Wave Direction Distributions off Sydney, New South Wales

M.A. KULMAR
Engineer, NSW Public Works, Manly Hydraulics Laboratory

Summary The deployment of a Datawell Directional Waverider buoy off the Sydney coast in March 1992 has provided the opportunity to compare wave direction information captured by the buoy with coincident observed/hindcast estimates and longer term data sets available in previously published material. Preliminary analysis of over two years of data captured by the Directional Waverider buoy suggests that the directional distribution differs from both the observed/hindcast coincident data and the longer term data sets. A higher level of wave energy from the SE-S and a lower occurrence of N-NE wave energy is evident in the Directional Waverider data set. Whilst a longer Directional Waverider record length will be required to confirm the results and provide seasonal and annual wave direction variations, future coastal zone studies along the NSW coast will benefit as the Sydney Directional Waverider buoy database continues to expand.

1 INTRODUCTION

NSW Public Works maintains a network of seven offshore non-directional Waverider buoys along the NSW coastline. Details of the network and the NSW Wave Climate have been included in earlier publications by Webb (1), Webb and Kulmar (2) and Wyllie et al (3). Since 1986, in an effort to routinely catalogue the data captured by the Waverider network, Annual Wave Climate Summaries have been published by NSW Public Works' Manly Hydraulics Laboratory (4).

An obvious shortcoming of the extensive NSW Public Works wave database, which now extends back over 20 years, is the paucity of quality wave directional information. A number of techniques to estimate wave direction have been evaluated by Manly Hydraulics Laboratory (MHL). The techniques examined are briefly discussed, together with any limitations. As a result of this work, wave directional information derived from land based observations and hindcasting has been incorporated in the wave database maintained by MHL.

The addition of a Datawell Directional Waverider (DWR) to the NSW Waverider network in March 1992 has provided the opportunity to measure deepwater wave direction off the Sydney coastline. The preliminary results of over two years of directional wave data collected at the Sydney site are presented in this paper. These results are compared to coincident directions estimated from shore observations or by hindcasting and also to longer term wave direction distributions available from previously published material.

It should be noted that whilst the DWR can provide information on the directional spectrum, the data sets available for comparison are only based on daily estimates of the principal wave direction. Hence the value of the principal wave direction calculated by the DWR system (that is, the direction which corresponds to the peak of the energy spectrum) will only be included in this paper.

2 NEW SOUTH WALES WAVE DIRECTION DATA

2.1 Wave Generation

The NSW coast is subject to a moderate to high energy wave climate. Waves are mainly generated in the Tasman Sea between NSW and New Zealand. Several types of meteorological systems that move over the Tasman Sea generate waves which approach the NSW coast. Tropical cyclones that develop during summer and early autumn in the Coral Sea east of Queensland generate swell which can travel into the Tasman Sea before arriving at the NSW coast (Figure 1). Detailed descriptions of wave generating systems that influence the NSW coast are included in Blain Bremner and Williams/Weatherex (5).

The large fetches available for wave generation in the Tasman and Coral Seas often result in wave energy from different fetches simultaneously approaching the NSW coast. On these occasions differentiation of the principal wave direction can prove difficult.

2.2 Wave Direction Measurement

The merits of several methods to estimate principal wave direction have been examined by MHL, including:

- radar imaging;
- aerial photography;
- boat and land based observations;
- electromagnetic current meters with a pressure sensor;
- hindcasting techniques using synoptic weather charts and other meteorological information;
- satellite imagery.

These techniques have met with mixed results. Whilst work by Webb (1) and PW (6) proved that wave direction could be measured by X-band radar, high operating costs and the labour intensive nature of the data reduction process prevented its introduction as a routine wave direction measurement system. The radar system has however been used successfully for several projects in which inshore wave refraction and diffraction information was required.

Vertical aerial photography, under favourable sea and weather conditions, was used to verify directions estimated from the radar images during the development of the radar system. Again, this method was not considered for routine direction measurement due to high costs and the dependence on favourable weather conditions necessary for safe low altitude (3,000m) flying operations.

