CHAPTER 28

Wind Specification for Spectral Ocean-Wave Models

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Abstract

This paper investigates the utility of winds obtainable from a numerical weather prediction model for driving a spectral ocean-wave model in an operational mode. Wind inputs for two operational spectral wave models were analyzed with respect to observed winds at three locations in the Canadian east coast offshore. Also, significant wave heights obtainable from the two spectral models were evaluated against measured wave data at these locations. Based on this analysis, the importance of appropriate wind specification for operational wave analysis and forecasting is demonstrated.

Introduction

Spectral ocean-wave models based on the energy balance equation are used operationally in many areas of the world oceans at present. The spectral models are capable of providing a detailed description of the sea-state in terms of a two-dimensional (frequency-direction) wave spectrum at a given location. For real-time operations, a spectral wave model utilizes winds which are generally extracted from an operational weather prediction model.

In this study, two operational spectral wave models are chosen for which wind inputs were analyzed with respect to observed winds at three selected locations in the Canadian Atlantic ocean; also, wave products from these models were evaluated against the observed wave data at these locations. Two sets of observed wind and wave data were utilized to evaluate the model products. Based on this evaluation, the importance of appropriate wind specification for operational wave analysis and forecasting is demonstrated.

Details of Models

The two wave models used in this study are the SOWM (Spectral Ocean Wave Model) of the U.S. Navy (see Pierson, 1982) and the ODGP (Ocean Data Gathering Program) model developed by Cardone et al (1974). The SOWM is a hemispheric model which provides operational wave forecasts for the three ocean basins of the northern hemisphere; the SOWM grid is designed on a gnomonic icosahedral projection with 325 grid points in each equilateral triangle and about 1575 ocean points over the

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northern hemisphere. The ODGP model has a nested grid (see Figure 1) and operates over the western north Atlantic ocean with a finer grid spacing than the SOWM in deep water and half of that spacing over the continental shelf region. The ODGP model uses 24 direction bands (as against 12 used in the SOWM) while both the models use 15 frequency bands. The governing equation for both models can be expressed as

$$\frac{\partial}{\partial t} E\ (f,\ \theta,\ \overline{x},\ t) + C_g . \nabla\ E = (A+BE)\ (1-E/E_{PM}) \qquad (1)$$

Here E is the energy density of the wave field described as a function of frequency f, direction θ, position $\overline{x}$ and time t; C_g is the group velocity of the wave in deep water, A and B are the linear and the exponential growth terms and E_{PM} is the Pierson-Moskowitz (1964) spectrum for a fully developed sea at a given wind speed. The Pierson-Moskowitz spectrum plays an important part in modelling the transition from a growing sea to a fully developed sea. Both the models use an empirically developed dissipation term which attenuates those frequency components travelling against the winds while the nonlinear wave-wave interaction term is neglected in both the models.

