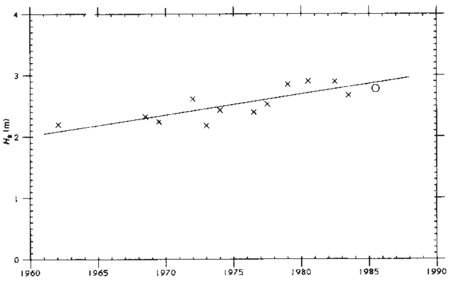
Has the north-east Atlantic become rougher?

SIR—Measurements of ocean waves made routinely by the Institute of Oceanographic Sciences during the past 25 years suggest that there has been a substantial increase in wave heights in the north-east Atlantic during the period. This trend presents particular problems for those concerned with estimating wave conditions for the design of offshore structures and coastal defences, including estimates of extreme conditions. These estimates are presently obtained by analysing the wave data or values hindcast from wind data assuming that the wave climate is stationary over the years. A better understanding of the climatic variability of ocean waves is needed so that we can assess the likely errors resulting from this assumption of stationarity and eventually take the variability into account in our estimates. Improved knowledge will ultimately be derived from the extensive spatial coverage which will be provided by routine satellite measurements of wave height and of surface wind velocity (together with improved wave hindcast models), but for the immediate future it will only come by continuing wave measurements at specific sites.

Several authors[1-3] have concluded that wave conditions over the North Sea and North Atlantic have become more severe in recent years. Their conclusions were based on visual estimates of wave height, on wind and surface pressure measurements and on wave forecast charts.

Instrumental wave records have been obtained by our Institute with few interruptions since January 1962 from a Shipborne Wave Recorder[4] fitted in the Seven Stones Light Vessel off Land's End. (We believe this to be the longest-running wave recording site anywhere in the world, funded since 1974 by the UK Department of Energy.) Estimates have been obtained from these records of significant wave height (H_s) at three-hourly intervals. H_s is defined as 4σ, where σ^2 is the variance of the sea surface elevation, and is approximately equal to a visual estimate of wave height. Mean values of H_s for each month have been calculated for all months for which at least 90 per cent of the data were successfully recorded, and annual means calculated from these monthly means — not necessarily January to December. The twelve annual mean H_s values obtained to December 1983 are shown plotted against time in the figure (denoted by ×). The mean for January–December 1985 is also shown (○), but 21 per cent of the January data and 16 per cent of the May data for this year are missing, so this value was omitted from the analysis described below.

The twelve annual means were ranked from 1 to 12, from the lowest value of 2.18 m (July 1972–June 1973) to the highest value of 2.90 m (1980). The sum of the ranks for the earlier six years was compared with the distribution of the sum assuming no trend; the Wilcoxon ranking test[5] rejects the hypothesis of no trend at the 99 per cent level. The straight line shown in the figure was fitted by linear regression. Its slope is 0.034 m yr^{-1} with a standard error of 0.008 — but the regression analysis assumes that annual means are normally distributed, which cannot be strictly true, since $H_s \geq 0$. Applying the Wilcoxon ranking test to monthly



Annual mean values of significant wave height (H_s) at Seven Stones Light Vessel. The value for 1985, denoted by '○', was calculated from an incomplete data set.

maxima raises problems of the significance of multiple tests, but each of the twelve months (with data to December 1985) has rank sums in the earlier portion of the data less than the expected value assuming no trend.

Modifications have been made over the years to the Shipborne Wave Recorder in the Seven Stones Light Vessel. However, since 1962 the basic measurement technique has not changed and the same method of estimating H_s from the records has been used throughout. We are confident that no instrumental factors can account for the trend in the data.

The 50-year return value of H_s, defined as the value which is exceeded on average once in 50 years, is used for the design of offshore structures in UK waters. At Seven Stones it is about six times the annual mean value of H_s, so a trend of 0.034 m yr^{-1} in the mean indicates an increase in the 50-year return value of about 0.2 m yr^{-1}, from 12 m in 1960 to 18 m in 1990 were the trend to continue.

This Institute has also obtained wave measurements at the north-east Atlantic Ocean Weather Stations (OWS) India (59 °N 19 °W) and Juliett (57.5 °N 20 °W) since the early 1960s until their withdrawal in 1975. These stations were occupied intermittently by ships of several nations, only a few fitted with a wave recorder, so it took several years to amass what was effectively a 'year's' data of 3-hourly records. However, compound 'years' at both OWS 'I' and 'J' were obtained for the early 1960s and again for the early 1970s. In the 1960s there was no significant difference between the probability distributions of H_s at the two stations, but by the early 1970s the median H_s at 'J' had increased by 11 per cent and at 'I' by 27 per cent. Wind speeds measured on board the weather ships did not show any such changes, but this is not necessarily inconsistent as waves are an integrated property of the wind over a large area. Meticulous investigations[6] of all the data revealed no instrumental or analytical reason for these changes; the increased severity of wave height appears to be real.

However, a major problem in determining long-term trends in H_s is the considerable variation from one year to the next. This is seen in the figure, in which the largest change is a drop of 17 per cent from 1971/72 to 1972/73, compaiable to the changes at OWS 'I' and 'J'. So it is possible, although unlikely, that the changes at the Ocean Weather Stations could be due to year-to-year variability rather than to a general trend. Clearly, routine measurements are required over many years at a site to determine any long-term trend. However, such measurements can only describe conditions at that site, they cannot differentiate between a widespread increase in severity and, say, a change in storm tracks. These problems will eventually be overcome by the spatial coverage provided by satellite measurements of waves — the radar altimeter gives a good estimate of H_s — and of wind velocities, from scatterometers, which can be fed into improved wave models; but the many years of data required will not be available before the next century. In the meantime we need to continue site measurements.

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Assumptions about suicidal behaviour of aphids

SIR—Two recent letters question several assumptions and conclusions from our paper on adaptive suicidal behaviour in aphids[1]. These letters reveal several misunderstandings about our study and about evolutionary ecology in general. Thus, we feel a reply is warranted.

First, Tomlinson[2] argues that our experimental rationale relies on the assumption that our two aphid populations are homogeneous at loci not involved in