On the fetch dependent drag coefficient over coastal and inland seas

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G.L. Geernaert
Department of Atmospheric Environment

J.A. Smith
Scripps Institute of Oceanography,
San Diego, California

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Data sheet

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Authors:	G.L. Geernaert[1] J.A. Smith[2]
Departments:	[1]Department of Atmospheric Environment, National Environmental Research Institute, Denmark. [2]Scripps Institution of Oceanography, University of California, San Diego
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Abstract:

The drag coefficient has been postulated by many investigators to depend on fetch. For constant windspeed and stability, laboratory data generally show an increasing drag coefficient with fetch while field observations show a decreasing dependence. In this study, we show that if one combines the spectral form of the roughness length proposed by Kitaigorodskii with the JONSWAP wave spectrum and extrapolate to very short fetch, then the predicted drag coefficient exhibits a behaviour which coarsely reproduces field and laboratory observations. The results indicate that the drag coefficient exhibits a maximum when the phase speed of the dominant wind wave has a value near 7 u*, where u* is the friction velocity. This corresponds to a maximum near 2 km fetch during moderate windspeed, and the maximum value of the drag coefficient corresponds to an increased fetch of 13 km for windspeeds of 20 m/sec. We furthermore show that the drag coefficient can be simply parameterized as a function of wave period and windspeed, and account for the influences of fetch and depth for ideal steady state conditions.

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Denmark
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Contents

1 Abstract

Fetch dependent drag coefficient

The drag coefficient has been postulated by many investigators to depend on fetch. For constant windspeed and stability, laboratory data generally show an increasing drag coefficient with fetch while field observations show a decreasing dependence. This disparity has led to suspicions on the quality of data and/or that one must unfold a more complicated set of processes regarding the coupling between waves and wind to explain the different trends. One would furthermore want to evaluate the practical application of such trends, and determine if there are parameterizations which can be developed and be based on a reduced set of dominant processes, which are relevant to most environmental conditions. In this study, we show that if one combines the spectral form of the roughness length proposed by Kitaigorodskii with the JONSWAP wave spectrum and extrapolate to very short fetch, then the predicted drag coefficient exhibits a behaviour which coarsely reproduces field and laboratory observations. The results indicate that the drag coefficient exhibits a maximum when the phase speed of the dominant wind wave has a value near 7 u*, where u* is the friction velocity. Furthermore, values of the drag coefficient for conditions of deep water wind waves exhibit a maximum near 2 km fetch during moderate windspeed, and the maximum value of the drag coefficient corresponds to an increased fetch of 13 km for windspeeds of 20 m/sec. We furthermore show that the drag coefficient can be simply parameterized as a function of wave period and windspeed, and account for the influences of fetch and depth for ideal steady state conditions.

2 Introduction

Momentum flux and wave state

When wind blows out over a coastal sea, the surface layer wind shear supports a downward momentum flux, or wind stress, which in turn drives the wave field. The surface wave field increases in energy with increasing fetch, with a decreasing peak wave frequency and increasing wave age. Parameterizing the behaviour of the drag coefficient has, in most part, relied on a paucity of field and laboratory observations and the incorporation of empirical models which are supported by theoretically-based qualitative arguments. In most part, the field observations suggest that the drag coefficient decreases with increasing fetch for constant windspeed (Geernaert, 1988a; Mahrt, et al., 1996); laboratory data, on the other hand, show the opposite trend with an increasing drag coefficient with fetch (Toba, et al. 1990; Jones and Toba, 1995)).

Disagreements between laboratory and field data

The dispute between the laboratory and field data analyses is on the sign of the power law assigned to the wave age dependence, i.e., the field observations in general suggest that the roughness length, z_0, inversely depends on wave age (Geernaert, et al., 1987; Smith, et al., 1992; Donelan, et al., 1993; Donelan, et al., 1995; Mahrt, et al., 1996), while the laboratory observations propose a direct dependence on wave age.

Roughness length models

There have been several models developed which are capable of characterising the fetch dependent drag coefficient. Hsu (1974), Byrne (1982), Donelan (1982), Geernaert, et al. (1986), Geernaert (1988a, 1990b), Nordeng (1991), and Juszko, et al. (1995) each use a form of the roughness length, z0, which is based on all or part of the surface wave spectrum. Geernaert (1988a, 1990b), Nordeng (1991), and Juszko, et al (1995) each have used some form of the Kitaigorodksii (1973) roughness length parameterization as a basis for their calculations. In the Geernaert (1988a) study, the JONSWAP spectrum was employed, where predictions were made for the range of fetches applicable to the original JONSWAP data set.

Kitaigorodskii roughness length

Using physical arguments summarised in Geernaert (1990a), Geernaert (1990b) applied the JONSWAP spectrum in a form dependent on wind stress rather than windspeed, applied the Kitaigorodskii expression for the roughness length, and found that the drag coefficient decreased with increasing wave age or fetch, for wave ages above a value of 10. Wave age was defined as c_0/u^*, where c_0 is the phase speed of the peak of the wind wave spectrum, and u^* is the friction velocity. The application of those results were for conditions when swell was absent.

