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WHITECAPS AND THE MARINE ATMOSPHERE

REPORT No. 6

by

David M. Doyle

Capaill Mhananáinn agus Caitheadh na dtonn

Aigeaneolaíocht Fhisiciúil

UNIVERSITY COLLEGE,

GALWAY, IRELAND.

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MARINE AEROSOL RESEARCH IN THE GULF OF ALASKA AND ON THE IRISH WEST COAST (INISHMORE)

by

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"Whitecaps and the Marine Atmosphere"
Report No. 6

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Thesis presented for degree of M. Sc.

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ABSTRACT

This study is concerned with the interdependence of 10m elevation wind speed, oceanic whitecap coverage and marine aerosol concentration. The field work is divided into two distinct phases.

On Inishmore Co. Galway aerosol concentrations and ambient meteorological conditions were monitored, at a coastal site, over a two year period. The station is described. The dependence of the concentration of the 'Large' and 'Giant' aerosol components of the marine atmosphere on wind speed, wind direction and other factors is discussed. The relationship of Giant maritime particles to wind speed is $N(2.5+) = 5.34 \times 10^{3}U^{1.39}$.

The STREX experiment took place in the Gulf of Alaska, from mid-October to mid-December 1980. The influence of such factors as 10m elevation wind speed, sea-surface temperature, and atmospheric stability on whitecap coverage and on the concomitant production of marine aerosol particles is evaluated. The degree of oceanic whitecap cover was estimated photographically.

The relationship between oceanic whitecap coverage, W, and wind speed, U, is $W = 6.22 \times 10^{-3}U^{2.21}$. There is an enhancement of the positive dependence of aerosol concentration upon whitecap cover with increasing droplet radius.

Both the Inishmore and STREX results are compared to previously published data sets. They are also compared to each other. The results of these comparisons are, in general, quite favourable.

ACHOMAIREACHT

Baineann an tráchtas seo leis an gcomhcheangailt atá ann idir luas na gaoithe ag 10m in airde, clúid mhara na gcapall Mananánn agus tiúchan aerósol ar farraige. Roinntear an obair sheachtrach ina dá chuid éagsúil.

Ar Inis Mór, Co. na Gaillimhe scrúdaíodh go grinn an tiúchan aerósol agus staid mheitéareolaíoch na timpeallachta, ar shuíomh cois farraige, le linn achar dhá bhliain. Pléitear an choi a mbrathann tiúchan na gcáithníní móra agus tiúchan na gcáithníní ollmhóra aerósol in atmaisféar mara ar luas agus ar aird na gaoithe agus ar dúile eile nach iad. Is é an gaol atá idir na cáithníní ollmhóra mara agus luas na gaoithe ná $N(2.5+) = 5.34 \times 10^3 U^{1.39}$.

Tharla an turgnamh STREX sa Murascaill Alaska, ó lár mí Dheireadh Fómhair go lár mí na Nollag 1980. Meátar tionchar gnéithe áirithe, cur i gcás luas na gaoithe ag 10m in airde, teocht dromchla na farraige agus buanseasmhacht an atmaisféir, ar chlúid na gcapall Mananánn agus ar dhéanamh na gcáithníní aerósol mara dá bharr sin. Rinneadh meastachán ar thoirt chlúid na gcapall Mananánn le cuidiú grianghraf.

Is é an gaol atá idir clúid mhara na gcapall Mhananánn, W, agus luas na gaoithe, U, ná $W = 6.22 \times 10^{-3} U^{2.21}$. De réir mar a théann ga na ndrioganna i méid bíonn an tiúchan aerósol níos spláiche ar chlúid na gcapall Mananánn.

Cuirtear torthaí Inis Mór agus torthaí STREX i gcomparáid le sonraí foilsithe cheana féin. Cuirtear i gcomparáid lena chéile iad chomh maith. San iomlán, is fabharach go maith iad torthaí na gcomparáidí seo.

Arna aistriú ag Uinsionn Mac Dubhghaill.

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Whitecap photographs were painstakingly analysed by Brenda Cully, Mary Luibheid, Tom Luibheid, Michael Lyons and Sinead O'Flanagan.

Finally, and most importantly, I would like to thank my parents, Kay and Peter, for their love and tolerance over the years.

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DEDICATION

"To my gal Lilly,

Bunkhouse Billy,

and the boys."

TABLE OF CONTENTS

"Exultation is the going
Of an inland soul to sea,
Past the houses - past the headlands -
Into deep Eternity -
Bred as we, among the mountains,
Can the sailor understand
The divine intoxication
Of the first league out from land?"

Emily Dickinson.

CHAPTER 1.

INTRODUCTION

Sources of atmospheric aerosol particles are many and varied, Aitken (1881) has stated, quite simply that "Everything in nature which tends to break up matter will contribute its share". A significant proportion of these aerosol particles have their origin at the sea surface. Oceanic whitecaps or whitehorses effect by far the most important contribution of these marine aerosol particles to the global atmosphere.

This study is concerned both with the generation of oceanic whitecaps and with the nature and influence on the marine environment of the aerosols which they produce.

The outline physics of whitecapping and of the concomitant production of aerosol particles is described in chapter 2. While a brief historical review of the subject is included as chapter 3.

The experimental work of the study has been divided into two distinct phases. Firstly a protracted measuring programme was performed at the U.C.G. island field station on Inishmore Co. Galway. Aerosol measurements have been made at this site over a period of about three years and in a broad range of meteorological conditions in an effort to establish the influence of various environmental factors on the aerosol concentration. This work is described and discussed in chapters 4 and 5.

The second phase of the experimental work involved an intensive two month series of measurements on board the NOAA research vessel OCEANOGRAPHER during the Storm Transfer and Response Experiment (STREX) which took place in the Gulf of Alaska from mid-October to mid-December 1980. This experiment involved simultaneous measurements of whitecap coverage, aerosol concentration and the appropriate meteorological variables. The collected results significantly augmented the limited data base in this area of investigation. This experiment is described and discussed in chapters 6 and 7.

CHAPTER 2.

WAVES, WAVE BREAKING AND THE GENERATION OF MARINE AEROSOL AT THE SEA SURFACE.

"We are no other than a row
Of magic shadow-shapes that come and go"
Omar Khyyam.

Introduction:

The turbulence and mixing which occur at the oceanic boundary layer make it one of the most dynamically active interfacial zones on earth. Breaking waves and the resulting whitecaps are among the most important direct agents in the promotion of this mixing. Whitecaps occur when unstable waves break at the sea surface thus entraining air in the form of bubbles. The whitecap is in essence the area at the surface of the sea in which the bubbles which have been submerged by the breaking of the wave are re-emerging.

Apart from having a major influence on turbulent mixing in the oceanic boundary layer whitecaps effect the most important contribution of sea-salt aerosol to the marine atmosphere under commonly encountered wind regimes. These aerosol particles play an important role in the initiation of rain i.e. they act as cloud condensation nuclei. But they can also cause severe corrosive damage to man-made marine structures and ships as well as enhancing the levels of heavy metals, bacteria, viruses, etc. in tl.e atmosphere

(Blanchard and Woodcock, 1980). Therefore an understanding of the processes that instigate wave breaking and thus the generation of marine aerosol is desirable.

There are several mechanisms responsible for the breaking of waves. In shallow water the influence of topography can cause breaking by shoaling, refraction, diffraction and deflection. However, in deep water, i.e. when depth of water is greater than about half the wavelength, the interactions of a) wind and wave, b) wave and wave, and c) currents and wave are the dominant mechanisms. In the context of this study the interaction of wind and wave is the most important aspect.

To a lesser degree the occurence and persistence of whitecaps is related to the water temperature and salinity (which control density and viscosity), the air/water temperature difference (thermal stability) and the presence or absence of surfactant material on the water surface.

2.2 The generation of waves by wind:

The generation of waves by wind action is imperfectly understood. The problem has been the subject of scientific debate since at least the last century. Several theories have been advanced over the years but none is entirely satisfactory.

In the mid-nineteenth century Kelvin and Helmholtz considered a theory concerning the interface between two fluids when there is a relative velocity between them. Theoretically waves would begin to form for wind speeds in excess of 6m/s, which is not a very close approximation to reality.

Later Jefferys (1924, 1925) proposed a "sheltering effect" as a model for the generation of gravity waves. He suggested that wind blowing past small capilliary waves would create eddies on their leeward side, leading to a slight drop in pressure in this area. This implies that more work would be done on the descending particles of the windward side than would be done against the air pressure as the particles ascend on the leeward side (Fig. 2.1). The net result would be the propagation of waves through the transfer of energy from the wind. The theory, however, has not been satisfactorily tested and the minimum velocity of about 1m/s for the generation of waves is still larger than is seen in nature.

As a result of the practical considerations associated with the second world war, Sverdrup and Munk (1947) devised a predictive method for the forecasting of wave occurence. They used the physical characteristics of waves as a basis for their calculations but more importantly they introduced the concept of the 'significant wave'. This is a notional wave whose height is equal to the mean height of the highest third of the waves on a record and whose period is the mean period of this third of the waves. This added a statistical element to forecasting and allowed for the application of mathematical models to the problem. While the theory was used successfully in the 'forties some of the assumptions have since been shown to be without foundation (Kinsman 1965).

In more recent years Banner and Melville (1976) have returned to the Jefferys model. They calculated that air flow separates from the tip of a breaking wave to cause the pressure differentiation which provides the net energy input necessary for the propagation of wind waves. Perhaps the most extensive numerical and experimental work in this area has been done by Longuet-Higgins and others in several papers (discussed later) in which advanced modeling techniques are used to simulate wave structures and origins. However, it is still recognised that the generation of wind waves is imprecisely understood.

2.3 Geometry of a wave:

When wind blows over a calm sea it will quickly produce small wavelets, if the wind persists these capilliary waves increase in dimensions and become larger or gravity waves. Capilliary waves will persist only while the wind is blowing whereas surface gravity waves once formed will continue until some limiting factor comes into play. A steady non-breaking wave is characterised by three properties, its wavelength (L), the water depth (d), and the wave height (H) (Fig. 2.1). It is the respective ratios and not the absolute values of these quantities which are important in defining any wave.

Once a wave has formed there are limits to the amount of energy that it can receive and still retain its stability. These limits were recognised and defined by Stokes (1880) and Michell (1893), (Fig. 2.2). Stokes' theories are based on classical hydrodynamics omitting friction but taking the boundary conditions into consideration (Sverdrup 1943). His results indicate that for low-but-finite amplitude waves the speed of propagation (the phase speed) increases with wave height. Thus for an ideal fluid the wave will take the form of a trochoid but as the amplitude increases the shape will increasingly deviate from the trochoid form, (Cokelet, 1977). Studies by Michell (1893) show that the wave will become unstable if the included angle is less than 120° and that in this instance the ratio of height to length (the steepness) is 1:7.

2.4 Breaking of open-ocean wind waves:

Once a wave has reached its maximum free standing energy, as defined by Stokes and Michell, only a small amount of energy need be applied to initiate breaking. The actual point of breaking is perhaps the least well understood aspect of the breaking mechanism. This is due to the ephemeral nature of whitecaps which, along with the almost infinite permutation of wave interactions in the open ocean, and scaling and other problems in simulation tanks, makes them difficult to measure.

Now in a non-breaking wave the fluid particles are moving forward more slowly than the phase velocity. But as the wave grows higher with respect to its length the particle velocity approaches the phase velocity. The wave has reached its limit of stability when these two velocities are equal. A further increase in wave height will cause the fluid particles to overtake the wave itself and breaking will ensue. It is interesting to note that as Cokelet (1977) has pointed out, the highest wave is not the most energetic. The phase speed, momentum and energy increase, reach maxima and then decrease as the highest wave is approached. This suggests that there are two possible wave heights for the same energy level and that a wave might 'jump' from one energy state to the other thus initiating breaking.

In the open ocean there are two main types of breaker, spilling and plunging, (Fig. 2.3).

The spilling breaker is the most common type of breaker in deep water (Banner and Phillips, 1974). The wave profile is characteristically almost symmetric. It tends to break gently at its crest trapping enough air for the resulting air-water mixture to be significantly lighter than the wave below it, (Longuet-Higgins and Turner, 1974). The wave steepness and included wave angle are close to the limiting values of Stokes and Michell. The wave and whitecap are now separate entities with the whitecap riding down the face of the wave as a distinct turbulent flow under the influence of gravity. The turbulent flow will effect entrainment of water from the wave below and air from the front of the 'white water' plume thus maintaining the density difference. The whitecap will persist as long as it is lighter than the wave below. Cokelet has indicated that "for a 30° surface slope corresponding to the 120° corner flow, the plume [of this type of breaker] must be about 8% air".

The second kind of deep-water breaking wave is the plunging breaker. This type of breaker is much less common than the spilling kind. The profile of a plunging breaker is characterised by a high degree of asymmetry, typically with a well rounded back and a concave front (Fig. 2.3). During breaking the leading edge steepens and quite suddenly the crest is thrown forward and the wave turns over on itself. In the process an oval shaped tube of air is encapsulated creating large numbers of small submerged bubbles which give the familiar white water appearance.

While stating that, "plunging breakers are beyond the reach of all known analytical approximations" Longuet-Higgins and Cokelet (1976) have produced a remarkable mathematical model for their numerical simulation. They tested their model by applying it to unsteady waves which had been produced by the application of non-uniform pressure distribution to the surface of a steady progressive wave. It was found that the wave steepened and developed a plunging breaker form. They also suggest that spilling breakers may begin by being similar in form to a plunging breaker but on a smaller scale.

2.5 Bubbles and the generation of marine aerosol:

Blanchard and Woodcock (1957) originally studied four mechanisms for the production of bubbles at sea viz: breaking waves, rain, snow and the supersaturation of the sea by spring warming. However, they concluded that the last three would be important only on a local or intermittent scale and that the first mechanism was the major one. The volume of air which is entrapped during and subsequent to the collapse of a breaking wave gives rise to a cloud of submerged bubbles. This cloud is carried by turbulence to a depth on the order of the wave height (Donelan, 1978). As previously noted, when these bubbles rise to the surface they form whitecaps. If no slicks or surfactant material are present the bubbles which reach the surface will burst almost immediately.

Work on the size distribution of bubbles beneath the surface has been done by Blanchard and Woodcock (1957). They recognised a spectrum of bubbles from less than 100μm to several millimeters in diameter. The concentration of all bubbles was about $10^8/m^3$.

On bursting these bubbles release two types of droplets into the atmosphere, film and jet drops. Film drops are created by the rupturing of the top thin film of the bubble as it drains subsequent to reaching the surface. When this happens the bubble immediately collapses and a vertical column of water is ejected from the cavity. The breakup of this 'jet column' gives rise to jet droplets. The size of the drops produced and the height to which they are ejected is dependent on the bubbles which produce them (Blanchard, 1963).

In certain conditions i.e. when wind speeds exceed about 10m/s, an important extra aerosol component may be due to "the impaction of spray droplets which have been mechanically sheared from the wave crest" (Monahan, 1982), this phenomenon has also been alluded to by Lai and Shemdin (1974) and Wang and Street (1978), (Fig. 2.4).

Stuhlman (1932), as reported by Blanchard (1958), has computed that drops from bubbles of less than 100μm diameter are ejected at speeds in excess of 30m/s. He also observed that the top jet drop will be ejected to a height on the order of one hundred times the original bubble diameter and its diameter will be about 10% of that of the parent bubble.

2.6 The nature of marine aerosol particles:

Some of these drops will quickly fall back into the sea while others will be borne aloft, the proportions of each being governed by the relative humidity and the degree of turbulence above the ocean. On entering the atmosphere the drops begin to evaporate and the amount of evaporation which occurs will depend on the relative humidity. However, the salt mass will remain the same and the particles are referred to as sea-salt aerosol. This is, perhaps, the largest natural contributer of particulate material to the global atmosphere.

It would appear to be obvious that particles which have their origin in the ocean would have a composition close to that of sea water. However, Blanchard (1963) has pointed out that while this would be correct for the 'giant' particles with radii greater than about 1µm it might not be strictly true for the 'large' particles with radii smaller than this. Indeed Blanchard also notes that "nuclei which originate in the sea come not from the bulk water, but from the surface layer whose chemistry may well be different". Horne (1969) has attributed this difference in composition to "interfacial ion fractionation processes accompanying the breaking of small bubbles at sea".

It is generally recognised that the percentage of the ocean that is covered by whitecaps increases as a function of the wind speed increase. The most extensive work in this area is that of Monahan (1971) and Monahan and O'Muircheartaigh (1980). In agreement with previous work (Blanchard, 1963; and Gatham and Trent, 1968), Monahan found that whitecaps begin to appear for wind speeds of about 3.5m/s. He also presents a power-law expression (eqn. 1) for the W(U) relationship which is applicable for wind speeds between 4 and 10m/s.

$$W = 1.35 \times 10^{-5} U^{3.4} \qquad \text{[Eqn. 1.]}$$

In Monahan and O'Muircheartaigh (1980) an extensive review of various whitecap versus wind speed expressions W(U) is presented. Here it is suggested that either :

$$W_{OLS} = 2.95 \times 10^{-6} U^{3.52} \qquad \text{[Eqn. 2.]}$$

or

$$W_{RBF} = 3.84 \times 10^{-6} U^{3.41} \qquad \text{[Eqn. 3.]}$$

be "adopted for the estimation of the fraction of the ocean surface covered by whitecaps from a measurement of winds at 10m elevation". (Where OLS is ordinary least squares and RBF is robust bi-weight fitting, these being the designations for the statistical methods used in the evolution of the individual expressions).

As noted above the entrainment of air during whitecapping gives rise to large quantities of submerged bubbles. Now it is accepted (Blanchard and Woodcock, 1980) that the most important mechanism for the production of marine aerosol is the bursting of these bubbles.

The relationship of marine aerosol production to wind speed has oft been studied, e.g. Monahan (1968), yet until recently little data were available describing simultaneous sea-salt aerosol concentration and oceanic whitecap coverage. Toba and Chaen (1973) collected such a data set from the western Pacific ocean. These measurements were later augmented by results from the JASIN (Monahan et al., 1982b; and 1983) and STREX (Monahan et al., 1982c, 1983, and the present study) experiments.

Toba and Chaen regard the W(U) function as a good "first approximation". Instead of U they prefer to use the dimensionless variable $u^* L/\nu$, where u^* is the friction velocity, L is the 'significant' wave length and ν is the kinematic viscosity of the air. And it is this quantity which they plot against droplet numbers.

Attempts have been made from these and laboratory studies to estimate the global flux of sea-salt aerosol (Blanchard and Woodcock, 1980; and Monahan et al., 1982a).

Summary:

In summary the Wind - Wave - Whitecap - Bubble -

Aerosol progression is a cause-and-effect sequence, with the production of whitecaps and aerosol particles being primarily dependent on the wind velocity.

Figure 2.1.

Schematic representation of sinusoidal wave characteristics. With wavelength (L), height (H) and speed (c) shown. The wave is moving from left to right. Note the water particle orbit directions and their exponential decay with depth.

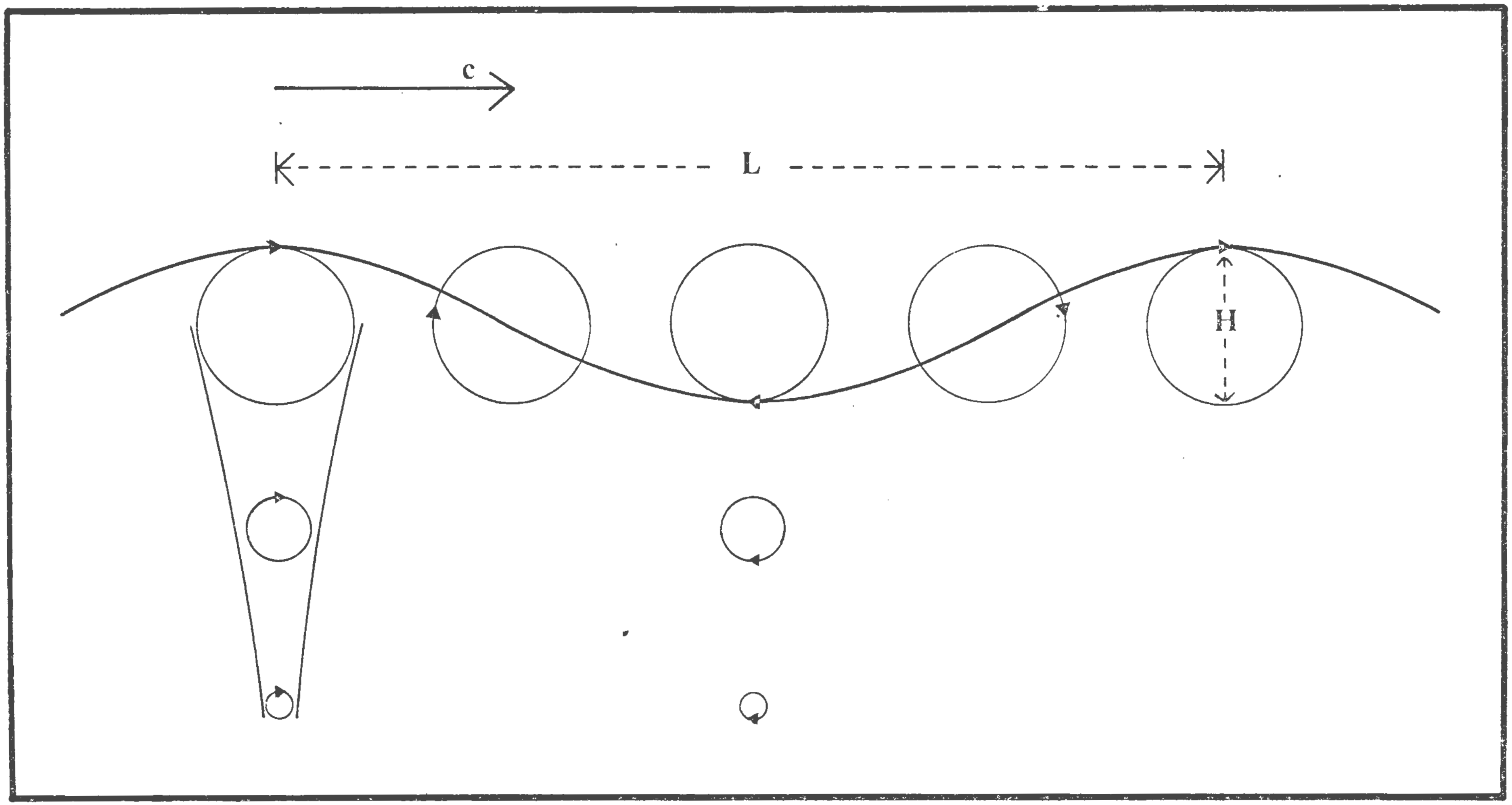


Figure 2.1. Schematic representation of sinusoidal wave characteristics.

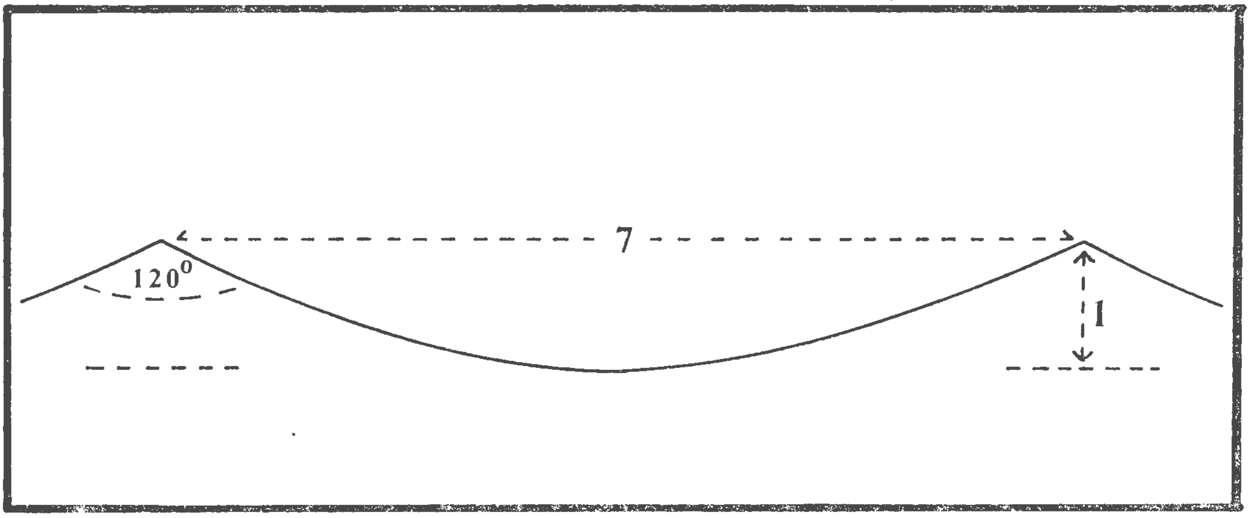


Figure 2.2.

Geometrical limitation of the steepest possible wave of Stokes and Michell. When the minimum included angle is 120° then the maximum steepness (H/L) is 1:7 or 0.142.

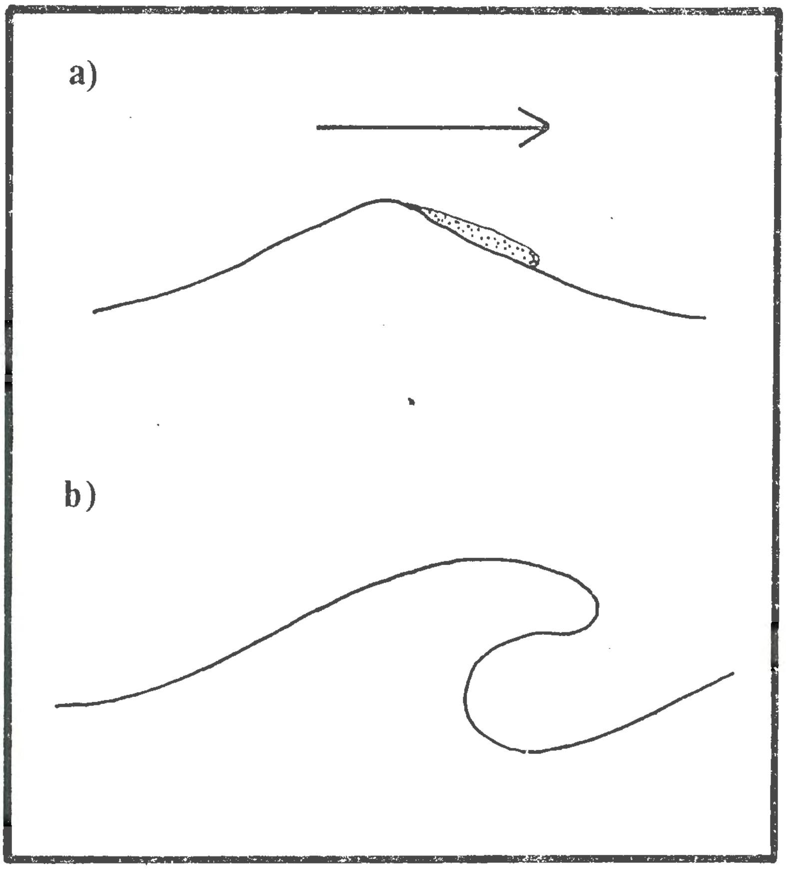


Figure 2.3.

Line sketch of a) spilling and b) plunging breakers. Wind direction is indicated by arrow. Note the almost symmetrical profile of the spilling wave and the high degree of asymmetry of the plunging breaker, with its well rounded back and concave front.

