SMHI RO
Nr 1, January 1986

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SMHIs tryckeri, Norrköping 1986

Issuing Agency
SMHI
S-601 76 Norrköping
SWEDEN

Report number
RO 1 (1986)

Report date
January 1986

Author (s)

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Title (and Subtitle)

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Abstract

A method is described which relates observed eularian current fluctuations to horizontal exchange coefficients. The method is applied to current meter time series from the southern and the central parts of the Baltic Proper and from the Bothnian Sea.

Energy spectras suggest that current fluctuations with a time scale shorter than 24 hours can be considered as turbulence in large scale circulation models and parameterized by an exchange coefficient.

The horizontal exchange is found to be horizontally uniform. The calculated exchange coefficients have a vertical variation ranging from 10-50 m s in the surface layer to 1-3 m s below 70 metres. Inertial or near-inertial oscillations are the most important physical processes that produce horizontal exchange.

Key words

Currents; horizontal exchange; Baltic Sea

Supplementary notes

Number of pages
27

Language
English

ISSN and title
0283-1112 SMHI Reports Oceanography

Report available from:
SMHI
HOa
S-601 76 Norrköping
SWEDEN

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1. INTRODUCTION

The circulation patterns within the Baltic Sea consist of very complex turbulent movements. Superimposed on the mean flow circulation patterns are eddy-like motions of varying intensity and scales. These eddy-like motions exist in both horizontal and vertical directions. The intensity and scales of horizontal eddies, however, are much greater than the intensity and scales of vertical eddies, because the horizontal extent of the Baltic is many times greater as compared to its depth. A direct consequence of this is the large scale transport and dispersion of chemical and biological substances from one area of the Baltic to another.

Generally, the transport and diffusion of chemical and biological substances is modelled as if it were similar to molecular diffusion, i.e., the diffusion rate is assumed to be the gradient of concentration multiplied by a factor referred to as "eddy diffusivity" or "turbulent exchange coefficient". In spite of the philosophical objections to such a hypothesis, many numerical modellers have actively pursued this hypothesis mainly because of its success in modelling many environmental diffusion problems. The basic question in all diffusion modelling problems is the appropriate choice and incorportion of the exchange coefficients in the transport equations. Theoretical and experimental studies suggest that the magnitude of the turbulent exchange coefficient increases with the scale of the phenomenon being considered. Large scale numerical transport models often employ horizontal grid size of many kilometres approximating all motions within the grid by a constant but large enough horizontal turbulent exchange coefficient appropriate to the chosen grid size. In this report a simple procedure is presented to calculate the horizontal exchange coefficients appropriate to model sub-grid turbulent motions in a large scale transport model, using the time series current meter data from several locations in the Baltic, particularly the large data base from the BALTIC-75 experiments.

The basic current meter data used in this analysis is drawn from four sources: Institut für Meereskunde (Baltic-75), SMHI, Dept. of Oceanography (University of Göteborg), and Institute of Marine Research (Finland). Figure 1 shows the geographic distributions of current meter stations in the Baltic Sea, and Table 1 gives a summary of the data base.

2. THEORETICAL CONSIDERATIONS

In order to develop a relation between the horizontal turbulent exchange coefficient and the current fluctuations observed at a fixed point, we follow Taylor's (1921) analysis. In a stationary and homogeneous field of turbulence, where we arbitrarily set the mean velocity to zero, the Langrangian particle displacements x(t) is given by:

$$x(t) = \int_0^t u'_\ell(t')dt' \qquad (1)$$

where u'_ℓ is the Lagrangian current fluctuations.

The horizontal exchange coefficient K_x, by definition, is related to the variance of x(t):

$$K_x = \frac{1}{2}\,\overline{\frac{dx^2}{dt}} = \overline{x\frac{dx}{dt}} = \int_0^t \overline{u'_\ell(t)\;u'_\ell(t')dt'} \qquad (2)$$

where the overbar in the conventional sense denotes ensemble averaging.

Introducing the Lagrangian correlation coefficient

$$R_\ell(\tau) = \frac{\overline{u'_\ell(t)\;u'_\ell(t+\tau)}}{\overline{u'^2_\ell}}$$

into (2) we have

$$K_x = \overline{u_\ell'^2} \int_0^t R_\ell(\tau) d\tau \qquad (3)$$

When the diffusion time has proceeded for long enough time for the velocity at time t to be uncorrelated with its value at t = 0, $R_\ell(\tau)$ will drop off from 1 to zero beyond some time lag $\tau = t_\ell$, the Lagrangian correlation time scale.

Physically t_ℓ is the decay time scale of those eddies, which contribute significantly to the diffusion. Therefore, for times $t > t_\ell$, the integral in (3) will approach a constant T_L, the Lagrangian integral time scale. This corresponds to the final phase of diffusion of a point source cloud in a stationary and homogeneous turbulence, where the horizontal turbulent exchange coefficient $K_x = \overline{u_\ell'^2}\, T_L$ attains a constant value.

Experimentally, it is rather difficult to measure Lagrangian current fluctuations and therefore the Lagrangian integral time scale. To make calculations of horizontal exchange coefficients, one would be tempted to use corresponding Eulerian values, which can be readily calculated from long time series of current measurements. In a stationary and homogeneous turbulence, the Lagrangian variance $\overline{u_\ell'^2}$ can be assumed to be equivalent to the Eulerian variance $\overline{u_e'^2}$ (Lumley and Panofsky, 1964). This equivalence is only valid for small scales, in which diffusion times are short and the particles retain their initial turbulent velocities. For calculating the Lagrangian integral time scale, a practical technique suggested by Hay and Pasquill (1959) forms the basis. The essential difference between Eulerian (fixed point) and Lagrangian velocities is that at a fixed point, velocity fluctuations appear rather more quickly, as turbulent eddies are advected past the instrument. Hay and Pasquill (1959) argued that if the fixed point velocity record is slowed down by a suitable factor, then it is possible to obtain velocity-history of drifting particles in a Lagrangian framework. Further they assumed that correlation functions in the Lagrangian and Eulerian framework have similar shapes but differ only by a factor on the time axis:

$$R_\ell(\tau) = R_e(\beta\tau)$$

where β is an empirical constant greater than unity.

Introducing these assumptions, horizontal exchange coefficients in terms of Eulerian statistics from (3) is given by:

$$K_x = \beta \, \overline{u_e'^2} \int_0^t R_e(\tau)d\tau \qquad (4)$$

Following the same arguments as above, one would expect $R_e(\tau)$ to drop off from 1 to small values beyond some time lag $\tau = t_e$, the Eulerian correlation time scale. For times $t > t_e$, the integral in (4) will approach a constant T_e, the Eulerian integral time scale, in which case the horizontal exchange coefficient is simply

$$K_x = \beta \, \overline{u_e'^2} \cdot T_e \qquad (5)$$

While it is relatively simple to calculate $\overline{u_e'^2}$ and T_e from time series measurements of currents, the factor β is rather difficult to establish. Among other things β is expected to depend on the energy spectra of turbulent fluctuations, intensity of turbulence and the stability. Values of β ranging from 1.3 to 11.3 have been reported for small-scale grid generated turbulence to large scale atmospheric turbulence. For an oceanic case Schott and Quadfasel (1979) reported a factor β' (a factor somewhat similar to β) around 1.4 ± 0.4 based on simultaneous Lagrangian and Eulerian measurements in the Baltic.

For the sake of simplicity we have arbitrarily set $\beta = 1$ in our calculations of horizontal exchange coefficients, since an appropriate value of β is rather difficult to establish. This means an under-estimation of the horizontal exchange coefficient.

As stated earlier, the above theoretical framework for calculating horizontal exchange coefficients is strictly valid in a field of stationary and homogeneous turbulence, which rarely exists in actual oceanic conditions. However, from the practical point of view, a climatology of the exchange characteristics can be established from a long time series of Eulerian currents, measured under actual oceanic conditions. The analysis presented in this report is aimed towards that goal.

3. ANALYSIS AND CALCULATIONS

The basic time series current meter data available for our calculations are hourly mean values of speed in cm sec.$^{-1}$ and direction in degrees measured from north. The data were resolved into East (u) and North (v) components. This preliminary analysis results in two time series u(t) and v(t), which are then used as basic data for the calculation of horizontal exchange coefficients.

