

Ekstreme havbølger

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Skjult budskap nr. 1:

- Mekanikk er gøy
- Statistikk er gøy
- Kombinasjonen av mekanikk og statistikk er **mer en dobbelt så gøy**

Skjult budskap nr. 2:

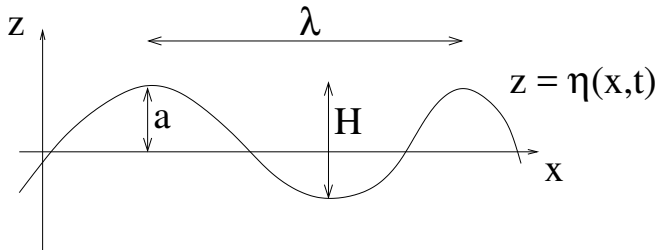
Som masterstudent kan du komme virkelig nær forskningsfronten, spesielt om du tar eksperimentell oppgave.

Prøv gjerne bachelor prosjekt emnet MEK3200 for å få en forsmak!

I det følgende vises spesielt bidrag fra:

- Anne Raustøl — Lektorstudent (kort master i laboratoriet)
- Stian Jorde — Lektorstudent (kort master i laboratoriet)
- Christopher Lawrence — Ph.D. student (numerisk)
- Odin Gramstad — Master og Ph.D.

Hva er en freakbølge?



- Overflatehevning $\eta(x, t)$
- Bølgelengde λ
- Amplitude a
- Bølgehøyde H

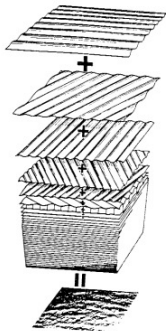
Ekstrem $\neq$ Freak $\approx$ Rogue $\neq$ Tsunami

- Ekstreme bølger
 - store fysiske dimensjoner (meter)
 - ikke nødvendigvis *uvanlig stor* eller *overraskende*
- Freak eller rogue bølge
 - *uvanlig stor og overraskende* sammenliknet med *vanlige* bølger
- Tsunami
 - en liten gruppe med *lange* bølger generert av en lokal hendelse, f.eks. jordskjelv eller ras

Hva er en “*vanlig*” bølge?

Gaussisk sjø = normal sjø

Superposisjon av statistisk uavhengige bidrag

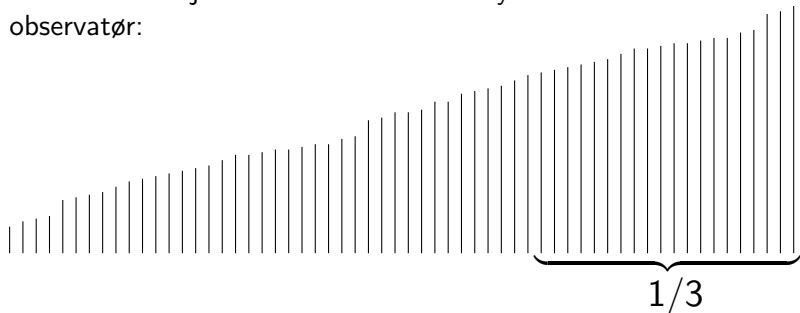


Bruk sentralgrenseteoremet fra statistikk.

Vår interesse er å se etter ikke-Gaussisk sjø!

Signifikant bølgehøyde $\approx$ vanlig

Klassisk definisjon svarer til visuelt inntrykk for en erfaren observatør:



$H_{1/3}$ = middelværdi av de 1/3 største bølgehøydene

Moderne definisjon:

$$H_s = 4\sigma$$

hvor σ er standardavviket til overflatehevningen.

For en Gaussisk sjø

$$H_s \approx H_{1/3}$$

For en 20 minutters tidsserie målt i et punkt i Nordsjøen anses en bølge å være en freakbølge dersom:

