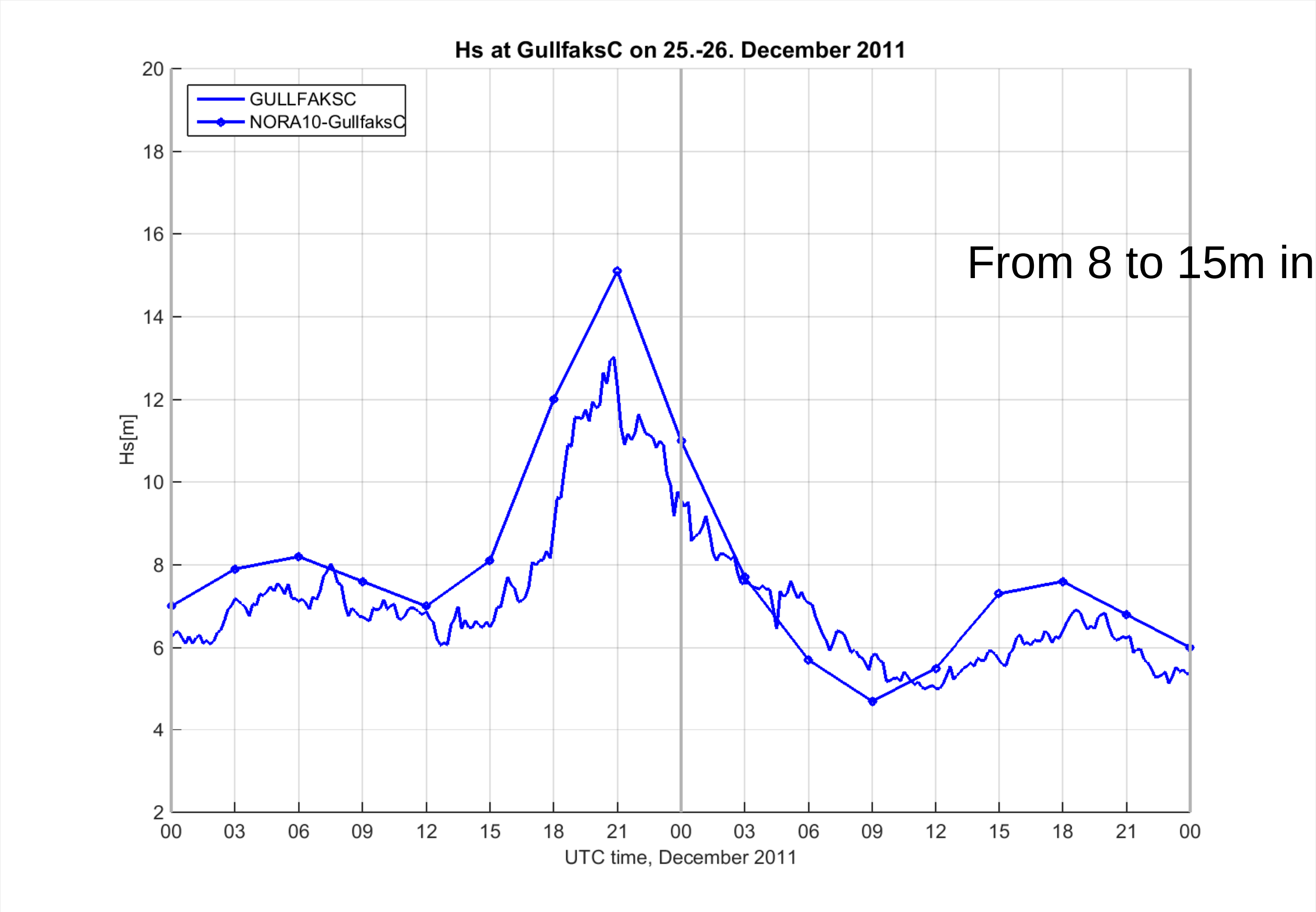
- Area of sea surface ~500 m away from platform (less when mounted on a ship), covering a 180° sector.
- Old systems have 30° resolution (scan **6** sectors (30 ° each) consecutively, for 2.5mins each), newer have 10° resolution.
- Spectral parameters are evaluated as the average of all 6 sectors for the last 3 full sweeps (i.e. time average of the last 45 minutes of measurements, and spatial average over the 180 deg area)
- Data are updated every 2.5 minutes as each new 30 degree sector is scanned