Drag coefficient versus waveage

Nordeng (1991) applied the Kitaigorodskii formulation to a wave spectrum characterised by Phillips equilibrium range and a Phillips coefficient parameterized in terms of inverse wave age. Instead of limiting the predictions to the range of wave age over which the wave spectrum was valid, Nordeng extended the predictions to wave ages as low as 2. His results indicated that the drag coefficient increased with wave age for values of c_0/u^* less than around 10, and the drag coefficient decreased with increasing fetch or wave age for wave ages above 10. The drag coefficient maximum was determined to be generally 50% higher than its counterpart for long fetch. Nordeng's results were compared to field observations (e.g., data reported by Geernaert, et al., 1987) and others for values of the wave age above 10; and they additionally compared to laboratory observations, thus shedding light on the controversial mix of laboratory and field observations reported by Toba (1990) and Jones and Toba (1995) where laboratory data showed an increasing drag coefficient with fetch.

In this paper, we take a similar approach as Nordeng, but use the JONSWAP spectrum to evaluate the maximum of the drag coefficient, and the slope of the drag-fetch dependence as a function of fetch. We extend the analysis by considering the wave spectrum written in terms of wind stress as the dependent parameter rather than windspeed, so that stability effects are not necessary to consider, and explore the dependence of shallow water on the drag coefficient.

To tackle the controversy between the laboratory results of Toba (1990) and Jones and Toba (1995), on the one hand, and the suite of field data sets, the analysis is conducted in this study also for extremely short fetch, within the range of laboratory studies. Limitations on the use of our results and suggestions for future research needs are also highlighted. In the next section, the basic theory is reviewed, including the model used in this study. In Section 3, the results are presented, which is followed by a brief discussion and summary.

3 Basic Theory and model equations

Logarithmic wind profile

The traditional method for calculating the air-sea momentum flux is to use easily measured bulk meteorological and ocean parameters, e.g., wind speed, U; air and water temperatures, T_a and T_w; and when available also relative humidity, RH; see Geernaert (1990a) for full details. The basis for estimating air-sea momentum flux, or wind stress, τ, using bulk measurements rests with the classical mean profile relations (see, e.g., Panofsky and Dutton, 1984), i.e.,

$$\partial U / \partial z = u^* / kz \, \Phi_M$$

where k is the von Karman constant (=.4), Φ_M, is a stability function, z is height above the mean surface, u* is defined as $\lambda / \rho l^{1/2}$, and ρ is air density. Integrating (1), one obtains the wind profile, i.e.,

$$U = \left(u^* / k \right) \left[In \left(z / z_0 \right) - \Psi_M \right]$$

where z_0 is the roughness length (which in turn is related to wave state). It follows from (2) that the momentum flux may be given by:

$$\tau = \rho \; C_D U^2$$

Drag coefficient

where C_D is the drag coefficient, which is defined as:

$$C_D = \left\{ k / \left[In\, z / z_0 - \Psi_M \right] \right\}^2$$

and Ψ_M is a stability function. The reader is referred to Geernaert (1990a) for analytical formulations of Ψ_M. Keeping with convention, all computations of the drag coefficient are based on meteorological variables representative of a height of 10 m above the surface.

Roughness lenght

Expressions for surface roughness based on wave state often reduce to the simple Charnock relation, i.e., z_0 is proportional to u^{*2}/g, where g is gravitational acceleration. The roughness length may also be expressed in terms of wave state according to the Kitaigorodskii (1973) formulation, i.e.,

$$z_0 = A \left\{ \int S(\omega) e^{-2kc/u^*} d\omega \right\}^{1/2}$$

where ω is wave frequency, and S is wave spectral density. Using field observations, Geernaert, et al. (1986) found the value of A to be 0.028.

JONSWAP wave spectrum

The JONSWAP formulation for S (Hasselmann, et al., 1973) and applicable for deep water waves, is:

$$S = 2\pi\, \alpha\, g^2\, \omega^{-5} \exp\Big(-1.25\left[\omega / \omega_0 \right]^4 + In\,\Omega \exp\Big(-.5\left[\omega - \omega_0 \right]^2 / \Sigma^2\, \omega_0^{\,2} \Big)$$

The parameter Ω has a value from JONSWAP of 3.3, and Σ has a value of .07 for $\omega<\omega_0$, and .09 otherwise. . The dominant wave frequency, ω_0, and coefficient, α, originally written in terms of windspeed, have been revised to be dependent on u* (Geernaert, 1990b) to be:

$$\omega_0 = 2.2\pi\, g / u^* \quad \left(gX / u^{*2} \right)^{-.33}$$

$$\alpha = 3.5 \left(gX / u^{*2} \right)^{-.22}$$

where X represents upwind fetch. The conversion of the JONSWAP spectrum from its dependence on windspeed to a dependence on wind stress was made by using their originally used drag coefficient value of 1.0 X 10^{-3} and noting that $u^*=C_D^{\,1/2}U$. This conversion is based on the assumption that the wave field is driven by the wind stress, and that stability effects in describing the wave state are eliminated when a u* dependence is used. Using equation (7), the value of wave age is easily related to dimensionless fetch for deep water waves, i.e.,

Wave age and dimensionless fetch

$$c_0 / u^* = .145 \left(gX / u^{*2} \right)^{1/3}$$

The computation of C_0 often requires information on depth if the wave field has evolved to such a degree that the longer waves interact with the sea floor. In this case, we compute the new c_0 by first incorporating the wave frequency from equation (8) and applying

$$\omega_0^{\,2} = gk \tanh kD$$

and

$$c_0^{\,2} = \left(g / k \right) \tanh kD$$

where D is water column depth.

