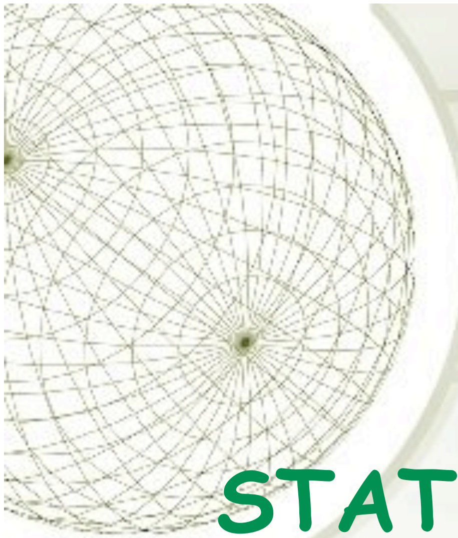

STATISTICAL PROPERTIES OF MECHANICALLY GENERATED SURFACE GRAVITY WAVES

A laboratory experiment in three-dimensional wave basin

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Study of extreme waves in ocean

- Probability of occurrence : essential for engineering purposes
- Deep comprehension of the physical mechanisms of generation

Operational methodology for forecasting

Oceanographic community studies: three conferences/workshop, sessions in large conferences, papers…

Extreme waves in optical systems, in acoustic turbulence in superfluid helium, in matter waves, in nonlinear lattices

Ultimate goal: determination of the shape of the exceedance probability function

Statistical theories with assumptions of stationarity

But:

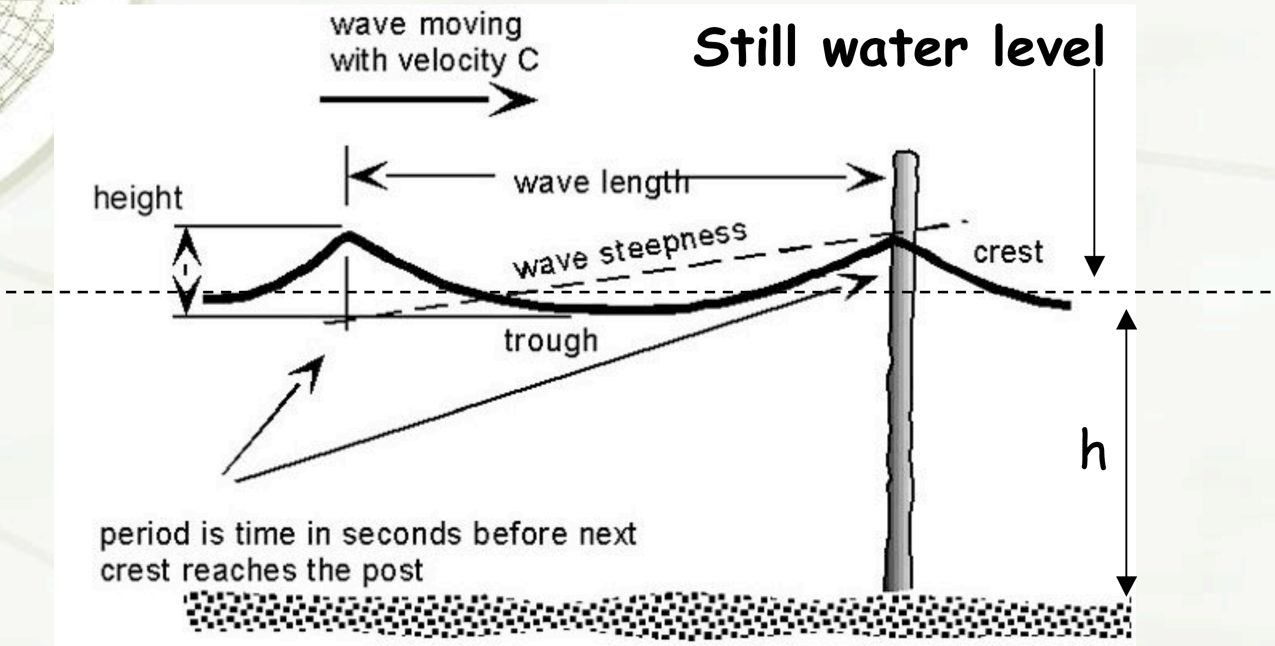
Real sea states changes in space and time

For prediction of extreme waves we need the maximum wave height distribution

But:

Analytical form of wave height distribution under linearity hypothesis (Rayleigh)

EXTREME WAVES



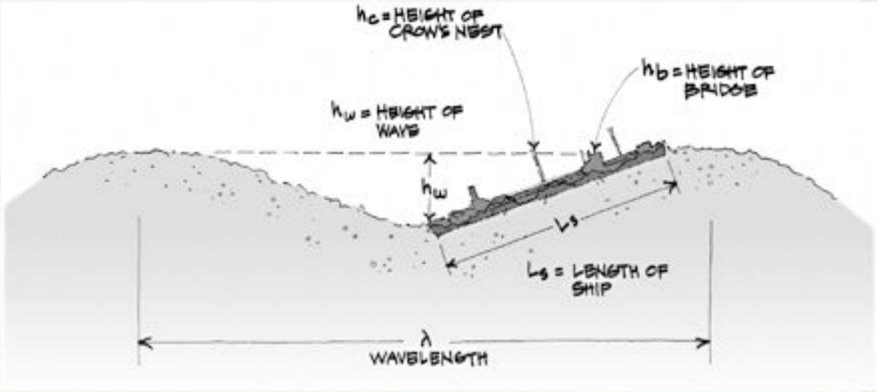
Significant Wave Height $H_s \approx 4\sigma$

Extreme wave $H > 2 H_s$ ($H > 8\sigma$)