Draugen and Heidrun, 11. Jan 2006

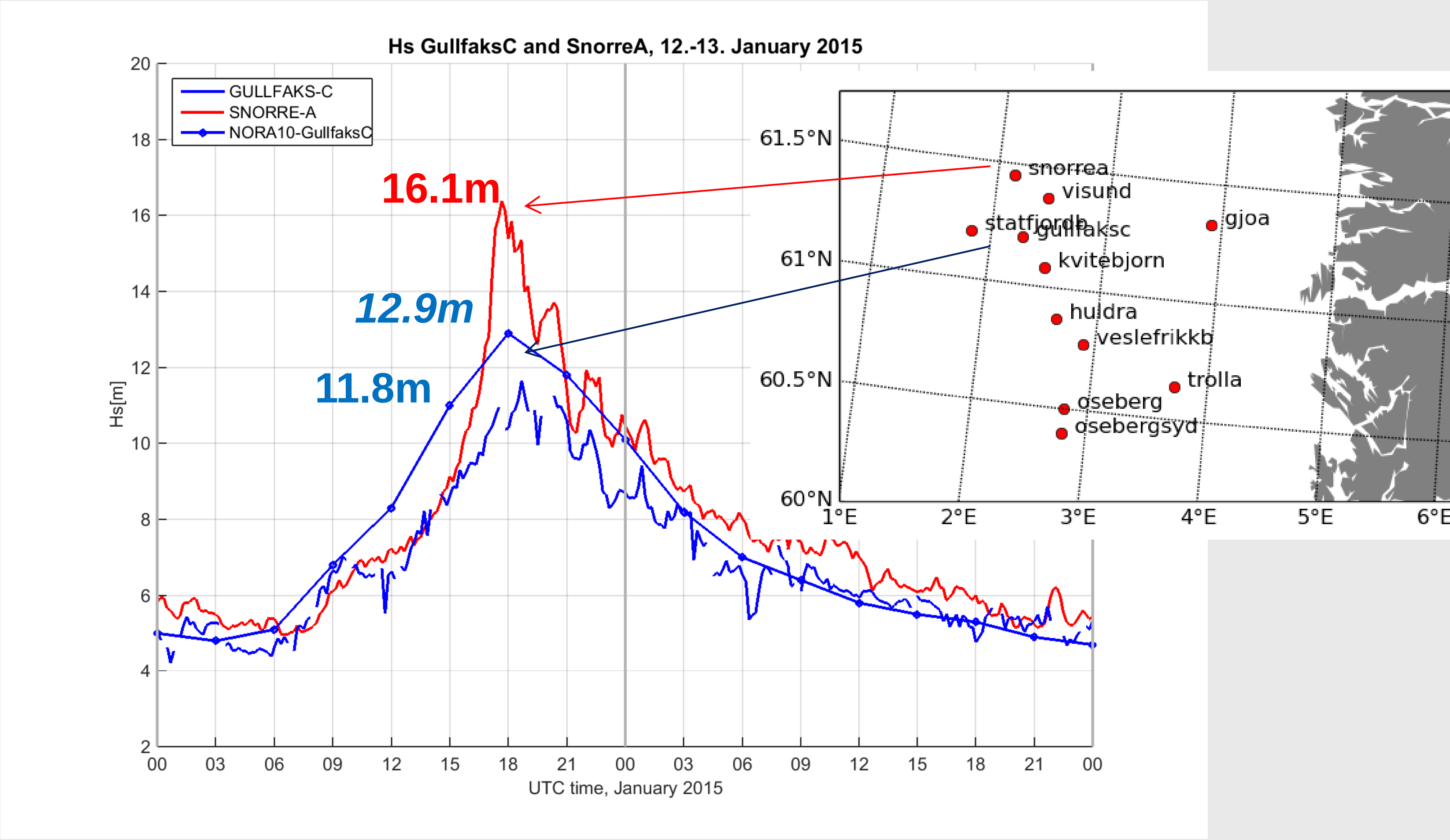


