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C.M. 1986/C:8
Ref. Biological Oceanography
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ANNUAL CYCLES AND PHENOMENA ON OTHER TIME SCALES
IN TEMPERATURE, SALINITY, NUTRIENTS AND PHYTOPLANKTON
AT HELGOLAND REEDE 1962 - 1984

by

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ABSTRACT

The long-term time series of temperature, salinity, plant
nutrients and phytoplankton biomass at Helgoland Reede in the
German Bight are investigated with respect to prominent time
scales by spectral analysis of variance. This analysis was based
on 23 years of data from 1962 to 1984.

The data are presented in the form of annual cycles by projecting
the data into one year, to demonstrate the dominant features of
the annual dynamics. It turns out that the cycles of diatoms and
silicate are inversely related to each other, more than are
diatoms and phosphate. The annual cycles of the nutrients nitrate
and nitrite are inversely related to the flagellates´ biomass.
The Elbe river outflow, which is directly related to the nitrogen
compounds, seems to prepare the situation for relatively high
flagellates´ biomass development during summer after diatoms
decrease due to the depleted silicate. Thus silicate seems to
limit the diatoms´ development in early summer at Helgoland, but
not phosphate or nitrate, and later on flagellates take over the
leading role.

Changing to the frequency domain, it turns out that the out-
standing frequency in many of the spectra is the annual frequen-
cy. There most of the variance is found for the parameters sea
surface temperature, phosphate, and nitrate. Salinity, nitrite,
ammonia, silicate, the phytoplankton entities, and Elbe river
discharge exhibit the bulk of their total variance in the fre-
quency band $1 < f < 10$ cycles/year. For phosphate, nitrate, and
nitrite the spectrum shows constant (or even decreasing) variance
for frequencies smaller than 1/year, while the variance de-
creases, similar to temperature, for frequencies larger than
1/year. Most of the parameters depend on frequency with a decay
rate of about -5/3 for frequencies > 10 cycles/year. Nitrate and
silicate exhibit a stronger decay with a rate of about -2.12,
Elbe river discharge with a rate of -3.43. In the frequency band

1

1 < f < 10 cycles/year most decay rates are weaker than -5/3 (except for phosphate and nitrate), between -0.5 (for diatoms) and -1.5.

1. Introduction

The Helgoland Reede time series are amongst the longest and most complex chemical and biological data sets on the European continental shelf. The time series were started in 1962 by the Biologische Anstalt Helgoland and include a period of rising human impact on North Sea coastal waters.

The Helgoland data set provides a unique possibility to investigate, on which time scales the essential processes within the coastal marine plankton system take place. Due to the lack of sufficiently long time series, only very few investigations exist about time scales in chemical and biological data sets and if, they usually refer only to very few state variables (e.g. TONT & PLATT, 1978).

As is known, in an isotropic turbulence field the spectrum decreases exponentially with wave number by a decay rate of -5/3. The first one applying this theoretical result to the interpretation of chlorophyll variance spectra was PLATT (1972), for time scales of hours. Since then many authors obtained wave number spectra for chlorophyll measurements on the basis of spatial sections. Statements about the spectral distribution of spatial variance have sometimes been transferred to time by assuming the validity of the "frozen field" hypothesis (OKUBO, 1980; PLATT & DENMANN, 1975). Results for time scales larger than 1 day are hardly given (e.g. TONT & PLATT, 1978).

The Helgoland data set allows for direct investigation of time scales in the range of, say, 5 days to 23 years. Long-term trends occurring on time scales from 2 to 23 years have been already presented and discussed by BERG & RADACH (1985), RADACH & BERG (1986), and GILLBRICHT (1986). Here we discuss mainly events and variances on the various shorter time scales in more detail.

It is undecided whether an exponential decrease of variance with a decay rate of -5/3 should be expected for the frequency ranges and location investigated here. In any case, it is striking that many of the parameters exhibit a decay of variance with a rate of about -5/3 for frequencies larger than 10 cycles/year.

2. Material and methods

Surface samples between Helgoland main island and the "Düne" (54° 11.3´N, 7° 54.0´E)) have been collected since 1962 , first on three days, later on five days per week. After temperature measurement, samples were analysed for salinity and the nutrients phosphate, nitrate, nitrite, ammonium, and silicate. Phytoplankton stock was estimated by the technique of UTERMÖHL (1958). Conversions to carbon follow STRATHMANN (1967). Phytoplankton is subdivided into diatoms and the rest, maily consisting of flagellates. Details of the data of single years can be taken from the annual reports of the BIOLOGISCHE ANSTALT HELGOLAND (1962-1984).

3. Annual cycles

To demonstrate the importance of the annual period compared to smaller periods, all 23 years of data are plotted into one year (Figs. 1a-12a). In Figs. 1b to 12b the mean annual cycles are presented, together with a confidence band of a width of two standard deviations. Thus the mean value for every day lies within this band with an error probability of much less than 0.1 %. In the following the term "variability" always means absolute variability.

Water temperatures and salinities off Helgoland are strongly influenced by wind, moving and mixing of water masses of different origin, and by river runoff, precipitation, and heat flux (BECKER, 1981). In winter time, occasionally drift ice is transported from coastal areas as far as Helgoland. Surface temperatures (Fig.1) follow a definite annual cycle. Summer maxima are reaching 16 to 20 °C. Variability in summer is less than in winter time, where minima are mostly higher or lower than the calculated mean values. Surface salinity (Fig.2) has also a typical mean course during a year, but large deviations from mean values occur. In general, salinities in March and May are higher and in April lower than published for the period 1965-1975 (WEIGEL, 1978). Much of the variations may originate in different meteorological forcing, causing the water with important freshwater admixtures to touch Helgoland or to flow northward along the Wadden Sea.

To judge the situation at Helgoland it is important to consider the discharge of the Elbe river (Fig. 3), as an indicator describing the continental run off. The annual cycle is dominated by isolated discharge events. The mean cycle represents only a poor impression of the dynamic of discharge. It has its maximum in April, its minimum in August. Variability has its maximum in January, its minimum in October. In summer strong discharge events occur very rarely. It is reasonable to compare the discharge of the Elbe river with surface salinity near Helgoland, and indeed, for time scales larger than two years a clear inverse relation can be established (BERG & RADACH, 1985).

The amount of nutrients in solution is the result of supplies by rivers and remineralization, and reduction by primary production and currents leaving the area. The different nutrients exhibit different annual cycles.

The concentration of phosphate (Fig. 4) is nearly constant from October till the end of March. Its decline in April and May is reflecting the uptake by multiplying diatoms. Comparing phosphate consumption with phytoplankton stock (Fig.10) we see hardly any relation (see also GILLBRICHT, 1986). To explain this we must be aware of the fact that production and not standing stock is the correct quantity to compare with phosphate decrease. Thus we can assume e.g. a high grazing pressure on the algae !

This state of low concentrations (0.25 m mol P/m^3) remains unchanged until July. Then phosphate increases again. Variability is strongest during late summer and early fall, while it is smallest during the phase of depletion in May/June. In times of rising phosphate contents in the water (beginning in July),

excretion and decomposition of organic matter and remineralization are providing more phosphate than the algae are able to consume.

The annual cycle of nitrate (Fig. 5) has its peak values in January/February and in May, with a relative minimum in March. The high level of about 25 units decreases from May to July down to less than 5 units. The concentration stays at this level until October. Then the concentration increases again until January to the winter level. Variability decreases steadily from January to September (excluding April), and it increases again in the same steady way to the winterly range of variability. The high values of nitrate in winter and spring seem to have a direct relation to the Elbe river discharge. Similar results were obtained earlier by LUCHT & GILLBRICHT (1978).

Nitrate distribution indicates more influence of river input than phosphate content. This can explain why the effect of the phytoplankton spring bloom is registered later than in the phosphate curve. Recovery of nitrate in solution is rather slow, partly because excreted nitrogen-compounds will be reused before oxydation, partly because remineralization is passing more steps and needs a longer time than that of phosphorus.

The annual cycle of nitrite (Fig. 6) has its highest values in December/January. From January on nitrite decreases until March, has a local maximum in April/May, and then decreases again strongly until June. It remains on this level until September and increases lateron steadily to the level of January. Variability is in winter about 5 times as large as in summer. Nitrite is recorded in amounts one order of magnitude lower than nitrate.

Nitrate and nitrite have indeed different annual cycles: The phase of depletion is for nitrite about one month earlier than for nitrate. The high values of nitrite in winter and early spring coincide with high values of the Elbe discharge. This may indicate slow processes of oxydation to nitrate in cold water.

Ammonia (Fig. 7) is another transitional nitrogen compound, excreted by animals, taken up by plants and oxydized by bacteria. There is no definite annual cycle, deviations from a mean value around 7.5 m mol/m³ are rather large. A predominance of degradation in this time of the year should result in slightly higher values during fall. The data seem to back this.

Total inorganic nutrient-N maps essentially the annual cycle of nitrate, after adding the fairly constant background of ammonia of about 7.5 m mol N/m³ (Fig.8).

For silicate (Fig. 9) the annual cycle starts in winter and in early spring (until April) with the highest concentrations. Silicate content drops distinctly during April and May, corresponding to the spring diatom bloom. However, as with the uptake of phosphate, a quantitative connection to the standing stock of phytoplankton cannot be established. The silicate consumption, as that of phosphate in spring, is ten times more than expected from the amount of plankton counted. Although small flagellates needing phosphate can be destroyed by fixation or concealed by detritus, it seems impossible to overlook a large

number of silicate containing diatoms. Consequently consumption and replenishment of phytoplankton should be much quicker than expected.

The low concentrations are observed until September. Then the concentration increases again to winter values. Obviously there is a very strong variability in winter (about 4 times that of summer). The high values in winter coincide with high amounts of discharge of the Elbe river.

Phytoplankton stocks (Fig. 10), presented by their carbon content, appear to develop in the "classical" form for our latitude with two maxima in April/May and August, but this picture is really formed by the superposition of many short-termed bloom events. While diatoms are dominating during the spring maximum, in summer time large stocks of flagellates are of equal importance. The standing stock in winter is about one to two orders of magnitudes smaller than the standing stock in spring and summer. Variability is - on a logarithmic scale -fairly constant, of about one order of magnitude (i.e. the factor of 10).

Diatoms (Fig. 11) appear in several maxima between April and September, with contributions of different species, whose abundance is partly predictable by their demands for light and temperature. Variability is least in winter (one order of magnitude) and greatest in summer (about two orders of magnitude).

Flagellates (Fig. 12) occur with small, naked forms in large numbers but with low carbon contents all the year round. Additionally, numerous dinoflagellates can be observed in summertime. From fall to spring a biomass of 20 - 30 mg C/m^3 is not exceeded. Carbon values during blooms of Ceratia reach 1000 mg C/m^3 !

To summarize, the annual cycles of diatoms and silicate seem to be inversely related. The same is true for diatoms and phosphate. Nutrients-N of nitrate and nitrite are inversely related to flagellates´ biomass, Elbe discharge and nitrate/ nitrite run parallelly. Therefore, the nutrient input of N-components by the river discharge reaching Helgoland prepares the basis for the build-up of flagellates´ biomass in summer. Diatoms are not able to fully use the nitrogen load of the water. It is in June, when blooms of flagellates first occur, that nitrate and nitrite fall off to the lowest levels. At this time silicate, which is vital for diatoms but not for flagellates, has decreased already to very low values. Thus it seems that silicate represents the limiting factor for diatoms, but not phosphate or nitrate. As the diatoms make only limited use of the plentiful phosphate and N-nutrients, flagellates take over the leading role and form the dominant amount of biomass.

4. Spectral analysis

Although there are several gaps of varying lengths in the series, the material is principally suited to investigate time scales from several days to 23 years. After interpolation we performed spectral analysis on the full time series.

5

Because we were interested in an as high resolution of the low-frequency part of the variance spectra as possible, we tried to avoid any loss of data. Therefore the Fast-Fourier-Transform with the necessity of N being a power of 2 could not be used. For the same reason, the usual technique of partitioning the series for getting a smoothed spectrum was not applied. We did spectral analysis with a real Fourier transform after prime factor splitting.

The dots in the figures of the variance spectra represent means of five (separated) variance values. The unit of variance is the square of the unit of the parameter in question. The confidence interval (JENKINS & WATTS, 1968) of the chi-square distributed mean variances for now 10 degrees of freedom is plotted for an error probability of 5% in the lower left edge of the figures. Because of the logarithmic scale, this interval is valid for all points of the spectrum.