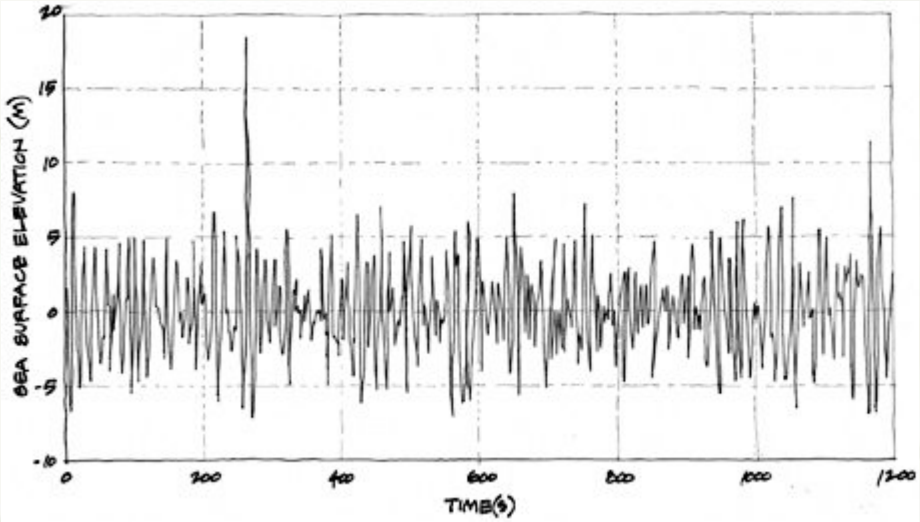
EXTREME WAVES

from *EXTREME WAVES, C. B. SMITH,Joseph Henry Press, Washington, D.C.*

February 1933
USS Ramapo wave : height ≈ 34 m ;
period = 14.8 seconds;
wavelength ≈ 340 m.

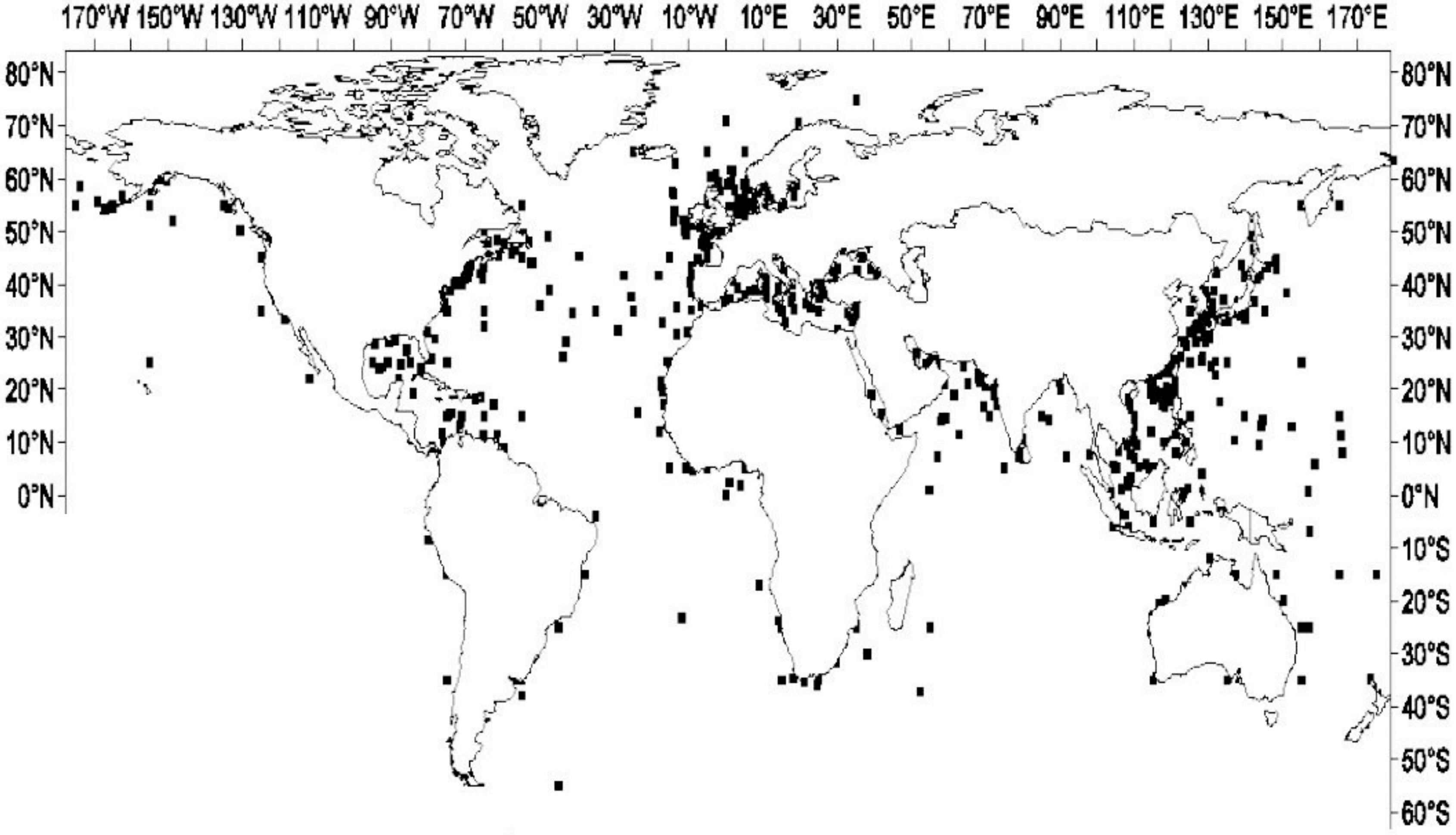


"New Year's" wave -January 1, 1995,
recorded at the Draupner oil platform.



