Radiation measurements from the Namib Desert

by

Karen Nott*

and

Michael J. Savage

Soil Science and Agrometeorology Department
University of Natal
Pietermaritzburg 3201
Republic of South Africa

Received: 6 July 1983
Accepted: 3 July 1984

*Present address:
P.O. Okaukuejo
via Outjo 9000
South West Africa/Namibia

ABSTRACT

Radiation measurements were performed at remote sites in the Namib Desert where ecological research projects are being undertaken. Since the radiation environment plays an important role in the ecology of desert plants and animals, the aim of this study was to make this information available to researchers working in the area. Incident short-wave radiant density, net radiant density, soil heat flux density and soil surface reflection coefficients were measured in the dunes and gravel plains along an east-west gradient, in the Namib Desert. Daily radiant density values ranged between 15 (June) and 26 MJ/m² (November). The annual radiant density for the Namib was 7 637 MJ/m² for 1982. Reflection coefficient values for bare sand (averaged between 10h00 and 15h00) show site differences. The highest recorded was on the plains. The soil heat flux density values were greatest near the coast (Rooibank) — typically 190 W/m² at local noon. The integrated value (for a 24 h period) was also greatest near the coast with negative values being experienced at Welwitschia Wash. However, net radiant flux density values were greatest for Welwitschia Wash due to its dark surface and the surrounding high walls of the wash.

CONTENTS

1 Introduction 165
2 Definitions and terminology 166
3 Materials and methods 166
3.1 Short-wave radiation 166
3.2 Soil heat energy 166
3.3 Net radiation 167
4 Results and discussion 168
4.1 Incident short-wave radiation 168
4.2 Reflection coefficients 168
4.3 Soil heat energy 169
4.4 Net radiation 171
5 Acknowledgements 172
6 References 173

1 INTRODUCTION

Energy is radiatively transferred from the sun to the earth with resultant energy changes occurring within the earth's atmosphere. This radiant energy (short wave-lengths) may be reflected, transmitted, absorbed and then reradiated or it may be converted to stored chemical energy at the plant leaf surface (Savage, 1980). Some of the short-wave radiation entering the earth's atmosphere is absorbed by dust and gas components and converted into long-wave radiation.

The radiation environment of many plants and animals is of great importance in establishing their thermal equilibrium in their natural environment. Radiation can also play a role in seed germination, flowering, plant productivity and survival. Animals are mobile and can thus modify their radiative loads by their physiological characteristics and behaviour (Axtell, 1966; Cloudsley-Thomson, 1979).

Plants and animals existing in a desert environment are often exposed to large radiation loads. Their survival has been the subject of much research. In studying plant and animal survival mechanisms, it has been necessary to monitor their environmental conditions and the local microclimate. Many of the deserts of the world have available radiation data. McGinnies, Goldman and Palore (1968) reviewed the work done on radiation for all deserts, but their emphasis was on climatological rather than micrometeorological parameters. In the Namib Desert, extensive research is being undertaken on the diverse endemic fauna of the dunes and gravel plains. Detailed information has been collected on the climate and microclimate of the Namib excluding radiation measurements (Schulze, 1969; Seely & Stuart, 1976).

The objective of this study was to collect radiation data in the Namib at eight sites. Hopefully these data will provide valuable information for the understanding of some of the survival mechanisms of plants and animals.

2 DEFINITIONS AND TERMINOLOGY

Radiant flux density (rfd) of incident short-wave (I_s) is the energy received at a surface, per unit time per unit area with units J $s^{-1}m^{-2}$ or W/m^2.

The reflection coefficient (r) of a surface is the ratio of reflected to incoming short-wave rfd, expressed as a percentage.

Soil heat flux density (F_s) is the amount of energy flux density entering or leaving a layer of sand at a given time with units J $s^{-1}m^{-2}$ or W/m^2.

The net radiant flux density of a surface (I_{net}) is the algebraic sum of all short-wave and long-wave energy flux densities at the surface. It can be expressed as

$$I_{net} = I_s - rI_s - L_u + L_d$$

where I_{net} is the net radiant flux density, I_s the incoming short-wave rfd, rI_s the reflected short-wave rfd, and L_u and L_d are the upward and downward energy flux densities, respectively. During the daytime, I_s is generally the dominant term in the radiation budget and hence I_{net} is positive. On clear nights, the dominant term is L_u, the short-wave and reflected short-wave energy terms being zero. On cloudy nights, the L_d term may be almost as large as the L_u term but opposite in direction, resulting in a I_{net} value close to zero.