The variance represented by certain frequency ranges were obtained by summing up the variance values in the original spectra (not shown) within these ranges (Parzevals theorem). The regression lines in the figures were calculated as least square fits in the double logarithmic scales along

$$\ln(\text{variance}) = a * \ln(\text{frequency}) + b.$$

In the spectra of salinity, nitrate, and nitrite the aliasing frequency of 14.7 days (i.e. 24.7 cycles/year) is significantly showing up. This frequency is the result of daily sampling in a region, where the M2-tide is of greatest importance.

5. Interpretation of spectra

From the spectra we can learn, on which scales the different processes - physical, chemical, or biological - may act and dominate the development of chemical and biological parameters in the sea. Here spectra were calculated for the time series of temperature, salinity, nutrients and phytoplankton (Figs. 13-24). The spectra exhibit different structures. The outstanding frequency in many of the spectra is the annual frequency, which is demonstrated by the calculation of the portions of variance as percentages of total variance of the spectrum within different frequency bands (Tab.1).

The variance of temperature (Fig. 13) at Helgoland is nearly exclusively found in the annual period, which could mean that the annual heating cycle dominates all other processes like advection of water masses with different temperatures and fresh water inflow. In contrast, variance of salinity (Fig. 14) is determined to 21% by the annual cycle; and 34% of the total variance is found in the range on 1 to 10 cycles / year. Long-term processes are even more important (25%) than the annual frequency. This is very similar to what the variances of Elbe river discharge teach (Fig. 15). 36% of variance is due to periods either longer or periods shorter than the annual period, suggesting that salinity may be determined by river runoff. In the range of shorter time scales than 0.1 year salinity shows 18%, but river discharge only 5% of variance, demonstrating that discharge events are not happening on such short scales. Thus salinity must be determined

by different processes on these scales.

The aliasing frequency (24.7 cycles/year) is significant in the salinity spectrum (see also BECKER & KOHNKE, 1978), but not in the temperature spectrum. This would occur, if e.g. temperature would be predominantly determined by the heating processes, acting on larger spatial scales than the processes regulating salinity, which are mainly connected to the river inflow.

Phosphate (Fig. 16) and nitrate (Fig. 17) contain 52% and 41% of their variance in the annual period, whereas nitrite (Fig. 18), ammonia (Fig. 19), and silicate (Fig. 20) have more than 35% of their variance in the range of 1 to 10 cycles/ year. Phosphate is hardly determined by processes on long time scales (8%), in contrast to nitrate (20%). Ammonia (Fig. 19), as an exception, has nearly no contribution of the annual frequency to total variance, and 61% of its variance is determined by processes on time scales less than 1 year. Long-term contributions to variance are small for nitrite (16%) and silicate (13%).

The bulk of variance in the plankton series (Figs. 22 - 24) is contained in the frequency band between 1 and 10 cycles/year and, for diatoms only, in the higher frequencies (37%). Flagellates (Fig. 24) behave very different from diatoms (Fig. 23): the former contain only 2% of total variance in the annual frequency, 66% in the range from 1 to 10 cycles/ year, and only 9% on shorter scales, whereas diatoms exhibit nearly the same part of variance in the two higher frequency ranges (36% and 37%) and only 11 and 16 % in the frequency ranges larger than or equal to one year. Thus we must assume that the variance spectra of diatoms and of flagellates must be based on different dynamics.

parameter	variance in % of total variance in the different frequency bands			
	$f < 1$	annual frequency $f=1$	$1 < f < 10$	$10 \leqslant f$
sea surface temperature	2	95	2	1
salinity	25	21	34	18
phosphate	8	52	26	14
nitrate	20	41	28	11
nitrite	16	36	41	7
ammonia	35	4	37	24
total inorganic nutrient-N	22	35	31	13
silicate	13	35	39	14
Elbe discharge	36	23	36	5
phytoplankton	9	21	39	31
diatoms	11	16	36	37
flagellates	23	2	66	9

Tab. 1: Portions of total variance in different frequency bands

The Helgoland Reede time series exhibit for most of the parameters a decay in the short period part of the spectrum resembling that of temperature (Tab.2). It is only Elbe river discharge, silicate and nitrite which show a much stronger decay in that part of the spectrum (the rates are -3.43, -2.13, and -2.11, resp.). For Elbe discharge this means a strongly decreasing importance of short term events, for scales less than a month. For the other two parameters the situation is not clear.

In the frequency band from 1 to 10 cycles/year the decay rates are generally, except for nitrate and nitrate, smaller than -5/3. They are relatively similar for sea surface temperature, and total nutrient-N. They are smallest for phytoplankton, especially for diatoms (-0.5). In this range nearly all parameters seem to be determined by processes which do not obey a -5/3 law.

A more detailed discussion of interrelations of the parameters will follow, when the cross spectra and coherence spectra are available.

parameter	slopes in the frequency band	
	$1 < f < 10$	$10 \leqslant f$
sea surface temperature	-1.4	-1.8
salinity	-1.1	-1.7
phosphate	-1.0	-1.8
nitrate	-1.6	-1.8
nitrite	-1.7	-2.1
ammonia	-1.1	-1.9
total inorganic nutrient N	-1.5	-1.9
silicate	-1.3	-2.1
Elbe discharge	-1.5	-3.4
phytoplankton C	-0.9	-1.5
diatoms	-0.5	-1.6
flagellates	-1.3	-1.7

Tab. 2: Slopes of variance spectra obtained by linear regression analysis for different spectral bands

6. Acknowledgements

7. References

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CENTIGRADE

a)

SURFACE TEMPERATURE
PROJECTED INTO 1 Y
CREWS OF M.B. 'ELLENBOGEN' AND 'AADE' / BAH

CENTIGRADE

a)

SURFACE TEMPERATURE
MEAN SEASONAL SIGNAL
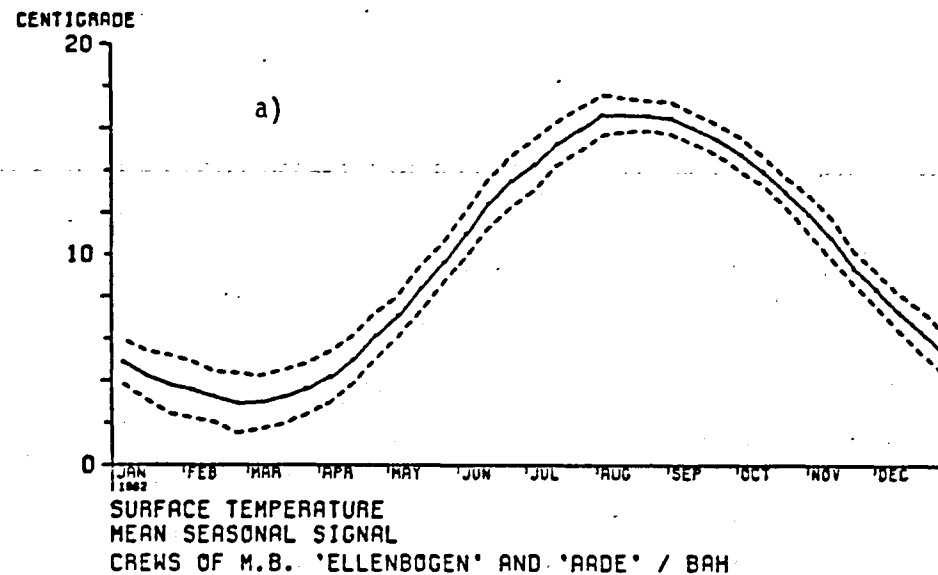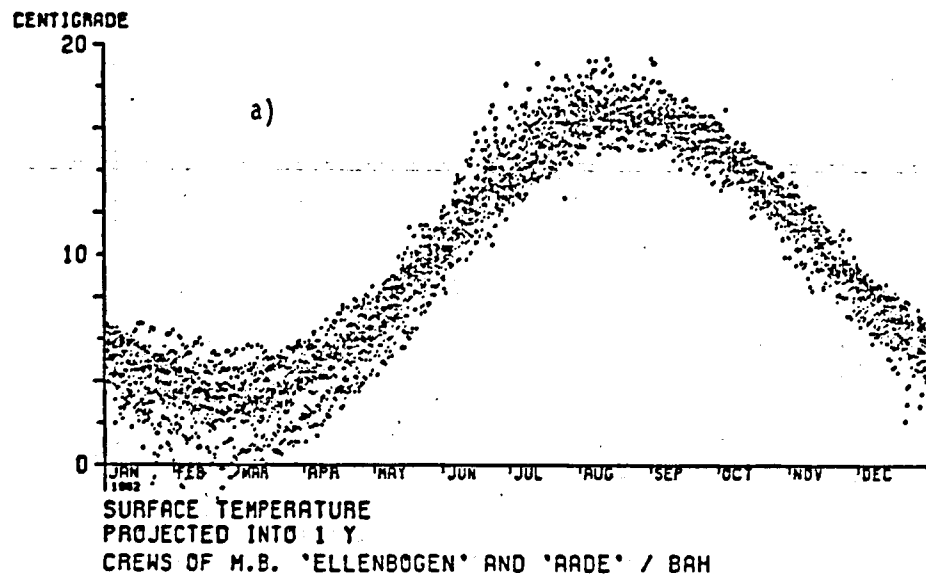CREWS OF M.B. 'ELLENBOGEN' AND 'AADE' / BAH

Fig. 1: Surface temperature at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day

0/00

a)

SALINITY
PROJECTED INTO 1 Y
B.METSCHER, K.TREUTNER / BAH

0/00

b)

SALINITY
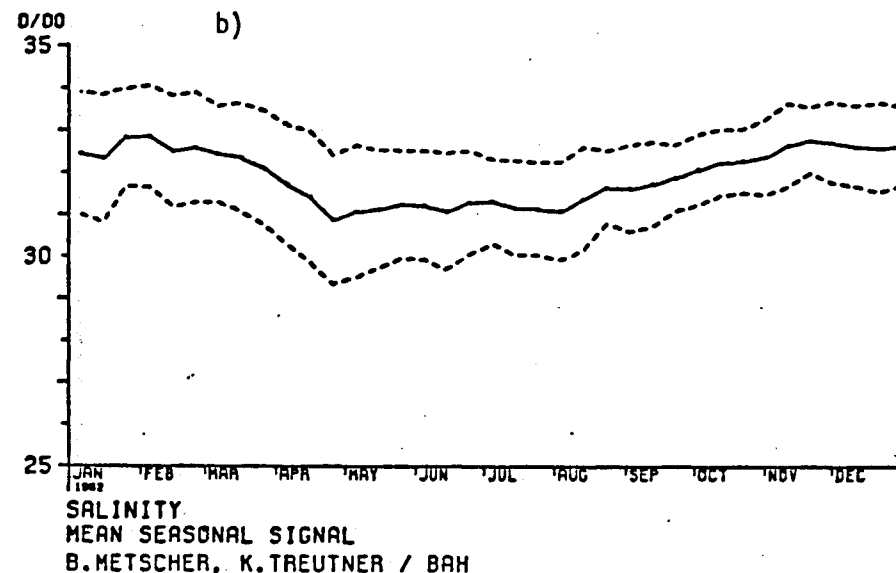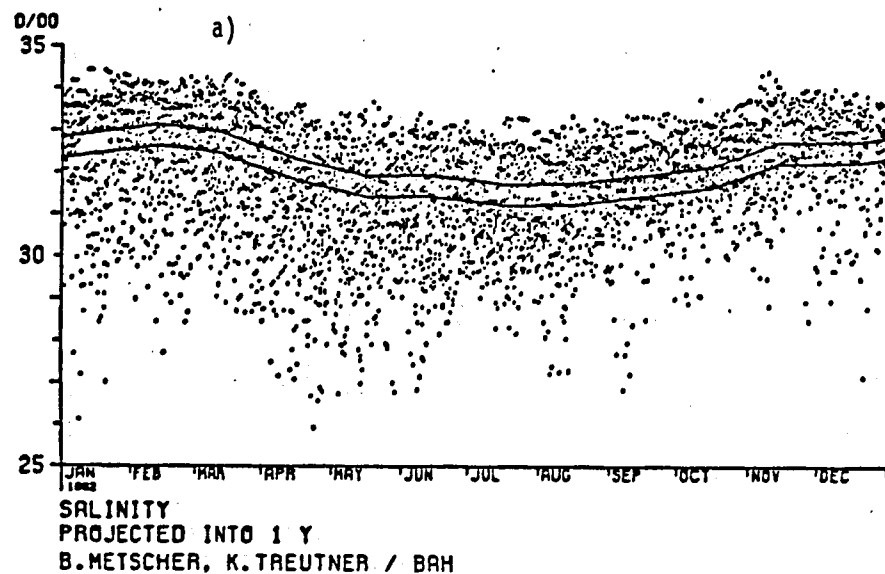MEAN SEASONAL SIGNAL
B.METSCHER, K.TREUTNER / BAH