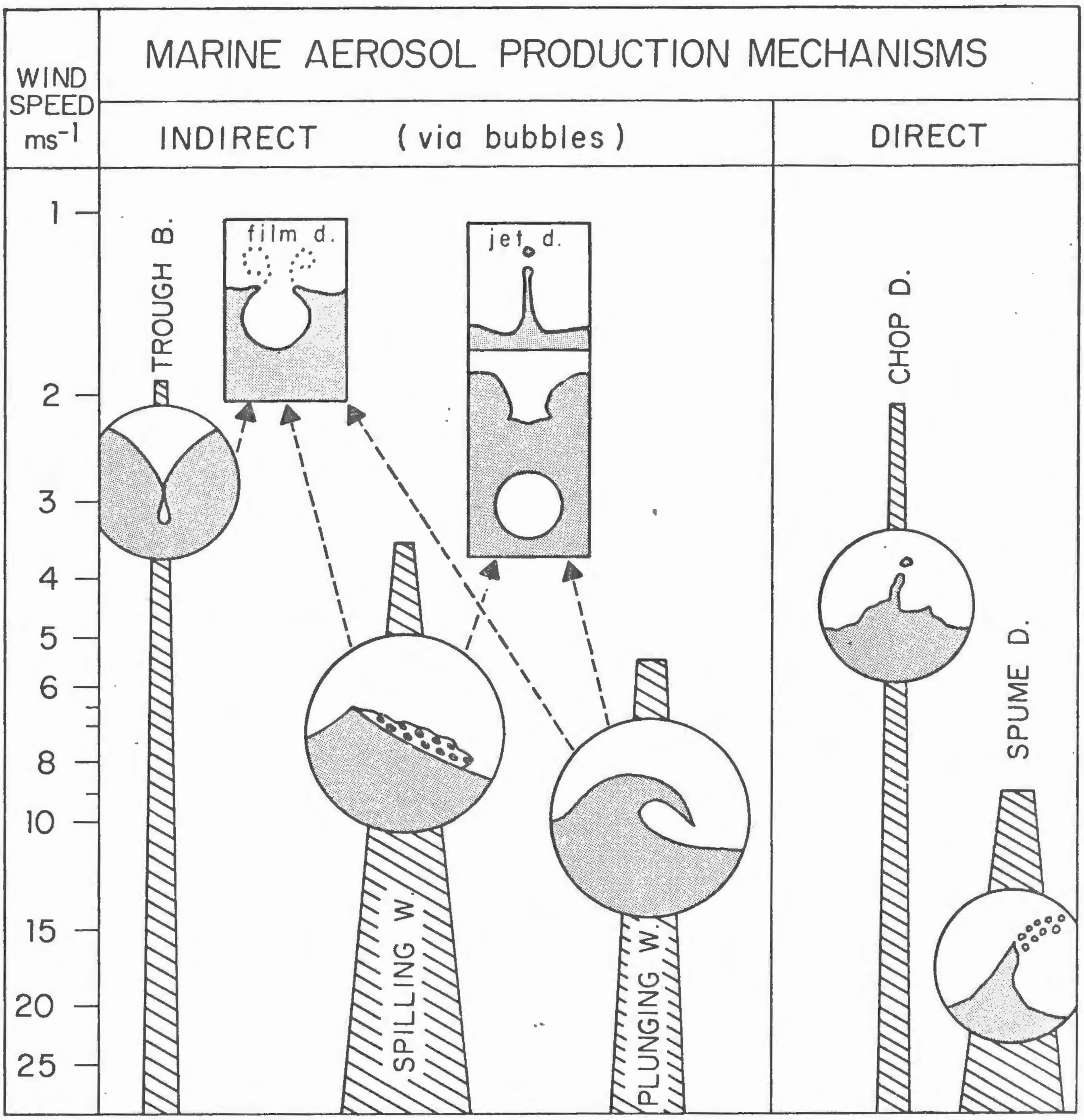


Figure 2.4.

Schematic representation of the relative importance of various marine aerosol production mechanisms. The relative widths of the shaded columns, at any particular wind speed, are meant to indicate the relative significance of the direct and indirect production mechanisms represented by the various columns.

Key: B, bubbles; d, droplets; D, drops; W, waves.

[from Monahan 1982].

CHAPTER 3.

HISTORICAL REVIEW

"Iron sharpens iron,
and one man sharpens another."
Proverbs.

Introduction:

This chapter is primarily concerned with the development of theories on the nature and origin of marine aerosol particles. The subject is intimately conected with the occurance of oceanic whitecaps which has been discussed in the previous chapter. The production of marine aerosol has for long been of special interest to observers in Ireland so a brief sub-section on the Irish contribution to this field has been included.

3.2 Aerosol research:

A name which is immediately associated with early work in the field of aerosol physics is that of John Aitken. In 1881, (in an elaboration of earlier work by Coulier, 1875) he used a laboratory expansion chamber to demonstrate the importance of atmospheric dust particles in the formation of water droplets from water vapour, thus suggesting a mechanism for the formation of clouds. He also proposed that "In all probability the spray from the ocean, after it is dried and nothing but a fine salt dust left, is perhaps one of the most important sources of cloud producing dust."

He developed a 'nucleus counter' for the purpose of measuring the concentrations of such particles and in later work (1911) he investigated their physical and chemical properties.

Although Wigand (1919) contended that the continents and not the oceans were the main source of cloud condensation nuclei (CCN), the production of aerosol particles from the sea remained as the focus of interest for most researchers (e.g. Owens 1926). Later Findeisen (1937) argued against a significant oceanic contribution, believing that droplets of less than 10μm in radius could not be produced by spraying. This notion was finally refuted by both Owens (1940) and Kohler (1941).

Wright (1940) demonstrated empirically that large amounts of sea-salt aerosol were indeed present in the atmosphere but a satisfactory mechanism for the injection of these particles had yet to be suggested. Wright resurrected the 'Melander effect' from the end of the last century which proposed a liberation of sea-salt particles through the direct evaporation of sea water. This mechanism was finally shown to be incorrect by Lodge et al., in 1954.

However, Stulhman (1932) and Jacobs (1937) had already recognised that the collapse of bubbles at the sea surface could be an important source of cloud condensation nuclei. This mechanism was again suggested by Woodcock (1948).

Intensive work by Boyce (1951) and Woodcock *et al.*, (1953), amongst others, soon uncovered the full importance of the bursting of bubbles in the process of injection of aerosol particles into the atmosphere. This process was confirmed using high-speed film by Kientzler *et al.*, (1954). This work focussed attention on the exact mechanism of bubble collapse.

It was also realised that besides the droplets which are produced by the disintegration of the upward jet of water (jet drops) other smaller drops are produced by the rupturing of the initial thin film on 'top' of the bubble (film drops).

Facy (1951) had already pointed out that the production of particles from isolated bubbles would be insignificant. Blanchard (1963) also concluded that the production rate from single bubbles would be low.

Blanchard and Woodcock (1957) had determined that breaking waves were the predominant mechanism for the production of bubbles. Blanchard (1963) also noted that the nature of the bubble spectra would determine the size and amount of aerosol particles produced by a breaking wave. Since that time a great deal of attention has been paid to bubble spectra e.g. Medwin (1970, 1977) and Johnson and Cooke (1979).

However, some confusion still existed over the nature of cloud condensation nuclei. Blanchard (1963) states that they will probably though not neccessarily have the same composition as that of sea water. Twomey (1971) suggested that because of the organic content of such particles they could not have their origin in the ocean. But as Blanchard (1971) has pointed out the presence of organic material in no way precludes an oceanic origin. He suggests that cloud condensation nuclei could be derived both from the sea and the atmosphere.

Extensive reviews in this area have been produced in recent years by Blanchard and Woodcock (1980) and Podzimek (1980).

Aerosol Research In Ireland:

Investigations into the aerosol content of the air have been carried out in Ireland for more than one hundred years. Over the years a considerable amount of maritime data have been collected from around the country, much of this on the western seaboard. These data provide useful background information for comparison with the measurements taken at the U.C.G. field station on Inishmore, Co. Galway.

Ireland lies in the path of the various westerly air masses which proceed from the North Atlantic ocean. These predominantly maritime winds coupled with the North Atlantic drift currents from the Gulf Stream System give the island its characteristic cool, temperate, oceanic type, climate. O'Connor (1981) notes that, on average, about 150 fronts pass over the country annually. The variability of this regime combined with the comparative absence of artificial sources of contamination is particularly suited to the sampling of the marine component of the natural aerosol.

As early as 1870 Sigerson was taking samples of air in and around the city of Dublin. This was in connection with the health effects of the contents of the atmosphere. At this time Tyndall, Stokes, Joly and others were engaged in the controversy over the "germ theory" of the propagation of disease which neccessitated microscopic analysis of the air. Sigerson also took samples from "the sea breeze" at various locations around the north and west coasts of Ireland. He found that glass exposed to the sea was quickly tarnished with 'crystals innumerable' which because of "their shape and the circumstances, were recognised as chloride of sodium, or common salt". He also noted that "Comparatively few crystals of sulphate of magnesia" were found.

By the turn of the century McClelland (1903) had begun work on the ionisation of the atmosphere, work that was to set the theme for research into atmospheric electricity in Ireland over the next several decades, e.g. McClelland and Nolan (1912), Nolan and Nolan (1937), Nolan and Doherty (1950), and Keefe et al., (1968).

The brothers J.J. and P.J. Nolan made important contributions to the field of atmospheric ionisation and the cloud condensation nuclei content of the air (Nolan and Guerrini, 1935, and Nolan et al., 1938). This work was eventually to lead to the development and refinement of the portable Nolan/Pollak photo-electric nucleus counter (Nolan and Pollak 1946), an improved version of which is described by Pollak and Murphy (1952).

The standard, 1957 model or Dublin instrument, calibrated by Metnieks and Pollak (1959), is regularly employed as a reference instrument (Hogan, 1981; and Winters et al., 1977), while variations on this model are still used to measure the Aitken component of the natural aerosol content of the atmosphere (Gras and Ayers, 1983).

The 'fifties saw an increase in aerosol related research especially by the members of the School of Cosmic Physics in Dublin under the direction of Prof. L. W. Pollak. Quite a lot of attention was paid to maritime measurements, particularly on the west coast (Pollak and Murphy, 1952; O'Connor and Sharkey, 1960; and Metnieks, 1958). Metnieks' sampling locations included a site on Inishmore Co. Galway, while O'Connor sampled extensively at Mace Head which is on the mainland only a few kilometers from the present site of the U.C.G. field station on the island. Several attempts have also been made to relate the aerosol concentration to other meteorological conditions, such as the work of McWilliam and Morgan (1955) and Georgii and Metnieks (1958). Indeed Aitken nuclei concentrations have been measured by the Irish Meteorological Service for over thirty years (O'Connor, 1981).

Research continued through the 'sixties at many centres around the country. O'Connor and others worked on the production of aerosols both in the field and in laboratory experiments (O'Connor and Sharkey, 1960; and O'Connor, 1963; 1966). Subsequently the trend was toward laboratory explorations of aerosol production mechanisms and measurements of electrically charged particles (O'Connor and Roddy, 1966; and Jennings and O'Connor, 1971).

A short review of the Irish contribution to the study of atmospheric aerosols is presented by O'Connor (1981).

CHAPTER 4.

THE INISHMORE FIELD STATION.

"Capaill Mhannáin ag rith i ndiaidh
a chéile go dtí an trá."
Pádraig Piarais.

Introduction:

In 1979 a marine aerosol sampling field station was established on Inishmore Co. Galway by the Physical Oceanography Unit of the Dept. of Oceanography at University College Galway (U.C.G.). Since that time the station has been the site of several monitoring experiments (see Appendix 4.2.), including a co-operative study with scientists of the Naval Postgraduate School (N.P.S.) in the summer of 1980. The field station was also the site of one stage of the Arctic Air Sampling Programme (Rahn, 1981).

A description of the location and makeup of the station follows. Relevant experiments and their instrumentation are also described. The results and conclusions of the various experiments are presented in chapter 5.

4.2 The station:

The field station is located on the windward shore of Inishmore. It is comprised of a fifty foot lattice mast and an adjoining instrument shelter with power being derived from a 2kW LISTER generator. The instrument probes and sensors are mounted on the mast while the chart recorders and data processors are housed in the shelter which also has seating accommodation for two to three operators. The station is situated in a barren limestone 'field' about 500m from the small village of Gort na gCapall and five kilometers due west of the main population centre and port of Kilronan (Figs 4.1/2/3).

Inishmore is the largest of the Aran Island group which straddle the mouth of Galway Bay. It has an area of 50 sq. kilometers and a population of some 1,100 people. The structure of the island is, geologically, very simple (Langridge, 1973; and Whittow, 1974). It is composed of largely undisturbed Carboniferous limestone dipping gently (0-10^{o}) south-westward toward the Atlantic Ocean. Almost the entire south-west coast is formed of vertical cliffs as much as 100m high in places. Those south of the station rise to about 20m, while immediately to the west is the low-lying cove of Portveeladone.

The area in the vicinity of the station is quite treeless with extensive areas of stepped limestone pavement and an intricate pattern of drystone walls. Despite the outward appearance, however, the ground flora is varied with many exotic ferns and other plants flourishing in the network of grikes which are a feature of the island.

4.3 Survey of field site:

It was felt neccessary to carry out a survey of the environs of the station in order to establish accurately the position and elevation of the lattice tower and to delineate the physical features which might influence the passage of aerosol particles to the monitoring probes. The survey encompassed an arc from 150-250° (from true north) around the station. Winds from outside this sector would travel some distance overland and so would not be representative of the open ocean.

Initially it was necessary to 'transfer' a spot-height some two kilometers across country using a level and staff. This was done in order to obtain the base height of the mast. The base figure of 19.20m is accurate to within a few cms (± .02m) which is more than sufficient for our purposes. The position of the tower within the 'field' was then established and a series of six radiating cross-sections were surveyed.

Using these figures and a 'stereo pair' of photographs of the area it was possible to draw an accurately contoured sketch map of the site (Fig. 4.4). The cross section profiles of figure 4.5 were also obtained from these data. They graphically illustrate the topography of the area and they give an indication of the 'flight paths' of aerosols from the ocean to the sensors on the tower.

4.4 Sampling considerations:

In general remote island stations offer many advantages for marine aerosol measurements. Amongst these is the considerable benefit of a data set collected at a fixed location over an extended period of time (Blanchard and Syzdek, 1972).

Inishmore is very favourably positioned for such measurements lying as it does in a prevailing westerly airflow with a fetch of several thousand kilometers over the north Atlantic Ocean. There are no important sources of anthropogenic contamination on the island and most minor sources, such as houses, are located on the leeshore well downwind of the sampling site.

However, as with all near-to-shore stations (Duce and Woodcock, 1971; and Blanchard and Woodcock, 1980), the Inishmore site suffers occasionally due to the proximity of the shoreline surf zone.

We have noticed that when the sea has a 'large' swell component and winds exceed 7-8m/s spray from the surf zone is visible above the cliffs in the area of the station. When these conditions prevail at high tide south-westerly winds (245-285°) could carry ejected particles upslope to the instruments. For 'southerly' winds this is far less likely to occur due to the increased distance to the foreshore and to the height of the cliffs immediately above the surf zone.

The problem of aerosols produced by the drying of seaweeds, as mentioned for example by O'Connor (1963), is also avoided as the nature of the rocky bottom and the sometimes stormy sea is not conducive to the growth of seaweeds above the low-water mark in this area. The additional problem of aerosols produced by the evaporation of seawater residue at low tide (Pollak and Murphy, 1952) has also been considered but has not been fully investigated.

4.5 Instrumentation on Inishmore:

For aerosol measurements to have any relevance they must be viewed in the context of the meteorological conditions prevailing at the time of their collection. The following meteorological parameters were measured at regular intervals during each collection period at the station: 10m Elevation Wind Speed (U_{10}), Wind Direction (WD), Relative Humidity (RH), and Air Temperature (Ta).

Time of day etc. was also noted, and where appropriate, sea-state, tide level, and local surf zone extent were recorded, either visually or, less commonly, on film. Meso-scale weather conditions were also taken into consideration.

Various aerosol particle measuring devices were used at different times depending on circumstances and availability. However, the standard monitor was a ROYCO aerosol particle counter model 225. This instrument consists of a mainframe unit which is connécted (via a vacuum line, clean-sheath air return and a signal/control cable) to a seperate optical sensor unit model 241. The mainframe instrument is housed in the shelter while the sensor is mounted on the tower in a protective cover. The sample intake hose extends to the six meter level on the tower which is about 25m above the sea.

The optical unit is responsible for the sensing of the particles and the generation of the data signal. An air sample is streamed through a beam of very highly focussed light. Any light scattered by aerosol particles present in this sample is collected in a 'light trap' which effectively acts as a dark-field microscope to screen out any non-scattered light.

The collected light is then focussed onto a photomultiplier tube which generates signal pulses in proportion to the intensity of the illumination falling on it. The amplitude of these signals is a function of the size of the particles, (there may, however, be problems with the interpretation of these signals, see Schacher et al., 1981). The pulses are then transmitted to the counter mainframe which contains the processing electronics. Here they are counted and sorted into two 'channels' on the basis of preset size criteria. At the end of each sampling interval the particle counts and corresponding size ranges are displayed on the plug-in module.

The counter will measure particles of 0.25μm radius and larger in concentrations of up to 3.5 X 10^9 per cubic meter. At high aerosol counts (much greater than 100,000 counts/minute) co-incidence errors must be taken into account. These errors are easily rectified by means of a simple correction graph. Inaccuracies may also occur when sampling particles of over 2.5μm radius in winds of more than a few meters/second, due to problems of non-isokinetic sampling.

For all experiments on Inishmore aerosol concentrations were measured in the size ranges 0.25-2.5μm (N0.25+), and greater than 2.5μm radius (N2.5+). Count intervals were usually of 60s. duration but 30s. and 300s. averages were sometimes taken, depending on the circumstances.

On two occasions during the project aerosol samples were taken using a portable Nolan/Pollak photoelectric nucleus counter, as described by Pollak and Murphy (1952). This is a straightforward device which estimates the number of water droplets which have formed on nuclei in the instrument's sample chamber where an overpressure has been released to form a fog. The principle is that the attenuation of a beam of light through the cloud is a function of the number of nuclei present in the sample. It was intended that these readings should be compared with similar readings taken previously in the same general area with this counter (Pollak and Murphy, 1952; O'Connor and

Sharkey, 1960; and Metnieks 1958).

During the period 23-28th. June 1980 a cooperative experiment was carried out at the field station with scientists from the Naval Postgraduate School (N.P.S.), Monterey, Cal. The usual meteorological parameters, wind speed etc. were monitored and whitecap coverage and local surf zone state were recorded photographically. At the same time aerosol size spectra were obtained using two Knollenberg counters mounted on the mast.

One of these probes was a Particle Measuring System's (P.M.S.) Classical Scattering Aerosol Spectrometer Probe (CSASP) while the other was a P.M.S. Active Scattering Aerosol Spectrometer Probe (ASASP) which detected droplets with radii between 0.5 to 15μm and 0.1 to 3μm respectively.

These are sophisticated aerosol measuring devices which operate on the principle that light scattered by a particle within a lasar beam is directly a function of the particle size (Schacher et al., 1981). The two probes cover overlapping size ranges between 0.1μm and 15μm radius They have the advantage of providing highly detailed aerosol size spectra for each data averaging period. The signals from these counters were processed by a mini computer in conjunction with a data acquisition system. A 'hard copy' of these data were made available on a printer unit. At the same time all of the data were being recorded, along with time of day etc, on a KENNEDY incremental tape recorder.

During the experiment a total of sixty-six marine aerosol size spectra were obtained. Unfortunately, for three of the four days on which samples were taken 'north westerly' winds (285-320° from true north) prevailed. This regime presented two problems. Firstly, the probe intake angle which had been fixed at 240°, differed by as much as 80° from the wind direction which would present sampling difficulties, due to the low angle of incidence of the particles to the intake orifices. And secondly, winds from this direction would have passed over the western part of the island and so would be liable to contain terrigenous contamination.

On the last day of sampling (27th. June) the prevailing winds were 'south-westerly' (215-250°). On this day eight aerosol spectra were obtained which are more representative of open ocean conditions. The results from these experiments are presented in the next chapter. All-in-all the experiments have been fruitful. The main problem has been the maintenance of sensitive electronic equipment in a hostile environment.

The specifications of the instruments used in the Inishmore experiments are given in Appendix 4.1.

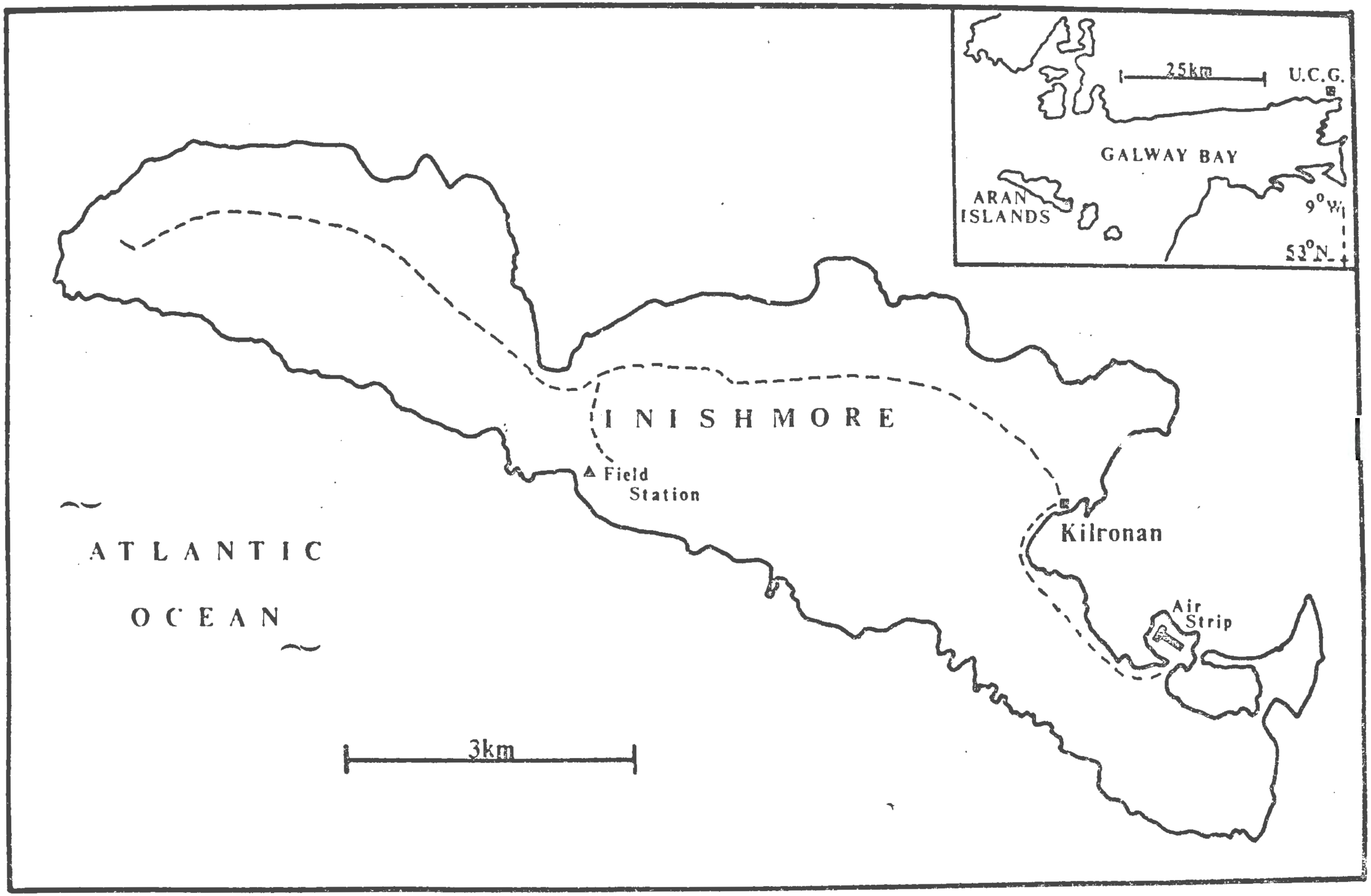


FIGURE 4.1:

Outline map of Inishmore showing location of aerosol sampling field station.

FIGURE 4.2:

Photograph of the field station on Inishmore showing a typical instrument array. Instruments mounted on the tower are as follows: at 10m the wind direction indicator and MUNRO cup anemometer, at 7m are the KEITHLEY 602 portable electrometer connected to an Oblensky filter which is itself directly connected to a vacuum pump at the base of the tower. The ROYCO aerosol particle measuring system optical unit is at 3m while the intake hose extends to an elevation of 6m. The instrument shelter is on the left with sensor cables passing through the cable-port. The screen containing the CASELLA thermohygrograph can be seen on the right.

FIGURE 4.3:

Instrument array on tower during U.C.G./N.P.S. co-operative experiment. The Classical Scattering Aerosol Spectrometer is at 11m, the CASELLA anemometer is at 9m, the Active Scattering probe is at 8m, and the temperature/humidity probe is at 6m. An experimental installation of the AEROWATT wind generator is in the left foreground.

FIGURE 4.2.

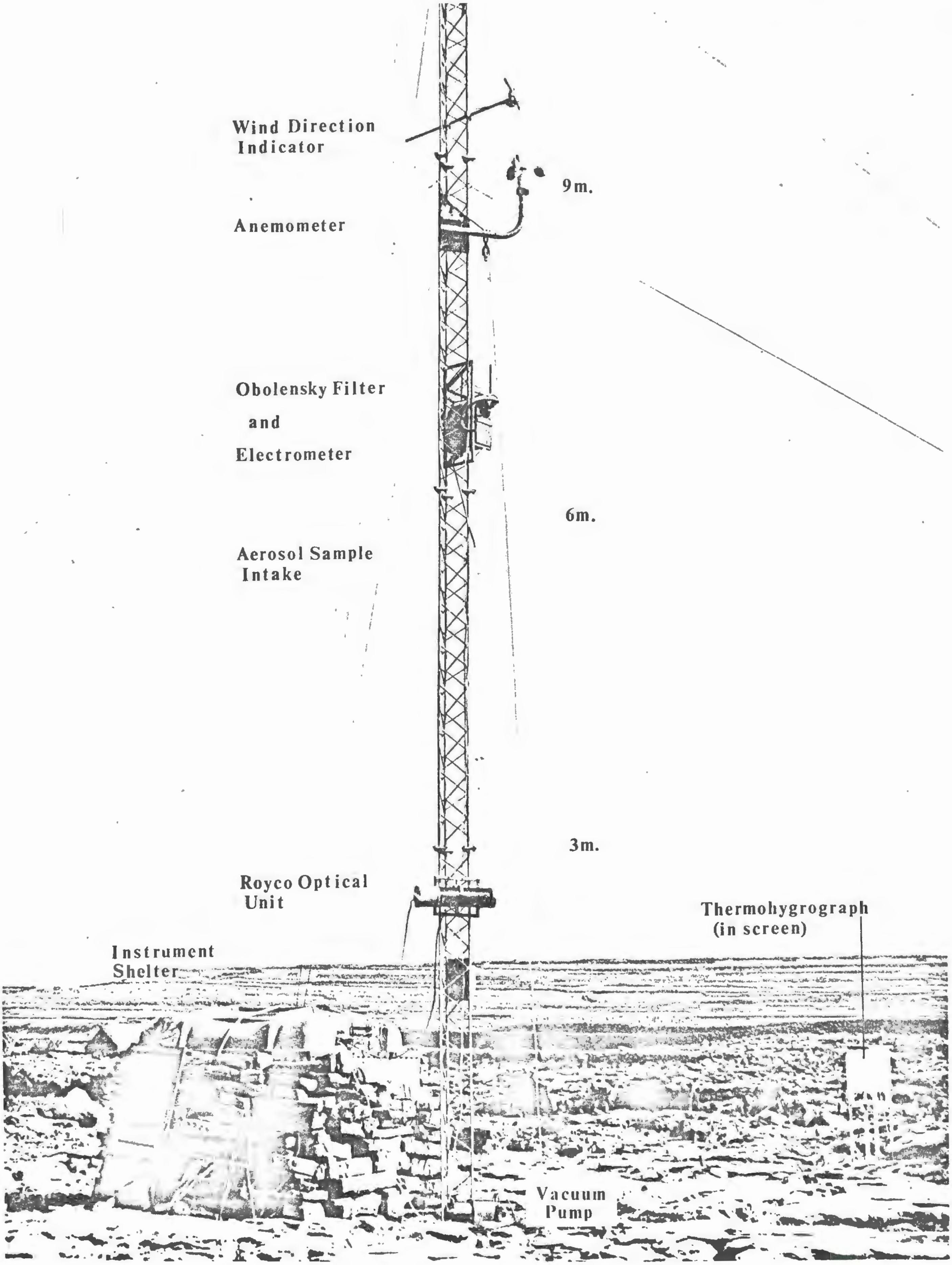
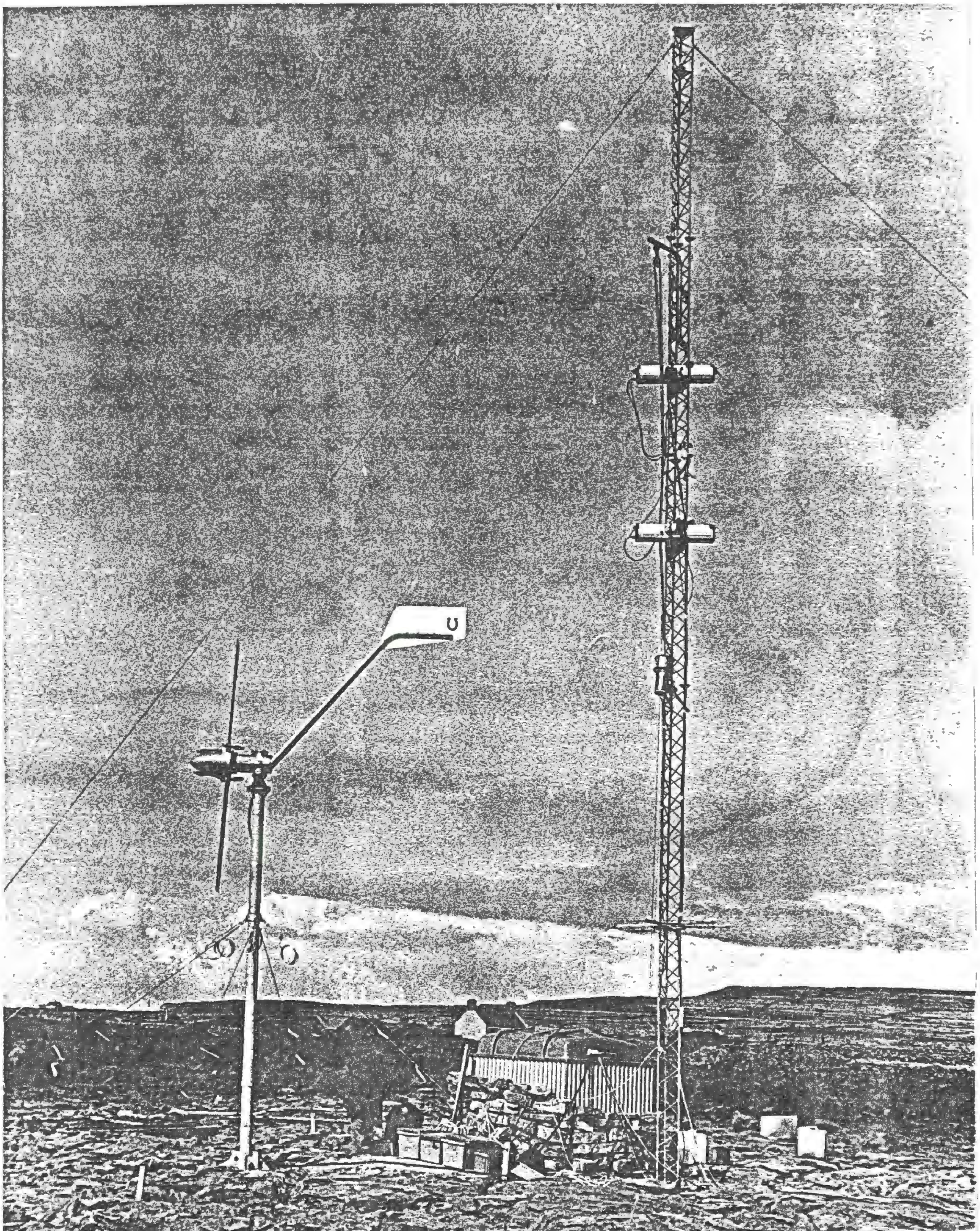

Wind Direction Indicator
Anemometer
9m.
Obolensky Filter and Electrometer
6m.
Aerosol Sample Intake
3m.
Royco Optical Unit
Thermohygrograph (in screen)
Instrument Shelter
Vacuum Pump

FIGURE 4.3.