3 MATERIALS AND METHODS

Instruments were erected above bare undisturbed sand at eight sites (Table 1) and measurements were taken every hour for 48 h. All measurements were performed manually using a millivoltmeter accurate to 0,1 mV. If calibration errors are included, it is necessary to be able to measure voltages from all radiation instruments to within about 0,3 mV. All voltmeters were battery powered.

3.1 Short-wave radiation

Incident and reflected short-wave radiation were measured using tube solarimeters (Monteith type). The sensing element is composed of two highly thermoconductive silver plates. One silver plate is coated with white paint having high reflectivity while the other is coated with black paint which has good absorptivity. The sensing element was sealed in a glass container filled with dry air to prevent condensation. The difference in temperature between the white and black plates under exposure to solar radiation, is measured by means of a series of thermocouples and a voltmeter powered by two 6 V batteries (10 A h). Measurements were accurate to within 5%.

Both tube solarimeters were calibrated against a Linke-Fuessner pyrheliometer and calibration equations obtained for each. For field measurements, one tube solarimeter was fastened to a black wooden board 100 mm in width and then attached to a photographic tripod stand so that the sensing element was horizontal and facing upwards. The second tube solarimeter was fastened to a T-shaped black wooden board and attached to a tripod so that the sensing element was horizontal and facing downward. These procedures reduced the effect of underside sensor radiant heating on the output voltage. The tripod was painted black to minimise the effect of reflected radiation on the measurements. The tube solarimeters were at a height of 500 mm above ground surface.

The first order weather station at Gobabeb has a bimetallic recording pyranometer. Data from this instrument for 1981 were used to obtain the average radiant density (radiant energy per unit area in J/m^2 or MJ/m^2) for each month of the year. Although the absolute accuracy of these measurements is within 10%, these data enabled comparisons to be made for the different times of the year.

3.2 Soil heat energy

The amount of energy per unit area per unit time entering or leaving the sand was measured using two soil heat flux plates, buried at a depth of 3 mm and placed

TABLE 1: Location of the eight sites in the Namib Desert at which radiation measurements were performed.

Site Name	Description	Latitude	Longitude	Altitude (m)	Approximate distance from the coast (km)
Rooibank	Dunes. Almost no vegetation	23° 10'S	14° 35'E	63	12
Jumbo	Sparsely vegetated dunes	23° 31'S	14° 52'E	350	43
Kahane	Sparsely vegetated dunes	23° 36'S	15° 01'E	450	53
Noctivaga	Sparsely vegetated dunes	23° 43'S	15° 14'E	600	95
Mniszechi's Vlei	Vegetated dunes	23° 43'S	15° 29'E	700	105
Far East	Densely vegetated dunes	23° 46'S	15° 47'E	936	130
Welwitschia Wash	Deep, dry, gravel wash	23° 37'S	15° 10'E	500	68
Ganab	Gravel plain	23° 09'S	15° 33'E	980	100

500 mm apart. The voltage output was measured using a millivoltmeter and then converted to energy units using the appropriate calibration constants. These measurements were accurate to within 5% (calibration being performed against a unit traceable to national standard).

3.3 Net radiation

A Middleton net radiometer was used. This instrument has a sensing element consisting of 250 thermojunctions bounded by two blackened plates. The element is protected by two polythene hemispheres

TABLE 2: Radiation data for Gobabeb for 1981 (Desert Ecological Research Unit).

