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An analysis of long-term trends in temperature and salinity at four English lightvessels

by

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INTRODUCTION

Using monthly means of sea surface temperature from the tables published by ICES (1962) for the years 1905-54, Tomczak (1967) used a linear regression technique to study long-term trends in sea surface temperature in the North Sea. A similar analysis of sea surface temperature for the years 1903-64 by Hill (1968) on data from two English lightvessels attempted a more statistical approach in which the linearity of the regressions and the significance of the regression slopes were tested. The aim of the present paper is to extend the analysis by the inclusion of more recent data, and the addition of salinity as a trend parameter.

METHOD

The positions of the four lightvessels considered in this paper, the Seven Stones, Varne, Galloper and Smith's Knoll, are shown in Figure 1. In order to decide on the analysis required for salinity data, the annual means and monthly means of surface salinity for each vessel were first plotted against time for whatever periods data were available between 1905 and 1970. In effect this was the complete 65 year period for the Seven Stones and Varne, from 1920 to 1970 for Smith's Knoll, and 1949 to 1970 for the Galloper lightvessel. It seemed from these data (as one example, the Seven Stones data are shown in Figure 2) that for many months there was a marked change in trend between 1955 and 1960, and it was therefore decided to treat the two periods 1905-60 and 1955-70 separately, for both salinity and temperature, except at the Galloper lightvessel where data collection began only in 1949.

It is well known that salinity is not always normally distributed, particularly in coastal areas, and hence, since the validity of the regression analysis to be used depends upon this assumption, it was necessary to test the distribution of salinity monthly means for normality. This was done for each lightvessel by selecting a group of months for which there appeared to be no significant trend with time and combining them about a common mean to form a test distribution. For the Seven Stone lightvessel, for example, the five months October to February were combined over the period 1905-60. These test distributions were then tested for skewness, and for kurtosis and for goodness of fit by χ^2, and in each case found to have no significant departure from normality, as indicated in Table 1, where β_1, the estimate of skewness, is calculated from

$$\beta_1 = m_3^2/m_2^3$$

and β_2, the estimate of kurtosis, from $\beta_2 = m_4/m_2^2$,

m_i being the ith moment of the distribution. For a normal curve $\beta_1 = 0$ and $\beta_2 = 3$.

Table 1 Normality tests for monthly means of salinity

	Seven Stones	Varne	Smith's Knoll	Galloper
χ^2	6.79 5 d.f.	6.04 5 d.f.	5.38 8 d.f.	8.47 6 d.f.
χ^2 5% value	11.07	11.07	15.51	12.59
β_1	0.002	0.04	0.08	0.27
β_2	3.30	2.90	3.04	3.22

Having established that it was reasonable to assume that the basic temperature and salinity monthly means were normally distributed - Hill (1968) refers for temperature - each monthly and annual regression of temperature and salinity on time was tested for linearity as described by Hill (1968). Of the 91 regressions tested for each parameter only three - March and April (1905-60) at Varne and December (1955-70) at Smith's Knoll - suggested departure from linearity at the 1 per cent level of significance for temperature, and two - August and Annual (1905-60) at Varne - for salinity. With this frequency of testing, it would be expected that about two of the tests would indicate non-linearity at the 1 per cent level of significance, even if none were present. Hence, it seemed reasonable to proceed with the analysis on a grouped basis, bearing in mind the possibility of non-linearity in these five regressions in the interpretation of the results. The final step in the analysis involved testing the significance of the regressions and establishing whether the slopes of the monthly mean regressions were different from the annual slope, and from each other.

The model used for this analysis of variance, which was programmed for an ICL 1907 computer, was

$$y_{ti} = \alpha_t + \beta_t(x_{ti} - \bar{x}_{t.}) + Z_{ti} \qquad \begin{matrix} t = 1 \;\ldots\ldots\; 13 \\ i = 05 \;\ldots\; 70 \end{matrix}$$

where y_{ti}, x_{ti} represent temperature (or salinity) and year, and α_t is the expected value of $\bar{y}_{t.} = \mathcal{E}(\bar{y}_{t.})$.

β_t represents the slope of the t th month (t = 13 being the annual slope) and Z_{ti} a random residual assumed to be independent and normally distributed.

The grouped analysis of variance of temperature for one of the more interesting cases, Smith's Knoll (1920-60), is given in Table 2.

