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MACRO- AND MICROCLIMATES OF THE ANTARCTIC COASTAL OASIS, MOLODEZHNAYA**

Abstract

The macroclimate and microclimates of an East Antarctica coastal ice-free area are described. Maximum, average, and minimum values for macro- and microclimatic parameters of temperature, relative humidity, freeze--thaw cycles, *et cetera* are presented graphically. Data show that summer microclimatic phenomena are better expressed than winter phenomena, correlating well with reduced wind velocity in the summer. The data are compared to other ice-free areas.

INTRODUCTION

Investigators in Antarctica have recognized the importance of the macro- and microclimates as determinant factors in the existence, distribution and density of primitive plant communities, microbial associations, and the other biota in the antarctic ecosystem (Cameron, 1969; Cameron, King, and David, 1970; Rudolph, 1971; Spain, 1971; Gannatz, 1971; Wise and Shoup, 1971). The effects of different microclimates on the extent and type of primary weathering and pedogenetic processes have been mentioned or emphasized by a number of workers, although in many cases, supporting data were not available (Markov, 1956, 1959, 1960; Markov, Bardin and Orlov, 1962; Glazovskaia, 1958; Voronov, 1958; Voronov and Spiro, 1963, 1964, 1965; Skeib, 1963, 1964; Nichols, 1966; Ugolini, 1963, 1964, 1970; Tedrow and Ugolini, 1966; Ugolini and Bull, 1965; Claridge

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and Campbell, 1968; McCraw, 1960; Long, 1965; Kelly and Zumberge, 1961; Black and Berg, 1963; Berg and Black, 1966; Avsiuk, Markov and Shumskiy, 1956; Grigoriev, 1962; Kapitsa, 1961; Claridge, 1965; Konovalov, 1967; and others). The lack of microclimatic data, especially concerning the spring and winter seasons, has led to possible inaccurate conclusions concerning the nature and rates of the physical and chemical degradation processes and their periods of activity. Knowledge of the microclimate of coastal oases assists in the explanation of the divergencies of these areas, in many parameters, from the overall situations in Antarctica.

Although ecological investigations in Antarctica are not numerous, and in many cases have barely progressed beyond the stage of simple description, the summer microclimates associated with soil arthropod, soil microbial, lichen, and moss communities have been characterized for a number of localities in Victoria Land (Pryor, 1962; Gressitt, 1962; Gressitt, Leech, and Wise, 1963; Wise and Shoup, 1971; Janetschek, 1963a, b, 1970; Boyd, Staley and Boyd, 1966; Spain, 1971; Rudolph, 1963, 1966a, b, 1971). The microclimates associated with moss communities have been studied in sectors of the Prince Harald Coast near the Japanese station, Syowa (Matsuda, 1964a, b). Other fragmentary data consisting of short period observations of various parameters of macro- and microlimate, such as presence of melt waters, soil surface temperatures, depth of thaw, etc., have appeared in numerous reports. Unfortunately, these have been, for the most part, the result of short term midsummer observations. The available data are summarized in the following sections, or are discussed within the body of this report as they have bearing on the data presented herein.

Rock surface temperatures of 25–30°C have been reported for the Bunger Oasis and Mirny areas on the Knox and Queen Mary Coasts (Markov, 1956; Avsiuk, Markov, and Shumskiy, 1956). Soil surface temperature maxima of up to 32°C have been reported in the same areas (Grigoriev, 1959; Rubin, 1965). Relative humidity values in these areas drop to as low as 10–15% during the summer period (Avsiuk, Markov, and Shumskiy, 1956; Weyant, 1966).

In the McMurdo area of Victoria Land, rock-air interface temperatures within the 50–70°F range have been reported (Kelly and Zumberge, 1961), while in the nearby „dry valleys" readings of 25°C have been obtained (Angino, Armitage, and Tash, 1961). In the latter area, soil surface daily temperature amplitudes of 30°C, with maxima of about 20°C, have been reported in midsummer (Ugolini and Bull, 1965). The existence of a large temperature differential in midsummer between shaded and exposed rock surfaces has been demonstrated (McCraw, 1960). Rock surface temperatures of above 32°C were recorded during study of moss-lichen communities (Rudolph, 1966a). Midsummer soil temperature profiles have been described in the „dry valleys" and idealized annual ranges indicated (Ugolini and Bull, 1965; Ugolini, 1963, 1964; Tedrow and Ugolini, 1966).

Maximum soil surface temperatures of 26°C and an annual temperature range of 63°C have been reported for the Soviet station, Novalazuruskaya, in Queen Maud Land (Averianov, 1968b).

Workers in the inland ice-free areas have observed melt waters proximal to dark colored rock materials when the general air temperature was far below freezing, indicating that above 0°C temperatures on dark surfaces are not restricted to the coastal belt (Long, 1965; Voronov, and Spiro, 1964).

Scattered observations on depth of thaw and active layer thickness are available from many of the ice-free localities of the continent. These indicate a range from some few centimetres to about two metres, but in many cases comparison is not possible because of the omission from the report of such data as color, particle size distribution, exposure, and moisture content of the soil materials. The variability of depth of thaw with exposure and moisture content has been demonstrated in Antarctica (Ugolini and Bull, 1965; Ugolini, 1964). Work on a number of sites near McMurdo Sound has indicated the general thickness of the active layer to be near one half meter (Nichols, 1966). This author determined the maximum thaw zone to be near 1.5 m in rock and 1 m in soils in an Enderby Land coastal site (MacNamara, 1969b).

Long-term studies of the hydrothermal dynamics associated with the growth and expression of patterned ground have been begun (Black and Berg, 1963, 1966). The short-term moisture variations in the active layers of soil materials in midsummer have been shown to be related to diurnal temperature gradients (Ugolini, 1963; Ugolini and Bull, 1965).

It has been shown that, as might have been expected, freeze-thaw cycles are more frequent on soil surfaces than at the standard meteorological level (Nichols, 1966).

Numerous indirect effects of climate have been reported. The preservation, if not the actual formation, of the salt crusts and laminae of soluble salts in the Victoria Land „dry valleys" is related directly to an arid climate (Gibson, 1962; Nichols, 1963; Tedrow, Ugolini, and Janetschek, 1963; Black and Berg, 1963; Ugolini, 1964, Torii, *et. al.*, 1966, 1970; Dort and Dort, 1969, 1970a, b). The desert crusts or varnishes and efflorescences of soluble salts developed on rocks and exposed soil materials indicate strong thermal gradients and upward migrations of solutions, while the widespread crusts and spalls of exfoliation have been related to thermal activities in the rock-air interfacial zone (Skeib, 1963, 1964; Markov, Bardin, and Orlov, 1962; Black and Berg, 1963; Markov, 1956, 1959, 1960; Glazovskaia, 1958;

Voronov and Spiro, 1964, 1965; Tedrow and Ugolini, 1966; Torii, 1970a). Frostshattering and felsenmeer formation are widespread occurrences (Nichols, 1966; Konovalov, 1967). The salinity of many water bodies in the „dry valley" region and the presence of aeolian deflation are indications of arid climate, and have been described as such by a great number of workers.

During the period of the 12th and 13th Soviet Antarctic Expeditions, the author conducted microclimatological investigations in the area of the Soviet Station Molodezhnaya, 67°40'S, 45°51'E, on the Enderby Land Coast. The oasis is one of numerous small ice-free areas along the western Enderby Land Coast and is referred to as the Tala Hills. Microclimatic data from this section of Antarctica are lacking. It is believed that this is the first report concerned with the description of the microclimate of a coastal ice-free area in East Antarctica. The studies herein reported were conducted from February, 1967, to February, 1968, in the vicinity of Molodezhnaya, as part of the cooperative scientific exchange of the United States Antarctic Research Program. The data for other periods, as well as part of the macroclimatic data, were furnished by the meteorological staff of the Soviet Antarctic Expedition. The assistance and cooperation of the members of the Soviet Antarctic Expedition is gratefully acknowledged.

THE MOLODEZHNAYA AREA

The oasis is a small 8–9 sq. km ice-free area of ridges of exposed gneisses, migmatized and granitized, separated by wide, partially ice-filled, valleys. Rock types of the oasis have been described (Myers and MacNamara, 1970). Valley floors range in altitude from below sea level to 40–50 m above this reference, while ridge crests range to near 100 m. Ridge-valley orientation is 135–210°. Adjacent to the oasis is the steeply rising glacial slope to the south, and the Alasheyev Bay to the north. Figure 1 shows the general location of the station.

METHODS AND MATERIALS

The station records of the Soviet Antarctic Expedition, 1963–1967, were abstracted and analyzed to create a base upon which to evaluate the „normalness" of the 1967 year, the 1967–1968 summer and the various microclimates. This report consists of 2 sections: General macroclimate, and the various facts of the microclimate that have been analyzed to date.