Gullfaksc 25. December 2011

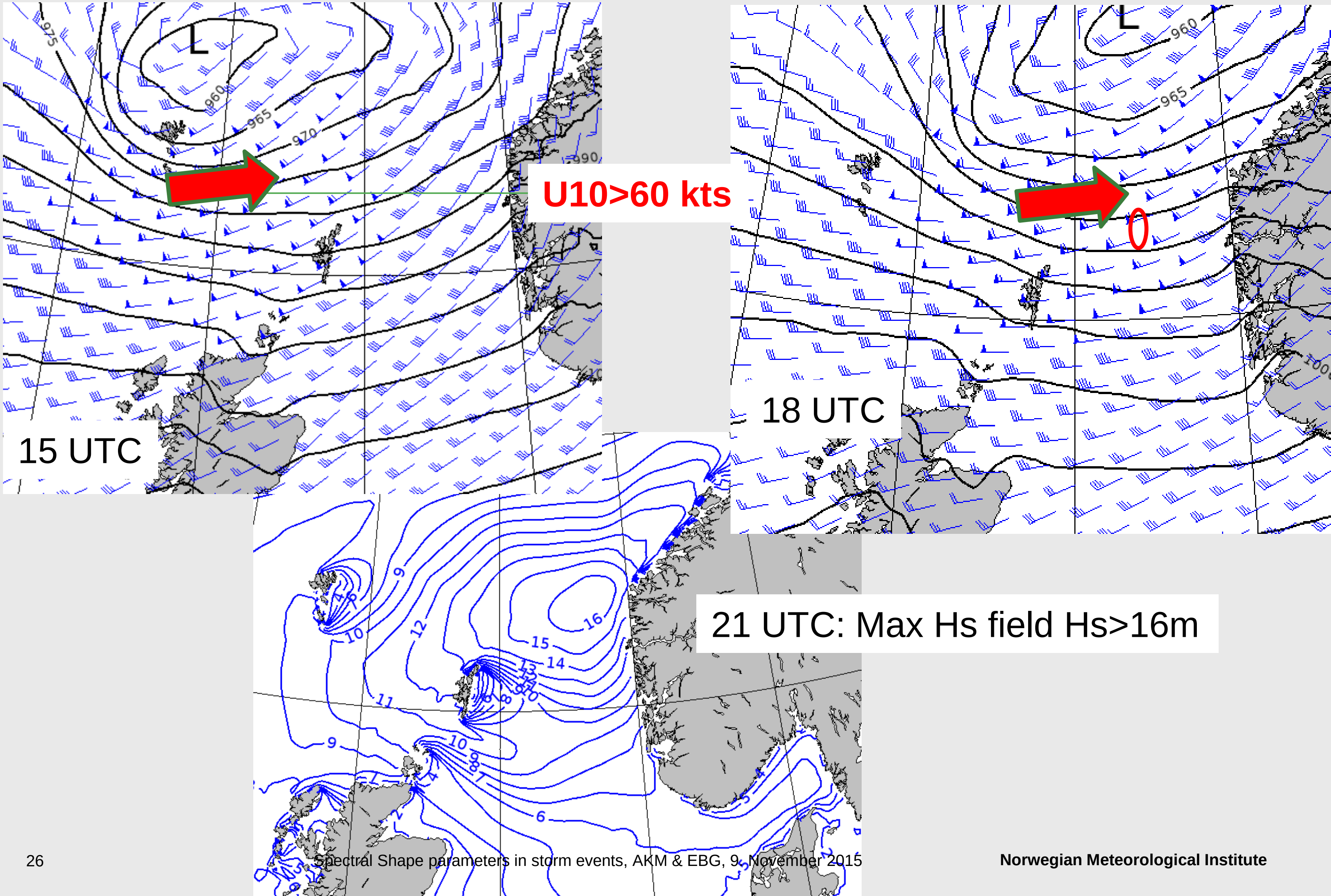


From 8 to 15m in 6 hrs!

