INVESTIGATIONS OF REQUIRED SAMPLING REGIMES FOR ENVIRONMENTAL PARAMETERS

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Abstract

The sensitivity of different sampling regimes in identifying interannual changes in environmental parameters was investigated using environmental data from Davis Station, Antarctica, from 1985 to 1987. Strong daily, depressional (4 to 5 days) and yearly cycles were seen in temperature, wind speed and pressure. Sampling daily maxima and minima would be sufficient to detect a 2 to 3°C change in monthly mean temperature over two years with a significance α of 0.05 and a power **P** of 0.8. Sampling wind speed continuously or as daily maxima and minima would be sufficient to detect a 10 to 20% change in monthly mean log-transformed wind speed α of 0.05 and **P** of 0.9.

Résumé

La sensibilité des différents régimes d'échantillonnage pour l'identification des changements interannuels dans les paramètres de l'environnement a été examinée à l'aide des données de l'environnement de la station Davis, Antarctique, de 1985 à 1987. D'importants cycles journaliers, dépressionnaires (4 à 5 jours) et annuels ont été notés pour la température, la force du vent et la pression atmosphérique. Il suffirait d'échantillonner les températures journalières maximales et minimales pour déceler une variation de 2-3°C dans la température mensuelle moyenne sur deux ans avec une signification α de 0.05 et P de 0.8. Un relevé continu de la force du vent ou des vitesses maximales et minimales journalières suffirait à déceler un changement de 10-20% dans la vitesse moyenne du vent transformée par calcul logarithmique avec α de 0.05 et P de 0.9.

Резюме

Чувствительность различных режимов регистрации данных при выявлении межгодовых изменений параметров окружающей среды была изучена на примере данных, полученных на станции Дейвис, Антарктика, за период с 1985 по 1987 гг. Изменения температуры, скорости ветра и атмосферного давления характеризовались ярко выраженными суточными, депрессионными (4-5 дней) и годовыми циклами. Регистрации ежедневных максимальных и минимальных показателей достаточно для выявления изменения среднемесячной температуры в 2-3°C на протяжении двух лет при значимости α в 0,05 и **P** в 0,8. Для того, чтобы выявить 10-20% изменения в среднемесячном

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логарифме скорости ветра при α=0,05 и **P**=0,9 достаточно постоянно регистрировать скорость ветра или регистрировать ежедневные минимальные и максимальные показатели скорости ветра.

Resumen

A partir de los datos ambientales de los años 1985 a 1987 procedentes de la estación antártica de Davis, se analiza la sensibilidad de distintos métodos de muestreo para determinar los cambios interanuales de los parámetros del medio ambiente. Se observan marcados ciclos diarios, anticiclónicos (4 a 5 días) y anuales de la temperatura, la velocidad del viento y la presión. El muestreo diario de la máxima y mínima bastaría para detectar un cambio mensual en la temperatura mínima media de 2-3°C en un período de más de dos años, con una significación α de 0.05 y una potencia **P** de 0.8. El muestreo continuo de la velocidad del viento o de la máxima y mínima sería suficiente para detectar un cambio de un 10 a 20% en la velocidad media mensual del viento, transformada logarítmicamente, con una significación α de 0.05 y una potencia **P** de 0.9.

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1. INTRODUCTION

Monitoring of selected environmental parameters is one of the basic components of the CCAMLR Ecosystem Monitoring Program (CEMP). This monitoring should be designed in such a way as to provide the information necessary to distinguish between changes in the monitored system induced by harvesting of particular species (especially krill) and changes resulting from environmental variability (SC-CAMLR-V, Annex 6, paragraph 40).

Two categories of environmental parameters were defined by WG-CEMP (1989): those which have a direct affect on the predators and those which affect predators indirectly through their influence on the distribution and abundance of prey. Within the first category the WG-CEMP selected sea ice cover, snow cover and local weather (air temperature, atmospheric pressure, wind direction and speed) for monitoring at land-based CEMP study sites (SC-CAMLR-VIII, Annex 7, Table 6).