Observations by the author were by thermocouples and maximum-mini-

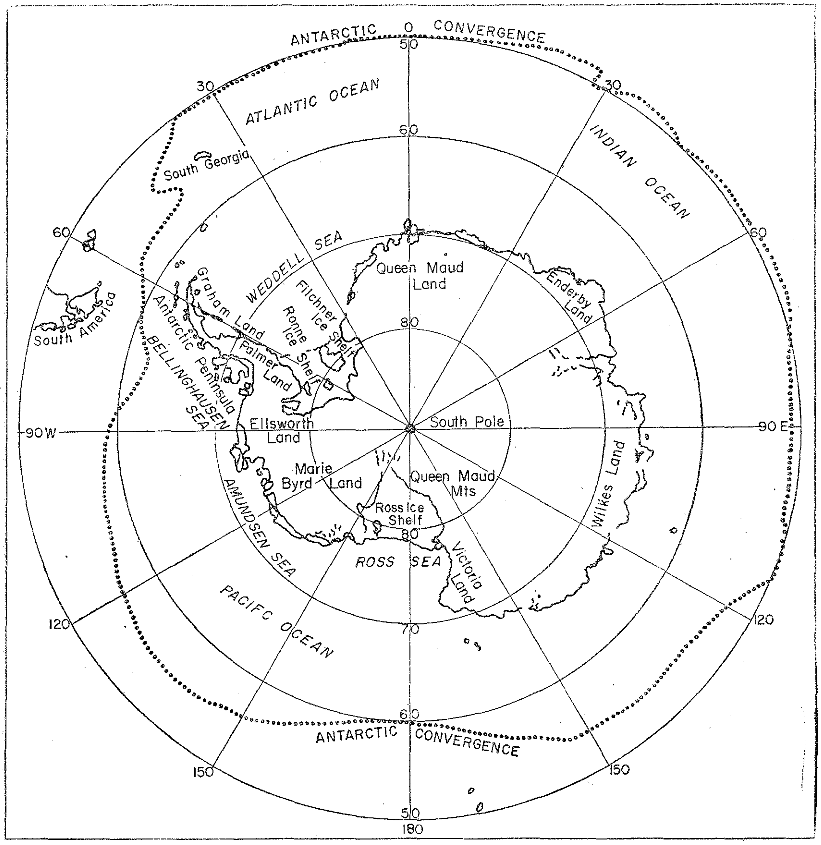

Fig. 1. Location of the Tala Hills Oasis, Molodezhnaya, Coastal Enderby Land, Antarctica

Locations of other localities mentioned in the text are indicated

mum thermometers visually read on a 8 times/day, every 3 hour, schedule. All thermometers and thermocouples were calibrated against each other and against the equipment of the Soviet Antarctic Expedition. All data have been recalculated to a standard (U. S. Bur. Standards) thermometer within 0.1°C. Relative humidity was by wet dry bulb apparatus. Wind speed was by recording anemometer.

MACROCLIMATE

The climate of Antarctica has been described as „more rigorous and severe than that of any land area on the entire planet" (Weyant, 1966). Within this foreboding framework of reference the area of the Tala Hills, Molodezhnaya, as well as other western Enderby Land coastal oases, occupies a relatively moderate situation as a result of latitudinal position. Molodezhnaya, 67°40'S, is a relatively recent station and the meteorological record is only of short duration (March 1963–February 1968 used in this report), however, these data combined with theoretical considerations allow generalizations and comparisons to be made.

AIR TEMPERATURE

The mean annual temperature is near –10.9° C. Annual temperature amplitude averages 37° C. The absolute recorded maximum and minimum are 9.4 and –40.1° C respectively. The latter figure may be an error in the 1965 Soviet records, for the value is recorded for March, a month when the average minimum, disregarding the 1965 value, is 20.7° C. If this is considered an error, as from all appearances it is, the absolute minimum is –37.5° C. Figure 2 shows the mean and extreme maxima and minima, and the average air temperatures on a monthly basis. Figure 2 excluded the March 1965 value. Figure 3 isolates the 1967 year which included one new minimum and three

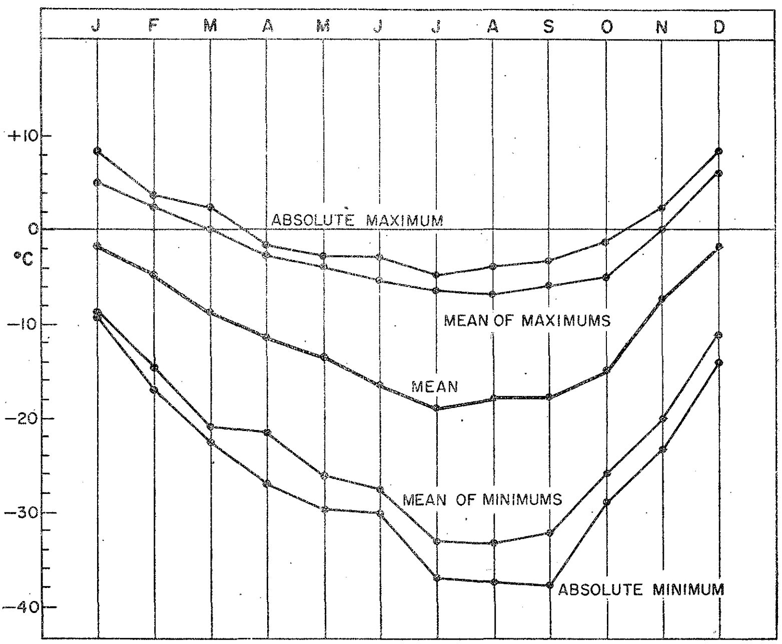

Fig. 2. Standard air temperature parameters of Molodezhnaya Station; Years of Record: 1963–1967

General trends revealed resemble those of other antarctic coastal regions, but are not nearly as cold

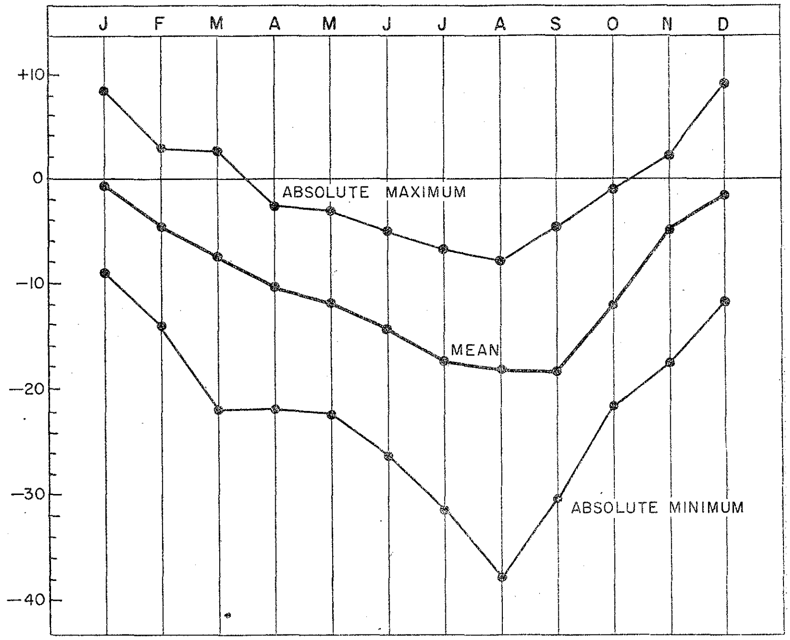

Fig. 3. Temperature data, 1967, Molodezhnaya Station

Comparison of Figures 2 and 3 reveals that 1967 was „normal", with non-significant deviations of the mean air temperature from the known pattern and value

new maxima. As the record is of such short duration, it is probable that new maxima and minima will continue to appear, extending the amplitude of temperature. The tentative ranges closely resemble those of other East Antarctic coastal sites (Novalazuruskaya, Mirny, Showa).

WIND VELOCITY AND ORIENTATION

The mean annual wind velocity is 10.1 meters/second. Dominant and prevailing winds are from the southeast quadrant. Figure 4 shows the annual percentage of orientations for the 1965–1966–1967 period. The data for the 1967 year are similar to the longer term composite. Figure 5 shows the average windspeed per direction for the 1965–1966–1967 period, and Figure 6 is the presentation of the 1967 data alone. Figure 7 shows the temporal pattern of wind velocity by month for 1967, illustrating the dominance of katabatic drainage winds from the glacial slope during the summer, spring, and fall periods when the sun is low on the horizon or beneath it. Other years are nearly identical in pattern.

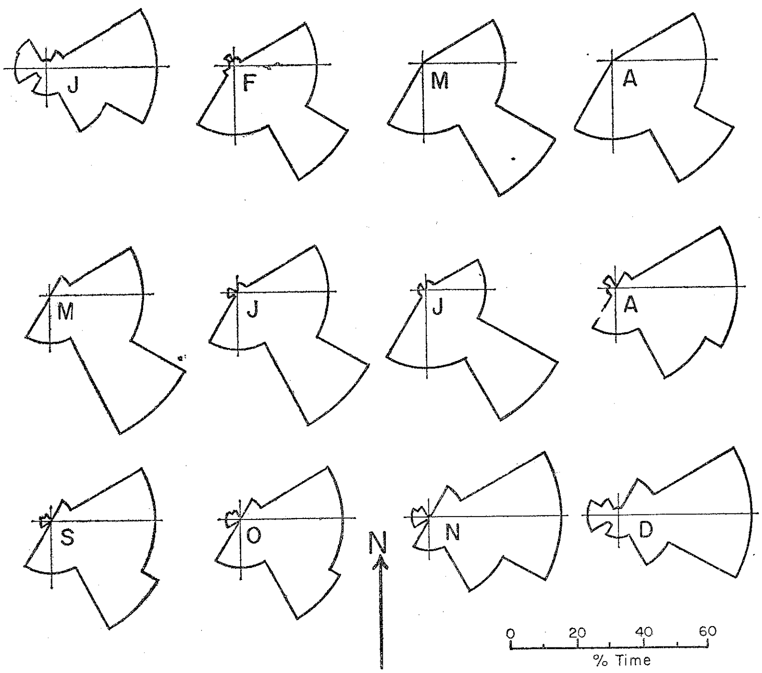

Fig. 4. Rosettes of average wind orientation, 1965–1967, by month

Calms are not included in calculations. Data on wind free periods are presented in Table III

Figure 8 presents the average, average maximum, and absolute maximum windspeeds and the absolute „gust" speeds by month for the period of record. Figure 9 shows the average percent of „calms" per month, as well as the 1967 data.