In order to calculate turbulent exchange parameters, an essential step is to separate the mean flow and fluctuations from the time series data. Numerical filtering technique is a very useful tool for this purpuse, i.e. to define the mean and fluctuations from long time series data. The selection of the appropriate filter is a crucial step for this type of analysis and requires some physical insight. Kinetic energy spectra of currents often provide the physical basis for design of appropriate digital numerical filters, which would separate mean flow and the fluctuations within a specified spectral window. The spectral minimum is a characteristic feature of the energy transfer from large scale and basin wide mean circulation to smaller fluctuations, such as inertial oscillations (Murthy and Dunbar, 1981). Kinetic energy spectra point out two characteristic features: a dominant peak near 14 h corresponding to the inertial oscillations and a minimum somewhere between 20 and 40 h (see Figure 2). Thus spectral minima can be used as a transition between the mean flow and the fluctuations. Accordingly, a digital low pass filter with frequency response equal to unity for periods longer than 48 hours and gradually decreasing to zero at 24 hours was designed and applied to time series current meter data (see Figure 3). The mean flow characteristics derived by the application of this filter is shown in Figure 4. The spectral characteristics shown in Figure 2 illustrate clearly that the filter removes almost all fluctuations shorter than 2 days. Thus all effects of free surface seiches, tidal and inertial motions appear as fluctuations, while oscillations with periods longer than two days remain as a part of the mean flow.

The running mean values $\bar{u}(t)$ and $\bar{v}(t)$ are subtracted from the instantaneous values $u(t)$ and $v(t)$ to define the fluctuations $u'(t)$ and $v'(t)$. The variance $\overline{u'^2}(t) = \overline{[u(t) - \bar{u}(t]^2}$ is often used as a measure of the magnitude of velocity fluctuations. The overbar indicates the usual time averaging.

Having calculated the variance, the next step in our analysis is to calculate the Eulerian integral time scale characteristic of these fluctuations. This is done by defining the Eulerian autocorrelation coefficient:

$$R_e(\tau) = \frac{\sum_{t=0}^{T-\tau} u'(t)\, u'(t+\tau)}{\left\{\sum_{t=0}^{T-\tau} u'^2(t) \sum_{t=0}^{T-\tau} u'^2(t+\tau)\right\}^{1/2}}$$

where T is the total time series record length.

The Eulerian autocorrelation coefficient was computed for u and v fluctuating components, and some examples are shown in Figure 5. The integral time-scale was then calculated by integrating the correlogram to the point of first zero crossing, where $R_e(t) = 0$. It is assumed that at that time the "turbulent eddies" have forgotten their origin. Thus the time scale T_e is given by:

$$T_e = \int_0^{t_0} R_e(\tau)d\tau$$

where t_0 is the time for the first zero crossing of the Eulerian correlogram.

Horizontal exchange coefficients K_x and K_y are calculated using equation (4) derived earlier. Parameters characteristic of horizontal exchange processes due to currents are calculated for all the available data base and summarized in Tables 2 a - d.

4. CHARACTERISTICS OF HORIZONTAL EXCHANGE

For time scales of motions of order 1 - 2 days covered in the present calculations, the structure of horizontal turbulence is nearly isotropic $(\overline{u'^2} \sim \overline{v'^2})$, and this is also reflected in other turbulence parameters, such as the Eulerian integral time scale $(\tau_u \sim \tau_v)$. The Eulerian integral time scales τ_u and τ_v are remarkably consistent, and the average being about 2 hours for all stations and at all depths, except for stations VP1/62 and VP2/60 (the latter instruments were placed within two meters from the bottom and probably very influenced by the bottom topography). The values of horizontal exchange coefficients range from 1 to 10 m^2 sec^{-1} and compare reasonably well within a factor of 2 or so with the values calculated by Jankowski and Catewicz (1984) for the Central Baltic. Higher values are generally obtained when the inertial oscillations are predominant in the time series. Presence of dominant inertial or near-inertial oscillations were observed in stations 6G and T39 (Figures 6 and 7) and in VP1 and VP2, all located in the surface layer (~ 10 m). The values of horizontal exchange coefficients in these cases ranged from 15 to 45 m^2 sec^{-1}, an order of magnitude greater than at the other stations. This indicates that in the presence of strong inertial oscillations, horizontal exchange is considerably enhanced.

Vertical variability of K_x and K_y was examined at stations where simultaneous time series current meter data were available from at least 4 - 5 depths. Figure 8 shows a plot of K_x and K_y with depth for these stations. Vertical variability of the horizontal exchange coefficients with depth is not particularly significant, although there is a mild indication of a minimum at 20 - 30 m depth and a maximum at deeper depth. This indicates that the momentum exchange to deeper depths is quite efficient. This is to be expected, since all current meter observations presented in Figure 8 were made in April - May, when the Baltic is vertically well mixed all the way down to the pychnocline at 60 - 70 m depth.

In an effort to look at the synoptic vertical variability of horizontal exchange coefficients, a composite plot of K_x and K_y with depth for all stations and all depths was constructed, as shown in Figure 9. Since the horizontal turbulent exchange is nearly isotropic ($K_x \sim K_y$), one could use such a plot as a general guide in designating bulk values of horizontal excange coefficients for different layers.

5. CONCLUSIONS

The present analysis indicates that the following bulk values of horizontal exchange coefficients are appropriate to simulate sub-grid motions in numerical transport and diffusion models, under the condition that the advective velocities are passed through a low-pass filter similar to that used for the calculation of the coefficients.

LAYER	HORIZONTAL EXCHANGE COEFFICIENT
0 - 15 m	10 - 50 m sec^{-1}
15 - 70 m	3 - 10 m^{2} sec^{-1}
> 70 m	1 - 3 m^{2} sec^{-1}

ACKNOWLEDGEMENTS

This study has been supported by SSI (National Institute of Radiation Protection). SMHI is deeply grateful to Dr. C.R. Murthy (Canada Centre for Inland Waters) for his collaboration. The authors thank J. Kielmann (University of Kiel), P. Alenius (Institute of Marine Research, Helsinki) and B. Håkansson (University of Gothenburg) for their contribution of current meter data, as well as Vera Kuylenstierna for typing and Eva-Lena Ljungqvist for drawing the figures.

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Table 1a

D A T A   S U M M A R Y

Station No. / Depth m	Instrument type	Sampling frequency min.	Duration	Number of hourly values
1/15	Aanderaa	10	750410--0518	910
1/35	"	10	750410--0518	910
2/16	"	10	750410--0518	908
2/26	"	10	750410--0518	908
2/37	"	10	750410--0518	908
2/57	"	10	750410--0518	908
2/67	"	10	750410--0518	908
3/16	"	10	750410--0518	910
3/26	"	10	750410--0518	910
3/36	"	10	750410--0518	910
3/67	"	10	750410--0518	910
4/15	"	10	750410--0518	909
4/25	"	10	750410--0518	909
4/35	"	10	750410--0518	909
4/55	"	10	750410--0518	909
4/62	"	10	750410--0518	909
5/67	"	10	750415--0504	450
6F/11	"	10	750416--0523	887
6F/66	"	10	750416--0523	887
6G/10	"	10	750416--0523	882
7/25	"	10	750412--0514	761
7/35	"	10	750412--0524	1013
7/55	"	10	750412--0524	1012
9/15	"	10	750412--0516	823
9/35	"	10	750412--0516	823
9/55	"	10	750412--0516	823
9/67	"	10	750412--0516	823