If F_i is the ratio of mean squares for $\frac{\text{row } i}{\text{row } 5}$ then it can be seen that a significant F_1 value indicates an overall regression, since β_o is real. The conditions for a common regression line for all monthly and annual means within a group are that both F_2 and F_3 are non-significant. A significant F_4 indicates that at least one of the slopes $\beta_t \neq \beta_c$, while a non-significant F_4 and significant F_2 or F_3 indicates that the slopes β_t are parallel, that is they have the same slopes but cannot be represented by a common regression line.

RESULTS

The significance levels established by the analysis of variance for grouped regression lines are given in Table 3, NS indicating not significant at the 5 per cent level.

Table 3 Analysis of variance for grouped regression lines

	Temperature				Salinity			
	F_1	F_2	F_3	F_4	F_1	F_2	F_3	F_4
Seven Stones								
1905-1960	1%	1%	1%	NS	NS	1%	1%	NS
1955-1970	NS	1%	1%	NS	1%	1%	1%	NS
Varne								
1905-1960	1%	1%	1%	NS	1%	NS	NS	NS
1955-1970	5%	1%	1%	1%	NS	NS	NS	5%
Smith's Knoll								
1920-1960	1%	1%	1%	1%	5%	1%	1%	5%
1955-1970	NS	1%	1%	1%	NS	NS	1%	NS
Galloper								
1949-1970	5%	1%	1%	5%	1%	1%	1%	NS

Insofar as temperature is concerned, the data from the Seven Stones and Varne lightvessels for the period 1905-60 indicate that there was an overall regression which could not reasonably be represented by a common regression line for all months or years, but that it was reasonable to assume that all the monthly regression lines and the annual regression lines had parallel slopes of 0.016 for Seven Stones and 0.012 for Varne. For the years 1920-60, the data from Smith's Knoll indicate an overall regression, no common regression line and at least one β_t different from the rest. It is therefore necessary to examine the individual monthly and annual regressions at this position, as shown in Table 2, where an indication of the significance of the individual monthly regression lines is given alongside each b_t. It can be seen from these significance levels that the overall significance is due entirely to significant monthly regressions for September, November and December, and that the remaining monthly regressions do not have a slope differing significantly from zero, which accounts for the F_4 value in Table 3. For the period 1955-70 the analysis of variance showed no evidence of significant regressions at Seven Stones or Smith's Knoll but indicated a 5 per cent level of significance in an overall regression at Varne, with no common regression, and at least one slope different from the rest. A similar situation obtained for Galloper (1949-70). In both these cases all the individual monthly and annual regressions were tested for significant departure from zero and all gave non-significant results. We may therefore conclude that there was no trend in temperature at any of the four lightvessels over the later periods. (The significant F_4 ratios at Varne and Galloper arose from the odd negative slope which was significantly different from b_c but not from zero.)

It may also be seen from Table 3 that the analysis of variance indicates that there is no overall regression at Seven Stones in salinity for the period 1905-60, although in the period 1955-70 there is a regression in which all the individual monthly and annual slopes are parallel (not common) and have the value $b_c = 0.008$, indicating a small but significant and general upward trend. A similar situation applies to Galloper (1949-70), where a downward trend of parallel regression lines of slope $b_c = -0.005$ is shown. At Varne, during 1905-60, an overall regression which could reasonably be represented by a common regression line of slope $b_c = -0.0013$ is indicated, but there are not sufficient data to show a significant regression for the period 1955-70. At the Smith's Knoll no regression is indicated for either period, although for 1920-60 this is established only by subsequent testing of the individual monthly regression lines, which all proved to be non-significant.

CONCLUSIONS

It can be concluded that there has been a general and long-term rise of sea surface temperature over the period 1905-60 at the Seven Stones and Varne lightvessels, consistent with the hypothesis of similar trends in all months, and a long-term warming at Smith's Knoll over the period 1920-60 in the months of September, November and December. However, no corresponding long-term increase in salinity could be determined during periods 1905-60 at any of the lightvessels, and indeed the Varne data showed a slight decrease. Thus the long-term warming cannot be attributed to an increase in the influx of Atlantic water through the English Channel as suggested by Hill (1968) from temperature data alone, and it is more likely that the warming is merely a reflection of the atmospheric changes over the North Atlantic which have produced a long-term increase in temperature of surface waters, over the first half of this century, in those sea areas adjacent to western Europe (Beverton and Lee 1965).