Shallow water effects

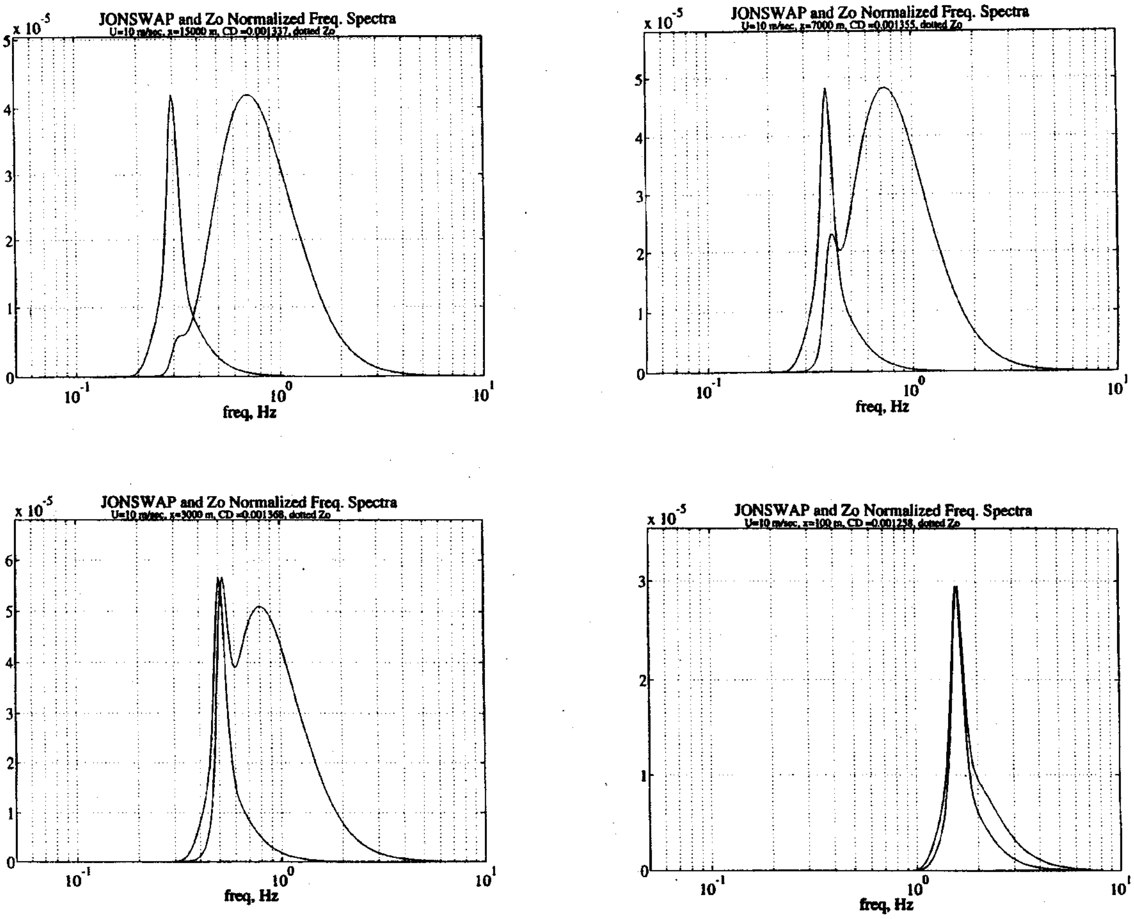
In general, offshore blowing waves are deep water waves if the depth continues to increase significantly with fetch. This generality usually holds since short fetch waves are generally rather small compared to the local depth. However, the depth must continue to increase with range in order for the growing waves to be classified as "deep water waves." In reality, most basins exhibit an increasing depth in the short fetch domain, i.e., from the coastline to a fetch of several kilometres, then the depth can be nearly constant with range. For this idealised basin, short fetch waves are governed by a deep water dispersion relation, and the waves will increasingly depend on the depth as they grow with inreasing fetch. We therefore will consider the fetch limited waves to be governed by deep water relations, or else governed by a weak depth dependence. (We recognise, on the other hand, that very shallow conditions can exist, but such conditions will not be dealt with here.)

It is noted herein that the formulation for z_0 described above assumes that the surface wave field can be decomposed into Fourier components and the contribution of each component to z_0 is summed. For highly non-linear fluid flow, this assumption is not necessarily valid, but it provides some level of approximation. Based on the assumption that the wave field is quasi-linear, we will assume that the relations documented above are valid within a small degree of statistical uncertainty, and proceed with an analysis which can provide quantitative results.