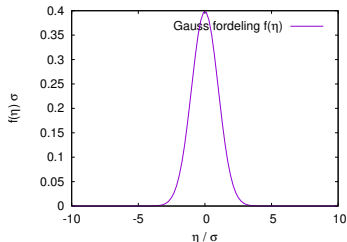
$$H > 2H_s = 8\sigma$$

eller

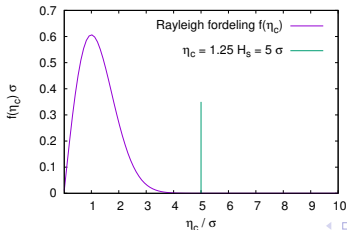
$$\eta_c > 1.25H_s = 5\sigma$$

Freake bølger i Gaussisk sjø

Gaussisk fordelt (normalfordelt) overflatehevning

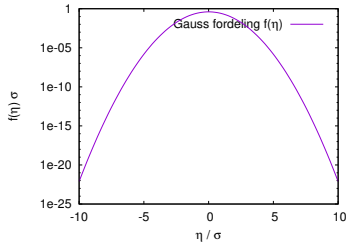


Kamhøyde blir omtrent Rayleigh fordelt

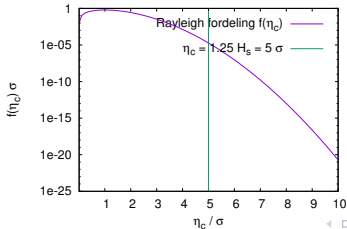


Freake bølger i Gaussisk sjø — logaritmisk akse

Gaussisk fordelt (normalfordelt) overflatehevning



Kamhøyde blir omtrent Rayleigh fordelt



Noen eksempler på freakbølger

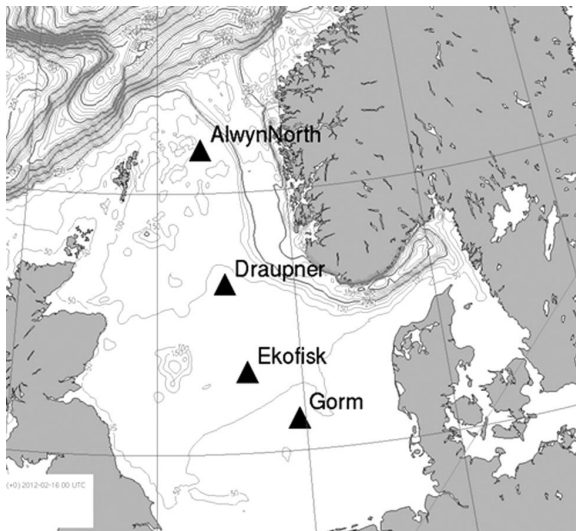
Definitivt freak bølger:

- Nyttårsbølgen på Draupner 1/1–1995
- Andrea-bølgen på Ekofisk 9/11–2007
- Bølgen som traff COSL Innovator på Troll 30/12–2015

Kanskje en freak bølge:

- Prestige-ulykken utenfor Spain 13/11–2002

Nyttårsbølgen 1/1–1995 på Draupner



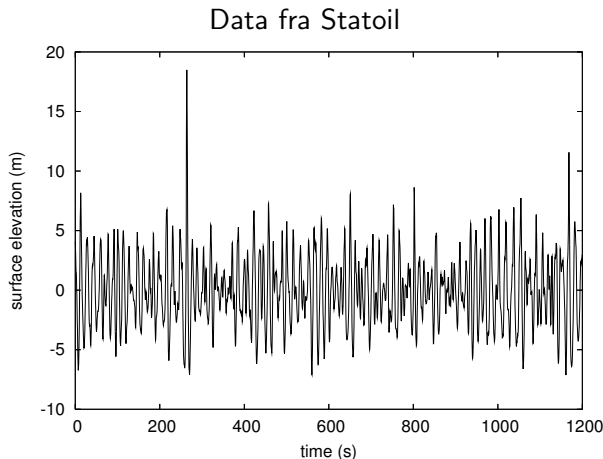
Fra Magnusson & Donelan (2013)

Draupner S og Draupner E



Fra Haver (2005). Foto: Øyvind Hagen, Statoil.

Nyttårsbølgen 1/1–1995 på Draupner

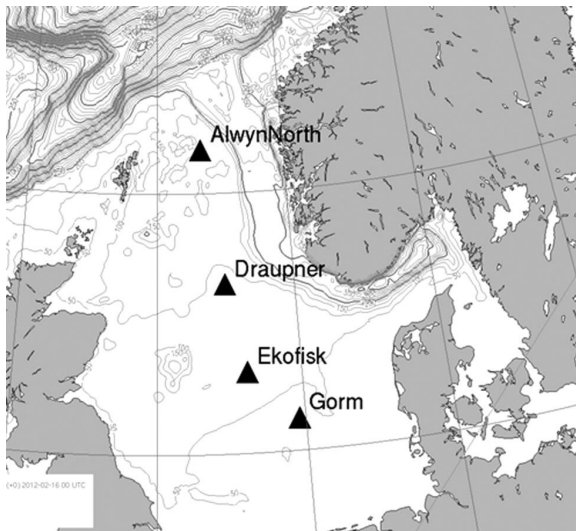


$$\eta_c/H_s = 1.56 > 1.25 \quad H/H_s = 2.15 > 2$$

kriterier for tidsserier av 20 minutters varighet i forhold tilsvarende Nordsjøen

Tilfredsstiller begge kravene for å være freakbølge!

Andrea-bølgen 9/11–2007 på Ekofisk



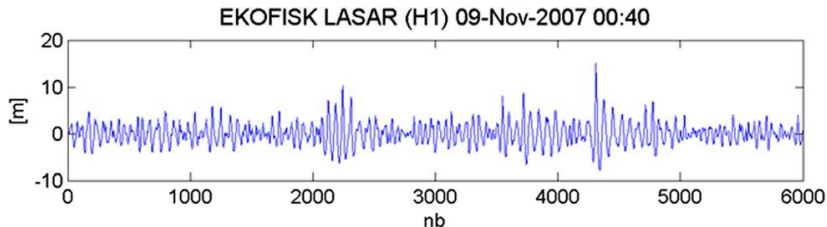
Fra Magnusson & Donelan (2013)

Ekofisk



Andrea-bølgen 9/11-2007 på Ekofisk

Data fra ConocoPhillips



$$\eta_c/H_s = 1.63 > 1.25 \quad H/H_s = 2.49 > 2$$

Fra Magnusson & Donelan (2013)

Andrea-bølgen er mer freak enn Draupner bølgen!