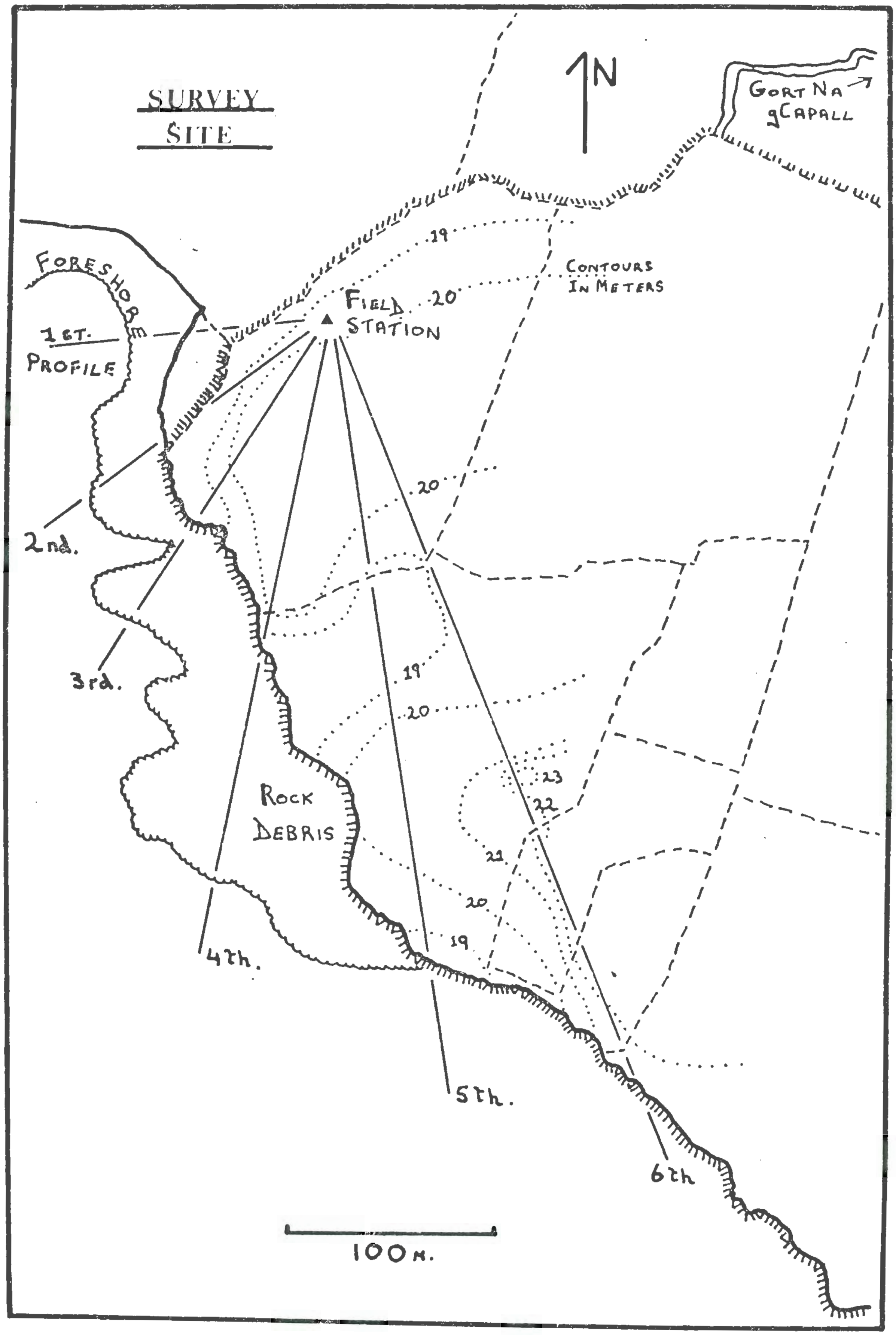


FIGURE 4.4:

Sketch map of the environs of the field station on Inishmore. Numbered lines correspond to profiles illustrated in Fig. 4.5. Contour lines are shown at 1m intervals along with prominent field boundaries.

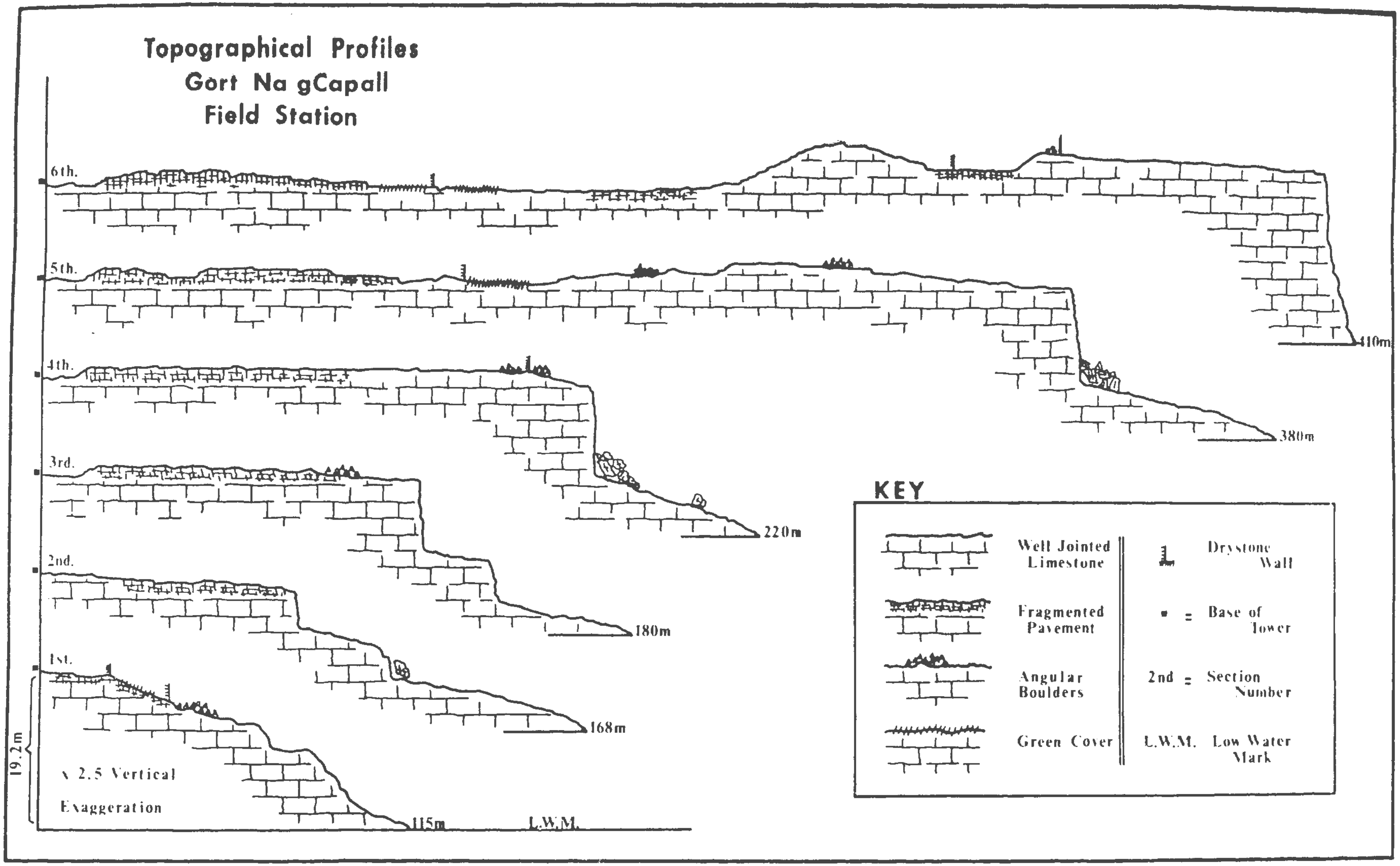


FIGURE 4.5:

Topographical sections through field station site. All profiles have their origin at the base of the tower (19.2m above O.D.) and radiate toward the foreshore.

CHAPTER 5.

RESULTS OF THE EXPERIMENTS ON INISHMORE

"To explore an island is to court obsession."
T. D. Robinson.

Introduction:

During two years of sampling on Inishmore a large body of aerosol and associated data was collected. In this chapter the aerosol data are analysed with respect to the dependence of particle concentration on variations in such factors as wind speed and direction and with regard to the origin of the aerosol particles. The data are compared to previously collected sets of broadly similar measurements, and as many of these earlier measurements were carried out at sea the factors influencing shoreline-, as opposed to shipboard-, measurements are noted. The comparative relationships of "smaller" to "larger" particles are also investigated.

5.2 The data:

On Inishmore aerosol measurements were made primarily with the ROYCO device. As stated in Chapter 4 aerosol concentrations were measured in two size ranges, the "larger" particles which include all those with radius greater than 2.5μm, (N2.5+) and the "smaller" particles with radii between 0.25 and 2.5μm, (0.25+). These ranges, which encompass the bulk of the atmospheric aerosol mass of marine origin, correspond closely to the so-called Giant and Large particles respectively (Roll, 1965) and, for convenience, will henceforth be referred to as such.

5.3 Aerosol dependence on wind direction:

In addition to a classification based on their size aerosols can be further categorised according to their origin i.e. according to the type and source of the "air mass" in which they are contained. A classification of the principle air mass types, as defined by McIntosh and Thom (1969), is presented in Table 5.1., and a schematic diagram of the various air masses which affect Ireland is shown as figure 5.1.

In order to categorise satisfactorily the Inishmore data in this fashion air mass movements and the resulting wind trajectories were extrapolated backward over several days. This was done using standard Royal Meteorological Society (R.M.S.) charts as well as "wind history" records derived from the measurements taken at the meteorological station at Belmullet, which is situated about sixty miles north of Inishmore. Figure 5.2. shows two examples of computer simulated wind history events for a six day period prior to measurements being taken. The straightforward track of the westerly airflow can be viewed with some confidence. The track of the easterly airflow is more complicated with the passage of a high pressure system being represented by the "loop" over the Celtic Sea. Because of such complications the simulations are accepted as being accurate only for a period of fourty-eight hours. Further insights into the origins of the air mass are based on the examination of the movement of frontal systems etc. using the R.M.S. charts.

Two main types of atmospheric aerosol are present at the station, continental particles which have their origins on land and oceanic particles which are derived primarily from the breaking of whitecap bubbles on the sea surface. The sampling situation on Inishmore is complicated by the presence of a small but active local surf zone. Contamination from this zone limits the number of oceanic measurements which can be truely recognised as such. Therefore, it has been assumed that three, rather than two, categories of aerosol have been sampled at the station depending on the direction of approach of the air mass in which the aerosol are contained.

The first class of aerosol is the maritime category which includes those particles whose flight path carries them directly across the open ocean to the instruments i.e. They approach from a broadly southwesterly (135-285°) direction. This is the predominant wind direction on Inishmore (the few trees on the West of the island have their growth stunted in this direction).

The second category includes those particles which approach from a "north to north-easterly" direction i.e. 315° through 360° to 105°, these are the land particles. Particles derived from the local surf-zone (285-315° to the west and 105-135° to the east) make up the third division. When the surf is particularly agitated, during high winds at high tide, these particles can have a considerable influence on aerosol counts. Also, as the waters in this area are particularly nutrient rich (as is apparent from the deep green colour), particle concentration may be increased due to the accumulation of organic surfactant material which can be several layers thick in such zones (Duce and Woodcock, 1972) i.e. the aerosol concentration will be much higher than on the open ocean. A synopsis of all data is contained in Table 5.2. The air-mass types follow the classification of McIntosh and Thom (1969) and a further sub-category is added according to the direction of approach to the instruments: Sea (S); Land (L); Surf Zone (Z).

5.4 <u>Aerosol dependence on wind speed:</u>

It is to be expected from previous work (Monahan *et al.*, 1982 and Latham *et al.*, 1982) that the strongest influence on the production of the larger marine aerosol particles will be the instantaneous wind speed. For the Inishmore data the relationships between the number concentration of the Large and Giant particles (N) and the wind speed (U) are shown in figures 5.3. and 5.4.

respectively. A regression line is fitted to the continental and maritime data within each size category using Ordinary Least Squares techniques. For each plot the aerosols have been sorted into wind speed increments and the mean and standard deviation calculated. The slopes and intercepts for the relationships appear in Table 5.3.

As can be seen from figure 5.3. there is but a weak to negative relationship between the Large continental and maritime particles and wind speed. This is to be expected, for aerosol particles with sub-micron radii tend to have residence times measured in hours or days rather than minutes (Prospero *et al.*, 1983).

There is, however, a strong positive relationship between the Giant, whitecap derived, maritime particles and the instantaneous wind (Fig 5.4) with a slope for the regression line of 1.39. The fit for the Giant continental particles versus the wind is less strong.

5.5 Other effects on particle concentration:

Apart from the dominant influence of wind speed the two meteorological parameters which would be expected to have an effect on particle concentration are relative humidity and turbulence (Toba, 1965).

During measurements on Inishmore the relative humidity varied from a minimum of 66% to a maximum of 96% with mean values of around 80%, indeed for most of the time values remained within about 10% of this mean figure. In analysing the aerosol results no direct allowence has been made for relative humidity fluctuations. However, because of the limited range and the comparitively few occasions when values exceeded about 90% it is safe to assume that relative humidity changes would have no significant effect on particle concentration (Latham et al., 1982).

It would also be possible for diffusivity due to increasing turbulence with increasing wind velocity to negatively effect the particle concentration (Tennekes and Lumley, 1972). Latham et al., (1982) have examined the effects of both mechanical and convective turbulence on the depth of the boundary layer. They concluded that, for maritime air, when wind speed related particle production rates are taken into account "a strong inverse relationship exists between the number concentration of large particles and mixing height". It is also noted here, however, that the changes in mixing depth and relative humidity are "small compared with the overriding effect of windspeed".

5.6 Comparison of results with similar data sets:

When considering the Inishmore measurements it has been assumed that they would be representative of results obtained at sea under broadly similar conditions. To a certain degree of course, this is not the case. Island measurements may differ from open ocean measurements for several reasons. Blanchard and Woodcock (1980) have indicated that winds on the open ocean may be about 1m/s higher than those crossing the windward shore of, even a small nearby island. The proximity of the surf-zone to the station on Inishmore has already been much alluded to. As noted by Duce and Woodcock (1970), surf contamination may influence both the concentration and composition of the particles reaching downwind instruments. On a local scale at the station topographical roughness (see chapter 4) may lead to turbulence and eddies which could affect wind speed measurements to an unknown degree. On some shore stations anthropogenic pollution could be a problem but this is not so for Inishmore. It is neccessary to bear this information in mind when comparing the Inishmore results with other data sets, especially those collected on the open ocean.

STREX 1980.

The Storm Transfer and Response Experiment (STREX) took place in the Gulf of Alaska in the winter of 1980. The experiment and its results are set out in chapters 6 and 7 of this study. Because of the failure of the ASASP probe during the STREX experiment no data are available on the contribution of the smaller particles to the atmospheric aerosol spectrum. However, for larger particles it is possible to compare the STREX and Aran data directly. The

Giant particle concentration on Inishmore can be compared to the calculated quantity N(2.5+), which is defined as the number of aerosol particles with radii greater than 2.5um, per cubic metre of air, as measured during STREX.

In order to calculate the quantity N(2.5+) from the STREX data-set a power-law fit for dN/dr, the number of aerosol particles per unit increment droplet radius, versus droplet radius, r, was assumed.

$$\text{Now, if} \quad dN/dr = Ar^{-b} \quad \text{then } N > r = \frac{A.r_0^{(1-b)}}{(1-b)} \qquad \text{[eqn 1]}$$

$$\text{so } N(2.5+) = \frac{A\ 2.5^{(1-b)}}{(1-b)} \qquad \text{[eqn 2]}$$

but V(r)dN/dr = dV/dr. So we must divide dV/dr, the fraction of the marine air volume filled by aerosol droplets, per unit increment droplet radius, by the volume of the droplet of appropriate aerosol radius to obtain dN/dr. Three dV/dr sets are available from the STREX data for droplet radii of (2,5, and 15μm). A straight line is then fitted to a graph of log dN/dr versus log r to find the equation: log dN/d = C+b log r or $dN/dr = 10^{C} r^{b}$. The quantities C and b are then substituted into equation 1, (where $A = 10^{C}$).

When N(2.5+) is plotted against U for STREX a slope of 1.40 is obtained and when N(2.5+), which is equivalent to the Giant particle range, is plotted against U for the Aran data a slope of 1.37 results. If the Aran winds are averaged over twenty minute to make them directly comparable with the STREX data a slope of 1.39 is obtained from a N(2.5+) versus U plot (Fig. 7.5).

It can be concluded that although they were collected under different circumstances there is significant agreement between the STREX and Inishmore results.

Lovett (1978).

Another set of broadly comparable readings were obtained by Lovett (1978) on board "stationary" weather vessels in the eastern-North Atlantic Ocean. Lovett was concerned not with number concentrations but with the 'total salt load' of the air as a function of wind speed. He used an expression of the form

$$\ln \theta = aU + b \qquad \text{[eqn 3]}$$

(Where θ is the sea-salt concentration in $\mu g/m^3$)

to represent the relationship of θ to U. He concluded that a slope (a) of 0.16 with a standard deviation of ± 0.06 was the best-fit to his data, i.e. it was the mean slope of the various regression lines which he fitted to the data set.

This fit is compared to previous studies of the same parameters by Woodcock (1953), at cloudbase near Hawaii, and by Toba (1965), aboard ship in the Pacific Ocean. These studies yielded slopes of 0.16 and 0.12 respectively. More recently Latham et al., (1982) report a value of 0.17 for a slope derived from shore based measurements obtained on the island of South Uist in The Western Isles of Scotland. Prodi *et al.*, (1983) report a best-fit for the 0 versus U relationship of $\ln c = 0.13U+1.77$ for data obtained on a cruise from the Mediterranean Sea to the Indian Ocean. Gras and Ayers, (1983) collected data at 94m elevation on the west coast of the island of Tasmania. They present an expression $\log v = 0.015U - 11.9$ as the best-fit for v, the salt volume, as a function of the wind speed in km/hr. When the Inishmore data are expressed in similar terms a slope of 0.027 is obtained.

On first sight it would not seem that the results outlined above would be comparable to the number concentration versus wind speed relationships as obtained on Inishmore. However if some simple assumptions are made useful comparisons can be drawn.

It must first be assumed that the quantity N(2.5+) is proportional to the mass concentration of whitecap derived sea salt particles on Inishmore. An examination of figure 5.6a. (the volume spectrum of aerosols on the island) will show this to be correct. There are two distinct maxima present on this curve. The most prominent occurs amongst the particles with radii in the sub-micron range. But the importance of this component is diminished for two important reasons. Firstly, a large proportion of the particles present in this 'bulge' are continental, non-sodium chloride, particles, and secondly, because of the protracted residence times of the sub-micron particles, their concentration would have little or no correlation with immediate wind speed (Fig. 5.4).

There is a second bulge on this diagram representing an increase in aerosol numbers with radii above about 2μm. This bulge corresponds to the whitecap derived particles which make up the bulk of the sea-salt load in the atmosphere. From this we can conclude that the quantity N(2.5+) will be essentially proportional to the total salt load and hence that the slope (a) of θ versus U should be directly comparable to that of N(2.5+) versus U.

When the aerosol results from Inishmore are expressed in a form similar to equation 5.3., i.e. $\ln N = aU + b$, the following relationship is found,

$$\ln N(2.5+) = 0.21U + 9.55 \qquad \text{[eqn 4]}$$

This result is well within the standard deviation range set by Lovett and almost exactly matches the sample figure which he presents. A diagram of ln N(2.5+) versus U for the Inishmore data appears as figure 5.5. It may also be noted that the slope of 0.21 compares quite favourably with the quoted results of Woodcock (1953), Toba (1965), Latham *et al*. (1982), Prodi *et al*. (1983) and Gras and Ayers (1983).

5.7 The U.C.G./N.P.S. co-operative experiment:

This experiment lasted for four days during the summer of 1980. The instrumentation and methods are fully described in Chapter 4. A total of 66 aerosol size spectra were obtained using two Knollenberg aerosol probes with overlapping size ranges capable of measuring both the background and newly generated aerosol components. A full suite of ambient meteorological parameters were also recorded during the experiment.

Weather conditions for three of the four days were less than favourable. During this period a north-westerly air flow was carrying a polar maritime air mass over the western part of the island, and perhaps, even across Slyne Head on the mainland, before reaching the instruments. On the fourth day of sampling eight good size spectra of 'clean' maritime air were obtained before rain prevented further sampling.

Wind speeds throughout the sampling periods were very constant with a usual range of from about 6 - 10m/s. It is hard to assess aerosol concentration wind dependence from measurements made over such a limited wind range. Despite the drawbacks of the unfavourable wind conditions the aerosol spectra contain many interesting features.

The curve shown as figure 5.6a (27/6/80) represents a typical size distribution spectrum for maritime air (250°). The bulge to the left indicates the residual, or background, level of the sub-micron radius range of particles, with residence times of up to several days. The bulge to the right represents Giant particles as derived from the bursting of bubbles caused by whitecapping at the sea surface.

Figure 5.6b (26/6/80) shows a spectrum for air which has been blowing across the island for several hours (320°). The most significant feature of this curve is the depletion of particles with radii greater than one micron as compared to the maritime air of 5.6a. This can be explained by the fallout of Large particles, with the island acting as a sink, but also may be partially due to the low angle of incidence of particles to the probe intakes. Nevertheless the presence of a discernable, if diminished, bulge shows that the spectrum represents modified maritime, rather than continental, air.

Figure 5.6c (24/4/80) shows a size spectrum for air which has been blowing fairly constantly across the surf-zone (305°). The enhancement of the bulge on the left in comparison to figures 5.6a and b. is indicative of the increased contribution of particles derived from bursting surf and foam bubbles in this zone.

This phenomena is also reflected in the diagram representing the respective number spectra for these data (Fig. 5.7). It is here indicated by the conspicuous bulge in the dashed surf zone curve which is more or less absent in the other two instances.

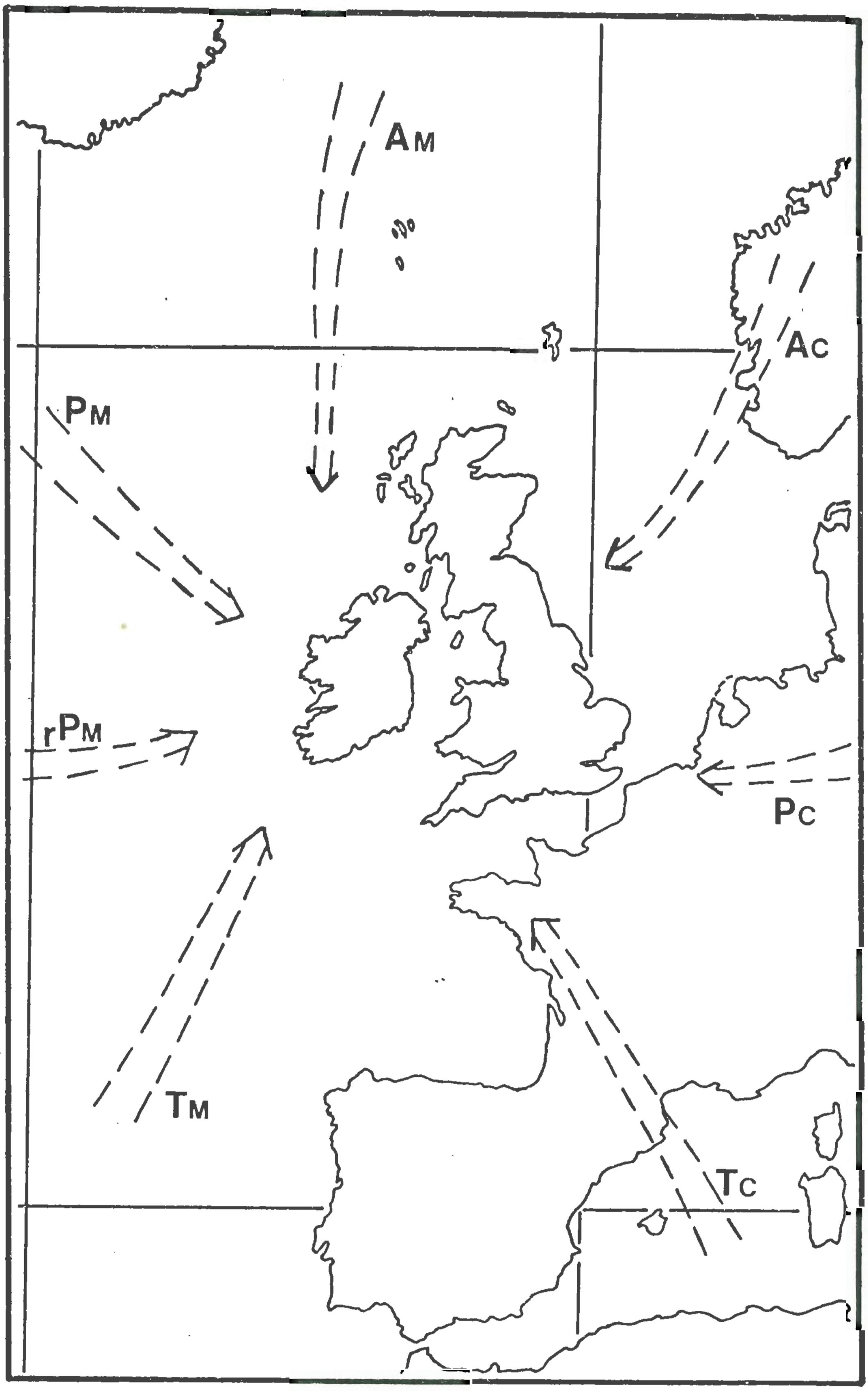


FIGURE 5.1:

Schematic representation of principle air mass types affecting Ireland [from McIntosh and Thom, 1969]. The air mass classifications are defined in Table 5.1.