The relatively low cost to obtain directional observations from boats or land makes this method attractive to provide routine directional information. However, observations from both boats and land have limitations. An observer on a boat, being close to the sea surface, has difficulty determining the principal wave direction unless a well defined, dominant wave train is present. Shore based observation, if undertaken from an elevated headland, can be more successful. However, wave refraction makes the estimation of the offshore direction difficult, particularly if the waves approach the coast at an acute angle (ie. N-NE and SSE-S for the NSW coast).

For shallow water sites (<25m) electromagnetic current meters used in combination with a pressure sensor or wave staff can provide an estimate of the directional spectrum. This instrumentation is normally employed to capture inshore direction data and has been used in several projects by NSW Public Works. For offshore applications however, the attenuation of the shorter period waves and the significantly increased installation and maintenance costs normally preclude use of the instrumentation in deep water.

Before the introduction of affordable wave recording instrumentation, the manual interpretation of weather systems and associated wind fields from synoptic weather charts and other meteorological information (hindcasting) was often used to estimate wave conditions. The ready availability of meteorological information makes hindcasting a cost effective technique to estimate wave direction. However, the manual interpretation of synoptic charts makes hindcasting a very subjective technique, particularly at times when it is difficult to identify wave generating weather systems and when more than one weather system that may generate swell is present.

Remote sensing of wave direction through satellite images has been the subject of much recent study by various organisations. MHL (7) is investigating the feasibility of acquiring wave direction information from imagery gathered by the SPOT satellite. At present, this is the only commercial satellite available capable of gathering data to a resolution sufficient to detect wave direction. The limitations of the SPOT satellite system include the low frequency of overpasses and the need for cloud free atmospheric conditions to obtain useful images. SPOT images have already been used to verify information captured by the DWR. This work is briefly discussed in Section 4.3.

Evaluation of the techniques outlined above concluded that for deepwater directional data, land based observations or hindcasting proved to be the most cost efficient methods. As a result of the ongoing work at MHL, daily observed and/or hindcast wave direction information is available since January 1985 for the seven NSW Public Works offshore Waverider stations. In addition, a hindcast wave direction has been assigned to the peak of all storm events recorded at each deepwater Waverider buoy station. This has resulted in the development of a storm history database that provides a wave height, duration, power and direction summary for storms recorded by each offshore Waverider station.

