COMMONWEALTH DEPARTMENT OF
TRANSPORT AND REGIONAL DEVELOPMENT

Meteorology

Proposal for a Second Sydney Airport
at Badgerys Creek or Holsworthy Military Area

5

Technical Paper

PPK
Environment & Infrastructure

Prepared for:

COMMONWEALTH DEPARTMENT OF
TRANSPORT AND REGIONAL DEVELOPMENT

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Explanatory Statement

This technical paper is not part of the Draft Environmental Impact Statement (EIS) referred to in paragraph 6 of the Administrative Procedures made under the Environment Protection (Impact of Proposals) Act 1974.

The Commonwealth Government is proposing to construct and operate a second major airport for Sydney at Badgerys Creek. This technical paper contains information relating to the Badgerys Creek airport options which was used to assist the preparation of the Draft EIS.

The technical paper also assesses the impacts of developing a major airport at the Holsworthy Military Area. On 3 September 1997, the Government eliminated the Holsworthy Military Area as a potential site for Sydney's second major airport. As a consequence, information in this technical paper relating to the Holsworthy Military Area is presented for information purposes only.

Limitations Statement

This technical paper has been prepared in accordance with the scope of work set out in the contract between Rust PPK Pty Ltd and the Commonwealth Department of Transport and Regional Development (DoTRD) and completed by PPK Environment and Infrastructure Pty Ltd (PPK). In preparing this technical paper, PPK has relied upon data, surveys, analyses, designs, plans and other information provided by DoTRD and other individuals and organisations, most of which are referenced in this technical paper. Except as otherwise stated in this technical paper, PPK has not verified the accuracy or completeness of such data, surveys, analyses, designs, plans and other information.

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Acknowledgments

Data used to develop the figures contained in this document have been obtained and reproduced by permission of the Australian Bureau of Statistics, NSW Department of Land and Water Conservation, NSW National Parks and Wildlife Service (issued 14 January 1997), NSW Department of Urban Affairs and Planning and Sydney Water. The document is predominantly based on 1996 and 1997 data.

To ensure clarity on some of the figures, names of some suburbs have been deleted from inner western, eastern, south-eastern and north-eastern areas of Sydney. On other figures, only 'Primary' and 'Secondary' centres identified by the Department of Urban Affairs and Planning's Metropolitan Strategy, in addition to Camden, Fairfield and Sutherland, have been shown.

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Introduction

CHAPTER 1 OVERVIEW OF THE PROPOSAL

1.1 INTRODUCTION

This technical paper address the potential meteorological impacts identified as part of the previously proposed development of the Second Sydney Airport at either Badgerys Creek or the Holsworthy Military Area. It contains information used to prepare the Draft Environmental Impact Statement (EIS) which addresses the overall environmental impacts of the Badgerys Creek airport options.

1.2 A BRIEF HISTORY

The question of where, when and how a second major airport may be developed for Sydney has been the subject of investigation for more than 50 years. The investigations and the associated decisions are closely related to the history of the development of Sydney's existing major airport, located at Mascot.

The site of Sydney Airport was first used for aviation in 1919. It was acquired by the Commonwealth Government in 1921, and was declared an International Aerodrome in 1935. In 1940 the first terminal building and control tower were opened.

In 1945 the airport had three relatively short runways. A major expansion began in 1947, and by 1954 the current east-west runway was opened. The north-south runway was first opened in 1954 and was extended to its current length in 1972. The present international terminal was opened in 1970.

Planning and investigations for a site for a second Sydney airport first started in 1946. A large number of possible sites both within and outside the Sydney Basin have been investigated.

The *Second Sydney Airport Site Selection Program Draft Environmental Impact Statement* (Kinhill Stearns, 1985) re-examined all possible locations for the second airport and chose 10 for preliminary evaluation. Two sites, Badgerys Creek and Wilton, were examined in detail and an EIS was prepared. In February 1986 the then Commonwealth Government announced that Badgerys Creek had been selected as the site for Sydney's second major airport.

The Badgerys Creek site, which is about 46 kilometres west of Sydney's Central Business District and is 1,700 hectares in area, was acquired by the

Commonwealth between 1986 and 1991. A total of $155 million has been spent on property acquisition and preparatory works.

Since 1986, planning for Sydney's second airport has been closely linked to the development of the third runway at Sydney Airport. In 1989 the Government announced its intention to construct a third runway. An EIS was undertaken and the decision to construct the runway was made in December 1991.

At the same time as investigations were being carried out on the third runway, detailed planning proceeded for the staged development of the second airport at Badgerys Creek. In 1991 it was announced that initial development at Badgerys Creek would be as a general aviation airport with an 1,800 metre runway.

The third runway at Sydney Airport was opened in November 1994. In March 1995, in response to public concern over the high levels of aircraft noise, the Commonwealth Senate established a committee in March 1995 to examine the problems of noise generated by aircraft using Sydney Airport and explore possible solutions. The committee's report, *Falling on Deaf Ears?*, containing several recommendations, was tabled in parliament in November 1995 (Senate Select Committee on Aircraft Noise, 1995).

During 1994 and 1995 the Government announced details of its proposed development of Badgerys Creek, and of funding commitments designed to ensure the new airport would be operational in time for the 2000 Olympics. This development included a 2,900 metre runway for use by major aircraft.

The decision to accelerate the development of the new airport triggered the environmental assessment procedures in the *Environment Protection (Impact of Proposals) Act 1974*. In January 1996 it was announced that an EIS would be prepared for the construction and operation of the new airport.

In May 1996, the present Commonwealth Government decided to broaden the environmental assessment process. It put forward a new proposal involving the consideration of 'the construction and operation of a second major international/domestic airport for Sydney at either Badgerys Creek or Holsworthy on a site large enough for future expansion of the airport if required' (Department of Transport and Regional Development, 1996). A major airport was defined as one 'capable of handling up to about 360,000 aircraft movements and 30 million passengers per year' (Department of Transport and Regional Development, 1996).

The Government also indicated that 'Badgerys Creek at this time remains the preferred site for Sydney's second major airport, subject to the favourable outcome of the EIS, while Holsworthy is an option to be considered as an alternative' (Minister for Transport and Regional Development, 1996). The two sites considered in this technical paper are shown in *Figure 1.1*.

Following the substantial completion of a Draft EIS on the Badgerys Creek and Holsworthy airport options, the Government eliminated the Holsworthy Military Area as a potential site for Sydney's second major airport. The environmental assessment showed that the Badgerys Creek site was significantly superior to the Holsworthy Military Area. As a result a Draft EIS was prepared which examines only the Badgerys Creek site. While this technical paper examines both the Badgerys Creek and Holsworthy airport options, only the parts of the assessment relating to the Badgerys Creek airport options were used to assist the preparation of the Draft EIS.

1.3 THE PROPOSAL

The Commonwealth Government proposes the development of a second major airport for Sydney capable of handling up to 30 million domestic and international passengers a year. By comparison, Sydney Airport will handle about 20 million passengers in 1997. The *Second Sydney Airport Site Selection Program Draft Environmental Impact Statement* anticipated the airport would accommodate about 13 million passengers each year (Kinhill Stearns, 1985).

A stated objective of the Government is the building of a second major airport in the Sydney region to a full international standard, subject to the results of an EIS. In the Government's view, Sydney needs a second major airport to handle the growing demand for air travel and to control the level of noise experienced by Sydney residents (Coalition of Liberal and National Parties, 1996).

Government policy (Coalition of Liberal and National Parties, 1996) indicates:

- that Sydney's second airport will be more than just an overflow airport and will, in time, play a major role in serving Sydney's air transport needs; and

- a goal of reducing the noise and pollution generated by Sydney Airport as much as possible and that the Government would take steps to ensure that the noise burden around Sydney Airport is shared in a safe and equitable way.

The assumptions made on how the Second Sydney Airport would operate and the master plans which set out the broad framework for future physical development of the airport are based on an operational limit of 30 million passengers a year. The main features include parallel runways, a cross wind runway and the provision of the majority of facilities between the parallel runways.

Consideration has also been given to how the airport may be expanded in the future and the subsequent environmental implications. Such an expansion could not proceed, however, unless a further detailed environmental assessment and decision making process were undertaken by the Government.

Five airport options are considered, as well as the implications of not proceeding with the proposal. Three of the airport options are located at Badgerys Creek and two are located within the Holsworthy Military Area. Generally, the airport options are:

- Badgerys Creek Option A which has been developed to be generally consistent with the planning for this site undertaken since 1986. The airport would be developed within land presently owned by the Commonwealth with two parallel runways constructed on an approximate north-east to south-west alignment;

- Badgerys Creek Option B would adopt an identical runway alignment to Option A, but provides an expanded land area and also a cross wind runway;

- Badgerys Creek Option C would provide two main parallel runways on an approximate north to south alignment in addition to a cross wind runway. Again the land area required would be significantly expanded from that which is presently owned by the Commonwealth;

- Holsworthy Option A would be located centrally within the Holsworthy Military Area and would have two main parallel runways on an approximate north to south alignment and a cross wind runway; and

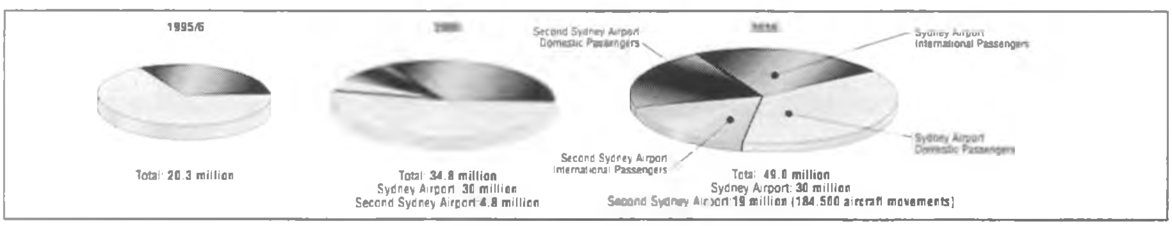
- Holsworthy Option B would be located in the south of the Holsworthy Military Area and would have two main parallel runways on an approximate south-east to north-west alignment and a cross wind runway.

To ensure that the likely range of possible impacts of the airport options are identified a number of different assumptions about how the airport options would be developed and operate have been adopted. These different assumptions relate to the number and types of aircraft that may operate from the airport, the flight paths used and the direction of take offs and landings.

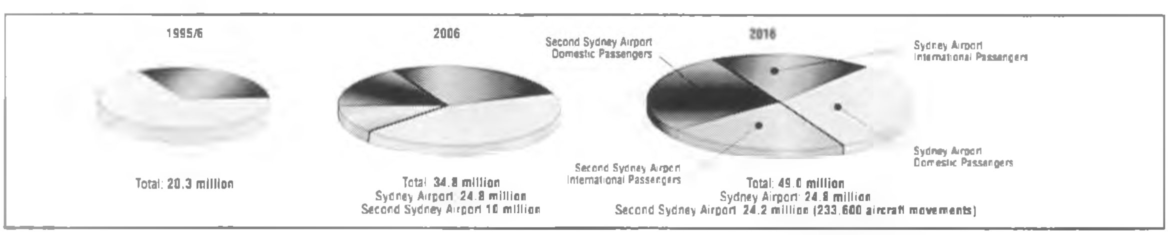
The number of flights into and out of the proposed Second Sydney Airport would depend on a number of factors including the types of aircraft that would use the airport and the associated numbers of passengers in each aircraft. The

Figure 1.1

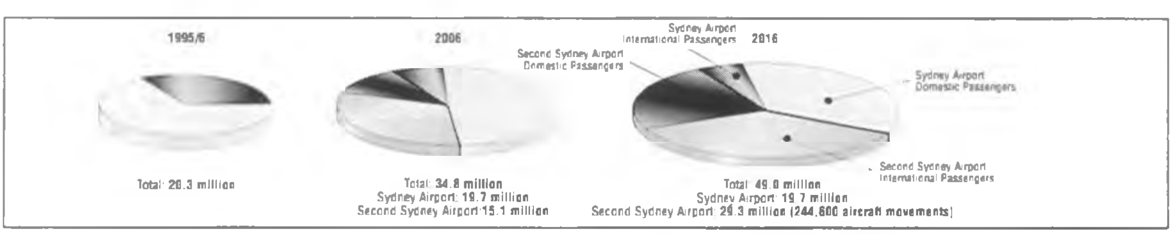
Potential Airport Sites Considered in the Draft EIS



Assumptions about Passenger Movements for Air Traffic Forecast 1



Assumptions about Passenger Movements for Air Traffic Forecast 2



Assumptions about Passenger Movements for Air Traffic Forecast 3

Figure 1.2

Summary of Passenger Movement Forecasts Used for Environmental Assessment

proposal put forward by the Government anticipates a major airport handling 30 million passengers and up to 360,000 aircraft movements per year.

Air traffic forecasts have been developed based on an examination of the number and type of aircrafts that would use the airport as it approaches an operating level of 30 million passengers per year. This examination has shown that if the airport accommodated about 245,000 aircraft movements each year, the number of air passengers would approach 30 million. This assumes a relatively high percentage of international flights being directed to the Second Sydney Airport. Therefore it is appropriate for this Draft EIS to assess the airport operating at a level of 245,000 aircraft movements per year, rather than the 360,000 originally anticipated by the Government. It has been assumed that this level of operation could be reached by about 2016.

1.4 AIR TRAFFIC FORECASTS

Cities around the world which have developed second major airports have responded to their particular needs in different ways. For example, the original airport in Dallas, United States, is now used for short range traffic that does not connect with other flights. Second airports in New York and Washington serve as hubs for particular airlines. In Taipei, Taiwan, smaller domestic aircraft use the downtown airport and larger international flights use a newer airport 40 kilometres from the city.

It is clear that each metropolitan area around the world has unique characteristics and the development of multi-airport systems respond to particular local circumstances. The precise role and consequential staging of development of the Second Sydney Airport would be the subject of future Government decisions. To assist in developing a realistic assessment of the potential impacts of the Second Sydney Airport, three sets of air traffic forecasts for the airport were developed. Each forecast assumes a major airport would be developed, however, this may be achieved at different rates of growth.

The three potential air traffic scenarios considered for the Second Sydney Airport are shown in *Figure 1.2*. They are:

- *Air Traffic Forecast 1* where the Second Sydney Airport would provide only for demand which cannot be met by Sydney Airport. This is an overflow forecast, but would nevertheless result in a significant amount of air traffic at the Second Sydney Airport. The proportion of international and domestic air traffic is assumed to be similar at both airports;

- *Air Traffic Forecast 2* where the Second Sydney Airport would be developed to cater for 10 million passengers a year by 2006, with all further growth after this being directed to the second airport rather than Sydney Airport. The proportion of international and domestic traffic is also assumed to be similar at both airports; and

- *Air Traffic Forecast 3* which is similar to Forecast 2 but with more international flights being directed to the Second Sydney Airport. This would result in the larger and comparatively noisier aircraft being directed to the second airport. It would accommodate about 29.3 million passengers by 2016.

1.5 OPERATION OF THE AIRPORT OPTIONS

At any airport, aircraft operations are allocated to runways (which implies both the physical runway and the direction in which it is used) according to a combination of wind conditions and airport operating policy. The allocation is normally performed by Air Traffic Control personnel.

Standard airport operating procedures indicate that a runway may not be selected for either approach or departure if the wind has a downwind component greater than five knots, or a cross wind component greater than 25 knots. If the runway is wet, it would not normally be selected if there is any downwind component. This applies to all aircraft types, although larger aircraft would be capable of tolerating relatively higher wind speeds. Wind conditions at the airport site therefore limit the times when particular runways may be selected. However, there would be a substantial proportion of the time, under low wind conditions, when the choice of runways would be determined by airport operating policy.

For the environmental assessment, the maximum and minimum likely usage for each runway and runway direction was estimated and the noise impact of each case calculated. The actual impact would then lie between these values and would depend on the operating policy which is applicable at the time.

The three airport operation scenarios were adopted for the environmental assessment, namely:

- *Airport Operation 1* shown in *Figure 1.3*. Aircraft movements would occur on the parallel runways in one specified direction (arbitrarily chosen to be the direction closest to north), unless this is not possible due to meteorological conditions. That is, take offs would occur to the north from the parallel runways and aircraft landing would approach from the south, travelling in a northerly direction. Second priority is given to operations in the other direction on the parallel runways, with operations on the cross wind runway occurring only when required because of meteorological conditions;

- *Airport Operation 2* shown in *Figure 1.4*. As for Operation 1, but with the preferred direction of movements on the parallel runways reversed, that is to the south; and

- *Airport Operation 3*. Deliberate implementation of a *noise sharing* policy under which seven percent of movements are directed to occur on the cross wind runway (equal numbers in each direction) with the remainder distributed equally between the two parallel runway directions.

Since a cross wind runway is not proposed at Badgerys Creek Option A, only Operations 1 and 2 were considered for that option.

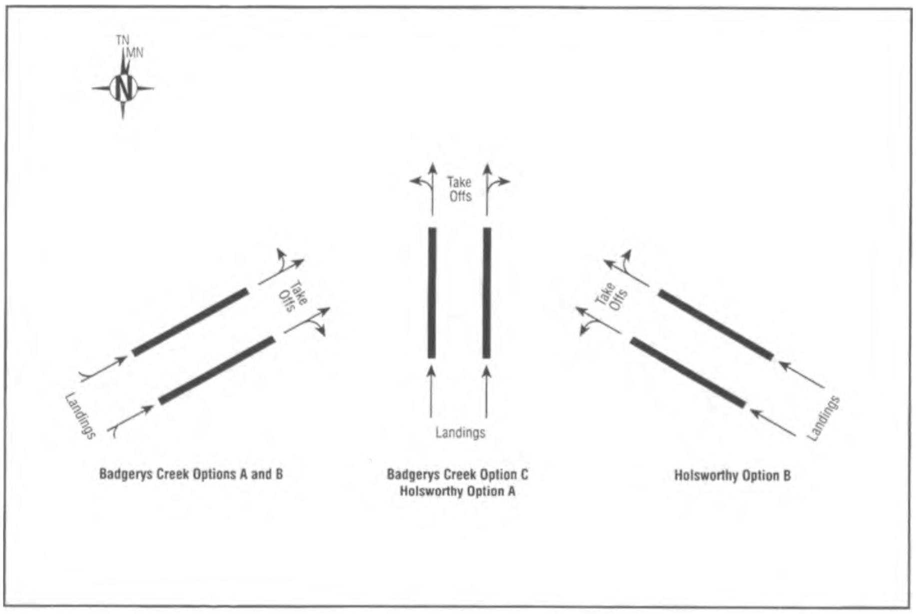


Figure 1.3

Predominant Directions of Movement of Aircraft for Airport Operation 1

Note: Cross wind runway used only when required because of meteorological conditions

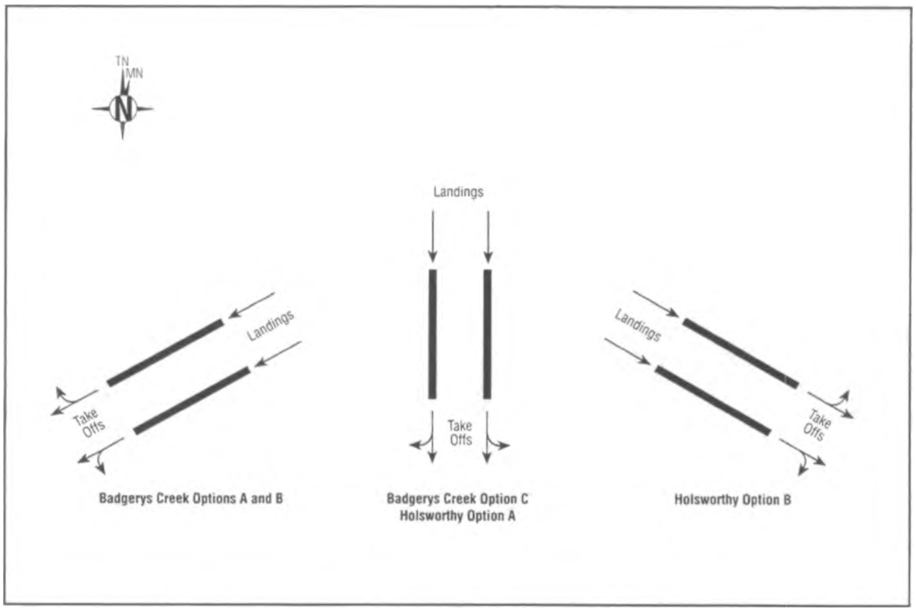


Figure 1.4

Predominant Directions of Movement of Aircraft for Airport Operation 2

Note: Cross wind runway used only when required because of meteorological conditions

CHAPTER 2 CONSULTATIONS

2.1 CONSULTATION

Preparation of this Draft EIS involved consultation with the community, other stakeholders, Commonwealth, State and local Governments and Government agencies.

2.2 COMMUNITY CONSULTATION

The primary role of the consultation process during the preparation of the Draft EIS was to provide accurate, up to date information on the proposals being considered and the assessment process being undertaken. From October 1996 to May 1997, ten separate information documents were released and over 400,000 copies distributed to the community. Four types of display posters were produced and 700 copies distributed. Over 140 advertisements were placed in metropolitan and local newspapers. Non English language documents were produced in 14 languages and over 20,000 copies distributed. Advertisements in seven languages were placed on ethnic radio.

Opportunities for direct contact and two way exchange of information with the community occurred through meetings, information days, displays at shopping centres, telephone conversations and by responding to written submissions. Through these activities over 20,000 members of the community directly participated in the consultation activities.

Written and telephone submissions received were incorporated into a database which grouped the issues in the same way as the chapters of the Draft EIS. The issues raised were progressively provided to the EIS study team to ensure that community input was an integral part of the assessment process.

Further details of consultation with the community and other stakeholders and its outcomes are contained in *Technical Paper No. 1 Consultation.*

2.3 OTHER CONSULTATION

Various Government departments and agencies were consulted during the preparation of the Draft EIS. These include the following:

Bureau of Meteorology

- measurements of wind and other meteorological parameters from the following sites;
  - Sydney Airport;
  - Bankstown Airport; and
  - Richmond Airport.

New South Wales Environment Protection Authority

- measurements of air quality parameters and meteorology from monitoring stations in Sydney;

- results from the Metropolitan Air Quality Study; and

- wind and temperature profiles from the Environment Protection Authority's summer campaign of measurements in western Sydney.

Australian Nuclear Scientific and Technical Organisation

- measurements of winds and other meteorological parameters measured at Lucas Heights.

Australian Water Technologies

- wind speed and direction data from sewage treatment works in the Sydney region and rainfall data from stations in the vicinity of Badgerys Creek.

Federal Airports Corporation

- air quality and meteorological data from monitoring stations at Sydney Airport and Botany.

CHAPTER 3 METHODOLOGY

This chapter briefly reviews the methodologies employed and the data sets used in the respective meteorological studies.

3.1 AIM AND SCOPE OF WORK

The scope of work comprised:

- collection of background information relating to regional and local meteorology of the Sydney region;
- identification of appropriate sources of meterological data and assessment of the suitability and limitations of data for use in noise impact and air quality modelling;
- review of meteorology and its influence on air quality in the vicinity of the airport options;
- provision of meterological information for noise impact studies;
- review of the prevalence of adverse meterological conditions in the vicinity of Badgerys Creek and Holsworthy; and
- assessment of likely useability of the airport options due to wind and adverse meterological conditions.

Assessment of runway useability due to wind was assessed by the Second Sydney Airport Planners (1997a), while the prevalence of adverse meterological conditions and useability due to factors other than wind was based on work undertaken by the Bureau of Meteorology(1997). Data on rainfall, wind speeds and directions and the frequency of temperature inversions was analysed for suitability and provided to the noise consultants for use in noise impact modelling. Details of the use of this data are contained in *Technical Paper* No.3.

3.2 INFORMATION SOURCES

Information sources for investigation of meterological influences on air quality and noise included:

- Bureau of Meteorology records from Sydney, Bankstown and Richmond Airports and other monitoring sites;
- the *Metropolitan Air Quality Study Final Report on Meteorology - Air Movements* (Hyde et al 1997) and NSW Environment Protection Authority measurements from the Summer Campaign of February, 1995;
- measurements of wind and other meterological parameters from Australian Nuclear Science and Technology Organisation at Lucas Heights and monthly average fine particle and lead levels measured in Sydney as part of the Aerosol Sampling Project;
- Australian Water Technology wind speed and rainfall data from selected sewage treatment plants and rainfall data from stations in the vicinity of Badgerys Creek;
- Federal Airports Corporation air quality and meterological data from Sydney Airport and Botany;
- Macquarie University measurements of surface winds from different sites in Sydney, including Badgerys Creek and lower atmospheric wind and temperature profiles measured during previous air quality investigations in Sydney; and
- previous investigations by Macquarie University and others of air quality and meteorology in Sydney.

Air quality and meterological data from the period July 1994 to June 1995 was purchased from NSW Environment Protection Authority, however discrepancies in the wind directions recorded at some stations were not able to be resolved in time for the use of this data in the Draft EIS. Therefore none of this data set was contained in the analysis of meterological conditions and data from a wide range of other sources had to be used instead.

The Technical Paper has been compiled on the basis of the available data outlined above. This data is not sufficient to fully define climatology for the study area however, , this data set is considered adequate to provide indicative information on the existing meteorological environment. Site specific surface and boundary layer meteorological observations would be needed at both Badgerys Creek and Holsworthy to provide a greater level of confidence.

3.3 METHODOLOGY

3.3.1 RUNWAY USEABILITY DUE TO WIND SPEED AND DIRECTION

Some aircraft have limitations on their ability to land in a cross wind. The civil Aviation Safety Authority (CASA) defines runway usability as "the proportion of time (expressed as a percentage) the winds at an aerodrome allow it to be used by aeroplanes with specified limiting cross-wind landing capability".

The cross wind and downwind components of the wind speed during aircraft landing is one of the limiting factors in safe airport operations. This component can be minimised by aligning the runways according to the preferred meteorological orientations as defined by the wind climatology at site.

International standards and recommended practices state that "the number of runways at an aerodrome should be such that the usability factor at the aerodrome is not less than 95 percent for the aeroplanes that the aerodrome is intended to service". Australia has adopted a planning goal for usability of 99.8 percent for capital city airports and 99.5 percent for other aerodromes (Second Sydney Airport Planners, 1997a).

Because it is not known exactly what the cross wind capabilities will be for aircraft using Second Sydney Airport, the master plan is based on cross wind component values grouped by reference field lengths as follows:

- 20 knots for aeroplanes with reference field length 1,500 metres or more;
- 13 knots for aeroplanes with reference field length of 1,200 metres or greater but less than 1,500 metres; and
- 10 knots in the case of aeroplanes whole reference field length is less than 1,200 metres.

The Bureau of Meteorology was commissioned by the Department of Transport and Regional Development to review existing long term wind data from Bankstown and correlate this data with data from Badgerys Creek and Lucas Heights. Bankstown's records were then used to analyse runway useability for both meteorologically preferred orientations and orientations supplied by the Second Sydney Airport Planners (Bureau of Meteorology, 1996).

The report produced by Bureau of Meteorology (1996) was used by Second Sydney Airport Planners (1997) to assist in runway useability analysis.

According to Second Sydney Airport Planners (1997), available wind data sources were analysed to determine the relative viability of proposed runway orientations for several sites proposed for the Second Sydney Airport. None of the datasets had both a long period of record and observation at all hours of the day. Similarities were found between short period datasets with observations at all hours and long period datasets for certain times of the day. On this basis, representative datasets were chosen for the sites under consideration and optimum crosswind runway orientations determined for designated main runway orientations.

3.3.2 OTHER INFLUENCES ON AIRPORT PLANNING AND OPERATIONS

The Bureau of Meteorology was commissioned by the Department of Transport and Regional Development to review existing meteorological data and to assess the likelihood of windshear and mechanical turbulence, rainfall, thunderstorms, low cloud and fog at the sites of the Badgerys Creek and Holsworthy airport options (Bureau of Meteorology, 1997).

3.3.3 INFLUENCES OF METEOROLOGY ON AIR QUALITY

Macquarie Research Limited collected meteorological data from a wide variety of sources and reviewed previous studies to determine the likely influences of meteorology on ambient air quality in the Sydney Basin, and in the vicinity of the sites of the Badgerys Creek and Holsworthy airport options. The report produced by Macquarie Research is contained in *Appendix A* for reference.

The vertical structure of wind and temperature at a location is determined by the prevailing meteorological conditions, such as:

- frequency of inversions and stable layers;
- synoptic winds;
- local and regional flows such as sea breezes and cold air drainage winds; and
- development of the mixing layer during the morning and the presence of elevated inversions.

These meteorological conditions vary from day to day throughout the year as a result of changes in the general circulation of the atmosphere. On a particular day, regions in Sydney can be affected by several different types of winds such as the synoptic wind, south-west drainage flow and spillover of air out of the Hawkesbury Basin. Each of these flows may have a distinct wind and temperature structure associated with it, which could have quite different implications for the dispersion of ground based and elevated emissions from a particular source.

The main issues that need to be considered in determining the influence meteorology on air quality are as follows:

- trapping of ground-based and near surface aircraft emissions under stable conditions;
- horizontal movement of emissions trapped within these stable layers;
- influence of the surface mixing layer and elevated inversions on the dispersion of airport and aircraft emissions;
- interaction between regional pollutants and near surface emissions from the airport sites at Badgerys Creek and Holsworthy; and
- associations between meteorology and photochemical smog in the vicinity of each airport site.

Near surface emissions include gaseous pollutants, fine particles and odours emitted from ground based airport and aircraft related activities, as well as emissions from aircraft in the lowest tens of metres above the ground. Elevated emissions refer to emissions from aircraft in the lowest 1,000 metres of the atmosphere.

3.3.4 INFLUENCES OF METEOROLOGY ON NOISE TRANSMISSION

Meteorological factors such as wind and thermal inversions can affect the propagation of sound. Changes in wind speed and direction and the presence or absence of thermal inversions could either reduce or increase the amount of noise transmitted from overflying aircraft and activities associated with construction and operation of the various airport options.

Macquarie Research analysed meteorological data which was available from various sources, and provided this data to the noise consultants, Wilkinson Murray. This data included wind speed and directions for monitoring stations as close as possible to the sites of the airport options, rainfall data, and information on the likely presence of thermal inversions.

Part B

Existing Environment

CHAPTER 4 EXISTING ENVIRONMENT

4.1 REVIEW OF DATA

Principal meteorological conditions that affect airport planning and operation and the dispersion of air pollutants include:

- wind speed and direction;
- inversions and mixing heights;
- rainfall and rainfall intensity;
- temperature;
- low cloud; and,
- fog.

This section of the technical paper summarises the existing meteorological conditions within the Sydney Basin and in the vicinity of the respective sites for each of the above parameters where sufficient information is available.

4.2 METEOROLOGY OF THE SYDNEY BASIN

4.2.1 WIND SPEED AND DIRECTION

A number of studies have been done on the influence of synoptic, regional and local meteorology on air quality in Sydney. While these investigations have focussed on air quality issues, many of the main factors identified as important for limiting dispersion of air pollutants, such as ground based inversions and local and regional wind flows at night can also affect transmission of noise. The amount of information about meteorology contained in the *Second Sydney Airport Site Selection Programme Draft Environmental Impact Statement* (Kinhill Stearns, 1985) was extremely limited for both Badgerys Creek and Holsworthy.

Wind direction in Sydney is generally governed by a large scale pattern of atmospheric circulation, but it is also influenced by regional and local wind flows, and topography of the Sydney basin. The Sydney basin is generally defined as the region bounded by high ground in the vicinity of Mittagong in the south, the Illawarra Escarpment to the east, the Blue Mountains to the west and high ground north of Richmond.

Within the Sydney basin there are several regional scale topographic features that are important for air quality. These include the Hawkesbury and Liverpool basins, the Parramatta River Valley and the Blacktown ridge. Within the Hawkesbury basin, there are several smaller scale topographic features such as the South Creek Valley, which control the direction of near-surface winds under stable atmospheric conditions at night.

Synoptic winds are winds which arise from differences in barometric pressure. In the southern hemisphere, winds blow anti-clockwise around regions of high pressure, and clockwise around low pressure systems. Regions of high pressure continually move from west to east across the continent, with an average frequency of five to six days (Gentilli, 1972). In summer, the mean path of these regions of high pressure is through Bass Strait, and the prevailing synoptic wind directions in Sydney are onshore. In winter, the mean path is north of Sydney, and the predominant synoptic wind directions in Sydney are west to south west.

While it is the prevailing synoptic weather pattern which produces day to day and seasonal changes in surface winds, temperatures, cloud and rainfall, the proximity of Sydney to the coast and the topography of the Sydney basin combine to create regional and local wind systems such as sea breezes and cold air drainage flows. These act to moderate or change the direction of synoptically driven winds (Bureau of Meteorology, 1990).

Sea breezes are primarily caused by daytime temperature differences between land and sea surface temperatures (the breeze heads towards the warmer of the two). Cold air drainage flows occur when air in contact with the earth's surface cools more rapidly than air at the same height (above sea level) but a greater distance from the surface. In this situation, the cooler, more dense air at the surface begins to flow downhill where it gradually merges and combines with other air flowing downhill, forming local and regional drainage flows.

4.2.2 INVERSIONS AND MIXING HEIGHTS

Important meterological conditions or features which influence the dispersion of air pollutants include or temperature inversions, synoptic winds, mixing layers, stable layers, regional wind flows, sea breezes and cold air drainage flows. A temperature inversion occurs when the temperature of the air in the atmosphere increases with height, rather than decreasing as is normally the case. A stable layer of cold air near the earth's surface can prevent air pollutants from rising into the atmosphere and being carried away by air currents (Wark et al, 1985). If inversions are relatively stable, pollutant levels can build up in the atmosphere over a number of days. Deeper inversions usually occur in the colder months.

In a well mixed atmosphere, temperature decreases with height at a rate of approximately 10 degrees Celsius per kilometre. The depth of the mixing layer below this can vary between tens of metres to several kilometres. In a stable layer, temperature decreases with height at a rate of less than 10 degrees Celsius per kilometre, and with increasing stability this temperature gradient can eventually become positive, leading to formulation of a temperature inversion close to the ground.

The time taken for a ground based temperature inversion to break down depends on its depth at sunrise and the amount of rate of heating of the lower atmosphere after sunrise. During summer, shallow ground based inversions will break down quickly after sunrise, however in the cooler months, decreased solar radiation means that it can take several hours for deeper ground based inversions to erode away.

4.2.3 RAINFALL

Rainfall over the Sydney Basin and on the higher ground to the north, south and west of the basin is extremely variable. The sites of the Holsworthy options lie in an area that receives substantially more rain than the sites of the Badgerys Creek options (Bureau of Meteorology, 1997).

Intense rainfall events in the Sydney Basin are typically associated with thunderstorms or east coast low pressure systems, which direct large amounts of moisture to shore. Seasonal variability of intense rainfall events in the Sydney Basin is therefore as much a function of wind direction as it is of the season. The proximity of the relatively warm Tasman Sea provides a moisture source when winds are onshore. This warmer air is capable of holding larger quantities of moisture than cool air thus more moisture is available for intense rainfall events in the warmer months.

Atmospheric stability also influences the occurrence of intense rainfall events. High surface temperatures lead to an unstable atmosphere which can produce thunderstorms if there is sufficient moisture available. Sea breezes supply the moisture to the near coastal inland zone where temperatures may be high enough to trigger thunderstorms. Thunderstorms occur most frequently in summer and early autumn.

Unstable atmospheric conditions also occur when mild ground temperatures are accompanied by extremely cold temperatures at higher altitudes. This situation, which typically occurs in spring may give rise to severe hail storms.

4.2.4 LOW CLOUD

Formation of low cloud in the Sydney Basin is a function of factors such as wind direction in the lower layers of the atmosphere, atmosphere stability and moisture availability and elevation of terrain above sea level. A low cloud event is essentially an event when a cloud base, which covers more than four octas (50 percent of the sky) occurs at a defined height.

Site specific data is relatively sparse - cloud observations are available for Bankstown and Sydney Airport only (Bureau of Meteorology, 1997).

4.2.5 AMBIENT AIR QUALITY

Ambient air quality is influenced by a number of meteorological parameters, principally:

- the synoptic weather situation;
- the thermal structure and winds in the lowest one to two kilometres of the atmosphere;
- trapping, transport and re-circulation of pollutants within sea breezes and cold air draining flows both inland and on the coast;
- trapping of pollutants within ground based inversions during the evening and overnight; and
- the trapping of pollutants within a shallow mixing depth below an elevated inversion during the morning.

Influences of these parameters on photochemical oxidants and other priority pollutants such as particulates and nitrogen oxides are discussed briefly below.

Photochemical Oxidants

The influence of meteorological parameters on photochemical smog production and transportation is distinct from that on other priority pollutants. As a result of the dependence of photochemical oxidants on warm air and solar radiation, the production of photochemical smog in Sydney is principally a summer phenomenon. Ozone concentrations typically peak during the summer months.

The specific conditions which interact to produce elevated ozone concentrations in Sydney have yet to be definitively characterised. However, the general mechanisms are relatively well understood. They include:

- a region of high pressure in the Tasman Sea with a ridge extending back into north-east NSW;
- warm air temperatures aloft at 0600 hours and continued warming of the boundary layer;
- overnight radiation inversions at the surface and deep warm air advection inversions above which together combine to produce a deep inversion at sunrise;
- light to moderate strength north-west to north-easterly synoptic winds; and
- afternoon sea breezes.

It should be recognised however, that despite the presence of these critical conditions, elevated ozone concentrations have been recorded simultaneously in different parts of the Sydney Basin under different meteorological conditions.

Other Priority Pollutants

In contrast to photochemical smog, elevated concentrations of the other priority pollutants such as particulates, carbon monoxide, and oxides of nitrogen, are commonly associated with cooler winter months. Elevated levels of these pollutants occur most frequently between late afternoon and early the following morning.

The increased levels recorded during winter occur as a result of the higher frequency of ground based inversions and cold air drainage flows during these months, which trap low level emissions and inhibit dispersion.

4.3 BADGERYS CREEK

4.3.1 WIND SPEED AND DIRECTION

Analysis of wind speed and direction at Badgerys Creek is based upon two years of wind data recorded by Macquarie University between 1990 and 1992.

The seasonal distribution of winds at Badgerys Creek is characterised by dominant south westerly winds in autumn and spring; in winter there is an increase in the frequency of winds from the west-north-west and north-west directions. The seasonal and monthly average frequency distributions in summer are less well defined.

Substantial diurnal variability in wind directions are observed in Sydney throughout the year.

Diurnal variations are evident throughout the year but are more marked in spring and summer. During this part of the year, the predominant winds have a predominant west to south-westerly direction in the morning, which is associated frequently with cold air drainage flows within the Hawkesbury Basin. They shift to a predominant east to south-east wind direction in the afternoon. This is commonly associated with the establishment of onshore synoptic winds and sea breezes. By late evening the influence of the sea breeze has largely decreased and there is a corresponding shift to lighter winds from the south to south-west.

4.3.2 INVERSIONS AND MIXING HEIGHTS

In the absence of measurements of the vertical structure of temperature above Badgerys Creek, it is not possible to provide firm estimates about the frequency of inversions at this location, their time of onset, increase in frequency with time during the night, and the height of these inversions at different times of the year.

However, there are a number of sources of information available that allow some estimates to be made. These include:

- data provided for noise impact assessment, based on the frequency time that wind speeds at Badgerys Creek were similar to those observed in drainage flow and when an inversion would be expected at the surface;
- the frequency of calms during the night at Richmond;
- statistics of cold air drainage flows at Fleurs and Badgerys Creek;
- Loewe's (1945) analysis of inversions measured by morning aircraft ascents above Richmond between 1937 and 1943; and
- the frequency of inversions measured at Lucas Heights in each month.

Measurements from these different sources have been combined to provide some estimates of the range of inversion frequency in each season. From these values, estimates were was made of the percentage frequency of time in each session, that an inversion might be observed at some time during the night. These are listed below:

- summer - 60 percent to 75 percent;
- autumn - 60 percent to 80 percent;
- winter - 60 percent to 95 percent; and
- spring - 60 percent to 85 percent.

Hence ground-based inversions could be expected to be present at Badgerys Creek on a high percentage of nights throughout the year.

Deep ground based inversions would be expected to be observed occasionally at Badgerys Creek during the summer, but could occur often in winter. Inversions are expected to form more quickly at night at Badgerys Creek than they would in more exposed locations such as Lucas Heights. In summer, these inversions would expected to be eroded away quickly after sunrise, however in winter this could take several hours.

4.3.3 RAINFALL

The Bureau of Meteorology (1997) estimated that Badgerys Creek experiences a median rainfall of between 700 and 800 millimetres per annum.

Monthly and Annual Rainfall data collected at Badgerys Creek between 1936 and 1986 are presented in *Table 4.1*.

TABLE 4.1 MONTHLY AND ANNUAL RAINFALL - PERCENTILES, EXTREMES AND MEANS (MILLIMETRES) FOR BADGERYS CREEK

Station	n	Percentile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Badgerys Creek 1936-1986	47	lowest	4	0	2	3	0	0	0	0	0	1	0	0	330
		10	13	18	18	13	5	5	1	3	1	5	8	4	420
		50	69	65	71	38	26	44	17	25	34	47	61	48	723
		90	231	224	201	137	160	187	71	115	84	140	152	195	1,205
		highest	311	436	329	202	238	417	191	188	130	196	355	277	1,695
		mean	92	91	93	59	59	69	31	40	37	60	73	73	777

Source: Bureau of Meteorology, 1997.
Note: n = Number of years of record.

4.3.4 LOW CLOUD

Cloud observations are available for Kingsford Smith Airport and Bankstown airports only. Extrapolation of cloud base heights from one location to another over different elevations and distances from the coast is tenuous, however in the absence of site specific data, cloud events recorded at Sydney and Bankstown Airport have been used to approximate the likely incidence of low cloud events at Badgerys Creek (Bureau of Meteorology, 1997).

A low cloud event occurs when more than four octas of cloud (50 percent of the sky) is covered with a cloud base at a defined height. In this case, a height of less than 220 metres above ground level was used to specify low cloud events. For Badgerys Creek, the average number of low cloud events measured over a 57 year period did not exceed eight per month except in March, and was less than four per month for most other months. (Bureau of Meteorology, 1997).

4.3.5 FOG

The only records found to contain visual observations of fog occurrence at Badgerys Creek are those taken at the McMaster Experimental Research Farm. Observations taken at this site cover a 17 year period, but only relate to the period 9.00 am to 3.00 pm. Therefore the figures may provide an underestimate, since fog typically occurs most frequently around sunrise (Bureau of Meteorology, 1997).

The number of days where fog causes surface visibility to be reduced to less than 1,000 metres peaks during the winter months. On average, fog which reduced visibility to below 1,000 metres is recorded approximately 10 days per year, however the highest number of days where a fog day has been recorded is 22 days.

4.4 HOLSWORTHY

4.4.1 WIND SPEED AND DIRECTION

The closest meteorological data for the Holsworthy sites is the measurements made at the Australian Nuclear Science and Technology Facility at Lucas Heights, where comprehensive records have been kept for many years.

In summer, north-east to southerly winds predominate as a result of the presence of onshore synoptic winds and sea breezes and southerly changes or "souther busters". The frequency of sea breezes in summer is approximately 27 percent and the onset of sea breezes at Lucas Heights in summer typically occurs three hours after the onset in Sydney.

In winter, the northward shift in general circulation results in the seasonal shift towards westerly synoptic winds. During winter there is a marked shift towards offshore synoptic winds dominated by south to north-west components. The frequency of sea breezes in winter drops to 12 percent, and the difference in onset times is reduced to one to one and a half hours.

4.4.2 INVERSIONS AND MIXING HEIGHTS

The average number of inversions in each month at Lucas Heights and their total duration are shown in *Table 4.2*.

The average number of nights with inversions in each month range from between 20 to 21 in the summer months and 27 to 29 in the winter months. The average duration of inversions was 6.4 to 7.3 hours in summer and 12.1 to 14 hours in winter. In summer, the low frequency of inversions occurs as a result of the relatively high frequency of north-east to southerly winds at night. These winds are generally neutral (refer *Appendix A*).

TABLE 4.2 AVERAGED NUMBER OF INVERSIONS AT LUCAS HEIGHTS

	Number of Nights with Inversions	Duration of Inversions (Hours)
January	21	6.4
February	20	7.3
March	24	9.2
April	24	10.7
May	27	13.4
June	27	14.0
July	27	12.3
August	29	12.1
September	26	10.3
October	24	9.7
November	21	7.5
December	21	7.0
Mean	**24.25**	**10.0**

Source: Charash and Bendum, 1968.

4.4.3 RAINFALL

The Bureau of Meteorology estimated that the Holsworthy sites would receive a median rainfall of approximately 1,100 millimetres per annum (Bureau of Meteorology, 1997).

Rainfall data has been collected from several stations within the Sydney basin. The closest site to Holsworthy Option A is Bankstown, while the closest site to Holsworthy Option B is Appin (elevation 160 metres). Rainfall records at Appin are likely to be indicative of conditions which would be experienced at Holsworthy Option B even though the elevation of the Appin site is lower than Holsworthy Option B. Monthly and Annual rainfall data recorded at Bankstown and Appin is presented in *Table 4.3* for reference.

TABLE 4.3 MONTHLY AND ANNUAL RAINFALL - PERCENTILES, EXTREMES AND MEANS (MILLIMETRES) FOR BANKSTOWN AND APPIN

Station	n	Percentile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Bankstown 1906-1979	56	lowest	2	0	4	2	2	0	0	0	1	3	0	0	445
		10	22	16	19	17	12	5	6	7	14	10	7	13	560
		50	75	75	85	52	43	57	41	39	42	47	54	49	935
		90	209	213	274	166	214	267	192	172	94	152	147	206	1,317
		highest	390	570	346	281	395	529	275	206	182	286	442	348	1,963
		mean	94	96	112	76	79	975	69	60	49	65	71	75	944
Appin 1907-1970	64	lowest	3	1	2	6	3	0	0	0	0	2	1	3	376
		10	16	9	14	15	9	7	12	7	11	15	14	12	540
		50	79	64	67	65	33	57	53	42	42	45	51	61	949
		90	183	224	240	175	202	275	189	161	104	138	139	176	1,358
		highest	432	560	325	444	551	511	344	326	168	412	436	322	1,968
		mean	90	97	89	86	84	105	79	60	51	64	70	80	955

Source: Bureau of Meteorology, 1997.
Note: n = Number of years of record.

4.4.4 LOW CLOUD

Data relating to low cloud observations are limited to data obtained Bankstown and Sydney Airports. Extrapolation of cloud base heights from one location to another over different elevations and distances from the coast is tenuous (Bureau of Meteorology, 1997).

The potential for low cloud at Holsworthy Options A and B has been estimated by assuming that low cloud base observed at Sydney Airport persists inland at a constant height above mean sea level. Over a 57 year period the number of events with more than four octas of cloud (50 percent of the sky) at or below 220 metres for Holsworthy Option A was estimated not to exceed 10 per month. Less than five events occurred for most months (Bureau of Meteorology, 1997). For Holsworthy Option B, the number of low cloud events did not exceed 14 per month (maximum), but for most months fewer than six low cloud events were measured.

4.4.5 FOG

No data on the incidence of fog at the Holsworthy sites is available. However, indicative information has been collected from the Roads and Traffic Authority's visibility monitoring station located on the F6 tollway between Sydney and Wollongong (Bureau of Meteorology, 1997). This station is at an elevation of approximately 400 metres, compared to approximately 174 metres at Holsworthy Option A and 260 metres at Holsworthy Option B.

The nature of the equipment is such that it cannot differentiate between cloud on the ground and fog. The relationship between the Roads and Traffic Authority data and actual conditions at Holsworthy is tenuous. Nevertheless, anecdotal evidence supports the view that low cloud and fog may be a persistent feature which would affect the eastern approaches to any airport at the site of Holsworthy Option B (Bureau of Meteorology, 1997).

Part C

Assessment of Impacts

CHAPTER 5 BADGERYS CREEK IMPACTS

5.1 INFLUENCES OF METEOROLOGY ON AIRPORT PLANNING AND OPERATION

The influence of meteorological conditions upon the planning and operation of the airport are discussed briefly below. A detailed analysis of the influence of wind and other respective parameters is provided by Bureau of Meteorology (1996 and 1997), and by Second Sydney Airport Planners (1997a).

5.1.1 RUNWAY USEABILITY DUE TO WIND

Available wind data sources were analysed to determine the relative viability of proposed runway orientations for several sites proposed for the Second Sydney Airport Second Sydney Airport Planners (1997a). None of the datasets had both a long period of record and observation at all hours of the day. Similarities were found between short period datasets with observations at all hours and long period datasets for certain times of the day. On this basis, representative datasets were chosen for the sites under consideration and optimum crosswind runway orientations determined for designated main runway orientations.

Runway usabilities for the master plan runway orientations at Badgerys Creek are as shown in *Table 5.1*. Australia has adopted a planning goal for runway useability of 99.8 percent at capital city airports and 99.5 percent for other aerodromes (Second Sydney Airport Planners, 1997a).

TABLE 5.1 RUNWAY WIND USABILITIES FOR BADGERYS CREEK OPTIONS

Option	Overall Wind Usability (Percent)		
	10 Knot Crosswind	**13 Knot Crosswind**	**20 Knot Crosswind**
Badgerys Creek Option A	94.15	97.25	99.84
Badgerys Creek Option B	97.75	99.30	99.96
Badgerys Creek Option C	99.23	99.91	99.99

Source: Second Sydney Airport Planners, 1997a.

Aircraft are grouped according to their reference field lengths, with larger aircraft able to cope with higher cross wind components (20 knots) than small aircraft (10 knots). While none of the Badgerys Creek airport options meet the useability criteria (Australian adopted planning goal) for all cross-wind component values for all aircraft types, operations by larger aircraft would be able to achieve the required usability level. Operations by aircraft with lower cross wind capability would be restricted for some of the time.

Wind monitoring has only been in place at Badgerys Creek since February, 1996 (Bureau of Meteorology, 1996). Additional data for Badgerys Creek, for the period 1990 to 1991 inclusive, was obtained from Macquarie University. Even together, these data represent a very short period of time in meteorological terms.

The term vertical wind shear describes a difference in wind speed, wind direction or both, over a short vertical distance and is often associated with increases in air temperature with height or with strong winds just above the surface.

The Great Dividing Range west of Badgerys Creek can generate significant turbulence depending on the low level wind speeds and atmospheric stability and in certain instances mountain waves or rotors may develop in the lee of the range. Such events constitute a recognised hazard to aircraft.

Vertical wind shear and mechanical turbulence is likely to be significant for aircraft operations at Badgerys Creek when there is strong westerly flow over the Dividing Range and when surface winds are strong (Bureau of Meteorology, 1996).

A quantitative assessment of the extent to which such events will affect usability at each site has not been undertaken due to the lack of verifiable site specific data. Additional instrumentation and specialist studies are needed to adequately investigate their effect and frequency.

5.1.2 RUNWAY USEABILITY DUE TO FACTORS OTHER THAN WIND

Aerodrome usability, can be adversely affected by heavy precipitation due to reduction in friction between the tarmac and aircraft tyres, particularly in strong cross-wind situations, and by reduction in visibility.

Badgerys Creek is likely to experience substantially less rainfall (700 to 800 millimetres per annum) than either Holsworthy Option A or Option B and is less prone to high intensity precipitation events. Airport usability at Badgerys Creek therefore may be marginally higher than at either Holsworthy Option A or Option B based on less frequent visibility reduction due to precipitation (Bureau of Meteorology, 1997).

Thunderstorms

The Bureau of Meteorology (1997) analysed two separate sources of information relating to thunderstorm occurrence in the Sydney Basin. The analysis suggests that there is no significant difference between the occurrence of lightning strikes and thunderstorms at Badgerys Creek and the Holsworthy sites.

Higher thunderstorm probability areas are marginally closer to Badgerys Creek than Holsworthy site and the proximity of Badgerys Creek to the Great Dividing Range is likely to reduce the lead time for thunderstorm warnings associated with cells generated over the range. The impact on aircraft operations would depend upon takeoff and landing flight paths used.

Low Cloud

Based upon the available data Badgerys Creek may experience fewer low cloud events than the Holsworthy sites (Bureau of Meteorology, 1997). The conclusions that have been drawn are necessarily tenuous due to the lack of verifiable site specific data.

Fog

Available radiation data suggests that the number of days where fog causes surface visibility to be reduced to less than 1,000 metres would peak during the winter months. On average, fog which reduces visibility to below 1,000 metres has been recorded approximately 10 days per year, however the highest number of days where a fog day has been recorded is 22 days. As fog data is only available for 9.00 am the above figures are likely to underestimate the true frequency (Bureau of Meteorology, 1997).

Modern navigation aids may enable adverse meterological conditions such as high intensity rainfall, thunderstorms, low cloud and fog to be overcome by large commercial aircraft. The impacts of such phenomena on some types of aircraft may be significant. Wind shear and mechanical turbulence affects aircraft of all sizes and is not able to be measured or predicted as readily as other phenomena without additional observational data and study.

Weather conditions other than wind can affect the useability of an airport. Air traffic procedures for dealing with poor visibility at an airport, such as in fog or heavy rain, are developed by Airservices Australia in conjunction with the Civil Aviation Safety Authority. The procedures are specified in Aeronautical Information Publication documents and are based on prescribed visibility minima for landings or takeoffs.

The decision to proceed with a landing or a takeoff in conditions of poor visibility rests with the individual pilot concerned and is usually based on the pilots training, experience, aircraft type, standard of electronic navigation equipment aboard the aircraft, and the requirements specified in the company operations manual. It is therefore not possible to estimate the proportion of time than an airport would not be useable due to weather conditions other than wind.

5.2 INFLUENCES OF METEOROLOGY ON AIR QUALITY

The vertical dispersion of near surface air pollution emissions is likely to be inhibited at Badgerys Creek on many nights of the year, due to the high frequency of ground based inversions. These trapped emissions could be carried towards the Camden Basin, when winds are blowing from a north easterly direction but it is likely that steep ground-based inversions would decouple air within the Basin, from emissions carried towards it from Badgerys Creek.

Alternatively, emissions could travel towards the Nepean River Valley and could become entrained in local and regional drainage flows and be carried northwards along the axis of the Hawkesbury Basin. This would occur at night. When local drainage flow along South Creek Valley is absent, near surface emissions could be carried east towards the Blacktown ridge and into the Liverpool Basin. This would occur when westerly cold air drainage flows or stable synoptic winds are present at Badgerys Creek.

On the basis of currently available air quality measurements, it appears that near surface air quality at Badgerys Creek would not be influenced by urban pollution from eastern Sydney, in particular the Liverpool Basin.

During winter, temperature inversions as deep as 600 metres are often present at sunrise, and it can take several hours for these inversions to be eroded away after sunrise. During the period that the inversions are being eroded away, near surface and elevated emissions will be carried towards the north until the drainage flow has gone, and then will be carried downwind away from the airport by the direction of the wind above.

In summer, if an elevated inversion was present above the Hawkesbury Basin, northerly winds would carry near surface and elevated emissions towards Camden and Campbelltown and could contribute to photo-chemical smog in the region. Alternatively, near surface and elevated emissions could contribute to photochemical smog levels in air carried across Badgerys Creek within the sea breeze and contribute to ozone levels as the air moves inland into the lower Blue Mountains.

Elevated emissions during the day from aircraft in the vicinity of Lake Burragorang will be dispersed rapidly by vertical mixing due to winds and convection. At night, it is unlikely that these elevated emissions will reach the surface, because of the formation of a layer of stable air above the lake. Potential impacts of air pollutants on drinking water supplies are discussed in *Technical Paper No. 7 - Geology, Soils and Water.*

CHAPTER 6 HOLSWORTHY IMPACTS

6.1 INFLUENCES OF METEOROLOGY ON AIRPORT PLANNING AND OPERATION

6.1.1 RUNWAY USEABILITY DUE TO WIND

At Holsworthy, local wind measurement records are not available. The Holsworthy Military Area is very large with extremely variable topography. Meteorological data from Lucas Heights has been extrapolated to the sites of Holsworthy Option A and B sites and runway orientation and usability estimated accordingly (Second Sydney Airport Planners, 1997a).

Data was available from Lucas Heights for two heights, 10 metres and 49 metres. The 10 metre data was deemed appropriate for determining optimum runway locations at the Holsworthy sites, after stability analysis had been undertaken by Macquarie Research to check for consistency between the two sets of data. Details of this stability analysis are contained in *Appendix A*.

Table 6.1 illustrates runway wind usabilities for the Holsworthy options. Australia has adopted a planning goal for runway useability of 99.8 percent at capital city airports and 99.5 percent for other aerodromes.

TABLE 6.1 RUNWAY WIND USABILITIES FOR HOLSWORTHY OPTIONS

Option	Overall Wind Usability (Percent)		
	10 Knot Crosswind	13 Knot Crosswind	20 Knot Crosswind
Holsworthy Option A	99.57	99.96	99.99
Holsworthy Option B	99.07	99.87	99.99

Source: Second Sydney Airport Planners, 1997a.

Aircraft are grouped according to their reference field lengths, with larger aircraft able to cope with higher cross wind components (20 knots) than small aircraft (10 knots). Options A and B do not meet the criteria (Australian adopted planning goal) for cross wind component values, however operations by larger aircraft would still be able to achieve the required useability level. Operations by aircraft with lower cross wind capability would be restricted some of the time.

The term vertical wind shear describes a difference in wind speed, wind direction or both, over a short vertical distance and is often associated with increases in air temperature with height or with strong winds just above the surface.

The Great Dividing Range can generate significant turbulence depending on the low level wind speeds and atmospheric stability and in certain instances mountain waves or rotors may develop in the lee of the range. Such events constitute a recognised hazard to aircraft.

Vertical wind shear and mechanical turbulence is likely to be significant for aircraft operations at Holsworthy when there is strong westerly flow over the Great Dividing Range and when surface winds are strong, due to the rugged local terrain at Holsworthy (Bureau of Meteorology, 1996).

A quantitative assessment of the extent to which such events will affect usability at each site has not been undertaken due to the lack of verifiable site specific data. Additional instrumentation and specialist studies are needed to adequately investigate their effect and frequency.

6.1.2 RUNWAY USABILITY DUE TO FACTORS OTHER THAN WIND

Rainfall

The Holsworthy sites are likely to experience substantially more rainfall than Badgerys Creek (median of 1,100 millimetres) and are more prone to high intensity precipitation events (approximately 15 percent higher intensities for similar return periods). Airport usability at Holsworthy Option A or B could be marginally lower than Badgerys Creek based on more frequent visibility reduction.

Thunderstorms

There appears to be no significant difference in occurrence of thunderstorms and lightning strikes between Holsworthy and Badgerys Creek options according to a normalised thunderstorm probability analysis. Higher thunderstorm probability areas are further from the Holsworthy sites than Badgerys Creek, giving increased warning time at Holsworthy (Bureau of Meteorology, 1997). Insufficient data exists to be more conclusive than this.

Low Cloud

Based upon the available data the Holsworthy sites may experience more low cloud events than Badgerys Creek. However, the conclusions that have been drawn are necessarily tenuous due to the lack of verifiable site specific data.

Anecdotal evidence and meteorological theory strongly suggest that the approach corridors to the Holsworthy site and the aerodrome sites themselves would be subject to persistent low stratus cloud caused by topographically induced uplift of moist air streams (southerlies and south-easterlies in particular). Due to the difference in elevation Holsworthy Option B site is likely to be worse affected than Holsworthy Option A (Bureau of Meteorology, 1997).

Fog

The available radiation data suggests that Holsworthy is more prone to fog events than Badgerys Creek. Holsworthy Option A may experience more fogs than Holsworthy Option B, due to its lower elevation and proximity to the Nepean Valley, but no data are available to make an objective comparison (Bureau of Meteorology, 1997).

Modern navigation aids may enable adverse meterological conditions such as high intensity rainfall, thunderstorms, low cloud and fog to be overcome by large commercial aircraft. The impacts of such phenomena on some types of aircraft may be significant. Wind shear and mechanical turbulence affects aircraft of all sizes and is not able to be measured or predicted as readily as other phenomena, without additional observational data collection and study.

Weather conditions other than wind can affect the useability of an airport. Air traffic procedures for dealing with poor visibility at an airport, such as in fog or heavy rain, are developed by Airservices Australia in conjunction with the Civil Aviation Safety Authority. The procedures are specified in Aeronautical Information Publication documents and are based on prescribed visibility minima for landings or takeoffs.

The decision to proceed with a landing or a takeoff in conditions of poor visibility rests with the individual pilot concerned and is usually based on the pilots training, experience, aircraft type, standard of electronic navigation equipment aboard the aircraft, and the requirements specified in the company operations manual. It is therefore not possible to estimate the proportion of time than an airport would not be useable due to weather conditions other than wind.

6.2 INFLUENCES OF METEOROLOGY ON AIR QUALITY

In summer, near surface emissions from Holsworthy Option A could be trapped by a stable layer of air. In summer, near surface emissions from Option A could be trapped within sea breezes and onshore synoptic winds and carried inland during the evening. However, they are unlikely to have any impact at the surface, instead becoming entrained within local and regional drainage flows.

Near surface emissions may move north towards the Liverpool Basin, but the formation of steep ground-based inversions within the basin after sunset would prevent such emissions from reaching the surface and they would become entrained in cold air drainage flow and east across Sydney. West and south-west stable drainage flows would carry near surface emissions towards the east and north-east and could impact on surface air quality in populated areas downwind.

The influence of urban related emissions on air quality in the vicinity of Holsworthy Option A in the cooler months of the year is likely to be minimal, because these emissions are trapped within ground based temperature inversions or stable layers of air.

The impacts of near surface and elevated emissions on Holsworthy Option B would be similar to those at Option A. The increased elevation of Holsworthy Option B is likely to result in increased wind strengths and a possible decrease in the frequency of cold air drainage flows and near surface inversions at night. As inversions are likely to be more shallow at Holsworthy Option B, they would break down more quickly after sunrise than at Option A , resulting in earlier dispersion and dilution of near surface and elevated emissions by the synoptic wind during the day.

It is unlikely that emissions from Holsworthy Option B would reach the surface of Lake Woronora, because of formation of a layer of stable air above the lake at nighttime. This would cause emissions to pass over the top of the catchment and be carried away by winds blowing across the plateau regions above the catchment. Potential impacts of air pollutants on drinking water are discussed in *Technical Paper No.7 - Geology, Soils and Water.*

Near surface emissions from Option B could be trapped within sea breezes and onshore synoptic winds during the late afternoon and evening, and during the night within cold air drainage flows and stable synoptic winds. These emissions could be carried inland towards Wedderburn, Appin and Douglas Park. This would on occasions have an impact on nighttime air quality at Wedderburn.

Emissions from Holsworthy Option B would be carried towards the north by a shallow layer of northerly flowing air, at nighttime, or towards the east and north-east if regional drainage flows are present.

Because of the increased distance between Holsworthy Option B and residential areas of the Sydney Basin, combined with the increase in elevation, and consequent enhanced dispersion, air quality in the vicinity of Holsworthy Option B is likely to be better than at Option A.

Part D

Environmental Management

CHAPTER 7 ENVIRONMENTAL MANAGEMENT

Analysis of meteorology for the various airport options has been based upon extrapolating data from the nearest most representative sites and applying these data to the proposed sites. This is due to the absence of site specific meteorological data. Conclusions based upon such an approach are therefore preliminary and would need to be reviewed when suitable data is available.

Analysis of meterological influences on air quality was limited by the fact that there were difficulties in resolving apparent orientation problems with wind monitoring in data for the period July 1994 to June 1995, which was purchased from the NSW Environment Protection Authority. These problems could not be satisfactorily resolved, and a decision was made not to consider this data in the analysis. Substitution of this data for a more recent data set which should not contain discrepancies identified in the 1994/95 data and consideration of this new data would assist in reducing uncertainties about the conclusions that have been drawn.

While preliminary conclusions have been drawn from available meterological data, there is a need for the collection of additional site specific monitoring data to verify assumptions that have been made in this analysis and to investigate adverse meteorological phenomena. Limitations of existing data and recommendations for future monitoring are outlined in the following sections.

A comprehensive program to measure the vertical structure of winds and temperature in the vicinity of the airport options would be required, while options remain under consideration. This information would be required for eventual operation of the airport and also to allow the impact of meteorology on air quality downwind in the airport to be more thoroughly assessed. This would involve installing remote sounding systems to measure the vertical structure of wind and temperature as well as siting meterological towers in strategic locations, incorporating systems and other instruments to measure rainfall, solar and net radiation. Air pollution monitoring systems should also be considered for the airport sites. For the Holsworthy options, a series of tracer experiments could also be carried out to provide a better understanding of the possible impacts of near surface emissions and odours on areas downwind of the airport sites.

A detailed discussion about the limitations of data used for conducting meterological studies and recommendations for monitoring are contained in *Appendix A*, and in the report by the Bureau of Meteorology (1996).

Part E

Summary of Meteorological Influences

CHAPTER 8 SUMMARY OF METEOROLOGICAL INFLUENCES

Meteorological factors such as wind speed and direction, rainfall, inversion layers and mixing heights, influence the usability of the proposed airport sites, as well as the dispersion and transportation of air pollutants and the transmission of noise from aircraft and airport operations.

Analysis has been based upon extrapolating data from the nearest most representative sites and applying these data to the proposed sites, due to the absence of site specific meteorological data. Conclusions based upon such an approach are therefore preliminary. There is a need for the collection of additional site specific monitoring data to verify the assumptions that have been made in this analysis.

Quantitative assessment of the extent to which adverse meteorological conditions will affect runway usability at each site has not been undertaken due to the lack of site specific data, however, preliminary conclusions have been able to be drawn about the potential impacts of these phenomena.

While none of the Badgerys Creek or Holsworthy airport options meets the criteria (Australian adopted planning goal) for all cross-wind component values for all aircraft types, operations by larger aircraft would still be able to achieve the required usability level. Operations by aircraft with lower cross wind capability would be restricted some of the time, for all five airport options.

High intensity rainfall and low cloud is likely to occur less frequently at Badgerys Creek than at either of the Holsworthy sites, while fog events are more likely at Badgerys Creek. Fog is more likely at Holsworthy Option A than Option B due to its lower elevation. There is no significant difference between occurrence of thunderstorms at Badgerys Creek and the Holsworthy sites, however the warning time would be less at Badgerys Creek due to the proximity of the Great Dividing Range, which often spawns thunderstorms.

Due to modern navigation aids, adverse meteorological conditions such as high intensity rainfall, thunderstorms, low cloud and fog may be able to be overcome by large commercial aircraft. The impacts of such phenomena for small and medium sized aircraft may be significant. Wind shear and mechanical turbulence affects aircraft of all sizes and is not able to be measured or predicted as readily as other phenomena.

The limited amount of meteorological data available for all of the airport sites has meant that only preliminary conclusions can be made as to the effect of meteorology on air quality in the vicinity of the sites of the airport options.

An overall view of the work carried out by Macquarie Research using available data (refer *Appendix A*) suggests that inversions are likely to occur more frequently at Badgerys Creek than Holsworthy and that they will cause emissions to be directed to more populated areas than the Holsworthy options. Holsworthy Option B, because of its elevation, is likely to have a lower incidence of inversions and such inversions will be shallower and will disappear more quickly, allowing pollutants to be dispersed relatively quickly.

Photochemical smog and ozone impacts are likely in populated areas downwind of both airport sites but the impact of near surface and elevated emissions is likely to be greater downwind of Holsworthy Option A, because the trajectory of air passing over this site is likely to have been carried from areas with larger sources of urban and industrial emissions sources, and there is a greater concentration of populated areas downwind of Holsworthy Option A compared with Holsworthy Option B. The relative impacts will need to be qualified by air quality modelling, once there is more information about the structure of winds and temperature at each site, and measurements of photochemical smog are made at the airport sites.

Analysis suggests that air emissions will not reach the surfaces of Lake Burragorang (near Badgerys Creek) or Lake Woronora (near Holsworthy) at nighttime, due to formation of layers of stable air in the vicinity of each catchment. Air emissions generated during the day would be dispersed from both areas. Potential impacts of air pollutants on drinking water supplies are discussed in *Technical Paper No.7 - Geology, Soils and Water.*

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Appendices

Appendix A

Meteorology Report

Second Sydney Airport Environmental Impact Statement Technical Report on Meteorology

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25 August 1997
58H233A PR_2498

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PART A: INTRODUCTION

CHAPTER 1 OVERVIEW OF FINDINGS

The limited amount of meteorological data available for all of the airport sites has meant that only preliminary conclusions can be made as to the influence of meteorology on air quality in the vicinity of the sites of the airport options. Quality problems in some meteorological data provided by the NSW Environment Protection Authority imposed limitations on the meteorology study, and this data was not able to be used with confidence for assessment of meteorological influences on air quality.

The available data suggests that inversions are likely to occur more frequently at Badgerys Creek than Holsworthy and that they would cause emissions to be directed to more populated areas than the Holsworthy options. Holsworthy Option B, because of its elevation, is likely to have a lower incidence of inversions and such inversions would be shallower and would disappear more quickly after sunrise, allowing pollutants to be dispersed relatively quickly.

The analysis suggests that air emissions will not reach the surfaces of Lake Burragorang (near Badgerys Creek) or Lake Woronora (near Holsworthy) at night because of formation of layers of stable air in the vicinity of each catchment. Air emissions generated during the day would be dispersed from both areas.

CHAPTER 2 STUDY BRIEF

Dr Robert Hyde was commissioned by Macquarie Research Pty Ltd on behalf of PPK Environment & Infrastructure Pty Ltd to undertake a study of meteorology of the sites of the airport options and of the potential influence of meteorology on air quality and noise impacts.

This was in response to issues raised in the November 1996 Guidelines for conducting the Draft EIS which were developed by Environment Australia. The Guidelines stated that specific meteorological issues to be considered and assessed included:

- relevant meteorological conditions (including frequency and characteristics of temperature inversions) and any topographic features which may influence noise or vibration impacts (p11);
- a description of the site's relationship to Sydney's air drainage basin and of diurnal and seasonal variations in air pollution levels and the influence of short term weather phenomena (p13); and
- relevant weather characteristics including winds, fogs and temperature inversions and any topographic features which may affect the dispersion of air pollutants (p13).

The prevalence of adverse meteorological conditions was also mentioned in the Guidelines (p15), however this was not part of the scope of work for Macquarie Research. The Bureau of Meteorology was separately commissioned by the Department of Transport and Regional Development to undertake this work and the findings of its study are reported in Bureau of Meteorology (1997).

CHAPTER 3 METHODOLOGY

3.1 AIMS AND SCOPE OF WORK

The aim of the meterological studies was meet the objectives set out in study brief provided by the Department of Transport and Regional Planning, and to respond to issues identified by the Commonwealth Environment Protection Agency. The objectives of the meterological studies were to:

- provide background information about regional and local meteorology in the Sydney Region;
- identify appropriate sources of meterological measurements, and assess the suitability and limitations of these data for use in noise impact and air quality modelling at the five airport options ;
- review meteorology and air quality in the Sydney Basin; and
- discuss the influence of meteorology on air quality at the five airport options.

To achieve the aims listed above, especially the impact of meteorology on air quality in the region, it was decided to first describe the different winds flows that are observed at the surface, and other important parameters such as the vertical structure winds and temperature in the lower atmosphere, before discussing linkages between meteorology and air quality. At the same time, it was necessary to determine appropriate sources of meterological information that could be used for calculating runway usability, noise impact assessment and air quality modelling.

This chapter gives details of the meteorological data obtained from a number of different sources; describes the geographic regions that are important for air quality in Sydney; and discusses some of the limitations of the currently available data, and the affect of these limitations on the aims and scope of work listed above.

Chapters 4 and *5*, discuss the existing environment. *Chapter 4* is concerned with describing the overall meteorology of the Sydney region in terms of: seasonal changes in wind flow throughout the year; sea breezes and nocturnal winds; temperature inversions and their breakdown after sunrise. The second half of *Chapter 4* discusses the vertical structure of winds and temperature in the vicinity of Badgerys Creek and the Holsworthy Military Area. *Chapter 5* is concerned with linkages between meteorology and air quality, in particular the issue of photochemical smog in summer, and the trapping of near-surface urban and industrial emissions in the cooler months of the year. This is followed by a discussion of the impact of meteorology on air quality in the vicinity of Badgerys Creek and Holsworthy Military Area. For reasons that are discussed below, this evaluation is currently only limited, and it has not been possible to satisfactorily describe the interaction between meteorology and air quality on the basis of hourly meterological and air quality measurements made at monitoring stations in the vicinity of Badgerys Creek and the Holsworthy Military Area.

Chapter 6 discusses the likely impact of meteorology on the dispersion of both near-surface and elevated emissions from the Badgerys Creek and the two Holsworthy airport options. The size of any impact of emissions on air quality downwind is not discussed in this report, since these issues are dealt with in *Technical Paper No. 6 - Air Quality*. *Chapter 7* discusses the limitation of the meterological data, both in general terms, and in the context of the limitation of these data in assessing the impact of near-surface and elevated emissions, on air quality downwind of the airport options at Badgerys Creek and the Holsworthy Military Area.

3.2 INFORMATION SOURCES

Information from the following sources were used in the meterological studies and as input to noise impact and air quality modelling.

Bureau of Meteorology:

- measurements of winds and other meterological parameters from the three main airports (Sydney, Bankstown, Richmond), and other automatic weather stations in the Sydney Region.

New South Wales Environment Protection Authority (EPA):

- measurements of air quality and meteorology from air quality monitoring stations in Sydney; wind and temperature profiles from the EPA's summer campaign of measurements in western Sydney during February 1995;

- results from the *Metropolitan Air Quality Study* (MAQS).

Australian Nuclear Scientific and Technical Organisation:

- measurements of winds and other meteorological parameters measured at Lucas Heights. Reviews of previous climatological studies and meteorological investigations at Lucas Heights; monthly average fine particles and lead levels measured in Sydney as part of the Aerosol Sampling project.

Australian Water Technologies:

- wind speed and direction data from selected sewerage treatment works in the Sydney region; rainfall data from stations in the vicinity of Badgerys Creek.

Federal Airports Corporation:

- air quality and meteorological data from monitoring stations at Sydney Airport and Botany.

Macquarie University:

- measurements of surface winds from different sites in Sydney, including from Badgerys Creek; lower atmospheric wind and temperature profiles measured during previous air quality investigations in Sydney. Reports of previous investigations into air quality in the greater Sydney Region.

3.3 REVIEW OF PREVIOUS WORK

Much of the previous work in Sydney has been concerned with the impact of synoptic, regional and local meteorology on air quality. Whilst these investigations have concentrated on air quality issues, many of the main factors identified as important for limiting dispersion, such as ground-based inversions and local and regional wind flows at night also have an impact on the transmission of noise.

In the *Second Sydney Airport Site Selection Programme Draft EIS*, (Kinhill Stearns, 1985), Holsworthy was eliminated early in the study as a suitable site, and the amount of information in the Kinhill Stearns report about meteorology and air quality in the vicinity of Badgerys Creek was extremely limited.

For the purpose of this technical report on meteorology, in order to limit unnecessary repetition, it was decided to discuss relevant previous work at the start of each section in *Chapter 4* and *Chapter 5*.

Throughout the report a number of meterological terms will be used, and a brief description of the most commonly used terms is given below. Where appropriate, more information is provided as part of the review of previous work in *Chapter 4*.

3.4 COMMONLY USED TERMS

3.4.1 THE SYDNEY BASIN

Wind flow in the greater Sydney region is strongly influenced by topography at a range of scales. For the purpose of air quality, the Sydney Basin has been defined as the region bounded by high ground in the vicinity of Mittagong in the south; the Illawarra Escarpment to the east, the Blue Mountains to the west, and high ground north of Richmond. The topography of the Sydney Basin is given in *Figure 3.1*. Also included in this figure, are the sites of the Macquarie University wind recorder network and the locations where vertical profiles of wind and temperature were made during the Sydney Brown Haze and Western Basin Experiments, (Hyde et al., 1980; Hyde et al., 1982). Some of the locations plotted in *Figure 3.1* are referred to in several sections of this report.

The affect of the topography of the region is to create a large basin with extensive changes in elevation from south to north, and west to east as illustrated by topographic profiles plotted in *Figure 3.2a,b*. Within the Sydney Basin there are several regional scale topographic features that are important for air quality. These include: the Hawkesbury and Liverpool Basins, and the Parameter River Valley, *Figures 3.3* and *3.4*. The Hawkesbury Basin is well defined north of St. Marys, since it is bounded by high ground to the north and west, and the northern plateau to the east, for example, *Figure 3.2b*. The southern limit of the Hawkesbury Basin is poorly defined, because topographic heights increase rapidly south of Camden, for example *Figure 3.2a*. The Hawkesbury Basin is separated from the Liverpool Basin and the Parramatta River Valley, by the 'Blacktown Ridge' which has an elevation of 70 to 100 metres above sea level, and extends from Castle Hill in the north, through Blacktown and Prospect Reservoir, then south between Camden and Campbelltown.

Within the Hawkesbury Basin, there are several smaller scale topographic features such as South Creek Valley, which are particularly important since they act to control the direction of near-surface winds under highly stable atmospheric conditions at night. Another important sub-region of the Hawkesbury Basin is a region of lower topography in the vicinity of Camden. This is part of the Nepean River Valley, but it is thought that the northward flow of stable air at night is blocked by higher topography 10 kilometres south-west of Badgerys Creek, between the lower Blue Mountains Escarpment and the ridge separating the Nepean River Valley from South Creek Valley, as illustrated in *Figure 3.5*. This results in a shallow enclosed topographic region south of Badgerys Creek, bounded by the 100 metre contour which has been named the Camden Basin, (Hyde and Johnson, 1990).

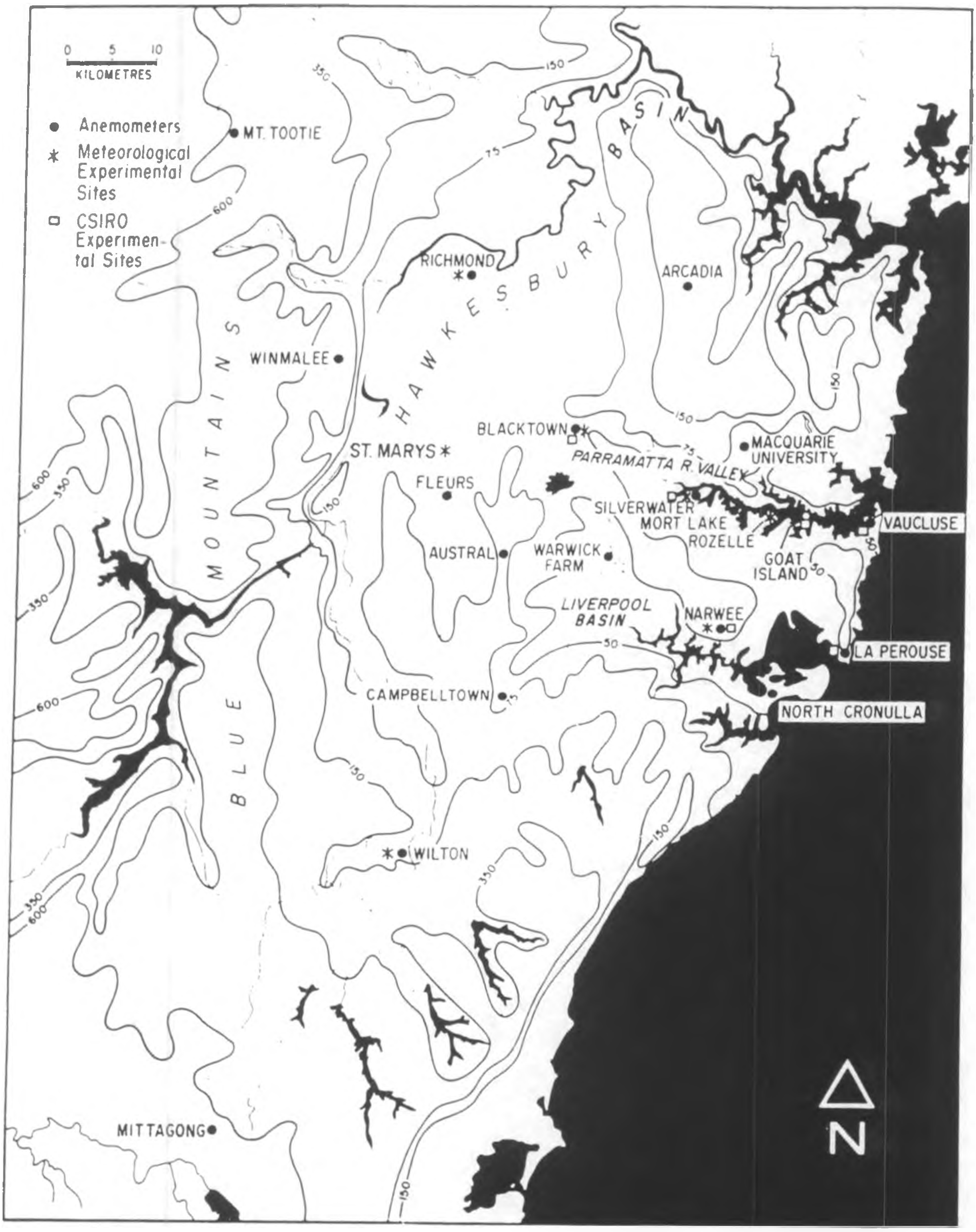


Figure 3.1 The Sydney Basin including location of Macquarie University wind recorders and vertical profiling sites during the Western Basin Experiment (Hyde et al, 1980)

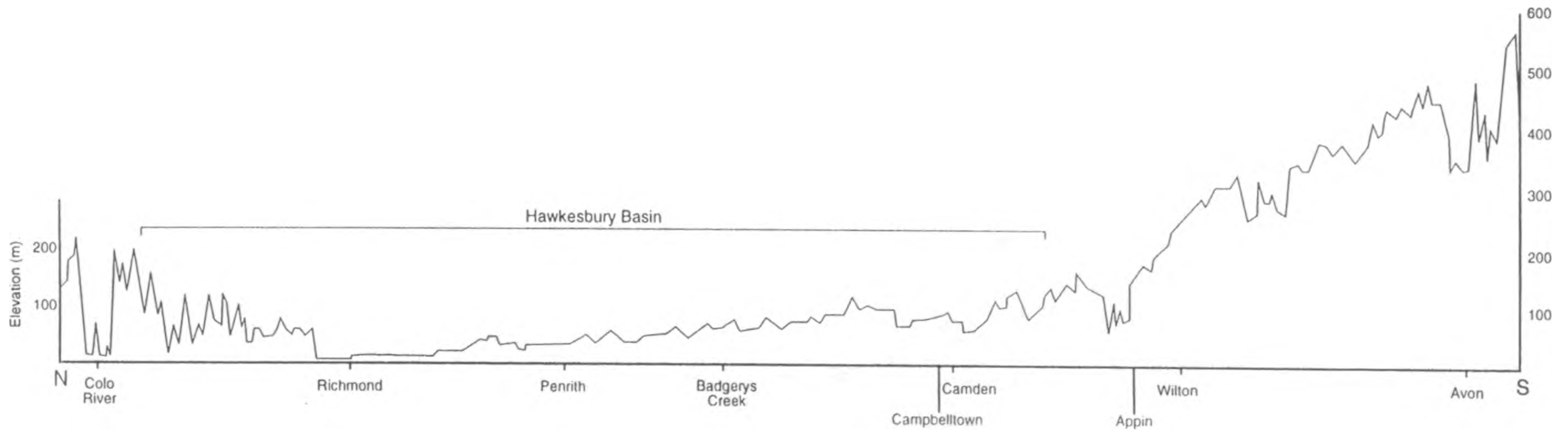


Figure 3.2(a) North - South topographic profile: Western Sydney Basin (Hyde and Johnson, 1990)

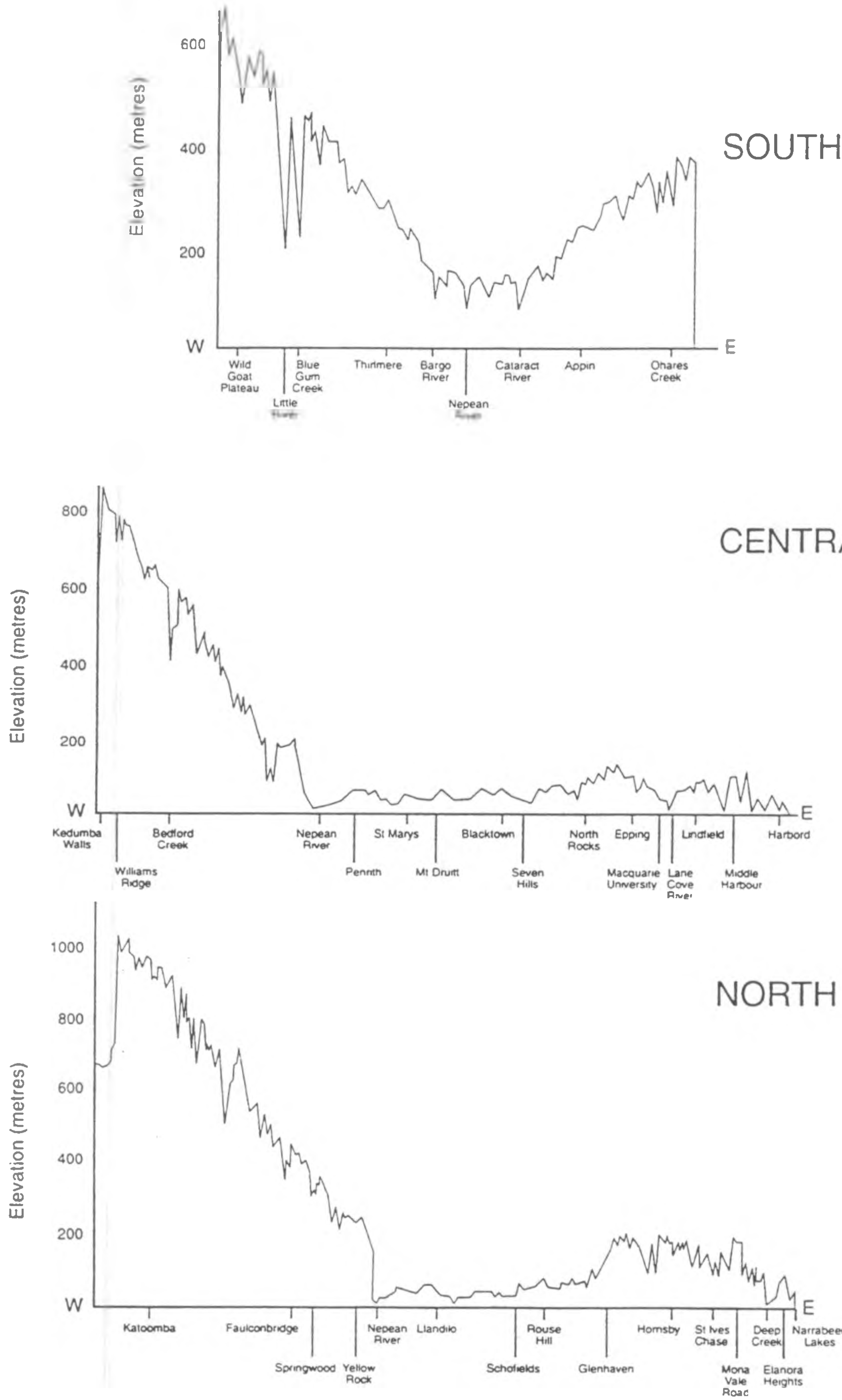
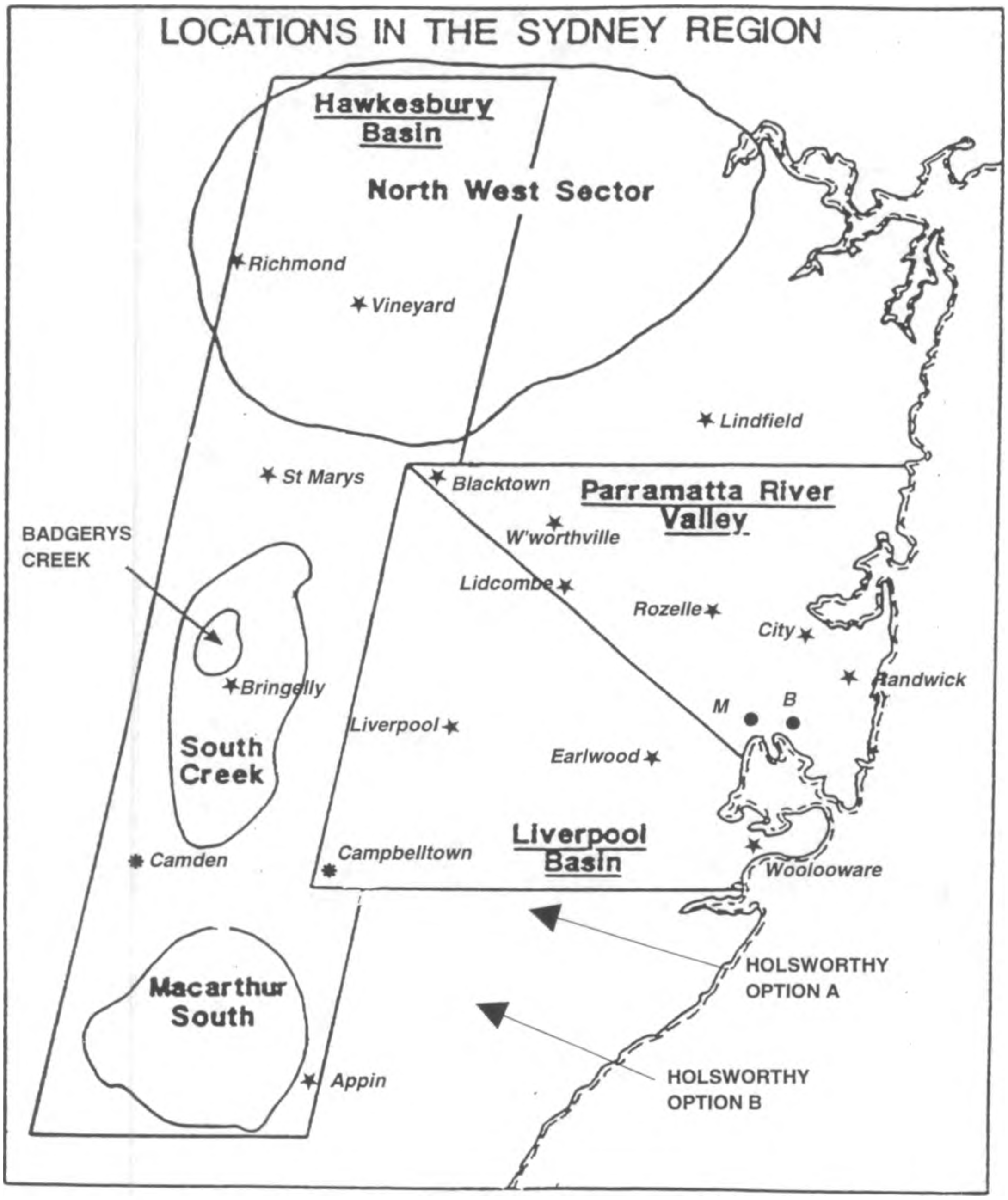


Figure 3.2(b) East - West topographic profiles across Sydney Basin (Hyde and Johnson, 1990)



Air Quality Monitoring Stations

★ NSW EPA

✸ Industry

● Federal Airpoprts Corporation

M = Sydney Airport

B = Botany

Figure 3.3 Schematic Outline of Topographic Basins within the Sydney Airshed, showing locations of NSW EPA, Industry, and Federal Airports Corporation Air Quality Monitoring Stations
Source: After Hyde and Johnson. 1990

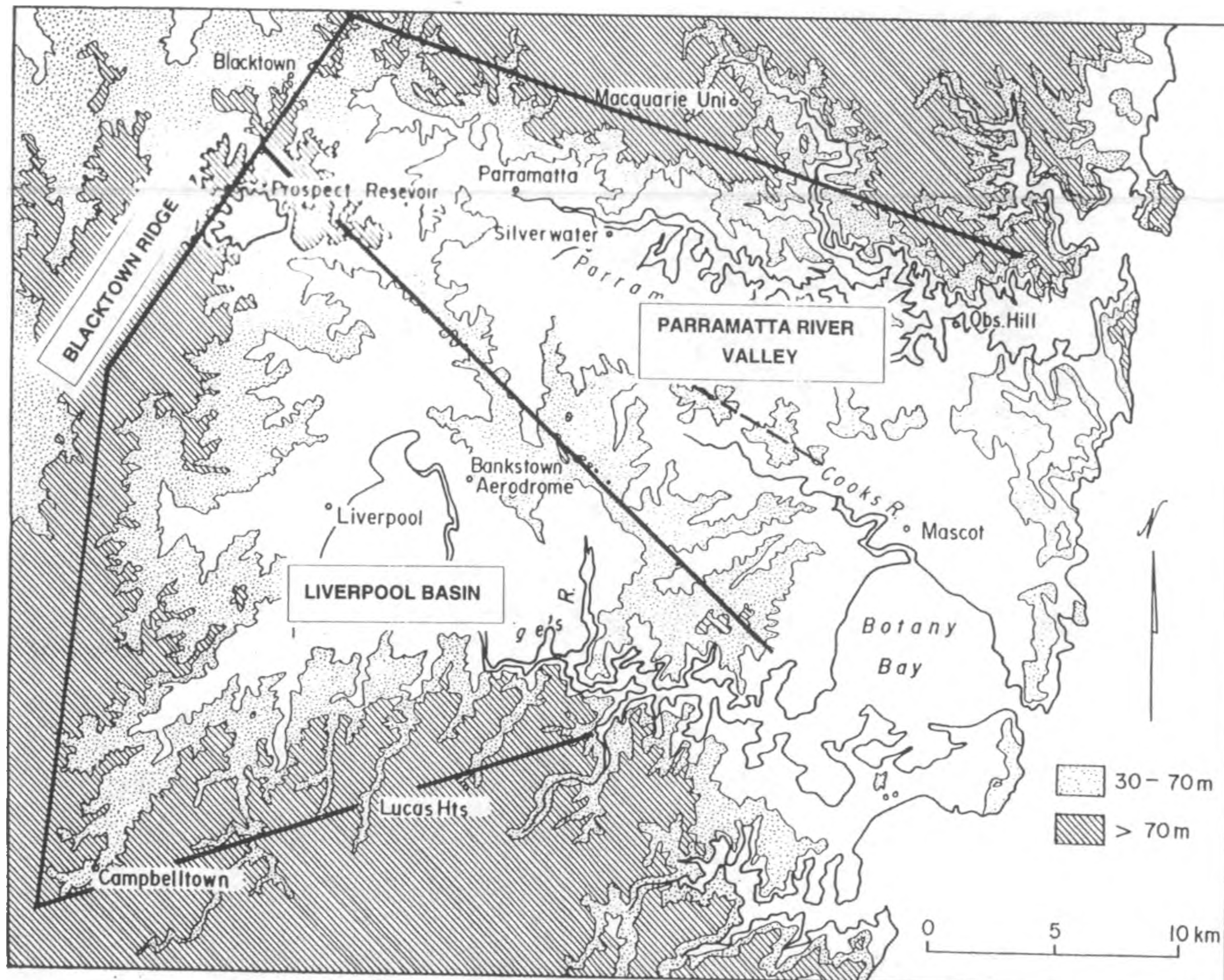


Figure 3.4 Topography of Eastern Sydney showing the Liverpool Basin (LB) and the Parramatta River Valley (PRV)

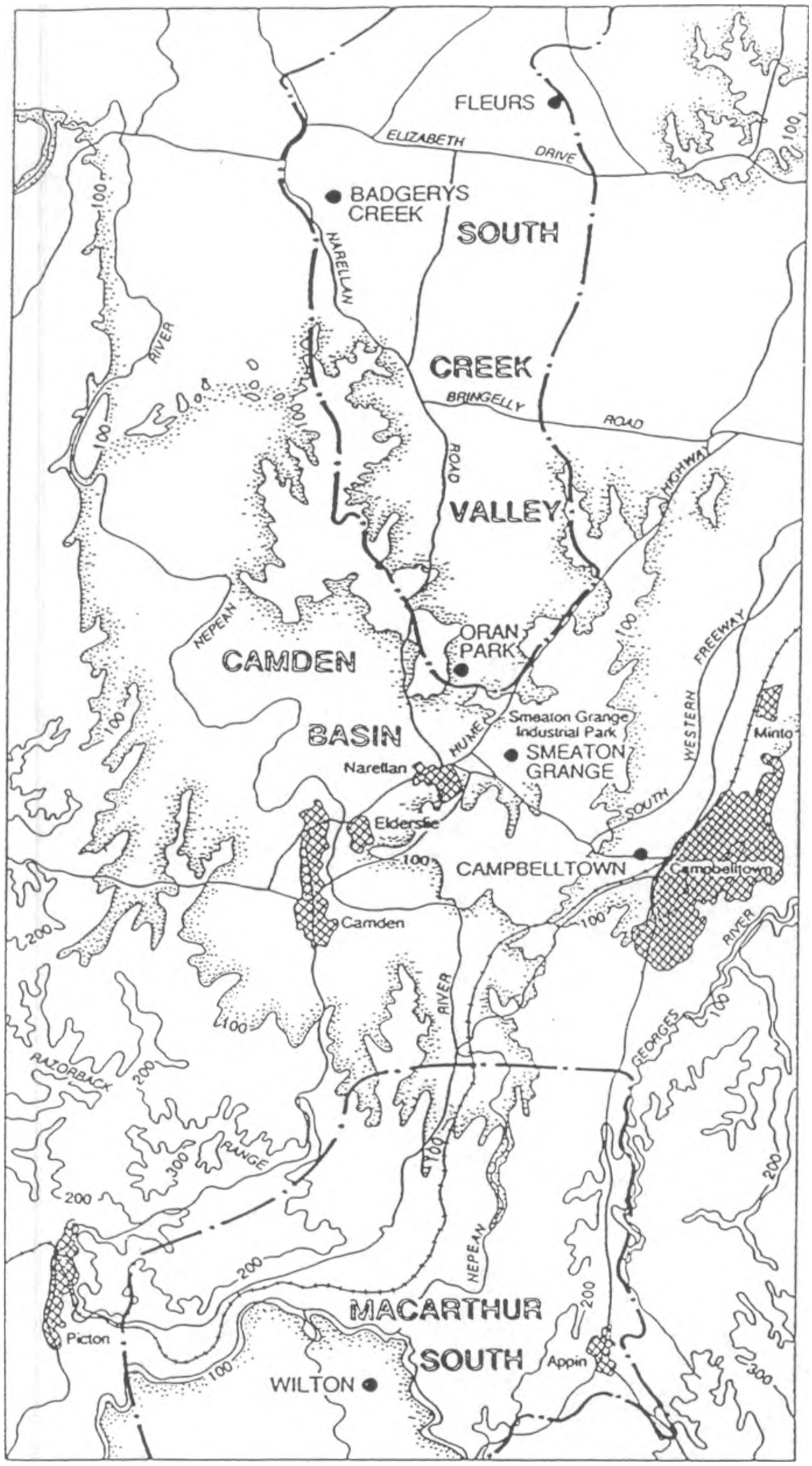


Figure 3.5 The Camden Basin (Hyde and Johnson, 1990)

The Parramatta River Valley starts at Blacktown, is by bounded by higher ground to the north, and separated from the Liverpool Basin by a shallow ridge 30 to 70 metres high, which stretches from Prospect Reservoir towards Botany Bay, *Figure 3.4*. This ridge separates the Paramatta River valley from the Liverpool Basin to the south. The Blacktown Ridge is the western boundary of the Liverpool Basin, whilst the southern boundary is defined by higher ground which slopes up towards the east from Campbelltown, and south from Holsworthy and Sutherland.