Bølgen som traff COSL Innovator 30/12–2015 på Troll

Troll-feltet





“Det var en helt alminnelig dag.”

Henning Bruvik, kaptein på COSL Innovator

Plutselig ble riggen truffet av en bølge. Én av de ansatte omkom momentant da bølgen slo inn vinduet på lugaren.

COSL Innovator

Flere vinduer ble ødelagt



COSL Innovator

Etterpå ble vinduene sveiset igjen med stålplater

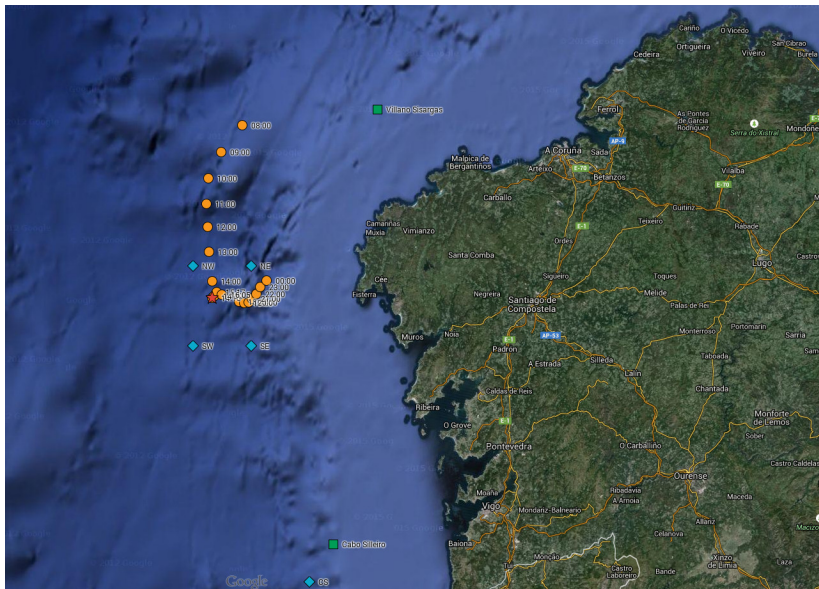


Prestige-ulykken 13/11–2002 og den etterfølgende katastrofen 19/11–2002 utenfor Spania

Prestige



Ulykken: Prestige blir skadet 13 november 2002

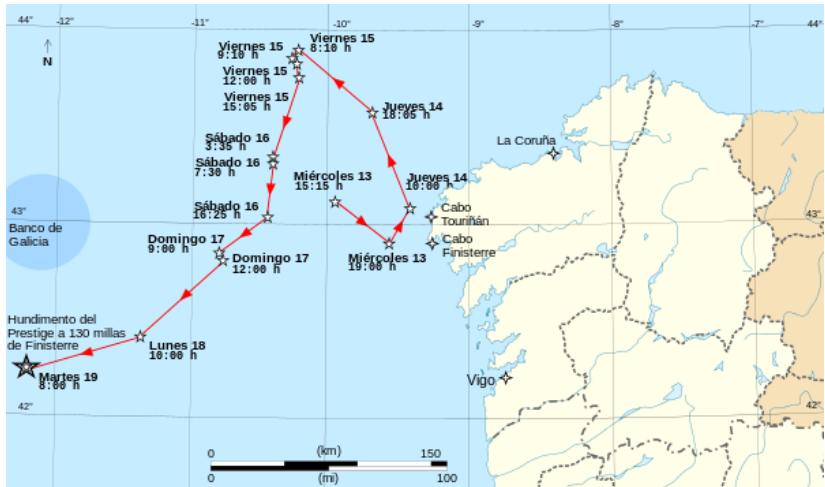


Ulykken: Prestige blir skadet 13 november 2002

Krenger litt mot styrbord



Katastrofen: Prestige taues 13-19 november 2002



Prestige knekker 19 november 2002



Prestige synker 19 november 2002



Prestige lekker olje etter 19 november 2002



Prestige oljeutslipp etter 19 November 2002



Prestige oljeutslipp etter 19 November 2002



Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 6 months or issues of general interest. They can be submitted by e-mail (science_letters@aaas.org), the Web (www.letterstoscience.org), or regular mail (1020 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

Spain's Earth Scientists and the Oil Spill

THE SPANISH COAST OF GALICIA IS CURRENTLY subject to an oil spill that, given its spatial and temporal extent, could become one of the worst spills ever. The Spanish and the local Galician governments have been maintaining for 30 days that, since 13 November, when the tanker *Prestige* ran into problems, every decision implemented throughout this crisis, including the key resolution of transporting the vessel offshore, was guided by the technical advice of Spanish experts. In our opinion, the recurrence and indiscriminate generalization implicit in such a statement entail a serious threat to the credibility of the Spanish Earth sciences community as a whole. Moreover, this crisis is revealing a serious malfunctioning of the national research system. This moves us, as marine and atmospheric scientists, and members of the Spanish Institute of Oceanography (IEO), National Research Council (CSIC), universities, and other research centers, to express the following:

