

ATTENUATION OF SURFACE WAVES DUE TO MONSOON RAINS: A MODEL STUDY FOR THE NORTH INDIAN OCEAN

P VETHAMONY, B PRASAD KUMAR* & YVB SARMA

*Coastal Processes Modelling Group, National Institute of
Oceanography, Dona Paula, Goa-403 004.*

**Centre for Atmospheric Sciences, Indian Institute of
Technology, New Delhi - 110 001.*

ABSTRACT

The dynamic interaction of intense rain with waves based on momentum exchange is applied to a second generation wave model to predict wave attenuation during monsoon. The scheme takes into account the characteristics of rain and wave parameters such as rain intensity, angle of incidence, fall velocity, wave amplitude and wave frequency. The model results pertaining to monsoon season of July 1987 show a maximum wave attenuation of about 28%. The results highlight the importance of including rain effect as a source parameter (negative mechanism) in the model for predicting waves over the north Indian Ocean during monsoons; otherwise, model (without rain) over predicts the actual waves.

1. INTRODUCTION

The interaction of rain with sea surface in the presence of wind is a quite complex non-linear problem. Rain can generate ripples, attenuate/enhance surface gravity waves and enhance/reduce surface roughness. The phenomenon of surface wave attenuation by intense rain is scarcely studied and most of the studies are confined to interaction between a single rain drop and water body only. Le Mehaute and Khangraonkar (1990) established a theory to determine the dynamic effect of intense rain on waves, based on the momentum

exchange between rain and water waves. Yang et al. (1997) studied the influence of rain on sea surface roughness through spatial measurements of wave slopes under various wind and rain conditions.

The north Indian Ocean experiences two monsoons, namely south west and north east and receives rainfall nearly six months in a year. As rain can attenuate ocean surface waves (mainly in the high frequency region), it is very apt to include rain effect in the wave model proposed for Indian seas (Vethamony et al. 1998) so that reliable wave predictions can be obtained for

monsoon months. With this in view, the theory proposed by Le Mehaute and Khangaonkar (1990) is employed in the present study to predict monsoon waves in the north Indian Ocean using uniform ECMWF analysed winds. Intense rain with low to moderate wind speeds (true for north Indian Ocean in the absence of cyclones during monsoons) is considered in the present study.

2. Wave model and damping coefficient

A second generation wave model based on energy balance equation is used. The sources and sinks by which energy is gained or lost by the spectral components are incorporated in the equation (The Golding, 1983) and given below:

$$\frac{\partial E}{\partial t} = -\nabla \cdot (C_g E) - \frac{\partial \{ (C_g \cdot \nabla \theta) E \}}{\partial \theta} + S_{in} + S_{nl} + S_{db} + S_{bot} \quad (1)$$

where, $E(f, \theta, x, t)$ is energy component with frequency, f direction, θ and travelling the distance x in time t . S_{in} = energy input (mainly winds); S_{nl} = redistribution of energy within the wave spectrum due to non-linear interactions; S_{db} = energy loss due to whitecapping and dissipation; S_{bot} = energy loss in shallow water due to bottom interaction and C_g is group velocity.

The details of formulation, computation of source and sink terms, solution for spectral energy etc. are given in Vethamony et al. (1998).

Equation (1) is solved numerically. For a pre-determined time step (Δt), the grid spacing (Δx) is decided by the condition, $\Delta x \geq C_g \Delta t$.

The wave damping or wave growth coefficient σ_1 can be formulated in terms of rain and wave parameters. It is assumed that wave amplitude varies exponentially with time and such a wave field can be defined by the classical linear Airy wave theory as follows:

$$a(t) = a_0 \exp(\sigma_1 t) \quad (2)$$

where amplitude $a(t)$ is related to an initial amplitude a_0 at time $t = 0$. The initial amplitude a_0 represents the wave amplitude predicted by the model in the absence of rain. Based on rain drop density (ρ_s), rain intensity (Q), terminal velocity of rain drops (V_r) and rain angle (α), σ_1 is written as,

$$\sigma_1 = \frac{\rho}{\rho_s} Q k \left[\frac{V_r}{2} \left(\frac{k}{g} \right)^{1/2} \sin \alpha - \frac{3}{2} \right] \quad (3)$$

where ρ = air density, k = wave number. In case of vertical rain ($\alpha=0^\circ$), equation (2) reduces to

$$\sigma_1 = -\frac{3}{2} \frac{\rho}{\rho_s} Q k \quad (4)$$

Substituting the value of σ_1 in equation (2), the variation of wave amplitude at a given point as a function of time is obtained.

3. Results and discussion

For the present study, the region bounded by 0-20°N and 50-90°E is chosen. The region is divided into 2.5°X2.5° square grids in the deep water and 0.5°X0.5° in the shallow water. Each

grid has a freedom in 16 direction bins with an angular resolution of 22.5° . Frequency bands are chosen from 0.03 Hz to 0.32 Hz with an interval of 0.01 Hz. To examine the role of different rain parameters on wave attenuation, the model experiment was conducted with uniform winds.

The values of rainfall intensity, terminal velocity of raindrops and rainfall angle are assumed to be 0.05 m/hr, 9 m/s and 0° respectively for the initial 24 hrs period. The maximum wave height attenuation is found to be 10.5%. When the rainfall intensity is increased to $Q = 0.15$ m/hr, (keeping remaining two parameters the same), the wave attenuation is found to be 28.3%. When the terminal velocity is reduced to $V_r = 5$ m/s, (keeping other two parameters, rainfall intensity and rainfall angle, the same), a net attenuation of 10.5% is observed. When the rainfall angle is assumed slanting, $\alpha = 60^\circ$, (keeping Q and V_r the same), an attenuation of 8.4% is achieved. Among the rain parameters, rain intensity is found to be the major contributor for wave attenuation and this is in agreement with the dynamic interaction theory proposed by Le Mehaute and Khangaonkar.

The effect of rain on ocean surface waves has been further investigated using ECMWF analysed wind fields available for July 1987 (Fig. 1). An active, monsoon prone area in the Arabian Sea bordering $67.5^\circ - 77.5^\circ\text{E}$ and $7.5^\circ - 20^\circ\text{N}$ is considered. The various rain parameters selected for this event are moderate rainfall with terminal velocity 6 ms^{-1} and rain intensity of 100 mmh^{-1} . The rain drop angle striking the water surface is taken from the scaling factor connecting rain angle with wind speed provided

in the WMO Report (1970) and it follows a logarithmic profile. A spline smoothing function relating rain angle and wind speed is provided to the model so that wind at each grid interval takes the corresponding rain angle. The results of numerical experiments show that wave attenuation by rain is maximum for high rain intensity and vertical or near vertical fall.

4. Conclusion

Model run for monsoon season (July 1987) shows considerable wave damping. The results suggest the importance of including rain effect as a source parameter in the energy balance equation itself, which is generally ignored in wave prediction models. Unlike on land, precipitation measurements over the oceans are very scanty. Weather satellites fitted with rain sensors like Tropical Rainfall Measuring Mission (TRMM) of European genesis can further improve the data base related to precipitation measurements over the oceans.

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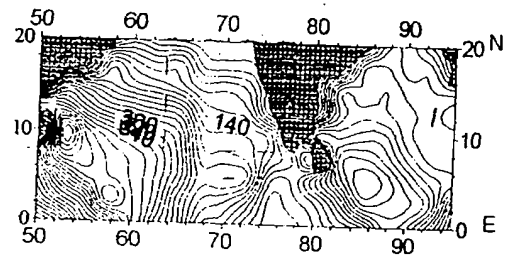
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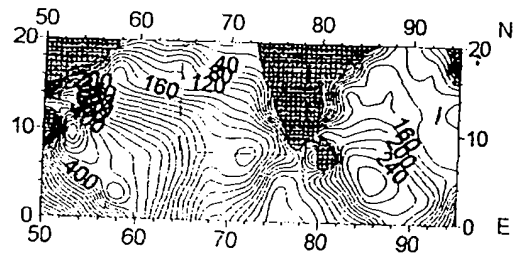
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(a) with rain



(b) without rain

Fig. 1. Significant wave height distribution on 02 July 1987