The diagrams of wind direction and velocity illustrate that the dominant and prevailing wind directions are the result of descent of cold air on the glacial slope (katabatic and drainage winds), the deflection effect of the earth's rotation (Corioli's Force), and superimposition by cyclic storms (frontal systems). The marked increase in occurrence of northerly winds in the summer season is due to the development of upslope breezes resultant from the intense heating of rock and soil surfaces within the oasis. These breezes, akin to the sea breezes of the more temperate regions, are usually quite shallow and weak. The general decrease in winds during the summer is due to lowered cyclonic activity and the isolation of the oasis by the inter-oasis transport of heated air. Winds increase both in frequency and average velocity on the

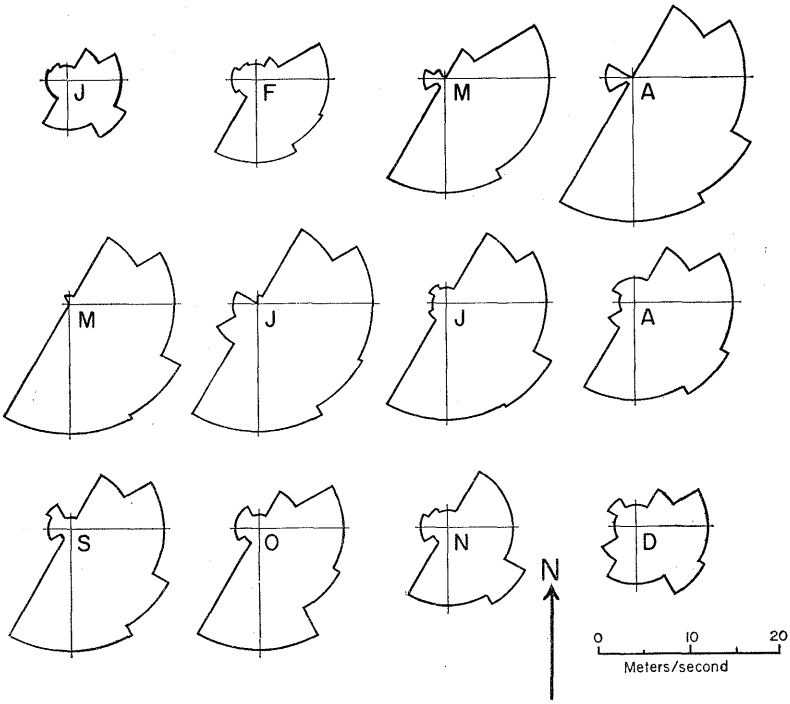

Fig. 5. Average speed of sustained winds, monthly by orientation, 1965–1967

The southerly winds, with the greatest occurrence values and windspeeds, represent superimposition of katabatic winds and frontal winds

glacial slope, relative to the oasis, during the summer period. There is, however, an apparent annual pattern of windspeed reduction within the oasis associated with the polar day and the shifting of storm tracks. There are little data, other than the short-term observations, to determine the extent of the reduction in Enderby Land, but it is evident from field observations that the drainage breezes begin earlier and stop later on the glacial slope than in the coastal oases during the summer period. On numerous occasions when only weak breezes were present within the oasis, strong drifting snow was observed on the glacial slope 3–5 kms inland.

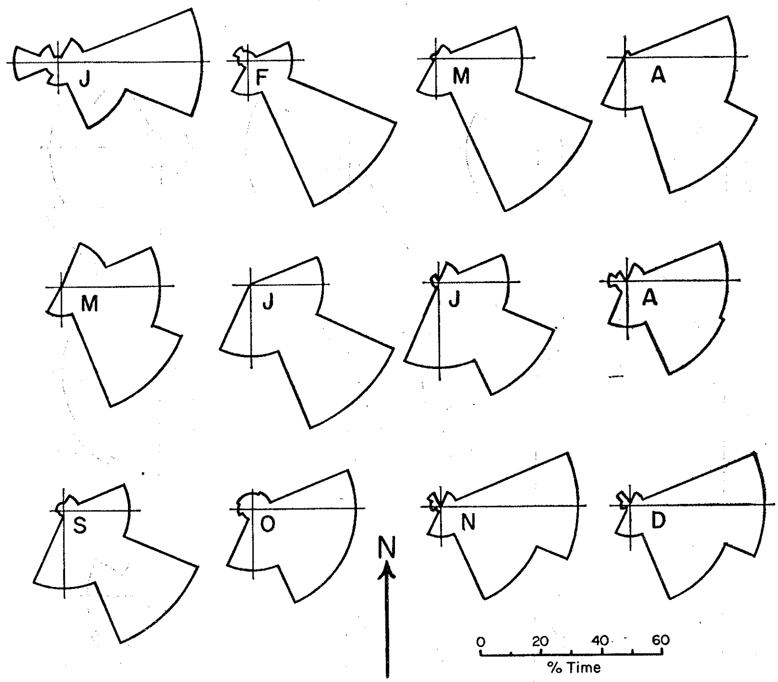

Fig. 6. Average windspeed by orientation, 1967

The major differences between the 1967 record and the composite depicted in Figure 5 are the lowered northerly component velocities in the fall months

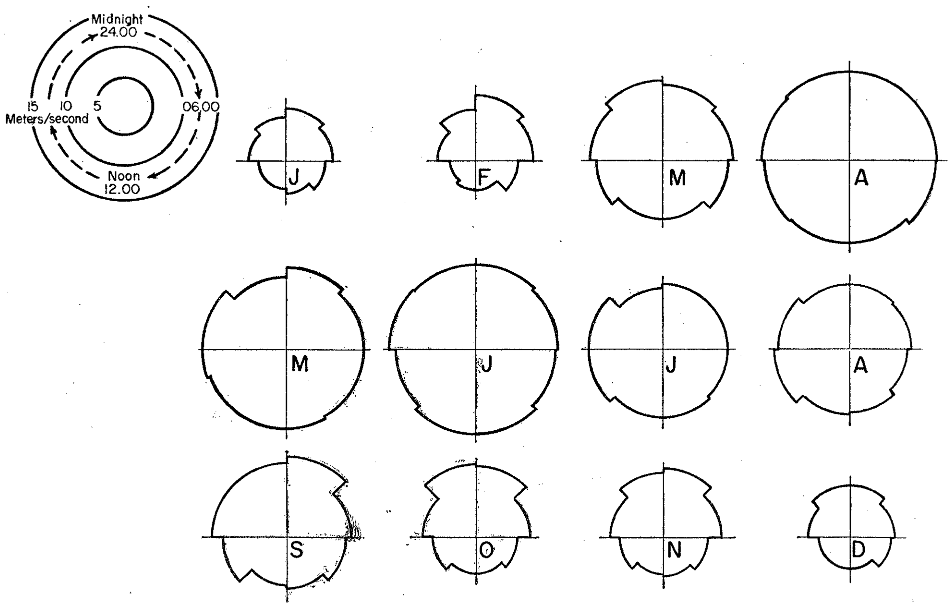

Fig. 7. Windspeed and its temporal distribution by month, 1967

The effects of katabatic winds are most evident from the data of the austral summer. The annual windspeed pattern is readily discernible

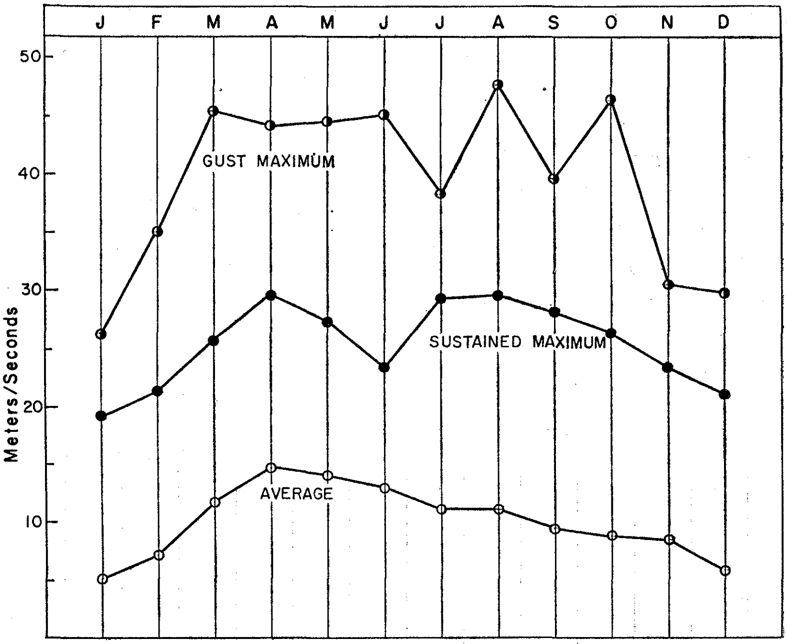

Fig. 8. Windspeed parameters, 1963–1967

It is thought that a longer record will result in a less erratic portrayal

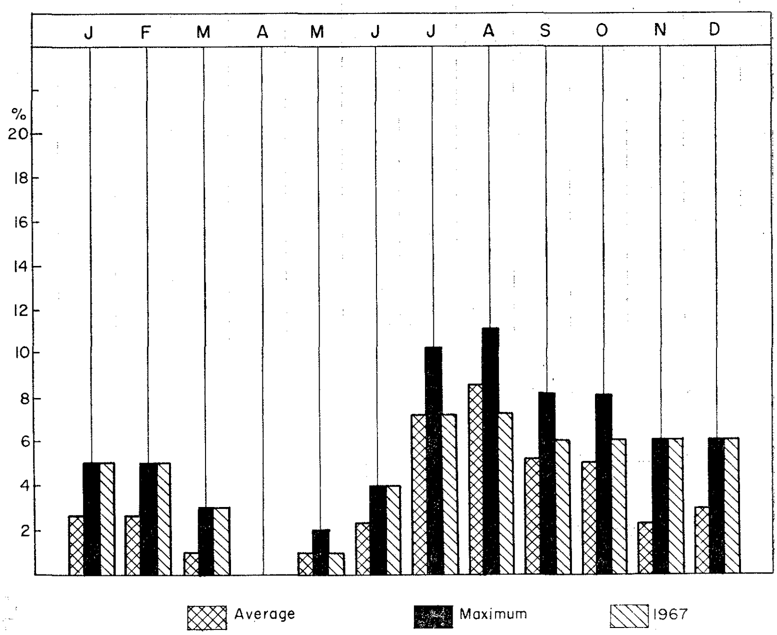

Fig. 9. Calm or windfree periods as percent of all observations

The data indicate the 1967 summer was characterized by lesser occurrences of winds than the other years of record. As microclimate is best developed during periods of calms, the data presented in this report may represent extremes

RELATIVE HUMIDITY

The annual average relative humidity is 66% and is remarkably stable from month to month throughout the year. Figure 10 shows the mean average, maximum average, and minimum average monthly relative humidities. There is considerable day-to-day variation during the summer months, with daily averages above 80% and between 40–50% not uncommonly occurring in the same month. The frequency of precipitation during the year, especially during the polar day, has influence on the mean relative humidity values.