1) Given the well-known winter climatology of the area of the spill, dominated by west-southwesterly winds and a south to north slope current on the sea (*J-11*), the decision to move the vessel from about 43°N, 9.5°W offshore to the southwest was a consequence of poor communication between the government officials dealing with the spill and the scientific and technical communities, rather than a deficit of knowledge. This move was responsible for the spreading (spatial amplification) of the spill, which now extends across about 900 km of shoreline. The position of the sunken ship at about 42°N, 12°W, 145 nautical miles off the south coast of Galicia will probably cause successive oil waves (temporal amplification) to arrive at the Spanish, Portuguese, and/or French coasts. Thirty days after the first spill (*J-1*), the Galician coast now faces a third, and possibly not the last, oil wave.

2) Once the oil spill had occurred, the poor coordination of the Spanish authorities has led to a very ineffective use of scientific institutions, resources, and knowledge, reflected in inexplicable delays and overlapping actions. For example, the first draft of a scientific action plan is dated 13 December, 1 month after the beginning of the crisis and 4 days after the first scientific commission was convened.

3) We demand that the Spanish authorities improve the mechanisms and logistics for scientific and technical consultation and refrain from making vague public statements that are seriously, and unfairly, damaging the image of Spanish marine and atmospheric sciences.

PABLO SERRET,¹ JOSÉ ANTONIO ÁLVAREZ-SALGADO,² ANTONIO BODÍ,³ AND 419 OTHER SCIENTISTS FROM 32 UNIVERSITIES AND 6 RESEARCH INSTITUTIONS⁴
¹Facultad de Ciencias, Universidad de Vigo, 36200

Image not available for online use.

A man walks along an oil-covered beach in Calor, northern Spain, 18 November 2002.

Vigo, Spain. ²Instituto de Investigaciones Maritimas, Consejo Superior de Investigaciones Cientificas (CSIC), Eduardo Cabello, 6, 36208 Vigo, Spain. ³Instituto Español de Oceanografía (IEO), Centro Costero de A Coruña, Muelle de Armas s/n, A Coruña, Spain.

⁴See www.sciencemag.org/cgi/content/full/299/5606/511/DC1 for a full list of all authors and affiliations.

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Revisiting Coauthor Responsibility

MICHAEL PHILLIPS' CONTENTION THAT CO-authors of fraudulent papers who signed those papers in the belief that the data were honest are themselves victims ("Should coauthors share liability?" *Letters*, 22 Nov., p. 1554) is a disturbing proposition that one would hope is not widely shared. It is unfortunately saddening rather than shocking that some would hew to such an idea. Certainly, if the scientific community is to retain and warrant the esteem of the public, then the notion that coauthors do not have sufficient knowledge of the details of the study they purport to have participated in to vouch for its integrity simply does not wash. As a practical matter, mandating such responsibility would serve two useful purposes: (i) to curb free-loading on papers by individuals with only marginal involvement and (ii) to provide a first line of defense against fraud. For those whose do not wish or have the time for this level of involvement, there is a long-standing tradition of acknowledgment short of authorship.

CORNELIUS COOPER

New York, NY, USA.

The Next Generation of Science Policy-Makers

DONALD KENNEDY ("AFTERMATHS," EDITORIAL, 29 Nov., p. 1679) is wise to advocate new means of encouraging science and technology training for future policy-makers in the United States. The National Defense Education Act is an informative model, not least for its expansive view of the critical skills the United States would require. By focusing on educating the next generation of public servants, however, Kennedy addresses only a part of the United States' intellectual deficit and only part of our opportunity.

In an era of dazzling opportunities across many scientific disciplines, our country has been disinvesting (1). Federally supported R&D shrank in 2000 to less than 0.7% of the gross domestic product—a level last seen before the Soviets launched Sputnik. A laudable bipartisan effort to double the NIH budget has nourished biomedical research and training, but a steady attrition of investment has weakened the physical sciences and engineering. The Department of Energy's funding for the physical sciences has decreased by 20% since 1993. The number of graduate students has dropped

Vårt bidrag: analysere bølgeforholdene når Prestige-ulykken skjedde



Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2015JC011161

Key Point:

- Discuss the crossing sea state and rogue wave probability during the Prestige accident

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Crossing sea state and rogue wave probability during the Prestige accident

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¹Department of Mathematics, University of Oslo, Norway, ²Department of Signal Theory and Communications, University of Alcalá, Spain, ³Centre for Ocean Engineering Science and Technology, Swinburne University of Technology, Melbourne, Australia, ⁴Now at DNV GL Strategic Research and Innovation, Høvik, Norway, ⁵Météo-France, Département Marine et Océanographie, Toulouse, France, ⁶Deceased April 5th, 2014