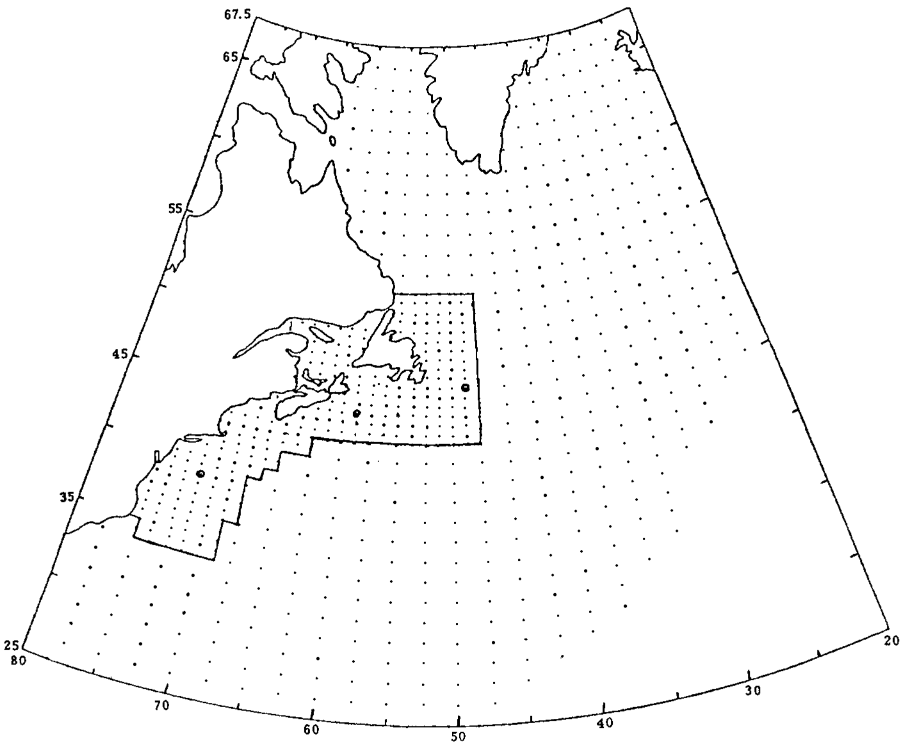

Figure 1: The operational ODGP model grid. The coarse grid has a spacing of 1.25° latitude by 2.50° longitude. The nested fine grid has half the spacing. Three circled grid points are the locations for wave model evaluation.

In SOWM, the terms A and B are modeled following the studies of Phillips (1957) and Miles (1957). The ODGP model uses an improved formulation of the term, A, following the studies of Inoye (1967) and Snyder and Cox (1966). Further, in the ODGP model, the growth algorithm was modified to allow for rapidly turning winds and the dissipation of bands travelling crosswinds was suppressed, so that at any time step no angular band is eligible for both growth and dissipation. Thus, the ODGP model has better spatial and spectral resolution and uses an improved growth algorithm than the SOWM.

Wind Input

The SOWM uses winds generated by the U.S. Navy's operational weather prediction model at Monterey, California. This operational weather prediction model is a global multi-level model which has a coupled boundary layer model where the influence of atmospheric stability is incorporated. The model generates analysis and forecast winds at 19.5m level which are then utilized to drive the SOWM; more details of the U.S. Navy's weather prediction model can be found in Mihok and Kaitala (1976).

For the ODGP model, the analysis winds are derived from the six-hourly north Atlantic surface charts prepared at the National Meteorological Centre (NMC) in Washington, D.C. (U.S.A.); these charts are reanalyzed based on latest ship weather reports and then digitized. A boundary layer model developed by Cardone (1969, 1978) is applied to generate effective neutral winds at 20m level above the ocean surface. According to Cardone (1969), a 20m-level wind speed of 24 knots under stable atmospheric conditions (air temperature warmer than water temperature) has the same effective wave generating ability as that of a 19-knot wind in neutral conditions and that of a 17-knot wind in unstable conditions (air temperature cooler than water temperature). Cardone's boundary layer model takes into account the (air-water) temperature difference at a given location and generates effective neutral winds at 20m level for driving the ODGP model. The forecast winds for the ODGP model are based on subjectively adjusted surface prognostic charts from the LFM (Limited-area Fine Mesh) model at NMC Washington; this 'man-machine mix' appears to provide an improved wind specification for the ODGP model.

Data

Two sets of wind and wave data measured at selected locations in the Canadian east coast offshore were used to evaluate the model products. The first set of data consisted of four storm events ranging from 3 to 5 days and selected from the historical weather charts dated 1 October 1983 to 31 March 1984. The movement of these storms off the Canadian coast is shown by the storm tracks in Figure 2. Each track shows the movement of the storm centre over the 2-day period which is marked on the tracks. Figure 2 also shows the three sites at which the model products were evaluated. Site 1 is near the NOAA buoy 44004 which is operated by the National Oceanic and Atmospheric Administration (NOAA), Washington. Sites 2 and 3 are near some of the oil rigs (Glooscap, Alma, Terra Nova) operated by various

