AIR-SEA INTERACTIONS

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Keywords: Wind waves, fully developed sea, tsunamis, swell, clapotis, seiches, littoral current, rip current, air-sea interactions, sea slicks, drag coefficient.

Contents

Summary

The marine system is part of the general geophysical system. Physical and chemical boundary interactions at the air-sea interface are essential factors in the marine system's dynamics Wind blowing over the sea generates surface waves and energy is transferred from the wind to the ocean's upper layer. The fluxes of the momentum, heat, chemicals... at the air-sea interface are usually parameterized by bulk formula which assumed that the fluxes are proportional to the magnitude of the wind velocity at some reference height (10m, say). Although these bulk formulas have abundantly been used in several generations of models, they can only give a rough representation of the mechanisms of air-sea interactions where wave's field's characteristics, bubbles and spray, surface slicks, heavy rainfalls...can play a significant role.

1. Introduction

Incoming short wave solar radiation and outgoing long wave radiation emitted by the earth surface, mediated by back and forth long wave emissions by clouds and aerosols - with its spatial variability due, in particular, to the earth's sphericity - constitute one of the cogent forcings of the atmosphere and ocean dynamics.

The resulting motions of air and water masses interact at their common boundary: the air-sea interface.

Although the concept of the "*sea surface*" or "*air-sea interface*" appeals to common sense and typical well-known surface phenomena like wind waves are easily observed, its definition as a "*boundary*" where momentum, energy and material are exchanged between the atmosphere and the ocean, and the associated mathematical formulation of the associated fluxes ("boundary conditions"), is not always straightforward.

In the following, one shall go from a simple, classical description of wind waves to an excursion into the complexity of wind forcing and its mathematical formulation in models.

2. Wind Waves

Wind blowing over the sea generates surface waves and energy is transferred from the wind to the ocean's upper layer.

The energy that the wind puts into the sea's upper layer initially in the form of surface waves is determined by the *wind speed*, the *wind duration* and the fetch (the *distance* over which the wind blows with relatively constant direction and speed).

For each wind speed there is a maximum of energy that can be transferred to the sea surface. Beyond, wave will break and the energy will be dissipated. When maximum transfer is achieved, a *fully developed sea* is said to exist. To obtain a fully developed sea, minimum values of both fetch and duration are required. There are relatively few places on the earth where fully developed seas can be produced for wind speeds exceeding 40 knots (an example of an area of extreme fetch is the South China Sea under the influence of the Monsoons). Waves move out of the area where they are generated in the direction in which the wind is blowing. Within the generating area, the waves are apparently chaotic and there is no obvious pattern of the sea surface. However, if this imbroglio is analyzed in the spirit of the mathematical technique of Fourier transforms, the wave field may be viewed as a superposition of sine-waves of various frequencies (periods) and wave-numbers (wavelengths). Such an elementary sine-wave may be expressed mathematically as $\eta = A\sin(\kappa x - \omega t)$

where η is the instantaneous displacement from the equilibrium position

x and t are respectively the position in the wind direction and time of observation

κ is the wave-number (equal to the inverse of the wave-length multiplied by 2 π)

ω is the frequency (equal to the inverse of the period multiplied by 2 π)

A is the amplitude (i.e. the *"wave height"* divided by 2).

For such a sine-wave of amplitude small compared to both the wave-length and the water depth, the *phase speed* (i.e. the speed at which an observer must move to see always the same "phase" e.g. the wave crest or the wave trough) is given by

$$c = \sqrt{g/\kappa \tanh(\kappa d)}$$

where d is the water depth, g the acceleration of gravity (~ 10 m s^{-2}) and tanh denotes the hyperbolic tangent.