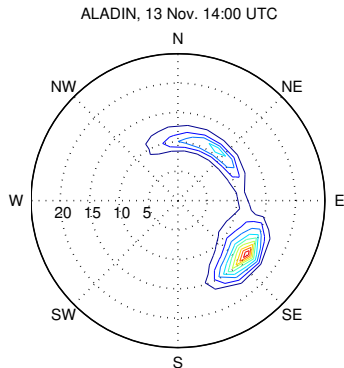
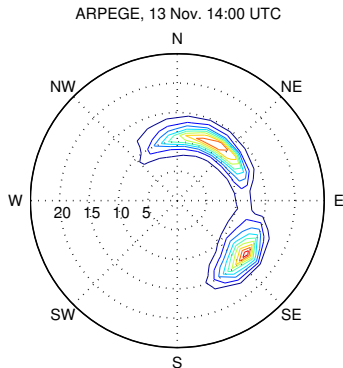
Abstract We discuss the crossing sea state and the probability of rogue waves during the accident of the tanker Prestige on 13 November 2002. We present newly computed hindcast spectra for every hour during that day at nearby locations, showing the development of a bimodal sea state with two wave systems crossing at nearly right angle. We employ four different nonlinear models capable of computing the phase-resolved sea surface from the hindcast spectra, allowing us to estimate statistics for the occurrence of rogue waves. At the location and moment of the accident, the models give expected values for the kurtosis $\kappa = 3.0119 \pm 0.0078$. The models coincide that the maximum crest elevation was about 5–6% larger than the expected maximum crest elevation in a Gaussian sea at the moment of the accident. We also conclude that the possible nonlinear interaction between the two crossing wave systems practically did not modify neither the kurtosis nor the largest crest elevation.

1. Introduction

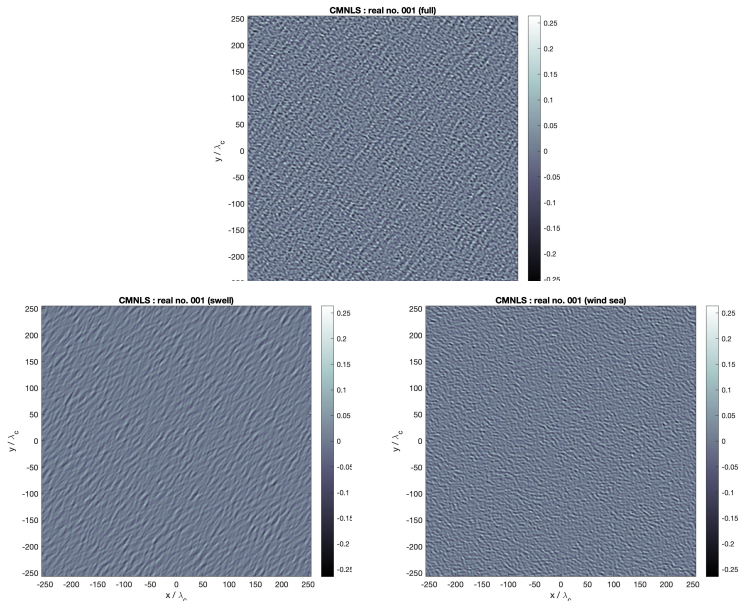
At 14:10 UTC (15:10 local time) on 13 November 2002, the oil tanker Prestige suffered damage on the starboard side of its hull while sailing southbound in the Traffic Separation Scheme off Cape Finisterre, Spain, at

Hindcast for 13 november 2002

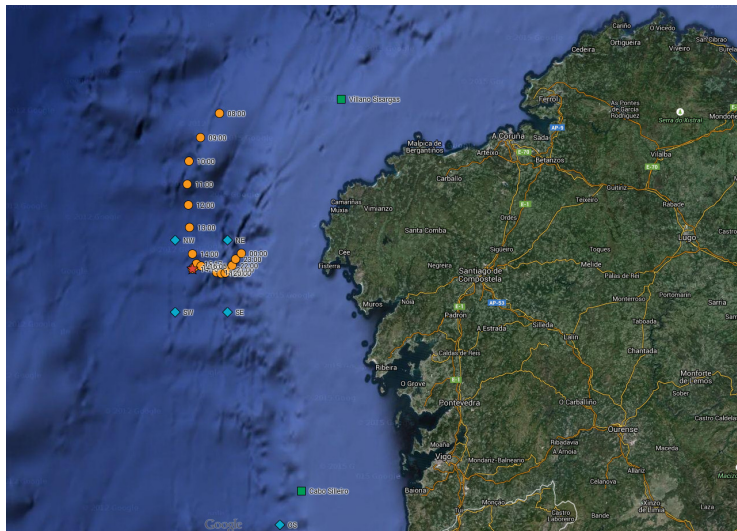
Sjøtilstand når ulykken skjedde:



Splitt bølgefeltet før analyse



Prestige sin bane 13 november 2002



Hindcast for 13 november 2002

To forskjellige modeller for vind

- ALADIN — en regional atmosfærisk modell
- ARPEGE — en global atmosfærisk modell

brukt i bølgemodell MFWAM (Meteo France WAM).

