POWER SPECTRAL ANALYSIS OF SNOW DENSITIES AT MIZUHO STATION, ANTARCTICA

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***Abstract*:** Power spectrum analyses were made of layer-to-layer variations of densities of core-samples recovered by drilling at Mizuho Station, Antarctica. The power spectra computed by the maximum entropy method show twenty-seven cyclic changes of snow deposition mode and consequently of climatic circumstances. The periods of the climatic changes are estimated to range from 6.1 to 389.4 years.

1. Introduction

Densities of snow and their variations with depth have been investigated at many sites on polar glaciers and ice sheets. However, layer-to-layer fluctuations of density or deviations from average profiles, which are recognized in many glaciers, seem to have been attributed to seasonal variations, local irregular changes in the mode of snow deposition and errors in density measurements (BADER, 1960; LANGWAY, 1967; GOW, 1968).

It is reasonable to consider that some of the variations might be explained in these ways, but that some may be caused by more significant changes in the snow deposition mode, perhaps associated with climatic changes. For the cores recovered at Mizuho Station large variations in the snow densities found around 35-m depth were caused by repeated occurrences of a colder climate or of a period with extremely low accumulation; this has been estimated to have taken place roughly 300 years before the present (MAENO and NARITA, 1979).

This concept suggests a method of obtaining information of past changes in the climate. The present paper is intended to estimate the time intervals of such climatic changes from power spectrum analyses.

2. Density Data for Spectrum Analyses

The density data used in the power spectrum analyses are those obtained for core samples recovered by drilling at Mizuho Station (70°41′53″S, 44°19′54″E; elevation 2230 m; mean annual temperature −33°C) in East Antarctica.

In the present analyses the numerical values of density at 2002 different points, from the surface to 124-m depth, at intervals of a few centimeters, which were compiled by NARITA and MAENO (1978), were averaged over 0.1 m intervals. Figure 1 shows the averaged density plotted against depth. The line in the figure is the regression curve obtained by the least-squares method:

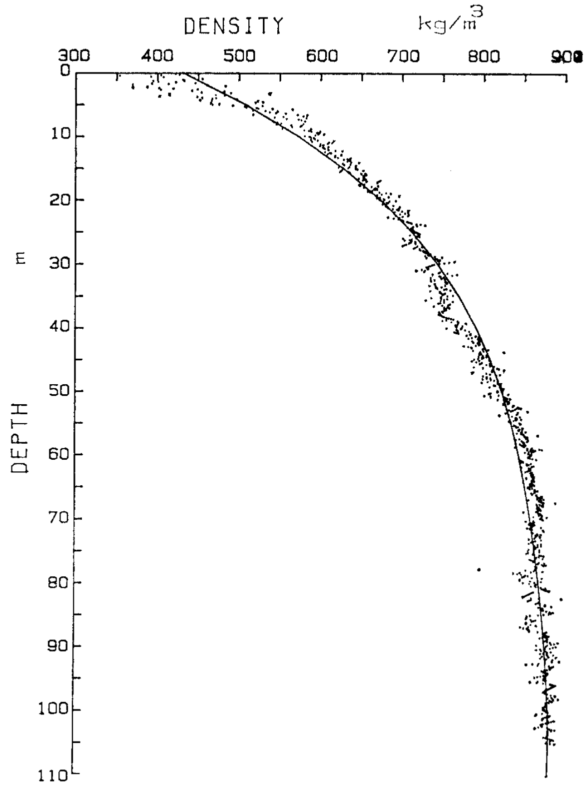

Fig. 1. Mean density in 0.1-m depth intervals, plotted against depth, at Mizuho Station. The line is the 4-th power regression curve, eq. (1).

$$\rho_{av}=A+Bz+Cz^2+Dz^3+Ez^4 , \qquad (1)$$

where ρ_{av} is the average density in kg/m³ at a depth z in meter, and numerical constants A, B, C, D and E are

$$A=431.618 \text{ kg/m}^3,$$

$$B=16.5838 \text{ kg/m}^4,$$

$$C=-0.258661 \text{ kg/m}^5,$$

$$D=1.97273\times10^{-3} \text{ kg/m}^6,$$

and

$$E=-5.94032\times10^{-8} \text{ kg/m}^7.$$

Spectral analyses have been made of the density data arranged at equal depth intervals. To take account of the thinning of layers due to densification, the thickness h_z of a layer with density ρ_z has been converted to that at the surface, assuming the conservation of mass within the layer:

$$h_z\rho_z=h_0\rho_0 , \qquad (2)$$

where h_0 and ρ_0 are respectively the thickness and density at the surface. In the calculations, ρ_z was estimated from eq. (1), and ρ_0 was set equal to 409 kg/m³, which is the mean of 18 values measured at different depths between the surface and 1.0-m depth.