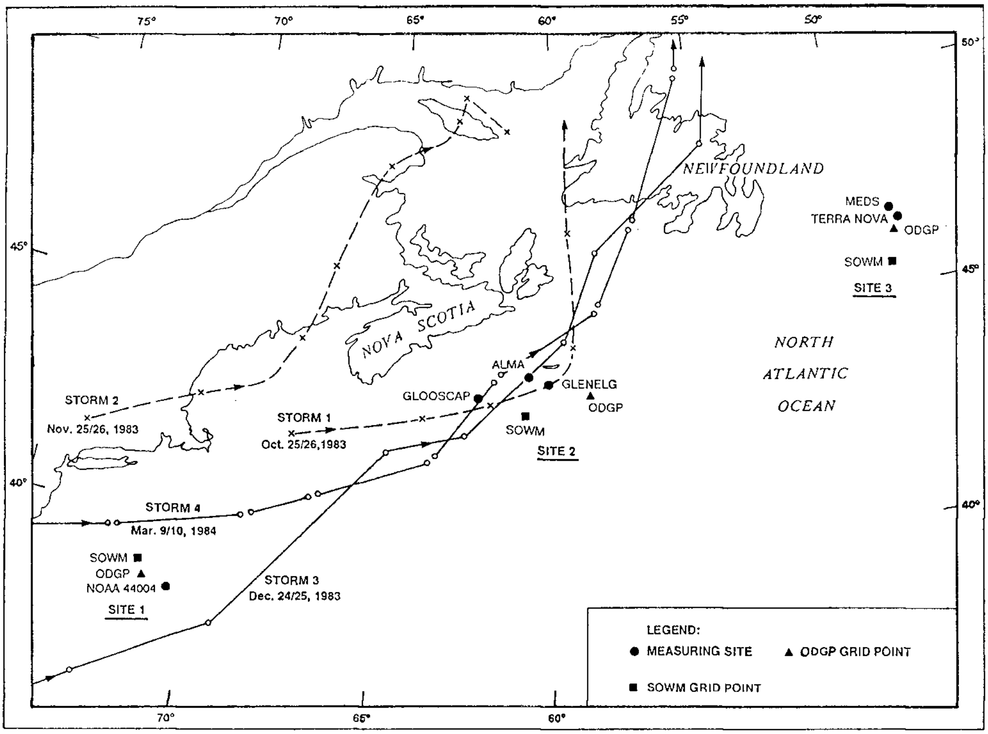

Figure 2: Locations of three sites and tracks of four storms selected for model evaluation.

oil companies. The wind and wave products generated by the two models (the SOWM and the ODGP) were evaluated for the four storm events.

The second set of data covered a two-month period from 15 January to 15 March, 1986; this was the period of a field project for the Canadian Atlantic Storms Program (CASP) during which a large amount of meteorological and oceanographic data was collected to study the evolution of winter storms that affect the Canadian Atlantic provinces. During the CASP field project, the ODGP model was run in an operational mode using two different wind inputs. One wind input was the operational wind field based on the man-machine mix as described above. The second wind input was provided by the weather prediction model of the Canadian Meteorological Centre (CMC) in Montreal. The CMC winds were extracted at the 0.998 sigma-level which corresponds to about 17m above the ocean surface in a standard atmosphere. The CMC winds were interpolated at the ODGP grid and were used without any modification, to drive the ODGP model. The CMC weather prediction model incorporates a surface turbulent flux formulation (Delage, 1985) so as to include the effect of atmospheric stability on wind variation in the vertical.

