Annals of Glaciology 3 1982

POSSIBLE CAUSES OF THE VARIATION IN MICROPARTICLE CONCENTRATION IN AN ICE CORE FROM MIZUHO STATION, ANTARCTICA

by

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ABSTRACT

Variation of the microparticle concentration in an ice core from Mizuho station, East Antarctica, does not show the annual cycle that has been demonstrated for ice cores from Antarctica and Greenland by other authors. Possible reasons for the lack of a annual cycle are considered and two causes are suggested. (1) Semi-annual variation of microparticle concentration as observed in drift-snow. The low particle concentration in March and in August to October is not due to minor particle transport, but to the dilution of microparticles transported mainly from arid regions in the southern hemisphere through the troposphere by falling snow. (2) Discontinuous surface-layer formation. A seasonal or an annual sequence of the variation in microparticle concentration in surface snow layers may be interrupted by the absence of surface snow-layer formation.

1. INTRODUCTION

Recent studies on microparticle concentration in Antarctic ice cores from Byrd station (Marshall 1962, Thompson 1973, Thompson and others 1975) and Dome C (Thompson and others 1981) and in Greenland ice cores from Camp Century (Hamilton and Langway 1967, Thompson 1977[a],[b]), yield two important results: one is that the highest concentration occurs when oxygen isotope compositions exhibit the greatest negative value, and the other is that microparticle variations could be used for dating ice cores. The cyclic variation in particle concentration within ice cores from Byrd station and Dome C, Antarctica, was suggested to be annual.

Microparticle analysis of a 147.5 m core from Mizuho station, Antarctica (44°20'E, 70°42'S, 2 230 m a.s.l., (Fig.1)) showed a cyclic variation in the concentration. This cyclic variation, however, cannot be assumed to be annual, as it was in the Byrd and Dome C ice-core analyses. This is due to the lack of seasonal or annual sequences of surface snow layers at Mizuho station, where strong katabatic winds prevail (mean annual wind speed is about 10 m s^{-1}), often causing snow redistribution following deposition (Okuhira and Narita 1978). Long-term interruption of 1 to 10 a in snow accumulation, and the disappearance of pre-formed surface layers due to sublimation and wind erosion, make the stratigraphic chronology of Mizuho ice cores difficult (Watanabe 1978, Watanabe and others 1979, Fujii 1981).

2. SAMPLE COLLECTION AND LABORATORY TECHNIQUES

2.1. Ice coring and drift-snow sampling

147.5 and 145.4 m cores were drilled at Mizuho station in 1972 and in the 1974-75 austral summer (Suzuki and Takizawa 1978). Microparticle analysis was conducted using vertical half-core sections from the 147.5 m core.

Freshly drifted snow, collected within a day after deposition, was sampled at sites up-wind from

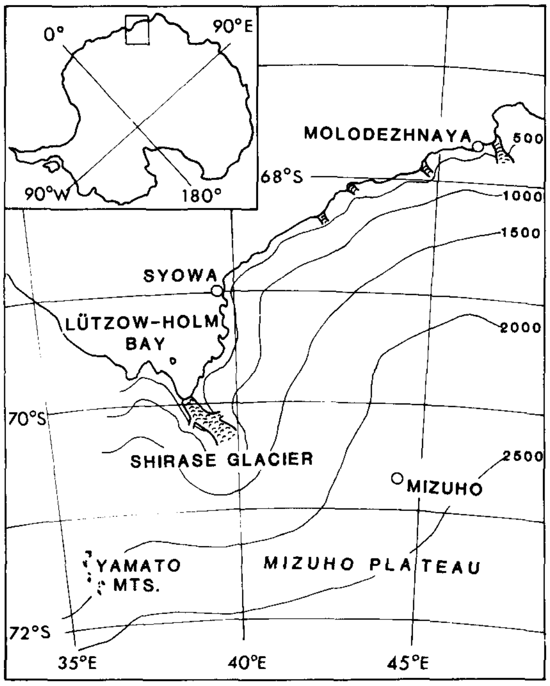

Fig.1. Location of Mizuho station.