3.4.2 METEROLOGICAL TERMINOLOGY

The following terms occur repeatedly throughout the report: synoptic winds and the synoptic weather pattern; local, meso-scale, and regional wind flows; temperature inversions and stable layers; mixing height; sea breezes and cold air drainage flows.

- Synoptic winds and the synoptic weather pattern:

Figure 3.6 shows typical summer and wintertime surface synoptic chart for Australia (Bureau of Meteorology, 1991). The lines on the chart join locations with the same atmospheric pressure. At a particular latitude, the smaller the separation between the adjacent lines, the stronger the wind speed. In the southern hemisphere winds blow anti-clockwise around regions of high pressure, and clockwise around low pressure systems.

- Well mixed atmosphere; mixing layer:

In a well mixed atmosphere, the temperature deceases with height at a rate of approximately 10 degrees Celsius per kilometre; the mixing height is the depth of the atmosphere above the surface where temperature decreases with height at this rate. The depth of the mixing layer can vary from a few tens of metres to several kilometres.

- Stable layers and temperature inversions:

In a stable layer, the temperature decreases with height at less than 10°C per kilometre. With increasing stability this vertical gradient of temperature decreases and can eventually increase with height. When the there is no increase in temperature with height, the atmosphere is said to be isothermal; in an inversion the temperature increases with height. Two examples showing the changes in temperature structure with time, and the formation of a temperature inversion close to the ground at Lucas Heights are plotted in *Figure 3.7*.

- Regional wind flow in Sydney:

In the context of this report this term applies to inter-regional transport of air; for example, Hunter Valley or Central Coast to Sydney, or Sydney to the Illawarra.

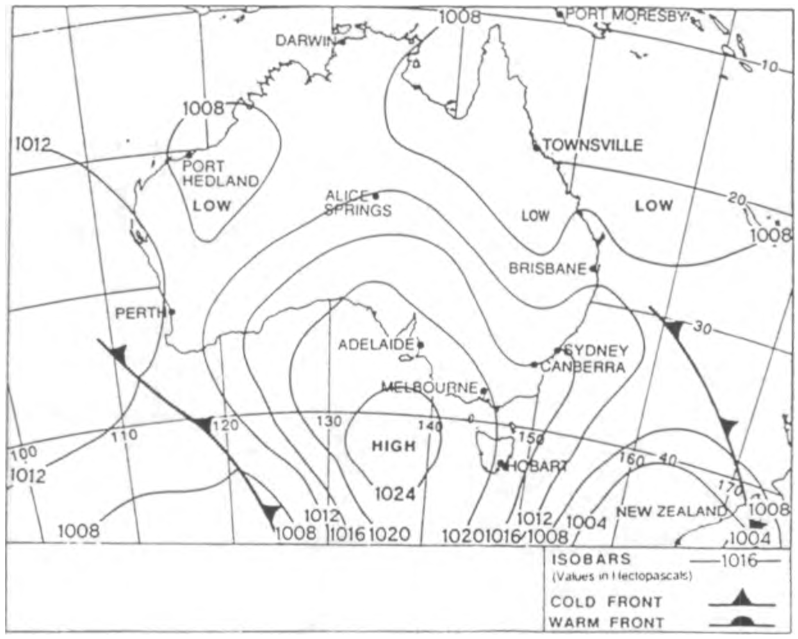
- Sea breezes and Cold Air Drainage Flows:

Sea breezes are primarily caused by daytime temperature differences between land and sea surface temperature, but can be modified by a range of other factors as explained in Chapter 4. Cold air drainage flows occur when air in contact with the surface, cools more rapidly than air at the same height, but some distance away from the surface. In this situation, the colder denser air at the surface starts to flow down-slope where it gradually merges and combines with air flowing down-slope elsewhere in the region. The accumulation of these slope winds then produce local and regional drainage flows. Some drainage flows observed in the Sydney basin can be quite deep and are usually referred to as regional flows. However, close to the surface, either as a result of local down-slope flows, or as a result of stable air being steering by smaller scale topography, shallower distinctive nocturnal winds are observed in some areas of Sydney. In this report these are called local drainage flow. Together, sea breezes and regional drainage flows are occasionally referred to in this report as meso-scale winds.

In Sydney, it is quite common for a number of different wind flows to be observed and in a number sections in this report these flows have been illustrated using copies of original wind charts from Macquarie University wind recorders. An example one of these wind charts from Blacktown on 29 June 1979 given in *Figure 3.8* and illustrates the complexity of winds that can be present during the day in the Sydney Basin. In *Figure 3.8* the top half of the chart indicates wind direction, and the trace is a plot of the instantaneous wind direction over the period of the record. The fluctuations in the wind direction trace are related to atmospheric stability and atmospheric turbulence, and allow characteristic wind flows to be identified. The lower half of the chart shows a series of sloping lines which are related to wind speed at the time of measurement. Instead of plotting instantaneous wind speed, this particular type of wind recorder measures 'wind run', and the slope of lines in the lower half of the chart are proportional to wind speed. The steeper the slope, the stronger the strength of the wind.

In *Figure 3.8* the chart record shows a period of southerly synoptic winds between 1100 and 1700 hours, followed by a sea breeze between 1700 and 2030 hours; regional south-west cold are drainage flow between 2030 and 0100 hours; 'spillover of cold air out of the Hawkesbury Basin across the Blacktown Ridge between 0100 hours and 1000 hours, and then a return to south-south-west to south-south-east synoptic winds after 1000 hours.

(a)



(b)

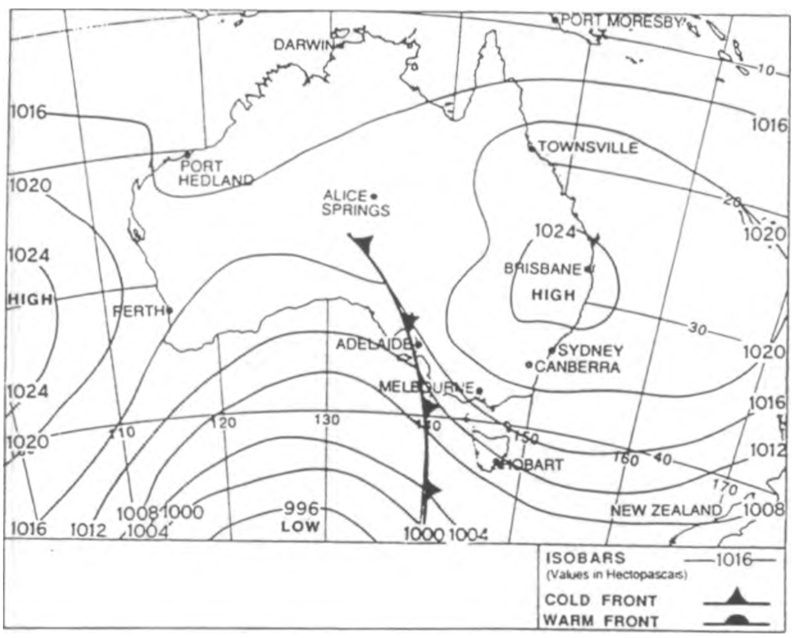
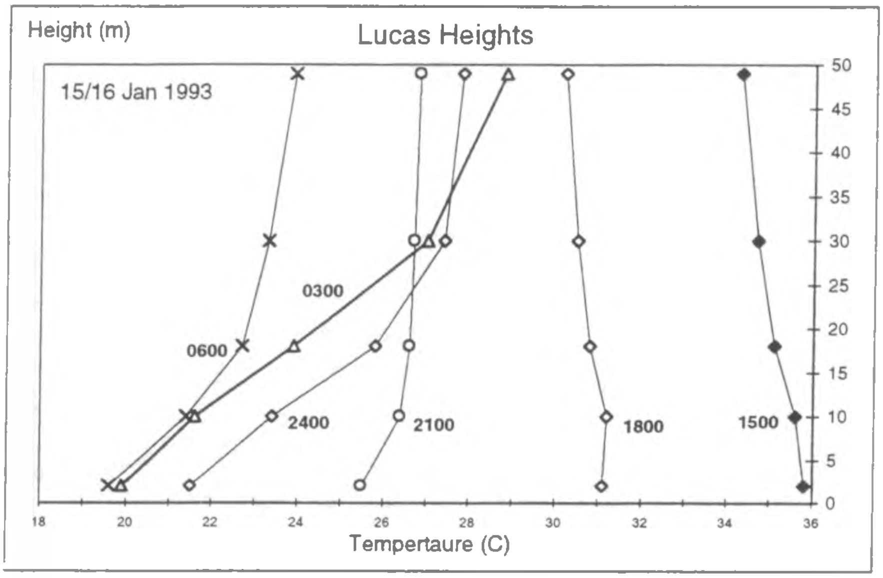


Figure 3.6 Typical mean sea level pressure charts: (a) Summer; (b) Winter (Bureau of Meteorology, 1991). Reproduced with the permission of the Bureau of Meteorology



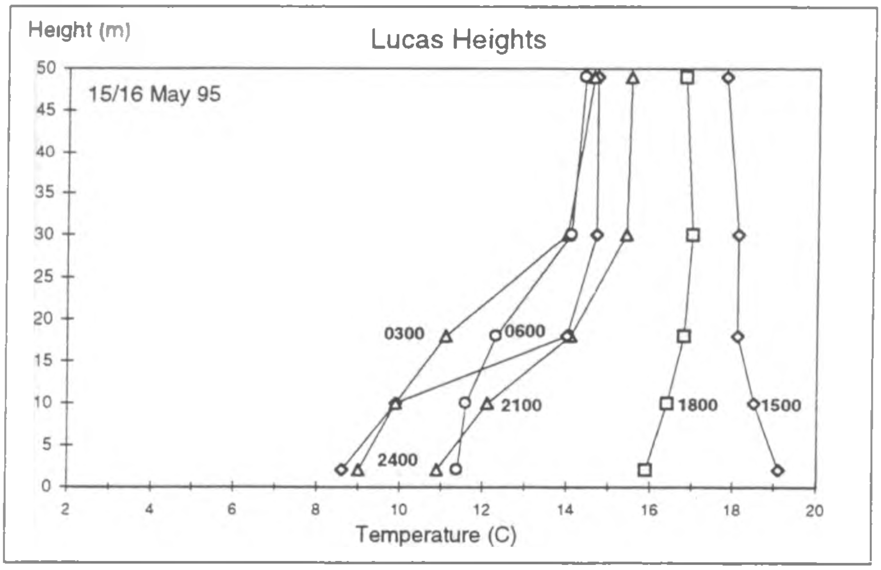


Figure 3.7 Formation of ground-based temperature inversions at Lucas Heights
Source: ANSTO, Lucas Heights

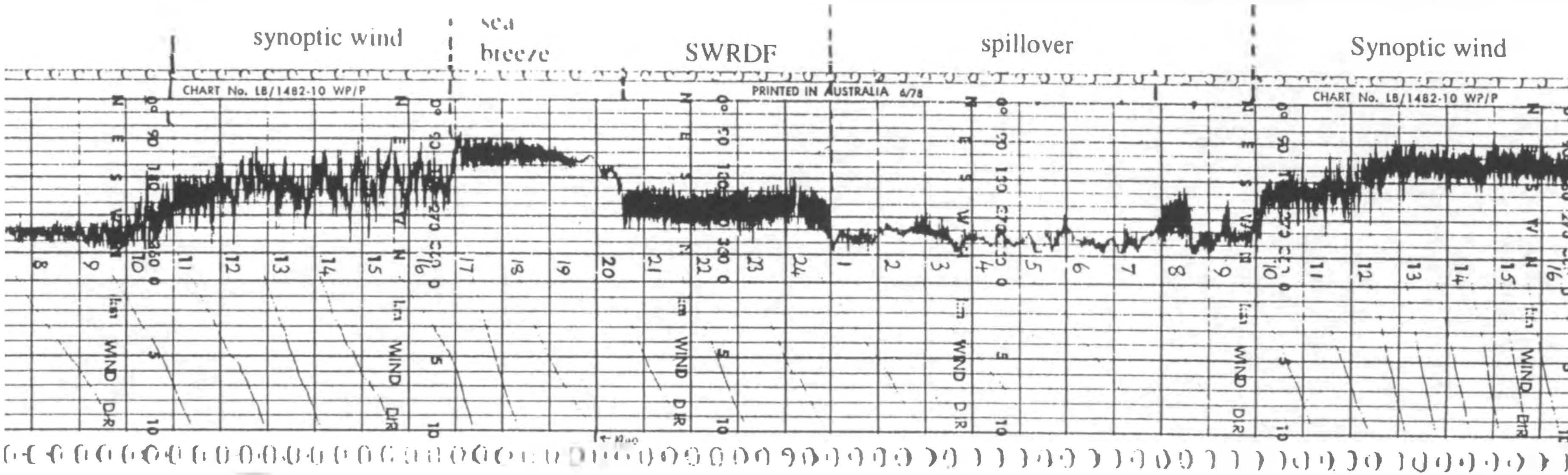


Figure 3.8 Wind direction (top) and wind run (bottom) 28-29 July 1979, Blacktown, showing periods of synoptic winds, sea breeze, southwest regional drainage flow (SWRDF) and 'spillover' of air out of the Hawkesbury Basin (Hyde et al, 1980)

In sections of the report dealing with wind speed and direction frequency distributions the following definitions have been used:

- Diurnal: the variation of wind speed and direction over the period of a day (that is, 24 hours), usually presented for three hour intervals; and
- Seasons:
  - Summer: December, January and February;
  - Autumn: March, April and May;
  - Winter: June, July and August; and
  - Spring: September, October and November.

3.5 METEOROLOGICAL DATA

3.5.1 INTRODUCTION

Meterological data from a range of different sources and locations were required as input to this and other studies for the Draft EIS. For the assessment of runway availability, noise impact predictions and local air pollution dispersion modelling it was necessary to obtain data measured as close as possible to the five airport sites being considered, whilst some components of air quality modelling carried out for the Draft EIS, required wind speed and direction measurements for the whole of the Sydney Region.

As a result of these different needs, and differences in the time that some of the data sets became available, it was necessary to compile and supply separate meterological data bases to meet the individual requirements of specific tasks undertaken for the Draft EIS.

3.5.2 BADGERYS CREEK - DATA FOR NOISE IMPACT PREDICTIONS AND AIR QUALITY MODELLING

Wind Speed and Direction

When work on the Second Sydney Airport EIS commenced in October 1996, it was thought that no long-term meterological data were available in the vicinity of Badgerys Creek. Some limited climatic and meterological measurements were available from the CSIRO Research Station in Elizabeth Drive, north of Badgerys Creek, but these data are of little use for the current Draft EIS. Wind measurements, based on observer estimations were only available for 9 am, and measurements of rainfall, required for the prediction of noise impacts and runway usage were only available as daily totals, and were not suitable, because the noise consultants required data averaged over much shorter periods of time.

During the analysis of wind data for the Second Sydney Airport EIS it was discovered that the Department of Aviation had measured wind speed and direction at Bringelly over a period of several years as part of the *Second Sydney Airport Site Selection Programme Draft EIS* (Kinhill Stearns, 1985). These data were not referred to directly in the Kinhill Stearns report, nor were wind statistics from the Department of Aviation's measurements program produced in the report. At present, the Department of Transport and Regional Development is endeavouring to determine the availability of these data from Bringelly, so that a longer period of wind records can be compared with the meterological measurement used for the current Second Sydney Airport EIS. It is thought that these data were recorded using a Dines anemometer, which means that the data would be useful for medium at to high wind speed conditions, but because of the high stalling speed of this instrument, low wind speed events are likely to be recorded as calms and may not be useful for the assessment of nocturnal wind conditions at Badgerys Creek at night, (Hyde et al, 1980; Potts et al, 1997).

The closest comprehensive Bureau of Meteorology weather station to Badgerys Creek is Bankstown Airport. Prior to 1982, three-hourly measurement of wind speed, wind direction, temperature, rainfall were available but not for the whole 24 hour period. Under stronger wind conditions, comparisons of Bureau of Meteorology winds from Bankstown and Macquarie University winds from Badgerys Creek were similar (Bureau of Meteorology, 1996). However, at other times of the day, the frequency and characteristics of light winds, cold air drainage flows and sea breezes at Badgerys Creek will be very different from those measured at Bankstown (Hyde and Johnson, 1990).

In 1995, the Bureau of Meteorology installed an automatic weather station at the Badgerys Creek airport site and this was commissioned in January 1996. However, when the noise impact prediction modelling commenced in October 1996, less than a year of meterological data were available from this weather station, and data from this station was not used for noise impact modelling.

Wind speed and direction have been measured at the Pacific Waste site in Elizabeth Drive since 1993, but were not considered valid for the purpose of this EIS.

The only other onsite measurements of wind speed and direction at Badgerys Creek were those made by Macquarie University during, and following the Pilot Study (Hyde and Johnson, 1990). As part of that study, Macquarie University was funded by the Commonwealth Department of Transport to install a mechanical wind recorder on the Badgerys Creek Airport, to supplement a network of similar wind recorders in western Sydney.

The anemometer at Badgerys Creek was installed in March 1990, and was operated until April 1992. It supplemented a network of similar Lambrecht Mechanical wind recorders that had been located throughout western Sydney as part of the of the Pilot Study to assist in the identification of sea breezes and cold air drainage flows in western Sydney. As discussed above, wind run and instantaneous wind direction are recorded inside the instrument and at Badgerys Creek, and for the Pilot Study one year of records were digitised to obtain hourly average values of wind speed and direction.

In the absence of any other, long-term data from this site, preferably with a shorter averaging period, additional data collected following the end of the Pilot Study were digitised to provide a two year period of wind data from the Macquarie University anemometer at Badgerys Creek. These data were then used for noise impact modelling, runway usage, and air quality modelling at Badgerys Creek. The availability of wind measurements during this period are shown in *Table 3.1*.

Inversions

Shortly after the commencement of work for the Second Sydney Airport EIS, the noise consultants required an estimate of the frequency of inversions at Badgerys Creek. In the absence of on-site measurement of the vertical structure of temperature in the vicinity of Badgerys Creek, estimates of the frequency of inversions were made on the basis of wind speeds commonly observed during periods of drainage flows at this location when a ground based stable layer or inversion would be expected at the surface.

Although speeds within drainage flows can vary from day to day, on the basis of an examination of wind charts from Badgerys Creek, it was found that drainage flows typically had speeds less than 2.5 metre per second, or less than 3.5 metres per second. Wind data from Badgerys Creek for the 1990 to 1992 period was then analysed to determine the percentage frequency of time during the night, that wind speeds in these speed ranges were observed. The results are listed in *Table 3.2*.

These data can only be viewed as approximate, since the results do not take into account, that on some occasions, for example when conditions are overcast, a stable layer or an inversion might not be present at the surface.

Rainfall

Information about rainfall in the vicinity of Badgerys Creek was required for runway usage and noise impact modelling. In the absence of short-term rainfall measurements from the CSIRO Research Station at Badgerys Creek, it was necessary to use two-minute and hourly rainfall measurements measured by Sydney Water at Warragamba Dam and West Hoxton. Three hourly rainfall totals from Bankstown Airport were used for times when no data was available from the Sydney Water stations.

Air Quality and Meteorological Data

Air quality and meteorological measurements for the period July 1994 to June 1995 were purchased from the NSW Environment Protection Authority and provided to PPK in mid-December 1996. Some of the meterological data were supplied on the basis that they needed to be treated with caution; for example, the data from Richmond were suspected of having an orientation problem, although the Environment Protection Authority was not able to provide a correction factor to allow these data to be adjusted, and data from St Marys was considered invalid because the data logger had been wrongly set to 540 degrees instead of 360 degrees, which meant that winds at that station did not appear to blow between west and north, as observed by Zib (1995).

In February 1997, whilst analysing these measurements to investigate linkages between meteorology and air quality in Sydney, it appeared that wind directions recorded by the Environment Protection Authority at its monitoring stations at Vineyard and Bringelly in western Sydney might not be correct.

A further analysis of the data showed that measurements from Richmond and Vineyard might also be affected by additional problems associated with the recording of the data at these stations. The Environment Protection Authority subsequently provided correction factors of -30 degrees and + 13 degrees for Bringelly, because the direction sensor at that station, had twice been incorrectly orientated; a -27 degree correction for Vineyard, and + 13 degree for Wollongong. Also provided by the Environment Protection Authority, was information that some data from Vineyard and Richmond, which had originally been flagged by the Environment Protection Authority as valid, were now considered by them to be invalid. However, whilst accepting that data from Richmond and St. Marys had different types of data logger recording problems, the Environment Protection Authority did not consider that a similar data logger problem existed at Vineyard, even though: (i) the orientation correction factor of -27 degrees did not appear to correct the measurements at this station when compared with data recorded nearby at the Bureau of Meteorology's wind station at Richmond, and (ii) that they had been supplied with supporting evidence, to show that there was something seriously wrong with the wind direction measurements recorded at the Vineyard monitoring station.

The Environment Protection Authority's assurance that other stations in their network were not similarly affected by orientation or data logger problems, was based on an examination of station log-books. However, it is clear from the inconsistencies in the wind values that have recently emerged during the course of analysing these data for this report, that the Environment Protection

Authority has not complied with the requirements of Australian Standard AS2923 - 1987 "Air Quality - Guide For The Measurement of Horizontal Wind For Air Quality Applications" (Standards Association of Australia, 1987), which requires:

- the wind direction sensor to be correctly aligned to true north; and
- that the output signal from the wind direction sensor corresponds to the direction of the wind as measured by the wind vane.

In view of the significant errors in wind direction measurements that were discovered during the analysis, and the fact that the Environment Protection Authority's assurance about the quality of their data, in terms of possible orientation problems, or problems with the recording of data at other stations in Sydney, was based solely on an examination of station log-books, rather than a comparison of their data with measurements from independent sources, PPK decided to return both the meteorological and air quality data to the Environment Protection Authority. PPK has raised the possibility with the NSW Environment Protection Authority of obtaining the meteorological and air quality measurements for the 1996 period.

(Note: The return of these data does not suggest that there were problems with air quality measurements made by the Environment Protection Authority. However, to properly identify source-receptor relationships, and linkages between meteorology and air quality, it is essential that both the orientation of the wind direction sensor, and the logging of these data comply with the requirements of Australian Standard AS2923 - 1987)

As a result of the decision to return the air quality and meteorological data to the Environment Protection Authority it is not possible to include the results of the analysis between meteorology and air quality at stations in the vicinity of Badgerys Creek and Holsworthy. Neither is it possible to comment on the frequency of inversions and cold air drainage flows in South Creek Valley, based on an analysis of the vertical measurements of wind speed and direction at Liverpool, and wind and temperature data from Bringelly.

3.5.3 HOLSWORTHY MILITARY AREA - DATA FOR NOISE IMPACT ASSESSMENT AND AIR QUALITY MODELLING

Comprehensive, high quality meterological measurements have been measured at Lucas heights since 1975, and are the closest source of reliable data to both Holsworthy airport options. Since 1991, 15-minute average measurements of temperature have been made at the 2, 10, 15, 30 and 49 metres levels on the meterological tower, whilst wind speed and direction are measured at the 10 and 40 metre heights.

Wind Speed and Direction

The four year period November 1992 to October 1996 was selected for modelling noise impacts at the Holsworthy sites. The 15-minute average wind directions measured at the 10 metre height at Lucas Heights were selected for use at both airport sites. The availability of wind, measurements during this period is shown in *Table 3.1*.

Whilst Holsworthy Option A is close to Lucas Heights and the elevation of there is 180 to 230 metres, Holsworthy Option B is located 15 kilometres south-south-west of Lucas Heights, 240 to 280 metres above sea level, compared with 150 metres at Lucas heights. In the early stages of work for the Second Sydney Airport Draft EIS, the use of the 49 metre winds from Lucas Heights was considered for Holsworthy Option B. However, as explained in *Appendix 1*, following an analysis of Macquarie University wind data measured at a height of 435 metres near Mount Keira North, about 23 kilometres to the south, it was decided that the 49 metre winds from Lucas Heights would be unrepresentative of near-surface winds at Holsworthy Option B. It was estimated, that for some wind directions, wind speeds at Holsworthy Option B would be five percent to eight percent higher than the 10 metre wind speeds from Lucas Heights. However, in view of the high degree of uncertainty involved, it was decided that the 10 metre measurements from Lucas heights were the most appropriate data to use to describe meterological conditions at Holsworthy Option B.

The other factor that was considered for the assessment of noise impact, was the likely change in near-surface wind speed that occur as the air flowed off the surrounding aerodynamically rougher, tree coved areas surrounding each airport site, onto the smoother surface of the runways. On the basis of micro-meteorological theory explained in *Appendix 1*, the 10 metre wind speeds measured at Lucas Heights were increased by 20 percent for noise prediction calculations.

Inversions

Information was required by the noise consultants about the frequency of inversions at Lucas Height with a gradient of one degree Celsius per 100 metres or greater. The four year period of temperatures measured at 10 and 49 metres was analysed and the frequency of inversions in this category are shown in *Table 3.3*.

Rainfall

On the basis of data provided by Sydney Water and Lucas Heights, the gradient of rainfall between the Holsworthy Option B and Lucas Heights was shown to be small and so rainfall measured at the same time as the wind data was used for noise impact predictions at both Holsworthy sites.

Data used for Air Quality Modelling

As explained in *Section 3.5.2*, air quality and meterological data from monitoring stations in the vicinity of Holsworthy were intended to be returned to the NSW Environment Protection Authority. An approach has been made by PPK to obtain measurements for 1996 from the Environment Protection Authority.

3.5.4 SUITABILITY AND LIMITATION OF THE DATA.

Badgerys Creek

Surface Winds

The Macquarie University anemometer at Badgerys Creek was a Lambrecht Woelfle mechanical wind recorder which has a pressure sensitive chart inside the instrument that records wind run and instantaneous values of wind direction. This is illustrated in *Figure 3.8*. The instrument was installed on a knoll at the northern end of the of the original airport site where the elevation was 100 metres (asl) and orientated to true north to within two to three degrees. The stalling speed of the instrument is approximately 0.5 metres per second.

The chart inside the instrument was changed every four weeks and then digitised to produce hourly average values of vector wind speed and direction. When directions are relatively constant the error in digitising the wind direction trace is estimated to be about five degrees. However, during periods of light winds, for example during the breakdown of the surface inversion after sunrise, wind directions can fluctuate significantly, making it more difficult to obtain accurate average vector wind speeds and directions under these conditions.

Vertical Structure of Winds And Temperature

For a comprehensive review of meterological conditions affecting noise and air quality in a region, it is necessary to have information about the vertical structure of winds and temperature in the lowest one to two kilometres of the atmosphere, as well as information about the variation of these parameters with time of day and season throughout the year.

There are a number ways of obtaining this information: by using specially equipped aircraft; by tracking balloons to measure the change in vertical wind speed and temperature with height; using tethered balloon systems which have an instrument package attached below them; or using sounding equipment, such as acoustic wind profilers to obtain measurements of wind speed and direction over relative shallow layers in the lowest few hundred metres of the atmosphere, and RASS/Radar systems that measure average wind and temperature over layers about 60 to 120 metres deep to around two kilometres above the surface. Acoustic profilers and RASS/Radar systems can be operated remotely and have the capability to provide continuous measurements of the vertical structure of wind and temperature at a site.

In previous experiments in Sydney, such as the Sydney Oxidant Study, the Western Basin Experiment, and the Sydney Brown Haze Experiment, an instrumented tethered balloon and the tracking of rising balloons have been used to obtain measurements of the vertical structure of wind and temperature. However, these systems are labour intensive, and it is often very difficult to forecast in advance, the type of meterological conditions needed to be investigated. Consequently, measurements are often instigated on days which are subsequently found to be inappropriate.

In recent years, especially in the USA, the remote sounding of winds and temperature in the lower atmosphere using acoustic wind profiles and RASS/Radar has usually been adopted as the most appropriate approach to obtaining these measurements, and the manually operated systems are now only used to supplement these continuous remote measurements. This approach was adopted in the recent Perth Airshed study, where one acoustic profiler and one RASS/Radar system was installed, and where necessary, these measurements were supplemented by tethered profiling and balloon releases, Western Power Corporation, (1996).

The NSW Environment Protection Authority recognised the need for these remote sounding systems in its tender document for the *Metropolitan Air Quality Study* which stated that 'one or more sounders will be employed in the Sydney Region for vertical profiling of the atmosphere' (Environment Protection Authority, 1992), and it had been expected that one of these sets of sounding equipment would be located in western Sydney. However, no remote sounding systems were installed in Sydney during the *Metropolitan Air Quality Study*.

In an attempt to measure of the vertical structure of wind and temperature on the two days required to be analysed in detail for the *Metropolitan Air Quality Study*, so that the Urban Airshed model could be properly validated, the NSW Environment Protection Authority carried out a campaign of measurements using tethered balloon systems and balloon tracking in January and February 1994. However, because of the difficulties of forecasting ozone episodes in advance, no vertical profiles of wind and temperature were made on the two detailed event days. As a result, it was not possible to interpret the complex meteorology that caused moderate to high concentrations of ozone to occur in western Sydney on these two days, and in the absence of these vertical measurements of wind and temperature it was not possible to completely validate the Urban Airshed model, (Cope et al., 1997; Hyde et al., 1997)

As a result of the Environment Protection Authority's decision not to install any of these systems in Sydney as part of *Metropolitan Air Quality Study*, there is only very a very limited amount of information available about the structure of winds and temperatures in western Sydney, and this has seriously limited the amount of information required to properly assess meterological conditions in the vicinity of Badgerys Creek.

Instead, it has been necessary to make use of the very limited number of profiles made in western Sydney as part of previous measurement program, for example, the Western Basin Experiment (Hyde et al, 1980), and the more recent data gathered by the NSW Environment Protection Authority during its summer campaign of measurements in 1995, (Enviromet Meteorological Consultants, 1995).

Holsworthy

Surface Winds

On the basis of information about calibration and other quality control procedures adopted by the Australian Nuclear Science and Technology Organisation and listed in *Appendix 2*, the meterological measurements from Lucas Heights are considered to be of very high quality, and there is a long period of records available to assess inter-annual variability of winds at this location. Details of the instruments used to record the measurements of wind and other meterological parameters at Lucas heights, quality assurance checks and validation procedures are given in *Appendix 2*.

Vertical Structure of Winds and Temperature

Although routine measurements of the vertical structure of wind and temperature in the lower atmosphere are not available at Lucas Heights, low-level wind and temperature measurements have been made on their 49 metre tower for many years which has provided reliable information about inversion statistics for use in the Second Sydney Airport Draft EIS. In addition, between 1975 and 1981 an acoustic sounder was operated at Lucas Heights, which provided information about the depths of mixing layers throughout the day and season. The echoes from the acoustic profiler which were recorded on a facsimile chart, were calibrated using tethered balloon ascents to measure the associated vertical structure of winds and temperature.

Meterological Measurements from other Organisations

Information about meterological measurements obtained from other organisations were listed in *Section 2*. Details about the type of instruments, their performance, and quality assurance procedures followed by other organisations who provided meterological measurements for this investigation are listed in *Appendix 2*.

PART B: EXISTING ENVIRONMENT

CHAPTER 4 EXISTING ENVIRONMENT

4.1 WIND SPEED AND DIRECTION

4.1.1 SYDNEY BASIN

The direction of the wind in Sydney on a particular day is governed by the large scale pattern of atmospheric circulation, but is frequently modified by regional and local wind flows. The dominant feature of the surface synoptic charts are the regions of high pressure which continually move from west to east across the continent, with an average frequency of five to six days (Gentilli, 1972). As one region of high pressure moves eastwards into the Tasman Sea, there is usually a period of strengthening warmer north to north-westerly winds, followed by a cooler south-east to south-westerly change as the next region of high pressure moves across eastern New South Wales (Bureau of Meteorology, 1991).

In summer, the mean path of these regions of high pressure is through Bass Strait and the prevailing synoptic wind directions in Sydney are onshore. In winter, with the movement of the sun into the northern Hemisphere, the mean path of these regions of high pressure cross the Australian continent north of Sydney (Gentilli, 1972). As a result, the predominant synoptic wind directions in Sydney during winter are west to south-west (*Figure 3.6*).

Whilst, it is the prevailing synoptic weather pattern which produces day to day, and seasonal changes in surface winds, temperatures, cloud and rainfall, the proximity of Sydney to the coast and the topography of the Sydney Basin combine to create regional and local wind systems such as sea breezes and cold air drainage flows which act to moderate or change the direction of the synoptically driven winds (Bureau of Meteorology, 1991).

The effect of changes in synoptic weather patterns and the moderating effect of sea breezes and cold air drainage flows on winds in Sydney is illustrated by the 0900 and 1500 wind roses from Sydney Airport and Richmond plotted in *Figure 4.1* (Bureau of Meteorology, 1991). In *Figure 4.1*, the length of the 'tail' for each of the eight main compass directions (that is, north, north-east, east, etc) gives the total percentage frequency of time that winds were blowing from the direction of the tail. In addition, each 'tail' has been divided into a number of segments which gives the percentage frequency of winds blowing from a particular direction in different ranges of wind speed. The percentage frequency of 'calms' is tabulated in the figures, and is also represented schematically by the diameter of the circle at the centre of each wind rose.

Sydney Airport - Bureau of Meteorology (1991)

In each month, the wind roses at 0900 and 1500 show a high frequency of winds blowing from the south, which occur as a result of the southerly changes in wind direction as each region of high pressure moves east across New South Wales into the Tasman Sea.

In Summer (January), the morning wind roses show winds blowing from a range of directions, with maximum frequency for southerly directions. The afternoon wind directions are mostly onshore, and result from a combination of onshore synoptic winds and north-east to south-east sea breezes.

Autumn (April) and Spring (October) are transition periods when the mean path of the sub-tropical high pressure systems cross Australia at about the latitude of Sydney. In Autumn, the frequency of easterly synoptic winds decreases as the mean path of the sub-tropical high moves north. At the same time, the frequency of sea breezes decline as a result of decreased surface heating during daytime. The frequency of cold air drainage flows increases as a result of: lighter synoptic winds; increasing length of nighttime; and the rapid cooling of ground surfaces after sunset often assisted by clear skies at night. The increase in nocturnal offshore drainage flows is clearly visible in the wind roses for 0900 with a high frequency of light winds from the west and north-west sectors. At 1500, these light westerly flows have gone and are replaced by onshore synoptic winds and sea breezes.

In Winter (July), the northward movement of the regions of high pressure result in predominantly south-west to west synoptic winds in Sydney. The frequency of sea breezes is at a minimum, whilst maximum length of nighttime favours the formation of cold air drainage flows at night. The combined effect of offshore synoptic winds and drainage flows at night is illustrated by the high frequency of light offshore winds blowing from the west and north-west directions at 0900. By 1500 these cold air drainage flows have gone, and the prevailing synoptic winds are west and southerly.

In Spring (October), the mean track of the sub-tropical high moves southwards; the frequency of onshore sea breezes gradually increases as a result of heating of the surface during daytime, while the frequency and duration of nocturnal drainage flows gradually decreases as the length of daylight increases. These changes are clearly visible in the wind roses for 0900 and 1500. In the morning, the frequency of west and north-west nocturnal winds decreases, whilst in the afternoon, the wind rose shows an increasing frequency of onshore synoptic winds and sea breezes.

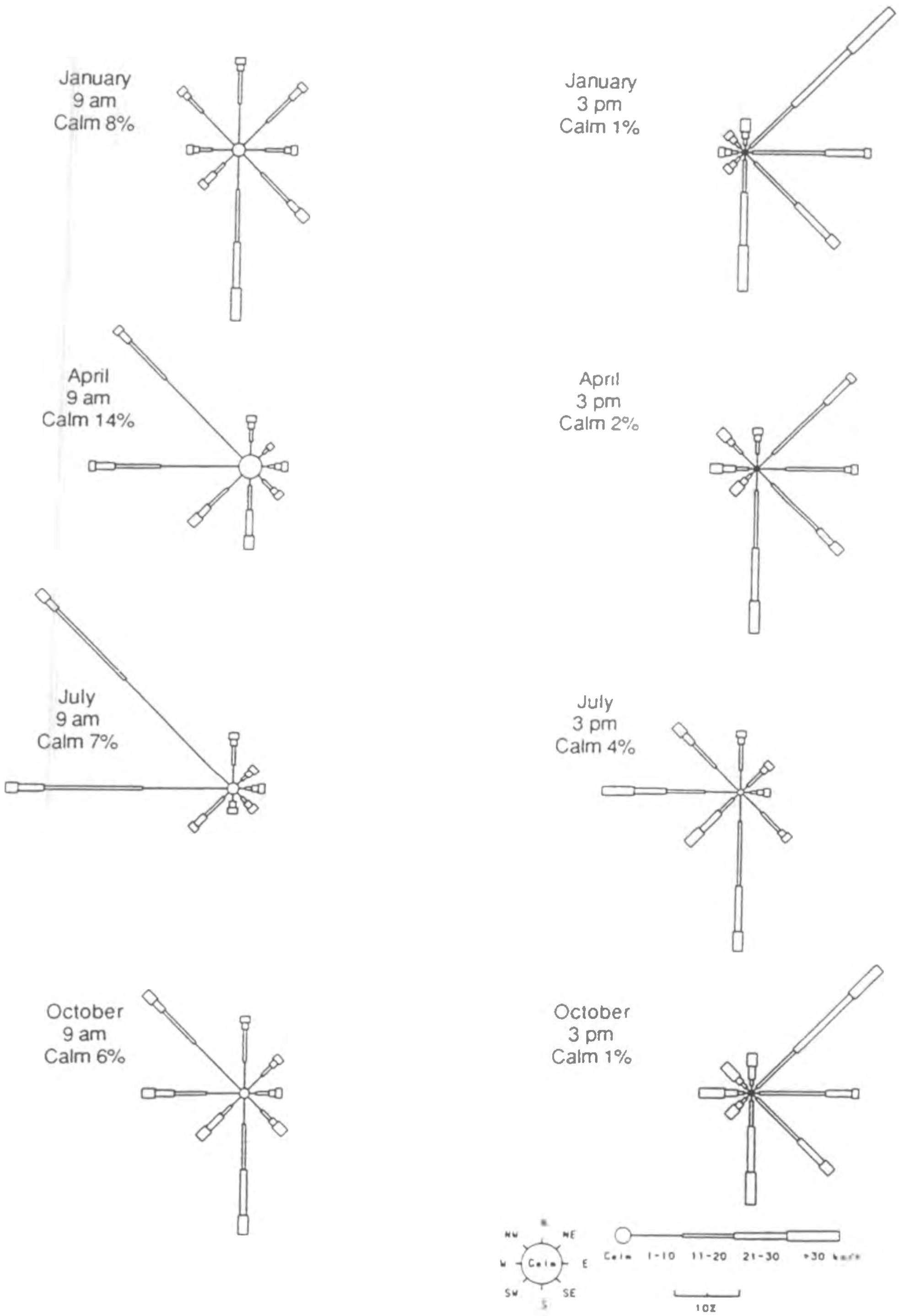


Figure 4.1(a) Seasonal wind roses, 9am and 3pm; Sydney Airport: 1939-1986 (Bureau of Meteorology 1991). Reproduced with the permission of the Bureau of Meteorology.

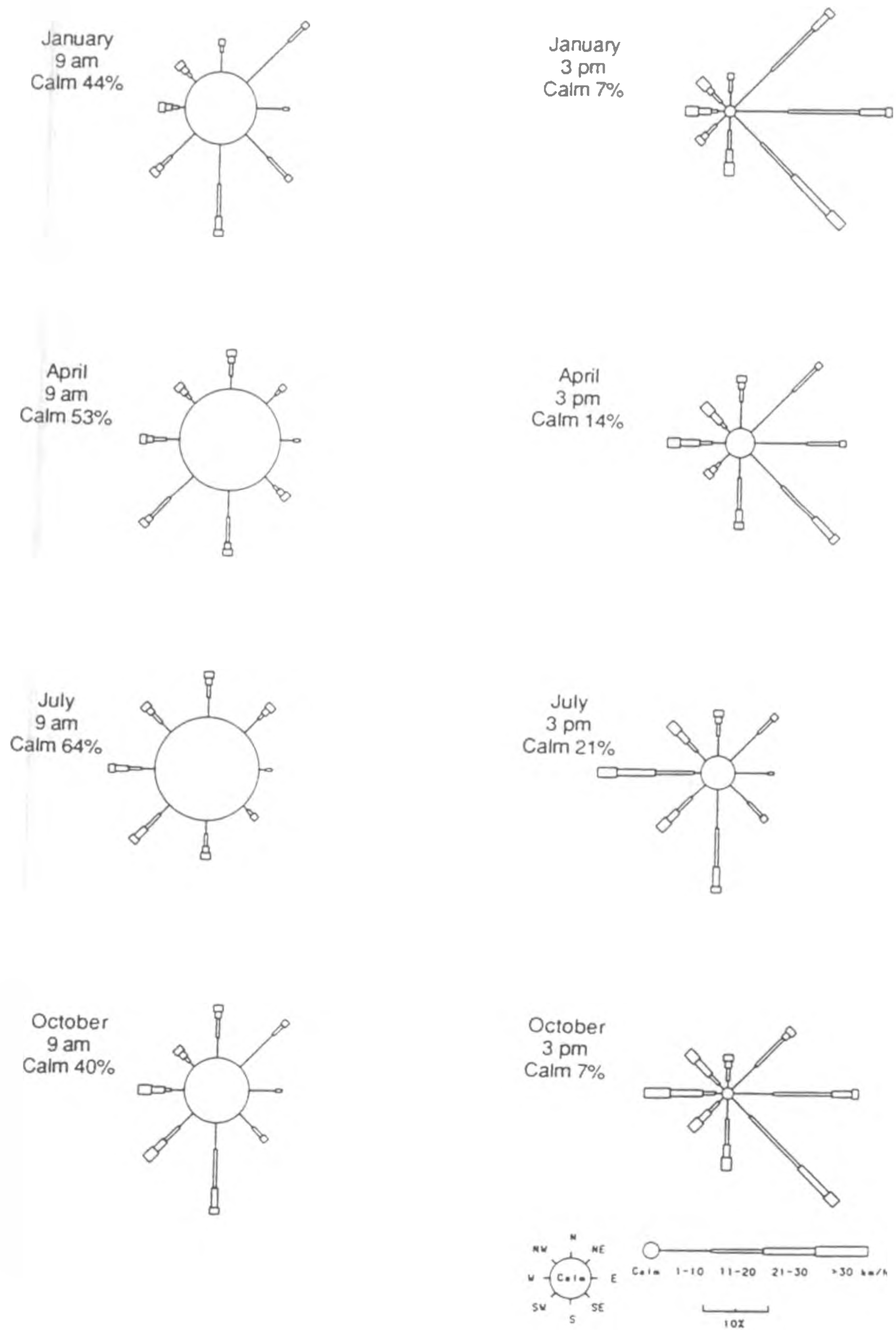


Figure 4.1(b) Seasonal wind roses, 9am and 3pm; Richmond: 1939-1986 (closed 1946 to 1953) (Bureau of Meteorology 1991). Reproduced with the permission of the Bureau of Meteorology.

Richmond - Bureau of Meteorology (1991)

Whilst the afternoon wind roses in *Figure 4.1* show winds blowing from specific directions, the morning wind roses show a high percentage frequency of calms and winds blowing from all directions. The high frequency of calms at Richmond during the morning reflects the combination of the high stalling speed of the Dines wind recorder (Potts et al, 1997), whilst light winds result in strong ground-based inversions and cold air drainage flows blowing from a range of directions (Hyde et al, 1980). By 1500, the ground-based inversions and cold air drainage flows have gone, and winds at Richmond provide a clearer picture of seasonal changes in synoptic wind directions and sea breezes.

In Summer (January), the prevalence of winds from the east reflects the overall onshore synoptic wind directions and the movement of the sea breeze into western Sydney during the afternoon. A similar pattern is observed in Autumn (April), although there is a decrease in the frequency of winds from the north-east to south-east directions and an increase in winds from the west.

In Winter (July), the frequency of winds from the west, south-west and south increases, reflecting the change to offshore synoptic winds in winter, whilst the frequency of onshore winds (north-east to south-east) decreases even further.

In Spring (October), the distribution of winds at 1500 is similar to April; the frequency of synoptic winds from the western sectors gradually decreases, while at the same time the frequency of onshore synoptic winds and sea breezes increase.

4.1.2 WIND DISTRIBUTIONS CALCULATIONS

Whilst *Figure 4.1* has the frequency of winds plotted in the form of wind roses, in this report the frequency of winds blowing from different directions has been plotted as histograms, for example, *Figure 4.2*. In these plots, the percentage frequency of winds blowing from 16 directions has been plotted (that is, north, north-north-east, north-east, east-north-east, etc). The height of the histogram shows the total percentage frequency of time, for the data that was available, when the wind blew from each direction. The shaded sections in each histogram give the percentage frequency of time when the wind blew from that direction for a range of wind speeds. For the analyses presented in this report the following ranges of wind speed in metres per second were used: greater than 0 to 1.4 metres per second; 1.5 to 2.5 metres per second; 2.6 to 3.9 metres per second; 4.0 to 6.0 metres per second; 7.0 to 9.9 metres per second; 10.0 to 12.5 metres per second and greater than 12.5 metres per second.

Note: These speeds can be converted to knots by multiplying speeds in metres per second by two; and into kilometres per hour by multiplying speeds in metres per second by a factor of 3.6.

4.1.3 BADGERYS CREEK

The discussion of winds at Badgerys Creek is based on the two years of wind data recorded by Macquarie University in 1991 and 1992. The annual distribution of winds at Badgerys Creek is plotted in *Figure 4.2*. The seasonal distribution is shown in *Figure 4.3*. Monthly variations are shown in *Appendix 3*.

In Autumn and Spring, the seasonal distribution of winds at Badgerys Creek is dominated by a high frequency of winds centred around the south-west directions. In Winter, the distribution is skewed; the highest frequency of winds is still from the south-west but there is an increase in the frequency of winds from the west-north-west to north-west directions. The seasonal and monthly average frequency distributions in summer are less well defined. There is a low frequency of winds from the west and northerly directions but the percentage of time that winds blow from other directions is similar.

On an annual basis, the frequency distribution is similar to that observed in Autumn and Spring; there is a high frequency of winds between south-south-west and west-south-west with a maximum frequency from the south-west. The frequency of winds blowing from other directions is relatively low.

While the seasonal and annual distributions plotted in *Figure 4.2* give the average frequency of winds from each direction, they mask the substantial diurnal variability in wind directions that are observed in Sydney throughout the year. These diurnal changes in wind direction are illustrated by the wind roses from Sydney Airport and Richmond plotted in *Figure 4.1*. However, these distributions only gave values for 9 am and 3 pm, and do not fully illustrate the substantial changes in wind direction that occur throughout the day in different months of the year.

The importance of the diurnal variability in wind directions at Badgerys Creek is illustrated by the wind speed and direction frequency distributions, plotted in *Figure 4.3* for three hourly intervals throughout the day for each season.

In summer, the winds between midnight and 0600 are dominated by light south-south-west to west-south-westerly cold air drainage flows within the Hawkesbury Basin. The frequency distribution at 0900 marks a period of transition between the breakdown of inversions and cold air drainage flows in the Hawkesbury Basin, and the onset of the predominantly onshore synoptic winds. By 1200 hours, the onshore synoptic winds are well established and during the afternoon the sea breeze moves into western Sydney. This is

Badgerys Creek (1990 - 1992)

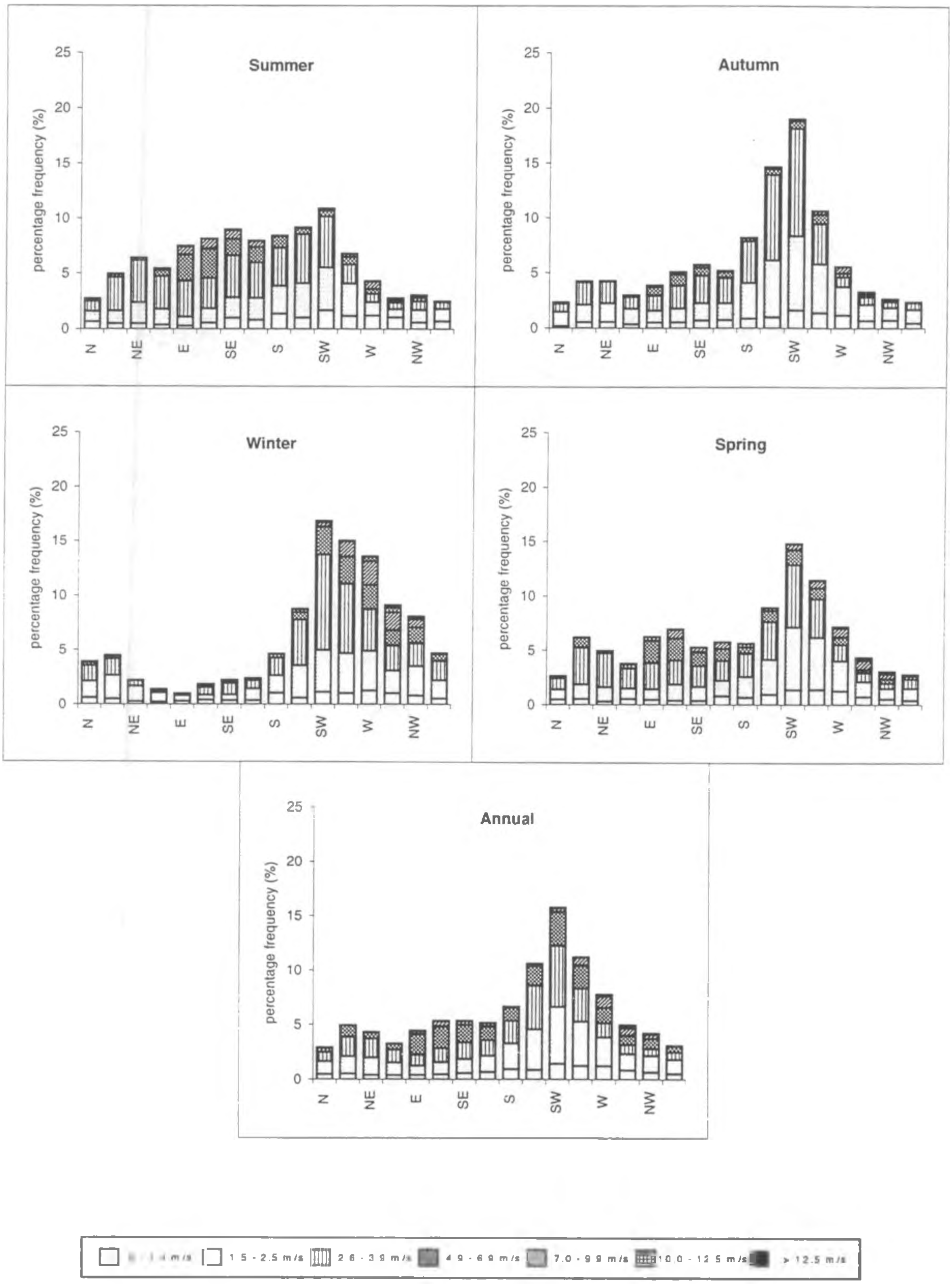


Figure 4.2 Seasonal and annual wind speed and direction frequency distribution, Badgerys Creek (1990 - 1992). Source: R. Hyde. Macquarie University Wind Data

Badgerys Creek - Summer (1990 - 1992)

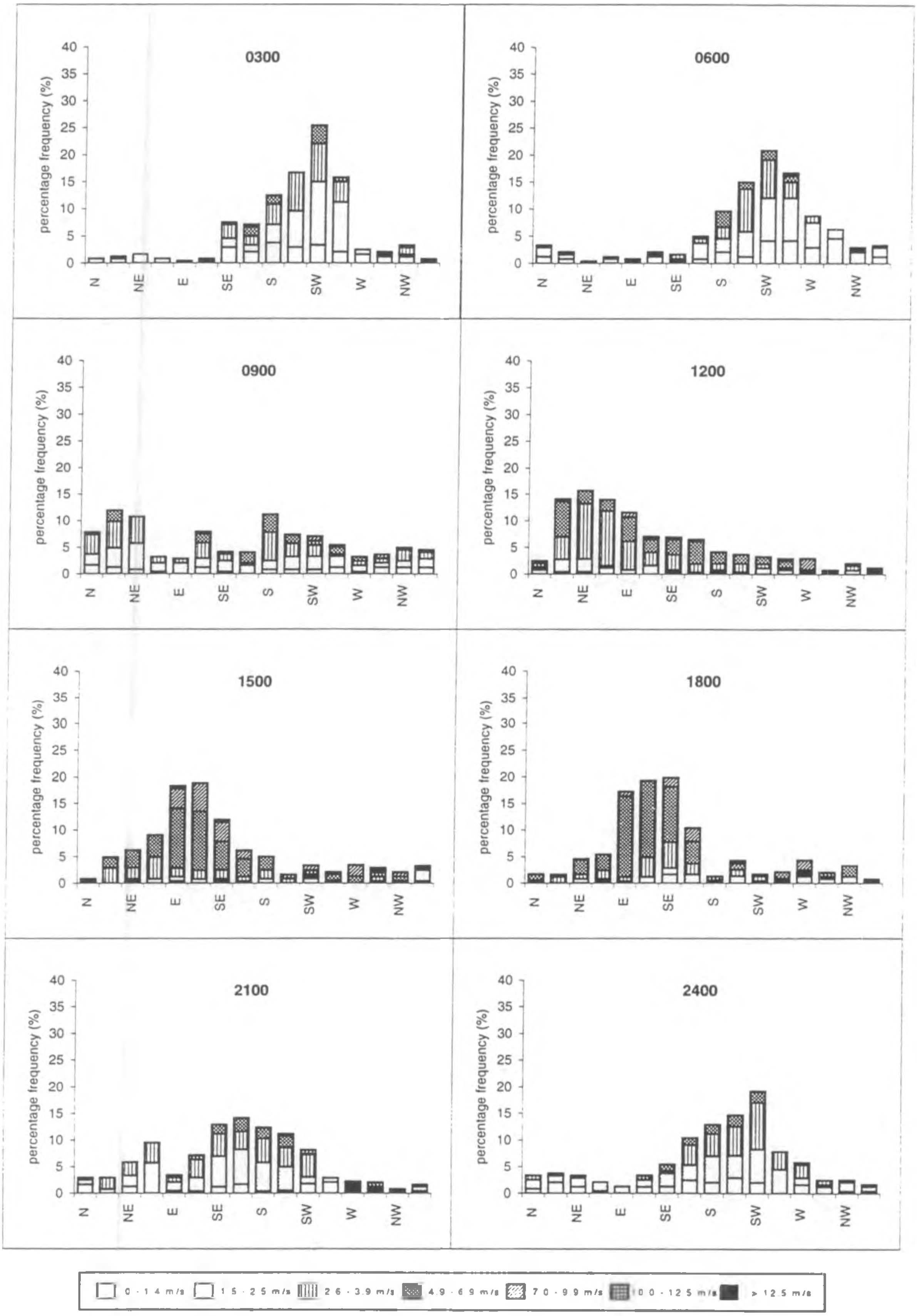


Figure 4.3(a) Three-hourly wind speed and direction frequency distribution, Badgerys Creek Summer (1990 - 1992). Source: R. Hyde, Macquarie University Wind Data

Badgerys Creek - Autumn (1990 - 1992)

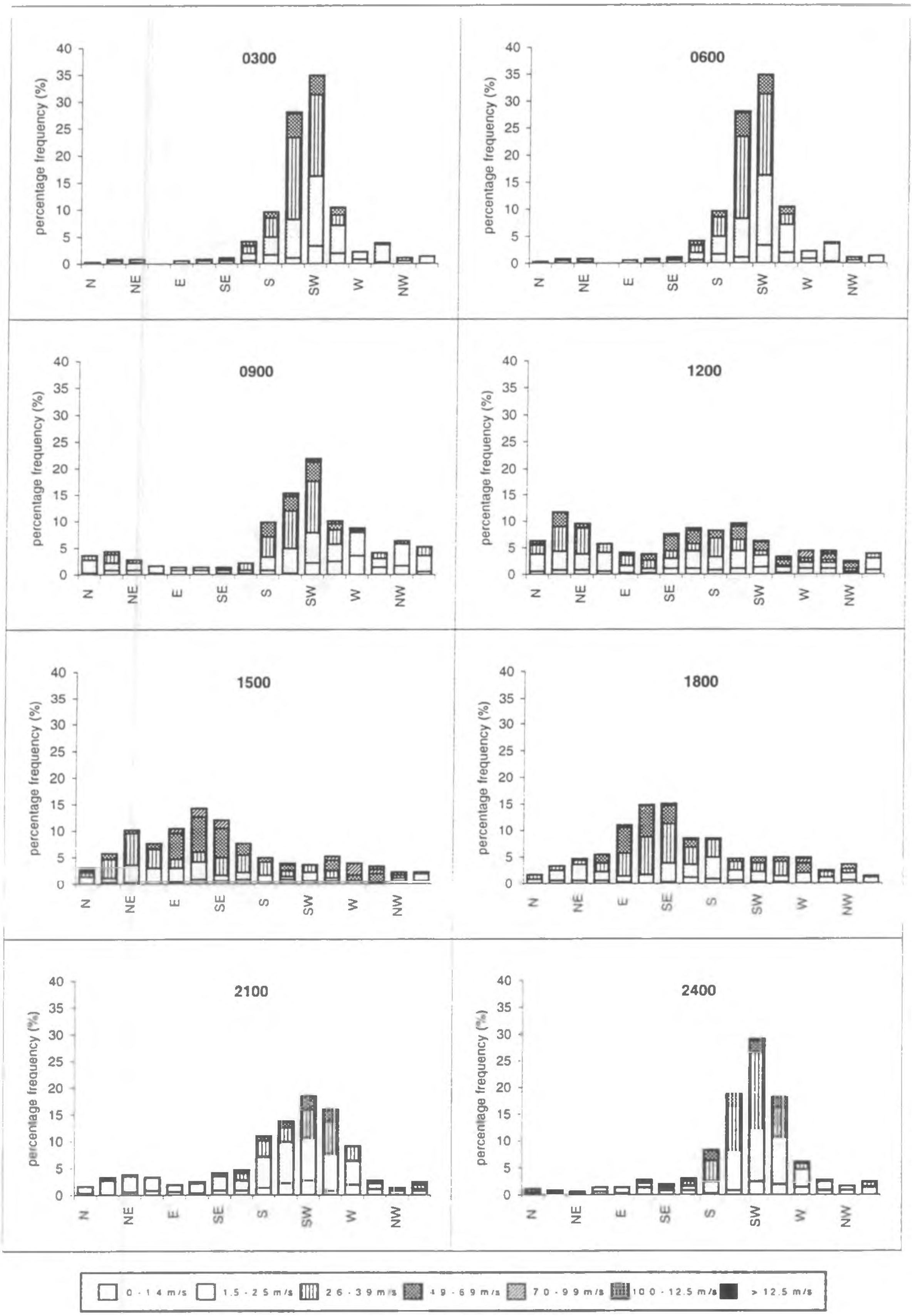


Figure 4.3(b) Three-hourly wind speed and direction frequency distribution, Badgerys Creek - Autumn (1990 - 1992). Source: R. Hyde, Macquarie University Wind Data

Badgerys Creek - Winter (1990 - 1992)

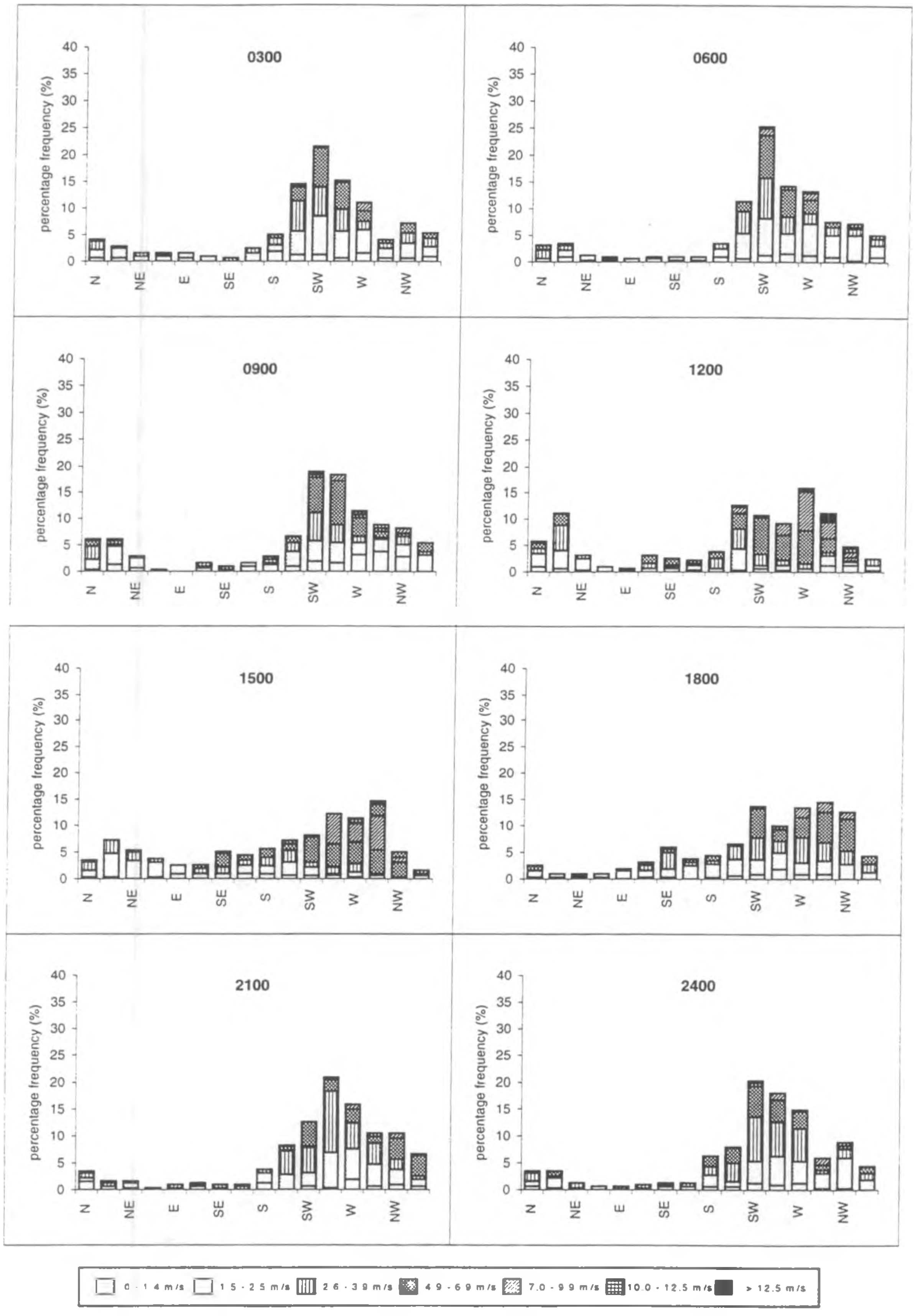


Figure 4.3(c) Three-hourly wind speed and direction frequency distribution, Badgerys Creek - Winter (1990 - 1992). Source: R. Hyde, Macquarie University Wind Data

Badgerys Creek - Spring (1990 - 1992)

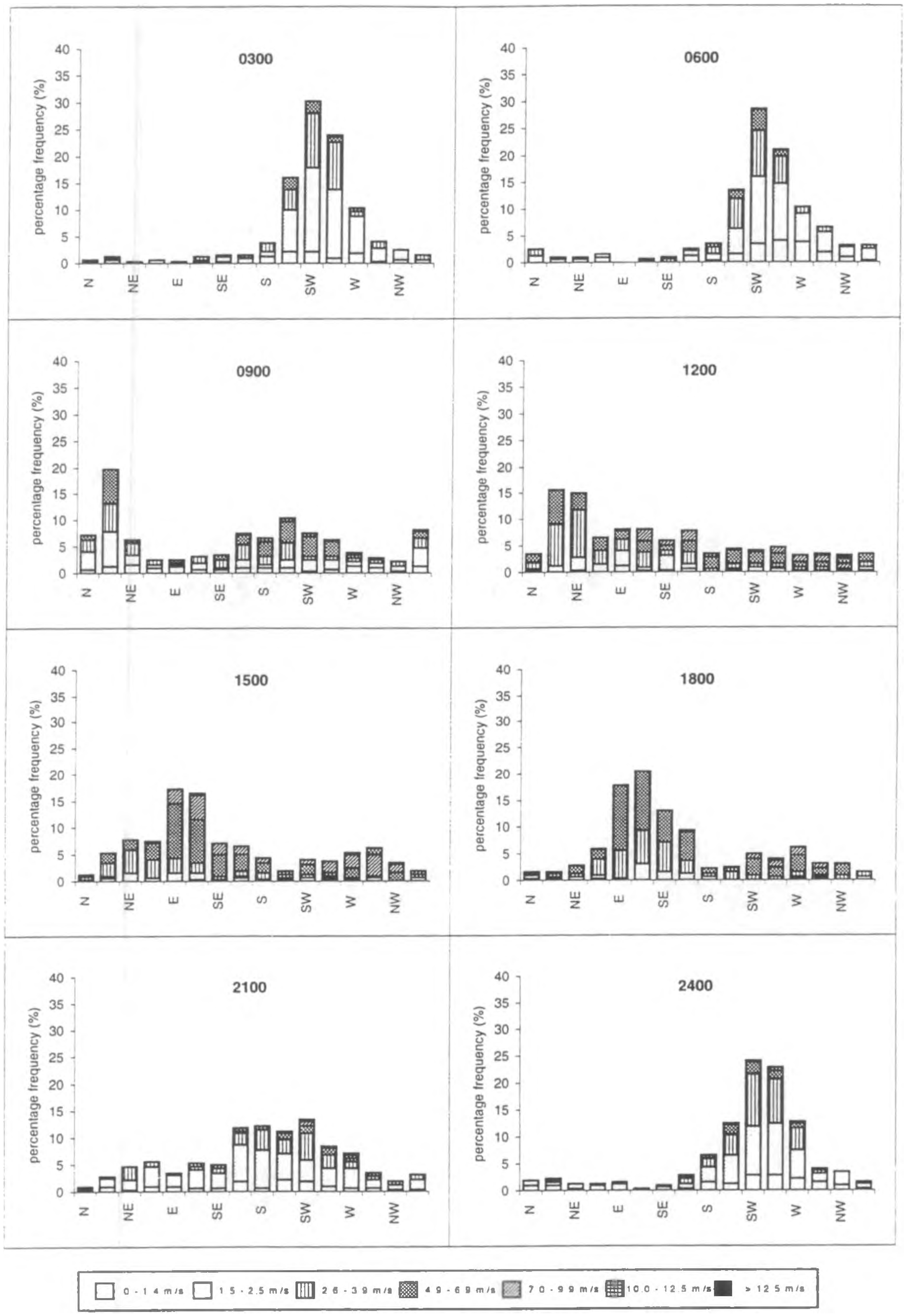


Figure 4.3(d) Three-hourly wind speed and direction frequency distribution, Badgerys Creek - Spring (1990 - 1992). Source: R. Hyde. Macquarie University Wind Data

illustrated by the significant increase in east to south-east winds at 1500 and 1800 hours. By 2100 hours the influence of the sea breeze has largely disappeared, and there is a gradual increase in the frequency of lighter winds from the south to south-west sectors.

In Autumn, south-west winds are well established by midnight; reach a maximum between 0300 and 0600, and are still observed to a lesser extent in the wind distribution at 0900. The distribution of winds at noon is even. Whilst there is an increase in winds from the east to south-east directions, the frequency of these afternoon sea breezes in Autumn is much lower than in summer. As a result, by 2100 hours, rapid cooling of the ground surface after sunset and generally lighter synoptic winds, allow light cold air drainage flows to form in western Sydney and produce a high frequency of nocturnal winds from the south-west.

In winter, synoptic winds are dominated by flow from the west and this is evident in the daytime distributions of wind direction plotted in *Figure 4.3*. By 0900 hours wind strengths have usually increased, and stronger westerly sector winds persist throughout the day. Overnight winds at Badgerys Creek in winter are dominated by south-west to north-west sector winds, and it is difficult to separate the contribution of nocturnal cold air drainage flows from synoptic winds with a similar direction.

Spring is the other transition period; the frequency of westerly sector synoptic winds have decreased, as illustrated by the wind distribution at 1200 and 1500 hours. Overnight cold air drainage flows are again a dominant feature in the wind flow distributions between midnight and 0600 hours. There is an increase in winds from the east and east-south-east directions at 1500 and 1800 hours as sea breezes once again move into the Hawkesbury Basin during the afternoon and early evening.

At present, inter-annual variability of wind flow at Badgerys Creek has not been discussed. The Macquarie University wind record is extremely limited, and there are substantial gaps in the availability of data in some months, *(Table 3.1)*. If the longer term wind data measured by the Department of Aviation at Bringelly as part of the previous site selection process for the *Second Sydney Airport Site Selection Programme Draft EIS* (Kinhill Stearns 1985) becomes available, it will be possible to compare these winds, and the Macquarie University measurements with long term records from Bureau of Meteorology stations in Sydney.

Additional information about wind flow in the vicinity of Badgerys Creek will be available when wind measurements from the NSW Environment Protection Authority monitoring station from Bringelly for 1996 are analysed in conjunction with the 1996 data from the Bureau of Meteorology's automatic weather station at Badgerys Creek.

4.1.4 HOLSWORTHY MILITARY AREA

The closest source of meteorological data is the Australian Nuclear Science and Technology facility at Lucas Heights where extensive meteorological measurements have been made for many years. A comprehensive review of the data from Lucas heights between 1975 and 1983 was reported by Clark, 1985, and the wind distributions presented in this report for the period between November 1992 and October 1996 gave results that were very similar.

The following wind frequency distributions were calculated using wind speed and direction measurements made at the 10 metre and 49 metre levels at Lucas Heights between November 1992 and October 1996:

- annual distributions (*Figures 4.4* and *4.5*);
- diurnal frequency distribution at three-hourly intervals in each season *(Figures 4.6 and 4.7)*; and
- annual distribution for each 12 month period between October 1992 and November 1996; and the annual distribution for the period 1975 to 1996 *(Figure 4.8 and 4.9)*.

The diurnal distribution of winds for each month at 10 metres and 49 metres are given in *Appendix 4* and *Appendix 5* respectively.

On a seasonal and annual average basis (*Figures 4.4* and *4.5*) the most striking difference between the two distributions is the much higher wind speeds at 49 metres, compared with wind speeds measured at 10 metres. This was discussed in *Chapter 3*, and occurs as a result of the effect of surface roughness leading to a decrease in wind speed close to the surface. A fuller explanation of the reasons for differences between wind speeds measured at 10 and 49 metres is given in *Appendix 1*. Otherwise, apart from differences in wind speeds between the two heights, and an increase in southerly sector winds at 10 metres, the two sets of annual distributions are quite similar.

In summer, the overall distribution is dominated by north-east to southerly winds, which occur as a result of summertime onshore synoptic winds and sea breezes, and southerly changes or 'southerly bursters' (Colqhoun, 1983; Bureau of Meteorology, 1991).

In winter, the northward shift in the general circulation results in the seasonal shift towards westerly synoptic winds, combined with cold air drainage flows across the region producing the wintertime seasonal distributions in *Figure 4.4*.

Lucas heights 10m (1992 - 1996)

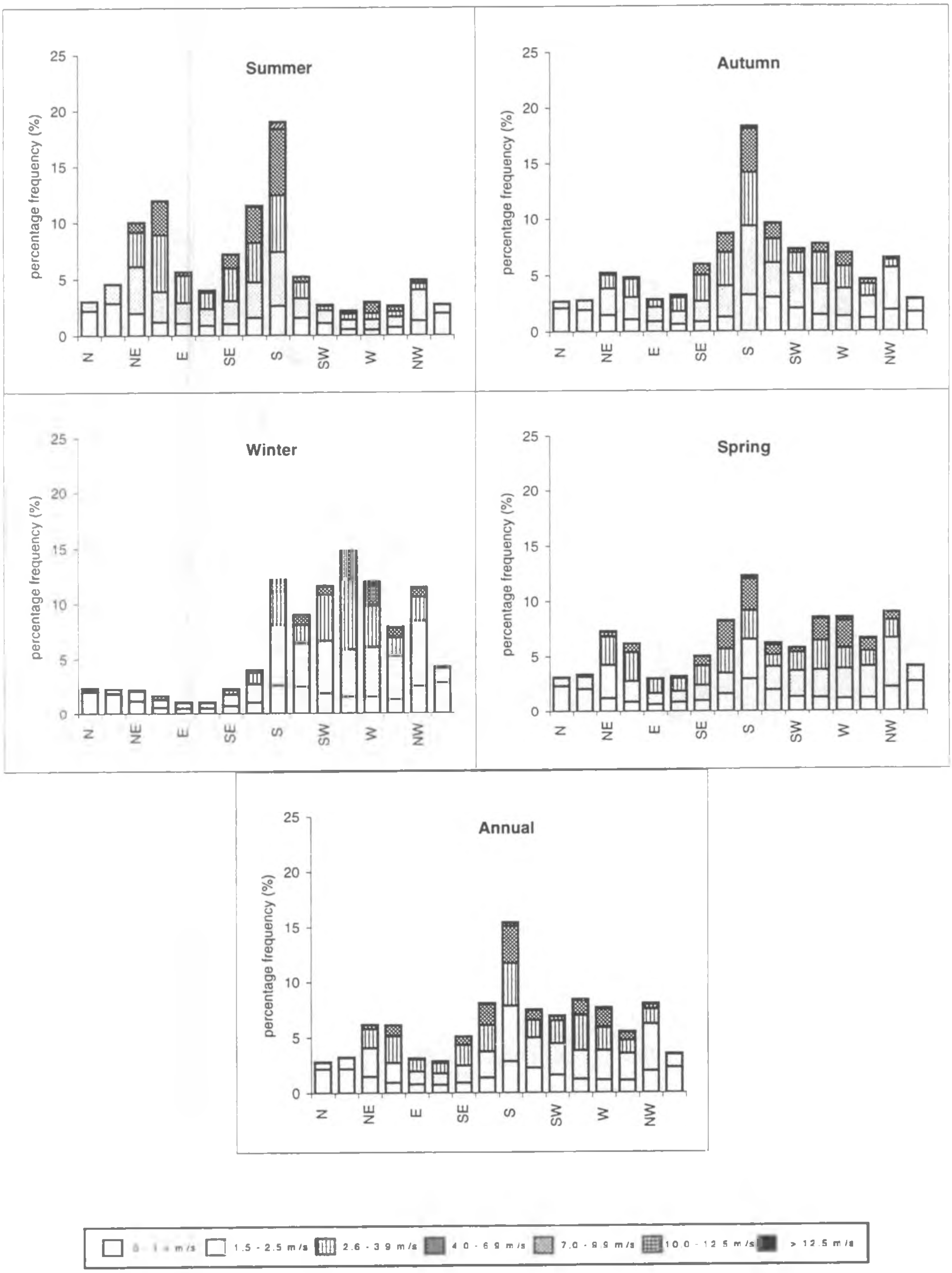


Figure 4.4 Seasonal and Annual wind speed and direction frequency distribution, Lucas Heights - 10 metres height - (1992 - 1996). Source: ANSTO

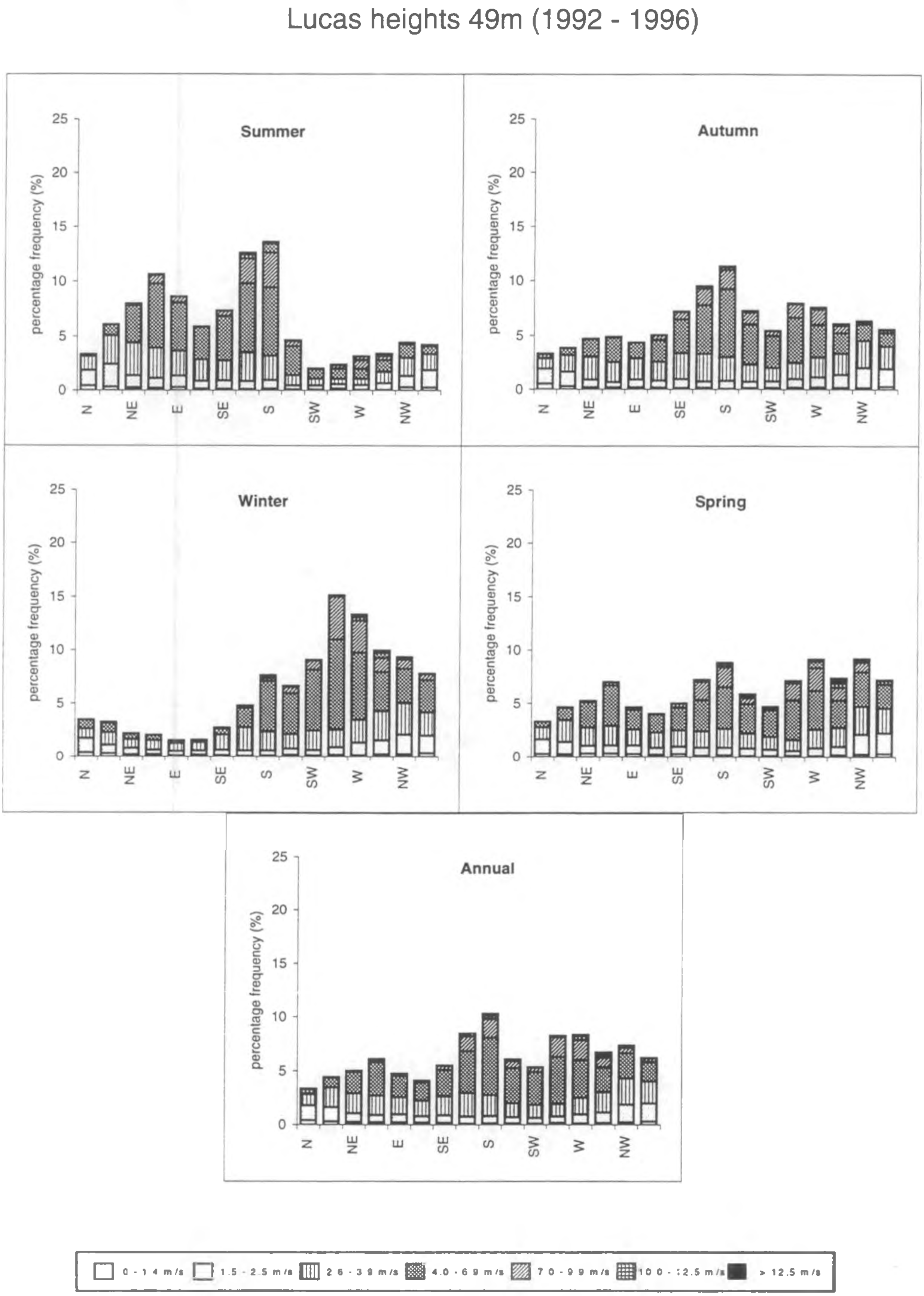


Figure 4.5 Seasonal and Annual wind speed and direction frequency distribution, Lucas Heights - 49 metres height - (1992 - 1996). Source: ANSTO

Lucas heights 10m Summer (1992 - 1996)

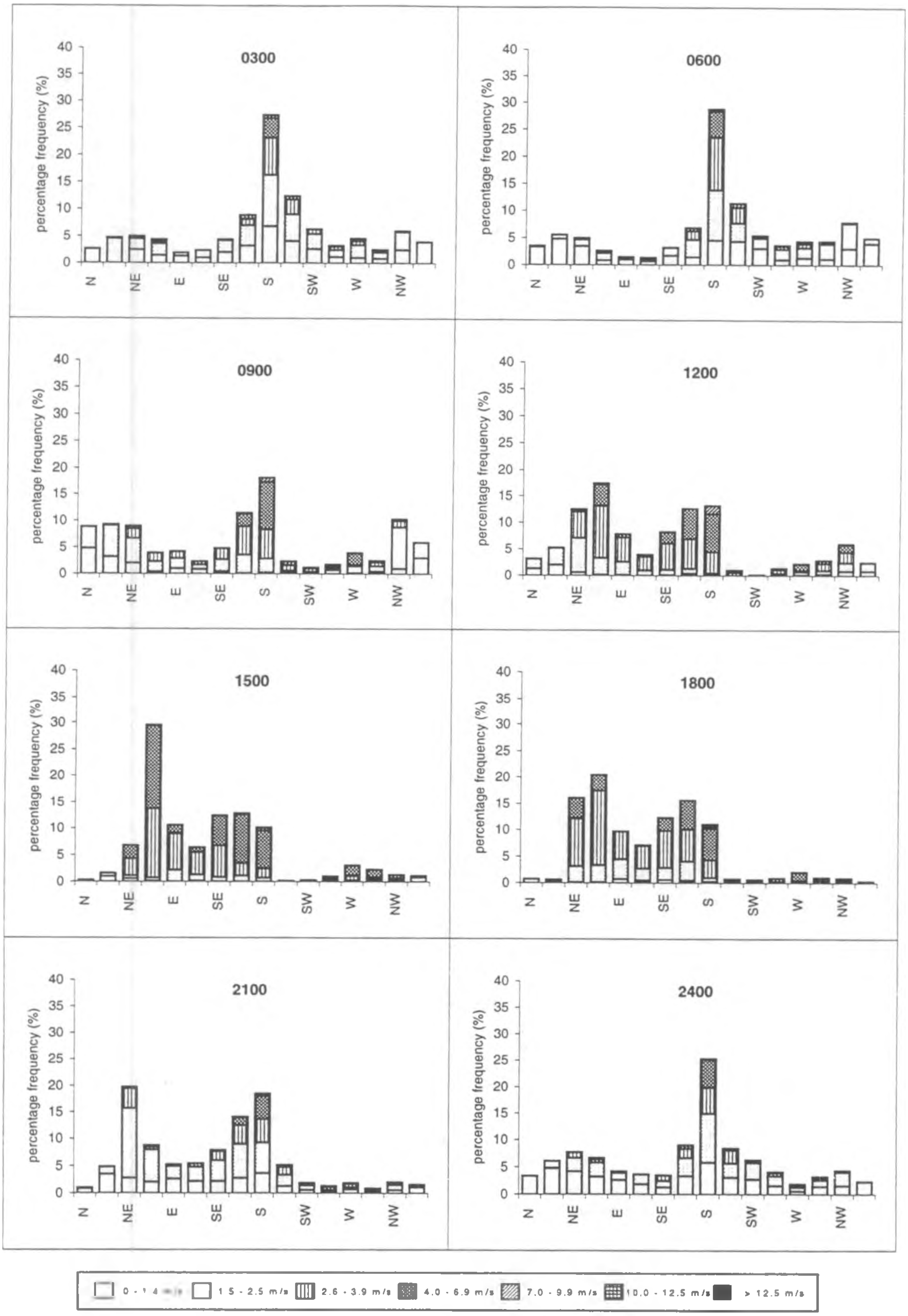


Figure 4.6(a) Three-hourly wind speed and direction frequency distribution, Lucas Heights (10m) Summer (1992 - 1996); Source - ANSTO

Lucas heights 10m - Autumn (1992 - 1996)

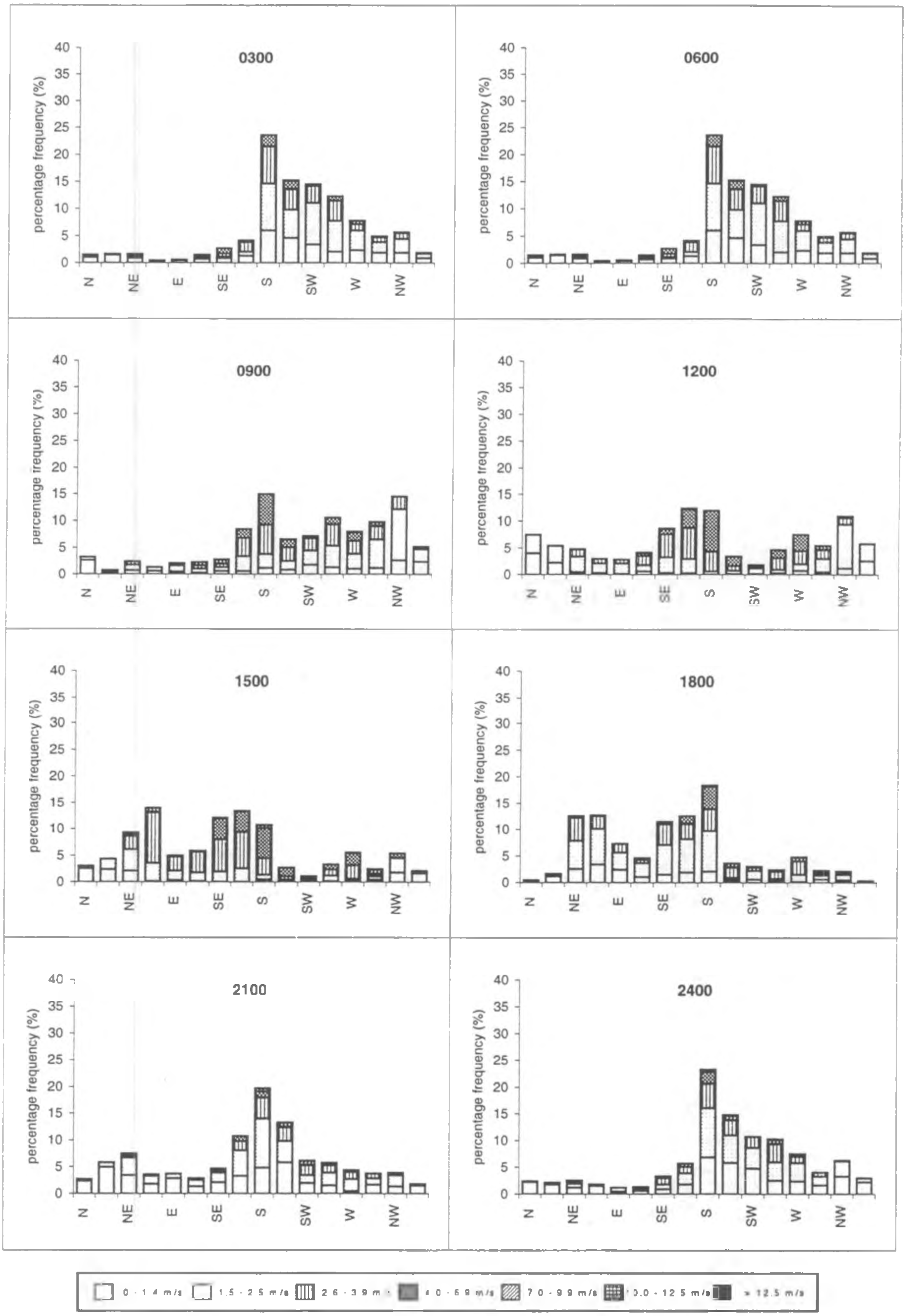


Figure 4.6(b) Three-hourly wind speed and direction frequency distribution, Lucas Heights (10m) Autumn (1992 - 1996); Source - ANSTO

Lucas Heights 10m - Winter (1992 - 1996)

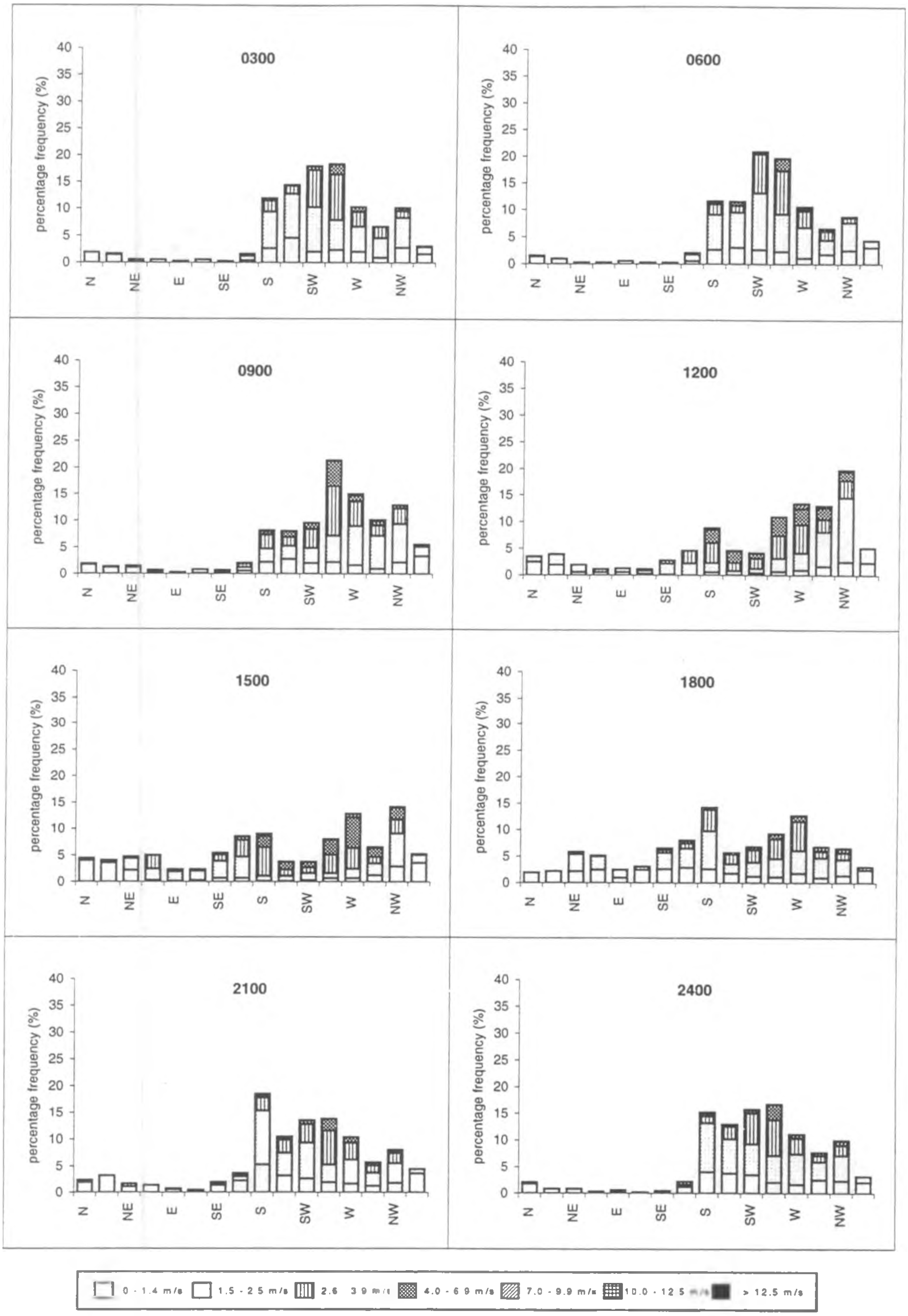


Figure 4.6(c) Three-hourly wind speed and direction frequency distribution, Lucas Heights (10m) Winter (1992 - 1996); Source - ANSTO

Lucas heights 10m - Spring (1992 - 1996)

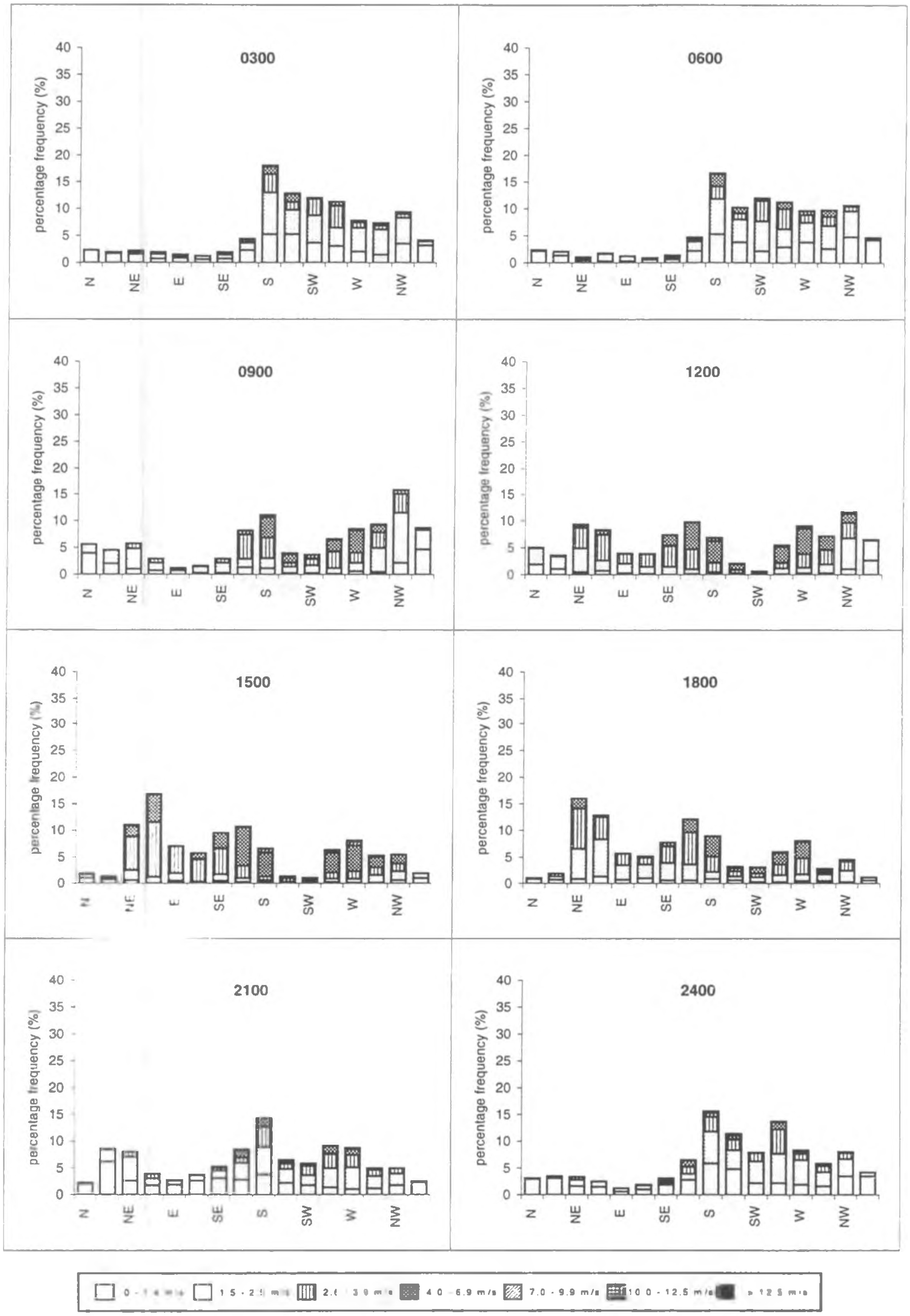


Figure 4.6(d) Three-hourly wind speed and direction frequency distribution, Lucas Heights (10m) Spring (1992 - 1996); Source - ANSTO

Lucas heights 49m Summer (1992 - 1996)

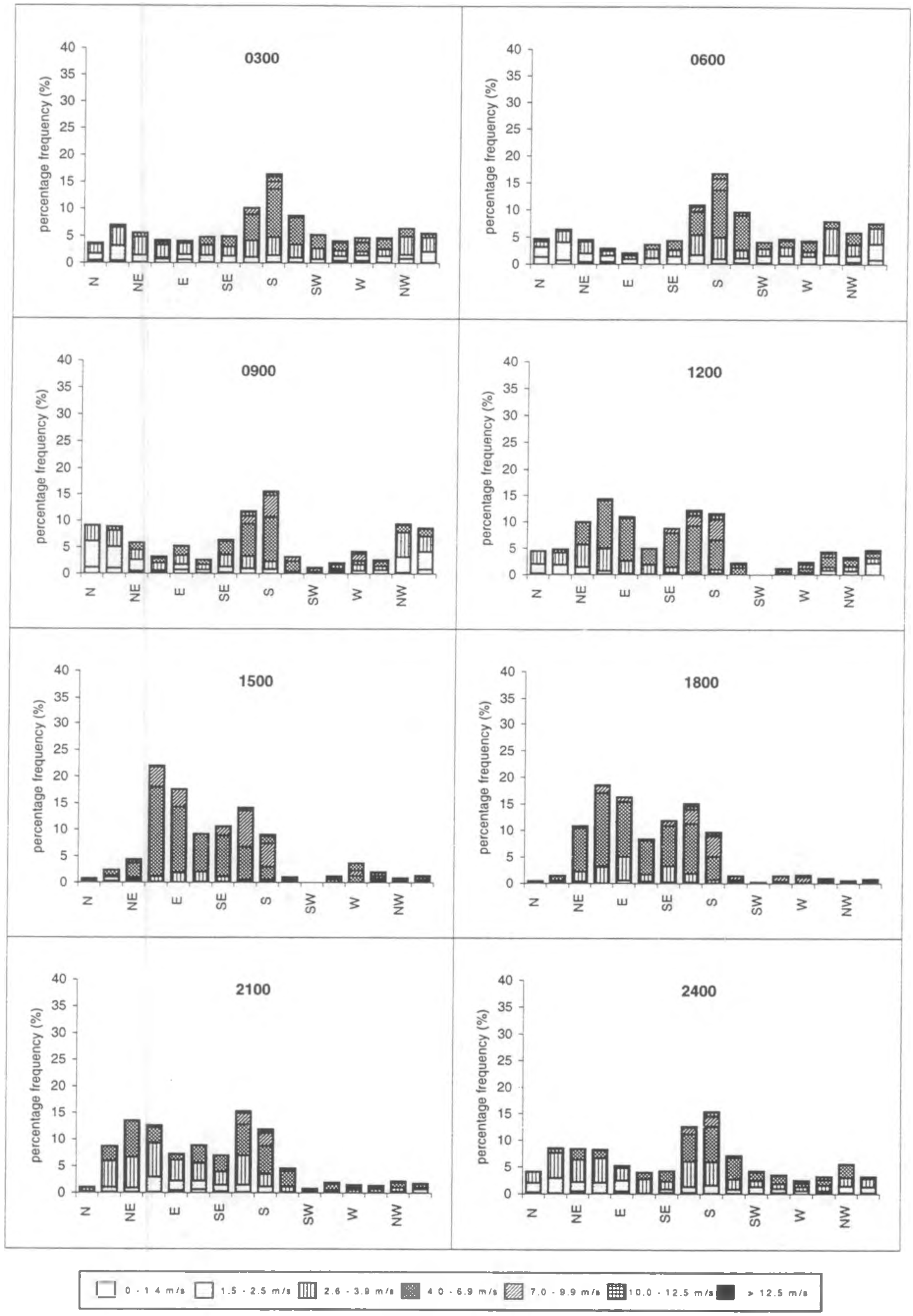


Figure 4.7(a) Three-hourly wind speed and direction frequency distribution, Lucas Heights (49m) Summer (1992 - 1996); Source - ANSTO