		Clear days		Cloud corrected
Month	Week no.	Daily radiant density (MJ/m²)	Maximum solar RFD (W/m²)	Monthly total radiant density (MJ/m²)
January	1	25,7	852	
	2	25,7	852	
	3	25,6	854	
	4	25,6	856	
	5	25,3	852	966
February	6	25,2	851	
	7	24,0	817	
	8	22,4	856	
	9	22,1	762	650
March	10	—	—	
	11	21,9	765	
	12	21,6	762	
	13	21,1	789	663
April	14	20,8	748	
	15	19,7	713	
	16	19,0	692	
	17	18,9	695	
	18	18,1	671	561
May	19	17,8	660	
	20	18,1	678	
	21	16,7	629	
	22	17,0	643	518
June	23	16,9	642	
	24	15,7	594	
	25	16,8	643	
	26	16,0	608	471
July	27	16,2	616	
	28	16,4	622	
	29	16,1	608	
	30	16,2	608	
	31	17,2	643	499
August	32	17,1	636	
	33	18,3	678	
	34	19,4	713	
	35	21,0	765	567
September	36	20,7	748	
	37	22,3	800	
	38	21,6	769	
	39	22,2	783	645
October	40	24,3	852	
	41	24,5	849	
	42	25,7	887	
	43	25,2	863	
	44	25,1	852	732
November	45	24,6	831	
	46	25,8	870	
	47	26,1	873	
	48	26,6	887	774
December	49	25,7	887	
	50	26,8	887	
	51	26,3	870	
	52	25,3	835	791
TOTAL ANNUAL (MJ/m²)				7 637

which are transparent over the full range of wavelengths encountered. These hemispheres were kept inflated and free of condensation by first pumping air over silica-gel and then across the sensor. A converted fish-tank pump powered by a 6 V battery (6 A h) was used for this purpose. The net radiometer was calibrated against a Linke-Fuessner pyrheliometer before and after use, according to the procedure of Idso (1974).

The net radiometer was mounted on a photographic tripod stand at a height of 500 mm above ground. Idso (1974) recommends a height of 200 to 250 mm provided the soil surface is dry and bare and the domes remain dust free. Due to excessive sand movement in the 200 to 250 mm layer during the frequent windy periods, a height of 500 mm was found to be more suitable.

4 RESULTS

4.1 Incident short-wave radiation

The recording pyranometer output was recorded on a weekly chart (Meteorological data, unpublished, Desert Ecological Research Unit). In order to obtain comparative estimates of daily radiant density values (MJ/m²), it was assumed that radiant density was half-sinusoidal. This sine function was integrated from sunrise to sunset and a theoretical daily radiant density (in MJ/m²) calculated. The maximum solar rfd for each day was obtained from the maximum value on the radiation chart.

The average theoretical daily radiant density for Gobabeb for each week of 1981 is presented, together with the average maximum solar rfd (W/m²) (Table 2). Both these values are for clear days. Since fog occurs at Gobabeb, this theoretical value was corrected to obtain relative estimates of the incoming solar rfd in the presence of fog. From the radiation chart, the percentage reduction in daily radiant density due to fog was visually estimated. The average estimated daily radiant density for each month was obtained and a monthly total calculated (Table 2). These values would vary somewhat from year to year, depending on the occurrence of fog. The monthly variation in the daily radiant density is shown (Fig. 1). The highest value occurred in November and the lowest in June. The highest maximum solar rfd values occurred between mid-October and mid-December.

4.2 Reflection coefficients

Oke (1978) states that most sandy deserts have high reflection coefficients and that the midday reflection coefficients of desert surfaces are in the range of 20 % to 45 %. The reflection coefficient is mainly affected by colour, particle size and soil moisture content (Gates, 1980).