Recorded by buoy in British Columbia–Alaska: December 1993, Cape Scott, height 31 m; December 1991, Hecate, height 30.5 m; December 1992, West Dixon height 26 m

FIVE YEARS (FROM 1995-1999) OF SHIPS ACCIDENTS DUE TO HEAVY SEAS (total number = 650) (collected from Lloyd's Marine Information Service)



MECHANISMS OF GENERATION OF EXTREME WAVES

- Linear superposition of waves

  narrow-band → Rayleigh distr. for wave height
  Tayfun distr. for wave crest

  + corrections for finite spectral bandwitdh

- Interactions waves - currents

  statistical properties as a function of currents properties not well known

- Modulational instability

- Crossing sea states

Modulational instability

(Phys. Rev.E, 2004; Phys. Fluid, 2005; Eur. J. Mech. B, 2006; J.G.R. 2007)

For random, long-crested waves in deep water in some conditions (large steepness and narrow band spectra) the exceedance probability, derived from Rayleigh, underestimates the probability of occurrence of extreme wave.

The kurtosis ***k*** of the surface elevation is significantly greater than the gaussian value and play the role of correction of the Rayleigh distribution

$$BFI = \frac{steepness}{spectral\ bandwidth} \qquad k \propto (BFI)^2$$

When we introduce the directional spreading of the initial spectrum, the occurrence of extreme waves is significantly reduced when the directionality broadens

Study the transition region between strongly non-Gaussian behavior (long-crested waves) and weakly non-Gaussian statistics (short-crested waves)

Crossed-sea states

(Phys. Rev. Lett. 2006)

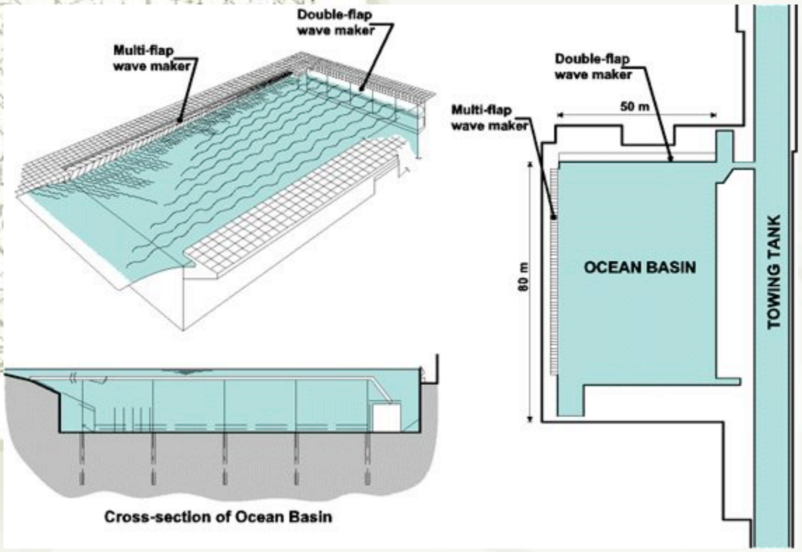
Study of the stability properties or a system described by two coupled nonlinear Schroedinger equations, each describing the evolution of a single spectral peak.

The growth rates of the perturbation depends not only on the length of the perturbation, but also on the angle between the two wave systems

From numerical simulations we expect that larger deviations from Gaussian behavior begin at angles > 40° and decrease approaching 70°

Study the nonlinear dynamics of non-collinear, co-propagating, random wave trains.

MARINTEK Wave facilities Trondheim, Norway

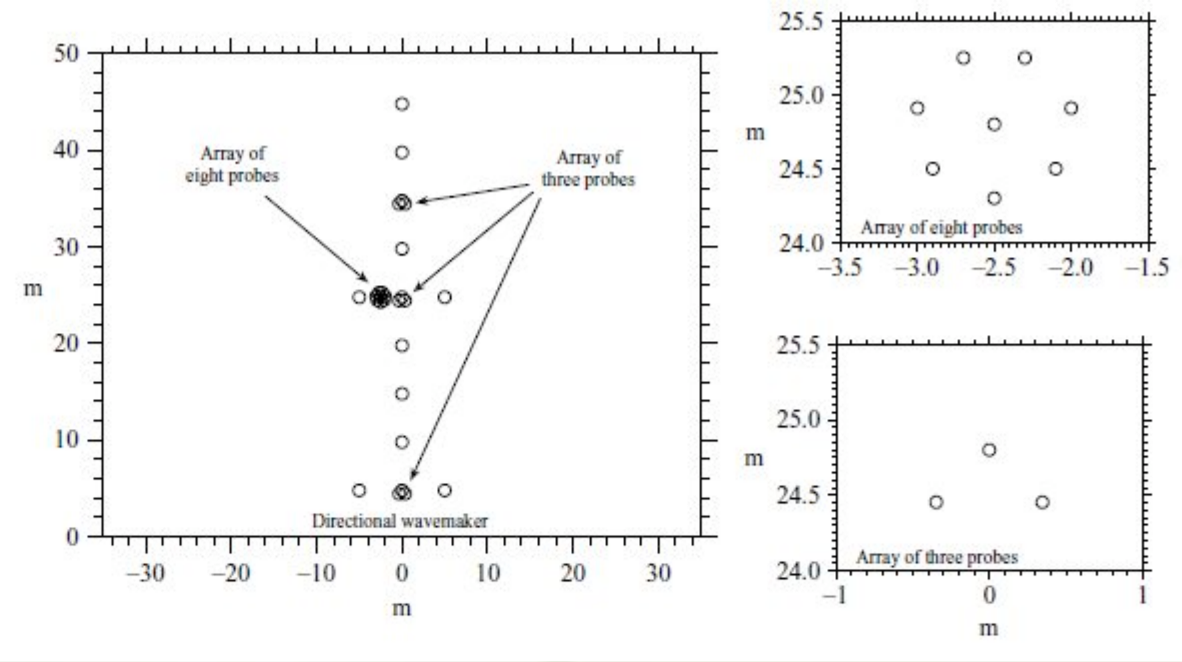


Water depth 3 m

f_{acq} 80 Hz

$\delta\eta$ ±1 mm

$\delta\eta_{rifl} \approx 5\%$ (30 min)