3 SYDNEY OFFSHORE WAVE DATA

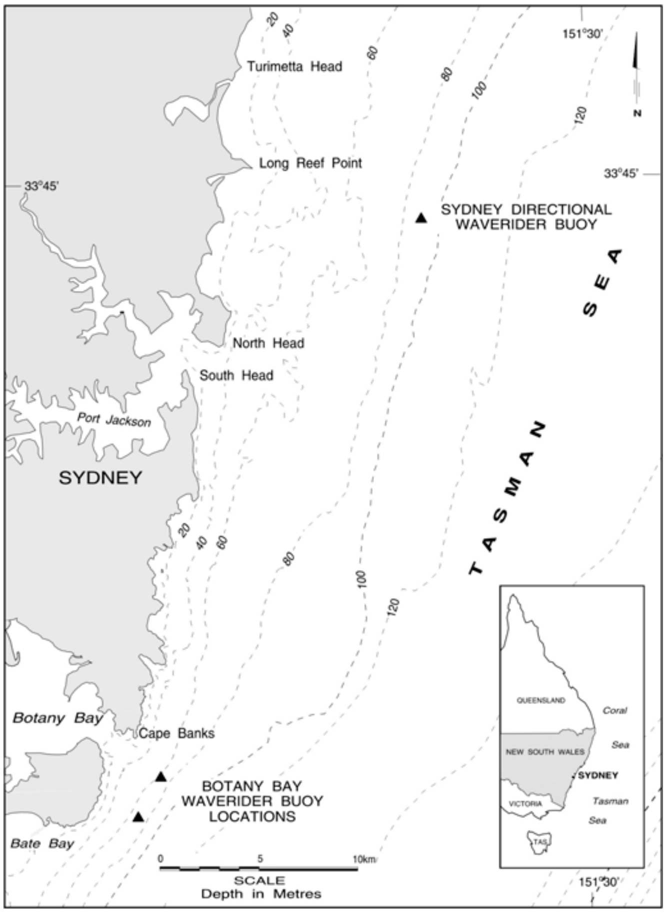

Figure 1 Sydney Offshore Wave Data Sites

Routine wave data collection off Sydney commenced in April 1971 when a Datawell Waverider buoy was deployed by Maritime Services Board, NSW approximately 3km off the entrance to Botany Bay in a depth of 73m (Figure 1). The wave climate, based on ten years of records at the Botany Bay Waverider sites, was summarised by Youll (8). This data set also included information on the principal wave direction distribution estimated from a combination of daily boat observations and hindcast estimates from synoptic charts. An update by Willoughby (9), examining 23 years of data captured by the Botany Bay Waverider system, is in preparation.

Since July 1987, NSW Public Works has maintained a deepwater (85m) Waverider buoy approximately 8km off

Sydney's northern beaches as part of the NSW Waverider network.

4 DATAWELL DIRECTIONAL WAVERIDER BUOY

4.1 General

As part of a study on wave direction measurement, MHL was commissioned by NSW Public Works' Coast and Flood Policy Branch to deploy a DWR off Sydney. The buoy commenced operation in March 1992 approximately 250m from the Sydney non-directional buoy (Figure 1). This dual deployment enabled a comparison of coincident wave height, period and spectral data recorded by each Waverider (non-directional and directional) system. It is of interest that the two buoys show a good correlation. The results of the comparison of the two buoys are given in PW (10).

4.2 Principle of Operation

The Directional Waverider buoy is manufactured by the Dutch company, Datawell (11). It is a spherical 0.9m diameter buoy that utilises a heave-pitch-roll sensor, two fixed 'X' and 'Y' accelerometers and a three axis fluxgate compass to measure both vertical and horizontal motion. A single point mooring is used with horizontal freedom ensured by the inclusion of two 15m rubber shock cords in the mooring system. An onboard processor converts the buoy motion to three orthogonal (vertical, north-south, east-west) translation signals that are telemetered to a shore station. The directional spectrum is also routinely calculated by the buoy and transmitted to the receiving station for storage. Following reformatting and quality control the data is added to the wave database resident at MHL.

4.3 Satellite Imagery Verification

As discussed in Section 2.2, images from the SPOT satellite have been acquired by MHL as part of a study on wave direction measurement. The images were selected to cover a wide range of offshore oceanographic and meteorological conditions to determine the criteria necessary to guarantee the selection of images that show well defined wave crests. This work verified the principal wave direction calculated by the DWR off Sydney. The direction of the wave crests measured from the SPOT images generally agreed within a few degrees of the wave direction measured by the DWR.

The results indicate that the DWR and satellite remote sensing can be successfully used to provide wave direction information. Further work refining the use of SPOT images is currently in progress at MHL.

5 WAVE DIRECTION DISTRIBUTIONS

Over two years of wave direction data captured by the DWR is available for comparison with three other deepwater wave directional data sets:

- a coincident record based on observed and hindcast direction estimates for the Sydney Waverider/DWR site;
- two longer term (10 and 18 years) records based on observed and hindcast directional estimates for the Maritime Services Board Botany Bay Waverider system.

Details of the four data sets examined, including the reference or source of the information, is presented in Table 1.

6 WAVE DIRECTION COMPARISONS

6.1 Preamble

The NSW coastline is generally orientated NNE to SSW. For this study, deepwater wave information is grouped into eight 22.5° direction bands relative to True North. The bands adopted represent the offshore compass directions that can approach the NSW coast (ie. N, NNE, NE, ENE, E, ESE, SE, SSE and S). Waves moving away from the coast generated by strong, long duration offshore winds (SW-NNW) have been recorded by the Sydney DWR. These only represent a 0.66% occurrence and are therefore not included.