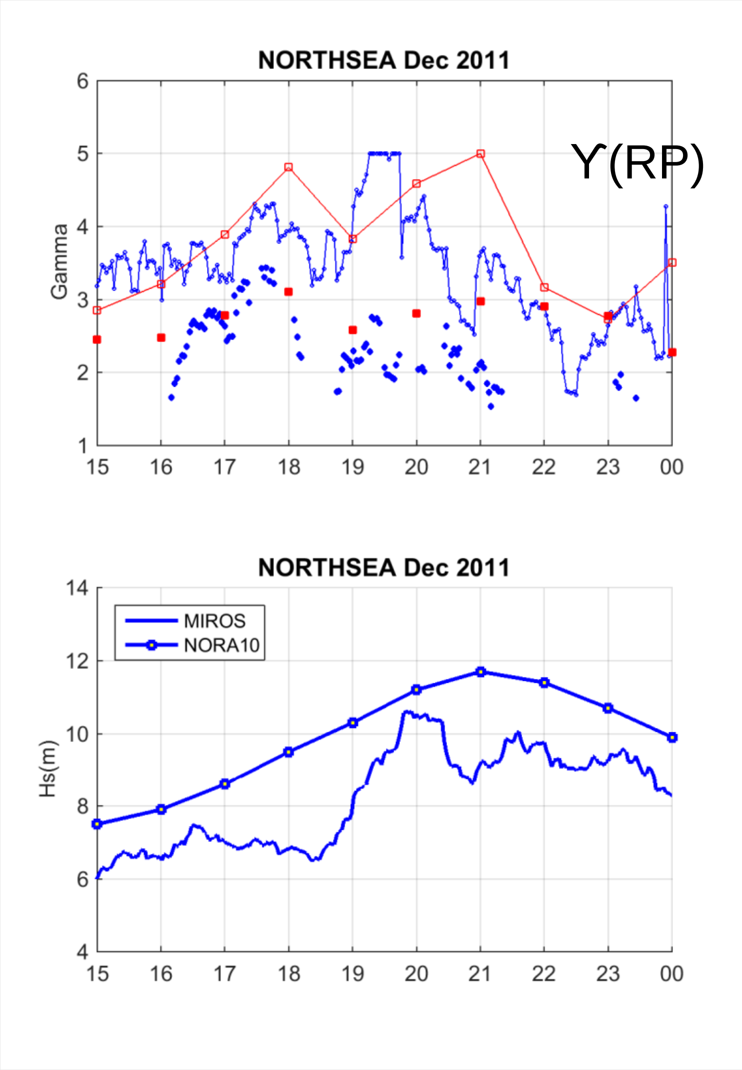
Gullfaks-C and Snorre-A 13. Jan 2015



Low system 25. Dec. 2011



Gamma values through storms



- ϒ (RP) using Hm0 and Tp for both model (red line) and observations (blue line) give values [4-5] at peak Hs values

- ϒ from MIROS spectra (blue dots) give highest ϒ (~3.5) in the strong forcing phase, and less than 3 at peak Hs.

- ϒ from NORA10 spectra have same tendency, but have less variations.

The model is here and at other sites in the North Sea (southern side of low) showing too strong forcing in the increasing phase of storm. It is suggested this is due to lack of resolving finer scale atmospheric conditions.

Gamma from MIROS measurements and NORA10

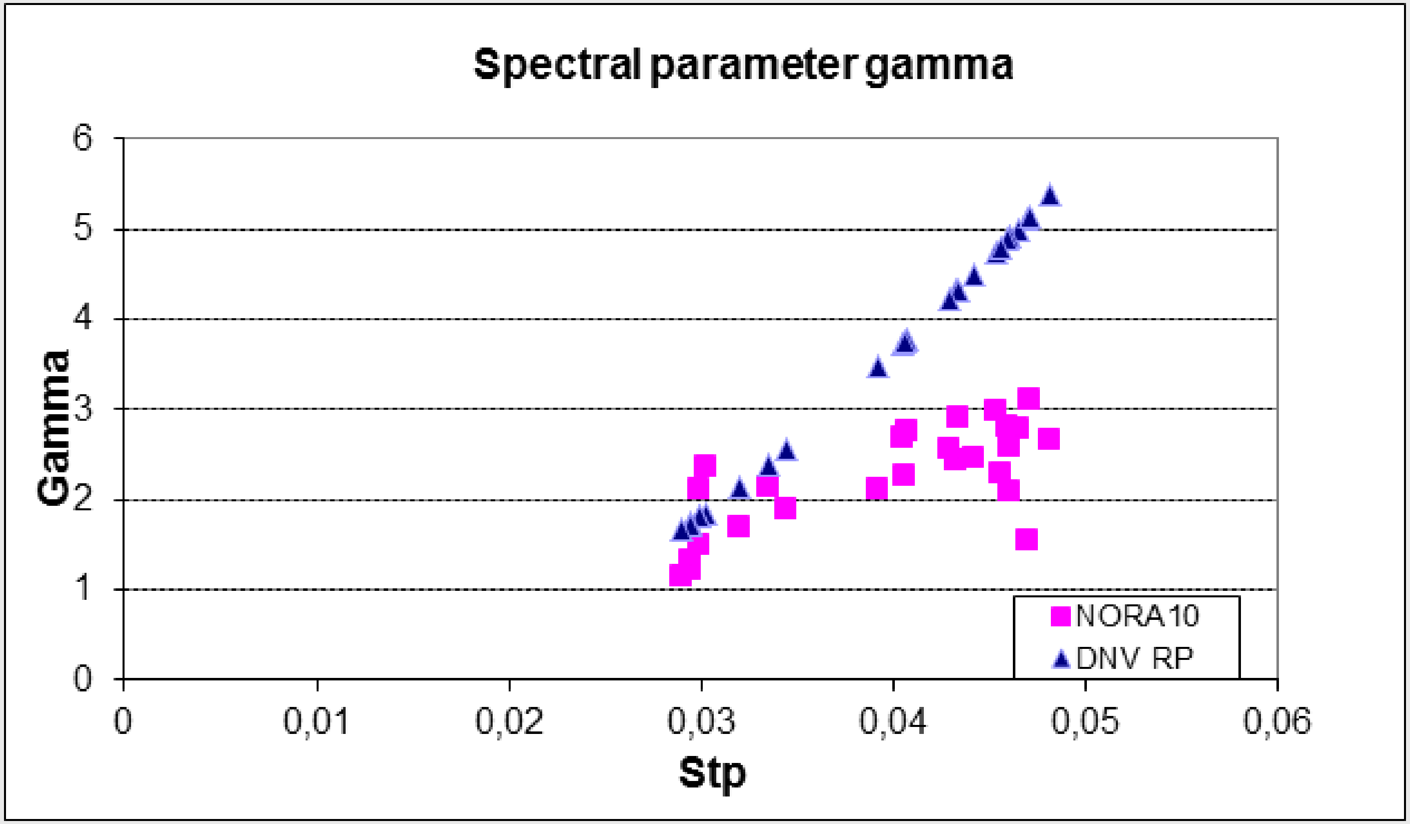
- NORA10 max values of γ are around 3 in two cases, but only in one of 7 cases at the maximum in storm. The other one is in a very strong forcing period.
- MIROS measurements give ~2.7 in two of the cases at a (seemingly) max in storm. Otherwise values are slightly above NORA10 values.