Table 1b

DATA SUMMARY

Station No. / Depth m	Instrument type	Sampling frequency min.	Duration	Number of hourly values
10/19	Aanderaa	10	750412--0505	555
10/29	"	10	750412--0517	830
10/39	"	10	750412--0517	830
10/58	"	10	750412--0515	798
11/35	"	10	750412--0517	832
14/55	"	10	750412--0508	621
15/19	"	10	750412--0517	847
15/39	"	10	750412--0517	847
T39/8	Geodyne	10	730730--0904	857
A/17	Aanderaa	30	800423--0610	1161
B/17	"	30	800423--0611	1177
C/17	"	30	800424--0613	1192
C/35	"	30	800424--0517	585
U/50	"	20	820702--0901	1455
U/85	"	20	820702--0901	1460
614/114	"	10	770603--0619	405
615A/25	"	10	770603--0619	396
615/70	"	10	770602--0619	405
616/37	"	10	770602--0619	406
SR9/30	"	10	770602--0618	382
VP1/13	"	10	780718--0803	310
VP1/30	"	10	780718--0803	310
VP1/62	"	10	780718--0803	310
VP2/13	"	10	780719--0803	300
VP2/60	"	10	780719--0803	300

Table 2 a

STN No. / DEPTH (m)	MEAN VELOCITY		VARIANCE			TURB. INT.		ENERGY			TIME SCALE		HORIZ. EXCH. COEFFICIENT	
	$\overline{u}$	$\overline{v}$	$\overline{u'^2}$	$\overline{v'^2}$	$\overline{u'v'}$	i_u	i_v	MEAN	TURB.	TOT.	τ_u	τ_v	K_x	K_y
	cm sec^{-1}		cm^2 sec^{-2}					cm^2 sec^{-2}			hrs		m^2 sec^{-1}	
1/15	-2.09	-2.62	8.5	10.9	1.29	0.87	0.98	32.64	11.02	43.66	2.13	2.28	6.6	8.9
1/35	-0.84	-0.91	17.27	21.24	-0.34	3.34	3.7	37.67	20.74	58.41	2.17	2.21	13.5	16.9
2/16	-4.04	0.26	6.9	8.13	1.59	0.65	0.70	56.95	9.08	66.05	2.28	2.48	5.7	7.3
2/26	-3.45	0.98	6.0	7.17	1.69	0.68	0.75	54.60	8.02	62.62	2.15	2.11	4.6	5.5
2/37	-3.10	2.14	8.84	9.89	1.93	0.79	0.83	59.03	10.82	69.85	2.04	2.14	6.5	7.6
2/51	2.58	2.29	7.87	8.9	0.15	0.81	0.87	37.11	8.9	46.03	1.92	1.83	5.5	5.9
2/67	1.6	4.5	5.75	7.88	2.54	0.49	0.59	81.03	7.86	88.86	1.90	2.29	3.9	6.5
3/16	-1.48	2.91	11.96	6.97	1.14	1.05	0.81	79.62	11.71	91.33	2.24	2.10	9.7	5.3
3/26	-2.27	4.11	10.03	5.25	0.93	0.67	0.48	71.73	9.3	81.04	2.08	2.0	7.5	3.8
3/36	-0.68	2.7	13.22	15.92	3.11	1.29	1.4	72.39	17.3	89.69	2.21	1.98	10.6	11.5
3/67	-0.65	-0.45	5.45	6.7	3.38	2.9	3.2	7.05	6.6	13.67	1.77	1.95	3.5	4.7
4/15	-2.96	-1.05	11.27	19.28	0.87	1.07	1.39	72.71	16.44	89.16	2.04	2.06	8.3	14.3
4/25	-2.29	-1.26	9.67	14.81	0.84	1.18	1.47	64.64	13.09	77.74	1.81	1.80	6.3	9.6
4/35	-1.52	-0.35	12.10	17.86	0.86	2.22	2.7	62.84	16.02	78.86	1.69	1.80	7.4	11.6
4/55	0.93	-0.97	16.54	20.7	2.4	3.02	3.38	43.76	19.67	63.43	1.76	1.77	10.5	13.2
4/62	2.61	-1.16	5.24	9.71	-0.94	0.80	1.09	31.94	8.54	40.48	1.52	1.96	2.9	6.9

Table 2 b

STN No. / DEPTH (m)	MEAN VELOCITY		VARIANCE			TURB. INT.		ENERGY			TIME SCALE		HORIZ. EXCH. COEFFICIENT	
	$\bar{u}$	$\bar{v}$	$\overline{u'^2}$	$\overline{v'^2}$	$\overline{u'v'}$	i_u	i_v	MEAN	TURB.	TOT.	τ_u	τ_v	K_x	K_y
	cm sec^{-1}		cm^2 sec^{-2}					cm^2 sec^{-2}			hrs		m^2 sec^{-1}	
5/67	0.56	-1.01	2.02	3.04	0.30	1.23	1.5	13.57	2.66	16.23	1.97	1.93	1.4	2.1
6F/11	2.25	1.89	23.26	27.88	-8.57	1.64	1.79	68.34	26.23	94.57	1.84	1.64	15.4	16.5
6F/66	1.2	0.66	9.7	12.61	0.57	2.28	2.60	17.33	11.37	28.71	1.98	1.96	6.9	8.9
6G/10	2.24	3.85	39.07	38.38	-12.16	1.4	1.39	100.24	40.44	140.68	1.86	1.81	26.1	25.0
7/25	-3.38	2.71	7.69	5.60	-1.34	0.64	0.55	48.05	7.46	55.5	1.99	1.92	5.5	3.9
7/35	-2.09	1.94	8.8	9.5	-2.27	1.04	1.08	51.25	9.98	61.23	1.97	2.06	6.3	7.1
7/55	2.03	2.09	13.32	18.54	1.75	1.25	1.48	52.48	16.92	69.44	2.09	2.17	10.0	14.5
9/15	-3.11	-1.87	10.56	9.73	-1.65	0.89	0.86	42.93	10.69	53.62	2.29	2.09	8.7	7.4
9/35	-2.9	-0.82	8.78	12.25	-4.07	0.98	1.16	52.54	11.15	63.69	1.85	1.91	5.9	8.4
9/55	-0.62	0.29	8.68	11.65	0.44	9.9	11.5	46.44	10.83	57.28	2.02	2.1	6.3	8.8
9/67	1.57	-0.96	9.19	10.57	0.41	1.64	1.76	31.19	10.37	44.57	1.88	1.94	6.2	7.4
10/19	-3.19	-0.29	16.22	15.54	-0.85	1.26	1.23	40.18	16.86	57.04	2.23	2.07	13.0	11.6
10/29	-0.85	1.42	9.94	7.99	1.42	1.91	1.71	39.48	9.57	49.05	1.99	1.92	7.1	5.5
10/39	0.37	1.64	16.80	17.26	1.38	2.44	2.47	48.67	17.80	66.47	1.79	2.00	10.9	12.5
10/58	-1.19	0.16	10.48	13.11	1.95	2.69	3.01	15.09	12.26	27.36	2.03	2.2	7.7	10.4

Table 2 c

STN No. / DEPTH (m)	MEAN VELOCITY		VARIANCE			TURB. INT.		ENERGY			TIME SCALE		HORIX. EXCH. COEFFICIENT	
	$\overline{u}$	$\overline{v}$	$\overline{u'^2}$	$\overline{v'^2}$	$\overline{u'v'}$	i_u	i_v	MEAN	TURB.	TOT.	τ_u	τ_v	K_x	K_y
	cm sec^{-1}		cm^2 sec^{-2}					cm^2 sec^{-2}			hrs		m^2 sec^{-1}	
11/35	0.53	-0.62	6.49	5.2	1.57	4.7	4.3	23.22	6.7	29.99	2.66	2.21	6.2	4.2
14/55	0.59	-2.1	11.08	15.5	2.88	1.5	1.8	21.97	14.36	36.33	2.12	2.18	8.5	12.2
15/19	-1.4	1.64	6.55	9.25	0.43	1.17	1.4	26.13	8.49	34.62	1.89	1.78	4.5	6.0
15/39	1.55	1.55	7.47	9.54	0.57	1.72	1.95	24.47	8.9	33.38	2.0	1.95	5.4	6.7
T39/8	1.44	-1.35	57.4	45.11	3.98	3.8	3.39	25.00	53.39	78.39	2.21	2.15	45.6	35.0
A/17	0.23	-1.26	11.9	6.83	0.13	2.69	2.04	57.06	10.39	67.46	2.09	2.01	8.90	4.6
B/17	-0.39	3.11	5.89	5.89	0.14	0.77	0.77	22.00	6.24	28.64	1.73	1.76	3.7	3.7
C/17	-0.76	-3.98	8.93	9.07	-0.46	0.74	0.74	30.10	9.32	39.43	1.86	1.87	6.0	6.1
4/50	-2.47	2.9	5.23	6.9	-0.45	0.59	0.69	36.38	6.32	42.69	1.76	1.76	3.3	4.4
4/85	-3.22	0.75	4.92	4.22	0-86	0.67	0.62	35.53	4.83	40.35	1.82	1.73	3.2	2.6
614/114	-0.67	1.54	2.03	2.34	-0.25	0.85	0.92	5.32	2.36	7.68	1.64	1.60	1.2	1.4
615A/25	-2.5	-2.67	5.67	4.72	-0.23	0.65	0.59	12.6	5.4	18.00	1.56	1.80	3.2	3.1
615/70	-1.16	-1.79	2.94	2.87	1.09	0.80	0.79	9.81	2.99	12.81	1.73	1.67	1.8	1.7
616/37	-0.16	-2.18	3.48	7.92	0.69	0.85	1.28	12.52	6.40	18.93	1.71	1.97	2.2	5.6
SR9/30	0.78	-2.02	4.74	4.32	-1.9	1.00	0.96	18.79	5.54	24.33	1.85	1.69	3.1	2.6