Lucas heights 49m - Autumn (1992 - 1996)

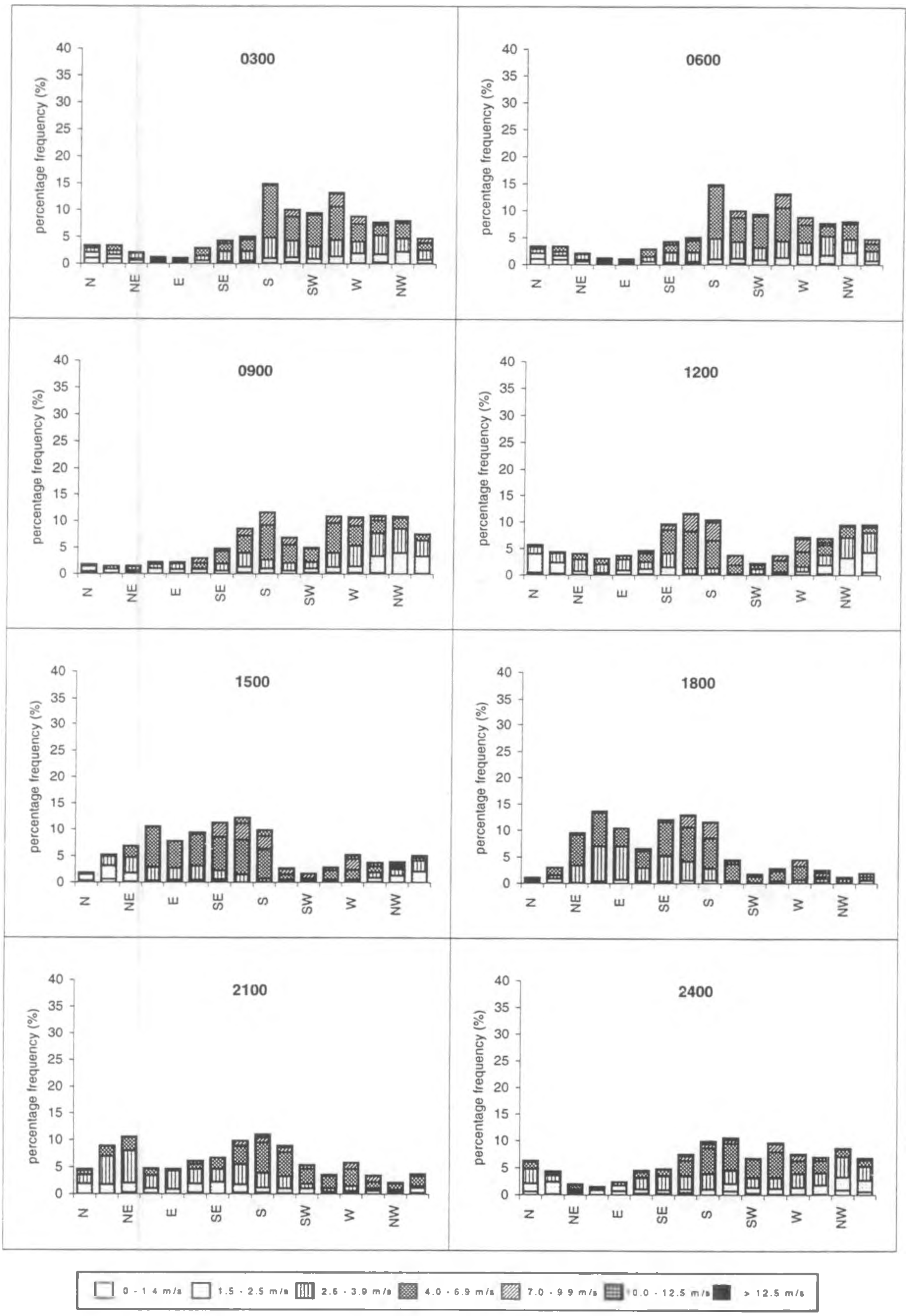


Figure 4.7(b) Three-hourly wind speed and direction frequency distribution, Lucas Heights (49m) Autumn (1992 - 1996); Source - ANSTO

Lucas Heights 49m - Winter (1992 - 1996)

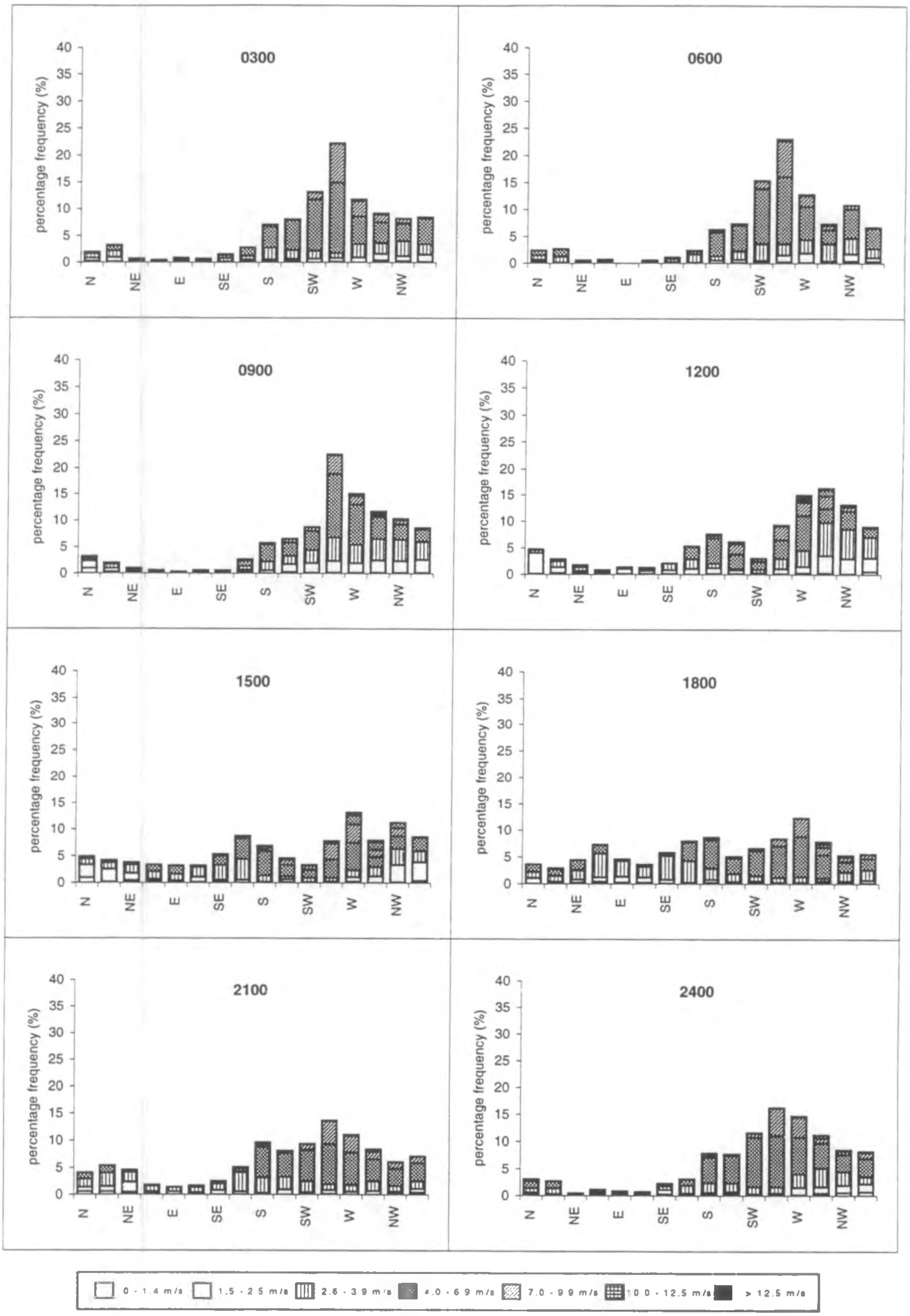


Figure 4.7(c) Three-hourly wind speed and direction frequency distribution, Lucas Heights (49m) Winter (1992 - 1996); Source - ANSTO

Lucas heights 49m - Spring (1992 - 1996)

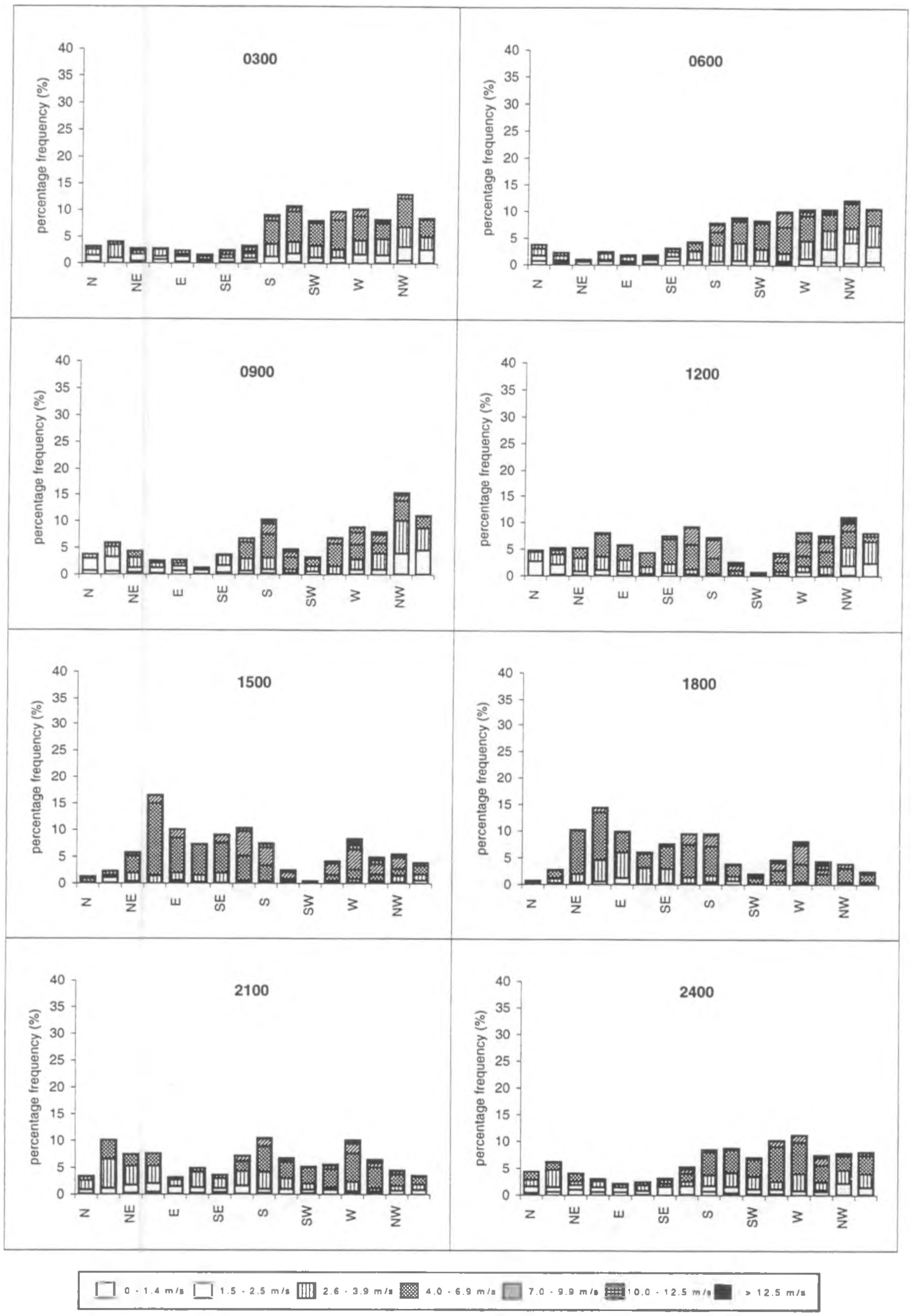


Figure 4.7(d) Three-hourly wind speed and direction frequency distribution, Lucas Heights (49m) Spring (1992 - 1996); Source - ANSTO

Lucas Heights (10m) - Annual Wind Frequency Distributions

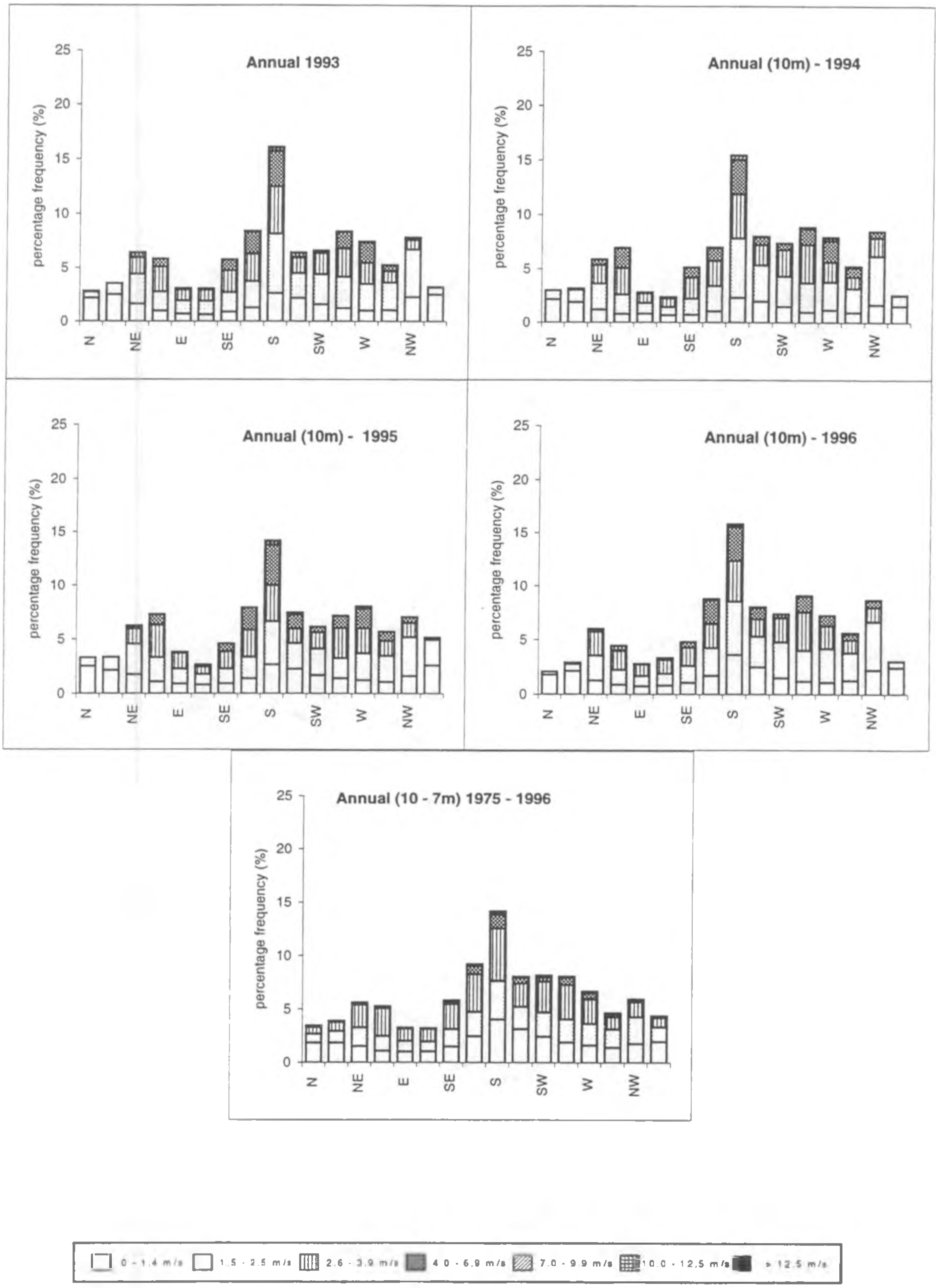


Figure 4.8 Annual wind speed and direction distribution, Lucas Heights (10m), (1993, 1994, 1995, 1996, and 1975 to 1996); Source - ANSTO

Lucas Heights (49m) - Annual Wind Frequency Distributions

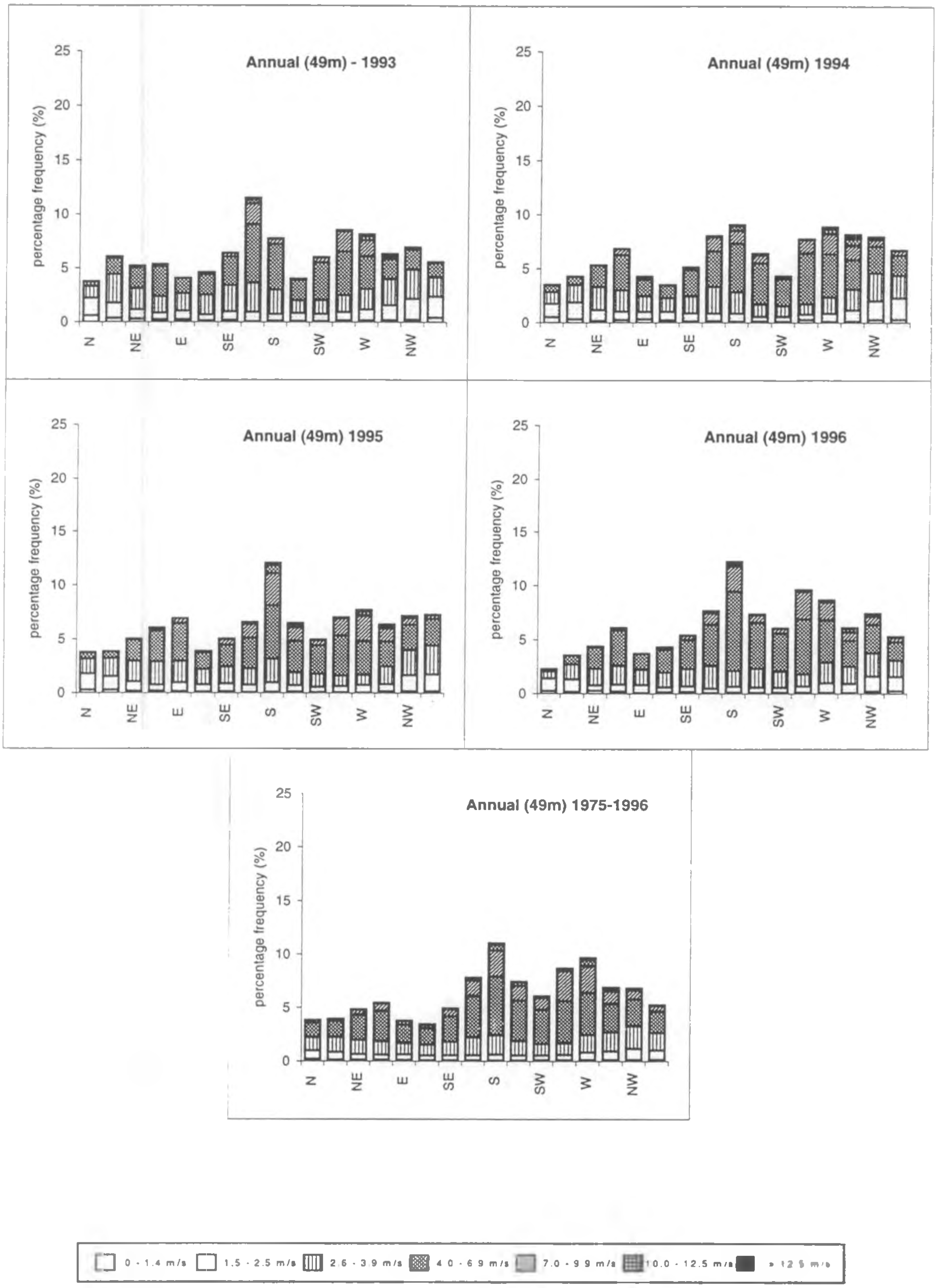


Figure 4.9 Annual wind speed and direction distribution, Lucas Heights (49m), (1993, 1994, 1995, 1996, and 1975 to 1996); Source - ANSTO

The Autumn and Spring wind frequency distributions at Lucas Heights result from the combined affect of changes in the direction of the synoptic winds, and seasonal changes in the frequency of sea breezes and drainage flows.

Variation of wind direction at Lucas Heights at three hourly intervals throughout the day in each season at 10 and 49 metres are shown in *Figures 4.6 and 4.7*.

In Summer, a dominant feature at all times of the day at 10 and 49 metres are southerly component winds, especially at 10 metres. After sunrise, there is a period of transition between the breakdown of nocturnal drainage flow after sunrise, and the onset of synoptic winds and sea breezes. In summer, the influence of the sea breeze is evident in the frequency distribution at 1200 hours, reaches a maximum at 1500 hours, and decreases by 1800 hours. At 10 metres, the predominant direction of the sea breeze is from the east-north-east direction, whilst at 49 metres there is also a strong component of winds within the sea breeze from the east.

The wind frequency distributions for Autumn, are less well defined. The wind distributions at 10 and 49 metres for 0900, 1200, 1500 and 1800, all show winds blowing from a wide range of directions. The influence of synoptic winds from the south, which are associated with the continual movement of regions of high pressure into the Tasman Sea are visible, whilst the presence of sea breezes is visible in the wind distribution for 1500 and 1800. During the night there is a marked change in wind directions to flow offshore. At 49 metres, the spread of wind direction is quite large and although the percentage frequency of winds blowing from each direction is relatively low, the main tendency is for winds at 49 metres to blow from directions between south and north-west. At 10 metres, the distribution is more skewed, with the highest frequency of winds at 10 metres blowing from the south; and a gradual decrease in the frequency of winds between south-south-west and north-west.

In winter, there is a marked shift towards offshore synoptic winds. The mid afternoon and early evening distributions are very flat showing the occasional influence of onshore winds, but in general the winds are dominated by flow from the south and north-west. Between 2100 hours and 0600 hours the following morning, wind directions at 10 and 49 metres are predominantly from the west-south-west, and there is evidence for a significant component of cold air drainage flows at 0900 hours.

In Spring, the diurnal variation in wind directions is less well defined. The wind distributions at 0900 and 1200 illustrate the range of synoptic wind directions that occur in Autumn, whilst the distributions at 1500 and 1800 show the re-emergence of the onshore afternoon sea breezes. Overnight, there is a shift at 49 metres to winds blowing between south-south-west and west-south-west and a corresponding increase in the frequency of winds blowing from the south to west directions at 10 metres as a result of nocturnal cold air drainage flows.

Inter-annual variability in the distribution of wind speed and direction at Lucas Heights has been examined. The annual frequency distribution for each of the four years used for this Draft EIS were calculated, as well a longer term frequency distribution using 20 years of data from Lucas Heights, *Figures 4.8* and *4.9*. Both the annual and the long term frequency distributions are very similar, which provides confidence that the four year period of measurements used for noise impact predictions for the Holsworthy airport options, are representative of the longer term wind record at Lucas Heights.

4.2 SEA BREEZES AND DRAINAGE FLOWS

As well modifying the overall distribution of wind, these meso-scale winds systems are often associated with episodes of high pollutant concentrations in Sydney.

4.2.1 SEA BREEZES IN SYDNEY.

There have been three main investigations into sea breezes in Sydney, Clark (1983), McGrath (1972) and Watt (1986). Clark analysed sea breeze statistics on the basis of surface and lower atmospheric measurements, and his results are discussed in Section 4.2.5. McGrath (1972) and Watt (1986) mostly concentrated on factors influencing the variability in strength, duration and inland penetration of the sea breeze at different locations in Sydney. Both studies contain a detailed review of both the mechanisms producing sea breezes and the factors that control the subsequent direction, duration and speed of inland movement of the sea breeze across a region. The main determinants are: land-sea surface temperature differences, the strength and direction of the synoptic wind, atmospheric stability within the synoptic flow, the orientation of the coast, inland topographic features such as mountain ranges or barriers, the rotation of the earth, vegetation cover and moisture content of the surface.

McGrath(1972) analysed the frequency of sea breezes in Sydney between 1968 and 1970 using analogue wind charts from Sydney Observatory, Sydney Airport, Bankstown and Richmond, as shown in *Table 4.1*. At the coast (Sydney Observatory and Sydney Airport), sea breezes occurred on average on almost 70 percent of days in Summer, decreasing to 19 percent to 26 percent of days in winter. Away from the coast, the frequency of sea breezes decreases; in summer, two thirds of the sea breezes were able to penetrate inland as far as Richmond, whilst in winter, 43 percent to 76 percent of sea breezes were able to reach Bankstown, but only 4 percent to 25 percent penetrated inland as far as Richmond.

McGrath (1972) also analysed the average time of onset of the sea breeze at these four locations, along with information about average duration, and the speed of the maximum gust within these sea breezes. Near the coast (eg Sydney Observatory), the average time of onset of the sea breeze in wintertime was between 1327 and 1421 hours, up to four hours later than in summer (0951 to 1113 hours). At the same time the duration and the speed of the maximum gust of sea breezes during winter, 5 to 7 hours and 5.6 to 7.9 m/s respectively was around half their summertime values, 10 hr 53 min to 12 hr 34 min; and 10.9 to 12.6 m/s.

At Richmond, the duration of the sea breeze in summer (5 hrs 30 min) was about half the value at the coast (10 to 11 hours), whilst in winter, the average duration of the sea breeze at Richmond was between 1 hr 30 min and 2 hr 30 min compared with an average wintertime average duration at the coast of five to seven hours. The speed of the maximum gust in wintertime sea breezes was between 1 and 3 m/s compared with 6 to 7 m/s at the coast, while in summertime, the speed of the maximum gust at Richmond (7.6 to 8.3 m/s) is around two thirds the speed at the coast (10.9 to 12.6 m/s).

The onset of the sea breeze at Sydney Airport was consistently later compared with Sydney Observatory, even though both locations are approximately the same distance inland from the coast. In summer, the average difference in the time of onset of the sea breeze was 50 minutes, and in winter, 16 minutes. McGrath (1972) attributed the difference in the time of onset to be a result of several factors: the combination of easterly component synoptic winds and a north-north-easterly sea breeze at Sydney Observatory tended to allow the sea breeze to accelerate up Sydney Harbour, while the moderating effect of Botany Bay and a weak local sea breeze circulation from the south, the "Botany Bay Breeze", Hawke (1973) combined to delay the onset of the sea breeze at Sydney Airport. This local sea breeze, which only occurs when conditions are calm, has an average speed of 2.2 m/s and an average duration of 55 minutes.

Watt (1986) analysed a number of days when the inland movement of the sea breeze was initially faster along Parramatta River Valley compared with the inland movement of the sea breeze inland from Sydney Airport. However, he observed that with increasing distance from the coast, there was less spatial variation in the position of the sea breeze front; for example he observed that sea breeze arrival times at Blacktown and Campbelltown, 35 and 30 km from the coast were very similar.

There is some limited information about the frequency of sea breezes at other locations in western Sydney. During the Western Basin Experiment in 1980, Macquarie University maintained a comprehensive network of wind recorders in Sydney (Hyde et al, 1980). Information about the percentage frequency of sea breeze occurrence at Wilton, Campbelltown and Blacktown are plotted in *Figure 4.10*. In that year, the maximum frequency in breezes was observed in April 1980 with sea breezes reaching these stations on 70 percent to 80 percent of days. In February and October 1980, sea breezes were observed in western Sydney on 50 percent to 55 percent of days, whilst in winter a much lower frequency of sea breeze occurrence was observed. At Blacktown, wintertime sea breezes were observed on 30 percent to 45 percent of days, whilst at Wilton the frequency had decreased to between 5 percent and 20 percent. At Campbelltown, apart from the very high frequency observed at all three sites in April 1980, the frequency of sea breezes ranged from 45 percent to 56 percent in the warmer months of the year to around 20 percent in winter.

4.2.2 COLD AIR DRAINAGE FLOWS IN SYDNEY

In 1965, Moss (1965) reported the results of an analysis of westerly nocturnal winds recorded at Sydney Observatory. He concluded that these winds occurred as a result of cold air flowing down from the Blue Mountains, would fill the Hawkesbury Basin with cold air to a depth of 10 to 45 metres, then overflow across the boundary into eastern Sydney as a "river of cold air about 27 kilometres wide and up to 90 to 120 metres deep, with speeds of up to 2.5 metres per second at Sydney".

Following Moss' analysis, the structure, frequency of occurrence and spatial distribution and temporal distribution in the Sydney basin has been the focus of considerable attention. Hawke (1977) analysed the results of morning drainage flows at Silverwater for synoptic winds from all directions. He found that the median depths of drainage flow at Silverwater ranged from 100 to 120 metres overall, but that the depth was affected by the direction of the synoptic wind, with depths of 70 metres below south to westerly synoptic winds and 250 metres beneath north-west to north-north-westerly winds.

During the Brown Haze and Sydney Hydrocarbon Experiments (Hyde et al 1982; Nelson et al., 1983), vertical wind profiles made at a number of locations in eastern Sydney (Silverwater, Rozelle, Goat Island, and Bondi) confirmed Hawke's results, although on occasions drainage flows up to 360 metres deep were observed.

The results of vertical wind and temperature profiles, and observations from an extensive network of surface wind recorders during the Sydney Brown Haze and the Western Basin Experiments provided a basis for a generalised classification of drainage flows in the Sydney Basin (Hyde et al., 1980). Two distinct regional drainage flows were identified, one from the west and one from the south-west, while close to the surface, a number of local drainage flows were observed. These included a shallow flow 50 to 100 metres deep from the north-west along Parramatta River Valley *(Figure 4.11)* and a 'South Creek Drainage Flow' a local drainage wind flowing towards the north in the Hawkesbury Basin, with depths between 100 and 200 metres. In addition,

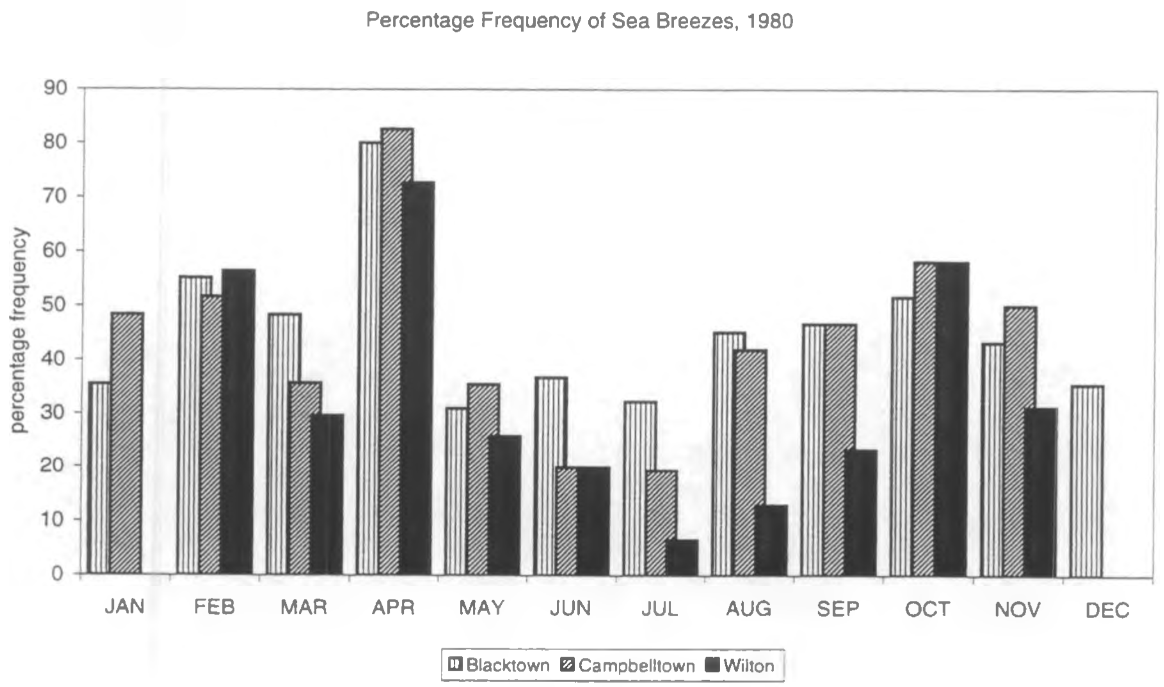


FIGURE 4.10: Percentage frequency of sea breezes at Blacktown, Campbelltown and Wilton, 1980, (Hyde and Johnson, 1990)

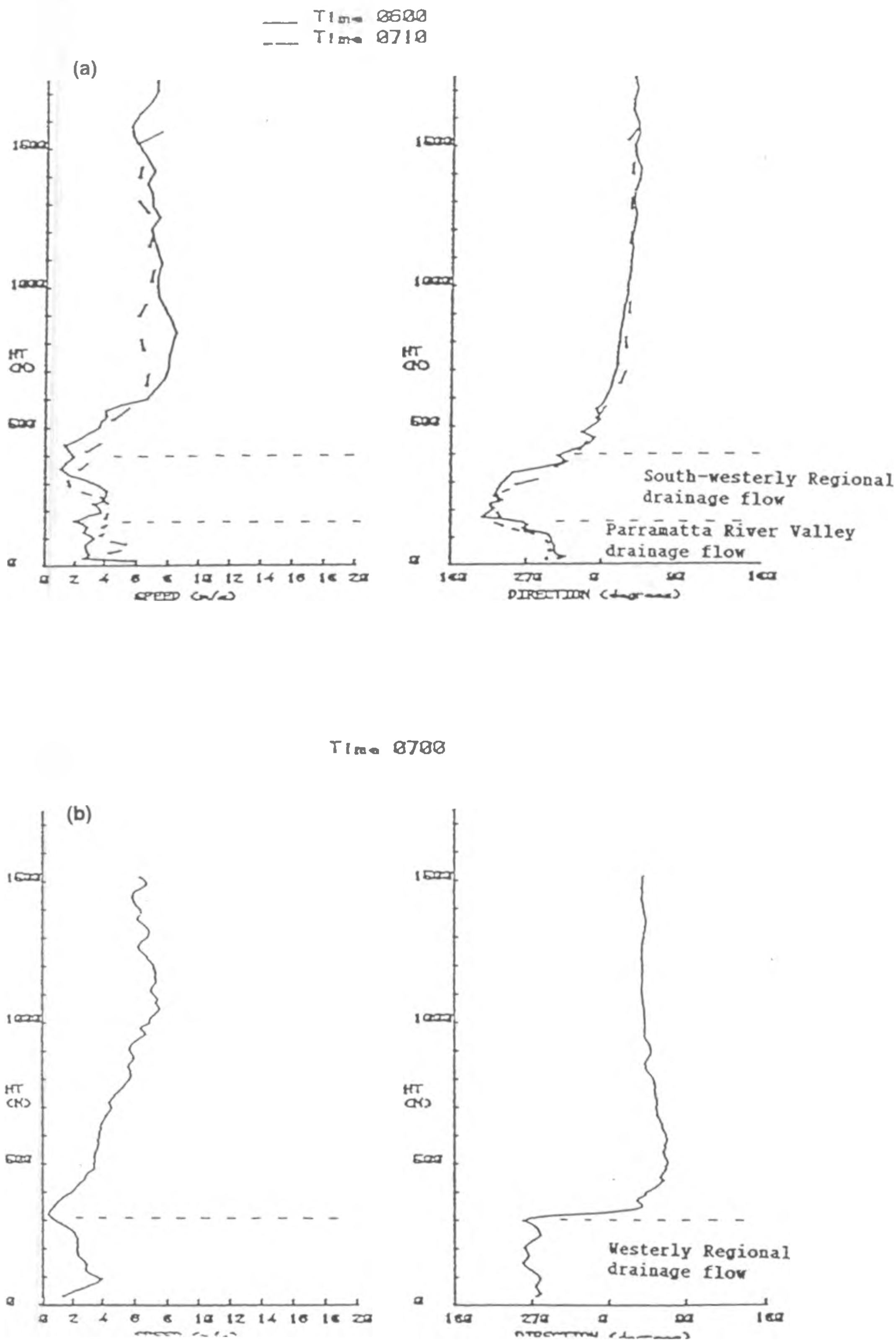


Figure 4.11 Profiles of wind speed and direction: (a) Silverwater 4 May 1978, 0600 and 0700 hours, showing south west regional drainage flow above shallow northwesterly Parramatta River drainage flow, (b) Rozelle 7 May 1980, 0700 hours, showing westerly regional drainage flow (Hyde et al, 1982).

'spillover' of cold air out of the Hawkesbury Basin into the Liverpool Basin and Parramatta River Valley, was observed in the surface wind observations at Blacktown and Prospect Reservoir, together with vertical profiles made at Blacktown (Hyde et al., 1980). On the basis of limited observations of the vertical wind structure at Blacktown the depth of 'spillover' appears to be 30 to 60 metres deep.

One of the features associated with cold air drainage flows is the fact that at the surface the winds within these flows might be quite light. However, wind speeds can increase rapidly with height above the surface, reach a maximum at about halfway through the depth of the flow, and then decreases again. The wind speed profile for 0700 hours in *Figure 4.11* shows some increase in speed above the surface, but wind profiles measured at Rozelle and Narwee, plotted in *Figure 4.12*, show much stronger winds above the surface within cold air drainage flows.

The first example in *Figure 4.11* shows wind profiles measured at Rozelle on 22 May 1980 at 0700 and 0750 hours, and shows wind speeds increasing from about 2 metres per second near the surface, but increasing to about 9.5 metres per second at 200 metres halfway though the depth of the westerly drainage flow (Hyde et. al, 1982). The other example shows a series of previously unpublished wind profiles, made at Narwee on 7 June 1980, between 0700 and 0900 hours (see *Figure 3.1* for location of Narwee). On this occasion the depth of the westerly drainage flow was about 300 metres, but again, wind speeds increased rapidly with height above the surface to reach 7.0 to 8.0 metres per second between 100 and 150 metres, about halfway through the depth of the drainage flow. These observations are important, since in the situation where near surface emissions are trapped below an elevated inversion during the breakdown of a ground-based inversion after sunrise, these stronger winds aloft will act to carry these emissions downwind and assist in the overall dispersion of emissions trapped within this surface mixing layer.

The wind profile plotted in *Figure 4.12* may also help to explain the high winds that are observed during the night at 49 metres at Lucas Heights, when cold air drainage flows are present. The wind histograms for 49 metres plotted in *Figure 4.7*, show that winds at these times can be between 4.0 and 9.9 metres per second. It possible that these higher winds within drainage flows at Lucas Heights occur as a result of the elevation there being 150 metres, which would be close to the height that maximum wind speeds are occasionally within drainage flows observed at lower elevations in eastern Sydney. In this situation the higher speeds observed at Lucas Heights may occur as a result of the drainage wind being forced to flow up the sloping ground surface within the Holsworthy Military Area, west of Lucas Heights.

By combining the observations of vertical wind profiles made at a number of locations across the Sydney basin, a generic pattern of cold air drainage flows in the Sydney basin was developed, incorporating both local and regional drainage flow, and this is illustrated in *Figure 4.13*, (Hyde et al., 1980).

During the Sydney Brown Haze and Western Basin Experiments, most of the observations were made in the cooler months of the year. As part of the Sydney Hydrocarbon Study (Nelson et al, 1983), some vertical profiles of wind and temperature were made in February 1980 at Wilton, and during the summer campaign of vertical measurements made by the NSW Environment Protection Authority during Metropolitan Air Quality Study, summertime vertical profiles of wind and temperature were made at St. Marys in February 1994 and 1995. The remnants of South Creek Drainage Flow were observed on two mornings in 1995, and these profiles are plotted in *Figure 4.14*. On the 2 February 1995, the depth of the flow was about 100 metres, while on 8 February 1995 the drainage flow was 200 metres deep (Micromet Environmental Consultants, 1995).

These data illustrate the day to day changes in the heights of local drainage flows in western Sydney, but there are insufficient measurements available to be able to evaluate the range and variability of drainage flow in the region. At Wilton, in the south of the Hawkesbury Basin, the depth of south to south west drainage flow varied between 80 and 200 metres; when shallow (80 to 100 metres) drainage flows were observed, the wind speed at 10 metres was less than 1.5 m/s, while for deeper drainage flows (180 to 200 metres) surface wind speeds were between 1.5 and 3.0 m/s, as shown on *Figure 4.8*, (Hyde et al., 1980)

Statistics on the frequency and duration of drainage flows in western Sydney were calculated for the Pilot Study, (Hyde and Johnson, 1990). Surface wind charts from Macquarie University wind recorders at Wilton, Campbelltown, Fleurs, Blacktown and Richmond were analysed and the percentage frequency and duration of drainage flows at these locations for 1980 are plotted in *Figure 4.15* and *4.16*. Well defined drainage flows were observed most frequently at Campbelltown, occurring on average on 67 percent of days; Fleurs in South Creek Valley six kilometres north-east of Badgerys Creek had the second highest frequency with 65 percent of days; and Wilton recorded an average frequency of 59 percent of days.

The northern part of the Hawkesbury Basin around Richmond experiences multi-directional drainage flows on an average of 64 percent of nights, whilst at Blacktown, drainage flows and 'spillover' out of the Hawkesbury Basin were recorded on an average of 42 percent of days. Therefore, although common, 'spillover' does not necessarily occur when drainage flows are present in South Creek Valley. This suggests that the height of local flows along South Creek may often be very shallow and lower than the ridge of higher ground at

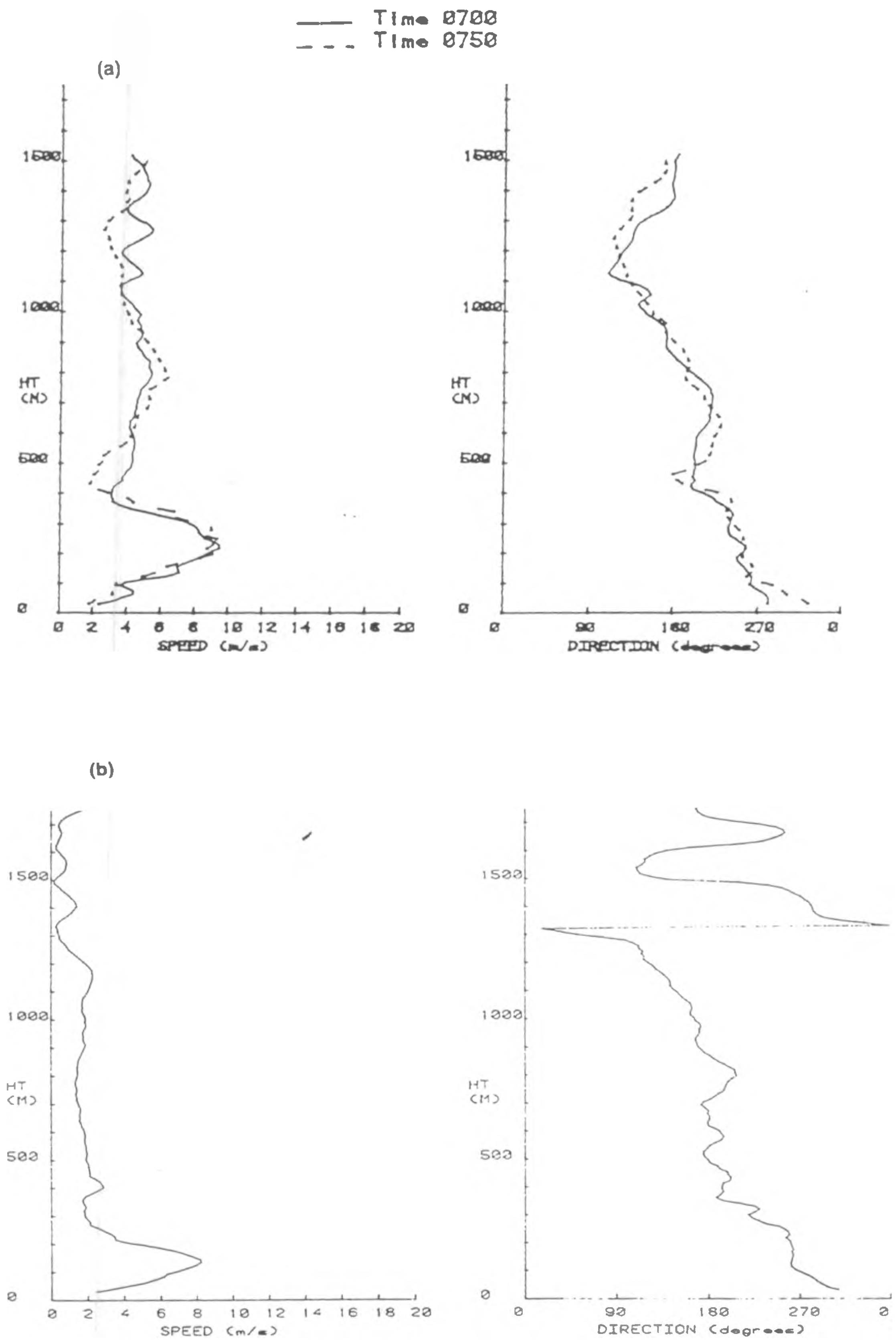


Figure 4.12 Profiles of wind speed and direction in eastern Sydney showing peak of wind speed within drainage flow across eastern Sydney: (a) Rozelle 22 May 1980, 0700 and 0750 hours, (b) Narwee 7 June 1980, 0900 hours (See Figure 3.1 for location)

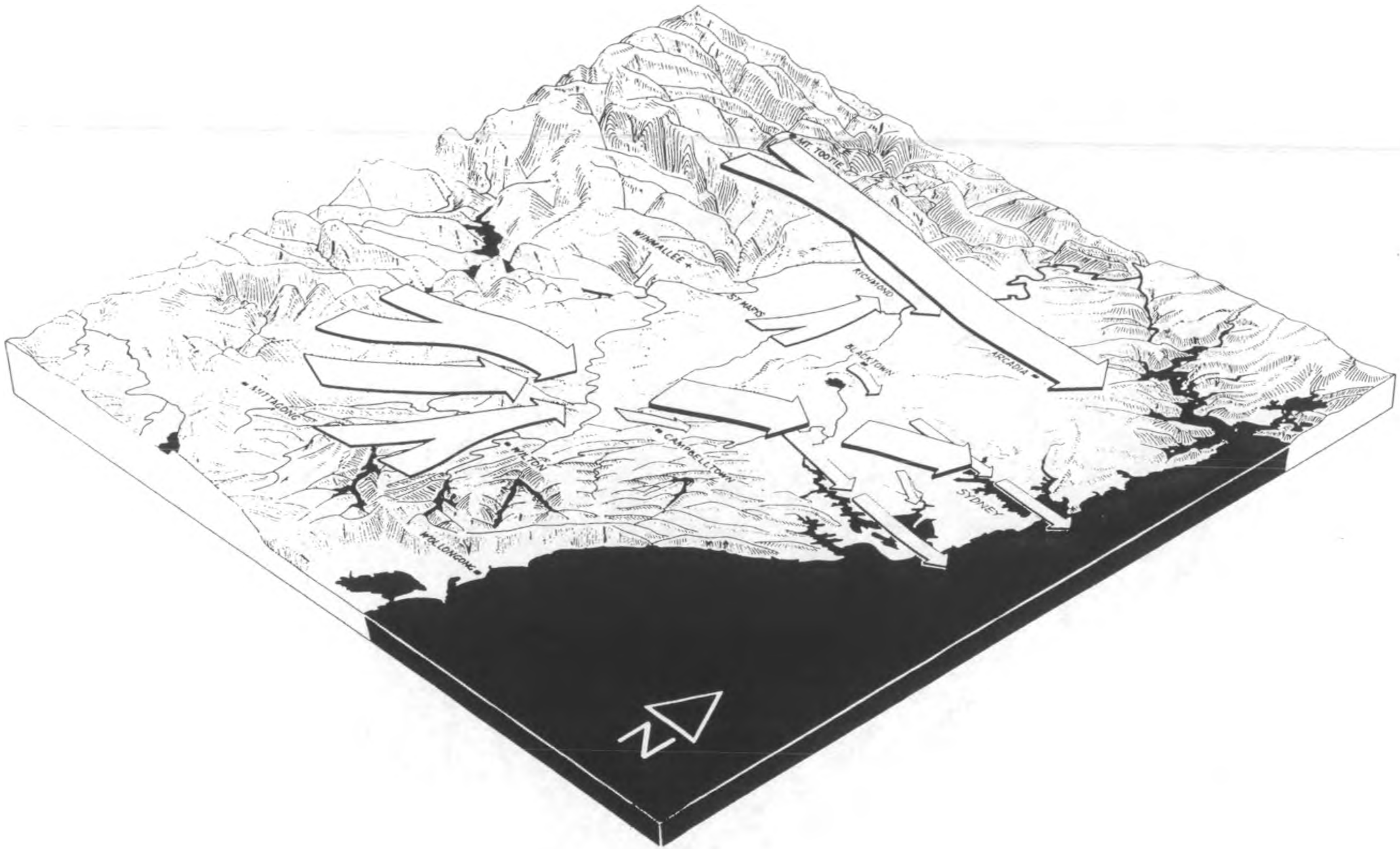


Figure 4.13 Regional and local drainage flows in the Sydney basin (Hyde et al, 1980)

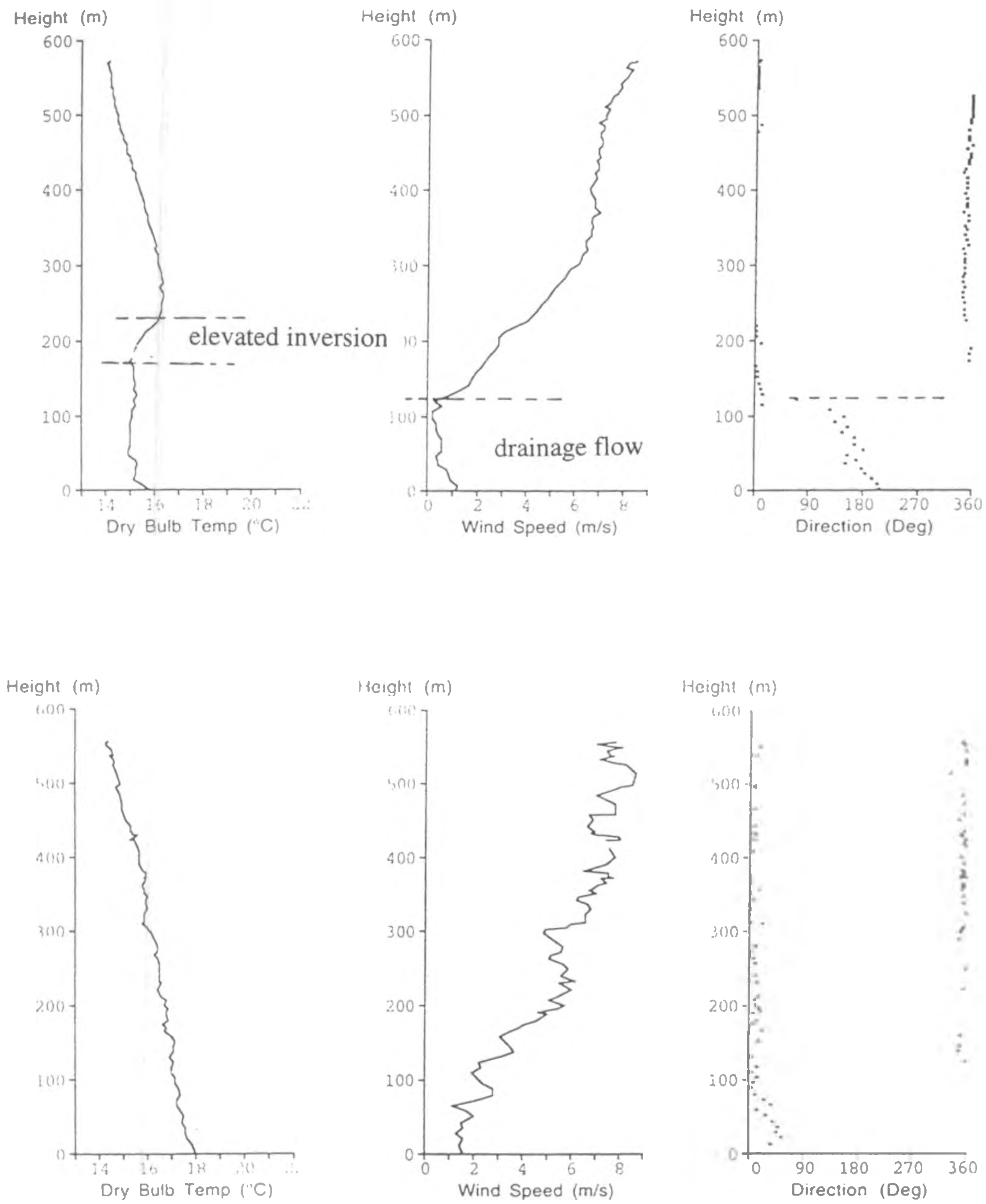


Figure 4.14(a) Profiles of temperature, wind speed and wind direction, St Marys 2 February 1995, showing breakdown of 100 metre deep southerly drainage flow in the Hawkesbury Basin (Enviromet Meteorological Consultants, 1995). Reproduced with the permission of the NSW EPA.

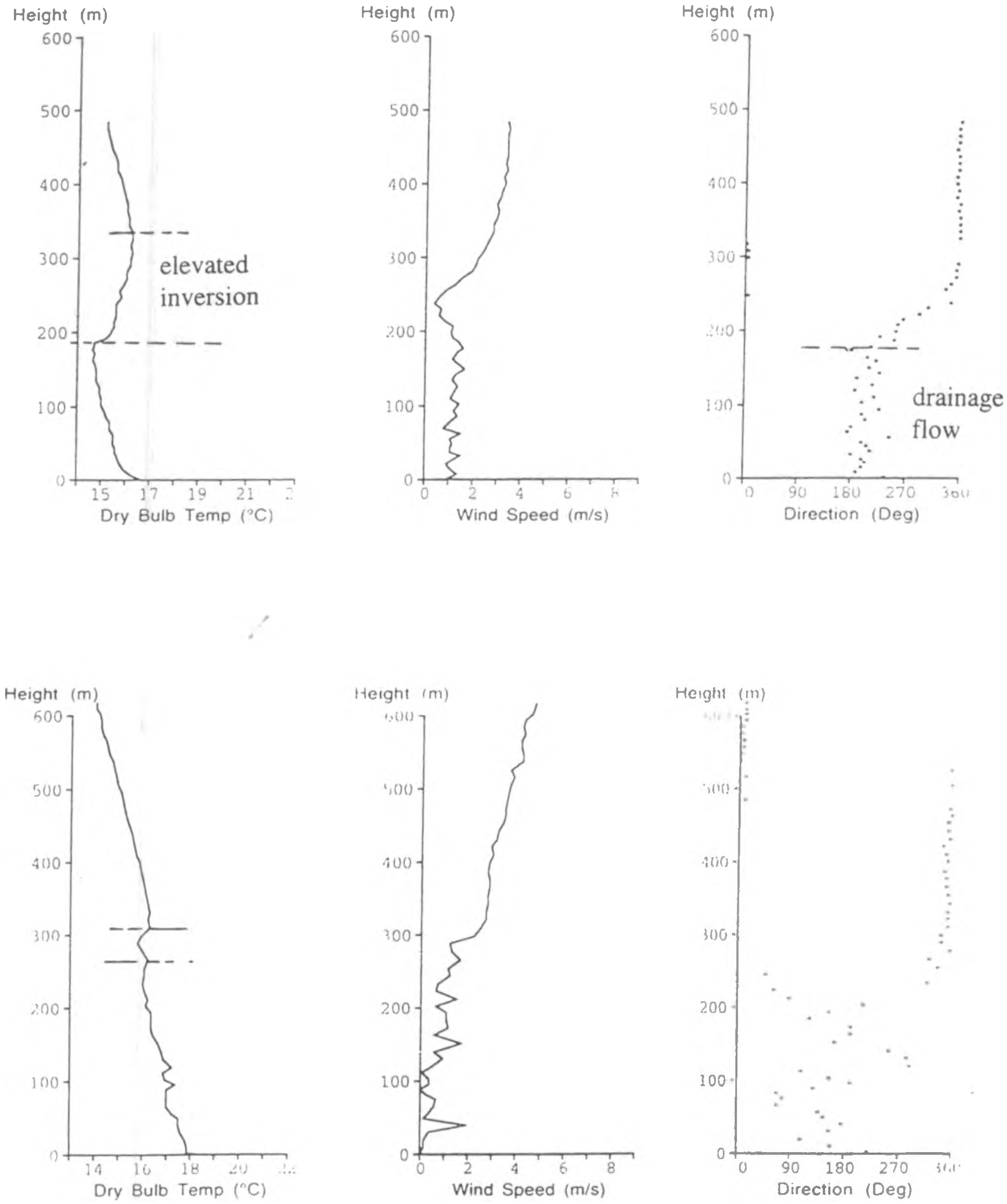


Figure 4.14(b) Profiles of temperature, wind speed and wind direction, St Marys 8 February 1995, showing breakdown of 180 metre deep southerly drainage flow in the Hawkesbury Basin (Enviromet Meteorological Consultants, 1995). Reproduced with the permission of the NSW EPA.

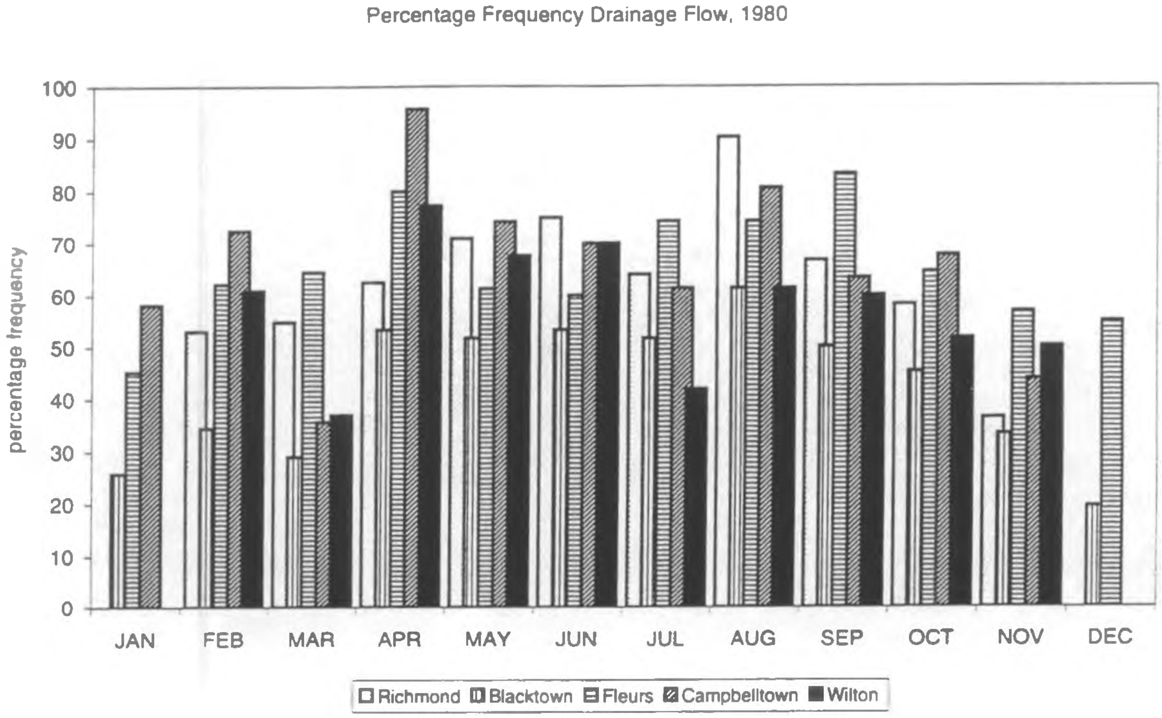


FIGURE 4.15: Frequency of occurence of drainage flow at 5 sites in 1980, (Hyde and Johnson, 1990).

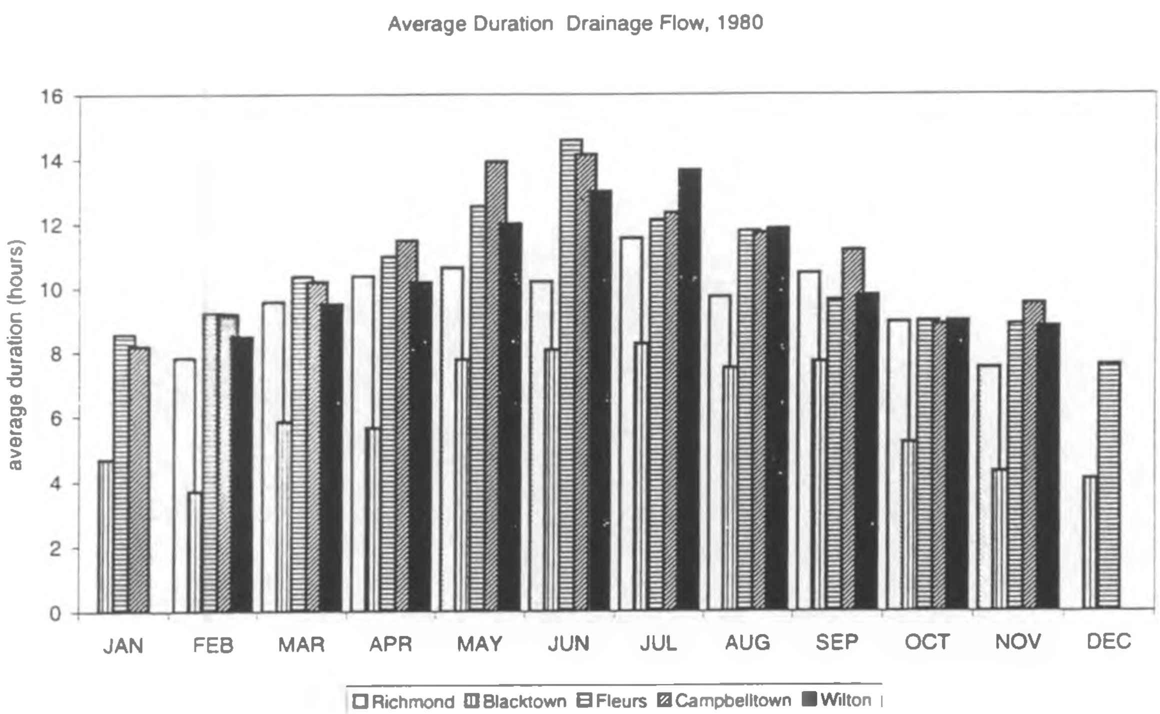


FIGURE 4.16: Average duration of drainage flows at 5 sites in 1980, (Hyde and Johnson, 1990).

Blacktown, possibly as a result of stronger synoptic winds. At Arcadia, on the plateau of higher ground, east of the northern section of the Hawkesbury Basin (see *Figure 3.1* for location), the average frequency of drainage flows was 29 percent.

The observed seasonal trend in the frequency of drainage flows is to be expected because of the large difference in the lengths of days between summer and winter. On average, for the stations plotted in *Figure 4.16*, Wilton, Campbelltown and Fleurs had the longest duration, ranging from around eight hours in the summer months to fourteen hours in winter, whilst the shortest durations were observed at Blacktown.

4.2.3 SEA BREEZE - DRAINAGE FLOW INTERACTIONS

Previous investigations into air quality and meteorology in the Sydney Basin have discussed the recirculation of polluted air within the region as a result of sea breeze/cold air drainage flow interactions (eg Hyde et al 1978 a,b; Hyde et al 1983a). The processes by which this situation occurs are explained below, and the sequence of events are plotted in *Figure 4.17* as a series of cross-sections showing changes in near-surface winds.

Recirculation of Air - Inland

The sequence of events leading to recirculation inland during the night are illustrated by the plots in figure 4.7a. The first cross-section shows a sea breeze moving across eastern Sydney into the Hawkesbury Basin. This particular example illustrates the situation that can occur in Autumn, when sunset occurs late afternoon, and a ground-based inversion or stable layer can form at the surface within the sea breeze.

During the evening, rapid cooling of the surface after sunset leads to the formation of ground-based radiation inversions and local and regional drainage flows within the Hawkesbury Basin. This ponding of air, plus the north-south gradient of topography as illustrated by *Figure 3.2a*, results in the formation of cold air drainage, flowing from south to north along the axis of the Basin. At the same time, intense ground-based inversions act to decouple air near the surface from south-west or west regional drainage flows above. These regional flows undercut the sea breeze above (cross-section two), pass over the top of local drainage flows within the Hawkesbury Basin, and across the ridge at Blacktown into eastern Sydney.

Eventually, the Hawkesbury Basin fills with cold air, which can then 'spillover' across the Blacktown ridge and flow down the Parramatta River Valley, undercutting the regional drainage flow above (cross-section 3). Measurements of winds by Macquarie University at Prospect Reservoir, show that air can also spill out of the Hawkesbury Basin into the Liverpool Basin (Hyde al., 1980).

Recirculation of Air - at the Coast

The first cross-section in *Figure 4.17b*, shows the situation, where at sunrise, cold air drainage flows are moving across eastern Sydney and out over the ocean. During the morning, heating of the land surface by solar radiation, results in the formation of a well-mixed layer of air over the ground. As illustrated in *Figure 4.22*, It may take several hours for this inversion to completely break down, and eventually allow air previously trapped below it, to mix with the synoptic wind above (cross-section 2).

Under favourable conditions, such as light synoptic winds, drainage flow air that has moved offshore during the morning, may not be so readily dispersed. Unlike a land surface, where the range of ground temperature may be several 10's of degrees, the diurnal range of temperature over an ocean surface may be less than 0.5 degrees. Therefore, in contrast to the situation over land, where a well mixed layer forms during the morning, any growth of a mixing layer over the ocean will be small, and air carried offshore within drainage flows may not mix and be dispersed by the synoptic wind above, as illustrated in cross-section two.

If conditions are favourable for a sea breeze to form, then the air previously carried offshore within cold air drainage flows during the morning, can be brought back onshore within the sea breeze, (cross-section three).

For many years, there has been speculation that photochemical smog, carried into south-west Sydney during the afternoon by the sea breeze , could be recirculated overnight within cold air drainage winds flowing north along the Hawkesbury Basin, or north-east across the Liverpool Basin into the eastern Sydney, (Hyde et al., 1978a). However , although sea breeze drainage flow interaction in south west Sydney is almost certain to occur on some occasions no carefully designed studies have been carried out to test this hypothesis.

During the Pilot Study, a series of wind and temperature profiles were made at Smeaton Grange, in the Camden Basin, and on one night, on the basis of the atmospheric moisture content within the sea breeze, sea breeze air could be identified in a southerly drainage flow later in the evening, (Hyde and Young, 1990).

Other evidence is more circumstantial; for example, *Figure 4.18* gives the percentage frequency of drainage flows and sea breezes observed at Wilton, Campbelltown and Blacktown in 1980, along with the percentage of time that sea breezes were followed by cold air drainage flows. At Wilton and Campbelltown, the frequency of nights that have cold air drainage flows following a sea breeze is quite similar to the frequency of occasions when sea breezes were observed, and it is difficult to imagine, that on some of these

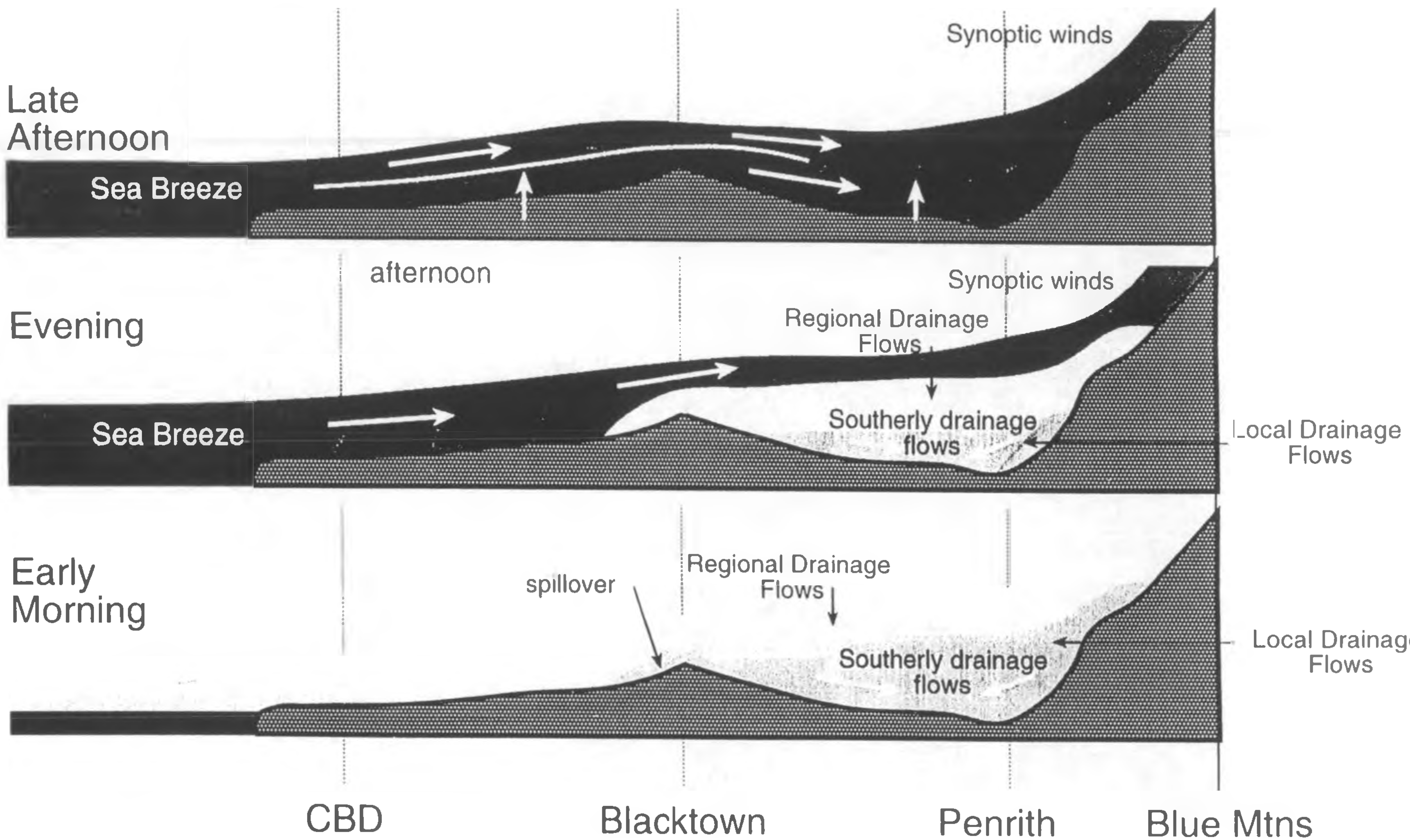


Figure 4.17(a) Sequence of meso-scale wind flows across the Sydney basin, late afternoon to early morning showing: the sea breeze moving into western Sydney late afternoon, the formation of cold air drainage flows in western Sydney, regional drainage flow undercutting the sea breeze, followed by air 'spilling' out of the Hawkesbury Basin, undercutting the regional drainage flow above.

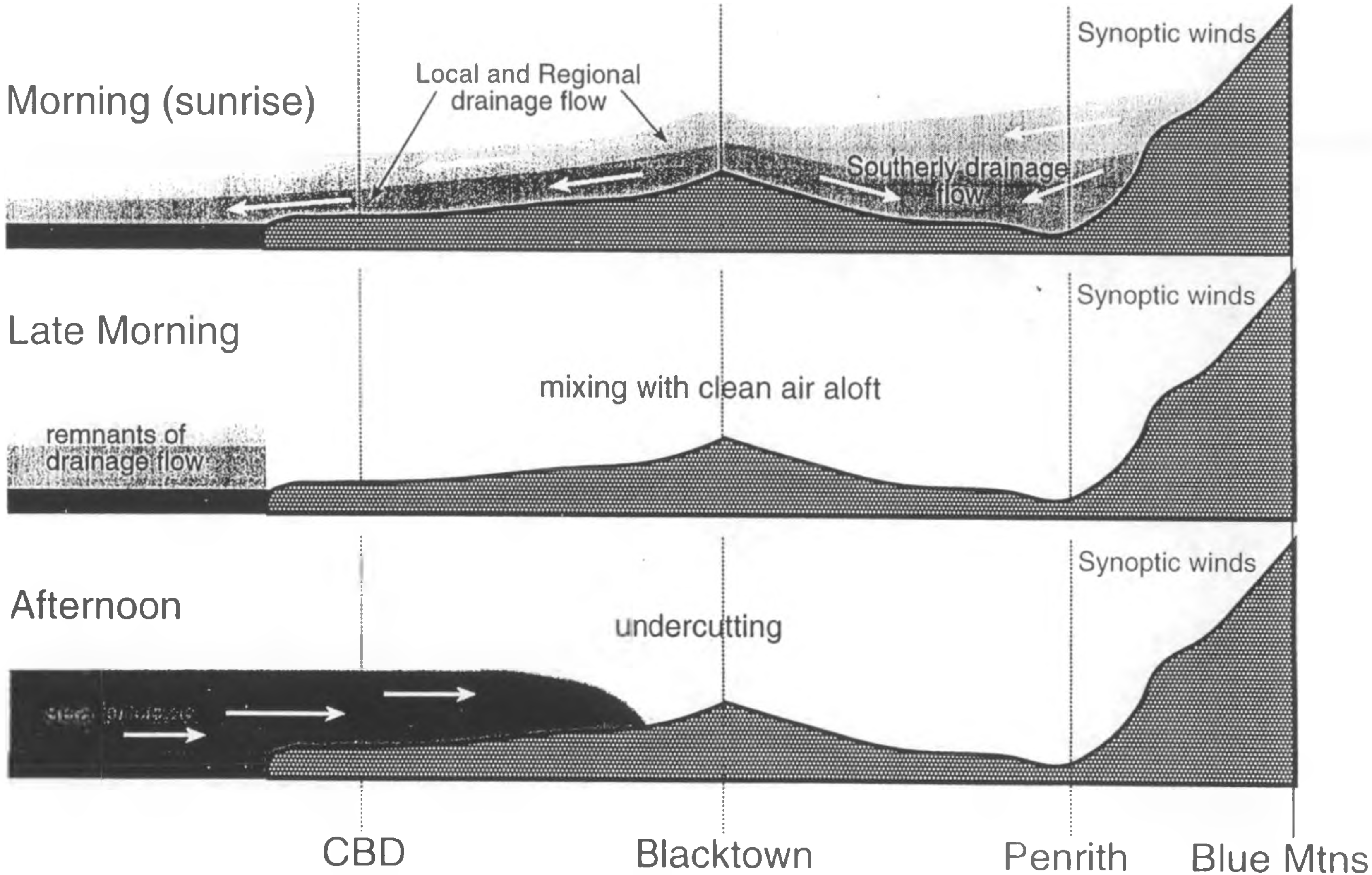


Figure 4.17(b) Sequence of meso-scale wind flows across the Sydney basin, morning(sunrise) to afternoon showing: the local and regional drainage flows moving across eastern Sydney and out to sea; the breakdown of drainage flow over the land late morning, and the inland movement of the sea breeze during the afternoon which undercuts the synoptic wind.

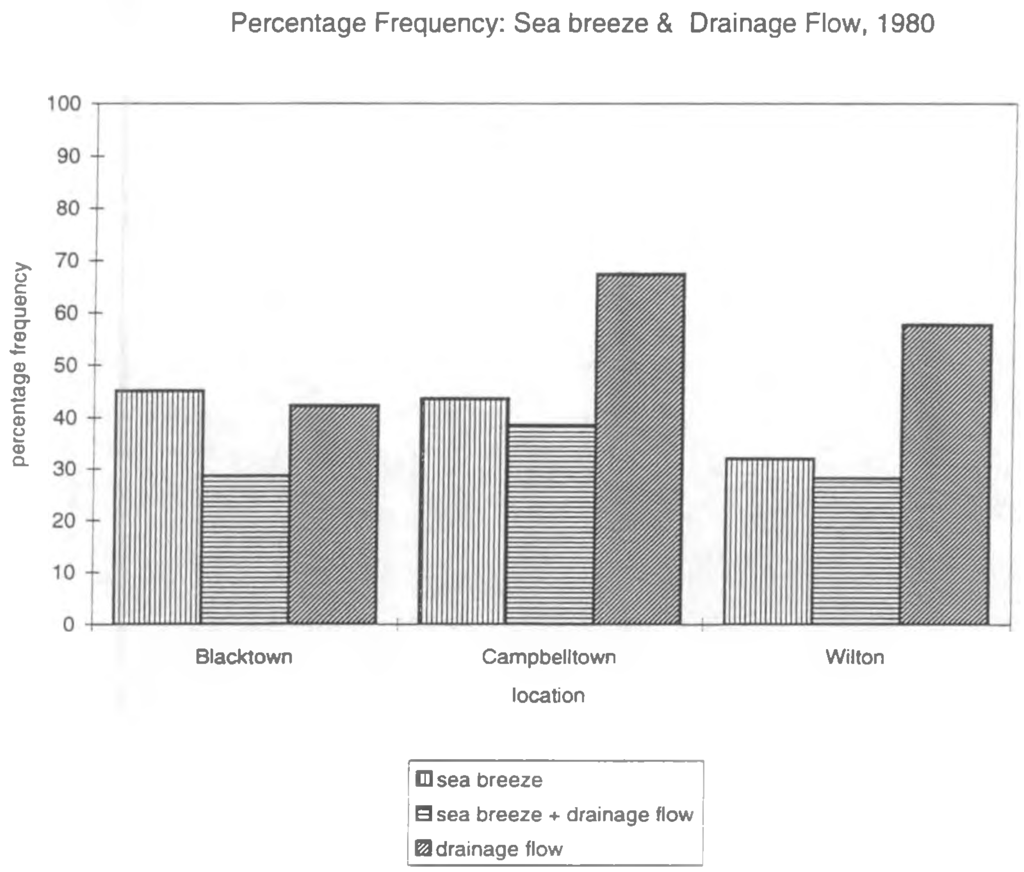


Figure 4.18: Percentage frequency of days when a sea breeze was followed by drainage flow at Blacktown, Campbelltown and Wilton, 1980
(Hyde and Johnson, 1990)

occasions, air carried inland within the sea breeze does not subsequently become entrained with a drainage flow.

The importance of sea breeze-drainage interaction flow on air quality in the Sydney basin is discussed in Chapter 5.

4.2.4 BADGERYS CREEK - SEA BREEZES AND DRAINAGE FLOWS

Sea Breezes

The histograms of wind speed and direction plotted in *Figure 4.3*, show that winds frequently blow from the east to south-east directions during the afternoon and early evening in summer, and it is likely that a percentage of these winds are sea breezes. The histograms for other seasons show the frequency of these winds decrease during Autumn, are virtually non-existent during the winter months, and then increase in frequency during Spring.

There has been some limited analysis of sea breeze occurrence, sea breeze onset times and duration at Badgerys Creek based on the original chart records from this wind station from 1990 and 1991. These data, which are listed in *Table 4.2,* show that the most frequent time of onset of sea breezes between November and May was between 1300 and 1400 hours but a significant number of sea breezes observed at Badgerys Creeks during these months were observed both earlier and later than the average time of arrival. The duration of sea breezes at Badgerys Creek ranges from two to eight hours, with the longest durations tending to occur during the summer months.

Cold Air Drainage Flows

Previous analyses of cold air drainage flows in western Sydney have mostly analysed data from locations where the stable nocturnal winds are steered to a large extent by local topography. However, the Macquarie University wind recorder at Badgerys Creek was located on a knoll well above South Creek Valley, and as a result, winds at night are both stronger, and less influenced by the constraints of local topography. However, as a result of this more exposed location, it is often much more difficult to positively identify drainage flows at Badgerys Creek except when these winds are undercutting sea breezes or synoptic winds that are not blowing from the west to south-west directions. In winter, it is often very difficult to determine whether south-west to westerly flows at night are occurring as a result of cold air drainage flows or are synoptic winds from the same directions.

As well as drainage flows that undercut the synoptic wind or the sea breeze, another quite distinct type of south-west flow is occasionally observed at Badgerys Creek during the night. On these occasions, instead of the drainage flow undercutting the sea breeze, the direction of the sea breeze rotates clockwise over a period of about two to three hours to be come a south-west flow which continues for the rest of the night. As the wind turns clockwise with time, the wind speed within the flow remains virtually unchanged. An example of an undercutting sea breeze and a sea breeze turning towards the south west are given in *Figure 4.19*.

Some limited analyses of cold air drainage flows at Badgerys Creek based on the analysis of the actual wind charts have been reported previously, (Hyde and Johnson, 1990). However, for this study, a different approach was adopted. Estimates of the percentage frequency of time that drainage flows occurred at Badgerys Creek were obtained by calculating the change in the percentage frequency of winds blowing from the drainage directions before sunrise, with the frequency of winds blowing from these same directions after the breakdown of these nocturnal flows. Estimates of the percentage frequency of cold air drainage flows at Badgerys Creek using this approach are listed in *Table 4.3*. The first column gives the times that were used to calculate differences in the frequency of wind from different directions. These times changed throughout the year, to take account of the earlier times of sunrise during summer, and the fact that cold air drainage flows in the cooler months of the year may not have been replaced by the synoptic wind at 0900 hours on some mornings at this time of the year.

Positive values in *Table 4.3,* indicate that winds blowing from these directions during the night had a lower percentage frequency of occurrence after sunrise, therefore providing an estimate of the frequency of cold air drainage flows from different directions during the night. Negative values indicate that the frequency after sunrise was higher than that recorded at night, suggesting that the winds from these directions at night may have been influenced by the synoptic wind, rather than cold air drainage flows. This approach does not appear to produce reasonable results in winter, because the synoptic winds blow in the same directions as drainage flows at Badgerys Creek. A better understanding of the frequency of drainage flows in the vicinity of drainage flows at Badgerys Creek will become available once the 1996 data from the Environment Protection Authority monitoring stations at Bringelly and St Marys have been analysed in conjunction with the Bureau of Meteorology data from Badgerys Creek.

The values listed in *Table 4.3* show that the predominant direction of cold air drainage flow is south-west, with a lower frequency of flows from the south-south-west and west-south-west directions. The frequency of drainage flows listed in *Table 4.3* vary considerably from month to month. The wintertime frequencies are not considered representative for the reason given above, whilst at other times of the year, the frequency of drainage obtained using this approach, varied between 34 percent in February to 67 percent in September. The wintertime values of 15 percent to 28 percent are very low, compared with the more reliable estimates from Fleurs plotted in *Figure 4.15*, where the

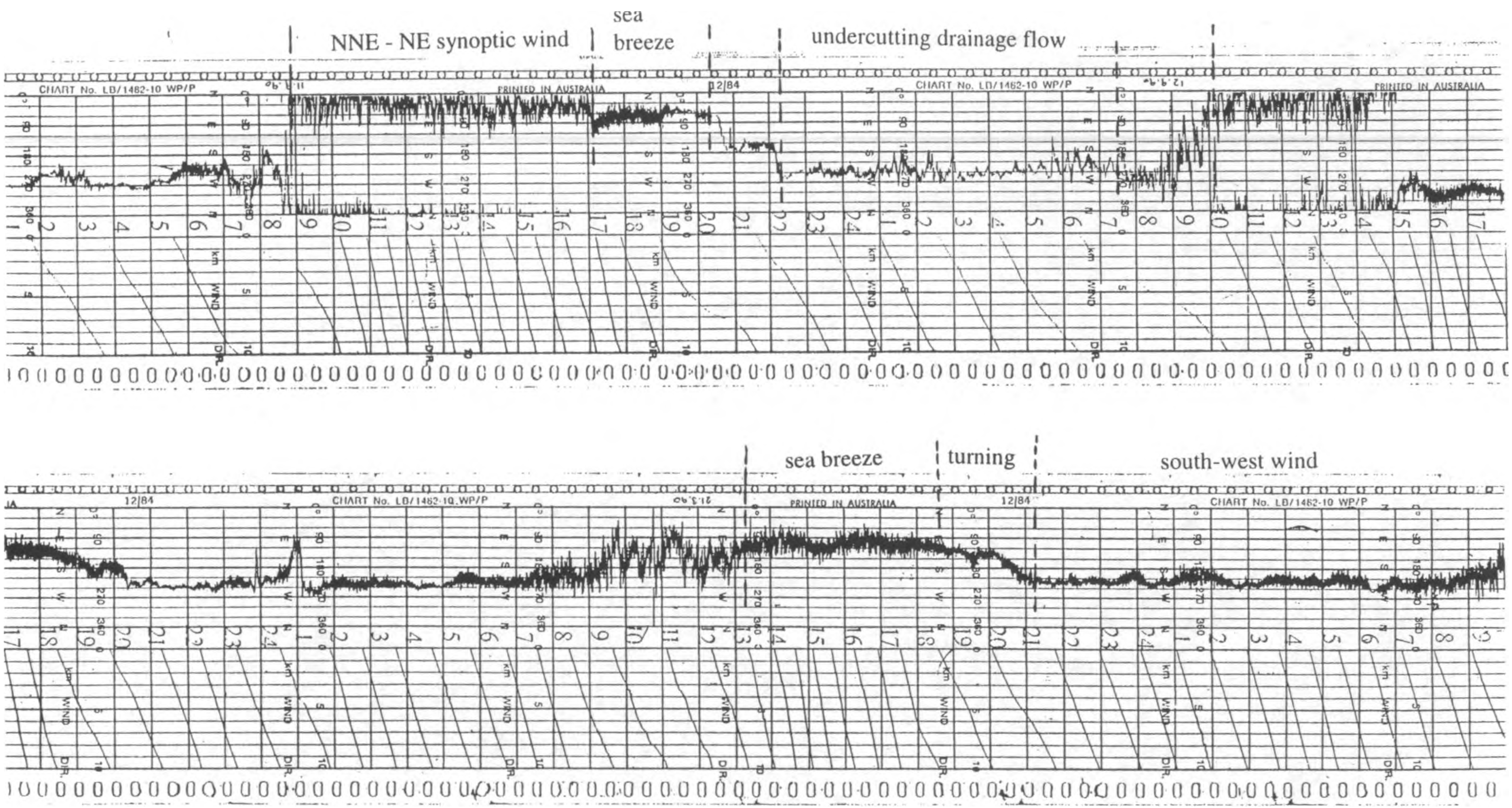


Figure 4.19 Wind trace from Badgerys Creek: (a) 12 September 1990 showing southwesterly cold air drainage flow undercutting an east to east-north-east sea breeze, and (b) 12 March 1990, east to east-south-east sea breeze turning clockwise with time between 1830 and 2100 hours to become a south westerly flow (R.Hyde, Macquarie University Wind Data)

frequency of cold air drainage flows in South Creek Valley during the winter months of 1980 was between 60 percent and 90 percent.

4.2.5 HOLSWORTHY OPTION A - SEA BREEZES AND DRAINAGE FLOWS

Sea Breezes

A detailed analysis of sea breezes at Lucas Heights was reported by Clark (1983), where he discussed the results of analysis of sea breeze events recorded at Lucas heights between September 1975 and March 1981. This coincided with a period when an acoustic sounder was operating at Lucas Heights to examine the structure of the atmosphere, and the study was based on echoes from this sounder, (Clark and Bendum, 1981).

The results of Clark's analysis of sea breezes at Lucas Heights on the basis of echoes from the acoustic profiler are listed in *Table 4.4*. The analysis used data from about 680 days when winds were blowing from between north-north-east to south-south-east, and the statistics are presented in terms of average values in each season. Included in *Table 4.4* are the average onset and final times of the sea breeze in each season as well as average wind speeds before and after the arrival of the sea breeze, and the average height of the sea breeze based on the height of echoes recorded by the acoustic profiler. Clark found that the average height of the sea breeze at Lucas Heights was 608 metres in the summer months, decreasing to 534 metres in winter, although with standard deviations of 212 metres and 189 metres respectively, it is clear that there were substantial differences in the height of the sea breeze from day to day.

Sea breezes from the north-east and east-north-east directions comprised 64 percent of the cases examined. These sea breezes were deepest in summer with average depths of 580 metres and 410 metres in winter. Sea breeze heights gradually deceased during the afternoon as a result of lower values of solar radiation, and the resulting cooling of the surface.

Drainage Flows

Clark (1985) plotted three hourly wind roses for 10 metre and 459 metre heights for the period mid-1975 to mid-1983, which gave very similar results to the frequencies plotted in *Figures 4.6 and 4.7*, for the years 1992 to 1996 analysed for this investigation. In each season Clark found that there were marked day to night shifts in wind direction which he considered occurred as a result of drainage flows. In summer, Clark found little evidence for the presence of westerly sector drainage flow at Lucas Heights, although he considered that the high frequency of winds from the south at night in summer could be a local drainage flow from the south. However, on the basis of an analysis of the stability of the atmosphere during these southerly flow carried out for this report, it was found that the atmosphere was only stable on 25 percent to 30 percent of these occasions, which suggests that a high proportion of these southerly winds observed at 10 metres during the night were not low-level drainage flows, (Section 4.3.3).

On the basis of experience elsewhere in the Sydney Region, one of the best ways of estimating the frequency of cold air drainage flows at a location is to analyse analogue wind charts if the instrument recording them is sufficiently sensitive, (Hyde et al, 1980). However, in the absence of any analysis of analogue wind charts at Lucas Heights, in order to estimate the frequency of cold air drainage flows at Holsworthy Option A, the same approach used for Badgerys Creek was adopted, and the results of this analysis, based on the frequency of winds at 10 metres and 49 metres are listed in *Tables 4.5 and 4.6* respectively.

At 10 metres, the main direction for cold air drainage flow at Lucas Heights are directions between south-south-west and west-south-west, with the highest frequency of occurrence being recorded form the south-south-west and south-west directions, *Table 4.5*. The value of drainage flows from these directions range from 12.4 percent in November to 37.6 percent in May. In the warmer months, there is evidence to suggest that a southerly cold air drainage flow is present, occurring between 6 percent and 11 percent of nights between November and April. Combining both the frequency of cold air drainage flows between south and west-south-west directions, gives estimates of drainage flow frequencies ranging between 22.4 percent of nights in November to 40 percent in July. Like the situation at Badgerys Creek, the wintertime cold air drainage frequencies may well be an underestimate of the true situation because of the high frequency of synoptic winds from these directions.

A similar analysis was carried out using the data from 49 metres at Lucas Heights, and these results are listed in *Table 4.6*. In summer, a much lower frequency of cold air drainage flows from the south direction was observed, suggesting that these southerly winds are very shallow.

To examine the low-level southerly drainage flow in more detail, the differences in temperature between 49 metres and 10 metres was obtained for the four year period October 1991 to September 1995. These data were then plotted against wind direction at 10 and 49 metres for the months of January, April, July and October as shown in *Figure 4.20*. Only stable conditions greater than isothermal were plotted, and the difference in temperature between 10 and 49 metres were converted into degrees Celsius per one hundred metres (°C/100m). Evidence for the existence of a shallow south to south-south-west layer of drainage flow can be seen in the scatter plots of temperature gradient versus wind direction at 10 metres. However, there is no corresponding concentration of points about these southerly directions at 49 metres which indicates the very shallow nature of this flow at 10 metres.

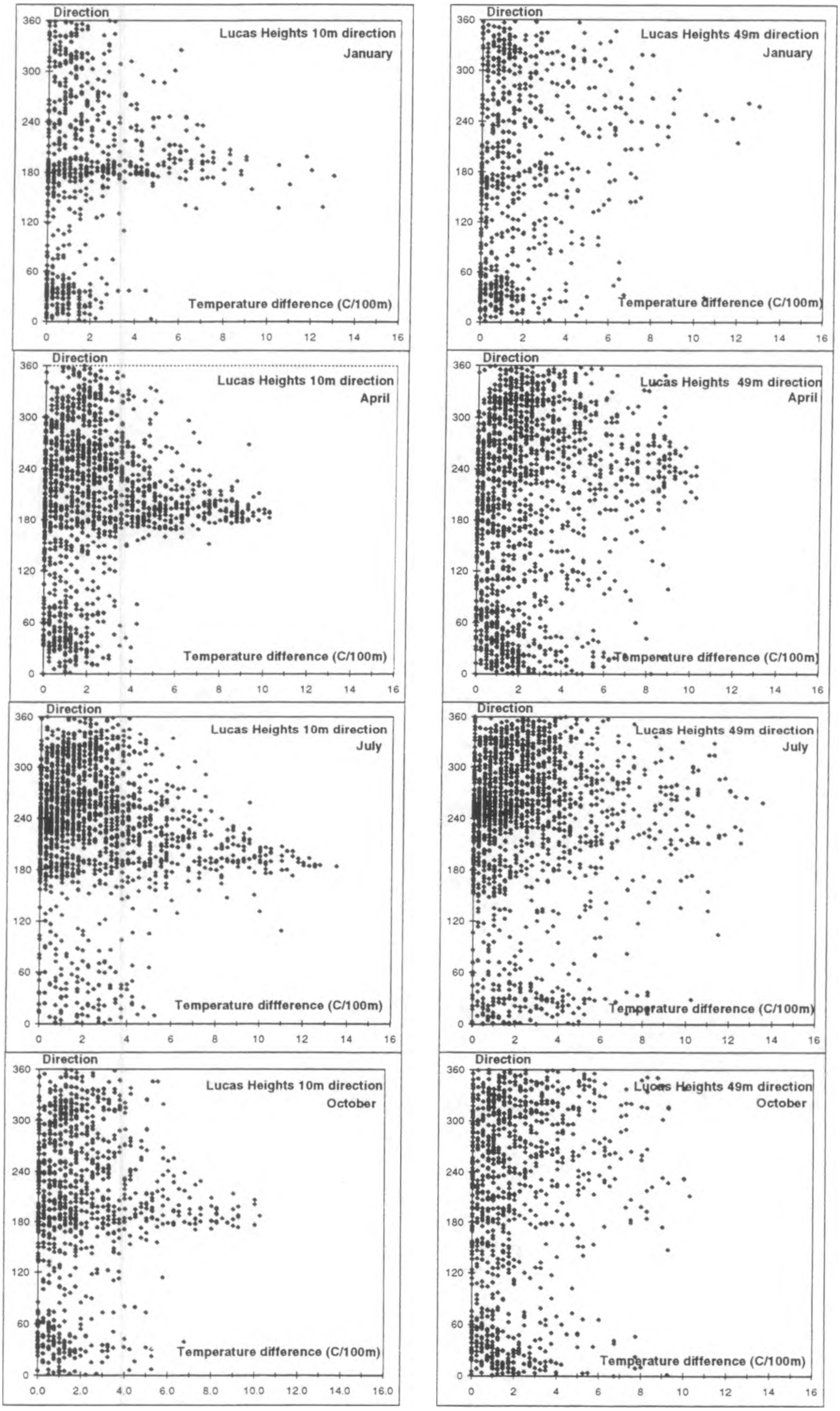


Figure 4.20 Lucas Heights (1992 - 1996); 49 - 10 metre temperature difference expressed as degrees Celcius/100 metres plotted against wind direction at 10 metres and and 49 metres

Overall, the percentage frequencies at 10 metres and 49 metres from the south-southwest to west-southwest direction are not all that different; the main exceptions are in March and April when at 49 metres the frequency of cold air drainage flows was estimated to be 14.4 percent and 12.6 percent respectively, while the corresponding values at 10 metres were 23.9 percent and 23.1 percent.

4.2.6 HOLSWORTHY OPTION B - SEA BREEZES AND DRAINAGE FLOWS

Sea Breezes

In the absence of any onsite data at Holsworthy Option B, the conservative approach would be to assume that the frequency of sea breezes observed at Holsworthy Option B was at Lucas Heights. However, it could be expected that some differences would occur, because Holsworthy Option B is about 100 metres higher than Lucas Heights. The only locations, apart from Lucas Heights where there has been any analysis of the frequency of sea breezes are Wilton and Campbelltown.

On an annual average basis, the frequency of sea breezes at Wilton (Douglas Park) which is 17 kilometres south-west of Holsworthy Option B, was 33 percent, compared with a value of 50 percent at Campbelltown, inland from Holsworthy Option A, *Figure 4.18*. These data suggest, that on an annual basis, the frequency of sea breezes observed at Holsworthy Option B could be somewhat lower than the frequency at Holsworthy Option A.

From the limited amount of data that has been analysed at Wilton and Campbelltown, the direction of the sea breeze at Holsworthy Option B may cover a wider a range of wind directions than Holsworthy Option A as illustrated in *Table 4.7*, showing the distributions of wind directions within sea breezes at Campbelltown and Wilton. At Campbelltown, inland from Holsworthy Option A, the predominant direction of the sea breeze is from the east-northeast direction, with 50 percent of sea breezes having this direction. The other two main direction for the sea breeze at Campbelltown are from the east (23.3 percent) and east-south-east direction (19.8 percent). However, at Wilton, there is a greater spread of sea breeze directions ranging from north-north-east to south-east. The north-north-east sea breezes observed at Wilton, may occur as a result of topographic steering of late afternoon sea breezes, whilst south-east sea breezes are likely to have formed in the Illawarra regions and moved up over the Escarpment and then flowed towards Wilton. Therefore, at Holsworthy Option B, whilst the predominant directions may still be from the northeast and east-north-east direction, a greater spread of wind directions within the sea breeze can probably be expected.

Drainage Flows

The estimates of cold air drainage flows at Holsworthy Option A are only approximate, and in the absence of routine profiles of winds and temperature in the vicinity of Lucas Heights, it is difficult at some times of the year to determine whether the observed winds were drainage flows or synoptic winds from the same direction.

The depths of drainage flows in Sydney vary considerably from day to day, and in eastern Sydney can range between 100 metres and 400 metres (Hyde et al., 1980). In south-west Sydney, less is known about the variation of drainage flow from day to day and season, and it is difficult to estimate what affect the increase in elevation between Lucas Heights and Holsworthy Option B will have on the frequency of drainage flows.

Some information about the frequency and height of drainage flows is available from Wilton, where a limited series of wind and temperature profiles were made in February 1980 (Hyde et al., 1980). An analysis of the depth of the drainage flows in this series of experiments, combined with an examination of surface wind records, found that if wind speeds at the surface were less than 1.5 metre per second then the depth of the drainage flow was between 80 and 100 metres, but when wind speeds were between 1.5 and 3.0 metres per second, the depth of the drainage flow increased to between 180 and 200 metres. By assuming that these criteria for the relationship between drainage flow wind speeds and depth are valid throughout the year, which can only be tested by a program of field experiments, the frequency of winds blowing from the predominant drainage wind directions was calculated on the basis of wind speed and direction frequency tables for 0300 hours for each month in 1980 and 1991. This is shown in *Table 4.8*.