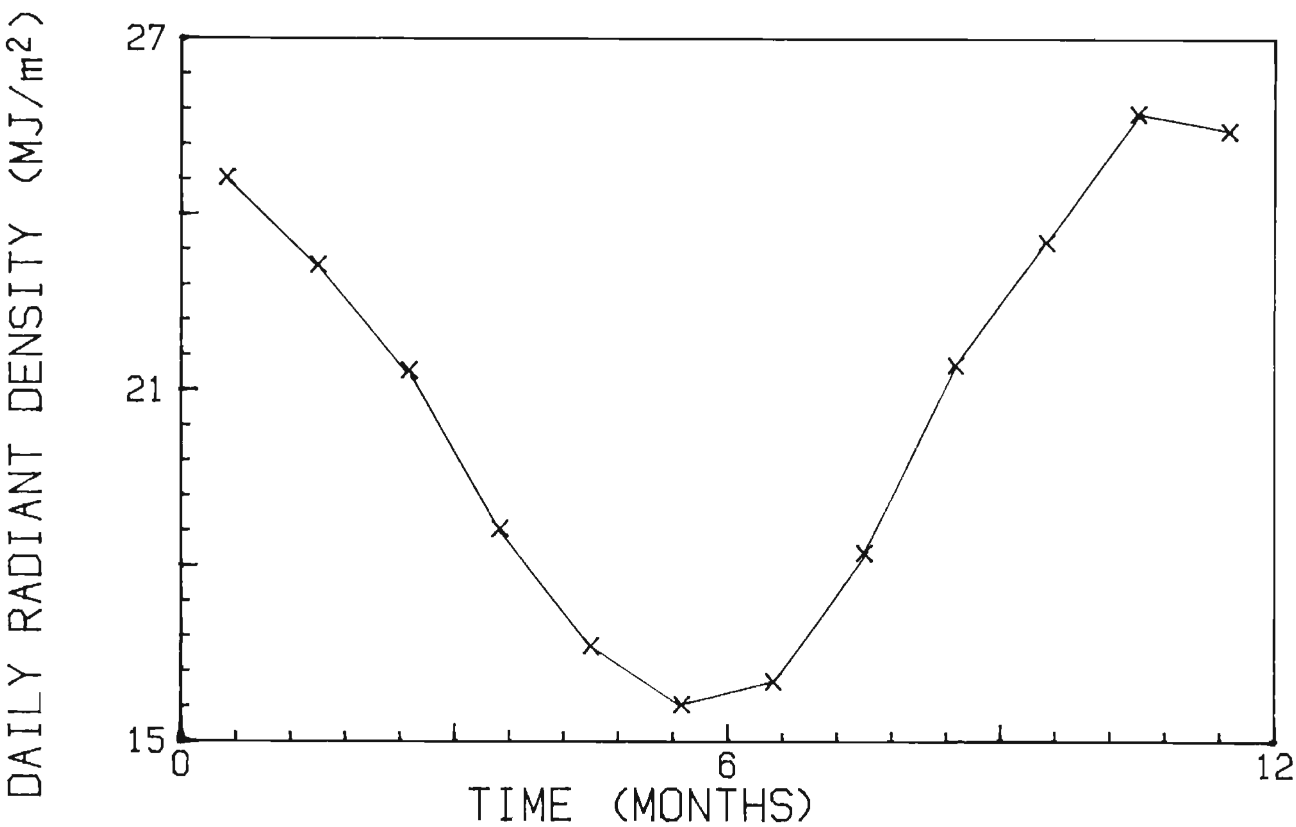

FIGURE 1: Estimated daily radiant density for Gobabeb (1981) as a function of time of year. Values were calculated from measured daily maxima and day length.

TABLE 3: Reflection coefficients for different sites in the Namib Desert during March/April 1982.

Site	Approximate distance from the coast (km)	Reflection coefficient (%)
Rooibank	12	24
Jumbo	43	23
Kahane	53	20
Noctivaga	75	24
Mniszechi's Vlei	105	25
Far East	130	25
Ganab	100	26
Welwitschia Wash	68	19

Measurements were only taken between 10h00 and 15h00 on clear days due to the comparatively low sun angle before and after these times. All these measurements were averaged to obtain the reflection coefficient for a particular site. The reflection coefficients for different sites in the Namib are presented (Table 3).

For sandy surfaces in the dunes, the reflection coefficient varied from 20% at Kahane to 25 % in the Far East. The highest reflection coefficient measured was on the gravel plains at Ganab and the lowest at Welwitschia Wash. The low reflection coefficient at Welwitschia Wash may be due to the dark colour of the surface and surroundings. Along an east-west gradient in the dunes, the reflection coefficient decreases from east to west between the Far East and Kahane, but then increases again towards the coast.

4.3 Soil heat energy

During the daytime, energy is absorbed by the sand and the soil heat energy is positive. The maximum energy loss occurs shortly after sunset (Fig. 2). The loss of energy to the atmosphere decreases as the night progresses, due to the limited amount of available energy in the top sand layer (Fig. 2). The diurnal variation in soil heat energy for four sites is presented (Table 4) and the difference between two sites, Far East and Rooibank, is shown (Fig. 2).