Table 2 d

STN No. / DEPTH (m)	MEAN VELOCITY $\bar{u}$	$\bar{v}$	VARIANCE $\overline{u'^2}$	$\overline{v'^2}$	$\overline{u'v'}$	TURB. INT. i_u	i_v	ENERGY MEAN	TURB.	TOT.	TIME SCALE u	τ_v	HORIX. EXCH. COEFFICIENT K_x	K_y
	cm sec^{-1}		cm^2 sec^{-2}					cm^2 sec^{-2}			hrs		m^2 sec^{-1}	
VP1/13	-1.79	-4.93	58.37	54.73	-4.36	1.46	1.41	21.31	56.81	78.12	1.61	1.64	33.7	32.3
VP1/30	-0.97	-2.96	19.07	16.48	-0.62	1.40	1.30	9.16	17.84	27.00	1.65	1.65	11.3	9.8
VP1/62	-0.75	-1.55	5.66	7.24	-0.84	1.38	1.56	5.93	6.57	12.51	1.36	1.41	2.8	3.7
VP2/13	-2.71	-5.80	49.85	36.97	-3.32	1.10	0.95	30.04	44.04	74.08	1.61	1.52	28.8	20.2
VP2/60	2.09	-0.27	0.80	0.48	0.003	0.42	0.33	4.33	0.65	4.99	0.98	1.01	0.28	0.18