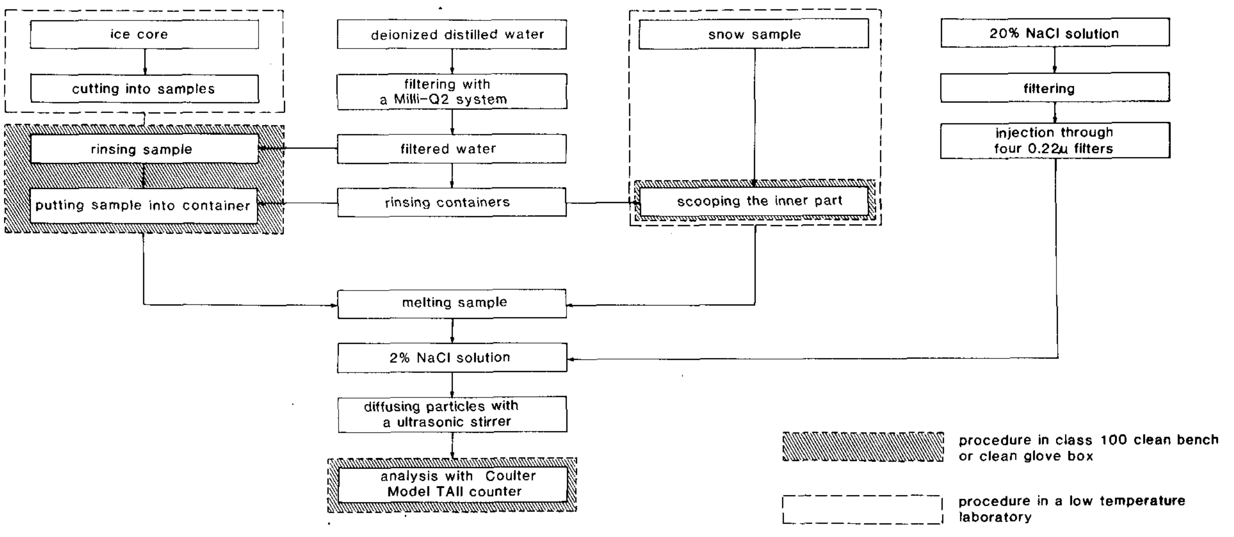

Fig.2. Procedure for counting particles in snow and ice samples.

any possible contamination at Mizuho station once every 3 to 4 d from February 1977 to January 1978. Snow drifts contain both new snow-fall and snow eroded from existing surfaces. As the surfaces which can be easily eroded are the newly formed ones, it can be said that snow in snow-drifts is composed mainly of newly fallen snow. To eliminate impurities from the inside wall of 250 ml polyethylene sample containers, the containers were cleaned by rinsing several times with drifted snow before sampling.

2.2. Sample preparation and particle counting

The procedure for counting particles in snow and ice samples is summarized in Figure 2. Sampling from an ice-core section was achieved by cutting the core into slices 20 mm thick with a band-saw; they were then rinsed thoroughly in a class-100 clean glove-box. In the case of snow samples, the inner part of the sample was used in an attempt to avoid contamination.

After melting the samples, they were converted into 2.0% NaCl electrolyte by injecting the appropriate amount of 20.0% NaCl solution using a plastic syringe with four 0.22 μm pore-sized Millex filter units. Suspended particles were diffused uniformly with an ultrasonic stirrer prior to analysis in a Coulter model TAII counter.

For particle analysis with the counter, a 12 μm aperture tube was used and particles were electronically separated into 16 size ranges between 0.25 and 8.00 μm in diameter; smaller-sized particles less than 0.63 μm in diameter were excluded from the analysis to avoid inaccurate counts due to electronic noise. 50 μℓ of melted sample was pulled through the aperture by the pressure difference established by means of a mercury manometer. This procedure was conducted in a clean glove-box.

3. SEASONAL VARIATION IN PARTICLE CONCENTRATION IN DRIFTED SNOW AND ITS INTERPRETATION

Microparticle concentration and size distribution were analysed for the melted samples of drifted snow (Fujii 1981[b]). The concentration of particles is shown in Figure 3 as the total number greater than 0.63 μm in diameter per 50 μℓ. The broken line in the figure shows the variation in the minimum level of particle concentration, which provides a more reliable indication because the concentration is thought to be less contaminated. As is seen in the figure, the semi-annual cycle is predominant in the particle concentration. Two maxima with a total number of 250 particles per 50 μℓ are seen, in January and February of the summer season and in May to July of the winter season, and two minima, with the total number less than 100 in March and in August to October of the intermediate seasons between summer and winter. Dust from arid regions in the southern hemisphere, extra-terrestrial particles, and dust from Antarctic oases are thought to be the most probable sources of insoluble particles contained in Antarctic snow, and interpretations of semi-annual variations in the microparticle concentration in drifted snow are made on this premise.