MARINTEK Wave facilities Trondheim, Norway

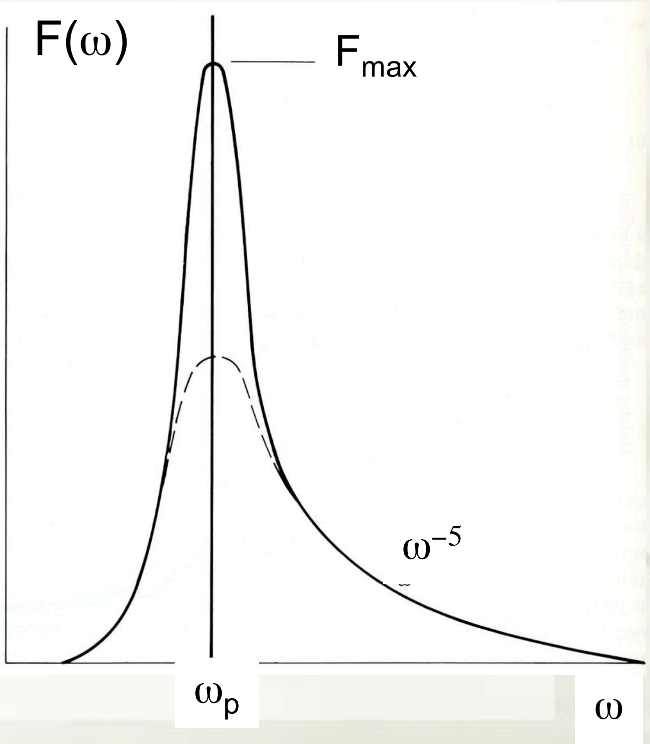
- Irregular waves

- Complex Fourier amplitudes randomly chosen from a Rayleigh distribution around the target spectrum

- Fourier phases randomly chosen from a uniform distribution between 0 and 2π

- Input wave spectra JONSWAP

$$F(\omega)=\frac{\alpha g^2}{\omega^5}\exp\left[-\frac{5}{4}\left(\frac{\omega}{\omega_p}\right)^{-4}\right]\gamma^{\exp(\omega-\omega_p)^2/2\sigma_j^2\omega_p^2}$$



T_p = 1 s L = 1.56 m $k_p h \sim 12.1$

- For a given spectrum, 4 realizations of random sea surface have been performed with different sets of amplitudes and phases.

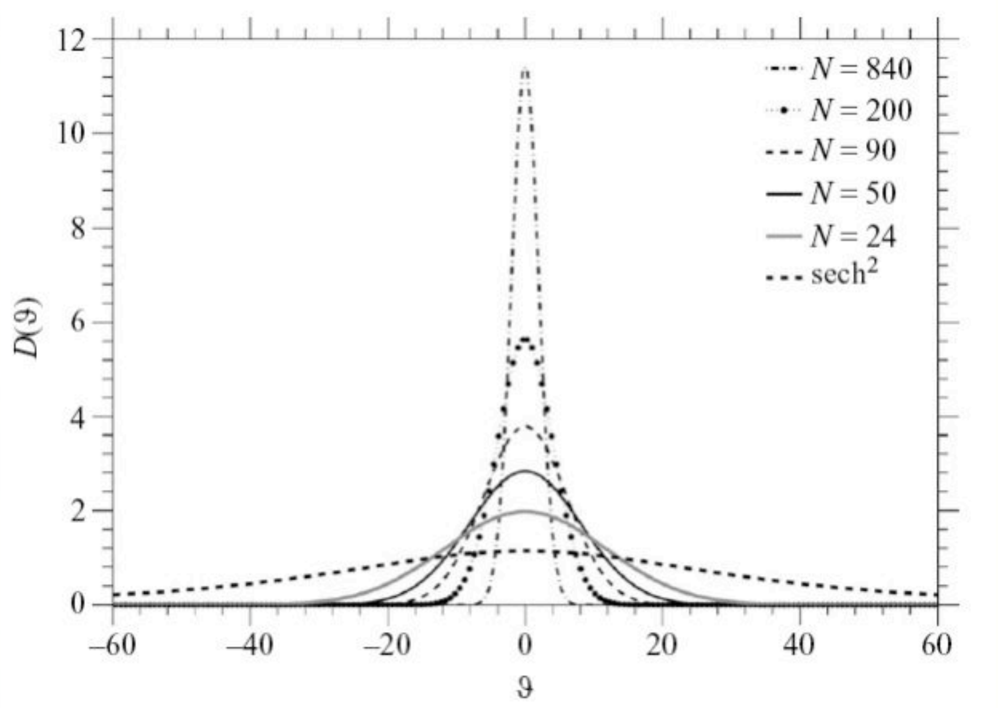
- For each test 20 min of wave records were collected (for analysis not considered the first three min)

- **DIRECTIONAL SPECTRA**: a $\cos^N(\theta-\theta_m)$ function is applied to model the energy. N = 840, 200, 90, 50, 24