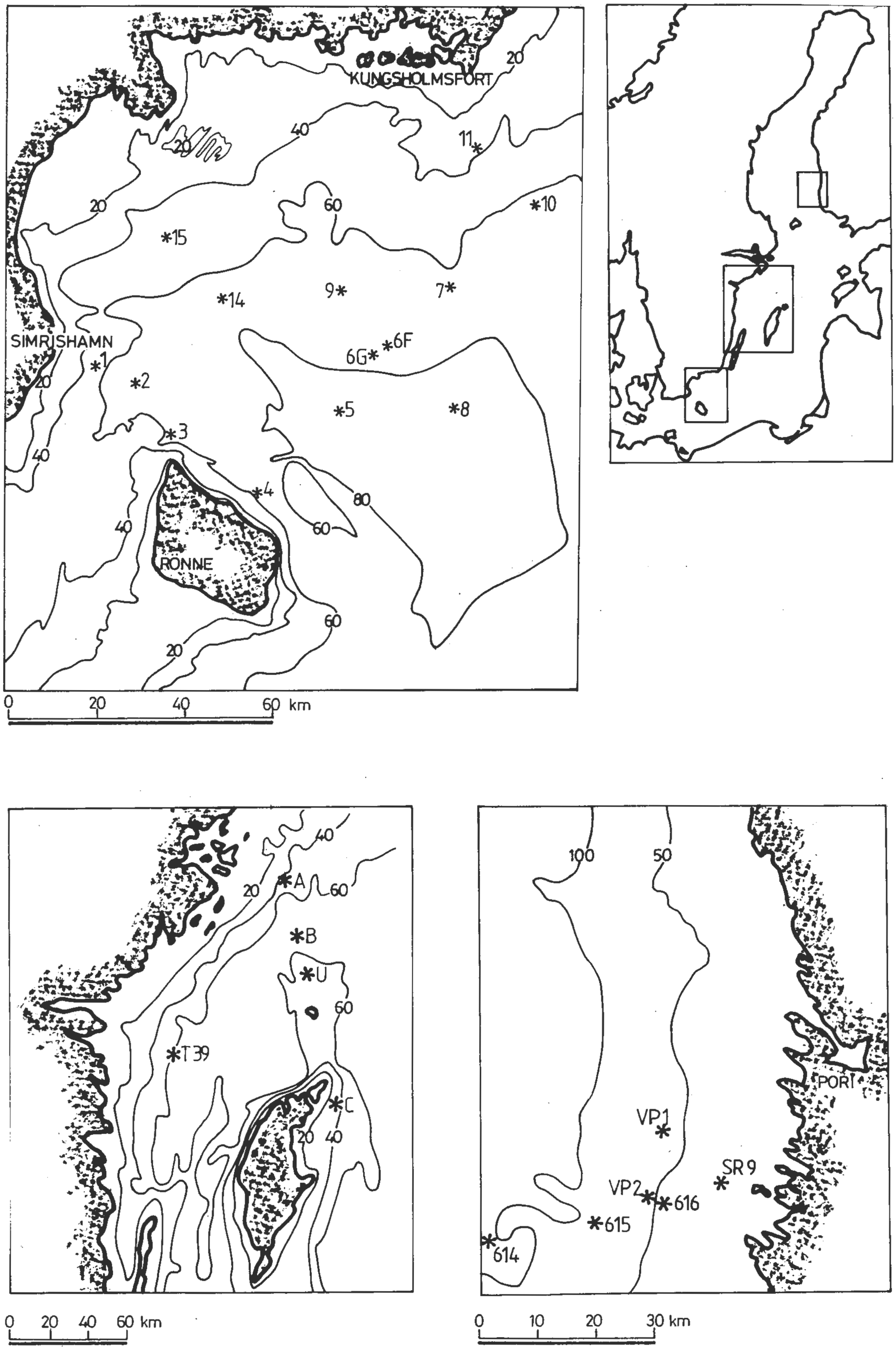


FIG. 1. GEOGRAPHIC DISTRIBUTION OF CURRENT METER STATIONS

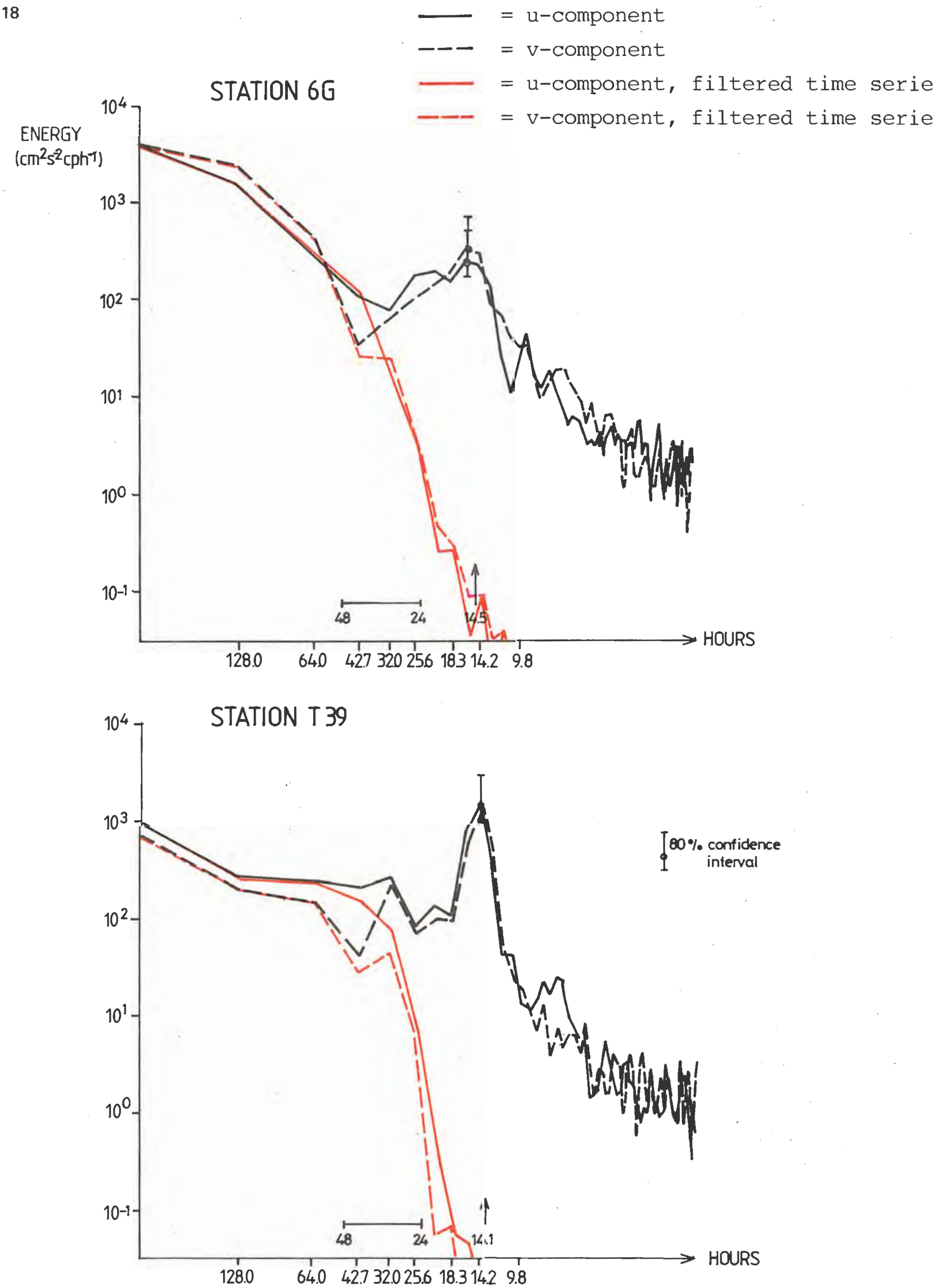


FIG. 2. KINETIC ENERGY SPECTRAS

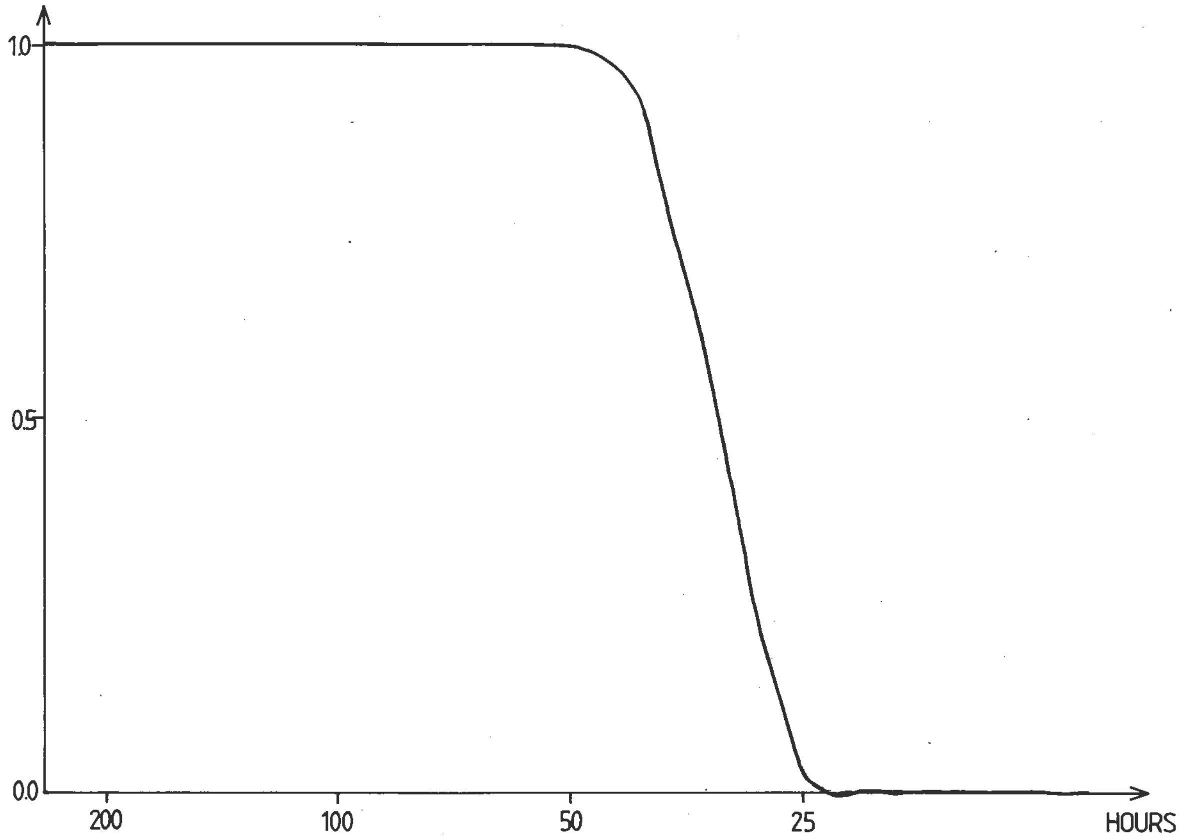


FIG. 3. RESPONSE FUNCTION OF LOW-PASS FILTER (24-48 HOURS CUT-OFF)