Fig. 2: Salinity at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day
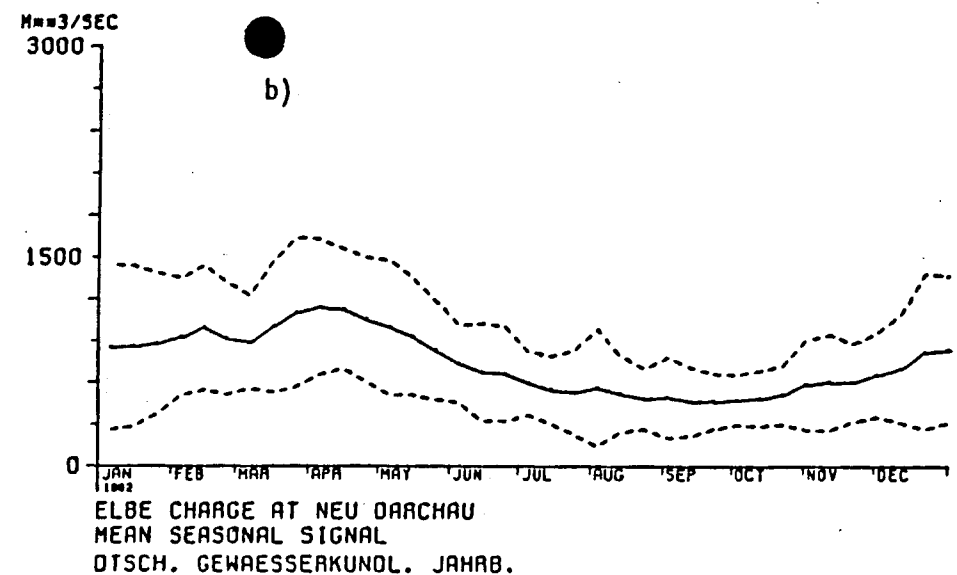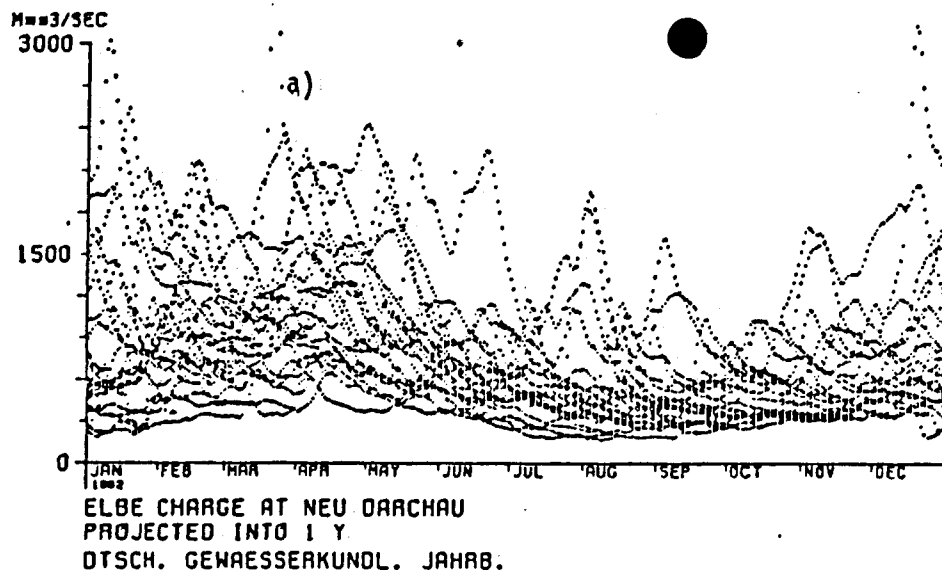
Fig. 3: Elbe discharge at Neu Darchau, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day
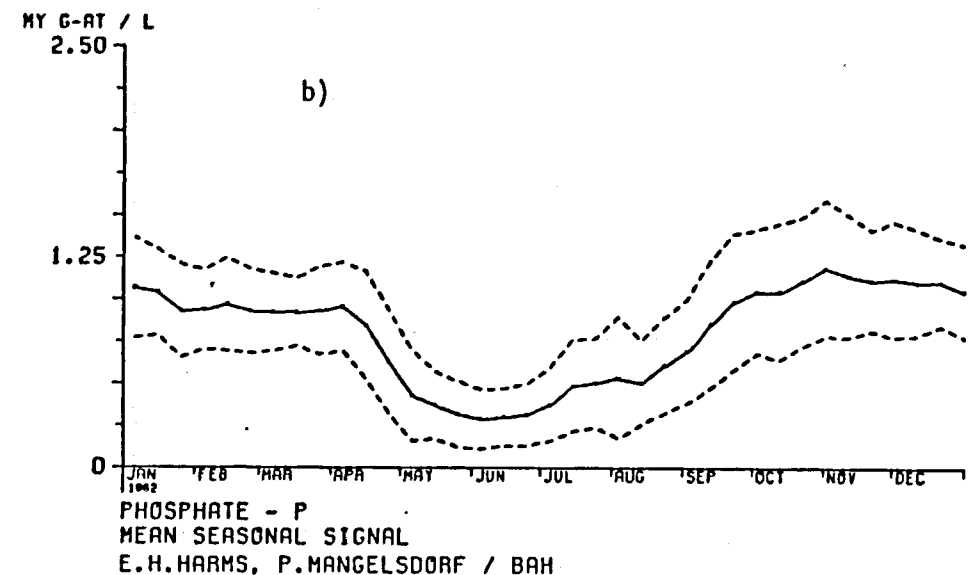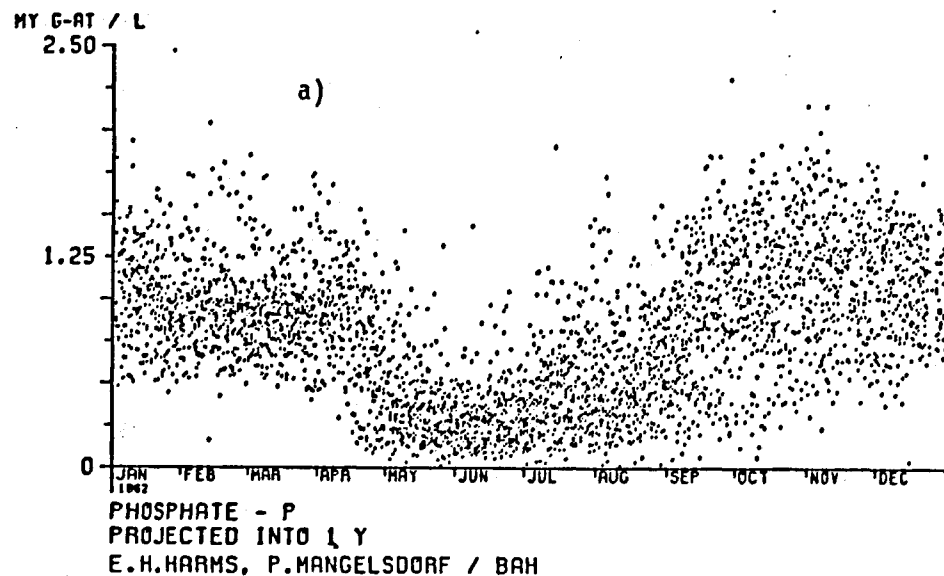

Fig. 4: Phosphate at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day

MY G-AT / L

a)

NITRATE - N
PROJECTED INTO 1 Y
E.H.HARMS, P.MANGELSDORF / BAH

b)

NITRATE - N
MEAN SEASONAL SIGNAL
E.H.HARMS, P.MANGELSDORF / BAH

Fig. 5: Nitrate at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day

MY G-AT / L

a)

NITRITE - N
PROJECTED INTO 1 Y
E.H.HARMS, P.MANGELSDORF / BAH

b)

NITRITE - N
MEAN SEASONAL SIGNAL
E.H.HARMS, P.MANGELSDORF / BAH

Fig. 6: Nitrite at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day

MY G-AT / L

a)

AMMONIA - N
PROJECTED INTO 1 Y
E.H.HARMS, P.MANGELSDORF / BAH

b)

AMMONIA - N
MEAN SEASONAL SIGNAL
E.H.HARMS, P.MANGELSDORF / BAH

Fig.   7: Ammonia at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day
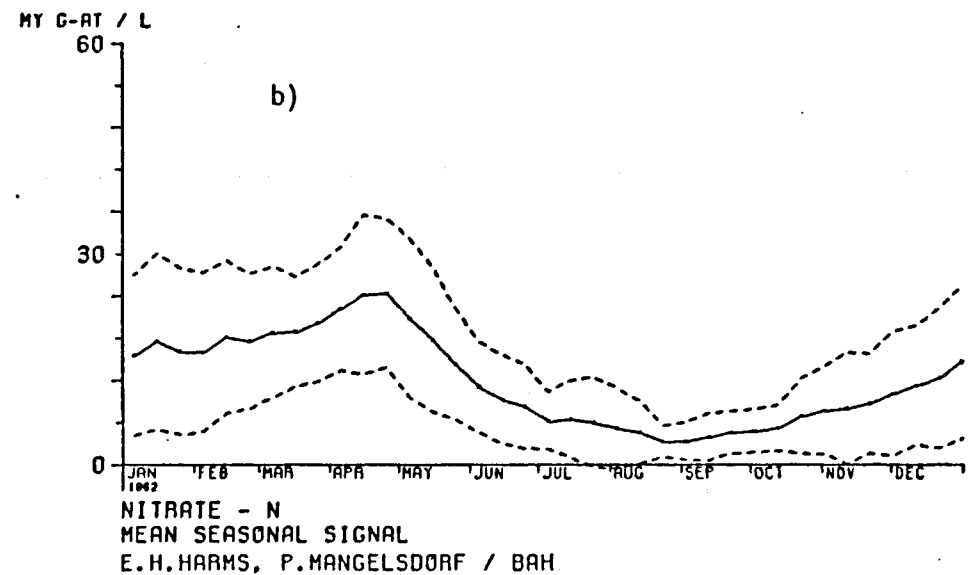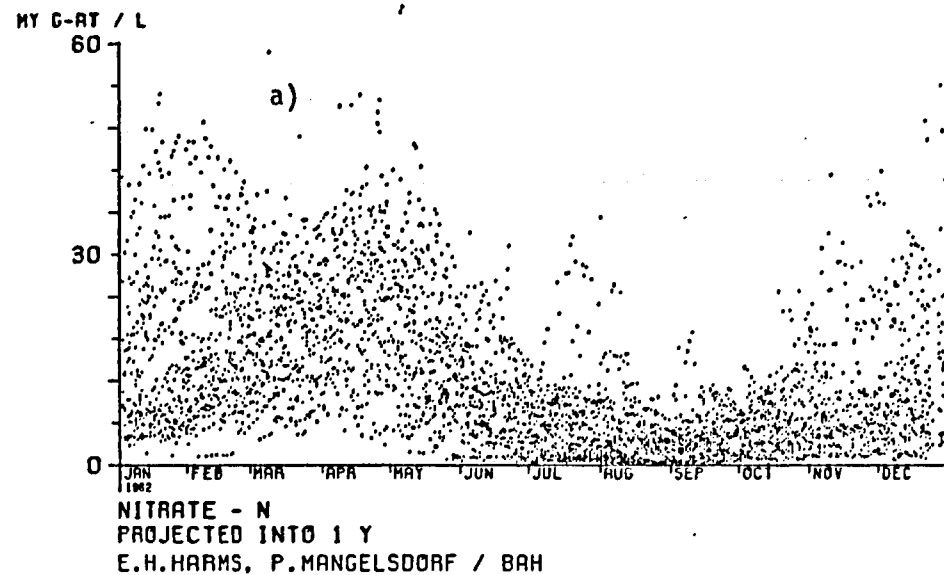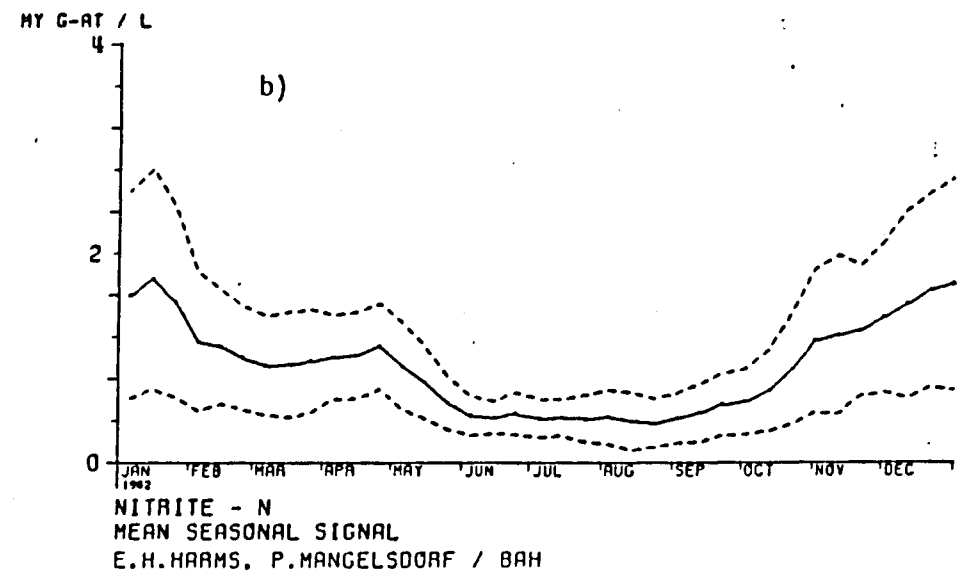
MY G-AT / L

a)