This does not, of course, preclude shorter-term variation of salinity over this period, and indeed it has been amply demonstrated by Dickson (1968) that 'accelerated inflows' of high-salinity water do occur with a periodicity of four years or so.

In studying the changes in sea surface temperature between 1951 and 1965 at the nine ocean weather stations (OWS), Rodewald (1967) found that there had been a general cooling trend but that this was most pronounced in the mid-Atlantic (OWS D), whereas at some ocean weather stations, in particular OWS A, there had been a noticeable warming. Of the three stations closest to the British Isles (OWS I, J and K) OWS I showed a general warming and OWS J and K a cooling. Hence it is not perhaps so surprising that our four lightvessel stations show no significant trend over the period 1955-70. Furthermore, Rodewald shows a mean pressure deviation from normal for the ten-year period 1956-65 (his Figure 3) which clearly indicates an anomaly circulation from the Skagerrak flowing south across the eastern half of the southern North Sea, Belgium and France before turning north across the Bay of Biscay and past the Seven Stones lightvessel. This anomaly circulation implies an increased northerliness of winds over the southern North Sea and Straits of Dover and an increased southerliness at Seven Stones which might account for the small but significant decrease in salinity over the period 1949-70 at Galloper and the similar increase at Seven Stones, which is not paralleled in sea surface temperatures.

The monthly mean regression slopes for salinity at the Seven Stones are noticeably largest in the months of May, June and July (around 0.014), and it can be seen from the ICES monthly mean charts (ICES 1962) that the surface isotherms have a pronounced northerly inclination at this time near the Seven Stones which is considerably less evident in the isohalines, which tend to run east/west. Hence, increased southerly winds could raise surface salinity without increasing surface temperature. The ICES charts also show that, whereas there is a consistent higher salinity tongue of Atlantic water pushing through the Straits of Dover and past the Varne lightvessel into the North Sea throughout the year, which usually includes the Galloper, and often includes Smith's Knoll, the isotherms show the warm tongue breaking down from April to September, largely because of the summer heating of the coastal waters. Thus an increase of northerly winds might well decrease salinity at all three lightvessels while not significantly affecting temperature, and in fact a negative trend overall does occur at Smith's Knoll and Varne also during 1955-70, although it is not sufficiently marked to attain statistical significance.

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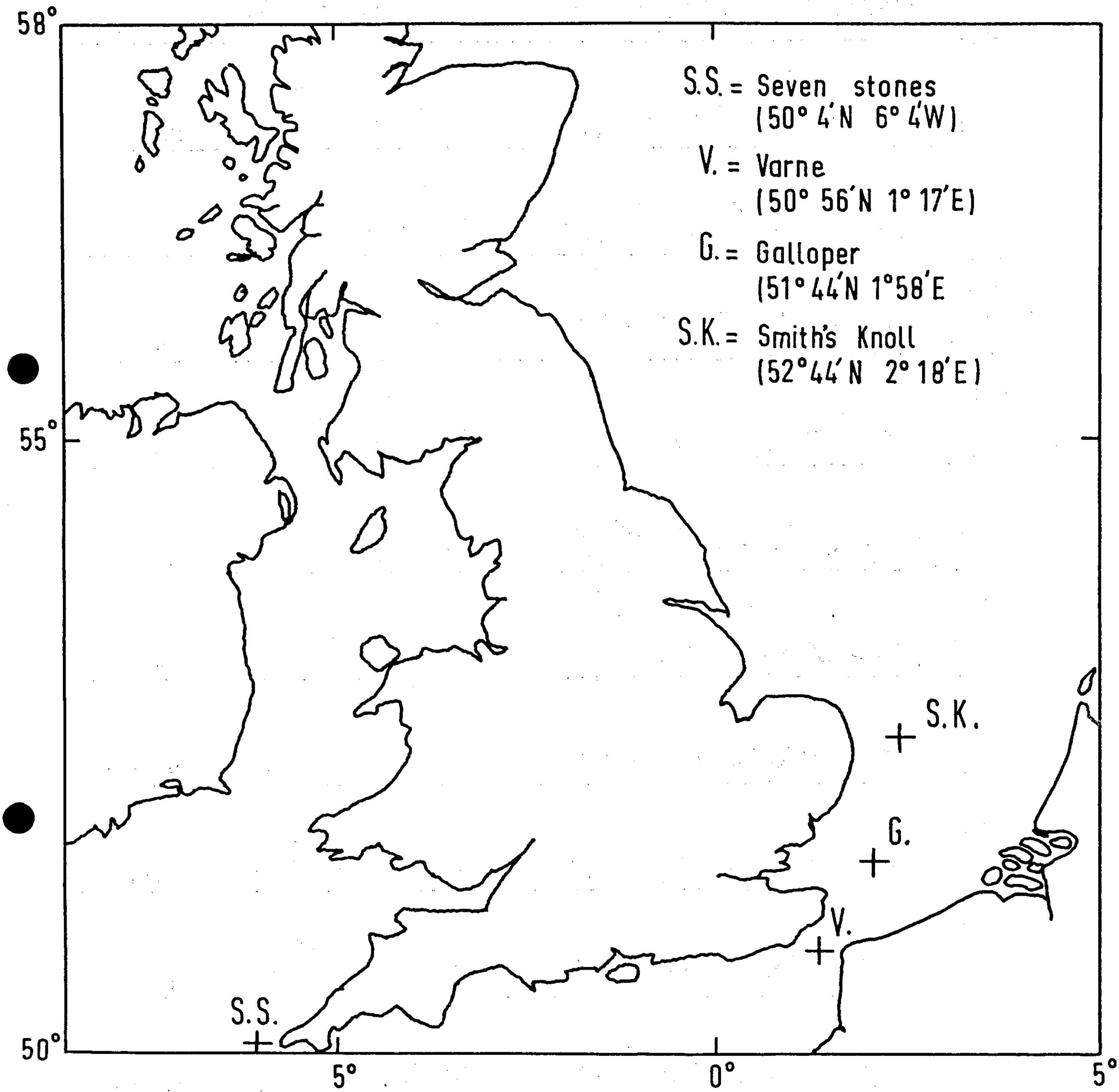