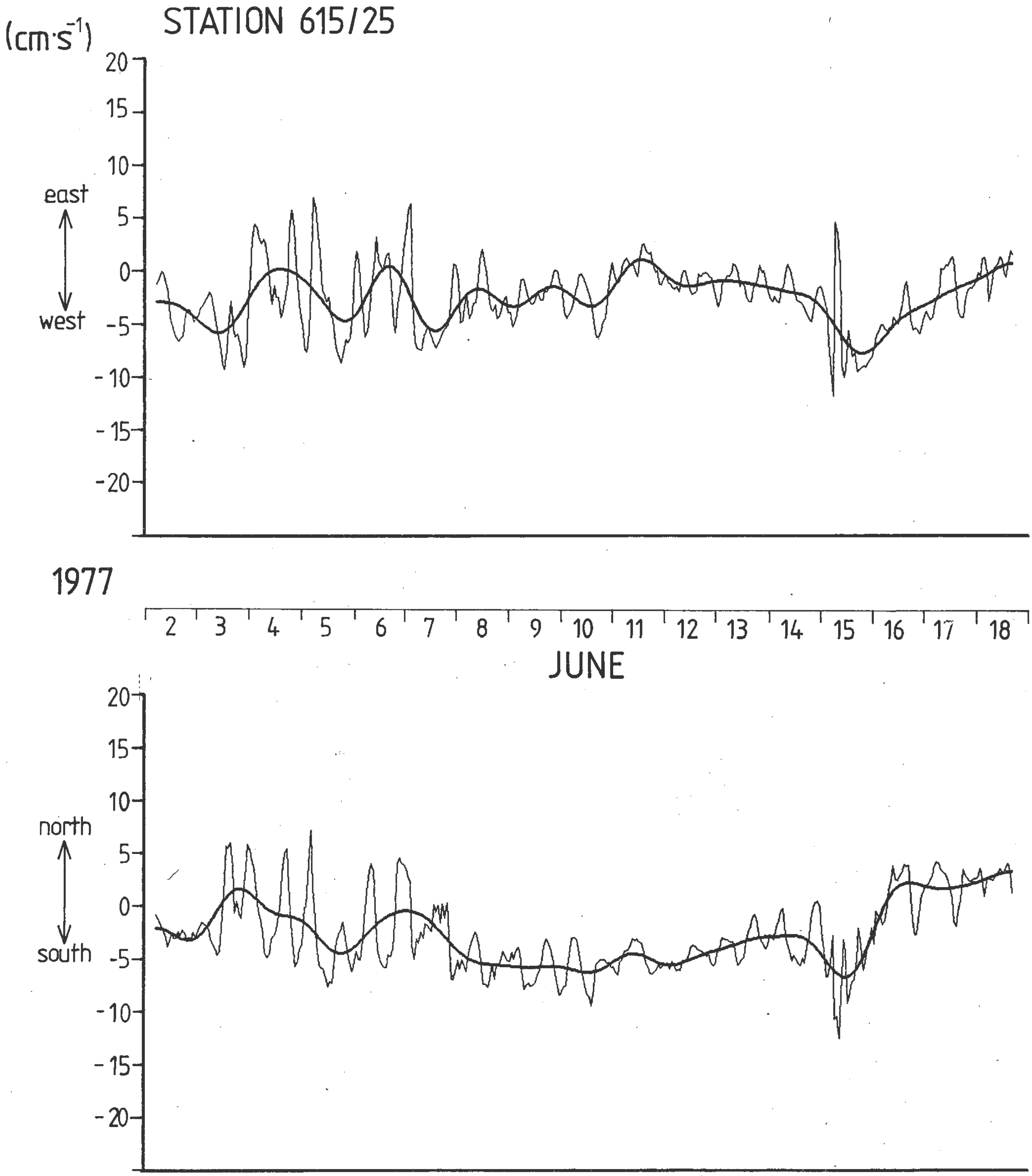
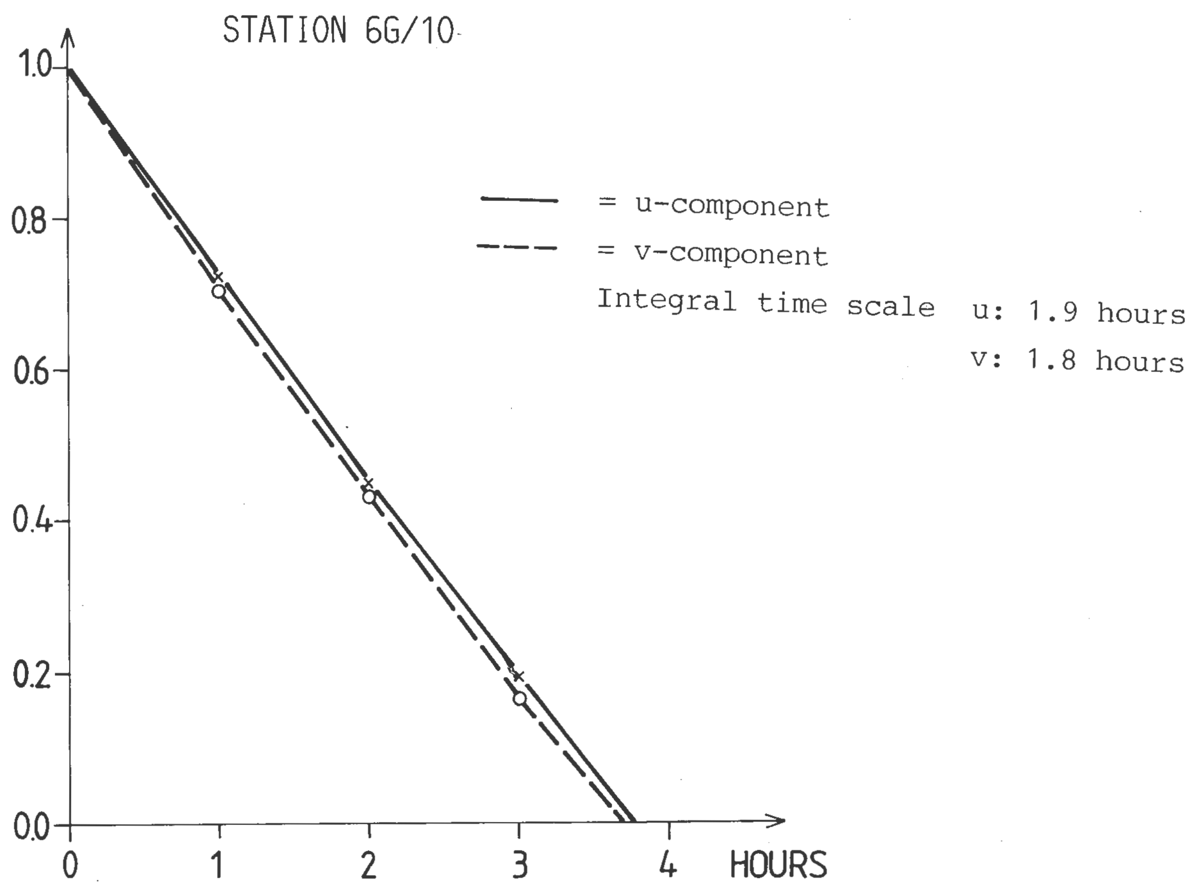


FIG. 4. MEAN FLOW CHARACTERISTICS WITH THE APPLICATION OF A 24-48 HOURS LOW-PASS FILTER (HEAVY LINE)



