

THE NOAA OCEAN WAVE MODEL HINDCAST FOR LEWEX

Directional wave spectra from the National Oceanic and Atmospheric Administration (NOAA) model hindcast during the Labrador Sea Extreme Waves Experiment are discussed in detail. The hindcast significant wave heights and spectra are found to be in reasonable agreement with the available estimates from two moored buoys. The NOAA spectra exhibit more energy at high frequencies than other models, possibly because of the lack of a proper dissipation term for whitecapping.

INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) global ocean wave model has been operating at the National Meteorological Center since late 1985. It is a second-generation model with the source terms, directional relaxation, and propagation scheme of Cardone's SAIL II model.¹ A swell attenuation term similar to that in the Ocean Data Gathering Project (ODGP) model and the U.S. Navy Global Spectral Ocean Wave Model (GSOWM) was added in September 1988 because the operational forecasts produced by the original model showed that it was retaining an excessive amount of energy in the swell portion of the spectrum.

The NOAA model provides forecasts of the directional wave spectra up to 72 h in the future at 3-h intervals over a $2.5^\circ \times 2.5^\circ$ latitude/longitude grid. Directional spectra are computed in fifteen frequency bands of variable width, with the first band centered at 0.03889 Hz and the last at 0.30833 Hz, and twenty-four directional bands of equal width. Wave growth is limited by the Pierson-Moskowitz (PM) fully developed spectrum corresponding to the input wind speed with Mitsuyasu's directional spreading function.²

The operational NOAA model, with the swell attenuation term included and no changes in time step or grid resolution, was used for the Labrador Sea Extreme Waves Experiment (LEWEX) hindcasts. As described by Cardone elsewhere in this volume, LEWEX winds were generated using a subjective blend of all available ship and buoy reports. These winds were provided at 2-h intervals on a $2.5^\circ \times 2.5^\circ$ latitude/longitude grid over the region of interest. Hindcasts were done over this enclosed region with the winds interpolated to the model 3-h time steps.

The NOAA wave model started from a flat sea on 9 March 1987 at 1200 UT. Hindcasts starting 72 h later, from 12 March at 1200 UT, were compared with the available data from a Norwegian Wavescan buoy (see Krogstad, this volume) at the location of HNLMS *Tydeman* (50°N , 45°W), and a Canadian-deployed Wavec buoy (see Keeley, this volume) at the CFAV *Quest* lo-

cation (50°N , 47.5°W). Each ship was located at a NOAA model grid point.

SIGNIFICANT WAVE HEIGHT

Figures 1 and 2 give the time histories of analyzed wind speed and direction, and hindcast and observed significant wave height H_s at the *Tydeman* and *Quest*, respectively.

In general, the hindcast made at the *Tydeman* agrees better with the Wavescan buoy estimates than the one at the *Quest* agrees with the Wavec buoy. On 15 March, the wind speed at the *Quest* increased from approximately 2 m/s to about 10 m/s and then decreased rapidly, while the wind direction also changed rapidly. The buoy H_s decreased substantially during the second half of 15 March and into 16 March, while the model H_s decreased only during the first half of 15 March and then remained relatively constant. On 16 March, the wind speed at the *Quest* increased from about 4.5 m/s to more than 14 m/s while turning by almost 90° . Although the buoy H_s increased sharply during this time, the model H_s remained almost constant, suggesting a need for improving the directional relaxation mechanism in the model.

During 18 March, the measured wind direction was relatively constant toward the north, while the wind speed decreased. Meanwhile, the buoy H_s decreased more rapidly and to lower values than those of the model, suggesting an insufficient dissipation term in the model.

DIRECTIONAL SPECTRA AT THE *TYDEMAN*

Buoy data were not available at the *Tydeman* until 14 March at 0600 UT. Selected directional spectra from the model and the buoy are shown in Figure 3.

