THE VARIATION OF COMPONENTS IN THE RADIATION BALANCE OVER DIFFERENT FYNBOS VEGETATION TYPES

MICHAEL IAN MORRIS

Submitted in part fulfilment of the Degree
of Master of Arts in Environmental Studies
University of Cape Town

April 1981

ABSTRACT

The primary aim of this research is to test whether fynbos vegetation has a high reflection coefficient, and the secondary aim is to consider the vegetation at the sites where the radiation measurements were carried out in order to determine whether similar vegetation structural types have similar radiation regimes. In order to do this six sites were selected in the Cape of Good Hope Nature Reserve. At each site the radiation fluxes were measured for three days during the late summer, giving a total of eighteen days of observation. In addition to the radiation measurements structural data was collected for the vegetation at each site so that comparisons between the radiation fluxes and vegetation could be made. Floristic data was also collected, to typify the vegetation at each site. It has been found that fynbos vegetation, as represented by this study, has an unusually low reflection coefficient which varies from 0,08 - 0,13. These values are below those recorded in the literature for other heathland vegetation. On the basis of a numerical classification of the vegetation structural data, it has been found that there is no clear relationship between the vegetation and the various components of the radiation balance.

ACKNOWLEDGEMENTS

My thanks go to my supervisor, Professor R.F. Fuggle, for his initiation of and assistance in this research. In addition, I owe a great deal to my wife for her encouragement and assistance with fieldwork. Further, I wish to thank our families for their encouragement and for the financial assistance, without which this degree could not have been completed. My thanks go also to the following people:

Mr. G.E.P. Wright, Chief Warden, and the staff of the Cape of Good Hope Nature Reserve for co-operation and assistance in collection of data;

Mr. A. Flepp, Senior Technician, School of Environmental Studies, U.C.T., for assistance with instrumentation and manufacture of ancilliary equipment;

Dr. C. Merry, Department of Land Survey, U.C.T. for data on solar altitude and azimuth;

Dr. E.J. Moll, for advice on the collection of vegetation structural data;

Miss E. Esterhuysen of the Bolus Herbarium and Jaqui Sommerville of the Botany Department, U.C.T., for identification of plant specimens; and finally Mrs. M. Stewart, for the typing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS USED

R_n	=	Net radiation
S_t	=	Incoming short-wave radiation
ρS_t	=	Outgoing short-wave radiation
L_d	=	Incoming long-wave radiation
L_u	=	Outgoing long-wave radiation
ρ	=	Reflection coefficient
β	=	Solar elevation
$\underline{T}$	=	Radiative temperature of vegetation
σ	=	Stefan-Boltzmen's constant ($5.67 \times 10^{-8} Wm^{-2} K^{-4}$)
ΔR	=	Output from net radiometer with uni-directional head
B	=	Black-body radiation from uni-directional head

Based on Montieth (1973)

CHAPTER 1

INTRODUCTION

A recent trend in ecology has been a movement towards the holistic study of ecosystems rather than the study of their isolated parts. In South Africa the holistic approach to the study of ecosystems can be seen in the Nylsvley Ecosystem Project (Huntley, 1978; Huntley & Morris, 1978) and in the Fynbos Biome Project (Kruger, 1978; Day et al, 1979). These projects include detailed studies of the physical systems related to the ecosystem such as soils, the availability of moisture and energy flows, as well as broader ecological studies on the functioning of vegetation and animal systems. As Hare (1973) suggests, ecologists and physical scientists have different interests, therefore it is necessary for there to be a convergence of both their ideas and methods in order that the complex interrelationships found in ecosystems be clearly understood.

In order to fully understand the functioning of any ecosystem, it is necessary to consider the role of energy and its flow through the system, as it is energy which is the basis of all interactions within the system (Odum, 1971). The source of the energy received at the earth's surface is the sun and the transfer of energy controls not only the biological systems, but also the physical processes that occur near the ground. Electromagnetic radiation accounts for the greatest amount of energy transfer, with convection, transpiration and photosynthesis also involved in the energy transfer to lesser degrees (Barry & Chorley, 1976; Gates, 1965a; Ross, 1975; Sellers, 1969). Of the spectrum of radiation present in the earth's atmosphere, short-wave radiation in the range of 0,3 - 3,0µm is the most important source of energy in atmosphere/vegetation interactions (Ross, 1975). Radiation in this part of the spectrum also accounts for most of the solar radiation that reaches the earth's surface (Fritz, 1958, quoted by Hutchison & Matt, 1977). Long-wave radiation in the spectral region of 3,0 - 100 μm also plays a part in the radiation regimes of ecosystems. The exchanges of radiation that are important in the consideration of the radiation regime of a vegetated surface are the incoming and outgoing fluxes of both short- and long-wave radiation. In addition there is the net radiation, which is the sum of the incoming and outgoing radiation fluxes. Finally it is useful to consider the reflection coefficient, which is the ratio between incoming and outgoing short-wave radiation. The reflection coefficient is therefore an indicator of the amount of short-wave radiation that is retained at any particular surface. A study of the radiation fluxes at a surface is the first step towards understanding the energy flows of an ecosystem, but should be considered in the light of the surface features for a full understanding of their role in the ecosystem.

The Cape flora, broadly termed fynbos, is an important vegetation system. Its importance is based on its richness in terms of the species present, even though it has relatively few families of plants. The distinguishing feature of fynbos is the presence of plants of the families Proteaceae, Ericaceae and Restionaceae. Fynbos vegetation, particularly that in the Southwestern Cape, provides an excellent opportunity for a study of the role of energy in a vegetation system as this vegetation exists in a heat stressed environment in that it has to survive hot summers during which there is little rain. A high transpiration rate is ruled out as a cooling mechanism because of the lack of water, so another strategy could be a high reflection coefficient to avoid heat stress. In studying the relationships between vegetation and other features of an ecosystem it is useful to do research in an area in which the vegetation is reasonably well defined. Hence the Cape of Good Hope Nature Reserve (Figure 1.1) was chosed for fieldwork. The Reserve also has the advantages of ease of access and of a field research station to act as a base for the survey.

This essentially micrometeorological study contributes to the understanding of the fynbos ecosystem by investigating the relationship between components of the radiation balance and

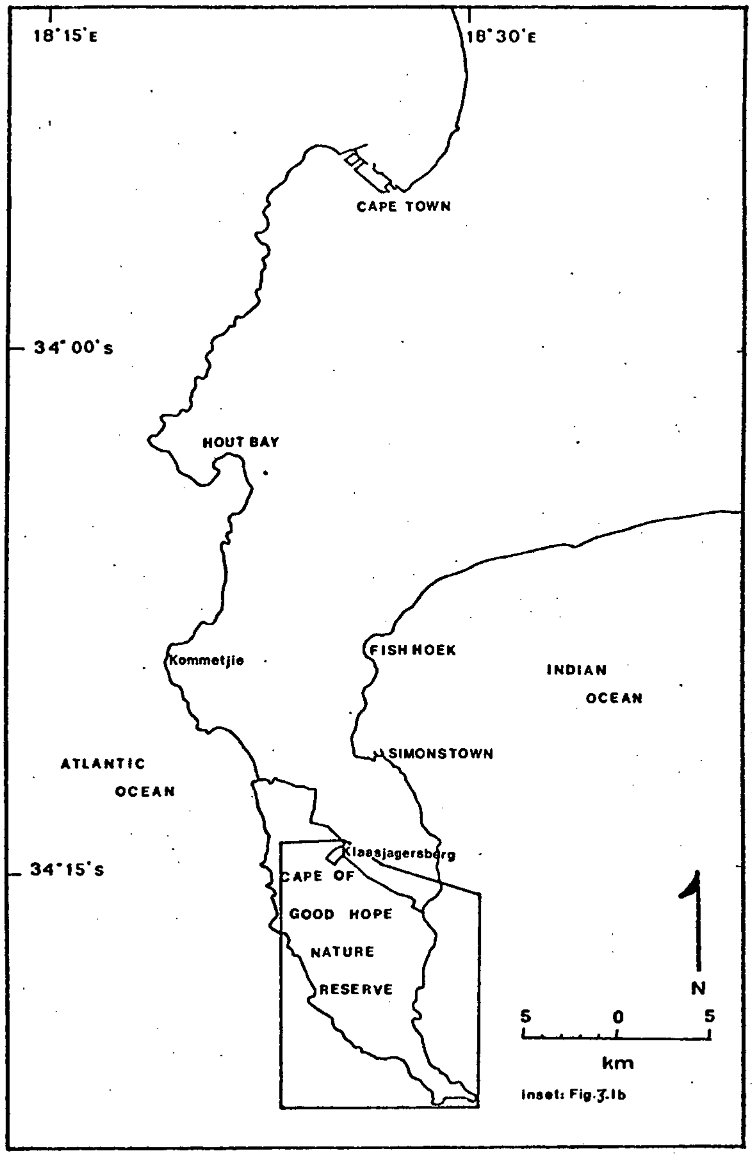


Figure 1.1 Location of study area

vegetation at specific sites in the Southern Cape Peninsula in summer. The aim of the study is to test whether fynbos vegetation has a high reflection coefficient as is expected from scleropholous vegetation. A secondary aim is to consider the vegetation at a number of sites to determine whether similar structural types have similar radiation regimes. In order to achieve these aims this work is organised as follows: Chapter 2 deals with the theoretical background to the radiation balance, an understanding of which is necessary in order to consider the differences in the radiation regimes. This chapter also provides information on the instruments used and the procedures involved in taking radiation measurements. In Chapter 3 the vegetation data are presented. The vegetation analysis includes the floristic data for the sites, each of which typifies the vegetation studied (fynbos). An explanation of the method used to classify the sites on the basis of the structure of the vegetation is given and results of the vegetation classification are also discussed. The classification of the sites on the basis of vegetation structural data allows for comparisons of the radiation regimes of each. Chapter 4 is concerned with the radiation data. In this chapter the variation of the different components of the radiation balance over three days at each site studied is considered. In Chapter 5 the implications of the radiation results are discussed together with relationships between the radiation results and the variation of vegetation types. Chapter 6 contains the conclusions drawn from this study and suggestions for further research.

CHAPTER 2

THE RADIATION BALANCE

In order to study the variation in components of the radiation balance it is necessary to define what the various components are. The radiation balance is the sum of the incoming and outgoing fluxes of short-wave and long-wave radiation. The various components of the radiation balance indicate the amounts of radiation that reach any surface and the amounts that are reflected or radiated from it. This chapter therefore outlines the different parts of the radiation balance, and in addition, indicates the way in which they are related to the radiation regime of a vegetated surface.

2.1 Components of the radiation balance

It has been noted that the radiation present in the atmosphere occurs in two spectral regions: 0,3 to 3,0 μm, which is short-wave (or solar) radiation; and long-wave radiation from 3,0 to 100 μm (Chang, 1968; Gates, 1965a; Kondratyev, 1964; Monteith, 1973; Munn, 1966). According to Ross (1975), these broad spectral bands can be subdivided with reference to their effect on vegetation. The ultra-violet (0,30 to 0,38 μm) has little effect on vegetation; photosynthetically active radiation, or visible light (0,38 to 0,71 μm) has significant thermal or photosynthetic effects; the near infra-red (0,71 to 3,0 μm) has thermal but not photosynthetic effects, and long-wave (3,0 to 100 μm) only has thermal effects. The ultra-violet comprises up to 4% of solar radiation, photosynthetically active radiation contributes from 21% to 46%, and near infra-red 50% to 79%, depending on prevailing conditions (Ross, 1975). For clear skies the photosynthetically active radiation therefore comprises about half of the short-wave radiation and can as a rough guide, be taken to contribute 50% of the incoming solar radiation (Monteith, 1973).

The exchanges of radiation at a surface consist of incoming short-wave radiation (0,3 - 3,0 μm), the short-wave radiation that is reflected from the surface, the long-wave radiation (>3,0 μm) from the atmosphere, and the long-wave radiation that is emitted by the surface (Gates, 1965a, 1965b; Monteith, 1973; Oke, 1978; Rosenberg, 1974). The sum of the outgoing short-wave and long-wave fluxes, subtracted from the sum of the incoming short-wave and long-wave fluxes gives the net radiation, which is then the sum of all the radiation available at a particular surface or vegetation canopy (Gates, 1965a; Monteith, 1973; Polavarapu, 1970). The net radiation therefore indicates the total amount of energy that is gained or lost by a particular surface.

An important feature of the radiation balance is the reflection coefficient, the ratio of incoming to outgoing short-wave radiation (also known as albedo, but the latter term strictly refers to radiation in the visible part of the spectrum; and reflectivity, which is wave-length specific (Monteith, 1973)). The importance of the reflection coefficient of a surface lies in the fact that it indicates the amount of solar energy that is available for physical and biological processes (Ahmad and Lockwood 1979; Bergland and Mace, 1972; De Walle and McGuire, 1973; Oguntoyinbo, 1974).

The radiation balance for any surface describes the fluxes of radiation over that surface. This can be presented in the form:

$$R_n = S_t - \rho S_t + L_d - L_u \qquad (1)$$

where R_n is the net radiation, S_t is the total incoming short-wave radiation, ρS_t is the total reflected short-wave radiation, L_d is the incoming long-wave radiation, and L_u is the long-wave radiation emitted by the surface. R_n for a surface is the "fundamental quantity of energy" (Rosenberg, 1974, p.33) that is available at the earth's surface for the processes of evaporation, transpiration, photosynthesis, and air and soil heat fluxes. When considering the radiation balance the incoming fluxes (S_t, L_d) are taken to be positive, while the outgoing fluxes ρS_t, L_u) are taken to be negative. As R_n is the sum of all the components, its sign will vary according to the magnitude of the different fluxes.

The radiation balance equation can be re-written in the form:

$$R_n = (1-\rho)\ S_t + L_u - L_d \qquad (2)$$

where the reflection coefficient (ρ) is equal to $\rho S_t/S_t$ and is always positive. The reflection coefficient indicates the amount of solar radiation that is reflected from the earth's surface at a particular point. The remaining solar-radiation is then available for physical and physiological processes. The reflection coefficient of a vegetation canopy is an important determinant in its energy balance as it determines the amount of incoming short-wave radiation that is retained by the canopy (Ross, 1975). It has been shown by various researchers in the U.S.A. (Billings and Morris, 1951), Australia (Pearman, 1966; Sinclair and Thomas, 1970) and the Mediterranean (Stanhill, et al, 1966), that heat-stressed vegetation tends to have a relatively high reflection coefficient so as to lower the heat loading on the plants. In addition, it has been found that there is usually a diurnal change in ρ, which may be due to a variety of causes, including solar altitude - which affects the amount of radiation that can penetrate the stand of vegetation (Arnfield, 1975; Munn, 1966; Rosenberg, 1974); changes in plant physiology e.g. wilting (Oke, 1978), and changes in the spectral composition of S_t (Robinson, 1966).

It is not practical to measure all of the components of equations (1) and (2) directly. It is, however, possible to calculate those fluxes that are not directly measurable. Direct measurements are made of R_n, S_t and ρS_t; indirect measurement is made of (S_t+L_d); and hence ρ, L_u and L_d can be calculated. The mean value for ρ can be calculated in a number of ways. Monteith and Szeicz (1961) used the sum of all the ρS_t and S_t measurements to calculate ρ. This method has also been found to be reliable by Bergland and Mace (1972), Fritschen (1967) and Idso et al, (1969b). Stanhill et al (1966) used the slope of the linear regression of ρS_t on S_t to determine ρ. Idso et al (1969b) found, however, that the method of Stanhill et al (1966) can, on the basis of the slope of the regression, produce a mean ρ which is lower than the minimum value of ρ , particularly when ρ changes with solar altitude. In order that the problem should not arise the method of Monteith and Szeicz was therefore used to calculate the mean reflection coefficient. [1.]

A Swissteco Model S-1 net radiometer, which is based on that described by Funk (1959), is used to measure R_n. In this instrument the sensing surfaces are covered by polythene hemispheres to prevent air movements from giving rise to spurious instrument responses as well as keeping the surfaces clean and free from damage. The polythene hemispheres are transparent to both short- and long-wave radiation; although polythene absorbs some long-wave radiation, the absorption bands are narrow so that the effect is negligible (Funk, 1959; Gates, 1965a). As the polythene hemispheres are flexible, dry nitrogen is pumped through them from a gas bottle. This keeps the domes rigid and removes any moisture from the inside of the domes. The presence of moisture in the domes causes inaccuracy due to absorption of radiation.

To measure $(S_t + L_d)$ a second Swissteco S-1, with a uni-directional cup attached over the lower sensing surface in place of the polythene hemisphere, is used. This metal cup is painted on the inside with Parson's optical black and a Copper-Constantan thermocouple is embedded in the base of the cup. The thermocouple is used to measure the temperature of the cavity, from which it is possible to calculate the radiation emitted by the cavity, B, from Stefan-Boltzman's law:

$$B = \varepsilon \sigma T^4 \qquad (3)$$

---

1. A check of the data used in this study revealed that at Sites 1, 3 and 5 the slope of the regression of ρS_t and S_t produced a mean value for ρ lower than the minimum measured and therefore supported the decision to use the Monteith and Szeicz method.

where ε, the emissivity of the unidirectional head was taken to be 0.98; σ is Stefan'Boltzman's constant which is $5{,}67 \times 10^{-8} Wm^{-2}K^{-4}$ (Weast, 1975), and T is the temperature of the cavity in degrees Kelvin. Instrument output gives radiation differences between the all-wavelength incoming radiation and the radiation from the uni-directional head. The all-wavelength incoming radiation $(S_t + L_d)$, is found by:

$$(S_t + L_d) = \Delta R + B \tag{4}$$

where ΔR is the instrument reading. Knowing S_t from direct measurement the long-wave fluxes may be easily calculated as outlined by Schwerdtfeger (1976): the outgoing all-wavelength radiation is calculated from:

$$(\rho S_t + L_u) = (S_t + L_d) - R_n \tag{5}$$

The incident long-wave radiation is:

$$L_d = (S_t + L_d) - S_t \tag{6}$$

and the outgoing long-wave radiation is:

$$L_u = (\rho S_t + L_u) - S_t \tag{7}$$

A Middleton Model CN9 Solari-Albedometer is used to measure S_t and ρS_t, from which ρ is calculated. On this instrument each sensing surface is covered by two glass domes, which are transparent to radiation in the spectral zone of 0,3 to 2,6 μm (manufacturer's specification). The use of a double dome reduces a possible error caused by the dome being heated and radiating long-wave radiation onto the sensing surface. The sensing surface of the albedometer and of both net radiometers is a Copper-Constantan thermopile. The advantage of this means of measurement is that the instrument response is stable, linear, accurate and easily registered (Gates, 1965a; Szeicz, 1968).

In order to consider the variation in the components of the radiation balance it is necessary to measure each of the components separately. The instruments used in this study, therefore, were two Swissteco S-1 net radiometers, one of which had a uni-directional cup attached, and a Middleton CN9 Solari-

Albedometer. From the values measured the remainder of the components could be calculated.

2.2 Radiation regimes of vegetation

Once the various components of the radiation balance have been determined it is possible to consider their variation in terms of the radiation regimes of the different vegetation surfaces. The radiation regime of a stand of vegetation is determined by a number of factors, as indicated by Carlson et al (1971), Gates (1965b), Monteith (1973) and Ross (1975). The most important of these factors are: (1) The spectral composition of the radiation and the proportions of direct to diffuse solar radiation. (2) The optical properties of the stand. These are the absorption, transmission and reflection characteristics of the surfaces within the stand. Natural surfaces reflect or transmit solar radiation, but absorb nearly all long-wave radiation which is then re-radiated. (3) The optical properties of the soil can affect the radiation balance, but may be ignored if there is a dense vegetation cover. (4) The structure of the stand, that is, the distribution of plants and the distribution, size and orientation of leaves on plants is also an important factor because of the effect it has on the distribution of radiation within the plant canopy by affecting the degree of penetration of direct sunlight. Although points (2) and (4) appear to be similar, the optical properties of the stand refer to the interaction of radiation with plants, while the architecture of the stand controls the way in which the radiation penetrates the stand before it reaches all the vegetation.

In addition to discussing the various components of the radiation balance it is useful to consider the radiative temperature of the vegetation ($\underline{T}$), which is related to the amount of long-wave radiation produced by the vegetation canopy. The radiative temperature indicates to what extent the vegetation is reducing its energy loading radiatively. A re-arrangement of Stefan-Boltzman's law is used to calculate $\underline{T}$:

$$\underline{T} = \sqrt[4]{L_u/(\varepsilon\sigma)} \qquad (8)$$

where ε is the emissivity of the surface and σ is Stefan-Boltzman's constant. Since a vegetation surface does not radiate as a black body, an emissivity of less than 1 must be used. Idso et al, (1969a) have found that emissivities for different plants vary. As the main purpose of finding the radiative temperature of the vegetation was to indicate diurnal changes, and to give order of magnitude temperatures, it was felt that an assumed emissivity would suffice. An emissivity of 0.98 was assumed, and Table 2.1 shows the difference in radiative temperature for different emissivities. It can be seen that

TABLE 2.1 : RADIATIVE TEMPERATURE FOR DIFFERENT EMISSIVITIES

LW = Outgoing long-wave radiation in watts/sq. metre
E = Emissivity
Temperatures (Columns 2-6) in degrees K.

LW	E=0,96	E=0,97	E=0,98	E=0,99	E=1,0
300,0	272,4	271,7	271,0	270,3	269,7
325,0	277,9	277,2	276,5	275,8	275,1
350,0	283,1	282,4	281,7	281,0	280,2
375,0	288,1	287,3	286,6	285,8	285,1
400,0	292,7	292,0	291,2	290,5	289,8
425,0	297,2	296,4	295,7	294,9	294,2
450,0	301,5	300,7	299,9	299,2	298,4
475,0	305,6	304,8	304,0	303,2	302,5
500,0	309,5	308,7	307,9	307,2	306,4

change of emissivity gives temperature differences of the order of 3^{0}K at characteristic atmospheric temperatures. For comparative purposes this variation is constant and thus can be regarded as unimportant. An assumed emissivity can therefore be used without significant error.

As the radiation regime of any surface is a function of the incoming radiation (both short-wave and long-wave) and the physical characteristics of the surface, the surface determines the nature of the outgoing fluxes. Hence the nature of the surface determines both the amount of reflection of short-wave radiation as well as the amount of long-wave radiation that is emitted. With a vegetated surface, as in this study, it is necessary then to make a detailed investigation of the physical characteristics of the vegetation being studied in order to understand the radiation regime.

CHAPTER 3

THE STUDY SITES

It is intended to determine the relationships, if any, between different vegetation types and the various components of the radiation balance, hence the vegetation of the sites is of particular importance. If the vegetation at the different sites, and the variation of the components of the radiation balance at the different sites, are compared, it should be possible to establish whether sites with similar vegetation have similar radiation regimes. Two approaches to the study of vegetation are possible, these being the study of vegetation structure, and the study of the floristics of the vegetation. Both of these approaches need to be considered in view of the need for comparative vegetation and radiation analyses, though the two approaches to vegetation analysis do not require the same intensity of study.

The structure of the vegetation determines the way in which radiation is distributed within the vegetation canopy (Ross, 1975; Stanhill, 1970; Yates, in press) so that structural analysis of the vegetation is necessary to assist in understanding differences in the radiation regimes of the various sites. The collection and manipulation of structural data is discussed in Section 3.2. While structural data is needed to interpret the relationships between vegetation and its radiation regime, there is also a requirement for some floristic data to "typify the vegetation units recognised" (Moll et al, 1976, p.45). This serves to identify the vegetation of the study sites. A detailed analysis of the floristics has not been attempted, and only the visually most obvious taxa were collected at each site for this purpose.

In selecting the vegetation sites a number of points with regard to the collection of radiation data had to be considered, particularly as the vegetation analysis is an aid to the interpretation of the radiation measurements. As the soil beneath the vegetation canopy can affect the radiation regime of different sites through absorption or reflection, it was necessary to choose sites which have a complete vegetation cover so that the radiation regimes of different sites are purely a function of the vegetation. In addition, it was important to have all the sites on ground with the same slope and aspect, as by changing these parameters the intensity of incoming short-wave radiation on the surface is altered. It was also necessary to consider ease of access to the site in order to transport equipment to them, though this was not an overriding factor as selection of vegetation types is of prime importance.

3.1 Site descriptions

The fynbos vegetation of the Cape is floristically important, as is indicated by Good (1974) who states that the Cape flora forms one of the six plant kingdoms of the world. This is based on the species richness and the high degree of endemism. Taylor (1972, 1978, 1979) defines fynbos vegetation floristically on the basis of a lack of single species dominance, as well as the notable presence of plants of the family Restionaceae (the "Cape reeds"). He also notes as a characteristic physionomic feature the presence of ericoid shrubs and proteoid bushes. The vegetation of the southern Cape Peninsula is given by Acocks (1953) as Macchia (Fynbos) (Acocks number 67), but this has also been further subdivided by Taylor (1969) into a number of different communities.

In selecting sites for the radiation measurements an attempt was made to find sites which would contain either a predominance of one of the fynbos elements, or a mixture of the major elements, so that comparisons of different vegetation types and their radiation regimes could be made. To this end a number of visits were made to the Cape of Good Hope Nature Reserve, and on these visits a member of the reserve staff assisted in the selection of sites by indicating areas where there are different vegetation types that have complete ground cover and are reasonably accessible.

Of the six sites selected (See Figure 3.1 for location) four (Sites 1, 3, 5, 6) are defined by Taylor (1969) as being Upland Mixed Fynbos while the other two (2 and 4) are classified by Taylor (1969) as Restionaceous Plateau Fynbos. For the analysis of vegetation data 10m x 10m plots were selected as it has been found that this size contains a representative sample of fynbos vegetation at any particular place (Werger <u>et al</u>, 1972).

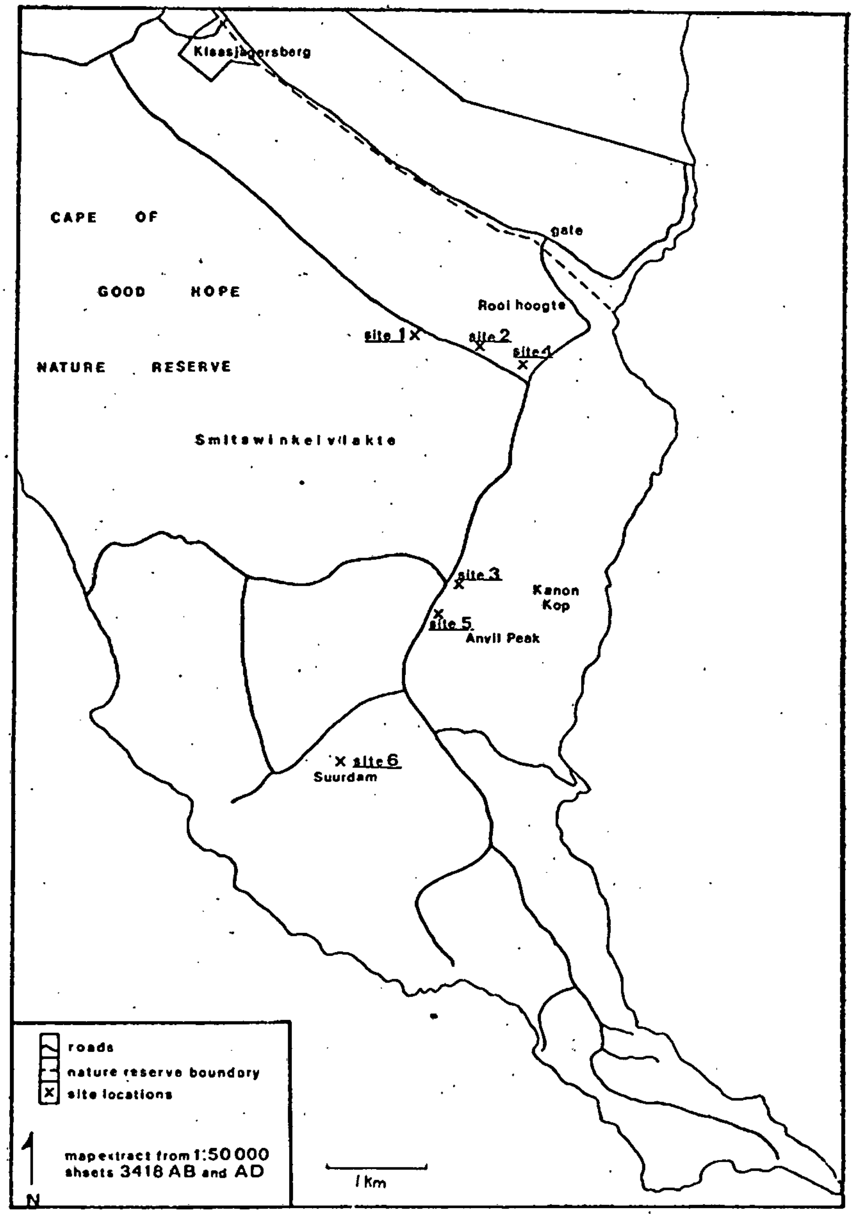


Figure 3.1 Location of study sites

A list of vegetation and related features of each of the sites is given in Table 3.1. Sites 1 and 2 are both dominated by plants of the family Restionaceae, although Site 1 contains tall plants and Site 2 short plants. At Site 3 the dominant vegetation, Berzelia abrotanoides, represents fairly tall vegetation with small leaves. Site 4 contains a mixture of the ericoid and restioid elements of fynbos, while Site 5 contains a mixture of the proteoid and ericoid elements with some of the restioid. The vegetation at Site 6 consists mainly of Ericaceae with some Restionaceae. Although the vegetation at the different sites is not of the same age, the youngest vegetation (5 years old at Sites 1, 2, 4) had reached a fairly mature stage at the time of measurement. The age of the vegetation is not, however, particularly important to this study as it is intended to compare the radiation regimes of different vegetation types and not different successional stages. The important factor is that all of the sites selected have a complete vegetation cover, so that although there are different soil colours the soil colour should not affect the radiation readings. The ground slope at Site 5 is small enough not to affect the radiation readings, and the soil moisture at Site 1 is not great enough to have an effect. Differences in the vegetation characteristics of the sites should be sufficient to be reflected in the radiation regime and therefore should enable us to establish the relationships, if any, between vegetation and the radiation balance.

3.2 Comparison of vegetation structure between sites

3.2.1 Methods of vegetation analysis

In order to analyse the vegetation structural data it is useful to utilize some kind of 'objective' means of sorting the data. A technique for the numerical classification of the sites into similar groups was selected. Of the techniques available the Czekanowski coefficient, also known as the Bray-Curtis measure (Bray and Curtis, 1957; Field and McFarlane, 1968) was selected in preference to the Canberra metric (Lance and Williams, 1967a) as it indicates homogeneous groups because it is not affected by large numbers of zeros in the data set, it is also appropriate for data sites containing few extreme values (Field, 1971; Clifford and Stevenson, 1975). A further advantage of the Czekanowski coefficient for this study is that it is abundance weighted, i.e. there is a greater contribution to the calculation of the similarity coefficient of those factors which are more abundant, than by those which are less abundant (Campbell, 1978; Linder and Campbell, 1979). Therefore, when applied to vegetation types, those with a high level of cover are emphasized in the production of a similarity matrix. It was assumed that the more abundant vegetation types would contribute most to the radiation balance, so the Czekanowski coefficient was considered most appropriate.

Of the clustering techniques available, neither nearest nor furthest neighbour are appropriate. Nearest neighbour sorting defines the distance between groups by the elements which are closest, hence "chaining" of the clusters tends to occur as new sites join existent groups rather than form separate ones. Furthest neighbour sorting defines groups on the basis of the most remote elements, and as such there is a tendency for sites to start new clusters instead of joining the existing ones (Campbell, 1978; Lance and Williams, 1967b). In group average sorting the most similar sites are formed into groups, after which the similarity coefficients of each group are averaged so that the clusters that have been formed can be regarded as single plots for each subsequent grouping, it is therefore an accurate means of defining group structures (Campbell and Moll, 1976; Williams _et al_, 1971). Group average sorting was therefore used in the clustering procedure.

3.2.2 Results of vegetation classification

Data were collected on the percentage cover of various leaf sizes in different height classes at the sites selected, with the method of data collection based on that of Lane (1980). The leaf sizes used are those defined by Raunkiaer (1934, quoted by Moll _et al_, 1976) with the addition of another size-class at the bottom of the scale so that the ericoid element of the fynbos can be included in the analysis. The leaf sizes used are picophyllous (leaf area $<10mm^2$), Leptophyllous (leaf area $<25mm^2$) and microphyllous (leaf area $< 9^2 \times 25mm^2$). In this study there were no plants with nanophyllous leaves (leaf area $<9 \times 25mm^2$)

or leaves larger than microphyllous. The scale used for vegetation cover follows the Braun-Blanquet system (see Werger, 1974), though with some modifications along the lines of those of van der Maarel (1979). The normal Braun-Blanquet cover class of 5-25% is broken into two, 4-12,5% and 12,5-25% cover in order to give a clearer indication of the vegetation of the site when there are a number of not very predominant vegetation types; in addition the usual Braun-Blanquet cover class of 75-100% is split into 75-95% and 95-100% in order to differentiate between high vegetation cover and virtually complete vegetation cover. The height classes used are <0,25m, 0,25-1,0m and >1,0m.