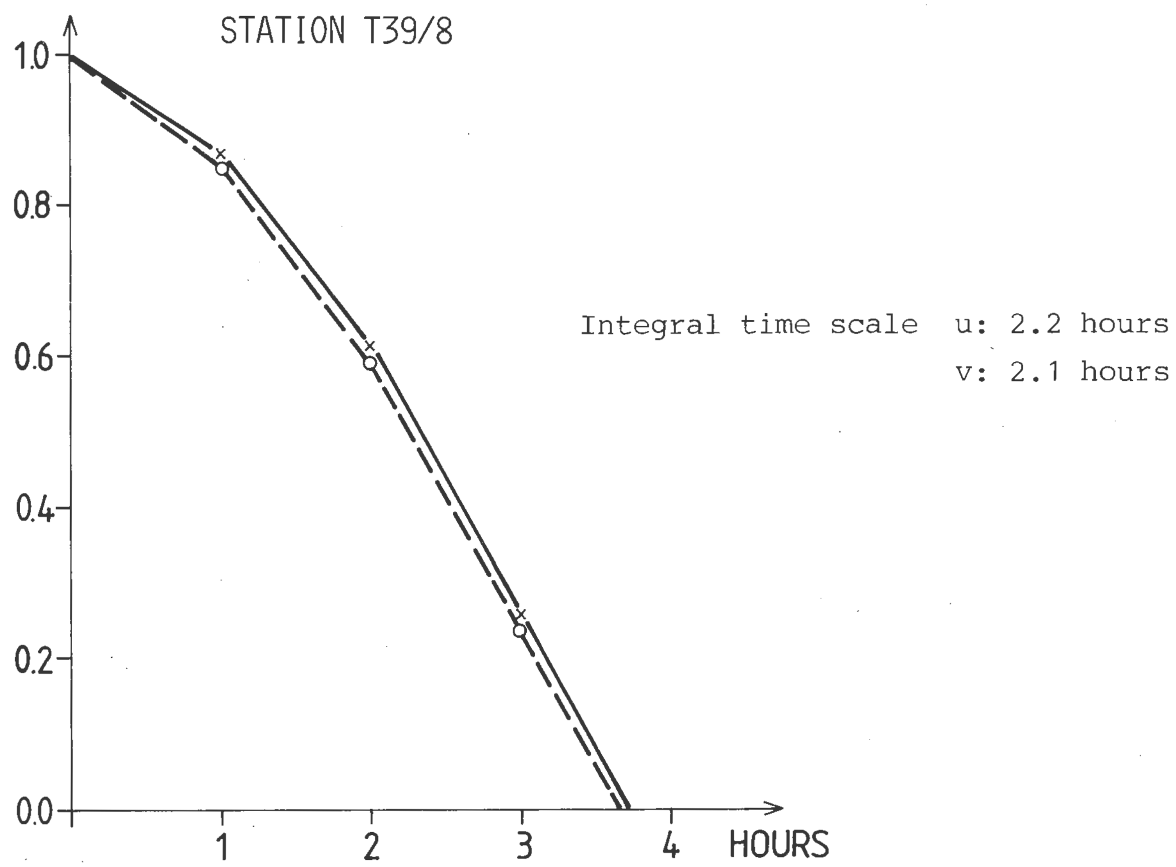


FIG. 5. AUTOCORRELATION COEFFICIENTS

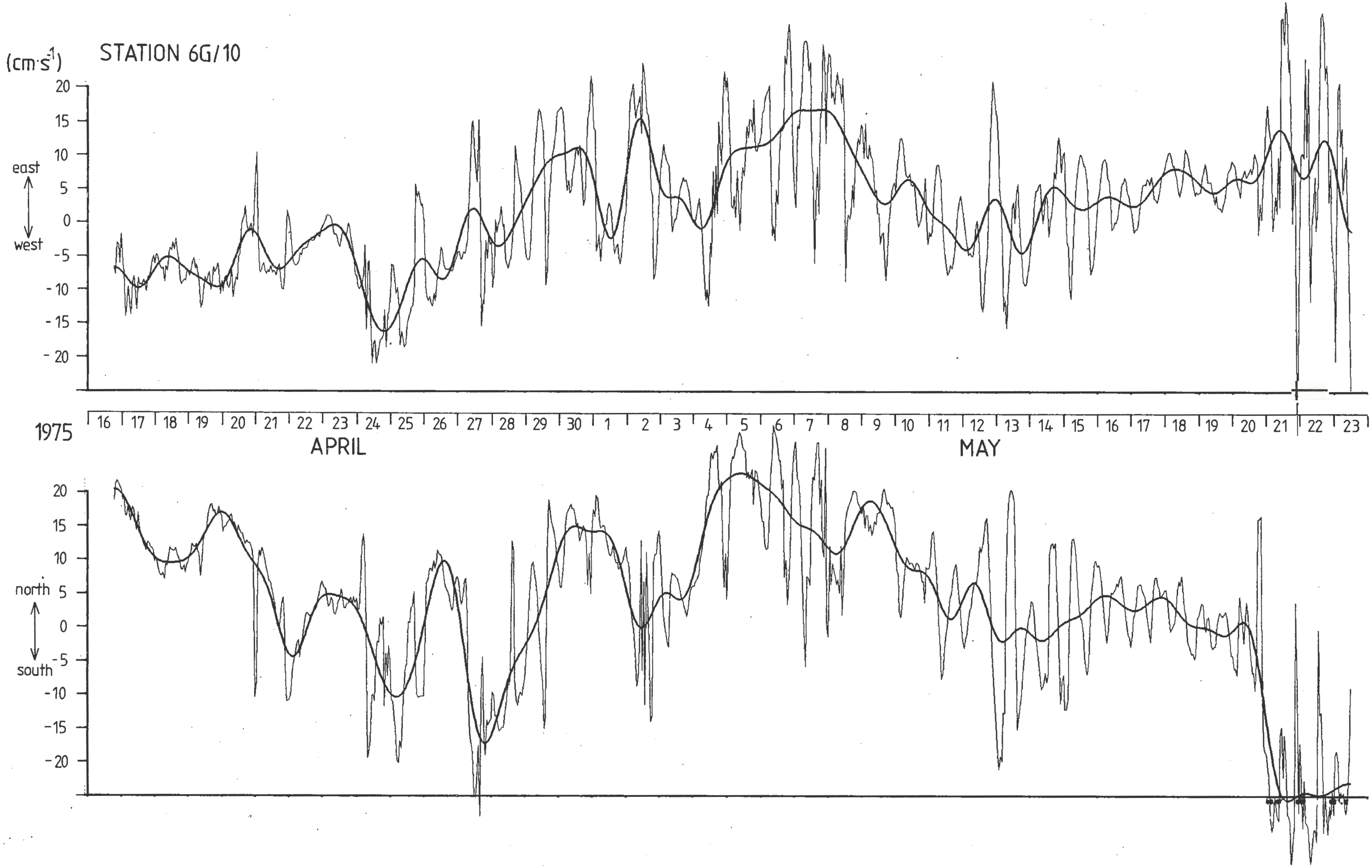


FIG. 6. TIME SERIE FROM STATION 6G (BORNHOLM BASIN)

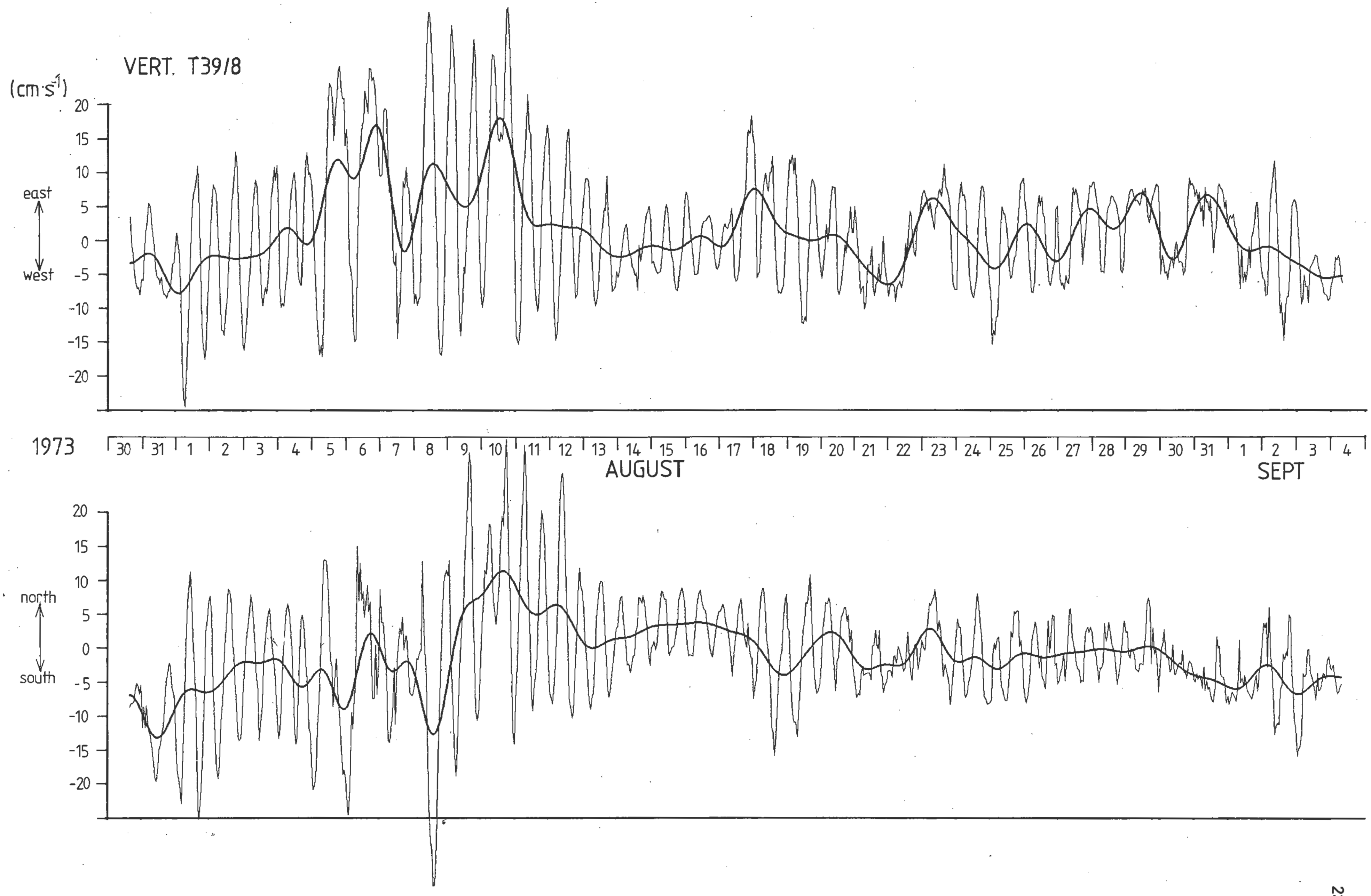


FIG. 7. TIME SERIE FROM STATION T39 (BETWEEN GOTLAND AND SWEDISH MAINLAND)

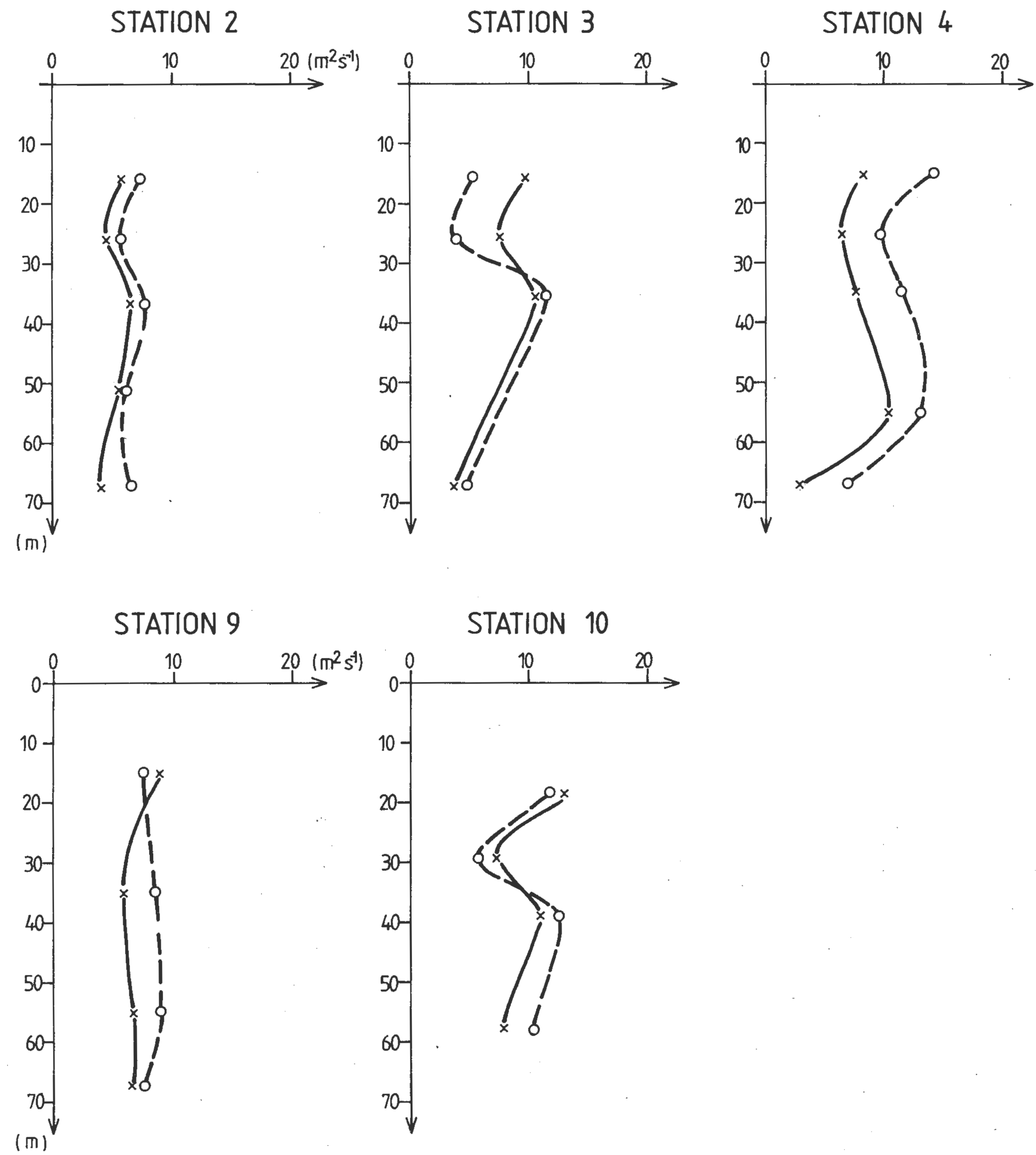


FIG. 8. VERTICAL VARIABILITY OF HORIZONTAL EXCHANGE COEFFICIENTS (BORNHOLM BASIN)

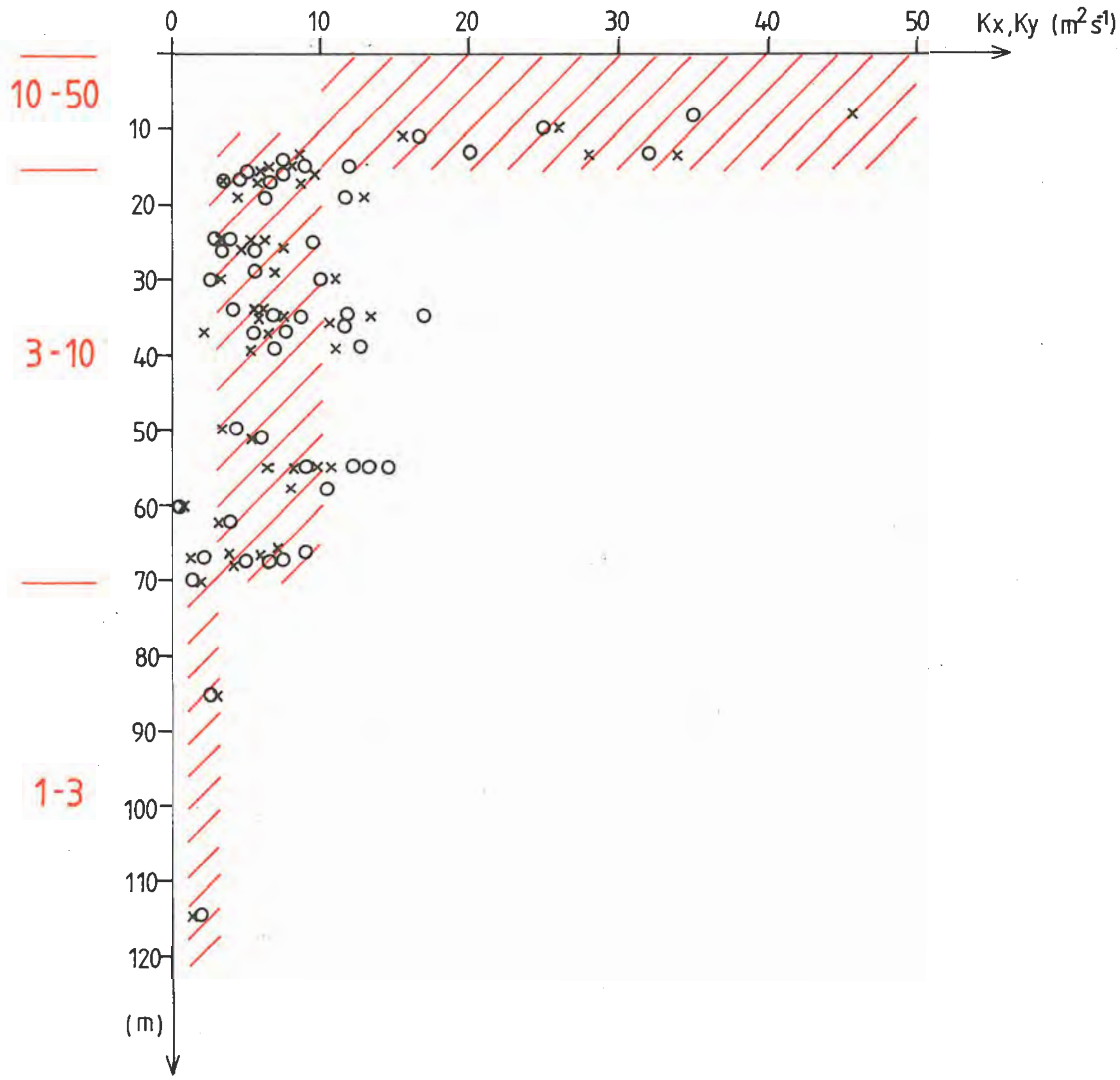


FIG. 9. VERTICAL VARIABILITY OF HORIZONTAL EXCHANGE COEFFICIENTS (ALL STATIONS)

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ISSN 0283/1112