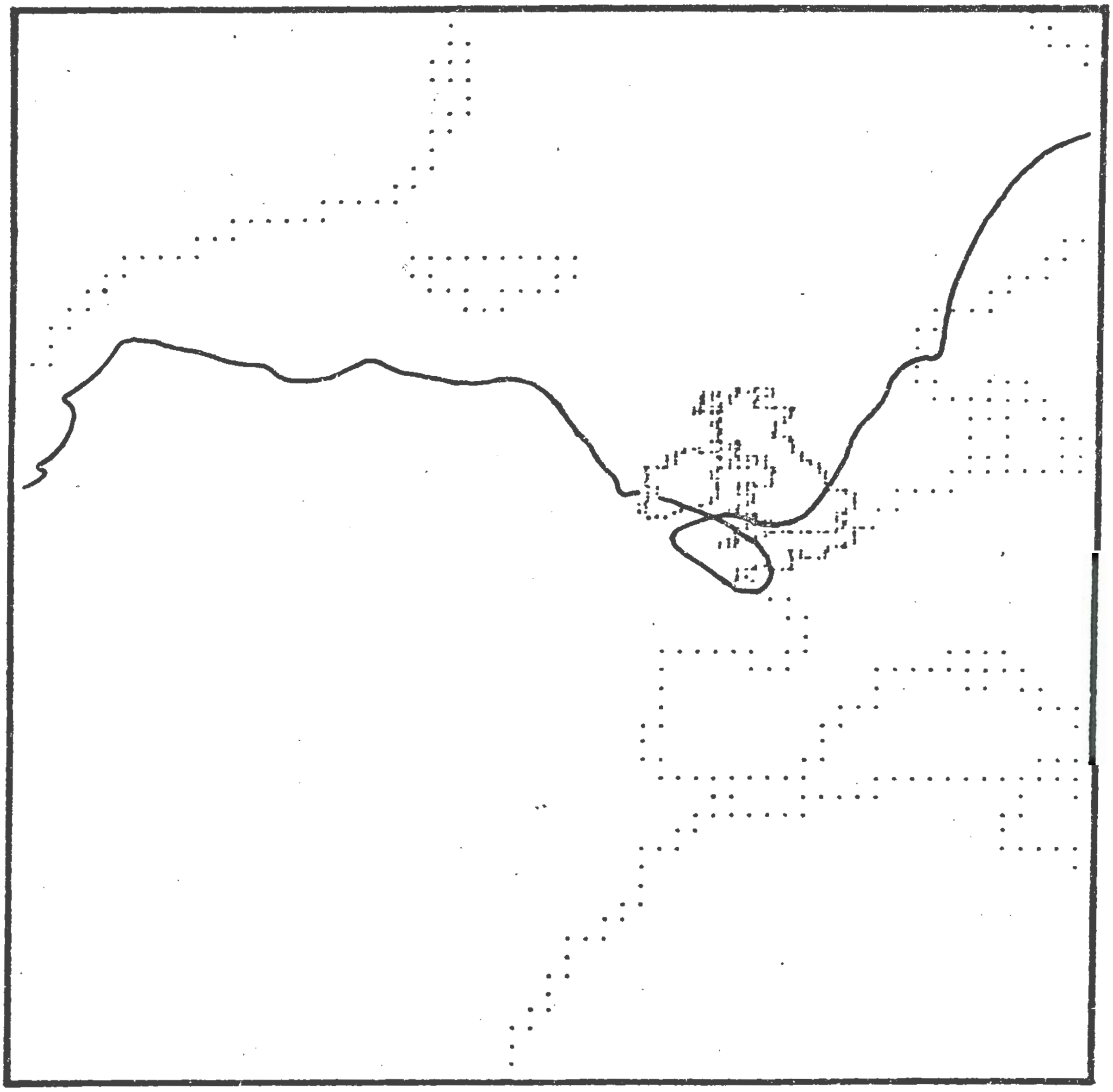


FIGURE 5.2:

Computer simulation of two sample six-day wind history records.

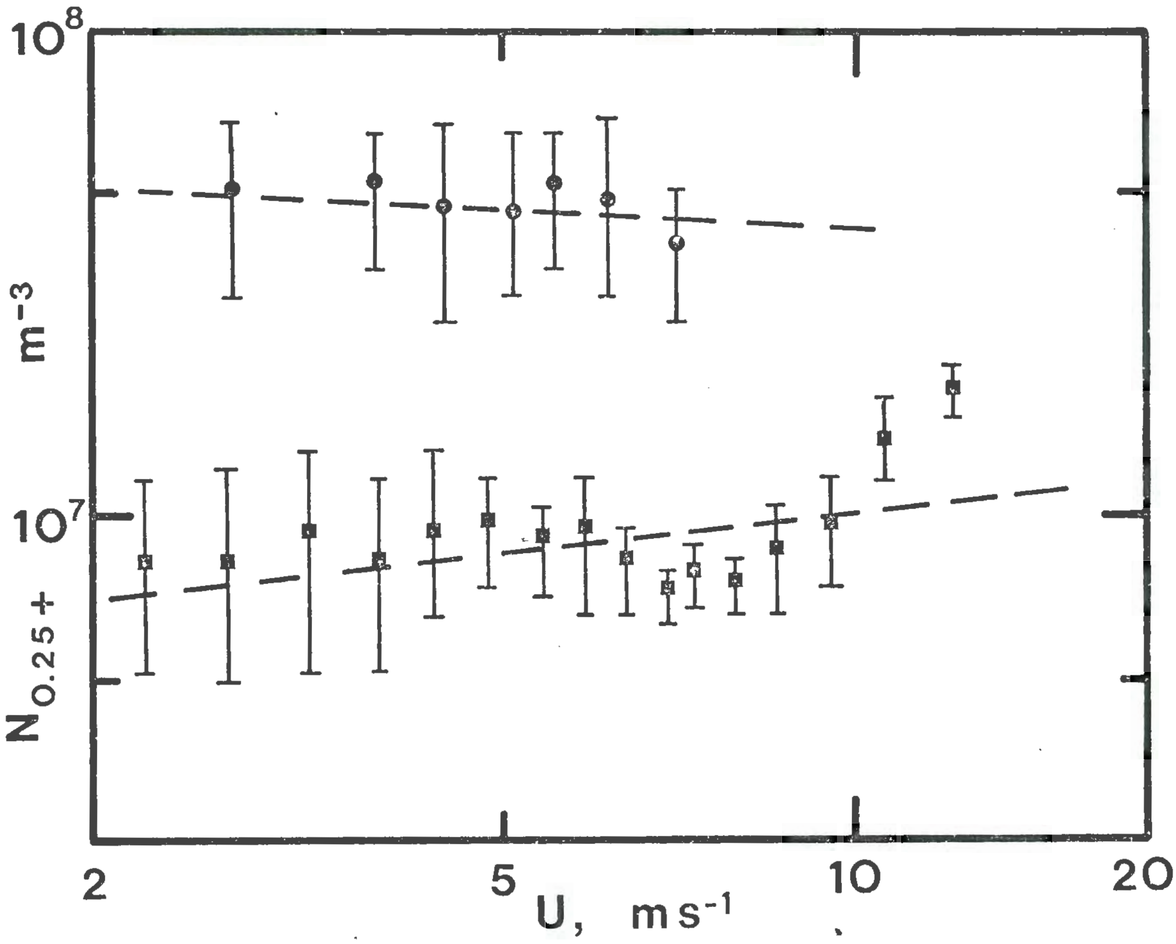


FIGURE 5.3:

The concentration of aerosol particles with radii greater than 0.25μm, N(0.25+), versus the wind speed (U). Circles: continental air. Dashed line: $N(0.25+) = 4.07X10^{7} U^{-0.21}$. Squares: maritime air. Dashed line: $N(0.25+) = 5.75X10^{6} U^{0.24}$. Both expressions based on the best O.L.S. fits to the data.

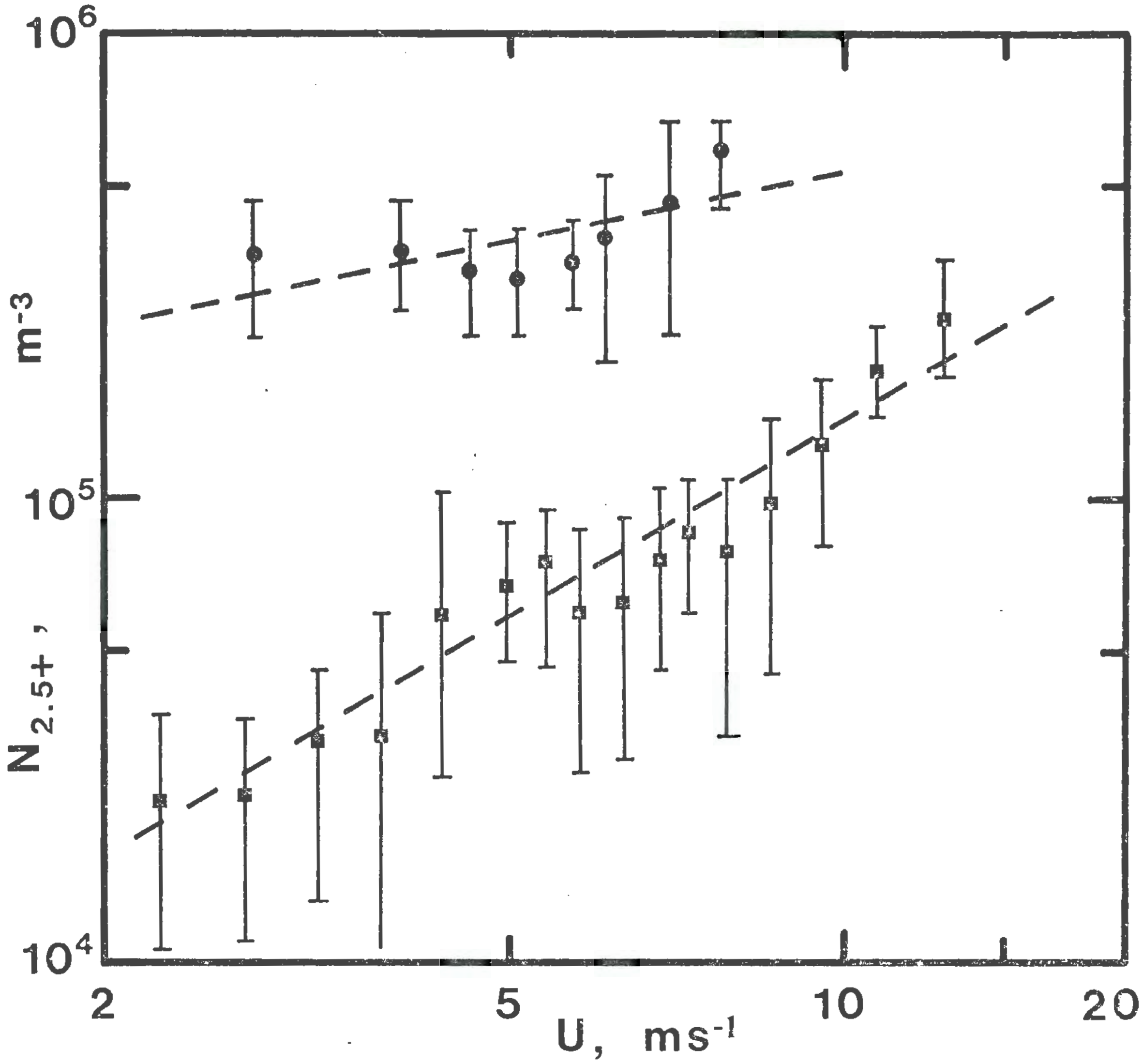


FIGURE 5.4:

The concentration of aerosol particles with radii greater than 2.5μm, N(2.5+), versus wind speed (U). Circles: continental air. Dashed line: $N(2.5+) = 1.45X10^5 U^{0.45}$. Squares: maritime air. Dashed line: $N(2.5+) = 5.37X10^3 U^{1.39}$. Both expressions based on the best O.L.S. fits to the data.

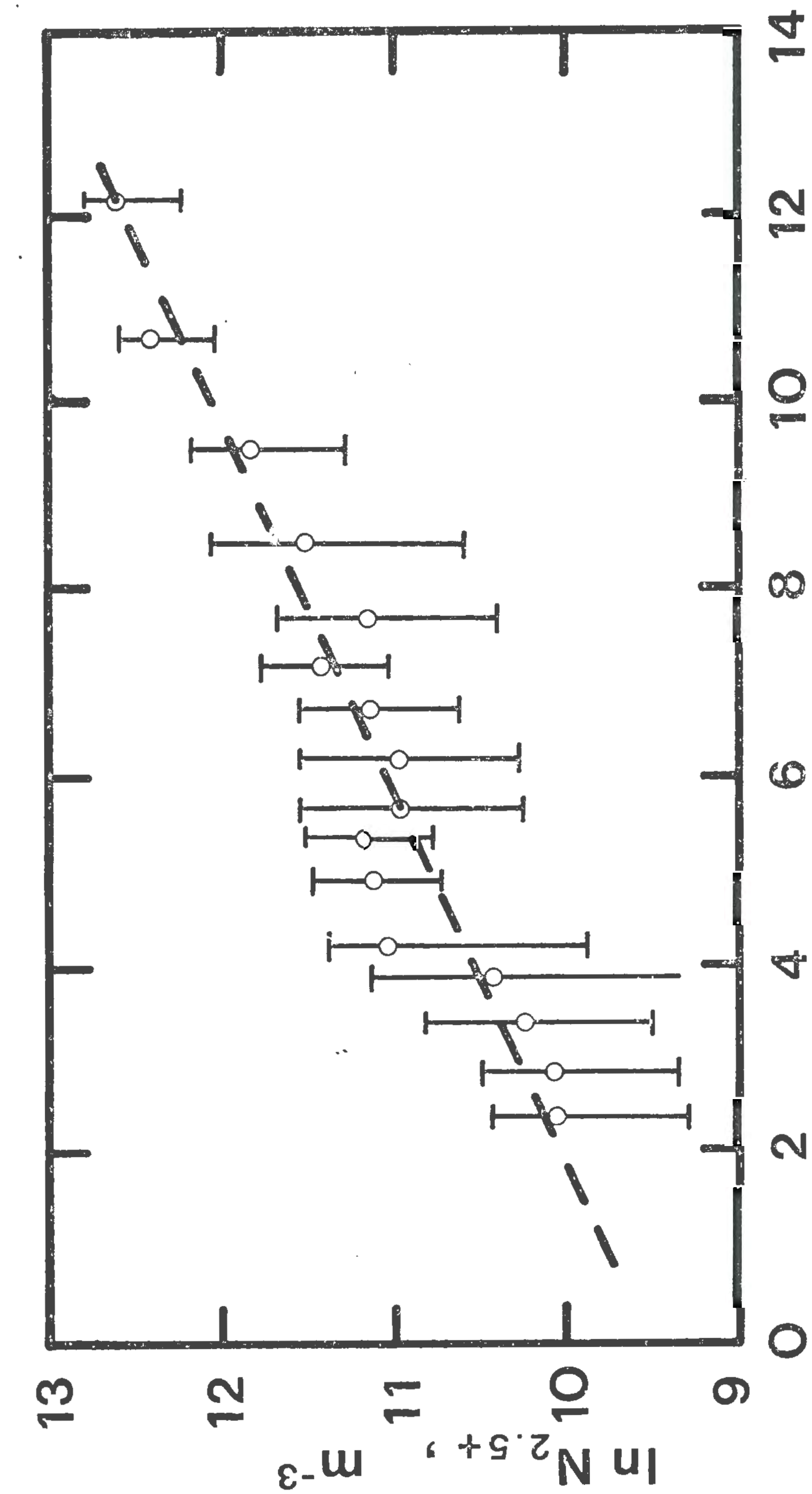


FIGURE 5.5:

The concentration of 'Giant' maritime aerosol particles, (N2.5+), versus wind speed, (U). Dashed fit has a slope of 0.21, for comparison with plots of Lovett (1978) and others, see text for details.

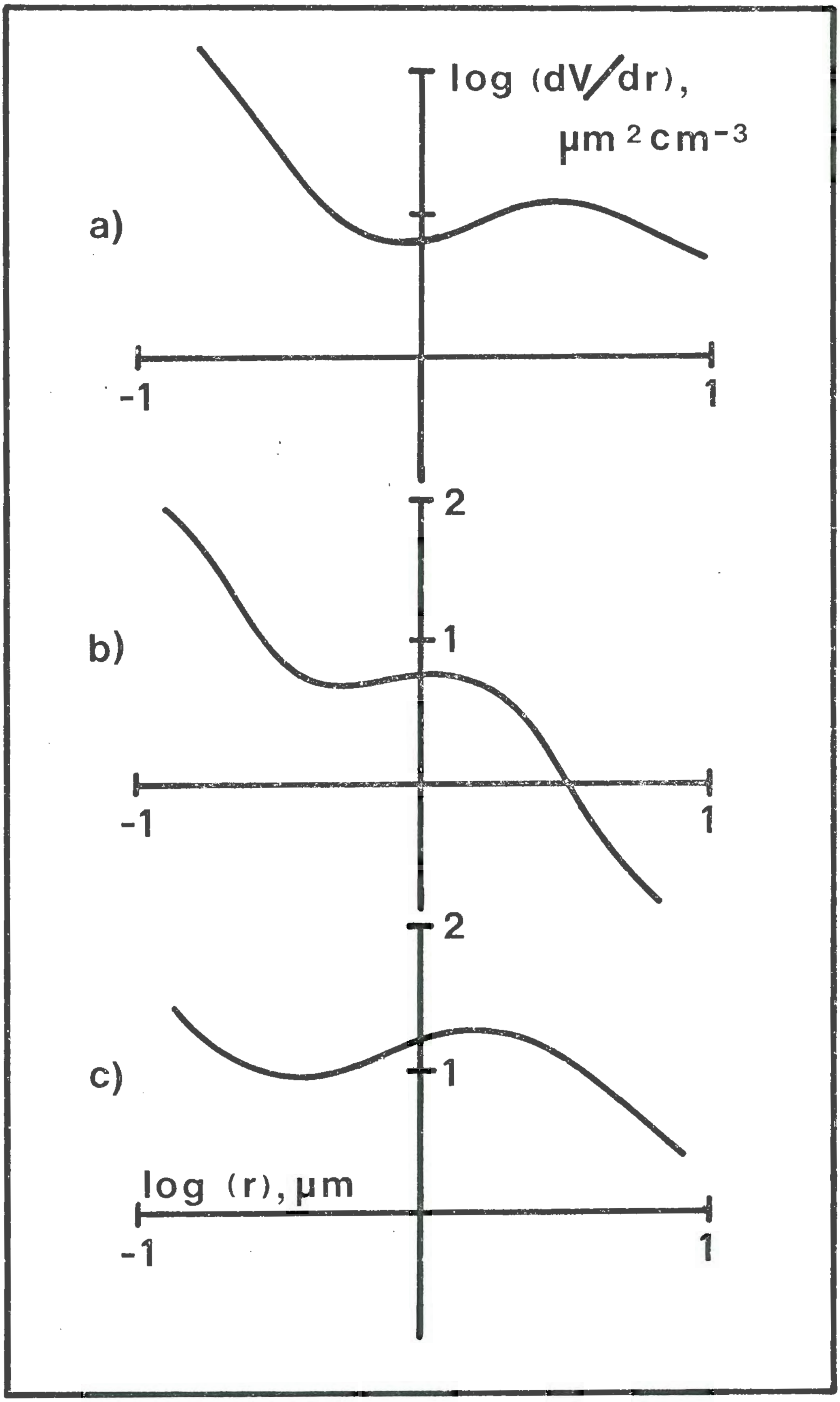


FIGURE 5.6:

Aerosol size distribution spectra as obtained during the U.C.G./N.P.S co-operative experiment on Inishmore. a) represents 'clean' maritime air; b) maritime air which has blown over land for several hours; c) maritime air which has been modified by the influence of the surf-zone.

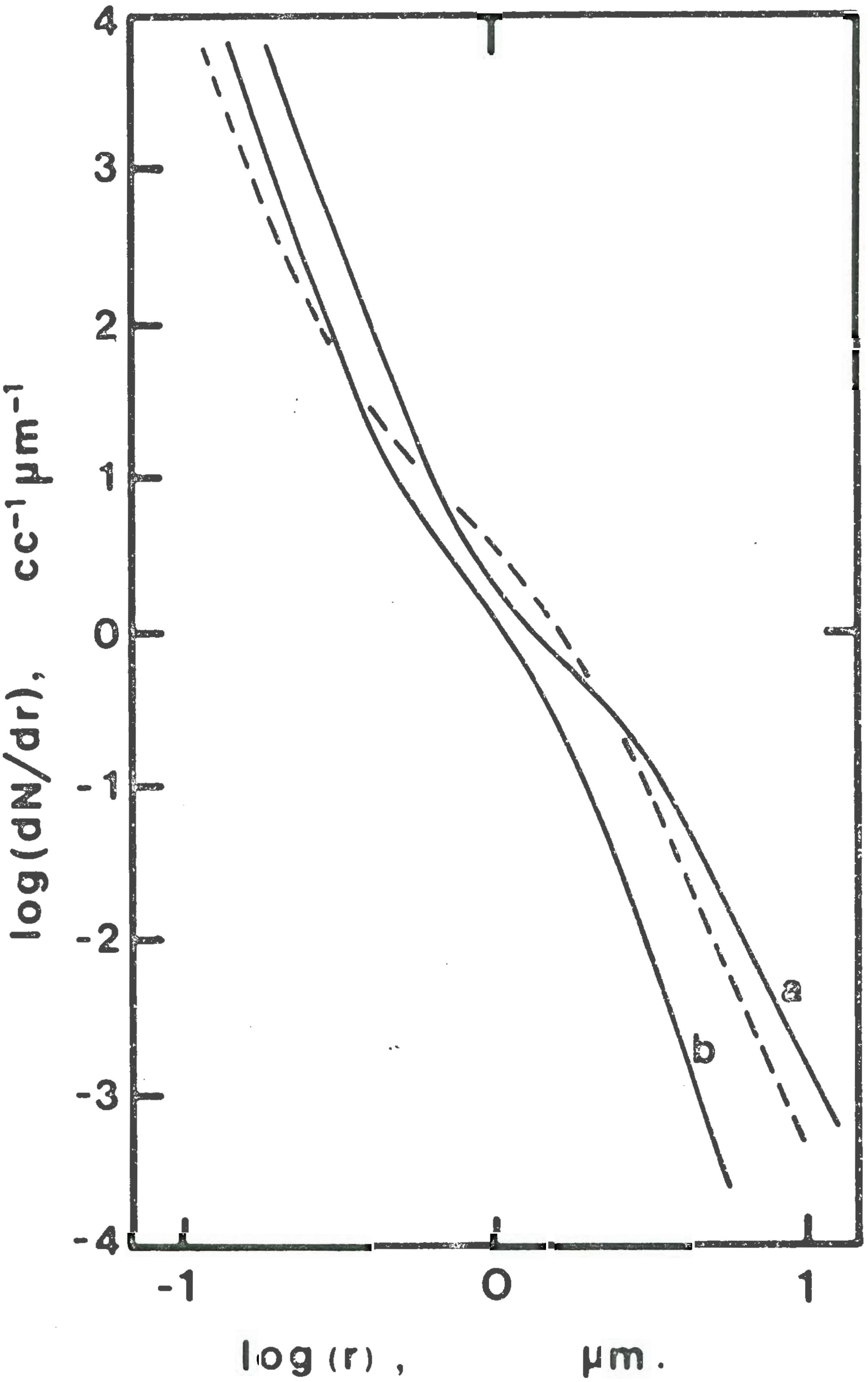


FIGURE 5.7:

Aerosol number spectra corresponding to the size distribution spectra of fig. 5.6. Note the rapid fall-off of concentration with increasing size.

TABLE 5.1.

CLASSIFICATION OF PRINCIPLE AIR MASS TYPES

Air Mass		Source Region	Properties At Source
Polar Maritime	Pm	Oceans In Latitudes > 50°	Cool, rather moist; unstable.
Polar Continental	Pc	Continents Close To Arctic Circle	Cold, dry, stable.
Arctic	A	The Arctic Basin	Very cold and dry; very stable.
Tropical Maritime	Tc	Sub Tropical Oceans	Warm, moist and unstable at surface.
Tropical Continental	Tm	Deserts In Low Latitudes	Hot and dry; unstable

[from McIntosh and Thom, 1969]

TABLE 5.2.

SYNOPSIS OF INISHMORE DATA

OBS #	DATE d, m, y,	U m/s	W.D.	Air Mass	No. INT	N(0.25+) m^{-3}	N(2.5+) m^{-3}
1	14, 2,'81	4.9	100°	Tc(l)	182	3.31E 7	2.69E 5
2	6, 3,'81	3.6	230°	Pc(s)	120	2.43E 7	6.10E 5
3	14, 5,'81	5.1	190°	rPm(s)	156	8.36E 6	2.96E 4
4/5	15, 5,'81	6.1	105°	Tc(l)	71	2.05E 7	3.41E 5
6	16, 7,'81	10.2	305°	Pm(z)	79	5.14E 6	2.98E 4
7	17, 7,'81	10.1	315°	Pm(z)	100	1.07E 7	2.31E 4
8	3, 9,'81	6.3	190°	Tm(s)	200	7.98E 6	8.19E 4
9	5,11,'81	6.7	125°	Tm(l)	30	9.74E 6	5.40E 4
11	19, 3,'82	11.5	300°	rPm(z)	25	3.81E 7	1.49E 5
12	21, 3,'82	4.8	285°	Pm(z)	32	6.54E 7	5.93E 5
13	15,11,'82	10.5	230°	Pm(s)	80	1.01E 7	1.68E 5

Wind speed (U), wind direction (W.D.), and aerosol concentration (N) values are averages for each observation period. The number of measurement intervals in each period is denoted by No. Int.

TABLE 5.3.

EXPRESSIONS FOR N(U).

	Maritime log C	Maritime γ	Continental log C	Continental γ
N(0.25+)	6.76	0.24	7.61	-0.21
N(2.5+)	3.73	1.39	5.16	0.45

CHAPTER 6

THE STREX EXPERIMENT

"It's all about the adventures of
A bold young Irish tar
Who sailed as a man before the mast
Of the Oceanographer."
Anon.

Introduction:

The Storm Transfer and Response Experiment (STREX) took place in the Gulf of Alaska from mid-October to mid-December 1980. The overall objectives of STREX were "to understand the physical processes of the boundary layers of the atmosphere and the ocean in mid-latitude storms, the interaction of the two boundary layers, and the interaction with larger scale phenomena" (Miyake, 1980).

The field phase of the experiment involved intensive and detailed meteorological and physical oceanographic observations from a number of ships, aircraft and satellites. These observations were co-ordinated from the central STREX office in Seattle, Washington.