TOTAL INORGANIC NUTRIENT - N
PROJECTED INTO .1 Y
NO3-N + NO2-N + NH4-N

b)

TOTAL INORGANIC NUTRIENT - N
MEAN SEASONAL SIGNAL
NO3-N + NO2-N + NH4-N

Fig.   8: Total inorganic nutrient-N at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day

MY G-AT / L

SILICATE - SI
PROJECTED INTO 1 Y
E.H.HARMS, P.MANGELSDORF / BAH

SILICATE - SI
MEAN SEASONAL SIGNAL
E.H.HARMS, P.MANGELSDORF / BAH

Fig. 9: Silicate at Helgoland Reede, 19 years of data projected into one year:
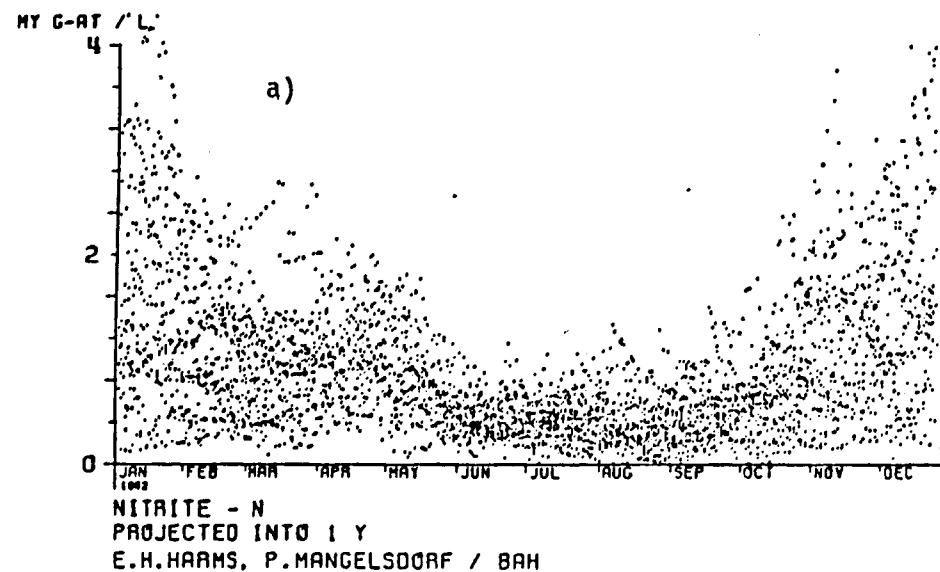a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day

MY G / L

PHYTOPLANKTON - C
PROJECTED INTO 1 Y
M.GILLBRICHT, E.HAGMEIER, K.TREUTNER / BAH

PHYTOPLANKTON - C
MEAN SEASONAL SIGNAL
M.GILLBRICHT, E.HAGMEIER, K.TREUTNER / BAH

Fig. 10: Phytoplankton at Helgoland Reede, 23 years of data projected into one year:
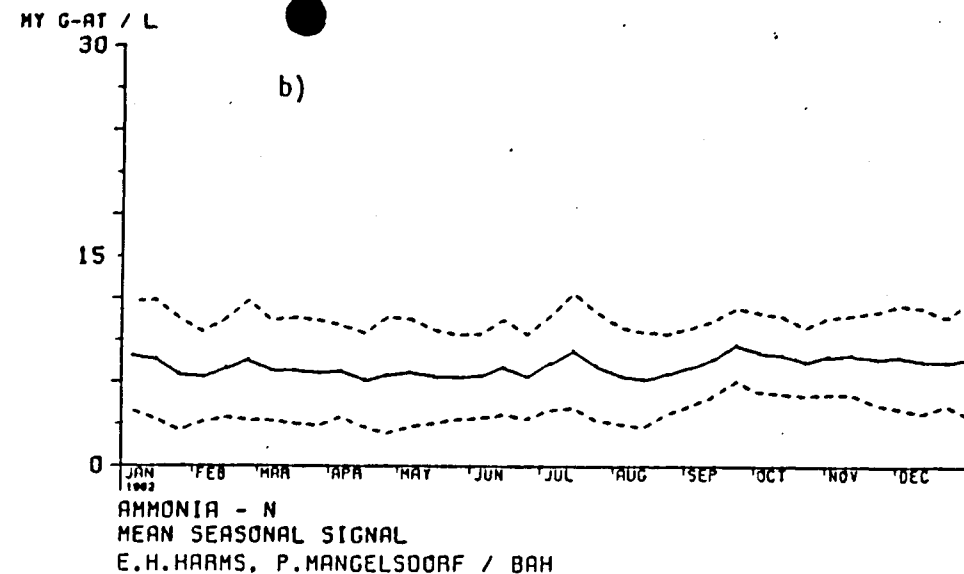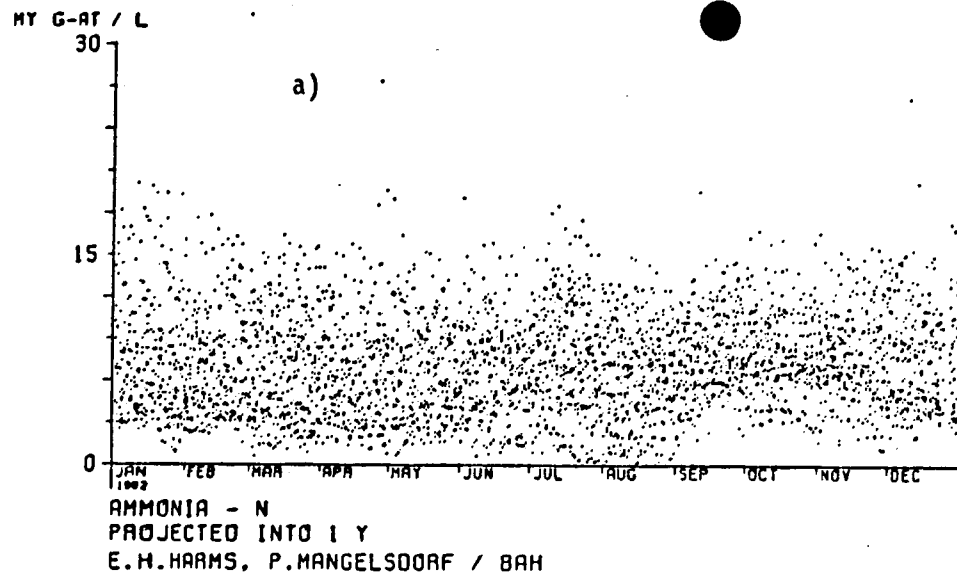a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day

MY C / L

a)

DIATOMS - C
PROJECTED INTO 1 Y
M.GILLBRICHT, E.HAGMEIER, K.TREUTNER / BAH

MY C / L

b)
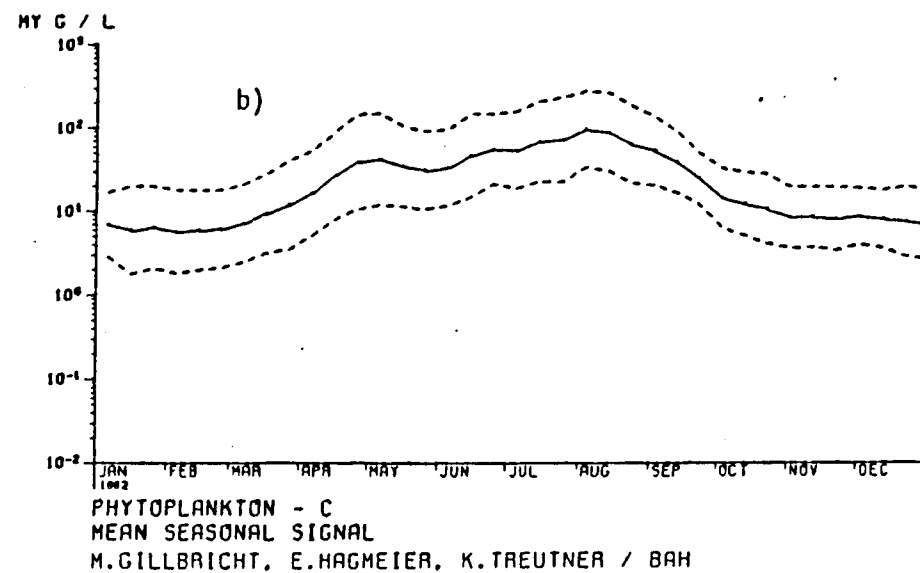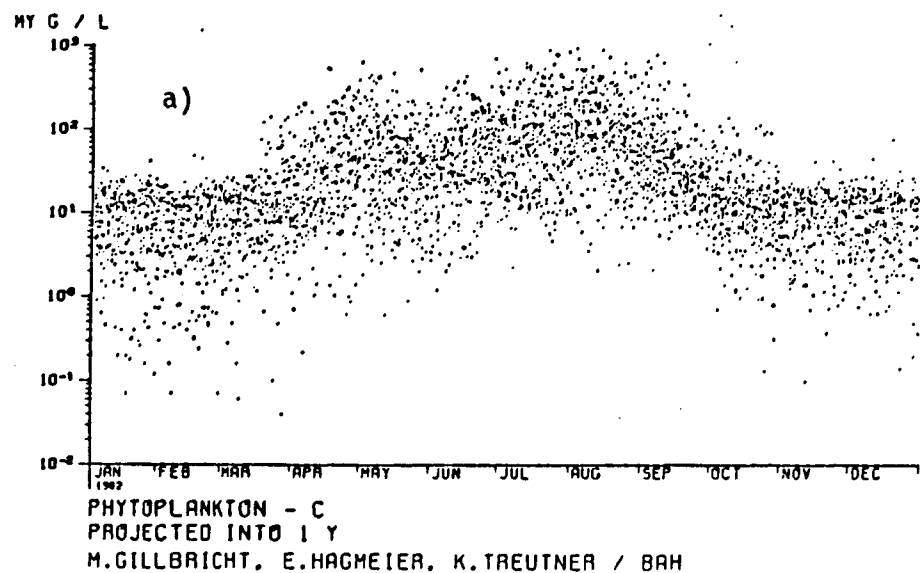
DIATOMS - C
MEAN SEASONAL SIGNAL
M.GILLBRICHT, E.HAGMEIER, K.TREUTNER / BAH