In *Table 4.8* the data have been divided into four categories; shallow (80 -100 metres) and deep (180-200 metres) for south and south-south-east directions which would carry air north into the Hawkesbury Basin, and shallow and deep flows from the south-south-west, south-west, and west-south-west directions which would carry air into the eastern half of Sydney. The elevation at Wilton is 167 metres above sea level, compared with the elevation at Holsworthy Option B is between 240 and 280 metres. Hence, shallow drainage flows at Wilton, in the second direction category, would probably not flow across Holsworthy Option B, but the deeper drainage flows with depths at Wilton between 180 and 200 metres should be observed, although as indicated by the values listed in *Table 4.8,* there were considerable differences between the frequency of drainage flows in each month in 1980 and 1991. Hence, like the situation at Holsworthy Option A there is a high degree of uncertainty about the frequency and depths of drainage flows at Holsworthy Option B.

4.3 INVERSIONS AND MIXING DEPTHS

4.3.1 INTRODUCTION

In an inversion, the temperature of the air increases with height. Information about their depth, seasonal variation in occurrence and duration are important because of their potential to trap pollutants and their role in the propagation of sound.

Temperature inversions can be:

- ground-based, where the temperature at the ground is cooler than the air above; or

- elevated, where at some height above the surface there is a layer of air where the temperature increases with height.

In Sydney, the most frequently observed ground-based inversions occur as a result of:

- rapid cooling of the ground after sunset;

- cold air drainage flows during the evening and overnight; and

- warm air advection - a synoptic situation observed most frequently in summer, where warmer continental air flows over a cooler land surface.

Elevated inversions in Sydney are observed :

- when cooler sea breeze air undercuts warmer air aloft;

- as a result of slow large scale descent of air within the atmosphere (subsidence inversions);

- in synoptic situations with the arrival of a cooler change; and

- when ground based inversions are eroded away by surface heating after sunrise.

On occasions, more than one of these different types of inversions can be present above the Sydney Basin at the same time (Bureau of Meteorology, 1991)

An example of the formation and breakdown of a ground-based inversion at Sydney Airport, and a subsidence inversion aloft is given in *Figure 4.21* (Colquhoun, 1983). During the evening, the ground-based inversion gradually increased in depth from 100 metres at 1910 hours to 300 metres the following morning at sunrise. Surface heating after sunrise gradually eroded away the inversion; for example between 0645 and 0800 hours the air temperature near the surface had increased from 8 degrees Celcius to 12.5 degrees Celcius. At the same time, convection between sunrise and 0800 hours had produced a well mixed layer of air about 100 metres deep.

The time taken to break down a ground-based inversion depends on its depth at sunrise and the amount and rate of heating of the lower atmosphere after sunrise. During summer, shallow ground-based inversions will breakdown quickly after sunrise as a result of increased radiation from the sun at this time of the year. However in the cooler months of the year, decreased solar radiation and deeper ground-based inversions at sunrise, means it can take several hours for them to erode away.

Once the ground-based inversion has gone, the depth of the mixing layer during the daytime is determined by the height of the elevated inversion and the amount of heat transferred from the surface into atmosphere during the day.

Inversions and Mixing Depths in Eastern Sydney

Information about temperature inversions and daytime mixing depths in eastern Sydney can be obtained from the vertical profiles of temperature which are routinely measured by the Bureau of Meteorology at Sydney Airport at 0600 and 1500 hours each day. As well as these routine observations, some commercial aircraft landing and taking off from Sydney Airport also make measurements of wind and temperature which can be used to examine inversions and mixing depths near the coast, (Hyde et al., 1997).

Other sources of information about the structure of inversions in eastern Sydney include: six years of temperature measurements made by the Bureau of Meteorology at the 10 metre and 110 metre levels on the television tower at Gore Hill (Armstrong, 1973, Colquhoun, 1983); a series of temperature profile measurements at Sydney Airport in 1984 (Colquhoun, 1983); and occasional temperature profiles made by Macquarie University in the Parramatta River Valley between 1975 and 1980 (Hawke, 1977, Hyde et al, 1982).

Information about the frequency and strength of inversions observed at Sydney Airport and Gore Hill were reported by Colquhoun (1983) who analysed the morning temperature profiles measured at Sydney Airport between 1977 and 1981 *(Tables 4.9 and 4.10)*, and six years of measurements from Gore Hill *(Tables 4.11 and 4.12)*. The data from Sydney Airport show that inversions with depths between 100 metres and 200 metres occurred most frequently, but there were a significant number of occasions when the depth of the inversion

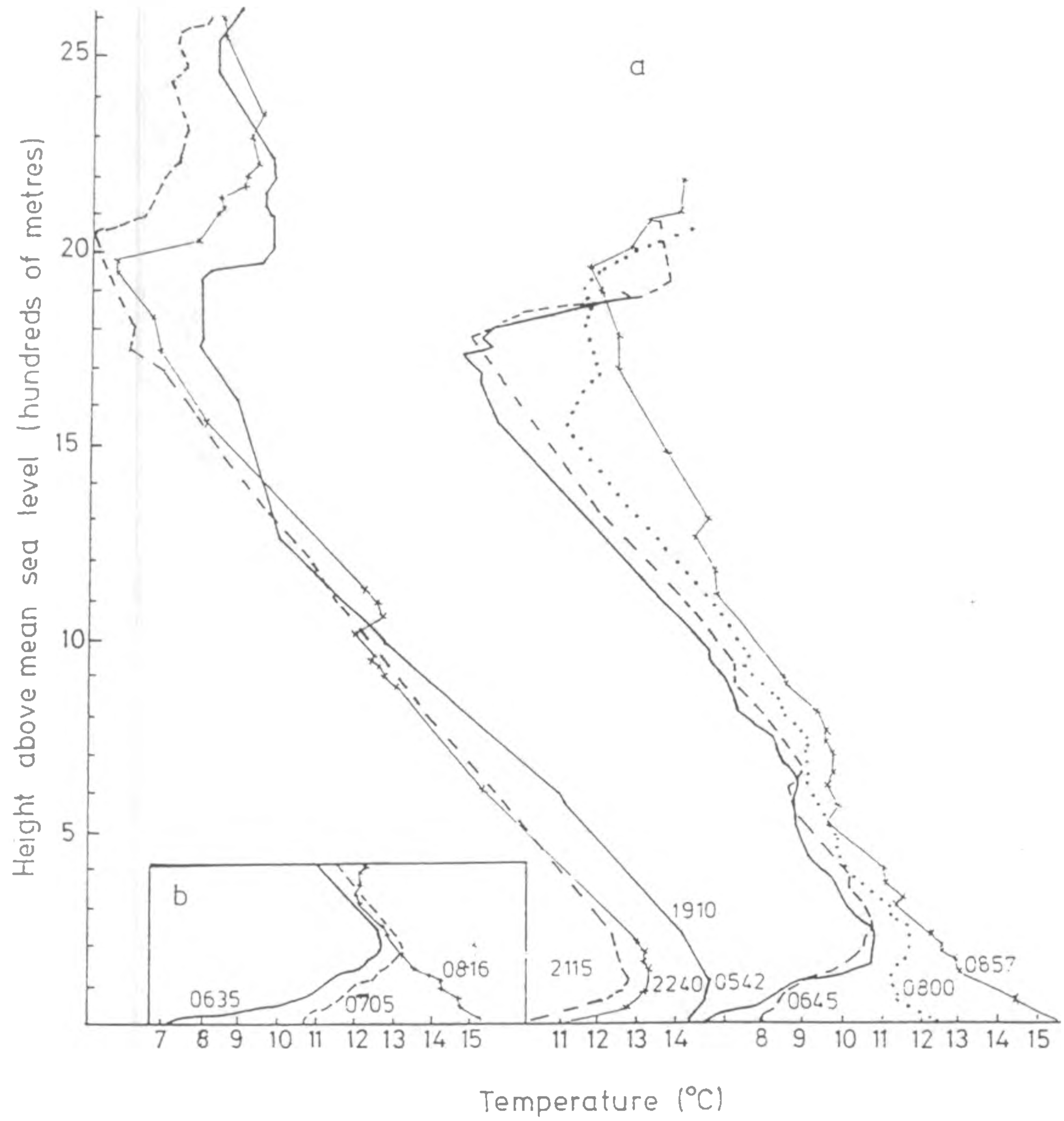


Figure 4.21 Temperature profiles - Sydney Airport: (a) formation of ground based inversion on 7 September 1974 and its breakdown on 8 September 1974, with a subsidence inversion aloft, (b) breakdown of a ground-based temperature inversion on 29 August 1974 (Colquhoun, 1983). Reproduced with permission of CSIRO.

was below 100 metres or between 200 metres and 500 metres. There was an increase in frequency of inversions between 700 metres and 2000 metres which are likely to be indicative of the overnight height of the subsidence inversion. Inversions at Sydney Airport occurred more frequently in winter with maximum heights between 100 metres and 400 metres, whilst in summer, most ground based inversions had heights less than 200 metres.

Colquhoun's (1983) analysis of temperature measurements from Gore Hill listed in *Tables 4.11 and 4.12* show inversions occurring on an average of 268 days each year, ranging from an average of 17 nights during summer to 28 nights in winter. In summer with longer periods of daylight, the frequency of inversions at Gore Hill with durations greater than six hours was low, whilst in winter as a result of increased length of night time, between half and two-thirds of the inversions observed at Gore Hill had durations between 12 and 15 hours.

Colquhoun (1983) reported the results of a series of temperature profiles made at Sydney Airport in August and September 1994. In this investigation, special temperature sensors attached to slow rising balloons were used to measure temperature and atmospheric humidity in the lower atmosphere. In this limited series of measurements, the depth of the ground-based inversion ranged from 50 to 300 metres, although on six of the fourteen days, the inversion was between 150 and 300 metres deep.

Measurements of the vertical temperature structure in the lower atmosphere made by Macquarie University in the Parramatta River Valley (Hyde et al., 1982) gave inversion depths similar to those observed by the Bureau of Meteorology at Gore Hill and Sydney Airport. On occasions, as illustrated by the temperature profiles plotted in *Figure 4.22*, the depth of the inversion can be quite shallow (*Figure 4.22a*), while on other occasions, inversion depths at sunrise were between 300 and 400 metres (*Figure 4.22b,c*).

The temperature profiles plotted in *Figure 4.22b & c* illustrate the breakdown of a deep inversion and the subsequent development of a mixing layer in the Parramatta River Valley. On both days increasing surface temperatures and convection during the morning gradually broke down the inversion. These measurements were made in May, when the amount of solar radiation received at the surface is lower than in summer, and on both occasions it took between five and six hours to completely erode away the inversion.

Inversions and Mixing Depths in Western Sydney

The only detailed information about the structure and frequency of inversions in western Sydney is contained in a paper by Loewe (1945). The results of his analysis, which are based on 1924 morning aircraft flights from Richmond airport between 1937 and 1943, are shown on *Table 4.13*. Loewe's analysis showed that inversions occurred most frequently in the winter half-year; 53 percent of nights had an inversion to 1000 feet (330 metres) and 65 percent of nights had an inversion to 2000 feet (600 metres). A second maxima in inversion frequency was observed between 2000 and 8000 feet (600 to 2600 metres) most likely due to the presence of subsidence inversions (Loewe, 1945).

In summer, the frequency of inversions was much lower. Loewe observed inversions between the surface and 2000 feet (600 metres) on 19 percent to 29 percent of mornings, but considered these values probably underestimated the true situation, because the average time of commencement of the summertime flights was 0725 hours and some shallow ground-based inversions might well have been eroded away before the ascents were made.

Another indicator for a high frequency of inversions in western Sydney is the percentage frequency of calms observed at Richmond during the night. Data from the Bureau of Meteorology shown on *Figure 4.29*, show a high frequency of calms at Richmond on many nights throughout the year with values at 0300 hours between 69 percent and 89 percent.

A limited number of temperature profiles have been obtained during field investigations since 1980. During the Western Basin Experiment and Sydney Hydrocarbon Study (Hyde et al., 1980, Nelson et al, 1983), Macquarie University measured wind and structure in western Sydney at Richmond, St, Marys and Wilton using a tethered balloon system and by tracking rising balloons. More recently, the NSW Environment Protection Authority made similar measurements at St Marys in January and February 1994 and 1995 (Micromet Environment Consultants, 1994, 1995).

Measurements by Macquarie University at night during winter at Richmond and St. Marys show ground-based inversions or stable layers extending to between 300 and 500 metres (*Figure 4.30*). More recent measurements made by the NSW Environment Protection Authority at St Marys in 1994 as part of Metropolitan Air Quality Study, show the remnants of 200 to 300 metre deep inversions, *(Figure 4.12a, Figure 4.12b and Figure 4.31)*.

Deep ground-based inversions are occasionally observed in the temperature profiles measured at Sydney Airport in summer where the inversion can be up to one kilometre deep. In these situations, warm air advection and an inversion at the surface combine to produce a very deep inversion layer over Sydney at sunrise, (Hawke et al., 1983; Hyde et al., 1997).

Whilst in the situations described above, the height of the surface mixing layer can be expected to increase with time during the morning and afternoon, it is thought that on some occasions in summer, the growth of the surface mixing layer during may be limited by a strong elevated inversion aloft. On some of

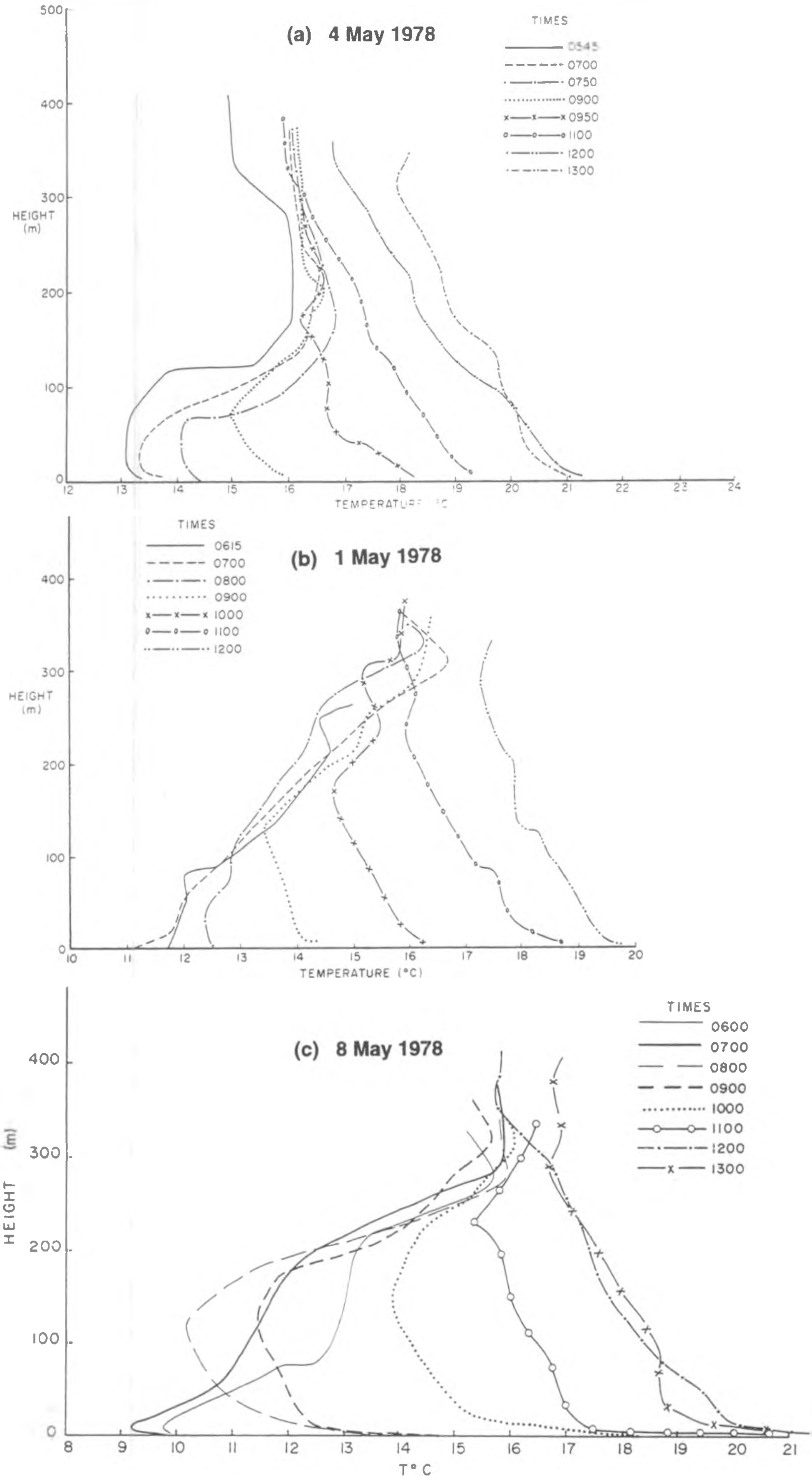


Figure 4.22 Temperature profiles made at Silverwater in the Parramatta River Valley, showing breakdown of inversions and stable layers within drainage flows: (a) 4 May 1978; (b) 1 May 1978, ( ) 8 May 1978 (Hyde et al., 1983a, Hyde et al., 1979).

the days examined for the Pacific Power Investigation and *Metropolitan Air Quality Study* (Environment Protection Authority, 1997a) when concentrations of ozone were high, it was thought that continued warming of the atmosphere aloft during the daytime, could limit the depth of the surface mixing layer in to between 500 and 600 metres (Johnson et al., 1993; Hyde et al., 1997). However, this hypothesis has not been verified by measurements of the vertical structure of temperature in western Sydney

Some additional evidence for decoupling of air within the Hawkesbury Basin from the synoptic wind above, is illustrated by wind profiles measured at Wilton on 21 February 1980. On this occasion wind speeds were light within the lowest 200 metres following the breakdown of a 200 metre drainage flow, but increased rapidly with height above, *(Figure 4.25)*. It is thought that such a situation could only occur if an elevated inversion was present at the top of the surface mixing layer. The frequency of these episodes is currently unknown, and whether these events are related to the overnight north winds frequently observed at Winmalee during the summer months(which are discussed in Section 4.3.5) can only be properly evaluated by a program of vertical measurements of wind and temperature.

4.3.2 DEPTHS AT BADGERYS CREEK

Inversions

In the absence of measurements of the vertical structure of temperature above Badgerys Creek, it is not possible to provide firm estimates about the frequency of inversions, their time of onset, increase in frequency during the night, and the heights of these inversions at different times of the year. However, there are a number of sources of information available that allow some estimates to be made. These include the data provided for the noise impact assessment, based on the frequency of time that wind speeds at Badgerys Creek were similar to those observed in drainage flows, the frequency of calms during the night at Richmond, *(Table 3.2)*; statistics of cold air drainage flows at Fleurs and Badgerys Creek, *Figure 4.15*; Loewe's (1954) analysis of inversions measured by morning aircraft ascents above Richmond between 1937 and 1945, *(Table 4.13)*; and the frequency of inversions measured at Lucas Heights in each month which are discussed in Section 4.3.3, and plotted in *Figure 4.27*.

Measurements from these different sources have been combined to estimate the percentage frequency of time in each season, that an inversion might be observed some time during the night, *(Table 4.15)*. These estimates are listed below:

Summer: 60 percent to 75 percent
Autumn: 60 percent to 80 percent

Winter: 60 percent to 95 percent
Spring: 60 percent to 85 percent

Hence, ground-based inversions could be expected to be present at Badgerys Creek on a high percentage of nights throughout the year.

In *Table 4.15*, no data for the percentage frequency of drainage flows at Badgerys Creek have been listed, because in winter it is very difficult on occasions to differentiate between drainage flows and synoptic winds. Measurements from Lucas heights have been included because, if inversions were observed there, then they could also be expected to be present at Badgerys Creek. It is considered that the values from Lucas Heights provide a lower estimate to the frequency of inversions that could be expected at Badgerys Creek, because conditions are more sheltered in the Hawkesbury Basin,(Hyde and Johnson, 1990).

The data in *Table 4.15* provide no information about the expected change in the frequency of inversions with time during the night. However, some indication can be obtained from the data listed in *Table 3.2*, where the data in column 'a' for each time gives the percentage frequency of time that winds below 2.5 metres per second were observed at Badgerys Creek in each month in 1990 and 1991, whilst the data in column 'b' gives the corresponding data for occasions when winds less than 3.5 metres per second were observed. As noted earlier in this report, the data in *Table 4.15* was based on the values of speeds within drainage flows at Badgerys Creek, when a stable layer could be expected at the surface.

The change in the percentage frequency of these winds with time in *Table 3.2*, indicate that inversions may form faster at night in the Hawkesbury Basin, compared with similar data from Lucas Heights, *Figure 4.22*. This is considered reasonable, in view of the more sheltered topography within the Hawkesbury Basin, where cooling of the ground surface would be expected to occur earlier than at the more exposed location at Lucas Heights, nearer to the coast.

Little information is available to estimate the heights of inversions at Badgerys Creek. Some statistical data is available from Loewe's (1945) analysis of morning aircraft ascents made from Richmond each morning between 1937 and 1943. There have also been some limited nighttime observations of the vertical structure of temperature at St Marys and Richmond, as illustrated in *Figure 4.23*, which showed that inversions could be as deep as 500 to 600 metres.

Loewe's observations are likely to give a reasonable estimate for the height of inversions at Badgerys Creek, *Table 4.13*. As mentioned above in Section 4.3.1, in the summer half year Loewe found that inversions were observed on

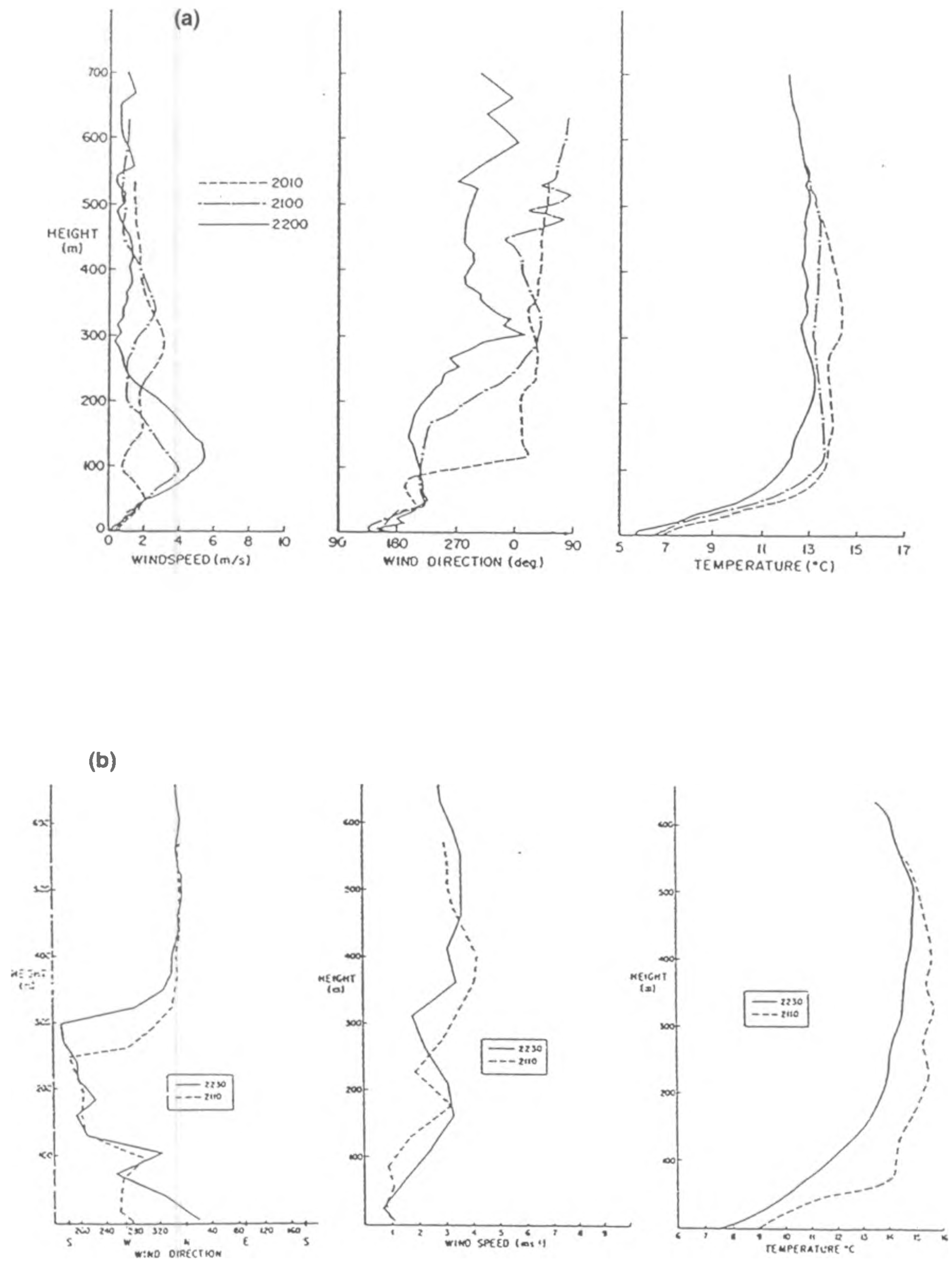


Figure 4.23 Wind and temperature profiles in the Hawkesbury Basin showing: (a) St Marys, ground-based inversion to 200 metres within south to south-west regional drainage flow, with isothermal temperatures above to 500 metres and, (b) Richmond, 400 to 500 metres deep ground-based inversion within 300 metre deep south to south-west drainage flow, with northerly synoptic wind above (Hyde and Johnson, 1990)

19 percent of mornings between the surface and 310 metres, and to 615 metres on 29 percent of mornings. In the winter half year, he observed inversions in the lowest 310 metres on 53 percent of mornings, whilst the inversions in the lowest 615 metres were observed on 65 percent of occasions.

Loewe considered that the value of 19 percent was probably an underestimate for the frequency of inversions in the lowest 310 metres in summer, because surface heating before the time of the morning aircraft ascent might have eroded away shallower inversions present at sunrise. This rapid erosion of ground-based inversions in summer is illustrated by the temperature profiles from the NSW Environment Protection Authority's summer campaign in 1995 which are plotted in *Figures 4.14a, 4.24*.

The recently analysed wind data from Winmalee which are discussed in Section 4.3.5, show a high frequency of northerly sector winds during the night, and it is thought that these winds in winter probably contribute to the deep inversions observed in western Sydney during the cooler months of the year. For example, the wind and temperature profiles from St. Marys, plotted in *Figure 4.23*, show an inversion within a 300 metre deep layer of south-west drainage flow along the Hawkesbury Basion, and then slightly less stable air in a northerly flow above.

As explained previously, deep ground-based inversions are also expected to be observed occasionally at Badgerys Creek during the summer months, as a result of the combination of a ground-based radiation inversion, or an inversion with cold air drainage flow along the Hawkesbury Basin, and warmer continental air flowing over the Sydney Basin at night. This situation can result in very deep inversions forming on some occasions, (Hawke et al., 1983, Hyde et al., 1997). The presence of these deep inversions above the Hawkesbury Basin can be seen in Loewe's statistics for the summer months, where deep inversions were observed in the lowest one to two kilometres on 13 percent to 15 percent of mornings, *(Figure 4.13)*.

Mixing Depths

The amount of information about mixing depths above Badgerys Creek is extremely limited, and very few observations have been made of the breakdown of ground-based inversions in western Sydney. Therefore, estimates of the depth of the surface mixing layer at Badgerys Creek can only be discussed in very general terms, making use of data measured in other parts of the Sydney Basin.

The rate of growth of the surface mixing layer at Badgerys Creek during the morning, when a ground-based inversion is present at sunrise, will depend on the amount of energy available to heat the ground. This heating produces convection, which increases the temperature of the air above the surface and results in the depth of the surface mixing layer increasing with time. The main driving force behind the energy required to heat the surface is radiation from the sun. In winter, the amount of energy reaching the surface is only half that received in summer, so the rate of increase in the depth of the mixing layer at Badgerys Creek could be expected to change significantly throughout the year.

In summer, when ground-based inversions are likely to be shallower at Badgerys Creek, the depth of the surface mixing layer is likely to increase rapidly after sunrise and an inversion present at sunrise will be eroded away quickly as illustrated by the NSW Environment Protection Authority temperature profiles plotted in *Figure 4.14, and Figure 4.24*. However, in the cooler months of the year, when the amount of solar radiation is lower and the inversions are expected to be deeper, the rate of increase in the depth of the surface mixing layer at Badgerys Creek is expected to be slower, and it may take several hours before a deep ground-based inversion is eroded away, as illustrated by the temperature profiles measured in the Parramatta River Valley, *Figure 4.22*. On two of these days, the inversions were between 300 and 400 metres deep at sunrise. On all three days it took several hours to erode away the inversion.

The examples plotted in *Figure 4.22* are important, because they illustrate that the breakdown of a ground-based inversion at Badgerys Creek may be different from day to day. In *Figures 4.22b and 4.22c* the depth of the inversions was between 300 and 400 metres, but the growth of the surface mixing layer on both days was quite different. For example, in *Figure 4.22b*, the surface mixing layer initially increased quite rapidly after sunrise, but then there was a restructuring of the near-surface layer, and the strength of the elevated inversion increased. Following this restructuring, the depth of the surface mixing layer increased at a slower rate compared with the example in *Figure 4.22c*, where a more linear increase in the depth of the mixing layer with time was observed. If similar differences occurred at Badgerys Creek, then the dispersion of near surface and elevated emissions could be different from day to day, even though at sunrise, the depth of the ground-based inversion might be similar.

Following the breakdown of a ground-based inversion at Badgerys Creek, the depth of the surface mixing layer will increase, but can then be limited by the presence of a subsidence inversion higher up, An example of a subsidence inversion is given in *Figure 4.21,* which shows an elevated inversion in the morning at around 1700 metres. Continued heating of the surface and convection results in an increase in the depth of the mixing layer during the day, although as temperature starts to fall in the afternoon and convective activity decreases , the depth of the mixing layer will not continue to increase.

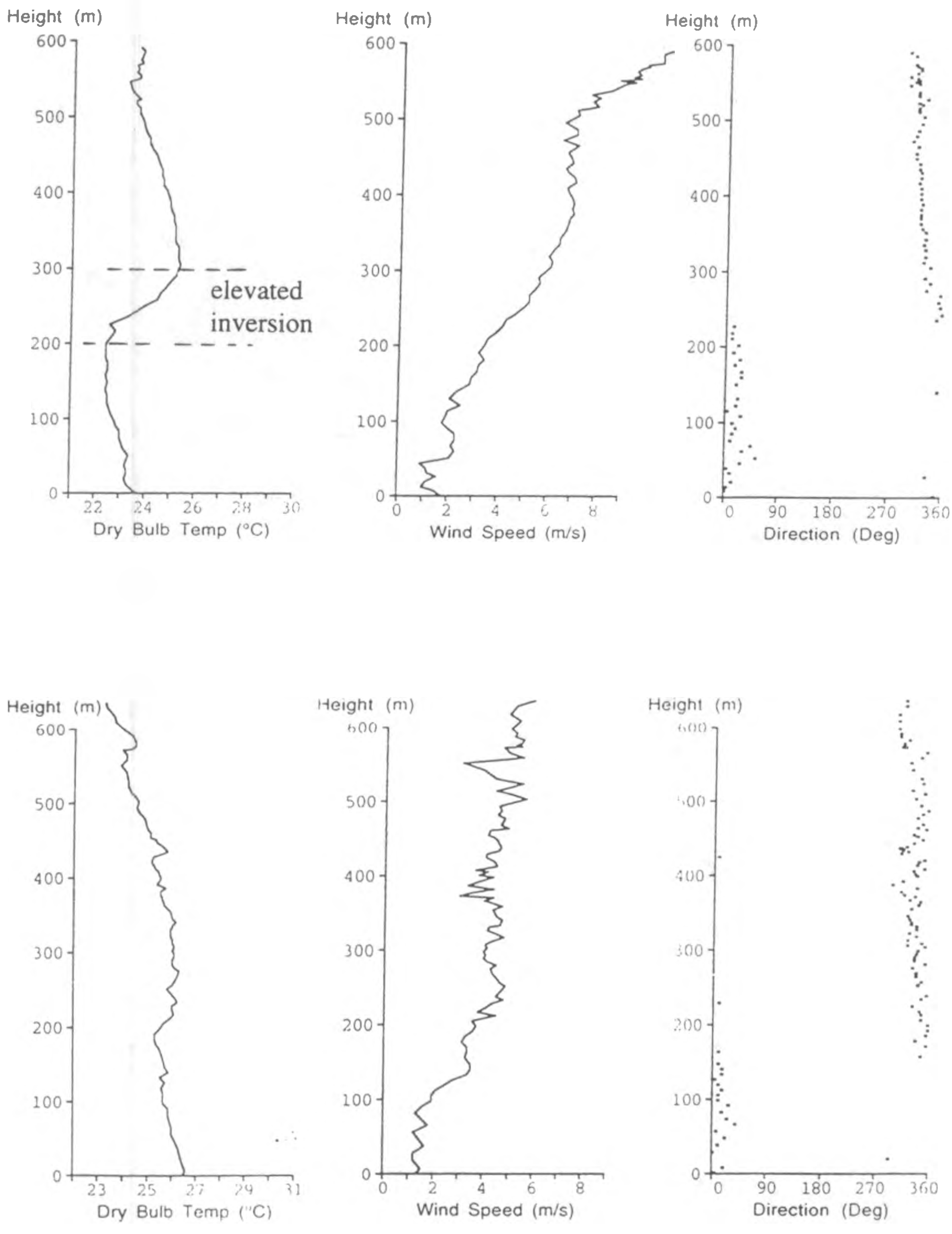


Figure 4.24 Profiles of temperature, wind speed and wind direction, St Marys 3 February 1995, showing remnant of 300 metre deep inversion within a northerly synoptic wind, with well mixed surface layer below (Enviromet Meteorological Consultants, 1995). Reproduced with permission of the NSW EPA.

Other factors limiting the height of the surface mixing layer in western Sydney which are applicable to Badgerys Creek were discussed above. These included the presence in summer, of very deep inversions as a result of ground-based inversions and warm air advection aloft, and the fact that on some days it could be possible in these situations for the depth of the surface mixing layer to remain between 500 and 600 metres deep. However, there are currently no observations to confirm this, although the profiles from Wilton, plotted in *Figure 4.25*, suggest that on some occasions, air above the surface of the Hawkesbury Basin could be decoupled from stronger winds aloft by the presence of an elevated inversion.

Another factor influencing the depth of the surface mixing layer at Badgerys Creek is the depth of the sea breeze. This decouples air at the surface from the synoptic wind above. However, as no measurements have been made of the depth of the sea breeze in western Sydney, it is not possible to estimate the depths likely to be observed at Badgerys Creek. Sea breezes can be quite shallow at the coast (Hyde et al., 1997), but as they move inland across the heated land surface the depth of the mixing layer within the sea breeze increases, although other factors, such as the strength and direction of the synoptic wind will also affect the depth of the sea breeze as it moves inland. However, late afternoon, as the land surface stats to cool, the depth of the mixing layer will start to decease, and eventually a stable layer may form at the surface (Clark and Bendum, 1981).

It is clear from this discussion that the depth of the mixing layer at Badgerys Creek will be controlled by a number of different factors, which will vary from day to day and with season. Until measurements are made of the vertical structure of winds and temperature in the vicinity of Badgerys Creek, it is not going to be possible to provide reliable estimates of the depth of the surface mixing depth, nor how the structure of this layer will change from day to day. Some estimate can be made on the basis of the morning vertical temperature profiles made each morning by the Bureau of Meteorology at Sydney Airport, but during recent studies such as the Pacific Power Investigation and *Metropolitan Air Quality Study,* the use of these coastal measurements to estimate the depth of the mixing layer in western Sydney proved unsatisfactory (Johnson et al., 1993; Hyde et al., 1997).

4.3.3 INVERSIONS AND MIXING DEPTHS AT HOLSWORTHY OPTION A

Inversions

The closest source of information regarding inversions and mixing heights in the vicinity of the Holsworthy airport sites are temperature measurements made on the meterological tower at Lucas Heights. The frequency of inversions at Lucas Heights was analysed by Charash and Bendum (1968), and their results are plotted in *Figure 4.26* and *Table 4.16*. *Figure 4.26* gives the average time of onset and end of the inversion in each month at Lucas Heights, and the average and extreme values of inversion strength between 6 and 49 metres. The average number of inversions in each month ranges from 21 percent in the warmer months of the year, and between 27 percent and 29 percent of nights between May and August, *(Figure 4.16)*. The average duration of inversions at Lucas Heights was 6.4 to 7.5 hours in summer and 12 to 14 hours in winter. Average, and extreme values which are given in parentheses, of inversion strength also changed with time of year, with values of 3.5 degrees (8.5 degrees) per 140 feet (23 metres) in June, to 1.4 degrees (5.6 degrees) in December, (Charas and Bantam, 1968).

A more detailed analysis of inversions at Lucas Heights is given in Clark (1990), based on temperatures measured at 9 and 49 metres. Clark found that overall, his values of average and extreme inversion strengths were lower than those reported by Charas and Bendum (1986), but attributed these changes to differences in the method of averaging these data for the two studies. He found that the trends of inversion frequency and strength were similar in both studies with increased strength, frequency and duration during the winter months, and an opposite trend in summer (Charas and Bendum, 1968; Clark, 1990).

For the Second Sydney Airport Draft EIS, a four year period of meterological measurements recorded at Lucas Heights between November 1992 and October 1996 has been used for the analysis of wind flow, runway availability and noise impact assessment at the two Holsworthy airport options. As part of the overall assessment of meterological conditions, temperature measurements made at the 10 metre and 49 metre heights have been analysed to assess the frequency of inversions between 1992 and 1996. The average frequency of inversions at Lucas Heights in each month are plotted against time of day in *Figure 4.27*. The height of each histogram gives the total percentage frequency of inversions or stable layer for each hour, whilst the shaded sections give the frequency of inversions of different strengths.

The values plotted in *Figure 4.27* are similar to the results obtained previously by Charas and Bendum (1968) and Clark (1990), with inversion frequency ranging from 30 percent some time during the night in the summer months, to 90 percent in winter. In summer, inversions commenced later than in winter as a result of changes in the length of daylight. However, in addition to these seasonal changes in inversion frequency at Lucas Heights, there were also seasonal changes in the rate that inversion frequency and strength increased with time during the night. Between November and February, the initial rate of increase in inversion frequency with time was low; it increased at a faster rate between March and May, and between September and October. From June to August, inversion frequency increased rapidly to high values very soon after sunset, then continued to increase more slowly with time during the

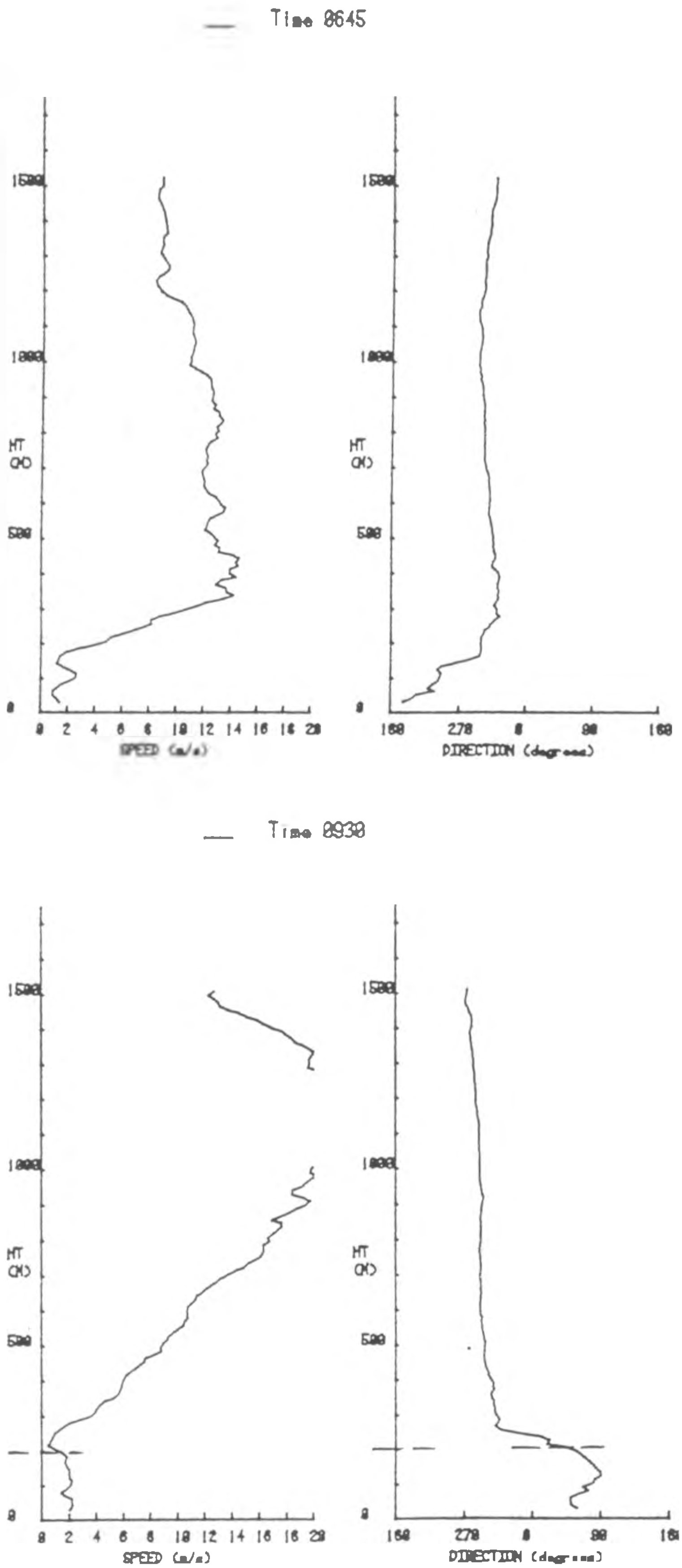


Figure 4.25 Profiles of wind speed and direction: Wilton (Douglas Park) 21 February 1980 showing remnants of 200 metre deep south to south-west drainage flow at 0645, and shallow east-north-east winds at 0930 below strong west-north-west synoptic winds above (Hyde et al, 1980)

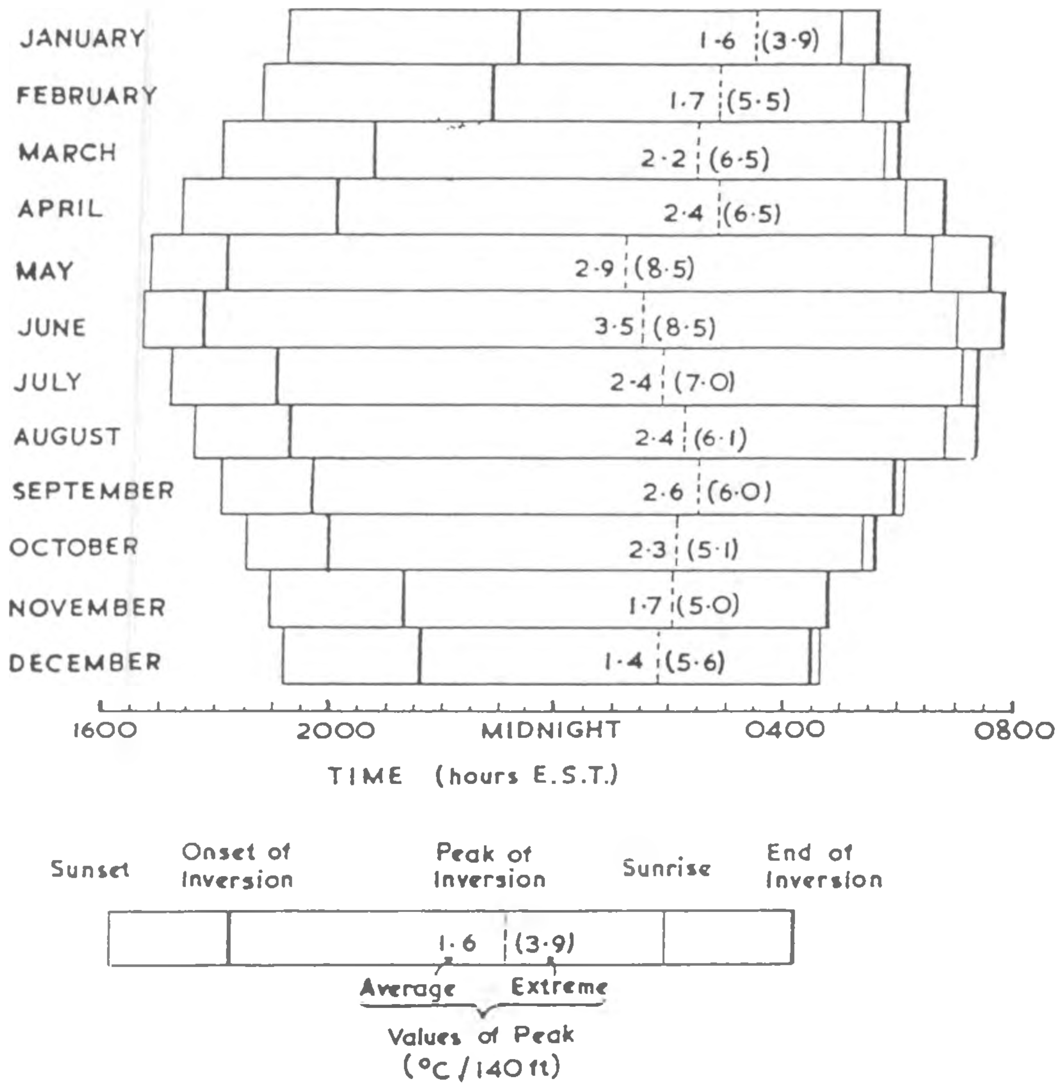


Figure 4.26 Lucas Heights: Monthly average times of occurrence of inversions (Charash and Bendum, 1968)

Lucas Heights - Frequency of Inversions: January to April (1992-1996)

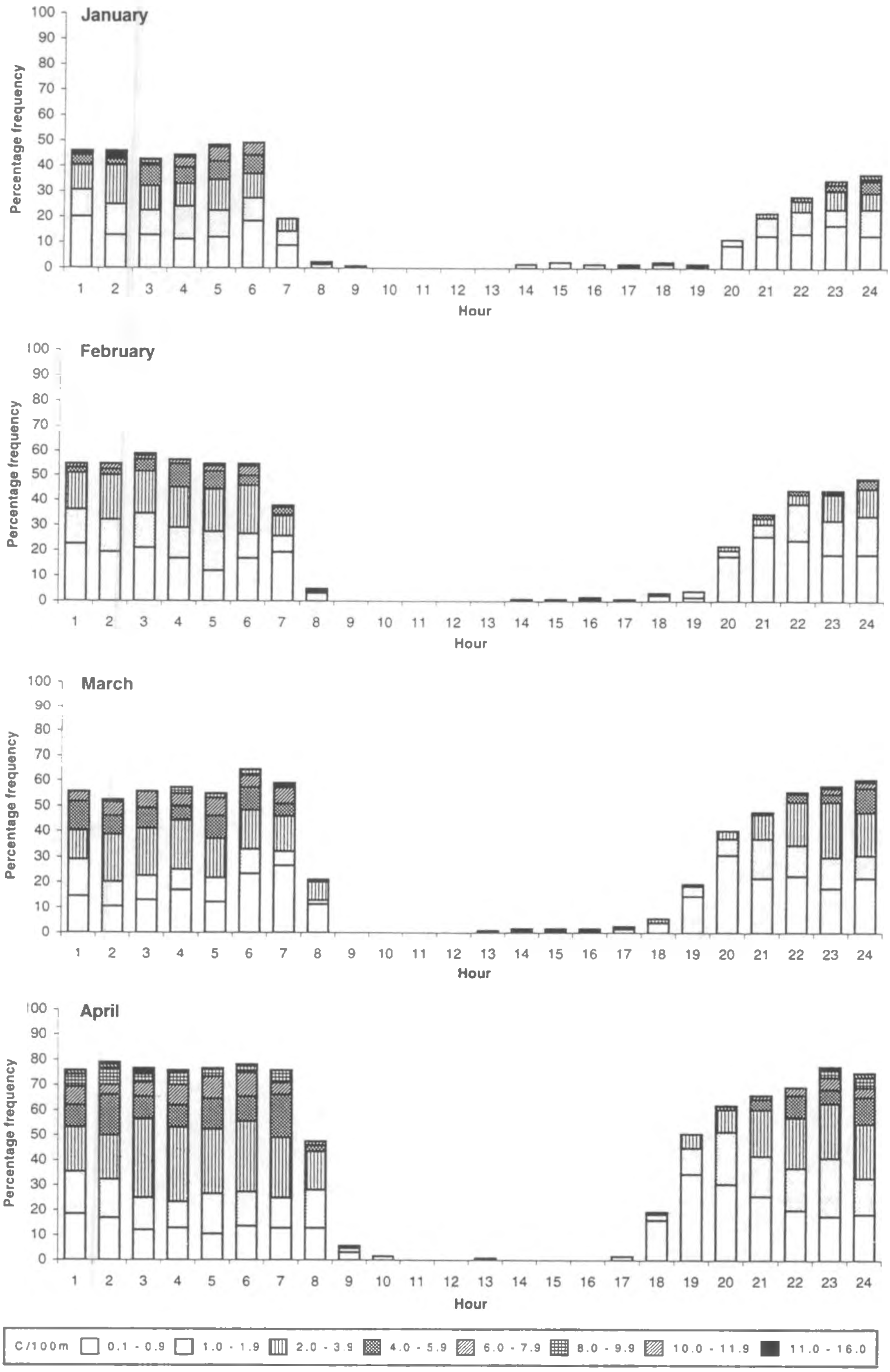


Figure 4.27(a) Temperaure difference (49m -10m) expressed as degrees Celsius/100 m in different ranges of inversion strength. Lucas Heights (1992 to 1996) Source - ANSTO

Lucas Heights - Frequency of Inversions: May to August (1992-1996)

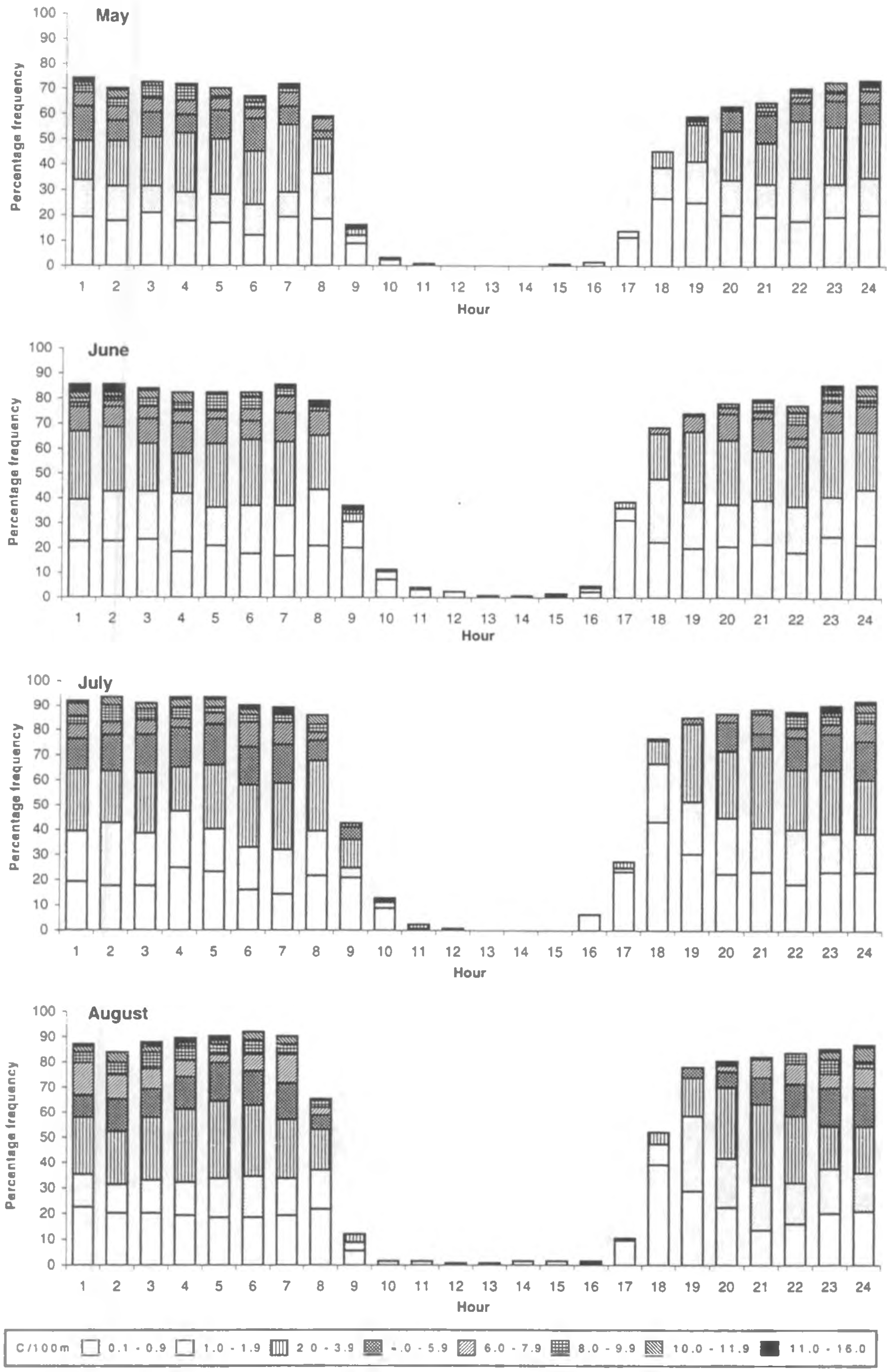


Figure 4.27(b) Temperaure difference (49m -10m) expressed as degrees Celsius/100 m in different ranges of inversion strength. Lucas Heights (1992 to 1996) Source - ANSTO

Lucas Heights - Frequency of Inversions: September to December (1992-1996)

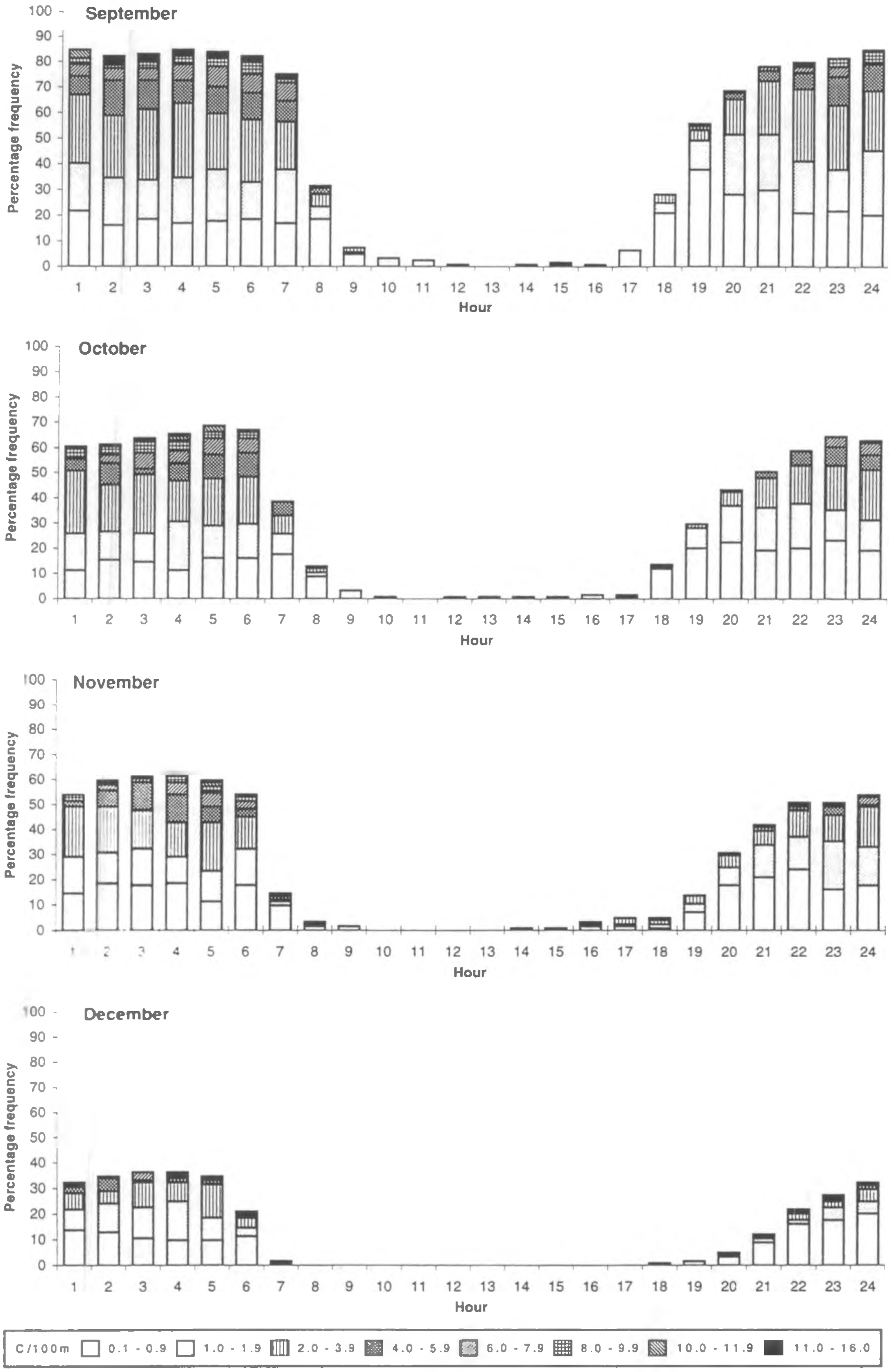


Figure 4.27(c) Temperaure difference (49m -10m) expressed as degrees Celsius/100 m in different ranges of inversion strength. Lucas Heights (1992 to 1996) Source - ANSTO

night. In most months of the year, the frequency of inversions remained relatively constant after midnight, then decreased soon after sunrise.

The percentage frequency of time that inversions of different strength occurred for different wind directions in each month are plotted in *Figures 4.28*. In these plots, the total percentage of time that nocturnal winds blew from each direction is given by the line, while the height of the histograms in *Figure 4.28* gives the percentage of times that winds from these directions were associated with stable layers and inversions. The period of time used to calculate these inversion frequencies is given in each plot; the length of time changes slightly during the year, to take into account seasonal changes in the length of daylight. In almost all months there was a high frequency of inversions when the wind blew from the south-west to north-west directions, probably as a result of inversions within cold air drainage flows or ground-based radiation inversions within offshore synoptic winds.

In summer, the low frequency of inversions in *Figure 4.27* occurs as a result of the relatively high frequency of north-east to southerly winds at night which are not stable. For example stable conditions only existed on 25 percent of occasions when the wind blew from the south at between 1800 and 0600 hours (*Figure 4.28*). The frequency of southerly winds that were stable increased to 30 percent in January when only measurements made between 2300 and 0600 hours were used. Hence the majority of these southerly winds, which were such a strong feature in summertime wind distributions plotted in *Figure 4.6*, were unlikely to be caused by a low-level southerly cold air drainage flow at Lucas Heights.

The percentage of time that stable layers and inversions formed in different ranges of wind speed January, April, July and October are plotted in *Figure 4.29*. In each month, the highest frequency of inversions occurred when wind strengths were below 2 metres per second at 10 metres above the surface. However, in July the percentage frequency of inversions or stable layers forming within stronger winds was much higher than in January.

Mixing Depths

Between September 1975 and March 1981, an acoustic sounder was operated at Lucas Heights to identify the depth of the mixing layer. This instrument receives a signal based on the strength of backscattered acoustic echoes produced by small scale turbulence in the atmosphere which is plotted as a grey scale on a facsimile chart. The echoes observed were calibrated during a program of tethered balloon ascents, (Clark and Bendum, 1981). Whilst the backscattered echoes do not provide qualitative measurements of the vertical structure of wind and temperature they can be used to provide climatological information about the depth of the mixing layer under different atmospheric conditions. An analysis of average mixing layer depths at Lucas Heights, based on 873 days of observations was reported by Clark (1983), and the results of his analysis of are listed on *Table 4.17*.

Following the breakdown of any stable layer that was present at sunrise, the average height of the recognisable echo in the morning was between 220 metres and 235 metres throughout the year, with a standard deviation of 65 metres in winter and 94 metres in summer. The average rate of rise of the surface mixing layer during the morning was between 160 and 176 metres per hour, although the standard deviation of 100 metres per hour indicates that the range of the rate of increase in height of the mixing layer during the morning could be quite large. The increase in depth of the mixing layer during the morning, occurs as a result of radiative energy available to provide heating of the surface, and is related to the size of the net (all-wave) radiation. This parameter is measured at Lucas Heights, and despite the average value in summer being twice that observed in winter, these changes in net radiation appear to have had little influence on the average rate of rise of the surface mixing layer between summer and winter.

The average final height of the surface mixing layer at Lucas Heights was 630 metres in winter and 728 metres in summer, although the standard deviation of these heights is again quite high, with 228 metres in winter and 225 metres in summer.

4.3.4 INVERSIONS AND MIXING DEPTHS - HOLSWORTHY OPTION B

Inversions

In the absence of any onsite measurements of the vertical temperature structure it is difficult to estimate how the frequency of inversions at Holsworthy Option B will differ from those measured at Lucas Heights where the ground elevation is 100 metres lower. This difference in elevation is likely to result in fewer inversions being observed at the southern airport site but these differences are impossible to quantify. It is likely that cold air drainage flows may be less frequent and shallower, and possibly stronger synoptic winds at this higher elevation may prevent ground-based stable layers and inversions forming as frequently. However, in view of all the uncertainties involved, it would probably be prudent at present to be to conservative, and assume that the frequency of inversions, and the directions of winds associated with them are similar to the data used to describe the situation at Holsworthy Option A.

Mixing Depths

The structure of the mixing depth at Holsworthy Option B, and its change with time during the day, will depend on the depth of any ground-based inversion present at sunrise and the presence of any subsidence inversion above. Even

Lucas Heights (1992 - 1996)
Frequency of Inversions in Different Wind Directions

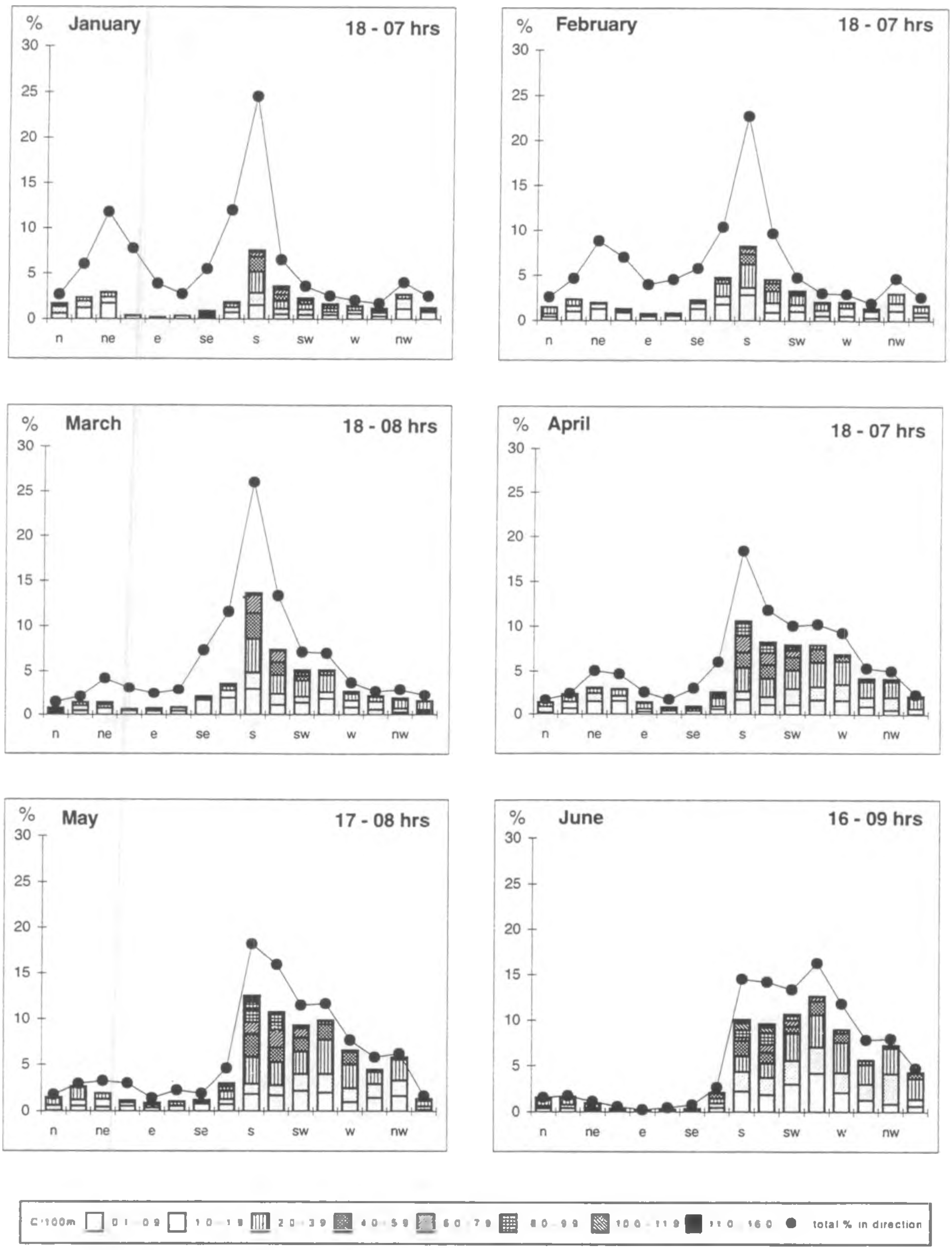


Figure 4.28(a) Frequency of inversions of different strength at Lucas Heights plotted against wind direction at 10 metres (1992-1996).
Source - ANSTO

Lucas Heights (1992 - 1996)
Frequency of Inversions in Different Wind Directions

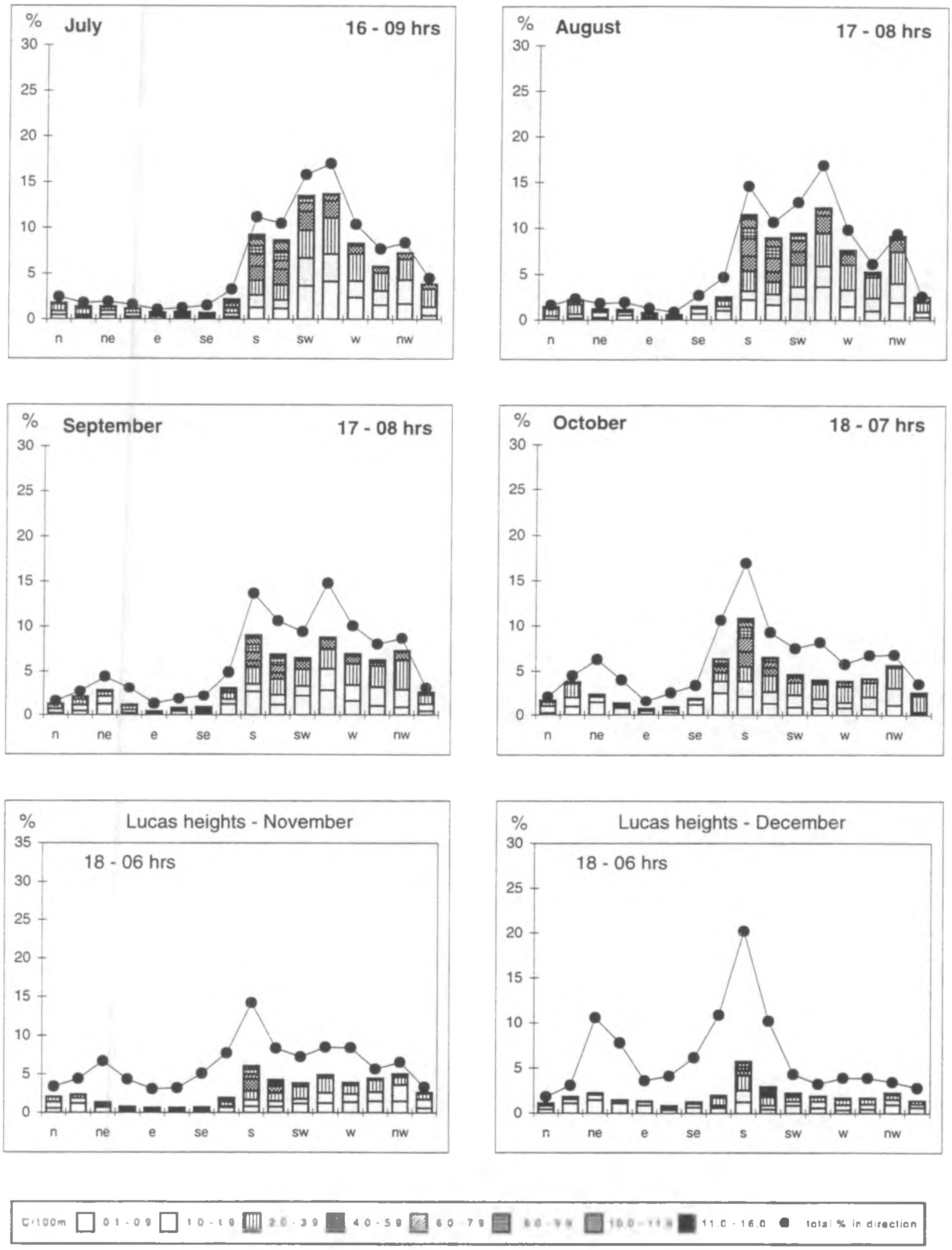


Figure 4.28(b) Frequency of inversions of different strength at Lucas Heights plotted against wind direction at 10 metres (1992-1996).
Source - ANSTO

Lucas Heights (1992-1996)
Influence of Wind Speed on Frequency of Inversions

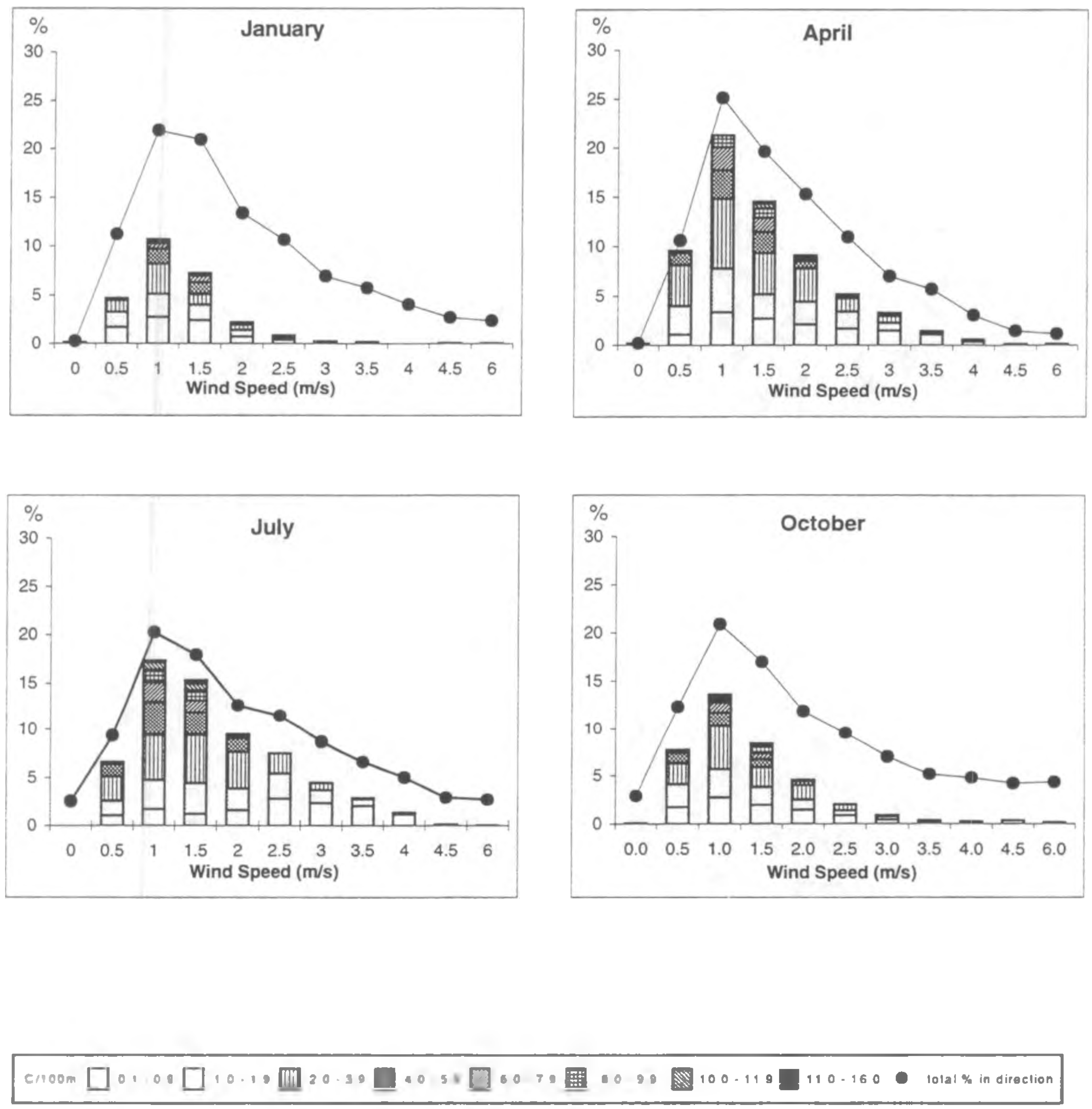


Figure 4.29 Percentage frequency of inversions of different strenghts at Lucas Heights January, April, July and October (1992-1996) in diiferent ranges of wind strength (metres/second) at a height of 10 metres: 0 m/s = 0 - 0.4; 0.5 m/s = 0.5 - 0.9; 1.0 m/s = 1.0 - 1.4; etc. Solid line gives total frequency of winds at Lucas Heights at Lucas in these ranges of wind speed between 1800 and 0800 hours. Source - ANSTO

if the frequency of ground-based inversions and drainage flow at Holsworthy Option B was similar to Holsworthy Option A, some decrease in height of ground-based inversions could be expected at Holsworthy Option B because of the increase in elevation. If this was true, then ground-based inversions would break down faster after sunrise, and allow near surface air to mix with the synoptic wind earlier than at Holsworthy Option A, but again, in the absence of any on-site measurements these possible differences cannot be quantified.

The other factor that could affect the depth of the mixing layer at Holsworthy Option B could be differences in the structure of sea breezes between Lucas heights and Holsworthy Option B, but in view of the lack of information about any possible differences, at this point in time, the most sensible approach would be to assume that the statistics of drainage flow structures observed at Lucas Heights will be similar to those at Holsworthy Option B.

4.4 NORTHERLY WINDS

Much of the information about winds discussed in previous sections of this chapter have focussed on seasonal changes in the direction and strength of the synoptic winds in Sydney, and on sea breezes and cold air drainage flows. This is understandable, considering that until recently, most of the winds have been made at 10 metres above the surface and generally where the height of the ground above sea level is relatively low. As a result, when the synoptic wind has been undercut by sea breezes or drainage flows, as illustrated in *Figure 3.8*, these surface winds do not provide information about winds some distance above the surface.

Some wind measurements are recorded at higher elevations in the Sydney Basin; for example, the Bureau of Meteorology maintains automatic weather stations in the Blue Mountains; the Environment Protection Authority has recently expanded its network of air quality monitoring stations further into south-west Sydney and installed stations at Bargo and Oakdale, *Figure 3.3*; and in 1980, during the Western Basin Experiment, Macquarie University measured winds at Mittagong, Mount Tootie, and Winmalee, *Figure 3.1*.

In time, these data will be analysed and provide information about the frequency of winds at these higher elevations, whilst winds recorded at the NSW Environment Protection Authority monitoring stations at Bargo and Oakdale are likely to provide valuable information about meteorology and air quality in south-west Sydney.

4.4.1 NORTHERLY WINDS - INLAND

This section discusses wind records measured by Macquarie University at Winmalee in 1980, to illustrate a characteristic north-north-west wind flow that is observed in the wind records from this station on many nights of the year, as illustrated by the histograms plotted in *Figure 4.31*. One of the most significant features of these plots, is the high frequency of north-north-west winds during the night, with winds from this direction occurring on 25 percent to 35 percent of all nights at 0300 and 0600 hours. Despite the high frequency of occurrence evident in the frequency plots for 0600 hours, there is little evidence for this north-north-west flow in the plots for 0900 hours.

The cause of the these winds is currently unknown, but may be linked to topographic steering of the synoptic wind when the atmosphere is stable, and on other occasions may be a northerly drainage flow.

Copies of a winter and summer wind trace recorded at Winmalee in 1980 are given in *Figure 4.30*. The trace from the 7/8 June 1980 shows this northerly flow being replaced by an north-east synoptic wind at 1100 hours on 7 June, but by 1700 hours which is almost the time of sunset, the northerly flow reappears and continues throughout the night, turning slightly anticlockwise with time, before breaking down the following morning, 8 June, at 1030 hours, (three and a half hours after sunrise). In contrast to the long period of nighttime northerly wind in winter, the second example shows the same flow occurring in summer. On 10 November, the northerly flow commenced at 2100 hours (about two and a half hours after sunset (EST)), and continued until 0730 hours the following morning, (two hours and forty five minutes after sunrise). In the evening of 11 November, the northerly flow reappeared at 2100 hours and continued until 0815 hours on 12 November, (three and a half hours after sunrise). Therefore, in the wintertime example, the northerly flow commenced around sunset, whilst in the November example it took about two and a half hours after sunset before it commenced. However, in both the winter and summer examples plotted in *Figure 4.30*, it took between two and a half and three and a half hours after sunrise to breakdown the northerly flow.

From the observations at Winmalee, it is clear that a northerly flow is frequently present above the Hawkesbury Basin during the night, and is blowing in the opposite direction to the south to south-west cold air drainage flow below. In western Sydney, the few wintertime profiles of temperature that are available, show ground-based inversions 500 to 600 metres deep, compared with inversion depths of 300 to 400 metres in eastern Sydney. Hence, it is possible, that in winter, this northerly wind may assist in forming the deep ground-based inversions in western Sydney, *Figure 4.23*.

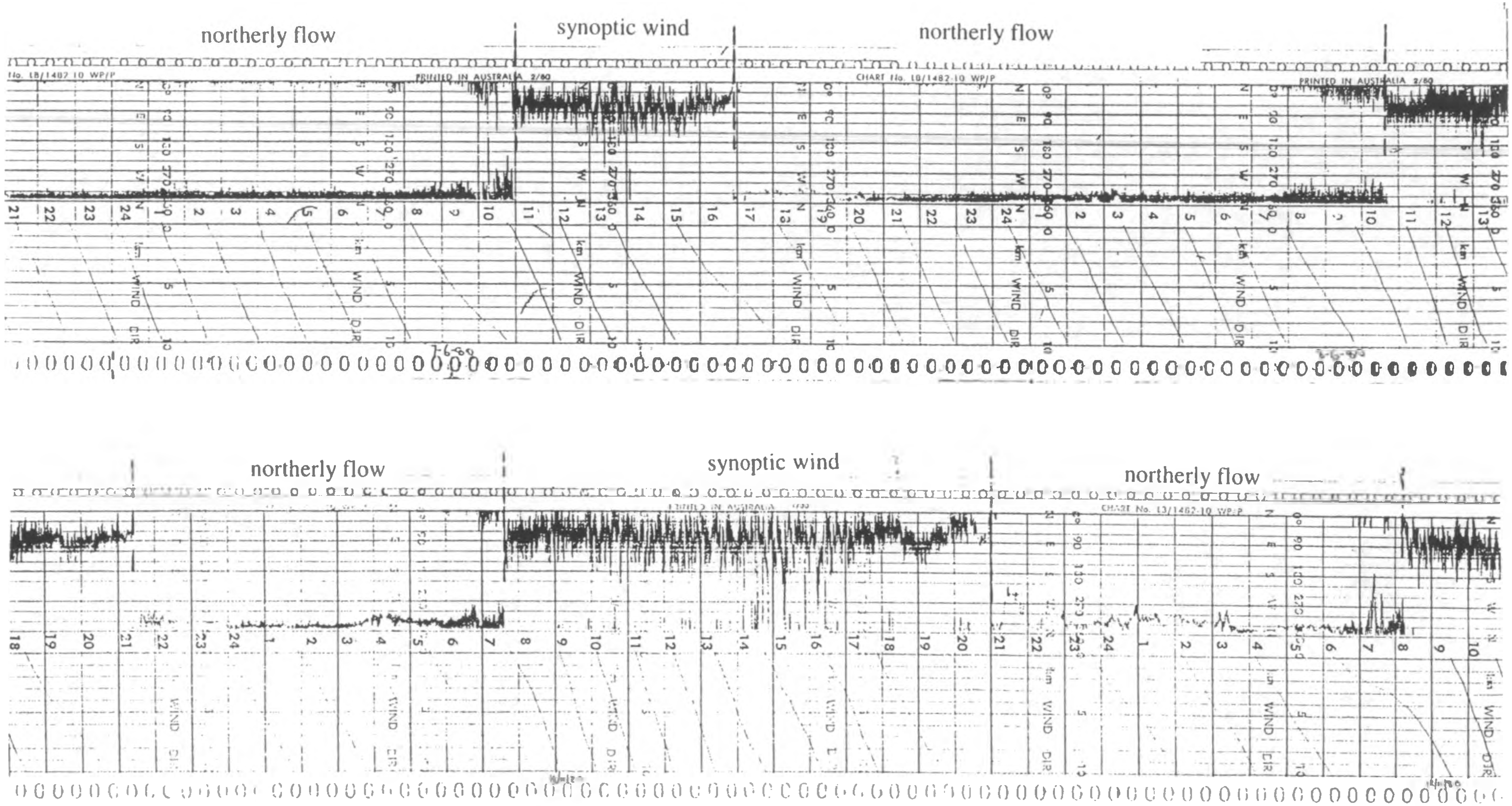


Figure 4.30 Winmalee flows at Winmalee: (a) Winter 7/8 June 1980 (b) Summer 11/12 November 1980 (R. Hyde, Macquarie University Wind Data)

Winmalee (Yellow Rock) Summer (1979 - 1980)

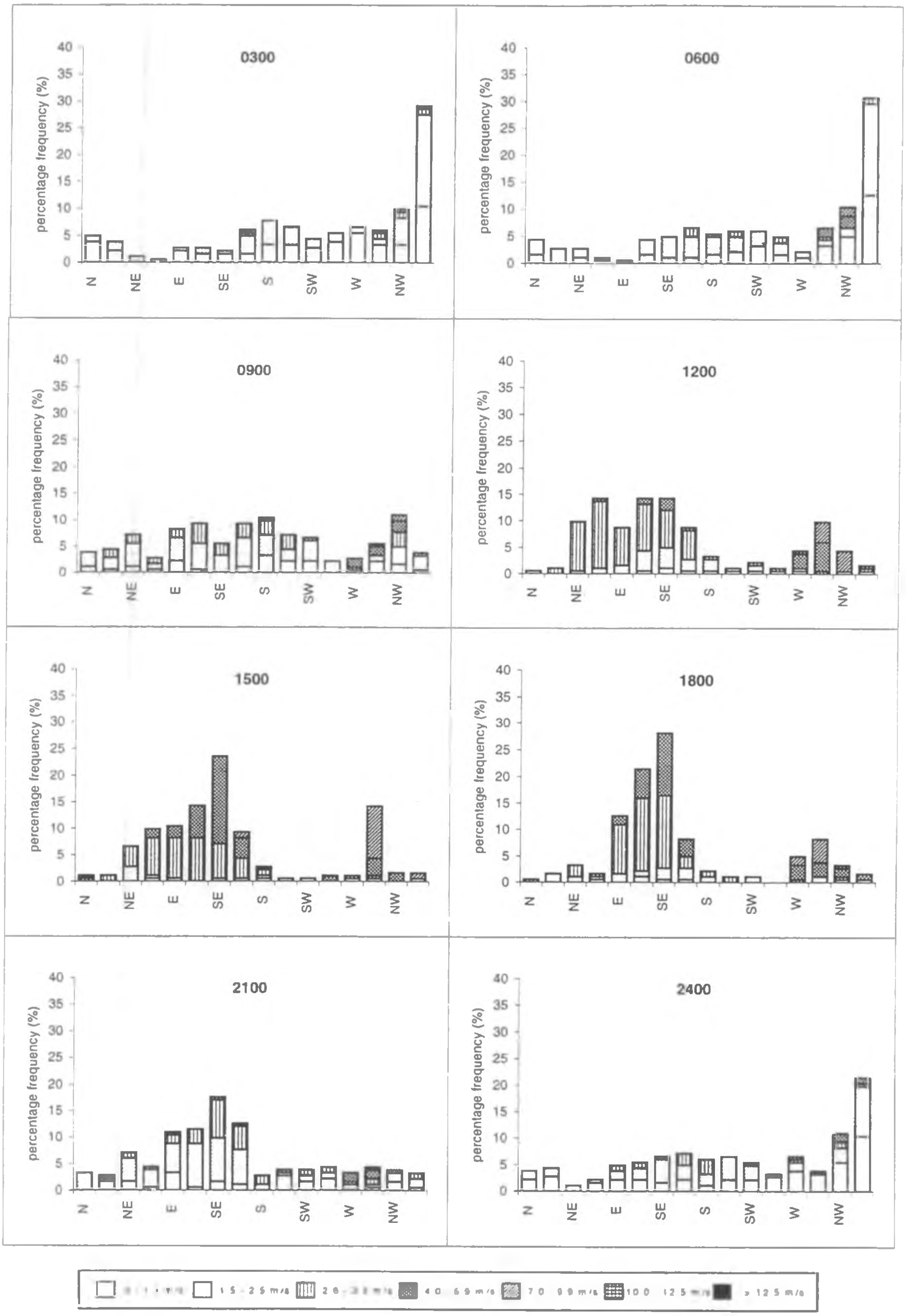


Fig 4.31(a) Three-hourly wind speed and direction frequency distribution, Winmalee - Summer (1979 - 1980)

Winmalee (Yellow Rock) Autumn (1980)

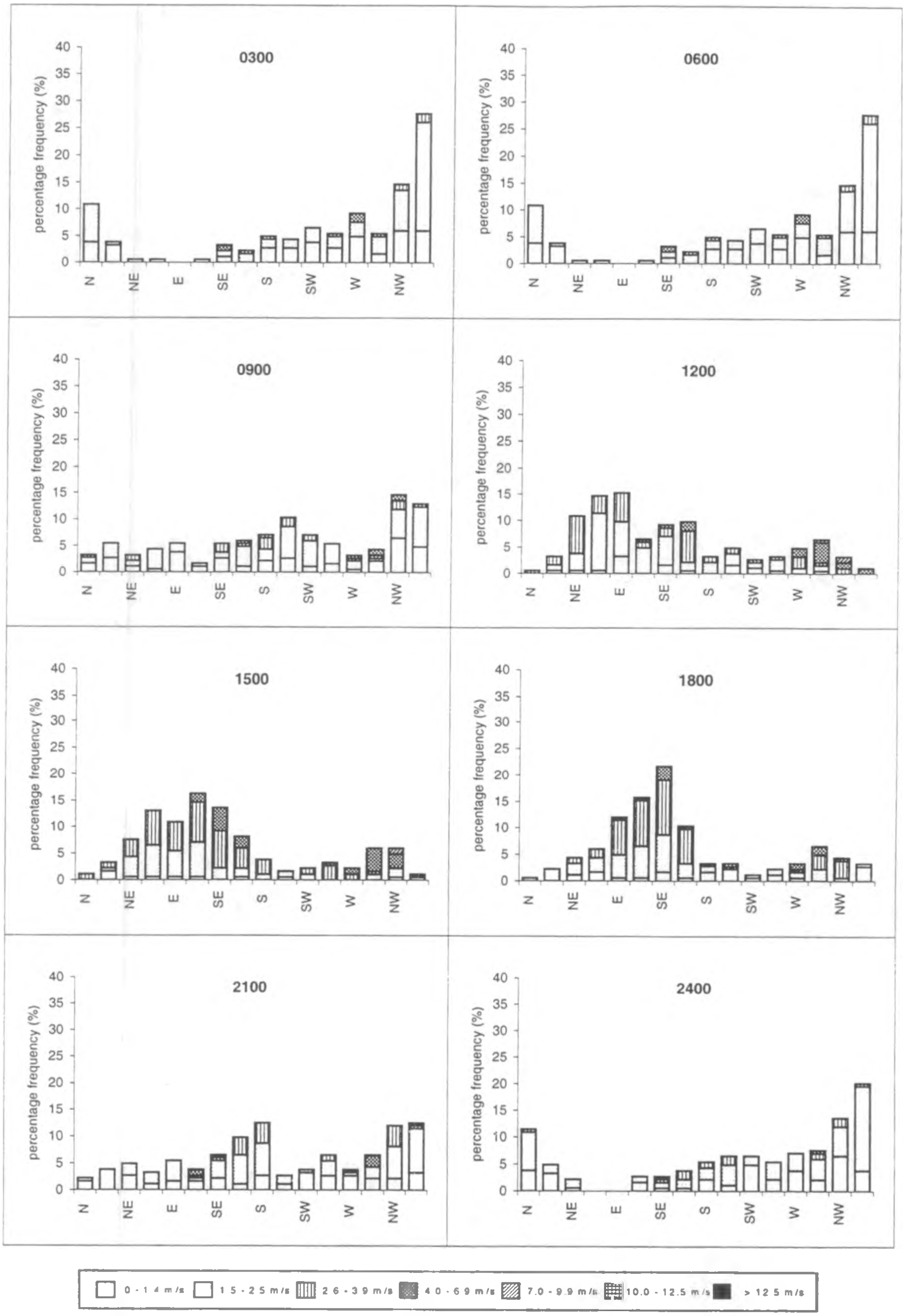


Fig 4.31(b) Three-hourly wind speed and direction frequency distribution, Winmalee - Autumn (1980)

Winmalee (Yellow Rock) Winter (1980)

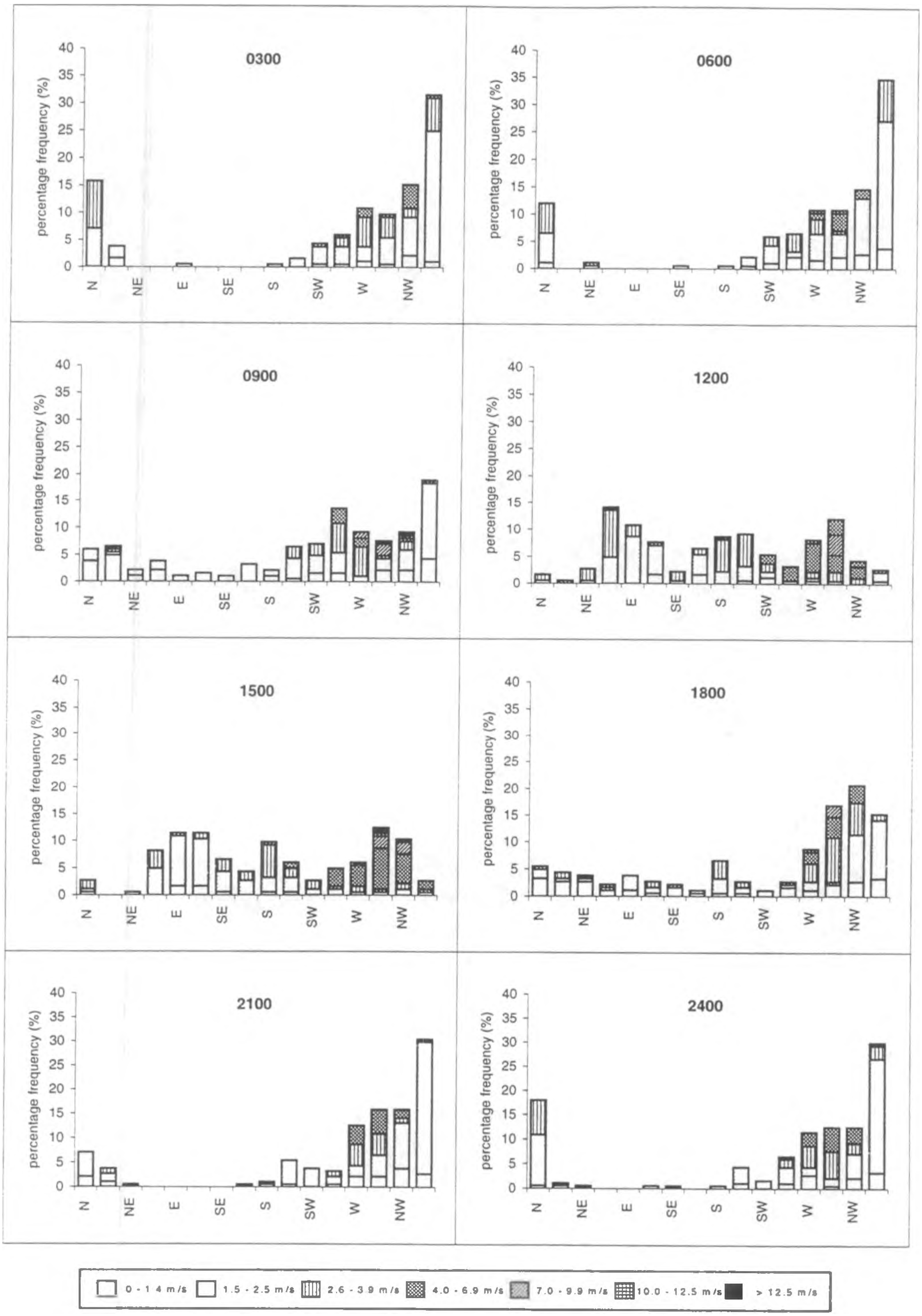


Fig 4.31(c) Three-hourly wind speed and direction frequency distribution, Winmalee - Winter (1980)

Winmalee (Yellow Rock) Spring (1980)

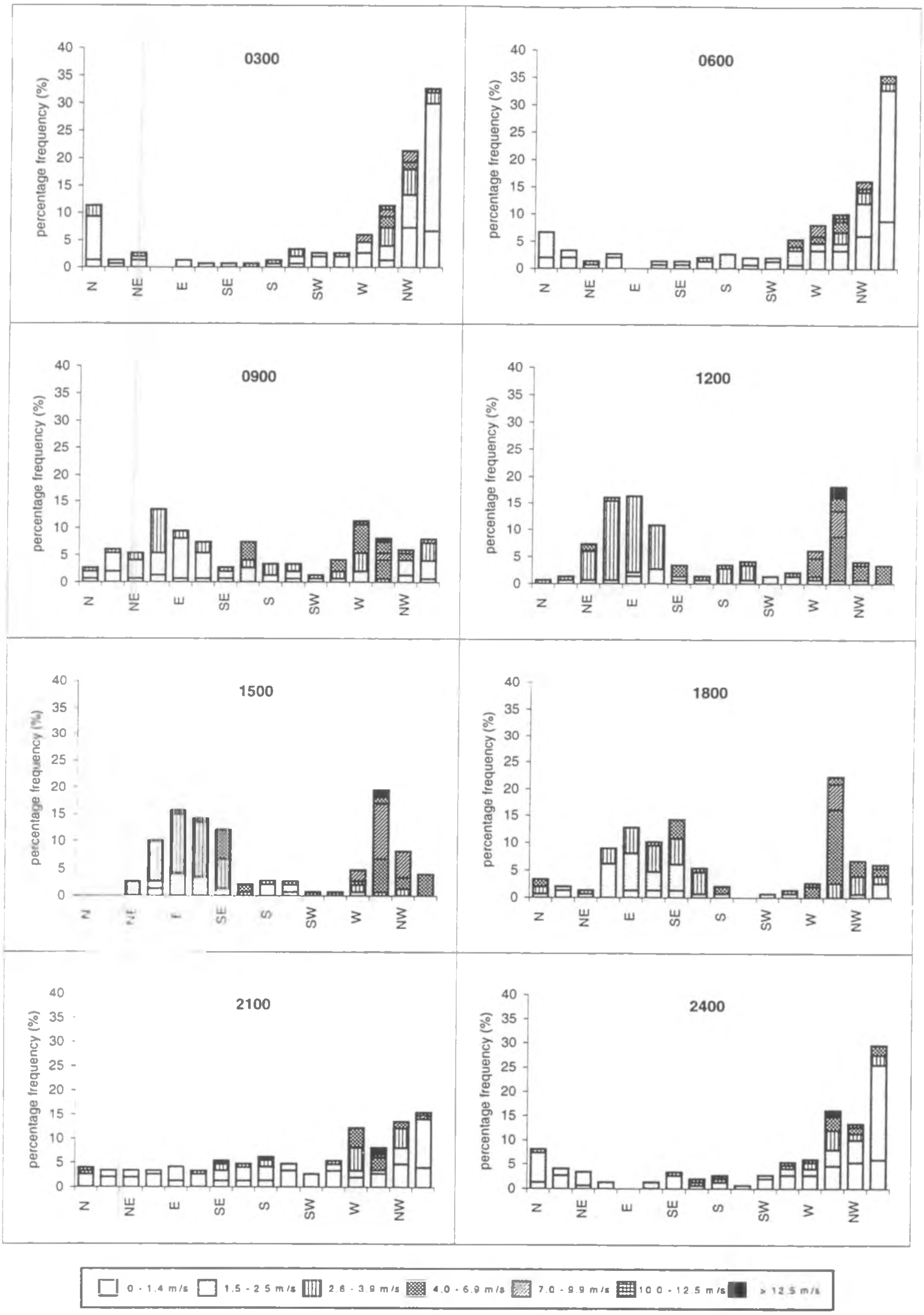


Fig 4.31(d) Three-hourly wind speed and direction frequency distribution, Winmalee - Spring (1980)

In the absence of routine vertical profiles of wind and temperature in western Sydney, it is not possible to speculate how these deeper inversions will affect the time it takes to erode them away after sunrise. In eastern Sydney, it can take till mid-day to completely erode away the inversions, *Figure 4.27*. However, heating during the morning of the east-facing slopes of the lower Blue Mountains, may create up-slope (anabatic) winds, which may speed up the breakdown of these deep wintertime inversions in western Sydney.

These northerly winds are also observed during the summer months, when the frequency of ground-based inversions and south to south-west cold air drainage flows in the Hawkesbury Basin is lower. In view of the high frequency of these events in summer, it is possible, that on some occasions, these northerly winds could contribute to the inter-regional transport of photochemical smog from source regions north and north-east of Sydney, and this possibility is discussed in more detail in Chapter 5.