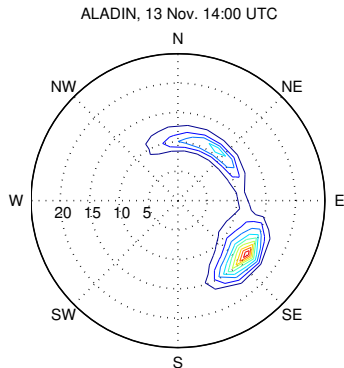
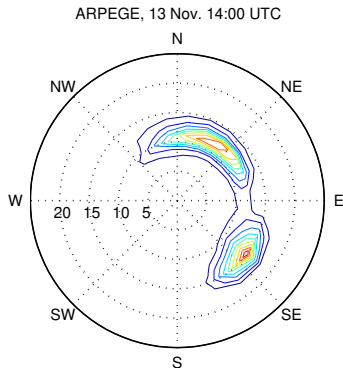
Fire steder, hver time for 25 etterfølgende timer.

Totalt 200 hindcast.

Ulykken skjedde i kryssende dønning og vindsjø av omtrent like store signifikante bølgehøyder og peak-perioder som krysset hverandre med rett vinkel 90° .

Hindcast for 13 november 2002

Sjøtilstand når ulykken skjedde:



Konklusjoner fra hindcast

- Ulykken skjedde i 90° kryssende sjøtilstand.
- Dønning og vindsjø hadde omtrent like store signifikante bølgehøyder og peak perioder.
- Steilheten var stor.
- Båndbredden var stor.
- Retningsspredning var stor.
- Modulasjonsustabilitet ikke viktig siden BFI var liten.

Ubesvart spørsmål:

- Hva var statistikken til freaky bølger i den kryssende sjøen?

Modeller for fase-oppløst bølgefelt

- HOSM
- CMNLS (Gramstad & Trulsen 2011)
- CMNLS med kun ledende ordens rekonstruksjon
- MNLS2 (Dysthe 1979; Trulsen, Kliakhandler, Dysthe & Velarde 2000)

Bruk hindcast som startbetingelse, generer 50 realisasjoner for havoverflaten, forplant framover i tid 11 steg av $10T_m$:

totalt 550 havoverflater

- for hver av de 25 timene for dagen ulykken skjedde
- for hver av de 4 modellene

For å regne ut sannsynlighetsfordeling trenger vi uforholdsmessig mye data.

Enklere å betrakte:

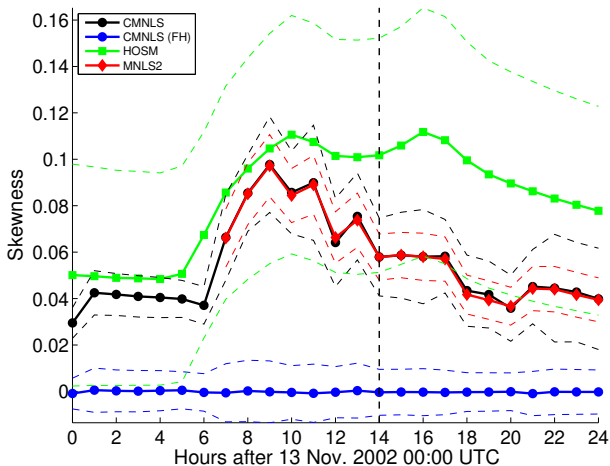
- Skjevhet — måler asymmetri mellom kam og buk

$$\gamma = \frac{E[(X - \mu)^3]}{\sigma^3}$$

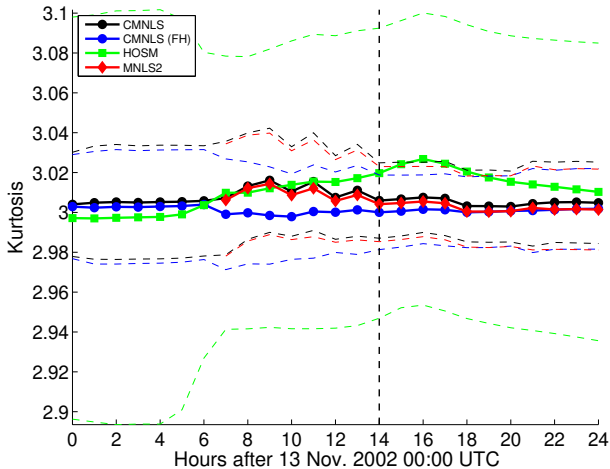
- Kurtose — måler hvor ekstrem fordelingen er sammenliknet med Gaussisk

$$\kappa = \frac{E[(X - \mu)^4]}{\sigma^4}$$

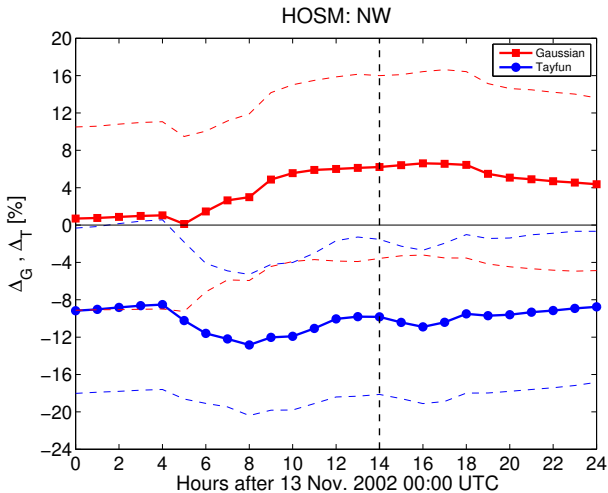
- Pieterbarg teori — hvor stor er den forventede største verdien