Fig. 11: Diatoms at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day
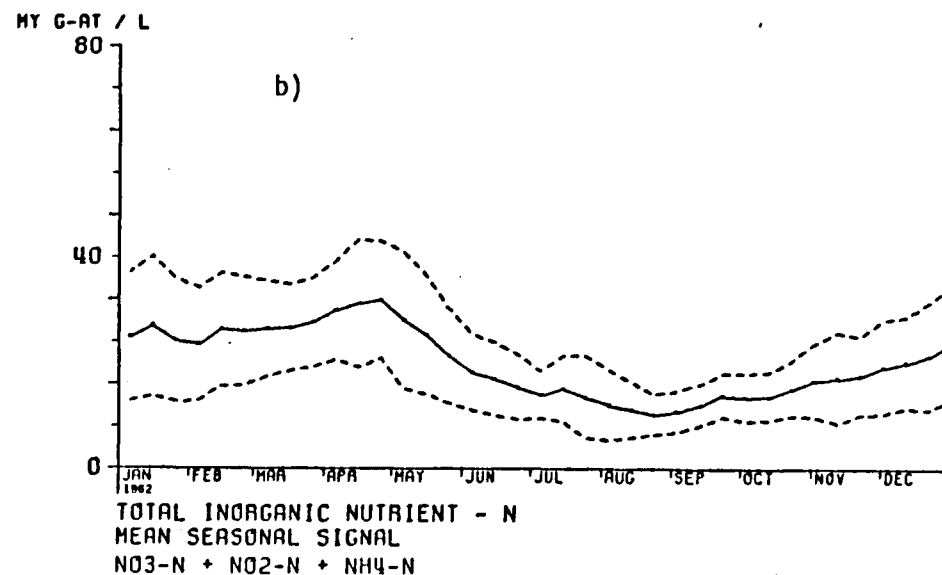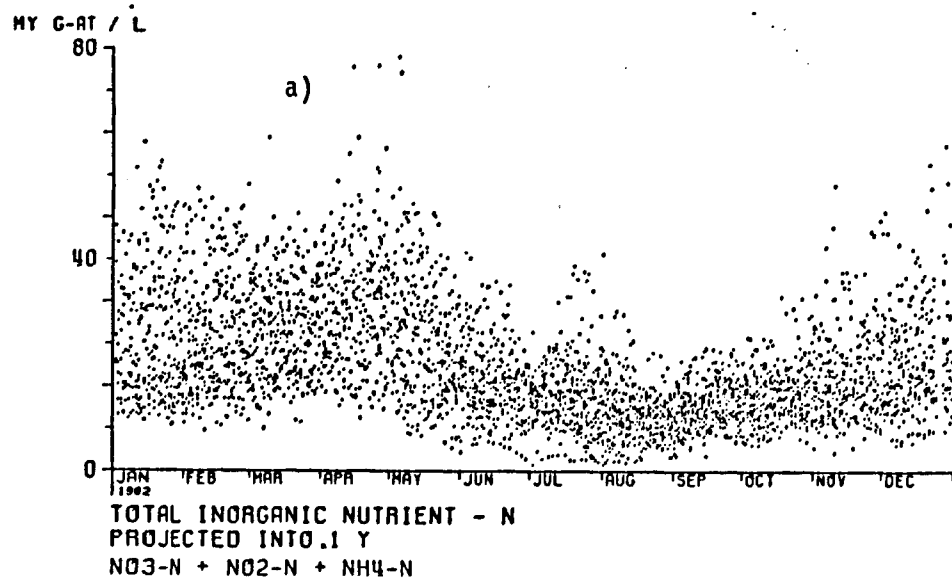
MY C / L

a)

FLAGELLATES - C
PROJECTED INTO 1 Y
M.GILLBRICHT, E.HAGMEIER, K.TREUTNER / BAH

MY C / L

b)

FLAGELLATES - C
MEAN SEASONAL SIGNAL
M.GILLBRICHT, E.HAGMEIER, K.TREUTNER / BAH
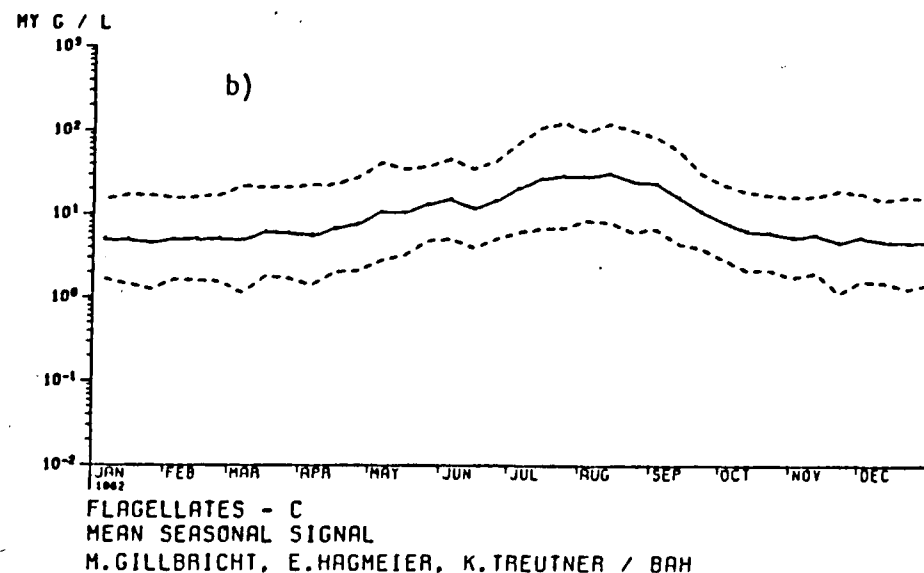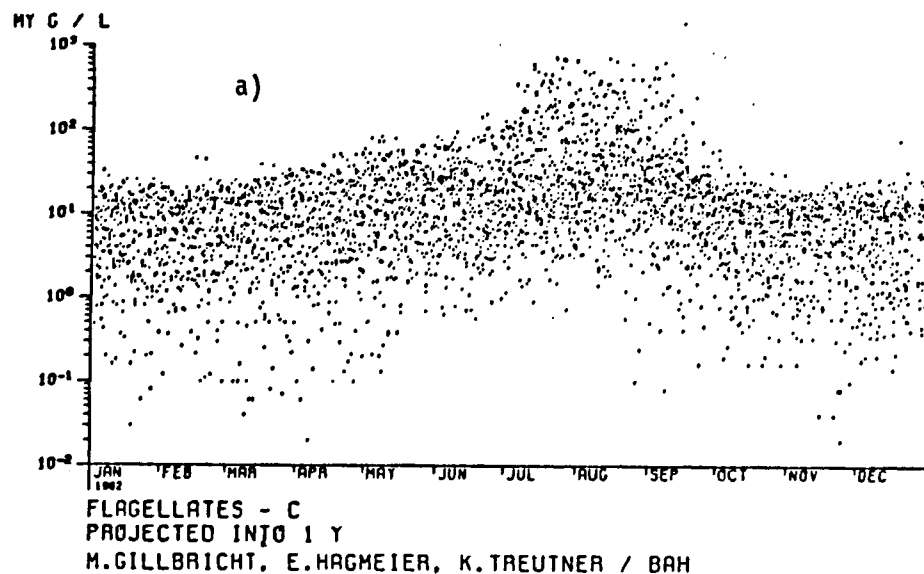
Fig. 12: Flagellates at Helgoland Reede, 23 years of data projected into one year:
a) all measurements b) mean annual cycle and standard deviations on the basis of the measurements of each day
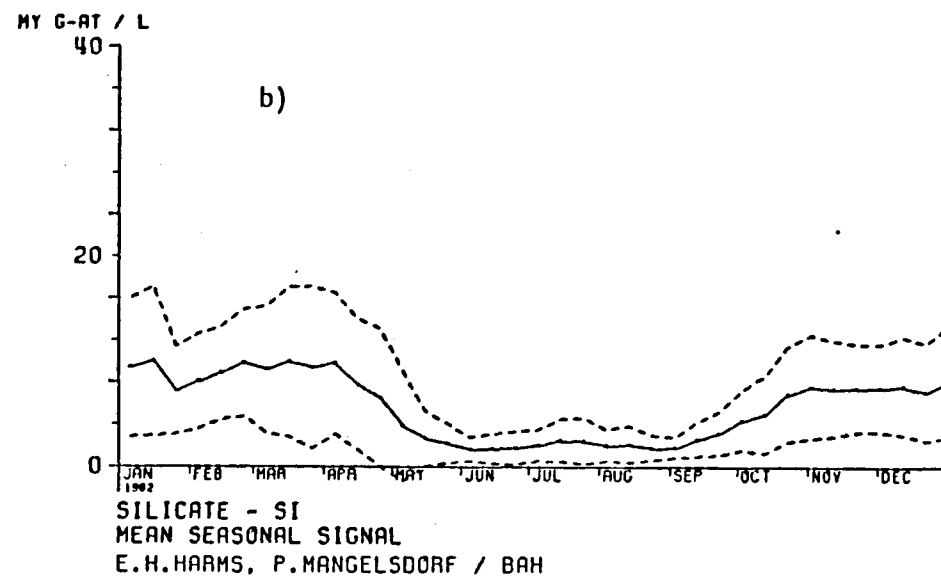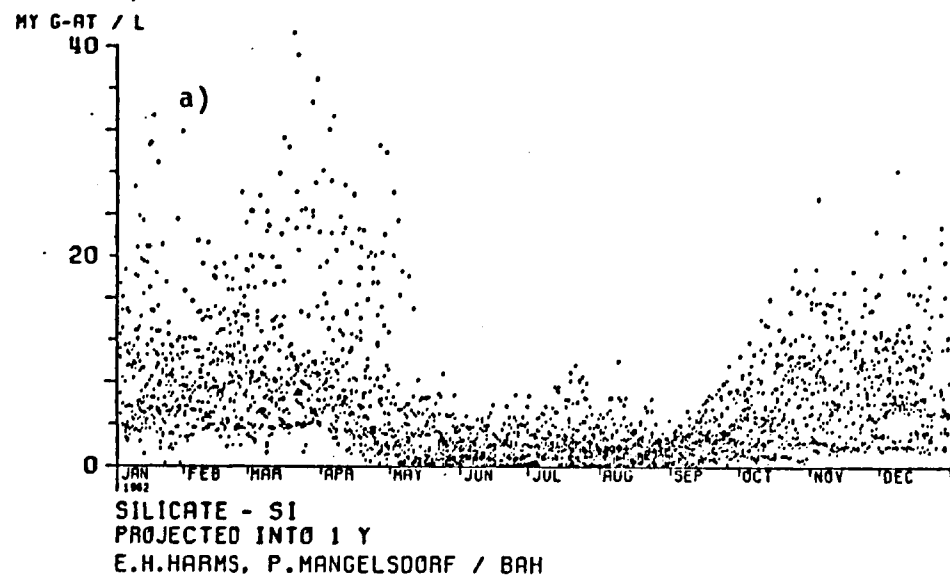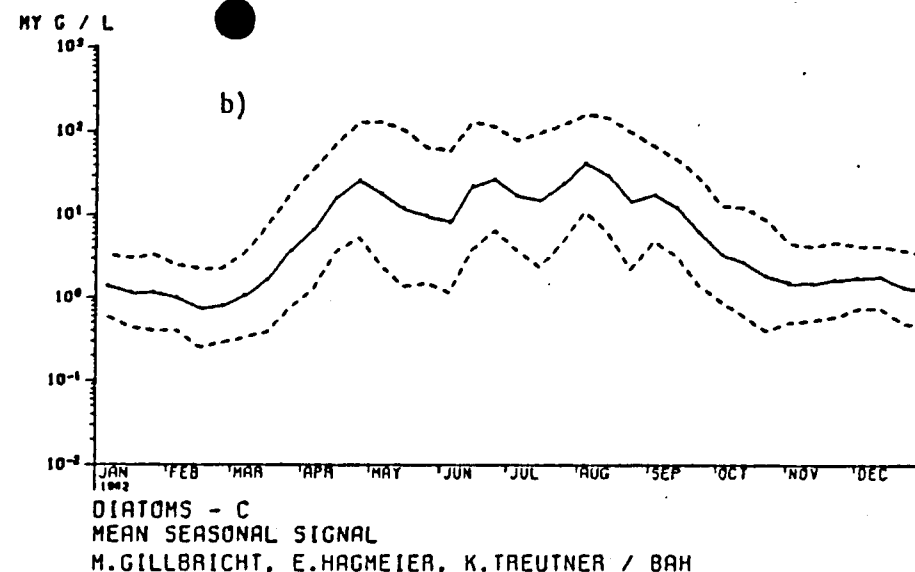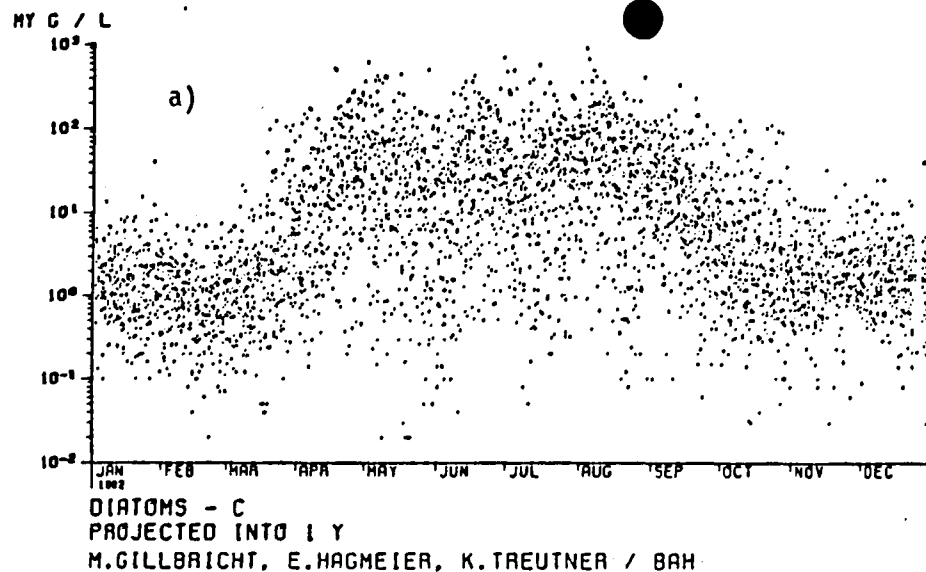
VARIANCE

