A SPECTRAL OCEAN WAVE MODEL

by

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ABSTRACT

An operational wave spectral model has been developed through the cooperative efforts of FLENUMWEACEN, NAVOCEANO and W.J. Pierson. The model contains two subdivisions: 1) wave energy growth based on a modified version of the Miles-Phillips growth mechanism and dissipation at individual grid points and 2) wave energy propagation from grid point to grid point. The energy calculations at each grid point are displayed in a 15 frequency/12 direction matrix. This distribution of wave energy by frequency and direction provides a quantum jump in Navy Weather Service's ability to provide sea surface definition. Evaluation using airborne laser and digitized wave data has been conducted.

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I. INTRODUCTION

On 12 December 1974, the United States Navy Fleet Numerical Weather Central began routine forecasting of the ocean wave spectra for the Northern Hemisphere oceans of the world. The Spectral Ocean Wave Model represents a milestone of significance in the marine forecasting field equal to that of the implementation of primitive equation atmospheric forecast models. Accurate forecasts of ocean waves are essential to improved use of the oceans and improved safety to life and property at sea. In an era when nations are looking more to the sea and their coastlines for food, energy, and bulk transport, accurate environmental assessments of the ocean and their impact on security and economy become more and more important. Some immediate benefits of spectral forecasts are: improve optimum track ship routing services, accurate surf forecasts for those who work or play in the surf zone, and a more precise description of the seas for environmentally sensitive marine engineering ventures such as designing and erecting offshore drilling platforms and pipe lines.

II. METHOD

Spectral ocean wave forecasts are produced by FLENUMWEACEN twice daily to 72 hours using forecast winds derived from the Fleet Numerical Weather Central Primitive

Equation model. Wave forecasts are available to the fleet in the form of radio FAX maps and teletype messages. The 72-hour fields are transmitted by 0830Z, PE12H.

It takes 80 minutes running time using the dedicated resources of 1 computer to produce the spectral wave forecasts.

The Northern Hemisphere Ocean Wave Forecast is the aggregate result of running 4 basin models simultaneously in the FNWC CDC-6500 computer. All of the basin models are identical except for grid. The Open Ocean Forecast Model is computed on an icosahedral gnometric projection. This grid has been positioned so that:

(1) intersections of triangles occur primarily over land.

(2) each triangle segment is primarily ocean area.

The grid spacing for the Open Ocean models varies from 100 nm to 180 nm, depending on grid location. The basic advantage of the icosahedral grid for ocean wave forecasting is that lines connecting grid points are great circles.

The Mediterranean Basin Model differs from the Open Ocean models in that the basin prediction grid is a conic conformal projection with a mesh length of 67 km (40 nm).

III. MODEL

The Ocean Wave Spectral Model is basically that developed over a decade ago by Dr. Willard J. Pierson and his group while at New York University. The operational adaptation of the model is the result of work by Mr. Sheldon Lazanoff of the U.S. Naval Oceanographic Office and by Mr. Norman Stevenson of the Fleet Numerical Weather Central.

The growth technique was originally developed by Inoue in 1967. Inoue combined the Miles instability theory with the Phillips resonance theory such that when the sea begins to grow from calm conditions, the resonance mechanism predominates and later, as the wind velocity begins to increase, the instability mechanism becomes more dominant. The Phillips theory essentially states that a resonance between the air-sea system could occur when a component of the surface pressure distribution moved at the same speed as a free surface wave of the same wave number (where the wave number, K, is equal to $2\pi/L$, and L is the wave length). The Miles instability theory states that the mean rate of energy transferred from the parallel sheer flow to the surface wave is proportional to the curvature of the wind profile at the height where the mean wind velocity is the same as the phase speed of the wave component.

The wave spectra which are computed for the given wind velocity at each time step are not allowed to exceed the Pierson-Moskowitz fully developed spectrum for the same wind velocity. The energy spectrum at each grid point is divided into a 15 frequency by 12 direction (30° increments) matrix. The delineation of the frequency bands is shown in Table 1. The highest frequency, in practice, is limited from 0.164 to 0.40 Hz and the wave energy within this frequency range is not propagated.