The output of the cluster program is a listing of the clusters formed and a dendrogram which shows the relationships between the different sites. The dendrogram showing the clusters found in this study can be seen in Figure 3.2 A dendrogram indicates the way in which sites join together to form clusters, but it is necessary to draw a cut-off point across the dendrogram in order to isolate the clusters. There is no objective way of inserting

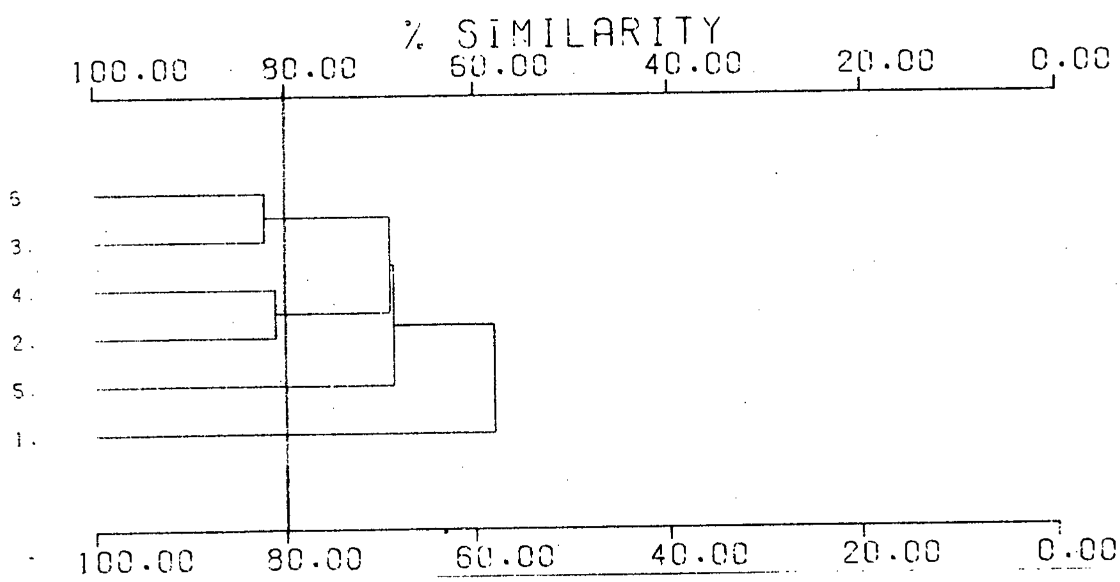


Figure 3.2 Dendrogram showing results of vegetation classification

the cut-off (Moll et al, 1976), so a choice has to be made subjectively of a level which does not give clusters which are too generalized or specific. In Figure 3.2 a cut-off of at over 82% gives no clusters, whereas one of between 69% and 81% gives two groups and two separate sites. Below 68% there is only one group with one separate site, and all the sites form one group at the 58% level. It would seem that the best classification comes from a cut-off of between 69% and 81%, and the 80% level is indicated in Figure 3.2.

In the clustering procedure, Sites 1 and 5 are classified on their own, Sites 2 and 4 form one group and Sites 3 and 6 form another. From Table 3.2, which contains the data used in the clustering procedure, the basis for the formation of the clusters can be seen. The distinguishing feature of Site 1 is the relatively high cover (in the class 50-75%) of tall restios, as well as the virtual lack of any vegetation other than restios (there being a less than 1% cover of picophyllous vegetation and a 25-50% cover of restios in the 0,25-1m height class). Site 5 is the only site which has more than 1% cover of microphyllous leaved vegetation, so that the presence of this large-leafed vegetation is the characteristic feature of the site. The grouping of Sites 2 and 4 is on the basis of the very high cover of restios in the 0,25-1m height class. The amount of cover of short restios overrides the difference in cover of picophyllous leaved vegetation (1% cover at Site 2, but 25-50% cover at Site 4). The final grouping of Sites 3 and 6, is also based on one particular vegetation type, with the high cover of Picophyllous leaved vegetation of between 0,25 and 1m in height being the most important feature. Had the 0,25-1m height class been subdivided (for instance into 0,25-0,50m and 0,50-1m) it is likely that Sites 3 and 6 would not have been so closely grouped as these sites have vegetation of different heights (see Table 3.1).

It has been possible to use a numerical classification technique to group the sites studied on the basis of their vegetation structure. Given the vegetative clusters formed it becomes

TABLE 3.2 : Data used to produce vegetation clusters

(i) The sites are arranged in the order of the dendrogram (Figure 3.2).

(ii) Figures in the columns refer to the number of species of each vegetation type or to the vegetation cover according to the modified Braun-Blanquet cover classes, viz.

1 = <1%
2 = 1 - 5 %
3 = 5 - 12,5%
4 = 12,5 - 25%
5 = 25 - 50%
6 = 50 - 75%
7 = 75 - 95%
8 = 95 - 100%

(iii) The leaf-size catagories are based on leaf area and are as follows:

Picophyllous (Picophyll.) = < 10 mm^2
Leptophyllous (Lepto.) = < 25 mm^2
Microphyllous (Micro.) = < 9 x 25 mm^2
Broad = leaf < 8 times as long as broad
Narrow = leaf > 8 times as long as broad

Structural Feature	SITE 1	5	2	4	3	6
Picophyll.<0,25m	-	-	-	-	-	2
Picophyll 0,25 - 1 m	1	5	1	5	7	7
Picophyll No. of spp.	1	3	1	4	2	4
Lepto. (Broad)<0,25m	-	2	-	-	1	-
Lepto. (Broad) 0,25 - 1m	-	2	1	-	-	-
Lepto. (Broad) No. of spp.	-	-	2	1	-	1
Lepto. (Narrow) 0,25 - 1m	-	-	-	-	2	2
Lepto. (Narrow) No. of spp.	-	-	-	-	1	1
Lepto. (Succulent)<0,25m	-	-	-	-	-	1
Lepto. (Succulent) No. of spp.	-	-	-	-	-	1
Micro (Broad) 0,25 - 1m	-	5	-	1	-	-
Micro (Broad) No. of spp.	-	1	-	1	-	-
Restio 0,25 - 1m	5	3	8	7	4	4
Restio 1 - 2 m	6	-	-	-	-	-
Restio No. of spp.	3	1	4	4	3	3
Stem mono. (Narrow)<0,25m	3	-	-	-	-	-
Stem mono. (Narrow) 0,25 - 1 m	-	-	-	-	1	1
Stem mono. (Narrow) No. of spp.	1	-	-	-	1	1
Total cover<0,25m	3	2	-	-	1	3
Total cover 0,25 - 1m	5	7	8	8	7	7
Total cover 1 - 2 m	6	-	-	-	-	-
Total No. of spp.	5	7	7	8	7	10
Litter cover	4	3	3	2	4	1

possible to consider whether the sites with similar vegetation have similar radiation regimes. By comparing the radiation regimes of the different vegetation groups, as well as the sites that make up the groups, it will be possible to see what, if any, relationships exist between different vegetation types and the radiation regimes of the sites.

CHAPTER 4

THE VARIATION OF RADIATION COMPONENTS

Once the vegetation sites had been selected the radiation measurements were carried out. At each of the sites the various components of the radiation balance were measured at half hourly intervals. The radiation fluxes were measured for three days at each site (i.e. a total of 18 days of measurement) so that minor fluctuations could be averaged out, and to provide a body of data sufficient to eliminate anomalous and erroneous observations.

The days of radiation observation at each site were selected at random, with the intervals between days of observation determined by the need to leave the field for logistic purposes and to correct equipment failures. On the days of observation the equipment was set up for a first reading at 07h00, which was 30 minutes after sunrise at the start of the field-work, but approximately 5 minutes after sunrise by the end of the field-work period. The final observations were made at 19h00, which was between 30 minutes and 5 minutes before sunset. Days of observation were only abandoned when there was equipment failure, or if it started to rain.

The instruments were placed at the centre of the vegetation sites on tripods placed in an east-west line with the heads of the instruments on the northern side, so that they would not shade each other. All the instruments have spirit levels attached to enable accurate levelling. Levelling was re-checked before each set of readings. The instruments were 0,5m above the vegetation surface, at which height they sense 95% of the upward flux from an area of $16m^2$, and 99% of the upward flux from an area of $78m^2$ (Munn, 1966; Reifsnyder, 1967). Individual signal leads were drawn out behind the instruments so as not to interfere with the readings. These were taken to a junction-box; a multi-core cable connected all instruments to a selector switch some 50m from the instruments. The selector switch was in turn connected to a Leeds & Northrup Model 8686 High Precision Millivolt Potentiometer. The selector switch allowed for rapid reading of the output from each of the instruments in turn. The potentiometer was placed some distance from the instruments so that the person reading the instruments did not effect the radiation fluxes recorded.

As stated earlier (Section 2.1), the temperature in the unidirectional head is measured with a thermocouple. In order to obtain the temperature of an object a reference temperature is required for the cold junction of the thermocouple. This was supplied by a mixture of crushed ice and water, giving a temperature of $0^{\circ}C$. The ice and water was shaken before the readings to ensure a temperature of $0^{\circ}C$.

The domes over the instrument sensing surfaces required some maintenance during field-work. Any foreign material on the outside produces anomalous readings by absorbing or reflecting radiation. Dew on an instrument can cause errors varying in size and sign (Petterson _et al_, 1973). The outside of the domes are usually kept free of aerosols and condensation by a supply of compressed air blown over the domes or by a heating ring. Unfortunately a power supply needed to operate the usual means of keeping the domes clean was not available, therefore the domes were cleaned manually before each of the early morning readings until dew stopped forming. For the rest of the day they were cleared when dust could be seen on them. As the polythene domes deteriorate over time, these were changed after every six days of measurement.

The order in which the instruments were read was as follows: the thermocouple temperature, R_n, ΔR, S_t, ρS_t. The mV readings were written onto previously prepared data sheets for later analysis. Manufacturer's calibrations were used for all instruments.

Once the field-work had been completed, the instrument readings were converted from mV to Wm^{-2} and the values for ρ and $\underline{T}$ were calculated. The data were then stored on magnetic disk for analysis using a UNIVAC 1100/81 computer (See Appendix 1 for the data which is listed by site and day of observation). Solar noon may be taken as 13h00 for all the days of observation. Data on the altitude (β) and azimuth of the sun at the time of all measurements is given in Appendix 2. Appendix 2 also contains information on the amount of cloud cover, type of cloud, and whether the sun was obscured, for all observations.

In order to illustrate the trends within the data-sets, scatter-plots were drawn using the GENPLOT plotting package (U.C.T. Computing Service, 1979). Subsequently, statistical analyses of the various components of the radiation balance which make up the radiation regimes of the vegetation studied were carried out in order to verify the trends suggested by the scatter-plots. The statistical analyses were carried out using the STATJOB (MACC, 1976A) and BMDP (Brown, 1977) statistical packages.

4.1 The Radiation regime

The relationship between the various components of the radiation balance at a particular surface makes up the radiation regime of that surface, with the radiation regime determined partly by factors independent of the surface and partly by the surface itself. Hence factors such as the amount and type of cloud obscuring the sun, or the angle of elevation of the sun which changes the thickness of atmosphere through which direct solar radiation has to pass to reach a particular point on the earth's surface, have an effect on the incoming fluxes at the surface. The form of the surface, such as the size and orientation of leaves as well as the relative amounts of reflection or absorption of the plants will also determine the radiation regime of a plant surface. In order to fully understand the radiation regime of a surface it is necessary to obtain data for the whole day so that diurnal trends and any differences before morning and afternoon can be seen, as various vegetation types have different radiation regimes. The variables considered in the radiation regime are incoming short-wave radiation (S_t), the reflected short-wave radiation (ρS_t), the reflection coefficient (ρ), the incoming long-wave radiation (L_d), outgoing long-wave radiation (L_u) and the sum of the incoming and outgoing radiation, the net radiation (R_n).

4.1.1 The reflection coefficient

The reflection coefficient (ρ), being the ratio between incoming and outgoing short-wave radiation, is an important part the radiation regime of any surface as it indicates the relative amount of solar radiation that is retained by the surface. For a vegetated surface it is useful to know how much solar radiation is retained as it is an indication of the energy loading on the plants. In Figure 4.1 the changes in ρ for the various days of observation at each site can be seen. The general trends evident in data listings and scatter graphs for each site will be discussed separately.

Site 1: The trends for all three days are similar with the lowest value for ρ being recorded in all cases after the sun has reached its highest altitude. For all three days ρ changes more rapidly in the afternoons than in the mornings. The general trend for this site is for a similarity of ρ for all times of recording, except for the early morning and late afternoon readings, as can be seen from Figure 4.1a (the value of 0 for 07h00 on 12.2.80 was due to instrument failure).

Site 2: As with Site 1 the lowest value of ρ was recorded after the solar zenith on 4.3.80 and 9.3.80. On 5.3.80 the readings were affected by cloud so that a minimum value cannot be defined. A feature which is apparent at Site 2 is a levelling off of ρ before 10h00, with an indication of a slight increase of ρ at 10h00. This feature is not apparent in the afternoon readings (see Figure 4.1b). There is again a large variation in the values for ρ for the different days in the early morning and late evening.

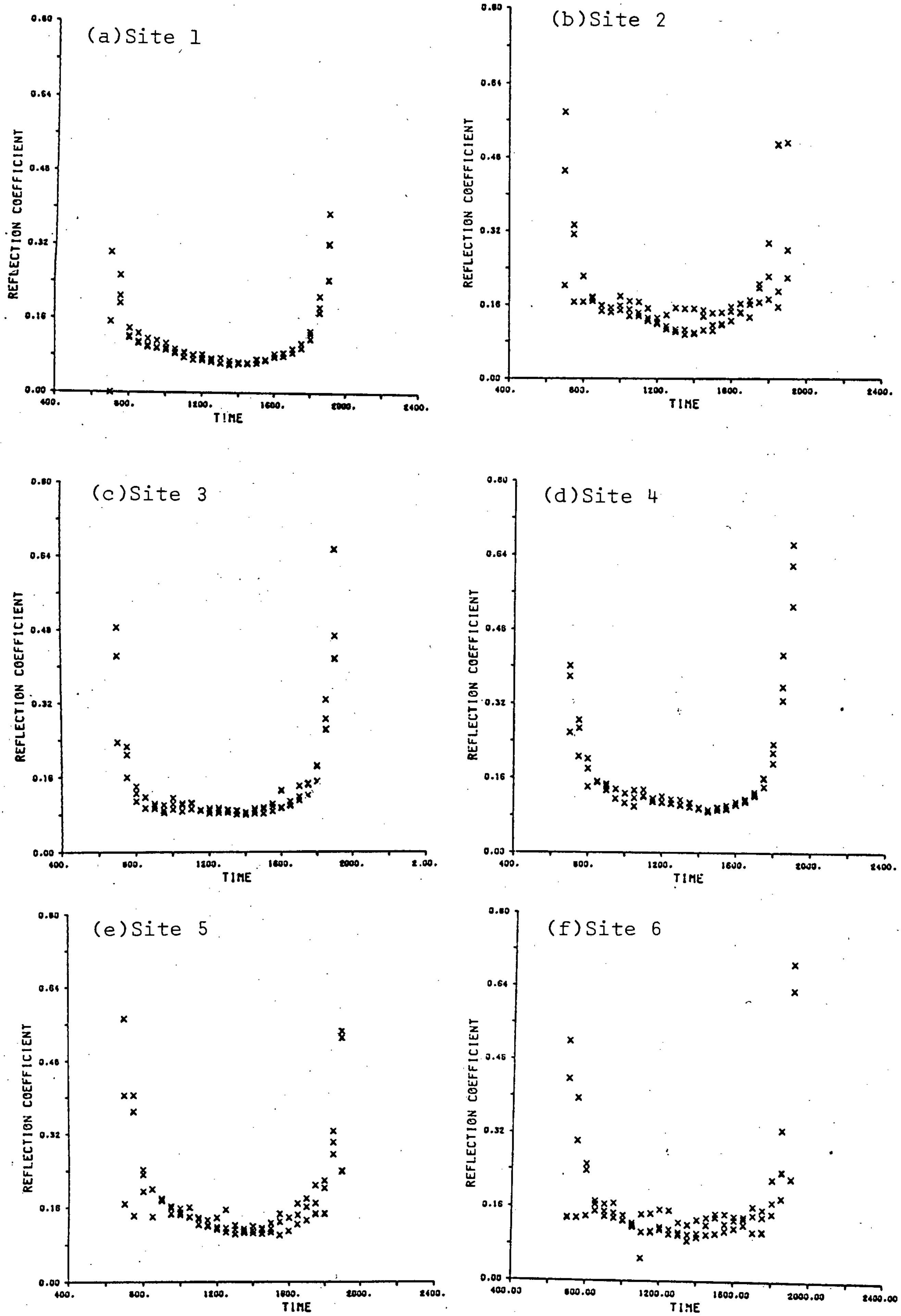


Figure 4.1 The daily trend of the reflection coefficient
(See Appendix 4 for detailed scatter-plots)

Site 3: The general trend of the value of ρ at this site is for a decrease in the morning, with an increase at 10h00 on all three days, ρ then decreases to a minimum half an hour after the solar zenith on 25.2.80 and 1 hour after the zenith on 27.2.80 and 3.3.80. As with the other sites, there is a much greater variation between the three days for the readings at the beginning and end of the days.

Site 4: The trend apparent at this site is again that of decreasing during the morning, increasing slightly after 10h00 then decreasing to a minimum after the solar zenith. There is also variation between the days in the early morning and late evening readings. On all three days the minimum value of ρ is reached $1\frac{1}{2}$ hours after the solar zenith.

Site 5: The trends of ρ at this site are fairly similar for the different days. On 17.2.80 and 19.2.80 ρ follows the same pattern until 15h30, but on 19.2.80 it drops to the minimum value recorded for the site before increasing again. On 20.2.80 ρ varies a great deal until 08h30 and increases at 12h00 and 12h30. Otherwise it is similar to the other two days. There is, again, great variation in the early morning and late evening values for the three days.

Site 6: The trends of ρ are not easily evaluated on 22.2.80 and 24.2.80 because of the fluctuations in the readings caused by changing cloud cover during the observations. As such 23.2.80 is described as being representative of this site. On 23.2.80 the minimum value of ρ was reached at the solar zenith. Apart from an anomalous reading at 11h00 caused by cloud, there does not appear to be the mid-morning increase in ρ found at the other sites. There is again a great difference between the days for the first and last readings.

There are two points which become clear from the daily trends of the reflection coefficient. First is that at every site there is a great deal of variation between the readings for the early morning and late afternoon over the days of observation. Secondly, at Sites 2, 3 and 4, there is a slight increase in the reflection coefficient in the middle of the morning that is not found for similar solar altitudes in the afternoon. From the scatter-plots of the daily trends of the reflection coefficient it can be seen that the reflection coefficient is generally low. The low reflection coefficients were confirmed by calculation of the mean value. The overall mean reflection coefficient (ρ) was calculated from the sums of all the outgoing short-wave radiation (ρS_t) and incoming short-wave radiation (S_t) measurements at each site (See Section 2.1). The mean values of ρ (Table 4.1) are generally low, particularly those of Sites 1 and 3 with values of 0,08 and 0,09 respectively. Even the highest values, of 0,13 for Sites 3 and 5, are not particularly high when compared with values obtained for other vegetation types (Section 5.1).

4.1.2 Radiation fluxes

The various radiation fluxes show some variation over time, as can be seen from the scatter-plots in Appendix 3. Similarities and differences in the radiation fluxes are clearly evident and occur over all the sites, particularly for the clear days.

The incoming fluxes (S_t and L_d) are not affected by the vegetation while the other (ρS_t, L_u and R_n) are. Both S_t and L_d show differences between the morning and afternoon values at the various sites. At Site 2, S_t is lower in the afternoon than the morning for the same β, while L_d is higher in the afternoon; at sites 4, 5 and 6, S_t is higher in the afternoon and L_d is lower. Both Site 1 and Site 3 have changes in the magnitude of S_t in the afternoon relative to the morning, with L_d smaller in the afternoon when S_t is larger, and vice versa. As both S_t and L_d are independent of the surface, their variations must be due to atmospheric conditions. It would seem, though, that there is some kind of relationship between the two fluxes as L_u tends to increase as S_t decreases.

The general trend of outgoing short-wave radiation (ρS_t) is for the afternoon values to be lower than the morning ones for the same solar altitude. At Site 3, however, ρS_t varies in relative intensity between morning and afternoon, suggesting that the vegetation should be subjected to a heat-loading unless some other mechanism for energy loss exists.

The relative intensity of outgoing long-wave radiation (L_u) in the morning and afternoon varies from site to site, with L_u being greater in the afternoon than the morning at Sites 1 and 2, but less at Sites 3, 4 and 5. At Site 6, L_u is generally greater in the afternoon for the same β, but not always. As L_u is not consistently higher in the afternoon than the morning for similar solar altitudes, long-wave radiative loss cannot necessarily be regarded as the mechanism for lowering the heat-loading on the vegetation caused by the low values for ρS_t in the afternoon.

The diurnal variation of net radiation (R_n) does not show any consistent trend over the different sites. At Sites 1, 3, 5 and 6 the afternoon values of R_n are lower than the morning for similar solar altitudes, while at Sites 2 and 4 the afternoon values are lower than the morning ones. In general, then, there is no pattern of similarities in the radiation fluxes at the different sites studied.

4.1.3 Radiative temperature of the vegetation

The radiative temperature of the vegetation gives an indication of the amount of energy that the vegetation is releasing radiatively. The radiative temperature of the vegetation can be used as an indicator of the amount of energy being radiated as there is a direct relationship between the outgoing long-wave radiation and the radiative temperature (see Section 2.2). As such, it is useful to consider the diurnal changes of the radiative temperature ($\underline{T}$) when discussing the radiation regime of fynbos vegetation.

At Site 1 there is a slight decrease in $\underline{T}$ during the morning, with a sharp increase around solar noon. On 4.2.80 $\underline{T}$ remains stable until the late afternoon, while on the other two days there is a decrease after 16h00. Site 2 shows a different pattern through the day. On 4.3.80 and 5.3.80 T shows some fluctuation, but does not vary greatly from the mean. On 9.3.80, however, T decreases until solar noon, after which it increases through the afternoon. The three days of measurement at Site 3 all show different trends. On 25.2.80 T remains stable through the morning apart from a decrease at 10h30. After solar noon T decreases, then remains stable for the rest of the day. During the morning of 27.2.80, T fluctuates somewhat, but shows a marked decrease at 10h30. It then remains stable (apart from an increase at 11h30) until 14h30, after which it increases for the remainder of the day. There is notable fluctuation in T on 3.3.80, but the general trend is a decrease in the morning, increasing at the middle of the day, and levelling off in the afternoon. There are two trends apparent in T at Site 4. On 26.2.80 and 28.2.80 T increases until 08h30, after which it decreases until 14h00. There is then an increase at 14h30 and T remains stable for the rest of the afternoon. On 2.3.80, T shows a general decrease until 12h00, after which it increases until 14h00 and is then the same as the other days, though with more fluctuation. At Site 5 T remains more or less stable until 15h30, after which it decreases slightly and then remains steady for the rest of the day. There is some fluctuation, most marked on 28.2.80 which was a cloudy day. Site 6 shows a great deal of fluctuation in T so that comparisons of the different days are difficult. On 23.2.80 (the relatively clear day), T is stable until 10h00, after which it increases, and then remains steady until 15h00. During the rest of the afternoon T gradually decreases. There is no clear pattern of similarities in the daily variation of T at the different sites, suggesting that the vegetation at the different sites does not react in the same way to the heat-loading produced by low reflection coefficients and the decrease in the amount of outgoing short-wave radiation in the afternoons.

From discussion based on a visual analysis of the components of the radiation balance which make up the radiation regimes of the sites studied a number of points are apparent. The main feature of the radiation regimes of the fynbos vegetation studied is the generally low reflection coefficient values and the decrease in the amount of outgoing short-wave radiation in the afternoons. Together these imply an increased heat loading on the vegetation. This is particularly interesting as it is unlikely that the heat-loading is being reduced radiatively as the outgoing long-wave radiation and the radiative temperature do not increase markedly. The question that next arises is whether these characteristics typify all the sites together and whether any relationship can be found between the components of the radiation balance when considered for all sites together.

4.2 Statistical relationships between components of the radiation balance

In addition to describing the variation in the individual values for the different components of the radiation balance at the various sites it is necessary to consider the relationships between the various components at each of the sites to fully understand the differences in the radiation regimesof the sites. In order not to be misled by spurious associations or to miss features that are not immediately obvious, it is essential to use statistical techniques which provide an objective measure of any relationships that may exist.

Given the relatively small number of recordings at each site it is necessary to have an accurate data input. Those variate values obviously reflecting the influence of extraneous factors on the recording instruments therefore had to be disregarded. From Section 4.1.1 for example it is clear that the first and last few values recorded for the reflection coefficient all fluctuate widely for each of the days of observation at each site. As has been suggested by a number of authors (Crabtree and Kjerve, 1978; Idso et al,1969b; Rouse and McCutcheon, 1972). The fluctuation of ρ is probably due to the low solar altitude (β) affecting the instruments by causing internal reflection in the instruments, and from the effect of the instruments' cosine response. In view of this, it was decided to use only data for solar altitudes greater than 30° and thus reduce the variance for each site. As the length of day changed during the field-work period, the number of observations for solar altitude greater than 30^o varied from 45 to 51 out of an original total of 75. Table 4.1 shows the number of observations used in the analysis of each site (i.e. the sum of all three days at each site).

The first task was to ascertain the form of the distribution of the data. Using the STATJOB UNISTAT 2 program (MACC, 1976b) the values obtained for skewness and kurtosis (Table 4.1) indicated that not all of the variables are normally distributed. (The non-normal distributions are: Reflection coefficient for Sites 1, 3, 5, 6; Incoming short-wave radiation for Sites 3, 5; Outgoing short-wave radiation for Sites 3, 4, 5; Incoming long-wave radiation for Sites 3, 4, 5; Outgoing long-wave radiation for Sites 4, 5, 6; Radiative temperature of the vegetation for

TABLE 4.1 Descriptive statistics for the sites.

SITE		1	2	3	4	5	6
Observations		51	45	48	47	51	51
Mean ρ		0,08	0,13	0,09	0,11	0,13	0,12
Skewness of	ρ	0,60	-0,19	1,29	0,52	0,56	-0,54
	S_t	0,50	-0,22	-1,16	-0,53	-0,81	-0,10
	S_t	0,50	-0,31	-1,32	-0,70	-1,47	-0,42
	L_d	-0,26	0,24	0,78	0,97	4,21	-0,06
	L_u	-0,30	0,08	0,31	-0,87	0,72	-0,95
	$\underline{T}$	-0,47	-0,09	0,24	-1,22	0,49	-1,13
	$\overline{R}_n$	-0,53	-0,05	-0,97	-0,18	-0,57	0,23
Kurtosis of	ρ	2,54	2,11	5,33	2,49	2,28	4,10
	S_t	1,92	1,48	3,86	2,31	2,80	1,86
	S_t	2,46	1,62	4,22	2,64	4,82	2,12
	L_d	4,08	1,40	3,54	5,18	24,05	5,39
	L_u	3,32	3,36	2,45	5,12	5,62	3,93
	$\underline{T}$	3,59	3,12	2,23	6,41	5,08	4,40
	$\overline{R}_n$	1,96	1,63	3,12	2,14	2,42	1,95

Sites 4, 6; Net radiation for Site 3). The BMDP program P5D (Brown, 1977) produced normal probability plots for each variable, further confirmed that the distributions were skewed (both positively and negatively) and therefore non-parametric statistical tests (Siegel, 1956) would be most appropriate if meaningful inferences were to be made from the data.

Calculation of correlation coefficients makes it possible to establish statistically which variables co-vary at all of the sites. The reflection coefficient and net radiation values were selected and their relationship with other variables was tested using Spearman's rank correlations (calculated using the BMDP program P3S for non-parametric statistics (Brown, 1977)).

4.2.1 Factors related to the reflection coefficient

The reflection coefficient (ρ) can be considered in relation to three factors. These are: the solar altitude (β), which can affect ρ (see Section 2.1), and the two fluxes which are used to calculate the reflection coefficient, which are the incoming short-wave radiation (S_t) and the reflected short-wave radiation (ρS_t). Table 4.2 shows the Spearman rank correlations of the reflection coefficient and the other factors, from which their co-variance may be ascertained.

TABLE 4.2 Factors related to the reflection coefficient

r_s values	Site 1	2	3	4	5	6
ρ vs. β	-0,78**	-0,47**	-0,62**	-0,42**	-0,75**	-0,53**
ρ vs. S_t	-0,74**	-0,77**	-0,61**	-0,48**	-0,80**	-0,79**
ρ vs. ρS_t	0,11	-0,43**	-0,09	0,02**	-0,26	-0,51**

** Significant at 99,5% level

The Spearman rank correlations of ρ and β (Table 4.2) show that there is a moderate negative correlation at all of the sites, indicating that as solar altitude increases, the reflection coefficient decreases. The scatter-plot of ρ and β (Fig. 4.2a) masks a definite trend in ρ for all of the days, viz. the afternoon values of ρ are all lower than the morning values for the same β, as illustrated in Figure 4.2b for 4.2.80. The correlation between ρ and β is low at Site 2, though two points are obvious

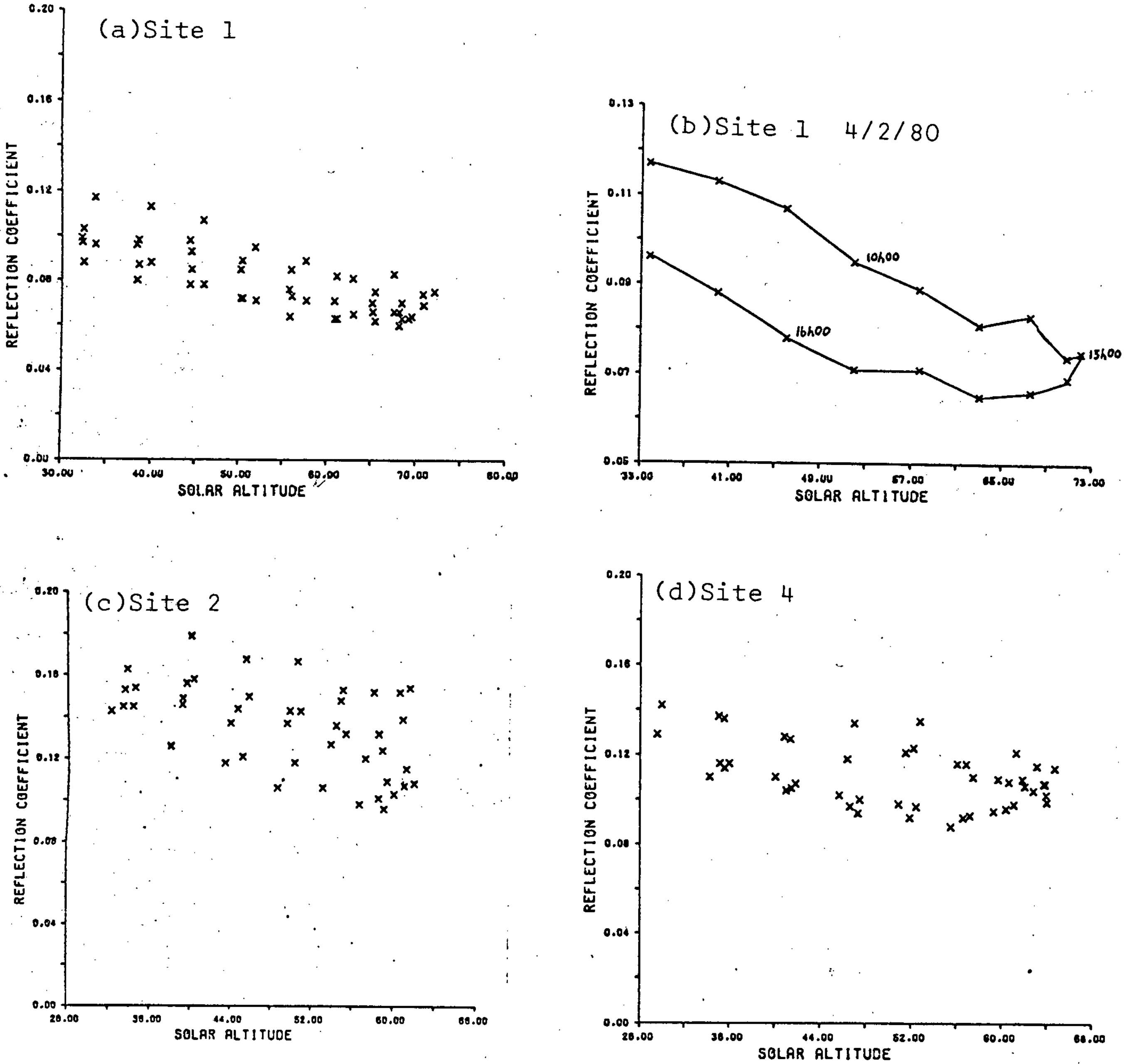


Figure 4.2 The relationship between the reflection coefficient and solar altitude (For detail see Appendix 4)

from Figure 4.2b. First, during 4.3.80 and 9.3.80 (clear days) ρ is lower in the afternoon, but is lowest on 9.3.80 for the same β. Second, the trend of ρ with changing β on 5.3.80 (a cloudy day) is the lack of appreciable changes of ρ relative to β. At Site 3 the correlation of ρ and β is strong. On all three days ρ is lower in the early afternoon than for the same β in the morning, but is greater in the late afternoon. Site 4 has the lowest correlation of ρ and β. This is largely due to the difference between the morning and afternoon values of ρ. On 26.2.80 there is very little difference between the reading from 09h00 to 10h30 and those from 15h30 to 17h00 (i.e. those with less than 47°). For the rest of the day, and on the other two days, the afternoon values of ρ are markedly lower than those for the morning (Figure 4.2.d). There is a strong correlation between ρ and β at Site 5. During 17.2.80 and 20.2.80 the morning and afternoon values of ρ are close, except for anomalously high values at 12h00 and 12h30 on 30.2.80 (see Appendix 1 for detail) which are due to instrument errors. On 19.2.80, however, the afternoon values of ρ are definitely lower than the morning ones for the same β. Finally at Site 6, as could be expected from the amount of cloud cover at this site, there is not a particularly strong correlation between ρ and β, and no clear diurnal trends. It would appear then that ρ is changing independently of β under cloudy conditions, but in clear conditions is lower in the afternoon.