In Figure 3A, the sea toward the north in the model spectrum is still developing, with a peak period of 9.7 s, in fair agreement with the Wavescan buoy (Fig. 3B). The

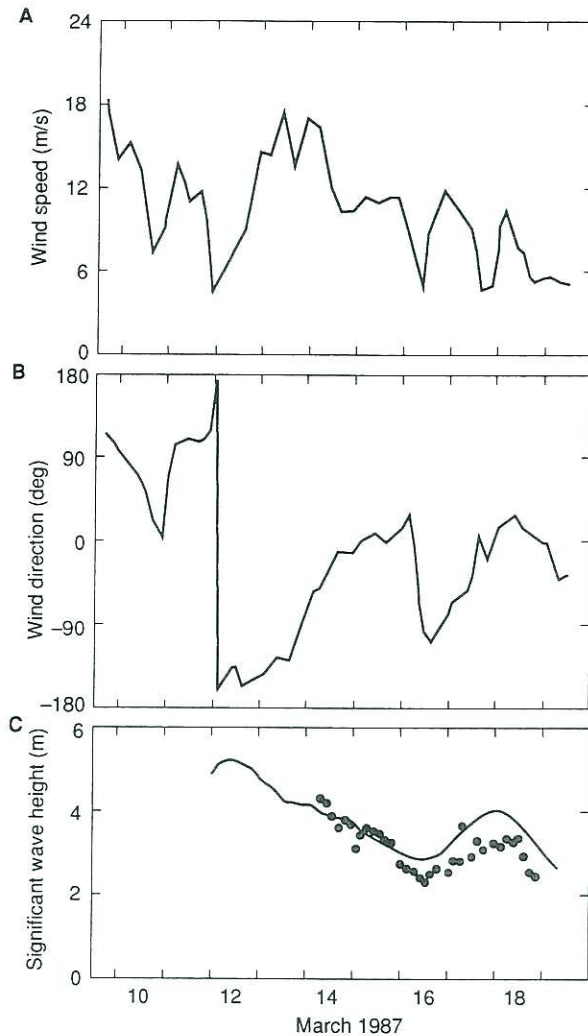


Figure 1. Time histories at the *Tydeman* from 9 March through 19 March. **A.** Wind speed. **B.** Wind direction. **C.** Significant wave height. A and B are LEWEX common winds; C is the NOAA model significant wave height hindcast (solid line) compared to Wavescan buoy measurements (solid dots). Wind directions are positive clockwise from north.

buoy shows an energetic system traveling toward the west-southwest, but this system is absent in the model. In contrast, the model shows a wave system to the south-southeast. This wave system can be traced back to swell from the Labrador Sea and was present in the model spectra since 12 March at 1200 UT.

This south-southeast-traveling swell was generated by strong winds over the Labrador Sea. Although these winds had turned toward the east, a wind toward the south-southeast at the 55°N, 50°W grid point contributed to the swell at the *Tydeman*. The long swell was traveling faster than the wind, with no attenuation in the model until the waves were propagating more than 90° from the local wind direction.

The development of the sea toward the north in the model is consistent with the hindcast winds at the *Tydeman* producing a nearly fully developed PM spectrum. Figures 1A and 1B show that the wind speed at the *Tyde-*