Table 1 Sydney Offshore Wave Direction Data Sets

Data Set	First Date	Last Date	% Data	Principal Wave Direction Origin	Reference / Source
Botany Bay 10 yrs	01-May-71	30-Apr-81	87	Daily boat observations (1971-75), hindcasting (1976-81)	Youll (8) & PW (12)
Botany Bay 18 yrs	09-Apr-71	23-Aug-89	Not Available	Daily boat observations (1971-75), hindcasting (1976-89)	Nielsen et al (13)
Sydney O/H 2 yrs	03-Mar-92	31-Dec-94	95	Daily land observations & hindcasting	NSW Public Works, Manly Hydraulics Lab
Sydney DWR 2 yrs	03-Mar-92	31-Dec-94	74	Hourly direction at peak of energy spectrum	NSW Public Works, Manly Hydraulics Lab

6.2 Total Directional Data Sets

The wave direction distribution for each complete data set is presented in Figure 2. A strong bias to the SE-S sector is apparent for the DWR data. The long term Botany Bay records correlate, while the shorter two year observed/hindcast data for the Sydney Waverider site displays a bias to the SE.

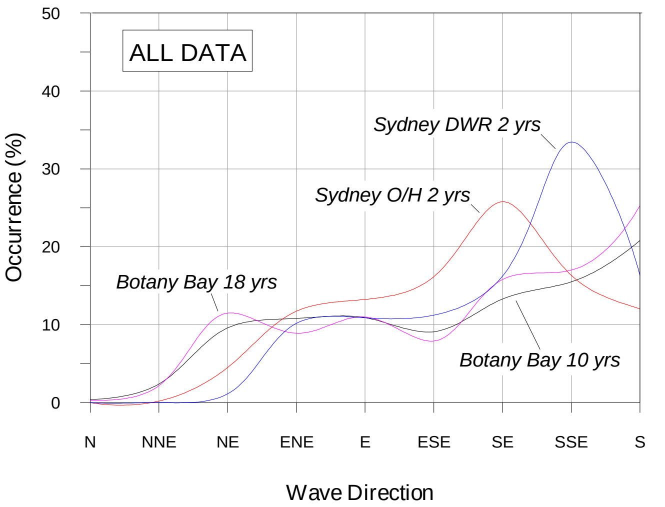

Figure 2 Wave Direction Distributions - All Data

The difference between the Botany Bay and Sydney data sets is believed to reflect the subjective nature of the techniques used to estimate the wave directions. However, it should be noted that the two year Sydney record may not be representative of the longer data sets for the Botany Bay site. The difficulty in assessing the degree of wave refraction present at the time of land observations may explain the higher occurrence for the N-NE and S directions. The significantly higher occurrence for the N-ENE directions for the observed/hindcast data also suggests that it is difficult to separate a locally generated N-ENE sea superimposed on a low, long period swell from the E-S directions. This situation often occurs during summer when the prevailing afternoon NE winds may appear to generate significant wave activity. Indeed, an underlying E-S swell may be present and not obvious to an observer or interpreted by the hindcaster. However, some caution must be exercised interpreting the lack of N-NE data recorded by the Directional Waverider. A significant percentage of the total buoy data loss occurred during the summer months when waves from these directions appear to be more frequent.

6.3 Storm Conditions

MHL classifies deepwater wave conditions as a storm event when a Significant Wave Height (Hsig) threshold of 3m is exceeded. Figure 3 includes the directional distributions for storm conditions (a 10 year data set for Botany Bay was not available).

Figure 3 indicates most storm events are generated in the southern Tasman Sea and approach Sydney from the SE-S directions. However, it should be noted that the low incidence of tropical cyclones in the Coral Sea during the DWR deployment would have contributed to less frequent recorded storm wave activity from the NE-E directions compared to the 18 year Botany Bay data record.