SURFACE TEMPERATURE PATCHED   5-F, FG=10, P=.05

LG(Y)=A+B=LG(X)   LG(Y)=A+B=LG(X)   LG(Y)=A+B=LG(X)
A= -1.745807   A= -1.663139   A= -1.070379
B= -0.677375   B= -1.413250   B= -1.79086
R=-0.823 P=0.050 N=4   R=-0.817 P=0.050 N=41   R=-0.927 P=0.050 N=793
RANDOM R AT P.N =0.950   RANDOM R AT P.N =0.308   RANDOM R AT P.N =0.070

Fig. 13: Variance spectrum of sea surface temperature

VARIANCE

The confidence interval for each spectral value is indicated in
the lower left; the regression lines for the 3 frequency bands
f < 1, 1 < f 10, f < 10 cycles/year are given together with the
number of values N and the significance threshold of the
correlation coefficient R.

SALINITY PATCHED   5-F, FG=10, P=.05

LG(Y)=A+B=LG(X)   LG(Y)=A+B=LG(X)   LG(Y)=A+B=LG(X)
A= -1.888291   A= -1.654349   A= -0.981321
B= -0.961131   B= -1.115874   B= -1.728748
R=-0.946 P=0.050 N=4   R=-0.770 P=0.050 N=41   R=-0.925 P=0.050 N=793
RANDOM R AT P.N =0.950   RANDOM R AT P.N =0.308   RANDOM R AT P.N =0.070

Fig. 14: Variance spectrum of salinity

VARIANCE

ELBE CHARGE AT NEU DARCHAU

5-F, FG=10, P=.05

LG (Y)=A+B=LG (X)
A= -2.212706
B= -0.601748
R=-0.938 P=0.050 N=4
RANDOM R AT P,N =0.950

LG (Y)=A+B=LG (X)
A= -1.9909
B= -1.476849
R=-0.852 P=0.050 N=41
RANDOM R AT P,N =0.308

LG (Y)=A+B=LG (X)
A= 0.055806
B= -3.429907
R=-0.977 P=0.050 N=788
RANDOM R AT P,N =0.070
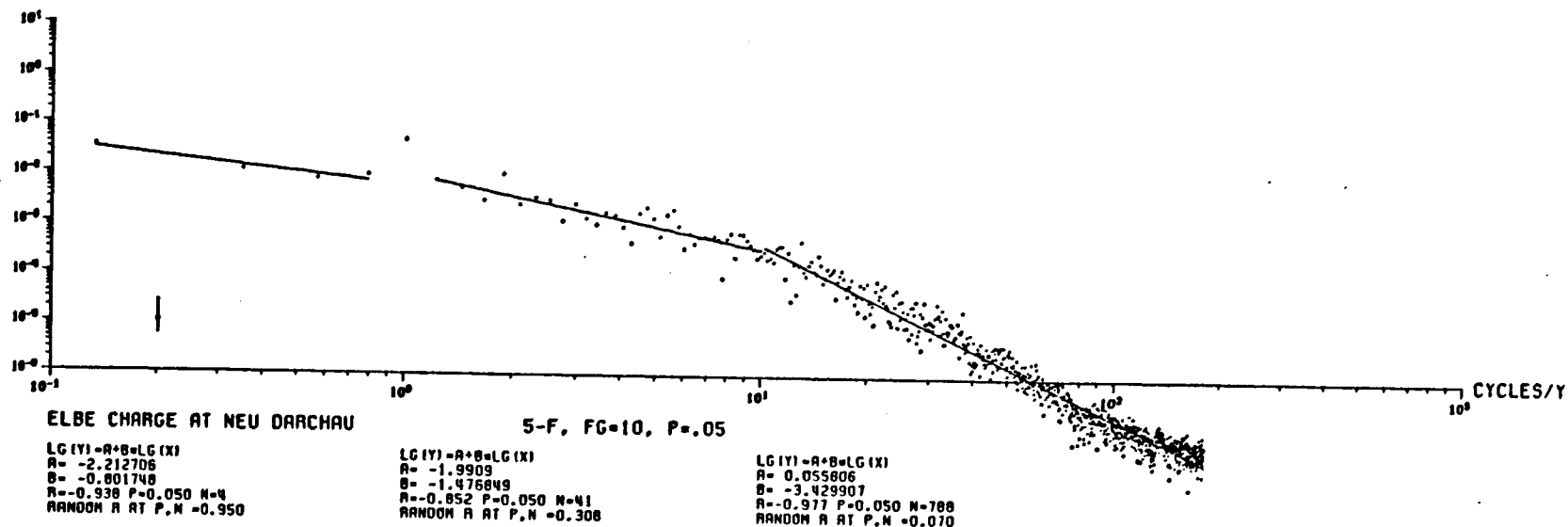
Fig. 15: Variance spectrum of Elbe discharge at Neu Darchau

VARIANCE

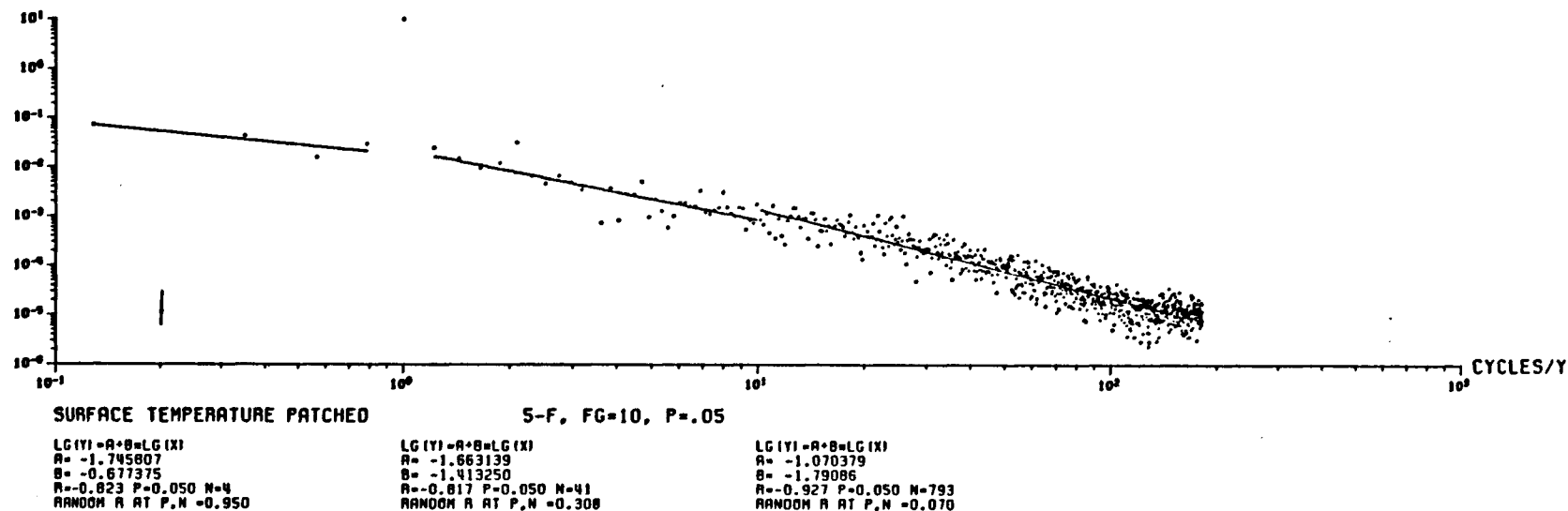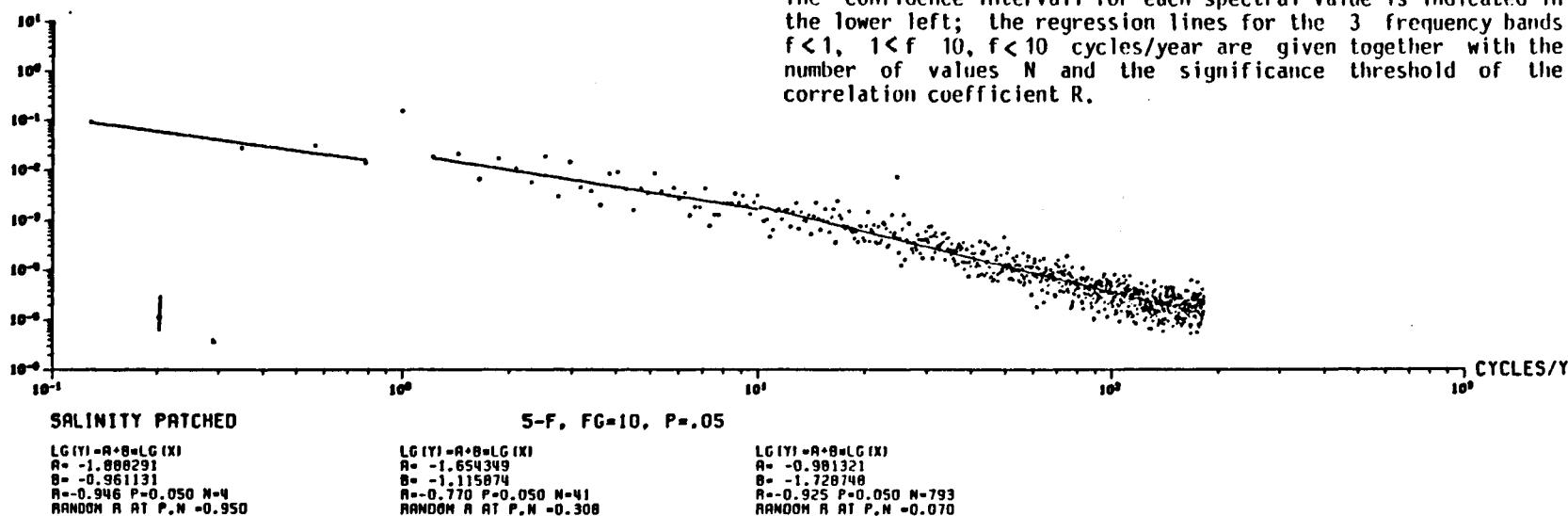The confidence intervall for each spectral value is indicated in the lower left; the regression lines for the 3 frequency bands f < 1, 1 < f 10, f < 10 cycles/year are given together with the number of values N and the significance threshold of the correlation coefficient R.