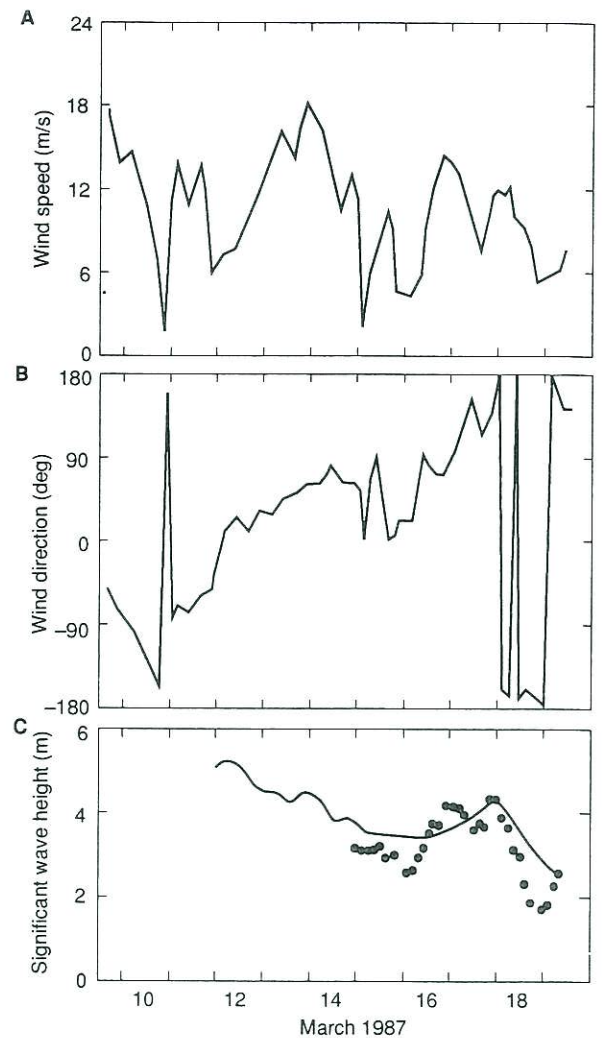


Figure 2. Same as Figure 1, but at the *Quest*. **C.** Solid dots indicate Wavescan buoy measurements.

man during 12 March increased monotonically from less than 6 m/s to less than 14 m/s, with constant direction. On 13 March, the wind speed remained steady at about 15 m/s but began to turn clockwise. The peak period for a fully developed PM spectrum generated by a constant 15-m/s wind is 10.9 s, in fair agreement with the peak period of 9.7 s shown by the model at 0600 UT on 14 March, when the wind speed began to decrease. During 14 March, the local wind continued turning clockwise but decreased in speed to 10.5 m/s at 1200 UT and remained relatively constant through 15 March.

The winds in the Labrador Sea and Davis Strait ceased blowing toward the southeast at 1500 UT on 12 March, decreased, and became intermittent. From 1200 UT, however, weak winds toward the southeast existed in the northern Labrador Sea, and they increased in intensity and extent well into 15 March. On 15 March at 1200 UT, a new Labrador swell arrived at the *Tydeman* with a phase speed of 15.2 m/s, consistent with a travel distance of about 650 km in 24 h. Even 6 h later, however, when this new swell was well established in the model

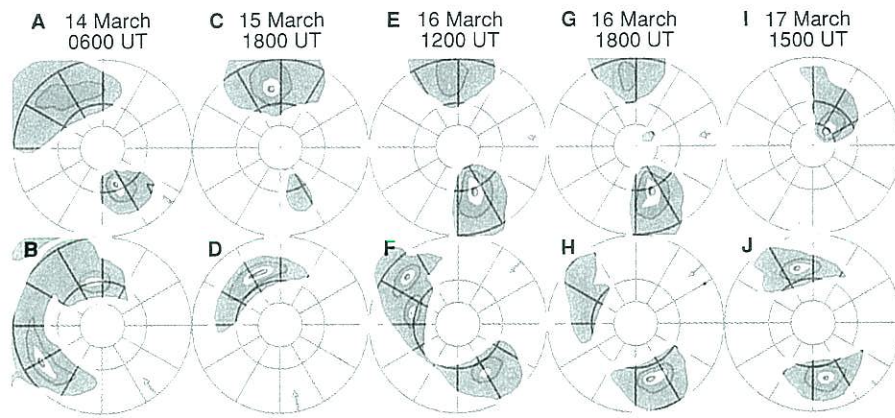


Figure 3. Normalized wave number spectral intercomparisons at the *Tydemman*. Top row: NOAA hindcast using LEWEX common winds. Bottom row: simultaneous estimates from Norwegian-deployed Wavescan buoy. Spectra are linear in wave number; outer circle is $2\pi/100$ rad/m. The arrows indicate wind direction and magnitude. All spectra are shown in the direction of propagation, with north toward the top.

(Fig. 3C), the buoy spectrum (Fig. 3D) showed no signs of it, although the buoy did show a system to the north-northwest with substantial angular spreading. It is not clear whether this discrepancy is from shortcomings in the model or in the LEWEX common wind field. It should be noted, however, that no measurements of surface winds were available in the Labrador Sea to guide the common wind estimates (see Cardone, this volume).

By 1200 UT on 16 March, the new swell to the south-southeast had become quite energetic in the model spectrum (Fig. 3E). The buoy spectrum (Fig. 3F), while not in good agreement, showed two strong systems. The new swell became the dominant peak in the model spectrum at 1800 UT on 16 March (Fig. 3G), with a wavelength at the peak of approximately 148 m, in good agreement with the swell toward the southeast in the buoy spectrum (Fig. 3H).