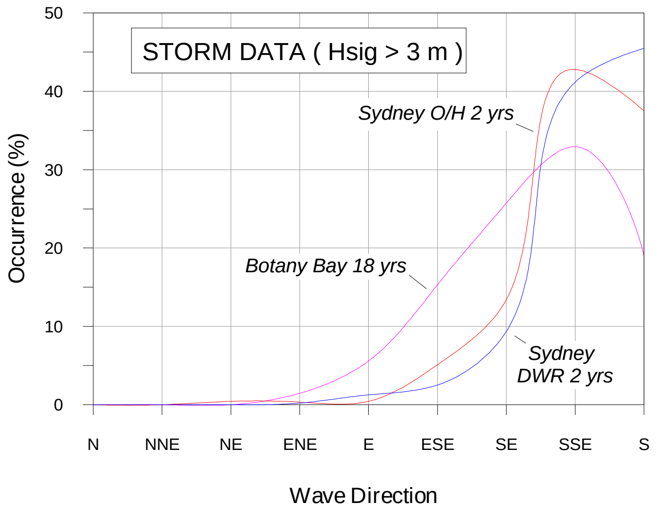

Figure 3 Wave Direction Distributions - Storm Data

The Botany Bay and Sydney observed/hindcast data differ significantly, which again may be attributed to the subjective nature of the direction estimating techniques used. Of interest is the good correlation between the DWR and the coincident observed/hindcast record (a poorer result was apparent for the full data sets, see Figure 2). This suggests that it is easier for an observer to identify wave direction during storm conditions when well defined swell is normally present. Hindcasting is also more reliable, the dominant wave generating weather system being easily identified on a synoptic weather chart, allowing better estimates of the storm wave direction.

6.4 Wave Period and Direction

Initial examination of the wave data sets suggested the direction distributions would also be influenced by wave period. A Zero Crossing Period (Tz) threshold of 7 seconds (s) was selected to restrict the distributions. Records with a Tz greater than 7s represent the higher energy (normally distant storms) events while the records less than 7s are typical of nearby storm events and locally generated seas. Figures 4 and 5 show these distributions.

The distributions for Tz<7s show very similar results to those presented for the full data sets (Figure 2), while the curves for Tz>7s display a bias to the S-SE directions like the storm wave distributions in Figure 3. These distributions again indicate the subjective nature of the observed/hindcast data with significant variation shown for the N-NE and SE-S sectors.

Figure 5 confirmed the results of earlier studies by Gordon and Hoffman (14). Their investigations included an examination of wave directions based on velocity oscillations recorded by two coincident six month electromagnetic current meter deployments off the Sydney coast. The current meters were placed in 60m and 80m water depth and were the first deployments to record deepwater wave direction off the NSW coast. Results showed a high bias to the SE-S for the longer wave periods (the shorter periods were attenuated by the water depth). The wave direction distribution curves obtained correlate with the DWR data shown in Figure 5.