Sampling strategies for weather conditions should be defined so that changes in environmental parameters can be confidently identified. Sample size and frequency should be chosen so that α, the probability of making a Type I error (rejecting the null hypothesis when there is no effect) and β, the probability of making a Type II error (accepting the null hypothesis when there is an effect) are both minimised. Type II errors are especially important in studies affecting conservation issues, where the penalty of not detecting a real effect may be the serious depletion of a protected resource (Peterman, 1990). The CEMP Working Group (1989) suggested that sampling strategies should be able to detect a 10% or 20% change in a parameter with a significance level $\alpha \leq 01$ and a statistical power of **P** $(=1-\beta) \geq 0.8$.

This paper examines several meteorological parameters measured at Davis Station, collected by the Australian Bureau of Meteorology. I will investigate the characteristics of the data and suggest sampling regimes that are sufficiently sensitive to changes in meteorological parameters.

2. METHODS

Data for 1985 to 1987 describing air temperature (dry bulb), atmospheric pressure, wind speed and direction were obtained from the Australian Bureau of Meteorology for Davis Station, Antarctica. The data were recorded at three hour intervals throughout the whole day at 0200, 0500, 0800, 1100, 1400, 1700, 2000 and 2300 (eight samples per day).

The data were first examined for general temporal characteristics, and in particular the presence of cyclic phenomena. Subsequently, sensitivity analyses were performed on the data assuming that the means and standard deviations calculated from the available data were approximations for the population mean and standard deviation, μ and σ. These analyses involve the calculation of the required sample size such that a certain level of change would be detectable at a significance level of α and at a power of **P**. The method of Sokal and Rohlf (1981) was used along the guidelines suggested in WG-CEMP-89/13. The required sample size, **n** was obtained from

$$n \geq 2(\sigma/\delta)^2(t\alpha[v]+t_2(1-P)[v])^2$$

where σ is the true standard deviation, δ is the smallest true difference that it is desired to detect, **v** the degree is of freedom (**=r(n-1)**, where **r** is the number of years or replicates over which the effect is detected), $\mathbf{t\alpha[v]}$ and $\mathbf{t_2(1-P)[v]}$ are obtained from a two-tailed **t** table with **v** degrees of freedom.

Temperature and wind speed were chosen for this analysis since they are probably the two most directly influential on predators; they were examined for the months of December, January, February and March, the months most important to predators. The period of a month was chosen for inter-seasonal comparisons (i.e., as the time period over which the calculations of μ and σ were made) for reasons that will be discussed later. Wind direction was not investigated since it requires a different type of analysis (Mardia, 1980).

3. TEMPORAL CHARACTERISTICS OF ENVIRONMENTAL PARAMETERS

All environmental parameters can be expected to display one or more of three temporal cycles: Daily, "Depressional" and Yearly. Daily cycles are triggered by daily heating and cooling. "Depressional" cycles are associated with the regular passage of depressions around the Antarctic continent. Yearly cycles are those associated with seasonal variation. Cycles of greater period are not considered here.

Figure 1 shows the variation in minimum daily temperature in January for 1985 to 1987. The 4- to 5-day depressional cycles are clearly seen. Figure 2 shows the same phenomenon in a plot of maximum daily pressure reading for January 1985. Figure 3 shows maximum daily wind speed in January for 1985 to 1987, demonstrating the effect of the depressional cycles and showing a strong gale in 1985. Figure 4 details wind speed data for January 1985 by three hour sampling period, and shows the daily cycle and its overlaid depressional cycle.

The occurrence of cyclic phenomena at Davis Station, including the suspected occurrence of cycles in other parameters, is shown in Table 1.

4. TEMPERATURE

Mean and standard deviation were calculated for minimum and maximum temperatures in January. Data for January 1985 and 1987 were combined for this calculation because they have similar mean values; data for January 1986 were not used because temperatures in that year were lower than for the other two years (see Figure 1). Maximum and minimum temperatures had means of 3.62 and -0.48 and standard deviations of 1.931 and 1.488 respectively (**n**=62). Sensitivity analysis for January, for two years of monitoring, is shown in Table 2. Summary information for the months December to March, taking α=0.05 and **P**=0.8, is given in Table 3.