Results and Discussion

The results of the model evaluation using the first set of data are presented in Figure 3 and Table 1. Figure 3 shows a sample wind and wave plot for storm 2 covering a period November 25-30, 1983. At site 1 (in Figure 3), the maximum wind speed of 38 knots was recorded at about 18GMT, 25 November, whereas the maximum significant wave height of 9m was recorded 12 hours later at about 06GMT, 26 November. At site 2 (on the Scotian Shelf), the storm produced maximum wind and wave heights during 26 and 27 November. As the storm moved north-eastward, it produced a maximum wind speed of 48 knots at site 3 (off Newfoundland) on 29 November (00GMT) and a maximum wave height of 8.5m about six hours later. An examination of the model plots shows that both the SOWM and the ODGP models produce similar wind speeds during the storm period; however, the ODGP model produces wave heights which agree more closely with observed wave heights than to SOWM wave heights. For a quantitative evaluation of the model products, a statistical analysis of the errors (model value-observed value) at all

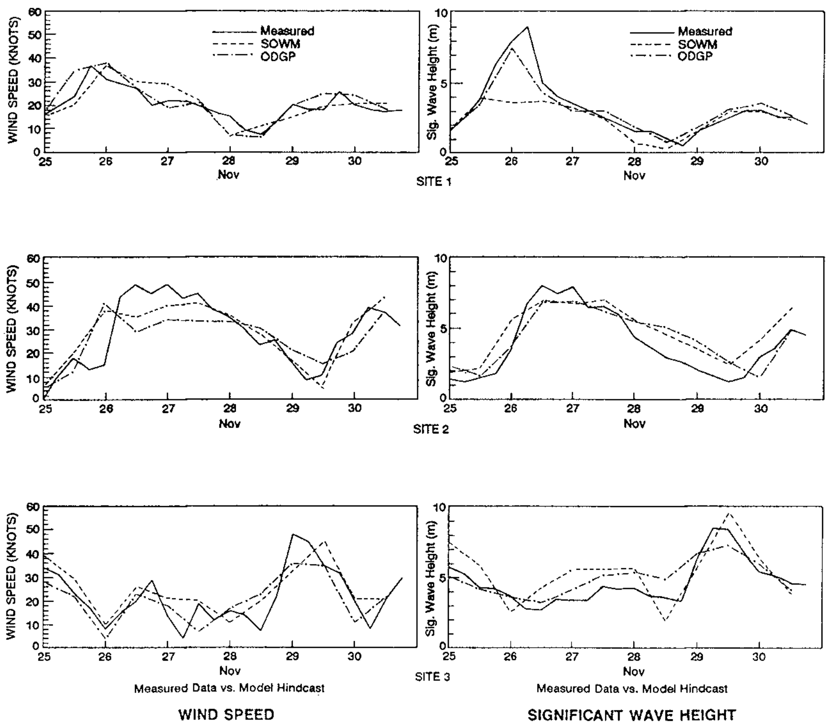

Figure 3: A sample plot showing variation of wind speed and significant wave height at three sites during the storm period November 25-30, 1983.

sites and for all 4 storm periods was made and Table 1 shows the Root Mean Square Error (RMSE) and the Mean Error (ME) together with values of the Scatter Index (SI) and the linear correlation coefficient (r) between model and observed values. The error statistics are prepared for hindcast (zero-hour forecast) products as well as for 24- and 48-hour forecast products. The results of this Table strongly suggest that the ODGP model performs better than the SOWM in a hindcast as well as in a forecast mode.

The results of the model evaluation using the CASP data set are presented in Figures 4 and 5 and in Table 2. The ODGP model was run in an operational mode during the CASP field project using the CMC winds as well as the 'man-machine mix' operational winds and the two products were designated as ODGP-CMC and ODGP-OPR respectively. In