Gamma from other sensors

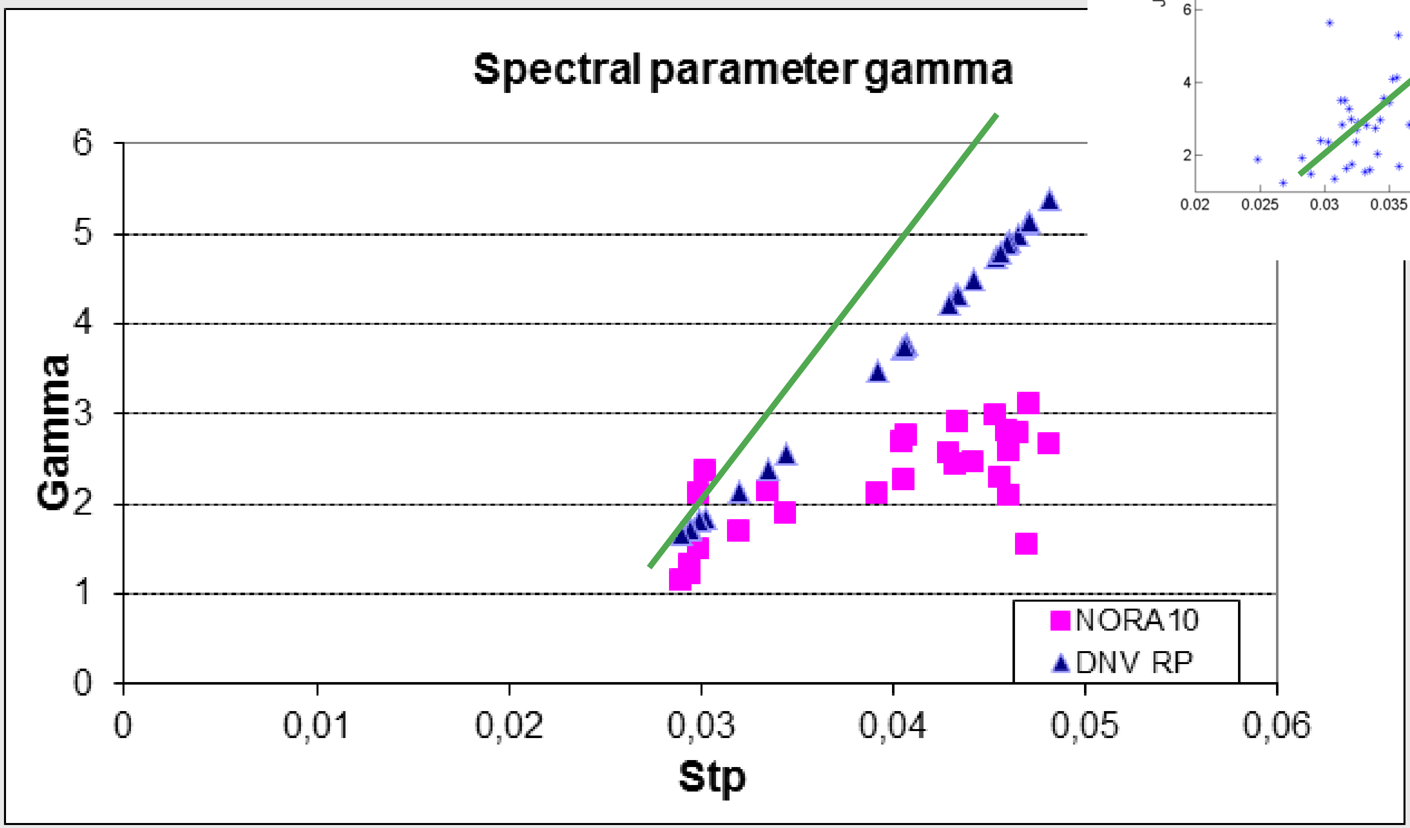
- Recorded values or those evaluated from 2Hz time series give much higher values than NORA10 or the MIROS.
- DNV-RP for Gamma = f(Hm0,Tp) also gives much higher values.
- Measurements from Ekofisk indicate a close to linear relation as given by by DNV-RP, but values obtained by 20 minutes records indicate even higher values.