Kurtose



Høyeste kam — HOSM



Da ulykken skjedde viser både CMNLS og MNLS2 og HOSM at:

- Skjevhet $\gamma = 0.0798 \pm 0.0219$
- Kurtose $\kappa = 3.0119 \pm 0.0078$
- Maksimum kamhøyde omlag
 - 5–6% større enn forventet maksimum kamhøyde for Gaussisk–Piterbarg teori
 - 9–10% mindre enn forventet maksimum kamhøyde for Tayfun–Piterbarg teori

Da Prestige-ulykken skjedde:

- var sjøtilstanden litt verre enn Gaussisk, men ikke så ille som Tayfun.
- hadde ikke den 90° kryssende sjøtilstanden noen effekt for å gjøre sjøtilstanden mer eller mindre ekstrem.
- var sjansen for en freakbølge ikke større eller mindre enn “vanlig”.

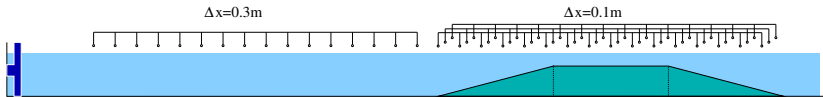
Det var et kjedelig resultat!

Viktig å formidle kjedelige resultater!

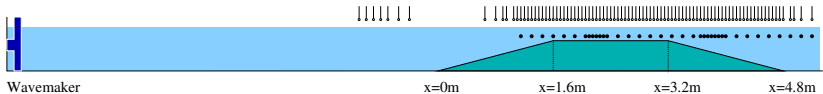
Hva med noe mer spennende?

Resultater for ekstreme bølger over en grunne

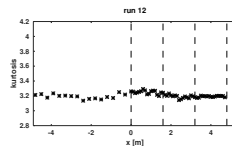
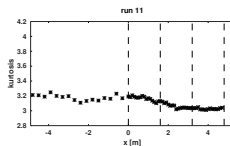
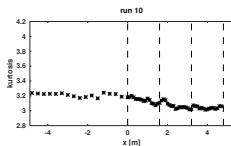
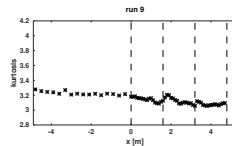
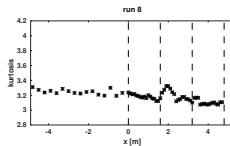
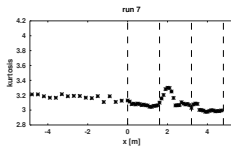
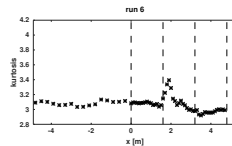
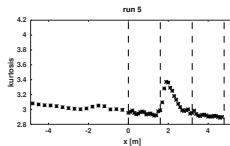
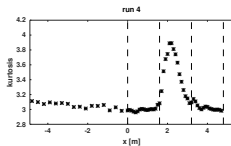
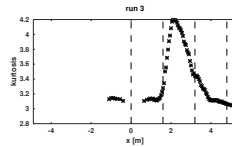
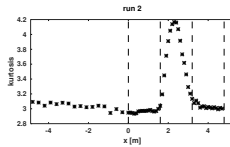
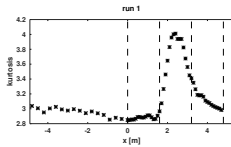
Masteravhandling til Anne Raustøl:



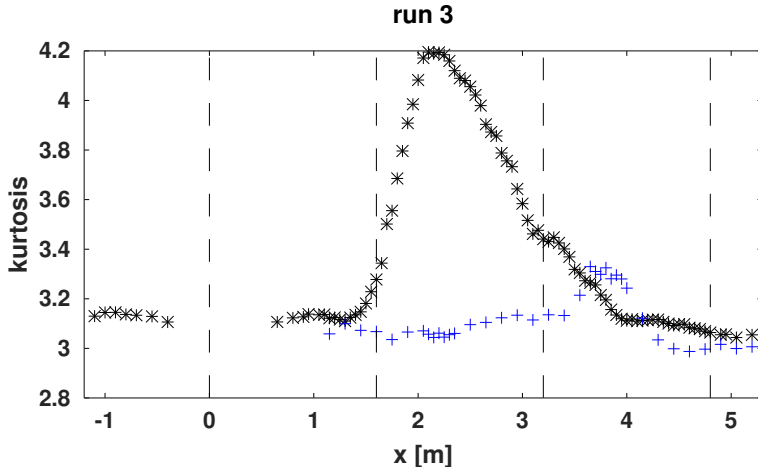
Masteravhandling til Stian Jorde:



Kurtose til overflateheving



Kurtosene til overflatehevning og hastighetsfelt er forskjellige



Hva vi pleier å undervise, i MEK3230, MEK4320, MEK4420 og MEK4600:

Overflatehevning og hastighetsfelt til bølger er to sider av samme sak, de oppfører seg likt evt. med et faseskift på 90° .