These results indicate that with a sample size of about 30 maximum and minimum temperature readings (1 per day), a mean temperature change of ±2°C in December and January could be reliably detected at Davis Station, but that in later months, when temperature starts falling rapidly, a mean temperature of ±3°C would be the smallest change reliably detected.

5. WIND SPEED

These data were first analysed using all the 1985 to 1987 data, i.e. data determined using a sampling regime of eight samples per day. The readings of wind speed at Davis Station for January 1986 and 1987 showed an approximately log-normal distribution with a mean of 1.99 (=7.32 kn) and standard deviation of 0.707 (**n**=496). Sensitivity analysis is shown in Table 4. This shows that sampling on a regular basis with about 250 samples per month (about eight per day) would be sufficient to identify changes of 10% in log mean wind speed.

The analysis above does not take into account the fact that there is a daily cycle in wind speed at Davis Station (see Figure 4). An alternative regime for sampling under these conditions is to record maxima and minima, in which case the sample size is fixed at 30 to 31 per month. The results of sensitivity analyses, conducted on log maximum daily wind speeds (kn) calculated from Davis Station data for 1985 to 1987 are shown in Table 5.

These results suggest that sampling maximum wind speed with one sample per day (**n**~30 per month) may produce data sufficient to identify 10% changes in maximum wind speed in January but would only identify changes of 20% in other months.

6. DISCUSSION AND CONCLUSIONS

Three possible sampling regimes that could be adopted for recording weather conditions are as follows:

(A) single 'spot' sampling once or twice a day at specified times;
(B) repeated sampling throughout the day at regular intervals; and
(C) sampling of daily maximum and minimum information alone.

It is evident that where a strong daily cycle is present method (**A**) will be inadequate to sample environmental parameters because it cannot be assumed that the daily pattern will duplicate itself exactly between days, seasons or years. Use of method (**B**) will yield most information and will also produce estimates for the values obtained using method (**C**). Thus for most parameters regime **B** is the most sensible regime since we know that daily cycles in the parameters do occur.

It is also evident that for parameters that do not exhibit daily cycles, increased frequency of spot sampling should increase the power to detect inter-seasonal changes in parameters.

In order to compare the local weather conditions in different breeding seasons, it is necessary to choose a time interval for which to calculate an index of an environmental parameter. For instance, spring temperature in 1989 may be compared with spring temperature in 1990. Because there is a great deal of seasonal change in Antarctic environmental conditions, choice of periods shorter than a few months is necessary. However, the presence of 4- to 5-day depressional cycles in many of the parameters studied here means that the time interval chosen should be greater than a few of these cycles. It is suggested that the choice of one month as a time interval may be sufficient to avoid spurious results associated with depressional cycles yet short enough to avoid significant seasonal influences.

The results of sensitivity analyses of temperature and maximum wind speed at Davis Station are given in Table 6. These results suggest that sampling temperature using regime (**C**) and wind speed with regime (**B**) would provide data that was sensitive to changes in conditions between years (i.e., changes in the parameters of the stated magnitudes could be detected with acceptably low probabilities of Type I and Type II errors).

The following are suggested regimes for the other environmental parameters:

Pressure	(**A**) or (**C**)	- daily cycles are unlikely in barometric pressure;
Wind direction	(**B**)	- spot sampling and max/min information have no meaning here;
Ice type	(**A**)	- daily cycles are unlikely;
Ice cover	(**A**) or (**C**)	- daily cycles are unlikely;
Snow cover	(**A**)	

Diurnal variability is one of the most significant causes of variation in environmental data. If parameters do show diurnal variation, the effective sample rate can be no more than one per day. Seasonal variability is also extremely important, especially in high latitudes and comparisons of weather conditions between years must take this into account. I have suggested that the shortest period that can be used to compare conditions between years at Davis Station is one month; shorter periods will be influenced by the depressional cycles identified in the data. This means that a sample size of about 30 readings is likely to be the most convenient to use in these studies, but this is sufficient to detect changes of only 2° to 3°C in temperature and 10 to 20% in wind speed. For example, the slightly lower mean maximum temperature in January 1986 (2.6°C compared with 3.7°C and 3.6°C for 1985 and 1986 respectively) would not have been detected with the required levels of significance and power.