Figure 1. Positions of the four Lightvessels

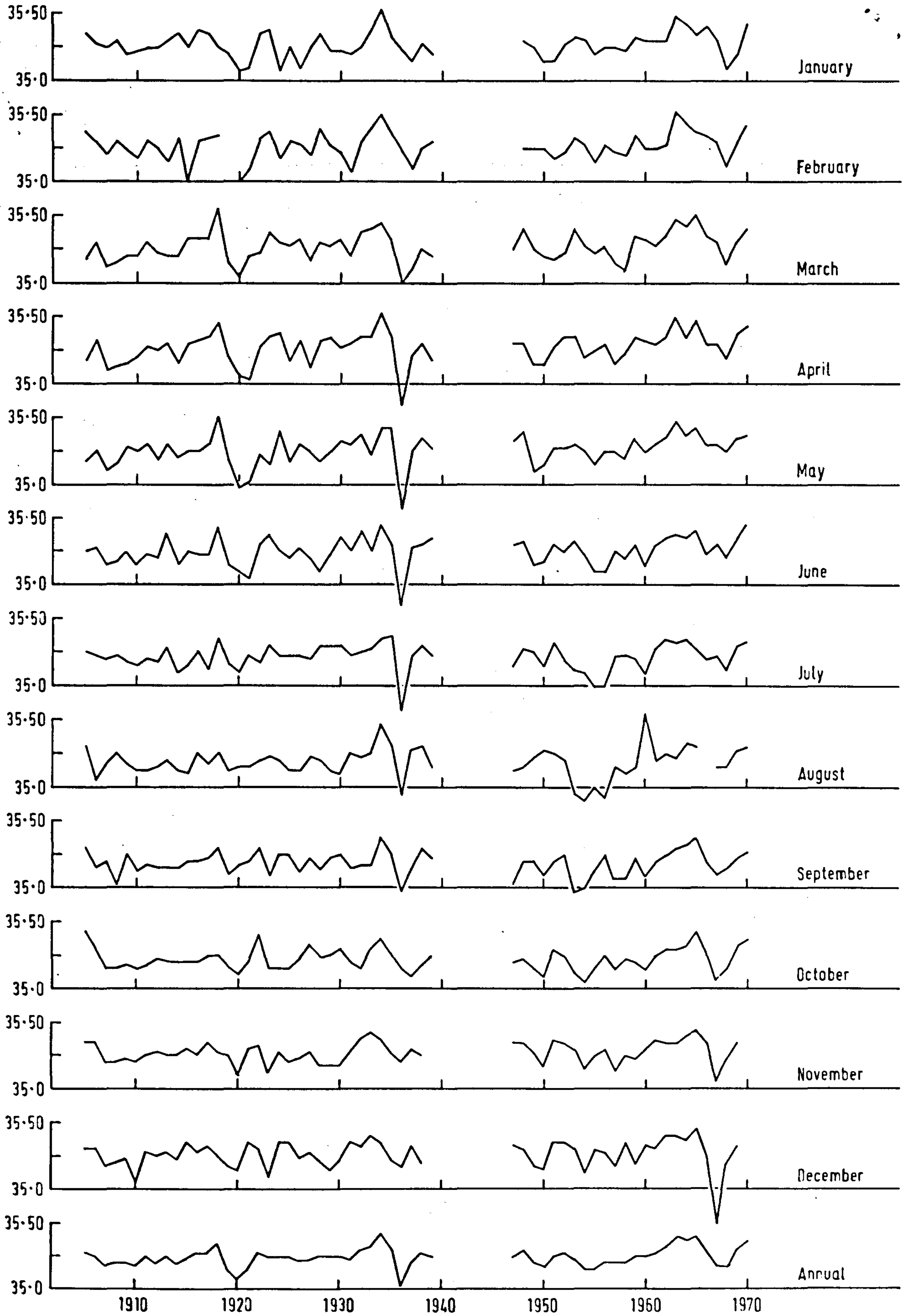

Figure 2. Mean monthly salinities at the Seven Stones Lightvessel for the period 1905-70

Table 2 Analysis of variance of temperature. Grouped regression lines at Smith's Knoll lightvessel (1920-1960)

	Source	Sum of squares	d.f.	Mean square	Expected value of mean square
1	Overall slope	$W_o b_o^2 = 13.64$	1	13.64	$\sigma^2 + W_o \beta_o^2$
2	Slope of means against within groups slope	$\frac{W_c W_m}{W_o}(b_c - b_m)^2 = 561.7$	1	561.7	$\sigma^2 + \frac{W_c W_m}{W_o}(\beta_c - \beta_m)^2$
3	About regression of groups means	$\sum_{t=1}^{13} n\left[\bar{y}_{t.} - \bar{y}_{..} - b_m(\bar{x}_{t.} - \bar{x}_{..})\right]^2 = 5976$	11	543.3	$\sigma^2 + \frac{1}{11}\sum_{t=1}^{13} n\left[\alpha_t - \bar{\alpha}_. - \beta_m(\bar{x}_{t.} - \bar{x}_{..})\right]^2$
4	Between slopes of group regressions	$\sum_{t=1}^{13} W_t(b_t - b_c)^2 = 23.61$	12	1.967	$\sigma^2 + \frac{1}{12}\sum_{t=1}^{13} W_t(\beta_t - \beta_c)^2$