4 Drag coefficient dependence on fetch, depth, waves, and wind

Frequency spectrum of the roughness length

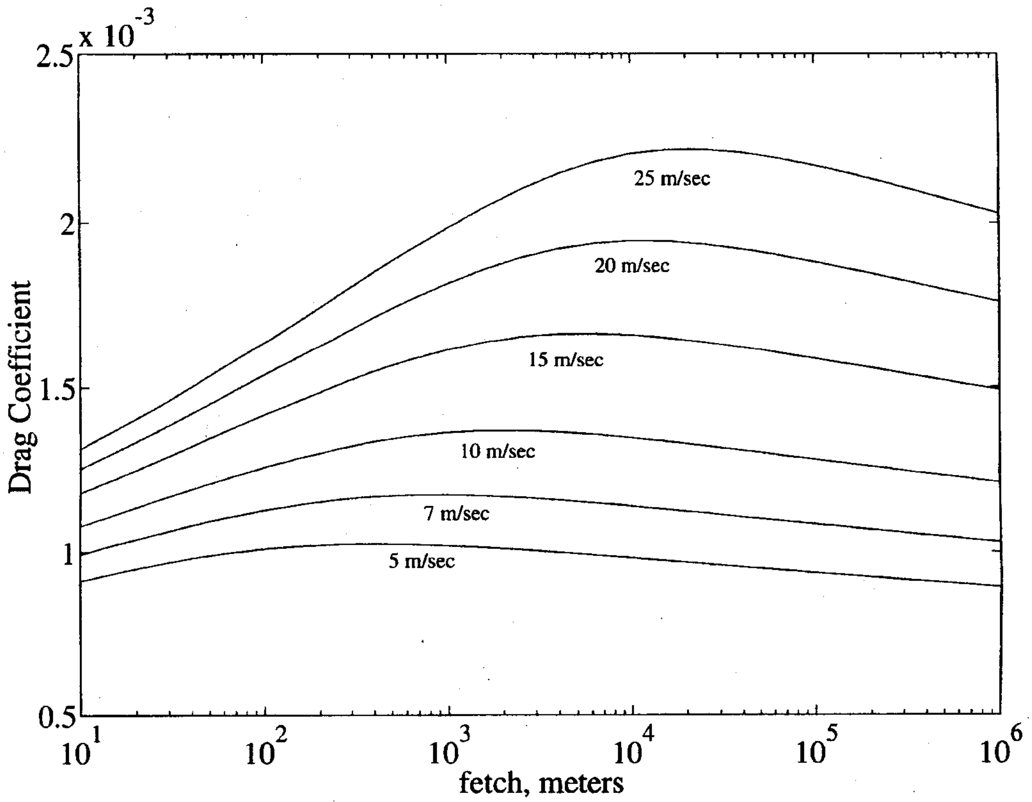
The use of the Kigaigorodskii roughness length expression in performing calculations of the drag coefficient is based on the assumption that short waves dominate the important contributions to the total roughness which, in turn, supports the stress. This assumption is illustrated by Figure 1a,b,c,d, which shows the spectrum of wind waves and the spectrum of the roughness length represented by the integrand in equation (5).



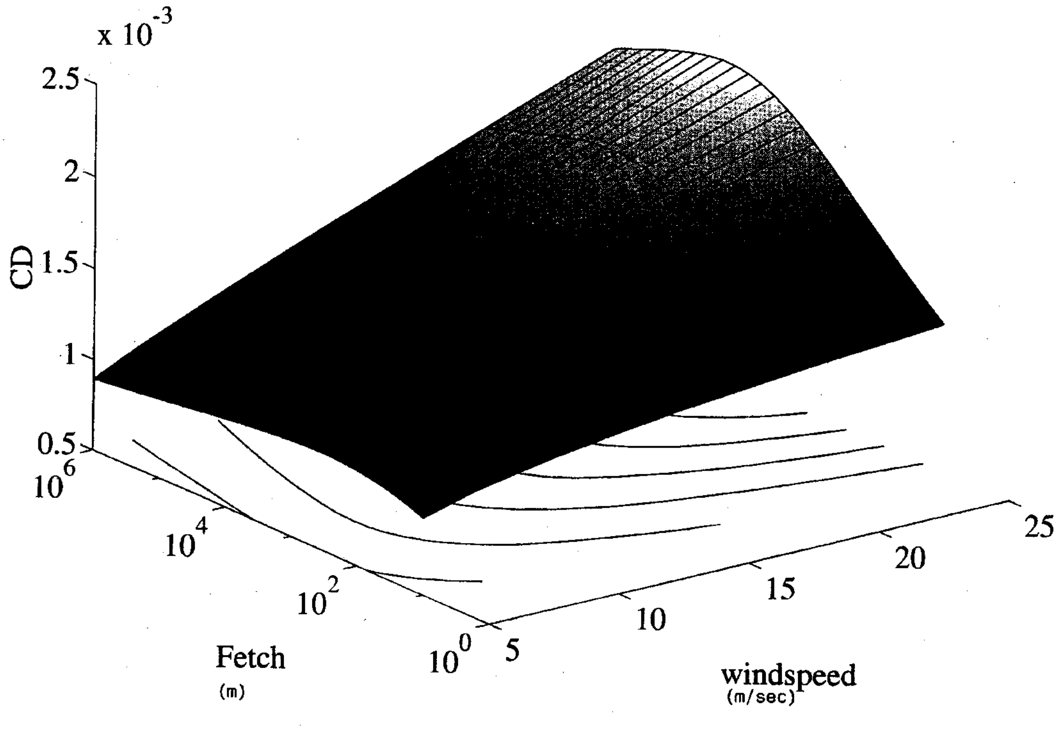
Figur 1 JONSWAP wave spectrum (left curve) and roughness length spectrum based on the Kitaigorodskii formula (right curve) for a neutral windspeed of 10 m/sec, deep water wave evolution. Panels a, b, c, and d, represent upwind fetches of 15 km, 7 km, 3 km, and 0.1 km, respectively