The main shipboard work of the project was performed aboard the National Oceanic and Atmospheric Administration (NOAA) vessel R.V. Oceanographer. Investigations were conducted in two legs, the first from 3 to 24 November and the second from 28 November to 15 December 1980. The U.C.G. experiment spanned both of these stages.

The U.C.G. group were involved in STREX for the purpose of obtaining additional photographic data for the estimation of oceanic whitecap coverage. It was also intended to relate these data to aerosol spectra and ambient meteorological measurements as obtained from the allied experiment of the Environmental Physics Group of the Naval Postgradute School (N.P.S.).

The simultaneous measurement of whitecap coverage and aerosol concentration has previously been reported on only two occasions viz: on board the R.V. Hakuho Maru in the East China Sea (Chaen, 1973; Toba and Chaen, 1973) and on board the R.R.S. Challenger during the JASIN experiment in the eastern North Atlantic Ocean (Monahan et al., 1982b). Consequently the informations collected during STREX have resulted in a significant extension of both the size and the meteorological range of the data base in this subject area.

6.2 Photographic Observations:

On the Oceanographer photographic observations were made from the forward watch space located on the flying bridge of the vessel at a height of 14.5m above the water line (Fig. 6.1). This vantage point, while partially protected from the wind, provided an unobstructed forward view of the sea and convenient sighting of the forward wind direction indicator. The camera was tilted so that it took in a field of view spanning about a 45° arc downward from a point just above the horizon.

All photographs were taken with BEATTIE Varitron automatic sequence cameras using Ektachrome type 5256 film. Each camera was fitted with an automatic data recording back which recorded an individual number and time of exposure on each frame. For each observation interval a series of thirty frames (ten at each of three f-stop settings) were exposed over a period of approximately three minutes. Sets of photographs were taken at hourly intervals where possible and synchronised with the thirty minute long measuring sequences of the N.P.S. group.

6.3 Aerosol and Meteorological Measurements:

Measurement of aerosol spectra and meteorological factors during STREX were performed by the N.P.S. group (Spiel 1981). It had been intended to measure aerosol spectra from 1 to 150 microns radius using three Particle Measuring Systems aerosol spectrometer probes with overlapping detection limits, the active scattering probe (model ASASP-300) with a detection range of droplet radii from 0.1 to 3μm, the classical scattering probe (model CSASP-100) with a detection range from 0.5 to 15μm and the optical array probe (model OAP-230X) with a detection range from 10 to 150 μm. However, adverse operating conditions disabled two of the probes (ASASP and OAP) and restricted the detection range to that of the CSASP i.e. 0.5 to 15μm radius.

The aerosol probes were mounted on a fixed platform on the foremast at a height of 22m above the water line. The various sensors for wind speed, wind direction, relative humidity, and wind speed fluctuations were also mounted on the foremast at a height of 28m above the water line. The sea surface temperature probe was suspended from a 4m boom on the starboard side.

Processing equipment for the data from all sensors was housed in the plot room (Fig. 6.2). Both aerosol and meteorological data were averaged over thirty minute intervals using a Hewlett-Packard computer (model 9825s) in conjunction with a DAS-32. Accurate time (local and G.M.T.) and a satellite fix of position were available from the ships computer a D.E.C./P.D.P. 11/34.

6.4 Data Analysis:

The photographic data from STREX were analysed using the manual technique of Monahan (1969), a method is quite similar to that adopted by Toba and Chaen (1973). Briefly, for each observation interval, this involves the selection for analysis of the exposure group which shows the best contrast. Each frame is then projected onto a sheet of paper and the outlines of the whitecaps are traced. The whitecap silhouettes are then exacted and weighed. As the density and analysed area of paper are also determined for each frame the fractional whitecap coverage can be easily obtained. The average whitecap cover and standard deviation over all frames in the interval is then calculated. Each interval is analysed by at least three analysts. The final values for whitecap coverage and standard deviation is the mean of the returns of all analysts.

A hard copy of the aerosol data was provided by D.E. Spiel of the N.P.S., the appropriate extracts for each observation interval appear as Table 7.2. The results obtained from these data are presented in the following chapter.

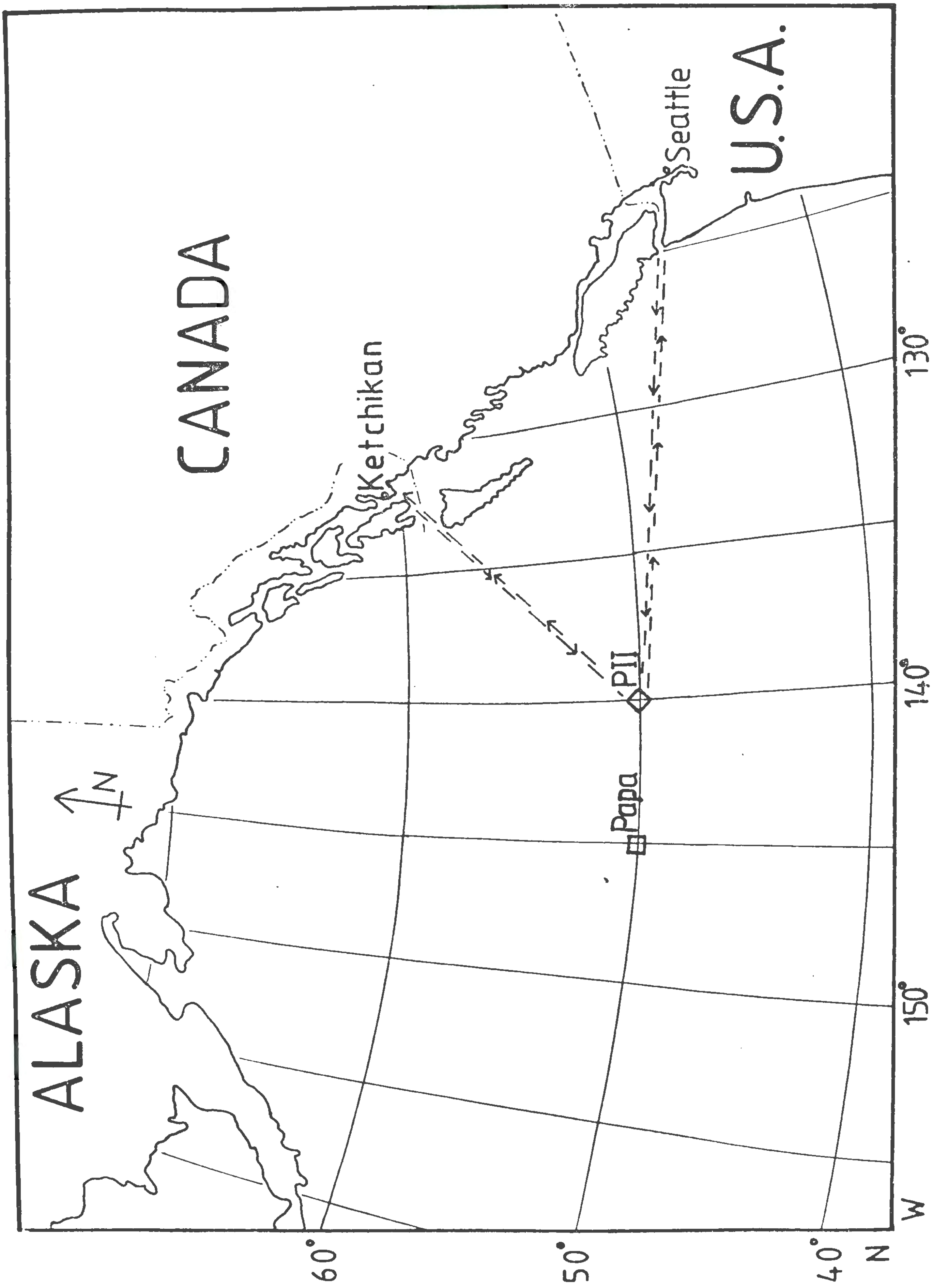


FIGURE 6.1:

Cruise track of the R.V. OCEANOGRAPHER, in the Gulf of Alaska, during STREX, 3 November - 15 December 1980.

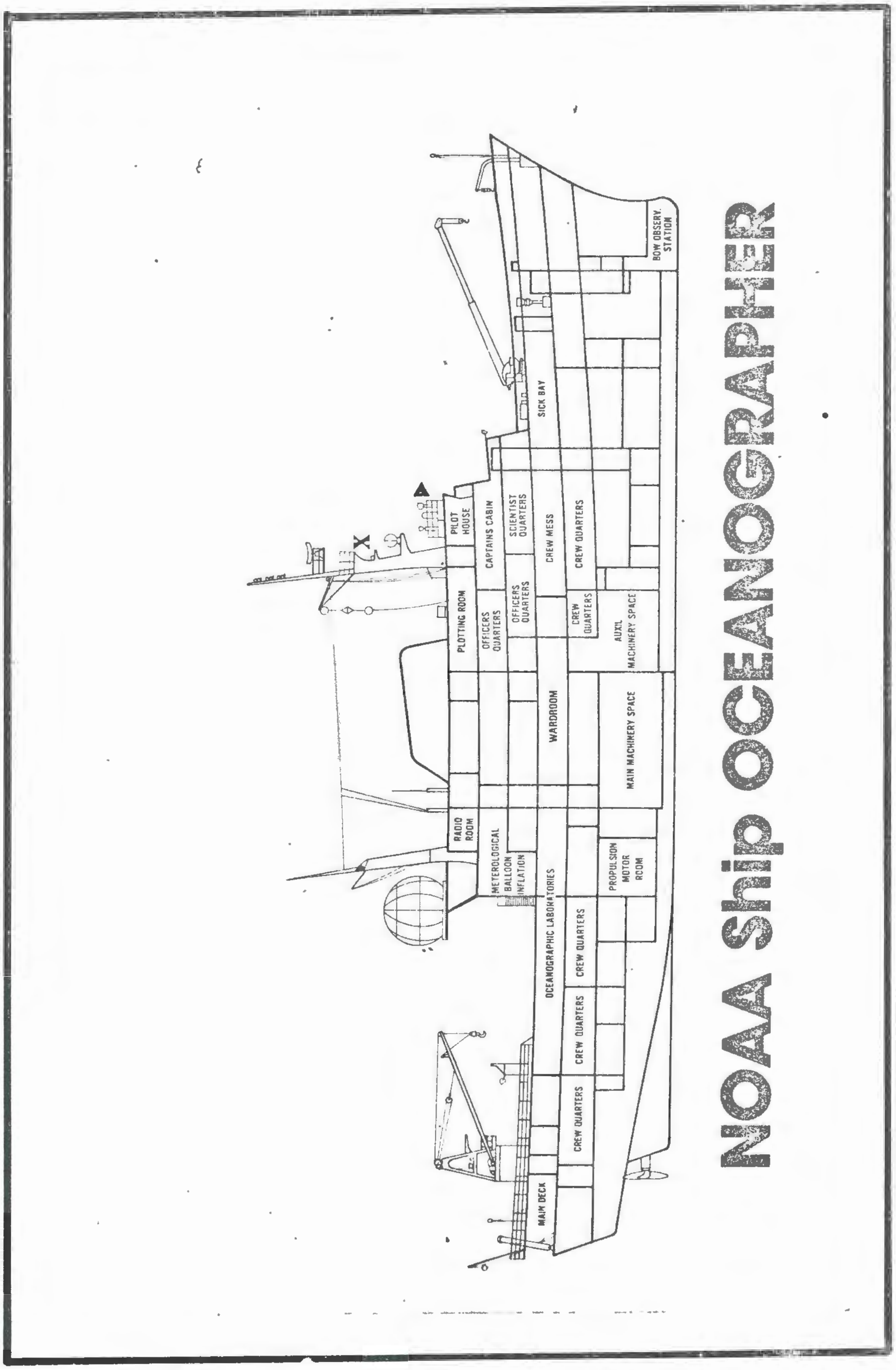


FIGURE 6.2:

Layout plan of the R.V. Oceanographer showing location of instruments(x)and position of photographic observation point(▶).

[from NOAA information sheet].

CHAPTER 7.

RESULTS FROM THE STREX EXPERIMENT

"I dreamed I heard a fiddle play
Or maybe that's a notion
And I dreamed I saw whitehorses dance
Upon that other ocean."
Ralph McTell.

Introduction:

In this chapter the final listings of the STREX data are tabulated. The relationships of whitecap coverage (W) to the ten-meter elevation wind speed (U) and aerosol concentration, as well as the influence of such factors as thermal stability and sea surface temperature are assessed. The results are also compared with previously published data sets.

The STREX data set comprises 87 observations of whitecap coverage, aerosol concentration, and ambient meteorological conditions (Table 7.1). Two intervals (500, 514) were found to be too poorly exposed for reliable analysis. In a further five intervals (486,508,518,539, 559) no aerosol data were available while nine intervals (494,95,99,503,05,09,27,44,61) were associated with unreliable aerosol statistics. In addition, because of the statistical methods involved, zero values of W are omitted, this occurs in only one case (548). Overall this limits the analysis of the various aerosol relationships to 70 intervals (Table 7.2).

Previous to the STREX experiment only two sets of data had been published which contained simultaneous observations of whitecap coverage, aerosol concentration, and ambient meteorological conditions. These were collected on board the Hakuho Maru in the East China Sea (Toba and Chaen, 1973) and on board the Challenger in the eastern North Atlantic during the JASIN experiment (Monahan et al., 1983), henceforth referred to as TC73 and JASIN respectively. In addition Monahan (1971) collected whitecap and relevant meteorological data in the west Atlantic and Caribbean mainly during the BOMEX experiment, which set will be referred to as MON71.

This composite data set comprises 262 cases. However, when W values of less than 0.008% are disregarded (16 from MON71, 12 from TC73, 2 from JASIN, and 1 from STREX), a total of just 231 "non-zero" intervals remain. This data-set is summarised in Tables 7.5. and 7.6. and is classified in accordance with the criteria outlined below.

For the descriptive purposes the following classifications of the data have been established:

Thermal Stability	Stable	$\Delta T < -0.4$ C
	Neutral	$-0.4 < \Delta T < 0.6$ C
	Unstable	$\Delta T > 0.6$ C
Wind Speed	Low	$U < 9.0$m/s
	High	$U > 9.0$m/s

and further for comparison with previously published results the following classification is made:

Sea Surface Temperature	Cold	$Tw < 12.5$ C
	Moderate	$12.5 < Tw < 14.0$ C
	Warm	$Tw > 14.0$ C

The 'Thermal Stability' (ΔT), which has been adopted as a measure of the stability of the air column above the sea surface is defined to be equal to the sea surface temperature(Tw) minus the air temperature(Ta). All wind speeds have been corrected to the standard height of ten meters using the method of Roll (1965). The sea-surface temperature categories have been established intuitively at distinct breaks in the overall data set. It is to be noted that the STREX results fall entirely within the cold category for water temperature and that a majority of the thermal stability designations for STREX are unstable (54 cases).

In the analysis of the STREX results the statistical method of ordinary least squares (O.L.S.) is employed for all relationships, curves having been fitted using the 'MLAB' package of The National Institute of Health, Bethesda, MD. Due to the high degree of scatter which is common in environmental data of this kind techniques which reduce the influence of "outlying" points might be useful. One such method, that of Robust Biweight Fitting (Gaver, 1979), has been employed by Monahan *et al.*, (1983) in the analysis of the TC73 and JASIN results and is here applied to some of the STREX relationships for comparison. As both of these methods involve linear regression in log-log space 'zero' values of W must be excluded.

7.2 The dependance of whitecap coverage on wind speed:

It has been established from previous work (Blanchard and Woodcock, 1980) that the major influence on whitecap coverage (W) is that of wind speed (U). Now this relationship can be expressed in the form of a power-law

thus $$W = \alpha U^{\lambda} \qquad \text{Eqn. 1.}$$

Such a W(U) relationship for the STREX data is shown graphically in figure 7.1. The dashed line represents an O.L.S. fit to the data expressed by $W\% = 6.22 \times 10^{-3} U^{2.21}$, with an error on the exponent of $\pm$ 0.41. The equivalent fit using R.B.F. techniques yield a λ value of 1.84 (see table 7.3). The λ values for the STREX W(U) relationship approximate to a quadratic form as opposed to the near cubic forms as obtained for previous data sets (Wu, 1979; Monahan and O'Muircheartaigh, 1980; and Monahan *et al.*, 1983).

It has been suggested (Toba and Chaen, 1973) that the wind friction velocity (U*) may be a more appropriate factor for scaling the degree of whitecap coverage. Toba and Chaen employed U* as one element of a dimensionless variable U* L/ν (where L is the significant wave height and ν is the kinematic viscosity of air) which they used as the independent variable for scaling W. When STREX W values are plotted against the corresponding U* values as obtained from stability dependent aerodynamic formulae (Monahan and Davidson, 1979) and using equation 1 a λ value of 2.14 was obtained.

It was also felt that the instantaneous wind speed might not be a good scalar for W, especially for a well developed sea. So it was decided to plot W against U6, the wind speed averaged over the six hour period prior to each data collection interval. In this case a λ value of 2.22 was obtained. Both of these exponents are well within the error margin for the straightforward W(U) relationship.

While recognising the primary effect of the wind speed on the whitecap coverage it must be remembered that other factors such as sea surface temperature and thermal stability may influence W significantly. Miyake and Abe (1948) presented experimental evidence that water temperature had a strong "influence on the life but little effect on the amount" of foam formed. They showed that as water temperature was raised from 0° C to 10° C the "life" of foam was reduced by about one half. In a simple sense such a relationship is evident from the STREX data. When all dependence on U is neglected and W is plotted against Tw using a power law of the form of equation 1 a λ value of -1.22 is obtained. This shows a generally negative relationship between W and Tw.

A division of the STREX data alone on the basis of sea surface temperature (SST) does not seem desirable as a sample of this size is unlikely to be statistically reliable. However, when the overall data set of 231 cases is analysed on the basis of SST subdivisions there is a definite trend with temperature as follows:

$$W\%(U) = \begin{cases} 9.279 \times 10^{-3}\ U^{2.112} & \text{Cold (STREX)} \\ 4.755 \times 10^{-3}\ U^{2.525} & \text{Moderate (JASIN)} \\ 3.301 \times 10^{-4}\ U^{3.479} & \text{Warm (MON71,TC73)} \end{cases}$$

(Spillane and Doyle, 1983).

The mean squared error (MSE) for this piecewise fit is 7.76×10^{-3} which is about a 10% improvement on the best single fit to the data which is given by $W(U) = 2.692 \times 10^{-3}\ U^{2.265}$, MSE = 8.56×10^{-3}.

When a piecewise fit is determined on the basis of thermal stability categories a poorer combined MSE of 8.37×10^{-3} results. On this evidance Tw has a stronger influence than T on W(U).

7.3 Aerosol concentration on whitecap coverage:

For the relationship of dV/dr, the fraction of the marine air occupied by droplets within a given radius interval, to W, the whitecap coverage, a power law of the form:

$$dV/dr = CW^{\gamma} \qquad \text{Eqn. 2.}$$

has been assumed.

The several panels of figure 7.2. show the relationship of dV/dr to W at three different droplet radii intervals. It is to be noted that the positive dependence of aerosol concentration on the whitecap coverage increases with increasing droplet radius. The C and γ values for these relationships are presented in Table 7.4. The values compare very favourably with those presented by Monahan et al., (1983) for the combined TC73 and JASIN data sets (see also table 7.4). The STREX aerosol data were collected at a height of 22m above the water line as compared to 6m and 14m reaspectively for the TC73 and JASIN sets. Also the STREX data set has a more limited measurement range due to the failure of the ASASP probe and this precludes the examination of the sub-micron portion of the aerosol spectra.

The enhancement of the positive dependence of aerosol concentration on wind speed with increasing droplet radius was noticed also by Monahan et al. (1983). They explained the phenomenon in terms of a slowly altering background resevoir of small particles due to the relatively large numbers of small droplets injected into the atmosphere during 'high-wind' events, coupled with slow settling rates for such particles, as compared to a rapidly altering resevoir of large particles due to 'low' injection numbers and 'fast' settling rates for these larger particles.

Toba and Chaen (1973) defined a quantity (θ) which was subsequently referred to as N(8+) and redefined by Monahan et al., (1983), as the number of aerosol particles per unit volume of air with radii, at 80% relative humidity, greater than 7.9um. This quantity has been determined for the STREX data and is plotted against W in figure 7.3. Assuming a power law dependance similar to equation 2 of the form:

$$N(8+) = CW^{\gamma} \qquad \text{Eqn. 3.}$$

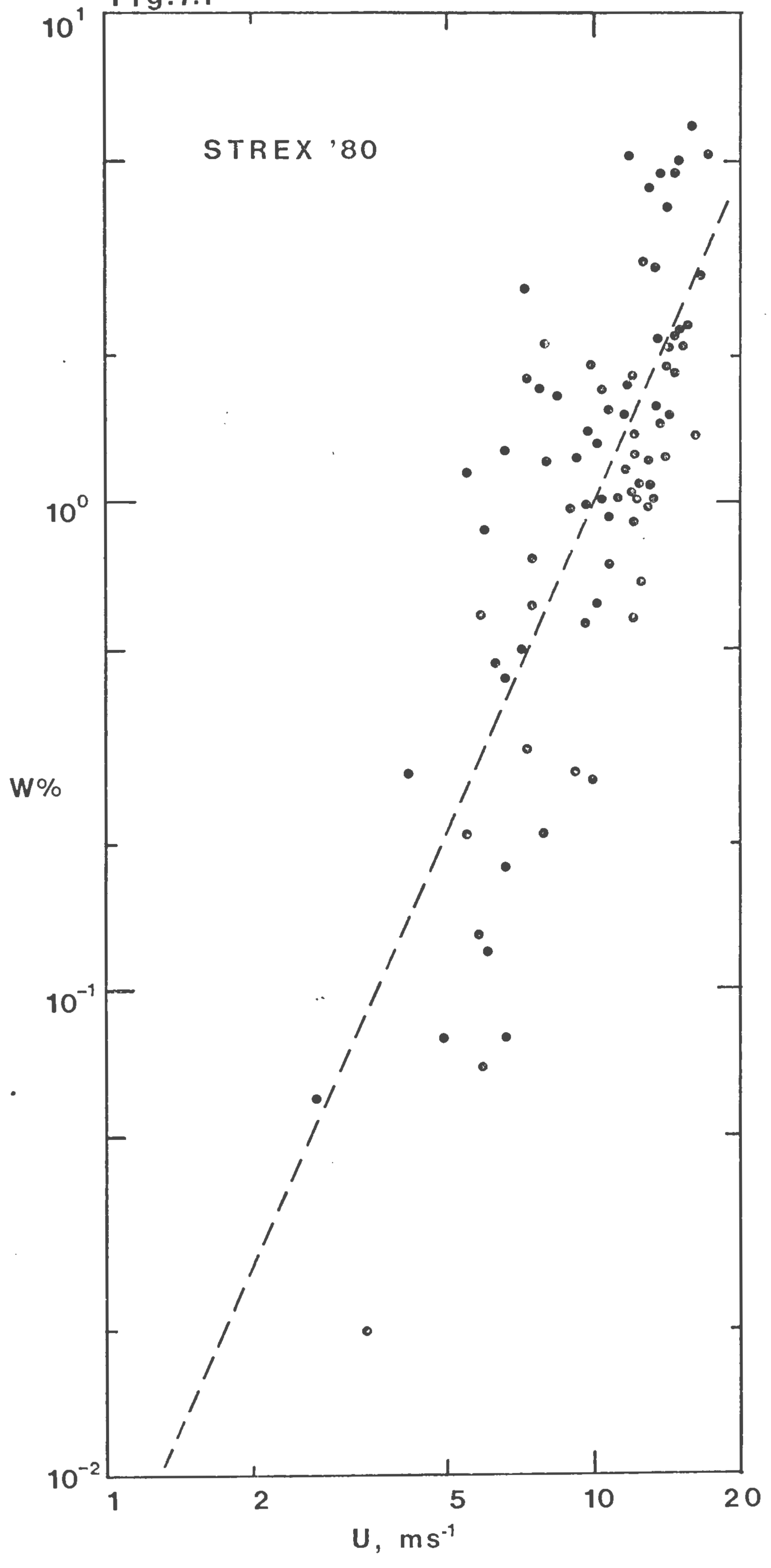
and again using an OLS fitting technique a γ value of 0.71 was obtained. This figure compares favourably with a value of 0.66 as obtained for the combined TC73 and JASIN data set also using OLS.

Having explored the dependance of aerosol concentration on whitecap cover and of whitecap cover on wind speed it is, perhaps, illustrative to examine the dependance of aerosol concentration on wind speed. Bearing in mind the argument for a more positive dependence of larger particle concentration on instantaneous whitecap coverage and using N(8+) as a measure of the concentration of these particles N(8+) has been plotted against U in figure 7.4. The dashed line corresponds to the best fit power law expression $N(8+) = 0.13 \times 10^{2} U^{2.270}$. There is thus a marked similarity between the W(U) and N(8+)(U) relationships.

A comparison of the STREX aerosol data with the aerosol data which was collected on Inishmore has been included in the previous chapter (section 5.6). The dependence of the calculated quantity N(2.5+) on the wind speed for the STREX data is shown graphically in figure 7.5. N(2.5+) is defined as the number of aerosol particles per cubic metre of air with radii greater than 2.5μm. The dashed line represents the best-fit to these data which corresponds to the expression $N(2.5+) = 7.41 \times 10^3 U^{1.41}$. The data which appear as figure 5.5 are also plotted on this diagram for comparison. The dashed line for the Inishmore (Aran) data corresponds to the expression $N(2.5+) = 5.37 \times 10^3 U^{1.39}$ which is the best fit to these data using OLS techniques. The similarity between these two expressions is striking.

In conclusion we see that the exponent (λ) values for the various STREX W(U) expressions approximate to a quadratic form rather than the near cubic forms obtained by previous authors. This discrepency is explained, to a large extent, by the trend of the exponent to increase with increasing sea-surface temperature. The results obtained for the inter-relationship of the aerosol concentration to whitecap coverage and wind speed show good agreement with those obtained by other authors for the same, or similar, relationships. And finally there is strong agreement between the Inishmore and Strex results.

Fig.7.1



Whitecap coverage (W%), v wind speed (U). Dashed line: $W = 6.22 \times 10^{-3} U^{2.21}$, best OLS fit to these data.

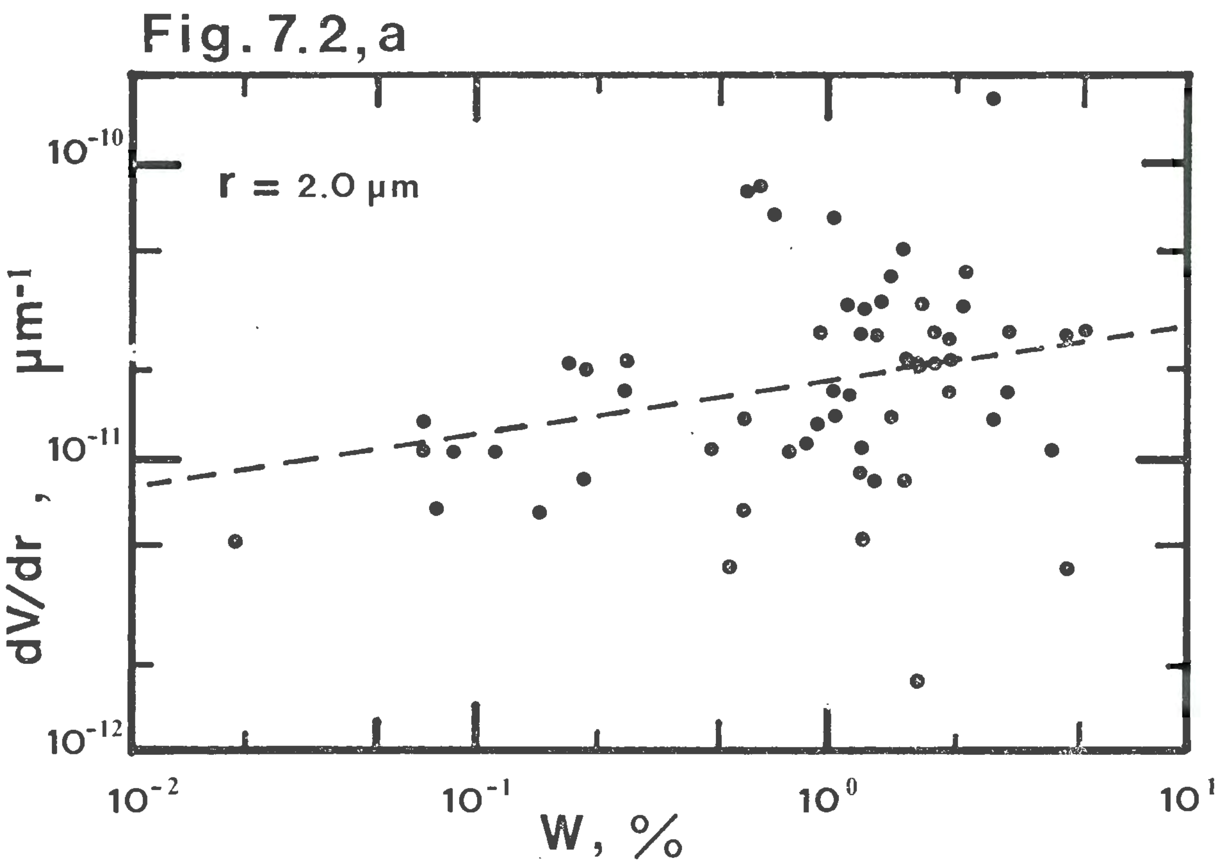


FIGURE 7.2a, b, c:

The fraction of the marine air volume filled by aerosol droplets per unit increment droplet radius (dV/dr), v percentage whitecap coverage (W%). Dashed lines:

a) $dV/dr = 1.66 \times 10^{-11} W^{0.15}$ (r=2.0μm)

b) $dV/dr = 8.13 \times 10^{-12} W^{0.36}$ (r=5.0μm)

c) $dV/dr = 1.91 \times 10^{-12} W^{0.72}$ (r= 15μm)

which represent the best OLS fit to these data.