Large N → long-crested waves

Small N → short-crested waves

Two values of BFI



- **CROSSED SEA STATES**: angle between the two systems β = 10°, 20°, 30°, 40°

- **UNIDIRECTIONAL WAVES**: Two values of BFI

Statistical properties of directional ocean waves (PRL 2009; J. Fluid Mech, 2009)

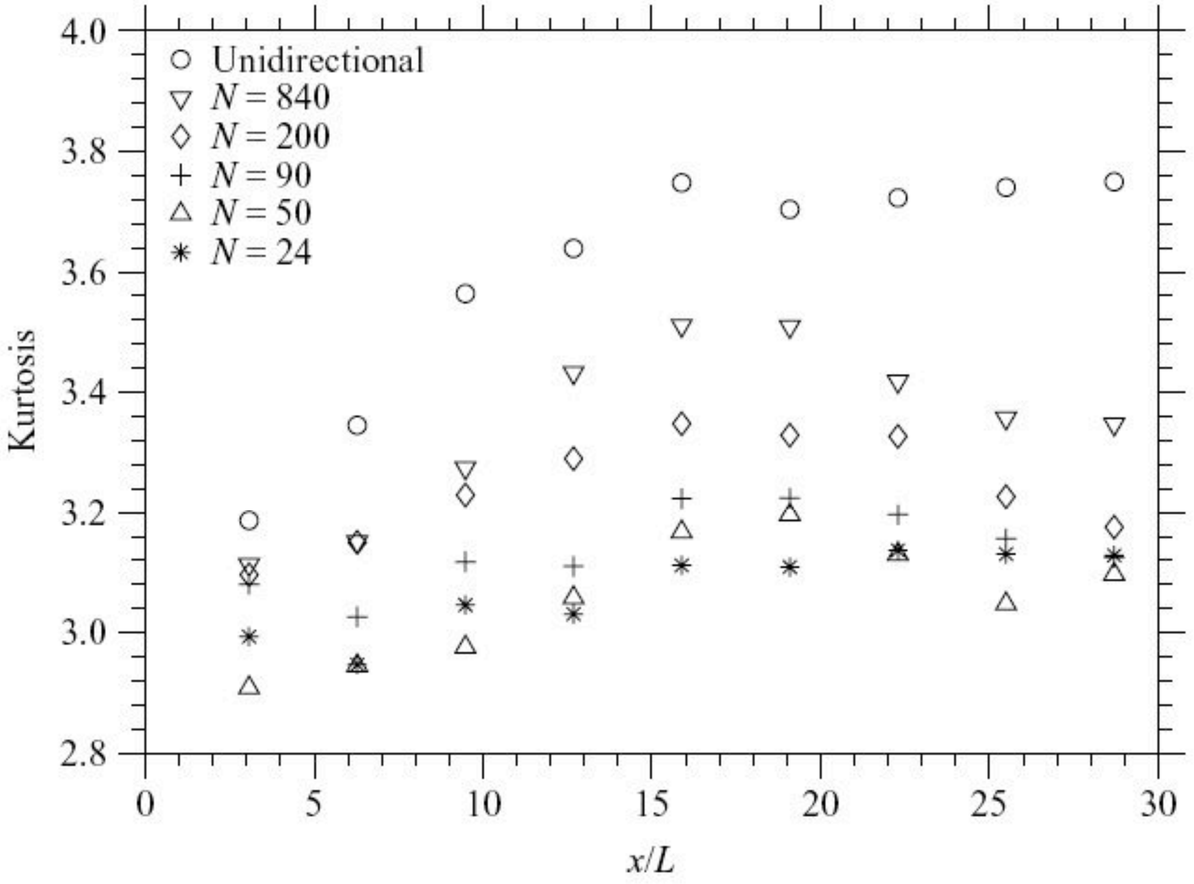
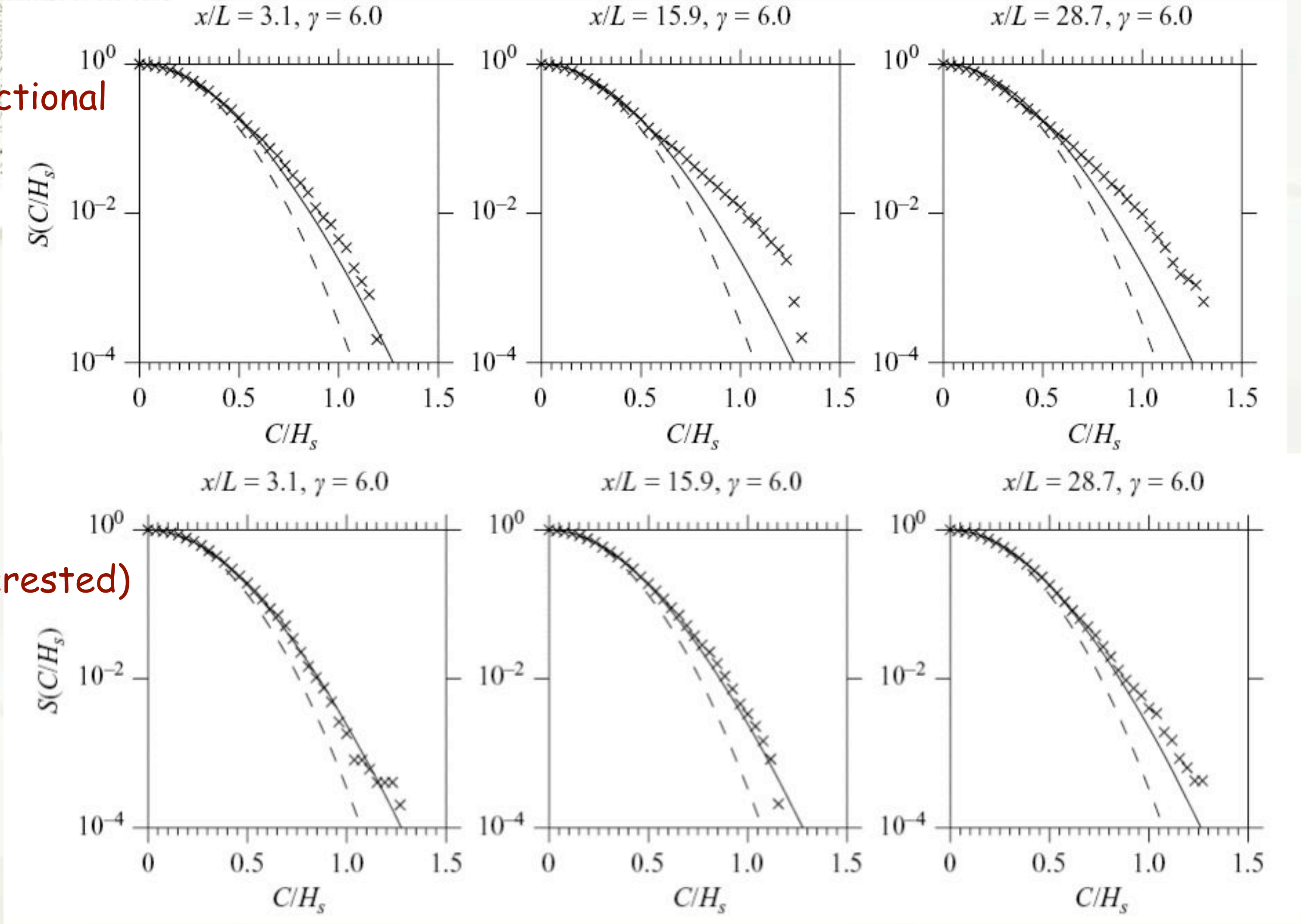