The sand surface of the Far East absorbs less energy during the day than does that of Rooibank. The difference is probably partly due to the higher reflection coefficient of the sand surface. At night, the sand surface at Rooibank loses more energy than does that

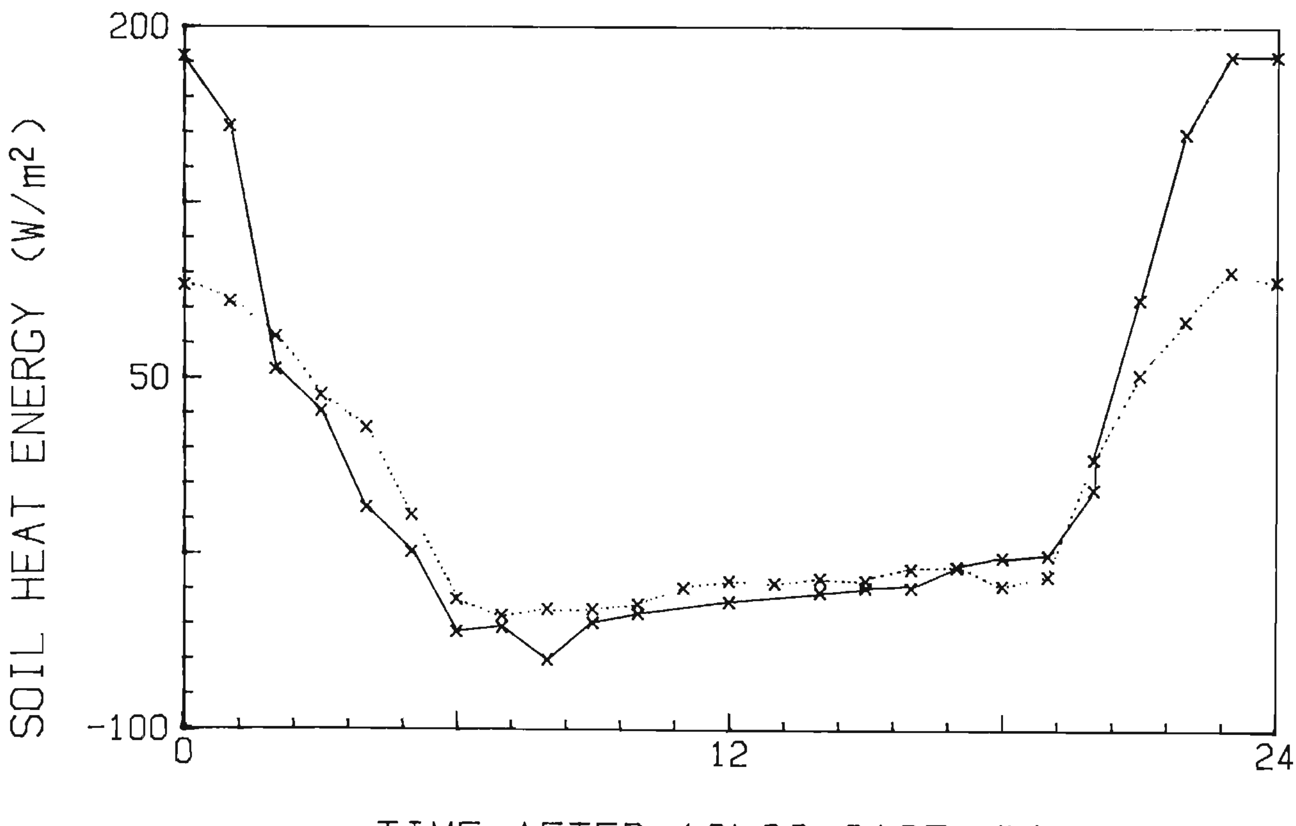

FIGURE 2: Diurnal variation in soil heat energy at Rooibank (—) and Far East (...) during March 1982.

TABLE 4: Diurnal variation in soil heat flux density F_s(W/m²) and selected percentages of F_s relative to the net rfd (I_{net}) for four sites. Measurements were performed during March/April 1982.