It would appear from the correlations of the reflection coefficient (ρ) and solar altitude (β) that β does not in fact play a large part in determining ρ. Only at sites 1 and 5 is there any reasonably strong correlation. The weaker relationships between ρ and β could be due to the difference between the morning and afternoon values of ρ.

As the solar altitude does not play a part in determining ρ at the sites studied, the relationship between the two components of ρ, incoming short-wave radiation (S_t) and outgoing short-wave radiation (ρS_t) are considered to see whether these affect ρ. From Table 4.2 it can be seen that the correlations between S_t and ρ are generally higher than those between β and ρ. At Site 1 there is a fairly strong negative correlation between S_t and ρ, with ρ decreasing with the increase in S_t during the day, then increasing as S_t decreases. A pattern which is immediately apparent if the points for any day are connected is that ρ is always lower during the afternoon than the morning for a given value of S_t (see Figure 4.3a for 4.2.80). At Site 2 the less well defined pattern was found at those times when there was cloud cover. The diurnal pattern is distinct for 9.3.80, ρ is lower in the afternoon for any value of S_t. The correlation for S_t and ρ is lower at Site 3, which is representative of lack of pattern in the distribution (see Figure 4.3b). In spite of only one day on which the sun was obscured by cloud (27.2.80) the diurnal trend found at the previous sites is not apparent. Site 4 has the lowest correlation between S_t and ρ. This is largely due to 26.2.80 which was a cloudy day. On the other two days, however, the diurnal trend of ρ being lower in the afternoon for any value of S_t still holds.

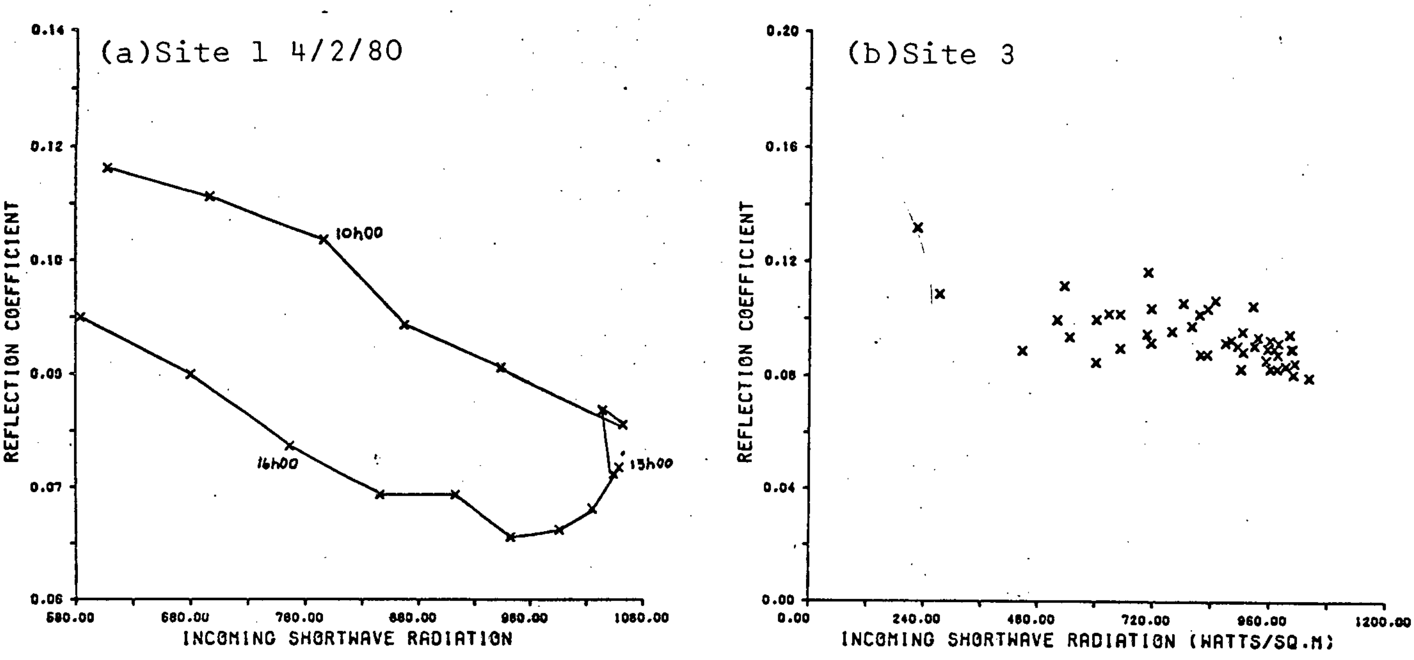


Figure 4.3 The relationship between incoming short-wave radiation and the reflection coefficient (For detail see Appendix 4)

There is the strongest correlation between S_t and ρ at Site 5 where the afternoon values of ρ are closer to those of the morning, though still being lower, for the two clear days (17.2.80 and 19.2.80). For the cloudy day, 20.2.80, the diurnal trend is not present, though the relationship between S_t and ρ can still be seen (see Appendix 1 for data). At Site 6 the correlation between S_t and ρ is also high, and is only marginally lower than for Site 5. For the one completely clear day (23.2.80) the diurnal trend found at the other sites is still present, though the afternoon values of ρ are just lower than the morning values. For the other days the diurnal trend is marked by fluctuations in S_t due to cloud cover, though the relationship between S_t and ρ is clear.

The incoming short-wave radiation (S_t) has a strong negative correlation with the reflection coefficient (ρ). The calculated values indicate that these two variables co-vary strongly, particularly at Sites 1, 2, 5 and 6. While the correlation coefficients of ρ and incoming short-wave radiation and solar altitude are generally the same, the co-variance of S_t and ρ is stronger than that of ρ and solar altitude at Sites 2 and 6.

From Table 4.2 it can be seen that the relationships between outgoing short-wave radiation (ρS_t) and ρ are particularly low. Even the strongest correlations (-0,43 at Site 2 and -0,51 at Site 6) are not particularly strong, so that there appears to be no co-variance between ρS_t and ρ.

In the summary, therefore, it can be said that the reflection coefficient co-varies moderately strongly with solar altitude and strongly with incoming short-wave radiation. There is, however, no relationship between the reflection coefficient and outgoing short-wave radiation.

4.2.2 Factors related to net radiation

Net radiation (R_n) is the sum of the incoming and outgoing radiation fluxes, and is the amount of radiation that is gained or lost by a vegetation surface. As the net radiation is the total amount of radiation that is gained or lost by a surface it is important to establish the extent of the association between the different radiation fluxes and R_n, as well as the relationship between the reflection coefficient (ρ) and R_n. Table 4.3 lists the correlation coefficients of the factors related to R_n.

TABLE 4.3 Factors related to net radiation

	Site					
r_s values	1	2	3	4	5	6
R_n vs. ρ	-0,74**	-0,78**	-0,57**	-0,51**	-0,68**	-0,66**
R_n vs. S_t	0,98**	0,98**	0,99**	0,99**	0,89**	0,86**
R_n vs. ρS_t	0,51**	0,83**	0,81**	0,81**	0,67**	0,84**
R_n vs. L_d	-0,27*	-0,70**	-0,56**	-0,63**	-0,44*	-0,35*
R_n vs. L_u	0,42**	-0,38*	-0,25*	-0,55**	0,19*	0,30*

** Significant at 99,5% level
* Significant at 90% level

The relationships between ρ and R_n are not particularly strong. There is a fairly high correlation between ρ and R_n of Site 1, with the noticeable presence of a diurnal pattern. The values of ρ are lower in the afternoon than in the morning. There is however, a marked decrease of R_n for similar values of ρ. Thus, although for all the data R_n decreases as ρ increases, for a given value of ρ the afternoon value of R_n will be substantially lower than in the morning value. Also for a given value of R_n, ρ will be lower in the afternoon than in the morning. There is a strong correlation between ρ and R_n at Site 2. On the clear days the diurnal change of a lower R_n for a given ρ in the afternoon, can be seen. On the cloudy day (5.3.80) the diurnal trend disappears, though the relationship between low ρ and high R_n still holds. At Site 3 the correlation between ρ and R_n is somewhat weaker than at the previous sites, though the relationship of R_n increasing for decreasing ρ still holds. For 25.2.80 the diurnal pattern of a lower R_n in the afternoon is not as clear as at previous sites, with the afternoon values of R_n remaining the same as those for the morning despite an increase in ρ when cloud started forming (even though the cloud cover was 1/8 cumulus which did not obscure the sun). A similar situation can be seen on 3.3.80. R_n stays the same at equidistant times from solar noon, in spite of ρ being generally lower in the afternoon, even when ρ increases and is higher than the morning value when 1/8 cirrus appeared. The lowest correlation is found between R_n and ρ at Site 4, indicating a moderate co-variance between ρ and R_n. On the two clear days (28.2.80 and 2.3.80) the decrease of ρ in the afternoon clearly does not lead to a decrease in R_n. At Site 5 the correlation of ρ and R_n is slightly higher than at Site 4, though it is still not particularly strong. On 17.2.80 and 19.2.80 (the days when there was no cloud) the diurnal change is clear. The substantially lower values of ρ in the afternoon are not related to a lower R_n. When there was cloud present, on 20.2.80, ρ tends to be higher than on the other days, though R_n drops when the sun is obscured.

The correlation between ρ and R_n for Site 6 is slightly lower than for Site 5, although there would appear to be some form of relationship between the two with R_n increasing with a decrease in ρ. For the clear day, 23.2.80, a difference between the morning and afternoon values of does not produce a marked decrease in the value of R_n. For the days when cloud was present, 22.2.80 and 24.2.80, the general trend of an increase in R_n for a decrease in ρ is apparent, though the differences between morning and afternoon values are not clear.

The strongest correlations are found between incoming short-wave radiation (S_t) and R_n. There is a very strong correlation between S_t and R_n at Site 1. Examination of the data (Appendix 1) shows that there are lower values in the afternoon than the morning. The relationship between S_t and R_n also holds at Site 2, even though there was cloud for all of 5.3.80 and part of 4.3.80. During 9.3.80 the values for the afternoon are slightly lower than for the morning except at 12h30.

The correlation at Site 3 is also very high. On the clear days the morning values are slightly higher than the afternoon ones. On 27.2.80, when there was cloud all day, a diurnal relationship cannot be seen. The highest correlation of S_t and R_n is found at Site 4. The afternoon values are higher than the morning ones on the two clear days (28.2.80 and 2.3.80) except for 16h00 and 16h30 on 28.2.80 and at 13h30 on 2.3.80. On 28.2.80 this relationship still holds in spite of the cloudy weather conditions (and hence varying S_t).

At Site 5 the correlation of S_t and R_n is lower, largely due to varying values on the cloudy day, 20.2.80. On the other two days the morning readings are higher than the afternoon ones.

Site 6 has the lowest correlation of S_t and R_n, which is not surprising considering the cloudy conditions encountered at the site. The correlation, however, is still high and indicates a strong relationship between S_t and R_n. Diurnal trends at this site are distorted by the variability of the fluxes.

In all cases, the correlations between ρS_t and R_n are lower than those of S_t and R_n. This is particularly marked at Site 1, where the points indicate a vertical distribution of R_n relative to ρS_t (see Figure 4.4). At Site 2 there is a strong correlation between ρS_t and R_n, though there is some dispersion of the points for the higher values of ρS_t and R_n. The reason for this can be seen in the diurnal trend apparent on 4.3.80 and 9.3.80 (clear days) when there is a slight change between the morning and afternoon relationships of ρS_t and R_n. At Site 3 there is still a strong correlation between S_t and R_n, though it is slightly lower than for Site 2. On the clear days (26.2.80 and 3.3.80) there is virtually no diurnal change between the morning and afternoon values of both ρS_t and R_n. The correlation between ρS_t and R_n at Site 4 is also strong. The diurnal variation of ρS_t can be clearly seen on 28.2.80 and less clearly on 2.3.80. On 26.2.80, a day of overcast, this trend is not apparent. For Site 5, the correlation of ρS_t and R_n is not particularly strong. This is due in part to some scattering of the points, and also, it would appear that the relationship is slightly non-linear. The strongest correlation is found at Site 6, in spite of some scattering of the points. Diurnal trends are not apparent at this site.

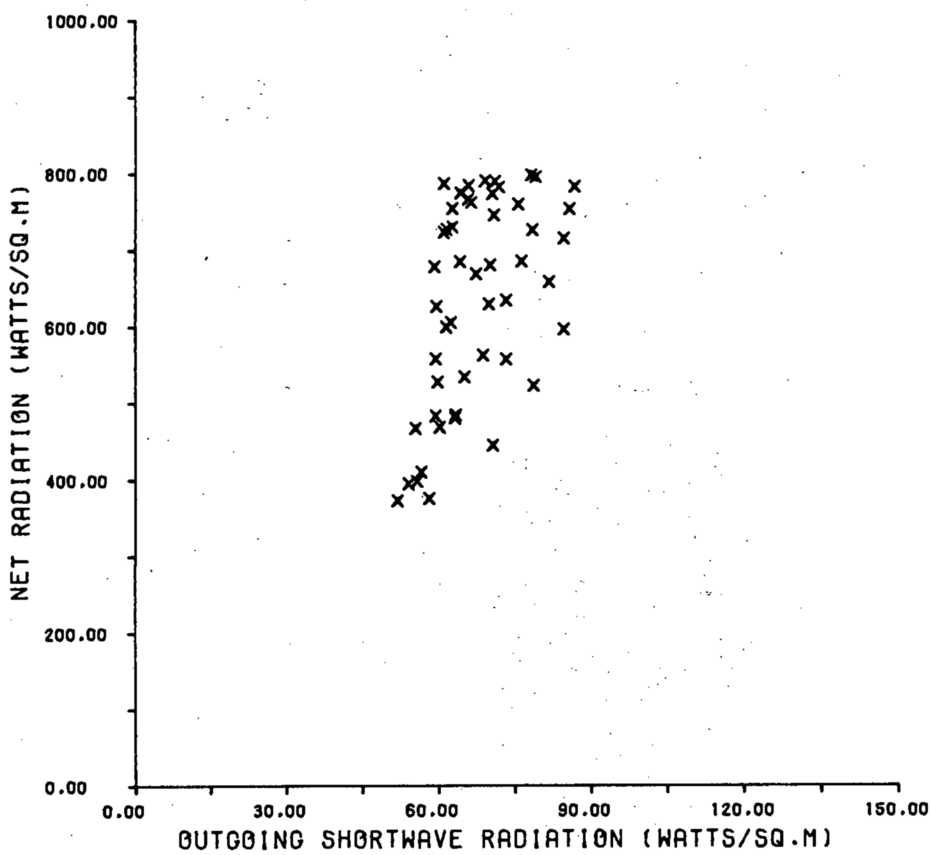


Figure 4.4 The relationship between net radiation and outgoing short-wave radiation at Site 1

It can be seen from Table 4.2 that the correlations between the long-wave fluxes and R_n are generally low. The low correlations are due to the small range of long-wave fluxes as compared with the range of R_n. The negative correlations indicate that the long-wave fluxes do not conform to the same trends as R_n (and also to the short-wave fluxes). This would be accounted for by fluctuation in L_d and L_u, as well as their general decrease until the early afternoon.

The net radiation of the sites studied has different associations with the various radiation fluxes which contribute to it. There is a strong positive relationship between net radiation and incoming short-wave radiation at all of the sites, and a generally strong positive relationship between net radiation and outgoing short-wave radiation. The relationship between net radiation and the reflection coefficient is fairly strong, and is negative as would be expected. There is also a slight negative relationship between incoming long-wave radiation and net radiation, and no co-variance between net radiation and the outgoing long-wave radiation.

From the foregoing two sections it has become apparent that there is a great deal of variability in the individual values of the radiation fluxes at the different sites studied. From the correlations between the various radiation fluxes the most obvious overall relationships have been highlighted but the variation between the sites is such that no clear trends emerge. It remains, then, to consider to what extent this variation is due to differences in the vegetation at the various sites.

CHAPTER 5

THE RELATIONSHIP BETWEEN THE DIFFERENT VEGETATION TYPES AND RADIATION REGIMES

Having found that the vegetation at the sites studied can be grouped on the basis of similarities in the vegetation structure (Section 3.2.2), and having considered the ways in which the radiation regimes of the sites differ, it is necessary to relate these two areas of study. It is possible to consider the ways in which the radiation balance over fynbos vegetation varies from that over other vegetation types. It is also possible, by considering the relationships between the vegetation and radiation to see the way in which the radiation balance varies with different fynbos vegetation types.

5.1 The Reflection Coefficient and Fynbos vegetation

The reflection coefficient (ρ) of a vegetation surface is an important indicator of the radiation regimes of the surface. This is because it indicates the relative amount of incoming short-wave radiation that is retained by the vegetation. It is therefore possible to consider, from ρ, whether the vegetation is likely to acquire a higher energy loading.

5.1.1 Anomalous low values

This study shows markedly low values of ρ (Table 5.1.b) for all the sites studied. As the sites were chosen to be representative of fynbos vegetation, it is suggested that the results are indicative of the radiation response of fynbos generally. The mean values for ρ that were found are lower than those for other mediterranean and heathland vegetation types (Table 5.1.a) and a variety of crops. In fact Table 5.1 suggests that the values for fynbos are comparable to forest vegetation rather than shrubland. Forest canopies tend to have low reflection coefficients

TABLE 5.1 Reflection coefficients of different vegetation types
(a) World Studies

	Reflection Coefficient	Type of Vegetation	Location	Author
Forest	0,16-0,18	Oak	Pennsylvania	De Walle & McGuire (1973
	0,12	Oak - Hickory	Tennessee	Stanhill (1970)
	0,09	Pine	U.K.	Stewart (1971)
Crops	0,25-0,27	Short Grass	U.K.	Monteith & Szeicz (1961)
	0,17-0,21	Maize	Canada	Graham & King (1961)
	0,19-0,20	Kale	U.K.	Monteith & Szeicz (1961)
	0,17	Sugar Cane	Barbados	Chia (1967)
Heath	0,23	Bracken	U.K.	Barry & Chambers (1966a)
	0,21	Tristiana Conferta	Queensland	Yates (in press)
	0,20	Semi-Steppe Bathà	Israel	Stanhill et al (1966)
	0,19	Bansia aemula	Queensland	Yates (in press)
	0,18	Gorse	U.K.	Barry & Chambers (1966b)
	0,17	Upland Heathland	Queensland	Yates (in press)
	0,16	Dune Heathland	Queensland	Yates (in press)
	0,16	Heeth	U.K.	Barry & Chambers (1966a)
	0,16	Flowering Heather	U.K.	Barry & Chambers (1966a)
	0,16	Evergreen Maquis Scrub	Israel	Stanhill et al (1966)
	0,16	Mediterranean Batha	Israel	Stanhill et al (1966)
	0,15	Wet Heathland	Queensland	Yates (in press)
	0,14	Sheltered Heathland	Queensland	Yates (in press)
	0,14	Heather	U.K.	Barry & Chambers (1966a)

TABLE 5.1 (continued)
(b) Fynbos Study area

	Reflection Coefficient	Type of Vegetation	Location
Fynbos	0,13	Elegia parviflora	Site 2
	0,13	Leucadendron laureolum, Erica sp.	Site 5
	0,12	Erica capensis, Elegia parviflora, Chondropetalum hookerianum	Site 6
	0,11	Restio sp. Erica laeta.	Site 4
	0,09	Berzelia abrotanoides. Restio ambiguus	Site 3
	0,08	Elegia cuspidata, Elegia parviflora	Site 1

because the depth of vegetation allows for the dissipation of radiation. The low values of ρ in the vegetation studied are, however, related to low canopies so there must be alternative strategies for dissipating the energy. The low value for ρ in fynbos would suggest that, unless there is a strategy for dissipating energy, the vegetation will have a high energy loading.

5.1.2 Vegetation height

It has been shown by Ogintoyinbo (1970) and Stanhill (1970) for a variety of vegetation types that a relationship exists between ρ and the height of vegetation. These relationships may be implied from the information in Figure 5.1, which also shows the change of ρ with vegetation height in fynbos. In addition, the relationship between ρ and vegetation height for some Australian heathlands is also shown (Yates, in press). It is clear that for fynbos ρ has the same trend of decreasing with increasing vegetation height, but the coefficients themselves are lower than for

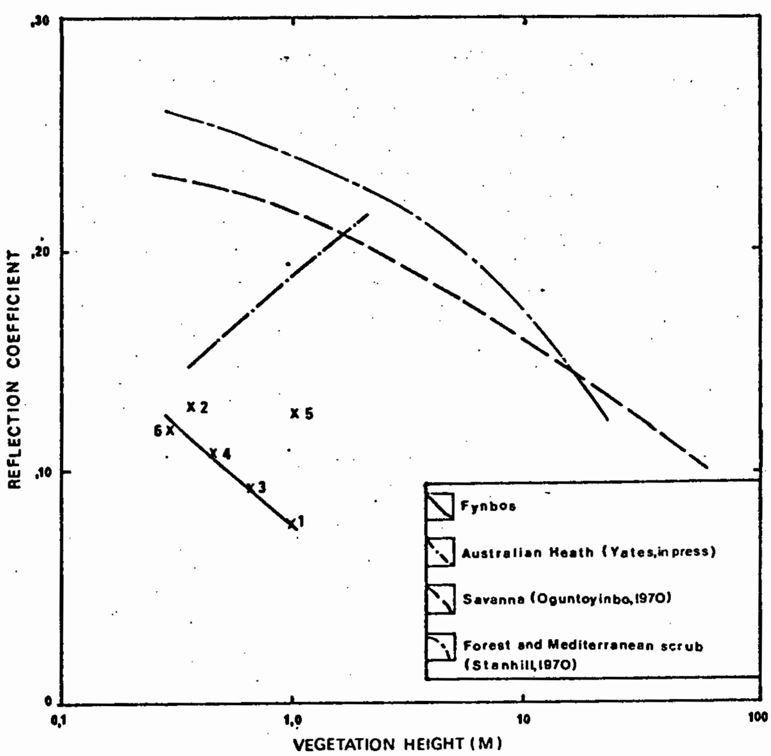


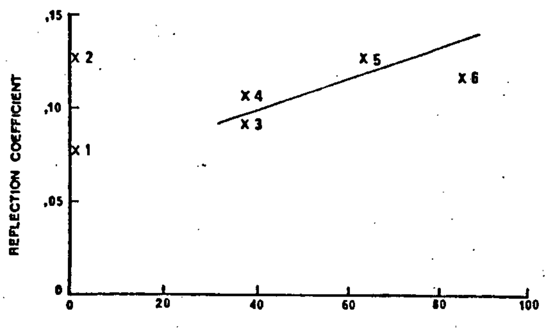
Figure 5.1 The change of the reflection coefficient with vegetation height (Figures refer to the sites studied)

other vegetation except some of the Australian heaths. The Australian data, however, indicates an anomalous relationship between ρ and vegetation height. Yates (in press) explains this as being a function of vegetation structure, suggesting that the presence of small-leaved plants produces a different reflectance in heathlands. From the fynbos data it would appear that plant structure may play a part in the canopy reflectance, in that Site 5 (which contains large-leaved <u>Leucadendron laureolum</u>) does not fit into the general trend of ρ decreasing with increasing vegetation height.

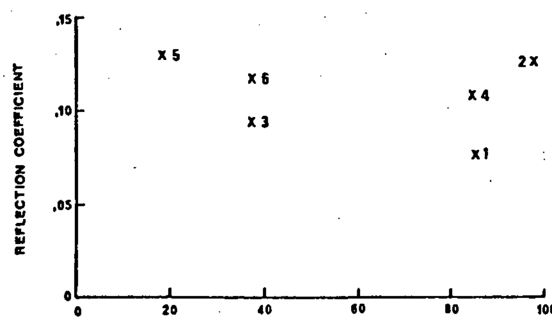
5.1.3 Vegetation structure

In order to establish which structural features are influencing ρ, the relationship between two structural features and ρ were plotted. These are the cover of picophylous leaves (that is, leaves with an area of less than 10mm^2) in the sites, and the cover of restioid plants. The results of each of these are shown in Figure 5.2a and 5.2b (in each of these the percentage of vegetation is taken from the mid-point of the cover classes for each type; see Section 3.2.1 for the cover classes). Interpolating a regression line (Figure 5.2a) illustrates that there is a positive relationship between ρ and the amount of picophyllous vegetation if Sites 1 and 2, where there is only a 1% cover of the vegetation type, are excluded.

Figure 5.2 The relationship between the reflection coefficient and the percentage canopy cover



(a) Picophyllous vegetation
r_s of sites 3 to 6 is 0,74



(b) Restioid vegetation

However, in the case illustrated by Figure 5.2b no best fit line can reasonably be interpolated. From this fact it may be deduced that there is no relationship between the amount of restioid vegetation and the reflection coefficient.

With regard to vegetation structure three generalisations may then be made: 1. There is a negative relationship between the reflection coefficient and vegetation height in the fynbos vegetation studied, with the reflection coefficient decreasing with increases in the vegetation height. 2. There is a positive relationship between the reflection coefficient and the amount of small-leaved vegetation present, i.e. the greater the percentage cover of small-leaved vegetation the higher the reflection coefficient. 3. There is no relationship between the reflection coefficient and the percentage cover of restioid vegetation.

5.2 Diurnal radiation variations and vegetation

While it has been shown that the mean value for the reflection coefficient (ρ) of fynbos vegetation shows unusual trends, it is also necessary to consider the diurnal variations of ρ and the other radiation fluxes. By doing this it should be possible to see which are the more important factors in the radiation balance. It will also enable relationships between the various components of the radiation balance and the different vegetation types to be found.

5.2.1 The diurnal variation of the reflection coefficient

In addition to ρ being particularly low for fynbos, the diurnal trend differs from that recorded for other vegetation types. It is notable that from the observations at all the sites, the afternoon values of ρ on clear days are lower than the morning values for the same solar altitude (β). Minor fluctuations from the general trend of a lower ρ in the afternoon occur at Sites 4 and 5, where the difference between the morning and afternoon values is small. Also Site 3 (see Tables 3.3 and 3.7 for vegetation data) differs from the other sites in that, although ρ is lower in the early afternoon, the late afternoon values are higher than the morning values of ρ at the same β. Despite this the general trend is clear, viz. the afternoon values for ρ are lower then the morning ones.

A diurnal variation of ρ in which there are lower values in the afternoon than in the morning is contrary to the findings of other workers who have reported afternoon reflection coefficients, over a number of surfaces, to be higher than those observed at similar solar elevations during the morning (Ahmad and Lockwood, 1979; Arnfield, 1975; Moore, 1976; Nkemdirim, 1972). A higher ρ in the afternoon has been explained by Ahmad and Lockwood (1979) and Moore (1976) in terms of water stress leading to wilting, and hence a higher ρ. Another argument which Ahmad and Lockwood (1979) put forward, is based on the work of Robinson (1966) and Nkemdirim (1972), holds that ρ should be higher in the afternoon because of changes in the spectral qualities of the short-wave fluxes. Conversely, two reasons which have been advanced for ρ being lower in the afternoon as is the case in this study. They are that wind changes the orientation of the vegetation so that a more reflective surface is presented in the morning, and secondly that the occurrence of dew produces greater reflectance (Ahmad and Lockwood, 1979; Colwell, 1974). The above reasons for diurnal variation in ρ do not explain the patterns observed in this study. The occurrence of dew cannot be considered, as during the course of the observations the unusual trends continued when all dew had evaporated. Deflection of the vegetation by the wind is unlikely as the trends are apparent regardless of wind direction and speed.

5.2.2 The Relationship between the reflection coefficient, other radiation fluxes and vegetation

The suggestion by Ahmad and Lockwood (1979) and Moore (1976) that changes in the reflection coefficient (ρ) may be due to changes in water stress is interesting when considering schlerophólous vegetation such as fynbos, which is usually characterised by adaptations to prevent water loss. A lower ρ would not appear to conform to this strategy as it leads to a higher radiation and heat load, and would therefore encourage water loss to offset this effect. An increase in the radiation loading is implied by the fact that the outgoing short-wave radiation (ρS_t) is usually lower in the afternoon than the morning for the same β, as discussed in Section 4.1. An increase in the radiation loading resulting from the lower afternoon values of ρ should, unless there is some strategy for reducing the heat loading, lead to an increase in the temperature of the vegetation. Ahmad and Lockwood (1979) quote Ahmad (1978) as finding a slight correlation between increasing leaf temperatures and decreasing ρ. In order to test whether this is the case in the study area the correlation between ρ and radiative temperature ($\underline{T}$) was calculated. All the correlation values are negative and low ($r_s < -0,05$) except for Site 1 at which r_s rises slightly to -0,66. The observations at Site 1 were, however, taken under completely cloud-free conditions, and as Ahmad and Lockwood (1979), Nkemdirim (1972, 1973) and Stanhill et al (1966) have found diurnal variation of ρ to be less marked under cloudy conditions, it is possible that varying cloudiness may be complicating an already weak relationship between ρ and $\underline{T}$. Examination of the data (Appendix 1) reveals that while there is a slight increase in $\underline{T}$ at most sites, this pattern is not clear in spite of ρ being consistently lower in the afternoon for the same β. There is, then, no evidence to suggest a close direct relationship between ρ and $\underline{T}$.

Higher vegetation temperatures imply an increase in the outgoing long-wave radiation (L_u), but it was found that there is no clear pattern of an increase in L_u in the afternoon (see Section 4.1). At Site 3 for example, which consists largely of Berzelia abrotanoides (Tables 3.3, 3.7), L_u is in fact lower in the afternoon than the morning, which would suggest that the vegetation at this site is not subject to a heat loading, a fact which is reinforced by consideration of ρS_t which is slightly higher in the afternoon than the morning. When L_u is higher in the afternoon it is only marginally so as the difference between morning and afternoon values of L_u is generally less than 50 Wm^{-2}. Though it can on occasion rise to 100 Wm^{-2} (Appendix 1) the slight increase L_u is not regarded as likely to be an effective means of reducing the heat loading on the vegetation.

A number of authors, for example Chang (1968), Monteith and Szeicz (1961), Oke (1978) and Robinson (1966), have further suggested that an increase in L_u should be reflected in a decrease in the net radiation (R_n) in the afternoon. At four of the sites studied R_n is, as expected, lower in the afternoon, though not markedly so (see Section 4.1). Yet at Sites 2 and 4, R_n is higher in the afternoon than in the morning for the same β, which means that at these sites the heat load is not offset by the lower ρ. Interestingly, from the vegetation analysis (Figure 3.1) Sites 2 and 4 are found to be similar. This suggests that similar vegetation has a similar radiation response.

From discussion of the reflection coefficient and the various radiation fluxes measured at the sample sites it has become apparent that the vegetation studied, and therefore fynbos in general, is subject to a heat loading. This may be the result of the low values for ρ, and may also be related to the difference from expected pattern in diurnal changes in all of the fluxes. As a result of the heat loading due to the low ρ it could be expected that there should be a vegetation response. There is no apparent wilting of the vegetation, which would, in any event, lead to an increase in ρ (see Section 5.2.1). The response to the increased heat load is not manifested in the radiation fluxes, so another mechanism must be found as the vegetation is not heating up. It is likely that the vegetation maintains thermal equilibrium by sensible heat loss to the atmosphere. The mechanisms involved are not, however, clear. It is possible that variations in the spectral characteristics of S_t cause changes in the diurnal trend of ρ. Study of these factors is not, however, within the scope of this work. It is, perhaps, a field in which there is a need for further research.

5.3 The contribution of the different fluxes to net radiation

Net radiation (R_n) is an important summary value reflecting the radiation regime of any surface. The calculated correlation coefficients for R_n and the four incoming and outgoing fluxes (Table 4.3) are discussed in Section 4.2.2. Section 2.1 discusses the relationships of the fluxes which contribute to R_n while Tables 3.1 and 3.2 summarise the vegetation of the different sites.

It is clear from the high correlation coefficients that R_n and the incoming short-wave radiation are closely related (r_s varies from 0,86 to 0,99, Table 4.3). Slightly lower correlations are found, however, for Sites 5 and 6. There was cloud present during the observations at Site 6, so this could be the reason for the lower correlation. At Site 5, however, cloud cover is not significant and, as the other parameters remain constant it is possible that vegetation factors may be responsible for the lower correlation especially when it is remembered that according to the vegetation classification (Figure 3.1), Site 5 was classified as an outlier. Reference to Table 3.1 reveals that Site 5 contains large-leafed Leucodendron laureodum and is therefore vegetatively dissimilar from the other sites.

When the relationship between R_n and outgoing short-wave radiation (ρS_t) is considered, Site 5 again stands out from the others by having a lower calculated correlation coefficient. In the vegetation classification Site 1 was also found to be an outlier in terms of its structure, consisting largely of tall Restionaceae. Furthermore the correlation between ρS_t and R_n is lower for Site 1 than that calculated for the other sites. As the only common factor in the sites having slightly lower correlations of ρS_t and R_n (Sites 1 and 5) is the fact that they were classified as different to the other sites and each other, it can be postulated that there is no direct link between vegetation structure and net radiation. In order to verify this, further study is required with a number of different vegetation types.

The long-wave fluxes, L_d and L_u are less directly associated with R_n, as can be seen from Table 4.3. At all the Sites there is a negative relationship between L_d and R_n. There is, however, a great deal of variation in the magnitude of the correlation coefficients. The outgoing long-wave radiation and net radiation are in no way related to each other as indicated by the variation in both magnitude and sign of the correlation coefficients.