The 1800 UT model spectrum on 16 March also shows the arrival at the *Tydemman* of a very long (500-m wavelength) swell toward the northeast, generated by a strong wind system well to the south-southwest. The Wavescan buoy spectrum does not show this swell until 1800 UT on 17 March, fully 24 h later than the model. As Cardone (this volume) and Gerling (this volume) discuss, this timing problem may be caused at least in part by errors in the LEWEX common winds.

With the local wind decreasing and turning from nearly west toward the northeast, the swell to the northeast becomes sea, and by 1500 UT on 17 March (Fig. 3I), it is the only wave system shown in the model. The buoy (Fig. 3J) continues to show a southerly propagating system.

DIRECTIONAL SPECTRA AT THE *QUEST*

Wave buoy spectra were available at the *Quest* starting at 0000 UT on 15 March. Selected NOAA model and buoy spectra are shown in Figure 4. At 0000 UT the model (Fig. 4A) shows a sea to the southwest and a swell to the northwest. The buoy spectrum (Fig. 4B) shows swell only to the north. During the latter part of 15 March, the NOAA model turned the wind sea (wind-driven sea) counterclockwise following the wind, and the wind sea coalesced with the existing swell toward the south. Both model and buoy retained the swell to the

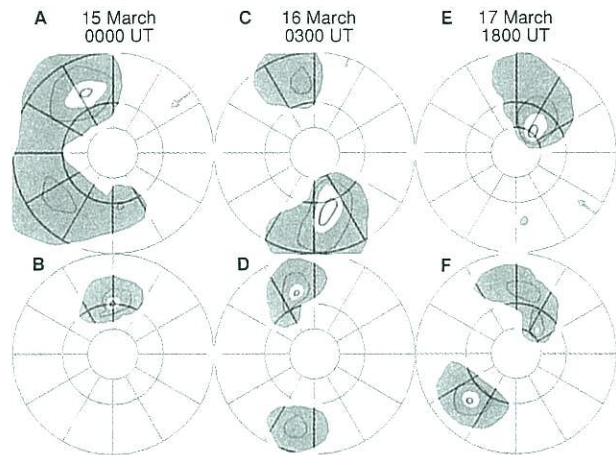


Figure 4. Normalized wave number spectral intercomparisons at the *Quest*. Top row: NOAA hindcast using LEWEX common winds. Bottom row: Canadian-deployed Wavec buoy. See Figure 3 caption for more details.

north during 15 March and most of 16 March. Early on 16 March, the buoy began to show a young sea toward the south. By 0300 UT, the model (Fig. 4C) and buoy (Fig. 4D) spectra showed a dominant wind sea toward the south.

By 1800 UT on 16 March, the model showed a swell to the northeast arriving at both the *Quest* and the *Tydemman*. Buoy spectra were not collected at the *Quest* between 0300 and 1200 UT on 17 March, but by 1800 UT the buoy (Fig. 4F) shows this swell to the northeast as a strong system. The model (Fig. 4E) has attenuated the system to the south almost completely, and the buoy, while still retaining it, shows it traveling more toward the southwest.

SUMMARY AND CONCLUSIONS

Except for 16 March and early 17 March, the model H_s and buoy H_s are in good agreement. Apparently the model does not respond well to rapidly turning winds increasing in speed. This problem might be attributable to inadequate directional relaxation. Further testing is needed.

In general, the NOAA spectra agree reasonably well with those estimated from the buoys and are consistent with the hindcast wind patterns. Discrepancies between the model and the buoys, as described above, may be caused by errors in the hindcast winds, by the buoy reflecting other processes such as swells propagating from outside the considered region, or by interactions with the Gulf Stream not accounted for in the model.

The NOAA model appears at times to inadequately account for dissipation of wave energy from whitecapping

and opposing winds. Improvement in these areas is being considered.

REFERENCES

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- ²Mitsuyasu, H., Tasai, F., Suhara, T., Mizuno, S., Ohkusu, M., et al., "Observations of the Directional Spectrum of Ocean Waves Using a Cloverleaf Buoy," *J. Phys. Oceanogr.* **5**, 750-760 (1975).