variation in 1969 and 1970 with lower values early in the year. The abnormally high value in May 1973 and low value in June 1975 are each the result of observations on a single night and may not truly represent the average conditions in these months.

The peak values of aerosol optical thickness range between 0.013 and 0.020 (depending on the assumed value of F_A). These are considerably less than the values for 700 nm determined by Elterman from searchlight measurements in 1964 and 1965[1] (0.027) and are also less than his value for 1970[12]. The average Adelaide value for 1973 is between 0.005 and 0.007. This is higher than the lidar-derived value of 0.004 obtained over California[10] for the same period, but much lower than Elterman's[8] value of 0.014 for the 'normal' stratosphere (when converted to 694 nm). The average of values for early 1976, 0.006–0.009 is slightly higher than the 1973 average and may indicate the presence of some residual dust from the eruption in October 1974 of Volcán de Feugo in Guatemala.

To obtain a reliable estimate of the minimum value optical thickness for the period of observation, a weighted average was calculated from those eight monthly values which were not statistically distinguishable from the lowest value. A value of $(7.4 \pm 0.2) \times 10^{-5}$ per steradian was obtained for the integrated backscatter function, which corresponds to an optical thickness of between 0.004 and 0.006. Thus the extreme values of aerosol optical thickness varied by a factor of at least three during the period 1969–76.

To relate the aerosol optical thickness for the lidar wavelength of 694 nm to the optical thickness for the solar spectrum, the extinction due to scattering was calculated for the two spectral distributions using the stratospheric aerosol size distribution given by Bigg[13]. The extinction of solar radiation is 87% of that for monochromatic radiation at 694 nm. Thus during the period 1969–76, the optical thickness of stratospheric aerosols for solar radiation varied from about 0.018 to 0.004.

An estimation of the reduction in the ground level solar flux at Adelaide during 1969–76 due to stratospheric aerosols can be obtained from the analysis of Cadle and Grams[14]. The energy lost due to upward scattering from a solar beam incident at a zenith angle of 60° varied between 0.5 and 0.15%.

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Anomalous results for tidal flow through the Pentland Firth

THE flow of water across the vertical component of the Earth's magnetic field induces a potential gradient in the water; measurements of the difference in voltage between the opposite sides of a tidal channel provide an indication of the magnitude of the tidal flow. Longuet-Higgins[1] derived the relationship between the potential gradient and the tidal flow for the case of uniform flow in a channel of semi-elliptic cross-section. By recording the difference in potential between the ends of submarine telephone cables valuable measurements have been obtained of flow through the Dover Strait[2,3] and through various channels in the Irish Sea[4,5]. However, recent cable measurements for tidal flow through the Pentland Firth are shown here to include anomalous results.

The study of the movement and dispersal of certain water masses over periods of years and, consequently, over large spatial zones is of increasing interest in connection with studies of dispersal of radioactive waste or fisheries investigations. Cable measurements are of particular value in such studies as they provide, at minimal cost, a continuous long-term record of the integrated flow across a particular section[6]. However, in recent years many of these cables have either been abandoned or replaced by 'repeated' cables. In the latter, power is fed along the cables to amplify the communications signal at repeated intervals and this tends to distort the measurement of the flow-induced voltage[7].

Unexpected results found from recording on cables crossing the Pentland Firth (Fig. 1) are particularly interesting. Two cables, running along closely parallel paths, link the Orkneys with the Scottish mainland. Recordings of voltage were made on these cables from February to October 1976, coinciding with the JONSDAP '76 oceanographic exercise in the North Sea. The measurements coming respectively from the two cables were very similar so only the results from cable 2 are presented. Tidal analyses of the recordings were made by dividing the data into six discrete sets each lasting 29 d. Despite the high noise level, the analyses produced consistent results for the principal harmonic constituents (Table 1). However, an examination of the propagation of the M_2 tidal constituent shows that the phase of this constituent calculated from the cable data (that is 18° for flow measured positive towards the east) does not accord with the general pattern of flow as deduced from other data sources (Fig. 1).

Values for the phase of the M_2 constituent of surface currents were calculated from the Admiralty Tidal Stream Atlas. Figure 1 shows values of 271° and 256° obtained for positions in the Firth and a value of 235° at a position slightly east of the Firth. As part of JONSDAP '76 current meter measurements were made at position 53 (58°37′ N, 2°25′ W). Tidal analyses of these measurements produced an M_2 value of 302° for flow along the major axis of the ellipse aligned 10°W of S. The phase of the vertical tide in this region is indicated by the co-phase lines in Fig. 1 and also by the values from the coastal gauges. Over the region in which the phase of the currents varies from 271° to 302°, the phase of the vertical tide varies from about 250° to

Table 1 Tidal analyses of voltages recorded on the Pentland Firth telephone cable

	Amplitude				Phase			
	1976		1978		1976		1978	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
O1	20	22	29	31	23°	24°	7°	19°
K1	44	47	82	20	172°	22°	193°	28°
μ2	45	24	50	6	251°	11°	254°	7°
N2	52	10	56	21	325°	7°	339°	6°
M2	231	3	236	3	18°	3°	19°	1°
L2	17	42	18	75	111°	21°	148°	51°
S2	105	11	111	20	61°	8°	66°	5°
M4	10	47	6	22	203°	14°	190°	92°
M6	6	57	12	16	69°	44°	66°	25°
	mV	%*	mV	%†				

* Standard deviation of results from six separate monthly analyses expressed as a percentage of the mean value of the constituent.

† Standard deviation of results from three separate monthly analyses.