5.4 Vegetation Type and Radiation Fluxes

Finally, having considered the variation of the components of the radiation balance at the different sites and found some slight evidence to suggest that vegetation plays a part, the general relationship between vegetation type and its radiation regime can be considered. By regarding each of the calculated values in the light of the vegetation classification (Section 3.2.2) it should be possible to establish whether similar fynbos vegetation types have similar radiation regimes.

Once the mean value for ρ has been found (Section 4.1.1) it is possible to ask the question of whether the vegetation sites, as samples of fynbos vegetation, are drawn from the same population in terms of their reflection coefficients. In other words, to consider whether fynbos vegetation as a whole has a distinctive reflection coefficient, or whether the various vegetation types have different reflection coefficients. In order to test whether the data for ρ for the different sites are part of the same population an analysis of variance test is required. The Kruskal-Wallis one-way analysis of variance (BMDP program P35 (Brown, 1977)), which is the most powerful non-parametric test (Siegel, 1956) because it preserves the magnitude of the scores by converting the ρ values to ranks, was used to test whether the null hypothesis of no difference among the average ρ values of the six sites held. The test statistic of 181,75, valid at the 99,9% level allows for rejection of the null hypothesis, and acceptance of the alternative hypothesis that at least one site is distinctly different from the others. From the vegetation analysis the expectation is that similar values of ρ would occur at Sites 2 and 4, and also that Sites 3 and 6 would be similar to each other with Sites 1 and 5 being different from each other and from the other two groups. In order to test whether the data for ρ for the two groups of sites with similar vegetation are drawn from the same population, the Mann-Whitney U Test was performed on the data for Sites 2 and 4 and Sites 3 and 6. In both cases the null hypothesis of the values being drawn from the same population was rejected, indicating that the values for ρ at Sites 2 and 4, and at Sites 3 and 6, are different. With regard to the other components of the radiation balance there is no real evidence to suggest that the vegetation grouping is directly related to the radiation balance.

It can be seen from the sites studied that there is no overall relationship between the classification based on type of vegetation and radiatiative response. As the sites were chosen to be characteristic of the dominant fynbos vegetation types, it may therefore be concluded that for fynbos as a whole no predictable relationships between radiation fluxes and vegetation type occurs, except for the anomalously low values of the reflectance coefficient which have been found to occur over this type of vegetation.

CHAPTER 6

CONCLUSION

The primary objective of this research was to determine whether fynbos vegetation has a high reflection coefficient as would be expected from sclerophyllous vegetation, and to consider the differences in the reflection coefficient of different fynbos vegetation types. In order to do this six sites were selected for study. These sites were classified on the basis of their vegetation structure as well as being characterised by their dominant species. At each site the radiation fluxes were then measured for three days, giving a total of 18 days of measurement. An unexpected but significant finding of this research is the low value for the reflection coefficient of fynbos vegetation. The mean reflection coefficients are 0,13 for a site dominated by Leucadendron laureolum and also for a site dominated by Elegia parviflora (a short Restionaceae), 0,12 for a site consisting mainly of Erica capensis, 0,11 for a mixture of Erica laeta and Restio sp., 0,09 for a site dominated by Berzelia abrotanoides and 0,08 for a site consisting largely of Elegia cuspidata (a tall Restionaceae). These values are surprisingly low, as they lie below those reported for other vegetation types including heathlands in other parts of the world. The low reflection coefficients suggest that the vegetation must be subjected to a higher than usual heat loading as it has been shown that the vegetation is not lowering the heat loading radiatively as the vegetation temperature does not increase markedly and the outgoing long-wave component is not large. If the vegetation were transpiring freely this heat load would be dissipated through latent energy fluxes associated with water loss, but sclerophyllous vegetation is characterised by adaptations to prevent water loss. The implication is that an alternative mechanism of heat loss must operate. A complete energy balance experiment will be needed to determine how this is achieved, but it appears reasonable to postulate that sensible heat loss is important in the energy balance of fynbos. This postulation is supported by circumstantial evidence of high surface area to volume of the long thin cylindrical structure of the Restionaceae, and of the small leaf size of Ericoid leaves. This topic is suggested for further investigation.

Another finding of this study is that there is a negative relationship between the height of the vegetation and its reflection coefficient. This trend is clear for the sites containing Restionaceae and Ericaceae. The site containing Proteaceae does not fit into the trend of the other sites, and it would require further study to ascertain whether this particular site shows an anomalous reflection coefficient, or whether the Proteaceae react differently to the other fynbos elements.

In considering the effect of vegetation structure on the reflection coefficient it has been found that there is a positive relationship between the percentage cover of small-leaved vegetation and the reflection coefficient (disregarding sites in which there is only a 1% cover of this type of vegetation). It has also been found that there is no relationship between percentage cover of Restionaceous plants and the reflection coefficient.

The diurnal trend of the reflection coefficient is ususual in that the afternoon values are lower than the morning values for equivalent solar altitudes. This trend is opposite to that for most vegetation types. Further investigation into the topic is suggested in order to aid understanding of the adaptation to a harsh environment by fynbos plants.

A secondary aim of the study was to determine whether similar vegetation structural types in the fynbos have similar radiation regimes. On the basis of the vegetation classification there is no consistent variation of the components of the radiation balance. It would seem then, that the general vegetation structure is not a determinant of the radiation regime of fynbos vegetation.

From this study of the variation in the components of the radiation balance over different fynbos vegetation types, it has been shown that there is no obvious relationship between vegetation grouped on the basis of its structure and components of the radiation regime occurring above that vegetation. The unusual responses of the vegetation to radiation may thus be considered as being related to the fynbos vegetation type as a whole rather than to any individual species occurring within this plant kingdom.

REFERENCES

ACOCKS, J.P., 1953: Veld Types of South Africa. Botanical Survey Memoir, 28, 192p.

AHMAD, S.B., 1978: Albedo studies of urban and agricultural surfaces near Leeds. Unpubl. M.Phil. thesis, University of Leeds.

AHMAD, S.B. & LOCKWOOD, J.G., 1979: Albedo. Progress in Physical Geography, 4, pp. 510-43.

ARNFIELD, A.J., 1975: A note on the diurnal, latitudinal and seasonal variation of the surface reflection coefficient. J. Appl. Met., 14, pp. 1603-8.

BARRY, R.G. & CHAMBERS, R.E., 1966a: A preliminary map of summer albedo over England and Wales. Quart.J. Royal Met. Soc., 92, pp. 543-8.

BARRY, R.G. & CHAMBERS, R.E., 1966b: Albedo variations in Southern Hampshire and Dorset. Weather, 21, pp. 60-5.

BARRY, R.G. & CHORLEY, R.J., 1976: Atmosphere, Weather and Climate, Methuen, London, 3rd Edition, 432p.

BERGLUND, E.R. & MACE, A.C., 1972: Seasonal albedo variation of Black Spruce and Sphagnum-Sedge bog cover types. J. Appl. Met., 11, pp. 806-12.

BILLINGS, W.D. & MORRIS, R.J., 1951: Reflection of visible and infrared radiation from leaves of different ecological groups. American Journal of Botany, 38, pp. 327-31.

BRAY, J.R. & CURTIS, J.T., 1957: An ordination of the upland forest communities of southern Wisconsin, Ecological Monographs, 27, pp. 235-49.

BROWN, M.B. (Ed.), 1977: BMDP-77 Biomedical Computer Programs P Series, University of California Press, Berkley, 880p.

CAMPBELL, B.M., & MOLL, E.J., 1976: A numerical method for classifying relevés collected in Braun-Blanquet phyto-sociological surveys. J. SAf. Botany 42, pp. 45-56.

CAMPBELL, B.M., 1978: Similarity coefficients for classifying relevés. Vegetatio, 37, pp.101-9.

CLIFFORD, H.T. & STEPHENSON, W., 1975: An Introduction to Numerical Classification. Academic Press, New York, 229p.

CARLSON, R.E., YARGER, D.N., & SHAW, R.H., 1971: Factors affecting the spectral properties of leaves with special emphasis on leaf water status. Agron J., 63, pp.486-9.

CHANG, JEN-HU, 1968: Climate and Agriculture. Aldine, Chicago, 304p.

CHIA, LIN-SIEN, 1967: Albedos of natural surfaces in Barbados. Quart. J. Royal Met. Soc., 93, pp. 116-120.

COLWELL, J.E., 1974: Vegetation Canopy Reflectance. Remote Sensing of Environment, 3, pp. 175-83

CRABTREE, S.J. & KJERFVE, B., 1978: Radiation balance over a salt marsh. Boundary Layer Met., 14, pp. 67-81.

DAY, J., SIEGFRIED, W.R., LOUW, G.N. & JARMAN, M.L., (Eds.), 1979: Fynbos ecology: a preliminary synthesis. S. Af. National Scientific Programmes Report, No. 40, 166p.

DE WALLE, D.R., & McGUIRE, S.G., 1973: Albedo variations in an oak forest in Pennsylvania. Agric. Met., 11, pp. 107-13.

FIELD, J.G., 1971: A numerical analysis of changes in the soft bottom fauna found along a transect across False Bay, S.A. J. exp. mar. Biol. Ecol., 7, pp.215-53.

FIELD, J.G. & McFARLANE, G., 1968: Numerical methods in marine ecology 1. A quantitative "similarity" analysis of rocky shore samples in False Bay, South Africa. Zoologica Africana, 3, pp. 19-37.

FRITSCHEN, L.J., 1967: Net and solar radiation relations over irrigated field crops. Agric. Met., 4, pp. 55-62.

FRITZ, S., 1958: Transmission of solar energy through the earth's clear and cloudy atmosphere. In: Carpenter, E.F., (Ed.). Transactions of the Conference on the Use of Solar Energy : The scientific Basis, University Arizona Press, Tuscon, Arizona, Vol. 1, pp. 17-36.

FUNK, J.P., 1959: Improved polythene-shielded net radiometer. J. Sci. Instruments, 36, pp. 367-70.

GATES, D.M., 1965a: Radiant energy - its receipt and disposal. Met. Monographs, 6, pp. 1-26.

GATES, D.M., 1965b: Energy Exchange in the Biosphere. Harper & Row, New York, 151p.

GOOD, R., 1974: The Geography of Flowering Plants. Longman, London, 557p.

GRAHAM, W.G. & KING, K.M., 1961: Short-wave reflection co-efficient for a field of maize. Quart. J. Royal Met. Soc., 87, pp. 425-28.

HARE, F.K., 1973: Energy-based climatology and its frontier with ecology. In: Chorley, R.J., (Ed.), Directions in Georgraphy, Methuen, London, pp. 171-92.

HUNTLEY, B.J., (Compiler) 1978: Nylsvley - A South African Savanna ecosystem project: objectives, organization and research programme. S. Af. National Scientific Programmes Report, No. 27, 37p.

HUNTLEY, B.J. & MORRIS, J.W., 1978: Savanna Ecosystem project: Phase 1 summary and Phase 11 report. S. Af. National Scientific Programmes Report, No. 29, 52p.

HUTCHISON, B.A. & MATT, D.R., 1977: The annual cycle of solar radiation in a deciduous forest. Agric. Met., 18, pp. 255-65.

IDSO, S.B., JACKSON, R.D., EHRLER, W.L. & MITCHELLS, T., 1969a: A method for determination of infrared emittance of leaves. Ecology, 50, pp. 899-902.

IDSO, S.B., BAKER, D.G. & BLAD, B.L., 1969b: Relations of radiation fluxes over natural surfaces. Quart. J. Royal Met. Soc. 95, pp. 244-57.

KONDRATYEV, K. YA., 1969: Radiation in the Atmosphere. Academic Press, New York, 912p.

KRUGER, F.J., (Compiler), 1978: A description of the Fynbos Biome Project. S. Af. National Scientific Programmes Report, No. 28, 25p.

LANCE, G.N. & WILLIAMS, W.T., 1967a: Mixed data classification programs. 1. Agglomerative systems. Aust. Computer J., 1, pp. 15-20.

LANCE, G.N. & WILLIAMS, W.T., 1967b: A general theory of classificatory sorting strategies. 1. Hierarchical systems. Computer J., 9, pp. 373-380.

LANE, S.B., 1980: Interpretation of Digital LANDSAT - 1 imagery from Velorenvlei, South Western Cape. Unpubl. M.Sc. Thesis, U.C.T., 159p.

LINDER, P. & CAMPBELL, B.M., 1979: Towards a structural-functional classification of fynbos: a comparison of methods. Bothalia, 12, pp. 723-9.

MACC, 1976a: Introduction to STATJOB Version 10. University of Wisconsin - Madison Computing Centre, Madison, 25p.

MACC, 1976b: UNISTAT 2 : Univariate Descriptive Statistics and Histograms. University of Wisconsin - Madison Computing Centre, Madison, 65p.

MOLL, E.J., CAMPBELL, B.M. & PROBYN, T.A., 1976: A rapid statistical method of habitat classification using structural and physiognomic characteristics. S. Af. J. Wild. Res., 6, pp. 45-50.

MONTEITH, J.L., 1973: Principles of Environmental Physics. Edward Arnold, London, 241p.

MONTEITH, J.L. & SZEICZ, G., 1961: The radiation balance of bare soil and vegetation. Quart. J. Royal Met. Soc., 87, pp. 159-70.

MOORE, C.J., 1976: A comparative study of radiation balance over forest and grassland. Quart. J. Royal Met. Soc., 102, pp. 889-900.

MUNN, R.E., 1966: Descriptive Micrometeorology. Academic Press, New York, 245p.

NKEMDIRIM, L.C., 1972: A note on the albedo of surfaces. J. Applied Met., 11, pp. 867-74

NKEMDIRIM, L.C., 1973: Radiative flux relations over crops. Agric. Met. 11, pp. 229-42.

ODUM, E.P., 1971: Fundamentals of Ecology. Saunders, Philadelphia, 3rd Edition, 574p.

OGUNTOYINBO, J.S., 1970: Reflection coefficient of natural vegetation, crops and urban surfaces in Nigeria. Quart. J. Royal Met. Soc. 96, pp. 340-441.

OGUNTOYINBO, J.S., 1974: Land-use and reflection coefficient (albedo) map for southern parts of Nigeria. Agric. Met., 13, pp. 227-37.

OKE, T.R., 1978: Boundary Layer Climates. Methuen, London, 372p.

PEARMAN, G.I., 1966: Reflection of visible radiation from leaves of some Western Australian species. Aust. J. Biol. Sci., 19, pp. 97-103.

PETERSON, J.T., FLOWERS, E.C. (Ed.) RUDISILL, J.H., 1973: Dew and frost deposition on pyranometers. J. Appl. Met., 12, pp. 1231-2.

POLAVARAPU, R.J., 1970: A comparative study of global and net radiation measurements at Guelph, Ottawa and Rotonto. J. Appl. Met., 9, pp. 809-14.

RAUNKIAER, C., 1934: The life Forms of Plants and Statistical Plant Geography. Clarendon Press, Oxford.

REIFSNYDER, W.E., 1967: Radiation Geometry in the measurement and interpretation of radiation balance. Agric. Met., 4, pp. 255-65.

ROBINSON, N., (Ed.), 1966: Solar Radiation. Elsevier, Amsterdam, 347p.

ROSENBERG, N.J., 1974: Microclimate: The Biological Environment. Wiley, New York, 315p.

√ROSS, J., 1975: Radiative transfer in plant communities. In: Monteith, J.L., (Ed.), Vegetation and the Atmosphere, Vol. 1., Principles. Academic Press, London, pp. 13-55.

√ROUSE, W.R. & McCUTCHEON, J.G., 1972: The diurnal behavious of incoming solar and infrared radiation in Hamilton, Canada. International Geography 1972, University Press, Toronto, pp. 191-96.

SCHWERDTFEGER, P., 1976: Physical Principles of Micro-Meteorological Measurements. Elsevier, Amsterdam, 113p.

SELLERS, W.D., 1969: Physical Climatology. Univ. Chicago Press, Chicago, 272p.

SIEGEL, S., 1966: Non-Parametric Statistics. McGraw-Hill, New York, 312p.

√SINCLAIR, R. & THOMAS, D.A., 1970: Optical Properties of Leaves of some species in arid South Australia. Aust. J. Botany, 18, pp. 261-73.

STANHILL, G., 1970: Some results of helicopter measurements of the albedo of different land surfaces. Solar Energy, 13, pp. 59-66.

STANHILL, G., HOFSTEDE, G.J. & KALMA, J.D., 1966: Radiation Balance of natural and agricultural vegetation. Quart. J. Royal Met. Soc., 92, pp. 128-40

STEWARD, J.T., 1971: The albedo of a pine forest. Quart. J. Royal Met. Soc., 97, pp. 561-64.

SZEICZ, G., 1968: Measurement of radiant energy. In: Wadsworth, R.M., (Ed.), The Measurement of Environmental Factors in Terrestrial Ecology. Blackwell, Oxford, pp. 109-30.

TAYLOR, H.C., 1969: A vegetation survey of the Cape of Good Hope Nature Reserve. Unpubl. M.Sc. Thesis, University of Cape Town, 154p.

TAYLOR, H.C., 1972: Fynbos. Veld & Flora, 2, pp. 68-75.

TAYLOR, H.C., 1978: Capensis. In: Werger, M.J.A., (Ed.), Biogeography and Ecology of Southern Africa. Junk, The Hague, pp. 171-229.

TAYLOR, H.C., 1979: Phytogeography. In: Day, J., SIEGFRIED, W.R., LOUW, G.N. & JARMAN, M.L., (Eds.), Fynbos Ecology: A preliminary synthesis. S. Af. National Scientific Programmes Report, No. 40, pp. 70-81.

U.C.T. Computing Service, 1979: GENPLOT: A general purpose plotting program to produce X-Y plots. U.C.T. Computing Service, Cape Town, 8p.

VAN DER MAAREL, E., 1979: Transformation of cover-abundance values in phytosociology and the effects on community similarity. Vegetatio, 39, pp. 97-114.

WEAST, R.C., (Ed.), 1975: Handbook of Chemistry and Physics 1975-1976. 56th Edit., Chemical Rubber Company Press, Cleveland (Ohio), 2351p.

WERGER, M.J.A., 1974: On concepts and techniques applied in the Zürich-Montpellier method of vegetation survey. Bothalia 11, pp. 309-23.

WERGER, M.J.A., KRUGER, F.J. & TAYLOR, H.C., 1972: A phyto-sociological survey of the Cape fynbos and other vegetation at Jonkershoek, Stellenbosch. Bothalia, 10, pp. 599-614.

WILLIAMS, W.T., CLIFFORD, H.T. & LANCE, G.N., 1971: Group size dependence: a rationale for choice between numerical classifications. Computer J., 14, pp. 157-62.

YATES, D.J. (in press): Optical Properties of heathlands. In: Specht, R.L., (Ed.), Ecosystems of the World: Heathlands and Related Scrublands.

APPENDIX 1

DATA SUMMARIES

Scatter-plots of short-wave and long-wave fluxes and net radiation can be found in Appendix 3.

The time of all readings is not in standard notation, hence 0700 should read as 07h00, and so on throughout.

The column headed "Reflectivity" refers to the reflection coefficient as defined in Section 2.1.

The outgoing fluxes are usually considered to be negative.

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 1

DATE : 800204

TIME	REFLEC-TIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.303	137	42	349	398	291	47
730	.209	256	54	291	357	283	138
800	.139	373	52	337	415	294	243
830	.128	486	62	323	415	294	332
900	.117	608	71	270	362	284	445
930	.113	697	79	236	331	278	523
1000	.107	795	85	246	359	284	597
1030	.095	866	82	248	373	286	659
1100	.089	953	85	228	380	288	716
1130	.081	1062	86	138	359	283	755
1200	.083	1044	87	228	401	292	784
1230	.074	1053	78	242	418	294	799
1300	.075	1058	79	230	412	293	797
1330	.069	1035	71	262	434	297	791
1400	.066	1006	66	277	450	300	767
1430	.065	962	63	284	453	300	731
1500	.071	912	64	287	450	300	685
1530	.071	845	60	285	444	299	626
1600	.078	766	60	303	451	300	558
1630	.088	680	60	277	414	294	483
1700	.096	584	56	310	440	298	398
1730	.108	482	52	324	448	300	306
1800	.128	363	47	312	422	295	207
1830	.175	218	38	374	453	300	101
1900	.247	51	13	333	412	294	-40

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 1

DATE : 800212

TIME	REFLEC-TIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.000	0	0	0	0	0	46
730	.193	217	42	311	377	287	109
800	.119	347	41	172	271	264	206
830	.110	429	47	315	394	290	302
900	.103	553	57	301	387	289	410
930	.098	650	63	273	379	287	480
1000	.093	742	69	270	381	288	563
1030	.089	821	73	265	377	287	635
1100	.085	905	77	250	392	290	686
1130	.082	961	79	229	385	289	727
1200	.075	1007	76	242	412	294	761
1230	.070	1034	72	251	429	296	784
1300	.064	1037	66	244	431	297	785
1330	.063	1030	64	242	432	297	775
1400	.062	1013	63	221	417	294	754
1430	.063	977	61	224	416	294	723
1500	.073	931	67	208	401	291	670
1530	.072	851	62	216	406	292	599
1600	.085	771	65	223	394	290	534
1630	.087	693	60	227	391	290	469
1700	.088	593	52	222	390	290	373
1730	.098	491	48	238	396	291	285
1800	.118	368	44	240	386	289	179
1830	.186	239	44	273	379	287	89
1900	.324	122	39	281	370	286	-6

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 1

DATE : 800213

TIME	REFLEC-TIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.153	82	13	336	376	287	29
730	.253	192	49	347	381	288	109
800	.122	297	36	340	398	291	203
830	.107	425	45	311	390	289	301
900	.099	550	54	291	392	290	394
930	.096	659	64	303	415	294	484
1000	.098	748	73	282	400	291	557
1030	.085	828	70	276	403	292	630
1100	.076	921	70	259	429	296	681
1130	.071	1004	71	207	393	290	747
1200	.070	1018	71	236	408	293	775
1230	.066	1049	69	223	411	293	791
1300	.063	1041	66	232	423	295	785
1330	.060	1029	61	232	411	293	788
1400	.066	1010	67	229	409	293	763
1430	.063	977	62	222	409	293	727
1500	.064	928	59	214	403	292	679
1530	.072	865	63	209	407	292	605
1600	.078	769	60	229	411	293	528
1630	.080	693	56	230	401	292	467
1700	.097	599	58	232	397	291	375
1730	.109	481	52	237	392	290	273
1800	.134	364	49	253	387	289	181
1830	.211	226	48	284	385	289	78
1900	.390	111	43	300	379	287	-10

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 2

DATE : 800304

TIME	REFLEC-TIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.451	58	26	318	402	292	-52
730	.313	152	48	317	389	289	33
800	.223	283	63	299	392	290	127
830	.174	409	71	277	404	292	211
900	.158	547	87	251	391	290	321
930	.154	653	100	242	356	283	439
1000	.158	700	110	259	388	289	460
1030	.150	771	115	247	385	288	519
1100	.143	837	119	236	382	288	572
1130	.132	888	117	248	403	292	617
1200	.124	932	116	234	387	289	664
1230	.115	948	109	253	401	292	690
1300	.108	958	104	239	394	290	698
1330	.107	891	95	296	398	291	694
1400	.101	935	95	259	410	293	689
1430	.148	281	41	258	428	296	70
1500	.118	492	58	324	466	303	291
1530	.121	1023	124	344	411	293	831
1600	.156	373	58	383	407	293	290
1630	.163	157	26	387	400	291	118
1700	.134	227	30	381	408	293	170
1730	.198	106	21	396	397	291	85
1800	.223	119	27	405	426	296	71
1830	.190	77	15	388	400	291	50
1900	.220	18	4	397	407	292	5

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 2

DATE : 800309

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.578	38	22	297	376	287	-62
730	.333	132	44	291	371	286	8
800	.222	242	54	270	373	286	85
830	.168	377	63	241	372	286	183
900	.147	494	73	220	362	284	279
930	.153	601	92	202	344	281	366
1000	.149	688	102	198	345	281	438
1030	.137	760	104	205	346	281	516
1100	.137	829	114	202	336	279	580
1130	.127	891	113	209	348	281	639
1200	.120	919	110	211	350	282	670
1230	.109	939	102	233	377	287	693
1300	.103	944	97	210	349	282	707
1330	.096	942	90	207	351	282	707
1400	.098	915	90	213	362	284	676
1430	.106	878	93	229	375	287	639
1500	.106	813	86	252	385	289	594
1530	.118	758	89	272	406	292	534
1600	.126	679	86	248	389	289	452
1630	.143	579	83	269	392	290	373
1700	.170	461	79	298	402	292	278
1730	.206	347	72	320	409	293	186
1800	.295	218	64	355	414	294	94
1830	.509	89	46	369	416	294	-2
1900	.513	34	18	327	407	293	-62

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 3

DATE : 800225

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.422	54	23	367	406	292	-8
730	.226	162	37	342	402	292	65
800	.110	351	39	261	399	291	173
830	.095	418	40	315	416	294	278
900	.094	545	51	286	411	293	369
930	.090	651	59	264	401	291	456
1000	.092	715	66	293	405	292	537
1030	.088	818	72	242	379	287	609
1100	.093	882	82	263	395	290	668
1130	.091	929	84	263	398	291	710
1200	.083	976	81	254	413	294	735
1230	.084	993	83	259	400	291	769
1300	.085	1012	86	220	377	287	769
1330	.081	1009	81	210	377	287	761
1400	.084	993	83	192	361	284	740
1430	.083	962	80	192	360	284	714
1500	.083	901	75	191	359	284	657
1530	.088	831	74	208	366	285	600
1600	.096	759	72	197	351	282	532
1630	.102	650	66	218	355	283	447
1700	.112	533	60	247	363	284	357
1730	.122	411	50	267	370	286	258
1800	.185	271	50	292	361	284	152
1830	.262	176	46	292	365	285	57
1900	.651	54	35	327	368	285	-22

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 3

DATE : 800227

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.236	60	14	336	399	291	-17
730	.209	142	30	342	408	293	46
800	.141	114	16	345	375	287	69
830	.096	399	38	286	403	292	244
900	.100	518	52	278	397	291	347
930	.102	627	64	239	370	286	431
1000	.104	715	74	255	380	288	516
1030	.102	815	83	232	363	284	601
1100	.105	926	97	265	361	284	732
1130	.089	445	40	325	385	289	345
1200	.090	970	88	217	359	284	740
1230	.095	1001	95	217	362	284	761
1300	.090	1007	91	215	352	282	779
1330	.090	1004	90	196	351	282	759
1400	.080	1042	83	178	374	286	763
1430	.093	961	90	180	340	280	711
1500	.096	904	87	191	345	281	662
1530	.104	832	87	256	357	283	645
1600	.132	225	30	325	362	284	158
1630	.109	272	30	344	382	288	204
1700	.142	186	27	346	372	286	134
1730	.144	473	68	290	360	284	335
1800	.151	165	25	317	377	287	81
1830	.285	169	48	327	365	285	83
1900	.415	48	20	291	368	285	-47

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 3

DATE : 800303

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.485	56	27	318	370	286	-23
730	.160	125	20	317	385	289	36
800	.127	272	35	281	397	291	122
830	.119	394	47	251	364	284	234
900	.105	517	54	235	356	283	342
930	.085	600	51	243	370	286	422
1000	.117	708	83	217	332	278	510
1030	.106	781	83	227	343	280	583
1100	.107	848	91	221	338	279	640
1130	.091	895	81	236	361	284	689
1200	.094	936	88	232	351	282	729
1230	.090	956	86	230	355	283	744
1300	.092	978	90	223	356	283	755
1330	.088	977	86	213	362	284	743
1400	.086	953	82	232	379	287	725
1430	.089	905	80	246	388	289	683
1500	.092	869	80	237	382	288	644
1530	.098	798	78	240	383	288	577
1600	.095	706	67	261	394	290	506
1630	.100	600	60	289	405	292	423
1700	.119	488	58	291	392	290	329
1730	.147	375	55	328	386	289	261
1800	.183	243	45	351	407	293	143
1830	.327	122	40	356	401	292	37
1900	.464	40	18	288	355	283	-44

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 4

DATE : 800302

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.401	70	28	278	355	283	-34
730	.267	167	45	275	369	285	29
800	.180	273	49	252	367	285	109
830	.153	403	61	208	340	280	210
900	.134	516	69	189	329	277	307
930	.137	619	85	186	333	278	388
1000	.128	718	92	184	332	278	479
1030	.118	800	95	112	263	262	554
1100	.121	876	106	221	370	286	621
1130	.116	929	107	200	331	278	690
1200	.109	984	107	163	327	277	713
1230	.106	1030	109	223	364	284	780
1300	.104	1121	117	211	356	283	858
1330	.109	827	90	175	356	283	556
1400	.095	969	92	227	372	286	730
1430	.088	918	81	230	376	287	690
1500	.098	871	85	235	375	287	646
1530	.102	798	81	252	389	289	579
1600	.110	720	79	266	397	291	509
1630	.110	621	68	292	417	294	428
1700	.129	508	65	313	417	294	339
1730	.159	393	63	323	401	291	252
1800	.235	254	60	354	405	292	143
1830	.426	114	48	383	421	295	28
1900	.665	46	31	340	396	291	-39

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 5

DATE : 800219

TIME	REFLEC-TIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.404	85	34	331	407	292	-24
730	.405	172	70	326	383	288	45
800	.242	288	70	346	414	294	150
830	.201	419	84	320	413	294	242
900	.178	529	94	309	412	294	331
930	.163	646	105	298	413	294	425
1000	.145	743	108	285	410	293	510
1030	.140	815	114	284	414	294	572
1100	.124	893	110	277	432	297	628
1130	.120	952	114	257	415	294	680
1200	.114	1006	115	249	421	295	719
1230	.108	1024	110	259	435	297	738
1300	.104	1032	107	242	417	294	750
1330	.107	1026	110	243	415	294	744
1400	.106	991	105	238	415	294	710
1430	.105	954	100	236	408	293	681
1500	.108	900	97	239	413	294	628
1530	.102	841	86	237	422	295	570
1600	.111	755	84	214	405	292	480
1630	.125	649	81	249	397	291	420
1700	.133	559	75	253	401	291	336
1730	.147	442	65	265	400	291	242
1800	.204	258	53	359	408	293	156
1830	.276	200	55	305	390	289	61
1900	.530	86	46	320	388	289	-27

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 5

DATE : 800220

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.168	14	2	397	397	291	12
730	.143	44	6	396	402	292	32
800	.196	68	13	400	397	291	58
830	.140	143	20	413	400	291	135
900	.175	180	32	380	388	289	141
930	.146	258	38	338	395	290	163
1000	.158	784	124	335	419	295	576
1030	.160	428	68	305	399	291	265
1100	.135	351	47	511	432	297	382
1130	.133	672	89	160	404	292	339
1200	.138	511	70	452	485	306	407
1230	.155	461	71	885	414	294	861
1300	.122	1031	126	249	392	290	764
1330	.115	996	115	267	396	291	752
1400	.120	1000	120	244	404	292	721
1430	.117	950	111	253	408	293	684
1500	.127	879	112	309	443	299	634
1530	.146	842	123	293	431	297	581
1600	.139	748	104	293	354	282	584
1630	.169	686	116	276	366	285	480
1700	.180	387	70	328	390	289	256
1730	.210	409	86	335	386	289	272
1800	.147	256	38	325	393	290	149
1830	.302	247	74	313	346	281	139
1900	.240	92	22	344	394	290	21

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 6

DATE : 800222

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.136	45	6	378	401	292	15
730	.136	67	9	370	407	293	21
800	.140	102	14	447	405	292	129
830	.166	109	18	364	385	289	70
900	.139	510	71	410	387	289	462
930	.169	403	68	320	378	287	277
1000	.141	206	29	625	444	299	357
1030	.125	381	47	383	431	297	286
1100	.050	878	44	-120	410	293	302
1130	.146	838	123	99	311	274	503
1200	.117	798	94	85	328	277	462
1230	.153	342	52	347	374	286	263
1300	.127	383	49	573	313	274	594
1330	.089	954	85	331	442	299	758
1400	.104	1135	118	162	393	290	787
1430	.122	614	75	150	383	288	305
1500	.139	411	57	273	368	285	259
1530	.146	273	40	349	383	288	199
1600	.133	176	23	351	401	291	103
1630	.140	124	17	451	416	294	142
1700	.163	128	21	407	390	289	125
1730	.109	161	17	298	394	290	48
1800	.147	65	10	399	408	293	47
1830	.182	50	9	396	402	292	36
1900	.225	53	12	369	393	290	17

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 6

DATE : 800223

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.439	86	38	391	400	291	39
730	.303	165	50	375	411	293	78
800	.252	249	63	383	402	292	168
830	.173	380	66	390	424	296	280
900	.166	536	89	339	397	291	389
930	.146	603	88	326	401	291	440
1000	.130	699	91	307	406	292	509
1030	.118	788	93	306	427	296	574
1100	.144	268	38	564	439	298	354
1130	.109	1031	113	225	351	282	793
1200	.112	1059	119	291	424	296	807
1230	.103	1007	104	257	420	295	741
1300	.101	1014	102	223	392	290	744
1330	.102	1104	112	189	394	290	787
1400	.097	990	96	253	425	296	722
1430	.102	944	97	215	409	293	653
1500	.104	902	94	227	432	297	602
1530	.110	829	91	221	423	295	537
1600	.116	755	87	211	418	294	461
1630	.123	659	81	211	416	294	373
1700	.143	573	82	221	418	294	294
1730	.140	468	66	215	412	293	206
1800	.172	341	59	239	411	293	111
1830	.239	212	51	273	411	293	24
1900	.693	91	63	293	369	285	-48

