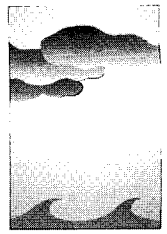
The Increasing Wave Height in the North Atlantic Ocean



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ABSTRACT

There are indications that the mean significant wave height at Seven Stones Light Vessel has increased in the period 1960–85. This is of considerable interest for the design of offshore structures and for coastal defense. In this note, the authors present new results based on the analysis of a collection of more than 20 000 hand-drawn wave charts. These charts were produced routinely between 1960 and 1988 in a manner that remained essentially unchanged throughout this period. The results are in remarkable agreement with the trend observed at Seven Stones Light Vessel.

1. Introduction

Measurements of the Institute of Oceanographic Sciences (Carter and Draper 1988; Bacon and Carter 1991) indicate a 2.4 cm yr^{-1} increase of the mean significant wave height at Seven Stones Light Vessel in the period 1960–85. This is of considerable interest for the design of offshore structures and for coastal defense (Carter and Draper 1988; Hogben 1994). Several modeling studies (Cardone et al. 1995; WASA Group 1995) have attempted to confirm the increase, and to extend the analysis to other locations. By lack of long series of wave observations these studies compute wave heights with a numerical wave model (Komen et al. 1994) using analyzed wind fields as input. Unfortunately, the quality of these wind fields is not stationary over the period concerned because observations and analysis techniques have improved with time. In this note, we present new results based on the analysis of a collection of more than 20 000 hand-drawn wave charts. These charts were produced routinely between 1960 and 1988 in a manner that remained essentially unchanged throughout this period. The ship-routing crew of forecasters consisted of the same persons during most of the time. While our knowledge of the dynamics of ocean waves increased greatly, they continued to use the empirical tools that had been developed in the late 1950s. The results are in remarkable agreement with the trend observed at Seven Stones Light Vessel.

A decadal change in wave climatology is of considerable importance for the design of maritime structures (Hogben 1994). This design is normally based on estimates of the 50-yr return wave heights that are made on the assumption that the wave climate is stationary. Decadal trends refute this assumption and necessitate a reconsideration of design criteria.

2. The wave chart analysis

In an attempt to confirm the reported wave height increase, we have analyzed operational wave height maps prepared by the ship-routing department of KNMI. An example of such a map is given in Fig. 1. Throughout the period 1960–88, these charts have been produced twice daily on a routine basis. The method of production has been described by Heijboer (1969) and was based on earlier work of Groen and Dorrestein (1976). In essence, a first-guess pressure analysis, based on weather charts, was used to prepare a wind analysis. From this, in turn, a wave analysis was derived by taking into account the growth characteristics of wind sea and the propagation of swell. During this procedure, all available (ship) ob-

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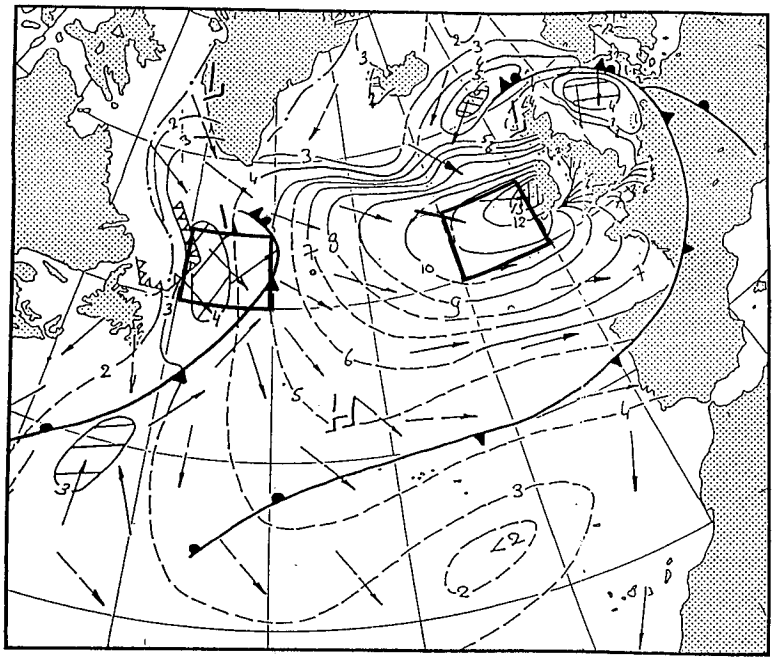

FIG. 1. One of the 20 000 wave analysis charts analyzed in this study. The boxes indicate the areas that are considered in this paper.

servations of wind and waves were considered and subjectively "assimilated." Observations from "reliable ships" obtained a high weight. The resulting analysis was an optimal blend of theoretical estimates based on the understanding of wave dynamics and—quality controlled—wind and wave observations. Throughout the years, work was done by the same people, working as a small dedicated team in rotating shifts. The success of the ship-routing advise of one staff member depended critically on the quality of the wave analysis made by another staff member. This stimulated mutual quality control (D. Heijboer 1995, personal communication). As a result, the product was of high and constant quality. Throughout the years, the method remained essentially unchanged and use was made of the same type of observations. In 1988 KNMI's ship-routing activities were terminated.