Time (hours)	Rooibank		Kahane		Far East		Welwitschia Wash	
	F_s	F_s/I_{net}	F_s	F_s/I_{net}	F_s	F_s/I_{net}	F_s	F_s/I_{net}
12h00	188,7	45			91,4	24	112,6	21
13h00	159,4	36	159,9	38	83,8	22	115,5	20
14h00	54,6	12	127,0	33	68,9	19	77,6	15
15h00	36,5	10	53,9	18	44,0	15	52,5	12
16h00	-3,7		29,6		29,5		5,7	
17h00	-22,7		-33,7		-6,7		-26,8	
18h00	-57,4		-71,8		-43,0		-68,4	
19h00	-55,1		-80,9		-49,6		-64,6	
20h00	-69,3		-65,8		-46,6		-57,7	
21h00	-53,0		-57,0		-46,8		-54,6	
22h00	-49,2		-37,7		-45,4		-52,4	
23h00	—		-50,4		-38,4		-47,5	
24h00	-43,5		-48,5		-34,8		-43,2	
01h00	-35,9		-50,4		—		-40,5	
02h00	-39,7		-47,4		-34,3		-41,6	
03h00	-38,0		-45,2		-35,0		-40,4	
04h00	-38,2		-43,3		-30,0		-32,8	
05h00	-29,2		-41,0		-29,2		-32,1	
06h00	-25,4		-45,9		-37,2		-29,2	
07h00	-23,6		-41,5		-32,6		-32,7	
08h00	3,8		17,3		16,7		-23,3	
09h00	85,0	69	56,2	28	52,8	22	-6,2	
10h00	155,9	58	119,5	39	76,4	24	111,4	74
11h00	188,5	51	134,6	33	96,6	30	116,3	24
12h00	188,6	45	156,1	36	92,9	25	127,4	24
Integrated value (MJ/m²) over 24 h	0,86		0,39		0,05		-0,51	

TABLE 5: Net radiation above bare sand for eight sites in the Namib for a 24 h period during March/April 1982.

Time (hours)	Net radiation (W/m²)							
	Rooi-bank	Jumbo	Kahane	Nocti-vaga	Mniszechi's Vlei	Far East	Ganab	Welwitschia Wash
12h00	417,0	441,4	421,7	458,5	432,0	386,1	440,8	543,0
13h00	437,9	459,4	423,2	555,4	449,1	385,0	458,9	545,8
14h00	439,1	439,1	389,3	574,3	427,2	359,0	449,0	523,2
15h00	356,8	379,8	304,0	599,1	426,8	303,5	404,2	457,3
16h00	285,1	264,2	217,3	300,5	335,1	206,8	314,4	357,8
17h00	175,3	173,7	105,2	171,4	228,5	93,7	184,0	224,7
18h00	38,2	90,6	-15,4	-49,5+	91,0+	-0,6	36,7	69,1+
19h00	-68,1	-71,9	-101,7	-40,9+	-31,2+	-105,8	-105,0	-28,2+
20h00	-65,3	-74,9	-99,1	-69,3	-80,9	-99,0	-105,8	-93,6+
21h00	-63,3	-73,4	-90,8	-72,1	-73,6	-92,9	-126,1	-82,4+
22h00	-60,3	-69,4	-87,3	-74,5	-70,0	-91,5	-119,2	-59,0+
23h00	-61,4	-74,0	-77,8	-74,7	-68,1	-87,0	-112,1	-82,0+
24h00	-60,2	-68,9	-75,7	-72,0	-54,8	-85,6	-104,5	-76,6+
01h00	-57,9	-76,7	-71,9	-70,1	-41,7	-81,4	-104,1	-52,6+
02h00	-58,0	-69,1	-68,7	-69,3	-57,5	-79,8	-103,4	-57,5+
03h00	-54,6	-65,5	-65,5	-69,2	-54,6	-80,8	-99,2	-19,2+
04h00	-35,9+	-64,8	-60,4	-70,2	-50,3	-78,9	-90,3	-17,1+
05h00	-19,4+	-60,5	-56,2+	-74,7	-52,3	-78,7	-89,4	-67,2
06h00	-27,2+	-59,7	-55,3+	-76,0	-50,5	-75,5	-87,2	-63,5
07h00	-24,4+	-52,7	-52,1+	-69,3	-41,1	-0,6	-76,3	-10,3+
08h00	5,6+	35,2	73,1	4,9	-23,3	136,1	72,7	31,9+
09h00	123,9	160,2	202,8	145,6	170,6	237,8	196,9	134,5+
10h00	267,2	282,6	303,6	266,8	285,5	318,8	305,0	150,5+
11h00	366,4	381,3	413,9	354,9	373,7	360,1	394,1	481,8
12h00	417,0	428,9	435,3	427,6	451,6	371,4	440,0	529,4
Integrated value (MJ/m²) for 24 h.	8,21	7,99	6,58	8,77	7,98	6,77	7,09	9,98

+ Indicates the presence of cloud or fog.

at Far East, since a greater amount of energy has been stored in the upper layers during the day. Unlike the Far East, there is little vegetation on the Rooibank dunes to form an insulating layer.