TITLE OF ANALYSIS: CAPE POINT MEASUREMENTS

SITE #: 6

DATE : 800224

TIME	REFLECTIVITY (RATIO)	INCOMING SHORT WAVE RADIATION (W/SQ.M)	REFLECTED SHORT WAVE RADIATION (W/SQ.M)	INCOMING LONG WAVE RADIATION (W/SQ.M)	OUTGOING LONG WAVE RADIATION (W/SQ.M)	RADIATIVE TEMP OF VEGETATION (DEG. K)	NET ALL WAVE RADIATION (W/SQ.M)
700	.520	75	39	336	383	288	-10
730	.396	118	47	386	389	289	68
800	.239	241	58	387	383	288	187
830	.151	426	64	320	394	290	288
900	.150	530	80	304	390	290	364
930	.136	641	87	293	397	291	450
1000	.131	730	96	332	421	295	546
1030	.121	806	98	305	427	296	586
1100	.107	895	96	258	406	292	651
1130	.107	942	101	267	412	293	696
1200	.155	594	92	327	396	291	432
1230	.112	765	86	194	379	287	494
1300	.106	740	79	372	419	295	614
1330	.123	655	81	179	380	288	373
1400	.133	376	50	403	401	291	329
1430	.138	321	44	309	376	287	210
1500	.146	242	35	411	374	286	244
1530	.125	402	50	258	363	284	247
1600	.141	338	48	389	393	290	286
1630	.135	295	40	343	399	291	200
1700	.108	800	86	-151	350	282	211
1730	.156	473	74	246	389	289	256
1800	.223	302	67	259	371	286	123
1830	.330	165	54	307	396	291	22
1900	.634	74	47	296	372	286	-47

SITE: 1

DATE: 4.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	9	104			
07h30	15	100			
08h00	21	96			
08h30	28	92			
09h00	34	88			
09h30	40	83			
10h00	46	78			
10h30	52	72			
11h00	58	64			
11h30	63	54			
12h00	68	41			
12h30	71	23			
13h00	72	0			
13h30	71	338			
14h00	68	320			
14h30	63	306			
15h00	58	296			
15h30	52	289			
16h00	46	282			
16h30	40	277			
17h00	34	273			
17h30	28	268			
18h00	21	264	1/8	Ci	No
18h30	15	260	1/8	Ci	Yes
19h00	9	256	1/8	Ci	Yes

SITE: 1

DATE: 12.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	8	102	1/8	Sc	NO
07h30	14	98	1/8	Sc	NO
08h00	20	94	1/8	Sc	NO
08h30	26	89	1/8	Sc	NO
09h00	32	85	1/8	Sc	NO
09h30	39	80	1/8	Sc	NO
10h00	45	75	1/8	Sc	NO
10h30	51	68	1/8	Sc	NO
11h00	56	61	1/8	Sc	NO
11h30	61	51	1/8	Sc	NO
12h00	66	38	1/8	Sc	NO
12h30	69	20			
13h00	70	0			
13h30	69	340			
14h00	66	323			
14h30	61	310			
15h00	56	300			
15h30	51	292			
16h00	45	285			
16h30	39	280			
17h00	32	275			
17h30	26	271			
18h00	20	267			
18h30	14	263			
19h00	8	259			

SITE: 1

DATE: 13.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	8	101	4/8	Sc	YES
07h30	4	97	1/8	Sc	NO
08h00	20	93			
08h30	26	89			
09h00	32	85			
09h30	38	80			
10h00	44	74			
10h30	50	68			
11h00	56	60			
11h30	61	50			
12h00	65	37			
12h30	68	20			
13h00	69	0			
13h30	68	340			
14h00	65	323			
14h30	61	310			
15h00	56	300			
15h30	50	292			
16h00	44	286			
16h30	38	280			
17h00	32	276			
17h30	26	271			
18g00	20	267			
18h30	14	263			
19h00	8	259			

SITE: 2

DATE: 4.3.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	4	95			
07h30	10	91			
08h00	16	87			
08h30	22	82			
09h00	29	77			
09h30	35	72			
10h00	40	66			
10h30	46	59			
11h00	51	51			
11h30	55	41			
12h00	59	29			
12h30	61	15			
13h00	62	359			
13h30	61	344			
14h00	59	330			
14h30	55	318	1/8	St	YES
15h00	50	308	5/8	Sc	YES
15h30	45	300	7/8	Sc	YES
16h00	40	293	8/8	St	YES
16h30	34	287	8/8	St	YES
17h00	28	282	8/8	St	YES
17h30	22	277	8/8	St	YES
18h00	16	273	8/8	St	YES
18h30	9	269	8/8	St	YES
19h00	3	265	8/8	St	YES

SITE: 2

DATE: 5.3.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	4	95	8/8	St	YES
07h30	10	91	8/8	St	YES
08h00	16	86	8/8	St	YES
08h30	22	81	8/8	St	YES
09h00	28	77	8/8	St	YES
09h30	34	72	8/8	St	YES
10h00	40	66	8/8	St	YES
10h30	46	59	8/8	St	YES
11h00	51	51	8/8	St	YES
11h30	55	41	8/8	St	YES
12h00	59	29	8/8	St	YES
12h30	61	14	8/8	St	YES
13h00	62	359	8/8	St	YES
13h30	61	343	8/8	St	YES
14h00	58	329	8/8	St	YES
14h30	54	318	8/8	St	YES
15h00	50	308	8/8	St	YES
15h30	45	300	8/8	St	YES
16h00	39	293	8/8	St	YES
16h30	33	288	6/8	St	YES
17h00	27	282	4/8	St	YES
17h30	21	278	4/8	St	YES
18h00	15	273	4/8	St	YES
18h30	9	269	7/8	St	YES
19h00	3	265	7/8	St	YES

SITE: 2

DATE: 9.3.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	3	93			
07h30	9	89			
08h00	15	85			
08h30	22	80			
09h00	28	75			
09h30	34	70			
10h00	39	64			
10h30	44	59			
11h00	50	49			
11h30	54	39			
12h00	57	27			
12h30	59	13			
13h00	60	359			
13h30	59	344			
14h00	57	331			
14h30	53	319			
15h00	49	310			
15h30	43	301			
16h00	38	295			
16h30	32	289			
17h00	26	284			
17h30	20	279			
18h00	14	274			
18h30	8	270			
19h00	2	266			

SITE: 3

DATE: 3.3.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	4	95			
07h30	10	91			
08h00	17	87			
08h30	23	82			
09h00	29	78			
09h30	35	72			
10h00	41	67			
10h30	46	60			
11h00	51	51			
11h30	56	41			
12h00	59	29			
12h30	62	15			
13h00	63	359			
13h30	61	343			
14h00	59	329			
14h30	55	317			
15h00	51	307			
15h30	45	300			
16h00	40	293			
16h30	34	287			
17h00	28	281	1/8	Ci	NO
17h30	22	277	1/8	Ci	YES
18h00	16	272	1/8	Ci	NO
18h30	10	269	1/8	Ci	NO
19h00	3	264	1/8	Ci	NO

SITE: 4

DATE: 26.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	5	97	6/8	St	YES
07h30	11	93	7/8	St	YES
08h00	18	89	6/8	St	NO
08h30	24	85	8/8	St	YES
09h00	30	80	7/8	St	YES
09h30	36	75	8/8	St	YES
10h00	42	69	7/8	St	YES
10h30	48	62	7/8	St	YES
11h00	53	54	5/8	St	YES
11h30	57	44	6/8	St	YES
12h00	62	32	7/8	St	YES
12h30	64	17	5/8	St	YES
13h00	65	360	6/8	St	YES
13h30	64	343	5/8	St	YES
14h00	61	328	4/8	St	YES
14h30	57	315	3/8	St	YES
15h00	52	304	2/8	St	NO
15h30	47	298	2/8	St	NO
15h00	42	291	2/8	St	NO
16h30	36	285	2/8	St	NO
17h00	30	280	1/8	St	NO
17h30	23	275	1/8	St	NO
18h00	17	271	1/8	St	NO
18h30	11	267	1/8	St	NO
19h00	5	263	1/8	St	NO

SITE: 4

DATE: 2.3.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	4	96			
07h30	11	91			
08h00	17	81			
08h30	23	83			
09h00	35	73			
10h00	40	67	1/8	Cs	NO
10h30	46	60	1/8	Cs	NO
11h00	52	52	1/8	Cs	NO
11h30	56	42	2/8	Cs	NO
12h00	60	30	2/8	Cs	NO
12h30	62	15	3/8	Cs	NO
13h00	63	359	4/8	Cs	NO
13h30	62	343	5/8	Cs	YES
14h00	59	329	3/8	Cs	YES/NO
14h30	55	317	1/8	Cs	NO
15h00	51	307	1/8	Cs	NO
15h30	46	299			
16h00	40	292			
16h30	34	287			
17h00	28	281			
17h30	22	277			
18h00	16	272			
18h30	10	268			
19h00	4	264			

SITE: 5

DATE: 17.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	7	100			
07h30	13	96			
08h00	19	92			
08h30	25	88			
09h00	31	83			
09h30	38	78			
10h00	44	73			
10h30	49	66			
11h00	55	58			
11h30	60	48			
12h00	64	35			
12h30	67	20			
13h00	68	1			
13h30	67	341			
14h00	64	325			
14h30	60	312			
15h00	55	302			
15h30	49	294			
16h00	44	287			
16h30	38	282			
17h00	32	277			
17h30	25	272			
19h00	19	268			
18h30	13	264			
19h00	7	260			

SITE: 5

DATE: 19.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	6	100			
07h30	13	96			
08h00	19	91			
08h30	25	87			
09h00	31	83			
09h30	37	78			
10h00	43	72			
10h30	49	65			
11h00	54	57			
11h30	59	47			
12h00	63	35			
12h30	66	18			
13h00	67	1			
13h30	66	342			
14h00	63	326			
14h30	59	313			
15h00	54	303			
15h30	49	295			
16h00	43	288			
16h30	37	283			
17h00	31	278			
17h30	25	273			
18h00	19	269			
18h30	13	265			
19h00	6	261			

SITE: 5

DATE: 20.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	6	99	7/8	St	YES
07h30	12	95	7/8	St	YES
08h00	19	91	7/8	St	YES
08h30	25	87	7/8	St	YES
09h00	31	82	6/8	St	YES
09h30	37	77	6/8	St	YES
10h00	43	72	4/8	St	NO
10h30	49	65	6/8	St	YES
11h00	54	57	6/8	St	YES
11h30	59	47	6/8	St	YES
12h00	63	34	7/8	St	YES
12h30	64	18	8/8	St	YES
13h00	67	0	3/8	St	NO
13h30	66	342	3/8	St	YES/NO
14h00	63	326	4/8	St	YES/NO
14h30	59	313	2/8	St	NO
15h00	54	303	3/8	St	NO
15h30	49	295	6/8	St	YES
16h00	43	289	3/8	St	YES/NO
16h30	37	283	4/8	St	YES/NO
17h00	31	278	6/8	St	YES
17h30	25	273	6/8	St	YES/NO
18h00	19	269	7/8	St	YES
18h30	12	265	7/8	St	YES/NO
19h00	6	261	7/8	St	YES/NO

SITE: 4

DATE: 28.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	5	97			
07h30	11	93			
08h00	17	88			
08h30	23	84			
09h00	29	79			
09h00	36	74			
10h00	41	68			
10h30	47	62			
11h00	52	53			
11h30	57	43			
12h00	61	31			
12h30	63	16			
13h00	64	360			
13h30	63	343			
14h00	60	328			
14h30	57	316			
15h00	52	306			
15h30	47	298			
16h00	41	291			
16h30	35	286			
17h00	29	281			
17h30	23	276			
18h00	17	272			
18h30	11	276			
19h00	4	263			

SITE: 6

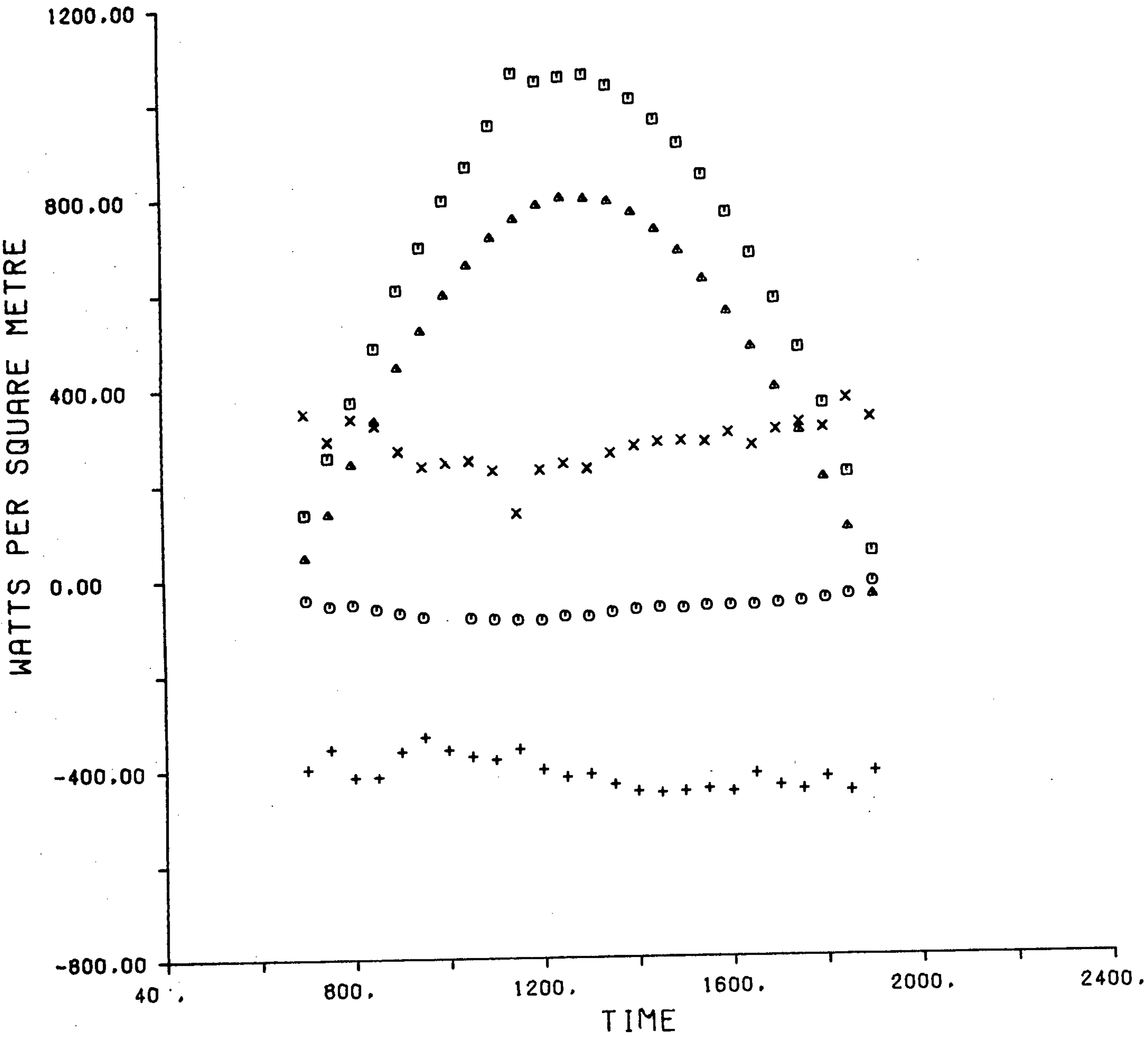
DATE: 24.2.80

TIME	SOLAR ALTITUDE	SOLAR AZIMUTH	CLOUD COVER	CLOUD TYPE	SUN OBSCURED
07h00	6	98	6/8	St	YES/NO
07h30	12	94	3/8	St	NO
08h00	18	90	1/8	St	NO
08h30	24	85	1/8	St	NO
09h00	30	81	1/8	St	NO
09h30	36	76	1/8	St	NO
10h00	42	70	1/8	St	NO
10h30	48	63	1/8	St	NO
11h00	53	55	1/8	St	NO
11h30	58	45	3/8	St	NO
12h00	62	32	7/8	St	YES
12h30	64	17	5/8	St	YES/NO
13h00	65	360	7/8	St	YES
13h30	64	342	7/8	St	YES
14h00	62	327	8/8	St	YES
14h30	58	315	8/8	St	YES
15h00	53	305	8/8	St	YES
15h30	48	297	8/8	St	YES
16h00	42	290	8/8	St	YES
16h30	36	284	8/8	St	YES
17h00	30	279	7/8	St	YES/NO
17h30	24	275	4/8	St	YES/NO
18h00	18	270	1/8	St	NO
18h30	11	266	1/8	St	NO
19h00	5	262	1/8	St	NO

APPENDIX 3

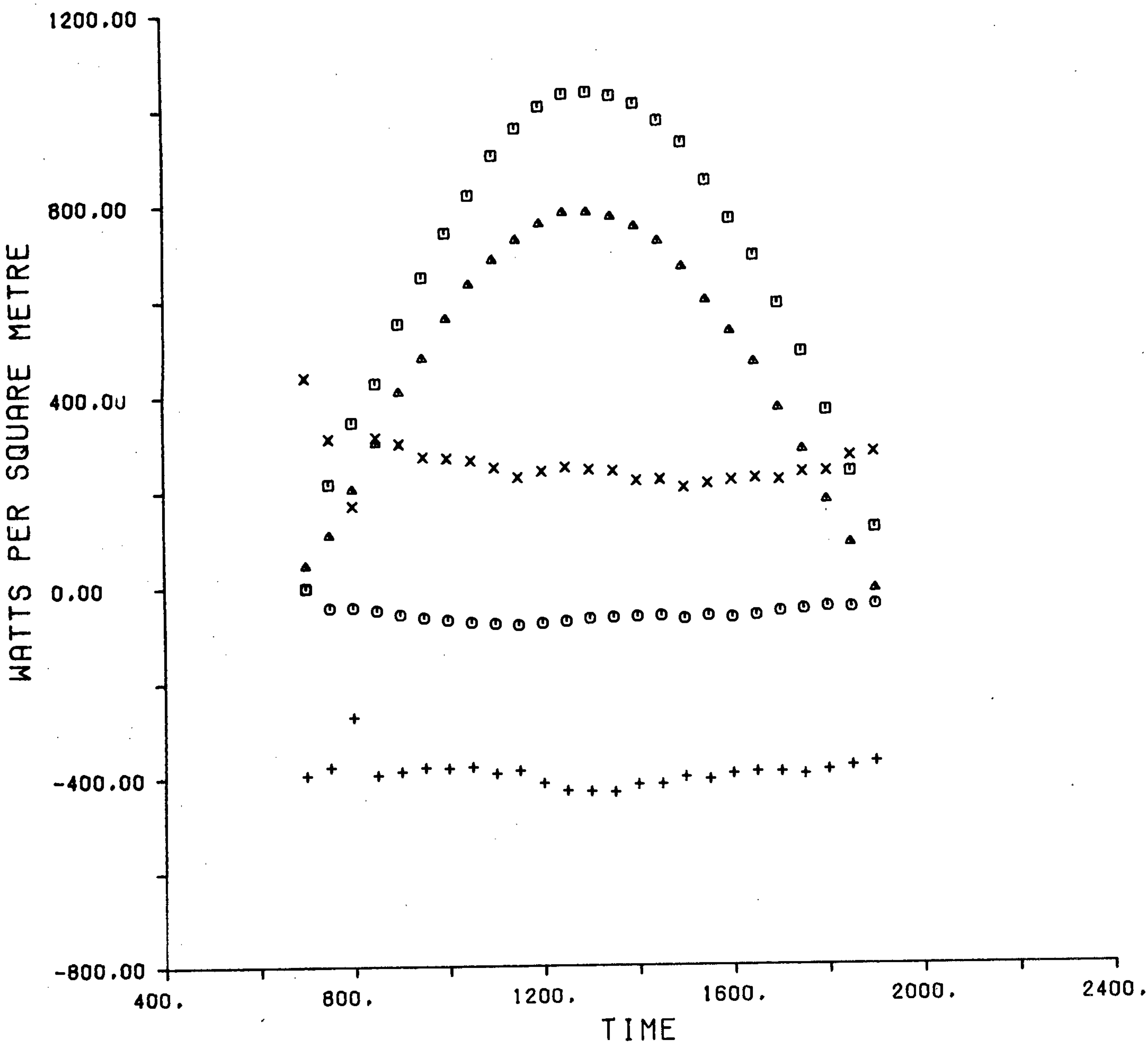
DIAGRAMS OF DAILY RADIATION FLUXES

The data for these diagrams can be found in Appendix 1.



SITE 1 : 4/2/80

- ⊡ INCOMING SW RADIATION
- ⊙ OUTGOING SW RADIATION
- × INCOMING LW RADIATION
- + OUTGOING LW RADIATION
- ▲ NET RADIATION



SITE 1 :12/2/80

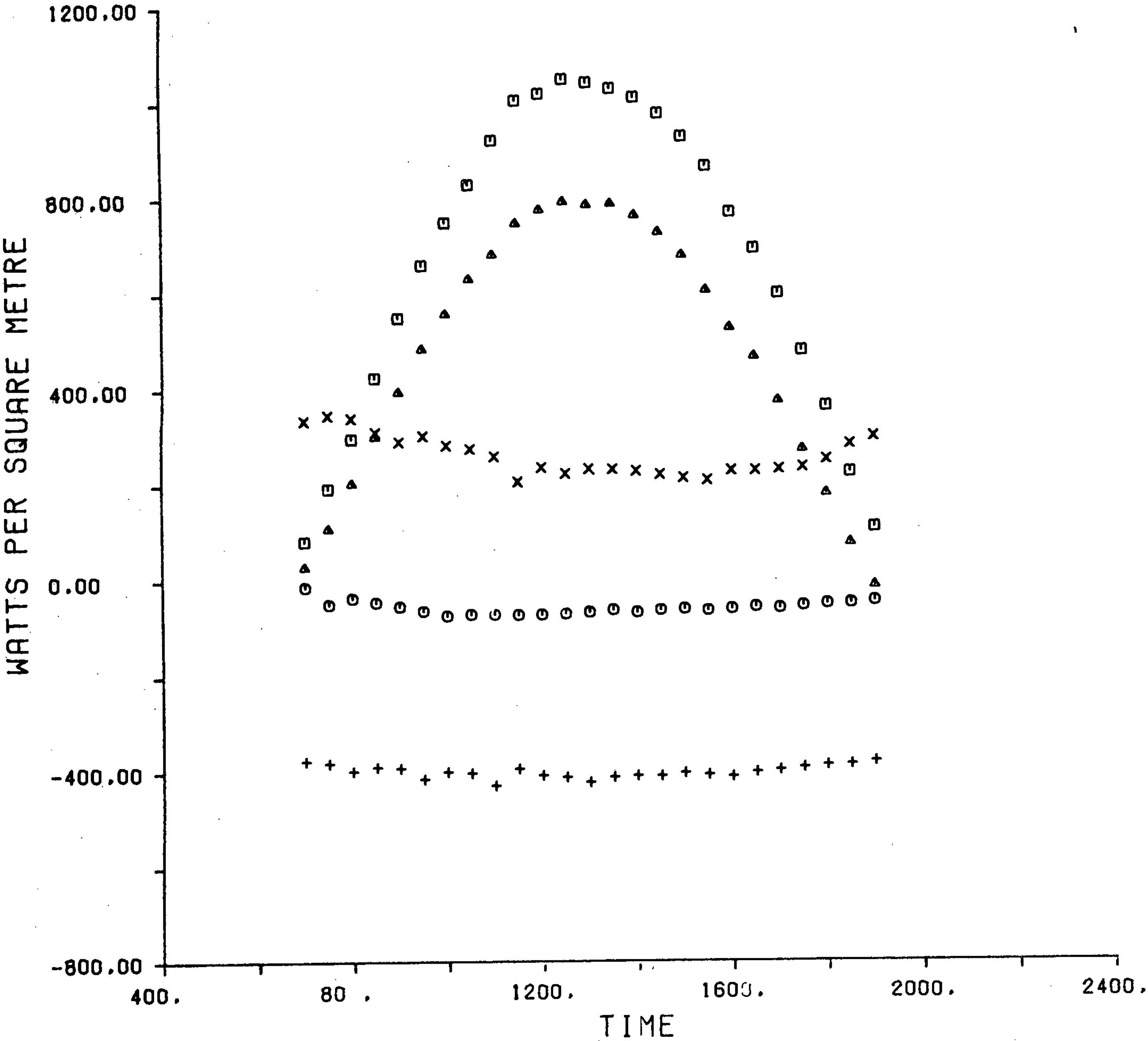
□ INCOMING SW RADIATION

○ OUTGOING SW RADIATION

× INCOMING LW RADIATION

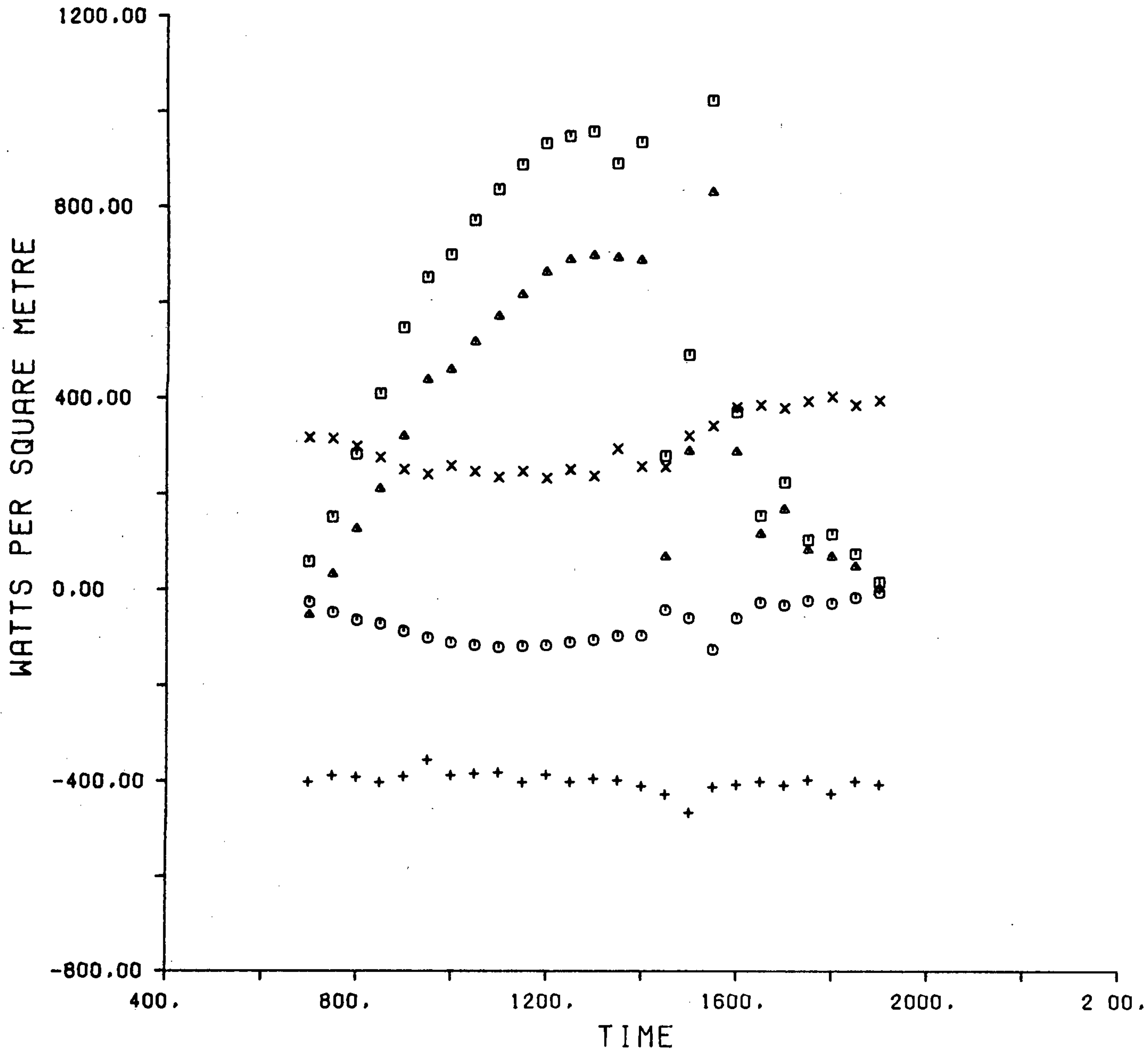
+ OUTGOING LW RADIATION

▲ NET RADIATION



SITE 1 :13/2/80

- ⊡ INCOMING SW RADIATION
- ⊙ OUTGOING SW RADIATION
- × INCOMING LW RADIATION
- \+ OUTGOING LW RADIATION
- ▲ NET RADIATION