Fig.7.2,b

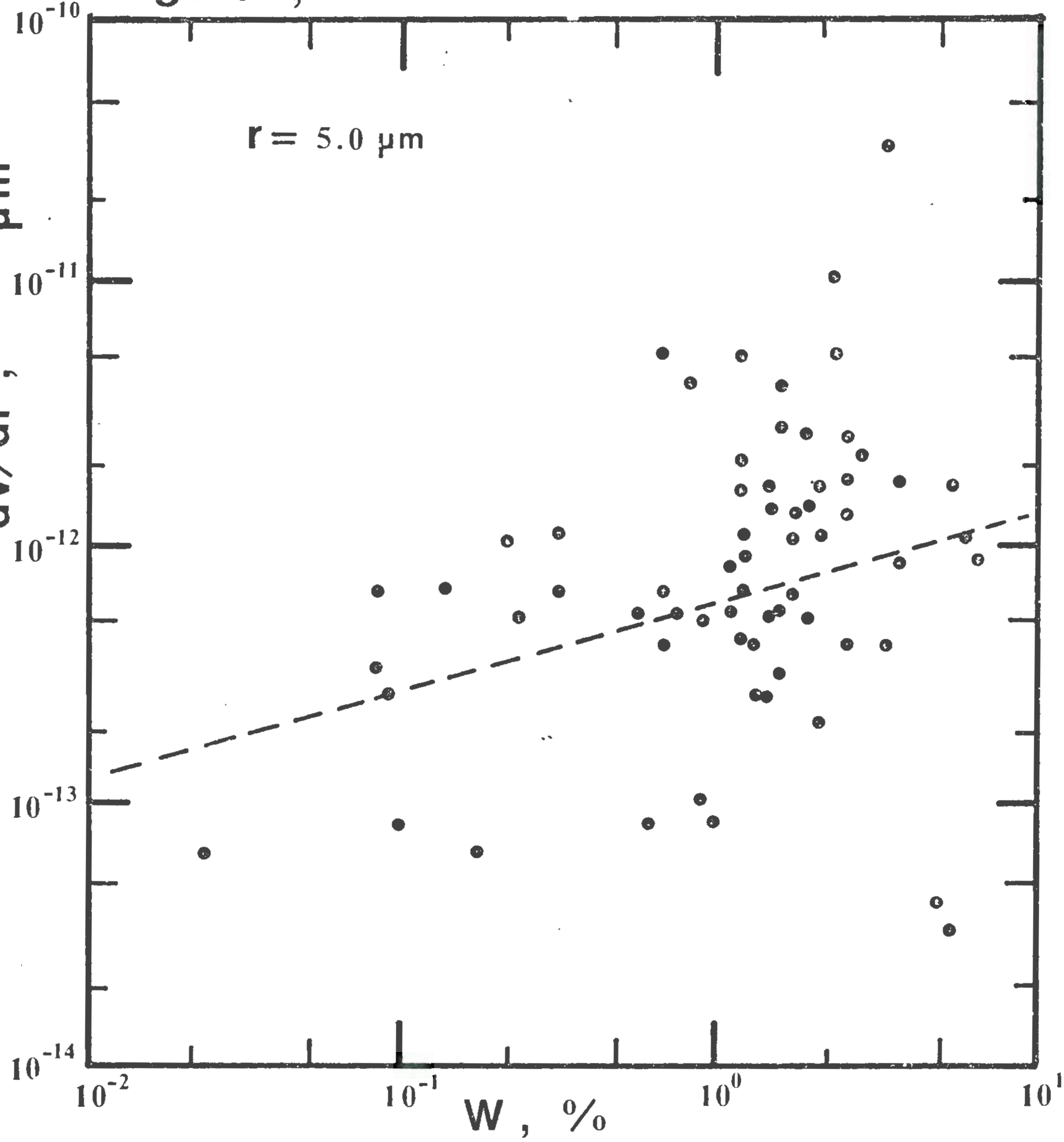


Fig.7.2,c

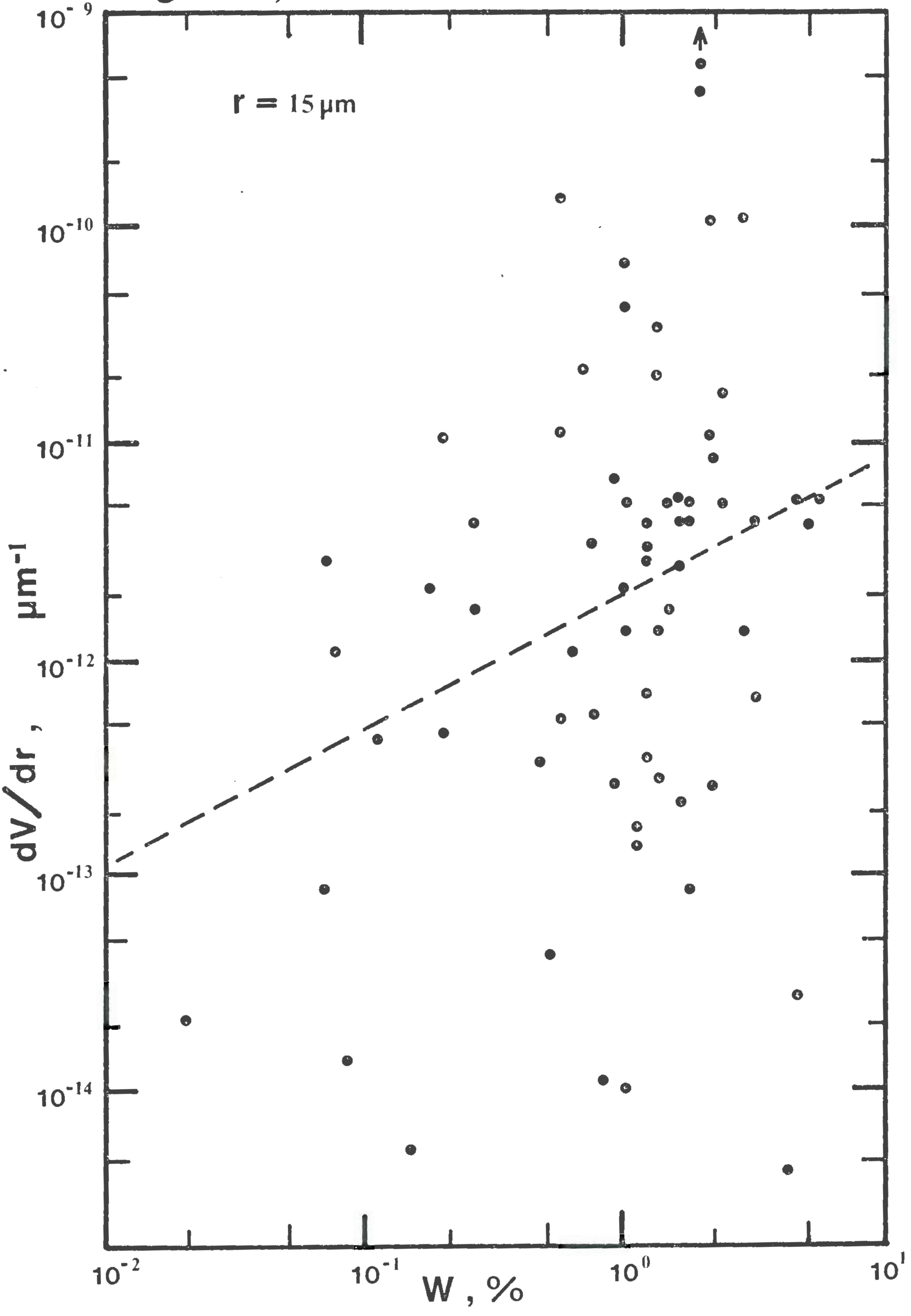


Fig. 7.3

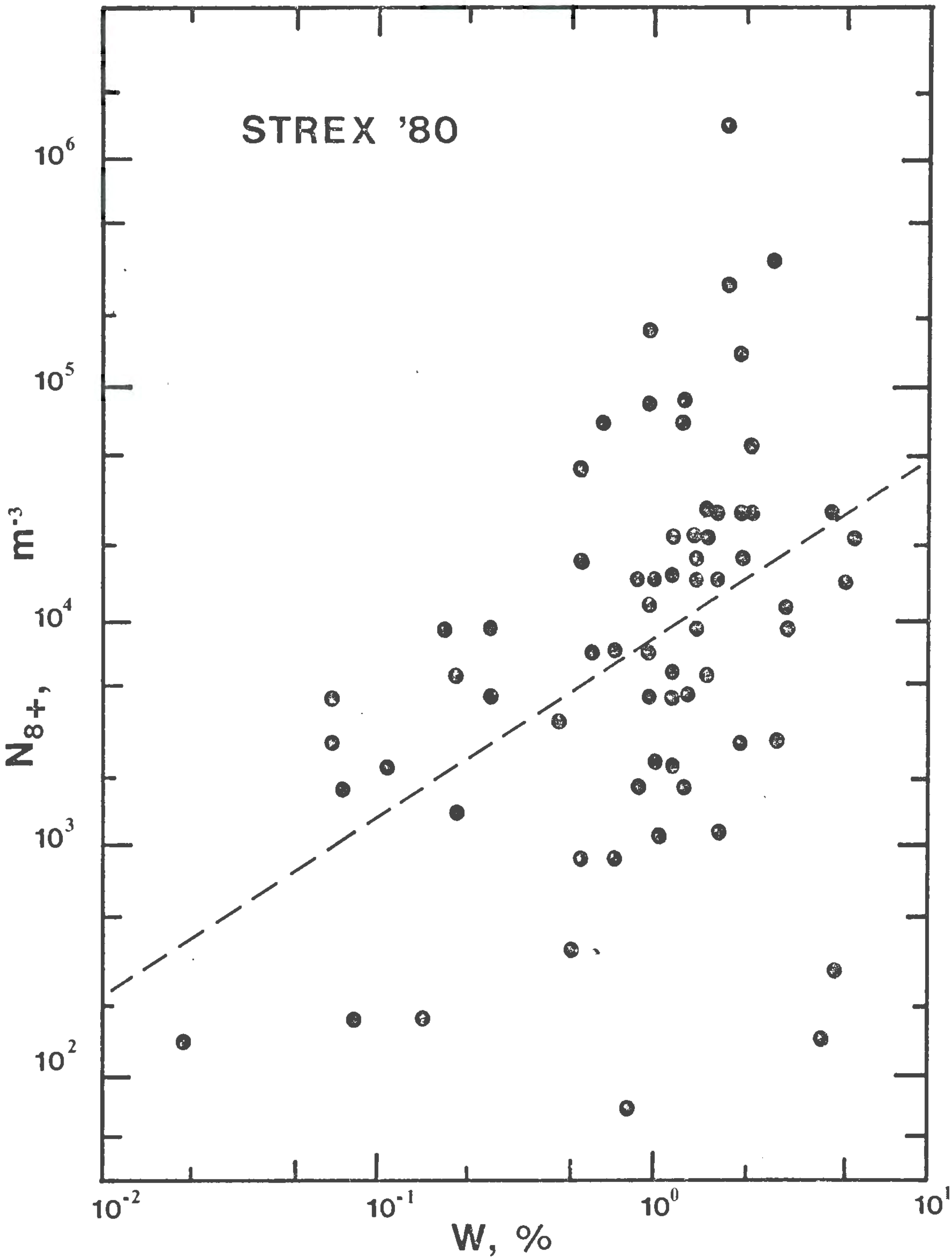


FIGURE 7.3:

The concentration of aerosol particles with radii, at 80% relative humidity, greater than 7.9μm, (N8+), v percentage whitecap coverage (W%). Dashed line: $N(8+) = 7.76 \times 10^3\ W^{0.71}$, which represents the best OLS fit to these data.

Fig.7.4

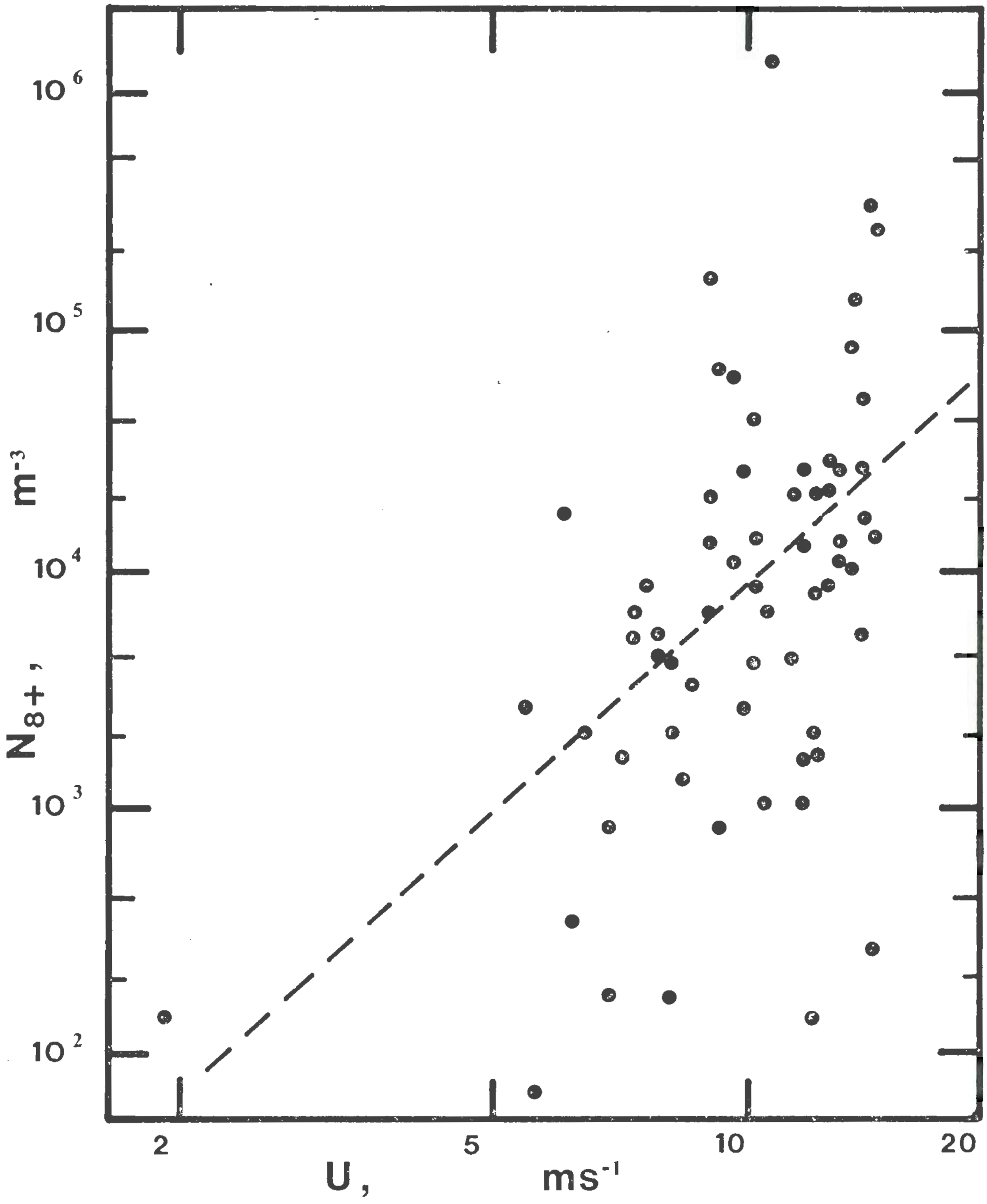
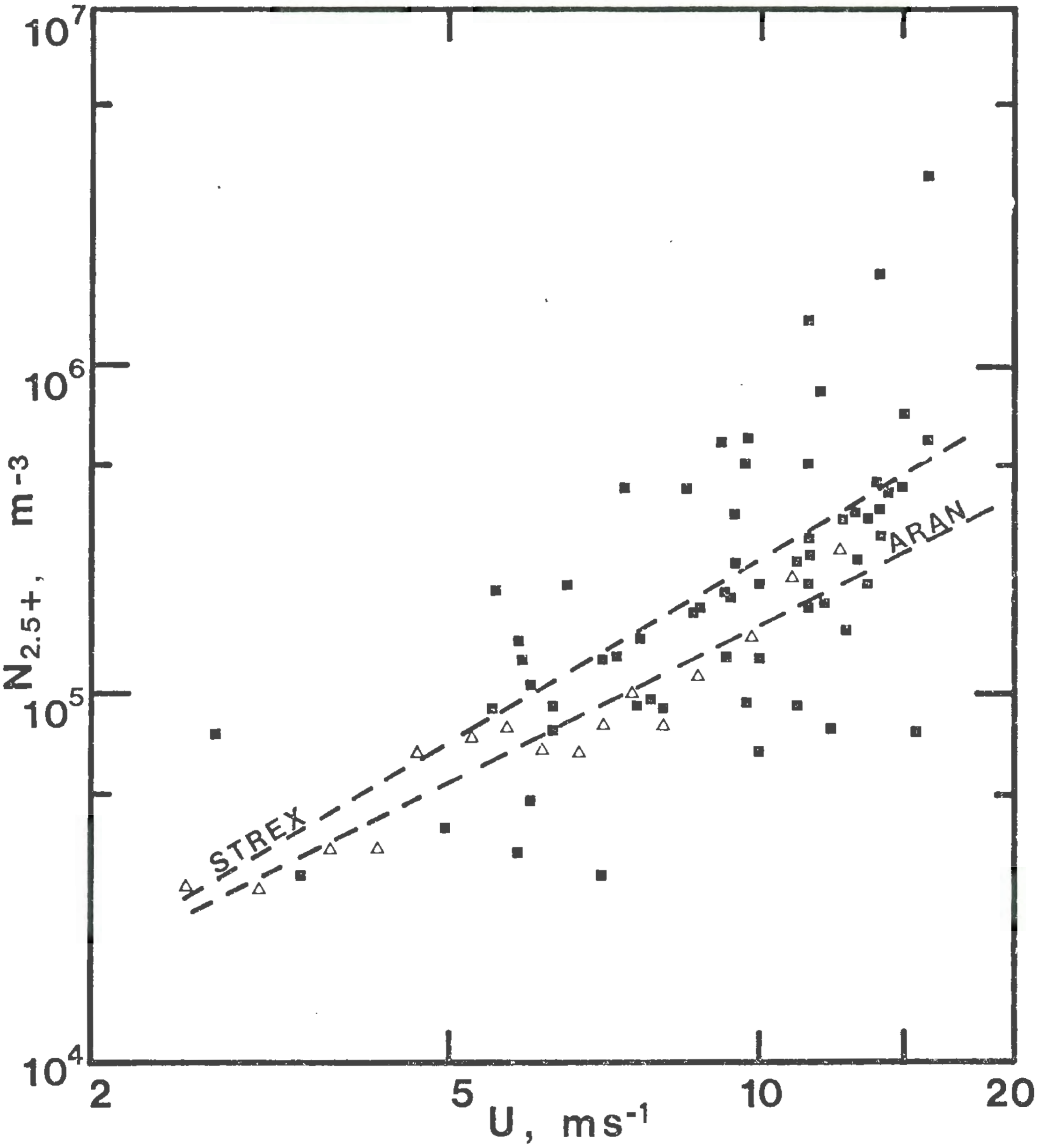


FIGURE 7.4:

The concentration of aerosol particles with radii greater than 7.9μm (N8+), v six-hour averaged wind speed (U). Dashed line: $N(8+) = 8.55\ U^{2.91}$, which represents the best OLS fit to these data.

Fig.7.5



The concentration of aerosol particles with radii greater than 2.5μm (N2.5+), v wind speed (U). Squares: STREX. Triangles: Inishmore. Dashed lines:

STREX $N(2.5+) = 7.41 \times 10^{3} U^{1.41}$

Inishmore $N(2.5+) = 5.37 \times 10^{3} U^{1.39}$

which represent the best OLS fits to these data.

TABLE 7.1.

STREX, LEG 1.

OBS #	Date	Time PST	Number of Photos.	U m/s	Ta °C	Tw °C	ΔT °C	TS	W %	Std. Dev.
480	11/06	1307	10, 9,10	9.1	9.36	9.86	0.50	N	0.28	0.12
481	11/07	0933	8, 8, 8	16.2	8.66	10.11	1.45	U	1.39	0.55
482	11/07	1056	7, 8, 9	15.4	8.70	10.12	1.42	U	2.36	0.69
483	11/07	1237	9,10, 9	14.3	7.46	11.11	3.65	U	1.90	0.39
484	11/07	1520	10,10,10	11.9	7.5	10.5	3.0	U	1.52	0.41
485	11/08	1056	10,10,10	9.8	6.80	10.17	3.37	U	0.99	0.22
486	11/08	1307	7, 8, 8	9.2	7.8	9.9	2.1	U	1.29	0.78
487	11/08	1450	8,10,10	9.8	5.82	10.17	4.35	U	1.40	0.56
488	11/08	1555	10,10,10	9.7	6.90	10.17	3.27	U	0.56	0.18
489	11/09	1039	9,10,10	10.4	7.24	10.24	3.00	U	1.04	0.24
490	11/10	1010	10,10,10	6.3	6.96	9.83	2.87	U	0.47	0.24
491	11/10	1118	9, 9,10	5.9	6.99	9.81	2.82	U	0.07	0.09
492	11/10	1407	11,10, 6	2.7	6.99	9.78	2.79	U	0.07	0.06
493	11/11	1053	10,10,10	5.5	8.78	9.78	1.00	U	0.21	0.25
494	11/12	0950	9,10,10	4.2	7.89	9.83	1.94	U	0.29	0.17
495	11/12	1054	8,10,10	6.3	8.89	9.81	0.92	U	1.28	0.23
496	11/12	1135	9,10,10	6.0	8.55	9.82	1.27	U	0.87	0.22
497	11/12	1435	6, 6, 5	10.8	8.74	9.77	1.03	U	0.74	0.36
498	11/13	1035	10,10,10	5.9	7.08	9.60	2.52	U	0.59	0.31
499	11/13	1135	10,10,10	7.5	8.26	9.66	1.40	U	0.62	0.21
501	11/14	1017	9, 8, 8	12.0	9.92	9.56	-0.36	N	1.39	0.36
502	11/14	1126	5, 5, 5	12.2	10.20	9.41	-0.79	S	0.92	0.80
503	11/14	1235	8,10,10	11.5	10.22	9.36	-0.86	S	1.53	0.62
504	11/14	1402	8, 8, 8	12.5	10.14	9.38	-0.76	S	1.08	0.20
505	11/15	1540	10,10,10	11.1	6.23	9.17	2.94	U	1.02	0.24
506	11/16	1106	10,10,10	5.8	6.65	9.19	2.54	U	0.15	0.09
507	11/16	1407	10,10, 8	6.0	7.76	9.20	1.44	U	0.12	0.06
508	11/17	1058	8, 8, 8	17.2	9.3	9.3	0.0	N	5.17	1.04
509	11/17	1300	10, 9, 7	14.5	8.14	9.13	0.99	U	4.79	1.16
510	11/17	1407	10,10,10	13.9	8.43	9.2	0.80	U	4.76	0.81
511	11/18	0944	10,10,10	11.9	8.18	9.09	0.91	U	5.12	0.85
512	11/18	1210	8, 7, 6	7.3	7.60	9.05	1.45	U	1.83	0.43
513	11/18	1335	9, 9, 9	7.9	8.07	8.93	0.86	U	2.13	0.50
515	11/18	1705	10,10,10	4.9	8.7	9.2	0.5	N	0.09	0.05
516	11/19	1010	10,10,10	10.3	8.09	8.92	0.84	U	1.69	0.56
517	11/19	1120	10,10,10	7.7	8.51	8.92	0.41	N	1.71	0.60
518	11/19	1300	10,10,10	6.6	8.7	9.1	0.4	N	0.45	0.14
519	11/19	1522	10,10,10	6.6	8.13	8.95	0.82	U	0.18	0.14
520	11/20	1040	7, 7, 7	10.7	7.17	8.92	1.75	U	1.55	0.25
521	11/20	1133	10,10,10	7.2	7.20	8.91	1.71	U	2.75	0.54
522	11/20	1340	10,10,10	9.0	7.33	8.89	1.56	U	0.98	0.27
523	11/20	1415	9, 9, 9	5.5	6.82	8.96	2.14	U	1.28	0.36
524	11/20	1520	9, 9, 9	7.5	7.10	8.93	1.83	U	0.77	0.22
525	11/20	1607	10, 9,10	7.9	7.09	8.89	1.80	U	0.21	0.09
526	11/21	1015	10,10,10	3.4	6.92	8.92	2.00	U	0.02	0.04
527	11/21	1255	10,10,10	7.3	7.42	8.96	1.54	U	0.31	0.09
528	11/21	1611	10,10,10	7.1	7.46	8.85	1.39	U	0.50	0.13

TABLE 7.1 (cont.), STREX, LEG 2.