If these northerly winds are decoupled by an inversion from a warmer north-west synoptic wind above, then it possible that the depth of the mixing layer in western Sydney during the morning may be limited by this elevated inversion. The importance of a relatively constant mixing depth on photochemical smog concentrations in western Sydney is discussed in Chapter 5.

4.4.2 NORTHERLY WINDS - AT THE COAST.

Macquarie University has operated a wind recorder at La Perouse for many years. It was installed in 1979 as part of the Sydney Brown Haze Experiment (Hyde et al, 1982), and has operating almost continuously since then. Wind records from this station show, that on many occasions in summer, the sea breeze is followed by a period of continuous flow from the north-north-east direction overnight. Before the Pacific Power investigation and *Metropolitan Air Quality Study* (Environment Protection Authority, 1997a) , it was thought that the along-shore wind observed at La Perouse was a continuation of the sea breeze. A similar situation had been observed in the Macquarie University wind records from Port Kembla Signal Station (Prescott, 1989) and it was assumed that this along-shore flow had occurred as a result of topographic steering of the synoptic wind by the Illawarra Escarpment.

During the *Metropolitan Air Quality Study* (Environment Protection Authority, 1997a), as part of the investigation of inter-regional transport from the Lower Hunter to Sydney, overnight north-north-east winds were also observed at Nobbys Head in Newcastle, and at the Bureau of Meteorology's automatic weathers station at Nora Head in the Central Coast, (Hyde et al, 1997).

The results of wind field modelling during Metropolitan Air Quality Study showed that these persistent along-shore flows overnight were a regional phenomenon, although the model results showed the flow some distance away from the coast, (Hurley and Manins, 1997), in contrast to the observations which showed this flow persisting throughout the night at the coast.

On the basis of some limited analysis of winds and temperatures measured by aircraft taking off from Sydney Airport , it appears that this layer of north-north-east wind can be decoupled by an inversion layer from north-north-west to north-west synoptic winds above (Hyde et al., 1997).

The implications of these northerly flows on air quality are not yet understood. Modelling by Metropolitan Air Quality Study, showed that these along-shore winds could be associated with southward transport of air from regions north of Sydney, which could be carried along the coast into Sydney and the Illawarra, (Hurley and Manins, 1997). However, it is important to note, that these conclusions have been based on the results of modelling alone, and it will be necessary some time in the future, to make measurements of the vertical structure of winds in these coastal regions to determine whether the model results are correct and it is possible for surface and elevated emissions from Newcastle and the Central Coast to be carried along the coast into Sydney and the Illawarra.

CHAPTER 5 RESULTS OF SURVEYS

This chapter reviews linkages between meteorology and air quality in the Sydney Region. Section 5.1 lists the major air quality and related air quality investigations that have taken place in Sydney since 1975 and discusses main meteorological factors that have been identified as being conducive to the formation of high pollutant concentrations of photochemical smog in summer, and the trapping of near-surface urban and industrial emissions in the cooler months of the year.

A review of linkages between meteorology and pollutant concentrations measured at air quality monitoring stations adjacent to Badgerys Creek and the Holsworthy Military Reserve, based on observations of pollutant concentrations and associated meteorological measurements are discussed in Sections 5.2 to 5.4.

5.1 REVIEW OF PREVIOUS WORK - SYDNEY BASIN

Since 1975 there have been several major air investigations into air quality in Sydney where the impact of meteorology on air quality has been examined:

- The Sydney Oxidant Study (1975 to 1977) - the occurrence of photochemical smog in Sydney;
- The Sydney Brown Haze Experiment (1977 to 1979) - the occurrence of wintertime fine particle pollution in eastern Sydney;
- The Sydney Hydrocarbon Study (1980) - non-methane hydrocarbons in Sydney's atmosphere; and
- The Metropolitan Air Quality Study - Metropolitan Air Quality Study (1993 to 1996) - emissions inventory, air chemistry, wind field modelling and the development of an urban airshed model for the greater Sydney region.

Other investigations include the 'Western Basin Experiment' which examined the structure of nocturnal winds in western Sydney (Hyde et al. 1980), and joint investigations by CSIRO, Division of Coal and Energy Technology and Macquarie University, for example: the 'Pilot Study' which examined air quality issues associated with the development of the Macarthur South and South Creek Valley regions of Sydney (Hyde and Johnson, 1990), an investigation of photochemical smog in Sydney for Pacific Power (Johnson et al. 1993), and the Aerosol Sampling Project (ASP) a collaborative project headed by the Australian Nuclear Science and Technology Organisation (ANSTO) at Lucas Heights which investigated the composition of fine particles less than 2.5 microns at 24 sites in eastern New South Wales in 1992 and 1993 (ANSTO, 1995).

The main outcomes of the Sydney Oxidant Study, the Sydney Brown Haze Experiment, the Western Basin Experiment and the Hydrocarbon Study were discussed at a conference held at Leura in May 1982 (Carras and Johnson, 1983).

The following meteorological factors were identified as the major factors influencing the occurrence of photochemical smog and fine particles in Sydney (Colquhoun, 1983; Clark, 1983; Hawke et al., 1983; Hyde et al., 1983 a,b,c):

- the synoptic weather situation;
- the thermal structure and winds in the lowest one to two kilometres of the atmosphere;
- trapping, transport and re-circulation of pollutants within sea breezes and cold air drainage flows both inland and at the coast;
- trapping of pollutants within ground-based inversions during the evening and overnight; and
- the trapping of pollutants within a shallow mixing depth below an elevated inversion during the morning.

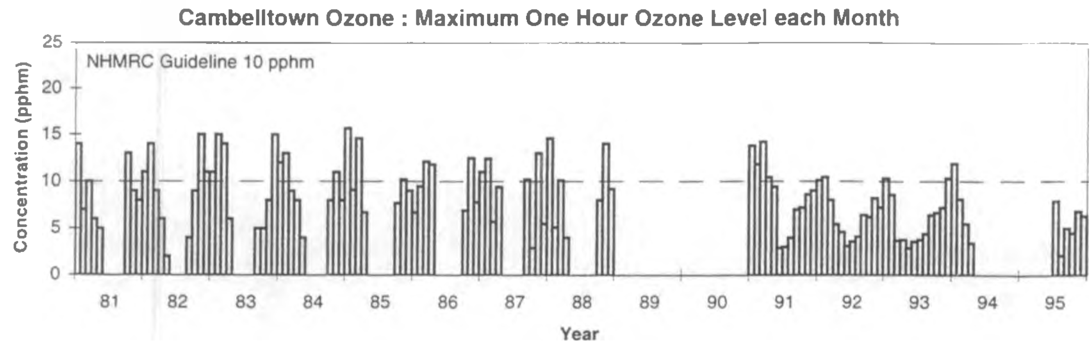
The influence of these processes on air quality in Sydney is discussed below.

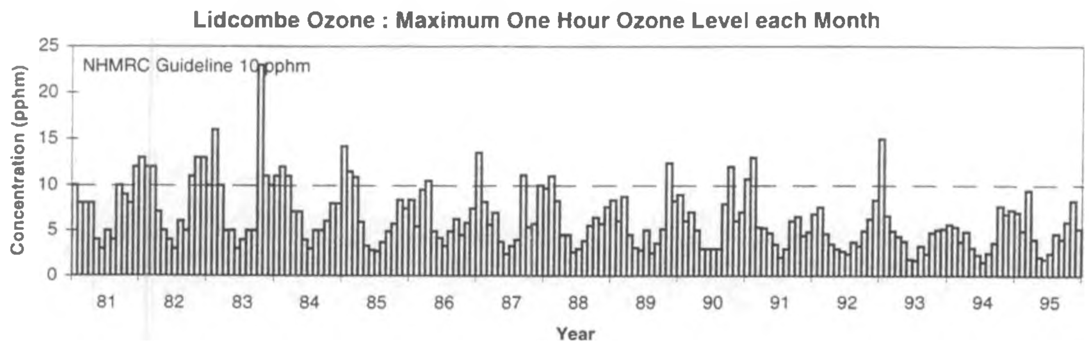
5.1.1 PHOTOCHEMICAL SMOG AND METEOROLOGY IN SYDNEY

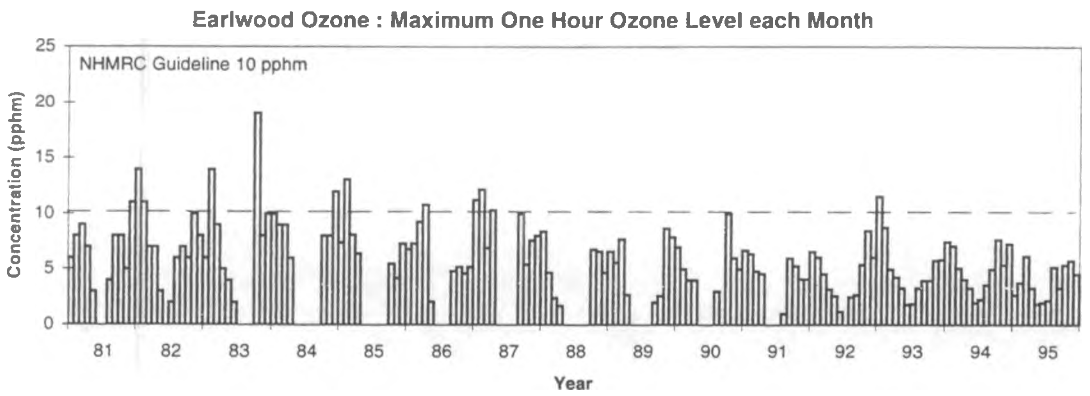
The formation of photochemical smog is influenced by a complex interaction of several process (Hyde at al 1990, Johnson et al., 1983). These include:

- the emissions of oxides of nitrogen and reactive organic hydrocarbons which are the precursors to photochemical smog;
- the subsequent chemical reactions; and
- meteorological processes.

As a result of the dependence on warm air temperature and increased solar radiation, photochemical smog in Sydney is a summertime phenomenon. This is illustrated by the time series plots in *Figure 5.1* which show maximum







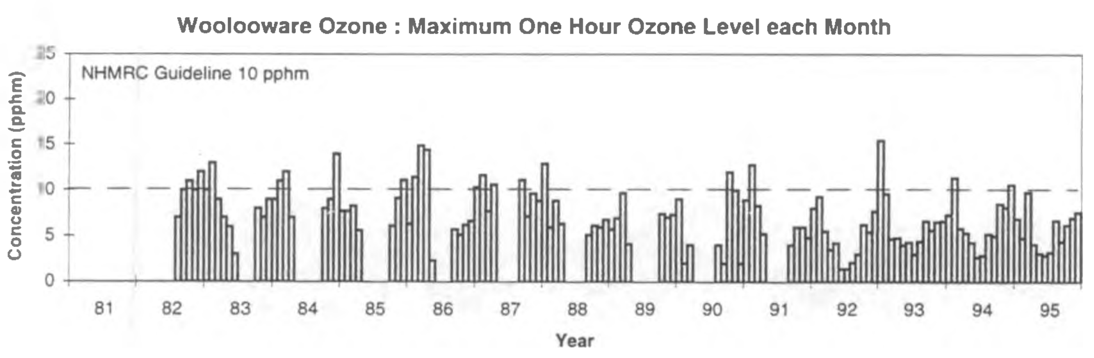


Figure 5.1 Time series of monthly maximum 1-hour concentrations of ozone, 1981 to 1995
Source: NSW EPA Quarterly Reports of Air Quality

hourly concentrations of ozone for stations in Sydney between 1981 and 1995. These data reveal show that ozone concentrations peak during the summer months, usually between December and February, and are low in winter.

The meteorological conditions that control the formation of photochemical smog are:

- the presence of stable layers and limited mixing depths during the morning that can inhibit the vertical dispersion of precursor emissions;
- solar radiation and air temperatures which determine the rate of the chemical processes; and
- atmospheric transport and dilution which determine the temporal and spatial distribution of photochemical smog downwind of the precursor source regions.

The specific combination of meteorological conditions, and way in which they interact and cause high concentrations of photochemical smog in Sydney to occur on a particular day, have not yet been identified (Hawke et al 1983; Hyde et al., 1997 Leighton and Spark, 1995). However, on the basis of the results from the investigations into photochemical smog listed above, some of the features that are commonly observed on these days are:

- a region of high pressure in the Tasman Sea with a ridge extending back into north-east New South Wales;
- warm air temperatures aloft at 0600 hours and continued warming of the atmosphere between one and two kilometres height above the surface during the day;
- overnight radiation inversions at the surface and a deep warm-air advection inversion above which together, combine to produce an inversion at sunrise that may be as deep as one kilometre;
- light to moderate strength north-west to north-easterly synoptic winds; and
- afternoon sea breezes.

On ozone event days in Sydney, photochemical smog can occur at different times of the day:

- within the deepening mixing layer after sunrise (morning ozone);
- under periods of synoptic winds (regional ozone); and

- within the afternoon sea breeze, (sea breeze ozone) .

During the investigations of photochemical smog in Sydney for Pacific Power (Johnson et al., 1993), it was observed that high concentrations of ozone could occur simultaneously in different parts of Sydney, but under quite different meteorological conditions. On the basis of the observed pattern of ozone concentrations and associated meteorology, Sydney was divided into four regions, using data from the more limited network of monitoring stations that were present in Sydney in 1991, *Figure 5.2*. A subsequent analysis of the frequency of ozone concentrations in these different regions for 1991, plotted in *Figure 5.3*, confirmed the existence of quite separate regions of ozone within the Sydney Basin (Hyde and Young, 1993). This showed that the distribution of ozone concentrations at Woolooware near Cronulla, and at Albion Park in the Illawarra were very similar despite the fact that these two monitoring stations are about 65 kilometres apart. Also, the distribution of ozone in the South-East Coastal Region, was the second highest in the Sydney Basin, even though ozone concentrations in the adjacent Eastern Region were significantly lower.

Photochemical Smog in Western Sydney

The trapping and transport of ozone across the Sydney Basin by the sea breeze has long been accepted as a major factor contributing to high concentrations of photochemical smog in Sydney (Hyde and Hawke, 1976; Hyde et al 1978a; Hawke et al., 1983; Johnson et al., 1993; Hyde et al 1997). In this situation, there is usually an abrupt increase in ozone concentrations coinciding with the arrival of the sea breeze. However, there is currently no knowledge of, or understanding about, the characteristics of sea breezes that are associated with these episodes of photochemical smog in west and south-west Sydney. On the basis of a few days examined during the *Metropolitan Air Quality Study* and the Pacific Power investigation, vertical temperature profiles measured by the Bureau of Meteorology at 1500 hours, and by commercial aircraft taking off from Sydney Airport, indicate that the depth of the sea breeze at the coast on these days might be quite shallow, (Hyde et al., 1997, Johnson et al., 1993).

Morning ozone in western Sydney is characterised by increasing concentrations after sunrise *(Figure 5.4b)*. It is measured under a wide range of wind directions but is usually associated with northerly sector winds. Ozone concentrations during this period can sometimes be high, but the absence of wind and temperature on these occasions means that it is difficult to interpret the meteorological conditions associated with these events (Hyde et al; 1997). During the Sydney Oxidant Study it was thought that morning ozone formed within northerly sector winds as a result of photochemical smog precursors being carried north within light overnight cold air drainage flows in western Sydney, then carried back southwards along the Hawkesbury Basin by light northerly synoptic winds (Hyde et al 1978a). Modelling by CSIRO, Division

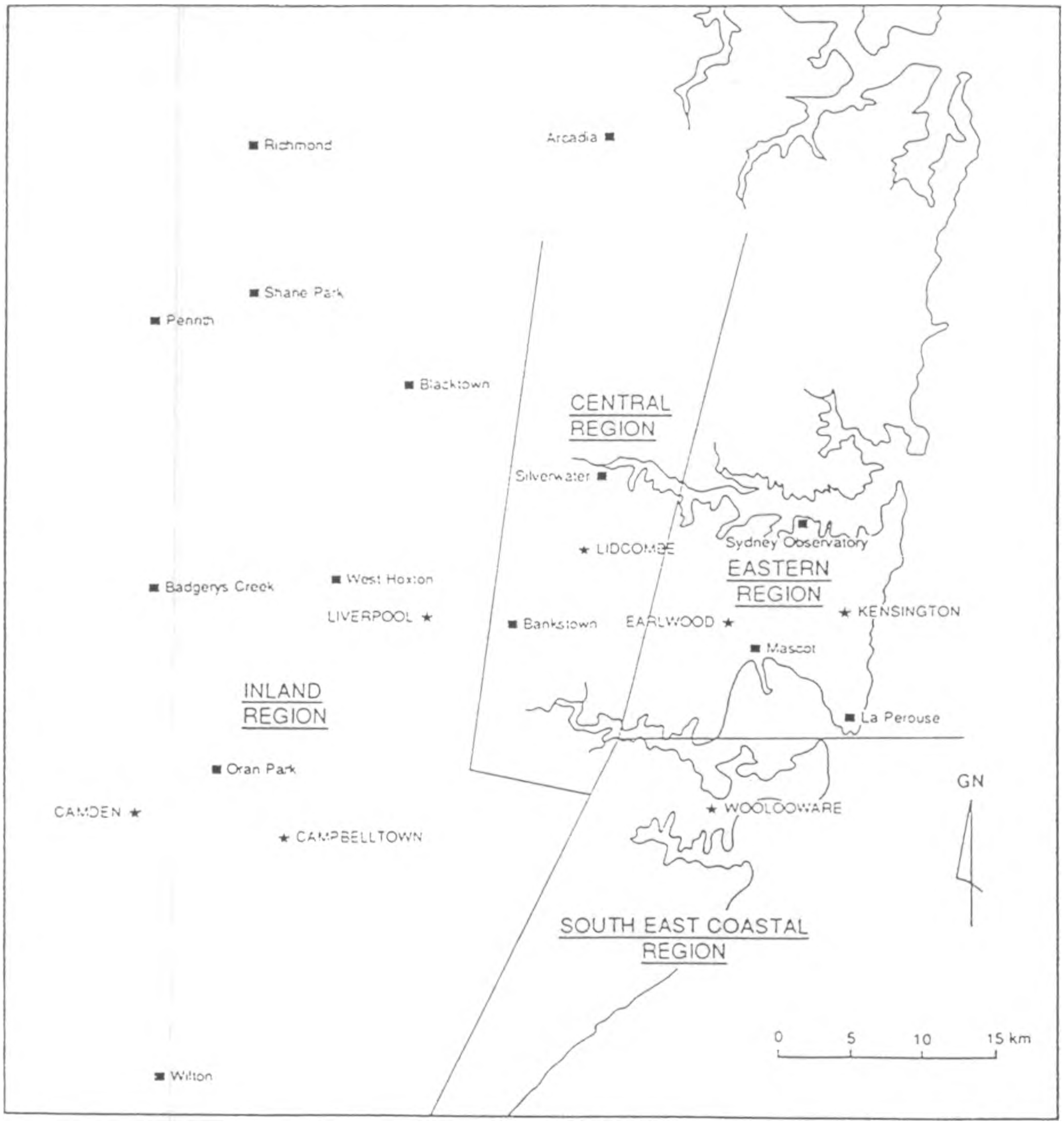


Figure 5.2 Partition of Sydney Basin into photochemical smog regions, based on an analysis of ozone data from October 1990 to March 1991(Johnson et al, 1993)

Air quality monitoring sites (✱), Bureau of Meteorology and Macquarie University winds recording sites (■)

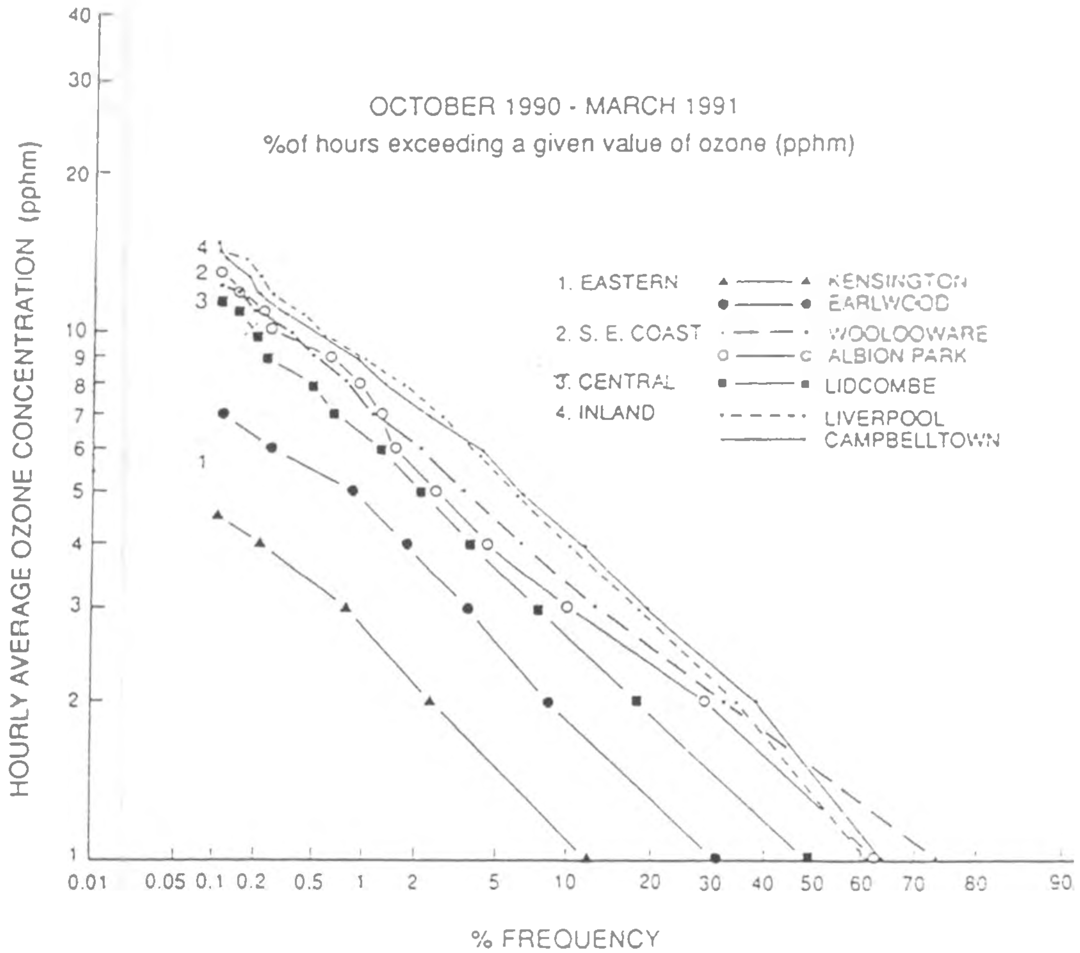


Figure 5.3 Cumulative frequency distribution of ozone concentrations in the Sydney Region, October 1990 to March 1991 (Hyde and Young, 1993)

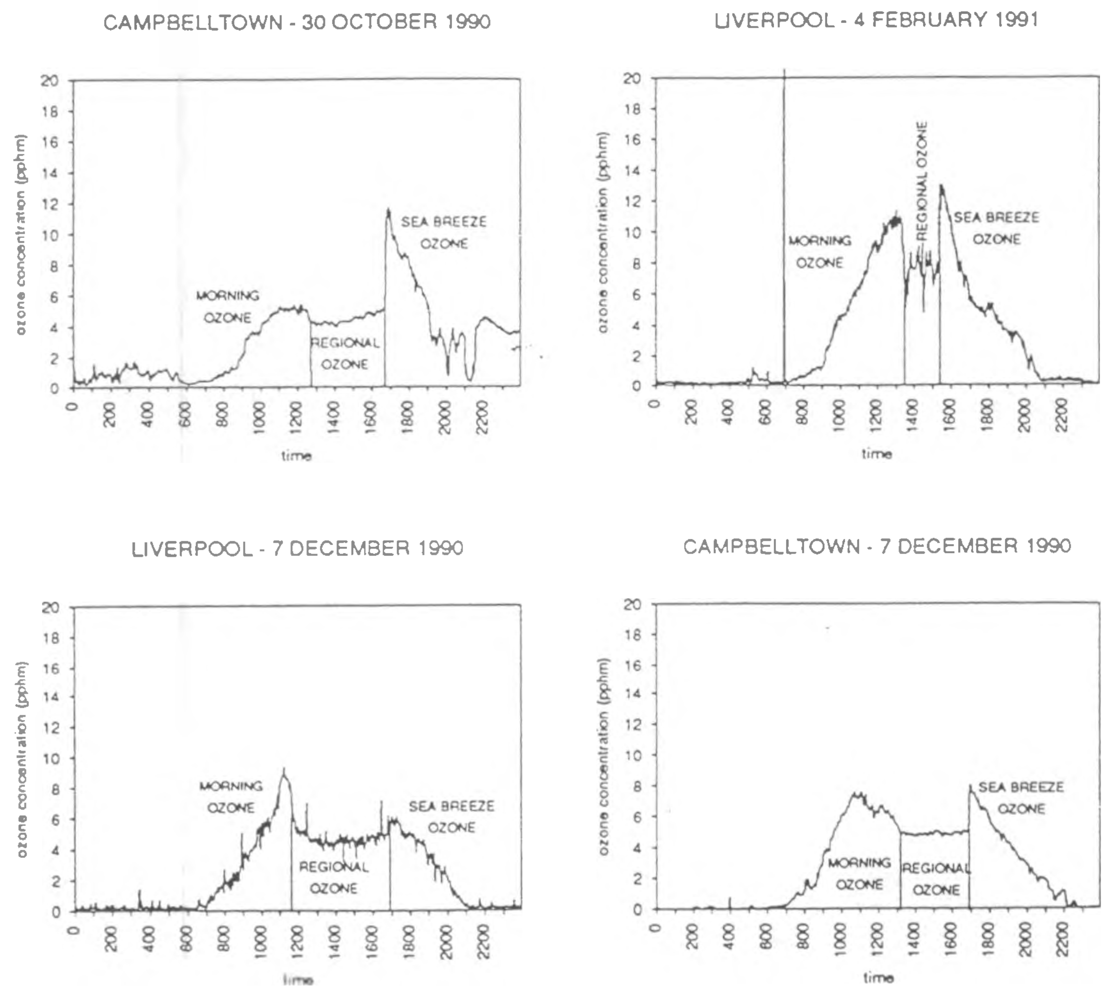


Figure 5.4(a) Time series of 2-minute average ozone concentrations at a selection of NSW EPA monitoring stations in western Sydney, showing periods of morning, regional and sea breeze ozone. Source: NSW EPA, (Hyde et al., 1997)

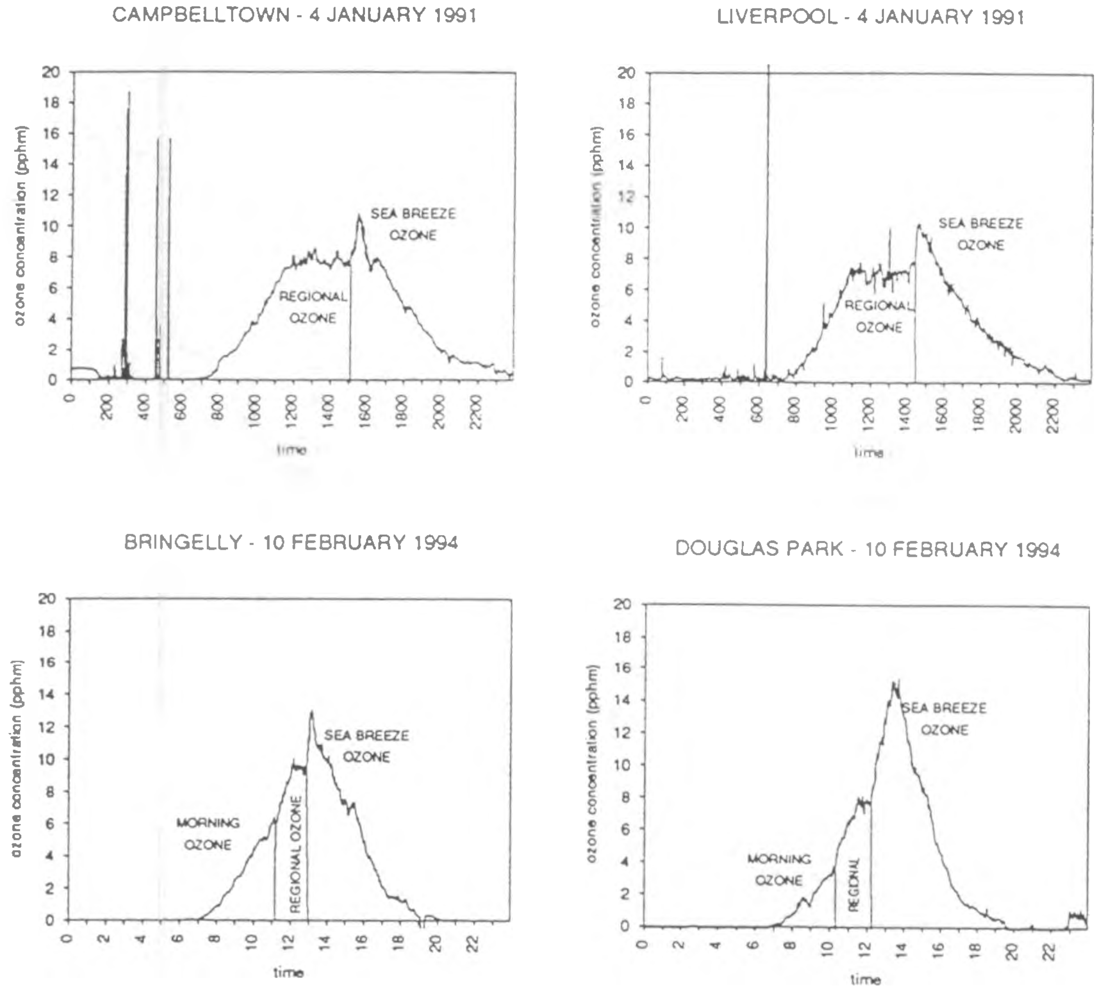


Figure 5.4(b) Time series of 2-minute average ozone concentrations at a selection of NSW EPA monitoring stations in western Sydney, showing periods of morning, regional and sea breeze ozone. Source: NSW EPA, (Hyde et al., 1997)

of Atmospheric Research in Melbourne as part of the *Metropolitan Air Quality Study* (Hurley et al, reported in Hyde et al., 1997) suggested a number of plausible, but as yet unvalidated hypotheses, to explain the existence of 'morning ozone':

- Ozone occurring as a result of local Sydney emissions carried into western Sydney during the morning by east to north-easterly winds

- Sydney emissions trapped overnight within western Sydney by a north-south rotor circulation through the combined effect of southerly drainage flow and synoptic northerly winds above;

- Sydney emissions could be recirculated overnight in western Sydney within a deep clockwise circulation from the blocking of north-north-easterly stable synoptic winds by the topography of the Sydney Basin; and

- Inter-regional transport of precursors from sources north of Sydney into western Sydney, during the afternoon and early evening within the sea breeze.

'Regional ozone' in western Sydney is usually characterised by a period of constant ozone occurring late morning/early afternoon with values between 4 and 10 parts per hundred million and is an easily recognisable feature in the time series of two-minute ozone concentrations (eg. *Figure 5.4*a). Before the *Metropolitan Air Quality Study,* the number of air quality monitoring stations in west and south-west Sydney was extremely limited, and it was thought that regional ozone occurred as a result of the transport of photochemical smog from precursor source regions in the Parramatta River Valley, or possibly as a result of inter-regional transport from the Central Coast (Hyde et al, 1978a, Hyde et al 1977). During the *Metropolitan Air Quality Study* there was a substantial increase in the number of monitoring stations in western Sydney and it is now clear that this late morning/early afternoon period of constant ozone is a regional phenomenon as illustrated in the examples in *Figure 5.4* (Hyde et al., 1997)

The period of constant ozone concentrations during this period of time is usually preceded by morning ozone, and terminated by an abrupt change in concentrations with the onset of the sea breeze. The length of time that regional ozone concentrations remain constant varies from day. For example as illustrated in *Figure 5.4a*, regional ozone concentrations measured at Bringelly and Douglas Park on 10 February 1994 remained steady at 9.5 and 7.5 pphm respectively for about one hour, whilst on 4 January 1991 concentrations at Liverpool and Campbelltown remained constant between 7.5 and 8 pphm for three hours.

On occasions, as illustrated by the time series of ozone measured from Bringelly, Douglas Park, Liverpool and Campbelltown in *Figure 5.4*, constant values can be preceded by a period when ozone concentrations increase almost linearly with time. The ramping up and plateau of ozone observed on these occasions is characteristic of a mass of precursors reacting in an approximate constant volume of air, without continuing emissions (eg similar to experiments in a smog chamber, Johnson, 1983). The plateau region of approximately constant ozone could also be explained as a result of equal, but opposite influences, for example a situation where the rate of smog production is equal to the rate of dilution by cleaner air, or by some other mechanism. However, it is unlikely that the combined effect of two unrelated influences would completely balance the positive and negative effects and result in the occurrence of the observed plateau in ozone concentrations

In the absence of vertical profiles of wind and temperature in western Sydney, it is difficult to determine the meteorological conditions associated with regional ozone. The pattern of ozone concentrations is consistent with ozone forming aloft, then mixing down to the surface once the mixing layer was deep enough. For example, one possible scenario, would be to have precursors trapped in a layer of north to north-east flow some distance above the surface in western Sydney and after sunrise, photochemical smog production would commence in this elevated layer. At the same time, morning ozone could form in the surface mixing layer, either from local precursor emissions, or as a result of precursors being carried into, or recirculated within, western Sydney during the night. Eventually, as a result of surface heating, the surface mixing layer could become deep enough to mix this elevated photochemical smog down to the surface. If this deeper mixing layer remained constant, which could occur if the layer of air was capped by an elevated inversion, then ozone concentrations might remain relatively constant for a time, provided there were no substantial new emissions of oxides of nitrogen into this layer (Hyde et al. 1997; Johnson, 1983).

The source of regional smog in western Sydney is uncertain. Modelling during the *Metropolitan Air Quality Study*, suggested that precursors from elevated sources north of Sydney might be trapped aloft and carried into the Sydney Basin overnight by north to north-east synoptic winds. In this situation precursors within this elevated layer of air, could react after sunrise to form ozone, and then as explained above, subsequently mix down to the surface when the mixing layer became deep enough, but again it should be noted that this hypothesis has not yet been verified.

Whilst the results of modelling during the *Metropolitan Air Quality Study* have not been substantiated by any detailed investigations of the meteorological conditions associated with periods of morning and regional ozone in western Sydney, the predictions of the model are supported to some extent, by measurements of ozone and sulphur dioxide made at Richmond on 9 and 10

February 1994 during periods of north-east to north-north-east synoptic winds and north-east sea breezes. Trajectories back from Richmond on 10 February 1994 were consistent with the transport of emissions being carried into the Sydney Basin from the Central Coast, (Hyde et al., 1997).

A factor contributing to the transport of photochemical smog and/or its precursors into the Sydney region from sources to the north and north-east, may be the high frequency of northerly winds observed during the night at Winmalee in the lower blue Mountains (Section). However, given the high frequency of these northerly winds during the night, and the relatively low frequency of episodes of moderate to high ozone concentrations in western Sydney before the arrival of the sea breeze, any hypothesis about inter-regional transport of emissions from north needs to be properly examined, by appropriate field investigations, rather than rely on the results of modelling alone.

Photochemical Smog and Meteorology in Eastern Sydney

During the analysis of 1991 data for the Pacific Power investigation (Johnson et al.,1993) it was observed that high concentrations of photochemical smog were occasionally observed in eastern Sydney and the Illawarra.

When the 1991 ozone values were recorded, there were no measurements of wind speed and direction at Woolooware or Albion Park, and hence it was difficult to identify the meteorological conditions associated with these ozone events. However, on the basis of previous work, and modelling during the *Metropolitan Air Quality Study*, it appears that two separate meteorological conditions might result in high concentrations occurring in the south-east coastal region, (Hyde et al., 1997; Cope et al 1997):

- offshore/onshore transport of photochemical smog within cold air drainage flows and sea breezes; and/or
- inter-regional transport from the Hunter Valley and Central Coast regions to Sydney and inter-regional transport of Sydney emissions into the Illawarra.

Recirculation of photochemical smog at the coast in Sydney was identified during the Sydney Oxidant Study (Hyde et al. 1978b). In this situation as explained in Section 4.3.3, photochemical smog precursors could be carried offshore during the morning within cold air drainage flows, and then brought back inland across the coast later in the morning within the sea breeze. An example illustrating this onshore transport of photochemical smog within the sea breeze is given in *Figure 5.5*. These values of ozone, total oxides of nitrogen and nitrogen dioxide plotted were measured at the two Federal Airport Corporation Monitoring stations at Botany and Sydney Airport on 17

October 1994. They show ozone concentrations increasing during the morning between 0800/0900 hours and noon, within light north-west to north-north-west direction winds, followed by a second increase in ozone concentrations as air previously carried offshore is brought back inland within the sea breeze (Federal Airports Corporation, 1994).

The other possible mechanism contributing to high concentrations of ozone measured at Woolooware, could be mixing down of ozone from aloft. Some examples of two-minute ozone concentrations measured at Woolooware are plotted in *Figure 5.6*. In these examples, the abrupt increase in ozone concentrations around 1000 hours is consistent with the mixing down of ozone from aloft although the possibility that the observed ozone could be occurring within a sea breeze cannot be eliminated.

The possibility that ozone observed in the coastal region of Sydney could occur as a result of inter-regional transport from the Hunter Valley and Cental Coast regions was an outcome of modelling carried out for Metropolitan Air Quality Study (Hurley at al,1997 in Hyde et al, 1997). In these examples the model results showed air from source regions north of Sydney being carried out to sea during the night and morning, then inland across the Sydney Basin within the sea breeze.

Inter-regional transport of photochemical smog into the Illawarra has long been an accepted mechanism for high concentrations of ozone measured at Albion Park. Measurements of ozone within north-east winds at Bellambi north of Wollongong were reported by Hawke et al (1983). They were considered to occur as a result of photochemical smog precursors being carried offshore from Sydney during the night and early morning within north-west cold air drainage flows, and their subsequent transport down the coast by north-north-east to north-east synoptic winds and sea breezes the following day.

The southward movement of such emissions is supported by wind measurements made by Macquarie University at Port Kembla in 1984 and 1985 (Prescott, 1989), and the presence of persistent overnight along-coastal flow, identified during the *Metropolitan Air Quality Study*. In addition, observations of the vertical structure of winds and temperature made at Albion Park during the Illawarra Sea Breeze Experiment, (Hyde and Prescott, 1985) illustrated the type of meteorological conditions that could explain the trapping and southward transport of photochemical smog into the Illawarra, *Figure 5.7*. In this example, warmer north-west air is flowing over the top of the Escarpment, while cooler moister northerly air is being carried along the coast towards the Illawarra. This type of situation could provide an efficient trap for pollutants being carried south from source regions north of Wollongong.

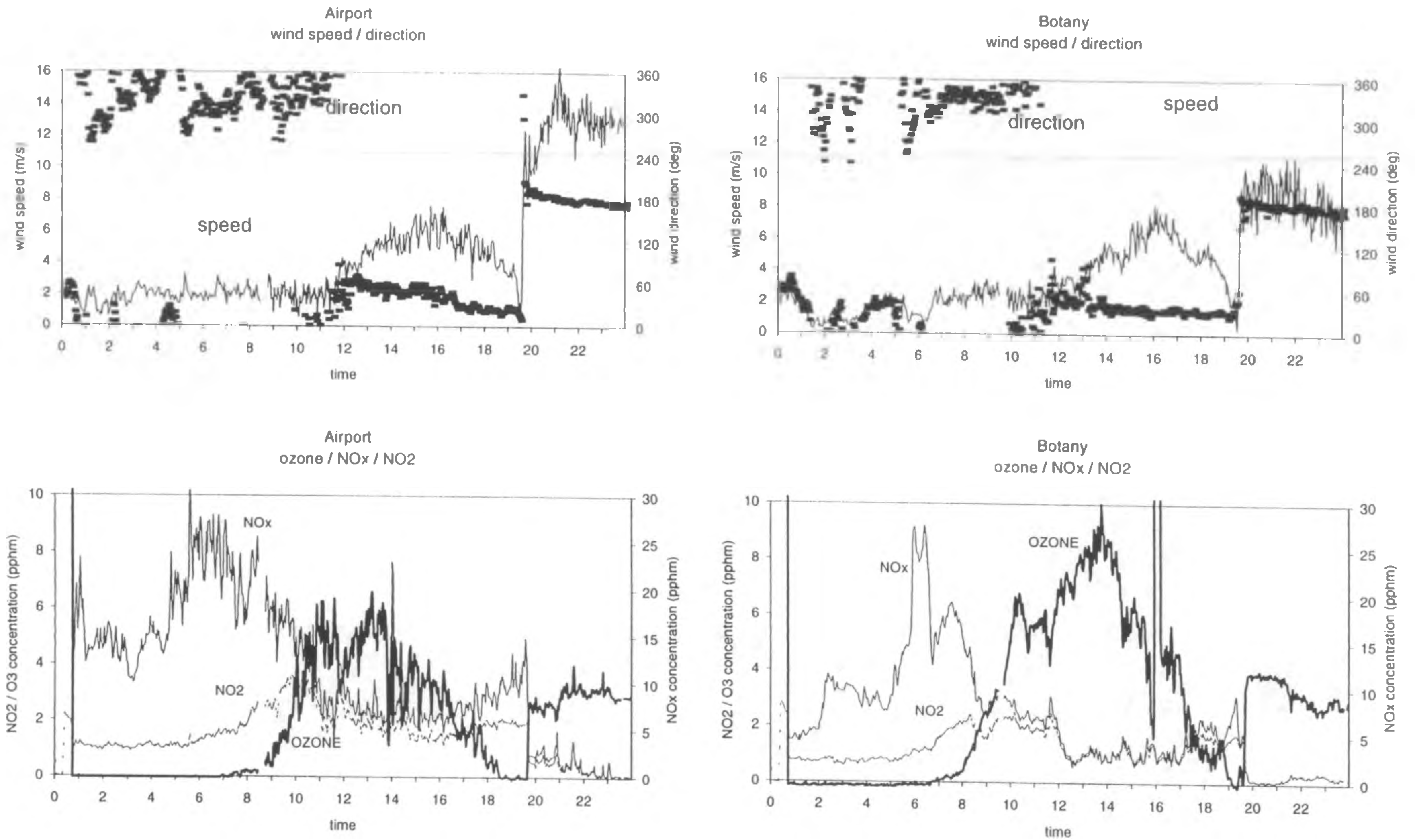


Figure 5.5 Diurnal variation in 2-minute average values of wind speed, wind direction, ozone, nitrogen dioxide and total oxides of nitrogen; Sydney Airport and Botany monitoring stations, 17 October 1994. Source - Federal Airports Corporation (1994)

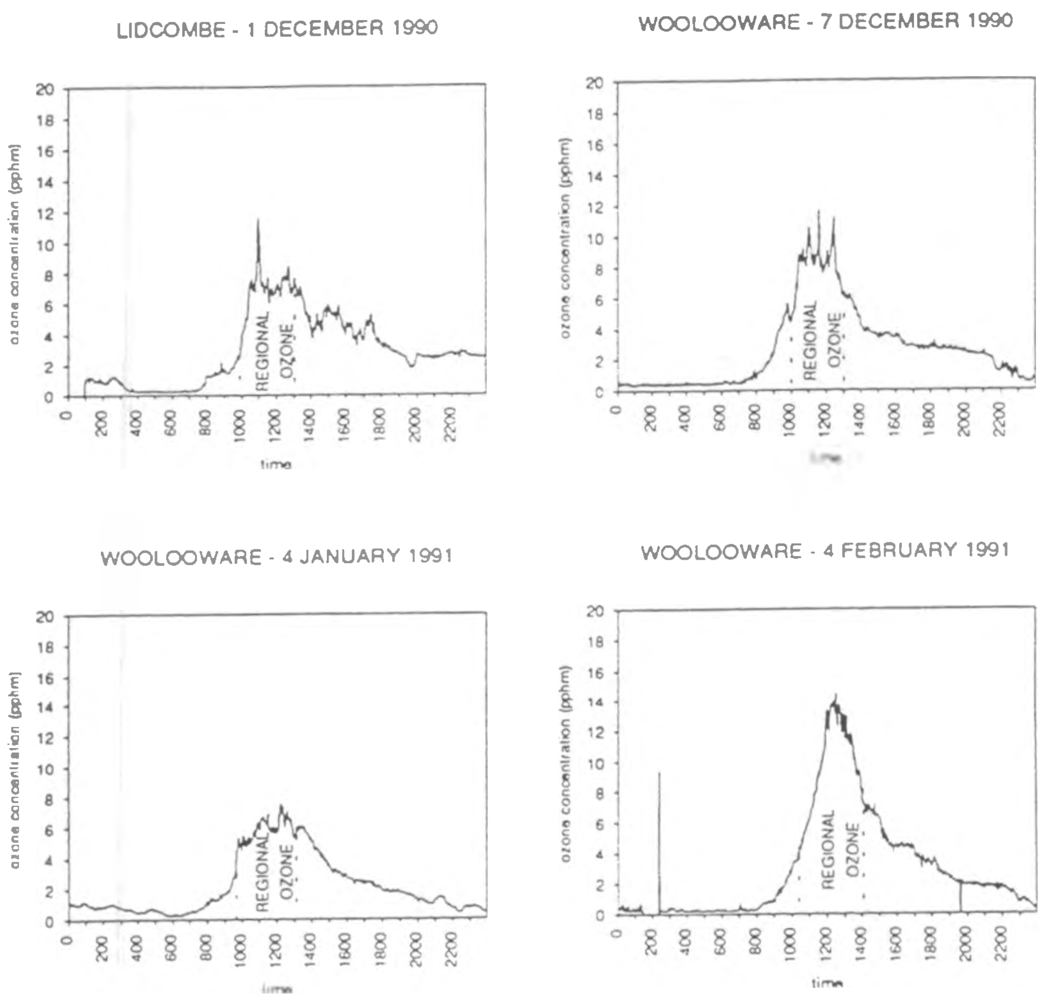


Figure 5.6 Time series of 2-minute average ozone concentrations at NSW EPA air quality monitoring stations at Woolooware and Lidcombe, showing periods regional Source: NSW EPA, (Hyde et al., 1997)

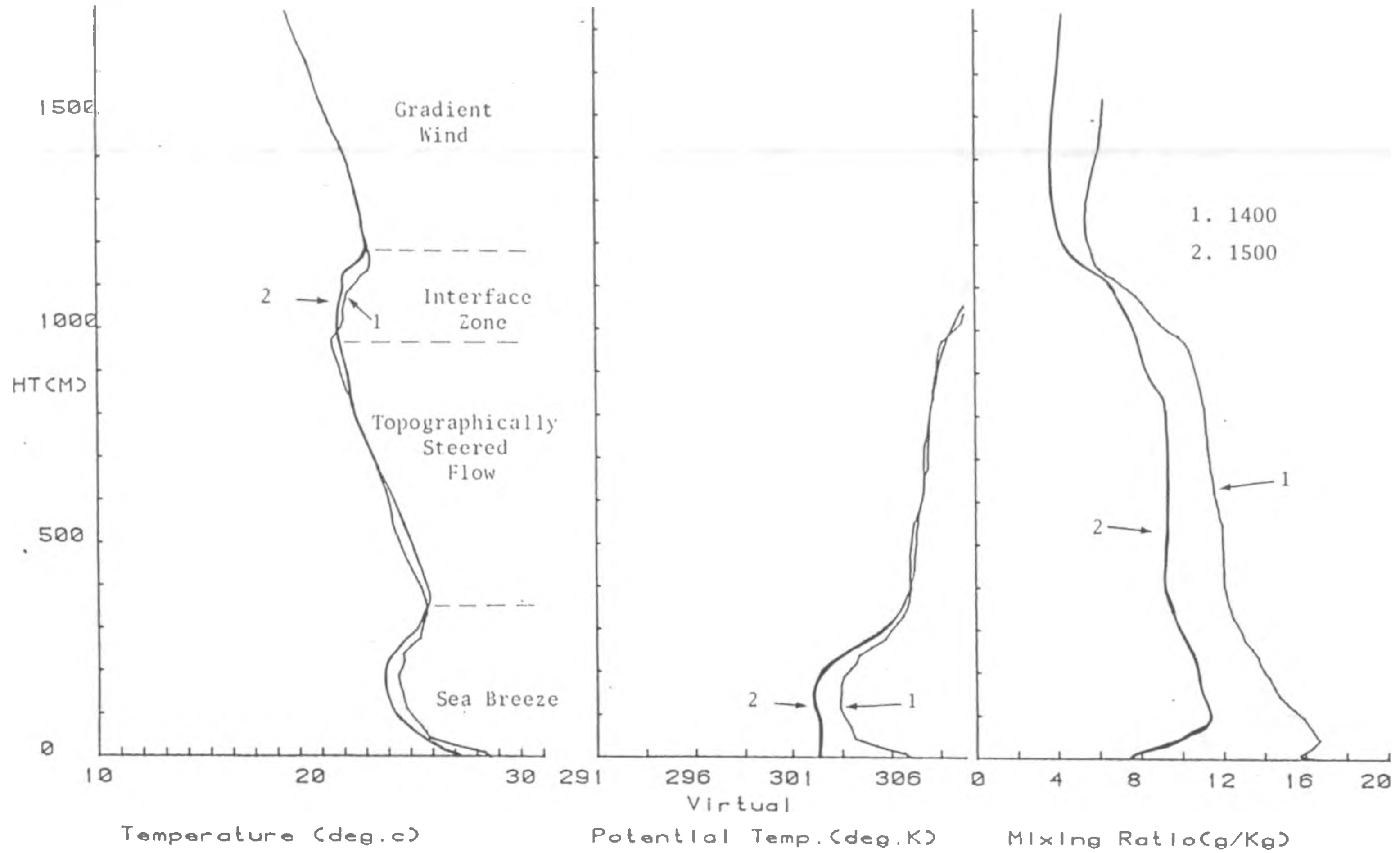


Figure 5.7 Temperature and atmospheric humidity (mixing ratio) profiles at Albion Park, 13 March 1984, showing a 300 metre deep sea breeze below topographically steered flow, and the synoptic wind above (Hyde and Prescott, 1984)

The other major meteorological factor influencing the occurrence of year to year changes in the meteorological conditions in Sydney and the Illawarra, was addressed in the Pilot Study and has been explained more recently in an investigation by the Bureau of Meteorology for the *Metropolitan Air Quality Study*, (Leighton and Spark, 1995).

The analysis in the Pilot Study showed a slight decease in the maximum annual hourly concentrations at stations in east and central Sydney between 1974 and 1990, but no change over this period at Camden, Campbelltown and Albion Park, (Hyde and Johnson, 1990). Thus, although the number of occasions when the NSW guideline for ozone in each year had decreased, it was concluded that this downward trend was likely to be at least due in part, to changes in weather conditions, rather than just as a result of the introduction of control strategies. Leighton and Spark (1995) concluded " that there have been trends in the synoptic patterns since 1978 which have partially contributed to a decrease in observed pollutants over Sydney but these trends cannot explain all of the decrease in observed pollution. The trends do not form part of a longer term trend over the 1965 - 1993 period".

5.1.2 THE INFLUENCE OF METEOROLOGY ON THE TRAPPING OF FINE PARTICLES, CARBON MONOXIDE, OXIDES OF NITROGEN, AND OTHER POLLUTANTS

In the cooler months of the year, reduced solar radiation and lower air temperatures inhibit the formation of photochemical smog, and concentrations of ozone between April and October are generally much lower than those measured during the summer months, *Figure 5.1*.

Between April and September, seasonal changes in the pattern of synoptic and meso-scale wind flows in Sydney, coupled with earlier time of sunset, concentrations of other types of pollutants, such as carbon monoxide, fine particles and oxides of nitrogen concentrations can be high. Unlike photochemical smog, where the highest concentrations are observed late morning or during the afternoon, higher concentrations of these other pollutants are more likely to be observed late afternoon and early evening, overnight, or during the morning for a few hours after sunrise.

Time series of monthly average lead concentrations, and the maximum hourly concentrations of total oxides of nitrogen, lead, and fine particles, measured at some NSW Environment Protection Authority stations in Sydney are plotted in *Figures 5.8* to *5.10* respectively. In each Figure, the highest concentrations are measured during winter, with much lower levels recorded in summer. The exceptions are lead concentrations measured in the Central Business District, which show little if any seasonal variation. This occurs as a result of emissions from vehicles in the city being trapped within the urban canyons, which inhibit their dispersion and dilution.

Higher concentrations of nitrogen dioxide, lead and fine particles in the winter months occur as a result of low level urban, vehicle and industrial emissions being trapped within ground-based stable layers and inversions during the evening and overnight, and within shallow mixing layers below an elevated inversion during the morning during the breakdown of these inversions after sunrise. In summer, with fewer cold air drainage flows, later time of sunset and less trapping of urban emissions overnight and during the morning, concentrations of these pollutants are generally lower.

Other evidence, illustrating seasonal changes in fine particles and lead in the Sydney region are plotted in *Figure 5.11*. These measurements were made during the Aerosol Sampling Project, and show monthly average fine particle concentrations and lead levels in the range less than 2.5 micrometres, measured at six stations in Sydney between January 1992 and June 1993, (ANSTO, 1995).

At Lidcombe, and Mascot there is a clear seasonal trend in the concentrations of fine particles less than 2.5 microns, as well as in the corresponding lead content of these samples. These seasonal variations in lead levels are similar to those measured at Lidcombe and Rozelle in *Figure 5.9*. At Campbelltown, lead levels are much lower, but some seasonal changes in concentrations can be seen. Monthly average lead concentrations measured at Badgerys Creek, Lucas Heights and Wilton were all low, reflecting the lower traffic densities in these regions.

The influence of weaker sea breezes and light onshore synoptic winds on particle concentrations in Sydney is illustrated by the time series of light scattering measurements by fine particles plotted in *Figure 5.12*. These measurements were made by CSIRO during the Sydney Brown Haze experiment and were reported in Hyde et al., 1982. The shading in the figure represents different periods of wind flows, synoptic winds, sea breezes, regional drainage flows and spillover across the ridge at Blacktown.

The diurnal changes in the concentrations of fine particles measured at Blacktown and other locations can be explained in terms of the trapping and re-circulation mechanisms described in Section 4.2.3 and illustrated by the cross-sections plotted in *Figure 4.17*. At Blacktown fine particles can become trapped during the afternoon and evening within an increasingly stable layer of air at the surface within a weakening sea breeze and/or synoptic wind moving into Western Sydney. Then, as illustrated in *Figure 4.17a*, the sea breeze is subsequently undercut by regional cold air drainage flows, and pollutants previously carried inland by the sea breeze can be carried back across the Blacktown Ridge into eastern Sydney. On some occasions, air spilling out of the Hawkesbury Basin undercuts the regional drainage flow, and again, fine particle concentrations can be high. During the night,

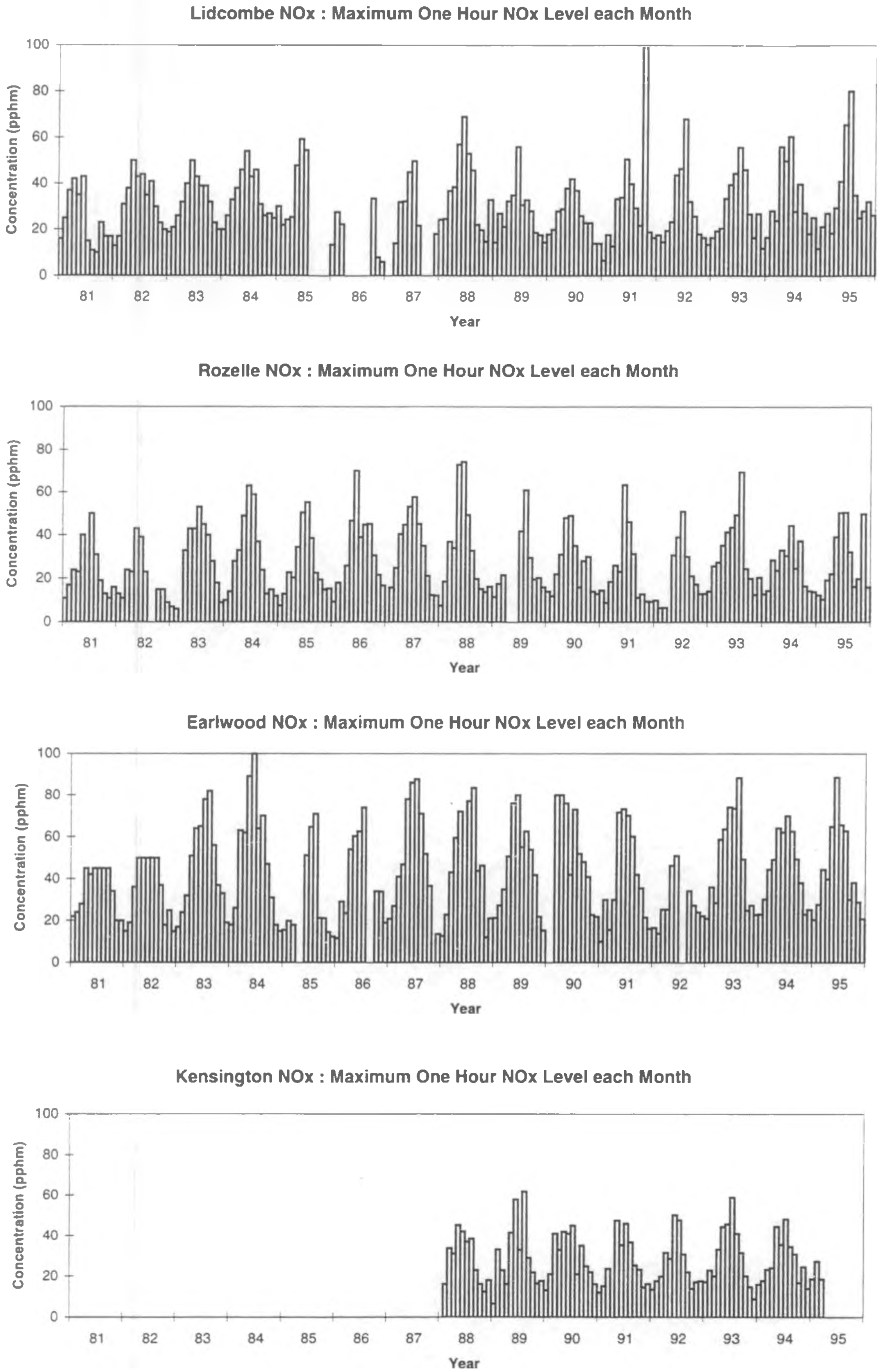
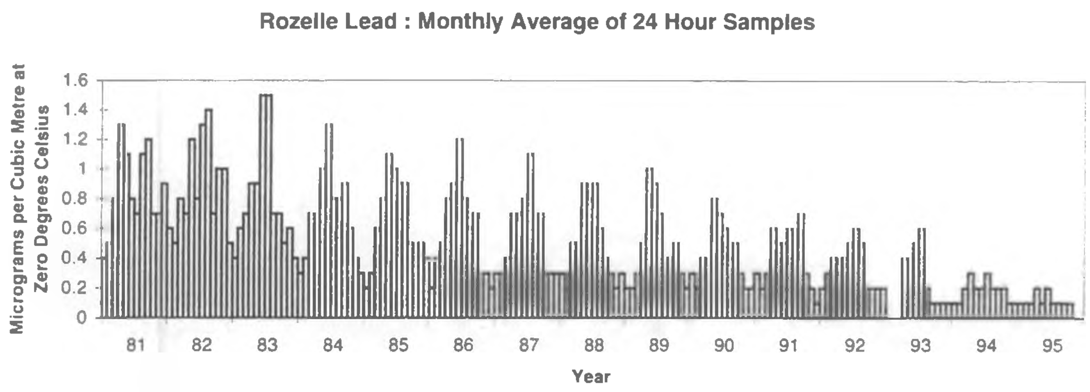
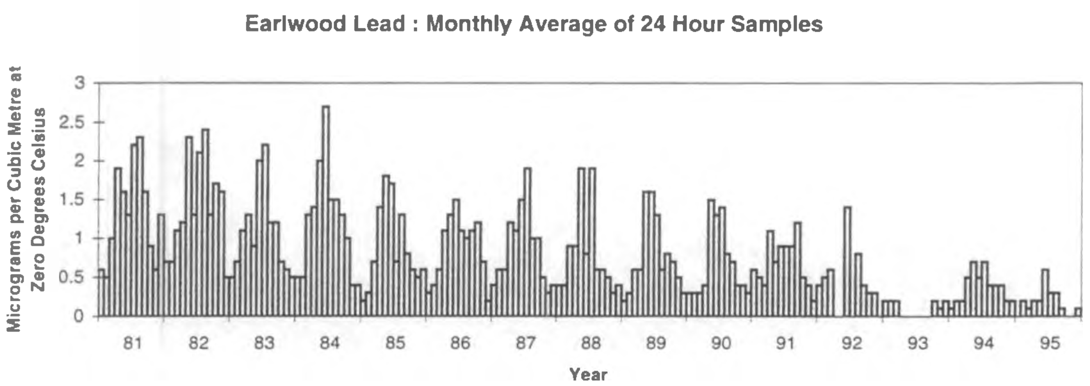


Figure 5.8 Time series of monthly maximum 1-hour concentrations of total oxides of nitrogen 1981 to 1995. Source: NSW EPA Quarterly Reports of Air Quality





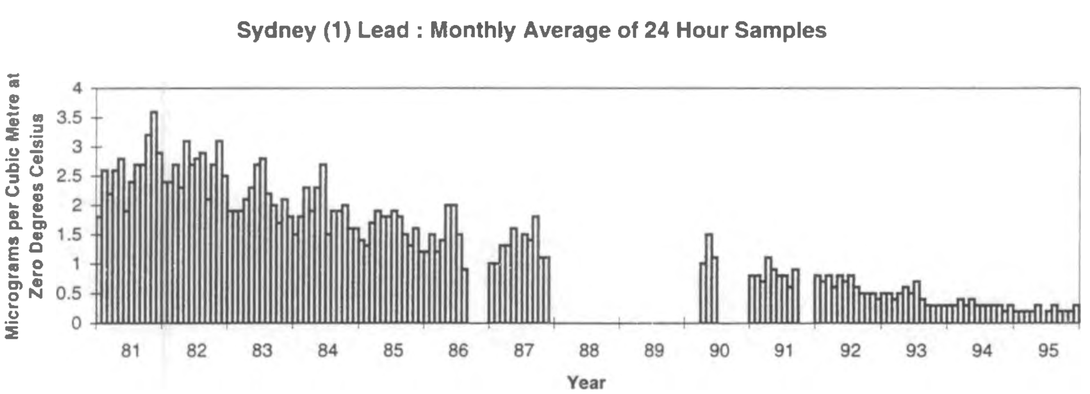


Figure 5.9 Time series of monthly average of 24-hour samples of lead 1981 to 1995. Source: NSW EPA Quarterly Reports of Air Quality

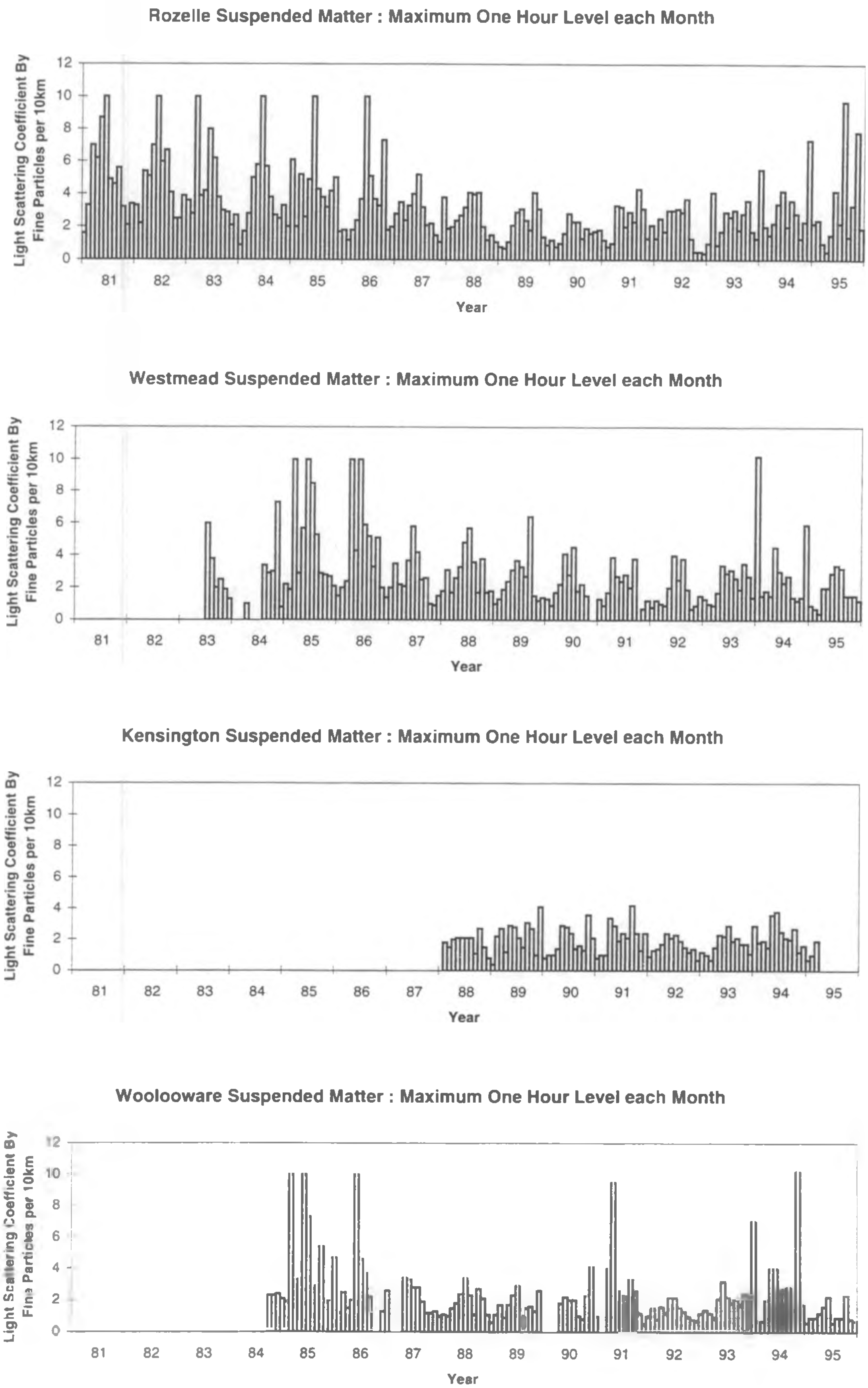


Figure 5.10 Time series of monthly maximum fine particles as measured by light scattering using a nephelometer. Source: NSW EPA Quarterly Reports of Air Quality

Particles Smaller Than 2.5 micron

Lead Content of Particles smaller than 2.5 micron

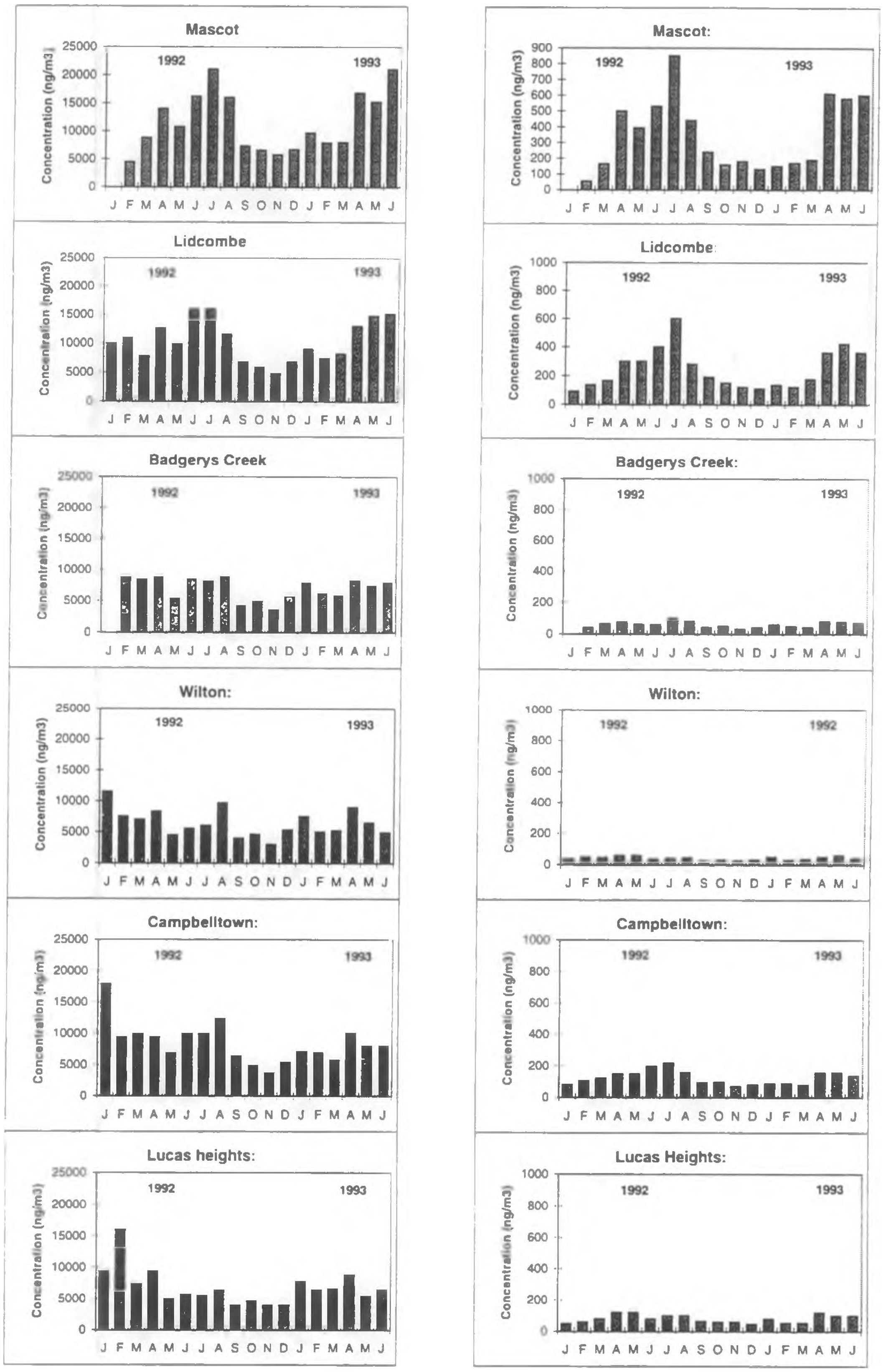


Figure 5.11 Time series of monthly average fine particles (< 2.5 um), and monthly average lead content January 1992 to July 1993. Source: Based on ANSTO (1995)

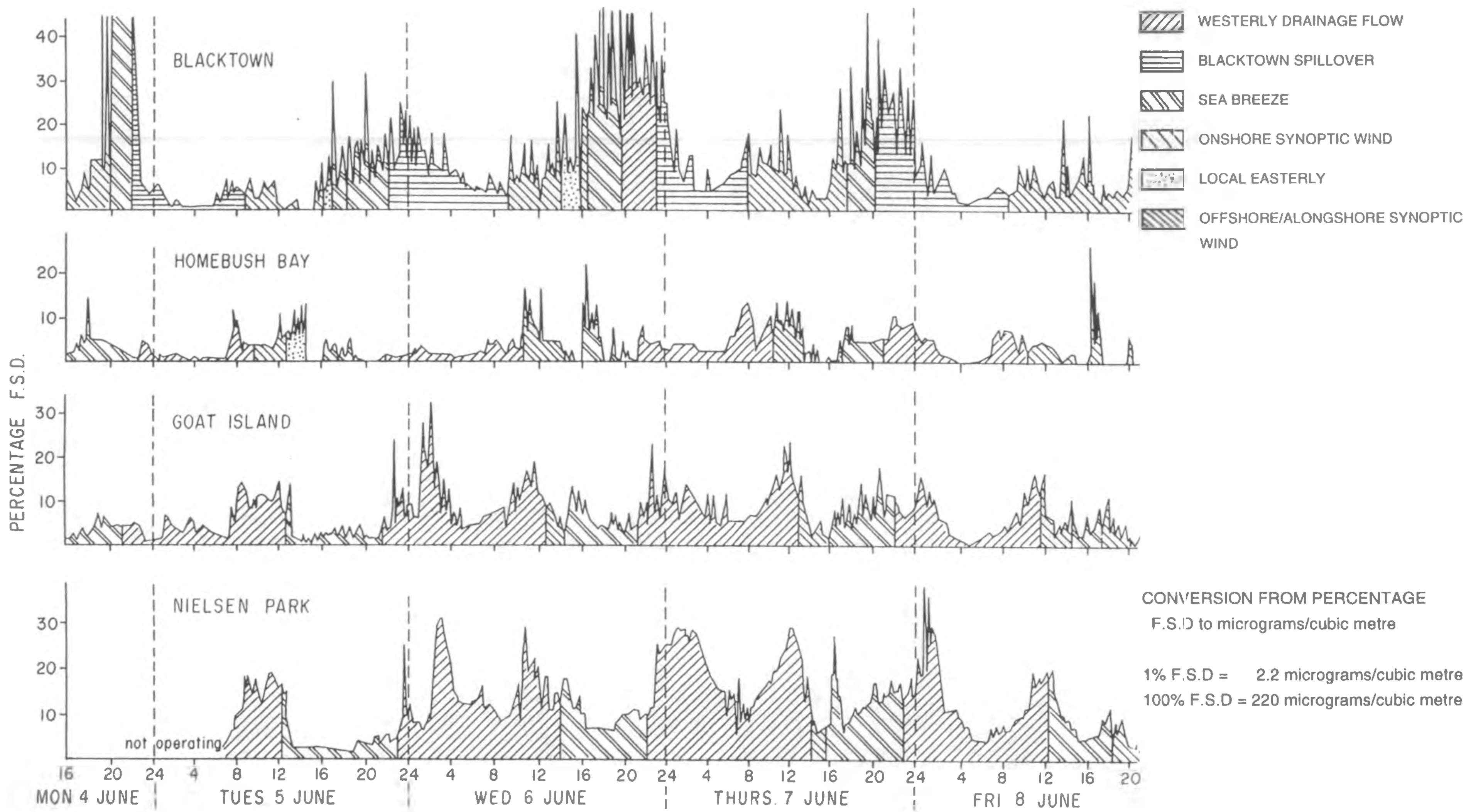


Figure 5.12 Fine particle measurements measured by nephelometer in the Parramatta River Valley, 4 to 8 June 1978 (Hyde et al, 1982)

concentrations gradually decrease as cleaner air is brought into eastern Sydney from regions west of Blacktown.

For a few hours after sunrise, fine particle concentrations increase again as morning emissions are trapped below an elevated inversion, which may take several hours to be completely eroded away, as illustrated in *Figure 4.22*.

In *Figure 5.12*, there is some evidence to suggest that fine particles carried offshore within the morning drainage flow are brought back inland within the sea breeze. For example, at Nielsen Park on 6 and 7 June 1979, the sea breeze arrived before the breakdown of morning inversion, and fine particles concentrations were moderate within the sea breeze, compared with the situation on 5 June when fine particle concentrations within the sea breeze were low.

The data plotted in *Figure 5.12* were measured before the introduction of controls on domestic and backyard burning in Sydney. Hence, the actual concentrations might be quite different from those currently measured by the Environment Protection Authority. However, the mechanisms for this recirculation of polluted air remain unchanged, and examples of this situation will be demonstrated once the 1996 data becomes available from the Environment Protection Authority.

More recent examples of the influence of nighttime stability on the trapping of urban emissions are presented in *Figure 5.13*. The measurements were made at the FAC air quality monitoring station at the northern boundary of Sydney Airport. Total oxides of nitrogen are a good indicator for the trapping of emissions; in *Figure 5.13(a)*, the associated time series of carbon monoxide measurements are plotted, while in *Figure 4.31(b)* non-methane hydrocarbons are plotted.

On 16 June 1994, *Figure 5.13(a)*, there were strong winds from the north-west to west during the daytime after 0900, then very light winds from the north-west after sunset. Between 0600 and 0900, concentrations of carbon monoxide and total oxides of nitrogen increased moderately, then decreased to very low levels during the period of strong offshore winds and good atmospheric dispersion. Pollutant concentrations of both carbon monoxide and total oxides of nitrogen increased rapidly after sunset within the light north-west winds as local urban emissions become trapped within an increasingly stable atmosphere. Concentrations continued to increase during the evening as emissions from regions further inland were carried off the surrounding urban areas across Sydney Airport, and then slowly decreased again during the night as cleaner air was carried across eastern Sydney by light north-west winds.

A similar pattern of diurnal pollutant concentrations was observed on 1 September 1994, *Figure 5.13(b)*, where non-methane hydrocarbons have been plotted instead of carbon monoxide. In this example, moderate strength south-east winds were present between 1300 and 1900 hours and average concentrations of non-methane hydrocarbons and total oxides of nitrogen were low. The occasional spikes of total oxides of nitrogen are associated with aircraft taking off across Botany Bay into the south-east winds. Concentrations initially increased after 0500 hours within north-west winds and then gradually decreased during the morning before 1300 hours, presumably as a result of an increase in mixing depth and vertical dispersion. After sunset, both non-methane hydrocarbon and total oxides of nitrogen increased rapidly and remained high until urban emissions, trapped within a stable atmosphere away from the coast, were carried across Sydney Airport by light west to north-west winds (Federal Airports Corporation, 1994).

A generalised pattern of pollutant concentrations observed in urban areas of Sydney during the cooler months of the year is plotted in *Figure 5.14*, (Hyde et al., 1997). This example uses a time series of hourly average concentrations of total oxides of nitrogen, but as illustrated by the examples in *Figures 5.12* and *5.13*, other pollutants such as fine particles, carbon monoxide or non-methane hydrocarbons would produce a very similar distribution.

Period I: Increased concentrations are favoured by the coincidence of the following factors:

- light winds and clear skies; and
- sunset between 1700 and 1800 hours

In this situation, a ground-based stable layer or inversion forms around sunset, at a time when vehicle emissions are high. As a result, these and other urban emissions become trapped close to the surface in pollutant concentrations and increase rapidly after sunset. During the evening, pollutant concentrations continue to increase, as emissions trapped within a stable surface layer upwind of a monitoring station, are carried across the region within light cold air drainage flows.

Period II: Late evening or early the following morning, concentrations begin to decrease as cleaner air is carried across the region. This is illustrated in *Figure 5.14*, where concentrations increase slightly with the onset of west-south-west winds around 2000 hours but then steadily decrease during the night following the onset of north-north-west wind at 2200 hours.

Period III: Pollutant concentrations in this period can occasionally be high, but on average, tend to less than those measured late afternoon/early evening during Period I. This is due to differences in atmospheric stability: during the evening, the temperature profile close to the ground tends to become increasingly stable as a result of radiative cooling at the surface, and the

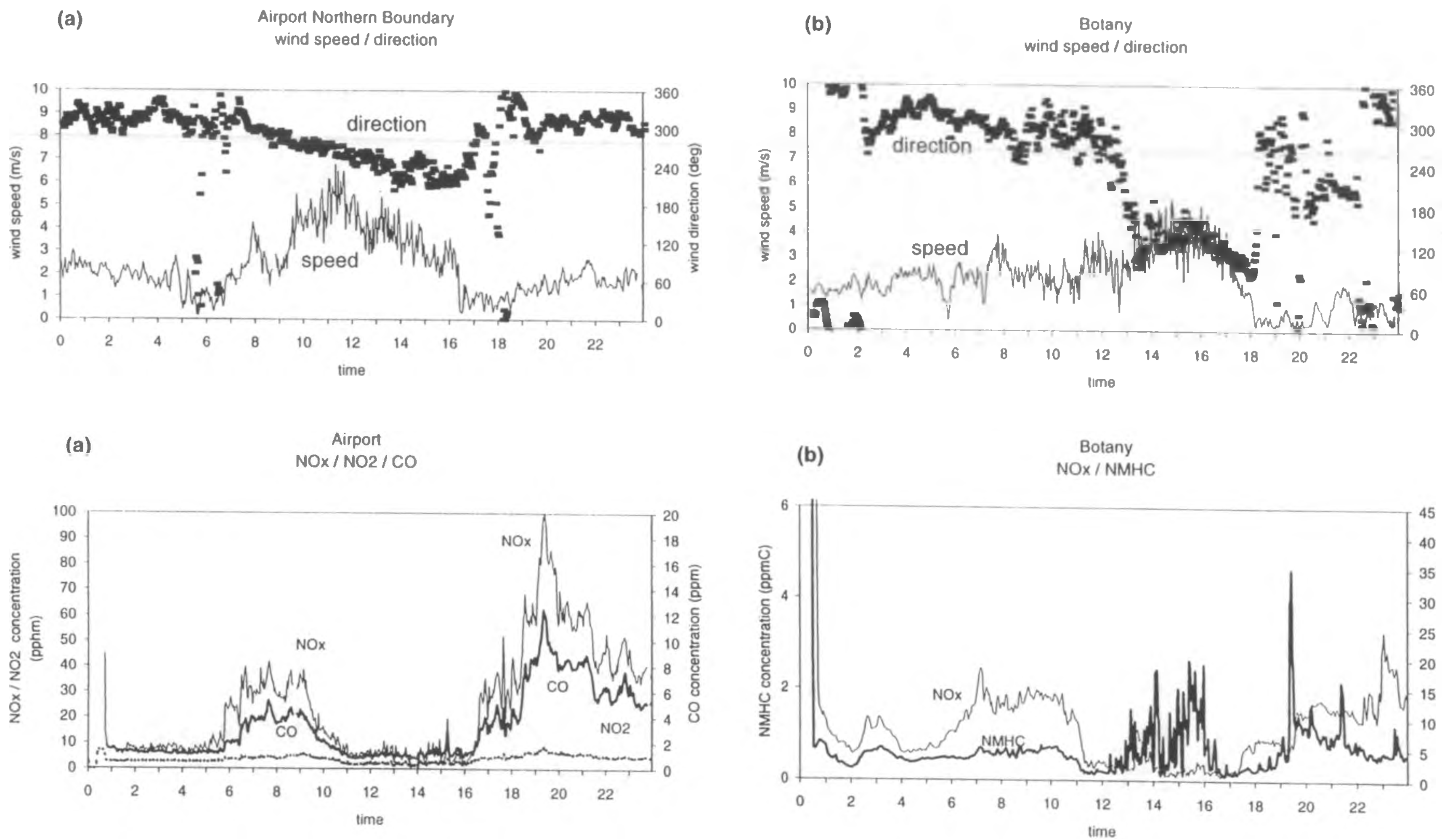


Figure 5.13: (a) Diurnal variation in 2-minute average values of wind speed, wind direction, carbon monoxide, nitrogen dioxide and total oxides of nitrogen, Sydney Airport, 16 June 1984, and (b) Diurnal variation in 2-minute average values of wind speed, wind direction, non-methane hydrocarbons, Botany, 1 September 1984. Source: Federal Airports Corporation (1994)

vertical dispersion of these pollutants is inhibited. During the morning, surface heating and convection establish a mixing layer above the surface and the depth of this layer increases with time. Hence, emissions of these pollutants into the atmosphere during this period, will be dispersed throughout this mixing layer, and concentrations will often be lower than those measured during Period I. However, as illustrated earlier, whilst it may take several hours before the ground-based inversion is completely eroded away, and so trapping of these pollutants continues, resulting in moderate or high concentrations during the morning.

5.2 METEOROLOGY AND AIR QUALITY IN THE VICINITY OF BADGERYS CREEK

The four Environment Protection Authority monitoring stations closest to Badgerys Creek are: Bringelly, St Marys, Blacktown and Liverpool, as shown in *Figure 3.3*. In the Hawkesbury Basin, Bringelly is the closest station, 7 kilometres south-east of Badgerys Creek, whilst the St Marys monitoring station is 13 kilometres to the north-north east. The Blacktown monitoring station is located on top of the 'Blacktown Ridge' separating the Hawkesbury Basin from the Parramatta River Valley, whilst the Liverpool station is 18 kilometres to the east, and separated from Badgerys Creek by the Blacktown Ridge.

In the absence of the Environment Protection Authority data, it is difficult at present, to comment about the impact of meteorology on air quality measured at monitoring stations in the vicinity of Badgerys Creek. At some locations, it might have been possible to describe the broad changes in air quality observed at some stations using meteorological data from other sources. However, previous experience has shown it can be very difficult to interpret linkages between air quality and meteorology in Sydney using air pollutant concentrations measured at Environment Protection Authority monitoring, and wind data from other sources close by, (eg. Johnson et al., 1993; Hyde et al., 1997).

This was the situation which existed prior to the *Metropolitan Air Quality Study*, where the only Environment Protection Authority monitoring station to measure winds electronically, was Lidcombe. Recent experience has shown, that the only satisfactory approach to understanding the influence of meteorology on air quality in Sydney, is to first examine the hourly averaged measurements, and then select suitable days for a more detailed analysis using the two-minute averaged data recorded at the Environment Protection Authority stations, (Johnson et al, 1993, Hyde et al 1997).

In the absence of hourly and 2-minute pollutant concentrations, the only measurements of air quality in Sydney available in the public domain, are the values reported in the Quarterly Air Quality Monitoring Reports published by the Environment Protection Authority. These give a monthly summary for a range of pollutants, including the maximum hourly concentration of a particular pollutant measured each month at stations in the Environment Protection Authority's air quality monitoring network.

Whilst, the monthly maximums in these reports cannot be used to examine the influence of meteorology on ambient air quality from day to day, the measurements do show changes in maximum concentrations over the period of a year, which can be linked to seasonal variations in weather conditions in Sydney.

The monthly maximum values of: total oxides of nitrogen, carbon monoxide, ozone, fine particles measured by light scattering, nitrogen dioxide measured at Bringelly, St. Marys, Blacktown and Liverpool for each month between 1992 and 1995 are plotted in *Figures 5.15(a)* to *5.15(b)*. The monthly average, of the daily one hour maximum concentration of fine particles less than 10 micro-metres are plotted in *Figure 5.15(d)*. Measurements of fine particles less than 2.5 micrometres, made during the Aerosol Sampling Project, between January 1992 and June 1993 at Mascot, Lidcombe, Campbelltown, Lucas heights, Wilton and Badgerys Creek, are plotted in *Figure 5.11*, (ANSTO, 1995). Carbon monoxide is not measured at Campbelltown,. Also included in *Figure 5.15(b)*, are the values of carbon monoxide recorded at the air quality monitoring station in the Central Business District of Sydney. These measurements provide a source of reference for carbon monoxide values recorded at monitoring stations in the vicinity of Badgerys Creek.

The measurements of total oxides of nitrogen and carbon monoxide plotted in *Figure 5.15a*, show seasonal changes at all four stations, with much higher concentrations being measured in winter than in summer. This is consistent with material discussed in Section 5.1.2 above, which illustrated how strong ground-based inversions and overnight cold air drainage flows influence wintertime pollutant concentrations in Sydney. In *Figure 5.15(a)* the highest maximum one hourly concentrations of total oxides of nitrogen were measured at Blacktown and Liverpool, with slightly lower concentrations measured at St. Marys. Very low values were measured at Bringelly. These data from Bringelly, *Figure 5.11*, combined with the measurements of the lead content of fine particles less than 2.5 micrometres, show that the contribution of motor vehicles to wintertime pollutant concentrations in the vicinity of Badgerys Creek is extremely small.

Monthly averages of the daily one hour maximum of fine particles (less than 10 micrometres measured using an instrument called a TEOM), and values of the fine scattering of light measured using an instrument called a

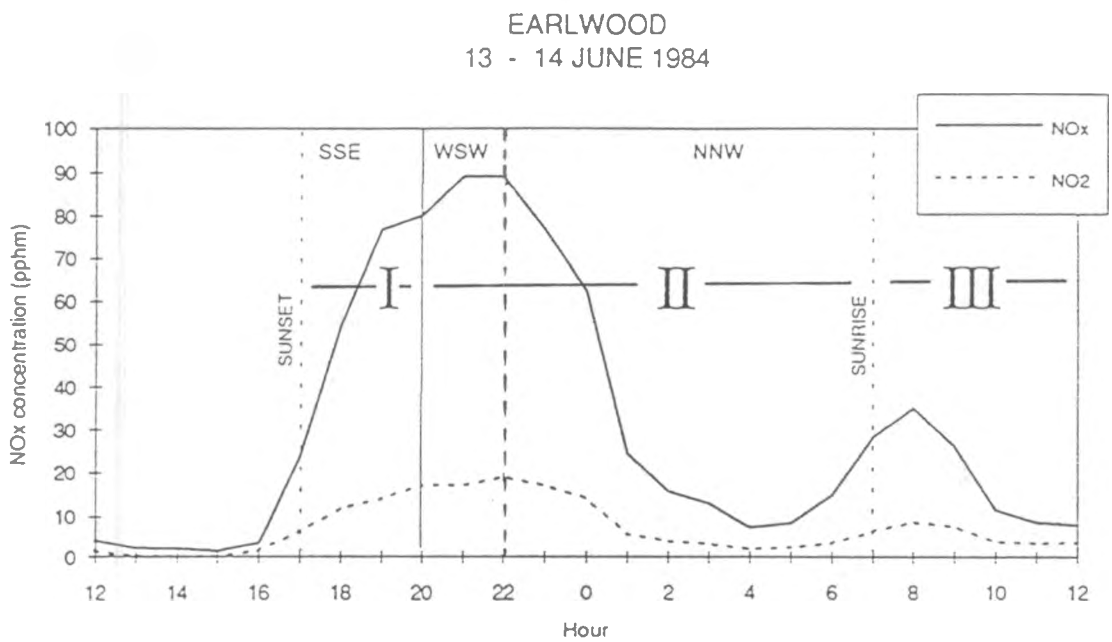


Figure 5.14 Total oxide of nitrogen, and nitrogen dioxide concentrations measured at the NSW EPA Earlwood air quality monitoring station 13-14 June 1984, showing trapping of low-level urban emissions during the afternoon peak traffic period (I), recirculation of emissions during the night (II), and trapping of morning emissions (III), (Hyde et al, 1997)

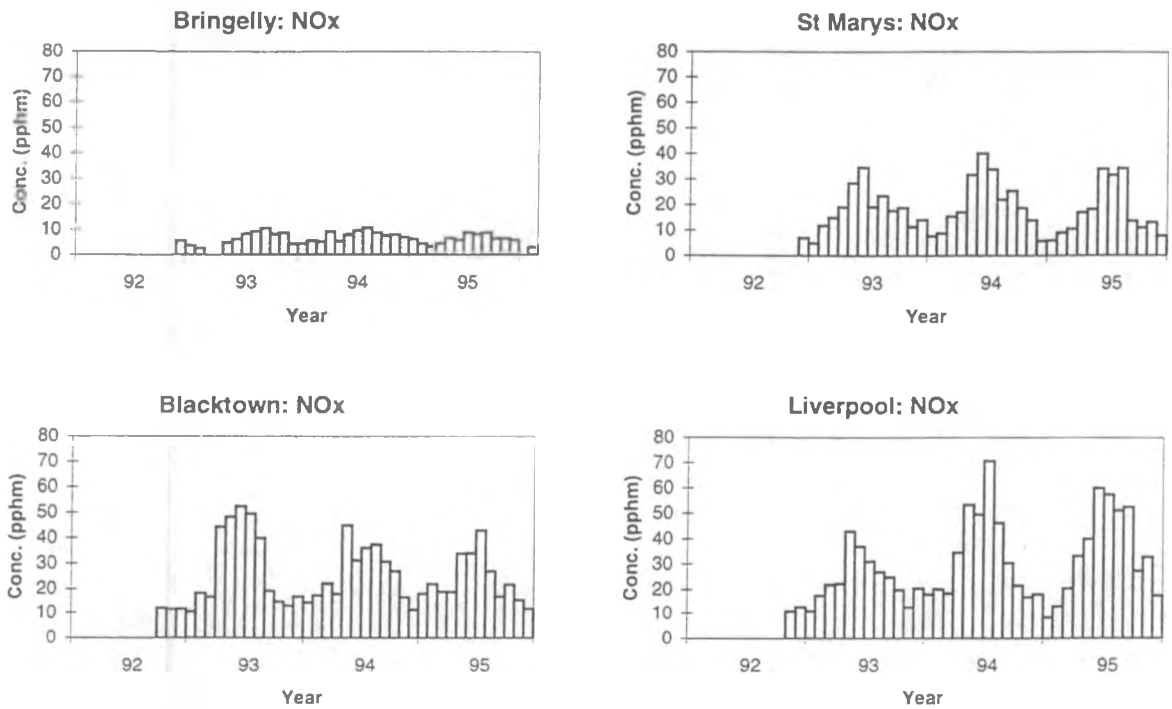


Figure 5.15(a) Time series of monthly maximum 1-hour concentrations of total oxides of nitrogen. Source: NSW EPA Quarterly Reports of Air Quality

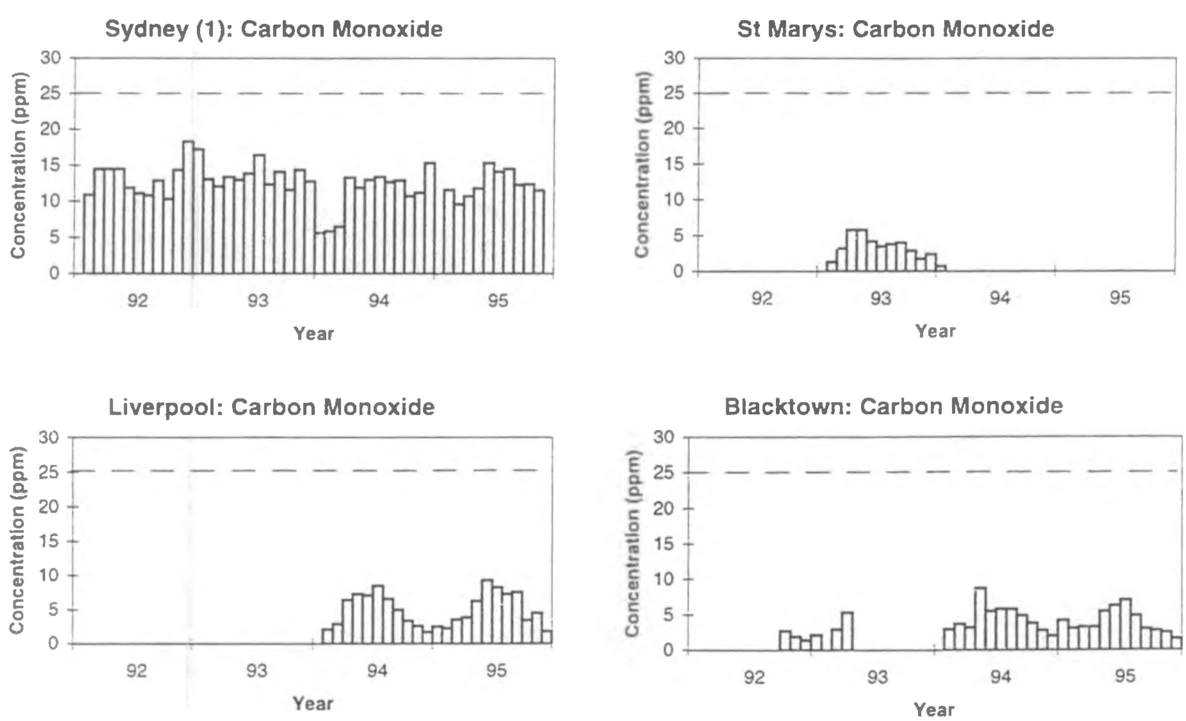


Figure 5.15(b) Time series of monthly maximum 1-hour concentrations of carbon monoxide NHMRC Guideline for 1-hour carbon monoxide - 25 pphm
Source: NSW EPA Quarterly Reports of Air Quality

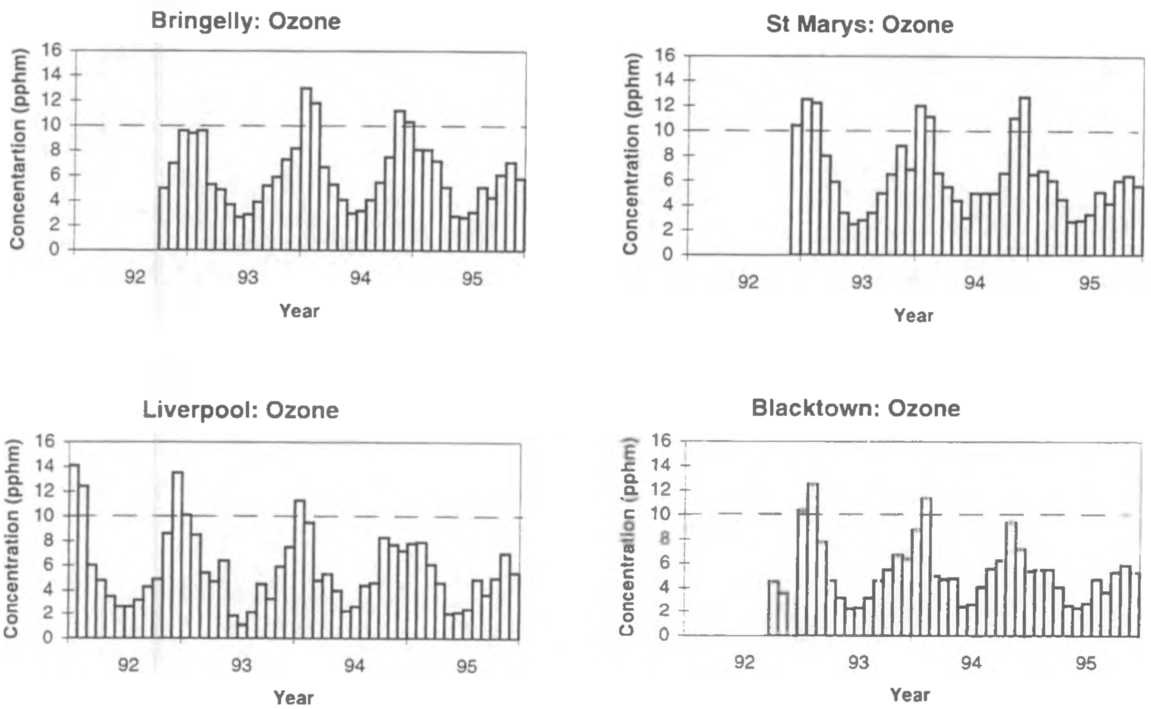


Figure 5.15(c) Time series of monthly maximum 1-hour concentrations of ozone
NHMRC Guideline for 1-hour ozone - 10 pphm
Source: NSW EPA Quarterly Reports of Air Quality

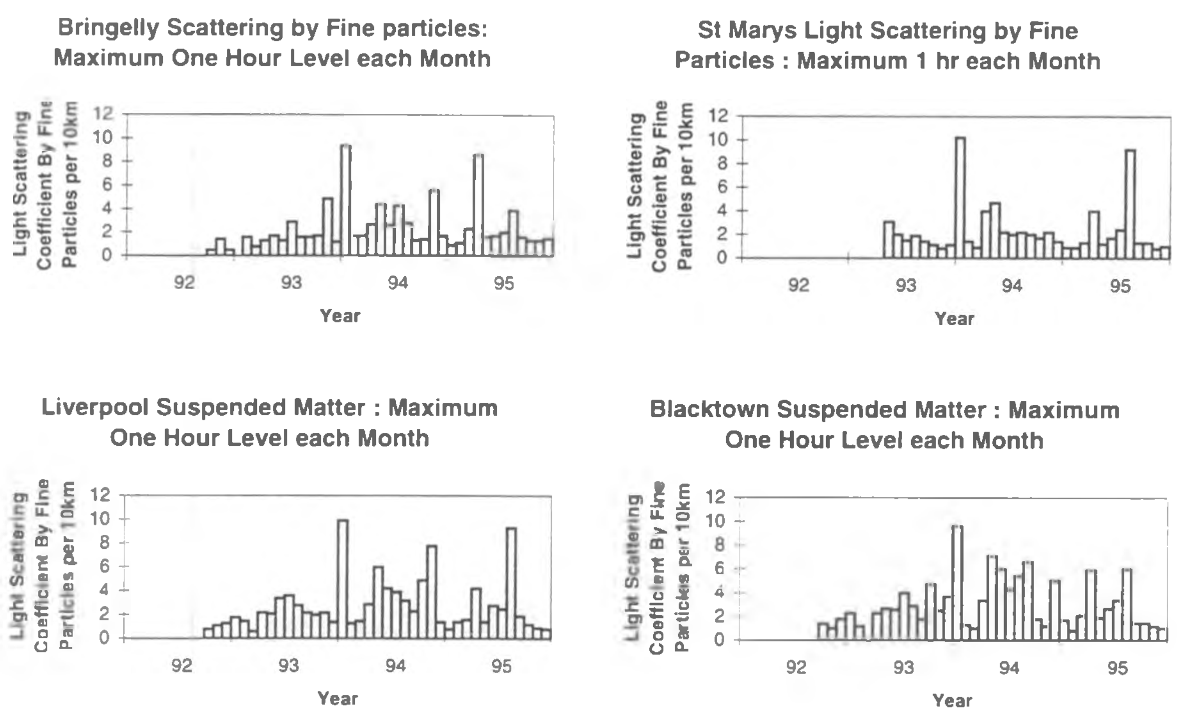


Figure 5.15(d) Time series of monthly maximum 1-hour concentrations of fine particles measured by nephelometer.
Source: NSW EPA Quarterly Reports of Air Quality

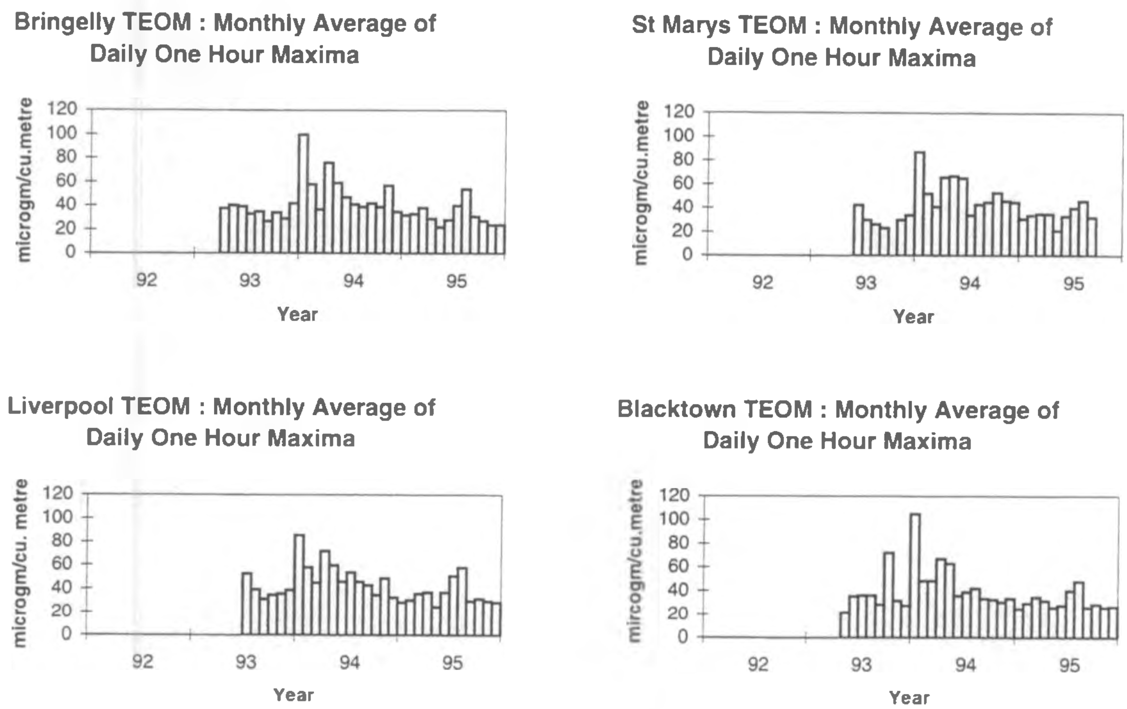


Figure 5.15(e) Time series of monthly maximum 1-hour concentrations of fine particles (> 10 um). Source: NSW EPA Quarterly Reports of Air Quality

nephelometer, between 1992 and 1995 are plotted in *Figure 5.15c* . These values show less seasonal variation, although the overall trend is for the higher values to be measured during winter. The reasons for the occasional high values of nephelometer measurements have not been investigated, but high values are occasionally observed in Sydney as a result of bush fires, hazard reduction burning or the occasional synoptic scale dust storm moving east across New South Wales.