The results of this study apply to the environmental conditions specific to Davis Station. Whilst the general principles of the effect of daily and depressional cycles may hold for other sites, analyses similar to this one should be carried out in other areas to investigate the effects of sample size on the expected detection efficiency before a particular sampling regime is chosen.

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Table 1: Occurrence of cyclic phenomena at Davis Station. Suspected occurrence of other parameters is shown in parentheses.

Parameters	Cycles		
	Daily	Depressional	Yearly
Temperature	+	+	+
Pressure		+	+
Wind Speed	+	+	+
Wind Direction	(+)	(+)	(+)
Snow cover	(+)	(+)	(+)
Ice type			(+)
Ice cover			(+)

Table 2: Sample size required to detect a change in January mean daily maximum temperature over two years of monitoring at Davis Station.

δ	α=0.1			α=0.05		
	P=0.6	**P=0.8**	**P=0.9**	**P=0.6**	**P=0.8**	**P=0.9**
1°C	27	47	65	37	60	80
2°C	7	12	16	10	15	20
3°C	5	5	7	6	8	10

Table 3: Sample size required to detect a change in maximum and minimum temperature at Davis Station monitored over a two-year period, at α=0.05 and **P**=0.8. Mean and standard deviations calculated using data from 1985 and 1987. Changes are shown as absolute changes in the mean temperature.

	Mean	Standard Deviation	Change 1°C	2°C	3°C
December max	2.273	1.812	53	13	7
December min	-2.253	1.738	48	12	7
January max	3.621	1.931	60	15	8
January min	-0.482	1.488	35	10	6
February max	-0.848	2.890	132	33	15
February min	-5.141	3.304	172	44	19
March max	-5.473	3.495	193	49	22
March min	-11.574	3.846	233	59	27

Table 4: Sample size required to detect a change in January mean wind strength over two years of monitoring at Davis Station.

δ	α=0.1			α=0.05		
	P=0.6	**P=0.8**	**P=0.9**	**P=0.6**	**P=0.8**	**P=0.9**
10%	93	157	217	125	199	266
20%	23	40	55	32	50	68
30%	10	18	24	14	22	30

Table 5: Sample size required to detect a change in log maximum wind speed at Davis Station monitored over a two-year period, at α=0.05 and **P**=0.8 or 0.9. Mean and standard deviations were calculated using data from 1985 and 1987. Changes are shown as percentage changes in the mean log maximum wind speed.

	Mean	Standard Deviation	P=0.8 Change 10%	P=0.8 20%	P=0.9 10%	P=0.9 20%
December	2.750	0.466	46	11	62	15
January max	2.635	0.368	31	9	42	10
February max	2.703	0.437	42	10	56	14
March max	2.624	0.514	62	15	82	21

Table 6: Results of analyses of temperature and wind speed data from Davis Station.

Parameter	Sampling Regime	Sample Size Per Month	Target Change Observed	Sensitivity
Temperature	max/min daily information	**n**~30	2-3°	High power of detection
Wind speed	daily multiple recording	**n**=8 per day for one month	10-20%	High
	daily multiple recording or max/min information	**n**~30	10-20%	High