In this four panel figure, the windspeed is chosen to be 10 m/sec for illustration, and the wave spectrum can be seen to move to higher frequencies for shorter fetch as expected. The roughness length spectrum, shown at the right in every case, is normalised to the height of the wave spectral peak. These panels in Figure 1 show that the high frequency part of the roughness length spectrum is nearly constant but the low frequency part broadens with increasing fetch and with increasing amplitude. One also notices that for long fetch, the roughness length spectrum is dominated by frequencies which are generally 2-8 times the peak of the wave spectrum, suggesting that any dominant wind wave influence on the roughness is via the long wave's influence on the shorter waves of the wave spectrum. It is only in this way that the wave age can be related to the stress using the Kitaigorodskii roughness length expression. For shorter fetches, the peaks of the roughness length and wave spectra begin to overlap, suggesting that there is a substantial interaction between wind wave total energetics and momentum flux. In contrast to the short fetch case, there will be more indirect process interactions for longer fetch if one wants to represent C_D in terms of bulk wind or wave parameters.

The first set of drag coefficient computations against bulk wave parameters, which in turn depend interactively on the drag coefficient, considers the case of deep water. Referring to Figure 2, we find that for all windspeeds there is a dramatic increase of the drag coefficient with fetch, and a slow decrease with fetch after the maximum has been reached. These results are also plotted three dimensionally in Figure 3 which shows, for deep water, how the drag coefficient depends on both windspeed and fetch as independent parameters.



Figur 2 Drag coefficient computations versus fetch, vor windspeeds ranging from 5 m/sec to 25 m/sec.



Figur 3 Three dimensional plot of drag coefficient versus fetch and windspeed for deep water waves.

In figure 4, the drag coefficient is plotted against wave age. The results show a maximum for a wave age of 7, and this maximum is nearly independent of windspeed. This maximum is substantially lower than the maximum reported by Nordeng (1991). Since the JONSWAP spectrum is computed herein against wave age rather than dimensionless fetch, i.e., by using the conversion described by equation (9), conditions of variable depth are able to be included in the calculations.

If one examines the set of equations in Section 2, one finds that calculations of the neutral drag coefficient may be performed if one has information containing the ten-meter height windspeed and either the dominant wave period, frequency, or phase speed. Routine buoy networks typically report windspeed and wave period, which suggests that the use of the model described herein could compute the drag coefficient using these two bulk parameters alone in addition to the known water column depth. We have plotted drag coefficients in Figure 5 in three dimensions, i.e., against wave period and windspeed. These computations provide a much simpler basis for providing more accurate drag coefficients for coastal shelf studies, when buoy observations are the only information available.