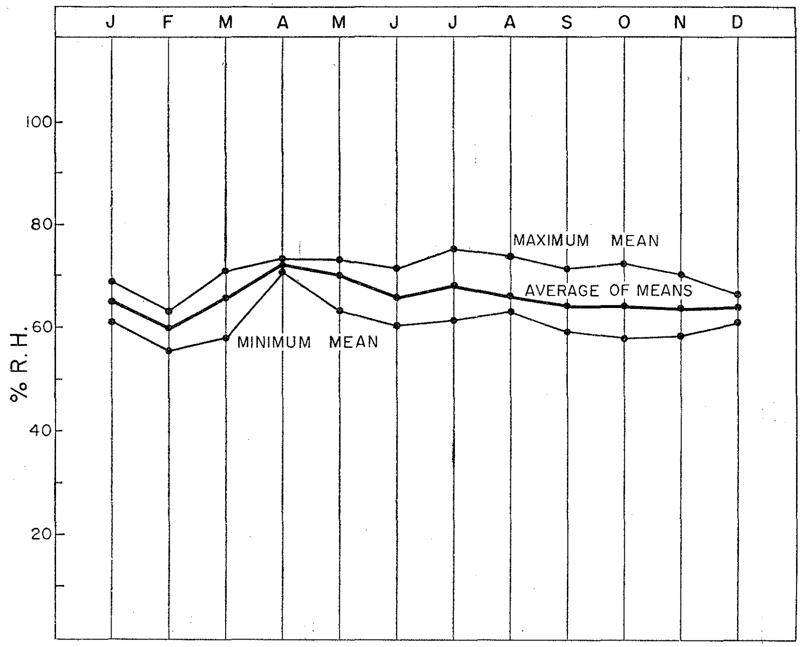

Fig. 10. Monthly relative humidity values, March 1963-March 1968, Molodezhnaya, Antarctica

Daily averages exhibit ranges in excess of 40%, maximums being greater than 80%

PRECIPITATION, BLOWING AND DRIFTING SNOW, AND ABLATION

The difficulties of accurate estimation of precipitation in areas characterized by drifting snow, such as the coastal oases, have been spoken of by numerous authors. Precipitation, with minor exceptions, occurs as snow, usually accompanied by strong winds. The ordinary snow gauge is most effective under calm conditions; otherwise drifting snow as well as falling snow enters the gauge. There is also alteration of the flow due to the gauge itself. The difficulties of determining, in darkness and under obscured skies, whether a snowfall or drifting is occurring increase the uncertainties associated with data collection (Wilson, 1968).

It has been indicated that mean annual precipitation can be approximated by mean annual snow accumulation in many sectors of Antarctica (Weyant, 1966). This criterion is not applicable to the coastal oases because they lie within the zone of ablation. Rubin (1965) has indicated that the average annual accumulation inland from Molodezhnaya is near 250 mm water equivalent. This is the case further inland than 10 kms, but in the immediate coastal zone, ablation processes dominate; and in the zone at 40 kms inland, the accumulation is slightly less than 250 mm (231 average, based on field data, 13th Soviet Antarctic Expedition) and then increases to the 90 km mark. These observations, in general, coincide with other estimates of the width of the ablation and transition zones (Bentley, *et al.*, 1964; Giovinetto, 1964).

Within the oasis itself, ablation and precipitation-snowdrifting may be very nearly balanced. The results of soil moisture studies conducted by the

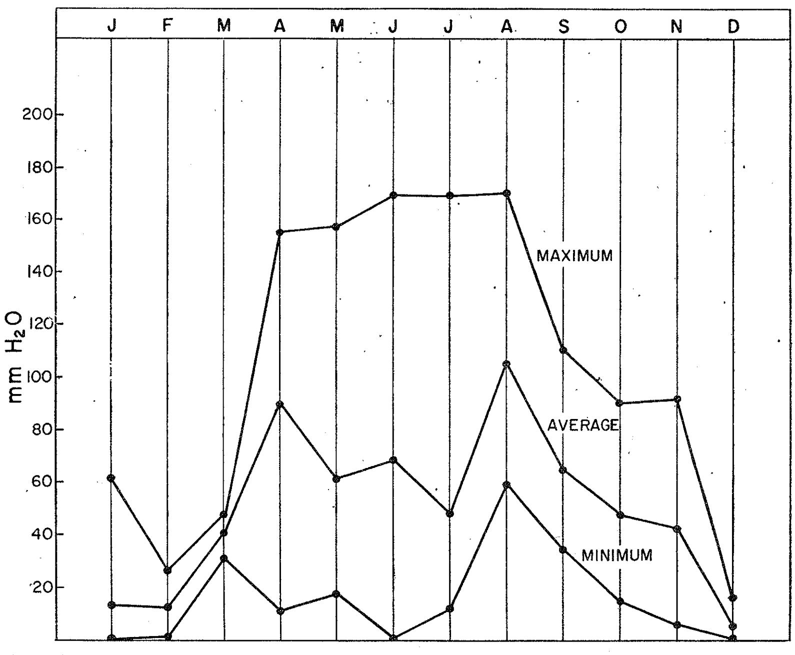

Fig. 11. Precipitation values per month, Molodezhnaya, Antarctica, 1963–1967

The aridity of the austral summer is in evidence

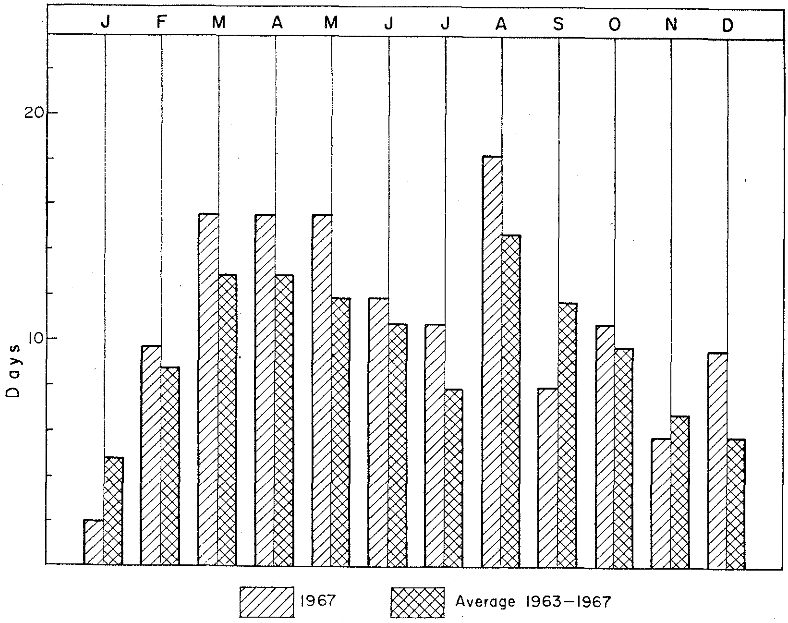

Fig. 12. Number of days per month with precipitation

author (MacNamara, 1969a, b) showed a quasi-stable state over the annual cycle, neither saturated nor depleted, but near the level of „field capacity". Further indications of a balance between additions and subtractions resulted from the detailed comparison of Operation High-Jump aerial photography (1946–47) with actual field conditions of 1967–1968 and aerial photography of 1965–1966. No significant differences could be detected within the oasis, although there were some indications that the borders of the oasis may be encroaching on the glacial slope; small nunataks, formerly covered within 1–3 kms of the oasis are being bared. These actions are explainable by the melting of ice adjacent to the heated rock-soil surfaces and the spreading of heated air without the boundaries of the oasis and are not the result of any sudden radical general warming of the regional climate.

Station records indicate average annual precipitation of 653 mm, with a range over the 5 years of record from 358 mm to 839 mm. Monthly distribution and annual totals are erratic, as illustrated by Figure 11. Sleet and rain occur rarely in the summer periods, having rather drastic effects on physical weathering processes. Snow crystal size and type are exceedingly variable. The degree of mineralization of the precipitation varies in a well-defined pattern with the season of the year (MacNamara, in press).