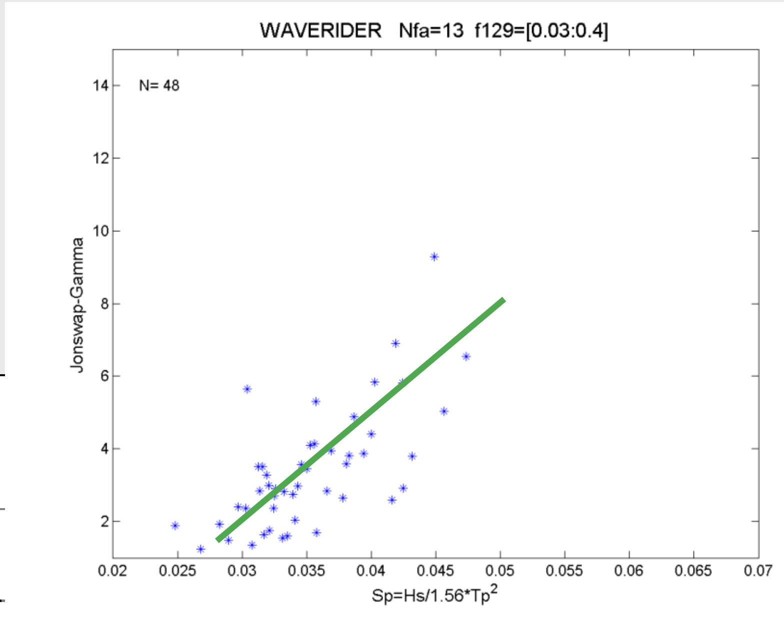
- Many questions are still unanswered and more data are to be analysed

Gamma vs peak steepness through a storm



Gamma vs Peak steepness





Conclusions

- ➢NORA10 gamma values peak at around 3, seldomly when Hs is at max. This may be a consequence of retrieving data from outside field of extremes (peak of very severe storms are constrained, with large horisontal gradients)
- ➢MIROS radar gives alike peakedness values as NORA10, though slightly higher.
- ➢Other wave sensors (buoys, downlooking lasers –> In-situ measurements!) give twice as high gamma values.
- ➢Gamma as retrieved from fitting J-spec to measured or modelled spectra seems to have a close to linear dependence on wave peak steepness

Future work

- Finer resolution in wave model spectrum
    - (24,25) → (36,36)
    - Hindcasts performed with finer grids.

- More quality controle on measurements
    - Energy at low-high frequency bands
    - Effect of different measuring periods (20-30-60min?)
    - …

Thank you for your attention

Aberystwyth Seafront, 2014.02.10
(picture by BBC)

Crew inspects damage after the aircraft carrier USS Hornet (CV 12) unexpectedly encounters a typhoon in 1945. U.S. Navy Photo.

Ekofisk, 80's. White, green and blue water. A wave recorder was in period up to 2008 situated on bridge north of the south flare tower.

A wave hit at unexpected height after Lilly, sept 2001 (platform was designed in the early 1970's)