SITE 2 : 4/3/80

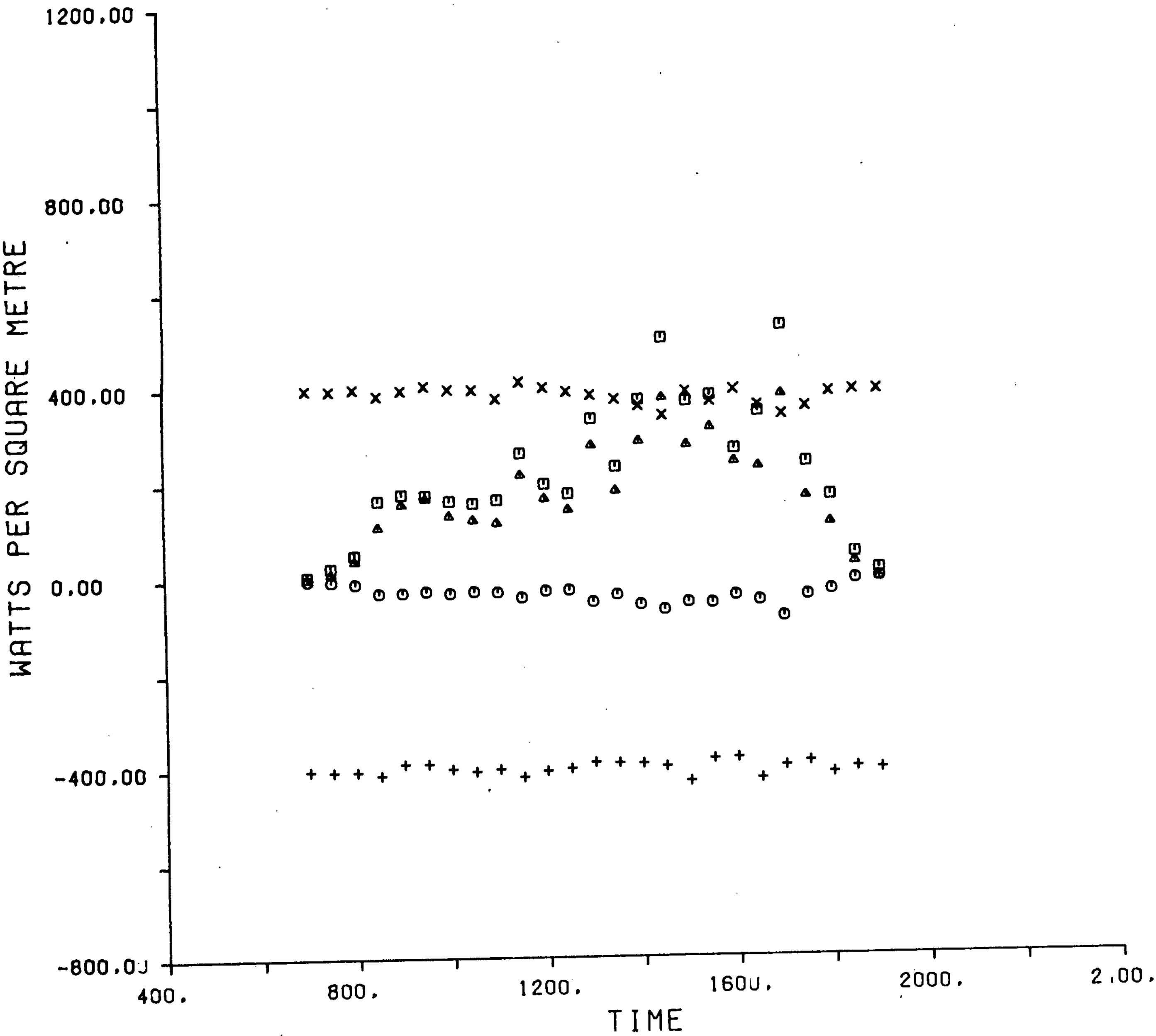
□ INCOMING SW RADIATION

⊙ OUTGOING SW RADIATION

× INCOMING LW RADIATION

+ OUTGOING LW RADIATION

▲ NET RADIATION



SITE 2 : 5/3/80

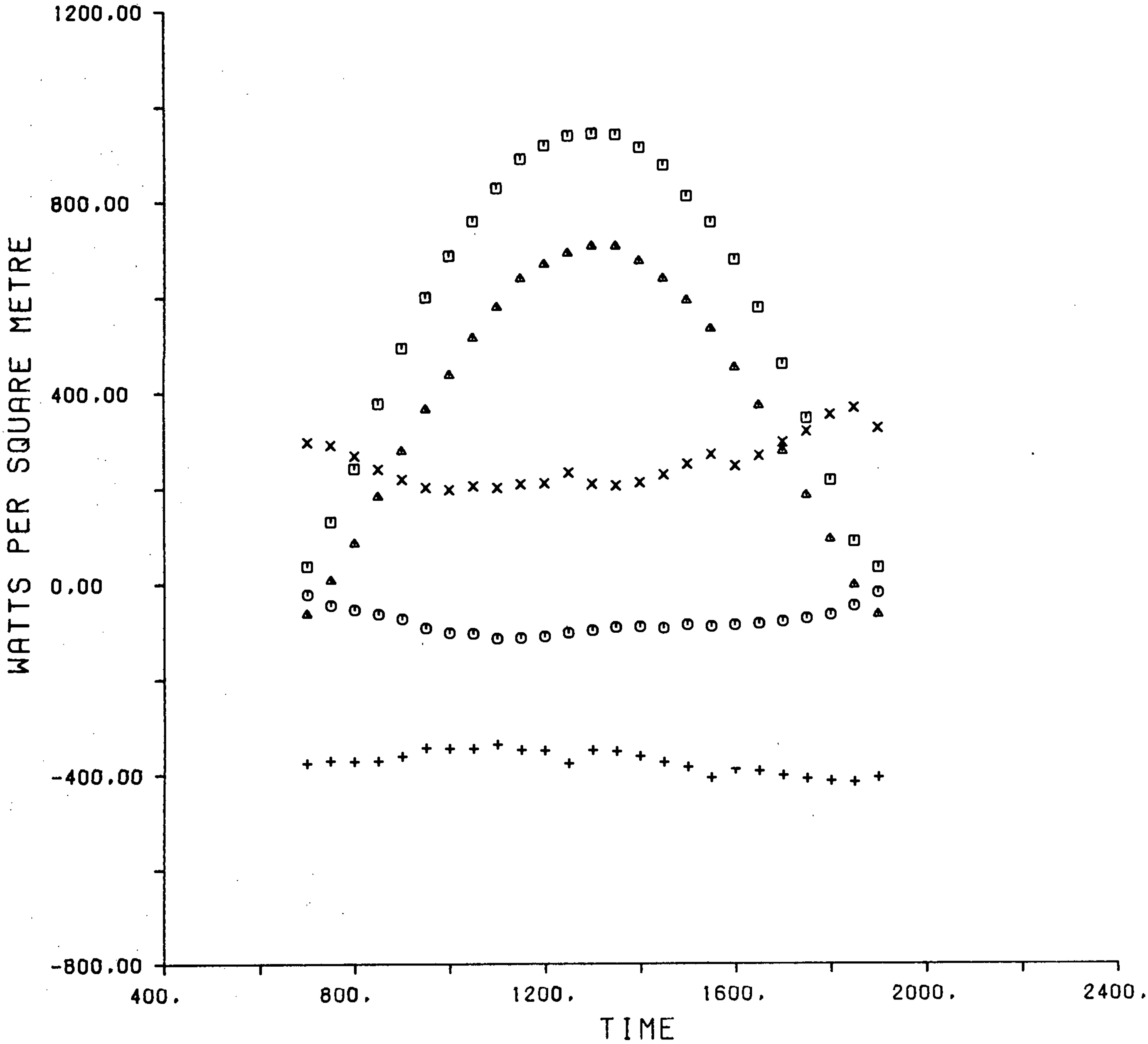
INCOMING SW RADIATION

OUTGOING SW RADIATION

INCOMING LW RADIATION

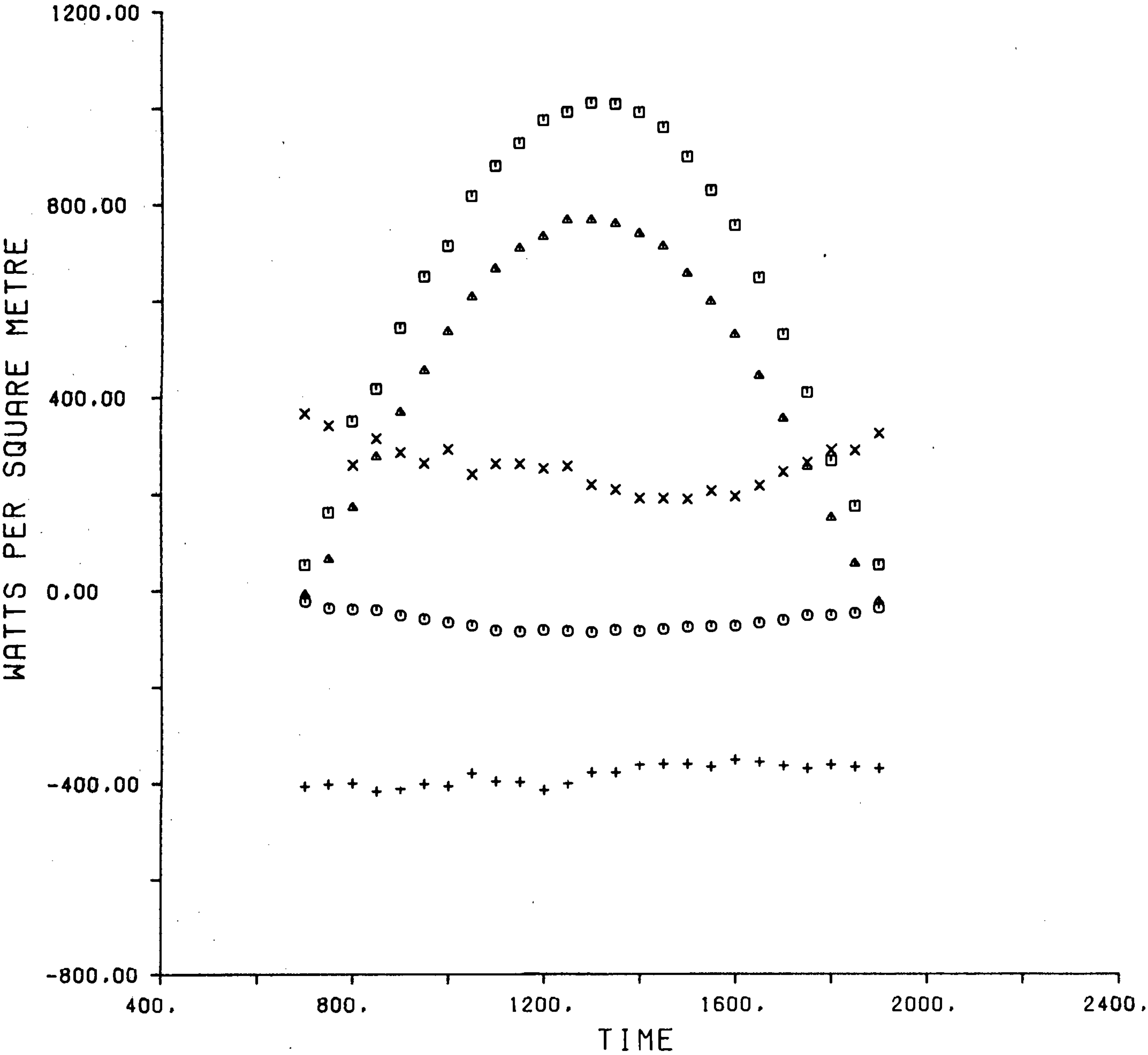
OUTGOING LW RADIATION

NET RADIATION


1200.00
800.00
400.00
0.00
-400.00
-800.00
WATTS PER SQUARE METRE
400.
800.
1200.
1600.
2000.
2400.
TIME

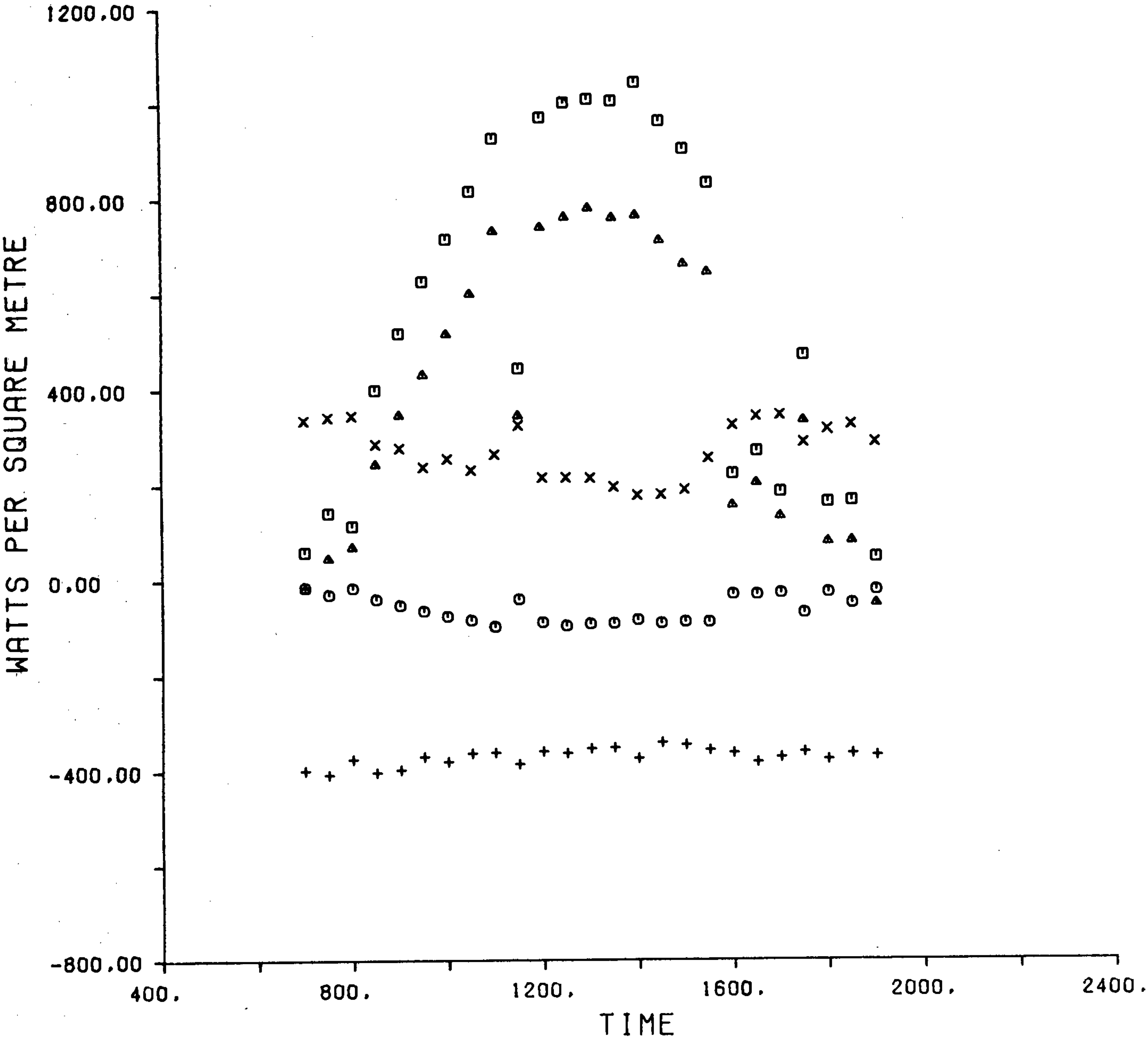
SITE 2 : 9/3/80

INCOMING SW RADIATION
OUTGOING SW RADIATION
INCOMING LW RADIATION
OUTGOING LW RADIATION
NET RADIATION



SITE 3 :25/2/80

- ⊡ INCOMING SW RADIATION
- ⊙ OUTGOING SW RADIATION
- × INCOMING LW RADIATION
- + OUTGOING LW RADIATION
- ▲ NET RADIATION



SITE 3 :27/2/80

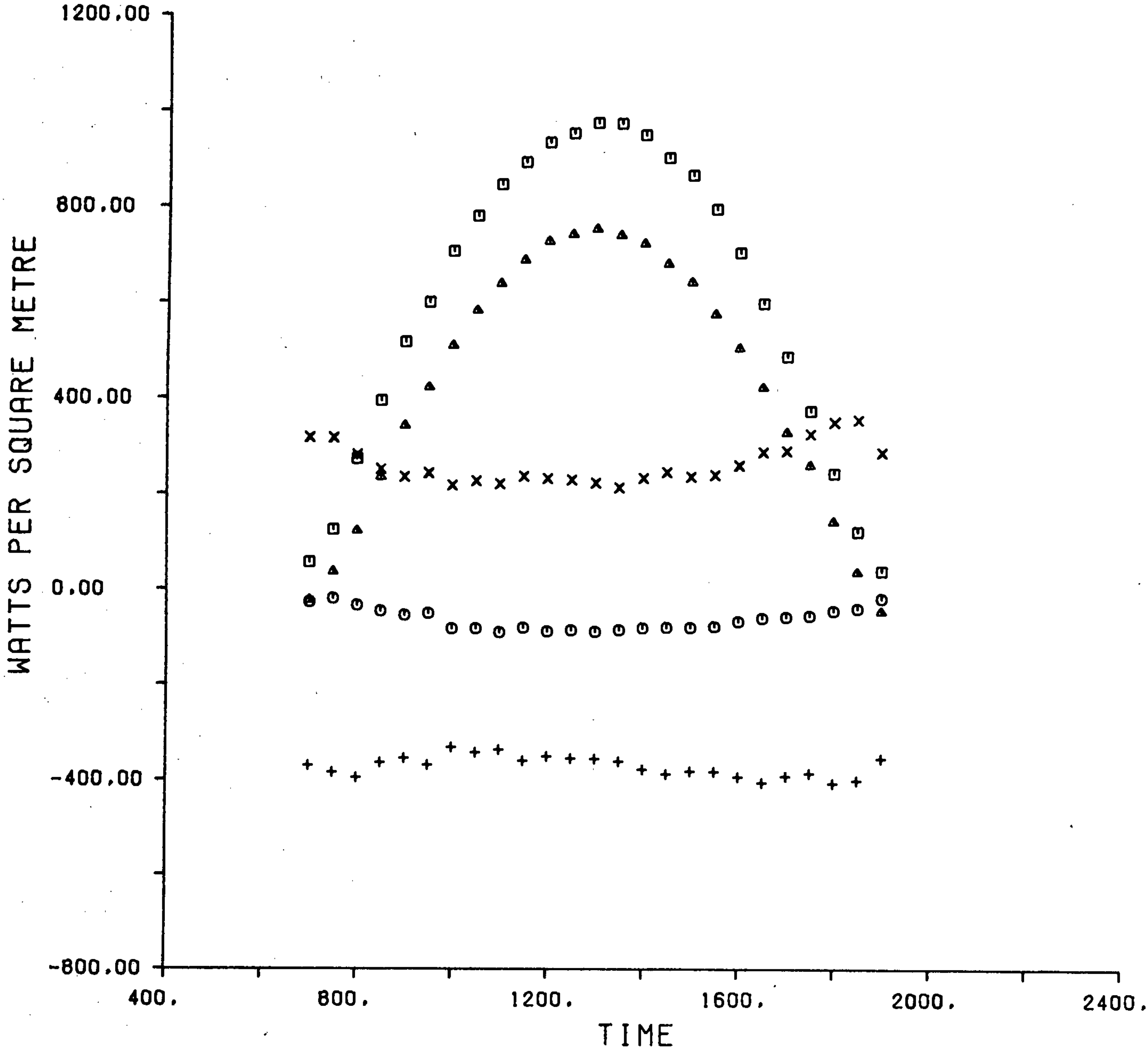
INCOMING SW RADIATION

OUTGOING SW RADIATION

INCOMING LW RADIATION

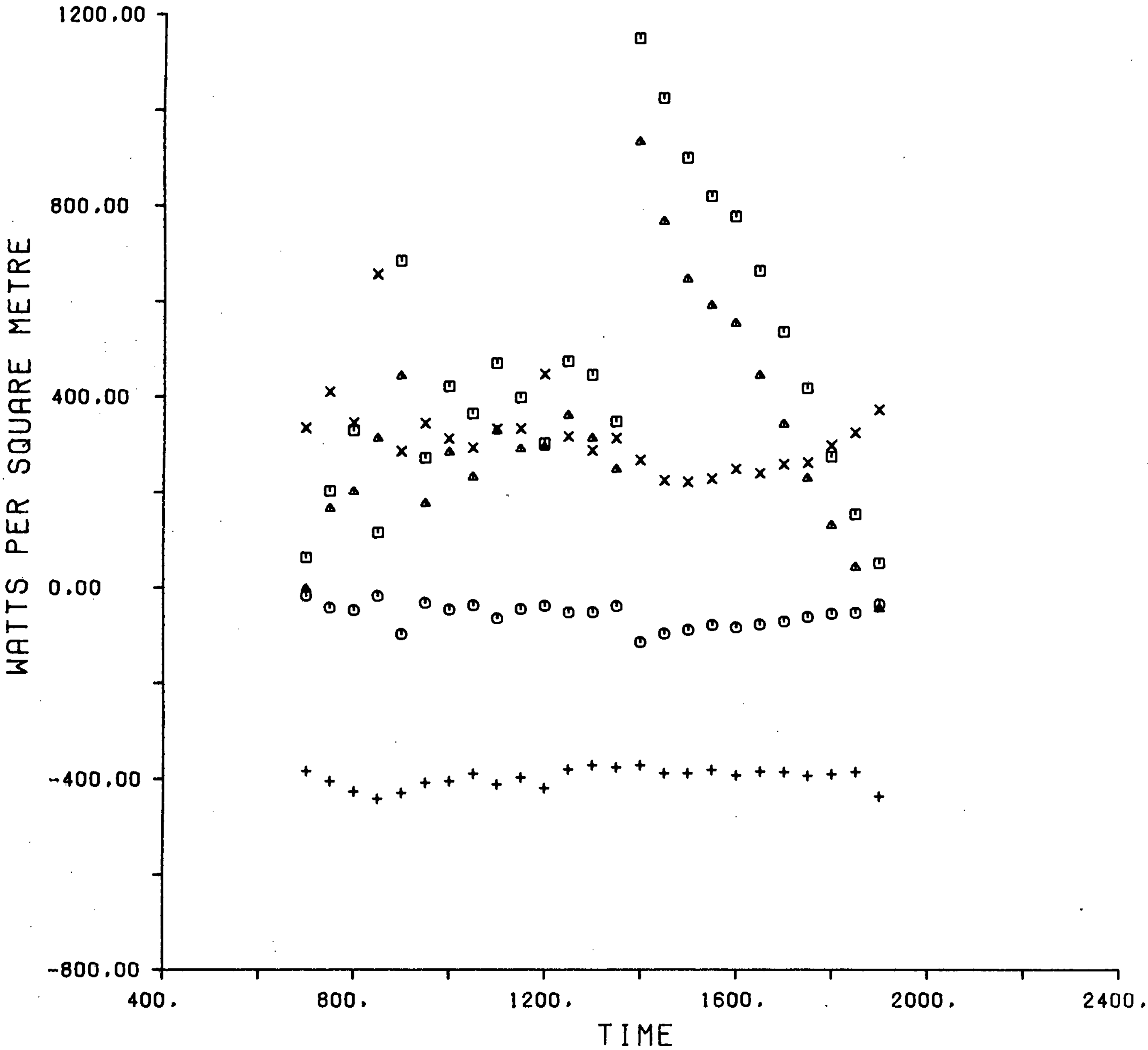
OUTGOING LW RADIAT ON

NET RADIATION


1200.00
800.00
400.00
0.00
-400.00
-800.00
WATTS PER SQUARE METRE
400.
800.
1200.
1600.
2000.
2400.
TIME

SITE 3 : 3/3/80

INCOMING SW RADIATION
OU GOING SW RADIATION
INCOMING LW RADIATION
OUTGOING LW RADIATION
NET RADIATION



SITE 4 :26/2/80

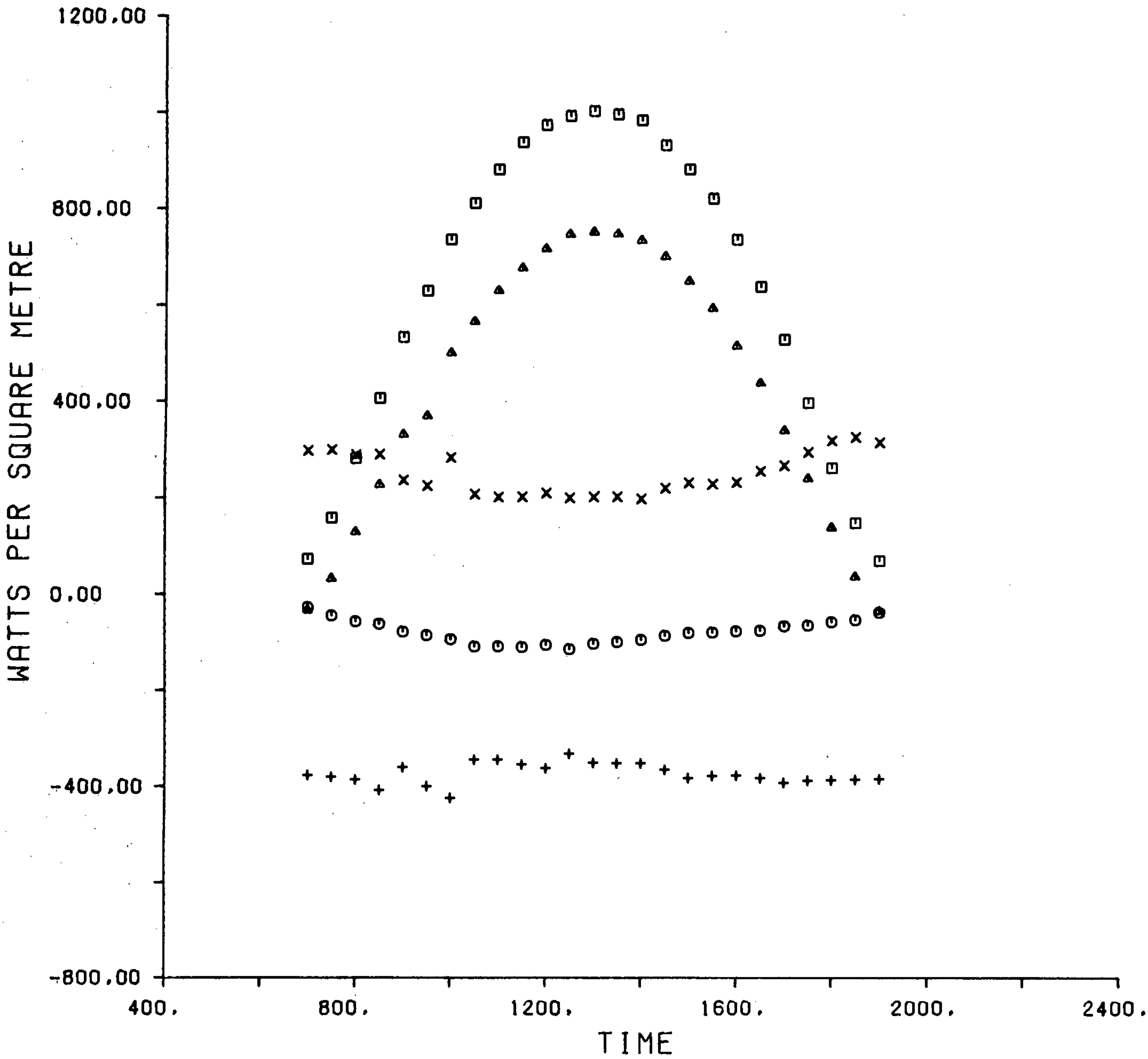
□ INCOMING SW RADIATION

○ OUTGOING SW RADIATION

× INCOMING LW RADIATION

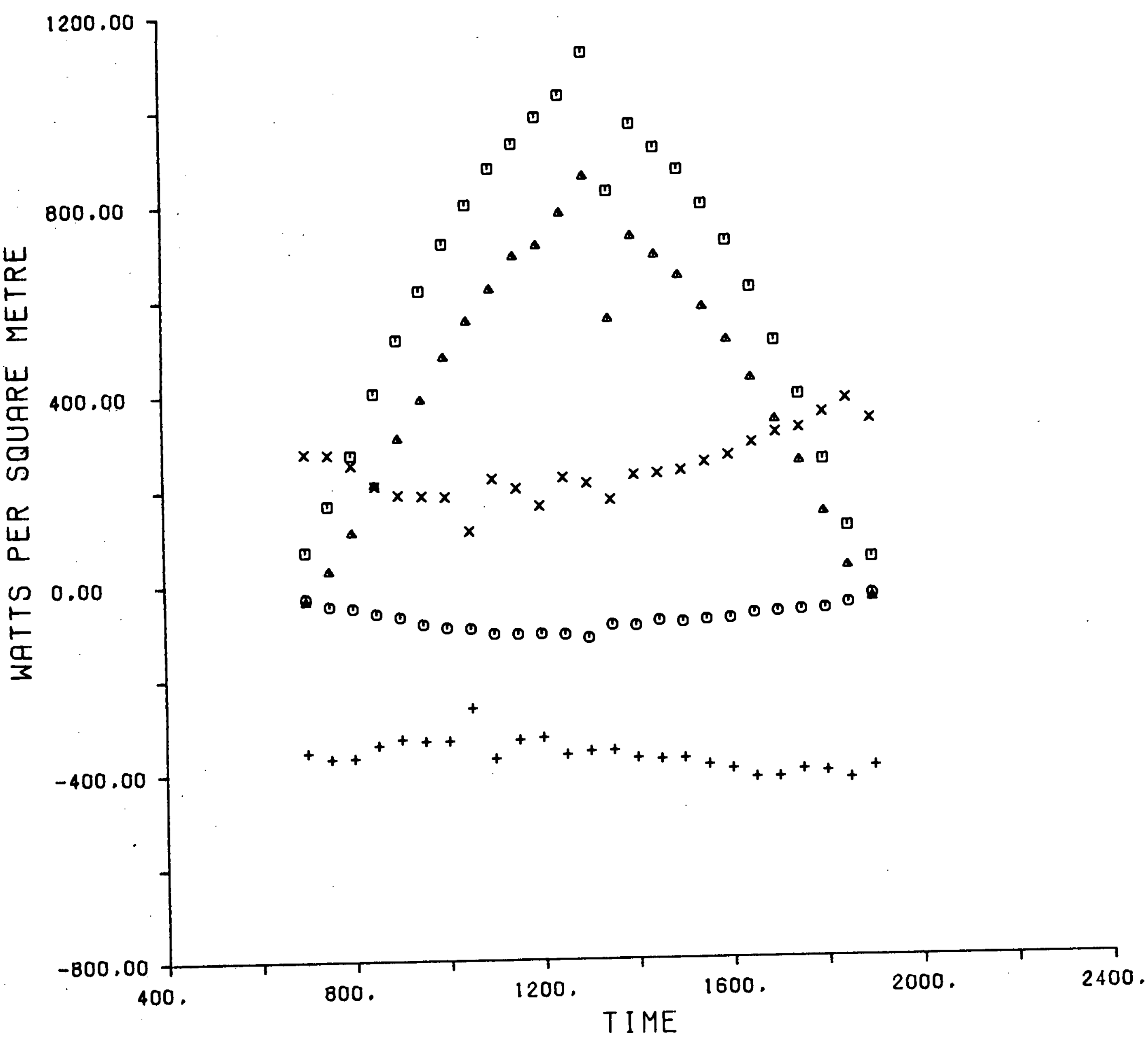
\+ OUTGOING LW RADIATION

△ NET RADIATION



SITE 4 :28/2/80

- ⊡ INCOMING SW RFDIA ION
- ʘ OUTGOING SW RADIATION
- × INCOMING LW RADIATION
- + OUTGOING LW RACIAT ON
- ▲ NET RADIATION