Drifting snow and blizzard conditions are an integral part of the climatic

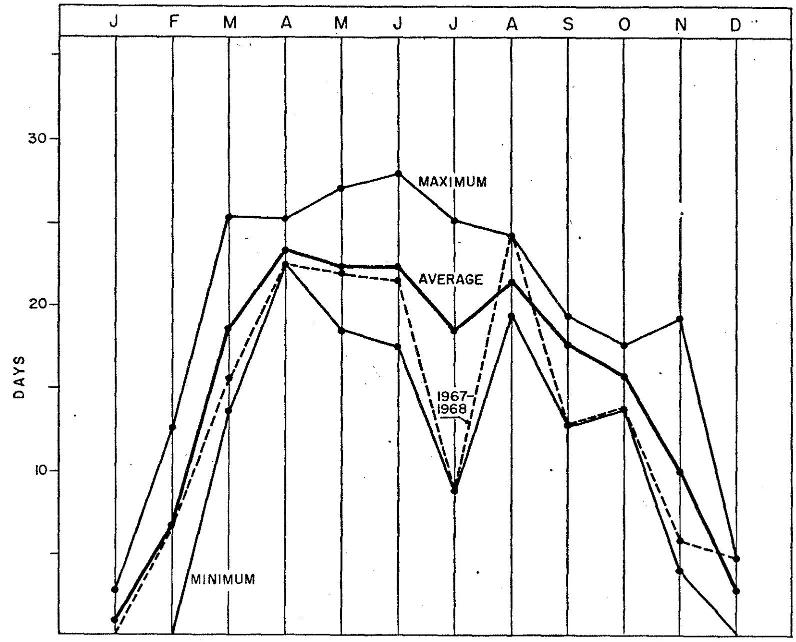

Fig. 13. Number of days, drifting snow was recorded at the 2 meter level

Average based on record from February 1963 to February 1968. Blowing snow often corresponds with well developed katabatic winds; especially during the summer period. Blowing snow is recorded an average of 185 days per year

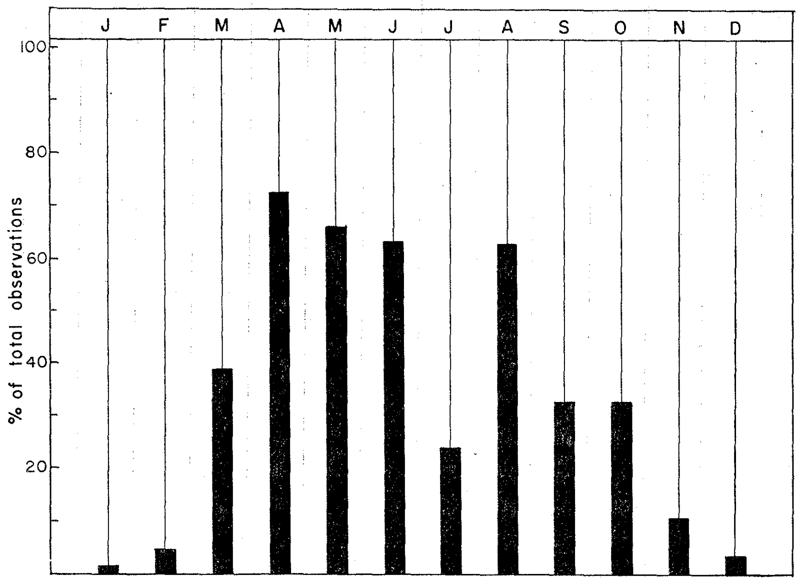

Fig. 14. Percent of total observations during which drifting snow was recorded, February 1967–February 1968

Observations were made eight times per day, every three hours conditions of the coastal oases. Drifting snow occurs during nearly all snowfalls, as well as at times when precipitation is not occuring. Figures 12, 13 and 14 illustrate precipitation and snow blowing phenomena.

CLOUDINESS

The average and ranges of monthly cloudiness are shown in Figure 15. Summer and fall cloudiness values are greatly influenced by the development of clouds over the open sea in the mid and latter parts of the solar day. The general cloudcover measurement does not, of course, show the distribution on the horizon of these clouds. Winter and spring cloudiness is controlled by regional factors. Complete cloud covers are not uncommon during the seasonal change periods. As with most Antarctic stations, the winter is the season of minimum cloudiness. Comparison of Molodezhnaya data with Rubin (1965) reveals good agreement based on latitudinal position.

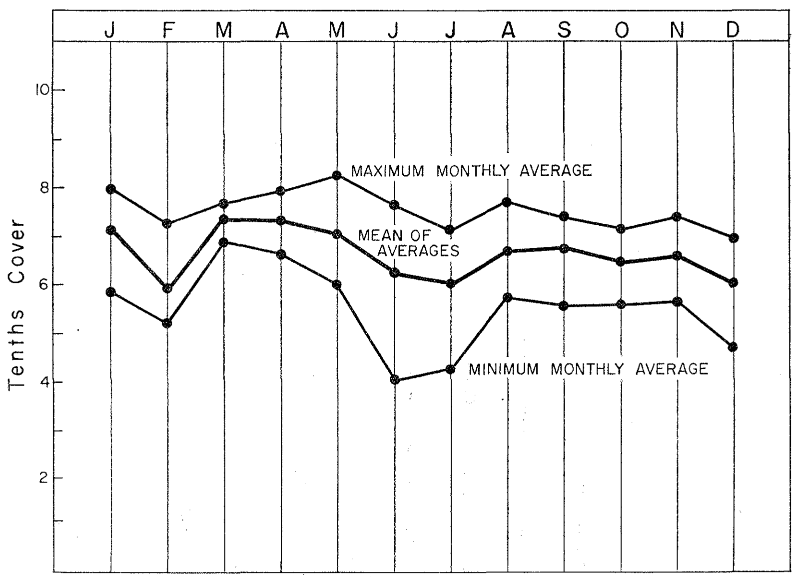

Fig. 15. Values of cloudcover, 1963–1967, Molodezhnaya Station

Data from USSR station record

ATMOSPHERIC PRESSURE

The pattern of atmospheric pressures is shown in Figure 16. Minimum pressures correlate with the change of the seasons and the migration of storm tracks.

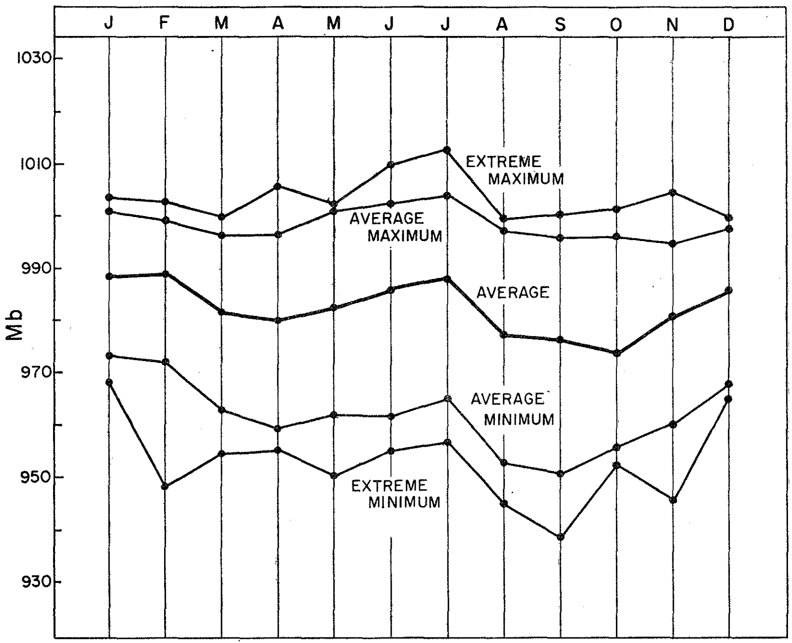

Fig. 16. Atmospheric pressure data, monthly averages, 1963–1967

DISCUSSION – MACROCLIMATE

Comparison of the single factor of mean monthly temperature with other antarctic stations (Table I) clearly shows the significance of latitudinal position (solar climate). The quantity of possible solar radiation, disregarding differences in cloudiness, available to heat the soil and lower layers of the air at Molodezhnaya is nearly twice as great as that at McMurdo Sound. It is significant that the Molodezhnaya region has a positive annual radiation balance, the exact value of which is not available at present (Personal communication, R. Eller, Actinometeorologist, 12th Soviet Antarctic Expedition). Other East Antarctica oases are reported to have positive radiation balances (Averianov, 1968; Bardin, 1970; Solopov, 1969; Simonov, 1971).

Based on the purely theoretical concept that all transformations and acti-

Table I

Comparison of Approximate Mean Monthly Temperatures, °C

	South Pole (90°S)	McMurdo Sound (77°40′S, 166°30′E)	Hallett Station (72°13′S, 170°19′E)	Molodezhnaya (67°40′S, 45°51′E)
January	–29	–4	–2	–1
February	–40	–9	–3	–4
March	–55	–19	–11	–9
April	–58	–21	–17	–11
May	–57	–23	–23	–14
June	–57	–24	–23	–17
July	–59	–27	–27	–19
August	–57	–29	–28	–18
September	–59	–24	–24	–17
October	–51	–20	–20	–15
November	–38	–9	–9	–7
December	–29	–4	–3	–1
Average	–49	–18	–15.5	–11.5

Data from various sources including Rudolph (1966); Nichols and Ball (1964), Tedrow and Ugolini (1966), U.S. Weather Bureau, Wexler and Rubin (1961), Rubin (1962).

vities within the ecosystem are related to available energy, it is necessary to assume, neglecting other limitations, that the rate processes and developmental stages of alterations within the coastal oases of western Enderby Land are significantly greater or even different from those of the more southerly areas, such as the McMurdo area, which have been investigated in great detail. The author's pedologic and weathering studies, presently being prepared for publication, are in agreement with this theory.

Relative humidity is another measure that has considerable applicability as a differentiating characteristic between antarctic areas. McMurdo, the central station of the U. S. Antarctic Research Program, reports a mean annual relative humidity rises of 57% and a mean annual temperature of –17.7°C. Mean relative humidity rises to 70% during the summer months (Tedrow and Ugolini, 1966). The Soviet stations Mirny and Bunger Oasis, Queen Mary and Knox Coasts, have mean annual temperatures near that of Molodezhnaya, but the mean annual relative humidity values are between 55 and 60%. It has been reported that the relative humidity in the Bunger Oasis drops to 10–15% during the summer season (Avsiuk, Markov, and Shumskiy, 1956; Weyant, 1966). The Soviet station, Novolazuruskaya, in the Schermaker Oasis of Queen Maud Land (70°46'S, 11°49'E), based on the short available record, has an annual temperature of –10.4°C with a mean annual relative humidity of 56% (Averianov, 1968b). Mean monthly relative humidity varies from 49 to 59% throughout the year (Artemiev, 1966). Molodezhnaya is considerably moister than these other stations. Even in midsummer, daily minimums seldom drop to 40% or daily averages to 50%. Numerous ecologists and microbiologists have indicated that moisture is the major limiting factor to the biota of the antarctic ecosystems and that relative humidity, even though evaluated at the standard level, is a means of estimating relative differences (Boyd, Staley, and Boyd, 1966; Gressitt, 1965; Janetschek, 1963, 1970; Boyd and Boyd, 1963). It has been concluded that the biotic spectrum in the Enderby Land coastal oases is denser than that of more arid areas (MacNamara, 1969c).