Summer time pollution measured at the monitoring stations in the vicinity of Badgerys Creek is largely restricted to increased concentrations of ozone, as illustrated in *Figure 5.15(c)*. During the Pacific Power investigation and Metropolitan Air Quality Study, it was found that the meteorological conditions associated with photochemical smog in western Sydney were complex and are not yet understood. As explained in Section 5.1.1 ozone concentrations can occur at different times of the day as illustrated by the two-minute time series plots of ozone concentrations from Bringelly on 10 February 1994, plotted in *Figure 5.4*a.

5.3 METEOROLOGY AND AIR QUALITY IN THE VICINITY OF HOLSWORTHY OPTION A

The air quality monitoring stations closest to the Holsworthy Military Reserve are located at Woolooware, Liverpool and Campbelltown and Appin. In 1994, the Appin monitoring station was located at St. Marys Towers near Douglas Park, but was then moved to a new location close to Appin. The other air quality measurements available for the Holsworthy region are the results of the Aerosol Sampling Program which were discussed in Section 5.1.2.

The maximum monthly one hour concentrations of total oxides of nitrogen, carbon monoxide, ozone, and fine particles measured by nephelometers from these stations are plotted in *Figure 5.16 (a)* to *5.16(d)*, whilst the monthly average of the daily maximum of fine particles less that 10 microns are plotted in *Figure 5.16(e)*.

Only limited measurements are available from the Wilton/Appin station as this has only recently been established and measurements of fine particles less than 10 microns have only just commenced.

Seasonal changes in levels of total oxides of nitrogen at Liverpool were discussed in Section 5.1.2 above, and show a high seasonal dependence with wintertime trapping of low-level emissions causing values to be high in the winter. Similar patterns are observed at Woolooware and Campbelltown. Carbon monoxide is not measured at Woolooware, or at Campbelltown, and only a very short record is available from Appin. However, these carbon monoxide measurements were made at the same location as the Aerosol Sampling Program data on fine particles and lead at Wilton, where very low values of lead were recorded, thus illustrating that very few vehicle emissions are available to be trapped, *Figure 5.11*.

Concentrations of fine particles less than 2.5 micrometres and the levels of lead in these particles measured at Lucas Heights adjacent to the Holsworthy Option A are low and similar to those recorded at Badgerys Creek, *Figure 5.11*.

Concentrations are measured at the three nearest stations to Holsworthy Option A (Woolooware, Liverpool and Campbelltown), *Figure 5.16c*, show photochemical smog concentrations reaching maximum levels in the summer months. At the inland sites, for example at Liverpool and Campbelltown, both non-sea breeze and sea breeze ozone events were measured as illustrated by the examples plotted in *Figure 5.4*. An additional example, which is important in the context of both the Holsworthy Option A and the Badgerys Creek options is plotted in *Figure 5.17*. This shows the two-minute ozone concentrations measured at Campbelltown on 4 January 1991, along with the wind speed and direction measured at the same time.

On this occasion, no morning ozone was observed, and the episode was restricted to a period of regional ozone during the morning and afternoon, followed by a second ozone event coinciding with the arrival of the sea breeze. During the morning and early afternoon, winds were north-east to north-north-west. In this period of time, ozone concentrations increased almost linearly until noon, then remained approximately constant before the arrival of the sea breeze at 1530 hours. Wind speeds increased significantly with the onset of the east-north-east sea breeze, ozone concentrations increased slightly, and then decreased steadily with time during the afternoon and evening.

On this occasion, ozone recorded at Campbelltown during the morning and early afternoon would at times have been carried south across the general region of Badgerys Creek by northerly sector winds. Then during the afternoon, the east-north-easterly sea breeze would have carried emissions from the Botany Bay region towards Campbelltown and passed over the general region of Holsworthy Option A.

In 1991, winds were not measured at the Liverpool monitoring station, but as illustrated in *Figure 5.4*, ozone concentrations at this station on 4 January 1991 were almost identical to those measured at Campbelltown, which suggests that meterological conditions on this day had to be very similar at both locations.

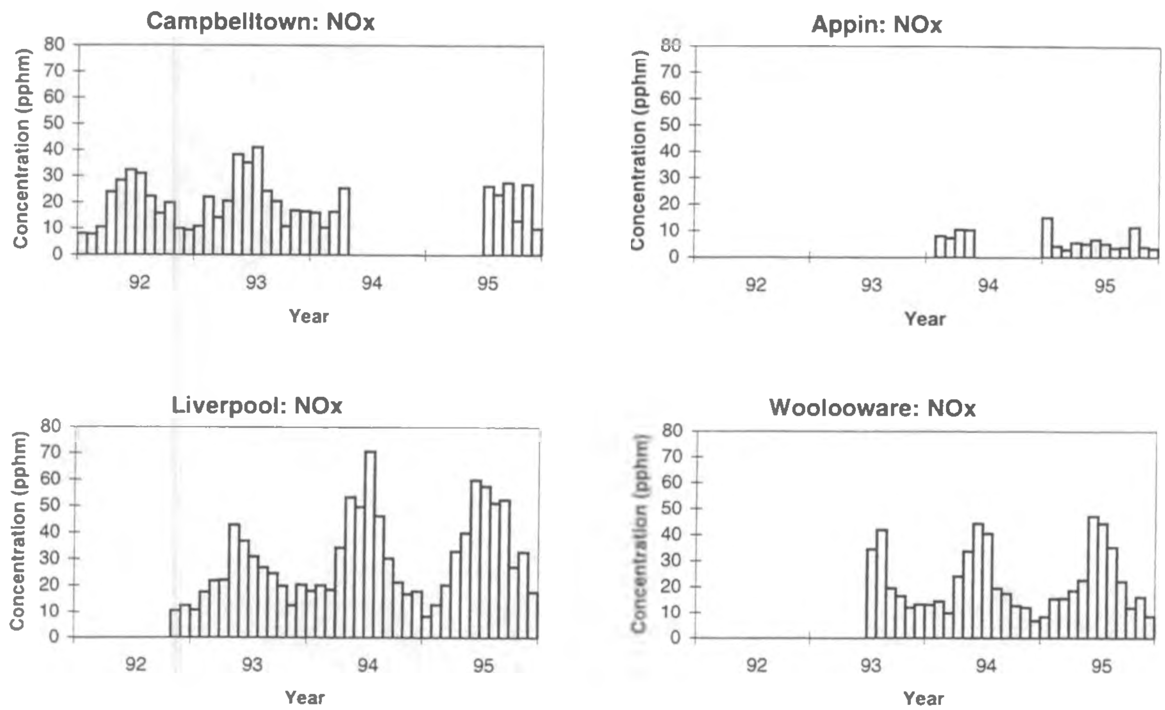
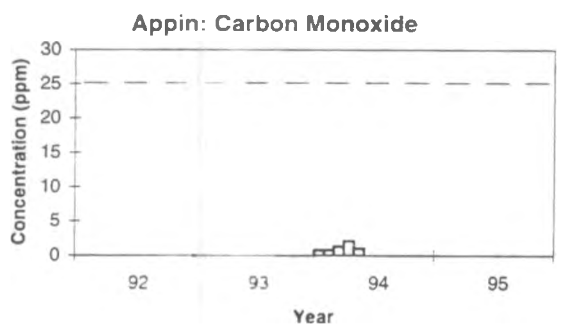


Figure 5.16(a) Time series of monthly maximum 1-hour concentrations of total oxides of nitrogen. Source: NSW EPA Quarterly Reports of Air Quality



No Measurements at Campbelltown

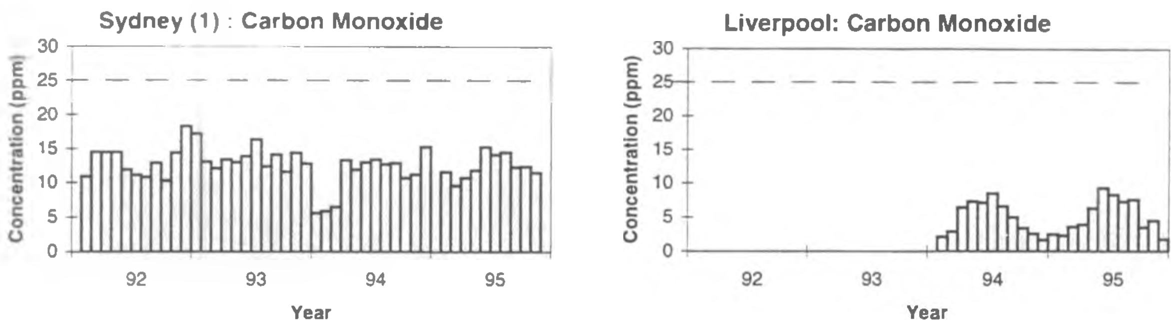


Figure 5.16(a) Time series of monthly maximum 1-hour concentrations of carbon monoxide NHMRC Guideline for 1-hour carbon monoxide - 25 pphm
Source: NSW EPA Quarterly Reports of Air Quality

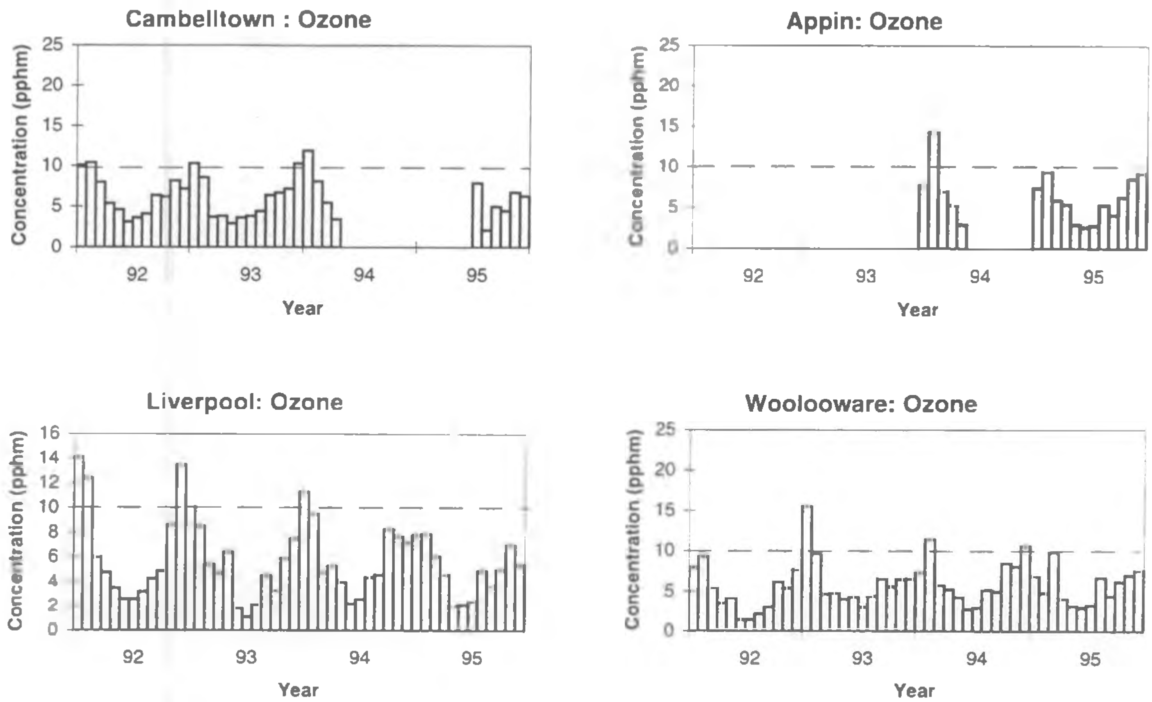
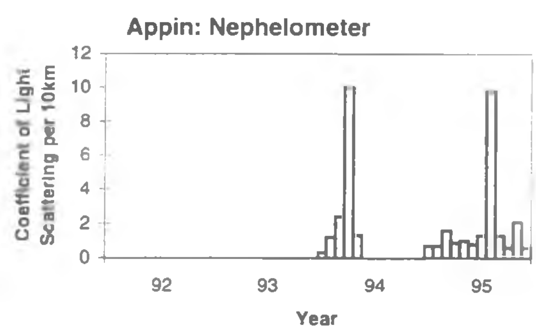


Figure 5.16(c) Time series of monthly maximum 1-hour concentrations of ozone
NHMRC Guideline for 1-hour ozone - 10 pphm
Source: NSW EPA Quarterly Reports of Air Quality

No Measurements at Campbelltown



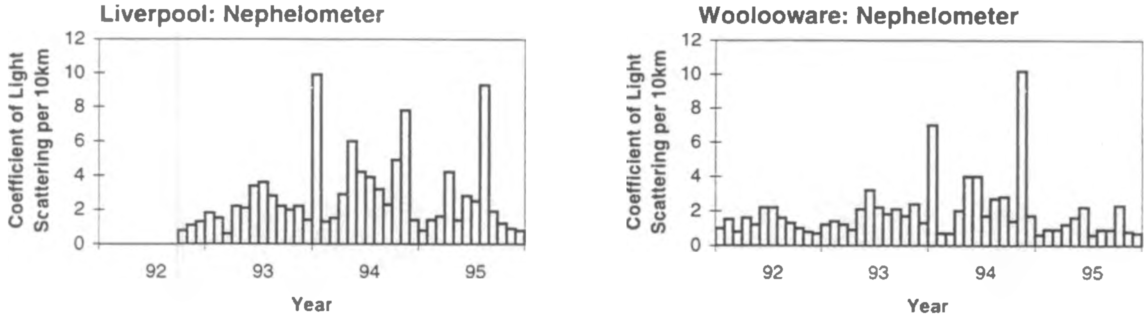
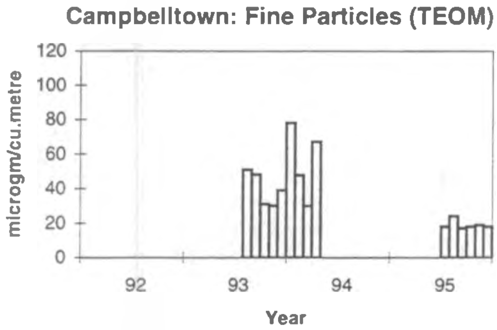
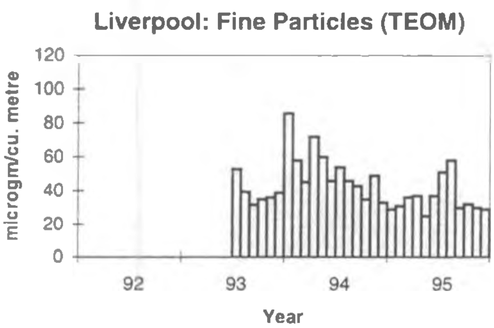


Figure 5.16(d) Time series of monthly maximum 1-hour concentrations of fine particles measured by nephelometer.
Source: NSW EPA Quarterly Reports of Air Quality



No Measurements at Appin



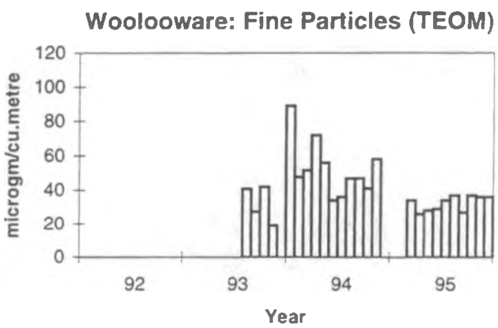


Figure 5.16(e) Time series of monthly maximum 1-hour concentrations of fine particles (> 10 um). Source: NSW EPA Quarterly Reports of Air Quality

CAMPBELLTOWN 4 JANUARY 1991

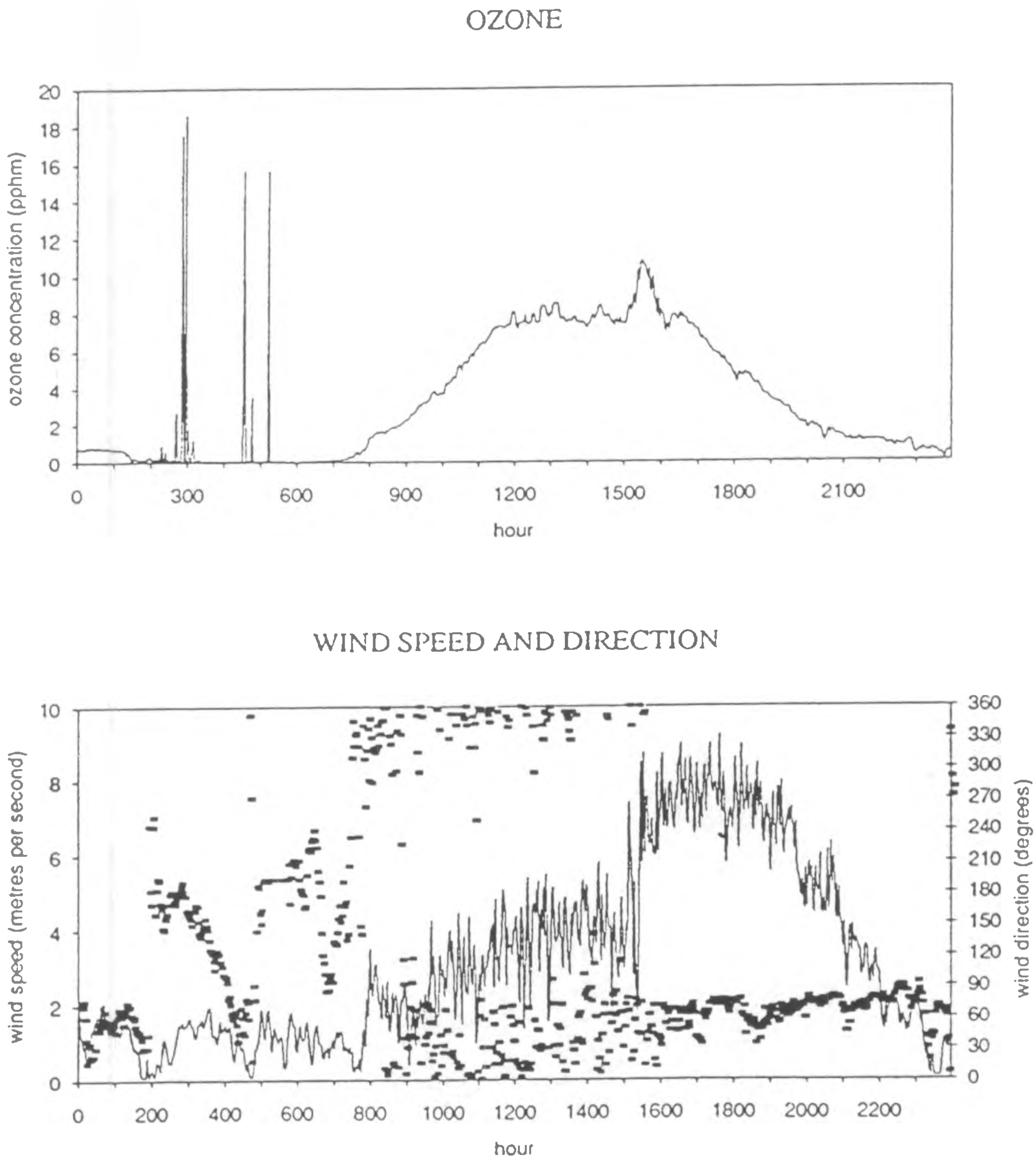


Figure 5.17 Campbelltown 4 January 1991: Two-minute average concentrations of ozone; two-minute average wind speed and wind direction (Hyde et al., 1997)

The direction of the winds within the sea breeze on 4 January 1991, are consistent with the results of an analysis of ozone events recorded at Campbelltown between December 1976 and February 1977 during the Sydney Oxidant Study (Hyde et al., 1978a), which are listed in *Table 5.1*. These results show that most of the ozone events recorded during the sea breeze at Campbelltown in this period were associated with winds blowing from the east-north-east direction (060° to 070°).

Moderate and high concentrations are occasionally observed at Woolooware, but as discussed in Section 5.1.1, there is currently little understanding about some of the mechanisms that cause ozone to be measured at this station. On the basis of observations of ozone and winds measured at the Federal Airport Corporations monitoring stations at Sydney Airport and Botany, it is likely that some ozone events occur within the sea breeze, *Figure 5.5*. However, as illustrated in *Figure 5.6*, it is possible that some ozone events observed at Woolooware occur as a result of ozone mixing down from aloft, (Hyde et al., 1997).

The transport of photochemical smog precursors and ozone along the coast from Sydney was discussed in Section 5.1.1, and is thought to occur as a result of emissions from Sydney being carried offshore overnight or during the morning, then carried south towards the Illawarra within the north-north-east coastal flow or a synoptic wind with the same direction. On the basis of work carried out during the Illawarra Sea Breeze Experiment, it appears that this layer of photochemical smog might be trapped within a layer of air a few hundred metres deep, and capped by an inversion formed by warmer air above, *Figure 5.7*. In this situation, this coastal layer of photochemical smog would not be observed at Holsworthy Option A. However, if inter-regional transport of ozone does occur on some occasions, then it might be possible that ozone mixing down from aloft during periods of regional ozone, as observed at Woolooware, Liverpool and Campbelltown, might also be measured at Holsworthy Option A.

5.4 METEOROLOGY AND AIR QUALITY IN THE VICINITY OF HOLSWORTHY OPTION B

The closest air quality monitoring stations to Holsworthy South are Campbelltown and Appin/Wilton. The record at Appin is short, since this station was only recently established. Carbon monoxide is not measured at Campbelltown and only a short record is available from Appin/Wilton, *Figure 5.16(a)*. However, these carbon monoxide measurements were made at the same location as the Aerosol Sampling Project data on fine particles and lead at Wilton, where very low monthly average concentrations of lead were recorded, illustrating that vehicle emissions at that location were low. Given the difference in elevation between Holsworthy Option B and the lower elevation of Appin/Wilton and Campbelltown, urban emissions trapped within ground based inversions at night at these lower elevations, would not be expected to be measured at Holsworthy Option B.

During the *Metropolitan Air Quality Study*, 1996), when the NSW Environment Protection Authority air quality monitoring station was located at Wilton (Douglas Park), moderate to high concentrations of ozone were recorded at this station on the 9 and 10 February 1994. On 10 February, as illustrated in *Figure 5.4a*, three periods of ozone were observed, although on this occasion, morning ozone concentrations were low. However, the period of regional ozone showed the characteristic ramping up and plateau of ozone within north-north-east to north-east winds during the morning, followed by a period of high ozone concentrations within east to east-north east winds, which would have carried this ozone across the vicinity of Holsworthy Option B.

Further information about photochemical smog levels in air passing over Holsworthy Option B, and the possible impact of near surface and elevated emissions on concentrations downwind, might be available once data from Appin are analysed in conjunction with the newly established NSW Environment Protection Authority air quality monitoring station at Bargo.

PART C: ASSESSMENT OF IMPACTS

CHAPTER 6 IMPACTS OF METEOROLOGY ON AIRPORT OPTIONS

Two important meteorological conditions that control the dispersion of emissions from a particular source are, the vertical structure of winds and temperature which together, assist or limit the vertical and horizontal dispersion of air pollutants. The vertical structure of wind and temperature at a location will be governed by the prevailing meterological conditions, such as the frequency of inversions and stable layers; synoptic winds; local and regional flows such as sea breezes and cold air drainage winds; the development of the mixing layer during the morning; and the presence of elevated inversions.

These meteorological conditions vary from day to day throughout the year as a result of changes in the general circulation of the atmosphere. On a particular day, as illustrated by the wind record in *Figure 3.8*, regions in Sydney can be affected by several different types of winds such as the synoptic wind, the sea breeze, south-west regional drainage flow, and 'spillover' of air out of the Hawkesbury Basin. Each of these flows may have a distinct wind and temperature structure associated with them, which could have quite different implications for the dispersion of ground-based and elevated emissions from a particular source.

The main issues considered in this section are:

- the trapping of ground-based, and near surface aircraft emissions under stable conditions;
- the horizontal movement of emissions trapped within these stable layers;
- the influence of the surface mixing layer and elevated inversions on the dispersion of airport and aircraft emissions;
- interaction between regional pollutants and near-surface emissions from airports at Badgerys Creek and Holsworthy; and
- associations between meteorology and photochemical smog in the vicinity of each airport site.

The term 'near-surface emissions' includes gaseous pollutants, fine particles and odours emitted from ground-based airport and aircraft related activities, as well as emissions from aircraft in the lowest few tens of metres above the ground. 'Elevated emissions' refer to emissions from aircraft in the lowest 1000 metres of the atmosphere.

6.1 BADGERYS CREEK AIRPORT OPTIONS

Except where specifically mentioned, comments about meteorology and the dispersion of near-surface and elevated emissions are common to all three options at Badgerys Creek. The term Badgerys Creek refers to an airport at this location.

6.1.1 OVERNIGHT TRAPPING OF NEAR-SURFACE EMISSIONS - BADGERYS CREEK

Overnight ground-based inversions or stable layers in the vicinity of Badgerys Creek will inhibit the vertical dispersion of near-surface emissions from an airport at this location. Although, at present, the amount of information about the frequency of overnight ground-based inversions and stable layers in the vicinity of Badgerys Creek is extremely limited, estimates can be made on the basis of other sources of information. These sources include: the frequency of nocturnal drainage flows based on previous analyses of cold air drainage winds in western Sydney, *Figure 4.15*; statistical information about the frequency of inversions above Richmond measured by morning aircraft ascents between 1937 and 1943, *Table 4.13*; limited profiles of wind and temperature in the Hawkesbury Basin made by the NSW Environment Protection Authority and Macquarie University, *Figures 4.14, 4.23, 4.24*; and the frequency of calms recorded at the Bureau of Meteorology's weather station at Richmond, *Table 4.14*, (Hyde et al., 1980; Micromet Environmental Consultants, 1995).

These data show that the frequency of inversions, and hence the frequency of trapping conditions, varies seasonally and with time during the night. For example, Loewe (1945) observed inversions above Richmond on 19 percent to 29 percent of mornings in summer and 53 percent to 95 percent of mornings in winter, *Table 4.13*. Measurements from Richmond, (*Table 4.14*) showed that calms were recorded on 68 percent to 89 percent of nights throughout the year between 0300 hours and 0600 hours. These 'calms' are often an artefact, induced by the high stalling speed of the Dines anemometer at Richmond (Potts et al, 1997). For example, measurements made in 1980 by Macquarie University close by, revealed a complex structure of multidirectional drainage flows at the surface during the night when the wind recorder at Richmond was showing calm conditions, (Hyde et al, 1980). However, because these near-surface drainage flows will be stable, then the high frequency of calms observed at Richmond during the night are likely, on most occasions, to be associated with ground-based inversions. Whilst the frequency of inversions at Richmond before sunrise is likely to be high, the rate at which the frequency of calms increases during in the evening changes with season. *Table 4.14* shows a rapid increase in the frequency of calms during the evening in winter, whilst in summer a much slower rate is observed.

Statistics on the frequency of cold air drainage flows in western Sydney, *Figure 4.15*, show a high frequency of drainage flows at some locations throughout the year. For example in 1980, stable cold air drainage flows were observed at Fleurs in South Creek Valley six kilometres north-east of Badgerys Creek on 45 percent to 55 percent of nights in summer; 60 percent to 80 percent of nights in Autumn; 60 percent to 74 percent in winter and 55 percent to 84 percent in spring. In addition to periods of drainage flow, ground-based inversions and stable layers will also be present during the evening and overnight within sea breezes and synoptic winds, as a result of radiation inversions forming within these flows after sunset.

Therefore, even in the absence of vertical temperature measurements at the vicinity of the Badgerys Creek, on the basis of information from a number of diverse sources, it is likely that a high frequency of ground-based inversions will exist at sunrise, although the time of onset of these stable layers in the evening could vary significantly in different seasons. Hence, the vertical dispersion of near surface emissions from and airport at Badgerys Creek is likely to be inhibited on many nights of the year, as illustrated by the data in *Table 4.15* which estimated that inversions might be observed some time in the night on 60 percent to 75 percent of nights in summer, and between 60 percent and 95 percent of nights in winter

If the NSW Environment Protection Authority meterological and air quality measurements for 1996 become available, it should be possible to obtain a better understanding about the frequency of trapping situations at night in the vicinity of Badgerys Creek. By analysing temperature and wind measurements from the 30 metre tower at the Liverpool Environment Protection Authority station, combined with near-surface measurements of wind and temperature from Bringelly and St. Marys, and data from the Bureau of Meteorology's wind station at Badgerys Creek, it should be possible to provide more information about the frequency of inversions and cold air drainage flows in South Creek Valley and at Badgerys Creek. Also, by analysing meterological and air quality measurements from Bringelly, it should be possible to obtain information about the time of onset and breakdown of overnight trapping situations in the vicinity of Badgerys Creek, since air pollution concentrations are extremely sensitive to changes in atmospheric stability.

6.1.2 HORIZONTAL MOVEMENT OF TRAPPED SURFACE EMISSIONS - BADGERYS CREEK

Except in special situations, such as the ponding of cold air in shallow basins, air within inversions is rarely stationary, even though to an observer at ground level, winds may appear almost calm. During the day, the speed of the wind increases with height away from the surface, and the same situation occurs at night. This is illustrated in *Figure 4.23*, which shows wind profiles measured within south-westerly cold air drainage flow at St Marys. In this example, winds at the surface were almost calm, but the wind profile for 2200 hours, shows speeds at 100 metres were about six metres per second (21 kilometres per hour). Therefore, depending on the height of the emissions, near-surface emissions, trapped within a stable layer can be carried quickly into other areas.

The current lack of knowledge about the vertical structure of winds and temperature in the vicinity of Badgerys Creek makes it difficult to provide informed comment about the frequency of time that near-surface emissions from Badgerys Creek would be trapped within a ground-based inversion or stable layer. It also makes it difficult to identify the regions that might be affected by these near-surface emissions from Badgerys Creek, since the direction of the winds associated with these trapping situations will vary with time of day and season.

During summer, autumn and spring the gradient of temperature above the surface within sea breezes and onshore synoptic in western Sydney will tend to become stable after sunset, therefore limiting the vertical dispersion of near-surface emissions from an airport at Badgerys Creek. When winds are blowing from the north-east and north-north-east directions and a stable layer or inversion is present at the surface, near-surface emissions from the airport will be carried towards the Camden Basin, a region of lower topography enclosed by the 100 metre contour, as illustrated in *Figure 3.5*. Whether these emissions from Badgerys Creek become trapped within the Camden Basin will depend on the rate of surface cooling and the subsequent increase in near surface stability within the Basin. If air near the surface of the Camden Basin cools more rapidly the air at Badgerys Creek, then emissions carried towards it from Badgerys Creek are likely to pass over the top of the Basin, since temperature profiles made at Smeaton Grange during the Pilot Study showed a strong inversion in the lowest 20 to 30 metres above the surface, (Hyde and Young, 1990).

Other evidence illustrating this decoupling is provided by measurements of wind flow at Wilton, Smeaton Grange, Oran Park and Badgerys Creek which showed, south to south-south-west cold air drainage winds passing over the top of the Camden Basin, (Hyde and Johnson, 1990). Hence, if emissions from the airport were carried within a stable atmosphere towards the Camden Basin late afternoon or early evening, they might well move over the top of the Camden Basin and subsequently become entrained In local and regional drainage flows in the evening and carried towards the north during the night.

In situations where late afternoon/early evening winds were stable and blowing from the east to south-east directions, near-surface emissions from the Badgerys Creek airport sites could travel towards the Nepean River Valley at the base of the Lower Blue Mountains escarpment. On the basis of winds recorded at Penrith, it was estimated that inversions would be present on 60 percent to 75 percent of all nights of the year between 2100 hours and 0600 hours the following morning. Furthermore, south to south-west local cold air drainage flows were observed on 30 percent to 50 percent of nights during the year (Hyde & Young 1992). These drainage flow frequencies appear low, when compared with the result of other analyses of drainage flows in the Hawkesbury Basin, but it was assumed that these low values at Penrith occurred as a result of local down-slope flows undercutting the main southerly local drainage flow along the Nepean River Valley. Consequently, the actual frequency of local south-to south-south-west drainage flow along the base of the lower Blue Mountains escarpment could well be much higher. Therefore, surface emissions carried within stable air towards toward the Blue Mountains Escarpment from Badgerys Creek, could subsequently become entrained within this local Nepean River Valley drainage flow, and carried northwards during the night.

The trapping of near-surface emissions from Badgerys Creek within cold air drainage flows was discussed in general terms above. However, in the absence measurements of the vertical structure of winds and temperature between Badgerys Creek and the Blacktown ridge to the east, it is difficult to provide an accurate assessment about locations downwind, which could receive near-surface emissions from Badgerys Creek, carried towards them during the night and early morning within local and regional drainage flows. The reason for this uncertainty is the range of drainage flow wind directions observed at Badgerys Creek, and lack of the information about the structure and depth of the local South Creek Valley drainage wind which flows towards the north between Badgerys Creek and the Blacktown Ridge.

The predominant directions of drainage flows observed at Badgerys Creek are west-south-west to south-south-west, with the highest frequency of nocturnal winds blowing from the south-west, *(Figure 4.3)*. South-south-west drainage winds are likely to carry near-surface emissions from Badgerys Creek north along the axis of the Hawkesbury Basin. However, it is difficult to be certain whether south-west and west-south-west winds at night, will carry airport emissions across the Blacktown Ridge into the Liverpool Basin, or whether these emissions will become entrained within the local and regional drainage flows within the Hawkesbury Basin and carried into regions north of the airport.

The situation is further complicated by the fact that the Macquarie University wind measurements used for this investigation were measured at a height of 10 metres at an elevation of 100 metres within the Badgerys Creek airport site, whilst the three options at Badgerys Creek have runway heights less than 100 metres. In Options A and B, the main north-east runways slope down towards the north-east with heights ranging from around 90 metres in the west to 70 metes in the east. In option C, two of the runways slope towards the north or east, and the heights of these runways are also lower than the height where the Macquarie University wind measurements were made. During the day, the affect of these relatively small differences in heights on wind speeds and directions at Badgerys Creek is likely to be small, but at night, a 20 to 30 metre change in height could result in much lighter winds being measured at the surface. These lighter winds, combined with the slope of the runways down towards the north or east, are likely create a situation where near-surface emissions remain within the Hawkesbury Basin and are carried north within low-level cold at drainage flows during the night.

One situation where this may not occur, are times when cold air drainage flows at Badgerys Creek are blowing from the west-south-west direction. If at the same time, local drainage flow along South Creek Valley was absent or very shallow, then near surface emissions from Badgerys Creek could be carried east towards the Blacktown ridge and into the Liverpool Basin.

6.1.3 INTERACTION BETWEEN REGIONAL AND LOCAL EMISSIONS - BADGERYS CREEK

On the basis of the fine particle measurements made at Blacktown during the Sydney Brown Haze Experiment and illustrated in *Figure 5.12*, it is clear that urban pollution from eastern Sydney can be trapped within a stable sea breeze or onshore synoptic wind and carried inland across the Blacktown Ridge into the Hawkesbury Basin. The evidence suggests that this polluted air can then be recirculated overnight into eastern Sydney within regional drainage flows and 'spillover' of air across the Blacktown ridge, Hyde et al 1980. As illustrated by the cross-sections drawn In *Figure 4.17*, it is thought, that urban pollution carried west across the ridge at Blacktown within this stable air, is decoupled from the surface, because of the early formation of ground-based inversions and local cold air drainage flows within the Hawkesbury Basin. If this occurs, then urban pollutants moving into the Hawkesbury Basin, but isolated from the surface by cooler air at the surface would not be measured at air quality monitoring stations within the basin

In the absence of an air quality monitoring station on the Blacktown ridge, east of Badgerys Creek, it is difficult to know whether urban pollution from the Liverpool Basin can be trapped within sea breezes and onshore gradient winds and carried west across the Blacktown Ridge towards Badgerys Creek. On the basis of the currently available air quality measurements, it appears that near surface air quality in the vicinity of the Badgerys Creek is not influenced by urban pollution from eastern Sydney.

The basis for this comment are the low monthly average lead levels which were measured In fine particles less than 2.5 microns at the CSIRO farm off Elizabeth Drive in 1992 and 1993 during the Aerosol Sampling Project, *Figure 5.11*, and the low monthly maximum one hour concentrations of total oxides of nitrogen measured at the Environment Protection Authority monitoring station between 1993 and 1993, *Figure 5.15(a)*. Both pollutants are good indicators for the presence of vehicle emissions trapped within near surface stable layers during the night. Concentrations of lead and total oxides of nitrogen at Badgerys Creek and Bringelly were low compared with similar measurements made in the more densely populated areas of eastern Sydney, *Figures 5.8, 5.9, 5.11*. Whilst the individual twice weekly lead values measured at Badgerys Creek during the Aerosol Sampling program have not been examined, and the more detailed air quality data from 1996 are not yet available, these low values suggest, that at least near the surface, the area around Badgerys Creek is not by affected urban pollutants trapped within stable layers, and carried inland during the late afternoon and early evening from the Liverpool Basin.

6.1.4 SURFACE MIXING DEPTH: THE IMPACT ON NEAR-SURFACE AND ELEVATED EMISSIONS - BADGERYS CREEK

After sunrise, heating of the surface by solar radiation, forms a mixing layer which increases In depth with time. Once this occurs, near-surface emissions from an airport at Badgerys Creek would no longer be trapped by a ground based inversion, but be able to disperse and be diluted by vertical mixing within the atmosphere. However, as the depth of the surface layer increases after sunrise, near-surface emissions from an airport at Badgerys Creek, trapped and carried downwind within a ground based inversion or stable layer, could be mixed rapidly down to the surface and may increase pollutant concentrations locally. Any increase in concentrations occurring at this time is likely to be transient, since the height of the surface mixing layer will continue to increase with time allowing vertical dispersion and dilution

The dispersion of emissions from aircraft in the lowest 1000 metres of the atmosphere, will depend on the presence, and height of any elevated inversions which could limit their vertical dispersion and the strength of the wind within the surface mixing layer which will disperse these aircraft emissions horizontally.

On the basis of Loewe's (1945) analysis of inversions above the Hawkesbury Basin at Richmond, and a few profiles of wind and temperature measured in the Hawkesbury Basin it is clear that the frequency and strength of inversions in western Sydney varies throughout the year. In winter, ground based inversions may be as deep as 600 metres at sunrise, (Loewe 1945, and *Figure 4.23)*. On the basis of observations of inversion breakdown in eastern Sydney (*Figure 4.22*) where the depths of the inversions within well developed regional drainage flows can be 300 to 400 metres, it can take several hours for these inversions to be completely eroded away and allow emissions trapped within the surface mixing layer to be dispersed and diluted by the synoptic wind.

A similar situation is expected to occur in western Sydney. During this time, the vertical dispersion of emissions from aircraft will be limited by the height of the inversions at the top of the surface mixing layer, although at the same time, these emissions will be dispersed and diluted by turbulent mixing and convection by winds within the surface mixing layer.

The directions that elevated emissions will be carried during the breakdown of deep ground-based inversions in the morning will be influenced by the directions of the winds within the inversion. The few observations available, show that drainage flows in the Hawkesbury Basin can be 200 to 300 metres deep, (eg *Figure 4.14; Figure 4.23*). Therefore, when deep inversions are present at sunrise, during the initial period of inversion breakdown, elevated emissions will be tend to be carried towards the north. However, once the inversion within the drainage flow has been eroded away, the vertical dispersion of elevated emissions will continue to be limited until the deep inversion is completely eroded away, but elevated emissions will be carried downwind and dispersed by the wind that is present above the drainage flow.

Knowledge about the structure of wind and temperature in western Sydney during the summer months is equally scarce. Loewe's (1945) analysis of inversion frequency at Richmond showed a much lower frequencies of inversions in the lowest 600 metres of the atmosphere during the summer half-year, with inversions measured on 19 percent to 29 percent of mornings. However, he acknowledged that these values might be low, because the aircraft accents were made some time after sunrise, and shallow inversions that might have been present at sunrise, might well have been eroded away by the time that the observations were made.

Measurements on two days from the NSW Environment Protection Authority's Summer Campaign in February 1995, plotted in *Figure 4.14* showed the remnants of 100 metre to 200 metre deep southerly drainage flow at St. Marys, and its subsequent breakdown accompanying with the rapid increase in the depth of the surface mixing layer with time. On another day, 3rd February 1995, when southerly drainage flow was absent, the profile made at 0910 hours shows the remnants of a 300 metre deep inversion within a northerly synoptic wind, which was quickly eroded away by surface heating, *Figure 4.24*. Hence, in these situations, whilst the vertical dispersion of ground-based emissions will initially be inhibited by these shallower ground based inversions, rapid surface heating in summer will quickly erode them away and allow near-surface and elevated emissions to be dispersed and diluted by the synoptic wind.

Whilst in the situations described above, the height of the surface mixing layer can be expected to increase with time during the morning and afternoon, it is thought that on some occasions in summer, the growth of the surface mixing layer during may be limited to a depth of between 500 and 600 metres by an elevated inversion, as a result of continued warm air advection during the day, (Hyde et al., 1997). However, this hypothesis has not been verified by vertical measurements of temperature in western Sydney.

Some additional evidence for decoupling of air within the Hawkesbury Basin from the synoptic wind above is illustrated by wind profiles measured at Wilton on 21 February 1980, *Figure 4.25*, when wind speeds were light within the lowest 200 metres following the breakdown of drainage flow, but increased rapidly with height above. It is thought that such a situation could only occur if an elevated inversion was present at the top of the surface mixing layer. In this situation, the vertical and horizontal dispersion of emissions from aircraft landing and taking off from an airport at Badgerys Creek could be restricted by light winds in the surface mixing layer. The frequency of these episodes is currently unknown, and whether these events are related to the overnight north winds frequently observed at Winmalee during the summer months can only be properly evaluated by a program of vertical measurements of wind and temperature.

6.1.5 METEOROLOGY AND PHOTOCHEMICAL SMOG - BADGERYS CREEK

The chemical reactions that produce photochemical smog are discussed in *Technical Paper No. 6 - Air Quality*. Photochemical smog includes ozone and other gaseous and non-gaseous by-products of the chemical reaction. In this section, the terms ozone and photochemical smog are used synonymously.

The impact of emissions from an airport at Badgerys Creek on photochemical smog in Western Sydney is discussed in the report on air quality for the Second Sydney Airport Draft EIS . This section is not concerned with the size of any increase in photochemical smog that might occur as a result of airport and aircraft operations at Badgerys Creek. Rather, the aim is to discuss the current state of knowledge about meteorological conditions during these episodes, and how they could impact on the dispersion of pollutants from an airport at Badgerys Creek.

The three types of ozone episodes observed in Western Sydney were discussed in Chapter 5; these are morning ozone, associated with a rapid rise in concentrations for a few hours during the morning; regional ozone, often characterised by a period of almost constant concentrations; and ozone within the sea breeze, *Figure 5.4*. These three periods of ozone were first identified during the Sydney Oxidant Study (Hyde et al 1978a), but the vertical structure of winds and temperatures associated with each category of ozone have not been measured, and the particular combination of meterological conditions in the greater Sydney region that cause these episodes of photochemical smog to occur on a particular day, have not been investigated.

During periods of morning and regional ozone, the impact on photochemical smog, of near-surface and elevated emissions from an airport at Badgerys Creek will depend on the vertical structure of winds and temperature within these layers, since these will influence the vertical and horizontal dispersion of these emissions, and their subsequent contribution to photochemical smog downwind of the airport. On the basis of the few photochemical smog episodes analysed during the Pacific Power and *Metropolitan Air Quality Study*, winds at the surface in western Sydney during periods of morning and regional ozone are usually northerly (Johnson et al. 1993; Hyde et al., 1997). Therefore, in this situation, if an elevated inversion was present some distance above the surface, near-surface and elevated emissions from Badgerys Creek would be carried towards the south and contribute to photochemical smog downwind. For example on 4 January 1991, during the period of regional ozone when concentrations around 8 parts per hundred million were measured at Campbelltown within northerly sector winds, *Figure 5.17*, winds at Oran Park, south of Badgerys Creek were northerly. Therefore, on this occasion near-surface and elevated emissions from Badgerys Creek would have been carried south towards Camden and Campbelltown and could possibly have contributed to photochemical smog concentrations downwind of the airport

The impact of ground based and elevated emissions from Badgerys Creek airport on photochemical smog within a sea breeze, will also depend upon the structure of wind and temperature within this flow, but will also be governed by the time that emissions enter the sea breeze, since photochemical reactions are governed not just by precursor concentrations and dilution within the atmosphere, but also by air temperatures and the amount of sunlight (Johnson 1993). However, since the direction of sea breezes at Badgerys Creek are predominantly east to east-south-east, photochemical smog within a sea breeze at Badgerys Creek will move inland into the lower Blue Mountains.

Whether it is possible for ozone and precursors of photochemical smog within the sea breeze to be recirculated overnight within the Sydney Basin, has been a subject for discussion for many years. Modelling during the *Metropolitan Air Quality Study*, produced two scenarios whereby Sydney emissions could be recirculated overnight within western Sydney, Hurley and Manins (1997). The first considered the situation where photochemical smog or its precursors were recirculated within a vertical rotor in western Sydney, with air being carried north along the Hawkesbury Basin during the night within cold air drainage flows and then back towards the south by a northerly synoptic wind above. The fact that a high frequency of northerly wind have been observed during the night at Winmalee in the Summer months, and southerly drainage flows are observed above the surface of the Hawkesbury Basin, suggests that this hypothesis is plausible. In this situation it is possible that near-surface and elevated emissions from Badgerys Creek could become entrained in this circulation and be carried towards the north within local and regional drainage flows, and the south again by a northerly wind.

The second scenario showed Sydney emissions trapped within a deep horizontal anti-clockwise circulation or air in Western Sydney during the night. The fact, that on some occasions, sea breezes at Badgerys Creek rotate anti-clockwise with time after sunset to become an overnight south-west flow, suggests that recirculation of Sydney emissions by this mechanism could occur on some occasions.

At present, there is a high degree of uncertainty about the structure of winds and temperature and associated with periods of morning and regional ozone measured in western Sydney before the arrival of the sea breeze. A number of plausible hypotheses about the source of the precursors that could result in these non-sea breeze events have emerged as a result of modelling carried out for the *Metropolitan Air Quality Study*. These include overnight inter-regional transport of precursors from source regions north and north-east of Sydney, as well as the two scenarios discussed above whereby Sydney emissions could be recirculated overnight in western Sydney.

Unfortunately, it has not been possible to verify any of these plausible hypotheses with a campaign of field measurements and routine observations of the vertical structure of wind and temperatures in western Sydney. Until these measurements are made, it is not possible on the basis of the limited meterological data currently available, to provide an objective assessment of the impact of meteorology in the vicinity of Badgerys Creek on the dispersion of emissions from elevated and near-surface emissions from an airport at this location and their subsequent contribution to photochemical smog concentrations downwind of the airport, especially during periods of morning and regional ozone.

6.2 HOLSWORTHY OPTION A

6.2.1 OVERNIGHT TRAPPING OF NEAR-SURFACE EMISSIONS - HOLSWORTHY OPTION A

The trapping of near-surface emissions from an airport at Holsworthy Option A would occur as a result of increasing stability of air near the surface in late afternoon and early evening. Two examples from Lucas Heights, illustrating the change in the gradient of temperature close to the ground are plotted in *Figure 3.7*. In each example, the temperature above the ground initially decreases with height, and is associated with favourable dispersion conditions. However, by late afternoon and early evening, radiative cooling of the surface, gradually results in the formation of a stable layer close to the surface and causes the temperature to increase with height thus forming an inversion which will inhibit the vertical dispersion of near surface emissions from Holsworthy Option A.

The inversion data analysed by Clark (1990), and the measurements presented in this report, *Figure 4.27*, showed large changes in the frequency of occurrence of inversions throughout the year. The maximum frequencies occur in June, July and August, when inversions were observed as often as 80 percent to 95 percent in some hours of the night, whilst in summer, ground-based inversions and stable layers were only observed on 30 percent to 50 percent of nights. There were also significant differences throughout the year in the rate that surface inversions increased with time during the night. In summer, the rate of increase in inversion frequency during the evening was low, whilst in winter, the frequency increased very rapidly after sunset.

Therefore, the percentage of time that near-surface emissions at Holsworthy Option A will be trapped by stable layers will vary significantly throughout the year, with the highest frequency of near-surface trapping conditions occurring during the winter months.

Late afternoon and early evening in summer, autumn and spring, before the shift to nocturnal wind directions occurs, the lower layers of sea breezes and on-shore synoptic winds, blowing across Holsworthy Option A, may become stable. In these circumstances, near-surface emissions from the airport will become trapped and carried inland. However, because of the high frequency of cold air drainage flows observed at Campbelltown (*Figure 4.15*), the onset of strong surface stability associated with this local cold air drainage flow, means that it is unlikely that any near-surface emissions from Holsworthy Option A would be measured at the surface. In this situation, near-surface emissions from Holsworthy Option A carried inland within these stable onshore winds would most likely pass over the top of drainage flow in the Campbelltown Valley and become entrained within regional drainage flow within the Sydney Basin, or dispersed by the synoptic wind.

6.2.2 HORIZONTAL MOVEMENT OF TRAPPED EMISSIONS - OPTION A

The factors expected to influence the horizontal movements of near surface emissions trapped within stable layers at Holsworthy Option A will be: the strength and direction of the wind between 10 metres and 49 metres above the surface; the overall slope of the topography surrounding the airport; and the slope of the runways at Holsworthy Option A.

The situation at Holsworthy Option A is complicated by the fact that a shallow layer of south to south-south-west air can be present at 10 metres, while the direction of the wind at 49 metres can be different, as illustrated by the three hourly seasonal wind histograms plotted in *Figures 4.6 and 4.7* and the scatter plots of wind direction against the difference in temperature between 49 metres and 10 metres, plotted in *Figure 4.20*. In the scatter plots, the southerly flow is visible at 10 metres, but there is no corresponding concentration of points from these southerly directions at 49 metres.

As well as the observed tendency for wind direction between 10 metres and 49 metres to turn clockwise with height, the histogram wind plots in *Figures 4.3* and *4.4*, and the wind profiles plotted under stable conditions in *Appendix 1*, show that wind speeds at 49 metres are approximately double those measured at 10 metres above the surface. Ten metre wind speeds at night, under stable conditions are typically less than 3.9 metres per second (14.5 kilometres per hour), whilst wind speed at 49 metres can be between 4.0 and 10 metres per second (14.5 to 36 kilometres per hour). The combined effect of both a change in the wind direction, and an increase in wind speed with height, would assist in the dispersion and dilution of near surface emissions from Holsworthy Option A that might be trapped within a stable layer during the night.

The presence of a well defined south to south-south-west shallow flow near the surface, coupled with the downward slope of the topography, and the corresponding slope of the main north-south runways at Holsworthy Option A, will lead to a situation where near surface emissions in the lowest 10 metres will on some occasions be trapped within a highly stable layer and flow down-slope towards the north. The frequency of time that these flows are likely to occur are plotted in *Figure 4.28*. In the summer months, the percentage of these stable, low-level southerly drainage flows is low. However, the frequency increases rapidly after March, remains high throughout the winter months into spring, and then decreases again after October. A feature of the wind direction inversion plots in *Figure 4.28*, is that the stability of these south and south-south-west flows is higher than the stability observed in the main regional drainage flows that blow from the south-west and west-south-west directions. Hence these low level stable layers will provide a very effective trap for near-surface emissions when the near surface wind are from these south and south-south-west directions.

Under these conditions, near-surface emissions will flow north towards the Liverpool Basin, and some will tend to be channelled down the gullies to the north of the airport site. However, it is considered unlikely that near surface emissions flowing towards the north from Holsworthy Option A will reach the surface of the Liverpool Basin, because at night, a steep ground based inversion can be expected to form rapidly within the Basin after sunset. This inversion will act to decouple urban emissions trapped within the Liverpool Basin, from near-surface emissions flowing down-slope from Holsworthy Option A. At the same time it, can be expected that local cold air drainage flows from the Campbelltown Valley will be flowing north-east across the top of the Liverpool Basin, and therefore, emissions moving down-slope from

Holsworthy Option A towards the Liverpool Basin are likely to become entrained in this flow and carried east across Sydney.

The other main wind directions at Holsworthy Option A which are likely to be associated with the trapping of near surface emissions, are stable winds blowing from the south-west to north-west sectors at night. Although a high frequency of inversions are observed when winds are blowing from these directions, *Figure 4.28*, the strong gradient of wind in the lowest 49 metres will carry these emissions rapidly east and north-east of Holsworthy Option A.

6.2.3 INTERACTION BETWEEN REGIONAL AND LOCAL EMISSIONS - OPTION A

On the basis of air quality measurements made at Liverpool, Woolooware and Campbelltown, it is clear that in the cooler months of the year, low level trapping occurs late afternoon and early evening at lower elevations within the Sydney Basin. This can be seen in the monthly maximum concentrations of total oxides of nitrogen measured at these stations, *Figure 5.16(a)*, and from the measurements of the lead content of fine particles measured during the Aerosol Sampling Project in 1992 and 1993, *Figure 5.11*. As part of this program, lead levels were also measured at Lucas Heights, and the monthly average concentrations were low compared with the more urbanised regions of Sydney. Therefore, on the basis of these measurements at Lucas Heights it is reasonable to conclude that urban emissions from eastern Sydney and the Liverpool Basin, trapped at night within a ground-based inversion of stable layer during the cooler months of the year, will not influence air quality at Holsworthy Option A.

6.2.4 SURFACE MIXING DEPTHS - IMPACT ON NEAR SURFACE AND ELEVATED EMISSIONS- HOLSWORTHY OPTION A

Comprehensive statistics about surface mixing depth are available at Lucas heights as a result of the acoustic profiling program undertaken between 1975 and 1981. On the basis of echoes from this instrument, which were calibrated using a program of tethered balloon profile ascents, (Clark and Bendum, 1981), facsimile records of echoes measured on 873 days were analysed to produce statistics on: the average height of the mixing depth in the morning; the rate of increase in depth of the mixing layer with time; and the height of the echo at the end of the observing period, *Table 4.17*. The average height of the recognisable echo in the morning was between 220 and 235 metres throughout the year, with a standard deviation of 65 metres in winter and 94 metres in summer. The average rate of rise of the surface mixing layer during the morning was between 160 and 176 metres per hour, although with a standard deviation of 100 metres per hour indicates that the increase in height of the mixing layer during the morning could be quite large. The average final height of the surface mixing layer at Lucas Heights was 630 metres in winter and 728 metres in summer, although the standard deviation of these heights is large, with 228 metres in winter and 225 metres in summer, (Clark, 1983).

During the daytime, wind speeds at 49 metres were usually between four and seven metres per second, as illustrated by the frequency plots in *Figure 4.7*. Therefore, combined with the fact that wind speeds tend to increase with height above the surface, even during periods when the surface mixing depth is increasing with time, winds above the surface at Holsworthy North will provide an environment where near-surface and elevated emissions are dispersed vertically and horizontally by these moderate strength synoptic winds.

Clark (1983) also analysed details of echo structure on 680 days in this period when sea breezes were observed, *Table 4.4*. He observed that the average height of the sea breeze at Lucas Heights was 608 metres in the summer months reducing to 534 metres in winter. As a result of the decrease in surface heating that occurs during the afternoon the average heights of the sea breeze before the onset of stable conditions at the surface was 560 metres in summer and 491 metres in winter. Therefore, apart from the contribution of these sea breeze events to photochemical smog which are discussed below, moderate to high wind speeds within sea breezes and onshore flows, will act to disperse and dilute near-surface and elevated emissions from Holsworthy Option A.

6.2.5 METEOROLOGY AND PHOTOCHEMICAL SMOG - HOLSWORTHY OPTION A

The nearest air quality monitoring stations to the Holsworthy North are the NSW Environment Protection Authority Woolooware, Campbelltown, and Liverpool. Campbelltown and Woolooware have reasonably long records of ozone concentrations, *Figure 5.1*, but monitoring of ozone at Liverpool was only carried out on a regular basis from the end of 1991.

Prior to the Metropolitan Air Quality Study, with the exception of Lidcombe, winds were not routinely measured at NSW Environment Protection Authority monitoring stations in Sydney and the Illawarra, and this has made it difficult to determine the source of ozone measured at monitoring stations in Sydney.

On the basis of work carried out during the Pacific Power Investigation, and Metropolitan Air Quality Study it was thought that ozone measured at Woolooware could occur as a result of two mechanisms; ozone carried inland within the sea breeze, and ozone mixing down from aloft, possibly as a result of inter-regional transport from source regions north of Sydney, *Figures 5.5* and *5.6*.

At Liverpool and Campbelltown, monitoring has revealed both that morning, regional and sea breeze events are recorded at these locations, *Figure 5.4*. One of the aims of this report was to analyse ozone data from these stations to determine the frequency of wind directions associated with ozone events recorded at stations in the vicinity of the Holsworthy Military Area, but this analysis will now have to wait until the 1996 Environment Protection Authority air quality monitoring data is analysed. However, as discussed in Chapter 5, wind directions associated with episodes of ozone measured within the sea breeze at Campbelltown between December 1976 and February 1997, showed that the predominant directions of the wind were 060 and 070 degrees, *Table 5.1*. This suggests that the sea breezes containing this ozone are likely to have originated in the Botany Bay region of Sydney, and passed over the general area of Holsworthy Option A towards Campbelltown.

Additional evidence for this trajectory can be seen in the plots of 2-minute concentrations of ozone and winds on 4 January 1991, *Figure 5.17*, where winds associated with ozone within the sea breeze were from the east-north-east, which would have carried this air across Holsworthy Option A.

The other issue requiring to be addressed, is the relative contribution to photochemical smog passing over Holsworthy Option A, of urban industrial emissions from the Botany bay region. Whilst this is not necessarily an important issue during the daytime, the wind statistics from Lucas Heights in the summer months, show a reasonable proportion of east-north-east to north-east winds which are not stable continuing to blow throughout the night, *Figure 4.28*. Therefore, when urban emissions, such as those from vehicles decrease during the evening, it is possible that elevated industrial emissions from the Botany Bay region could move across Holsworthy Option A into south-west Sydney, collecting near-surface emissions from Holsworthy Option A on the way. For reasons explained earlier, these emissions from Botany Bay and Holsworthy Option A are not likely to be measured at ground level in the vicinity of Campbelltown, because of the high frequency of local drainage flows there at night. However, if these precursors are carried inland from Botany Bay during the evening and overnight, they could become entrained within regional drainage flows, and then contribute to morning photochemical smog the following day.

6.3 HOLSWORTHY OPTION B

Holsworthy Option B is located 15 kilometres south-south-west of Lucas Heights, 240 to 280 metres above sea level, compared with 150 metres at Lucas Heights. In the early stages of work for the Second Sydney Airport Draft EIS, the use of the 49 metre winds from Lucas Heights was considered for Holsworthy Option B. However, as explained in *Appendix 1*, following an analysis of Macquarie University wind data measured at a height of 435 metres near Mount Keira North, about 23 kilometres to the south, it was decided that the 49 metre winds from Lucas Heights would be unrepresentative of near-surface winds at Holsworthy Option B. It was estimated, that for some wind directions, wind speeds at Holsworthy Option B would be 5 percent to 8 percent higher than the 10 metre wind speeds from Lucas Heights. However, in view of the high degree of uncertainty involved, it was decided that the 10 metre measurements from Lucas Heights were the most appropriate data to use to assess meteorological conditions at Holsworthy Option B.

During the daytime, it could be expected that winds at Holsworthy Option B would be similar to those measured at Lucas Heights, although some increase in speeds could be expected because of the increase in elevation between the two sites. Other areas of uncertainty are: the frequency of sea breezes, and their time of onset and depth; and the frequency of inversions and cold air drainage flows at night. These issues are dealt with later in this section, and again in Chapter 7.

In the absence of any on-site data at Holsworthy Option B, the approach taken here has been to assume that the statistics and observations of sea breezes, mixing depths, cold air drainage flows and the frequency of near-surface inversions at night, would be similar to those expected to occur at Holsworthy Option B. However, where possible, factors that may change the frequency of these meterological conditions are discussed in the appropriate sections below.

6.3.1 OVERNIGHT TRAPPING OF NEAR-SURFACE EMISSIONS - HOLSWORTHY OPTION B

Overnight trapping of near-surface emissions at Holsworthy Option B will occur late afternoon and early evening, as radiative cooling of the surface gradually results in the situation where air near the surface is cooler than the air above, thus forming a ground-based inversion which inhibits the vertical dispersion of emissions. In the absence of onsite measurements of the vertical structure of wind and temperature at Holsworthy Option B, a conservative approach would be to assume that the frequency of inversions, *Figure 4.27*, and the directions of the winds within them, *Figure 4.28*, are the same at Holsworthy Option B as measured at Lucas Heights. This is likely to be an overestimate of the true situation, since at this higher more exposed location, the synoptic wind may result in a decrease in the frequency of ground-based radiation inversions, and as explained in Chapter 4, the frequency of cold air drainage flows at Holsworthy Option B may be lower than that recorded at lower elevations further north. However, none of these assumptions about a possible reduction in the frequency of inversions at Holsworthy Option B can be quantified, so the conservative approach of using the data from Lucas Heights remains the most appropriate approach to estimating the frequency of trapping situations at Holsworthy Option B.

6.3.2 HORIZONTAL MOVEMENT OF TRAPPED SURFACE EMISSIONS - HOLSWORTHY OPTION B

Trapping of near surface emissions at Holsworthy Option B will occur within sea breezes and on-shore synoptic winds during the late afternoon and early evening, and during the night within cold air drainage flows and stable synoptic winds. Late afternoon and early evening, a stable layer may form at the surface within these onshore winds, as illustrated by Clark and Bendum's 1981 boundary layer profiling experiments at Lucas Heights. In this situation, near surface emissions from Holsworthy Option B could be trapped close to the surface and carried inland towards Wedderburn, Appin and Douglas Park. Since there is little difference in height between Holsworthy Option B and Wedderburn, it is likely that low level emissions from Holsworthy Option B, will on occasions, have an impact on nighttime air quality at Wedderburn. In the absence of on-site measurements of nighttime winds and near surface stability at Holsworthy Option B, it is difficult to estimate the frequency of times that Wedderburn could be adversely affected. However, on the basis of the inversion - wind direction histograms plotted in *Figure 4.28*, the percentage of times that stable winds are likely to blow from the east-north-east, east, and east-south-east directions is expected to be low.

West of Wedderburn, the height of the topography decreases rapidly, *Figure 3.2*. At Wilton, in the base of the valley, a high frequency of drainage flows are observed at night, with an annual average frequency of 58 percent in 1980, compared with 67 percent at Campbelltown. Therefore, if near-surface emissions from Holsworthy Option B move into the south of the Sydney Basin, they are likely to pass over the top of the highly stable air below, and will not affect air quality at the surface.

On the basis of the 10 metre and 49 metre wind data from Lucas Heights, and the analysis of drainage flow directions at Wilton, *Table 4.8*, two separate drainage flows could be observed at Holsworthy Option B; low-level, south to south-south-west highly stable local drainage flow observed at 10 metres but not at 49 metres, and south-west to westerly regional drainage flows.

Since the topography at Holsworthy Option B slopes down towards the north, as well as to the west, a highly stable layer of northerly flowing air can be expected to be observed at night. This stable layer of air will act as an efficient trap for low-level emissions at Holsworthy Option B, and will carry these emissions towards the north. The presence of Punchbowl Creek, immediately to the north is likely to increase the frequency of time that these southerly flows are observed at Holsworthy Option B. However, as there are no residential areas close to the north which could be affected by these near-surface emissions, the impact of these emissions on regional air quality will be low.

West to south-west winds will carry near-surface and elevated emissions from Holsworthy Option B towards the Lake Woronora catchment areas. During the daytime, and when neutral conditions are present at night, vertical and horizontal mixing by the wind and convection will act to quickly disperse and dilute these emissions and carry them away from the vicinity of Holsworthy Option B. However, at night, especially during Autumn, Winter and Spring, when the frequency of west to south-west stable winds is expected to be high, then the situation is more complicated and is discussed in more detail below.

Conservative calculations contained in *Technical Paper No. 7 - Geology, Soils and Water* have shown that even if these emissions from Holsworthy Option B were able to reach the surface of Lake Woronora, they would pose no health problems. However, because of differences between the microclimate at Holsworthy Option B in the evening, and the corresponding changes within the catchment area, it is highly unlikely that near-surface emissions from Holsworthy Option B would reach the surface of the lake.

To explain this situation, it is best to first consider the changes in microclimate that are likely to occur within the catchment area late afternoon and early evening. The factors that together will govern the microclimate within the catchment are: the size of the catchment; wind speeds within the catchment compared with those at Holsworthy South; the temperature of the water at the surface of the lake; and the time that air in contact with the sloping surface of the ground within the catchment starts to cool and flow down-slope and accumulate over the top of Lake Woronora, compared with changes in near-surface temperature with time at Holsworthy Option B.

Within the catchment, it is likely that winds will be lower than those on the surrounding plateau, because of the shielding affect of higher ground surrounding the catchment. This factor, combined with earlier shading of ground within the catchment, is likely to result in a situation whereby, air in contact with the ground surface within the catchment will cool and then flow down-slope and accumulate over Lake Woronora. The catchment stretches for about 13 kilometres to the south-south-east along the eastern branch of the lake, and about 8 kilometres along the western branch. Therefore, there will be a continual down-slope flow of air during the evening and overnight, which will increase the depth of the layer of air accumulating within the catchment. Ultimately, continued cooling within the catchment is likely to result in the situation whereby this accumulating air spills out over the top of the catchment, and is carried away by winds blowing across the plateau region above the catchment.

At the same time that cooling of the ground surface within the catchment is occurring, air near the surface at Holsworthy Option B will also start to cool and result in a situation whereby near-surface emissions will become trapped within a stable layer of air. If cold air drainage flows or stable south to west synoptic winds are present, they will carry these near-surface emissions from Holsworthy South towards the catchment area and Lake Woronora. If at this time, the catchment has not filled up with cold air draining down the sloping topography surrounding Lake Woronora, these emissions from Holsworthy South could flow over into the catchment area. However, they will be isolated from the surface of the lake, by the layer of cooler air below, that had previously accumulated within the catchment before the emissions from Holsworthy Option B moved east.

As mentioned above, air flowing down-slope within the catchment will continue accumulating with time, as a result of continued cooling of sloping ground within the catchment. Since winds within this surface layer are expected to be calm or very light, and because air carried into the catchment from Holsworthy South is likely to be warmer, then as the depth of the layer of air above the surface of the lake increases with time during the night, any near-surface emissions carried into the catchment from Holsworthy Option B, will move upwards with time. Eventually, as a result of the continued accumulation of cooler air within the catchment, near surface emissions from Holsworthy Option B will spill out of the catchment and be carried away by near-surface winds on the plateau.

The situation that is likely to occur at night within the Lake Woronora catchment can be illustrated by describing a series of vertical wind and temperature profiles that were made in the vicinity of the bridge across the Woronora River Valley by the Australian Nuclear Science and Technology Organisation in May 1990, (Clark, 1990). A selection of profiles on two nights are plotted in *Figures 6.1* and *6.2*. Details of profiles made on two nights are given in *Tables 6.1 and 6.2* whilst the depth of the valley in the vicinity of the bridge is 80 to 100 metres, and is 6.4 kilometres north-east of Lucas Heights.

Table 6.1 gives a summary of measurements at selected heights within the valley on 3rd and 4th May 1990, along with wind and temperatures measured at Lucas Heights. During the night, the temperature of the air within the valley decreased from 14 degrees at 2220 hours to around 10 degrees at sunrise the following morning. Air temperatures 10 metres and 49 metres at Lucas Heights also cooled with time during the night with the 10 metre temperatures remaining about 2 degrees warmer than the air within the valley, whilst temperatures at 49 metres were about 5 degrees higher. The following morning, surface temperatures increased rapidly within the valley with surface temperatures higher than those at Lucas heights and this would result in good convective mixing and dilution.

The wind and temperature profiles for the ascent between 0017 and 0027 on 4th May are plotted in *Figure 6.1*. These show an isothermal layer of air above the floor of the valley, and an inversion above. The wind profile shows light

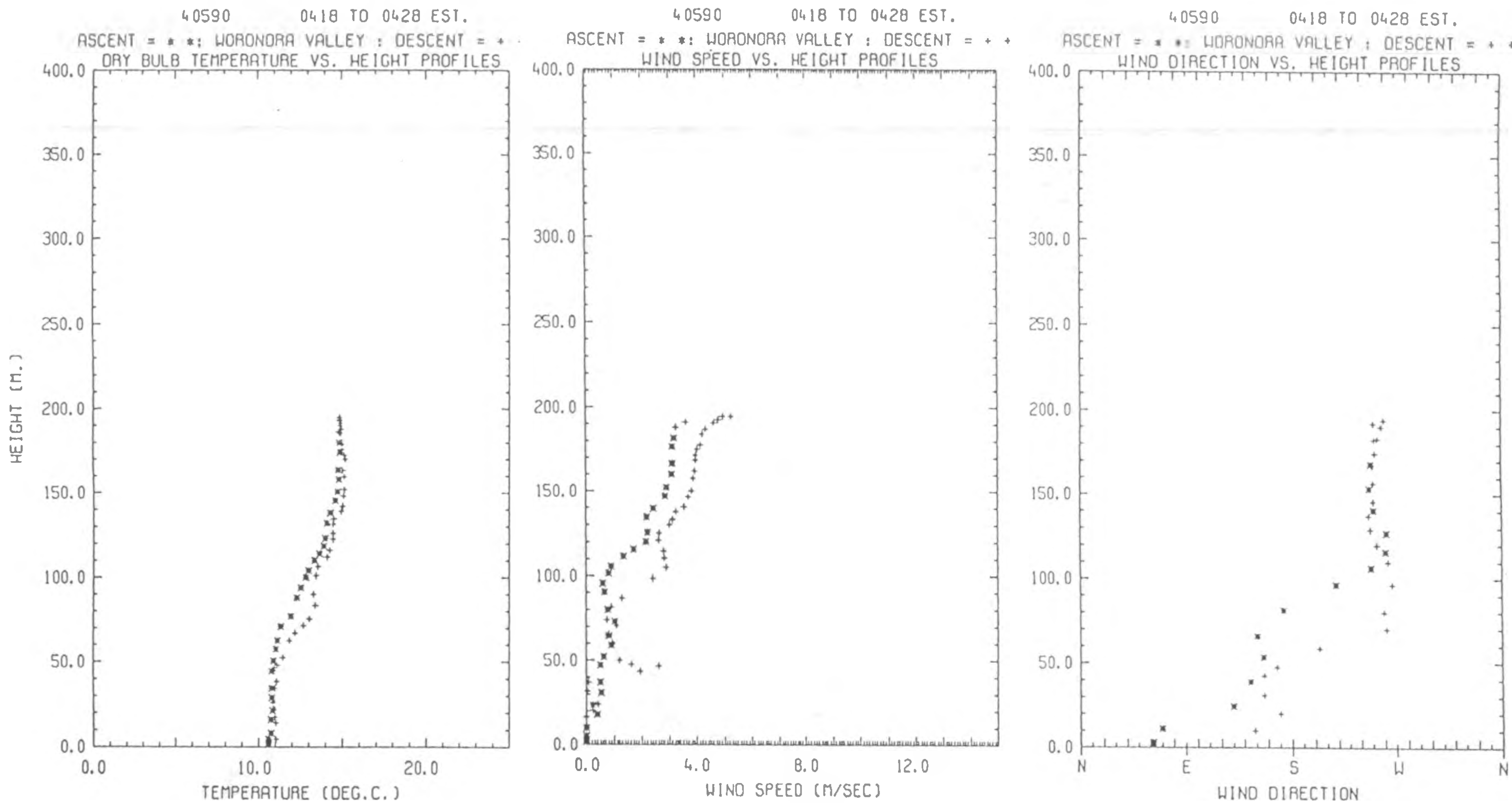


Figure 6.1 Temperature, wind speed and wind direction profiles in the Woronora River Valley, 4 May 1990 (Clark, 1990)

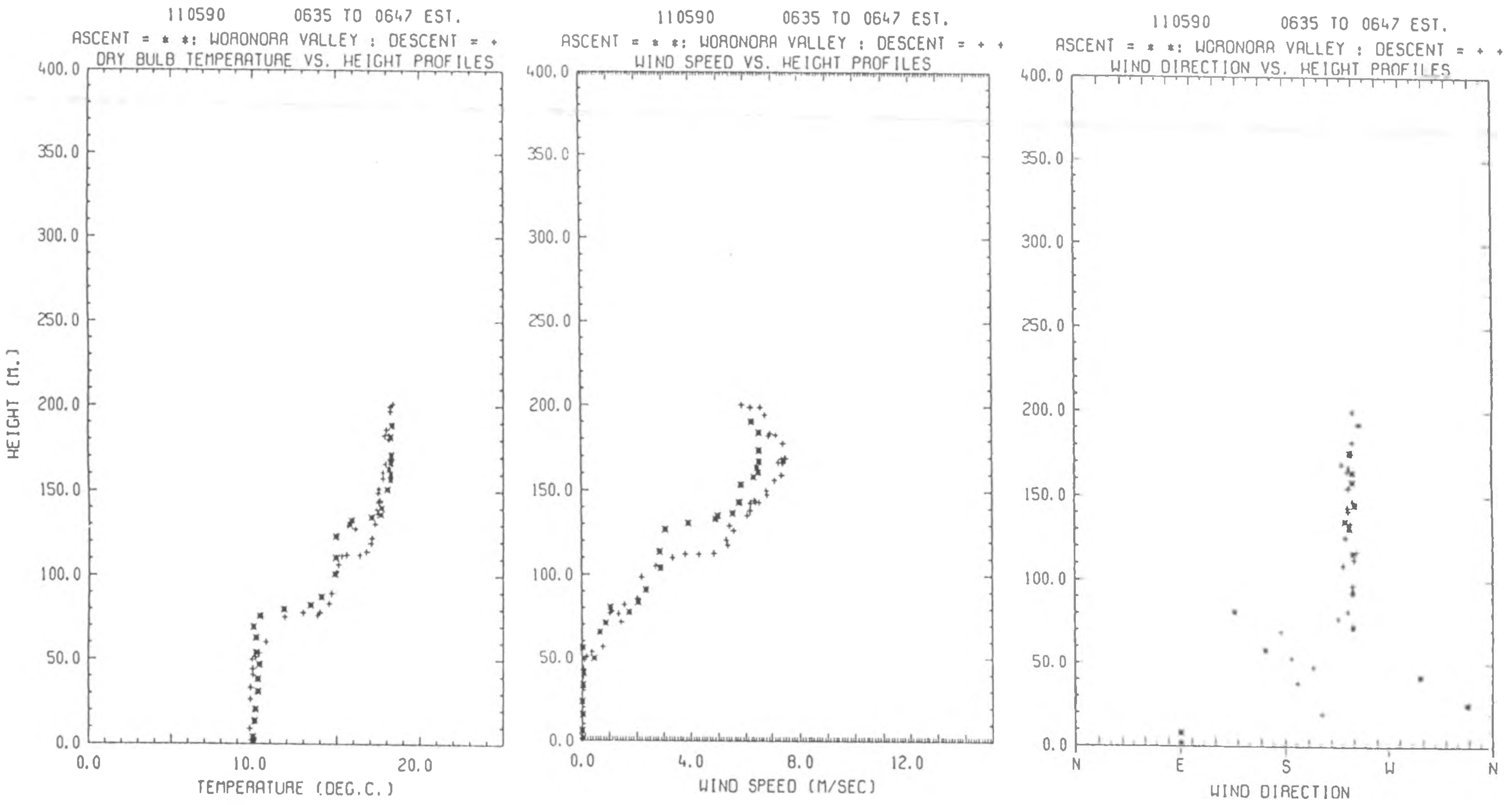


Figure 6.2 Temperature, wind speed and wind direction profiles in the Woronora River Valley, 11 May 1990 (Clark, 1990)

winds within the valley, which then increase sharply with height within the inversion above the top of the valley.

A similar situation was observed on 11 May 1990, as illustrated by the data in *Table 6.2* and the profiles plotted in *Figure 6.2*. This series of observations commenced at 0416 and continued until 0951. *Table 6.2* shows that temperature within the valley were more than 3 degrees colder than the 10 metre air temperature at Lucas heights, whilst the 49 metre Lucas Heights temperatures were up to 6 degrees warmer than the air within the valley. The temperature profile for 0635, which was made when temperatures were close to minimum, show an isothermal stable layer of air within the valley and a strong inversion above, Wind speeds measured at the same time were almost calm within the valley, but again, increased rapidly with height within the inversion above the valley.

These profiles illustrate the situation likely to exist in the vicinity of Holsworthy Option B, where the depth of the Lake Woronora Catchment, immediately west of Holsworthy Option B is between 100 and 130 metres, and therefore the same order of magnitude as the depth of the Woronora River Valley where the measurements described above were made.

Except for the situation, where some near-surface emissions from Holsworthy South initially move east into the lake Woronora catchment, but are isolated from the lake below by the accumulation of air draining down sloping topography within the catchment, near surface emissions from Holsworthy Option B trapped within a ground-based inversion and moving towards the east, will pass over the top of the catchment, as illustrated by the temperature profiles from the Woronora River Valley in *Figures 6.1* and 6.2.

6.3.3 INTERACTION BETWEEN REGIONAL AND LOCAL EMISSIONS - HOLSWORTHY OPTION B

The nearest air quality monitoring station to Holsworthy South is the Environment Protection Authority station at Appin/Wilton. Whilst measurements started there only recently, the data suggest that the contribution of urban emissions to air quality in this region of Sydney is low. For example, concentrations of total oxides of nitrogen are very low (*Figure 5.16a)*, and lead levels measured at Wilton in the Aerosol Sampling Project were the lowest in the Sydney Basin (*Figure 5.11*). Since these emissions will be trapped close to the surface during stable conditions at night, and there is likely to be better ventilation and dilution on the higher ground in the vicinity of Holsworthy Option B, it is not expected that urban, non-photochemical smog pollution, will contribute to air quality levels at Holsworthy Option B.

6.3.4 SURFACE MIXING DEPTHS - IMPACT ON NEAR SURFACE AND ELEVATED EMISSIONS - HOLSWORTHY OPTION B

The structure of the daytime mixing depth is expected to be similar to that observed at Holsworthy Option A. In the absence of any onsite measurements, the conservative approach would be to assume that the growth of the surface mixing layer after sunrise, would be similar to that observed at Lucas Heights. Thus, the dispersion of near-surface and elevated emissions would be similar to Holsworthy Option A. In the morning, this approach might slightly underestimate the time for any ground-based inversions to breakdown after sunrise, because it is likely that drainage flows and radiation inversions will be shallower at Holsworthy Option B because of the increase in elevation at this site. Hence, near surface emissions may well be dispersed slightly earlier.

However, because drainage flows may well be shallower at this higher elevation, and thus the depth of the ground-based inversion within the flow would then be lower, inversions at Holsworthy Option B might break up slightly sooner than at Holsworthy Option A, hence dispersing near-surface and elevated inversions earlier.

6.3.5 METEOROLOGY AND PHOTOCHEMICAL SMOG - HOLSWORTHY OPTION B

If the trajectory of the air within sea breezes is similar at Holsworthy Option B to Holsworthy Option A, then it is possible that ozone concentrations at this southern airport site might be lower, since the source regions for this air is likely to have originated south of Botany Bay. However, as illustrated by the measurements of ozone at Wilton (Douglas Park) on 10 February 1994 (*Figure 5.4a*), high concentrations of ozone were measured in east to east-north-east winds, which would have carried it across the general region of Holsworthy Option B. Therefore at present, until the NSW Environment Protection Authority data are examined in more detail it is not possible to comment about the levels of photochemical smog expected to be measured at Holsworthy Option B, or properly comment on the impact of near-surface and elevated emissions on photochemical smog concentrations downwind.

CHAPTER 7 METEOROLOGY - RECOMMENDATIONS AND LIMITATIONS

The purpose of this chapter is to discuss what meteorological data were available at the time of preparing the Second Sydney Airport EIS. Special attention will be given to clarifying the lack of suitable data in the vicinity of each airport site; the impact of limitations on the availability suitable measurements to assess runway usage; noise impact assessment, and modelling local air pollution dispersion. This section will also consider the impact of any gaps and/or discrepancies found in the available data which have hampered the assessment of local and regional air quality, and the impact of near-surface and limited discussion about the impact of near-surface and elevated emissions from each airport site on local and regional air quality.

This section on limitations is followed by a series of recommendations which this consultant believes are required to provide necessary information relating to assessment of airport operations, and a more comprehensive understanding about the impact of near-surface and elevated emissions from each airport site, on local and regional air quality.

7.1 BADGERYS CREEK

7.1.1 LIMITATIONS OF METEOROLOGICAL DATA AND THEIR IMPLICATIONS FOR THE ASSESSMENT AT BADGERYS CREEK

The paucity and quality of meteorological data required to properly address the issues of runway usage, noise impacts, air quality modelling, linkages between meteorology and existing air quality, and the impact of meteorology on the dispersion of near-surface and elevated emissions has been discussed elsewhere in this report.

The previous Draft EIS for the Second Sydney Airport at Badgerys Creek, (Kinhill, 1985) contained little information about meteorology in the vicinity of Badgerys Creek, and it is surprising that no recommendations for an on-going program of meteorological measurements were made. Even if these measurements had been restricted to information on the vertical structure of wind and temperature in the lowest 30 metres to 50 metres of the atmosphere, together with measurements of rainfall, many of the problems experienced in assessing meteorological conditions at Badgerys Creek for the purpose of this Draft EIS for the Second Sydney Airport would have been avoided.

The assessment of wind conditions at Badgerys Creek has been limited, as Macquarie Research was not aware, at the start of work for the Second Sydney Airport Draft EIS, of the existence of wind measurements made by the Department of Aviation as part of the Second Sydney Airport Site Selection Programme (Kinhill Stearns, 1985). There is no direct reference to the existence of these data in the Kinhill Stearns (1985) report, and it is surprising that these measurements were not used to describe wind conditions at Badgerys Creek. Furthermore, this information has still not been obtained which is unfortunate, since these measurements, in conjunction with the Macquarie University records could have been used to examine the longer term trends of winds at this location

The Department of Aviation wind measurements will probably not prove very useful for obtaining statistics about the frequency of cold air drainage flows in the vicinity of Badgerys Creek, since the Dines wind recorder used to measure these data has a high stalling speed and light winds are not recorded (Potts, 1997). The high stalling speed of this instrument results in a high percentage frequency of calms being recorded, which are often unrepresentative of the actual winds conditions in a region, (Hyde et al., 1980).

The data selected for the assessment of runway usage, noise impact assessment, air quality modelling and the overall assessment of meteorology at Badgerys Creek, were recorded at Badgerys Creek between 1990 and 1992, as part of an on-going program aimed at assessing the characteristics of near-surface flows in the Sydney Basin. The instrument located at Badgerys Creek was installed during the Pilot Study (Hyde and Johnson, 1990), was part of a network of Lambrecht Mechanical wind recorders located throughout western Sydney in 1990.

This particular type of instrument records values of wind run and instantaneous wind direction on a chart inside the wind recorder. Hourly average values of wind speed and direction are obtained by digitising these charts. The measurements obtained in this process, cannot be considered as accurate as those obtained by electronically recorded values of wind speed and direction, and in normal circumstances the use of this type of wind data would not be considered suitable for assessing meterological conditions as part of the site selection process for a major airport. However, as mentioned previously, in the absence of any other suitable data at the commencement of work for the Second Sydney Airport Draft EIS, there was no alternative but to use the data measured at Badgerys Creek by Macquarie University.

These data from the Macquarie University wind recorder at Badgerys Creek do not provide the 10 minute average wind speed and direction measurements required for the impact of noise assessment at Badgerys Creek, since the instrument measures wind run and not instantaneous wind speed and there is no information about wind gusts. Furthermore, the current digitising program does not provide information about the standard deviation wind direction which can assist in compiling meteorological files for modelling the dispersion of near surface and elevated emissions from the airport.

Apart from the lack of high quality wind measurements at Badgerys Creek, no short term measurements of rainfall were available close to Badgerys Creek to assist in the calculations of runway usage and associated noise impact assessment. Rainfall data from Warragamba Dam and West Hoxton was obtained from Sydney Water, and for periods when these data were missing measurements from Bankstown had to be used.

The other important meteorological information that was not available for the assessment of meteorological conditions in the vicinity of Badgerys Creek was information about the vertical structure of winds and temperature above the Hawkesbury Basin. These data are essential to assess the stability of the atmosphere both near the surface and in the lowest 1000 metres. Therefore, statistics on inversion depths, strength and frequency of occurrence are not available to identify situations where the vertical dispersion of near-surface and elevated emissions could be limited by inversions during the night, and by elevated inversions the following morning during the deepening of the surface mixing layer.

Some limited measurements of the vertical structure of the lower atmosphere in western Sydney have been made by the NSW Environment Protection Authority and by Macquarie University, which were used to identify possible adverse metrological conditions which could inhibit the vertical dispersion of emissions from Badgerys Creek, but these measurements do not provide the basis for a proper assessment of the vertical structure of winds and temperatures above Badgerys Creek.

Measurements made by Loewe (1947) between 1937 and 1943 provide some information about the vertical structure of temperature in western Sydney, but because the ascents were made only once day, there is no information about the inversion structure overnight, the increase in mixing depth the following day, or the presence of elevated inversion that could be present above the Hawkesbury Basin during the day, and continue to inhibit the vertical dispersion of emissions from Badgerys Creek.

The other vital measurements that are missing, are measurements of the vertical structure of winds above Badgerys Creek, their variation in strength and direction with time, especially during the night and after sunrise, during the breakdown of any overnight ground-based inversion. On the basis of the limited amount of observational data in western Sydney, it is believed that a complex structure of nocturnal winds can be present above the Hawkesbury Basin. Hence the absence of comprehensive information about the strength and directions of these winds within these flows overnight and the following morning, makes it difficult to assess the contribution of these winds to the dispersion of elevated emissions at night, and the dispersion and dilution of near-surface and elevated emissions from Badgerys Creek the following morning.

The few nighttime observations of wind available above the Hawkesbury Basin, and the measurements of winds at Winmalee just inland from the lower Blue Mountains Escarpment, show that winds in the lowest 100 metres to 300 metres above the surface of the Hawkesbury Basin may be flowing towards the north as part of a combination of local and regional drainage flows, but above this surface flow, winds may be from the north. During the cooler months of the year it is thought that these northerly winds observed at Winmalee, may contribute to the deep ground-based inversions that have been observed in western Sydney.

The absence of vertical winds in the vicinity of Badgerys Creek also makes it very difficult at present, to determine possible interaction between drainage flows observed at the surface at Badgerys Creek, and air flowing north along South Creek Valley. South Creek Drainage flow occurs partly as a result of local down-slope flow from sloping ground in the Valley. However, a major contribution to flow along South Creek Valley, occurs as a result of air flowing across the top of the Camden Basin in the vicinity of Oran Park, which is then steered by topography along South Creek Valley. There is currently no information about the depth or horizontal extent of this flow along the Valley which makes it impossible to determine whether air within a drainage flow at Badgerys Creek, becomes incorporated into this northward flowing air, or when nocturnal wind at Badgerys Creek are more westerly, whether air flowing over Badgerys Creek passes over the top of South Creek Drainage flow, and across the Blacktown ridge into the Liverpool Basin.

It is unfortunate, that at the start of the *Metropolitan Air Quality Study*, the NSW Environment Protection Authority decided not to proceed with the installation of vertical sounding equipment, since if one system had been installed in western Sydney, measurements from this equipment would have provided valuable information about the vertical structure of wind and temperature necessary for a proper assessment of meteorological conditions associated with airport operations at Badgerys Creek.

7.1.2 LIMITATIONS OF METEOROLOGICAL DATA - IMPLICATIONS FOR AIR QUALITY IN THE VICINITY OF BADGERYS CREEK

The Second Sydney Airport Site Selection Programme Draft EIS, (Kinhill Stearn, 1985) commented on regional air quality in the Sydney Basin, and the inland transport of photochemical smog within the sea breeze. However, if that report had also contained a recommendation for a program of air quality measurements at Badgerys Creek, a longer term record of air quality would have been available for the region. These measurements, in conjunction with on-site meterological records, would have provided valuable information about linkages between meteorology and air quality in the vicinity of the airport.

Until the commencement of the *Metropolitan Air Quality Study*, in 1993, no continuous monitoring of air quality in western Sydney had been made by the NSW Environment Protection Authority, and the only air quality measurements available were those from the industry monitoring sites at Campbelltown and Camden. At the beginning of the *Metropolitan Air Quality Study*, the NSW Environment Protection Authority installed air quality monitoring stations at St Marys, Bringelly and Blacktown and upgraded the station at Liverpool. Hence, there is a now a good network of air quality measurements in the vicinity of Badgerys Creek. However, as mentioned elsewhere in this report, it was decided to return the 1994/95 meteorological and air quality data to the NSW Environment Protection Authority, and it is not possible at present, to comment on the existing air quality in the vicinity of Badgerys Creek, or comment on the observed linkages between meteorology and air quality at these monitoring stations.

These matters will be addressed once the 1996 air quality monitoring data becomes available. In addition, because the NSW Environment Protection Authority measures vertical winds and temperatures at Liverpool, these measurements, in conjunction with wind and temperature data from Bringelly and St Marys, and meteorological measurements from the Bureau of Meteorology at Badgerys Creek which commenced in 1996, may be able to provide some estimates about the frequency of ground based inversions in the vicinity of Badgerys Creek and more information about low level wind flow at Badgerys Creek and along South Creek Valley.

In the absence of near-surface measurements of wind and temperature, no estimate of the frequency of time that near-surface inversions are present at Badgerys Creek, or how these vary seasonally and with time during the evening is possible. Consequently, it is difficult to determine the impact of near surface emissions trapped within a stable layer, on residential areas downwind of the airport. As discussed in Chapter 6, it is thought unlikely that near-surface emissions from Badgerys Creek would become trapped within the Camden Basin, but it is impossible to say unequivocally this could never occur.

Likewise, informed comment concerning the locations downwind from an airport at Badgerys Creek, which might be affected by near-surface emissions and odours carried towards them at night cannot be stated, since the interaction between nocturnal winds observed at Badgerys Creek, and air flowing down South Creek Valley is unknown. However, given the close proximity of Luddenham to the Badgerys Creek sites, it is inevitable that these areas so close to the boundary of the Badgerys Creek options will be affected by odours and other emissions.

Another major area of uncertainty is the situation regarding photochemical smog in western Sydney. Whilst it is common knowledge that on some occasions, moderate to high concentrations are observed in western Sydney as a result of inland transport of emissions from eastern Sydney, it is less well known that similarly high concentrations are occasionally observed during the morning and afternoon before the arrival of the sea breeze. These pre-sea breeze ozone events were discussed in Chapter 5, but at present nothing is known about the vertical structure of winds and temperatures associated with these episodes of morning and regional ozone, nor is there any information about the source of the precursors from which this ozone has formed.

The wind directions during periods of morning and regional ozone are usually from the north or north-north-east. As a result of modelling undertaken for the *Metropolitan Air Quality Study*, as reported by Hurley and Manins in Hyde et al., 1997, a number of scenarios about the possible source of morning and regional ozone emerged, including: the vertical and horizontal recirculation of Sydney's emissions overnight; and inter-regional transport from the Upper Hunter Valley, Newcastle and the Central Coast. However, it has to be remembered that these model results, while plausible, are based on the results of modelling for a few carefully selected days, and that currently, none of these hypotheses have been verified and validated by a carefully designed program of measurements.

The NSW Environment Protection Authority's decision not to install remote sounding equipment in western Sydney for the *Metropolitan Air Quality Study*, and instead conduct a much less reliable campaigns of field measurements, has resulted in the situation where the meteorological situations associated with periods of morning and regional ozone are not understood, and urban airshed model developed for this study has not been properly validated, because of the absence of vertical measurements of wind and temperature in western Sydney.

These, as yet unexplained episodes of morning and regional ozone, have serious implications for future development in western Sydney, since the source of the precursors forming this ozone is unknown. In addition, the current lack of information about the vertical structure of winds and temperature in the lower atmosphere during these events, means that at present, it is not possible to provide reliable estimates about the impact of near-surface and elevated emissions from Badgerys Creek on photochemical smog concentrations downwind of the airport during these non-sea breeze ozone events.

7.1.3 RECOMMENDATIONS

The most urgent need is for a comprehensive program measuring the vertical structure of winds and temperature in the vicinity of the Badgerys Creek airport site. These measurements are required to obtain information about: the overall structure of winds and temperatures in the lower atmosphere; the strengths and depth of ground-based and elevated inversions at night; and the development of the surface mixing layer the following morning. This information is required for the operation of the airport and would also allow the impact of near surface and elevated emissions on air quality downwind of the airport to be properly assessed.

To obtain measurements of heights between one and two kilometres above the surface it is recommended that a RASS/Radar system be employed in conjunction with an acoustic wind profiling system. For example, wind and temperature could be measured over height intervals of about 60 to 120 metres with averaging periods of half an hour, using one of the currently available commercial systems on the market, and more detailed information about the structure of winds in the lowest few hundred metres could be obtained using an appropriate acoustic sounding system.