There are two interesting asymptotic cases of behavior of the tanh function viz

$$\tanh(\kappa d) \sim \kappa d \qquad \text{for } \kappa d \ll 1$$

$$\tanh(\kappa d) \sim 1 \qquad \text{for } \kappa d \gg 1$$

This leads to a distinction between so-called *"shallow water"* waves ($\kappa d \ll 1$, depth much smaller than the wavelength) and *"deep water"* waves ($\kappa d \gg 1$, depth much larger than the wavelength). The corresponding velocities are

$$c_s = \sqrt{gd} \qquad\qquad c_d = \sqrt{g/\kappa}$$

One should not be confused by the expressions “shallow water” waves and “deep water” waves. A “deep water” wave is not necessarily a wave in deep water. It is the ratio of the depth to the wavelength that matters. For instance, *tsunamis*, waves of seismic origin have such long wavelengths that they are “shallow water” waves throughout the deep ocean.

It is important to note that “deep water” waves have speeds depending on the wavelength i.e. long waves travel faster than short waves. For “sallow water” waves, all waves have the same speed but this speed is a function of the water depth.

Outside the generating area, as long “deep water” waves travel faster, they outstrip the short waves and leaving behind the confused wave field of the generating area (called “*sea”*) give rise to a much smoother wave field (called *“swell”*).

As a wave passes a given point, it generates a loop motion of the disturbed water particles (easily visualized with a tracer) quite different of course from the motion of the passing wave itself. For “deep water” waves, the orbits are circular and decrease in size rapidly with depth. In “shallow water”, the waves produce elliptical orbits and while vertical motions tend to zero at the bottom, horizontal motions remain of the same order of magnitude over most of the water column and can drastically affect the transport of sediments.

Standing waves resulting from the interaction of two progressive waves of the same frequency and wave-number moving in opposite directions (such as when a wave reflects from a barrier) create a situation of *“clapotis”*. “*Seiches”* are standing waves where water is caused to slosh back and forth as in a closed tank. Waves approaching a beach ultimately become “shallow water” waves; they travel with the same speed which decreases with depth. On the contrary, the orbital speed of the water particles increases and somehow the particles overtake the wave which becomes unstable and breaks. The water from the breaking wave is carried towards the beach and must return to the sea. If the waves come in at an angle to the beach, there is a longshore current (called “littoral current”) where two opposite longshore currents meet they join and move out towards the sea forming what is called *“a rip current”*.

In forecasting ocean waves, one is mainly interested in the amount of energy transferred from the wind and its distribution over waves of all frequencies and wave numbers, i.e. the *“energy spectrum”*.

Energy spectra show high energy contained in a band of intermediate frequency waves and dropping off for lower and higher frequencies. Increasing the wind speed leads to high waves (the maximum of the curve is greater) and more energy going into long waves, i.e. the spectrum is shifted to smaller frequencies. A similar shift is observed as the wind duration or the fetch is increased.

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Biographical Sketches

Born in Ans, Belgium, on June 6, 1937, **Prof. Jacques C.J. Nihoul** and his wife are currently residing in St. Severin, Belgium. After receiving his Engineering Degree from Liège University in 1960, Prof. Nihoul was awarded his M.Sc. Degree in Mathematics from MIT University (USA) in 1961 and his Ph. D. in Applied Mathematics and Theoretical Physics from the University of Cambridge (UK) in 1965. He served as an Air Force Officer during his National Service in 1964-1965 at the Royal Military College of Belgium and was elected to full Professorships in Liège and Louvain Universities in 1966.

Prof. Nihoul sat on numerous international committees including SCOR, IAPSO and GLOBEC. He is at present Editor of the *Journal of Marine Systems*, *Earth Science Reviews*, *Oceanography Section*, and one of the Editors of *Mathematical and Computer Modelling*. President of the National Committee of Oceanography of the Royal Academy of Belgium, Prof. Nihoul is a Member of the Russian Academy of Natural Sciences and of the Academia Europaea. Author of some 200 papers in international journals, he was awarded the Francqui Prize for Medical and Natural Sciences in 1978.

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