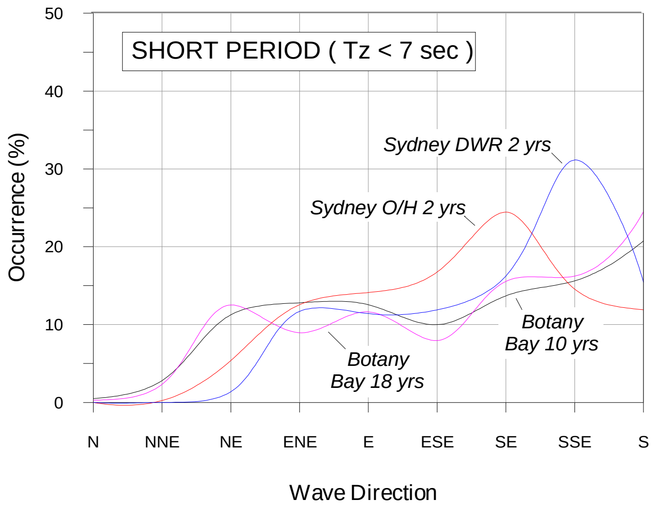

Figure 4 Wave Direction Distributions - Tz less than 7s

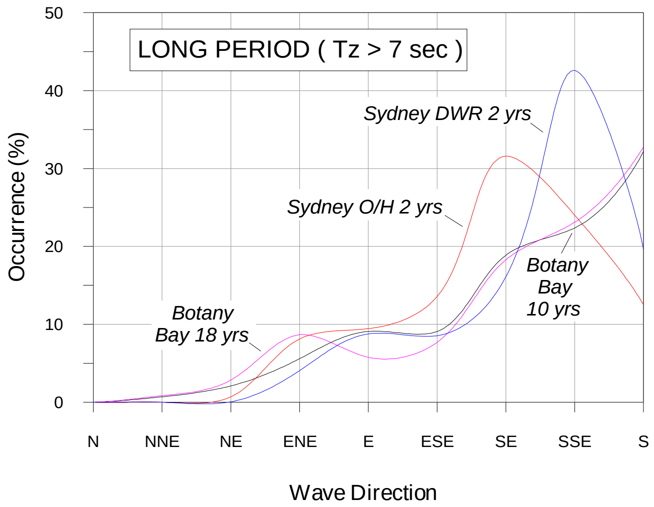

Figure 5 Wave Direction Distributions - Tz greater than 7s

6.5 Wave Height and Direction

Presentation of the wave direction distributions which include wave height occurrence thresholds is provided through the use of directional roses (Figure 6). The SE-S direction bias is again evident for the three distributions shown, particularly from the SSE for the DWR (10 year Botany Bay not available). The low incidence of N-NE waves recorded by the DWR is also emphasised here.

Figure 6 also illustrates the relatively low occurrence of storm wave activity present in each data set, particularly from the N-NE directions. This confirms the earlier suggestion that there has been a low incidence of tropical cyclones since the DWR was deployed. Further, the swell generated by tropical cyclones in the Coral Sea may not be sufficiently large to be classified as a storm by the time it reaches the Sydney coast, even though significant storm events may have been recorded on the NSW north coast. This result alone indicates that even the existing Waverider records which date back to the 1970s may not be representative of the long term (50-100 year) wave climate for the NSW coast. The low incidence of tropical cyclone generated storm events since 1970 is detailed in Blain Bremner and Williams/Weatherex (5).

7 DISCUSSION

Comparison of the four wave direction data sets outlined in Section 6 indicates that an effective record length of at least five years is necessary to confirm the difference between the DWR and the longer term Botany Bay observed/hindcast direction estimates. Nevertheless, a stronger bias to the SE-S directions is evident for the DWR data, while a surprisingly low level of wave energy approaches from the N-NE. The dominant SE-S energy is higher than previously determined, particularly during storm events.

The higher occurrence of wave energy from the SE-S is believed to explain anomalies associated with attempts by Gordon and Hoffman (14) to match surf zone sediment calculations on the NSW north coast with observed shoreline changes using an early observed/hindcast direction distribution. Further, wave refraction model studies at several locations along the NSW coast also adopted the early directional distributions. Hence, the degree of wave penetration into bays and estuaries and any associated erosion/accretion and sediment transport calculations may have been improved with the use of the more accurate measured directional data.

It is emphasised that the results from the DWR presented here should be treated as preliminary only. When a longer data set (at least five years) is available it is anticipated that comparisons included here will be updated and published. In addition, a five year record length will allow the study of seasonal and annual wave direction variations. In the longer term, the DWR database may provide information on any changes in the wave directional climate due to future climatic change.

Based on hindcast results from the NSW Public Works wave database, wave direction distributions at other locations along the NSW coast are different to those presented in this paper. Hence directional data for the Sydney region should not be applied to sites north and south of Sydney.

8 CONCLUSIONS

A DWR has been deployed off the Sydney coast since March 1992. Over two years of directional wave data has been collected at the Sydney site.