It is clear from the limited number of wind and temperature profiles that are available in western Sydney, and from the analysis of winds from Winmalee in the lower Blue Mountains, that a complex structure of winds can be present above the Hawkesbury Basin at night. In the lowest 100 metres to 300 metres above the surface, a well defined south to south-south-west drainage flow may be present, whilst above this, the wind can be flowing in the opposite direction. Acoustic profiling systems are capable of measuring accurate wind speeds and directions over height intervals between 15 metres and 30 metres, which would allow more information about the structure of vertical winds to be obtained, especially during periods of drainage flows at night.

The lowest measurement level for say a 915 megahertz RASS/Radar system is around 60 to 120 metres above the surface, so it recommended that a 100 metre meteorological tower be installed close-by, to measure the structure and temperature between the surface and 100 metres in more detail. To provide data on atmospheric stability it is recommended that at some levels on this mast, wind speed and direction should also be measured. In addition to these vertical measurements of wind and temperature, it would be expected that other meteorological parameters such as rainfall, solar and net (allwave) radiation would also be measured.

It is important that the location of the equipment recommended above, is selected on the basis of the need to resolve a number of issues concerning the dispersion of near-surface and elevated emissions from the airport, as well as meeting the requirement to be able to use the measurements from these systems to optimise the operation of an airport at Badgerys Creek. It is this consultants opinion, that the optimum site for the RASS/Radar, acoustic wind profiler and the meteorological tower would be halfway between Badgerys Creek Airport site and the Blacktown Ridge to the east. This would locate it in the vicinity of South Creek Valley, which is one of the key regions where detailed information about the vertical structure of wind and temperature in the lowest 100 metres is required in order to assess areas downwind of the airport that could be affected by emissions and odours at night. At the same time, equipment installed at this location would be close enough to the Badgerys Creek airport site to provide the routine upper level information required for the operation of the airport. In addition, data recorded by these systems would provide almost on-site information about the vertical structure of the atmosphere in the vicinity of the NSW Environment Protection Authority's Bringelly air quality monitoring station, and allow more informed comment to be made about linkages between air quality and meteorology in the vicinity of Badgerys Creek.

In addition to the basic meteorological facility in South Creek Valley, it is recommended that a 50 metre meteorological tower be installed on the airport site to assist in the interpretation of the microclimate near the surface of the airport, so that the downwind movement of near-surface emissions from the airport under stable wind conditions can be properly assessed. Measurements at this location could be integrated into those being made by the Bureau of Meteorology, so long as it was possible to combine their specific meteorological measurements with those requires to assess the microclimate at the airport in order to properly assess the impact of near surface emissions from the airport on residential areas downwind.

It is also recommended that a 30 to 50 metre meteorological tower measuring wind and temperature be installed on the Blacktown Ridge which separates the Hawkesbury Basin from the Liverpool Basin to the east. These measurements in conjunction with data recorded at Badgerys Creek and South Creek Valley would provide information about possible transport of airport emissions towards the east, and the corresponding movement of near surface emissions trapped in stable layers in the Liverpool Basin late afternoon within sea breezes or weak onshore synoptic winds.

To supplement these meteorological measurements, it is recommended that a comprehensive air quality monitoring station be installed on top of the Blacktown Ridge for the minimum of a year, adjacent to the meteorological tower, to assess inter-regional transport of air pollutant from the Liverpool Basin into the Hawkesbury Basin and vice versa.

Presently, the air quality monitoring stations at Bringelly and St Marys do not measure carbon monoxide. It is recommended that the NSW Environment Protection Authority be approached to install monitors to measure carbon monoxide at both monitoring stations.

At present it is difficult to be certain which direction the near-surface emissions from Badgerys Creek will be carried under stable conditions at night. The possible impact of emissions and odours from Badgerys Creek on residential areas north and north-north-east of the airport during periods of nighttime flow is uncertain. It is thought that emissions trapped within a stable layer late afternoon and early evening when winds are from the north to north-east direction would not become trapped within the Camden Basin. However, it is not possible to state unequivocally that this could not occur, and it is recommended that a series of tracer experiments be carried out during the evening and overnight under stable atmospheric conditions in order to provide better estimates about the possible impact of near-surface emissions and odours on residential areas downwind of Badgerys Creek.

As the NSW Environment Protection Authority measures a comprehensive range of air pollutant at Bringelly and St Marys, the benefit of a similar monitoring facility at Bringelly would appear to be limited. However, in view of the concern about photochemical smog in western Sydney, and the current uncertainty about the sources of precursors leading to morning and regional ozone before the arrival of the sea breeze, it is recommended that an AIRTRAK 2100 series monitoring system be installed at Badgerys Creek. This equipment is specially designed to measure a range of photochemical smog parameters, and measurements from this system, combined with data on the vertical structure of winds and temperature, and the speciation of reactive organic hydrocarbons during episodes of photochemical smog, would allow the impact of near-surface and elevated emissions from an airport at Badgerys Creek on photochemical smog concentrations downwind to be evaluated more comprehensively. The measurements might also allow a better understanding of the source of the precursors that result in episodes of non-sea breeze ozone in western Sydney.

7.2 HOLSWORTHY OPTION A

7.2.1 LIMITATIONS OF METEOROLOGY - IMPLICATIONS FOR THE ASSESSMENT AT HOLSWORTHY OPTION A

Although on-site measurements are always preferable, in view of the close proximity of Holsworthy Option A to Lucas Heights, the winds from that station were considered representative and indicative of near surface meteorological conditions likely to be observed at the northern airport site.

Whilst sea breezes and synoptic winds are expected to be similar to those measured at Lucas Heights, and no difference in the frequency of inversions is expected, there may be some differences in the frequency of low level wind directions measured at night under stable conditions. The topography at Holsworthy North slopes towards the north, and the frequency of shallow stable winds from the south and south-south-west direction may be higher that observed at Lucas Heights.

7.2.2 LIMITATIONS OF METEOROLOGICAL DATA - IMPLICATIONS FOR AIR QUALITY IN THE VICINITY OF HOLSWORTHY OPTION A

The main limitation is the current lack of information about the vertical structure of winds and temperature above Holsworthy Option A, and the lack of air quality monitoring close-by. There are a number of air quality monitoring stations at lower elevations, for example at Woolooware, Liverpool and Campbelltown where ozone and other parameters are measured, but no monitoring stations closely at a similar elevation in the vicinity of Holsworthy Option A.

On the basis of some limited analysis of wind directions associated with photochemical smog events recorded at Campbelltown, it appears that the trajectory of air containing this ozone is likely to have originated in the Botany Bay region of Sydney, and been carried across the general region of Holsworthy Option A. Hence, the lack of suitable air quality and meteorological data at this airport site makes it difficult to properly evaluate the contribution of near surface and elevated emissions from Holsworthy Option A on photochemical smog levels downwind.

The other limitation is concerned with the lack of on-site low-level measurements of wind and temperature, required to properly assess the impact of near surface emissions on residential areas to the east and north east, under stable conditions at night. As mentioned above, it is possible that the frequency of highly stable, shallow south and south-south-west local drainage flows might be higher at Holsworthy Option A than at Lucas Heights. In this situation, a higher proportion of the near surface emissions would be carried toward the north and become entrained within drainage winds above the Liverpool Basin.

Regardless of whether these changes take place or not, one of the main areas of uncertainty about air quality at Holsworthy Option A, is the overall dispersion of near surface emissions trapped within stable nocturnal west to southerly winds. The data from Lucas Heights show both wind direction and wind speeds changing significantly on some occasions between 10 and 40 metres, and it is not clear what the combined affect of these two separate shears would have on the dispersion of these near surface emissions and their possible impact on residential areas downwind of the airport.

7.2.3 RECOMMENDATIONS

If Holsworthy Option A was selected as the site for the Second Sydney Airport, it would be necessary to measure the vertical structure of winds and temperature in the lowest 1 kilometre to 2 kilometres of the atmosphere. These measurements are required for the operation of the airport, and to obtain information necessary to properly evaluate the impact of near surface and ground level emissions on air quality in the region. Information is required about: the structure of winds and temperature in the lower atmosphere; the strength and depth of ground based and elevated inversions at night; and the development of the surface mixing layer the following morning.

To obtain the necessary measurements of wind and temperature to heights of between one kilometre and two kilometres above the surface it is recommended that at RASS/Radar system be employed in conjunction with an acoustic wind profiling system. The RASS/Radar would provide measurements of wind and temperature over heights intervals of about 120 metres, whilst the acoustic profiling system would provide more detailed information about the structure of winds in the lowest few hundred metres and would be particularly useful to provide information about the heights of shallow sea breezes and cold air drainage flows.

In addition to be vertical measurements of wind and temperature it would be expected that other meteorological parameters such as rainfall, solar, and net (allwave), radiation would also be measured.

Because of the need to understand the impact of near-surface stable layers and inversions, which will trap near-surface emissions from an airport at Holsworthy Option A, it is recommended that a meteorological tower between 50 metres and 100 metres high be located adjacent to the other profiling systems. Wind and temperature measurements would need to be made at several levels on this mast so that the down-wind transport and dispersion of near-surface emissions from Holsworthy Option A and their impact on residential areas down-wind of the airport could be assessed in more detail.

Because of the large changes in wind speed and wind direction that are observed at Lucas Heights and which could also be expected to be present at Holsworthy Option A, it is recommended that a series of tracer experiments be carried out during the evening and overnight under stable atmospheric conditions in order to provide a better understanding of the possible impact of these near-surface emissions and odours on residential areas down-wind of Holsworthy Option A.

It is recommended that an AIRTRAK 2100 series photochemical smog monitor be located at Holsworthy Option A, so that the contribution of near surface and elevated emissions from the airport on ozone concentrations downwind can be properly evaluated. Other, standard air quality monitoring may need to be located at Holsworthy Option A, depending on the outcome of any air quality management plan developed for the airport.

7.3 HOLSWORTHY OPTION B

7.3.1 LIMITATIONS OF METEOROLOGICAL DATA AND THEIR IMPLICATIONS FOR THE ASSESSMENT AT HOLSWORTHY OPTION B

Holsworthy Option B is located approximately 15 kilometres south-south-west of Lucas Heights. The elevation of the site is between 240 and 280 metres, and is therefore approximately 100 metres higher than the base of the meterological tower at Lucas Heights. Therefore, unlike the situation at Holsworthy Option B, which is only a few kilometres away from the source of meteorological measurements at Lucas Heights, it is inevitable that there will be some differences in meteorological conditions between these two locations. However, in the absence of any on-site measurements, or other sources of meteorological data close by, for the purpose of the Second Sydney Airport it was necessary to use the data from Lucas Heights.

During the daytime when synoptic winds are present at the surface, the difference in winds between Holsworthy Option B and Lucas Heights may not be very different, although some increase in wind speeds could be expected because of the increase in elevation.

The major areas of uncertainty are: the frequency of ground-based stable layers and inversions at night; the frequency of local and regional drainage winds and predominant direction of these flows; the heights and frequency of ground based inversions; and the frequency of occurrence and the structure of sea breezes at this higher elevation.

There is no source of information close-by, which allows any informed comment to be made about the affect of the increase in elevation on sea breezes at Holsworthy Option B, although some estimate for summertime can be made on the basis of data analysed for the Pilot Study, Hyde and Johnson, 1990. This showed that the frequency of sea breezes observed 1980 at Wilton 17 kilometres south-west from Holsworthy Option B in 1980 was 33 percent compared with 58 percent recorded at Campbelltown.

The other main differences between meteorological conditions at Lucas Heights and those at Holsworthy Option B, are likely to be the frequency of inversions and cold air drainage flows. It was apparent from a limited series of vertical profiling at Wilton in February 1980, that the depth of drainage flow at that site depended on the speed of the nocturnal drainage wind. If wind speeds within the drainage winds were less than 1.5 metres per second, then the hight of the flow was between 80 to 100 metres, but when wind speeds were between 1.5 and 3.0 metres per second, the depth of the drainage flow was between 180 and 200 metres deep.

Therefore, low drainage flows at Wilton in summer would be unlikely to spill over across the plateau at Holsworthy Option B, but depending on the direction of these drainage flows, deeper south-west flows at Wilton could be observed at Holsworthy Option B. No observations of drainage flow depths have been made at Wilton during the winter months, so there remains a level of uncertainty about the frequency of drainage flows at Holsworthy Option B.

Although, the lack of on-site measurements at Holsworthy Option B, imposes limitations on the reliability of use of Lucas heights data to predict night-time wind conditions at this site, because of its higher elevation, the depth of ground-based inversions within cold air drainage flows would be expected to be lower, and hence the surface mixing layer would break down earlier after sunrise.

7.3.2 LIMITATIONS OF METEOROLOGICAL DATA - IMPLICATIONS FOR AIR QUALITY IN THE VICINITY OF HOLSWORTHY OPTION B

Whilst there are uncertainties about the vertical structures of wind and temperature at this site, situations will arise where ground-based stable layers and inversions result in the trapping of near-surface emissions at Holsworthy Option B. On occasions when wind directions are easterly and the air close to the surface is stable, these emissions will be carried towards the west and could impact on residential areas in the vicinity of Wedderburn. However, in view of the lack of on-site meteorological measurements, it is not possible at present, to estimate with certainty, the percentage of time that these regions could be effected by emissions and odours from Holsworthy Option B.

Under west to south-west stable winds, near-surface emissions from Holsworthy South have the potential to be carried north-east and east into the Lake Woronora catchment area. However as explained in Chapter 6, on the basis of the microclimatic conditions expected within the catchment region, it is thought unlikely that near-surface emissions from Holsworthy Option B would reach the surface of the lake. Whether the assumptions discussed in the previous chapter are valid, can only be determined by a comprehensive investigation of the wind and temperature structure within the Lake Woronora catchment area.

At present there are no air quality measurements on the plateau in the vicinity of Holsworthy Option B, although the NSW Environment Protection Authority currently makes measurements of air quality at Appin 14 kilometres to the south-west and at Bargo 35 kilometres to the southwest, and there is an industry air quality monitoring station at Campbelltown. Because of its high elevation, local air quality in the vicinity of Holsworthy Option B is most unlikely to be affected by pollutants other than photochemical smog carried towards it from urban areas to the north and north-east. In the absence of any knowledge about the height of sea breezes and the wind and temperature structure within them, it is difficult at preset, to properly assess the impact of impact of near-surface and elevated emissions on concentrations of photochemical smog down-wind of Holsworthy Option B.

7.3.3 RECOMMENDATIONS

If Holsworthy Option B was selected as the site for the Second Sydney Airport, it would be necessary to measure the vertical structure of winds and temperature in the lowest 1 kilometre to 2 kilometres of the atmosphere. These measurements are required for the normal operation of the airport, and to properly assess the impact of near-surface and elevated emissions down wind from the airport. Information is required about: the structure of winds and temperature in the lower atmosphere; the strength and depth of ground based and elevated inversions at night; and the development of the surface mixing layer the following morning.

To obtain the necessary measurements of wind and temperature to heights of between one kilometre and two kilometres above the surface it is recommended that at RASS/Radar system be employed in conjunction with an acoustic wind profiling system. The RASS/Radar system would provide measurements of wind and temperature over heights of about 120 metres, whilst the acoustic profiling system would provide more detailed information about the structure of winds in the last few hundred metres and would be particularly useful to provide information about the heights of shallow sea breezes and cold air drainage flows.

In addition to be vertical measurements of wind and temperature it would be expected that other meteorological parameters such as rainfall, solar, and net (allwave) radiation would also be measured.

Because of the need to understand the impact of near-surface stable layers and inversions, which will trap near-surface emissions from an airport at Holsworthy Option B, it is recommended that a meteorological tower between 50 metres and 100 metres high be located adjacent to the other profiling systems. There would need to be wind and temperature measurements made at several levels on this mast so that the down-wind transport and dispersion of near-surface emissions from Holsworthy Option B, and their potential impact on residential areas to the west and north-west of the airport could be assessed in more detail.

It is recommended that a series of tracer experiments be carried out during the evening and overnight under stable atmospheric conditions, in order to provide a better understanding of the possible impact of these near-surface emissions and odours on residential areas down-wind of Holsworthy Option B, especially the transport of emissions and odours into the Wedderburn region 6 kilometres to the west.

It is recommended that an AIRTRAK 2100 series monitoring system be installed at Holsworthy Option B to measure the characteristics of photochemical smog at this location. Other standard monitoring equipment may be required, depending on the outcome of any air quality management plan developed for Holsworthy Option B.

It is recommended that a combination of micro-meteorological measurements and tracer studies should be carried out at Holsworthy Option B and in the Woronora Catchment to assess the possible transport of near surface emissions into the catchment under stable conditions at night. A possible approach to understanding interaction between the microclimate within the catchment and stable air above, could be to install a tall meteorological tower within the catchment to examine variations in the microclimate above the lake. The tower would need to be instrumented at several levels to measures winds, temperature and atmospheric humidity. A possible location for the tower might be on the spur of land where the two branches of the lake converge.

It would be prudent as part of the tracer and micro-meteorological experiments to install one or more lower meteorological towers at locations where air accumulating above the lake overnight, could spill out of the catchment and flow down-slope towards the north.

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Appendix 1

Analysis of Winds at Lucas Heights

Appendix 1
Analysis of Wind and Lucas Heights

Introduction

The closest source of comprehensive meterological data to the Holsworthy Military Reserve are the measurements made at the Australian Nuclear Science and Technology Organisation (ANSTO) at Lucas Heights. This organisation maintains a 49 metre tower at Lucas Heights and makes measurements of wind speed at the 10 metre and 49 metre levels. Temperatures are measured at heights of 2, 10, 15, 30, and 49 metres on the mast. Measurements have been made at Lucas Heights since 1975. The system was ungraded in 1991, and values are now recorded electronically and averaged over 15 minute periods.

The Lucas Heights meterological facility is about 5 kilometres west-south-west from Holsworthy Option A. The elevation at the base of the meterological tower is about 150 metres, compared with 150 to 190 metres at Holsworthy Option A. Holsworthy Option B is 15 kilometres south-south-west of Lucas Heights, and the elevation there is between 230 and 280 metres.

At the start of work for the Second Sydney Airport Draft EIS, a number of questions about the use of the Lucas Heights data needed to be resolved. These included:

- the possibility that the wind speeds at 10 metres were too low, because of possible sheltering affects of buildings and other obstacles in the vicinity of the meteorological tower at Lucas heights;
- whether it would be more appropriate to use the 49 metre winds for runway usage and noise impact assessment at Holsworthy Option B because of the difference in elevation between the two sites; and
- whether an increase in 10 metre wind speeds could be expected as a result air moving off the aerodynamically rougher tree covered surface surrounding the airport, onto the smoother grass covered areas adjacent to the runways.

Factors Governing the Gradient of Wind Speed in the Lower Atmosphere

To address this issue it is necessary to consider the parameters that affect the decrease in wind with height speed close to the ground. For the situation where the wind is flowing over a horizontally homogeneous surface, there are well established and accepted relationships in the micro-meteorological literature to describe the factors that influence the decrease in wind speed with height, (Ayra, 1988; Stull, 1988). These include:

- the roughness of the underlying surface, and the height of the individual elements that contribute to this roughness;

- the overall strength of the wind; and
- the stability of the atmosphere.

The roughness of the underlying surface, exerts a shearing stress (τ) on the air flowing over the surface, and governs the rate at which the wind speed decreases with height. Although the wind might be strong some distance above the surface, close to the ground the wind speed has to fall to zero, and a scaling parameter called the roughness length is used (z_0) to describe the theoretical height where the wind speed becomes zero. For taller roughness elements, such as buildings or trees, it is necessary to take account affect the increase in height by introducing a second scaling parameter called the zeroplane displacement length (d), which effectively moves the height of ground surface up a certain distance, to take account of the affect of the increased height on of the roughness elements on the height where theoretically, the wind speed should become zero.

The size of the shearing stress, the friction velocity and the zeroplane displacement length, can be determined from wind tunnel and observations in the field and there is now a comprehensive body of literature which gives representative values for d and z_0 over different surfaces, (eg. Ayra, 1988; Oke, 1987; Brutseart, 1982). For a horizontally homogeneous surface the change of wind speed with height (du/dz)in the lowest few ten of metres of the atmosphere can be expressed as

$$\frac{du}{dz} = \frac{u_* \ln(z - \frac{d}{z_0})}{k} \phi_m$$

where u_* is a scaling parameter, proportional to the shearing stress, k is von Karman's constant (0.41), and ϕ_m is a correction factor to take account of the stability of the atmosphere.

The gradient of temperature close to the surface also has an affect on the decrease of wind speed with height. Convection during the daytime, assists in the vertical distribution of turbulence generated by the wind flowing over the surface, and results in a slight decrease in the change of wind speed with height, (Thom, 1975).

Conversely, under stable conditions, for example with a ground-based inversion where the temperature increases with height above the surface, the gradient of temperature acts to damp out the atmospheric turbulence and wind speed decreases with height at a faster rate. In between these two conditions is the situation, called neutral, where neither convection or atmospheric stability are influencing the turbulent structure of the wind, and the decrease in height in these circumstances is then governed by the roughness, or shearing stress of the underlying surface. These neutral conditions can occur when there are overcast conditions, or when wind speeds become high enough to counter the affects of convection or stability on the gradient of wind speed close to the ground.

A convenient approach to describing the stability of the atmosphere is to examine the affect convection during the daytime, or the affects of an inversion at night on the gradient of wind speed near the surface, by examining the ratio of these by buoyancy forces to the turbulent energy of the wind to obtain a non-dimensional grouping of parameters called the bulk Richardson Number, (Ri), (eg. Stull, 1988). On the basis of extensive field experiments the stability of the atmosphere can be divided into three broad categories of stability; unstable (Ri < -0.01); neutral ($-0.01 < Ri < +0.01$); and stable (Ri $> +0.01$), Thom (1975).

The Gradient of Wind Speed at Lucas Heights

The change of wind speed with height at Lucas heights was reported by Clark (1983) based on an analysis of approximately two years of measurements comparing wind speeds between 7 and 49 metres. Clark divided the data into three hourly intervals and obtained relationships between the wind speeds at the two heights and the regression equations are plotted in *Figure A1.1*, along with the correlation coefficients. During the daytime when convection could be expected , 1200 and 1500 hours the wind speed at 7 metres was approximately 60 percent of the wind at 49 metres, while at night, say between 0000 to 0300; and between 0300 to 0600 hours when stable conditions would be expected to occur on many occasions, the wind speed at 49 metres was approximately twice the wind speed at 7 metres.

To determine the affect of stability on the gradient of wind at Lucas Heights using the data supplied by ANSTO for the Second Sydney Airport EIS, 15 minute average data measured at 10 metres and 49 metres were plotted against each other as shown in *Figure A1.2a*. The data used for this analysis were the 15-minute average for 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 hours for the period April 1994 to March 1995.

The data plotted in *Figure A1.2a* were then divided into the three classes of stability discussed above; unstable, neutral and stable. The results are plotted in *Figures A1.2b* to *A1.2d*. Considering that the topography in the vicinity of Lucas Heights can hardly be described as homogeneous the linear trend for unstable conditions plotted in *Figure A1.2b* is encouraging. There is slightly more scatter for neutral conditions, but it is clear from the data plotted in *Figure A1.2.d* that a high proportion of the scatter observed in *Figure A1.2a*, occurs as a result of highly variable relationship between the 10 metre and 49 metre wind speeds when conditions are stable.

For unstable conditions, winds at 10 metres are approximately 62.5 percent of the speeds at 49 metres which agrees with the data from Clark (1983) plotted in *Figure A.1.1*. However, when conditions are stable, the speed of the wind at 49 metres can be at least twice as high as the speeds at 10 metres, which illustrates the affect of atmospheric stability on dampening out turbulence and reducing the speed of the wind close to the surface.

Whilst the data in *Figure A1.2.b* show a good relationship between wind speeds at 10 metres and 40 metres, in order to examine the possible influence of buildings and other obstacles on the gradient of wind speed at Lucas Heights, hourly average wind speeds measured between 0800 and 1700 hours in 1995 were divided into four wind direction sectors: NW to NE; NE to SE; SE to SW; and SW to NW, and the results are plotted in *Figure A1.3*. Except for the case where winds were blowing from the northern sector, the relation between the winds at the two heights for the westerly (NW to SW); southerly (SW to SE); and easterly (NE to SE) sectors is surprisingly linear, given the roughness of the surrounding topography. Winds from the northern sector show a high degree of scatter, which suggests that winds from these directions are being affected by topographic or other local affects.

In summary, taking into account the data from Clark (1983), the partition of the data into unstable, neutral and stable categories, and the variation of wind speed with height over four 90 degrees wind direction sectors, apart from the case of the lighter winds from the north, the affect of buildings and other obstacles on the gradient of winds speed with height at Lucas Heights appears to be minimal. On the basis of these analyses, it appears that, apart from northerly winds, the gradient of wind speed between 10 metres and 40 metres observed at Lucas Heights is governed by the large scale roughness of the region and the prevailing atmospheric stability, rather than the affects of buildings and other obstacles in the vicinity of the meterological tower at Lucas heights.

Increase in Wind Speed with Height of Topography

During the course of work for the Second Sydney Airport EIS, it was necessary to decide whether to use the 10 metre or 49 metre wind speeds from Lucas Heights for Holsworthy South, because of the higher elevation at the southern airport option. The topography on the Holsworthy Military Reserve has a slope downwards towards the north and west by about 2 degrees. A number of wind tunnel and field experiments have been conducted to examine the affect on wind speeds of sloping topography (Finnigan, 1988), but almost all these studies have been concerned with isolated hills or ridges with slopes well in excess of the 2 degrees slope in the Holsworthy Military Area, and were not considered relevant to the current problem.

In an attempt to resolve the issue about a possible increase in wind speeds because of the increased elevation at Holsworthy South, wind measurements made by Macquarie University in 1984 near Mount Keira during the Illawarra Sea Breeze Experiment, (Hyde and Prescott, 1984), were compared with wind data measured simultaneously at Lucas Heights. The Mount Keira North anemometer was located in the grounds of the Wollongong Observatory where the elevation is 435 metres above sea level, and is approximately 35 kilometres south-south-east from Lucas Heights. The height of the vegetation in the area was between three and five metres high. In 1984, winds at Lucas Heights were measured at 7 and 49 metres, and the data was extracted from analogue charts to obtain half-hourly average values of wind speed and direction.

In view of the limited time available, the analysis was restricted to 1984. Data from both sites were divided into four seasons:

Summer:	December, January, February
Autumn:	March, April and May
Winter:	June July and August
Spring:	September, October and November,

For each season, the data was further subdivided into 90 degree wind direction sectors:

Northerly:	NW to NE
Easterly:	NE to SE
Southerly:	SE to SW
Westerly:	SW to NW

Each data set was then analysed to extract data for times when the wind was blowing simultaneously from the same sector at each location, and was further divided into day and nighttime periods (Eastern Standard Time):

Day:	0800 to 1700 hours
Night:	1700 to 0800 hours

While this division of day and night does not take into account the marked seasonal changes in the length of daylight throughout the year, it provides a common reference period.

The following analyses were undertaken for 1984:

Lucas Heights (7m)	versus	Mt Keira North (10m)
Lucas Heights (49m)	versus	Mt Keira North (10m)
Lucas Heights (7m)	versus	Lucas heights (49m)
Lucas Heights (10m)	versus	Lucas Heights (49m), using data from 1995.

In 1995 the 10m and 49 wind data at Lucas Heights were recorded electronically and 15-minute average values calculated. These higher quality data were then used to assist in determining relationships between the wind speeds observed at Lucas Heights and Mount Keira,

A selection of the plots showing the comparison between wind speeds at the two locations are given in *Figures A1.4a* and *A1.4b*, for daytime wind conditions for the west and south sectors. The data for 1995 show a high correlation between wind speeds at 10 and 49 metres. The slope of the points for 1995 vary slightly with wind direction and this is to be expected in view of the annual data plotted for different sectors in *Figure A1.2*. Plots of the 7 metre winds versus the 49 metre winds at Lucas Heights in 1984 show a relationship between the two sets of wind speeds with the scatter occurring as a result of extracting the data by hand, and the poorer sensitivity and higher stalling speed of the Dines anemometer.

Winds at Mount Keira plotted against the winds at 10 and 49 metres from Lucas Heights also showed a high degree of scatter. However, a relation between the 49 winds from Lucas Heights and the 10 metre winds at Mount Keira could be identified, particularly for winds blowing from the north, south and westerly sectors. These are the directions where the fetch over the complex terrain would be similar, whereas winds from the east would be affected by the significant differences in the terrain east of Lucas Heights and Mount Keira which is close to the Illawarra Escarpment. Although there has been no statistical analysis of the relationship between the winds plotted in *Figures A1.4a,b* on the basis of visual estimates of the relationships between wind speeds and directions for all seasons, the following approximate values for the ratio between Mount Keira and Lucas Heights 10 metre winds were obtained:

Southerly winds:	1.0
Westerly winds:	1.23
Northerly winds:	1.14

Winds from the eastern sector were excluded because of differences between the fetch at Lucas Heights and Mount Keira North. Even though the elevation at Mount Keira North is about 280 metres higher than the elevation at Lucas Heights, the 49 metre winds at Lucas Heights were significantly higher than the 10 metre winds at Mount Keira, and this is attributed to the influence of surface roughness on the gradient of wind speed close to the surface.

Eleven kilometres south of Holsworthy South airport site, the height of the topography is similar to that at Mount Keira. Assuming that the wind speeds at this location would be similar to those measured at Mount Keira, it would be possible to apply a proportional scaling for winds at Holsworthy Option B, based on changes in the height of the topography between Lucas Heights and the southern airport option. On the basis of the relationships listed above, this would increase winds from the west by approximately 8 percent, winds from the north by 5 percent, with no correction applied to southerly winds. The appropriate correction for easterly component winds cannot be determined. However, in view of the large distance between Lucas Heights and Mount Keira, and the overall complexity of the terrain in this part of the Sydney Basin, it was decided as a result of this analysis, that the most prudent approach would be to use the unscaled 10 metre winds from Lucas Heights at Holsworthy Option B, and accept that there will be probably be some slight increase in the 10 metre wind speeds between the north and southern airport sites.

Adjustments to Wind Flow as a Result of Changes in Surface Roughness

When air flows over a boundary separating surfaces with different aerodynamic characteristics, the upwind equilibrium wind profile will gradually adjust to the change in the surface roughness as the air moves downwind from the boundary (Garrett, 1990; Walmsley, 1989; Zhenjia at el., 1990). If an airport was built on the Holsworthy Military Area, then the situation would arise, where the airport would be surrounded by a rougher tree covered surface, while the runways would be surrounded by grass covered areas. In this situation, air flowing over the aerodynamically rougher regions surrounding the airport, would react to a change in surface roughness as the air moved across the boundary of the airport.

In order to calculate the approximate the change in wind speed that would occur in this the situation, it was necessary to assume that the gradient of wind speeds observed Lucas Heights would be similar that measured on the Holsworthy Military Option B. The next step was to calculate the aerodynamic characteristics of the 'surface' that resulted in the observed good relationship between the 10 metre and 49 metre winds at Lucas Heights. To calculate the different parameters such as roughness length and zeroplane displacement length, it would normally be necessary to have wind speeds at least three heights, and to check that the calculations were made when atmospheric conditions were neutral.

Since wind speeds were only available for two heights, 10 metre and 49 metres, and it was decided to use an average slope of the observed relationship between the winds measured at the two heights for the south, west and east sectors plotted in *Figure A1.3*, and assume that the wind at 10 metres was approximately 60 percent of the wind at 49 metres. Using this approach, and a relationships between the height of the roughness elements; roughness length and zeroplane displacement length, published in Monteith (1973), the following parameters were derived:

Height of roughness elements (h):	3.2 metres
Roughness length (z_0):	2.0 metres
Zeroplane displacement length (d):	0.4 metres

The next step was to calculate the expected increase in wind speed as the air moved across the boundary of the airport. On the basis of the parameters listed above, an estimate of roughness length of 0.45 centimetres, for a grass covered surface on an airport, (Brutsaert, 1982) it was possible, using techniques published in the scientific literature to calculate the change in wind speed at 10 metres above the surface as the air moved across the boundary of the airport, (Ayra, 1988; Garrett, 1990; Walmsley, 1989; Semprevevia et al., 1990). For the situation at the Holsworthy sites two cases were examined; one where the wind was blowing across the airport at right angles to the main runways, which gave a distance of about 250 metres between the trees at the boundary and the runway; and the other for the situation where the wind was blowing parallel to the main runways.

For the cross-wind situation, the calculations showed an increase in wind speed of about 10 percent could be expected between the boundary and the runway; whilst for the case where the wind was blowing parallel to the runway the wind speed would gradually increase with distance, and reach an equilibrium situation where the wind at 10 metres would be approximately 24 percent higher than the upwind speed.

Factors such as changes in thermal characteristics between the airport and the surrounding tree-covered areas, as well as wind flow within the tree canopy, will have some affect on wind speeds downwind of the boundary, particularly for the cross wind situation. However, in the absence of any on-site information about these affects, the values above give a first approximation for the increase in wind speeds that could be expected at the Holsworthy sites as a result of the change in surface roughness at the boundary of the airport. In the light of these calculations, for the purpose of runway usage and noise impact assessment, 10 metre wind speeds from Lucas Heights were increased by 20 percent.

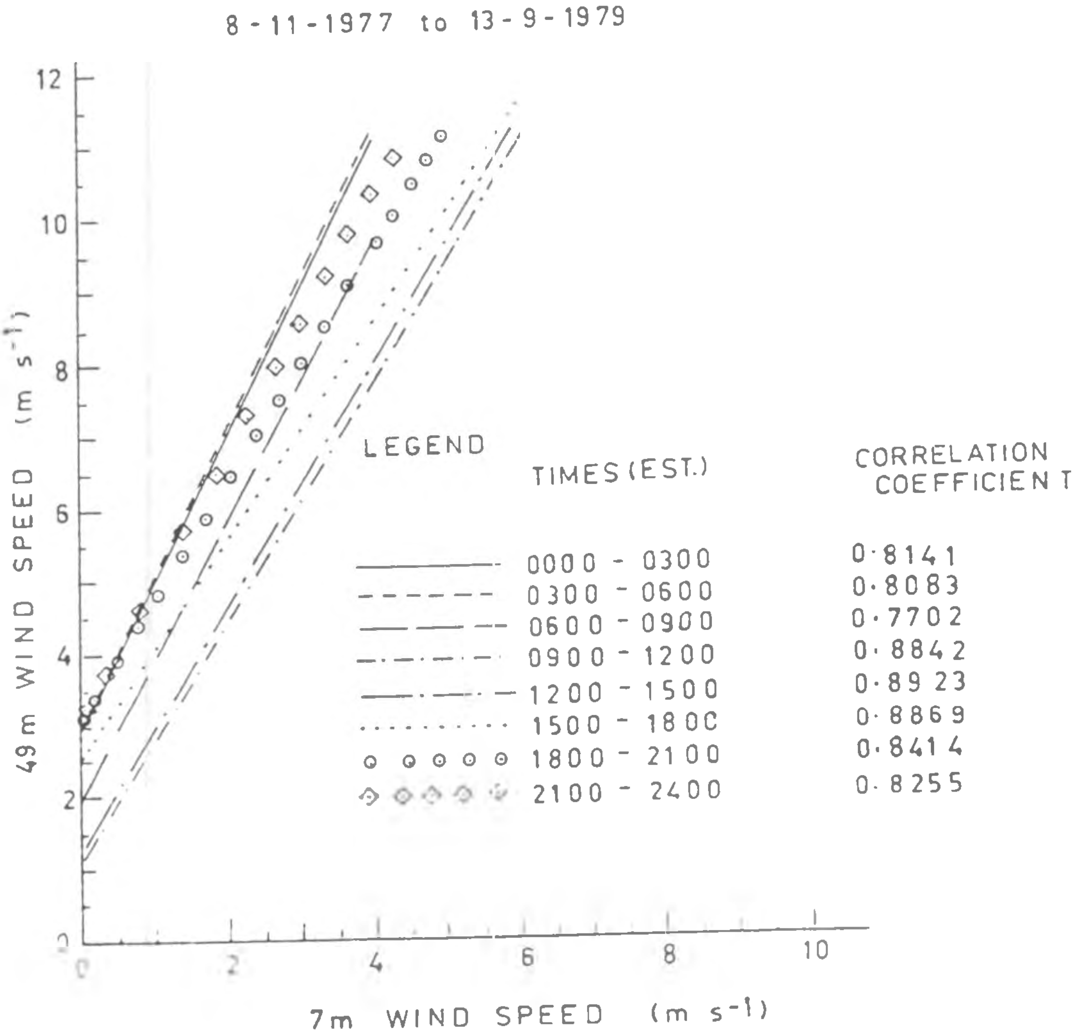

Figure A1.1 Regression lines obtained by plotting 49 metre wind speeds against 7 metre wind speeds at Lucas Heights, for three hourly intervals throughout the day; November 1977 to September 1979. Source: Clark, 1993. Reproduced with permission of CSIRO

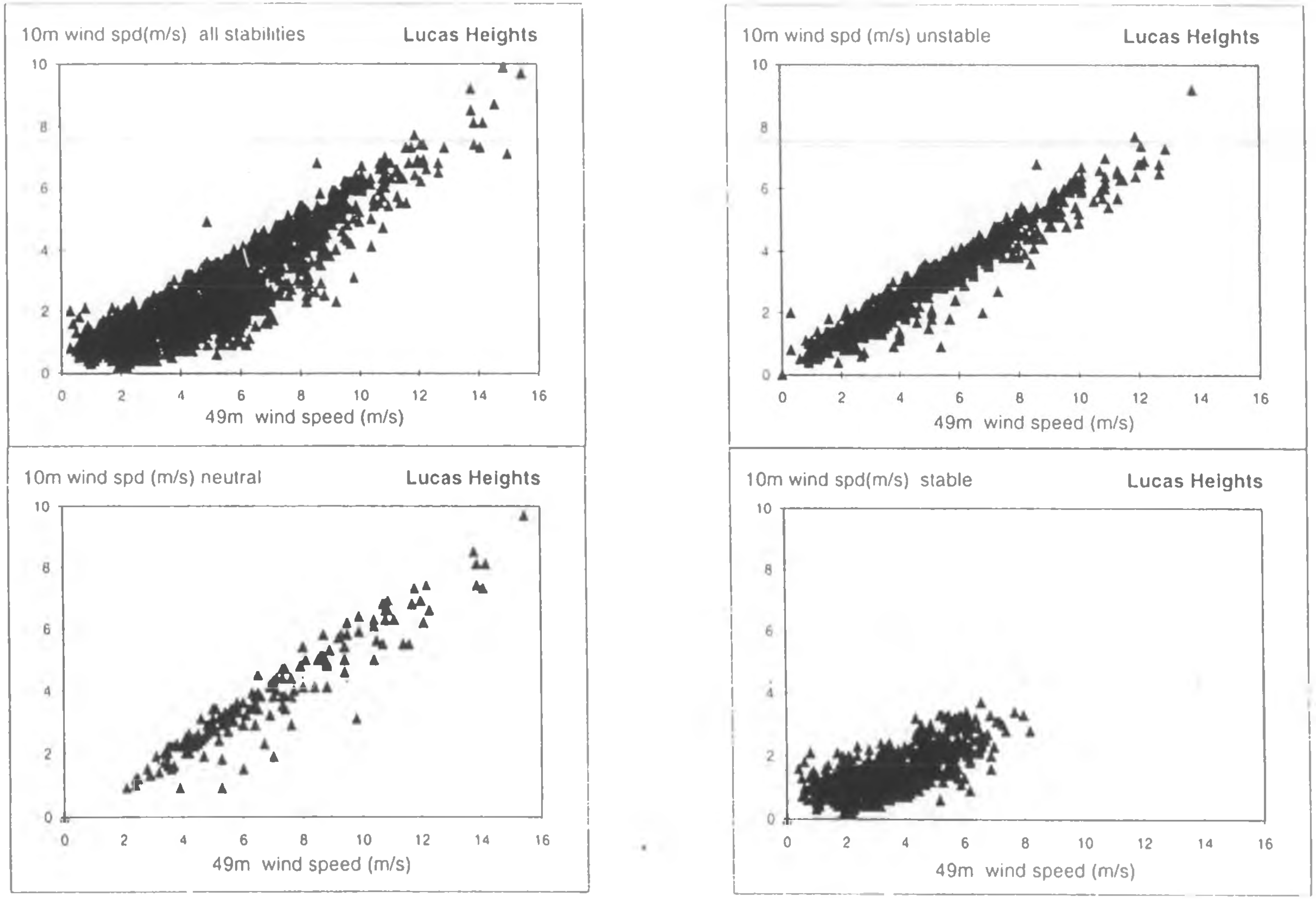

Figure A1.2 Plots of wind speed at 10 metres against wind speed at 49 metres for different conditions of atmospheric stability; (a) all stabilities; (b) unstable; ( ) neutral; (d) stable

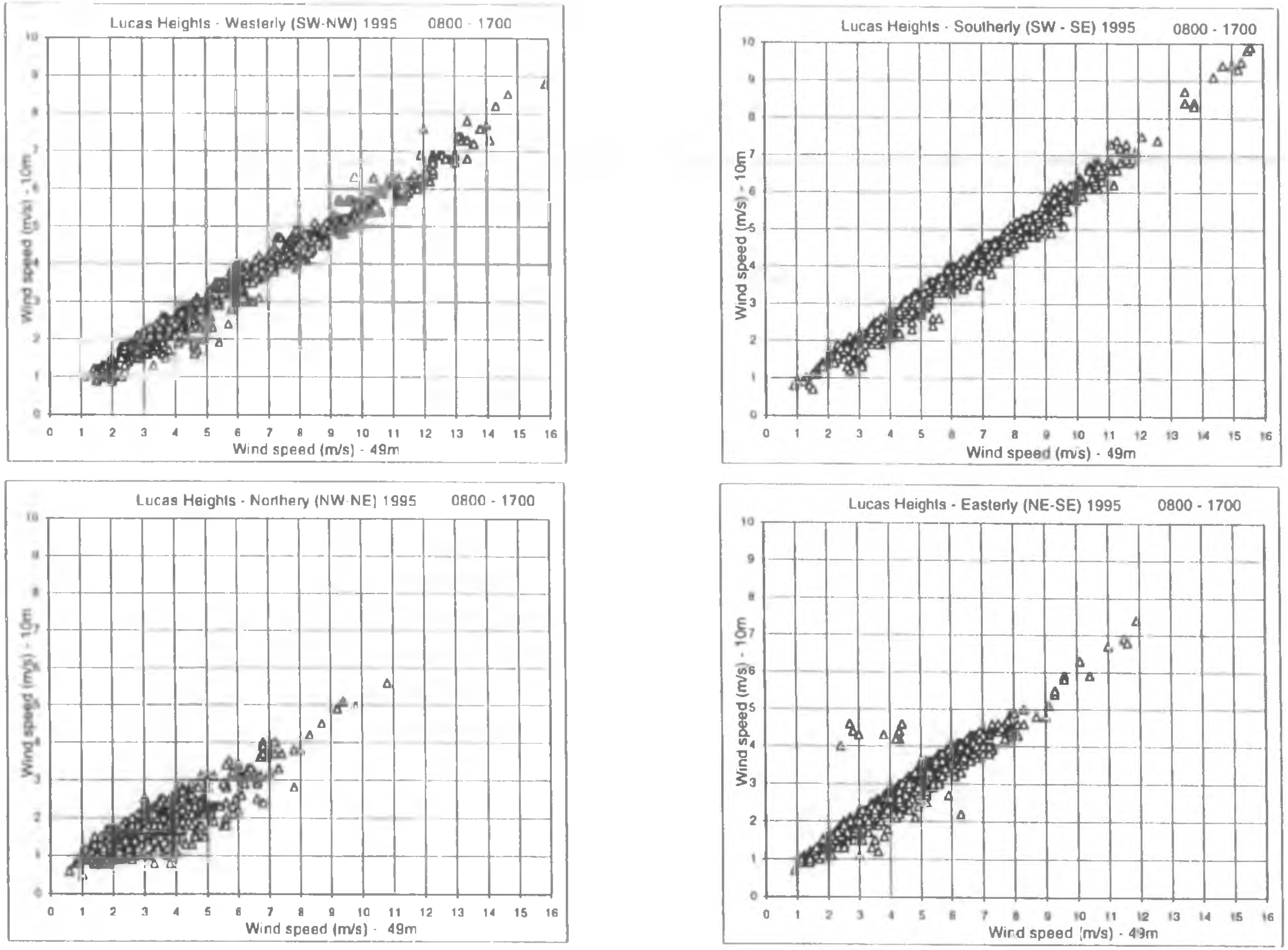

Figure A1.3 Lucas Heights 10 metre versus 49 metre wind speeds for 1995 in four sectors :Westerly, Southerly, Northerly and Easterly, wind directions
Source: ANSTO, Lucas Heights

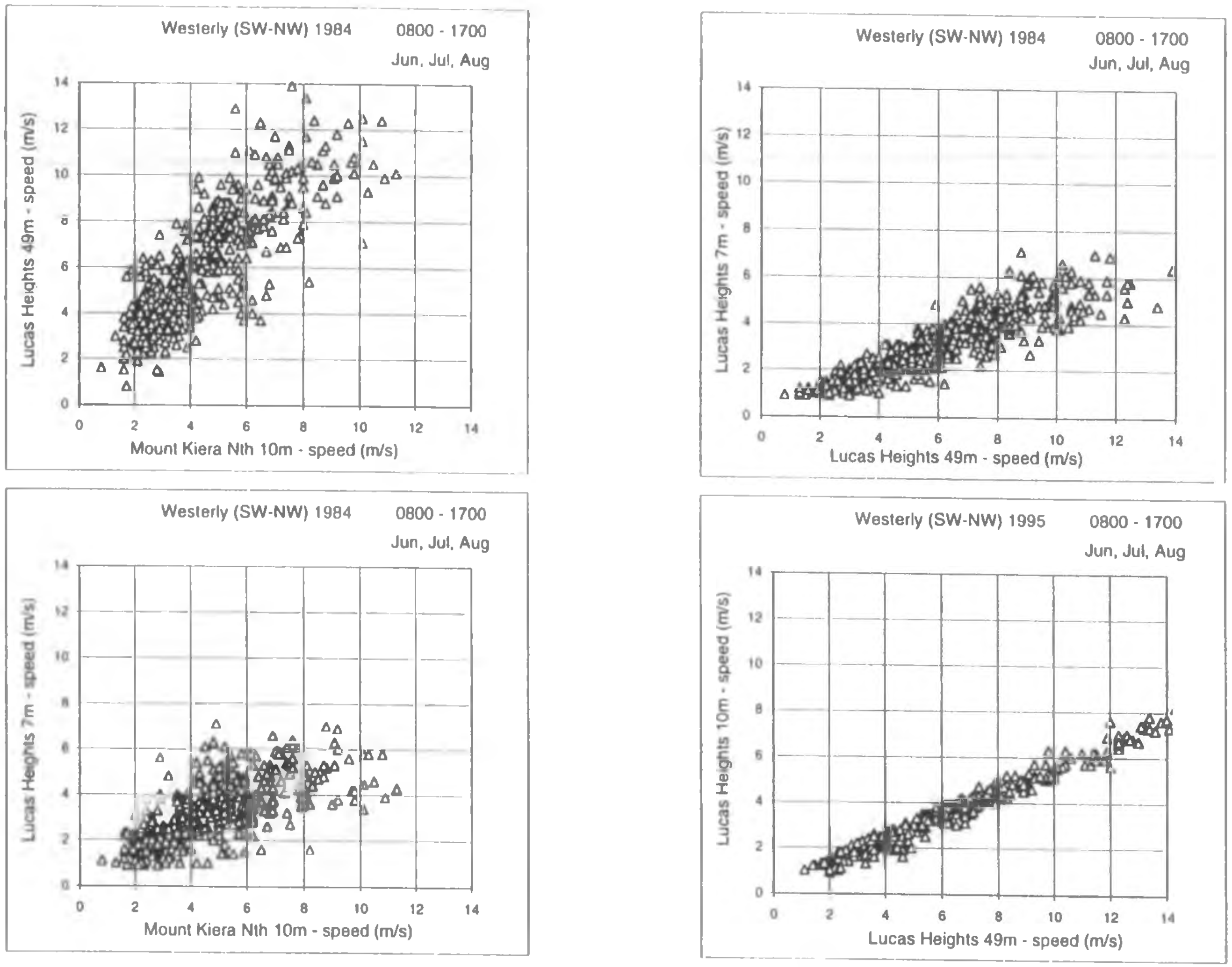

Figure A1.4a Comparison of Lucas Heights and Mount Kiera wind speeds, for westerly sector wind directions, 1984, and 10 metre versus 49 metre winds westerly sector winds at Lucas Heights in 1995. Source: ANSTO - Lucas Heights wind data

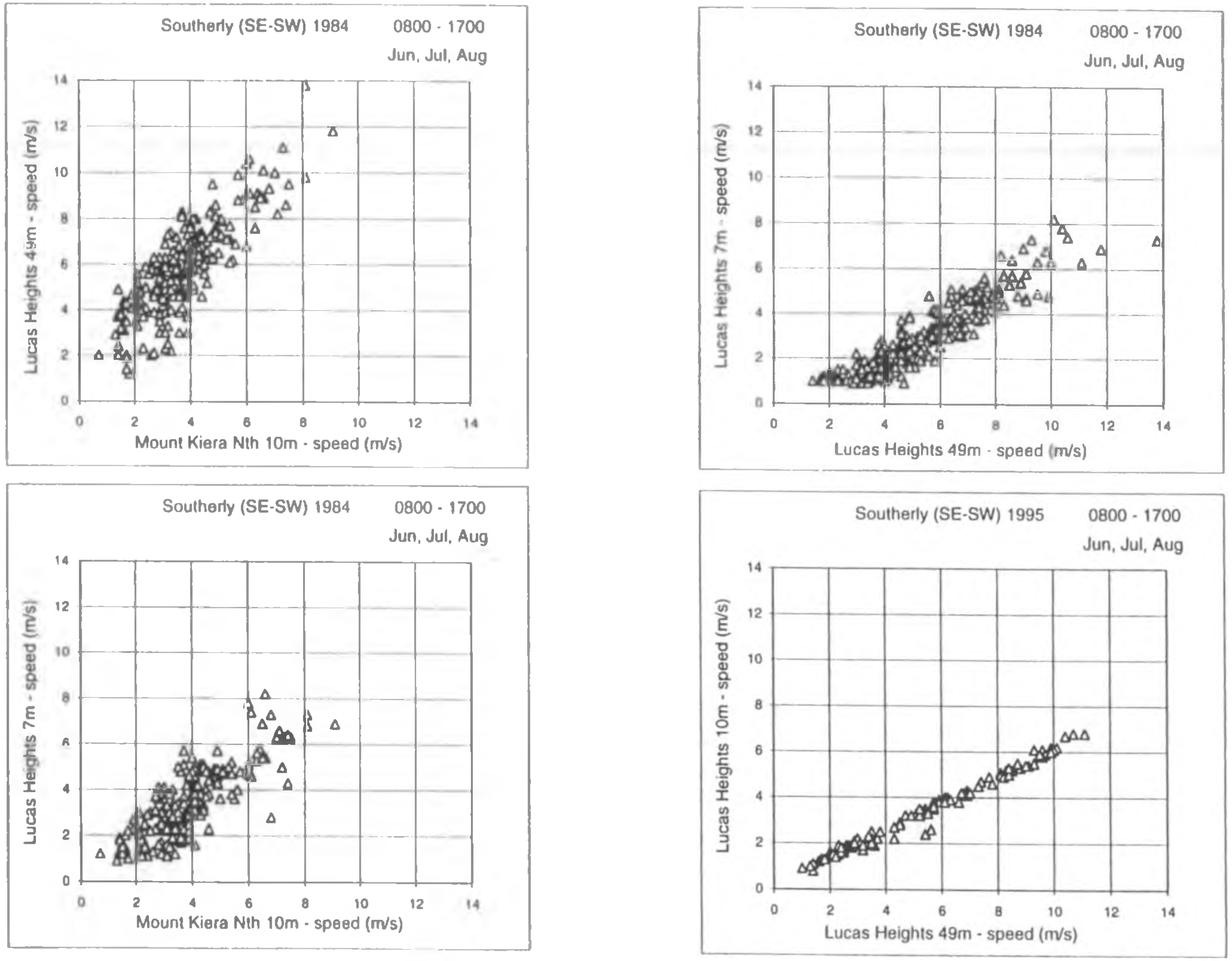

Figure A1.4b Comparison of Lucas Heights and Mount Kiera wind speeds, for southerly sector wind directions, 1984, and 10 metre versus 49 metre winds southerly sector winds at Lucas Heights in 1995. Source: ANSTO - Lucas Heights wind data

Appendix 2

Specifications of Meterological Equipment, Calibration Procedures for Meterological Data used in the Second Sydney Airport Draft EIS

Appendix 2: Wind Speed and Direction - Instrument Specification and Calibration Procedures

Organisations who made wind data available for the purpose of air quality modelling, noise impact assessment and the assessment of meteorology in the region were asked if they could provide information about the equipment used to measured these parameters, the procedures for calculating average wind speed and direction, and the calibration and quality assurance checks undertaken by each organisation.

A2.1 Bureau of Meteorology

Data from three types of instrument have been used in the EIS for the second Sydney Airport:

(i) Historical data where wind speed and direction were measured by a Dines anemometer which uses a pressure sensitive approach to measure wind speed. These instruments have high stalling speed and are likely to underestimate values of wind speed (Hyde et al., 1980; Potts et al., 1997; per. Com. Bureau of Meteorology, 1997).

(ii) Wind data measured at automatic weather stations:

Fort Denison - R.M. Young.

Threshold velocities - speed 0.4 m/s
- vane 0.8 m/s

Other automatic weather stations: Synchotachs - wind vane (model 706); wind speed (model 732)

Threshold velocity: wind speed: < 1m/s; wind direction 1 m/s

Wind Speed and Direction Calculations:

At automatic weather stations the Bureau of Meteorology calculates both one-minute and ten-minute averages

Wind speed: one minute scalar average speeds calculated on the basis of samples taken every second; ten minute average wind speeds calculated on the basis of scalar averaging of the one-minute average wind speeds

Wind direction: one minute scalar average wind directions calculated from the one-second samples of wind direction (the procedure adopted by the Bureau of Meteorology has an inbuilt check to determine whether the wind direction passes through north in sequential samples, in which case the measurements are adjusted accordingly); ten minute average wind directions are calculated from the one minute scalar average wind directions with the same procedure adopted to account for cases where sequential one-minute average values pass through north.

Instrument Performance and Calibration Checks:

Wind speeds are checked by estimation against a hand-held anemometer every six to eight months. Wind speeds measured are adjusted upwards by 25% to account for the difference in height exposure between the instrument located at 10 metres and the height of the hand held anemometer.

Wind vanes are orientated to true north and checked against a hand-held compass taking account of the offset required for the magnetic variation.

A2.2 Australian Nuclear and Science and Technology Organisation - Lucas Heights

Since 1991 wind speed and direction have been measured using a Climatronics WMIII

Wind speed and direction thresholds: between 0.3 m/s and 0.4 m/s when new

Wind Speed and Direction Calculations:

Sampling period:	10 seconds
Average period:	15 minutes

Vector average wind speed and directions were used for the purpose of the EIS. Scalar average wind speeds are also calculated at Lucas Heights.

Instrument Performance and Calibration Checks:

Yearly calibration of sensors, or more regularly if there are any signs of performance degradation. Wind speed and direction are displayed on a computer screen and updated every ten seconds allowing visual checking of instrument performance.

Wind speeds sensors are calibrated once a year in a wind tunnel at Lucas Heights using a secondary standard which has been calibrated at the CSIRO Division of Atmospheric Research in Melbourne.

Wind directions are checked by rotating the vane to known orientations. The wind vane is orientated to magnetic north and the data is corrected to true north by taking into account of the magnetic variation after the collection of the raw data.

Temperature measurements were used for the purpose of calculating inversion frequency and strength. The sensors are calibrated once a year using a water bath.

A2.3 Australian Water Technologies

Wind monitors R M Young sensors model 05305 (standard) and 05701 (sensitive)

Wind speed thresholds	0.4 m/s standard; 0.2 m/s sensitive
Wind direction threshold:	0.4 m/s standard; 0.3 m/s sensitive

Wind Speed and Direction Calculations:

Sampling rate: 1 second
Averaging period: 15 minutes and 1 hour
Scaler average wind speeds; unit vector wind directions

Instrument Performance and Calibration Checks:

Field checks - once per year
Laboratory checks - once per year

Data quality checked three times each week, and corrective action initiated immediately if an anomaly encountered

Status of automatic weather stations checked on a fortnightly basis

The automatic weather stations at Bondi, Cronulla, and North head are located on roof tops with good exposure to regional winds. The heights of the roofs are different at each location and the wind data have not been corrected to 10 metre heights. The automatic weather stations at Glenfield and Liverpool are located at 10 metre heights with good exposure to regional winds

Wind direction sensors are orientated to true north as accurately as possible

A2.4 Federal Airports Corporation

Wind sensors. Met One (wind speed - 010c; wind direction - 020c)

Threshold velocities for wind speed and direction: 0.3 m/s

Wind Speed and Direction Calculations:

Sampling period: 1 second
Averaging period: 2 minutes and 1 hour
Vector average wind speed and directions

Wind vane orientated to true north taking account of magnetic variation.

Performance Checks

Wind directions checked by rotating vane to known orientations
Visual check of analogue chart record of wind speed and direction each week, with corrective action taken if an anomaly observed
Monthly check of analogue chart and vector average wind speeds and directions

A2.5 Macquarie University

Instrument: Lambrecht 1462 mechanical wind recorder which measures instantaneous wind direction and wind run on a pressure sensitive chart inside the instrument

Threshold for wind speed and direction when new: 0.5 m/s

Wind vane orientated to true north taking account of magnetic variation

Hourly average wind speed and direction obtained by digitising instantaneous wind direction and wind from analogue chart

Appendix 3

Diurnal Wind Speed and Speed and Direction Analyses at Three-Hourly Intervals in each Month at Badgerys Creek

Badgerys Creek - January 1990/92

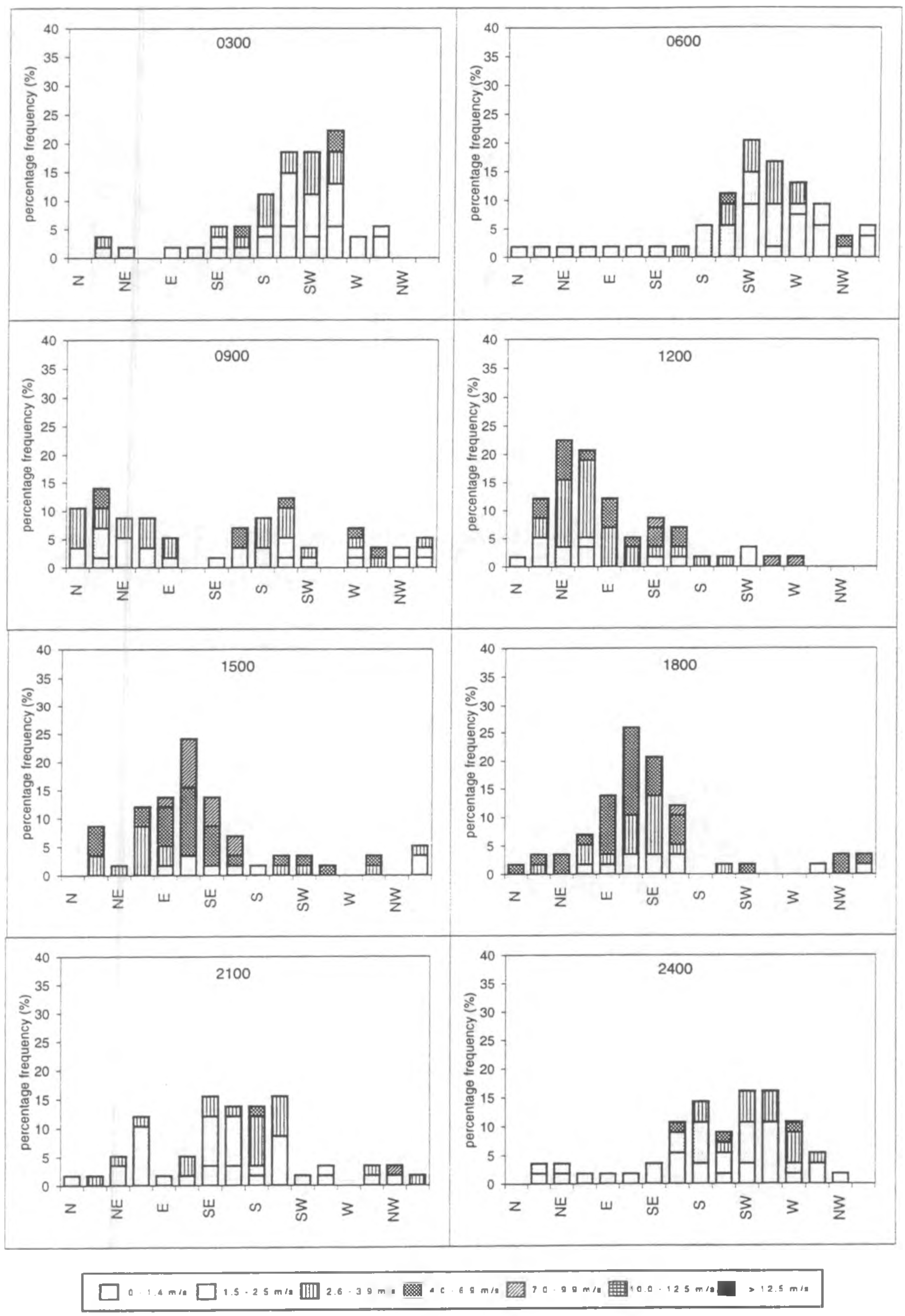

Figure A3.1 Three-houly wind speed and direction frequency distribution, Badgerys Creek January (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

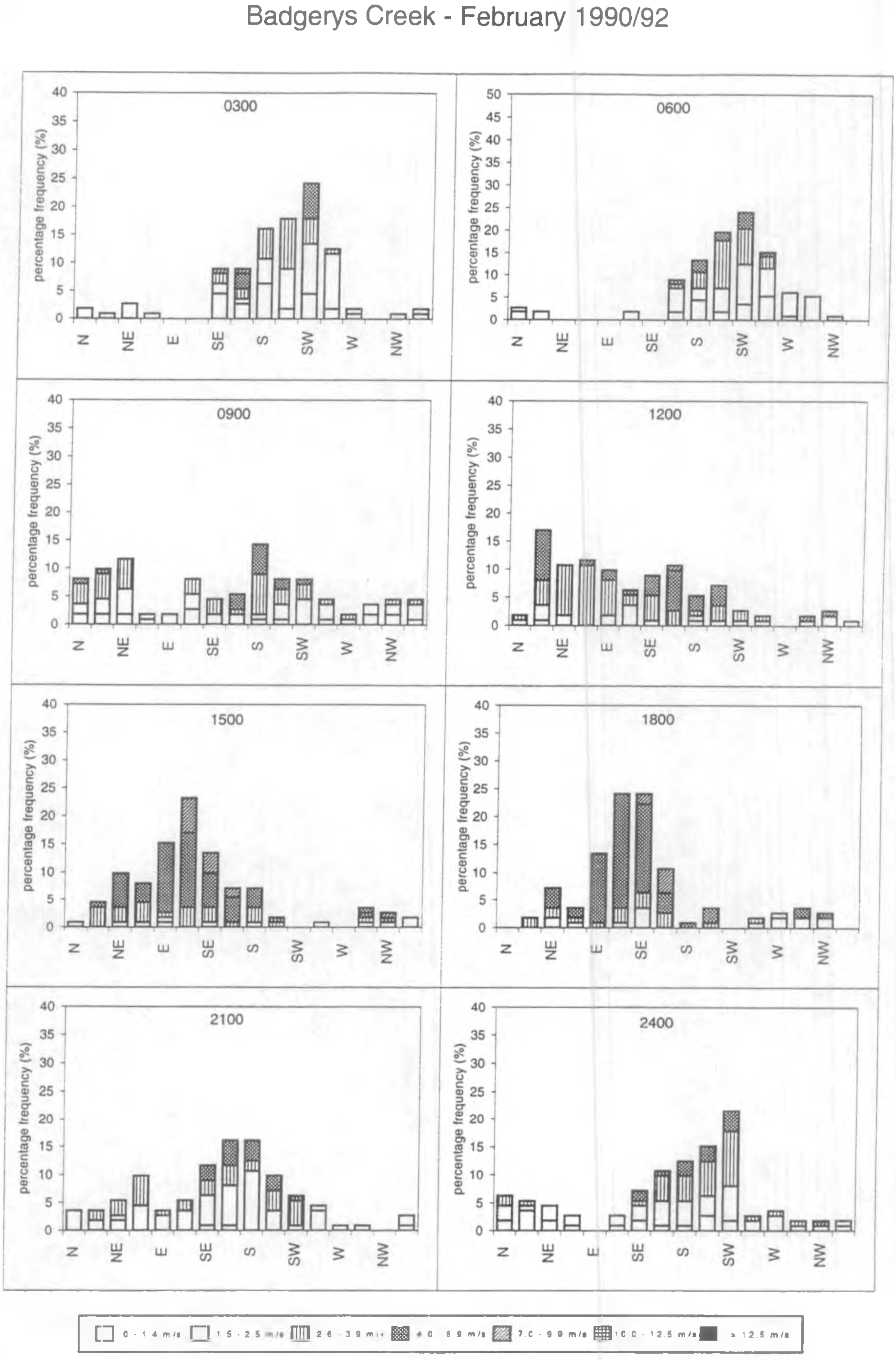

Figure A3.2 Three-houly wind speed and direction frequency distribution, Badgerys Creek February (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

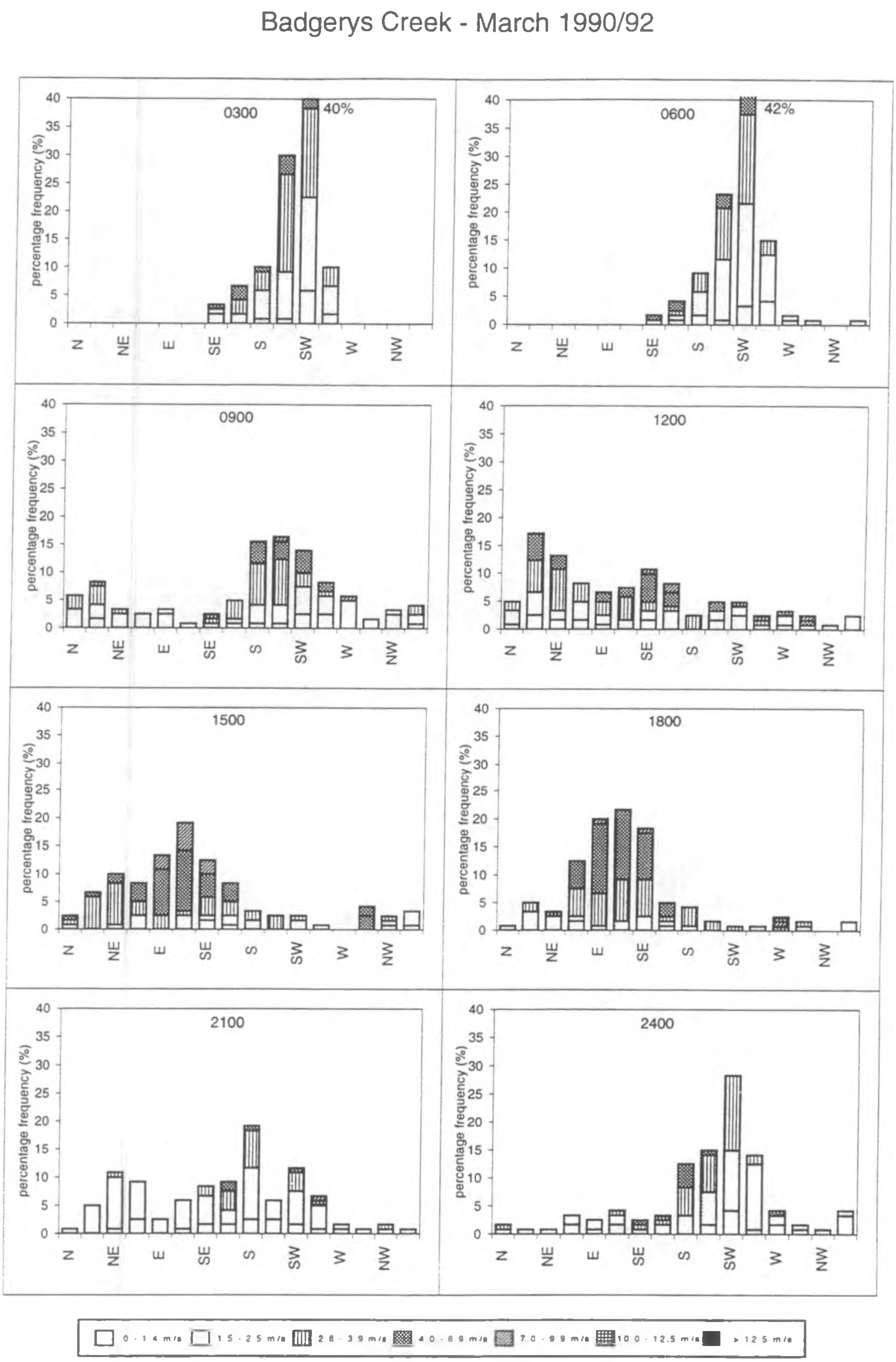

Figure A3.3 Three-houly wind speed and direction frequency distribution, Badgerys Creek March (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - April 1990/92

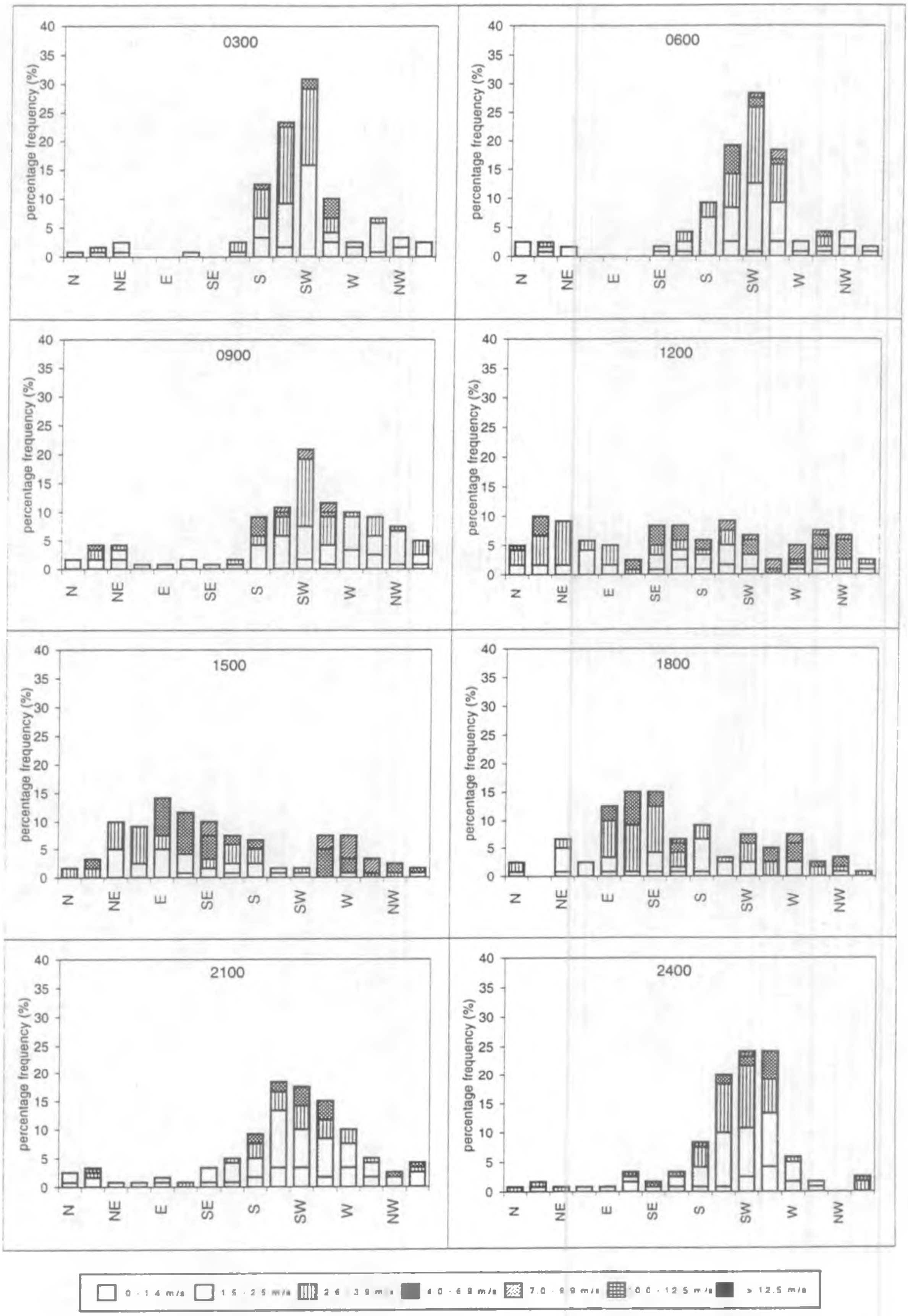

Figure A3.4 Three-houly wind speed and direction frequency distribution, Badgerys Creek April (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - May 1990/92

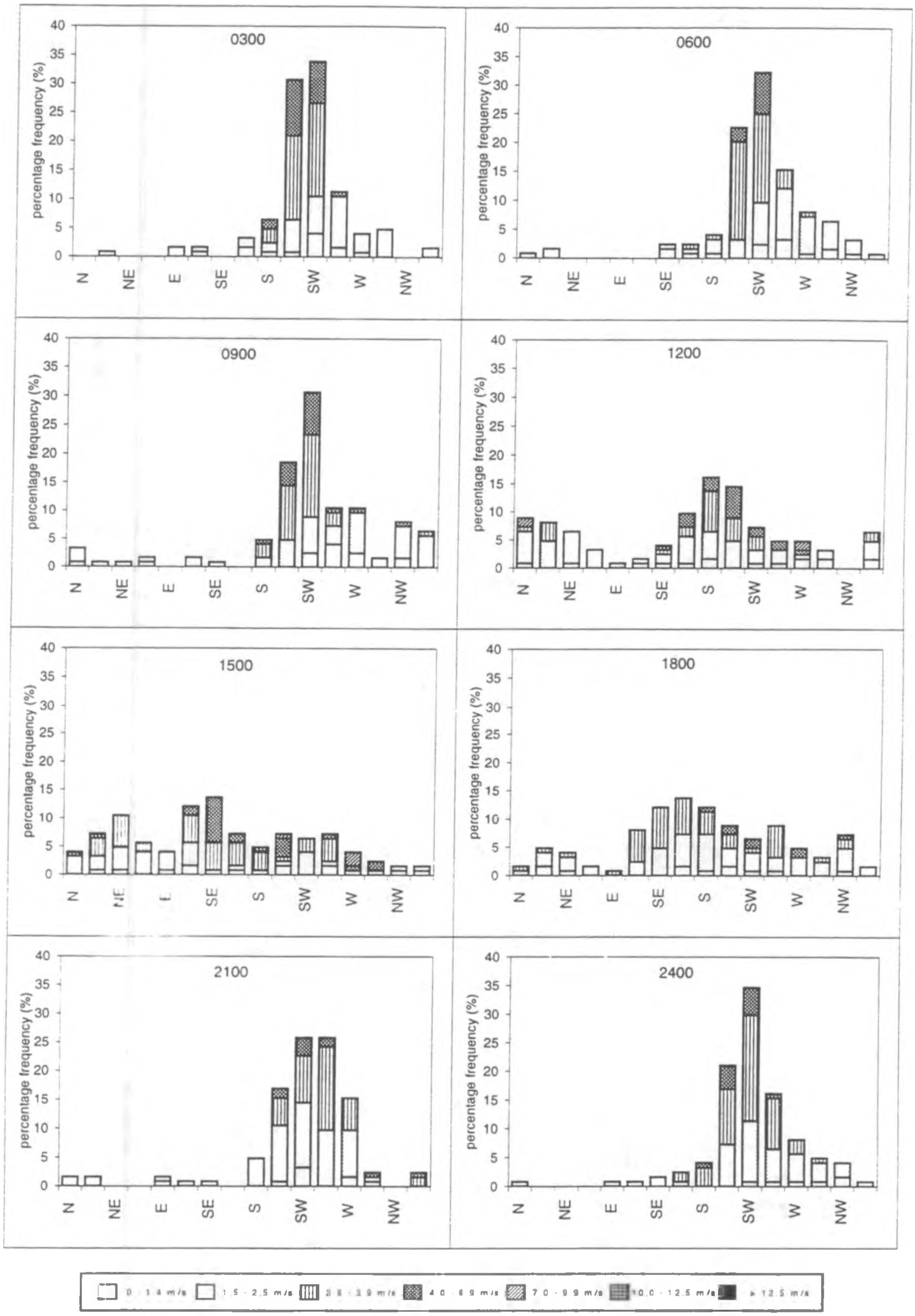

Figure A3.5 Three-houly wind speed and direction frequency distribution, Badgerys Creek May (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - June 1990/92

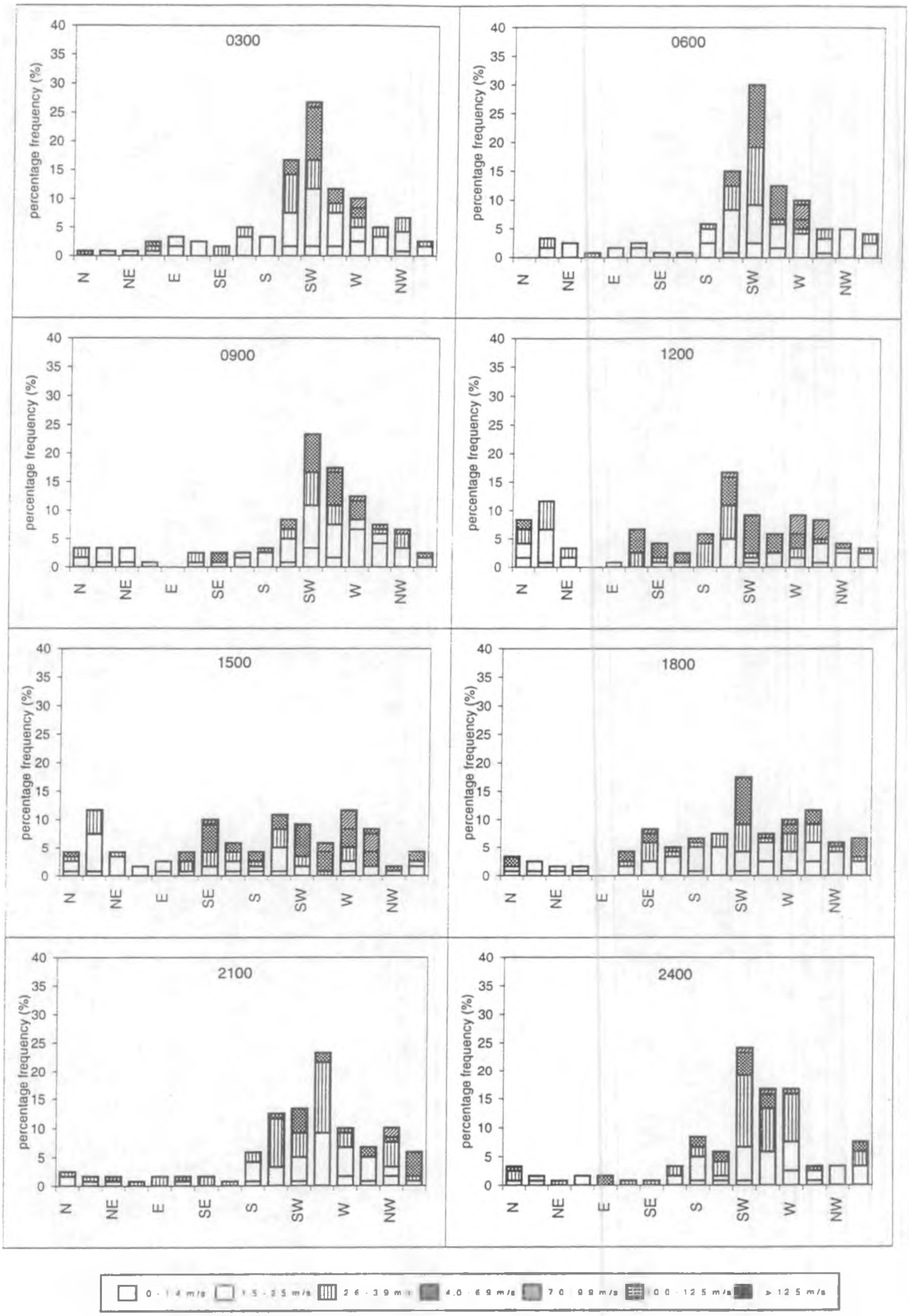

Figure A3.6 Three-houly wind speed and direction frequency distribution, Badgerys Creek June (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - July 1990/92

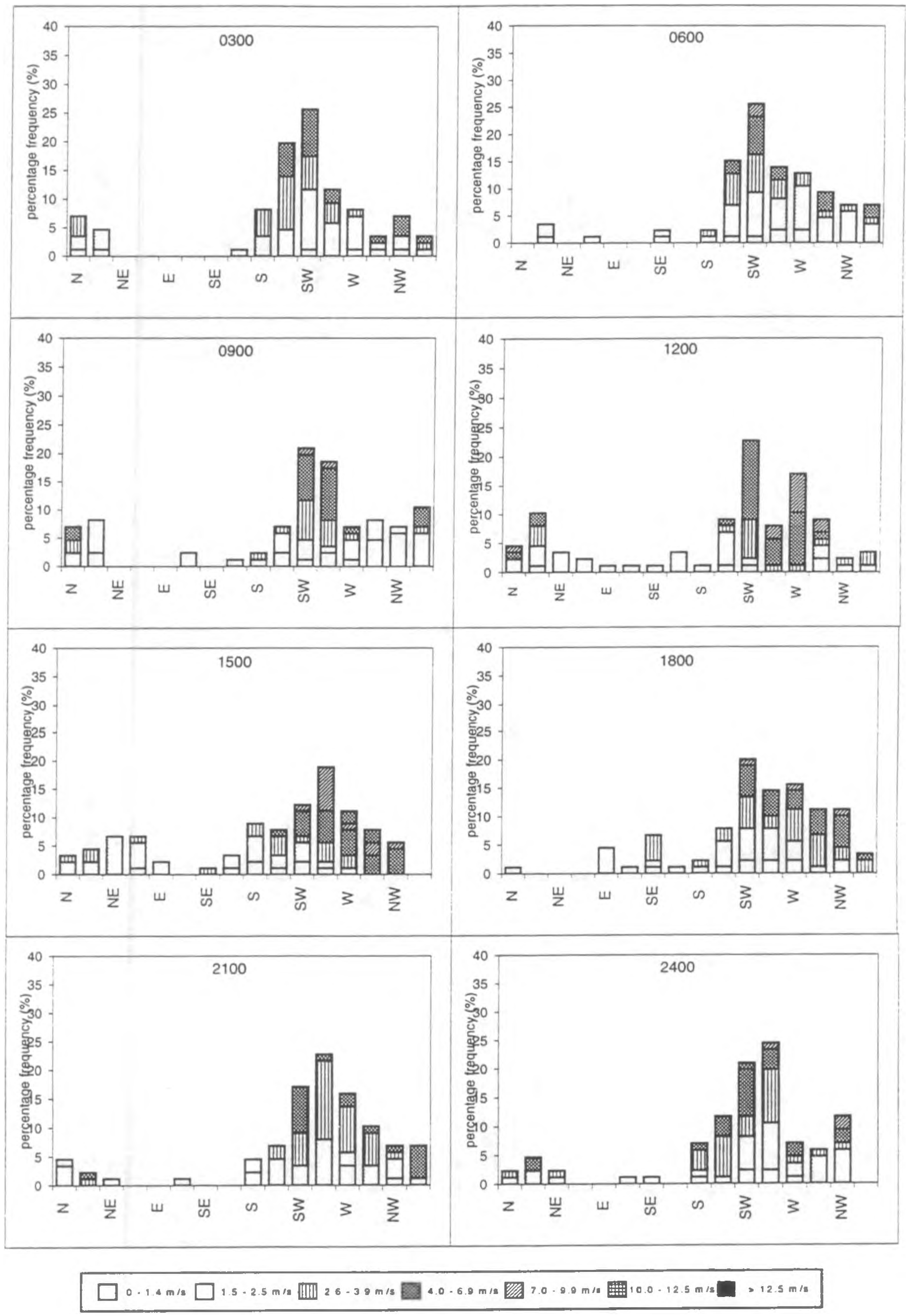

Figure A3.7 Three-houly wind speed and direction frequency distribution, Badgerys Creek July (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - August 1990/92

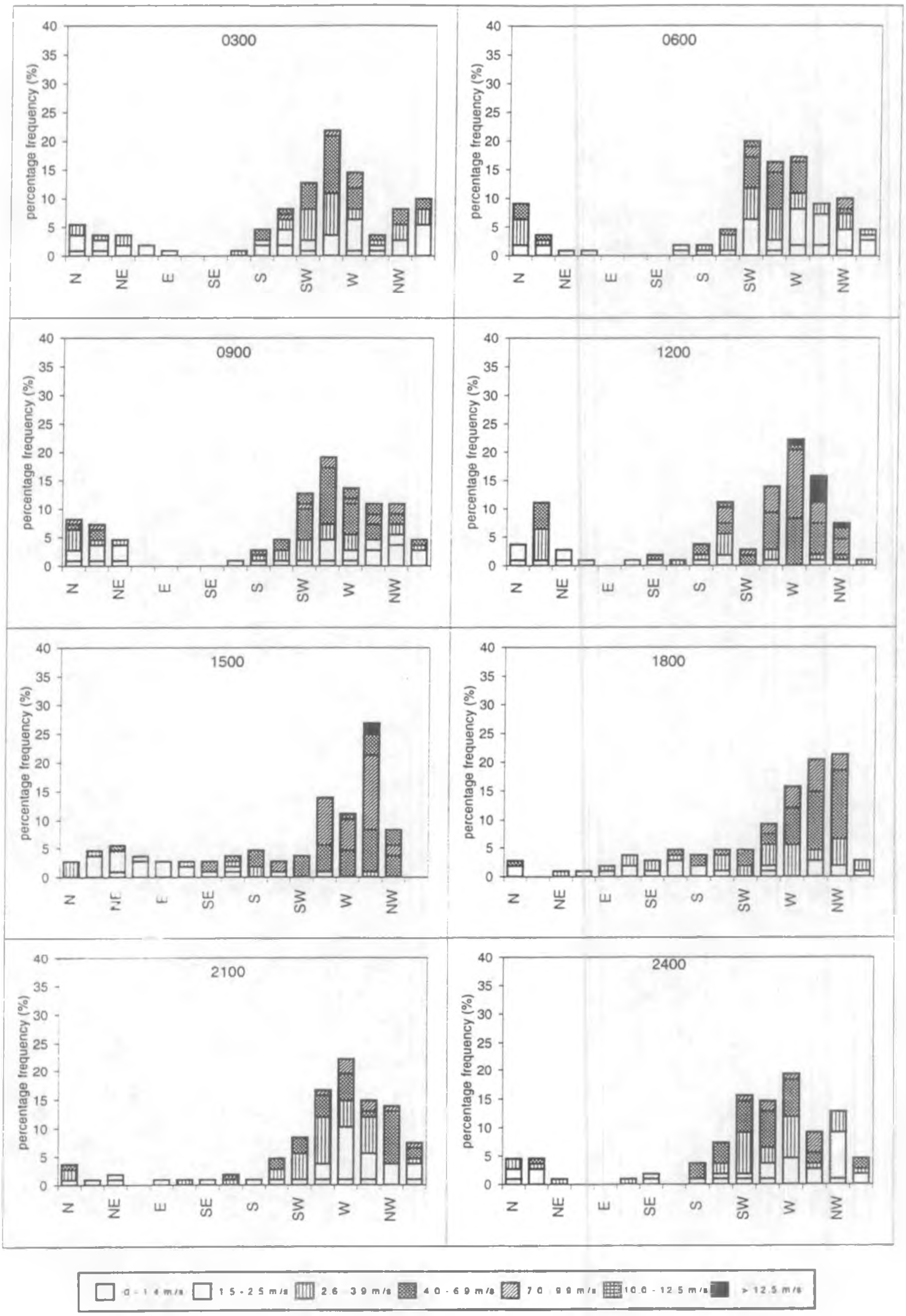

Figure A3.8 Three-houly wind speed and direction frequency distribution, Badgerys Creek August (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - September 1990/92

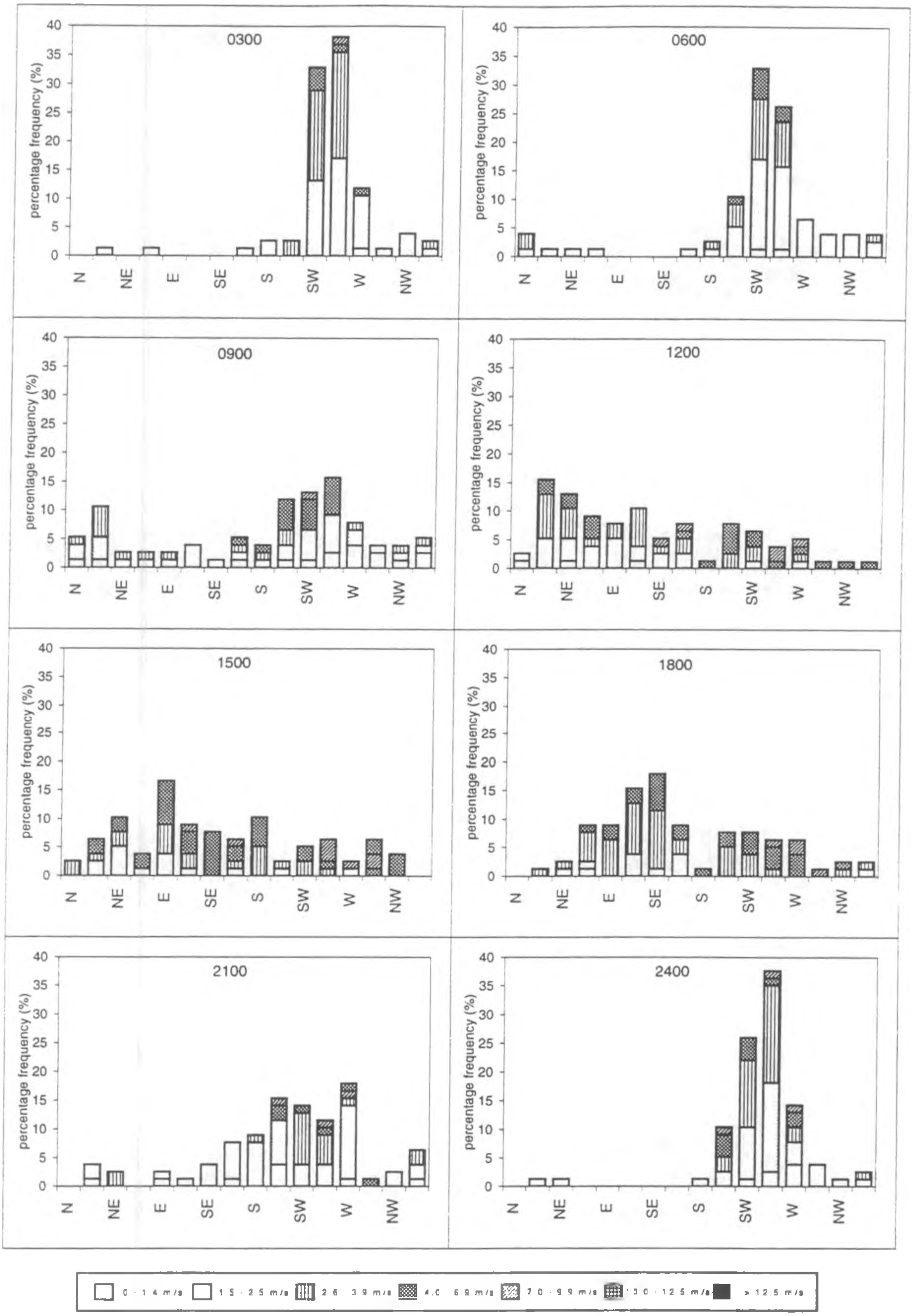

Figure A3.9 Three-houly wind speed and direction frequency distribution, Badgerys Creek September (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - October 1990/92

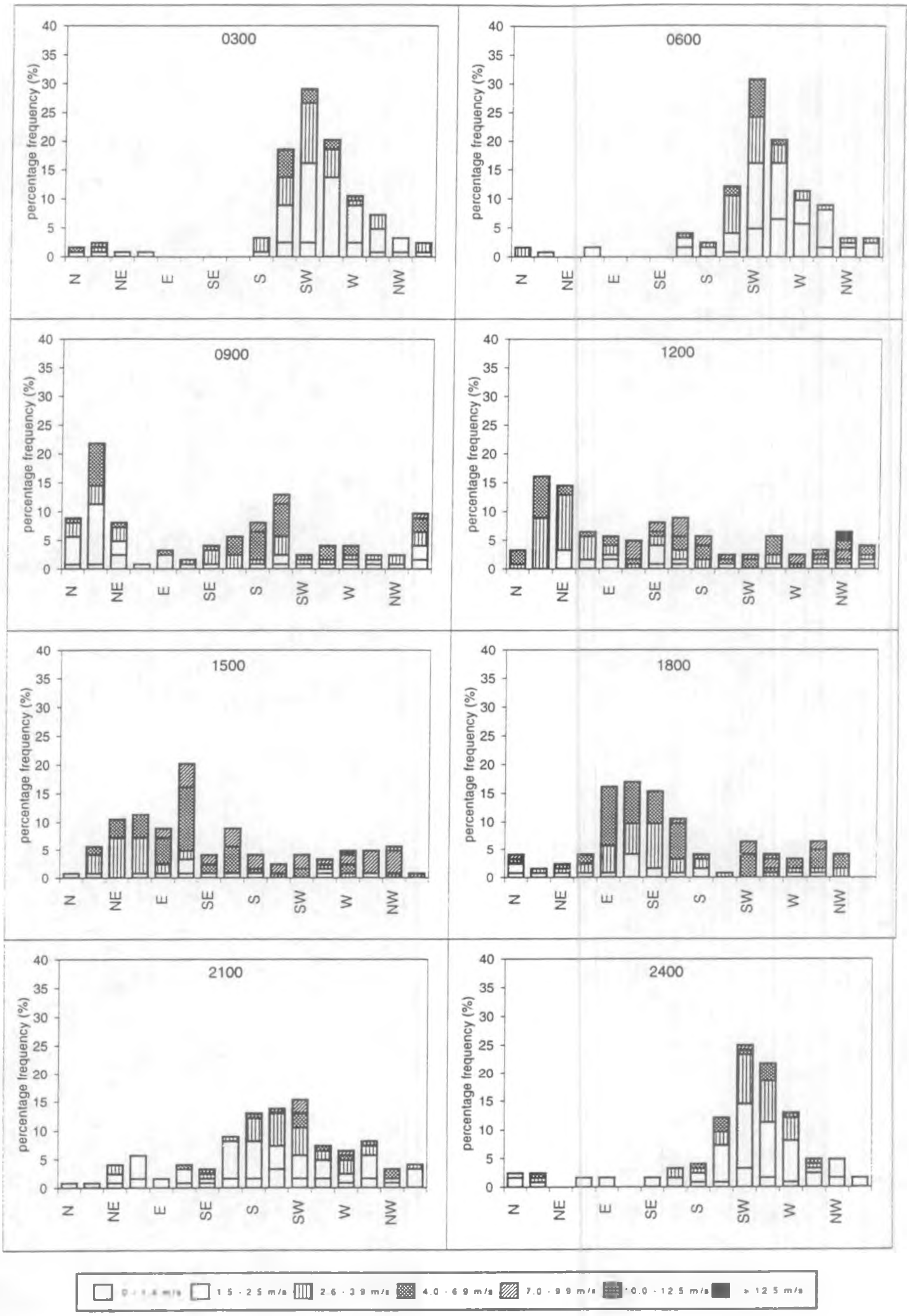

Figure A3.10 Three-houly wind speed and direction frequency distribution, Badgerys Creek October (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - November 1990/92

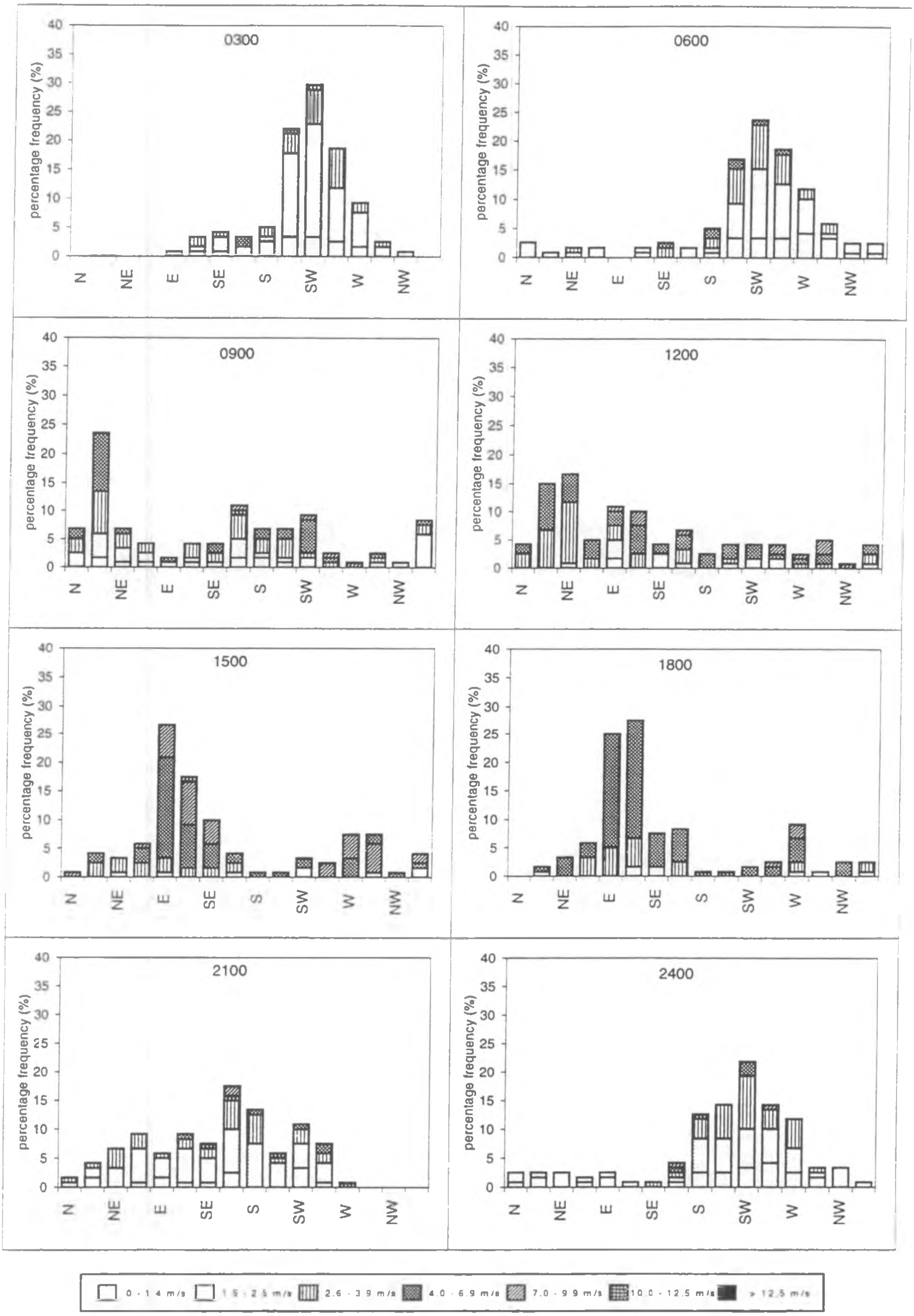

Figure A3.11 Three-houly wind speed and direction frequency distribution, Badgerys Creek November (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Badgerys Creek - December 1990/92