FIGURE 19. Kurtosis as a function of distance from the wavemaker for different values of N for experiment B.

Statistical properties of directional ocean waves (PRL 2009; J. Flu. Mech, 2009)

Unidirectional

N = 24
(Short-crested)



Statistical properties of crossed-sea states

(subm., 2009)

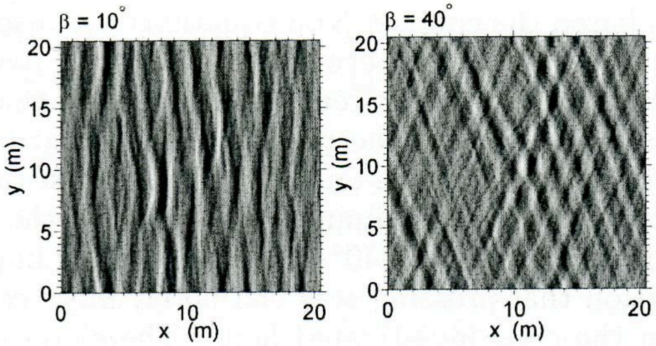


FIG. 2: Examples of simulated surface elevation.

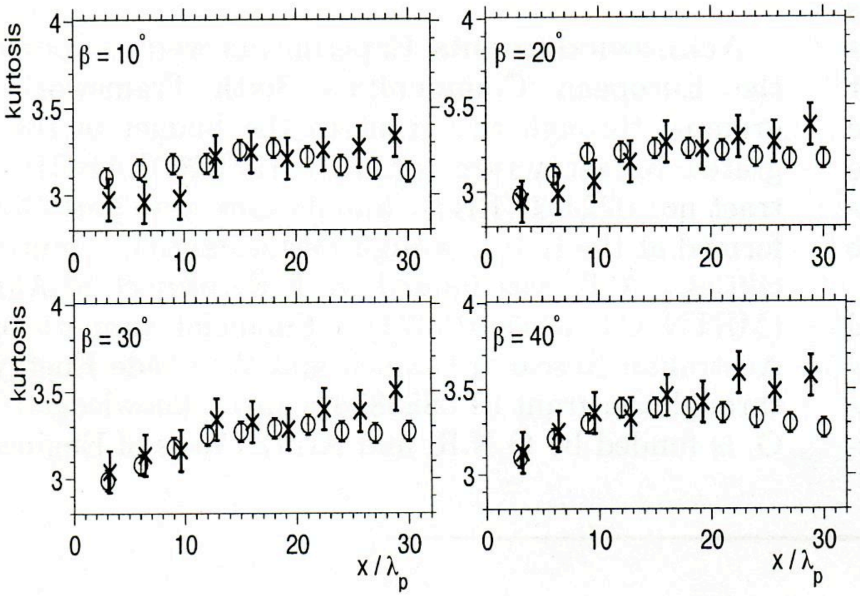
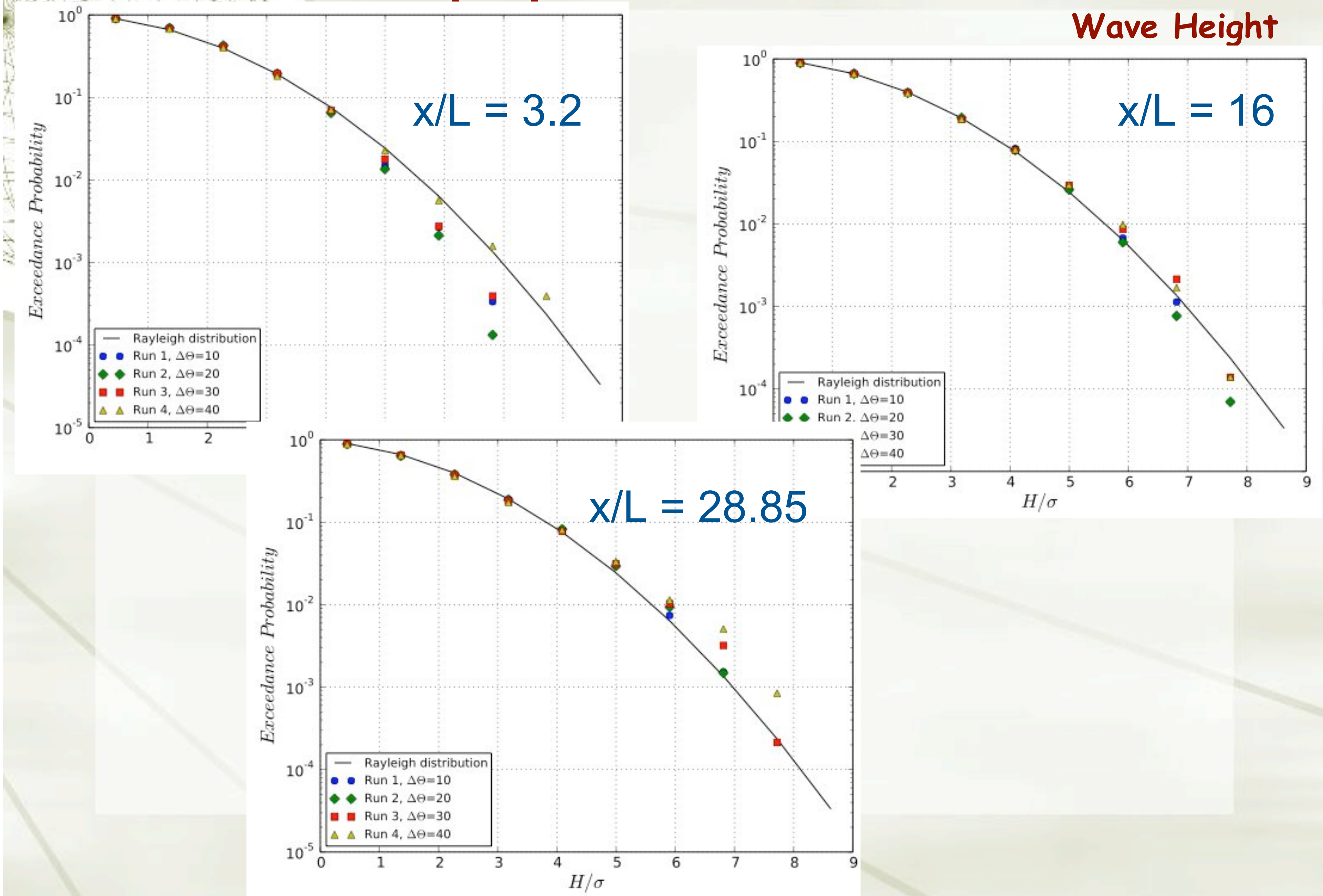


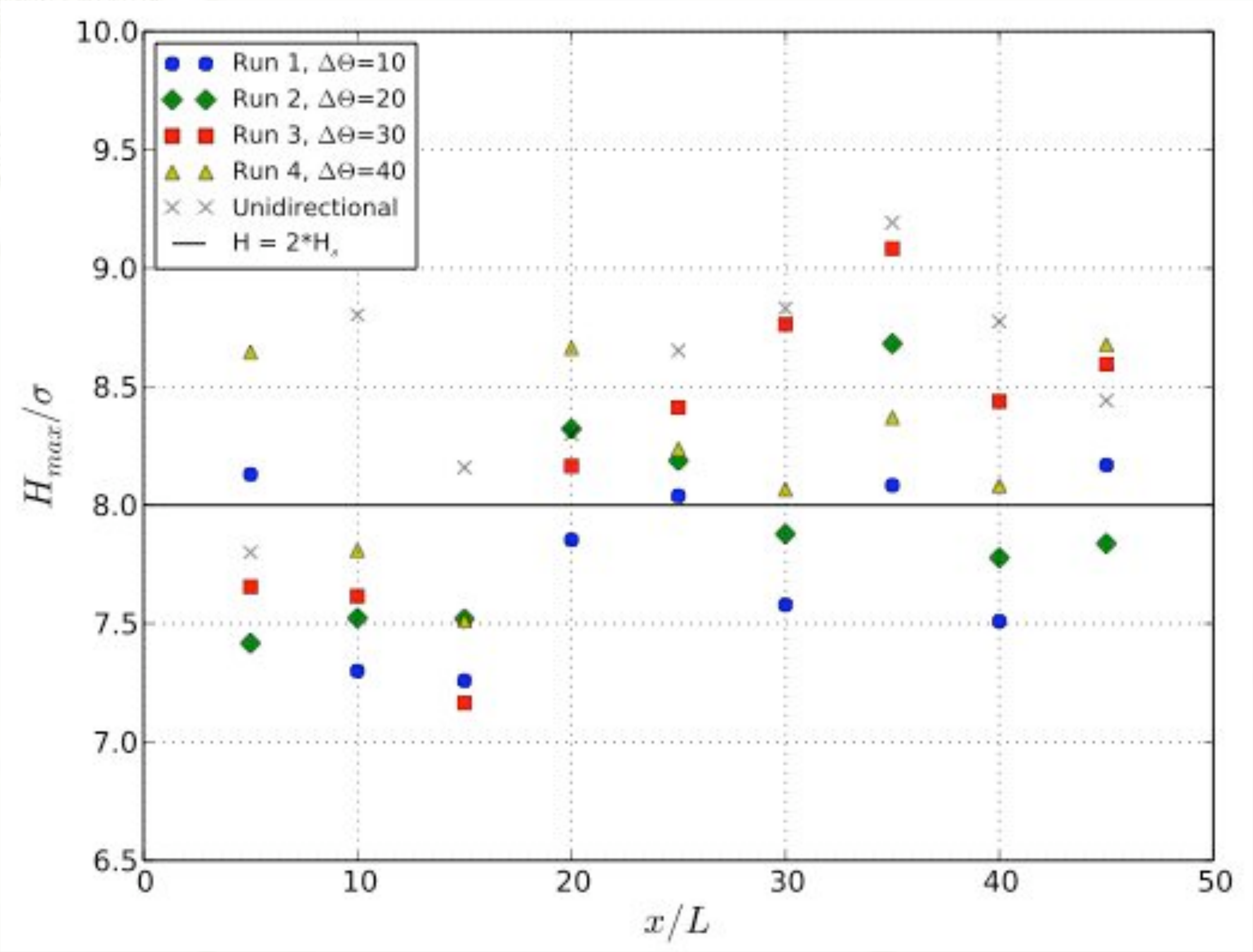
FIG. 3: Spatial evolution of the kurtosis: laboratory experiments (×); numerical simulations (o).