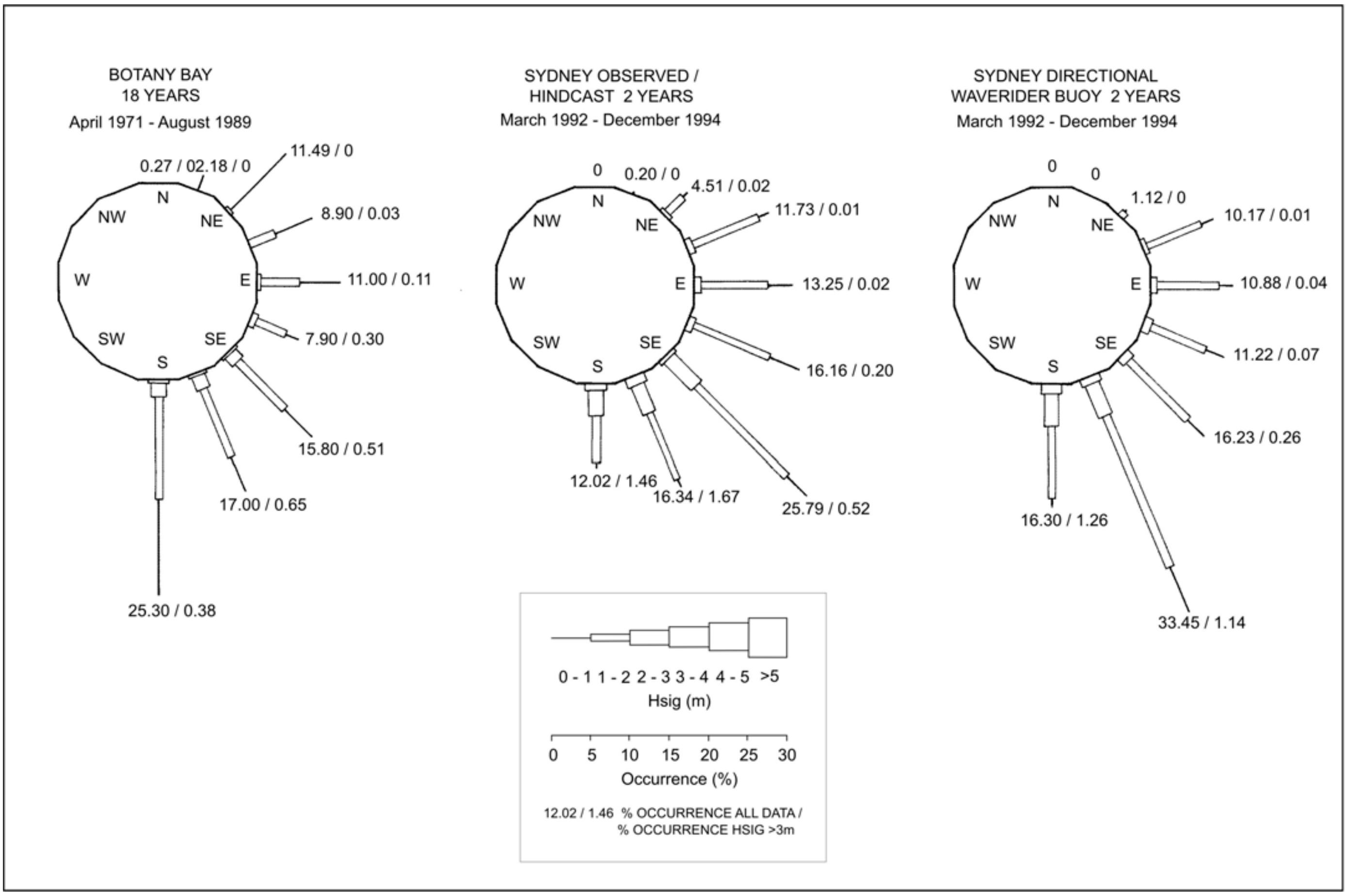

Figure 6 Wave Direction Occurrence Roses

Direction information was compared to three data sets based on daily observed/hindcast estimates; two long term (10 and 18 years) and one coincident. The preliminary results indicate:

- the directional distribution from the DWR differs from both the long term and coincident observed/hindcast data sets;
- a stronger bias to the SSE-S directions is evident for the DWR data, particularly for storm events;
- the difficulty of estimating the effect of wave refraction by a land based observer was highlighted, particularly when the offshore waves approach the coast at an acute angle to the seabed contours (N-NE and SSE-S);
- the subjective nature of wave direction hindcasting is implied by the difference between the long term and coincident observed/hindcast data sets;
- at least five years of directional wave data from the Sydney DWR site is required to confirm the differences discussed in this paper between the DWR and the other data sets and to examine seasonal and annual variations in wave direction.