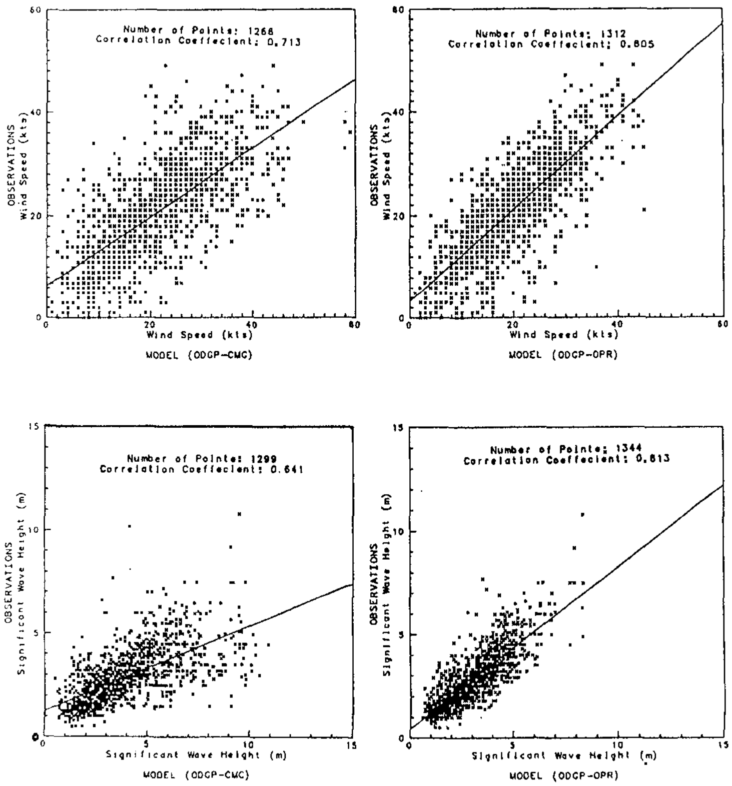

Figure 4: Scatter diagrams between observed versus model wind speed and significant wave height at all sites during the CASP field project 15 January - 15 March, 1986. The regression lines between observed and model values are also shown.

Figure 4 are shown scatter diagrams between model and observed values of wind speed and significant wave heights at analysis time (zero-hour forecasts). The data set covered the two-month period (15 January - 15 March, 1986) of the CASP field project and all three sites were included with two locations assigned to each site. The wind and wave

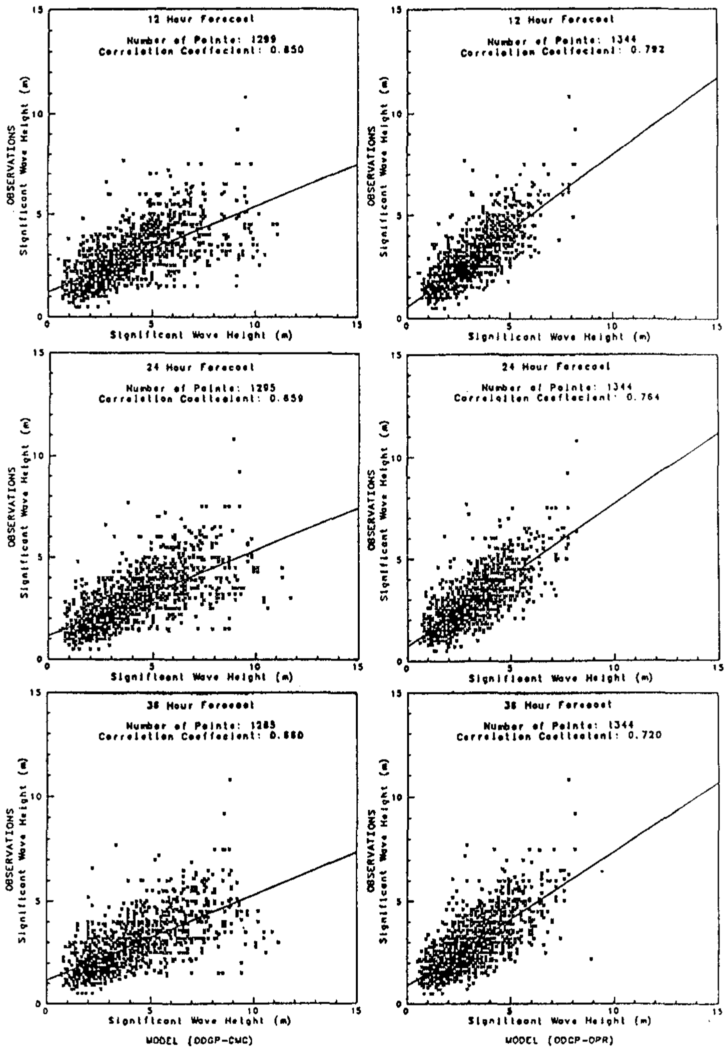

Figure 5: Scatter diagrams between observed versus model significant wave height, at 12-, 24- and 36-hour forecast times. Left: wave heights from model ODGP-CMC; Right: wave heights from model ODGP-OPR.