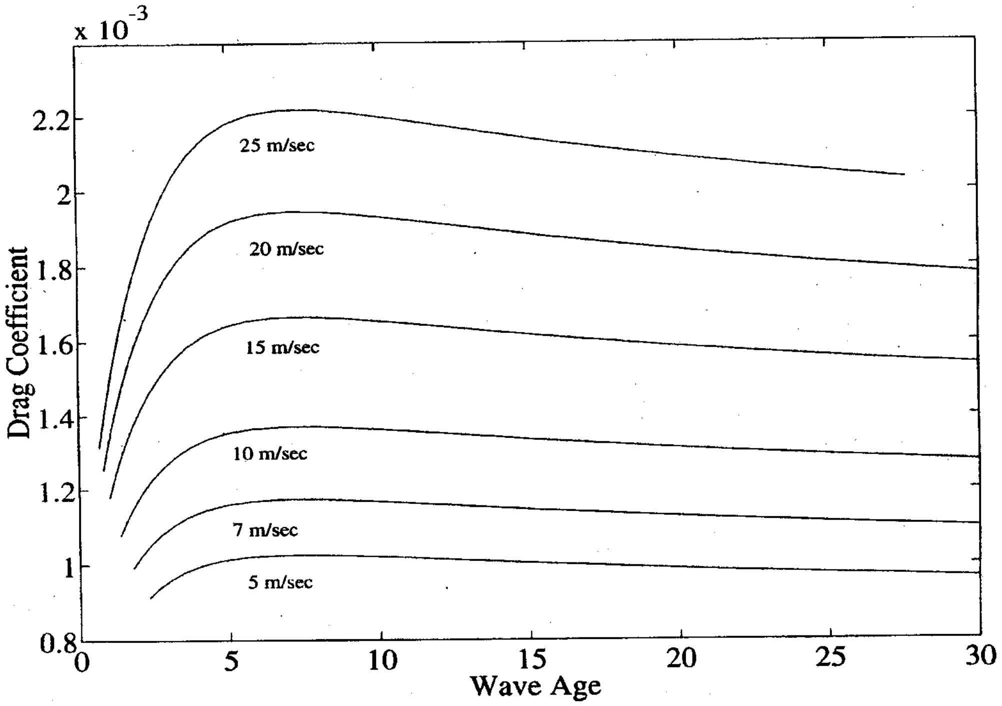
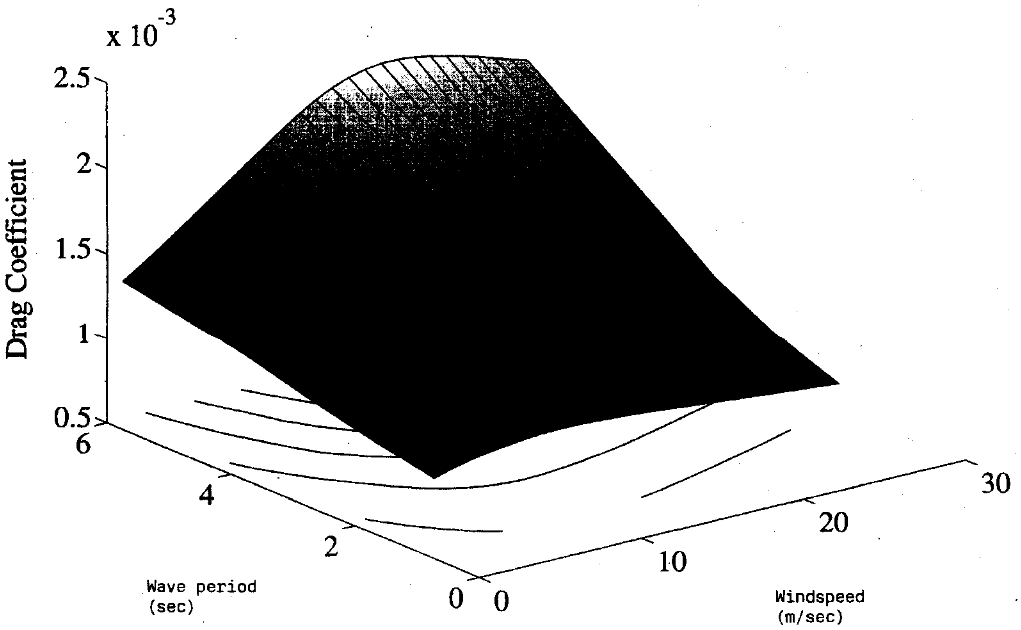


Figure 4 Drag coefficient versus wave age. Note that the computations are independent of water column depth.



Figur 5 Three dimensional plot of the drag coefficient versus wave period and windspeed. Note that the computations are independent of water column depth.

5 Discussion

Role of shoaling waves

In general, coastal short fetch wind waves do not encounter a strong depth effect unless either the windspeeds are high or the sea floor bottom does not deepen very rapidly. However, in the case of wind waves propagating from one shore to another within an internal bight or sea, developed wind waves encounter rapidly shallowing conditions and the waves will respond by steeping with decreasing wavelengths and phase velocities. In this case, the dynamics of wind and wave coupling becomes extremely complex, and the drag coefficient increase cannot be easily predicted using simple spectra such as JONSWAP, and applications of the Kitaigorodskii expression for the roughness length are too simplistic. Nonetheless, measurements of the drag coefficient increase due to shoaling waves have recently been reported by Anctil and Donelan (1996), which indicate a strong dependence on inverse wave age, i.e., a trend similar but not necessarily the same as the predictions reported herein.

In these computations, we have assumed that the windspeed has remained constant with fetch over the study domain. This assumption may be violated under certain conditions, in particular when the change in roughness and/or stratification between land and water is so dramatic that wind acceleration over the sea can occur. Furthermore, the internal boundary generated by the step-change in roughness at the coastline, which is important in governing the flux profiles (Garratt, 1992), has not been considered in this study and will need a focused future effort to determine its importance and impact.

In the computations of the wave dependence, it is also assumed that the domain exhibits sufficient horizontal homogeneity such that the energetics supported by the JONSWAP spectrum are valid. It is also assumed that the high frequency part of the JONSWAP spectrum is valid. We admit that the use of the simple parameterization of the high frequency part of the JONSWAP spectrum carries large risk, since the high frequency spectral behaviour is in general poorly understood at present. The reader is referred to the discussion of Figure 1, where we note that the high frequency part of the JONSWAP spectrum is extremely important in computing the roughness length over the full range of windspeeds and fetches. We are also note that the JONSWAP spectrum does not consider swell, and that the high frequency part of wave spectra, in general, are extremely sensitive to the presence of swell. Therefore, we view our results to be relevant only for conditions absent of swell, and irrelevant for swell dominated seas.