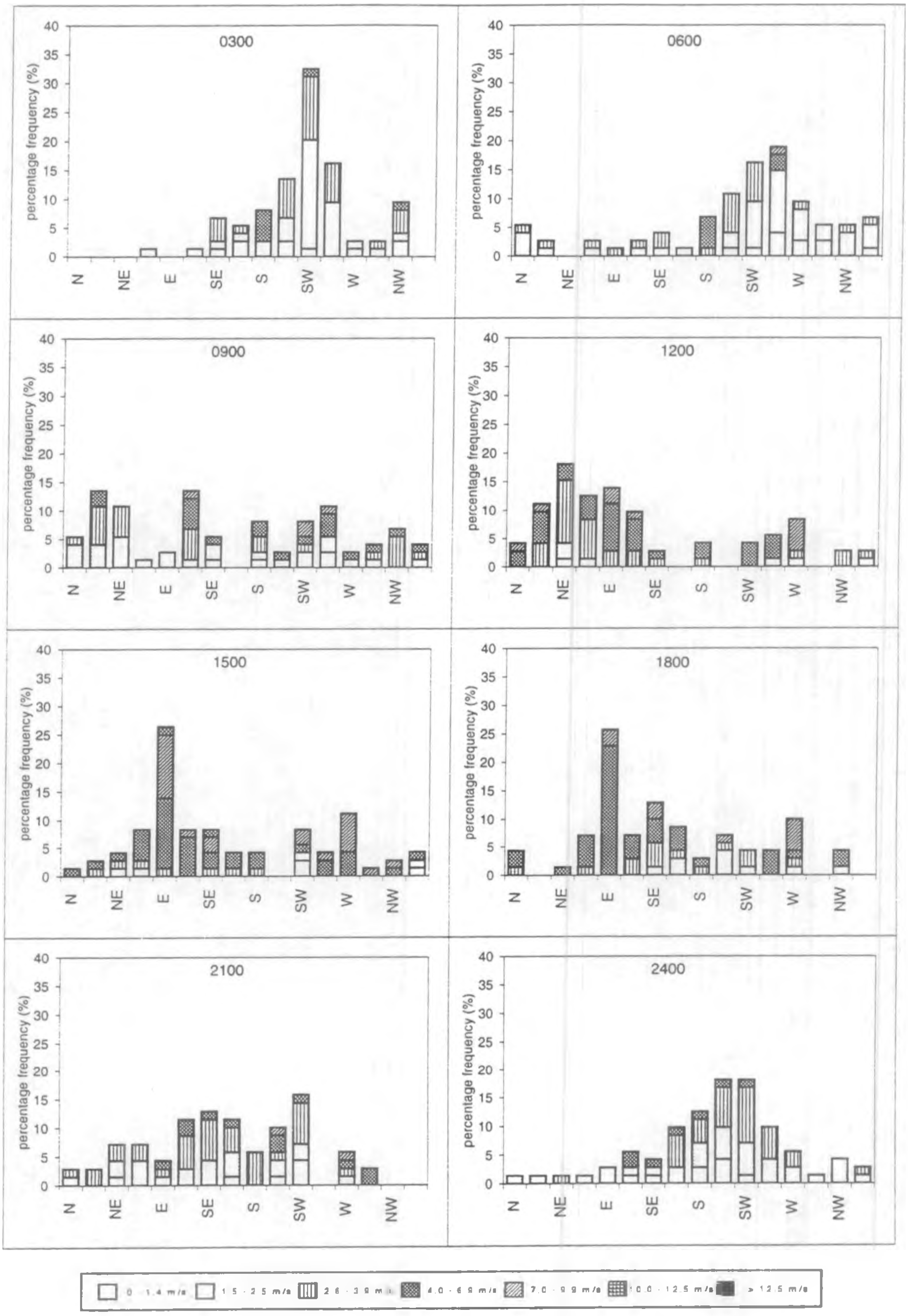

Figure A3.12 Three-houly wind speed and direction frequency distribution, Badgerys Creek December (1990 - 1992); Source - R. Hyde, Macquarie University Wind Data

Appendix 4

Diurnal Wind Speed and Speed and Direction Analyses at Three-Hourly Intervals in Each Month at Lucas Heights - 10 metres

Lucas Heights (10m) - January 1993/96

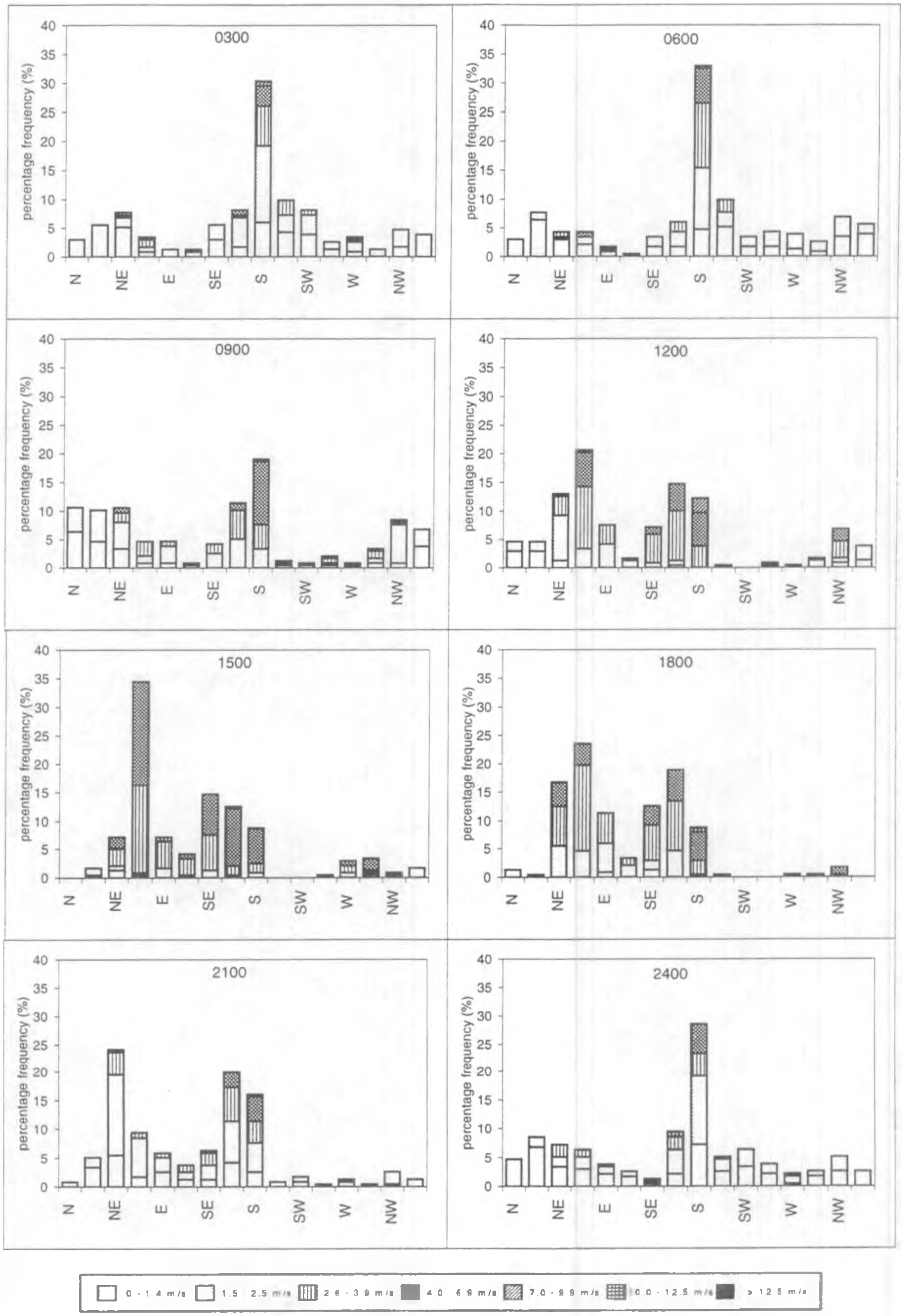

Figure A4.1 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) January (1993-1996); Source - ANSTO

Lucas Heights (10m) - February 1993/96

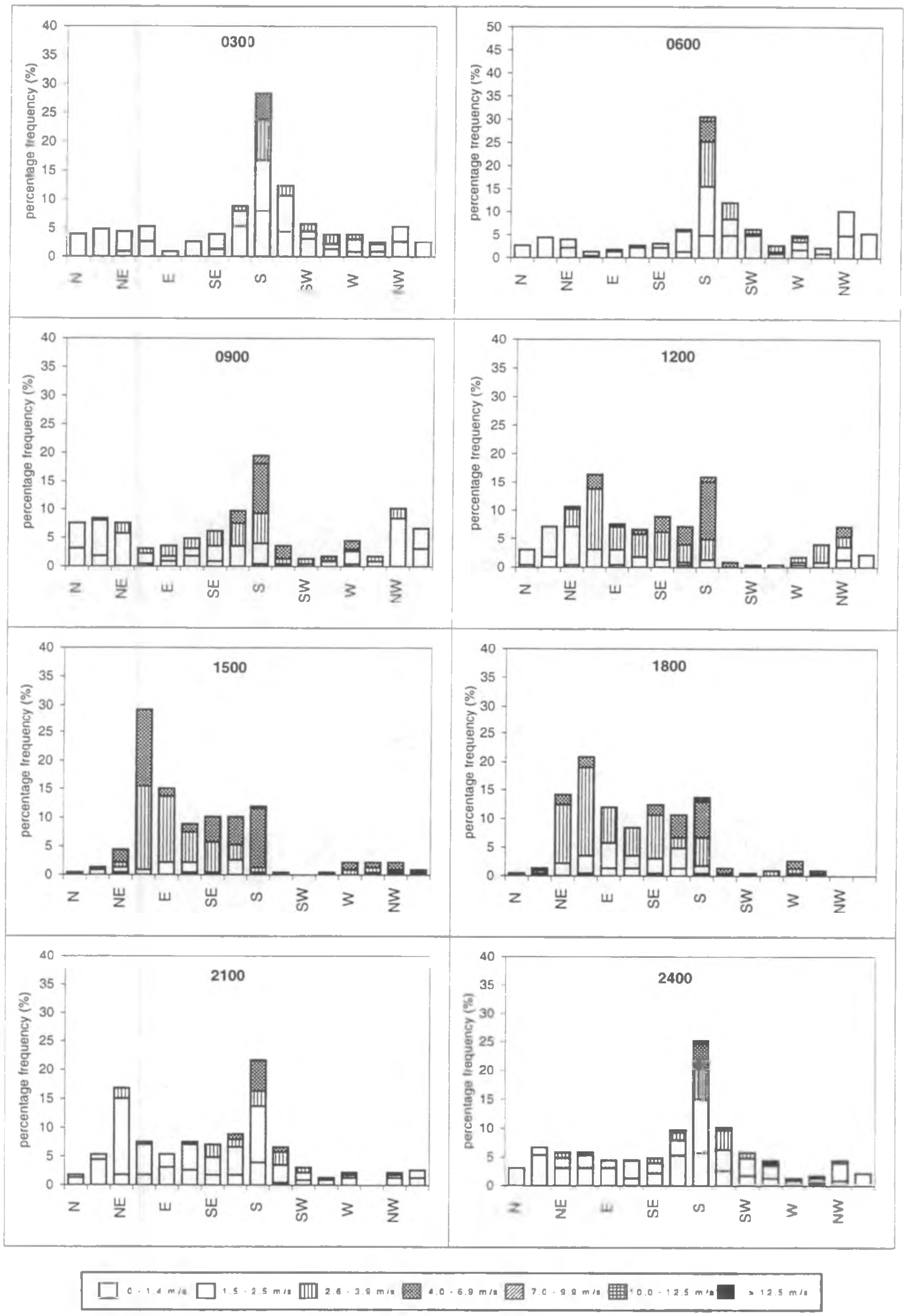

Figure A4.2 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) February (1993-1996); Source - ANSTO

Lucas Heights (10m) - March 1993/96

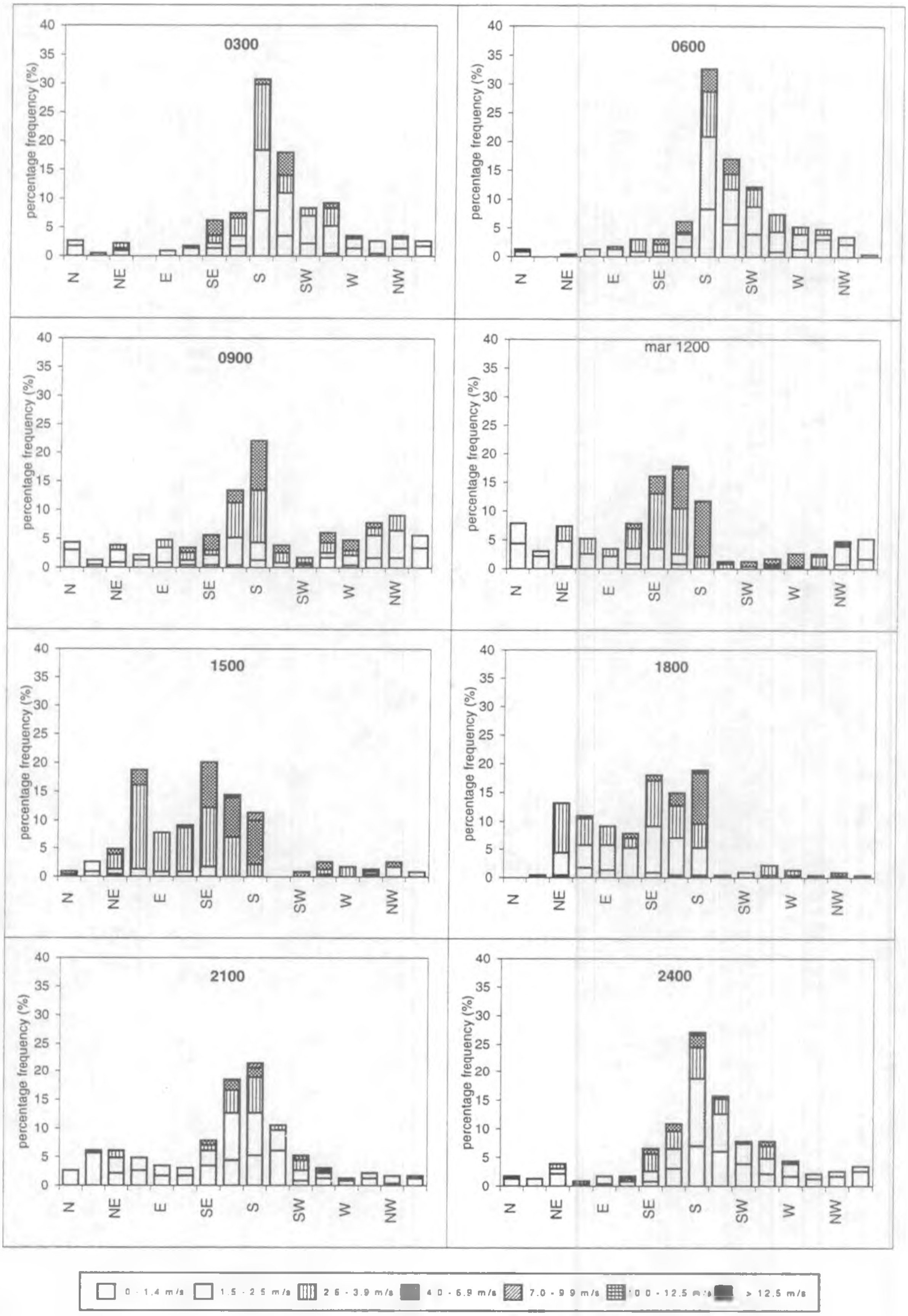

Figure A4.3 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) March (1993-1996); Source - ANSTO

Lucas Heights (10m) - April 1993/96

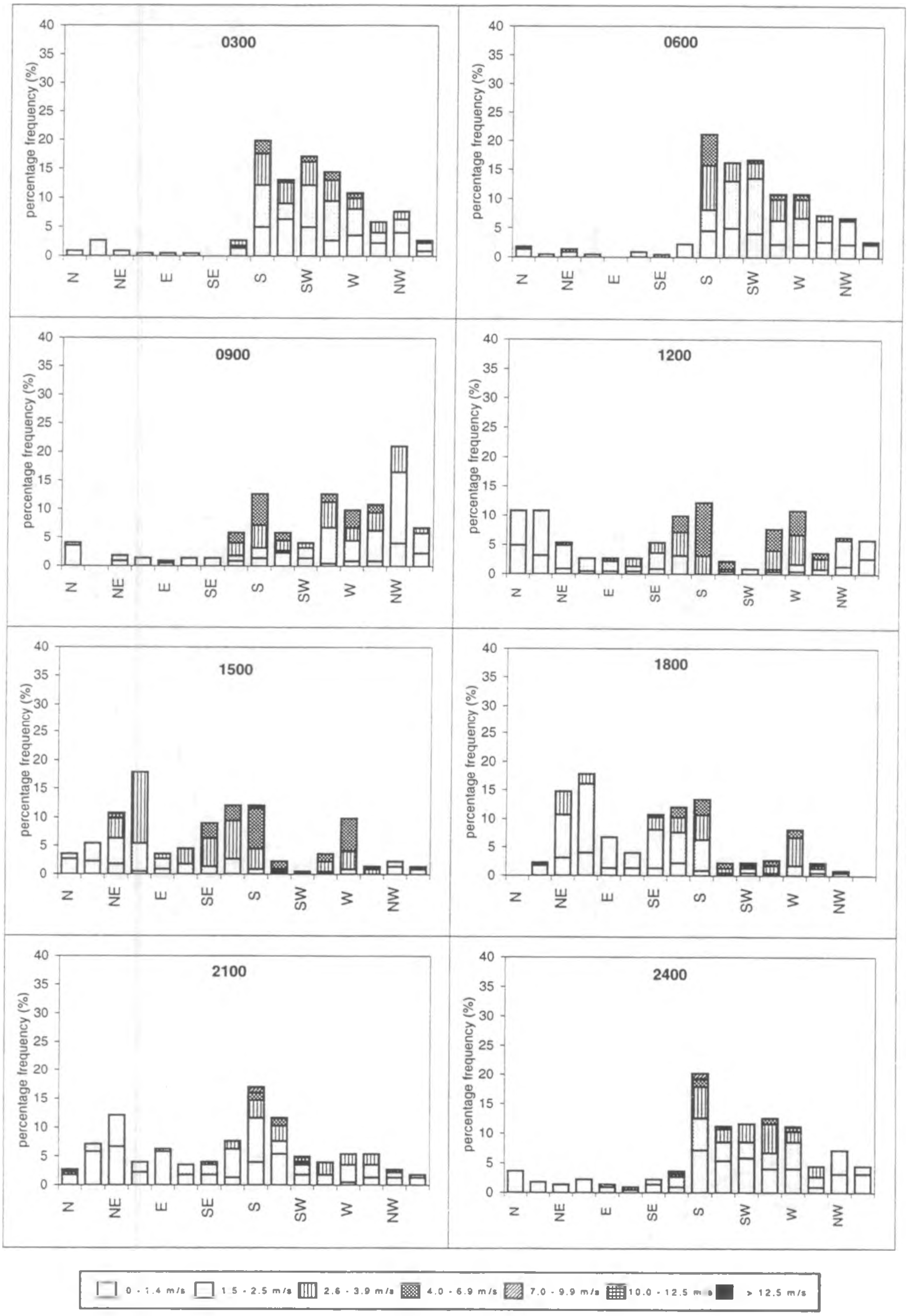

Figure A4.4 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) April (1993-1996); Source - ANSTO

Lucas Heights (10m) - May 1993/96

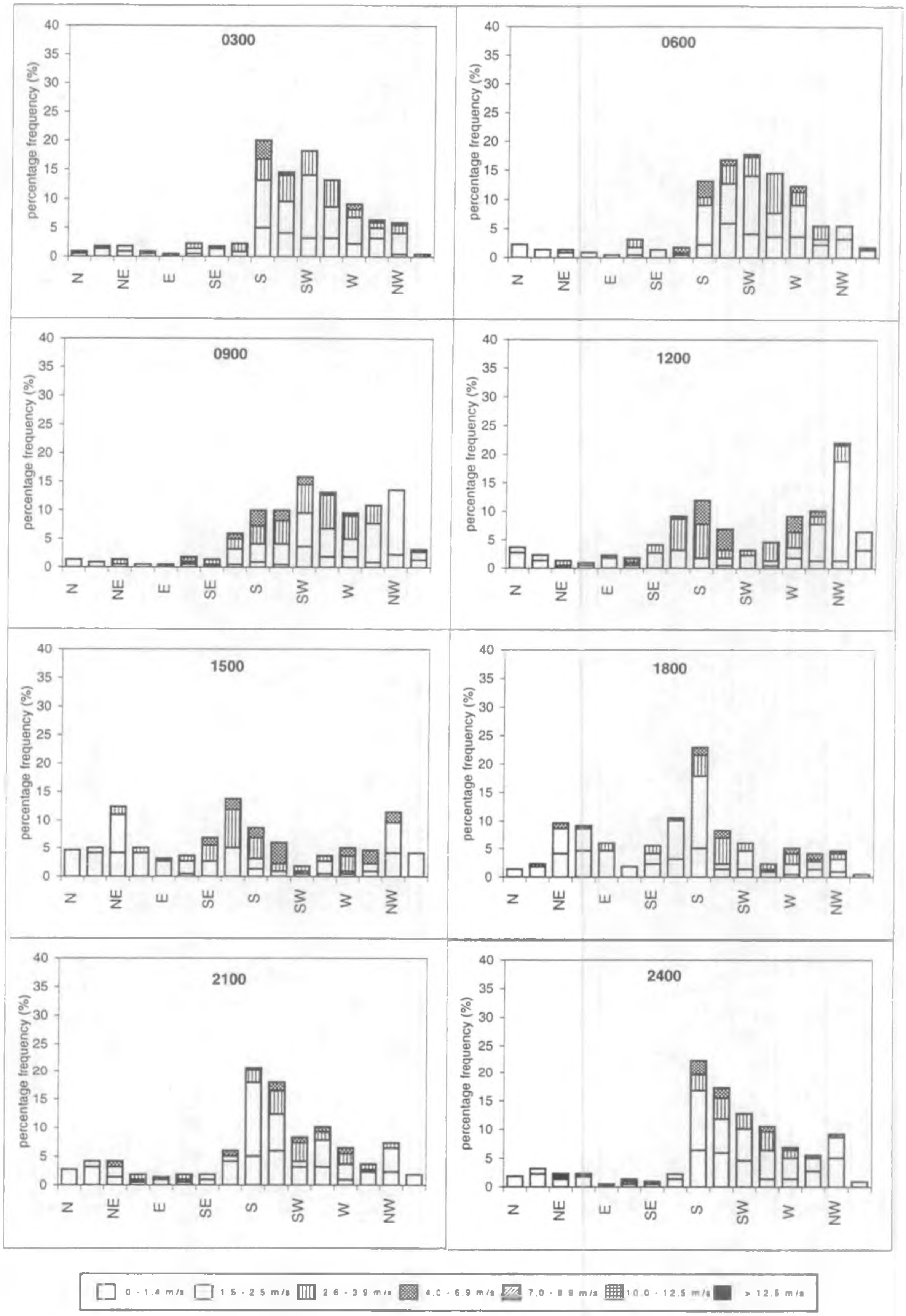

Figure A4.5 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) May (1993-1996); Source - ANSTO

Lucas Heights (10m) - June 1993/96

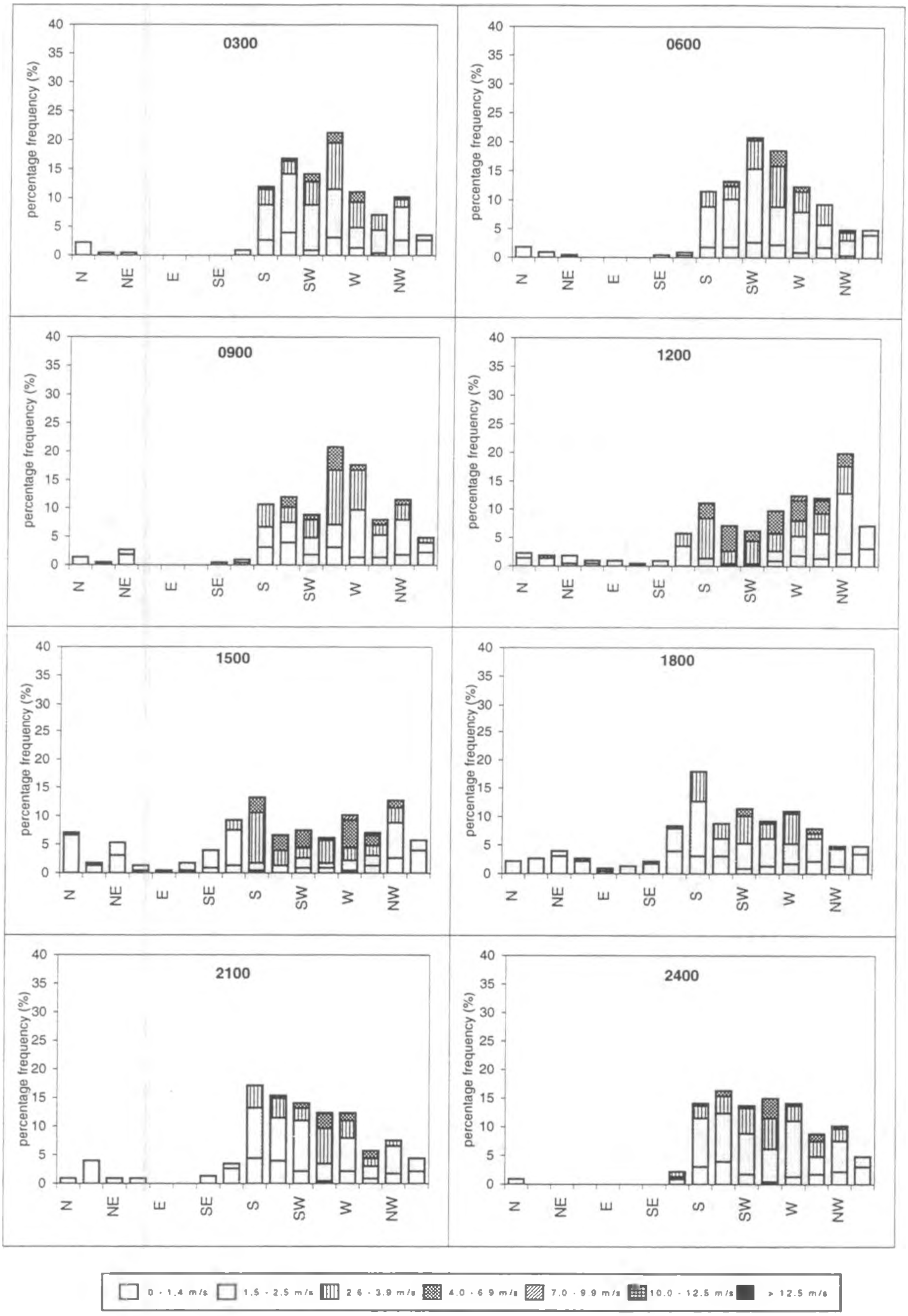

Figure A4 6 Three-houly wind speed and direction frequency distribution. Lucas Heights (10m) June (1993-1996); Source - ANSTO

Lucas Heights July 1993/96

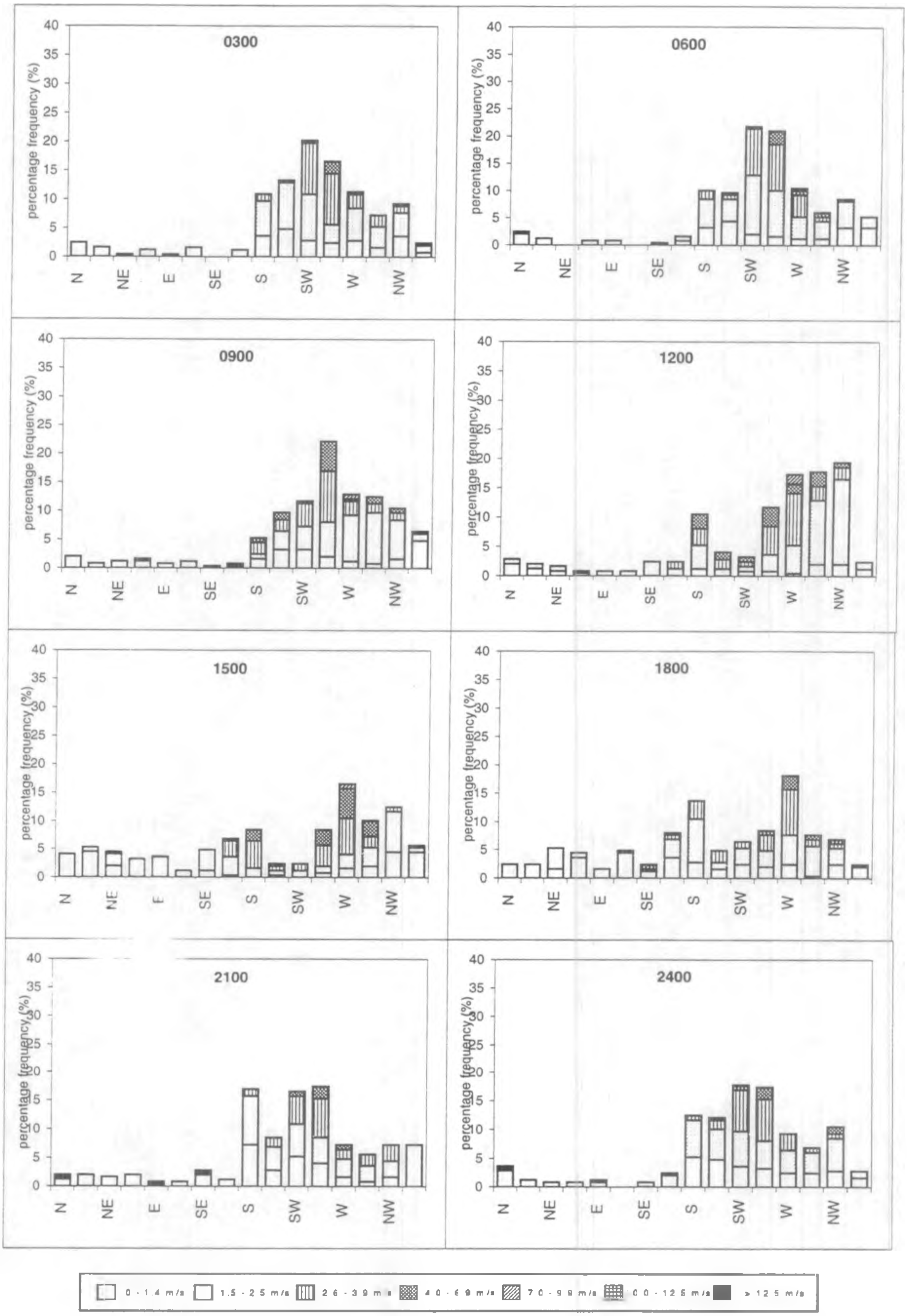

Figure A4.7 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) July (1993-1996); Source - ANSTO

Lucas Heights 10m August 1993/96

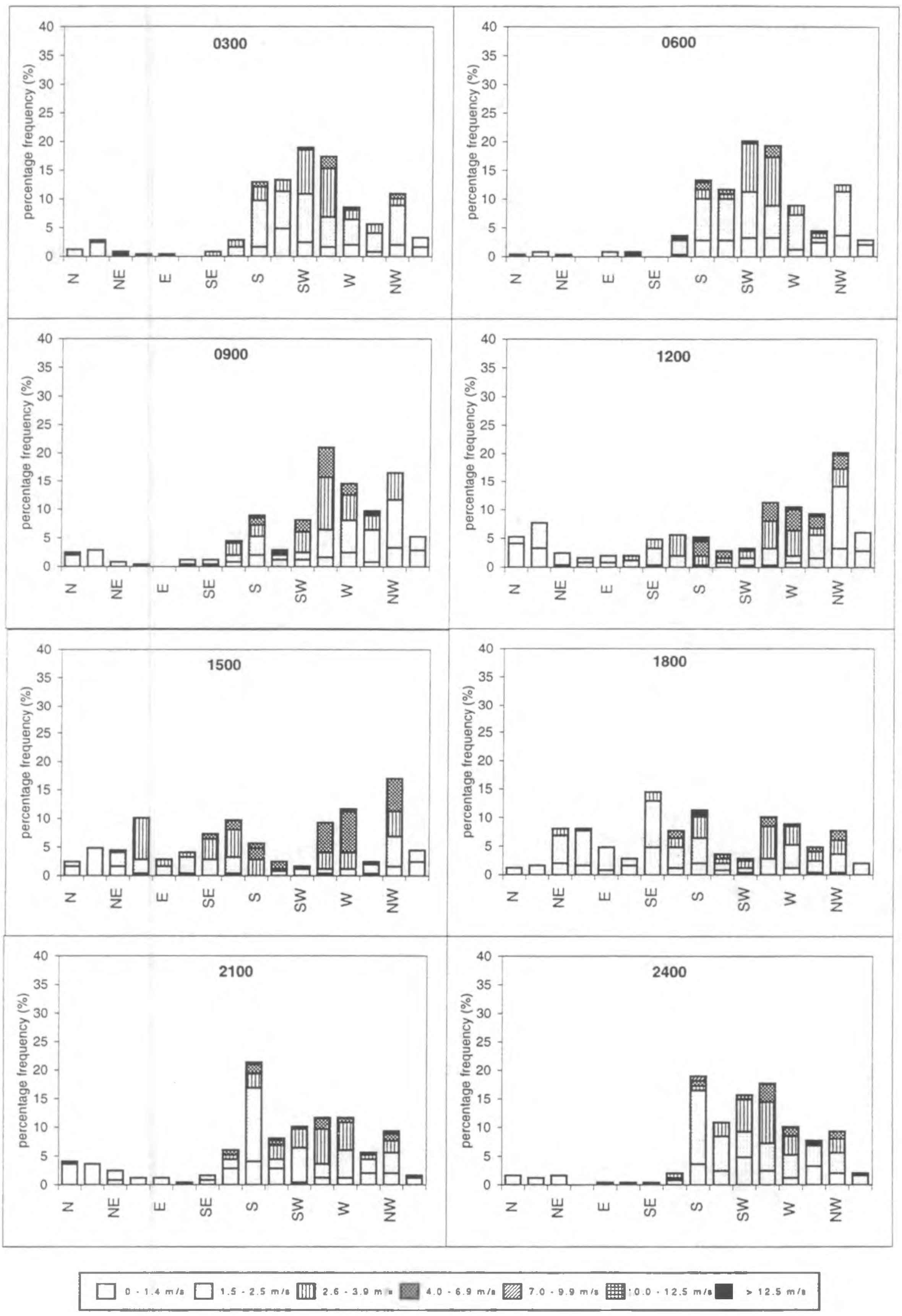

Figure A4.8 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) August (1993-1996); Source - ANSTO

Lucas Heights September 1993/96

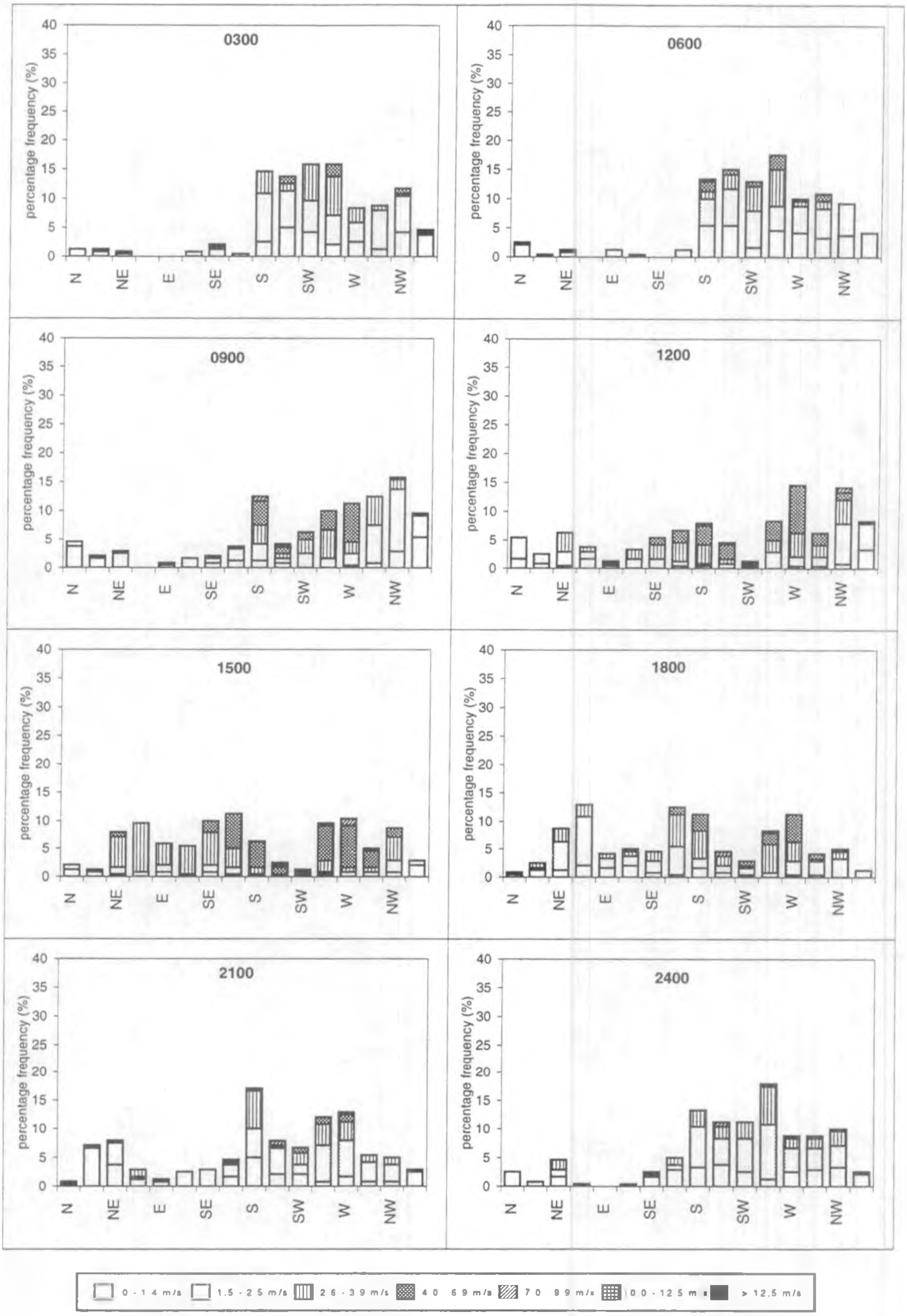

Figure A4.9 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) September (1993-1996); Source - ANSTO

Lucas Heights - 10m October 1992/95

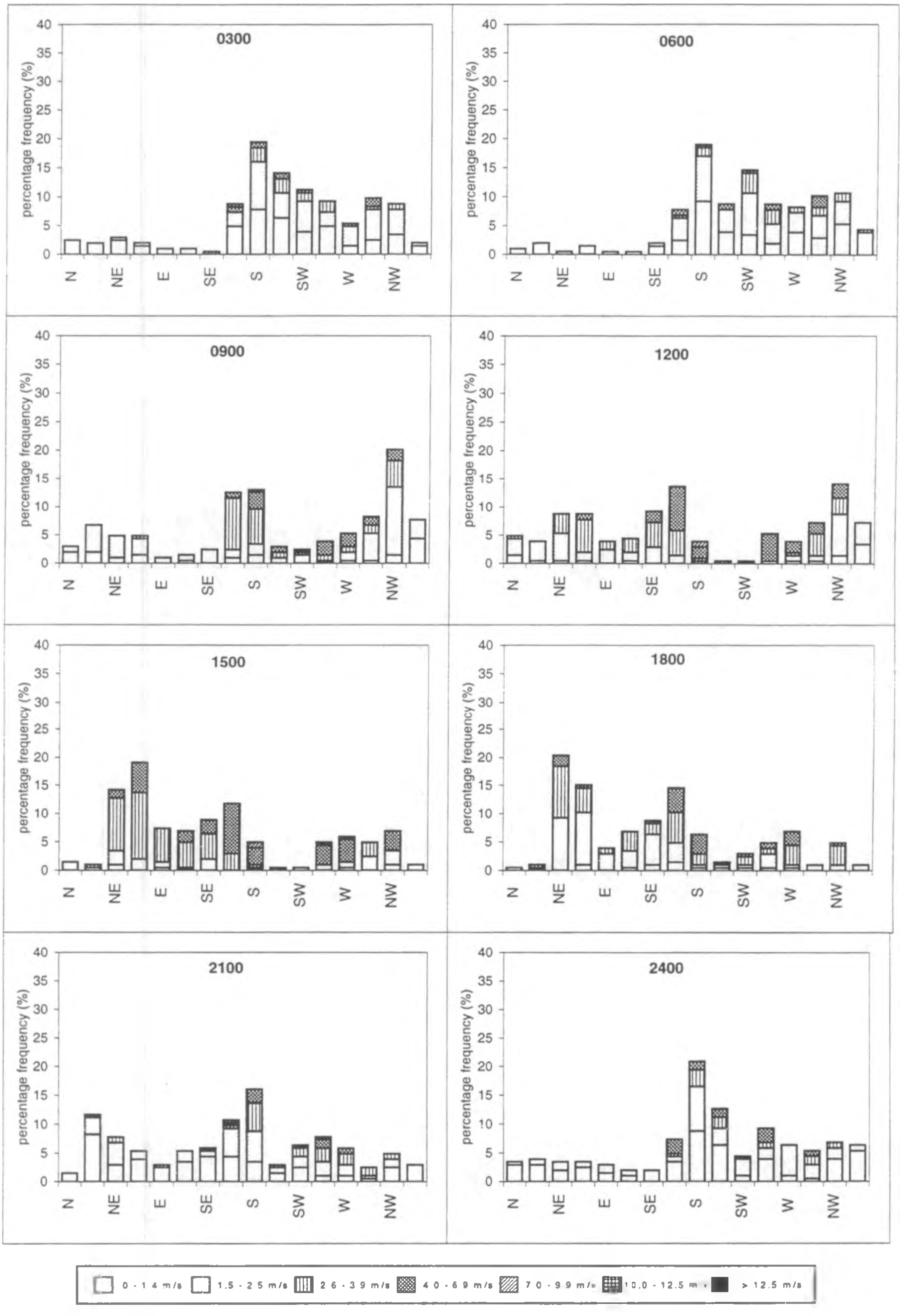

Figure A4.10 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) October (1993-1996); Source - ANSTO

Lucas Heights 10m November 1992/95

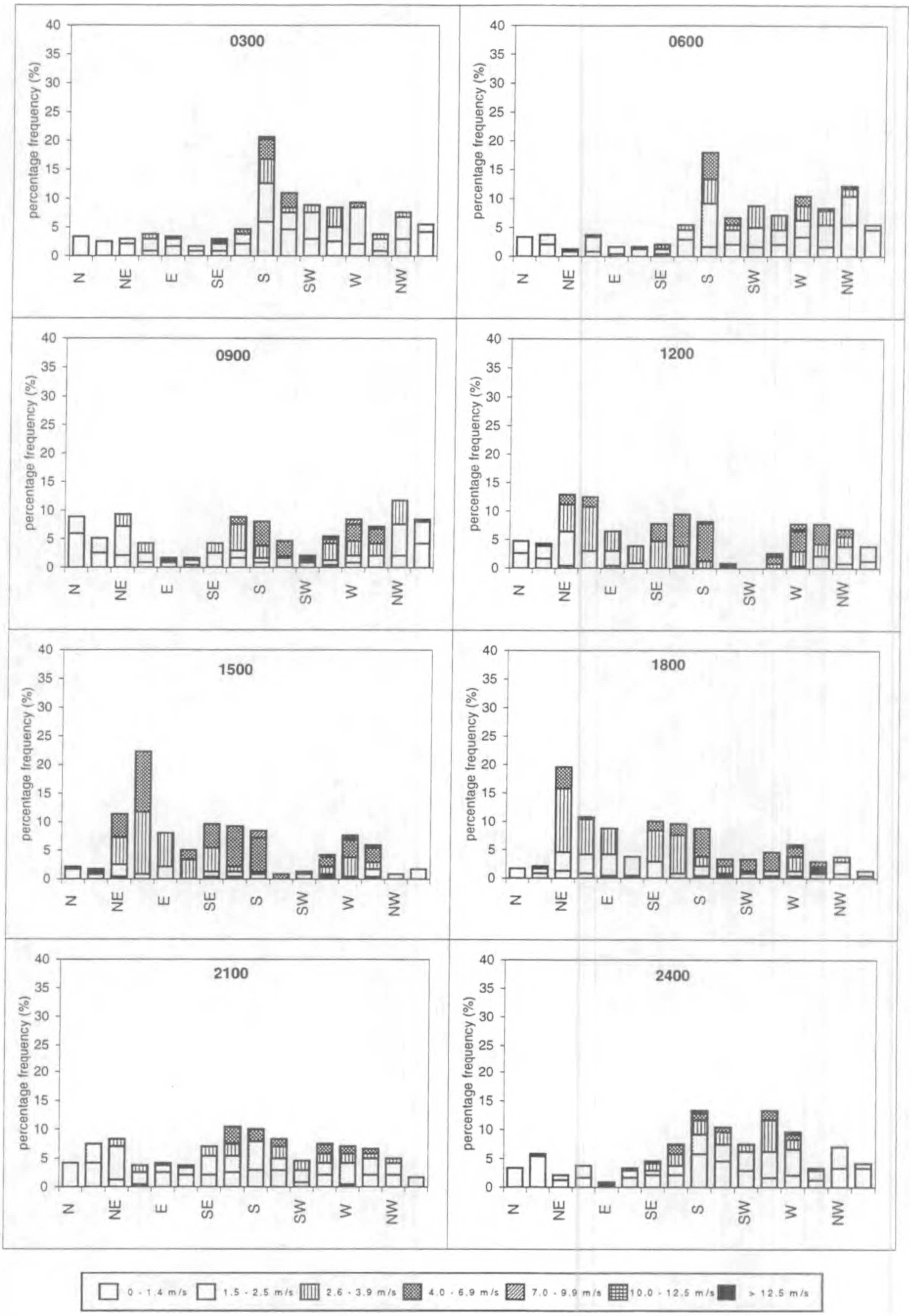

Figure A4.11 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) November (1993-1996); Source - ANSTO

Lucas Heights - 10m December 1992/95

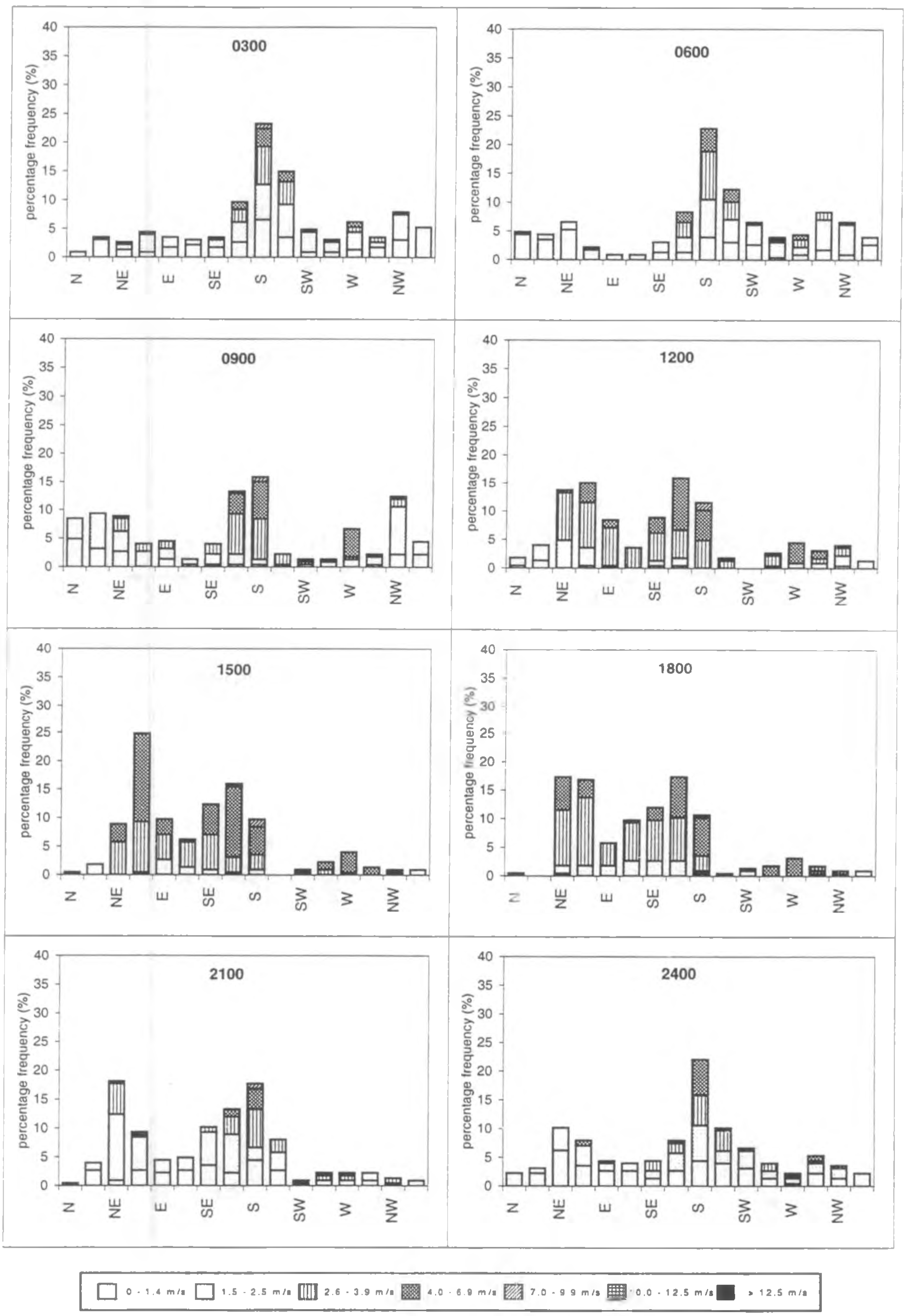

Figure A4.12 Three-houly wind speed and direction frequency distribution, Lucas Heights (10m) December (1993-1996); Source - ANSTO

Appendix 5

Diurnal Wind Speed and Speed and Direction Analyses at Three-Hourly Intervals in Each Month at Lucas Heights - 49 metres

Lucas Heights (49m) - January 1993/96

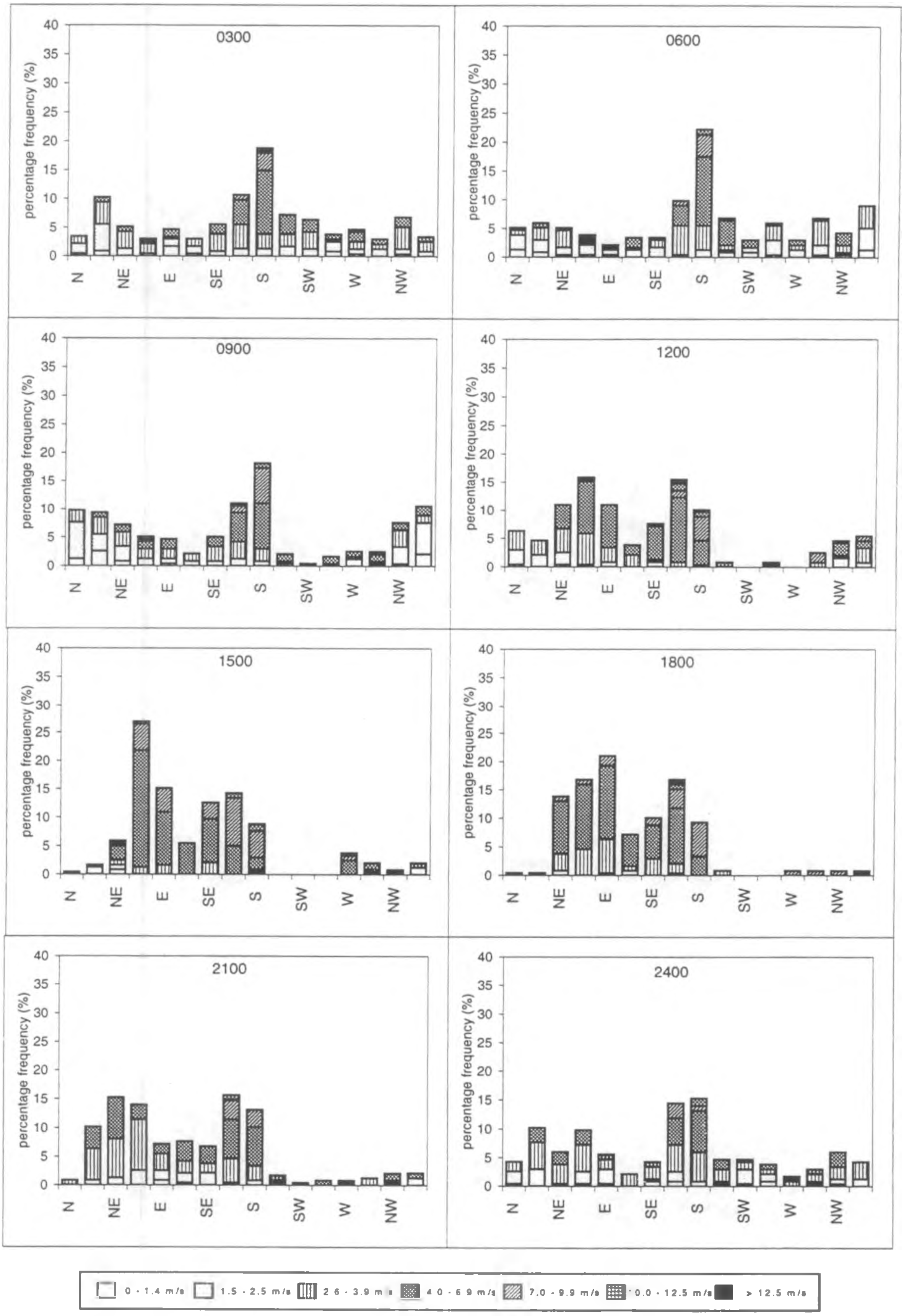

Figure A5.1 Three-hourly wind speed and direction frequency distribution. Lucas Heights (49m) January (1993 - 1996); Source - ANSTO

Lucas Heights (49m) - February 1993/96

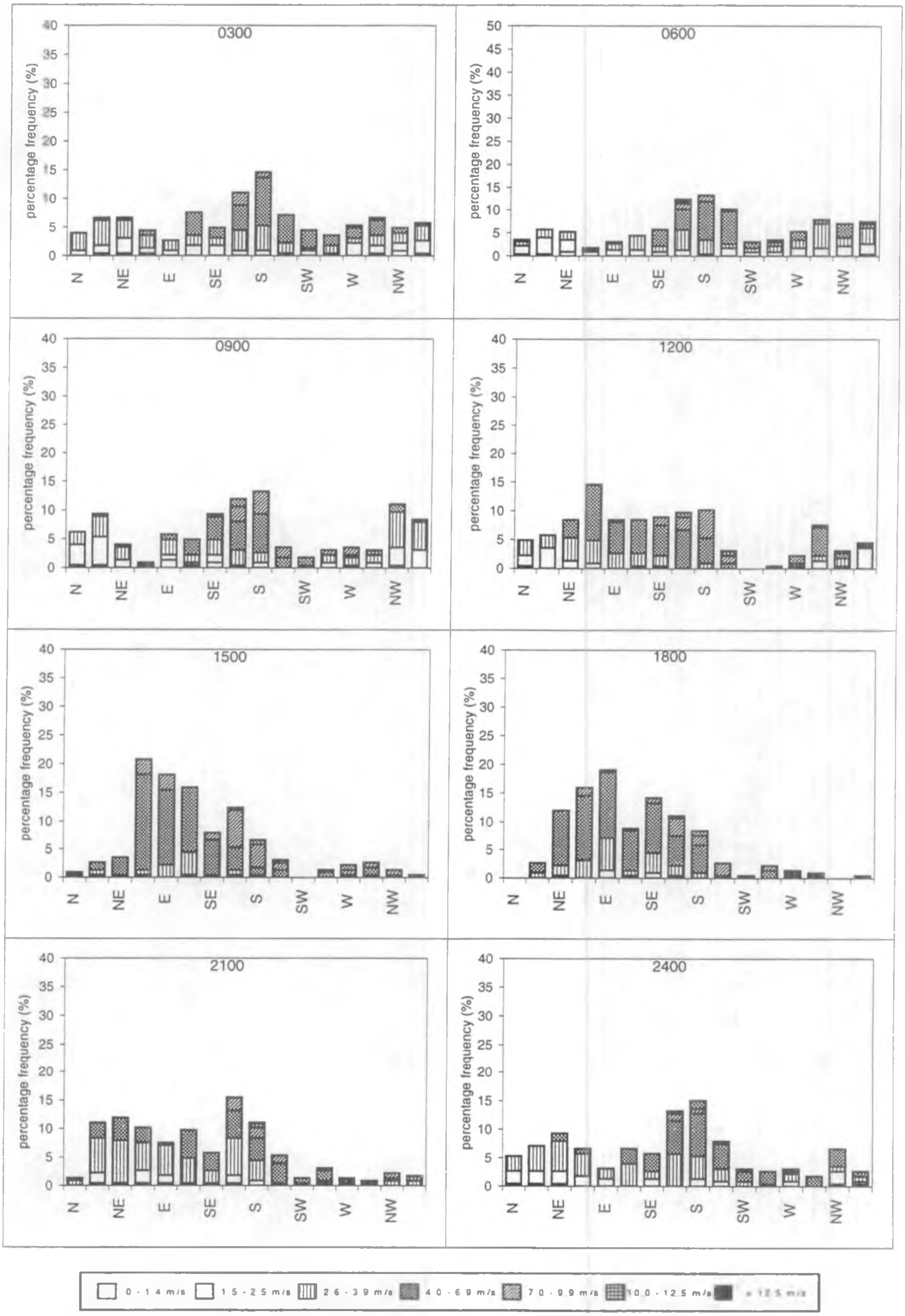

Figure A5.2 Three-hourly wind speed and direction frequency distribution. Lucas Heights (49m) February (1993 - 1996); Source - ANSTO

Lucas Heights (49m) - March 1993/96

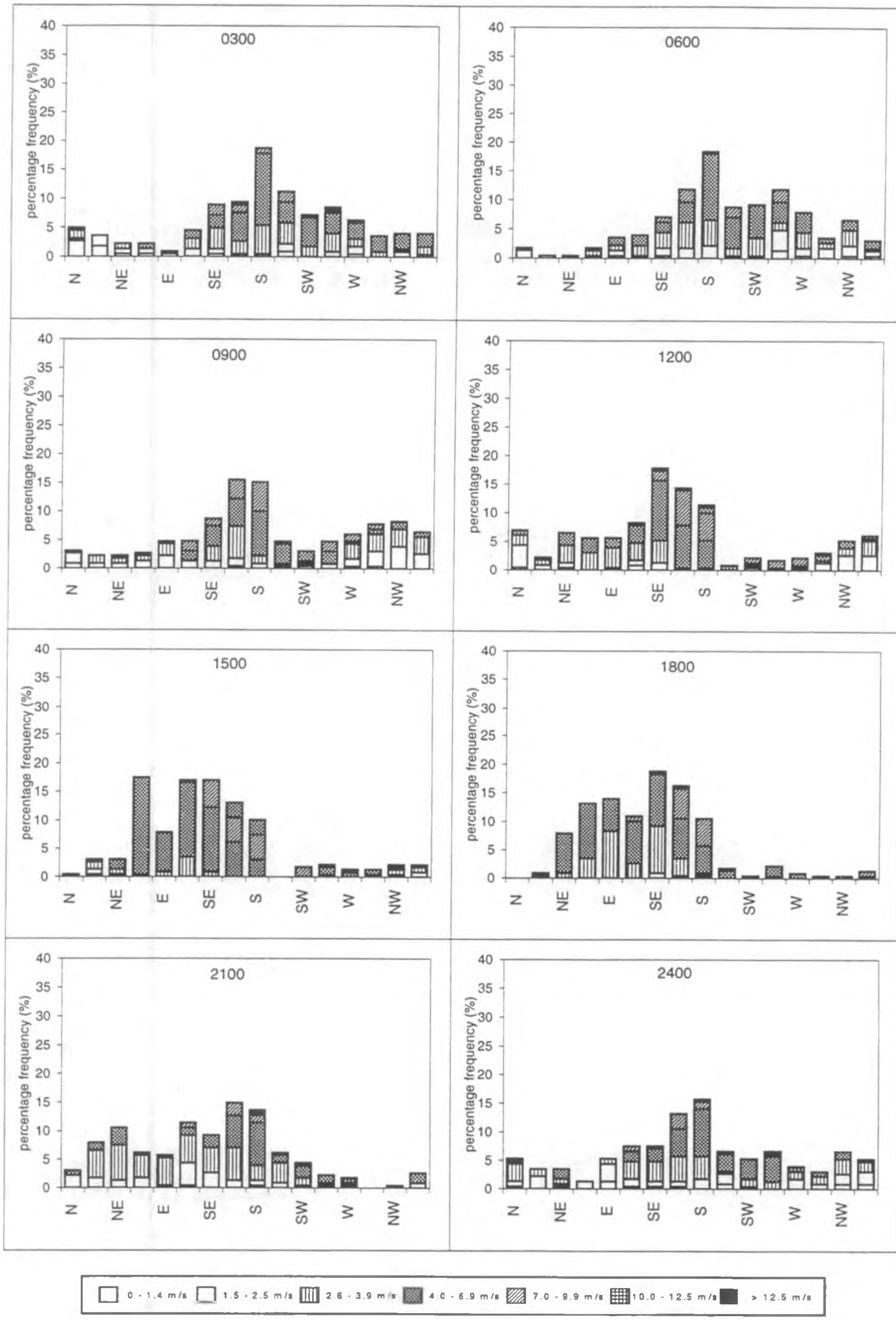

Figure A5.3 Three-hourly wind speed and direction frequency distribution. Lucas Heights (49m) March (1993 - 1996); Source - ANSTO

Lucas Heights (49m) - April 1993/96

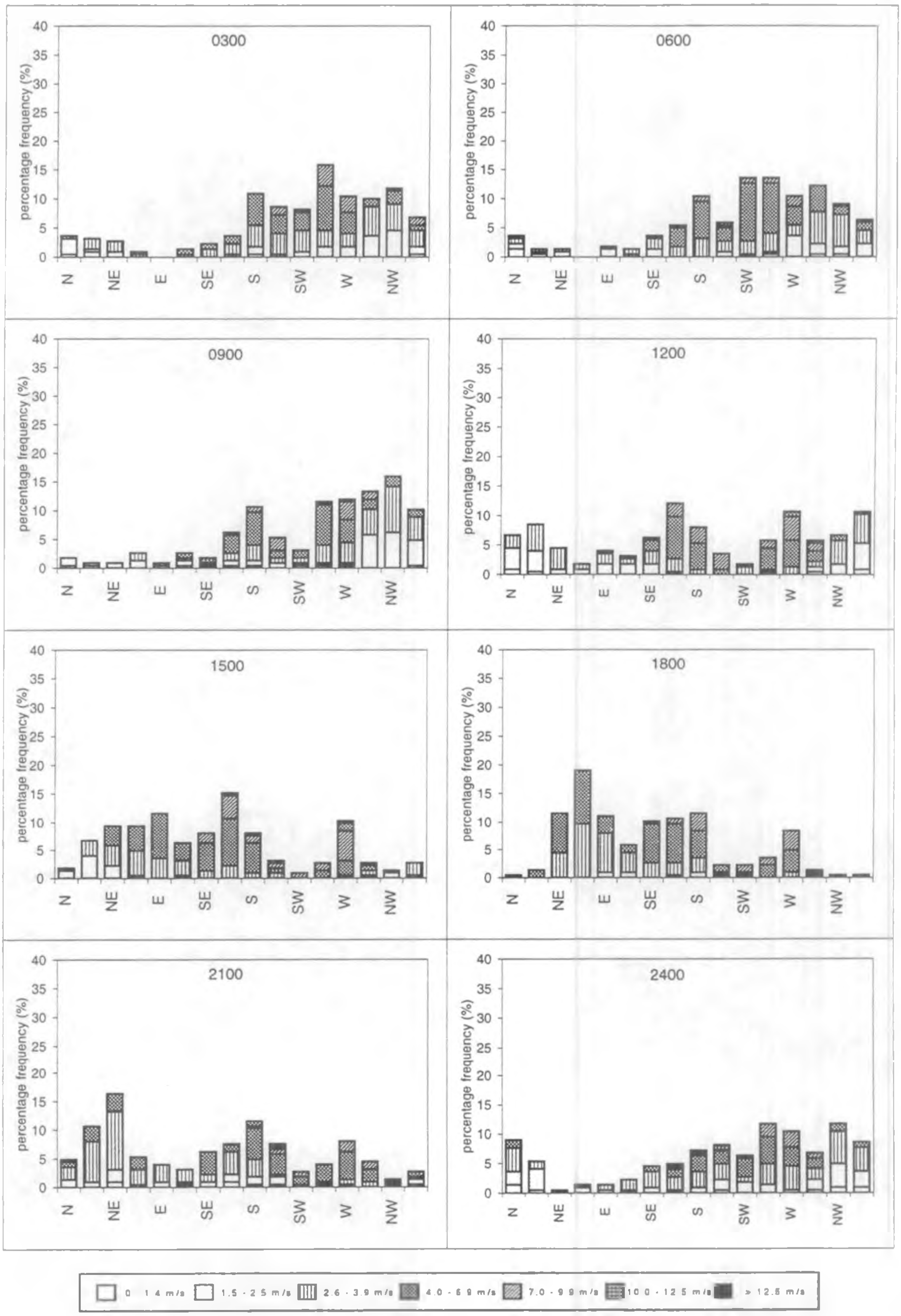

Figure A5.4 Three-hourly wind speed and direction frequency distribution. Lucas Heights (49m) April (1993 - 1996); Source - ANSTO

Lucas Heights (49m) - May 1993/96

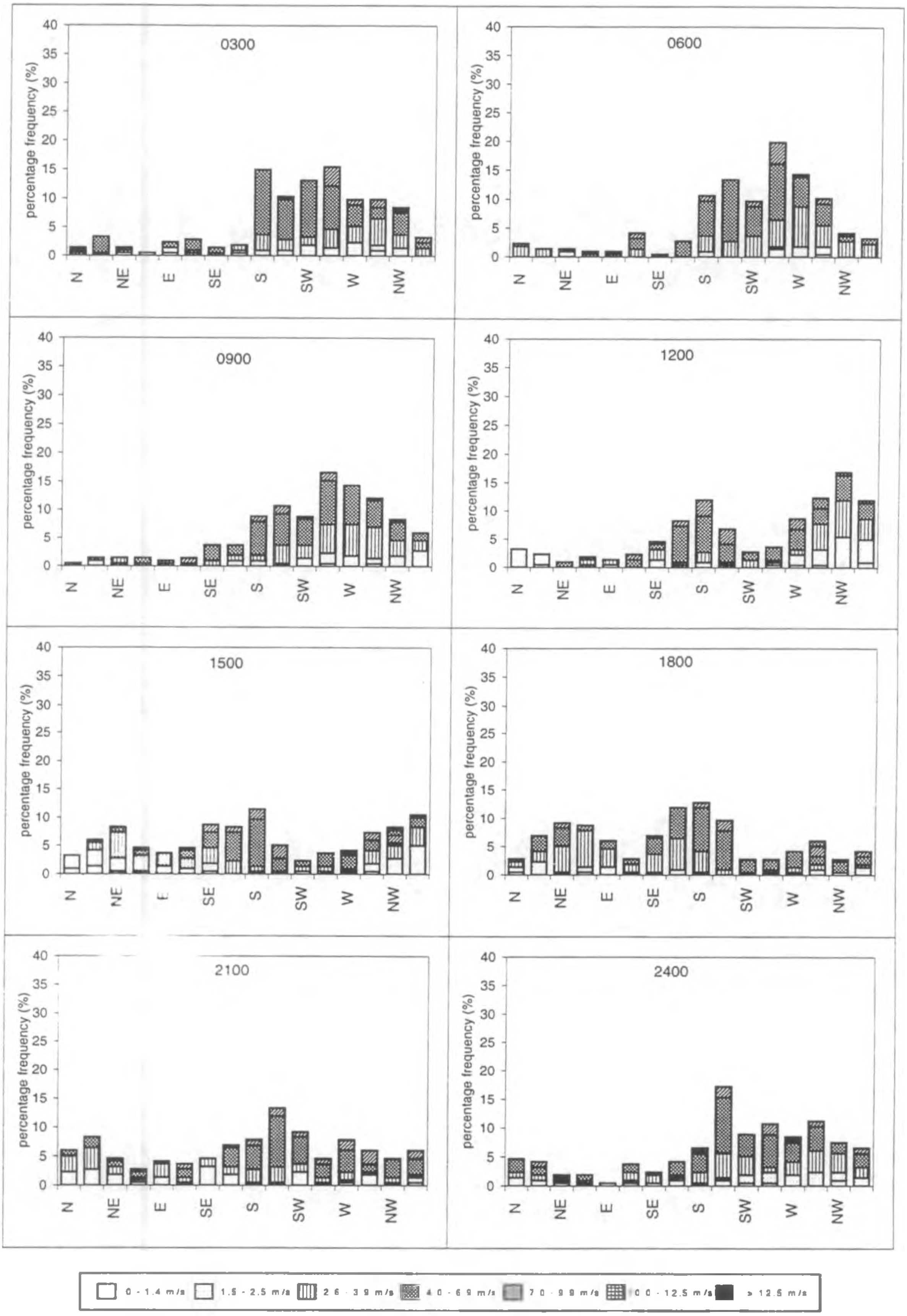

Figure A5.5 Three-hourly wind speed and direction frequency distribution. Lucas Heights (49m) May (1993 - 1996); Source - ANSTO

Lucas Heights (49m) - June 1993/96

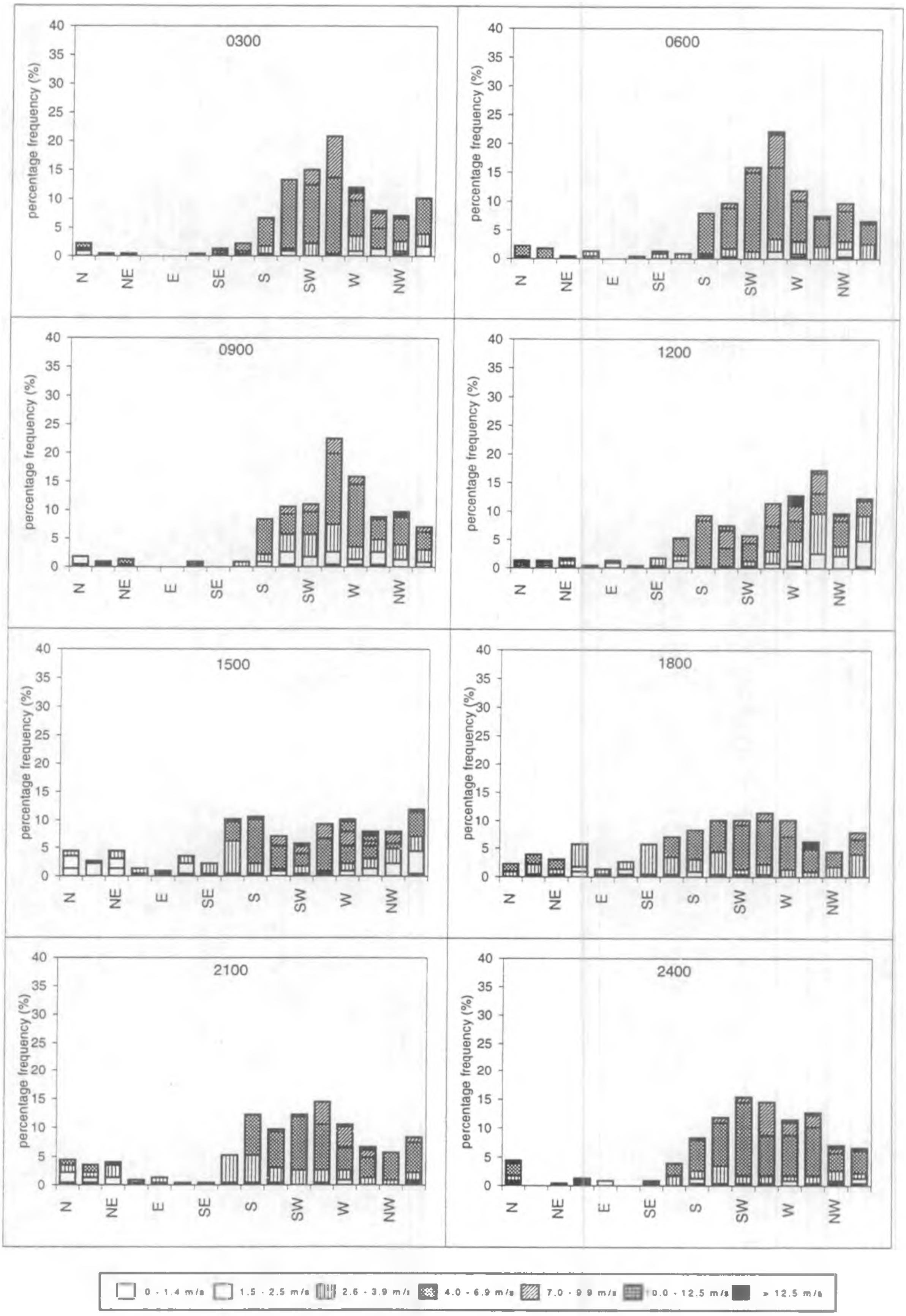

Figure A5.6 Three-hourly wind speed and direction frequency distribution. Lucas Heights (49m) June (1993 - 1996); Source - ANSTO

Lucas Heights (49m) - July 1993/96

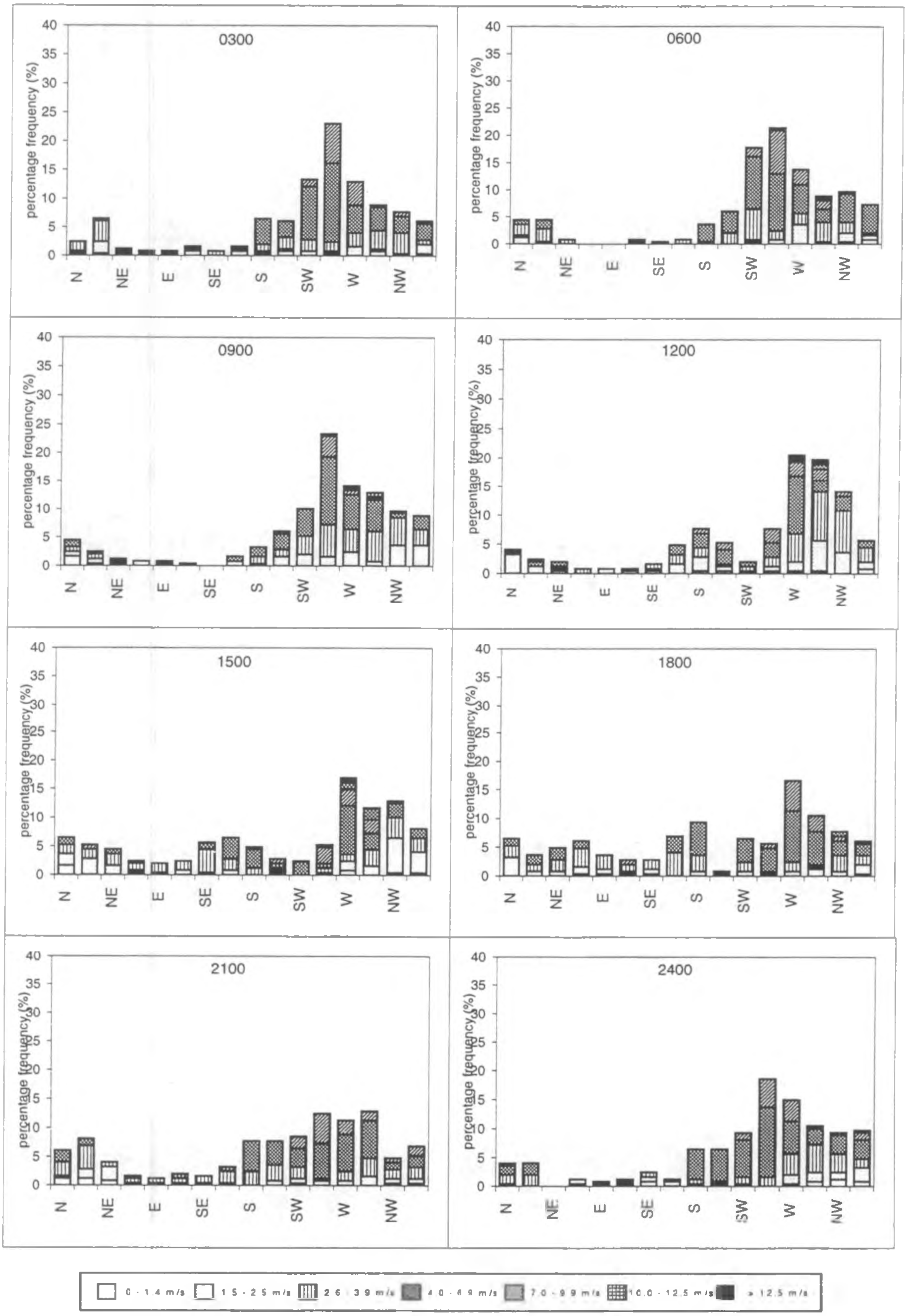

Figure A5.7 Three-houly wind speed and direction frequency distribution, Lucas Heights (49m) July (1993-1996); Source - ANSTO

Lucas Heights (49m) - August 1993/96

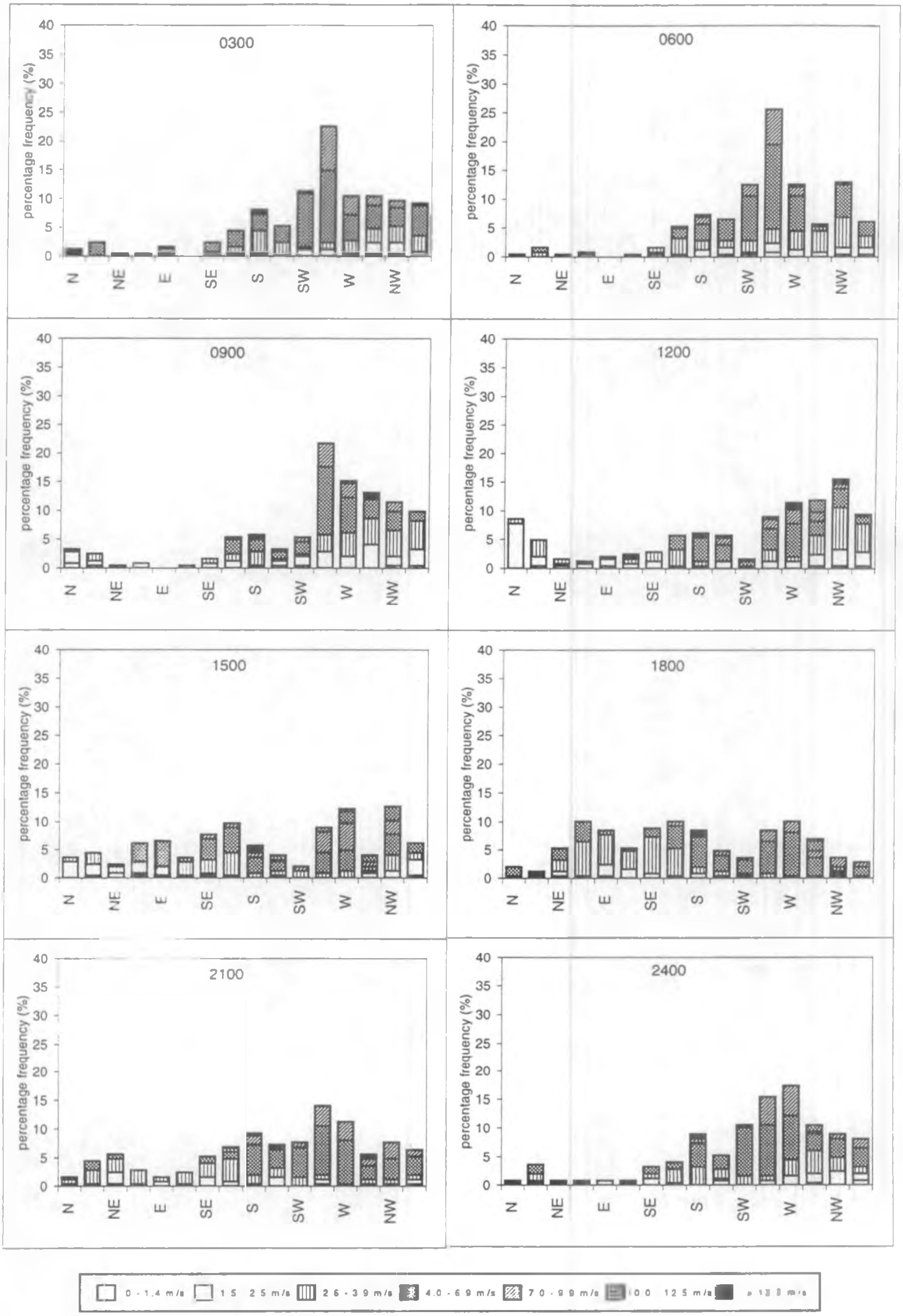

Figure A5.8 Three-houly wind speed and direction frequency distribution, Lucas Heights (49m) August (1993-1996); Source - ANSTO

Lucas Heights (49m) - September 1993/96

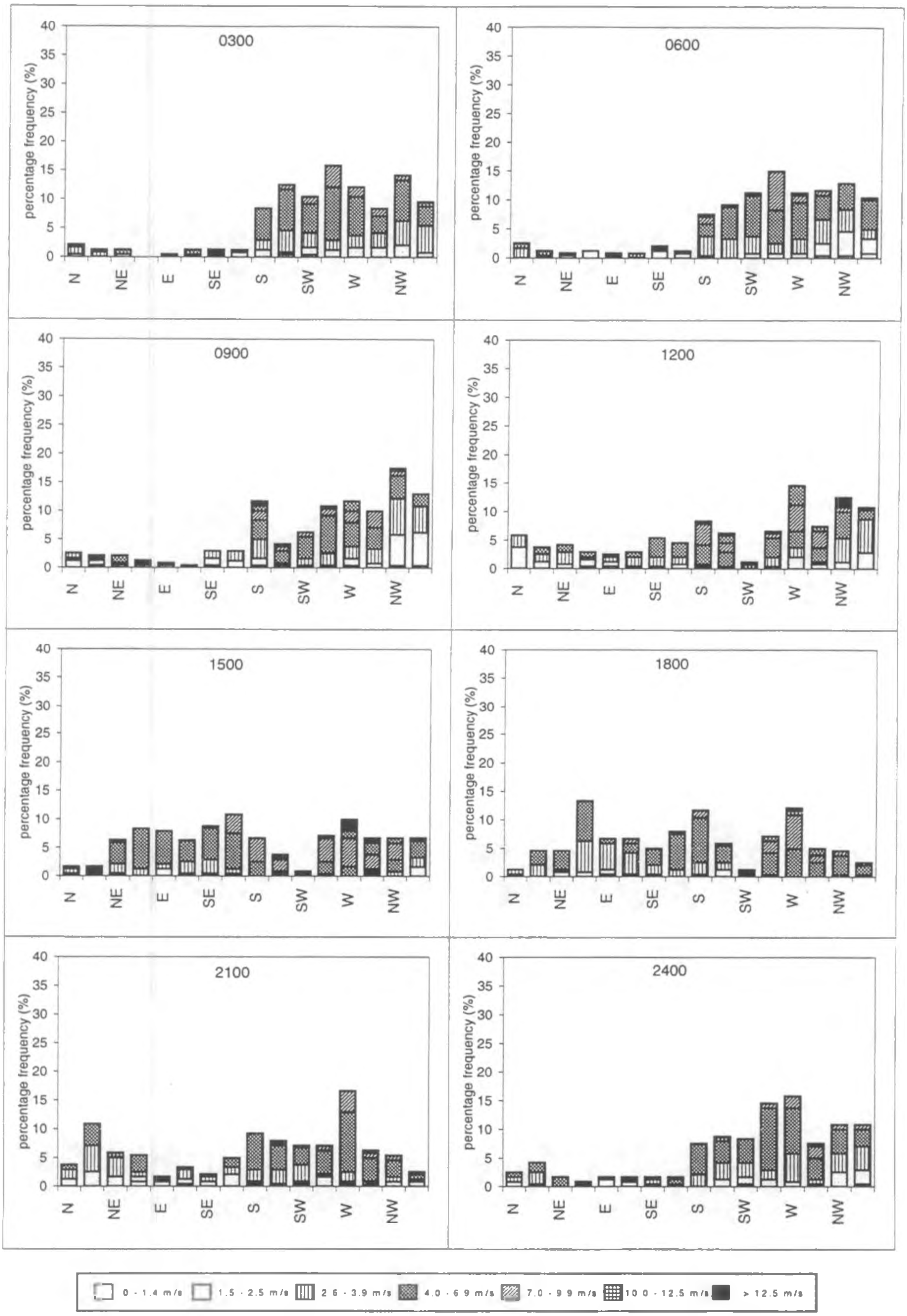

Figure A5.9 Three-houly wind speed and direction frequency distribution, Lucas Heights (49m) September (1993-1996); Source - ANSTO

Lucas Heights (49m) - October 1992/95

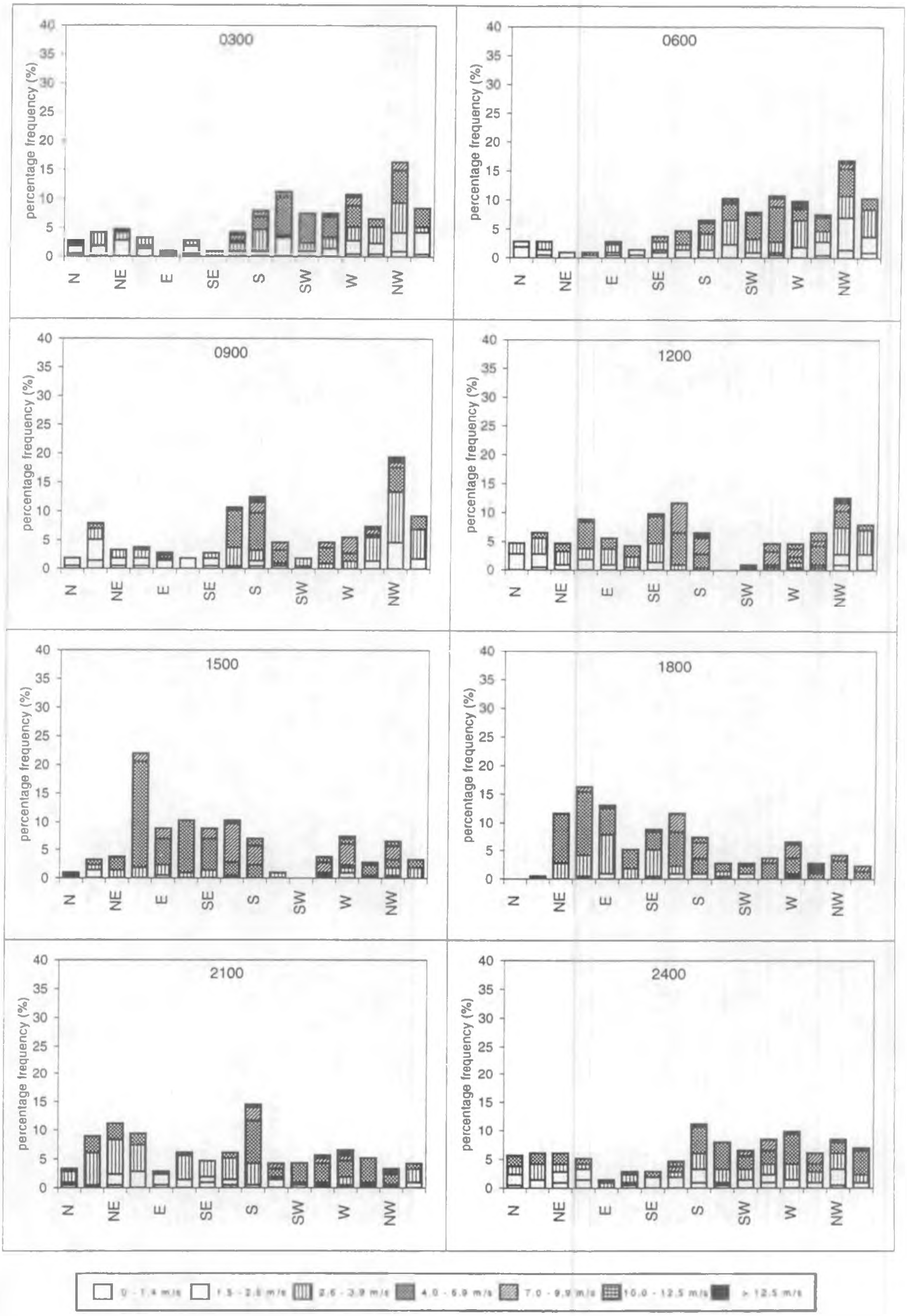

Figure A5.10 Three-houly wind speed and direction frequency distribution, Lucas Heights (49m) October (1992-1995); Source - ANSTO

Lucas Heights (49m) - November 1992/95

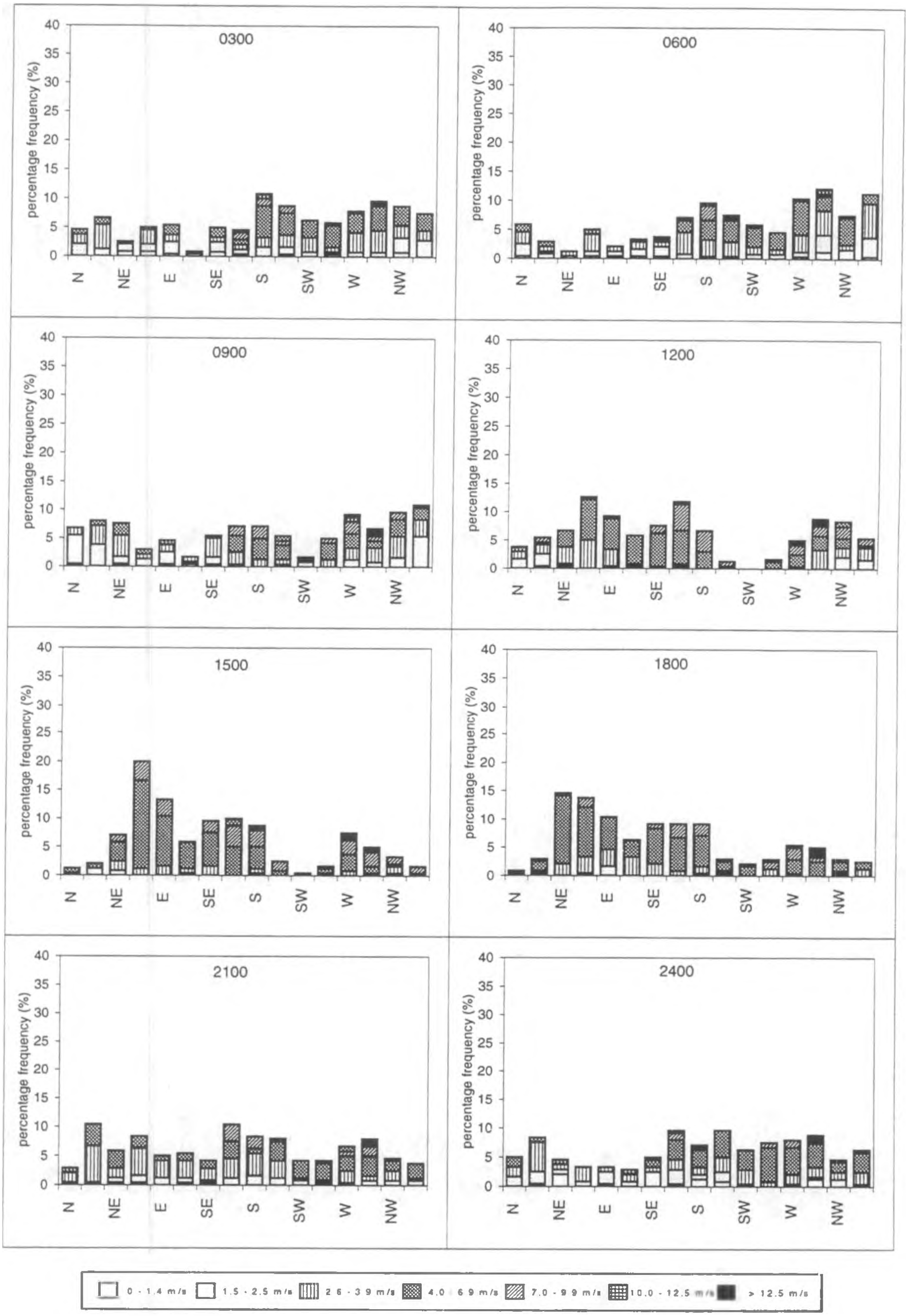

Figure A5.11 Three-houly wind speed and direction frequency distribution, Lucas Heights (49m) November (1992-1995); Source - ANSTO

Lucas Heights (49m) - December 1992/95

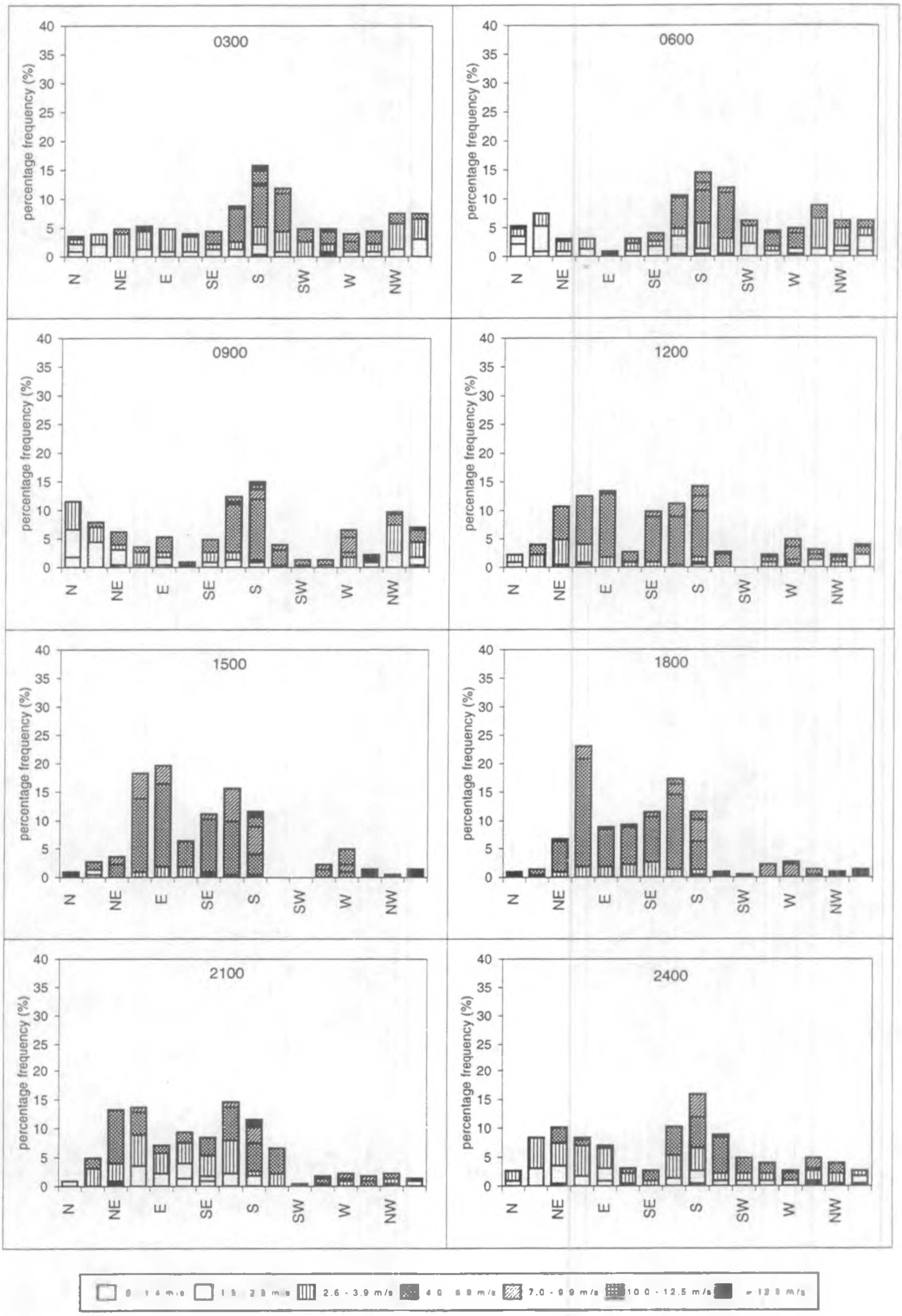

Figure A5.12 Three-houly wind speed and direction frequency distribution, Lucas Heights (49m) December (1992-1995); Source - ANSTO