PHOSPHATE - P PATCHED

5-F, FG=10, P=.05

LG (Y)=A+B=LG (X)
A= -2.999294
B= -0.082232
R=-0.213 P=0.050 N=4
RANDOM R AT P,N =0.950

LG (Y)=A+B=LG (X)
A= -2.968305
B= -1.039637
R=-0.678 P=0.050 N=41
RANDOM R AT P,N =0.308

LG (Y)=A+B=LG (X)
A= -2.054192
B= -1.789383
R=-0.921 P=0.050 N=792
RANDOM R AT P,N =0.070

Fig. 16: Variance spectrum of phosphate

VARIANCE

NITRATE - N PATCHED   S-F, FG=10, P=.05

LG (Y)=A+B=LG (X)
A= -0.055552
B= -0.653364
R=-0.926 P=0.050 N=4
RANDOM R AT P.N =0.950

LG (Y)=A+B=LG (X)
A= 0.200706
B= -1.568864
R=-0.859 P=0.050 N=41
RANDOM R AT P.N =0.308

LG (Y)=A+B=LG (X)
A= 0.654295
B= -1.802146
R=-0.912 P=0.050 N=792
RANDOM R AT P.N =0.070

Fig. 17: Variance spectrum of nitrate

VARIANCE

The confidence interval for each spectral value is indicated in the lower left; the regression lines for the 3 frequency bands $f < 1$, $1 < f$ 10, $f < 10$ cycles/year are given together with the number of values N and the significance threshold of the correlation coefficient R.
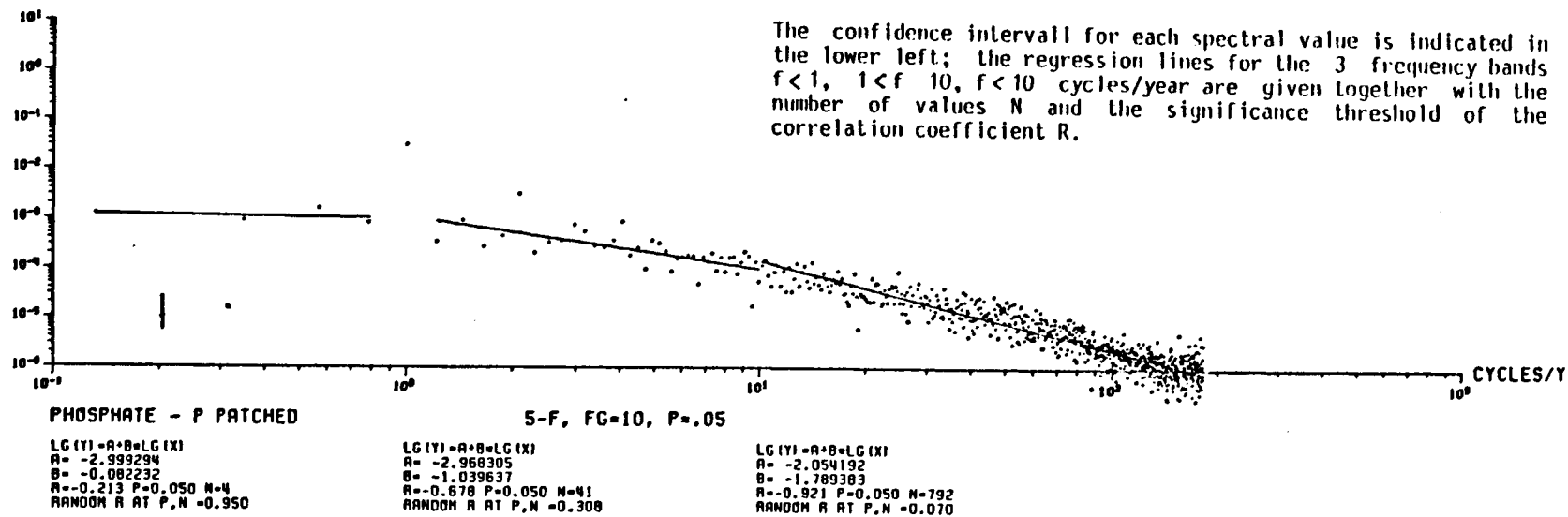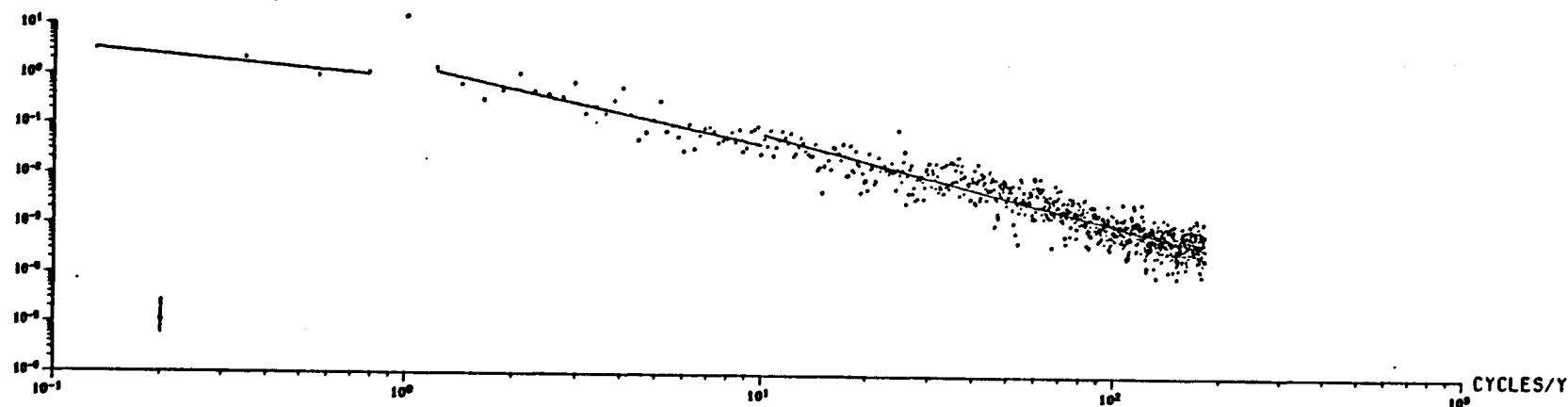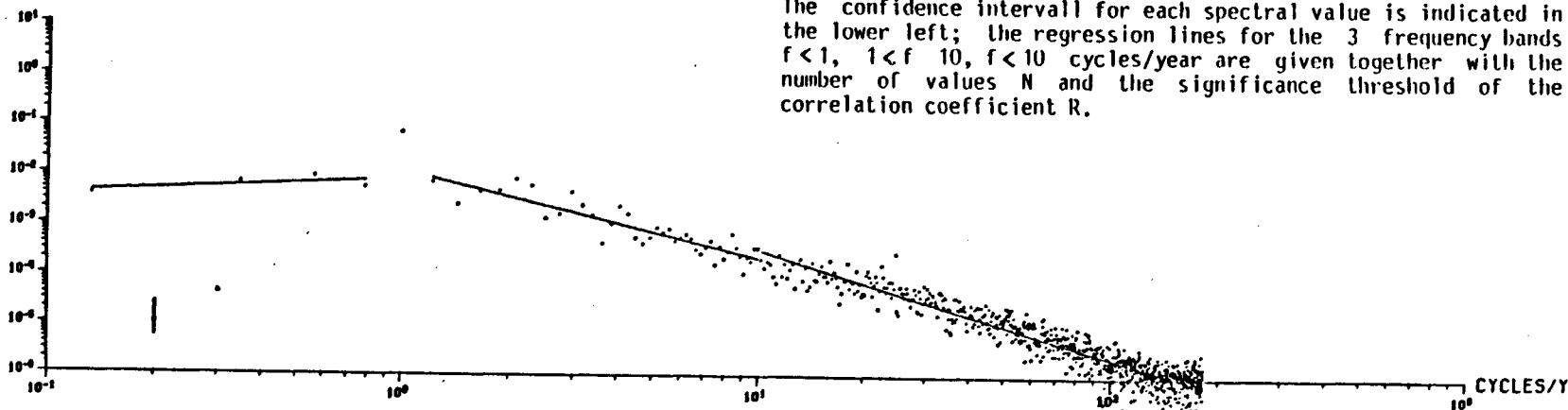
NITRITE - N PATCHED   S-F, FG=10, P=.05

LG (Y)=A+B=LG (X)
A= -2.091574
B= 0.308315
R=0.674 P=0.050 N=4
RANDOM R AT P.N =0.950
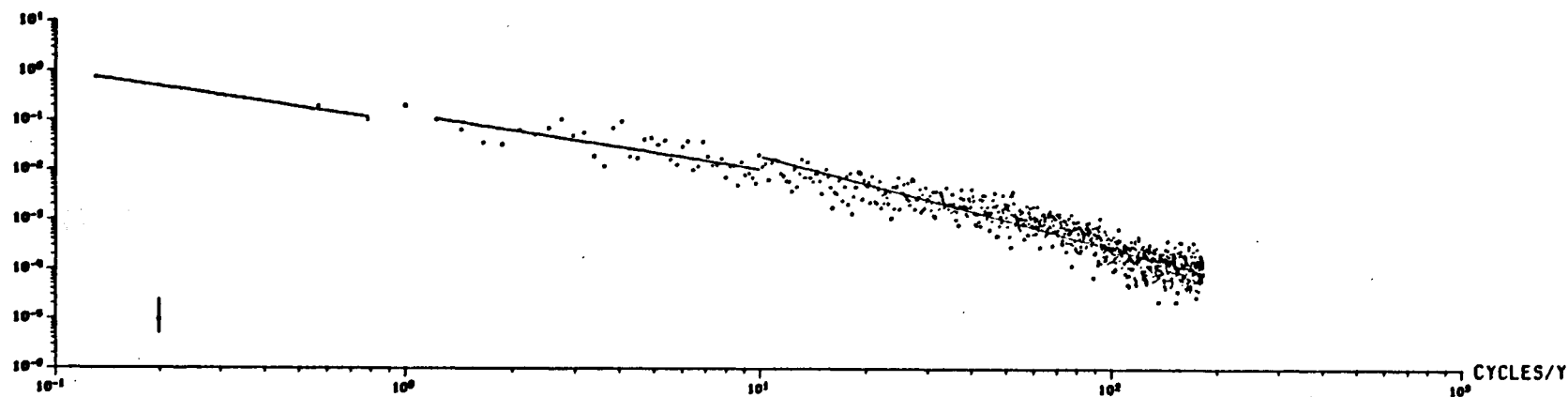
LG (Y)=A+B=LG (X)
A= -1.925575
B= -1.719654
R=-0.893 P=0.050 N=41
RANDOM R AT P.N =0.308

LG (Y)=A+B=LG (X)
A= -1.354664
B= -2.131459
R=-0.941 P=0.050 N=792
RANDOM R AT P.N =0.070

Fig. 18: Variance spectrum of nitrite

VARIANCE

AMMONIA - N PATCHED   S-F, FG=10, P=.05

LG (Y) =A+B*LG (X)   LG (Y) =A+B*LG (X)   LG (Y) =A+B*LG (X)
A= -1.053847   A= -0.879029   A= 0.116936
B= -1.044023   B= -1.111362   B= -1.847262
R=-0.988 P=0.050 N=4   R=-0.757 P=0.050 N=41   R=-0.923 P=0.050 N=792
RANDOM R AT P.N =0.950   RANDOM R AT P.N =0.308   RANDOM R AT P.N =0.070

Fig. 19: Variance spectrum of ammonia

VARIANCE

The confidence interval for each spectral value is indicated in the lower left; the regression lines for the 3 frequency bands f<1, 1<f<10, f<10 cycles/year are given together with the number of values N and the significance threshold of the correlation coefficient R.
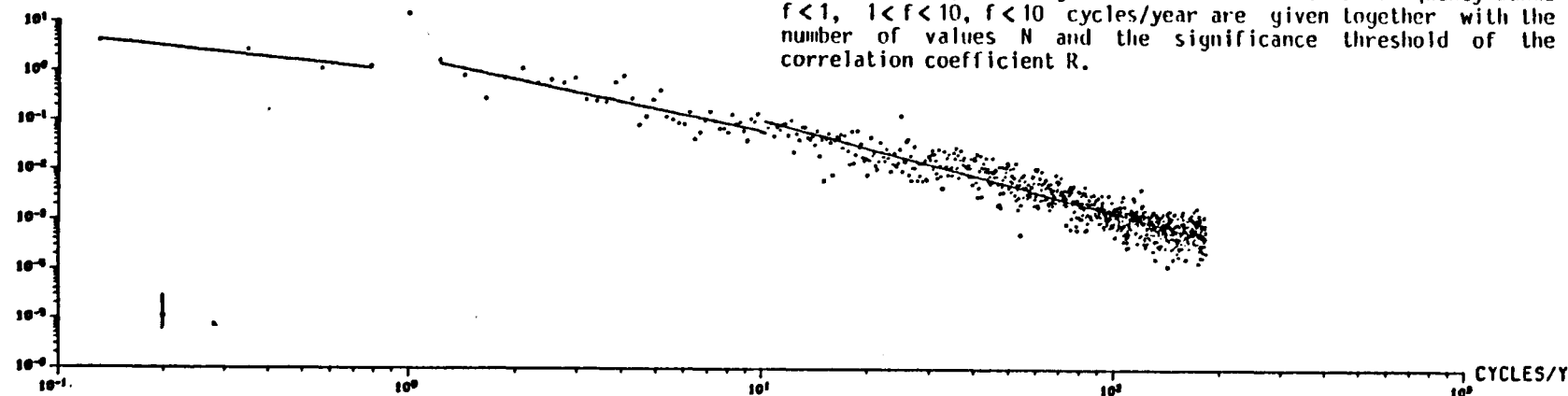
TOTAL INORGANIC NUTRIENT - N PATCHED   S-F, FG=10, P=.05