Statistical properties of crossed-sea states

Wave Height



Statistical properties of crossed-sea states



Conclusions

Detailed analysis of some of the statistical properties of the surface elevation:

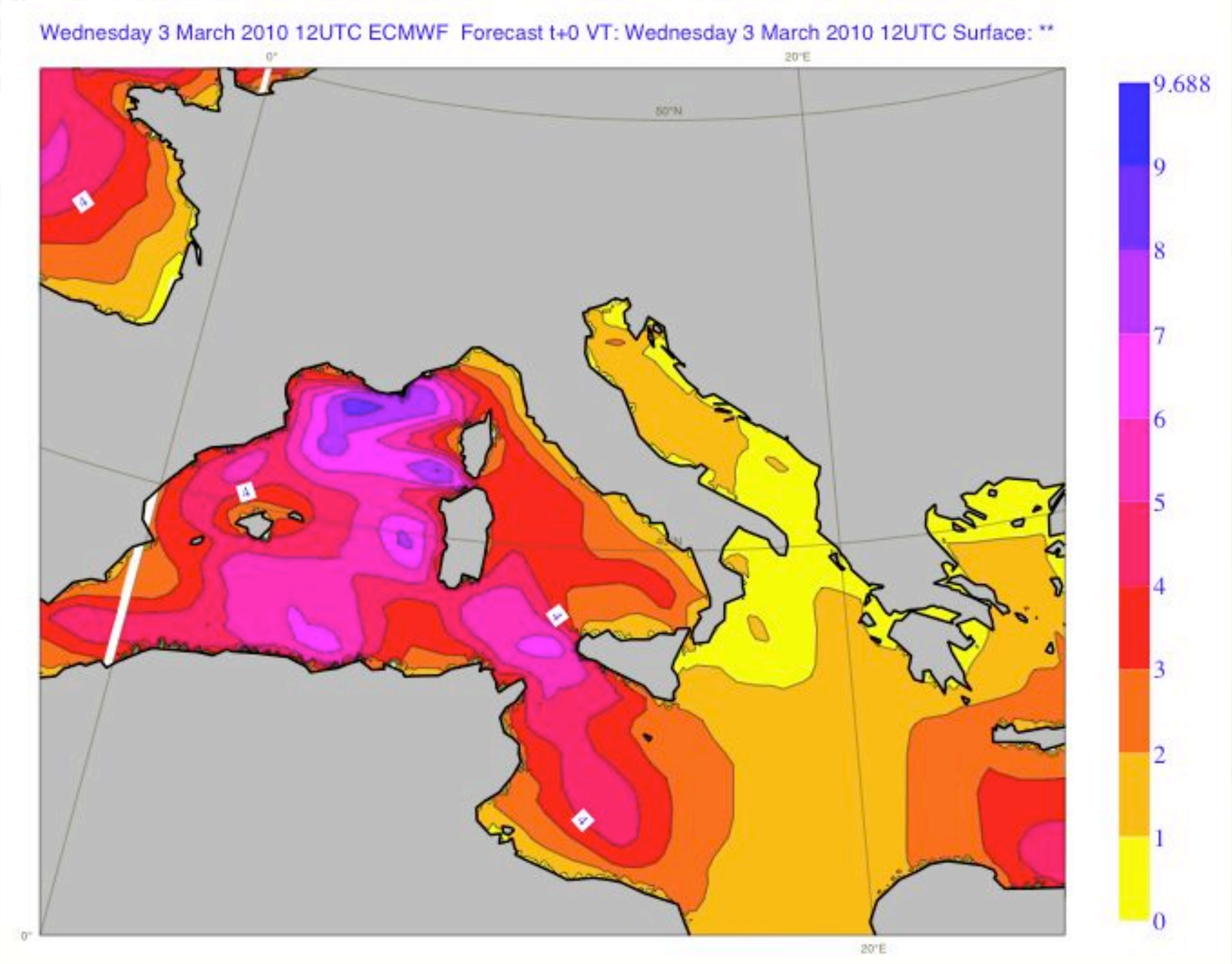
- departures from Gaussian statistics particularly significant if waves are long-crested. For more short- crested (spreading) conditions, extreme wave occur less often: the modulational instability process seems to be quenched.

- in crossing-sea conditions, departures from Gaussian behavior become more evident with increasing angles between the two wave systems

Important: contribute to forecasting

Majesty Louis Event (March 2010)

from P.A.E.M. Janssen, Head Ocean Waves Section, ECMWF



H_{max} (m)