data were evaluated at four standard meteorological times (00, 06, 12 and 18GMT) during each day of the CASP field project; this provided a sample of 1300 or more data points (excluding missing values) for model validation. The scatter diagrams of Figure 4 suggest that at analysis time, the man-machine mix or the 'OPR' winds provide a slightly better diagnosis of winds when compared with observations at the three sites; this is also indicated by a higher value of the linear correlation coefficient between model and observed wind speeds. The scatter diagrams for significant wave height at analysis time shows that the ODCP-OPR provides significantly better values than those provided by ODGP-CMC. Figure 5 shows the scatter diagrams between model and forecast wave heights at 12-, 24- and 36-hour forecast times. In general, wave heights obtained using OPR winds provide less scatter and higher correlation coefficients with corresponding observed values than those generated using CMC winds. For a quantitative evaluation of the wind and wave products, various error statistics were calculated and these are presented in Table 2. An examination of the wind speed statistics shows that the Mean Error (ME) of the OPR winds has been significantly reduced, most certainly due to the man-machine mix procedure; this, in turn produces smaller RMSE (Root Mean Square Error) for the wind speed and consequently smaller RMSE for the wave height in analysis as well as in forecasting mode.

These error statistics, however, do not provide any information about the spatial differences in the wind fields generated by two different wind models. In order to get an appreciation of these differences, Figures 6 and 7 are presented which show a comparison of wind fields generated by the CMC and the OPR (man-machine mix) models for 16 February 1986. Both the wind fields (in Figures 6A and 6B) refer to the 00GMT analysis time while in Figure 7 are shown differences in the two wind fields obtained by subtracting the OPR wind field from the CMC wind field. The vector at each point in Figure 7 represents the difference in the wind direction while the number at the end of the vector represents the difference in wind speed. A vector parallel to the latitude lines indicates no difference in wind direction between the two wind fields. A positive number indicates that the CMC wind speed is greater than the corresponding OPR wind speed. These three Figures (namely six, seven and eight) show clearly the spatial differences in the two wind fields, particularly in the vicinity of the low pressure centre southwest of Newfoundland where the differences in wind speed and wind direction can be as large as 20 knots and 45 degrees respectively. Furthermore, it can be seen that the CMC weather prediction model in general produces surface marine winds with a definite positive bias when compared against the corresponding ODCP winds; this positive bias appears to produce larger Root Mean Square Error and Scatter Index for ODCP-CMC wave heights as shown in Table 2.