9 ACKNOWLEDGMENTS

Wave data presented in this paper was collected by NSW Public Works and the Maritime Services Board, NSW. The deployment of a DWR off Sydney was initiated by Angus Gordon. His support during the project is appreciated. Analysis of the DWR data was possible through software developed by Tony Bolton and Ari Roizenblit. Verification of the measured wave directions by SPOT satellite images was carried out by Mark Howden.

10 REFERENCES

1. Webb, A.T., (1983), “Wave Climate of the New South Wales Coast”, 6th Australian Conference on Coastal and Ocean Engineering, poster paper, Gold Coast, Institution of Engineers, Australia, July 1983.
2. Webb, A.T. and Kulmar, M.A., (1989), “Coastal Wave Climate of New South Wales - An Update,” 9th Australasian Conference on Coastal and Ocean Engineering, pp. 374-379, Adelaide, Institution of Engineers, Australia, December 1989.
3. Wyllie, S.J., Kulmar, M.A. and Davidson, P.J., (1992), “Development of Design Offshore Wave and Ocean Level Conditions for the New South Wales Coastal Zone”, 1992 Coastal Management Conference, Kiama Municipal Council, November 1992.
4. NSW Public Works, (1986-95), “New South Wales Wave Climate Annual Summary”, Manly Hydraulics Laboratory, Reports MHL 465, 520, 547, 560, 581, 600, 627, 655, 695, September 1986, October 1987, October 1988, November 1989, October 1990, September 1991, October 1992, September 1993, October 1994.
5. Blain Bremner and Williams / Weatherex, (1985), “Elevated Ocean Levels - Storms Affecting N.S.W.

Coast 1880 - 1980", for NSW Public Works, Coastal Branch, Report No. 85041, December 1985.

6. NSW Public Works, (1986), "Development of a Radar Facility to Measure Wave Direction and Currents", Manly Hydraulics Laboratory, Report MHL 456, April 1986.
7. NSW Public Works, (1993), "Wave Direction Study - Satellite Imagery Progress Report No. 2", Manly Hydraulics Laboratory, Report MHL 641, March 1993.
8. Youll, P.H., (1981), "Botany Bay Waverider System - Ten Years of Records", 5th Australian Conference on Coastal and Ocean Engineering, pp. 245-251, Perth, Institution of Engineers, Australia, November 1981.
9. Willoughby, M. A., (1995), "NSW Central Coast Wave Climate - 1995 Update", 12th Australasian Coastal and Ocean Engineering Conference, Melbourne, Institution of Engineers, Australia, May 1995.
10. NSW Public Works, (1995), "Deployment of a Directional Waverider Buoy off Sydney", Manly Hydraulics Laboratory, Interim Report MHL 656, April 1995.
11. Datawell, (1990), "Operation and Service Manual for DIRECTIONAL WAVERIDER from serial No. 30023", Datawell bv - Laboratory for Instrumentation, October 1990.
12. NSW Public Works, (1987), "Collaroy / Narrabeen Beaches Coastal Processes Hazard Definition Study", Coastal Branch, Report No. 87040, December 1987.
13. Nielsen, A.F., Lord, D.B. and Treloar, P. D. (1993), "Marine Aggregate Proposal - Coastal Processes", for Metromix Pty Ltd, Geomarine Report No. 50-002-R10, July 1993.
14. Gordon, A.D. and Hoffman, J.G., (1984), "Sediment Transport on the South-East Australian Continental Shelf", 19th International Conference on Coastal Engineering, Vol 2 pp 1952-1967, Houston, Texas, American Society of Civil Engineers, September 1984.