Kan dette være feil?

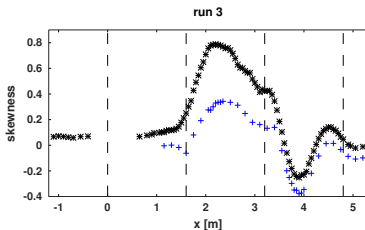
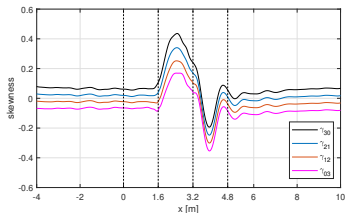
Indikator for om to prosesser er to sider av samme sak: Co-momenter

$$\frac{E[(\eta - E[\eta])^m (v - E[v])^n]}{\sigma_\eta^m \sigma_v^n}$$

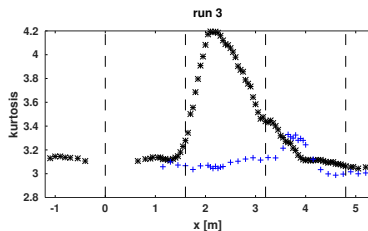
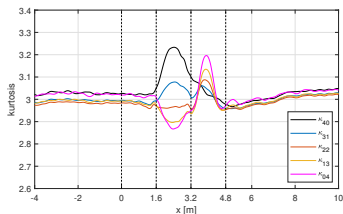
Co-skjevhet: $m + n = 3$, fire varianter: $\gamma_{3,0}, \gamma_{2,1}, \gamma_{1,2}, \gamma_{0,3}$

Co-kurtose: $m + n = 4$, fem varianter: $\kappa_{4,0}, \kappa_{3,1}, \kappa_{2,2}, \kappa_{1,3}, \kappa_{0,4}$

Auto- og co-skjevhet mellom overflatehevning og hastighet. Vertikale streker angir hjørnene til grunna. Simuleringer til venstre, eksperimenter til høyre.



Auto- og co-kurtose mellom overflatehevning og hastighet. Vertikale streker angir hjørnene til grunna. Simuleringer til venstre, eksperimenter til høyre.



- Det kan være betydelig økning i skjevhet og kurtose over toppen av grunna, dersom den er tilstrekkelig grunn.
- Hastighetsfeltet kan ha statistiske egenskaper svært forskjellig fra overflatehevningen.
- Trenger vi forskjellige kriterier eller teorier for freakbølger i hastighetsfelt og i overflatehevning?

Artikkel i topp-tidsskrift basert på arbeid til tre masterstudenter:

J. Fluid Mech. (2020), vol. 882, R2, doi:10.1017/jfm.2019.861

JFM RAPIDS
journals.cambridge.org/rapids



Extreme wave statistics of long-crested irregular waves over a shoal

Karsten Trulsen^{1,†}, Anne Raustøl¹, Stian Jorde¹
and Lisa Bæverfjord Rye¹

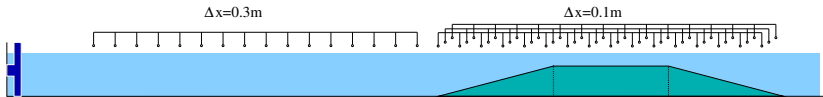
¹Department of Mathematics, University of Oslo, 0371 Oslo, Norway

(Received 14 August 2019; revised 23 September 2019; accepted 14 October 2019)

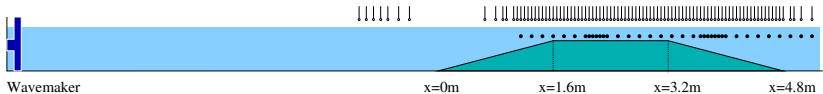
We report laboratory experiments of long-crested irregular water surface waves propagating over a shoal. For a sufficiently shallow shoal we find that the surface elevation can have a local maximum of skewness and kurtosis above the shallower part of the shoal close to the edge on the incoming side, and a local minimum of skewness over the downward slope on the lee side of the shoal. We find that the

Resultater for ekstreme bølger over en grunne

Masteravhandling til Anne Raustøl:



Masteravhandling til Stian Jorde:



Skjult budskap nr. 1:

- Mekanikk er gøy
- Statistikk er gøy
- Kombinasjonen av mekanikk og statistikk er **mer en dobbelt så gøy**

Skjult budskap nr. 2:

Som masterstudent kan du komme virkelig nær forskningsfronten, spesielt dersom du tar eksperimentell oppgave.

I det foregående har jeg spesielt vist bidrag fra:

- Anne Raustøl — Lektorstudent (kort master i laboratoriet)
- Stian Jorde — Lektorstudent (kort master i laboratoriet)
- Christopher Lawrence — Ph.D. student (numerisk)
- Odin Gramstad — Master og Ph.D.

Bachelorstudenter: Få en forsmak på hvor gøy dette er: Ta MEK3200 - Prosjektoppgave i mekanikk!