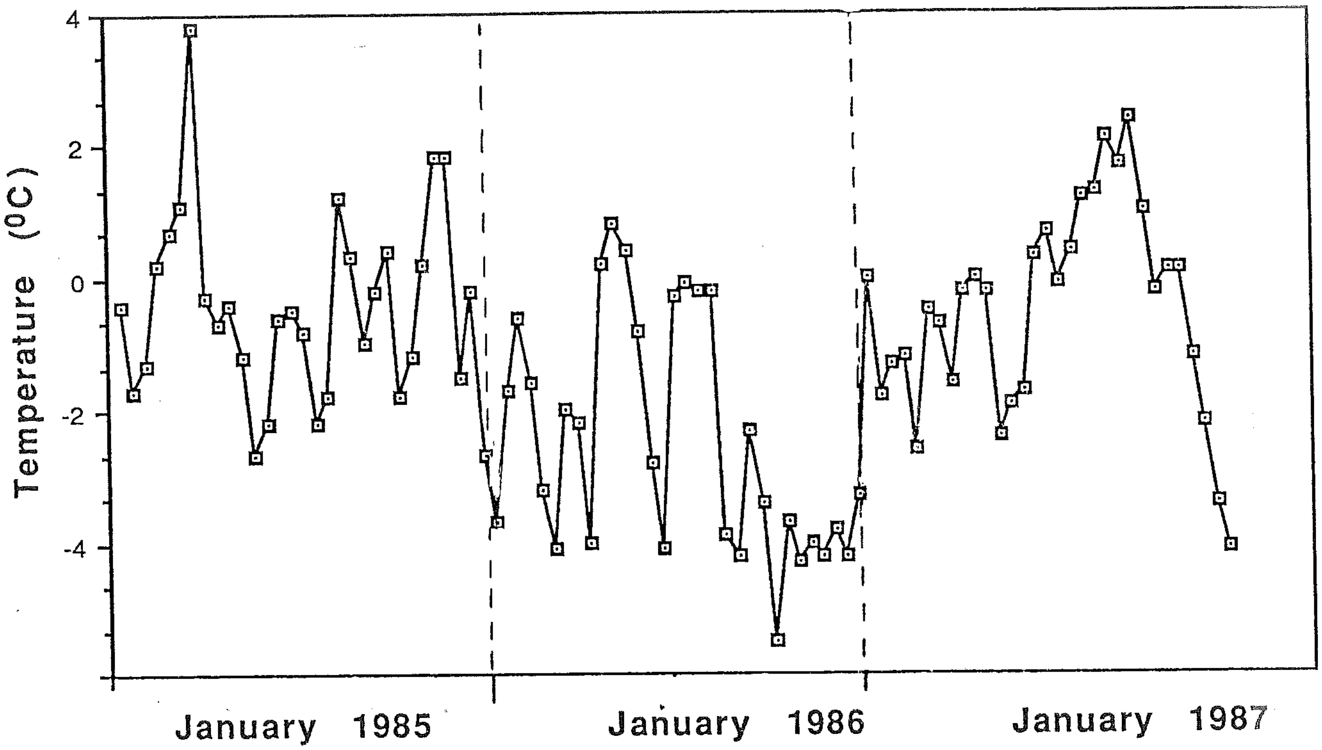

Figure 1: Mean daily temperature in January for 1985 to 1987, Davis Station, showing the effect of depressional cycles.