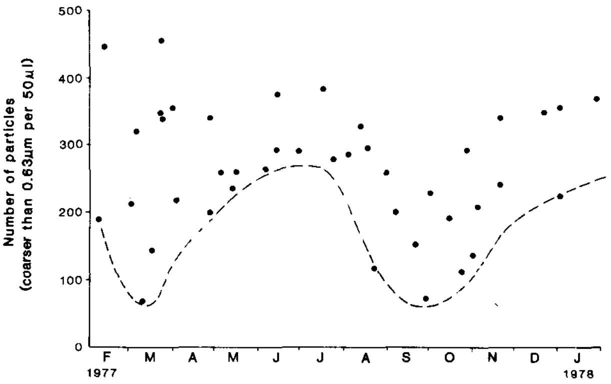

Fig.3. The seasonal variation in microparticle concentration in drifted snow collected at Mizuho station in 1977. The concentration is given as the total number greater than 0.63 μmin diameter per 50 μℓ of melted sample.

Arid regions in the southern hemisphere are prime candidates for supplying crustal material to the Antarctic ice sheet. Cloud and rain systems over the southern oceans must remove particles during long-distance transport to Antarctica (≈6 000 km), but a small proportion (estimated by Shaw (1979) to be 5%) is transported over the top of the storm systems and travels to Antarctica.

Air mass transport from the lower latitudes to the Antarctic is strengthened by the development of predominant low pressure systems when the zonal index is high. The zonal index at four standard isobaric surfaces between Marion Island (37°52'E, 46°53'S) and Syowa station (39°35'E, 69°00'S) in 1977 shows a semi-annual cycle, being high in March and September and low in June and December throughout the troposphere, at least above 850 mbar (Fujii 1981[b]).

Corresponding to such semi-annual variation in atmospheric circulation, the transport of air mass and moisture increases in the intermediate seasons over Syowa station as shown in Figure 4. If we assume that (1) this pattern does not change much over Mizuho station, and (2) the northerly air mass flux and the net moisture flux are in proportion to the microparticle flux and the amount of snow-fall, respectively, then the transport of microparticles would increase in March and in July to October and the amount of snow-fall in March and in August to September. These show quite similar tendencies.

However, the snow-fall dilutes the concentration of microparticles. In order to study this effect, the ratio between the air mass flux and moisture mass flux is examined. A two-month running mean of this ratio, shown by a broken line in Figure 4, indicates the semi-annual variation with two minima in February-March and in August-September, which coincides quite well with that in microparticle concentration in drifted snow.

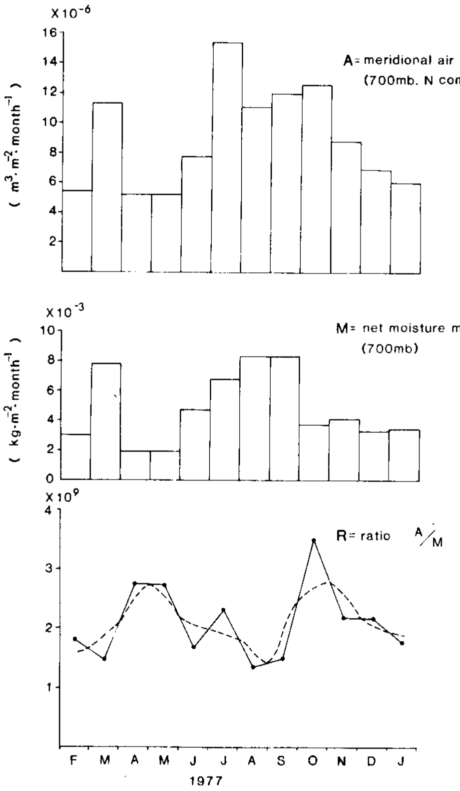

Fig.4. Monthly variation of the northerly air mass flux (A: above), the net moisture flux (M: middle), and the ratio (R=A/M: below) at 700 mbar over Syowa station during the period from February 1977 to January 1978.

It is, therefore, reasonable to consider that the low particle concentration in drifted snow in March and in August to October is not due to minor particle transport from the lower latitudes but to the dilution of transported microparticles by falling snow.

Particles of extra-terrestrial origin and from exposed ground in Antarctica have also been examined. The number and size of black spherules, which are probably extra-terrestrial particles (described by Langway (1970)), in 1 kg surface-snow samples from Mizuho station were analysed. The proportion of black spherules greater than 0.6 µm in diameter is estimated to be 0.7 ppb from the examined size distribution.

Though there are no data available on particle flux into the atmosphere from the exposed land area in Antarctica, the deposition rate over the entire plateau has been estimated at 3 x 10^{-15} kg m^{-2} s^{-1} for particles 0.1 to 1.0 µm in diameter (Shaw 1979), which corresponds to 1.9 ppb of mineral component in Antarctic snow for a snow precipitation rate of 50 kg m^{-2} a^{-1}. These two values of 0.7 and 1.9 ppb are quite small in comparison with the examined total particle composition of 10 to 20 ppb. Therefore, these two sources are insignificant.

4. DISCONTINUOUS FORMATION OF SURFACE SNOW LAYER

4.1. Season of layer formation

Figure 5 shows the mean monthly net accumulation of snow obtained by the measurement of nine snow stakes from June 1976 to December 1980 (Nishio 1978, Fujii 1979[a], Wada and others 1981). Deposition of snow frequently occurs in February and March and forms a relatively thick layer. January, August, October, and November are months of secondary importance for snow deposition and layer formation. Though the surface level rises at a rate less than 1 mm per month in April to July due to condensation (Fujii 1979[b]), snow deposition hardly occurs in these months. It is, therefore, probable that a seasonal sequence of variation of microparticle concentration in surface snow is interrupted by the absence of layer formation at Mizuho station.

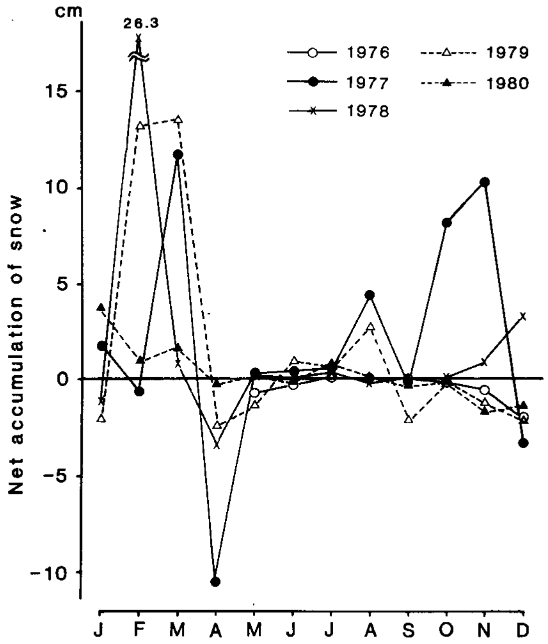

Fig.5. Mean monthly net accumulation of snow obtained by the measurement of nine snow stakes at Mizuho station from June 1976 to December 1980.

4.2. Interruption of an annual layer formation

Absence of an annual layer is a phenomenon which usually occurs at an altitude of 1 800 to 3 200 m on Mizuho plateau (Watanabe 1978). Figure 6 shows the cross-sectional sequence of annual layers from 1973 to 1977 along a stake line (Nos. 1 to 101), of the 202-stake array at Mizuho station. As is seen in the figure, an annual snow layering at Mizuho station is characterized by discontinuity and high year-to-year variability. According to the statistical analysis of the 202-stake data obtained in 1972 to 1978 (Fujii 1981[a]), two layers were formed, once in every two years on the average. Watanabe and others (1979) show the probability of the occurrence of a long-term

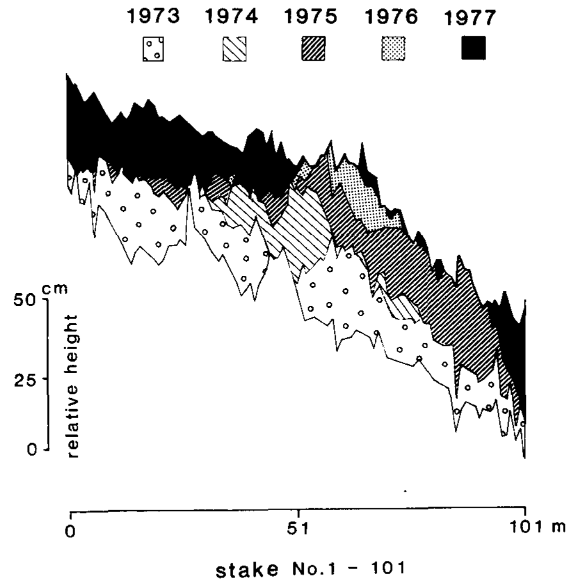

Fig.6. Cross-sectional sequence of annual layers from 1973 to 1977 along a stake line (Nos.1 to 101) of the 202-stake array at Mizuho station.

interruption in layer formation which lasts from several to about ten years on Mizuho plateau.

The absence of an annual layer at Mizuho station is mainly due to lack of snow deposition in a given year. Strong summer sublimation of 50 kg $m^{-2}a^{-1}$ (70 mm in depth) occurs especially on a glazed surface consisting of a multilayered ice crust (Fujii 1979[b]). In some years, the pre-formed annual layer disappears due to sublimation. The absence of an annual layer causes the disappearance of an annual variation of the microparticle concentration. The ice crust is visible as a distinct ice layer even in the core section at 100 m depth (Narita and others 1978).

5. VARIATION OF MICROPARTICLE CONCENTRATION IN MIZUHO STATION ICE CORE

Concentration of microparticles in a Mizuho station ice core varies with depth, but the interpretation of the variation is not as simple as it is for a Byrd or Dome C core from Antarctica, or for a Camp Century core from Greenland, mainly because of the frequent interruption of layer formation.

Figure 7 shows a profile of the total number of particles greater than 0.63 μm per 50 μℓ of a melted ice sample from a section between the depth of 67.81 to 68.19 m. There were some ice crusts of 0.8 to 1.0 mm thick, and layer boundaries without an ice crust.

As described in a previous section, the existence of an ice crust suggests the interruption of an annual layer formation. A layer boundary without an ice crust is presumed to have formed in a relatively short interval of time before it is covered with the upper layer (Watanabe and others 1978).

A boundary between layers nos.4 and 5 probably indicates the surface in the mid to late summer, judging from the observation of vanishing progress of surface ice crust at Mizuho station in January 1978 which existed extensively in the vicinity for more than 20 months (Fujii and Kusunoki in press).

After mid to late summer, layers nos.5 to 7 superimposed in a relatively short period. As the concentration of microparticles is low in the layers nos. 5 and 6, these layers might be formed in the autumn season. No.7 layer, which shows a higher concentration, was probably formed in winter or summer. Thick layer no.8 has no layer boundary, which indicates that continuous snow deposition occurred. Therefore, the cyclic variation in microparticle concentration can be interpreted as a seasonal sequence, taking account of the semi-annual variation of microparticle concentration in drifted snow. Therefore, the annual accumulation rate can be estimated from the figure to be about 100 mm of snow or 80 to 90 kg m^{-2}. As the annual accumulation rate is close to the average value of 106 kg m^{-2} estimated from the stratigraphic interpretation of the Mizuho core at depths between 20.5 and 65.5 m by Watanabe and others (1978), the present interpretation of the microparticle concentration variation seems reasonable.

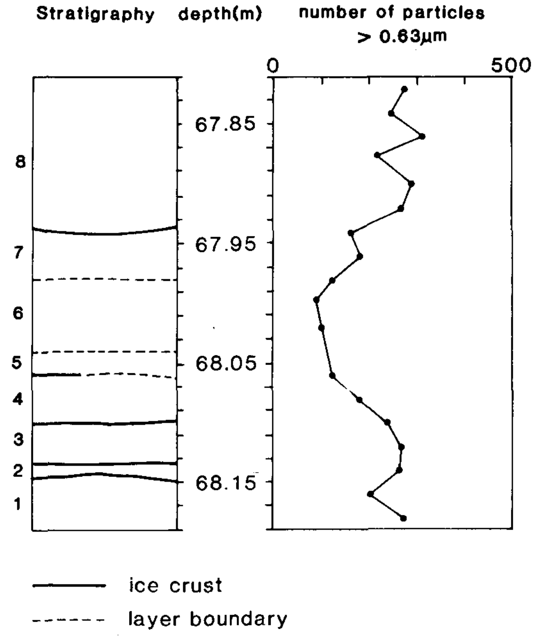

Fig.7. Variation in total number of microparticles greater than 0.63 μm per 50 μℓ of melted sample in a 0.38 m core between 67.81 and 68.19 m depth from Mizuho station. The core stratigraphy is illustrated on the left of the diagram.

Though the ice-crust surface, which is a glazed surface, was lowered about 70 mm through sublimation (Fujii 1979[b]), the microparticle concentration is not noticeably high in core samples which include the ice crust. This suggests that the particles from below the surface are blown off by wind immediately after they appear on the surface.

The several processes which may cause variations in microparticle concentration in the core from Mizuho station are summarized in Figure 8. The main factors are (1) particle transport from lower latitudes to the Antarctic ice-sheet surface through the troposphere and the dilution effect of falling snow, and (2) the process of surface layer formation. Observation of the microparticle concentration in the drifted snow for a longer time than 1 a is needed to relate it to the microparticles in the ice core.

ACKNOWLEDGEMENTS

The authors are greatly indebted to Dr Okitsugu Watanabe, Dr Yasunobu Iwasaka, and Dr Kikuo Kato of the Water Research Institute, Nagoya University, and Dr Hajime Nakamura of the Geophysics Research Laboratory, University of Tokyo, for their valuable advice.

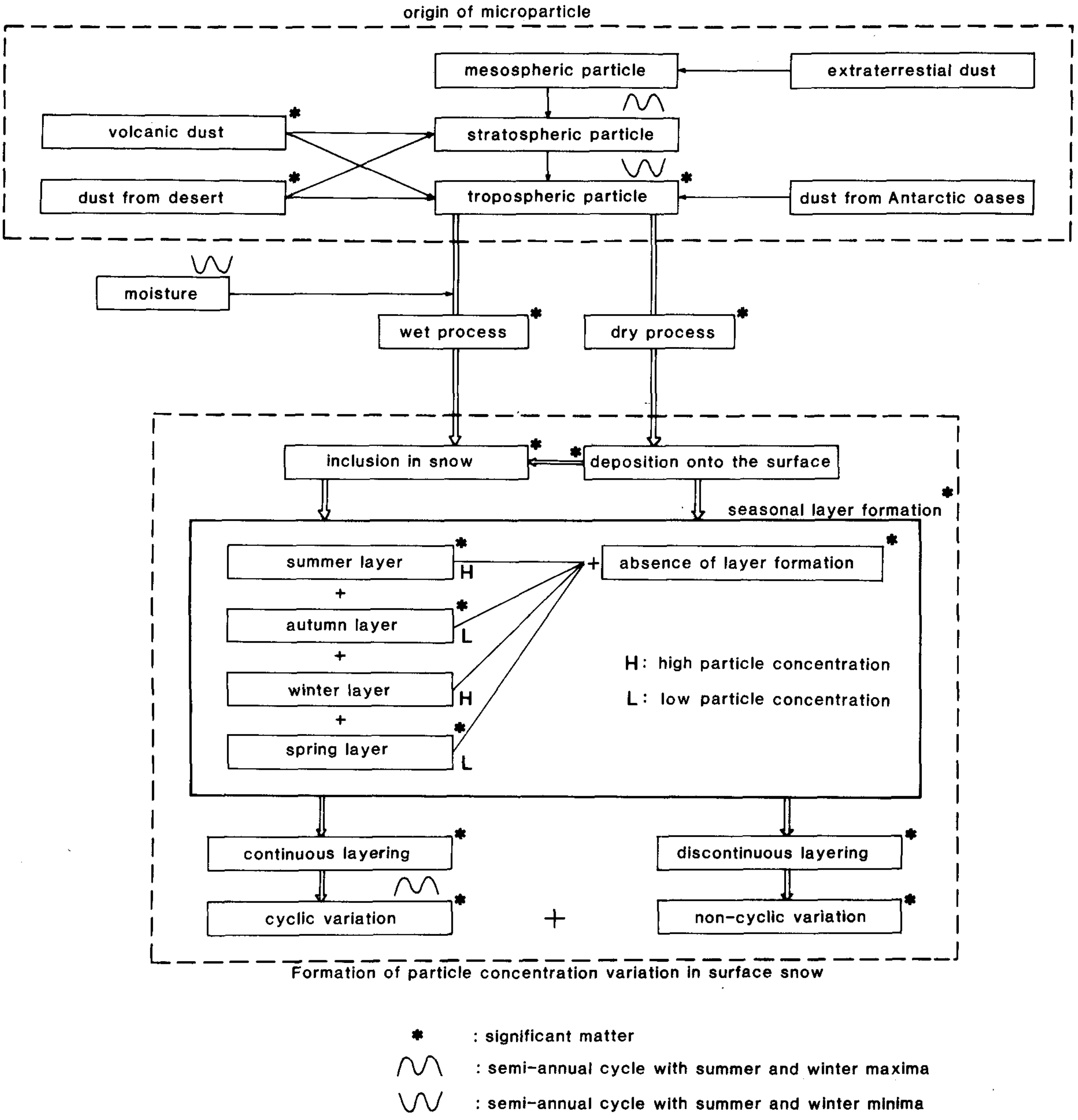

Fig.8. A model of the formation process in the variation of microparticle concentration in surface snow at Mizuho station.

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