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Dansk Resumé

Den fetch-afhængige drag-koefficient over kystnære farvande

Faglig rapport fra DMU nr. 230

G. L. Geernaert, J.A. Smith

De i rapporten omtalte resultater kombinerer JONSWAP bølgespektret med Kitaigorodskii udtryk for ruhedslængde, begge lavet udfra friktionshastigheden i stedet for vindhastighed. Beregninger foretaget med denne model, støtter de generelle resultater publiceret af Nordeng (1993) i at der er et maksimum i drag-koefficientens størrelse ved moderat kyst fetch. Men, hvor Nordeng beregnede maksimum til at være for en bølgealder på 10, viser beregninger i nærværende arbejde at maksimum er nærmere på 7, og ligeledes finder vi et mindre fald i størrelsen af drag-koefficienten med fetch efter at maksimum er nået end Nordengs. Forskellen mellem de to resultater opstår højest sandsynligt pga. specifikation af bølgespektrets indflydelse på momentflux og drag-koefficienten, da både drag-koefficienten og vindhastigheden er inkluderet i nærværende arbejde for at beregne JONSWAP spectral energierne.

Resultaterne er også anvendt til praktisk brug ved at beregne kritiske fetch værdier som en funktion af vindhastighed, hvorved drag-koefficientens maksimum kan findes. Disse beregninger er relevante for uoverensstemmelser mellem grupper der diskuterer drag-koefficientens positive contra negative afhængighed af bølgealder. Begge afhængighedsforløb kan være rigtige idet korte fetch betingelser i laboratorium giver en stærk forøgelse af drag-koefficienten med bølgealder; og felt dataene giver en faldende drag-koefficient med bølgealder. Vi antager, at hvis dybden er sådan, at bølgerne kun i mindre grad afviger fra bølgeligninger på dybt vand, vil beregningerne med den beskrevne model være gyldige. Denne hypotese er baseret på vigtigheden af bølgehastigheden som en parameter ved bestemmelse af drag, og denne hypotese bør afprøves både teoretisk og ved forsøg.

Det konkluderes, at drag-koefficienten kan bestemmes ved hjælp af informationer om bølgeperioder, vanddybde, og vindhastigheden alene. Dette betyder, at med bøje-informationer om vindhastighed og bølgeperioder, vil man være i stand til rutinemæssigt at beregne drag-koefficienten uden brug af fetch information. Dette er illustreret i Figur 5.

Grundet usikkerheden i beregningerne som følge af den forenklede formulering af bølge spectra i det høje frekvensområde, anbefales det, at fremtidig indsats bliver lagt i at karakterisere det korte bølgeområde af spektret. Indtil højfrekvensområdet af bølgespektret er defineret for forskellige fysiske betingelser der inkluderer swell interaktion, er det ikke muligt at udføre tilfredsstillende modellering af flux spectral interaktion med bølgefeltet. På den anden side, brug af

JONSWAP eller andre spektra giver os gode argumenter i tilfælde af uoverensstemmelser (som antydet i introduktionen) og giver estimater af flux afhængigheder som er nødvendige ved udarbejdelse af strategier der kan imødegå fremtidige oceanografiske indsatsområde mere kvantitativt.

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Frederiksborgvej 399
PO Box 358
DK-4000 Roskilde
Denmark
Tel: +45 46 30 12 00
Fax: +45 46 30 11 14

Management
Personnel and Economy Secretariat
Research and Development Section
Department of Atmospheric Environment
Department of Environmental Chemistry
Department of Policy Analysis
Department of Marine Ecology and Microbiology

National Environmental Research Institute
Vejlsøvej 25
PO Box 413
DK-8600 Silkeborg
Denmark
Tel: +45 89 20 14 00
Fax: +45 89 20 14 14

Department of Lake and Estuarine Ecology
Department of Terrestrial Ecology
Department of Streams and Riparian areas

National Environmental Research Institute
Grenåvej 12, Kalø
DK-8410 Rønde
Denmark
Tel: +45 89 20 17 00
Fax: +45 89 20 15 14

Department of Landscape Ecology
Department of Coastal Zone Ecology

National Environmental Research Institute
Tagensvej 135, 4
DK-2200 København N
Denmark
Tel: +45 35 82 14 15
Fax: +45 35 82 14 20

Department of Arctic Environment

Publications:
NERI publishes professional reports, technical instructions, and the annual report. A R&D projects' catalogue is available in an electronic version on the World Wide Web.
Included in the annual report is a list of the publications from the current year.

Faglige rapporter fra DMU/NERI Technical Reports

1997

Nr. 193: Miljøundersøgelser ved Maarmorilik 1996. Af Johansen, P, Riget, F. & Asmund, G. 96 s., 100,00 kr.

Nr. 194: Control of Pesticides 1996. Chemical Substances and Chemical Preparations. By Køppen, B. 26 pp., 40,00 DKK.

Nr. 195: Modelling the Atmospheric Nitrogen Deposition to Løgstør Bredning. Model Results for the Periods April 17 to 30 and August 7 to 19 1995. By Runge, E. et al. 49 pp., 65,00 DKK.

Nr. 196: Kontrol af indholdet af benzen og benzo(a)pyren i kul- og olieafledte stoffer. Analytisk-kemisk kontrol af kemiske stoffer og produkter. Af Rastogi, S.C. & Jensen, G.H. 23 s., 40,00 kr.

Nr. 197: Standardised Traffic Inputs for the Operational Street Pollution Model (OSPM). Af Jensen, S.S. 53 pp., 65,00 DKK.

Nr. 198: Reduktion af CO_2-udslip gennem differentierede bilafgifter. Af Christensen, L. 56 s., 100,00 kr.

Nr. 199: Photochemical Air Pollution. Danish Aspects. By Fenger, J. (ed.). 189 pp., 200,00 DKK.

Nr. 200: Benzin i blodet. Kvantitativ del. ALTRANS. Af Jensen, M. 139 s., 100,00 kr.

Nr. 201: Vingeindsamling fra jagtsæsonen 1996/97 i Danmark. Af Clausager, I. 43 s., 35,00 kr.

Nr. 202: Miljøundersøgelser ved Mestersvig 1996. Af Asmund, G., Riget, F. & Johansen, P. 30 s., 50,00 kr.

Nr. 203: Rådyr, mus og selvforyngelse af bøg ved naturnær skovdrift. Af Olesen, C.R., Andersen, A.H. & Hansen, T.S. 60 s., 80,00 kr.

Nr. 204: Spring Migration Strategies and Stopover Ecology of Pink-Footed Geese. Results of Field Work in Norway 1996. By Madsen, J. et al. 29 pp., 45,00 DKK.

Nr. 205: Effects of Experimental Spills of Crude and Diesel Oil on Arctic Vegetation. A Long-Term Study on High Arctic Terrestrial Plant Communities in Jameson Land, Central East Greenland. By Bay, C. 44 pp., 100,00 DKK.

Nr. 206: Pesticider i drikkevand 1. Præstationsprøvning. Af Spliid, N.H. & Nyeland, B.A. 273 pp., 80,00 kr.

Nr. 207: Integrated Environmental Assessment on Eutrophication. A Pilot Study. Af Iversen, T.M., Kjeldsen, K., Kristensen, P., de Haan, B., Oirschot, M. van, Parr, W. & Lack, T. 100 pp., 150,00 kr.

Nr. 208: Markskader forvoldt af gæs og svaner - en litteraturudredning. Af Madsen, J. & Laubek, B. 28 s., 45,00 kr.

Nr. 209: Effekt af Tunø Knob vindmøllepark på fuglelivet. Af Guillemette, M., Kyed Larsen, J. & Clausager, I. 31 s., 45,00 kr.

Nr. 210: Landovervågningsoplande. Vandmiljøplanens Overvågningsprogram 1996. Af Grant, R., Blicher-Mathiesen, G., Andersen, H.E., Laubel, A.R., Grevy Jensen, P. & Rasmussen, P. 141 s., 150,00 kr.

Nr. 211: Ferske vandområder - Søer. Vandmiljøplanens Overvågningsprogram 1996. Af Jensen, J.P., Søndergaard, M., Jeppesen, E., Lauridsen, T.L. & Sortkjær, L. 103 s., 125,00 kr.

Nr. 212: Atmosfærisk deposition af kvælstof. Vandmiljøplanens Overvågningsprogram 1996. Af Ellermann, T., Hertel, O., Kemp, K., Mancher, O.H. & Skov, H. 88 s., 100,00 kr.

Nr. 213: Marine områder - Fjorde, kyster og åbent hav. Vandmiljøplanens Overvågningsprogram 1996. Af Jensen, J.N. et al. 124 s., 125,00 kr.

Nr. 214: Ferske vandområder - Vandløb og kilder. Vandmiljøplanens Overvågningsprogram 1996. Af Windolf, J., Svendsen, L.M., Kronvang, B., Skriver, J., Olesen, N.B., Larsen, S.E., Baattrup-Pedersen, A., Iversen, H.L., Erfurt, J., Müller-Wohlfeil, D.-I. & Jensen, J.P. 109 s., 150,00 kr.

Nr. 215: Nitrogen Deposition to Danish Waters 1989 to 1995. Estimation of the Contribution from Danish Sources. By Hertel, O. & Frohn, L. 53 pp., 70,00 DKK.

Nr. 216: The Danish Air Quality Monitoring Programme. Annual Report for 1996. By Kemp, K., Palmgren, F. & Mancher, O.H. 61 pp., 80,00 DKK.

Nr. 217: Indhold af organiske opløsningsmidler og phthalater i legetøj. Analytisk-kemisk kontrol af kemiske stoffer og produkter. Af Rastogi, S.C., Worsøe, I.M., Køppen, B., Hansen, A.B. & Avnskjold, J. 34 s., 40,00 kr.

Nr. 218: Vandføringsevne i danske vandløb 1976-1995. Af Iversen, H.L. & Ovesen, N.B. 2. udg. 55 s., 50,00 kr.

Nr. 220: Interkalibrering af bundvegetationsundersøgelser. Af Middelboe, A.L., Krause-Jensen, D., Nielsen, K. & Sand-Jensen, K. 34 s., 100,00 kr.