LG (Y) =A+B*LG (X)   LG (Y) =A+B*LG (X)   LG (Y) =A+B*LG (X)
A= -0.007798   A= 0.284449   A= 0.896022
B= -0.730144   B= -1.465876   B= -1.865943
R=-0.931 P=0.050 N=4   R=-0.850 P=0.050 N=41   R=-0.922 P=0.050 N=792
RANDOM R AT P.N =0.950   RANDOM R AT P.N =0.308   RANDOM R AT P.N =0.070

Fig. 20: Variance spectrum of total inorganic nutrient-N

VARIANCE

SILICATE - SI PATCHED   5-F, FG=10, P=.05

LG (Y)=A+B=LG (X)
A= -1.32178
B= -1.601559
R=-0.996 P=0.050 N=3
RANDOM R AT P,N =0.997

LG (Y)=A+B=LG (X)
A= -0.238823
B= -1.251497
R=-0.788 P=0.050 N=34
RANDOM R AT P,N =0.339

LG (Y)=A+B=LG (X)
A= 0.816283
B= -2.10994
R=-0.936 P=0.050 N=651
RANDOM R AT P,N =0.077
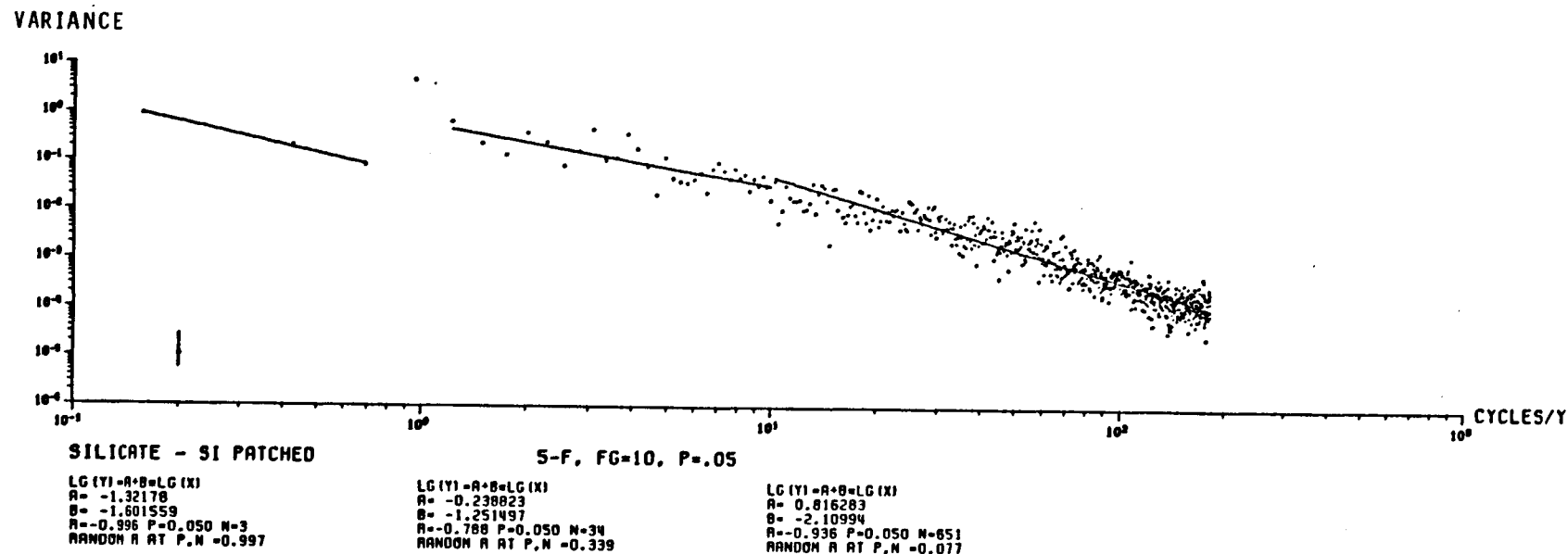
Fig. 21: Variance spectrum of silicate

VARIANCE

The confidence interval for each spectral value is indicated in the lower left; the regression lines for the 3 frequency bands f<1, 1<f 10, f<10 cycles/year are given together with the number of values N and the significance threshold of the correlation coefficient R.

PHYTOPLANKTON - C   5-F, FG=10, P=.05

LG (Y)=A+B=LG (X)
A= -1.072003
B= -0.546861
R=-0.858 P=0.050 N=4
RANDOM R AT P,N =0.950

LG (Y)=A+B=LG (X)
A= -0.70888
B= -0.889133
R=-0.655 P=0.050 N=41
RANDOM R AT P,N =0.308

LG (Y)=A+B=LG (X)
A= -0.034414
B= -1.516189
R=-0.882 P=0.050 N=792
RANDOM R AT P,N =0.070

Fig. 22: Variance spectrum of phytoplankton

VARIANCE

DIATOMS - C   5-F, FG=10, P=.05

LG (Y) =A+B=LG (X)   LG (Y) =A+B=LG (X)   LG (Y) =A+B=LG (X)
A= -0.176432   A= -0.278205   A= 0.810196
B= -0.219351   B= -0.495766   B= -1.587794
R=-0.354 P=0.050 N=4   R=-0.466 P=0.050 N=41   R=-0.887 P=0.050 N=792
RANDOM R AT P.N =0.950 RANDOM R AT P.N =0.308 RANDOM R AT P.N =0.070
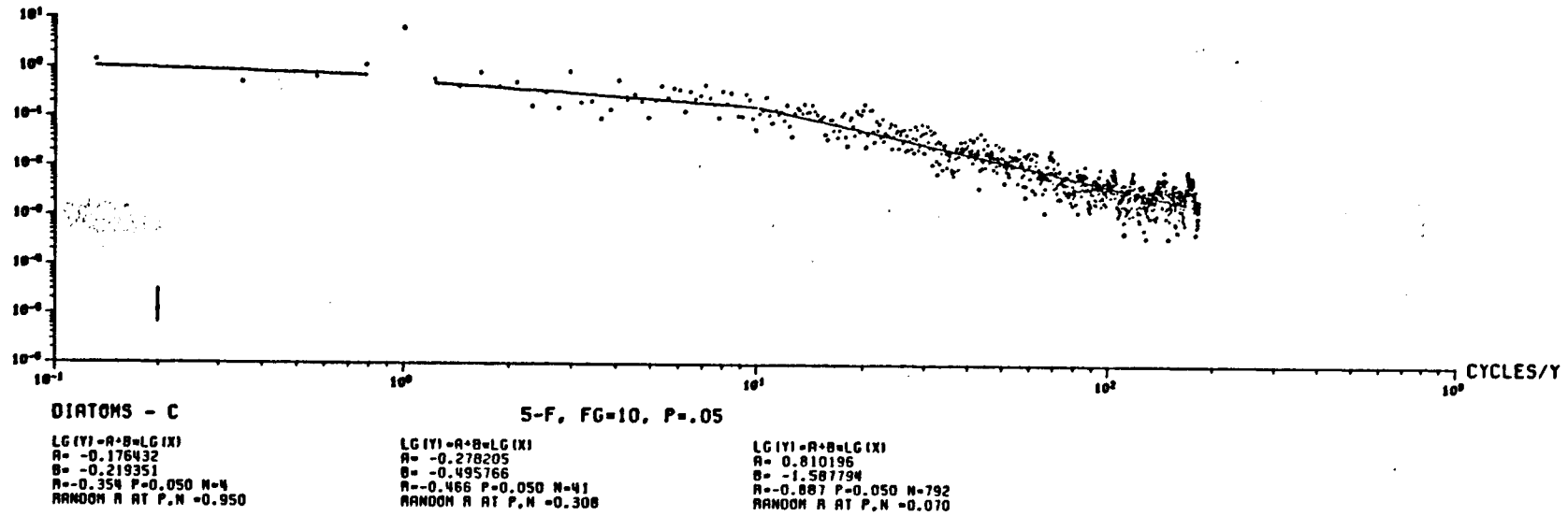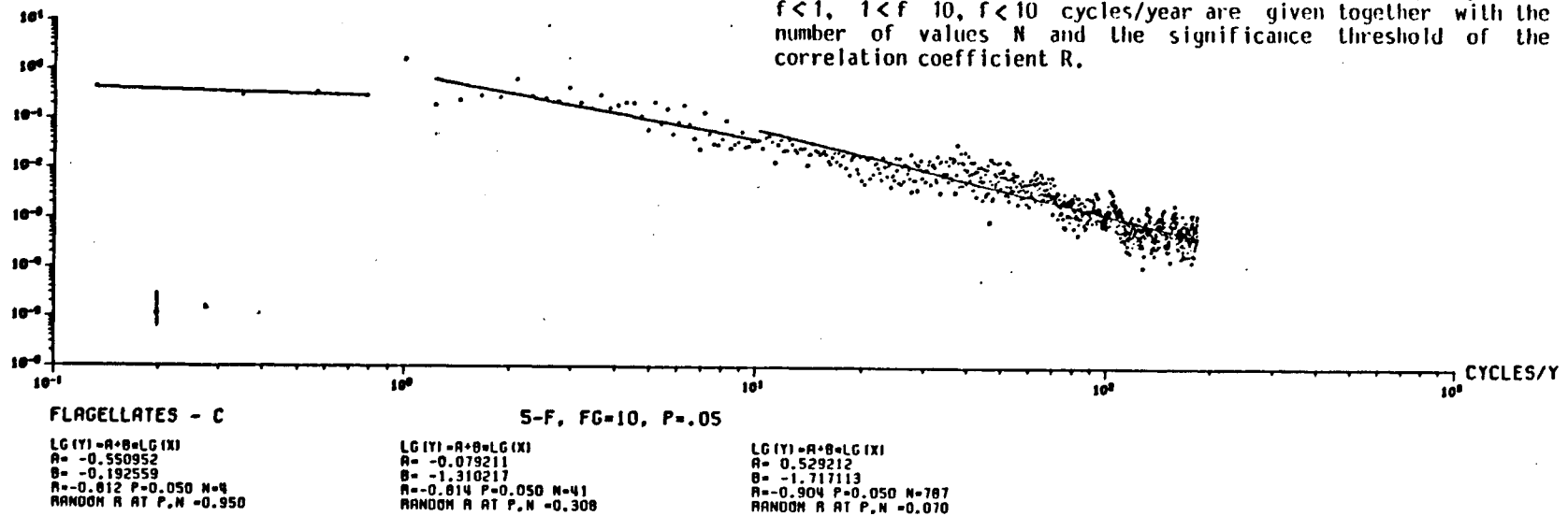
Fig. 23: Variance spectrum of diatoms

VARIANCE

The confidence intervall for each spectral value is indicated in the lower left; the regression lines for the 3 frequency bands f<1, 1<f 10, f<10 cycles/year are given together with the number of values N and the significance threshold of the correlation coefficient R.

FLAGELLATES - C   5-F, FG=10, P=.05

LG (Y) =A+B=LG (X)   LG (Y) =A+B=LG (X)   LG (Y) =A+B=LG (X)
A= -0.550952   A= -0.079211   A= 0.529212
B= -0.192559   B= -1.310217   B= -1.717113
R=-0.612 P=0.050 N=4   R=-0.814 P=0.050 N=41   R=-0.904 P=0.050 N=787
RANDOM R AT P.N =0.950 RANDOM R AT P.N =0.308 RANDOM R AT P.N =0.070

Fig. 24: Variance spectrum of flagellates