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320°. Thus maximum flows apparently occur within 1 h of tidal high water throughout this region. Therefore the anticipated M_2 phase for flow across the cable section would be in the range 280°–340° compared with the recorded value of 18°.

An examination of the non-tidal (or residual) component from the cable signal shows a reasonable correlation ($r = 0.71$) between the easterly flows through the Pentland Firth and the southerly flows measured by current meters at the nearby position 53. There was no indication of either a significant wind-driven component or a seasonally varying flow component in the residual signal.

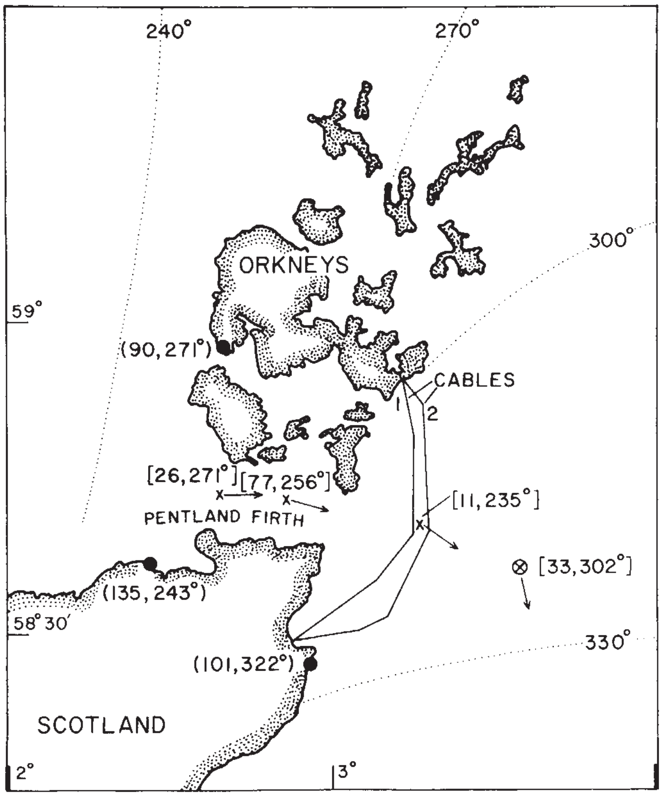

Fig. 1 Propagation of the M_2 tidal constituent in the region of the Pentland Firth. ●, Tidal elevation data in cm; ×, tidal steam data in cm s^{-1} (from Admiralty Tidal Stream Atlas); ⊗, current meter data from JONSDAP '76; co-phase lines shown dotted.

One explanation for the anomalous M_2 phase follows from the work of Robinson[8] who showed that cables respond in a complex fashion to flow over a wide area surrounding the termination points of the cable. He also showed that non-uniformity in sea-bed conductivity can complicate the general integral. In this region, the variability in both the coastline and the tidal stream patterns tends to invalidate the application of simplified formulae of the kind derived by Longuet-Higgins. In addition, the northerly latitude and part east–west alignment of the cable increase the noise level on the cable[9]. The question also arose as to whether any error had been introduced either in the instrumentation or in the data processing.

To establish the validity of these results the recordings were repeated over a 3-month period, July–September 1978. One of the cables had been severed in the interim period and so measurements could only be made on cable 2. To avoid repeating possible errors from the earlier experiment, the recording equipment was installed by a scientist not involved in the earlier recordings. Also, the programmes used to convert the original data into hourly values for subsequent analyses were rewritten. The data were sub-divided into three discrete sets, each of 29 d duration, for the purpose of tidal analyses. The results, shown in Table 1, closely agree with the values obtained from the 1976 recordings. Thus the voltage recordings from the Pentland Firth submarine cables seem to provide a useful indication of residual flow through the channel but produce an anomalous M_2 tidal signal.

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A simple approach for identifying and measuring acidification of freshwater

ACIDIFICATION of lakes and rivers accompanied by the loss of fish populations is a problem in Scandinavia[1–4], northeastern USA[5,6], and southeastern Ontario, Canada[7,8]. These areas have granitic or other siliceous bedrock types, thin and patchy podsolic soils, and extremely soft and poorly buffered surface waters, and receive precipitation which is decidedly acidic (volume-weighted average *p*H 4.0–4.6). Sulphate, whose principal source is precipitation, is usually the major anion in these acidified waters. In similar areas such as northern Scandinavia and northwestern Ontario, in which precipitation is not acidic (*p*H > 5.0) such oligotrophic pristine softwaters generally have *p*H levels >5.5, and bicarbonate is the major anion[9–11]. Acidification of such waters entails a decrease in the bicarbonate buffer (alkalinity) with only minor decreases in *p*H, and then after exhaustion of the bicarbonate an increase in acidity to *p*H levels well below 5.0. Because of the severe damage to fish populations, and other biological consequences, the decreases in *p*H that characterise the later stages of the acidification process are of major concern. We need, therefore, a simple 'early warning' indicator that identifies lakes and rivers which are undergoing the first stage of acidification, the loss of alkalinity, but which have not yet reached the stage of marked *p*H decreases. Furthermore, we need quantitative estimates of the degree of acidification. We show here that excess sulphate concentrations, or current calcium concentrations and alkalinities can provide such an estimate.

If bicarbonate is still present, simply measuring alkalinity will not reveal whether or not acidification has occurred unless pre-acidification alkalinity data are available for comparison. Unfortunately, few such data exist. However, in unacidified waters bicarbonate alkalinity is present in approximately equivalent concentrations as the sum of calcium and magnesium (less that of sea-spray origin). As the ratio Ca/Mg is also relatively constant, and *p*H is closely related to alkalinity and acidity, plots of *p*H and calcium should distinguish between

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