During summer, there is a net surface energy input, but during winter there is a net loss. The net input or output of energy by the sand can be calculated by integrating the hourly soil heat energy values (Table 4). Since the measurements were taken in the transition period between summer and winter, the net values (Table 4) are near zero. The negative value for Welwitschia Wash is due to the site being in a deep wash where the sun reaches it for fewer hours each day compared to the other sites.

4.4 Net radiation

A desert is characterised by large radiant energy input and output. The large solar input is offset by the relatively high reflection coefficient of the surface as well as long-wave radiation losses. Low latitude deserts have a maximum net radiation value during summer of approximately 600 W/m^2 (Oke, 1978). The maximum value measured in the Namib during late summer varied between 435 W/m^2 and 600 W/m^2.

Net radiation values for eight sites for a period of 24 h are presented (Table 5). A 48 h net radiation curve is also shown (Fig. 3). At night, I_{net} is negative becoming positive approximately two hours after sunrise. The maximum I_{net} value at Welwitschia Wash occurred at 13h00 (South African Standard Time, SAST). Before sunset I_{net} becomes negative and reaches a minimum value at 20h00. At this time, the maximum amount of radiation is being emitted by the sand surface. This amount decreases throughout the night due to the limited amount of available energy in the surface layers of the sand. During the 48 h of measurements at Welwitschia Wash, the first night of measurements was clear and the curve smooth. On the second night cloud was present for some time, followed by fog between 02h30 and 04h30. The peaks on the curve for the second night indicate the presence of cloud.

The integrated net radiation values show the net input or output of energy occurring above the sand surface (Table 5). This amount is positive for all sites under consideration, indicating that over a 24 h period there is a net energy input. The net input was greatest at Welwitschia Wash. This is possibly due to the lower reflectivity of the dark surface. The long-wave radiation emitted by the high sides of the wash could also have contributed to the energy input.

Assuming that I_{net} is partitioned between the atmosphere and the soil and that there is negligible soil surface evaporation, it is possible to calculate the percentage energy entering the soil, F_s/I_{net}, and that entering the atmosphere, $I\text{-}F_s/I_{net}$ (Table 4). Of note is that for Rooibank and Welwitschia Wash in particular, the F_s/I_{net} ratio generally decreases throughout the