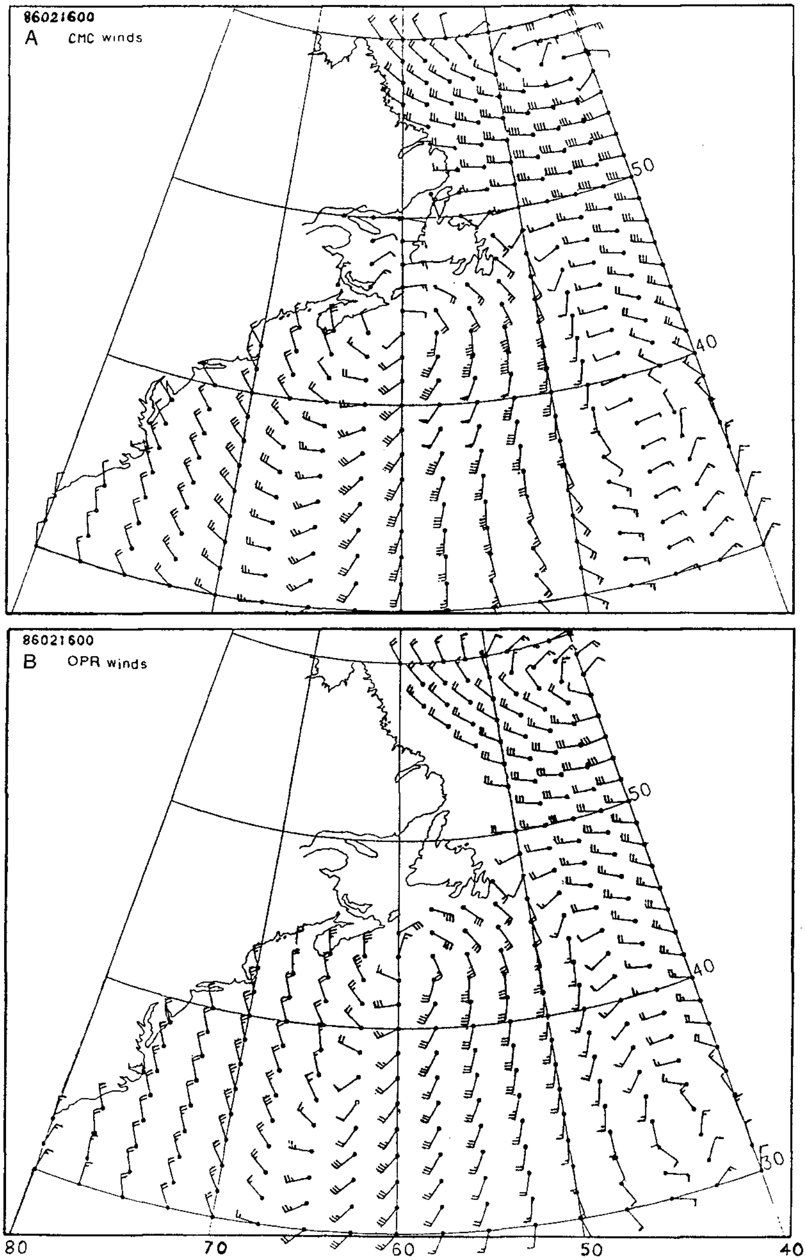

Figure 6: North Atlantic surface wind field, 16 February 1986, 00GMT.
A: CMC Model; B: OPR 'Man-Machine Mix' model.

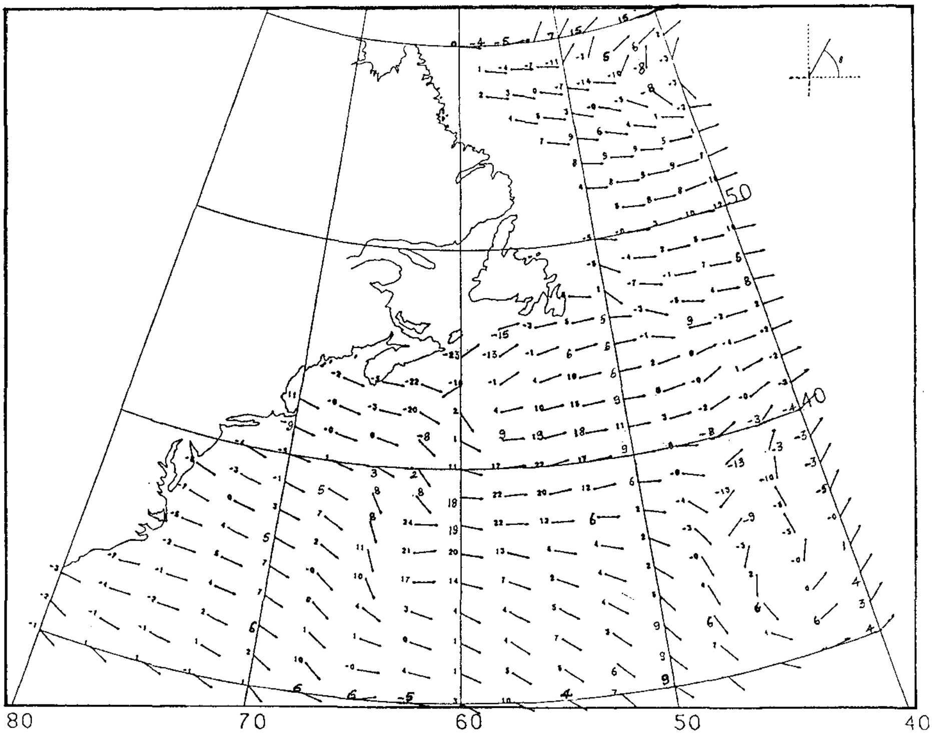

Figure 7: Scalar and vector differences between CMC and OPR wind fields. The vector represents the difference in wind direction (see inset), while the number indicates the difference in wind speed between the two wind fields.

Concluding remarks

The results presented here demonstrate the usefulness of accurate wind specification for driving an operational wave model. The man-machine mix procedure used in the operational running of the ODGP model generates winds which are superior to those produced either by the U.S. Navy's wind model or by the CMC wind model. Furthermore, the study demonstrates the need to adjust the CMC winds for application to a spectral ocean-wave model.

Acknowledgements

The evaluation of the SOWM and the ODGP was done by the MacLaren Plansearch Ltd., Halifax, on contract from the Meteorological Services Research Branch of the Atmospheric Environment Service, Downsview, Ontario. The authors are grateful to Dr. Vincent Cardone, of Ocean-weather Inc. Cos Cob, Connecticut (U.S.A.) for his valuable input in preparation of the paper. This project was supported by the Canadian Government Panel on Energy Research and Development.

TABLE 1

SUMMARY OF ERROR STATISTICS FOR SOWM AND ODGP MODELS AT ALL SITES
(Four storm cases as shown in Figure 2)

	Parameter	WIND SPEED (Knots) Forecast Time 00 hr	24	48	WAVE HEIGHT (Metres) Forecast Time 00 hr	24	48
SOWM	RMSE	11.0	13.8	14.4	1.72	2.25	2.15
	SI	53	67	68	48	63	60
	ME	4.4	5.2	4.3	0.69	0.69	0.66
	r	0.58	0.36	0.17	0.64	0.34	0.38
	n	106	103	102	133	129	127
ODGP	RMSE	10.3	11.8	12.3	1.22	1.67	1.57
	SI	50	57	59	35	47	44
	ME	2.4	5.0	4.1	0.45	0.68	0.42
	r	0.57	0.52	0.34	0.77	0.61	0.55
	n	127	127	127	158	158	158

RMSE: Root Mean Square Error

SI: Scatter Index = $\frac{\text{RMSE}}{\text{Mean Observed Value}} \times 100$

ME: Mean Error;

r: linear correlation coefficient between model and observed values

n: Number of observations

TABLE 2

ODGP-CMC vs. ODGP-OPR; SUMMARY OF ERROR STATISTICS
(CASP data, 15 January - 15 March, 1986)

	Parameter	WIND SPEED (Knots) Forecast Time 00 hr	24	48	WAVE HEIGHT (Metres) Forecast Time 00 hr	24	48
ODGP-CMC	RMSE	7.6	8.5	9.7	1.9	2.0	2.0
	SI	36	41	47	65	69	70
	ME	0.9	2.5	2.9	1.0	1.2	1.2
	r	0.71	0.67	0.56	0.64	0.66	0.64
	n	1268	1268	1228	1299	1295	1275
ODGP-OPR	RMSE	5.9	7.9	9.3	0.8	1.0	1.1
	SI	28	38	44	30	34	37
	ME	-1.3	-0.5	-1.1	0.2	0.2	0.1
	r	0.81	0.62	0.48	0.81	0.76	0.69
	n	1312	1312	1312	1344	1344	1344

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