oceanographers is limited, international collaboration should be invited for each voyage.

The recent tendency to build ever larger oceanographic vessels has some merit, particularly since these ships with their long cruising ranges can explore remote ocean areas. However, the cost of operating a large ship is high. Regions such as the South Indian or East Pacific Oceans might be more suitably explored by an adaptation of the naval task force or whaling fleet concepts. A scientific "mother ship", ideally a light aircraft carrier, would act as a mid-ocean base, providing refuelling, repair, hospital, recreation and scientific processing services to a group of small, relatively short range oceanographic vessels. Not only would the observations cost less than comparable observations made by large oceanographic vessels, but entirely new and valuable oceanic and atmospheric measurements could be made from the aircraft carrier.

OCEAN-WAVES*

P. R. PISHAROTY

OCEAN-WAVES generated by wind form the most conspicuous interaction between the atmosphere and the ocean. The formation of breakers, foam and spray may perhaps change the quantities like evaporation and heat exchange by an order of magnitude and also provide the giant nuclei for the initiation of precipitation. Knowledge about wind generated ocean-waves can be broadly classified as under :—

(*i*) The precise physical processes responsible for the transference of energy from the wind to the water waves ;

(*ii*) A correct description of the waves so generated ;

(*iii*) Forecasting of the ocean-waves from the antecedent wind conditions.

Wave Generation.—According to Jeffreys (1925) a *uniform* wind passing over a set of already existing waves induces a deficit of pressure on the leeward side of the crests and an excess on the windward. The component of this variable pressure distribution in-phase with the wave-slope supplies energy for the wave development. The consequences of this theory are not fully borne out by the empirical facts of observations.

According to Phillips (1957, 1958) a random variation of normal pressure associated with the onset of a *turbulent* wind produces waves which then develop most rapidly through a resonance mechanism occurring when a component of the surface pressure distribution moves at the same speed as the free surface wave with the same wave number.

Miles (1957) has developed a theory based on a *laminar flow* of the wind with a *logarithmic shear* and is an improvement on the Kelvin-Helmholtz theory of instability of an interface with a density-discontinuity and a velocity-discontinuity.

Apparently, there is a transition frequency (Phillips, 1961), depending on the fetch and duration, below which waves develop according to the resonance-mechanism of Phillips and above which according to the shear-instability-mechanism of Miles. Much work remains to be done in the theoretical as well as in the experimental field. We do not know the exact wind distribution in the first ten metres above the surface of a large water body, let alone the ocean. Are there eddies ? Is the flow laminar ? What are the variations of wind with height when the surface is unruffled and when it is violently agitated ? These are questions for which we do not have definite answers. Let us hope that the Indian Ocean Expedition will provide some of the answers.

Description of an Ocean Surface Agitated by Wind.—The best description of an ocean surface under the action of a strong wind acting over a sufficiently long fetch for a sufficiently long time, appears to be given by a 'stationary gaussian surface'. There appears to be a spectrum of simple-harmonic waves with the individual wave-fronts having all possible orientations and random phases, the total energy remaining finite. The mathematical expression for such a state is :

$$\eta (x, y, t) = \int_0^{\infty} \int_{-\pi}^{\pi} \cos\left[\frac{\mu^2}{g} (x \cos\theta + y \sin\theta) - \mu t + \epsilon (\mu, \theta)\right] \sqrt{[A (\mu, \theta)]^2 d\mu d\theta}.$$

The total energy is proportional to :

$$E = \int_0^{\infty} \int_{-\infty}^{\pi} [A (\mu, \theta)]^2 \, d\mu d\theta = \int_0^{\infty} [A (\mu)]^2 d\mu$$

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* Abstract of a talk delivered at the symposium on "Oceanographic Research and Related Topics" held at the 28th Annual Meeting of the Indian Academy of Sciences, Bombay, December 1962.

η is the displacement, μ the angular frequency, g the acceleration due to gravity, θ the inclination of the wave-front to the wind direction, $\epsilon(\mu, \theta)$ the random phase and A (μ, θ) the amplitude of the wave of frequency μ and orientation θ.

The spectral distribution of E is not precisely known. Neumann (1953) has suggested a semi-empirical spectrum, though all do not agree with it.

Forecasting of Ocean-waves.—As long as non-linear effects can be disregarded, individual waves propagate independent of each other. Deep-water waves are highly dispersive and the wave energy is propagated with the group velocity which is half the phase velocity, g/μ.

At any point inside an area of generation of waves, the entire wave spectrum will be present, provided the fetch and the duration of the wind are long enough. The associated wave parameters like the average height, the significant height, 'sun glitter', etc., can be computed once the energy spectrum is known. At any point outside the area of generation, it is possible to estimate for any moment the range of the wave periods present, their total energy and hence the wave-parameters. Their computation is based on the relation

$$P_a da = \frac{2a}{E} e^{-a^2/E} da$$

where $P_a da$ is the probability of an amplitude between a and $a + da$, and E is the amplitude integral

$$\int_{\mu_1}^{\mu_2} [A(\mu)]^2 d\mu.$$

A few wave statistics based on the Neumann spectrum are given in Table I.

TABLE I

Wind in knots	E-value in ft.²	Range of periods in secs. From	To	Average amplitude in ft.	At least one wave in 10,000 waves is higher than
10	0·2	1·0	6·0	0·4	1·4 ft. (15 hrs.)†
20	7·7	3·0	11·1	2·5	9 ft. (30 hrs.)
30	58·7	4·7	16·7	6·8	24 ft. (45 hrs.)
40	247	6·5	21·7	14·0	50 ft. (60 hrs.)

† Represents the average time for 10,000 waves to pass a place.

MEASUREMENT OF RADIATION AND HEAT BALANCE OVER THE INDIAN OCEAN*

MISS ANNA MANI

PRECISE, quantitative measurements of the total energy transferred at the ocean-atmosphere boundary and at the top of the atmosphere are required for a study of the transformation of solar energy into kinetic, potential and chemical energy within the atmosphere. The thermal energy available to the oceans is given by:

$$Q_0 = Q_s - Q_r - Q_e - Q_t$$

where Q_s is the incoming solar radiation from the sun and sky, Q_r the solar radiation reflected from the sea surface, Q_e the latent heat of evaporation and Q_t the turbulent heat flux into the atmosphere. The thermal energy available to the atmosphere is given by:

$$Q_a = R_{ab} + Q_{ec} + Q_t$$

where R_{ab} is the energy absorbed in the atmosphere and Q_{ec} the latent heat of evaporation subsequently released through condensation. Q_{ee}, Q_t and Q_e are obtained from the determination of vertical fluxes of water vapour, heat and momentum supplemented by condensation observations. Q_s and R_{ab} are measured directly by using pyranometers and radiometers, both ground-based and airborne, supplemented by satellite observations.

The radiation balance at the surface of the earth, R, is the difference between the absorbed and outgoing radiation,

$$R = Q_s \ (1 - a) - I$$

where a is the albedo of the earth and I the effective outgoing radiation. Measurements of radiation balance and of components of heat balance over the Indian Ocean are planned during the International Indian Ocean Expedition from a network of over 70 land stations and from oceanographic ships, to be supplemented by the meteorological observations over both land and sea.

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