3. Results of Power Spectrum Analyses

Figure 2a shows the differential density, defined as

$$\Delta\rho = \rho - \rho_{av} , \quad (3)$$

plotted against the depth. Negative values of $\Delta\rho$ are noted especially in the 0–5 m and 30–40 m depth ranges; the former may be attributed to incomplete fitting of data by eq. (1), but the latter corresponds to the climatic change mentioned in the first section.

With the assumption of the mass conservation discussed in the preceding section, differential densities at 0.1-m depth intervals (as measured at the surface) were calculated and are given in Fig. 2b. In the calculation interpolation was made by use of the Spline function (Ishida, 1982). The depth given is that corrected to the surface, that is the depth of snow expected if snow accumulated without densification.

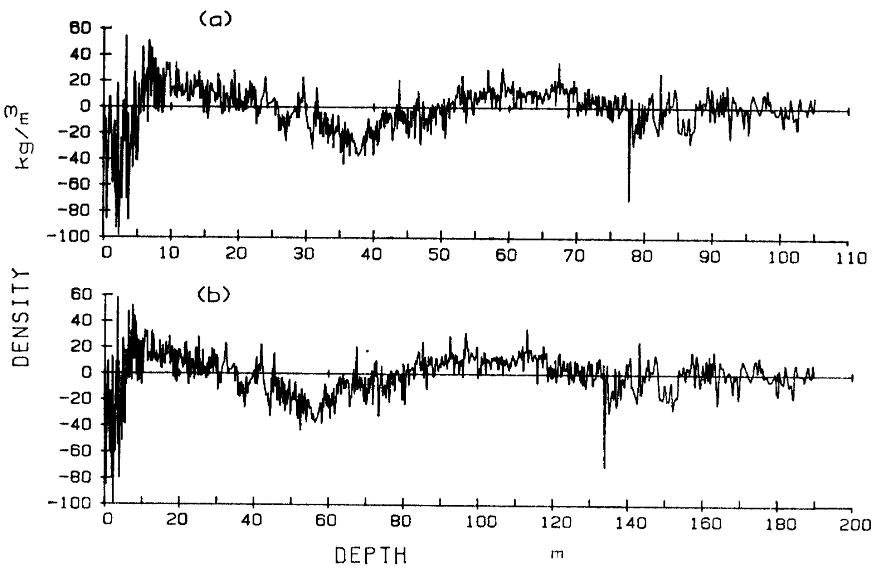

Fig. 2. Differential density plotted against depth. The depth in the lower figure (b) is that converted to the surface, that is, the depth expected when the snow deposited did not undergo densification.

Power spectra were computed by applying the maximum entropy method (MEM) developed by J. P. Burg (Hino, 1977). Figures 3 and 4 give the power spectra obtained by performing 101-term Fourier transforms for the range of frequencies corresponding to wave numbers from zero to 5.0 m^{-1}. The wave number corresponds to the Nyquist frequency. The prediction error filter was calculated to 40 terms from 500 density data contained in a 50-m depth range. In the calculation the depth range was shifted towards deeper depths by the amount of 10 m. More details of the MEM applied to the present analyses are reported elsewhere (Ishida, 1981; Ishida and Maeno, 1983).