The model requires rather elaborate bookkeeping in which a wave train history is continuously updated by a 3-hourly observed wind analysis cycle. Waves are generated by the observed wind input and then propagated across the oceans of the world, grid point by grid point.

The ocean wave forecast then takes the wave energy distribution history established by the analysis cycle and projects it ahead along with new energy inputs from the forecast wind fields.

The wind input for the spectral analyses cycle is produced on a global 2-½ degree Lat/Long grid. It is called the "marine wind" which is the geostrophic wind derived from the analysis sea level pressure fields, and modified to correct for the effects of curvature and stability. This is our approximation to the wind you would observe at sea. For the marine wind analyses, the

Table 1

Central Frequency (H_z)	Central Period (Seconds)	Frequency Bandwidth (H_z)
0.164	6.1	.164 - ∞
0.153	6.5	.142 - .164
0.133	7.5	.125 - .142
0.117	8.6	.108 - .125
0.103	9.7	.097 - .108
0.092	10.9	.086 - .097
0.083	12.0	.080 - .086
0.078	12.9	.075 - .080
0.072	13.8	.069 - .075
0.067	15.0	.064 - .069
0.061	16.4	.058 - .064
0.056	18.0	.053 - .058
0.050	20.0	.047 - .053
0.044	22.5	.042 - .047
0.039	25.7	.036 - .042

resulting field is subjected to a variational analysis to minimize differences between computed and observed marine winds. The wind used to grow waves is assumed to blow at the same speed and direction for the whole 3-hourly analysis or 6-hourly forecast period. At forecast time, the output is from the Planetary Boundary Layer Model.

Accurate specification of wind input is essential to the spectral wave model. For a fully arisen sea, a 5-knot wind error at 25 knots will result in a 5-foot error in specifying the sea height. Therefore, we are becoming more concerned over sources of wind error. The old standards of reporting winds within 5 knots and 10 degrees is no longer adequate for accurate wave specification.

Waves are grown and dissipated at each grid point based on the wind input. The energy of new waves is propagated outward from the generating point through a 180-degree arc centered on the wind direction. The wind also affects wave energy dissipation. Second-order effects such as wave-wave interaction are not accounted for in the model. Once energy has been grown and dissipated at a point, it propagates outward at the wave group velocity appropriate for the wave frequency, where it is accumulated with the energy from other wave trains at adjacent grid points, and again repropagated with time.

The operational Primitive Equation (PE) model computes prognoses every six hours out to 72 hours on a twice-daily basis. Surface wind velocity prognoses are then computed by the Planetary Boundary Layer (PBL) model. As yet there are no statistics available for determining the accuracy of the PBL wind velocity prognoses. It is known that the PE model moves typical weather systems at approximately 82% of the actual speed of the systems because of truncation errors in the second order differencing scheme used in the PE model.

Frictional wind velocities (U_*) are computed from the analyzed or forecasted wind speeds and are the actual input to the wave spectral model growth equation. For a given wind speed, U_* can vary considerably depending on whether stable, neutral or unstable conditions exist. An unstable condition occurs when the underlying sea surface temperature is warmer than the above air temperature. The wave energy growth rate is the highest under unstable conditions. As an example, if winds were measured at 20 meters, a wind speed of about 24 knots would be needed under stable conditions to produce the effective wave generating conditions and 17 knots under unstable conditions. The present operational wave spectral model only calculates U_* for neutral conditions; thus, growth rate errors can exist if stable or unstable conditions actually exist. The greatest errors would occur under stable conditions.

Note that the above example was based on wind measured at 20 meters above the sea surface. The vertical change in wind speed in the marine boundary is considered to have a logarithmic profile from the sea surface to the top of the layer. Stable conditions produce the more significant deviations from the purely logarithmic profile than equivalent unstable conditions do.

The initial growth equation, Phillips Resonance Theory, was derived from winds measured at 6.1 meters while the remainder of the growth equation and the Pierson-Moskowitz fully developed spectra were derived from winds measured at 19.5 meters.

IV. OUTPUT

Considering the number of grid points contained within the area covered by the SOWM, it is evident that it is difficult to select the optimum subsets of information without exceeding the communications limitations of the users. Two basic forms of information have been selected; large-scale depiction of a single sea condition such as significant wave height by means of data fields suitable for plotting and, a complete description of the spectral energy matrix at selected geographic locations. Six basic parameters have been defined and produced in field form suitable for mapping or areal display.