An initial attempt to digitize the large number (more than 20 000) of charts failed because of their complexity, caused by the large amount of detailed information on height and direction of wind sea and swell. Instead, we have now made a semimanual digitization for five selected areas (boxes of 10° long × 5° lat) in the North Atlantic Ocean. In each box, the maximum and the minimum wave height were extracted manually for all available charts. The resulting numbers were processed numerically. Annual distributions of the 12-h box maxima as well as the box mean [= 0.5 (maximum + minimum)] are derived for 1961 until 1987. For two boxes the results are already available. In Fig. 2 the distribution of the area mean values is represented by the annual upper 1st, 10th, and 50th percentiles. Figure 2a gives the results for box 1 east of Newfoundland (50°–55°N, 50°–40°W); Fig. 2b is for an area west of Ireland (box 2; 50°–55°N, 20°–10°W). Both time series have a decadal trend. To quantify this trend, we have made various regressions, which confirm their significance. A typical result is 2.3 (2.7) cm yr^{-1} for box 1 (2) as regression coefficient for the 50th percentile time series of the mean wave heights. This is in good agreement with the trend measured at Light Vessel Seven Stones near Land's End and at Ocean Weather Station Lima, at 57°N, 20°W (Bacon and Carter 1991). There is also agreement between our analysis and a similar analysis by Neu (1984) for the period 1970–82.

3. Discussion and conclusions

Our analysis does not reveal the origin of the observed change. There has been quite some discussion (Hogben 1994) about the absence of a trend in the observed wind statistics at Seven Stones. However, this does not need to bother us, as the wave response to atmospheric forcing is quite nonlocal (Komen et al. 1994). Kushnir et al. (1995) made a canonical correlation analysis of modeled wind and wave variability. From this it appears that variations in wave climatology in the eastern North Atlantic may be related to variations in the meridional pressure difference in the central part of the North Atlantic Ocean (the North Atlantic oscillation, NAO), and the associated variations in mean zonal circulation. A recent analysis by Hurrell (1995) has revealed that the NAO (in winter) has increased since 1960. This suggests that the wave height trend at Seven Stones is due to a change in swell rather than to a change in wind sea. This hypothesis received recent support from an analysis of COADS data by Gulev (1995). It should be noted that so far it has not been possible to attribute the observed change to either an anthropogenic cause or to natural climate variability on decadal timescales.

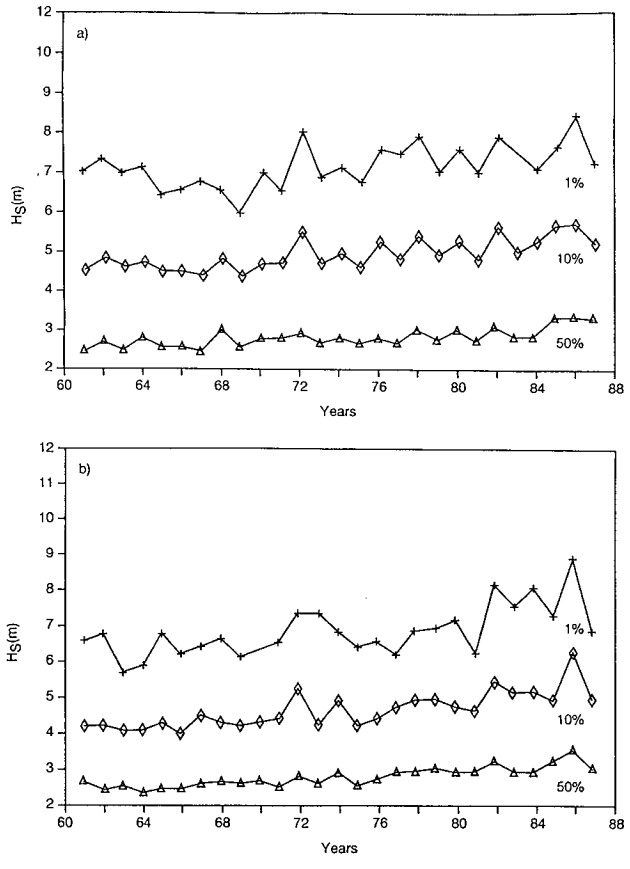

FIG. 2. Time series of the upper 1st, 10th, and 50th percentiles of the annual distribution of the area mean significant wave height. Panel (a) gives the results for box 1 east of Newfoundland (50°–55°N, 50°–40°W); (b) is for an area west of Ireland (50°–55°N, 20°–10°W).

Further studies of decadal wave climate changes are strongly recommended. The main point of this note is to present new observational evidence for a decadal increase in wave height in the North Atlantic Ocean.

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