In the power spectra shown in Fig. 3, many peaks appear and most of them seem to be meaningful in the sense of the ensemble mean, since each of them appears near the same wave number in the five spectrum curves for different depth ranges. The

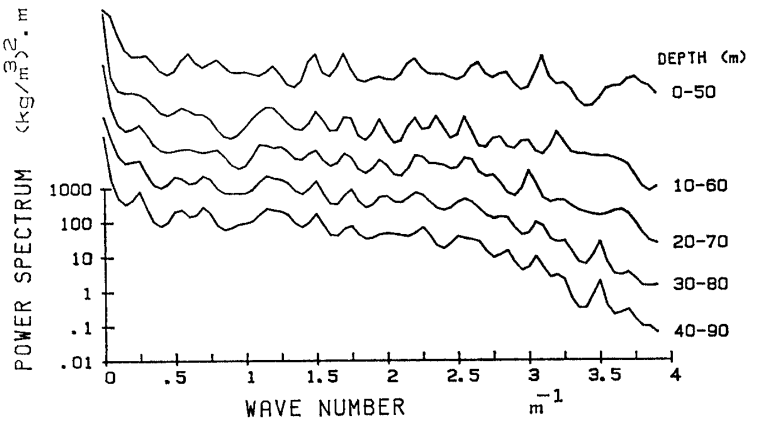

Fig. 3. Power spectra (50-m depth range) for permeable snow. Each spectral curve is shifted upwards by a unit scale. Depths indicated are those converted to the surface.

Table 1. Wave numbers at peaks (Fig. 3), means, wave lengths and corresponding periods. In calculating the periods the annual accumulation rate and surface density were set to be 70 kg/m²·a and 409 kg/m³ respectively.

Depth range (m)	0–50	10–60	20–70	30–80	40–90	Mean	Wave length (m)	Period (a)
Wave number	6	4	5	5	5	5	4.00	23.4
($\times 1/20\ m^{-1}$)	12	11	12	10	11	11	1.82	10.6
	16	14	16	14	14	14	1.43	8.3
	24	23	23	23	23	23	0.87	5.1
	30	30	30	30	30	30	0.67	3.9
	34	34	34	35	35	34	0.59	3.4
	39	39	39	40	40	39	0.51	3.0
	44	44	44	44	45	44	0.45	2.6
	53	51	51	51	50	51	0.39	2.3
	57	56	55	56	57	56	0.36	2.1
	62	60	60	61	61	61	0.33	1.9
	65	64	64	65	64	64	0.31	1.8
	69	—	—	70	70	70	0.29	1.7
	75	—	73	74	74	74	0.27	1.6

wave number at peak and the mean are given in Table 1. The spectra shown in Fig. 3 are for permeable snow; according to the measurement by MAENO *et al.* (1978), the air permeability of the core samples decreases with depth and becomes nearly zero at 55-m depth (840 kg/m³). The critical depth corresponds roughly to 100 m when converted to surface density.

Figure 4 shows power spectra for all the 15 depth ranges. Most of the peaks appearing in the spectra from the permeable snow also appear here at almost the same wave numbers. It should be mentioned, however, that the accuracy of density measurements decreases with depth, due to the presence of minute cracks and sometimes of fracturing of core samples at depths deeper than about 70 m (NARITA *et al.*, 1978).

Power spectra were calculated from the whole series of density data to find cyclic

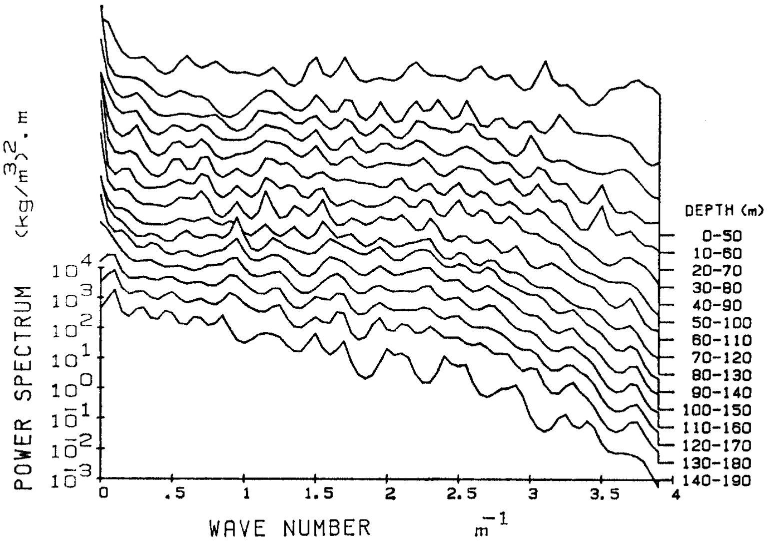

Fig. 4. Power spectra (50-m depth range) plotted against wave number. Each curve is shifted as in Fig. 3, and depths are those converted to the surface.

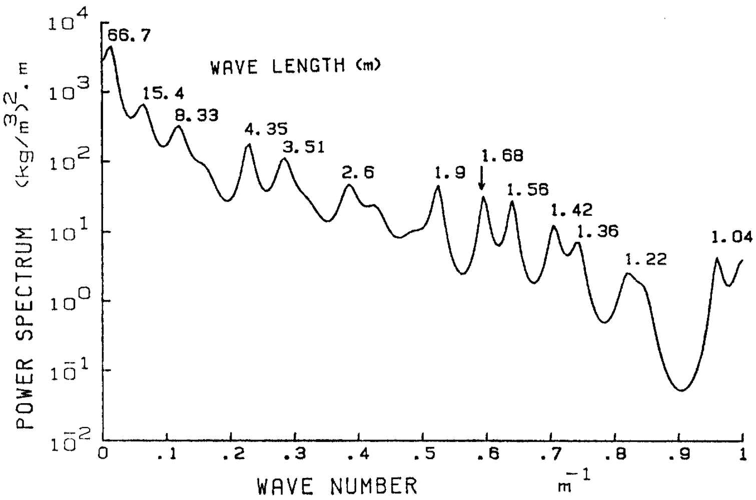

Fig. 5. Whole-depth power spectrum plotted against wave number. Figures are wave lengths at peaks.

changes of longer periods. Mean densities over 0.5-m depth intervals were computed, and MEM was applied to the differences between them and the average density given by eq. (1). Forty terms of the prediction error filter were computed and Fourier transform was performed to 201 terms in the wave number from zero to 1.0 m^{-1}, which corresponds to the Nyquist frequency.

The power spectrum obtained is shown in Fig. 5, in which thirteen clear peaks can be recognized. WATANABE *et al.* (1978) made similar spectral analyses of the density variations at Mizuho Station and obtained periodic changes with wave lengths of 0.45 and 4.45 m, as measured at 14-m depth. The figures correspond respectively to 0.64 and 6.37 m as measured at the surface. Their calculation method is different from MEM, but their result is in agreement with the present results.

4. Concluding Remarks

From the power spectrum analyses of density variations from core-samples recovered at Mizuho Station, we suggest that many periodic changes of snow deposition mode and of climate have occurred. The wave numbers of the power spectra peaks, converted to time intervals, are tabulated in the last columns in Tables 1 and 2. In the computation the accumulation rate was set equal to 70 kg/m^2·a, based on the estimate by MAENO and NARITA (1979) and NARITA and MAENO (1979).

Table 2. Wave lengths and corresponding periods estimated from the whole depth-range power spectrum in Fig. 5. The annual accumulation rate and surface density were set to be 70 kg/m^2·a and 409 kg/m^3 respectively.

Wave length (m)	Period (a)
66.7	389.4
15.4	89.9
8.33	48.6
4.35	25.4
3.51	20.5
2.60	15.2
1.90	11.1
1.68	9.8
1.56	9.1
1.42	8.3
1.36	7.9
1.22	7.1
1.04	6.1

For the present the meteorological or climatological explanation of the twenty-seven periodic variations of climate, which might have occurred at Mizuho Station, is a difficult problem and this study should be followed by more extensive investigations in the future. However, the cyclic changes with shorter periods of a few or several years (Table 1), are considered to be related with the complex mode of formation of snow layers in the katabatic wind region where Mizuho Station is located.

WATANABE (1978) noted the frequent absence of annual layers in the altitude range of 1800 m to 3200 m on the Mizuho Plateau. The phenomenon is partly the result of small or no deposition of snow, but FUJII (1981) recently reported the important effect of sublimation in producing missing annual layers. Consequently the cyclic changes with shorter periods in the density variations are probably due to complex deposition-erosion processes and sometimes to missing layers.

To obtain a more definite understanding of the periods obtained above, it is necessary to perform similar spectral analyses on density data from different sites on the Mizuho Plateau, and possibly from other physical properties, such as oxygen isotope concentration.

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