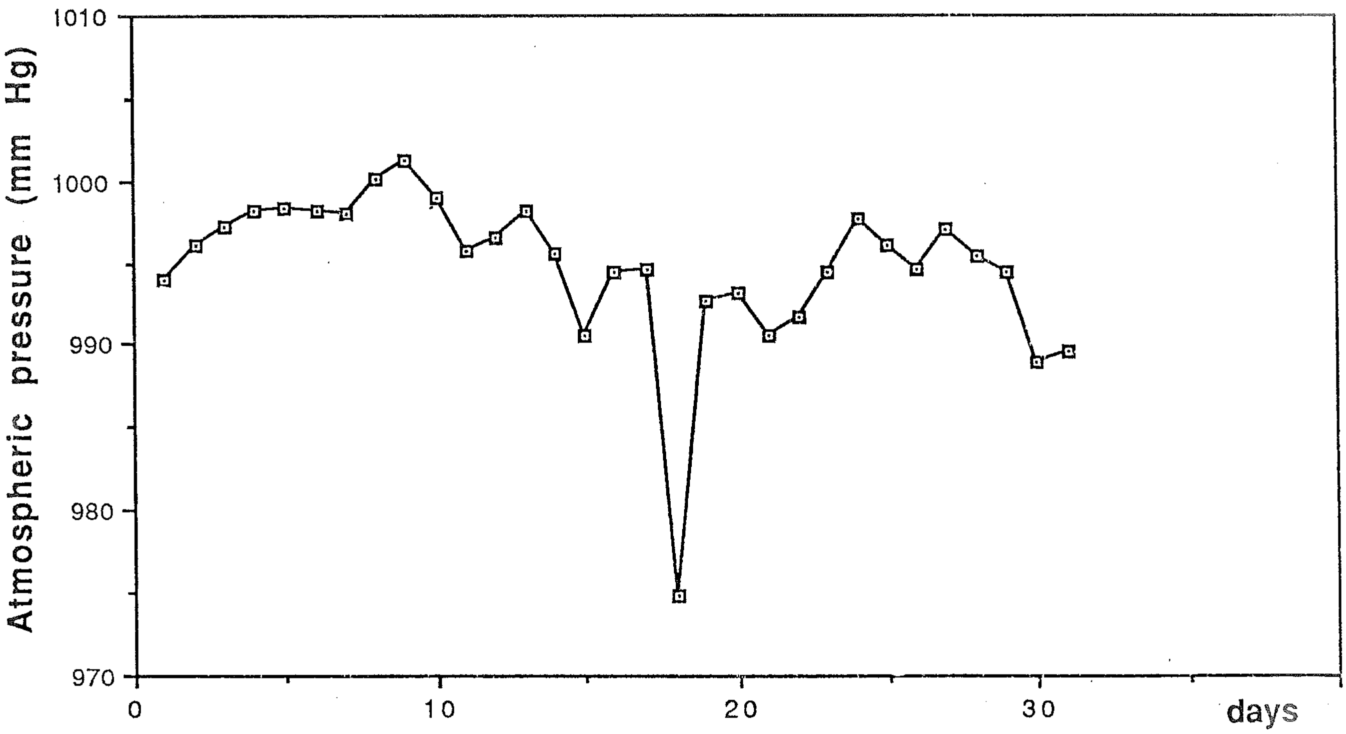

Figure 2: Maximum daily pressure for January 1985, Davis Station, showing the effect of depressional cycles.