They are:

(1) Significant wave height (HW). This is average of the highest 1/3 of all waves present or $H_{1/3} = 4\sqrt{E_2}$, E_2 is total energy at grid point.

(2) Primary Wave Train (PDW). The center of the directional arc in which the maximum spectral energy occurs.

(3) Primary Wave Train Period (PPW). The center of the wave period band containing maximum energy within the primary direction band.

(4) Secondary Wave Train Direction (SDW). The center of the directional arc containing the next highest wave energy total, if this total is at least 20% of the primary directional total and is separated from the PDW by a relative minimum in the energy versus direction curve. If no computed directional arc fits these criteria, then the SDW is the same as PDW, <u>if</u> a secondary period exists as described in (5) below.

(5) Secondary Wave Train Period (SPW). If SDW exists as a different direction from PDW, then SPW is found as is PPW in (3). If SDW does not exist as a separate direction, then SPW is the center period of the band containing maximum energy outside the PPW, providing it is separated from PPW by a relative minimum and contains at least 20% of the energy within the PPW band. If neither of the above criteria are met for the SPW and SDW, then both are considered non-existent.

(6) Whitecap Coverage (WTCPS). The whitecap function represents the percentage of sea surface covered by whitecaps. It is obtained by an algorithm which considers the interaction between propagated wave energy and newly generated wave energy.

Wave spectrum messages are created from preselected points and transmitted over the communications lines as shown below.

031500 POSITION LAT 35.88N LON 170.97W VALID 00Z 15 MAR 74

	DIR - FROM -								
PERIOD	121	61	31	301	271	241	211	181	151
6.1	0	0	0	0	18	41	43	21	4
6.5	0	0	0	0	19	17	18	8	1
7.5	0	0	0	0	22	13	12	5	0
8.6	0	1	2	0	28	0	0	0	0
9.7	0	4	5	5	19	0	0	0	0
10.9	0	9	18	54	22	0	0	0	0
12.0	0	17	11	1	2	0	0	0	0
12.9	0	14	34	3	2	0	0	0	0
13.8	0	13	23	5	1	0	0	0	0
15.0	0	6	52	14	0	0	0	0	0
16.4	0	0	5	4	0	0	4	0	0

SIG HT 10.22 FT

V. FUTURE IMPROVEMENTS

The initial thrust to improve the present operational model will be slanted towards improving the wind input. Forecast wind fields will be output every three hours rather than the present six hours so that the wind input can coincide with the basic time step of the wave spectral model. Investigations have determined that the Cardone Planetary Boundary Layer Model will produce wind fields better suited for use as input to the spectral model than the existing

FNWC wind analyses and prognoses. This improvement will be added on 10 September 1975.

Another modification that would significantly improve the wave spectral model is to increase the number of direction bands used to define the directional spectra from the present 12 bands (30° increments) to 24 bands (15° increments). This would better define the travel path of the wave energy over long distances. Unfortunately, doubling the number of direction bands would also double the amount of computer storage and computation time needed to operate the computer model. Computation time and storage are not presently available for this improvement.

Next generation environmental satellites promise wind and/or spectral wave information which will permit finer resolution analyses as well as extending the coverage into the Southern Hemisphere. Again, the problem here will be the availability of computer processing capability.

Much more needs to be done with output format and applications. For example: we need to create a field of "seas," probably on the basis of wave steepness, we need ship response curves for directional wave spectra and we need shallow water wave models to shoal and refract the energy. Of special interest to this group is the problem of correlation of the spectral energy with ambient noise in the ocean.

VI. CONCLUSION

The operational icosahedral-gnomonic Spectral Ocean Wave Model (SOWM) is a product superior to the FNWC singular wave model, the previous operational model. The singular wave model was limited from growing waves greater than 44 feet and could not adequately describe complex wave conditions. The SOWM considers the total wave energy in a 15-frequency band by 12 direction bands matrix in a grid point and propagates the energy throughout the grid system as a function of frequency and direction. Knowledge of the distribution of the wave energy as a function of frequency and direction over the ocean will permit our forces to take greater advantage of the environment in operations at sea.