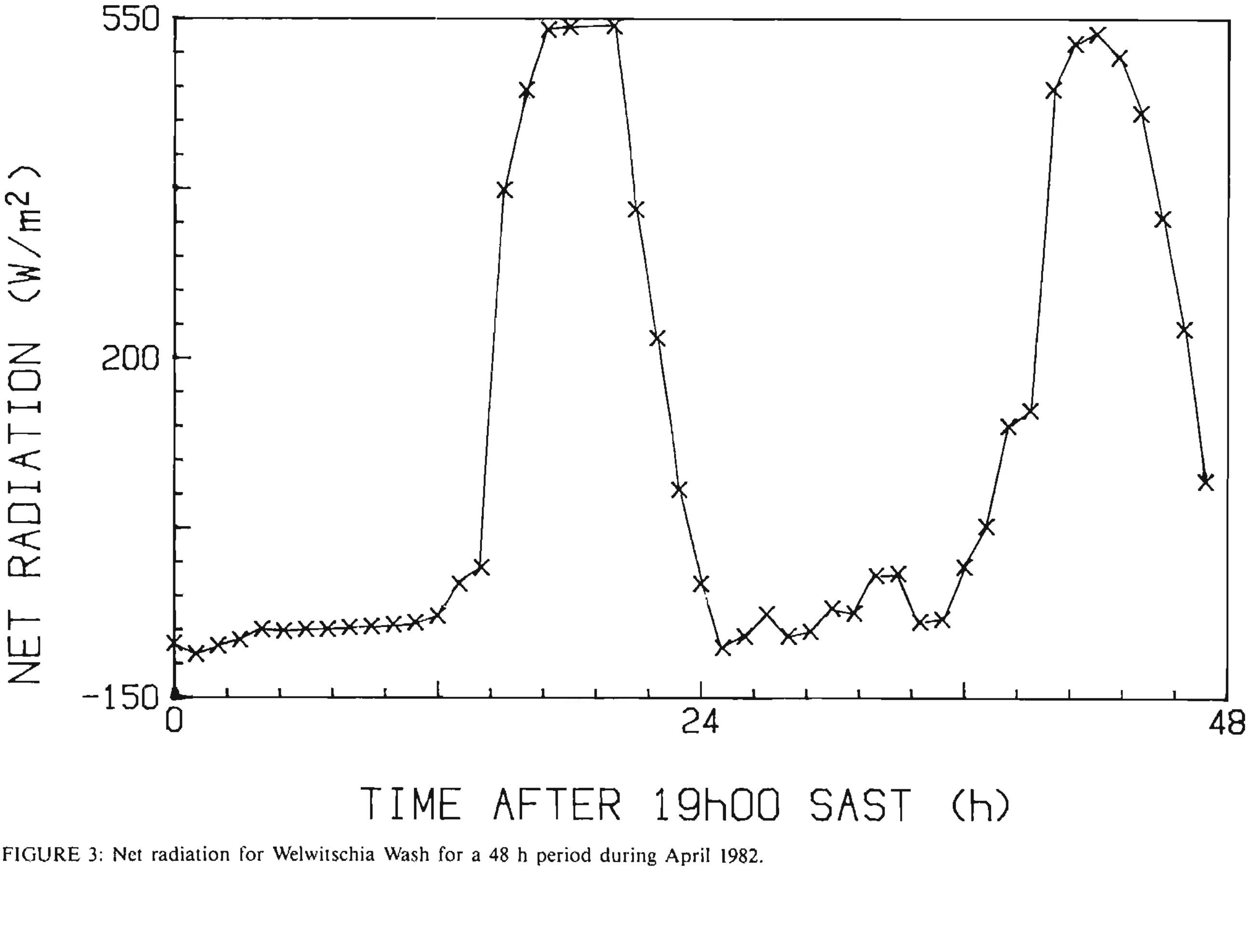

FIGURE 3: Net radiation for Welwitschia Wash for a 48 h period during April 1982.

day. That is, the percentage energy entering the soil is decreasing throughout the day whilst that entering the atmosphere continually increases.

5 ACKNOWLEDGEMENTS

The authors thank Dr M.K. Seely for her advice and support and the staff of D.E.R.U. for its assistance. The Department of Agriculture and Nature Conservation is thanked for permission to work in the Namib-Naukluft Park and for use of facilities at Gobabeb. The University of Natal, CSIR, Sonnex Group of Companies in SWA/Namibia and the Ernest Oppenheimer Memorial Trust are thanked for materially and financially supporting this research.

6 REFERENCES

AXTELL, R.W.
1966: Orientation by *Holbrookia maculata* to solar and reflected heat. *Southwestern Naturalist* **5**: 45—47.

CLOUDSLEY-THOMSON, J.L.
1979: Adaptive function of the colours of desert animals. *J. Arid Environ.* **2**: 95—104.

GATES, D.M.
1980: Biophysical Ecology. Springer-Verlag, New York.

IDSO, S.B.
1974: The calibration and use of net radiometers. *Advances in Agronomy* 7(5): 261—275.

McGINNIES, W.G., GOLDMAN, B.J. and PALORE, P.
1968: Deserts of the World: An appraisal of research into their physical and biological environments. Univ. of Arizona Press, Tuscon, Arizona.

OKE, T.R.
1978: Boundary layer climates. Methuen and Co. (Ltd.), London.

SAVAGE, M.J.
1980: Radiation and some of its important applications in agriculture. *Vector* **11**: 12—14.

SCHULZE, B.R.
1969: The climate of Gobabeb. *Scient. Pap. Namib Desert Res. Stn* **44**: 59—68.

SEELY, M.K. and STUART, P.
1976: Namib climate: 2. The climate of Gobabeb, ten year summary 1962/1972. *Bulletin of the Desert Ecological Research Unit*, Gobabeb, August 1976.