OBS #	Date	Time PST	Number of Photos.	U m/s	Ta °C	Tw °C	ΔT °C	TS	W %	Std. Dev.
529	11/29	1112	10,10,10	15.7	5.79	7.35	1.56	U	5.86	1.24
530	11/29	1218	9, 9, 9	13.5	5.88	7.41	1.53	U	1.56	0.36
531	11/29	1335	10,10,10	13.4	5.78	7.37	1.59	U	3.03	0.65
532	11/29	1505	9, 9, 9	13.6	5.46	7.39	1.93	U	2.17	0.38
533	11/29	1612	9, 9, 9	13.8	5.47	7.38	1.91	U	1.50	0.50
534	11/30	1234	10,10,10	8.0	5.26	7.01	1.75	U	1.22	0.41
535	11/30	1515	10,10,10	8.4	4.79	7.06	2.27	U	1.66	0.33
536	12/01	1445	10,10,10	10.8	3.77	7.39	3.62	U	0.93	0.18
537	12/02	1125	8,10, 8	12.8	3.54	7.21	3.67	U	1.23	0.24
538	12/02	1230	8, 8, 8	14.3	3.72	7.18	3.46	U	2.11	0.36
539	12/02	1615	10,10, 9	14.5	4.7	7.1	2.4	U	2.21	0.58
540	12/02	1655	9, 9, 9	15.1	5.16	7.25	2.09	U	2.10	0.65
541	12/03	1050	10,10,10	13.3	5.47	5.37	-0.10	N	1.03	0.20
542	12/03	1120	8,8,8,9	12.2	5.65	5.50	-0.15	N	1.01	0.33
543	12/03	1230	8,10, 8	12.1	5.50	5.63	0.13	N	1.00	0.60
544	12/03	1330	9, 9, 9	12.0	5.45	5.60	0.15	N	1.84	0.36
545	12/04	1455	9, 9, 9	10.1	5.09	5.74	0.65	U	0.62	0.18
546	12/04	1550	10,10,10	10.2	5.30	5.72	0.42	N	1.34	0.42
547	12/05	1110	10,10,10	6.3	4.51	6.08	1.57	U	0.08	0.06
548	12/05	1615	10,10,10	3.3	4.72	5.84	1.12	U	0.00	0.00
549	12/06	1025	10,10,10	12.9	6.5	7.2	0.7	U	0.98	0.22
550	12/06	1057	10,10,10	12.1	6.36	5.74	-0.62	S	1.26	0.25
551	12/06	1157	9, 9, 9	12.5	6.57	5.71	-0.86	S	0.69	0.21
552	12/06	1308	10,10,10	12.2	6.90	7.19	0.29	N	0.58	0.15
553	12/07	1450	8, 8, 8	11.7	7.38	5.97	-1.41	S	1.76	0.35
554	12/07	1550	9, 9, 9	9.8	7.44	5.79	-1.65	S	1.94	0.32
555	12/08	1040	7, 8, 9	14.2	8.48	5.96	-2.52	S	1.51	0.20
556	12/08	1200	9, 8, 9	12.6	8.89	5.94	-2.95	S	3.16	1.83
557	12/08	1307	8, 8, 8	14.0	8.94	5.90	-3.04	S	1.25	0.28
558	12/08	1428	7, 8, 8	14.5	8.85	5.92	-2.93	S	1.87	0.39
559	12/08	1605	9, 9,10	12.9	8.6	6.0	-2.6	S	1.08	0.22
560	12/11	1203	8, 8, 9	13.0	7.07	5.14	-1.93	S	4.42	0.69
561	12/11	1303	5, 6, 5	14.8	7.20	5.19	-2.01	S	5.09	1.03
562	12/11	1403	4, 4, 4	14.2	7.36	5.11	-2.25	S	4.07	0.82
563	12/11	1507	7, 7, 7	11.6	7.42	5.30	-2.12	S	1.16	0.26
564	12/11	1617	5, 5, 6	9.9	7.35	5.38	-1.97	S	0.27	0.22
565	12/12	1125	6, 6, 5	15.0	9.21	7.39	-1.82	S	2.30	0.82
566	12/12	1510	5, 5, 6	16.5	9.21	7.39	-1.82	S	2.90	0.47

OBS # : Observation Interval Number.
Time :Pacific Standard (PST = GMT - 8hrs).
Photos: Number of photographs analysed by each operator in each interval.
U : 10m elevation wind speed.
The Thermal Stability (TS) is expressed by the quantity ΔT, the difference between the sea and air temperatures (Tw-Ta). U: Unstable N: Near Neutral S: Stable. Near Neutral defined as $-0.4 < \Delta T < 0.6$°C.

TABLE 7.2.

AEROSOL CONCENTRATIONS, STREX LEG 1.

OBS #	dV/dr, μm^{-1} r=2.0μm	dV/dr, μm^{-1} r=5.0μm	dV/dr, μm^{-1} r=15μm	N(8+), m^{-3}
480	1.72E-11	7.26E-12	1.60E-12	4.33E 03
481	2.95E-11	2.84E-11	3.91E-11	8.78E 04
482	2.87E-11	2.12E-11	1.57E-11	5.96E 04
483	2.67E-11	5.10E-11	4.37E-10	2.74E 05
484	1.25E-11	1.06E-11	5.93E-12	1.48E 04
485	1.49E-11	2.05E-11	1.22E-12	1.14E 04
487	2.91E-11	4.53E-11	2.25E-11	6.50E 04
488	1.41E-11	6.72E-12	5.43E-13	9.14E 02
489	1.41E-11	6.08E-11	4.30E-11	1.64E 05
490	9.85E-12	5.36E-12	3.74E-13	3.53E 03
491	1.18E-11	7.60E-12	2.91E-12	4.02E 03
492	9.92E-12	3.84E-12	8.37E-14	2.74E 03
493	1.82E-11	5.82E-12	1.11E-11	1.28E 03
496	1.09E-11	9.53E-13	1.12E-14	6.09E 01
497	1.07E-11	1.21E-12	5.53E-13	9.14E 02
498	6.45E-12	4.42E-12	1.01E-11	1.71E 04
501	2.82E-11	6.05E-12	3.01E-13	1.64E 03
502	2.73E-11	5.73E-12	2.42E-13	1.58E 03
504	3.38E-11	4.06E-12	1.22E-13	1.16E 03
506	6.91E-12	6.95E-13	4.81E-15	1.83E 02
507	9.66E-12	6.34E-12	3.83E-13	2.25E 03
510	4.02E-12	3.10E-13	2.89E-14	3.05E 02
511	2.30E-11	1.12E-11	4.28E-12	1.47E 04
512	1.44E-11	2.19E-12	8.75E-14	1.04E 03
513	2.27E-11	4.70E-12	2.64E-13	2.74E 03
515	9.59E-12	8.33E-13	1.34E-14	1.83E 02
516	5.09E-11	2.54E-11	3.91E-12	2.80E 04
517	5.15E-11	1.54E-11	2.73E-12	2.12E 04
519	1.95E-11	1.04E-11	2.31E-12	8.83E 03
520	1.16E-11	6.59E-12	1.80E-12	7.86E 03
521	1.36E-11	4.63E-12	1.52E-12	2.80E 03
522	7.03E-11	9.78E-12	1.22E-12	6.34E 03
523	1.11E-11	3.01E-12	3.12E-13	2.01E 03
524	9.60E-12	5.81E-12	3.70E-12	6.58E 03
525	8.34E-12	5.31E-12	4.19E-13	5.79E 03
526	5.03E-12	7.77E-13	2.12E-14	1.22E 02
528	3.94E-12	8.26E-13	3.94E-14	3.72E 02

TABLE 7.2 (cont.)

AEROSOL CONCENTRATIONS, STREX LEG 2.

OBS #	dV/dr, μm^{-1} r=2.0μm	dV/dr, μm^{-1} r=5.0μm	dV/dr, μm^{-1} r=15μm	N(8+), m^{-3}
529	1.59E-12	9.88E-12	5.71E-12	2.05E 04
530	1.82E-11	1.42E-11	5.76E-12	2.25E 04
531	1.47E-11	1.68E-11	4.01E-12	1.07E 04
532	2.15E-11	1.90E-11	9.75E-12	1.86E 04
533	1.19E-11	1.15E-11	5.58E-12	1.74E 04
534	7.94E-12	5.67E-12	7.16E-13	4.63E 03
535	8.64E-12	5.30E-12	1.95E-13	6.03E 03
536	1.36E-11	9.36E-12	6.21E-12	1.52E 04
537	5.13E-12	3.11E-12	2.71E-12	4.93E 03
538	1.69E-11	1.49E-11	1.21E-11	2.98E 04
540	2.86E-11	2.69E-11	1.08E-10	1.29E 05
541	1.43E-11	7.10E-12	2.10E-12	1.18E 04
542	1.57E-11	1.14E-11	5.22E-12	1.49E 04
543	1.74E-11	1.93E-11	7.32E-11	8.89E 04
545	8.83E-11	5.24E-12	1.17E-12	6.64E 03
546	7.85E-12	3.72E-12	1.46E-12	4.63E 03
547	6.83E-12	2.81E-12	1.14E-12	1.71E 03
549	1.17E-11	4.44E-12	1.11E-14	4.03E 03
550	2.42E-11	1.56E-11	3.16E-12	1.47E 04
551	5.71E-11	4.64E-11	2.33E-11	6.34E 04
552	7.41E-11	5.55E-11	1.44E-10	4.16E 04
553	2.14E-11	1.17E-11	5.81E-12	1.48E 04
554	2.06E-11	1.13E-10	2.64E-08	1.53E 06
555	3.90E-11	1.55E-11	5.98E-12	2.36E 04
556	2.77E-11	7.94E-12	7.04E-13	9.62E 03
557	3.52E-11	1.59E-11	4.88E-12	2.29E 04
558	3.48E-11	1.69E-11	3.96E-12	2.94E 04
560	2.84E-11	1.77E-11	6.15E-12	2.80E 04
562	1.05E-11	4.88E-13	3.66E-15	1.24E 02
563	1.49E-11	2.54E-12	1.58E-13	2.13E 03
564	2.00E-11	1.16E-11	4.78E-12	8.22E 03
565	3.97E-11	2.15E-11	5.29E-12	3.05E 04
566	1.80E-10	4.01E-10	1.23E-10	3.71E 05

TABLE 7.3.

EXPRESSIONS FOR W(U)

		STREX		TC73+JASIN	
		log α	λ	log α	λ
	W(U)	-2.21	2.21	-3.59	3.47
O.L.S.	W(U6)	-2.24	2.22		
	W(U*)	0.91	2.14		
R.B.F.	W(U)	-1.81	1.84	-3.35	3.31

TABLE 7.4.

EXPRESSIONS FOR dV/dr(W)

	STREX		TC73+JASIN	
Droplet Radius	log C	γ	log C	γ
2.0μm	-10.78	0.15	-----	----
5.0μm	-11.09	0.36	-10.21 (-10.32)	0.36 (0.34)
15μm	-11.72	0.72	-9.56 (-9.16)	0.86 (1.43)

EXPRESSIONS FOR N(8+)(W) AND N(8+)(U)

	STREX		TC73+JASIN	
	log C	γ	log C	γ
N(8+)(W)	3.89	0.71	(3.56)	0.66 (0.71)
N(8+)(U)	1.12	2.70	(0.81)	3.19 (3.23)
N(8+)(U6)	0.93	2.91		

(Values derived: OLS, bracketed values: RBF).

TABLE 7.5:

Comparison of conditions during STREX with those during previous whitecap observation experiments.

TEN-METER WIND SPEED U (m/s)

DATASET	MEAN	STD DEV	MINIMUM	MAXIMUM
MON71	6.92	3.00	0.66	17.40
TC73	6.89	3.38	2.40	16.60
JASIN	6.03	2.81	2.50	15.30
STREX	10.47	3.51	2.70	17.20

SEA SURFACE TEMPERATURE Tw (°C)

DATASET	MEAN	STD DEV	MINIMUM	MAXIMUM
MON71	26.58	3.82	17.40	30.55
TC73	24.48	2.62	20.90	29.00
JASIN	13.24	0.41	12.50	14.00
STREX	8.07	1.71	5.11	11.11

SEA/AIR TEMPERATURE DIFFERENCE ΔT (°C)

DATASET	MEAN	STD DEV	MINIMUM	MAXIMUM
MON71	0.216	1.135	-2.40	3.15
TC73	-0.937	2.245	-6.40	1.60
JASIN	0.835	0.911	-1.80	3.20
STREX	0.854	1.772	-3.04	4.35

PERCENTAGE WHITECAP COVERAGE W%

DATASET	MEAN	STD DEV	MINIMUM	MAXIMUM
MON71	0.5	0.10	0.0	0.76
TC73	0.7	0.14	0.0	0.73
JASIN	0.6	0.13	0.0	0.81
STREX	1.5	0.13	0.0	0.59

TABLE 7.6:

Distribution of overall whitecap dataset following classification of sea-surface temperature, thermal stability and wind speed as defined in the text.

		LOW WIND SPEED				HIGH WIND SPEED				OVERALL DATASET			
THERMAL STAB.		U	N	S	TOTAL	U	N	S	TOTAL	U	N	S	TOTAL
SURFACE TEMP.	COLD	25	3	0	28	29	9	19	57	54	12	19	85
	MOD.	35	14	6	55	7	3	1	11	42	17	7	66
	WARM	29	35	26	90	4	5	12	21	33	40	38	111
TOTALS :		89	52	32	173	40	17	32	89	129	69	64	262

CHAPTER 8.

CONCLUSIONS

Whitecaps are formed at the sea surface when waves reach their limit of stability and are forced to break in order to dissipate excess energy. The ultimate source of this energy is the wind blowing across the ocean.

The area of the ocean surface which is covered by whitecaps is a function of the wind speed. Under commonly encountered wind regimes whitecaps effect the most important contribution of sea-salt aerosol particles to the marine atmosphere. Consequently the concentration of sea-salt aerosol particles can be assumed to be a function of the wind speed.

During the STREX experiment meteorological, aerosol concentration and, whitecap coverage data were collected which significantly augmented the size and meteorological range of the data base in this subject area. For the results obtained during the STREX experiment the best fit to the W(U), whitecap coverage versus wind speed, relationship is expressed by: $W\% = 6.22 \times 10^{-3} U^{2.21}$. When a similar expression is calculated for the combined data sets of Toba and Chaen (1973) and Monahan et at. (1983) a value of 3.47 is obtained for the exponent. The discrepancy can be, at least partially, explained by the comparitive coolness of the sea surface during STREX.

The importance of the sea surface temperature effect on whitecap coverage is illustrated in chapter 7, section 7.2, where the exponent is seen to increase with increasing water temperature.

In relating the aerosol concentration to whitecap coverage there occurs an increasing dependence, with increasing droplet radius, of dV/dr on W, (figure 7.2). A similar trend was noted by Monahan *et al.*, (1983).

The calculated quantity N(2.5+) is defined as the concentration of aerosol particles, with radii greater than 2.5μm, per cubic meter of air. When this quantity is plotted against wind speed, U, for the STREX data the following best fit relationship occurs:
$N(2.5+) = 7.41 \times 10^{3} U^{1.41}$, and for the Inishmore data the best fit relationship is: $N(2.5+) = 5.37 \times 10^{3} U^{1.39}$, both using OLS techniques. The similarity between these two expressions is encouraging.

The Inishmore results also compare quite favourably with those obtained on other island stations (Latham *et al.*, 1982).

The STREX results have been useful in adding to our understanding of the W(U) relationship, of the further dependence of W on sea surface temperature and to a lesser degree on atmospheric stability. From table 7.6 we see a need for further investigations in high winds, especially with warmer water temperatures and in stable atmospheric conditions.

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APPENDIX 4.1.

INSTRUMENTS

Wind Speed: MUNRO (London) cup generator anemometer IM124.

Wind Speed Indicator: Initially a MUNRO Mark II velocity indicator dial was used but more recently the anemometer has been connected to one channel of a PHILLIPS chart recorder PM8221. The dial is now used as a backup.

Wind Direction: Various visual techniques were used until a 'home made' wind vane was constructed in the lab. This instrument while uncomplicated is sensitive enough for our purposes.

Relative Humidity and Air Temperature: MUNRO sling psychrometer and CASELLA Thermohygrograph (T9154) in a meteorological screen.

Aerosol particle measuring devices: ROYCO particle measuring counter (model 225) with plug-in module (model 519) and optical sensor (model 241).

Space Charge: An Obolensky filter (Monahan *et al*., 1981) is used. This is an air filter which is connected to a KEITHLEY 602 electrometer. As the air passes through the filter the space charge is 'captured' and a corresponding current is registered on the electrometer.

During the U.C.G/N.P.S co-operative experiment additional instruments were:

Wind Speed: CASELLA sensitive anemometer model 2145C.

Relative Humidity and Air Temperature: LiCl humidity/temperature probe, HYGRODYNAMICS Ltd. 15-1818W.

Aerosol Counters: P.M.S. Classical Scattering Aerosol Spectrometer Probe (CSASP - 100). P.M.S. Active Scattering Aerosol Spectrometer Probe (ASASP - 300). [P.M.S. = Particle Measuring Systems Ltd.]

Processing Equipment: P.M.S. Data Acquisition System DAS-32, HEWLETT-PACKARD Computer 9825S, H-P Printer 9871A, KENNEDY Incremental Tape Recorder 1600/360.

APPENDIX 4.2.

EXPERIMENT LOG

The U.C.G. field station on Inishmore was established in August 1979, however, installation work was not completed until April 1980. Because of the exposed nature of the site and the high-salt content of the air constant maintenance work such as painting and the replacement of stay-wires has been neccessary.

Nevertheless twelve experiments each of several days duration have been performed. There now follows a descriptive log of these experiments.

16th. November 1979; The first aerosol, whitecap and wind data were taken at the station. The Nolan/Pollak counter was used for the aerosol measurements.

23 - 26 April 1980; The instrument tower was extended to its full height of 15M. As part of the Arctic Air Sampling Programme the University of Rhode Island large volume air sampler was installed at a site about 400m east of the station. Preperations were also made for the installation of an experimental wind driven generator.

23 - 28 June 1980; The U.C.G./N.P.S. co-operative experiment was performed at this time. This represented the first comprehensive set of aerosol and meteorological measurements undertaken at the station. Some sixty six

aerosol size spectra were obtained using two Knollenberg counters (see Apdx. 4.1.).

20 July 1980; Strong winds damaged the tail of the 'wind generator', further tests were postponed until repairs could be effected.

12 - 14 February 1981; The first measurements were taken at the station using the ROYCO sampling instrument. This trip was designated GNG01.

5 - 7 March 1981; Data trip GNG02. Over 350 aerosol samples were taken in an eight hour period on the 6th.

8 - 11 April 1981; A topographical survey of the station site and environs was performed (see text).

13 - 16 May 1981; Data trip GNG03/04/05. Over 250 aerosol and meteorological measurements were taken during a two day period.

15 - 18 July 1981; Data trip GNG06/07. Approximately 200 aerosol and meteorological measurements were taken over a period of one and a half days.

2 - 5 September 1981; Data trip GNG08. About 200 aerosol and meteorological measurements were taken in a seven hour sampling period.

4 - 7 November 1981; Data trip GNG09. After only two hours of data collection on the 5th. the ROYCO timing mechanism broke down. This made further sampling impossible.

16 - 24 March 1982; Data trip GNG10. In addition to aerosol concentration and ambient meteorological conditions, space charge density was also monitored for the first time on this trip. These measurements were taken in collaboration with Mr. P. Bowyer of the Oceanography Dept. U.C.G.

20 - 24 July 1982; Data trip GNG11. Several hours of aerosol, space charge and meteorological measurements were taken.

13 - 20 November 1982; Data trip GNG12. From the 15th. to the 18th. several hundred aerosol, electric charge and the usual range of meteorological measurements were taken. The samples were collected in a broad range of conditions in an effort to establish the influence on the results of such phenomena as rain showers, surf-zone spray and non-isokinetic sampling in high wind speeds.

APPENDIX 5.1

Full set of raw meteorological and aerosol concentration data as collected at the field station on Inishmore Co. Galway.

Data trip GNG01, 14th Feb. 1981,
182 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1320	4.0	95	68	340432	37681031
1321	5.0			263446	30284388
1322	4.0			333016	37721643
1323	6.0			361268	38554008
1324	5.0	105		226719	29123244
1326	7.0			238373	26693246
1328	6.0			250027	28884164
1329	5.0			256737	27246626
1330	4.5			282516	30048840
1331	4.0			319243	34581822
1332	5.5			306177	30632943
1333	4.5			216831	24505154
1334	4.0			264506	28444144
1335	5.0			222128	25730217
1337	5.0			203765	23424880
1339	5.0			219656	21377340
1340	6.0			223541	24998852
1342	7.0	85		149380	19156404
1344	6.0			179398	26815435
1346	5.0			222128	30762901
1347	6.0		72	241551	29593634
1348	7.0			183989	25010152
1349	6.0			142670	18675066
1351	5.0			192817	26804487
1352	5.0			229898	30767139
1353	5.0			228838	26419205
1354	4.5			208356	24782726
1355	4.0			322775	35127785
1356	5.5			232370	32139817
1357	4.0	97		271216	37608283
1358	6.5			232370	27761866
1359	6.5			293111	38691382
1400	6.0			377513	63223728
1401	6.5			220363	37298574
1403	5.0			233429	32676952
1404	6.5			230604	30215878
1405	6.0			150440	20604656
1406	6.0			182223	23929173
1407	6.0			201999	25307855
1408	7.0			173394	24298563
1409	7.0			175866	24117753
1411	6.0			265918	41360459
1412	6.0	105	68	245789	36969089
1413	5.0			242258	35983811
1414	5.0			385635	49483877
1416	5.5			296642	37646423
1417	5.0			347495	38375669

1418	6.0			269450	29321006
1419	5.5			234842	32239757
1420	6.0			235901	34578290
1421	6.0			259562	34570521
1423	5.5			271569	38361543
1424	5.5			259209	38220991
1425	5.5			294170	40728681
1426	4.5			208709	27516783
1427	5.5			280044	34642210
1428	5.0			286048	44021061
1429	4.5			327366	45056485
1430	5.0	100	80	411061	55208726
1431	5.0			286048	38687497
1432	6.0			375041	48872581
1433	6.0			459089	60920157
1435	4.5			255324	36725065
1436	5.0			256737	34375231
1437	4.5			278279	35322722
1438	5.0			331957	48429030
1439	5.0			265565	35797350
1440	4.5			243317	34014316
1441	5.5			245083	32071307
1443	5.0			263093	35293058
1444	4.5			266978	33096136
1445	6.0	103	68	194230	21973097
1447	5.5			263446	40564821
1448	5.5			248614	34980524
1449	4.5			230957	32528631
1450	4.0			289226	42356331
1451	4.0			292758	33547104
1453	3.5			342551	41019673
1454	5.0			209062	24498797
1455	5.0			227426	24848412
1456	5.0			241905	28886989
1457	6.0			234842	32716858
1458	7.0			196702	22781095
1459	7.0	100	72	203412	21214539
1504	6.0			224247	24458185
1505	6.0			245436	35388407
1506	4.0			342198	46147706
1507	4.5			331604	46065423
1508	5.0			305471	39164244
1509	6.0			211887	25067009
1510	6.5			207649	24061955
1511	6.0			223541	27782349
1512	5.5			226013	28818832
1513	5.5			262740	34593122
1514	5.5			301233	37938474
1515	7.0			194230	23923875
1516	7.0	105	62	197408	23288213
1520	5.5			203058	42059688
1521	5.5			170569	28317718
1522	5.0			208356	31410924

1523	4.5			136314	18651052
1524	5.5			305118	34332501
1525	6.0			214712	24287969
1526	5.5			348908	45224936
1528	6.0			368331	46697908
1529	6.0			310062	41305368
1530	6.0			235195	31722045
1531	5.0	99	64	317125	40209910
1536	4.5			197408	23211580
1537	5.0			239079	28140792
1538	5.0			330191	39666418
1539	7.5			248261	32416684
1540	6.0			268744	31334997
1541	6.5			263800	32717917
1542	6.5			334782	39707030
1543	6.0			166331	23331296
1544	5.5			276513	35752854
1545	4.5			276513	35993699
1547	4.5			341845	42042384
1548	6.0			382457	44871084
1549	4.5			275807	34547213
1550	5.0	100	64	161034	17732167
1553	4.5			217184	23109874
1555	3.5			246495	33075654
1556	3.5			224247	27949387
1557	5.0			185401	23851127
1558	4.5			167038	21140379
1559	4.5			182576	21401000
1600	5.0			179045	18817384
1601	4.5			234842	22793808
1603	4.5			162447	17728635
1604	4.0			136667	15026362
1605	3.0	100	59	163153	17783373
1608	4.0			204824	20854330
1609	4.0			168450	17992788
1610	4.0			216831	26091486
1611	4.0			253911	28748556
1612	3.0			274394	32868710
1613	4.0			331250	37925761
1614	4.0			164566	20254335
1616	4.0			180457	20832788
1617	3.0			199174	19985944
1618	4.0			240845	28607298
1619	4.5			409296	49988875
1620	4.0			309002	41056754
1621	3.0			354205	45333352
1622	4.0			372569	48823847
1623	3.0			259209	32504970
1624	4.0	120		299467	38218166
1625	4.0			284635	30039658
1626	3.0			208356	22748252
1627	5.0			263800	29963025
1628	5.0			406824	43675684

1629	4.0			459796	47603374
1630	5.5			398348	46399853
1631	5.0			264506	32484841
1632	5.0			257796	31714276
1633	4.0	105	64	314299	38689969
1634	4.5			391992	47235749
1635	4.0			324188	39784015
1636	3.0			318537	37170735
1638	4.0			258149	28734783
1639	4.5			288167	33480359
1640	4.0			290639	32934396
1641	3.0			236960	27479702
1642	3.0			346436	37077858
1643	3.0			370803	41133033
1644	3.5			309002	36551670
1645	3.0			347848	41575878
1646	4.5			264153	27310899
1647	3.5		64	388460	40293958
1648	4.0	154		352792	39070661
1649	4.0			233782	25326924
1650	3.0			390579	37769318
1651	3.0			502879	54337162
1653	3.5			301586	32454117
1654	3.5			400820	39811561
1656	3.0			472156	49677754
1657	3.5			454145	55685120
1658	3.0			345023	40237808
1659	3.0			412121	38228760
1700	3.5			311121	29406467

Data trip GNG02, 6th. March 1981.
120 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1048	4.2	215	98	780452	28419777
1049	4.0			738781	24921513
1050	4.5			873683	26396957
1051	4.5			994459	27272759
1052	4.2			822830	24620279
1053	4.0			1173504	34029148
1054	4.0			967973	26551635
1055	4.0			1109231	29531834
1056	3.5			1183039	31820220
1057	3.0			860969	25501732
1058	2.5	236		892753	24483965
1059	2.5			836249	24815569
1100	2.0		98	745491	24527755
1106	2.0			1947600	53790492
1107	1.5			1465555	40994600
1108	2.0			2187033	59483912
1109	1.5			1082039	30874848
1110	2.0			1079567	29737718
1111	2.0			917120	28065218
1112	2.2			936543	27589178
1114	2.0			1191161	32629277
1115	2.0			2097334	52879022
1116	2.0			1862845	45761365
1117	2.0	268		1508286	37135067
1118	1.8			1211290	31900384
1505	4.0	270	93	336194	27359633
1506	4.5			266978	19622204
1507	5.5			240139	19181831
1508	5.5			152205	12289480
1509	5.5			195642	17484258
1510	4.5			315712	18020687
1511	5.0			147968	11386486
1512	4.5			183282	12493952
1513	5.5			146555	8048550
1514	4.2			171628	9407809
1515	4.5			238020	13269107
1516	4.2			237314	15146431
1517	5.2			162447	10993788
1519	5.0			171982	13306188
1520	5.5			282869	22079041
1522	4.5			414593	27125144
1523	4.8			442491	29504642
1524	4.0			557970	33741687
1525	4.2			558676	29349964
1526	3.0			707351	30141011
1527	3.0			1086277	43377629
1528	4.0			444610	16616225

1529	3.8			448495	23361314
1530	2.4	268		1113469	46423867
1534	4.0		89	310415	13595061
1535	3.0			567505	22739424
1536	3.8			781158	42588348
1537	3.2			506764	25111505
1538	3.6			619771	26734211
1539	3.0			385988	16903686
1540	3.4			1062616	47095197
1541	3.8			400820	22921294
1542	3.2			295936	18231515
1543	3.4			361621	25301498
1545	3.2			492991	28151739
1546	3.0			348201	15331480
1547	2.4			263446	11745636
1627	3.0			494404	20133559
1628	3.2			367271	14830366
1629	4.0			376453	13905830
1630	3.8			352792	13774459
1631	4.2			412121	15475210
1632	3.8	240		339020	13784701
1633	3.8			386341	14685576
1634	4.4			344670	13043094
1635	4.2			294876	11871002
1637	4.0			371862	13654036
1638	4.5			397995	15731241
1639	4.0			392345	16339359
1640	4.2			475334	17654474
1641	3.5			452026	18758056
1642	4.2			448142	19388421
1643	4.0			354205	13605302
1644	3.0			285695	13887113
1645	3.8			376100	14126899
1647	3.8			431191	17926397
1648	3.5			377513	32287432
1649	4.0			343257	13913246
1650	3.5			427306	16350306
1651	3.8			433663	15783154
1652	3.5			302999	12514081
1653	3.8			398348	16546655
1654	3.5			402939	16175499
1656	2.5			472156	17791142
1657	3.8	220	90	288873	12360463
1658	3.5			340432	13640264
1659	3.8			406117	16094982
1700	3.5			454145	17216220
1701	3.0			594697	21561682
1702	4.0			564680	19299782
1703	3.8			337607	14541492
1704	3.5			622243	23441478
1705	3.8			652260	23118702
1707	3.5			603173	23564726
1708	3.5			627540	25951993