SITE 4 : 2/3/80

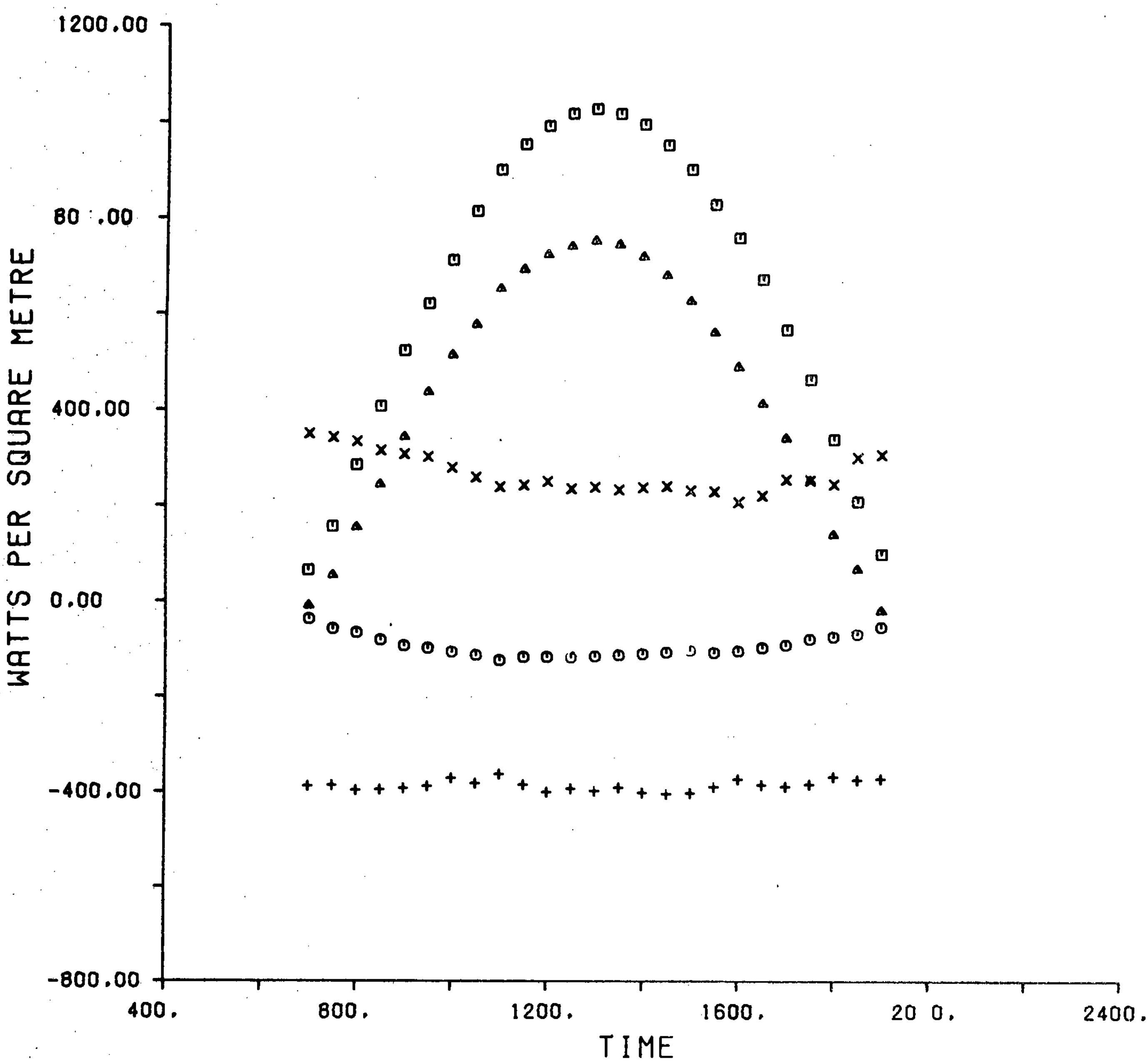
⊡ INCOMING SW RADIATION

⊙ OUTGOING SW RADIATION

× INCOMING LW RADIAT ON

\+ OUTGOING LW RADIAT ON

▲ NET RADIATION



SITE 5 :17/2/80

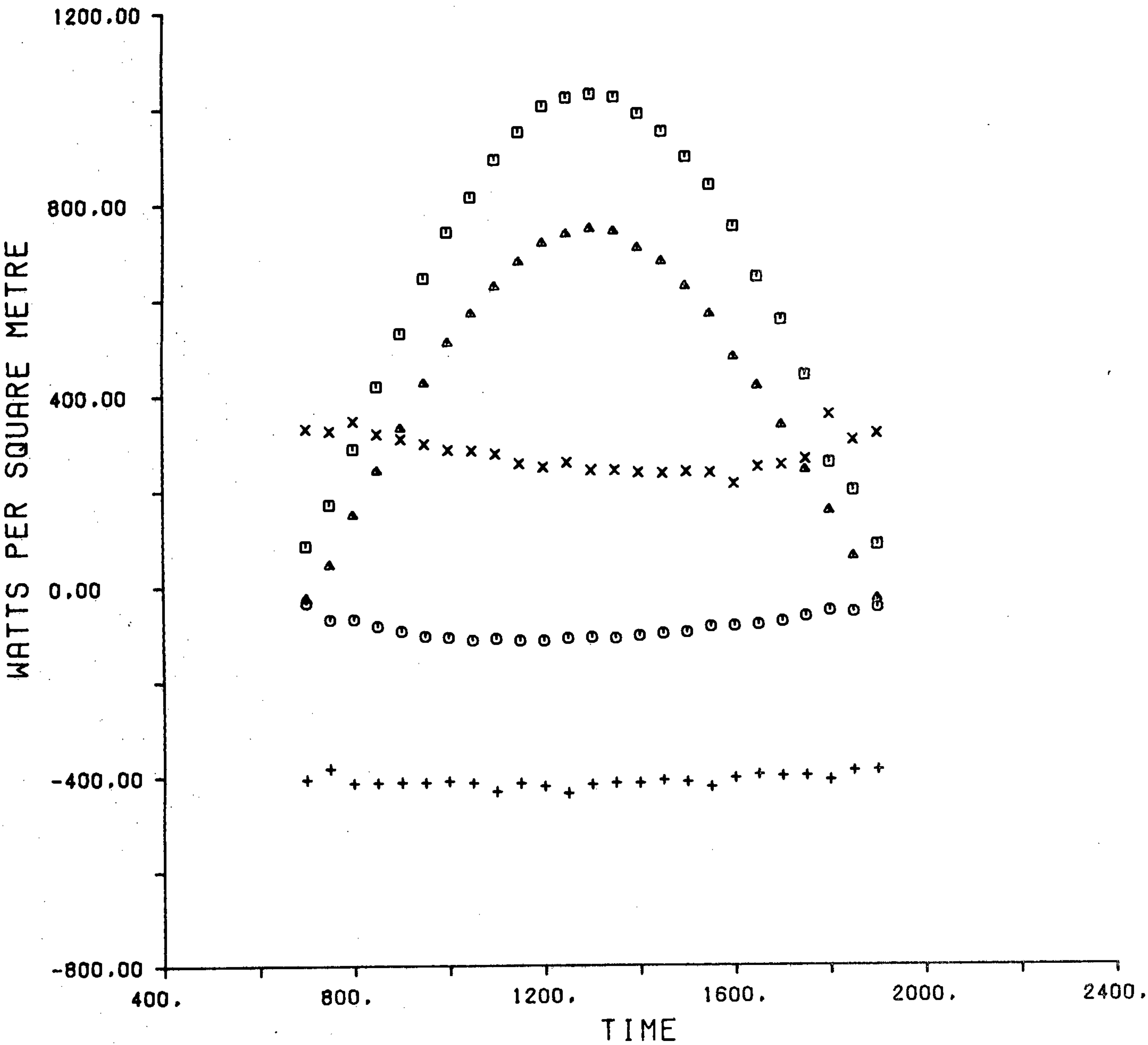
□ INCOMING SW RADIATION

○ OUTGOING SW RADIATION

× INCOMING LW RADIAT ON

\+ OUTGOING LW RADIATION

▲ NET RADIATI ON



SITE 5 :19/2/80

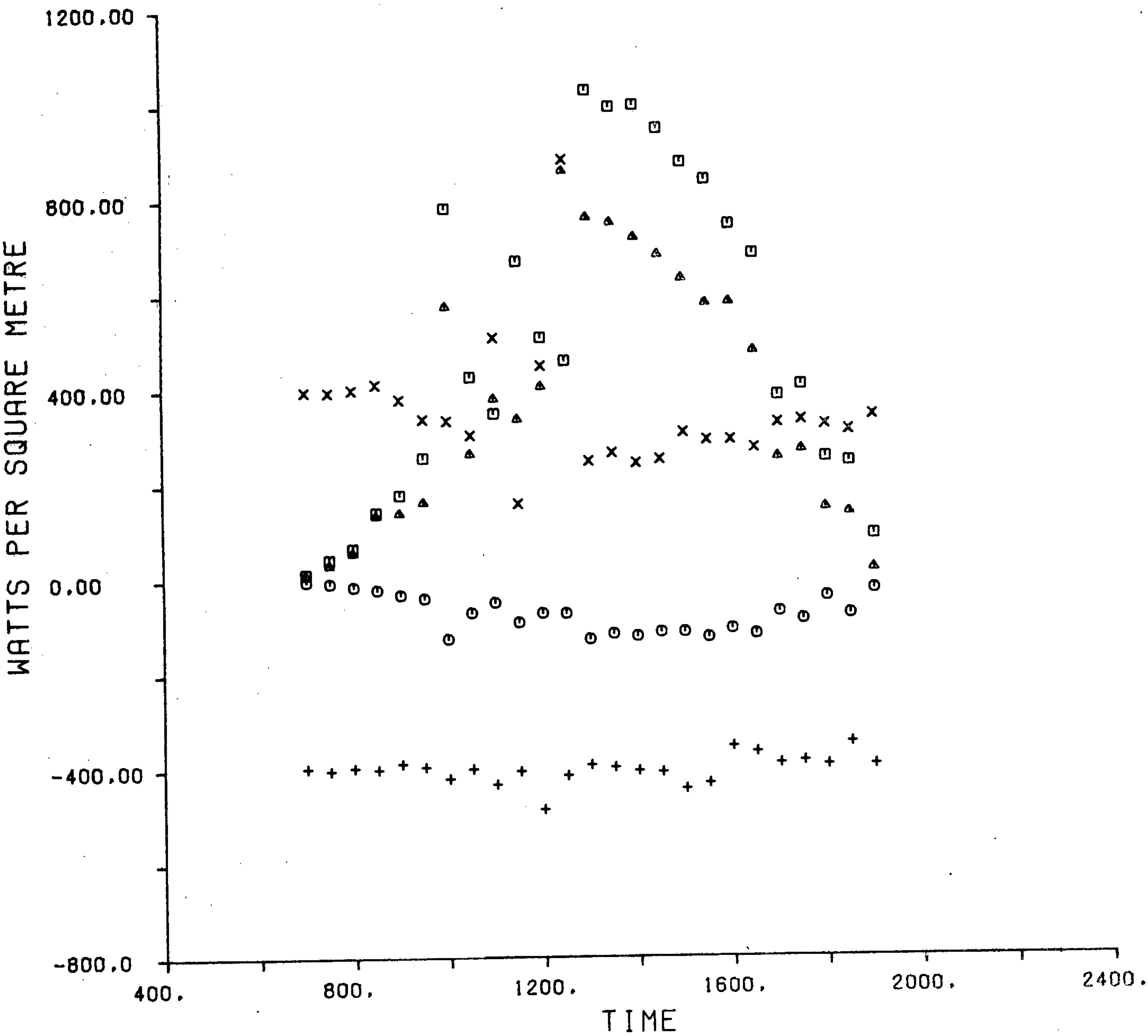
□ INCOMING SW RADIATION

⊙ OUTGOING SW RADIATION

× INCOMING LW RADIATION

+ OUTGOING LW RADIATION

▲ NET RADIATION



SITE 5 :20/2/80

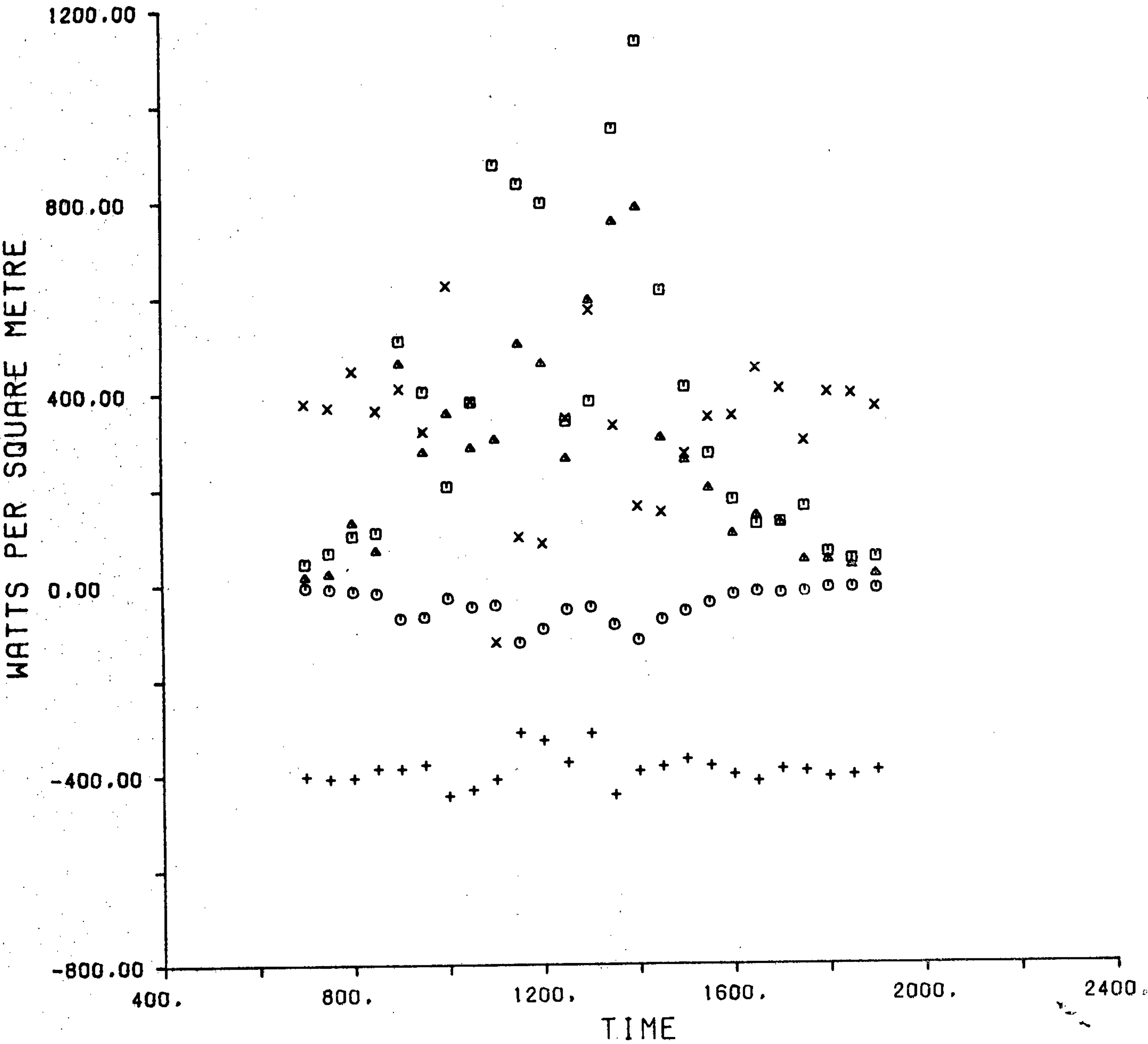
INCOMING SW RADIATION

OU GOING SW RADIATION

INCOMING LW RADIFTION

OUTGOING LW RADIATION

NET RADIATION



SITE 6 :22/2/80

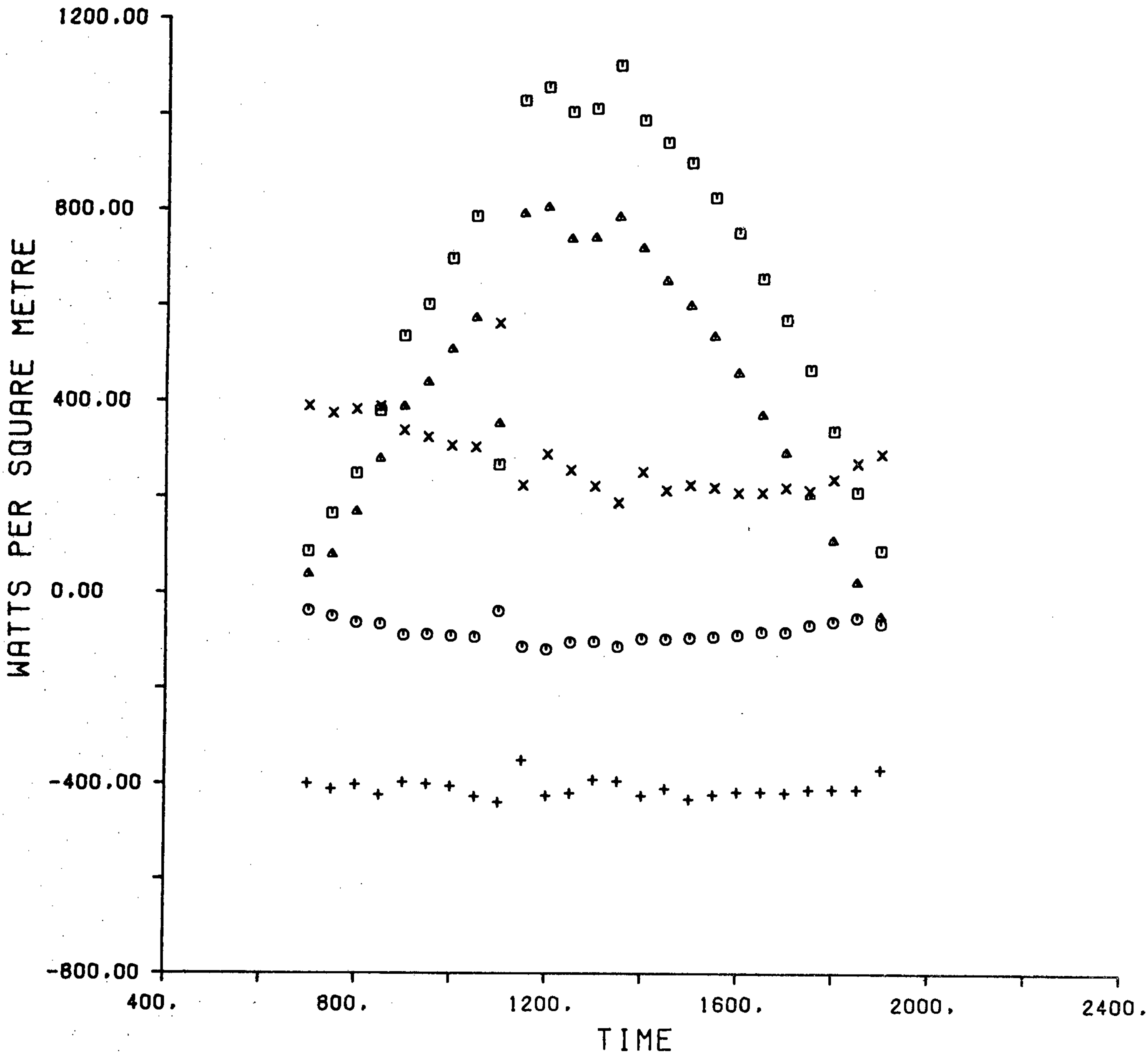
INCOMING SW RADIATION

OUTGOING SW RADIATION

INCOMING LW RADIATION

OUTGOING LW RADIATION

NET RADIATION



SITE 6 :23/2/80

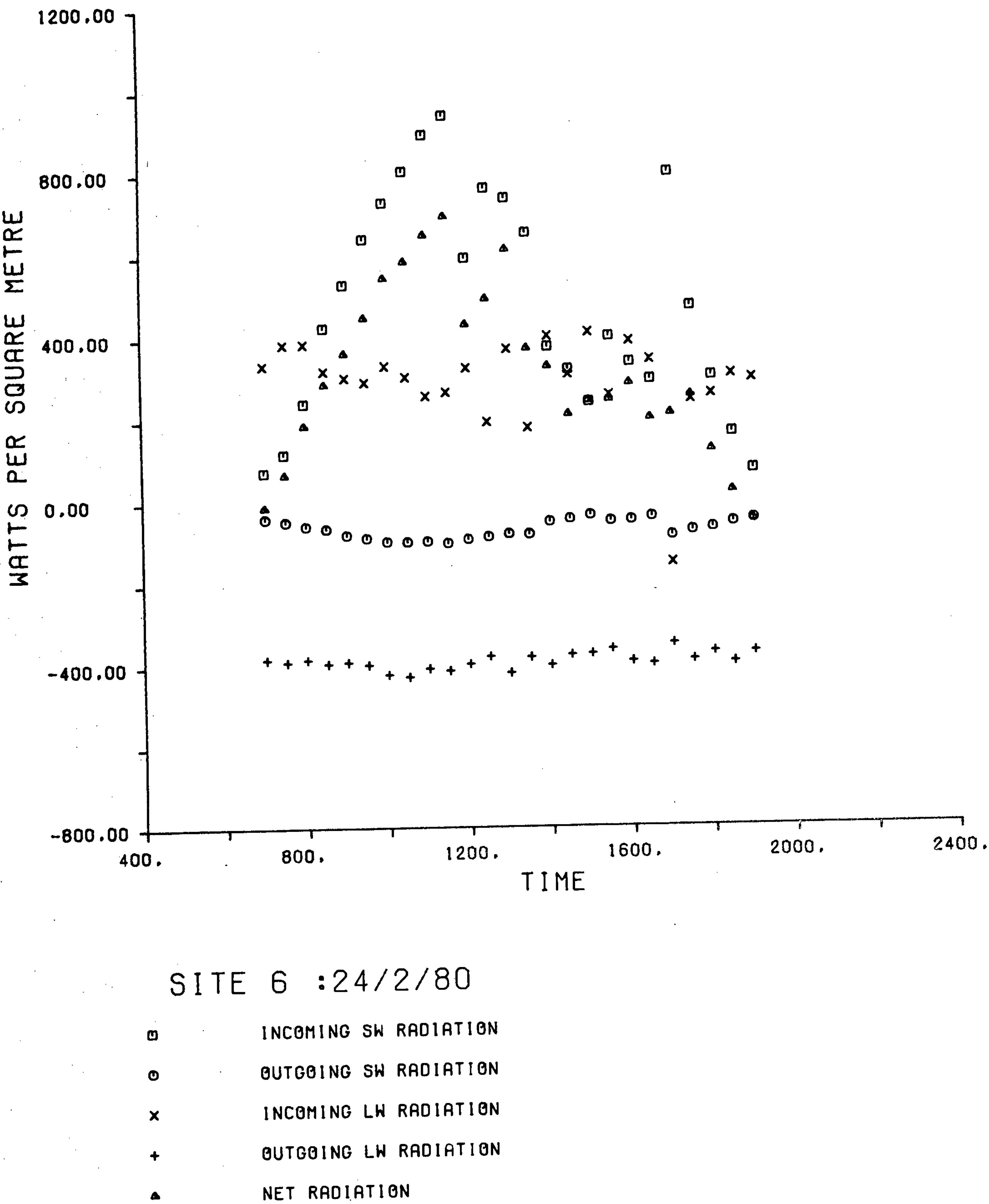
□ INCOMING SW RADIATION

○ OUTGOING SW RADIATION

× INCOMING LW RADIATION

\+ OUTGOING LW RADIATION

▲ NET RADIATION


1200.00
800.00
400.00
0.00
-400.00
-800.00
WATTS PER SQUARE METRE
400.
800.
1200.
1600.
2000.
2400.
TIME
SITE 6 :24/2/80
INCOMING SW RADIATION
OUTGOING SW RADIATION
INCOMING LW RADIATION
OUTGOING LW RADIATION
NET RADIATION

APPENDIX 4

DETAIL OF FIGURES 4.1 TO 4.4

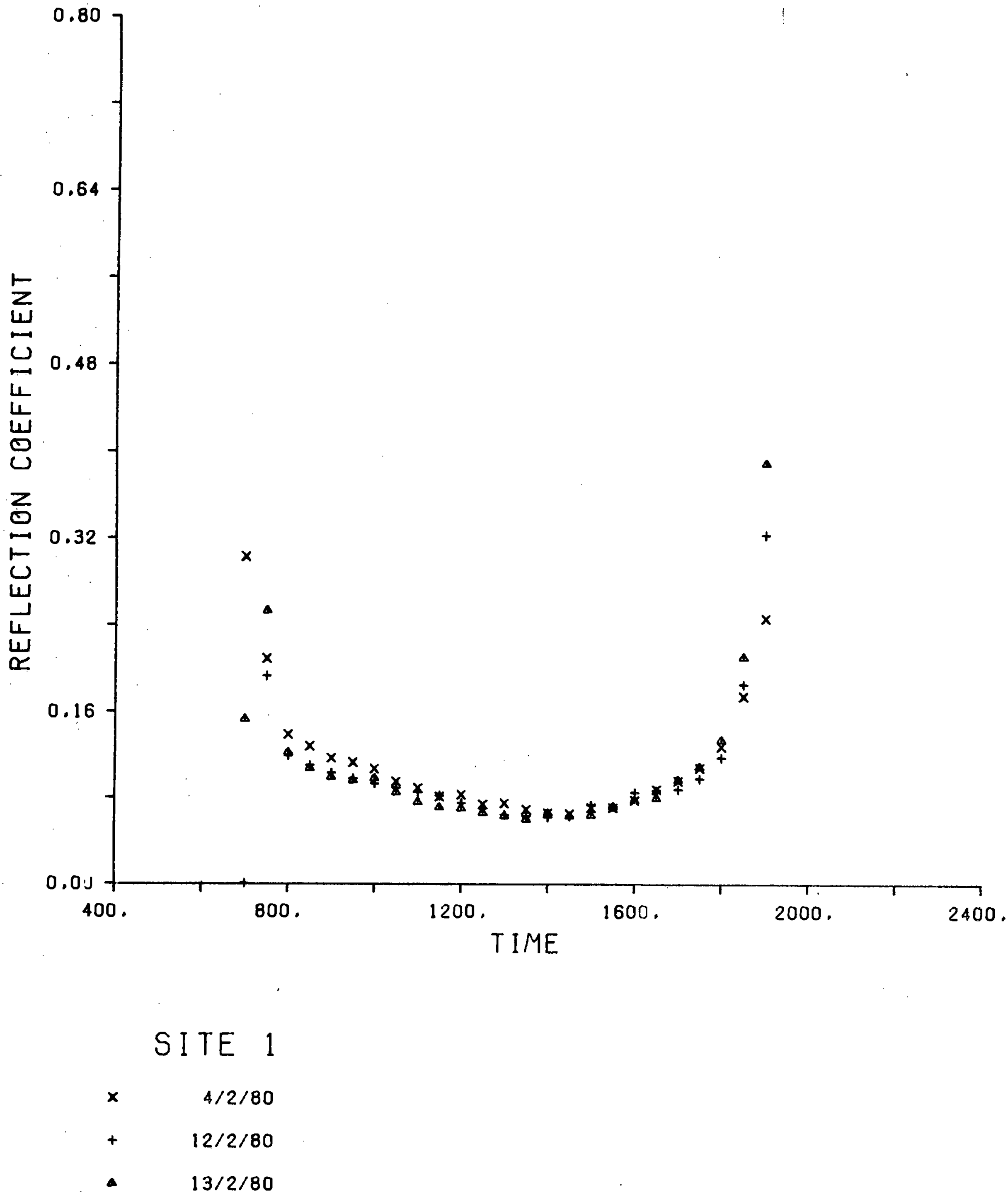
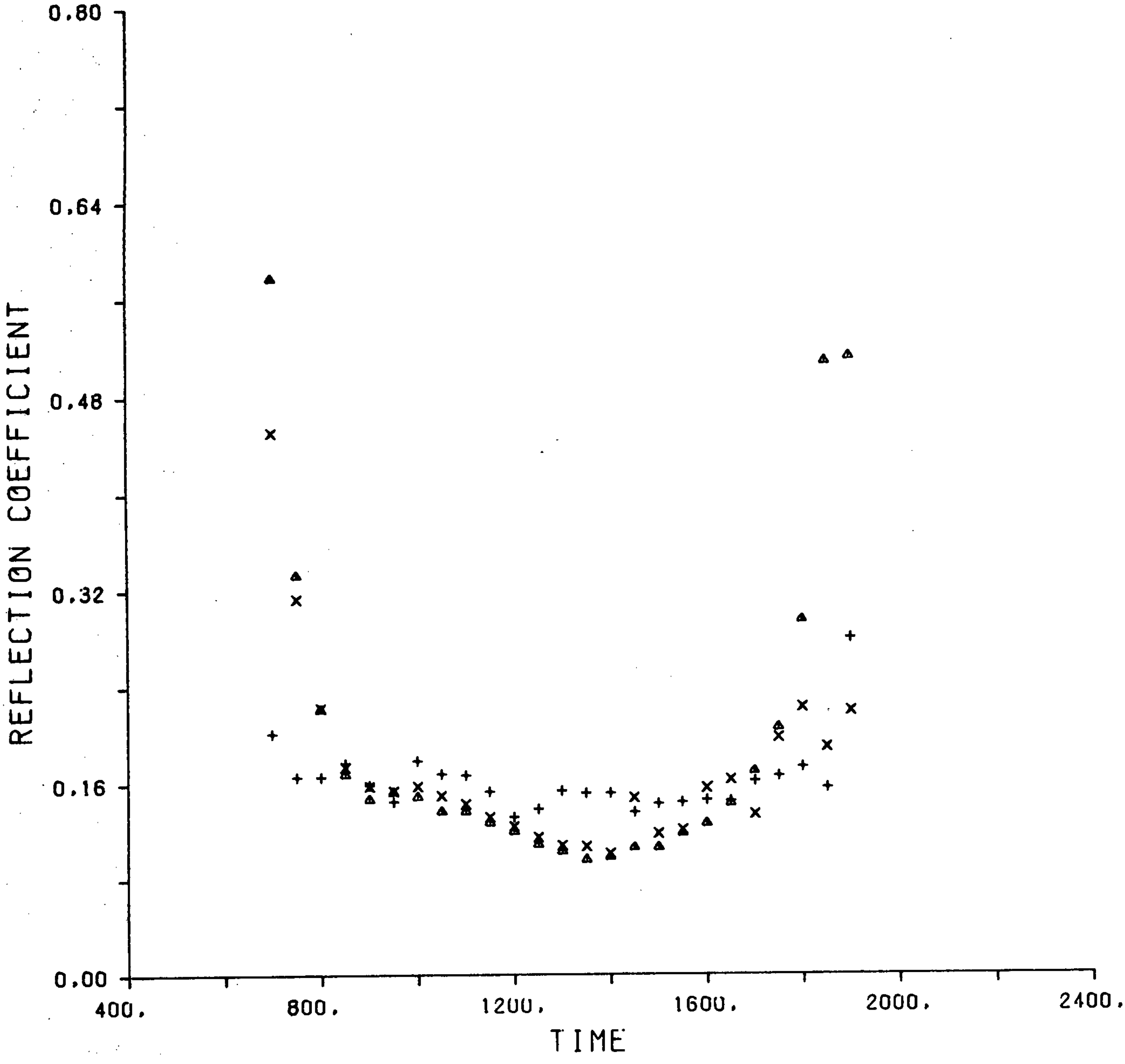

0.80
0.64
0.48
0.32
0.16
0.00
REFLECTION COEFFICIENT
400.
800.
1200.
1600.
2000.
2400.
TIME
SITE 1
× 4/2/80
+ 12/2/80
▲ 13/2/80

Figure 4.la



SITE 2

× 4/3/80

+ 5/3/80

▲ 9/3/80

Figure 4.1b

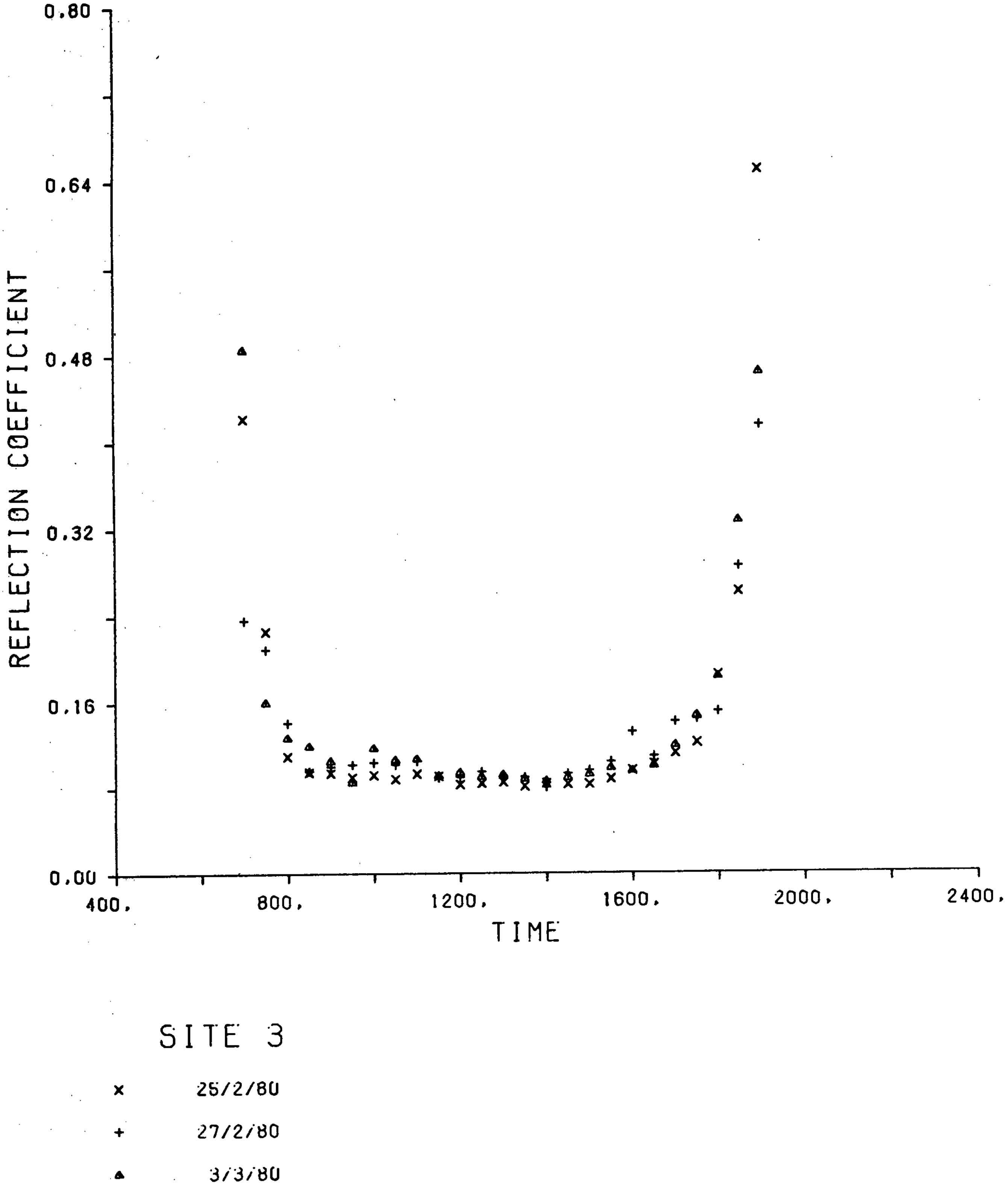
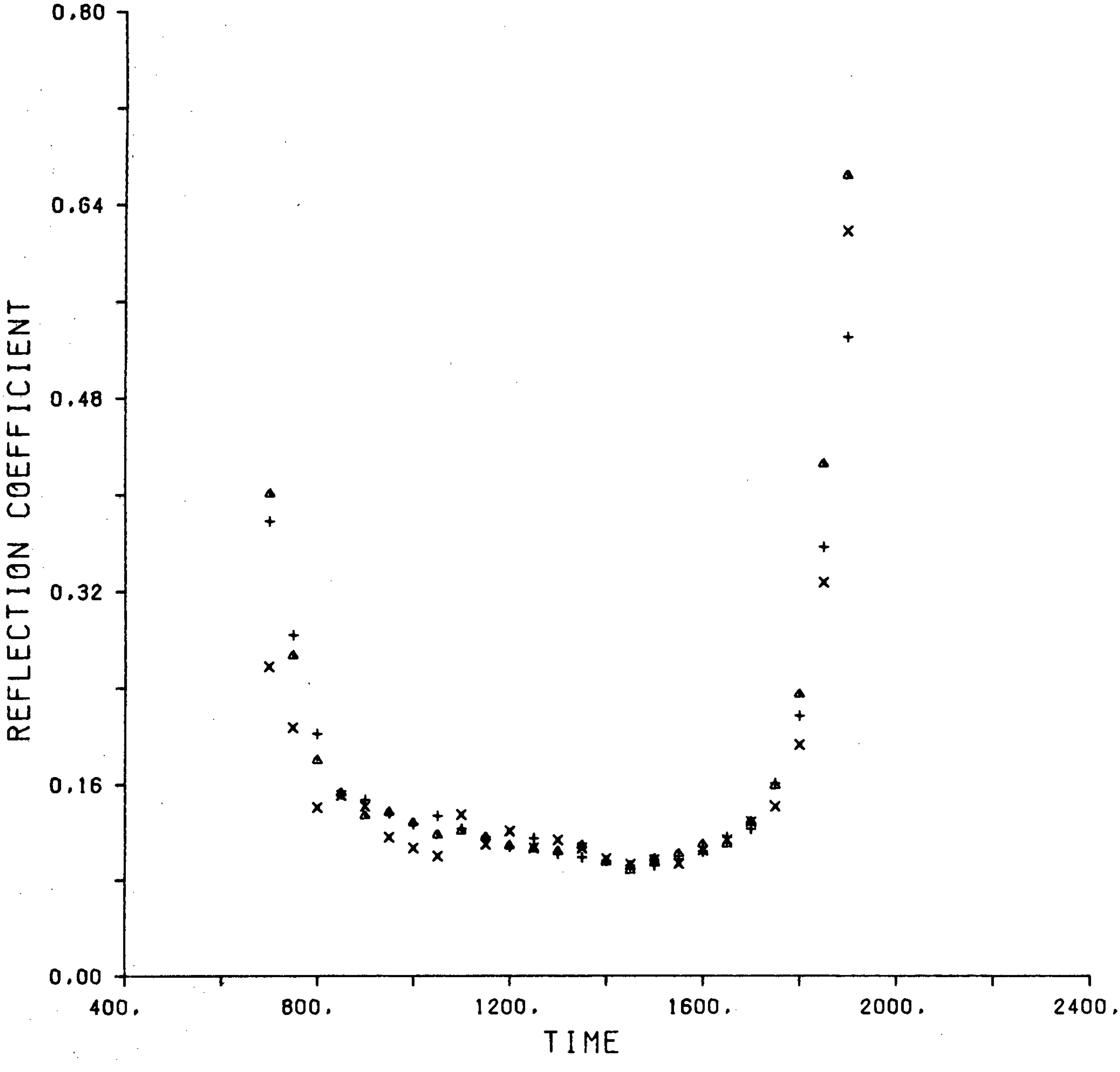

REFLECTION COEFFICIENT
0.80
0.64
0.48
0.32
0.16
0.00
400.
800.
1200.
1600.
2000.
2400.
TIME
SITE 3
× 25/2/80
+ 27/2/80
▵ 3/3/80

Figure 4.1c



SITE 4

× 26/2/80

+ 28/2/80

▲ 2/3/80

Figure 4.1d

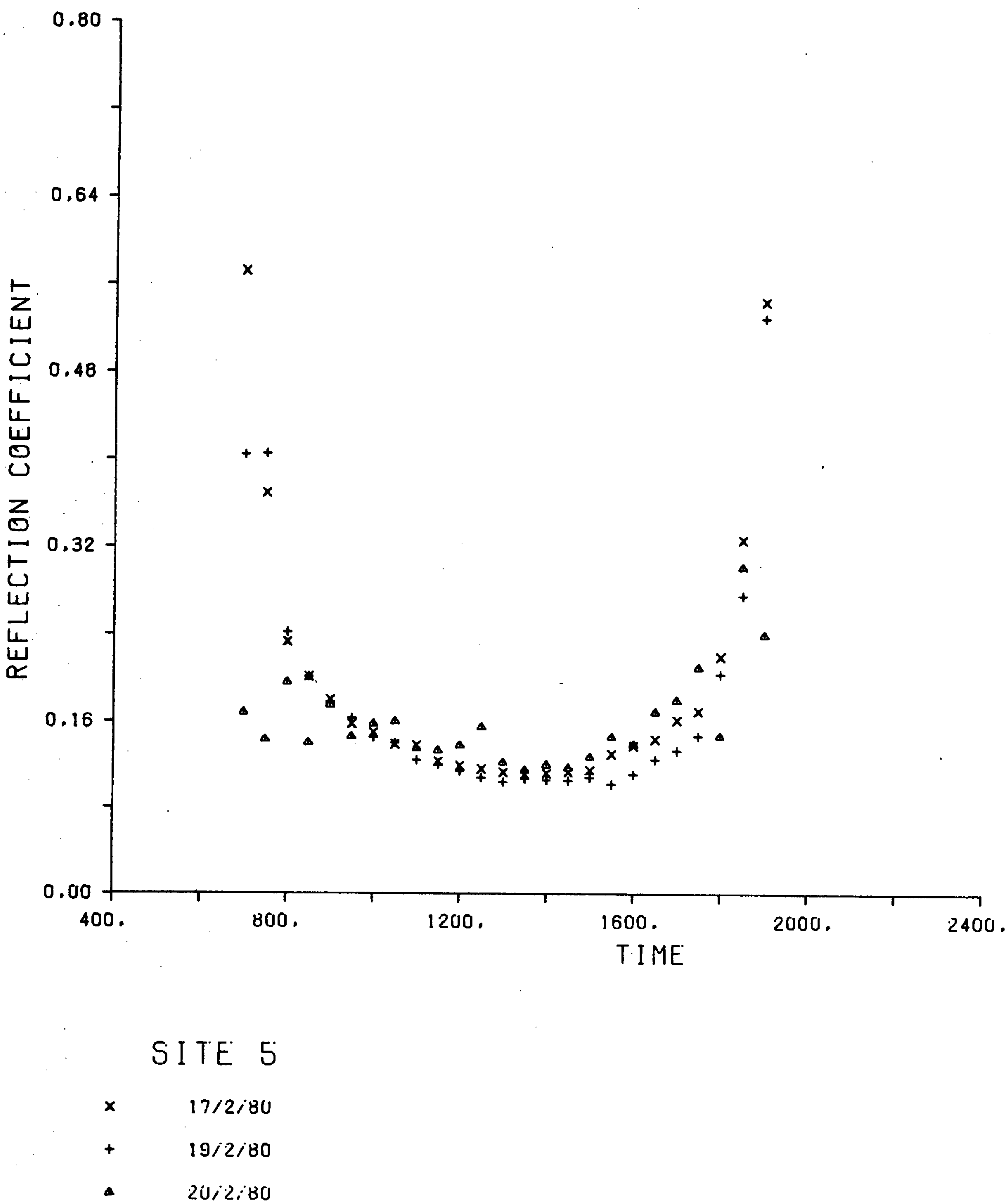
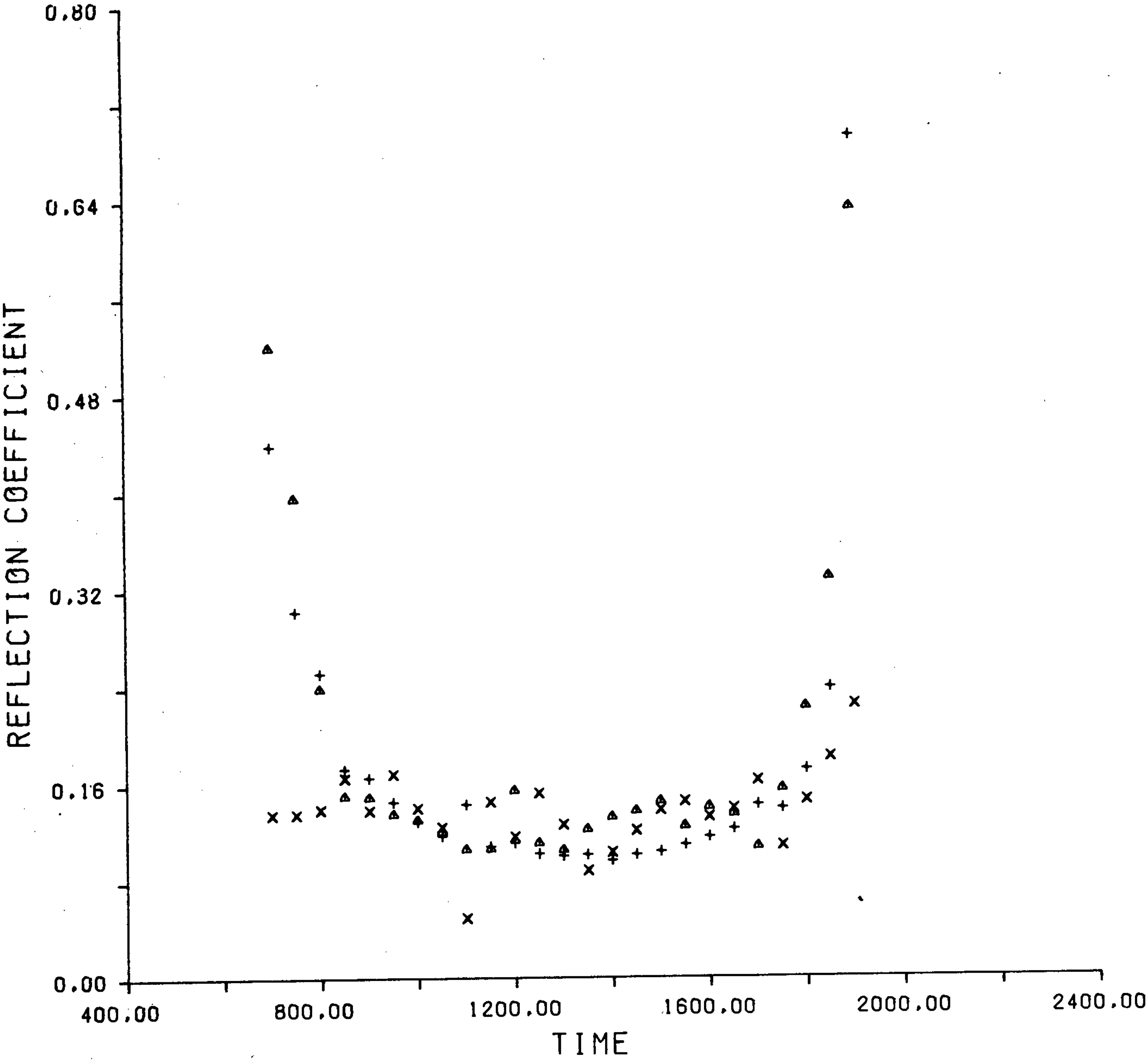

0.80
0.64
0.48
0.32
0.16
0.00
REFLECTION COEFFICIENT
400.
800.
1200.
1600.
2000.
2400.
TIME
SITE 5
17/2/80
19/2/80
20/2/80

Figure 4.1e



SITE 6

× 22/2/80

+ 23/2/80

▵ 24/2/80

Figure 4.1f

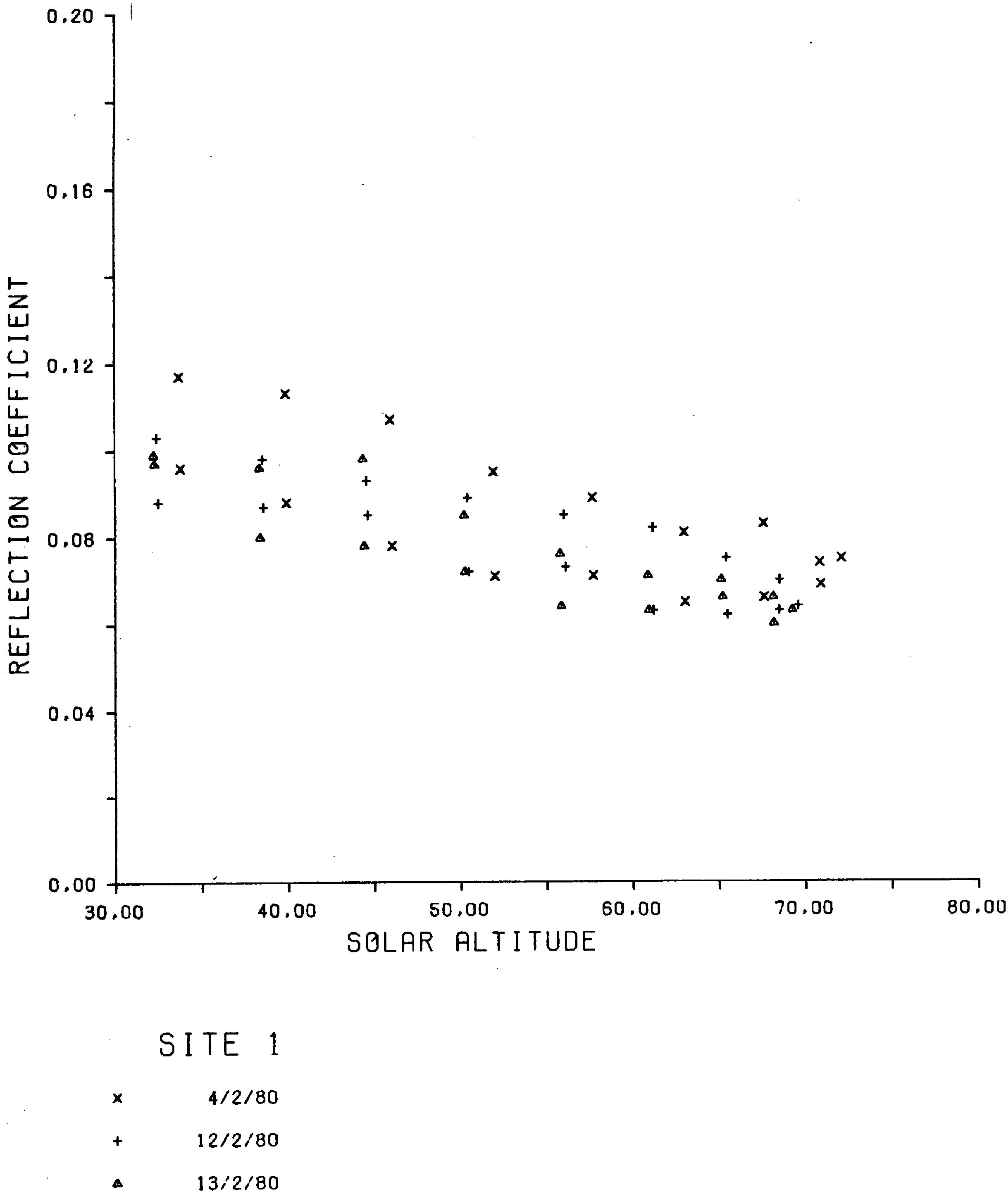

0.20
0.16
0.12
0.08
0.04
0.00
REFLECTION COEFFICIENT
30.00
40.00
50.00
60.00
70.00
80.00
SOLAR ALTITUDE
SITE 1
× 4/2/80
+ 12/2/80
△ 13/2/80

Figure 4.2a

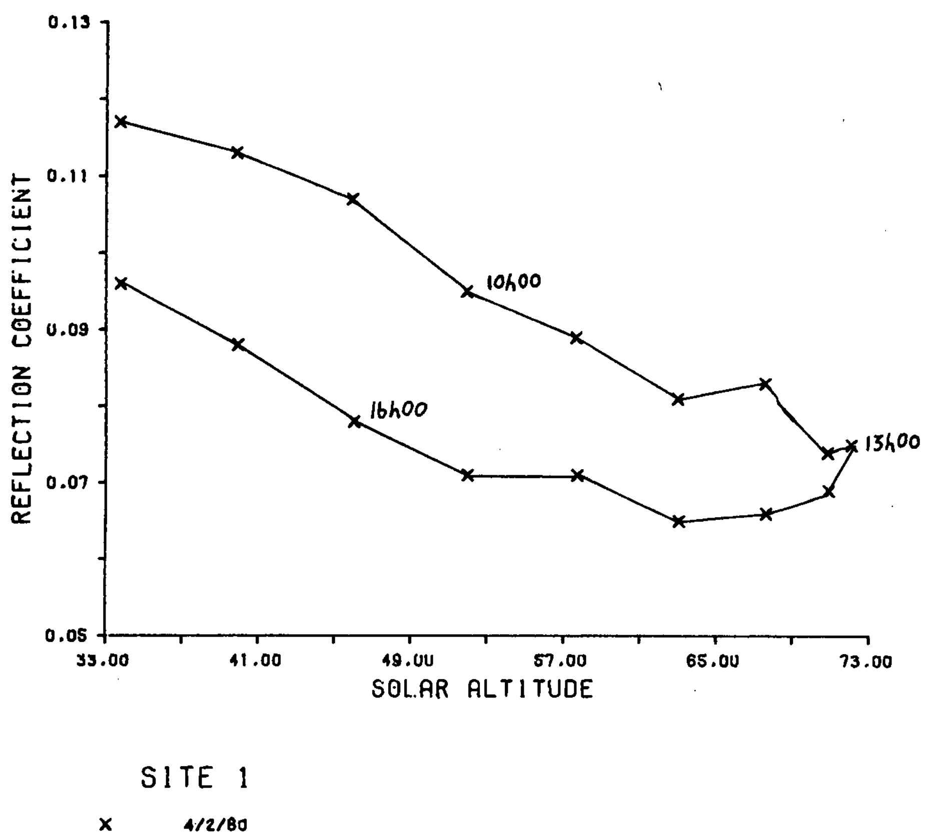
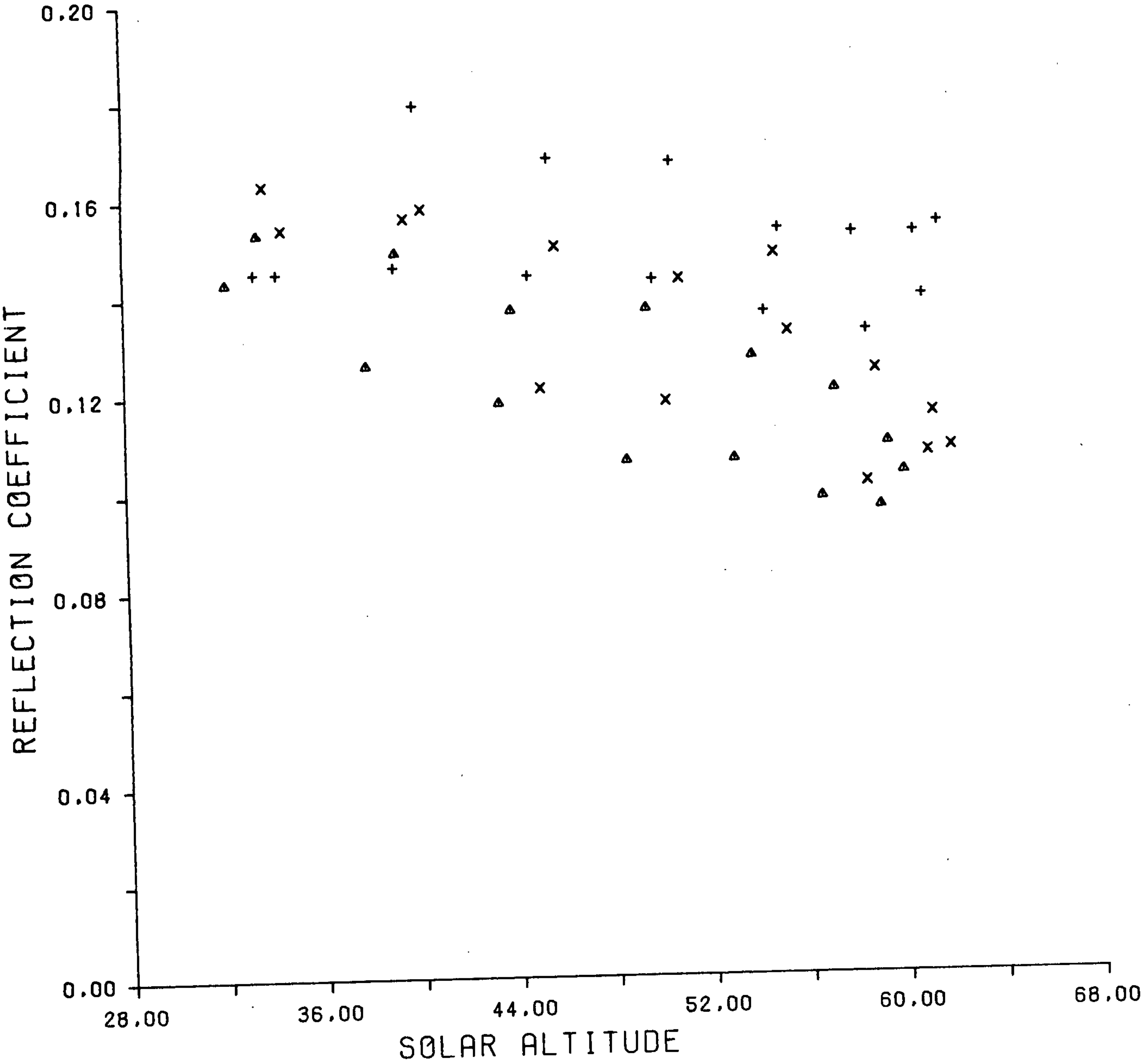

0.13
0.11
0.09
0.07
0.05
REFLECTION COEFFICIENT
33.00
41.00
49.00
57.00
65.00
73.00
SOLAR ALTITUDE
10h00
16h00
13h00
SITE 1
x 4/2/80

Figure 4.2b



SITE 2

× 4/3/80

+ 5/3/80

△ 9/3/80

Figure 4.2c

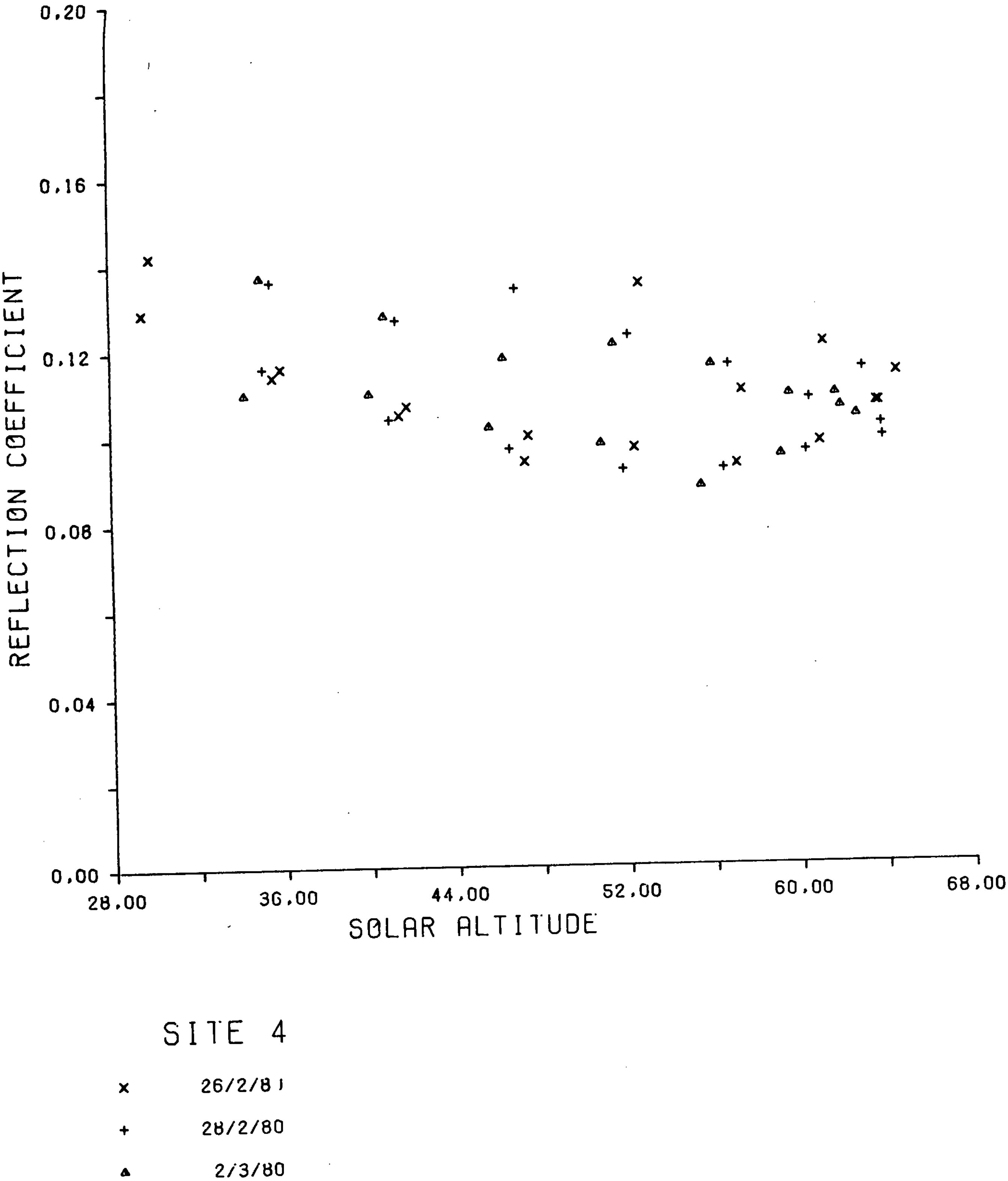

0.20
0.16
0.12
0.08
0.04
0.00
REFLECTION COEFFICIENT
28.00
36.00
44.00
52.00
60.00
68.00
SOLAR ALTITUDE
SITE 4
× 26/2/81
+ 28/2/80
▲ 2/3/80

Figure 4.2d

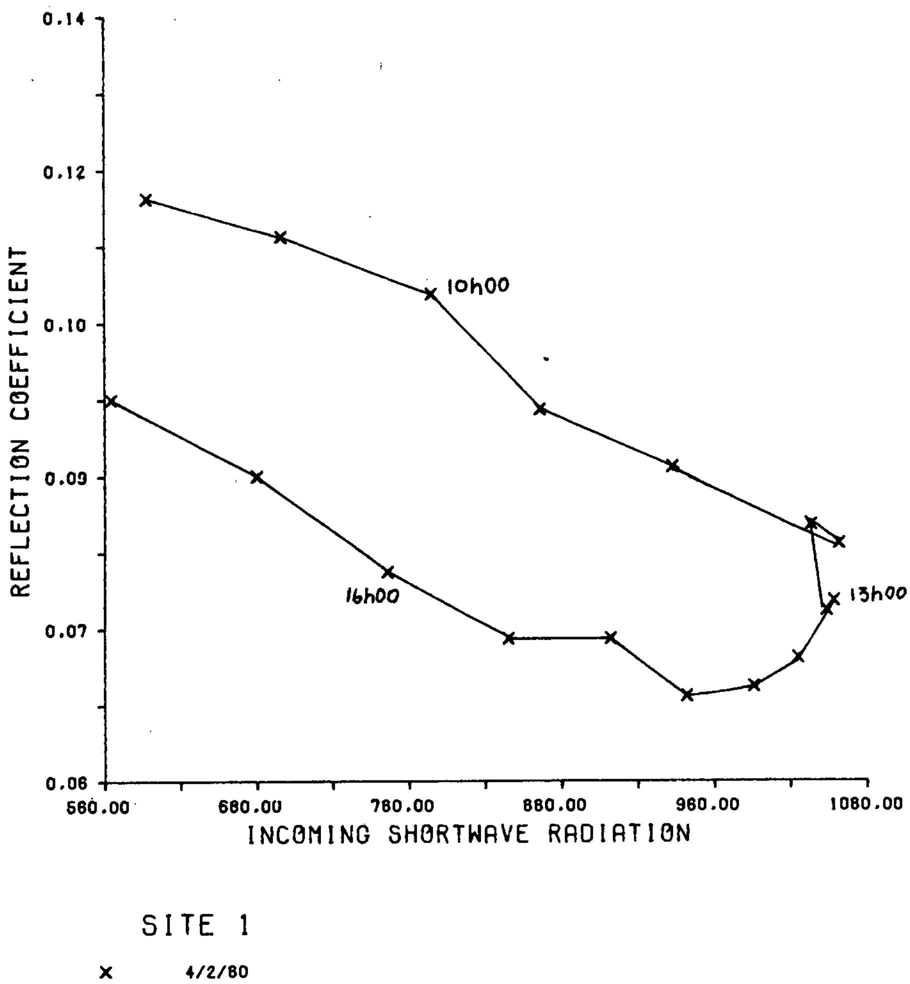

0.14
0.12
0.10
0.09
0.07
0.06
REFLECTION COEFFICIENT
10h00
16h00
13h00
560.00
680.00
780.00
880.00
960.00
1080.00
INCOMING SHORTWAVE RADIATION
SITE 1
x 4/2/80

Figure 4.3a

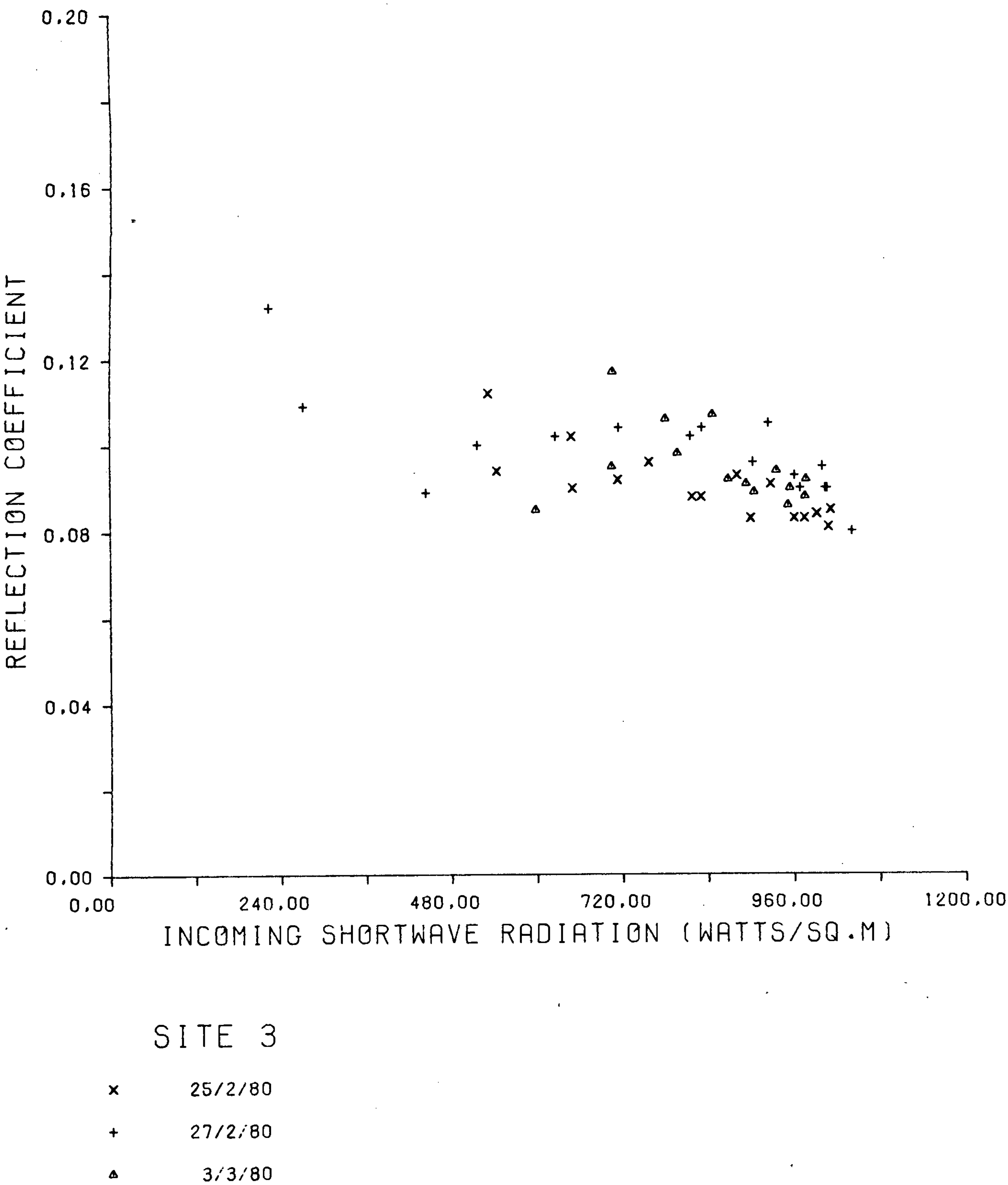
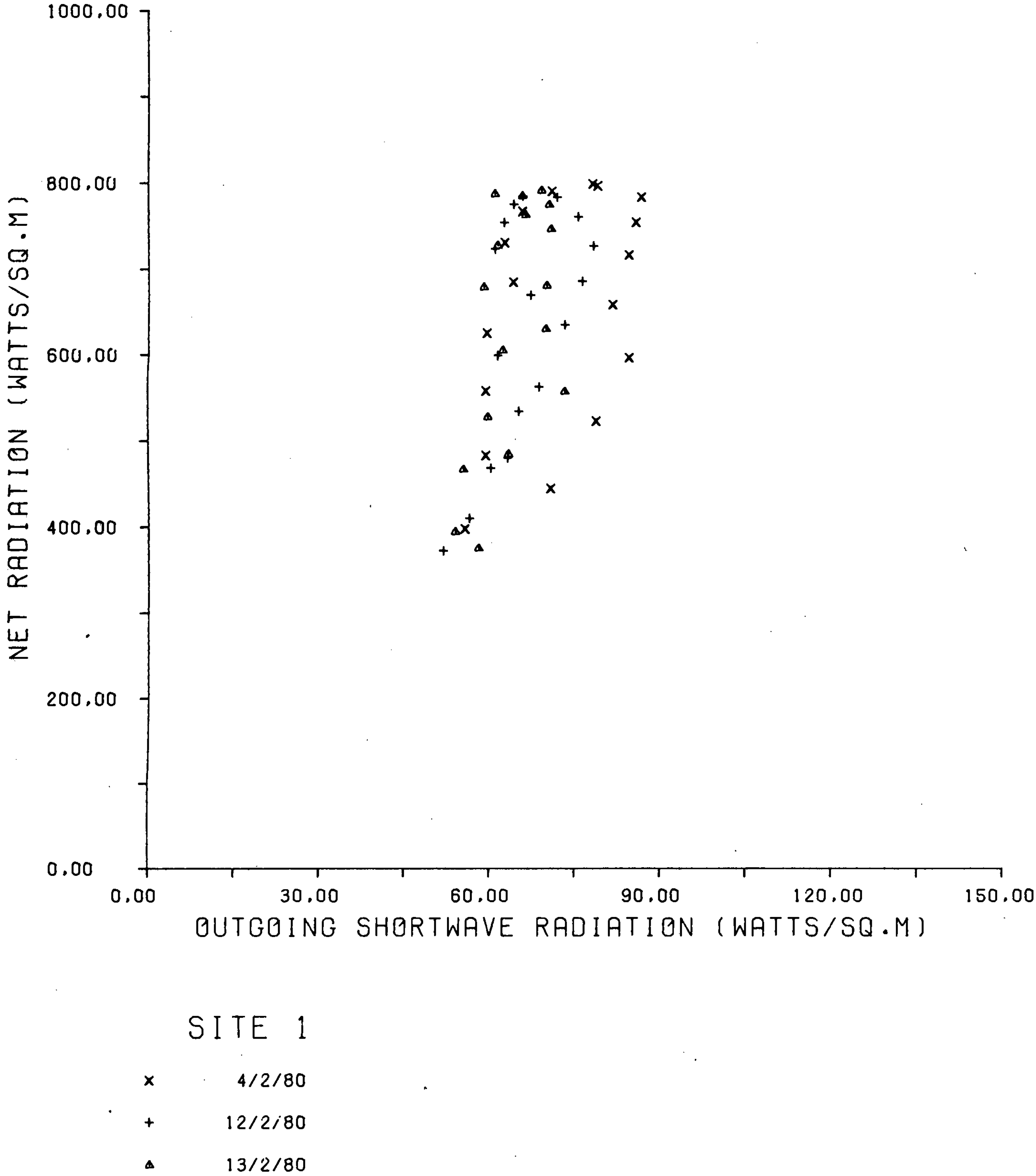

0.20
0.16
0.12
0.08
0.04
0.00
REFLECTION COEFFICIENT
0.00
240.00
480.00
720.00
960.00
1200.00
INCOMING SHORTWAVE RADIATION (WATTS/SQ.M)
SITE 3
× 25/2/80
+ 27/2/80
Δ 3/3/80

Figure 4.3b



1000.00
800.00
600.00
400.00
200.00
0.00
NET RADIATION (WATTS/SQ.M)
0.00
30.00
60.00
90.00
120.00
150.00
OUTGOING SHORTWAVE RADIATION (WATTS/SQ.M)
SITE 1
× 4/2/80
+ 12/2/80
Δ 13/2/80

Figure 4.4