5	About regression within groups	$\sum_{t=1}^{13}\sum_{i=20}^{60}\left[y_{ti} - \bar{y}_{t.} - b_t(x_{ti} - \bar{x}_{t.})\right]^2 = 333.9$	387	0.8627	σ^2
6	TOTAL	$\sum_{t=1}^{13}\sum_{i=20}^{60}(y_{ti} - \bar{y}_{..})^2 = 6909$	412		

$b_o = 0.014$: $b_c = 0.011$: $b_m = 2.892$

Group	Mean y	b_t	P
January	6.32	0.021	NS
February	5.18	0.004	NS
March	5.21	-0.006	NS
April	6.42	-0.026	NS
May	8.90	-0.001	NS
June	12.02	-0.004	NS
July	14.87	0.005	NS

Group	Mean y	b_t	P
August	16.56	0.012	NS
September	16.32	0.028	5%
October	14.38	0.025	NS
November	11.13	0.038	1%
December	8.46	0.042	5%
Annual	10.37	-0.003	NS

Where $W_o = \sum_{t=1}^{13}\sum_{i=20}^{60}(x_{ti} - \bar{x}_{..})^2$, $W_c = \sum_{t=1}^{13}\sum_{i=20}^{60}(x_{ti} - \bar{x}_{t.})^2$, $W_m = \sum_{t=1}^{13} n(\bar{x}_{t.} - \bar{x}_{..})^2$, $W_t = \sum_{i=20}^{60}(x_{ti} - \bar{x}_{t.})^2$

β_m = slope of line on which the overall monthly means lie.

Greek letters represent expected values of observed parameters represented by Roman letters, e.g. $\beta_t = \mathcal{E}(b_t)$ etc.

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