Owing to the differential thermal behavior of water and land-ice, climates controlled or influenced by the sea differ from those associated with the interiors of continents. The rate of continentality is not a function of distance from the sea. For example, the coastal state of New Jersey, bordering the Atlantic Ocean, is said to have a continental climate (Biel, 1958). Numerous authors (Voronov and Spiro, 1963, 1964, 1965; Voronov, 1961; Markov, 1956; Avsiuk, Markov, and Shumskiy, 1956; Zakhariev, 1969; Schwerdtfeger, 1970) have made reference to the marine and continental climates of the ice-free areas, and the preponderance of continental type climates in the antarctic oases. Continentality can be calculated in various ways. The annual range of temperature (difference between the average monthly temperatures of the warmest and coldest month) is one criterion. Values of 22 degrees or more are associated with continental climates. Such calculation for Molodezhnaya yields a value of 18, or modertely maritime. Similar calculation for the „dry valley" areas of Victoria Land yields a value of 25, or moderately continental. Another criterion for the calculation of continentality is the comparison of the October and April temperatures. Because of the slow warming and cooling of water, the autumn (April) is much warmer than the spring where marine influences prevail. For Molodezhnaya the value is 4, while for McMurdo the value is 1. A third criterion for the calculation of continentality is the use of the „thermoisodromic quotient". This value is arrived at by dividing the difference of the April and October temperatures by the annual range of temperature; the resulting small value is multiplied by 100. Marine stations record high quotients while continental stations have low values. The thermoisodromic quotients for Molodezhnaya and McMurdo are 22.2 and 4 respectively. It is obvious that the coastal oasis of Molodezhnaya has a maritime climate by all applied criteria of determination.

The rate of the temperature fluctuations between consecutive days is a useful climatological measurement. Regions with frequent air mass movements have high interdiurnal temperature variabilities (2 or more), while areas with less frequent air mass movement have lower values. The calculation on a monthly basis allows the portraying of seasonal trends. The values are also a measure of the bioclimatological stress impressed on man and his operation (Dalrymple and Frostman, 1971). Table II is the interdiurnal variability values for Molodezhnaya based on the 1967 year. Monthly precipitation, and the average monthly air pressures and ranges are included in the table for camparison.

Although the data indicate considerable average interdiurnal variability and an apparent lessening of air mass movement effects during the polar day, there is no readily recognizable relationship to atmospheric pressure or precipitation. It is clearly shown that the summer climate is controlled to a great extent by the solar climate (latitudinal position) while the winter climate is dependent upon advective processes.

SUMMARY OF MACROCLIMATE

The coastal oases of western Enderby Land are snown to differ from the majority of the other ice-free areas by possessing maritime climates, high precipitation values, and high relative humidities. Blowing and drifting snow, high annual and well developed katabatic drainage winds, considerable diurnal temperature variation, and erratic distribution of precipitation are characteristic properties of the macroclimate. The oasis Molodezhnaya, owing to its latitudinal position and expanses of soil and rock, is strongly heated during the summer months.

MICROCLIMATE

The inland ice-free areas of the antarctic continent have been classified as „cold deserts" (Markov, 1959; Korotkevich, 1967; Ugolini and Bull, 1965; Tedrow and Ugolini, 1966). The previous section of this paper has shown that the climates of coastal oases, especially along the Enderby Land coast, are maritime and relatively wet, and, therefore, these oases cannot be considered parts of the arid cold desert, but a special subdivision thereof.

DATA AND DISCUSSION

Microclimate expression is a negative function of wind speed and is therefore dependent upon both wind speed and skin friction. Observations in Germany (Hellman, as reported by Biel, 1961) have shown that where „calms" at the standard level were only 7% of the observations, the corresponding percentage at the two inch level was near 30. Table III lists the average

Table II

Calculated interdiurnal variability values for Molodezhnaya

Selected meteorological parameters are included for compartitive purposes

	J	F	M	A	M	J	J	A	S	O	N	D
Interdiurnal Variability	1.6	1.8	2.2	3.1	2.9	3.4	3.0	3.6	3.2	2.6	1.1	1.3
Atmospheric Pressure mb.	989.8	991.1	981.8	980.2	984.0	983.0	982.5	980.1	979.7	982.0	983.3	987.5
Range mb.	28.8	14.5	31.8	49.0	40.0	30.9	35.4	48.1	41.6	40.2	30.5	32.3
Precipitation mm	1.0	6.3	48.4	207.1	156.1	73.1	18.3	153.0	33.4	23.1	91.2	15.3

Table III

Occurrences of periods of „calm", years of record and 1967–1968 year

1967–1968 recorded a greater percentage of calm periods, accentuating development of microclimatic phenomena

Month:	J	F	M	A	M	J	J	A	S	O	N	D
% calm:	2.4	2.4	1.0	0.0	1.0	2.4	7.3	8.3	5.3	5.0	2.3	3.0
1967–1968	5	5	3	0	1	4	7	7	6	6	6	6

and 1967–1968 distribution of calms at Station Molodezhnaya by month as recorded at the standard level.

Although calms are not common at the standard level, calm and near calm conditions exist near the active surface-air interface at nearly all times that wind speed at the standard level is less than 3 m/second during the „polar day". This development of interfacial calm layers is a result of skin friction and the corresponding effect of the upslope and vertical components of the heated air adjacent to the active surface. As shown in Figures 5 and 6 the dominant and prevailing directions of wind are from the southeast quadrant, hence calms and eddies commonly develop on the lee, or northerly sides of boulders, cliffs, and ridges. As the solar climate associated with the latitudinal position of 67°41'S results in a coincidence of the lee side with the heated side, spectacular microclimatic differences exist between northern and southern exposures. The temperatures recorded at the microlevel on southern exposures nearly alwyas coincide with the temperatures recorded at the standard two meter level, while in eddies and less on northern slopes, air temperatures in the middle of the polar day may rise to 4–6°C warmer. This is the result of both the reduced air turbulence and motion and the increased heating of northern exposures. The heating of the lowermost air layers is, of course, a function of the heating of the underlying active surface, but the heat transport from the interface is dependent on wind velocity. Table IV shows the maximum and minimum temperatures recorded at the indicate levels from March, 1967 to late February, 1968 at a site on a level, normally windswept, site near Molodezhnaya.

At a nearby site rock-air interface temperatures exceeded 42°C on several occasions, but were of short duration and were never revealed at the 3 cm level. The great difference between temperature maxima at the extreme levels demonstrates the strong heating of the lowermost air layers over heated soil.

Table IV

Extreme Temperatures Recorded at Indicated Elevations above Soil Surface, 1967–1968

Elevation M.	Maximum °C	Minimum °C
0.00	41.0	–40.0
0.03	39.2	–39.1
0.25	21.6	–37.5
1.00	12.1	–36.3
2.00	9.4	–35.1

The data indicate that summer microclimatic phenomena are better expressed than winter phenomena, correlating well with reduced wind velocity in the summer.

Horizontal temperature gradients are present also within the coastal oases, but are of short duration and not sharply differentiated because of the mixing that occurs during transport. The greatest differences are observed by the comparison of interfacial temperatures of various materials. For example, a set of simultaneous measurements at the 3 cm level over soil and rock surfaces showed average temperature to be 39.7° C, while on adjacent glacial ice, the corresponding average was 0.6° C. Figure 17 shows the temperature differentials that may exist between adjacent surfaces of different colors and different positions. In actuality, the temperature differentials at any given time may exceed the recorded values, which are based on weekly averages of daily maxima. Position maxima differ 3–4 hours because of angular relationship to insolation, but the difference in temperature of different colored surfaces is only a matter of minutes, with the lighter colored materials lagging slightly in heating. Horizontal temperature variations only can be recognized within the oasis very close to the active surfaces in heterogeneous areas of snow patches, rocks, and soil. Table V shows the temperature extremes as recorded at a site within the oasis and a corresponding site 3 kms from the

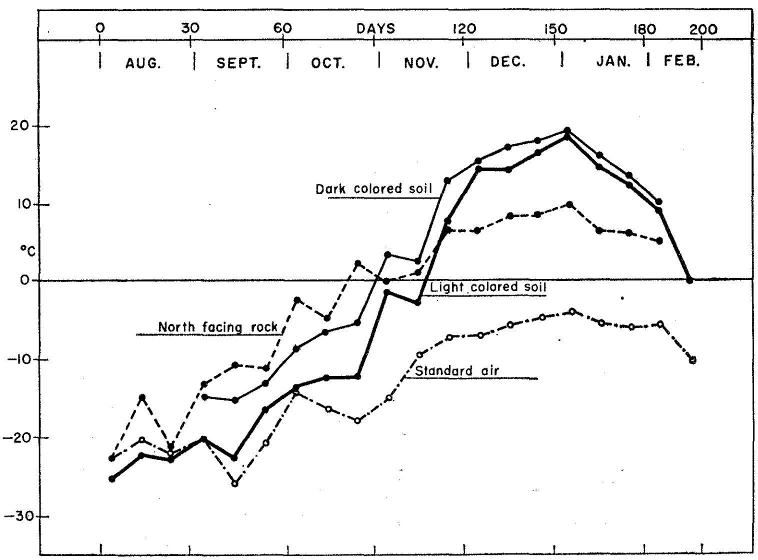

Fig. 17. Monthly average maximum temperatures developed on indicated surfaces

The light and dark colored soils were adjacent, sharing identical exposures and moisture relationships. The effect of lowered albedo is evident in the higher temperatures reached by the darker soil

Table V

Temperature Extremes within the Oasis Area
and at a Nearby Ice-Covered Site, 1967

Elevation	Oasis Area Maximum °C	Oasis Area Minimum °C	Ice Area Maximum °C	Ice Area Minimum °C
0.10	29.7	–39.8	3.90	–40.3
0.50	21.3	–38.7	5.10	–39.9
1.00	12.2	–38.5	5.10	–39.9

oasis on continental ice. The local effect of rock and soil heating is effectively demonstrated, as is the determinant of whether the temperature gradient is negative or positive by the nature of the underlying surface.