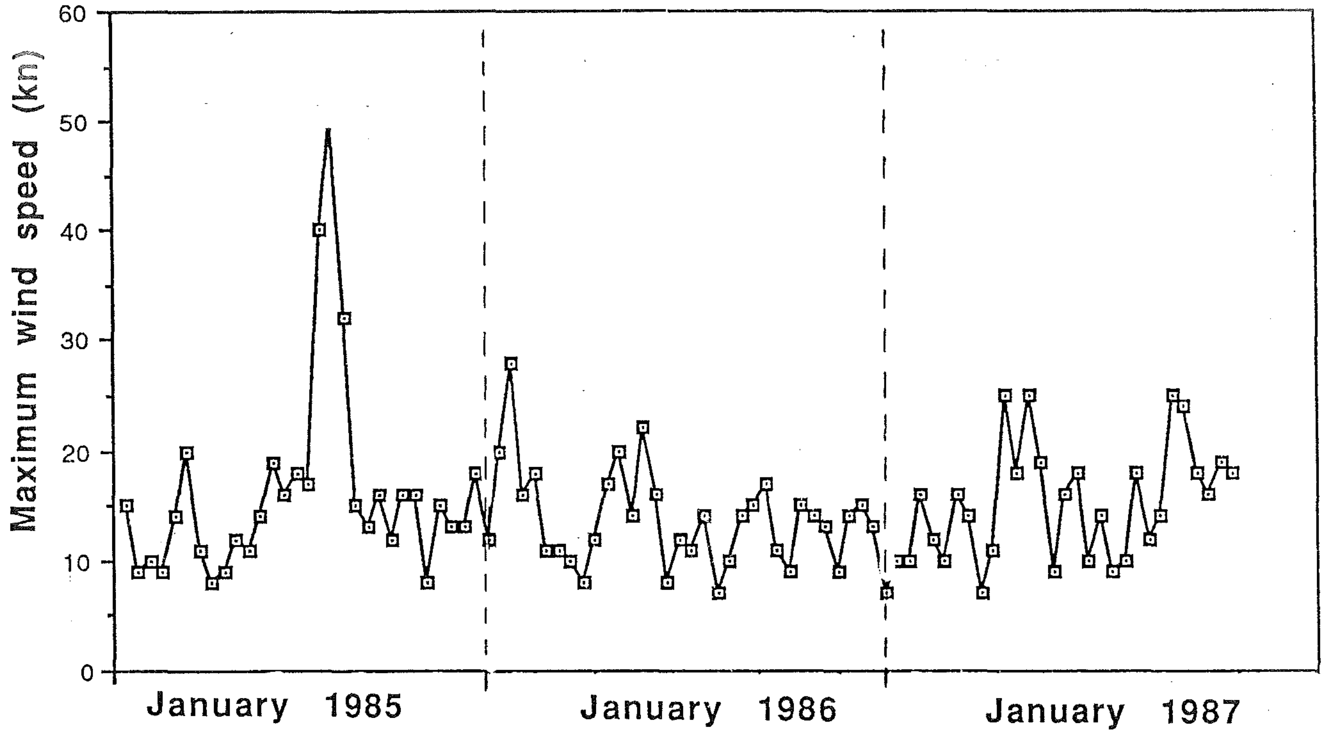

Figure 3: Maximum daily wind speed in January for 1985 to 1987, Davis Station, showing the effect of depressional cycles.

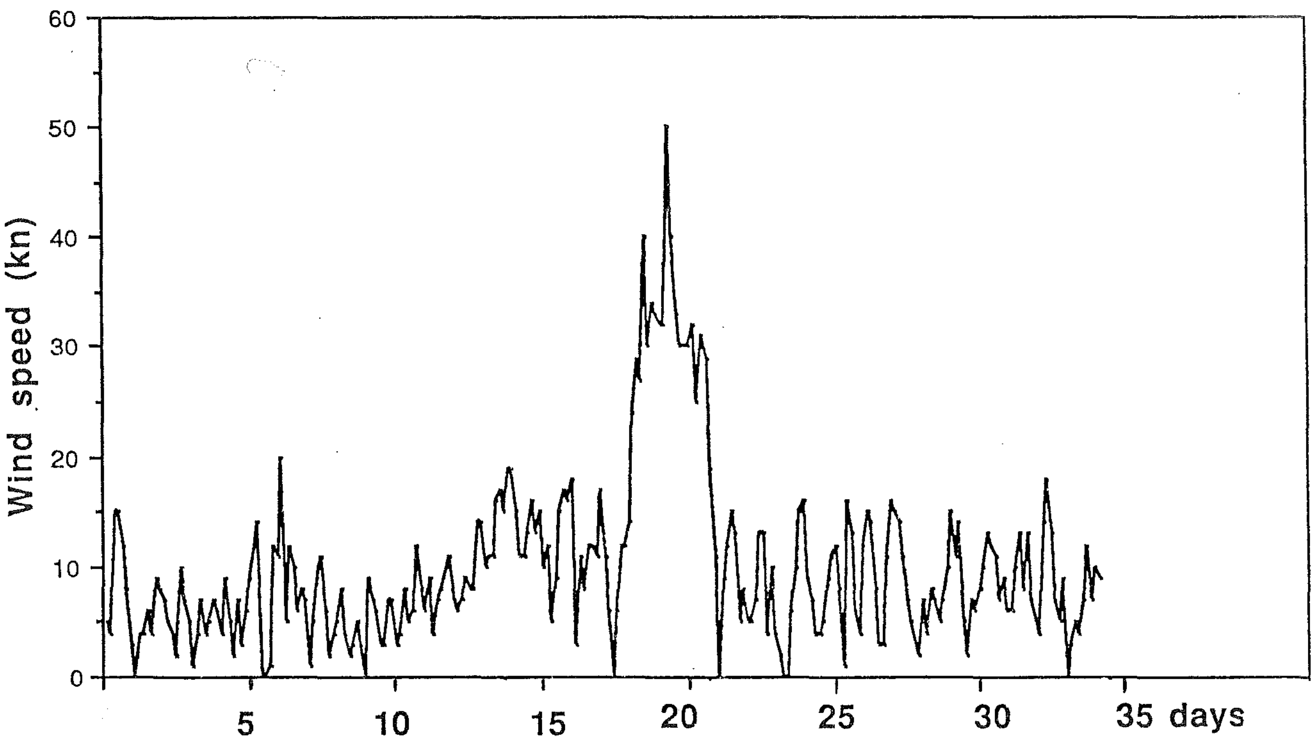

Figure 4: Daily wind speed by three hour sampling period for January 1985, Davis Station, showing daily cycles.

Légende des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras