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Directional Waves Simulated for a Severe Cyclone and a Typical Monsoon Season in the North Indian Ocean

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ABSTRACT

A second generation wave model has been used to simulate waves generated in the north Indian Ocean during (i) an exceptional severe cyclone which occurred in November 1977 and (ii) a typical monsoon month of July 1987. The model has been formulated in terms of source functions using the basic energy balance equation. The cyclone waves are simulated over an area of 1000 km² which includes the location (off Pondicherry), where wave data is available for comparison. The wind input to the model is derived from the isobars using a storm model. The ECMWF analysed winds of July 1987 are used to simulate the monsoon waves. The model results have been found close to the observed wave parameters.

1 INTRODUCTION

The first operational wave prediction technique was used by Sverdrup and Munk[8]. The SWAMP group[9] carried out extensive inter-comparison experiments with various wind-wave prediction models and pointed out the limitation of each model in predicting waves for all kinds of wind fields and extreme situations. The third generation wave model WAM, developed by the WAMDI group[11] is based on physical processes rather than empirical relations and can be used in a global as well as regional domain. Khandekar[4] compiled the state-of-art of the development of wave prediction procedures and their utility for real time operations and applications. Though considerable research effort is put in towards the development of suitable wave models for forecasting, the contribution of each individual term in the energy balance equation is still to be understood.

The Indian Ocean, comprising of the Arabian Sea and the Bay of Bengal, is influenced by the southwest and northeast monsoons. In addition, the Indian seas frequently experience cyclones during monsoons and these persist for a few days. For several ocean engineering purposes, the information on surface waves during monsoons is of prime importance. As in-situ measurements are very expensive, a good model can provide the required wave information for any practical application. With this in view, a coupled discrete wave

model has been used to predict surface waves of the Indian seas.

As a first case, this model has been used to hindcast waves generated during a cyclone which occurred off Pondicherry in the Bay of Bengal during 17-19, November 1977. This particular event was chosen because wind fields for every one hour is available continuously over the specific region (off Pondicherry) and wave data is also available at the above region for comparison. The ECMWF analysed winds of July 1987 (representing southwest monsoon) are used for the prediction of waves during monsoon; the model results are compared with visual observations available in the Indian Daily Weather Report[3].

2 MODEL DESCRIPTION

Evolution of two dimensional ocean wave spectra in the form of energy balance equation can be expressed as

$$dE(f, \theta, x, t) / dt = S(f, \theta, x, t) \quad (1)$$

where $E(f, \theta, x, t)$ is energy component with frequency f , direction θ and travelling the distance x in time t . S describes the sources and sinks by which energy is gained or lost by a spectral component travelling at its group velocity. According to Golding[2] the appropriate expansion of equation (1) is

$$dE/dt = \partial E / \partial t + \nabla \cdot (C_g E) + \partial \{ (C_g \cdot \nabla \theta) E \} / \partial \theta \quad (2)$$

where C_g is the group velocity of spectral component. The group velocity and direction of propagation are time dependent when following a parcel of wave energy in the presence of variable water depth. The middle term on the R.H.S. of equation (2) represents propagation and the last term describes refraction. The R.H.S of equation (1) is expanded as

$$S = S_{in} + S_{nl} + S_{ds} + S_{br} \quad (3)$$

The source term S_{in} represents the energy input from the atmosphere which is mainly due to winds and is always positive. The non-linear wave-wave interaction (S_{nl}) plays a dual role as a source (positive) as well as a sink

(negative) mechanism. The dissipation due to white-capping and wave breaking (S_{db}) is a sink (negative) mechanism. S_{bot} is energy loss in shallow water due to bottom interaction and is a sink (negative) mechanism. Combining equations (2) and (3), the energy balance equation (1) can be rewritten as

$$\partial E / \partial t = -\nabla \cdot (C_g E) - \partial \{ (C_g \nabla \theta) E \} / \partial \theta + S_m + S_{nl} + S_{db} + S_{bot} \quad (4)$$

Equation (4) is solved numerically. Assuming that a wave may reach its fully developed stage during the prediction duration, for a pre-determined time step (Δt), the grid spacing (ΔX) is decided by the condition $\Delta X \geq C_g \Delta t$. The different terms in equation (4), the integration of source terms, the numerical scheme employed and the solution method are outlined in Prasadkumar[6].

3 DATA AND METHODOLOGY

During monsoons, severe storms occur in the Bay of Bengal and the Arabian Sea with strong winds of the order of 100 km/h. These strong winds generate very high waves which are usually not reported by the ships of opportunity, since they avoid voyaging in cyclone zones. By chance, a few observations were sometimes made, and we have one such data point at the cyclone area for comparison with model results. Moreover, analysed or forecast winds over the Arabian Sea or the Bay of Bengal with required grid size and time interval were not available on regular basis during the study period. Therefore, wind fields generated using a storm model for the severe cyclone which occurred over the Bay of Bengal in November 1977[10] were used in the model. For this purpose, the wind field is computed on a grid system with a size of 50 km X 50 km, increasing from the storm centre towards its periphery. The resultant wind field is obtained for the time levels from 0000 hr of 17 November 1977 to 0000 hr of 19 November 1977[Fig.1]. As wind fields should be available continually for a few days at the specified region for hindcast, the region bounded by the locations 14.75°N, 80.5°E ; 10.25°N, 80.5°E and 14.75°N, 84.0°E ; 10.25°N, 84.0°E (wherein the specified location is included), is taken as the common region and wind fields for different time levels are given as input to the model. The deep water grid size is chosen as 2.5° X 2.5°, whereas, it has been reduced to 0.5° X 0.5° in the shallow water.

4 RESULTS AND DISCUSSION

The versatility of the wave model is tested for the waves off Pondicherry (12.2°N, 81.2°E) observed during the above cyclone. This location is approximately 5 km away from the hindcast position. Wind fields are provided at an interval of 6 hours from 17-19 November,

1977 for the common region which includes the location, A[Fig.1]. Winds at the specified location A (off Pondicherry) is shown in Fig.2. The maximum wind speed is \cong 58 kts. A positive trend is observed in the wind speed for the first 24 hours with its peak on 18 November 1977 at 0000 hr, when the storm centre was located approximately 200 km away from the location, A. A rapid downward trend from 24 hour onwards indicates waning of the storm. The corresponding hindcast wave parameters for sea, swell and their resultant for the storm period at the location A are given in Table 1 and Fig. 3. The observed wave height at the hindcast location on 18 November 1977 at 0000 hr was 7.0 m[5] and the corresponding model wave height is 6.9 m (Table 1). The model result is in good agreement with the observed value. The resultant model wave periods also show that the waves are in general swells, as reported by Pant et al[5].

The resultant wave height[Fig.3] shows a linear growth in the beginning (up to first 12 hr) and thereafter an exponential mode of growth, in conjunction with the joint Phillips-Miles growth theory for a growing wind sea. After 20 hrs, 'overshoot' and 'undershoot' mechanisms are noticed. These features strongly adhere to the fact of non-linear wave-wave interaction process and supports the earlier findings of Barnett and Wilkerson[1] and the JONSWAP experiments. The possibility of wave breaking dissipation also cannot be ignored when the fully developed state is approached. At this stage both non-linear wave transfer and wave breaking dissipation jointly control further growth.

The contours as well as perspective plots of spectral energy [Figs. 4 & 5] show the shift of spectral peak from 0.31 Hz at $t = 1$ hr to 0.11Hz at $t = 18$ hr. This rapid shift of the spectral peak focuses the dominating character of non-linear energy transfer mechanism which pumps energy from high frequency part of the spectrum to low frequency. Another noteworthy feature is the directional shift from ≈ 300 to 180° with time upto $t = 24$ hr [Figs. 4 & 5] and concentration of spectral energy in a small region around 180° , resembling an unidirectional spectrum. After the passing of storm (storm approached the location A at 0000hr of 18 November 1977), the spectral peak again shifted towards higher frequencies (from ≈ 0.05 Hz to 0.14 Hz) in the next 24 hrs.

In another case, the model has been run for a typical monsoon month of July 1987 using ECMWF analysed winds; the spatial coverage extends from 0 to 20°N and 50°E to 90°E with 2.5° x 2.5° grid spacing in the deep water and 0.5° x 0.5° spacing in the shallow water. The representative model output for seas, swells and resultant waves are obtained for 03, 10, 17 and 24 July 1987 at 0900 hr [Fig. 6]. These model results are compared with ship observations available during the above period at

0830 hr. The correlation between the observed and model values shows a good comparison.

5 CONCLUSION

A second generation wave model used for the north Indian Ocean successfully reproduced the waves generated during a severe cyclone and monsoon season. The model results clearly explain the features such as wave growth, energy transfer and energy dissipation. The model waves show good comparison with a few available observed wave parameters. This model can be used for regional wave forecasting for the Indian seas on regular basis.

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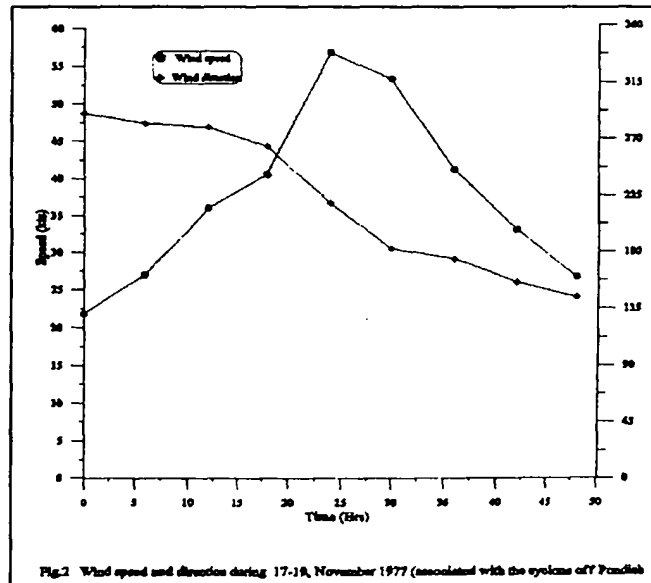
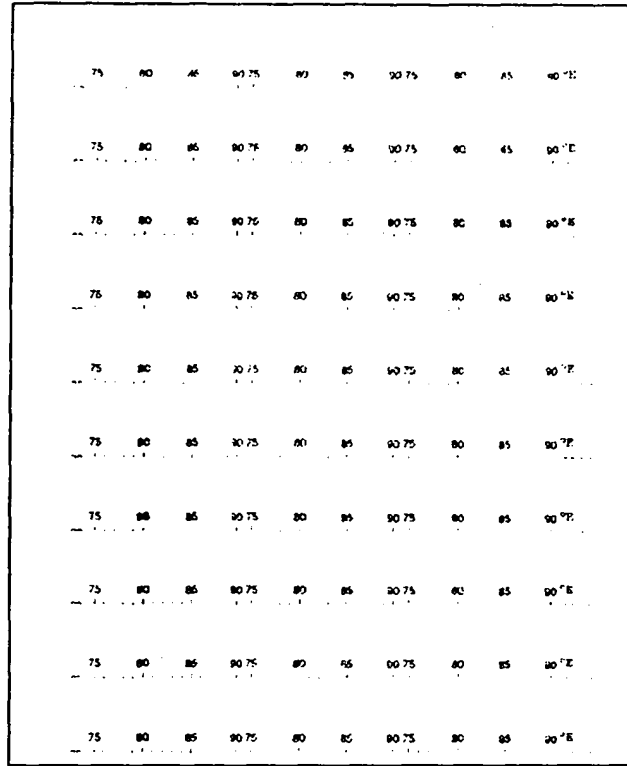
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Table-1 Wave Model results of Bay of Bengal cyclone during 17 - 19 November, 1977 off Pondicherry

Date	Time (hrs)	St. No.	Average			Sea			Swell			Peak Period (s)
			Height (M)	Period (S)	Dir. (°N)	Height (M)	Period (S)	Dir. (°N)	Height (M)	Period (S)	Dir. (°N)	
17Nov1977	0001	1	0.59	3.7	290.5	0.56	2.8	290.0	0.19	4.8	290.5	3.1
"	0006	1	1.64	5.6	290.9	1.58	4.3	291.8	0.42	7.7	291.3	4.3
"	0012	1	2.64	5.2	270.4	2.54	6.0	274.8	0.72	11.1	275.8	5.9
"	0018	1	5.13	7.3	184.4	4.88	8.6	188.5	1.59	16.7	186.6	8.3
18Nov1977	0000	1	7.39	9.0	170.9	6.90*	10.6	165.5	2.64	25.0	184.8	11.1
"	0006	1	10.06	9.9	153.9	8.22	10.4	139.7	5.81	33.3	170.7	16.6
"	0012	1	7.20	8.1	152.8	6.28	8.9	141.0	3.53	33.3	171.5	12.5
"	0018	1	5.28	7.1	147.5	4.29	7.1	141.7	3.08	33.3	157.0	7.7
19Nov1977	0000	1	4.02	6.5	142.4	3.74	7.5	138.9	1.48	33.3	153.0	7.7
"	0006	1	3.16	5.9	138.8	2.88	6.5	135.4	1.32	25.0	143.0	6.4

* corresponding observed value is 7.00m



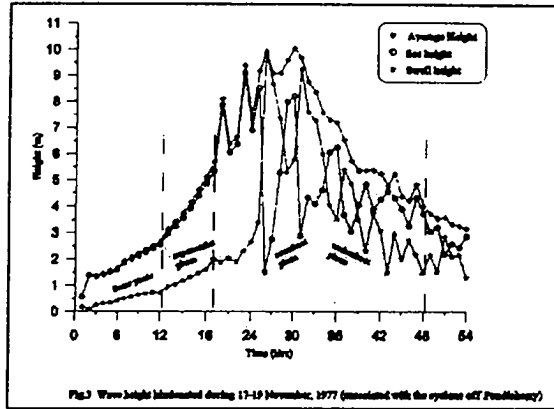


Fig.3 Wave height (m) estimated during 17-19 November, 1977 (associated with the cyclone off Pondicherry)

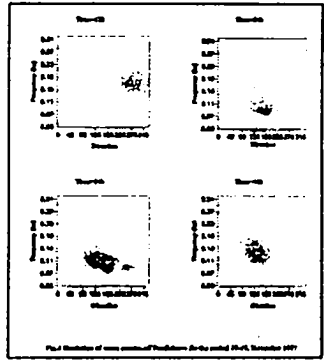


Fig.4 Direction of wind associated with cyclone for the period 08-32, November 1977

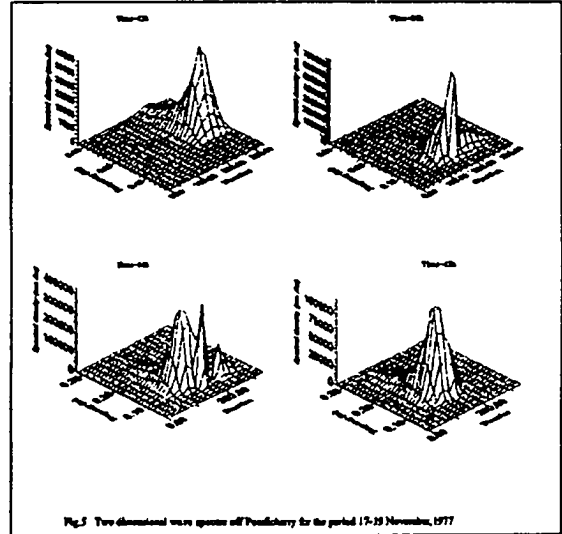


Fig.5 Two dimensional wave spectra off Pondicherry for the period 17-19 November, 1977