Although masked by the averaging techniques used in Figure 17, there are times when the dark colored soil temperature maximum is less than that of the light colored soil as a result from the microclimatic phenomena of impingement and melting of drifting snow; the evaporation and melting using energy that otherwise would have been available to heat the surface. The drifting of snow at ground level is a very common occurrence in the Enderby Land coastal oases, occurring on 195 days during the period of study (180–210 days average per year of record). When blowing snow impinges on a rock or soil surface which is above freezing, melting occurs. Minor „snow shadows" are formed in the lee of cobbles, gravels and other surface irregularities. Since the phenomena during the polar day are manifested usually in the afternoon, evening, and early morning, the dark colored surfaces are sometimes above freezing and become coated with a „slush" which increases albedo and absorbs energy during subsequent melting and evaporation. Comparison of field notes with the plotted data indicates that this occurred on all days in which the dark colored soil temperature was less than the light colored soil temperature. The latter, not being above freezing at the time of drifting snow impingement, was not coated with a dense slush, but only with thin powdery snow shadows which rapidly melted and/or sublimated-evaporated.

The drifting snow, an impractical to measure form of precipitation, periodically replenishes the soil moisture contents of the surface horizons. Apparently, based upon the study of the complete annual cycle of a number of sites within the Molodezhnaya Oasis, a balance exists between soil moisture, runoff, and the total effective precipitation, including drifting snow (MacNamara, 1969b). Figure 18 shows the short-term variations of soil moisture content that occur in surface soil layers as related to solar conditions and drifting snow.

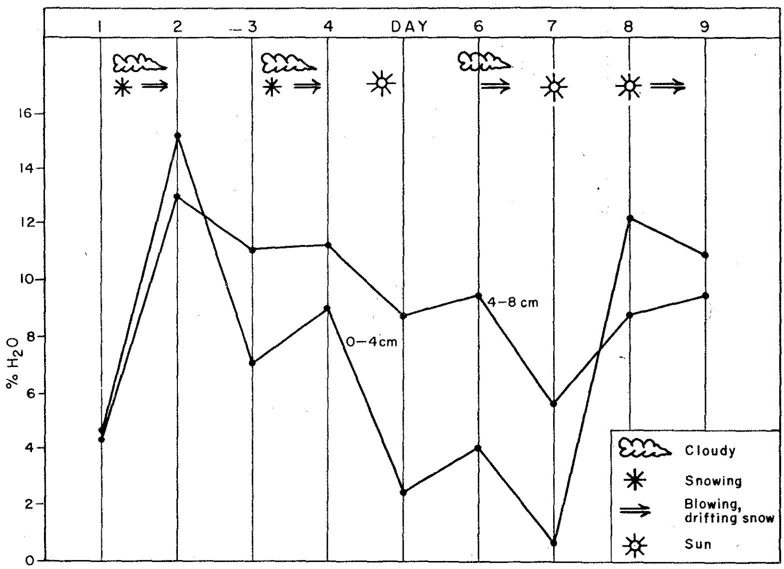

Fig. 18. Soil moisture content dynamics as affected by daily weather conditions

The close relationship of the surface layer to the weather is evident on the 8th day, where replenishment of soil moisture occurs from blowing snow, as well as demonstrated by preceding depletion of surface soil moisture by evaporation during periods of high effective solar radiation

The seasonal pattern of soil moisture variation has been discussed by the author in previous publications (MacNamara, 1969a, b). However, where other factors are equal, subsoils on southern facing slopes tend to be at higher soil moisture contents than northern slopes. Soils on southern slopes possess slightly thicker lag gravel deposits (desert pavement) developed by the predominant and prevailing winds. The lowered insolation heating-evaporation potential associated with solar climates of southern exposures and the thicker lag gravel result in higher soil moisture contents. The lag gravel, with irregular shaped void spaces, has a very low thermal conductivity, hence, the extreme thermal gradients with enormous evaporation potentials do not directly affect the underlying moist soils.

Very interesting data have been obtained by the study of surface temperatures of bare mineral soils and soils colonized by moss and moss-lichen plant communities (Fig. 19). The soils associated with moss communities have surfaces which are finer in particle size distribution than unvegetated soils. Moss covered soils lack well-developed desert pavements. The moss mat entraps mineral particles and blowing snow carried by saltation or as part of the bedload in the wind, while the si es are generally in lees. The entrapped snow melts, and readily infiltrates. The entrapped mineral particles settle to

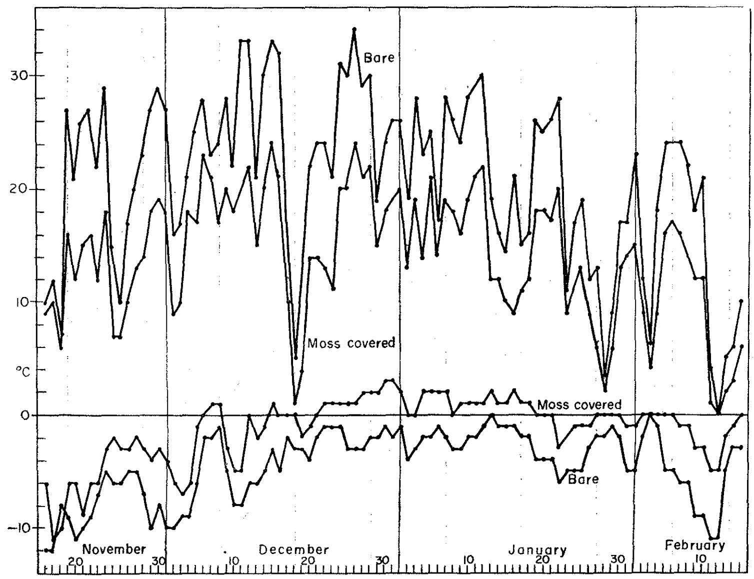

Fig. 19. Daily maximum and minimum soil surface temperatures, 1967–1968

Bare mineral soil contrasted to moss covered soil. The moss cover limits both daily and seasonal temperature fluctuations

the underlying soil surface, becoming incorporated into the accumulative soil. The vegetation surfaces is the active surface of microclimate; therefore the actual soil surface under moss mats does not undergo the strong heating and remains moister than bare mineral soils. The great amount of void space and the insulation-low thermal conductivity effects of the moss mat are not only manifested in lowered diurnal heating, but also in lowered diurnal cooling. This results in a greater number of frost-free days at the root level or mineral soil surface than are recorded at the active surface level of bare mineral soils. The greater moisture content from the entrapment of blowing snow, the greater hygroscopicity of the finer textured soil, and the conservation related to the latent heat of water also are contributing factors to the longer frost--free season at the rooting level. Soil moisture studies show that, based on weekly measurements, the contents of water under free drainage conditions in moss communities are 45–55% greater on the average than bare mineral soils. The soils under moss mats are seldom depleted below 4% soil moisture content.

The combination of the microclimatological factors and the accumulative nature of the moss mats creates an „autoecological-autoenvironmental" condition differing greatly from the unvegetated, windswept parts of the oases.

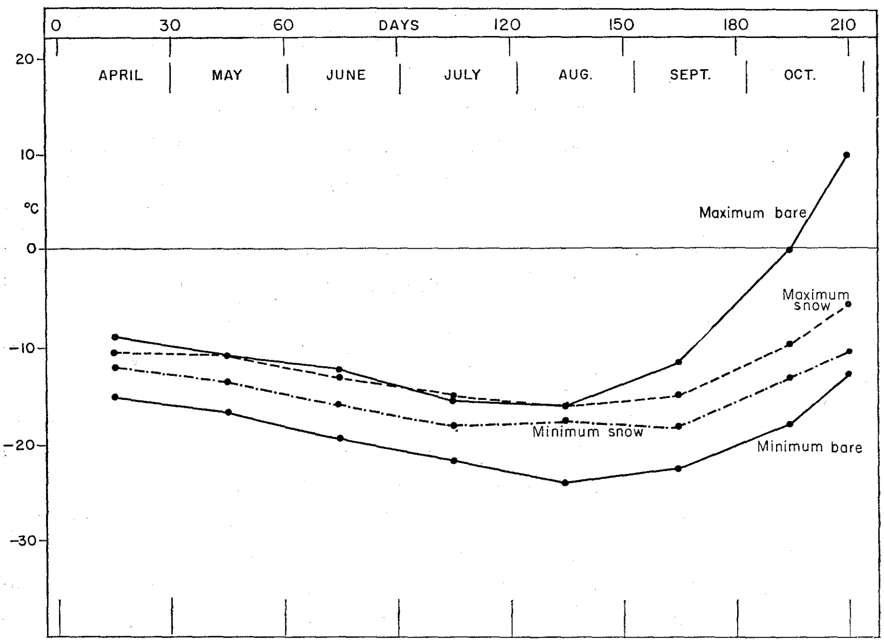

Fig. 20. Average monthly soil surface temperatures, 1967

As described in the text, the snow covered site corresponded with the location of a lush moss community

The significance of the length of time that the moss rooting zone does not undergo freezing is probably both physiological and physical. The latter in the sense that freeze-thaw actions that could rupture or break tender rootlets by either external movements or internal expansion-contraction are limited; hence, growth can occur uninterruptedly.