1709	3.0			591166	25647581
1710	3.8			646257	27328203
1711	3.5			691459	29994808
1712	4.0			556911	25774714
1713	4.2			557970	26933739
1714	4.0			501467	23934117
1715	4.0			453086	24694793
1716	4.5			465799	22114708
1717	4.0			439313	24012162
1719	4.2			524774	31724870
1720	4.0			462621	26880414
1721	3.8			649435	35952381
1722	3.8			649788	33729680
1723	3.5			559383	27834967
1725	4.0			704173	37981205
1726	3.5			800581	43582454
1727	3.8	210	94	790340	40721971
1728	4.0			695697	38501036
1729	4.0			905113	43836719
1730	3.8			613767	32589725

Data trip GNG03, 14th. May 1981.
156 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1153	6.0	210	65	12360	8539423
1154	6.0			13066	11213798
1155	5.0			31076	9928346
1156	5.5			24367	8327888
1157	5.5			27898	10076668
1158	6.5			14478	8133305
1159	6.0			16951	11242756
1200	5.5	203		18716	8438423
1202	6.0			14478	7552380
1203	6.0			20129	12481592
1204	6.5			13419	12864402
1205	6.5		59	15538	8569087
1206	7.0			15185	5470231
1207	6.5			12713	8774971
1208	6.0			19069	12540214
1209	6.0			25073	12978468
1211	5.5			9888	7462681
1212	6.0	185		11653	7348261
1221	6.0			47674	10778369
1222	5.5			62506	11160473
1223	5.0			68157	13012723
1224	6.5			29664	9207928
1229	6.0	185	59	34608	6756389
1230	5.5			31429	7109888
1231	5.5			36020	9843238
1232	6.5			31076	6235498
1233	6.5			34255	7350734
1235	6.0			35667	12738329
1236	6.0			43436	10390967
1237	6.0			40964	9344596
1238	6.0			27192	9010167
1239	6.0			33195	9485854
1240	5.5			40964	9155663
1241	5.0			49087	9749654
1242	4.5			72041	15672619
1243	4.5			55443	18397847
1246	4.5			50499	8465969
1247	5.0	185		54384	11732216
1249	5.5			63566	12724203
1250	5.0			59681	8895747
1251	5.0			51206	8337423
1253	4.5			34961	6520487
1254	5.5			40964	5831499
1255	4.5			33195	5803248
1256	4.5			44496	8753783
1257	5.0			48381	9803333
1258	5.5			71335	9422994

1259	4.5			55443	9544476
1300	5.0			50853	11202850
1301	4.5			50853	10731753
1302	5.5			38139	7421010
1304	5.0			44143	8057026
1305	6.0			76632	17016693
1306	5.5			65685	11756936
1307	5.5			65332	10692554
1308	5.0	185		48027	8416881
1309	5.0		59	73807	14402000
1402	4.0			43083	15857314
1403	4.0			34961	7970505
1405	3.5			44143	12681472
1406	4.0			36020	12522910
1407	3.5			42730	18601965
1408	3.5			43790	16377852
1412	3.5			56150	11724447
1413	3.0			26132	10737757
1414	3.0			42024	13698886
1415	3.5			34608	10060776
1416	3.5			27192	7312594
1417	3.5	175	58	39905	9875021
1418	4.0			44849	10621572
1419	3.5			30723	6994762
1420	3.5			14125	4729684
1422	3.5			37433	7007476
1423	2.5			38139	9371082
1424	3.0			37433	10006038
1425	3.0			31429	12550808
1427	2.5			30370	12651102
1428	2.5			25779	12723850
1429	3.0			21541	11000497
1430	3.0			8475	3875777
1431	2.5			20482	5994300
1432	2.5	170	58	13419	3814329
1434	3.0			33902	9877846
1435	2.5			54031	15424357
1436	3.0			35667	9444183
1437	3.0			19423	5972758
1438	3.0			17657	4961701
1439	3.5			22954	8983681
1441	4.0			13419	6231261
1442	2.5			18010	7201000
1443	2.5			27898	10244059
1444	2.5			25779	10456299
1445	3.0			8475	4864233
1447	3.0			22601	8404521
1450	2.5	176	56	22777	8555491
1452	3.0			12183	3442996
1454	2.0			16951	4201377
1456	2.5			9534	4357998
1458	3.0			8122	5244041
1500	2.5			10241	5699423

1502	2.5			10947	5547217
1504	2.5	170	56	14832	4754404
1506	3.5			15714	6817660
1508	3.5			7769	3643583
1510	3.0			11653	3921862
1512	3.5			10064	4044228
1514	3.5			10064	4173126
1517	4.0			9181	4591074
1519	4.0			11124	5987767
1521	4.2			10064	5750982
1523	4.0			11653	4401435
1525	4.5			12536	5464051
1528	4.0			15008	5662519
1530	4.0			14125	5488418
1532	4.0			6533	4615618
1534	4.5			11477	4181072
1536	5.0			13419	5019793
1538	5.5			20659	6929783
1540	5.5			27015	5957749
1542	6.0			36550	10186319
1544	6.2			32489	6771751
1546	6.0	177	58	33195	7736369
1548	6.0			30193	5548100
1550	6.5			21188	4995426
1552	8.5			32136	7538784
1554	8.2			33725	6392472
1556	7.5			29134	8581624
1558	8.0			40258	8116531
1600	8.0			18540	5885531
1602	6.5			46262	10086909
1605	7.0	175	58	52089	10506623
1607	7.0			29311	7098058
1609	7.0			20482	5736503
1611	7.0			15538	4942278
1613	7.0			17304	4181072
1615	7.5			18893	4704434
1618	7.0			16068	6334203
1620	6.5			22424	5289067
1622	6.5			22248	6482524
1624	7.0			22071	8020828
1626	7.0			20305	6832315
1628	6.5	163	64	21718	5262758
1630	7.0			18540	5820905
1632	7.0			23307	7014009
1635	6.2			21895	6308600
1637	7.5			20835	6387704
1639	8.0			14655	5869816
1641	8.0			18363	6468045
1643	8.0			21365	6515543
1645	7.8			28075	6332084
1647	9.5			26485	6570987
1649	8.5			24190	9074969
1651	8.0	160	60	24896	8409995

1653	8.2	23660	6353802
1655	8.0	30547	6723193
1658	8.0	25779	7179811

Data trip GNG04/05, 15th. May 1981.
105 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1157	7.5			598582	26358464
1158	7.5	108	68	592225	23732117
1200	7.0			573155	20604656
1202	6.5			560089	18985835
1203	6.5			542079	22152848
1204	6.0			521949	17910858
1205	6.5			801641	29132426
1206	6.0			513474	21028078
1207	7.0			494404	16253544
1208	6.0			943959	31369959
1209	6.5			767739	27379762
1210	8.0			642725	25180016
1212	7.5			479219	16292743
1213	7.5	108	64	428012	15578329
1214	7.5			413533	14165039
1215	7.0			613767	24404507
1216	7.0			527246	21956499
1217	6.5			678393	23725054
1218	6.5			630718	21699762
1220	7.5			407530	17587730
1221	7.5			433310	19264820
1222	7.5			400114	13918190
1223	7.0			471096	15357966
1224	7.5			521243	16151132
1225	7.0			678746	31634112
1227	7.5			542079	23711988
1228	6.5			524068	19518379
1229	6.0			636015	24850884
1230	6.0			614474	21624895
1231	6.0			474628	17451769
1234	6.0			326660	17243766
1236	5.5	100	63	223894	14961030
1237	5.5			222835	15684273
1238	5.5			232370	17897439
1239	5.5			336548	26652988
1240	5.5			264153	17986079
1241	5.0			248261	16721463
1243	5.5			287813	24121284
1245	5.0			180457	12437095
1246	5.0			264506	19172649
1248	5.0			176219	13097125
1249	4.5			289579	18609734
1250	4.5			243317	15993982
1251	4.5			235548	16715812
1252	4.5			280044	21244557
1254	5.0	100	65	234488	19955927
1255	4.0			237667	19010908

1256	4.5			205530	13792470
1257	4.5			245083	15969615
1258	4.0			247202	15185278
1259	4.0			287460	18346287
1300	4.5			320656	19216792
1403	3.5	98	64	148674	14002945
1404	4.5			146908	14857558
1405	5.0			220363	25576245
1406	5.0			202705	30278738
1407	4.0			256383	29360558
1408	5.0			226719	27450744
1409	5.5			263093	30802100
1411	5.0			223188	21055270
1412	4.8			226719	32035286
1413	4.5			229191	29844368
1414	5.0			241905	31597738
1415	5.0			325247	37336007
1416	5.5			290639	22938598
1417	5.5			410708	36482454
1419	5.0			371156	40612143
1422	4.5			273688	31444119
1423	5.0			414593	42092178
1440	4.5	104	78	428719	25418742
1441	4.5			388107	27483234

Data trip GNG06, 16th. July 1981.
79 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1424	10.0	305	79	27898	4269182
1425	8.5			31076	4332395
1426	9.0			45555	5540154
1427	9.0			42730	5462462
1428	9.5			30594	2912395
1430	11.0			10947	2977727
1431	11.5			20835	3281432
1432	12.0	303	79	30017	3804441
1433	9.0			34608	4999134
1434	10.0			30723	3693554
1435	11.5			39905	4772415
1436	11.0			24013	4362059
1437	10.0			20482	3692494
1438	10.0			20482	3557592
1439	11.5			19423	3693907
1441	11.5			19776	3887431
1442	10.0			20482	3851410
1443	10.5			21541	3989843
1444	10.5			18716	4049878
1445	9.0			16244	3790316
1447	9.5	300	83	14832	3599970
1448	9.0			22601	4042462
1449	10.0			25073	4069301
1450	11.5			14125	4158294
1451	11.0			14125	4054116
1453	12.5			13066	3993728
1454	10.5			17304	4301671
1456	12.0			17657	4264944
1459	10.0			20835	4593370
1500	12.0			30370	4508968
1501	10.0			17304	4367709
1502	9.5			17657	4549226
1503	12.0			31429	5050340
1504	8.5			37433	5404193
1506	9.5			25073	4976886
1507	12.5	300	75	36374	5114260
1510	10.5			25779	5031977
1511	10.5			24720	5202193
1512	12.0			31429	5060582
1513	9.5			40258	5484710
1514	10.0			28604	5198309
1516	9.5			34608	5646098
1517	8.5			26839	5361109
1518	10.0			28604	5173235
1519	9.5			27545	5024561
1521	11.0			27192	5316259
1522	10.5			27545	5351927

1523	10.5			32489	5460696
1524	11.0			39905	5675409
1525	8.0	298	83	35314	5591007
1528	9.0			43436	6198418
1529	8.8			61800	8373091
1531	7.5			49440	7543551
1533	9.5			17304	5403840
1534	10.0			21541	5172176
1535	9.8			28604	5329326
1536	9.0			46615	6680816
1537	9.5			34255	5984412
1538	11.0			33195	6042328
1539	10.5			22954	4862820
1541	9.0			28251	4997015
1542	10.5			28251	5354046
1543	10.0			24720	5401368
1544	11.2	302	79	28604	5621378
1545	10.5			44496	6591823
1546	11.5			51559	7294583
1547	10.2			40964	6327316
1548	11.2			36374	6136971
1549	9.0			36020	5547923
1551	10.0			22248	5492126
1552	10.5			25779	5660930
1553	9.5			28957	5833618
1555	10.0			26132	5807839
1556	10.5			29664	6322726
1557	9.0			55443	7490226
1558	8.8			58622	8281273
1559	12.0			35667	6342502
1600	10.0	310	79	43436	6411365
1602	9.5			61094	6646560

Data trip GNG07, 17th. July 1981.
100 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1107	9.0	312	77	25779	10863477
1108	9.5			27545	11058767
1109	10.0			38846	10742701
1110	11.0			26132	10674191
1111	10.0			36020	10140234
1112	11.0			26839	9861248
1113	9.5			26132	9896563
1114	11.0			9888	10117632
1115	11.0			25073	10268779
1116	9.5			35314	10345412
1118	10.0			33548	9914573
1119	10.0			10241	8437364
1120	10.5			10594	7765327
1121	9.5			13066	8043253
1122	10.0			12006	8283392
1123	9.5			13419	8409112
1124	11.0			15891	8620647
1125	10.0	313	63	7062	8756255
1127	10.0			13772	8931415
1128	9.5			22601	9357309
1129	8.0			32136	9461134
1130	8.0			21188	9716812
1132	9.0			19776	9948829
1133	8.0			20482	10050535
1134	9.5			33195	10167426
1135	11.0			31783	10060776
1136	10.0			26485	10061129
1137	12.0			23660	10325282
1138	11.0			26485	10500443
1139	11.5			20129	9899388
1140	11.5			26839	9912101
1141	10.0			13772	9704452
1142	9.5			8122	10475369
1143	10.2	308	74	17657	11175658
1144	11.0			27192	10631460
1145	11.5			21188	10304447
1147	9.5			31076	10348943
1148	11.0			16597	10130699
1149	11.5			15891	10302681
1150	12.0			13066	9963308
1151	12.5			31783	10240880
1152	10.0			19069	10086909
1153	10.5			11653	9933643
1155	10.5			12006	10363422
1156	11.0			15185	10255713
1157	9.8			22954	10622984
1158	9.5			37080	10598970

1159	9.8			28957	10856061
1200	10.8			20482	10595792
1201	10.5			9181	10244765
1202	10.0	310	75	7769	10692907
1204	11.0			37433	10822512
1205	11.5			11300	10461597
1206	11.5			13772	10307272
1207	10.0			25779	10572838
1208	10.0			31076	10773071
1209	9.5			28604	10869833
1210	10.5			24013	10382492
1212	10.0			13772	10114807
1213	10.5			9888	10319279
1214	11.0			23307	10881134
1215	9.5			38492	11361766
1217	8.0			24013	11254409
1218	10.0			30370	11406615
1213	9.0			31783	11524213
1220	10.5	326	75	20482	11278070
1221	10.0			16244	11549993
1222	8.5			23660	12186362
1223	10.5			22601	12139040
1224	10.0			25426	12114320
1225	9.5			43083	11853698
1226	11.5			19423	11507262
1228	12.0			34608	11372713
1229	11.0			32842	11162591
1230	9.5			21541	11564472
1231	9.0			20835	11547874
1232	9.5			6356	11327157
1233	8.0			21541	11330336
1234	10.0			21895	11511500
1235	10.0			25073	11842398
1237	10.5			27545	12524322
1238	9.5			8122	11647814
1239	9.0			21895	12382358
1241	12.0			11300	11877006
1242	11.5			26839	12152107
1244	10.5	316	70	34255	11996016
1245	11.0			29664	12464288
1246	9.8			37433	12988709
1247	10.0			28957	12932912
1248	9.5			24720	12557165
1249	8.0			18363	12193425
1250	8.5			18010	12079712
1251	10.5			26839	11517503
1252	10.0			28957	11552818
1253	9.5			28251	11455703
1255	9.5			36374	11804964
1256	10.0			31429	11883362
1257	9.0			26839	11971649
1258	10.0			21541	11682069
1259	10.0	310	70	28604	11828978

Data trip GNG08, 3rd Sept. 1981.
200 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1058	5.5	148	82	52618	9434295
1059	5.0			58975	9367550
1101	6.0			67097	10020870
1103	6.0			65332	9235474
1104	6.5			51912	10018045
1106	5.5			74160	9501746
1107	6.0			56503	8595573
1108	5.5			67804	9367903
1109	6.5			61800	8705402
1110	7.0			77692	9446655
1111	5.0			74513	10318219
1112	5.5			68510	9052191
1114	5.5			60741	9334708
1115	5.5			59328	8532360
1117	5.0			78045	9385208
1118	5.5	158	79	75573	9371082
1119	5.5			84401	9260900
1120	5.5			69922	9079736
1121	5.0			77692	9881731
1123	4.5			72394	9542358
1124	5.0			62859	8594514
1125	5.5			71335	8525297
1126	6.0			67450	9071614
1127	5.0			60741	8459612
1128	5.5			63213	8687038
1129	5.0			79457	9780025
1131	5.5			118303	11149172
1132	5.5	162	83	129604	12458990
1133	6.0			167744	13027202
1134	5.5			119010	10763536
1135	6.0			93583	10453121
1136	4.5			104178	10407212
1137	5.0			80164	9594976
1138	5.5			75573	8960726
1140	6.0			71688	9087506
1141	5.5			63566	9025705
1142	6.0			84755	10020517
1144	5.0			76985	9808983
1145	5.5			75220	9113285
1146	5.5			66744	9047953
1147	6.5			72394	9828053
1148	5.5			72041	9526819
1149	5.0	166	83	72394	9939647
1152	5.0			54737	9267963
1153	5.0			74160	10594733
1154	5.5			100999	12016852
1155	6.0			77692	10610624

1157	5.0			70276	10306212
1158	4.5			67097	9599567
1205	5.5			83695	9414872
1206	6.0			72748	9623581
1207	6.0			69216	9764486
1208	6.0			64978	8971674
1209	5.5	167	80	66744	9450540
1210	5.0			65685	9956951
1211	5.5			69922	10323870
1212	5.5			79104	9585795
1215	5.5			90052	9692445
1216	6.0			89699	11366004
1217	5.5			91111	10752589
1218	5.0			94289	11237458
1219	5.5			94289	10020164
1221	5.5			115831	12341393
1222	5.0			135608	12865815
1223	4.5			120069	11184487
1224	4.5			139492	13728197
1225	4.0			123601	13183999
1226	5.5			110181	11694782
1228	5.0	167	77	95349	10680900
1229	5.5			92877	10136702
1230	5.5			98880	11722328
1231	5.0			87580	11011798
1234	5.5			78751	9838294
1235	5.5			78045	8875618
1236	5.5			79104	8932828
1237	5.0			88639	10045591
1238	5.5			97468	10729988
1424	5.5			52971	6473166
1425	5.5	188	70	55090	6793116
1426	5.0			72748	7144143
1427	5.5			78751	7764621
1428	4.5			88992	7310828
1429	5.0			75573	6425844
1431	5.5			80870	7098940
1432	5.0			77692	6774399
1433	5.0			60034	5969580
1434	5.5			69216	6626078
1435	5.0			62506	6034205
1436	6.0			51206	5920139
1438	5.5			39552	5211728
1439	5.0			50146	6090709
1440	5.5	194	70	57915	6436792
1444	6.0			81576	6785347
1445	6.0			86873	6562865
1446	6.5			81929	7004297
1447	6.0			96762	7966620
1448	6.5			113006	8343427
1449	8.0			98174	6822074
1450	7.0			104884	6910007
1452	7.0			84048	6574519

1454	7.0		62506	5918726
1455	7.0		86873	7421010
1456	7.0		73101	5965342
1457	6.0		58269	5515434
1458	6.0		59328	5436682
1459	6.0		50146	5240686
1500	6.0		42730	5245630
1501	6.0		36727	4936627
1502	6.5	196 70	43790	5453633
1503	6.0		43436	5752395
1504	5.5		66038	6156041
1507	5.5		58622	5631266
1508	6.5		73101	6532847
1509	6.0		74160	7249027
1510	6.5		78398	6653623
1511	6.0		51912	5673643
1512	6.0		94643	7951435
1513	6.5		78045	5975583
1514	6.5		70276	6025730
1515	7.0		74866	6651858
1516	7.0		107709	7424541
1517	8.0		84401	5757339
1518	6.5		75220	5697304
1519	7.0		92171	6879637
1520	7.5		73454	5474822
1521	7.5		69569	5606545
1522	8.0		71335	6063869
1523	7.5		70982	5731912
1526	7.5		76632	6315663
1527	7.5		60741	6120373
1528	7.0		69569	6166282
1529	6.0		61447	5945919
1530	6.5		81223	6773340
1531	7.0		70982	6346386
1533	7.5		98880	5859045
1534	7.5	204 74	89699	6822074
1535	7.5		72041	6113310
1536	7.5		72394	5496717
1537	7.0		76279	6548033
1538	7.0		94289	6647620
1539	8.0		80164	5986884
1540	6.5		87580	6883521
1541	8.0		111240	6661746
1542	7.5		71335	5704014
1544	7.5		74513	6252096
1545	7.0		74866	6156394
1546	7.5		74513	6717896
1547	8.0		82636	6003128
1548	7.5		90758	6650445
1549	8.5		72041	6031733
1551	7.5		70276	6092474
1552	7.0		75220	6214310
1553	7.5		97468	7919652

1554	7.5			94996	6902238
1555	7.0			91111	6927311
1556	8.0	203	68	90758	7024427
1557	8.5			98174	6165929
1558	8.5			78045	6184292
1559	8.0			79104	6276110
1600	8.0			100646	7003591
1601	8.0			96762	6723546
1602	8.0			105943	6994056
1603	8.0			90405	7010301
1605	7.5			114066	7661149
1606	8.0			96762	7535076
1607	7.5			98880	6923427
1608	8.5			85108	7710589
1609	7.5			116185	8498105
1610	7.0			106296	7423835
1611	7.0			100999	6651504
1612	7.0			99234	7269510
1613	7.0			98174	8057379
1614	6.5			93230	6562865
1615	6.5			77692	6427963
1616	6.5			82636	7160388
1617	6.0			85461	6964392
1618	7.0	203	69	81223	7312947
1619	7.0			108062	8159085
1621	7.0			113713	7417478
1622	5.5			106650	7530485
1623	7.5			111240	8409112
1624	6.5			92171	8364616
1625	7.0			94289	7418184
1627	7.0			75926	6884934
1628	7.0			90405	6847147
1629	7.0			94289	7062920
1630	6.5			89699	7728247
1631	7.0			86520	6466809
1632	7.0			87933	7738488
1633	6.5			75573	6763805
1634	7.0			81929	6625018
1636	7.0	204	75	82636	6901179
1637	6.5			77692	6646914
1638	7.0			88639	7060801
1639	6.5			113713	8186630
1640	7.0			106296	7116951
1641	8.0			85461	6639851
1642	8.0			86167	8802870
1643	8.0			109828	8643601
1644	7.0	190	75	103824	7479632

Data trip GNG09, 5th Nov. 1981
30 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1134	6.0	126	80	43436	8981209
1135	5.0			62506	8967789
1136	5.5			51912	9223820
1137	5.0			53678	9354131
1138	7.5			57209	9682557
1139	7.0			60034	9801567
1140	8.0			52265	10066073
1141	7.0			59681	10284671
1142	5.0			55090	10343293
1143	5.5			55797	10300209
1144	5.5			60387	10557299
1145	7.0			68510	10566128
1147	6.0			59681	10530460
1211	6.0	128	76	58975	9574847
1212	8.0			45908	9403571
1213	8.5			42730	9557190
1214	8.0			61094	9725640
1215	6.5			52265	9689973
1216	6.0			43436	9544476
1217	9.0			38492	9615459
1218	7.0			55797	9805805
1220	7.5			58622	9739413
1221	7.5			50853	9585441
1222	6.0			54031	9758130
1223	6.0			60387	9881025
1224	5.5			55443	9926934
1225	7.5			46968	9430410
1226	8.0			54737	9546242
1227	7.0			52971	9455131
1229	7.5	122	78	47321	9563193

Data trip GNG11, 19th March 1982.
25 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1440	12.0	270	66	279162	42802001
1445	12.5			18504	29642439
1450	12.5			43436	34735440
1455	11.0	275	66	88922	44239305
1500	9.0			139351	49202419
1505	9.5			293252	53218890
1510	10.0	275		252923	46994692
1515	9.0			296501	49910760
1520	8.5	275	78	334076	58705225
1525	9.5			295441	54495372
1535	11.0	275	74	321574	55879139
1540	10.5			252287	55543480
1545	10.5	292	82	344387	60808986
1550	13.0			64978	27183766
15505	10.8			26839	20267755
1551	10.8			40258	22123890
15515	12.2	295	80	38139	27368108
1552	13.2			37433	21513654
15525	13.6			56503	24078906
1553	14.0			36727	23439006
15535	12.0			35314	21984751
1601	12.0			82706	34939064
1606	13.4	315	75	61871	32596435
1639	12.0	300		133630	30203486
1644	12.0	300	70	158491	31203486

Data trip GNG12, 21st. March 1982.
32 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1315	8.2	275	86	525551	45873665
1320	7.4			678464	63747726
1325	7.8			693366	63529058
1330	7.4			873471	85461332
1355	4.2	280	78	557970	66391448
1405	3.8			588553	70899710
1410	3.6			579230	72268574
1420	3.8			561572	68347312
1425	3.8		77	596110	69848182
1430	3.5			672531	73892340
1435	3.2			725432	81698279
1440	4.6	290	76	510154	66696707
1445	6.2			236042	36602241
1450	6.2			396794	49648372
1455	6.6			410708	51855464
1500	6.5		76	401456	49328987
1336	5.8		84	725715	75352174
1337	6.0			634603	64138023
1338	5.4			670271	66512930
1339	4.6			915354	84881466
1340	4.2			658264	74401152
1345	4.0	275	82	659676	74688966
13455	3.8			589047	65544604
1346	3.4			521243	57155267
13465	3.2			718298	80637358
1347	3.2			697816	70100893
13475	3.6			384222	47858346
1348	3.6			772683	83132687
13485	3.5			785396	89430693
1349	4.6			543138	66191567
13495	4.5			331250	38814983
1350	5.5	280		357383	37471615

Data trip GNG13, 15th Nov. 1982.
80 intervals.

TIME	U m/s	W.D	RH %	N, m^{-3} (2.5+)	N, m^{-3} (0.25+)
1130	8.0	250	80	17304	4873410
1131	8.0			46262	8560250
1132	8.5			31429	8214170
1133	8.0			19423	4926380
1134	8.0			19423	4643860
1135	8.0			28251	6250680
1137	9.0			16244	4873410
1138	9.5			60034	8185920
1139	9.5			130310	12596710
1140	8.0			174807	11191190
1141	9.0			199880	15139360
1142	9.0			156090	11346580
1143	9.5			200233	12752100
1144	9.5	225	88	180810	9884550
1146	9.0			134548	9044060
1147	10.0			96055	7839840
1148	8.5			124307	9019340
1149	10.0			82283	7380750
1150	8.5			90405	6610890
1151	9.0			97115	7190050
1152	9.5			82636	7207700
1153	9.5			62153	5502010
1154	9.0			86873	6180050
1156	9.5			70629	5879880
1157	9.0			113713	7546730
1158	9.5	240	80	98527	8969900
1159	9.5			125013	10364830
1200	10.0			89345	7091170
1210	9.5	235		127132	7789411
1215	9.0	230	80	114489	7033255
1220	10.0	235		197337	11928424
1225	9.0	235	84	155313	9817458
1230	10.0	235	75	120705	8255705
1235	9.0	235	75	150298	10468801
1240	10.0	235	83	133418	9338734
1245	10.0	235		140552	10845466
1250	9.5	235	81	137726	10217643
1255	10.0	235		165342	11504649
1300	10.0	240	95	168168	11339871
1305	9.5	240	93	214288	12713185
1310	11.0	245		178056	11277081
1320	12.0	240		158491	11308511
1325	10.0	240	86	150087	10374581
1315	10.0	240	81	183353	12713256
1330	10.5	240		176219	12697505
1335	11.0	240	83	174877	12909393
1340	11.0	235		173818	12532727

1345	10.5	235	83	159480	11755806
1350	11.0	235		159551	11755806
1355	11.5	230	86	191051	13843323
1400	11.5	230		175937	12980022
1405	11.0	230	86	229544	17539561
1410	10.5	225		271922	18677468
1415	12.5	225	86	238797	18081075
1420	13.0	225		214218	16378063
1425	12.5	225	97	249109	19360240
1430	12.0		86	247555	19407279
1440	12.5	220		244800	16527232
1445	12.5	230	94	241975	17202094
1450	12.0	230		261963	18277212
1455	14.5	230	94	241410	16668420
1500	13.0	230		267543	18661788
1505	12.5	230	94	301304	18755937
1510	13.5	230		303069	21965610
1515	12.5	230	97	329202	22711172
1520	12.0	235		364799	26438840
1525	12.5	230	97	275948	21628214
1530	12.5	230		303776	22758282
1535	14.0	230	97	228767	16103457
1540	13.0	230		203765	14941960
1545	12.0	235	97	279126	19124762
1550	12.0	230		263870	17779912
1555	12.0	230	97	301304	20317619
1600	11.0	230		264082	18128114
1605	12.0	230		318537	22444335
1610	12.5	230	97	250521	17759288
1615	11.0	230		116820	15734561
1620	12.0	235	91	82353	13600005
1625	12.5	235		111240	12289480
1630	12.5	230	91	121411	12626876