The winter environment of a moss community at Molodezhnaya has been evaluated. Figure 20 shows the maximum and minimum soil surface temperatures of bare mineral soil and the soil under a moss community. The moss communities are located in wind-protected lee sites and are therefore sites of snow accumulations of variable depth. This snow cover, for the most part, is removed by sublimation-ablation processes by early November. Comparison of the absolute temperature ranges during the winter season shows a reduction in seasonal range, but it seems unlikely that this is the major determinant factor in moss community establishment. The further improbability of the snow cover-insulation effect being determinant is supported also by field observations of thin (to 0.5 m) elongated moss mats growing in lees of ridges and boulders where no deep snow accumulates. It is probable that the major determinant factor for the establishment of mosses is initial protection from the wind-driven snow, ice, and rock particles which can physically destroy the mosses. This conclusion is in agreement with other observers (Dodge, 1965; Rudolph, 1966, 1971). Removal of protecting boulders in early July resulted in complete destruction of the strip-like moss communities by early November. The presence of the snow cover, with its dampening effect on interdiurnal variations, may have significance to the physiology and/or physical disruptions by frost action of the moss community. Field observations indicate the most luxuriant moss mats, with soil moisture regimes apparently approximate to more impoverished communities, are found where snow accumulations occur.

Wind is a marked determinant factor in the microclimate of the coastal oases. That the upslope breezes have considerable effect on the underlying soil was shown by a series of soil moisture content determinations carried on using artificial canned soil profiles attached to a water source. Although the quantitative figures are meaningless, the soil that was protected from the wind remained relatively moister by 25–45% and colder by a measurable amount over the short period of experimentation.

The insulating effect of the coarse gravel or desert pavement surface on the soil moisture content was investigated in some detail. Where desert pavements are well developed, soil moisture within the lag gravel may be reduced to nearly zero (0.09% or less) and salt crusts be formed at the gravel surface, while at 15–20 cm beneath the surface, the soil may be visibly moist, 6–8% water by weight. The honeycomb fabric with large void spaces of the lag gravel layer has low thermal conductivity and, as well, creates a zone of stagnant air which may be at a far higher absolute humidity than the lowermost atmospheric layer.

Relative humidity at the microlevel, determined sporadically over the 1967–1968 summer showed two trends. In mid-day, when the soil surface temperature was maximum, the degree of saturation with water vapor of the lowermost air was far less than that of the standard level, although the absolute humidity was greater. In some periods when solar insolation was reduced or cut off by the curvature of the earth and the general southerly rise of the continental ice, the relative humidity at the lowermost levels approached, and sometimes reached, the saturation level. The minimum recorded relative humidity for the 1967–1968 season was 27% when the air temperature at the 3 cm level was 33°C.

Solar climate (exposure climate) appears to be a major factor in the distribution of the freeze-thaw cycles on various surfaces. Compensatory factors of short-term temperature variations apparently result in a nearly equal number on all surfaces, as seen in Figure 21. Early in the polar day, the northern exposure undergoes daily thawing while the southern exposure remains frozen,

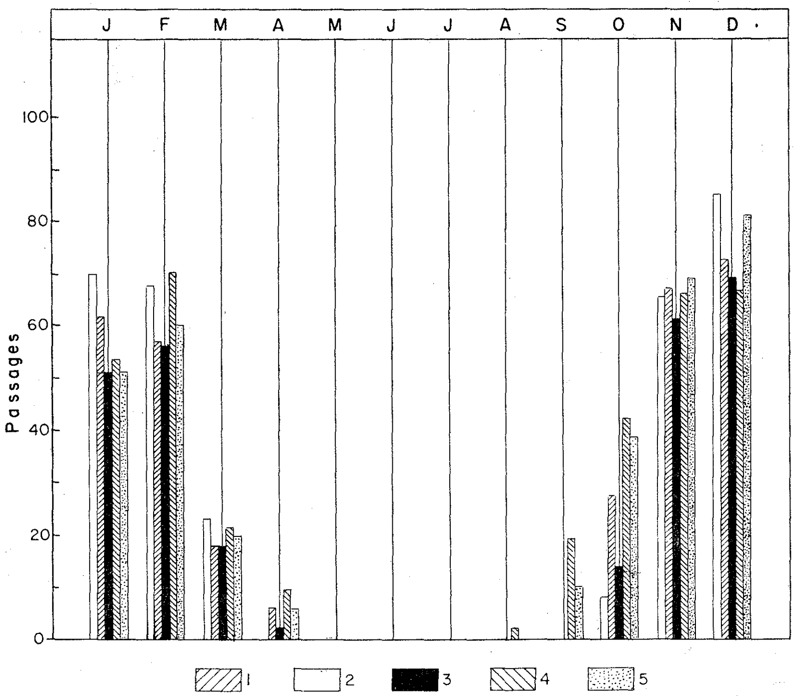

Fig. 21. Minimum number of passages across 0°C threshold, 1 February 1967 to 28 February 1968, for indicated surfaces

These data indicate only the minimum passages, as recording was by maximum-minimum thermometer, every 3 hours. 1. light colored soil; 2. dark colored soil; 3. vertical rock face – south exposure; 4. vertical rock face – north exposure; 5. horizontal rock face

while during the mid-season, the southern exposure, being heated to a lesser extent, undergoes freezing at times that the heating of the northern has been so great that it remains above the zero threshold. The number of freeze-thaw cycles illustrated exceeds any other reported values.

It is readily apparent from field observations that the rate of snow melt on northern exposures is more rapid than on southern. It was originally thought that the rate of thaw of the soil should also be more rapid on northern slopes. However, studies during 1967–68 did not reveal significant differences in either rate or depth of thaw of similar materials with different exposures. The greatest variations between rates and depths of thaw were related to soil moisture content, thickness of the desert pavement, and presence of deep snow cover.

Soils moisture deficiencies, as evidenced by the concentrations of soluble salts extractable from lag gravel surfaces and gravimetric soil moisture content determinations, develop both on the stronger heated north-facing slopes and the windswept southern exposures. The deflationary effect of the winds apparently removes quantities of these salts from the mainland sufficient to balance the amounts of salts deposited by aerosols and precipitation. This conclusion is reached from data on salt concentrations in runoff waters, lakes, and soil profiles (MacNamara, in press). The salt cycle appears to be nearly in balance in the coastal oasis.

THE RELATIONSHIP OF THE MICROCLIMATE OF THE MOLODEZHNAYA OASIS TO OTHER ICE-FREE AREAS IN ANTARCTICA

The surface temperatures and ranges reported in this study exceed those reported from other areas, but, in general, the differences are of low magnitude and are probably related to latitudinal position. The maximum and minimum soil surface temperatures at Molodezhnaya were 41 and –41° C, while the corresponding values for Novalazuruskaya were 26 and –37° C. Soil surface temperatures of 25–30° C have been reported for the Bunger Oasis and Mirny areas, with maxima to 32° C reported at later dates (Markov, 1956; Avsiuk, Markov, and Shumskiy 1956; Grigoriev, 1959; Rusin, 1958). Midsummer soil surface maxima of near 20° C with daily ranges if near 30° C were reported in the dry valley areas of Victoria Land (Ugolini, 1963; Ugolini and Bull, 1965) and idealized soil temperature profiles from this area indicate annual ranges of 20° C (Tedrow and Ugolini, 1966).

In the McMurdo area of Victoria Land rock-air interface temperatures of 50–70° F have been reported (Kelly and Zumberge, 1961), while in the nearby dry valleys readings of 25° C have been obtained (Angino, Armitage, and Tash, 1961). Maximum rock surfaces temperatures in excess of 32° C have been indicated to repeatedly occur at Cape Hallett (Rudolph, 1966). At Molodezhnaya the absolute maximum was 42° C with temperature greater than 30° C occurring on 15 days between November and January.

The available data on depth of thaw and active layer thickness from the various parts of the continent indicate general increase in values with more northerly latitudinal positions. In the dry valleys, a soil material containing only 1% of water was indicated to have thawed 20 cm in 1961–62 (Ugolini, 1963; Ugolini and Bull, 1965). The McMurdo Sound area has been indicated to have an active layer thickness of near one half meter (Nichols, 1966). The range of active layer thicknesses in the coastal oases on the Knox and Queen Mary Coasts is indicated to be up to 2 m with soil materials normally near 1 m (Grigoriev, 1959). In the Enderby Land oases, based on soil profile characteristics and a number of excavations, the average depth of thaw is near 1 m under normal moisture conditions and is considerably greater in drier deposits (MacNamara, 1969a).

The greatest microclimatic differences between inland ice-free areas and the coastal oases is the dominance of unidirectional drainage winds which carry drifting snow into the exposed soil areas. In the dry valley area of Victoria Land, the winds are not unidirectional over the course of the year, but are apparently dominated by westerlies in the winter and easterlies in the summer (Ugolini and Bull, 1965). The soils are arid, characterized by alkaline pH, and are saline. Moist soils are only found proximal to snowbanks and glaciers, or where the ice-cemented layer („wet" permafrost) is reached by the summer thaw (Ugolini, 1963; Ugolini and Bull, 1965; Tedrow and Ugolini, 1966; McCraw, 1960).

The existence of soil moisture and unidirectional dominant and prevailing winds allows the establishement of plant communities, which as shown in this report create microenvironments by „autoecological" effects. Other reports by the author indicate pedogenetic differences (MacNamara, 1969a, b, c).

As a result of lowered albedo, the thermal regimes of rock and soil surfaces differ significantly from that of snow surfaces.

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